General Gaseous Calorimeter Digitizer: Digitization from 1mm Simulated cells

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Outline

- Introduction
  - Efficiency & Multiplicity: objective effects to be reproduced
  - Method
- Comparison with CALICE TB data
  - MicroMegas: Aug 2008 Small Chamber Muon

    (2009 JINST paper, doi:10.1088/1748-0221/4/11/P11023)
  - RPC: May 2012 SPS cubic meter data, Pion + Muon
  - RPC: 2011 PS cubic meter, Muon
- Analysis with Digitization tool
  - Multiplicity & FD as a function of Energy and threshold
  - Efficiency and Purity of Fractal Dimension based PID

Avalanche @ Gaseous Detector

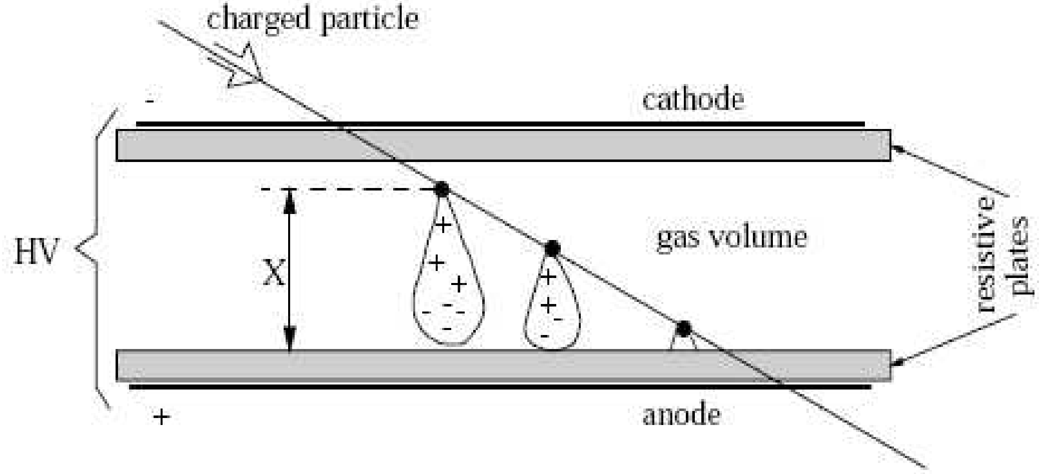
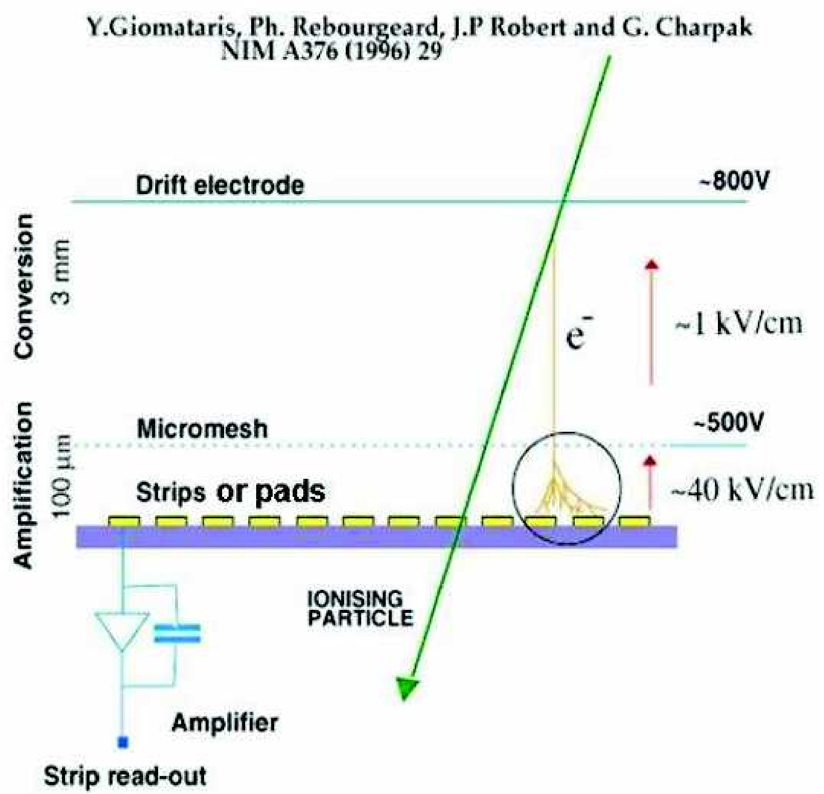
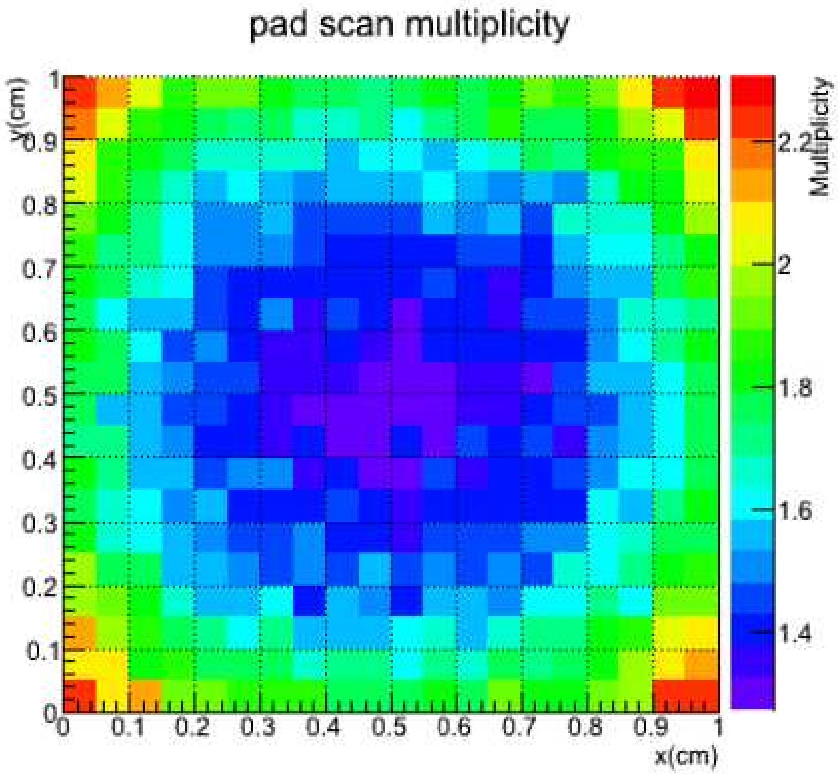


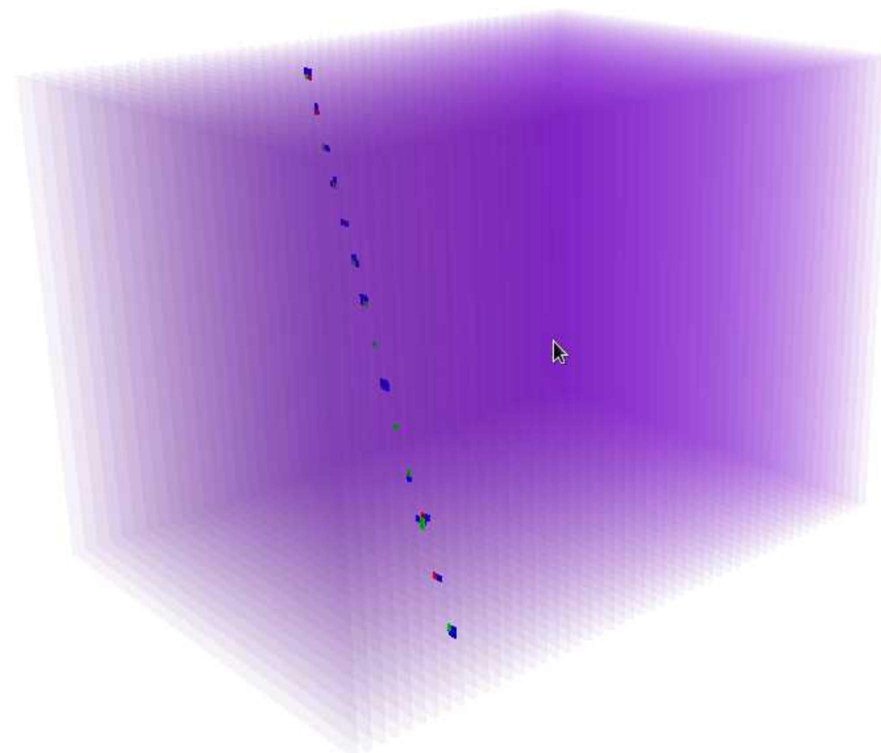
Fig. 1. Sketch of RPC gap.



- Signal: Charge image induced from avalanche
- Digitizer: estimate induced charge at each cell
- Systematic effects: Efficiency (ε) & Multiplicity (μ)

Position Dependency of μ: Finite size of charge image

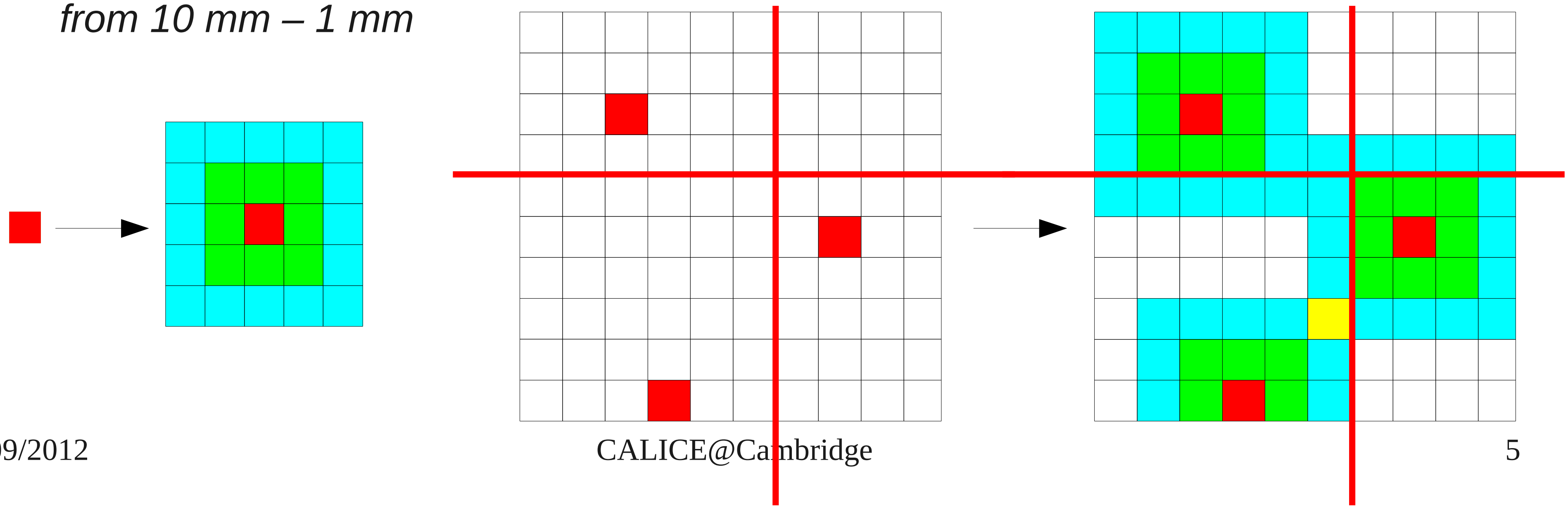




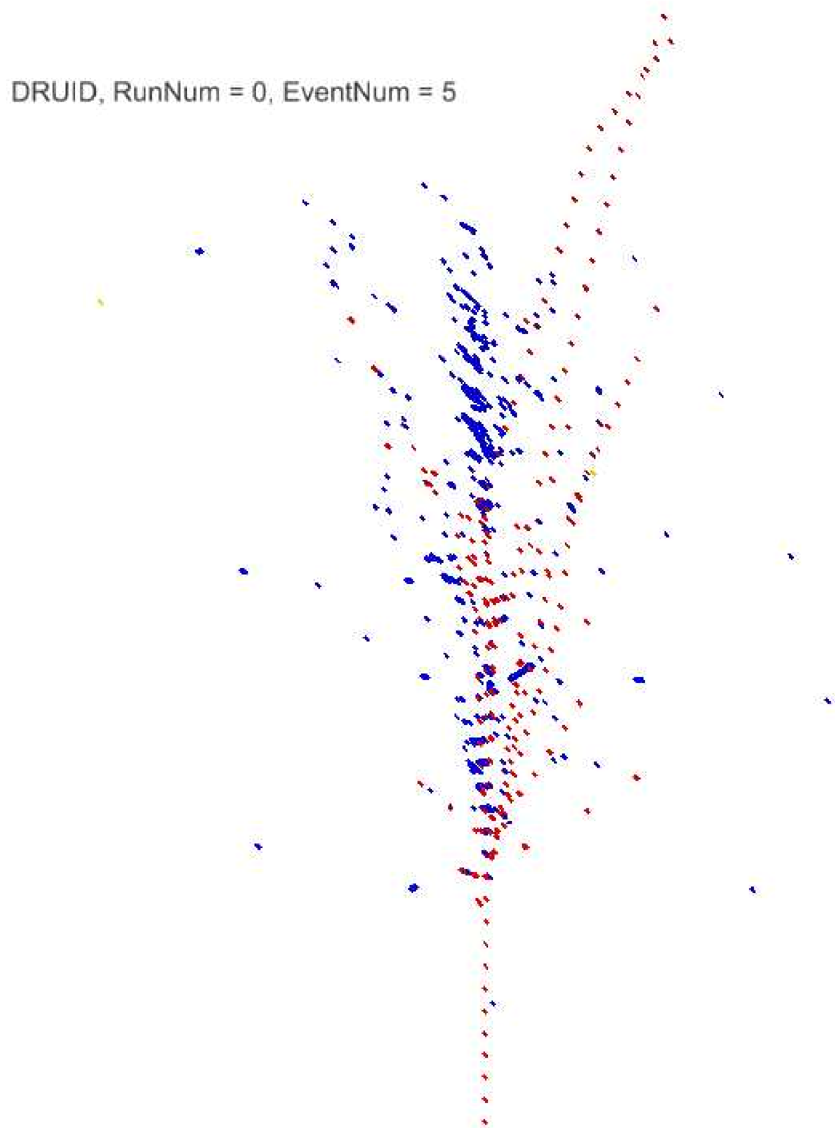
- **Yacine**: μ = μ(x, y) measured from GRPC cosmic ray data
- Charge image size: width ~ 1mm ~ GRPC gas gap thickness
- To reproduced the multiplicity: need position information of ~ mm precision
- Idea: Digitize from 1mm simulated hit

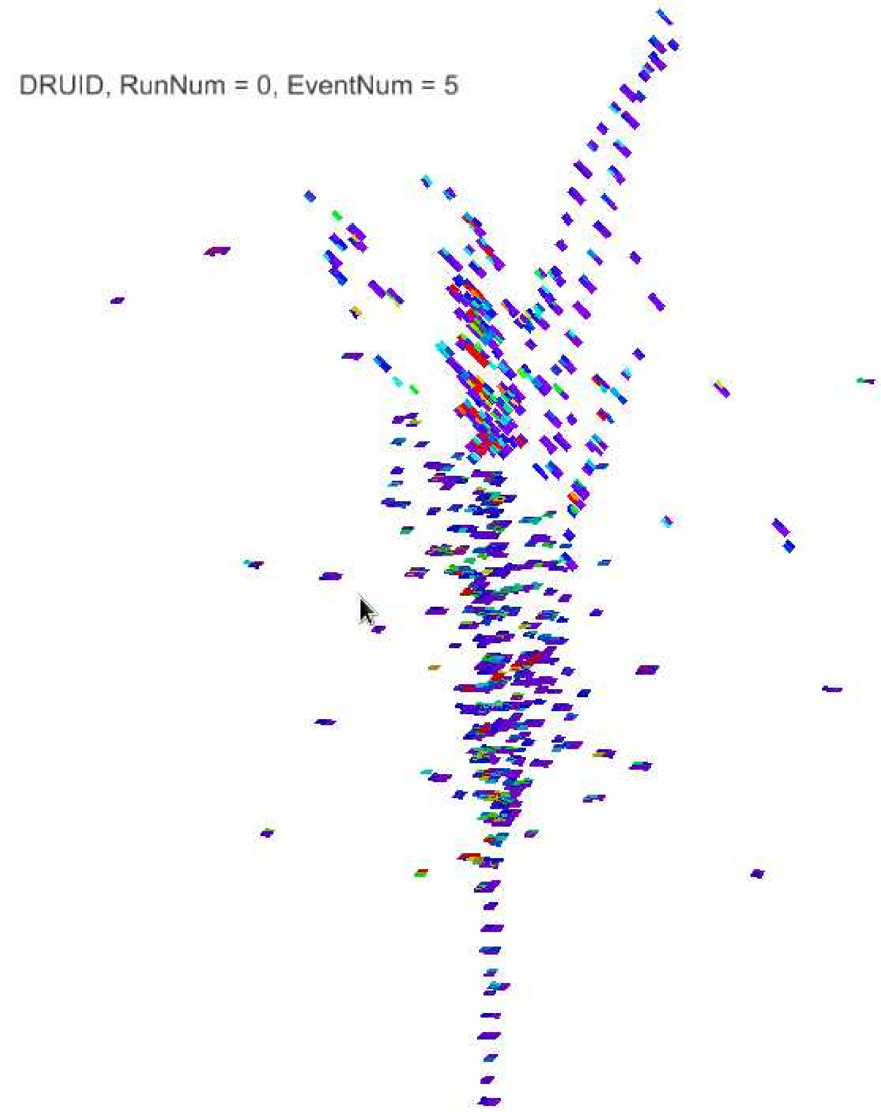
Method

- Parametrize 1mm simulated hit with:
  - Induced charge spectrum (unbiased measurement: ε-threshold scan)
    - *Polya function:* $P(x) = Nx^a e^{-bx}$ *a, b > 0 & MPV = a/b*
  - Charge spatial distribution table
- Accumulate charge within objective area ~ digitized hit
- *Remarks*
  - *Two sets of parameters are in principle needed: EM/hadronic hits*
  - *Controllable data size: num of hits increased ~ 3 times for hardonic showers, scaling from 10 mm – 1 mm*



Simu & Digi hits

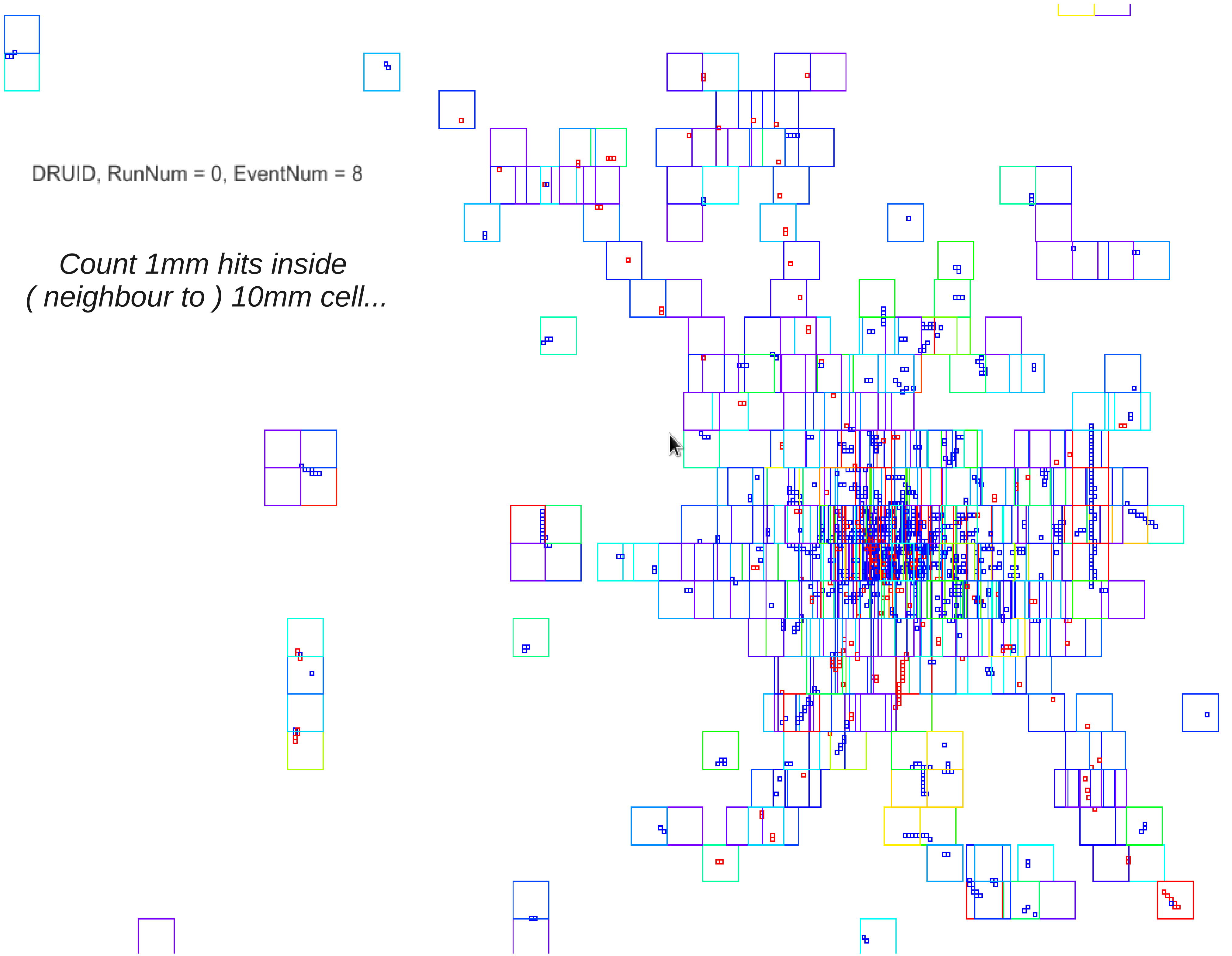




Left: simulation level (1 mm cell: size scaled by 3. Colour: EM, Had)
Right: Digitization level (10mm cell. Colour to charge, MPV ~ 1.1 pC/1 mm hit)

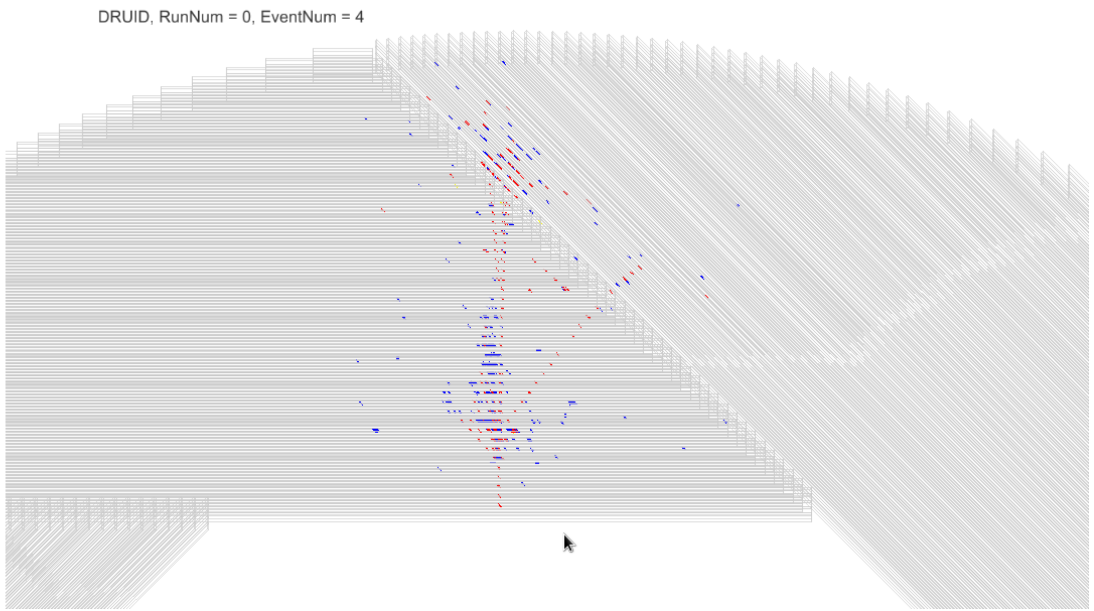
DRUID, RunNum = 0, EventNum = 8

Count 1mm hits inside (neighbour to) 10mm cell...



TB-MC comparison

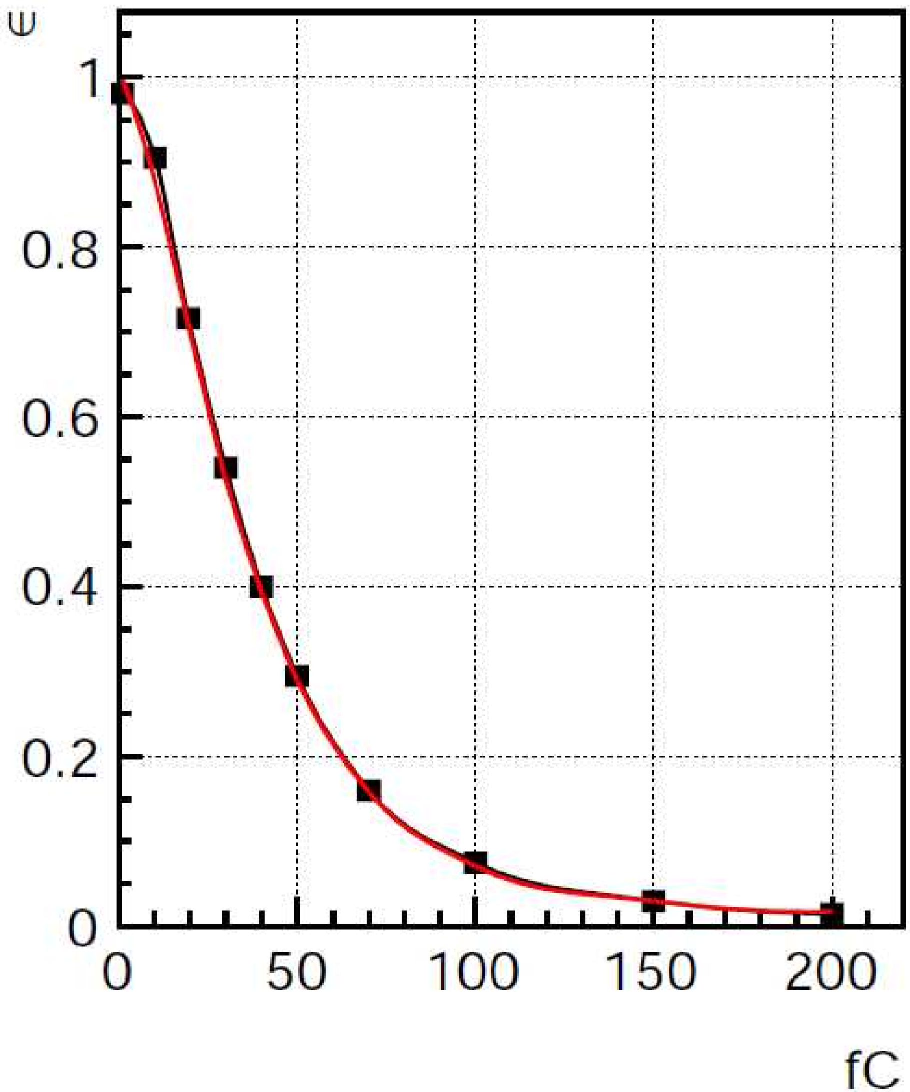
- Simulated Sample: approximation to test beam prototypes geometry
    - Particles shot in to ILD DHCAL with different types (e+, pi, mu...) and energies (1 – 100 GeV), 1k – 10k events at each point

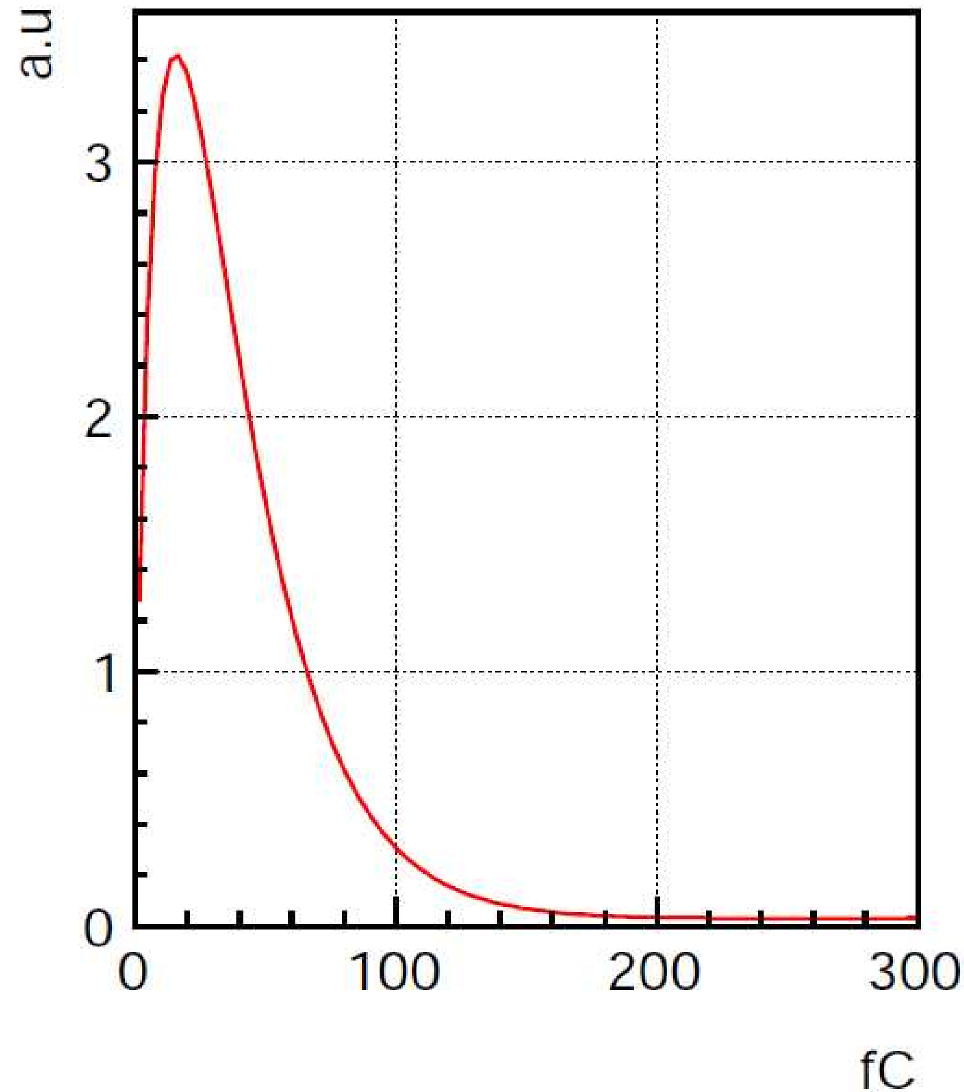


- Test beam data samples:
    - MicroMegas: Aug 2008, Small chamber, Muon
    - GRPC: May 2012 cubic meter, Muon + Pion
    - GRPC: 2011 PS cubic meter, Muon

- Task: Properly parametrize 1mm hits to reproduce the test beam result

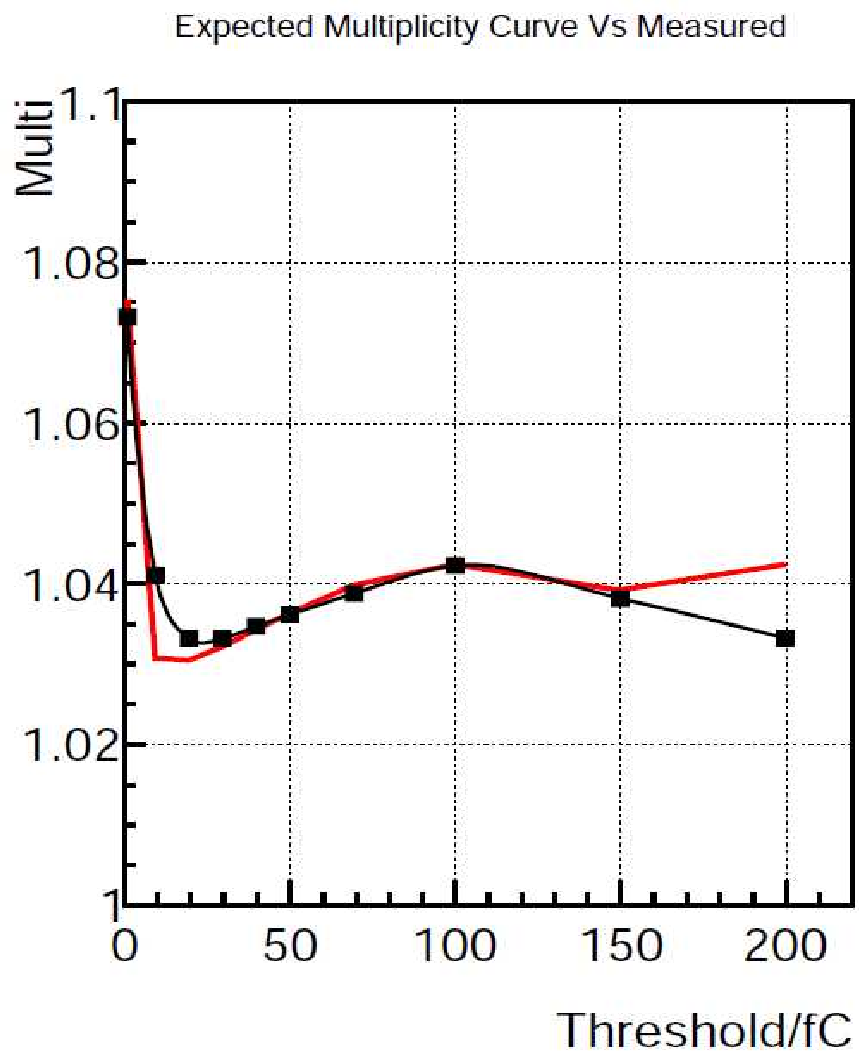
MicroMegas: ε-threshold scan & PDF of MIP hit Induced Charge

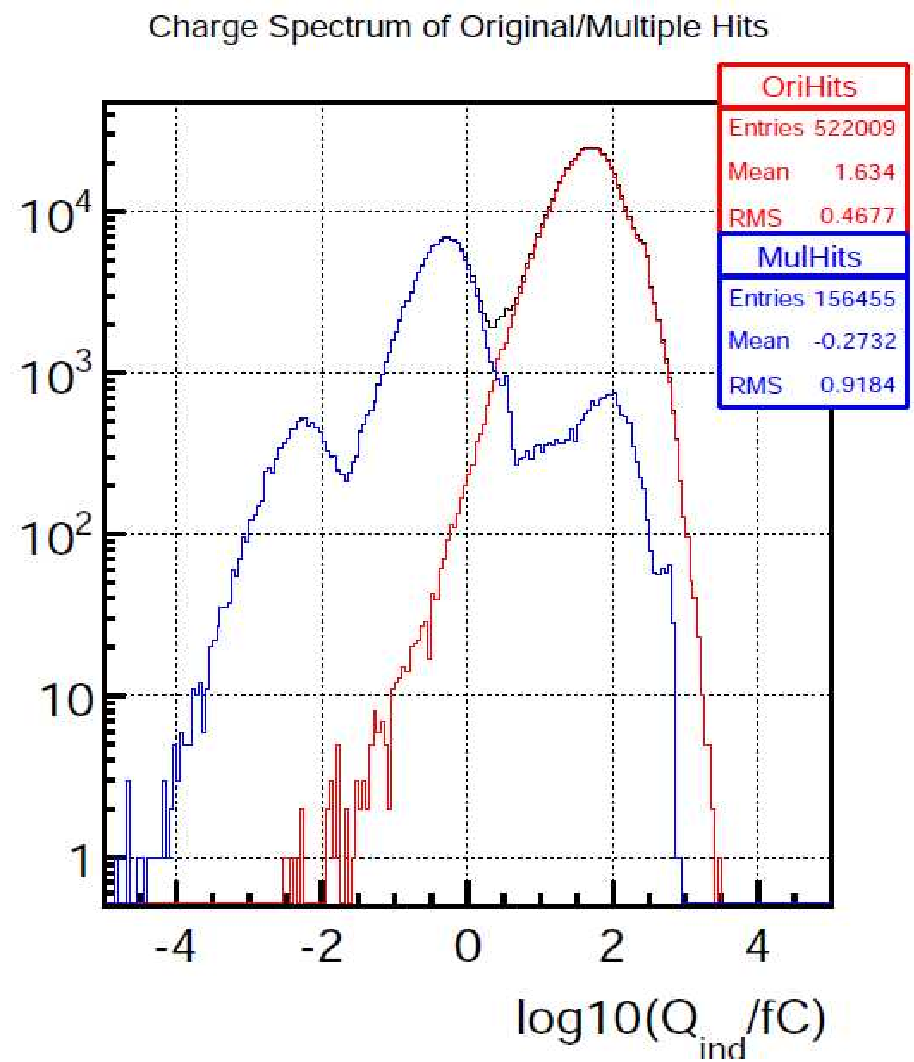




Expected Induced Charge for 1 Mip ($x^{0.7}e^{-0.045*x}+0.03$) defined in (0, 300fC)

MM: μ(threshold) & Digi hit Induced Charge Spectrum

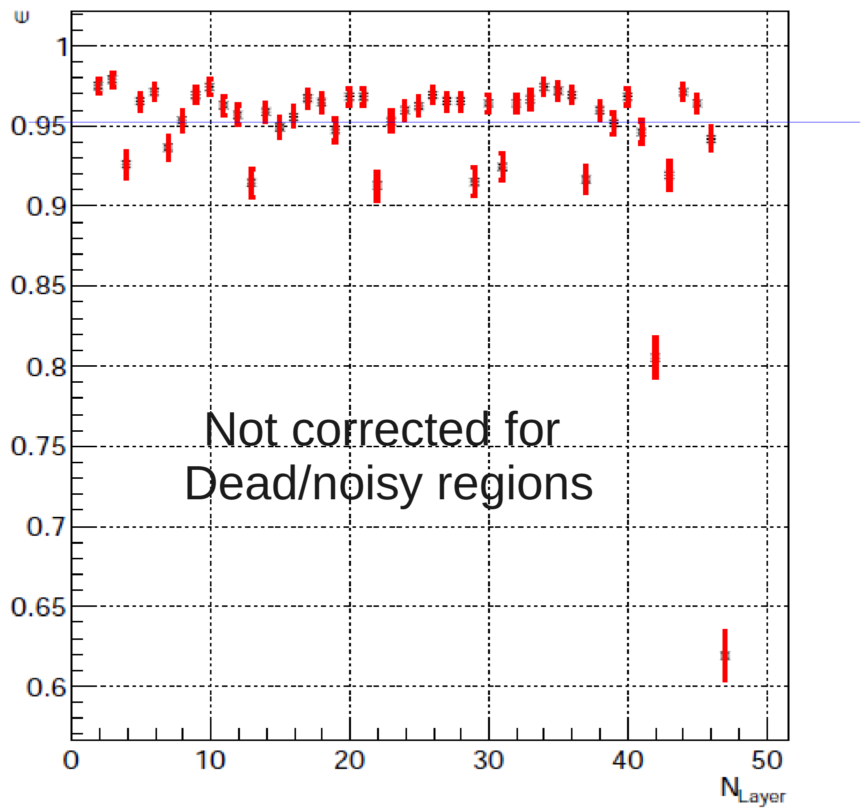


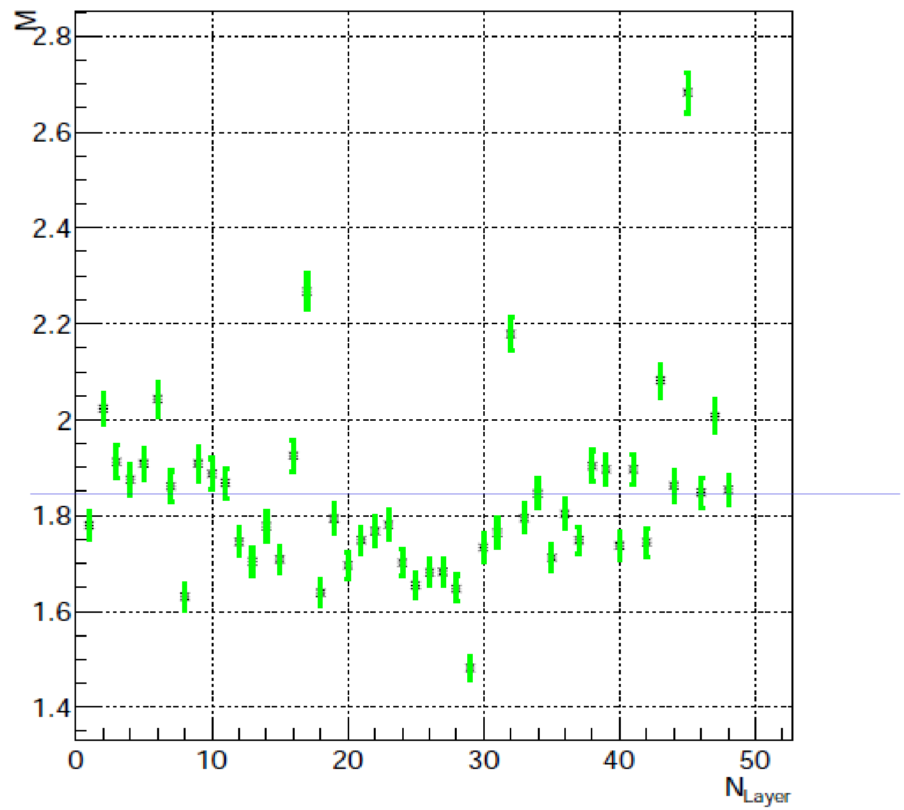


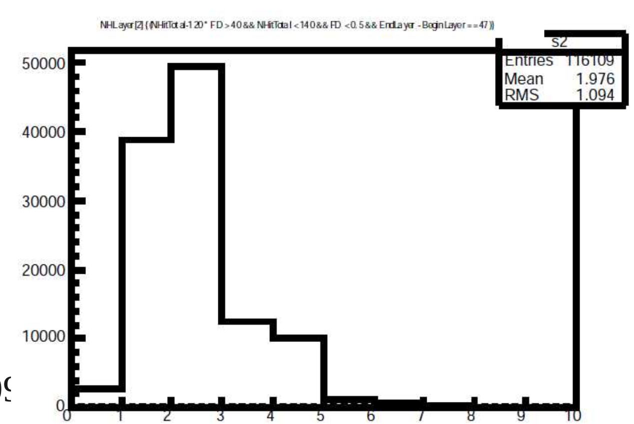
$\mu(T) = 1 + N(\text{multiplicity hits with } Q > T)/N(\text{original hits with } Q > T)$

Bump at T = 100fC: explained as delta-ray gamma effect...

GRPC May 2012 data: ε & μ for muons



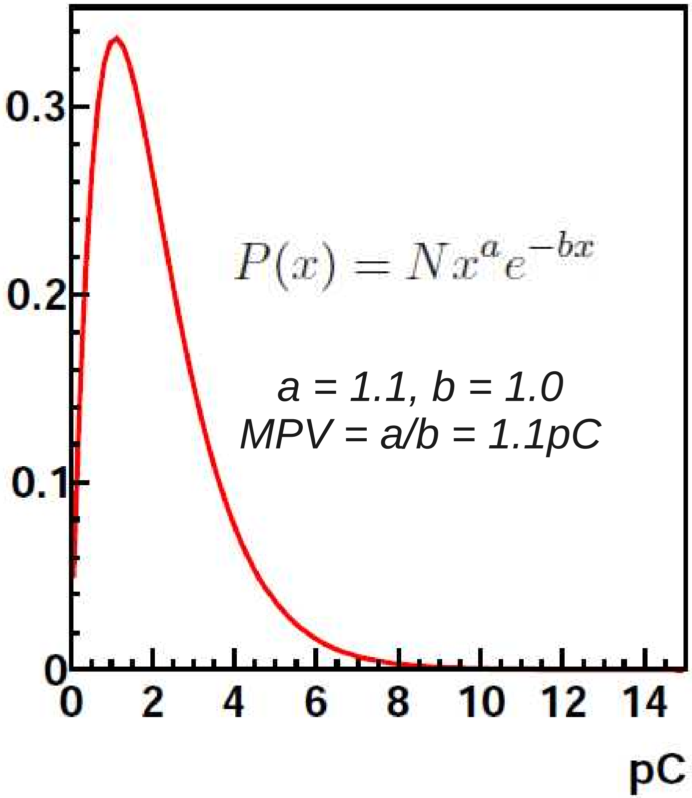


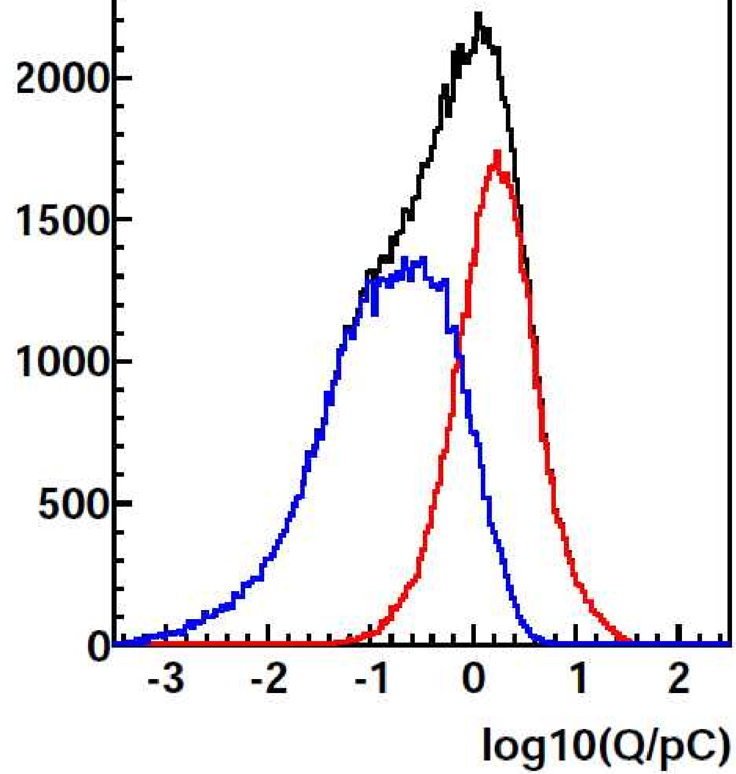


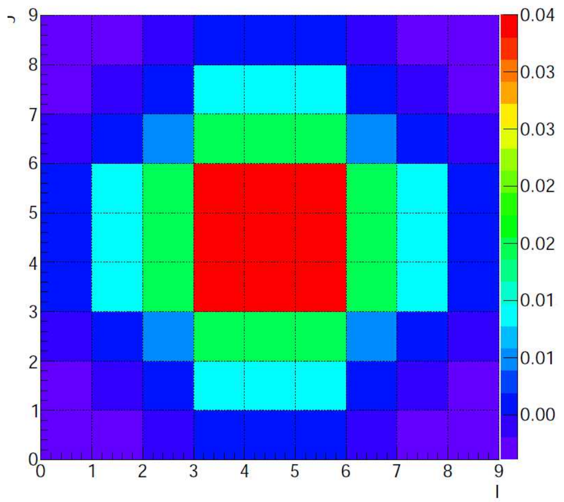
Using long Beam MIP in Run 714565, 714573
Negligible statistic error (Nevt = 106109).
error bar scaled for 10 times.

Eff = 1 – Nevt(0-hits)/Nevt(total)
EffErr = sqrt(eff(1-eff)/Nevt)*
Mul = <Nhits (Nevt (>0 hits)) >
MulErr = RMS(Mul)/sqrt(Nevt)

GRPC MIP hits parametrize





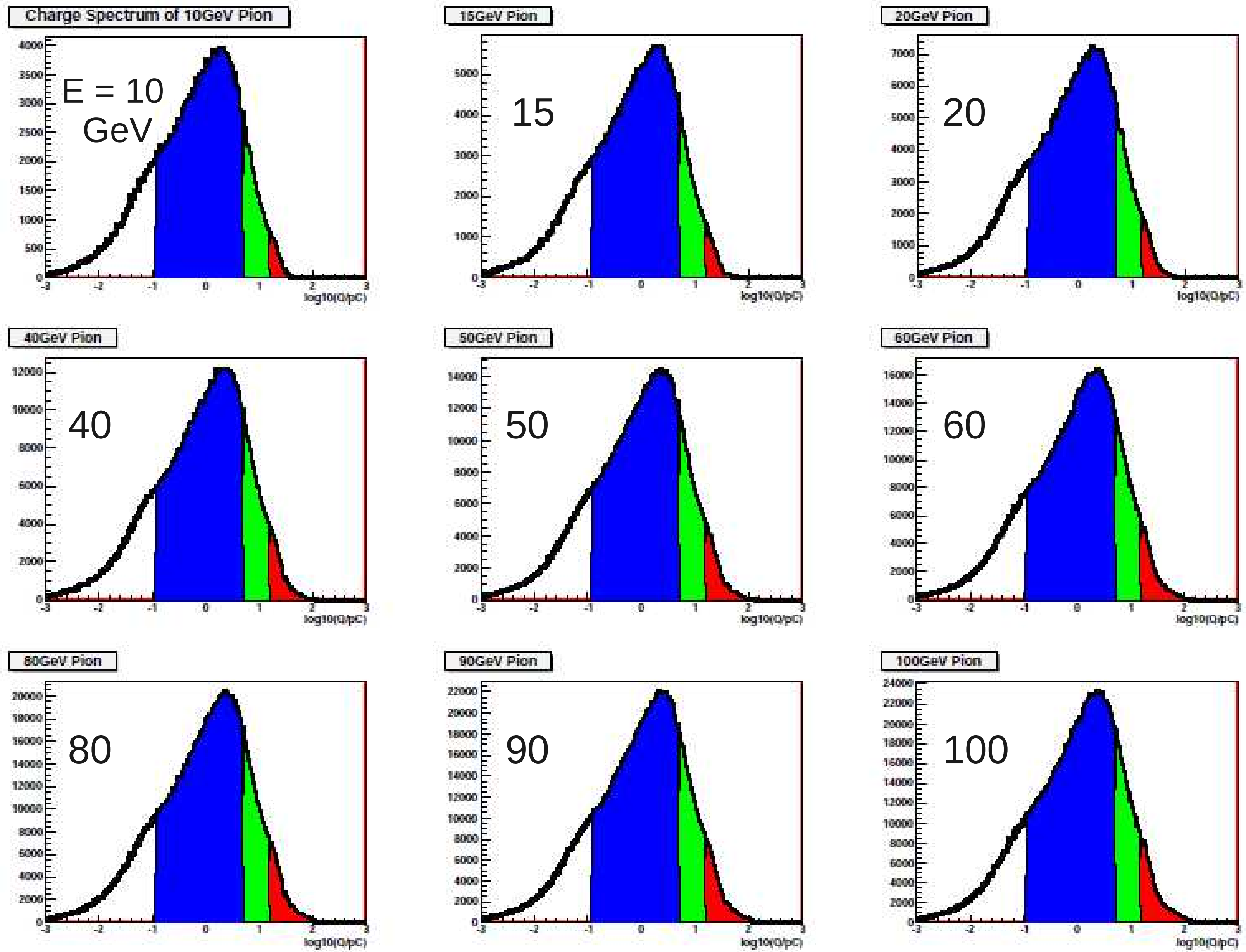


Charge Spatial Distribution

Simulated Sample: 1k 40GeV Muon events
Reproduced eff ~ 98%, mul ~ 1.82 @ First Threshold

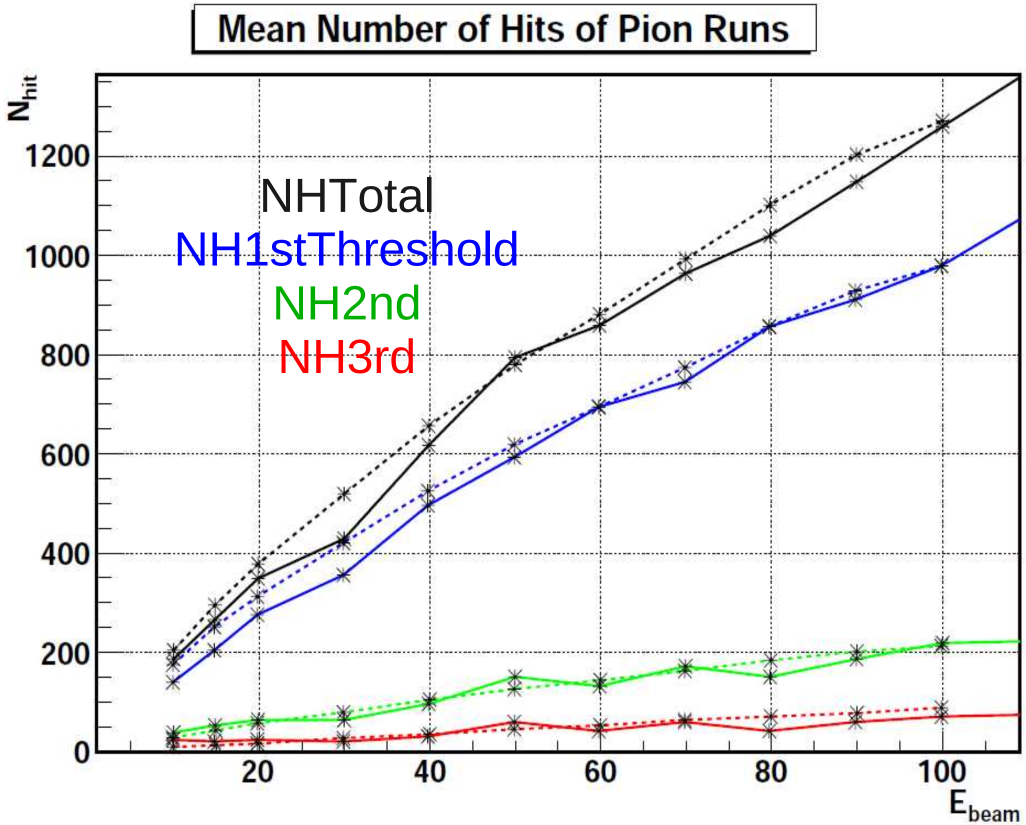
Remark: SDHCAL Thresholds: 0.114, 5.0, 15.0 pC

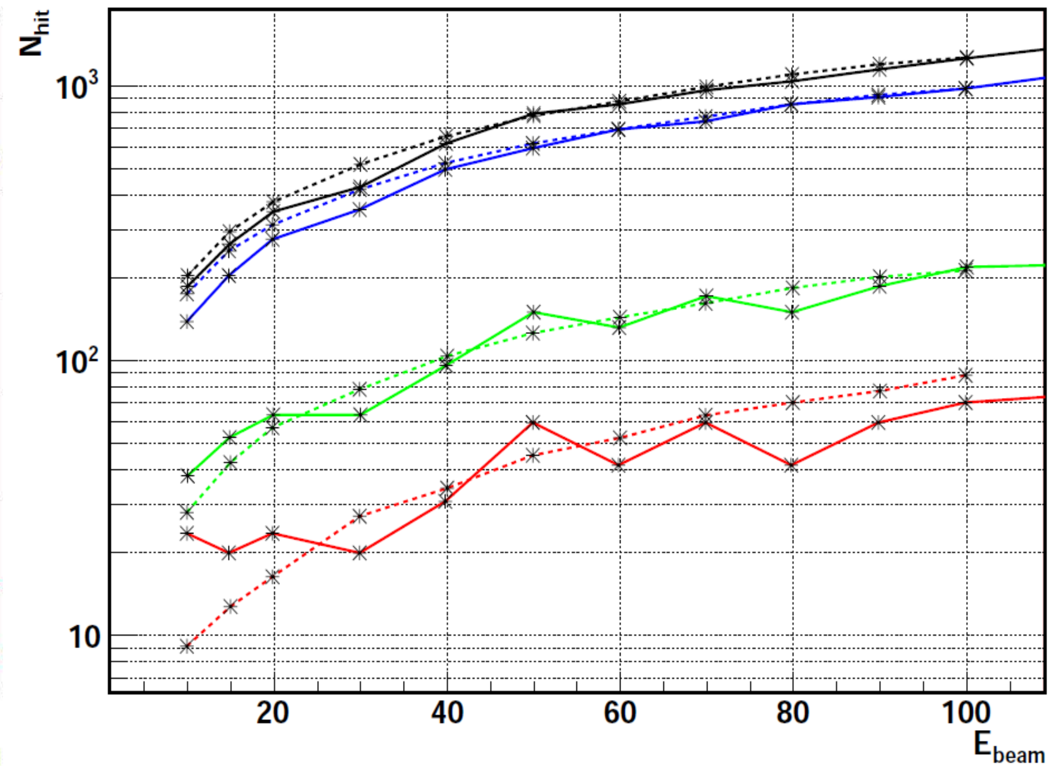
GRPC Cells: Q for Pi



Apply the same parameters on Pion Samples...

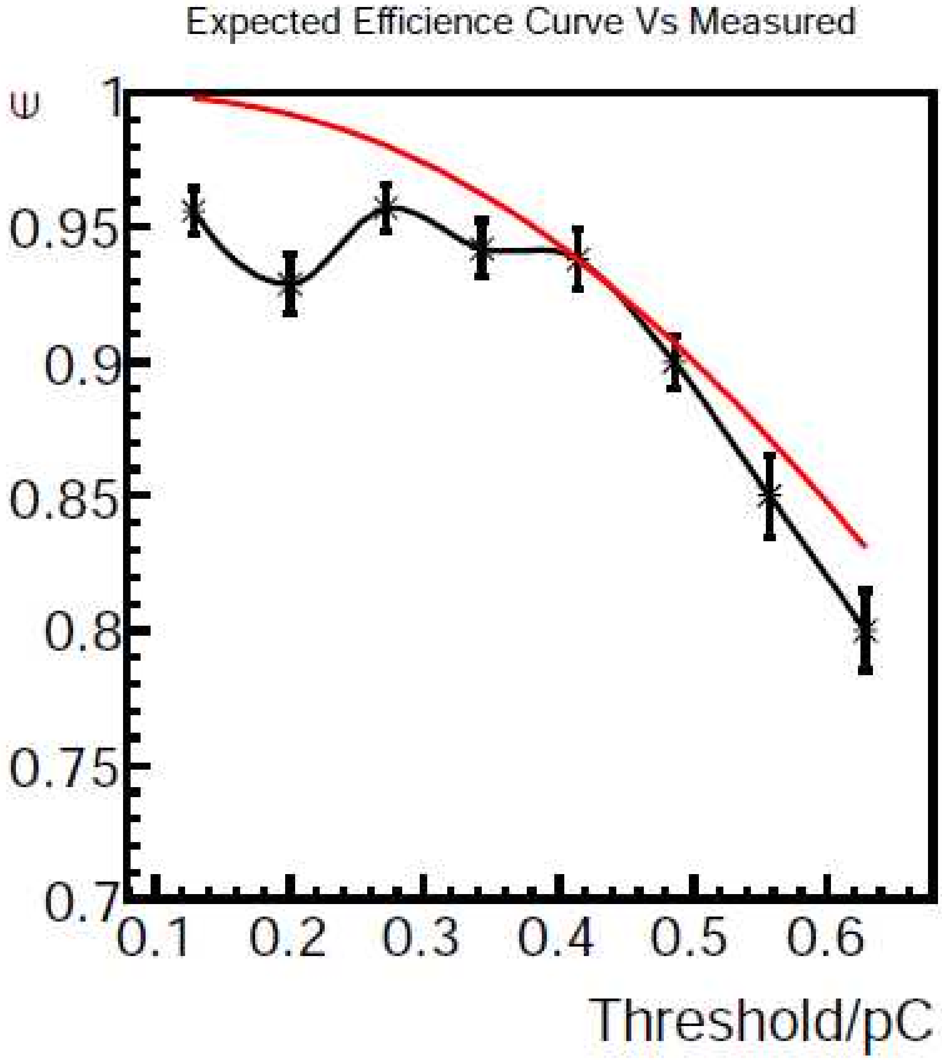
MC-TB: NHits of pion at GRPC

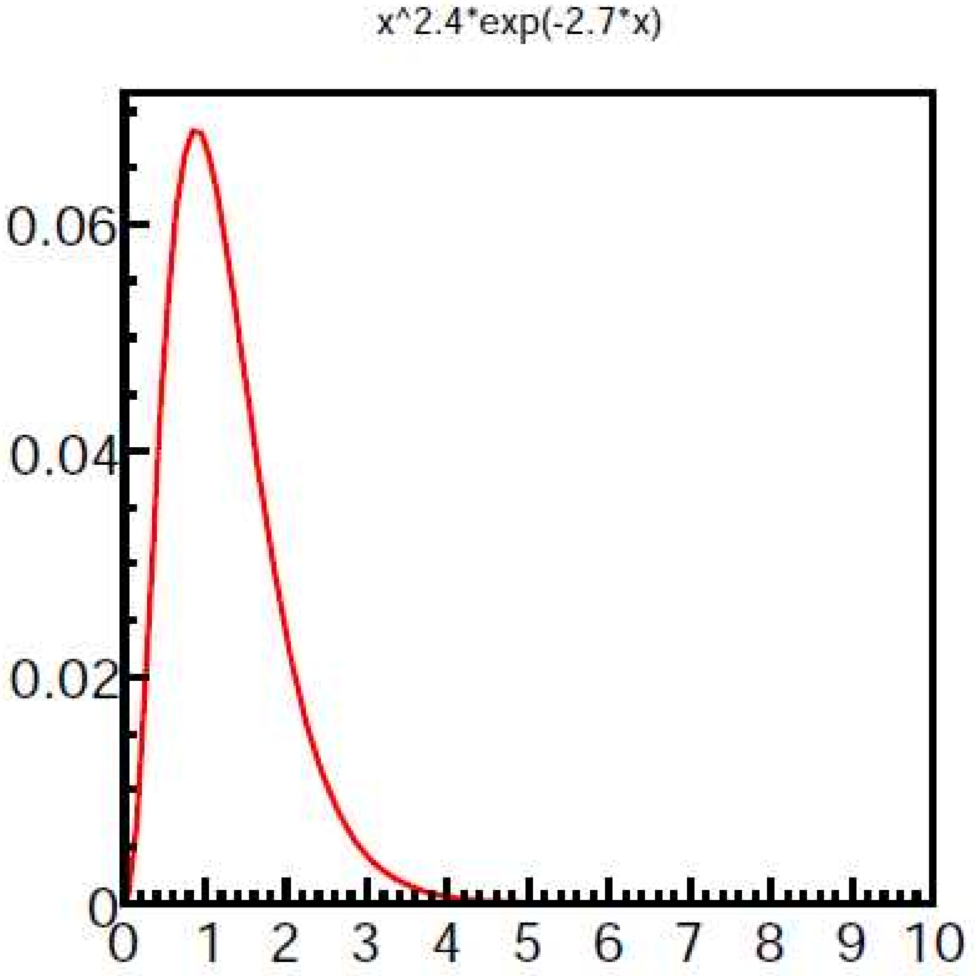




- Solid line: TB measurement. Dashed line: Simulation + Digitization
- Remarks:
  - *TB: mean value of Nhits distribution, no noise/leakage event subtraction*
  - *MC: not exactly the same geometry*

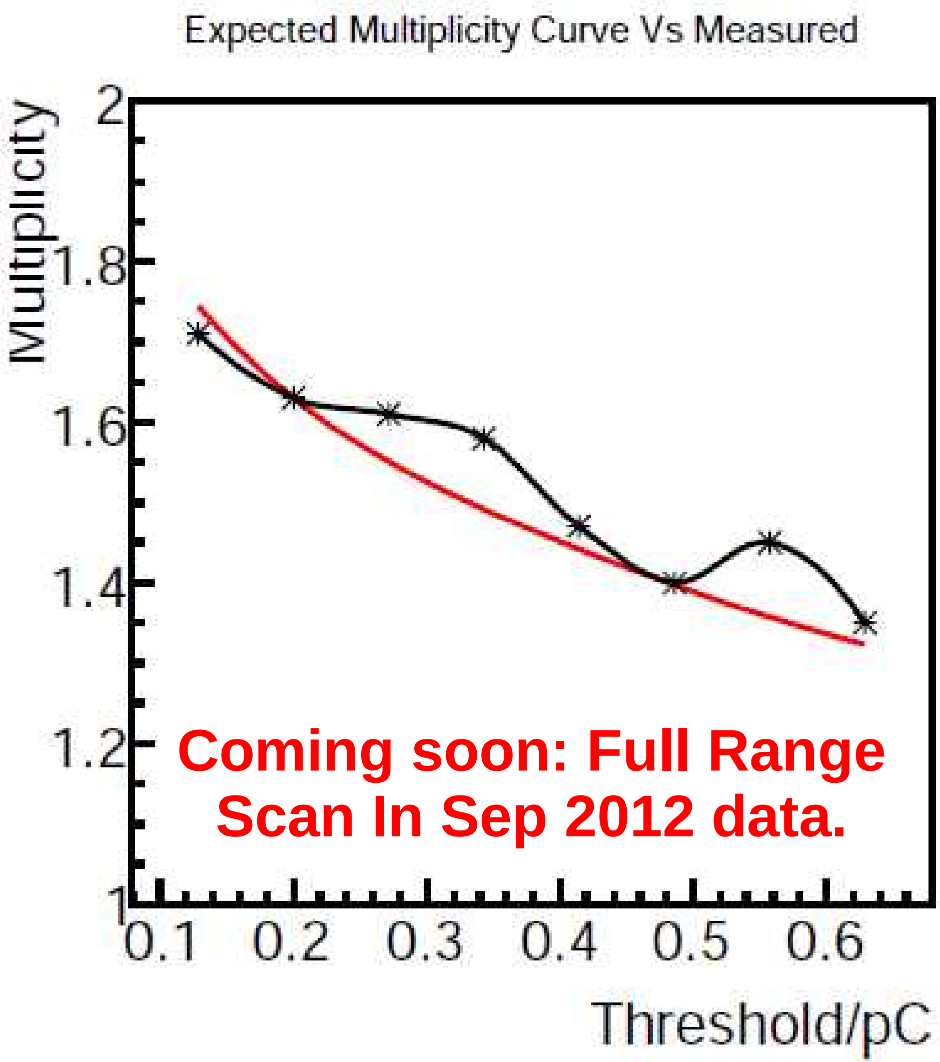
GRPC: PS 2011 data, threshold scan

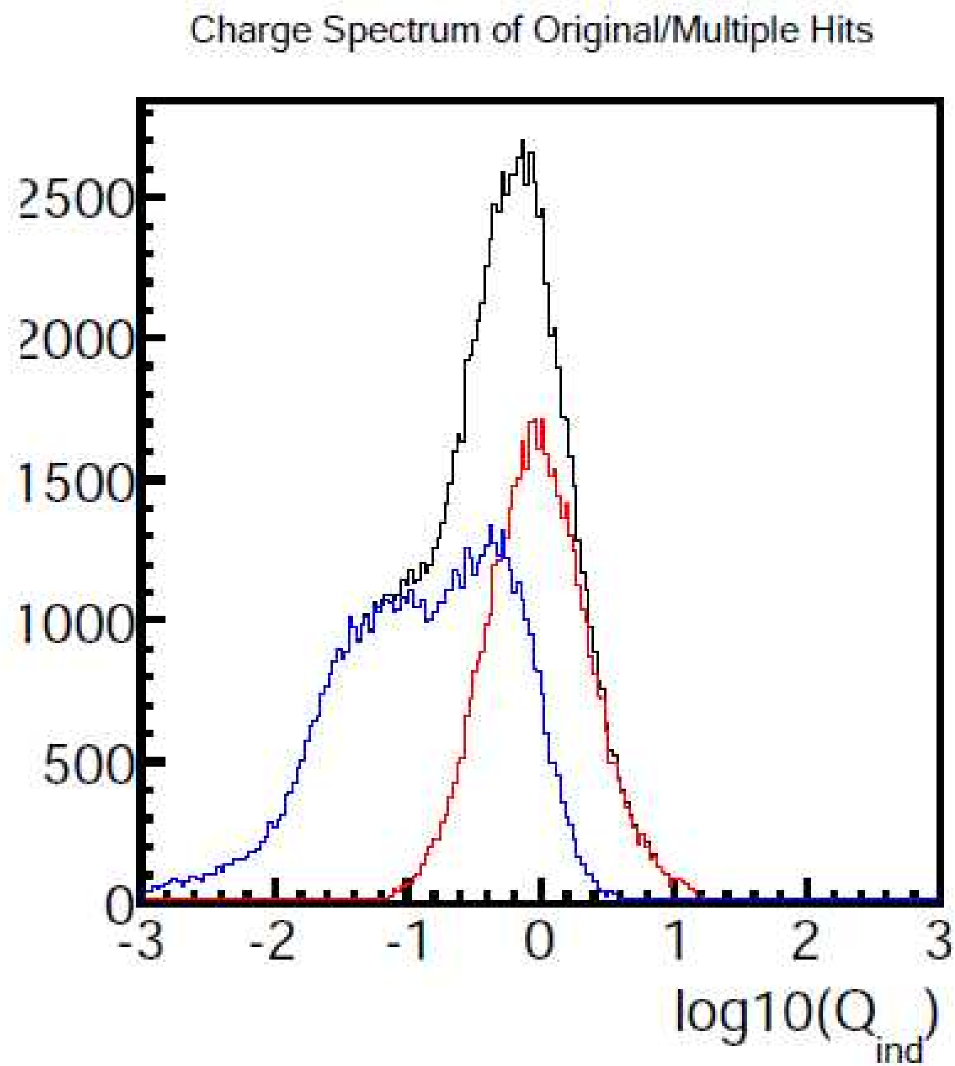




Left plot: in case of multiple hits, the efficiency will be reduced since the charge is shared by multiply pad. Become more significant at high thresholds.

GRPC PS 2011 data: threshold scan





Parameters slightly changed compare to May 2012 data: temperature & conditions...

Gaseous Calorimeter Digitizer as a Marlin Module

- Estimation of induced charge: Reproduces the efficiency and multiplicity effects
- Agrees with MicroMegas and GRPC TB observation with proper parametrization
- Input: 1 mm hits sample
  - Position information
  - Straight forward to be digitized into different output cell size: ideal samples for cell size optimization study
  - Controllable number of hits

```
.begin MySmallCellDigi
ProcessorType SmallCellDigi

DigiCellSize   10

UsingDefaultDetector   0

ChargeSpatialDistribution 0.1 0.2 0.3 0.6 0.6 0.6 0.3 0.2 0.1

PolyaParaA   1.1

PolyaParaB   1.0

PolyaParaC   0.0

ChanceOfKink   0

KinkHitChargeBoost   1

HCALCollections   HcalBarrelCollection

HCALThreshold 0.114 5 15

OverwriteFile   0

TreeName   DHCAL

TreeOutputFile   DigiHit_Muon.root

.end ----------------------------------------
```

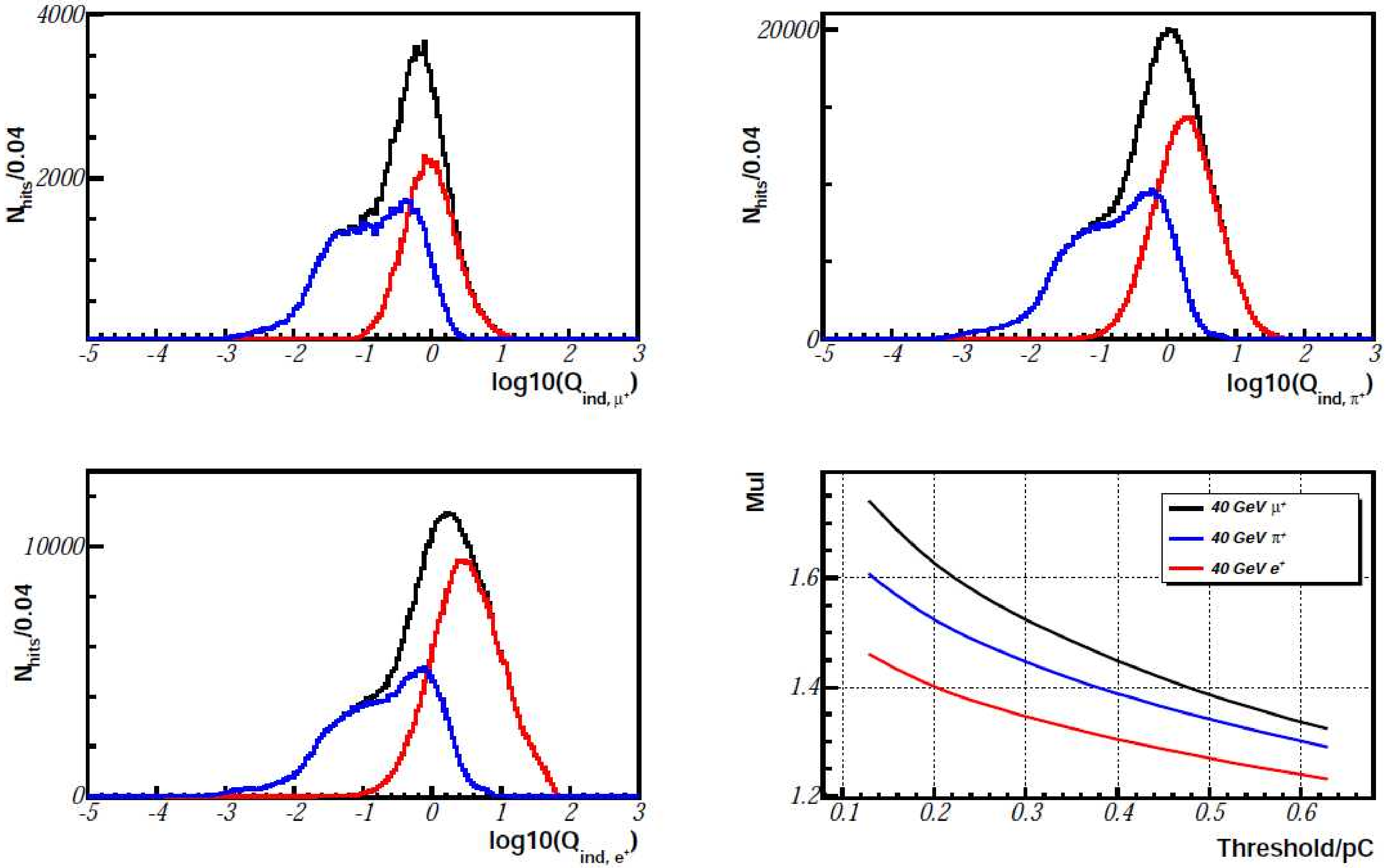
0 = enable self setting
1 = MicroMegas;
2 = GPRC @ PS 2011

GPRC May 2012 Settings

Analysis with Digitization: Parametrize $\mu/FD = \mu/FD(\text{Threshold, Energy})$

Parameters set according to GRPC 2011 PS data
Muon hits: $\mu = 1.71$ & $MPV(Q) = 0.89$ pC/hit

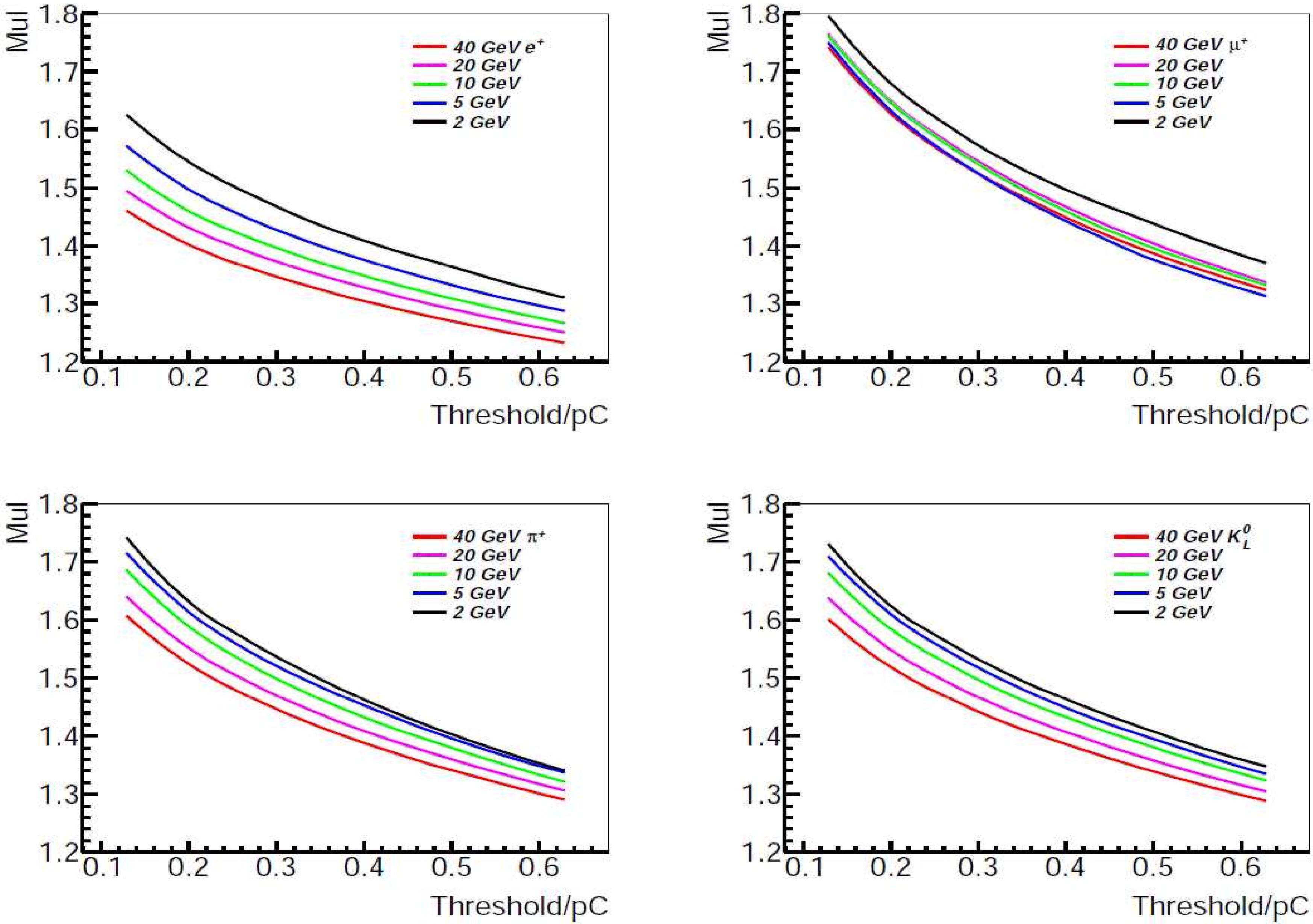
μ(thres) at 40GeV samples:
μ(mu) > μ(pi) > μ(e)



Multiplicity at EM/Had Shower: Not a direct observable.

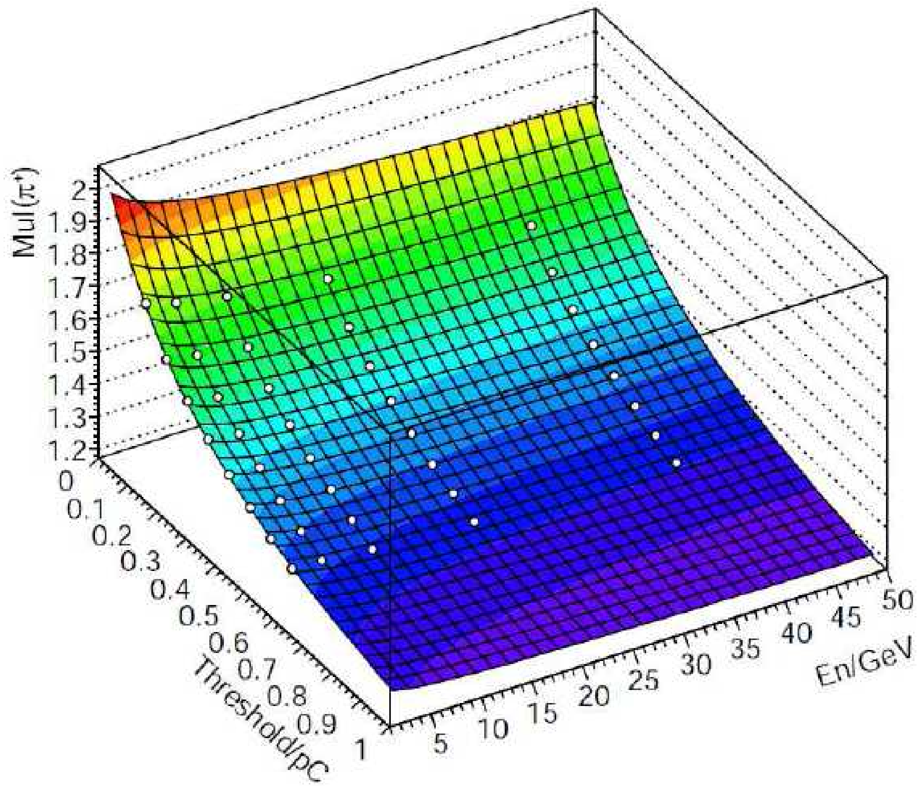
Define: μ(T) = 1 + N(multiplicity hits with Q > T)/N(original hits with Q > T)

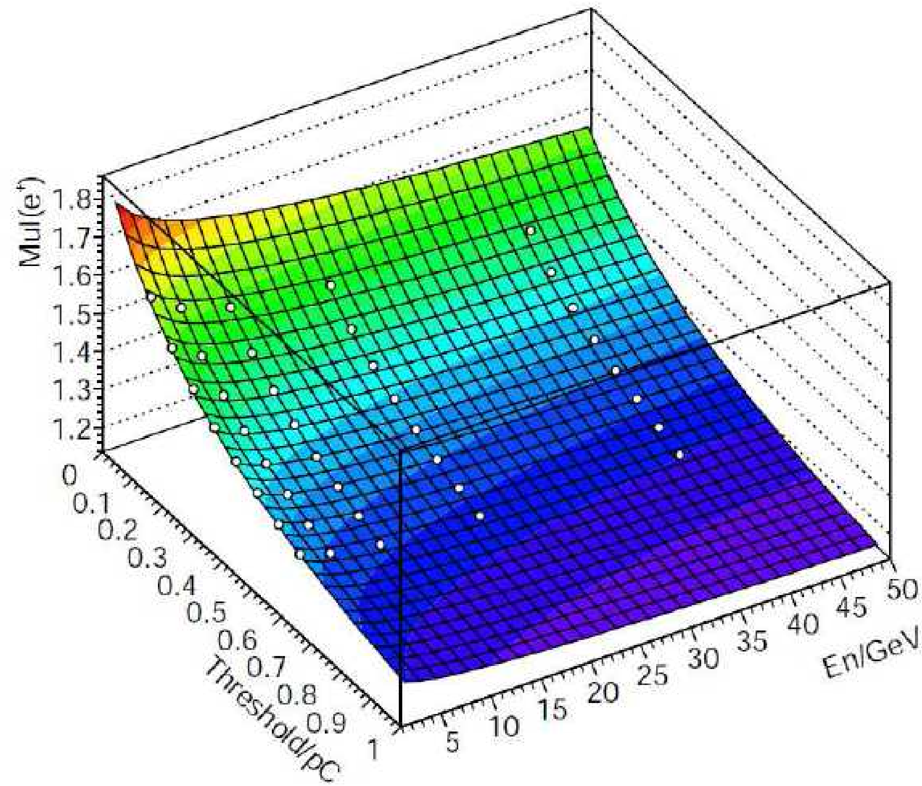
μ(thres) at different energies



Multiplicity at EM/Had Shower: Decrease with shower energies

μ = μ(threshold, energy) for EM/Hadronic shower

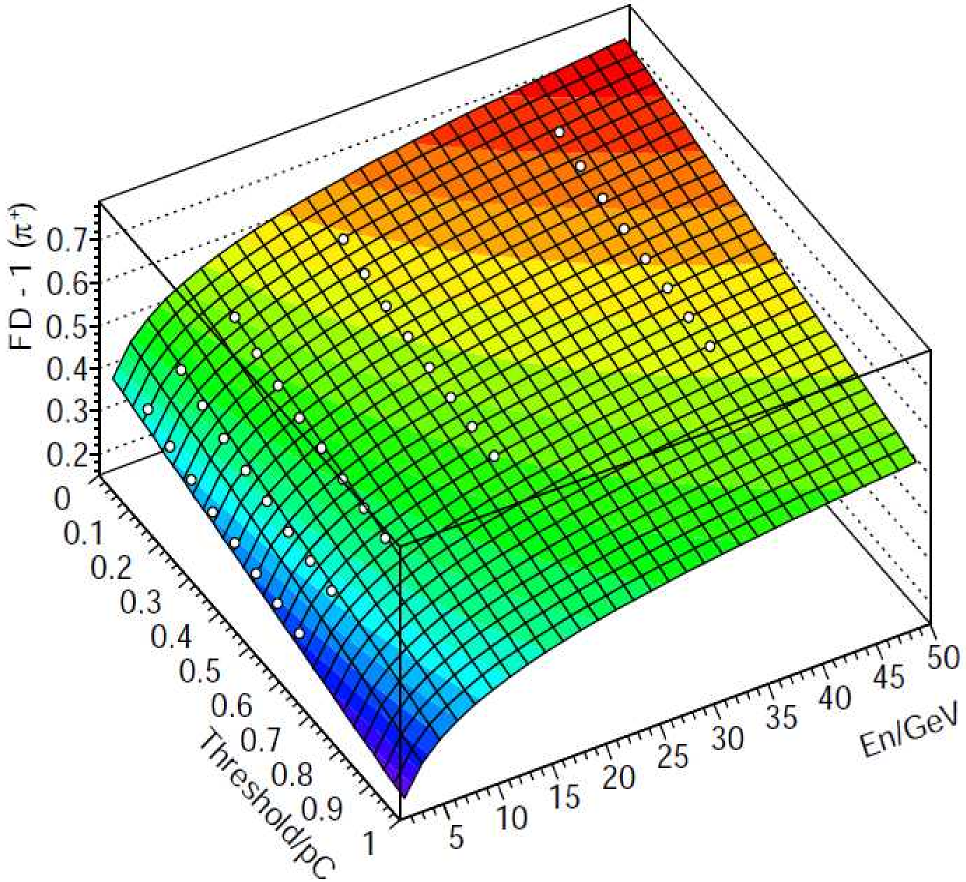


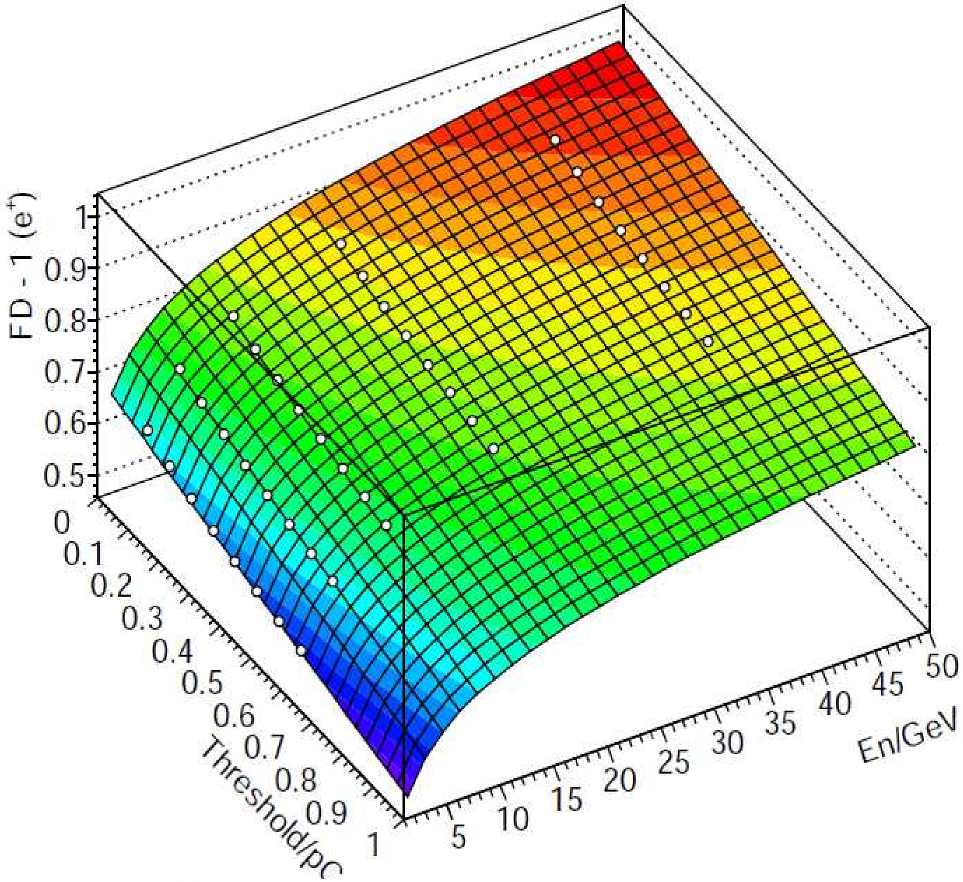


$$M_{had}(E,T) = 1 + 0.045 \times \frac{7.9 - log_{10}(E/GeV)}{0.33 + T/pC}$$

$$M_{em}(E,T) = 1 + 0.064 \times \frac{5.3 - log_{10}(E/GeV)}{0.39 + T/pC}$$

FD = FD(threshold, energy)





$$FD_{em}(E,T) = 1 + (0.35 + 0.15 \times log_{10}(E/GeV)) \times (1 + \frac{0.83}{1.16 + T/pC}).$$

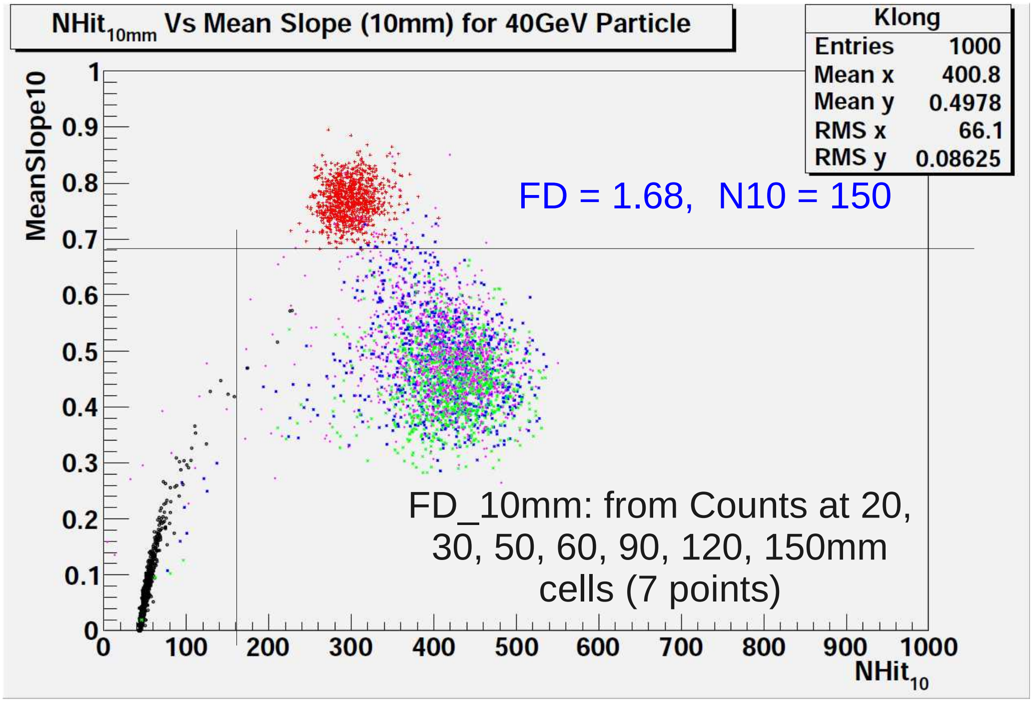
$$FD_{had}(E,T) = 1 + (0.105 + 0.103 \times log_{10}(E/GeV)) \times (1 + \frac{1.85}{1.02 + T/pC}).$$

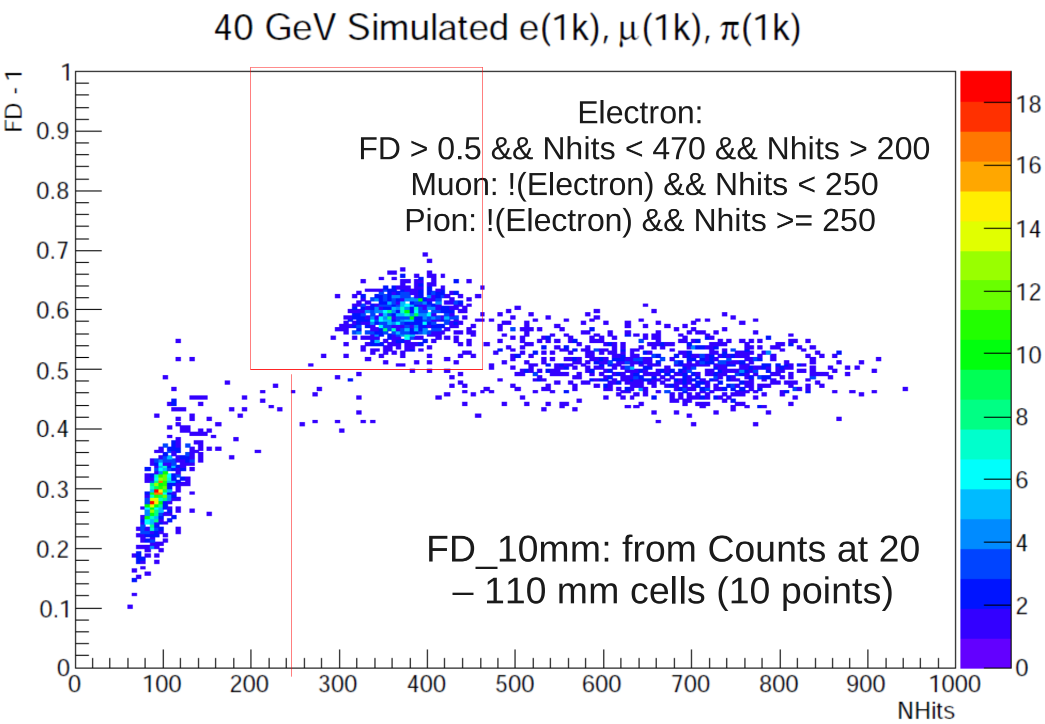
Digitizer parameters dependent coefficient & Universal tendency

Analysis with Digitization:
FD-based PID on Digitized Sample

Parameters set according to GRPC 2012 May SPS data
Muon hits: μ = 1.82 & MPV(Q) = 1.1 pC/hit

Separation after digitization





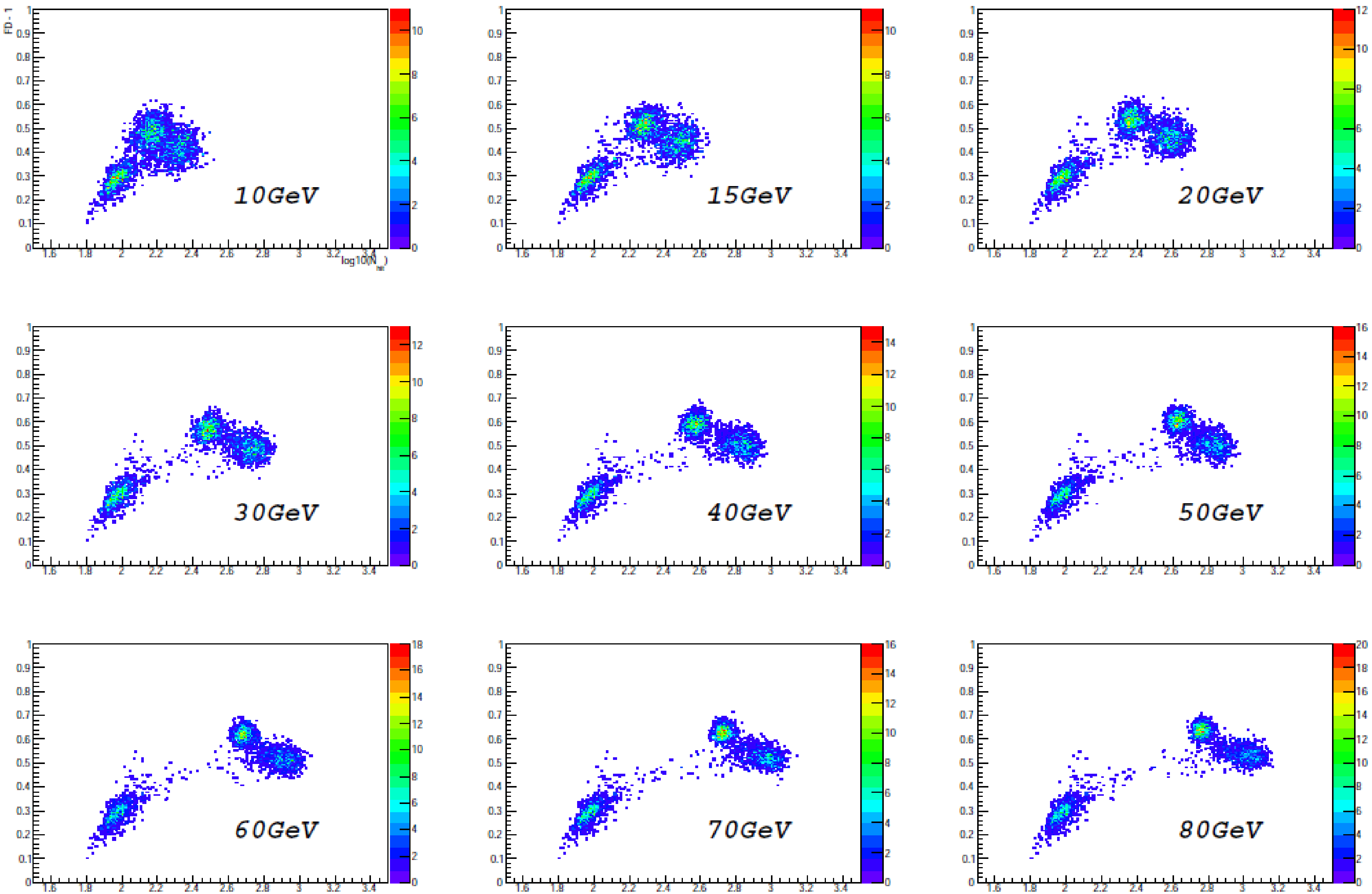
Output / *Input*

Simu	e+	u	h
e+	1000	0	0
u	0	995	5
h	17	14	969

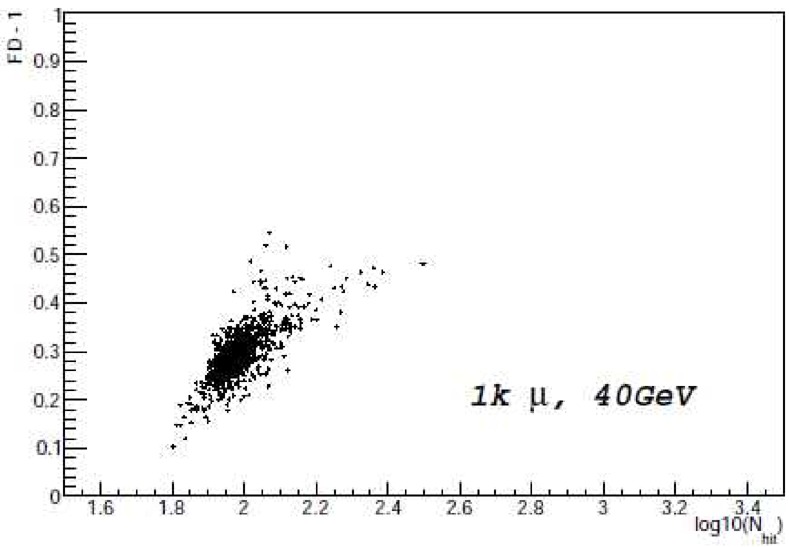
Digi	e+	u	pi
e+	997	0	3
u	0	998	2
pi	24	14	962

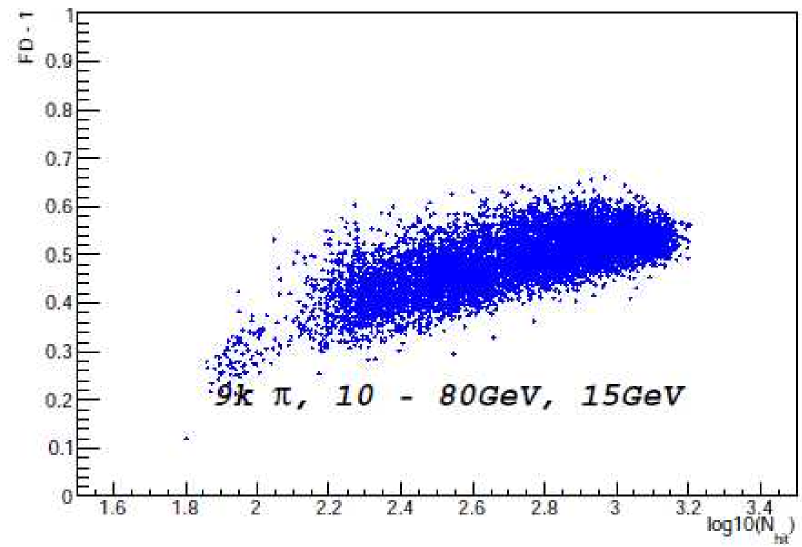
Conventional method: using total number of hits and total FD
At high energy: ideal separation kept after digitization

Conventional separation: Clear until 10GeV

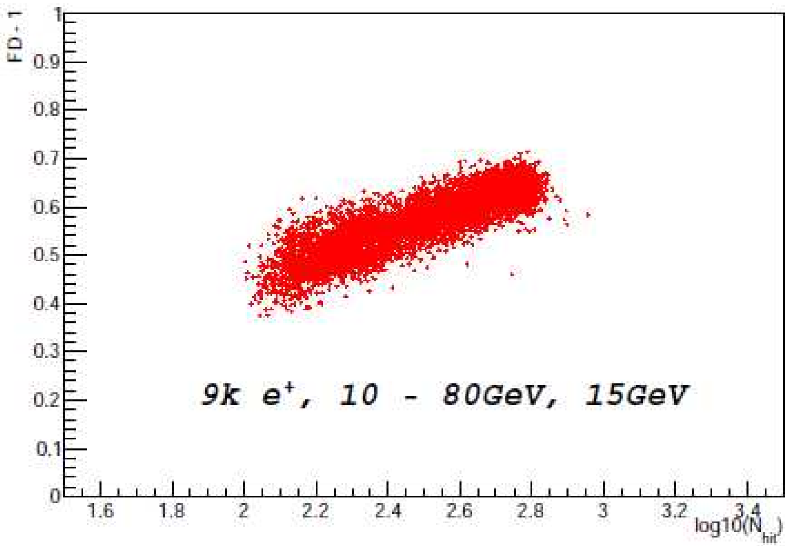


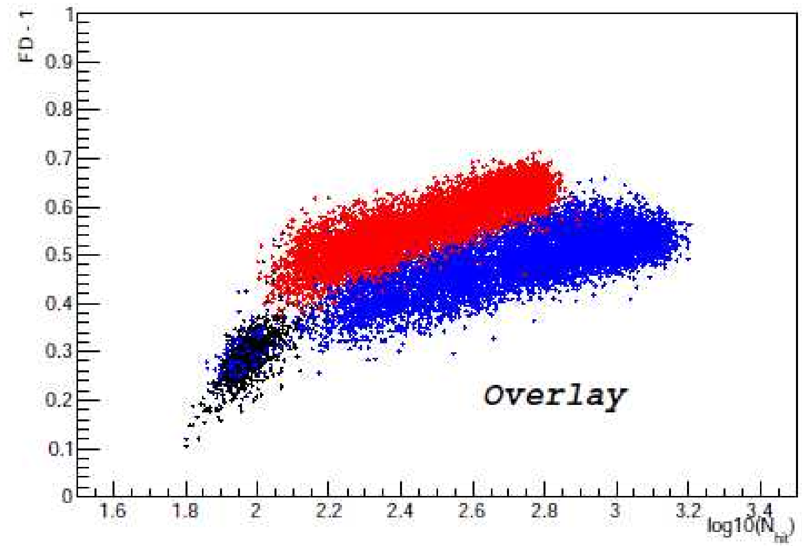
Conventional: Global Separation





Q > 114 fC (First Threshold)



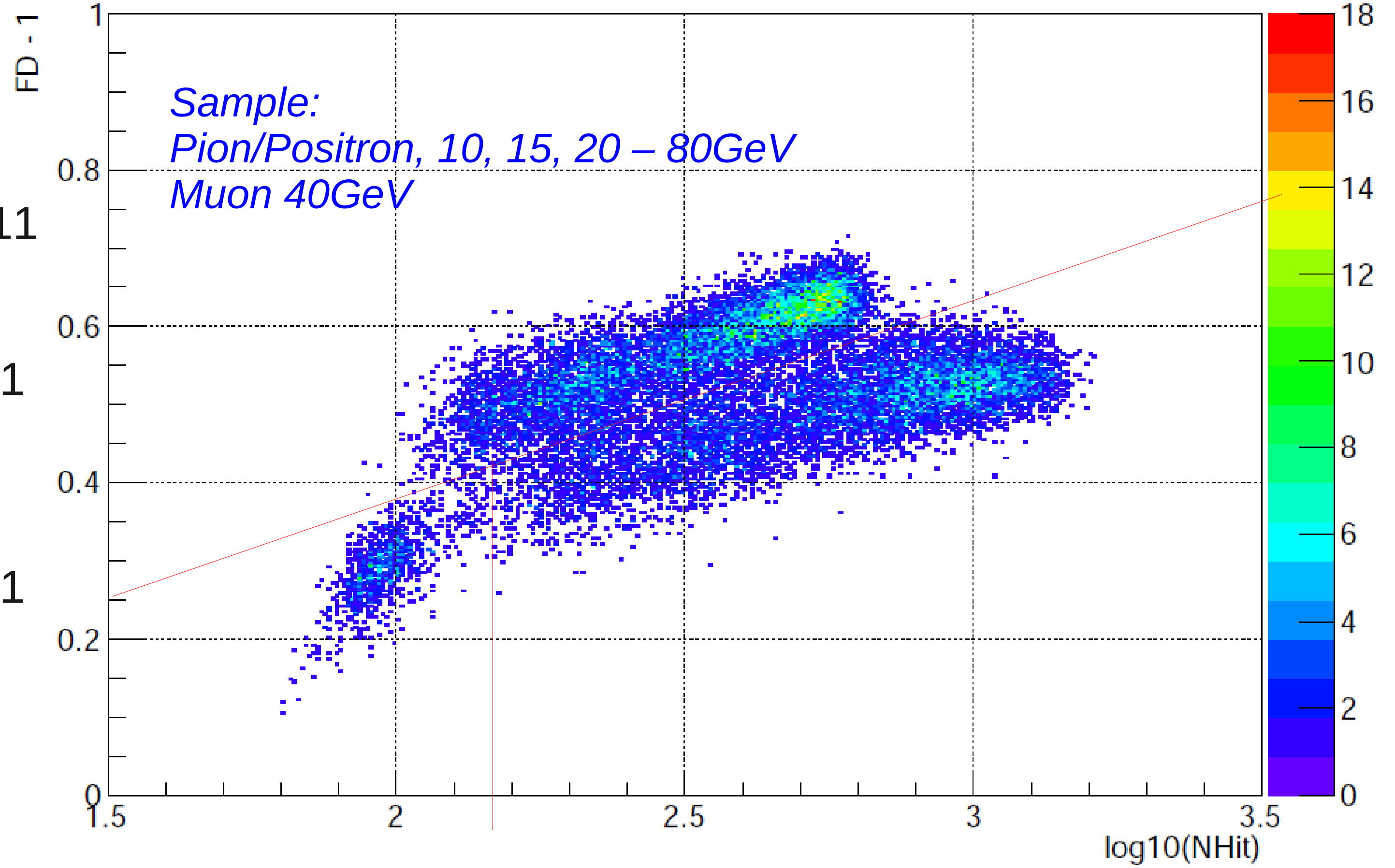


Global Separation

Positron:
0.25*log10(NHits) - FD <= 0.11

Pion:
0.25*log10(NHits) - FD > 0.11
Nhits > 150

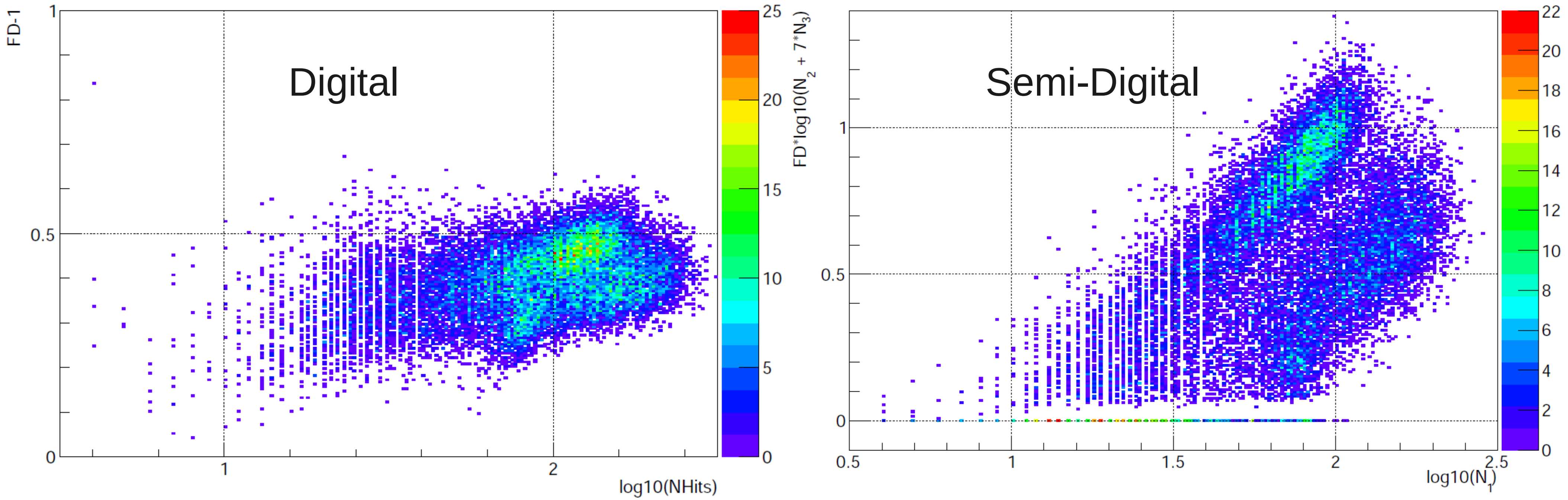
Muon:
0.25*log10(NHits) - FD < 0.11
Nhits <= 150



Without knowing shower energy!

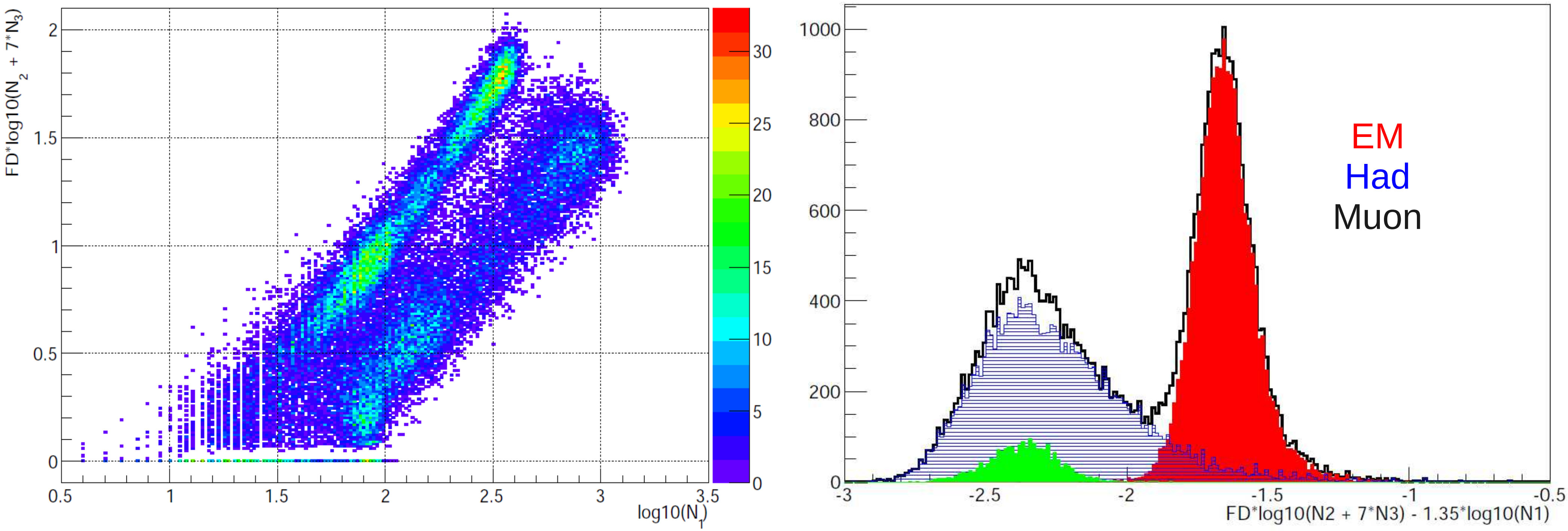
	e	pi	mu
e	8799 (97.8%)	197	4
pi	492	8376 (93.1%)	132
mu	24	19	957 (95.7%)

Changeling at LowE: Using Semi-Digital Info



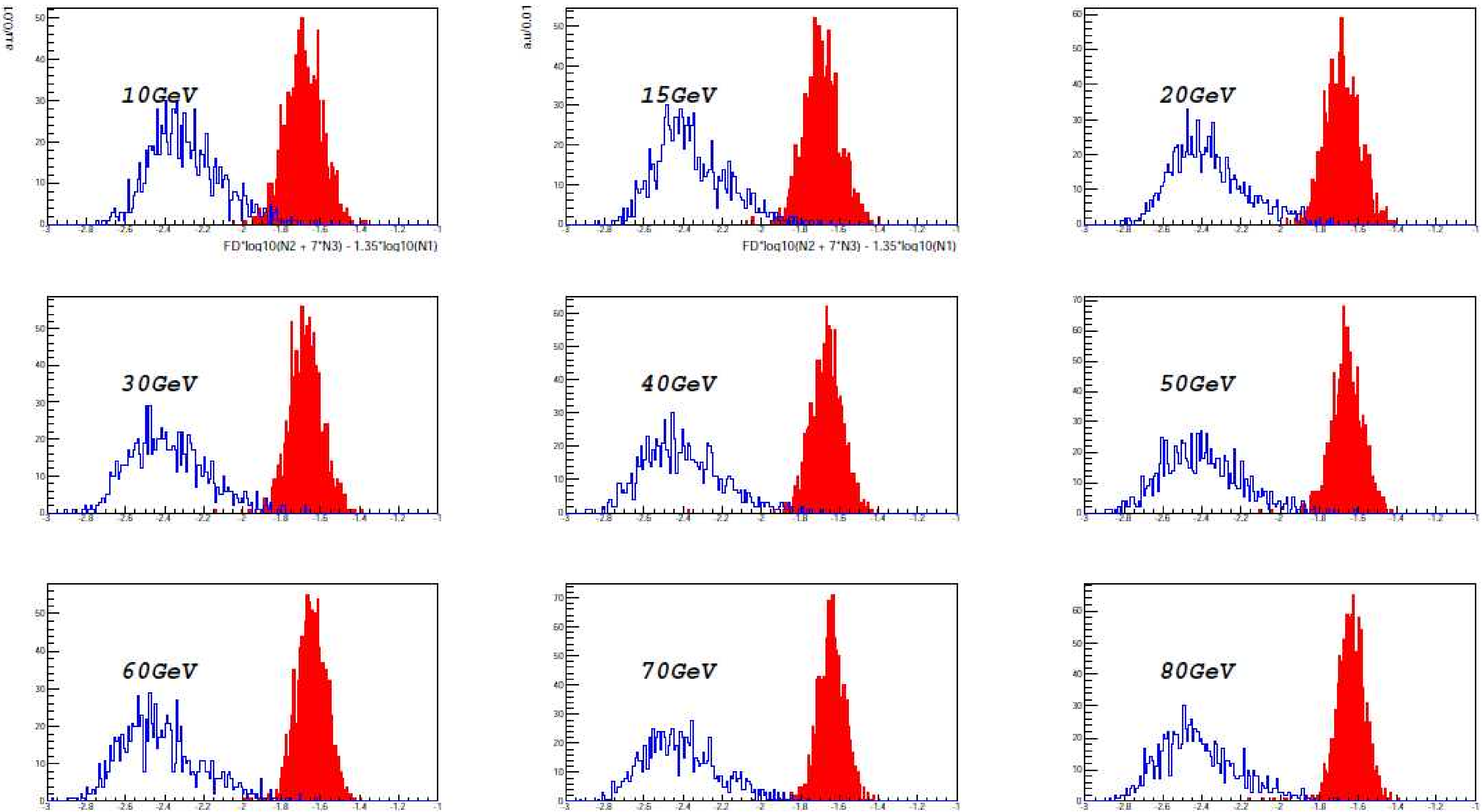
- Sample: 1 – 10GeV e/pi (step = 1GeV); 5GeV Muon.
- Conventional Separation: Become difficult when energy < 10GeV
- Semi-Digital information *(a demonstration)*
  - Variable: log10(N1), FD*log10(N2+7*N3)

Semi-Digital
Global Separation

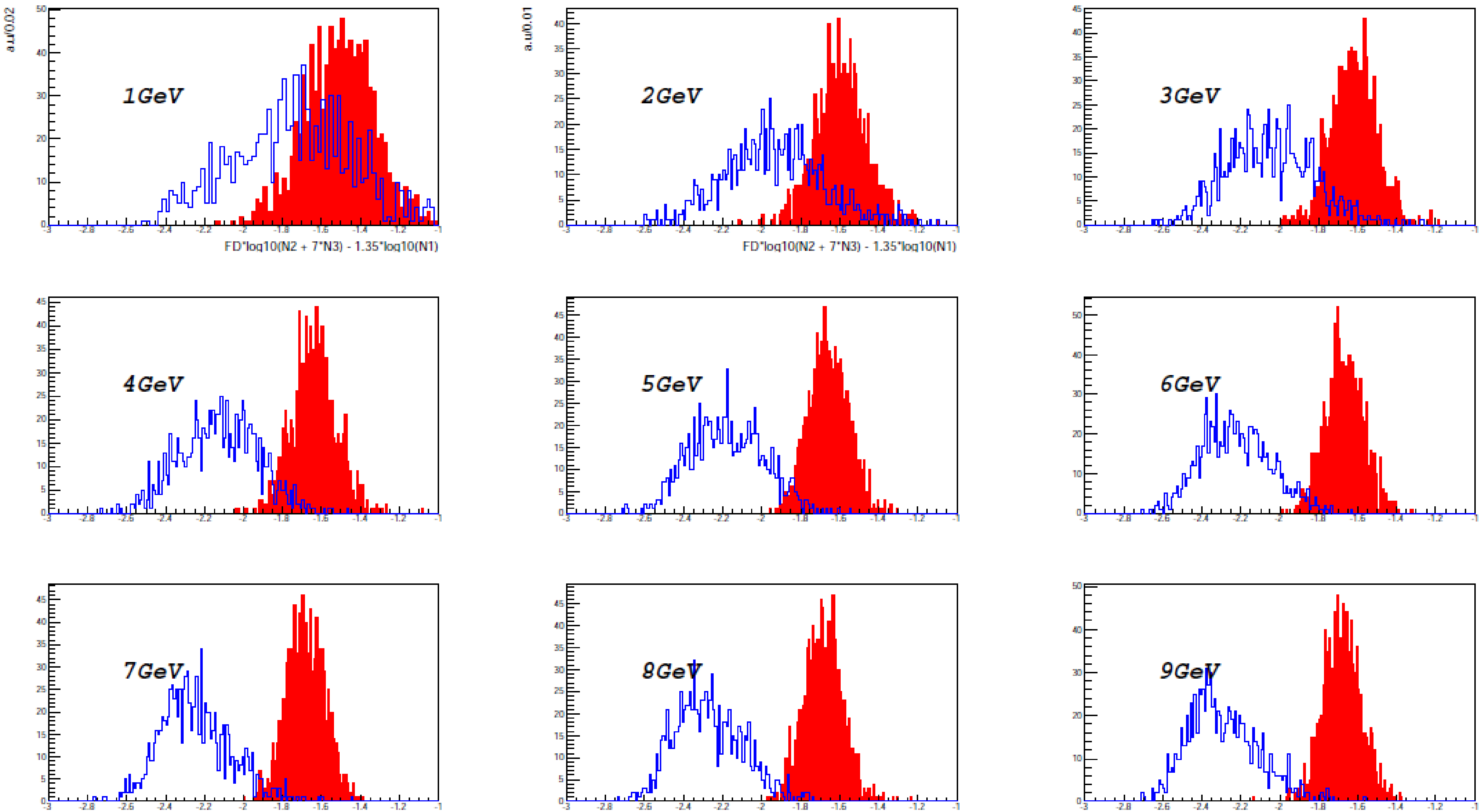


- Sample: 18k e/pion (1 – 10, 15, 20 – 80GeV) and 2k Muon (5, 40GeV). 38k total events
- Variable for e-pi separation: FD*log10(N2 + 7*N3) – 1.35*log10(N1)

Semi-Digital e-pi Separation: En ≥ 10GeV



Semi-Digital e-pi Separation: En < 10GeV



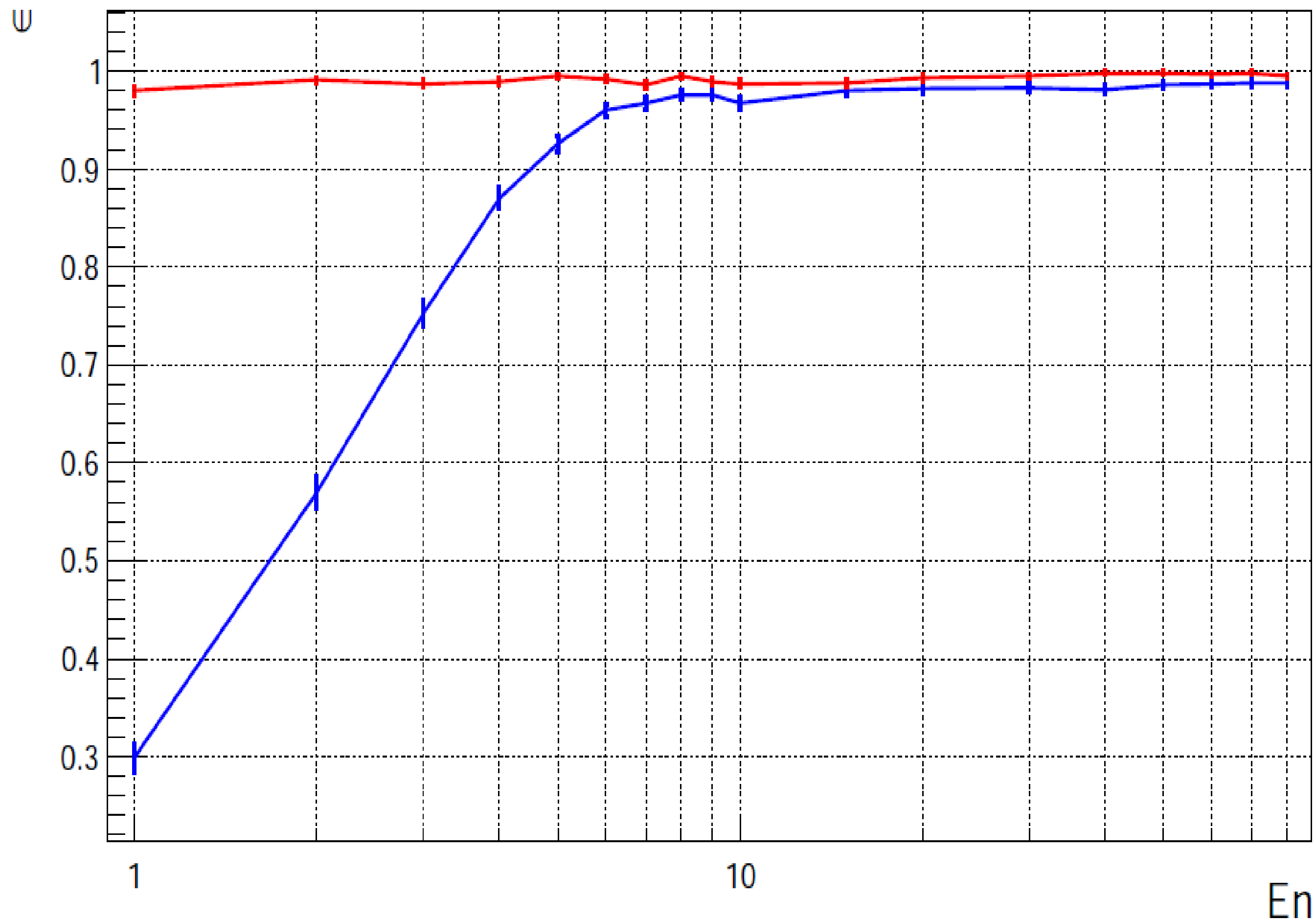
Efficiency with simple Cut

*Variable: FD*log10(N2 + 7*N3) – 1.35*log10(N1)*

Positron: V > 1.9
ε > 98% at any Energy
ε ~ 100% at En > 10GeV

Pion: V ≤ -1.9
ε > 98% at En > 10GeV
ε > 95% at En > 5GeV

Drops quickly to lower energy



Cut & Thresholds: not optimized

Summary

- General Gaseous Calorimeter Digitizer has been developed:
  - Parametrize 1mm simulated hit with an induced charge spectrum and spatial charge distribution table
  - Reproduce MicroMegas/GRPC test beam result with proper parameters: a solid base for MC based analysis
  - *Remark:*
    - *Possible extension: Parametrize 1mm EM/Hadron hit independently*
    - *Spinoff: ideal sample for cell size optimization*

- Analysis with Digitizer: 1, FD & Multiplicity as a function of energy/thresholds
  - Multiplicity of EM/Had shower: Defined
    - Multiplicity decrease with shower energy (and threshold): another source of the saturation effect at detector with digital readout
  - FD: increase with shower energy and decrease with threshold

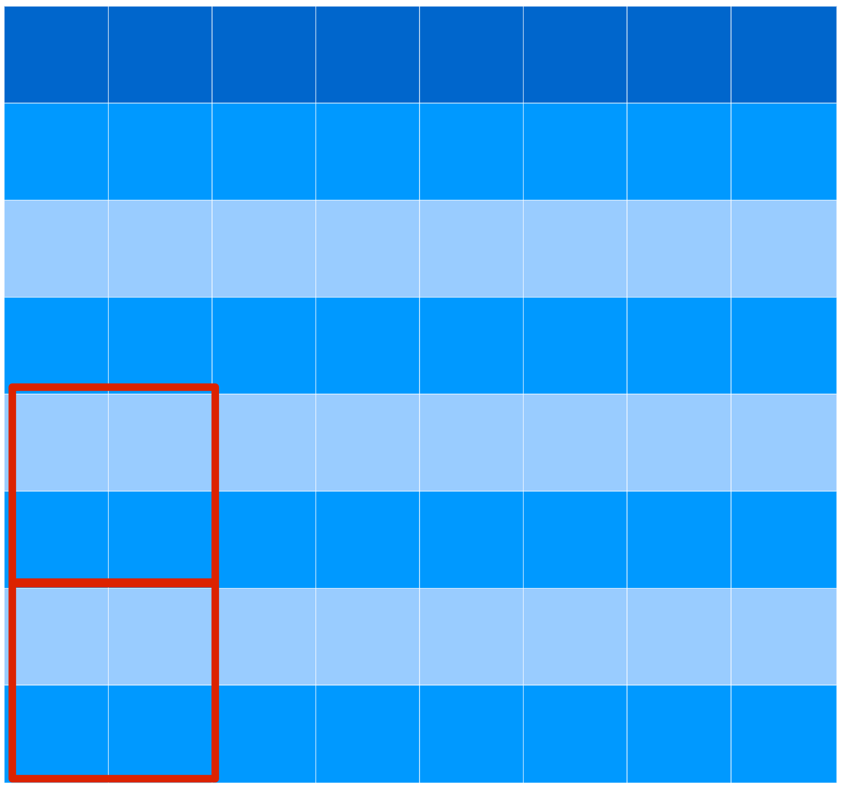
Summary

- Analysis with Digitizer: 2, PID efficiency at Digitized sample
  - Conventional method (based on total hit number and total FD)
    - Ideal performance at energy > 10GeV (for mixed sample with same energy)
    - Allows a global separation without energy information: efficiency ~ 95%
  - Using Semi-Digital information
    - Improves global separation at E > 10GeV: ε ~ 99% in e-pi separation
    - Clear separation at energy > 5GeV
    - ...

Not the end of the story...

FD @ SDHCAL

SDHCAL TB: totally 48 active layers, each layer consist of 96*96 = 9216 cells with 3 thresholds

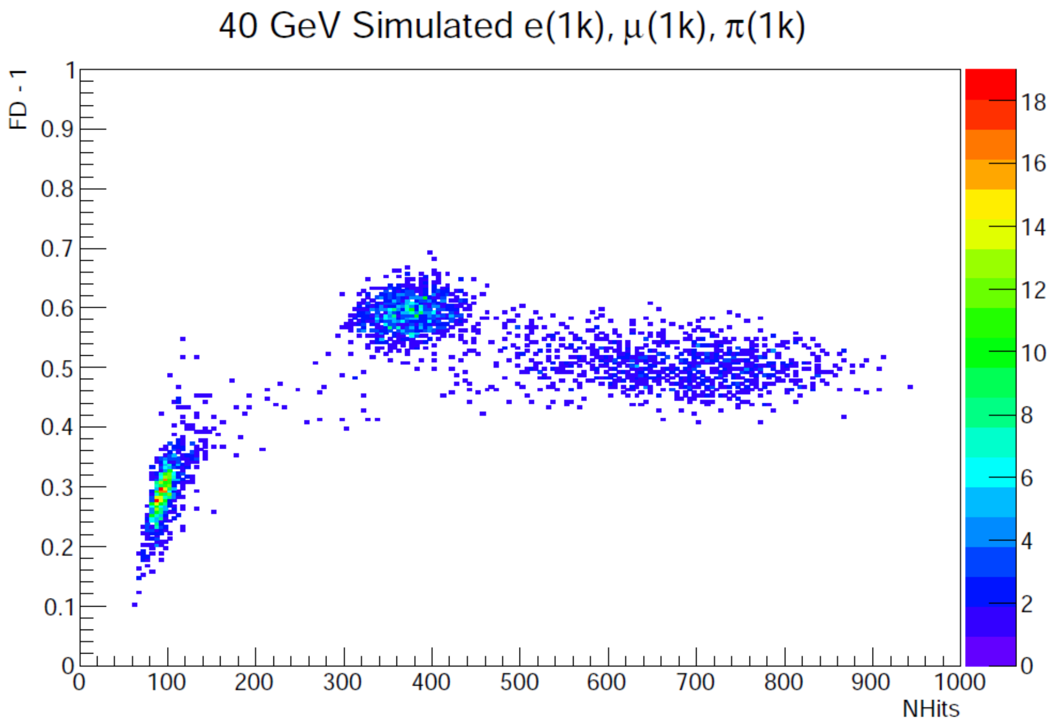


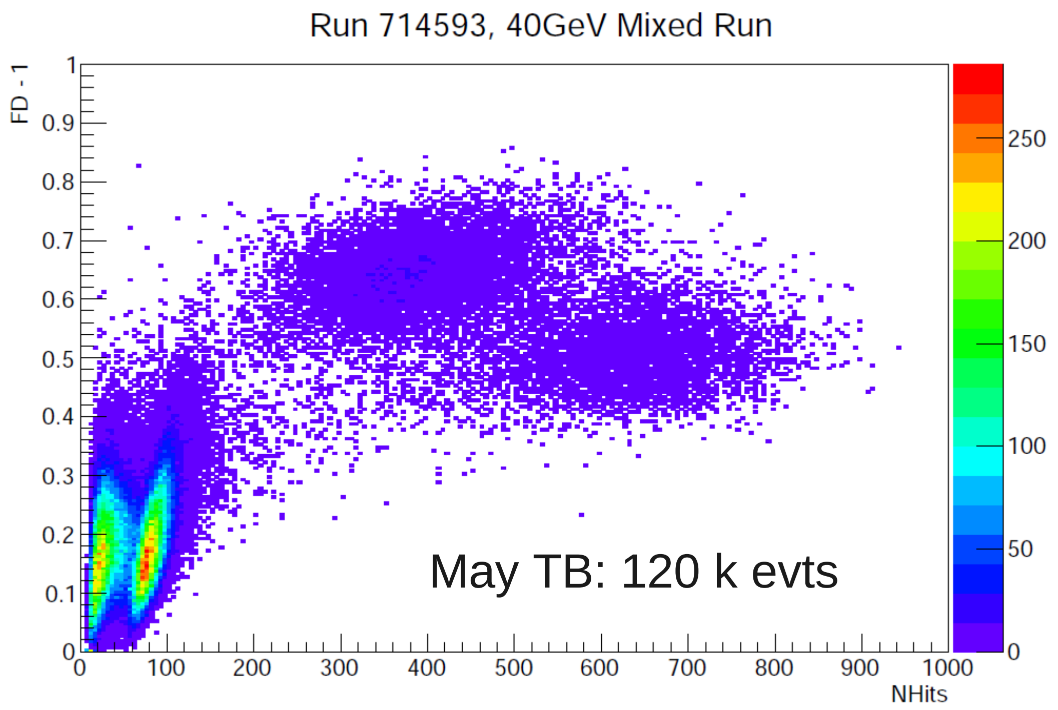
FD Measured from total # hits:

- Varying scale by grouping neighbouring cells
- Count Number of hits at different scale *(define RN**x** = N**1**cm/N**x**cm)*

FD = <log(RNx)/log(x)>; x = 2 – 11 cm

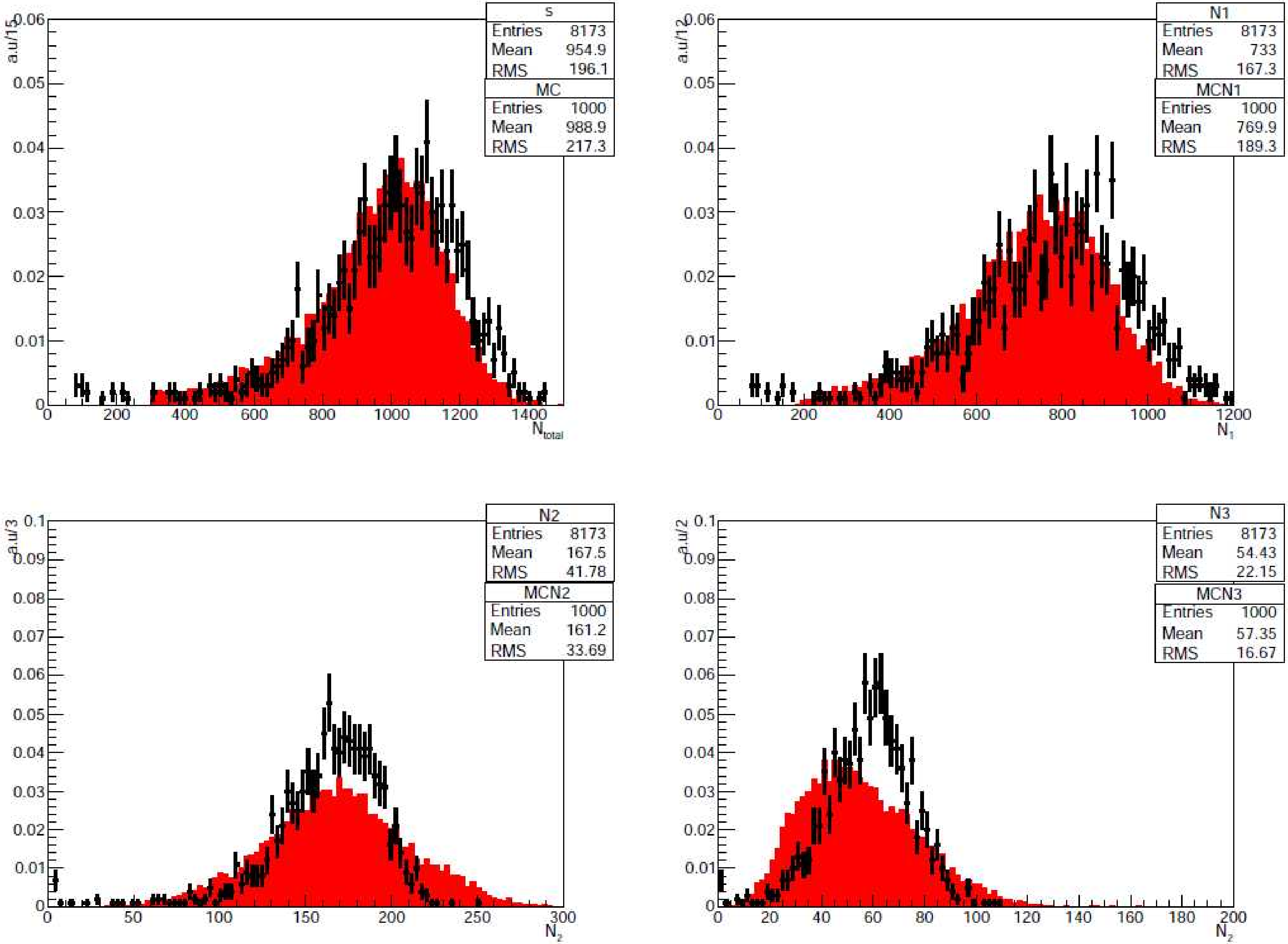
Local Separation: 40GeV



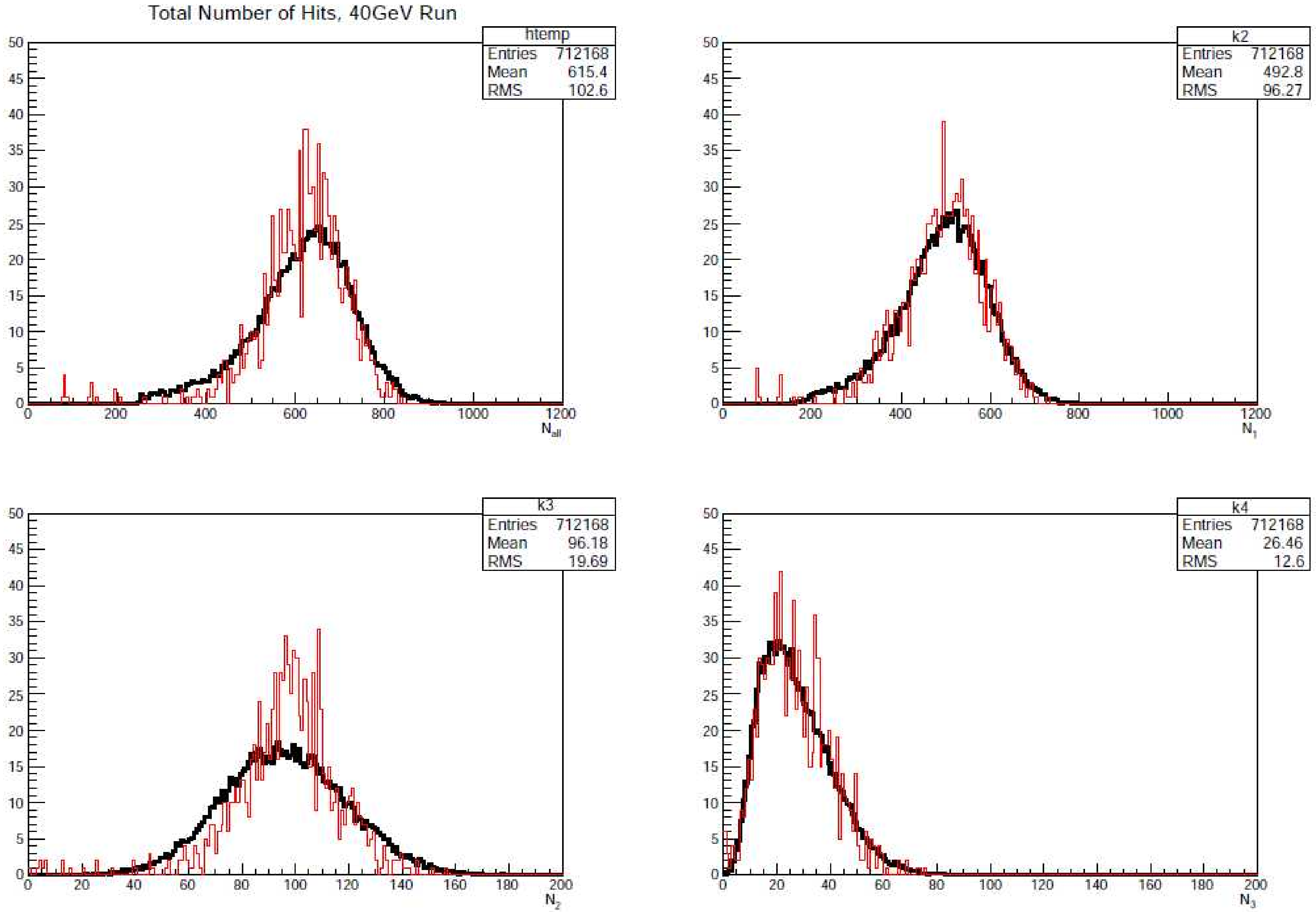


With test beam data: cleaning and leakage events subtraction is needed...

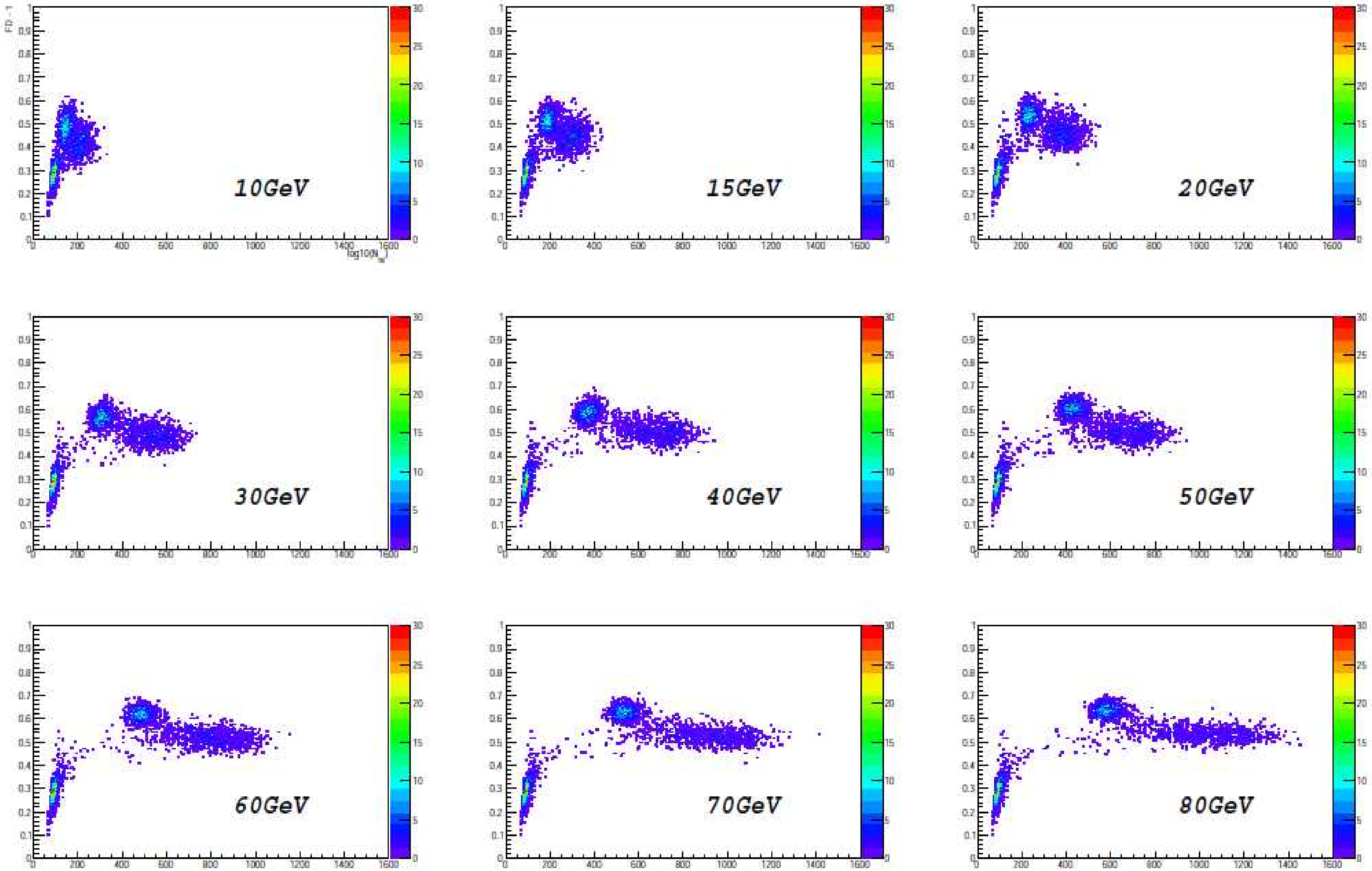
MC-TB: Global Tuned, 70GeV Pion



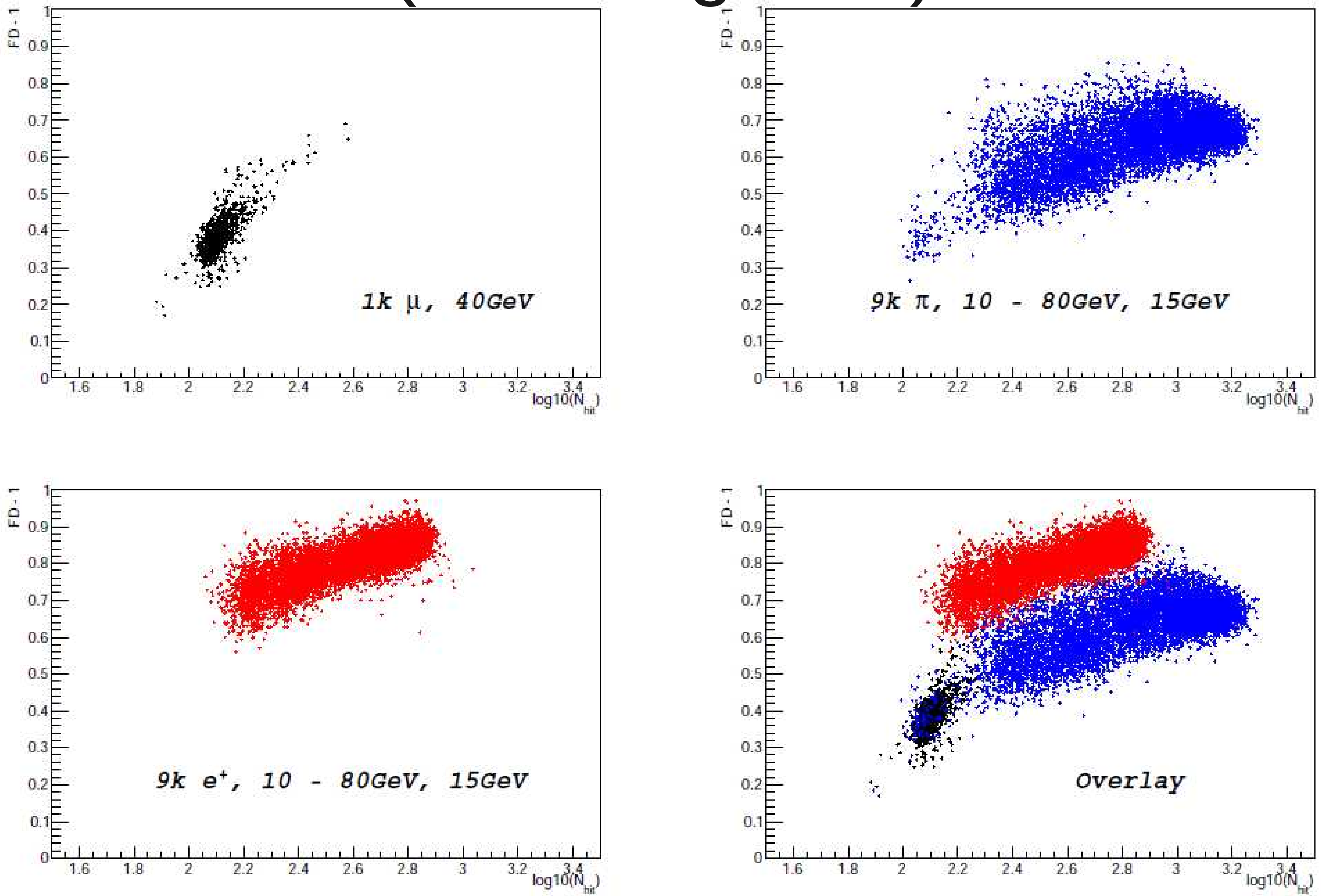
MC-TB: locally Tuned, 40GeV Pion



Separation at different E



FD Vs #Digitized hits (no charge cut)

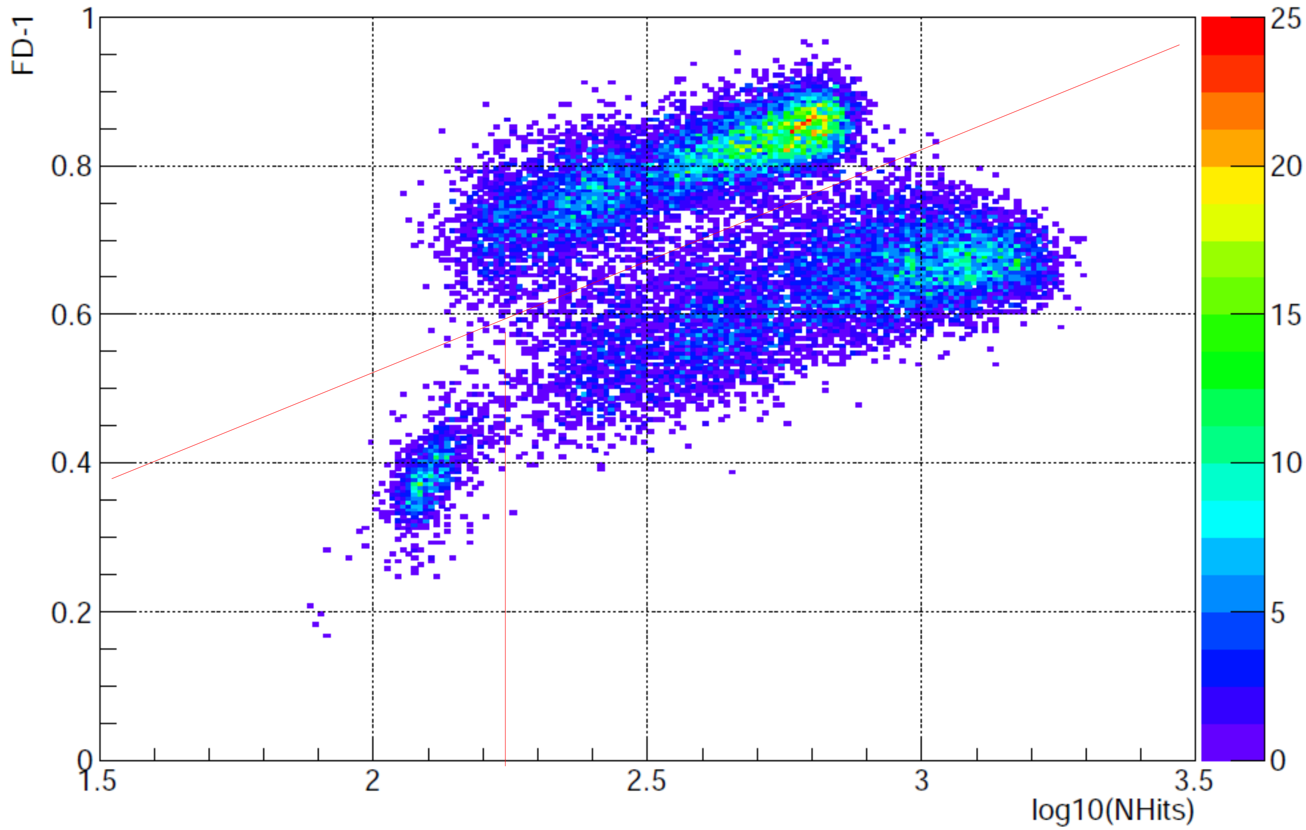


Global Separation (no charge cut)

Positron:
0.3*log10(NHits) - FD <= 0.06

Pion:
0.3*log10(NHits) - FD > 0.06
Nhits > 178

Muon:
0.3*log10(NHits) - FD > 0.06
Nhits <= 178



Without knowing shower energy!

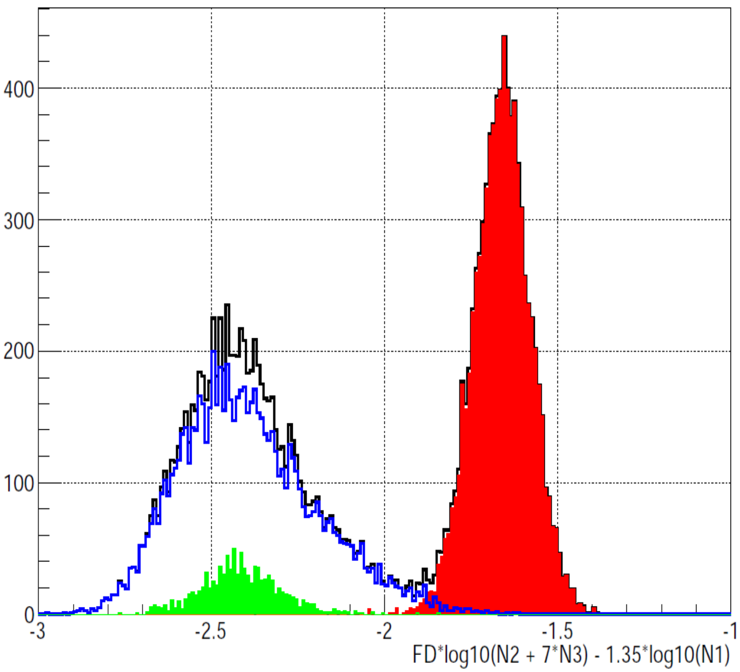
No side leakage

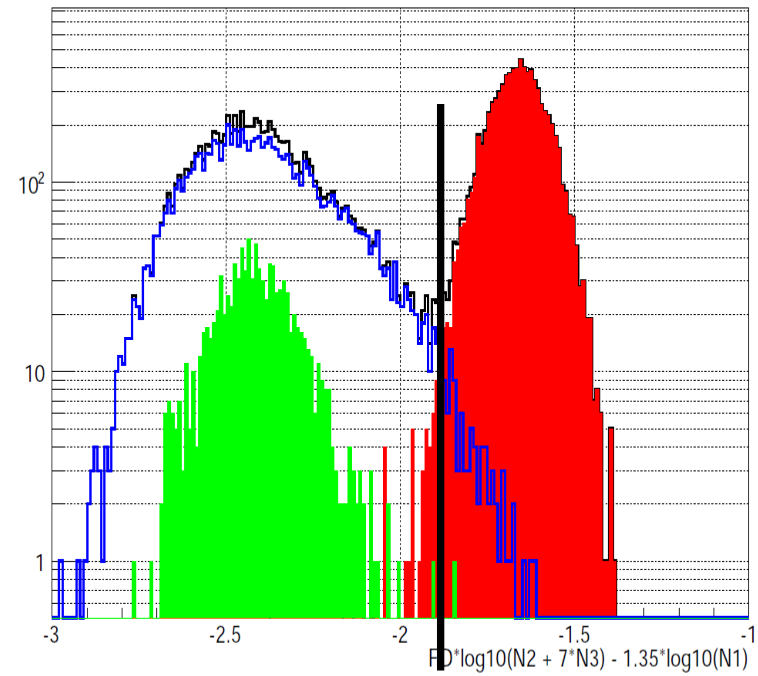
	e	pi	mu
e	8930 (99.2%)	70 (0.8%)	0
pi	217 (2.4%)	8660 (96.2%)	123 (1.4%)
mu	0	28	972

Global e-p Separation

E > 10 GeV
Cut at Var = -1.9

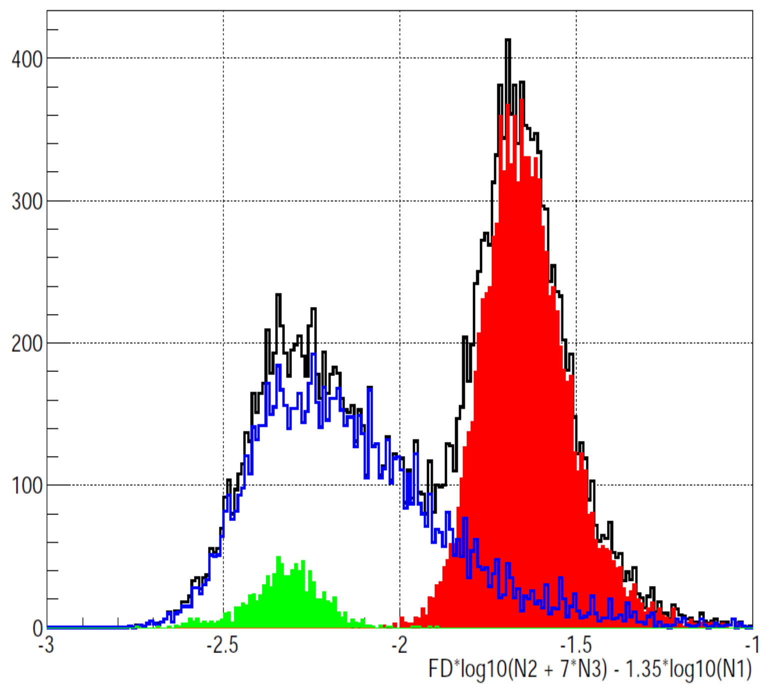
	e	pi
e	7962~ 99.5%	38
pi	125	7875~ 98.4%

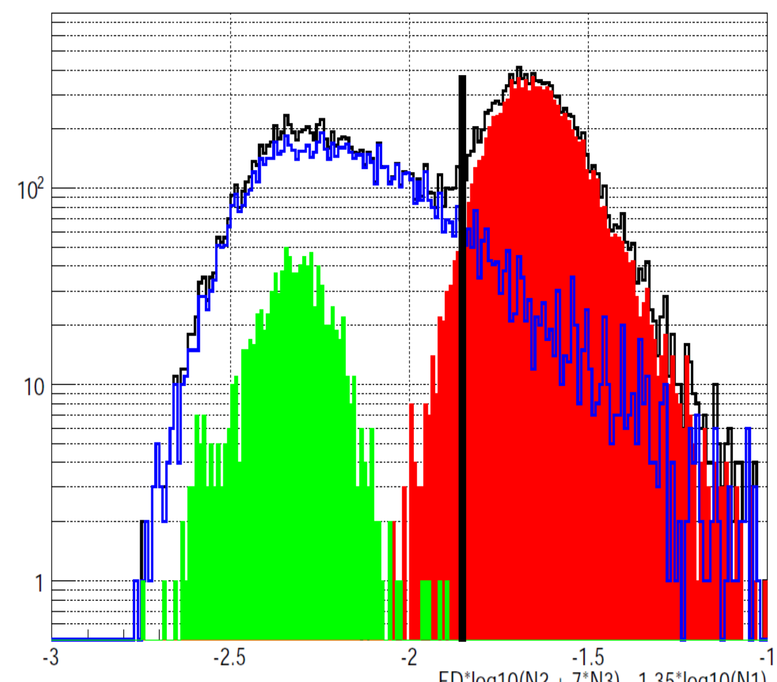




E <= 10 GeV
Cut at Var = -1.85

	e	pi
e	9679~ 96.8%	321
pi	1393	8607~ 86.1%





12/09/2012