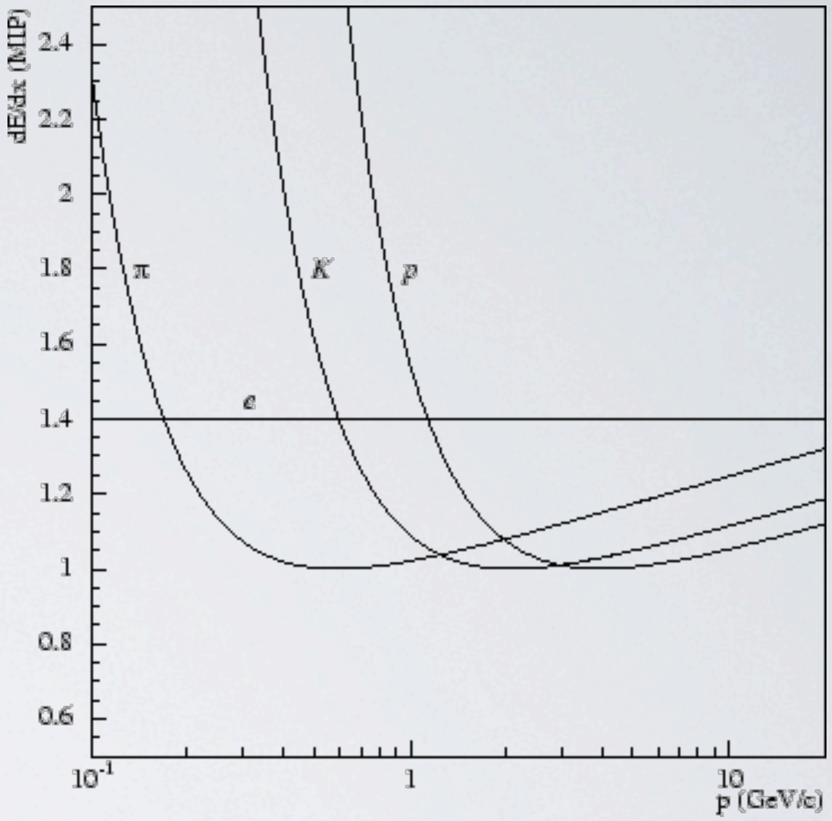
# Energy deposition-based (low) momentum estimation

- Very low momentum tracks are reconstructed in VXD only: worse momentum resolution.
- Study momentum estimation based on E deposition in silicon:
  - cf. : H. Bichsel, NIM A562 (2006) 154-197.
    and: ALICE: arXiv:hepex/0104006v1
  - Should improve $\Delta p/p$ of $\pi^{\pm}$ < 100-150 MeV.
  - May be used to constrain the helix fit to improve impact parameter and vertexing?
  - May be used to define an input to the track index quality (currently $\chi^2$) to select among several track candidates?
  - May be used to define an input to reject bkg hits?




- How does it work?
  After pattern recognition:
  - given the clusters associated to a track
  - given the track θ
  - if you know that your track is due to a π

  ➛ estimate momentum based on E deposition in silicon detectors in the sensitive region where $\Delta E \sim 1/\beta^2$.

- In VXD: all layers provide analogue read-out output.
  - PXD: 2 silicon pixel layers with 5 bits ADC,
  - SVD: 4 DSS layers with 10 bits ADC.

I. Ripp-Baudot
Belle II tracking meeting
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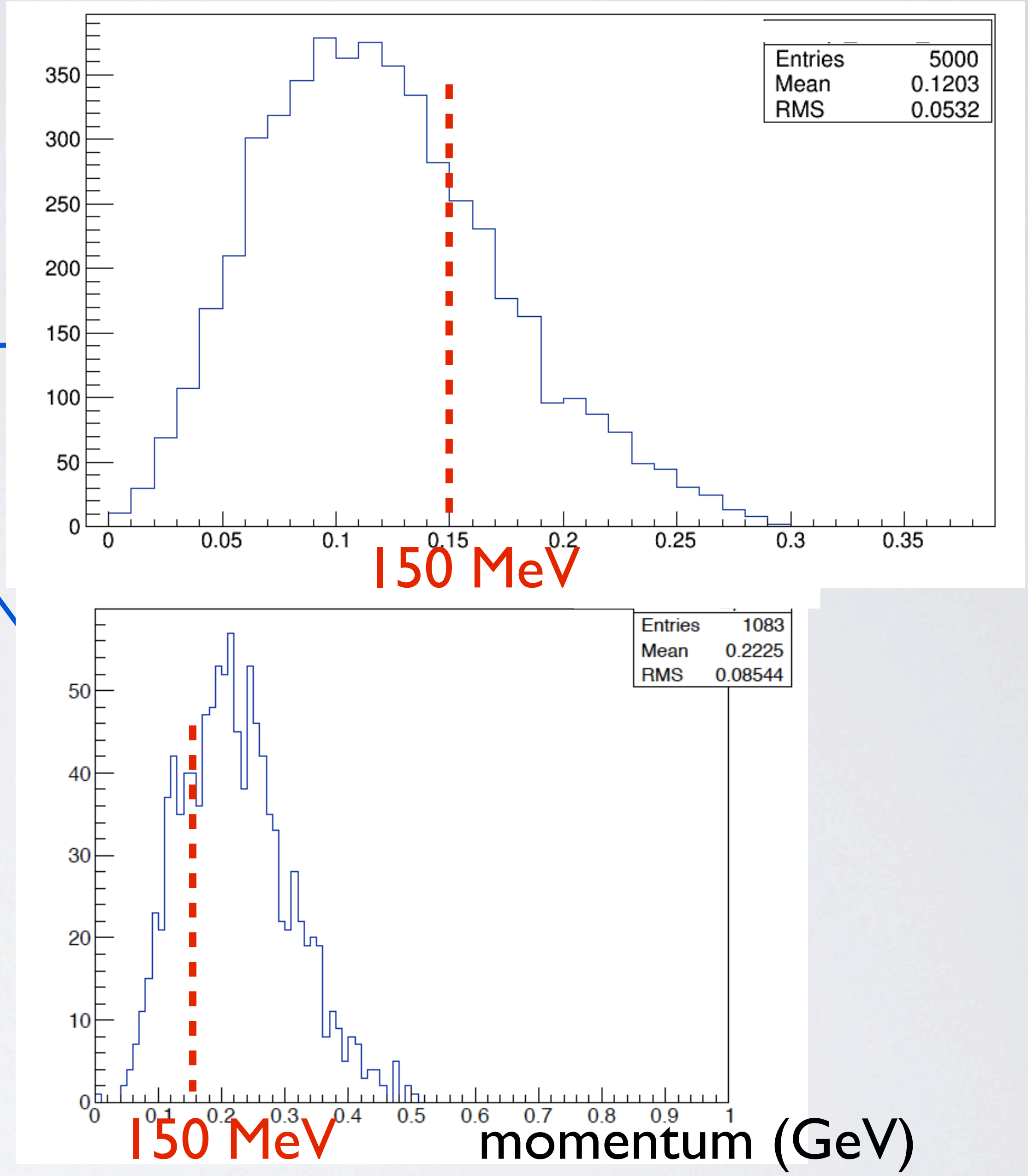
# Very low momentum tracks?

- Flavour tagging based on the $\pi_{soft}$ charge:

  $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^0_{signal}\, B^0_{tag}$

  with $B^0_{tag} \rightarrow D^{*-}$ and $D^{*-} \rightarrow D^0\, \pi^-_{soft}$

  $e^+e^- \rightarrow c\,\bar{c} \rightarrow D^{*+}\, X_c\, x$ with $D^{*+} \rightarrow D^0\, \pi^+_{soft}$




- Track helix radius considerations:

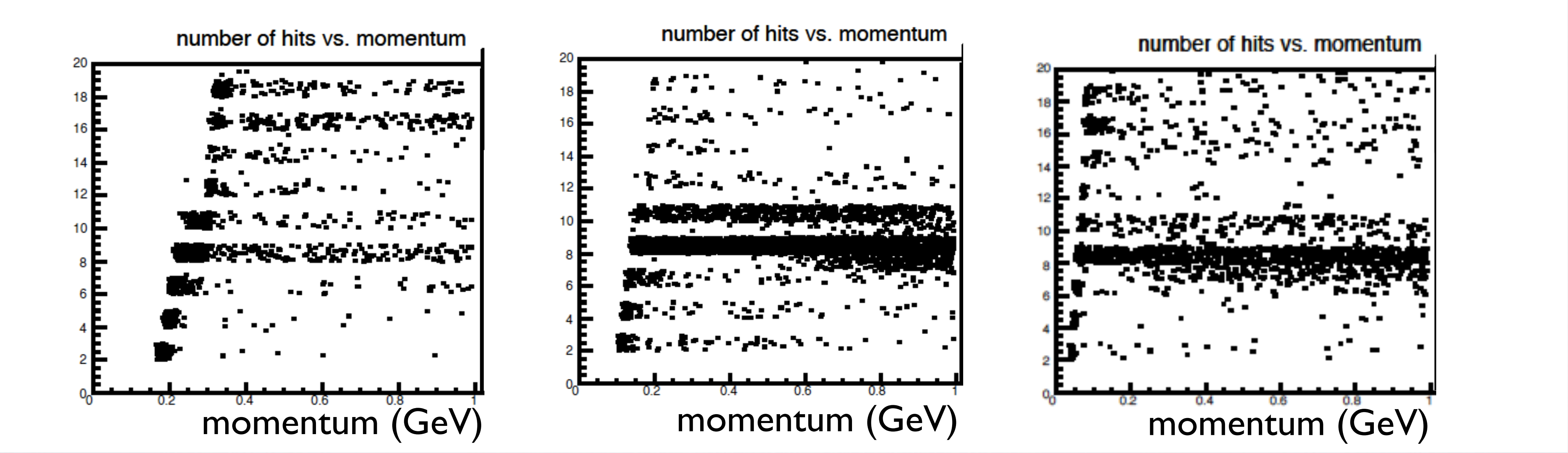
SVD: radius = 3.8 - 13.5 cm
CDC: radius = 16 - 112 cm
magnetic field B = 1.5 T

➛ perpendicular tracks ($\theta$ = 90°) need: ~ 40 MeV to reach the CDC
~ 150 MeV to reach the middle of the CDC.

ECL: radius = 125 - 162 cm ➛ need: ~ 330 MeV to reach the middle of the ECL (➛ destroyed).

# p, K, π stopping power = f(p)

5000 **perpendicular** particles generated π, momentum 40-1000 MeV,
(N.B.: θ = 90° and only VXD simulated ➛ curling tracks ➛ more hits).



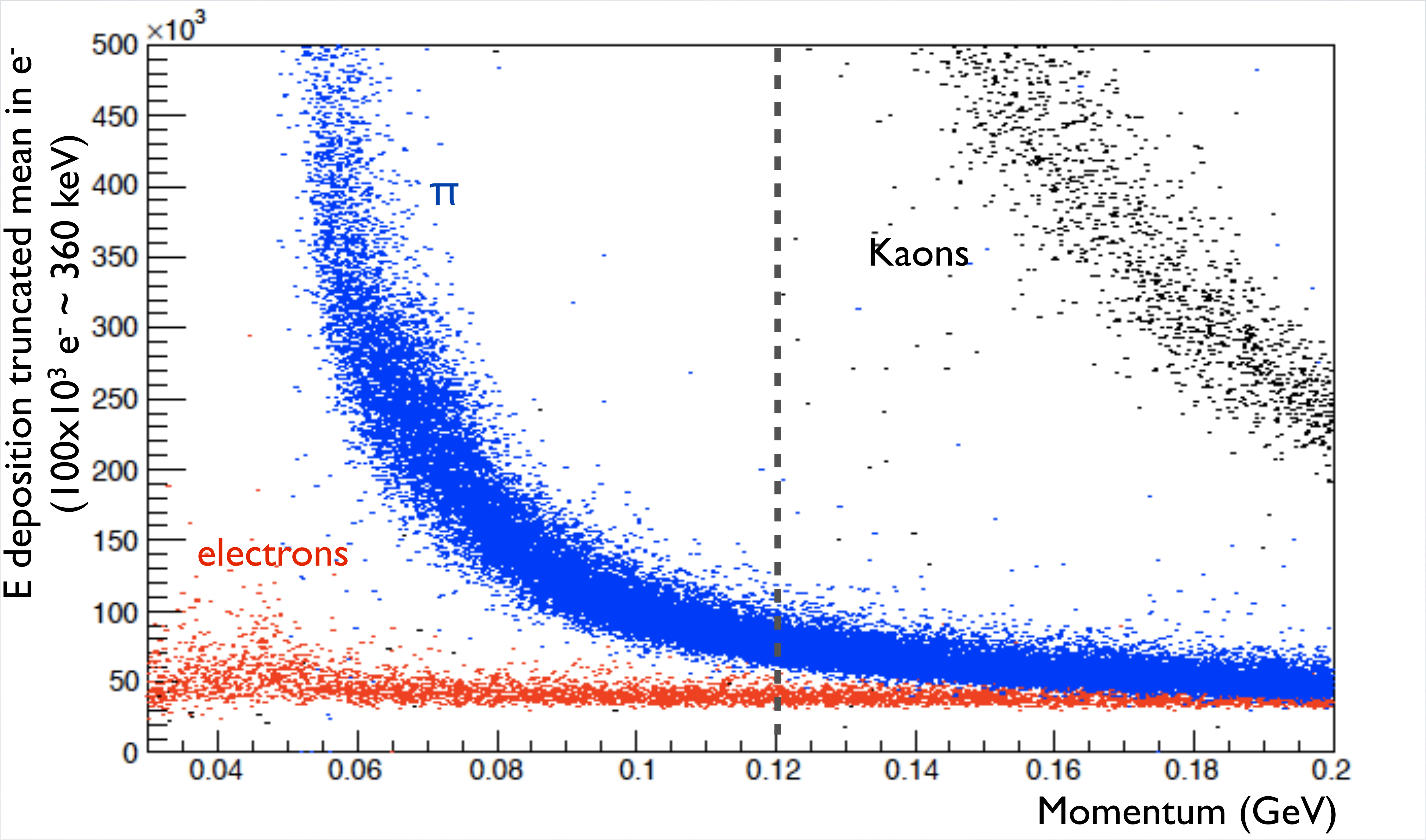

protons:
need > 200 MeV
to cross > 1 SVD layer.

Kaons:
need ~150 MeV
to cross > 1 SVD layer.

π:
always cross the
whole SVD

➛ low momentum track with at least 3 clusters is a π.
(electron case on next slide)

# electrons??



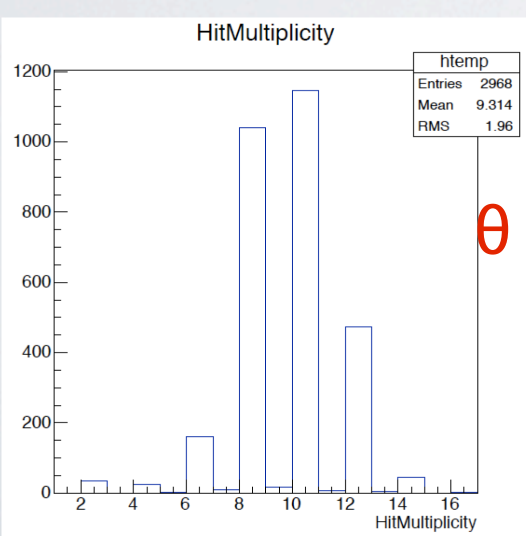

Up to ~ 120 MeV: π tracks can be disentangled from electrons (and also from K, p).

# basf2 input parameters

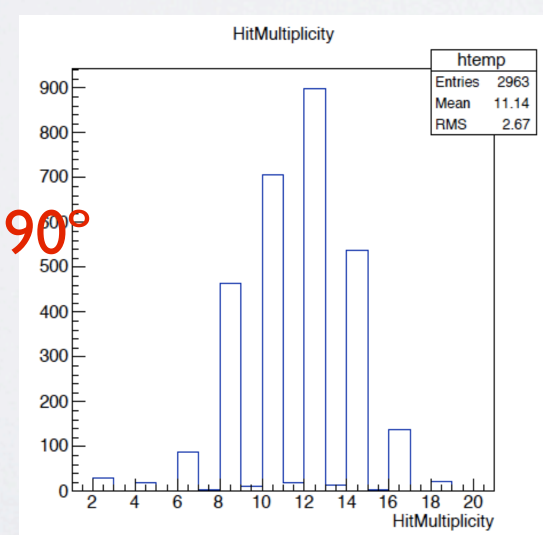
- No pattern recognition and no track reconstruction applied in the Energy deposition study  (of course yes to produce the helix-fit momentum resolution curve).

- Simulation inputs:
  - Generator:  ParticleGun, exactly 1 $\pi^{\pm}$ shot /event.
  - Momentum distribution:  uniform distribution between 40 MeV and 1.2 GeV, or fixed value.
  - $\theta$ distribution:  uniform in cos$\theta$ within acceptance [17., 150.]° or fixed value.
  - $\varphi$ distribution:  uniform within [0., 360.]°
  - Detector simulation:
    restricted to:  MagneticField, BeamPipe, PXD, SVD (at the beginning).
    or  whole Belle II detector simulation (now because I realised that $\pi$ may be destroyed in calorimeter or curl back).

$\theta$ = 90°

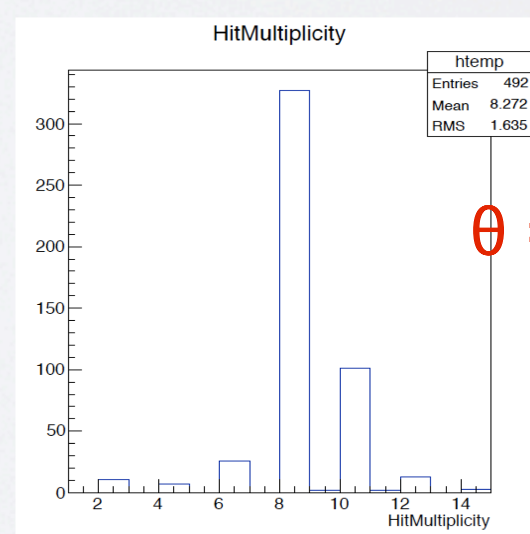



whole detector

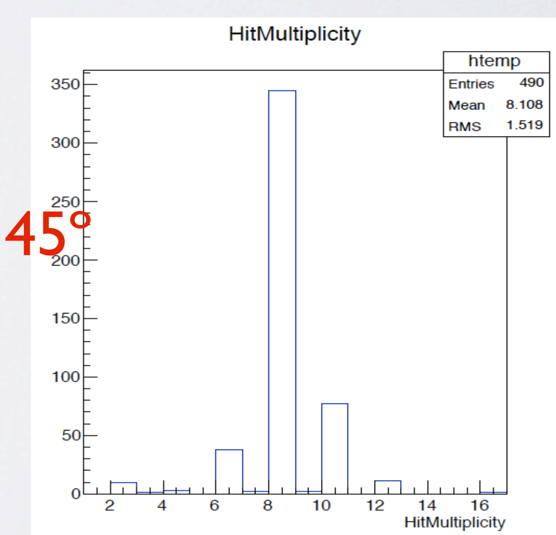



inner tracker only

$\theta$ = 45°




whole detector



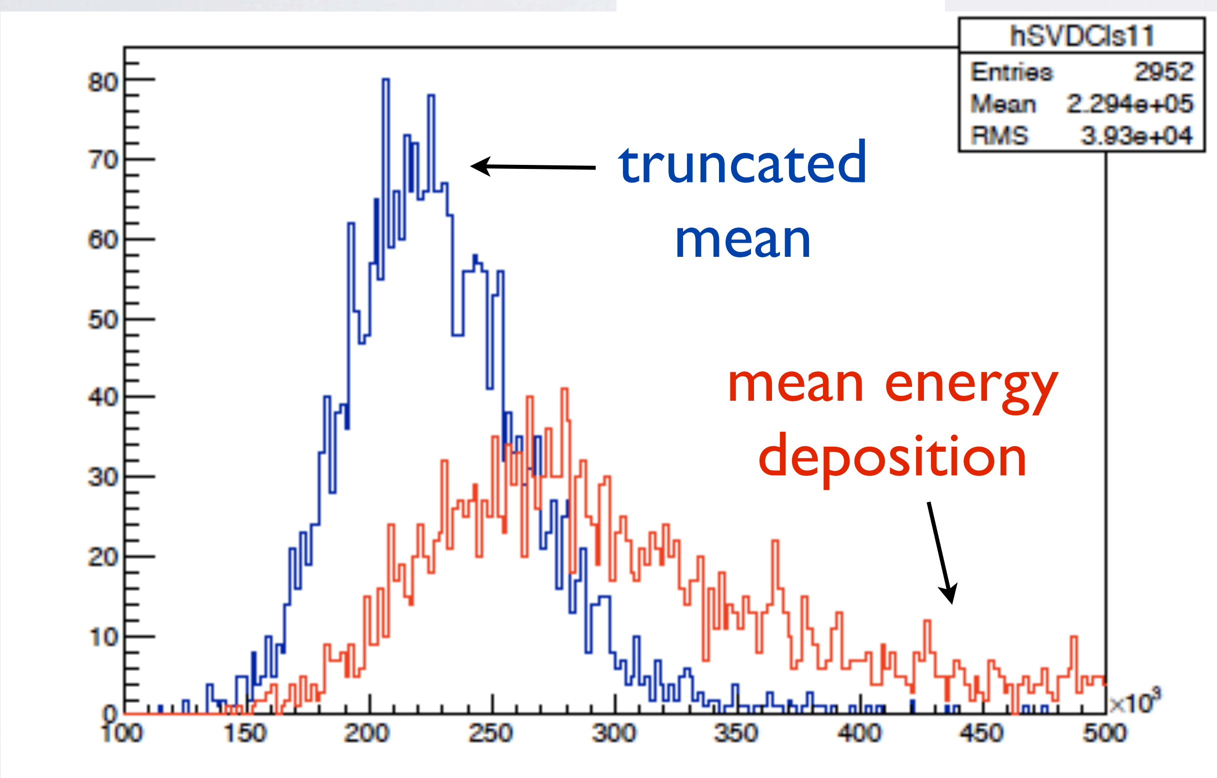

inner tracker only

# Energy deposition in silicon

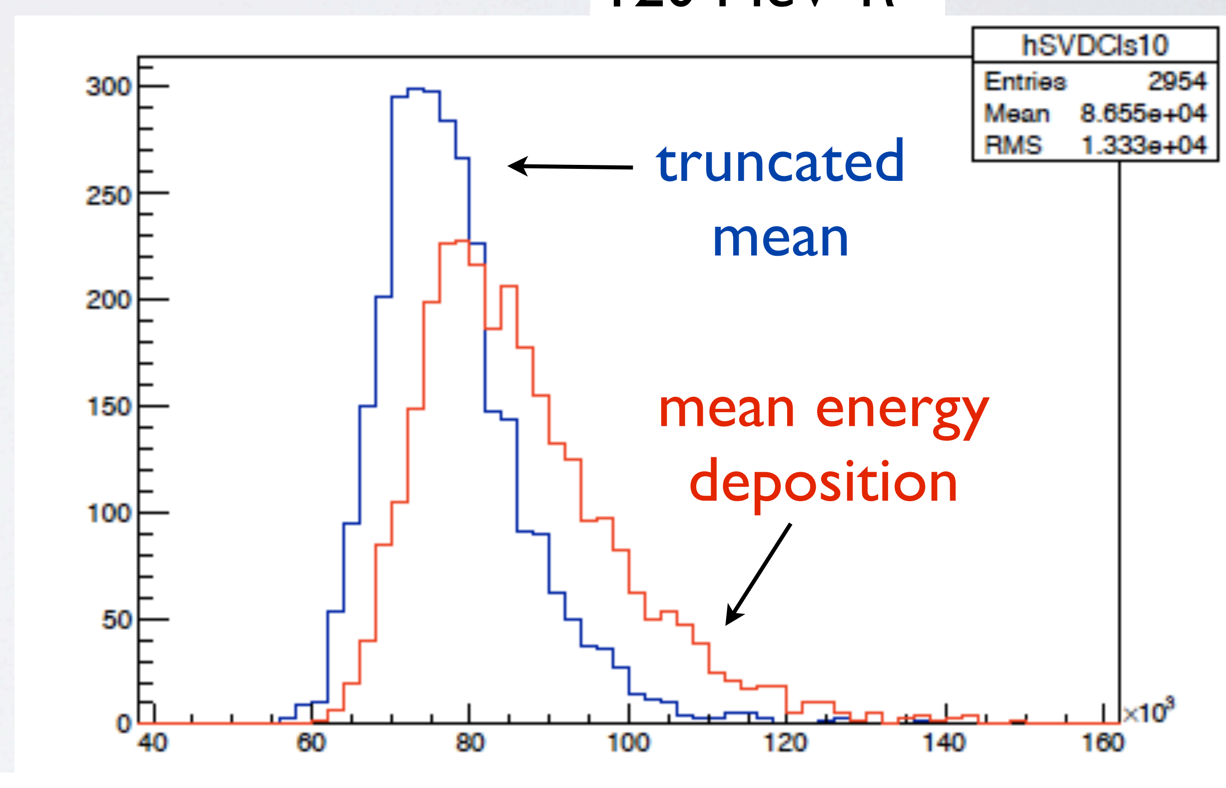
- Up to now: only SVD studied.
  For each already-reconstructed track:
  compute mean value of Energy deposition in 1 layer with reconstructed hits.

  trunc_mean = mean of Energy deposition in each SVD layer
  but the 2 highest values (mainly measured from same wafer)
  to reduce the Landau tail.

70 MeV π




120 MeV π

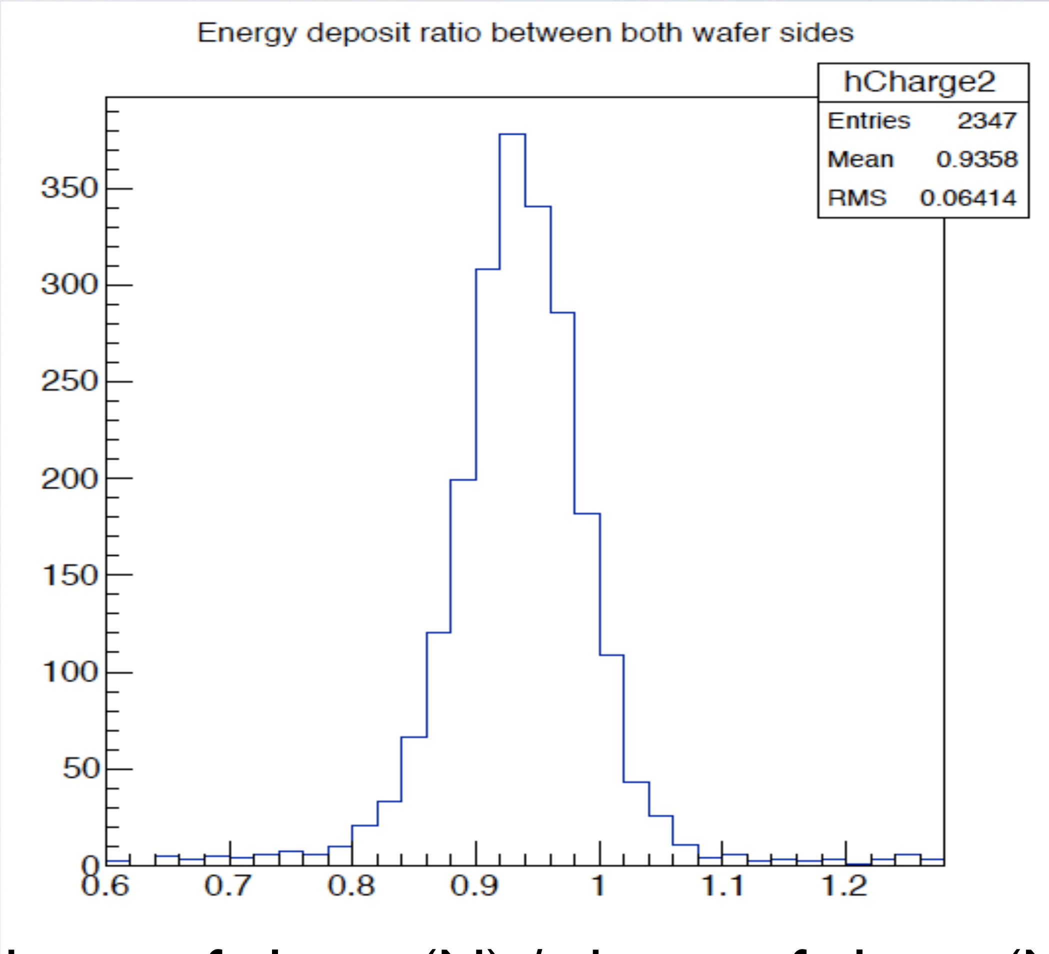



Mean cluster charge in $e^-$ ($100 \times 10^3$ $e^-$ ~ 360 keV)

# Double-sided layer measurement

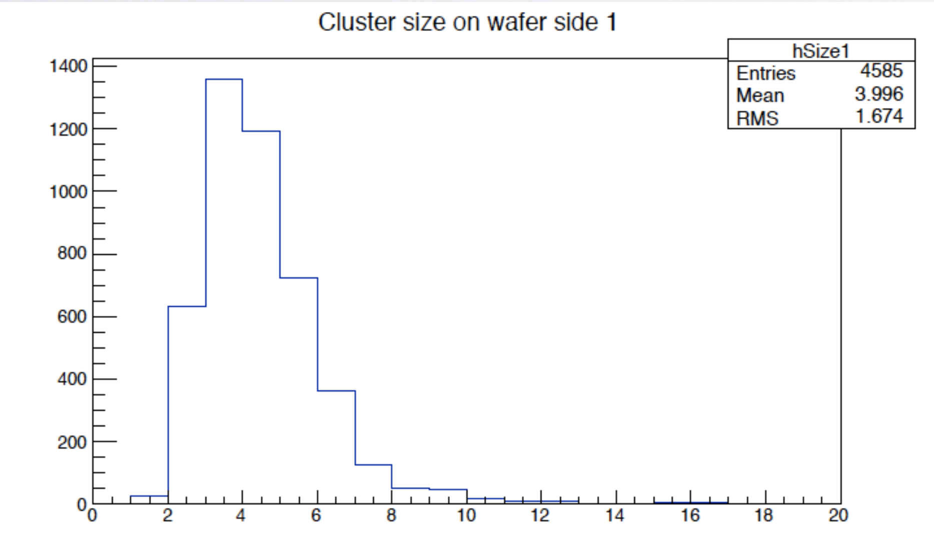
- Good correlation between the 2 measurements by a same wafer for a crossing particle, but mean value ≠ 1:
  - Is it due to the different orientation of both sides strips w.r.t. the crossing track?
  - Or is it due to a ≠ gain on both sides?
  - Or something else?

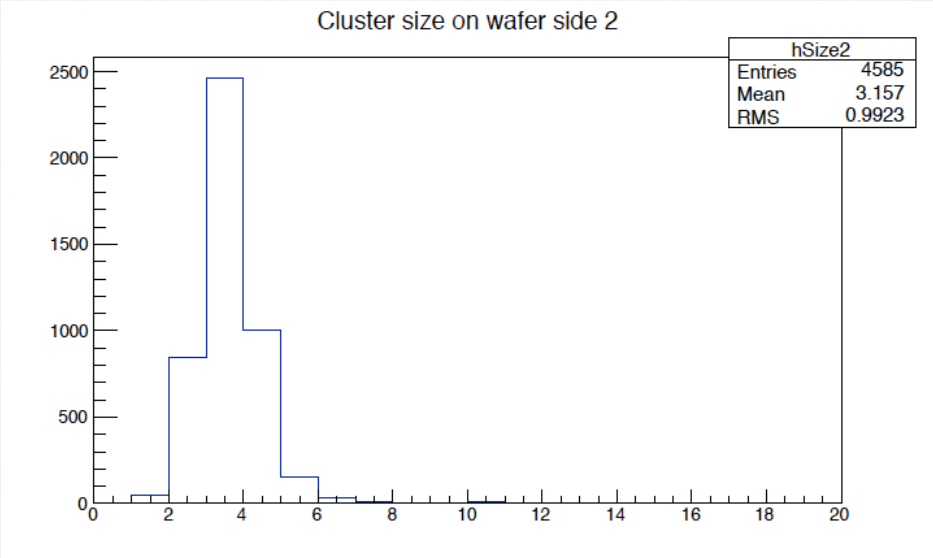
➢ Should be taken into account if we want to further improve the momentum resolution.




charge-of-cluster(N) / charge-of-cluster(N-1)
(if same sensor)

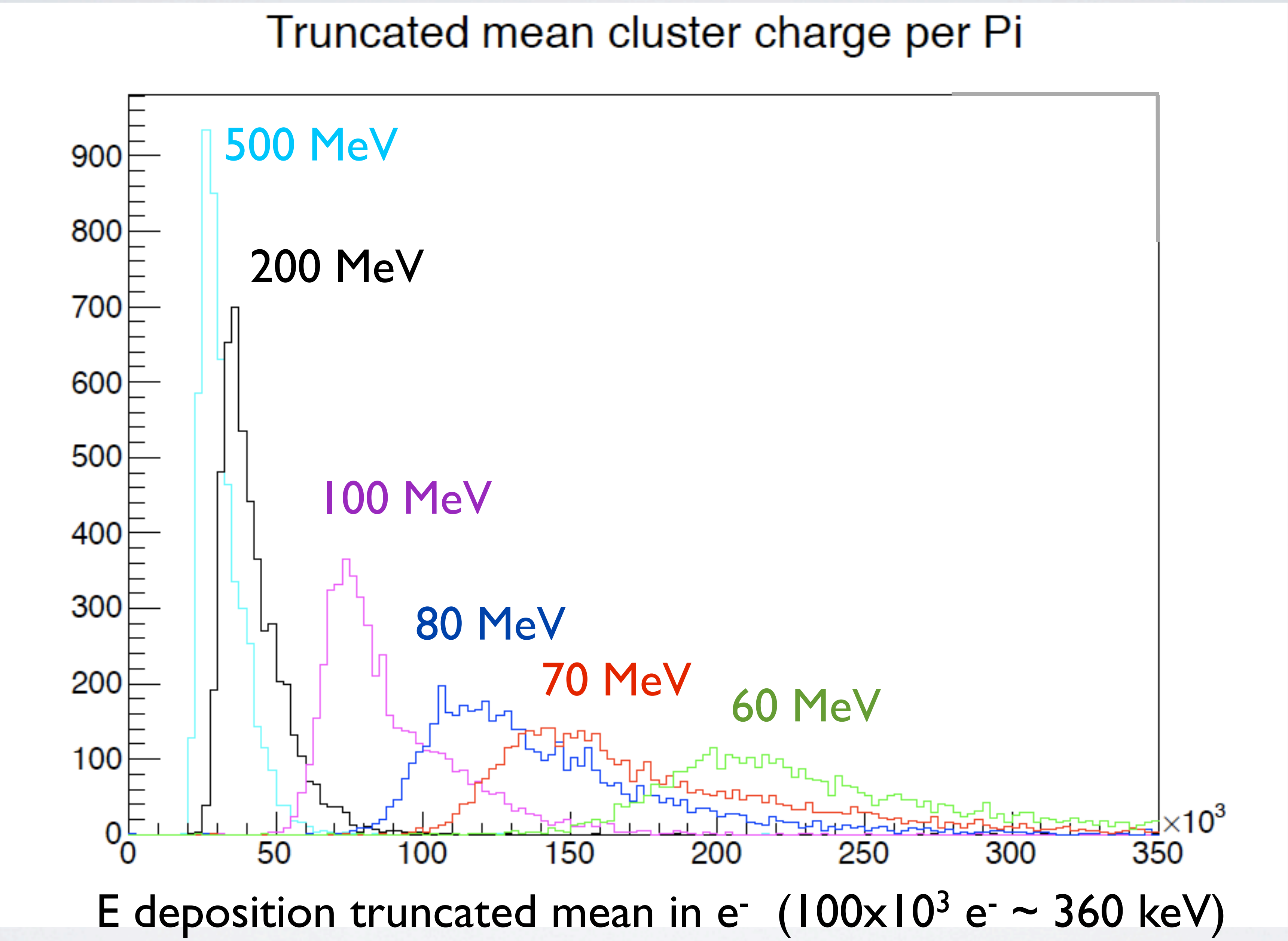
- Observed: different cluster sizes on both sides:
  ➢ mean ratio ≠ 1 may be due to strip orientation.




1000 π
momentum = 80 MeV
θ = 45°
whole detector simulated

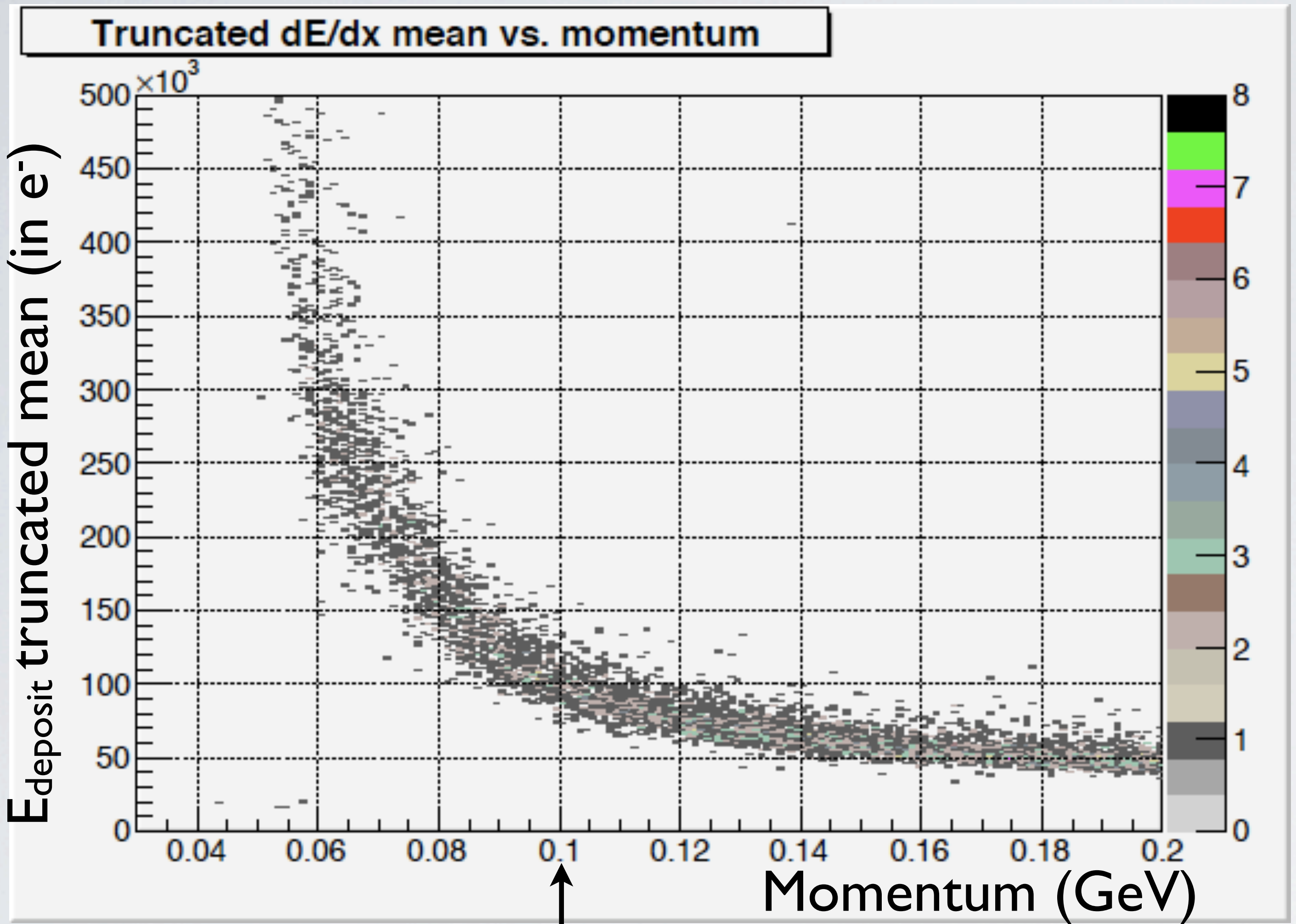
# E deposition truncated mean distributions




Quality of the momentum estimation will depend on:

- separation between MPV
- dispersion of the distribution

# Edeposit vs. momentum

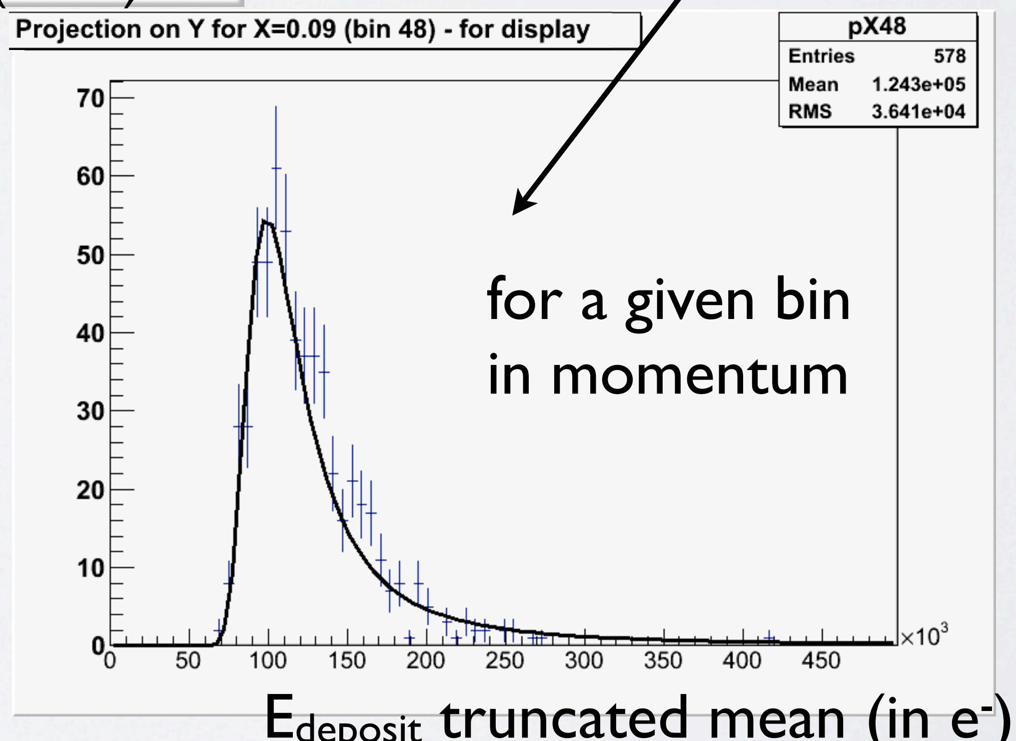



Different estimation have been tried:

- Highest bin
- Gaussian Fit
- Landau Fit ➛ chosen method

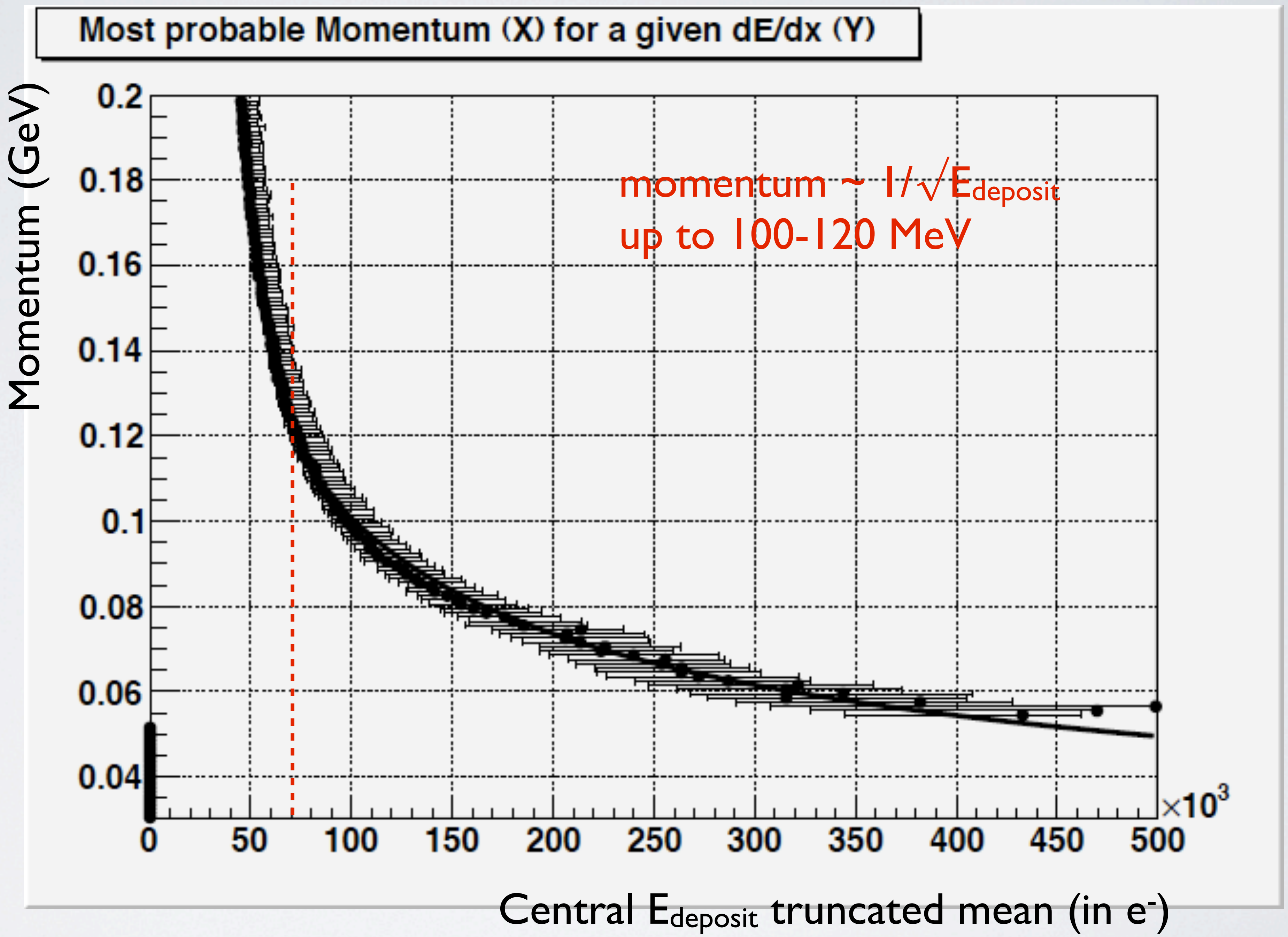
for each bin in momentum, plot the distribution of $E_{deposit}$ truncated mean:

➛ does not depend on Momentum spectrum (≠ from: plot of Momentum distribution for each dE/dx slices)



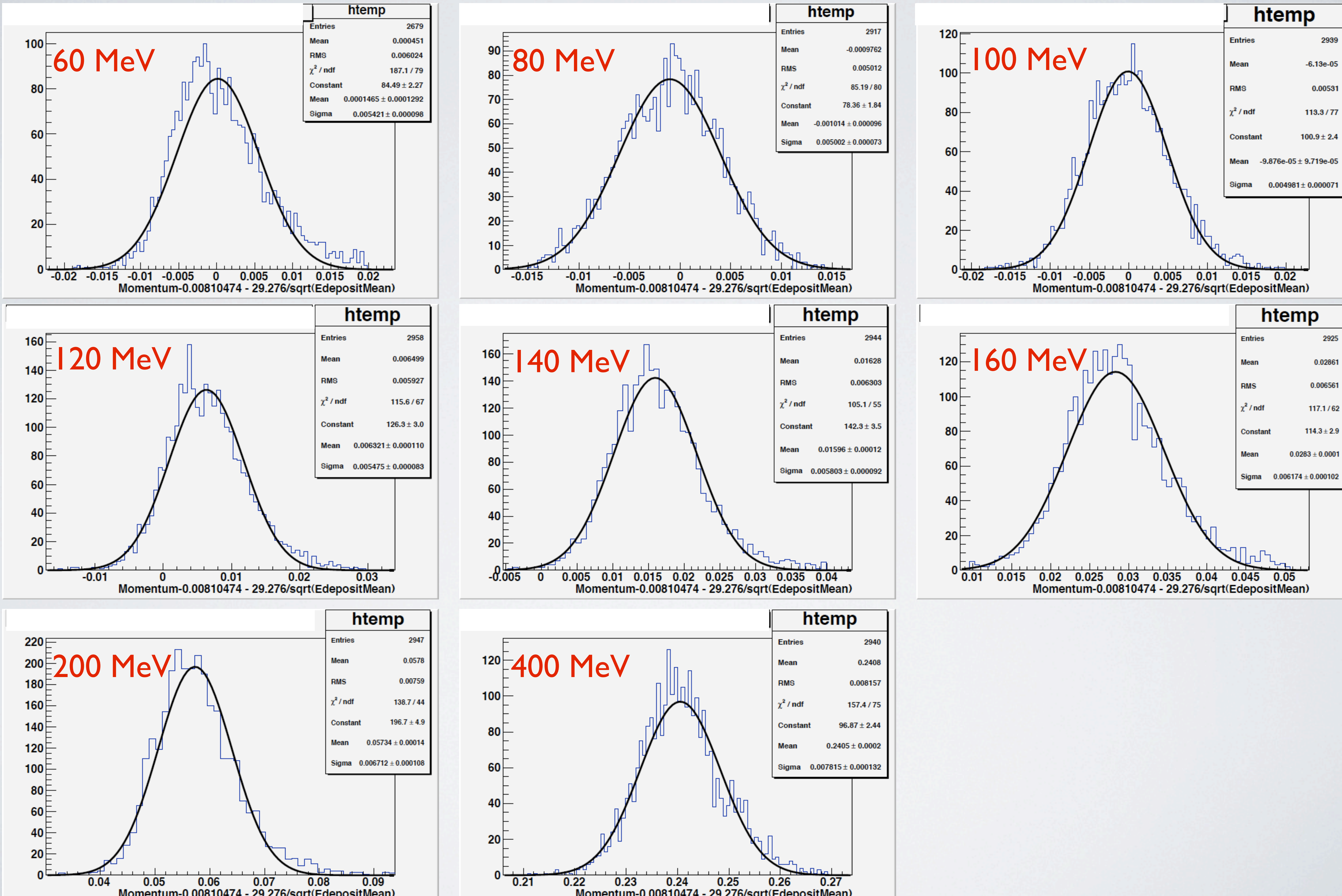

for a given bin in momentum

# Momentum estimation from Edeposit

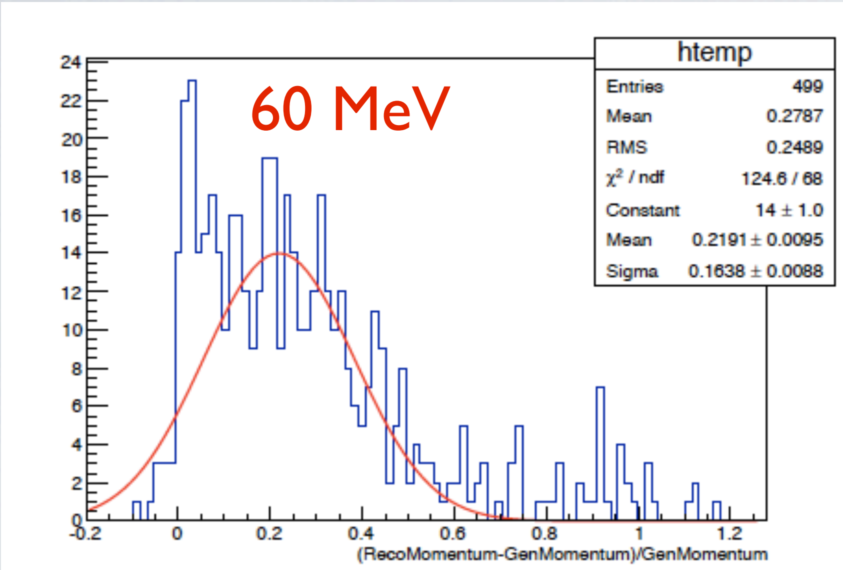


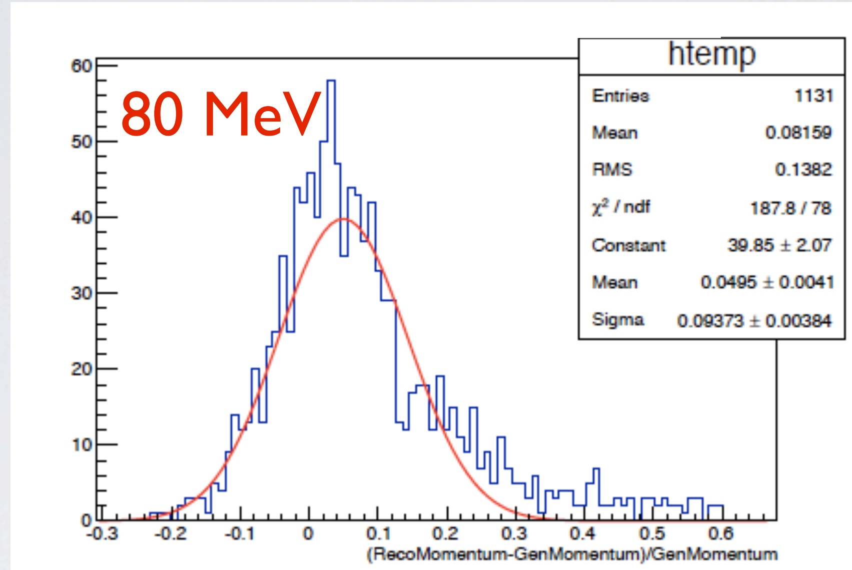

- uncertainty bars: 1σ coverage
- points: central dE/dx value (Landau MPV)

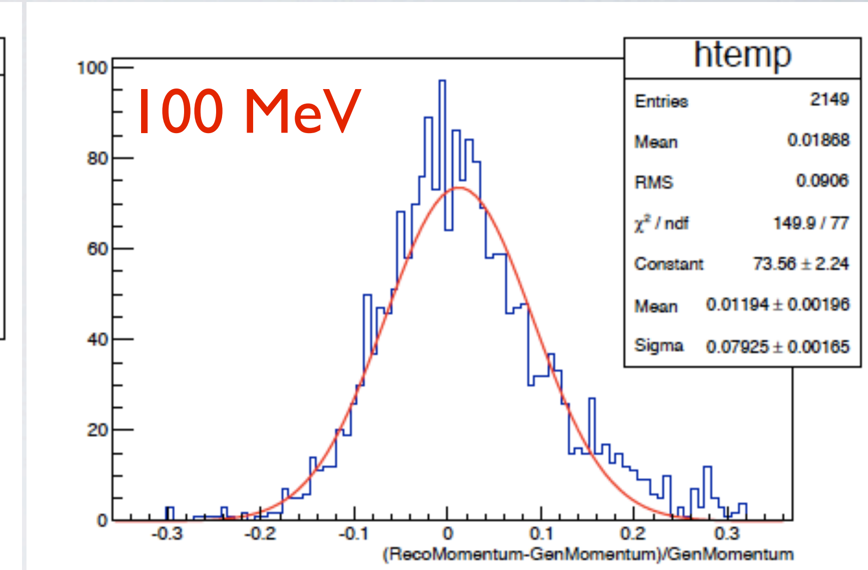
# ΔE-momentum residue $(p_{reco} - p_{true})$

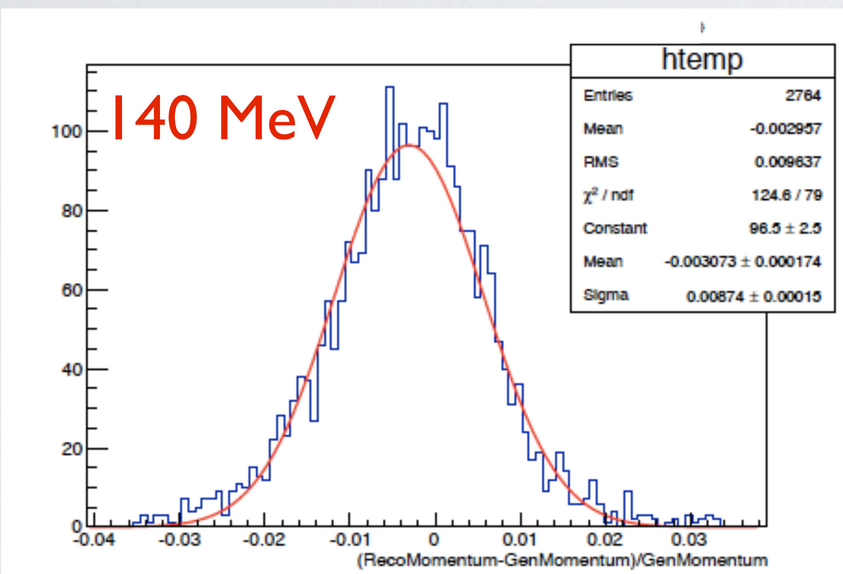


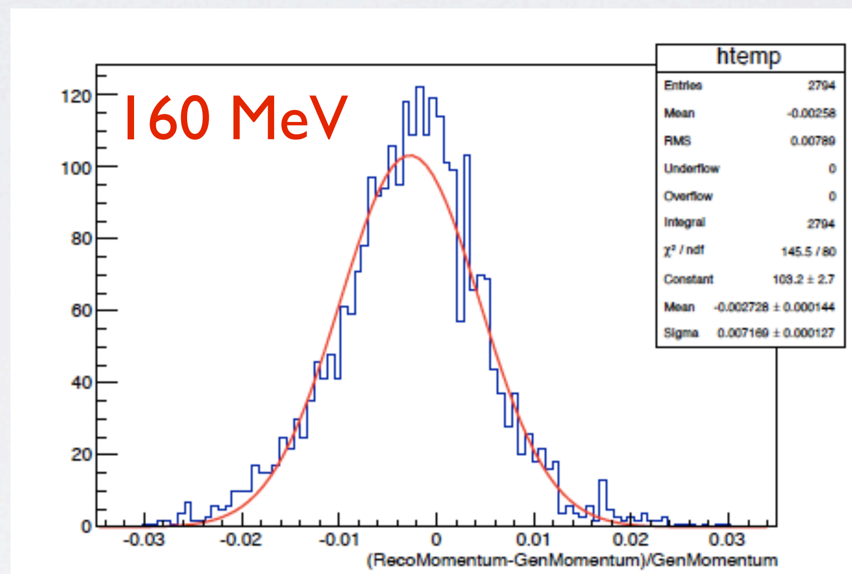
# Helix-momentum resolution Δp/p

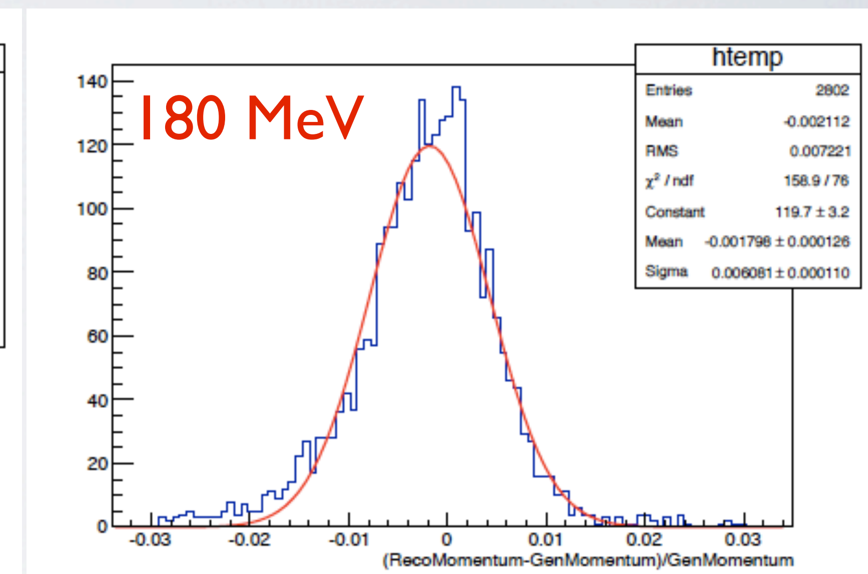


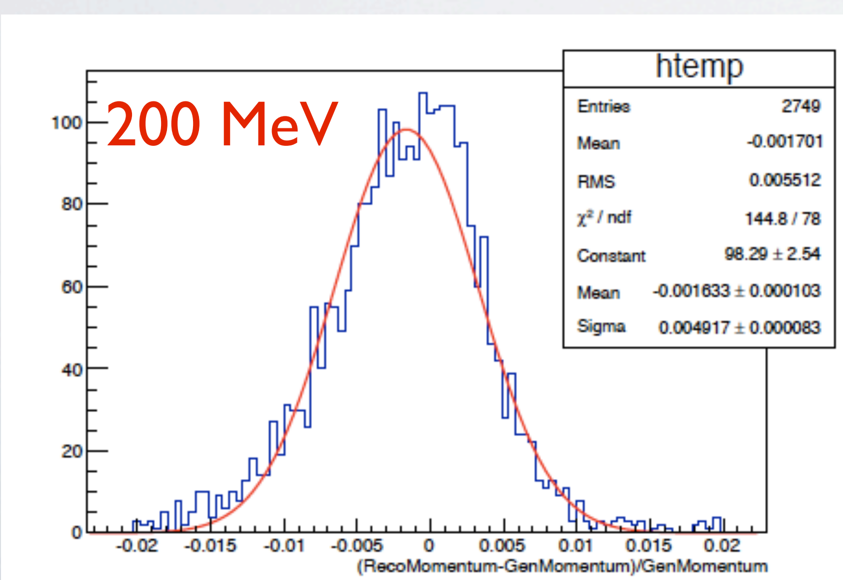



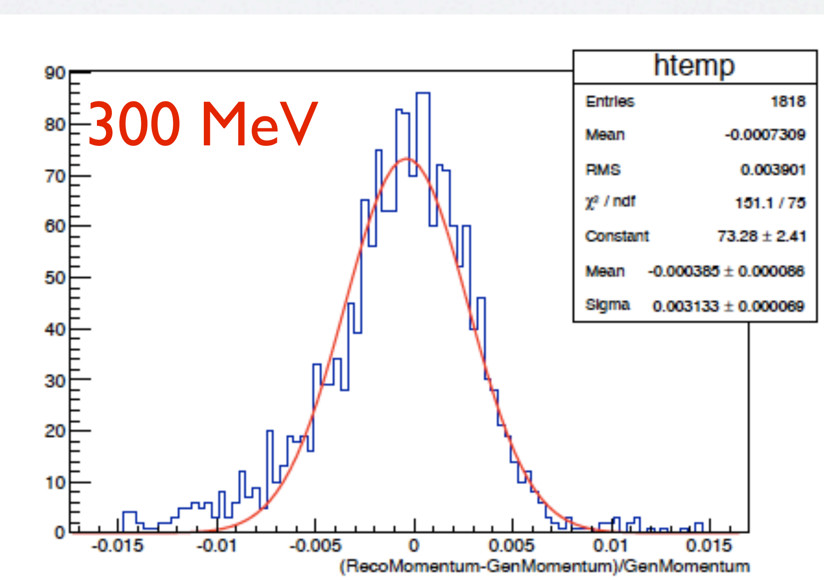



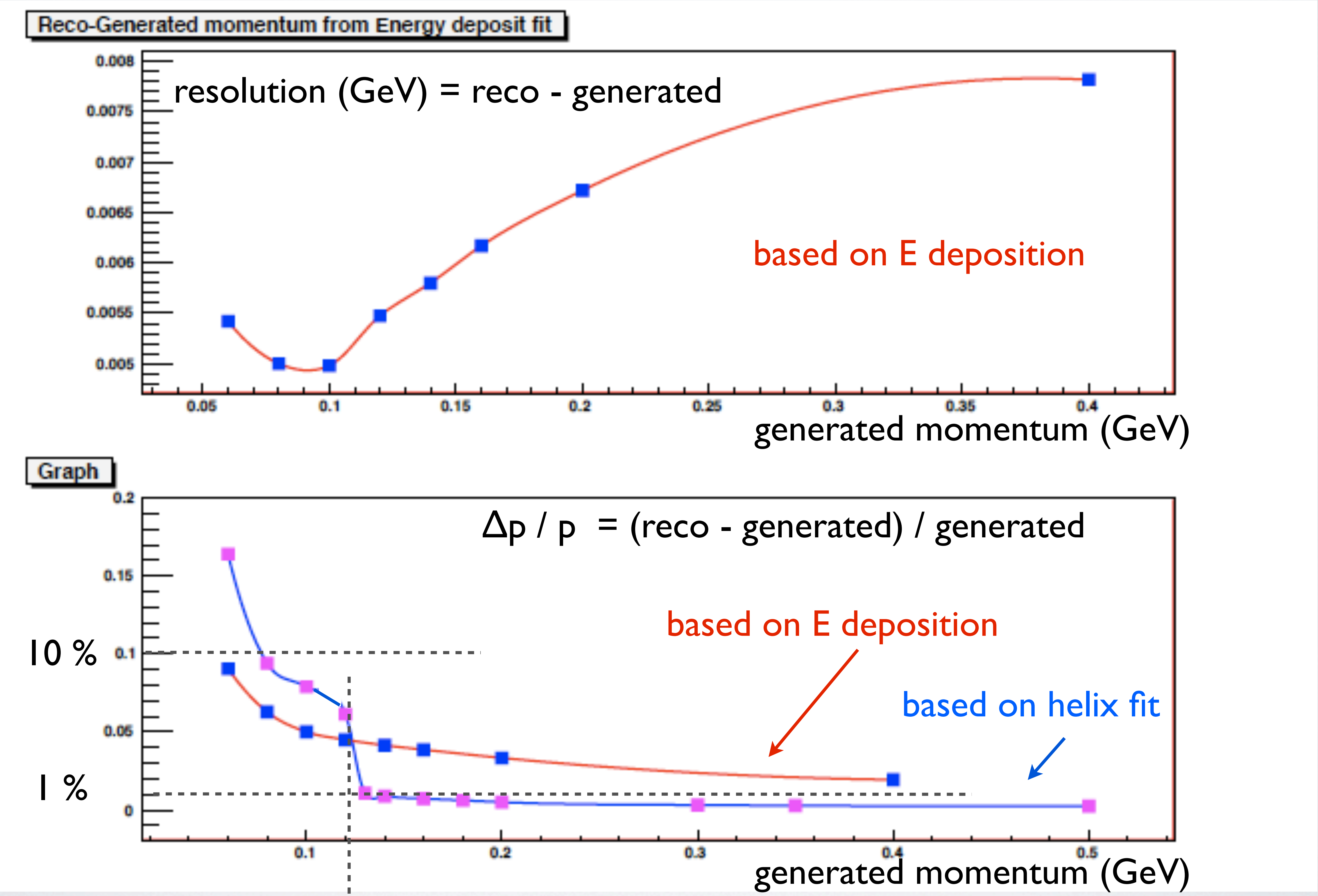



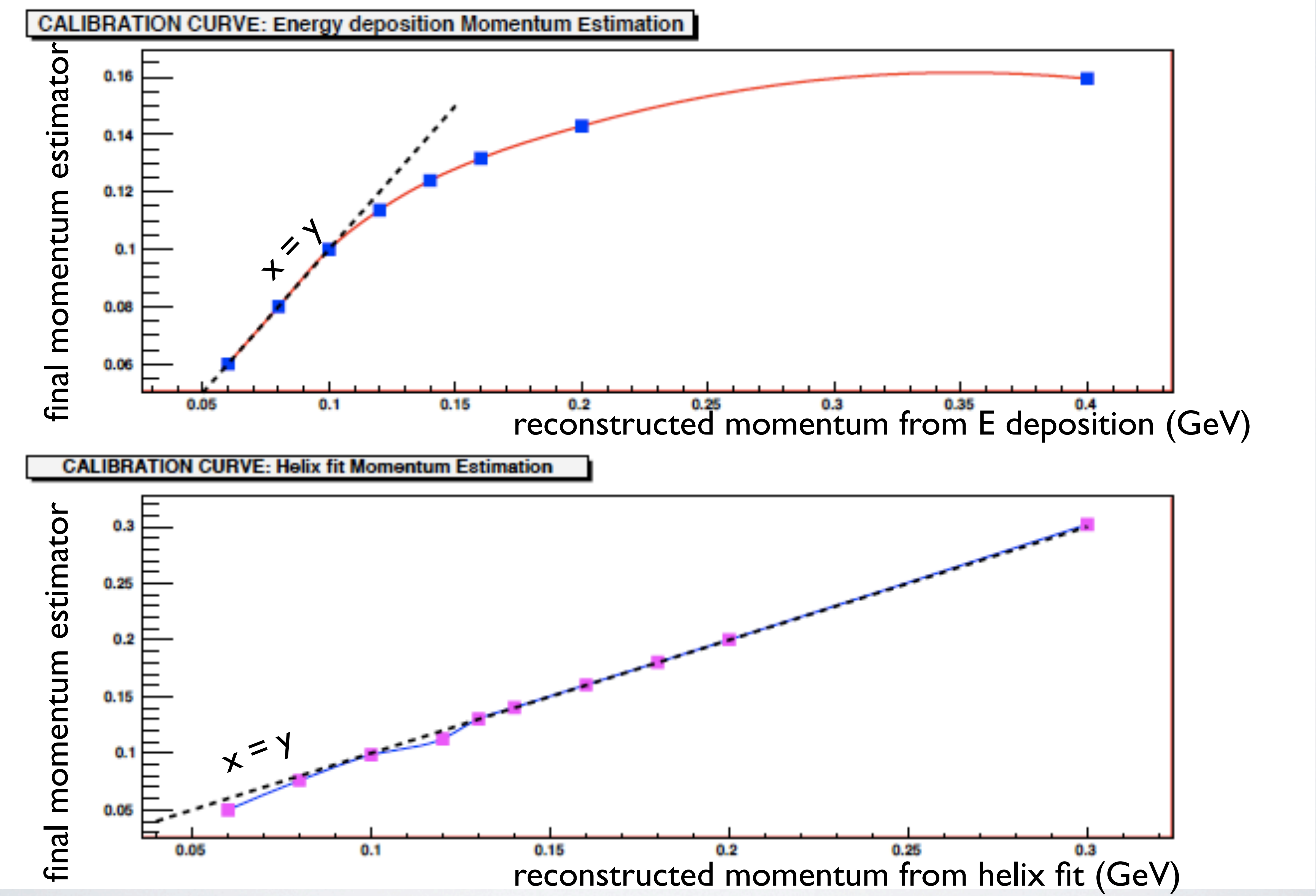



# Momentum resolution




~ CDC is also used for helix track fit

# Bias



CALIBRATION CURVE: Energy deposition Momentum Estimation
final momentum estimator
0.16
0.14
0.12
0.1
0.08
0.06
x = y
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
reconstructed momentum from E deposition (GeV)
CALIBRATION CURVE: Helix fit Momentum Estimation
final momentum estimator
0.3
0.25
0.2
0.15
0.1
0.05
x = y
0.05
0.1
0.15
0.2
0.25
0.3
reconstructed momentum from helix fit (GeV)

# Adding DepFET information

same constant for
SVD and PXD (silicon)

- To add pixel layers information:

  current truncated mean ΔE per layer → $dE/dx = \text{constant} \times \dfrac{\sum \Delta E}{N_{SVD} \times path_{SVD} + N_{PXD} \times path_{PXD}}$

  with: $path = \text{layer-width} / \sin \theta_{track}$ ;

  and: $\text{layer-width}_{SVD} = 300$ µm, $\text{layer-width}_{PXD} = 70$ µm (correct?)

  Need to stick (calibrate) $\Delta E_{PXD}$ to $\Delta E_{SVD}$, due to different electronic gains.

  ➛ still, does not take into account:
  - Larger ΔE fluctuations due to smaller path in DepFET layers ;
  - Different precision on ΔE due to different ADC dynamic ranges in SVD w.r.t PXD.
  - Energy loss along the path (also true for SVD-only method).

- ΔE fluctuations could be taken into account by switching to a maximum likelihood method using a Moyal function.
  Should also improve momentum resolution if estimation with SVD only.

# Comments and next steps

- Generalisation for tracks ∀ θ: done.
  - Switch from ΔE/layer to dE/dx (take into account actual path length = layer-width / sin θ).
  - Checked for SVD layers: works fine, same resolution as at 45°.

- No pattern recognition applied in this study:
  based on clusters associated to a simulated particle ➛ best case!
  Only correct clusters used: what resolution reached in real life?

- Adding DepFET clusters: does it help?

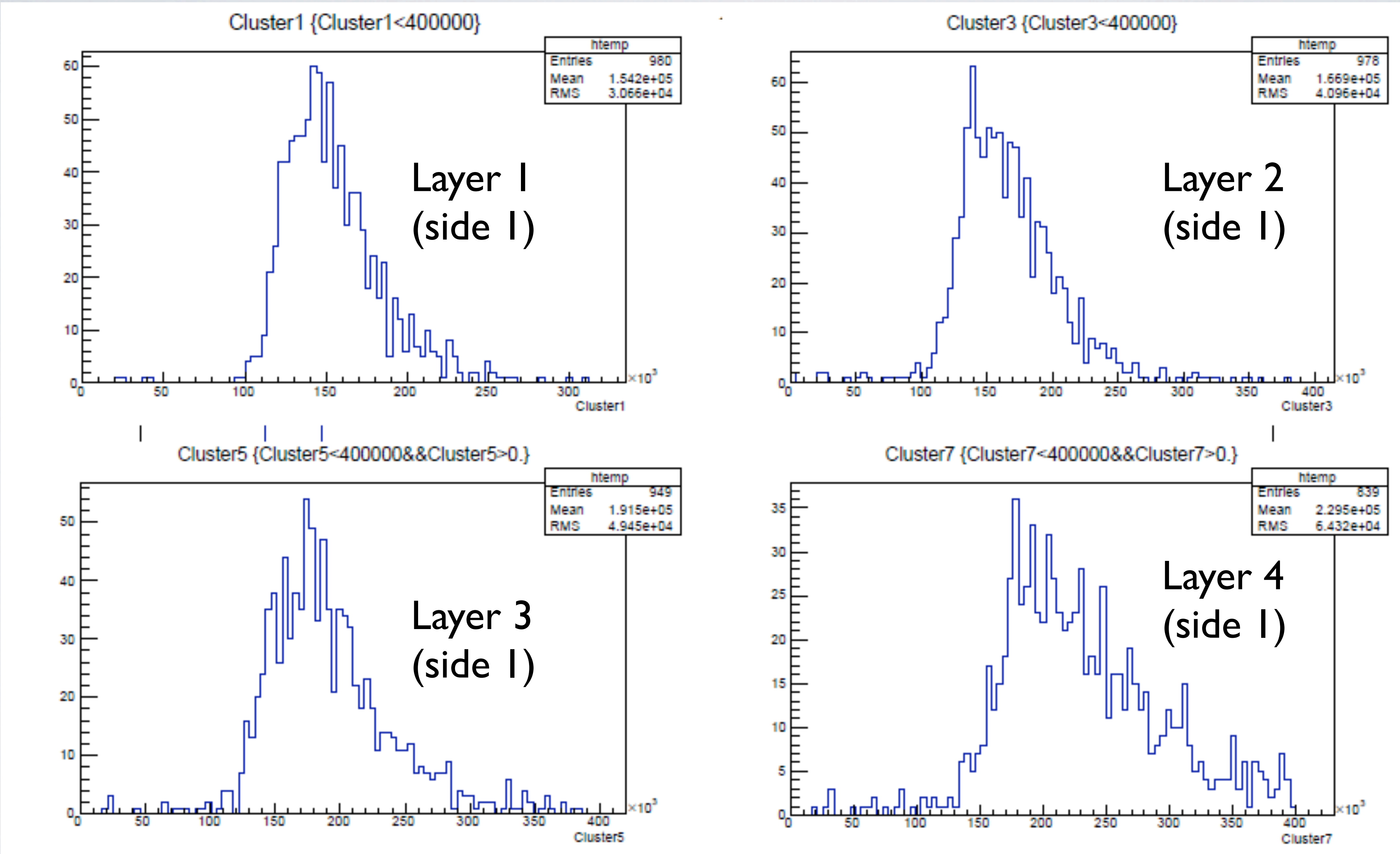
- Resolution of momentum estimated through Energy deposition in silicon layers could be further improved:
  - Correct for the difference between both sides measurement.
  - Take Energy loss and momentum decrease in each layer into account (see next slide).

    - MIP : $E_{loss}$ ~ 120 keV/layer (300 μm of silicon)
    - 100 MeV: K $E_{loss}$ ~ 1 MeV/layer π $E_{loss}$ ~ 0.3 MeV/layer
    - 50 MeV: K $E_{loss}$ ~ 10 MeV/layer π $E_{loss}$ ~ 0.7 MeV/layer

  - Switch to a likelihood fit using a Moyal function,
    or add Variance and Skewness information (has already been investigated).

➛ not clear if further improvements are needed w.r.t. the simple $1/\beta^2$ parametrisation.

# Energy loss after each layer crossing




1000 π
p = 80 MeV
θ = 45°

- E deposition actually increases with crossed layers (momentum decreases).
  But ΔE seems <~ E fluctuations.
  Other hint: $1/\beta^2$ parametrisation seems suitable (fit is nice).