The Charged Particles Stepper In Calorimeters & Coil

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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

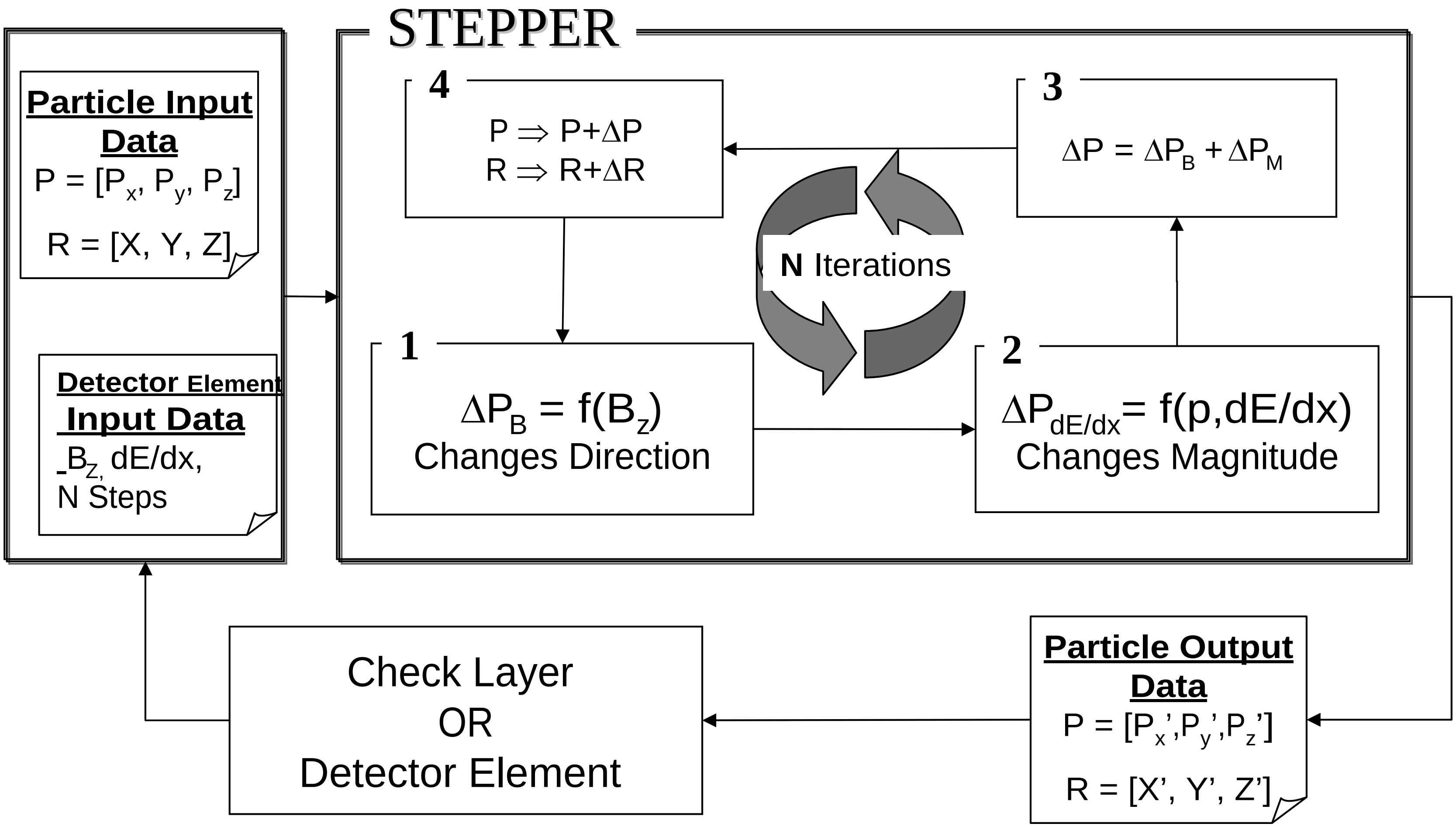
•An Helical path is assumed for the passage of particles through matter and an helical swimmer is used for the track extrapolation through detector elements.

•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 perfects 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 ~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:

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

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

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

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

The 2nd term in p_x and p_y is the usual qv×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, clight =3E08m/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 px,py,pz,E and the old Position x(n),y(n),z(n).

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

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

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

ΔT(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.

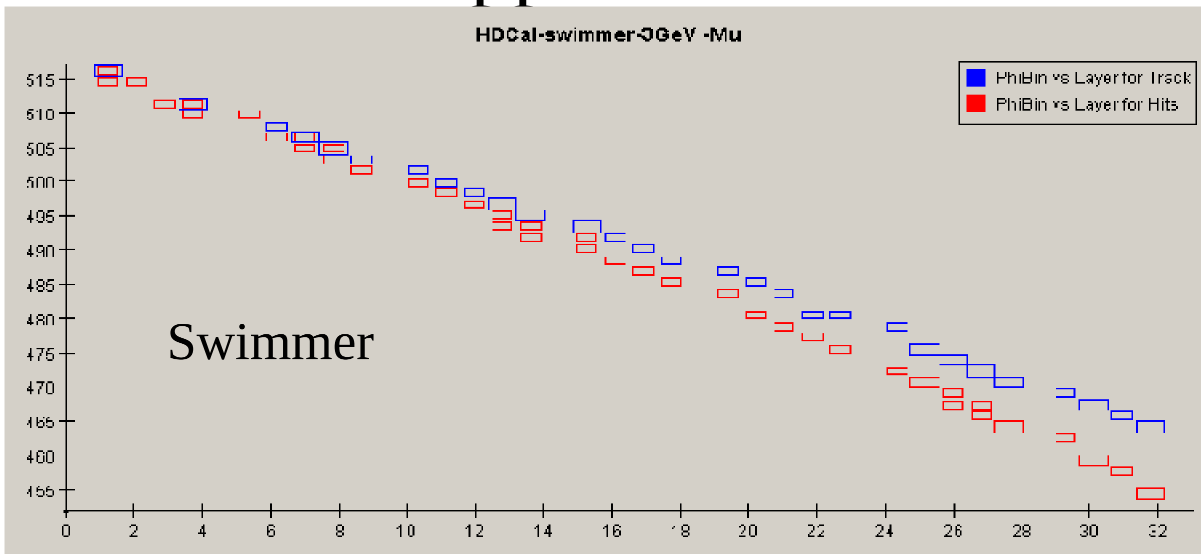
4)Swimmer Versus Stepper In HCAL & MUDET

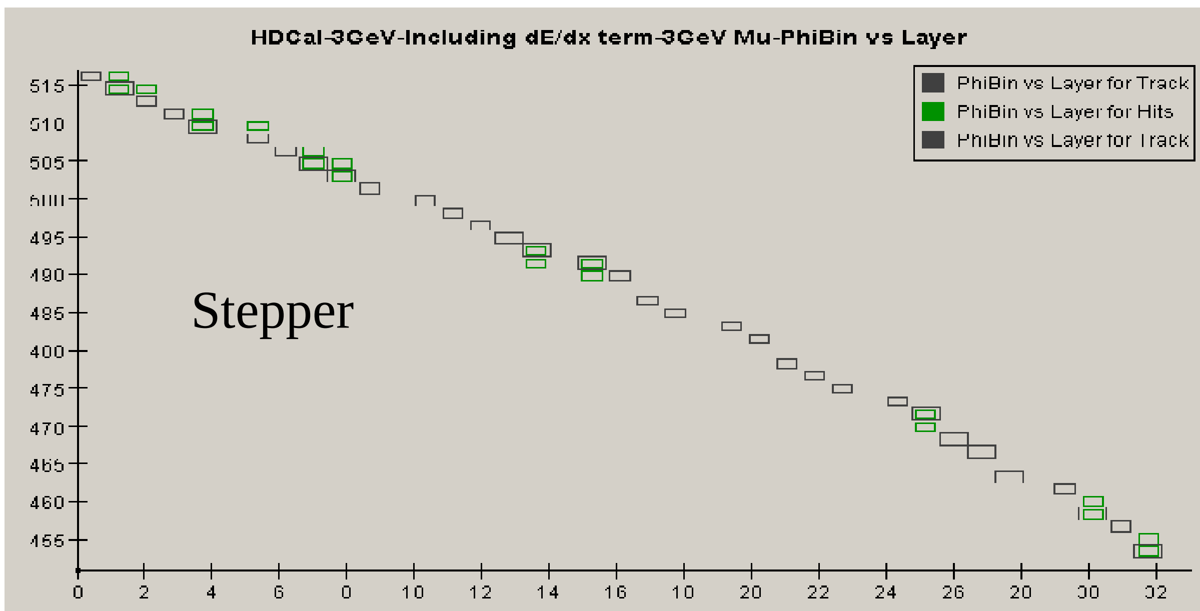
For particles at/above 20 GeV/c, the swimmer is representing properly the hits, but, at lower energy the effect of the energy loss on the trajectory is important.
We will concentrate in the low energy range.
Next slide represents the overlay of the hits and the track extrapolation with the swimmer and the stepper for the same 3 GeV/c muon. In x is given the layer number 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

ΦBin



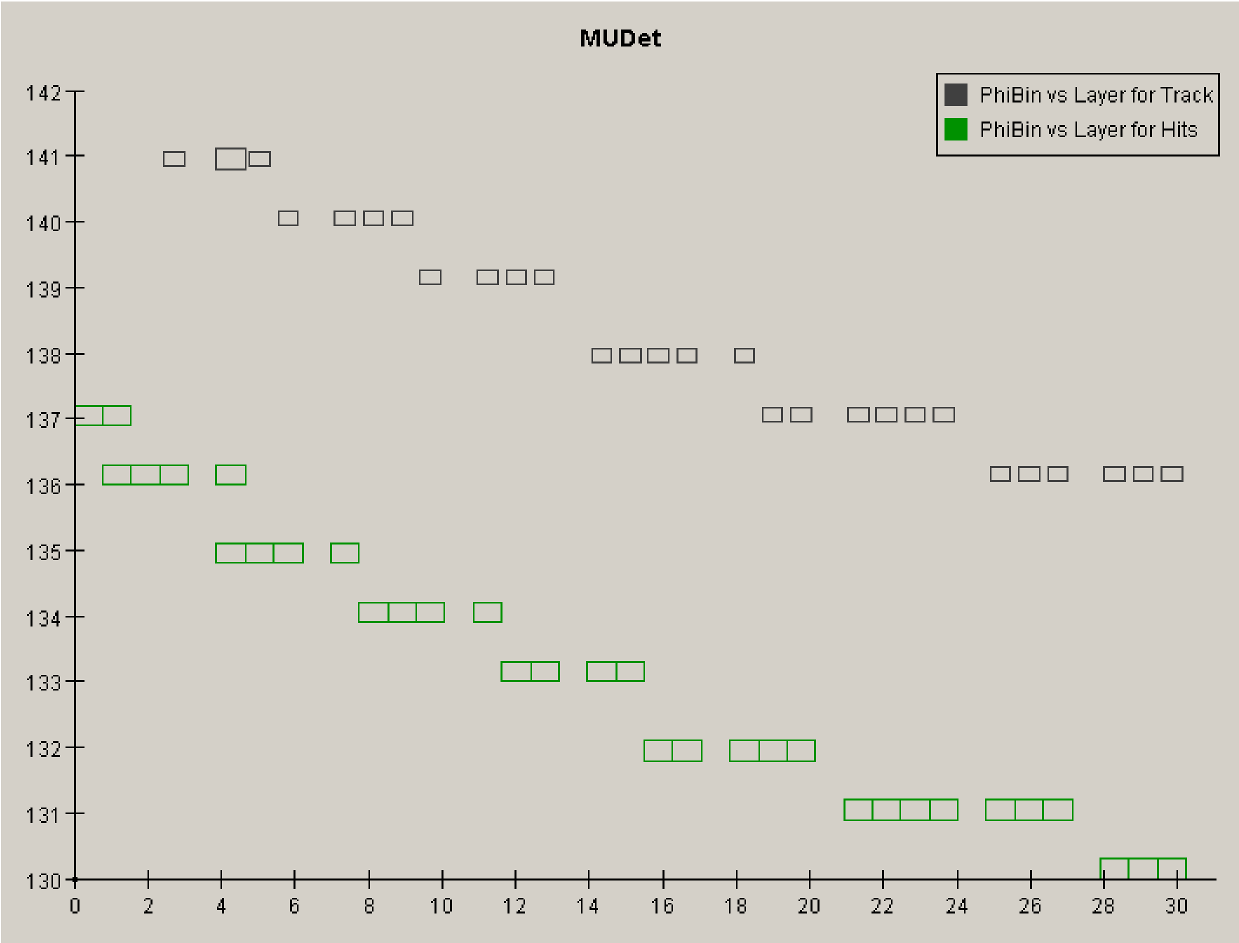


Layer Number

Swimmer in MUDET – 3 GeV/c Muons

300 ΦBins – 32 Layers

ΦBin

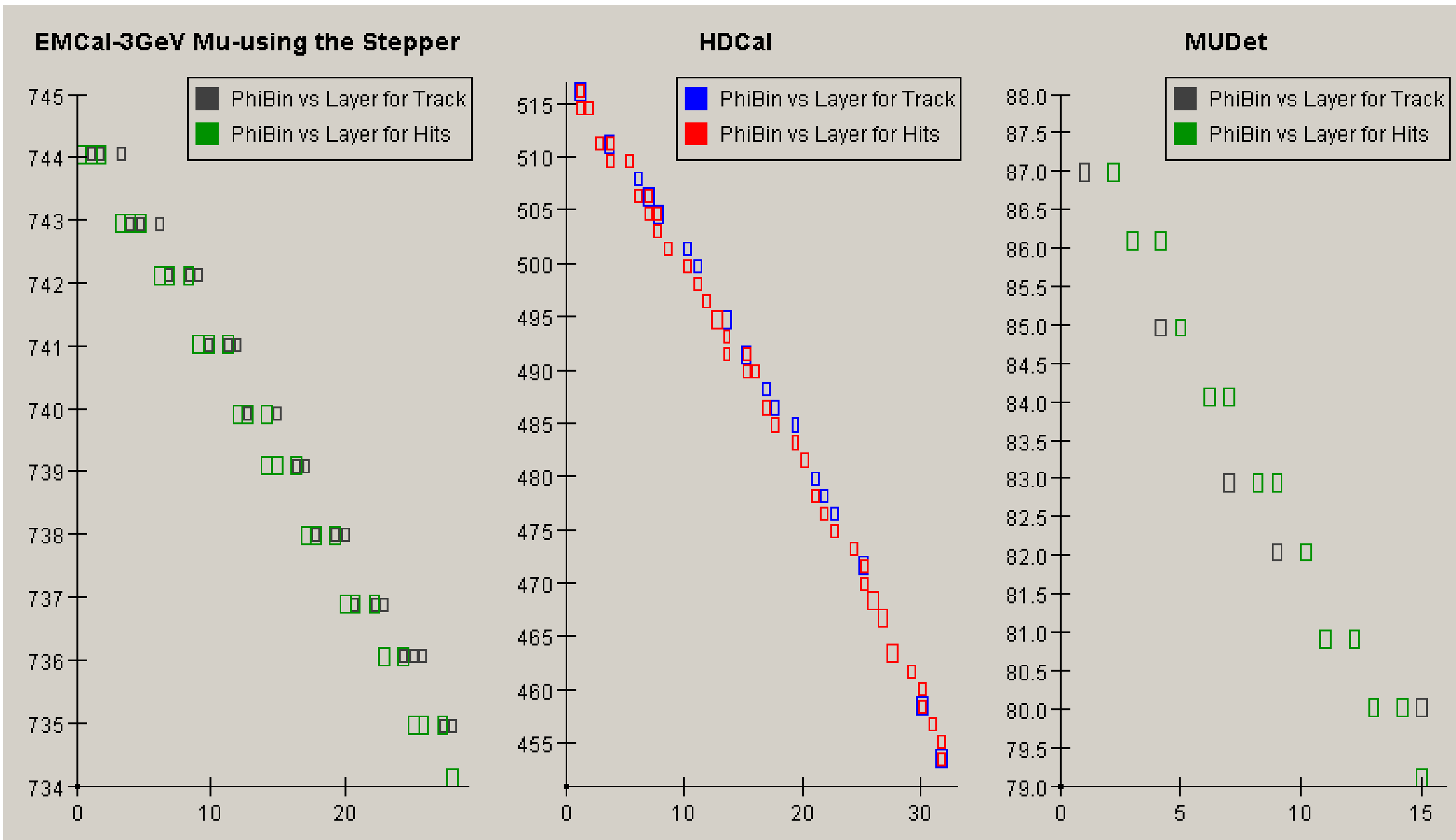


Layer Number

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

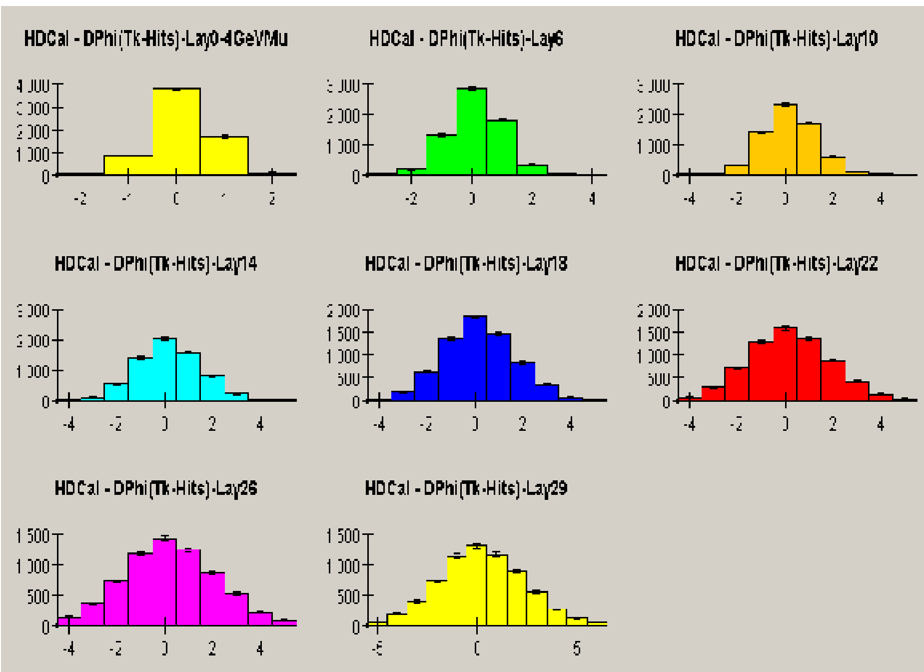
1680 Bins – 30 Layers **1200 Bins – 34 Layers** **300 Bins – 32 Layers**

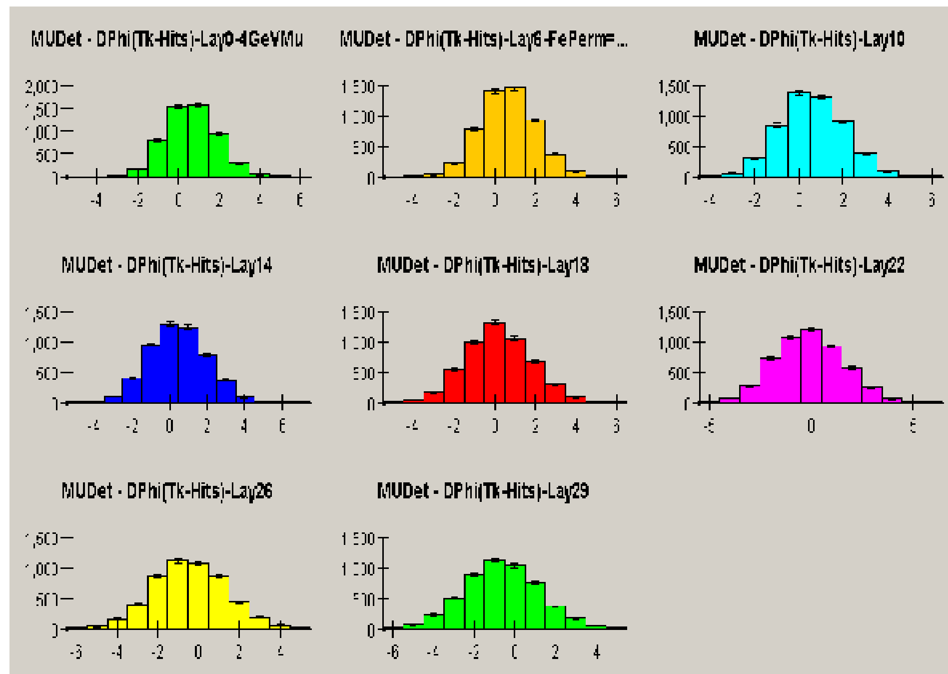
ΦBin



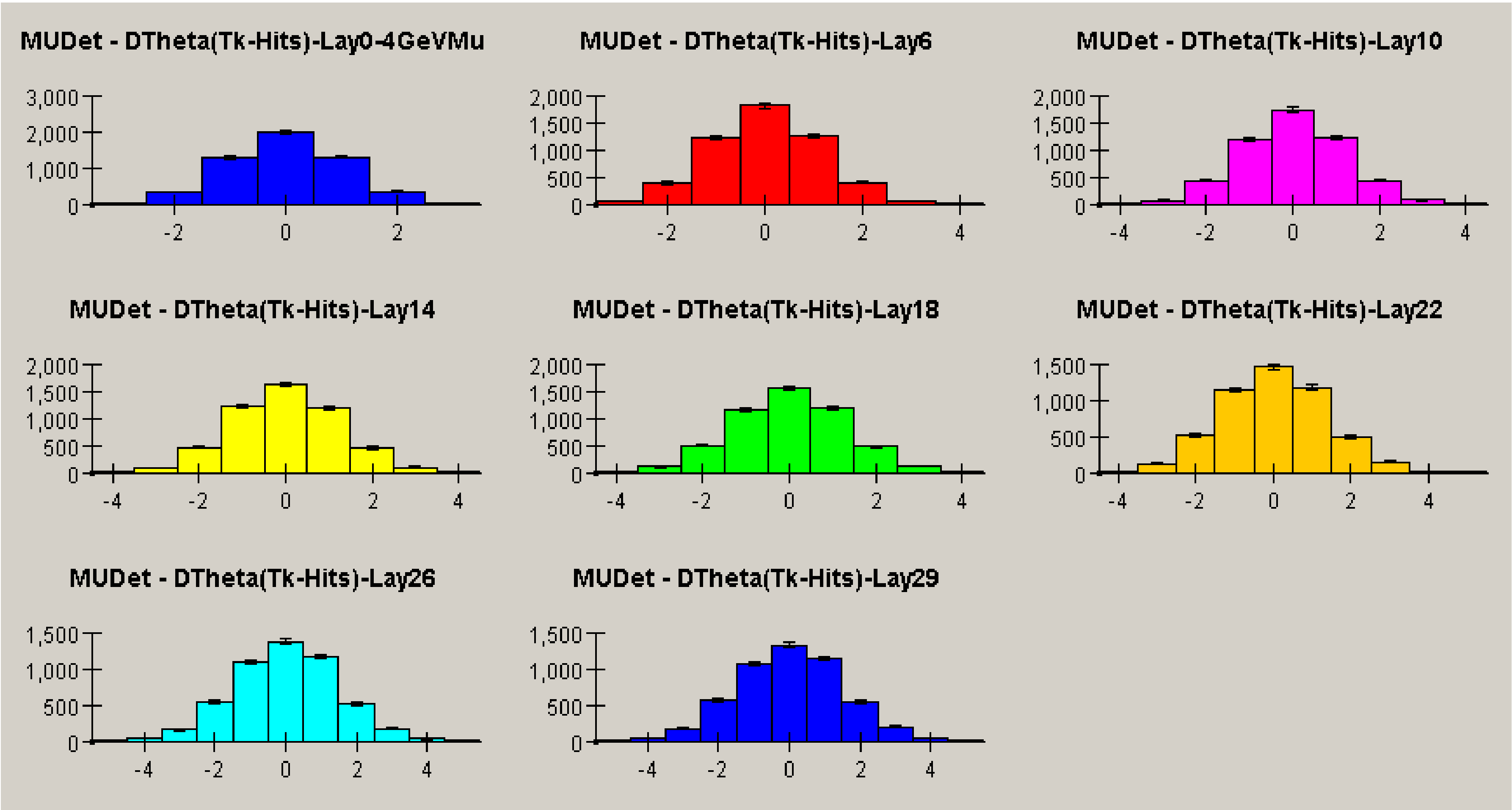
Layer Number

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

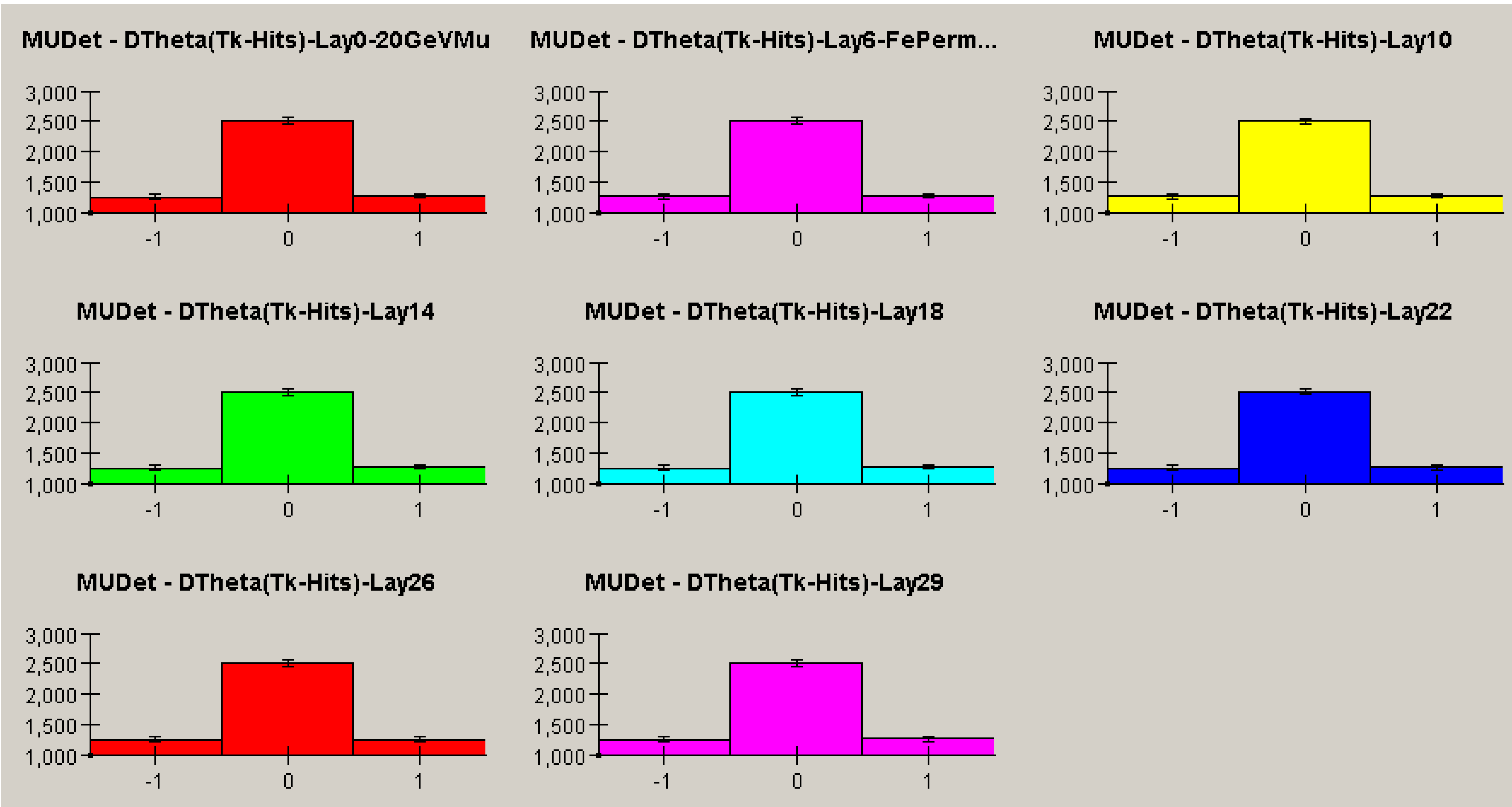




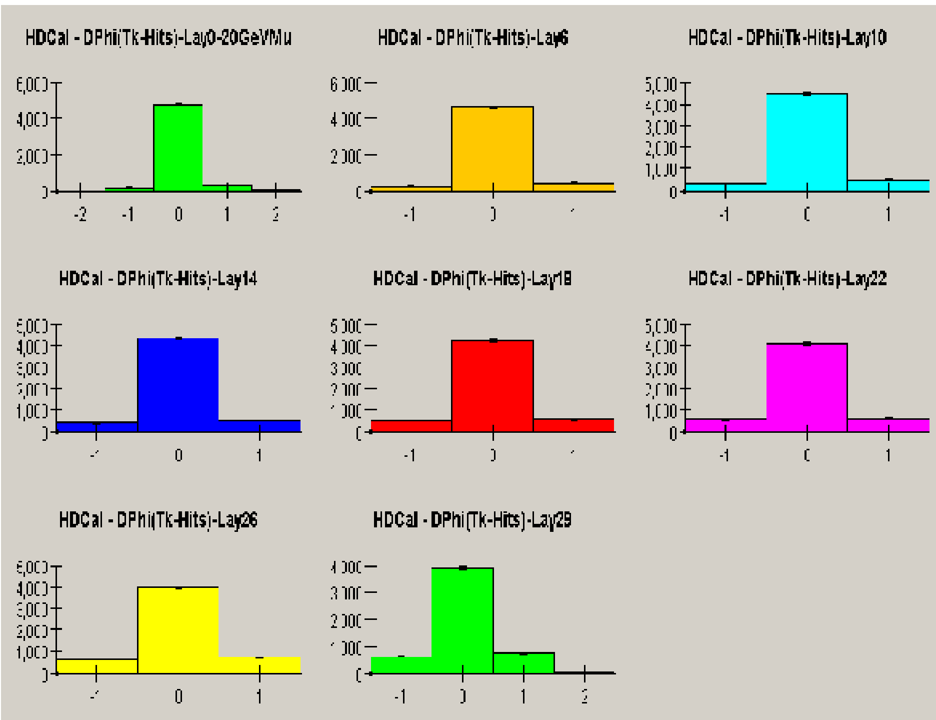
The ΔT (track-hit)- 4 GeV Muons in MUDET

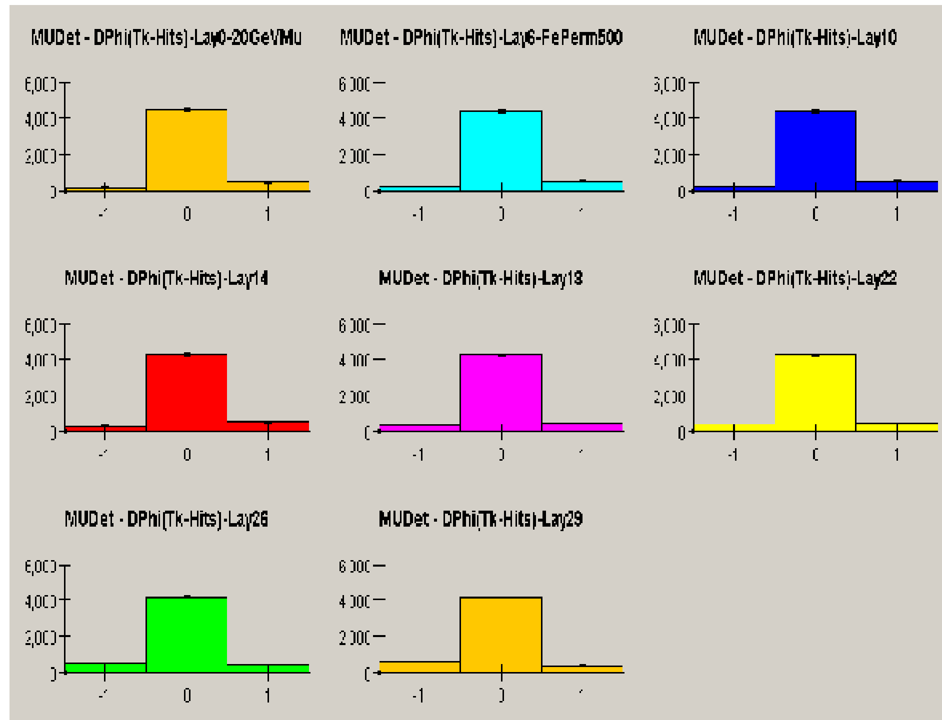


The ΔT (track-hit)- 20 GeV Muons in MUDET

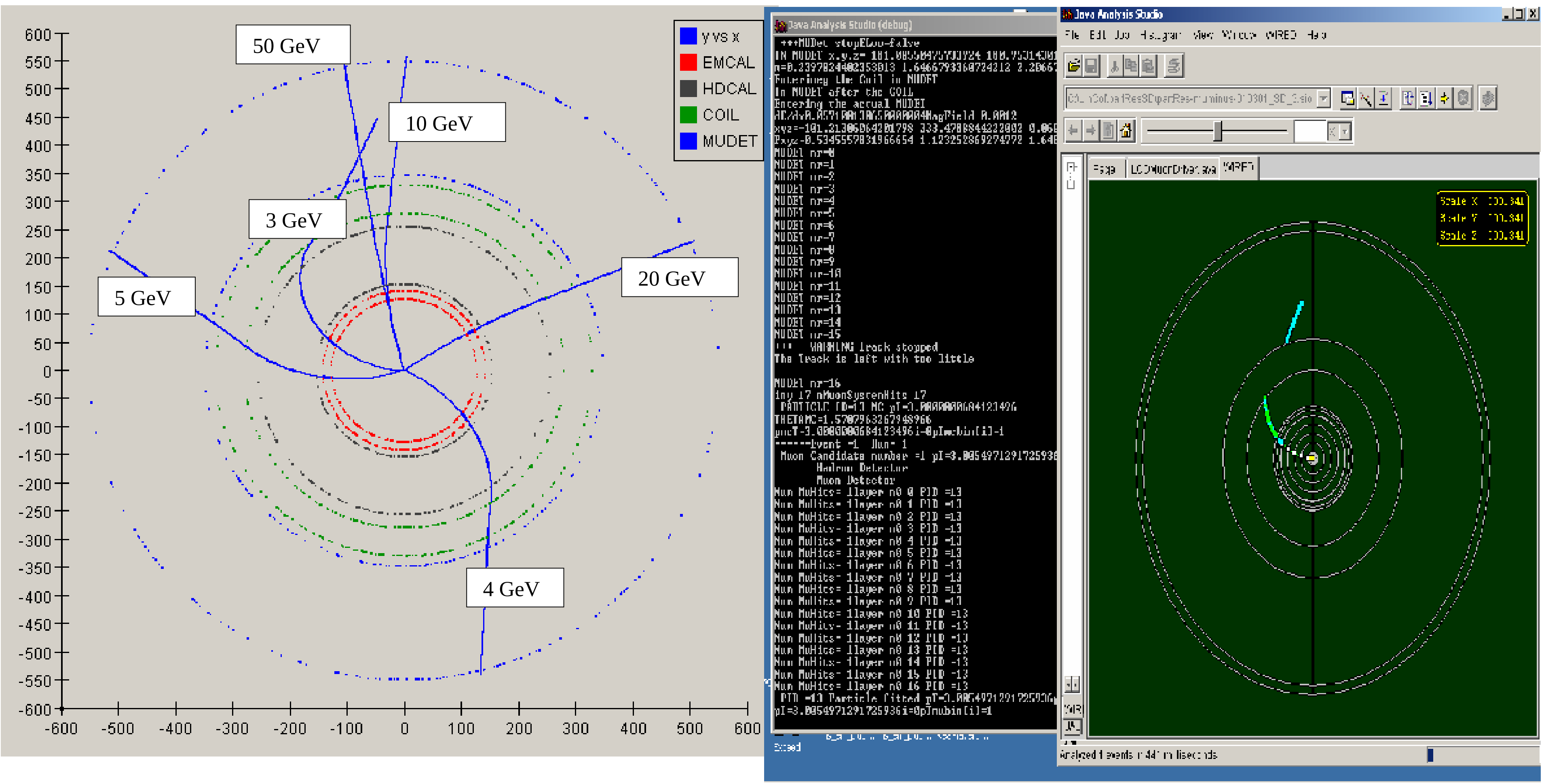


The ΔF (track-hit) – 20GeV Muons HCAL(left) MUDET(right)

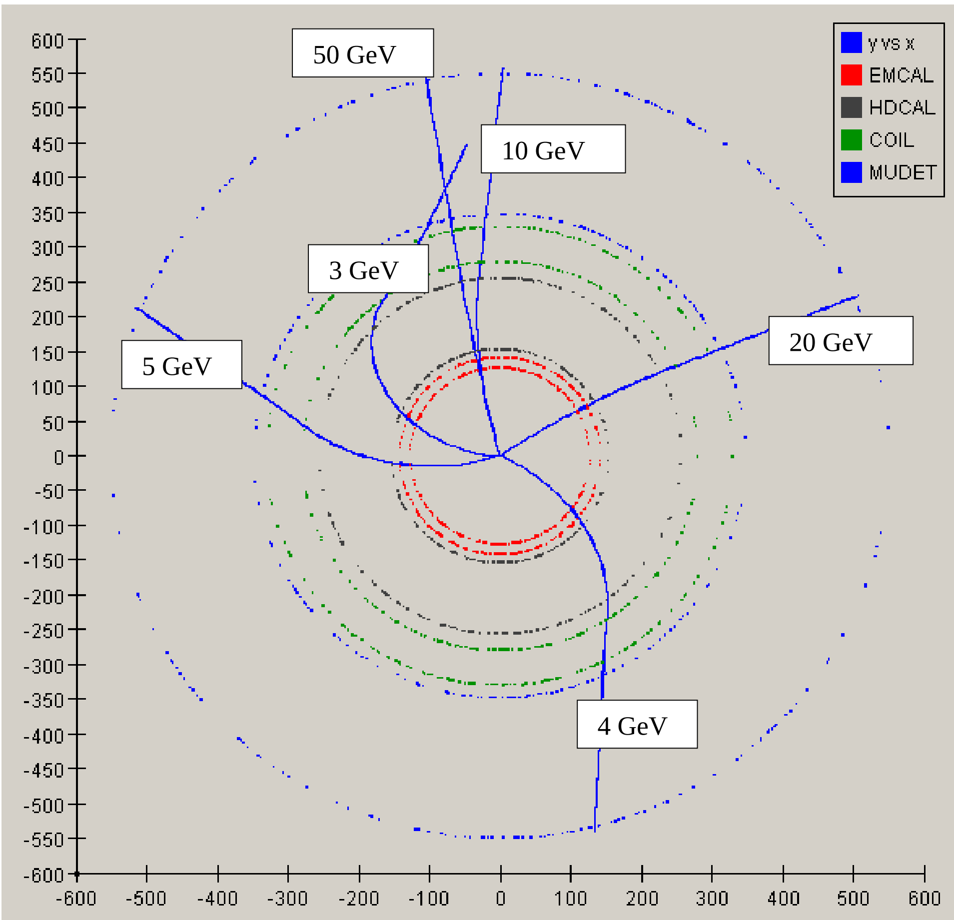


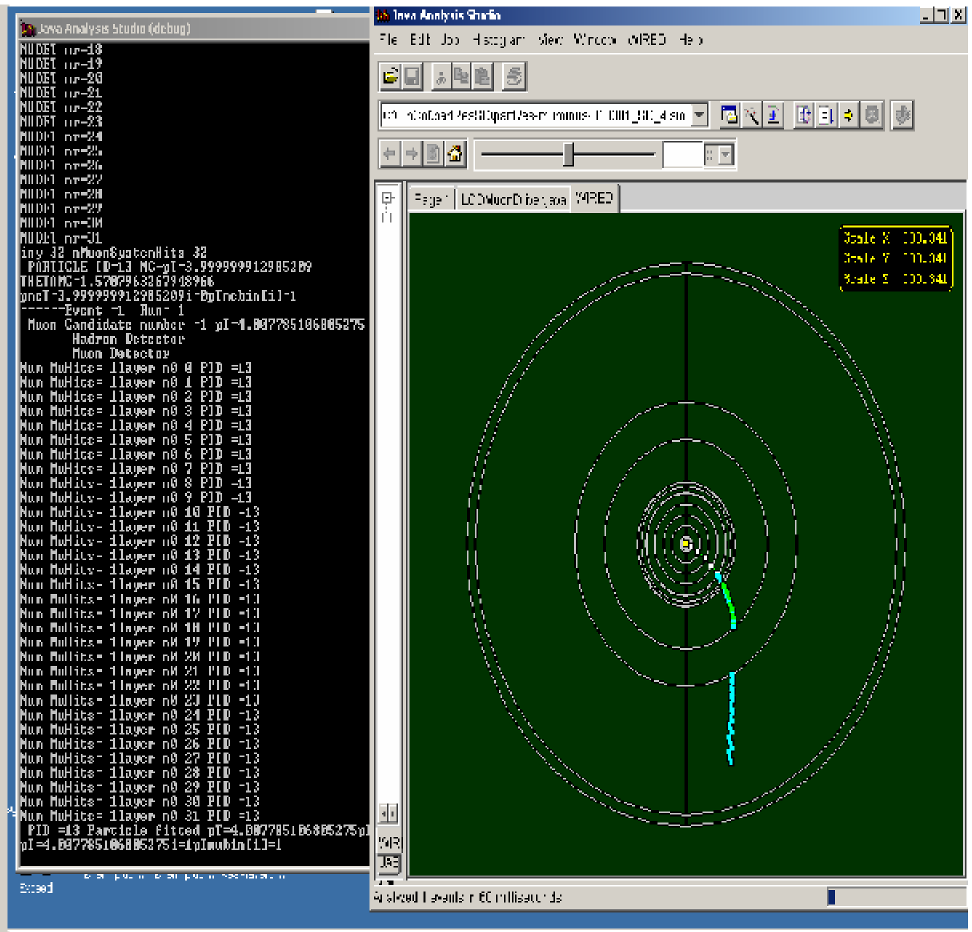


5)Distribution (x,y) &The Event Display
3 GeV/c

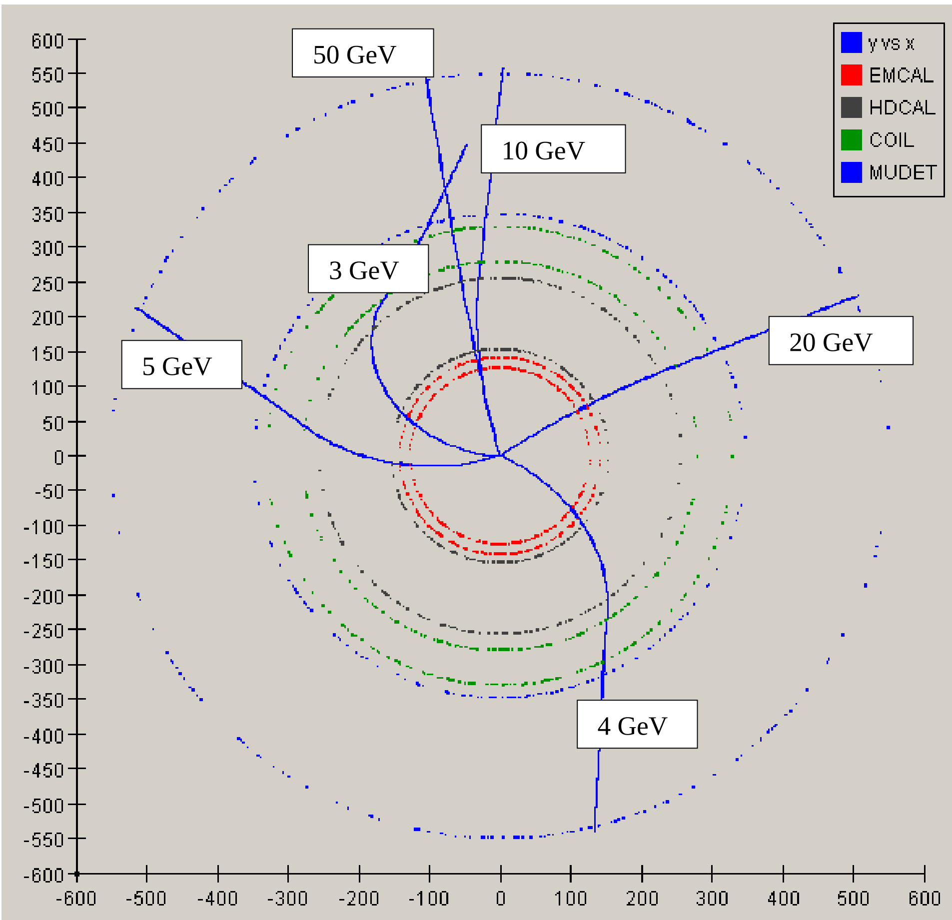


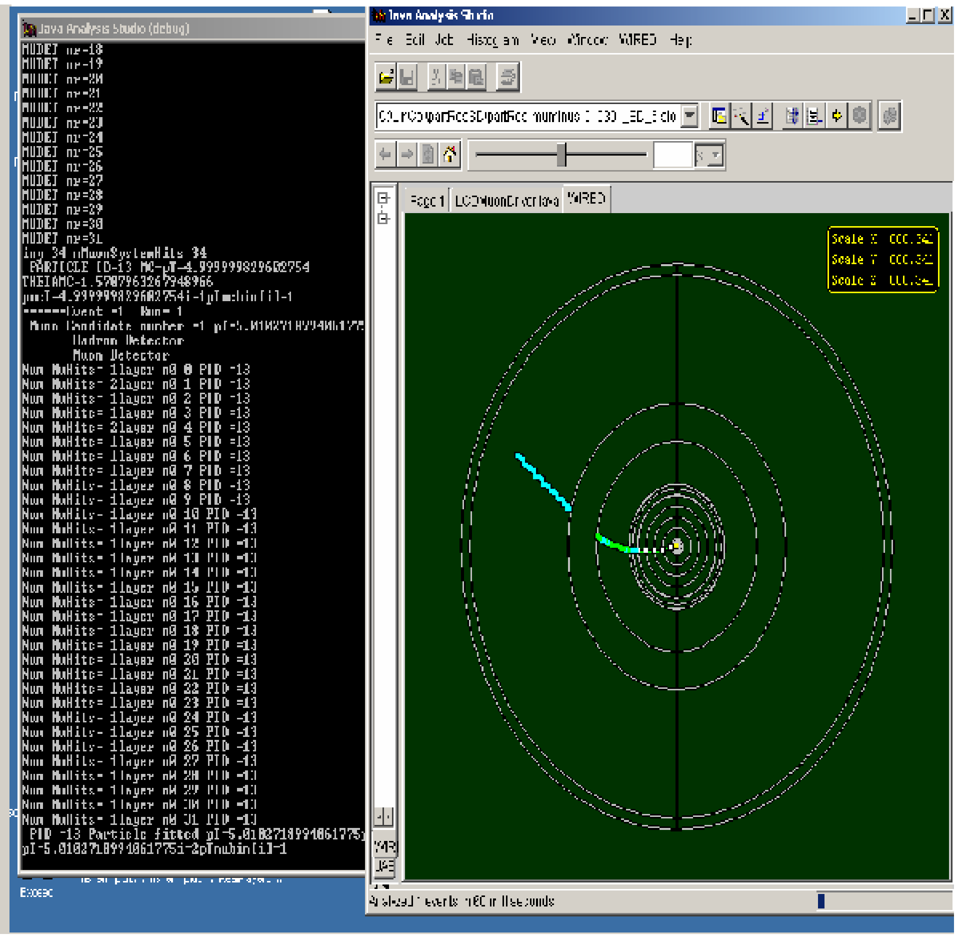
Distribution(x,y)&The Event Display
4 GeV/c



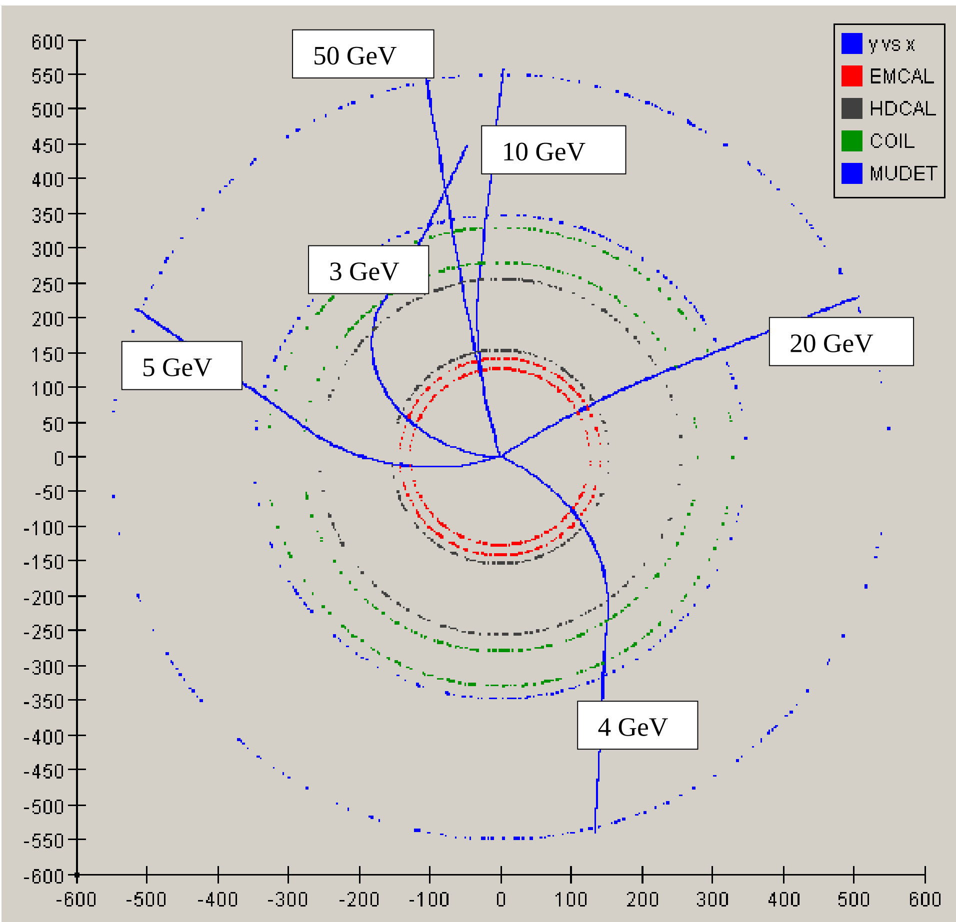


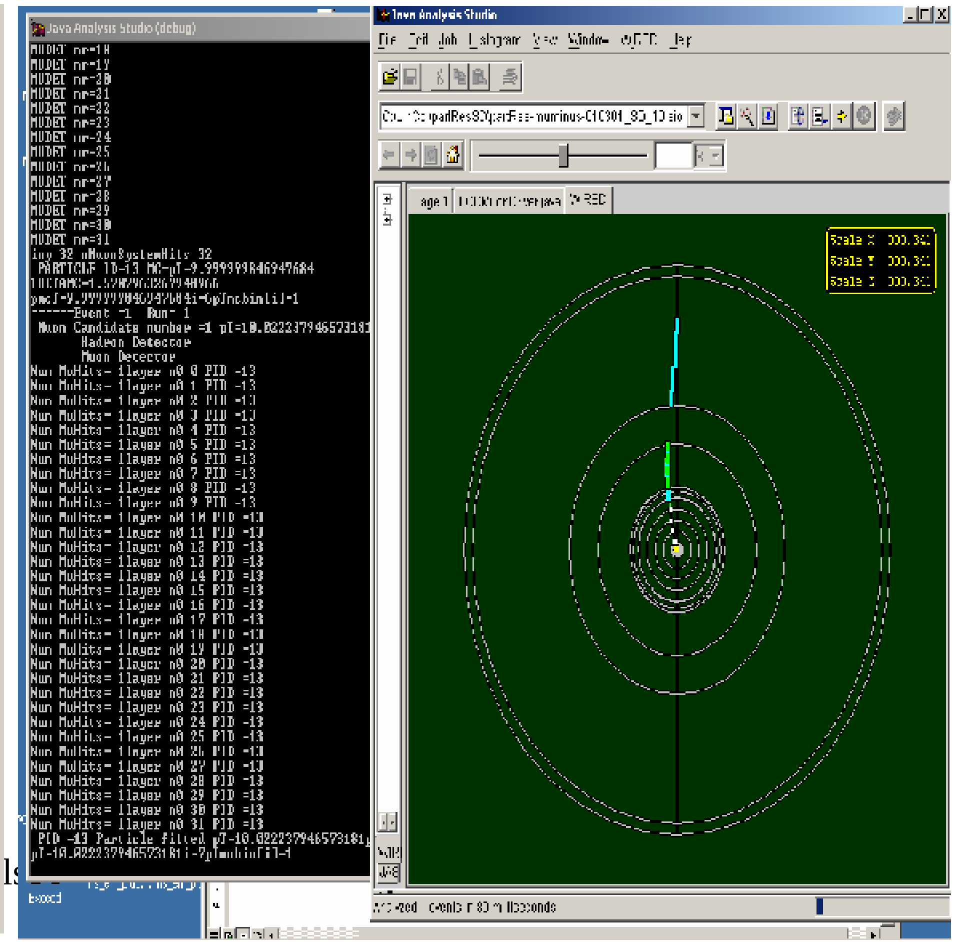
Distribution(x,y) & The Event Display 5GeV/c



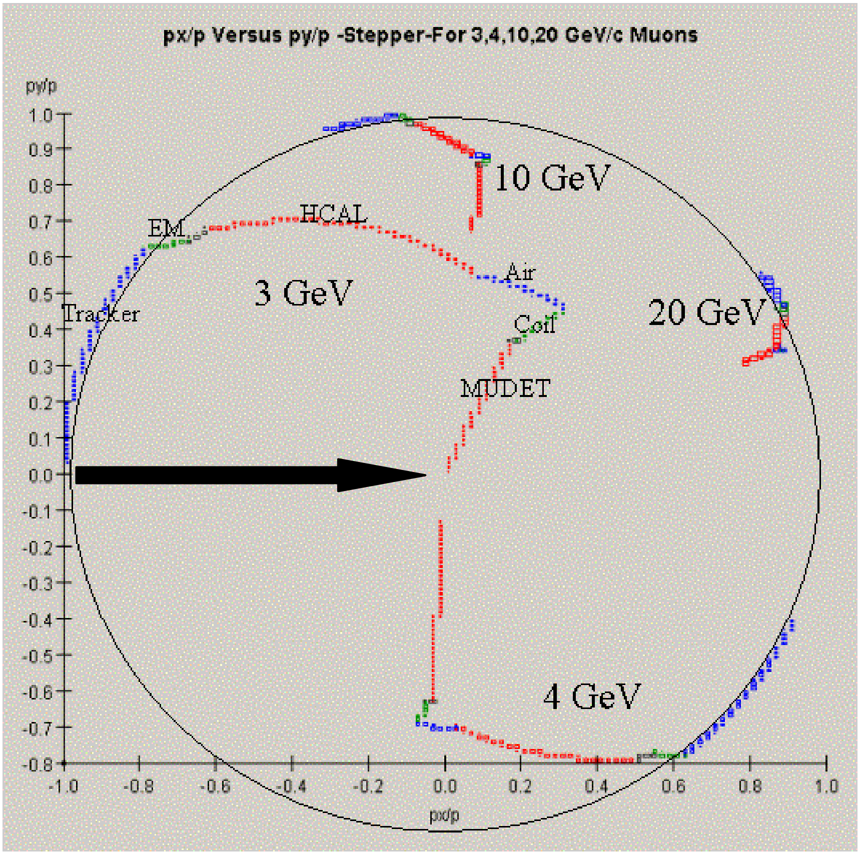


Distribution(x,y) & The Event Display
10 GeV





The Momentum Behavior In The Detector Components



Explained in more details in the next transparency

The Distribution (p_x/pStart, p_y/pStart)

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 px and py change due to the magnetic field Bz in such a way that sqrt(p_x*p_x + p_y*p_y) 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.

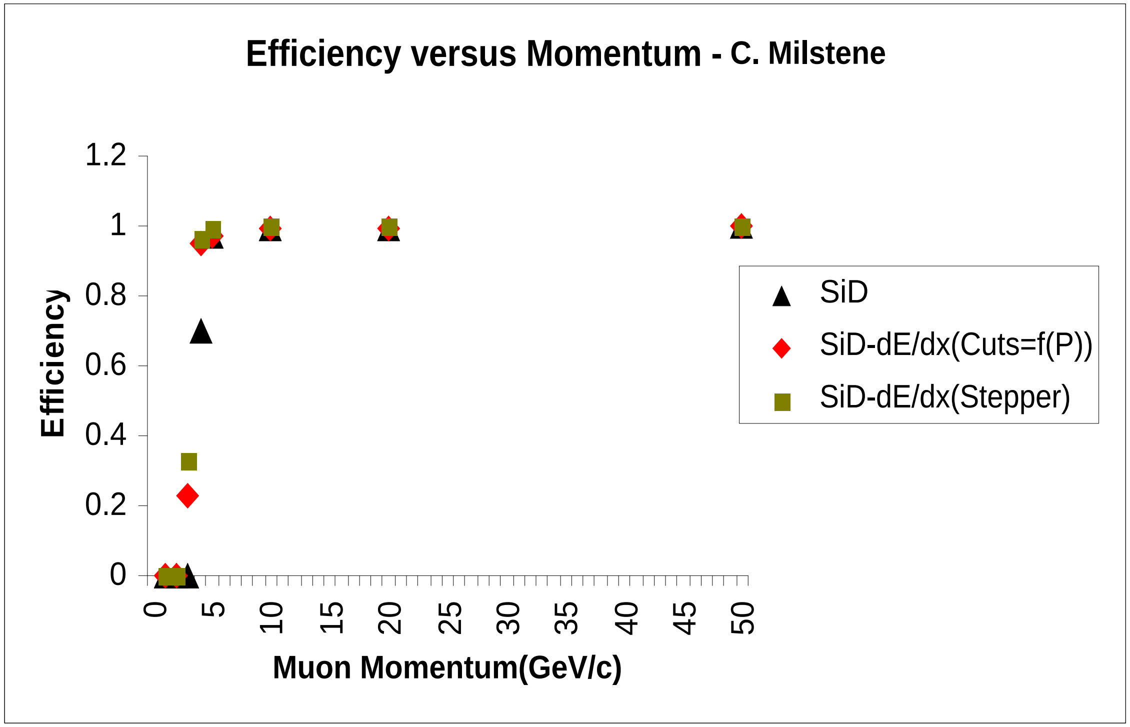
Then, in the Calorimeters, the particle looses energy, and therefore momentum in the material encountered.

It looses more energy in HCAL than in ECAL (the S((dE/dx) *? x) being bigger). It goes on loosing 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 stops there in MUDET, in about 20 layers or less.

The position x, y on the other hand, was starting at radius =sqrt (x*x + y*y)~0 and increases to end up at a radius ~362 cm for a 3 GeV Muon.

The 4 GeV/c muon is left with ~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 10GeV/c and 20 GeV/c Muons.

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)

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

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

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

The Particle Momentum (2)

Moving particles lose energy in the material by dE/dx,
Approximation: dE/dx ~Constant=Ct for a path length Δs in step n

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

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.

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

And if step is small enough one can approximate
a'~a=p_x(n)/P(n), b'~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

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

$$r(n+1)^2 - r(n)^2 = [x(n+1)^2 + y(n+1)^2] - [x(n)^2 + y(n)^2]$$

$$= [\{x(n) + \mathrm{v}_x(n) * \Delta T(n)\}^2 + \{y(n) + \mathrm{v}_y(n) * \Delta T(n)\}^2] - [x(n)^2 + y(n)^2]$$

$$r(n+1)^2 = r(n)^2 + 2 * d * r(n) + d^2$$

ΔT(n) is the solution of an equation of the second order.