# Filtering Out Hadrons From μ Candidates In B-Bbar Jets-

C. Milstene- January 7,2004- SLAC -LC Workshop

The Detector

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Mu Efficiency & Hadrons Contamination

Resolution of Ambiguities using HCAL

Conclusion

# The SD Detector

**Amount of Material in front of MuCal**

EMCAL 0.87 Λ
HCAL 4.08 Λ –> A Total 6.22 Λ
The Coil 1.27 Λ

A Magnetic Field of 5 Tesla

**MuCal:**

Outer_Radius 660.5cm(up to 550cm Instrumented)
Inner_Radius 348.5cm
A Total 312 cm

**The Unit:** Fe 5cm + Gap 1.5cm RPC/gap
48 Layers /32 Layers Instrumented
80cm Fe = 16 planes

# The Algorithm

<u>The Muons Candidates</u>

• Extrapolation of a reconstructed Track to the Calorimeters

• A set of **hits in HDCal &&EMCal** within $(2\Delta\phi, 1\Delta\theta)$ bins from the track (bin size $\pi/600$) is collected.

• At least **16 hits in MuCal** within a momentum dependent $(\Delta\phi, \Delta\theta)$ bins from the track $\Delta\Phi_{bins}$(Tk-HDCal)=**Max(2*20/P , 2)** and $\Delta\theta_{bins}$(Tk-HDCal) =**Max((20/p)+1 , 2)-** (bin size $\pi/150$). as a way to account for the Energy loss by dE/dx (function of E).

•The Momentum dependant cut has allowed to expand the **low energy** end from 4 GeV/c down to 3GeV/c. It also improves the detection efficiency energy for Muons below 6 GeV/c.

<u>Remark:</u> We are looking only in the Barrel Detector.

# The Algorithm(continue)

The Hadron suppression:

- Hadrons tend to produce multi-hits/Layer, the Muons **1hit/Layer** or at most two. This requires at least 8 layers for 16 hits and a **cut** in the Number of layers of multiplicity >= 3 hits/Layer , allows to get rid of more than 50% of hadrons without affecting the muons.

Remarks:

- The End-Caps have been accounted for by a cut in 0.95 rd<Θ<=2.2 rd

- The Compton Scattering has been studied extensively and it has been shown to be included in smearing the angles ~1 bin in the MuCal and EMcal and 2 bins in the HDCal and is covered by our Θ and Φ cuts.(see http://home.fnal.gov/~caroline - multi_scat.pdf)

- The dE/dx was accounted for by a Momentum Dependant cuts in angle in MuCal as mentioned above.

# The Data

The Data:

•Sets of 5000 single $\mu/\pi$ produced at 3,4,5,10,20,50 GeV at SLAC are used to define the cuts.

• A set of 10K- 500GeV $e^{+-}e^{-}$->BB_bar with the CM_energy of the B going as low as 2 GeV and produced at NIU using Pandora-Pythia is studied using those cuts.

The $\mu$ detection efficiency is compared in Jets and Singles

# Jets and Singles

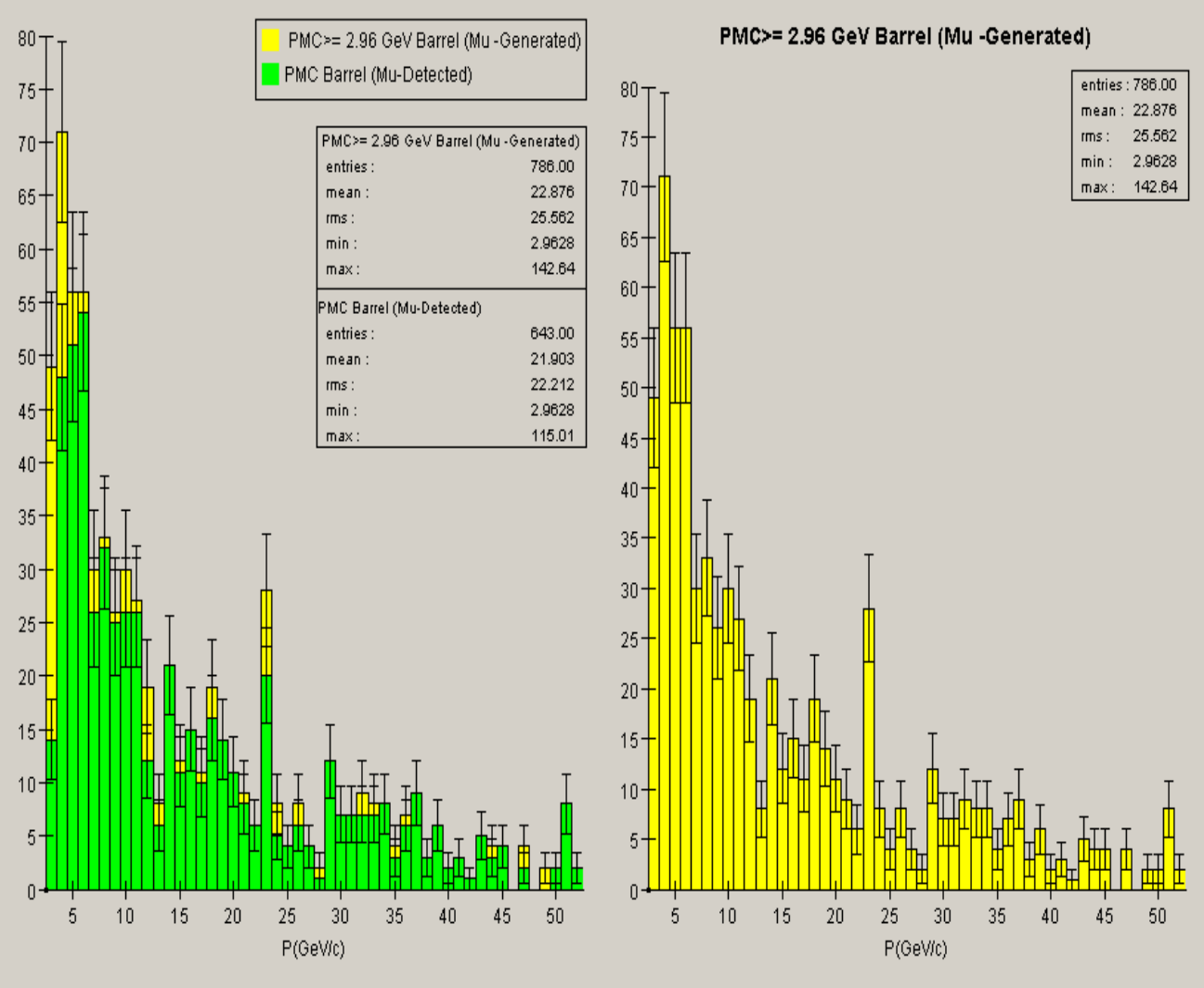
The Muon Momentum Distribution and Detection efficiency :

-The Momentum distribution is shown only for the B-Bbar jets
In the Barrel alone.
-The Muon Detection Efficiency is reported in the next figure together with the results for the singles.

•One gets an overall mean Detection Efficiency for Muons above 3GeV/c of **81.8+/-4.4% .**
•At 3 GeV/c the Detection efficiency is **28.57%+/-8.75%** versus **23.11%+/- 0.75%** for singles.
•Above 5 GeV the detection efficiency is **~100%.**

A cut below 2.9 GeV for the generated Muons takes care of those Mu which dont reach the Muon Detector.

# P-Distribution of Muons Generated versus Detected in the Barrel from 10000 B-Bbar



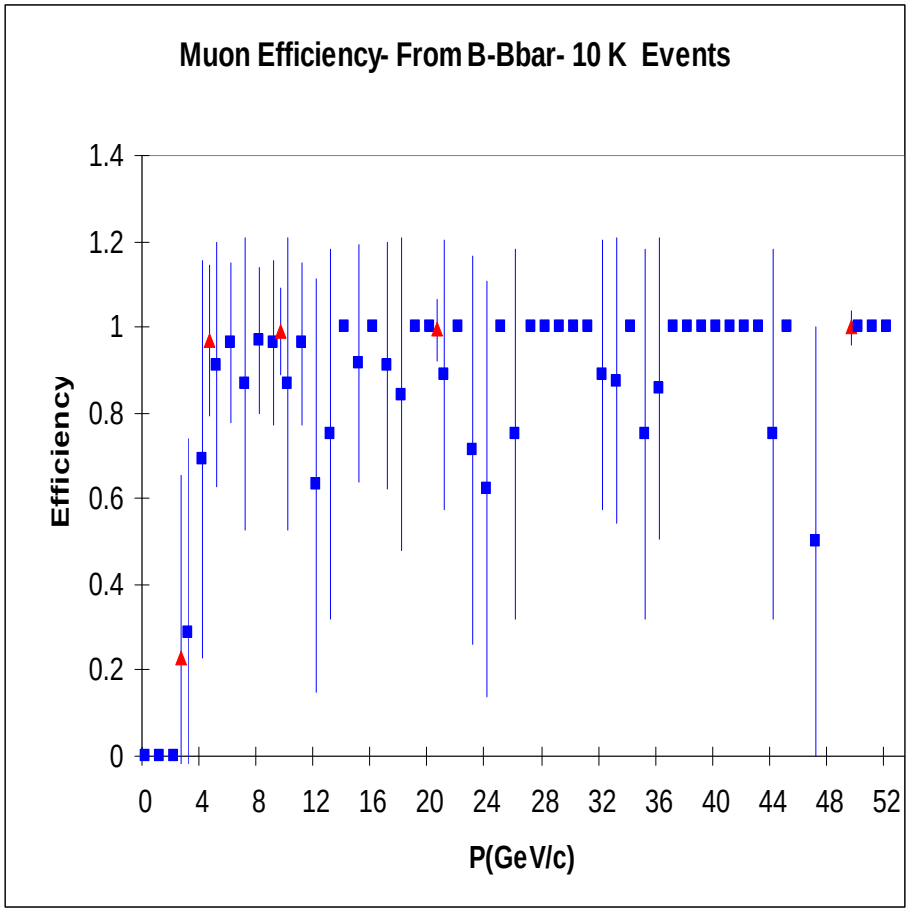

P(GeV/c)- 1 GeV/bin

Left figure overlays

- Detected in green
- Measured in yellow

The figure to the right is to check the overlapp

# Momentum Dependant Muons Detection Efficiency for Jets and Singles



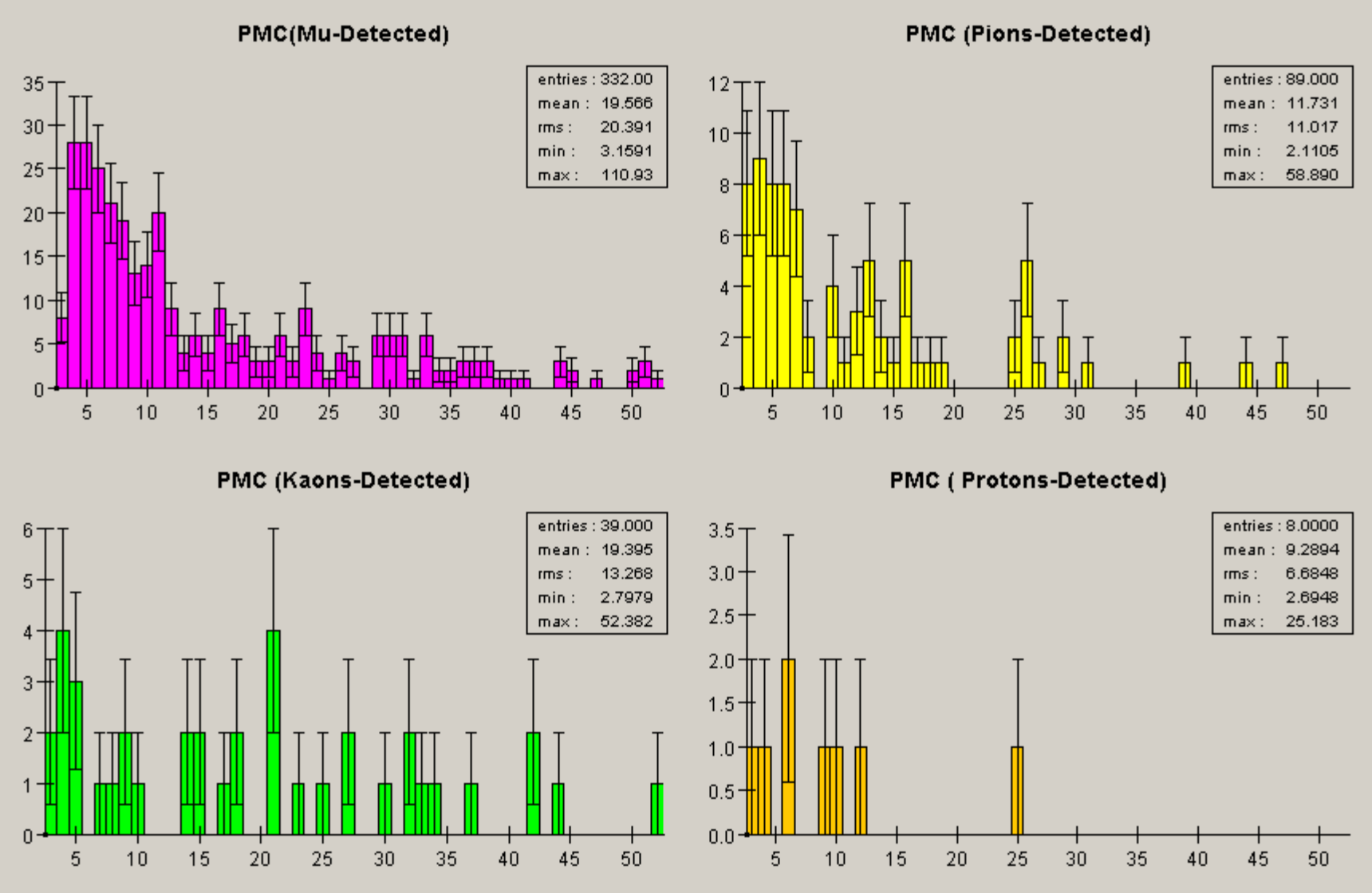

- In Blue : the Detection Efficiency for Muons from 10000 B-Bbar Events.
- In Red : the Muon Detection efficiency from the samples of 5000 single Muons using the same Algorithm.

# The Hadron Contamination in Jets

The Hadron contaminating the Muons Candidates was studied using 5000 B-Bbar events. 136 Non-Muons did pass our algorithm
As shown in the next figure.
The Algorithm was built on the **information** from the **Tracker** and the **Muon Detector** alone.
We found that for >70% of those Non-Muons candidates, there is a Muon in the vicinity with a $\Phi$, $\Theta$ within the $\Delta\Phi$ and $\Delta\Theta$ cuts as shown By the Event Display in the next slide.
Checking the Muon-Detector one finds, indeed, an association to a Muon Hit located in the 1$^{st}$ Layer of the detector . The detail of Of a few such events is shown next.

We will show that HCAL can remove part of the ambiguities

# Hadron Contamination- From 5000 B-Bbar



# Typical cases Of Hadrons Passing The Muon Algorithm

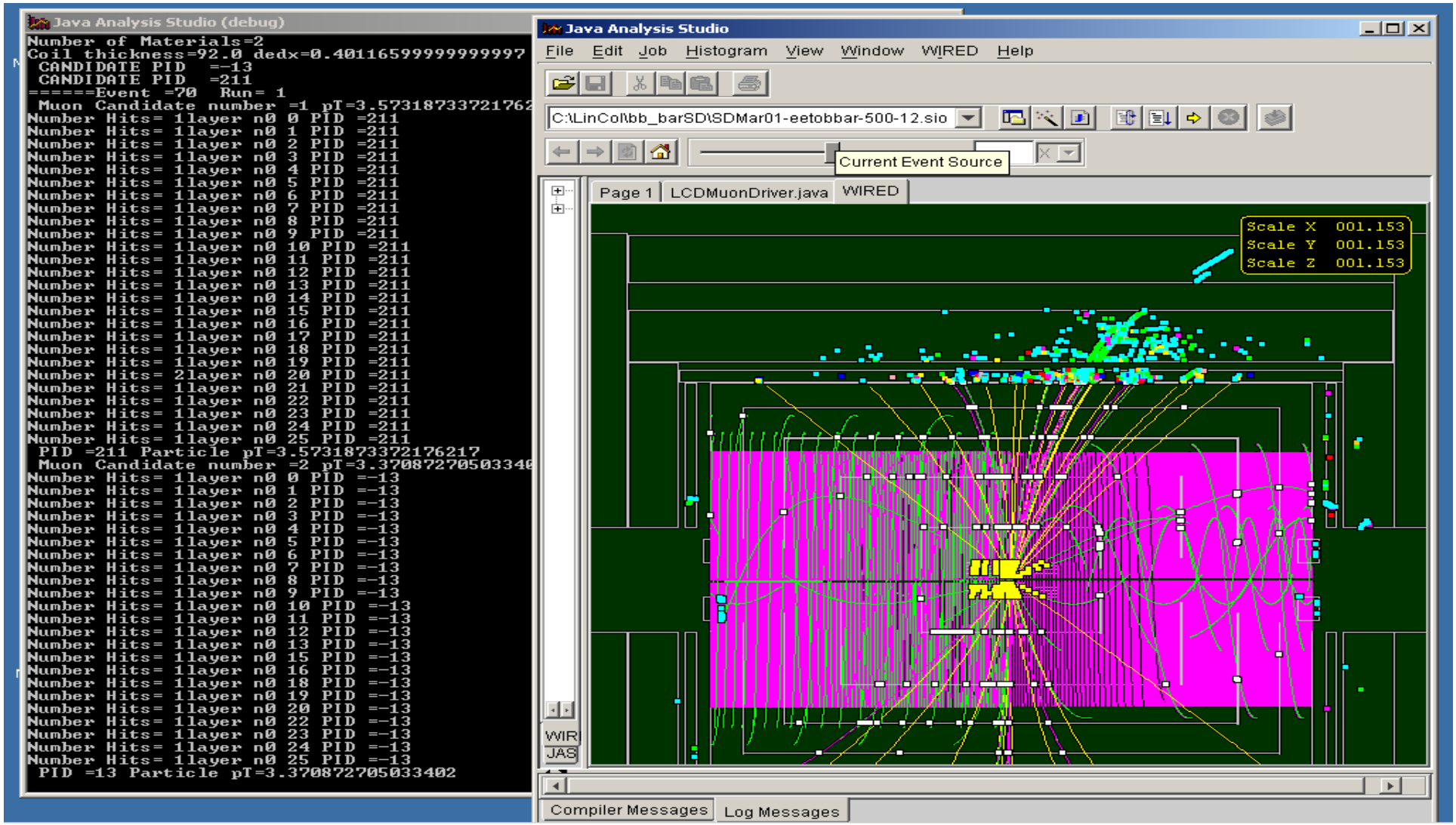
2 Cases with Hadrons passing the Muon Algorithm by SHARING the HITS with a Muon in the Muon Detector. This is ~95% of the cases of wrong Track ID passing the Algorithm. A typical such event was shown in the Event Display.

- Pi-Track associated to Mu Hit in Event Number = 112-Run 11
  **PI** : p=4.4744 GeV, phi=112.42
  **MU**: p=5.10158GeV, phi=112.68

- Pi-&K Tracks associated to Mu Hit in Event Number =326-Run13
  **K** : p=16.62,phi =338.24
  **PI**: p=16.26,phi =338.503
  **MU**: p=16.44, phi =335.908

All 3 Particles share the Mu Hits in MUDet

# Typical “2 Mu Candidates” in B-Bbar
# 1 is a Pi(3.6GeV)&1Mu(3.6GeV)
# Each 31 Layers- Sharing MuDet Hits(?)



# The response of the Hadron Calorimeter

•In the study with singles one requests 1Hit of the track in HCAL and don't ask any requirements from the MUDET.

We will first compare the hit Pattern of Muons and Pions, looking at the Multiplicity and the number of layers with activity.

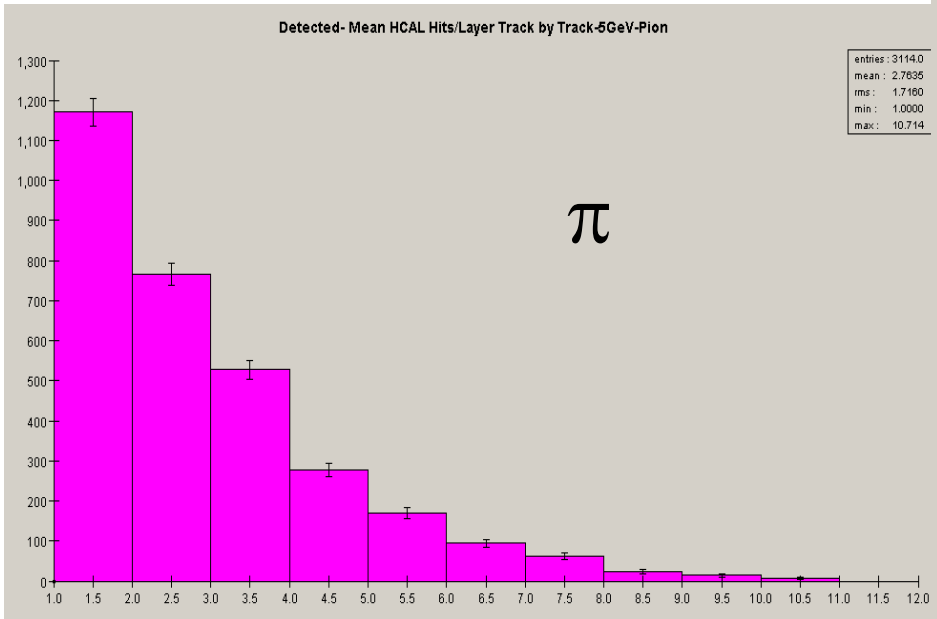
•We used single Pions and Muons at 3,5,10,20,50 GeV/c

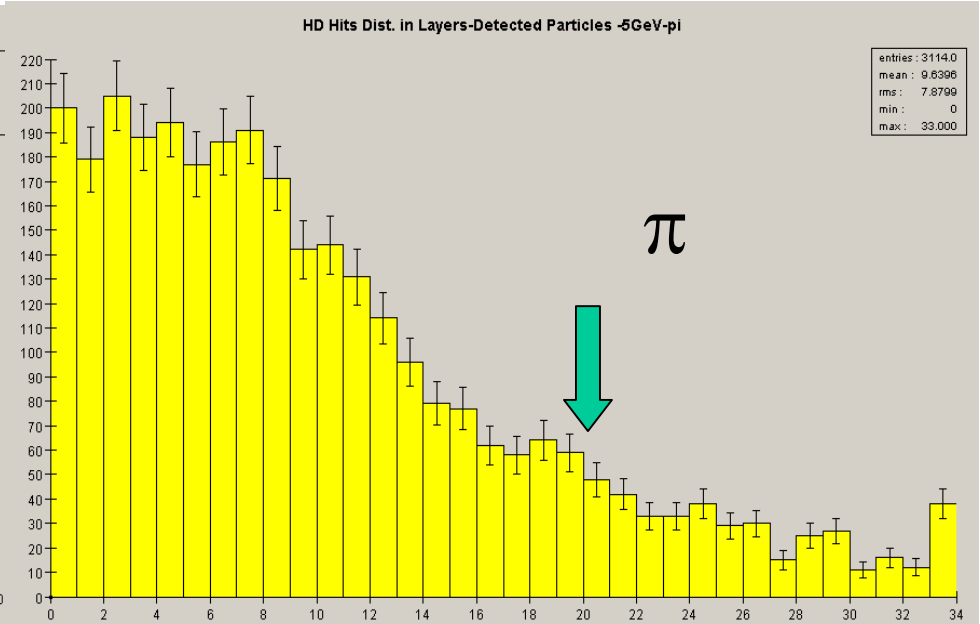
•In the next few slides are studied :The mean number of layers with hits as well as the mean number of hits/layer/track for both single Pions and Muons

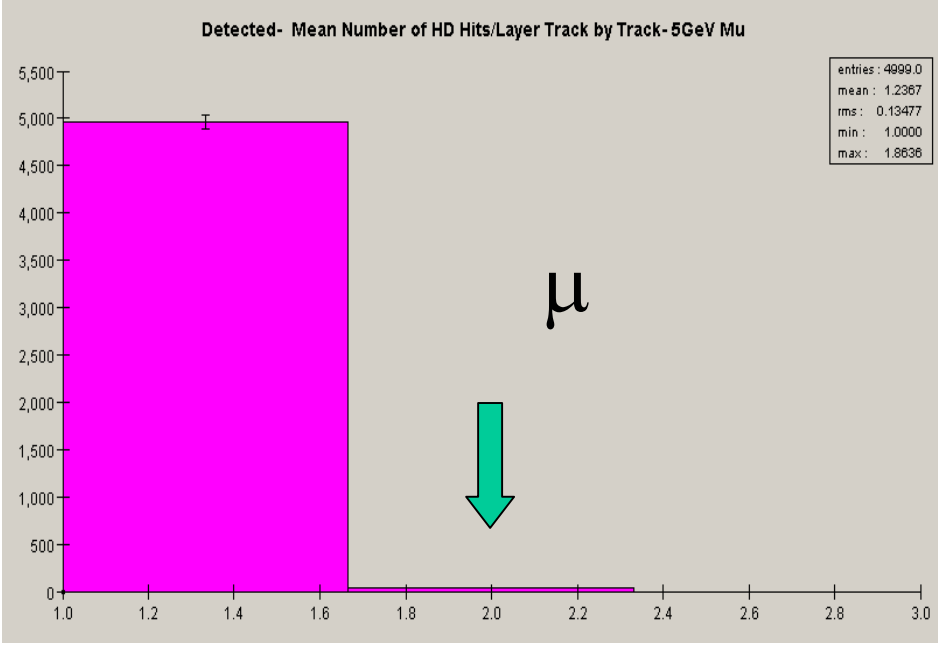
# Hit Pattern in HCAL

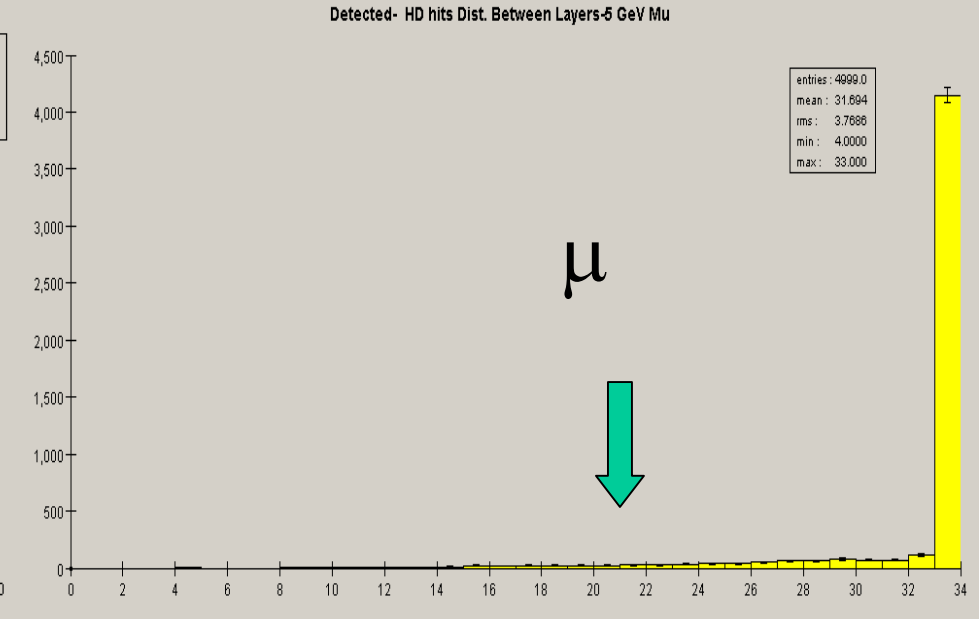
•The total number of layers involved in each event is shown In the next 2 transparencies at 5GeV and 10 GeV.
•A cut at 20 Layers can be used from 5 GeV. It allows to get rid of the bulk of the Pions without really depleting the Muons.
•At higher Momentum the cut could be shifted at 25 layers as seen on the 10 GeV slide.

# Layers & Hits - 5GeV Single Pi's & Mu's

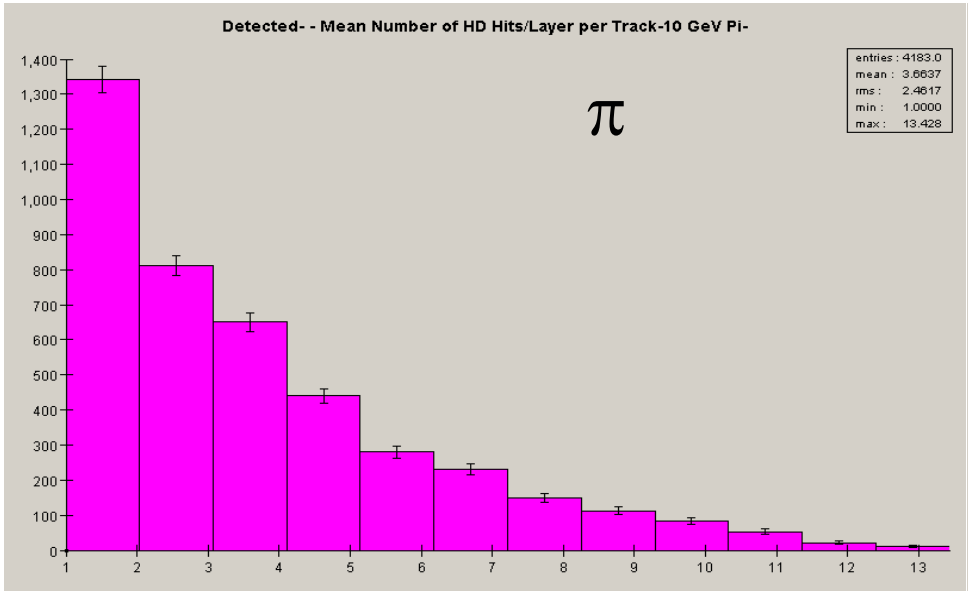


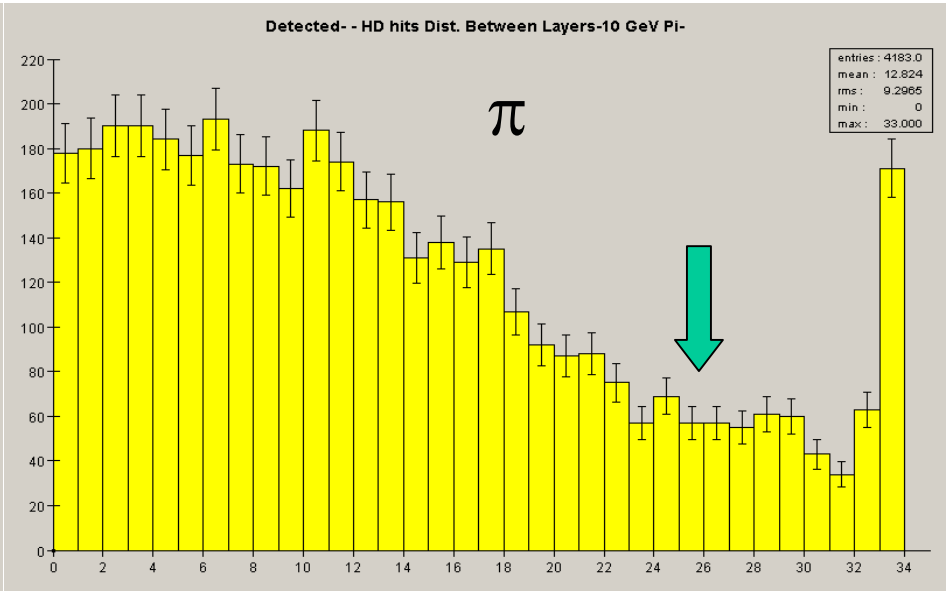



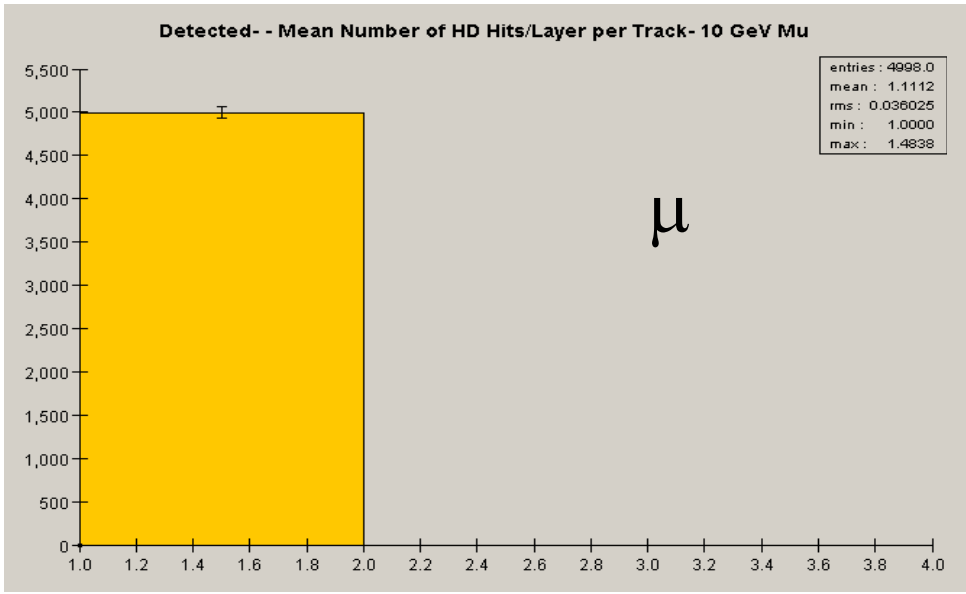



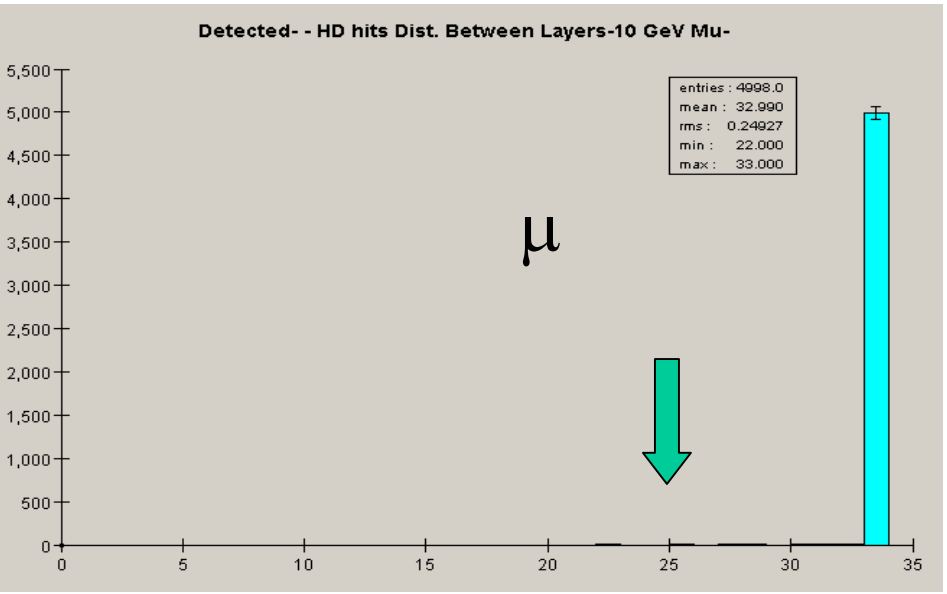



# Layers & Hits - 10 GeV Single Pi's & Mu's



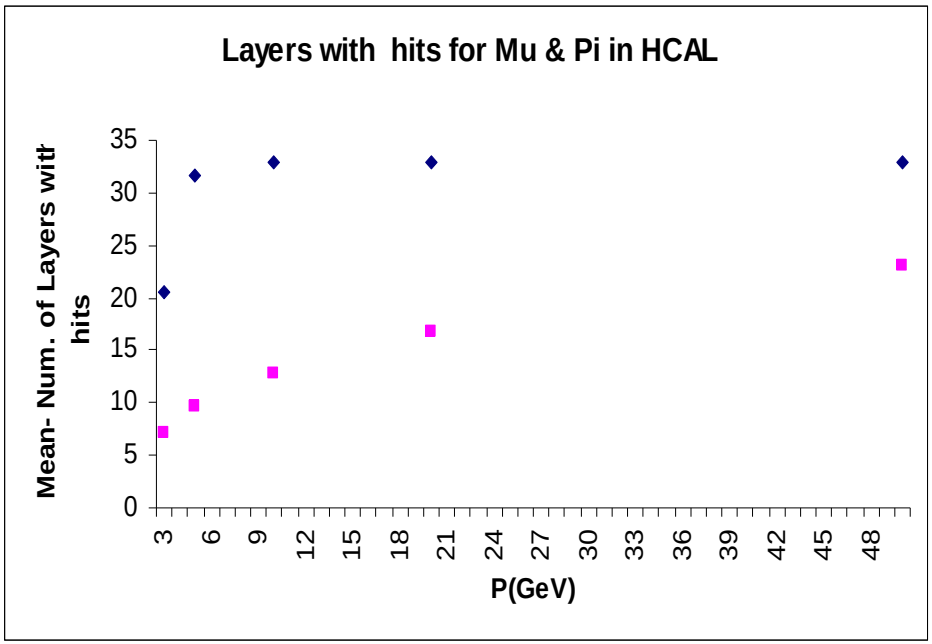



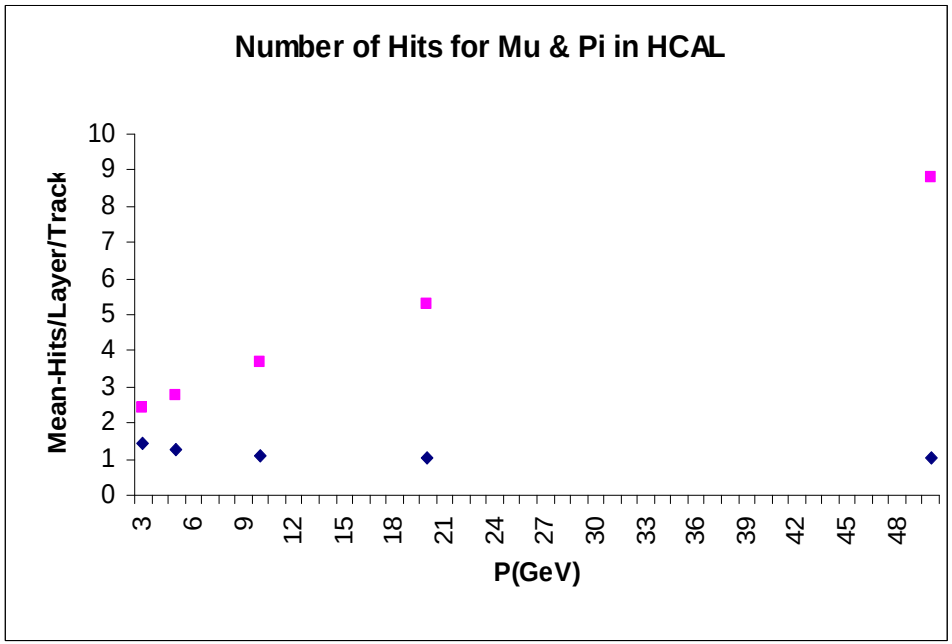
# Hit Pattern in HCAL(continue)

Blue Diamonds: The Muons, Pink squares: the Pions are shown as A function of Momentum.

Left Figure, above 3 GeV the Muon leaves hits all the way to layer 34, not so for the Pions.

Right Figure, the hits/layer each track is also fairly constant ~1 hit/layer for the Muons, not so for the Pions.



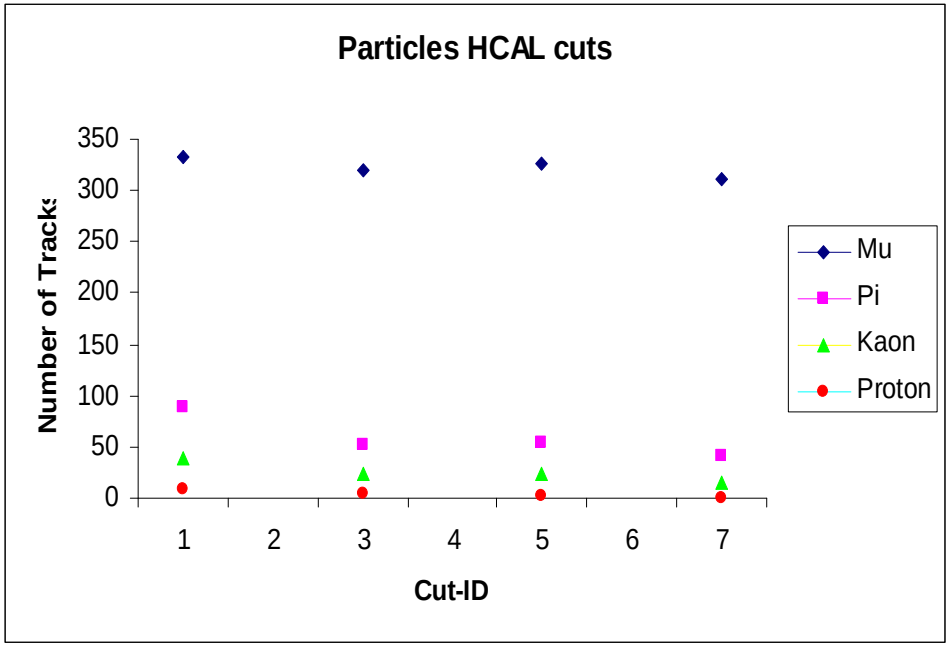
# Applying the cuts in B-Bbar Jets Events

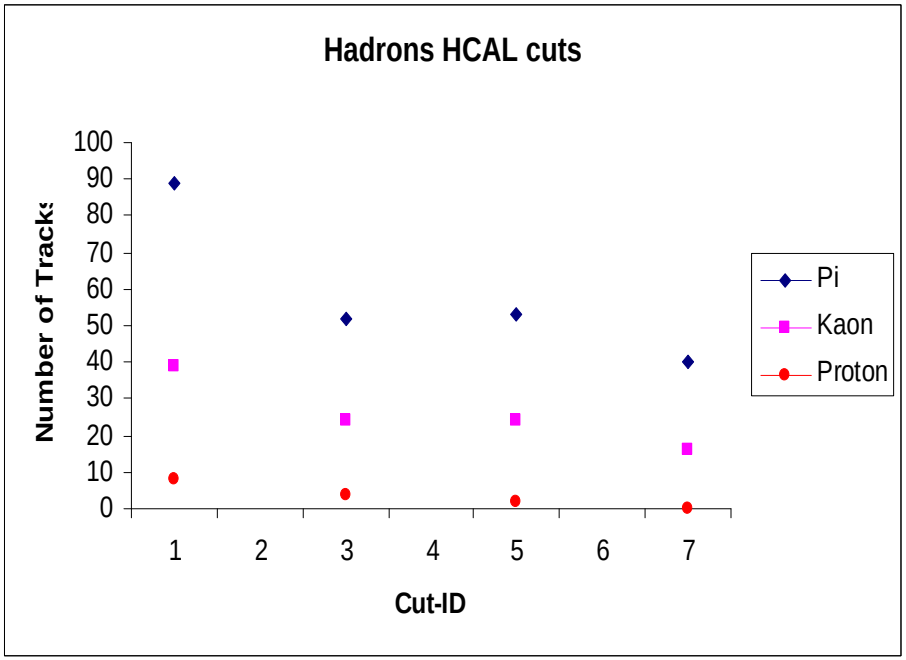
•To resolve the ambiguities the cut in the Maximum number of Layers with hits per track is applied and the 2 next slides show the Muons and the Contamination before and after the cut.
Again the HDCal information allow to get rid of ~50%
Of the contamination leaving the Muons almost untouched

Using also the Cut on the Hits/layer event by event, together With the Maximum Number of Layers cut allow to get rid Of 75% of the Contamination.

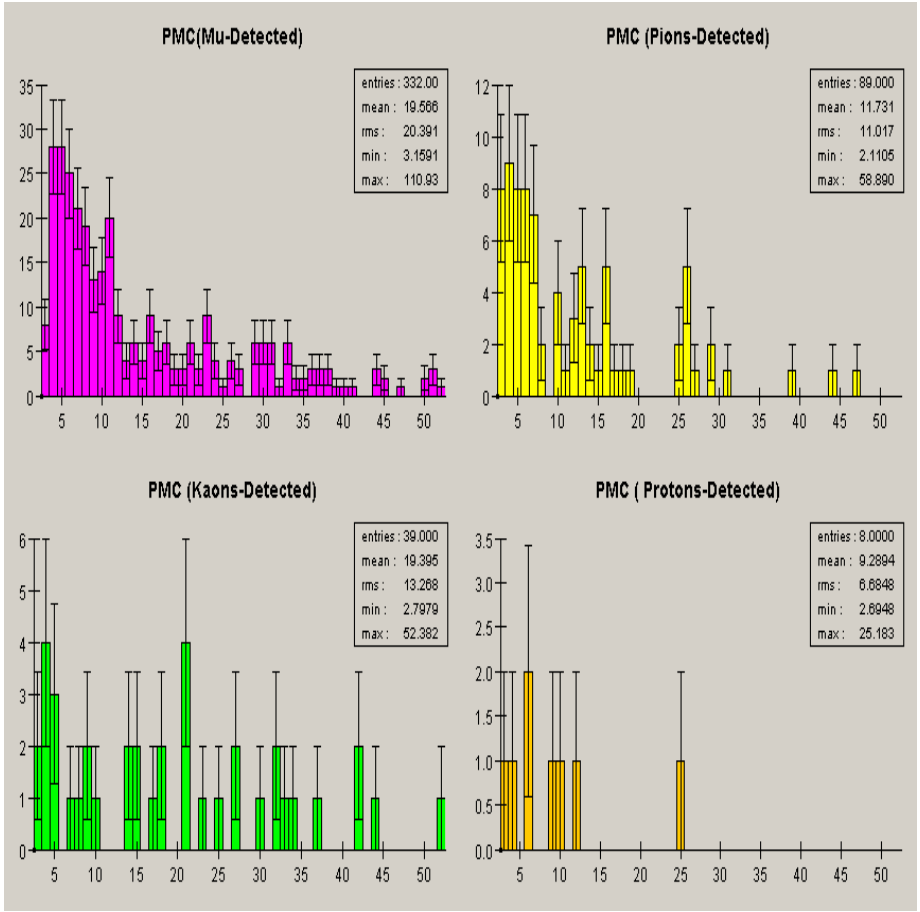
# The Sample of Muons and Hadrons Before and After HCAL Cuts have been included

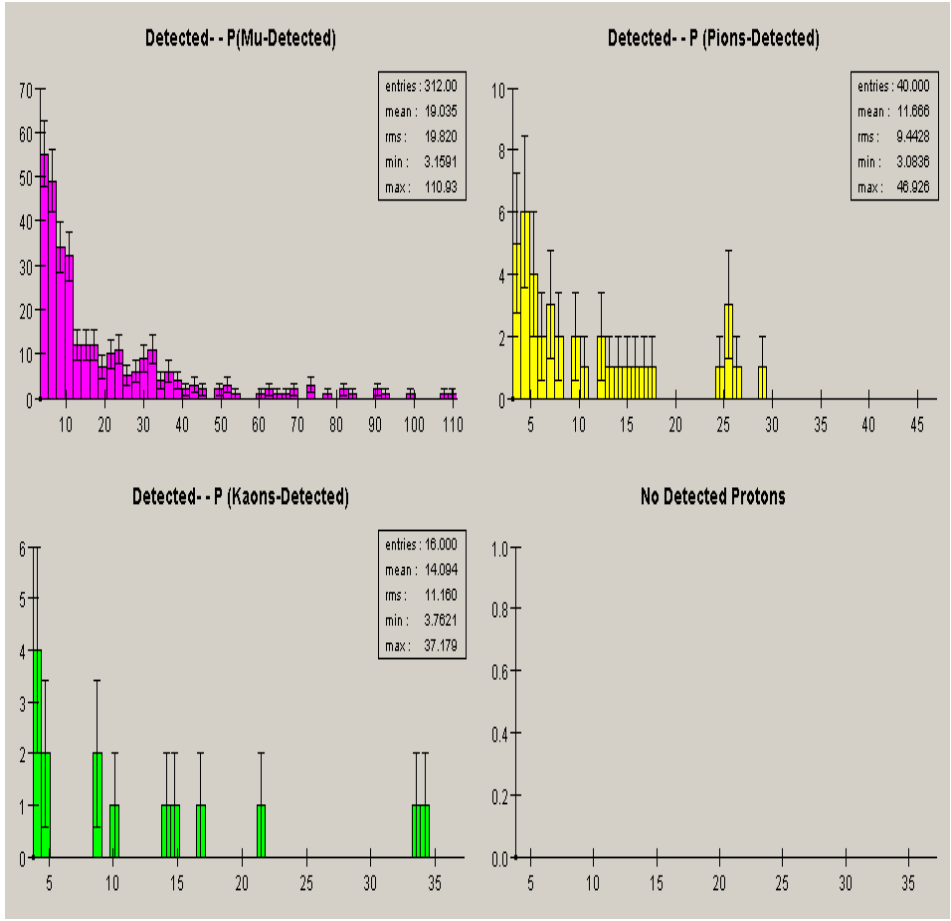
X=Cut Label: 1= No Cuts
3= Hits/Layer/Track cut
5= Cut on the Number of Layers
7= Combined cuts



# Before & After Maximum Layer & Hits/Layer Cuts Combined 5000 B-Bbar Events



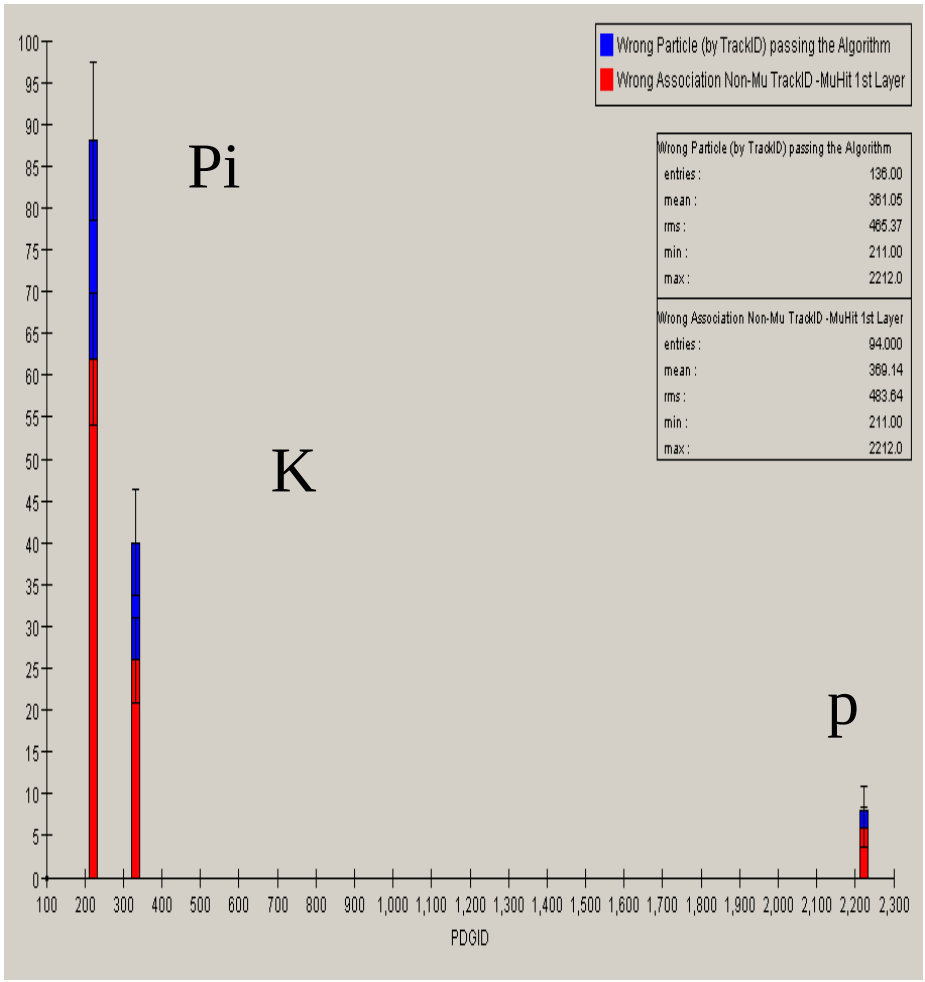
# Wrong Particle Wrong Association-From 5000 B- Bbar events

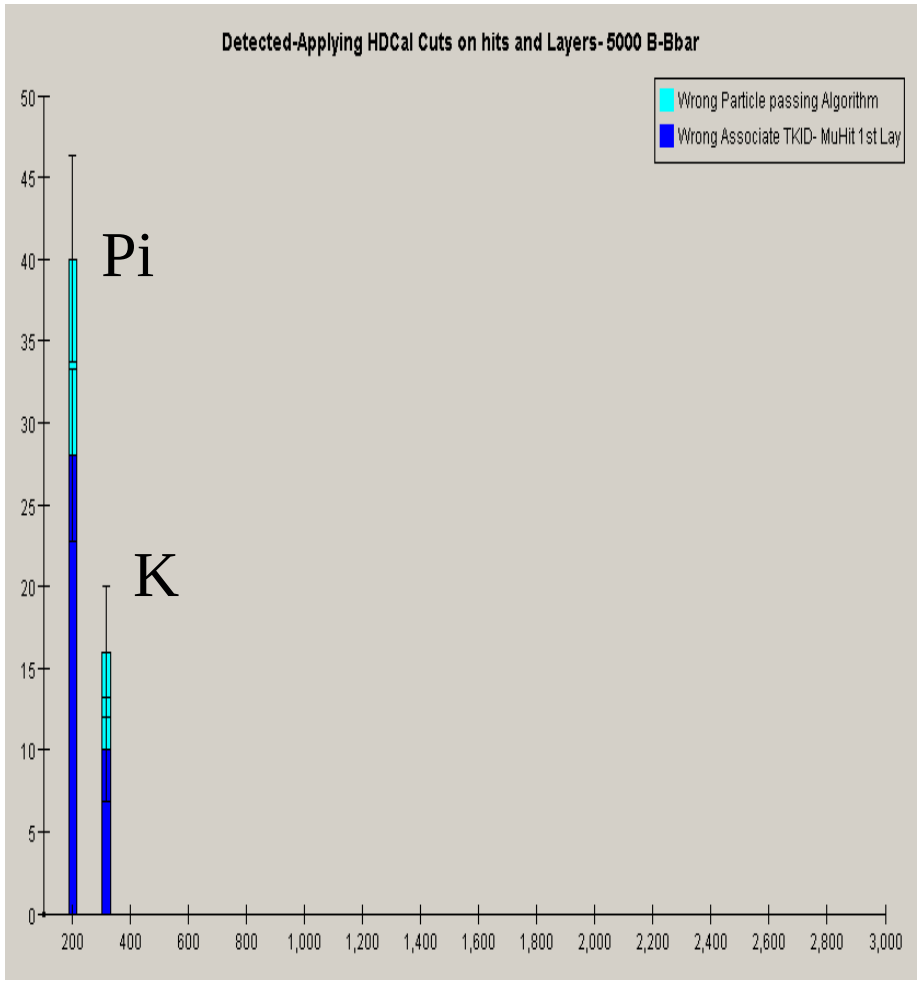
Is represented next figure, before HCAL cuts (left figure) and after HCAL cuts (right figure).

•In the left figure:
In Blue: Non Muons passing the Algorithm,136 tracks
In Red : Those non-Muons with a Hit in the 1$^{st}$ layer of MuCal with a Muon Monte-Carlo ID, 94/136 = ~70% of them

•In the right figure:
Light Blue(instead of Blue) and Dark Blue(instead of Red). Half of the Hadron contamination is gone.

# Wrong Particle Wrong Association-From 5000 B- Bbar events(continue)



# Conclusion

Using the information from HCAL has allowed to clean the μ candidates
Getting rid of 75% of the contamination.
The high energy region above 30 GeV has been totally cleaned up, and
The medium energy range has been depleted from part of the hadrons.
In a stepper, which takes care of the loss of energy by dE/dx in the
Material at each step, one would be able to flag the tracks which run
out of energy, namely the Hadrons low energy region.

# Backup Slides

# The Data

**PANDORA** is a parton-level Event generator which includes:
- Bremssthralung
- Initial States Radiations
- Full treatment of Polarization effects

Events produced by Pandora are processed by **PYTHIA** used to
-Simulate gluon showering
-Fragmentation of final state quarks
-**TAUOLA** is used to decay Tau-leptons

There are NO RADIATIVE CORRECTIONS included

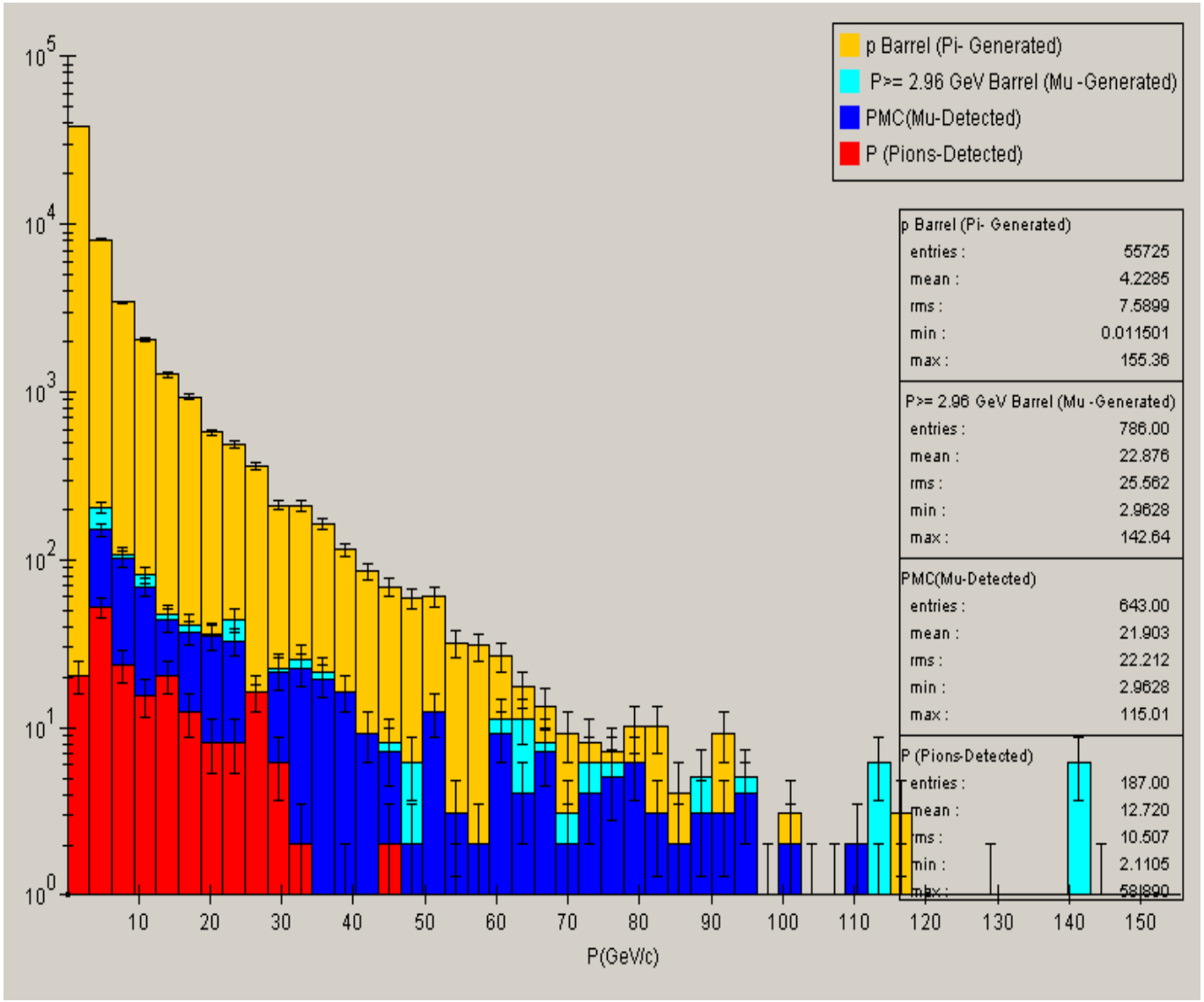
# Hadrons Contamination

The Hadron contamination with their P distribution

In the next figure is reported the Momentum distribution for the Generated and Detected Pions and Muons in 10K B-Bbar events.

•There are ~70 times more Pions produced than Muons in the B-Bbar Events.
•One get a **Pion Rejection of ~300 to 1** from a sample of 10000 B-Bbar.
•The Contamination for 940 particles passing the algorithm is
P Contamination : 19.9% +/- 1.6%
K Contamination: 9.04% +/- 1.02%
Proton - : 2.66% +/- 0.54%

# P-Distribution of Mu&Pi Generated versus Detected from 10000 B-Bbar



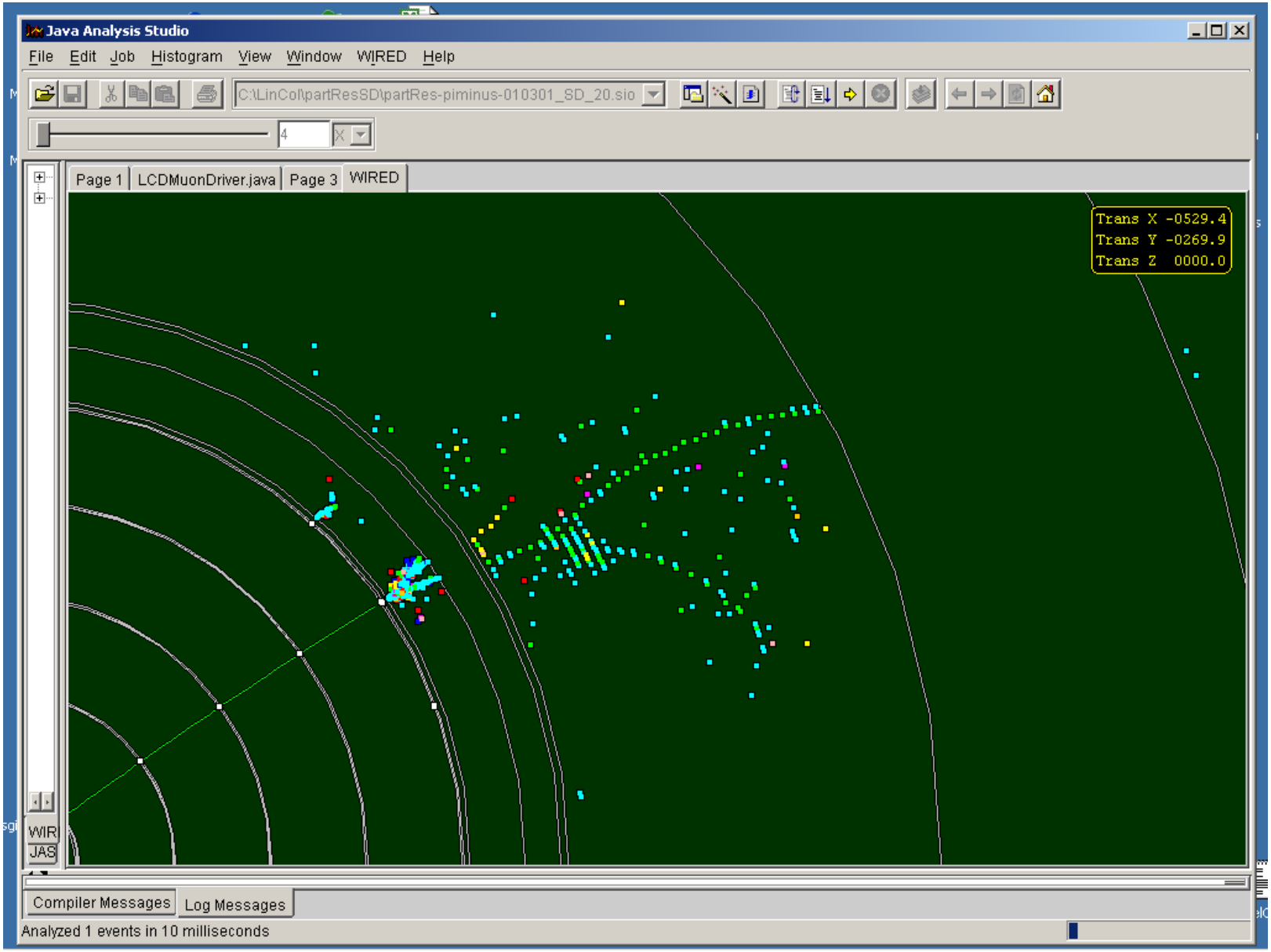

P(GeV/C) -1GeV/bin

- Generated Pions in Yellow
- Generated Muons in light blue

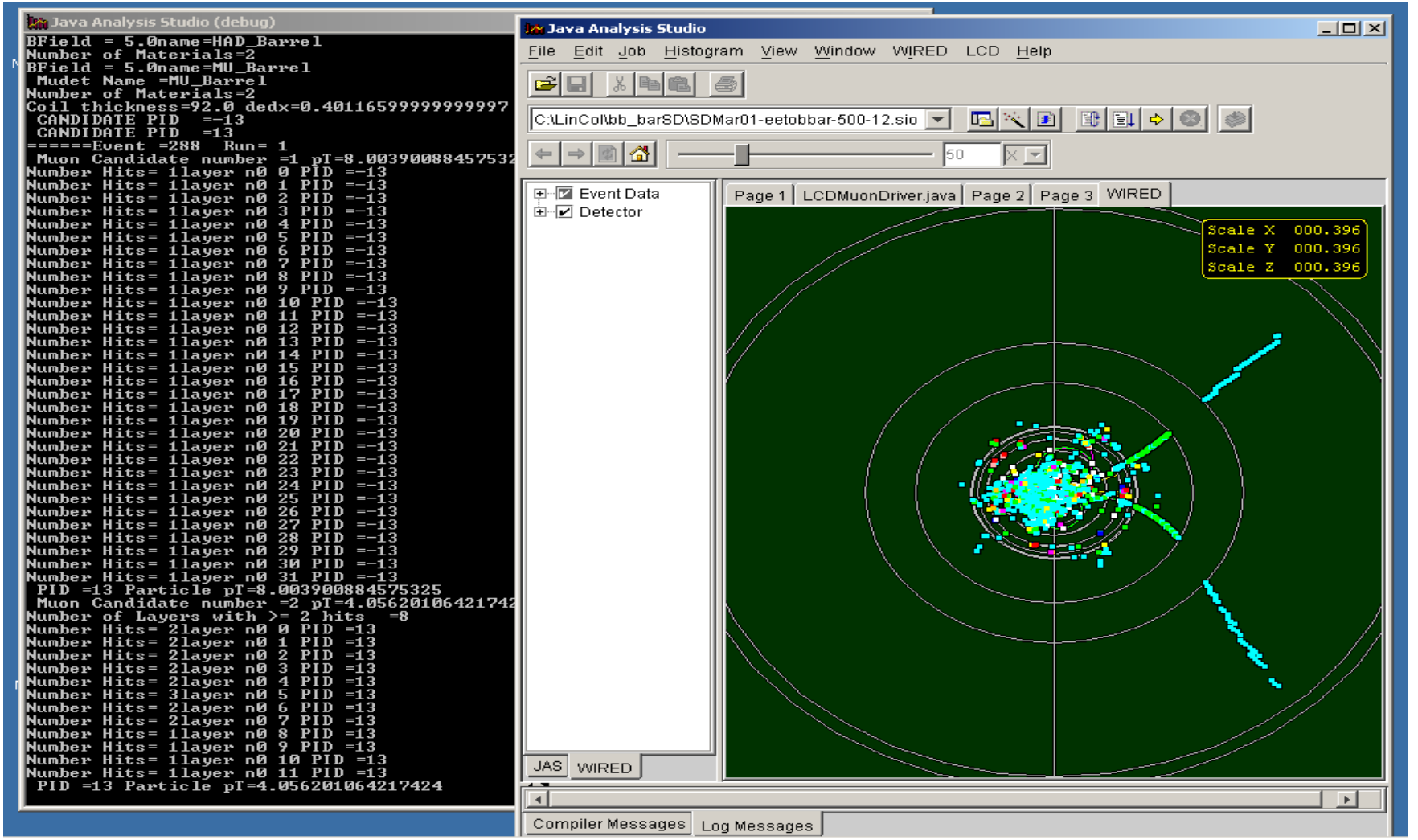
- Detected Muons in navy blue
- Pions Detected as Muons in Red.

**The Pion Rejection is shown to be ~300 to 1**

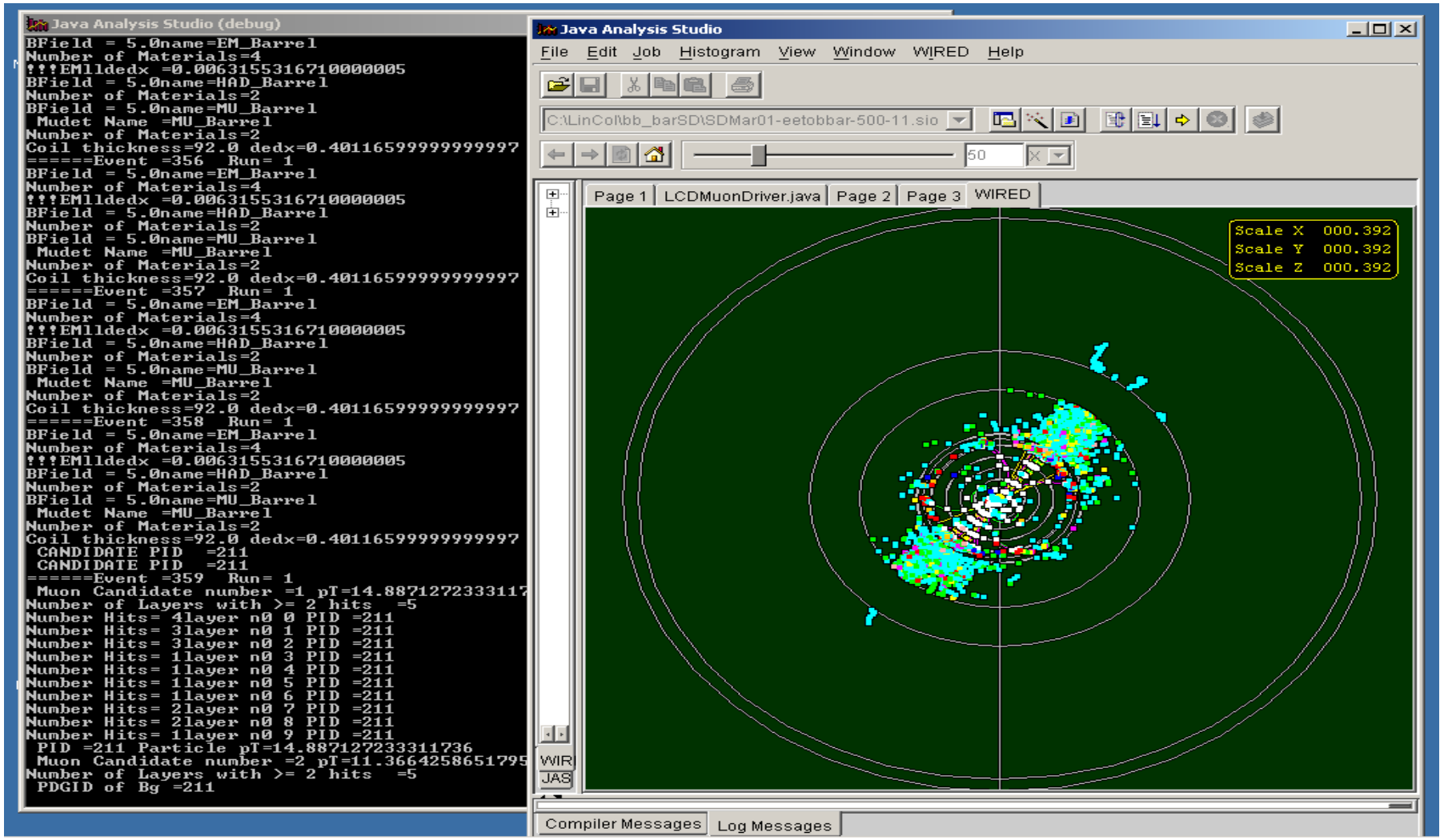
# 0-HCAL Hits-20GeV –Pi-



# B-Bbar to 2 “Candidates” Mu(8GeV) -Mu(4GeV) Mu(4GeV) With 12 Layers (7*2hits/Layer+1*3hits/Layer)



# B-Bbar- 2 “Typical” Pions
# 1Pi(15GeV)-1pi(11.4GeV)
# 15 GeV- 3 Layers >=3 hits, 11.4 GeV No Track Fit



# 2GeV m Curling in HCAL