FCAL Test Beam Data and Geant4 Simulations

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On behalf of the FCAL collaboration

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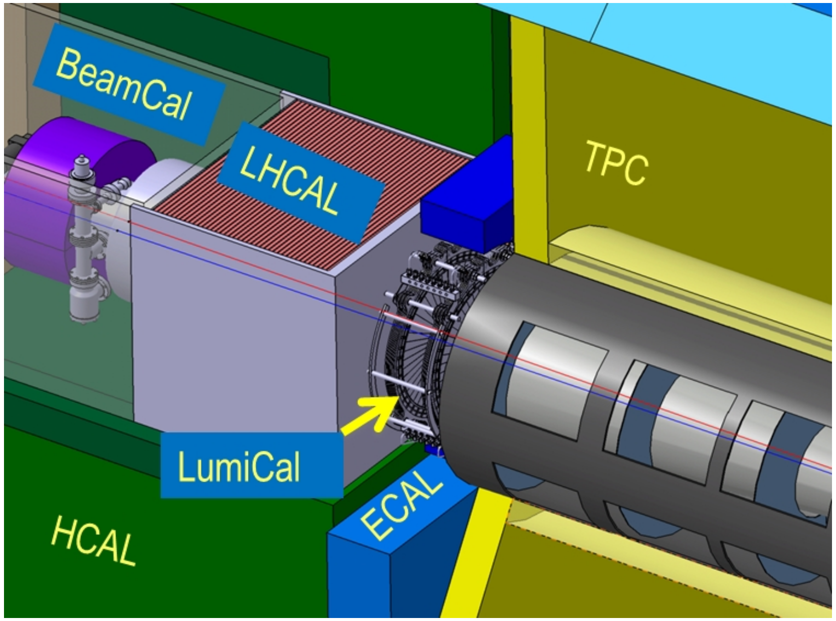
Outline

- Introduction
- Beam test design in simulations
- LumiCal calibration
- Clustering algorithms and position reconstruction
- Summary

LumiCal in LC Experiments

Goals:

- Precise integrated luminosity measurements;
- Extend a calorimetric coverage to small polar angles. Important for physics analysis.



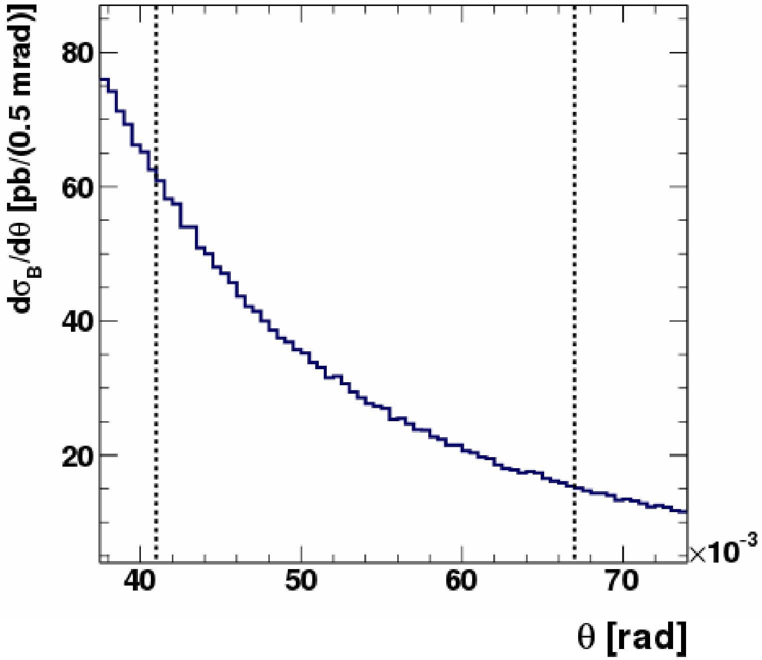
LumiCal Design:

- Electromagnetic sampling calorimeter;
- 30 layers of 3.5 mm thick tungsten plates with 1 mm gap for silicon sensors;
- symmetrically on both sides at ~2.5m from the interaction point.

Luminosity measurement: $L = \frac{N_B}{\sigma_B}$

N_B – Bhabha events in a certain polar angle (θ);

σ_B – integral of the differential cross section over the same θ range.

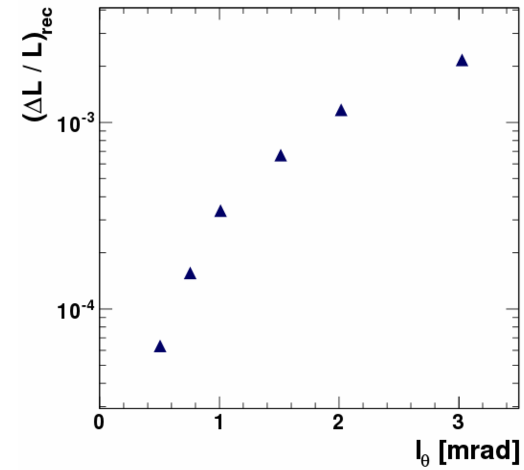


LumiCal Geometry

Uncertainty in luminosity measurement depends on the polar angle bias Δθ and minimum polar angle θ_{min} as:

$$\left(\frac{\Delta L}{L}\right)_{rec} \approx 2\frac{\Delta\theta}{\theta_{min}}$$

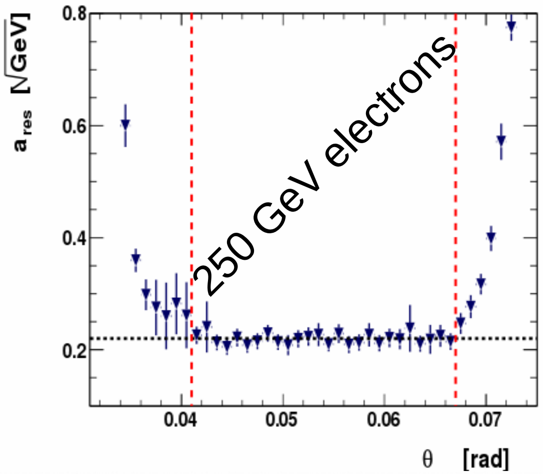
Δθ depends on polar angular pad size l_θ.



For l_θ=0.8 mrad, $\Delta L/L = 1.6\cdot10^{-4}$.

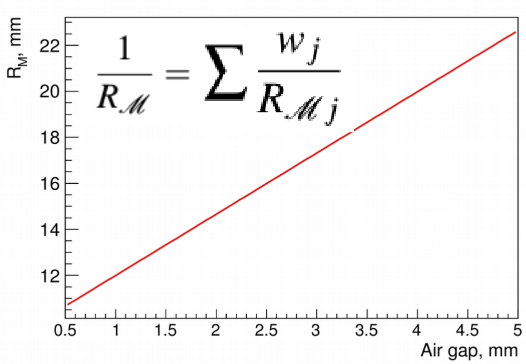
Energy resolution: $$\frac{\sigma_E}{E} = \frac{a_{res}}{\sqrt{E_{beam}\ (GeV)}},$$

a_{res} = (0.21±0.02) $\sqrt{GeV}$.



LumiCal fiducial volume: 41 < θ < 67 mrad

R_M as function of the air gap between 3.5 mm thick tungsten plates



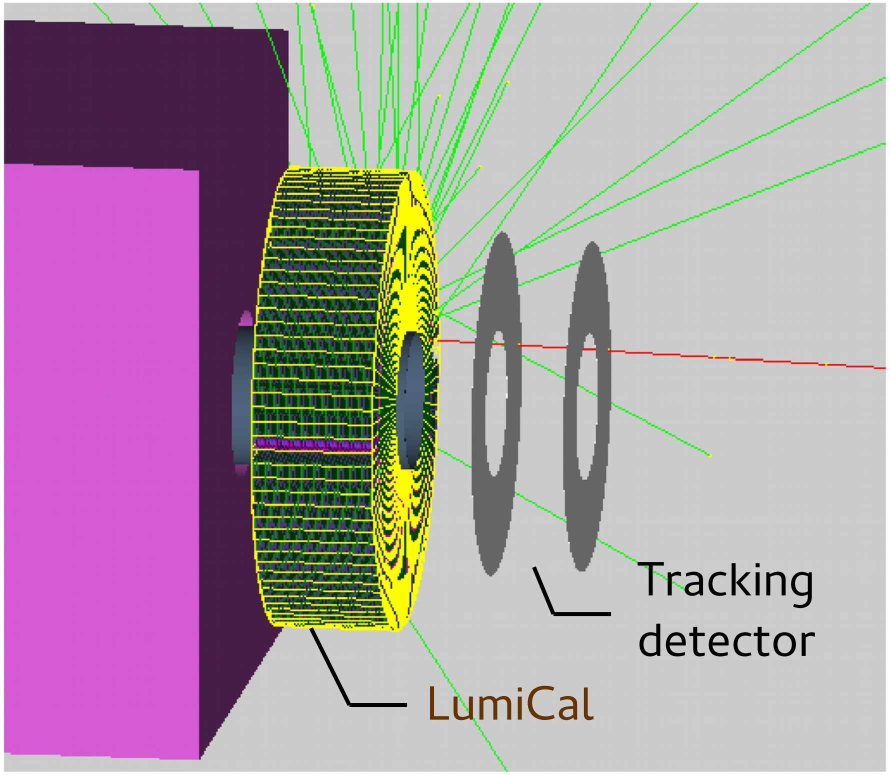
Reducing air gap from 4.5 mm to 1 mm gives R_M: 21 mm -> 12 mm.

Tracking Detector in Front of LumiCal

- Improve polar angle measurement accuracy;
- LumiCal alignment;
- Provide more information to enable e/γ identification, important for various physics studies, e. g. photon structure function study, important for BSM searches.

Studied in Simulations

- Modified versions of LuCaS (Geant4 app. For LumiCal simulation);
- Two layers of Si sensors with different thickness and distance to LumiCal;
- No negative affects on reconstruction in LumiCal;
- High efficiency of e/γ identification for tracker with submillimeter position resolution for single e or γ event.



Study e/γ identification in beam test

Beam Test Goals

DESY test beam facilities:

- Electron beam 1 – 6 GeV;
- Dipole magnet 1 – 13 kGs;
- EUTelescope with 6 planes of Mimosa26 detectors;

Performance of the compact LumiCal prototype:

- Detector modules performance: noise, saturation, S/N, etc;
- Energy response to e^- beam of 1 – 6 GeV;
- Electromagnetic sower development study, Moliere Radius measurement.

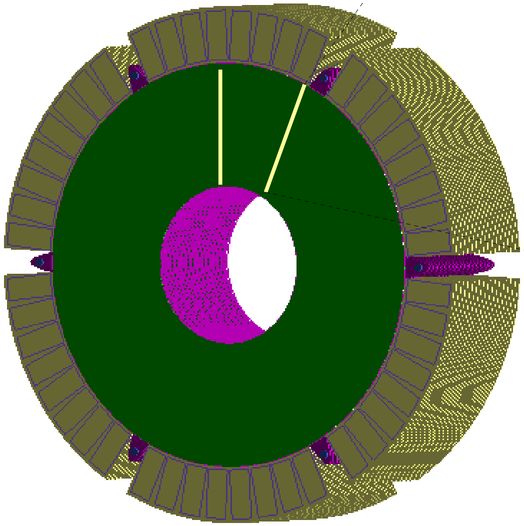
e/γ identification with tracking detector in front of LumiCal:

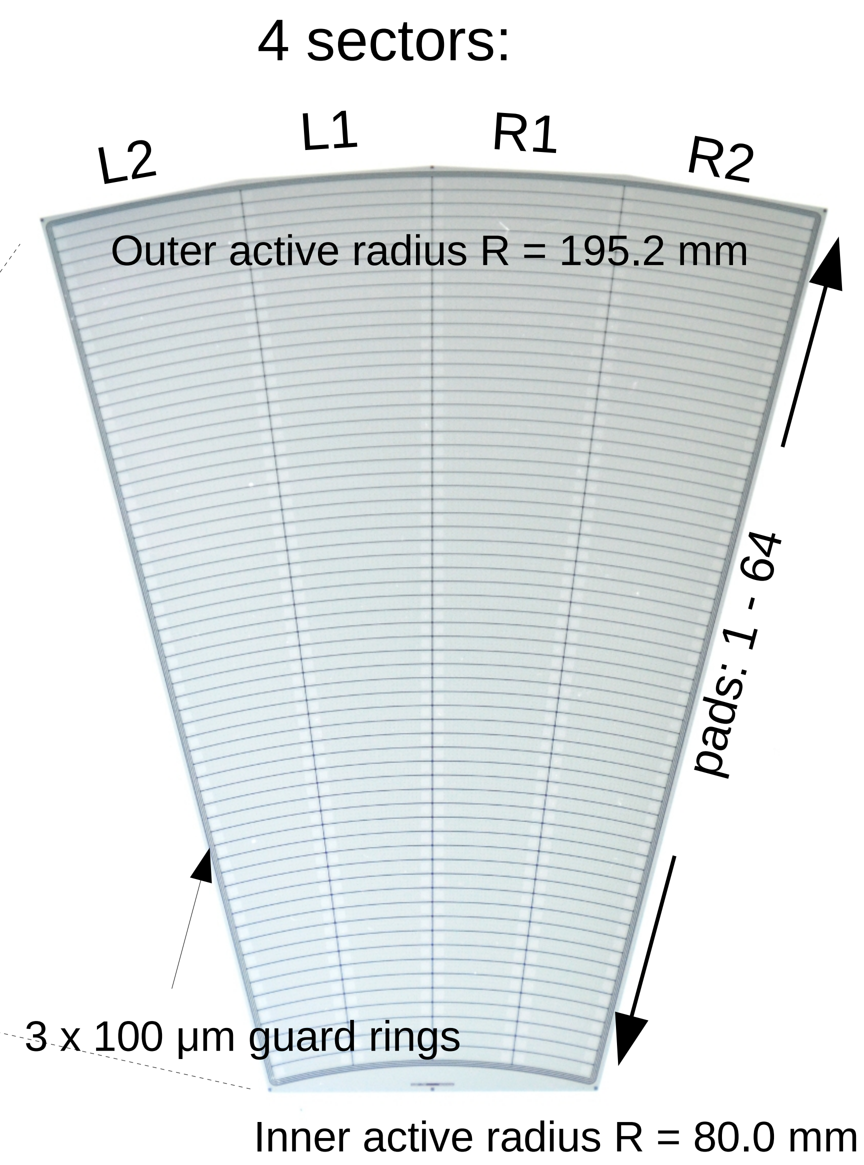
- Back scattering as a function of distance from LumiCal;
- Identification efficiency.

LumiCal and Sensor Design

- Silicon sensor
- thickness 320 μm
- DC coupled with readout electronics
- p+ implants in n-type bulk
- 64 radial pads, pitch 1.8 mm
- 3 guard rings
- 4 azimuthal sectors in one tile, each 7.5°
- 12 tiles make full azimuthal coverage

LumiCal thickness:
$30X_0$ –> 13.5 cm.





Saturation in Readout with SRS and APV-25

Next generation of LumiCal electronics is under development and will be available in 2017.

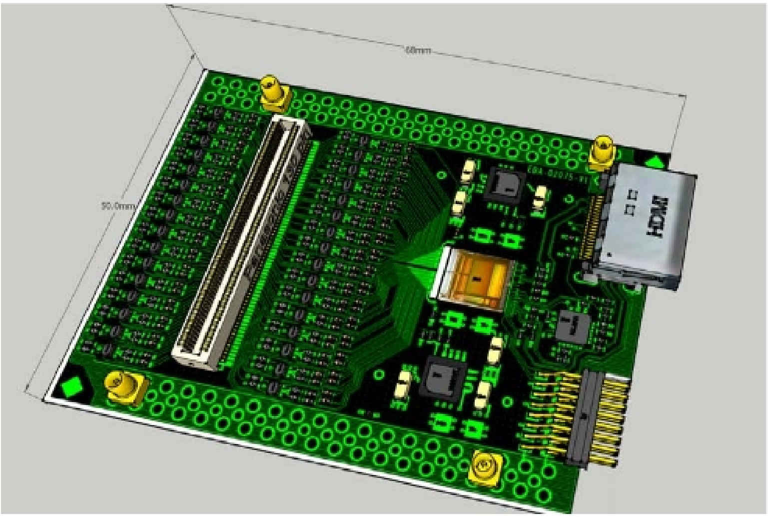
Temporary alternative solution:

Front-end chip APV25:

- Designed for CMS silicon microstrip detectors (used for Belle II SVT);
- 128 channels;
- Shaping time (min): 50 ns;
- Supports both signal polarities;
- Sampling rate 40 MHz;
- Supported by SRS;
- Available at CERN stock.

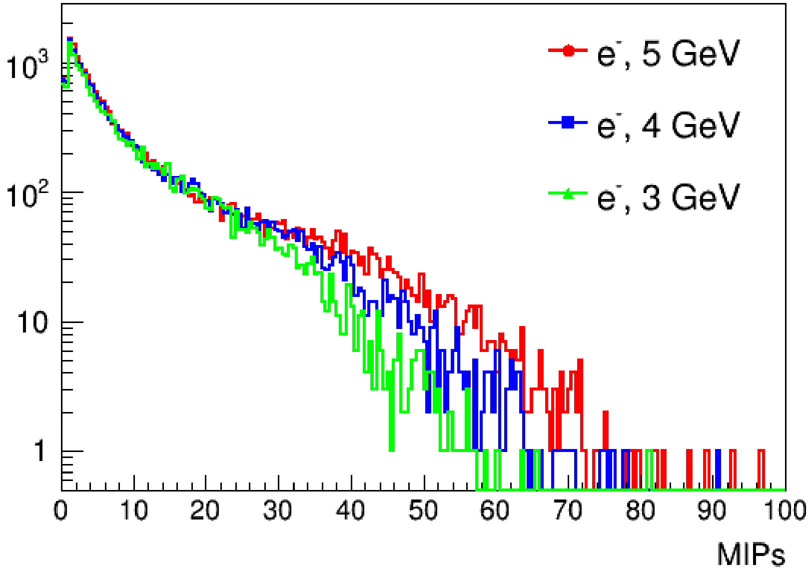
The APV-25 range in case of LumiCals sensor: ~ 8 MIPs

Additional circuit: "charge divider" - could help to avoid saturation.



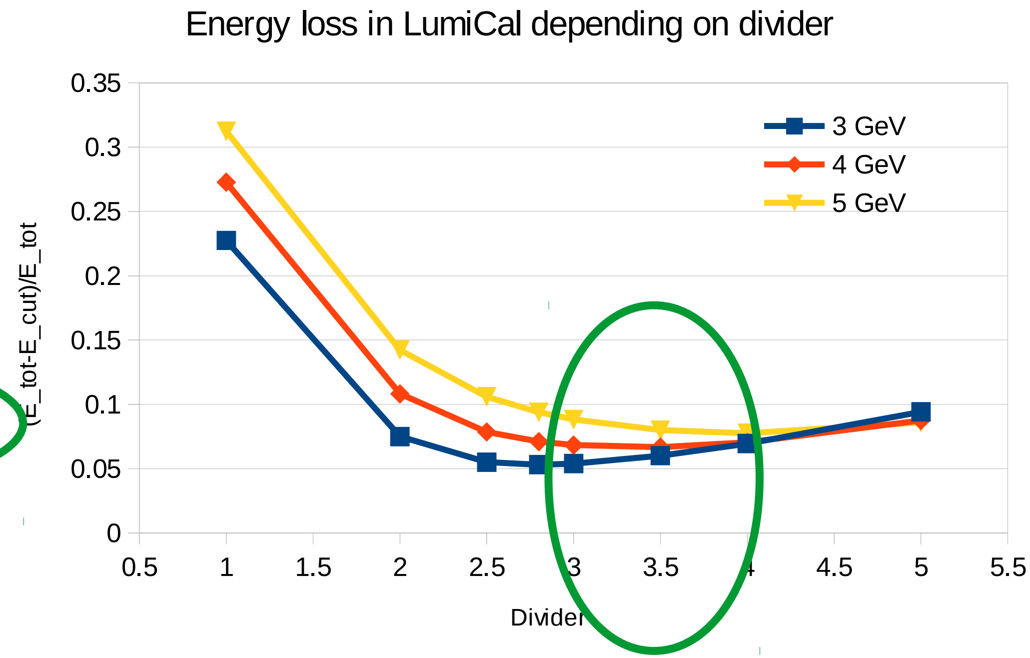
Front-end board (hybrid) with APV25 chip

Simulated energy deposition in single sensor pad in 5-th layer (after $5X_0$).



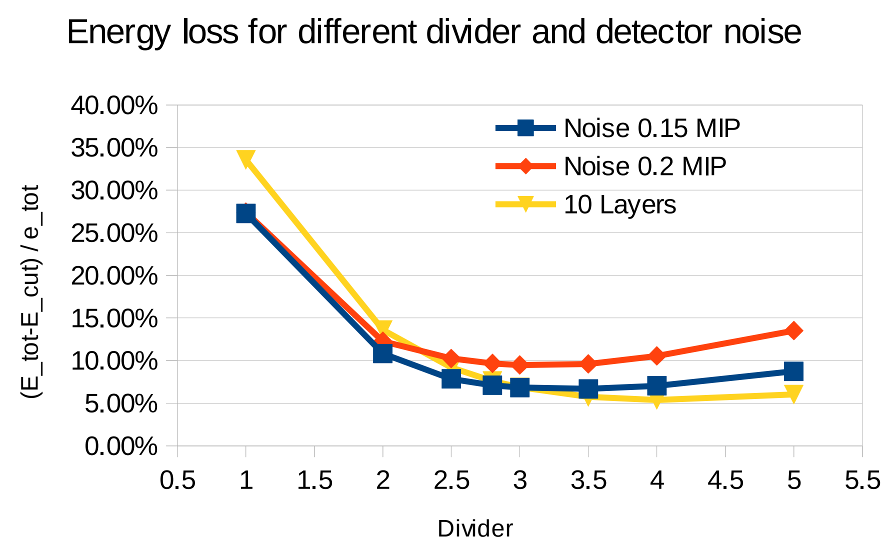
Charge Divider for Optimizing APV-25 Range

Divider	3 GeV	4 GeV	5 GeV
1	22.75%	27.27%	31.25%
2	7.49%	10.81%	14.23%
2.5	5.50%	7.86%	10.60%
2.8	5.31%	7.10%	9.39%
3	5.39%	6.83%	8.82%
3.5	6.01%	6.68%	8.00%
4	6.95%	7.04%	7.76%
5	9.42%	8.75%	8.59%



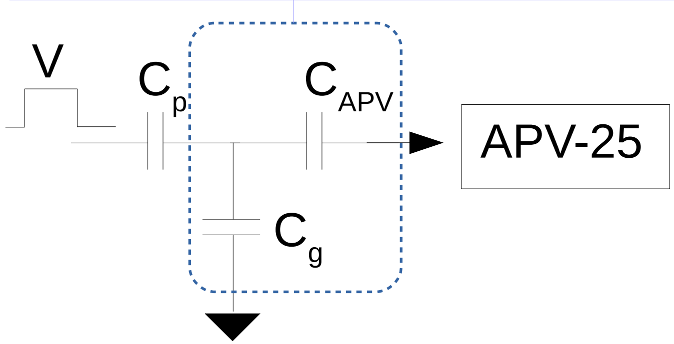
Affect of noise for 4 GeV beam and smaller number of layers (10)

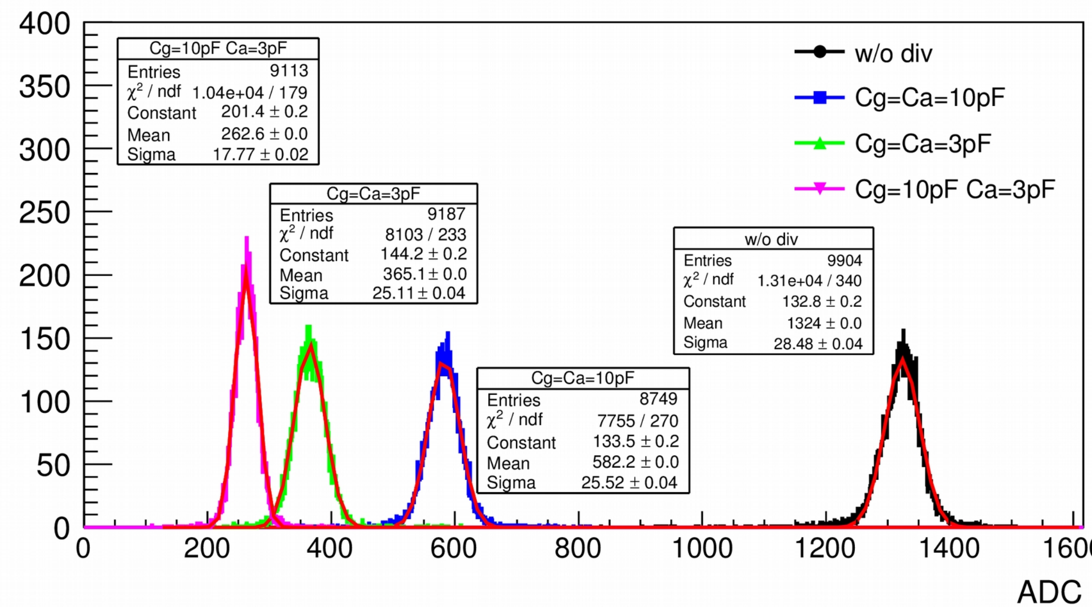
Divider	Noise 0.15 MIP	Noise 0.2 MIP	10 Layers
1	27.27%	27.42%	33.57%
2	10.81%	12.26%	13.60%
2.5	7.86%	10.24%	9.18%
2.8	7.10%	9.67%	7.61%
3	6.83%	9.48%	6.86%
3.5	6.68%	9.60%	5.74%
4	7.04%	10.55%	5.39%
5	8.75%	13.51%	6.03%



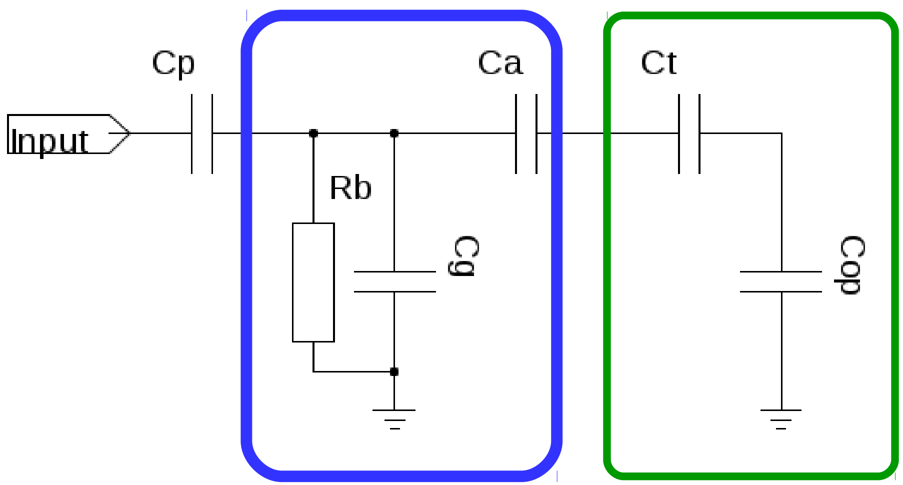
Divider Implementation Tests

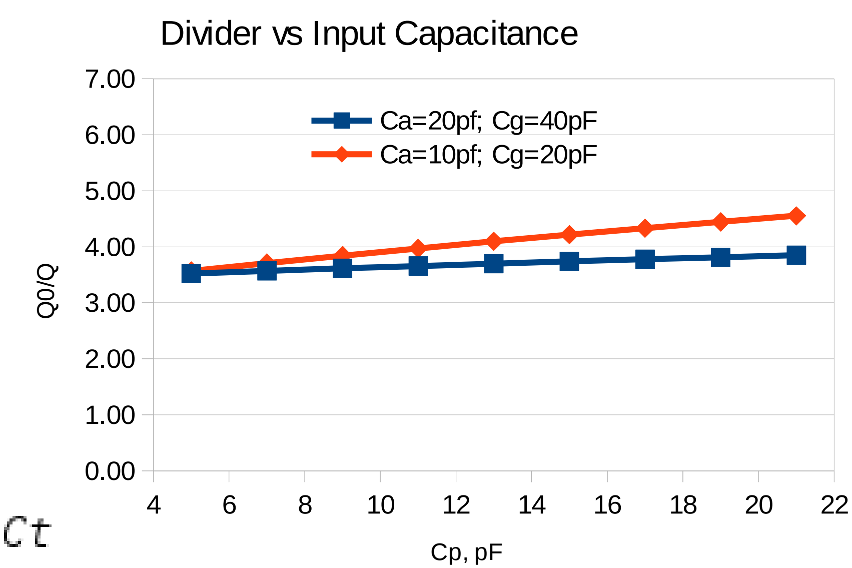
Can be implemented as a small PCB connected to LumiCal detector module and APV-25 board.





$C_{op} = C_{fb}(K+1)$; $C_{fb} = 0.15\ pF$; $K \sim 10^{10}$?





$(C_g\omega)^{-1} \ll R_b$;

$$\frac{Q_0}{Q} = \frac{Ca\,Cg + Ca\,Cp + (Cp + Cg + Ca)\,Ct}{Ca\,Ct + Ca\,Cp}$$

Identification of Particle Signal with Neural Network

Signal with time response function of CR-RC filter:

$$V = \frac{e^{\frac{t0-t}{\tau}}(t-t0)P0}{\tau}$$

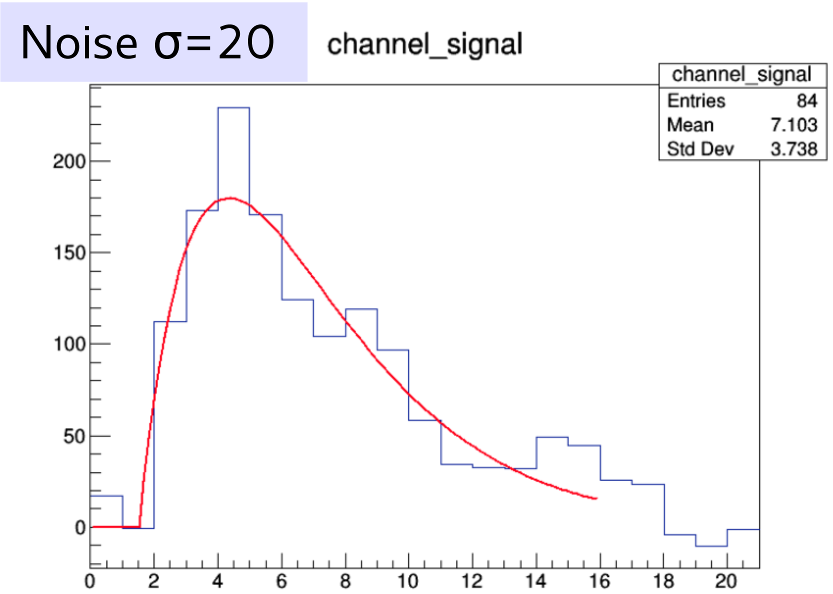
τ, and t0 are known parameter of the readout

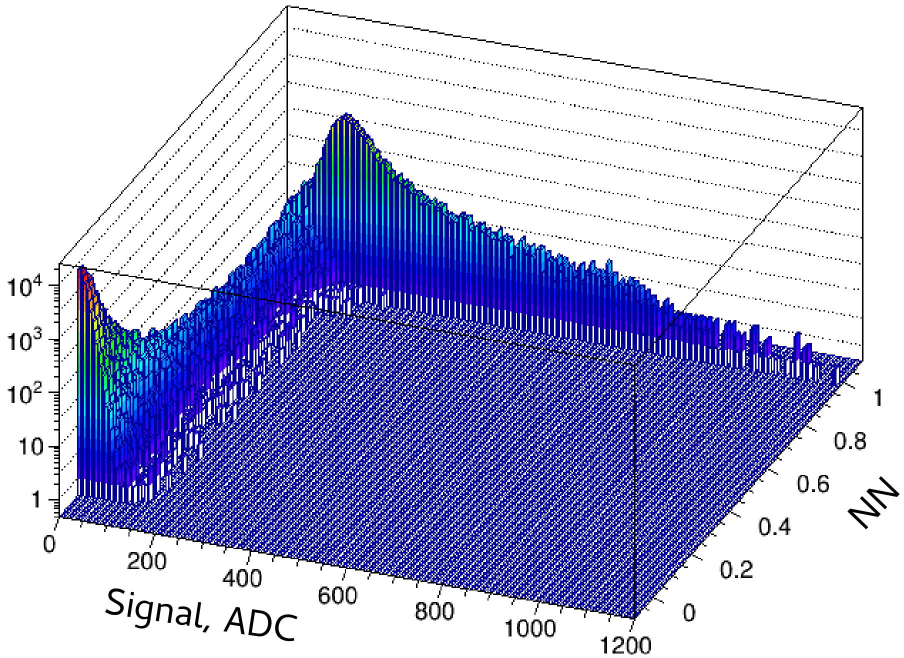
Neural network is tested to identify the signal in raw data:

- Input layer 21+1 nodes, one hidden layer with 10+1 node;
- Regularization;
- Training set is generated using the formula with random amplitude and noise generated from Landau and Gaussian distributions respectively.

Some specific noise patterns were revealed to be included in training set

NN demonstrate excellent signal identification in noisy environment

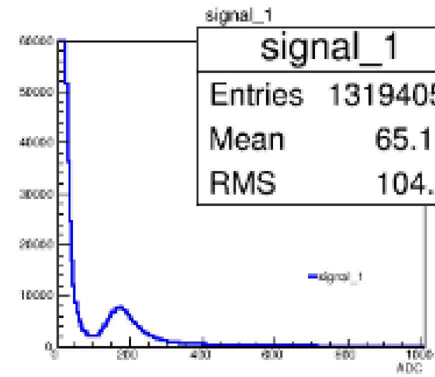




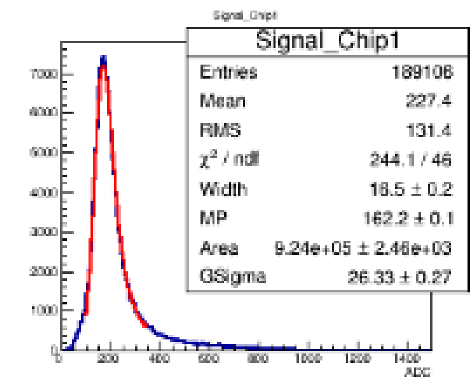
LumiCal Energy Responce

Cosmic muon events are collected for calibration.

No cuts

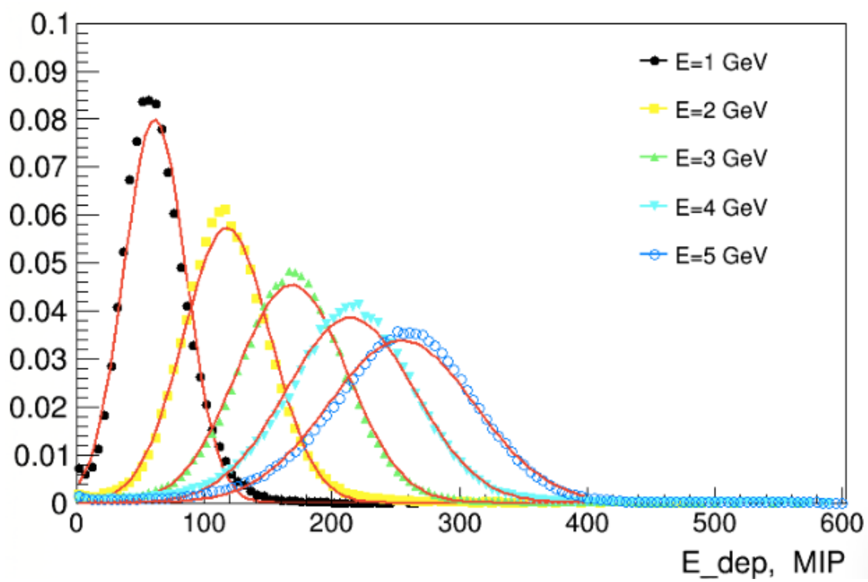


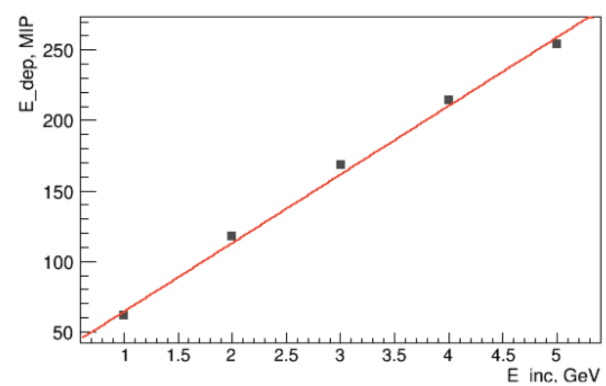
NN cut

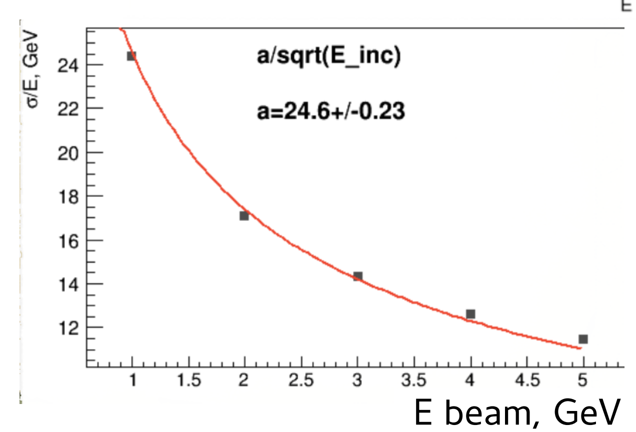


Energy deposited in LumiCal sensor by cosmic muon (ADC)

LumiCal response
when running with charge divider

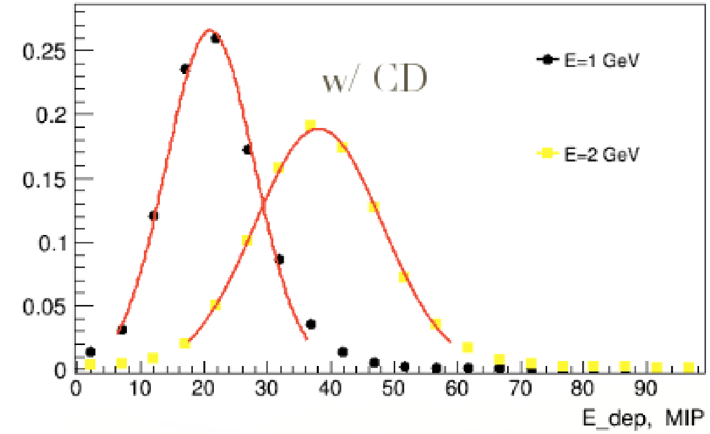


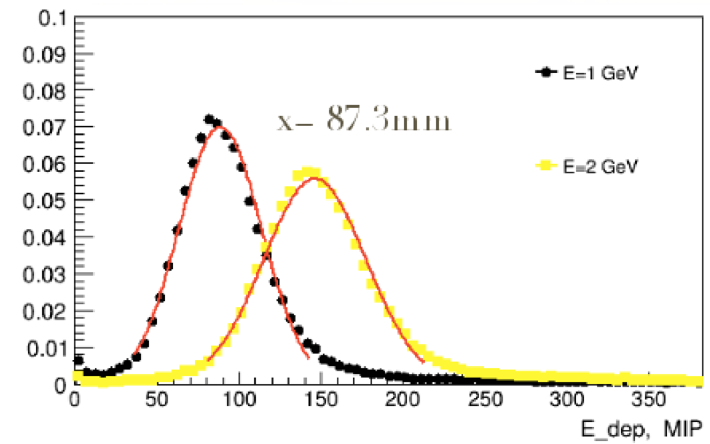




Charge Divider Calibration

Calibration factor can be estimated by comparison of
the deposited energy in LumiCal
with and without charge divider
for 1 GeV and 2 GeV beams,
where the affect of saturation is relatively small.



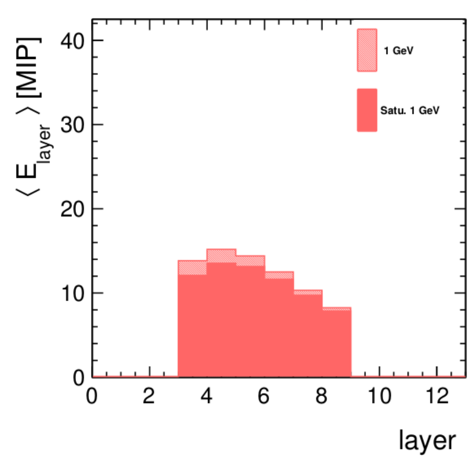


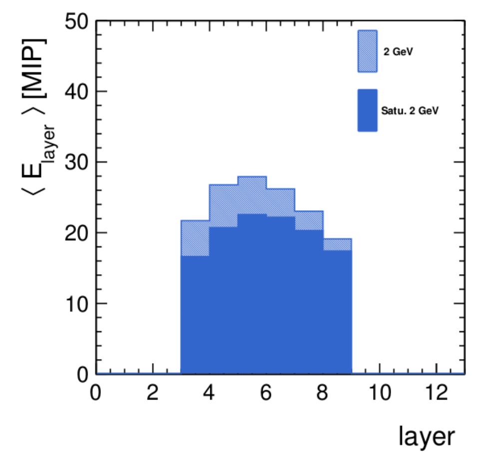
Estimation for

- 1 GeV beam is 4.22 and
- 2 GeV beam – 3.84

The simulations with Geant4 showed that correction for the saturation is:

- 10 % for 1 GeV beam and
- 20 % for 2 GeV beam

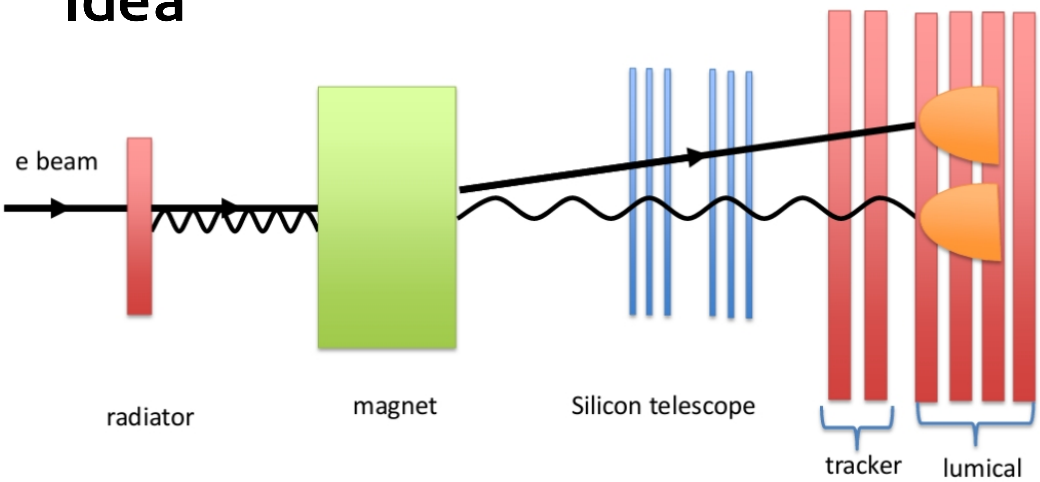




- Taking into account this correction the calibration factor in both measurements is around 4.7.
- As expected there is dependence on the input capacitance observed in different beam positions.

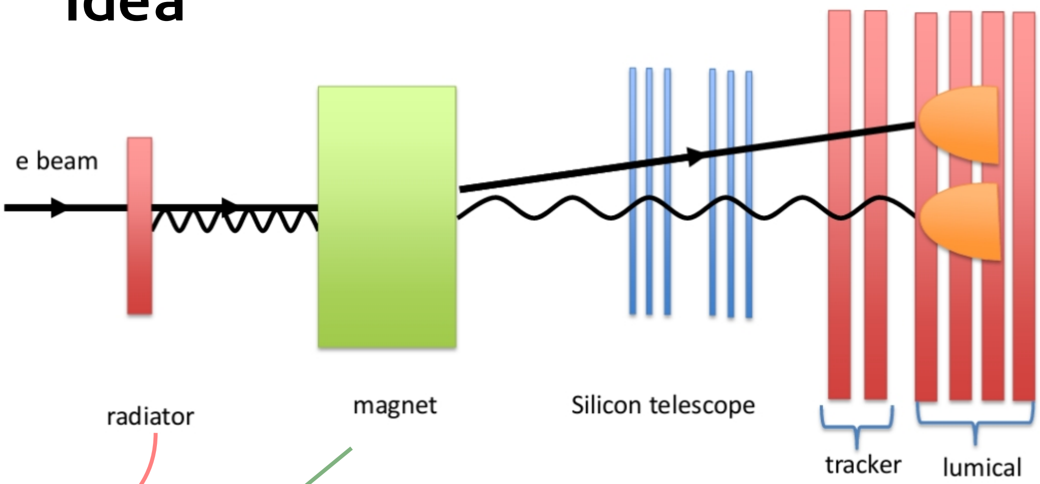
Test-beam Design

Idea

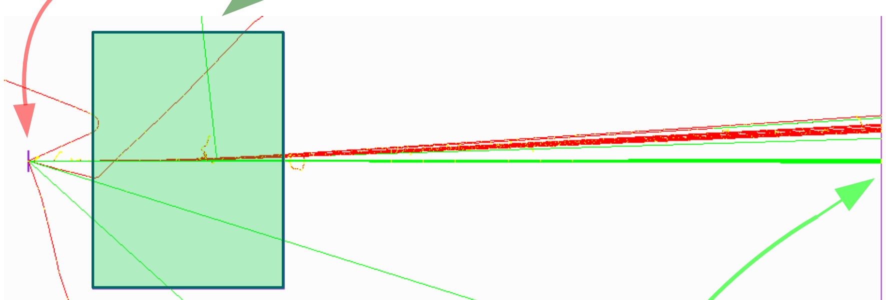


Test-beam Design

Idea

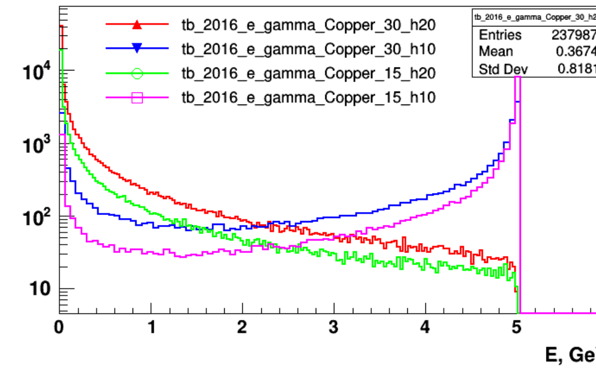


Electrons



Geant4 simulation

Photons

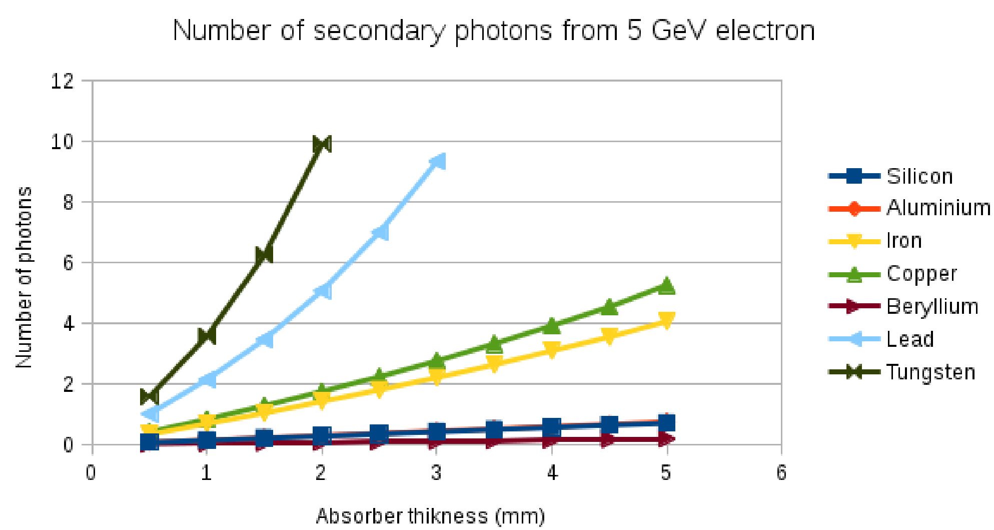


e- of 5 GeV

1.5 mm of Copper target

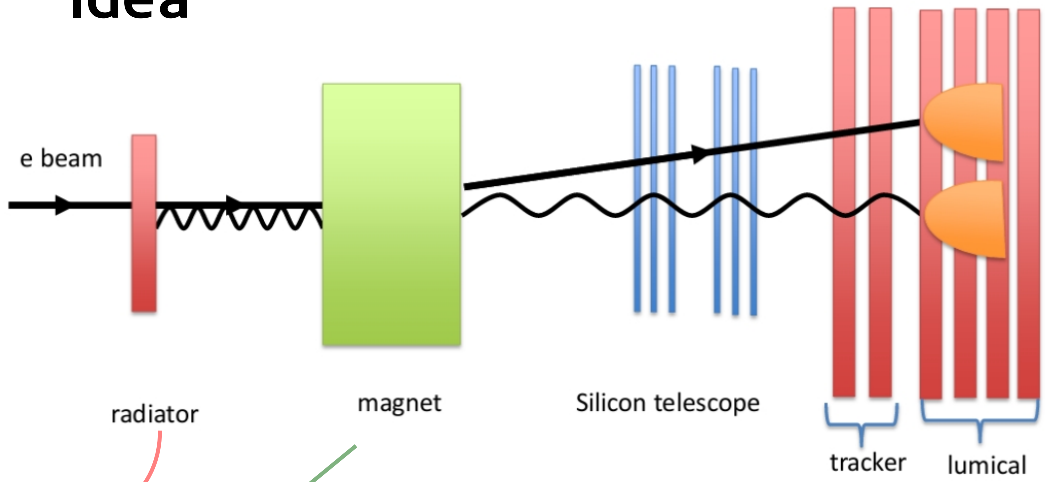
Number of secondaries per event :

- Gammas = 1.28;
- electrons = 0.5193;
- positrons = 0.02402

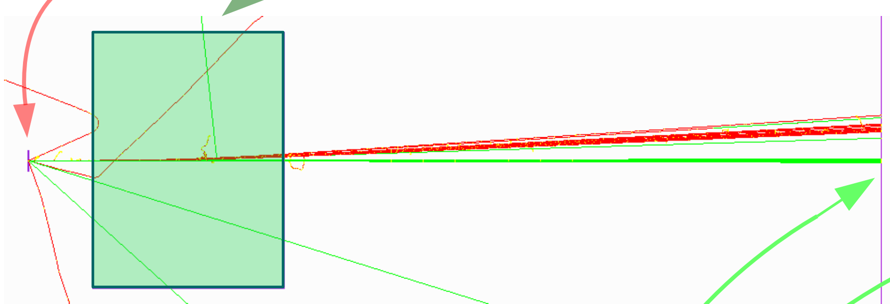


Test-beam Design

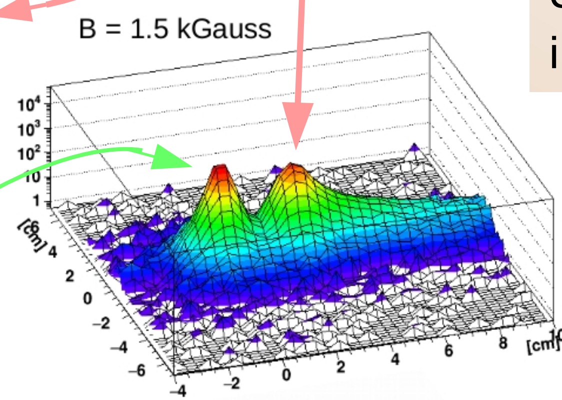
Idea

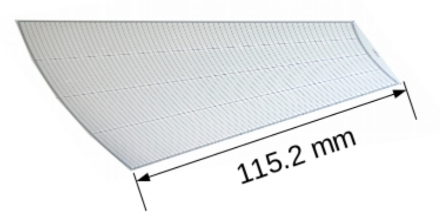


Electrons



Geant4 simulation





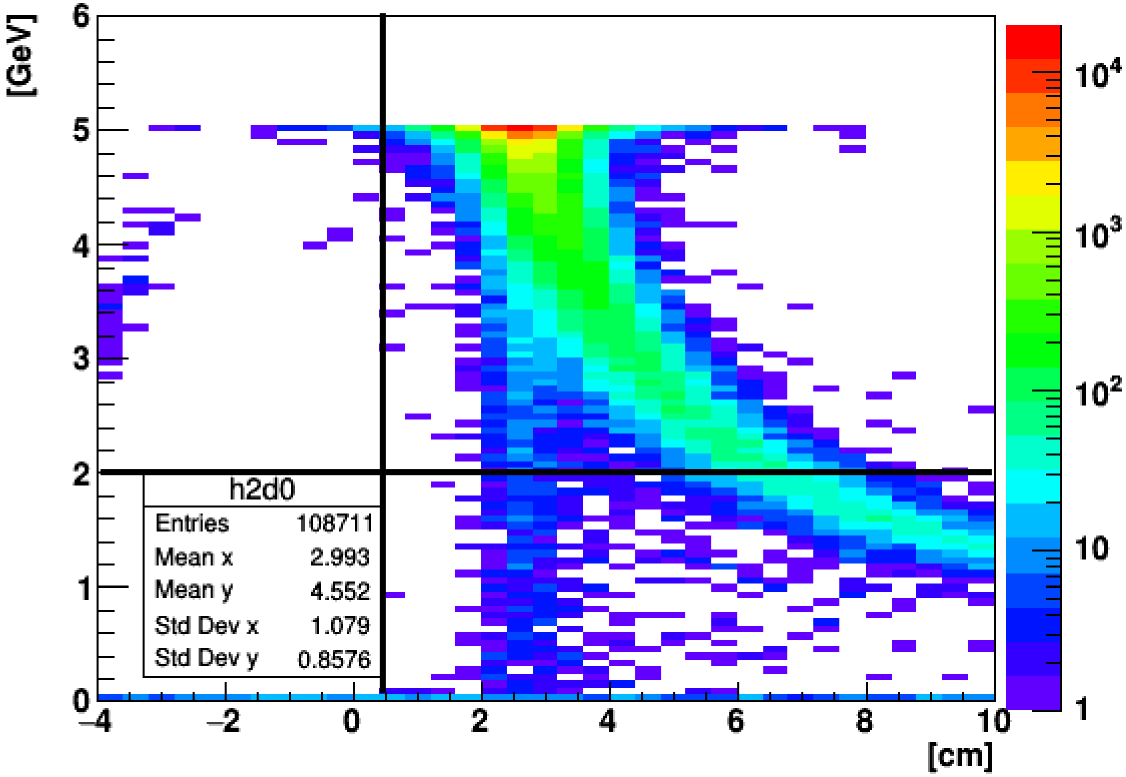
Photons

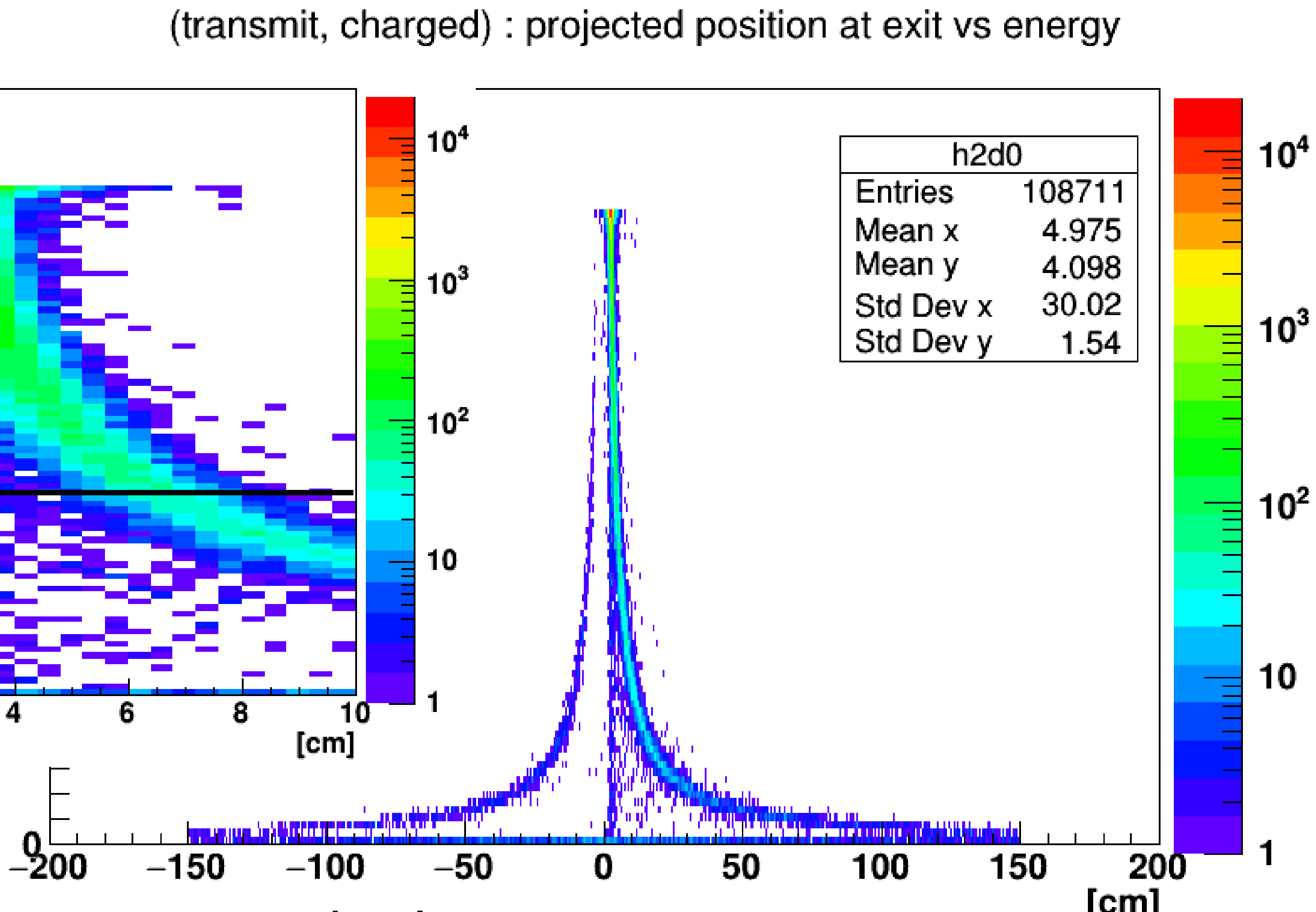
Need to optimize

- **B** field,
- positions of telescope and LumiCal

so that both e and γ beams go through telescope and can be spatially resolvable in LumiCal.

Electron Position vs Energy



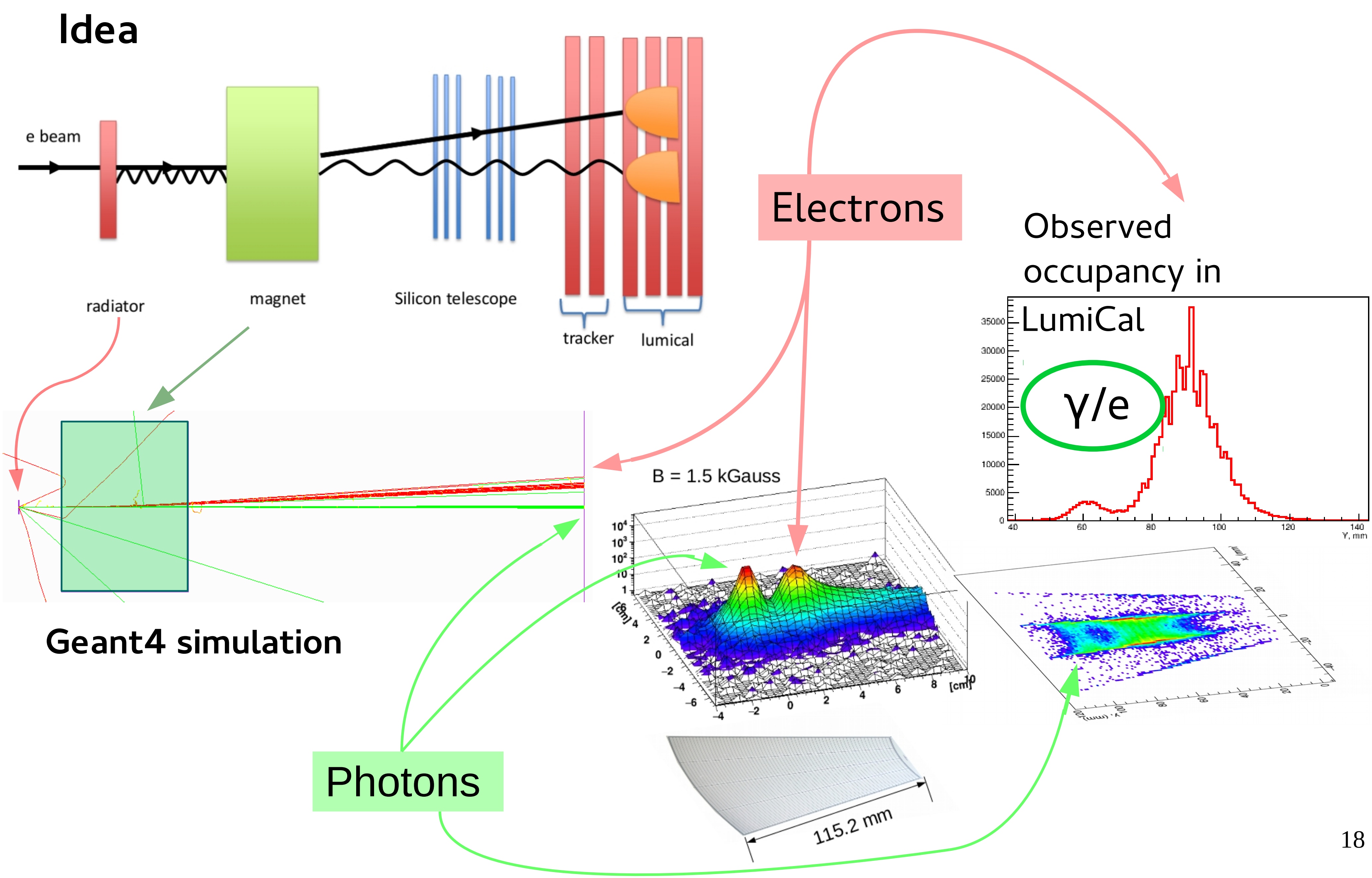


B = 1.5 kGauss;
Cu, d = 1.5 mm;
Distance from the magnet to LumiCal ~3 m.

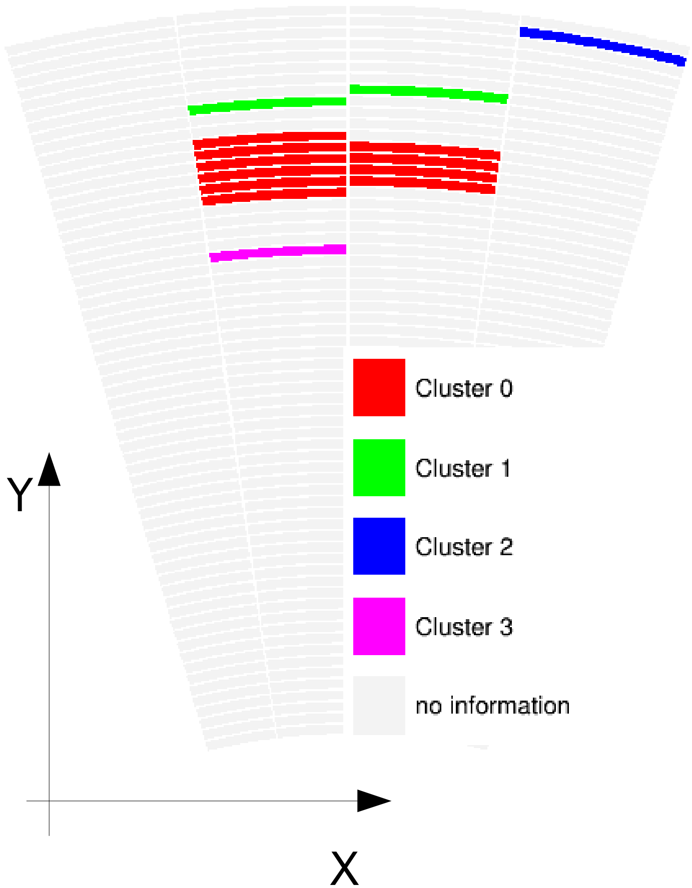
Electron energy in the range 2 GeV – 5 GeV : 86% of events
3 GeV – 5 GeV : 82% of events

2 GeV – 4 GeV : 10%
3 GeV – 4 GeV : 6.6%

Test-beam Design



Clustering Algorithms



E-clustering:
First looks for hits with local maximum of deposited energy and consider them as seeds of the clusters.
Then all neighboring pads with descending energy are assigned to the seeds. Used in Zeus:

- Capable of resolving spatially joined clusters;
- Sensitive to the fluctuation in shower development.

Linking neighboring pads:
Looks for the closest neighbors (with distance no more then 1 pad in any direction) and then collects them to the cluster

- Very simple.

k-means:
Widely used in machine learning. Essentially, assigns points to cluster centers and locate them to minimize sum of the distances:

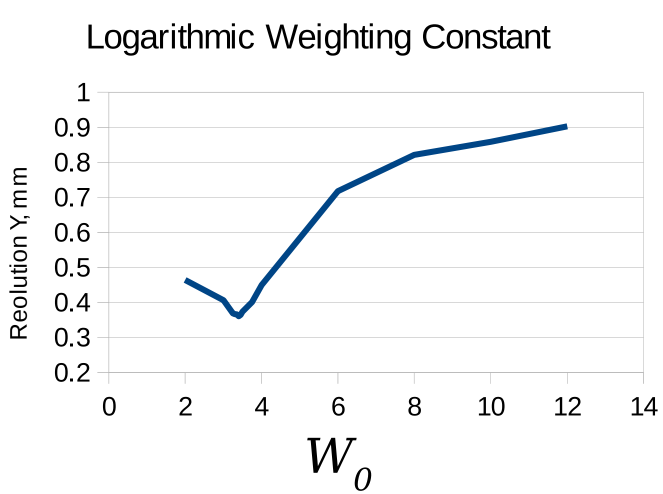
- Different implementations are available, easy to try;
- It assumes a certain given number of clusters and does not use all physics information;

Cluster Position Reconstruction in Simulations

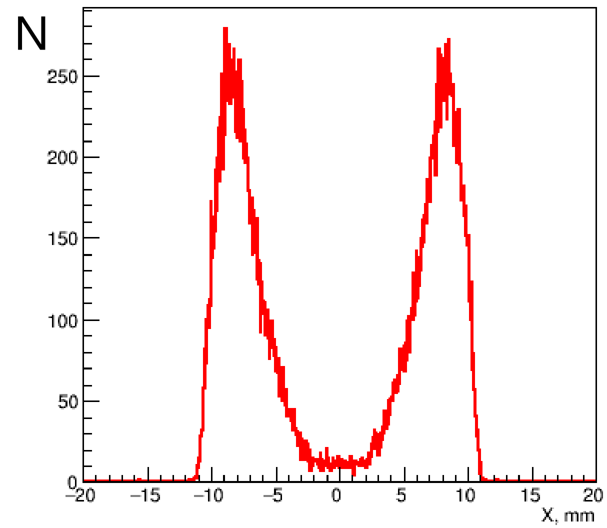
- Logarithmic weighting:

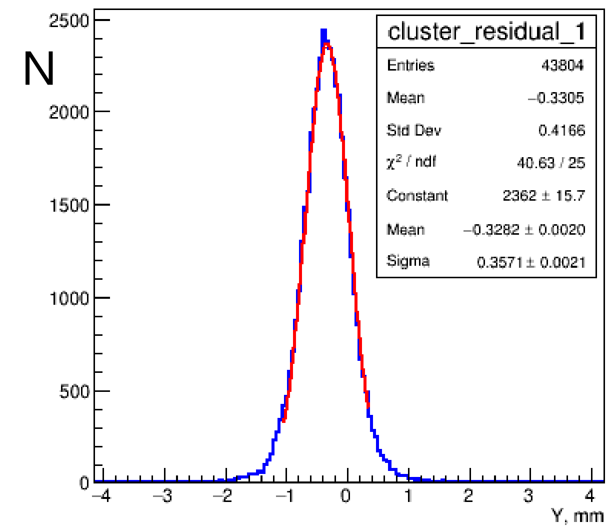
$$Y_s = \frac{\sum\limits_n n w_n}{\sum\limits_n w_n},$$

$$w_n = max\left\{0; W_0 + \ln\frac{E_n}{\sum\limits_n E_n}\right\},$$



At W_0 = 3.4
Y resolution is 0.36 mm

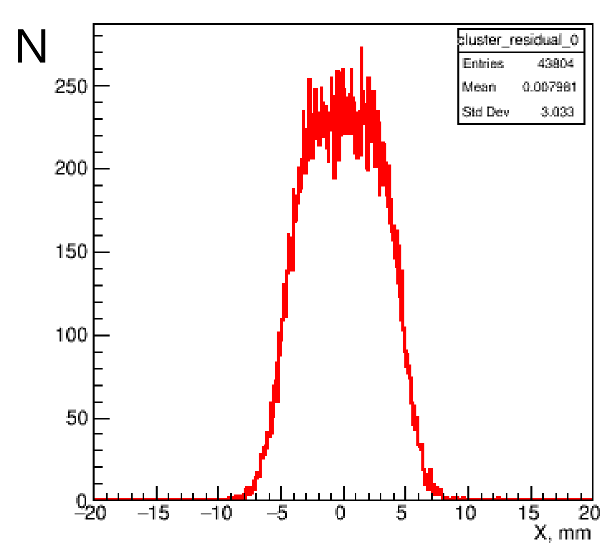


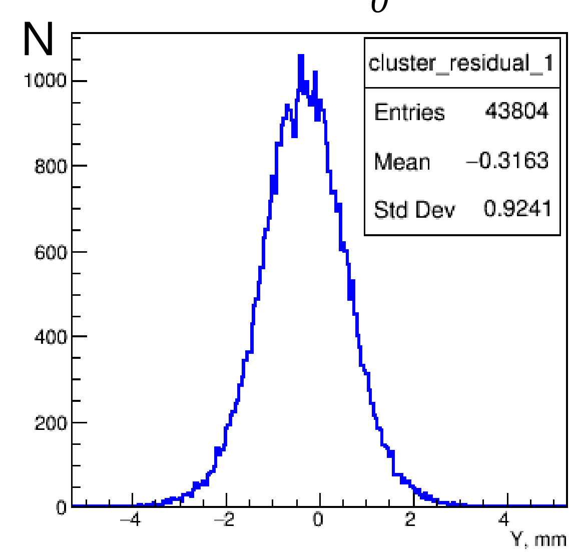


$W_0 = 3.4$

Distributions of X and Y residuals for

$W_0 = 12.0$

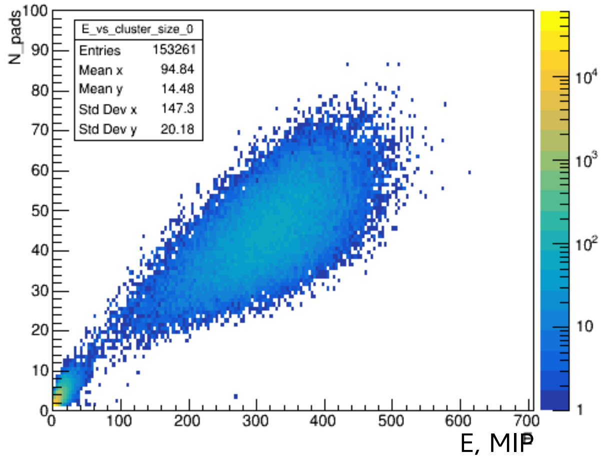


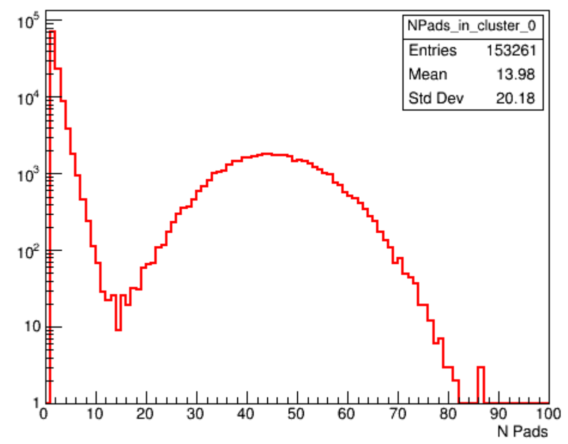


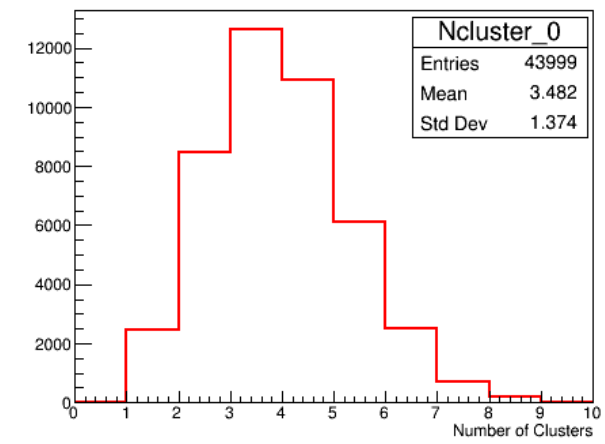
Clusters: MC vs Data

5 GeV electron beam

MC Simulations





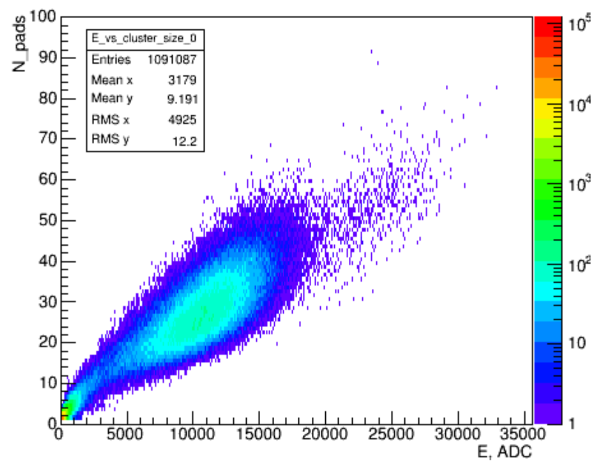


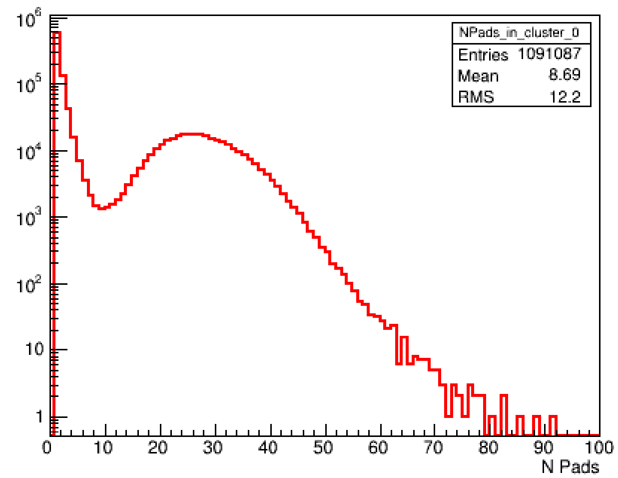
Custer energy vs size

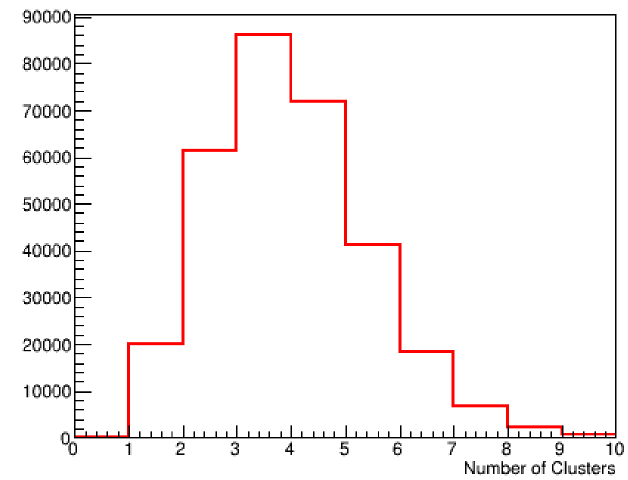
Custer size

Number of clusters

Data



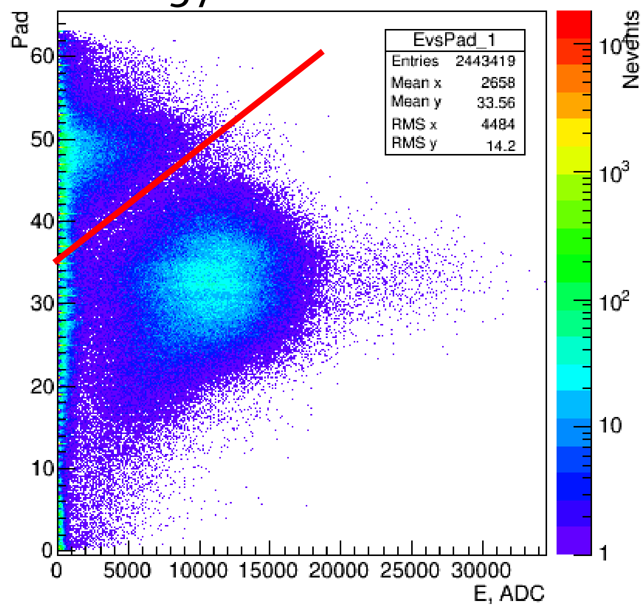




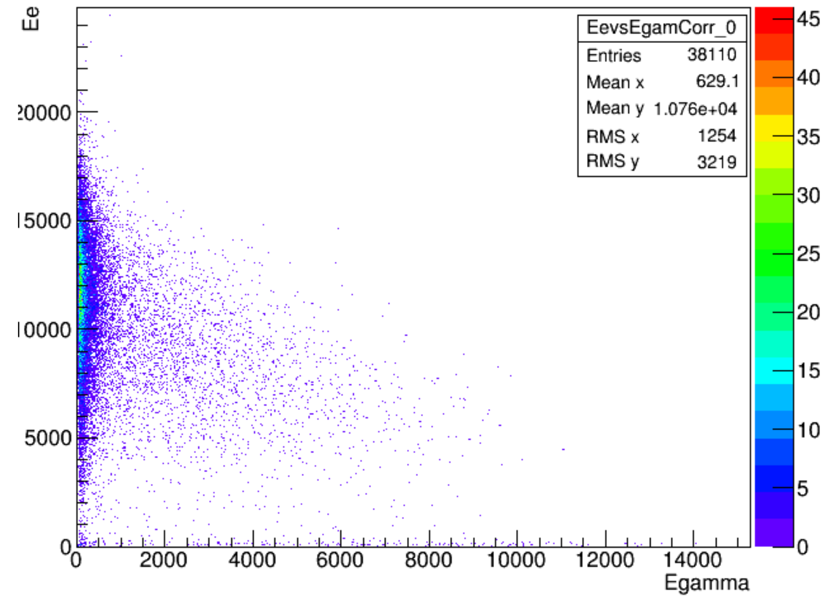
Simulation does not take into account electronic noise,
which might explain the difference in cluster size

Electron and Photon Energy

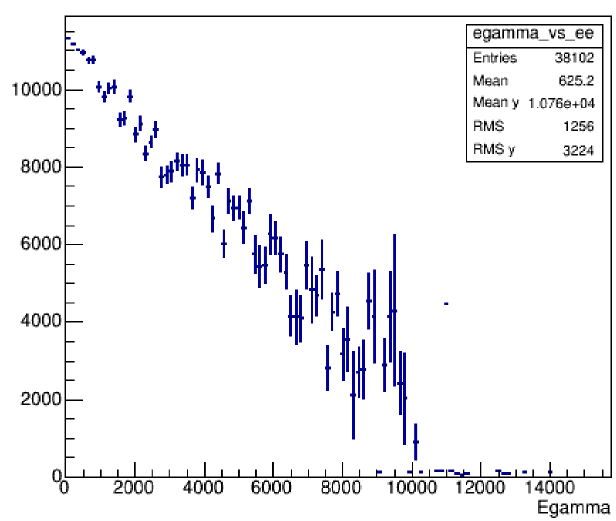
Clusters position vs energy. Data.

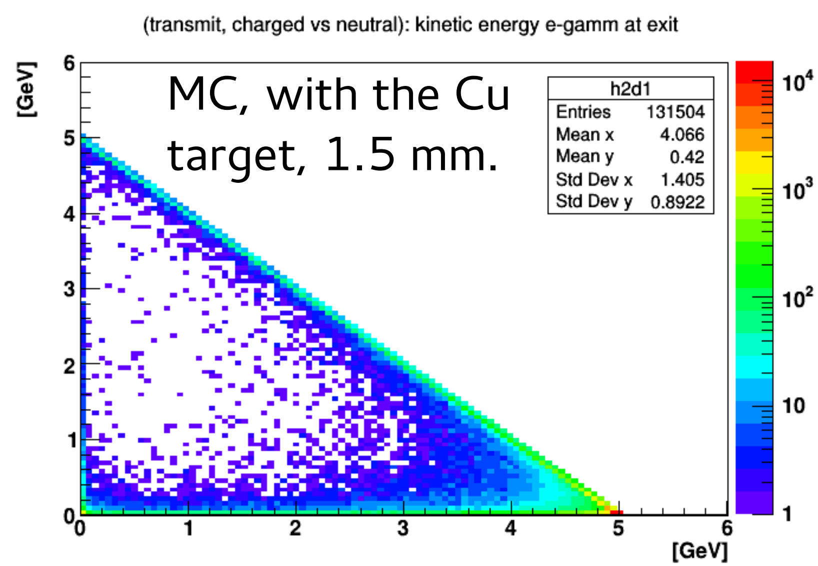


Ee, Eγ correlation, Data



Ee vs Eγ profiling plot. Data.





Summary

- The design of the beam test setup and detector components were studied and optimized in simulations. It has been successfully realized at DESY and allowed to collect data for e/γ identification study in LumiCal combined with tracking detector.
- Neural network was successfully applied to identify the particle signal in raw detector data.
- Different cluster reconstruction algorithms were implemented and tested in simulation and data. Their performance is in good agreement for MC and data.
- Cluster position reconstruction with logarithmic weighting algorithm was optimized in simulation (W_0=3.4). It will be compared to the data using the position of the particle reconstructed in telescope.
- Ongoing study on back scattering and e/γ identification.