Analog vs. Digital Hadron Calorimetry for the ILC

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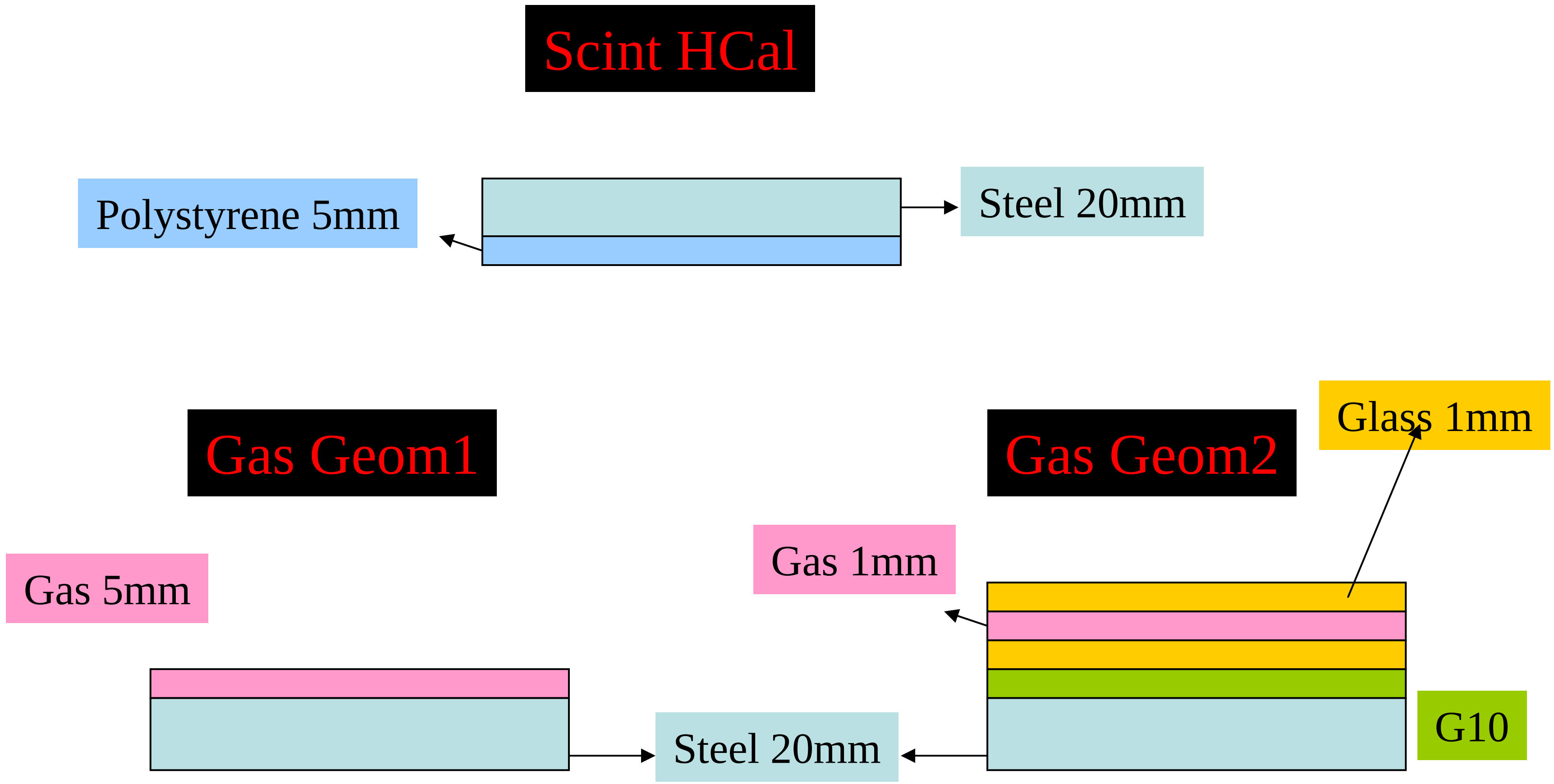
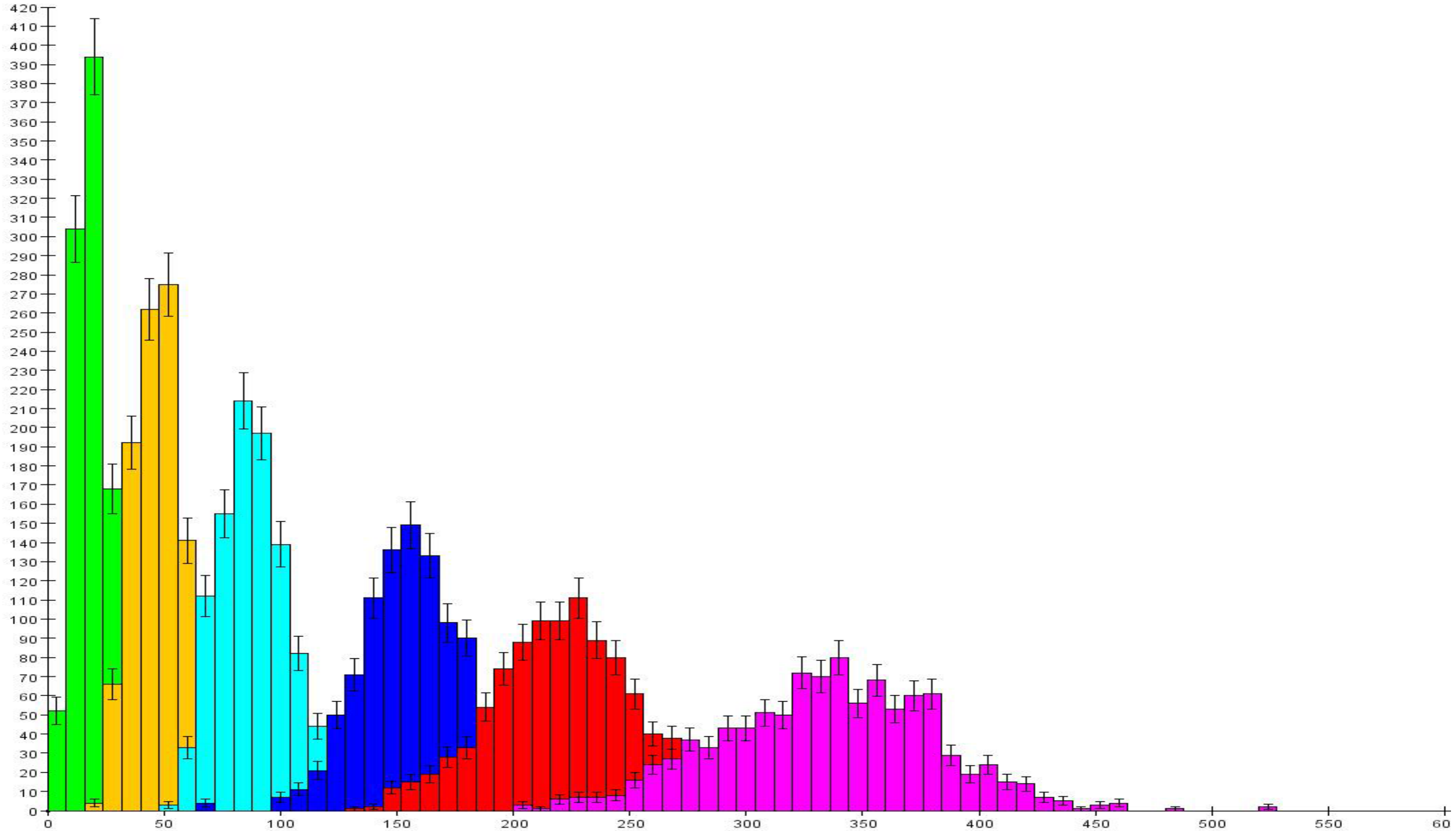
Introduction

- We consider a hadronic calorimeter with a few thresholds (1–3).
- Compare gas and scintillator as live media:
  - Single particle energy resolution,
  - Shower width,
  - Clustering.

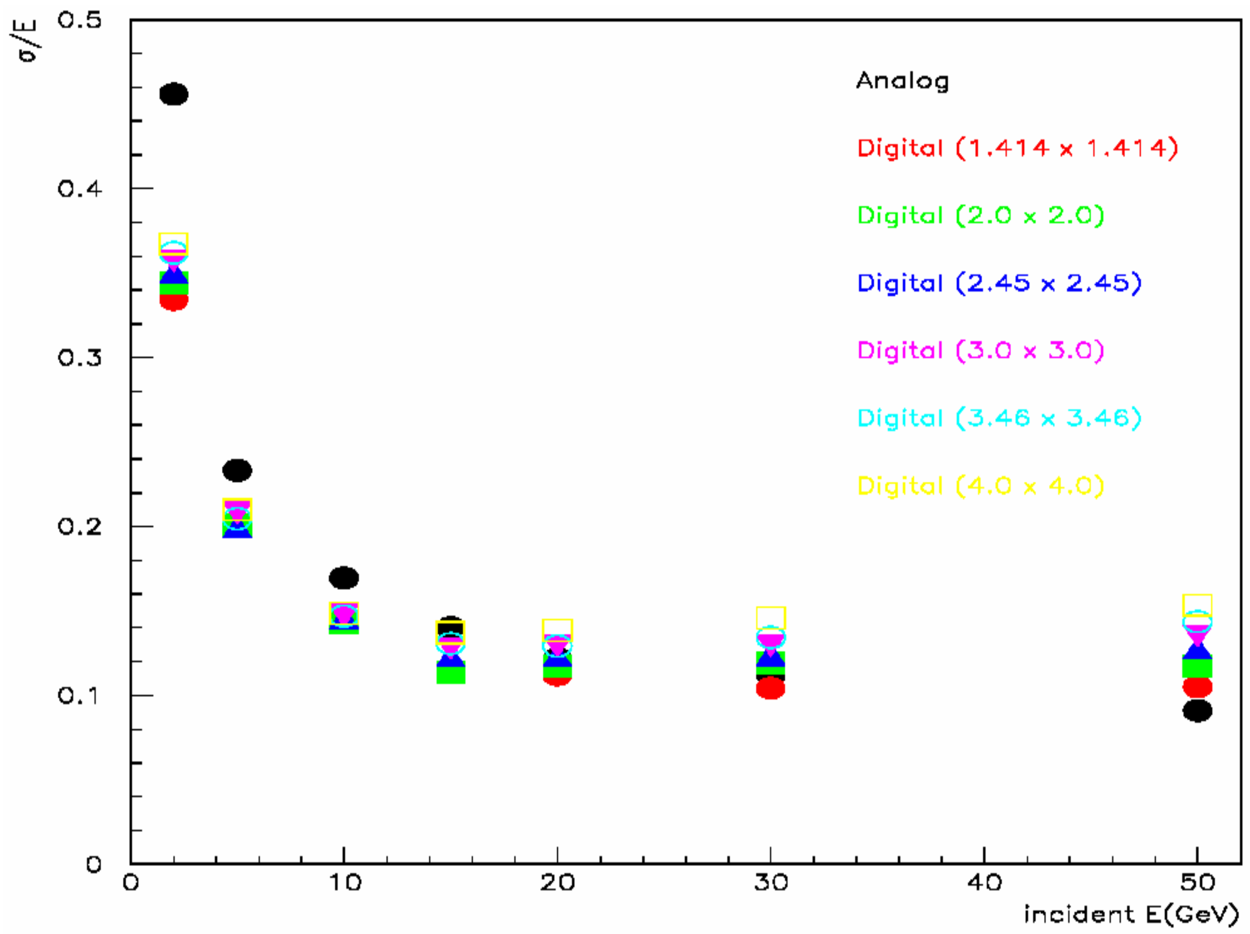
Geometries Considered



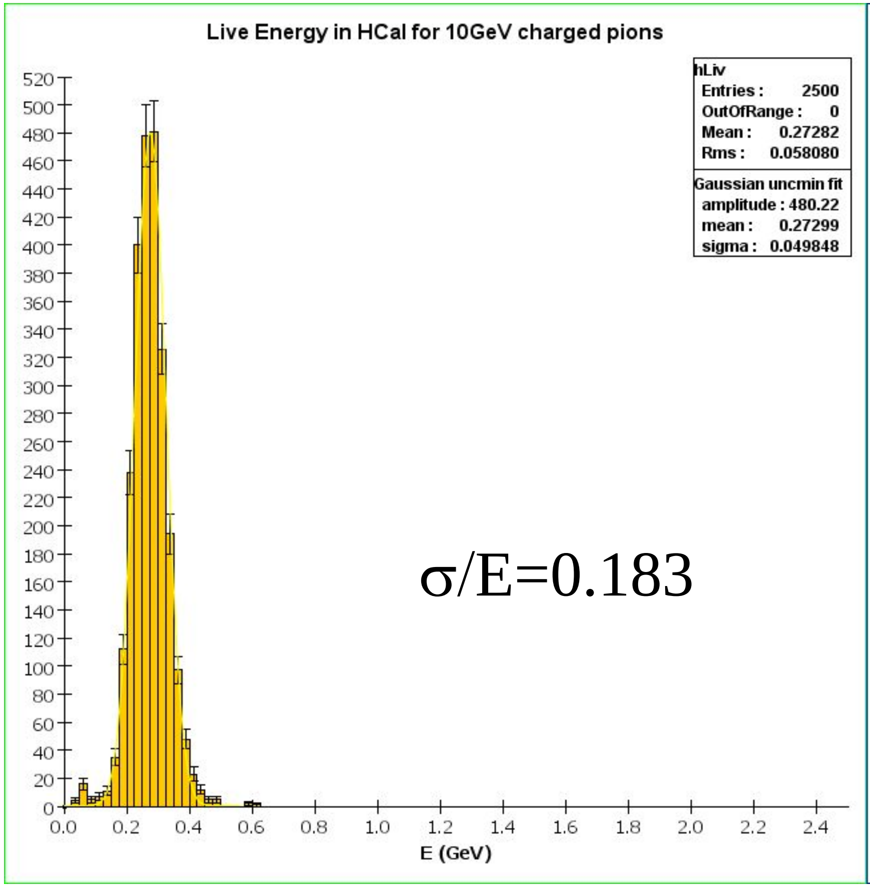
Number of cells hit by π^+s of 2, 5, 10, 20, 30, 50 GeV

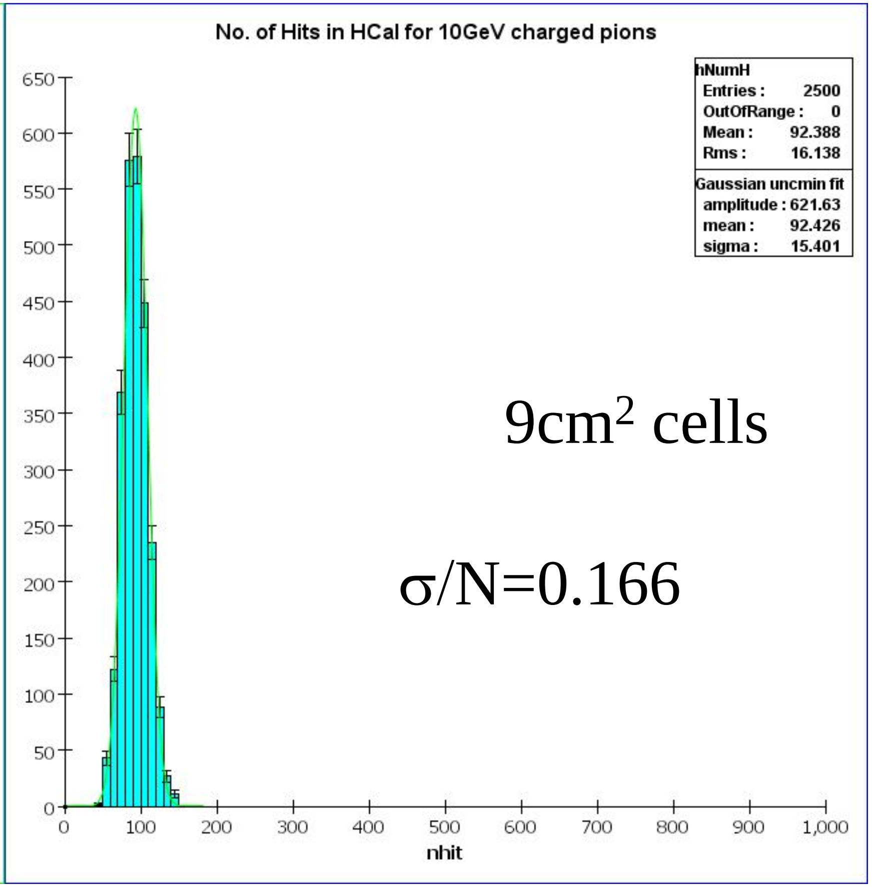


π^+ energy resolution as function of energy for different (linear) cell sizes

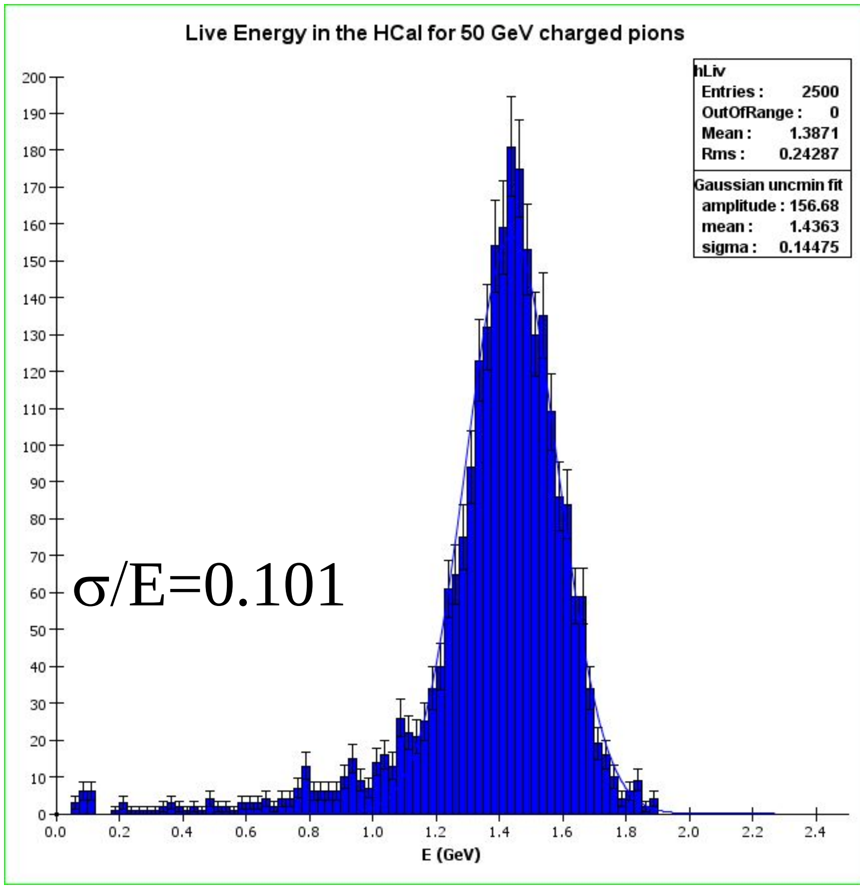


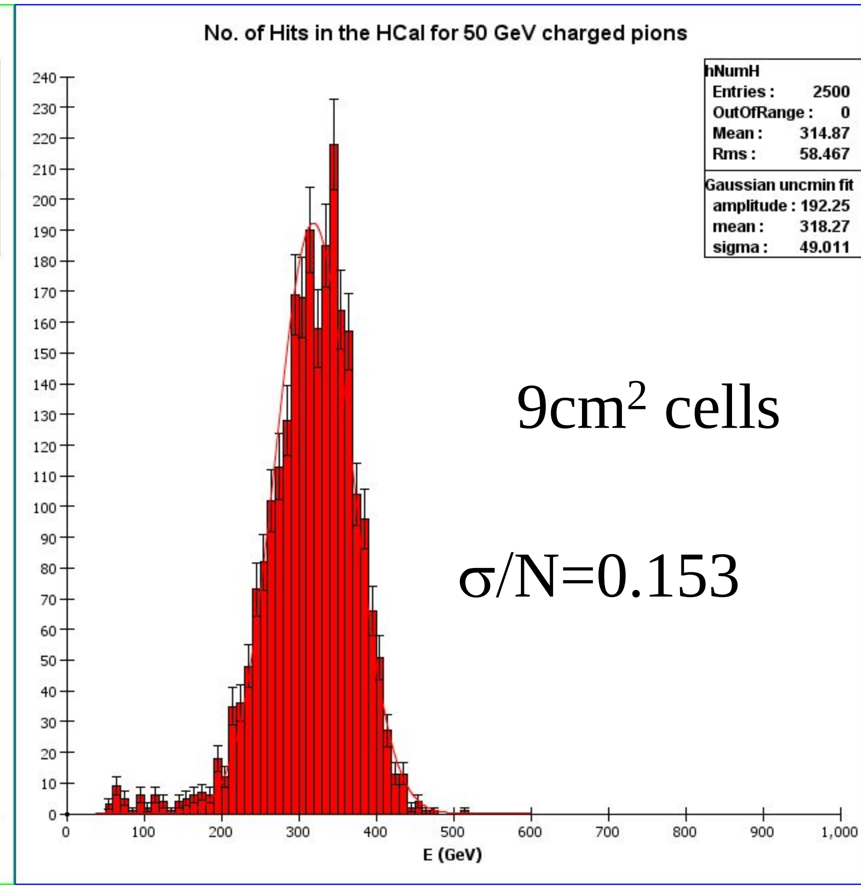
Energy resolution for 10 GeV π^+s



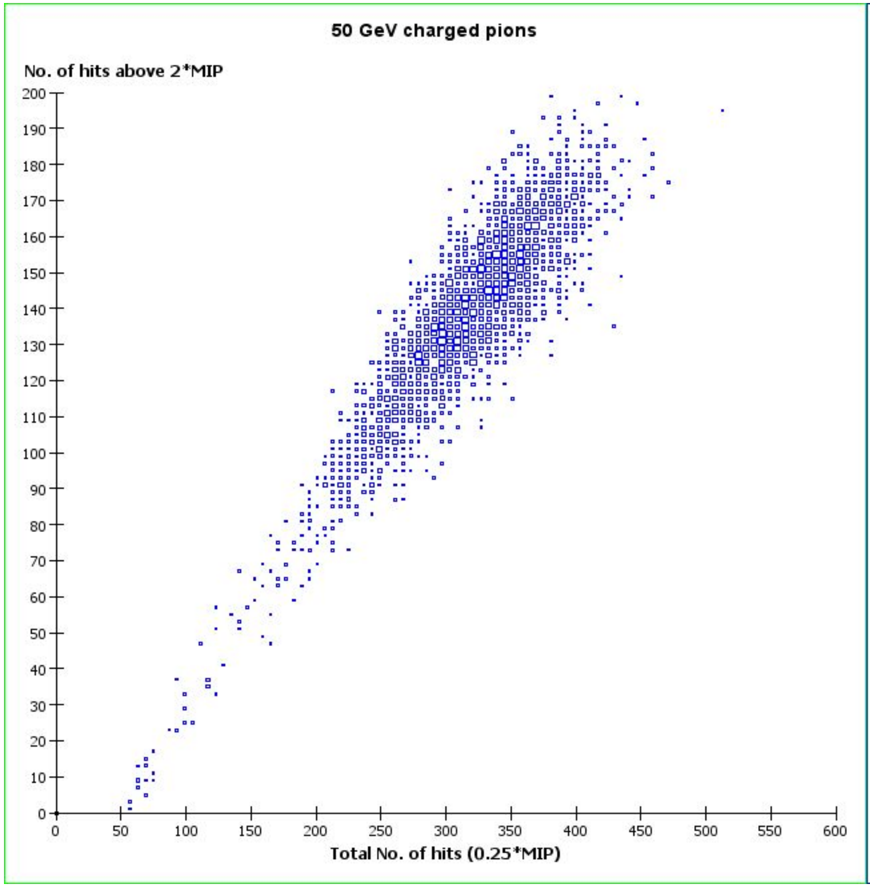


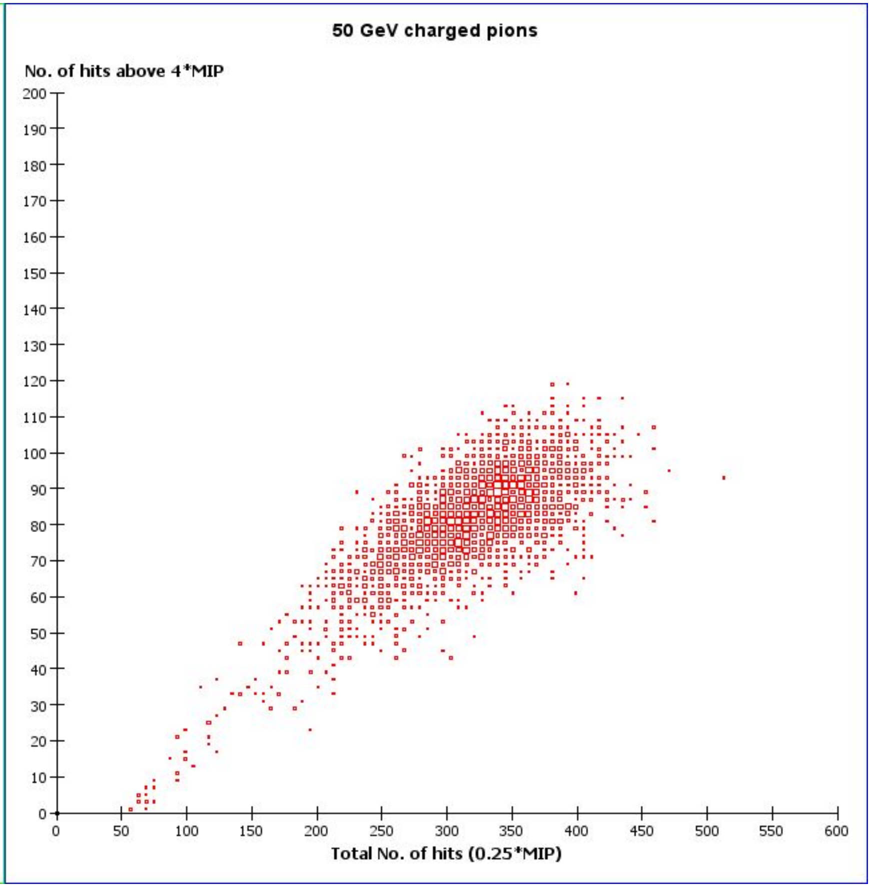
Energy resolution for 50 GeV π^+s



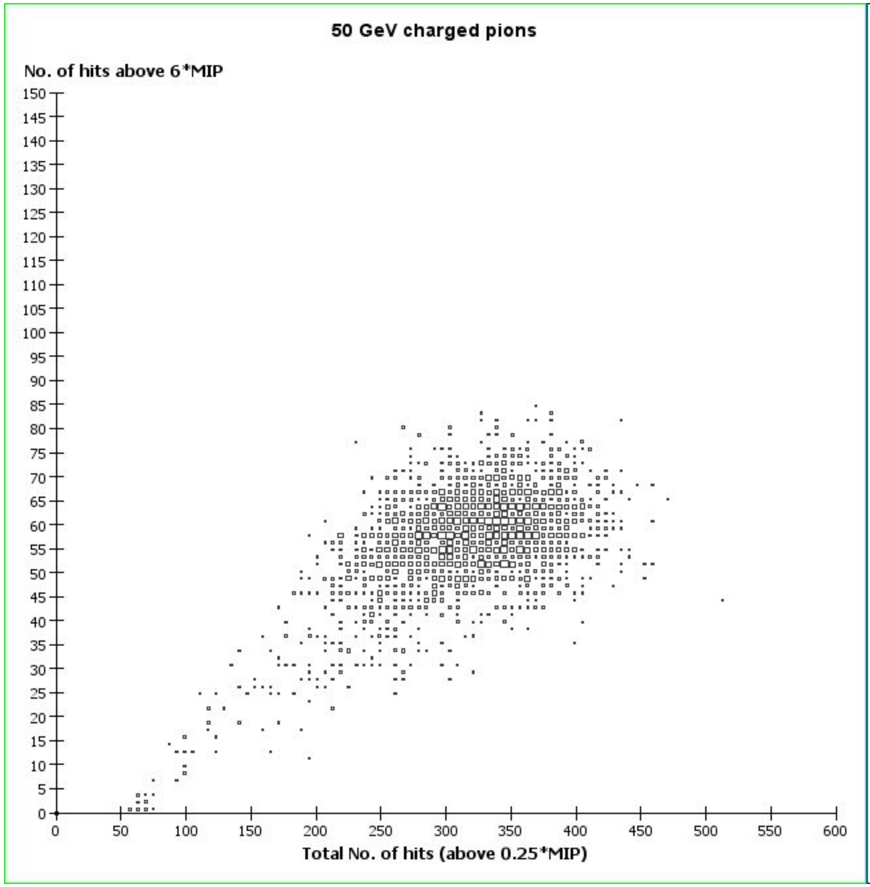


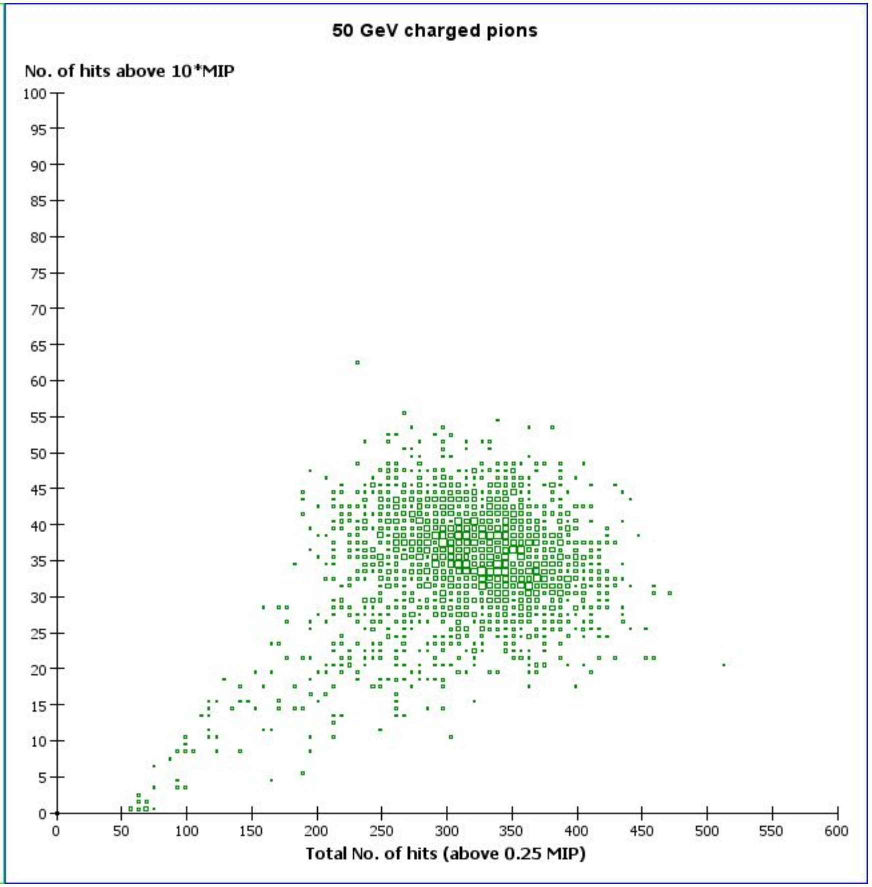
Nhit correlations for different cell energy thresholds



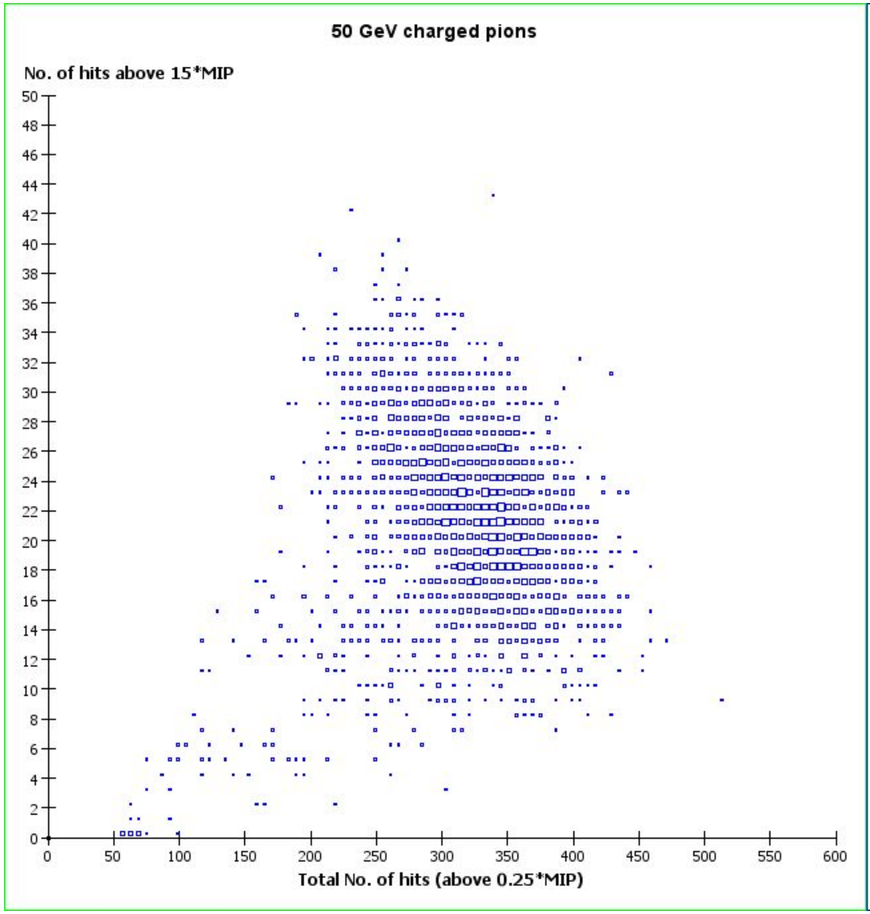


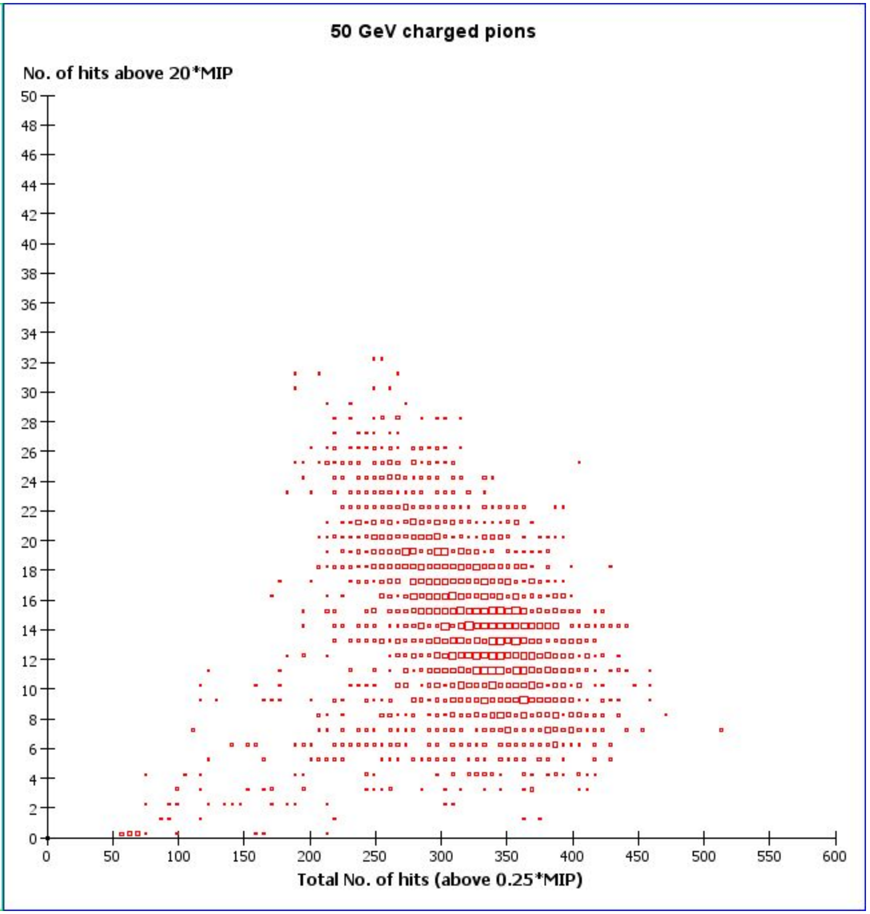
Nhit correlations for different cell energy thresholds



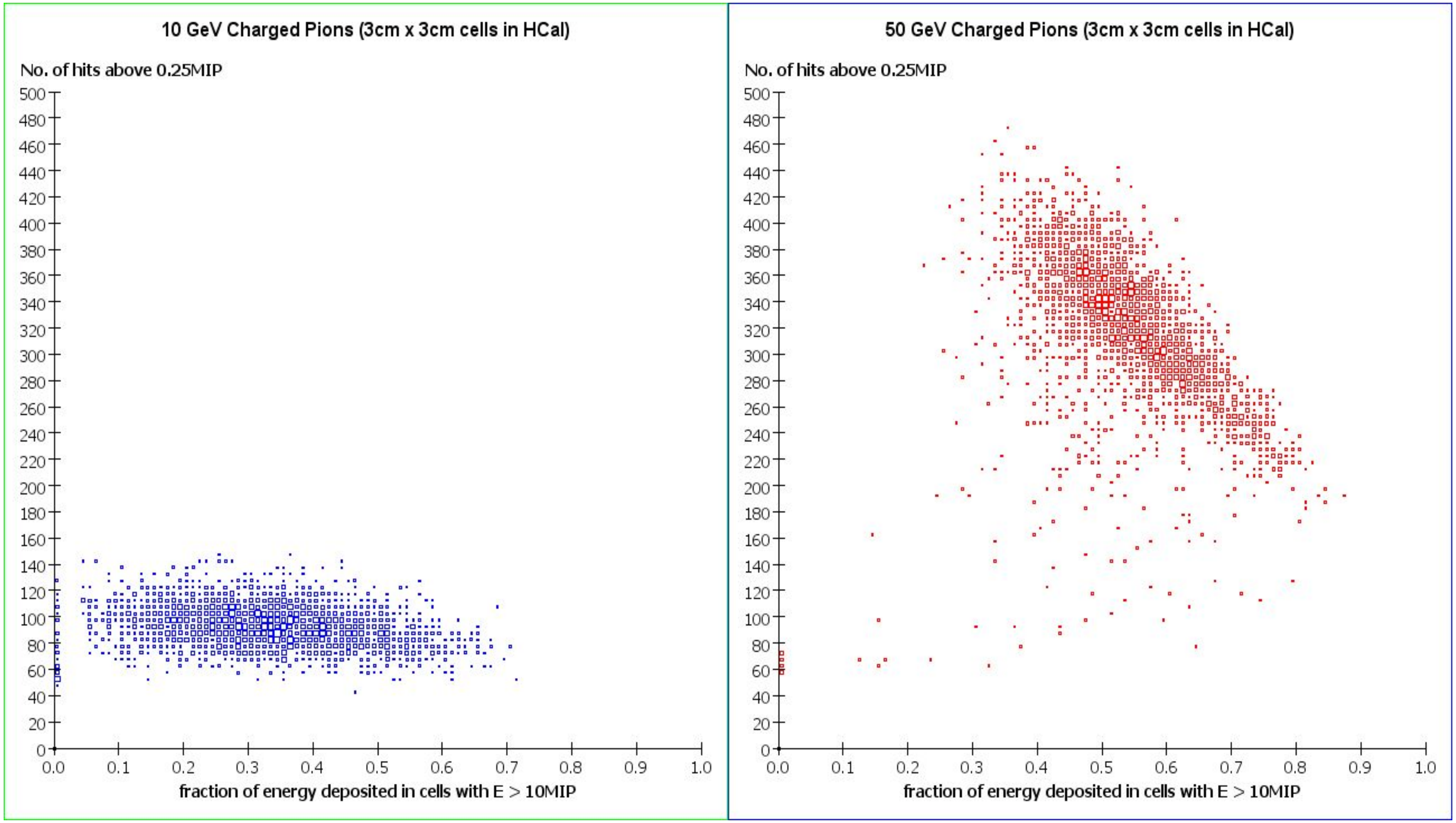


Nhit correlations for different cell energy thresholds





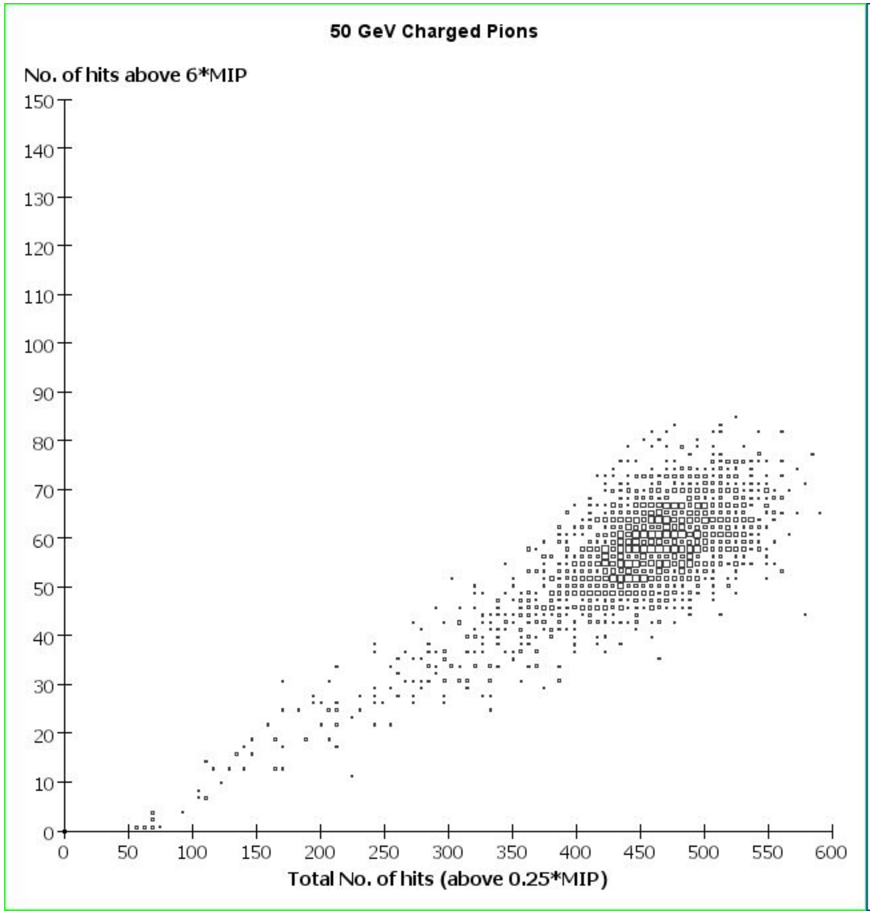
Alternatively,

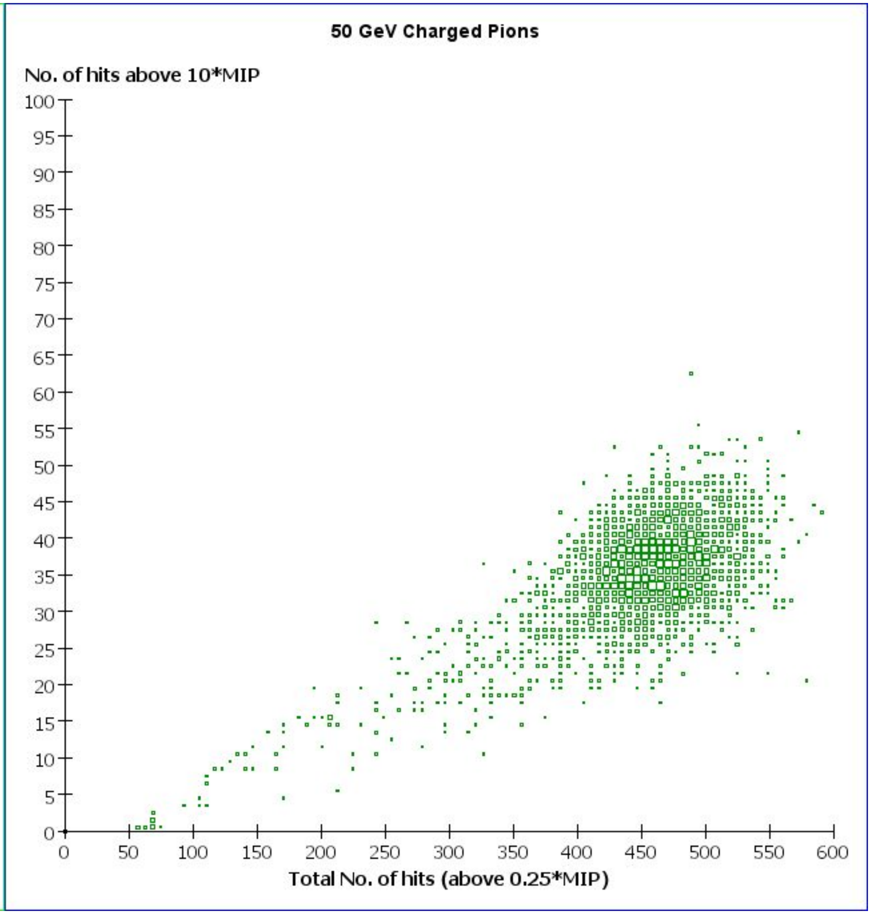


Compensation

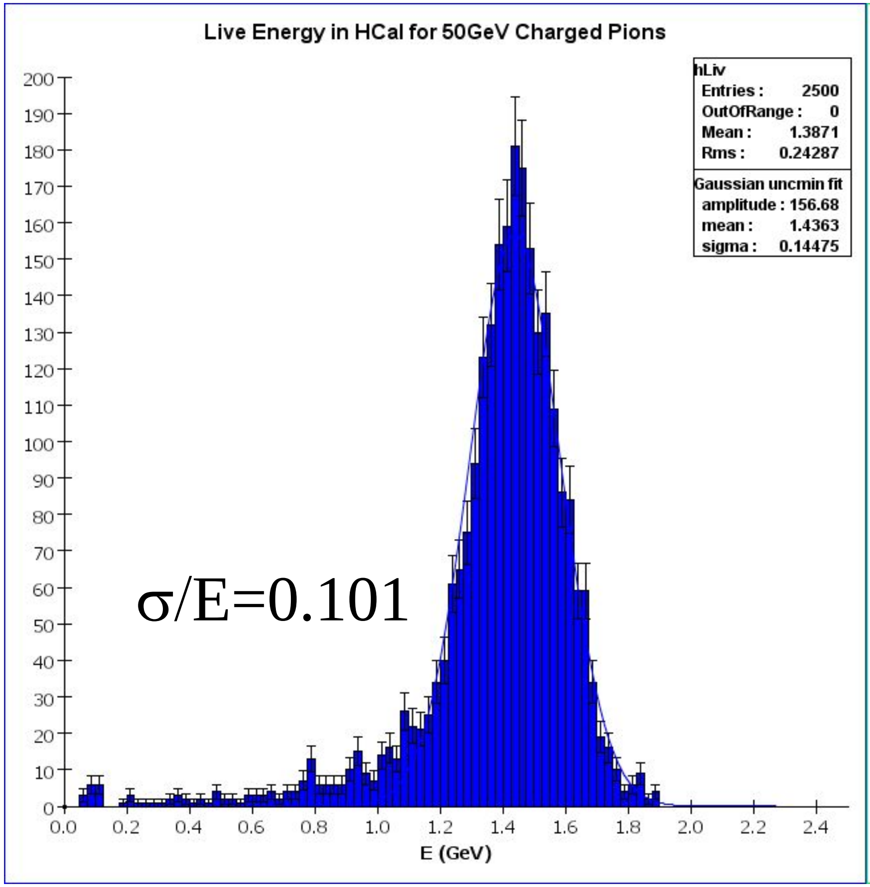
- Cell counting has its own version of the compensation problem (in scintillators).
- With multiple threshold this can be overcome by weighting cells differently (according to the threshold they passed).
- In MC, 3 thresholds seem to be adequate

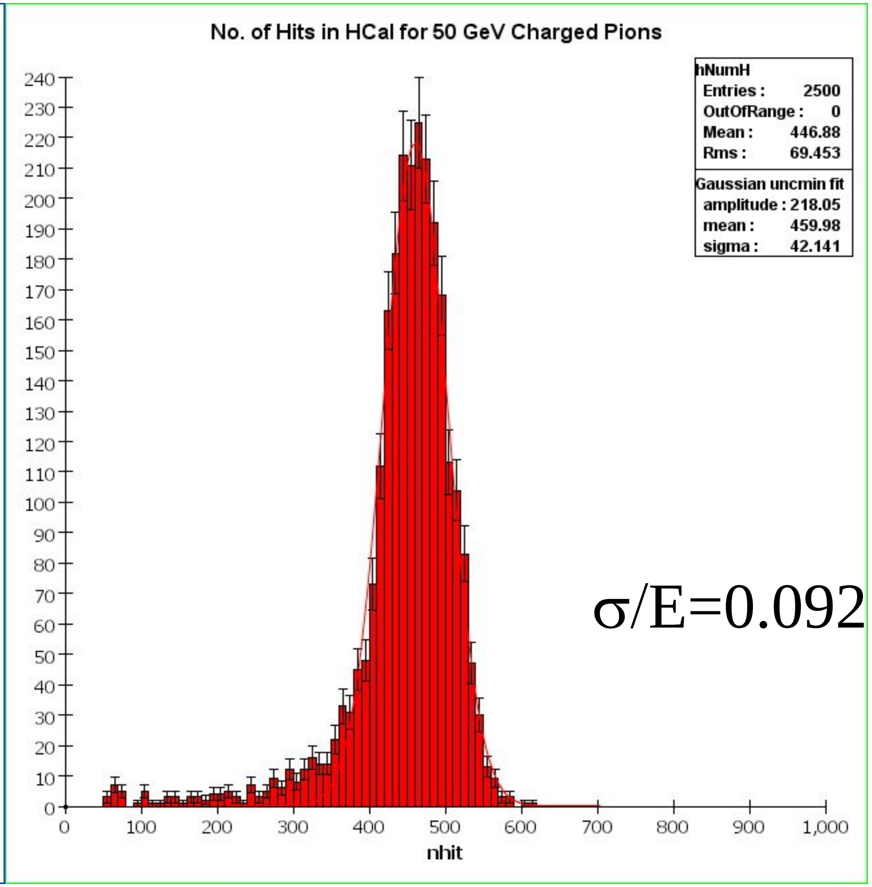
After semi-digital treatment



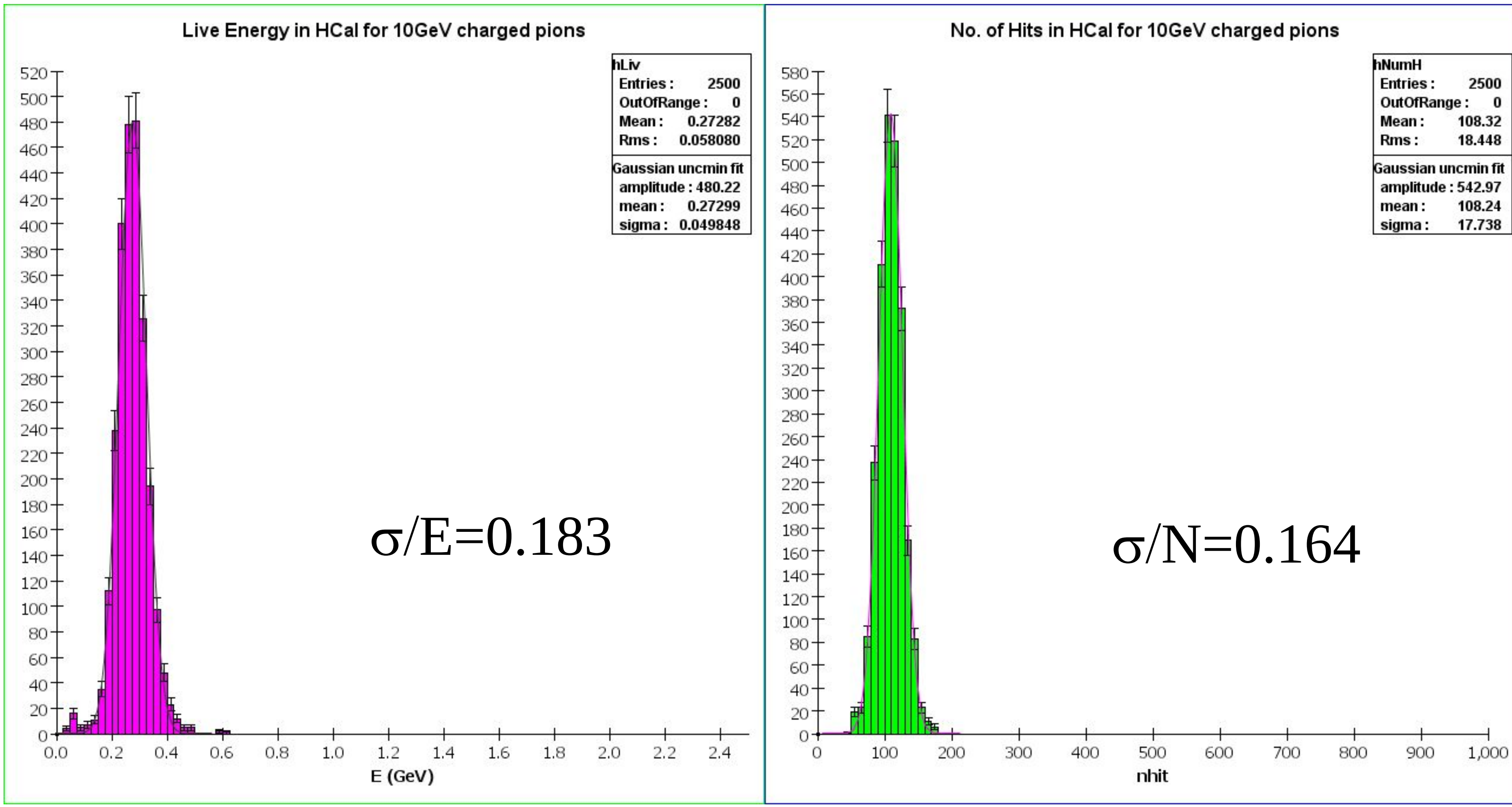


Energy resolution: 50 GeV π^+s

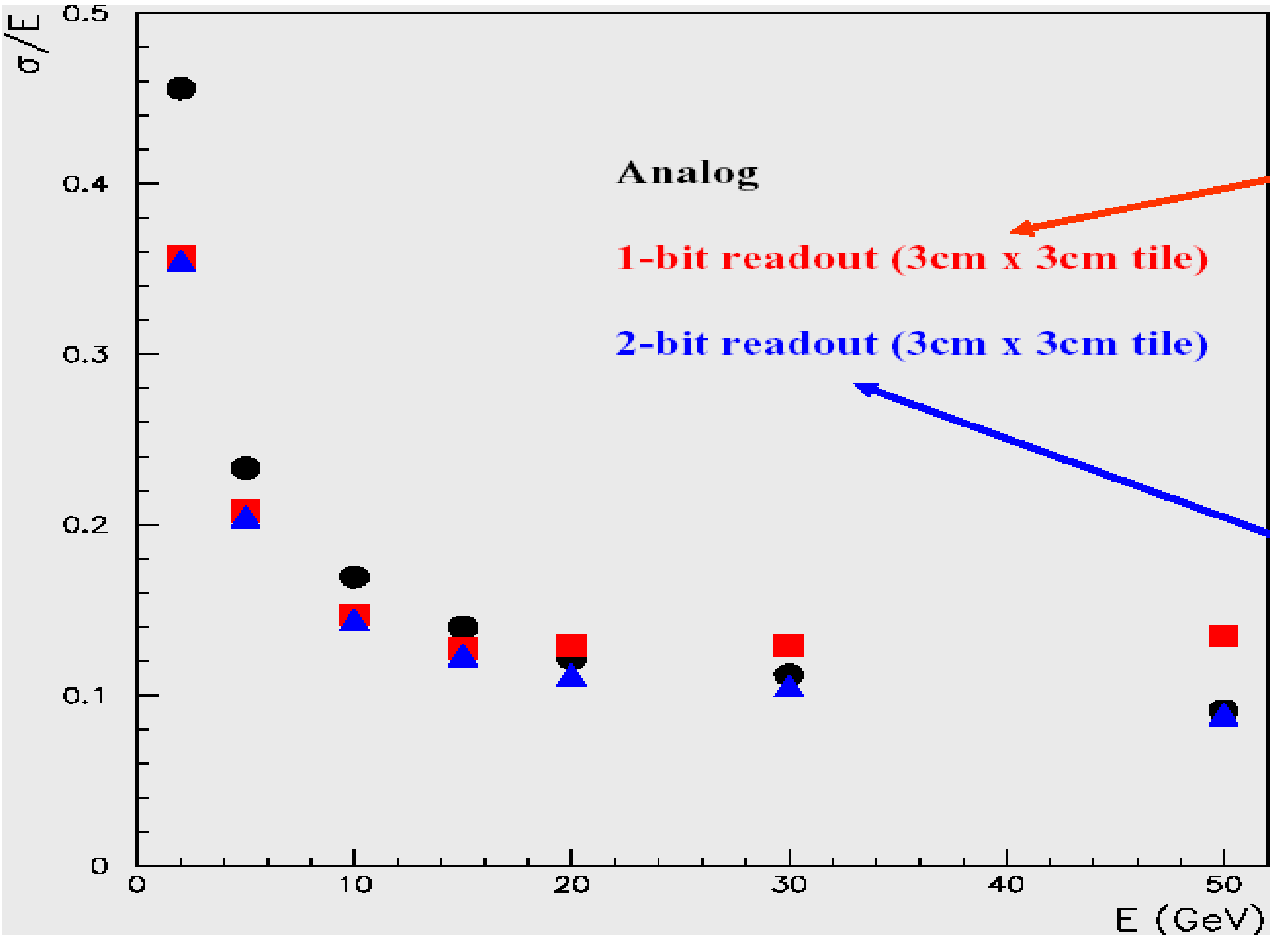




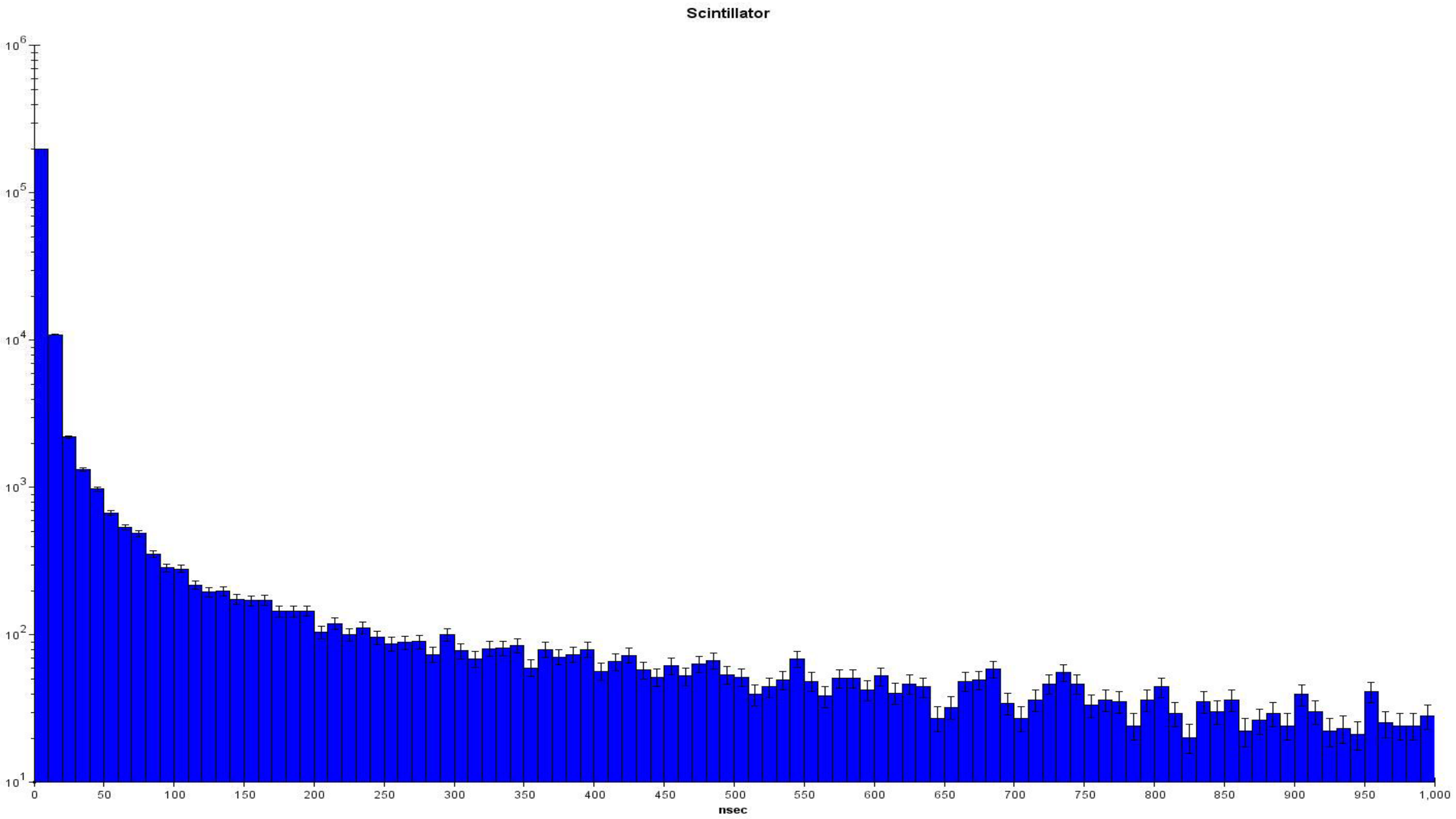
Energy resolution: 10 GeV π^+s



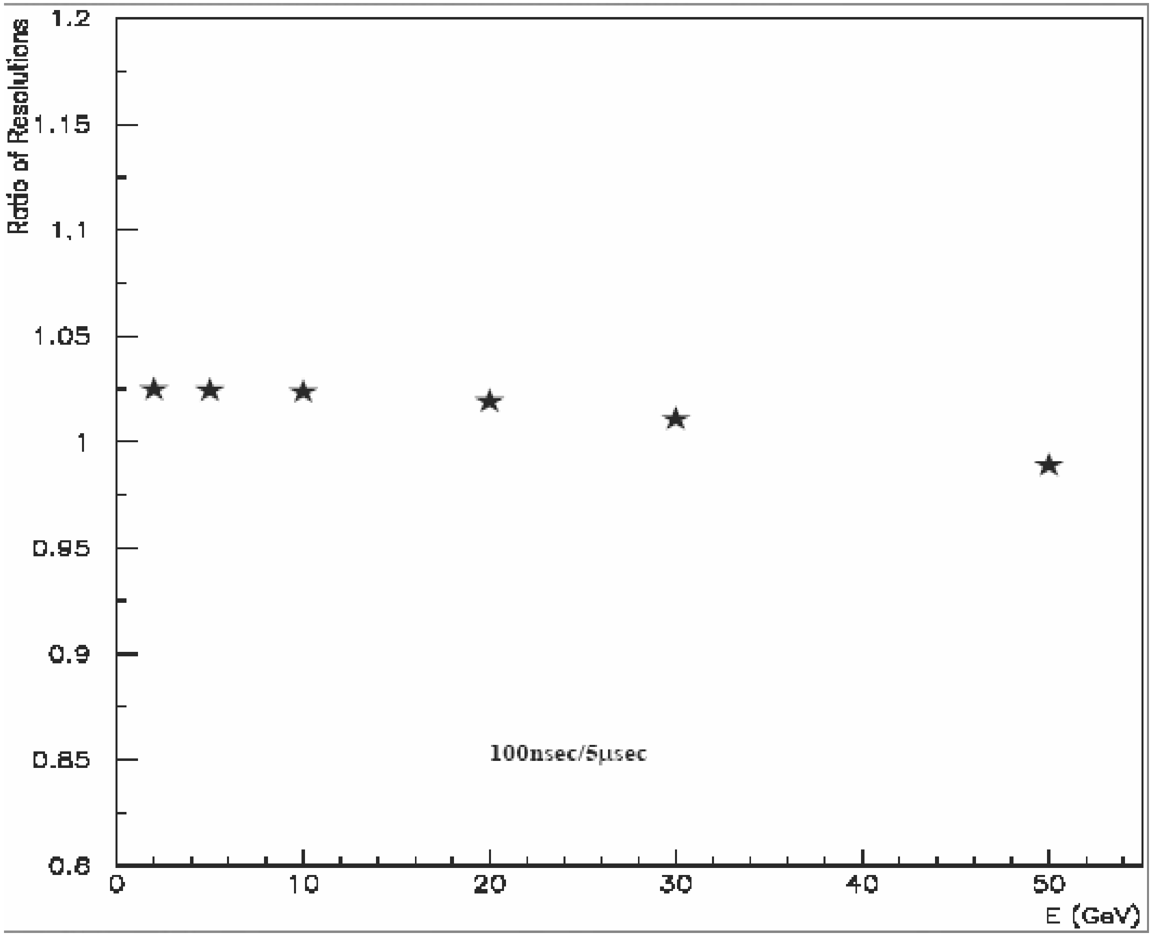
π^+ energy resolution vs. energy



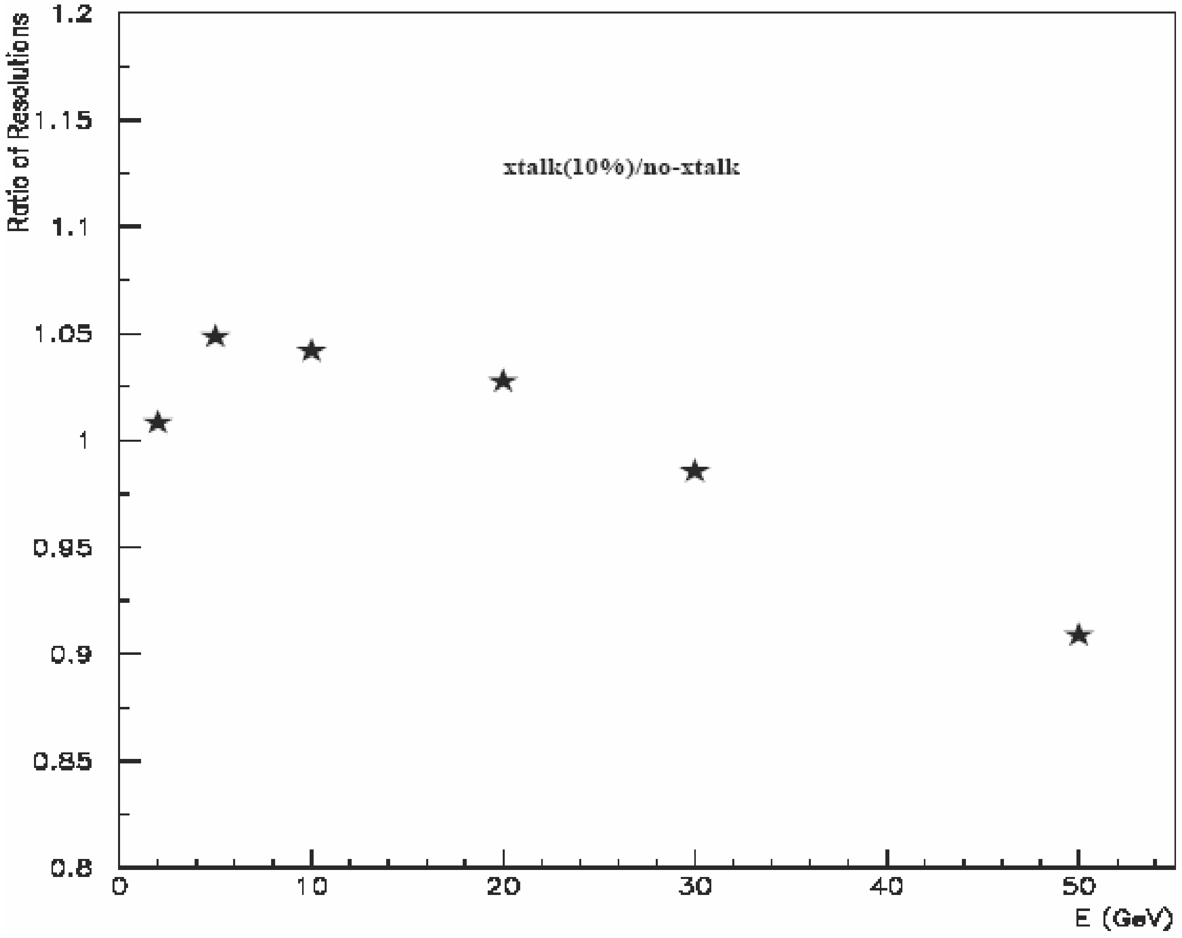
Time of flight



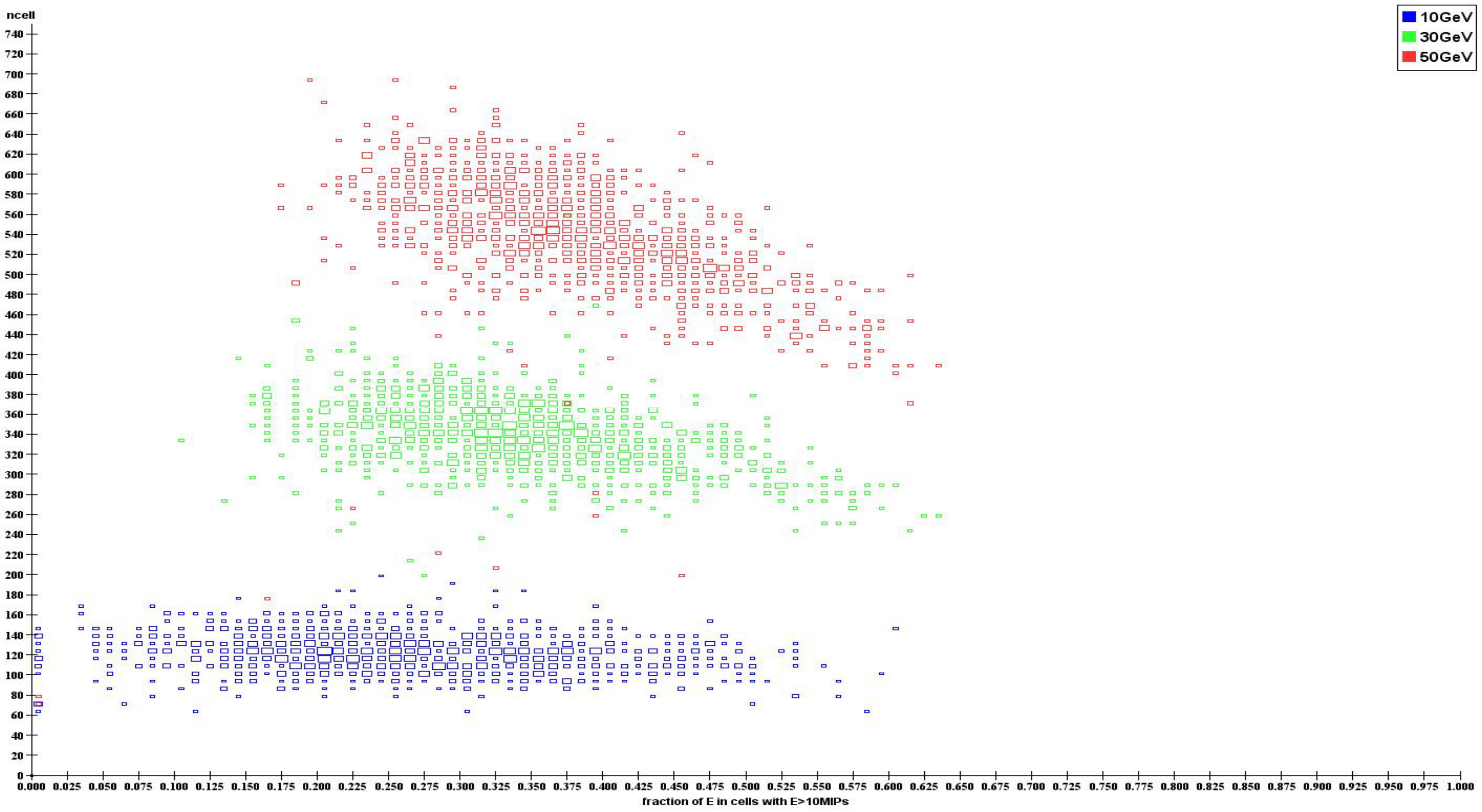
ToF dependence



Cross-talk
(10% of cell E leaks equally to 4 neighbors)



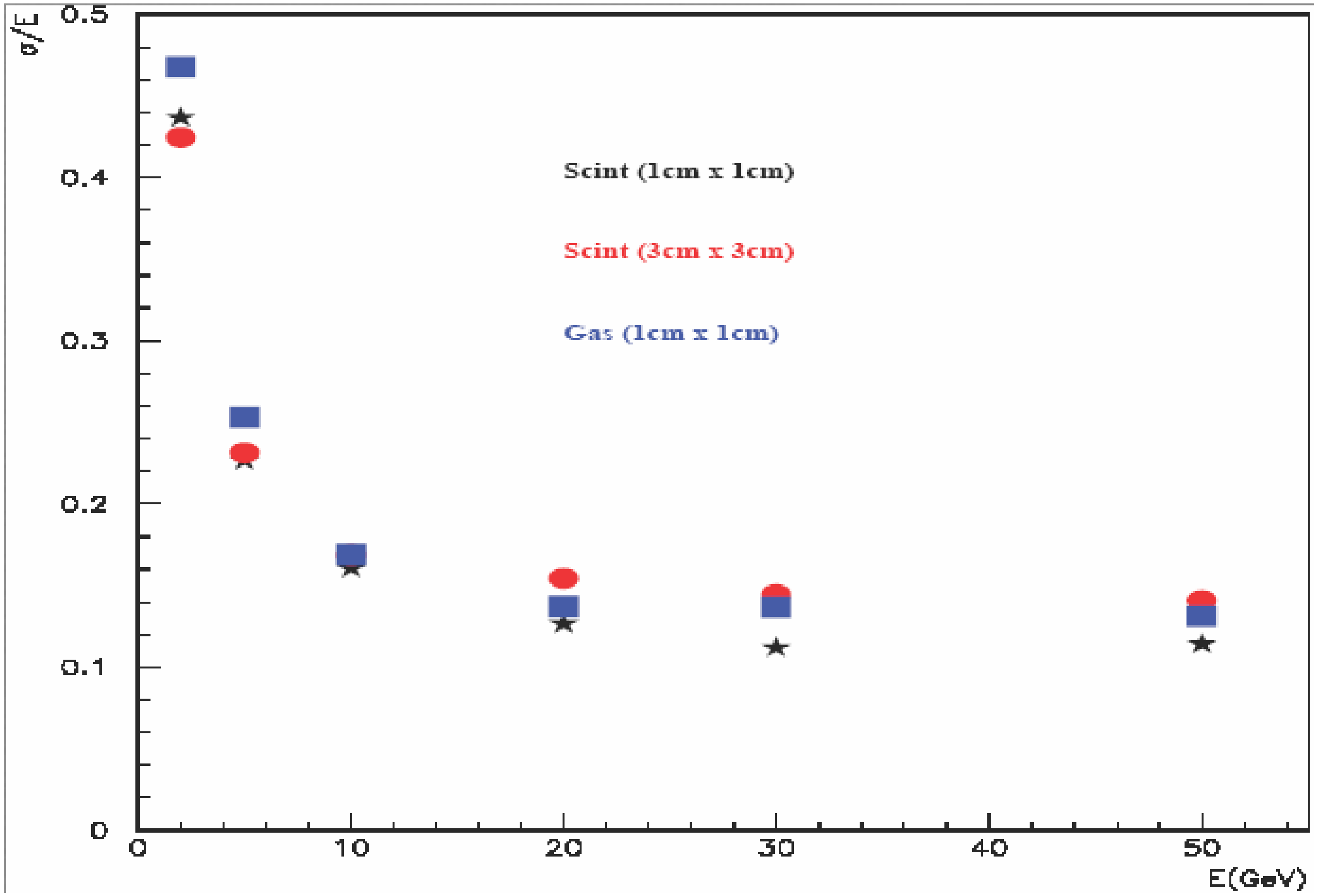
Nhit vs. fraction of π^+ E in cells with E>10 MIP: 1cm x 1cm scintillator cells



Nhit vs. fraction of π^+ E in cells with E>10 MIP: Gas vs. scintillator

π^+ energy resolution vs. energy

Multiple thresholds not used



Non-linearity

- Nhit/GeV varies with energy.
- This will introduce additional pressure on the “constant” term.
- For scintillator the non-linearity can be effectively removed by “semi-digital” treatment.

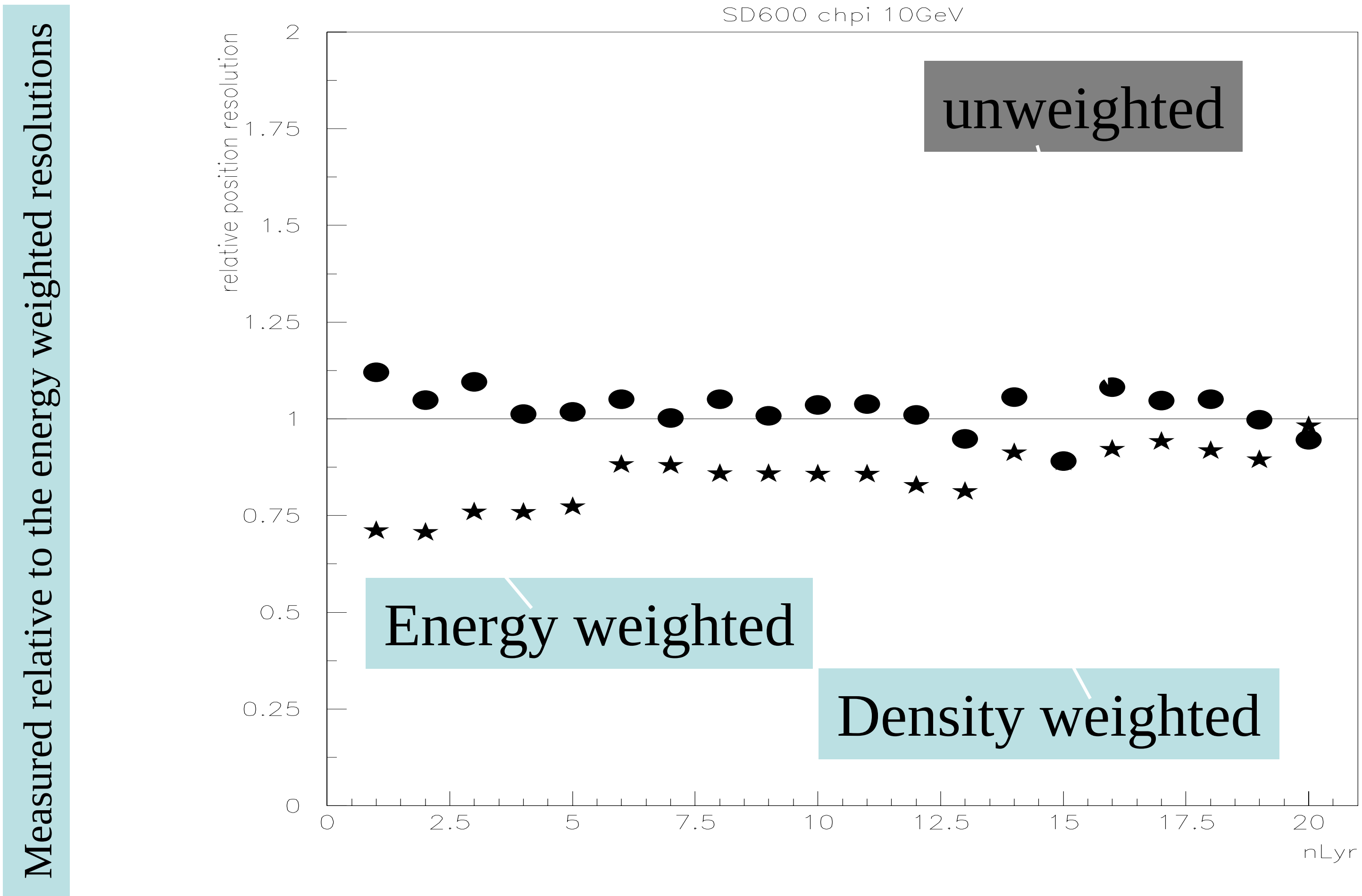
Density of hits

- Need a hierarchy in the absence of an energy measurement.
- Local density of hits is an obvious candidate.
- A simple-minded density variable:

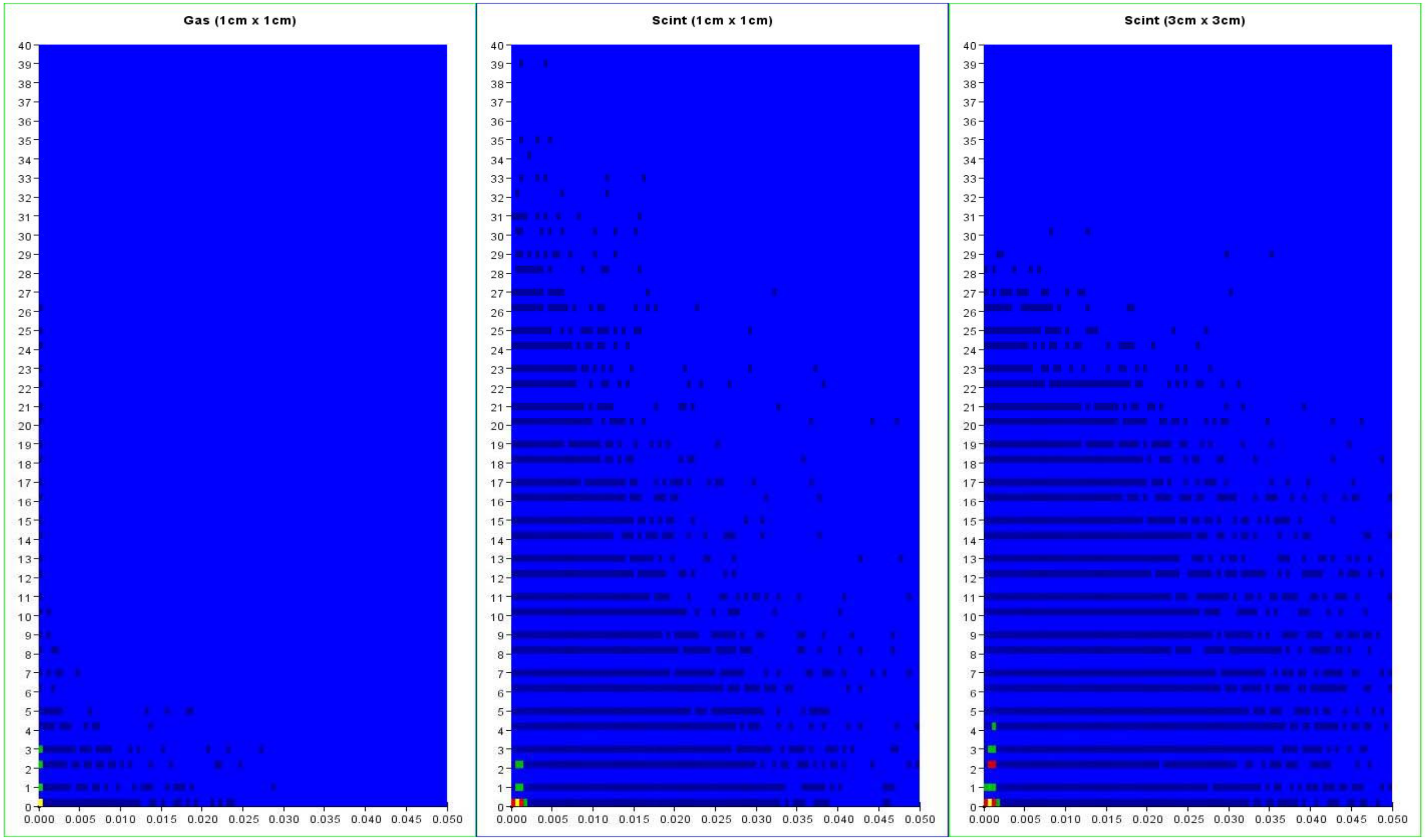
$$d_i = \Sigma\, (1/R_{ij}),$$

where R_{ij} is the angular distance between cells i & j.

Position resolution



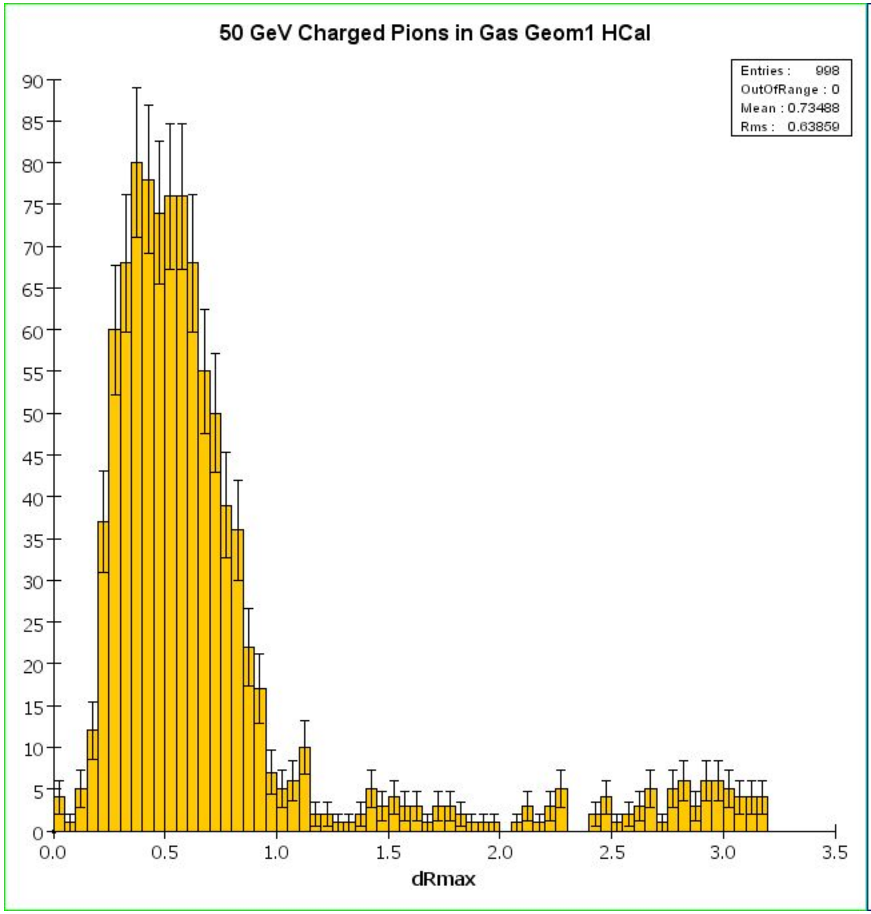
Density vs. Energy

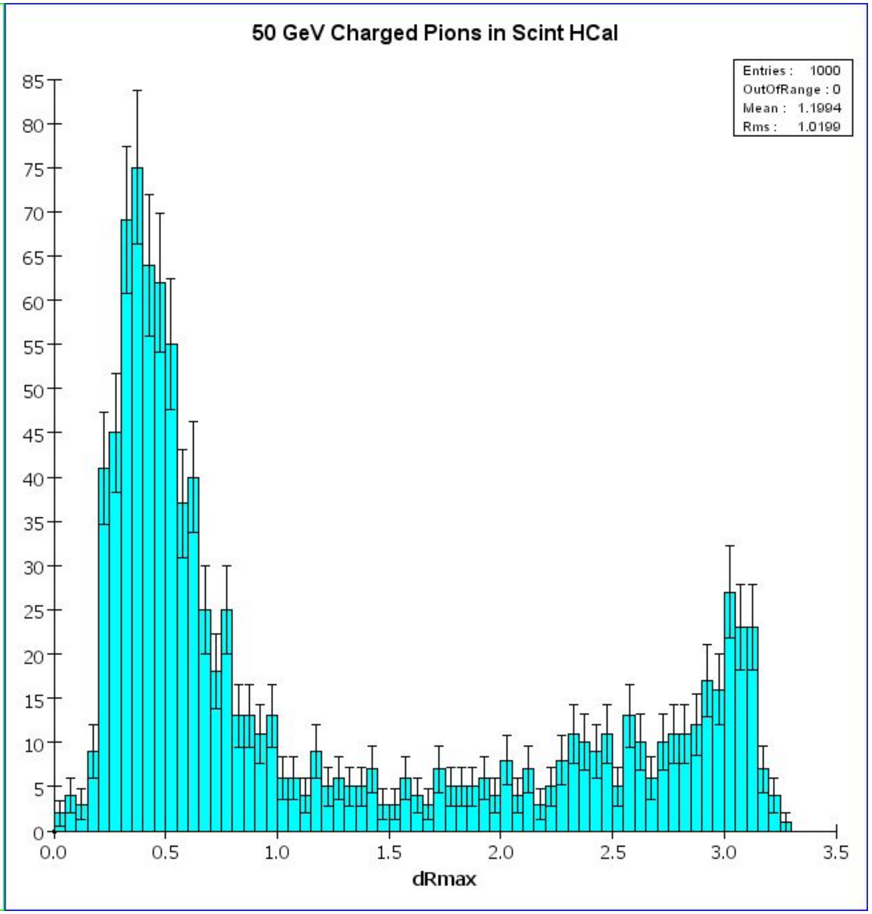


Width

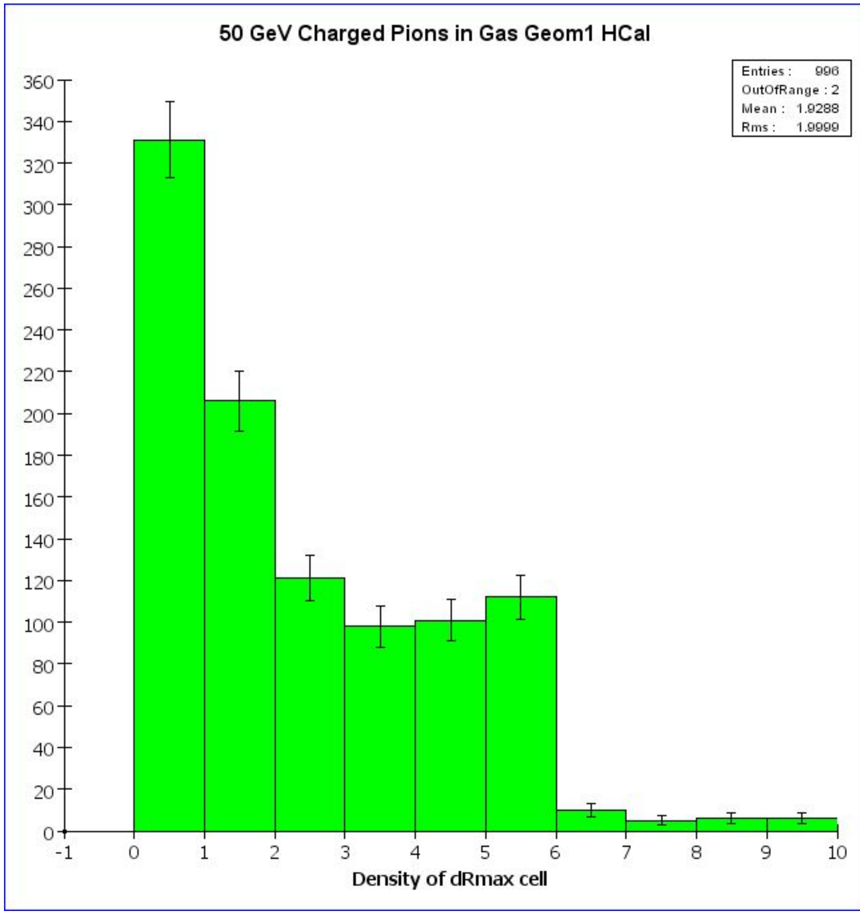
- Find centroid $\{\Sigma w_i x_i / \Sigma w_i\}$
- 'width' = $\mathrm{sqrt}(\Sigma w_i R^2_i / \Sigma w_i)$
- Three weights were used:
  - Unweighted (w_i=1)
  - Energy weighted (w_i=E_i)
  - Density weighted (w_i=nearest-neighbor occupancy in a 5x5 window in lyrs k-1,k,k+1)

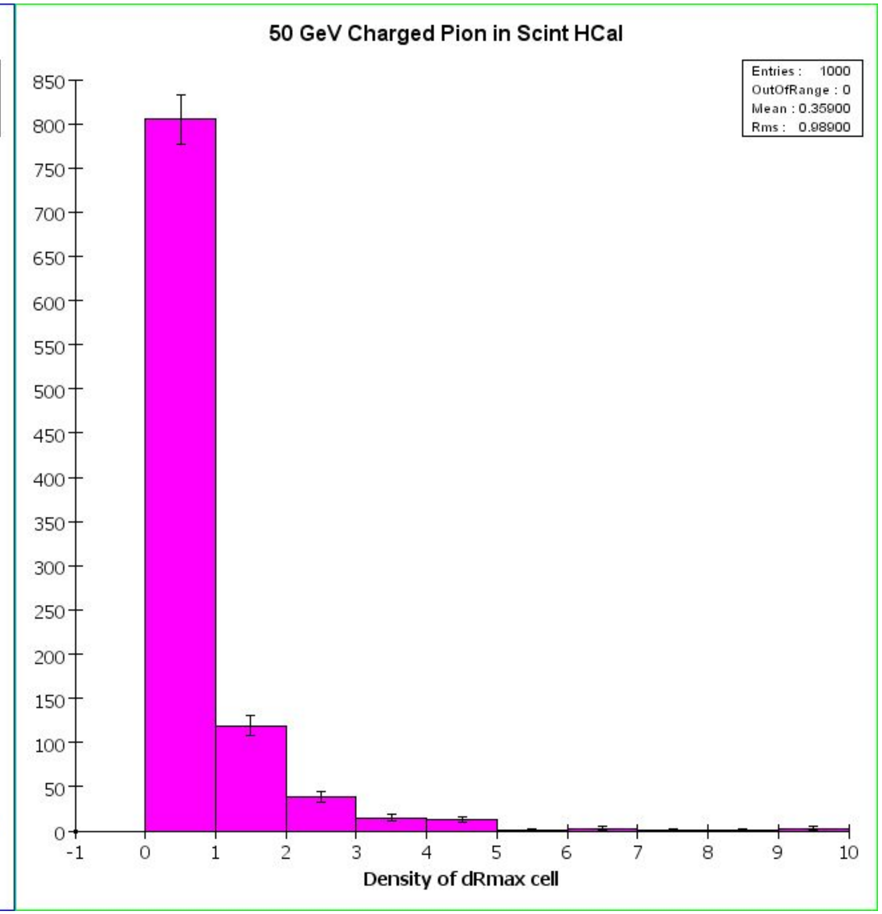
Distance to farthest cell



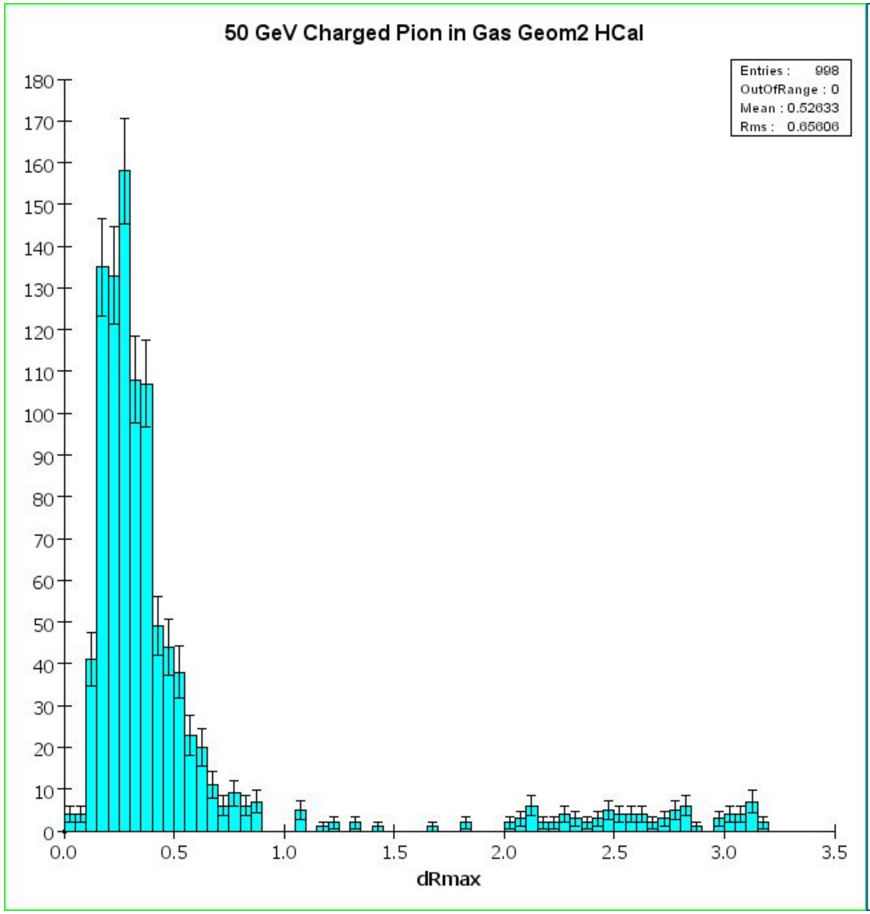


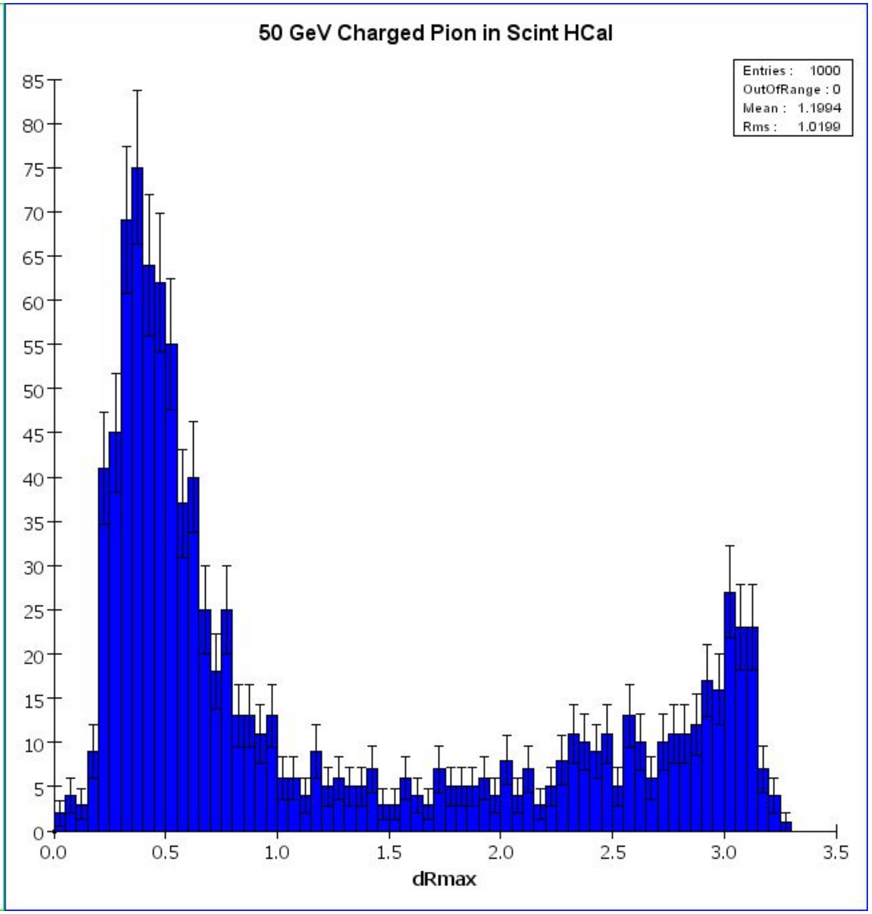
Density of farthest cell



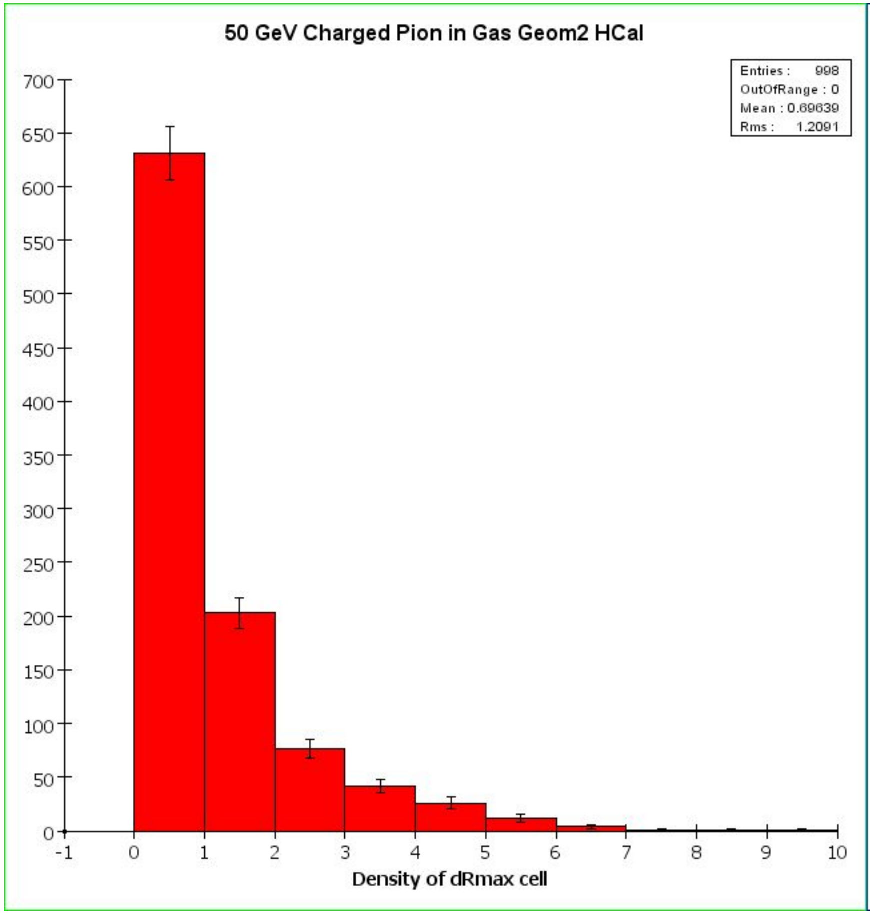


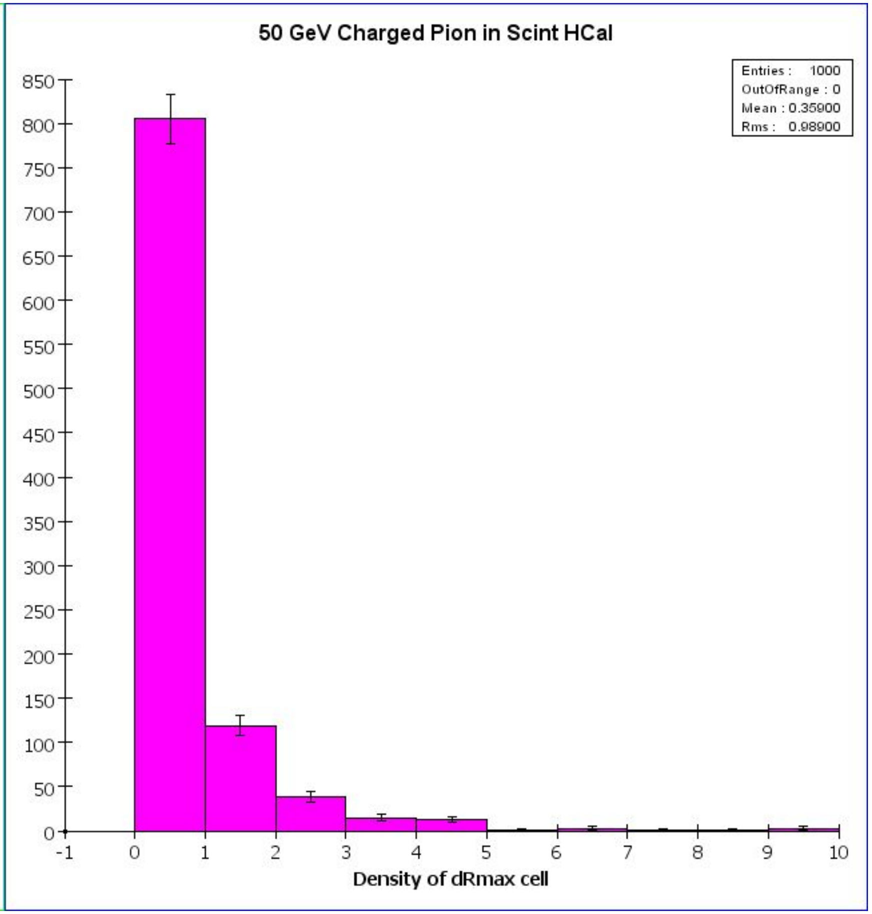
Distance to farthest cell



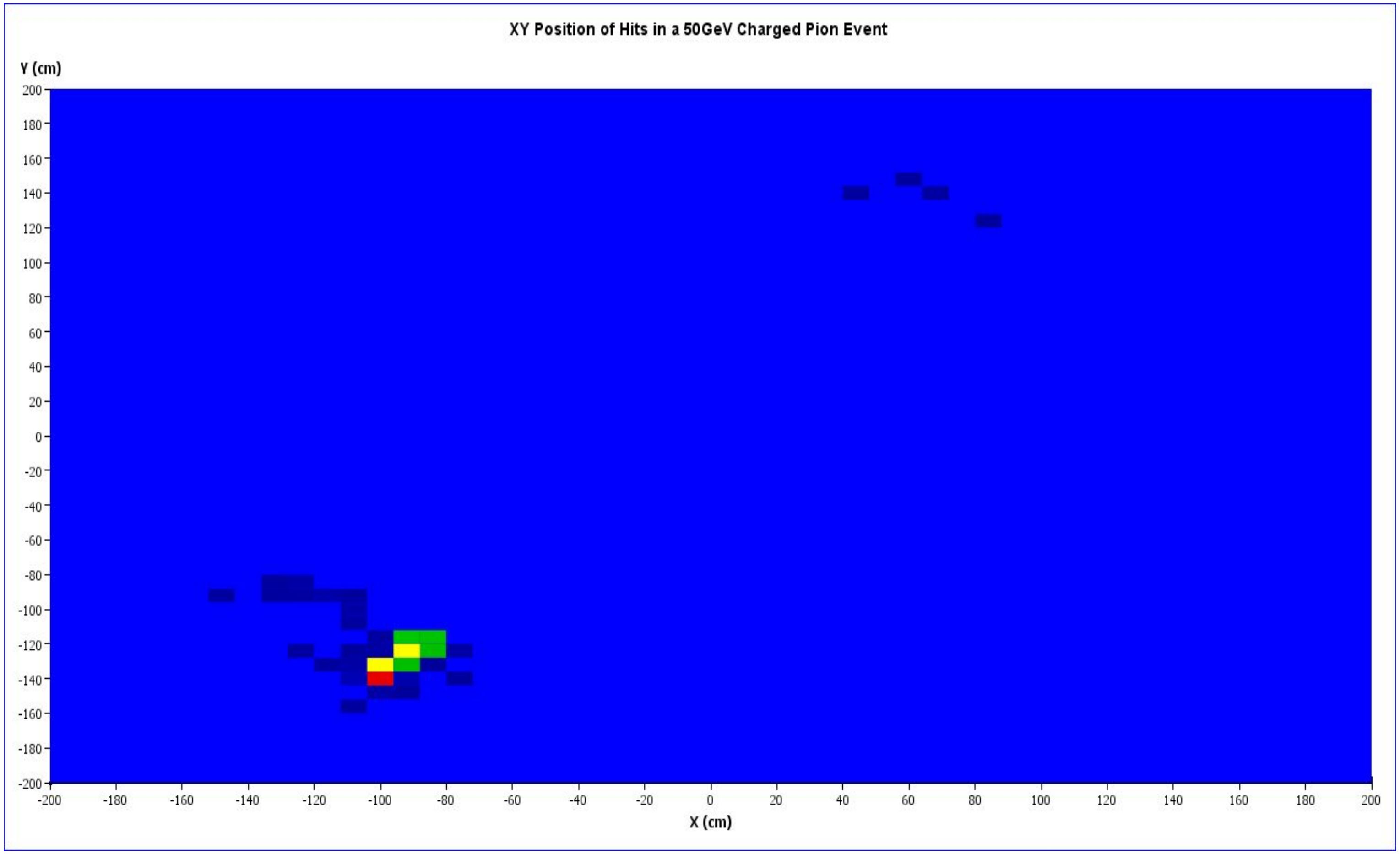


Density of farthest cell

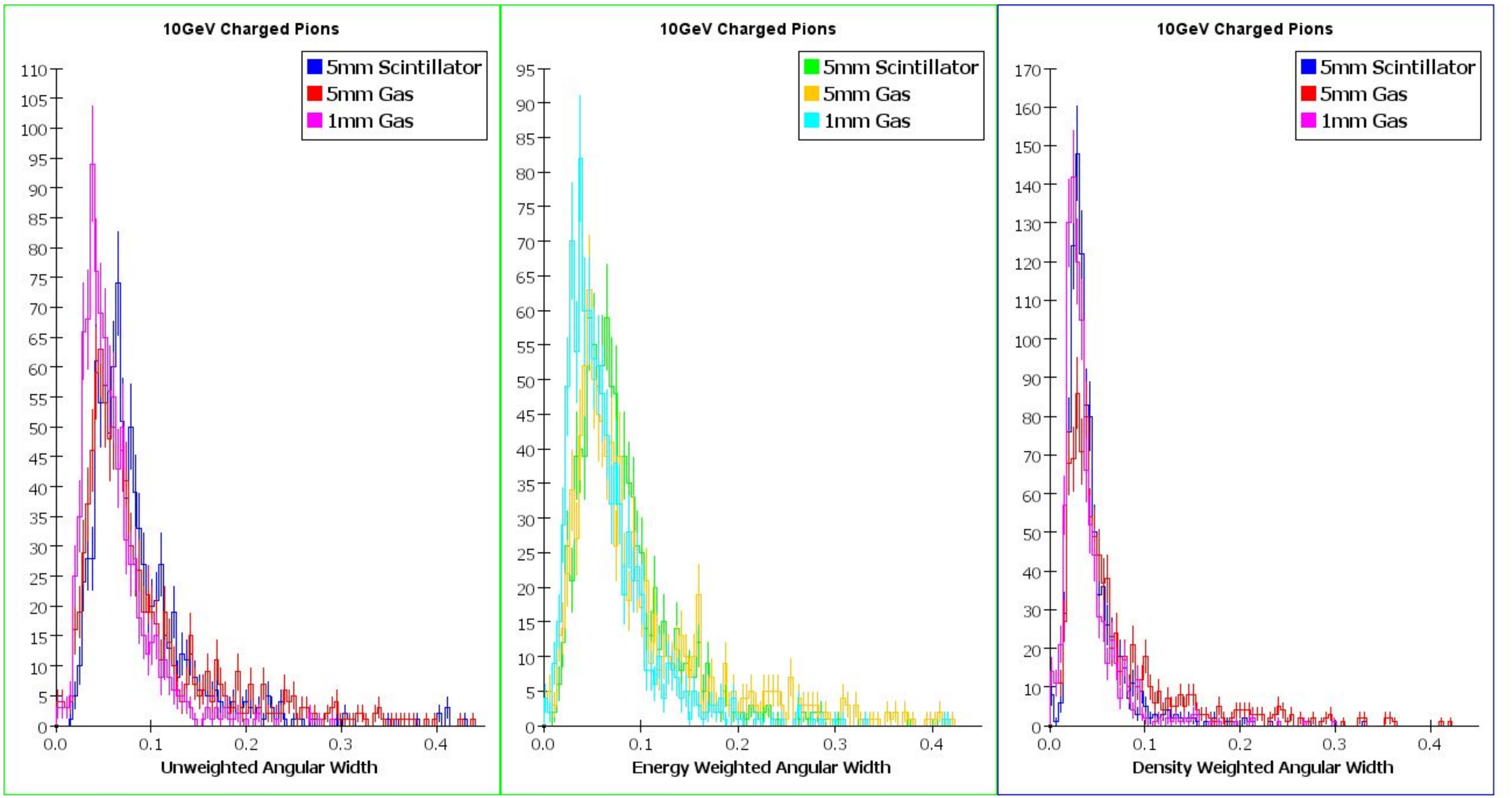




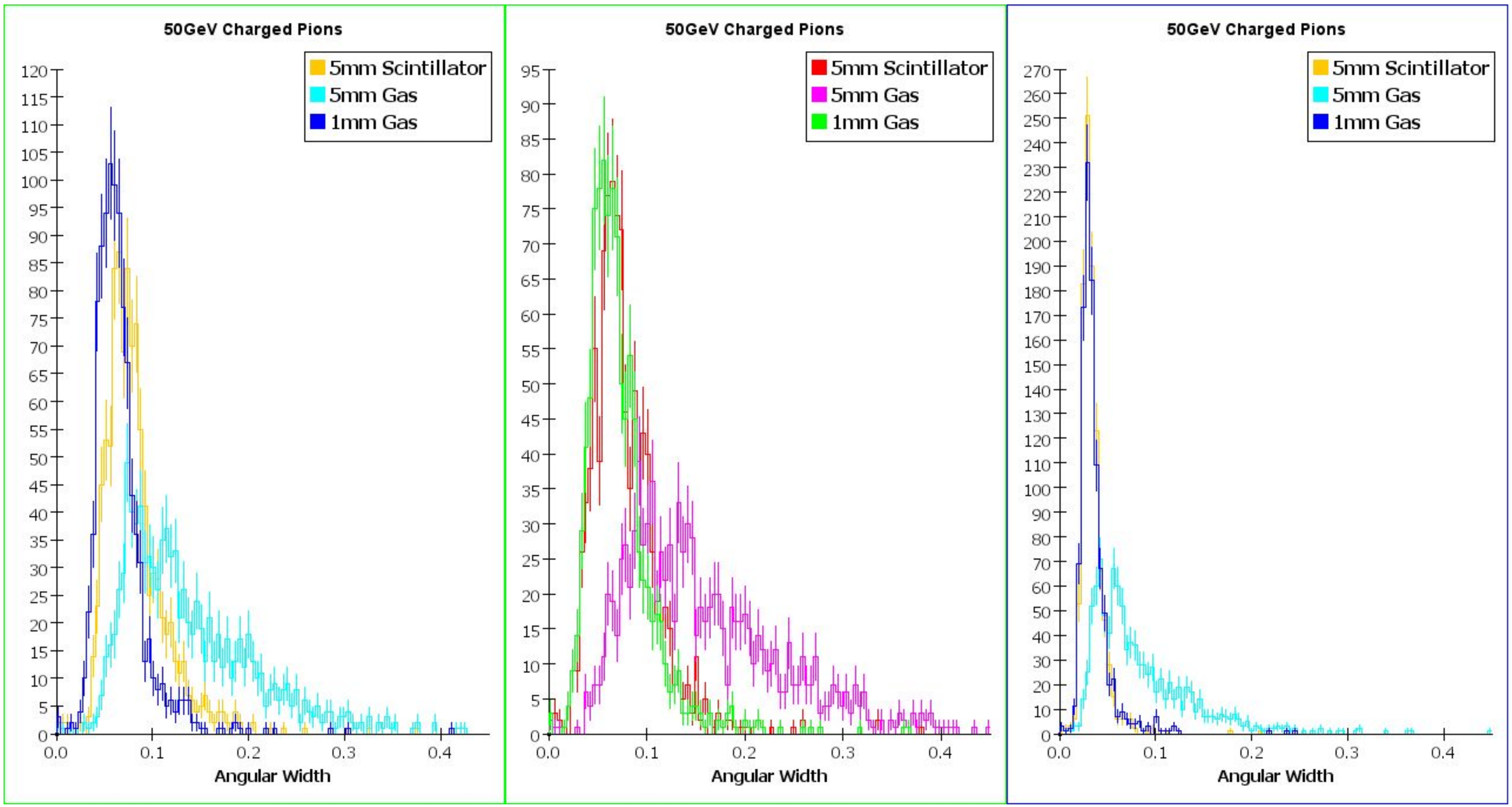
Backscatter



Shower width for 10GeV $\pi^{\pm}$

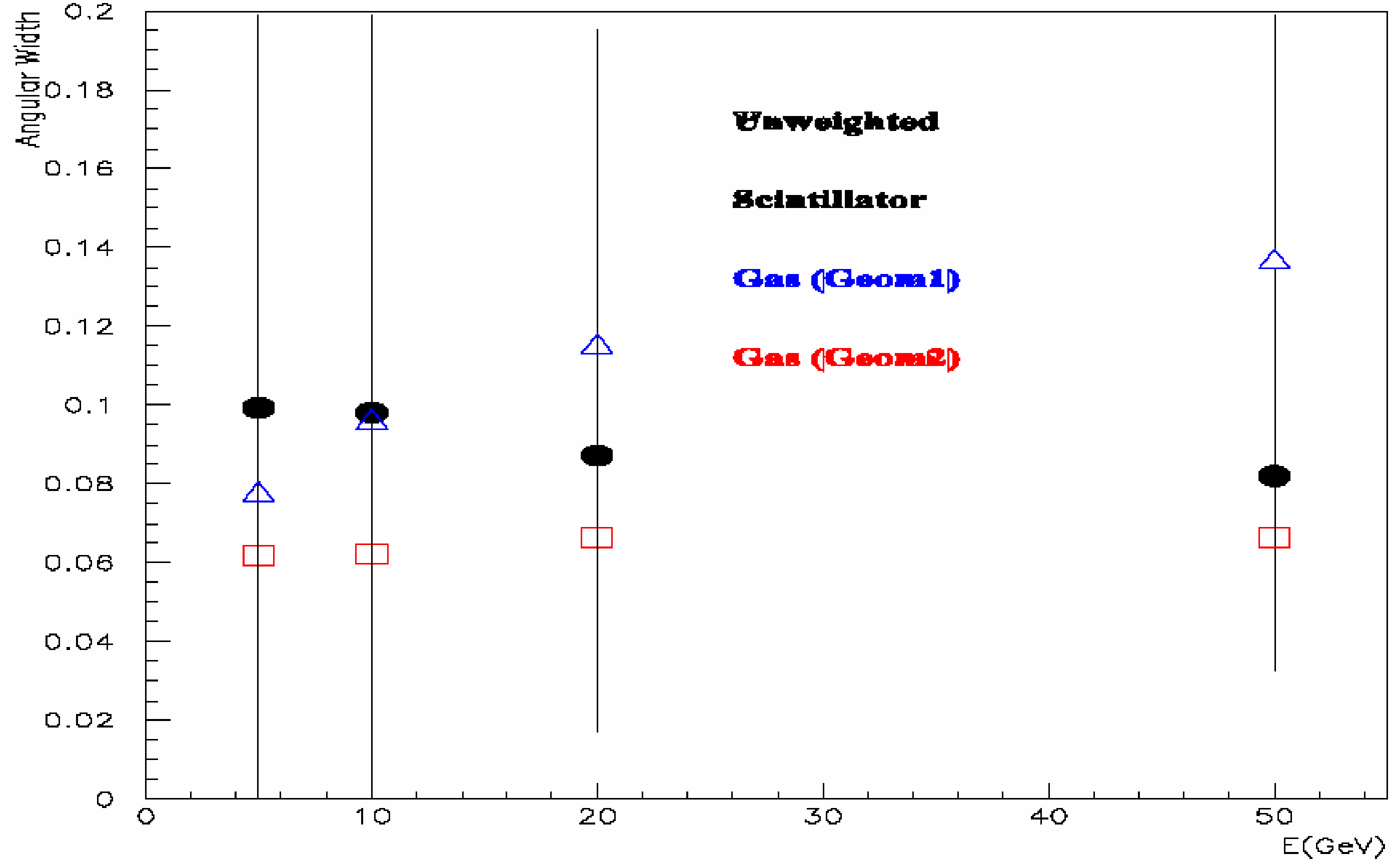


Shower width for 50GeV $\pi^{\pm}$

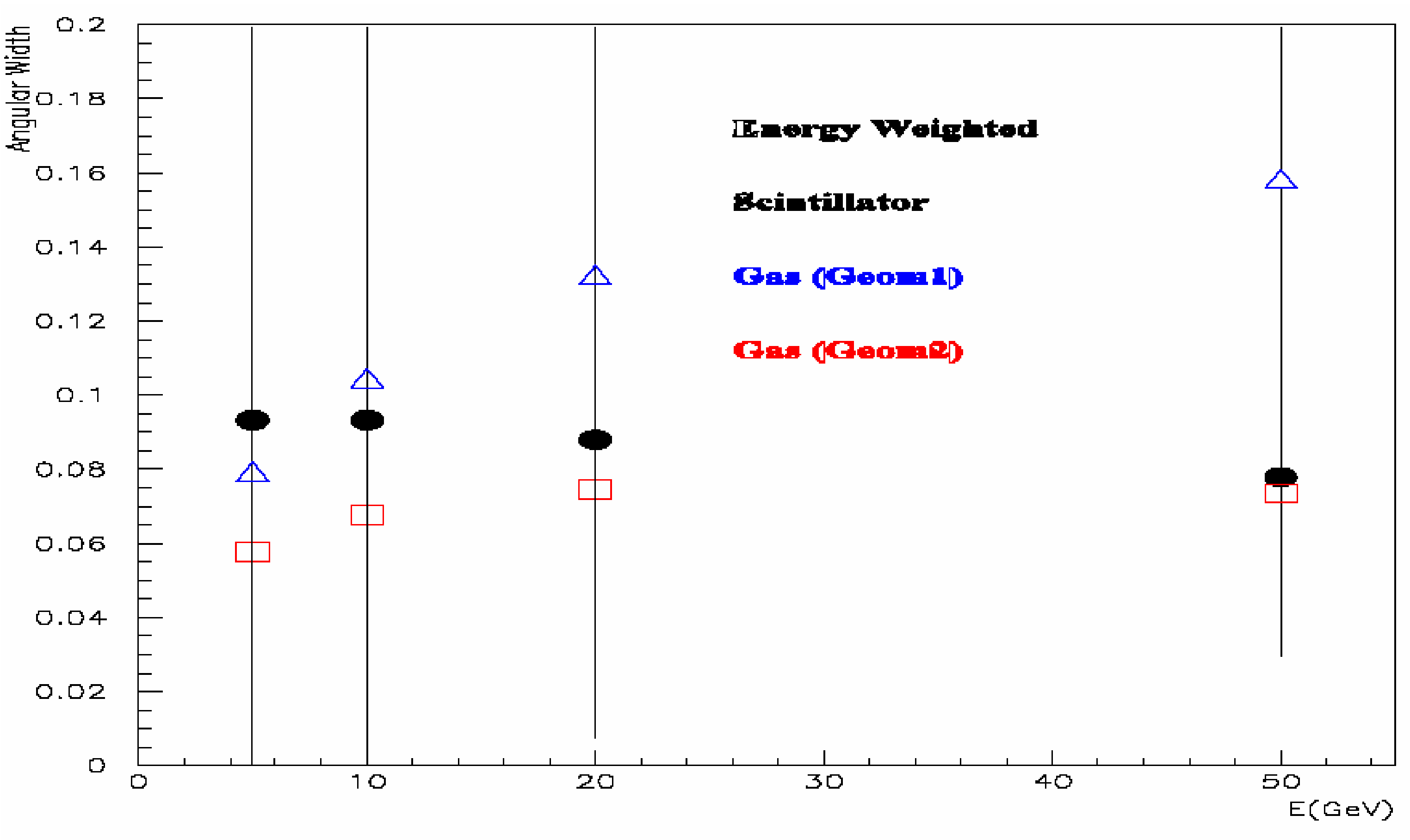


$\pi^{\pm}$ angular width

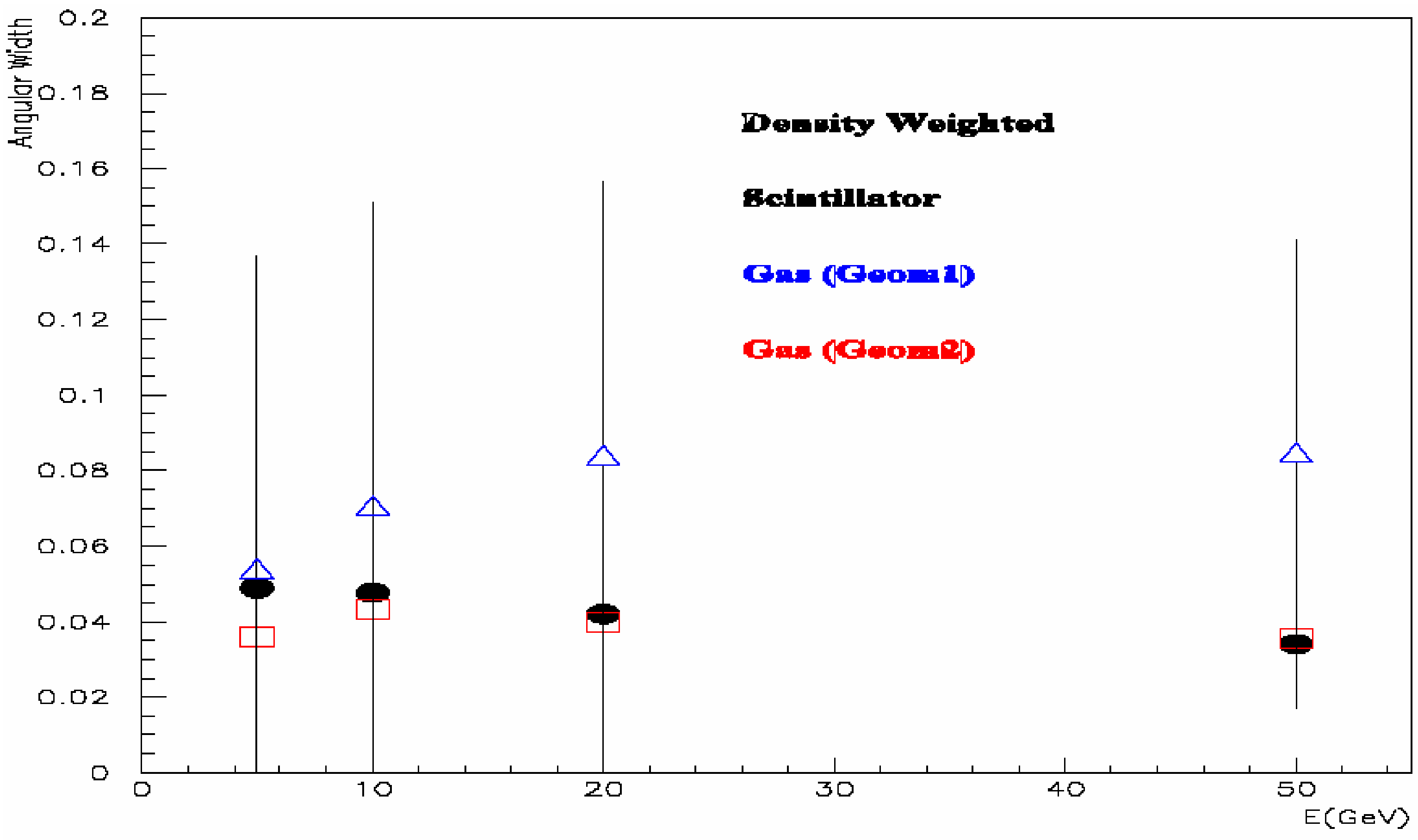
rms shown as bars



$\pi^{\pm}$ angular width: energy weighted



$\pi^{\pm}$ angular width: density weighted



Comments

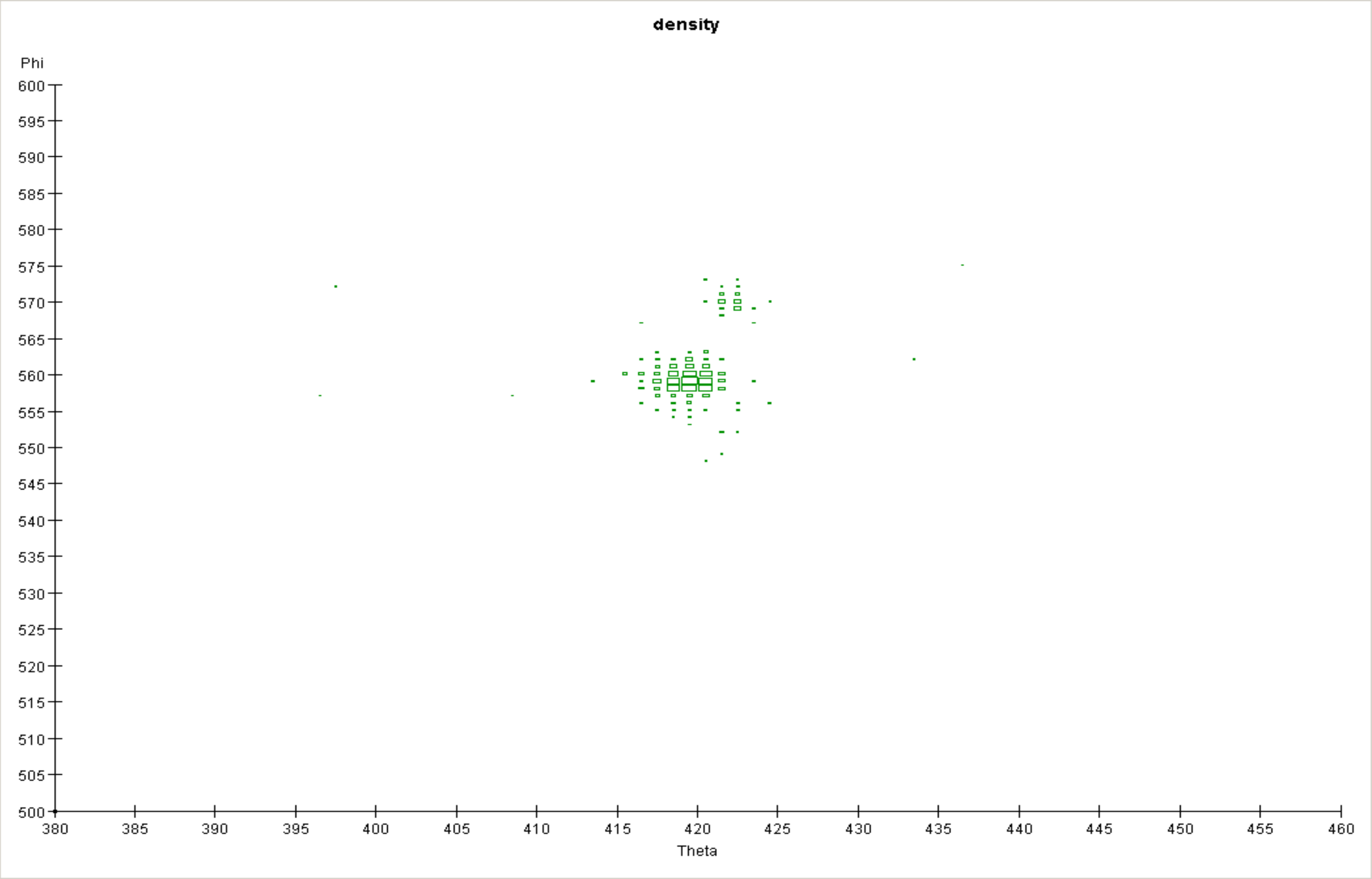
- There is no clear cut case either way at the moment; detailed studies of assessing impact needed.
- Will look at cluster separability next.
- Need to evaluate this in the global context of calorimeter performance.

Clustering

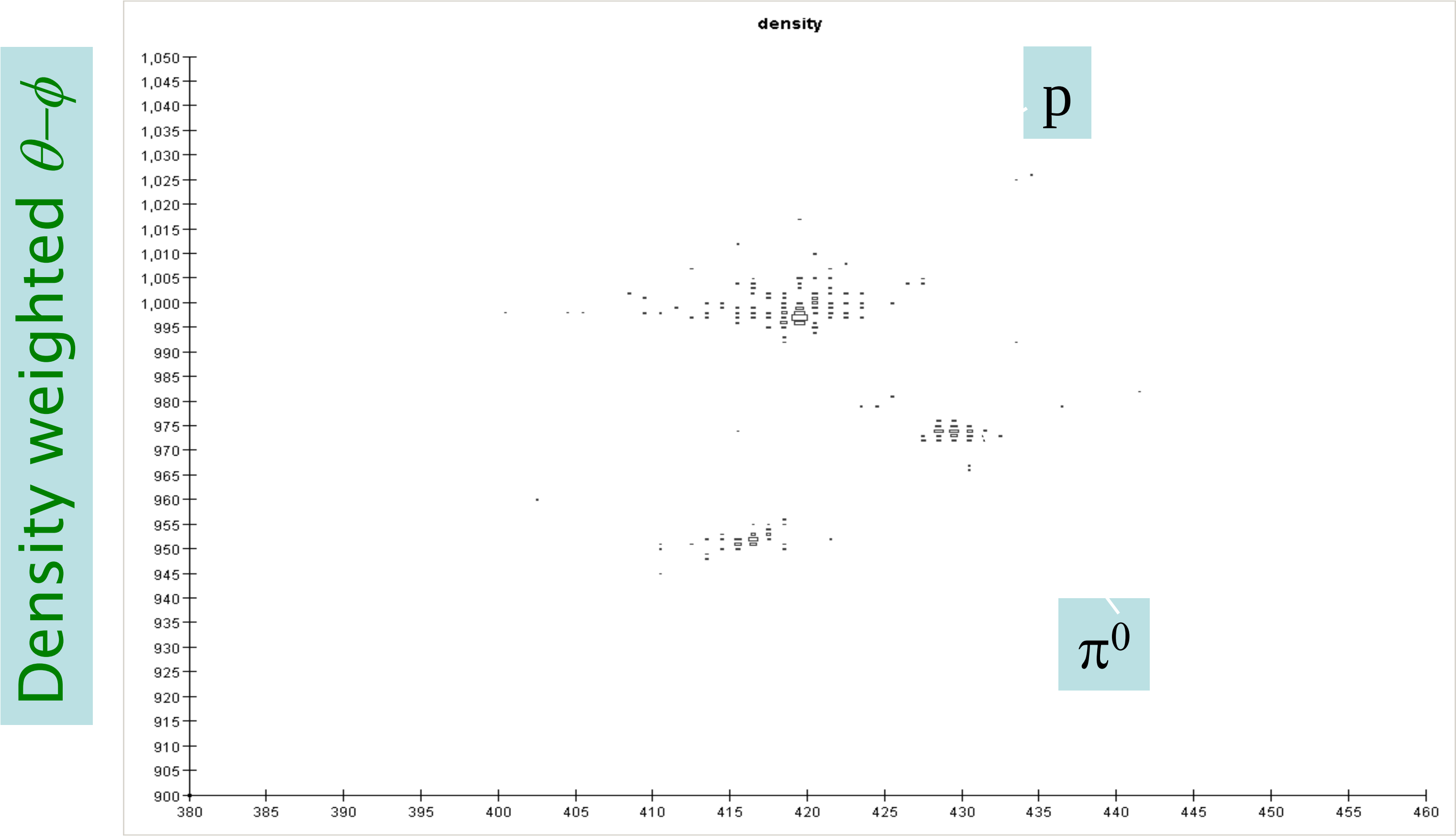
- Clustering based on local density works well.
- It is an alternative to track-seeded clustering.
- Can be used in the ECal and HCal.
- Full PFlow implementation gives encouraging results.

10 GeV $\pi^0 \rightarrow \gamma\gamma$

Density weighted θ–ϕ



$\Sigma^+ \rightarrow p\pi^0 \rightarrow p\gamma\gamma$



Summary

- Large parameter space in the nbit-segmentation-medium plane for hadron calorimetry. Optimization through cost-benefit analysis?
- Scintillator and Gas-based 'digital' HCals behave differently.
- Need to simulate detector effects (noise, x-talk, non-linearities, etc.)
- Need verification in test-beam data.
- More studies underway.