Track Segment Analysis in AHCAL

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Purpose

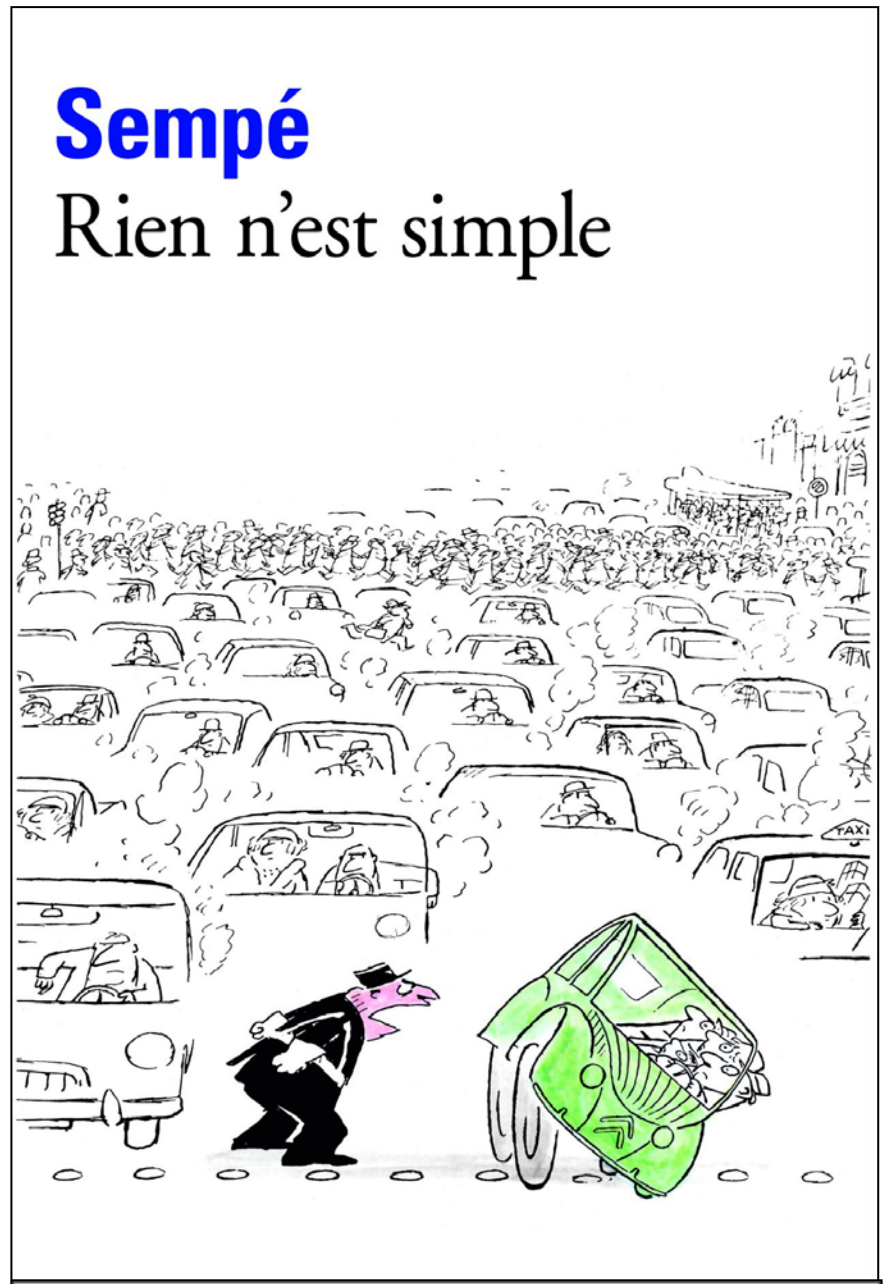
Particle showers produce very large amounts of secondary particles.

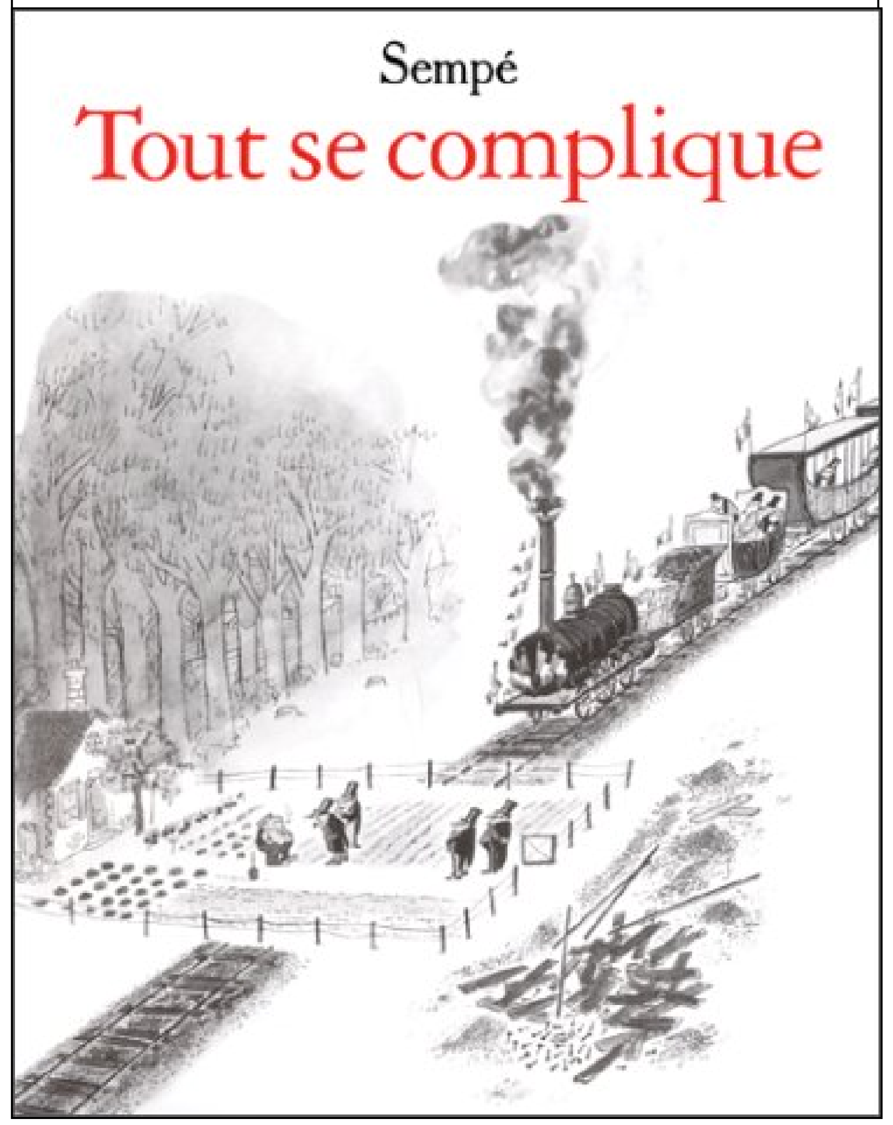
Would it be possible to use these in principle “minimum ionizing particles”(MIPs) to establish an ***in situ* calibration** of the detector?

In the **ideal** case, all detected particle tracks or segments would behave the same way, independent of their type or energy. This is needed because the mix in a real detector would be unknown.

In **practice** this cannot be that simple, there might be dependencies, there will be corrections due to angles and other systematics …

But how far can one go? A “simple” robust method is proposed here.

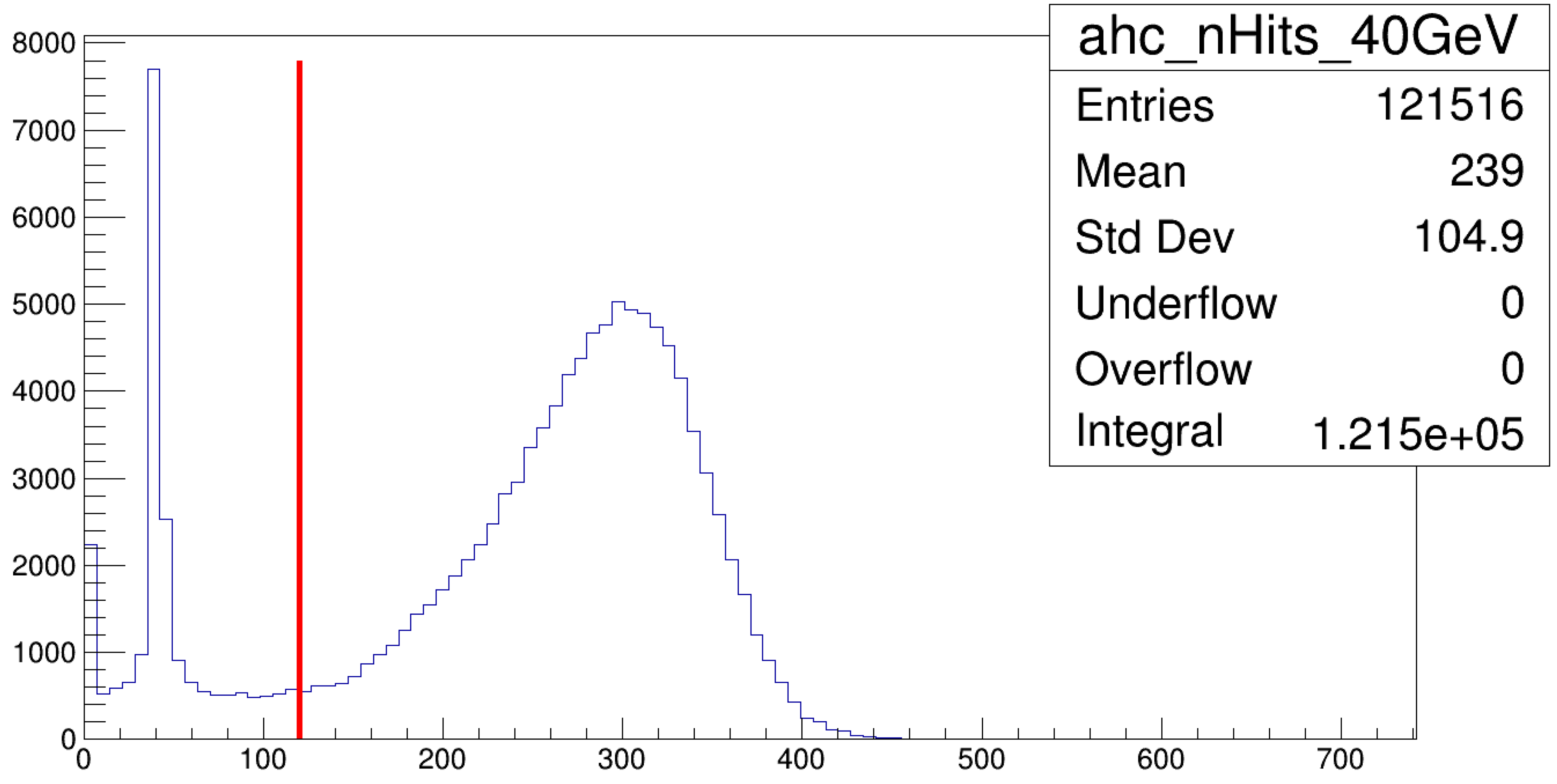


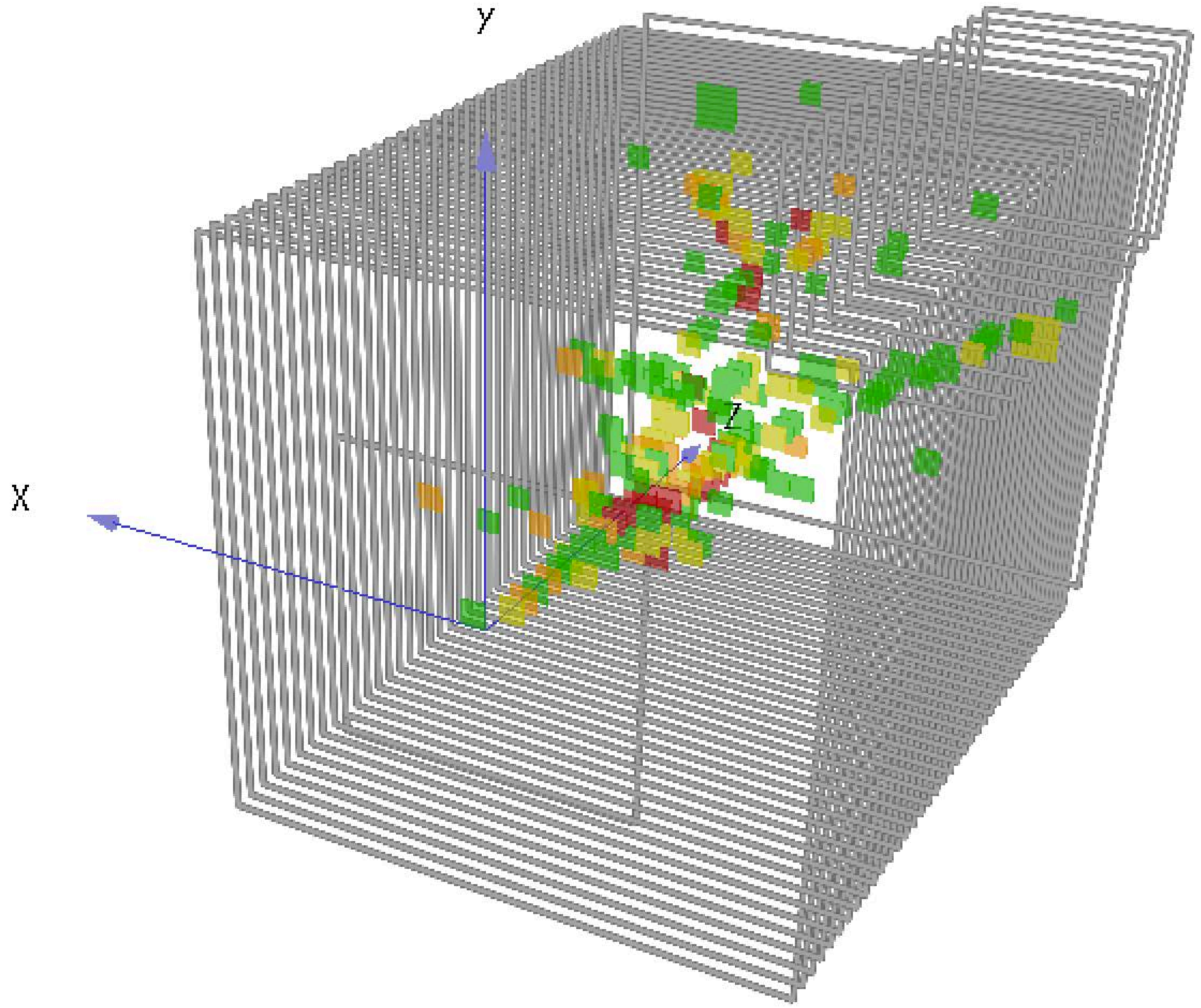


Event Selection

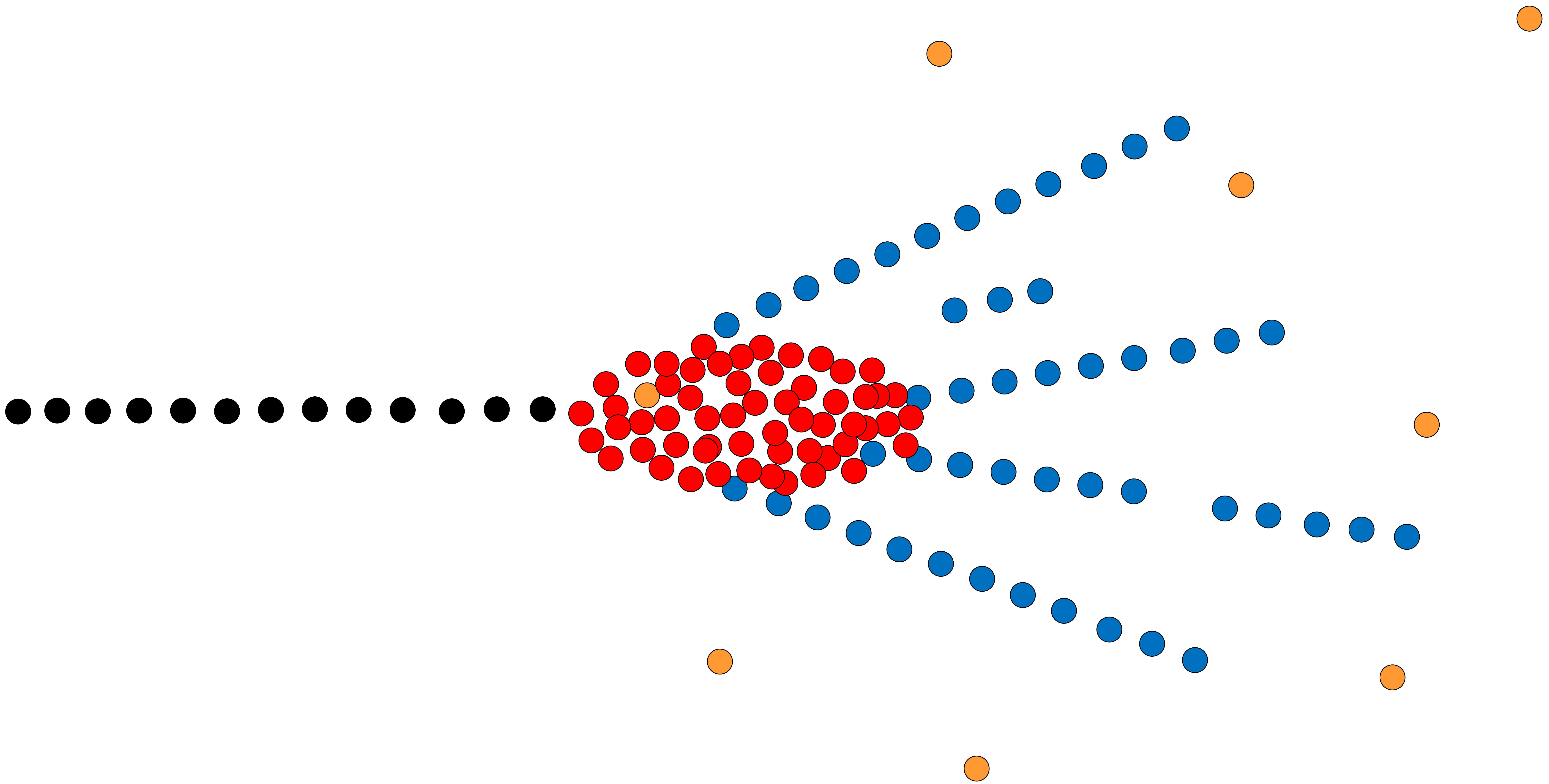
Data from June 2018, taken at the CERN SPS, with e,π,μ beams from 10 to 200 GeV

e.g. pions: reject muon contamination
with a simple cut on the number of hits





Shower Hits: Clusters



Finding Track Segments

The method uses **connectivity** properties and the inertial tensor.

with hit

Connectivity: how many neighbors does a calorimeter cell have in 3D (from 0 to 26)?

1) Reject hits with connectivity < 1: outliers or isolated hits

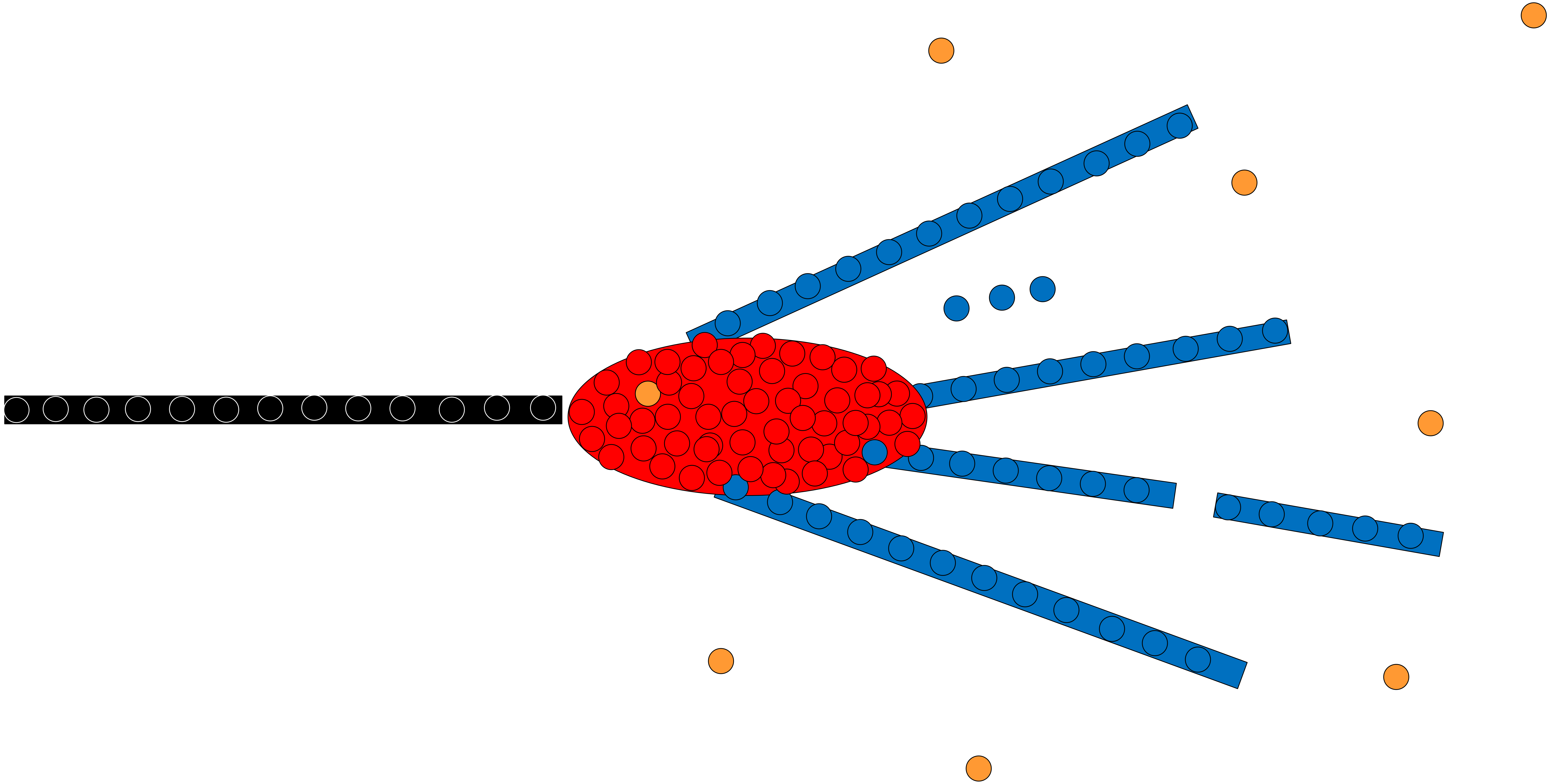
2) Reject hits with connectivity > 8: shower core(s) [the start of the shower comes for free]

3) Refresh connectivity 3D map

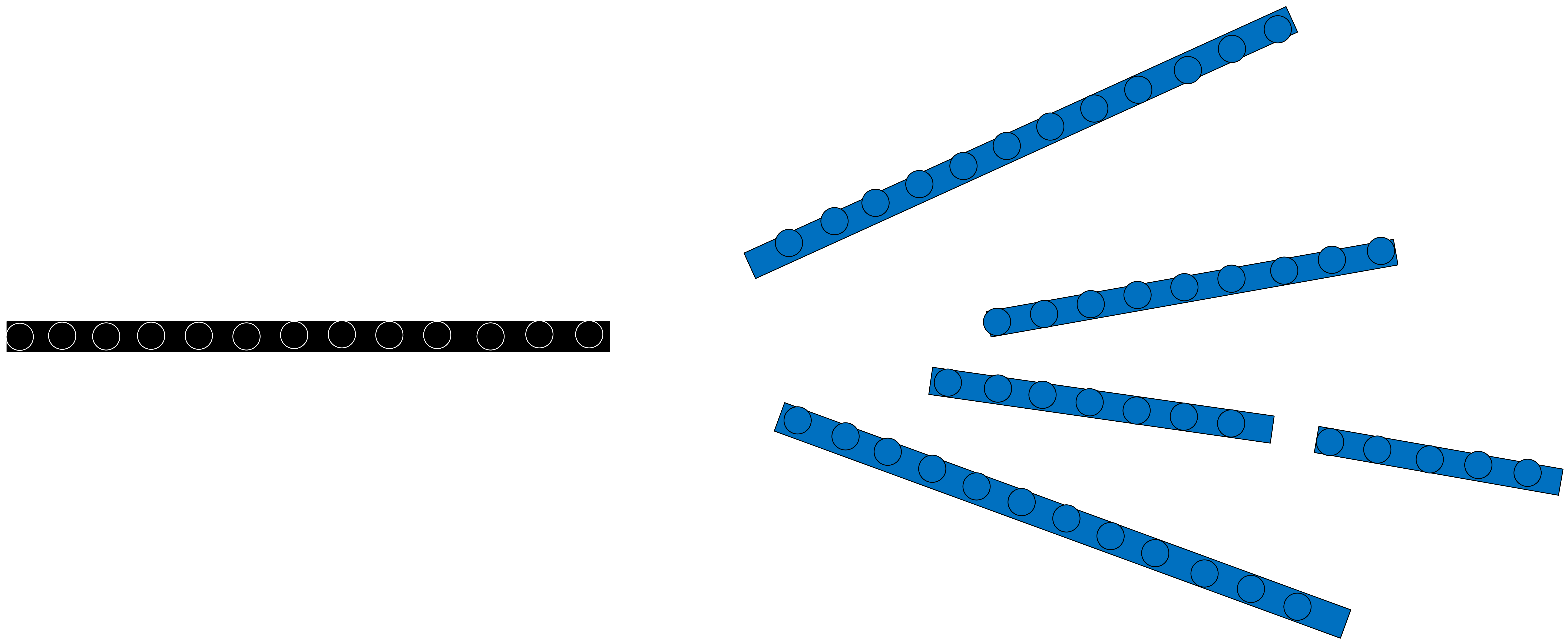
4) Minimum chosen for segment candidates from the remaining clusters: 4 hits.
(<4 is deemed too few to identify reliably and >4 will reduce the statistics) *[systematic]*

5) Primary track of the event is specially tagged, since most likely not to be a MIP

Shower Objects: Primary, Core, Tracks, Outliers



Shower Objects: Primary, Tracks



Track Segment Identification

The surviving clusters are a list of hits, each a 5D entity (t,x,y,z,E). *[time not used yet]*

Clusters are characterized with the **inertial tensor**:

$$\mathbf{I} = \sum_{\mathrm{i=1}}^{\mathrm{N}} \begin{pmatrix} y_i^2 + z_i^2 & -x_i y_i & -x_i z_i \\ -x_i y_i & x_i^2 + z_i^2 & -y_i z_i \\ -x_i y_i & -y_i z_i & x_i^2 + y_i^2 \end{pmatrix}$$

[weights E_i are folded in]

which can be diagonalized:

$$\mathbf{I} = \sum_{\mathrm{i=1}}^{\mathrm{N}} \begin{pmatrix} e_1 & 0 & 0 \\ 0 & e_2 & 0 \\ 0 & 0 & e_3 \end{pmatrix}$$

yielding the longest axis via e_1. A loose cut of $e_1/(e_2^2+e_3^2)^{½} < 0.1$ enforces straightness.

Number of Track Segments per Event (averages)

Beam Energy	Muons	Electrons	Pions
10 GeV		1.04 ± 0.22	1.50 ± 0.72
20 GeV		1.17 ± 0.43	1.72 ± 0.90
30 GeV		1.06 ± 0.30	1.77 ± 0.95
40 GeV	~1.26 (broken or double)	1.05 ± 0.25	1.89 ± 1.04
50 GeV		1.10 ± 0.39	
60 GeV		1.07 ± 0.31	1.91 ± 1.07
70 GeV		1.10 ± 0.39	
80 GeV		1.17 ± 0.51	2.00 ± 1.14
90 GeV		1.21 ± 0.56	
100 GeV		1.28 ± 0.66	
120 GeV			2.01 ± 1.16
160 GeV			2.03 ± 1.18
200 GeV			2.07 ± 1.20

most data sets
~ 200 kEvents

Slow increase with energy, as expected.

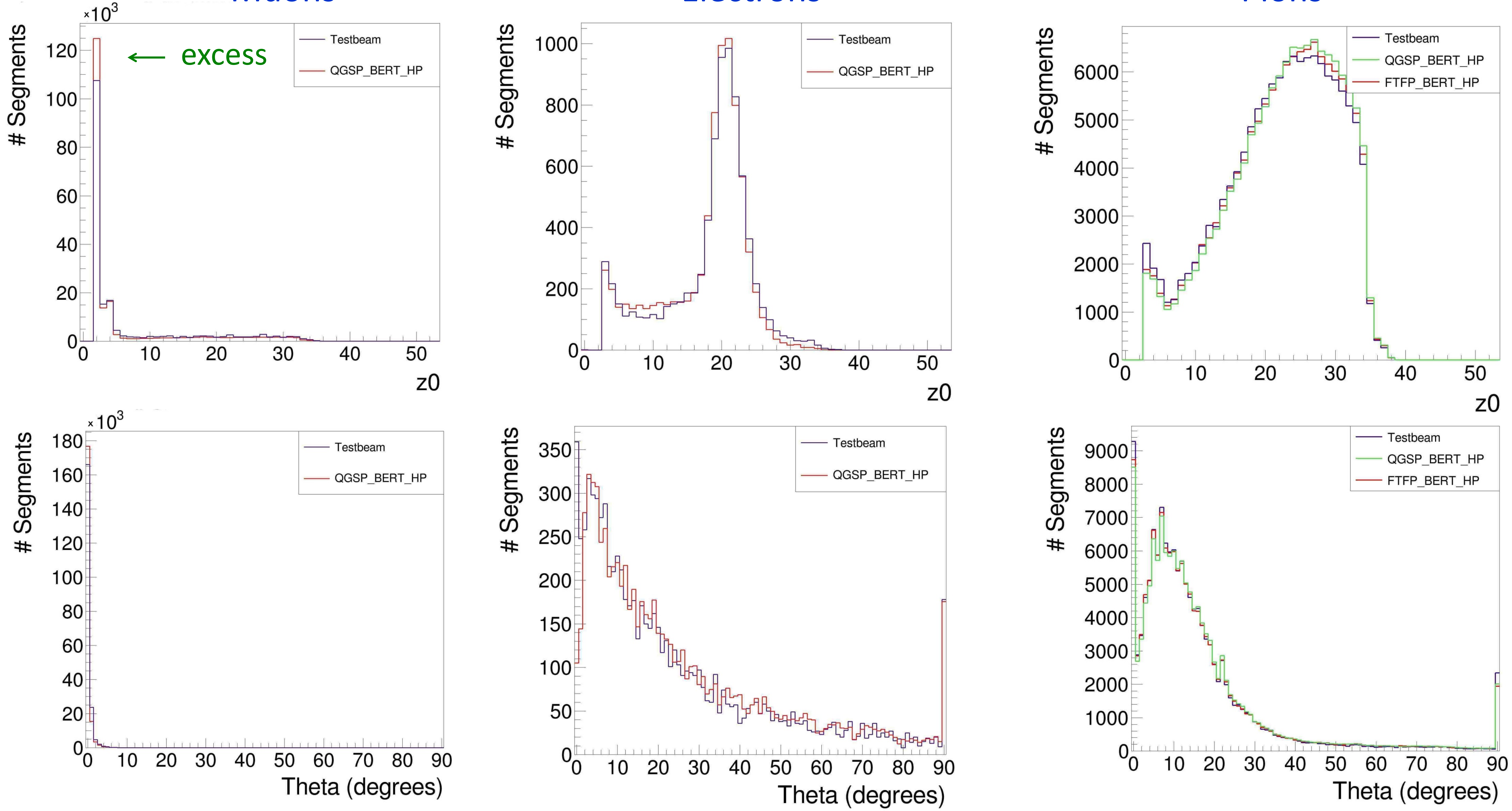
MC Comparisons for #Segments found

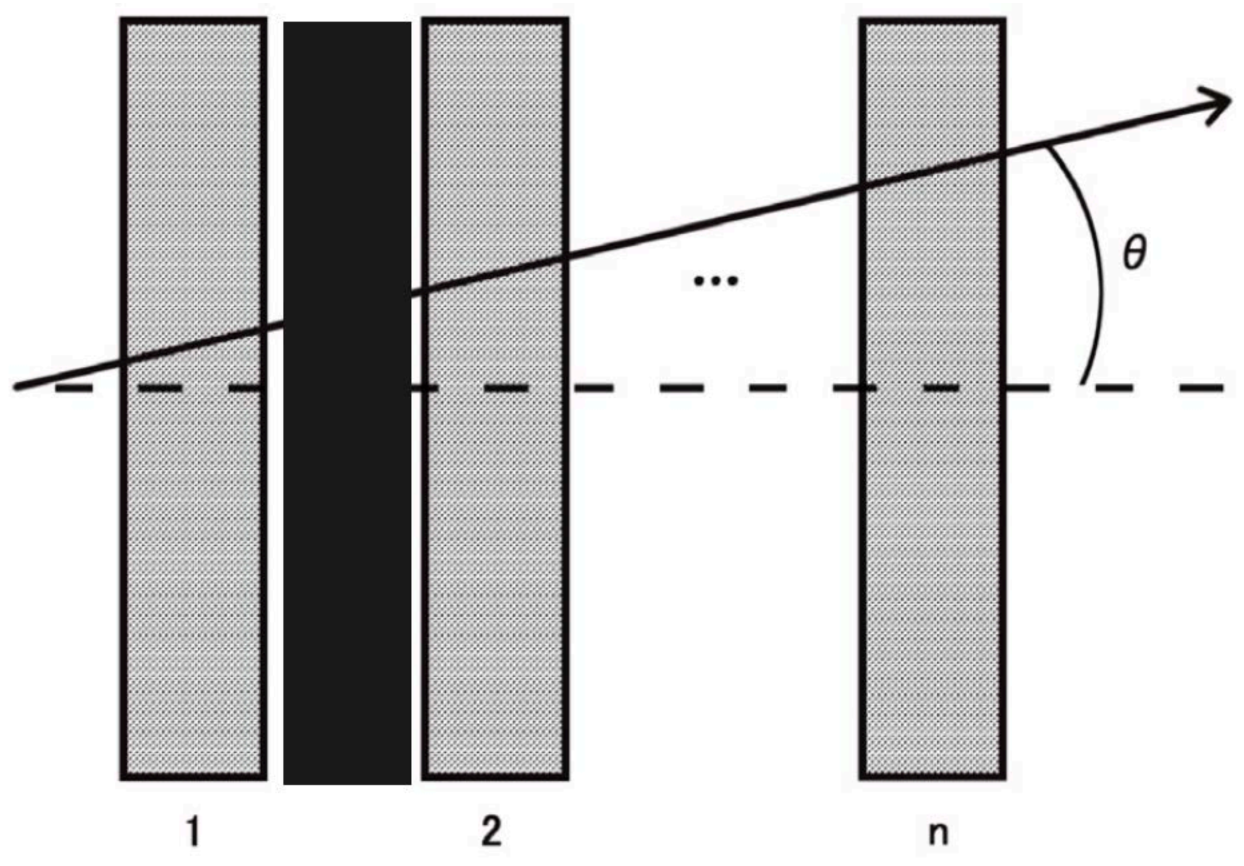
Normalization Data/MC taken from the number of found segments. Selected plots:

40 GeV — Muons — Electrons — Pions

vs 1st layer:

vs θ angle:





Geometrical Angular Dependence

Path length in tile is a function of the polar angle θ:

$$L_\theta = \frac{L_{0^o}}{\cos\theta} \quad \text{so that one expects:} \quad E_\theta = \frac{E_{0^o}}{cos\theta}$$

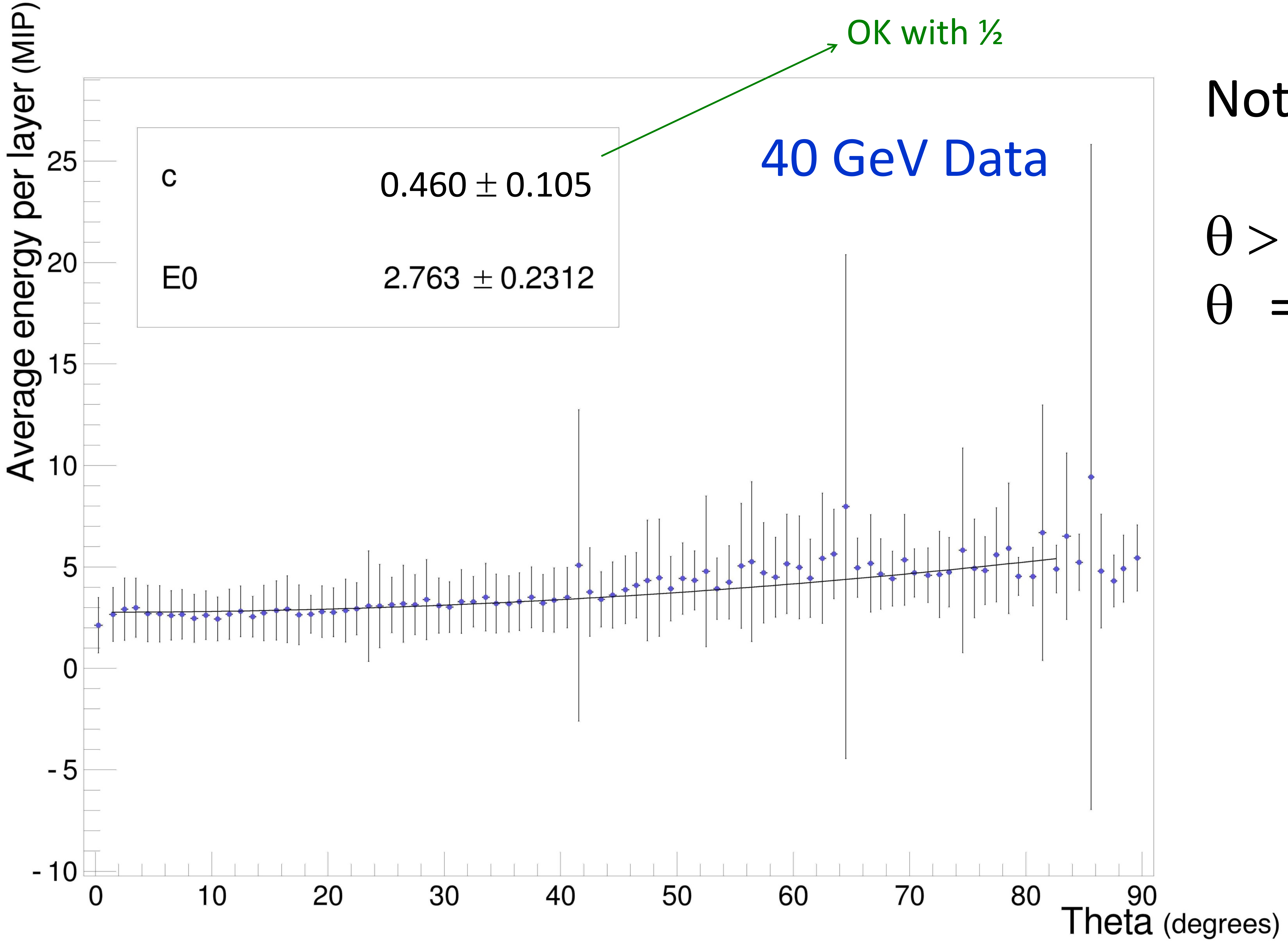
Option 1: assume this is exact (risky) and make the correction

Option 2: (chosen) fit the data with: $E_\theta \approx E_{0^o}(1 + \frac{1}{2}\theta^2 + \frac{5}{24}\theta^4 + \ldots)$

See how well the dependence holds: $E_\theta \approx E_{0^o}(1 + c\theta^2)$ is c=½ ?

The fitted E_{0^o} value per layer becomes the “calibration reference number” (in MIP units)

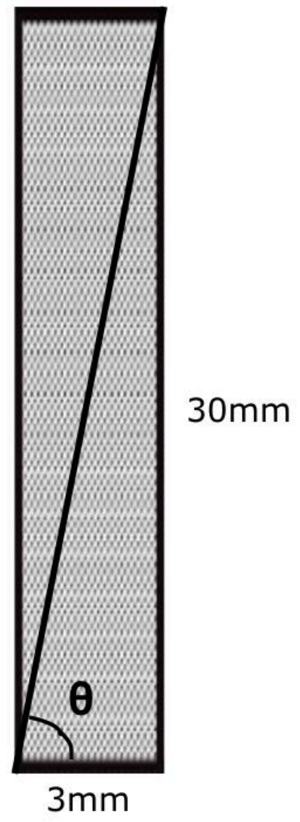
Angular Dependence for Electrons



Not in the fit:

$\theta > 84°$ (cell geometry)

$\theta = 0°$ (observed residual primary contamination)



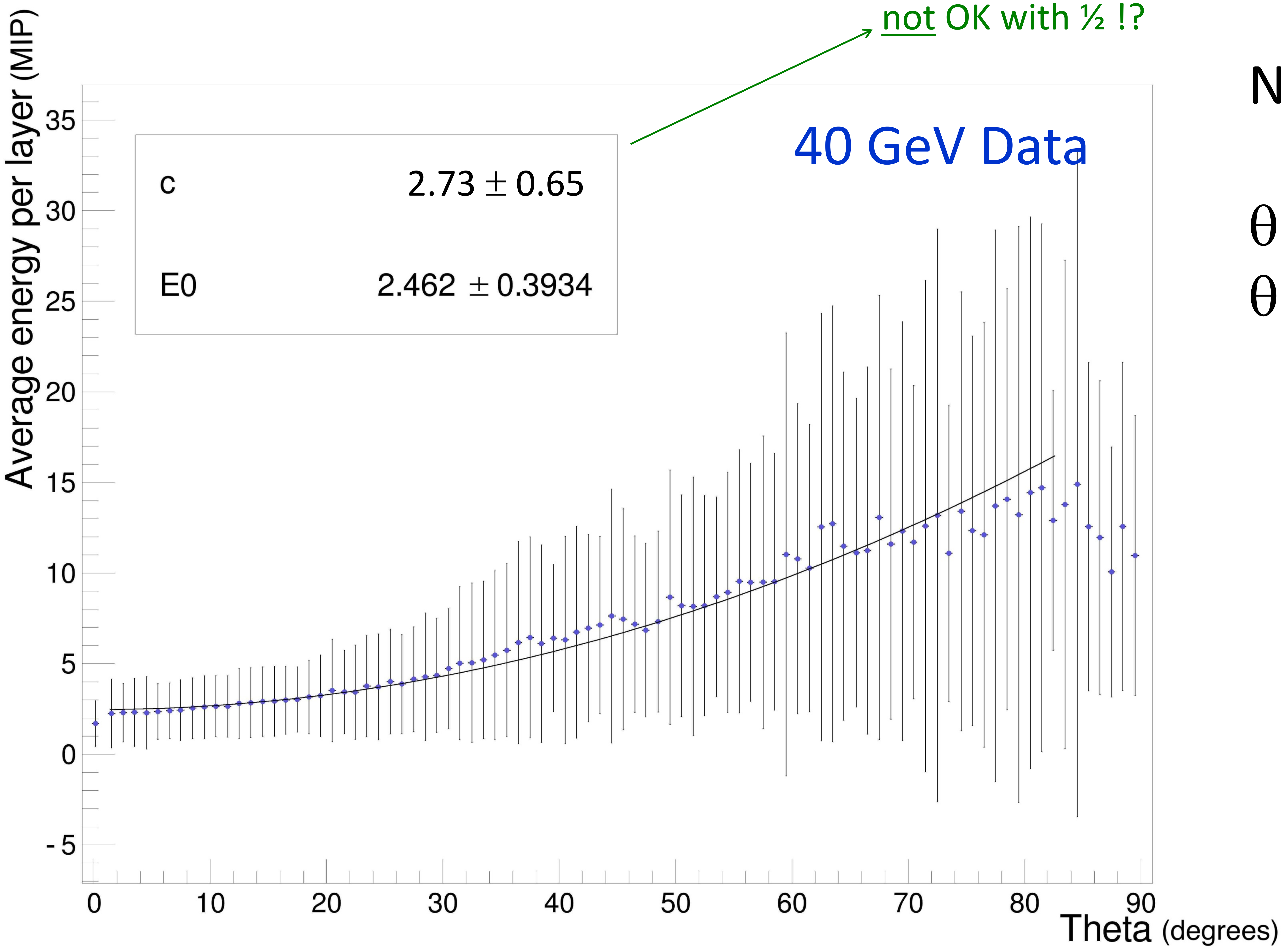
Average E_{0^o} results 10-100 GeV:

Data: 2.724 ± 0.079 MIP

MC$_{(QGSP)}$: 2.647 ± 0.077 MIP

all compatible with each other

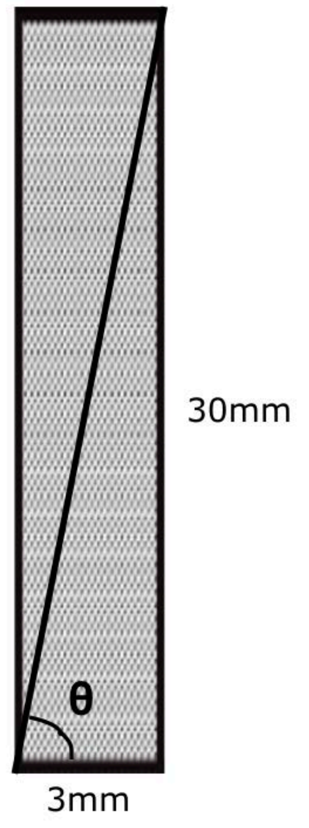
Angular Dependence for Pions



Not in the fit:

$\theta > 84°$ (cell geometry)

$\theta = 0°$ (observed residual primary contamination)



Average E_{0^o} results 10-200 GeV:

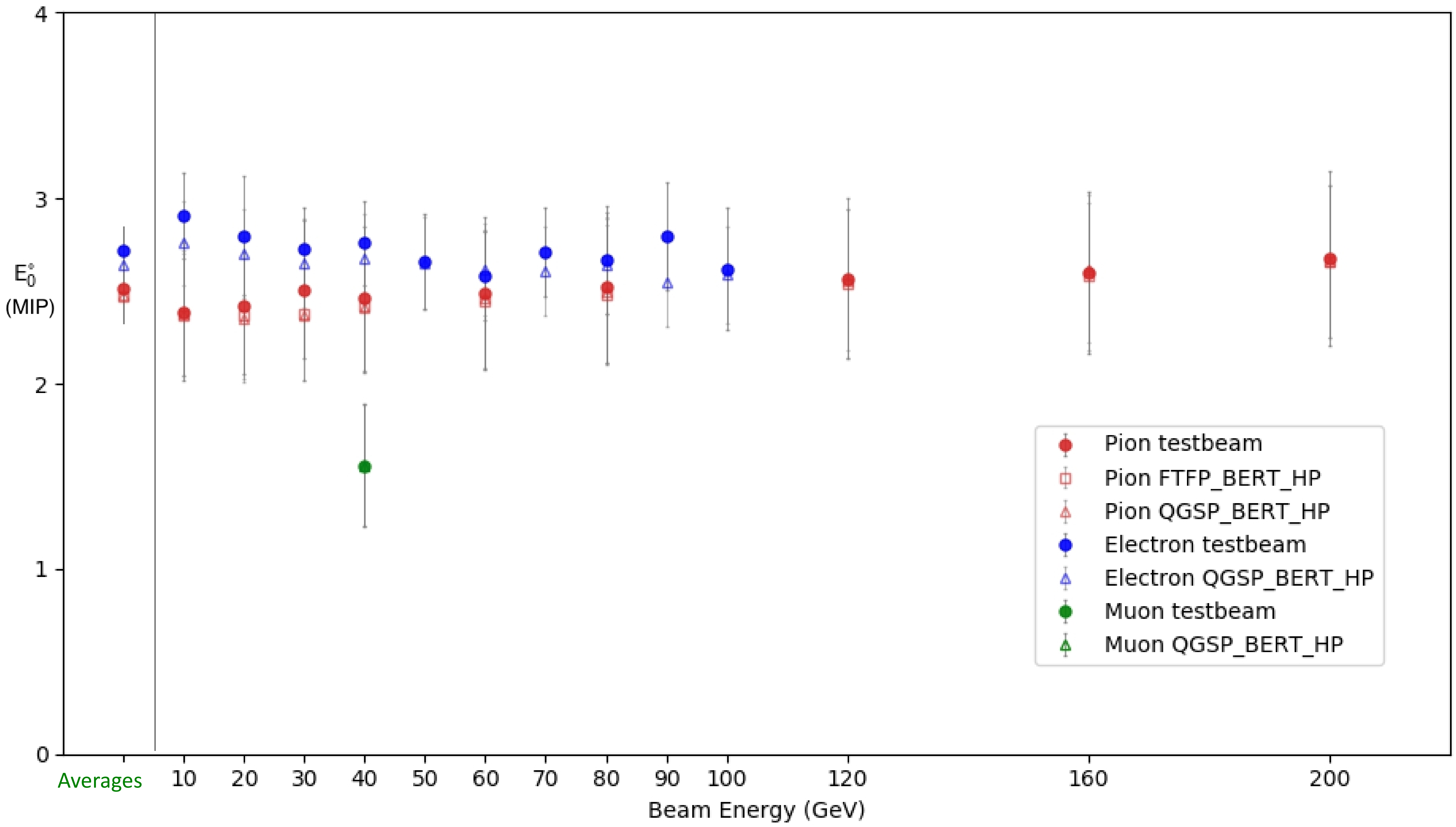
Data: 2.509 ± 0.135 MIP

MC(QGSP): 2.472 ± 0.117 MIP

MC(FTFP): 2.466 ± 0.117 MIP

all compatible with each other

Summary of E_{0^o} Results



Open Questions & Systematics

All results are preliminary. Open questions (to be investigated) remain for segments:

1) Muon rate discrepancy Data/MC: attributed to double events or broken clusters.

2) Angle θ dependence for pions: the "c" factor is ~5 times too large, which however does not affect the extrapolated values (same for Data and MC).

3) Muon numbers lower: lack of time to be studied but offered for comparison.

4) Values are θ=0 are systematically lower: related to muon beam contamination?

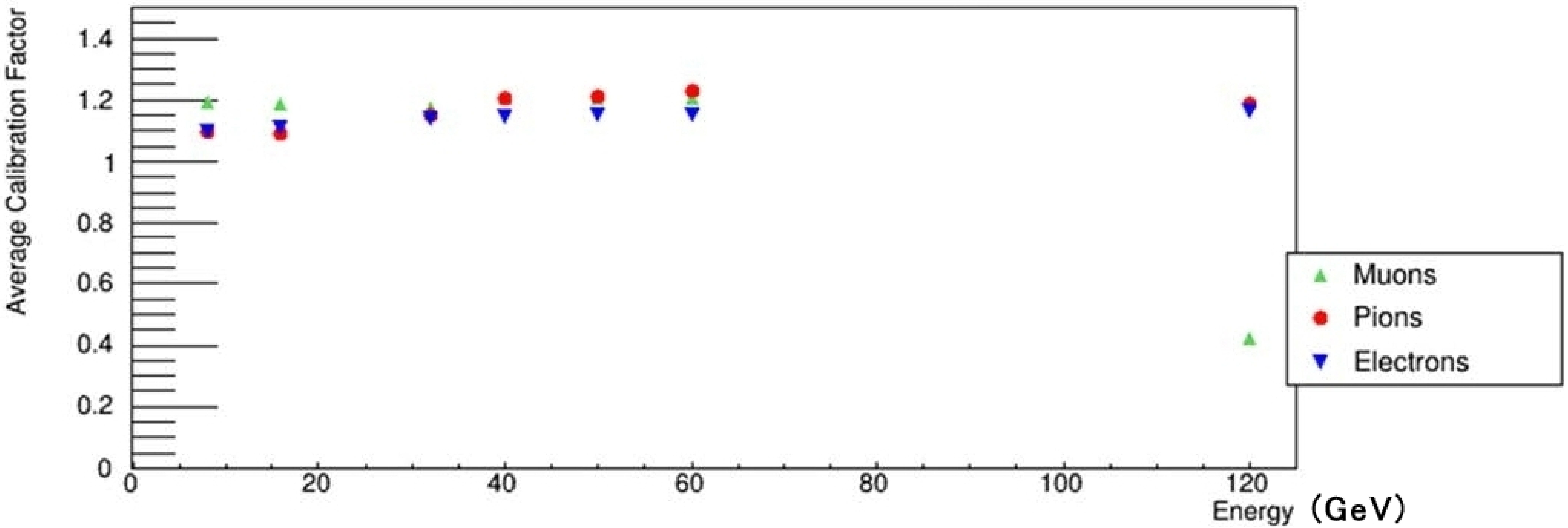
The following systematic errors for E_{0^o} have been estimated: (1), (4) and beam energy dependence, yielding:

Electrons:	$2.73 \pm 0.08 \pm 0.09$ MIP
Pions:	$2.50 \pm 0.13 \pm 0.05$ MIP

some discrepancy electrons-pions

DHCAL

A very similar study has been performed with DHCAL and presented at the 2018 CALICE Collaboration Meeting in Mainz: (see extra slide for other previous CALICE studies)



AHCAL

Electrons:	$2.73 \pm 0.08 \pm 0.09$ MIP
Pions:	$2.50 \pm 0.13 \pm 0.05$ MIP

DHCAL

Electrons:	$1.14 \pm 0.01 \pm ?$ arbitrary units
Pions:	$1.17 \pm 0.03 \pm ?$ arbitrary units

Summary and Outlook

The possibility of using secondary track segments for *in situ* calibration in a detector has been investigated with AHCAL.

The potential is there but some effect have still to be understood and the statistics required for absolute single channel calibration may be overwhelming. Looking at single cells is the next step.

Still, given a stable and reliable trigger in a detector, a constant self-monitoring of the data relative calibration at the few-% level should be attainable.

Extra

CALICE and Track Segments

Track Segment Calibrations

AHCAL

Track segments in hadronic showers in a highly granular scintillator-steel hadron calorimeter (CALICE)
arXiv:1305.7027 [physics.ins-det] 29 Jul 2013

Calibration Studies and the Investigation of Track Segments within Showers with an Imaging Hadronic Calorimeter (Shaojun Lu for CALICE)
arXiv:0910.3820 [physics.ins-det] 20 Oct 2009
use most probable value of energy loss for high quality tracks

Track Segments in Hadronic Showers: Calibration Possibilities for a Highly Granular HCAL (Frank Simon for CALICE)
arXiv:0902.1879 [physics.ins-det] 11 Feb 2009
cell by cell calibration foreseen, but high statistics required

SDHCAL

Tracking within Hadronic Showers in the CALICE SDHCAL prototype using a Hough Transform Technique (CALICE)
arXiv:1702.08082 [physics.ins-det] 8 May 2017
Hough Transform adapted to shower properties

DHCAL

The CALICE digital hadron calorimeter: calibration and response to pions and positrons (Burak Bilki for CALICE)
CALOR 2014: Journal of Physics: Conference Series 587 (2015) 012038
method described in paper, seeded by 4-layer searches

F.Corriveau *IPP/McGill University* – DHCAL Calibration Status Report – 2018.03.08 – CALICE Week Mainz

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