

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

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JINST-002-0506- C. Milstene, G. Fisk, A. Para

The Detector

(Not quite SiD)

ECal (30Layer)	HCal (34Layer)	Coil	Mudet (32Layer)
X0 - 21.75 Λ - 0.872 dE/dx - 190MeV	X0 - 39.44 Λ - 4.08 dE/dx - 800MeV	X0 - 13 Λ - 2 dE/dx - 362MeV	X0 - 87.15 Λ - 10.2 dE/dx - 1400MeV
<u>Segmentation:</u> $\Delta\Phi = \Delta\theta = 3.7$ mr	<u>Segmentation:</u> $\Delta\Phi = \Delta\theta = 5.23$ mr		<u>Segmentation:</u> $\Delta\Phi = \Delta\theta = 21$ mr

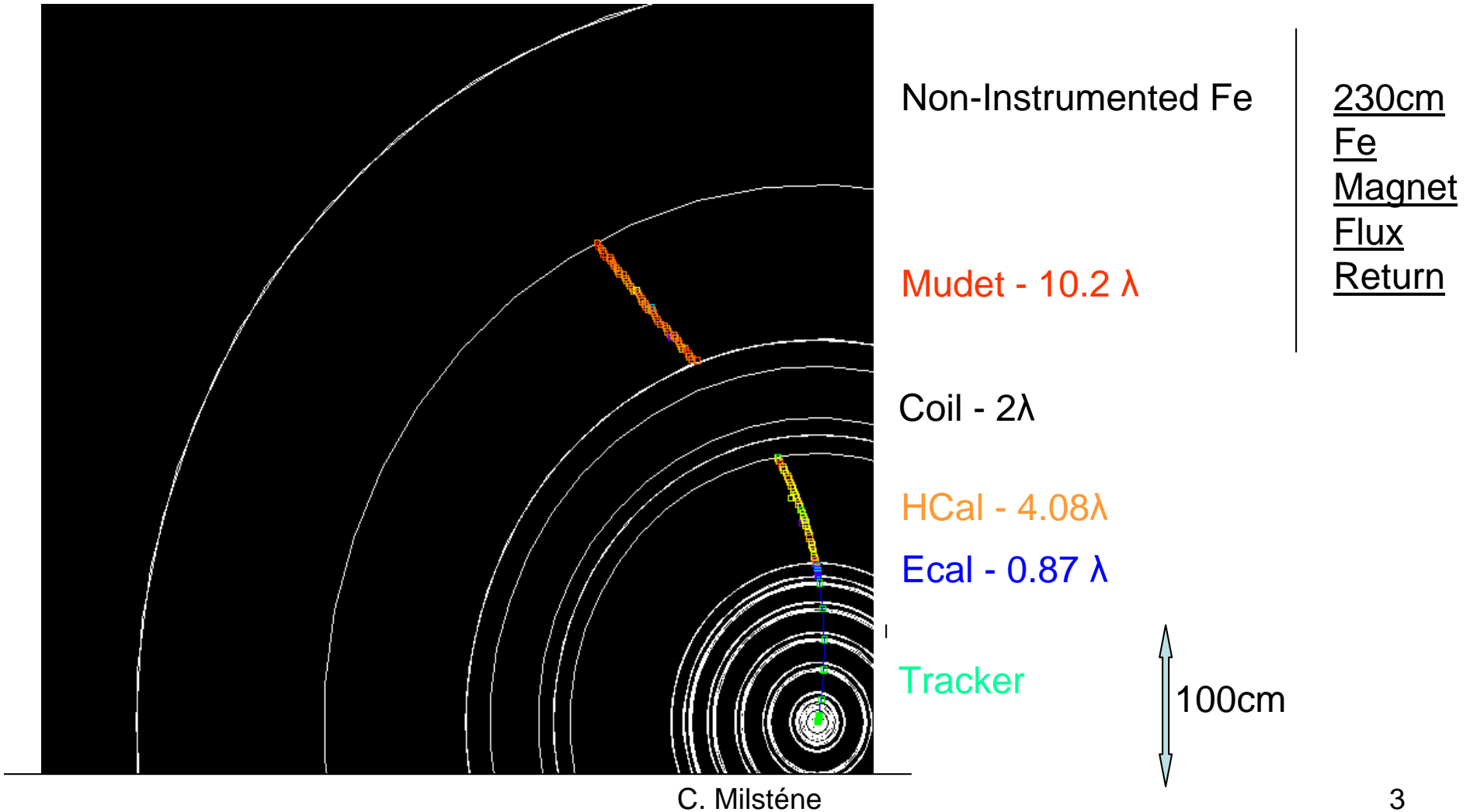
Mu Detector:

230cm thick for the magnet flux return:

5 cm Fe plates

32 instrumented gaps.(1.5cm Sc)

The Detector Display



Quadrant SiD

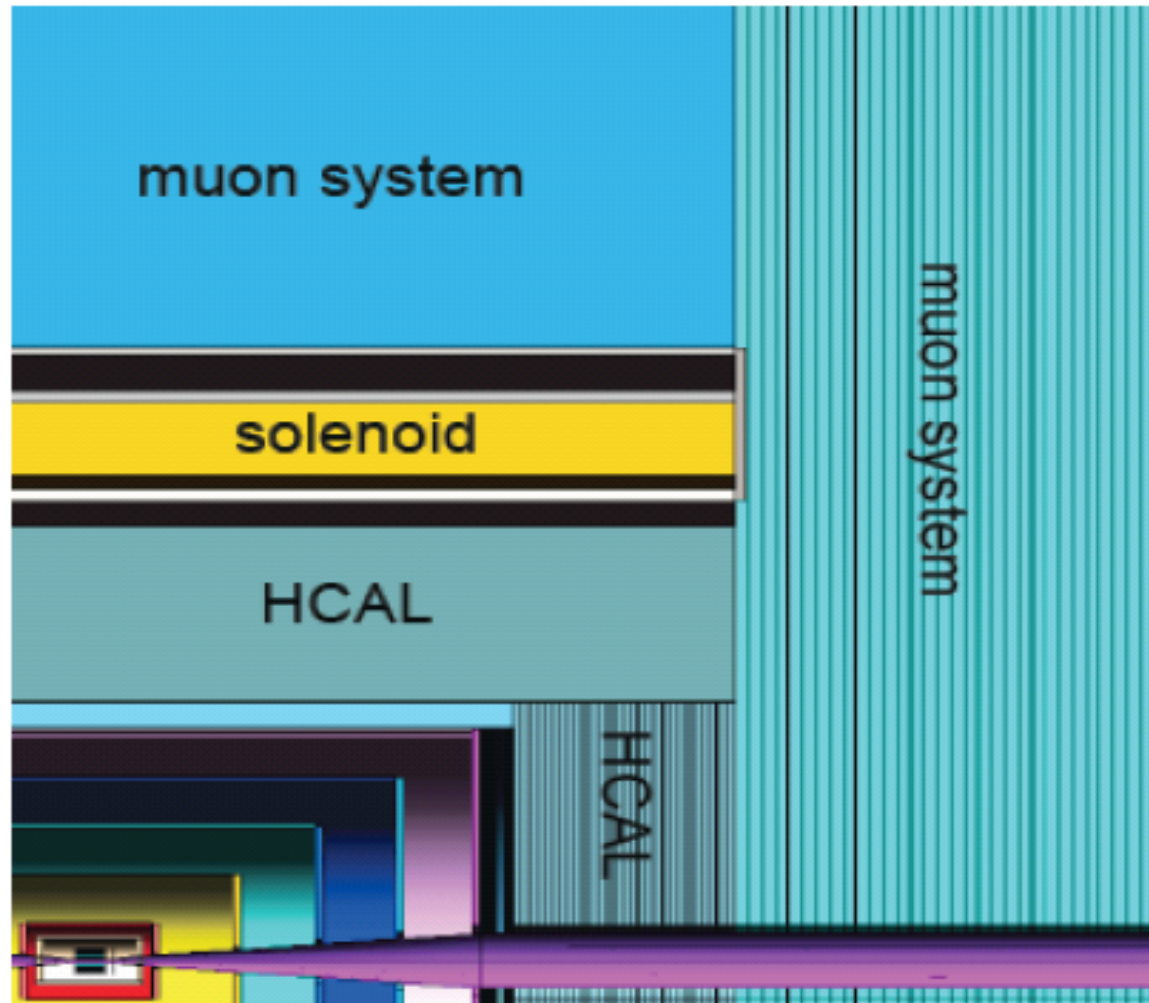


Figure 1 Illustration of a quadrant of SiD.

The Stepper

- The Stepper software simultaneously includes dE/dx and $q \mathbf{v} \times \mathbf{B}$ effects,
- We study the effect on single mono-energetic particles
- The effect on $b\bar{b}$ jets

Stepper-Analytical Form

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

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

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

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

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

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

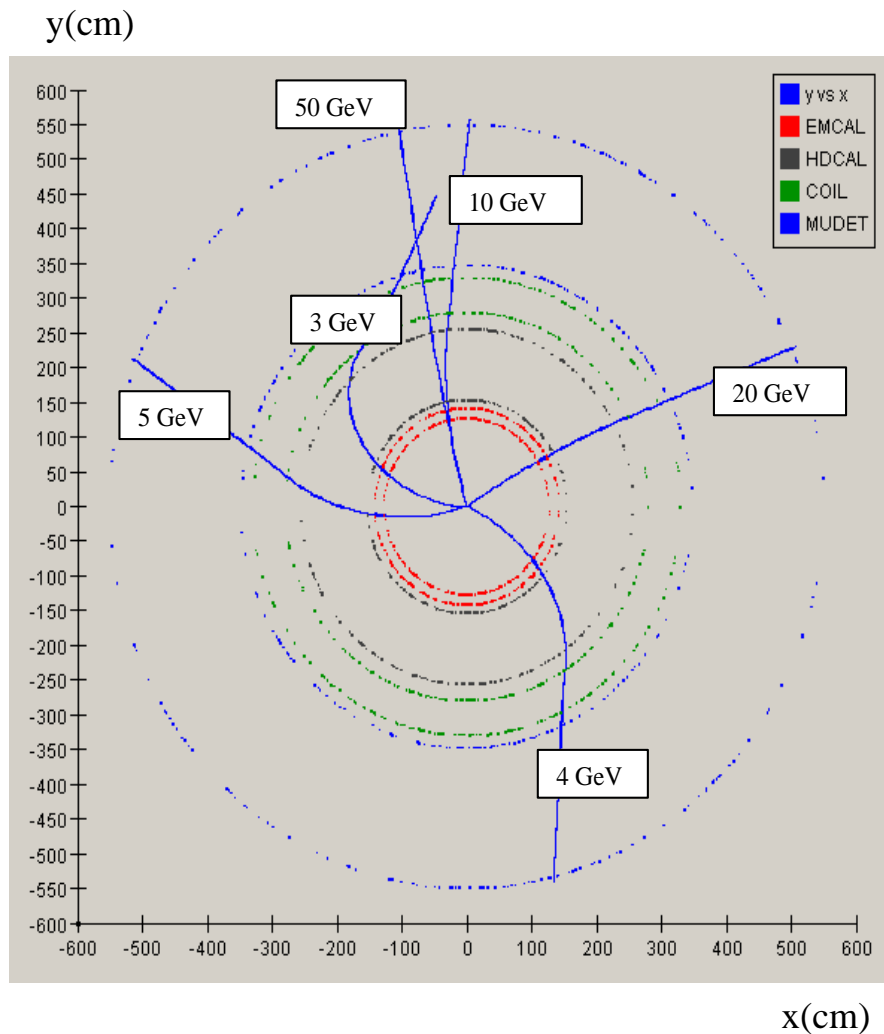
$$x(n+1) = x(n) + \frac{p_x(n+1)}{E(n+1)} * c_{light} * \delta t(n) ;$$

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

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

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.

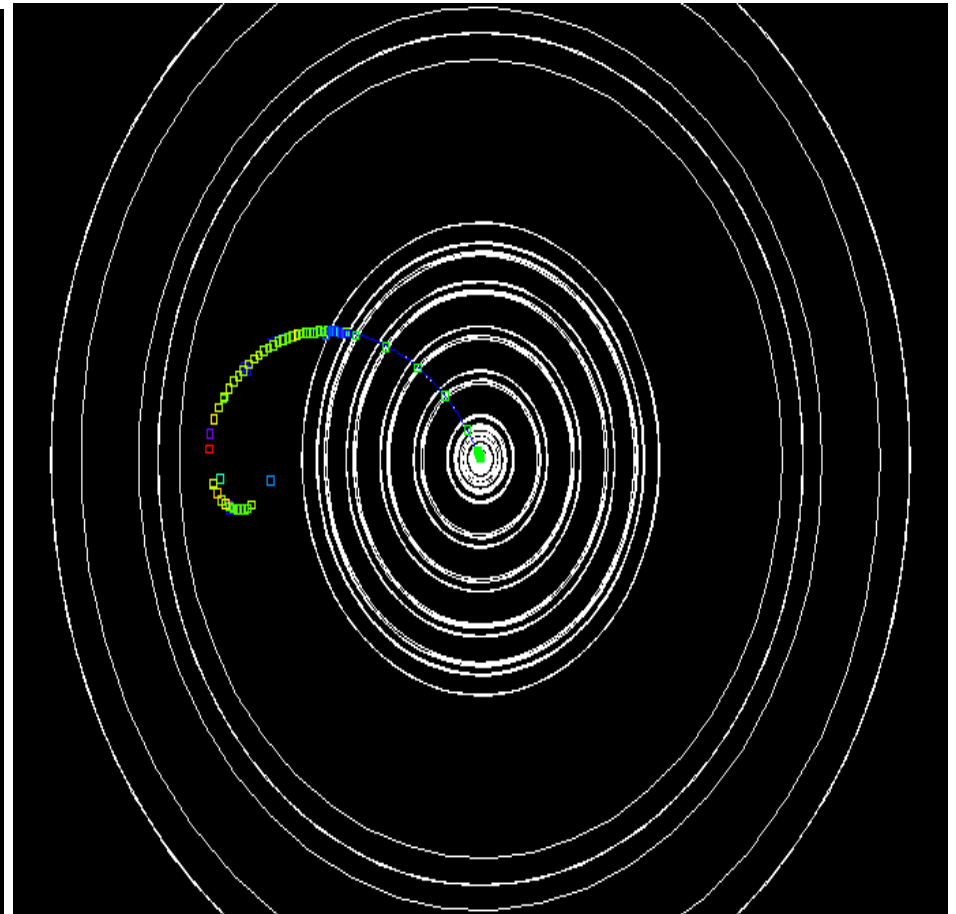
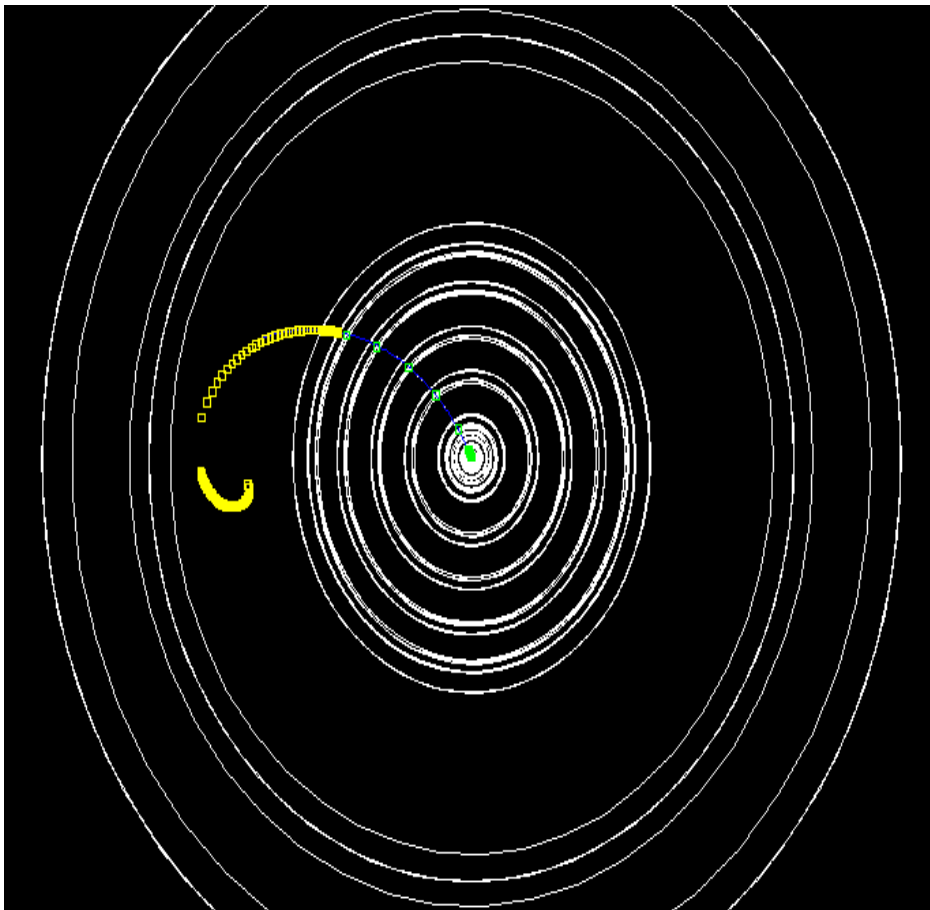
Single Muons-Reconstructed by the Stepper B=5 Tesla Magnetic Field



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

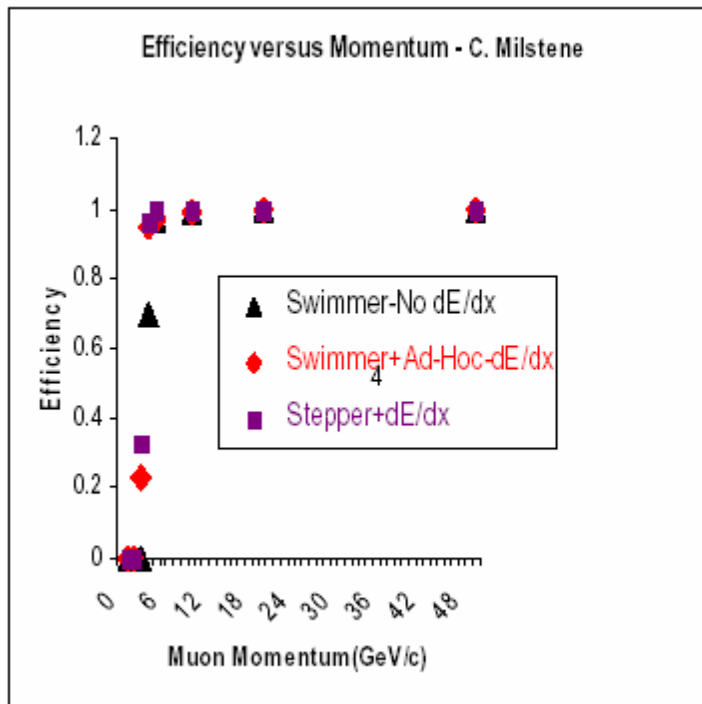
2GeV Muon Curling Back in HCal Reconstructed And Simulated -Details



Reconstructed-Yellow
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Simulated- Green and blue
8

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 developed.

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

Runge-Kutta Correction

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

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

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

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

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

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

$$\Delta p_z B = 0.$$

Is the Field dependant change
In Momentum

$$\delta = 1 + 0.25\alpha^2 B^2 , \eta = 0.5\alpha^2 B^2$$

The Jets Data

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

10000 $b\bar{b}$ jets events generated with Geant4

- $P > 3\text{GeV}$ required in order for the Muon to reach the Muon Detector
- A polar angle cut define the barrel.
[0.95-2.2]rd

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

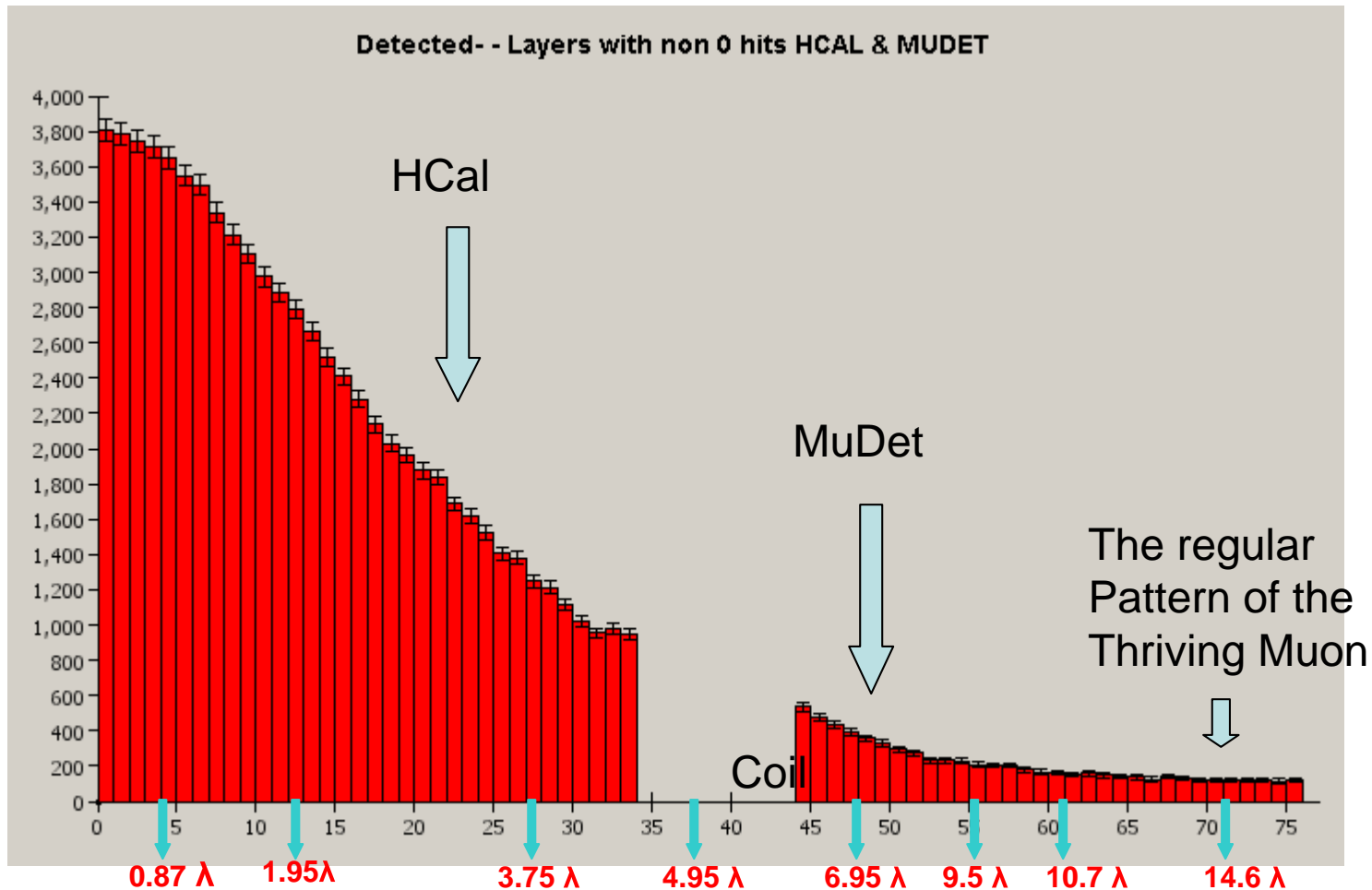
For each Charged track with a good fit in the tracker hits are collected in a road in $(\Delta\Phi, \Delta\theta)$ in ECal, HCal and MuDet

-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 One or Two Hits in HCal and Mudet (MIP-like)



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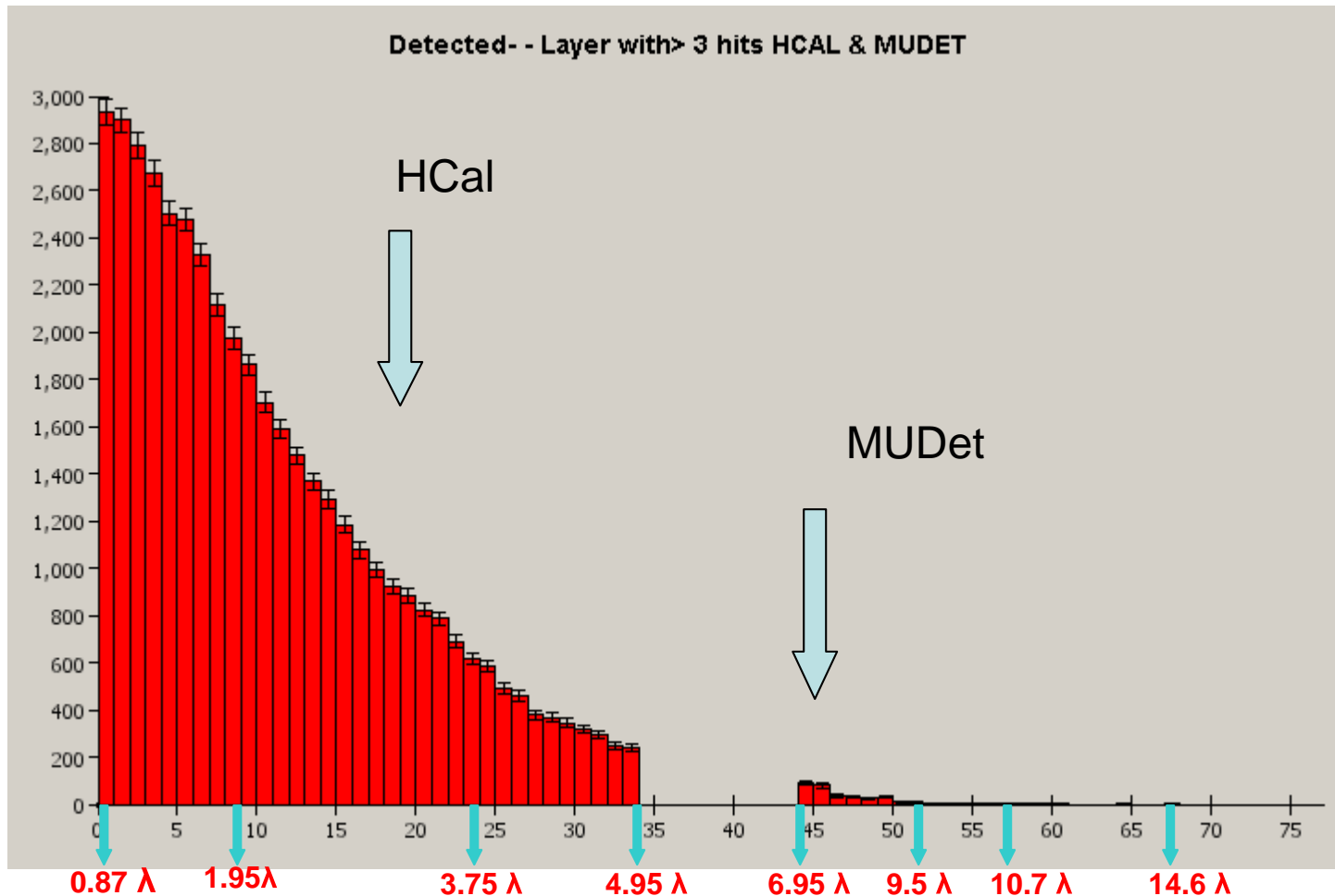
Filter to Hadrons-The Cuts

Hadrons tend to interact → Irregular hit patterns

They don't reach out

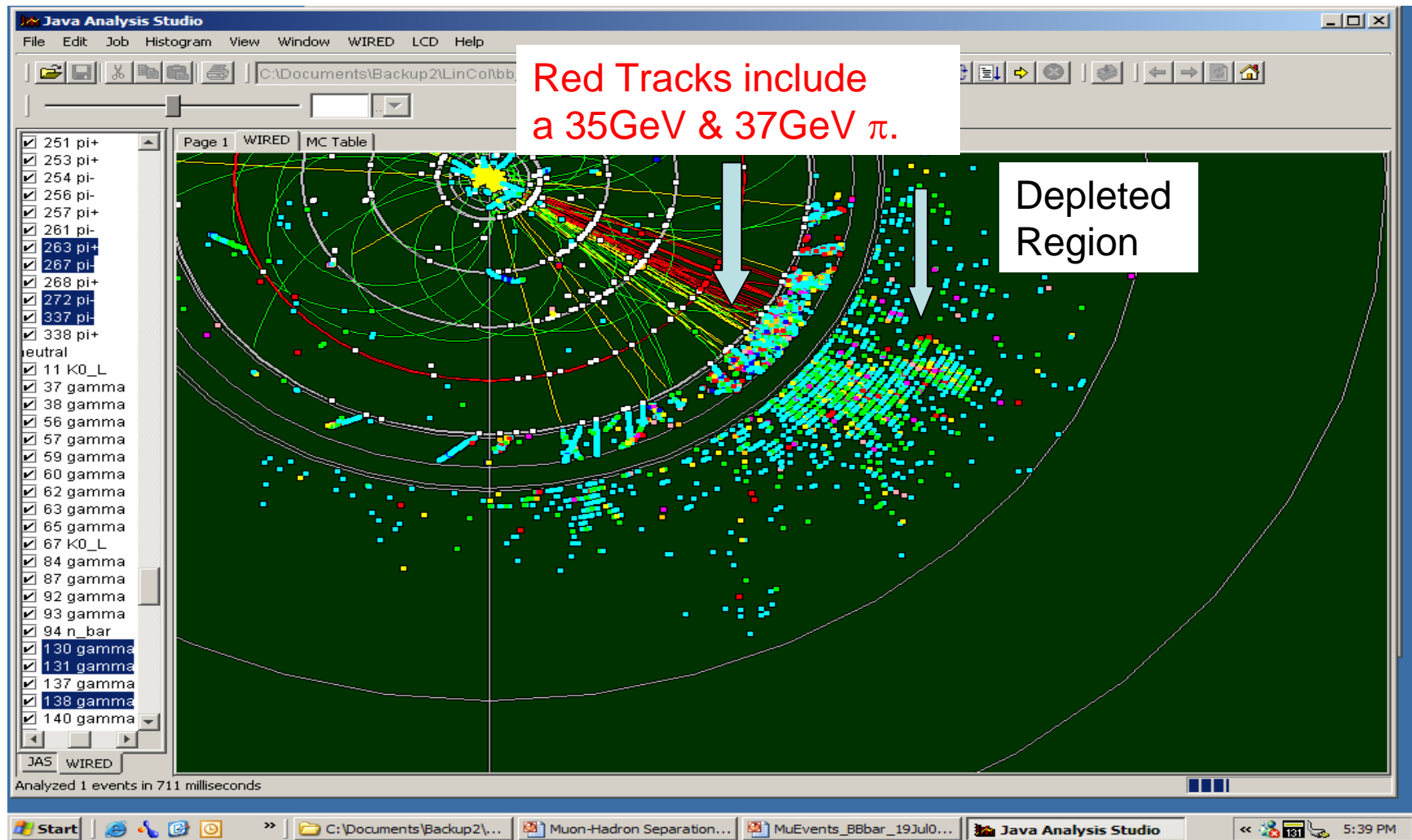
- 1/ we cut on large energy deposit in the path
- 2/ we cut on void on 2-3 consecutive layers
- 3/ we require at least 1 hits on the last 4 layers of HCal and less than 4 hits/layer (still allows neutral from neighbor tracks)

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

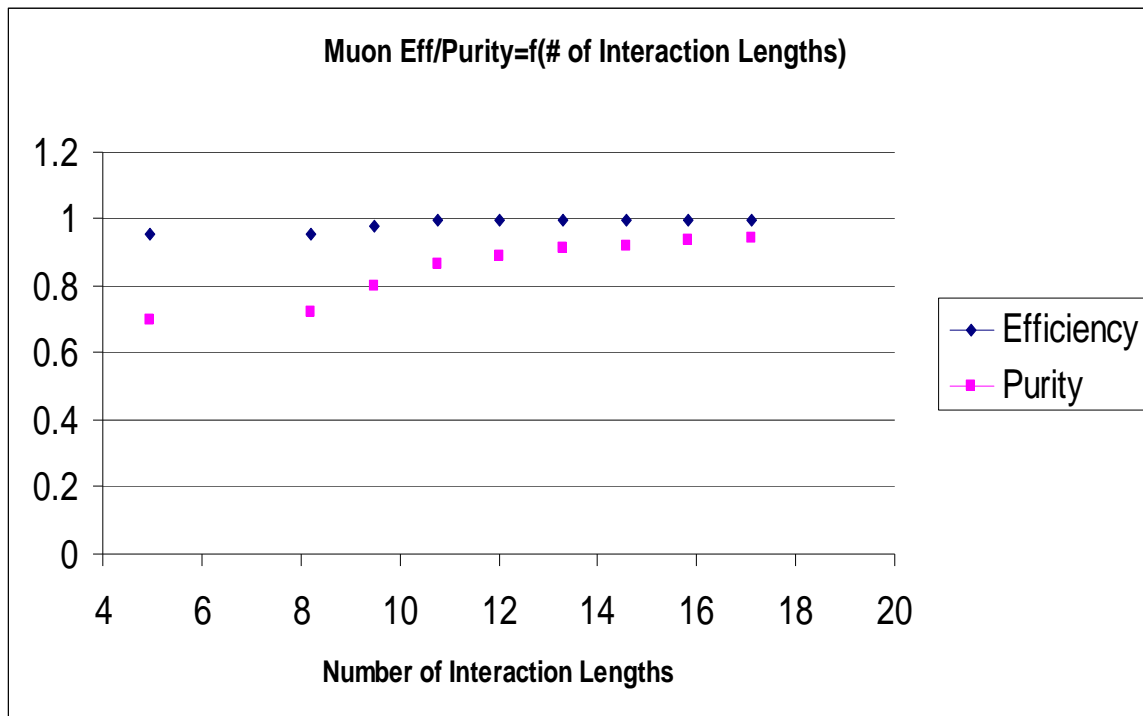


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b Interacting Hadron Content



Purity versus Efficiency



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

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

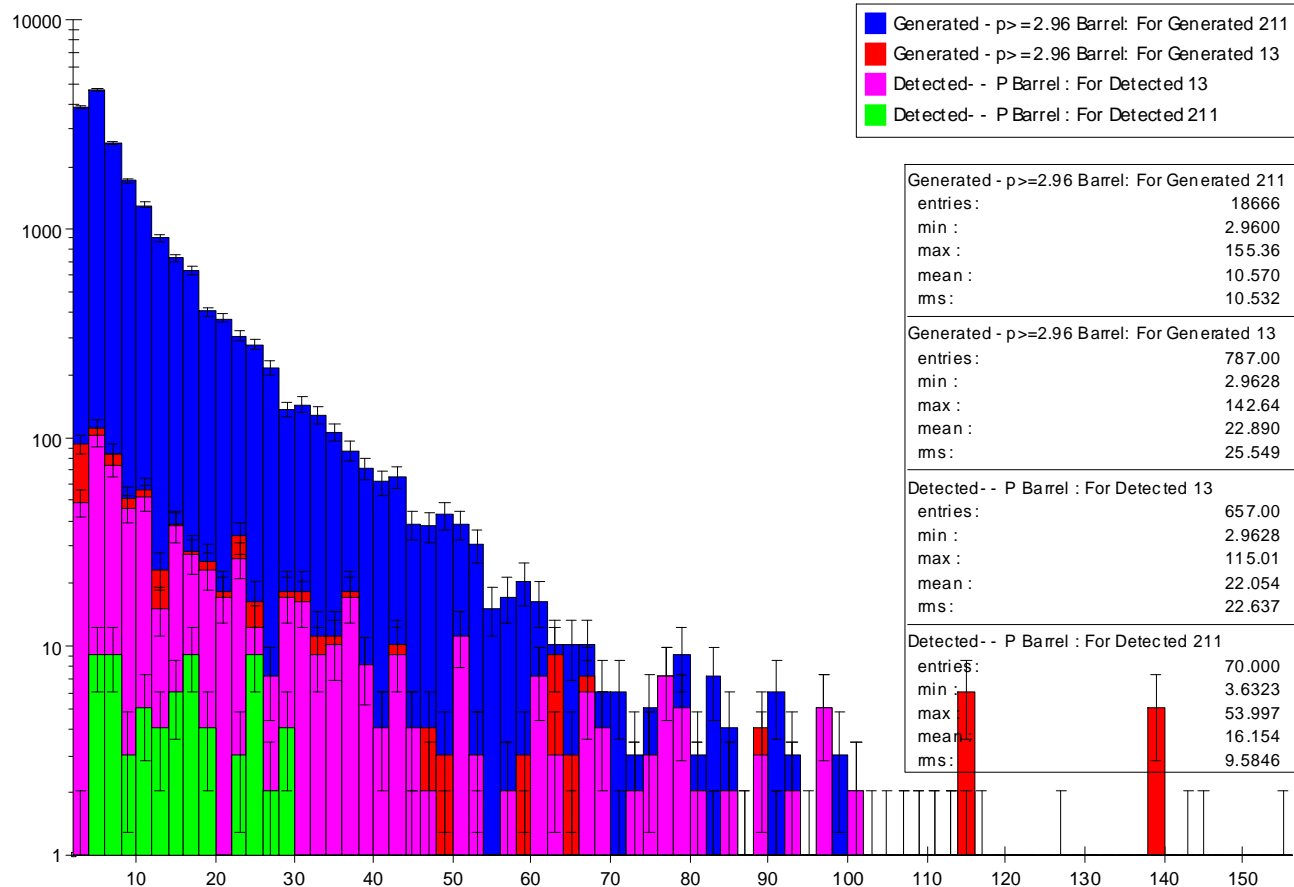
Conditions for 10,000 b-b _{bar}	Muons	Pions	K's	Protons
Tracker Recons & Final Tracks	739	18024	4303	1712
Good Fit Tracker	715	17120	4072	1579
1 or 2 hits in each of the last 5 layers of Hcal. (No 0's)	700	357	204	15
MuDet ≥12hits, ≥12layers	671	77	50	5
Min Mudet Hits=1,2 Max Mudet Hits≤7	670	69	39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

Momentum distributions in b jets

In $b\bar{b}$ jets events the muon is $\sim 1.7\%$ 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

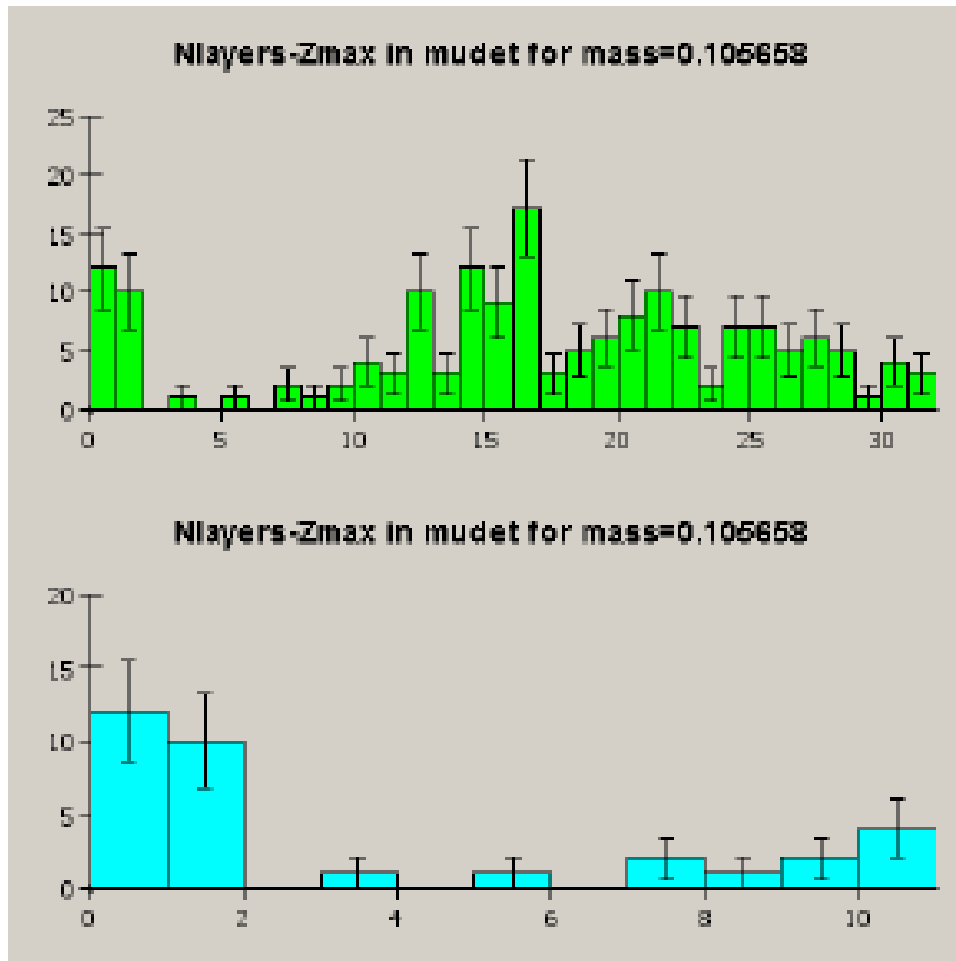
Conclusion

- A study of Muon ID and Purity in the detector shows that in $b\bar{b}$ events 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.

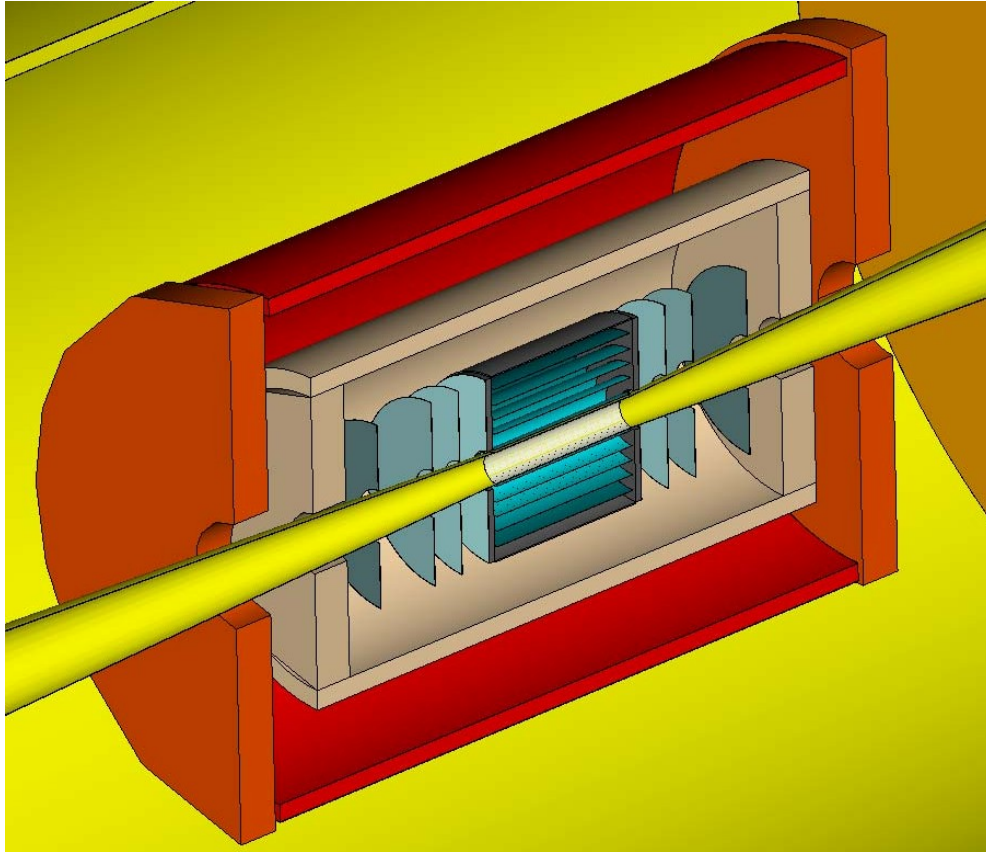
Last Layer With Activity



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



Extra Info

-Ecal $r_{min}=127\text{cm}$, $r_{out}=142\text{cm}$ -> 15cm

$Z=210\text{cm}$; $0.25W+0.05Si+0.2(\text{air}+G10)$ -> $d=0.5\text{cm}$

-Hcal $r_{min}=154\text{cm}$, $r_{out}=250\text{cm}$ -> 102cm

$Z=312\text{cm}$; $2\text{cmFe}+1\text{cmSc}$ -> $d=3\text{cm}$

-Mudet $r_{min}=348\text{cm}$, $r_{out}=540\text{cm}$ -> 192cm

$Z=313\text{cm}$; $5\text{cmFe}+1.5\text{cmSc}$ -> $d=6.5\text{cm}$

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