R&D for the DUNE ND ECAL

- Status at MPP -

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showing work together with **Lorenz Emberger** (MPP)

DUNE Near Detector Workshop, CERN, November 2017

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Scope & Disclaimer

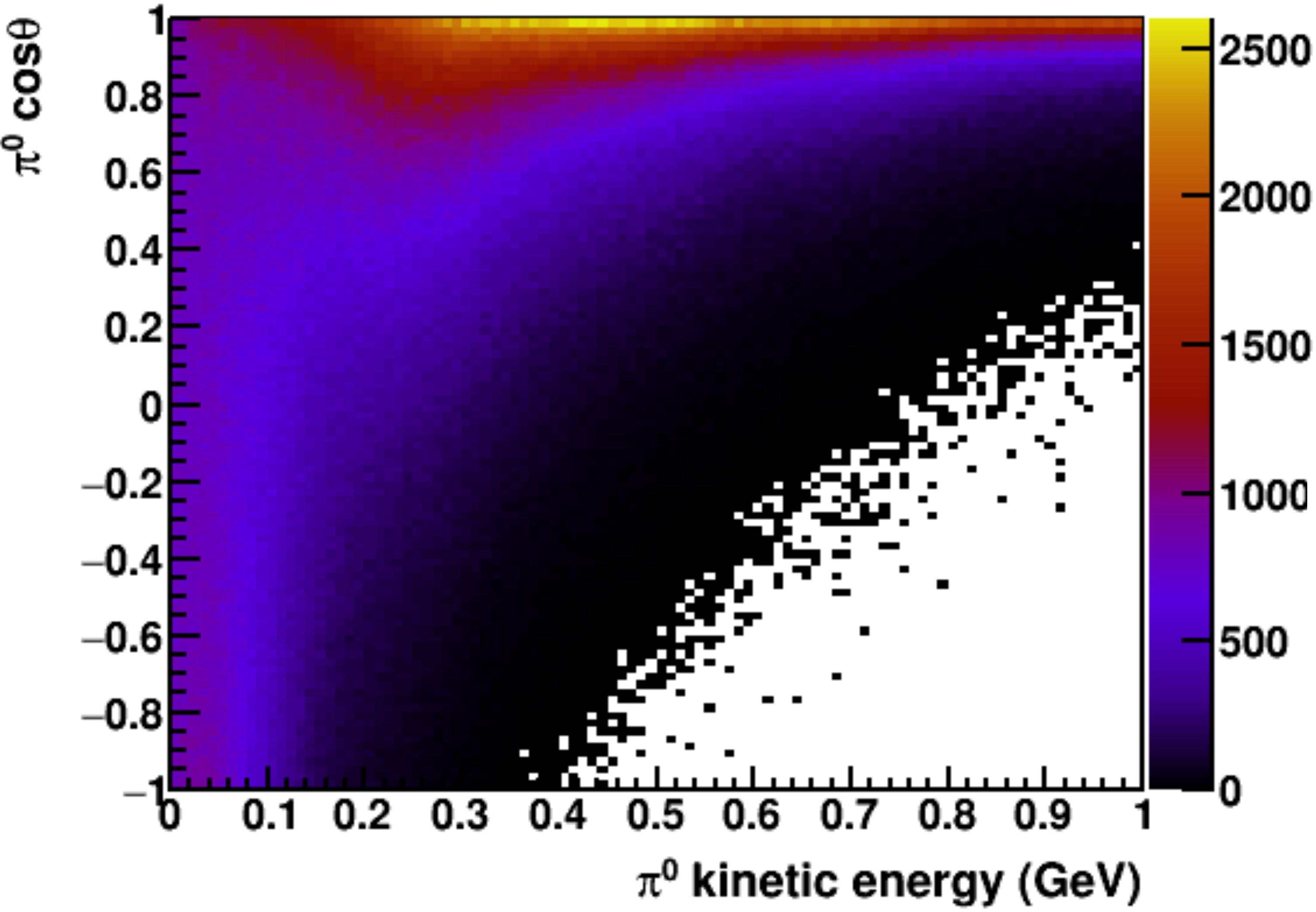
- Have started a first simulation study at MPP - at the moment one MSc student
- As a first step: Study possible benefits of granularity
- New addition since August: Different absorber materials, different readout granularity
  - Not yet realistic - no digitization, noise, etc included

- In parallel some first hardware studies are beginning - building on overlap with CALICE activities at MPP

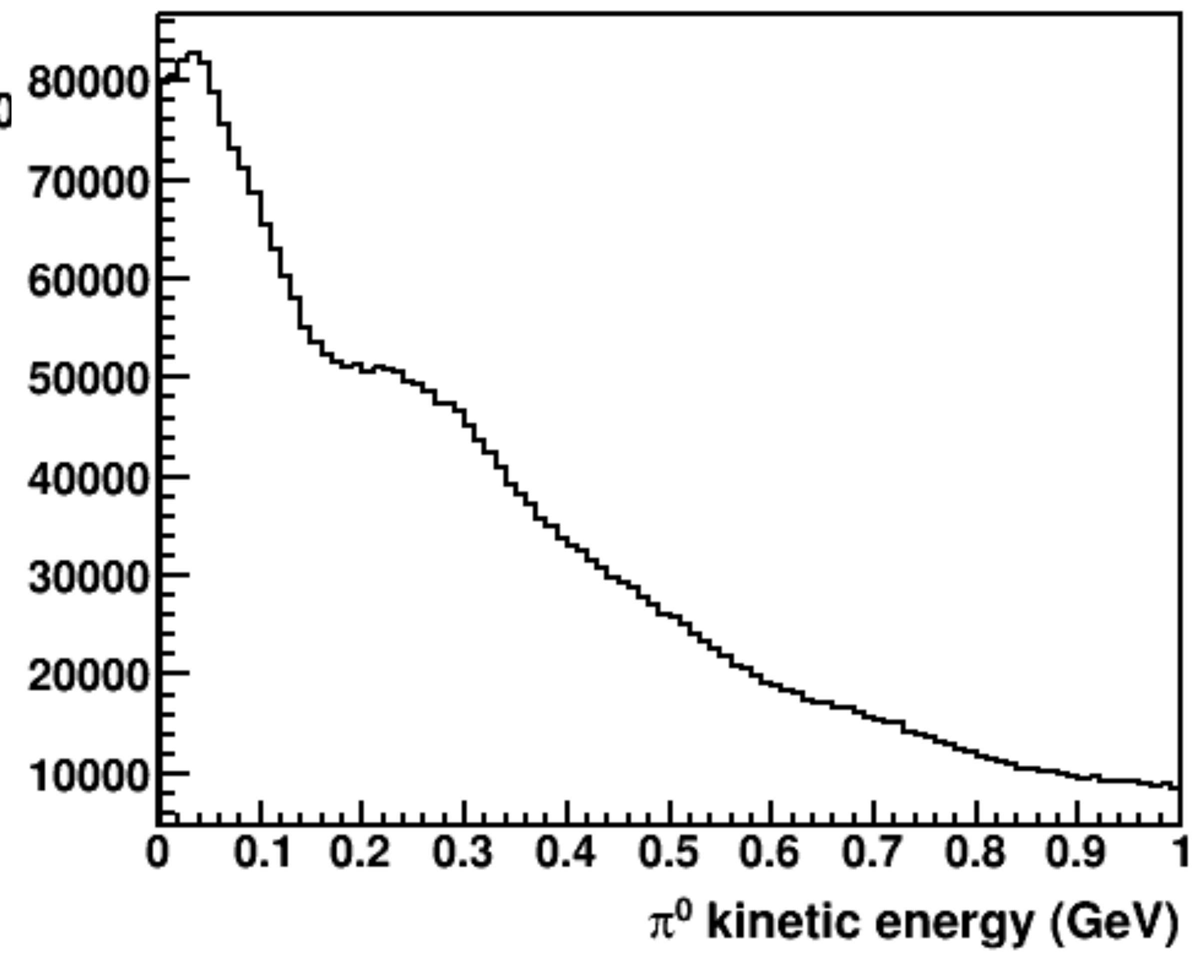
Hope to get feedback on where to take this study!

Setting the Stage: Neutral Pions in the ND

- One of the primary goal of the ND ECAL is the measurement of neutral pions in ν interactions



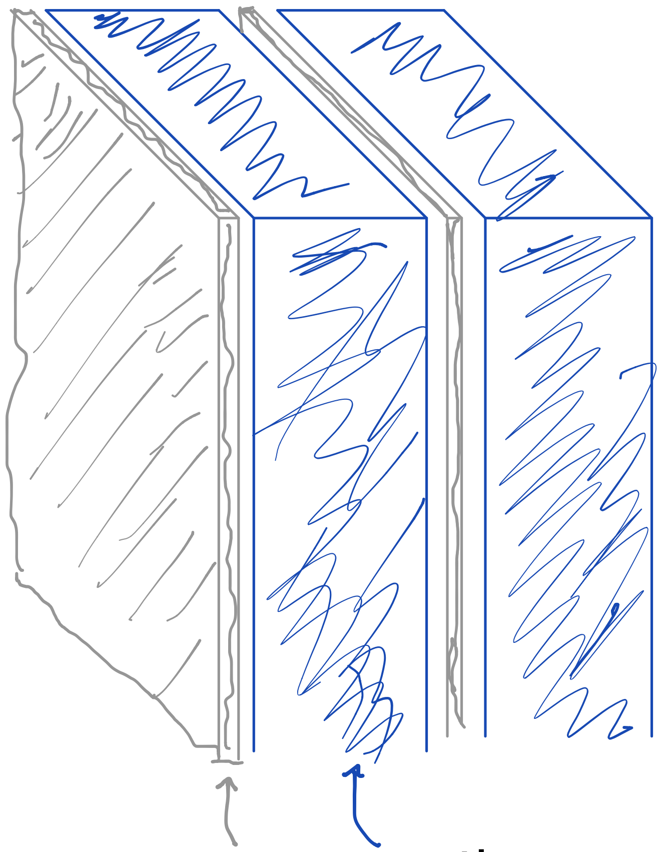
- Typical π^0 energy low - most produced essentially at rest of from resonance decays with 200 - 300 MeV
  - ➯ Need to reconstruct few 100 MeV γ



plots curtesy of Chris Marshall

Preliminary, rough Detector Concept

- Sampling structure roughly based on CDR geometry:
  1 cm plastic scintillator between absorber plates



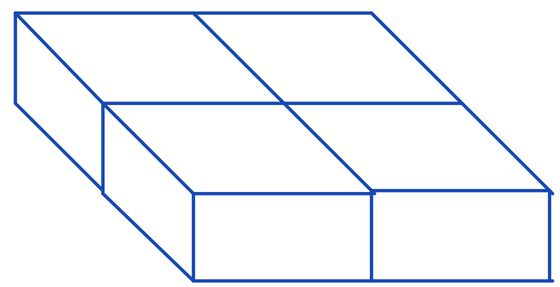
absorber

active:
10 mm
plastic scint.

Absorber scenarios:
CDR: 1.75 mm Pb
also studied: 1 mm Pb, 2 mm Cu

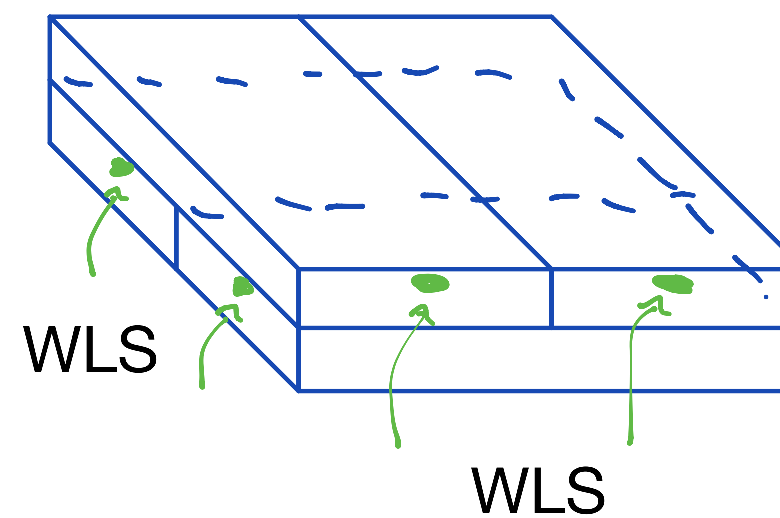
2D segmentation of active layer

idealized (and currently simulated)



possibly ***more realistic:***

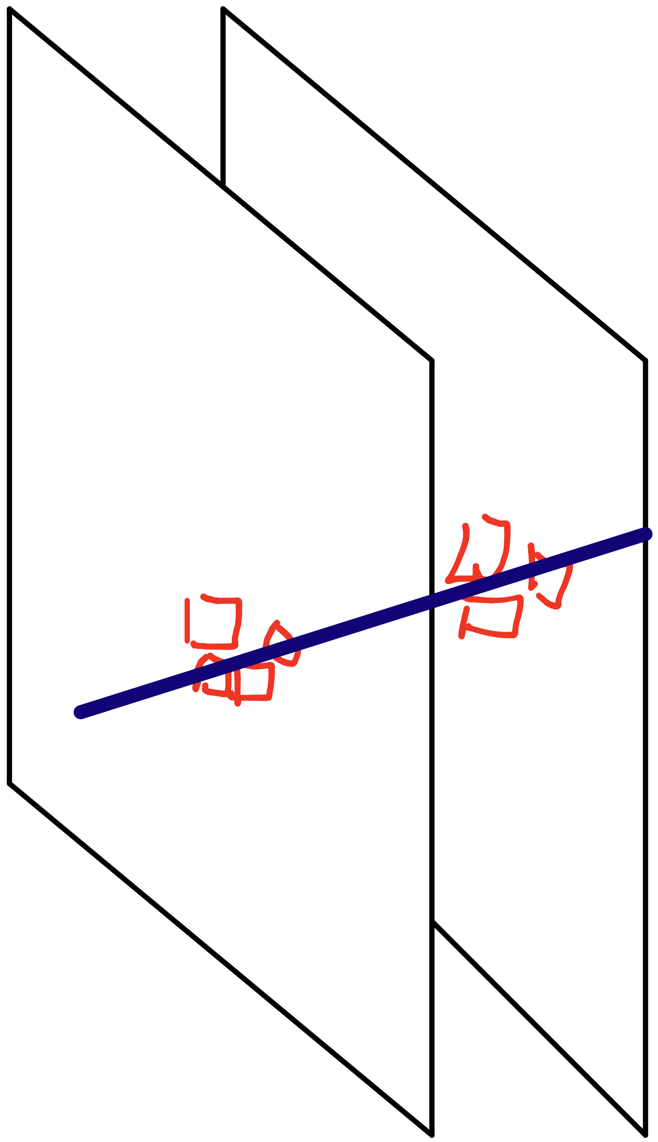
Orthogonal crossed strips, with embedded WLS for light collection, SiPM readout on both ends, strip segmentation potentially with “megatile” solution



⇨ hardware R&D starting at MPP

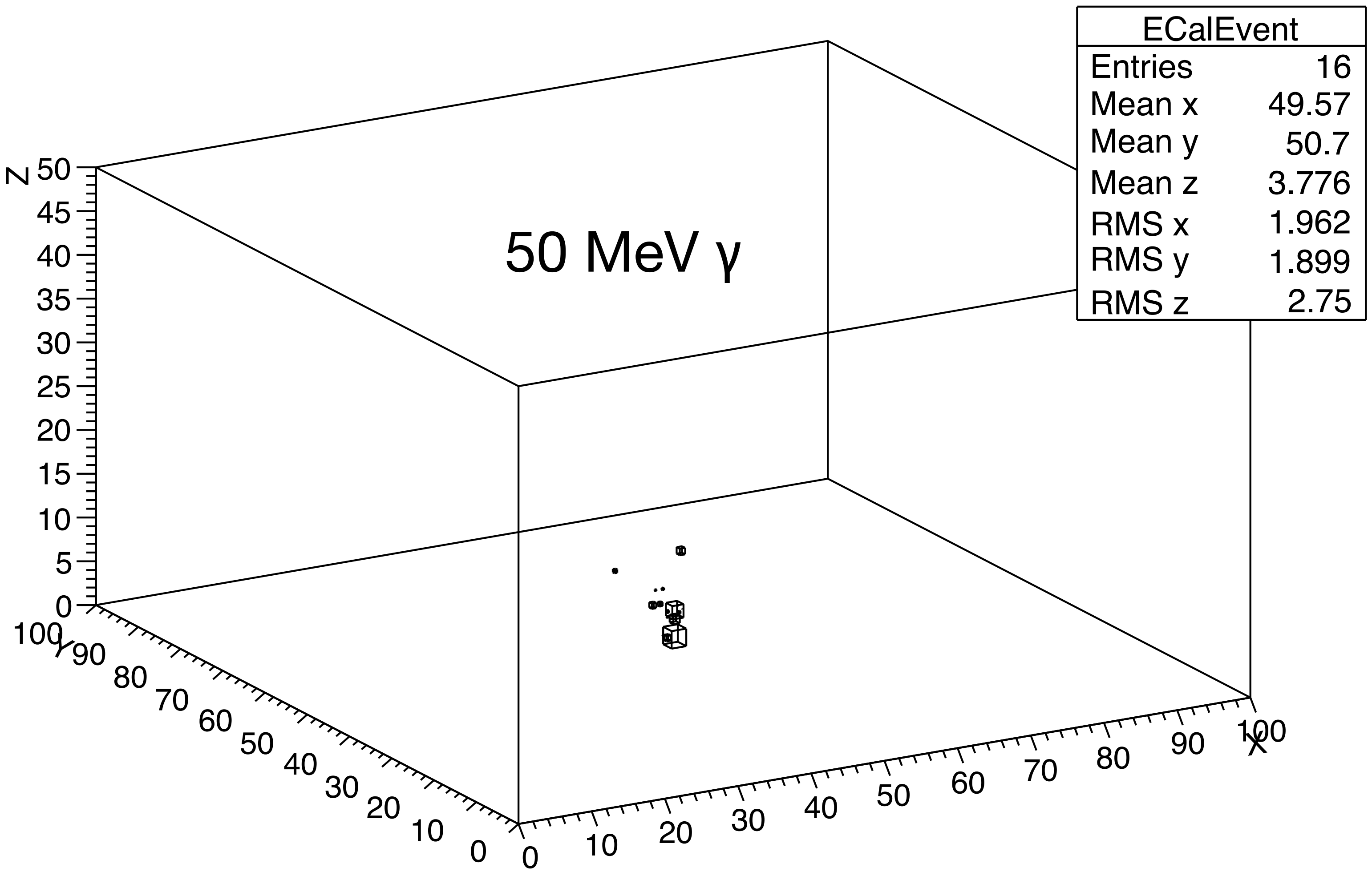
The Simulation Study

- Simulations using GEANT4 10.03
- Simple layer structure, for now one calorimeter segment
  - 50 layers, 1 x 1 m^2 - some studies also with 100 layers to reduce leakage
  - 1, 1.75 mm lead absorber, 2 mm Cu absorber per layer
  - 10 mm plastic scintillator
  - Different granularity simulated - tile sizes to fit into 1 m^2: 10 x 10, 20 x 20, 25 x 25, 40 x 40, 50 x 50 mm^2



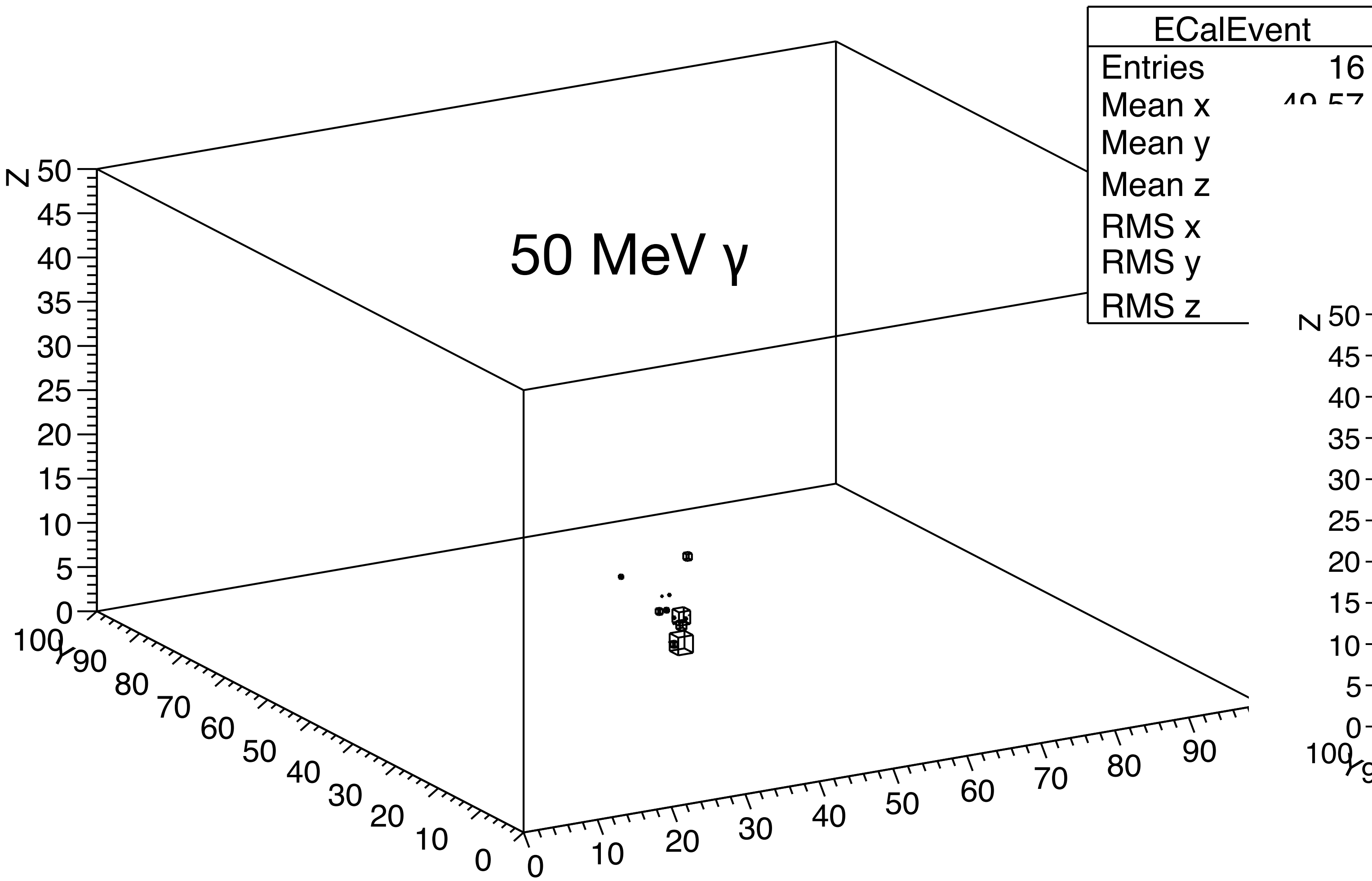
- Very simplified photon reconstruction:
  - Layer-wise formation of center-of-gravity (calculated from all cell in a layer that have some energy - not cut-off at present)
  - 3D Straight-line fit through COGs (weighted by energy deposit) to get "photon vector"
    - For π^0 event reconstruction: Using MC truth information to assign calorimeter cells to photons

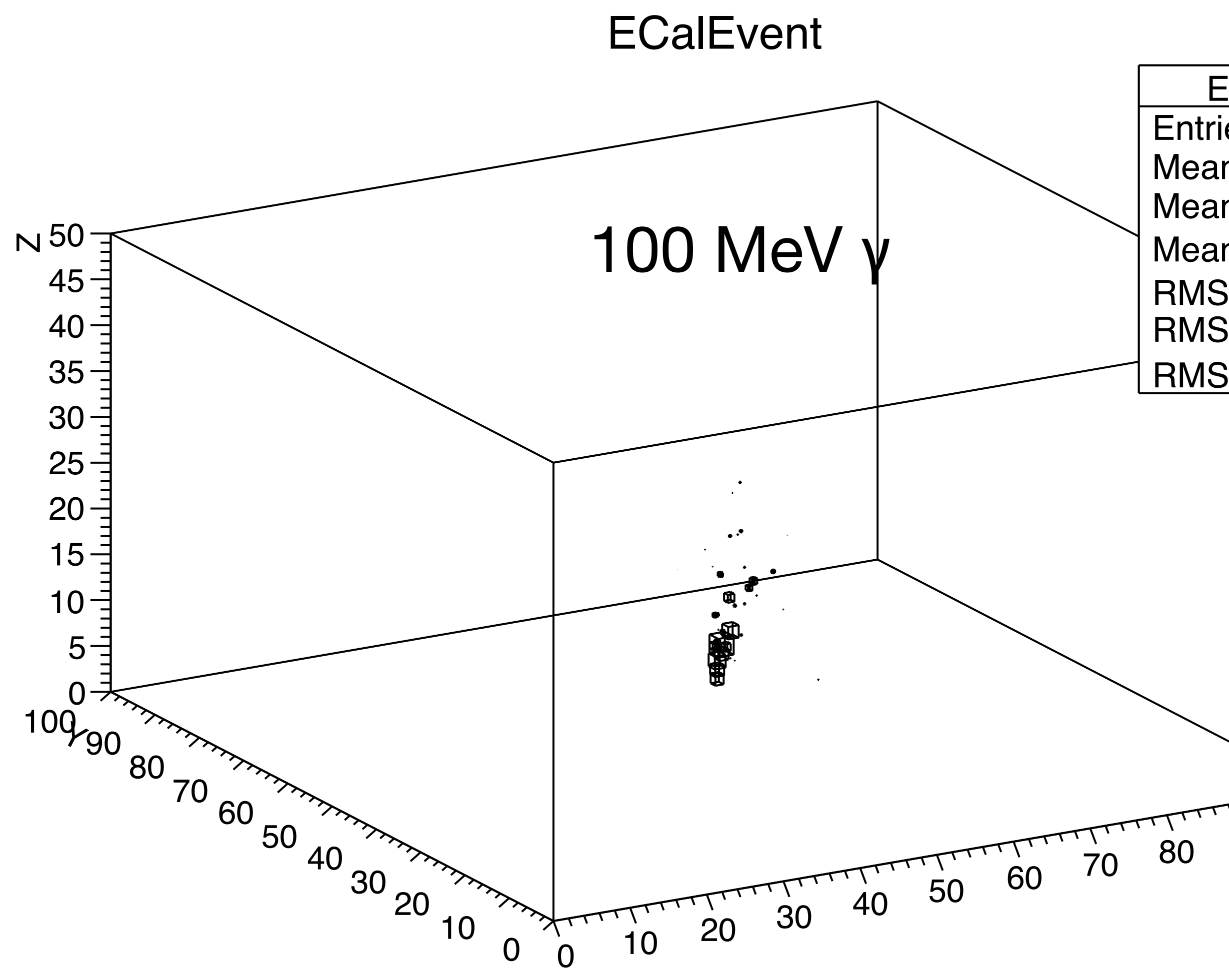
Simulations: Single γ Events



1.75 mm Pb absorber

Simulations: Single γ Events





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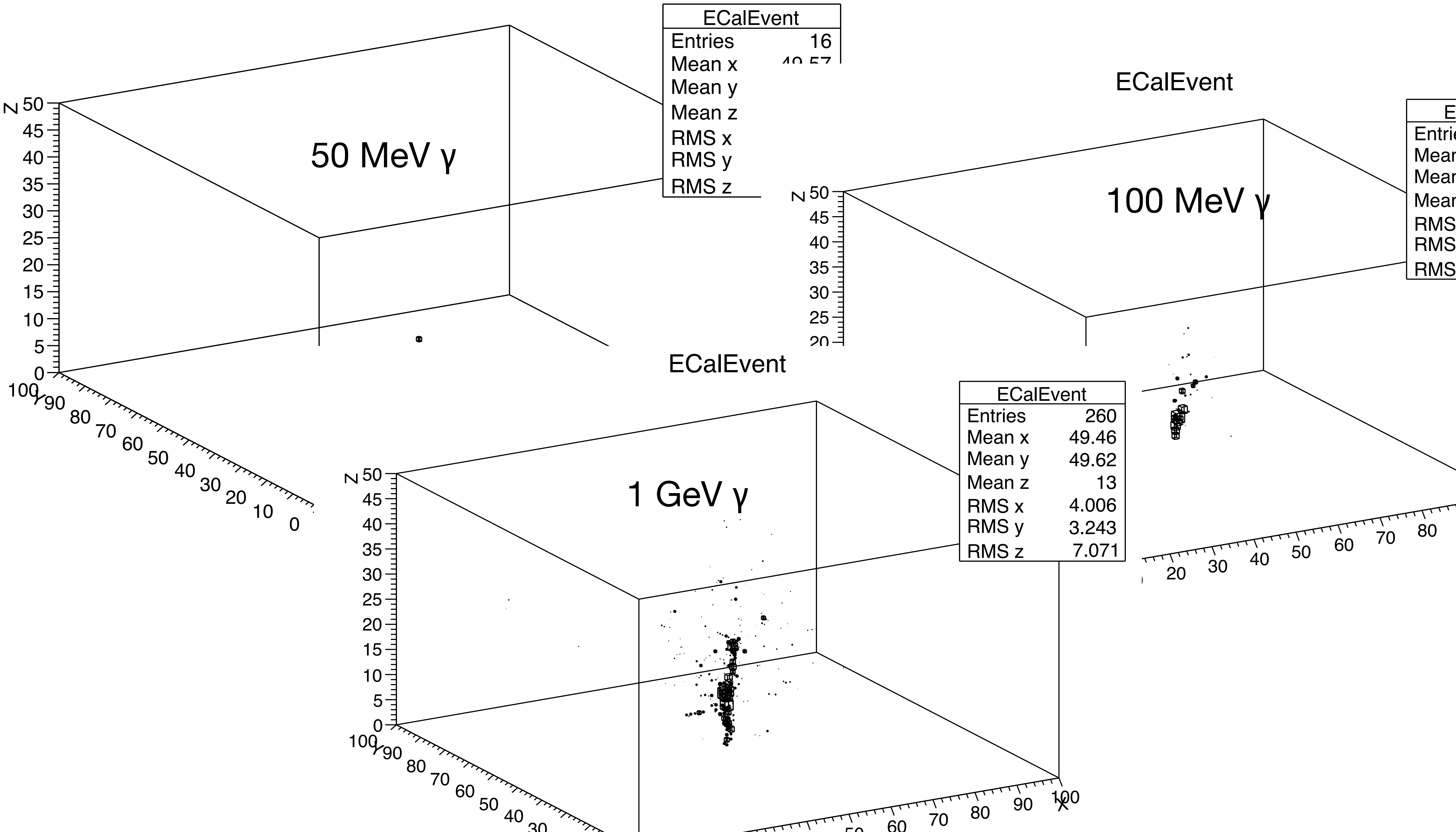

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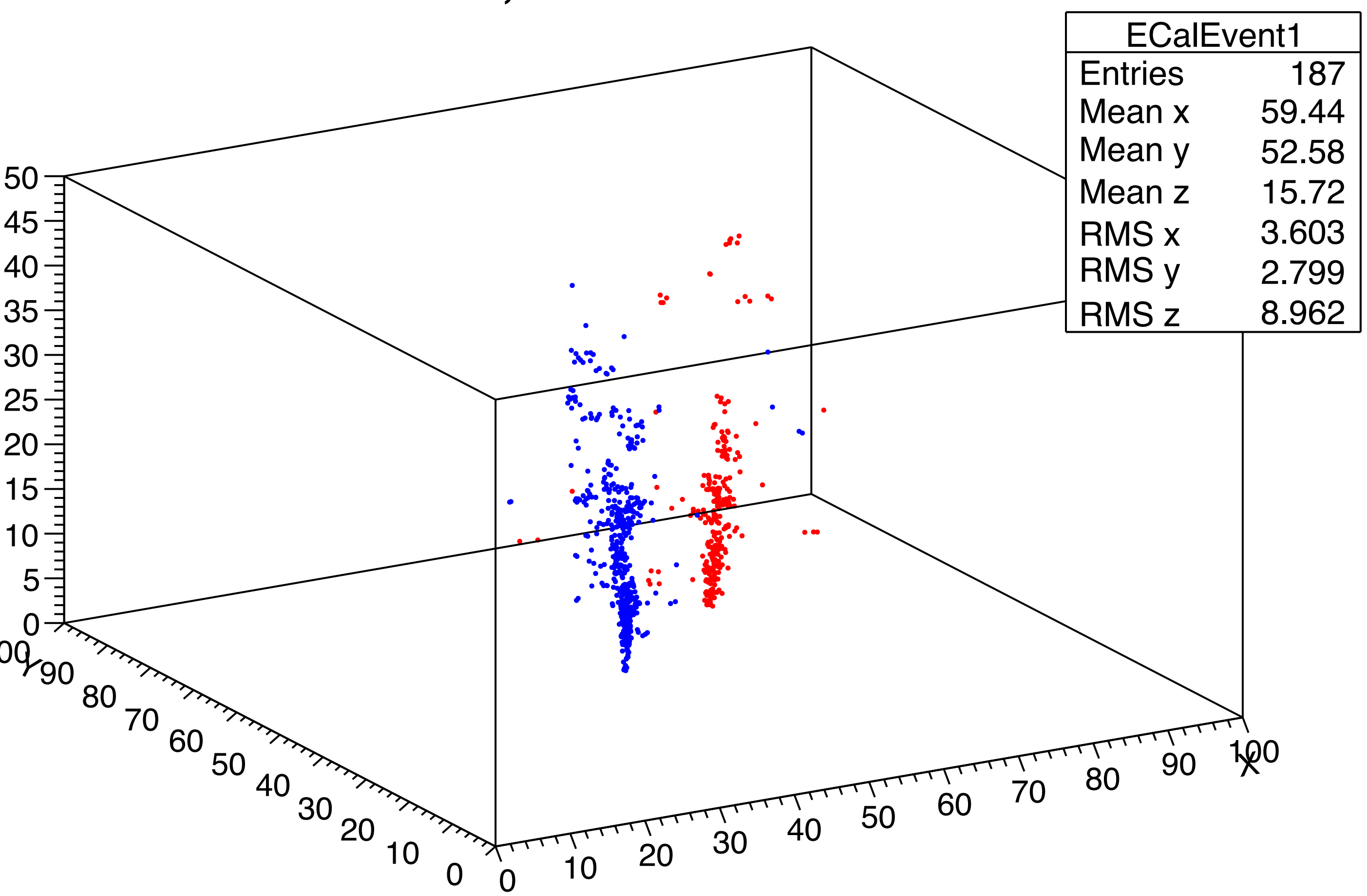
Simulations: Single π^0 Events

2 GeV π^0, 1 m from calo



- Deposits by the two photons separated using truth information in GEANT4 (propagating parent photon info through tracking)

photon 1

photon 2

1.75 mm Pb absorber

Simulations: Single π^0 Events

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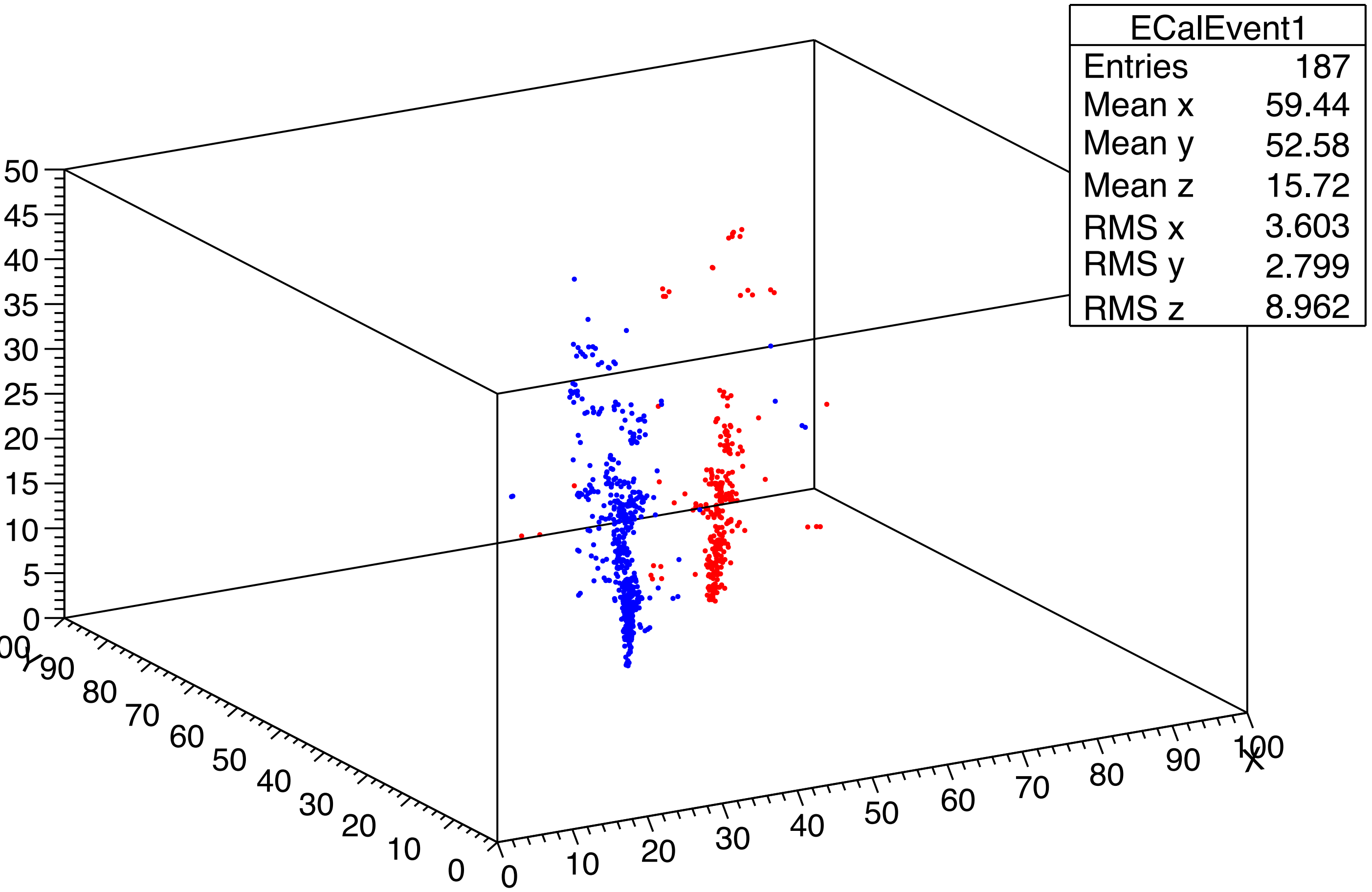

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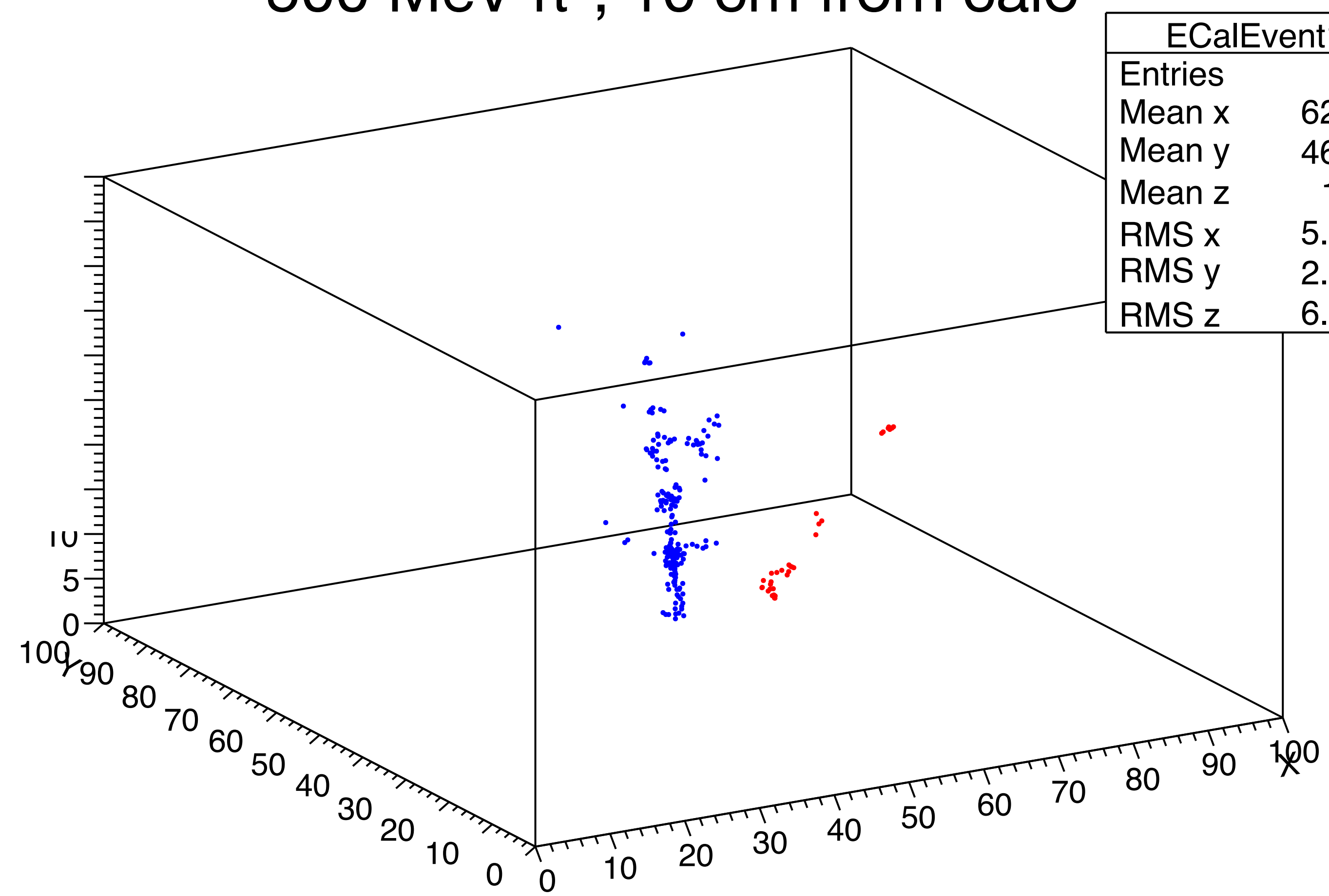
500 MeV π^0, 10 cm from calo



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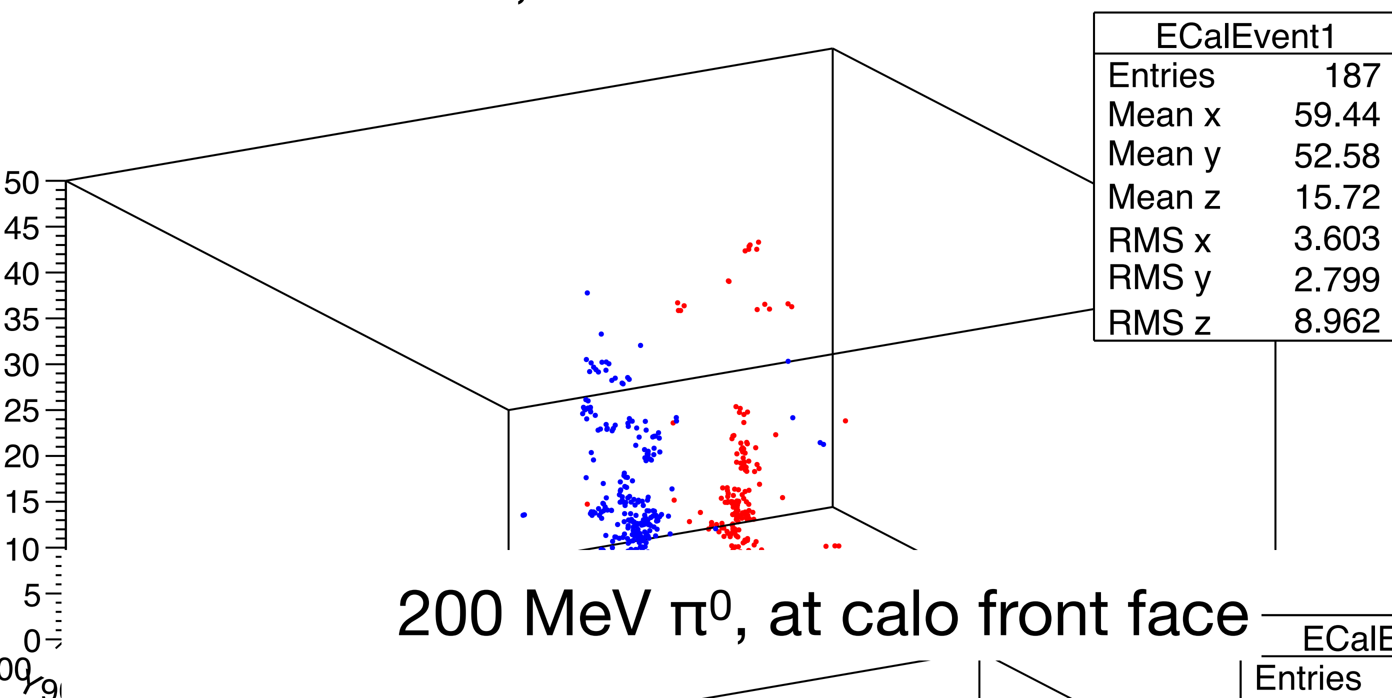
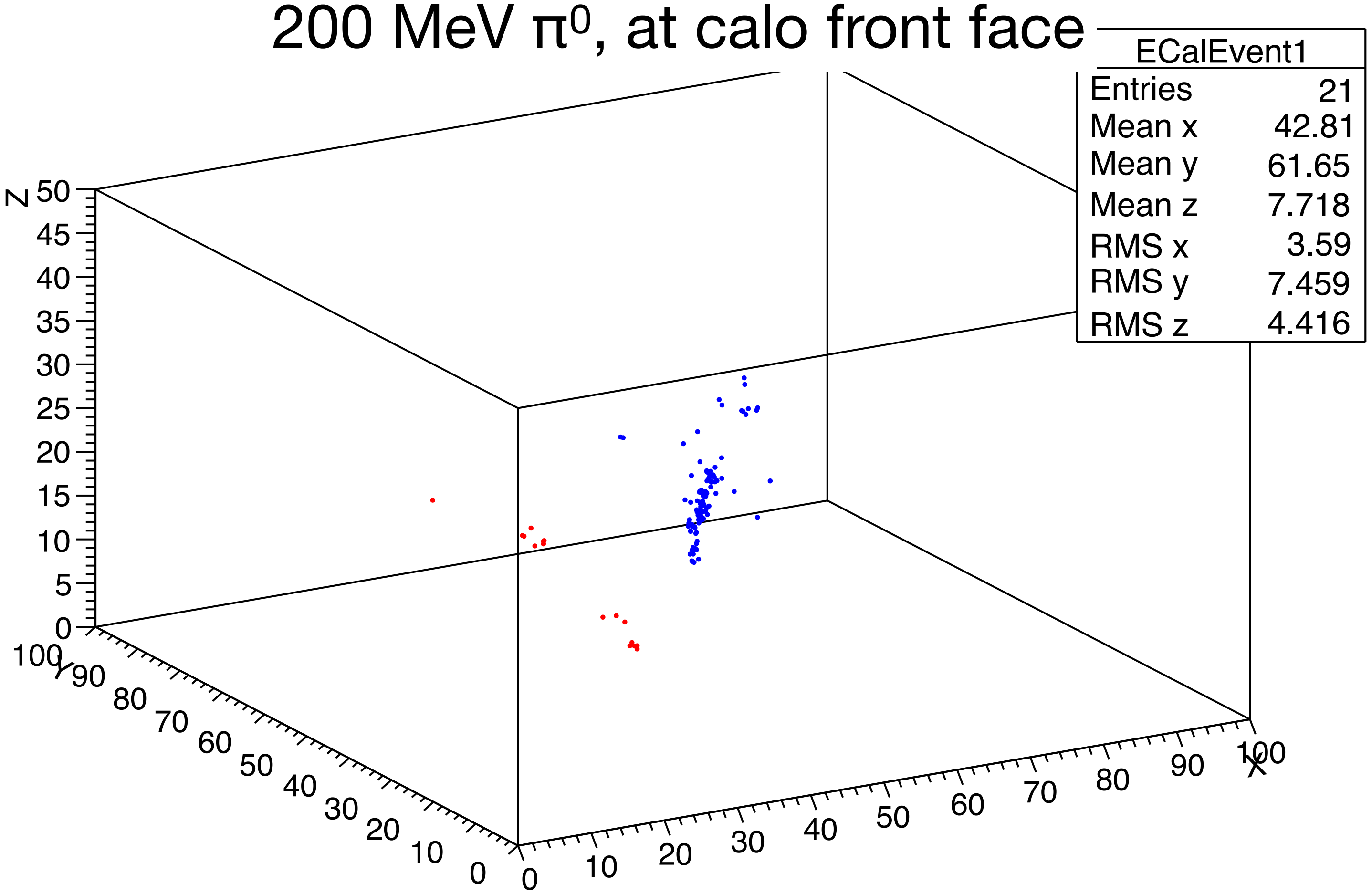


200 MeV π^0, at calo front face



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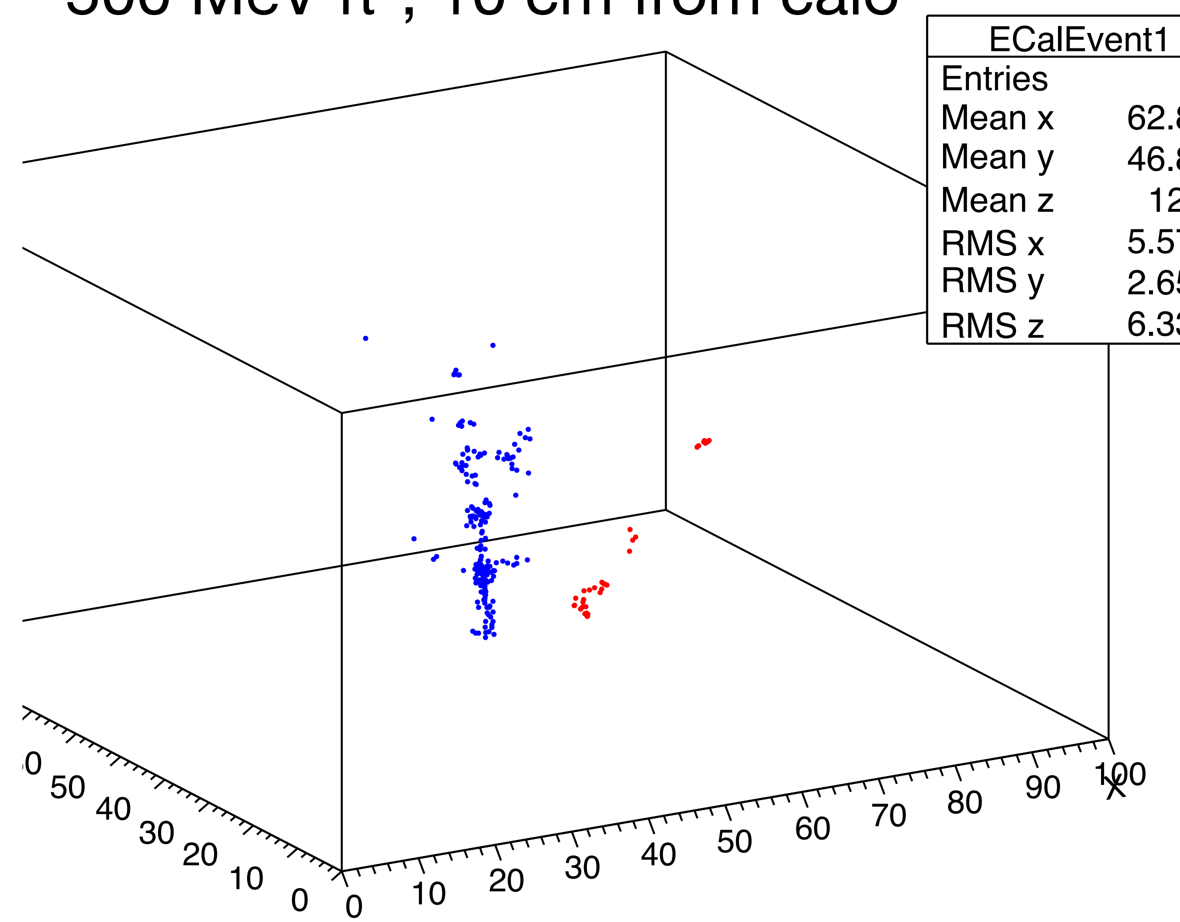


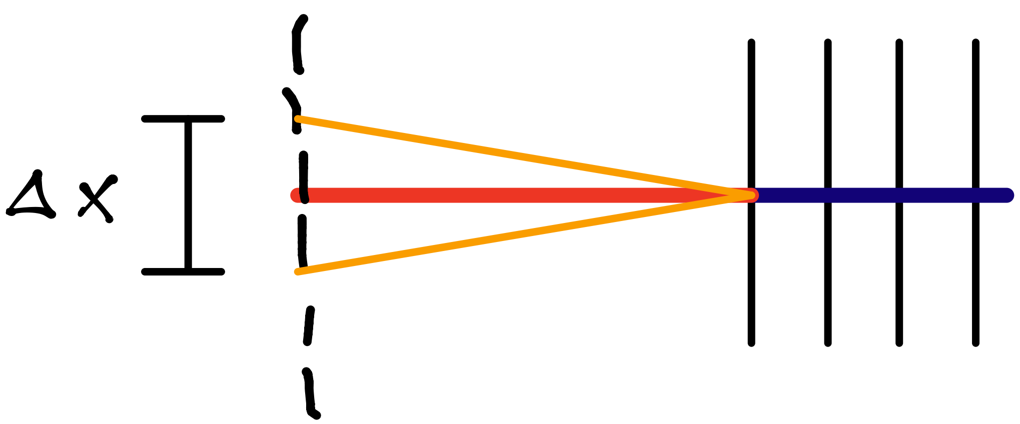
photon 1

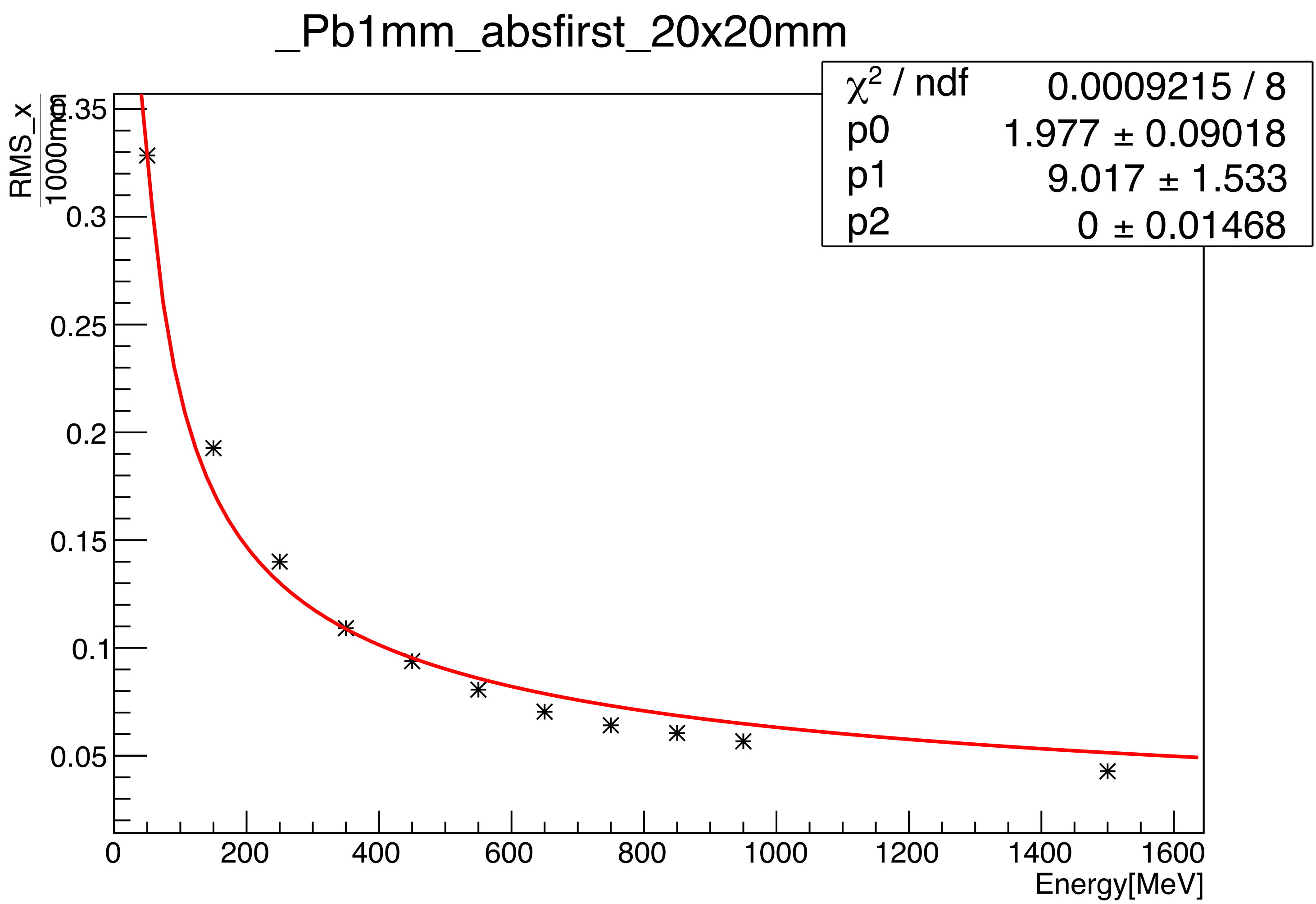
photon 2

1.75 mm Pb absorber

Figure of Merit: Angular Resolution

- Extrapolating the reconstructed photon direction (3D line fit) to a plane 1 m from the the calorimeter front face
- Resolution given as the RMS of the deviation from the true position divided by true distance along photon direction

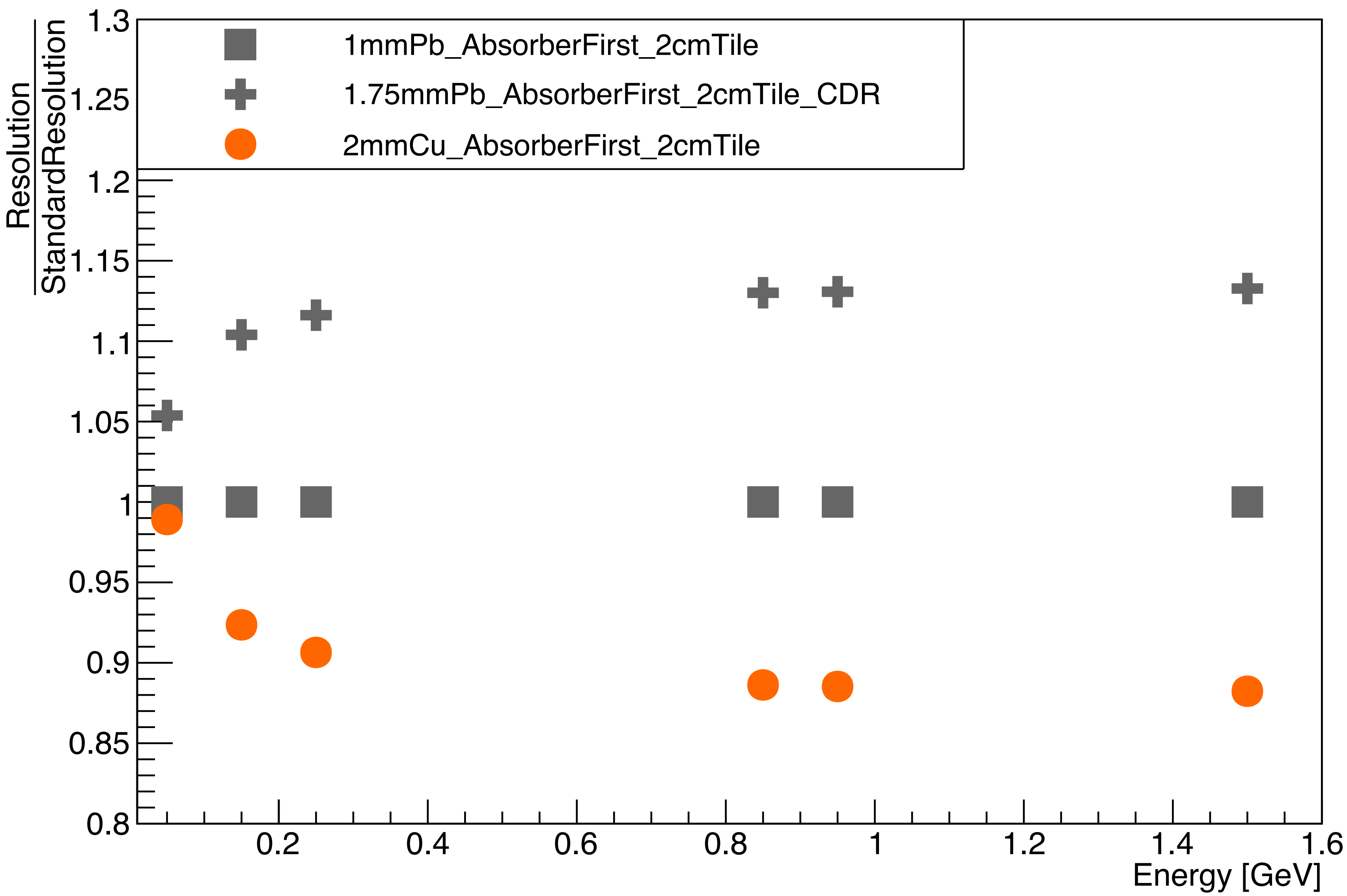




Comparing Different Geometries: Absorber Type

- Baseline: 1 mm Pb, cell size 20 x 20 mm^2

Effect of Absorber material and thickness



Thinner absorbers (in units of X_0) results in better resolution - no surprise!

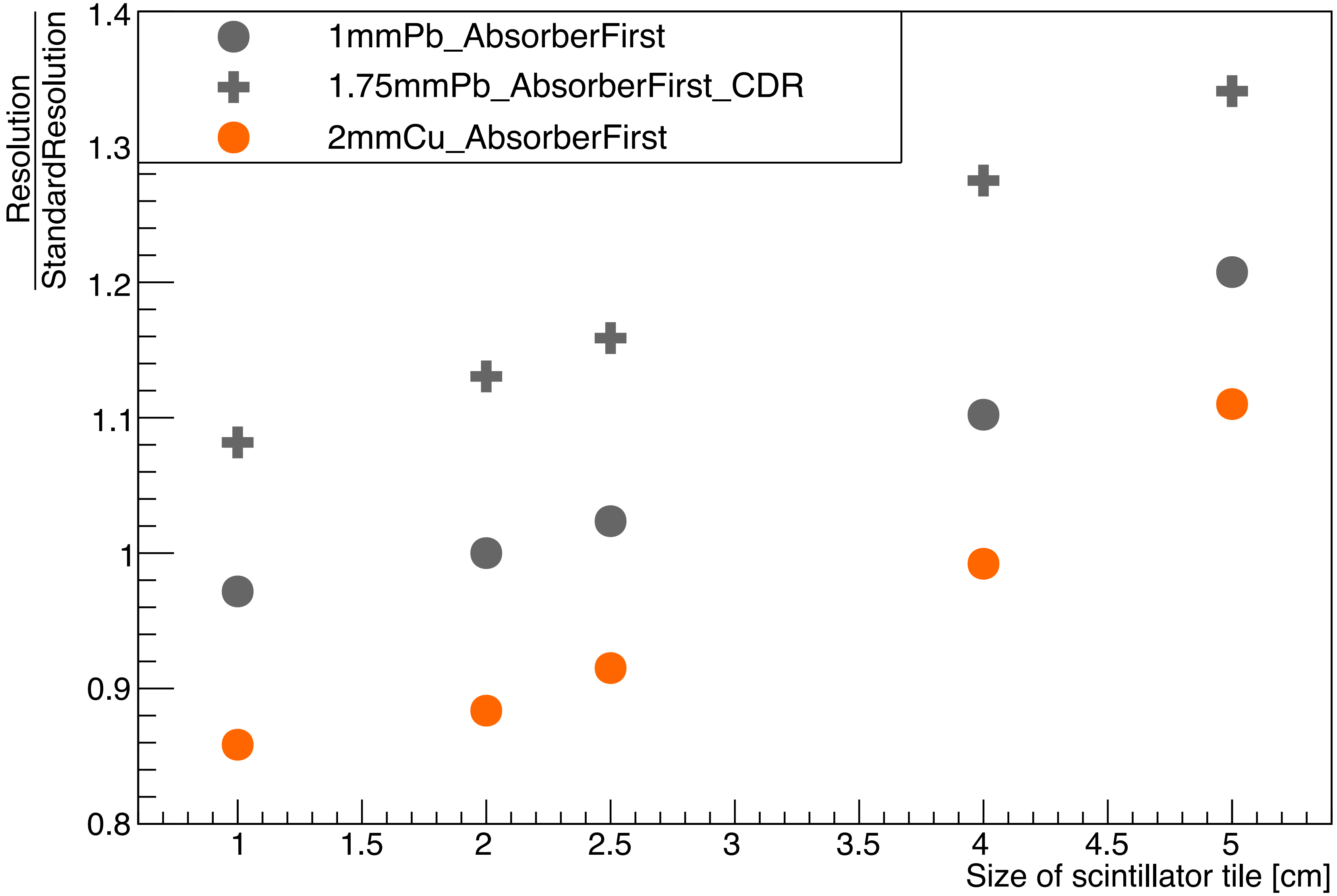
Advantage Cu:
probably a geometrical effect - comparable absorber X_0 in for both materials, 10% larger “lever arm” with Cu

Comparing Different Geometries: Granularity

- Baseline: 1 mm Pb, cell size 20 x 20 mm^2

Effect of detector granularity

- N.B.: No digitization, no thresholds, no noise in current simulation

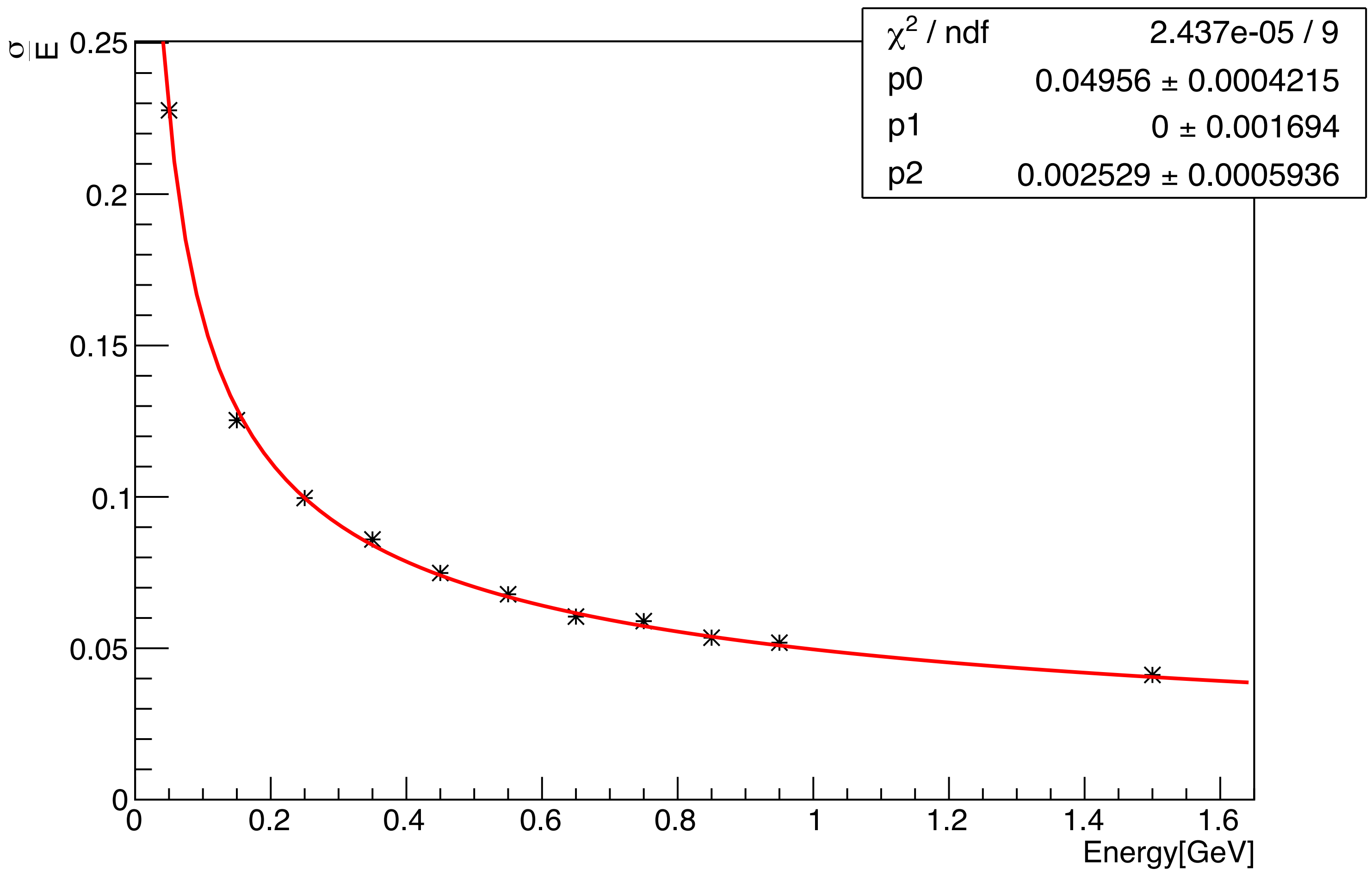


Higher granularity better - with thin absorbers indications of saturation when going below 2 cm edge length

Advantage Cu:
probably a geometrical effect - comparable absorber X_0 in for both materials, 10% larger “lever arm” with Cu

Comparing Different Geometries: Energy Resolution

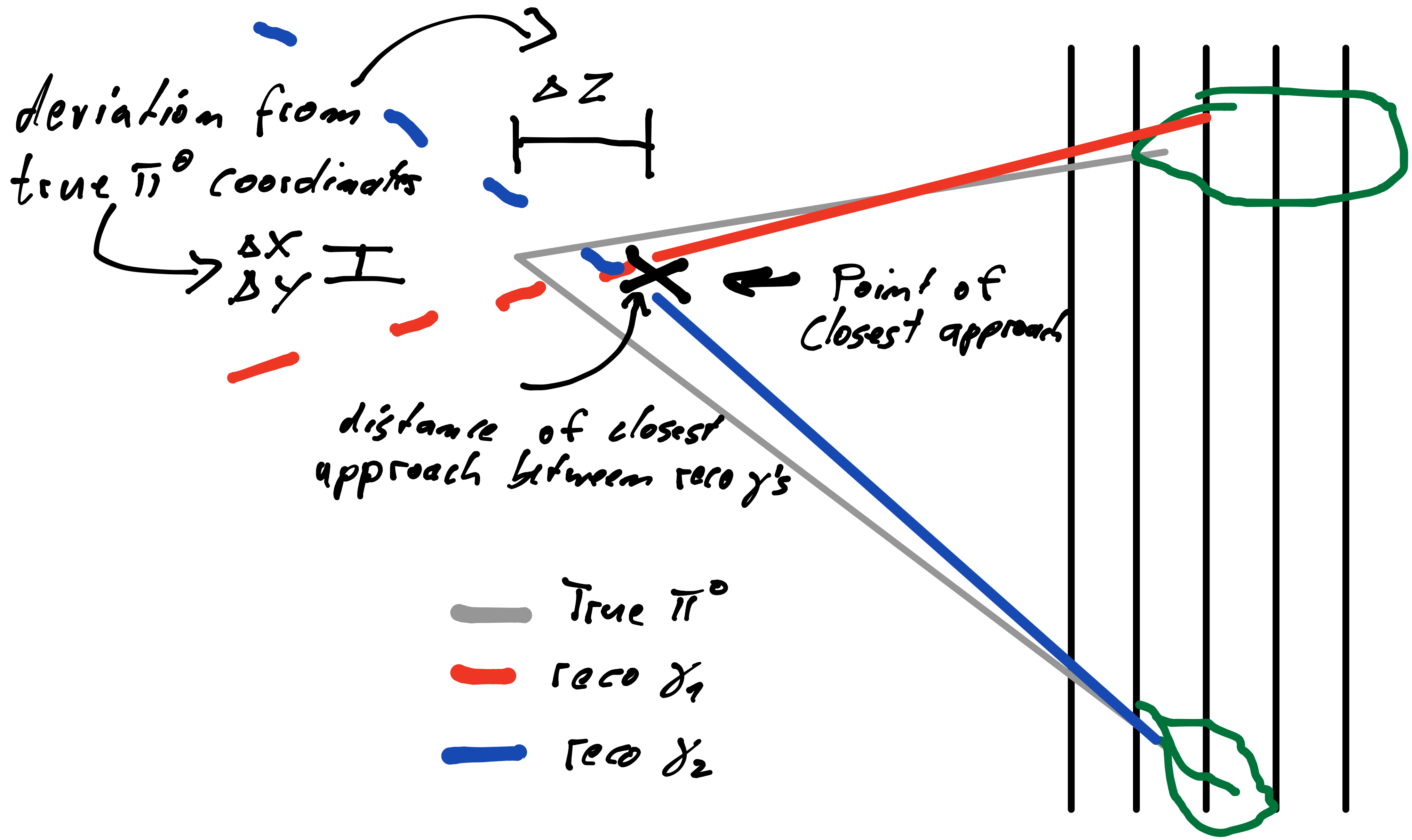
- A first look at the raw energy resolution - based on energy deposited in scintillator, ignoring any form of detector effects
  - Realistic resolutions probably ~ x2 worse
  - Here: 100 layers deep calorimeter to ensure containment



- CDR geometry:
  ~ 5% stochastic term
- 1 mm Pb absorbers
  ~ 3.3% stochastic term
- 2 mm Cu absorbers
  ~3.6% stochastic term

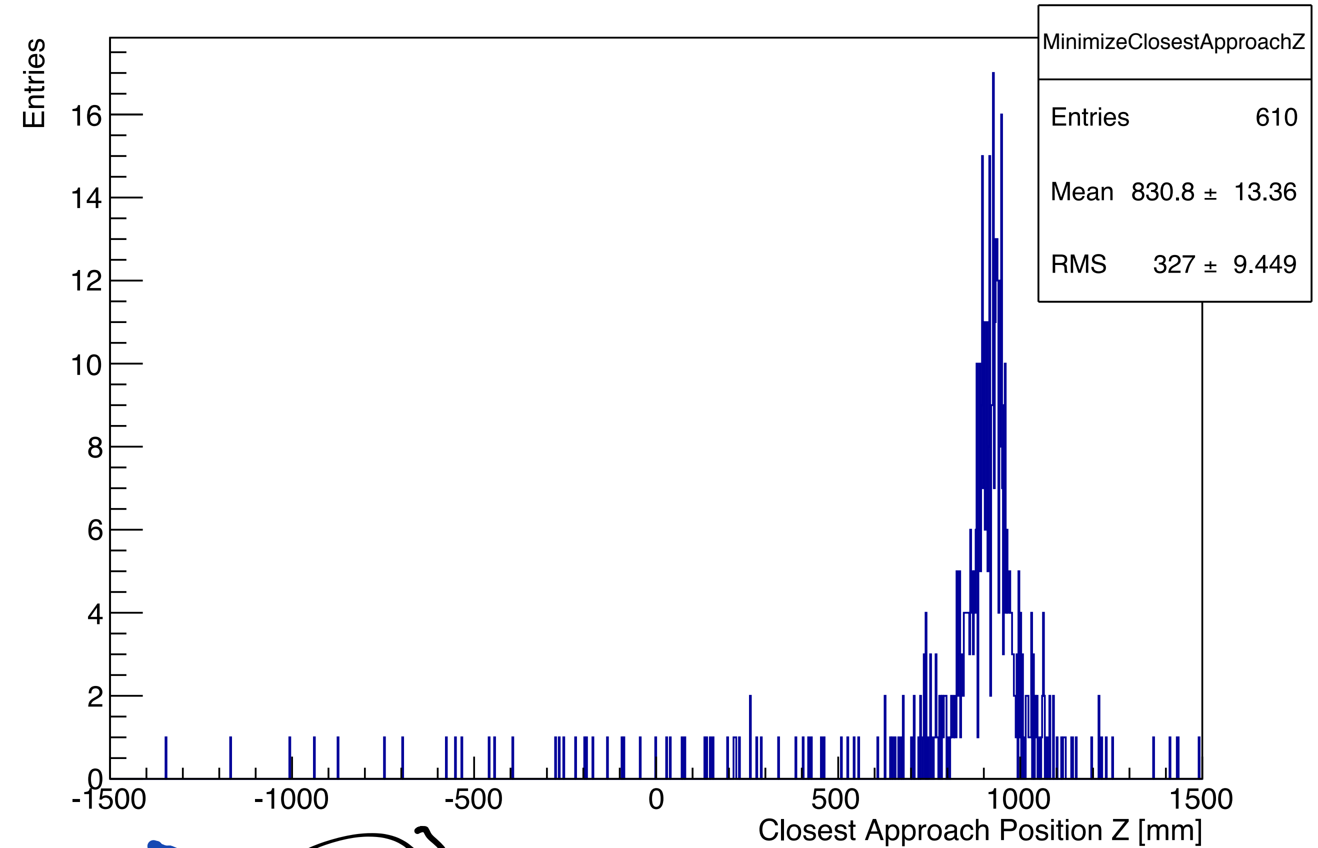
First Poor Man's Neutral Pion Reconstruction

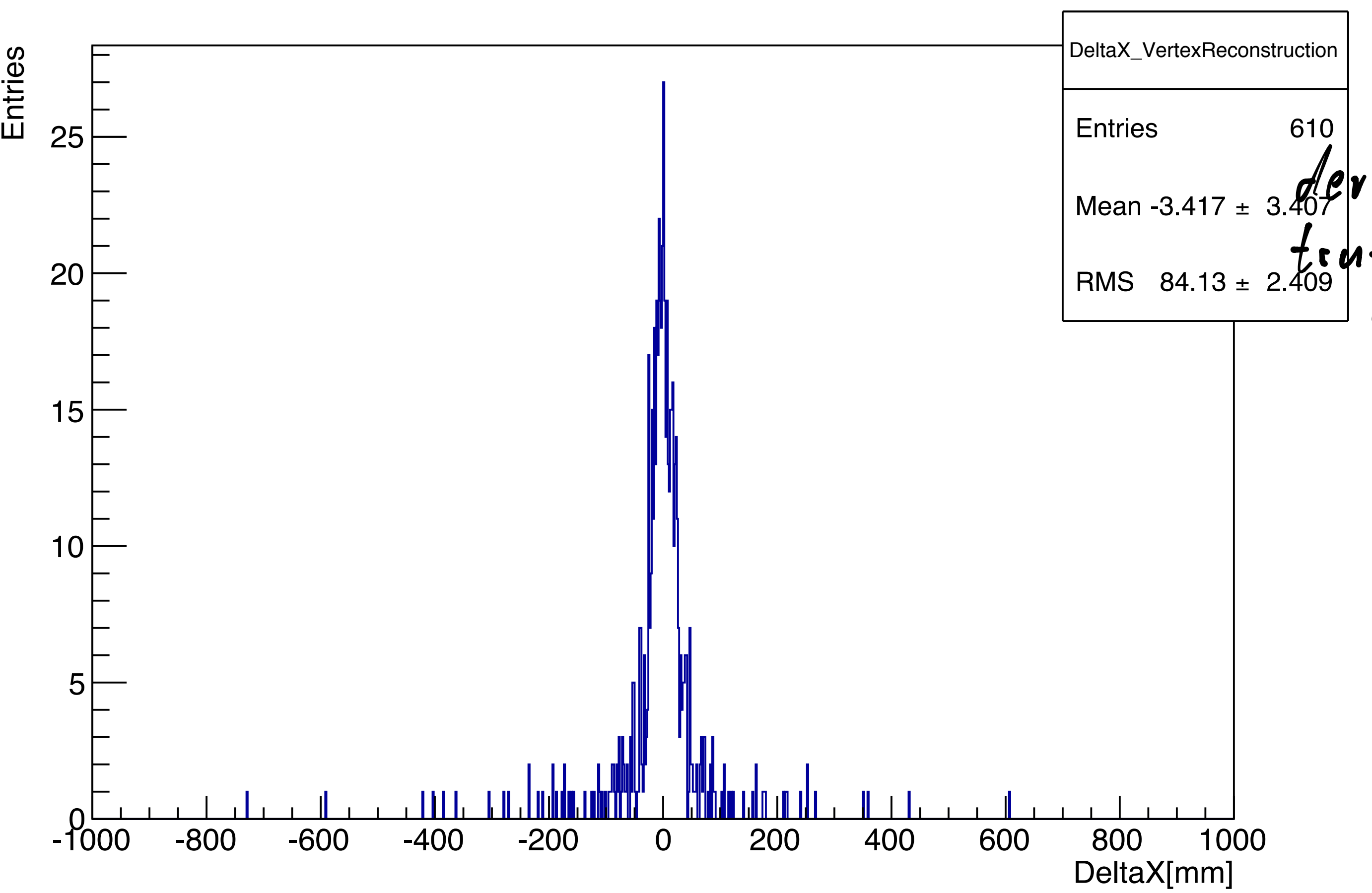
- Simple neutral pion reconstruction:
  - Straight-line fit of each of the photons
  - Take π^0 position as the point of closest approach of the two lines, taking into account the expected resolution depending on photon energy

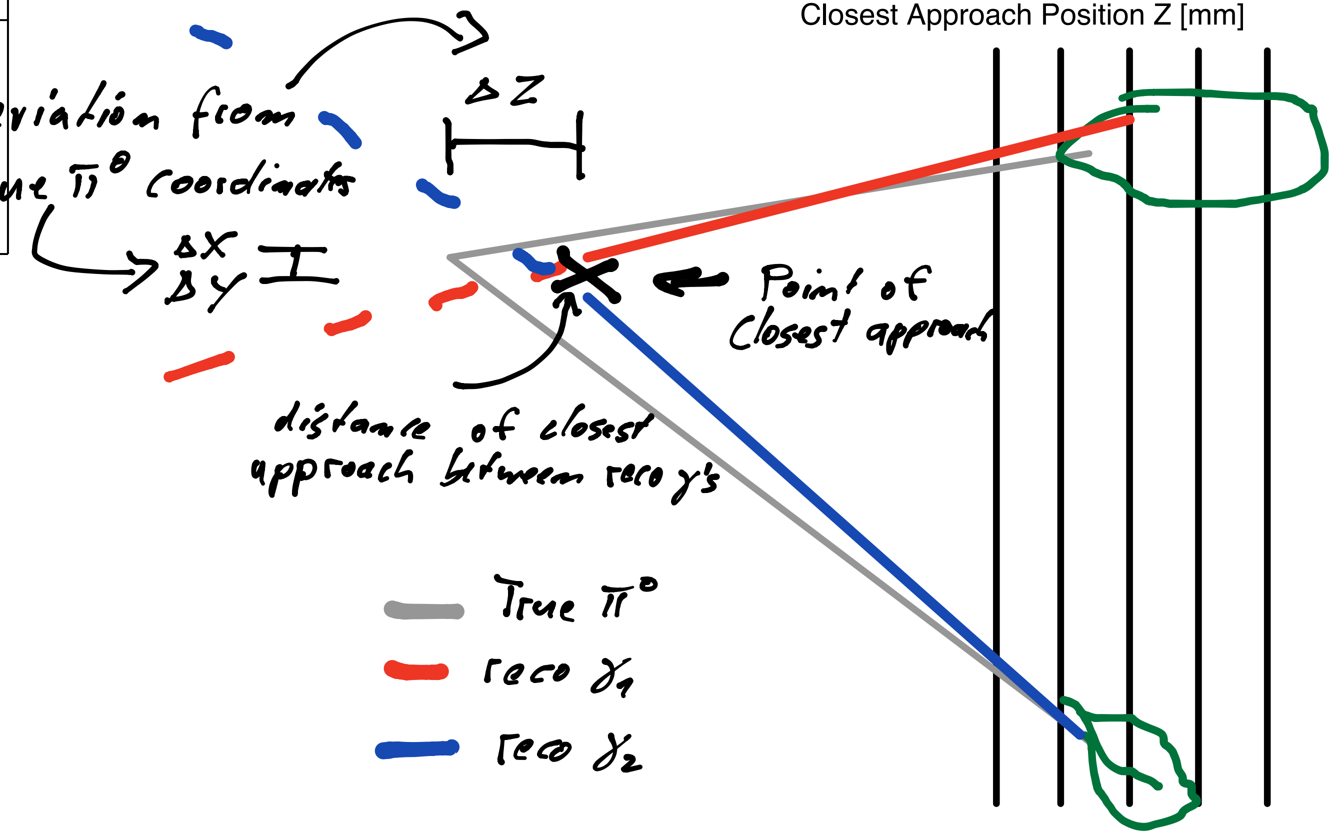


First Poor Man's Neutral Pion Reconstruction

- 300 MeV π^0, 1 m away from calorimeter

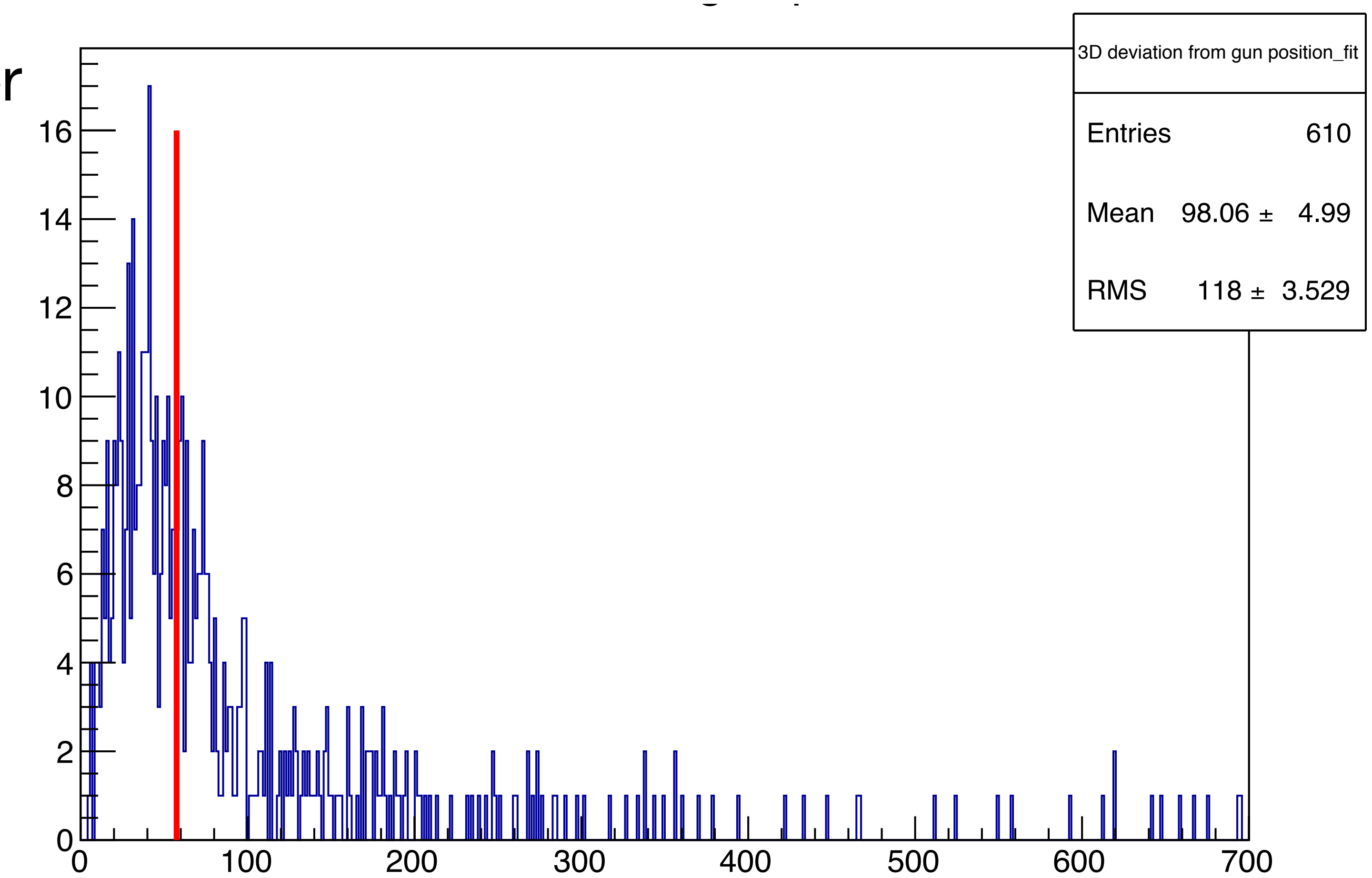






First Poor Man's Neutral Pion Reconstruction

- 300 MeV π^0, 1 m away from calorimeter
  - Distance of reconstruction origin position from true π^0 origin: median ~ 60 mm



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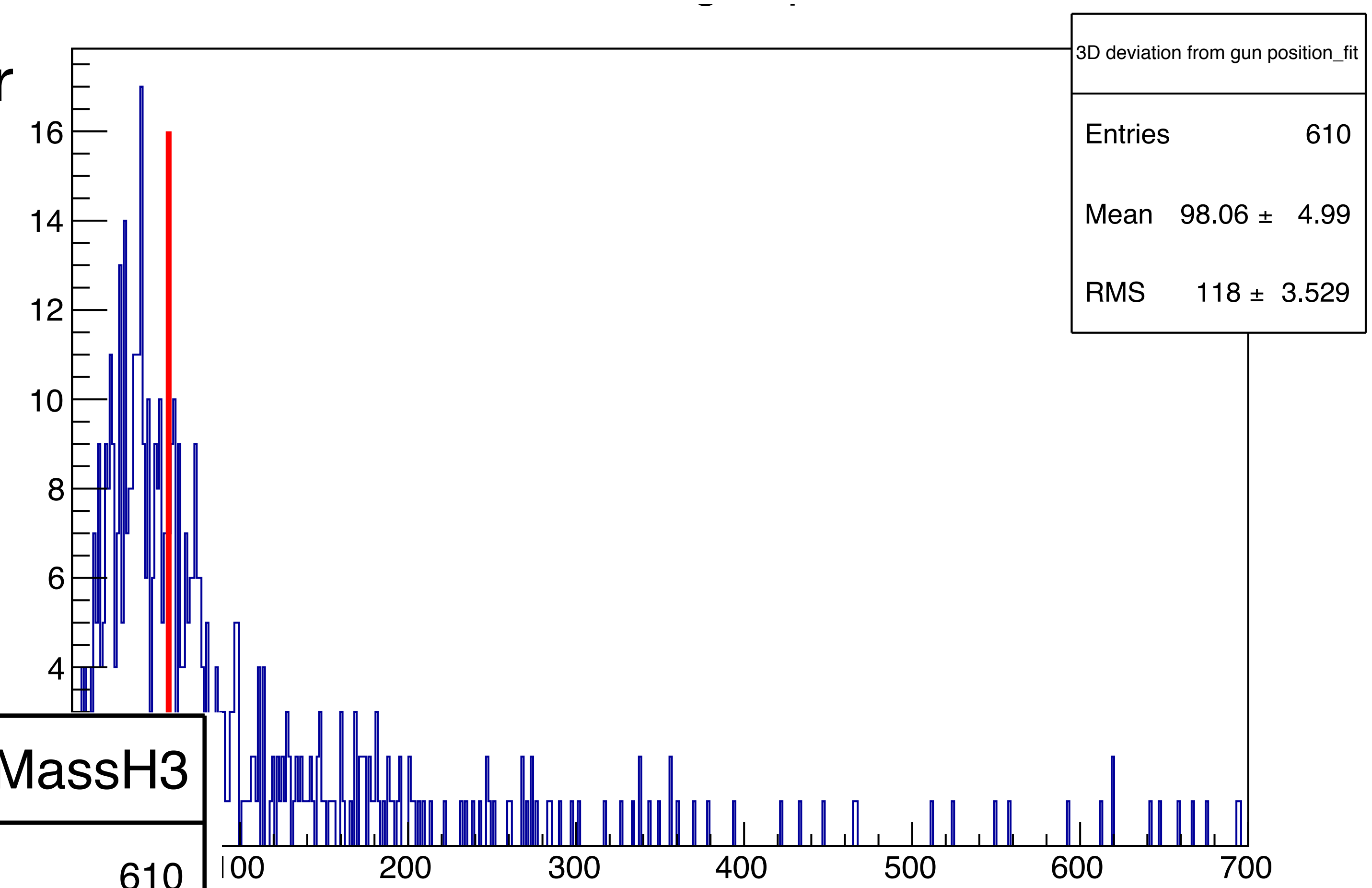
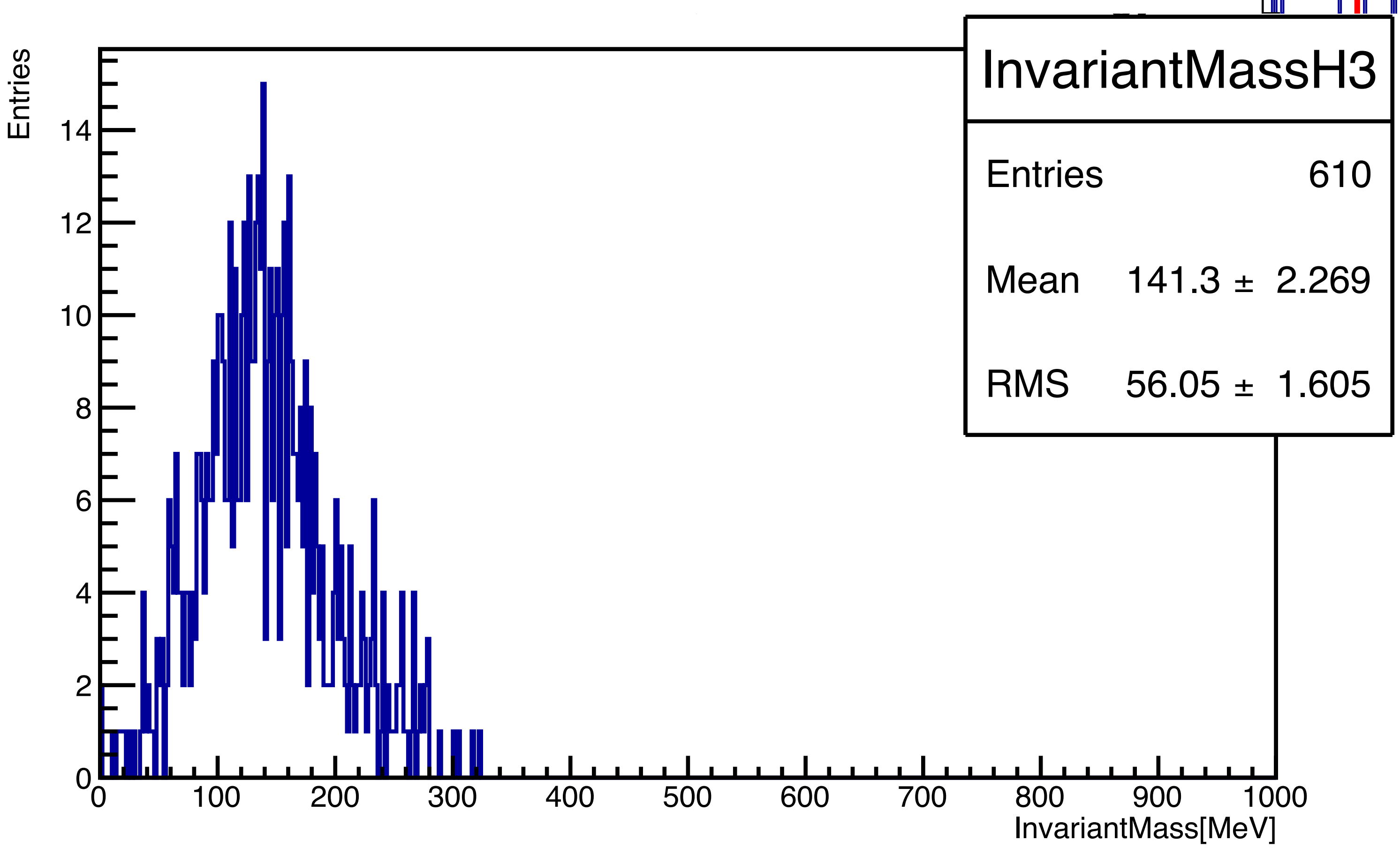
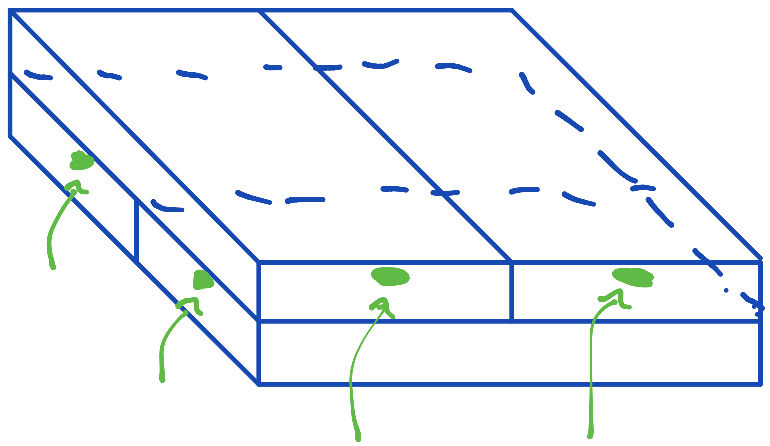




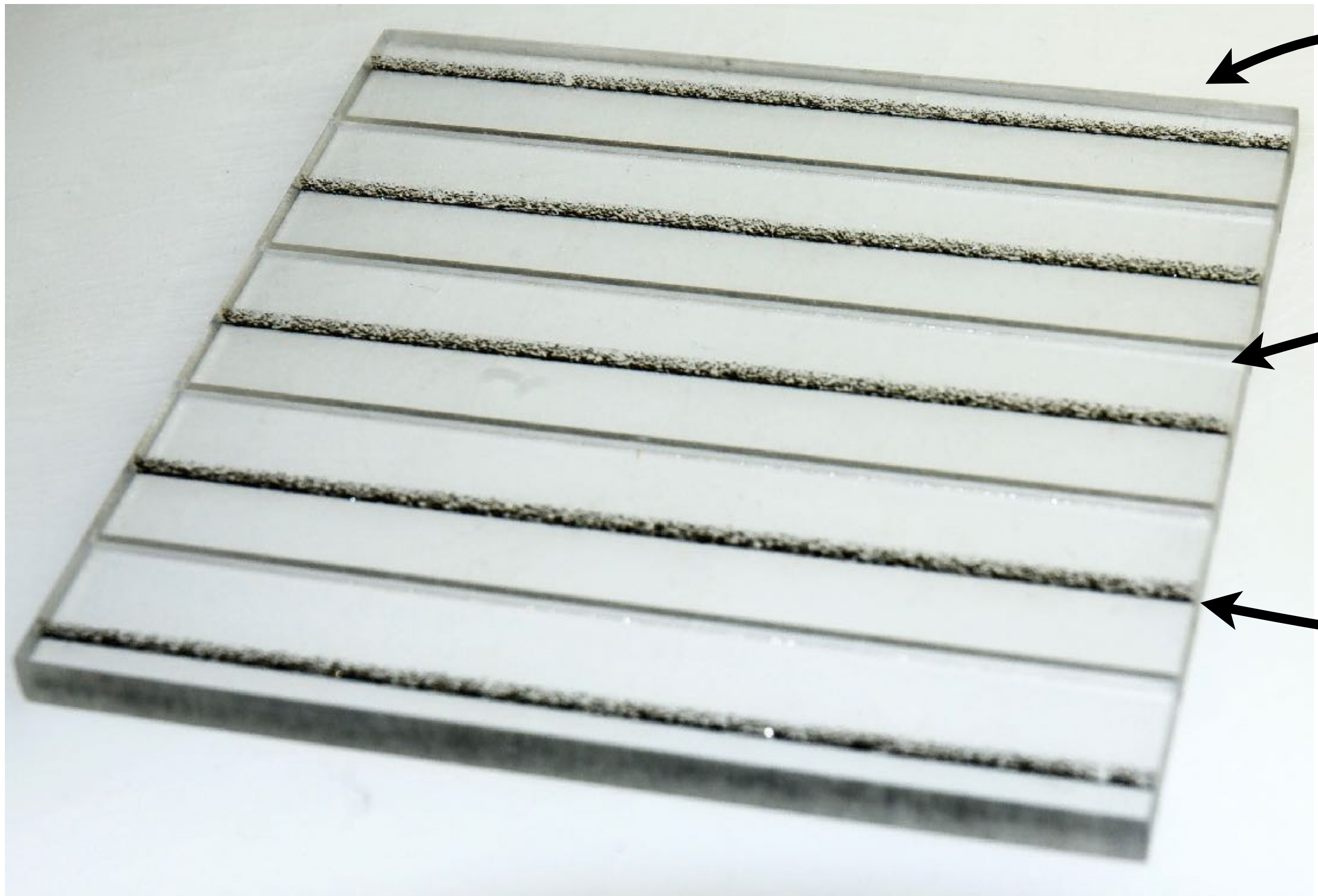
- Invariant mass, reconstructed position and energy
  - N.B.: No detector effects considered!

Hardware R&D: Scintillator Elements

- The most likely solution to achieve effective granularities of 2 x 2 cm^2: crossed strip readout
  - Standard solution: Individually packaged scintillator bars



- Currently studying alternative techniques to obtain strip segmentation in larger scintillator plates: Subsurface laser engraving



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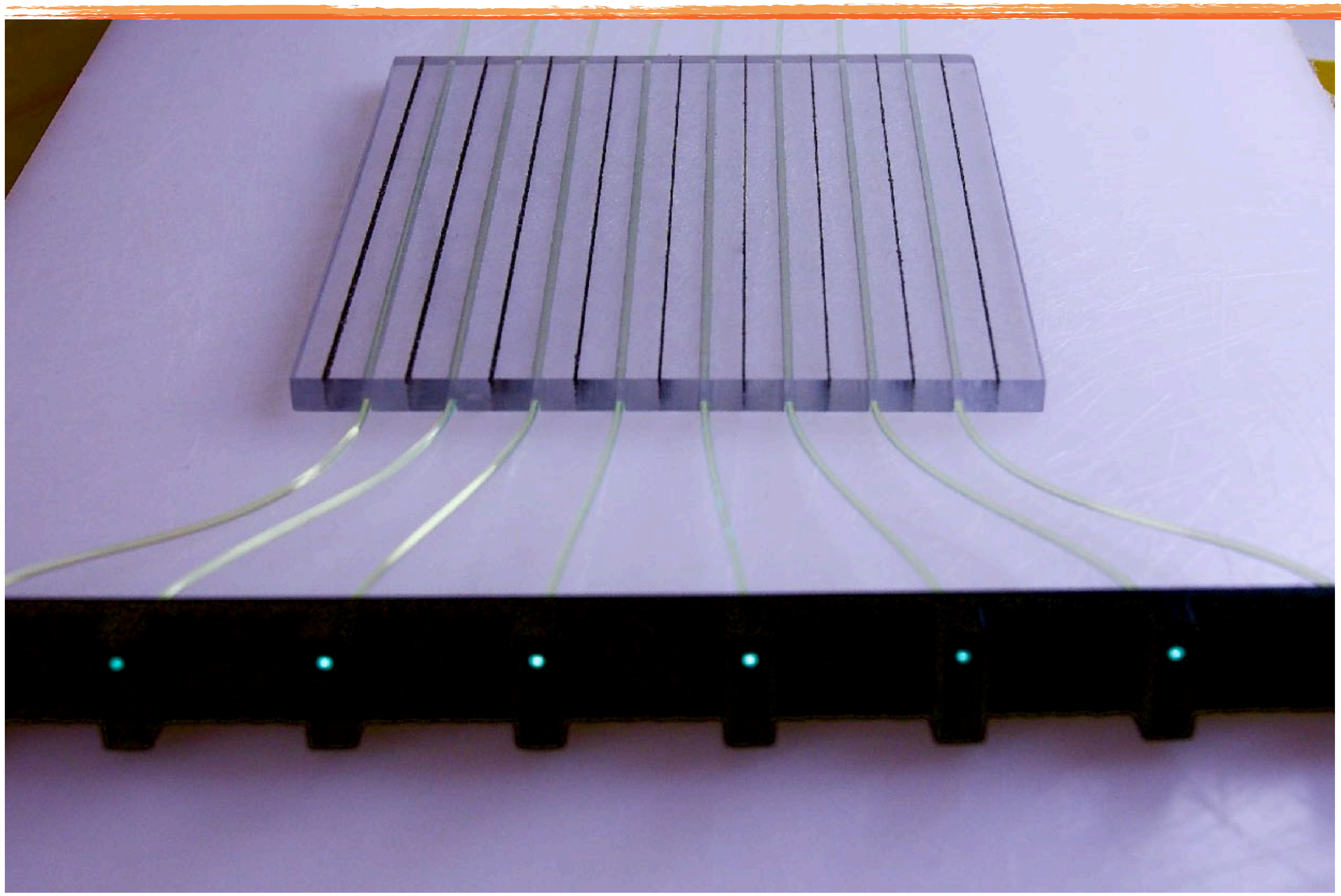
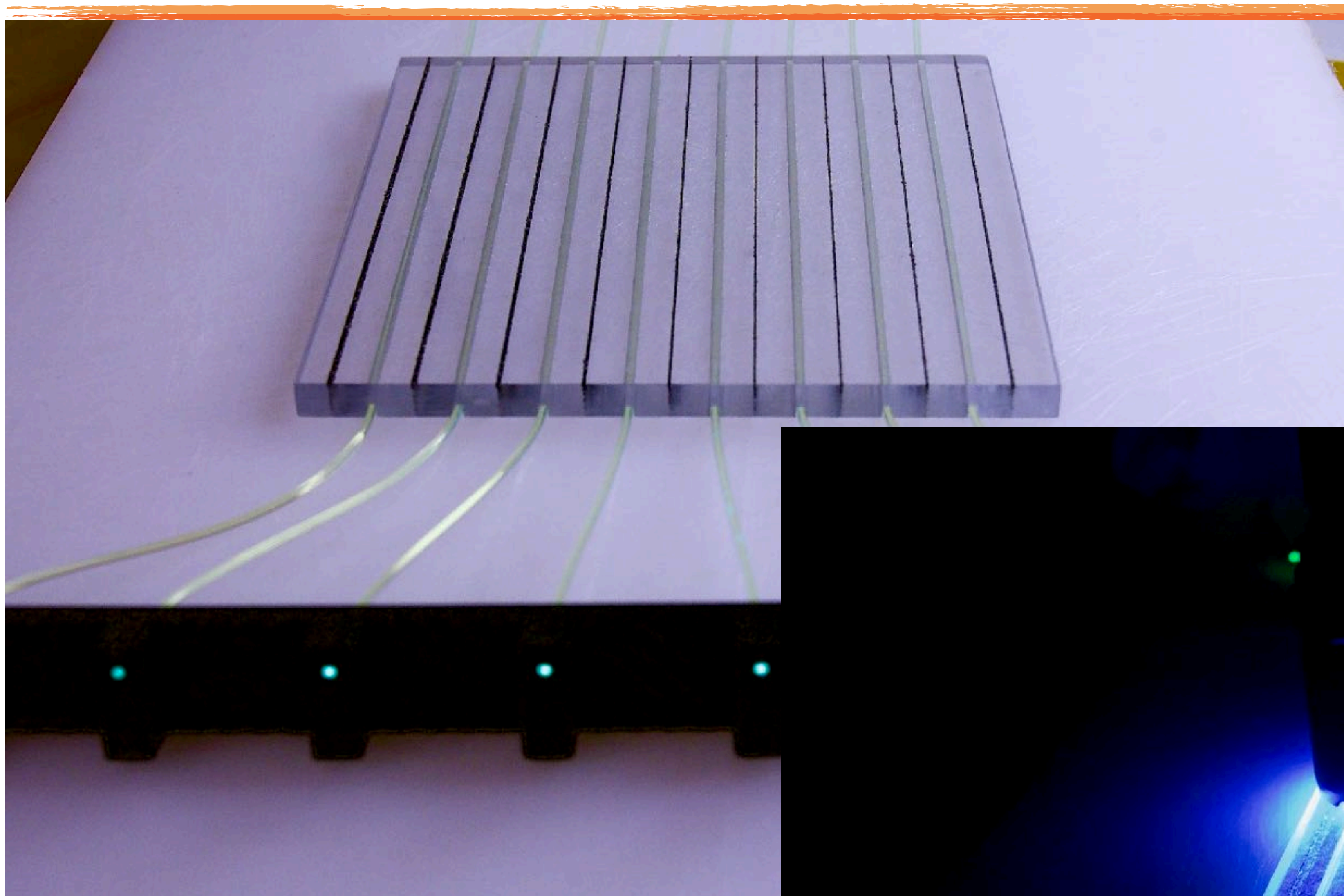


- WLS fibers inserted in first prototype (1 cm spacing), coupling mechanics to SiPM readout available, preamp board in production

- subdivision semi-transparent - sharing of light across multiple strips, possibly provides sub-strip spatial resolution

Hardware R&D: Scintillator Elements



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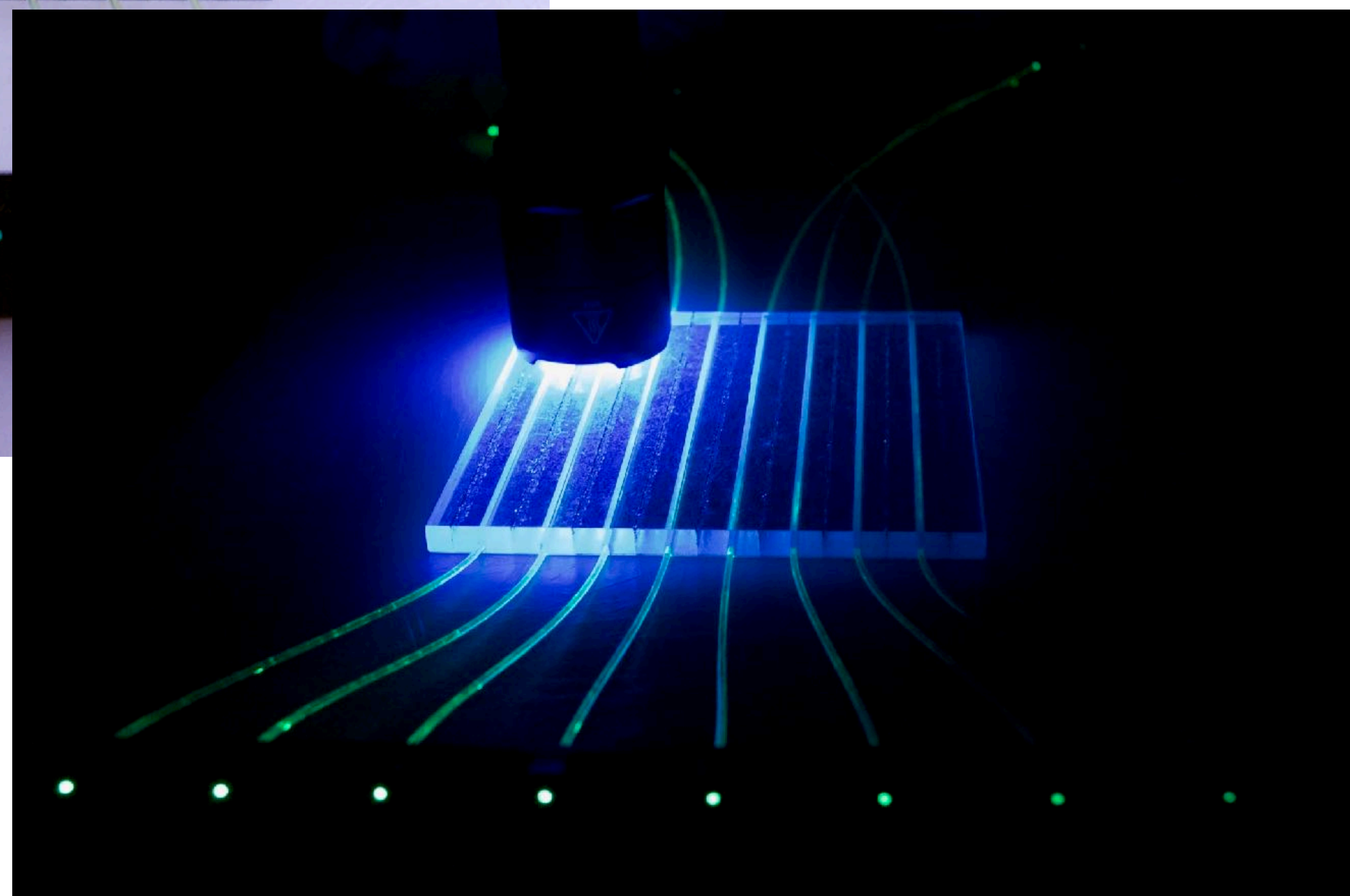

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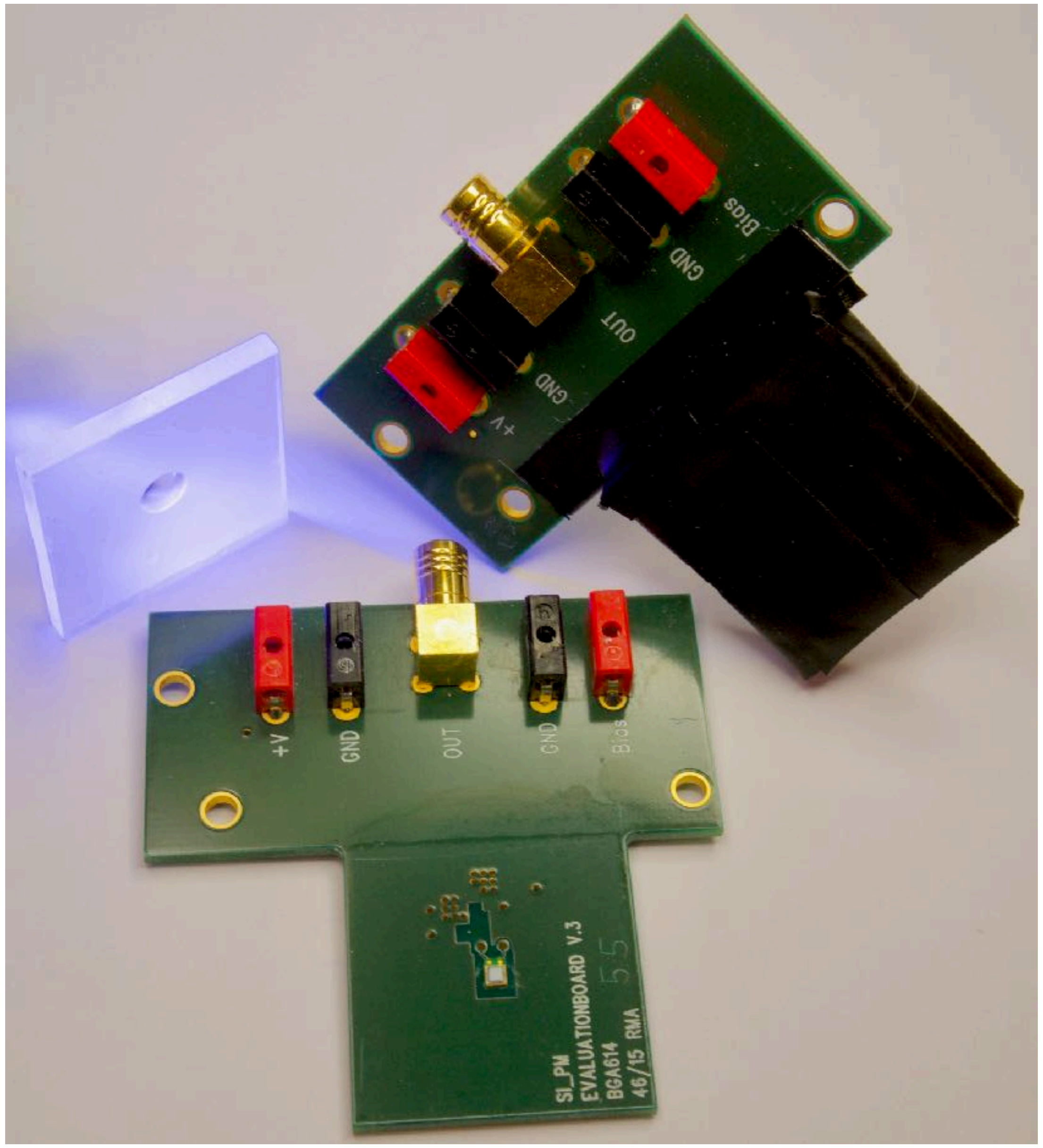
Hardware Studies

- Builds on CALICE activities - expertise in development and readout of small scintillator tiles with SiPMs
  - High speed digitizer readout:
    Will also provide results on time resolution
  - Studying different scintillator materials
    - PVT as a first step
    - PEN prototypes coming soon
    - also considering others, such as PMMA

- Longer term: Have to develop a readout scheme suitable for more than a handful of channels - will also depend on final ND requirements
  - Waveforms over extended periods?
  - Time-stamped hits?
  - …

Scintillator cells used for SuperKEKB commissioning



Conclusions & Next Steps

- A certain degree π^0 location accuracy can be achieved with a relatively granular ECAL
  - Thinner absorbers, higher effective granularity helps for photon pointing accuracy

- ***Next***:
  - Introduce energy cuts per cell to add realism (with input from hardware R&D)
  - Potentially more robust cluster definition - still exploring ideas
    - possibly improve shower direction reconstruction (more sophisticated fit)
  - Explore more complex geometries:
    - Varying longitudinal sampling to address real-world space constraints while keeping resolution for low-energy photons
    - Study impact of dead region within ECAL: Pressure vessel of HP-TPC
  - Extend π^0 study - explore full relevant energy range
  - Look at neutrons
  - First hardware studies