



UNIVERSITÀ DEGLI STUDI DI BARI
“ALDO MORO”

Dipartimento Interateneo di Fisica “M. Merlin”

SCUOLA DI DOTTORATO DI RICERCA IN FISICA

Settore scientifico-disciplinare: FIS/01

Trigger Performance of the ALICE Silicon Pixel
Detector

Dott. Valerio Altini

Ciclo di Dottorato XXIV

ESAME FINALE 2012



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Introduction

ALICE (A Large Ion Collider Experiment) is a general-purpose, heavy ion detector at the CERN Large Hadron Collider (LHC) designed to address the physics of strongly interacting matter and quark-gluon plasma (QGP) at extreme values of energy density and temperature in nucleus-nucleus collisions. The experimental programme consists of recording data from heavy ions collisions (Pb-Pb) at various energies up to $\sqrt{s} = 5.5$ TeV per nucleon pair, collisions at lower energies and with lighter ions, in order to investigate the properties of the QGP at different temperatures. Data collected during proton-proton runs at different energies up to the nominal $\sqrt{s} = 14$ TeV are necessary as reference data for the heavy-ion programme and address specific strong-interaction topics for which ALICE is complementary to the LHC general-purpose detectors ATLAS and CMS. The Silicon Pixel Detector (SPD) is the innermost sub-detector of ALICE. It is a fundamental element for the determination of the position of the primary vertex as well as for the measurement of the impact parameter of secondary tracks originating from the weak decays of strange, charm, and beauty particles. A special feature of the SPD is that it provides a prompt trigger signal, called *fast-OR*, which can contribute to the experimental L0 trigger decision. The role of the SPD and the fast-OR trigger was crucial and unique during the cosmic data-taking campaign and the global commissioning phase of the ALICE detector in 2008 and 2009. It was also important for the first physics results obtained and published by the ALICE Collaboration with the data collected during the first years of running with proton beams and lead beams.

I participated to the commissioning and the optimization of the performance with and without beams, and to the running of the SPD. I extensively

worked on performance analyses, concerning especially the fast-OR trigger, that were reported both in public notes and articles. This work provided an important input for the first papers on charged-particles multiplicity density studies in proton-proton collisions and lead-lead collisions which were based on SPD data triggered by the fast-OR; the methods developed were also important to define the online monitoring which guaranteed, and continues to do so, the optimal data-taking performance.

The first chapter gives an overview of the physics of ALICE and the results obtained in the first year of LHC operation with lead beams. The ALICE detector and its trigger system are described.

The second chapter describes the *Inner Tracking System* (ITS) and the SPD, with information about their components and performances evaluated with cosmic-ray data and collision data. The fast-OR trigger is described in details, underlying the importance of the synchronism between the fast-OR signal elaboration clock frequency and the LHC bunch crossing frequency.

Chapter 3 describes a method to evaluate the SPD detection efficiency using cosmic-ray tracks and presents the first results. This measurement allowed to validate all the optimization procedure performed during the commissioning phase without beams and to support the measurements of charged-particles multiplicity with the first proton-proton collisions delivered in November 2009.

Chapter 4 presents the fast-OR trigger performances. The study of the fast-OR trigger performance was mandatory to understand the data recorded with proton and lead beams and to maximize the data taking efficiency. The data taking scenario, with reference to the LHC accelerator working properties, is introduced in order to motivate the choices done for the performed analysis. The methods to determine the performance of the fast-OR trigger are described and the results are given.

The last chapter presents a study of the fast-OR trigger capability, that was performed in order to understand how to select events in lead-lead collisions. The trigger efficiency and the purity are evaluated as a function of the centrality of the events. The last part of this chapter introduces the use of silicon vertex detectors in experiments at hadron colliders, discusses

the heavy-flavour trigger for a future ALICE ITS upgrade and presents the first quantitative performance studies for a trigger based on beauty baryon tagging.

Chapter 1

The ALICE Experiment at LHC

1.1 Physics

In Quantum Chromodynamics (QCD) the strong interaction among quarks depends on their colour charge. When quarks are placed in a medium this charge is screened with increasing density. The density can be increased either by raising the temperature, so that collisions between quarks produce more quarks and gluons, or by compressing the system, thereby increasing the baryon density. If the density increases beyond a certain critical value one expects that the interaction between quarks no longer confines them inside a hadron, so that they are free to travel longer distances and deconfine. The understanding of this transition from a confined to a deconfined phase, the so called quark-gluon plasma QGP, and therefore the understanding of the QCD phase diagram is of utmost importance and has attracted both experimental and theoretical attention. The experimental results are coming from both cosmology and heavy ion collisions. First evidence of the creation of the QGP medium was obtained at fixed target experiments at CERN SPS in Pb-Pb collisions at 158 GeV per nucleon [1]. More recently, in gold nuclei collisions at the Relativistic Heavy Ion Collider (RHIC, Brookhaven National Laboratory, USA), a temperature beyond 200 MeV was reached [2] and direct results indicating the creation of QGP have been obtained. The QCD phase diagram is shown in Fig. 1.1. The x and the y axis are the baryon chemical potential, μ_B , and the medium temperature, respectively. The phase transition at $\mu_B \rightarrow 0$ is a rapid crossover [3] which occurs at

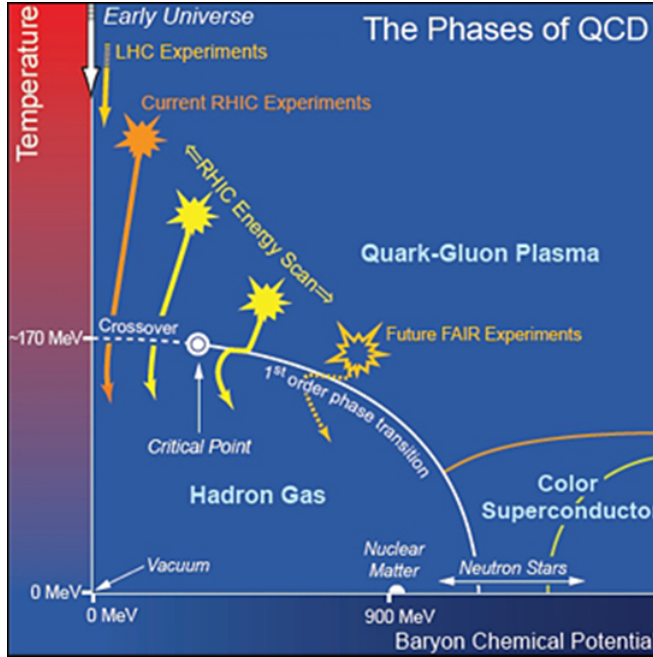


Figure 1.1: Schematic QCD phase diagram for nuclear matter. The dashed and solid lines show the phase boundaries for the indicated phases. The solid circle depicts the critical point. Possible trajectories for systems created in the QGP phase at different accelerator facilities are also shown.

$T \sim 170$ MeV and the transition temperature is expected to decrease as μ increases. At the critical point the phase transition is calculated to turn into a first-order phase transition. The observable confined hadronic matter is below the transition line. Nuclei have a temperature of ~ 5 MeV and a potential of ~ 900 MeV. Fig. 1.1 also shows the possible trajectories for systems created in the QGP phase at different accelerator facilities. Current heavy-ion experiments at RHIC (Phenix and STAR) and ALICE at LHC (but also ATLAS and CMS detectors should be considered since they have a specific heavy-ion programme [4] mostly complementary to the ALICE one) aim to achieve very high energies and thus small chemical potentials, which allow them to investigate the properties of the matter that filled the early universe during the first microseconds after the big-bang. Future projects (Energy Scan at RHIC [5] and Facility for Antiproton and Ion Research (FAIR) [6]) are working at a larger density in the phase diagram and address to the discovery of the critical point.

The evolution of the heavy-ions colliding system can be naively divided

into three stages consecutive in time. The first stage is the thermalization, during which the system reaches the plasma temperature, the partons are freed and the QGP is created. Then the plasma expands and finally it freezes out. The hadronization happens during the expansion. The particle abundances and thus the chemical composition of the exploding fireball are frozen almost directly with the hadronization and are very weakly affected by hadronic rescattering. This is called *chemical freeze-out*. The hadron spectral shapes, on the other hand, reflect the parton and hadron scattering processes in the medium throughout the whole expansion stage. The system freezes when no more scattering occurs and this is called *kinetic freeze-out*. The ALICE detector is expected to measure a broad range of physics observables [7, 8] in order to define the properties of the created quark-gluon plasma. Day-one measurements of global event features such as multiplicity, transverse energy flow and zero-degree energy flow define the geometry: impact parameter, shape and orientation of the collision volume, number of interacting nucleons. Nuclear modifications to the parton distribution function can be extracted comparing global event features and, more directly, specific hard processes (e.g. heavy flavours) in pp and AA collisions. Heavy flavour production and jet fragmentation will probe parton kinematics and energy loss in the plasma phase. The elliptic flow is sensitive to plasma properties like the shear viscosity and the equation of state. Prompt photons can reveal the thermal radiation from the early phase. Particle ratios and transverse momenta are governed by thermodynamical properties and by the hydrodynamical evolution at and around the phase transition. Particle interferometry measures the space time evolution of the collision.

Event characterization

The initial geometry of the collisions is essential to study how the available center-of-mass energy is redistributed in the phase space. The collision geometry is defined by three equivalent quantities, the impact parameter, the centrality and the number of participant nucleons. The centrality is expressed as a percentage ranging from 0% for the most central collisions, i.e. zero impact parameter, up to 100% for the most peripheral collisions.

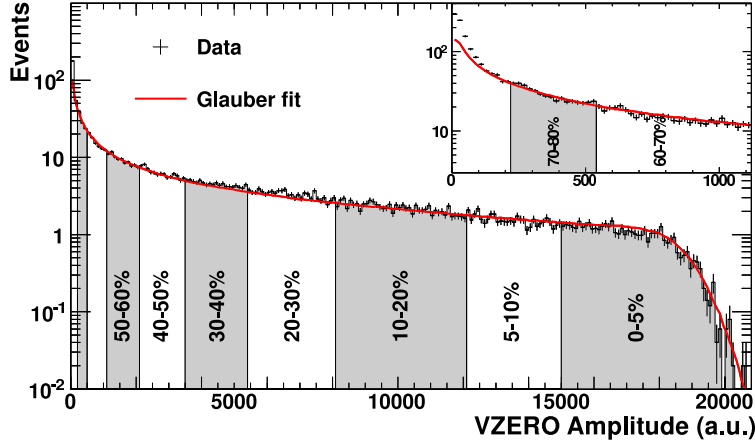


Figure 1.2: Distribution of the signal amplitude of the forward detector VZERO ($2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$). The curve shows the result of the Glauber model fit to the data. The vertical lines separate the various centrality classes which in total correspond to 88% of the most central ion collisions.

In the ALICE experiment the centrality is determined using the signal amplitude of a forward scintillator detector called VZERO ($2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$). The centrality of the collision .Fig 1.2 [9] shows the VZERO amplitude in arbitrary units for a data sample of about 6.5^4 events. The superimposed solid line is a mix of the Glauber model which describes the collision geometry and a negative binomial distribution which describes the particle production. The fit is restricted to the amplitudes below 88% of the hadronic cross section, taking into account only the region in which the event selection is fully efficient and the contamination by electromagnetic processes is negligible. The first step in characterizing the system produced in heavy-ions collisions is to define the initial conditions in terms of processes involved in the collisions and initial energy density. The measurement of the charge-particle multiplicity density is relevant to constrain the dominant particle production mechanism, reflecting the interplay between hard parton-parton scattering processes and soft processes. This measurement is also essential to estimate the initial energy density. The Bjorken formula, equation 1.1.1, shows the expression for the initial energy density ε_{Bj} as a function of the hadron transverse energy rapidity density and the approximation of the charged particle multiplicity pseudorapidity density $dN_{ch}/d\eta$ (τ and R are the QGP

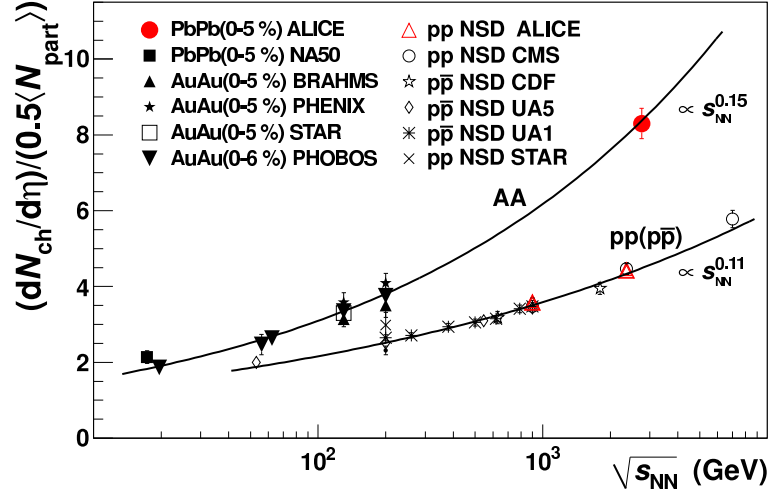


Figure 1.3: $dN_{ch}/d\eta$ per participant pair for central nucleus-nucleus and nonsingle diffractive $p p$ ($p\bar{p}$) collisions, as a function of $\sqrt{s_{NN}}$.

fireball parameters, the former is the fireball proper time, the latter is its effective transverse radius).

$$\varepsilon_{Bj}(\tau) = \frac{1}{\pi R^2 \tau} \frac{dE_T}{dy} \approx \frac{1}{\pi R^2 \tau} < m_T > \frac{3}{2} \frac{dN_{ch}}{d\eta} \quad (1.1.1)$$

$dN_{ch}/d\eta$ in the central rapidity region ($|\eta| < 0.5$) for various centrality classes has been measured by the ALICE detector [10, 9], accessing a new energy regime ($\sqrt{s_{NN}} = 2.76$ TeV) in high-energy nucleus-nucleus collisions. Figures 1.3 and 1.4 show $dN_{ch}/d\eta$ as a function of the centre of mass energy per nucleons pair for most central collisions (0%-5%) and as a function of the centrality (i.e. average number of participants $\langle N_{part} \rangle$) at a fixed energy. The multiplicity is scaled by the average number of participating nucleons pairs $\langle N_{part} \rangle / 2$. A significant increase, by about a factor two, in the pseudorapidity density is observed by ALICE at $\sqrt{s_{NN}} = 2.76$ TeV with respect to the results obtained at RHIC with Au-Au collisions at $\sqrt{s_{NN}} = 0.2$ TeV. It is interesting to note (figure 1.3) that the energy dependence is steeper for heavy-ion collisions than for $p p$ and $p \bar{p}$ collisions over a wide range of energies. The centrality dependence of the multiplicity in figure 1.4, on the other side, is quite similar to that observed at RHIC. The more direct measurement of ε_{Bj} from hadron transverse energy density is currently underway. Preliminary results [11] for the transverse energy

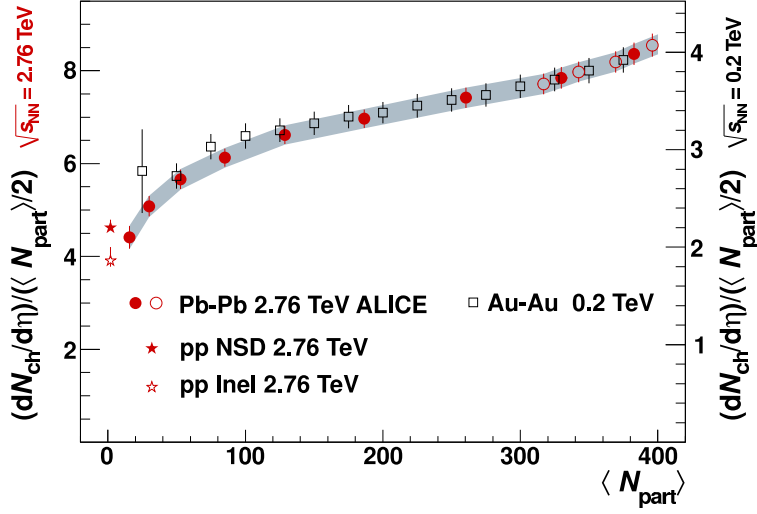


Figure 1.4: Dependence of $(dN_{ch}/d\eta)/(\langle N_{part} \rangle / 2)$ on the number of participants for Pb-Pb and Au-Au collisions. The scale for Au-Au collisions at $\sqrt{s_{NN}} = 0.2$ TeV is shown on the right-hand side and differs from the one at $\sqrt{s_{NN}} = 2.76$ TeV by a factor 2.1. Values for non-single-diffractive and inelastic p p collisions are shown.

pseudorapidity density show once again that the centrality dependence at LHC energy is similar to the one at lower energy at RHIC and that the $dE_T/d\eta$ magnitude is increased by a factor 2.5. The ALICE results on multiplicity studies prove that $(\tau \varepsilon_{Bj})_{LHC} \geq 2.8 \cdot (\tau \varepsilon_{Bj})_{RHIC}$ [11]. Since τ (eq. 1.1.1) is expected to decrease from RHIC to LHC, it is possible to claim that the energy density of the QGP fireball and so its temperature increase by at least a factor three from $\sqrt{s_{NN}} = 0.2$ TeV to $\sqrt{s_{NN}} = 2.76$ TeV.

The study of the dynamic evolution of the QGP fireball is also important to characterize events and to give constraints to the initial temperature and equation of state of the system. Experimentally, the space-time extension of a source can be accessed by interferometry measurements of identical bosons. This technique is called HBT (Hanbury Brown-Twiss). The HBT analysis has also been used in ALICE in order to measure the extension and the living time of the QGP fireball at the moment of the kinetic freeze-out, by measuring correlated pions [12]. The pions are produced in couples which are close in the three-momenta phase-space. The correlation function is defined as a function of the difference of the three-momenta of the pions couples and as a function of the extension radii of the source in

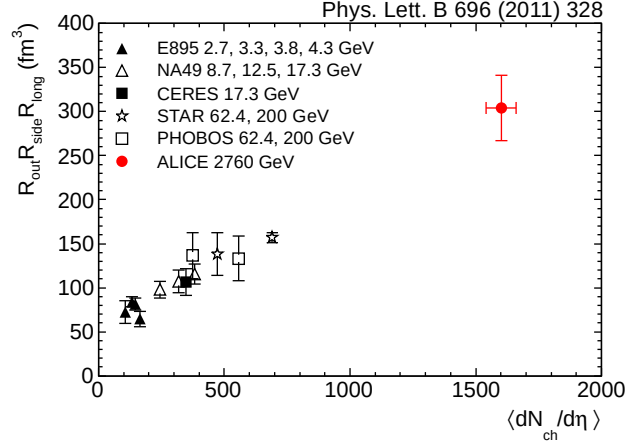


Figure 1.5: Product of the three HBT radii. The ALICE result is compared to those obtained for central gold-gold and lead-lead collisions at lower energies.

the transverse plane, R_{out} and R_{side} , and along the beam, R_{long} . Fixing the average three-momenta of the pions one can fit the experimental data with the correlation function and extract the HBT radii. Figure 1.5 shows the product $R_{out} \cdot R_{side} \cdot R_{long}$ for systems created in central ion-ion collisions at different energies. The volume of the fireball depends linearly on the charged-particle pseudorapidity density. The fireball created at LHC results two times bigger than the one created at RHIC (STAR). The total duration of the longitudinal expansion τ_f , i.e. at the kinematic freeze-out, can be evaluated from R_{long} . Figure 1.6 shows the long-lived QGP fireball created at LHC.

The ALICE first results from event characterization indicate that the fireball created at the LHC is hotter, lives longer and expands to a larger size (at freeze-out) than the one created at lower energies.

Anisotropic flow

A fundamental observable which is sensitive to the properties of the interacting hadronic matter created in ultra-relativistic heavy-ion collisions is the distribution of the number of particles in the transverse plane relatively to the beam direction. When two nuclei collide at non-zero impact parameter, the geometrical overlap region and so the original matter distribution are anisotropic (almond shaped), see left-side of the image 1.7.

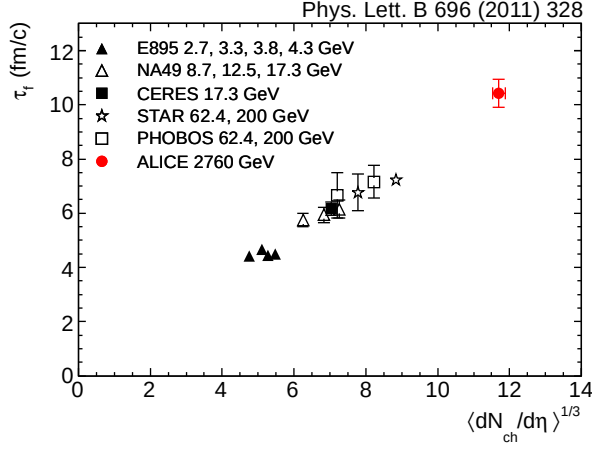


Figure 1.6: Kinematic freeze-out time extracted from R_{long} . The ALICE result is compared to those obtained for central gold-gold and lead-lead collisions at lower energies.

If the matter is interacting, the spatial asymmetry is converted via multiple collisions into an anisotropic momentum distribution, see right-side of the cartoon in figure 1.7. The measurement of the azimuthal angle anisotropy of the produced particles gives access to important information about the initial condition of the plasma like the shear viscosity and the fluid-dynamic equation of state. The azimuthal dependence of the particle yield d^3N/d^3p can be explicitly written using a Fourier expansion and leaving $d^2N/dp_t dy$ as a weight. The Fourier coefficient of the harmonic order n is defined in equation 1.1.2,

$$v_n = \langle \cos[n(\phi - \Psi_n)] \rangle \quad (1.1.2)$$

where Ψ_n is the angle of the initial state spatial plane of symmetry, that is the azimuthal angle of the reaction plane in figure 1.7 with respect to the laboratory frame. The angular brackets denote a statistical average over many events. The coefficients v_n are p_T and y dependent. v_1 is called direct flow and v_2 elliptic flow. The direct flow in ultrarelativistic heavy-ion collisions is proved to be negligible due to the nuclear transparency. The contribution of the elliptic flow to the Fourier expansion is more relevant and has been measured by the ALICE detector [13]. The Ψ_n angles are not known experimentally, so they are estimated from measured correlations between the observed particles. The correlations between two and four

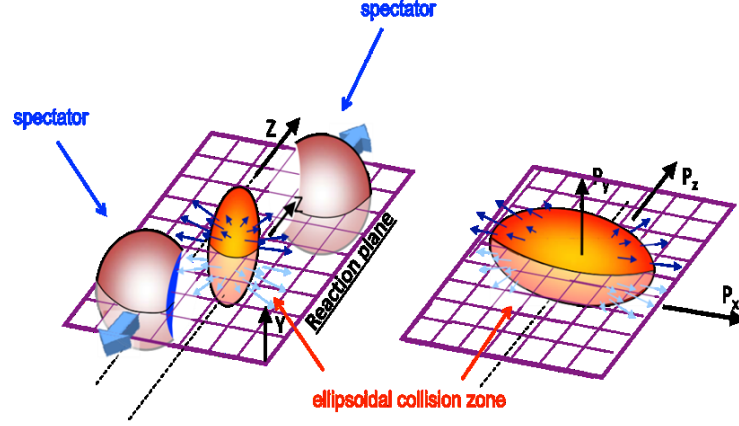


Figure 1.7: Schematic view of a peripheral nuclei collision. The geometrical interaction region is almond shaped and cut into two by the reaction plane. The azimuthal anisotropic space distribution of the interaction region, left side, gives origin to the anisotropic distribution in the momenta space, right-side.

particles are reported. They are named $v_2\{2\}$ and $v_2\{4\}$, and they are defined as $\langle \cos[n(\phi_1 - \phi_2)] \rangle$ and $\langle \cos[n(\phi_1 + \phi_2 - \phi_3 - \phi_4)] \rangle$ respectively. $v_2(p_t)$ for the centrality class 40%-50% obtained with 2 and 4 particle correlation is shown in figure 1.8(a). The $v_2\{4\}(p_t)$ transverse momentum dependence is qualitatively the same for the three centrality classes in figure 1.8(b). A similarity is observed at ALICE LHC and at RHIC for the p_t -differential elliptic flow at low p_t (see shaded area in figure 1.8). The integrated elliptic flow as a function of the center of mass energy is shown in figure 1.9. The flow at ALICE LHC is 30% larger than the one at RHIC and this is caused by the increase in the mean p_t . The elliptic flow results obtained at ALICE are well predicted by an hydrodynamics description and give compelling evidence for strongly interacting matter which appears to behave like an almost perfect (inviscid) fluid.

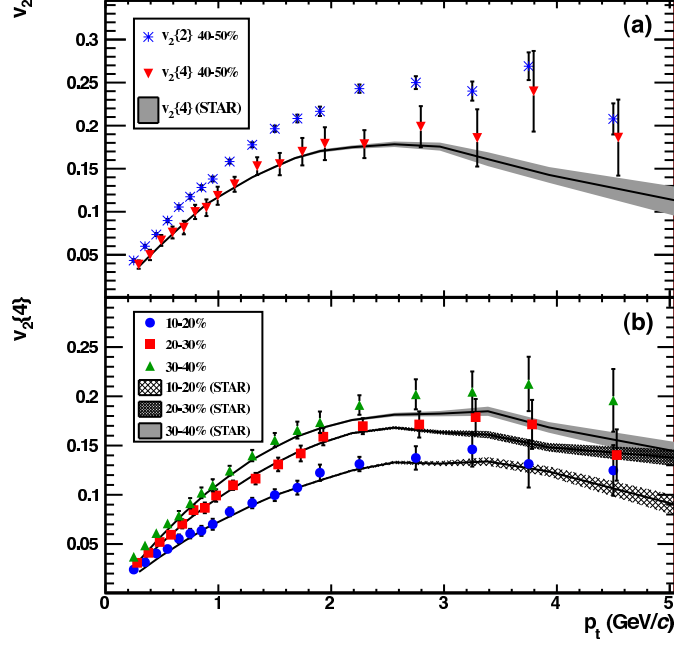


Figure 1.8: (a) $v_2(p_t)$ for the centrality bin 40%-50% using 2 and 4 particle correlation. RHIC data for Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV are also shown. (b) $v_2\{4\}(p_t)$ for various centrality classes compared to RHIC results.

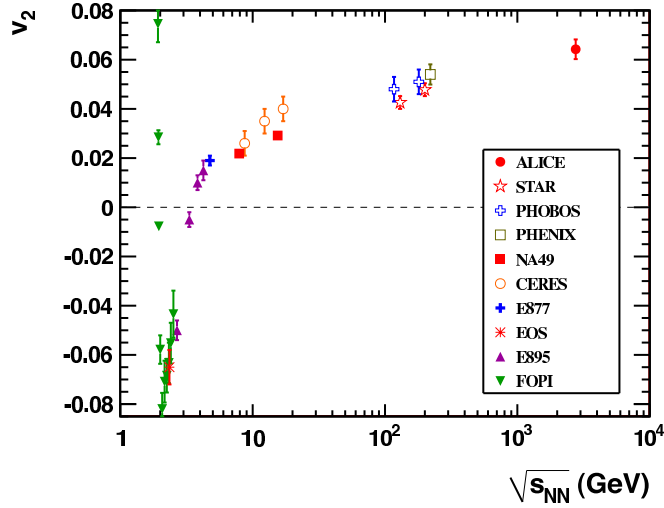


Figure 1.9: Integrated elliptic flow in the centrality class 20%-30% as a function of different energies at different experiments.

High- p_t suppression

Evidence of the hot and dense medium created in ultrarelativistic heavy-ion collisions comes from the observation of the momenta spectrum of the particles produced in the collisions. High- p_t hadrons are produced mainly in the fragmentation of high- p_t partons that originate in hard scattering processes. If the hard partons travel across the QGP medium they lose energy via multiple interactions with the medium before they fragment. The result is that the final momenta spectrum of the hadrons would be significantly different if no medium was created. The comparison of the p_t spectrum with the one obtained in a system where no medium is created is mandatory. The ALICE detector observed the charged particle high- p_t suppression in Pb-Pb collisions at $\sqrt{s}_{NN} = 2.76$ TeV with respect to proton-proton collisions at same energy¹ [14]. To quantify the QGP medium effects, the so called *nuclear modification factor* R_{AA} is used. R_{AA} as a function of the transverse momentum is defined in equation 1.1.3.

$$R_{AA}(p_t) = \frac{(1/N_{evt}^{AA})d^2N_{ch}^{AA}/d\eta dp_t}{\langle N_{coll} \rangle (1/N_{evt}^{pp})d^2N_{ch}^{pp}/d\eta dp_t} \quad (1.1.3)$$

$R_{AA}(p_t)$ is the ratio of the charged particles p_t and pseudorapidity differential yield in Pb-Pb to p-p collisions per event (N_{evt}), scaled by the number of binary nucleon-nucleon collisions $\langle N_{coll} \rangle$. The $R_{AA}(p_t)$ measurement and its prediction by theoretical models are important to fix the initial conditions of the nuclei collisions. In figure 1.10 the measured nuclear modification factor for both central, 0%-5%, and peripheral, 70% - 80%, collisions is shown. In peripheral collisions the R_{AA} for $p_t > 2$ GeV/c is large (about 0.7) and there is no p_t dependence, indicating a weak parton energy loss. In central collisions the nuclear modification factor is significantly different from 1. It has a strong dependence on p_t unto 6 – 7 GeV/c, it reaches a minimum of $R_{AA} \approx 0.14$ and it rises to $R_{AA} \approx 0.35$ at $p_t = 10$ GeV/c. While the R_{AA} shape in central collisions, in the low- p_t region is justified by the chemical recombination of the hadrons in the plasma (which clearly does not occur in proton-proton collisions), the suppression of high- p_t particles provides evidence for the strong parton energy loss and the dense plasma medium created at LHC. Future developments in the analysis will include fine measurements of specific particle species.

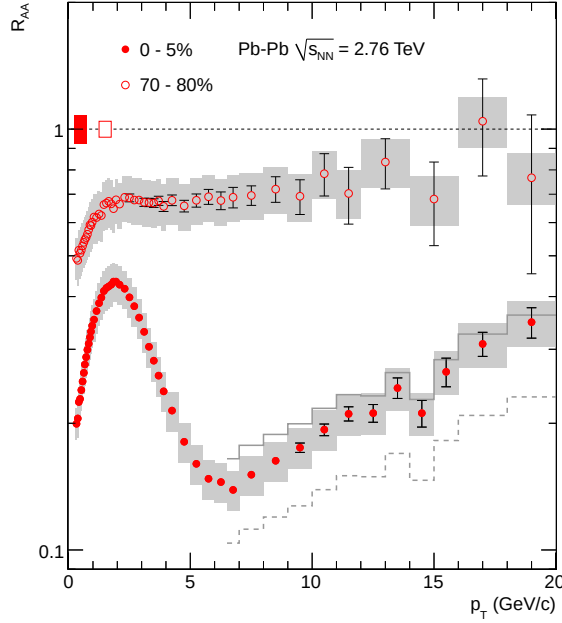


Figure 1.10: R_{AA} (see equation 1.1.3) in central (0-5 %) and peripheral (70-80%) Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The boxes contain the systematic errors in the data. Solid and dashed lines indicate different methods for the proton spectrum extrapolation¹.

Heavy-quark production

Heavy-quarks (charm and beauty) provide sensitive probes of the collision dynamics both at short and at long timescales. Heavy-quark production is an intrinsic perturbative phenomenon which occurs in the early stage of the collision. On the other hand, the long lifetimes of the charm and beauty hadrons allow them to live throughout the evolution time of the plasma. Studies of heavy-quarks spectra should allow a more detailed understanding of non-perturbative QCD processes in the low-momentum region, while high-momentum probes would improve the study of the plasma measuring the heavy-quark energy loss through the whole extension of the dense medium. The number of $Q\bar{Q}$ couples is not supposed to change indeed, though their transverse momentum distributions are supposed to do. R_{AA} as defined

¹Proton-proton reference data were not directly available at the time of the measurements (December 2010). Values for proton spectrum are extrapolated from results of inelastic p-p collisions at $\sqrt{s_{NN}} = 0.9$ and 7 TeV measured by ALICE detector. LHC provided only on March 2011 p-p collisions at $\sqrt{s} = 2.76$ TeV.

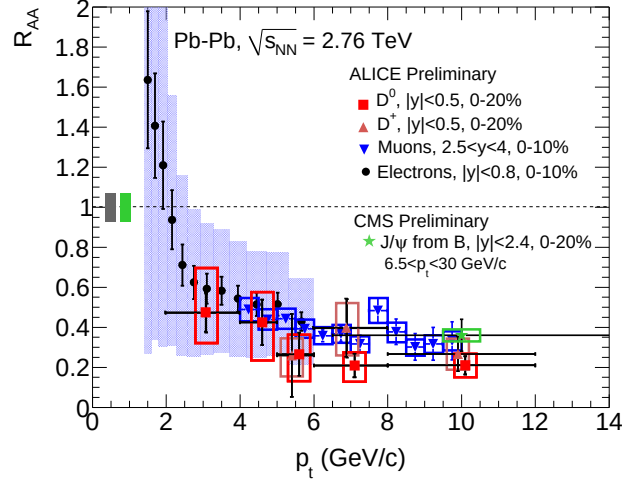


Figure 1.11: R_{AA} for identified D -mesons spectra, for inclusive e^- and μ^- production, measured by the ALICE detector. CMS result for J/Ψ from B mesons is also shown.

in the equation 1.1.3 but with differential open-charm and open-beauty production cross-sections is the most intuitive variable to study the plasma effects. Interesting preliminary results of R_{AA} for D -mesons, electrons and muons are shown in figure 1.11. The high- p_t suppression is clearly visible. Inclusive lepton processes are particularly useful because heavy-quark decay in the lepton channel is the most favored and is supposed to dominate up to the mass of the Z^0 with respect to Drell-Yan processes.

Quarkonia

The temperature of the QGP is of the same order of magnitude of the $c\bar{c}$ and $b\bar{b}$ binding energies, so a quarkonium suppression is expected to occur due to the shielding of the binding potential by colour screening, leading to the breakup of the quarkonium states: Ψ' , χ_c , J/Ψ and also the Υ family. The CMS detector has directly observed the Υ suppression via $\mu\mu$ invariant mass and it measured a $\approx 31\%$ suppression [15].

1.2 The ALICE detector

The ALICE detector has been designed to deal with the challenging experimental conditions of lead-lead collisions at LHC energies, up to $\sqrt{s_{NN}} = 5.5$ TeV. The most stringent design constraint is the very high particle multiplicity. Originally, the estimates for the charged particle multiplicity density at mid-rapidity spanned from 2000 to 8000. More recent extrapolations from RHIC measurements (see figure 1.3) point to lower values, in the range from 1500 to 4000. The ALICE design was then optimized for a value of about 4000, but also tested with simulated multiplicity densities up to twice that amount. The recent result for the measured charged particle multiplicity density in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, in central rapidity, yields 1601 ± 60 [10] while the expected value at $\sqrt{s_{NN}} = 5.5$ TeV (value obtained extrapolating the dashed line in figure 1.3) is of the order of 2000. The designed detector performance gives a significant margin of operating the detector through the whole LHC heavy-ion programme of the next years. The robustness of the tracking is ensured by providing three-dimensional hit information with many points (up to 150) in a moderate field of 0.5 T. A large dynamic range for momentum measurements in the barrel region is provided, spanning from a few tens of MeV/c up to 100 GeV/c. This is achieved with a combination of very low material budget, 13% X_0 [16] for the full tracker, and a large tracking level arm up to 3.5 m. ALICE employs all the known Particle Identification (PID) techniques: ionization energy loss dE/dx , time-of-flight, transition and Cherenkov radiation, electromagnetic calorimetry and muon filters. The ALICE instrumented part is concentrated over two units of rapidity around mid-rapidity for the barrel detectors, and also covers 1.5 units in rapidity at small angles for muon measurements. ALICE trigger capability allows the collected data sample to be enriched with rare signals, using selective triggers which operate at several levels (specific triggers for jets, high- p_t electrons, photons and muons). Nevertheless, global properties measurements and other rare signals (like heavy flavour decays) which are difficult to select at trigger level require the collection of a large statistic of minimum bias events or central collision events. The collection of the

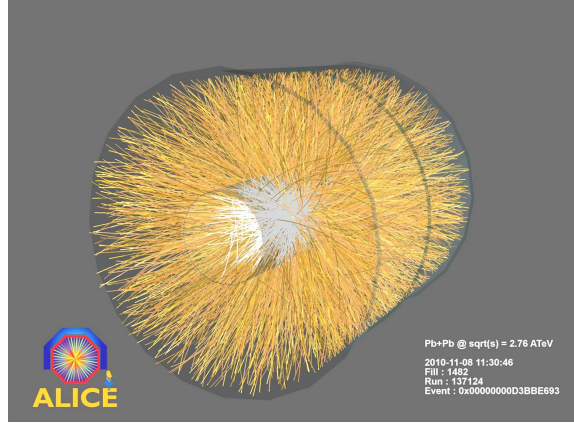


Figure 1.12: Reconstructed tracks in the ALICE central barrel for a central Pb-Pb collision event at $\sqrt{s_{NN}} = 2.76$ TeV.

large foreseen amount of data during the few weeks per year of LHC operation with heavy-ions is guaranteed by the excellent performance of the Data Acquisition system, which transfers data to a permanent storage at velocities up to 1.3 GB/s. A picture which shows the huge amount of tracks reconstructed by the ALICE detector in a central Pb-Pb collisions event at $\sqrt{s_{NN}} = 2.76$ TeV can be found in figure 1.12.

The detector schematic view is shown in figure 1.13. The central barrel detectors are enclosed in the L3 magnet, which provides a solenoidal magnetic field of 0.2 T and 0.5 T. Tracking and PID are performed in the full polar angle in the central pseudo-rapidity region $|\Delta\eta| < 0.9$. The main tracking detector is the 90 m³ large Time Projection Chamber (TPC). Despite its intrinsic limitations concerning speed and data volume, this tracking device guarantees a reliable performance for momentum and double-track resolution in an environment of several thousand charged particles in the acceptance. The TPC also performs PID via dE/dx measurements in the non-relativistic region and in the relativistic rise up to few tens of GeV/c [16]. The inner radius of the TPC, ≈ 90 cm, was determined by the maximum acceptable hit density, while the outer one, ≈ 2.5 m, by the request of achieving a dE/dx resolution of 7-8 %. A performance measurement for proton-proton collisions at $\sqrt{s} = 7$ TeV is shown in figure 1.14. A key role for tracking with the ALICE detector is played by the Inner Tracking System (ITS), which consists of

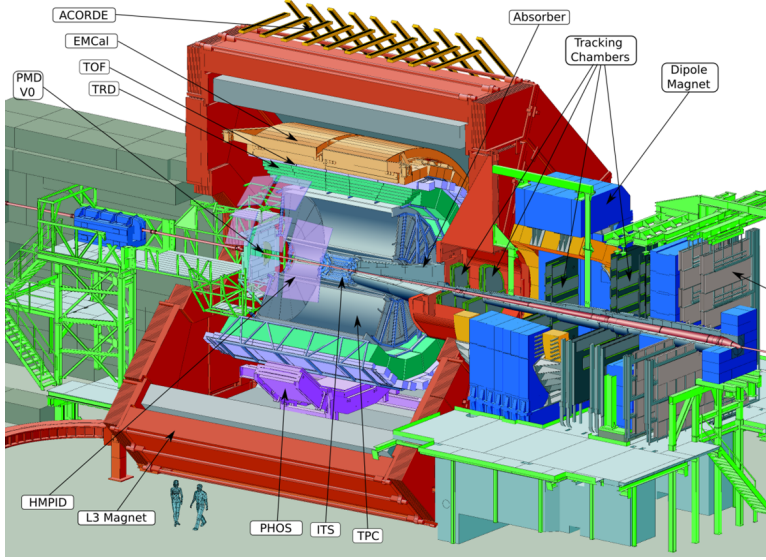


Figure 1.13: Schematic view of the ALICE detector.

six coaxial cylindrical layers of silicon detectors (Silicon Pixel Detector, Silicon Drift Detector and Silicon Strip Detector), displaced, with respect to the interaction point, from a radius of 3.9 cm to a radius of 49 cm. The ITS has a key role in reconstructing secondary vertexes from heavy flavour and strange particle decays, in tracking and PID at low-momentum and in improving of the impact parameter resolution. A more detailed description and the performance of the ITS will be given in the next chapter.

Particle identification for many different particles over a broad range of momentum is provided by the various subsystems of the ALICE detector. A Transition Radiation Detector (TRD, see figure 1.13) is placed just outside the TPC, at 2.90 m. It identifies electrons above 1 GeV/c and also reconstructs their tracks along about 50 cm in $r\varphi$ plane. The Time of Flight (TOF) system is a gaseous detector based on the Multigap Resistive Plate Chamber technology. It measures the time of flight of particles flying 3.78 m in the $r\varphi$ plane from the primary vertex (see TOF position in figure 1.13), with a resolution of 40 ps. The TOF identifies particles in the intermediate momentum range, below 2.5 GeV/c for pions and kaons and up to 4 GeV/c for protons, with a π/K and p/K separation better than 3σ [16]. The TOF performance for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV is shown in figure

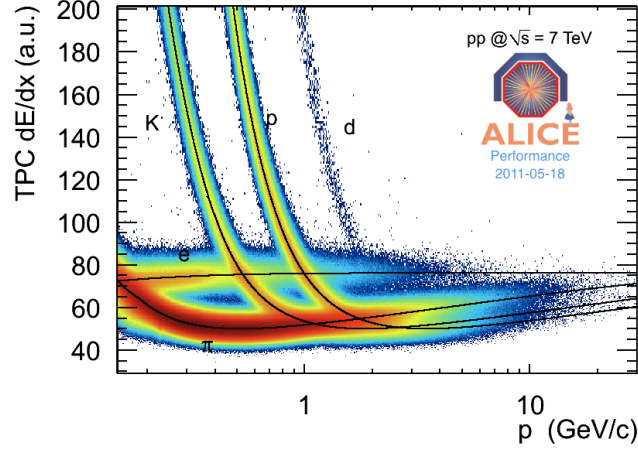


Figure 1.14: TPC PID performance for p-p collisions data at $\sqrt{s} = 7$ TeV. The dashed lines are a parametrization of the Bethe-Bloch curves.

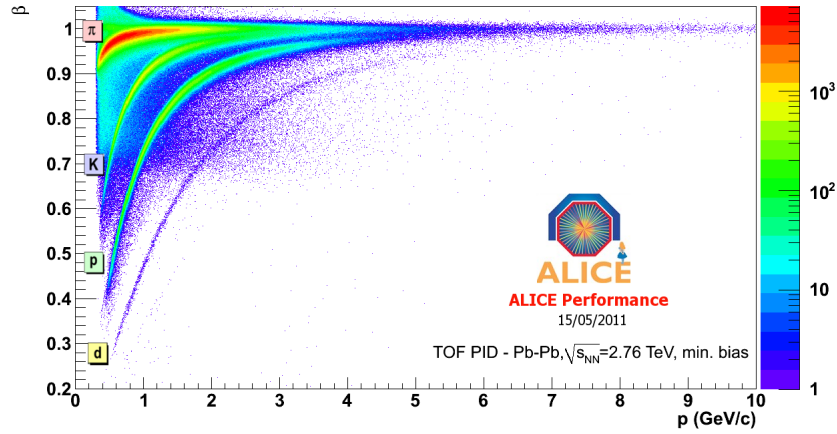


Figure 1.15: TOF PID performance for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

1.15. The HMPID is a ring imaging Cherenkov detector which extends and improves the hadron identification capabilities to higher momenta, up to 5 GeV/c, in 10% of the barrel acceptance.

Direct photons and photons from neutral mesons decays are measured by two calorimeters, the PHOS and the EMCal detectors. The initial ALICE configuration foresaw the only PHOS detector, which is a high-resolution and high-granularity electromagnetic calorimeter, composed of state-of-the-art scintillating crystals (PbWO_4). The small PHOS acceptance, clearly visible in the schematic view of figure 1.13, lead the collaboration to approve, in

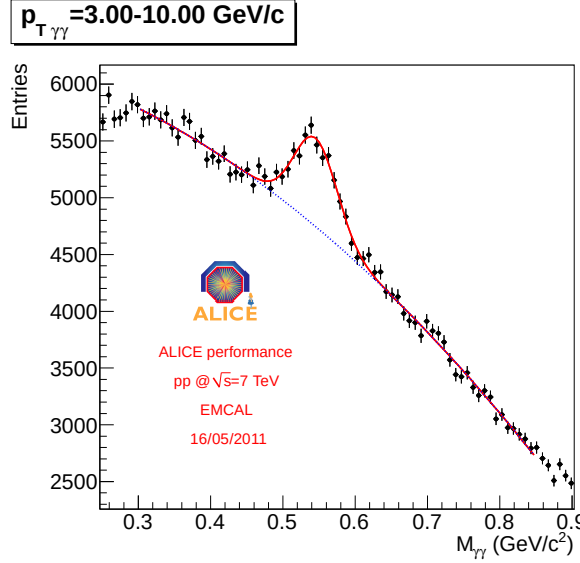


Figure 1.16: *EMCal performance: double- γ invariant mass with the η meson peak, for the p_t range 3 - 10 GeV/c, in p-p collisions at $\sqrt{s} = 7$ TeV.*

2009, the installation of the second calorimeter EMCAL. The EMCAL covers a large acceptance and could be realized at relative low cost at the expense of less granularity and resolution. The EMCAL detector will play a leading role in measuring jet production rates and fragmentation functions, together with the tracking detector in the barrel. A performance plot for the EMCAL double- γ invariant mass resolution is shown in figure 1.16; the η meson peak in the given p_t range clearly separates from the background in p-p collisions at $\sqrt{s} = 7$ TeV.

The current barrel detectors configuration up to spring 2011 is sketched in the transverse-section schematic view in figure 1.17. The tracker detectors, TPC and ITS, are fully installed, 3 out of 5 PHOS modules have been constructed and are in place, 7 out of 18 TRD supermodules and 4 out of 10 EMCAL modules have been installed. Both TRD and EMCAL will be completed by the end of 2011.

The forward muon arm is primarily designed to measure the production of heavy-quark resonances (J/Ψ , Ψ' , Υ , Υ' , Υ'' ,) via single and double-muon channels in the forward region, in the range $-4 < \eta < -2.4$. It consists of an absorber of $\approx 10 \lambda_{int}$ (staring at 90 cm from the primary vertex) used to

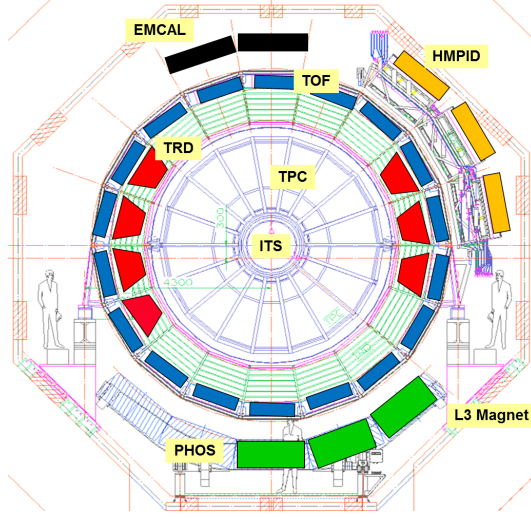


Figure 1.17: ALICE barrel detectors configuration in spring 2011.

shield the muon arm from the high number of hadrons created in the lead-lead collisions; a dipole magnet (next to the L3 magnet) with a 3 T field and 10 planes of high-granularity thin cathode strip tracking chambers. A second absorber $\approx 7 \lambda_{int}$ thick is placed further down from the muon chambers. It shields 4 planes of fast Resistive Plate Chambers (see black arrow with no label on right side of figure 1.13) and is used for muon identification and triggering.

Other small and specialized detectors complete the rich composition of the ALICE detector. Two sets of Cherenkov counters mounted around the beam pipe (the T0 detector) measure with very high precision (> 25 ps) the event time. Two arrays of segmented scintillator counters, the V0, cover high pseudorapidity regions in both positive and negative direction. The V0 detector is used as a trigger detector and also for the measurement of global properties of the events (see *Event characterization* in section 1.1). An array of 60 large scintillators, ACORDE, on top of the L3 magnet, is used to trigger on cosmic rays and to study the cosmic rays physics down in the ALICE cavern. The Forward Multiplicity Detector (FMD) provides multiplicity information over a large fraction of the solid angle ($-3.4 < \eta < -1.7$ and $1.7 < \eta < 5$). Two planes of gas proportional counters, the Photon Multiplicity Detector (PMD), measure the multiplicity and spatial

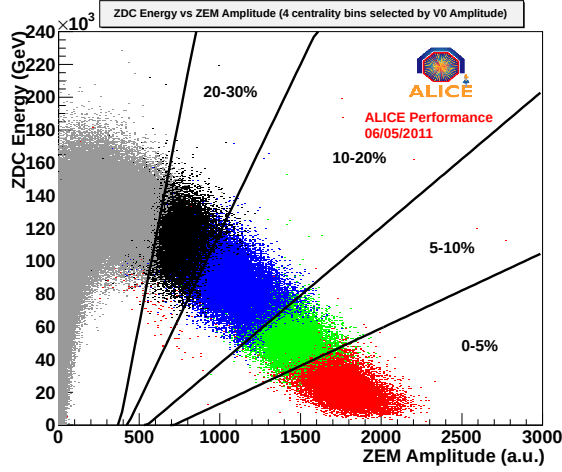


Figure 1.18: Correlation of energy deposits in ZDC and ZEM calorimeters for Pb-Pb collisions events at $\sqrt{s_{NN}} = 2.76$ TeV. Four centrality classes are determined by the V0 detector. Points for the different classes are bounded (solid lines) by specific correlation function between ZEM and ZDC energies.

distribution of photons event-by-event in the region $2.3 < \eta < 3.7$. Two sets of compact hadronic calorimeters which compose the so-called Zero Degree Calorimeter (ZDC), placed at about 116 m from the primary vertex in both sides. Each set is composed of two parts, one tungsten made and the other one brass made, for a fast counting of neutrons and protons, respectively. The ZDC calorimeters count the spectator nucleons and at regime will be used for triggering on the event centrality in heavy-ion collisions. The ZDC information alone is not sufficient to determine the centrality event-by-event because it is ambiguous. The more the A-A event is peripheral the more the fragments produced in the interaction remain inside the beam pipe and so the energy deposit into the ZDC is as low as it is in more central collisions. So, in addition to the ZDC, two more electromagnetic calorimeters (ZEM), placed at about 7 m from the primary vertex, are used to solve the ambiguity. The number of photons produced from π^0 decays monotonically increases with the event centrality. The correlation between the energy deposit in ZEM and ZDC is shown in figure 1.18. It is evident that the only combined information of both calorimeters can select events of a certain centrality class.

1.3 Trigger and data taking

The interaction rate of inelastic Pb-Pb collisions at the nominal energy $\sqrt{s_{NN}} = 5.5$ TeV and at the nominal LHC luminosity, $L = 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$, is 8 kHz [16]. The ALICE trigger system is optimized to take a decision for every inelastic lead-lead process. The trigger decisions are only taken by trigger detectors, or by simple logic combinations (NOT, AND, OR) of them. The difference in the readout time of the detectors led to the design of a 3 level (L0-L1-L2) parallel trigger system, which allows the system to read-out the data from faster detectors, while slower detectors are busy reading out the data belonging to the previous event. The use of a previous decision (L0) before the first-level (L1) decision is a typical ALICE feature. The trigger signals reach the detectors with a latency, after the collision time, of 1.2 μs , 6.5 μs , and 88 μs for L0, L1 and L2 respectively. L0-accepted sets the BUSY and no more L0 signals are accepted before L1 and L2 take a decision. Both L1 and L2 can kill trigger signals at L0 time. L1-accepted means that data are accepted and the ALICE detector awaits the L2 decision. If L2-accepted occurs the data are finally stored. The 88 μs L2 latency is constrained by the TPC past-future protection. In order to avoid pile-up, the trigger system has to wait for the ionization electrons at zero pseudorapidity, from previous and current events, to be drifted to the TPC endcaps. The L2 latency is also useful to let the detectors provide a more elaborated trigger decision. The latencies turned into rates are for the L0, L1 and L2 levels, 833 kHz, 154 kHz and 11 kHz respectively, and so, as a matter of fact, ALICE is able to take a decision for each of all the 8 kHz inelastic events.

The online event selection includes another level, called High Level Trigger (HLT) [16]. The HLT is a software trigger level. The HLT system is a computer farm which elaborates data coming from detectors via the Data Acquisition system (DAQ)[16], performing a raw tracking and PID. The DAQ archiving rate is about 1 GB/s, while the data volume rate in Pb-Pb collisions, at nominal luminosity and after all the trigger selections can easily reach 25 GB/s. The HLT will take the last decision in selecting the events of most interest before they could be definitely sent to permanent storages.

The online system which controls the ALICE trigger system is called Central Trigger Processor (CTP). The CTP logic is defined by the specification of a set of inputs, a set of outputs and the rules describing the relations between them. A *class* is a group of trigger inputs. A *cluster* consists of several classes as input and a group of readout-detectors on its output. The cluster becomes active if at least one of its classes is active. The active cluster sends the trigger signals to its readout-detectors. There are 24 inputs for L0, 20 inputs for L1 and 6 inputs for L2. Every trigger-detector provides different inputs, of the same level or of different levels. The detectors providing a L0 signal are: Muon Chambers, T0, PHOS, ZDC, EMCal, ACORDE, TOF, V0, TRD and Silicon Pixel Detector. The detectors providing a L1 signal are: PHOS, TOF, TRD, ZDC and EMCal. Today none of the detectors provide an L2 signal. The L2 decision is therefore always set to positive.

The typical data-taking scenario is as follows. The list of readout-detectors participating in the data-taking is loaded by the Experimental Control System (ECS) [17] into a *partition*. The ECS loads the clusters from the CTP. The readout-detectors of the clusters have to be included in the partition. Several clusters, which may have one or more detectors in common, can be associated to a single partition. Several partitions can run in parallel while taking data, provided different detectors are included in different partitions. The only requirement for the clusters into the partitions, and so for the trigger classes of the clusters, is to define a competitive trigger logic, i.e. different clusters in the partition must have the same probability to occur. In order to avoid the rare-trigger classes being killed by minimum-bias classes, it is possible to set a *share-time*, that is the time in which classes can be active. Another possibility is the *downscaling*: the CTP can arbitrarily inhibit a trigger signal (at the level of L0, L1 or L2) or an entire trigger class. Detailed information about data-taking, readout-detectors, trigger-detectors, partitions, clusters, classes and more are stored for each run in the ALICE Electronic Logbook [18]. In figure 1.19 a picture extracted from the Electronic Logbook is shown. It is an intuitive view of the data-taking condition and is constantly used by shifters in the experimental area. It summarizes what has been described above.

☒ Readout Detector						☐ Trigger Detector						☒ Trigger & Readout Detector										
B E A M	R U N	P A R T I T I O N	H L T M O D E	D U R A T I O N	S U B E V E N T S	Detectors																
						A C C O R D E	C D P A Q V	E M C A L T E S T	F M D	H M P I D	M U O N S T R G	P H O S	P M D	S D	S P D	S S D	T O	T O F	T P C	T R D	T R I G G E R	V O D C
Y	158598	PHYSICS_1	B	14.2 m	115.7 k	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
		1			16.2 k	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
		2			42.8 k	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
		3			56.7 k	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒
		4			100	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒

Figure 1.19: Picture taken from the ALICE Electronic Logbook. The ALICE data-taking configuration is shown. The boxes with the tick in the first row of the green table are the readout-detectors included in the partition PHYSICS_1 for the run 158598. Four trigger clusters, rows from 1 to 4, are defined for this partition. The boxes with the tick in each row indicate the readout-detectors associated to the correspondent cluster. The red circles point out the trigger-detectors which are included in at least one of the trigger classes defined in the cluster.

Chapter 2

ITS and SPD

2.1 The Inner Tracking System

The main tasks of the silicon Inner Tracking System (ITS) are to improve the primary vertex resolution up to values better than $100\text{ }\mu\text{m}$, to reconstruct the secondary vertexes of hyperons, D and B mesons, to track and identify particles with momentum below $200\text{ MeV}/c$ that do not reach the TPC, to improve the momentum and angle resolution of the tracks reconstructed by the TPC and to extend tracking and particle identification (PID) to particles traversing the dead region of the TPC. The ITS contributes decisively to all the physics topics addressed by the ALICE experiment.

2.1.1 Layout

The ITS consists of six cylindrical layers of silicon detectors located at radii between 3.9 cm (around the beam-pipe) and 43.6 cm . The full ITS coverage is $|\eta| < 0.9$. The outermost radius is determined by the necessity of matching tracks with those from TPC, while the inner one is the minimum allowed by the beam-pipe radius. The closer to the primary vertex the first layer is the better the resolution of the impact parameter is. An ITS schematic view is shown in figure 2.1. The two innermost layers are pixel detectors (Silicon Pixel Detector, SPD), the two central layers are drift detectors (Silicon Drift Detectors, SDD) and the two outermost layers are double-sided μ -strip (Silicon Strip Detectors, SSD). The four outer layers, SDD and SSD, have an analogue readout that allows to identify particles via dE/dx measurements in the Bethe-Bloch non-relativistic ($1/\beta^2$) region. The ITS, fully assembled around the beam pipe, is shown in figure 2.2. The blue

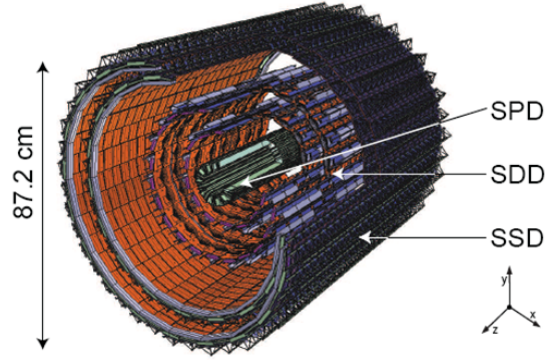


Figure 2.1: Schematic view of the Inner Tracking System (ITS). The two innermost layers are pixel detectors (Silicon Pixel Detector, SPD), the two central layers are drift detectors (Silicon Drift Detectors, SDD), and two outermost are double-sided μ -strip (Silicon Strip Detectors, SSD) layers.

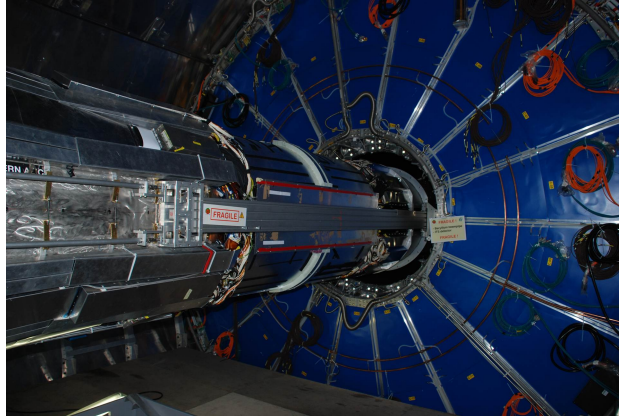


Figure 2.2: ITS fully assembled around the beam-pipe. The blue round wall is the endcap of the TPC before being slid around the ITS.

Parameter	SPD	SDD	SSD
Radii r_{inner}, r_{outer} (cm)	3.9 , 7.6	15.0 , 23.9	38.0 , 43.0
Coverage $ \eta_{inner} , \eta_{outer} $	1.9 , 1.3	1.1 , 1.0	0.9 , 0.9
Spacial precision $r\varphi$ (μm)	12	35	20
Spacial precision z (μm)	100	25	830
Two tracks resolution $r\varphi$ (μm)	100	200	300
Two tracks resolution z (μm)	850	600	2400
Max. occupancy ¹ inner layer (%)	2.1	2.5	4.0
Max. occupancy ¹ outer layer (%)	0.6	1.0	3.3

Table 2.1: ITS parameters.

round wall is the endcap of the TPC before being slid over the ITS. The choice of three different technologies at different distances from the primary vertex was driven by the necessity of having a good point resolution and a low occupancy per layer in lead-lead central events¹, with the constraint of the cost of the technology at the time of the construction. The parameters for each of the three detectors are summarized in table 2.1 [16].

The momentum and impact parameter resolutions at low- p_t are dominated by the contribution of multiple scattering. To reduce multiple scattering the volumes and the effective thickness of the ITS detectors and the services (cabling and cooling) have been kept as small as possible. The total amount of radiation length for the full ITS is less than 8% X/X_0 . The percentage of radiation length as a function of the radius is shown in figure 2.3, where the different layer technologies are specified [16]. The lifetime of the sensors is supposed to last, keeping a satisfactory performance, for ten years. The total expected dose of radiation is a few tens of Gray for the outer parts and about 270 krad for the innermost layer. The radiation tolerance of the front-end electronics has been proven to be well above those values (~ 10 Mrads)[16].

¹It refers to the 8000 charged particles at mid-rapidity in central Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV, see paragraph 1.2

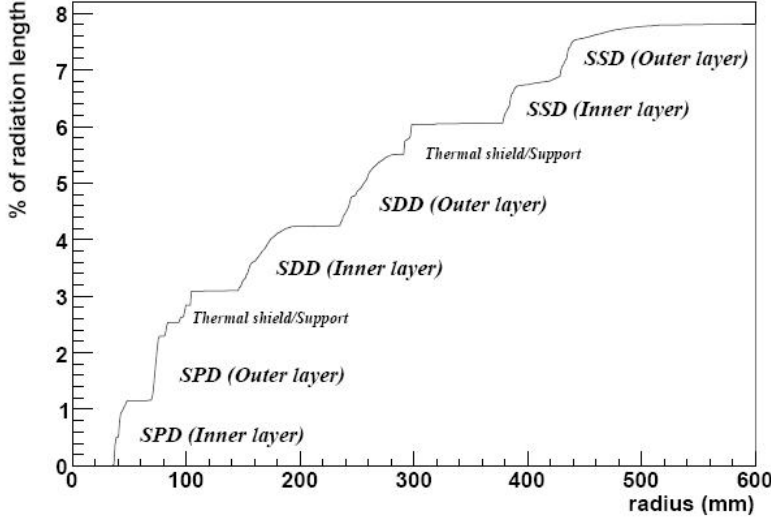


Figure 2.3: Percentage of radiation length as a function of the radius for the full ITS, including detectors and services.

2.1.2 Performance

The ITS is composed of 2198 modules placed and oriented in the space according to six roto-translational parameters. The resulting 13188 parameters need to be fine-tuned in order to have a realistic description of the detector with respect to the nominal construction specifications. The alignment of the detector is the first fundamental step before any track reconstruction can be made. The ITS has been efficiently aligned using cosmic and collision tracks. The points are used as input for a software algorithm based on global or local minimization of the residuals, called Millepede [19]. The validation of the SSD survey measurements after the installation has been done using cosmic tracks. The SPD and the SSD planes have been aligned separately and then with respect to each other, using cosmic tracks with no magnetic field. The SDD survey measurements were then validated and the SPD-SSD four planes were used to confirm and refine the calibration measurements of the charges drift time. The full ITS was finally aligned using cosmic tracks with no magnetic field and with the 0.5 T magnetic field. The data from proton-proton collision sample, together with cosmic tracks, have been used to complete (e.g. to align the modules close

	SPD1	SPD2	SDD1	SDD2	SSD1	SSD2
res. misalign. $r\varphi$ [μm]	<10	<10	60	60	<15	<15
res. misalign. z [μm]	negl.	negl.	50	50	100	100

Table 2.2: ITS planes residual misalignment.

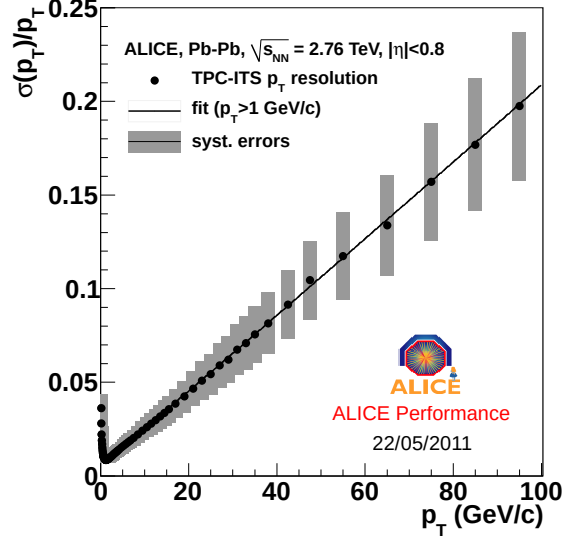
to the flat polar angle) and improve the alignment. The relative alignment of the ITS to the TPC has been performed in the meantime. The achieved alignment is well in agreement with the Monte Carlo ideal alignment within a random gaussian misalignment with a sigma of the order of the detector intrinsic precision. Results close to the final ones have already been reached for SPD and SSD using cosmic-ray data collected in 2008 [20]. The residual misalignment evaluated for all the ITS layers is summarized in table 2.2 [21].

Track reconstruction is performed in ALICE using an iterative algorithm which builds a track-point search-road, taking into account the local description of the various layers of the detector. The algorithm is called Kalman filter [16]. The tracking strategy will be described in detail in paragraph 4.4. The main role in the tracking is carried out by the TPC. Nevertheless only the combination with the ITS points gives the best performance in terms of momentum resolution, primary vertex reconstruction and impact parameter resolution. In figure 2.4 (a) the relative transverse momentum resolution is shown for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for tracks reconstructed with TPC and ITS. The resolution at low $p_t \lesssim 1$ GeV/c is dominated by multiple scattering but it is still less than 4% thanks to the ITS. The impact parameter resolution in the transverse plane ($d_0r\phi$) as a function of p_t , for tracks reconstructed with TPC and ITS is shown in figure 2.4 (b) (circular points). The impact parameter resolution is the convolution of the resolution of the track-position and the vertex resolution. The $d_0r\phi$ is the σ of the gaussian fit of the track Distance of Closest Approach distribution. The asymptotic impact parameter resolution is less than 10 μm . The agreement with Monte Carlo (triangular points in figure 2.4 (b)) is within 10%, but this value can be improved to ~ 1 % by further improving the description of the material budget [21].

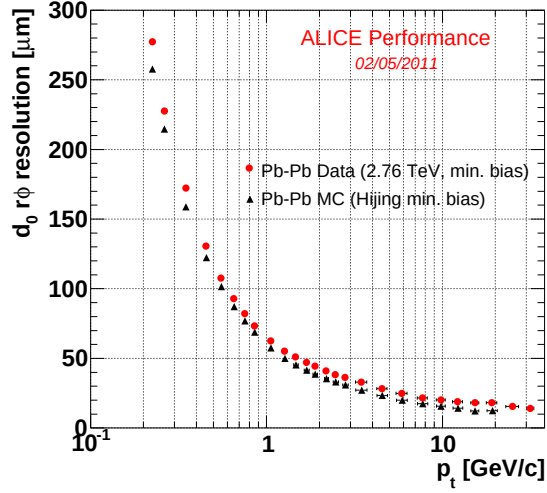
The ITS alone is used to extend the tracking capability to the very low- p_t region down to ~ 100 MeV/c, that is outside the TPC capabilities. An optimized tracking algorithm has been developed to reconstruct tracks with the ITS detector [22]. The ITS standalone tracking is robust and highly efficient. The transverse impact parameter resolution is shown in figure 2.5 (a) (circular markers), the points are evaluated from p-p collisions at $\sqrt{s} = 7$ TeV. The performance is the same as in the combined TPC+ITS tracking for the intermediate momentum region $0.2 \text{ GeV/c} \lesssim p_t \lesssim 1 \text{ GeV/c}$. The measurement is extended down to 90 MeV/c where the multiple scattering dominates and the resolution is $\lesssim 850 \mu\text{m}$. The resolution degrades with respect to the full TPC+ITS tracking for momenta greater than 1 GeV/c. The asymptotic resolution is of the order of $50 \mu\text{m}$. This is due to the limited number of points (six in total) and the small level arm of the ITS. The Monte Carlo (triangular markers in figure 2.5 (a)) is in excellent agreement with the data.

The tracking efficiency of the ITS is measured extrapolating the reconstructed TPC primary tracks to the ITS and checking if there are points which can be attached to it. The evaluation of this efficiency is shown in figure 2.5 (b) as a function of the track transverse momentum p_t for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Squared and circle markers, full for data and empty for Monte Carlo, give the efficiency for ITS tracks requiring at least two hits in two different layers of the ITS and at least one hit in one of the SPD layers, respectively. The efficiency is flat to 95% in the region of transverse momentum below 1 GeV/c if one requires at least two hits in the ITS and systematic drops of $\sim 15\%$ when requiring at least one hit in the pixel detector due to off modules. The performance degradation at high- p_t ($>1 \text{ GeV/c}$) is 5% for both conditions on hits. The agreement with Monte Carlo is extremely good (below the % level) in the low- p_t region, while the Monte Carlo slightly differs from data in the higher- p_t region of the circle markers datasets.

The SDD and the SSD analogue readout has a dynamic range large enough to provide the dE/dx measurement of low momentum ionizing particles [16]. This feature provides the ITS with a standalone capability for particle identification at very low- p_t . In figure 2.6 the dE/dx is shown as a function

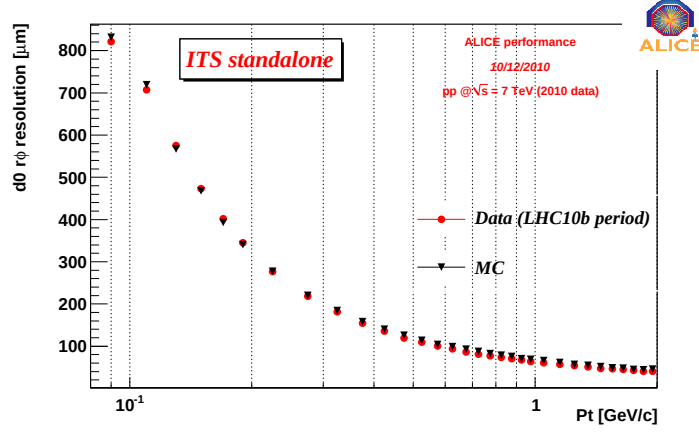


(a)

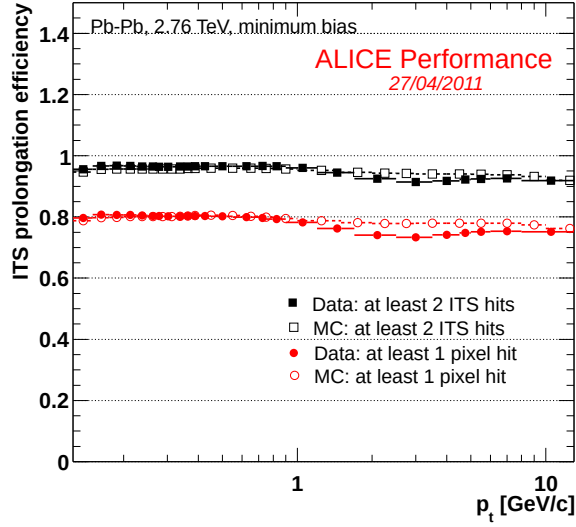


(b)

Figure 2.4: Tracking performance of ALICE using TPC and ITS points. Data from Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and Monte Carlo are shown. (a) Relative transverse momentum resolution as a function of the p_t and (b) transverse impact parameter resolution as a function of the track transverse momentum.



(a)



(b)

Figure 2.5: Tracking performance of the ITS detector. Data from Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and Monte Carlo are shown. (a) Transverse impact parameter resolution as a function of the transverse momentum for ITS standalone tracks. The resolution is the convolution of the resolution of the track-position and the vertex resolution. The $d_0 r_\phi$ is the σ of the gaussian fit of the track Distance of Closest Approach distribution. (b) Track reconstruction efficiency with ITS standalone measured by the extrapolation of TPC tracks to the ITS. Two tracks samples are defined, requiring at least two hits in two layers of the ITS and at least one hit in the SPD layer, shown by squared and circular markers respectively.

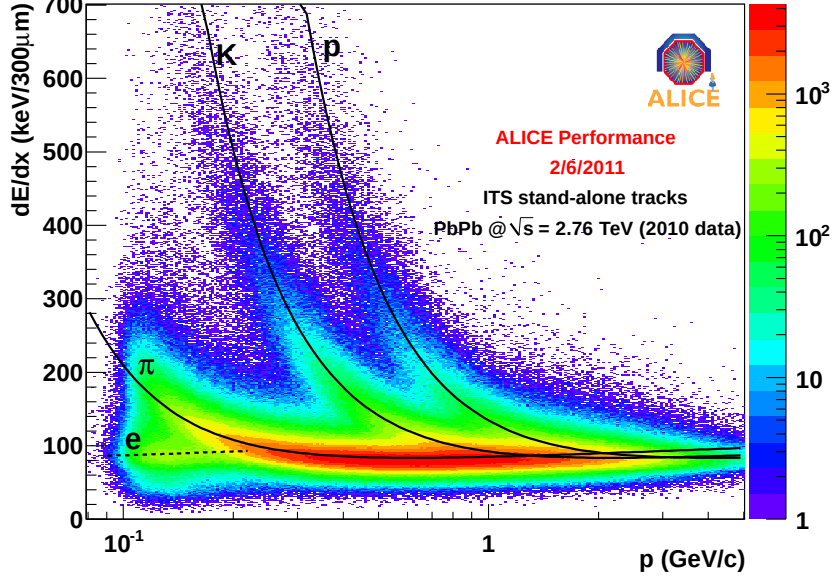


Figure 2.6: dE/dx of charged particles vs momentum measured by the ITS standalone in Pb-Pb collisions at 2.76 TeV. The solid lines are a parametrization of the detector response based on the Bethe-Bloch formula[23].

of the momentum in Pb-Pb collisions at $\sqrt{s}_{NN} = 2.76$ TeV. The solid lines are a parametrization [23] of the detector response based on the Bethe-Bloch formula. The ITS allows for hadron separation below 100 MeV/c, a region outside TPC and TOF PID capability. Good separation between pions and kaons is achievable up to ~ 0.5 GeV/c and between proton and kaons up to ~ 1 GeV/c.

2.2 The Silicon Pixel Detector

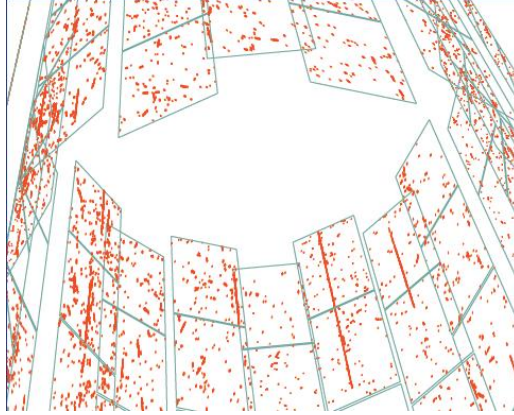
The Silicon Pixel Detector, SPD, is the innermost detector of ALICE. It consists of two layers of hybrid silicon pixel detectors placed at radii of 3.9 cm and 7.6 cm, respectively. The SPD is a fundamental element for the determination of the position of the primary vertex as well as for the measurement of the impact parameter of secondary tracks originating from the weak decays of strange, charm, and beauty particles. The physics targets are addressed by the SPD requirements of low material budget, high spatial precision, high double-track resolution and capability to work in an

environment with a high density of tracks, keeping a low occupancy for most central lead-lead collisions (see values in table 2.1). A special feature of the ALICE SPD is that it provides a prompt trigger signal, called fast-OR, which can contribute to the experimental L0 trigger decision. The pixel detector was installed in the experimental area in June 2007. The commissioning started in December 2007. During the first injection tests in June 2008 the SPD was able to record the first signs of life of LHC by registering secondary particles from beam dump upstream ALICE (figure 2.7 (a)). In the following months the SPD participated in the ALICE cosmic campaign which aimed to test the integration with all the experimental sub-systems and to acquire data for the alignment. Since the LHC start-up in November 2009 (figure 2.7 (b)), the SPD has been recording the LHC activities and in particular the first proton induced collisions in ALICE (figure 2.7 (c)). The SPD has recorded data and triggered events for the whole ALICE program with proton runs in 2010/11 and for the accomplished LHC heavy-ion program in November 2010 and 2011.

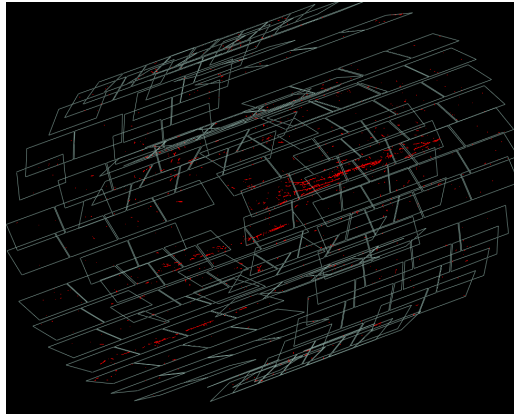
In this section a description of the layout and of the front-end electronics of the pixel detector will be given. The SPD *fast-or* trigger capability will be put in evidence.

2.2.1 Layout

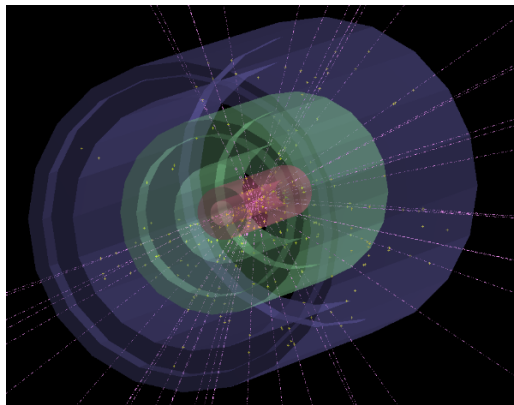
The average distance of the inner pixel layer from the beryllium beam pipe is ~ 9 mm. The SPD is composed of two half-barrels (see figure 2.8) mounted face-to-face around the beam-pipe and attached together. Each half-barrel is segmented into five sectors. The sector is the basic element of the mechanical structure of the SPD. It consists of a rigid carbon-fibre support $200\ \mu\text{m}$ thick in the sensitive region (see figure 2.9 (a)). It supports six longitudinal (i.e. along the beam axis) detector planes called *staves* and it contains the cooling pipes which are directly embedded in the carbon-fibre structure and run along each of the six planes, underneath the staves. A schematic view of the cross section of two close sectors is shown in figure 2.9 (b), where detailed construction parameters are expressed in millimeters. The geometry of the layers is optimized in order to have full coverage in the $r\varphi$ plane reducing to the minimum the overlaps between adjacent staves, which would increase



(a)



(b)



(c)

Figure 2.7: (a) Tracks generated by particles produced at the upstream dump during injection test. The figure shows a detail of the wire frame display of the inner layer; a straight longitudinal track ($\simeq 130$ mm in length) is clearly visible. (b) Event registered on November 20, 2009 evening during LHC circulating beams. (c) ITS view in ALICE event display. A collision event seen on November 23, 2009 with SPD in pink.

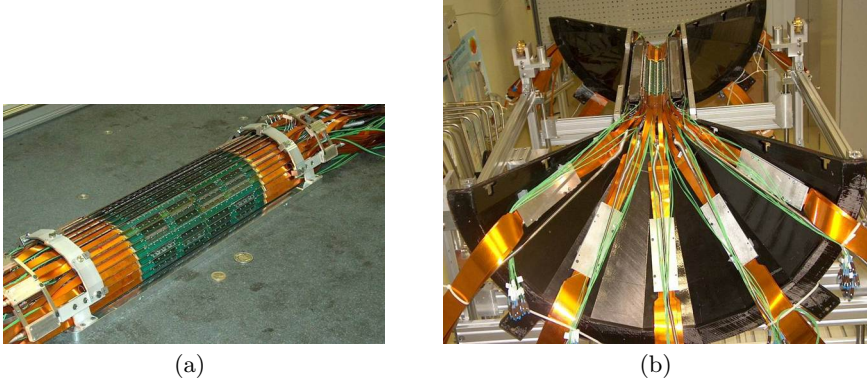
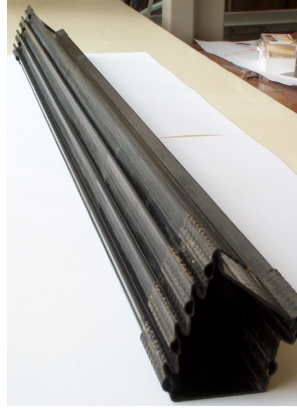


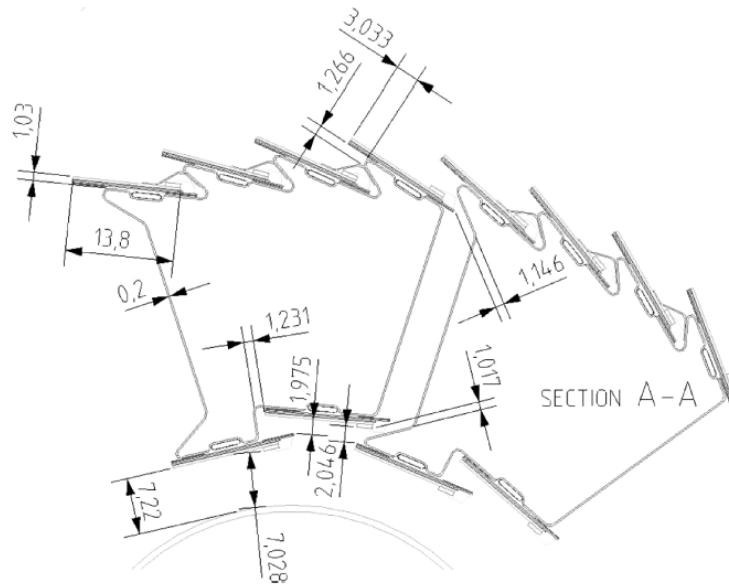
Figure 2.8: SPD half-barrel. Outer layer surface (a) and inner layer surface (b).

the material budget. The geometry of the inner layer alternates staves at two different radii which differ by about 4 mm (see figure 2.9 (b)). The radial distance from the interaction point is evaluated in the $r\varphi$ plane at the center of the stave. The inner layer staves are perpendicular to the radial distance line. The geometry of the outer layer is called *turbo*: all the staves are placed at the same radial distance and tilted with respect to this, at the same angle.

Every single stave is composed of two *half-staves* (HS) [16], see figure 2.10. The half-stave is the independent modular unit of the pixel detector. The full detector is composed of 120 HS. The half-stave consists of two *ladders*, a Multi Chip Module (MCM), a multilayer bus and a grounding foil made of kapton. The ladder is the detector element of the SPD. It is a two-dimensional matrix sensor, flip-chip bonded to five front-end chips. The MCM provides the communication between front-end electronics and the back-end electronics housed in the control room. It is connected to the back-end electronics via three single-mode optical fibres: two of them are used to transmit LHC clock and serial control to the HS, while the third one is used to transfer data produced by the detector. The two ladders and the MCM are glued on the grounding foil and the bus is glued on top of them. In figure 2.10 (b) all the components of the half-stave are shown in the correct spatial position before the gluing processes. The bus has five layers of high-density aluminium-polyimide. It provides the power to the front-end electronics and connects each of the five front-end chips to the



(a)



(b)

Figure 2.9: (a) Sector: carbon-fibre support of the pixels detector staves. (b) Schematic view of the transverse section of two adjacent sectors.

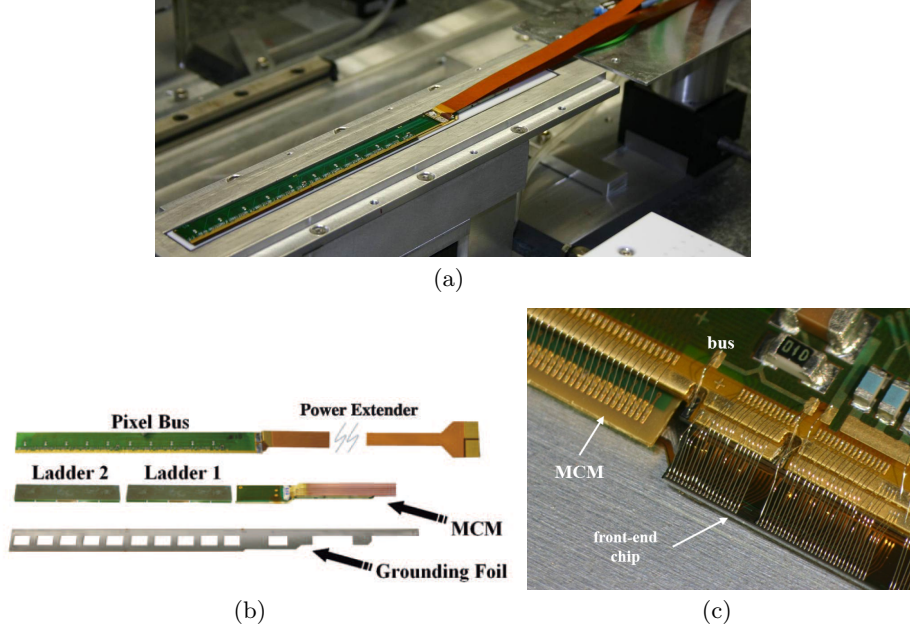


Figure 2.10: (a) SPD half-stave. (b) Half-staves components before assembling. (c) Zoomed view of a fully assembled half-stave. Close-up on wire-bondings connecting the bus with the MCM and with the front-end chip.

MCM. The electrical connections between chips and bus and between MCM and bus are realized with the wire-bonding technique. The wire-bonding connections are performed once the HS components are glued. A zoom on the HS wire-bondings is shown in figure 2.10 (c).

The sensor is a matrix of silicon p^+ -type implantations on a n^- -type Si substrate 200 μm thick. The sensor is connected via flip-chip bonding [24] to the five frontend readout chips. The electrical bonding is realized with a bump of SnPb alloy. The readout chip, ALICE1LHCb [25], is an ASIC circuit based on commercial CMOS technology at 0.25 μm . The pixel cell is 50 μm ($r\phi$) x 425 μm (along beam axes). Each front-end chip has 8192 channels of pixels arranged in a matrix of 32 columns and 256 rows (figure 2.11). The SPD contains 1200 readout chips and about 10^7 pixels. Each pixel is an independent readout-channel and provides digital information on whether it has been fired or not. The front-end electronics close to the sensitive area is mandatory since no off-detector electronics could manage such an amount of independent channels. The configuration of the chips can be optimized tuning the 44 internal DACs. Nevertheless the



Figure 2.11: SPD readout chip ALICE1LHCb [25].

final configuration was found optimizing the values of 10 DACs [26] which tune the global parameters of the single chip unit and of the whole HS. The internal circuitry of each pixel can be schematized as in figure 2.12. The circuitry is divided into an analog part and a digital part. The signal induced by a charged particle crossing the pixel sensor (*input pad*) is decoupled from the low reversed bias current (*feedback bias circuit*), amplified (*pre-amp*) and shaped by two differential shapers (*shaper 1* and *shaper 2*) in the first stages of the analog part. A *global threshold* is then applied to the whole chip. Signals above the threshold are digitized in the *discriminator*. At the level of the discriminator three bits are available to fine-tune the threshold of the single pixel. A *mask* can be eventually applied in case of noise. The capacitor C_{test} is used to induce a *test-pulse* which simulates the crossing charged particle. Offset and height of the test-pulse can be tuned by 2 DACs. The test-pulse has been used for testing and characterizing the chips in order to select those to be mounted in the SPD detector. The test-pulse played a key role during the commissioning phase without beams and today it is routinely used to monitor the status of the pixel detector electronics. For the pixel test strategy the test-pulse amplitude has been set to 100 mV in order to simulate normal incident minimum ionization particles crossing the sensor. The digital signal out of the discriminator is synchronized to the internal clock. The digital electronics is synchronous to the 10 MHz clock (CLK). A digital signal called *fast-OR* is promptly generated in parallel to

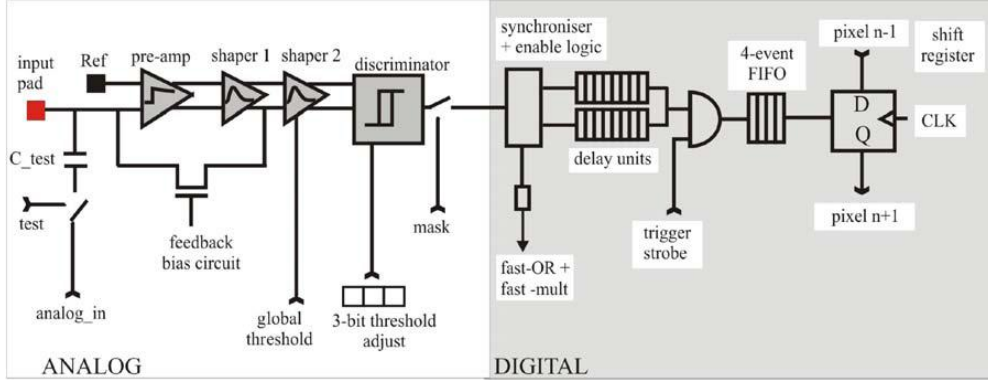


Figure 2.12: Circuit schema of a pixel cell of the SPD ALICE1LHCb readout chip.

the signal out of the discriminator. The fast-OR signal and the signal which carries the information about the hits are treated by different circuits. The hit-signal is properly delayed by the *delay units* to be put in coincidence with the *trigger strobe* signal. The triggered hit is temporarily stored in a four-position *FIFO* buffer and finally it is stored in a memory cell of the *shift register*. There are 32 shift registers, one for each column of the chip, containing 256 memory cells; each memory cell corresponds to a row of the chip. The chip is read out row by row at the 10 MHz clock frequency. The 10 chips in a half-stave are sequentially readout one after the other. The 120 HS are read in parallel. It takes $256rows \times 100ns \text{ clock cycle} \times 10chips = 256 \mu s$ to readout the full detector. During this time the detector is *busy* and no more trigger strobe signals are received.

2.2.2 Fast-OR trigger and Pixel Trigger system

The digital signal called fast-OR (FO) is promptly asserted on the presence of at least one pixel firing in a given readout chip. The FO signal, which is extracted from the chip, is the logical OR of all the signals generated at the level of the pixel cells. The circuitry dedicated to the fast-OR is tuned by four DACs which are used to improve the efficiency and the uniformity response of the whole matrix. The ten FO signals of the HS are sent to the MCM which transmits them in the datastream at each clock cycle. 1200 FO signals are extracted from the detector every 100 ns. Figure 2.13 shows the scheme of the paths covered by the FO signals. Fast-ORs are sent

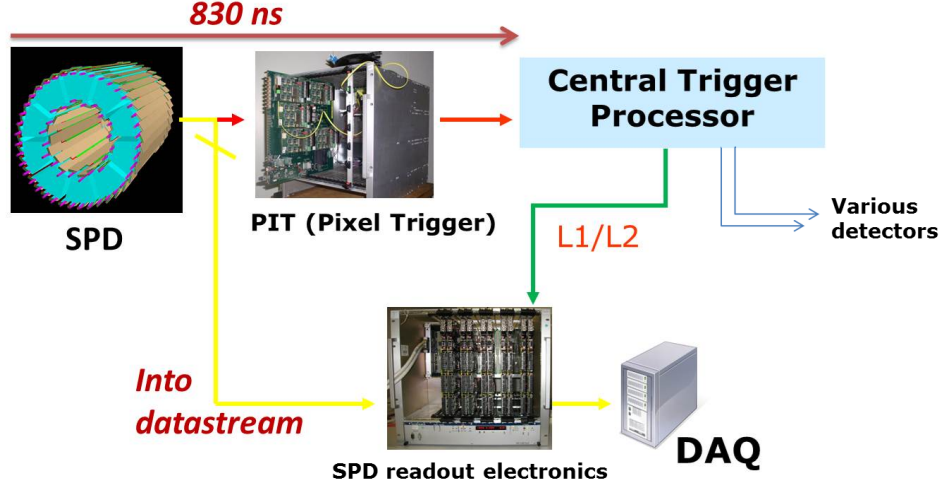


Figure 2.13: Schematic view of the fast-Or signals processing. The 1200 FO signals are extracted from SPD every 100 ns. The Pixel Trigger system elaborates them and a pre-processed signal is delivered to the ALICE Central Trigger Processor with an overall latency of 830 ns. All the FO signal are also written in the data for every triggered event (L1/L2) by the readout electronics.

both to the readout electronics to be written in the data payload and to the Pixel Trigger System (PIT). The Pixel Trigger system [27] elaborates in real time the 1200 FO signals received from the detector in order to generate the pre-processed signal for the ALICE level 0 trigger. The SPD on-detector electronics takes 350 ns to transmit the Fast-OR signals, the propagation delay on the fibers from the detector to the PIT is about 200 ns and the transmission of the results to the CTP requires 25 ns. Because of the 830 ns constraint on the overall latency, the PIT electronics has only 225 ns to extract and process the fast-OR signals. The Pixel Trigger System electronics is composed of ten optical receiver boards (OPTIN) and one processing motherboard (BRAIN). The ten OPTIN boards deserialize the received data and extract the 1200 fast-OR signals from the data flow. Each OPTIN board receives data fibers from the 12 half-staves corresponding to two half sectors. The BRAIN electronic boards process the FO signals elaborating various algorithms, which can be based on coincidence logic or counting based logic.

The SPD electronics works with a 10 MHz clock and the FO signals are synchronous to the internal clock. The LHC bunch crossing frequency is 40

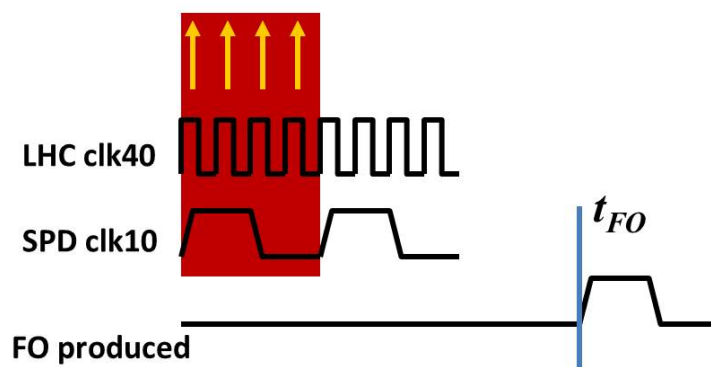


Figure 2.14: Time relationship between LHC 40 MHz clock and SPD 10 MHz clock. The SPD integrates four consecutive bunch-crossings (red region). The interactions can occur in the positions indicated by the yellow arrows. There is only one FO signal, produced at the time t_{FO} , associated to the four consecutive bunches.

MHz, therefore the SPD clock integrates four consecutive bunch-crossings, as shown in the red region of figure 2.14. The yellow arrows indicate where the interactions can occur. The FO signal associated to the four consecutive bunches is produced at the t_{FO} instant. All the FO signals are synchronized to the same integration period covering the same set of bunch-crossings. Two electronic registers align the SPD clock to the LHC clock: the *BClock*, which provides 25 ns shifts, and the *FineDelay1*, which can fine-tune the alignment down to a level of a tenth of nanosecond.

Chapter 3

SPD Detection Efficiency, first results

3.1 Detection efficiency with cosmic-ray tracks

The first global commissioning of the ALICE detector performed in 2008 consisted basically of cosmics data acquisition. Almost all the amount of data collected by the ITS has been taken using as L0 input in CTP the SPD fast-OR trigger output, called 0SCO. The 0SCO trigger output consists of a logic AND between at least one hit in the top-outer SPD layer and at least one hit in the bottom-outer SPD layer (see the sketch in figure 3.1). This choice of the trigger made the data acquisition very efficient in terms of number of cosmic-ray tracks passing through the ITS planes and reduction of background events due to FO noise. The collected cosmic data sample has been used to align the ITS as explained in section 2.1.2. The achieved good quality of the SPD alignment [20] is fundamental to evaluate the SPD efficiency with the developed method [28].

The method developed to evaluate the SPD efficiency uses only SPD points. The SPD point is referred to a *cluster* of contiguous fired pixels. The coordinates in the three-dimensional space refers to the center of gravity of the cluster. Hereafter *point* and *cluster* are being used indifferently. The efficiency is defined as the ratio:

$$Eff = \frac{N_{succ}}{N_{probe}}$$

where N_{succ} and N_{probe} are the number of clusters produced by a sample of probing tracks and the number of probing tracks in that sample, respectively.

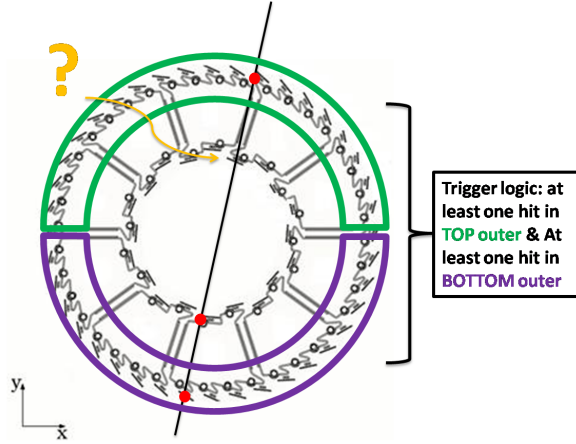


Figure 3.1: Transversal section (xy) of the SPD barrel. The trigger logic consists of a logic AND between at least one hit in the top-outer SPD layer (green region) and at least one hit in the bottom-outer SPD layer (violet region). The method to evaluate SPD efficiency uses only SPD points (red circles). The first two points are in the outer layer and the third one is in the inner layer. A probe track, indicated in this sketch by the black line, is built and provides a prediction for the fourth point, indicated by the question mark, in the inner layer hemisphere opposite to that of the third point (indicated by the question mark).

The probing track is built using three space points: two points are in the outer layer and they are thought to produce the trigger condition. The third point is in the inner layer. The probing track makes a prediction for the fourth point in the inner layer hemisphere opposite to that of the third point. The fourth point is sought according to such a prediction thus providing the method to estimate the efficiency of the detectors intersected by the probing tracks. This kind of analysis provides the evaluation of the efficiency of the inner layer only, due to the bias introduced in the outer layer by the trigger logic. The schematic of the method is shown in figure 3.1. The analysis presented here has been performed using cosmic data taken without magnetic field.

Starting from the two reconstructed points on the outer layer, the line passing through them is considered, and a third reconstructed point compatible with the line, within the errors, is searched for in the inner layer. This third point is accepted if its distance from the line is less than a cut-value, calculated in global coordinates system (i.e. in space). In such a case, the three points are fitted using a straight line by means of the ordinary least squared method and the probing track is built. Two

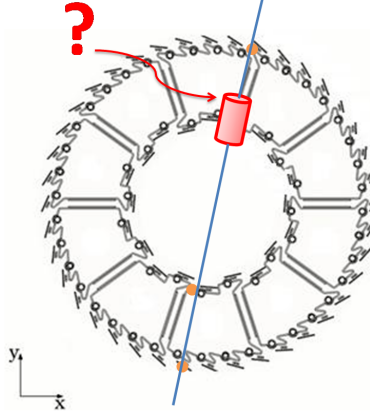


Figure 3.2: Sketch of the first searching criterium to associate a cluster to a probing track. The probing track, indicated by the blue line, is built by fitting a straight line to three reconstructed points (indicated by the orange closed circles) by means of the least squared method. A reconstructed point compatible with the track is searched for, looking at its distance in space from the probing track.

methods are considered when searching for the fourth point. In the first method, a fourth point compatible with the probing track is searched for by considering the distances in space between the fitted straight line and the other reconstructed points of the event in the inner layer hemisphere opposite to the one of the third point. In the evaluation of the efficiency, the basic unit of the SPD is chosen to be the chip. If a reconstructed point is found with a distance less than a given cut value, then both N_{succ} and N_{probe} of the chips to which the fourth point belongs, are increased by unity. If no point can be found, then only N_{probe} of the chip intersected by the probing track is increased by unity, provided that the chip was active in data acquisition (checked run by run). A sketch of this method is drawn in figure 3.2. The second method consists of looking for the fourth point within a fiducial area using the local module coordinate system (x_{loc}, z_{loc}) : this fiducial area is defined as a rectangle centered at the intersection of the probing track with the module surface whose sides are cut-values. The same cuts are applied *a priori* to the probing track based on the distance of the point of intersection from the borders of the chip, this is to avoid ambiguities among the chips intersected by the track. In such a way, the probing tracks which are close to the borders of a chip are not considered. A sketch of this

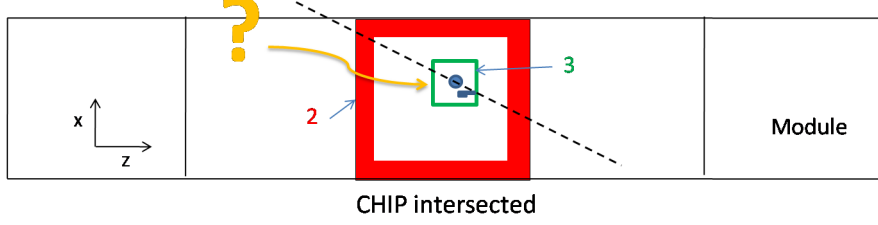


Figure 3.3: Sketch of the second method to search for clusters compatible with the probing track. In this sketch an SPD module with its five chips is shown in the local coordinate system (x, z) . The probing track, indicated by the dashed black line, intersects one of the chips in the point indicated by the blue dots. A cut is applied a priori to the probe track based on the distance between this point of intersection and the borders of the chip; therefore, all the tracks passing through the red frame (2) are not considered. The reconstructed points found inside the fiducial area, defined by the rectangle (3) centered at the intersection point, are considered compatible with the probing track.

method is shown in figure 3.3.

The second method has a better resolution on the chip intersected and it is also more sensitive to the alignment since the possibility to predict the wrong chip increases. The first method, on the contrary, smears the efficiency between close chips and is less sensitive to the accurate knowledge of the geometry. In the left panel of figure 3.4 the distribution of the third point residuals is shown, for a Monte Carlo simulation (black line) and for 2008 data (red line). Imposing the cut for the third point equals 1 mm, the distribution of the residual for the fourth points is considered. In the right panel of figure 3.4 the fourth point residual distribution in the first method is shown. In figure 3.5 the distributions of residuals for the fourth points in the second selection method are shown. The left and right panels show the distributions of the local x and z coordinates, respectively.

Two different geometries are used for the Monte Carlo simulation and for the data. The MC simulation uses the ideal geometry in which an estimated residual misalignment is then applied. The residual misalignment corresponds to the one expected (see the discussion in paragraph 2.1.2) after the detector is finally aligned using a high-statistics sample of pp collisions. The difference between the ideal geometry and the one in which the residual misalignment is applied is called Δ_{MC} . The data have been processed using at that time the best knowledge of the actual geometry, the

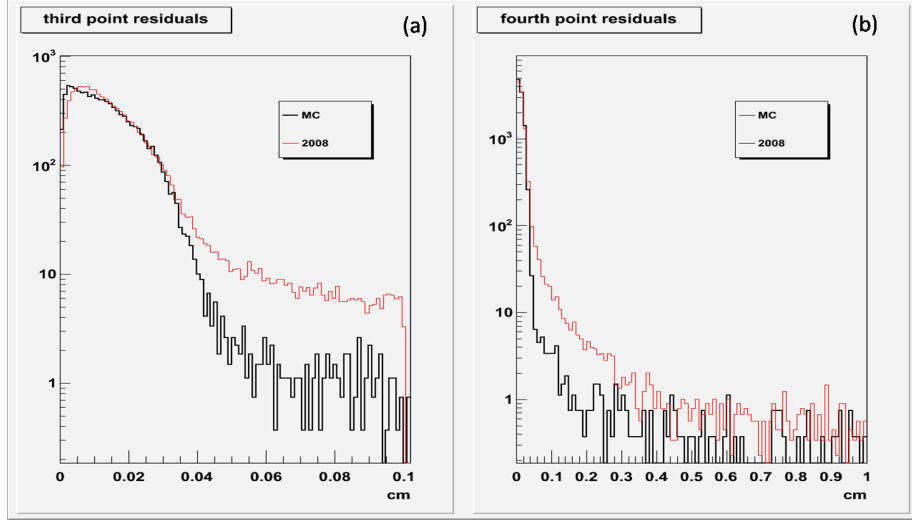


Figure 3.4: Left panel: distribution of the closest distances in space between the track predictions (line through two points in the outer layer) and the third point for the Monte Carlo simulation (black) and data (red). Right panel: distribution of the closest distances in space between the track predictions (through three points) and the fourth point in the inner layer for Monte Carlo simulations (black) and data (red).

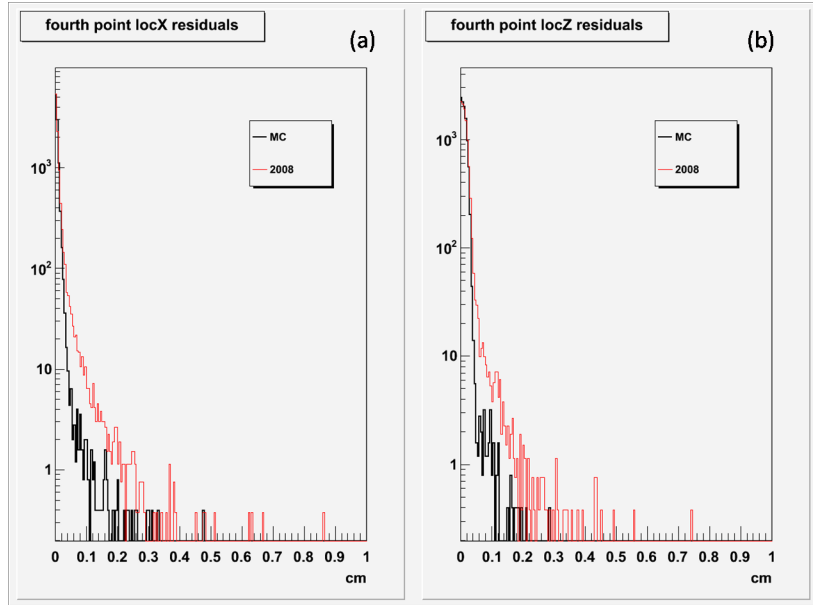


Figure 3.5: Distributions of residuals for the fourth point in the local coordinate system of the module. Results for Monte Carlo simulation are shown in black, data in red.

one realigned with cosmic tracks. Δ_{Data} is the difference between the actual detector geometry and the realigned one. The observed difference between the residual distributions (figure 3.5) in Monte Carlo and data can therefore be associated to the inequality $\Delta_{MC} < \Delta_{Data}$. Data used in these plots come from a sample of about 1.5×10^5 thousands events triggered by SPD and without magnetic field.

3.1.1 Analysis and results

The whole cosmic sample of 2008 comprises all the different SPD commissioning steps made in 2008. The sample used to evaluate the SPD efficiency is the selected sample in which the SPD is most stable and best optimized. This sample has about 5.7×10^4 events. The cut chosen for the third point is set at 1 mm. This value is good for background rejection and, at the same time, it keeps a good statistics of probing tracks with a good 3-points linear fit. The cut value of 1 cm is used when considering the first selection method for finding the fourth-point. In figure 3.6 the resulting chip-by-chip efficiency is shown. The chip key number, plotted on the x -axis, uniquely points out the chip of an HS. The numbering is organized as follows: the ten chips of an assigned HS are consecutive. The ten chips of the second HS, in the same stave of the previous one, are successively lined up. The staves are counted counterclockwise starting from $\varphi = 0$. The empty parts in the plot correspond to the chips which were always off during the data acquisition of the selected sample. In figure 3.7 the chip-by-chip statistics are shown; the blue points correspond to the number of times the probing tracks have intersected a chip and the red points to the number of times the fourth point was associated to a probing track. A cluster of ten chips in the region near to chip number 225 is affected by lower efficiency. This cluster is identified as the half-stave 5A0 in the online numbering scheme of the SPD [29]. This half-stave was known to be of problematic configuration. Its lack of statistic is a sign of frequent exclusions from data acquisition. A single point which is low and has a large error bar corresponds to chip 133. This single chip is known to be 50 % off due to hardware reasons. The overall plane efficiency of the inner layer is calculated integrating all the entries of all chips, excluding chip 133 and all the chips of the half-stave

5A0. The integrated statistic is of the order of 2.8×10^4 and the efficiency is 99.86 ± 0.02 %. The analogous result for the Monte Carlo simulation is 99.77 ± 0.02 %.

It is interesting to observe how sensitive the method is to improvements in the configuration of the detector. The chip efficiency for the whole 2008 cosmic statistics sample is shown in figure 3.8. Seven HS with a non optimal configuration, including 5A0, have a lower efficiency, as shown in the black circles of figure 3.8. The overall efficiency, still excluding bad configured HS, was slightly lower ($\lesssim 1\%$) with respect to the final one.

The second method for the fourth point selection is considered next. The cuts for both the x and z local coordinates were set at 2 mm. This has the effect of reducing the chip statistics because tracks passing through the borders of the chips are excluded. The overall statistic is of the order of 1.5×10^3 . The integrated efficiency is evaluated excluding chip 133 and half-stave 5A0 and it yields 99.40 ± 0.20 %. The equivalent Monte Carlo result is 99.91 ± 0.02 %.

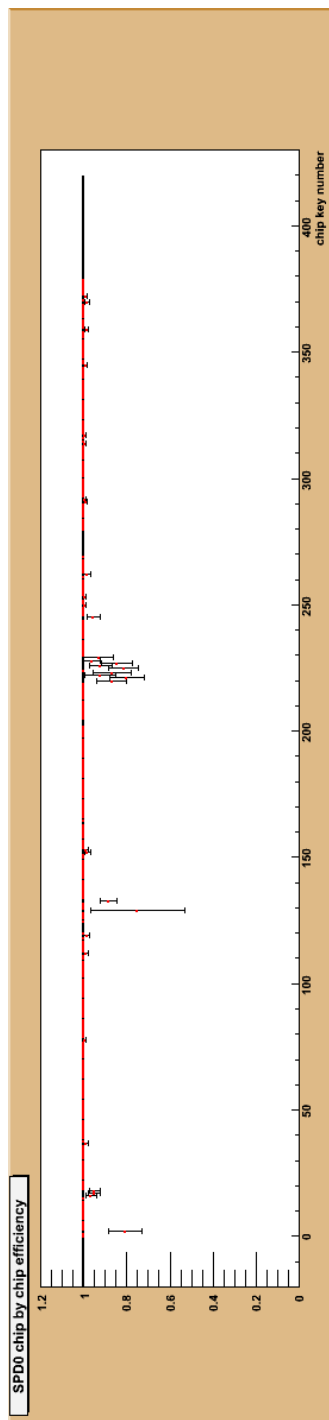


Figure 3.6: Chip-by-chip inner layer efficiency.

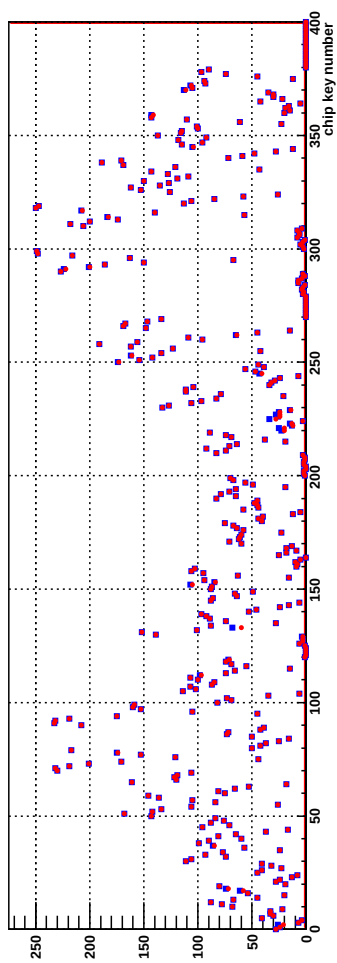


Figure 3.7: Chip-by-chip inner layer statistics. Points in blue are the number of times probing tracks have investigated, points in red are the number of times the fourth point is found.

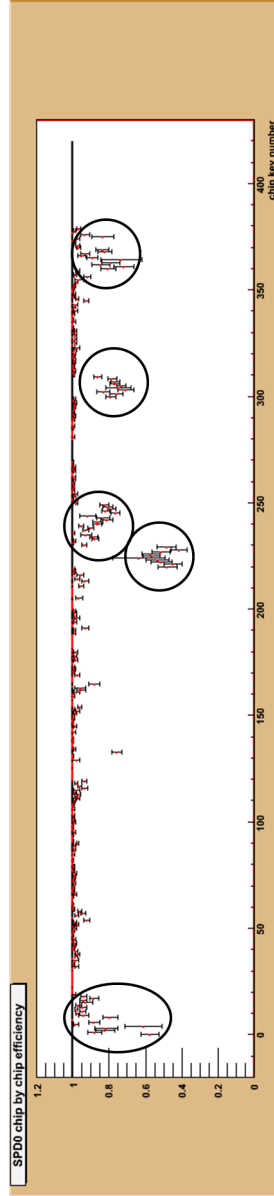


Figure 3.8: *Chip-by-chip inner layer efficiency for the full 2008 cosmic data sample.*

The efficiency of the active part of the detector in the Monte Carlo simulation is set at 100 %. However, due to the differences in the geometry descriptions, Monte Carlo simulation and data can be affected in a different way by two effects: ambiguities between active and dead chips and non-hermetic acceptance of the detector. The ambiguities between active and dead chips can occur if the simulated track passes through the border of a dead chip but the prediction of the probing track points toward an adjacent active chip. This effect is suppressed using the second method for the fourth point selection. The non-hermetic acceptance of the SPD is due to the geometry, which is optimized for tracks coming from a primary vertex and not for cosmic tracks. These two effects occur both in the Monte Carlo simulation and data, but their amount can be different due to the different geometry descriptions. The systematic uncertainty is associated to the method used and is calculated taking the difference between Monte Carlo results from both selection-types. It affects the overall efficiency by 0.14%.

The efficiency could be affected by background. The background is evaluated studying uncorrelated events; the probing track is built in one event and the fourth point is looked for in the next uncorrelated event. The background ratio, Bkg , is the probability to find a cluster compatible with a probing track in uncorrelated events, and is used to correct the measured value of efficiency, Eff_{raw} . The true efficiency, Eff_{true} , can be derived by solving the equation 3.1.1.

$$Eff_{true} = Eff_{raw} - (1 - Eff_{true}) \cdot Bkg \quad (3.1.1)$$

Bkg is 10.84 % for the first selection method and Eff_{true} is 99.84 %. The second selection method, on the contrary, returns a negligible value of Bkg .

The methods developed and the results obtained validate the procedures used to calibrate the detector. Therefore the results obtained can be extended as order of magnitude also to the efficiency of the outer layer. The measured efficiency, greater than 99%, is compatible with the results obtained at test beam [30] and has been taken into account to evaluate the systematic uncertainty in the measurement of the charged particles pseudorapidity density in proton-proton collisions at $\sqrt{s} = 900$ GeV [31].

Chapter 4

SPD Trigger Performance

The prompt trigger capability of the pixel detector is decisive for the ALICE experiment. The role of the SPD during cosmic data taking was explained in subsection 3.1. The trigger strategy during the first year of LHC operation was to collect a large amount of minimum bias events therefore the fast-OR trigger was included in the definition of the minimum bias trigger class and was systematically used for the whole data taking period. The study of the performance of the fast-OR trigger system was mandatory to understand the data and to maximize the data taking efficiency. The data taking scenario is introduced in this section in order to motivate the choices done for the performed analysis. The methods to determine the performance of the fast-OR trigger are described and the results are given.

4.1 Data taking scenario

The V0 detector and the SPD provide the L0 trigger inputs used in the the Minimum Bias trigger class, named usually *CINT1B* (review subsection 1.3 for the terminology concerning the trigger). The VZERO detector consists of two arrays of 32 scintillator tiles placed at distances $z = 3.3$ m and $z = -0.9$ m from the nominal interaction point, covering the full azimuthal angle within $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C). Two more signals were used to define the CINT1B class; these signals are taken from the two beam pick-up counters (BPTX), one on each side of the interaction point, and they indicate the presence of the passing bunches. In proton-proton collisions at 0.9 TeV [31, 32] and at 7 TeV [33], the minimum-bias trigger required a hit either in one of the VZERO counters or in the SPD

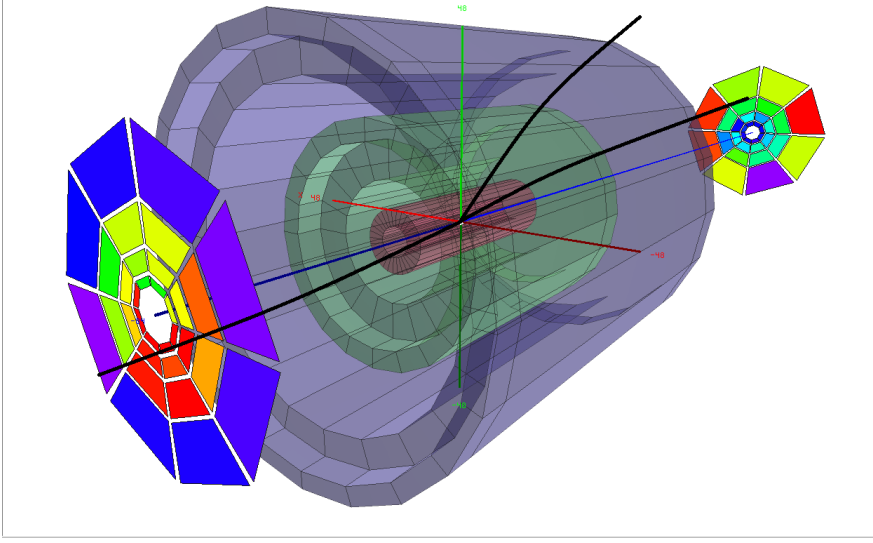


Figure 4.1: Sketch of the two V0 scintillator arrays and the ITS. The minimum-bias trigger requires a hit in either one of the VZERO counters or in the the SPD detector, i.e it requires at least one charged particle anywhere in the 8 units of pseudorapidity.

detector; essentially it required at least one charged particle anywhere in the eight units of pseudorapidity covered by these trigger detectors (the 3D view of the the V0 and the ITS, with SPD in pink, is shown in figure 4.1). In p-p collisions at the intermediate energy $\sqrt{s} = 2.36$ TeV only the SPD was used because the V0 was unavailable. The BPTX signals were in coincidence with the detector inputs. The definition of the minimum bias in lead-lead collisions was different but the same trigger detectors were used. The threshold for the SPD input was set to at least two fast-OR signals fired in the outer layer in order to reduce the QED background. The trigger required two out of three of the following conditions [10]: (i) SPD input active, (ii) a signal in V0A, (iii) a signal in V0C.

The LHC accelerator works at the bunch crossing frequency of 40 MHz. The beams are injected from SPS into the two rings of LHC: beam 1 into ring 1 and beam 2 into ring 2, running clockwise and counterclockwise respectively (see figure 4.2). Particles in the beams are grouped in *bunches*. The bunch is confined inside the 25 ns bunch crossing clock cycle. It has to be mentioned, for completeness, that the machine RF frequency is 400 MHz and so the particles are actually confined in one tenth of 25 ns [34]

(called *bucket*). Bunches of protons and lead nuclei at the energies of 450 GeV and 178 GeV respectively are injected. After the injection process is finished the beams are accelerated and finally induced to collide in the four intersection points where ALICE, ATLAS, CMS and LHCb detectors are placed (see figure 4.2). All these different stages define the LHC *fill*. The fill is over when the beams are lost, due to problems in the machine, or when the instantaneous luminosity goes naturally to zero due to collisions in the experimental areas. The bunches are injected into LHC according to a predefined temporal sequence called *filling scheme*. The bunches in a ring are spaced by multiples of the 25 ns bunch crossing. Bunches in ring 1 and ring 2 are coupled to each other and synchronized in order to collide in an intersection point. The bunches in the couples intersect each other and never to other bunches from other couples. For symmetry reasons the couple which intersects in one point will intersect also in its symmetric point in the ring. So, looking at the figure 4.2, the same couples of bunches collide in both ATLAS and CMS while two other sets of couples collide in ALICE and LHCb only. The filling scheme contains information about the time in which the bunches in the rings will intersect or pass through a given experimental area: the unit of time is the bunch crossing, 25 ns, and the number of bunch crossings, $BCid$, separating the bunches from the experimental area are counted. The maximum separation is the full ring circumference (~ 27 km) and it corresponds to 3563 bunch crossings. The motion of the bunches is periodic with period $\sim 88.9 \mu s$, that is the bunches revolution time in the rings.

In section 2.2.2 it has been stressed out that the SPD fast-OR trigger provides a signal which integrates four consecutive bunch crossings. Nevertheless the filling schemes provided by the machine during the first year of data taking never foresaw bunches spaced less than two SPD clock cycles. The integration time of the pixel-hit data was set to three consecutive clock cycles, centered on the bunch crossing of the event, by tuning the length of the strobe signal (see section 2.2.1). The use of such a wide strobe length represents a conservative choice which cancels the probability of losing pixel-hit data due to a non optimal synchronization. On the other hand the correct synchronization is mandatory to have a correct real time elaboration

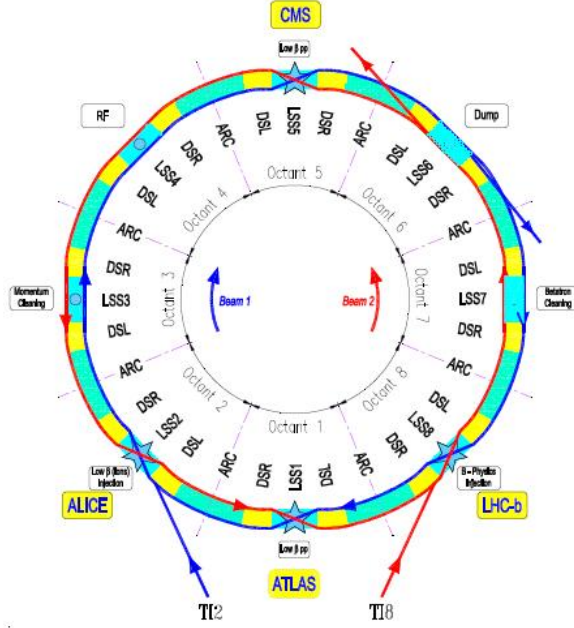


Figure 4.2: LHC rings schematic view. The beams run into the two rings of the 27 km LHC tunnel. Beam 1 and beam 2 run clockwise and counterclockwise respectively. The beams cross in the four experimental points where the detectors are built. The four detectors are ALICE, ATLAS, CMS and LHCb.

of the L0 signal by the PIT. The methods used to measure and optimize the synchronization and the performance of the fast-OR trigger are tackled in the next sections.

4.2 Fast-OR Efficiency

The first fundamental step is to test the correct functioning of the off-detector systems related to the FO trigger. In figure 4.3 the schematic view of the FO signals processing is shown (see also figure 2.13 in section 2.2.2). The 1200 FO signals are extracted from the SPD every 100 ns and split into two different paths. The PIT system elaborates them and provides the L0 input signals to the CTP. The FO signals are also stored in the back-end electronics. When an event is triggered the FO bits and the L0, L1 and L2 inputs activated are registered in the data. A method to check the correct elaboration of the PIT L0 signals and the correct writing of the FO bits by the back-end electronics has been developed. The method is based on offline data analysis. The algorithms elaborated online by the PIT are

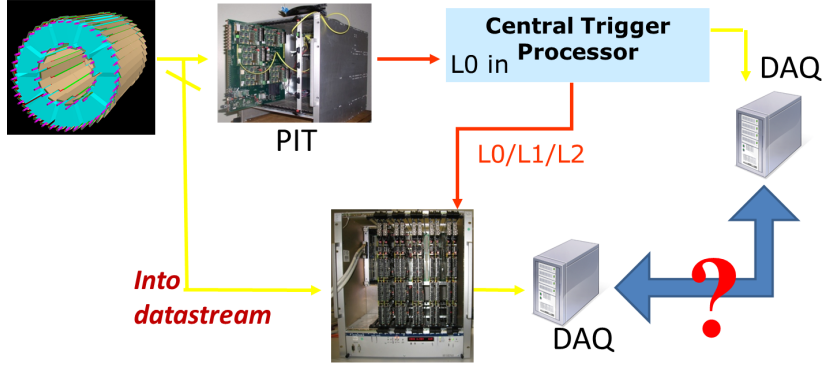


Figure 4.3: Schematic view of the FO signal processing. The 1200 FO signals are extracted from the SPD every 100 ns. The Pixel Trigger system elaborates them and a pre-processed signal is delivered to the CTP. For every triggered event (i.e. an event in which the sequence L0/L1/L2 is true) the FO signals are written into the data by the readout electronics and the sequence of L0, L1 and L2 is written into the data by the CTP.

imposed offline on the FO bit data to check the correspondence with what is received by the CTP.

In the first weeks of data taking with proton-proton collisions at $\sqrt{s} = 7$ TeV the L0 inputs connected to the CTP were five. Different thresholds in terms of FO fired chips were set to different inputs. The input used to define the minimum bias trigger class, called 0SMB, used a threshold requiring at least one fired chip, as explained in section 4.1. The other inputs were not used to trigger, nevertheless the CTP registered them in the data. The other inputs were called 0SBK, 0SH1, 0SH2 and 0SH4. The thresholds set were respectively: at least two fired chips; at least 20 fired chips in the inner layer; at least 40 fired chips in the inner layer; at least 40 fired chips in the inner layer in coincidence with at least 40 fired chips in the outer layer. The method described above was applied for the first time to the data collected in p-p collisions at $\sqrt{s} = 7$ TeV. In table 4.1 the results obtained for a data sample of 1.1×10^5 events triggered by the V0 detectors are shown. The first column shows the trigger inputs, the second column shows the percentage of the events in which the input is triggered in the data but the signal is not sent to the CTP and the third one shows the percentage of events in which the input signal is sent to the CTP but the data miss the trigger condition.

L0 input	match %	Data & !PIT %	!Data & PIT %
0SMB	99.61	0.39	0
0SBK	99.39	0.61	0
0SH1	86.65	13.55	0
0SH2	69.84	30.16	0
0SH4	67.40	32.60	0

Table 4.1: FO trigger system validation studies. The first column shows the trigger inputs, the second column shows the percentage of events in which the input is triggered in the data but the signal is not sent to the CTP and the third column shows the percentage of events in which the input signal is sent to the CTP but the data miss the trigger condition. The inputs were called 0SMB, 0SBK, 0SH1, 0SH2 and 0SH4. The thresholds set were respectively: at least one fired chip; at least two fired chips; at least 20 fired chips in the inner layer; at least 40 fired chips in the inner layer; at least 40 fired chips in the inner layer in coincidence to at least 40 fired chips in the outer layer.

It was observed that the PIT was affected by inefficiency. In order to spot a systematic inefficiency in the chips a further test is performed within the method. The test is the following: the events with one FO bit active and no 0SMB registered by the CTP are selected and the chips giving the FO bit are identified. On the contrary, if the inefficiency is at the level of the back-end electronics the events with 0SMB and with one pixel-fired chip are selected and those chips are identified. In figure 4.4 the chips having a FO bit active without giving the 0SMB are displayed. The chips are identified by the chip key, as explained in section 3.1.1. The groups of chips are part of the same half-staves. The half-staves which did not participate in the elaboration of the 0SMB signal were twelve and they were part of two adjacent half sectors. It was found soon after that the two half sectors share the same OPTIN (review section 2.2.2) which activated an uncontrolled automasking electronic feature. The bug in the PIT system was immediately fixed and the matching restored to 100%. The impact of the 0SMB inefficiency on the CINT1B trigger class has been also evaluated. The fraction f of lost minimum bias events is defined in equation 4.2.1,

$$f = \frac{2 \times e}{N_{CINT1B} + 2 \times e} \quad (4.2.1)$$

with N_{CINT1B} being the number of CINT1B events recorded and e being the number of events which are not triggered by the V0 detector but are

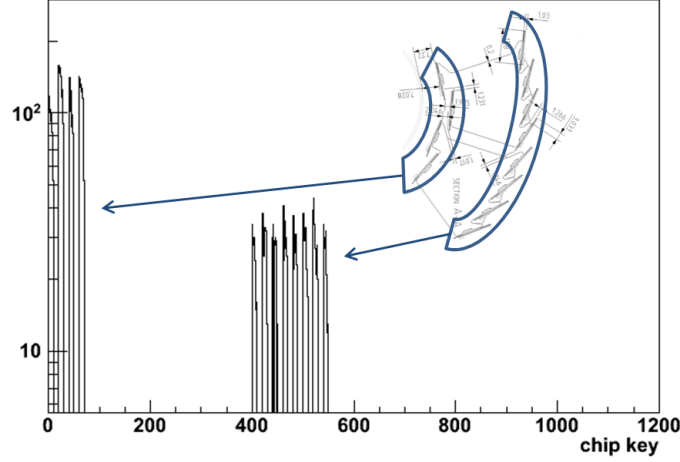


Figure 4.4: Chips having a FO bit active without giving the OSMB for a data sample of 1.1×10^5 proton-proton collisions events at $\sqrt{s} = 7$ TeV triggered by the V0 detector. The events selected are those with a single FO fired chip and no OSMB L0 input delivered to the CTP.

triggered by the OSMB input activated by FO signals in one half sector. The fraction of lost events given by the test was $f = 3.6 \cdot 10^{-4}$.

The method to debug the FO trigger system just described was applied in the experimental area during the commissioning phase with beams in proton-proton collisions at $\sqrt{s} = 7$ TeV. The method is currently implemented in the automatic checks which guarantee the good quality of the data of the SPD detector. It is important to stress that the results of this check-up test and in particular the perfect matching between data and online PIT elaboration signals, give reliability to any other study based on offline data analysis of the SPD FO trigger.

Fast-OR signal efficiency

A method has been developed to evaluate the efficiency of the FO signal production for each of the 1200 readout chips. The method is entirely based on offline data analysis. It consists of checking whether a FO signal is produced or not when the chip matrix has been fired by at least one pixel hit. If the FO is found active the chip is considered efficient. The analysis was carried out separately for the four different phase relationships

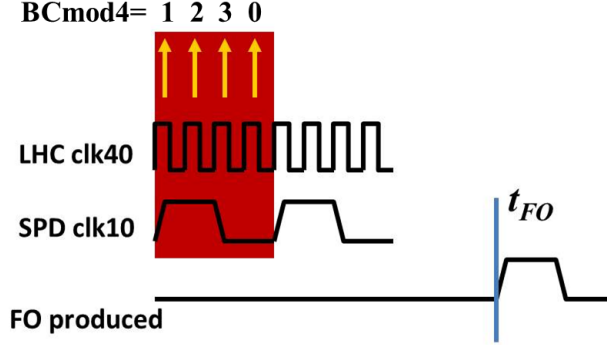


Figure 4.5: Time relationship between LHC 40 MHz clock and SPD 10 MHz clock. The SPD integrates four consecutive bunch-crossings (red region). The interactions can occur in the positions indicated by the yellow arrows and named $BCmod4$ equals to 1, 2, 3, 0. There is only one FO signal, produced at the time t_{FO} , associated to the four consecutive bunches.

between the SPD and the LHC clock. A different behavior depending on the relative phase was observed. It was possible to understand this effect with the statistics collected during first proton-proton collisions ($\sqrt{s} = 900$ GeV) delivered in November 2009. The results obtained, which are shown hereafter [35], were fundamental to understand the data at the time of the first multiplicity density studies in proton-proton collisions [31, 32, 33]. In the ALICE global time reference system the collision event occurs in a defined BCid, which is indicated relatively to the SPD time reference system by taking the remainder of the BCid number divided by four, the so called $BCmod4$. The four possible bunch-crossings in which the interaction can occur have the $BCmod4$ number equal to 1,2,3 and 0 as shown in figure 4.5. The way the $BCmod4$ number is ordered is irrelevant so the historical approach is to be used. The first filling-schemes for p-p collisions at $\sqrt{s} = 900$ GeV were called 4x4a, 4x4b, 4x4c and had two couples of interacting bunches in ALICE corresponding to $BCmod4$ equals to (0,3) and (1,3). In p-p collisions at $\sqrt{s} = 2.36$ TeV the scheme was 2x2 with only one couple of interacting bunches with $BCmod4$ equal to 2. The FO efficiency for a data sample of 1.1×10^5 events in the 4x4c scheme, triggered by the V0 and with $BCmod4$ equals to 3, is shown in figure 4.6. The top part shows the chip-by-chip efficiency, while the bottom part shows the statistics per chip when a pixel is fired (blue marker) and when a FO signal is found

(red marker). The efficiency is the ratio of these numbers. All the chips are numbered from 0 to 1199 (x axis). The modulation of the statistics follows from the detector layout and in particular from the position of each individual chip along the beam axis with respect to the interaction vertex: entries from 0 to 399 indicate chips in the inner layer, closer to the interaction point, while entries from 400 to 1199 indicate the outer layer ones. The ramp structure is due to the chips acceptance with respect to rapidity, with the highest peaks for chips in the central region and the lowest peaks for chips in the high rapidity region. Holes in the efficiency distribution come from the part of the detector which is switched off. Apart from single isolated inefficient chips, groups of low efficiency chips are part of the same critical HSs. This is the case of chips around 250 and 750 and chips between 1050 and 1150. The overall efficiency is greater than $\approx 99\%$ (655 chips out of 904 have efficiency greater than 99%). The same values of efficiency have been evaluated for BCmod4 equal to 0 and 2. The BCmod4 equals to 2 represents an exceptional case, for proton-proton collisions at $\sqrt{s} = 2.36$ TeV the only 0SMB input was used to trigger the events. Nevertheless the 0SMB threshold (i.e. at least one FO bit active) does not introduce an observable bias in the efficiency measurement. The FO signal efficiency is also evaluated selecting events with 0SMB in the data sample of figure 4.6, and the difference $FOeff - FOeffB$ between the efficiency of the unbiased sample and the efficiency of the forced biased sample is shown in figure 4.7.

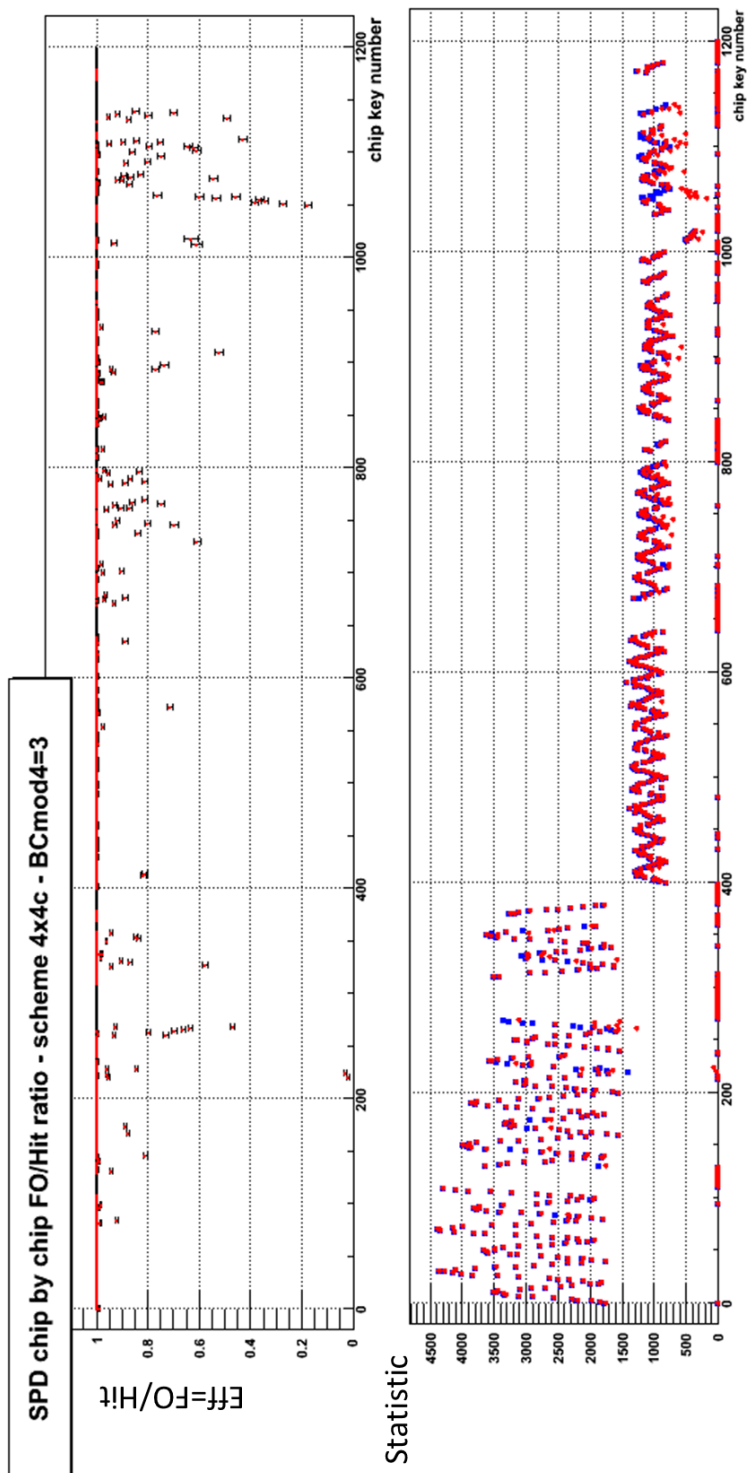


Figure 4.6: (top) chip-by-chip FO signal efficiency evaluated for a sample of data of p-p collisions at $\sqrt{s} = 900$ GeV triggered by the V0 detectors, in BCmod4=3. (bottom) Statistics per chip when a pixel is fired (blue marker) and when a FO signal is found (red marker). The efficiency is the ratio of these numbers.

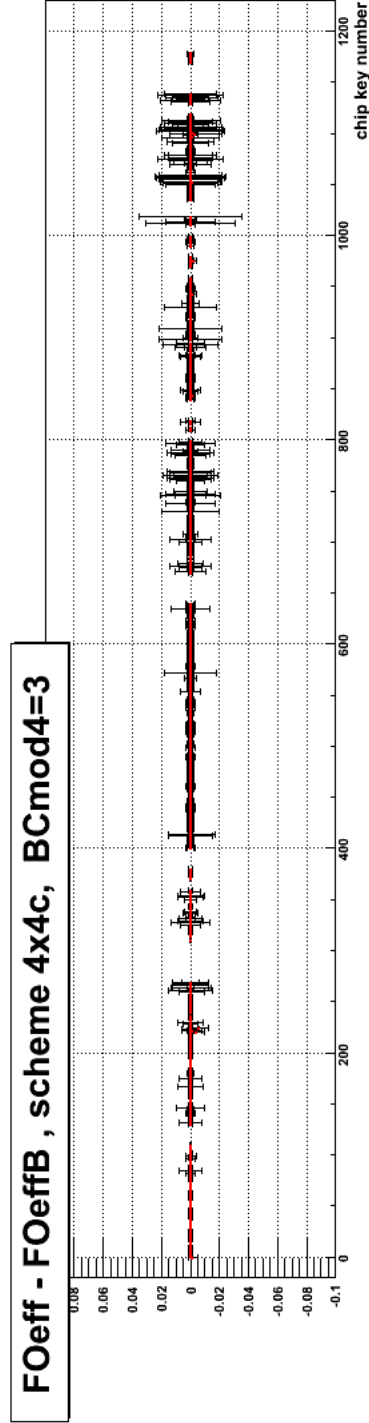


Figure 4.7: Chip-by-chip difference between FO efficiency evaluated with the unbiased sample (i.e. triggered by the V0 detectors) and the FO efficiency evaluated with the forced biased sample (i.e. triggered by OSMB).

For BCmod4 equal to 1 and 0 the positions of the interaction are close to the rising edges of the SPD clock (see figure 4.5), and it may happen that the corresponding FO signals are assigned to the previous or following 10 MHz clock cycle (BCmod4=1 and BCmod4=0 respectively) due to the intrinsic internal spread in time of the FO signal propagation. As a consequence, the trigger information may not be propagated with the proper timing t_{FO} with respect to the datastream of the correct event and the trigger efficiency is lower. The timing effects on the efficiency can be stressed if the SPD clock and LHC clock are not perfectly aligned. No effect is observed for BCmod4 equal to 2 but a significant reduction of efficiency is observed for BCmod4 equal to 1. In figure 4.8 the FO efficiency (top) and the statistics (bottom) are shown for a data sample with filling scheme 4x4c and BCmod4=1. The overall efficiency drops down from about 99% to about 75%. This means that the SPD clock anticipates the LHC clock. Therefore the SPD clock is shifted left so that the rising edge on the left of figure 4.5 (BCmod4=1) is partially out of the red region while the rising edge on the right (BCmod4=0) is well inside the red region.

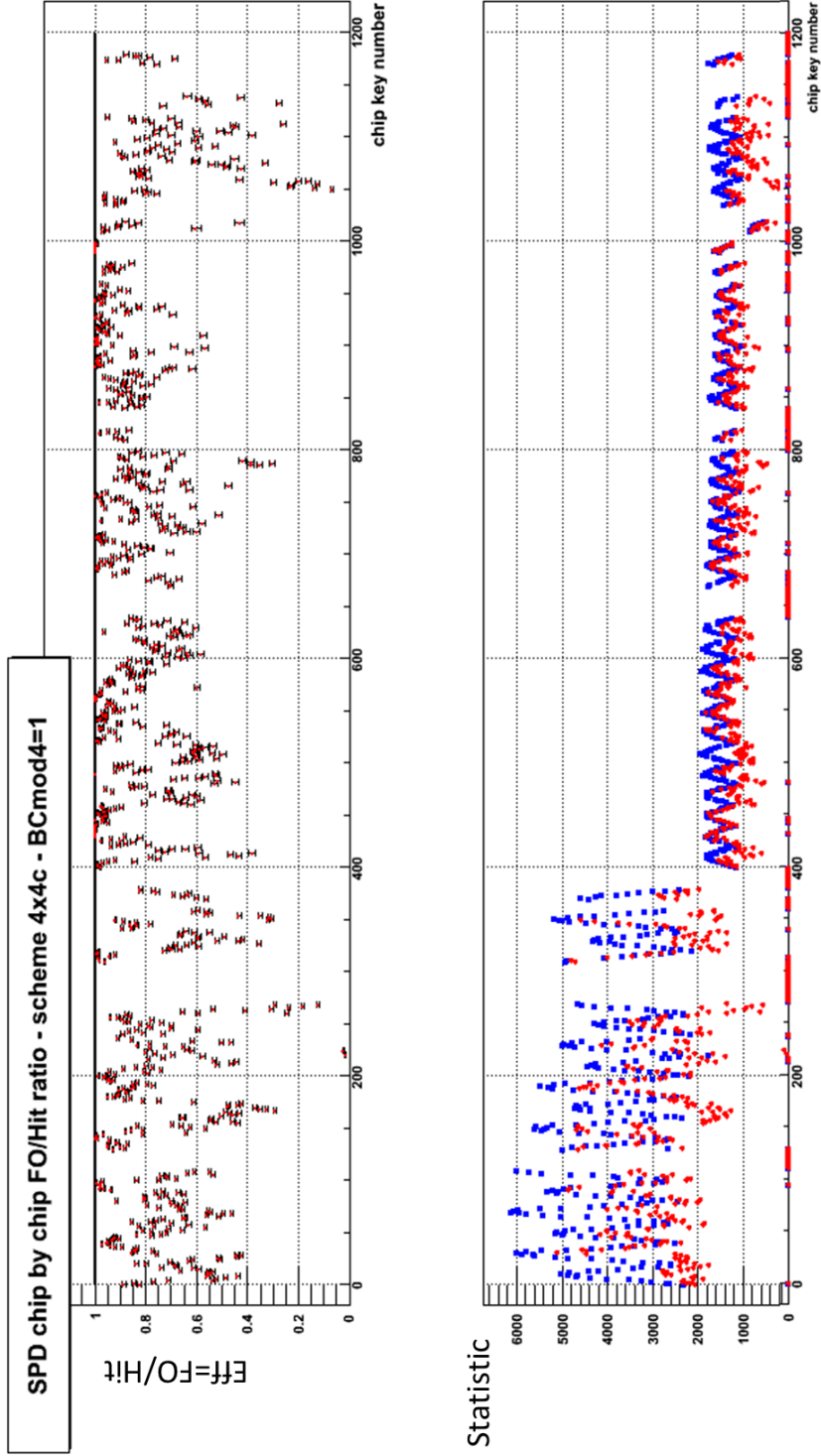


Figure 4.8: (top) chip-by-chip FO signal efficiency evaluated for a sample of data of p-p collisions at $\sqrt{s} = 900$ GeV triggered by the V0 detectors, with BCmod4=1. (bottom) Statistics per chip when a pixel is fired (blue marker) and when a FO signal is found (red marker). The efficiency is the ratio of these numbers.

The method introduced provides a powerful tool to monitor the performance of the FO trigger system and it is constantly in use in the experimental area as a reference measurement. The results obtained applying this method to the first collisions data gave rise to a fine tuning of the alignment of the SPD clock with respect to the LHC clock.

SPD clock alignment

The synchronization between the SPD clock and the LHC clock is mandatory in order to optimize the performance of the FO trigger and to balance its response among the four phase relationships. The distribution in time of the average number of fired pixels $\bar{n}(t)$, measured in proton-proton collision events, is the convolution of two effects: the natural time spread of particles produced in the collisions reaching the detector and the internal time spread associated to the elaboration of the signals in the analog circuitry up to the discriminator. Both the pixel hit signal and the FO signal are affected by these two effects (review figure 2.12 in section 2.2.1). The digital elaboration of the data integrates multiples i of the 100 ns clock cycle. Therefore it is not possible to directly measure $\bar{n}(t')$ at a given time t' . The only measured quantity is the integral function $\bar{N}(t')$, defined in equation 4.2.2.

$$\bar{N}(t') = \int_{t'-i \cdot 100\text{ns}}^{t'} \bar{n}(t) dt \quad (4.2.2)$$

$\bar{N}(t)$ is measured for various values of t by tuning the clock shift. If two consecutive measurements $t = t'$ and $t = t' + \epsilon$ are such that ϵ is small compared to the integration time $i \cdot 100\text{ns}$ and if $\bar{n}(t)$ is null for $t \rightarrow -i \cdot 100\text{ns}$, one can interpret $\bar{N}(t)$ as the characteristic function of the pdf $\bar{n}(t)$ and write the 4.2.3.

$$\bar{N}(t) = \int_{-\infty}^t \bar{n}(\tau) d\tau \longrightarrow \bar{n}(t) = \frac{d\bar{N}(t)}{dt} \quad (4.2.3)$$

Taking the discrete limit for the right expression of equation 4.2.3 one obtains:

$$\bar{n}(t') = \frac{\bar{N}(t' + \epsilon) - \bar{N}(t')}{\epsilon} \quad (4.2.4)$$

A scan to determine $\bar{N}(t')$ has been performed by changing the clock shifts t' with steps ϵ of few nanoseconds (tuning the *BClock* and the *FineDelay1* as

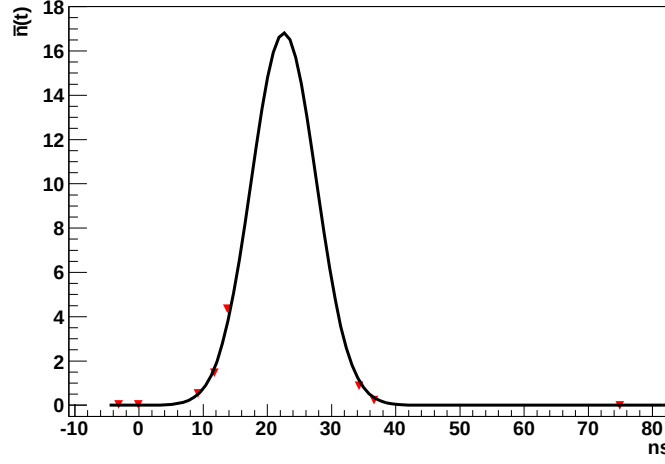


Figure 4.9: Distribution in time of the average number of fired pixels $\bar{n}(t)$ in proton-proton collisions at $\sqrt{s} = 7$ TeV.

explained in section 2.2.2) and integrating over $i = 1$ clock cycles. Dedicated runs with proton-proton collisions at $\sqrt{s} = 7$ TeV were taken for each clock shift. Equation 4.2.4 was used to evaluate the distribution of the average number of fired pixels. In figure 4.9 the results of the scan are shown in red triangular markers. The points of the scan are not enough to define the shape of $\bar{n}(t)$ in the whole time range. The aim of the scan was indeed only to observe the limits of the interval in which the distribution starts to rise from zero and falls down to zero. In addition to this, it is important to stress that the ordinary activity of ALICE data taking was interrupted in order to perform the scan. The solid line in figure 4.9 represents a reasonable guess for the fit function of the distribution. The fit function is a gaussian centered in 22.5 ns with $\sigma = 5$ ns. In view of the outcome of this measurement the SPD clock was shifted 8.4 ns forward. In figure 4.10 the distributions of the average fired pixels are shown for collisions occurring in all the four phase relationships. The areas under the curves which are inside the red rectangle (i.e. the SPD clock cycle) contribute to the synchronized production of the FO signals at the time t_{FO} . If the collisions occur in the rightmost phase, part of the distribution is out of the clock cycle. In the gaussian hypothesis the area beyond $t = 100$ ns (in the interval $[2.1\sigma, +\infty[$) is of the order of 2%. One can assume that 2% of the FO signals in this phase, will be statistically

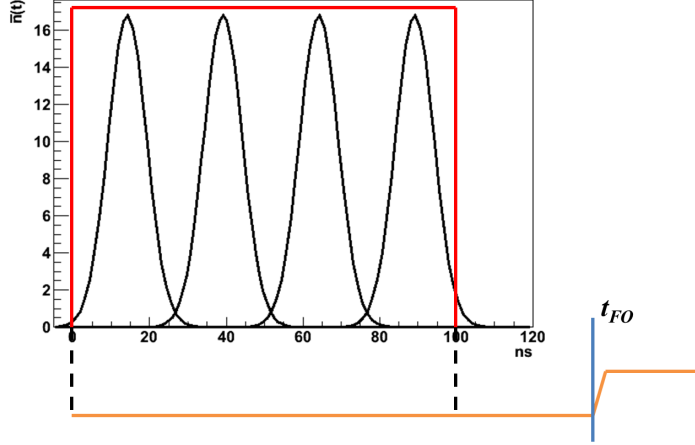


Figure 4.10: Distribution in time of the average number of fired pixels $\bar{n}(t)$ for collisions occurring in the four phase relationships of the SPD clock with respect to the LHC clock. The areas under the curves which are inside the red rectangle (i.e. the SPD clock cycle) contribute to the synchronized production of the FO signals at the time t_{FO} .

lost.

Fast-OR signal efficiency: final results

The FO signal efficiency is finally evaluated and checked for the four phase relationships in proton-proton collisions at $\sqrt{s} = 7$ TeV [36]. In figure 4.10 the four different distributions are shown, corresponding to the four different phases of the events, numbered from 0 (left) to 3 (right). The FO efficiency per chip for phase 0 is shown in the top part of figure 4.11 and the correspondent statistics is shown in the bottom part. The same efficiency distribution is observed for phases 1 and 2. As expected from the clock alignment results explained above, the efficiency for these three phases is maximized, while a slight drop is expected for phase 3. Figure 4.12 shows the FO efficiency for phase 3. A general reduction of efficiency for all the chips is observed.

Table 4.2 summarizes the results of the integrated efficiency for all the four phases. The measurements confirm the expected drop of about 2% for phase 3. The configuration in which three out of four phases are fully efficient and the fourth has a 2% drop is preferred because of the LHC filling schemes.

During the commissioning phase of 2010 and early 2011 LHC did not fill all the bunches with particles. In this way it was possible to move the SPD clock (by tuning the *BClock* as explained in section 2.2.2) in order to have most of the interactions in the fully efficient positions.

The method for the determination of the FO efficiency was also applied

Phases	Efficiency [%]
Phase 0	$98,778 \pm 0,002$
Phase 1	$98,745 \pm 0,004$
Phase 2	$98,653 \pm 0,002$
Phase 3	$96,840 \pm 0,003$

Table 4.2: Integrated FO signal efficiency for the four different phase relationships of the interactions with respect to the SPD clock. The phases are numbered from 0 to 3 for collisions occurring respectively from the first quarter to the last quarter of the SPD clock cycle. The data are from proton-proton collisions at $\sqrt{s} = 7$ TeV.

on the occasion of the first heavy-ion runs in autumn 2010 for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [37]. The results obtained for the four phases are summarized in table 4.3. The efficiency values are consistent, as expected, with those obtained in proton-proton collisions. However the phase dependence is slightly enhanced in Pb-Pb. The differences observed between the values in table 4.2 and the ones in table 4.3 are related to the fact that in Pb-Pb collisions there is a higher track occupancy per chip and a broader distribution in time of the fired pixels.

Phases	Efficiency [%]
Phase 1	$99,232 \pm 0,004$
Phase 2	$99,223 \pm 0,004$
Phase 3	$99,172 \pm 0,005$
Phase 4	$96,466 \pm 0,005$

Table 4.3: Integrated FO signal efficiency for the four different phase relationships of the interactions with respect to the SPD clock. The phases are numbered from 0 to 3 for collisions occurring respectively from the first quarter to the last quarter of the SPD clock cycle. The data are from lead-lead collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

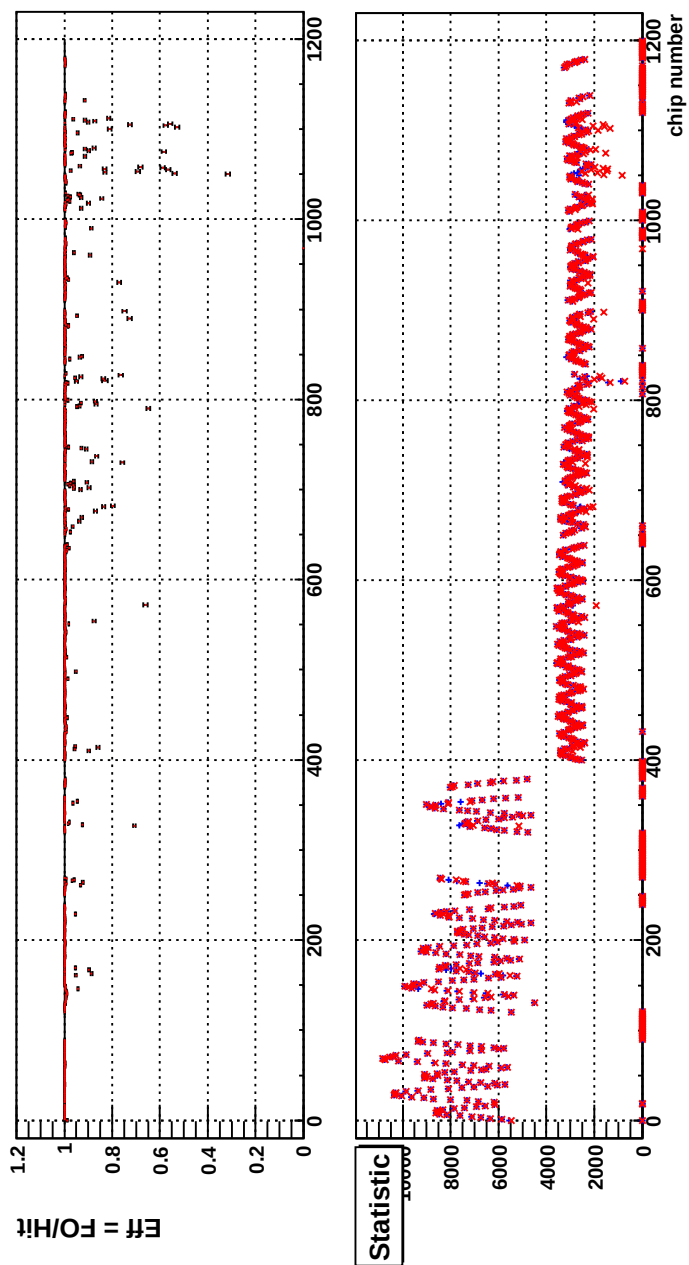


Figure 4.11: Top part: chip-by-chip FO signal efficiency for clock phase 0 (bunch crossing in the first quarter of the SPD clock). Bottom part: statistics per chip when a pixel is fired (plus marker) and an FO signal is found (cross marker). The efficiency is the ratio of these numbers. The data are from proton-proton collisions at $\sqrt{s} = 7$ TeV.

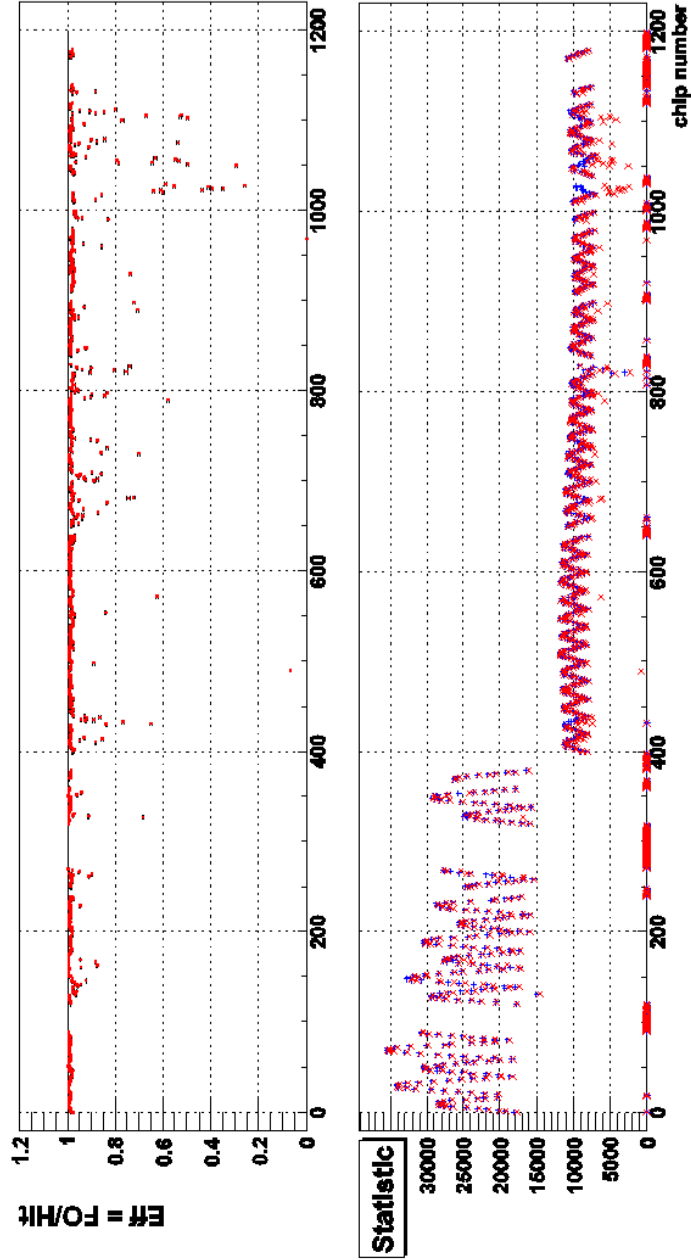


Figure 4.12: Top part: chip-by-chip FO signal efficiency for clock phase 3 (bunch crossing in the last quarter of the SPD clock). Bottom part: statistics per chip when a pixel is fired (blue plus marker) and an FO signal is found (red cross marker). The efficiency is the ratio of these numbers. The data are from proton-proton collisions at $\sqrt{s} = 7$ TeV.

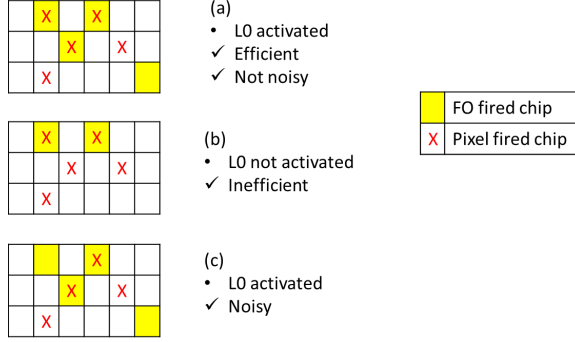


Figure 4.13: Method to evaluate the performance of the FO trigger. The L0 input is assumed to be activated for $THR = 3$. The boxes in the three matrices represent the chips fired by a pixel-hit (red cross) and fired by the FO bit (yellow filled box). (a) L0 is active and N_{match} is equal to three: L0 is considered efficient and not noisy. (b) L0 is not activated but the fired chips exceed the L0 threshold: L0 is considered inefficient. (c) L0 is active but N_{match} is less than three: L0 is considered noisy.

4.3 Trigger Performance

A method to evaluate the performance of the FO trigger has been developed. This method is a natural extrapolation of the method used to determine the FO signal efficiency described in section 4.2. The physical observable used for the measurements is the pixel hit. In each event the number of chips N_{match} with the correct matching between pixel hit and FO hit is counted. If N_{match} exceeds the threshold THR of the given L0 input, the L0 input is considered efficient. If the L0 input is activated but N_{match} is less than THR the L0 is considered noisy. The image in figure 4.13 explains how the method works. The L0 input is assumed to be activated for THR equal to three. The boxes in the three matrices represent the chips, which can be fired by at least one pixel hit (red cross) and with the FO bit active (yellow filled box). In case (a) L0 is active and N_{match} is equal to three: L0 is considered efficient and not noisy. In case (b) L0 is not activated but the fired chips exceed the L0 threshold: L0 is considered inefficient. In case (c) L0 is active but N_{match} is less than three: L0 is considered noisy. The efficiency and the noise for a L0 input are calculated as in equation 4.3.1, and 4.3.2 respectively.

$$Eff(L0) = \frac{\text{events in case (a)}}{\text{events in case (a)} + \text{events in case (b)}} \quad (4.3.1)$$

Eff. %	Phase 0	Phase 1	Phase 2	Phase 3
0SMB	99.976±0.002	100	99.965±0.002	100
0SBK	99.344±0.272	92.369±0.402	91.966±0.270	83.322±0.541
0SH1	90.161±0.311	89.970±0.435	89.014±0.296	78.688±0.567
0SH2	88.502±0.409	88.672±0.570	87.595±0.387	75.035±0.731
0SPF	91.097±0.788	91.324±1.117	90.830±0.746	77.476±1.538

Table 4.4: FO trigger efficiency for different L0 inputs and for the four phases relationships between SPD clock and LHC clock. The efficiency, defined in equation 4.3.1, is evaluated for a data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV triggered by the V0 detectors. The inputs tested were 0SMB, 0SBK, 0SH1, 0SH2, 0SPF, corresponding respectively to at least 1 FO fired chip, 130 FO fired chips, 65 FO fired chips in the outer layer, 70 FO fired chips in the outer layer and 170 FO fired chips.

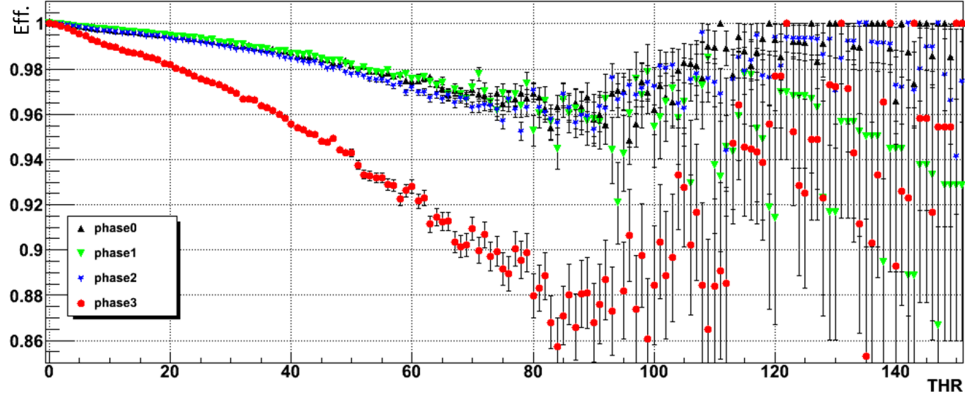
$$Noise(L0) = \frac{\text{events in case (c)}}{\text{events in case (a)} + \text{events in case (c)}} \quad (4.3.2)$$

The method was applied to a data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV trigger by the V0 detectors. All the inputs connected to the CTP were tested: 0SMB, 0SBK, 0SH1, 0SH2, 0SPF, corresponding respectively to at least 1 FO fired chip, 130 FO fired chips, 65 FO fired chips in the outer layer, 70 FO fired chips in the outer layer and 170 FO fired chips. They were tested in all the four different phase relationships. Only the 0SMB was used as trigger input for the minimum bias class CINT1B. The other inputs were continuously changed in order to test the high multiplicity triggers. The results are shown in tables 4.4 and 4.5. The 0SMB input is fully efficient and the level of noise is negligible, that is there is always a matching between a fired chip and a FO signals produced: the multi-track environment in proton-proton collisions is such that the drop in efficiency on phase 3 (see figure 4.12) does not to affect the 0SMB efficiency. On the other hand, the combination of the FO signals efficiencies becomes significantly important when requiring higher thresholds for the L0 inputs. A drop in the efficiency is observed both in the most efficient phases (phases 0, 1 and 2) and in the events in phase 3 with respect to the other phases. Noise, as expected, is independent of the phase. The higher the L0 inputs threshold is the higher the contribution is.

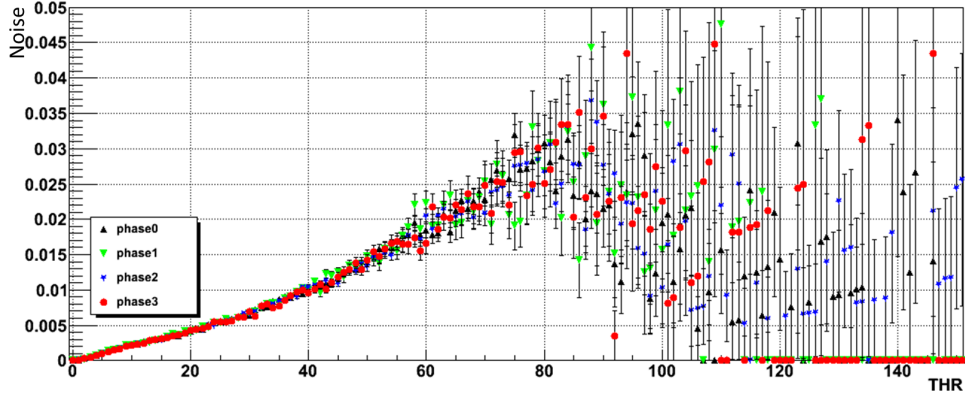
Noise %	Phase 0	Phase 1	Phase 2	Phase 3
OSMB	$1.5 \pm 0.4 \cdot 10^{-3}$	$2.2 \pm 0.7 \cdot 10^{-3}$	$2.2 \pm 0.5 \cdot 10^{-3}$	$0.8 \pm 0.4 \cdot 10^{-3}$
OSBK	1.303 ± 0.127	1.543 ± 0.192	1.379 ± 0.120	1.472 ± 0.190
OSH1	0.649 ± 0.088	0.488 ± 0.106	0.550 ± 0.074	0.559 ± 0.116
OSH2	0.758 ± 0.117	0.726 ± 0.161	0.735 ± 0.106	0.717 ± 0.163
OSPF	1.738 ± 0.376	2.030 ± 0.580	1.309 ± 0.306	0.695 ± 0.346

Table 4.5: FO trigger noise for different L0 inputs and for the four phases relationships between SPD clock and LHC clock. Noise, defined in equation 4.3.2, is evaluated for a data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV triggered by the V0 detectors. The inputs tested were OSMB, OSBK, OSH1, OSH2, OSPF, correspond respectively to at least 1 FO fired chip, 130 FO fired chips, 65 FO fired chips in the outer layer, 70 FO fired chips in the outer layer and 170 FO fired chips.

In order to have a deep and complete understanding of the FO trigger performance, the method just described was applied to all the possible thresholds and to all the possible counting logics, by setting the thresholds THR for the chips in the inner layer only, outer layer only, both together and for both layers in logical AND. This extension can be done since all the studies based on the offline FO data analysis are robust and simulate the real online triggering processing, as shown in section 4.2. Data from proton-proton collisions at $\sqrt{s} = 7$ TeV, triggered by the V0 detectors, have been considered for this study. The high QED background and the extremely high track multiplicity [10] in Pb-Pb collisions was not ideal to scan a wide range of THR with good statistic. In figure 4.14 efficiency and noise for the four phases as a function of the threshold THR set in the inner layer are shown. The efficiency curve is steeper for phase 3, as expected, while the other curves for other phases are similar in the whole THR range. It is shown that the noise curves, as already observed, are phase independent. The events with $THR \geq 90$ are very rare in p-p collisions and they are dominated by background events. The rise in efficiency is indeed due to beam-gas interactions and to the presence of the beam-halo. The beam background is composed of particle *splashes* which cross the half-staves in their entire length with a high number of fired pixels per chip, and therefore enhance the FO efficiency per chip. In figure 4.15 the typical hit map for a splash event is shown. Following the online numbering scheme [29] the x



(a) Efficiency



(b) Noise

Figure 4.14: Efficiency (a) and noise (b) for the four phases as a function of the L0 input threshold THR set in the inner layer. Data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

axis represents the chip number of the half-stave, and the y axis the half-stave number in Equipment 11. In HS 0 a high particle horizontal flux is clearly visible. The same behavior of figure 4.14 is observed when imposing a threshold in the outer layer, see figure 4.16, and when imposing a threshold in the total number of chips, see figure 4.17. It is interesting to notice that the background rise appears at the same threshold $THR \sim 90$ in both the inner and the outer layer. This emphasizes the described topology of the beam background events. An L0 input based on the logical AND between the thresholds in the inner and in the outer layer was also imposed. The results for efficiency and noise are shown in figure 4.18 for events in phases 2 and 3. The measurements for phases 0 and 1 are the same as for

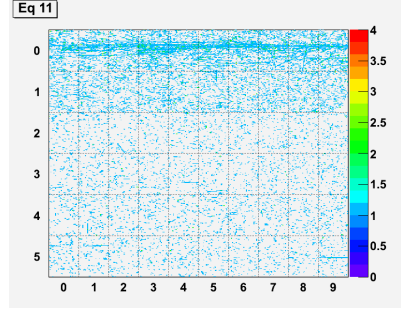


Figure 4.15: The typical hit map for a splash event in proton-proton collisions at $\sqrt{s} = 7$ TeV. Following the online numbering scheme [29] the x axis represents the chip number of the half-stave while the y axis represents the half-stave number in Equipment 11. In HS 0 a high particle horizontal flux is clearly visible.

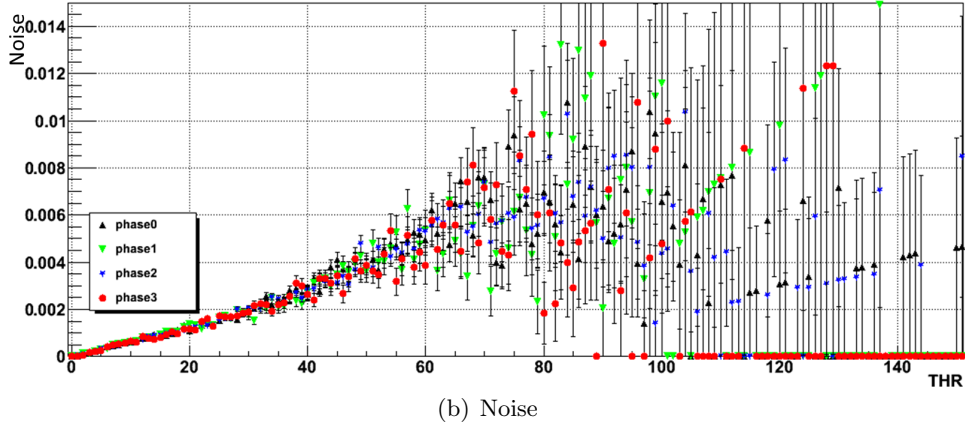
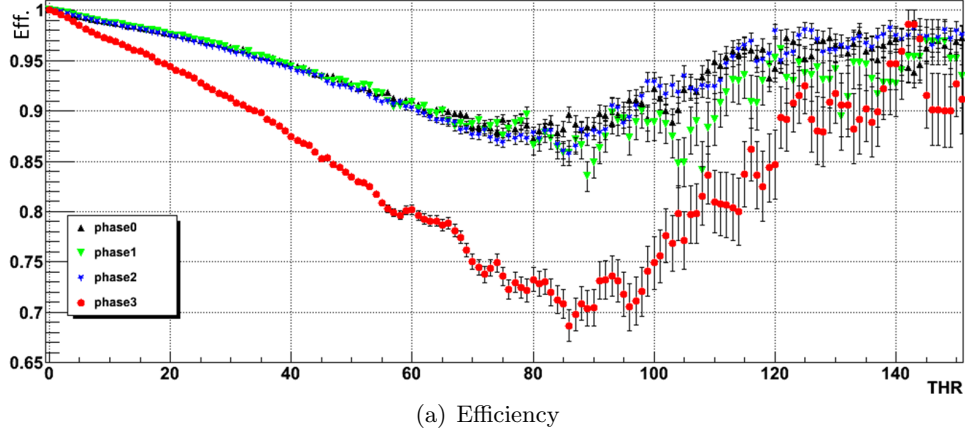


Figure 4.16: Efficiency (a) and noise (b) for the four phases as a function of the L0 input threshold THR set in the outer layer. Data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

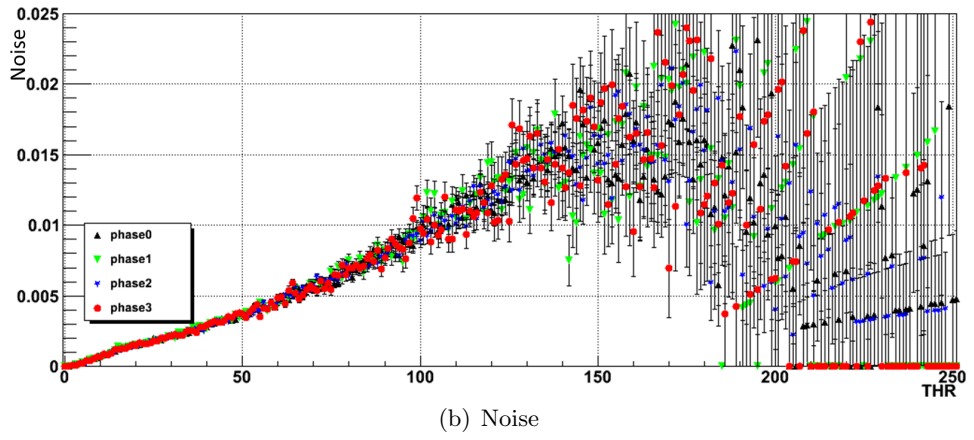
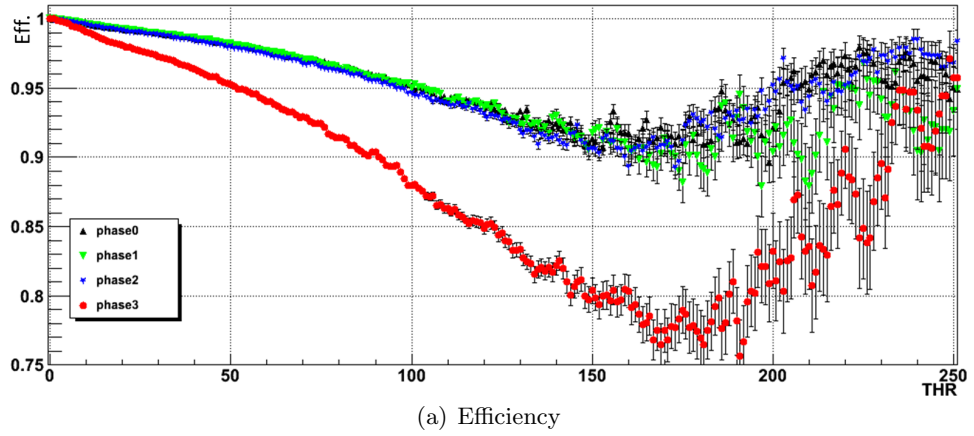
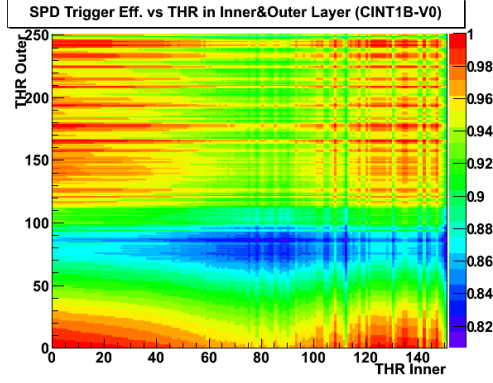


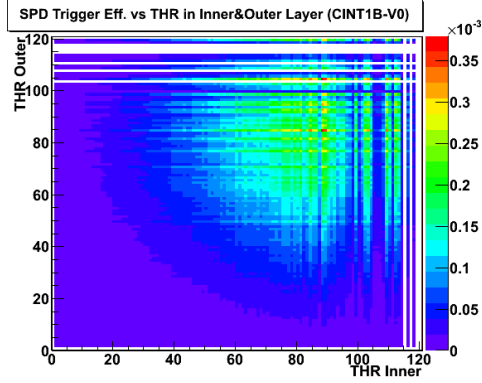
Figure 4.17: Efficiency (a) and noise (b) for the four phases as a function of the L0 input threshold THR set in the total number of chips. Data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

phase 2. The x-axis and the y-axis represent the thresholds THR in the inner layer and in the outer layer respectively. The z-axis represents the percentage values of efficiency and noise. The two corresponding plots in the two phases show the same behavior except for the different z-range in the efficiency measurements: phase 3 is affected by an efficiency reduction of $\sim 10\%$ in the interesting region out of the beam background (x and $y < 90$).

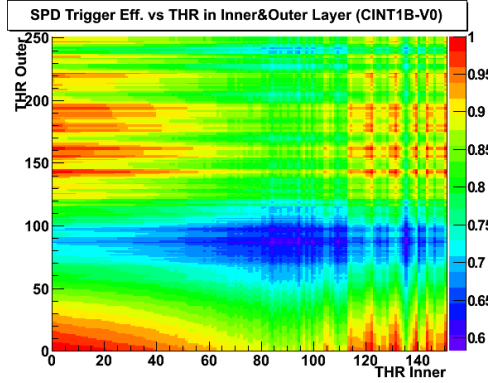
A further step in the study of the FO trigger performance is to correlate the number of FO bits to the first fundamental physical signal provided by the silicon pixel detector, that is the *cluster*. The cluster is an aggregate of fired pixels sharing a side with one another. In the offline reconstruction of raw data, a specific algorithm finds the clusters and assigns coordinates in space to them. The three space coordinates are used to reconstruct the tracklets (short track segments in the SPD compatible with the event vertex [31, 32]) and the tracks. The cluster-finder algorithm also excludes in its search the clusters built with pixels recognized as noisy. The cluster multiplicity reflects the physics behind any interaction. The efficiency of selecting events with a number of clusters NCl was evaluated, setting a threshold in the number of active FO bits. The data sample used is composed of minimum bias (CINT1B) proton-proton collision events at $\sqrt{s} = 7$ TeV. The ALICE official procedure to select p-p collisions candidates out of the background events (for more details see references [31, 32, 33]) was applied. The V0 detectors are used to remove beam-gas and beam-halo events by requiring their timing signals to be compatible with particles produced in collision events. The background is also rejected by exploiting the correlation between the number of clusters and the number of tracklets. In figure 4.19 the correlations in the outer layer between the number of clusters NCl and the activated FO bits are shown for all the CINT1B events and for the collision candidate events. The beam background events are of the type already shown in figure 4.15, with a high number of crossed chips and an high number of fired pixels and clusters. Those events are completely removed with this procedure, as shown in figure 4.19 (although only zoomed axis are shown). The trigger efficiency for a given NCl and for a given FO



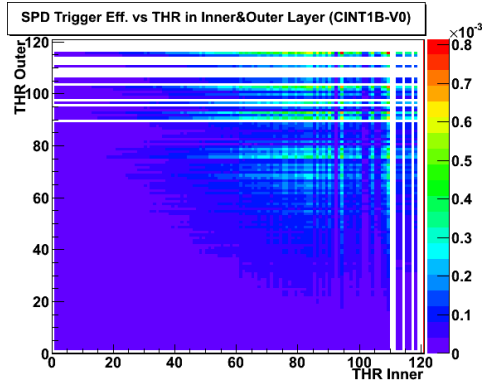
(a) Efficiency Phase 2



(b) Noise Phase 2



(c) Efficiency Phase 3



(d) Noise Phase 3

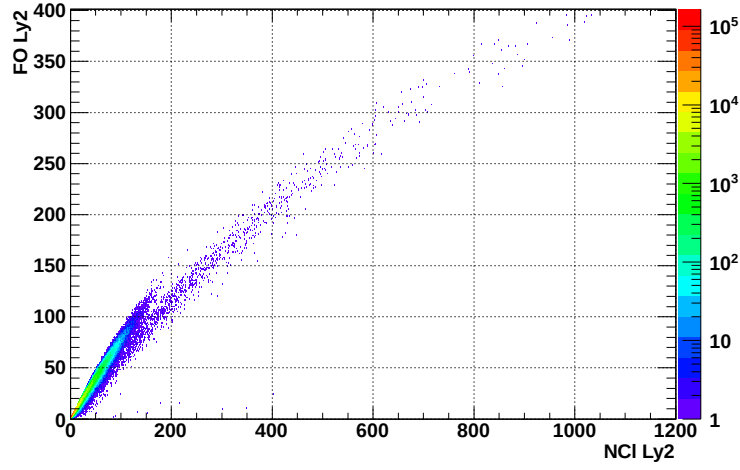
Figure 4.18: Efficiency (a,c) and noise (b,d) for events with phase (2,3) as a function of the $L0$ input threshold THR set in the inner layer (x -axis) and in the outer layer (y -axis). Data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

threshold is evaluated counting the entries, in the plot 4.19 (b), of the 2D bins that exceed the FO threshold and have a NCl number of clusters, see equation 4.3.3.

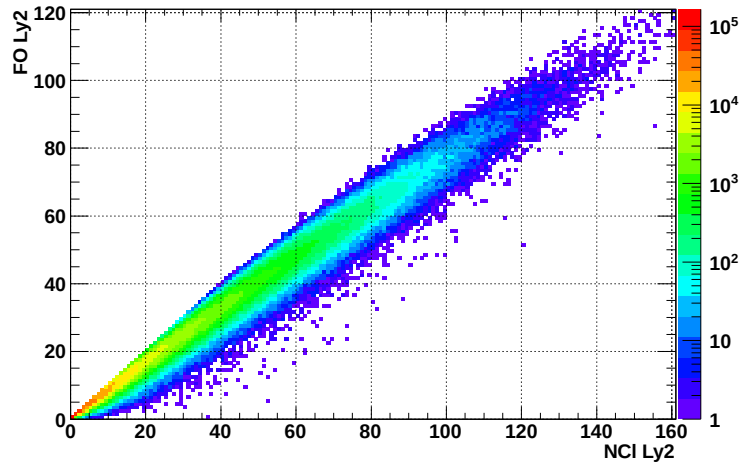
$$Eff(NCl|FO) = \frac{\sum_{biny \geq FO} Entries_{binx=NCl}}{\sum Entries_{binx=NCl}} \quad (4.3.3)$$

In figure 4.20 the efficiency as a function of the cluster multiplicity is shown in the case of the 0SMB L0 input ($FO=1$). The efficiency is practically 100 % for all the inelastic collisions. A slight inefficiency ($1\% \div 4\%$) is observed for very low multiplicity events, $NCl = 1, 2$, interpreted as diffractive events. The contribution of noise pixels becomes more significant in such events, especially for $NCl = 1$. There is an algorithm used to tag the noisy pixels which prevents them from forming a cluster. The 0SMB input appears noisy in 4% of $NCl = 1$ events because the clusters are not formed. Nevertheless the noisy pixels properly generate the FO signals with 100% efficiency and very low noise, as proven in tables 4.4 and 4.5. The efficiency 4.3.3 is evaluated for all the possible FO L0 input thresholds and for all the cluster multiplicities, for the inner layer and for the outer layer separately. The cluster multiplicity in one single layer gives a better extrapolation for the track multiplicity. In figure 4.21 the efficiencies for the inner layer and for the outer layer are shown. The possibility to trigger events with higher FO thresholds in proton-proton collisions is still under study since events with high multiplicity tracks are gaining much physics importance, as demonstrated in the analysis [38] by the CMS collaboration. The output 0SH1 ($FO \geq 65$ in Layer 2), in particular, was studied during the first two years of data taking with proton beams: in figure 4.22 the efficiency as a function of the cluster multiplicity in the outer layer is shown.

Once the measurements on the FO trigger performance are exploited, it is necessary to evaluate the impact of using, in the experimental area, a trigger based on FO counting logics. This has to be done in order to optimize efficiency of data collection and physics content of the triggered events. The basic rules one has to take into account when using different trigger inputs have been explained in section 1.3. These rules are also useful



(a)



(b)

Figure 4.19: Correlations in the outer layer between the number of clusters NCI and the FO activated bits for all the $CINT1B$ events (a) and for the collision candidate events (b) for a data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

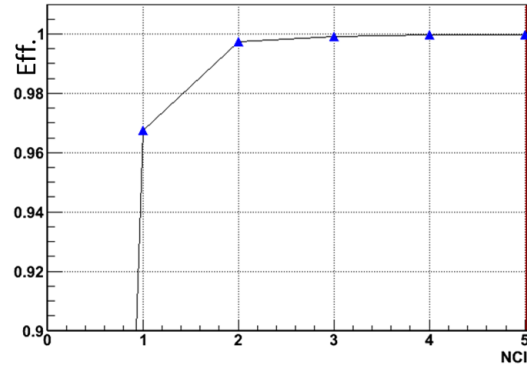
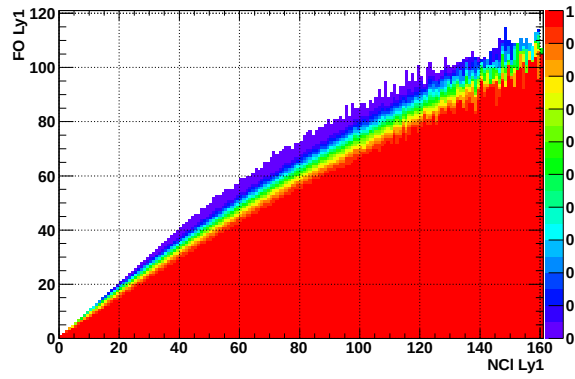
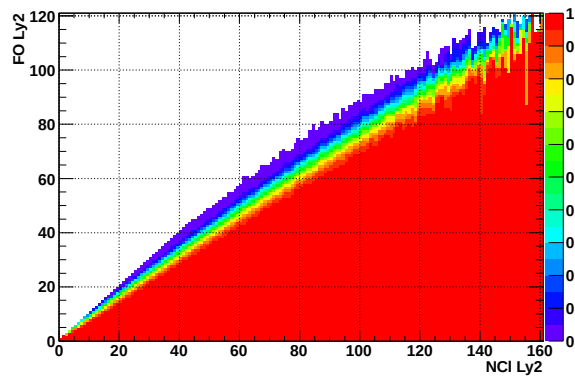


Figure 4.20: Trigger efficiency as a function of the cluster multiplicity using the 0SMB L0 input ($FO=1$), for a data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.



(a)



(b)

Figure 4.21: Trigger efficiency as a function of the cluster multiplicity (x -axis) and of the FO threshold (y -axis) in the inner layer and in the outer layer, (a) and (b) respectively. Data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

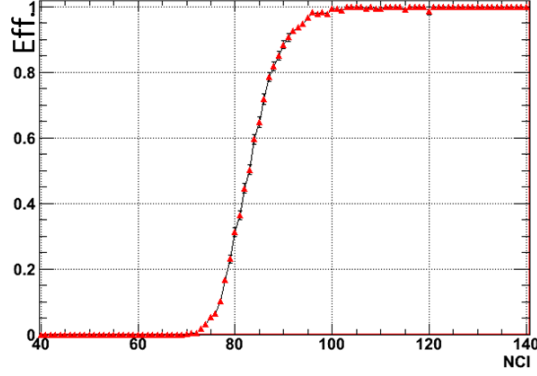
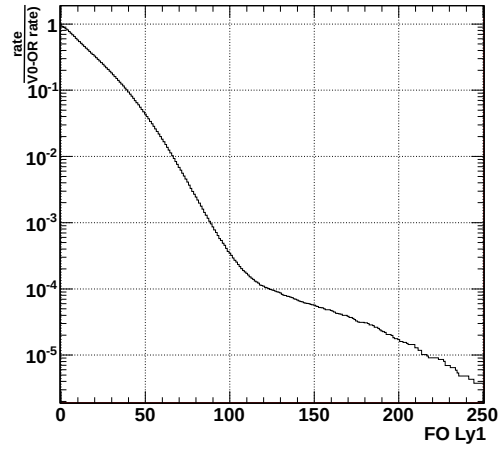


Figure 4.22: Trigger efficiency as a function of the cluster multiplicity using the 0SH1 L0 input ($FO \geq 65$ in Layer 2), for a data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

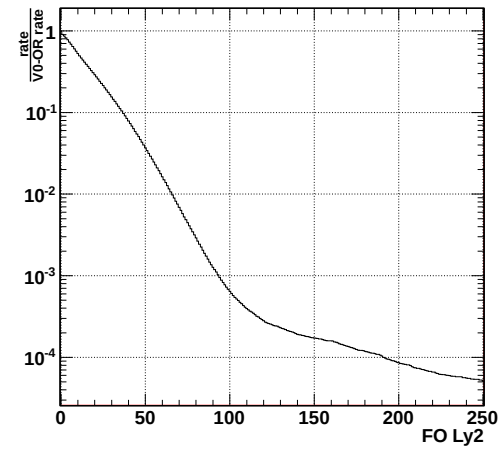
to build partitions with competitive trigger classes and clusters. The trigger rates were so evaluated for the L0 inputs with all the relevant FO thresholds in the inner layer, in the outer layer and in both layers. The measurements are given as the fraction of events exceeding the threshold in proton-proton collisions at $\sqrt{s} = 7$ TeV triggered by the logic OR of the V0 counters. The V0-OR trigger rate is left as a free parameter to measure in any different machine condition. The ratio of the FO trigger by the V0-OR rate is shown as a function of the FO threshold in figure 4.23. The bumps in the curves at high FO thresholds are due the beam background.

4.4 FO Efficiency, the absolute measurement

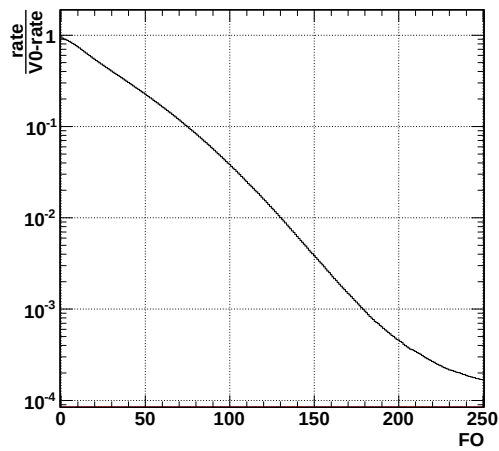
A more sophisticated method has been developed to measure the performance of the FO signal production. The method is embedded into the standard algorithm which performs the tracking in the ALICE detector and uses reconstructed tracks in the ITS and the TPC as probing tracks. The probing tracks make a prediction on the intersected chips. The FO bit is checked according to such a prediction thus providing the method to estimate the efficiency of the FO signal production. This method checks for a FO signal regardless of whether a pixel is fired in the chip matrix or not: it takes into account dead areas and the possibility of the FO not having the pixel-hit (assuming that the probability of having a noisy FO correlated to the track is null). The method provides therefore an absolute measurement



(a)



(b)



(c)

Figure 4.23: Ratio of the FO trigger by the V0-OR rate as a function of the FO threshold in the inner layer, in the outer layer and in total, (a), (b) and (c) respectively. Data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

of the FO signals and so by extension of the FO trigger. The results will be shown for p-p collisions at $\sqrt{s} = 7$ TeV in comparison with a Monte Carlo simulation. It is explained hereafter how the tracking is performed and how the method is embedded in it, how the SPD dead areas and the FO signals are treated in the MC simulations.

Tracking

Track reconstruction is performed via a Kalman filtering algorithm [16]. Charged tracks are parameterized by five parameters describing a helix and by a covariant matrix describing the uncertainties on them. The algorithm depends significantly on the definition of a set of initial values, the *seeds*, for the parameters and for their covariant matrix. Starting from the seeds, the algorithm looks for points to be added to the track. The search-road is determined by the uncertainty on the track extrapolation and on the point position at a given plane, taking into account deviations due to the interaction with the material of the plane (energy loss, multiple scattering). The track reconstruction is performed in the following steps. The first one is sketched in figure 4.24. The primary vertex is reconstructed using the SPD tracklets and is used to set the seeds. The search-road starts from the outermost pads of the TPC, where the track density per unit area is lower, and continues inward, up to the innermost pads. This process is repeated a second time without the primary vertex constraint (i.e. taking into account tracks originating from decays, secondary interactions etc.) and looks for points on the ITS planes. At the end of this first step the track-finding efficiency is about 90% for low momenta, $p_t = 200 - 300$ MeV/c, and increases above 95% at higher momenta [16]. The fake-track probability ranges from about 10% to less than 1% for low and high momenta respectively. In the second step the Kalman filter is reverted and the search-road starts with much more precise track parameters from outside (i.e. SPD inner layer) to outside, looking for matching points also in TRD, TOF and HMPID, see figure 4.25. In this stage the PID is performed. In the third and last step the tracks are refitted inward (see figure 4.26), the track parameters are finally determined and the PID performed.

The FO signals are checked when refitting inward in the third step and the prediction on the SPD modules is thus optimized. The SPD layer in which the FO are searched for is excluded during the entire processing of the tracking algorithm in order to unbiased the measurement.

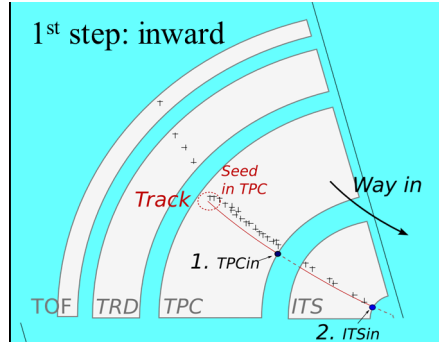


Figure 4.24: First step of the Kalman filter tracking algorithm. The primary vertex is reconstructed using the SPD tracklets and is used to set the seeds. Then the search-road starts from the outermost pads of the TPC, where the track density per unit area is lower, and continues inward unto the innermost pads. This process is repeated a second time without the primary vertex constraint and continues through the ITS planes.

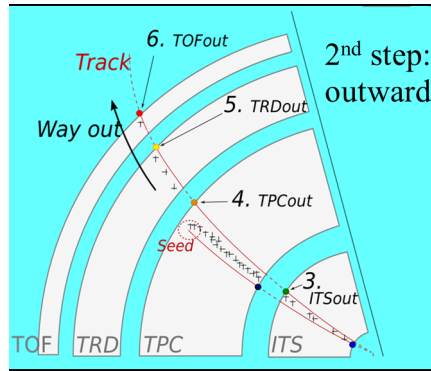


Figure 4.25: Second step of the tracking algorithm. The Kalman filter is reverted and the search-road starts with much more precise track parameters from inside to outside, looking for matching points also in TRD, TOF and HMPID.

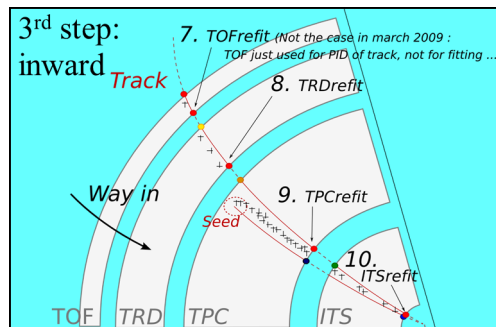


Figure 4.26: Third and last step the of the tracking algorithm. The tracks are refitted inward, the track parameters are finally determined and PID performed.

Inefficient and dead pixels

The description of the detector response in terms of dead and inefficient channels is fundamental in the Monte Carlo simulations. An algorithm was developed in order to tag dead and inefficient pixels. The ALICE analysis framework, called AliRoot [39], does not include the possibility of simulating the inefficiencies. The algorithm just keeps alive or switches-off the tagged pixels as results. The algorithm is based on the pixel hit maps accumulated

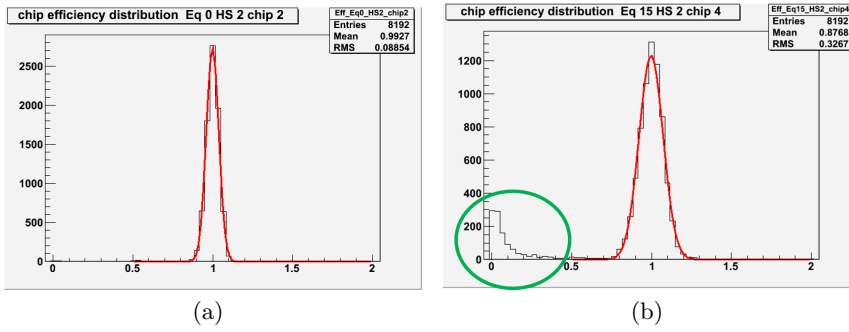


Figure 4.27: Efficiency distributions for pixels in tow chips. The red superimposed lines is the gaussian fit for pixels with efficiency close to 100% ((a) and (b)). A group of pixels in the green circle of figure (b) is affected by low efficiency. The two plots refer to a data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

over all the available statistics in beam-beam runs. The average number of entries per pixel is evaluated at the level of the single chip. The distribution of the fraction entries for each pixel with respect to the average number of entries is studied chip-by-chip. In figure 4.27 (a) and (b) the distributions for two different chips are shown. The typical distribution for an efficient chip is in figure 4.27 (a). The dead pixels and the low efficiency pixels appear in figure 4.27 (b) as group of entries close to zero, far away from the distribution of pixels with a high efficiency. A cut is so imposed to reject the anomalous pixels in the distribution 4.27 (b). The pixels with a number of entries smaller than 40% of the average number of entries in the given chip have been switched-off in the MC simulation. The location of the inefficient and dead pixels in the chip matrixes is not random. These pixels tend to gather in the columns close to the chip borders and in the chip corners. This behavior is known since the time of the construction phase, during the test

and the characterization of the modules.

The FO signals in the MC are assigned when the chips are fired by at least one pixel-hit. The dead and the inefficient pixels do not participate in the generation of the FO signals and the measured FO signal efficiency described in section 4.2 (i.e. with the pixel-hit method) has to be applied at the level of the analysis, after simulation has been completed.

Analysis and Results

The method was tested on real data and the results are compared with a dedicated MC simulation. The probing tracks considered in the method are those whose projection on the modules plane were distant an assigned cut value from the chips borders. The cut value is set for both the distance along the beam axis z and the distance in the r - φ plane direction and is optimized to reduce as much as possible wrong associations between adjacent chips. The cut let the method keep a naturally safe distance from the borders and the corners of the chips. Here is where the dead and inefficient pixels are most concentrated and where the measurement is most sensitive to the performance of the algorithm to tag them. The inner and the outer layers are treated separately since their different radial position and geometry play a different role in the tracking. The track error distributions are shown for r - φ and z in the inner layer and the outer layer in figure 4.28: the agreement between data and MC is extremely good. The cuts are in units of σ , the error on the projection of the track onto the detector plane. A $3 \cdot \sigma$ cut is imposed in the inner layer and a $2 \cdot \sigma$ cut in the outer layer, corresponding to an average distance of about $600 \mu\text{m}$ in both r - φ plane and z axis directions. The FO efficiency for data is shown in figures 4.29(a) and 4.30(a), for chips in the inner and the outer layer, respectively. The figures 4.29(b) and 4.30(b) show the statistics of the probing tracks, in blue markers, and the successes, in red markers. The FO efficiency and the corresponding statistics for an MC simulation are shown in figures 4.31 and 4.32, for chips in the inner and the outer layer, respectively. The FO signal production efficiency evaluated with the pixel-hit is multiplied chip-by-chip by the MC efficiencies. The integrated efficiencies are summarized in table

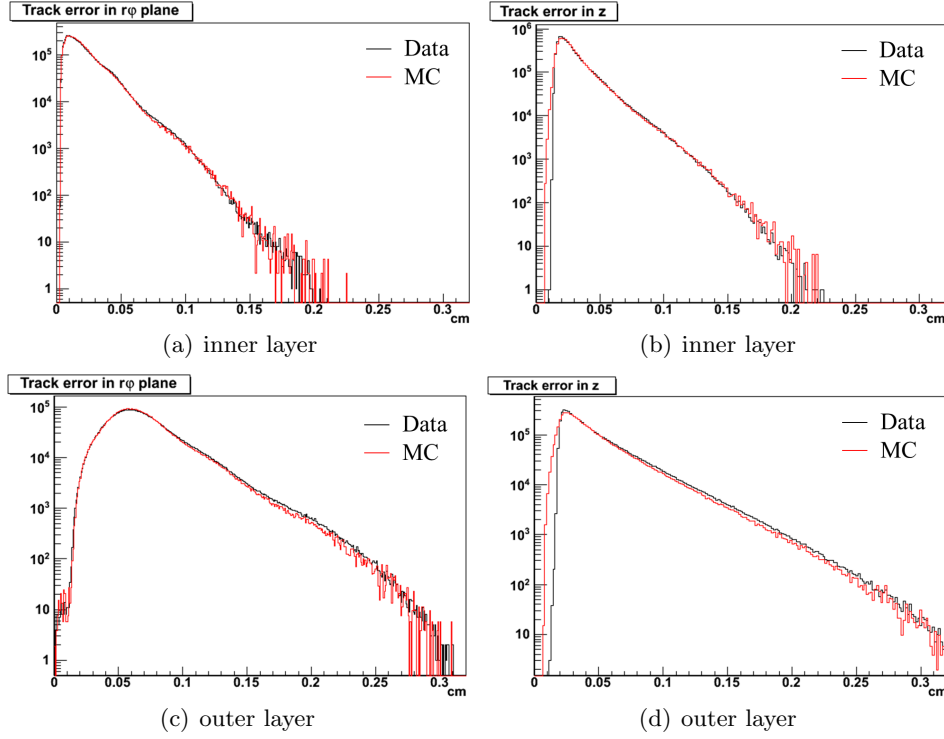


Figure 4.28: Errors on the projection of the reconstructed tracks onto the SPD modules planes. ((a),(b)) and ((c),(d)) refer to inner layer and outer layer, respectively. ((a),(c)) and ((b),(d)) refer to the module coordinates in the $r\phi$ plane and along the beam axis z , respectively. The plots refer to a data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

Eff. %	Data	MC	MC * FO(w. <i>Pixel-hit</i>)
Inner layer	$96.432 \pm 7. \cdot 10^{-3}$	$97.572 \pm 6. \cdot 10^{-3}$	96.983
Outer layer	$93.952 \pm 9. \cdot 10^{-3}$	$96.743 \pm 6. \cdot 10^{-3}$	94.701

Table 4.6: FO efficiency integrated for all the chips in inner and outer layer. The efficiency is evaluated for data in p - p collisions at $\sqrt{s} = 7$ TeV (second column), for the Monte Carlo simulation (third column) and the Monte Carlo simulation corrected by the integrated efficiency of the FO signals production using the method of the *pixel-hit*.

4.6 for data, MC and MC corrected by the efficiency. The difference between the data and the corrected MC is 0.5% and 0.7% for the inner and the outer layer respectively.

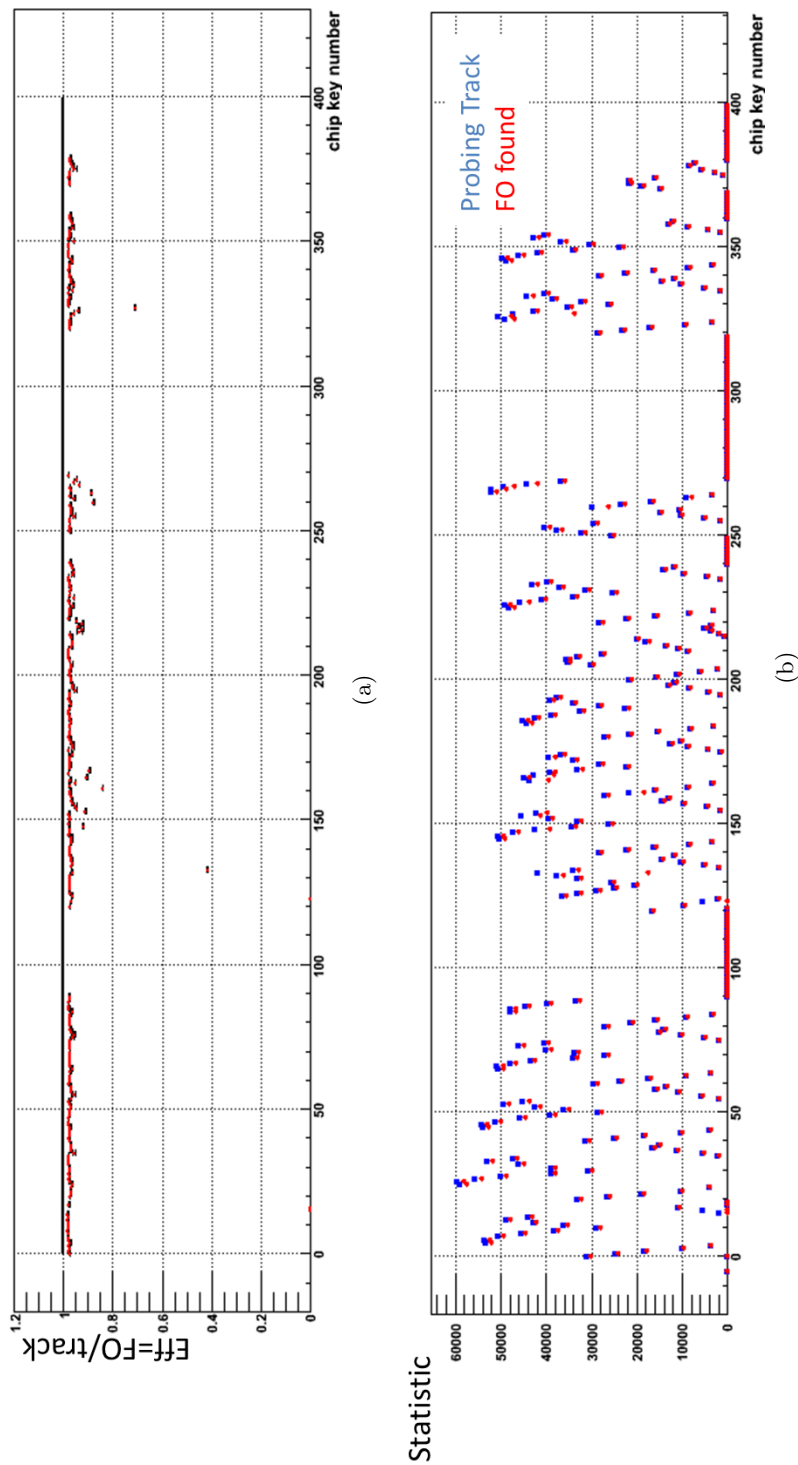


Figure 4.29: (a) FO signal efficiency for chips in the inner layer using the method with tracks. (b) Statistics of the probing tracks, in blue markers, and successes, in red markers: the efficiency is the ratio of the successes over the probing tracks. Data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

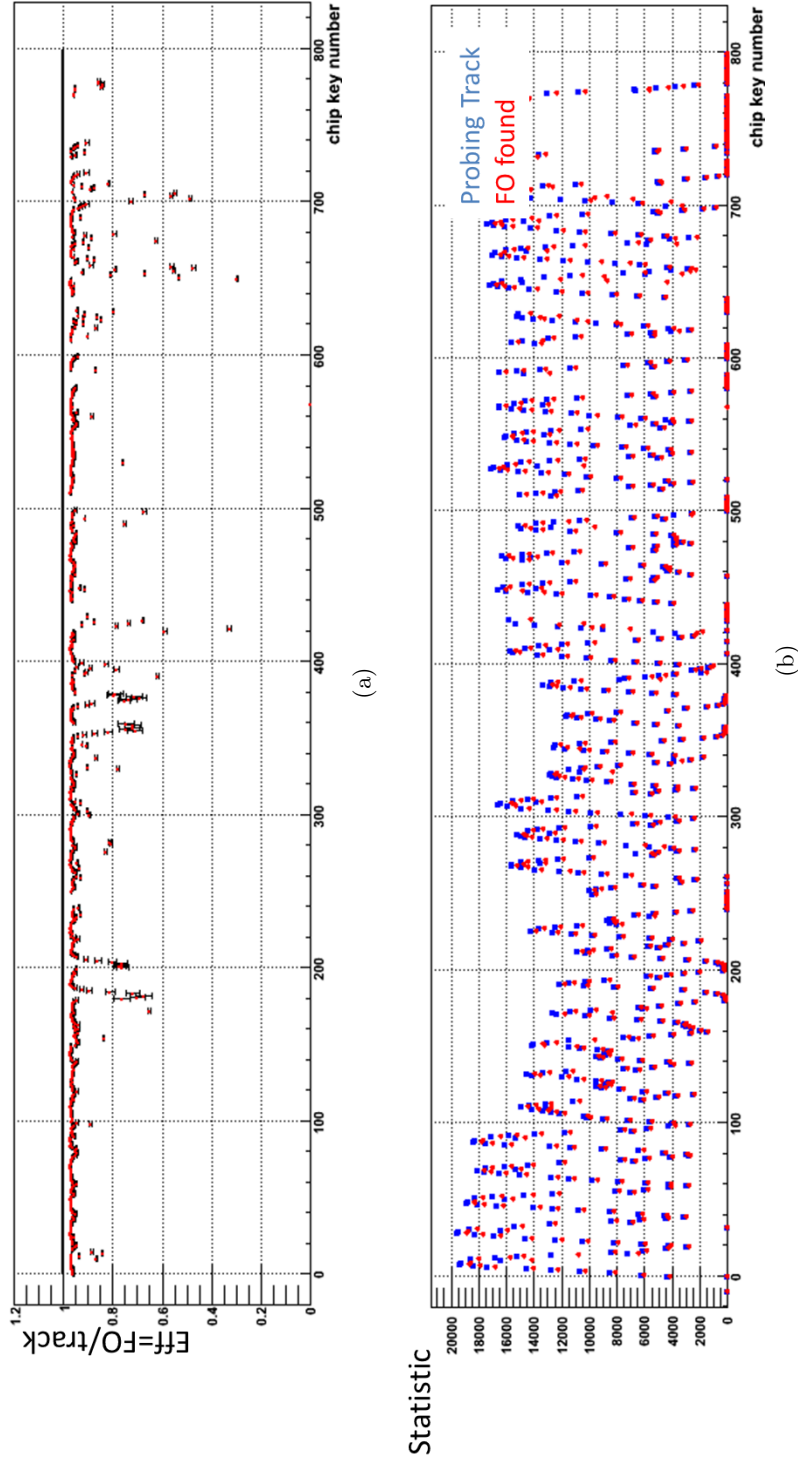


Figure 4.30: (a) FO signal efficiency for chips in the outer layer using the method with tracks. (b) Statistics of the probing tracks, in blue markers, and successes, in red markers: the efficiency is the ratio of the successes over the probing tracks. Data sample of proton-proton collisions at $\sqrt{s} = 7 \text{ TeV}$.

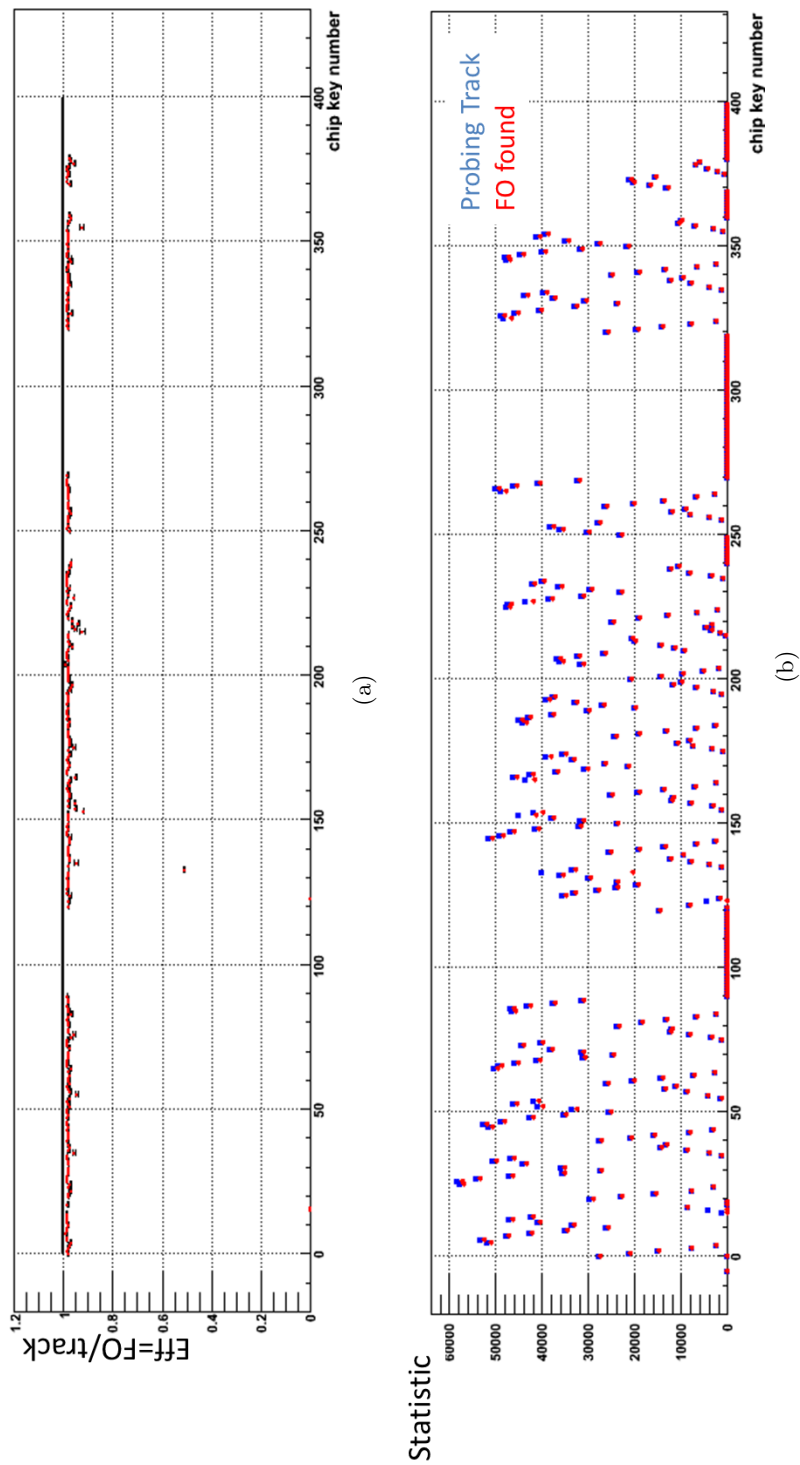


Figure 4.31: (a) FO signal efficiency for chips in the inner layer using the method with tracks. (b) Statistics of the probing tracks, in blue markers, and successes, in red markers; the efficiency is the ratio of the successes over the probing tracks. Monte Carlo data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

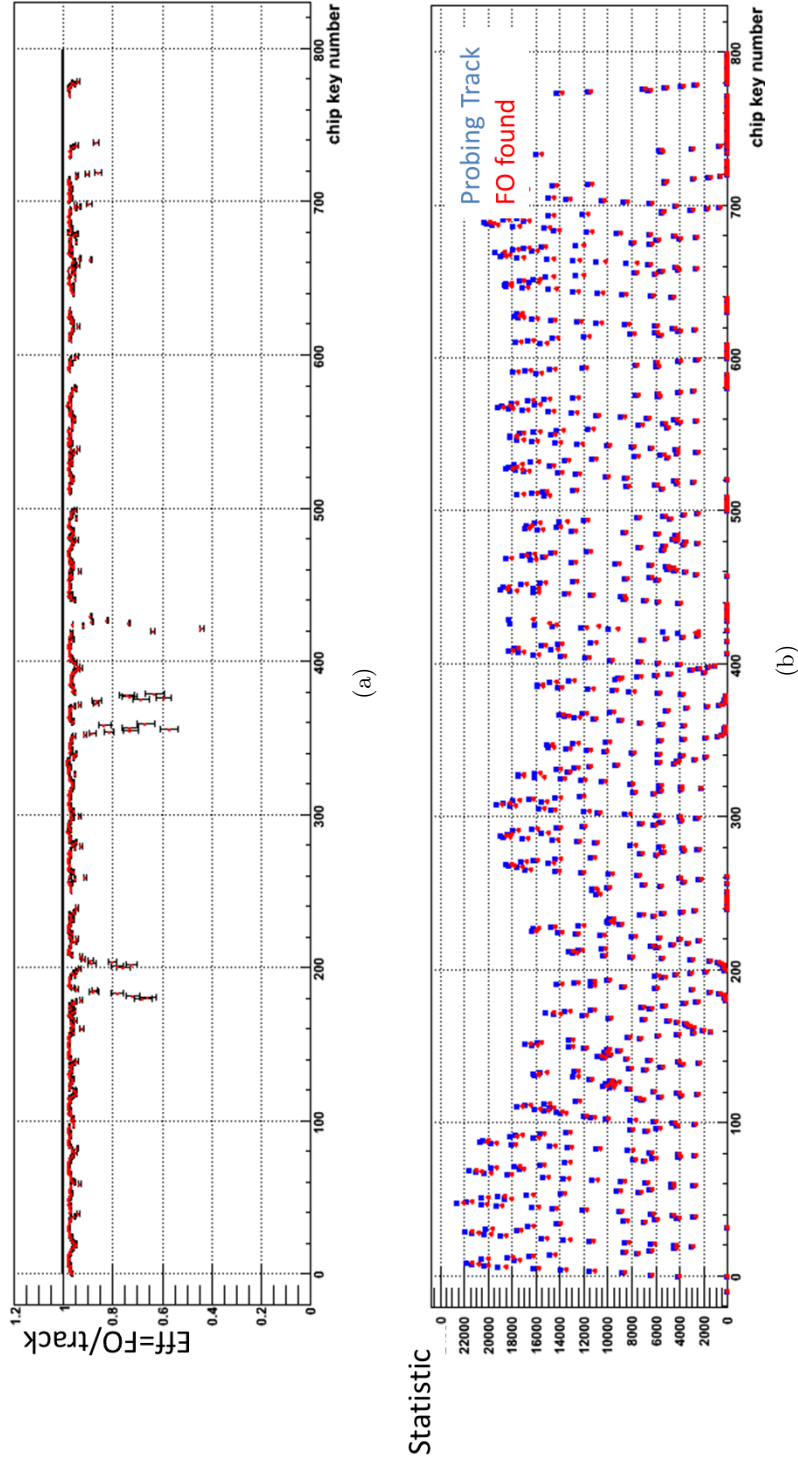


Figure 4.32: (a) FO signal efficiency for chips in the outer layer using the method with tracks. (b) Statistics of the probing tracks, in blue markers, and the successes, in red markers: the efficiency is the ratio of the successes over the probing tracks. Monte Carlo data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV.

The impact point distribution of the probing tracks is shown in the plane of the ladder (i.e. five chips) when the FO has been found: the integrated maps for all the ladders in the inner layer and in the outer layer are shown in figure 4.33. The central area in the five chips is more populated due to the dead and the inefficient pixels at the borders. This effect is more visible in the corresponding efficiency distributions in the ladder maps as shown in figure 4.34.

The data and the corrected MC are compared chip-by-chip. In figure 4.35 and 4.36 the difference between data and corrected MC is evaluated, chip-by-chip, for the inner layer and for the outer layer, respectively. The two distributions are fitted with a polynomial function of order zero $p0$. The fits return $p0_{inner} = -0.39\%$ and $p0_{outer} = -0.44\%$ with extremely good χ^2/ndf being equal to 0.02/276 and 0.37/666, respectively. These results give reliability to the whole machinery developed to describe the averaged behavior of the SPD down to the level of the single chip and provide an absolute measurement of the FO efficiency. The method described above is embedded in the AliRoot code and it is systematically used in each run in order to assure the quality of the data.

The description at the level of the single pixels has to be though improved and need more statistics to be performed. An improvement is indeed required in the description of the dead and the inefficient pixels. The FO efficiency in data and in MC¹, as a function of the impact track coordinates on the ladder plane, is shown in figure 4.37 and figure 4.38 for ladders in the inner layer and outer layer, respectively. The main differences between data and MC are concentrated, as expected, at the borders of the chips and this is evident for the columns at the borders as shown in the z-direction plots in figures 4.37 and 4.38.

¹MC is not corrected for the FO signal efficiency. The correction effect would be though a shift at lower efficiency without changing the coordinate dependency.

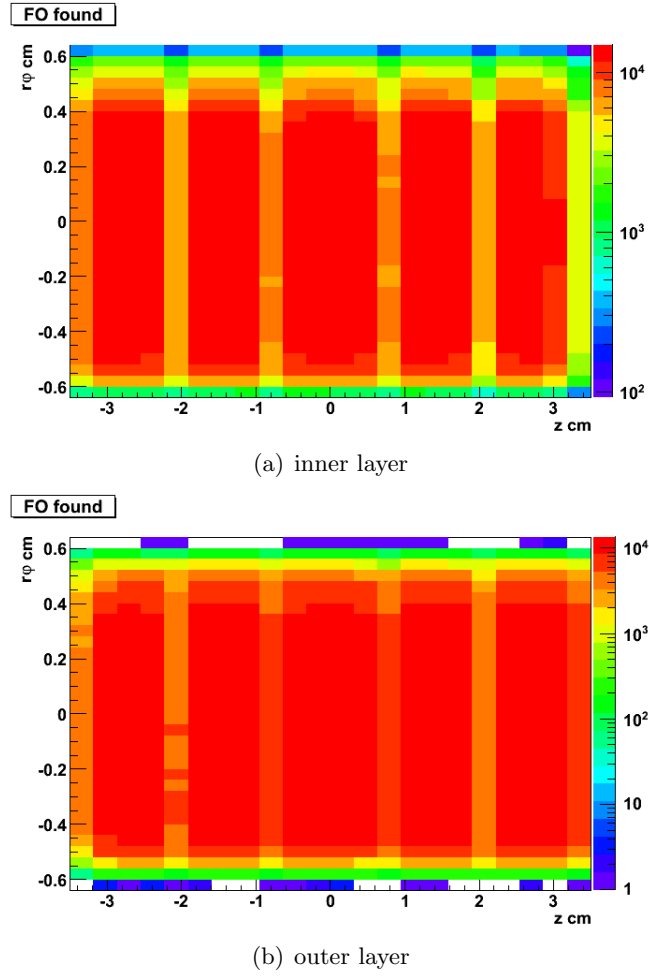
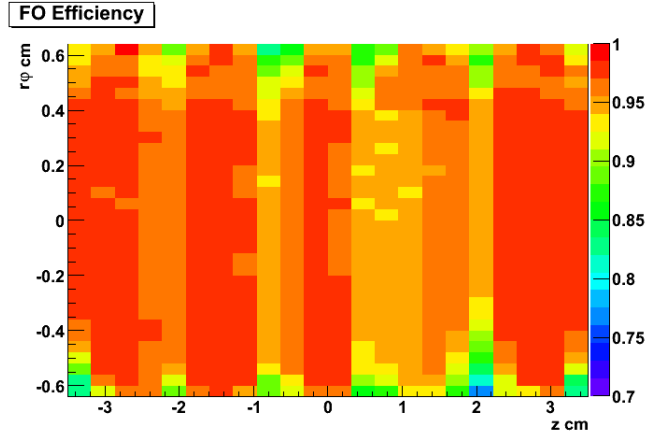
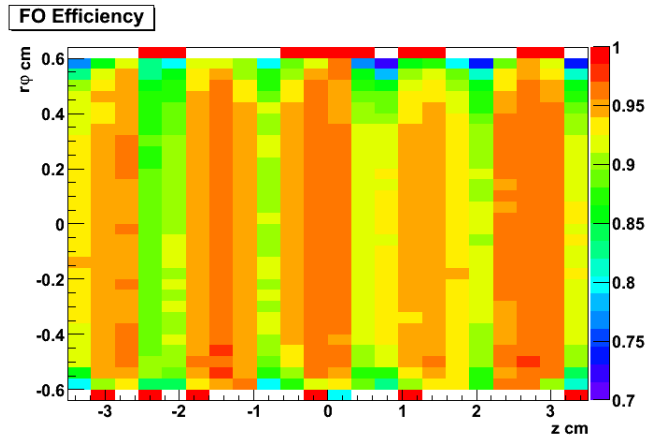


Figure 4.33: Maps of the track impact points when the FO signal, according to the prediction, is found active. The maps refer to the five chips in a ladder and are the integrated maps of all the ladders in the correspondent layer. Data are from proton-proton collisions at $\sqrt{s} = 7$ TeV.



(a) inner layer



(b) outer layer

Figure 4.34: FO signal efficiency maps for the five chips in a ladder. The maps are the integrated maps of all the ladders in the correspondent layer. Data are from proton-proton collisions at $\sqrt{s} = 7$ TeV.

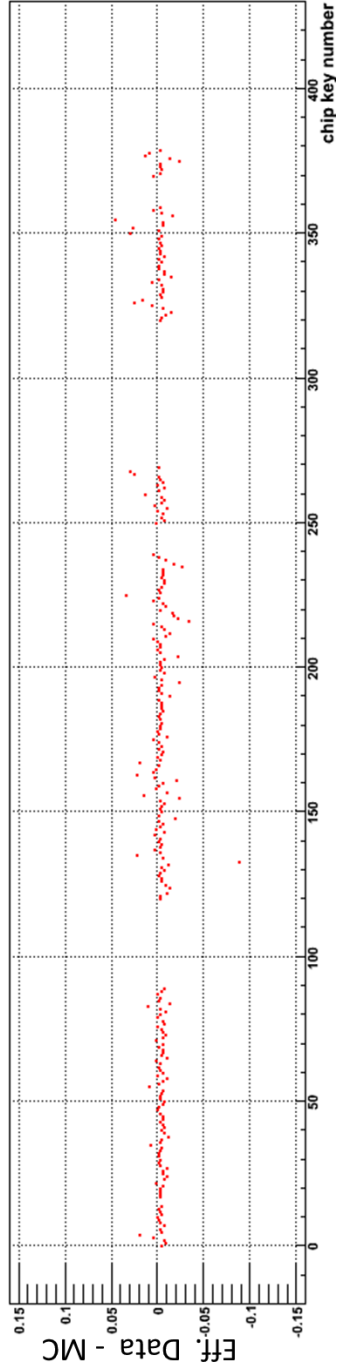


Figure 4.35: Difference between the FO efficiencies evaluated with data and the ones evaluated with corrected MC for the chips in the inner layer. Events are proton-proton collisions at $\sqrt{s} = 7$ TeV.

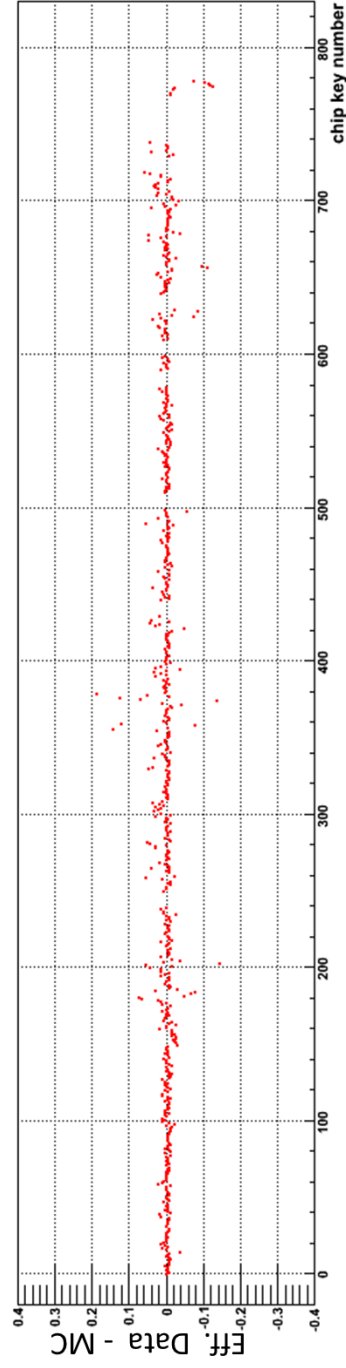


Figure 4.36: Difference between the FO efficiencies evaluated with data and the ones with corrected MC for the chips in the outer layer. Events are proton-proton collisions at $\sqrt{s} = 7$ TeV.

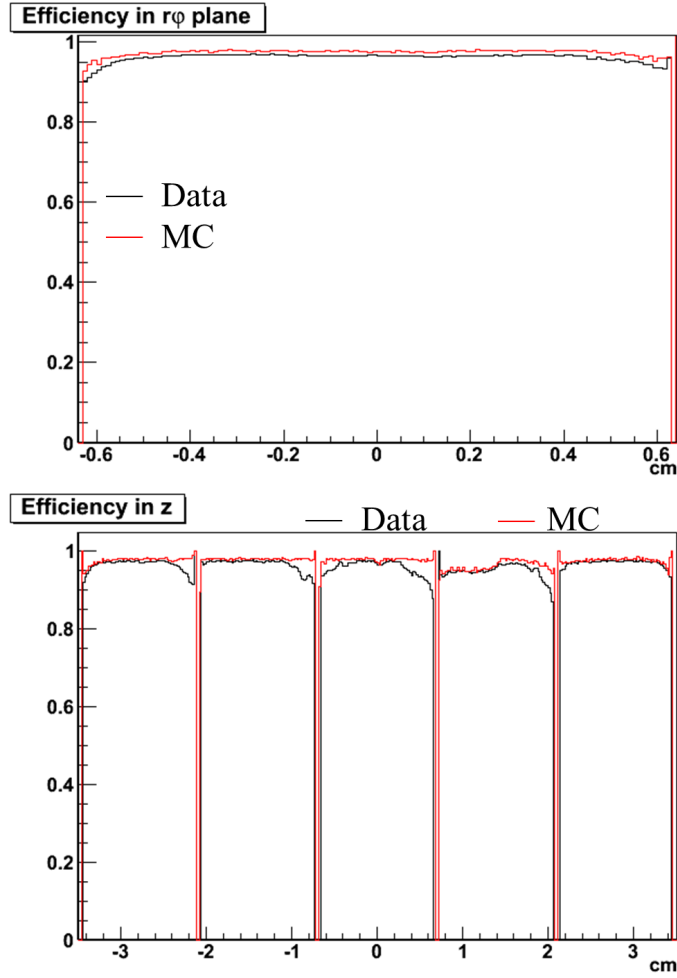


Figure 4.37: Inner layer FO efficiency as a function of the impact track coordinates on the ladder plane. The efficiency refers to an integrated efficiency over all the ladders in the inner layer.

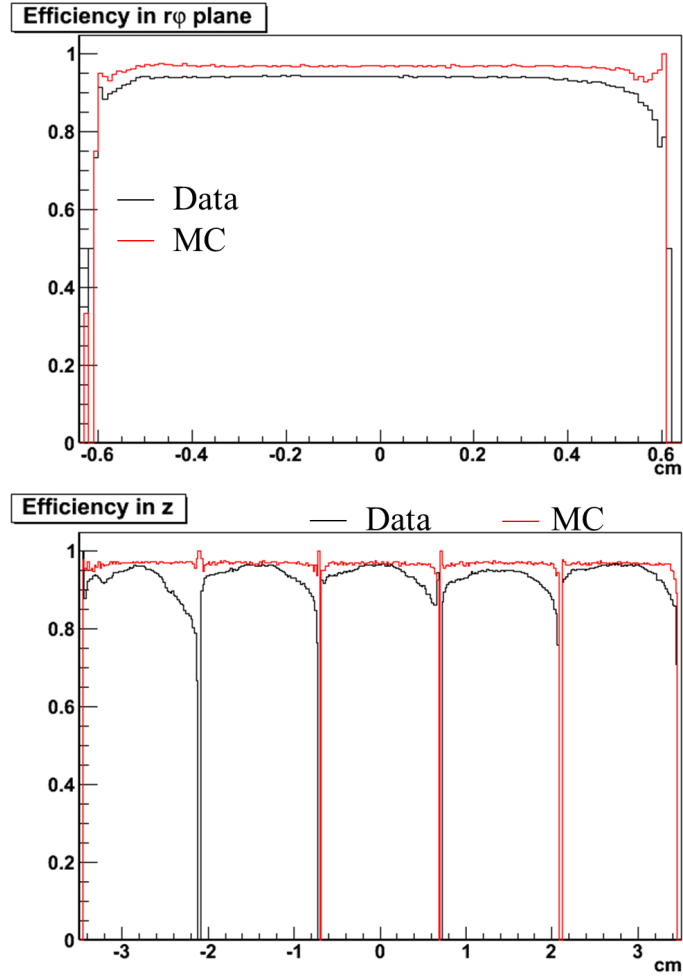


Figure 4.38: Outer layer FO efficiency as a function of the impact track coordinates on the ladder plane. The efficiency refers to an integrated efficiency over all the ladders in the outer layer.

4.5 Event centrality selection in Pb-Pb collisions

Hadronic processes are described in a simple geometrical picture in the Glauber Model. The Glauber model assumes point-like nucleons without distinguishing protons from neutrons. Nucleons move in straight-line trajectories, the nucleon-nucleon cross section is independent of the other nucleons in the nuclei and is independent of the number of collisions the two nucleons have undergone before. The inputs to the model are the nuclear density profile, which is given by Woods-Saxon distribution, and the total nucleon-nucleon inelastic cross section, measured experimentally by the Van der Meer scan technique [40] and is about 7 mb for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [41]. The collision geometry determines the number of nucleons participating in the nucleus-nucleus interaction. The definition of centrality is based on the assumption that the impact parameter is monotonically related to the particle multiplicity or the energy produced at mid-rapidity. The measurement of the centrality in Pb-Pb collisions is fundamental in order to characterize experimentally the events in terms of the geometry and the initial conditions. It has been explained in section 1.1 how the centrality is measured in ALICE and it has been shown that it is important that all the physics observables be measured and compared in different centrality classes. The centrality of the collision is determined analyzing offline data from the forward scintillator detector V0. Fig 4.39 (taken from section 1.1) shows the VZERO amplitude in arbitrary units. The superimposed solid line is a mix of the Glauber model which describes the collision geometry and a negative binomial distribution which describes the particle production. The vertical lines separate the various centrality classes which in total correspond to $\sim 90\%$ of the most central ion collisions. The combination of the ZDC and the ZEM forward calorimeters can be used to trigger centrality by detecting spectators as explained in section 1.2.

It is worth reminding that having dedicated trigger on centrality is useful for enriching statistics in predefined centrality classes, to have better control and to optimize the data taking during the limited period of time in which heavy-ion collisions are delivered by LHC (i.e. one month per year). The new idea is to trigger on centrality by measuring directly in the central

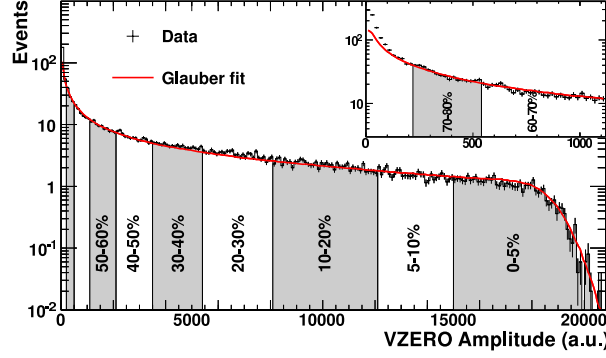
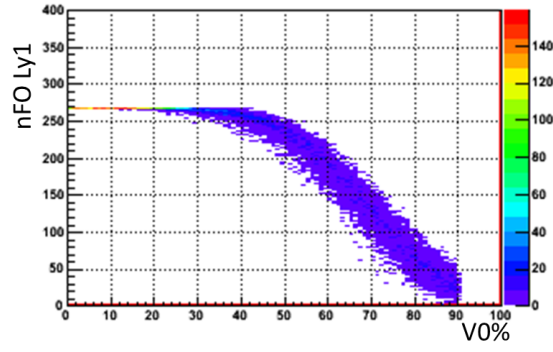


Figure 4.39: Distribution of the signal amplitude of the forward detector VZERO ($2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$). The curve shows the result of the Glauber model fit to the data. The vertical lines separate the various centrality classes which in total correspond to 88% of the most central ion collisions.

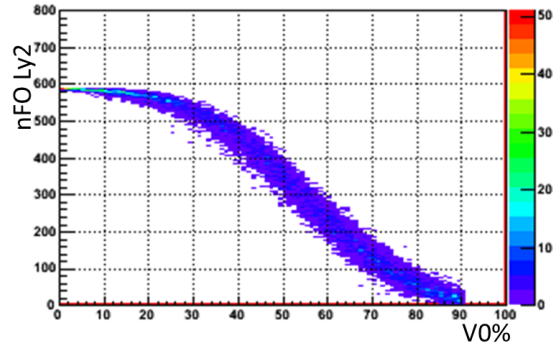
barrel region the charge particles produced in the collision. The advanced know-how and the proved robustness of the SPD fast-OR trigger (described in section 4) make it an optimal candidate for achieving this goal. The performance of the fast-OR trigger using a counting-based logic algorithm has been evaluated. The V0 detector information is used to determine the centrality of the events, called *V0 percentile*. The V0 percentile ranges from 0% to 90% for the most central to the most peripheral events, respectively. The study has been performed on data from Pb-Pb collision at $\sqrt{s_{NN}} = 2.76$ TeV, compared to a dedicated Monte Carlo simulation.

The number of FO signals activated as a function of the V0 percentile is shown in figure 4.40 for inner layer, outer layer and in total for an MC simulation. Given the high charge particle multiplicity and the large acceptance of the chips in the inner layer ($\sim 1 \text{ cm}^2$ active area at $\sim 4 \text{ cm}$ distance from the primary vertex), the number of active FO saturates in the range from 0% to 30 %, see the plateau in figure 4.40 (a). In the outer layer the saturation is less significant as expected and so the use of the outer layer only to define L0 inputs gives more flexibility to the thresholds being imposed. The distributions observed in figure 4.40 reproduce well the ones with data of figure 4.41.

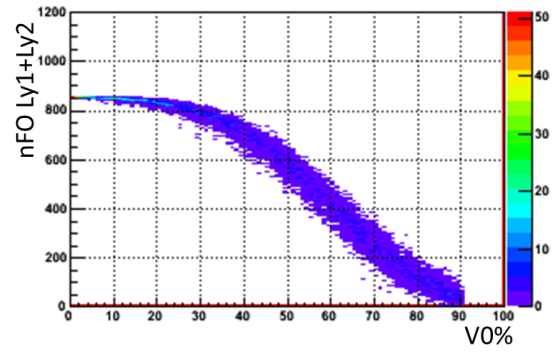
The efficiency and the purity of the trigger are first studied as a function of the FO threshold N_{FO} in order to select events in the centrality classes from 0% to an upper limit. Efficiency and purity are defined, at a fixed V0



(a)

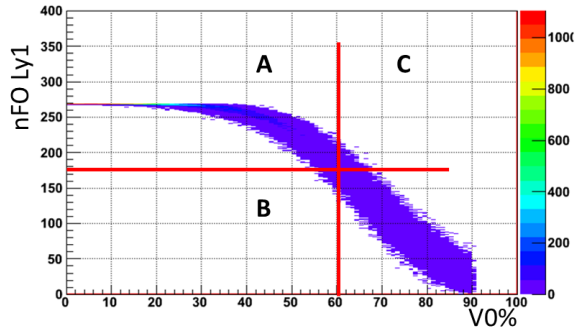


(b)

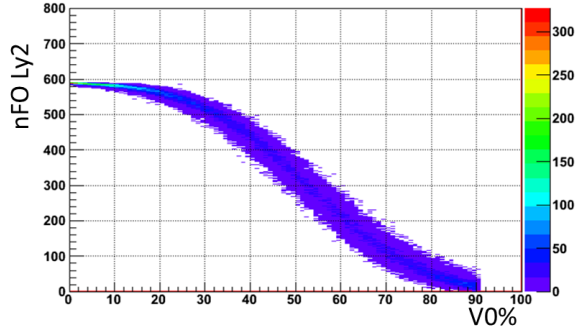


(c)

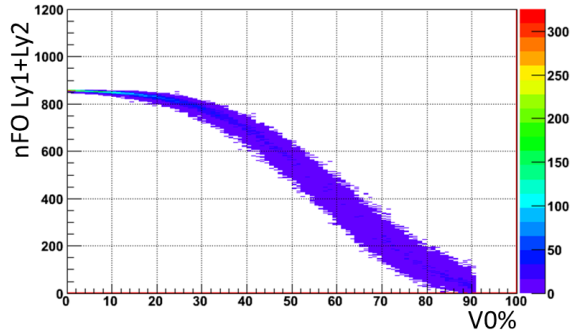
Figure 4.40: FO signals activated as a function of the events centrality determined by V0 detector, V0percentile. The FO are counted in inner layer, outer layer and in total in (a), (b) and (c) respectively. The plots refer to a Monte Carlo simulation of Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.



(a)



(b)



(c)

Figure 4.41: FO signals activated as a function of the events centrality determined by V0 detector, V0percentile. The FO are counted in inner layer, outer layer and in total in (a), (b) and (c) respectively. The plots refer to data from Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

percentile upper limit, as in equations 4.5, with A, B and C the total entries in the regions shown in figure 4.41 (a).

$$\begin{aligned} Efficiency(FO|V0percent) &= \frac{A(FO)}{A(FO) + B(FO)} \\ Purity(FO|V0percent) &= \frac{A(FO)}{A(FO) + C(FO)} \end{aligned} \quad (4.5.1)$$

The efficiency and the purity are shown for MC simulation in figure 4.42. The x -axis represents the upper limit in centrality range $[0\%, V0\%]$ and the y -axis is the FO threshold NFO to be set in inner layer, outer layer and in total, from top to bottom respectively. The colour curves are flat for $V0 > 90\%$ because no percentile is assigned to those events and so they are replicated in each centrality percentage from 90% to 100%. The points in the transient region between the yellow region and the red one is the best compromise between efficiency and purity. In these regions both efficiency and purity are $\sim 90\%$ for a wide range of central classes. The transient region for the inner layer is the narrowest due to FO saturation and in the range $[0\%, 30\%]$ is too tight to be considered in a practical case. This is the reason why a threshold being set only in the outer layer is more versatile. The efficiency and the purity have been measured also in data and the results are showed in figure 4.43. The background in the data results as the large orange region in the purity plots. The efficiency and the purity for nine centrality classes as a function of the FO threshold NFO , for both data and MC simulation, are shown in figures 4.44, 4.45 and 4.46 (NFO respectively set in inner layer, outer layer and in total). The beam background changes the slope of the purity curves in the data. The contribution of the background is enhanced for high values of NFO , this is because it consists of high multiplicity events of the same type as those seen in proton-proton collisions (see figure 4.15). The values in the interval around the intersection point of the efficiency curve and the purity curve maximize the performance of the trigger in the Monte Carlo simulation. A level of efficiency and purity greater than the 95% in all the centrality classes can be reached. The presence of the background lets the purity in the data to reach a plateau at a lower value, which is wider and wider as the centrality range increases. A good working point would be thus in the the knee of the plateau. In this way

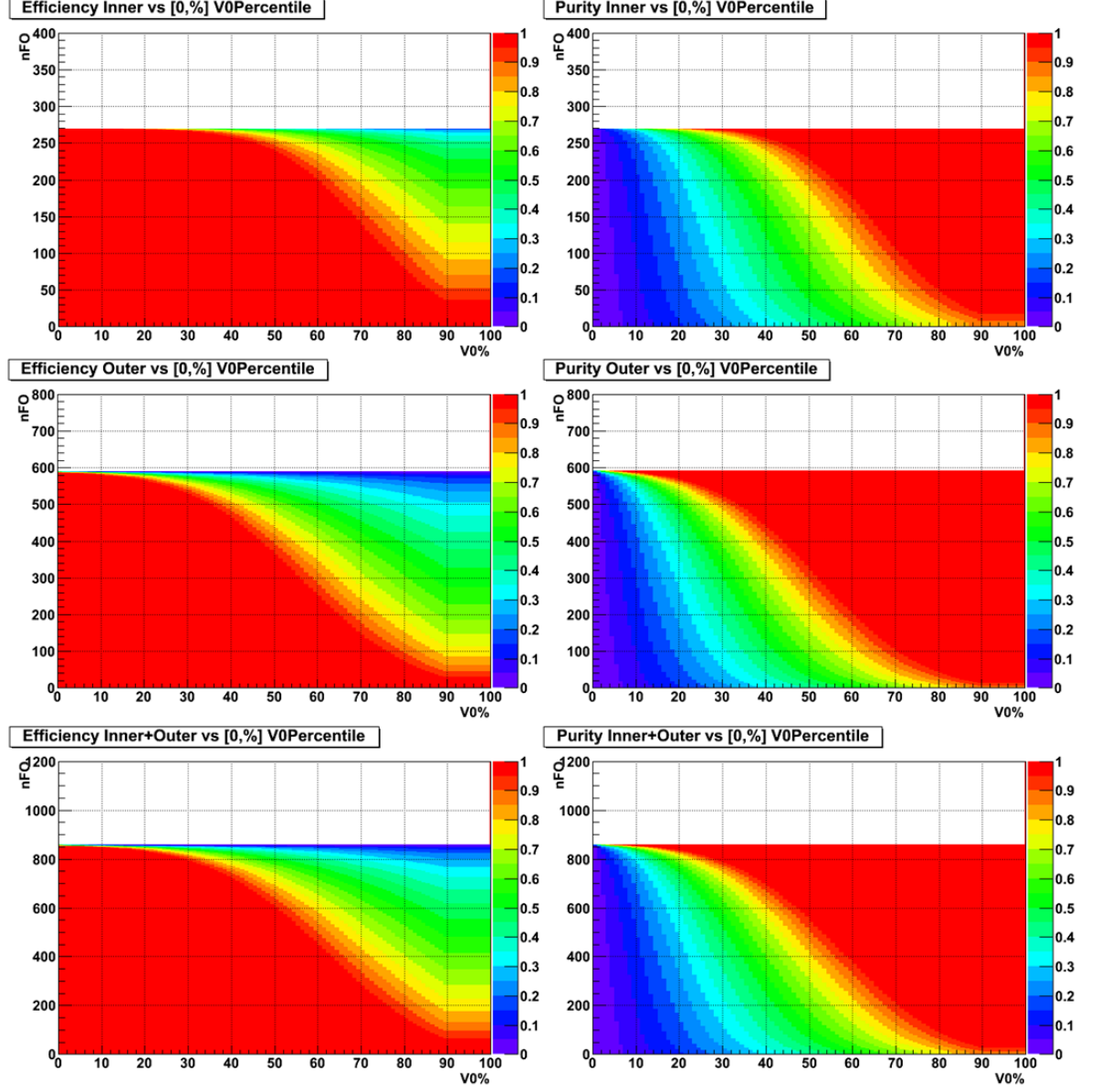


Figure 4.42: FO trigger efficiency and purity as a function of NFO threshold set for events in all centrality class $[0\%, V0\%]$. NFO is set to inner layer, outer layer and in total from top to bottom respectively. The plots refer to a Monte Carlo simulation of Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

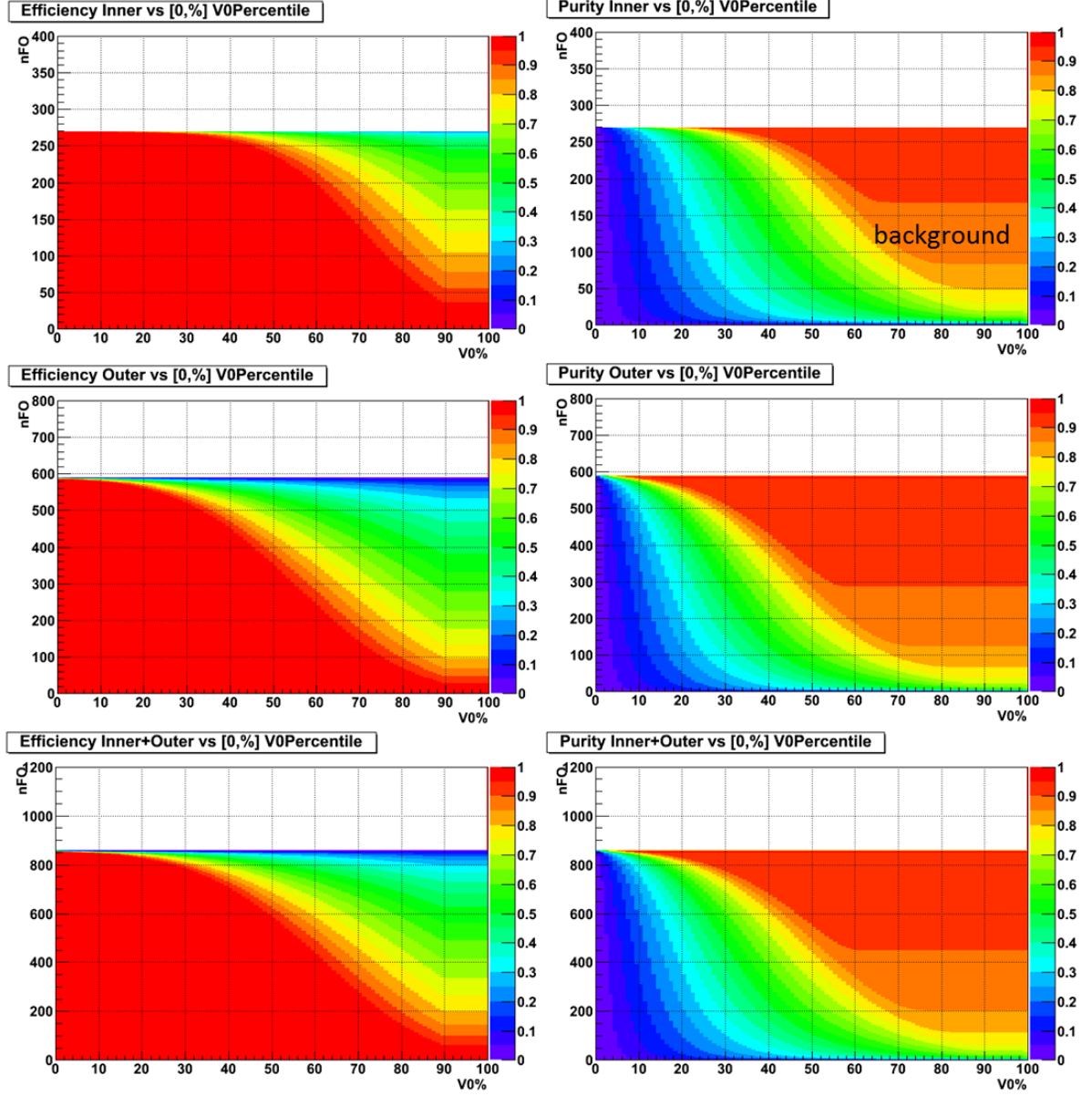


Figure 4.43: FO trigger efficiency and purity as a function of NFO threshold set for events in all centrality class $[0\%, V0\%]$. NFO is set to inner layer, outer layer and in total from top to bottom respectively. The plots refer to data from Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

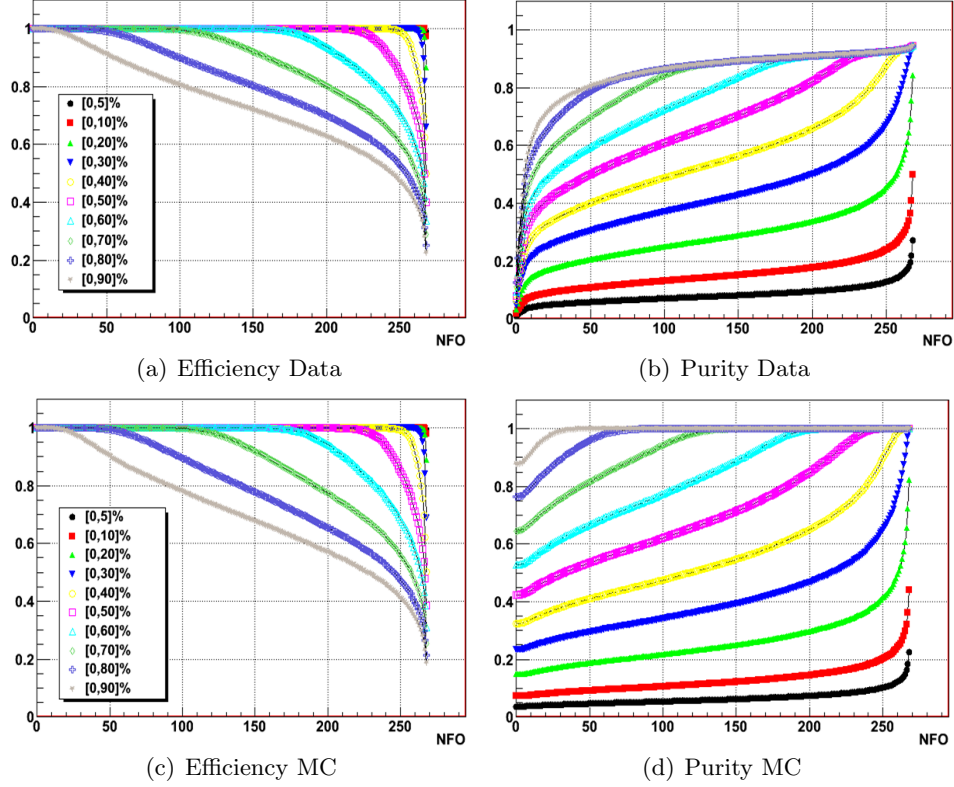


Figure 4.44: Efficiency and the purity for nine centrality classes as a function of the FO threshold NFO set in the inner layer. The plots refer to Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in data (a)(b) and Monte Carlo (c)(d).

the efficiency is kept $\geq 95\%$ and the purity ranges from 90% in most central collisions to 80% in the $[0\%,90\%]$ class collisions. The purity in the classes in the wider centrality classes, from $[0\%,70\%]$ to $[0\%,90\%]$, can be also chosen to be still at 90%, accepting the drop of efficiency down to 60%. This kind of choice is still acceptable since its effect is to reduce the data acquisition rate which is anyway dominated by the slow TPC (~ 500 Hz of readout rate).

Another method has been studied in order to select events in a defined centrality intervals with both lower and upper limit as free parameters. The method consists of applying FO counting thresholds both as lower threshold and upper threshold. Efficiency and purity are defined as in 4.5, with A, B,

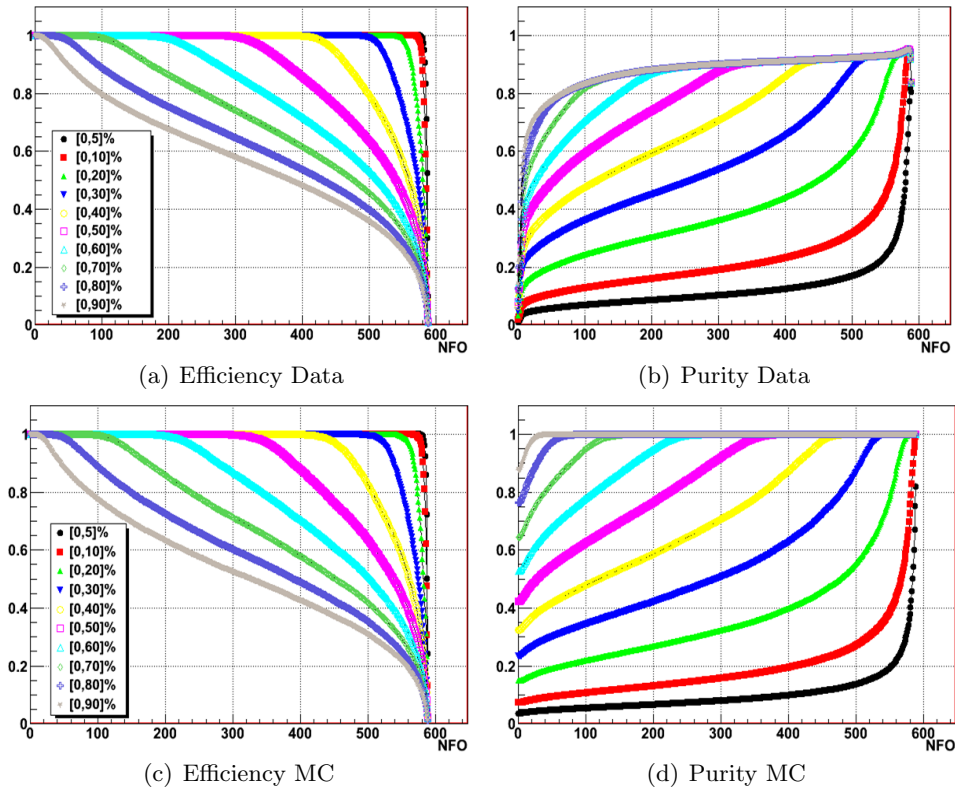


Figure 4.45: Efficiency and the purity for nine centrality classes as a function of the FO threshold NFO set in the outer layer. The plots refer to Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in data (a)(b) and Monte Carlo (c)(d).

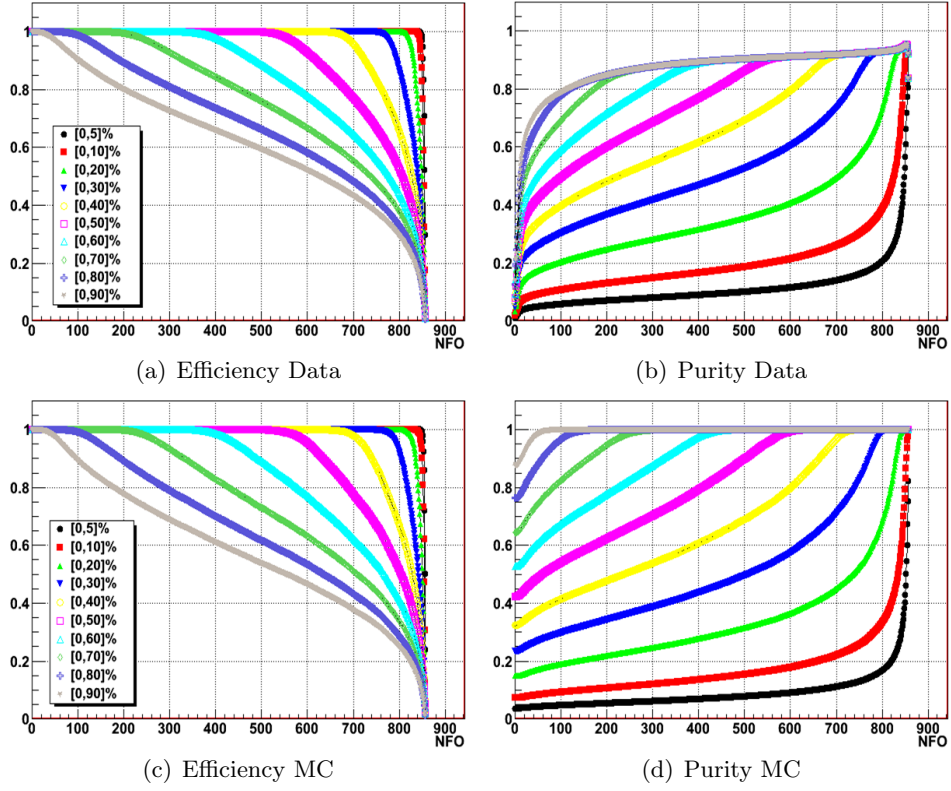


Figure 4.46: Efficiency and the purity for nine centrality classes as a function of the FO threshold NFO set in total. The plots refer to Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in data (a)(b) and Monte Carlo (c)(d).

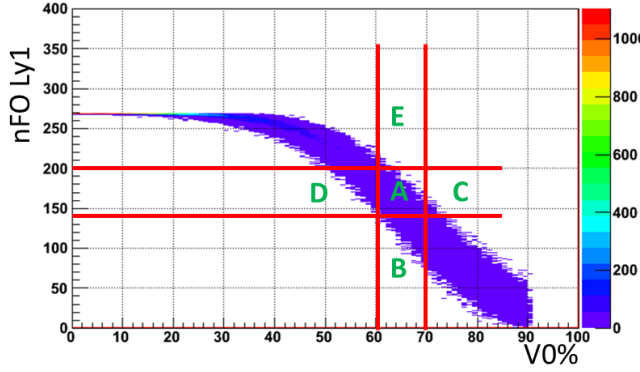


Figure 4.47: FO signals activated as a function of the events centrality determined by V0 detector, V0percentile. The FO are counted in inner layer. The plots refer to data from Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

C, D and E the sum of the entries in the regions indicated in figure 4.47.

$$\begin{aligned} Efficiency &= \frac{A}{A + B + E} \\ Purity &= \frac{A}{A + C + D} \end{aligned} \quad (4.5.2)$$

The limit to this method is the contamination by the background, especially when selecting the most peripheral classes of events. The purity of the event class [50%,60%] as a function of the FO thresholds in the outer layer is shown in figure 4.48 for MC and data. The purity in MC reaches the 100% in the red region while in the data its highest value is of the order of 65-70%. The maximum purity reachable decreases to $\sim 20\%$ in the most peripheral class [80%,90%]. The centrality class intervals in which the NFO distributions (see figure 4.41) are too tight are not considered since they do not give significant results. For these centrality class intervals the previous method has to be directly applied. The efficiency and purity distributions are shown superimposed in the same plot with the same colour scale for the percentage values in z -axis. The efficiency distribution is filled with colours while the purity one keeps only the coloured contours. This is the best way to display the working point regions. The efficiency and the purity as a function of threshold set in the inner layer is shown in figure 4.49 for six different centrality class intervals starting from the 30% most central with amplitude 10% of the cross section.

In figure 4.50 the efficiency and the purity as a function of threshold set in

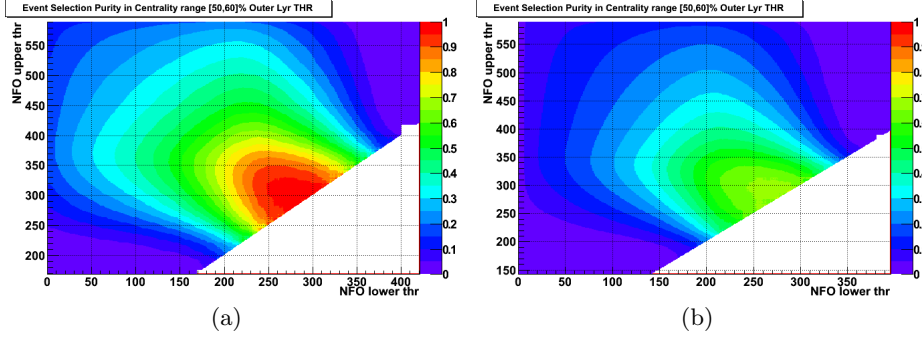


Figure 4.48: Purity in the centrality class [50%,60%] as a function of the FO thresholds, upper and lower value, set in the outer layer. The plots refer to Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for a Monte Carlo simulation (a) and data (b).

the outer layer is shown for eight different centrality class intervals starting from the 10% most central with amplitude 10% of the cross section.

The efficiency and the purity as a function of threshold set in the total number of chips is shown in figure 4.51 for six different centrality class intervals starting from the 10% most central with amplitude 10% of the cross section.

The methods showed so far have been applied to a sample of data of the minimum bias Pb-Pb collision events recorded at the end of 2010. The results obtained are being taken into account for the heavy-ion runs with higher luminosity in 2012 and on, accordingly to the request of scaling the acquisition rate triggering on the more central events.

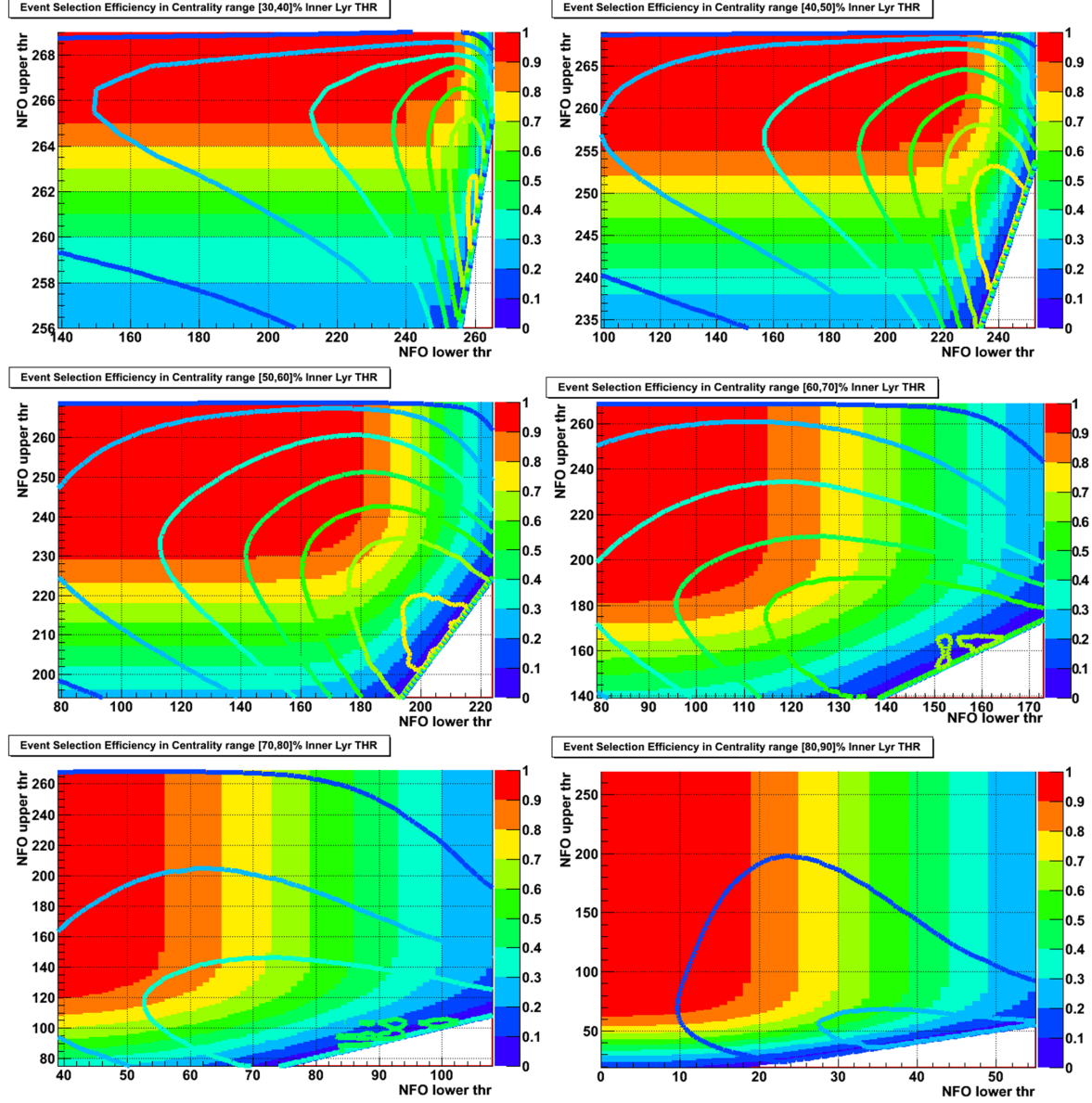


Figure 4.49: Efficiency and purity superimposed distributions as a function of threshold set in the inner layer, in data from Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The distributions are shown for six different centrality class intervals starting from the 30% most central with amplitude 10% of the cross section.

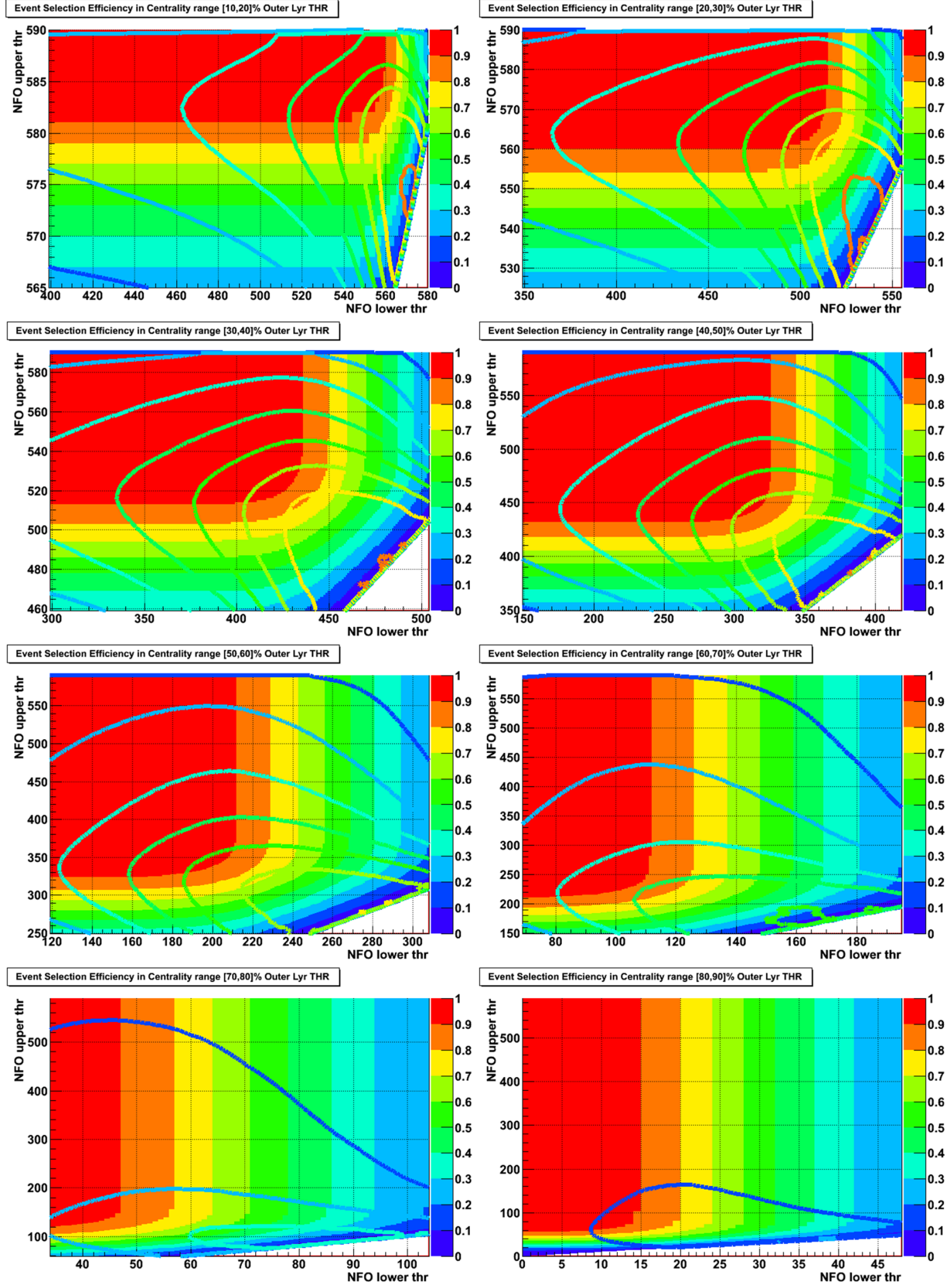


Figure 4.50: Efficiency and purity superimposed distributions as a function of threshold set in the outer layer, in data from Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The distributions are shown for eight different centrality class intervals starting from the 10% most central with amplitude 10% of the cross section.

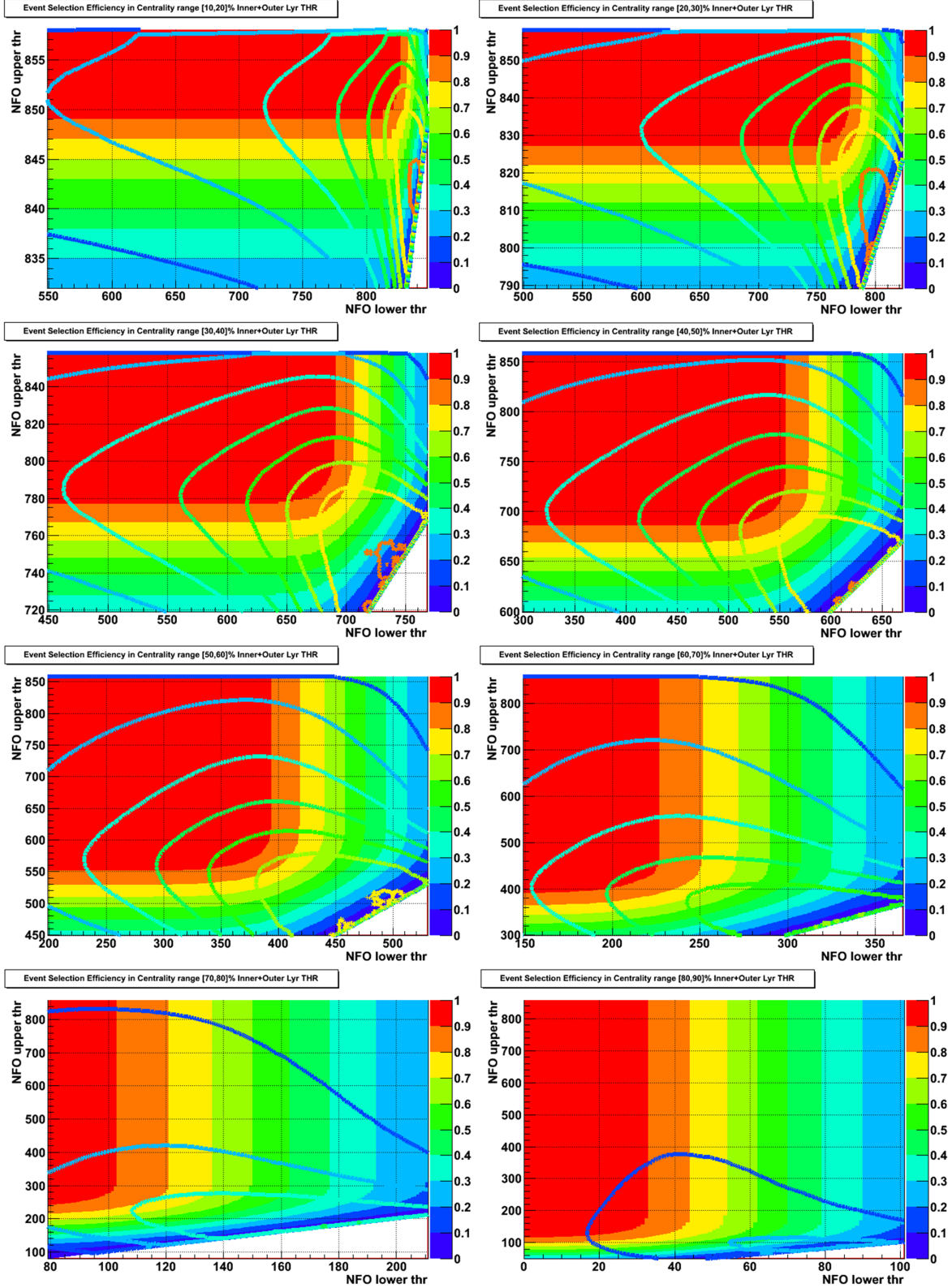


Figure 4.51: Efficiency and purity superimposed distributions as a function of threshold set in total, in data from Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The distributions are shown for eight different centrality class intervals starting from the 10% most central with amplitude 10% of the cross section.

Chapter 5

Trigger study for a future upgrade

Heavy quarks are produced in the early stages of the collisions between heavy ions. They are produced essentially in hard-scattering processes and live for the whole QGP fireball lifetime. The study of open heavy-flavour baryon spectra should allow a more detailed understanding of non-perturbative QCD processes in the low-momentum region, while high-momentum probes would improve the study of the plasma measuring the heavy-quark energy loss through the whole extension of the dense medium. The production of the charm and beauty baryons are also of particular interest to access the thermalization of heavy flavour in the medium giving indications and constraints to the different thermal and coalescence models. Given the large amount of energy available in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV, $c\bar{c}$ and $b\bar{b}$ couples are expected to be produced in a significant amount (respectively about 100 and 5 per event in most 5% central). The ALICE detector triggers on heavy-flavour hadrons in the central barrel via their semi-leptonic decays with at least a high- p_t electron in the EMCal and in the TRD. An extremely efficient trigger would be based on the online evaluation of the invariant mass of the desired hadron. It is feasible to foresee this trigger for a new silicon Inner Tracking System detector.

The project for an upgraded ITS is today under discussion [42]. The new ITS detector aims to improve impact parameter resolution, standalone tracking performance and standalone PID capabilities, accessing very low p_t measurements. Topological trigger capabilities based on the selection of charged tracks associated to a displaced vertex and based on on-line PID

measurements, are expected to pave the way for the collection of rare signals like charm baryons such as Λ_c and exotic signals like beauty baryons such as the Λ_b .

A brief introduction on the use of silicon vertex detectors as trigger detectors in experiments at colliders is given in this section. First quantitative studies about physics performance for a trigger based on Λ_b^0 tagging are presented.

5.1 Vertex detectors triggering at colliders

The Silicon Vertex Trigger system has been one of the major upgrades completed by the Collider Detector at Fermilab (CDF) experiment at Tevatron proton-antiproton collider. It consists of a real-time tracking device capable of reconstructing 2D silicon tracks with the offline quality resolution [43]. This allows the selection of low-momentum heavy-flavour-enriched events: lifetime based selections like impact parameter cuts are in fact a well known tool for discriminating $b\bar{b}$ and $c\bar{c}$ physics events from the mostly prompt hadronic background typical of hadron colliders. Beauty meson decay channels and charm meson branching ratios have been used as a benchmark to test the vertex detector trigger performance and the achieved resolution was, already in the first commissioning phase, close to the world averaged measurements [44].

Still at Tevatron Fermilab, one of the keystones of the canceled BTeV experiment was its sophisticated three-level trigger. The trigger was designed to reject 99.9% of light-quark background events and retain a large number of B decays. The BTeV Pixel Detector provided a 3-dimensional, high resolution tracking system to detect B signatures. The Level 1 pixel detector trigger was proposed as a track-segment finder and a vertex finder which analyzed every accelerator crossing, 2.5 MHz [45].

The experience and the R&D at Tevatron show that the use of the pixel detector in the first level trigger decision in order to have online vertexing and tracking reconstruction is technologically feasible. The challenge in the use of such a system at ALICE LHC would be the sustainable rate and the high background from the high track multiplicity density in lead-lead collisions.

5.2 First studies for a trigger on Λ_b^0

The number of Λ_b^0 candidates which can be collected during heavy-ion data-taking is evaluated in this section. The data are supposed to be collected at the nominal energy, $\sqrt{s_{NN}} = 5.5$ TeV, and luminosity, $L = 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$, foreseen for lead-lead collisions at LHC. The events are expected to be triggered by a topological based and PID based decision, provided by the future ITS upgraded detector.

The time constraint for taking such a trigger decision is the L2 latency of $88 \mu\text{s}$, being extended to $100 \mu\text{s}$ which is the total online memory time of the TPC, after which time the data are definitively lost. The maximum rate for the trigger to take a decision is then 10 kHz. The rate foreseen for the total inelastic cross section is 8 kHz [16]. Therefore the trigger can take a decision on each event.

The total number of $b\bar{b}$ couples per event in the 5% most central events is 4.56 [8]. The branching ratio for the $b\bar{b}$ to go into $\Lambda_b^0 + \bar{\Lambda}_b^0$ is 4% and the 14% of these are produced in the rapidity range $|y| < 1$ [8]. The expected yield for $\Lambda_b^0 + \bar{\Lambda}_b^0$ is 2.64×10^{-2} per event. The yield for minimum bias events is 0.54×10^{-2} per event. This last value is obtained by applying binary collision scaling to next-to-leading order perturbative QCD predictions [46]. The $\Lambda_b^0 + \bar{\Lambda}_b^0$ production rate is 43.2 Hz.

The Λ_b^0 ($m = 5.62$ GeV and $c\tau = 417 \mu\text{m}$) is tagged via its decay with Λ_c^+ in the final state and with Λ_c^+ decaying into $pK^-\pi^+$. The branching ratio for the Λ_c^+ to go into $pK^-\pi^+$ is $5\% \pm 1.3\%$ [47]. The Λ_b^0 branching ratios for the available decay modes are not pure measurements and do not give significant indications for the inclusive $\Lambda_b^0 \rightarrow \Lambda_c^+ + \text{anything}$ [47]. The only one which is known is the semi-exclusive lepton decay $\Lambda_b^0 \rightarrow \Lambda_c^+ l^- \bar{\nu}_l \text{anything}$ which is about 10%. There are though theoretical considerations which predicts a high branching ratio. The inclusive Λ_c branching ratio has been evaluated for the PYTHIA decayer [48], tested in a simulation for a sample of generated Λ_b^0 as explained in the following, and is 73.1%.

A Monte Carlo simulation has been set up using PYTHIA event generator [48] for beauty production in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV. The phase space for $7. \times 10^5$ produced Λ_b^0 has been extracted. A second Monte

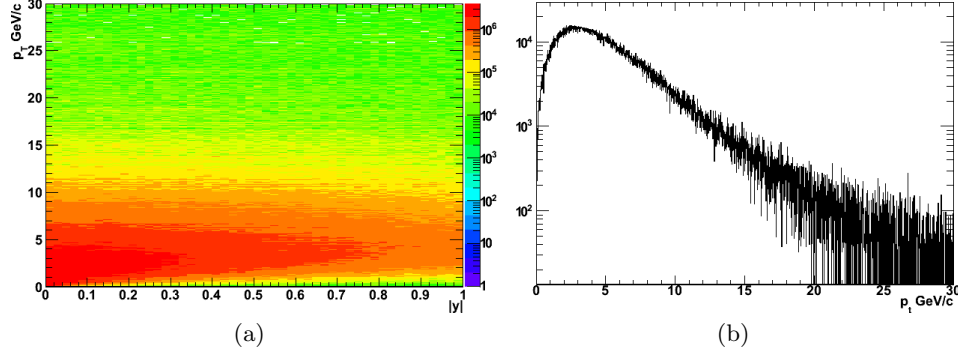


Figure 5.1: Λ_b^0 kinematics for the decay chain $\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow pK^-\pi^+) + X$. Plots refer to Monte Carlo simulation of minimum bias Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV.

Carlo simulation has been set up to increase statistics of Λ_b^0 with $pK^-\pi^+$ from Λ_c^+ in the final state. Only Λ_b^0 have been generated, uniformly in rapidity and transverse momentum, and being decayed by PYTHIA. The Λ_b^0 phase space from the first simulation has been applied a priori to this second simulation. The number of candidate Λ_b^0 decaying to $\rightarrow \Lambda_c^+ (\rightarrow pK^-\pi^+) + X$ is 10^7 , their phase space and the p_t spectrum, both divided by the bin amplitude, is shown in figure 5.1. The fraction of potentially reconstructable Λ_b^0 is evaluated requiring the $pK^-\pi^+$ being in the TPC acceptance $|\eta| < 0.9$ and with a low p_t cut of 100 MeV. The fraction is 22.21%, integrating in the full p_t spectrum. The fraction per bin of the reconstructable Λ_b^0 is shown in figure 5.2 in the phase space and as a function of p_t . The spectra of $pK^-\pi^+$ in the acceptance is shown in figure 5.3. The Λ_c^+ decay vertex distance in space is shown in figure 5.4.

The expected yield for Λ_b^0 candidates is $3. \times 10^{-5}$ per event, to be multiplied by the branching ratio $BR(\Lambda_b^0 \rightarrow \Lambda_c^+ + X)$. The rate of the signal is 2.4×10^{-1} Hz. Assuming 20 days of realistic heavy ion running per year and an efficiency of delivered collisions of 30%, the effective data taking time is 5×10^5 s per year [42]. The collected signal statistics are then $N_{tot}(\Lambda_b^0) = 1.2 \times 10^5$ per year. The effective maximum readout rate is determined by the TPC and is, taking into account the track multiplicity expected for lead-lead collisions, of the order of 520 Hz. Scaling the readout rate from the 8 kHz interaction rate the collected statistics becomes

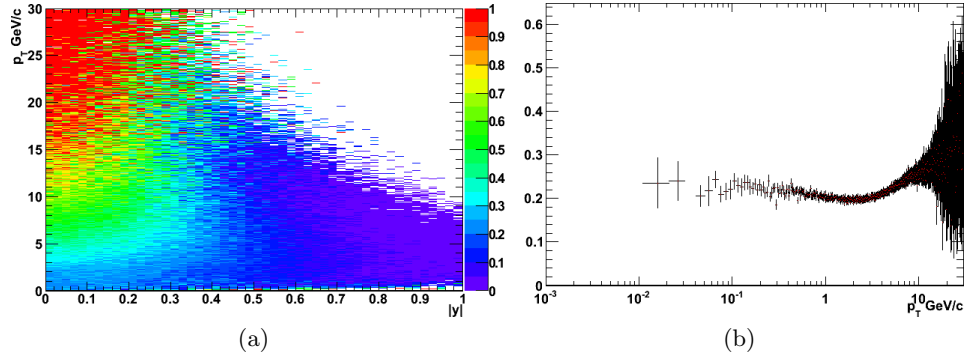


Figure 5.2: Fraction of $\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK^-\pi^+) + X$ with $pK^-\pi^+$ in TPC acceptance $|\eta| < 0.9$ and with a low p_t cut of 100 MeV. The fraction is shown per bin in the phase space (a) and as a function of p_t (b). Plots refer to Monte Carlo simulation of minimum bias Pb-Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV.

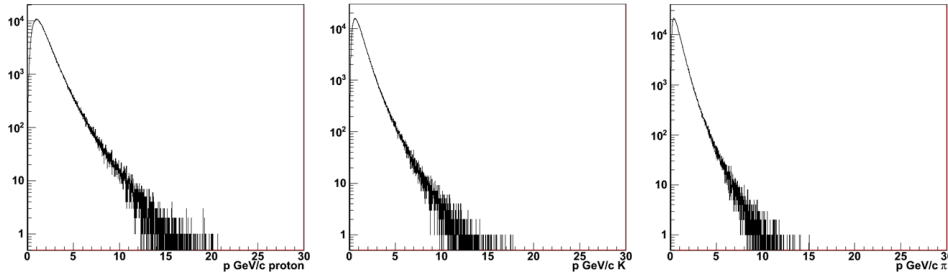


Figure 5.3: Spectra of $pK^-\pi^+$ in the acceptance ($|\eta| < 0.9$ and with a low p_t cut of 100 MeV). Monte Carlo simulation for $\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK^-\pi^+) + X$ in $\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK^-\pi^+) + X$.

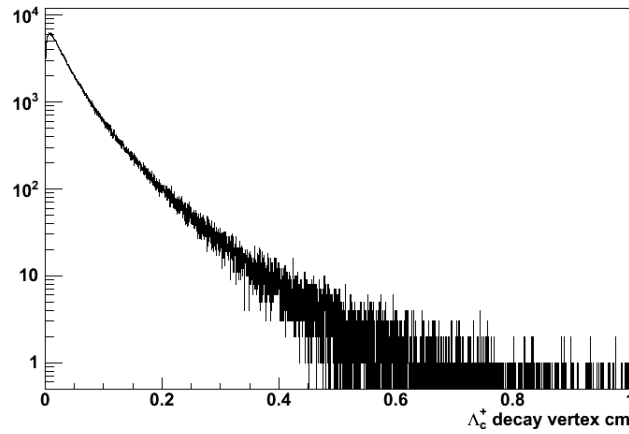


Figure 5.4: $pK^-\pi^+$ displaced vertex from reconstructable $\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK^-\pi^+) + X$.

$N_{tot}(\Lambda_b^0) = 7.8 \times 10^3$ per year. These numbers are reported in table 5.2 for different p_t bins.

p_t range GeV/c	yield/event	yield Hz	$N_{tot}(\Lambda_b^0)/\text{year}$	yield Hz (520 Hz)	$N_{tot}(\Lambda_b^0)/\text{year}$ (520 Hz)
< 1	1.22×10^{-6}	9.80×10^{-3}	4.90×10^3	6.37×10^{-4}	3.18×10^2
$1 \leq p_t < 2$	3.13×10^{-6}	2.50×10^{-2}	1.25×10^4	1.62×10^{-3}	8.14×10^2
$2 \leq p_t < 3$	4.16×10^{-6}	3.33×10^{-2}	1.66×10^4	2.16×10^{-3}	1.08×10^3
$3 \leq p_t < 4$	4.23×10^{-6}	3.38×10^{-2}	1.69×10^4	2.20×10^{-3}	1.10×10^3
$4 \leq p_t < 5$	3.80×10^{-6}	3.04×10^{-2}	1.52×10^4	1.98×10^{-3}	9.90×10^2
≥ 5	1.34×10^{-5}	1.07×10^{-1}	5.36×10^4	6.97×10^{-3}	3.48×10^3

Table 5.1: $\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK^-\pi^+) + X$ yields for different p_t ranges with $pK^-\pi^+$ in TPC acceptance $|\eta| < 0.9$ and with a low p_t cut of 100 MeV. The numbers have to be multiplied by the $BR(\Lambda_b^0 \rightarrow \Lambda_c^+ X)$. Rates of the expected yield and rates when taking into account the maximum sustainable readout-rate of TPC (520 Hz), are reported. Taking into account an effective data taking time is 5×10^5 s per year the total number of candidates is reported $N_{tot}(\Lambda_b^0)$.

The yields of the background candidates is considered. The background candidates are the reconstructed Λ_c^+ from inclusive $pK\pi$ decay. The combinatorial of $pK\pi$ coming from a displaced vertex reconstructed by using the actual ITS and by performing PID with TPC-TOF is considered. The background is evaluated on a data sample of 1.4×10^3 minimum bias events in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The number of candidates in the invariant mass range $[2, 2.5]$ GeV/ c^2 is 2.1×10^8 . Λ_c^+ invariant mass, p_t spectrum and decay length are shown in figure 5.5. The mean value of the Λ_c^+ -signal mass is taken equal to 2.28 GeV/ c^2 with σ equal to 0.009 GeV/ c^2 for p_t greater than 3 GeV/c [42]. The mass peak is assumed being extracted by the online trigger in the interval $\pm 5\sigma$. A cut in the secondary vertex distance is applied. The number of candidates per event for different cut values and p_t ranges are showed in table 5.2. The values which are smaller than one being multiplied by the 8 kHz interaction rate represent the estimation of the expected trigger rates.

The Λ_b^0 candidate yields shown in table are evaluated for the different cuts in the $pK\pi$ decay vertex and Λ_c^+ transverse momentum that give

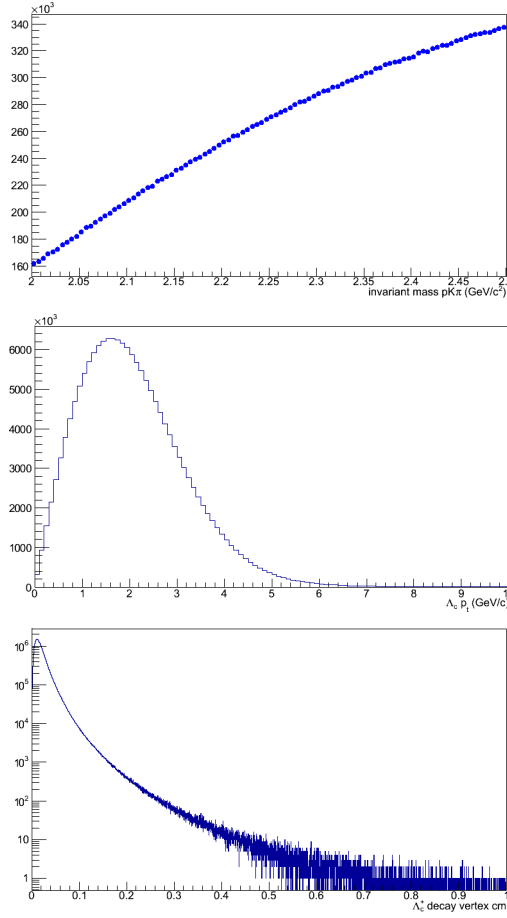


Figure 5.5: Inclusive $\Lambda_c \rightarrow pK\pi$ background candidates. Data sample of 1.4×10^3 minimum bias events in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

a trigger rate which is not saturated to the interaction rate. The total number of reconstructable Λ_b^0 is shown in table 5.2 for different p_t bins. The downscaling to the TPS readout rate is performed and the numbers are shown in table 5.4.

The study proposed in this section gives first quantitative reasons to pave the road to an ITS topological trigger for the future upgrade. The expected yields per year in the high transverse momentum region are encouraging and justify a deep investigation on the Λ_b^0 channel. The improved performance of the future ITS detector will improve the online background rejection, the trigger rate shown can be so considered as lower limits, enriching the statistics for lower transverse momenta values.

$pK\pi$ vertex cut (cm)	Λ_c candidates p_t cut GeV/c				
	$p_t < 2$	$p_t \in [2, 3)$	$p_t \in [3, 4)$	$p_t \in [4, 5)$	$p_t \geq 5$
0.08	83/evt	20/evt	6.7/evt	1.6/evt	0.44/evt
0.1	40/evt	9.8/evt	3./evt	0.79/evt	0.19/evt
0.15	10/evt	2.2/evt	0.66/evt	0.18/evt	0.05/evt
0.2	3.80/evt	0.75/evt	0.19/evt	0.05/evt	0.015/evt

Table 5.2: Yields for inclusive $\Lambda_c \rightarrow pK\pi$ background candidates for different decay vertex cuts and p_t bins. Data sample of 1.4×10^3 minimum bias events in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

Λ_c p_t cut GeV/c	$p_t(\Lambda_b)$ GeV/c				
	$p_t < 2$	$2 \leq p_t < 3$	$3 \leq p_t < 4$	$4 \leq p_t < 5$	$p_t > 5$
$pK\pi$ vertex cut 0.08 cm					
$p_t > 5$	0	0	0	4.8×10	8.53×10^3
$pK\pi$ vertex cut 0.1 cm					
$4 \leq p_t < 5$	0	0	3.6×10	1.55×10^2	1.94×10^3
$p_t > 5$	0	0	0	2.6×10	6.60×10^3
$pK\pi$ vertex cut 0.15 cm					
$3 \leq p_t < 4$	0	2	2.4×10	$6. \times 10$	7.53×10^2
$4 \leq p_t < 5$	0	0	6	3.7×10	8.40×10^2
$p_t > 5$	0	0	0	5	3.57×10^3
$pK\pi$ vertex cut 0.2 cm					
$2 \leq p_t < 3$	0	2	8	1.8×10	2.19×10^2
$3 \leq p_t < 4$	0	0	5	1.4×10	3.21×10^2
$4 \leq p_t < 5$	0	0	0	0	3.88×10^2
$p_t > 5$	0	0	0	0	2.01×10^3

Table 5.3: Total number of possible reconstructed Λ_b when imposing a cut in $pK\pi$ vertex distance and for different Λ_c p_t cuts. The 8 kHz interaction rate is considered and a data taking integration time of 5×10^5 s per year. The numbers refer to a Monte Carlo simulation and have to be multiplied by the $BR(\Lambda_b^0 \rightarrow \Lambda_c^+ X)$.

Λ_c p_t cut GeV/c	$p_t(\Lambda_b)$ GeV/c				
	$p_t < 2$	$2 \leq p_t < 3$	$3 \leq p_t < 4$	$4 \leq p_t < 5$	$p_t > 5$
$pK\pi$ vertex cut 0.08 cm					
$p_t > 5$	0	0	0	3	5.54×10^2
$pK\pi$ vertex cut 0.1 cm					
$4 \leq p_t < 5$	0	0	2	$1. \times 10$	1.26×10^2
$p_t > 5$	0	0	0	1	4.29×10^2
$pK\pi$ vertex cut 0.15 cm					
$3 \leq p_t < 4$	0	0	1	3	4.8×10
$4 \leq p_t < 5$	0	0	0	2	5.4×10
$p_t > 5$	0	0	0	0	2.32×10^2
$pK\pi$ vertex cut 0.2 cm					
$2 \leq p_t < 3$	0	0	0	1	1.4×10
$3 \leq p_t < 4$	0	0	0	0	$2. \times 10$
$4 \leq p_t < 5$	0	0	0	9	2.5×10
$p_t > 5$	0	0	0	0	1.3×10^2

Table 5.4: Total number of possible reconstructed Λ_b when imposing a cut in $pK\pi$ vertex distance and for different Λ_c p_t cuts. The 520 Hz TPS readout rate is considered and a data taking integration time of 5×10^5 s per year. The numbers refer to a Monte Carlo simulation and have to be multiplied by the $BR(\Lambda_b^0 \rightarrow \Lambda_c^+ X)$.

Conclusions

The work described in this thesis was aimed to the study and the optimization of the Silicon Pixel Detector performances. The methods developed were necessary to validate all the optimization procedures conducted during the commissioning phase without beams and to understand and monitor the quality of the data since the first proton-proton collisions delivered in November 2009. The performance measurements and the results obtained also supported the first physics measurements about the charge particle multiplicity density in proton-proton and lead-lead collisions. The thesis work most concentrates on the study of the SPD prompt trigger signal, called fast-OR, which contributes to the first level trigger decision in the ALICE experiment. The use of the fast-OR trigger is unique among all the other vertex detectors at LHC. The advanced know-how and the robustness of the fast-OR trigger, demonstrated in this thesis, made it, and still do, fundamental and extensively used for the data-taking with beams and even for commissioning with cosmic rays.

The success in using the silicon vertex detector in the trigger logic of the ALICE detector paves the way for a future upgrade of its trigger capabilities. The project for an upgraded silicon Inner Tracking System is today under discussion and its role can be strengthened by implementing more elaborated trigger capabilities based on online topological reconstruction of the events and particle identification.

List of acronyms

ALICE - A Large Ion Collider Experiment

LHC - Large Hadron Collider

QGP - Quark Gluon Plasma

QCD - Quantum Chromodynamics

RHIC - Relativistic Heavy Ion Collider

FAIR - Facility for Antiproton and Ion Research

SPS - Super Proton Synchrotron

PID - Particle Identification

TPC - Time Projection Chamber

ITS - Inner Tracking System

SPD - Silicon Pixel Detector

HS - half-stave

PIT - Pixel Trigger System

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