Performance Studies of the SiD Muon Detector Of The Linear Collider In Jets

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1. The Detector
2. The Algorithm
3. The Candidate
4. The major issues : Muon detection in jets,
   - Mu Detection Efficiency, b-bbar jets are used in this study
   - Hadrons (π , K , proton) background
   - The Timing
5. Conclusions

1-Introduction

- In the detection of Muons in Jets, the power of rejection of hadrons is as important as the muon detection per-se.
- There are 2 categories of hadrons which are candidates muon:

1- Hadrons which make it to the Muon Detector and leave a signature consistent with the algorithm. Those occur in both single events and Jets.

2- Hadrons which do not reach the Muon Detector but "borrow" hits from a neighbor particle in jets. Those occur only in jets and can get rejected by improving the algorithm

- We will present the Muon Detection Efficiency in Jets and "Filter out " the Hadron background with HDCal.

2-The MUCal-SiD Detector

<u>Amount of Material in front of MuCal</u>

EMCAL 22X0 – 0.87 Λ –190MeV lost by dE/dx

HCAL 39.5X0 – 4.08 Λ – 800MeV lost by dE/dx

The Coil 5.6 X0 – 1.27 Λ – 218MeV lost by dE/dx

<u>Total</u> = *<u>67</u>* X0 – *<u>6.22</u>* Λ – *<u>1200</u>*MeV *lost by dE/dx → Cut<3GeV*

A Magnetic Field of 5 Tesla

MuCal 9 X0 – 9.6 Λ– 1600MeV lost by dE/dx

<u>MuCal:</u>

Outer_Radius 660.5cm(up to 550cm Instrumented)

Inner_Radius 348.5cm

A Total 312 cm(202cm instrumented)

<u>The Unit:</u> Fe 5cm + Gap 1.5cm scintillator

48 Layers /32 Layers Instrumented

80cm Fe = 16 planes

3a-The Muon Candidate

•The original code of the μ package of R. Markeloff has been modified to use a stepper in order to extrapolate the tracks and collect the hits. This allows to include the effects of the Magnetic field and account for the dE/dx

• A set of **hits in HDCal &&EMCal** within ($3\Delta\phi, 3\Delta\theta$) bins from the track (HDCal bin=$\pi/600$); and ($2\Delta\phi, 2\Delta\theta$) (EMCal bin= $\pi/840$) is collected.

• At least **14hits in MuCal** within ($2\Delta\phi, 2\Delta\theta$) bins from the track (MuCal bin= $\pi/150$), *in14 layers or more & a mean* ℓ *< 2hits/layer*.

<u>Remark:</u> We are looking only in the Barrel Detector,accounted by a cut in Θ, 0.95 rd<Θ<=2.2 rd

3b)The Candidate-Extension of the Algorithm

The actual Algorithm requires:

- A Charged track with a good fit in the tracker
- In the Muon detector we require at least 14 Layers/14 hits.
- In order to allow for random scattering which are bigger for lower particle momenta, we use the same Momentum dependant angle cut than with the swimmer for the track below ~ 10 GeV, namely, ($\Delta\phi$, $\Delta\theta \sim 1/p$) .
- We use the very last end of the Hadron Calorimeter as an extension of the muon detector in order to improve the hadron rejection and the hadron-muon separation.

3c-The Hadron Calorimeter End - Extension of the Muon Detector

The information of the very end of the Hadron calorimeter, the 4 last layers, is used as an extension of the Muon Detector to improve the hadronic rejection.

- In the next figures, one can see that in jets events as well as in single events, the muon has a continuous pattern of hits in each layer up to the end of HCal, on the other hand, hadrons tend to interact well before the end of the Hadron Calorimeter. The products of the interactions are scattered from the region spanned by the extrapolated track and leave a void of hits at the back of the Hadron Calorimeter.

- By requiring a hit in each one of the4 last layers of the Hadron calorimeter, we will take advantage of:

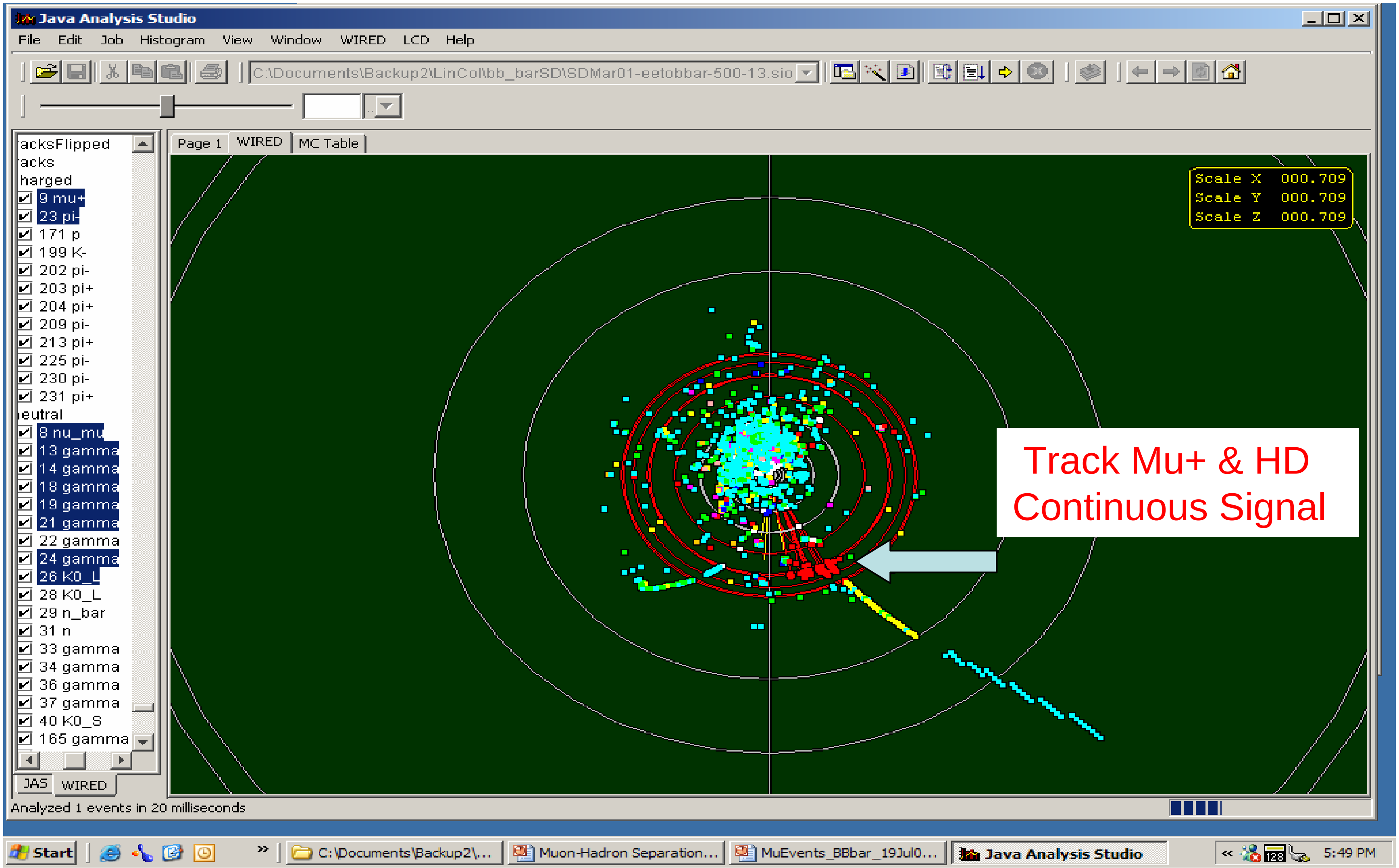
  1_The Muon distinctive repetitive pattern in the detector

  2_ The refined granularity of the hadron Calorimeter , 5mrd bins

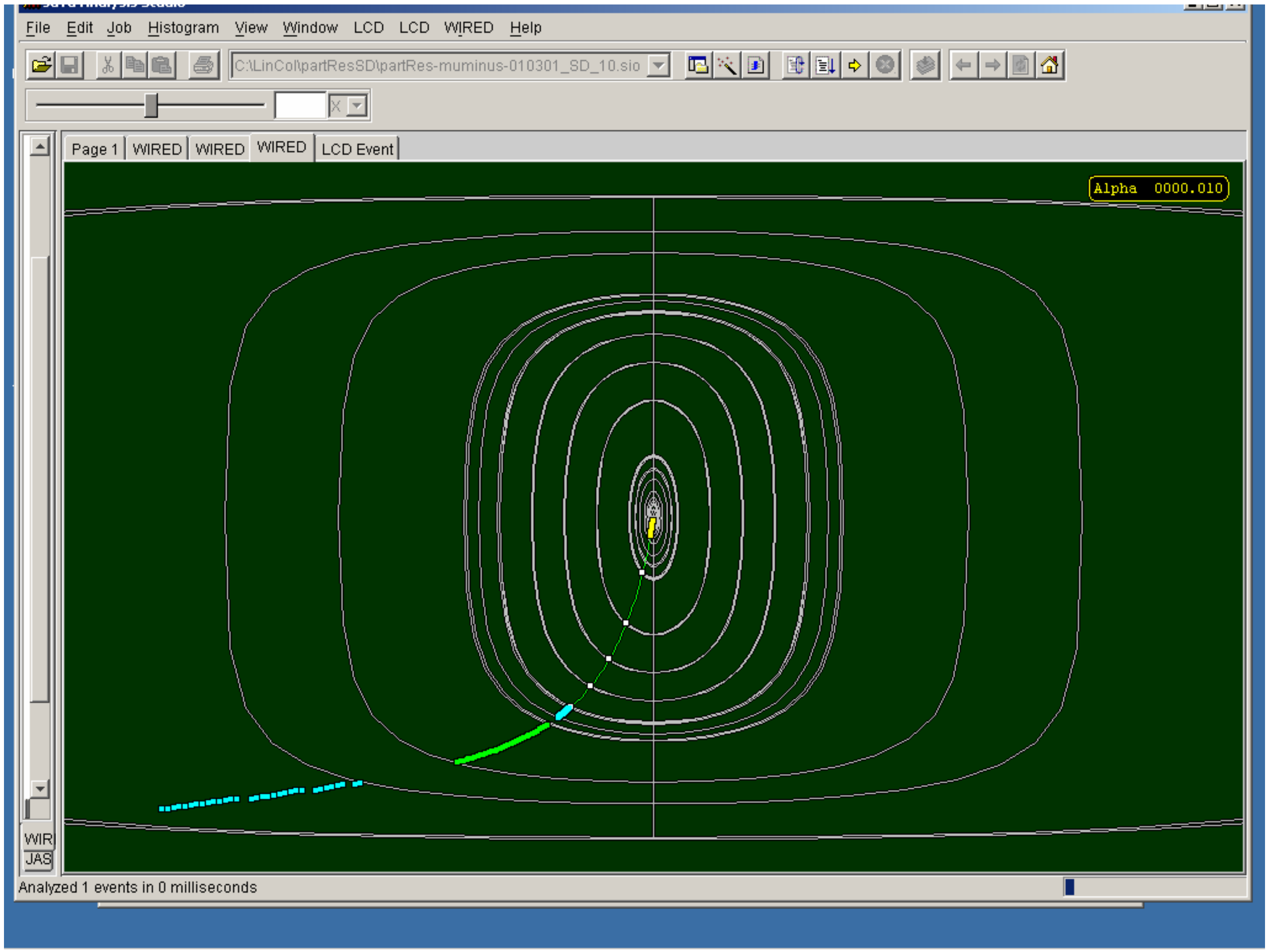
  3_ This fine granularity is specially useful since the hadron calorimeter is located before the Coil and less material on which to scatter is on the way.

Using those 3 properties HCal will be able to filter out part of the hadrons before they reach the Muon Detector and improve the rejection efficiency.

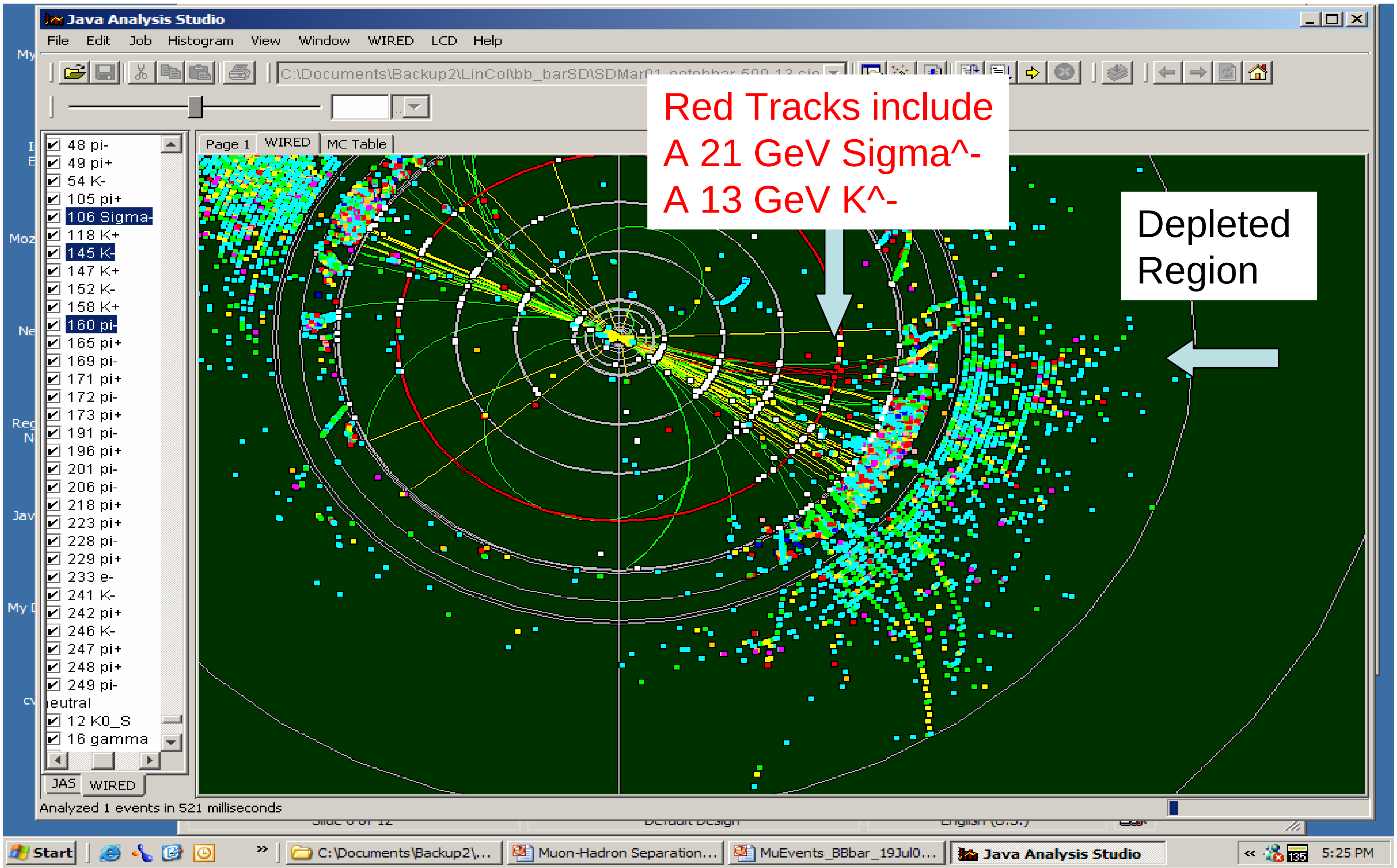
A "Typical Muon" In A B-Bbar Event Shows The Same Regular Pattern in HD than in MUDET



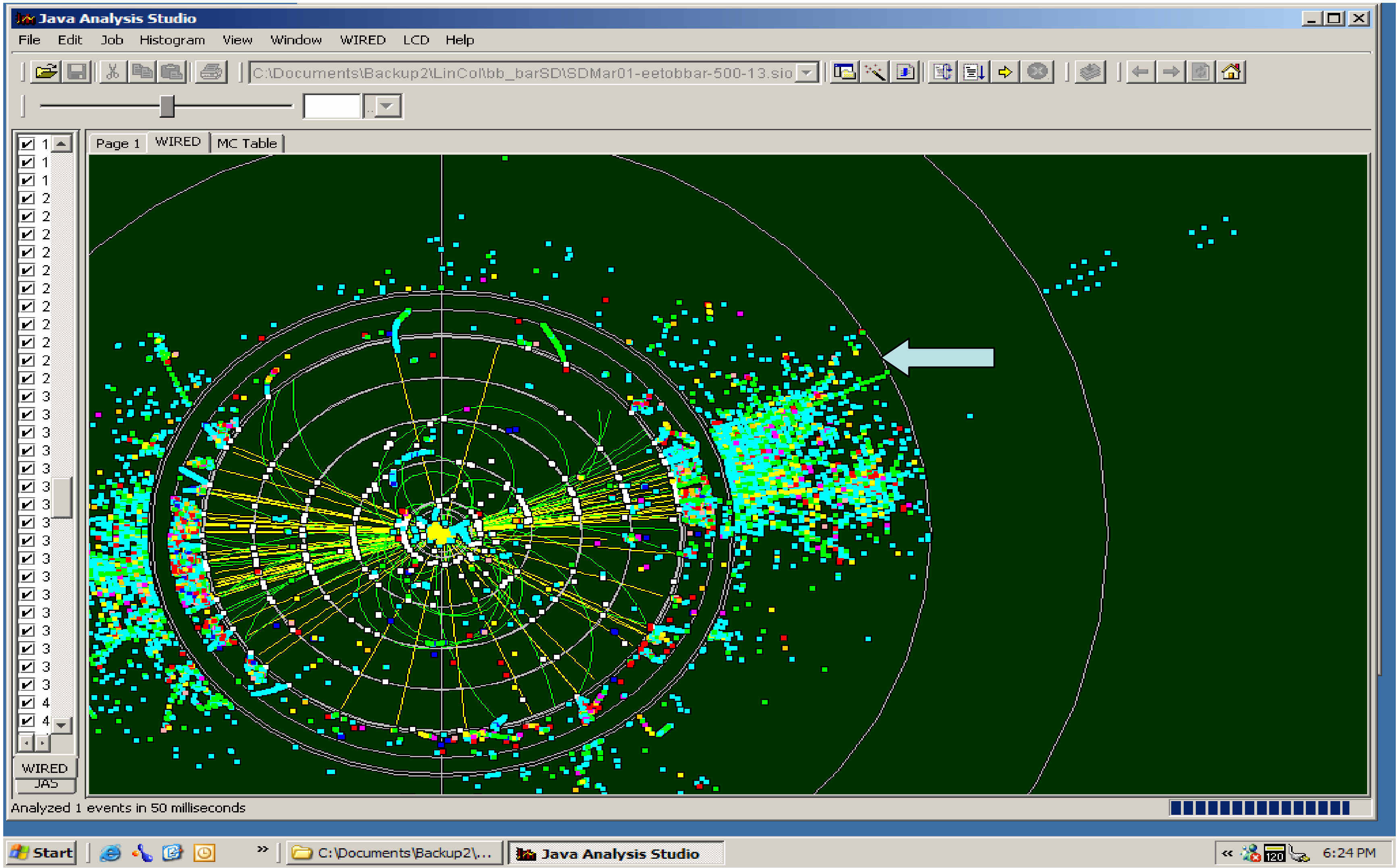
A “ Typical” 10 GeV Single Muon



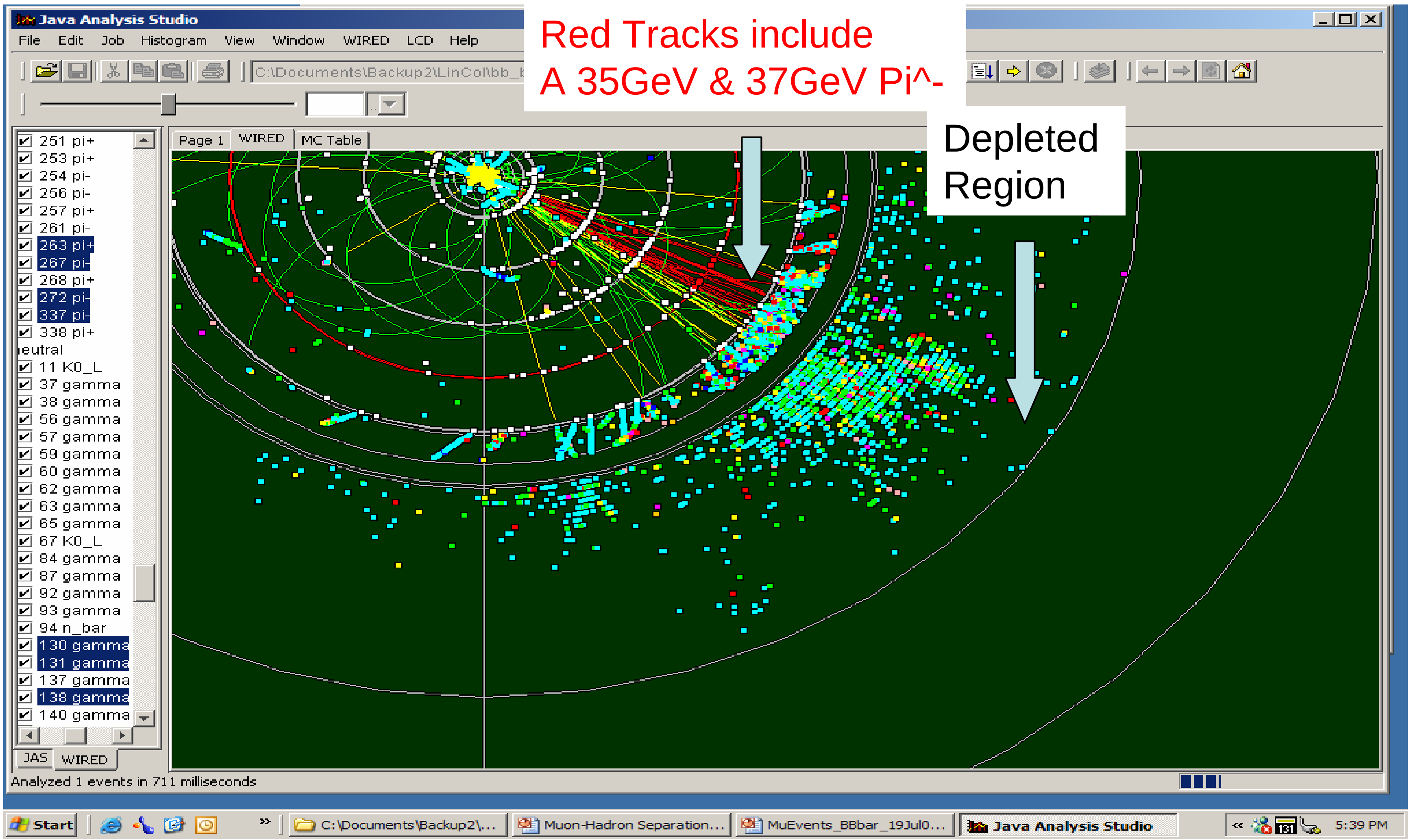
“Typical Hadrons” in HD- 4 Last Layers. Depleted Region Extrapolated From the Tracker



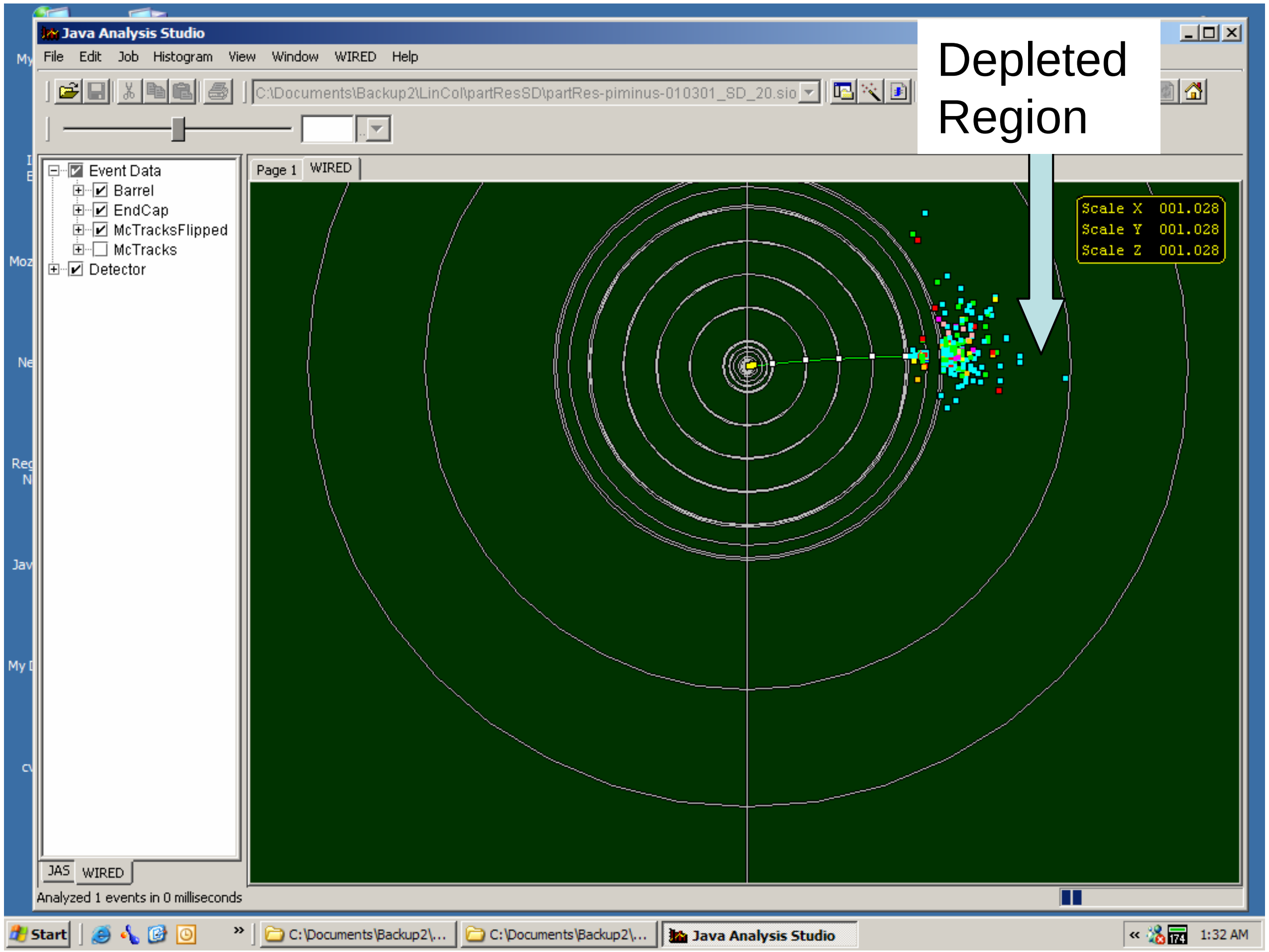
B-Bbar Event – Signal Gaps In HD (and Mudet)



B-Bbar Event


Red Tracks include
A 35GeV & 37GeV Pi^-
Depleted
Region
Java Analysis Studio
File Edit Job Histogram View Window WIRED LCD Help
Page 1 WIRED MC Table
251 pi+
253 pi+
254 pi-
256 pi-
257 pi+
261 pi-
263 pi+
267 pi-
268 pi+
272 pi-
337 pi-
338 pi+
ieutral
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
JAS WIRED
Analyzed 1 events in 711 milliseconds

20 GeV Single Pion



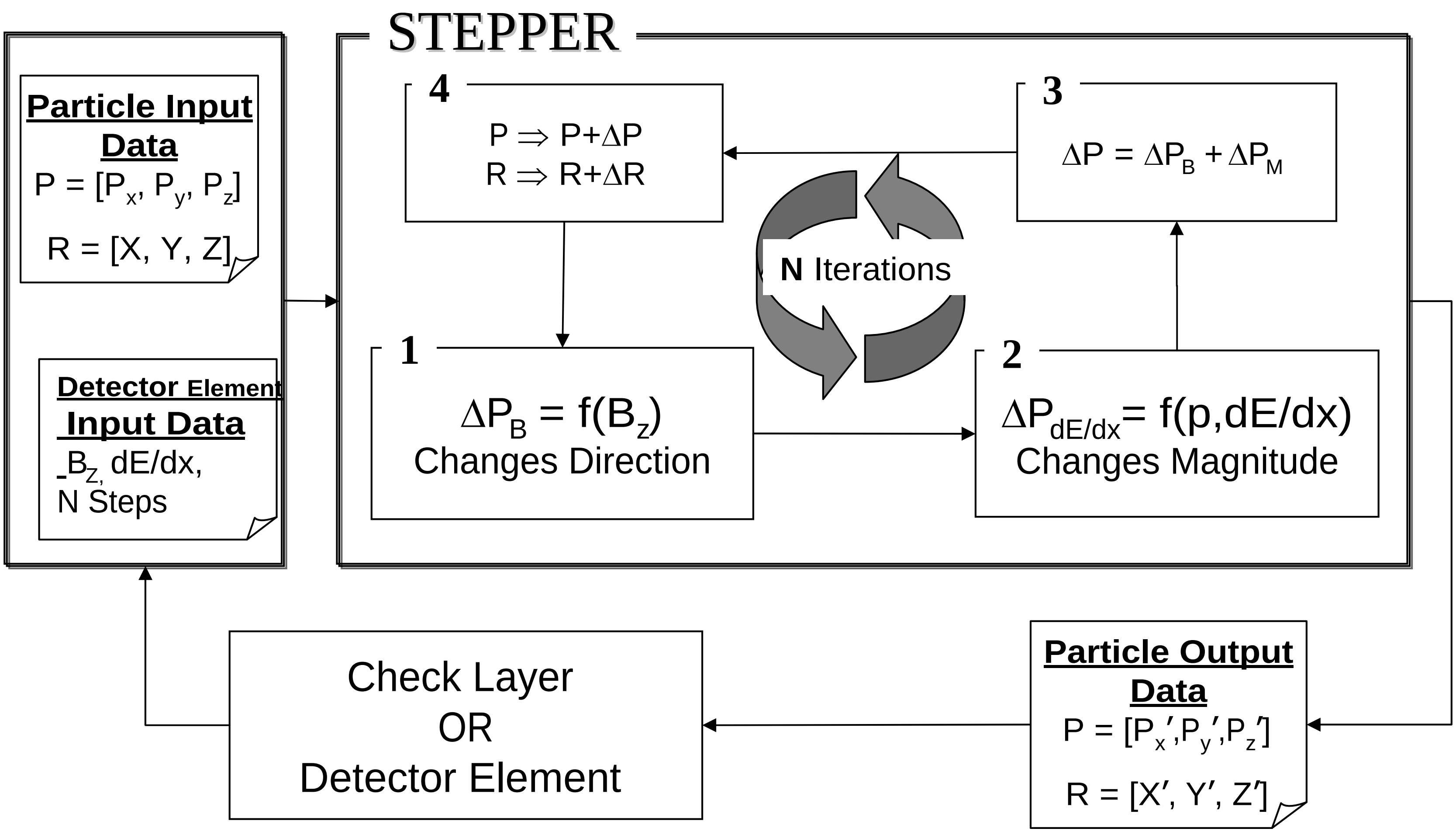
3d-The Stepper

Is briefly described below and the improvement in detection efficiency shown on single events.

- The stepper processing flow

- The stepper algorithm
- The Detection Efficiency

Stepper Processing Flow



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 re-calculated after each step as a function of the new values px,py,pz,E and the old Position x(n),y(n),z(n).

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

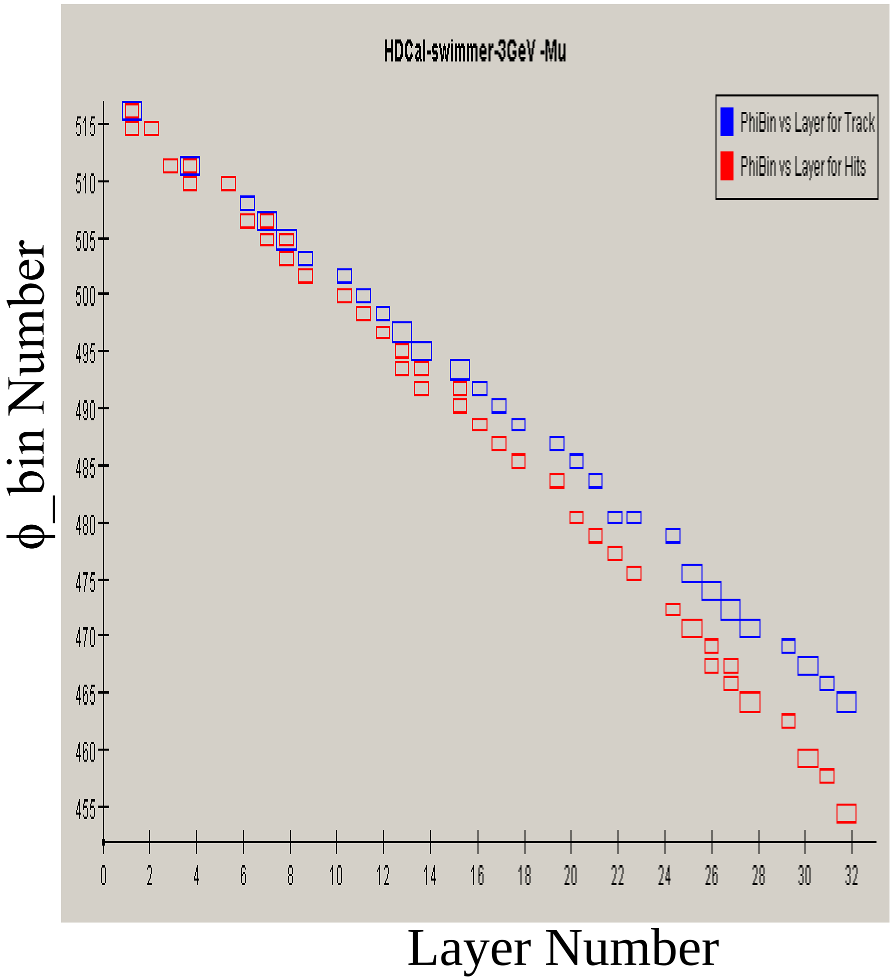
$$y(n+1) = y(n) + \frac{p_y(n+1)}{E(n+1)} * clight * \Delta t(n)$$

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

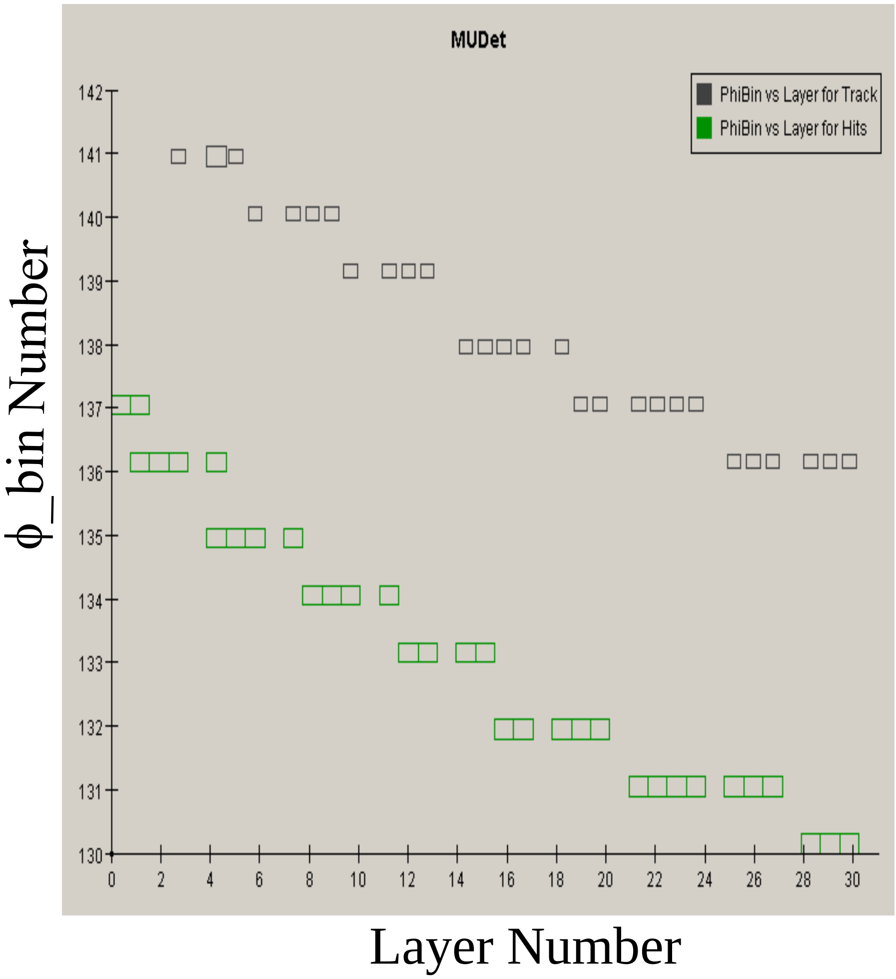
ΔT(n) is the time of flight in seconds of the particle at step n .

The Swimmer in HDCal and MuDet –
Φ Bin =f(Layer) Tracks versus Hits

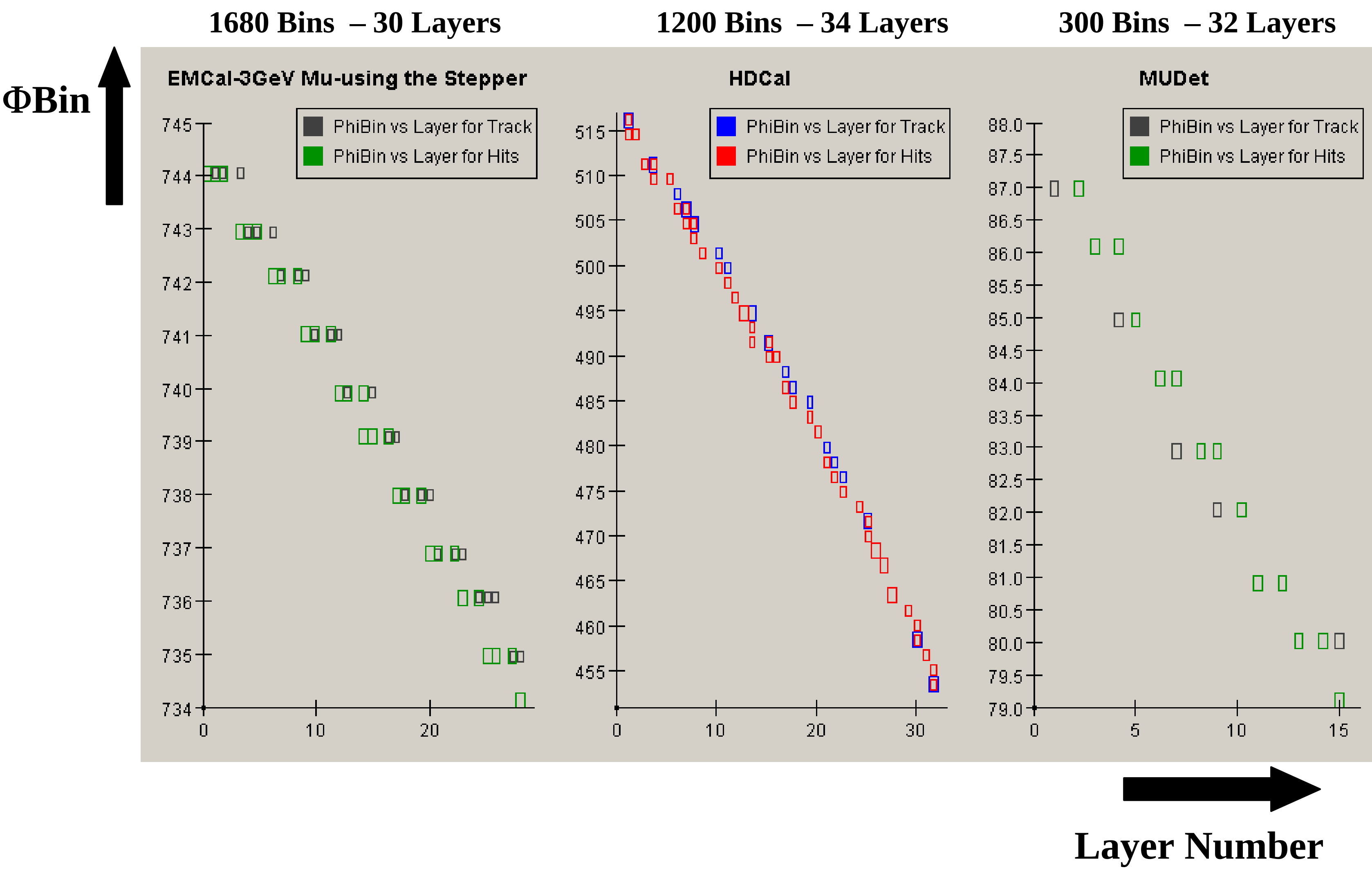
H Cal- 1200 Φ_bins-34 Layers



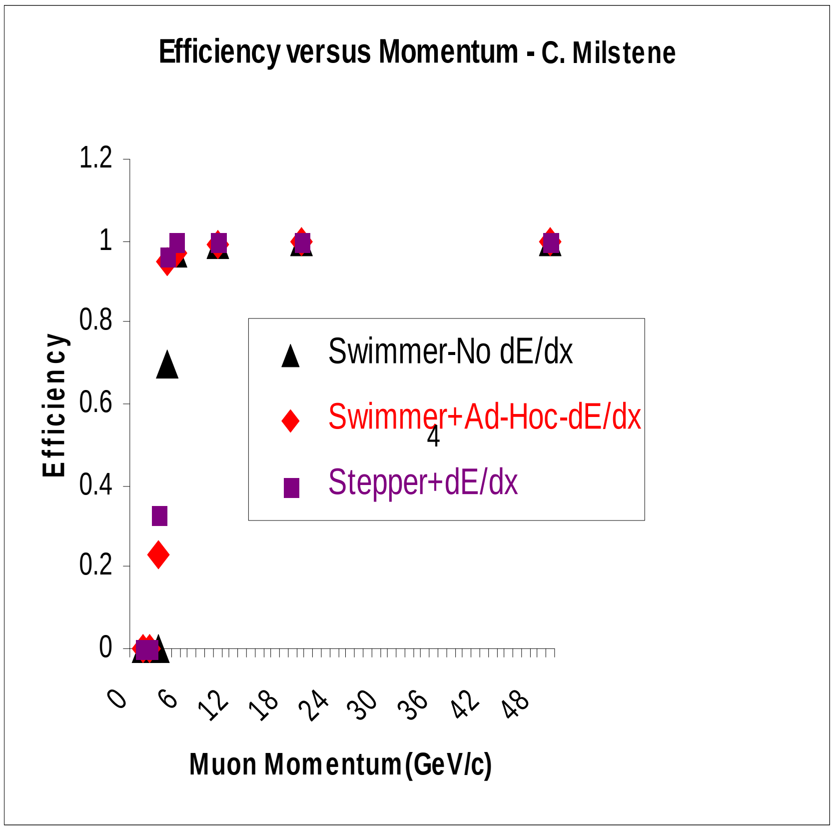
μ Det – 300 Φ_bins-32 Layers



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



Muon Detection Efficiency Improvements In Lower Momenta Range with the Stepper



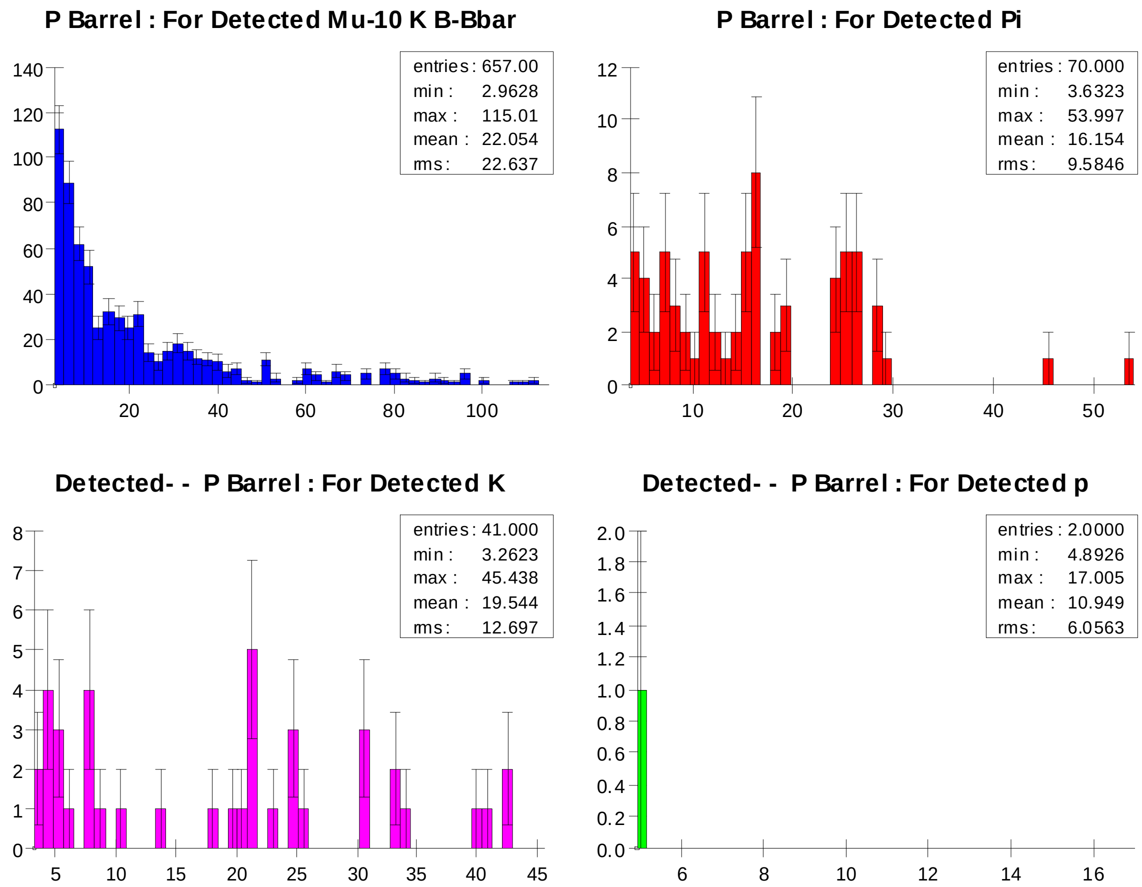
E(GeV) \ Techn.	3	4	5	10
No dE/dx	0.06 %	70%	97%	99.%
Ad-Hoc dE/dx	23%	95%	97%	99.%
V x B + dE/dx	33%	96%	99%	100%

Gene Fisk

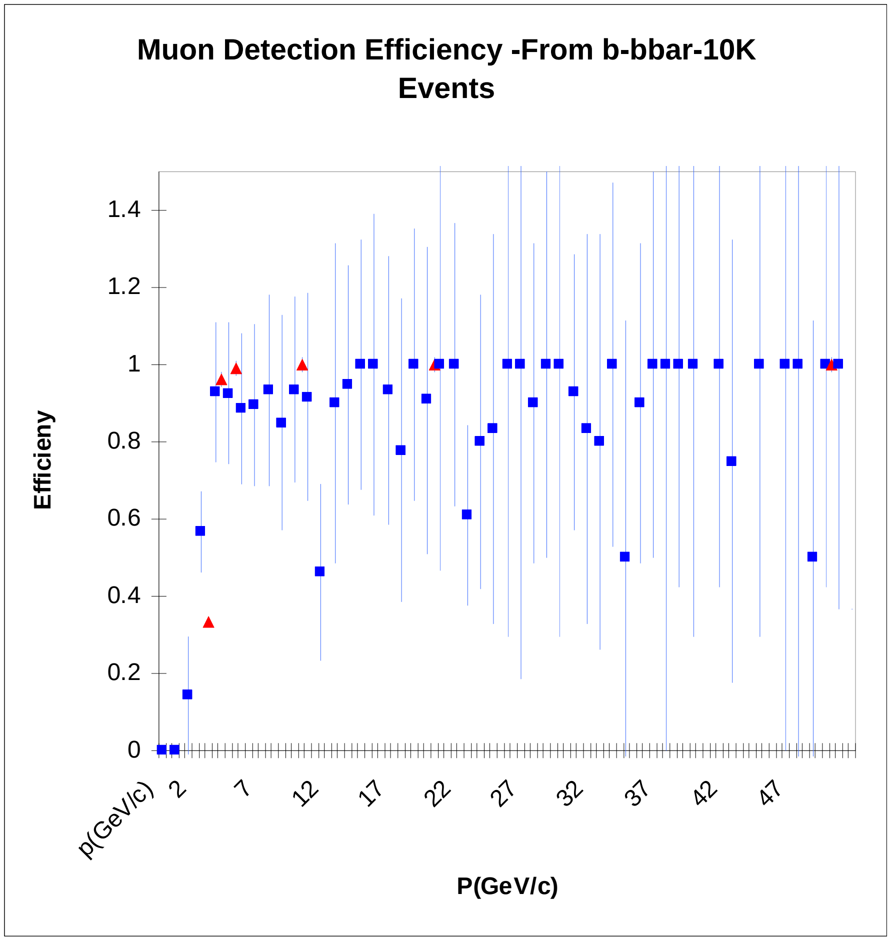
4- Detection Efficiency in jets

- In the next transparencies, the momentum distribution of the signal and main backgrounds are shown after applying our algorithm.
- We normalize to generated particles above 2.96 GeV and not to the whole momentum range , since particle with Momenta < 3 GeV are not reaching the Muon detector.
- Then the Muon detection efficiency in jet is shown for ≠P
- The hadron background is discussed
- Following is summarized the Momentum distribution of generated and detected muons in jets overlayed to their main background, the pions.

Detected MU/Pi/K/p-10k BBbar



Muon Detection Efficiency

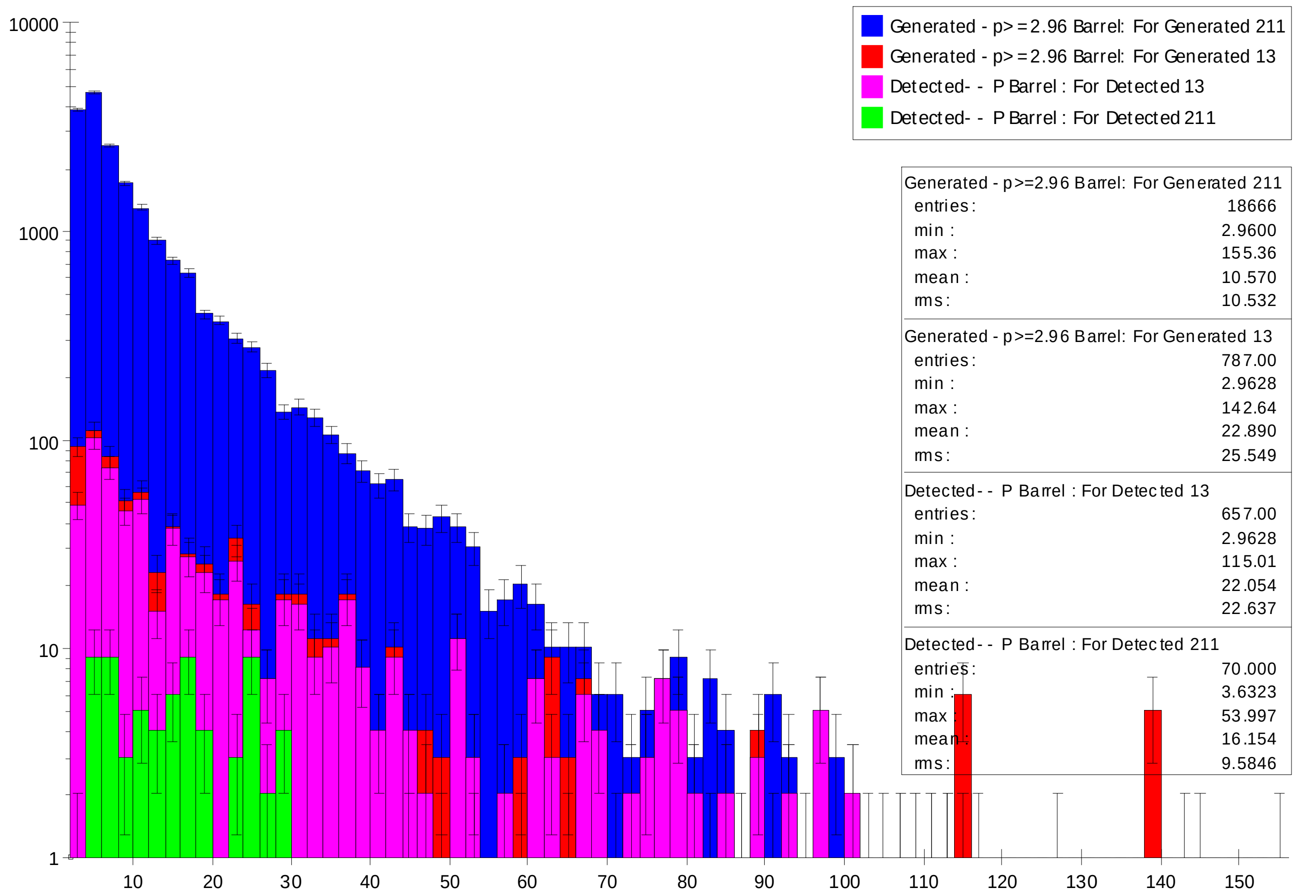


•Blue the jet points, with ~1/p angle cut At low momenta

•Red the single data points, before Making the Momentum dependant Cut.

By opening the angular cuts for the low Momenta, the efficiency at 3 GeV is now ~60%, instead of 33%

10k b-bbar-Pions & Muons Generated With P>2.96 GeV



P(GeV/c)- 2GeV/bin

- Generated Pions in Blue
- Generated Muons in Red
- Detected Muons in Magenta

- Pions Detected as Muons In Red

<u>Remark:</u>

Below 2.96 GeV the Particles do not reach The Muon Detector

Background: Rejection Efficiency

	Pion BG	K BG	Proton BG
Generated >3 GeV	18666 (55805)*	4473 (8310)*	1622 (2816)*
Detected	70	41	2
Rejection Efficiency	1 to 267	1 to 109	1 to 811

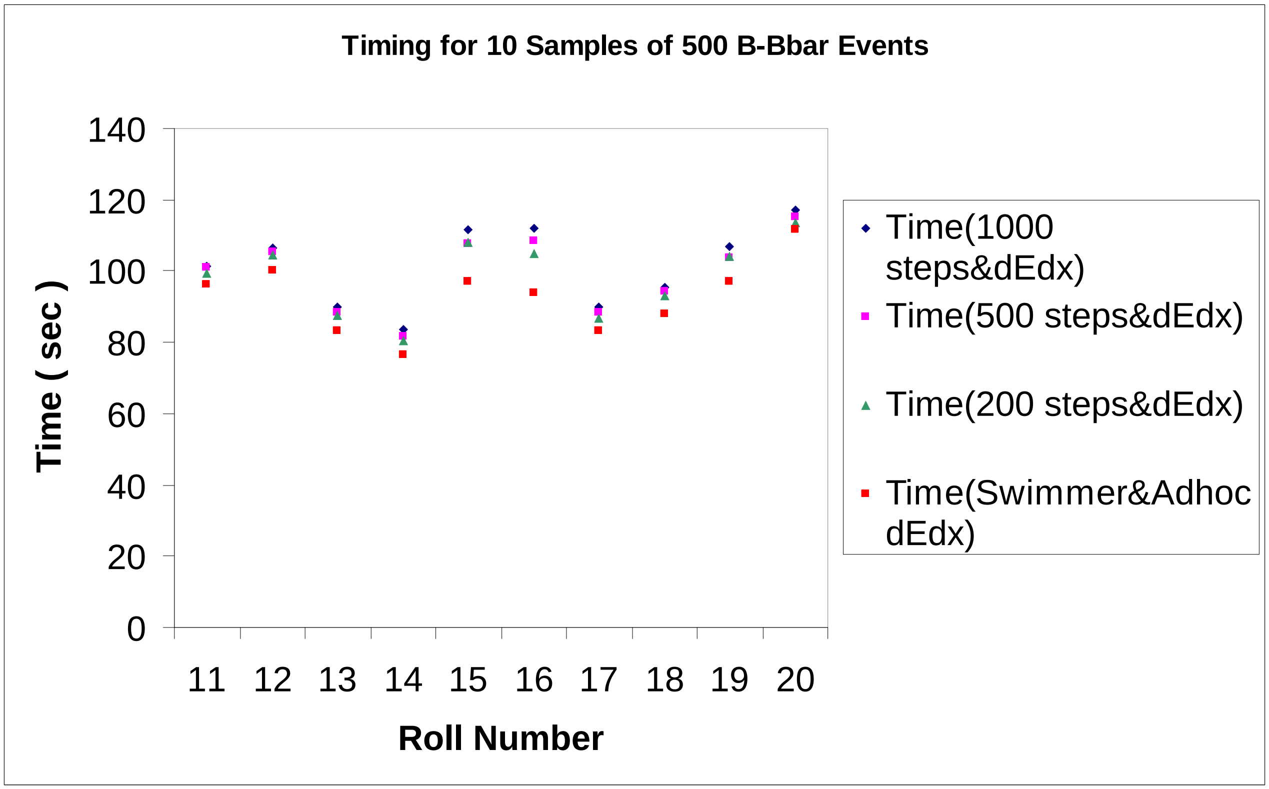
•Generated Particles above >2.96 GeV used To calculate the Rejection Efficiencies.

Using he swimmer we were getting after cuts ~603 Muons, 111 Bg

Now with the stepper & the HDCal filtering we Get:
657 Muons, 113 Bg

*The total Generated
69% of the Muons(787 out of 1147muons) have a Momentum above ~3 GeV.
One notices that less than 34% of the pions, 54% of the kaons and 58% of the protons Have a momentum above ~3 GeV.

Timing Using b-bbar samples of 500 events



•Both the Code, of the Muon reconstruction And of the stepper have been optimized.

•The figure represents The time measured for 10 Samples of 500 b-bbar
a) While requiring 200, 500, and 1000 steps In the tracker
b) With the swimmer

Remark:

•*The present code with the stepper is only 4% slower than the previous code with the swimmer*

• *The time difference between 200 steps and 1000 steps in the stepper is small, showing that the time spent in the process does not dominate the software*.

Conclusion

- In the lower Energy end the Muon detection efficiency has been shown to improve by ~30% by using :

  1-the stepper

  2-and ad-hoc cut to absorb the scattering

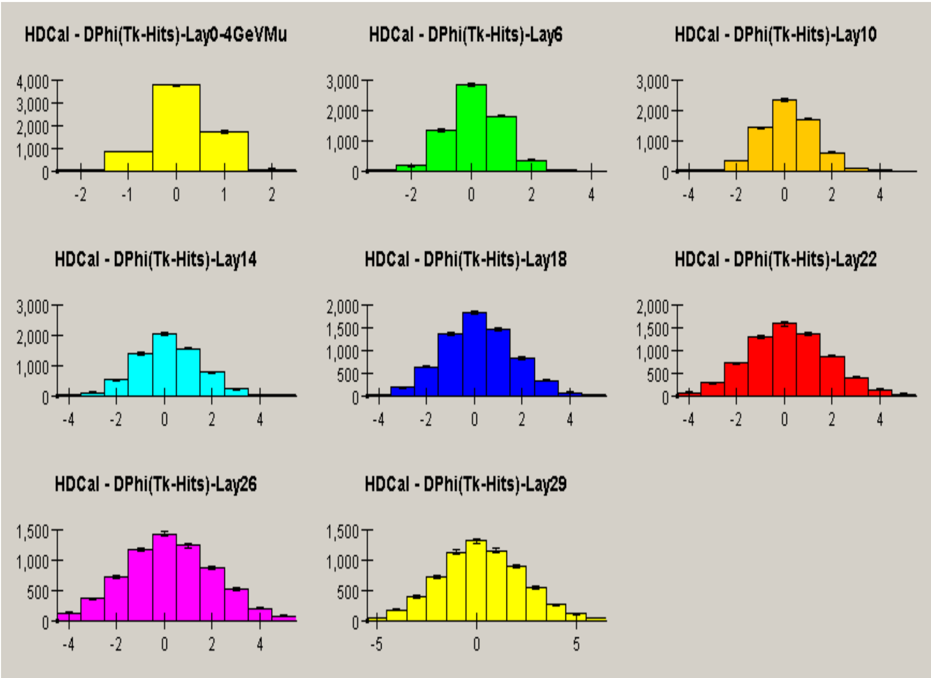
  3-The very 4 last layers of HCAL as an extension of Mudet as a new algorithm using HDCal with no Mu Loss

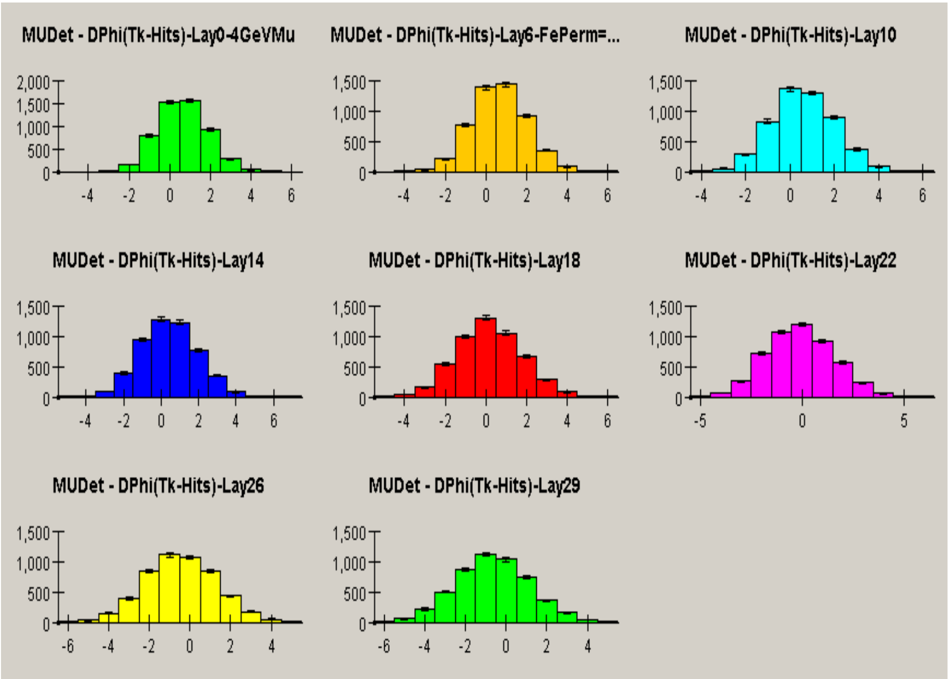
- The rejecting power, normalized to the generated pions above 3 GeV is1 to 227 and replacing the ad-hoc cut by a more elaborate cut should bring more benefit in resolving the background.

Remark: The stepper code will be available as well as the updated Mu code on freehep

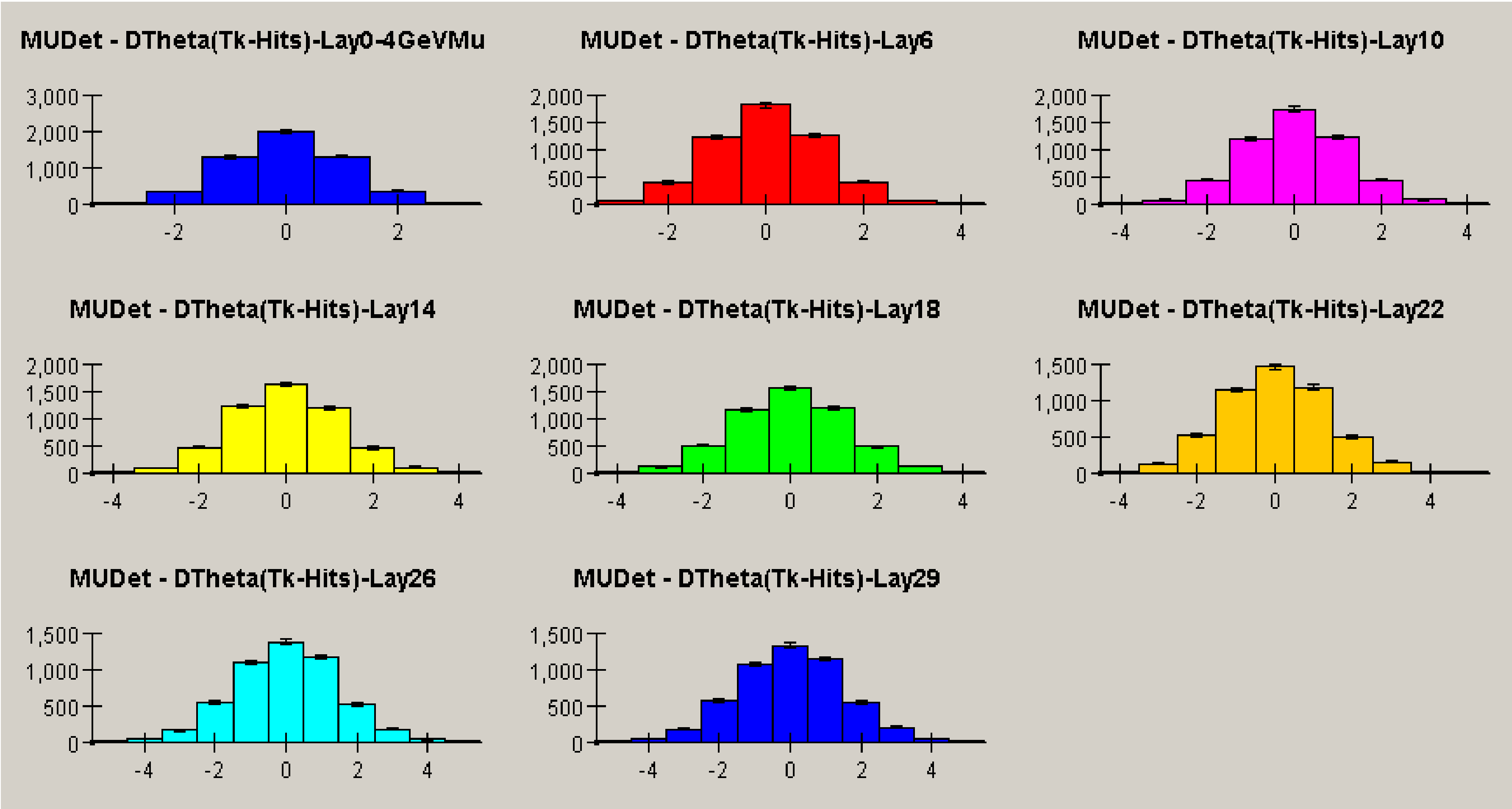
Backup

5d-The ΔΦ (track-hit) – 4GeV Muons HCAL(left) MUDET(right)

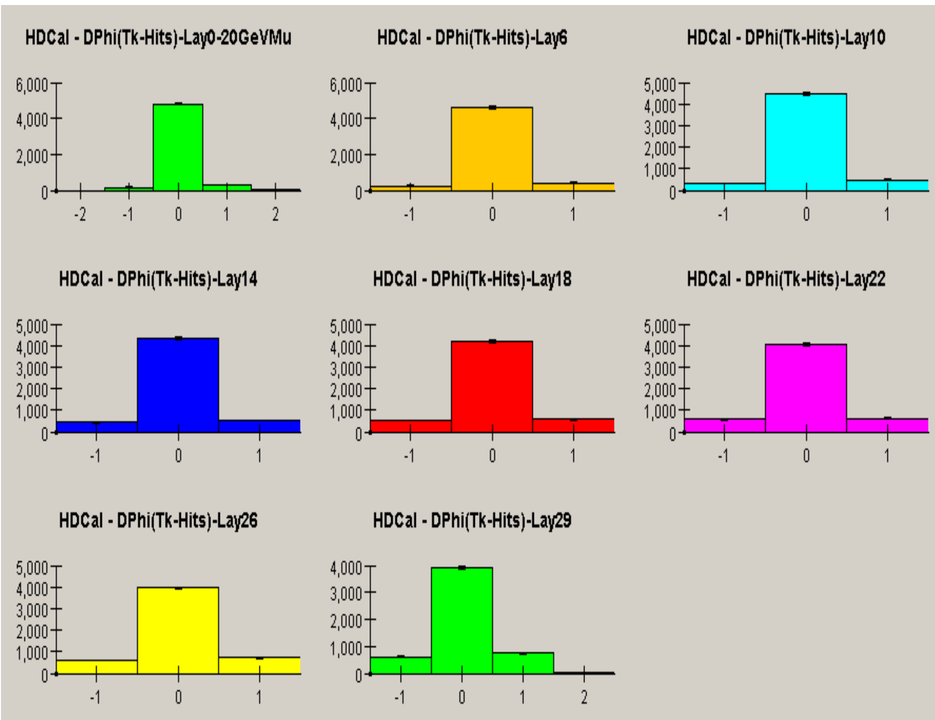


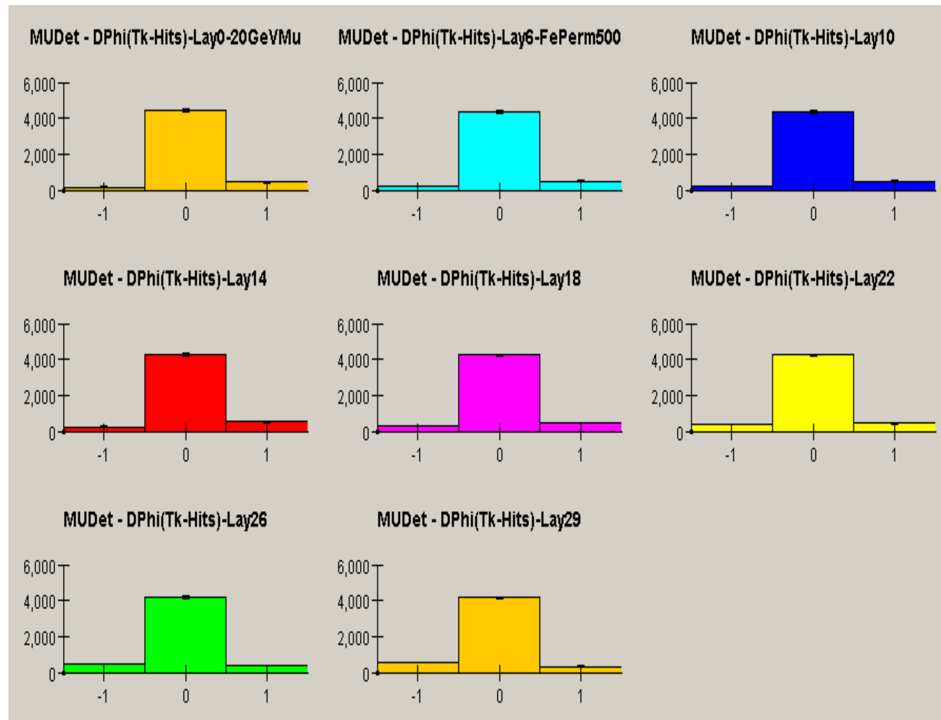


5e-The ΔΘ(track-hit)- 4 GeV Muons in MUDET

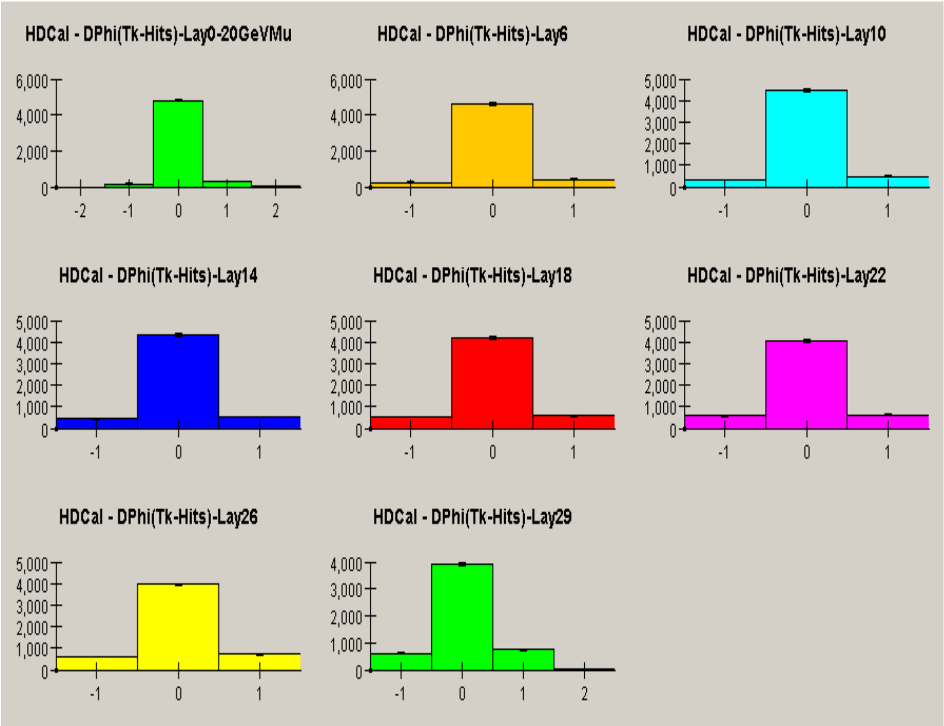


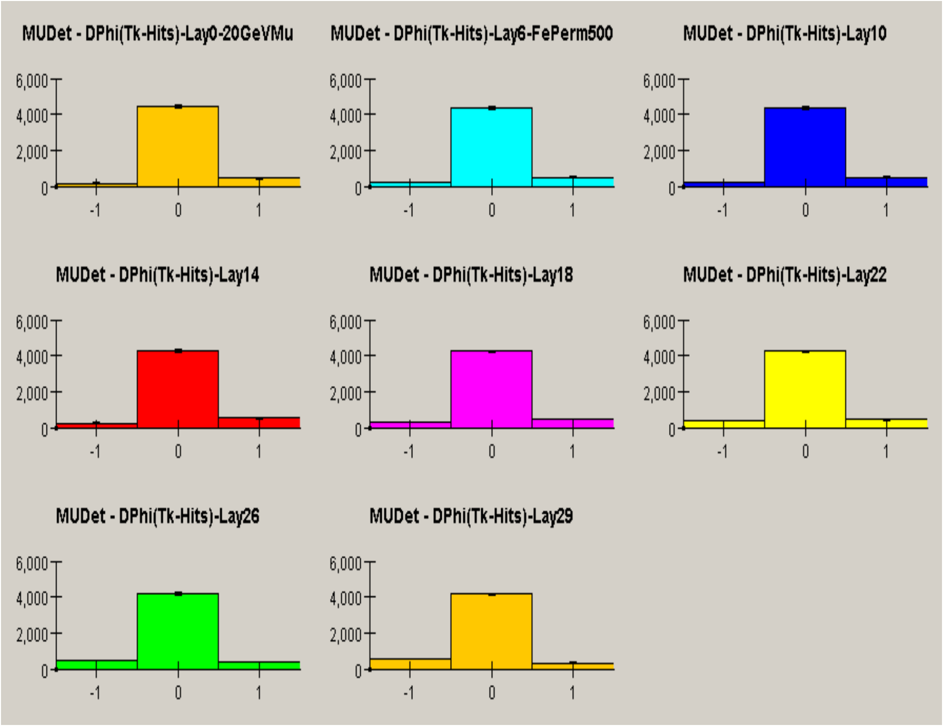
5g-The ΔΦ (track-hit) – 20GeV Muons HCAL(left) MUDET(right)





5g-The ΔΦ (track-hit) – 20GeV Muons HCAL(left) MUDET(right)





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 (cont)

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

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

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.

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

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

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

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

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

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

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

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

Layers Involved along the particle trajectory with a 5 GeV Mu(3left) and a 5 GeV Pi(3right)-EM- HD- Mudet