Université Paris-Sud

European Organisation for Nuclear Research (CERN)

Study of the decay $K_S^0 \to \pi^0 \mu\mu$ with the LHCb experiment

Internship Report

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From June 16^{th} to August 29^{th} 2014

Contents

1 Introduction

For my first year of Master in Fundamental Physics, I had to do a three months internship. After being selected to take part in the CERN Summer Student program, I had the chance to work with the LHCb Experiment on the analysis of the decay $K_S^0 \longrightarrow \pi^0\mu\mu$ with the help of my supervisor Xabier Cid Vidal.

Furthermore the Summer Student program offers a cycle of lectures with several topics : Particle Physics, Cosmology, Nuclear Particles, Colliders and Accelerators, ... From July 1^{st} to August 8^{th}, we attended each morning three lectures and several workshops and visits were organized by the Summer Student Team. Thus I had the chance to visit the detectors LHCb and CMS and the CERN Data Center that stores LHC data and distributes it everywhere through the Worldwide LHC Computing Grid.

Most of my work was done with PyROOT which is a Python extension that allows the use of ROOT classes[1] with the Python interpreter.

2 The CERN and the LHC

2.1 The CERN

The European Organisation for Nuclear Resarch[1] is an European research organisation based near Geneva on both sides of the French-Swiss border. Its main purpose is to provide the infrastructures needed for high-energy physics such as accelerators, computanional facilities, R& D,... There are many experiments that take place at CERN such as the ones about particle physics with the LHC but there are also experiments about antimatter (AEGIS, ALPHA), dark matter (CAST) or nuclear physics (ISOLDE).

It was founded by 12 states in Western Europe but now there are 21 member states and 7 observers. CERN employs 4000 employees and hosts above 10,000 visiting scientists and engineers from all over the world. CERN is world-famous for the discovery of the Higgs Boson but it is also the place of the discoveries of W and Z bosons. It is also the place where the World Wide Web was invented in 1990.

2.2 The LHC

The LHCb experiment is one of the four major experiments at the LHC (Large Hadron Collider) which is located near Geneva in Switzerland. The LHC is a synchroton of 27 km of circumference : in its tunnel, two beams of protons collide at the location of the detectors of the different experiments. Protons are accelerated until they reach an energy of 8 Tev in the rest frame[2] (4 TeV for each proton beam). It allows the detectors to detect new particles created by the collision of two protons.

The two major experiments of the LHC are ATLAS and CMS. Even if they are multi-purpose experiments, the first goal was to detect the Higgs Boson, which they achieved in July 2012. They are also looking for Physics beyond the Standard Model, such as SuperSymmetry. ALICE is designed for the analysis of Heavy-Ion collisions[3] and the study of Quark Gluon plasma.

[1]The acronym CERN is for Conseil Européen pour la Recherche Nucléaire, a provisional council formed in 1952.

[2]The energy was 7 TeV in 2010-2011, 8 TeV in 2012 and is expected to be 13 TeV in 2015.

[3]Pb-Pb, Pb-p and p-Pb.

The LHCb experiment is built for the analysis of the violation of the CP symmetry through the physics of the b quark. The Standard Model is built on symmetries and C (charge conjugaison), P (parity) and T (time reversal) are three major ones. As long as we know, every process in Particle Physics is CPT invariant but it can break C, P or CP as many experiments have proved since 1964. It leads to differences of behaviour between particles and antiparticles that can be experimentally observed. The study of the CP violation is about measuring and analysing these assymmetries.

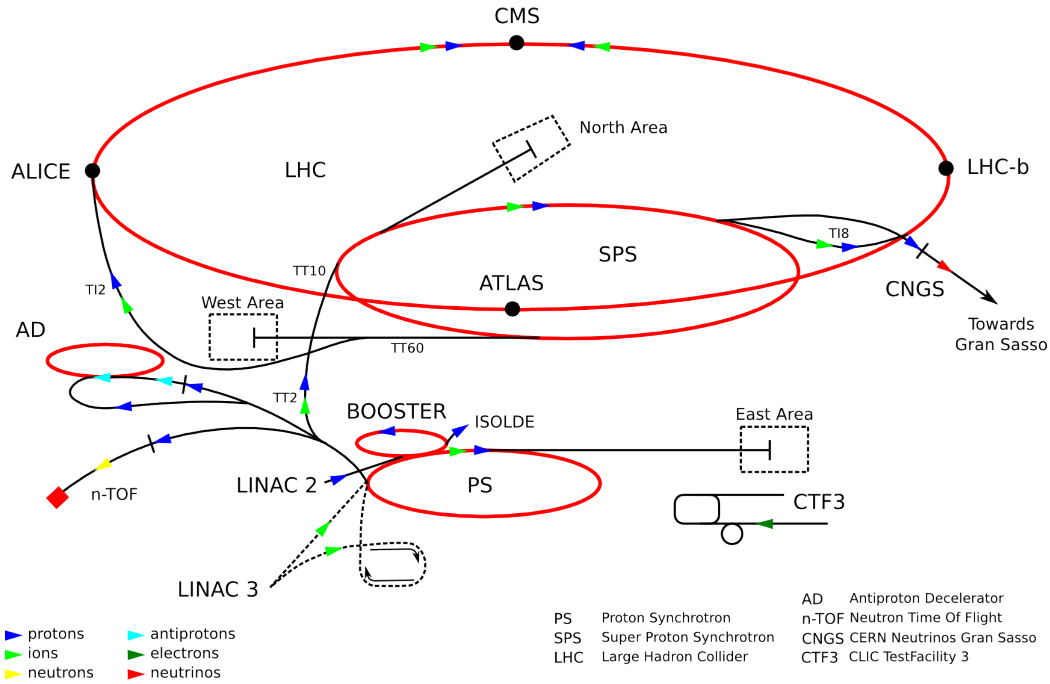

Figure 1: Map of the accelerators complex.

2.3 The LHCb detector

The LHCb detector is not surrounding the collision point like CMS or ATLAS detectors but is a single arm forward spectrometer. This design is supported by the facts that simulations showed that pairs of quark-antiquark $b\bar{b}$ are created in two narrow forward and backward cones. To be able to do precise measurements, the experiment focused on the forward cone.

The detector is composed of

- a VErtex LOcator to be able to determine precisely the collision point of two protons[4] and the location of the decay of particles created by this collision[5].
- Trackers (TT, T1, T2, T3) to reconstruct the trajectories of particles.
- Cherenkov detectors (RICH1, RICH2) are used for particle identification (PID) which is one of the strong points of LHCb experiment. For instance, it is used to discriminate pions from kaons.

[4]Primary Vertex
[5]Secondary Vertices

- The magnet curves the trajectories of charged particles so their momentum can be measured.
- Calorimeters (HCAL, ECAL) for measuring the energy of particles and for PID.
- Muons chambers (M1,..,M5) that detect muons.

The beams cross each other at a frequency of 40 MHz. The amount of data produced is too large to be stored. The detector is thus completed by a trigger system that has to select only the "interesting data". It uses the different elements of the detectors to decide to collect the data or to reject it based on how relevant the events are. The trigger system is divided in three levels (L0, HLT1, HLT2) and each step rejects events based on more and more precise selection cuts. For instance,the first level of trigger (L0) select only muons with high tranverse momentum. The quantity of data after trigger is still huge but it can be stored and is usable.

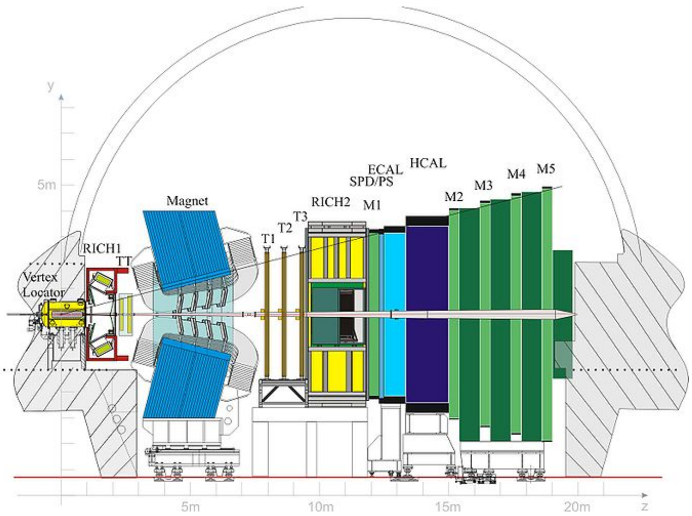

Figure 2: Schéma du détecteur LHCb.

3 The decay $K_S^0 \longrightarrow \pi^0\mu\mu$

3.1 Doing s physics at LHCb ?

The LHCb detector was build to study b physics. The general layout and the parametrization of the trigger are made to focus on b mesons such as B^0, B_s^0 or $B^{\pm}$. Most physicists at LHCb are working on b physics. Some people realised it was also possible to study c physics and they build a charm physics group inside LHCb.

It's much more complicated to do s physics at LHCb because they are light particles and decay in particles with small p_T that are hard to reconstruct. Nevertheless there are $\sim 10^{13}$ K_S^0 per fb^{-1} of data[6] and LHCb produced 3 fb^{-1} in 2012. Even if it is challenging to study such particles, the analysis of $K_S^0 \longrightarrow \pi^0\mu\mu$ at LHCb may be possible[7].

3.2 The main goal of the analysis

The neutral kaon, K^0 (with a mass of 497.6 MeV/c^2 [5]), composed by a down quark and a strange antiquark ($s\bar{d}$) can be seen as a superposition of two other particules :

- the K_L^0, for "K-long" which is formed from $\frac{d\bar{s}+s\bar{d}}{\sqrt{2}}$. It is long because its lifetime is 5.12×10^{-8} s.
- the K_S^0, for "K-short" which is formed from $\frac{d\bar{s}-s\bar{d}}{\sqrt{2}}$ with a lifetime of only 8.95×10^{-11} s.

The branching fraction of $K_L^0 \longrightarrow \pi^0\mu\mu$ is the probability of the K_L^0 to decay in this channel. It is interesting because it could be sensitive to New Physics [3]. This branching fraction has several contributions : one from the Standard Model, one from the CP violation process and, maybe, one from New Physics. If we are able to precisely know the first ones and the total branching fraction, then we could conclude on the presence of New Physics in this process.

The problem is : the lifetime of the K_L^0 is so high that, most of the times, a K_L^0 produced by a pp collision in the LHCb detector would decay outside the detector, we say that it "flies" too much. So we can't directly study this decay and get the branching fraction. But we can know the CP violating amplitude through the decay of $K_S^0 \longrightarrow \pi^0\mu\mu$. Its actual measured value[8] is $(2.9^{+1.5}_{-1.2}) \times 10^{-9}$ with a relative error of $\sim$ 50%. Our main goal is to improve the accuracy on the measurement of the branching fraction of $K_S^0 \longrightarrow \pi^0\mu\mu$ in order to constrain the CP violation amplitude of $K_L^0 \longrightarrow \pi^0\mu\mu$ and access New Physics.

4 First selection cuts

4.1 The origin of Background

The main goal of an analysis is to separate the signal from the background. The first job is thus to identify the different origins of the background.

[6]The barn (b) is a unit for cross-section : $1\ b = 10^{-28}\ m^2$. The inverse barn (b^{-1}) is related to the number of pp collisions produced and is used to measure the amount of data.

[7]The different prospects of K_S^0 analysis at LHCb can be found in [2]

[8]The first observation of the decay and the measurement of its branching ratio is due to the NA48 experiment at CERN in 2004 [4].

There is always combinatorial background in data, it comes from the way the reconstruction of particles is done. For each pp collision, there are particles that leave tracks in the detector. Then a software blends all of the tracks to reconstruct the original particles that decayed in the detector. It can happen that two tracks, that are not physically related, match according to the software, the combination is not relevant and becomes noise.

Another problem is the possible misidentification of particles. This idea comes from the analysis of $K^0_S \longrightarrow \mu^+\mu^-$ which was the thesis work of my supervisor [7]. The identification of particles is one of the strong points of the detector but it remains a probability of a pion misidentified as a muon of 1%. The main channel of decay for K^0_S is $K^0_S \longrightarrow \pi^+\pi^-$ with a branching fraction of 0.69. So we have :

$$BF(K^0_S \rightarrow \pi\pi_{doubleMisID}) \approx 0.69 \times 0.01^2 \approx 6.9\ 10^{-5} >> 10^{-9}$$

Even if it is a small ratio, it is still huge compare with the branching fraction we are looking for. Therefore we expect $K^0_S \rightarrow \pi\pi_{doubleMisID}$ to be a huge part of the background. With the same idea of misidentificated pion, we can also have :

- $\Lambda, \overline{\Lambda} \rightarrow p\pi$
- $K^0_S \rightarrow \pi^0\mu\nu_\mu$

Another type of background is the interaction of particles with the detector. Particles from the pp collisions can interact with the matter of the different parts of the detector and induce a signal which looks like a K^0_S. We will discuss later this type of background.

4.2 First cuts

In order to separate the signal from the background we need to find selection cuts that make a separation between "good" candidates, our K^0_S that decay into two muons and a pion, and "bad" candidates : the background. To achieve it, I studied several quantities and compare their distributions with Monte-Carlo data and real data.

Monte-Carlo refers to simulations of pp collisions with the modelisation of the behaviour of the detector. Because we can choose to simulate only the type of process we want to study, this data sample is our signal.

The first goal is to get rid of the $K^0_S \rightarrow \pi\pi_{doubleMisID}$ candidates. These candidates come from an actual K^0_S, the idea is to reconstruct the $\pi\pi$ mass : we assume that the two muons are actually two pions and we calculate the invariant mass of the particle that decayed into these two particles. If the two particles come from a K^0_S, the mass distribution should peak at the K^0_S mass : 497 MeV/c^2

As it can be seen in the graph 3, the mass distribution of Monte-Carlo signal has no peak but the distribution of data has one. By cutting this peak, we will remove the $K^0_S \rightarrow \pi\pi_{doubleMisID}$ candidates. We can use the same method for $\Lambda \rightarrow p\pi$ and $K^0_S \rightarrow \pi^0\mu\nu_\mu$: we reconstruct the $p\pi$ and πp masses for the first case and the $\pi^+\mu^-$ and $\mu^+\pi^-$ masses for the second. We finally get the plots 4 and 5. There is a peak at 1100 MeV/c^2 in the $p\pi$ mass distribution and a peak at 250 MeV/c^2 in the $\pi\mu$ one.

I drew the K^0_S mass distribution, graph 6, before and after the $\pi\pi$ mass cut, to illustrate its

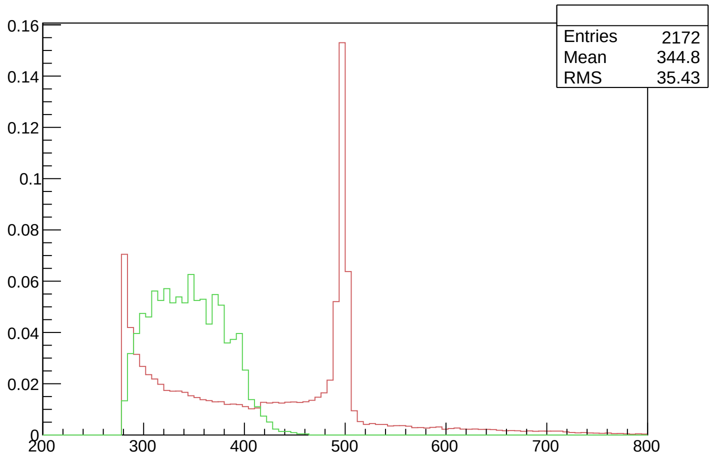

Figure 3: Distribution of $\pi\pi$ mass. Data and MC

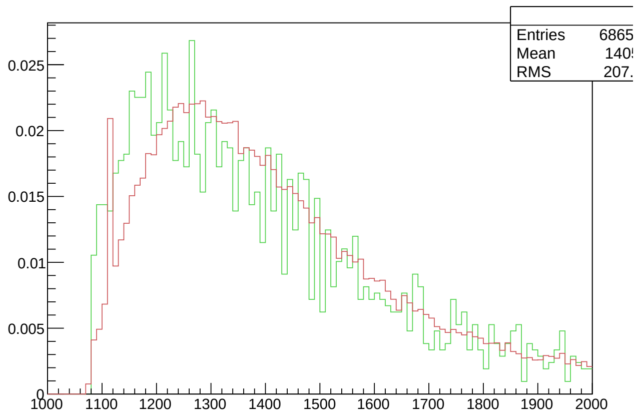

Figure 4: πp mass. Data and MC

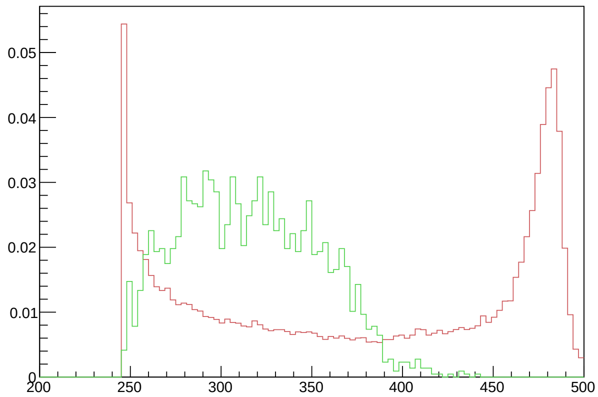

Figure 5: $\pi\mu$ mass. Data and MC

effect. The straight line at 600 MeV$/c^2$ is caused by the prescaling of the sideband[9]. The data sample is divided in two : the signal region, below 600 MeV$/c^2$ and the sideband above.

We also studied other quantities and some of them are good candidates to make cuts. First I studied the distribution of the transerve momentum[10] of the π^0. Even though it seems like a discriminating variable, the cut between signal and background is not clear. In order to have an optimized cut, we need to use more powerful statistical tools such as Boost Decision Trees (BDT).

The possibility of building a cut with the probNN of both muons is easier. The probNN is the probability for the muon to be a real muon (1) instead of a pion (0). I plotted the distribution of the maximum probNN of the two muons. On the graph 7, it appears that a cut at 0.1 is able to discriminate signal from background.

[9]The sideband is "prescaled". Only a small fraction of the candidates in the sideband, randomly chosen, are stored.

[10]The transverse momentum (p_T) is defined as : $p_T = \sqrt{p_x^2 + p_y^2}$

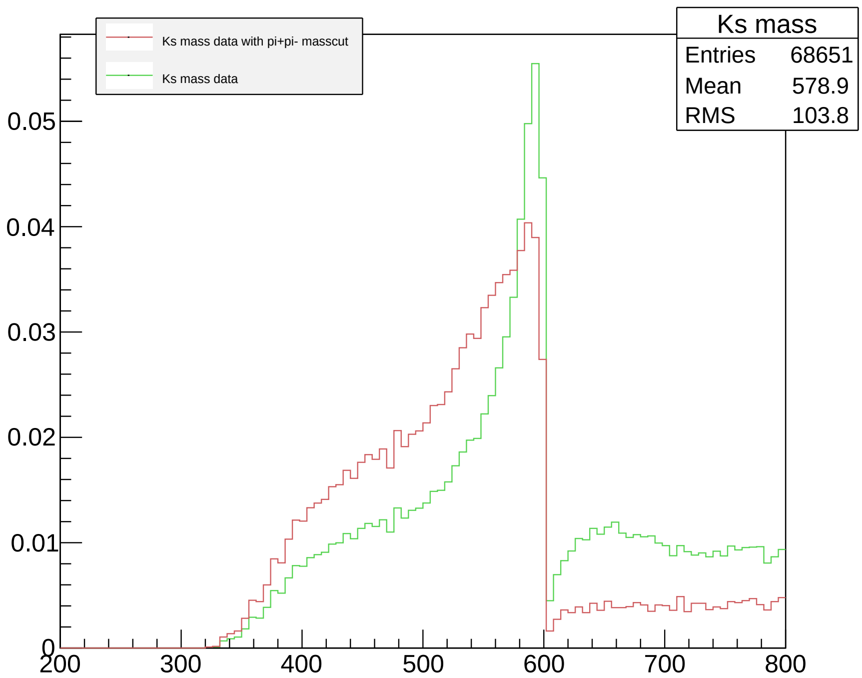

Figure 6: Distribution of K_S^0 mass with and without the $\pi\pi$ mass cut.

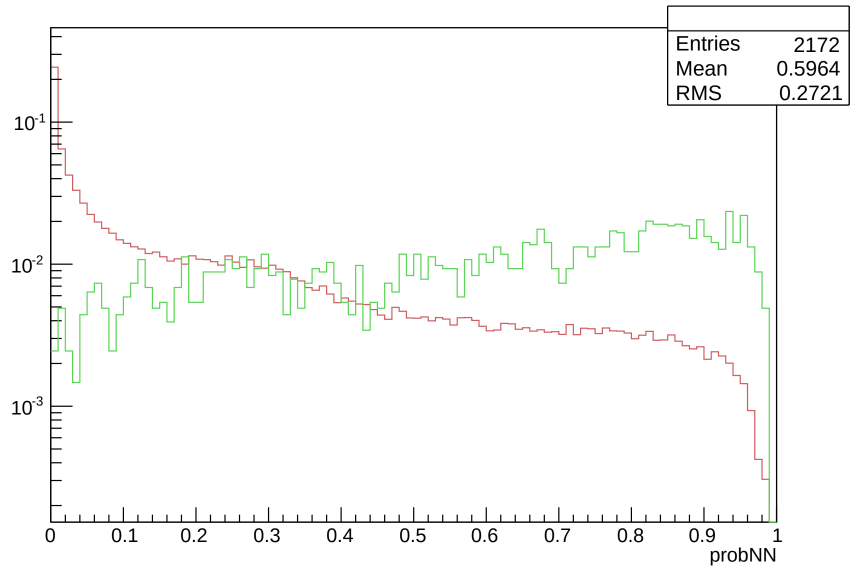

Figure 7: Distribution of the maximum of both muons probNN with a log scale. Data and MC

Finally we have four cuts we can apply on data to remove the candidates with misidentified pions :

- $\pi\pi$ mass < 460 MeV$/c^2$
- $1110 < p\pi$ mass < 1140 MeV$/c^2$
- $\pi\mu$ mass > 260 MeV$/c^2$
- probNN of both muons > 0.1

4.3 Interaction with the Detector

The interaction of particles with the matter of the detector can produce signals that look like real K^0_S. If it's the case, the coordinates of the vertex of the fake K^0_S should be related to the location of materials inside the detector. If we plot the x coordinate as a function of the z coordinate, we should see a pattern.

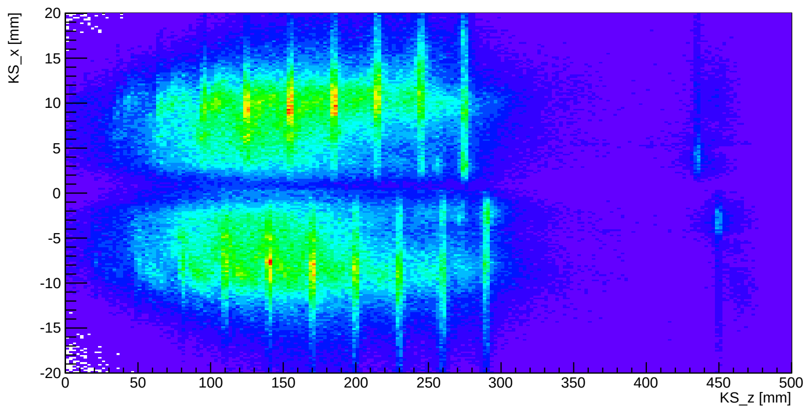

Figure 8: 2D plot of the x and z components of the K^0_S vertex.

There are vertical stripes in the graph 8 which are the silicon stripes inside the VErtex LOcator. We can't build a cut with this plot but we will use it later with a BDT.

4.4 Position of the π^0

Another promising path is the reconstruction of the π^0. It is a particle very difficult to reconstruct because it is leight and decays, most of the time, into two photons. To build the candidate with two muons and a pion, a π^0 is randomly choosed among all the pions produced for each event[11].

To determine if the π^0 really comes from the K^0_S, we can compare the positions of the two photons and the expected position of the π^0 by reconstructing its direction assuming that it comes from the K^0_S. Using the energy and momentum conservations and the direction of the K^0_S given by the two vertices, we get this equation with $p_{/\!/}(\pi^0)$ as the unknown :

$$(p_{/\!/\pi^0} + p^2_{/\!/}) + m(K^0_S)^2 \ = E^2 + p_{\perp\pi^0} + p^2_{\perp} + 2E^2\sqrt{m^2_{\pi^0} + (p^2_{/\!/} + p^2_{/\!/\pi^0})}$$

[11] An event is a pp collision.

$$p_{/\!/}, p_{\perp}, E = \text{addition of the quantities for both muons}$$

$$/\!/ and \perp \text{ refer to the direction of the } K_S^0$$

$p_{/\!/}, p_{\perp}, E$ are known through the momenta and the masses of both muons. If the π^0 comes from the K_S^0, we can numerically solve the equation and get the expected position of the pion. If not, the position should be far away from the positions of the two photons or the equation can't be solved for the candidate. So this is a two levels cut : if there is no solution, we reject the candidate, if the position of the π^0 is too far from the barycentre of the two photons, we also reject it.

We noticed that most candidates in data don't pass the first level and that both distributions of distance between the expected position of the pion and the barycentre of the positions of the two photons are very similar for Data and Monte-Carlo signal. The graph 9 shows the two distributions and that is impossible to find a clear separation between signal and background. The cut is built only on the rejection of the candidates without numerical solution of the equation. The table 1 summarizes all the cuts.

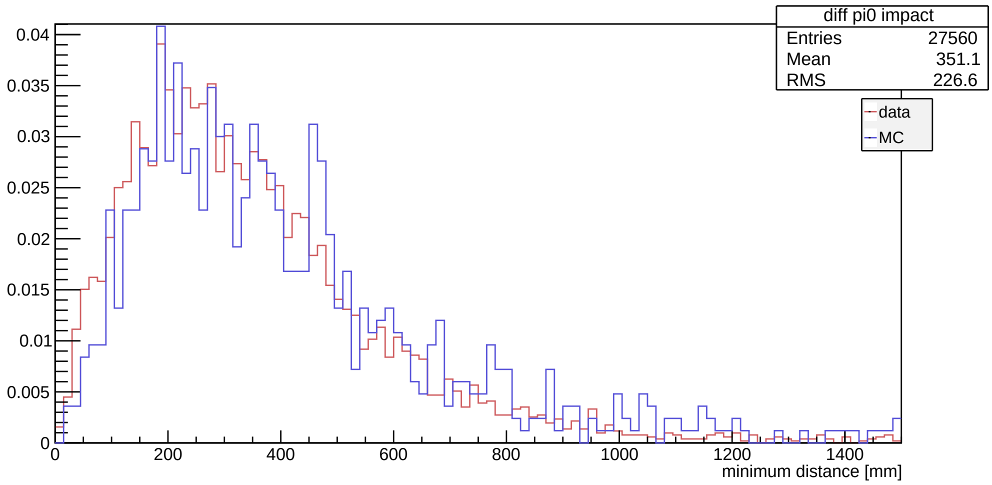

Figure 9: Distribution of the distance in the window mass of the K_S^0 for Data and MC

Name	Description
$\pi\pi$ mass	$\pi\pi$ mass < 460 MeV$/c^2$
issolved	the equation of the π^0 position has a solution
$\pi\mu$ mass	$\pi\mu$ mass > 260 MeV$/c^2$
$p\pi$ mass	$p\pi$ mass < 1110 MeV$/c^2$ or > 1140 MeV$/c^2$
probNN	probNN of both muons > 0.1

Table 1: List of the Selection Cuts.

4.5 Efficiencies

To be sure that the cuts are really separating signal from background, we need to calculate the efficiency for each cut in the K_S^0 mass window and in the sideband for both data and Monte-Carlo.

The efficiency ϵ is defined as :

$$\epsilon_{cut} = \frac{N_{\text{cand that pass the cut}}}{N_{\text{cand total}}}$$

If we have two cuts, $cut1$ and $cut2$, and we first calculate the efficiency of $cut1$, ϵ_{cut2} becomes :

$$\epsilon_{cut2} = \frac{N_{\text{cand that pass cut1 and cut2}}}{N_{\text{cand that pass cut1}}}$$

In tables 2 and 3, I computed all the efficiencies :

Selection cut	Efficiency in the K_S^0 mass window (%)	Efficiency in the Sideband (%)
$\pi\pi$ mass	75.8	28.8
is solved	27.7	7.5
$\pi\mu$ mass	49.8	61.3
$p\pi$ mass	91.6	92.9
probNN	3.2	3.0
All Cuts	**0.31**	**0.037**

Table 2: Cut efficiencies for Data events.

Selection cut	Efficiency in the K_S^0 mass window (%)	Efficiency in the Sideband (%)
$\pi\pi$ mass	99.7	99.9
is solved	76.7	63.7
$\pi\mu$ mass	90.1	89.0
$p\pi$ mass	93.3	96.2
probNN	53.0	43.8
All Cuts	**34.1**	**23.9**

Table 3: Cut efficiencies for MC events.

It appears that the cuts are doing that we want them to do : they kill many more candidates in data, which is mostly composed by background, than in Monte-Carlo which is our signal. For instance, in the K_S^0 mass window, where the signal should be, the efficiency of all cuts combined is 0.31% in data and 34.1% in Monte-Carlo.

Even though it is already quite efficient, we have to push forward the analysis and even better separate the signal from the background.

5 Working with the Grid

For the next part of my work I used the Grid to create new samples of real and simulated data and increase statistics.

5.1 The Worldwide LHC Computing Grid

The Worldwide LHC Computing Grid is a giant collaboration of computing facilities all over the world interlinked. Its major goal is to provide ressources to store, distribute and analyze data. It was born in 2002 when it was clear that CERN couldn't provide a computer center powerful enough to take care of all the data the LHC would create. The choice was to use the Grid technology, invented by Foster and Kesselman in 1999. Each state builds computing centers with a logic of layers or Tiers :

Tier 0 : The CERN Data Centre, in Geneva, and the Wigner Research Centre for Physics, in Budapest. All data from the LHC pass through this center but they only store a copy of raw data and redistribute it to the Tier 1 sites.

Tier 1 : 13 computing centres with huge storage facilities. They are responsible of the storage of reconstructed data and the distribution of simulated data produced by Tier 2 sites.

Tier 2 : 160 universities or other research centers, they store a part of reconstructed data and they provide and reconstruct simulated data (e.g. Monte-Carlo data).

Tier 3 : local computing ressources whithout any contract of accessibility.

40 countries are involved in the Grid project with 170 computing centers. An average number of 2 million jobs run every day on the Grid[12].

5.2 Submitting jobs to the Grid

The preliminary samples of data were adequate to build the first cuts but when we tried other tests, they were not sufficient anymore. Moreover, we needed dedicate samples of background to better understand it.

My job was to use the Grid to reconstruct new samples of different real and simulated data :

Data : The reconstruction of real data with $K^0_S \longrightarrow \pi^0\mu\mu$. I used half the data taken in 2012 to build this sample.

simulated signal : The reconstruction of simulated data of $K^0_S \longrightarrow \pi^0\mu\mu$.

minimum bias : The reconstruction of simulations of pp collisions without any constraint on the result of them only the modelisation of the detector itself.

$b\bar{b}$ **inclusive :** This sample comes from the modelisation of pp collisions with the constraint of at least the creation of one $b\bar{b}$ pair in each collision. It is a good simulation of what comes after the trigger.

[12]More information about the Grid can be find on : http://wlcg-public.web.cern.ch/ .

To do that, I submit jobs to the Grid, i.e. I send a script to create a tree[13] and a file with the location of the raw data needed. Raw data are located in the storage facilities that are available for the Grid. Then the work is divided in several jobs that will be executed somewhere in a computing center related to the Grid. When all the jobs are done, I can download them and merge the output data to construct my final tree. I will later be able to analyze it with ROOT.

6 Understanding the background composition

In order to understand the actual composition of the background in the signal region, we have performed different studies :

- we have analyzed different Monte-Carlo background samples.
- we have studied the two sidebands of our data samples.

The two sidebands are defined as follow : the left sideband takes all the candidates with $M(K_S^0) < 420$ MeV/c^2 and the right sideband, the candidates with $M(K_S^0) > 600$ MeV/c^2.

The goal of this study is to identify the different components of the background before and after the first cuts we designed. It is really important because the strategy to clean the data depends on the origin of the background. For instance, we could use a BDT against combinatorial background but it is not efficient against peak background such as $K_S^0 \longrightarrow \pi^{\pm}\pi^{\mp}$, which was described before.

6.1 Monte-Carlo Background samples

My first job was to use the two Monte-Carlo background samples : minimum bias and $b\bar{b}$ inclusive. Monte-Carlo is really helpful because we can use the Truth Matching : the true identity of the reconstructed particles can be determined by relating them to the initially generated MC particles. For instance, a misidentified pion which pass the reconstruction because it really looked like a muon, will be correctly identified by the truth matching. The mother of the particle will be also known and we can back track the decay chain on six generations.

The goal was to identify the components of background and the informations would allow us to be able to find new peak background if they exist.

First, we looked for candidates with all the four particles, the two photons from the π^0 and the two muons, coming from the same ancestor and we asked if this common ancestor was a K_S^0. We couldn't find any candidates with all the four particles coming from the same ancestor in the minimum bias sample and only two candidates with a common ancestor, but no K_S^0, in $b\bar{b}$ inclusive.

Then, we looked for candidates with the two muons coming from the same ancestor. We also asked if this ancestor was a K^0, a K_L^0 or a K_S^0. It turns out that 8.5% or the candidates in the $b\bar{b}$ inclusive sample and 20% in the minimum bias sample matched. When the ancestor is something else, most of the time, it is a Λ.

We did the same work after applying the cuts and then, all of the candidates with a K^0 or a Λ for ancestor were gone. We also drew the distribution of the mass of the K_S^0 and there is no peak as it can be seen in the graph 10. All of this work shows that the background is predominately combinatorial after applying the cuts.

[13] In high energy Physics, a Tree is the common way to store data in a file in order to analyze it. More

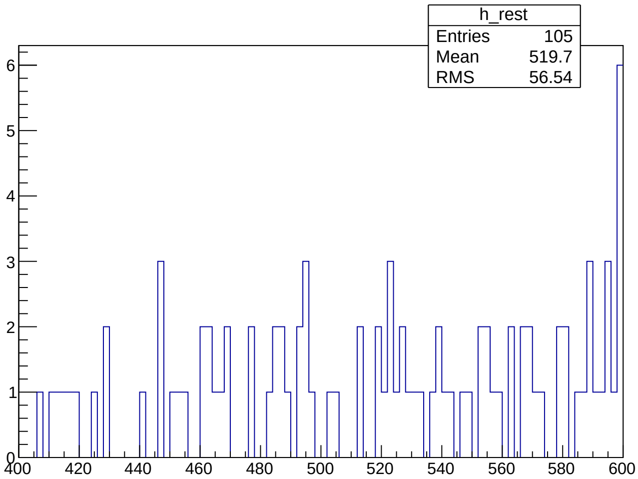

Figure 10: $M(K_S^0)$ after cuts (minimum bias)

6.2 Armenteros-Podolansky plots

The Armenteros-Podolansky plot[14] is a 2D plot to analyze the dynamics of a two-body decay (e.g. $X \longrightarrow p_1\ p_2$). The two variables of the plot are :

$$\alpha = \frac{p_{1/\!/} - p_{2/\!/}}{p_{1/\!/} + p_{2/\!/}} \text{ and } p_{X\perp}$$

The projections $/\!/$ and $\perp$ refer to the direction of the X particle. When we draw the graph, we can easily identify some patterns which are related to different decays, it is the main force of the method. Especially, we can identify $\Lambda \longrightarrow p\pi$ and $K_S^0 \longrightarrow \pi^\pm\pi^\mp$ as it can be seen in the graph 11[15].

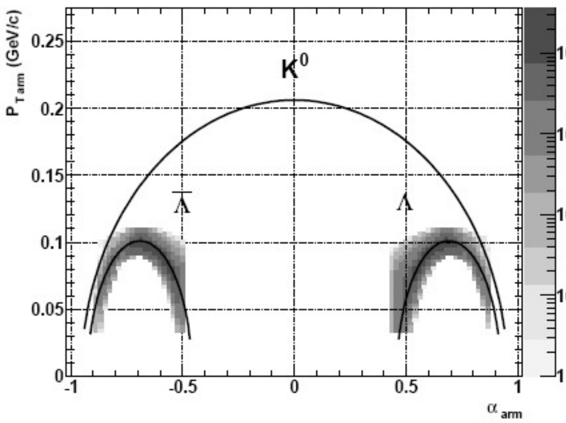

Figure 11: An example of the structures that can be seen in an Armenteros-Podolansky plot.

informations on Trees can be find on http://root.cern.ch/root/html/TTree.html .

[14]This method was invented by Podolansky and Armenteros in 1953-54, [6]

[15]I didn't make this graph. It can be find at http://mars.if.pw.edu.pl/ radman/work.htm .

In our data, I drew four Armenteros-Podolansky plots : for each sideband, before and after the cuts. As it can be seen in the graphs 12 and 13, most of the peaking background (Λ and K_S^0) is in the right sideband with a small component of Λ in the left sideband. After the cuts, all of these candidates are killed and only combinatorial background remains as it can be seen in the graphs 14 and 15.

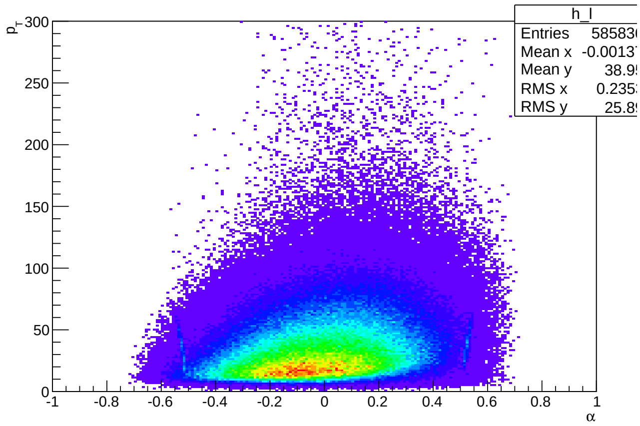

Figure 12: Left sideband.

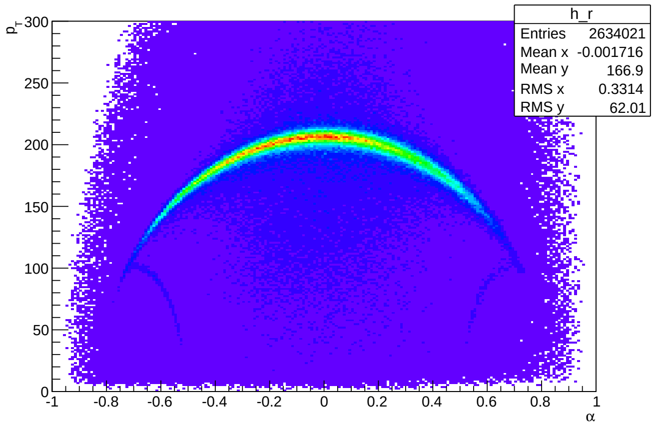

Figure 13: Right sideband.

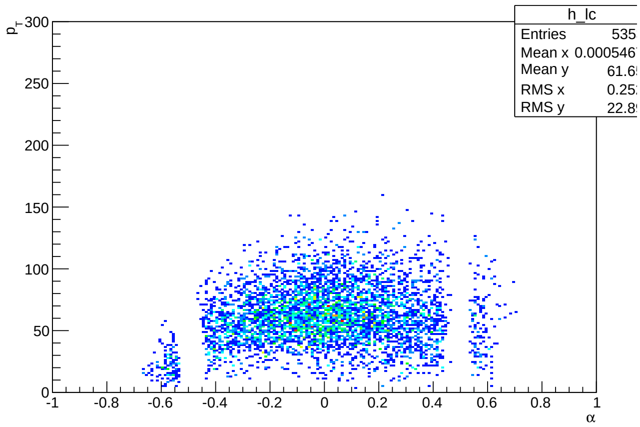

Figure 14: Left sideband (after cuts).

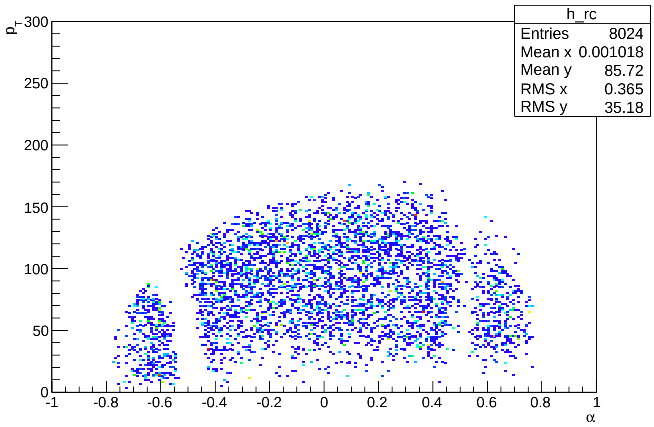

Figure 15: Right sideband (after cuts).

6.3 New variables

In order to find further discrimination between signal and the remaining background, we have tested new variables. Here is the list of these variables :

- KSdissig_r : K_S^0 distance of flight significance.
- KSips : the significance of the impact parameter of the K_S^0
- $p_T(K_S^0)$: the transverse momentum of the K_S^0
- DOCA : Distance Of Closest Approach
- SV_x, SV_y and SV_z[16]

The distance of flight is the distance covered by a particle before its decay. The impact parameter of the K_S^0 is the minimum distance between the K_S^0 and the primary vertex and the DOCA is the minimum distance between the tracks of the two muons.

As an example, graphs 17, 18 and 16 show the distributions of KSdissig_r, Ksips and $p_T(K_S^0)$. We clearly need more statistics for the Monte-Carlo signal to correctly build a cut but it seems that the peak of the signal is quite far away from the peak of the distributions of both sidebands for each variable.

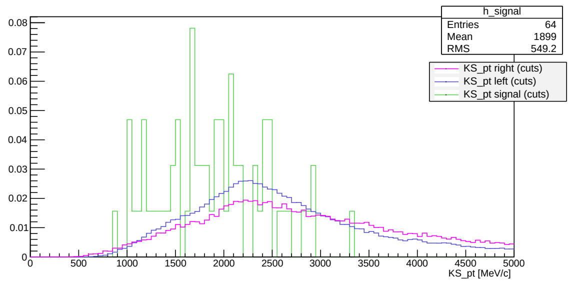

Figure 16: $p_T(K_S^0)$ after cuts for left and right sidebands and MC signal.

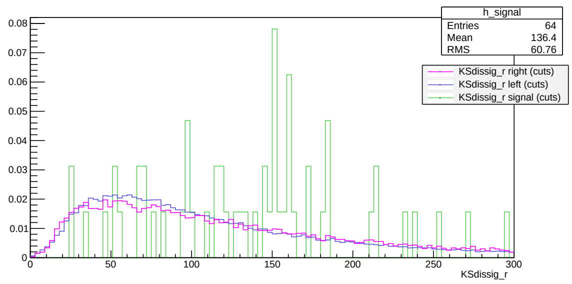

Figure 17: KSdissig_r after cuts for left and right sidebands and MC signal.

[16](SV = Second Vertex)

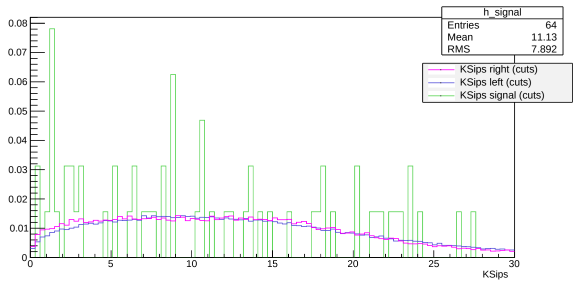

Figure 18: KSips after cuts for left and right sidebands and MC signal.

7 Conclusion

7.1 The analysis of $K_S^0 \longrightarrow \pi^0\mu^+\mu^-$

The analysis of the decay $K_S^0 \longrightarrow \pi^0\mu^+\mu^-$ is very challenging because of the small branching fraction and the difficult reconstruction of the π^0. Yet some progress has been made during the summer and we now understand better the background of the analysis and how to fight against it. We have been able to design cuts that are discriminating and we were able to build a cut on the π^0 with the reconstruction of its expected position.

We have also been able to describe the origin of our background before and after the cuts through the use of different Monte-Carlo samples and the sidebands of the data sample. It appears that most of the peaking background is located in the right sideband and is killed by the application of the cuts. Only material interactions and combinatorial background remain after.

Several variables were tested and some of them are good candidates for designing new cuts. Even if we can be confident about these variables, we still need more statistics, especially for the Monte-Carlo signal, to be sure. We also use only half the data taken in 2012 and we didn't use the data taken in 2011. The anlysis would benefit from the use of all the data.

7.2 Working at CERN

I had the huge opportunity of being a Summer Student and working at CERN for three months. I discovered and used new tools such as Python and PyROOT to write the scripts needed for my analysis. I learned a lot about data analysis in Particle Physics and how to study the background of a data sample.

The lectures gave also the opportunity to hear about several different topics related to High Energy Physics. I had the opportunity to visit two detectors and the Computer Centre, which are great memories.

Because summer students come from all over the world, I also had a great time to speak with people from different cultures. I also improved my hability to speak English.

8 Acknowledgments

This Summer was really fantastic and I had a great pleasure to work in the LHCb collaboration. I would like to thank the LHCb secretariat and the Summer Student Team for the organization. I also want to thank every lecturer, it was really interesting and about so many different subjects. I want to thank Maria for her help and all my friends of the Summer Student. Last but not least, I want to thank my supervisor, Xabier, for his constant help, all of his answers to my questions and for giving me the chance to do such an amazing internship.

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