

The Charged Particles Stepper In Calorimeters & Coil

C. Milstene, April 2, 2004.

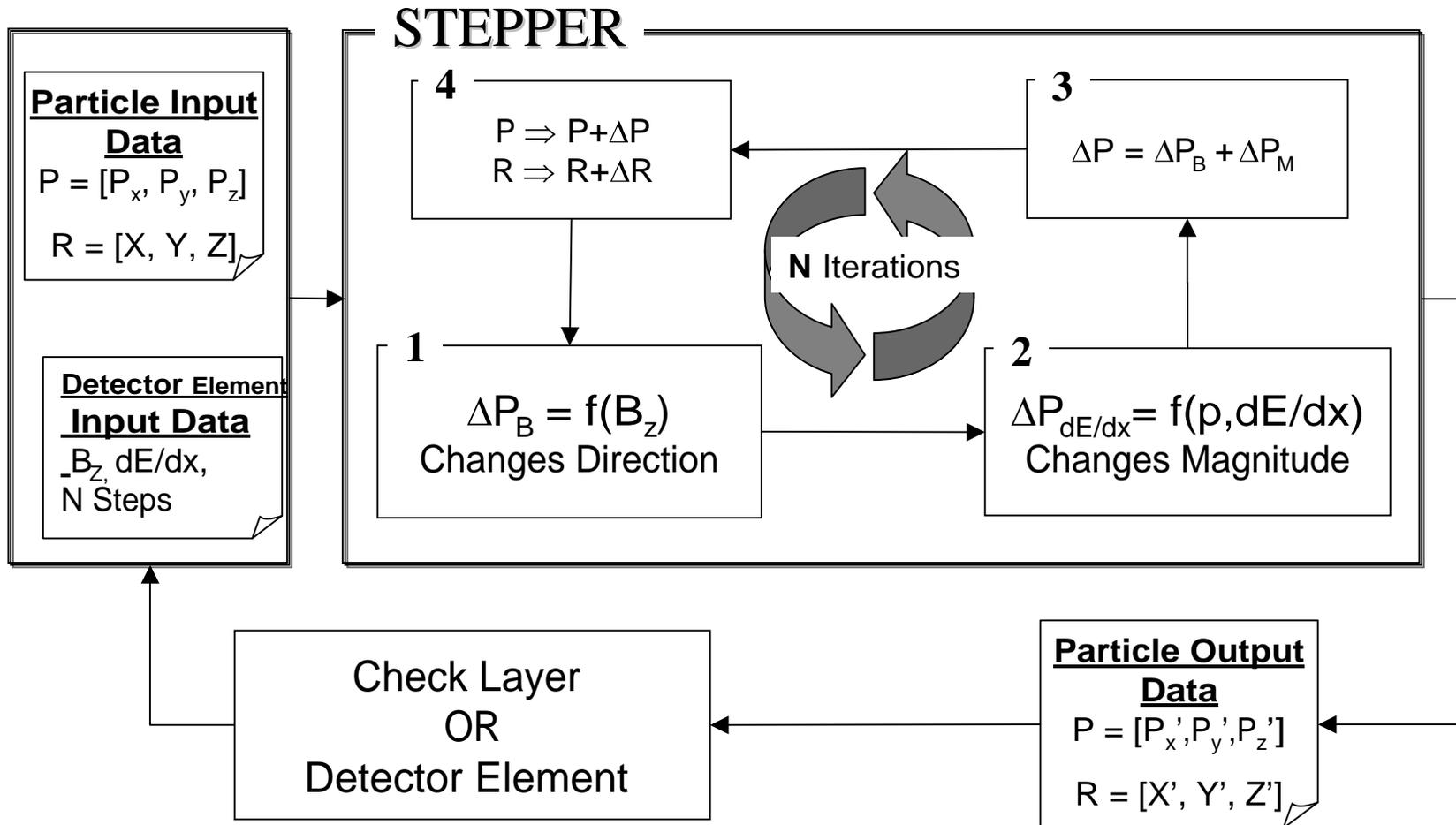
Fermilab/N.I.U

- 1) Introduction: The Stepper code written in December 2003, was tested extensively with the Muon package in January and released to SLAC-CVS - February 24-2004. The test with the Mu Package is presented below.
 - 2) The Algorithm of the Stepper
 - 3) The package
 - 4) Swimmer versus stepper in HCAL and MUDET
 - 5) Distribution(x,y) & The Event Display
 - 6) Muon Detection Efficiency
-
- 5) Conclusion

1) Introduction

- An Helical path is assumed for the passage of particles through matter and an helical swimmer is used for the extrapolation.
- However when taking properly into account the properties of energy loss through the material, as is done at generation by GEANT, there is a discrepancy with the generated events.
- The effect being more important for the dense material of HCAL, the COIL or MUDET, whereas the Swimmer gives perfect results in the TRACKER.
- A Stepper that account for energy losses in the material is discussed using Muons at different energies, e.g. 3,4,5,10,20,50 GeV/c

Stepper Processing Flow



2) Algorithm-The General Formula

- One starts with a particle at the interaction point (IP), at a given Position $\sim 0,0,0$, Momentum (p_x, p_y, p_z) and Mass.
- The Motion through matter in a magnetic field is given between step n and $(n+1)$ by:

$$p_x(n+1) = p_x(n) + 0.3 * q * \frac{p_y(n)}{E(n)} * c_{light} * B_z * \Delta T(n) + \gamma_x(n)$$

$$p_y(n+1) = p_y(n) + 0.3 * q * \frac{p_x(n)}{E(n)} * c_{light} * B_z * \Delta T(n) + \gamma_y(n)$$

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

$$\gamma_i(n) = \Delta P_i^{Matter} = \left(\frac{dE}{di} \right) * \frac{E(n)}{P(n)} * \frac{p_i(n)}{P(n)} * \Delta s ; i = x, y, z$$

The 2nd term in p_x and p_y is the usual $q\mathbf{v} \times \mathbf{B}$ term due to the field B_z and the 3rd term comes from energy loss in material.

Here p_x, p_y, p_z are in GeV/c, $E(n)$ in GeV, $c_{light} = 3E08\text{m/s}$, Δt in seconds.

The Particle Position

The new position $x(n+1), y(n+1), z(n+1)$, in cm, is recalculated after each step as a function of the new values p_x, p_y, p_z, E and the old Position $x(n), y(n), z(n)$.

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

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

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

$\Delta T(n)$ is the time of flight in seconds of the particle at step n .

3)The Package

The Muon package generated at NIU by R. Markeloff, and extended to include EMCAL Barrel.

Same extrapolation of good fitted tracks from the tracker through EMCAL, HDCAL, the coil, MUDET collecting hits within a Defined angle, but the stepper with dE/dx loss included has replaced the swimmer there and in ALL the material in between

Remark: In the tracker both the stepper and the swimmer give the the same result.

4)Swimmer Versus Stepper In HCAL & MUDET

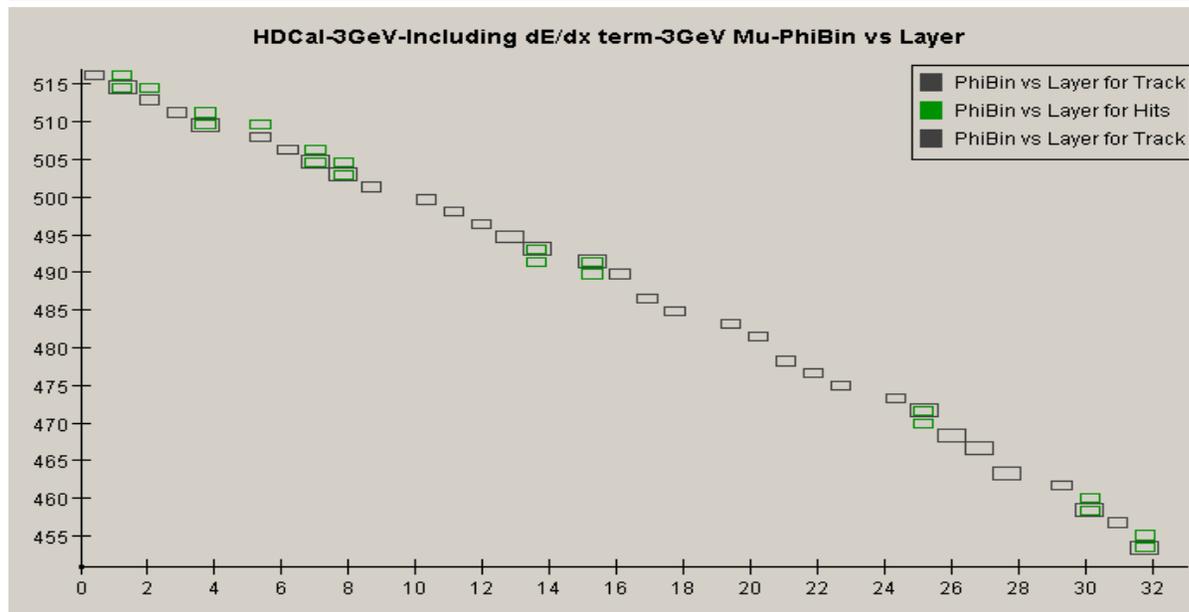
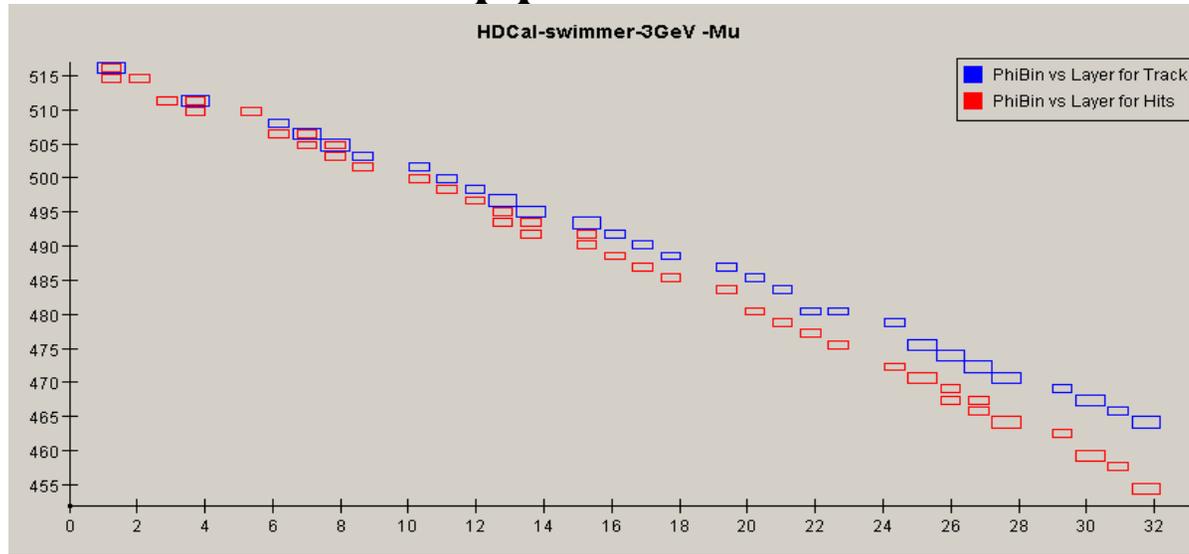
For particles at/above 20 GeV/c, the swimmer is representing properly the hits, but, at lower energy the effect of the energy loss on the trajectory is important.

We will concentrate in the low energy range.

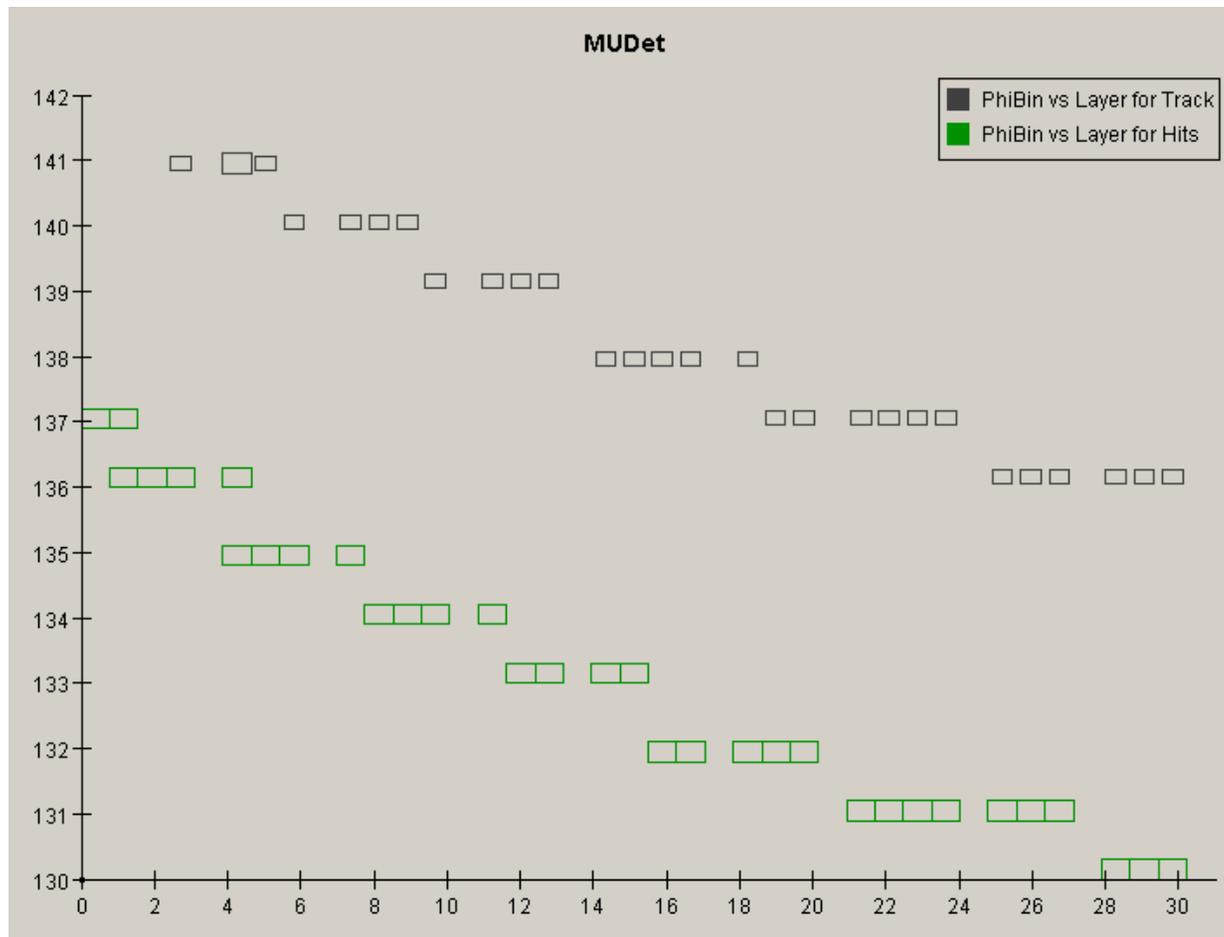
Next slide represents the overlay of the hits and the track extrapolation with the swimmer and the stepper for the same 3 GeV/c muon. In x is given the number of layers and in y the angle bin. The results are getting worse the farther we are from the Interaction Point as shown for MUDET in next to the following slide.

Following the 2 next slides, there is a good agreement track/hits with the stepper in the 2 calorimeters EM,HAD as well as in MUDET

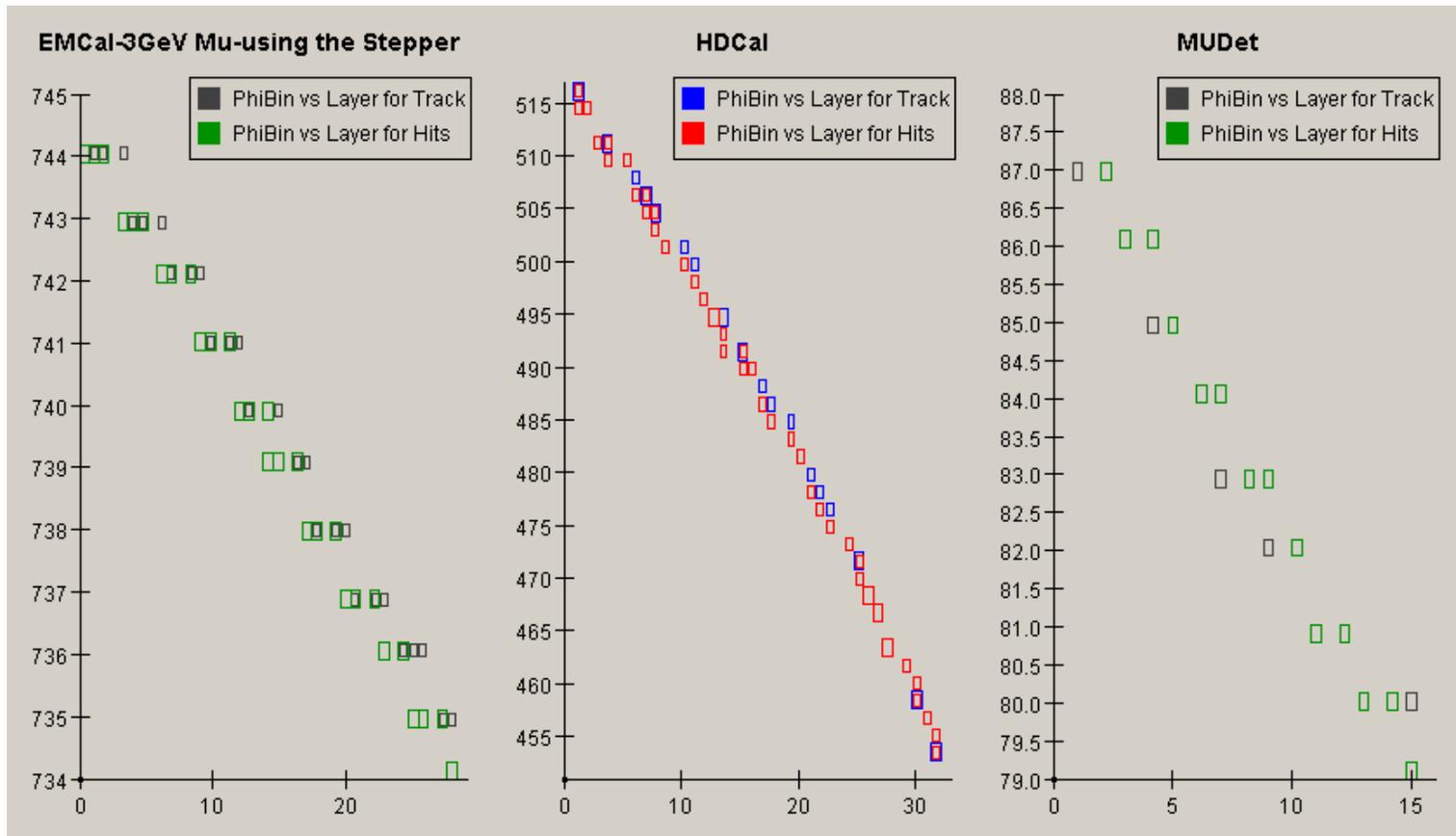
Swimmer Versus Stepper in HCAL-3 GeV Muons



Swimmer in MUDET – 3 GeV/c Muons

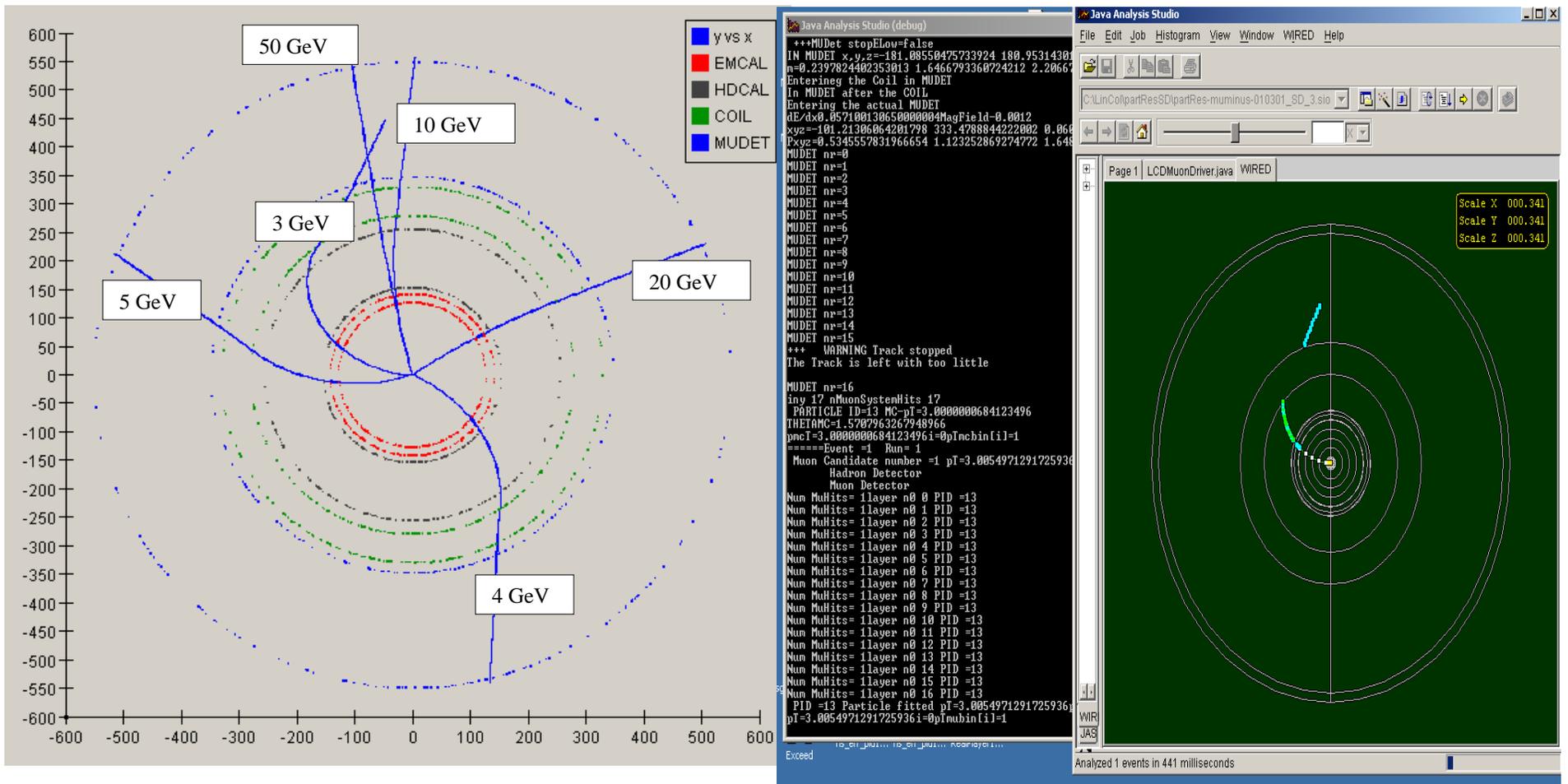


The Stepper in EMCAL-HCAL and MUDET Angle Bin versus Layer-3GeV Muons



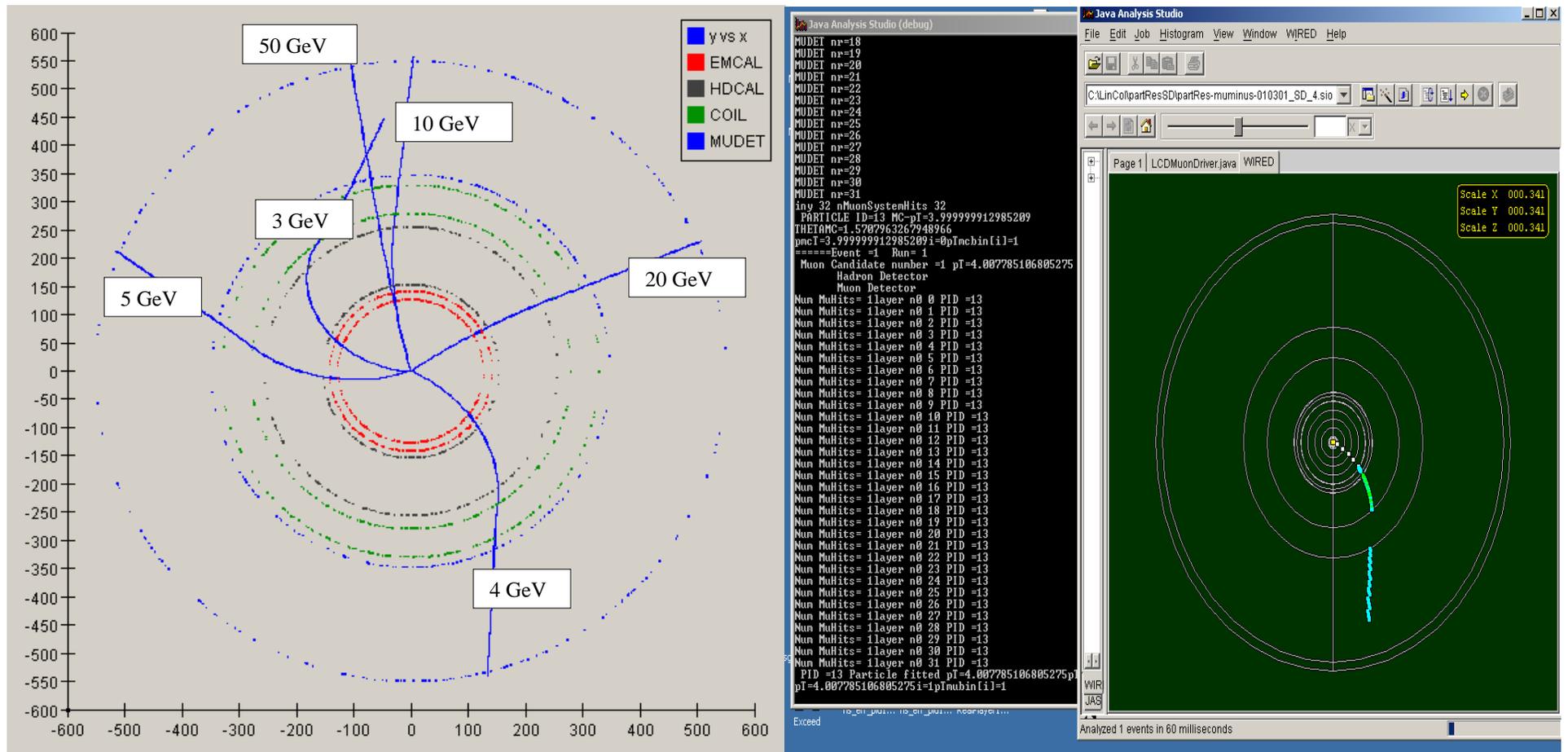
5) Distribution (x,y) & The Event Display

3 GeV/c



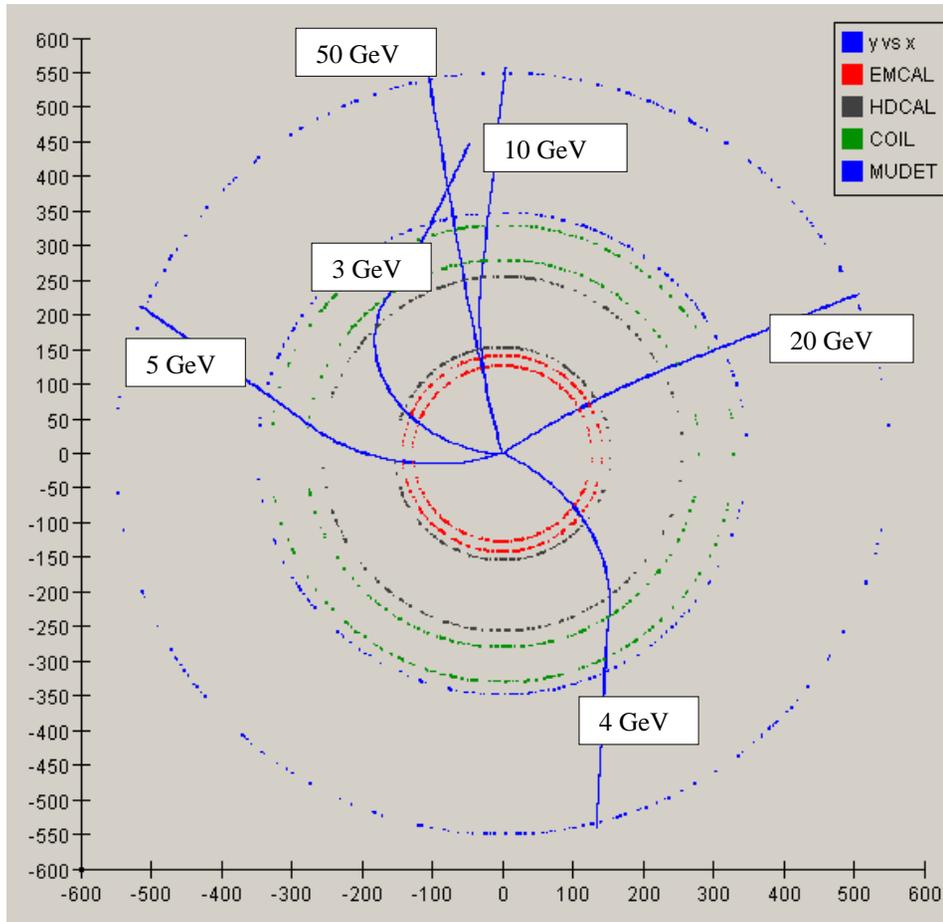
Distribution(x,y)&The Event Display

4 GeV/c

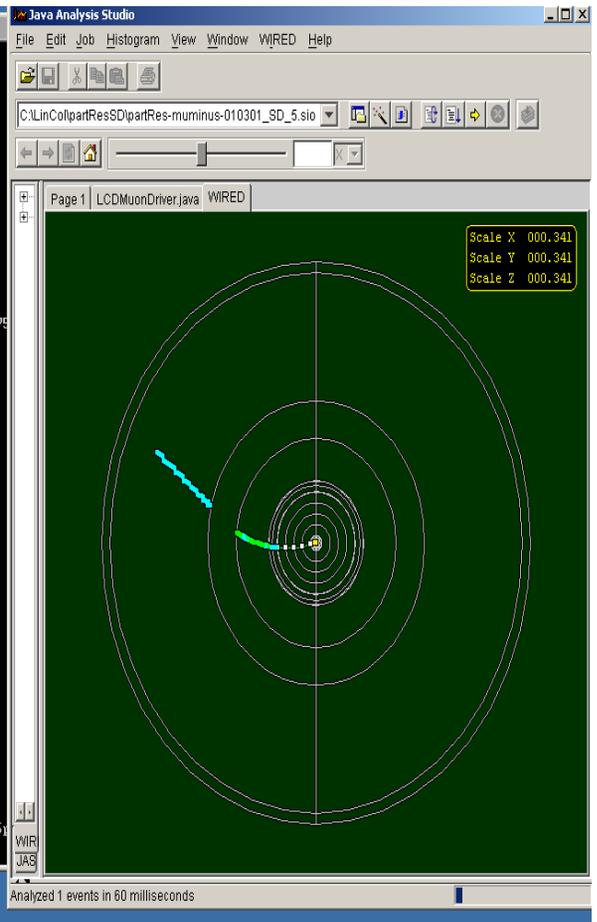


Distribution(x,y) & The Event Display

5GeV/c

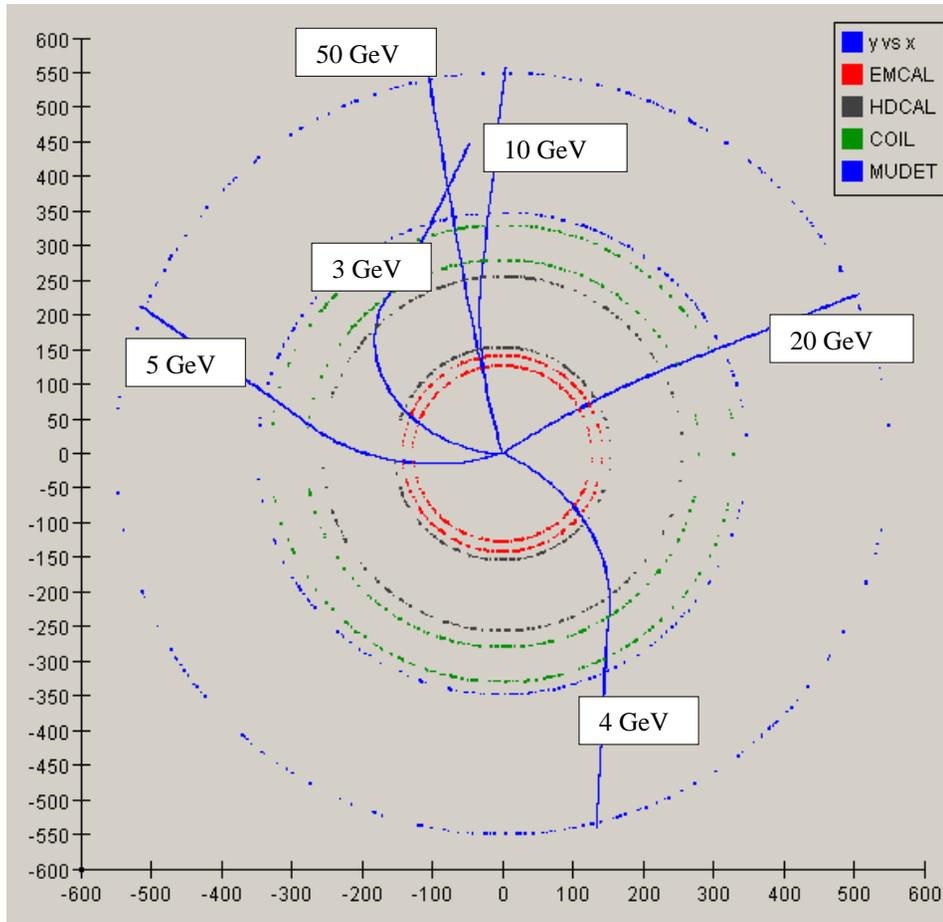


```
Java Analysis Studio (debug)
MUDET nr=18
MUDET nr=19
MUDET nr=20
MUDET nr=21
MUDET nr=22
MUDET nr=23
MUDET nr=24
MUDET nr=25
MUDET nr=26
MUDET nr=27
MUDET nr=28
MUDET nr=29
MUDET nr=30
MUDET nr=31
iny 34 nMuonSystemHits 34
PARTICLE ID=13 MC-pt=4.999999829602754
THEIATMG=1.5707963267948966
pmc1=4.999999829602754i=1pImubin(i1)=1
====Event #1 Run #1
Muon Candidate number =1 pT=5.0102718994061775
Hadron Detector
Muon Detector
Num MuHits=11layer n0 PID =13
Num MuHits=11layer n1 PID =13
Num MuHits=11layer n2 PID =13
Num MuHits=11layer n3 PID =13
Num MuHits=11layer n4 PID =13
Num MuHits=11layer n5 PID =13
Num MuHits=11layer n6 PID =13
Num MuHits=11layer n7 PID =13
Num MuHits=11layer n8 PID =13
Num MuHits=11layer n9 PID =13
Num MuHits=11layer n10 PID =13
Num MuHits=11layer n11 PID =13
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Num MuHits=11layer n28 PID =13
Num MuHits=11layer n29 PID =13
Num MuHits=11layer n30 PID =13
Num MuHits=11layer n31 PID =13
PID =13 Particle fitted pT=5.0102718994061775
pT=5.0102718994061775i=2pImubin(i1)=1
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Distribution(x,y) & The Event Display

10 GeV



Java Analysis Studio (debug)

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MUDET nr=21
MUDET nr=22
MUDET nr=23
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MUDET nr=26
MUDET nr=27
MUDET nr=28
MUDET nr=29
MUDET nr=30
MUDET nr=31
iny 32 nMuonSystemHits 32
PARTICLE ID=13 MC-pT=9.999999846947684
THETAMC=1.5707963267948966
pncI=9.999999846947684i=6pinchin[i]=1
=====Event #1 Run=1
Muon Candidate number =1 pT=10.022237946573181
Hadron Detector
Muon Detector
Num MuHits= 11ayer n0 PID =13
Num MuHits= 11ayer n1 PID =13
Num MuHits= 11ayer n2 PID =13
Num MuHits= 11ayer n3 PID =13
Num MuHits= 11ayer n4 PID =13
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Num MuHits= 11ayer n27 PID =13
Num MuHits= 11ayer n28 PID =13
Num MuHits= 11ayer n29 PID =13
Num MuHits= 11ayer n30 PID =13
PID =13 Particle fitted pT=10.022237946573181
pT=10.022237946573181i=7pinchin[i]=1
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Java Analysis Studio

File Edit Job Histogram View Window WIRED Help

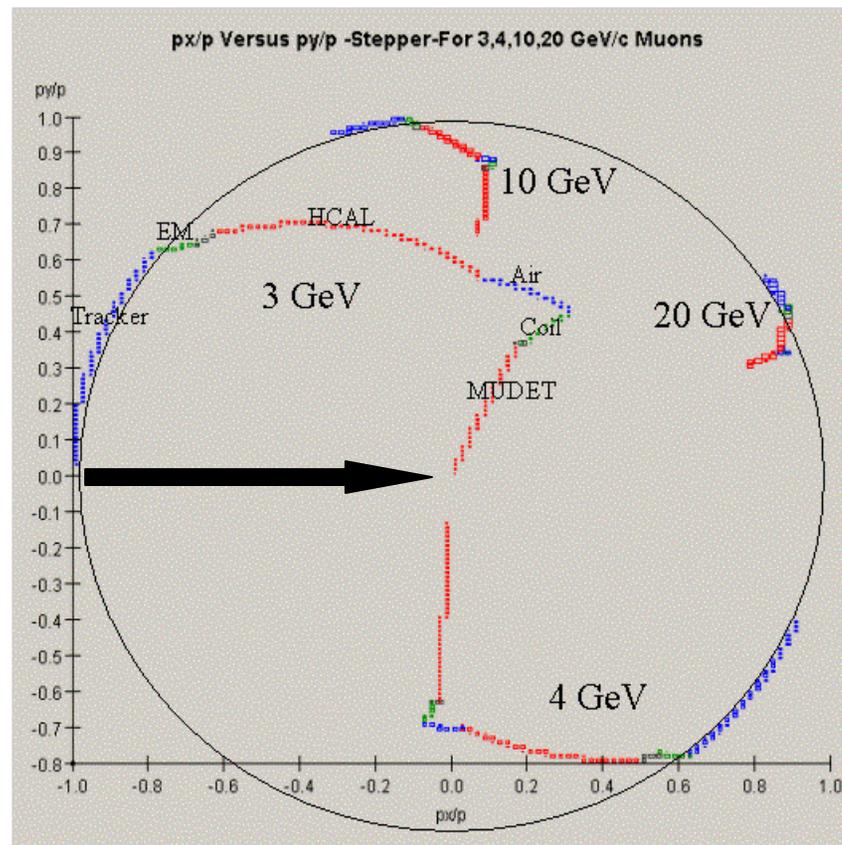
C:\LinCol\partResSD\partRes-muminus-010301_SD_10_sio

Page 1 | LCDMuonDriver.java WIRED

Scale X 000.341
Scale Y 000.341
Scale Z 000.341

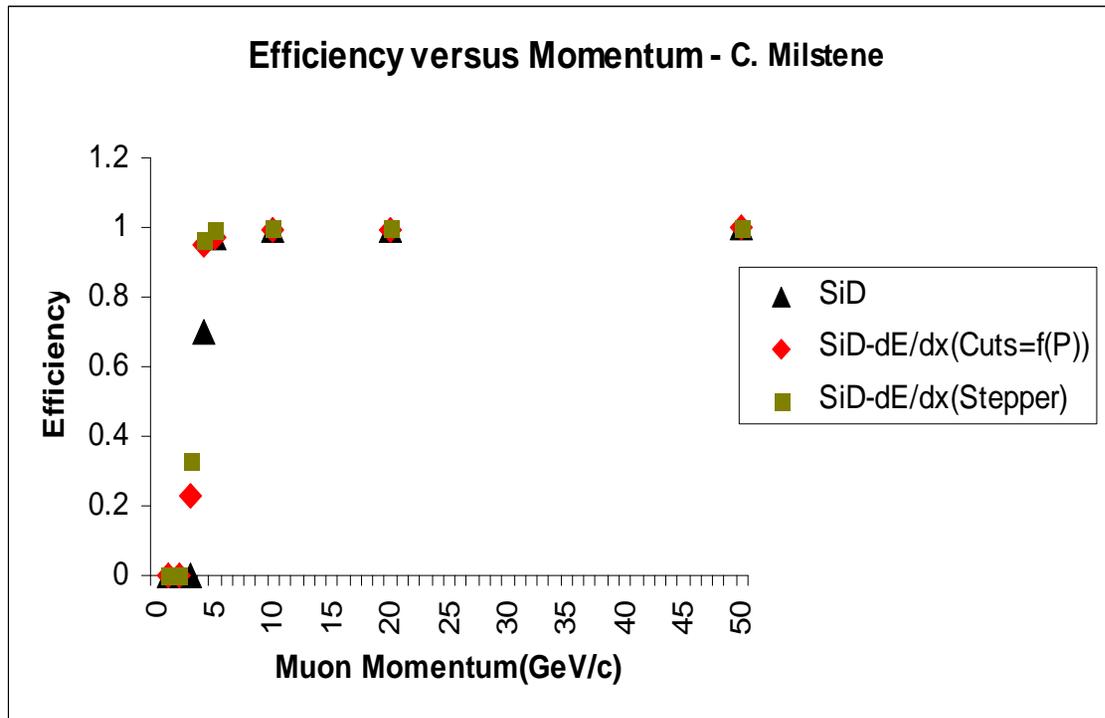
Analyzed 1 events in 80 milliseconds

The Momentum Behavior In The Detector Components



Explained in
more details
in the next
transparency

6)The Muon Detection Efficiency



For 3 GeV/c Muons: The Efficiency went from: ~ 0.6% -> 23% ->33% Stepper
 For 4 GeV/c Muons: The Efficiency went from: ~70% -> 95.2% ->96.2% Stepper
 For 5 GeV/c Muons: The Efficiency went from: ~97% -> ~97% ->99.6% Stepper
 For 10GeV/c Muons: The Efficiency went from: 98.96% -> 98.96%->99.98% Stepper
 At higher energy the improvement is more subtle.

7) Conclusions

The Stepper, by inclusion of the dE/dx gives a better fit to the Muons generated with Geant, especially in the low energy range and The tracks stick to the one shown by the Event Display(coded independently) both in shape and size.

The Muon Detection Efficiency improves at low energy, reaching 96% already at 4 GeV/c.

Without the involvement of Gene Fisk this work would not have been possible, thanks are due also to Adam Para for important comments and suggestions.

Backup

The Particle Momentum

One can write for the term material dependant (details next)

$$\gamma_x(n) = \Delta P_x = \left(\frac{dE}{dx} \right) * \frac{E(n)}{P(n)} * \frac{p_x(n)}{P(n)} * \Delta s$$

$$\gamma_y(n) = \Delta P_y = \left(\frac{dE}{dx} \right) * \frac{E(n)}{P(n)} * \frac{p_y(n)}{P(n)} * \Delta s$$

$$\gamma_z(n) = \Delta P_z = \left(\frac{dE}{dx} \right) * \frac{E(n)}{P(n)} * \frac{p_z(n)}{P(n)} * \Delta s$$

The Particle Momentum (2)

Moving particles lose energy in the material by dE/dx ,

Approximation: $dE/dx \sim \text{Constant} = Ct$ for a path length Δs in step n

$$\Delta E = \left(\frac{dE}{dx}\right) * \Delta s \quad \&\& \quad \Delta E = \frac{dE}{dP} * \Delta P = \frac{P(n)}{E(n)} * \Delta P \rightarrow \Delta P = \frac{E(n)}{P(n)} * Ct * \Delta s$$

At start of the step, momentum directions : $p_x/P = a$, $p_y/P = b$, $p_z/P = c$.

Due to B_z change in directions to $p_x'/P' = a'$, $p_y'/P' = b'$, $p_z'/P' = c'$

Angles at the center of the step: $(a+a')/2$, $(b+b')/2$

One can use the center of the step to express Δp_x , and Δp_y as follow.

$$\Delta p_x = \Delta P * \frac{a+a'}{2} \quad ; \quad \Delta p_y = \Delta P * \frac{b+b'}{2}$$

And if step is small enough one can approximate

$$a' \sim a = p_x(n)/P(n), \quad b' \sim b = p_y(n)/P(n)$$

The Time Of Flight

Below one expresses the components of the velocity as a function Of p,E and the light velocity. If d is the step size one gets for the Radii between steps n and n+1 the following relations

$$V_i(n) = \frac{p_i(n)}{E(n)} * c_{light} ; i = x, y, z$$

$$\begin{aligned} r(n+1)^2 - r(n)^2 &= [x(n+1)^2 + y(n+1)^2] - [x(n)^2 + y(n)^2] \\ &= [\{x(n) + v_x(n) * \Delta T(n)\}^2 + \{y(n) + v_y(n) * \Delta T(n)\}^2] - [x(n)^2 + y(n)^2] \\ r(n+1)^2 &= r(n)^2 + 2 * d * r(n) + d^2 \end{aligned}$$

$\Delta T(n)$ is the solution of an equation of the second order.

The Distribution (p_x/p_{Start} , p_y/p_{Start})

WARNING: The following distributions are very different in behavior than the x, y distributions. They are in fact the COMPLEMENTARY .

One starts with the maximum momentum, e.g. 3 GeV/c, then in the tracker p_x and p_y change due to the magnetic field B_z in such a way that $\sqrt{p_x^2 + p_y^2}$ stays constant, the material in the Tracker being negligible. The particle Momentum is staying at its maximum. One sees that p_x/p and p_y/p stay on the circle of radius 1.

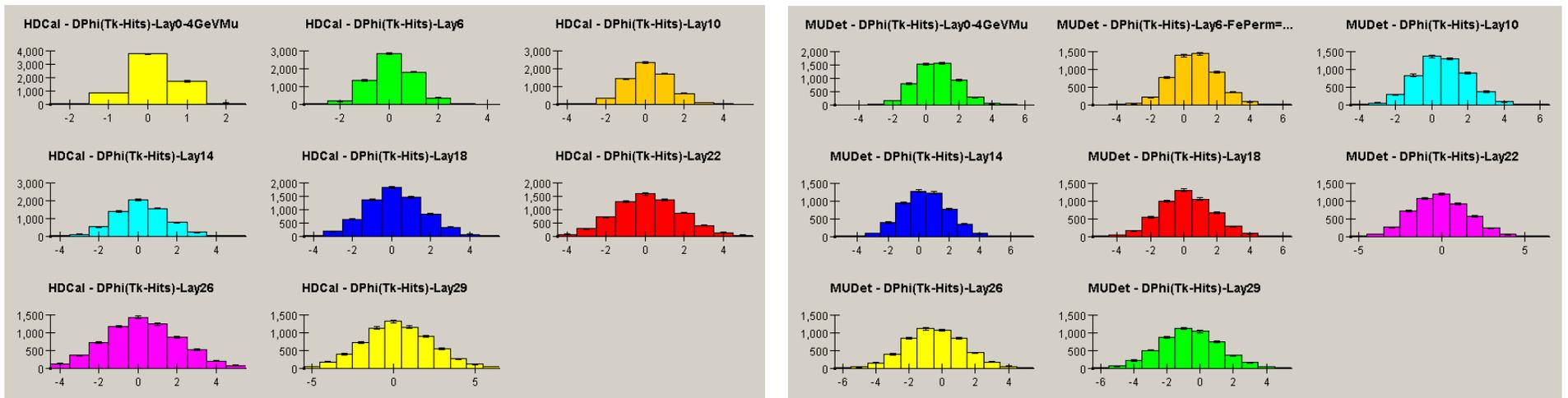
Then, in the Calorimeters, the particle loses energy, and therefore momentum in the material encountered.

It loses more energy in HCAL than in ECAL (the $S((dE/dx) \cdot x)$ being bigger). It goes on losing energy in the COIL and in MUDET , but there, the magnetic field is inverted and smaller in magnitude. Therefore the momentum starts high and ends up at or close to zero at 3 GeV/c, and the particles often stop there in MUDET, in about 20 layers or less.

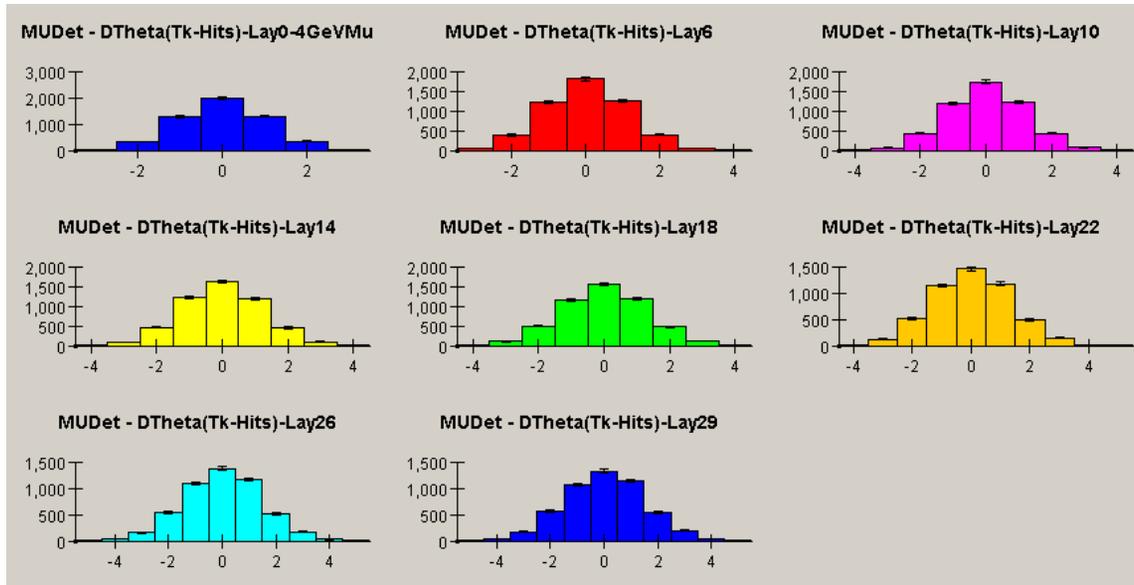
The position x, y on the other hand, was starting at radius $=\sqrt{x^2 + y^2} \sim 0$ and increases to end up at a radius ~ 362 cm for a 3 GeV Muon.

The 4 GeV/c muon is left with $\sim 10\%$ of its energy, and the higher the Muon Momentum the smaller the change in radius (the smaller the proportion of momentum loss), as can be seen in the curves above for 10 GeV/c and 20 GeV/c Muons.

The ΔF (track-hit) – 4GeV Muons HCAL(left) MUDET(right)



The ΔT (track-hit)- 4 GeV Muons in MUDET



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