Calorimeters for strong-field QED experiments

Oleksandr Borysov
Tel Aviv University

On behalf of the TAU group

TEL AVIV UNIVERSITY אוניברסיטת תל אביב

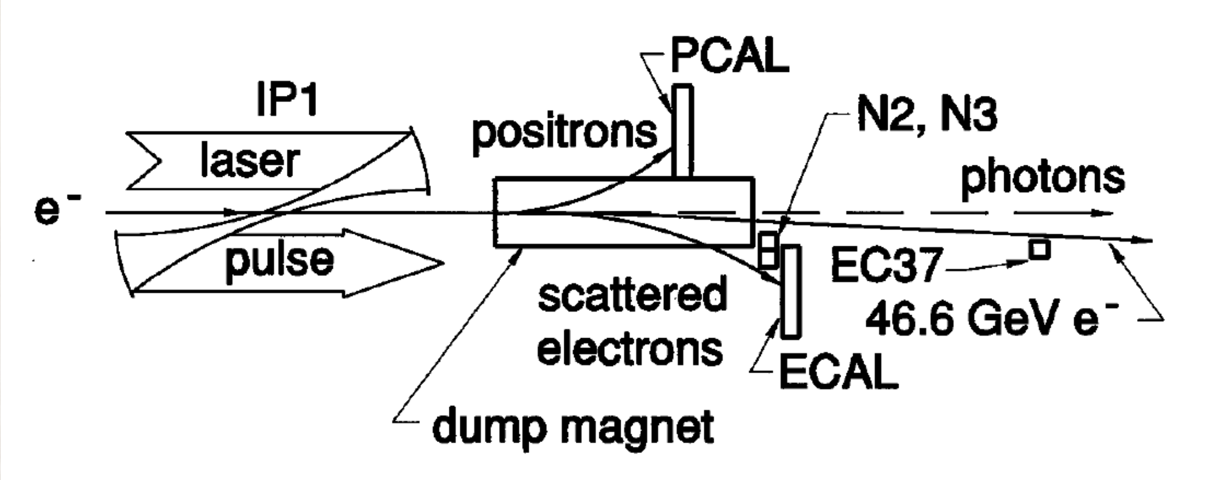
QED Workshop,
DESY, August 23, 2018

Outline

- Introduction
- Design and assembly of the thin detector module for electromagnetic sampling calorimeter
- Test-beam of the calorimeter prototype
- Electromagnetic shower development study
- Particle position reconstruction
- Summary

Calorimeters at SLAC Experiment

PCAL and ECAL
are Si-W sampling calorimeters



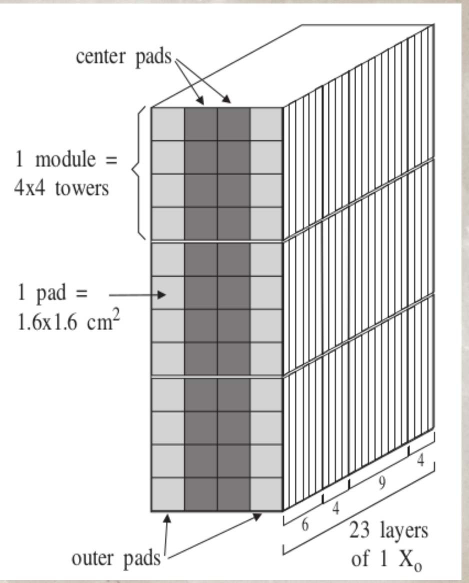
Schematic layout of the experiment.
Phys. Rev. Lett. 79, 1626 (1997)

The PRD paper has a reference[1] to test beam study of the prototypes of the (probably) related calorimeters designed for SLD (SLAC Large Detector):

- The luminosity monitor and small angle tagger (LMSAT)
- medium angle silicon calorimeter (MASC).

Calorimeter is detector which can:

- Measure energy of the particles;
- Determine impact position;
- With good energy and position resolutions when combined with spectrometer could provide an information about the number of particles;
- Provide timing information (if R/O support) often useful for signal/background separation.



ECAL

[1] IEEE Trans. Nuc. Sci. NS-37 , 1191(1990)

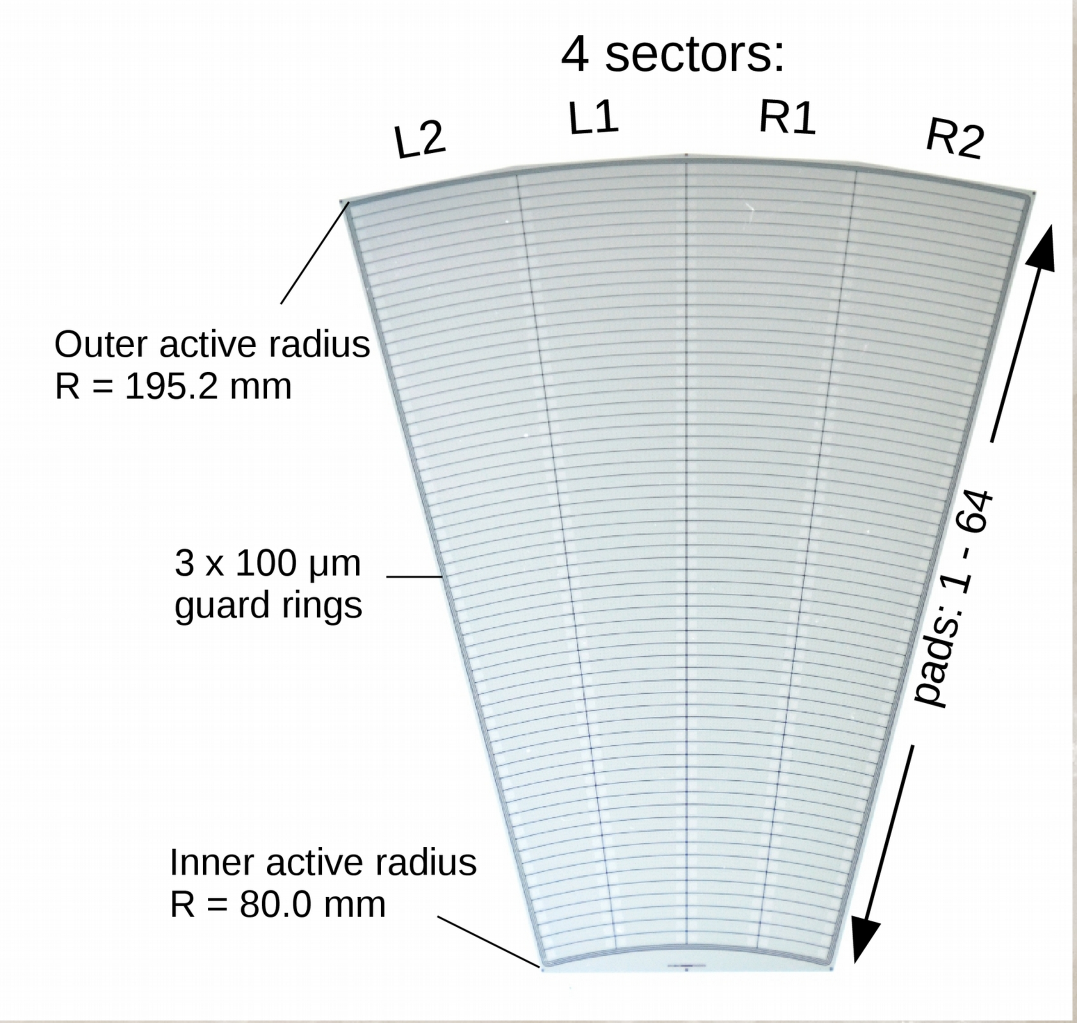
Luminosity Measurement and LumiCal Sensor

- LumiCal is a calorimiter designed for measurement of an integrated luminosity in Linear Collider experiments (ILD, CLIC).
- It has challenging requirements on position reconstruction accuracy and geometrical compactness.
- Its development and study is carried out by FCAL collaboration.

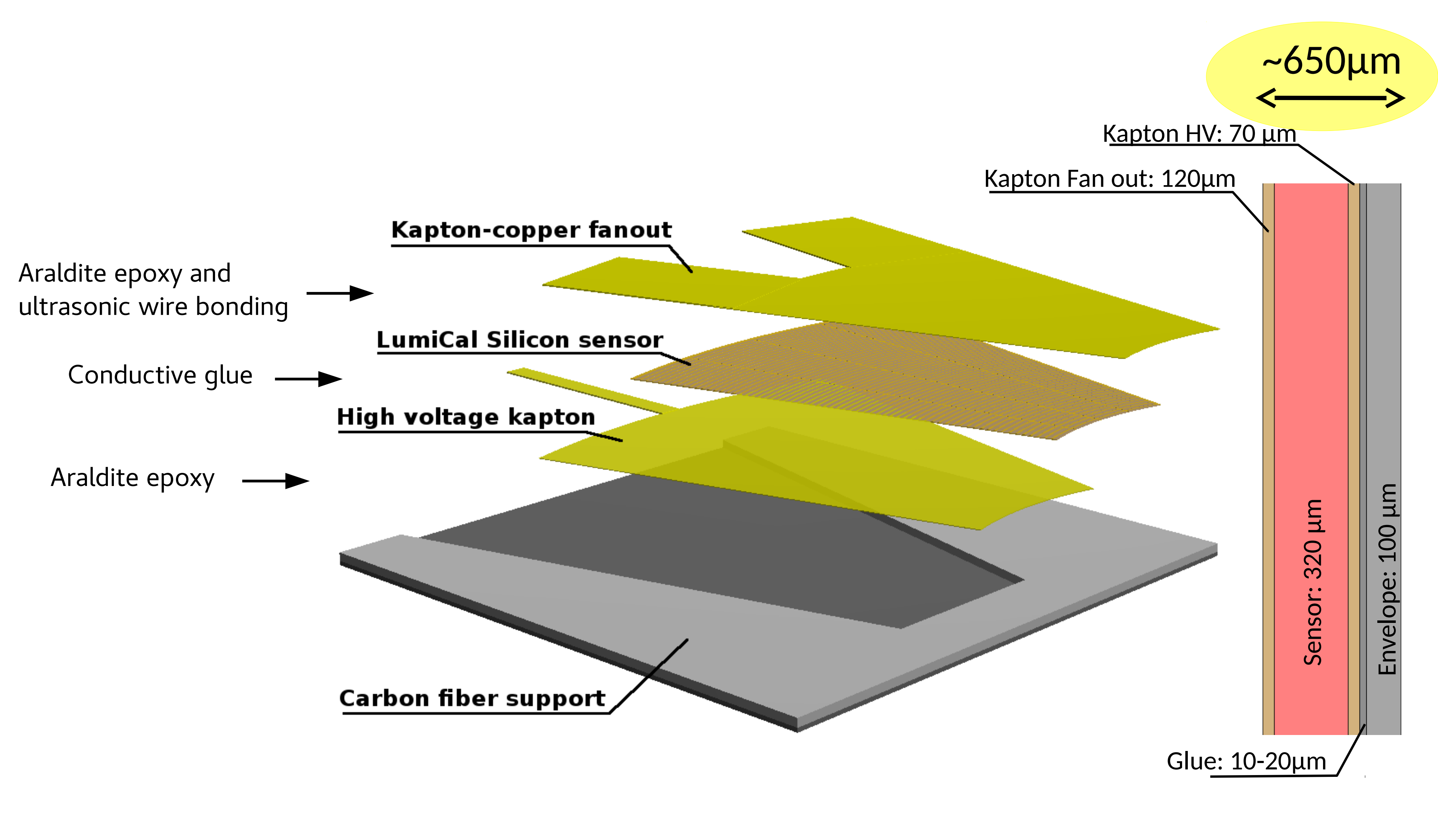
ILD LumiCal thickness:
$30X_0$ -> 13.5 cm.

Silicon sensor prototype is designed for ILD

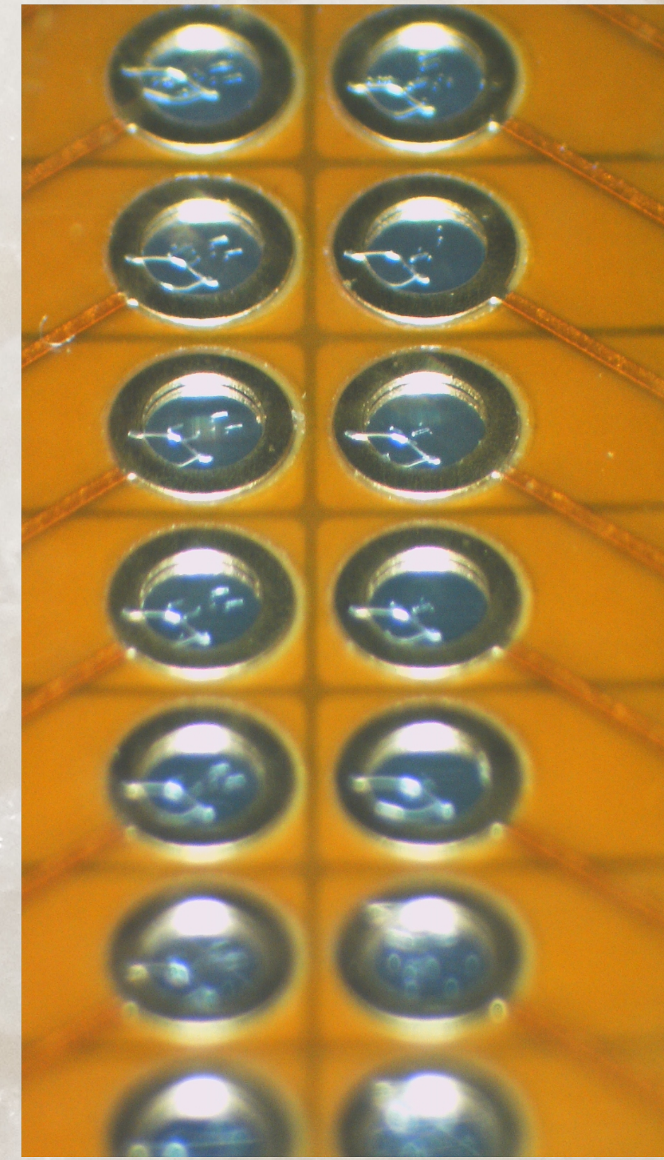
- thickness 320 µm
- DC coupled with readout electronics
- p+ implants in n-type bulk
- 64 radial pads, pitch 1.8 mm
- 4 azimuthal sectors in one tile, each 7.5°



Design of the Thin Detector Module

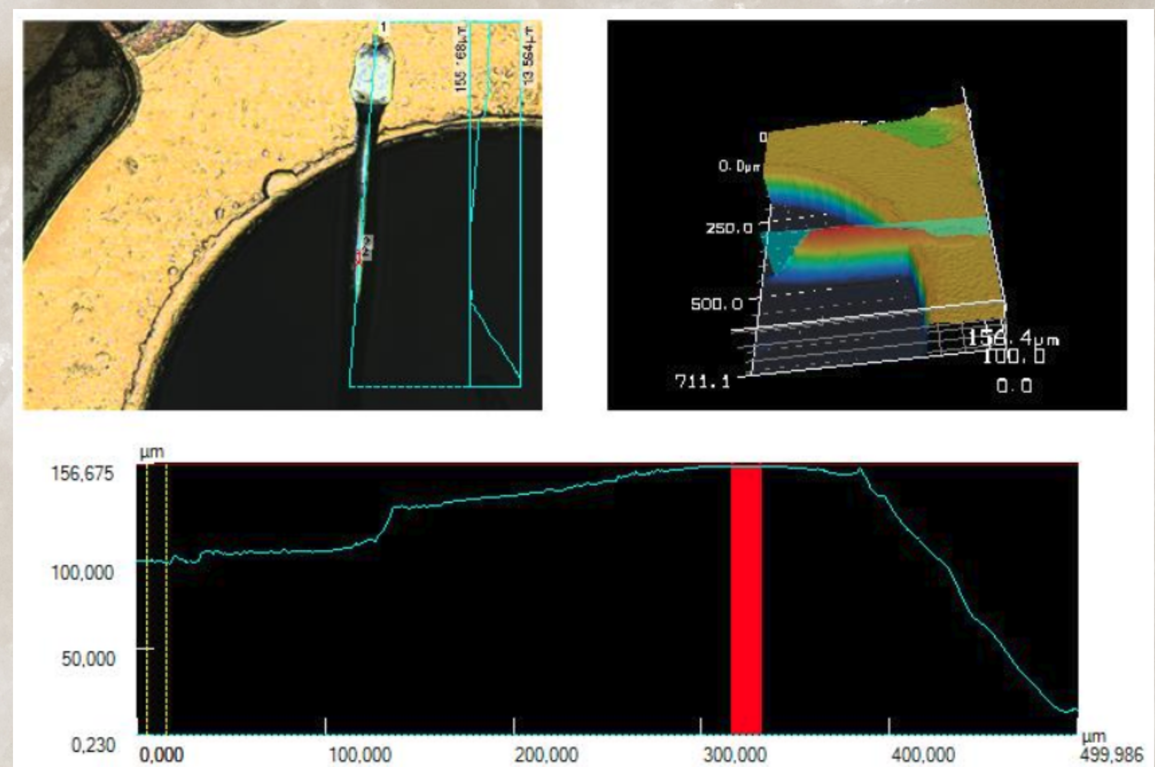


Wedge Wire Bonding for Front-end Contact



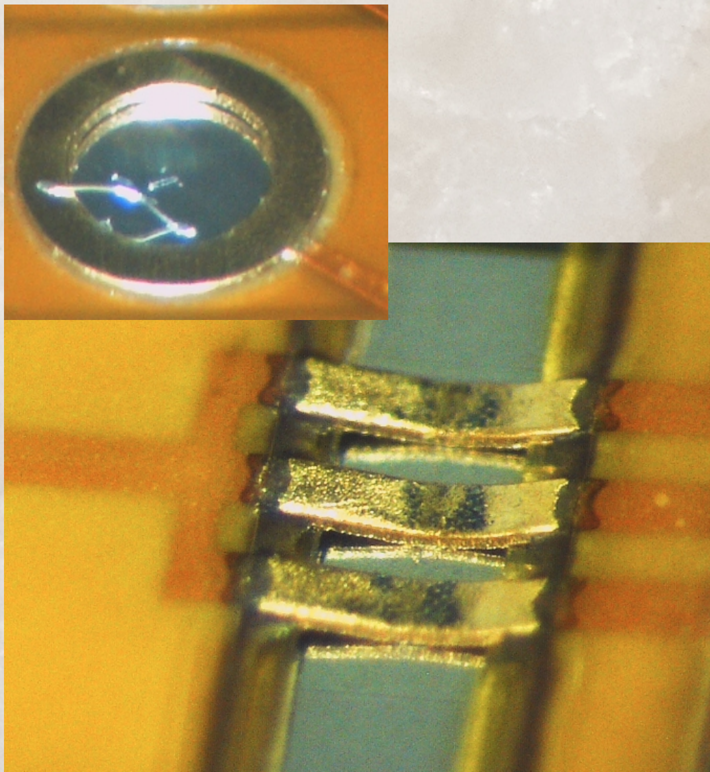
Achievable size of the bonding loops is in the range 50 µm - 100µm.

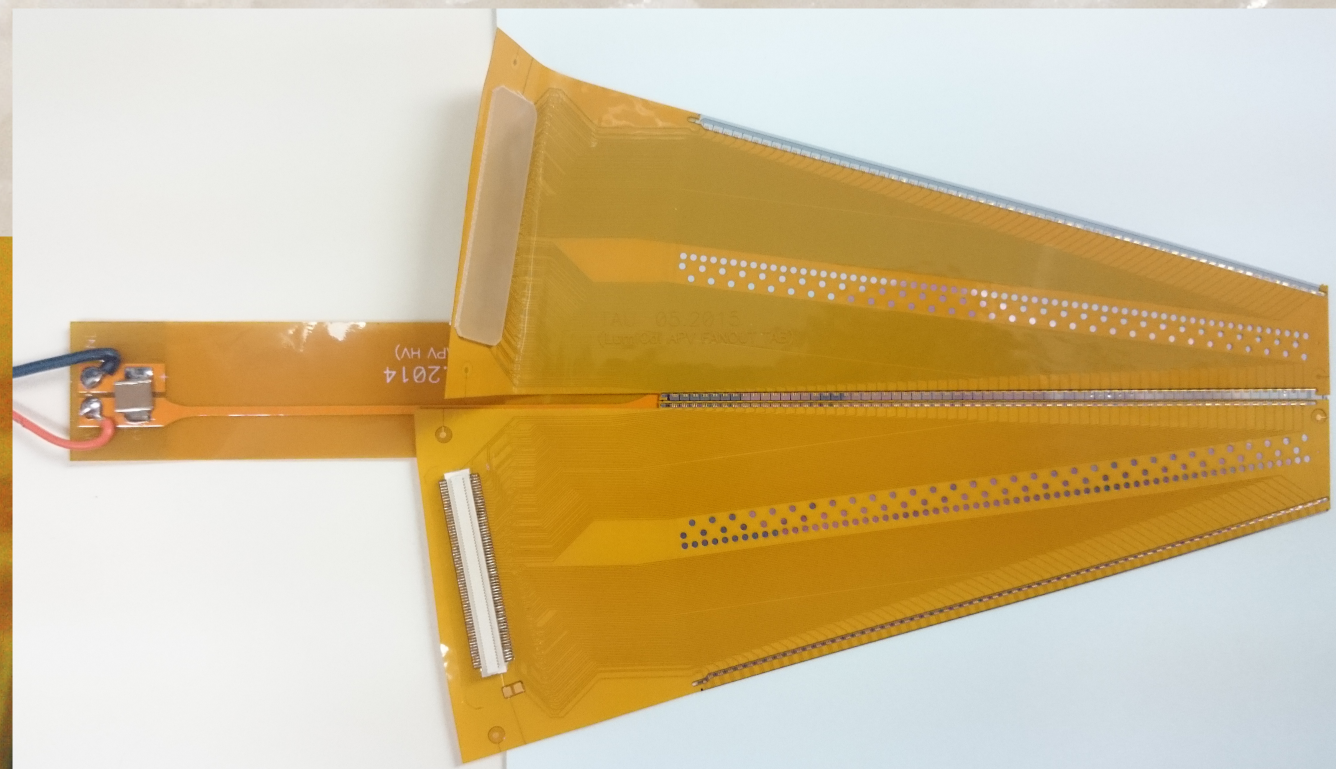
Bonding loop measured with 3D laser scanning confocal microscope at DESY Zeuthen.



TAB Technology for Front-end Contact

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





Single point Tape Automated Bonding (TAB):

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

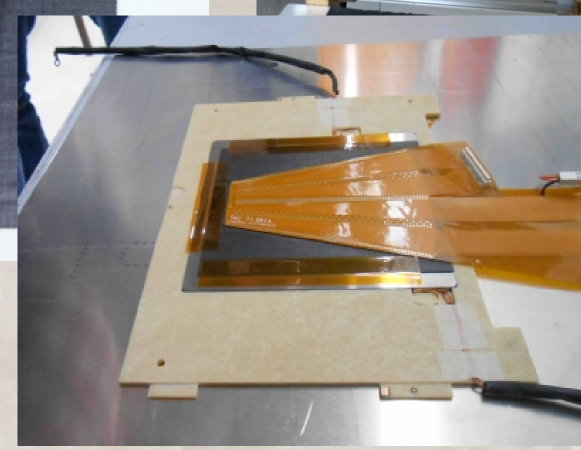
Thin Detector Module in Mechanical Frame

Kapton fanout

HV contact

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

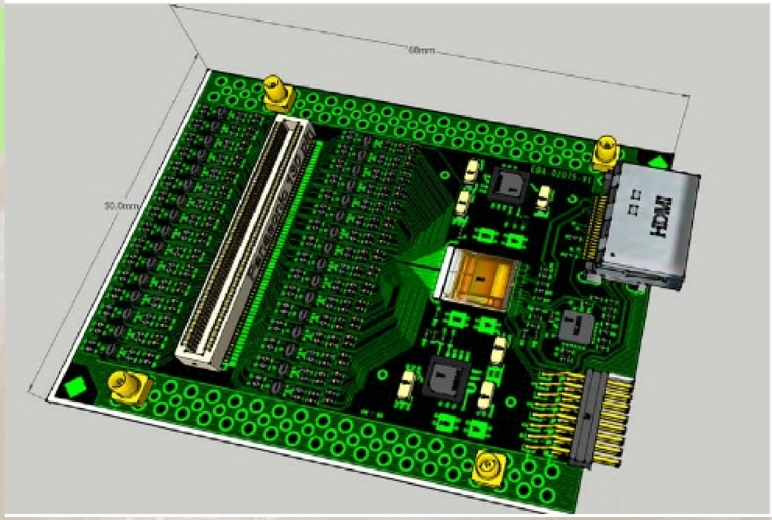
Carbon fiber supporting structure (“envelope”) provides mechanical stability and easy stack assembly.



- 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 in AGH (Cracow) and will be available in 2018-2019.



Front-end board (hybrid) with APV25 chip

Temporary alternative solution:

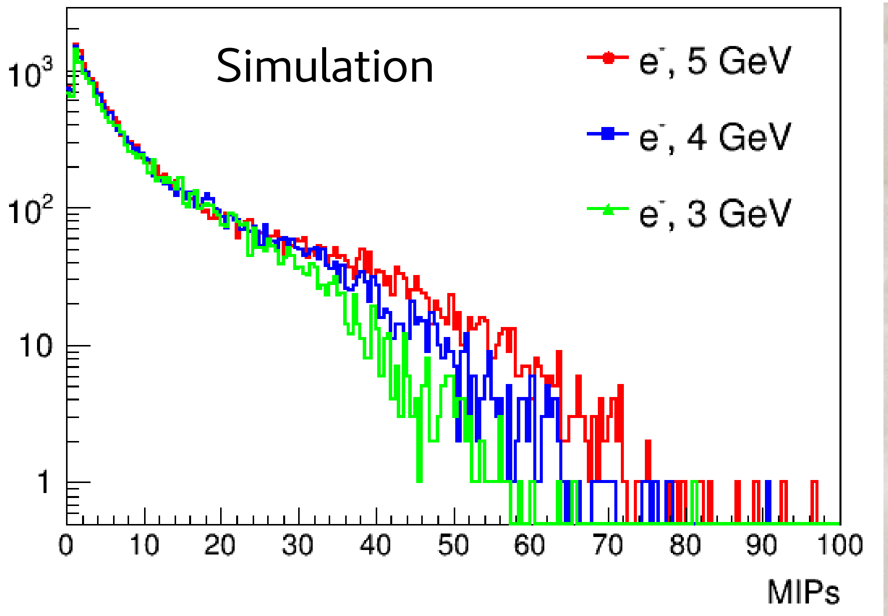
Front-end chip APV25:

- 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.

Energy deposition in sensor pad in 5-th layer,



Thin Module Beam Test Goals, Setup

DESY test beam facilities:

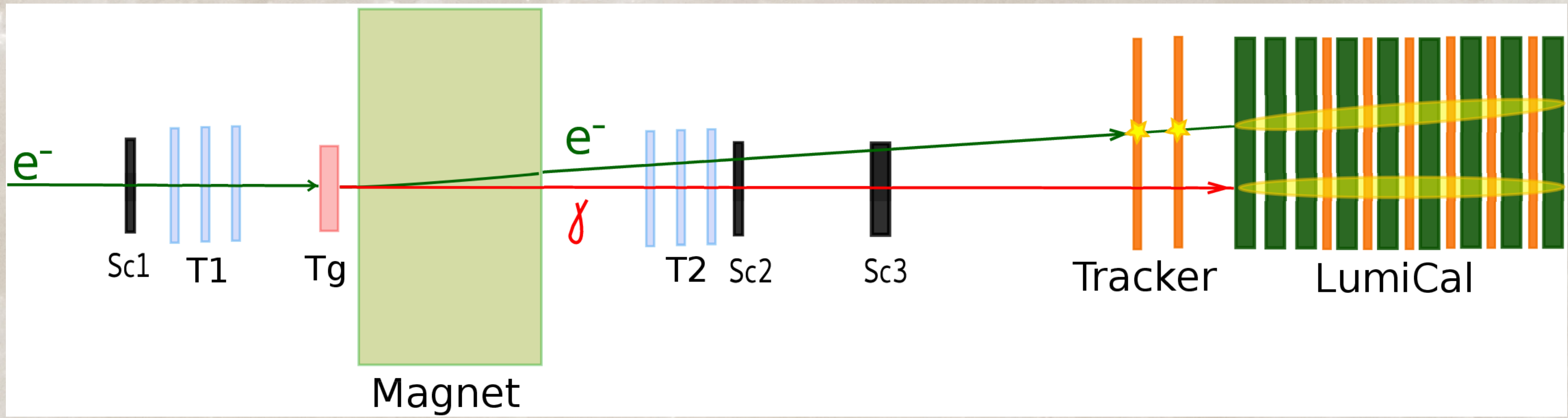
- Electron beam 1 – 6 GeV;
- Dipole magnet 1 – 13 kGs;
- EUTelescope with 6 planes of Mimosa26 detectors;

Performance of the compact LumiCal prototype:

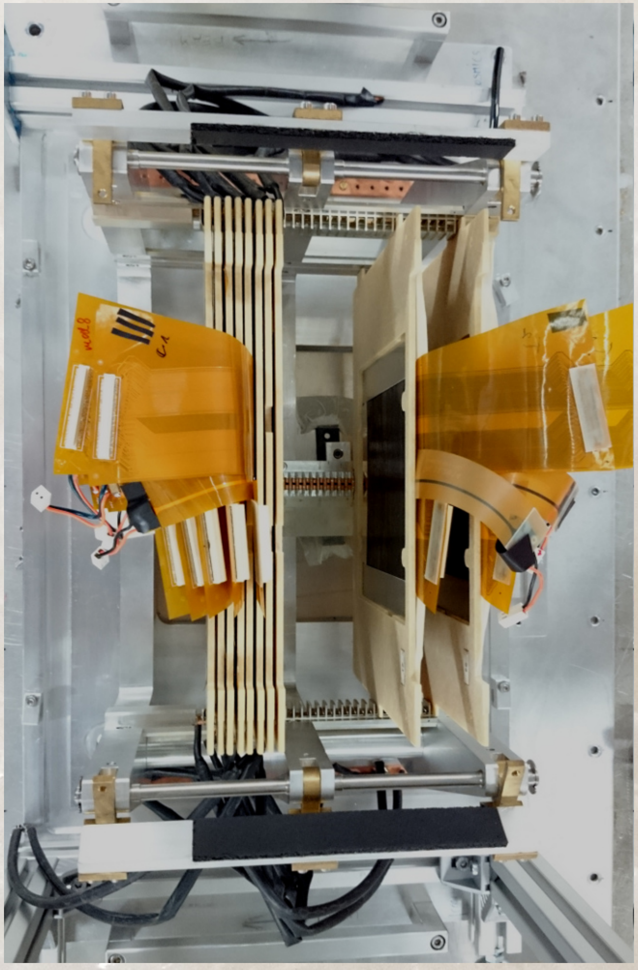
- Detector modules performance: noise, saturation, S/N, etc;
- Energy response to e^- beam of 1 – 6 GeV;
- Electromagnetic shower development study, Moliere Radius measurement.

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

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



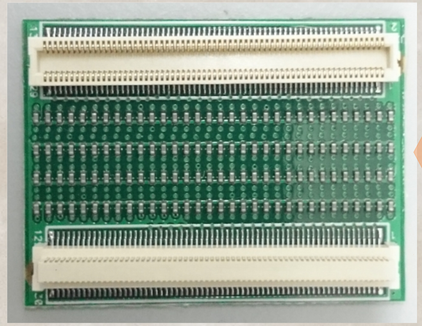
LumiCal Beam Test Installation



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°

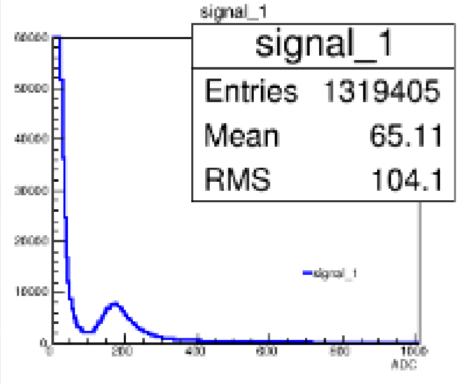


Charge divider board, 37x28 mm².

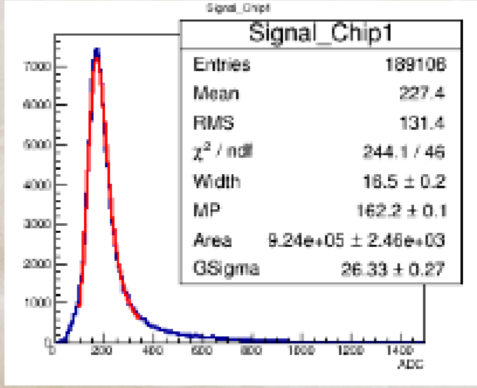
Energy Response of the Calorimeter

Cosmic muon reconstruction in LumiCal module readout by APV25

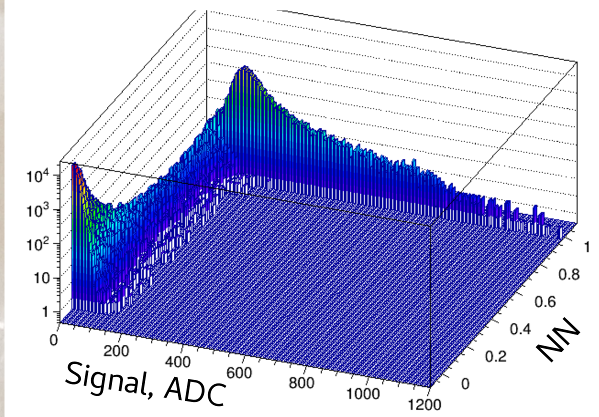
No cuts



NN cut

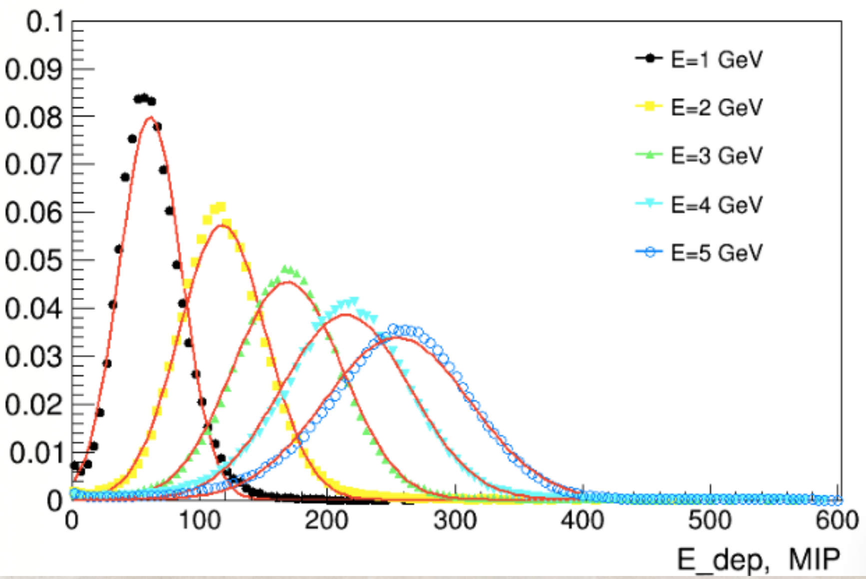


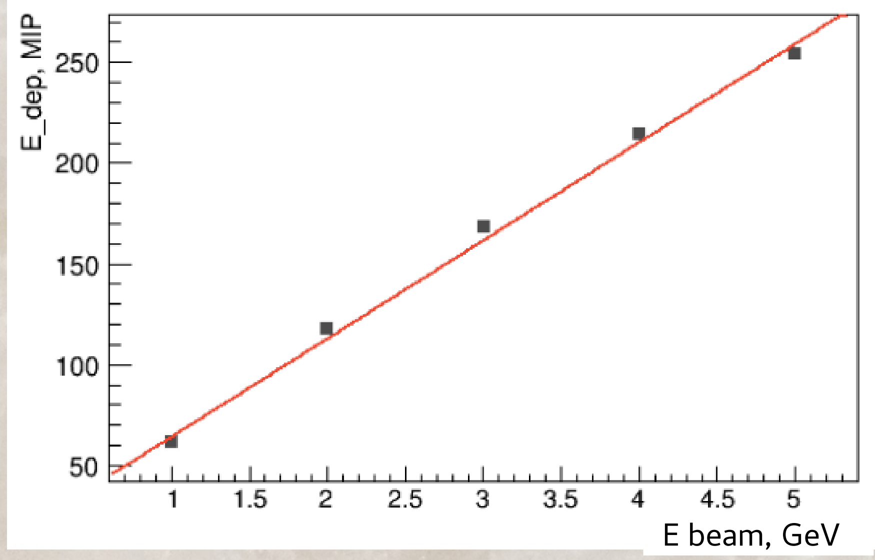
Signal selection with neural network (NN)



Energy deposited in LumiCal sensor by cosmic muon (ADC)

LumiCal response when running with charge divider

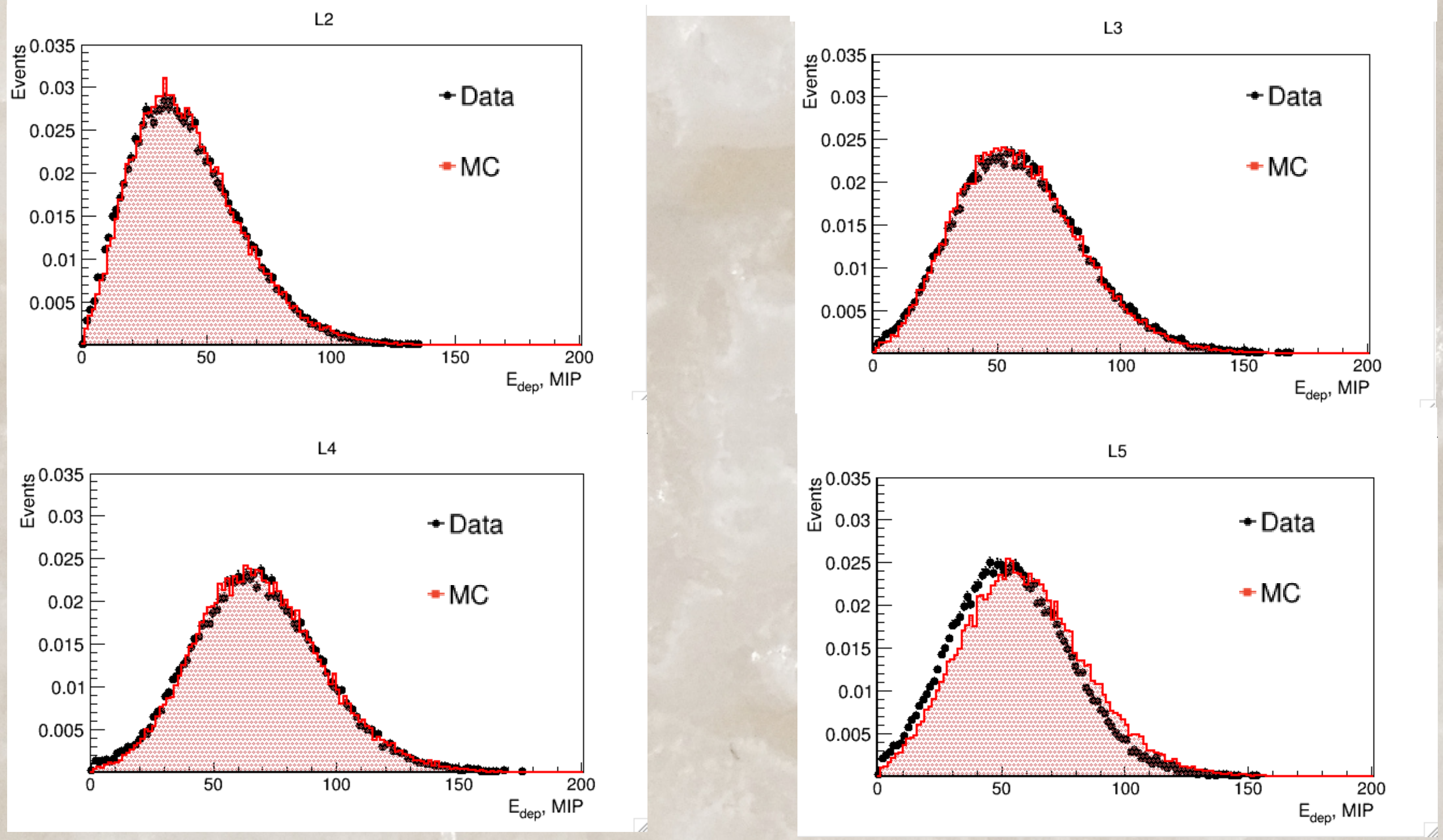




Longitudinal Shower

Work in progress…

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



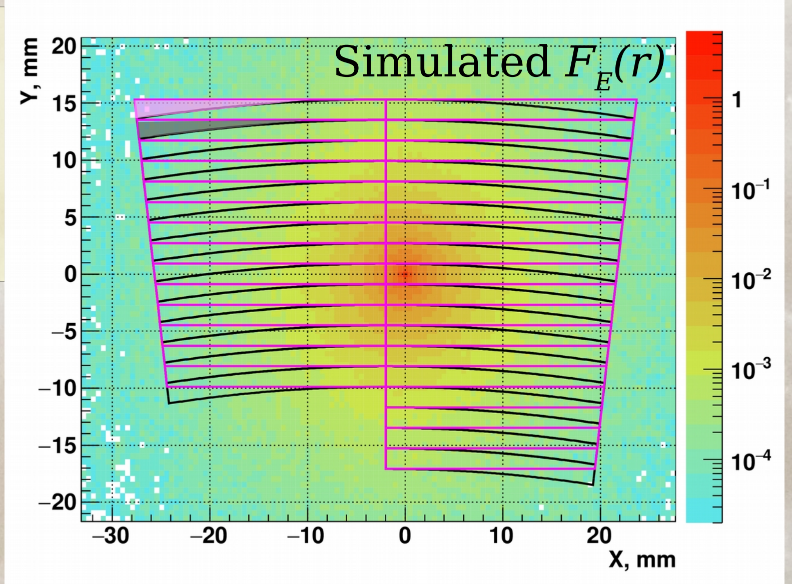
- The difference between data and MC for layer 5 to be understood.
- Possible reasons: noisy channels cause loss of information about small depositions which becomes significant as shower develops.

Shower Study in Transverse Plane with LumiCal Sensor

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**.

(Eur. Phys. J. C 78 (2018) 135 [1705.03885])



Grid – LumiCal sensor, sectors L1, R1.

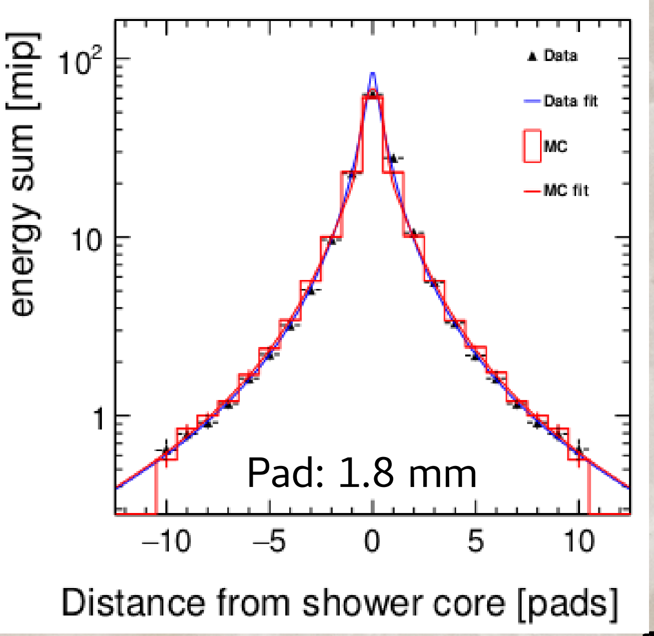
Average distribution of deposited energy in transverse plane:

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

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

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

$$E_n = \int_{S_n} F_E(r)\,\mathrm{d}S,$$



S_n corresponds to the area of the pads with radial position R_n.

Fit parameters are found by fitting E_n to MC and data.

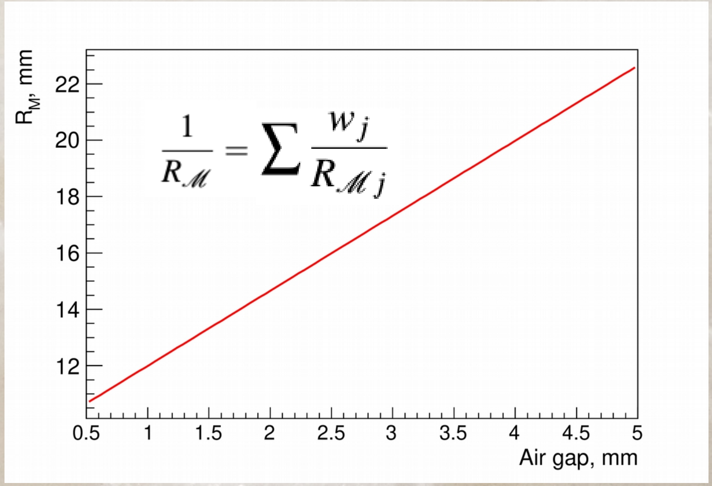
Assuming $F_E(r, \{p_i\})$ normalized to unity,
Moliere radius R_M can be found from the equation:

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

Shower Study in Transverse Plane

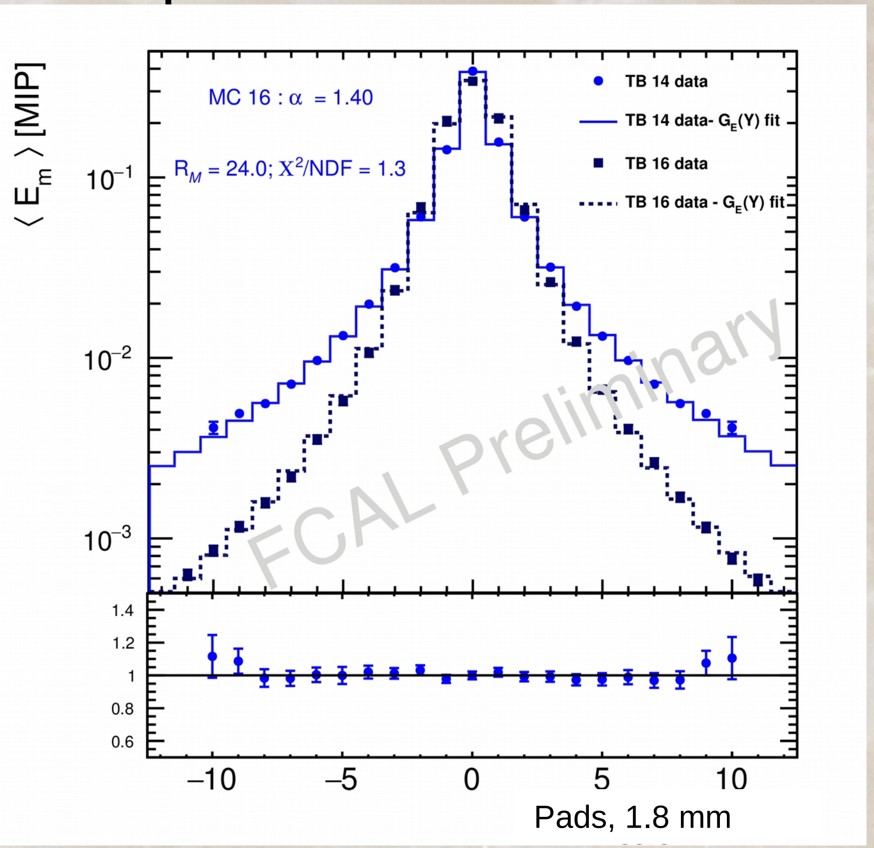
The dependence of R_M on the gap between absorbers can be estimated using the formula recommended by PDG for composite materials.

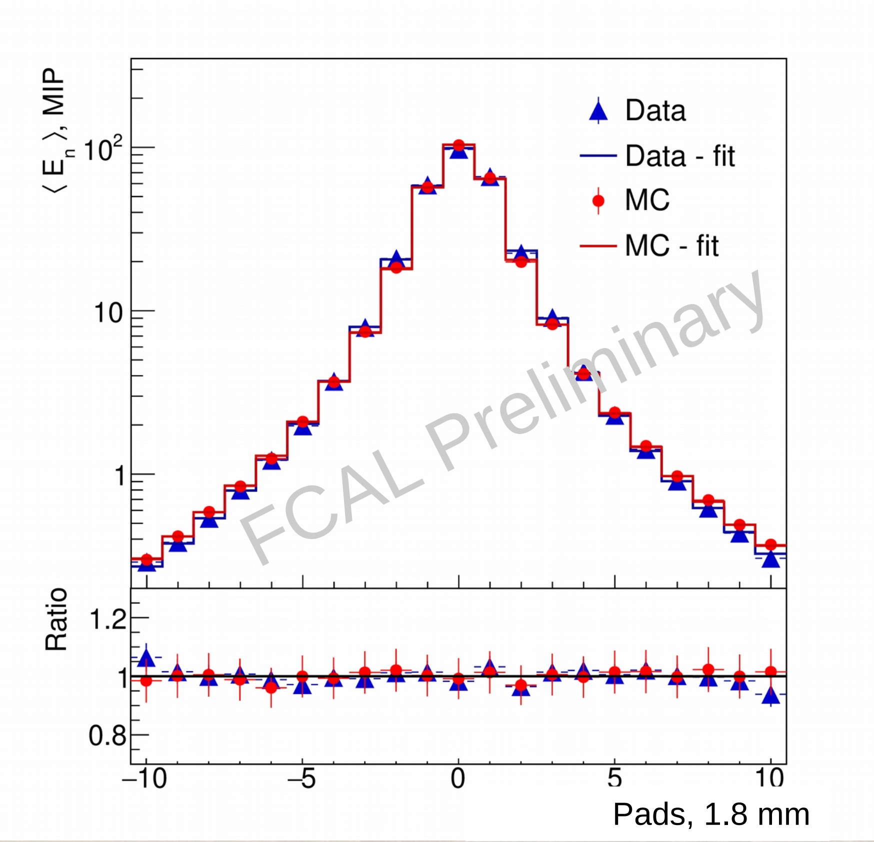
R_M as function of the air gap between 3.5 mm thick tungsten plates



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

Comparison of transverse shower in TB2016 (compact design) with TB2014





Position Reconstruction and e/γ Identification

5 GeV electron beam

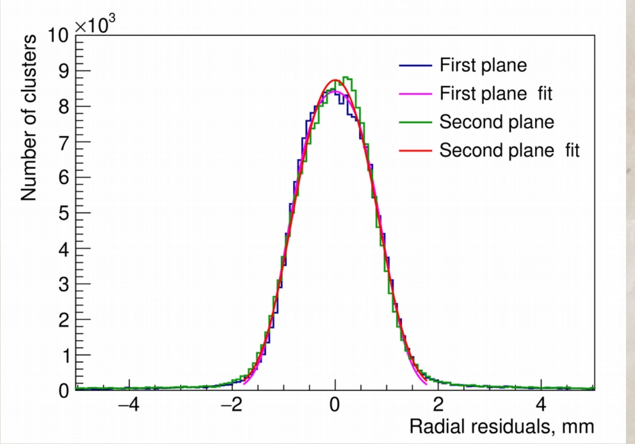
Reasonable agreement between parameters of reconstructed clusters in simulation and in data.

Position reconstruction with logarithmic weighting:

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

At W_0 = 3.4, resolution is:

- 0.36 mm (MC);
- 0.44 mm (Data, with misalignment).

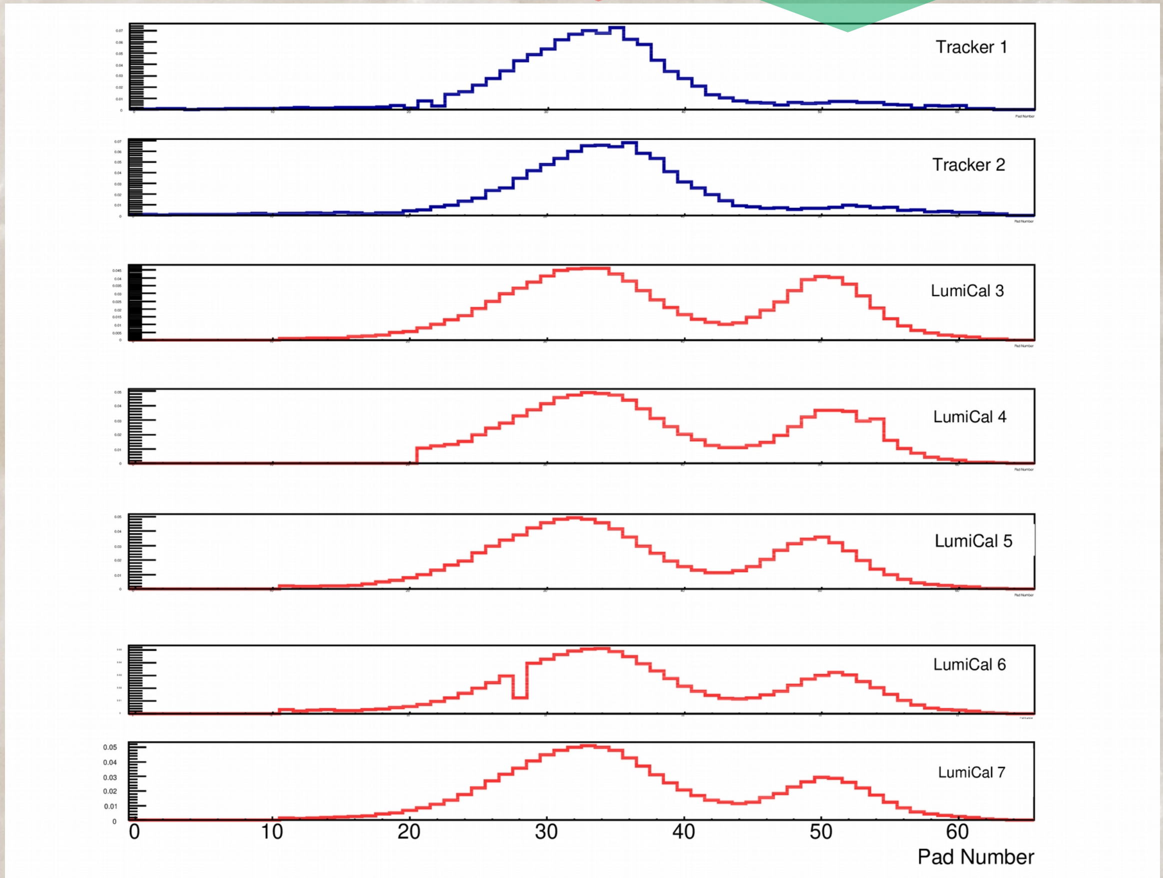


Residuals between position in calorimeter and tracking planes

Occupancy plot shows electron and photon showers

electron

photon



Identification efficiency:

- electron ~95%
- photon ~87%

Summary

- Possible detector requirements as presented in last LUXE meeting[1] :
  - up to ~10^{11} photons, with typical energy 1–10 GeV.
  - ~10^{10} electrons, typical energy will be 1–10 GeV.
  - 1–10^9 positrons, typical energy will be 1–10 GeV.
  - The electrons will be separated from the positrons and will also have some spread due a magnetic spectrometer.
- The presented prototype of electromagnetic calorimeter does not match directly these requirements, but its compact design and small Moliere radius make it good starting point for further development.
- One LumiCal module prototype with TAB technology has been produced and installed for the beam test. Reasonable data were collected, further analysis will give more information.
- The calorimeter (LumiCal) prototype with eight modules of submillimeter thickness installed in 1 mm gap between tungsten absorbers, was tested with electron beam. Data analysis is in progress and preliminary results are following:
  - LumiCal prototype demonstrates good linear response to the beam of 1 GeV – 5 GeV.
  - 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 resolution of particle position reconstruction in radial direction of the sensor with logarithmic weighting algorithm for 5 GeV electrons is 0.36 mm (MC) and 0.44 mm (Data). The difference is explained by misalignment of sensitive layers.

[1] 09.08.2018, presented by Matthew.