Studies of muon identification in dimuon final state decays at LHCb, CERN

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A description of the summer student project at CERN, LHCb
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1 Introduction

At the LHCb collaboration the search for new physics is done through rare decays and the analysis of CP violation. Decay channels that are used for this research are $B_s^0 \to \mu^+\mu^-$, which is an example of a rare decay, and $B_s^0 \to J/\Psi\Phi$, where the J/Ψ decays into two muons, an example of a channel used to study CP violation. Because both the channels produce muons, correct muon identification is very important for the LHCbp physics goals. The goal of this project is to improve the identification of the muons in the final state. This was done by optimizing already existing muon identification programs. They were analized and studied using Monte Carlo data. In the last weeks of the program, another method of identifation was tested.

2 Physics introduction

2.1 Decay channels

In this project two decay channels played an important role. The first one being $B^+ \to J/\Psi K^+$, in which a B meson decays to a J/Ψ and kaon, and the J/Ψ immediately to two muons. The kaon can also decay in a muon, but it could also be into an electron for example. The second decay channel that was studied is a B meson decaying into a kaon and pion, $B \to K\pi$, which both can decay further into muons.

2.2 The IsMuon definition

The muon identification algorithm is based on hits (particles detected) in the last four (of five) stations of the muon system of the LHCb detector. To let a particle pass the qualification of being a muon, there are a number of required hits in some (or all) of the muon stations. This depends on the momentum of the particle (higher momenta particles will travel further, reaching also the final muon stations). When a particle travels through the detector, its track can be determined using the VELO and the tracking stations. When this track is known, a Field of Interest (FOI) in the muon stations is opened, where the corresponding muon is expected. All hits inside this FOI are saved. See Figure 2. A particle will receive the qualification IsMuon if it leaves hits in the muon stations according to the following table:

Track momentum (GeV/c)	Required stations
$3 < p < 6$	station M2 and M3
$6 < p < 10$	station M2 and M3 and (M4 or M5)
$p > 10$	station M2 and M3 and M4 and M5

Table 1: Stations required to have a hit for tracks at different momenta

2.3 Misidentification

The IsMuon qualification is not completely reliable. To determine how the IsMuon qualification should be improved, the distinction between four different types of misidentification (misid) was made. The types of misid are:

Misid type	Description
1	Underlying event: the whole matched track is the kaon/pion, coming from the B^+, but the kaon/pion does not decay to muons
2	The whole matched track is the kaon/pion, coming from the B^+, later decaying into muons
3	The whole matched track is a muon, coming from the kaon/pion, coming from the B^+
4	The muon in the t-stations comes from the kaon/pion in the velo

Table 2: Stations required to have a hit for tracks at different momenta

An event with misid type 1 could look like this:

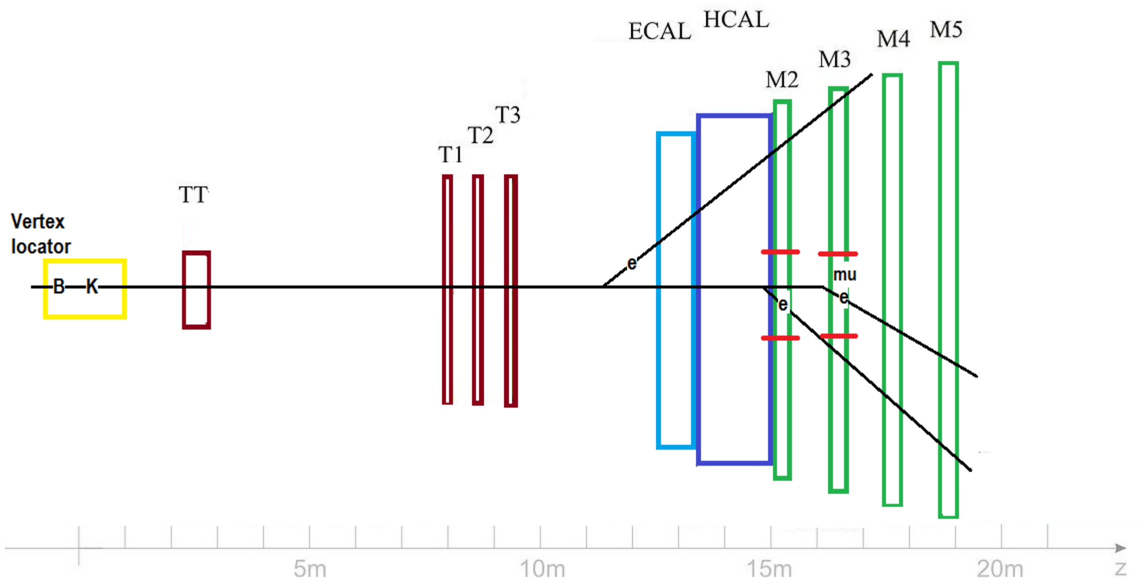

Figure 1: Example of an event of misid type 1: B to K to electrons. The electrons produce hits within the Field of Interest inside the muon stations, and are therefore identified as muons. The muon is inside the FOI in M3, but is not coming from the kaon.

3 New IsMuon

To understand the composition of misid, hits in the FOI that are not coming from one of the muons the kaon/pion decayed into, are filtered out. This I have done in a few steps :
1. Compare the hits in the muon stations with the daughters of the kaon/pion. 2. Only keep the hits if the key[1] of the muon hit is the same as the key of the muon daughter of the kaon/pion. 3. Once the non corresponding hits are filtered out, IsMuon is applied again. 4. The misid type is determined.

[1]The key is a unique number of a particle. Using this, comparison between two possibly the same particles is possible.

4 Analysis of new IsMuons definition

For the misid, the fraction of each of the four types is determined to analyse the new IsMuon definition. For the two different decay channels, the result looks like this:

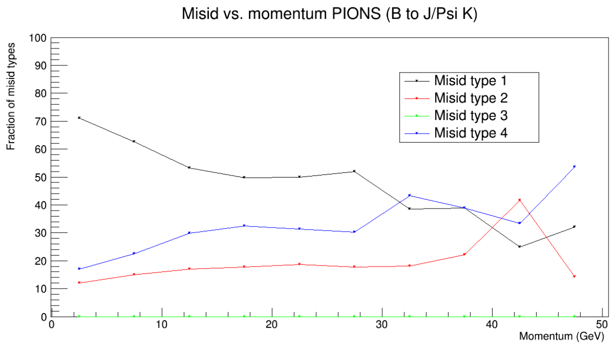

Figure 2: Fraction of misid types for pions in $B^+ \to J/\Psi K^+$

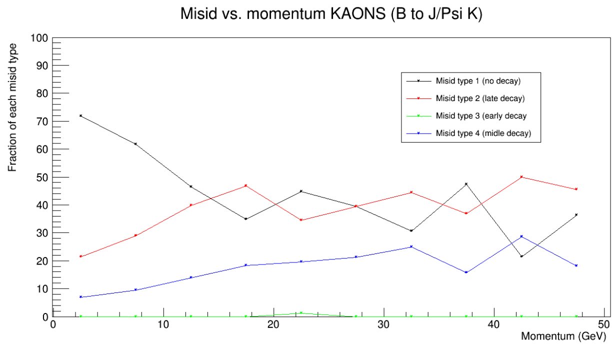

Figure 3: Fraction of misid types for kaons in $B^+ \to J/\Psi K^+$

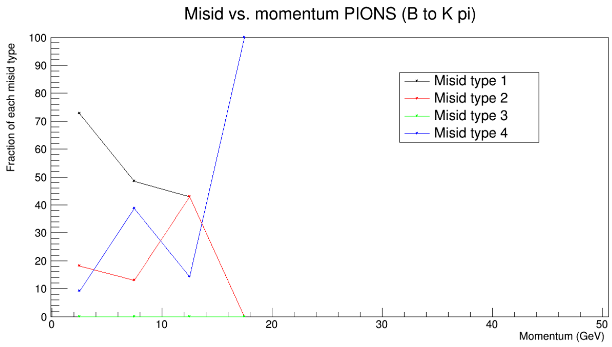

Figure 4: Fraction of misid types for pions in $B \to K\pi$

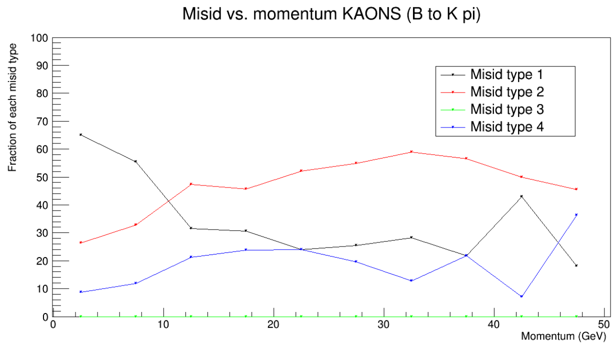

Figure 5: Fraction of misid types for kaons in $B \to K\pi$

It is clear to see that at low momenta, misid type 1 is most common, and at high momenta types 2 and 4 become more frequent. Misid type 3 is very rare. The graph of pions from $B \to K\pi$ breaks down above 20 GeV, because there was no data for it in the studied events.

5 Pull's instead of FOI

Another usefull definition is the Pull of a hit in the muon station, which is defined as:

$$PULL_{X,Y} = \left[\frac{PosExt - PosHit}{\sqrt{(\Delta PosExt)^2 + (\Delta PosHit)^2}} \right]_{X,Y} \tag{1}$$

In words, the Pull is the difference between the position that is determined by extrapolating a track into the muon station and the position of a hit in the muon station, divided by the errors in both. For signal hits, Pull's are expected to follow a Gaussian distribution. The arrival probability of the Pull's in the muon stations can be used to determined the number of hits. This can be done in real data.

6 Analysis of Pull's

The analysis of the Pull's was based on looking at the distribution of good hits, meaning hits that were closest pull and came from the muon in the decay. Background hits are from kaons, for which no definition of good hits exists. From the below graphs, the Gaussian distribution of the signal muons is clear. The kaon background is flat.

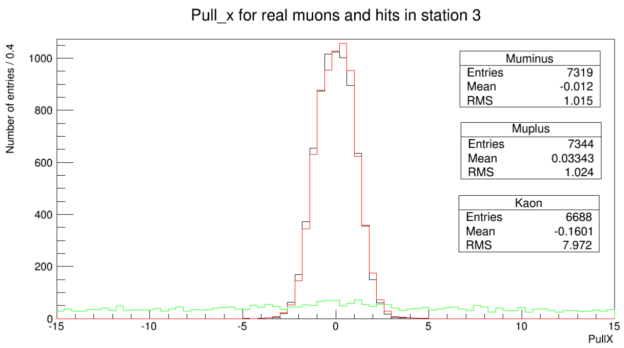

Figure 6: Fraction of misid types for pions in $B \to K\pi$

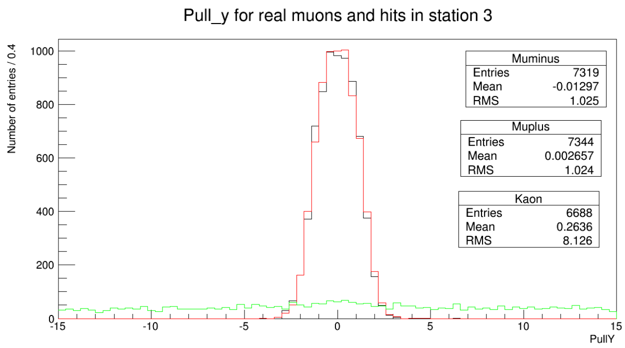

Figure 7: Fraction of misid types for kaons in $B \to K\pi$

7 Conclusion

In this project, different aspects of the Muonid in LHCb were studied. The first one used the FOI opened by expanding a track into the muon system to identify muons. The second one used the smallest Pull, closest to track extrapolation, to gain the hits in the muons system. The IsMuon definition using the FOI was studied by filtering out the hits in the muon system that were not coming from the track. After that a fraction per misid type was calculated. For the Pull's, the distribution of signal hits was studied.

8 Word of thanks

This project was done during my 8 weeks as a summer student at CERN in the summer of 2013. I would like to thank my supervisor, Xabier Cid Vidal, for all his help on the project during my stay at CERN. When he was not there, Paula Alavarez Cartelle was there to help me, so I would like to thank her too.