Muon Purity and Detection Efficiency Variation With Depth in an SiD Type Detector

C. Milstene- Fermilab-Sept19-2006

In collaboration with: G. Fisk and A. Para (Fermilab)

arXiv:physics.inst-det/0609018C. Milstene, G. Fisk, A. Para

The Detector

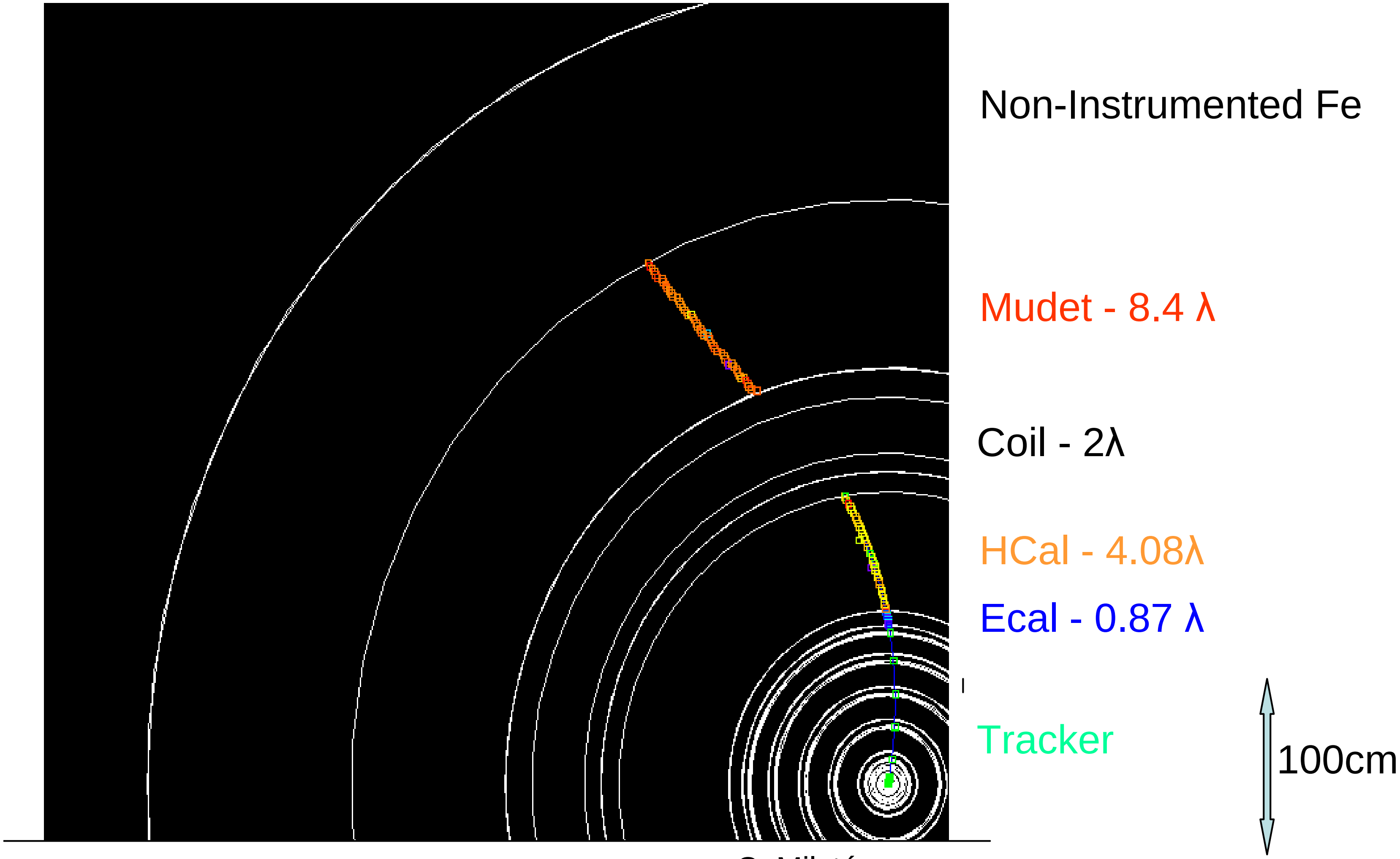
(Not quite SiD)

ECal (30Layer)	HCal (34Layer)	Coil	Mudet (15Layer)
X0 - 21.75 Λ - 0.872 dE/dx - 190MeV <u>Segmentation:</u> ΔΦ =Δθ= 3.7 mr	X0 - 39.44 Λ - 4.08 dE/dx - 800MeV <u>Segmentation:</u> ΔΦ =Δθ= 5.23 mr	X0 - 13 Λ - 2 dE/dx - 362MeV	X0 - 79.5 Λ - 8.4 dE/dx - 1400MeV <u>Segmentation</u>: ΔΦ =Δθ= 21 mr

Mu Detector:

240cm thick for the magnet flux return:
10 cm Fe plates
15 instrumented gaps.

The Detector Display



Non-Instrumented Fe

240cm
Fe
Magnet
Flux
Return

Mudet - 8.4 λ

Coil - 2λ

HCal - 4.08λ

Ecal - 0.87 λ

Tracker

Quadrant SiD

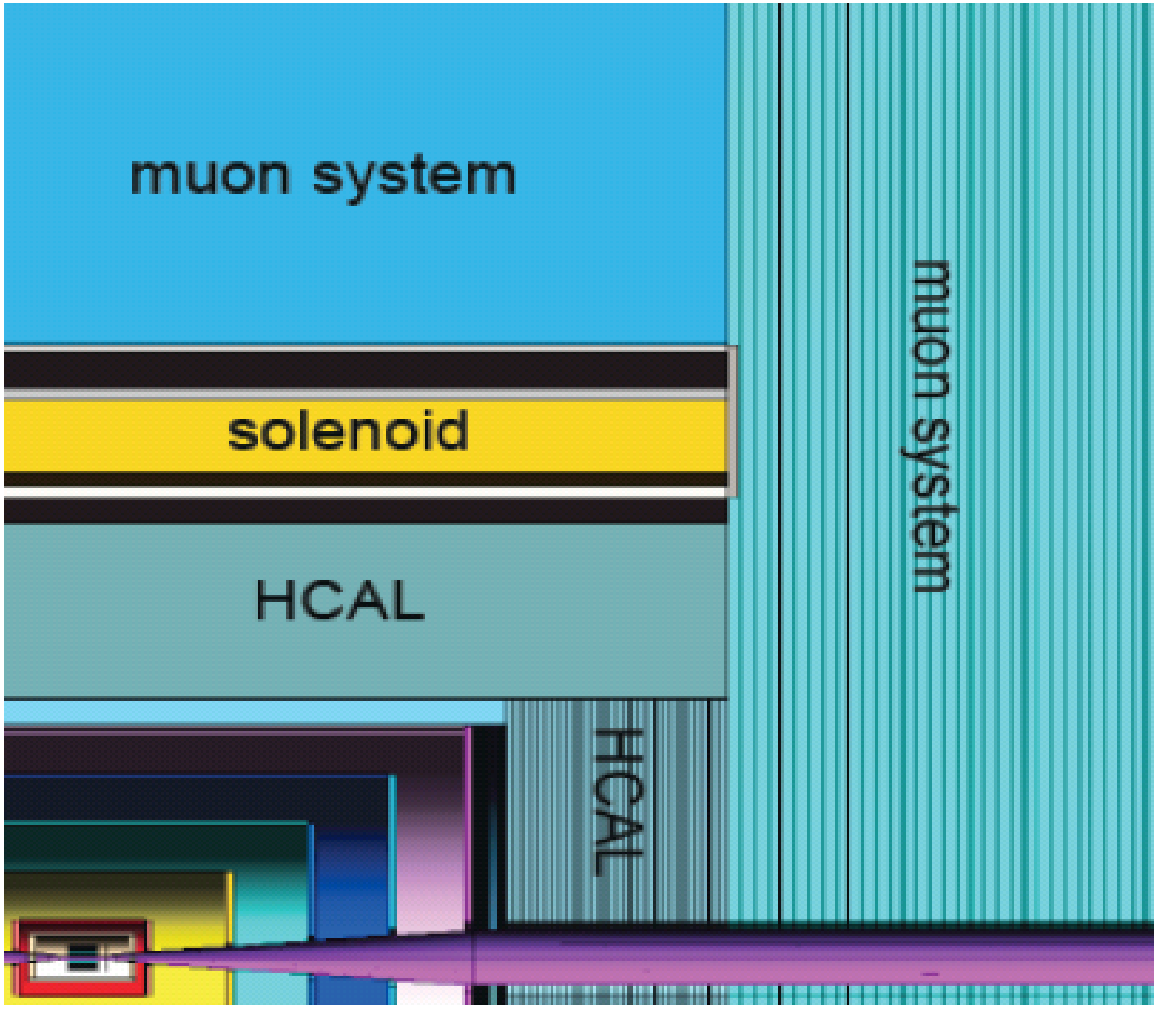


Figure 1 Illustration of a quadrant of SiD.

The Stepper

- The Stepper software simultaneously includes dE/dx and q*v x B effects,
- We study the effect on single mono-energetique particles
- The effect on bbar-b jets

Stepper-Analytical Form

arXiv:physics.inst.det/0604197-C. Milstene, G. Fisk, A. Para

$$p_x(n+1) = p_x(n) - 0.3 * q * \frac{p_y}{E(n)} * c_{light} * B_z * \delta t(n) - \gamma_x(n) \;;$$

$$p_y(n+1) = p_y(n) + 0.3 * q * \frac{p_x}{E(n)} * c_{light} * B_z * \delta t(n) - \gamma_y(n) \;;$$

$$p_z(n+1) = p_z(n) - \gamma_z(n) \;;$$

$$\gamma_i(n) = \frac{\mathrm{dE}}{\mathrm{d}_i} * \frac{\mathrm{E(n)}}{|\,\mathrm{p(n)}\,|} * \frac{\mathrm{p_i(n)}}{|\,\mathrm{p(n)}\,|} * \delta s \;;\; i = x, y, z \;.$$

q is the charge,
Bz the magnetic field,
dt(n) the time spent and
ds the path length
in one step

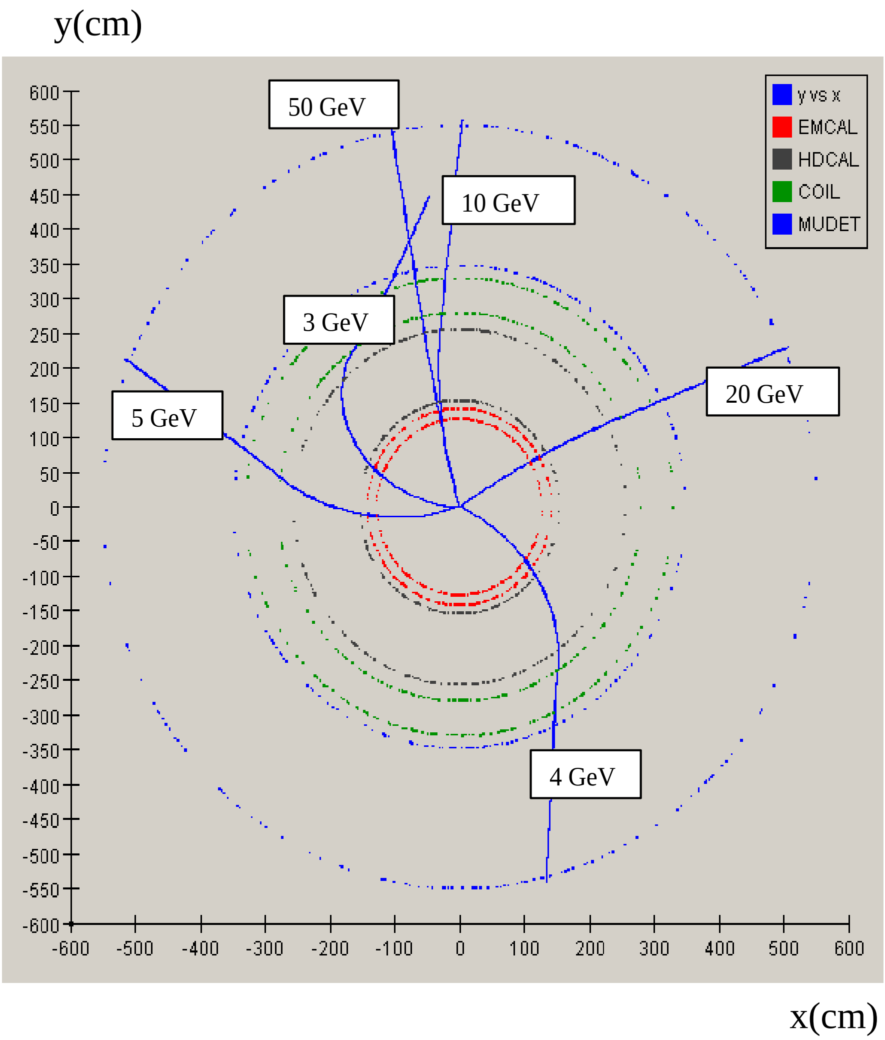
$$x(n+1) = x(n) + \frac{p_x(n+1)}{E(n+1)} * c_{light} * \delta t(n) \;;$$

$$y(n+1) = y(n) + \frac{p_y(n+1)}{E(n+1)} * c_{light} * \delta t(n) \;;$$

$$z(n+1) = z(n) + \frac{p_z(n+1)}{E(n+1)} * c_{light} * \delta t(n) \;.$$

Mixed units are used, px, py, pz are in GeV/c, E(n) in GeV,
clight =3x108 m/s,
δt in seconds, Bz in Tesla
The point (x(n+1),y(n+1),z(n+1)) is the position at step n+1, after the momentum change to px,y,z(n+1) at step n.

Single Muons-Reconstructed by the Stepper
B=5 Tesla Magnetic Field

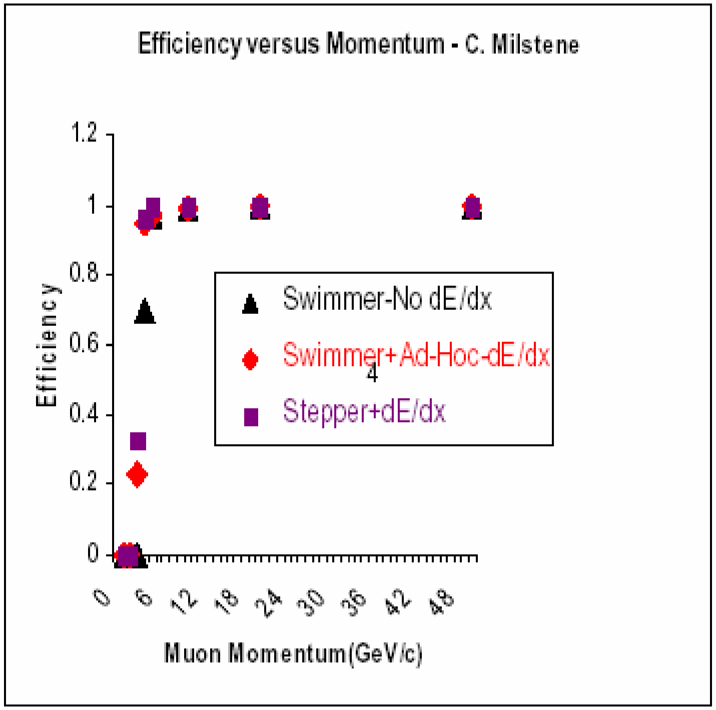


EMCAL	-2	RED	Rings
HDCAL	-2	BLACK	Rings
COIL	-2	GREEN	Rings
MUDET	-2	BLUE	Rings

- 3 GeV Muons curling by the high B field In the tracker, Ecal, HCal

- 50GeV Muons straight

Muon Reconstruction Efficiency



E(GeV) \ Techn.	3	4	5	10
No dE/dx	0.06 %	70%	97%	99.%
Ad-Hoc dE/dx	23%	95%	97%	99.%
V x B + dE/dx	33%	96%	99%	100%

The Stepper has been improved further by a Runge-Kutta method and A Kalman-filter stepper has been developped.
arXiv: physics.inst-det/0605015-C.Milstene,G.Fisk,A.Para

Runge-Kutta Correction

- We now focuses mostly on lower momenta, ~30% of the data reaching the muon detector (3GeV≤ p <5GeV) . The approximation $\Delta p_T / \Delta t \sim dp_T / dt$ is insufficient here, at least at the end of their path.. Here ΔpT (GeV/c) is the variation in pT of a particle going through a field B (Tesla) for a timeΔt(s).

$$dp_T / dt = \alpha \bar{\mathrm{v}} \times \bar{B} \text{ , } with\ \alpha = 0.3q(1/E)c_{light}dt$$

$$\int \alpha \ \bar{\mathrm{v}} \times \bar{B} \ dt$$

E is the particle energy in GeV, q its charge in electron units, clight (m/s). In a 5 Tesla magnetic field, for low momenta, one has to calculate the integral in order to obtain the finite difference equation of motion

$$\Delta p_x B = (\alpha / \delta).p_y.B_z - \eta.p_x$$

$$\Delta p_y B = (\alpha / \delta).p_x.B_z - \eta.p_y$$

$$\Delta p_z B = 0.$$

Is the Field dependant change
In Momentum

$$\delta = 1 + 0.25\alpha^2 B^2 \text{ , } \eta = 0.5\alpha^2 \mathrm{B}^2$$

The Jets Data

arXiv:physics.inst.det/0605015-C. Milstene, G. Fisk, A. Para

10000 bbar-b jets events generated with Geant4

- P>3GeV required in order for the Muon to reach the Muon Detector

- A polar angle cut define the barrel.

The Algorithm

Rely on the 2 main characteristic properties of the muon

1. The muon creates a repetitive pattern of 1 to 2 hits per cell all the way
2. The muon travels deep without interacting whereas hadrons are filtered out

Each Charged track with a good fit in the tracker hits are

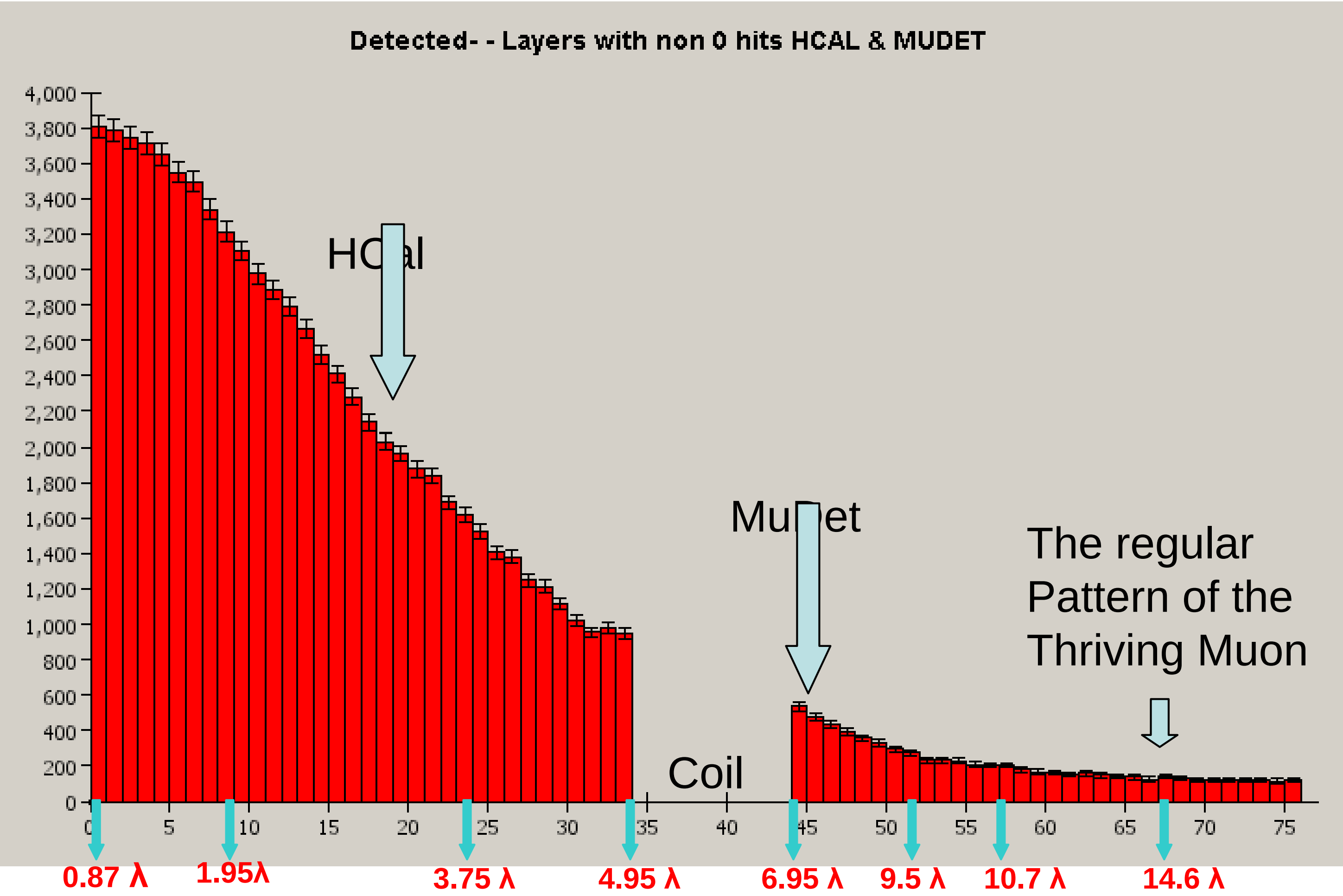
Collected in a road in (ΔΦ,Δθ) in ECal, HCal and Mudet

-Accounting for v&B and dE/dx effects

-requiring no more than 2 hits/cell

-requiring a given depth reached into the Muon detector

Layers with Non-zero Hits in HCal and Mudet



The regular
Pattern of the
Thriving Muon

Filter to Hadrons-The Cuts

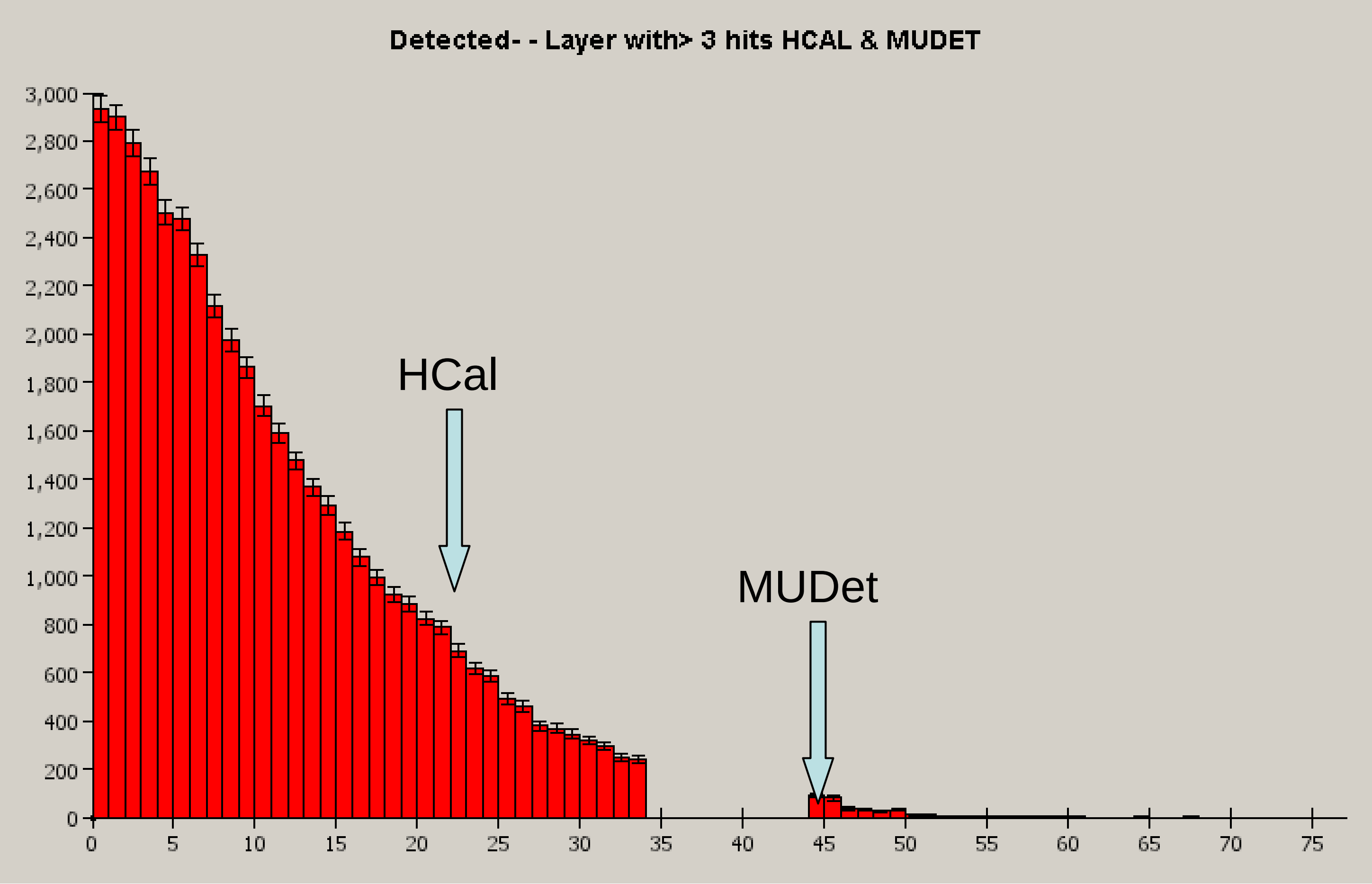
Hadrons tend to interact → Irregular hit patterns
They don't reach out

1/ we cut on large energy deposit in the path

2/ we cut on void on 2-3 consecutive layers

3/ we require at least 1 hits on the last 4 layers of HCal and less than 4 hits/layer (still allows neutral from neighbor tracks)

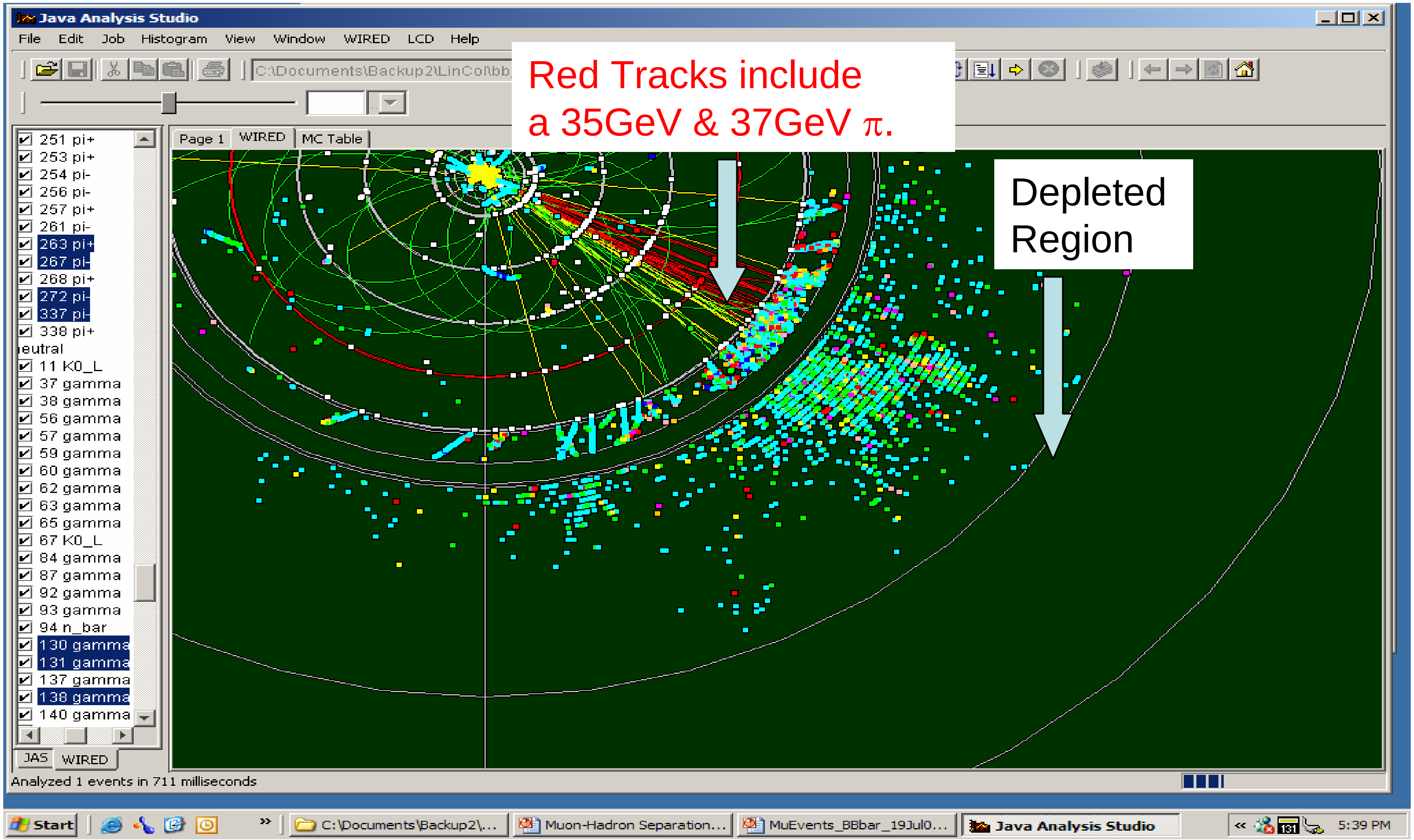
Layers with > 3 Hits
(Typical of Hadron activity) In HCal & Mudet



HCal

MUDet

A b Interacting Hadron Content



Red Tracks include a 35GeV & 37GeV π.

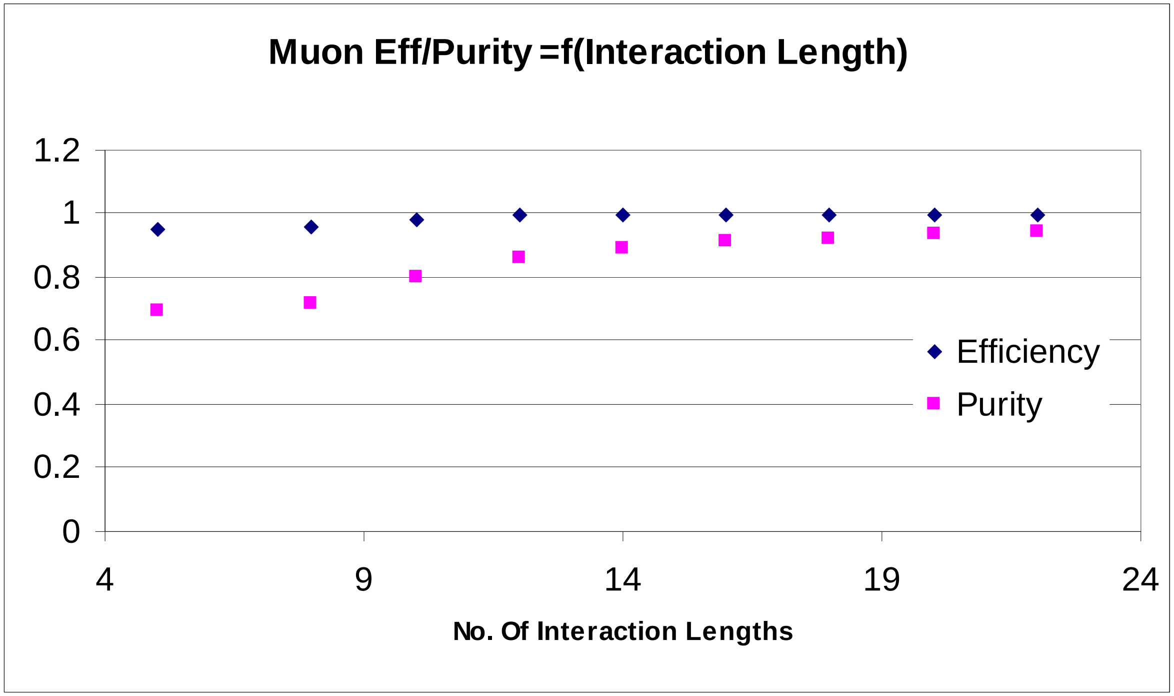
Depleted Region

☑ 251 pi+
☑ 253 pi+
☑ 254 pi-
☑ 256 pi-
☑ 257 pi+
☑ 261 pi-
☑ 263 pi+
☑ 267 pi-
☑ 268 pi+
☑ 272 pi-
☑ 337 pi-
☑ 338 pi+
eutral
☑ 11 K0_L
☑ 37 gamma
☑ 38 gamma
☑ 56 gamma
☑ 57 gamma
☑ 59 gamma
☑ 60 gamma
☑ 62 gamma
☑ 63 gamma
☑ 65 gamma
☑ 67 K0_L
☑ 84 gamma
☑ 87 gamma
☑ 92 gamma
☑ 93 gamma
☑ 94 n_bar
☑ 130 gamma
☑ 131 gamma
☑ 137 gamma
☑ 138 gamma
☑ 140 gamma

Analyzed 1 events in 711 milliseconds

C. Milsténe

Purity versus Efficiency



The Purity improves from
69% end of HCal (4.95λ)
to
94% end of Mudet(15 λ)

The Efficiency improves
from 95% to 99.6%

Remark: Muons which do not enter the layer e.g. bending into the endcaps at a certain level of their path, are not included in the normalization.

HCal & MuDet Barrel - Purity and Efficiency Cuts

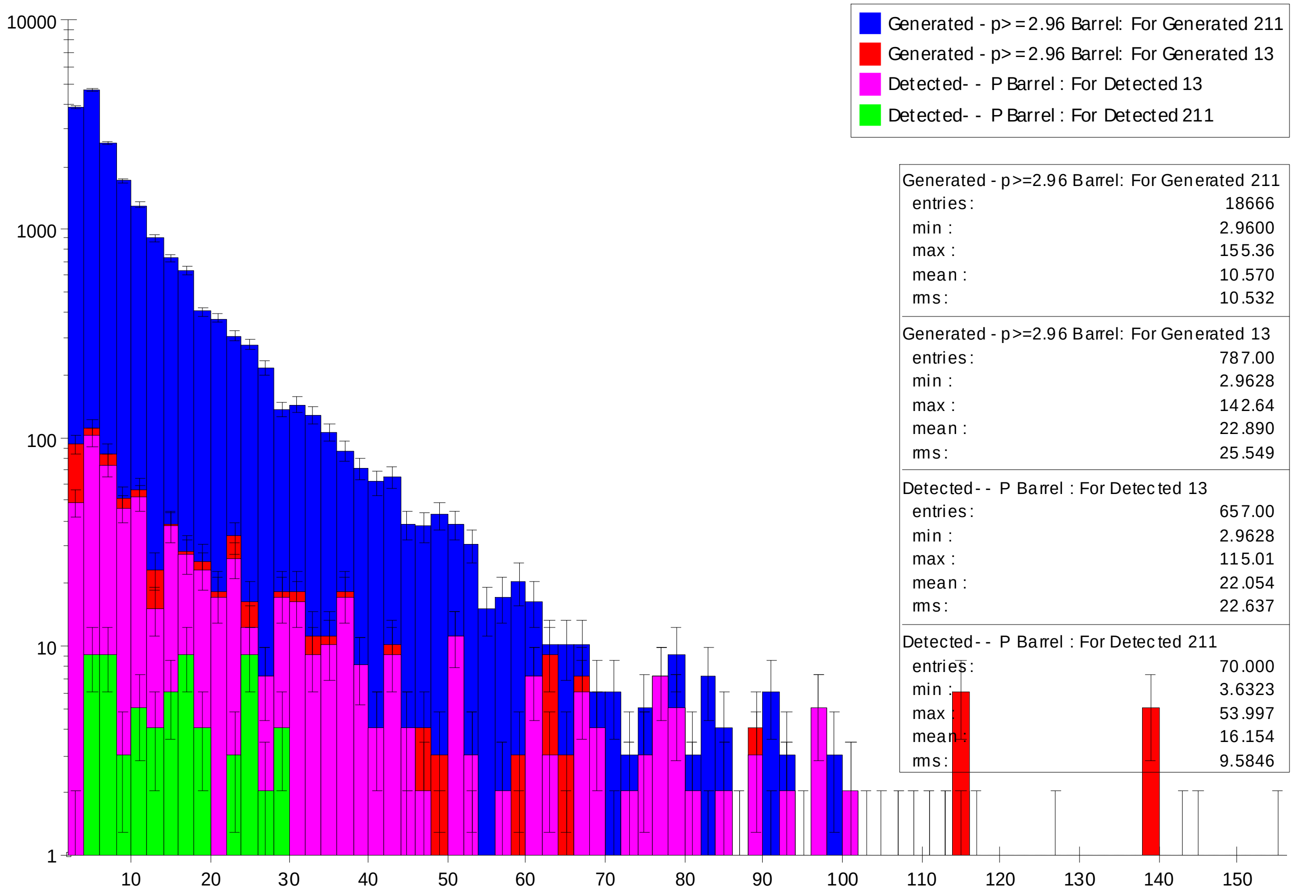
Conditions for 10,000 b-b_bar	Muons	Pions	K’s	Protons
Tracker Recons & Final Tracks	739	18024	4303	1712
Good Fit Tracker	715	17120	4072	1579
1 or 2 hits in each of the last 5 layers of Hcal. (No 0’s)	700	357	204	15
MuDet ≥12hits,≥12layers	671	77	50	5
Min Mudet Hits ≤2 Max Mudet Hits≤7	670	69	39	5

Momentum distributions in b jets

In bbar-b jets events the muon is ~1.7% of the particle population

	π	k	proton	μ
Total Gen	55805	8310	2816	1147
Gen > 3GeV	18666	4473	1622	787
Fract. >3GeV	34%	54%	58%	69%
Recon>3GeV	18024	4303	1614	739
Good Fit	17120	4072	1579	717
Identified As μ	69	39	5	670
Rejection Efficiency	1/261	1/104	1/322	93.5%

Mu& Pions Background Generated/Detected By Mu Algorithm- Out Of 10000 b-bbar Jets



P(GeV/c)- 2GeV/bin

Signal:

- Generated Muons in Red
- Detected Muons in Magenta

Background:

Generated Pions in Blue

Detected Pions by Mu Algorithm In Green

Remark:

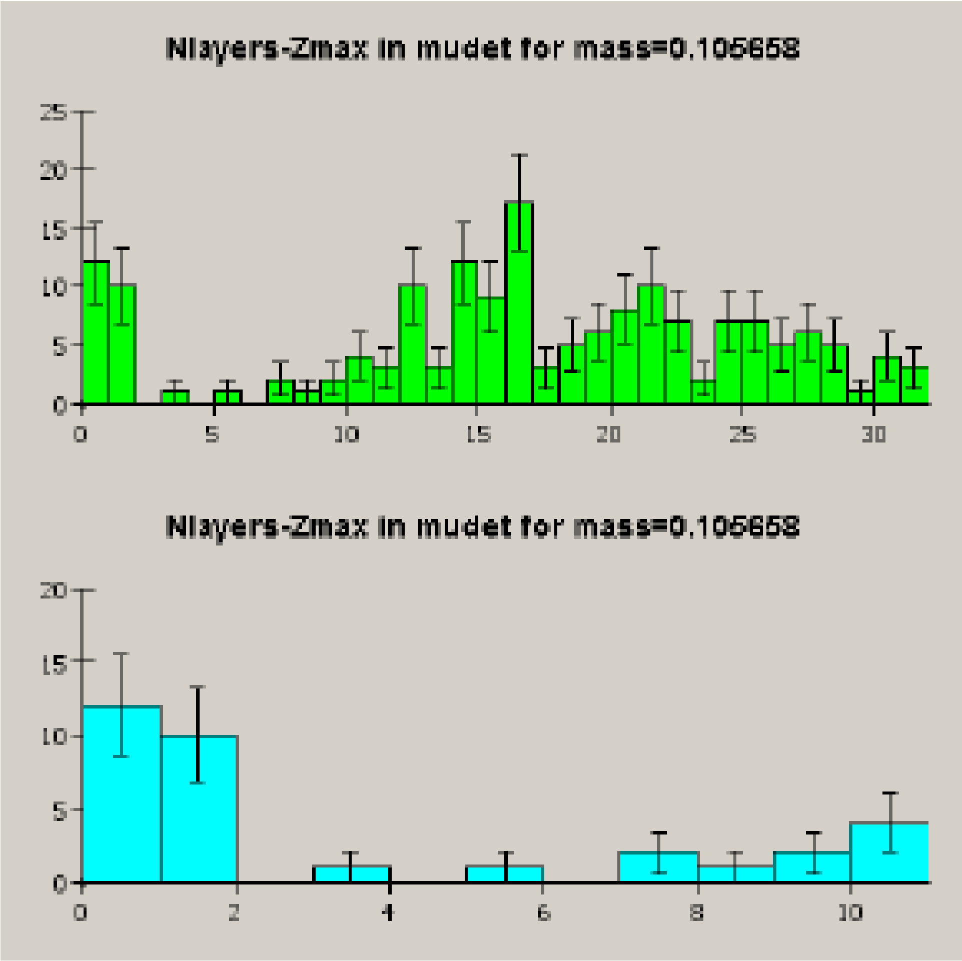
Below 2.96 GeV the Particles do not reach The Muon Detector

Conclusion

- A study of Muon ID and Purity in the detector shows that in bbar-b jets one is able to identify the muons (1.7% of the population) with an efficiency which can reach 99.6% and a purity of 95%
- We have also shown that we get a steady improvement of purity and muon efficiency with depth. The purity rises from 69% at the end of HCal to 94% at the end of Mudet and the efficiency from 95% to 99.6%

  It requires just the instrumentation of part of the return iron of the magnet.
- The code is being developed to take a better care of the muons at the end of their trajectory.
- Due to small losses of barrel muons to the endcap the muon efficiency will improve further with the inclusion of the endcap to the code in development.

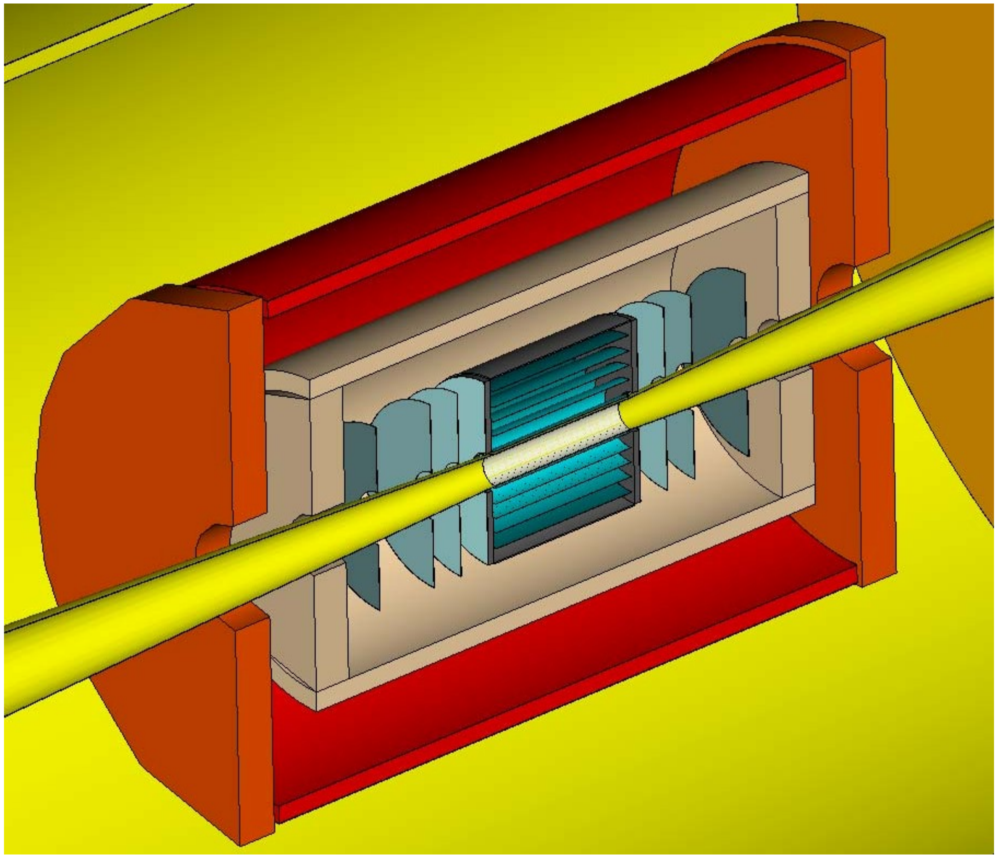
Last Layer With Activity



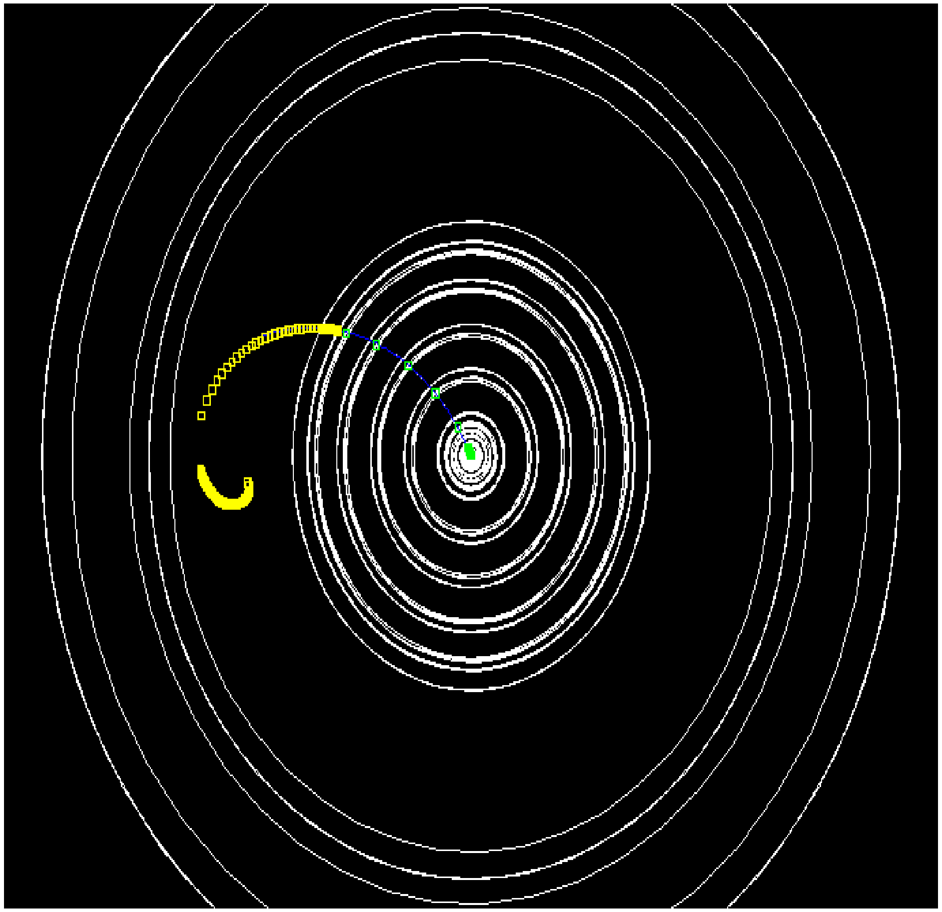
The upper figure shows the layer number where the muon reaches z-max. All the muons that reach z-max in layer 11 or higher meet the μ ID requirement. I.e. they are detected. The plot shows that most of the barrel muons above 3 GeV/c stay in the barrel and meet the muon penetration requirement for μ ID.

The lower figure is a blow-up of the upper histogram that shows the exit layer for those muons that do not meet the penetration requirement of 12 or more layers. 33 barrel muons exit the barrel before they reach z-max, so they are un-detected muons; they do not penetrate ≥12 layers.

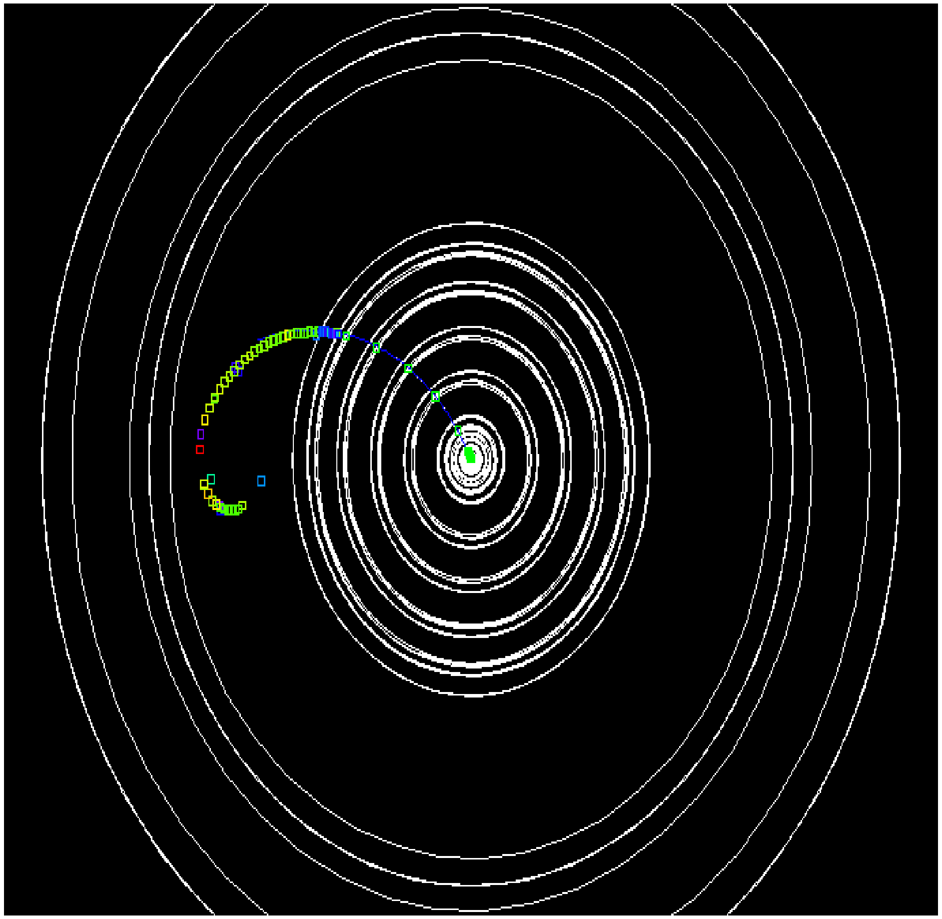
Vertex Detector & 1st Tracker Layer



Reconstructed And Simulated -Details



Reconstructed-Yellow



Simulated- Green and blue