Test Beam Results with Ultra Thin LumiCal Detector Planes

Oleksandr Borysov
Tel Aviv University

On behalf of the FCAL collaboration

CHEF17, Lyon
October 3, 2017

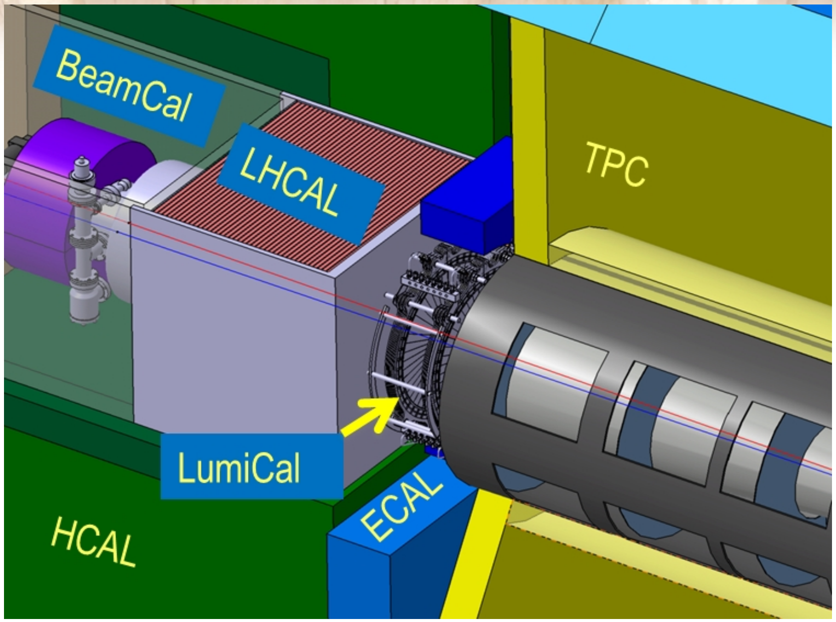
Outline

- Introduction
- Design and assembly of the thin LumiCal module
- Test-beam setup
- Electromagnetic shower development study
- Particle position reconstruction in LumiCal
- Summary

LumiCal in LC Experiments

Goals:

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



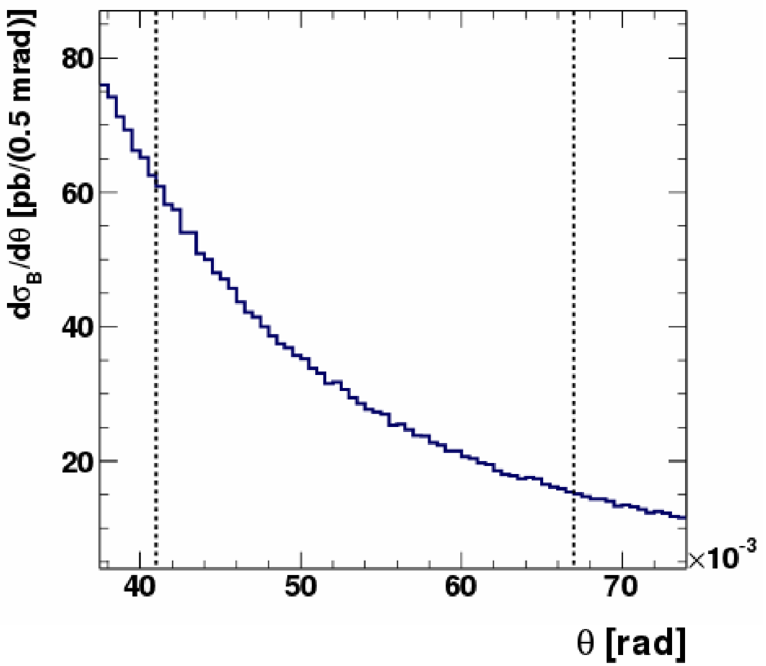
LumiCal Design:

- Electromagnetic sampling calorimiter;
- 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);

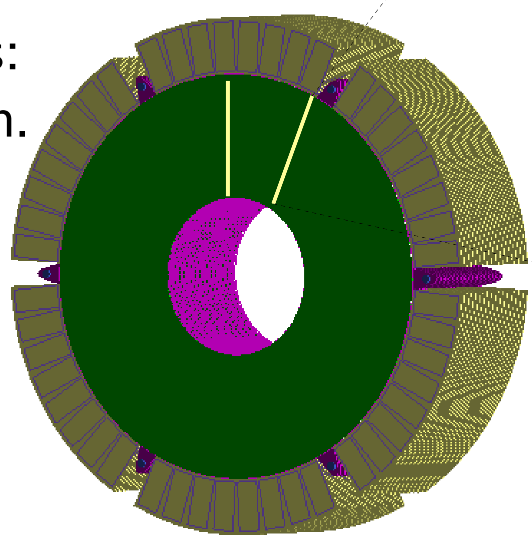
σ_B – integral of the differential cross section over the same θ range.

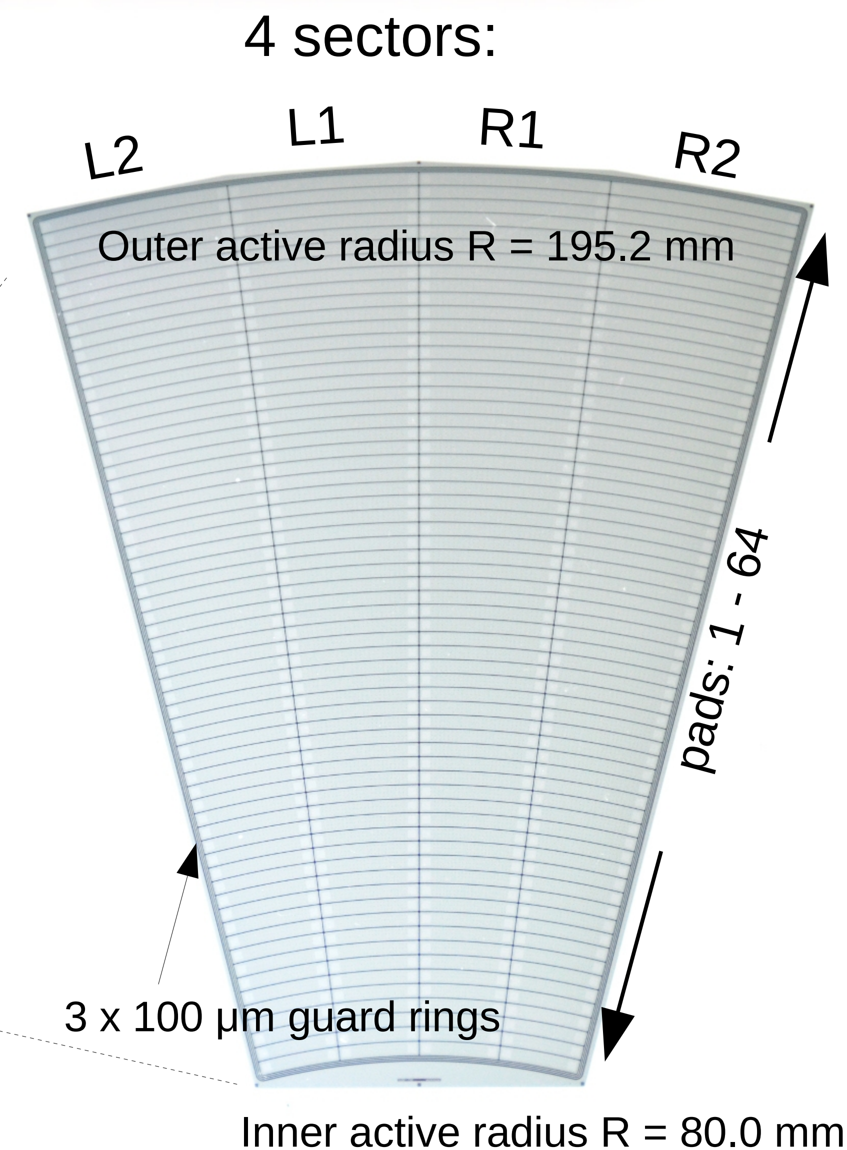


LumiCal and Sensor Design

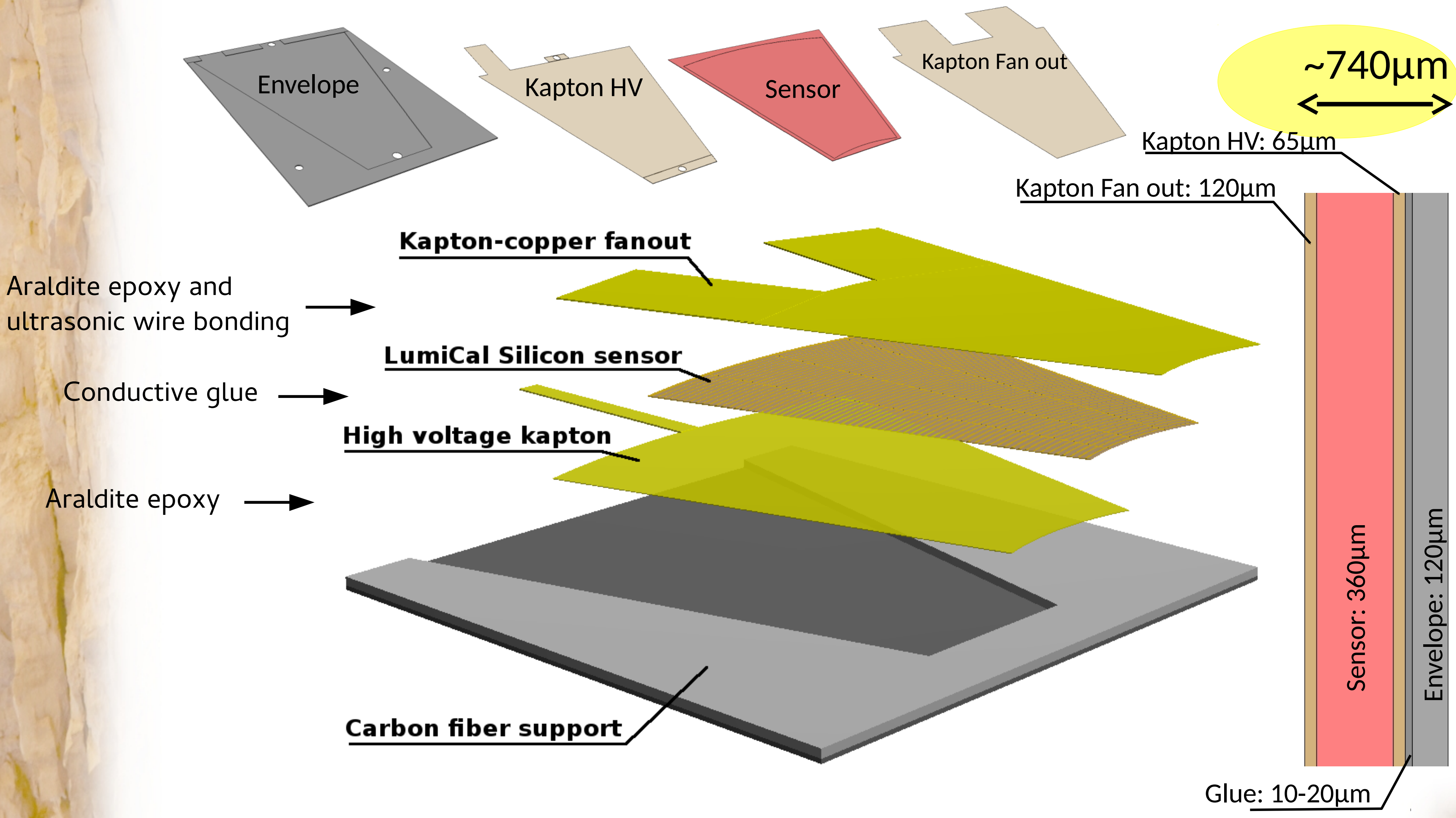
- Silicon sensor
- thickness 320 µm
- DC coupled with readout electronics
- p+ implants in n-type bulk
- 64 radial pads, pitch 1.8 mm
- 3 guard rings
- 4 azimuthal sectors in one tile, each 7.5°
- 12 tiles make full azimuthal coverage

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

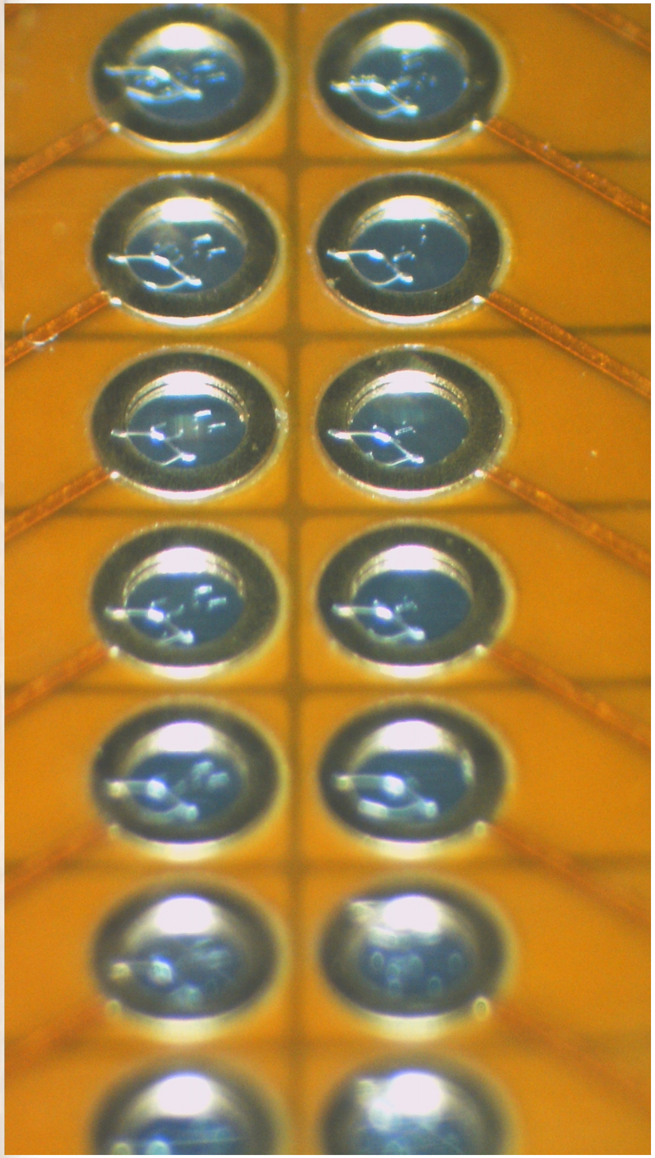




Design of the Thin LumiCal Module

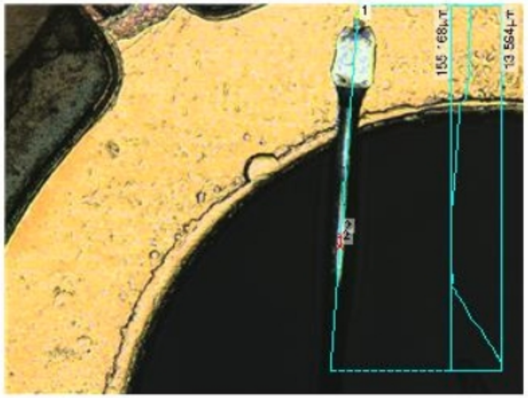


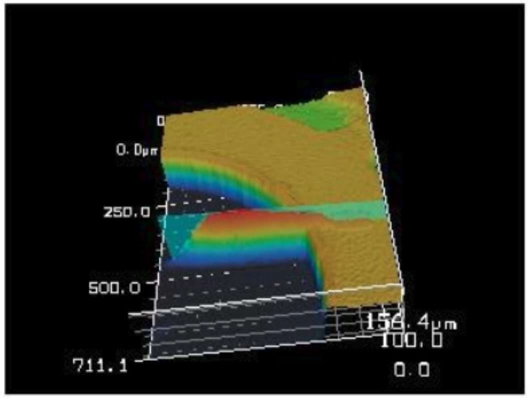
Wedge Wire Bonding for Front-end Contact

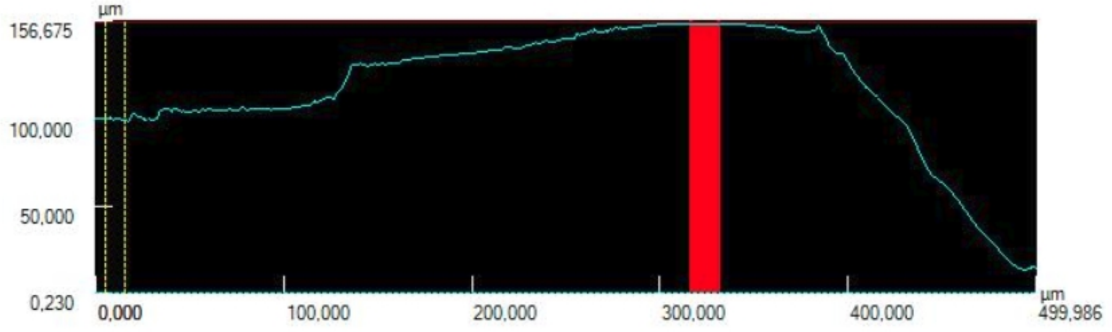


Achievable size of the bonding loops is in the range 50 µm - 100µm.

Bonding loop measured with 3D laser scanning confocal microscope at DESY Zeuthen.

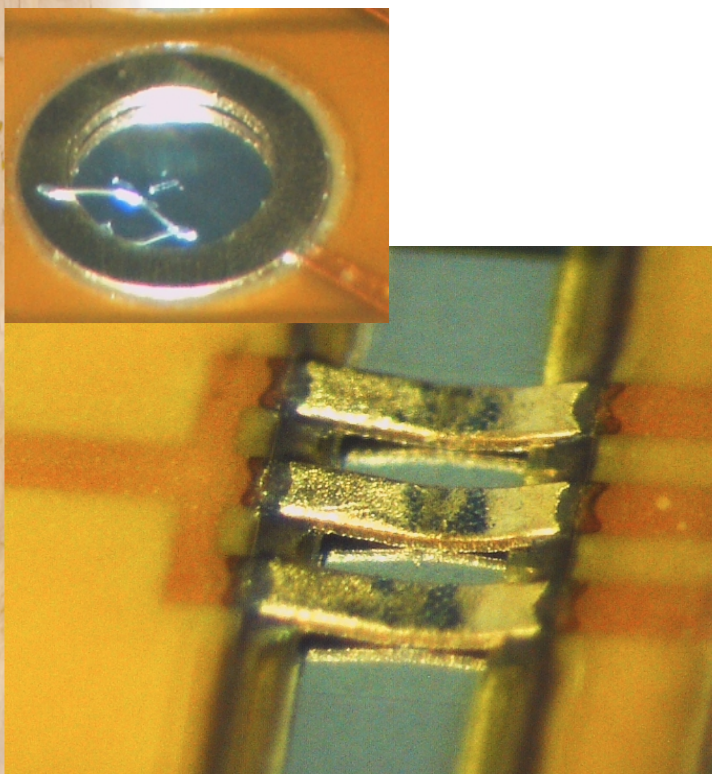


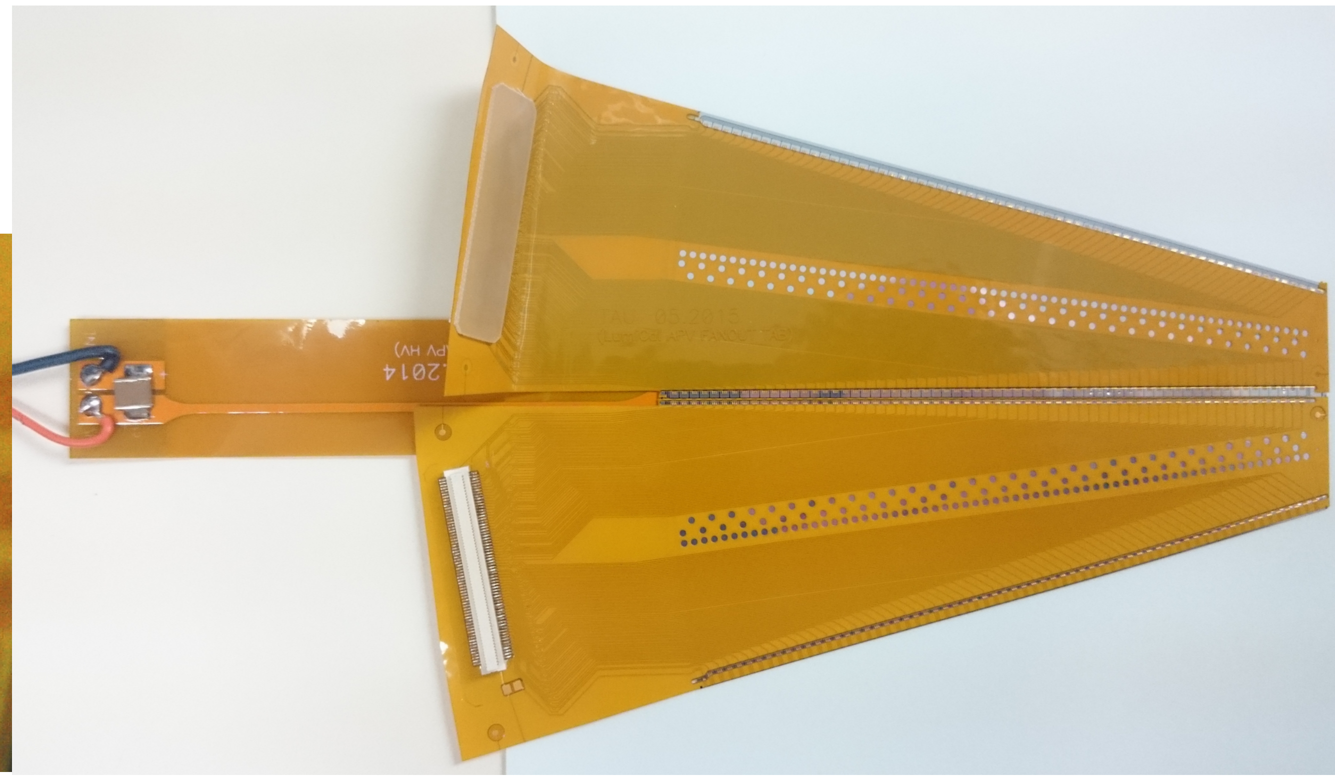




TAB Technology for Front-end Contact

Search for long-term stable contact between sensor and readout electronics which meets LumiCal geometrical (compactness) requirement





Single point Tape Automated Bonding (TAB):

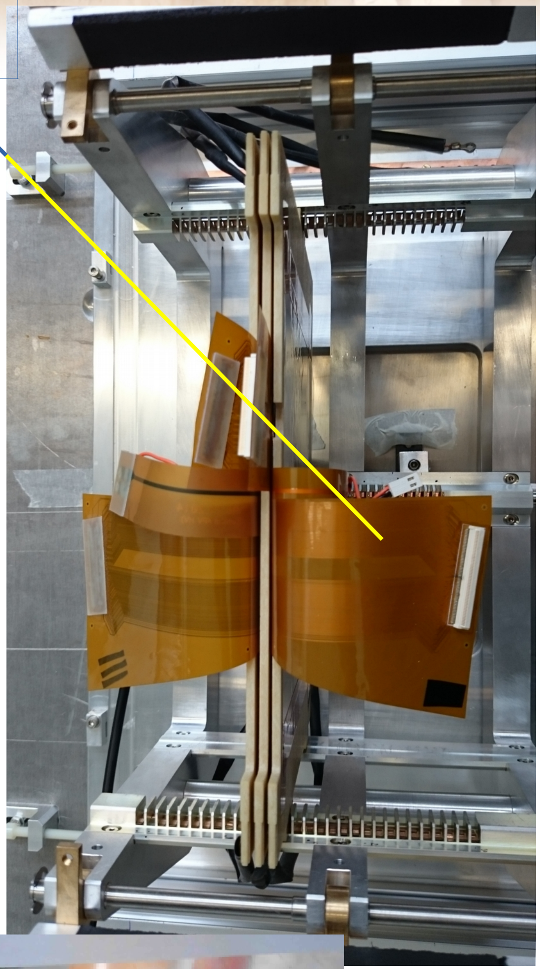
- No wire loop, the bond can be covered by the glue for better protection;
- One LumiCal module is assembled and tested using TAB technology.

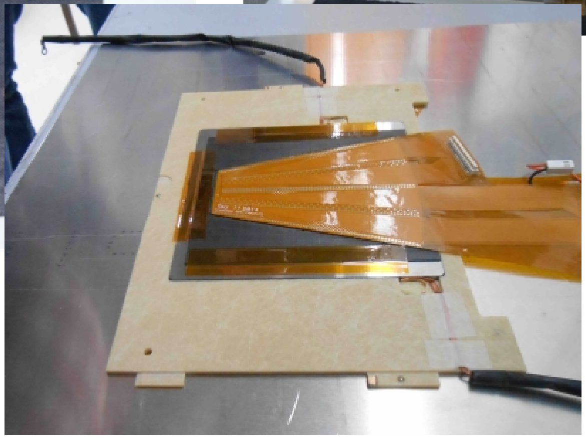
Thin LumiCal Module in Mechanical Frame

Kapton fanout

130 pin Panasonic connectors provides interface to APV-25 hybrid and SRS DAQ system.

Carbon fiber supporting structure ("envelope") provides mechanical stability and easy stack assembly.





- 8 thin modules with full readout (> 2k channels);
- 2 used as a tracker / tagger for e/γ separation;
- 6 used in calorimeter (3 - 8 X0) in 1 mm gap between tungsten;

Readout with SRS and APV-25

Next generation of LumiCal electronics is under development and will be available in 2018.

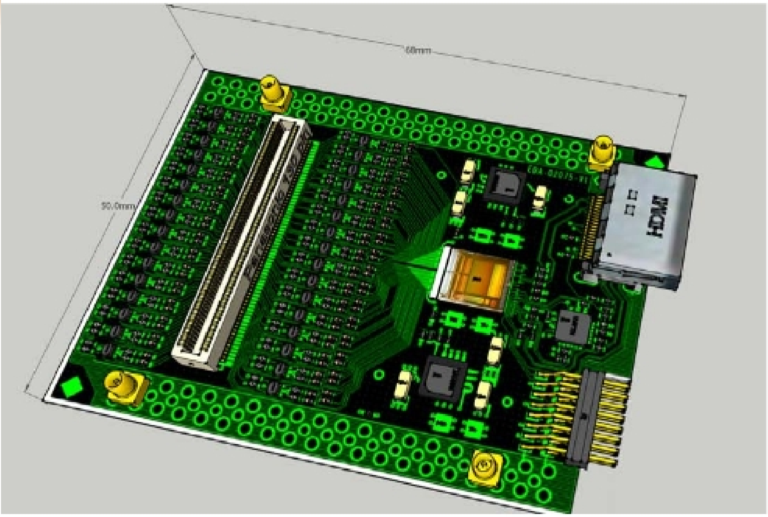
Temporary alternative solution:

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 polarity;
- Sampling rate 40 MHz;
- Supported by SRS;
- Available at CERN stock.

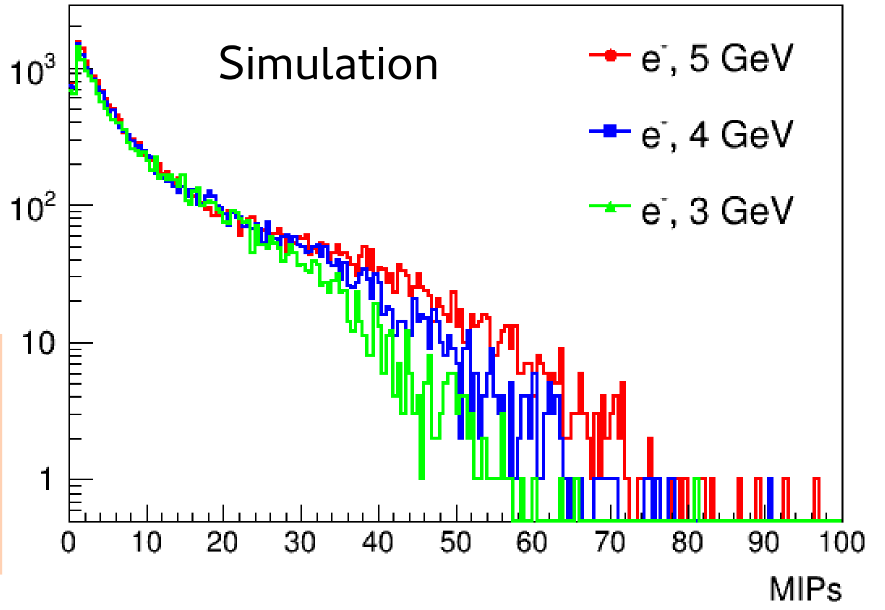
The APV-25 range in case of LumiCals sensor: ~ 8 MIPs

Additional board of "capacitive charge divider" was designed and produced to reduce saturation effect.



Front-end board (hybrid) with APV25 chip

Energy deposition in sensor pad in 5-th layer,



Thin Module Beam Test Goals, Setup

DESY test beam facilities:

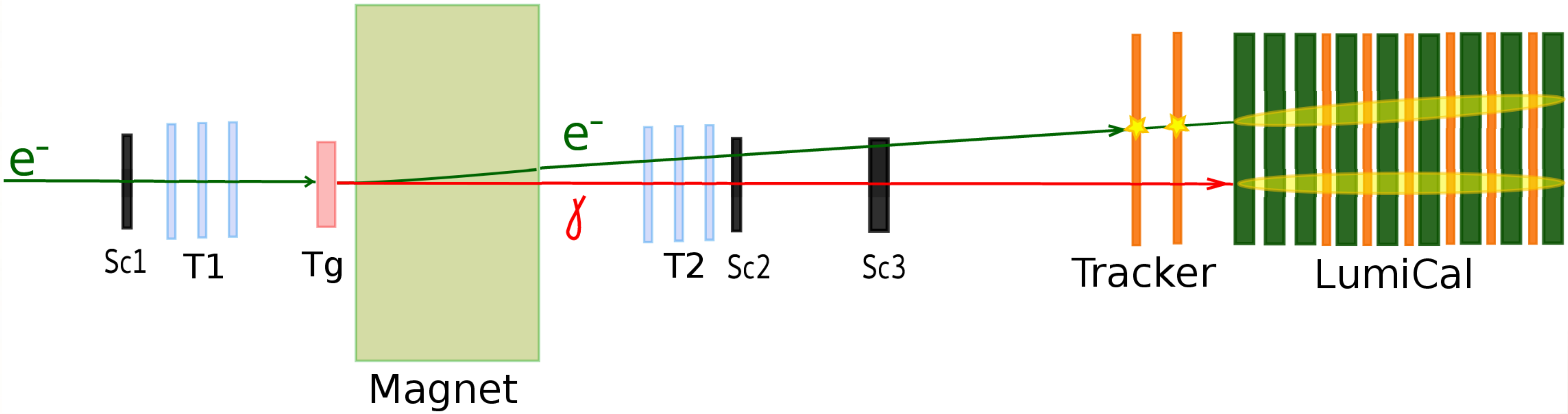
- Electron beam 1 – 6 GeV;
- Dipole magnet 1 – 13 kGs;
- EUTelescope with 6 planes of Mimosa26 detectors;

Performance of the compact LumiCal prototype:

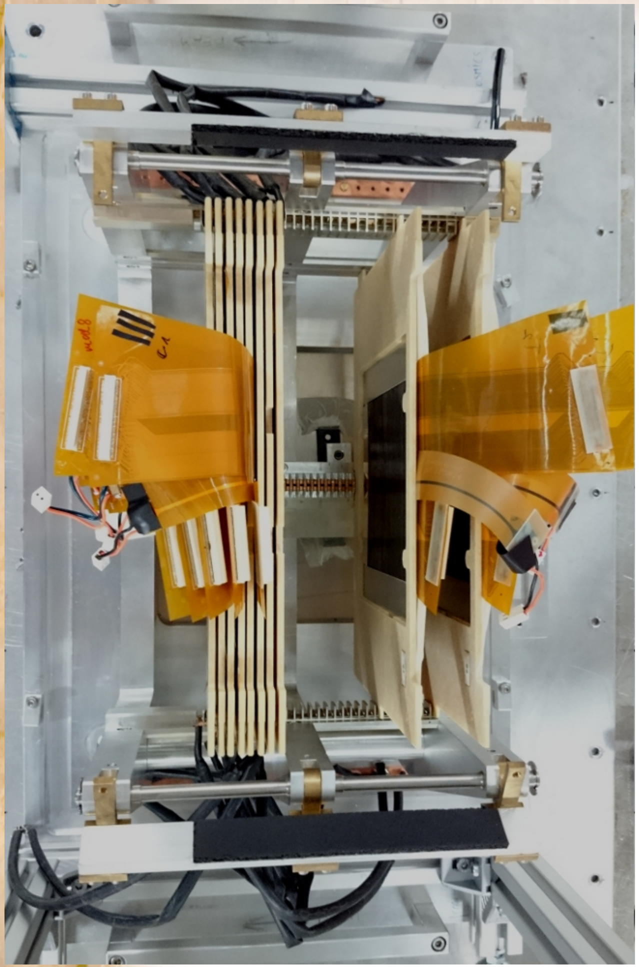
- Detector modules performance: noise, saturation, S/N, etc;
- Energy response to e^- beam of 1 – 6 GeV;
- Electromagnetic shower development study, Moliere Radius measurement.

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

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



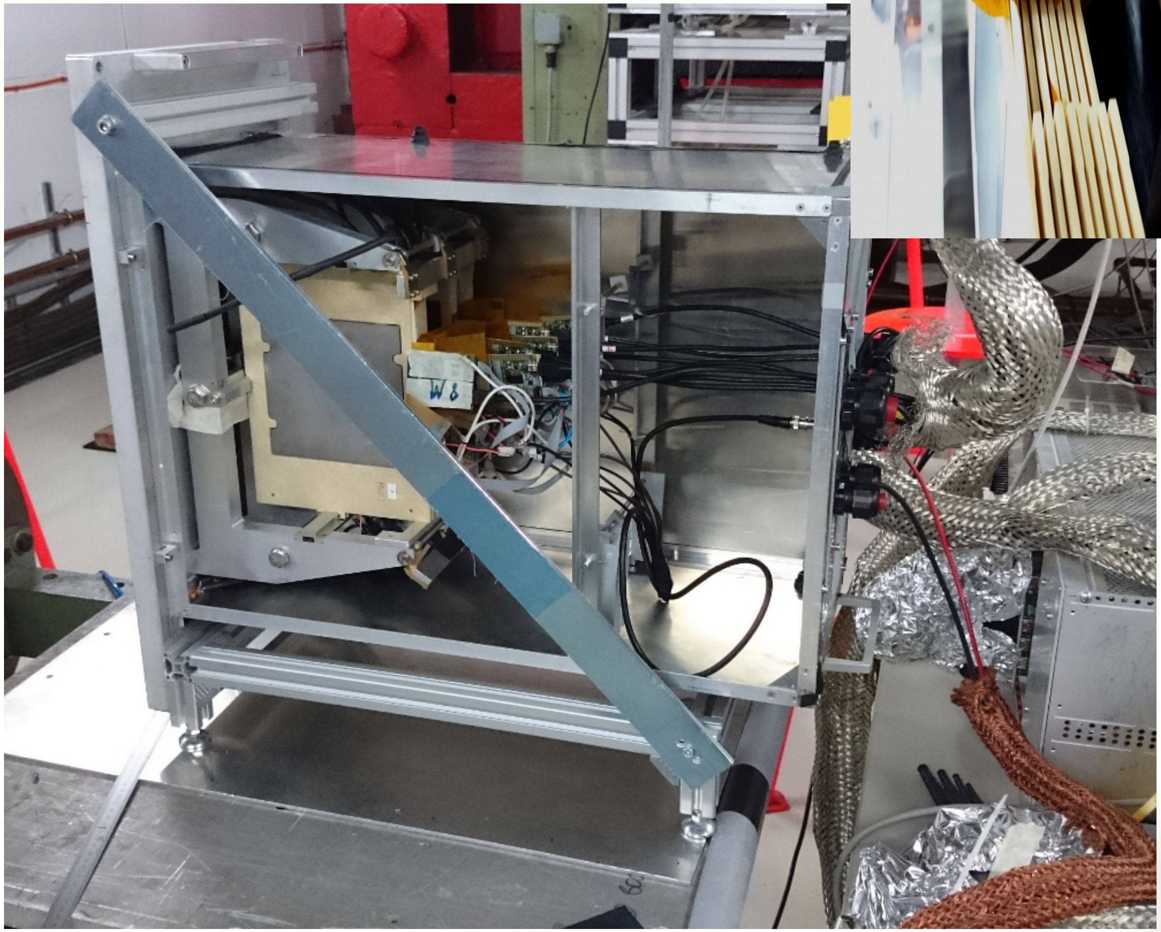
LumiCal Beam Test Installation

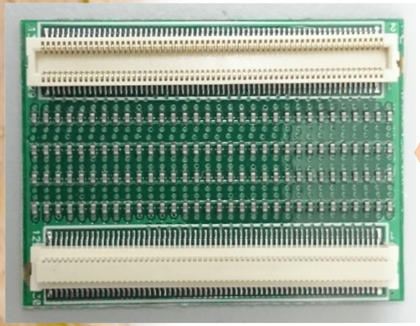


Top view of the thin modules in a stack

APV-25 front-end boards connected to the short side of the fan-out

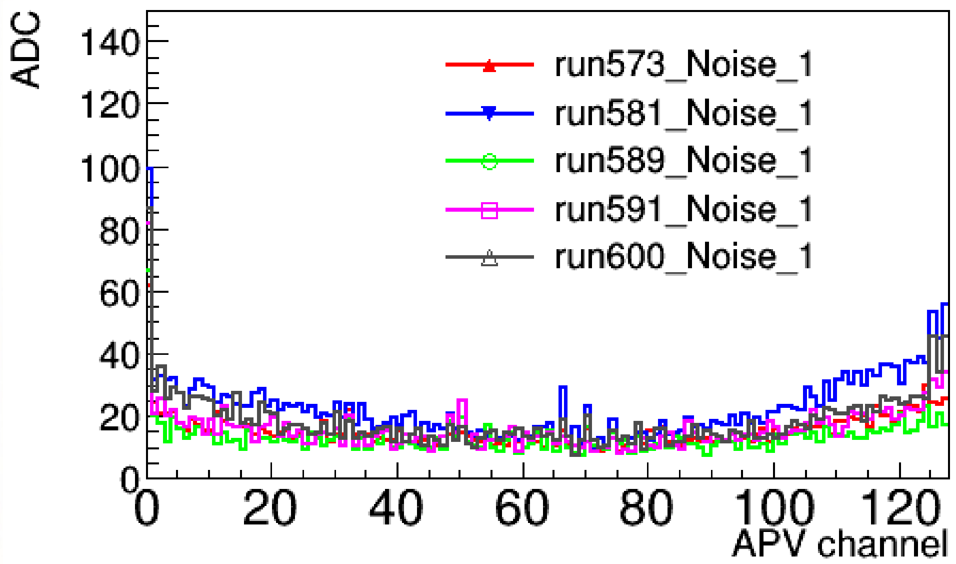
Mainframe rotated by 90°

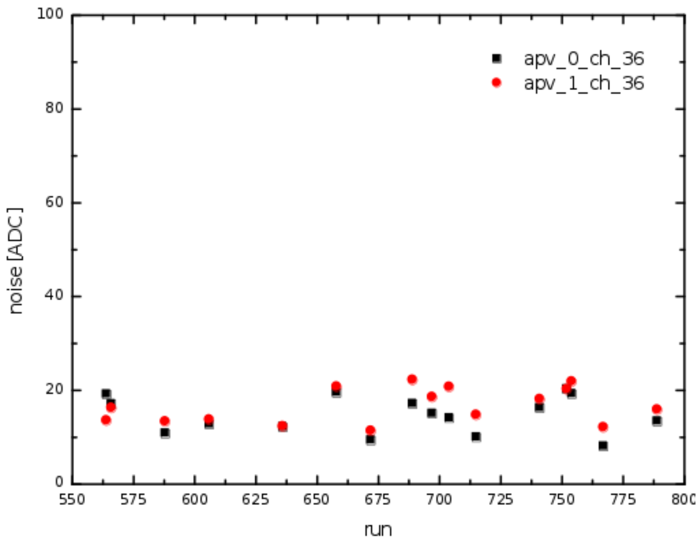




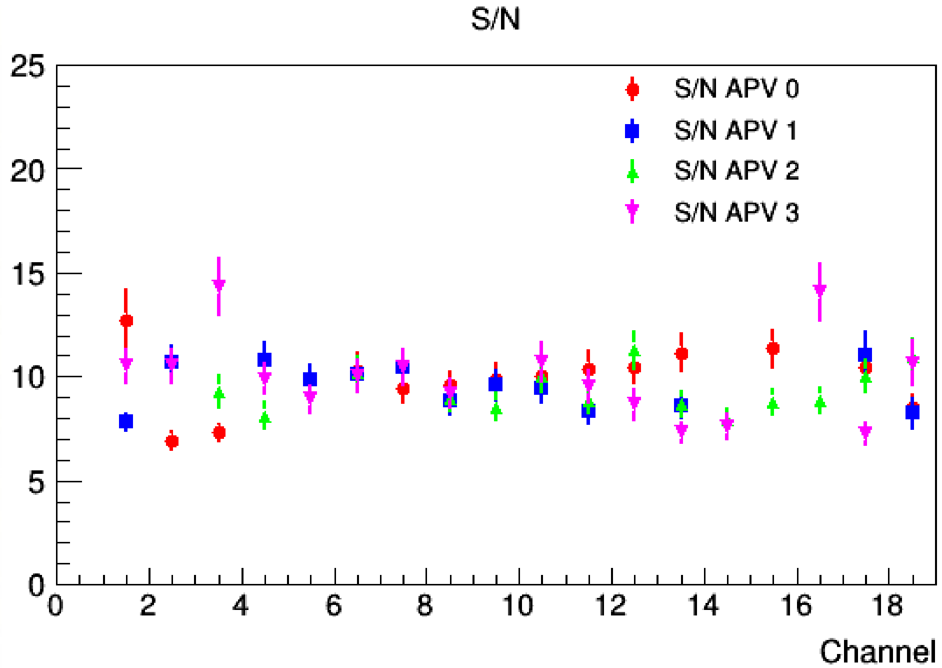
Charge divider board, 37x28 mm².

Noise in Tracking Planes





Noise change during TB

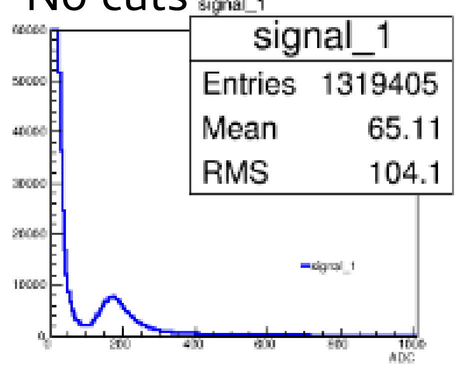


- Signal to noise ration is evaluated for the channels of tracking planes;
- 5 GeV e^- deposition is considered as a signal (close to MIP).

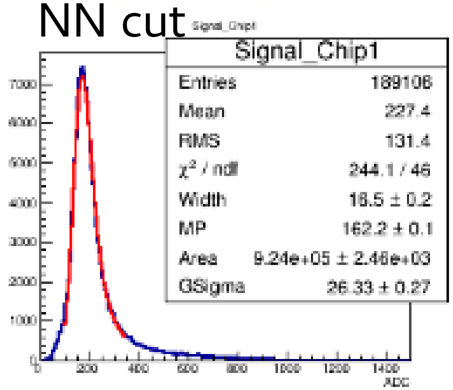
LumiCal Energy Response

Cosmic muon events are collected for calibration.

No cuts

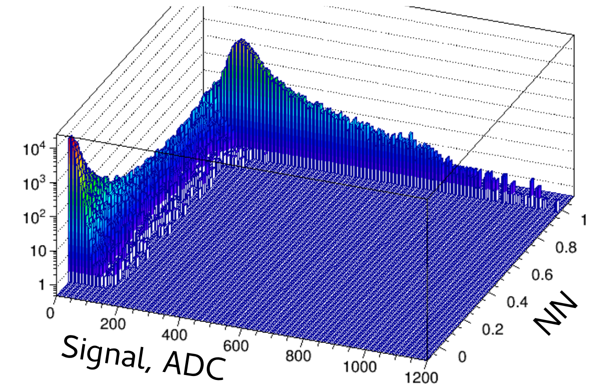


NN cut

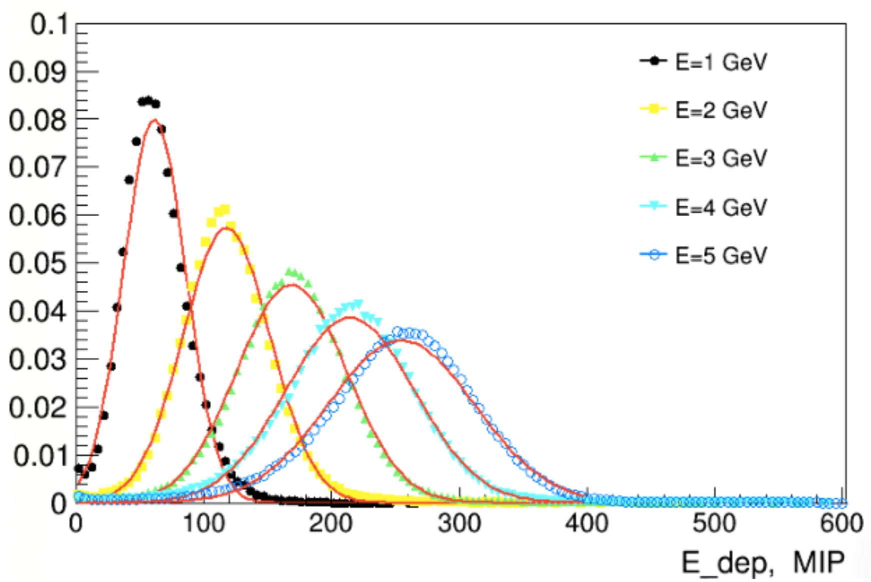


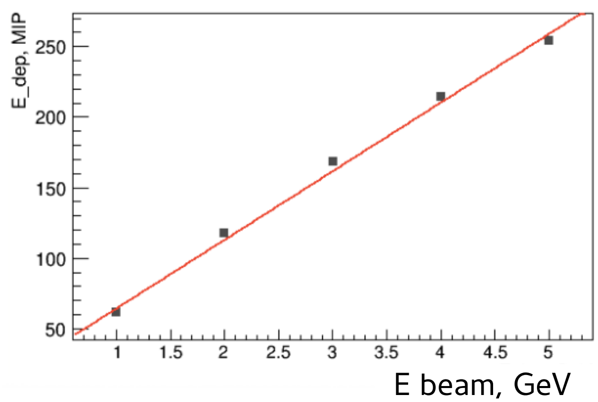
Energy deposited in LumiCal sensor by cosmic muon (ADC)

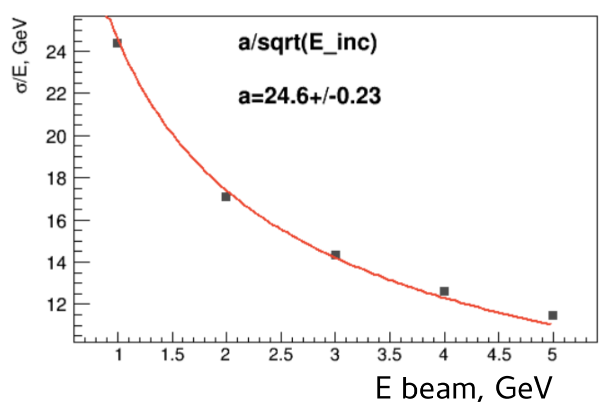
Signal selection with neural network (NN)



LumiCal response
when running with charge divider

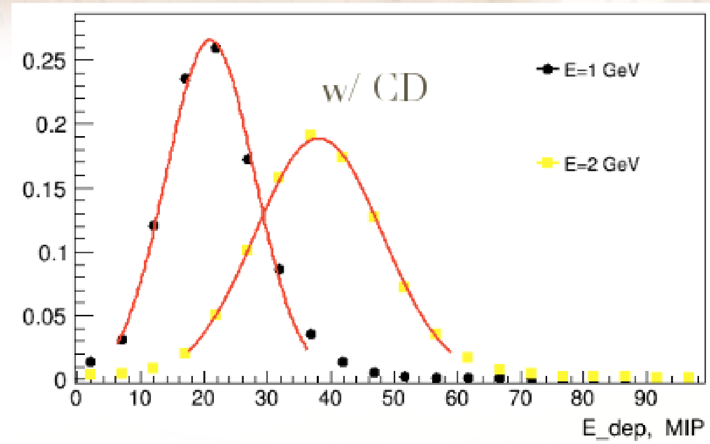


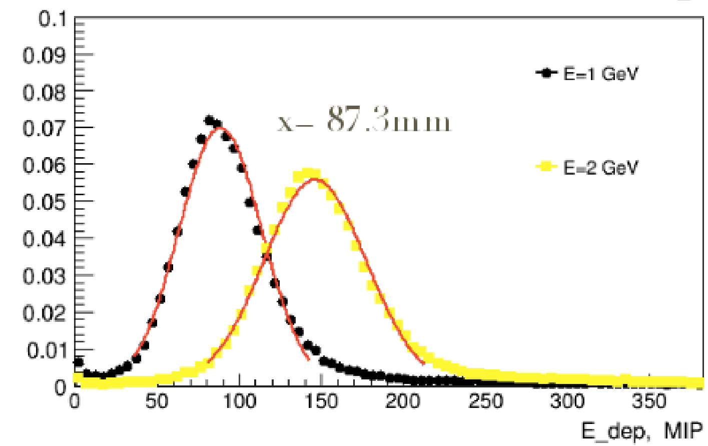




Charge Divider Calibration

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.



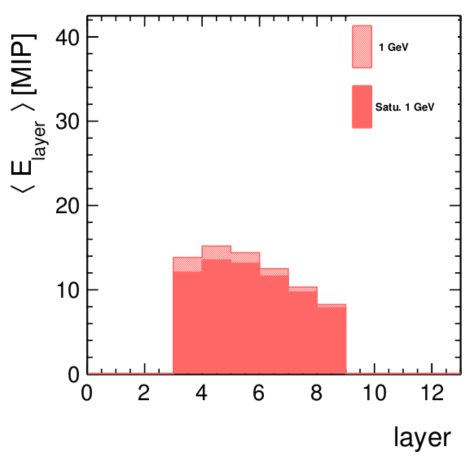


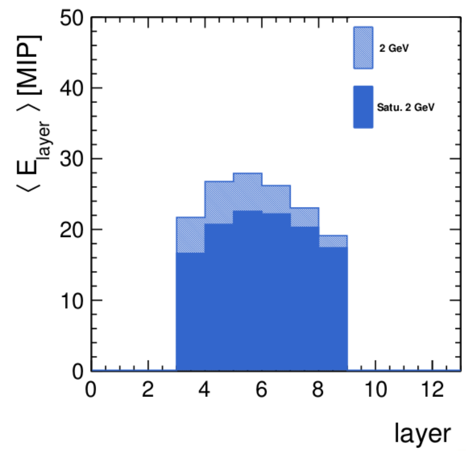
Estimation for

- 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



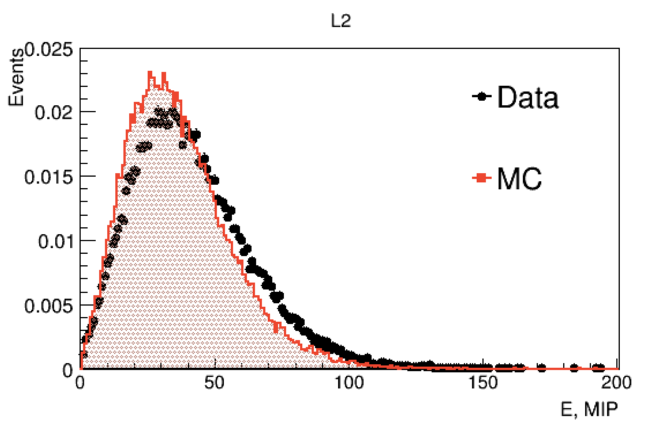


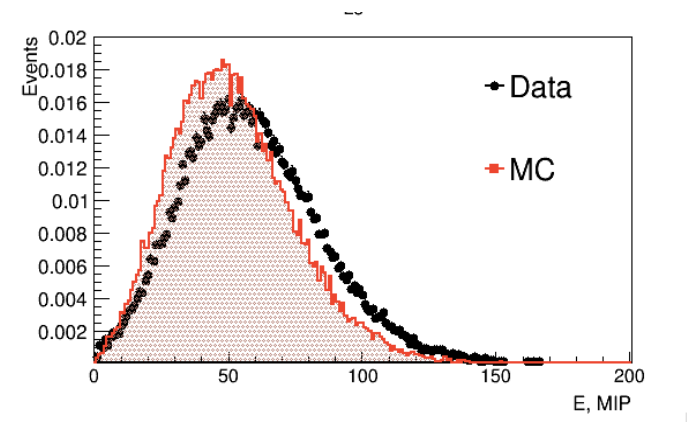
- Taking into account this correction the calibration factor in both measurements is around 4.7.
- As expected there is dependence on the input capacitance observed in different beam positions.

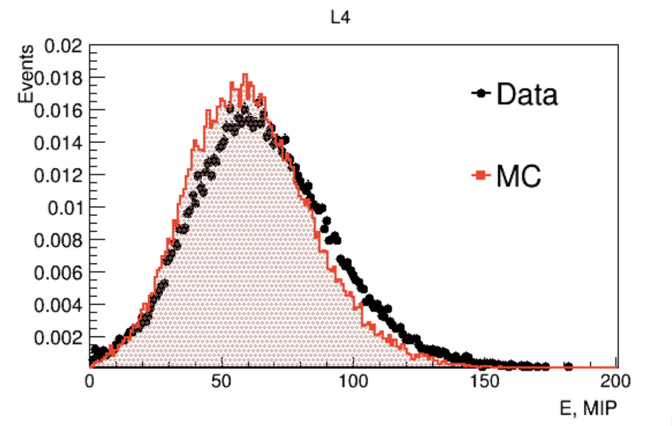
Longitudinal Shower

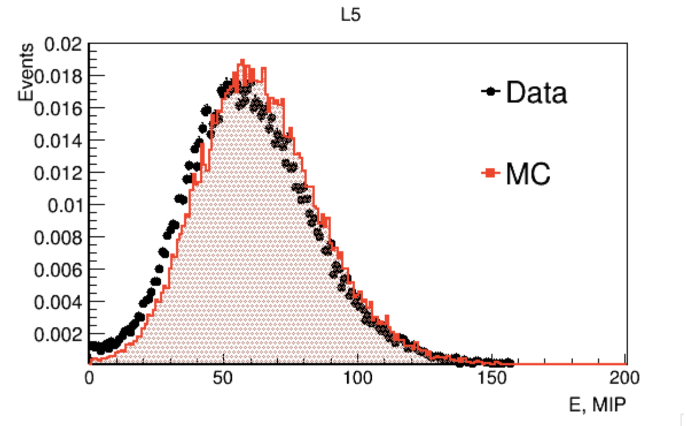
Work in progress...

Sensitive layers are installed after 3, 4, 5, 6 tungsten plates, it roughly corresponds to 3, 4, 5, 6 X0.









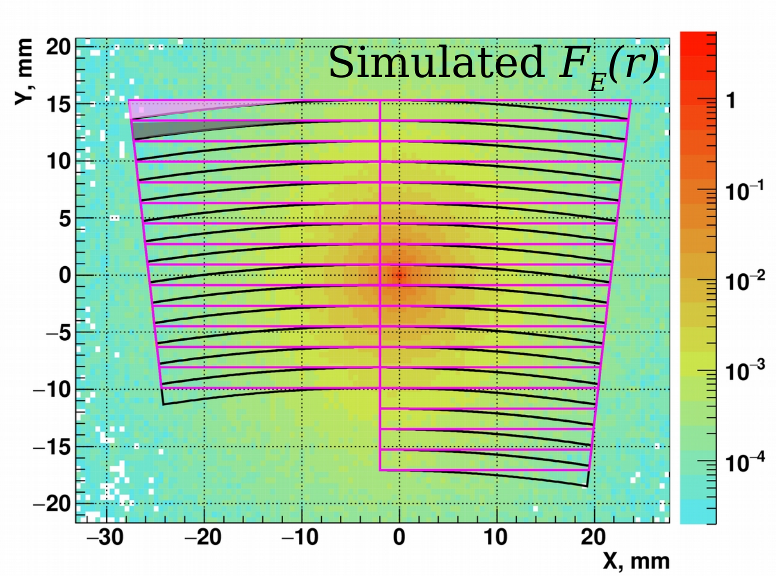
- Inaccuracy in calibration is responsible for the difference between data and MC.

Shower Study in Transverse Plane

Procedure was developed for 2014 beam test of LumiCal prototype at CERN (PS, 5 GeV e- beam).

Result is **R_M=24.0 ± 0.6(stat.) ± 1.5(syst.) mm**.

(arXiv:1705.03885)



Grid – LumiCal sensor, sectors L1, R1.

Average distribution of deposited energy in transverse plane:

$$F_E(r) = A_C e^{-\left(\frac{r}{R_C}\right)^2} + A_T \frac{2r^\alpha R_T^2}{(r^2+R_T^2)^2}$$

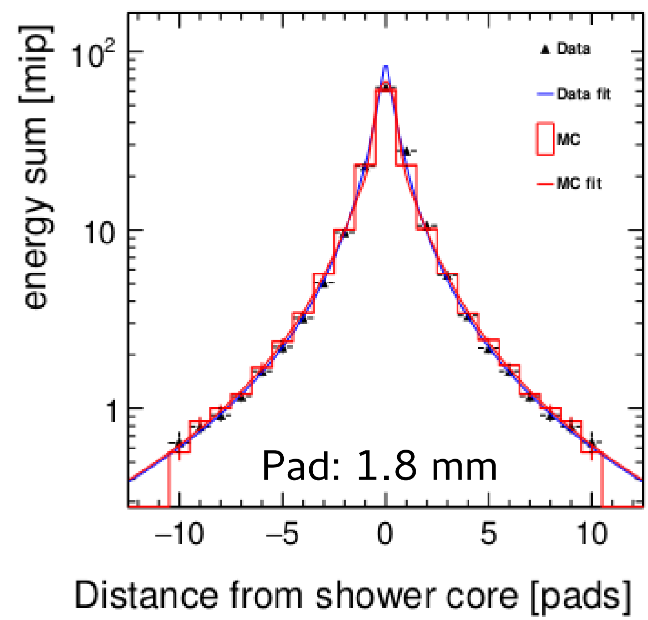
$r=\sqrt{x^2+y^2}$ – the distance from the shower center;

A_C, A_T, R_C, R_T, α – fit parameters.

$$G_E(y) = \int_{X_{min}}^{X_{max}} F_E(\sqrt{x^2+y^2})dx$$

$\{Xmin\ , Xmax\ \}$ correspond to the area connected to readout.

Fit parameters are found by fitting G_E(y) to MC and data.



Assuming $F_E(r, \{p_i\})$ normalized to unity,

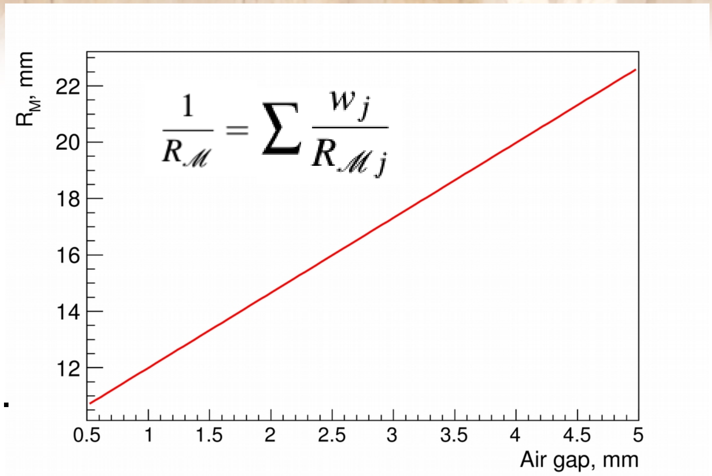
Moliere radius R_M can be found from the equation:

$$0.9 = \int_0^{2\pi} d\varphi \int_0^{R_{\mathscr{M}}} F_E(r)rdr$$

Shower Study in Transverse Plane

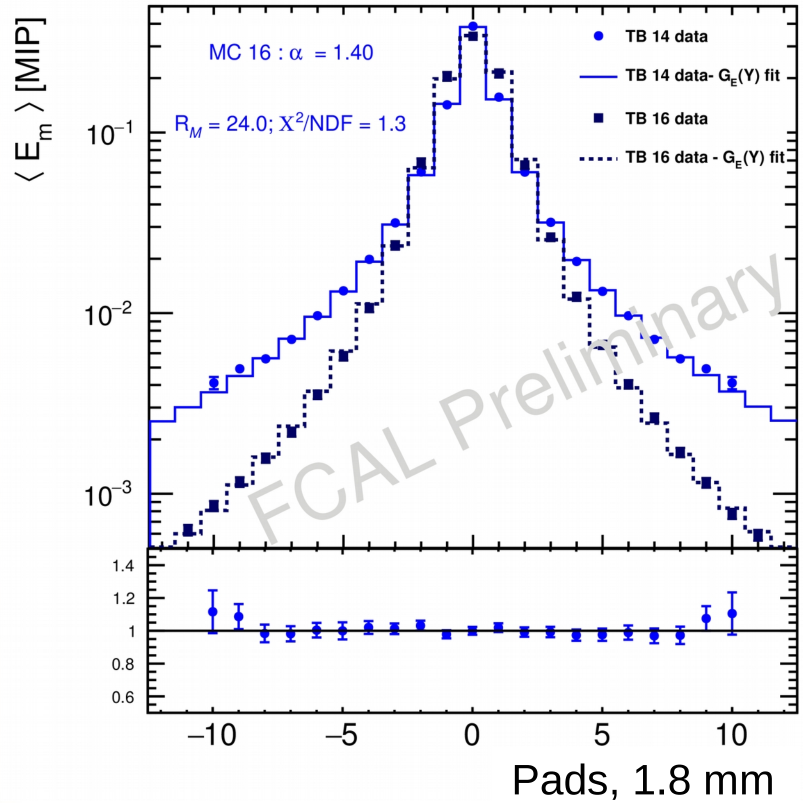
The dependence of R_M on the gap between absorbers can be estimated using the formula recommended by PDG for composite materials.

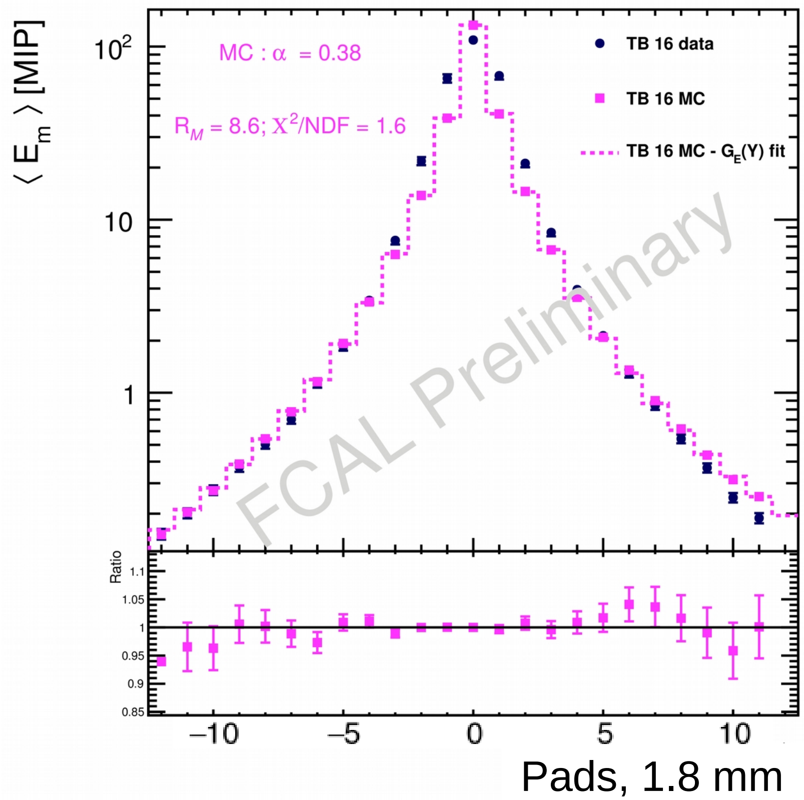
R_M as function of the air gap between 3.5 mm thick tungsten plates



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

Comparison of transverse shower in TB2016 with TB2014

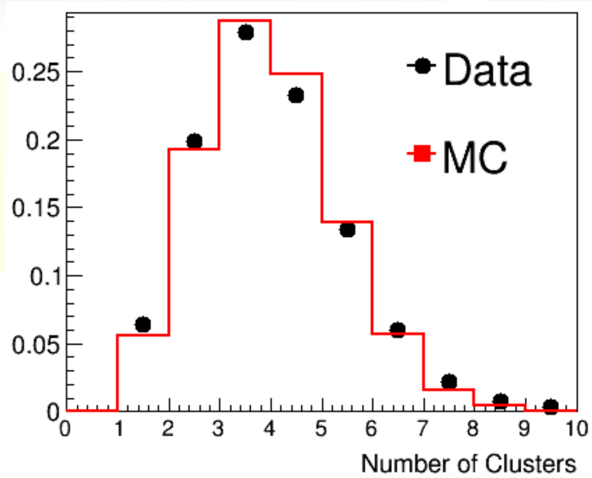




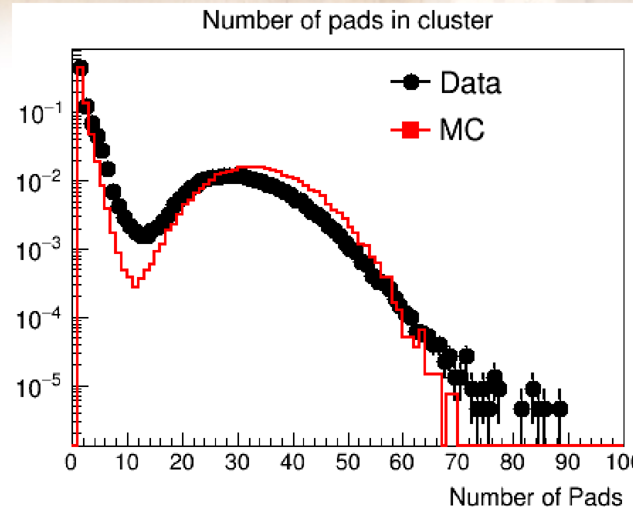
Clusters: MC vs Data

5 GeV electron beam

Reasonable agreement between parameters of reconstructed clusters in simulation and in data.



Number of clusters

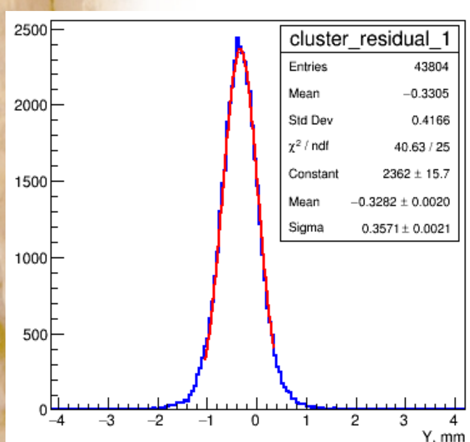


Cluster size

Position reconstruction with logarithmic weighting:

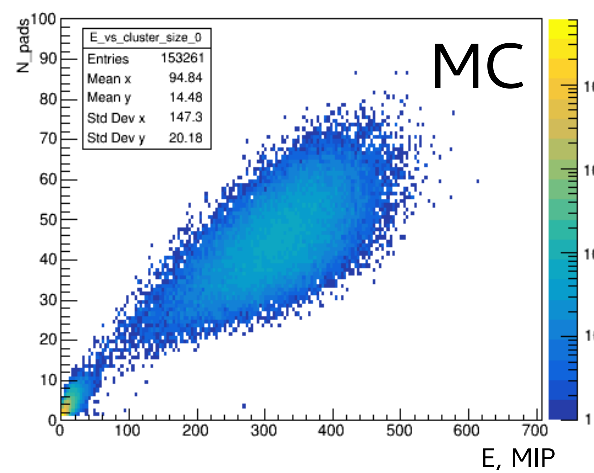
$$Y_s = \frac{\sum_n n w_n}{\sum_n w_n},$$

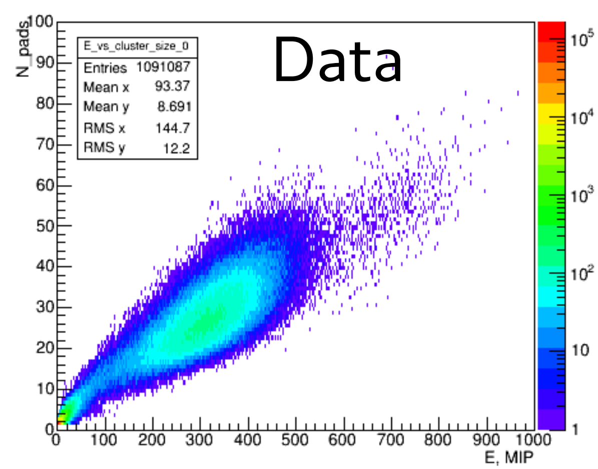
$$w_n = max\left\{0; W_0 + \ln\frac{E_n}{\sum_n E_n}\right\},$$



At W_0 = 3.4

Y resolution is 0.36 mm





Cluster energy vs size

Summary

- Thin LumiCal module with submillimeter thickness was developed and produced. Its geometry meets requirements of LumiCal conceptual design.
- The LumiCal prototype with eight thin modules and existing mechanical structure was assembled and tested with beam. Data analysis is in progress.
- One LumiCal module prototype with TAB technology has been produced and installed for the beam test. Reasonable data were recorded, further analysis will give more information.
- Charge divider circuit has been designed and used to adapt APV-25 chip for LumiCal readout significantly reducing the number of data with saturated channels.
- LumiCal prototype demonstrated good linear response.
- Compact assembly of LumiCal with thin detector module results in significantly narrower transverse shower compared to previous beam tests and much smaller Moliere radius.
- The performance of clusters reconstruction for data and MC are in good agreement. The resolution of particle position reconstruction in LumiCal with logarithmic weighting algorithm for 5 GeV electrons is 0.36 mm.