

Summer Student Programme

Flow mode studies for ϕ meson in PbPb run2 data

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Abstract

Elliptic flow for ϕ meson is measured in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ALICE detector at the Large Hadron Collider. ϕ mesons have similar mass to protons and as a result one would expect a mass ordering similar to that of protons in low p_T region. Since a particle type grouping in the intermediate p_T values is expected, ϕ mesons must follow the same trend as other mesons, i.e. pions and kaons. Therefore a preparation of the software embedded in the official resonance package was required. As a first step the aim was to include the generic framework calculations for the elliptic flow mode v_2 . Finally, the project aims to give an insight to the behaviour of the flow modes in different pT values for this unique particle species.

1 Introduction

This study deals with the anisotropic flow which is one observable to characterise the properties and evolution of a system of quark gluon plasma created in the collision of nuclei. Measuring the anisotropic flow in general can constrain the created system's initial conditions and transport properties such as the shear viscosity η/s or the bulk viscosity ζ/s .

It is furthermore interesting to measure the anisotropic flow of different particle species. Doing this, an ordering of the flow distributions based on the investigated particles' rest mass in the low p_T region (roughly 0 to 2 GeV/c) was observed in previous studies from which one can learn about the interplay between the radial flow and the anisotropic flow. Likewise, a grouping of the obtained flow measurements based on the particle type (mesons vs. baryons) has been observed in the intermediate p_T region (roughly 2 GeV/c to 6 GeV/c). From these results it is possible to learn about the effect of quark coalescence which is the main particle production mechanism in such a system.

2 ALICE Experiment

ALICE is the only dedicated experiment at CERN to study heavy-ion collisions. This experiment is designed to study QCD related phenomena as well as the quark gluon plasma at high energy densities and temperatures. A layout of this detector is shown in Fig.1. The detector consists of a central barrel surrounded by a 0.5 T solenoid magnet and a forward muon spectrometer with a dipole magnet of 0.67 T. The central barrel covers the full azimuthal angle and a pseudorapidity range of $|\eta| \leq 0.9$. It consists of an Inner Tracking system (ITS) made of silicon detectors for tracking and vertex determination, a Time Projection Chamber (TPC) for global tracking and particle identification based on the specific energy loss dE/dx in the employed gas, a Transition Radiation Detector (TRD) and a Time-Of-Flight (TOF) which are both used for further particle identification.

Outside the TOF additional acceptance limited

detectors are installed: a High Momentum Particle Identification Detector (HMPID), an Electro-Magnetic CALorimeter (EMCAL) and a PHOTon Spectrometer (PHOS).

At each side of the detector along the beam axis further detectors such as the V0, the T0 and the Zero-Degree Calorimeter (ZDC) are placed to measure e.g. the centrality (V0 and ZDC) or start time of the ion collision (T0) respectively.

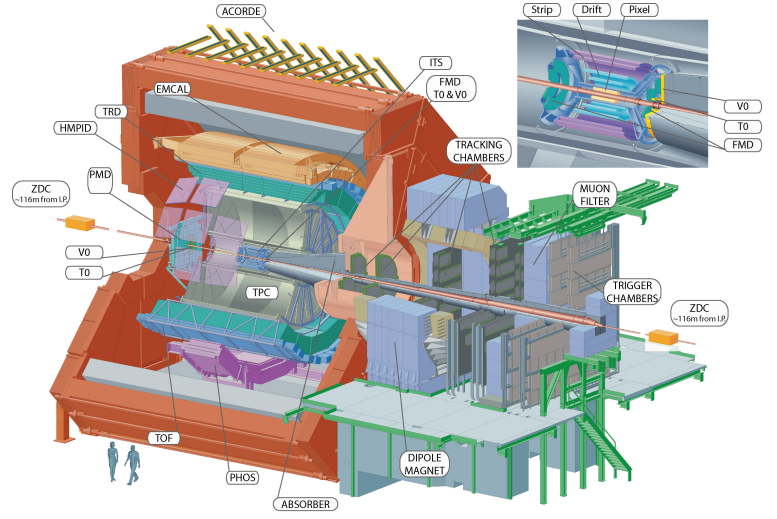


Figure 1: Schematic drawing of the ALICE detector.

3 Run 2 Dataset

The analysis is based on Pb-Pb collision data taken in run 2 during 2015. The 77 run numbers are contained in "RunList_LHC15o_pass1_CentralBarrelTracking" [2].

4 Theoretical Framework

In non-central collisions of heavy-ions, e.g. lead (Pb), the overlapping collision region is not a perfect almond shape which gives rise to higher order spatial anisotropies. In the created low viscous medium this can translate into an anisotropy in momentum space. This behavior is referred to as anisotropic flow [3].

Theoretically, the structures in the anisotropic flow can be described using a Fourier expansion of the invariant triple differential distributions given in equation 1

$$E \frac{d^3N}{dp^3} = \frac{1}{2\pi} \frac{d^2N}{p_T dp_T dy} \left(1 + 2 \sum_{n=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)] \right) \quad (1)$$

where E is the energy of the particle, p the momentum, p_T the transverse momentum, φ the azimuthal angle, y the rapidity and Ψ_n the symmetry plane angle. The Fourier components or *flow modes* v_n can be written as

$$v_n(p_T, y) = \langle \langle \cos[n(\varphi - \Psi_n)] \rangle \rangle. \quad (2)$$

where the double brackets denote the sums over all particle over all events. However this is a mathematical derivation with few physical arguments. Since symmetry plane angle Ψ_n is inaccessible, different methods have been implemented to measure flow coefficients. One of these methods is the generic framework. In this analysis, a 2 particle correlation technique is used in which the particles of interest (POI) selected from one subevent in the pseudorapidity range are correlated with the

reference particles from another subevent allowing to theoretically calculate the flow coefficient. Therefore two quantities referred to as P and Q vector have to be defined which are given in equation 3 and 4.

$$\mathbf{P}(p_T) = \sum_{i \in \text{POI}}^m w_i e^{in\varphi_i} \quad (3)$$

$$\mathbf{Q} = \sum_{j \in \text{RFP}}^M w_j e^{in\varphi_j} \quad (4)$$

The P vector is defined as the sum over the exponentials of the azimuthal angle of m particles of interest (POI) with same p_T value, in this analysis, for ϕ mesons. The weight w_i gives a measure of any non uniform acceptance and efficiency respectively and is set to 1 in this analysis. The Q vector is defined as the sum over the exponentials of the azimuthal angles of M reference particles (RFP) which are defined as all charged particles with $0.2 < p_T < 5$ GeV/c.

The generic framework provides an algorithm which allows to calculate harmonics of the anisotropic flow. An example is the elliptic flow $v_2(p_T)$ which is given as

$$v_2(p_T) = \frac{\left\langle \frac{\mathbf{P}(p_T)_2^a}{m} \cdot \frac{\mathbf{Q}_2^{b*}}{M} \right\rangle}{\sqrt{\left\langle \frac{\mathbf{Q}_2^a}{M} \cdot \frac{\mathbf{Q}_2^{b*}}{M} \right\rangle}}. \quad (5)$$

In equation 5 the numerator describes the scalar product of P vector and Q vector complex conjugated scaled to the number of POIs with same p_T value and the number of RFPs per event, respectively. P vector and Q vector are always chosen from two different pseudorapidity regions. All scalar products are summed up over all events that have passed the event selection criteria. In this analysis, the pseudorapidity gap between the two subevents is set to $|\Delta\eta| > 0.2$. The denominator, referred to as reference flow, is the normalization based on all reference particles.

5 Analysis

5.1 Track Selection and Particle Identification

The ϕ meson ($m_{\text{PDG}} = 1019.460 \pm 0.016$ MeV/c²) as particle of interest is identified by reconstructing its decay products. In order to do this the decay $\phi \rightarrow K^+ K^-$ with a branching ratio of 0.489 ± 0.005 is used which is tried to be extracted with help of the information from ITS, TPC, TOF and the V0 detector. After the event selection [4] roughly $5.3 \cdot 10^7$ events are accepted. Figure 2 illustrates the centrality distribution of the accepted events. Each 10 % centrality bin contains roughly $540 \cdot 10^3$ events.

The charged kaons are identified in two steps: a set of quality cuts is applied on all reconstructed charged tracks also referred to as **StandardITSTPCtrackCuts2011**. A good charged track has to fulfill the following criteria:

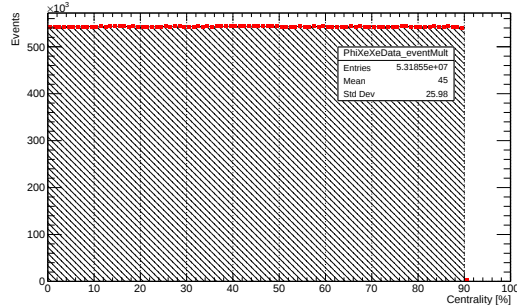


Figure 2: Centrality of all selected events with roughly $540 \cdot 10^3$ per 10 % centrality bin.

1. minimum number of crossed rows in TPC: $N_{rows,TPC} \geq 70$.
2. minimum ratio of number of crossed rows to number of findable clusters in TPC: $R_{findable} \geq 0.8$.
3. maximum χ^2 per cluster in TPC: $\chi^2_{TPC} < 4$.
4. kink daughters rejected.
5. ITS refit required.
6. TPC refit required.
7. minimum number of clusters in SPD: $N_{cls,SPD} \geq 1$.
8. maximum χ^2 in TPC-Constrained global: $\chi^2_{global} < 36$.
9. p_T -dependent cut (7σ) on the distance of closest approach to the primary vertex in the transverse plane: $DCA_{xy} < 0.0105 + 0.035p_T^{-1.01}$.
10. cut on the distance of closest approach to the primary vertex in the beam direction, $DCA_z < 2$ cm.
11. maximum χ^2 per cluster in TIS: $\chi^2_{ITS} < 36$.

All tracks fulfilling these requirements are accepted as charged particles. The particle identification procedure relies on the response of the TOF detector (t_{TOF}) and the specific energy loss (dE/dx) measured by the TPC detector where kaons are selected by requiring their signal to lie within maximum 2 standard deviations from dE/dx and t_{TOF} in a given transverse momentum. This PID criteria is illustrated in the left hand side of Fig. 3. The right panel in Fig. 3 shows the specific energy loss dE/dx as a function of the transverse momentum p_T of the charged kaons with the TOF and TPC PID requirements.

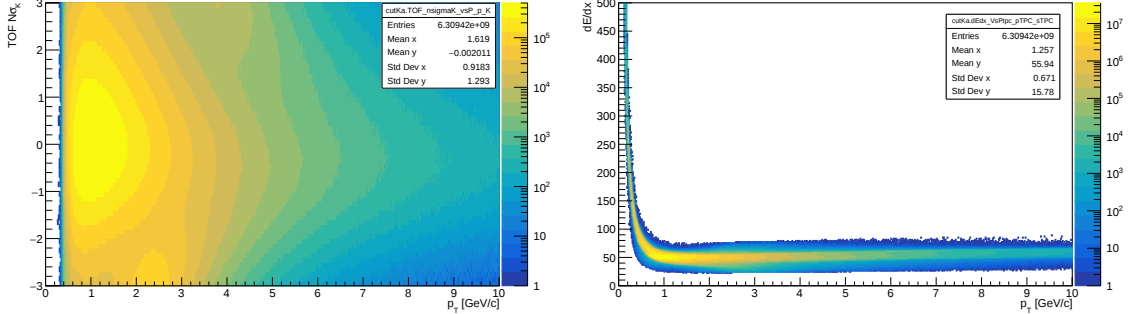


Figure 3: **Left:** Accepted events based on the TOF requirements of $|N\sigma_{TOF}| < 3$ as a function of p_T . **Right:** Specific energy loss dE/dx as a function of p_T after the PID cut criteria.

5.2 Invariant Mass Analysis

An invariant mass (m_{inv}) analysis is carried out to extract the yield of ϕ mesons and background particles referred to as N^{sig} and N^{bkg} respectively in equation 6. The knowledge of these numbers is required to further calculate the flow mode v_2 of the reconstructed ϕ mesons here indicated as v_2^{sig} .

$$v_2^{tot}(m_{inv}) = v_2^{sig} \frac{N^{sig}}{N^{sig} + N^{bkg}}(m_{inv}) + v_2^{bkg} \frac{N^{bkg}}{N^{sig} + N^{bkg}}(m_{inv}) \quad (6)$$

Pairs of successfully identified kaons of opposite charge in the same event referred to as unlike-sign pairs, are studied as a function of centrality, p_T and m_{inv} . This procedure yields a distribution describing signal and background with a peak around the rest mass of the ϕ meson.

To estimate the background a subset of 5 events is picked every time and the kaon from one event is paired with the opposite charged kaons from the other events. This method is called event mixing. For background estimation the events are required to be "similar" in terms of centrality

and topology. Therefore it is required that the difference in centrality shall be $\Delta C \leq 5\%$ and the difference in the z coordinate of the primary vertex position must satisfy $\Delta z_{vertex} \leq 1$ cm. In order to extract the signal, the obtained background distribution is scaled to the integral of the unlike-sign distribution in a region towards higher invariant masses behind the ϕ meson resonance indicated with two vertical blue lines in the left panel of figure 4. The region is chosen to be within $1.06 \text{ GeV}/c^2 \leq m_{KK} \leq 1.10 \text{ GeV}/c^2$ which is not biased by the resonance itself.

Subtracting the scaled background distribution from the unlike-sign pair distribution yields a distribution with a more distinct peak around the rest mass of the ϕ meson. However, the estimated background is generally not equal to the background shape of the unlike-sign distribution and therefore a non-flat structure remains in the subtracted distribution referred to as residual background.

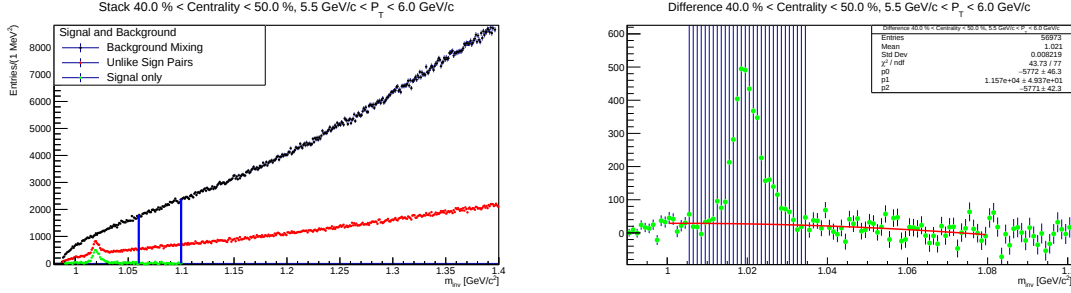


Figure 4: **Left:** Mixing background in black, unlike-sign distribution with ϕ meson peak around its rest mass in red and the difference between the two distributions is green. The two vertical lines indicate the region based on which the scaling is done. **Right:** The difference of the two distributions with the distinct peak around $m_{inv} = 1.02 \text{ GeV}/c^2$ associated with the ϕ resonance. The residual background is estimated based on the the fit indicated via the red line.

To quantitatively estimate the residual background distribution, the errors of the data points around the rest mass of the ϕ meson are set to an arbitrarily high number such that when fitting the distribution only the background shape to the left and the right of the peak region is statistically significant (see right panel in figure 4). This background, as well as the distribution from the background event mixing, is parameterised by a polynomial of second order. The ϕ meson peak is parameterised by a Voigtian function as given in equation 7. It is defined as the convolution of a Breit-Wigner curve with a Gaussian, used to describe the physical resonance and to take into account the detector resolution respectively.

$$\text{Voigtian}(m_{inv}, m_{KK}, \sigma, \Gamma) = \frac{A}{(2\pi)^{3/2}\sigma} \exp\left\{-\frac{(m_{inv} - m_{KK})^2}{2\sigma^2}\right\} \frac{\Gamma}{(m_{inv} - m_{KK})^2 - \Gamma^2/4} \quad (7)$$

Based on the parameters obtained from the residual background in the right panel in figure 4 the whole distribution shown in the right panel of figure 4 is fitted using a superposition of the described Voigtian and a second order polynomial:

$$f_{fit}(m_{inv}, m_{KK}, \sigma, \Gamma) = \text{Voigtian}(m_{inv}, m_{KK}, \sigma, \Gamma) + \text{pol2}(m_{inv}). \quad (8)$$

The results are illustrated in the left panel of figure 5. So, knowing the fit parameters of f_{fit} gives the yield of ϕ mesons N_{sig} and using a polynomial of second order to furthermore describe the background distribution obtained from the event mixing yields the background contribution N_{bkg} .

5.3 Extraction of v_2

The p_T differential elliptic flow, v_2 , is measured by implementing a calculation of the latter into the analysis code based on the generic framework (see equation 5). Its extraction works as follows: The distribution obtained from equation 5 is fitted to v_2^{tot} given in equation 6. Here N^{sig} and N^{bkg} are each obtained from the invariant mass analysis whereas the fit parameters v_2^{sig} and v_2^{bkg} are assumed to be a constant value and a $\text{pol2}(m_{inv})$ respectively.

Since the distribution consists of the elliptic flow of the ϕ meson and of any background contribution, the distribution is expected to have a rather flat evolution as function of the invariant

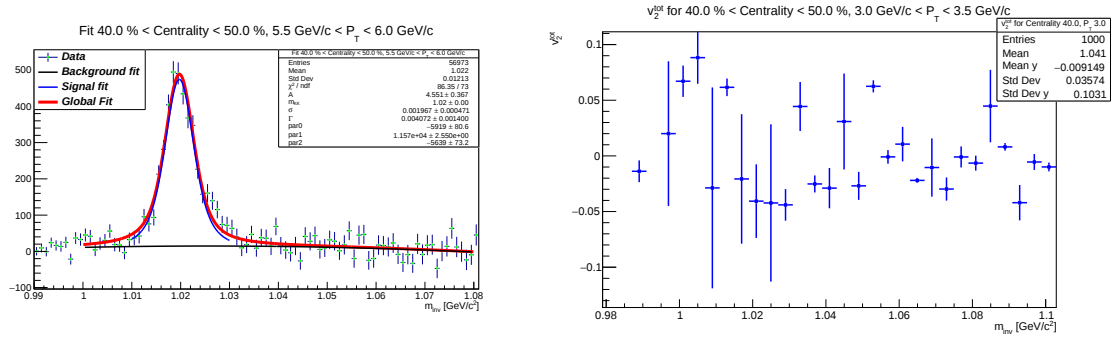


Figure 5: **Left:** Fit of the extracted signal (red) with the superposition of a Voigtian (blue) and a second order polynomial (black). Here, A is the amplitude, m_{KK} is the rest mass of the ϕ meson, σ is the detector resolution, Γ is the width of the ϕ resonance and par(0,1,2) are the parameters of the pol2. **Right:** First results of the elliptic flow distribution of the ϕ meson. The expected dip of the distribution around the rest mass of the ϕ meson is clearly missing.

mass describing the elliptic flow of the background and is supposed show a dip towards smaller values of v_2 for the region around the rest mass of the particle of interest.

However, first results obtained from the analysis which are illustrated in the right panel of figure 5 do not match the expectations yet. The distribution of the elliptic flow as a function of the invariant mass has no visible dip around the rest mass of the ϕ meson, hence it is not possible to extract a meaningful value for v_2 .

5.4 Outlook

Further investigations regarding the implemented analysis code need to be carried out to finally receive the expected results such as they are shown exemplary in the left panel of figure 6 based on data from a recent flow analysis on the same data set [5]. Having these, the previously described fitting procedure can be carried out and in turn it is possible to obtain a p_T differential distribution of v_2 (right panel) to compare the latter with differential elliptic flow distributions of other particle species as explained in the introduction.

Based on the theory of the generic framework model, the implementation can then be extended to more complicated quantities like non-linear flow modes.

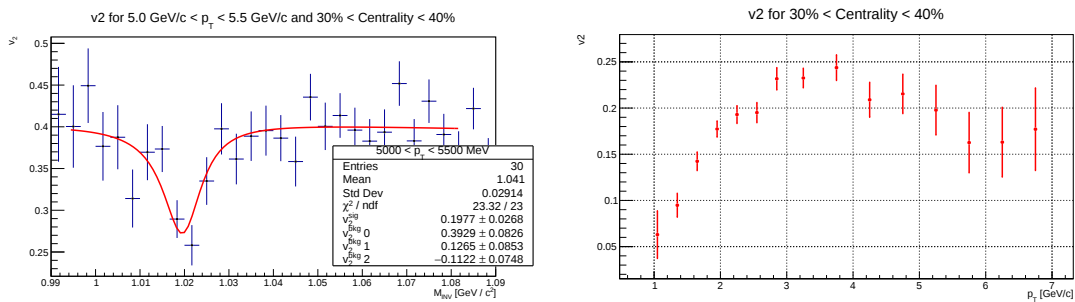


Figure 6: **Left:** v_2 distribution of a recent analysis to illustrate how the elliptic flow can be obtained by a fit. The distribution decreases around the rest mass of the ϕ meson. The fitting procedure is performed as described in the previous chapter. **Right:** p_T differential distribution of v_2 based on the fit values obtained for the elliptic flow for the ϕ meson.

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