Muon ID Algorithm Development-and MultiScattering

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•Part of the μ 's below 5 GeV are lost with the actual algorithm.
We will try to broaden our acceptance toward low energy μ's .

•The starting point:

–$\Delta\phi$(Tk-Hits)=4bins, $\Delta\theta$(Tk-Hits)=2bin in the Mu Detector

$$\Delta\phi_{bin} = \Delta\theta_{bin} = 21 mrd$$

–$\Delta\phi$(Tk-Hits)=3bins, $\Delta\theta$(Tk-Hits)=1bin in the HAD Calorimeter

$$\Delta\phi_{bin} = \Delta\theta_{bin} = 5.2 mrd$$

–Nhits = 12 hits, in the Mu Detector

• The Goal: Increase the Acceptance to Low Energy μ

– 1)By Improving the existing cuts

– 2)By Including the EM Calorimeter into the ID package.

Improving the Cuts

The low energy μ ‘ s are considerably bent by the 5 Tesla Magnetic Field and replacing the fixed angle cut by a 1/p Angle Cut might be very useful.

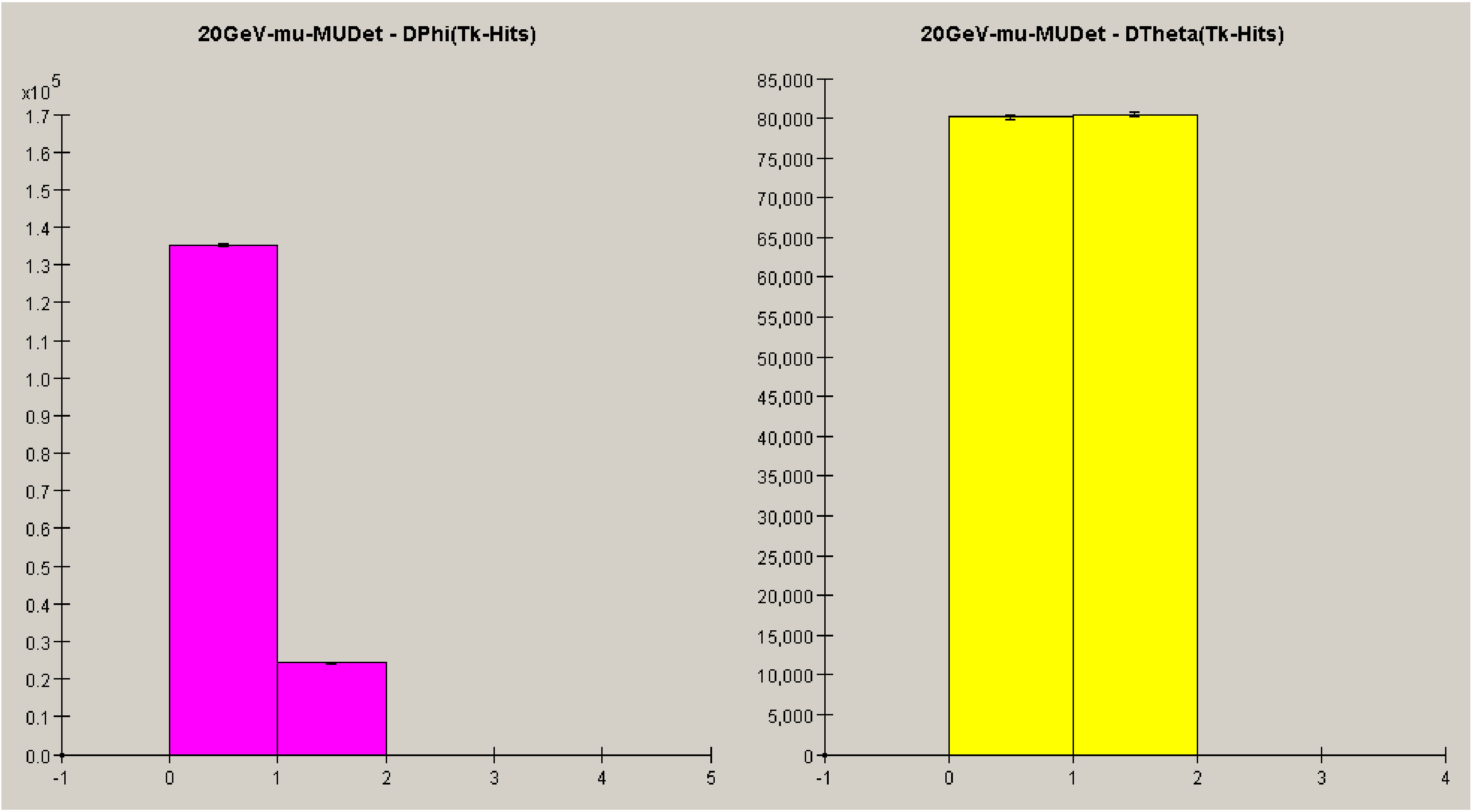
We will first define our 1/p cut in the Mu Detector, using the actual distributions of $\Delta\phi$(Tk-Hits), $\Delta\theta$(Tk-Hits) at higher energy. The 20 GeV distributions shown in the next figure have been chosen.

<u>The cuts</u> :

$\Delta\phi(\text{Tk-Hits}) = \text{Max}(\ (2\text{bins}*20/P_{mom}),2\text{bins})$

$\Delta\theta(\text{Tk-Hits}) = \text{Max}(\ 1\text{bin}*(1+(20/P_{mom})\ )\ ,\ 2\text{bins})$

Distribution of Δϕ(Tk-Hits) , Δθ(Tk-Hits) For 20 GeV μ



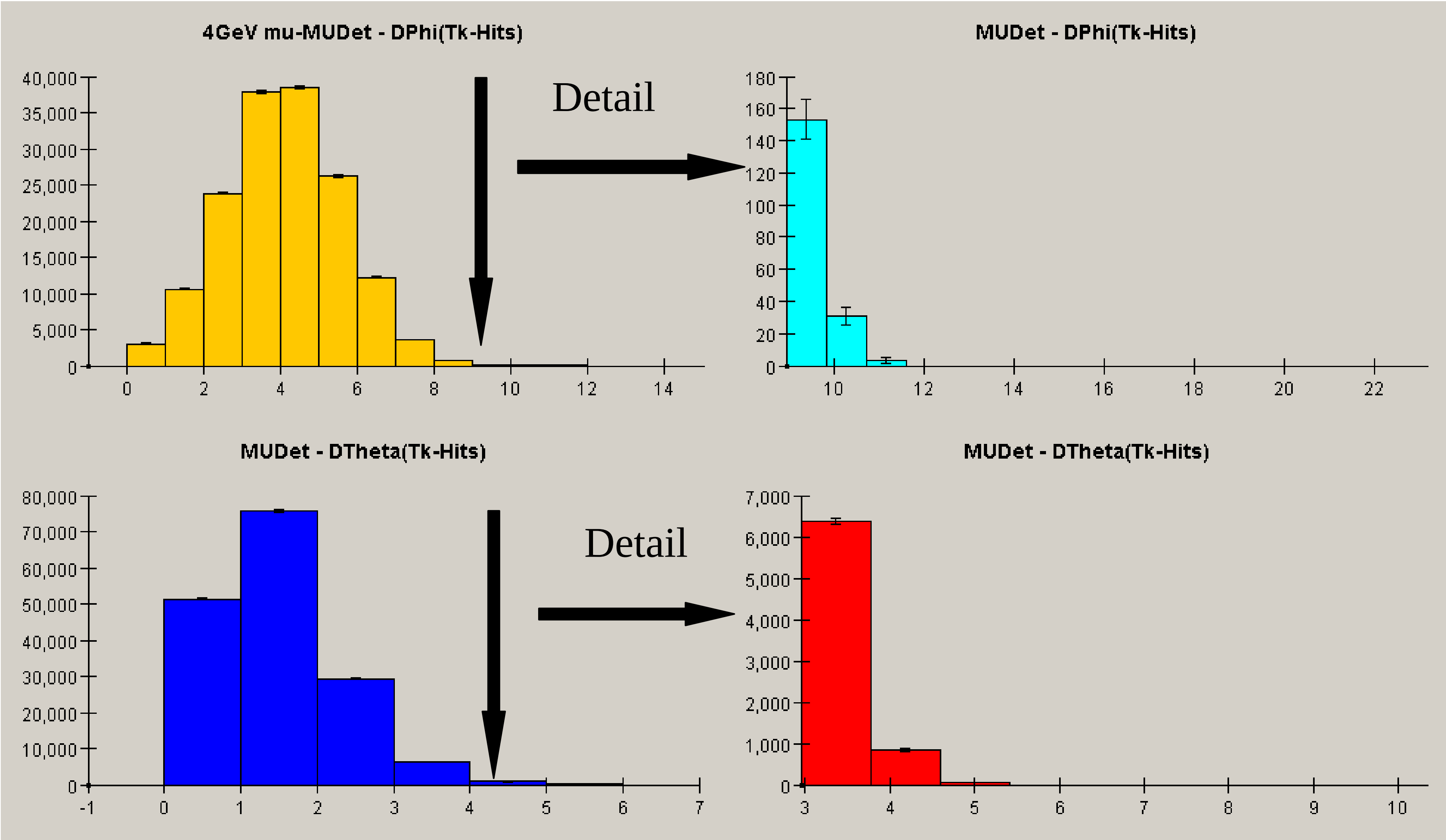
Distribution of $\Delta\phi$(Tk-Hits) , $\Delta\theta$(Tk-Hits) (continue1)

<u>This corresponds to the cuts:</u>

At 3GeV/c: $\Delta\phi$(Tk-Hits) = 13 bins, $\Delta\theta$(Tk-Hits) = 7bins
At 4GeV/c: $\Delta\phi$(Tk-Hits) = 10 bins, $\Delta\theta$(Tk-Hits) = 6bins
At 5GeV/c: $\Delta\phi$(Tk-Hits) = 8 bins, $\Delta\theta$(Tk-Hits) = 5bins
At 10GeV/c: $\Delta\phi$(Tk-Hits) = 4 bins, $\Delta\theta$(Tk-Hits) = 3bins
At 20GeV/c and Above : $\Delta\phi$(Tk-Hits) = 2 bins, $\Delta\theta$(Tk-Hits) = 2bins

There is a good agreement with those cuts, as shown at lower Energy as seen at 4 GeV/c in the next figure.

Distribution of $\Delta\phi$(Tk-Hits) , $\Delta\theta$(Tk-Hits) 4GeV/c - μ

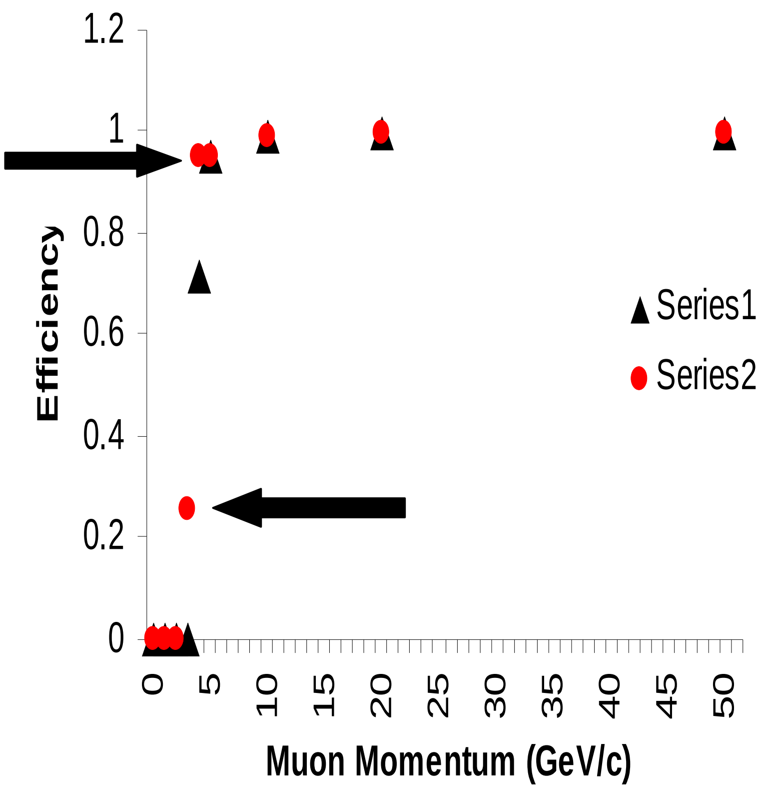


Distribution of $\Delta\phi$(Tk-Hits) , $\Delta\theta$(Tk-Hits) (continue2)

<u>Applying those cuts</u> <u>the μ Acceptance rises:</u>
At 3 GeV from 4/5000 μ ~0.08% to 1263/5000 μ ~25.3%
At 4 GeV from 3792/5000 μ~75.84% to 4770/5000 μ~95.4%
At 5 GeV the gain is negligible and above the cuts coincide with the previous constant cuts.
<u>Remark</u>: At 2 GeV and below, the μ ‘s curl in the magnetic field and don’t reach the Mu Detector

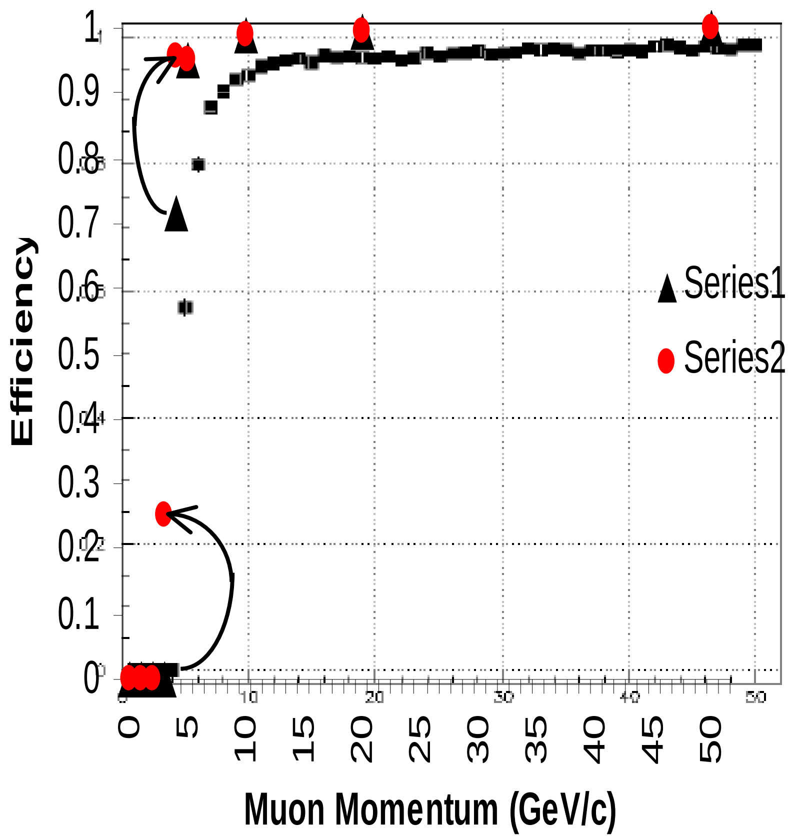
In the next figure the m detection efficiency curve is represented With the new improved acceptances at low energies.

Single Muon Efficiency = F(Particle Momentum)



In red are represented the
Points with (1/p) angle cut
dependence
The point at 3GeV/c which
raised From 0.08% (x axis)
Black triangle to 25.3% and
at 4GeV/c from ~75.8%
to ~95.4% and tops the 5 GeV/c
Points obtained in the previous
algorithm.

Muon Efficiencies =f(p)



μ <u>Efficiency for SD</u> :
Represented on top of the plot of M.Piccolo for Tesla , without and with <u>DeDx</u> <u>Correction</u>. <u>Low Momenta</u> are mostly affected by the DeDx Correction

We use M. Piccolo algorithm:

- A μ stub crossing at least 8/11 planes (80cm of steel)
- A stub is defined by angular hits consistency in MuCal: The matching is within:

$$\Delta\Phi \sim 40\text{mrd} \quad \Delta\theta \sim 40\text{mrd}$$

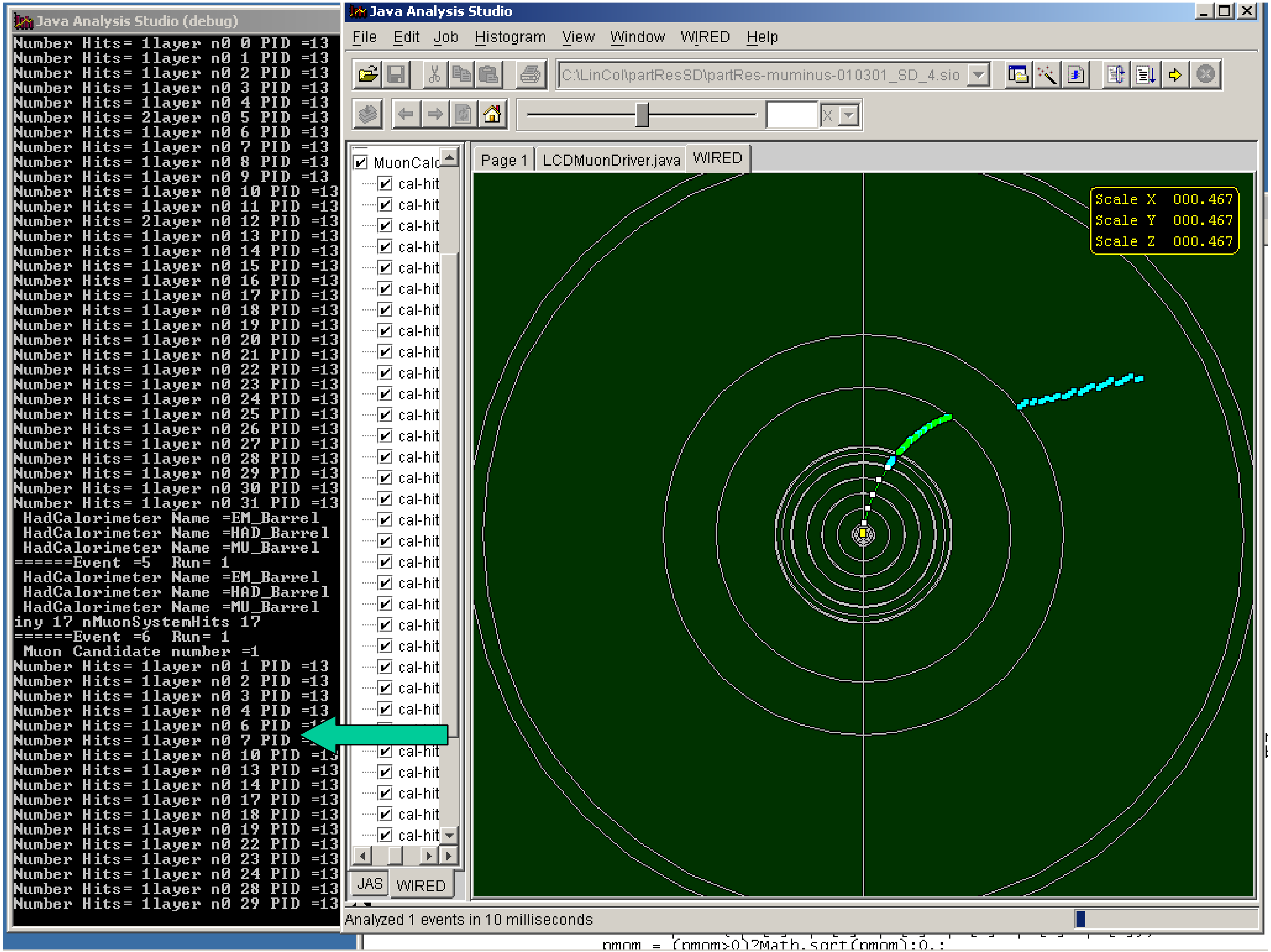
TESLA : Black squares
SD : Black triangles
Red circles <u>after DeDx</u> Correction

Examples of Events Which benefited the cuts

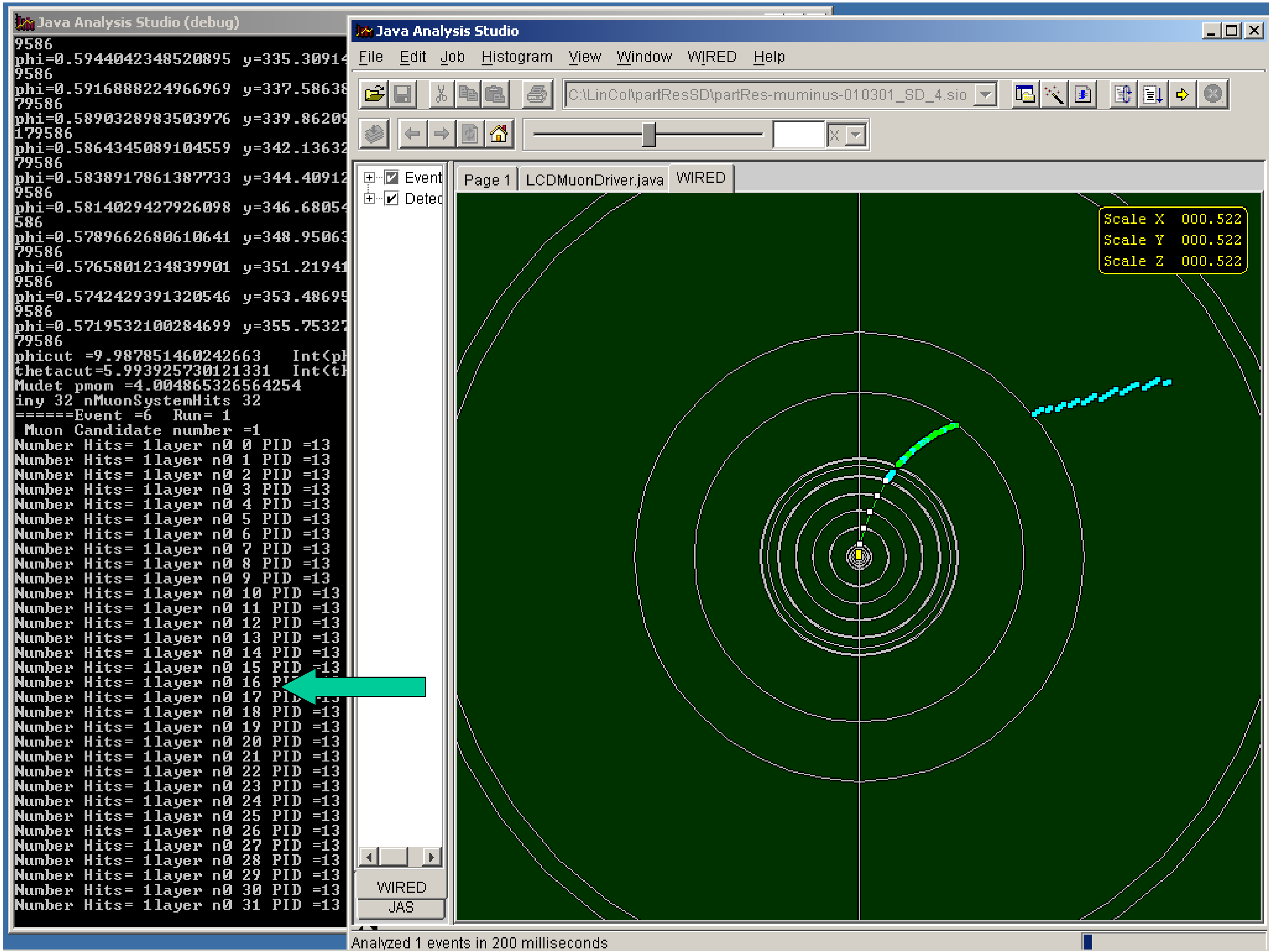
•The momenta dependant cuts did contribute a lot at low energy.
•It allowed to increase the number of Hits collected in the Calorimeters Along the reconstructed track.

•A few Typical muons are shown in the next figures with the improvement fron “Before” And “After” the (1/p) dependant cuts.
• A Double Muons detected in b b_{bar} jets is also shown with the Number of hits collected each track.

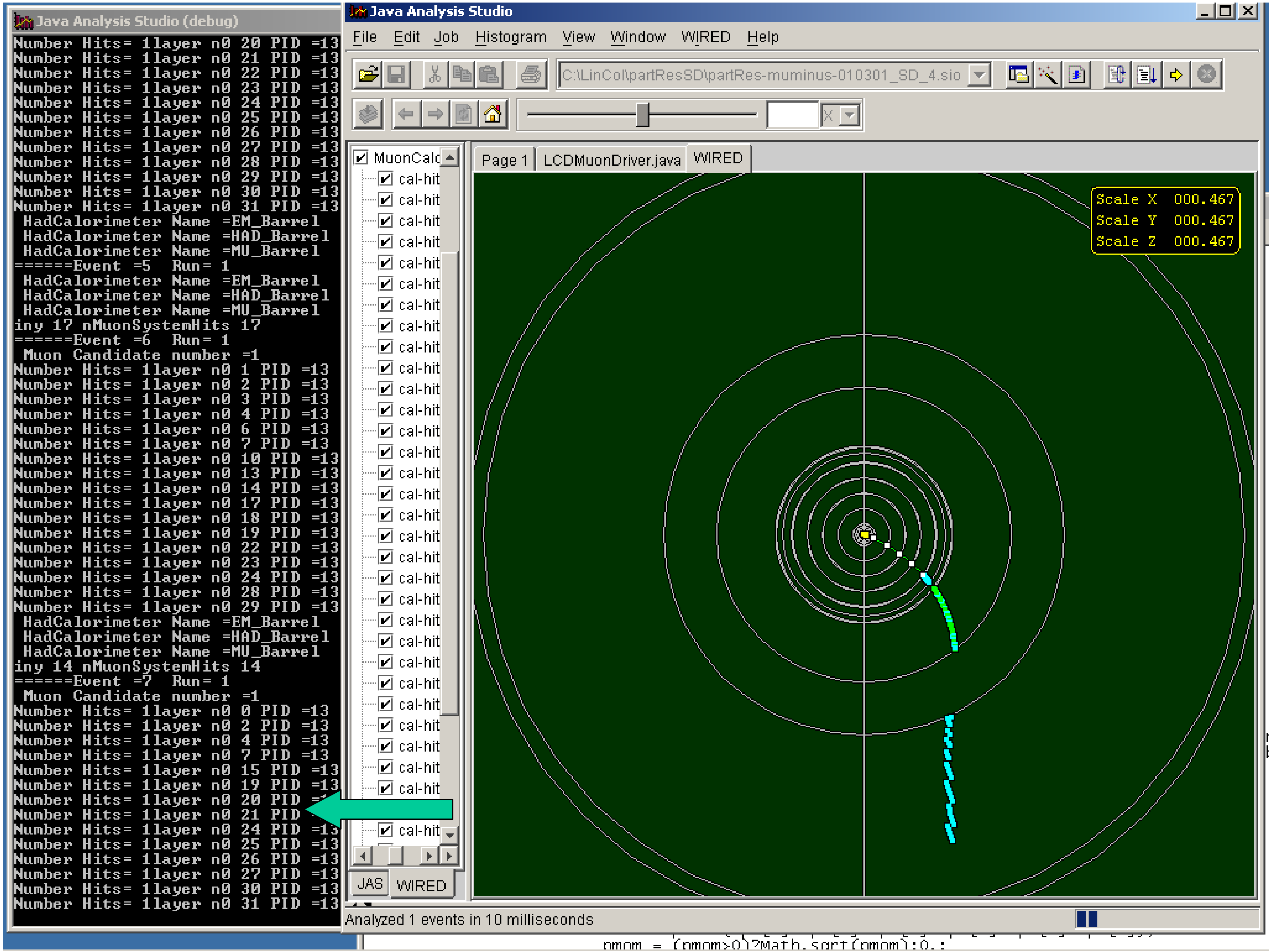
BEFORE-Mu 4GeV-MuDet 17Hits-Constant PhiCut &ThetaCut-Evt 6 Run 1



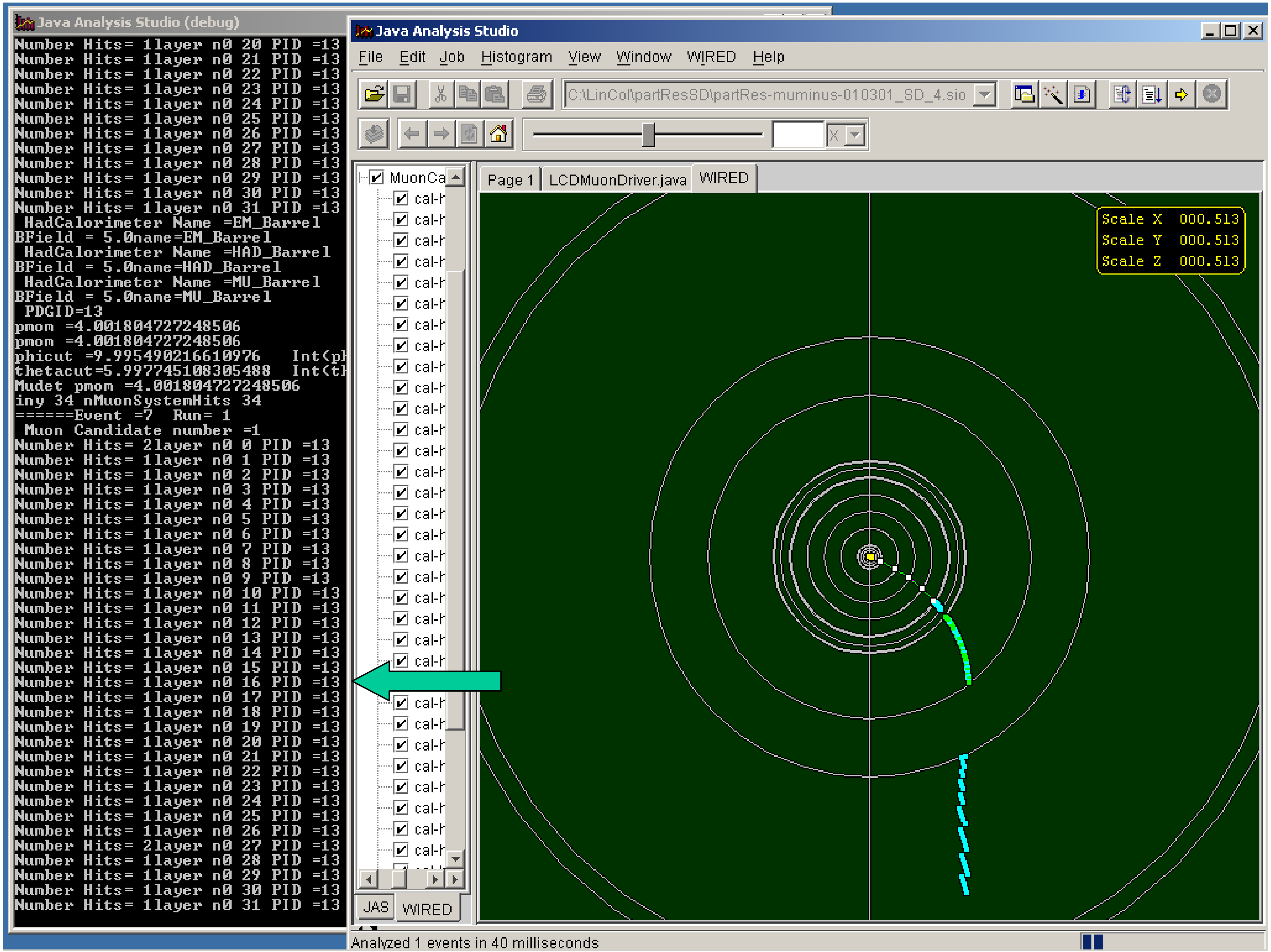
AFTER-Mu 4GeV-MuDet 32Hits- PhiCut &ThetaCut= f(1/p)- Event 6-Run 1



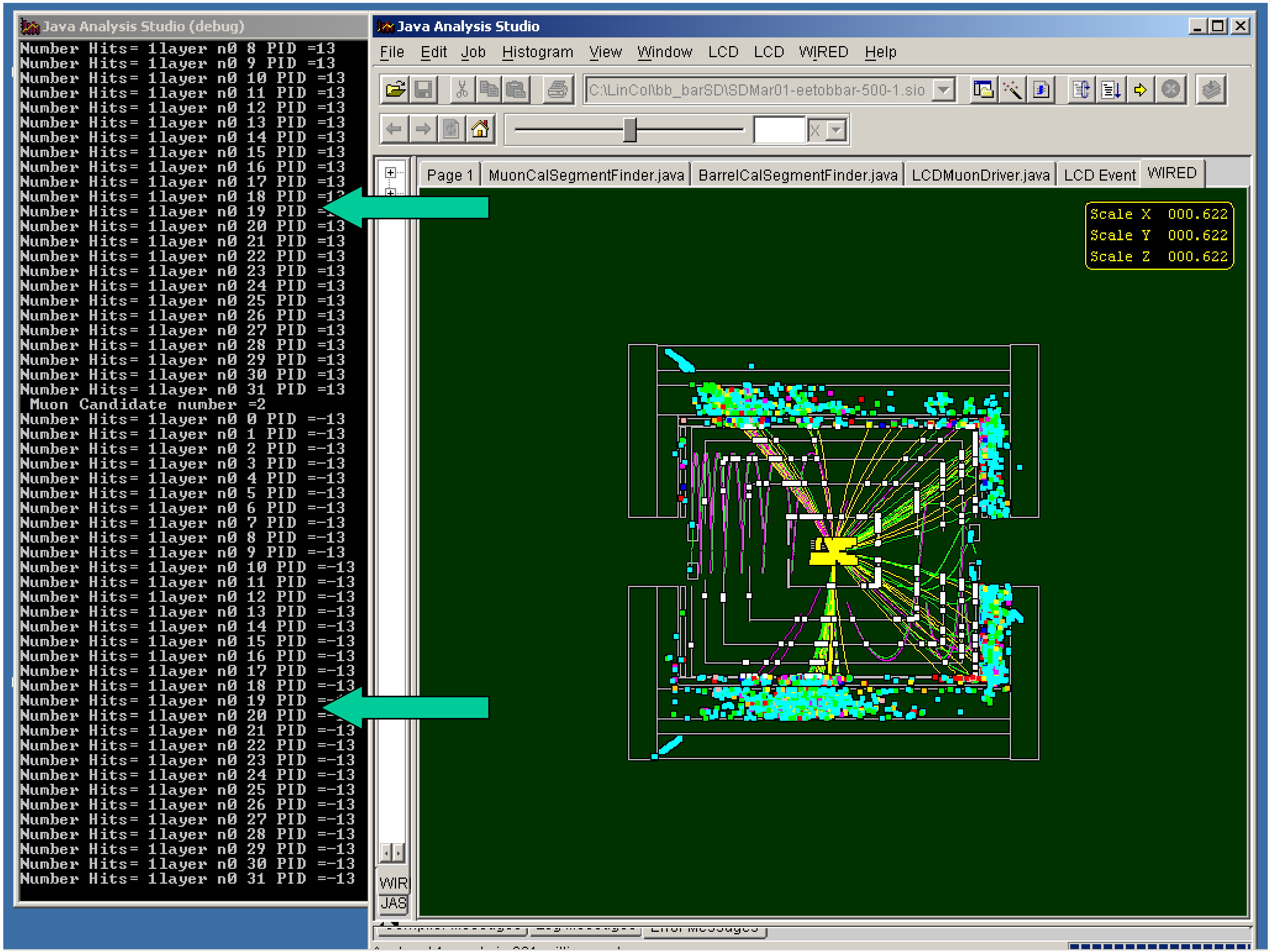
BEFORE Mu 4GeV-MuDet 14Hits-Constant PhiCut&ThetaCut - Event 7-Run 1



AFTER-Mu 4GeV-MuDet 34Hits - PhiCut&ThetaCut = f(1/p)- Event 7-Run 1



BB_bar 2 Detected μ –(Show 31 Hits Both μ's)-
Evt 135



The Multiple Scattering

•The Effect of the multiple scattering on the $\Delta\theta$(TK-Hits)bins and $\Delta\phi$(Tk-Hits)bins from layer 0 to the last layer will be studied in some detail.

•The effect due to the material prior to the detector will be included.

•The multiple scattering in the EM Calorimeter will be calculated, then in the HAD Calorimeter, and the Mu Detector including all the Material in the way, e.g. ~10cm C in between the EM and the HAD, And the coil before the Mu Detector. DX0 will be calculated and $\Delta\theta$ (which depends on θ) and $\Delta\phi$ evaluated for extreme cases.

The bin size is:

For EM= 4mrd, for HAD=5.2mrd, for MuDet = 21 mrd.

Sampling X0_EM - X0_HAD- X0_MuDet

EM:	
W:0.25cm	X0_EM=0.35*2=0.70cm
other:0.25cm	
HAD:	
Steel:3cm	X0_HAD=1.76*(4./3.)=2.34cm
other:1cm	
MuDet:	
Steel:5cm	X0_MuDet=1.76*(6.5/5.)=2.29cm
other:1.5cm	

DX0_EM, DX0_HAD, DX0_MuDet =F(Layer Number)

The number of radiation length encountered by the particles depends in the number of layers gone through.

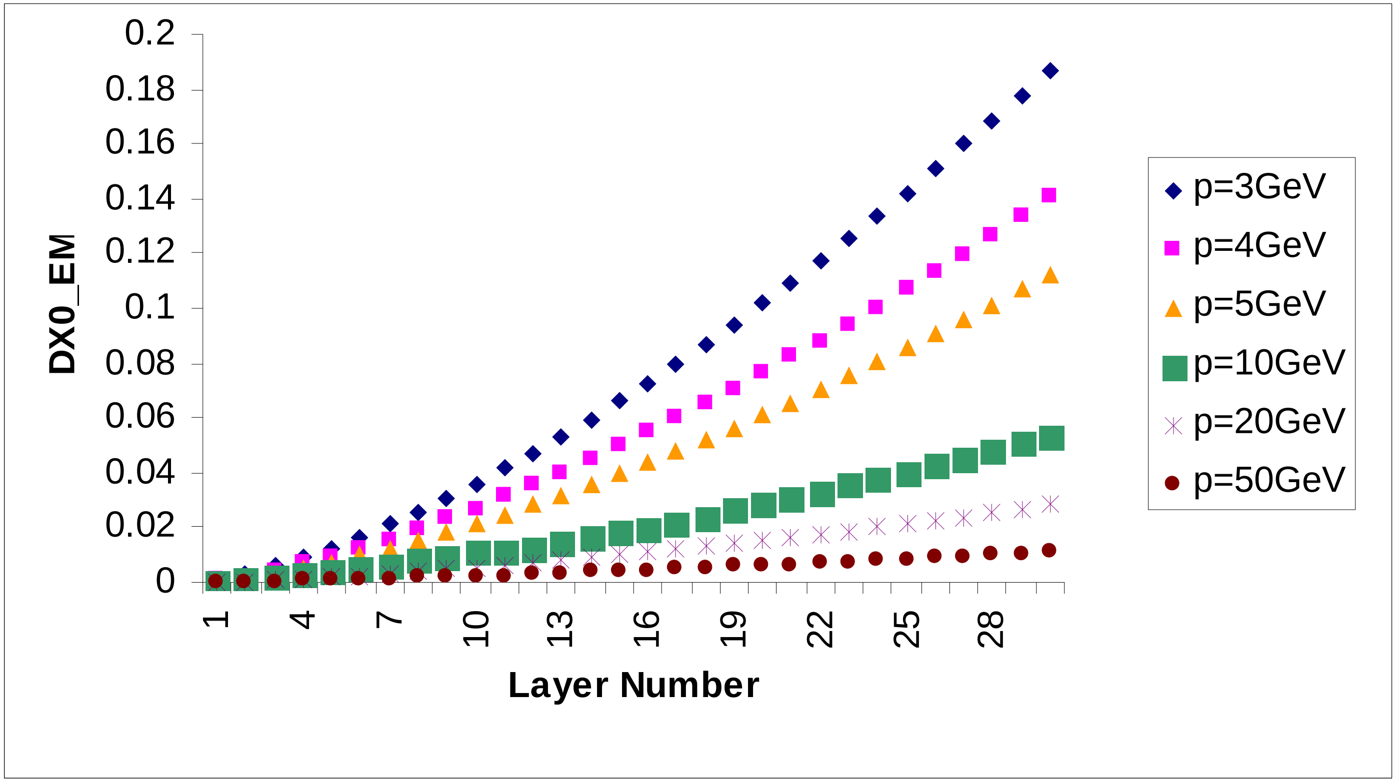
$\Delta X0 = 1/\mathrm{sqrt}(3) * .014/p * \mathrm{sqrt}(N*d/Xo) * N*d$

p is the particle momentum GeV/c
N is the number of layers
d is the layer thickness in cm

EM: d/X0 = 0.5/0.7 ; N = 0-29
HAD: d/X0 = 4./2.34 ; N = 0-33
MuDet: d/X0 = 6.5/2.29; N = 0-31/48
(0-31 instrumented)

ΔX0_EM=F(Layer Number)

ΔX0_EM at the highest at low energy and in the last layer



DX0_EM, DX0_HAD, DX0_MuDet =F(Layer Number) (continue)

Each of the calorimeters is part of the Detector and as such the Particles experience Multiple Scattering in material before reaching the calorimeter. This has not been accounted for yet.

For the <u>HAD</u> calorimeter, mostly the whole EM calorimeter:(~0.56/p)
And ~10cm of Carbon left in between detectors(~0.059/p)

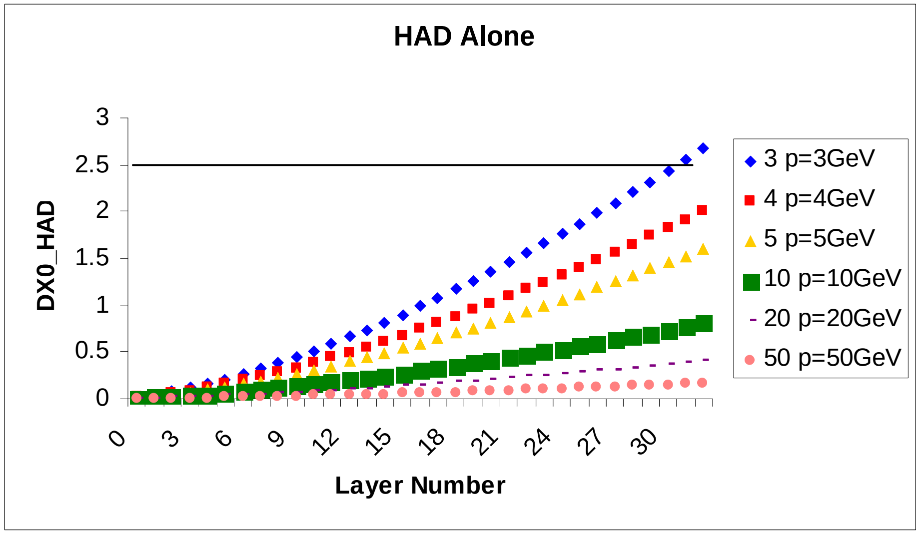
Dx0_HAD_Deteco= sqrt(DX0_EM_Tot*DX0_EM_Tot +
DX0_C *DX0_C +
DX0_HAD*DX0_HAD)

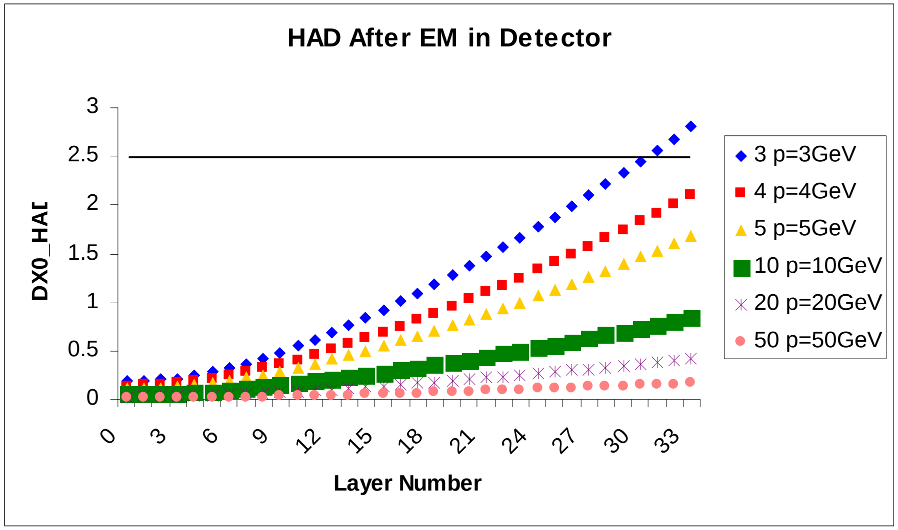
For <u>MuDet</u> mostly EM(~0.56/p),HAD(~8.38/p) the Carbon and the Coil(~2.39/p):

DX0_MuDet_Deteco = sqrt(DX0_EM_Tot*DX0_EM_Tot +
DX0_C *DX0_C +
DX0_HAD_Tot*DX0_HAD_Tot +
DX0_Coil *DX0_Coil +
DX0_MuDet *DX0_MuDet)

ΔX0_HAD=F(Layer Number)- HAD Calorimeter in SD_Detector

The plots of DX0_HAD for HAD Calorimeter alone and after
The EM Calorimeter are shown below.
The smallest values are affected the most
e.g. 0.1882 instead of 0.0141 at 3GeV Layer 1
,but 2.7998 instead of 2.7934 at 3GeV Layer 33.
By one order of magnitude higher in HAD than in EM



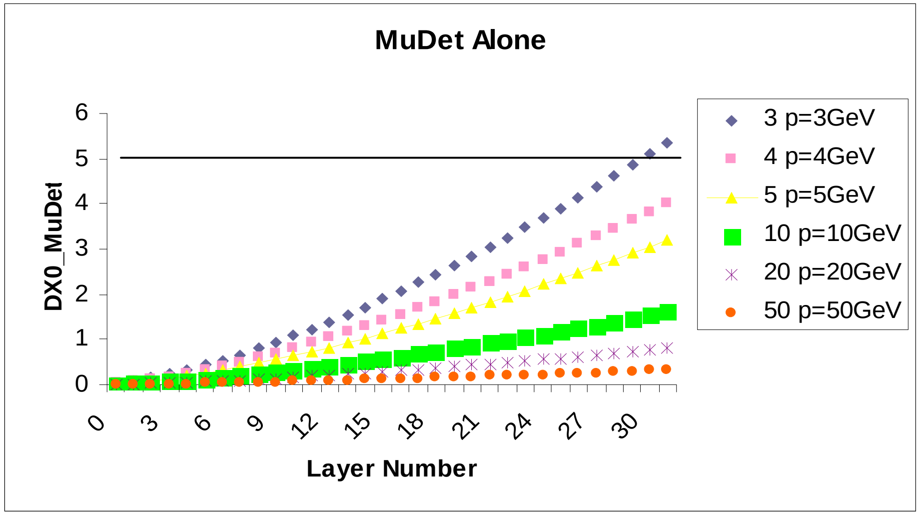


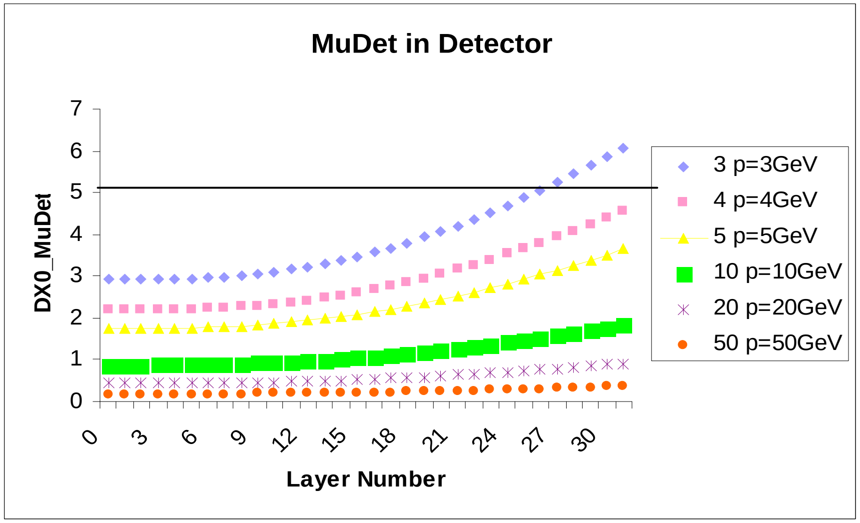
ΔX0_MuDet=F(Layer Number)- MuDet in SD_Detector

The plots of DX0_MuDet for MuDet Calorimeter alone and inside the detector, with the particles multiple scattering in the EM and HAD calorimeters and the Coil.

•It appears clearly that the small values in the first layers are affected the most, the highest values which could increase the cuts staying almost unchanged , with a softer slope .

•Three times bigger in MuDet than in HAD calorimeter





$\Delta\phi$, $\Delta\theta$ (continue1)

The cell in EM :

$\Delta\phi_{cell}$ = $\pi/800$ =4mrd

The cell in HAD:

$\Delta\phi_{cell} = \pi/600 = 5.2$ mrd

Looking at each detector

As a separate entity the figures show

In the EM :

R=R0+N*d, R0= 125cm

$\Delta\phi < 0.18/125 = 1.4$ mrd smaller than the cell

In the HAD :

$\Delta\phi < 2.8/240 = 10.4$ mrd smaller than 2 cells

And $\Delta\theta = 1/((R/\Delta X0 \sin^2\theta)-\text{ctg}\,\theta)$ ranges from 0 to $\Delta X0/R$ the size of the cell.

$\Delta\phi$, $\Delta\theta$ (continue2)

The cell in MuDet:

$\Delta\phi_{cell} = \pi/150 = 21$ mrd

In the MuDet :

R=R0+N*d, R0= 348.5cm , N = 32/48

From the figure one get

$\Delta\phi < 6.08/348.5 \sim 17.5$ mrd smaller than the MuDet cell

$\Delta\theta = 1/((R/\Delta X0 \sin^2\theta)-\mathrm{ctg}\,\theta)$ ranges from 0 to $\Delta X0/R$:

For a 3 GeV μ in layer 33 $\Delta\theta < 6.08/348.5 \sim 17.5$ mrd (see fig.)

Conclusion:

The Multiple Scattering is included in 1-2 cells of EM and 2-3 Cells in the HAD as well as in MuDet. A 2-3 cells cut will include the Multiple Scattering within 1 Standard deviation.

Multiple Scattering (Conclusions)

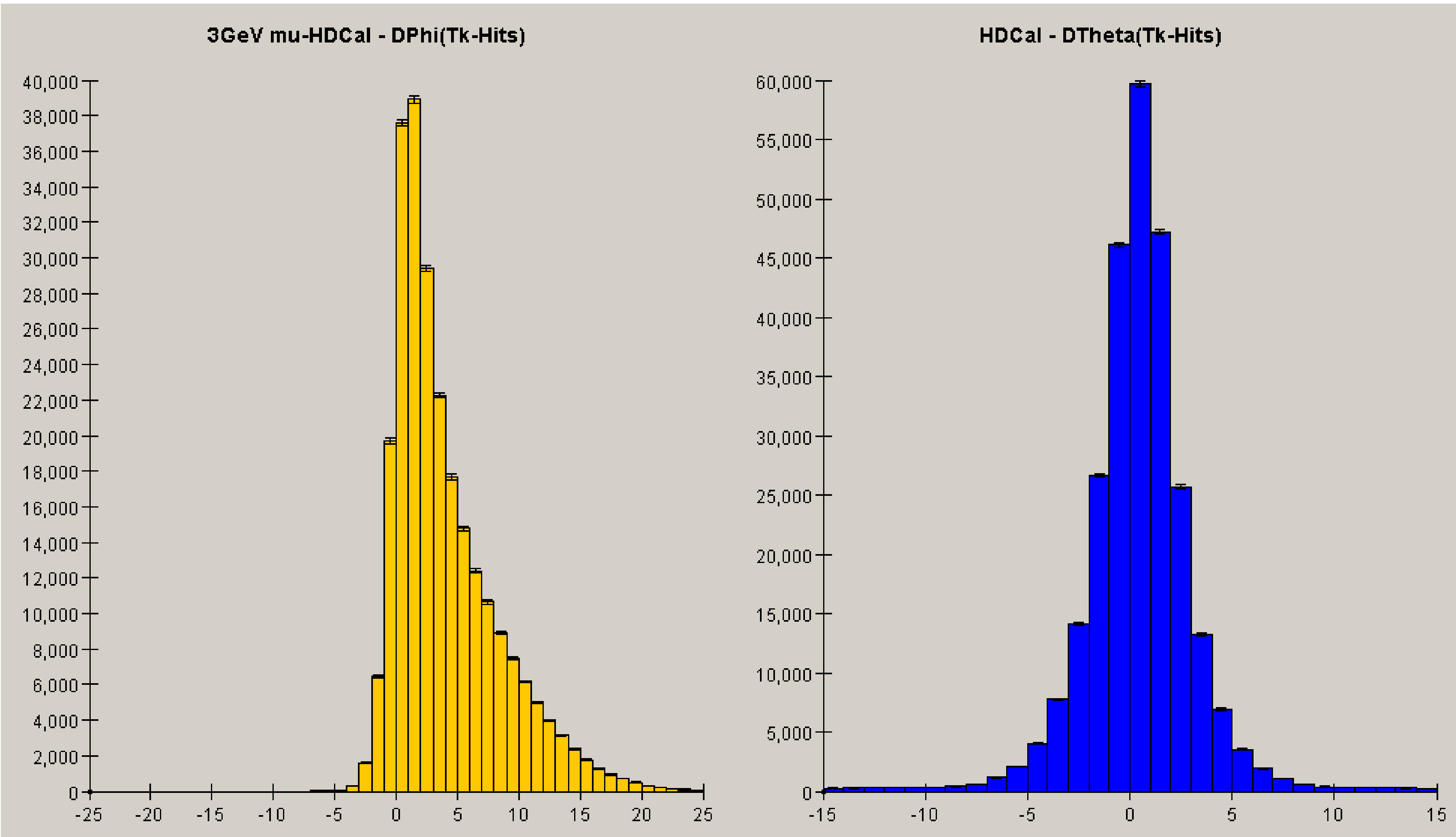
<u>Conclusion:</u>

•The multiple scattering is not a problem it is included within 1-2 bins in the EM , 2-3 bins in the HAD and within 1-2 bins Of the MuDet

Therefore even at low energy it does not account for the larger Cuts needed.

•Looking at the distributions $\Delta\phi$(Tk-Hits) and $\Delta\theta$(Tk-Hits) without Taking the absolute value, one notices a clear asymmetry , next Figure, and it comes from the fact that the loss of Energy of the particle in the material is not accounted for in the extrapolation of the track (Ron Cassell: the swimmer does not).

Asymmetry in Δϕ(Tk-Hits)



The Loss of energy through DeDx

•We will find out if the loss of energy through DeDx is accounting for most of the $\Delta\phi$(Tk-Hits),$\Delta\theta$(Tk-Hits).

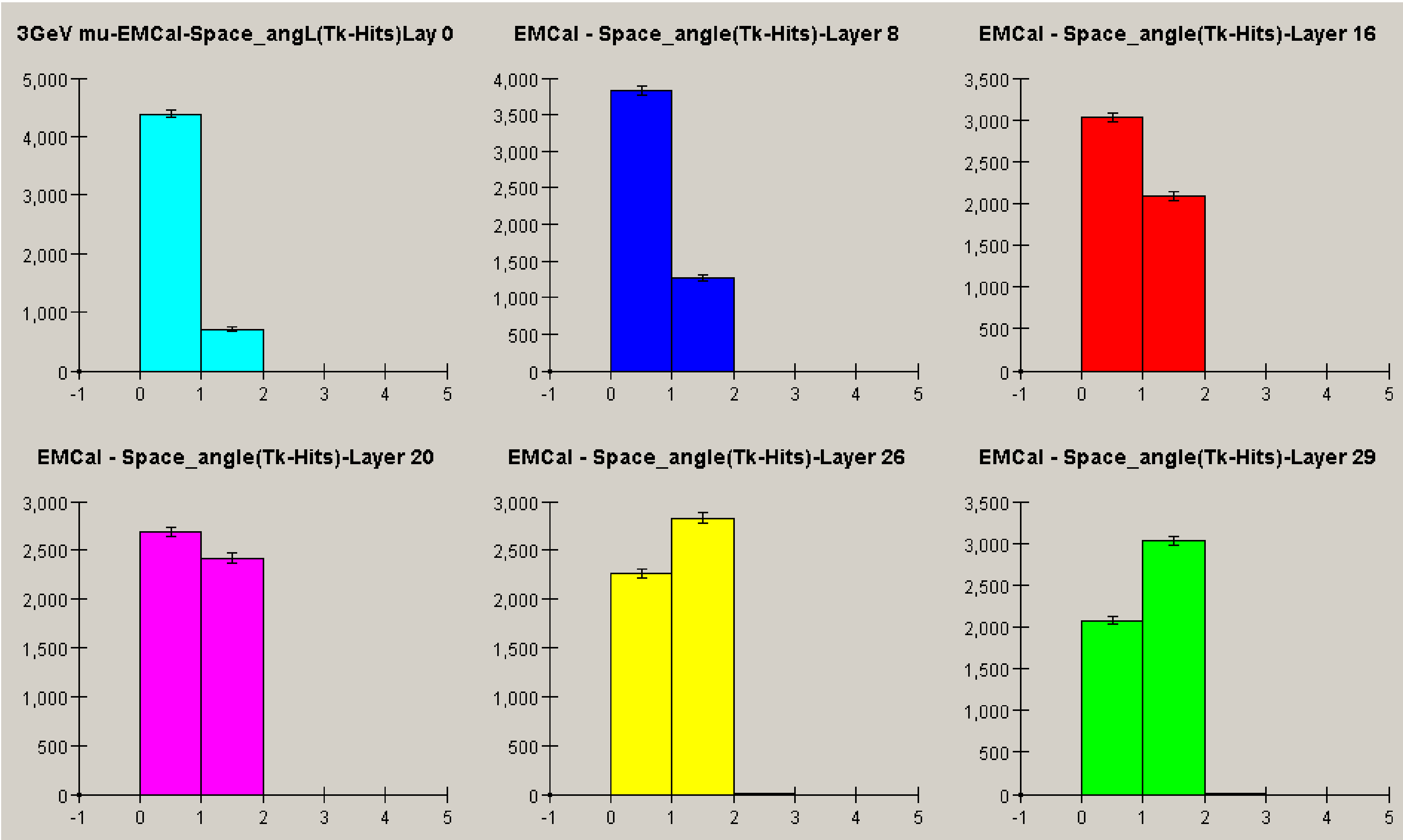
•The effect should be stronger at lower energy, e.g, at 3 GeV/c than at 10GeV/c since a bigger proportion of energy is taken out. At a given energy it increases the farther we go from the Interaction Point, e.g. the effect is stronger in MuDet than in EM Cal, and in MuDet stronger in layer 30 than in Layer 0 as can be seen in the next figures.

•This will be studied through the space angle:
Space_angle =Sqrt($\Delta\phi$(Tk-Hits)^2+$\Delta\theta$(Tk-Hits)^2).

Study with A. Para

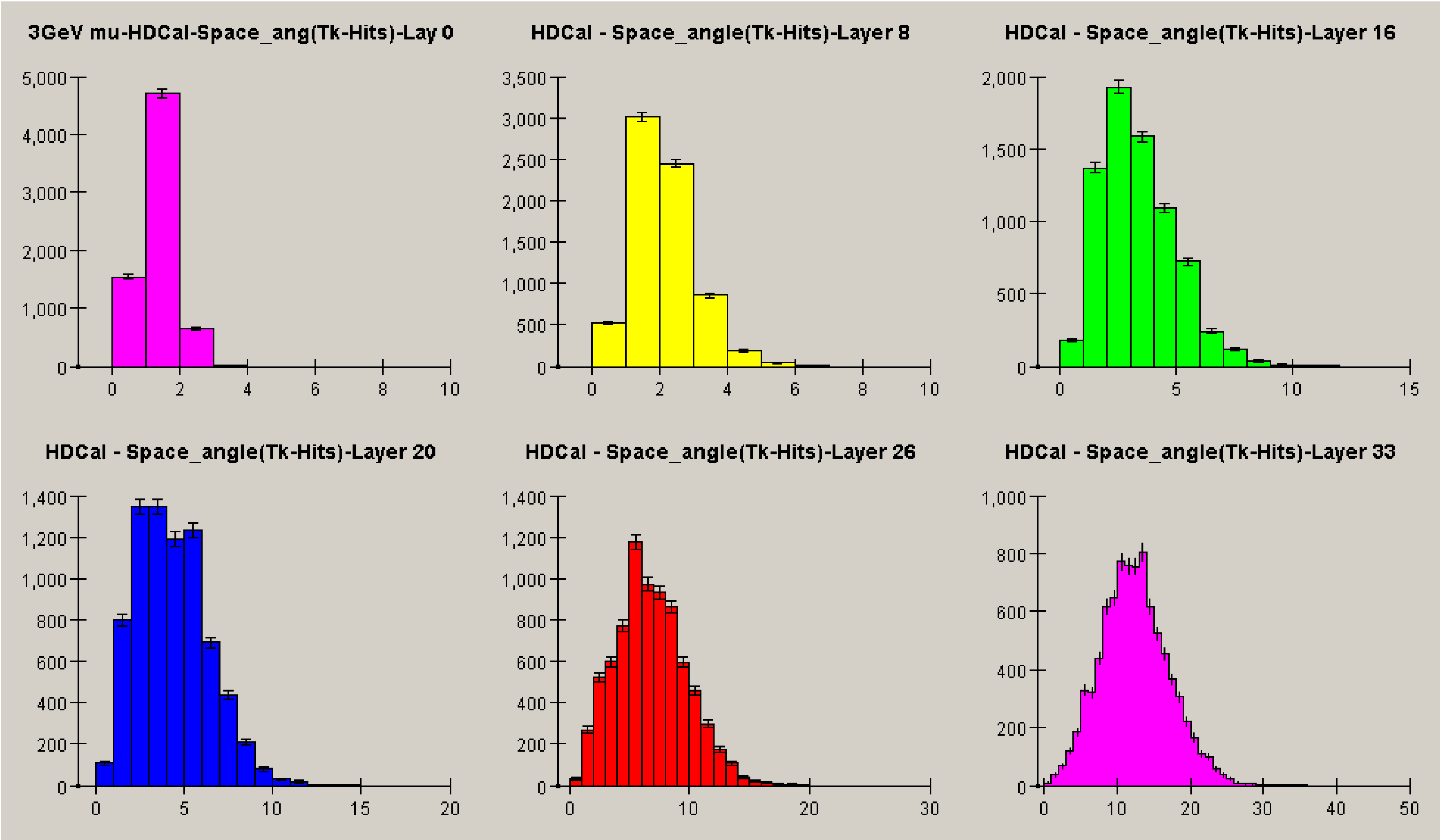
DeDx:Space_angle Study-at 3 GeV/c

In the EMCal, shown are layers 0,8,16,20,26 and 29



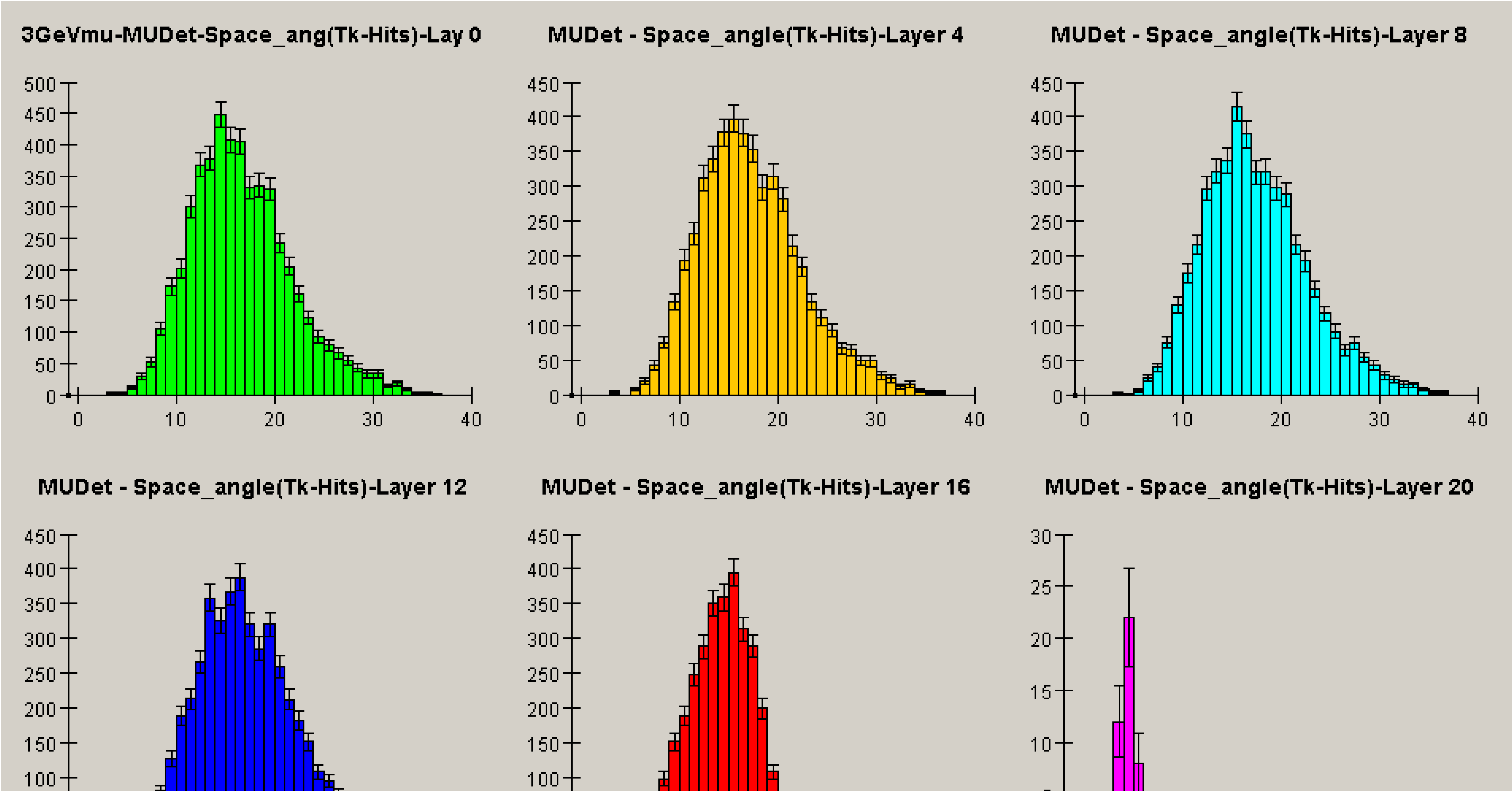
DeDx:Space_angle Study-at 3 GeV/c (continue1)

In HADCal bigger spread than EMCal where it is barely felt
Sown in layer 0,8,16,20,26,33 it increases with the Layer Number.



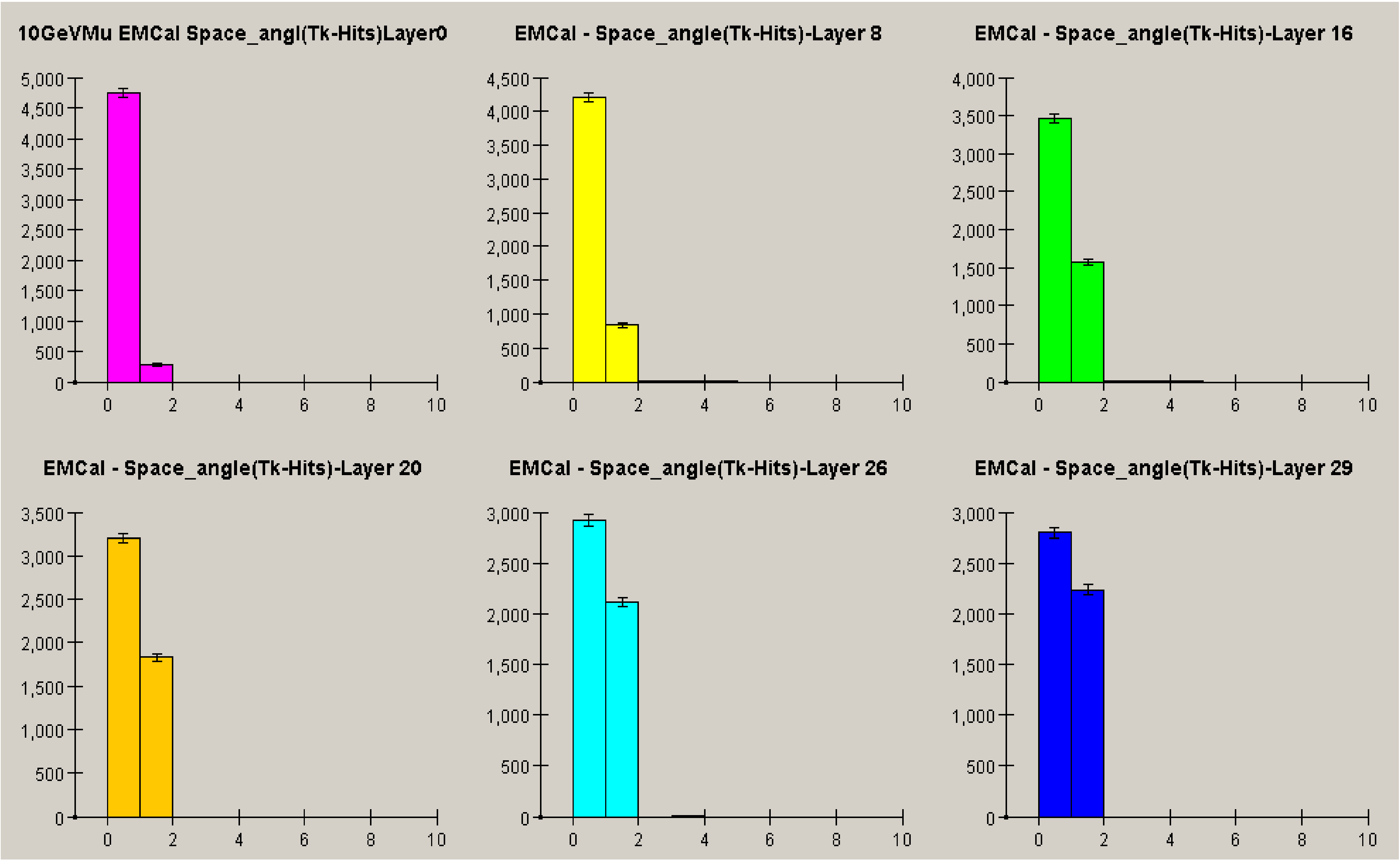
DeDx:Space_angle Study –at 3 GeV/c(cont.2)

In My Det bigger spread than HAD Calorimeter
Shown In layers 0,4,8,12,16,20



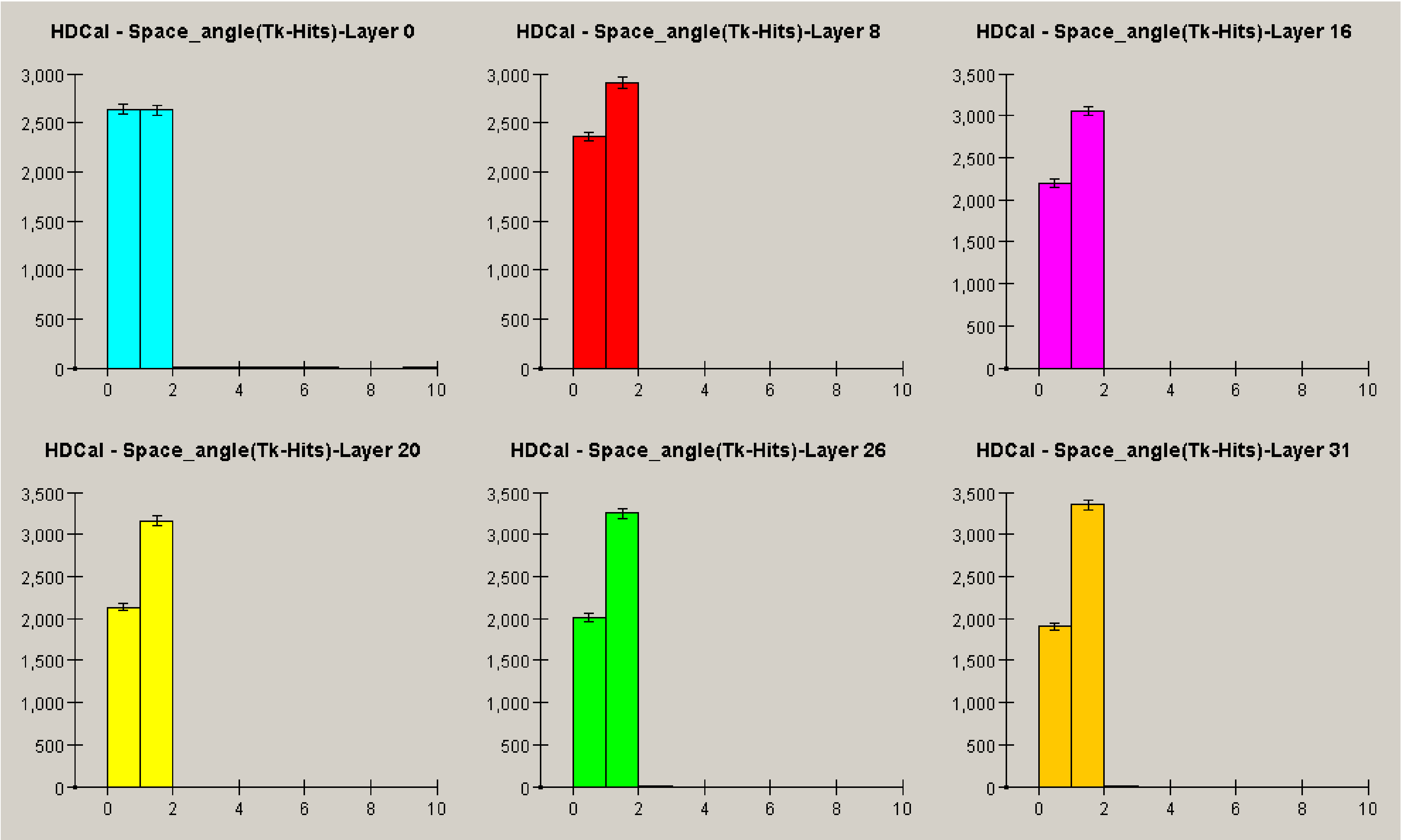
DeDx:Space_angle Study μ at 10 GeV

shown in EMCal layers 0,8,16,20,26,29 the spread barely change



DeDx:Space_angle Study μ at 10 GeV/c

shown in HAD Cal layers 0,8,16,20,26,31 the spread barely change



Next to come

- Include the DeDx in the track extrapolation tight consequently the angle cuts in HAD Cal and MuDet, using the information extracted from Multiple Scattering studies.

- Take advantage of the information of EM Cal (low energy μ)

- Study of the energy repartition between detectors using hadrons(especially between HAD Cal and MuDet)

- Jet studies
- And More to come (in discussion with G. Fisk)

$\Delta\phi$, $\Delta\theta$

As a result: Calorimeter hits will deviate from the track extrapolated from the tracker by an angle ($\Delta\phi$, $\Delta\theta$) .

$\Delta\phi = \Delta X0/R$
$\Delta\theta$: is calculated below

$\Delta X0/\sin(\Delta\theta) = r1/\sin\theta$
$r1 = R/\sin(\theta + \Delta\theta)$
$\sin(\theta+\Delta\theta)/\sin\theta = R/(\Delta X0 \sin\theta)$
$\sin\theta \cos(\Delta\theta) + \sin(\Delta\theta) \cos\theta/\sin(\Delta\theta)$
$=R/(\Delta X0 \sin\theta)$
$\sin\theta \,\mathrm{ctg}\,\Delta\theta + \cos\theta = R/(\Delta X0 \sin\theta)$
$\mathrm{ctg}\,\Delta\theta = (1/\sin\theta)^* ((R/\Delta X0 \sin\theta) - \cos\theta)$
$\Delta\theta \sim \mathrm{tang}(\Delta\theta) = 1/((R/\Delta X0 \sin^2\theta)-\mathrm{ctg}\,\theta)$