Recent FCAL Test Beam Results

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On behalf of the FCAL collaboration

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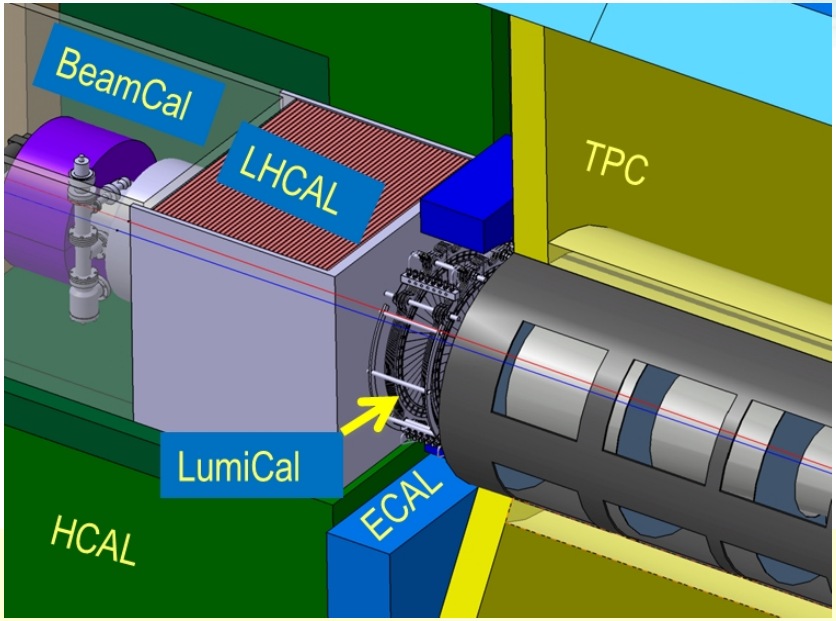
Overview

- LumiCal detector in linear collider experiments
- Test of LumiCal multi-plane detector prototype
- Thin LumiCal module design
- Test Beam of LumiCal with thin module
- Summary

LumiCal in the Forward Region

Goals:

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



LumiCal:
- electromagnetic calorimiter;
- 30/40 layers (ILC/CLIC) 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.

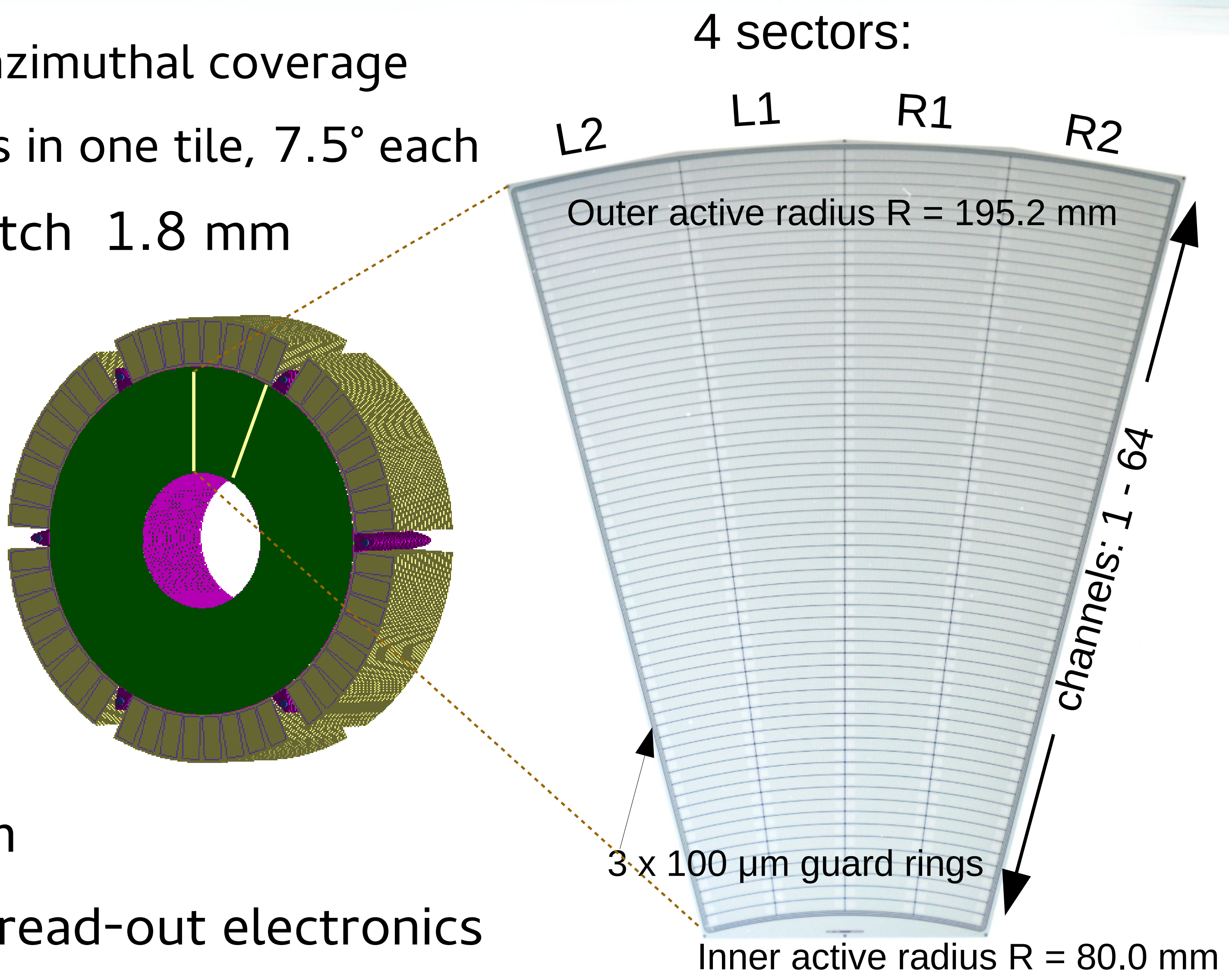
The integrated luminosity is measured by counting number N_B of Bhabha events in a certain polar angle (θ) range of the scattered electron.

$$L = \frac{N_B}{\sigma_B}$$

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

LumiCal Design

- 12 tiles make full azimuthal coverage
- 4 azimuthal sectors in one tile, 7.5° each
- 64 radial pads, pitch 1.8 mm



- Silicon sensor
- thickness 320 µm
- DC coupled with read-out electronics
- p+ implants in n-type bulk

TB-2014 LumiCal Configurations

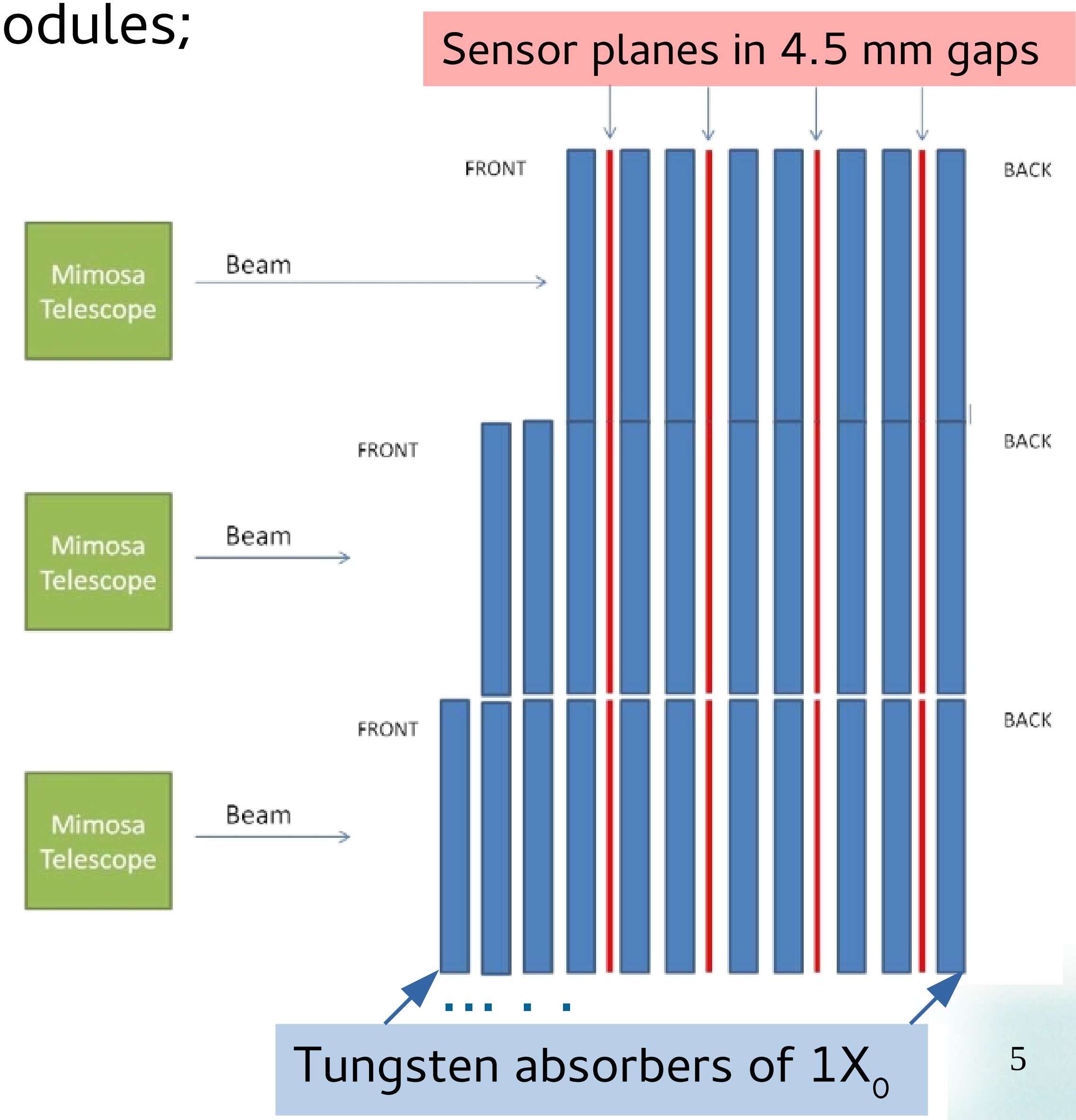
First check of multi-plane operation of the LumiCal prototype with 4 detector modules;

Three different configuration for the LumiCal were used.

CERN PS beam at T9

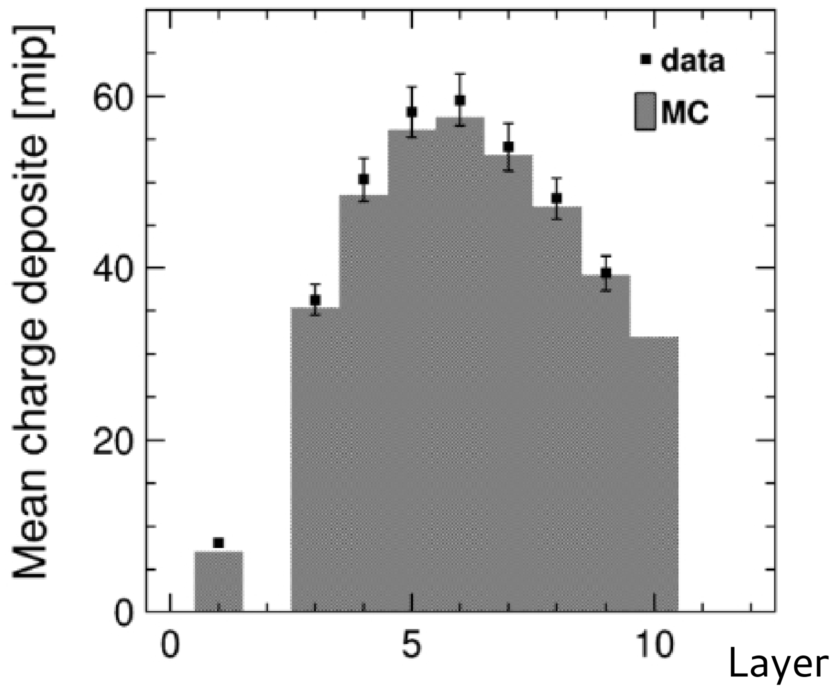
5 GeV beam;
Trigger on:
- Electrons and muons;
- Hadrons.

For different configurations 55k-75k e- events were collected.

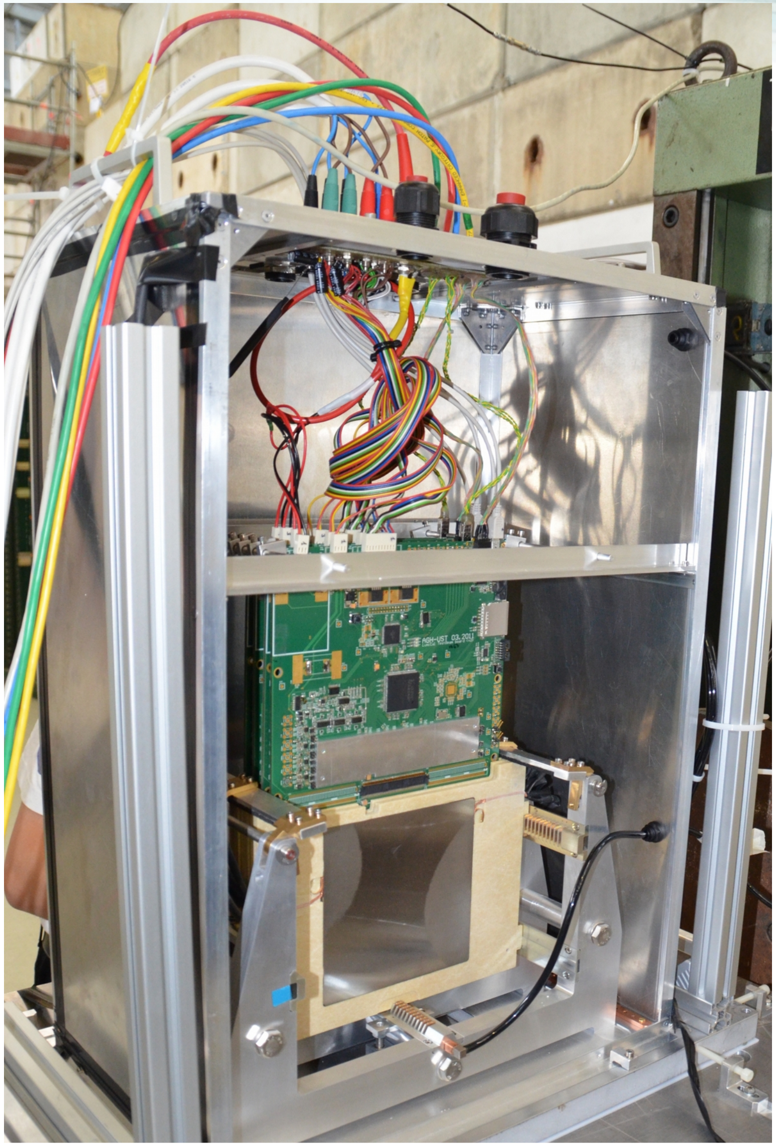


Beam Test of LumiCal Multilayer Prototype

- CERN PS 5 GeV/c e- (muons, used for calibration);
- 4 LumiCal detector modules;
- 10 tungsten absorber plates in permaglas frames;
- Mechanical frame for precise (±50μm) positioning of absorber layers;
- 3 configurations for longitudinal scan of the electromagnetic shower.



Longitudinal shower development



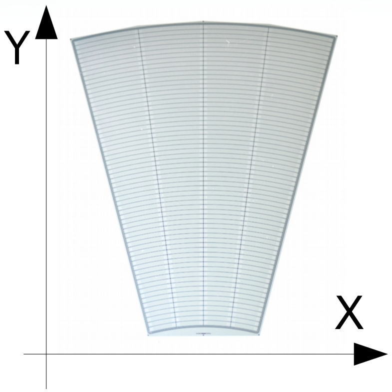
Four LumiCal modules in stack

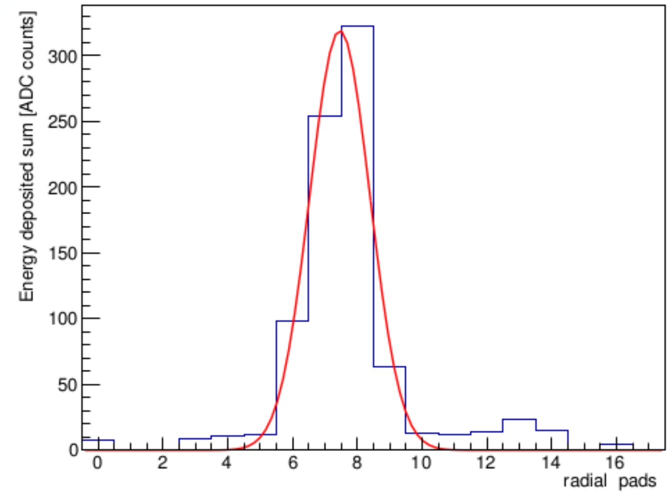
Position Reconstruction

- Logarythmic weighting:

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

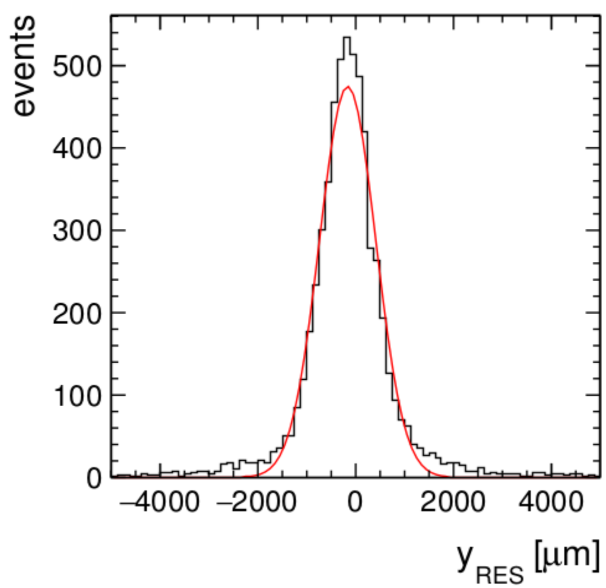
$$w_n = max\left\{0; W_0 + \ln\frac{E_n}{\sum_n E_n}\right\},$$





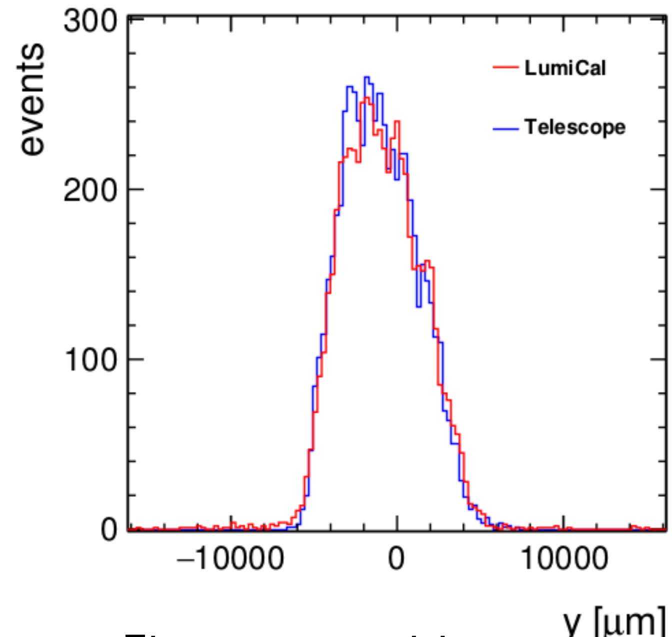
Single event project to transverse plane

- Gaussian fit to deposited energy distribution in transverse plane



Resolution is about 0.5 mm

Distribution of the residuals between positions in LumiCal and telescope



Electrons position distribution (beam profile)

Shower Study in Transverse Plane

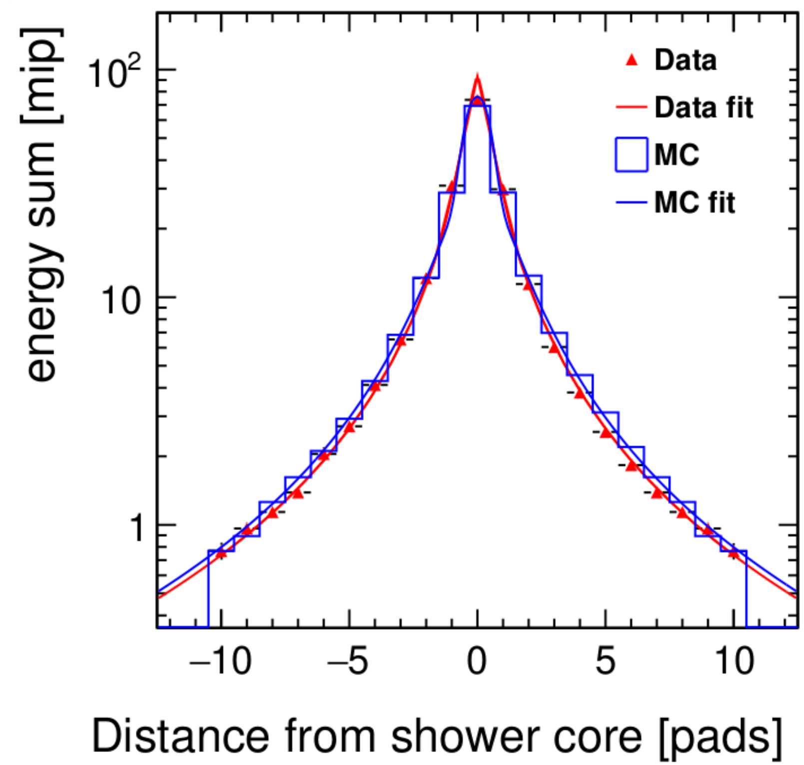
Transverse shower profile is approximated as

$$F_{E(r)} = (A_C)e^{-(\frac{r}{R_C})^2} + (A_T)\frac{2rR_T^2}{(r^2+R_T^2)^2}$$

r – the distance from the shower center;
A_C, A_T, R_C, R_T – fit parameters.

Moliere radius R_M can be found from the equation:

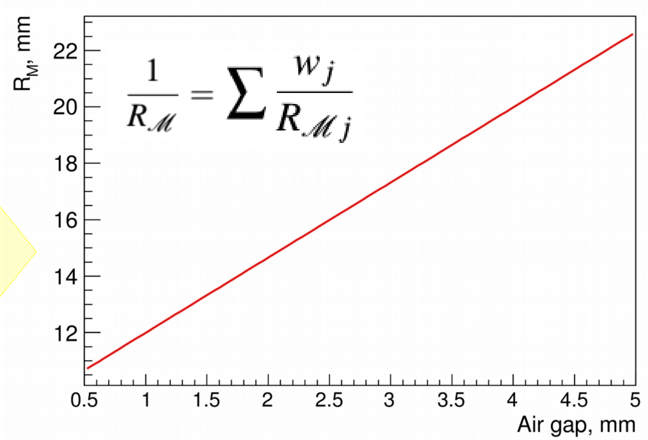
$$0.9 = \int_0^{2\pi} d\varphi \int_0^{R_{\mathcal{M}}} F_E(r) r dr$$



For the configuration with four detectors at $3X_0$, $5X_0$, $7X_0$ and $9X_0$, preliminary result gives R_M = 1.6 ± 0.2 cm for the data;

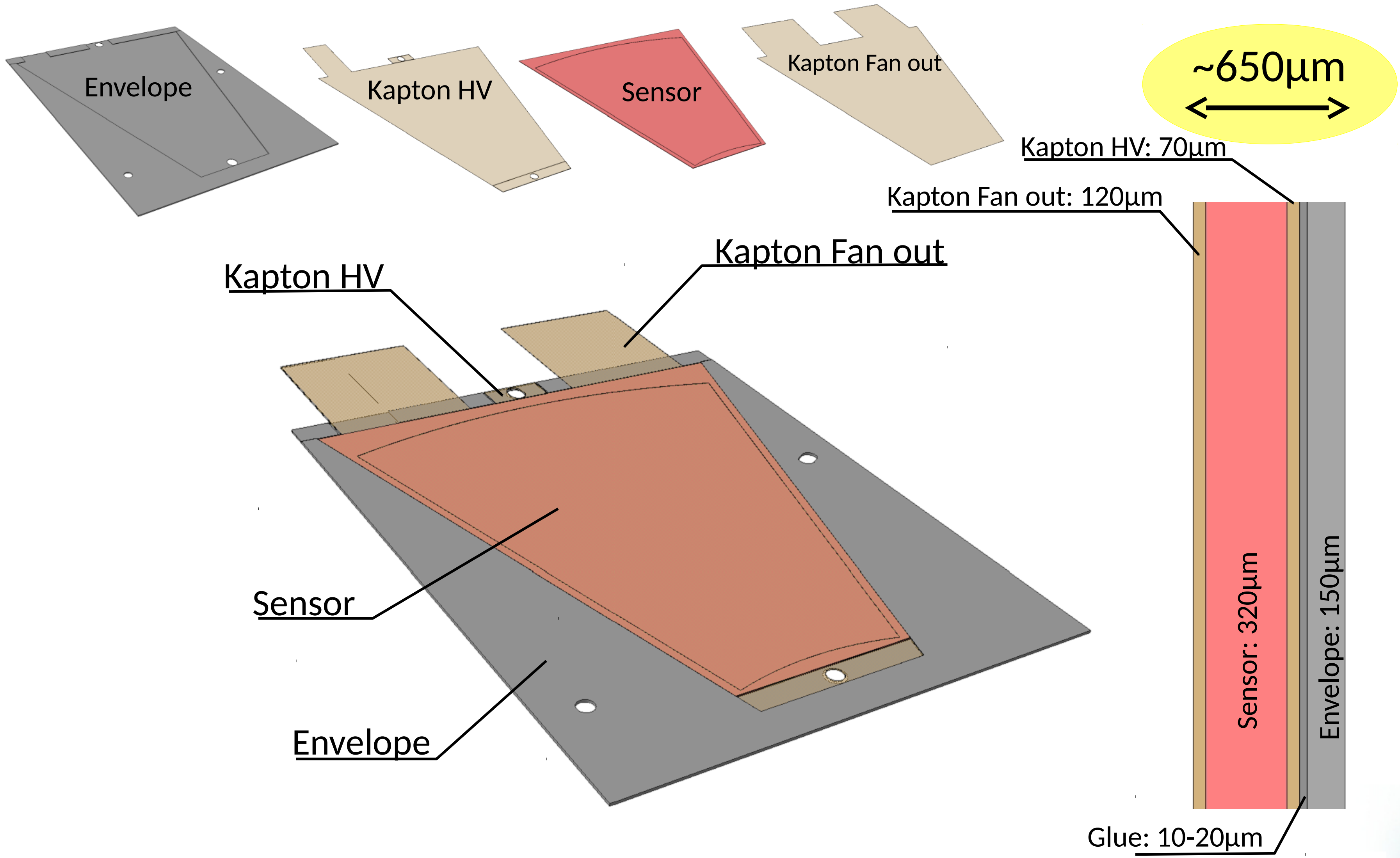
Analysis in progress...

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.

Design of the Thin LumiCal Module

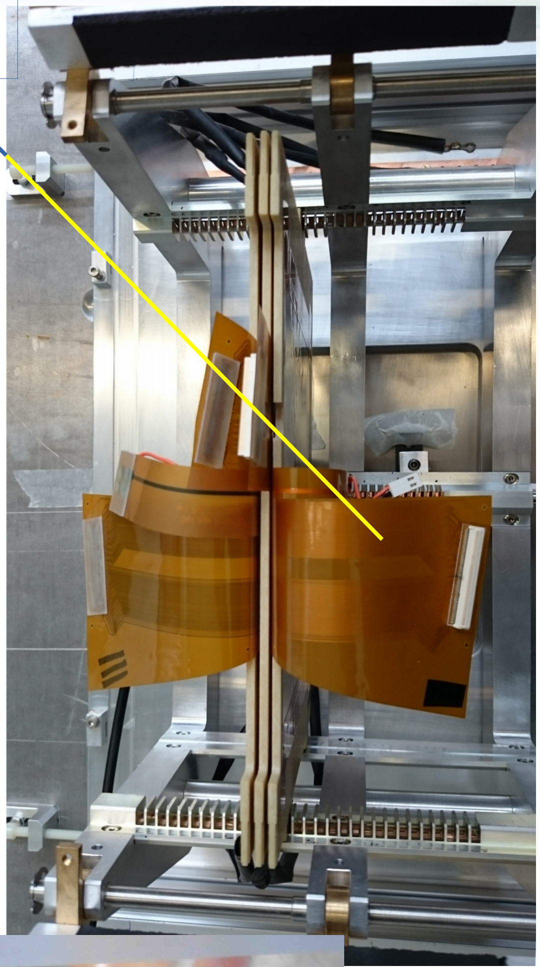


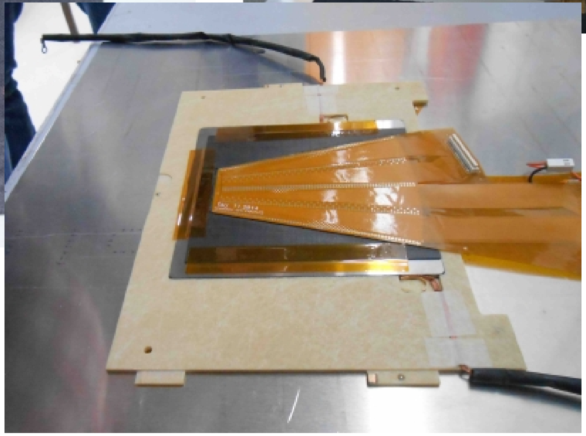
Thin LumiCal Module in Mechanical Frame

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

Kapton fanout

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





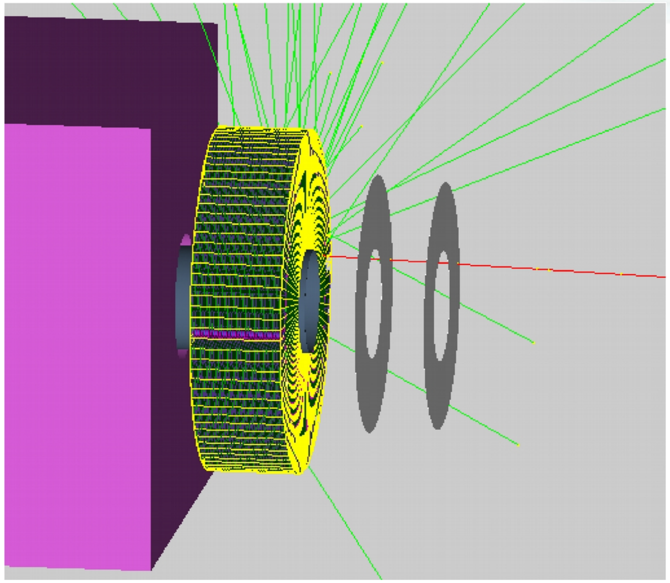
- 4 modules were successfully tested with e- beam at DESY in October 2015. Data analysis is in progress.
- 4 additional modules were prepared for the beam test in August 2016 including one assembled with TAB bonding technology.

TB-2016 Objectives

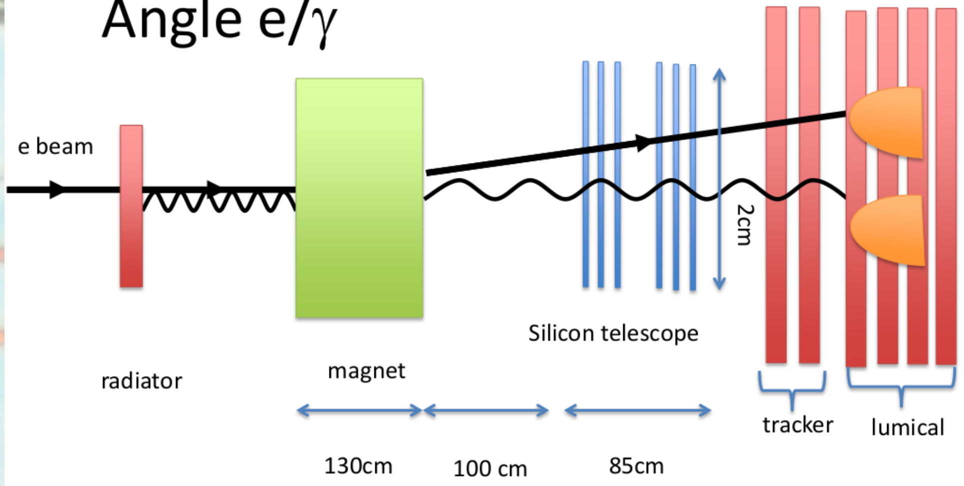
- In TB 2015 for the first time we had full sensor readout;
- Total number of readout channels 4x256.

Ideas

1. Verify the tab bonding (or other candidates if ready)
2. Add more W layers
3. Use of a tracker in front of lumical to identify electron/photon



Angle e/γ



If we want both photon and e inside the telescope :

$\tan\theta$ =2/(130+100+85)= 6 mrad = 0.4 degrees

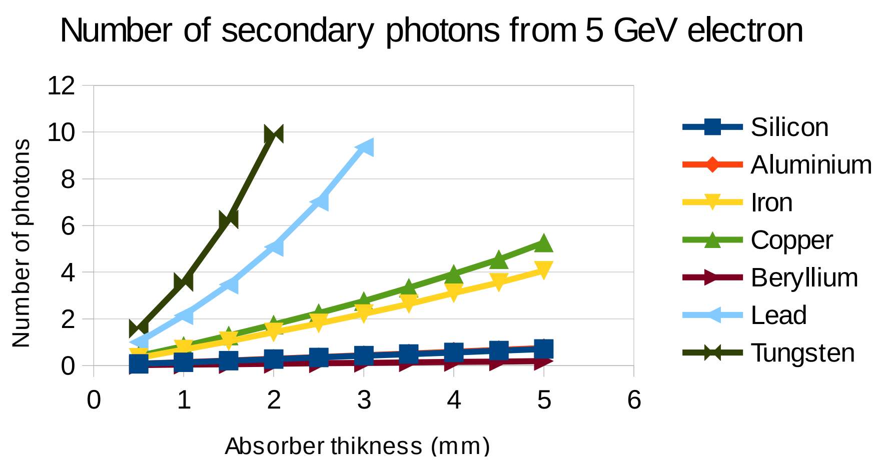
Identification e/γ

- Need to create e/γ
- Need to curve the e trajectory
- Need to have both of them in the silicon telescope
- Need to have a silicon tracker in front of the lumical detector and both e and γ inside

Absorbers for Photons Production

The run was 100000 e- of 5 GeV through **1.5 mm** of Copper (density: 8.96 g/cm3)
Number of secondaries per event :

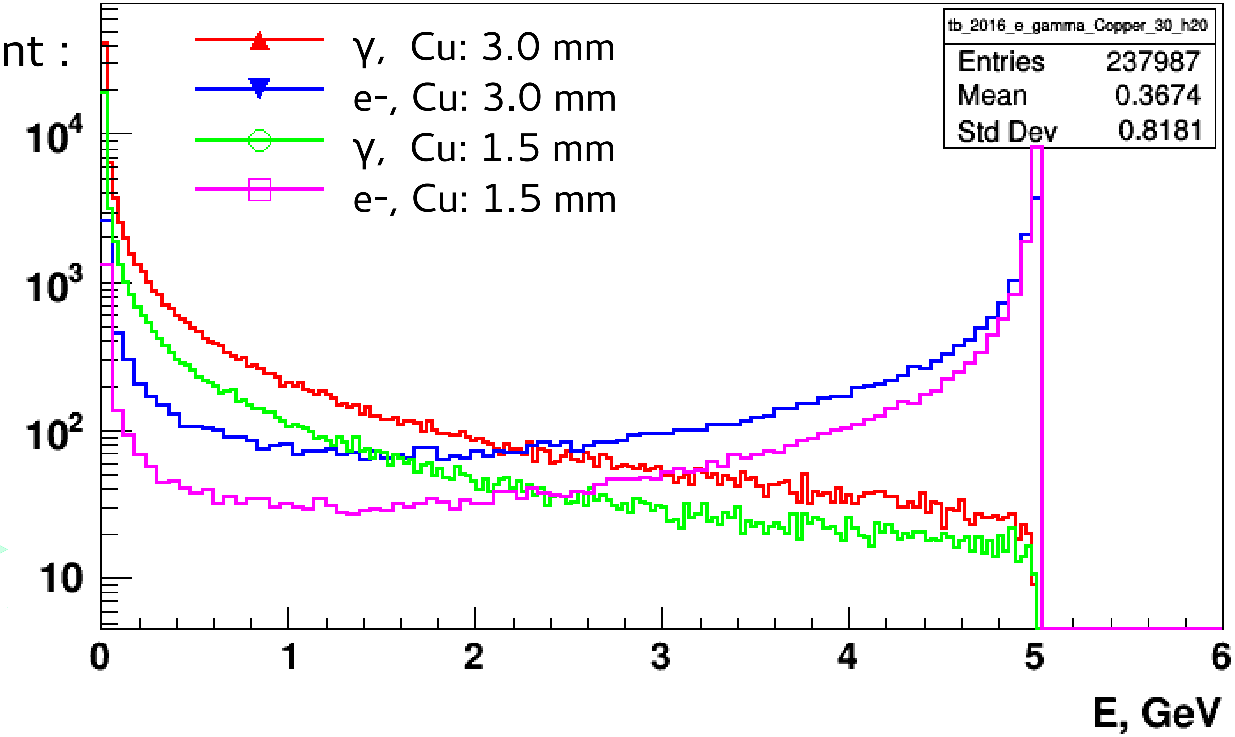
- Gammas = 1.28;
- electrons = 0.5193;
- positrons = 0.02402



3 mm of Copper
Number of secondaries per event :

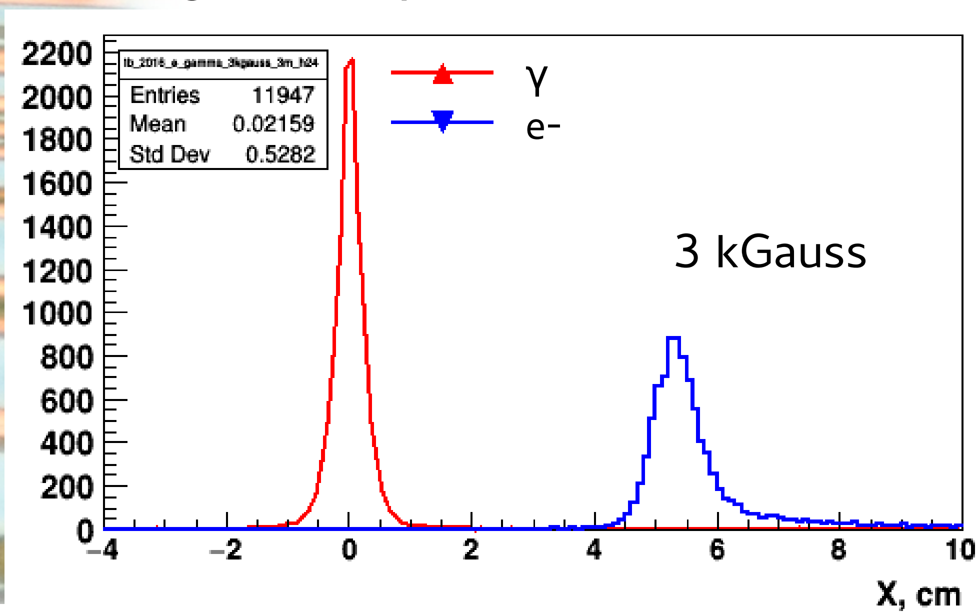
- Gammas = 2.758;
- electrons = 1.274;
- positrons = 0.09292

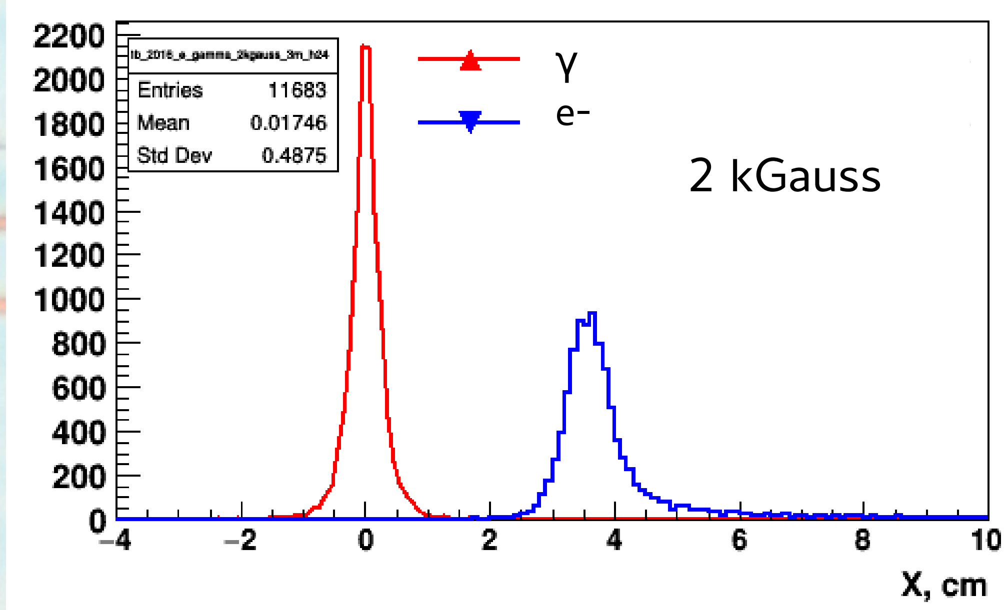
e-, γ spectra



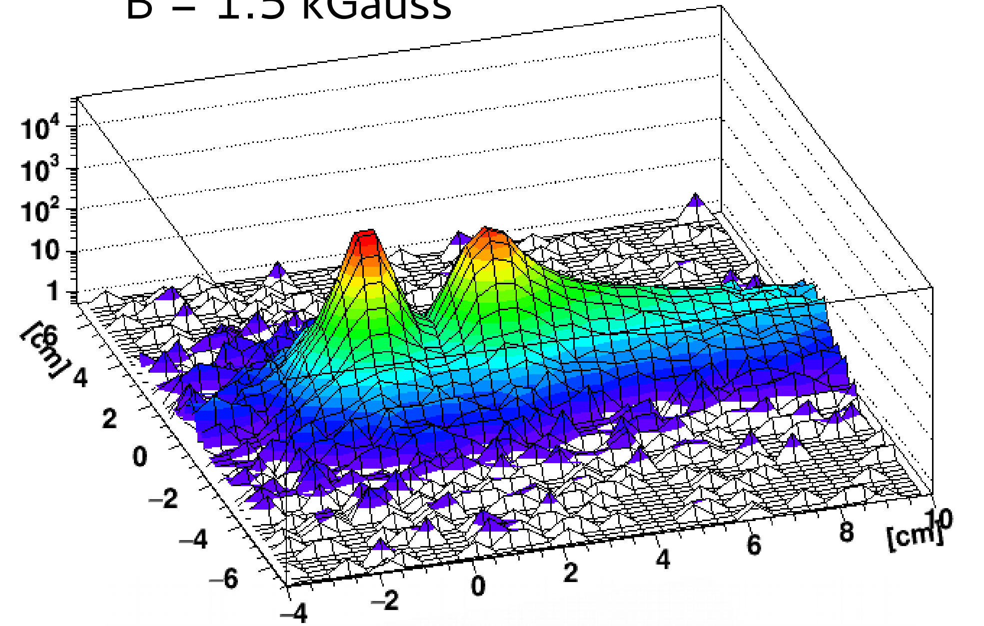
Electron and Photon Beam Position

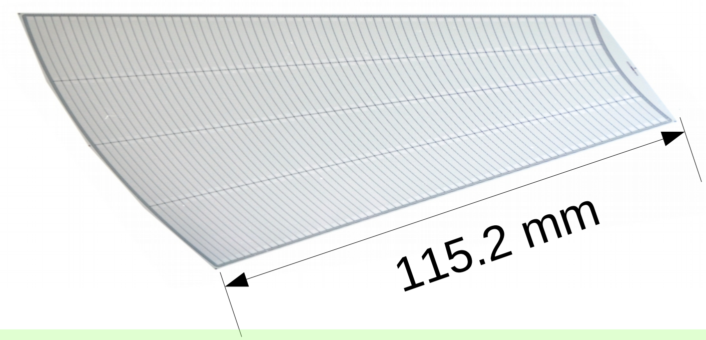
DESY, T21 with dipole magnet geometry was considered





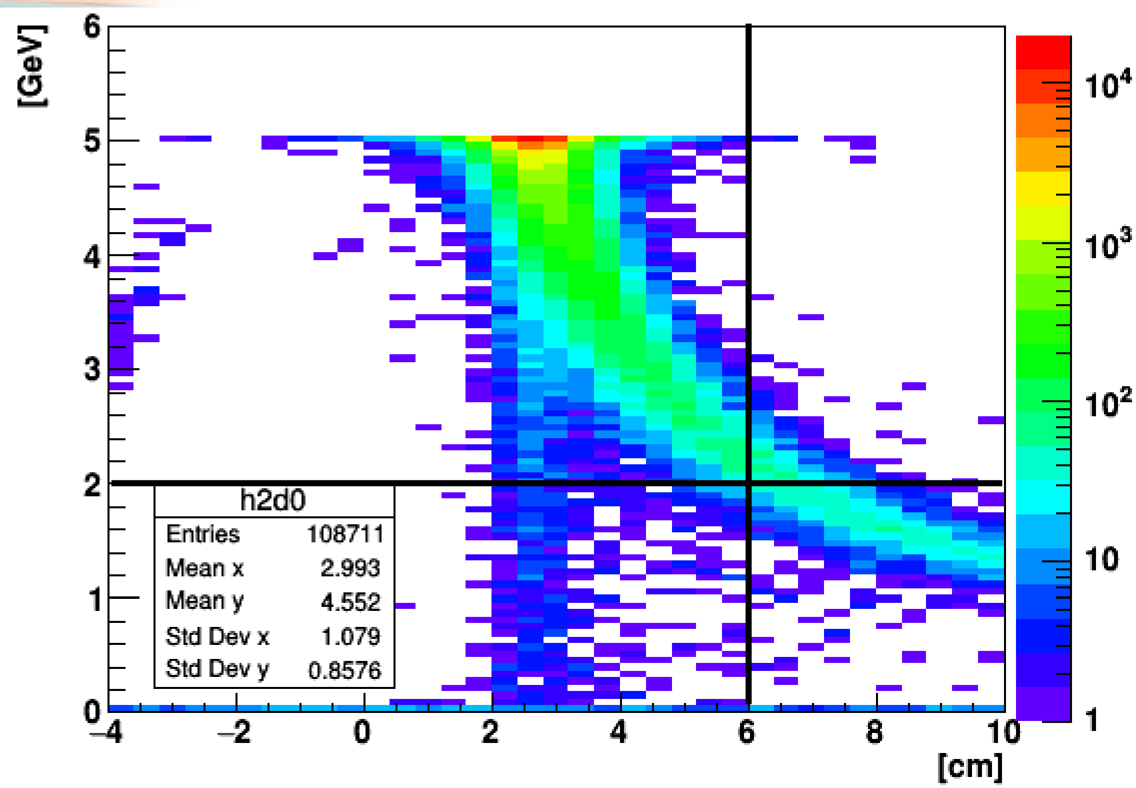
B = 1.5 kGauss

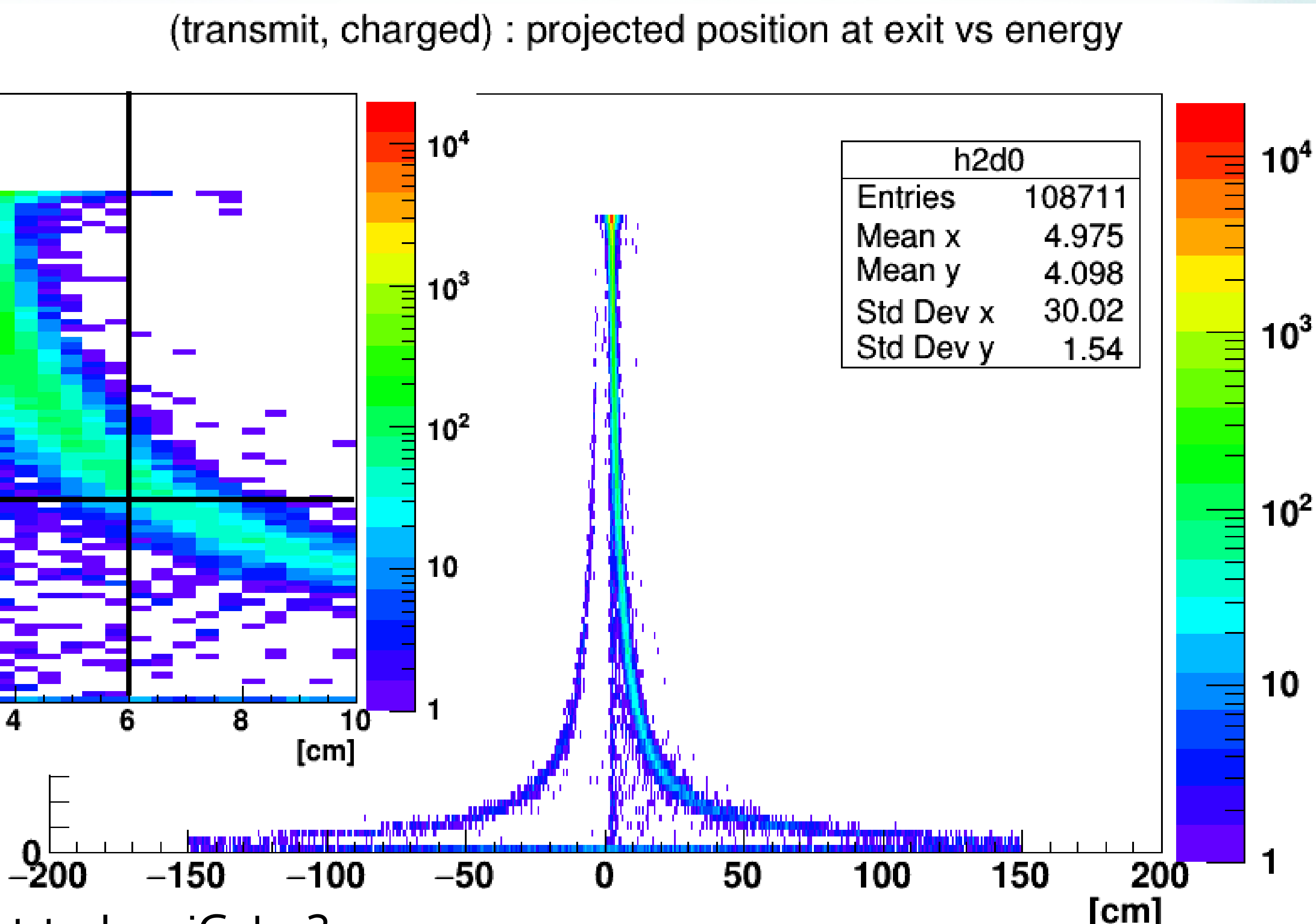




- $e^-\gamma$ angle ~ 4/400 = 10 mrad;
- That was an indication to position LumiCal;
- Magnetic field was optimized experimentally.

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%

Readout with SRS and APV 25

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

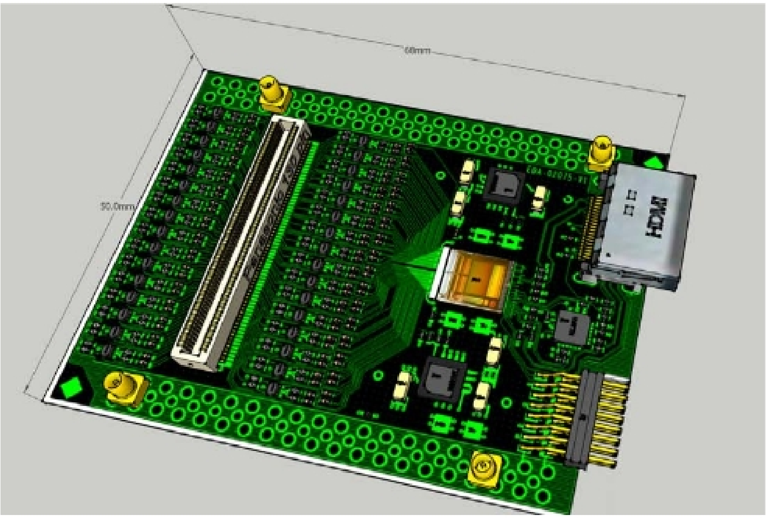
Temporary alternative solution:

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

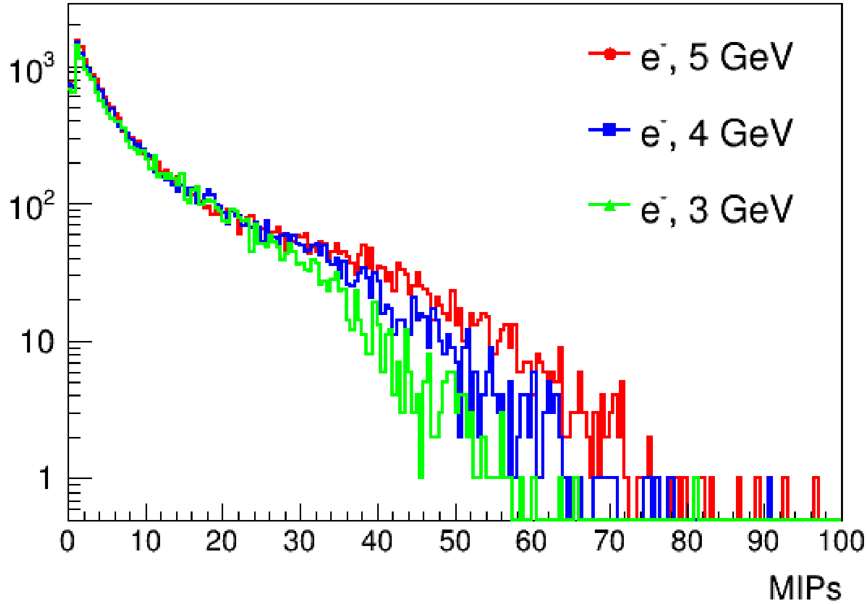
The APV25 range in case of LumiCals sensor: ~ 8 MIPs

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

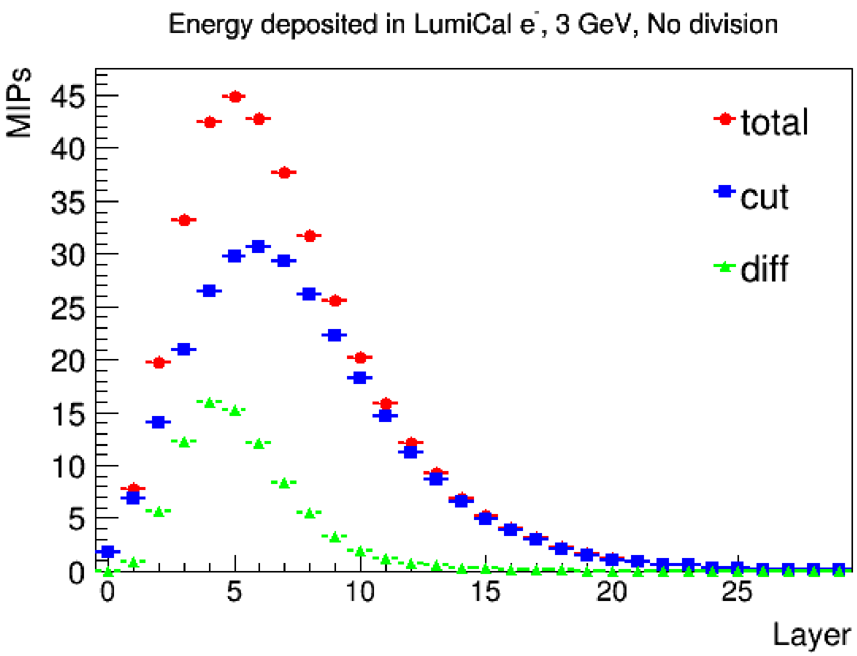


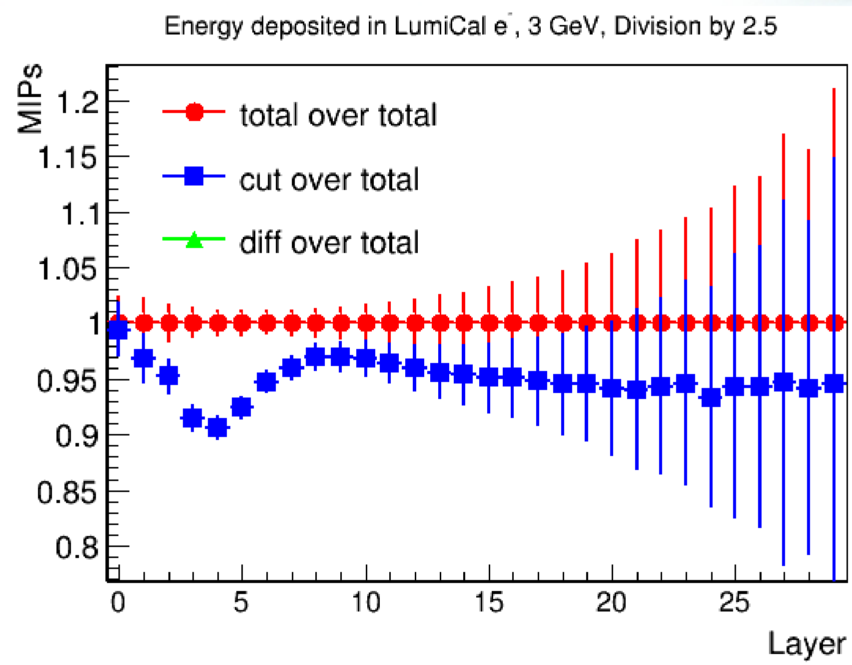
Front-end board (hybrid) with APV25 chip

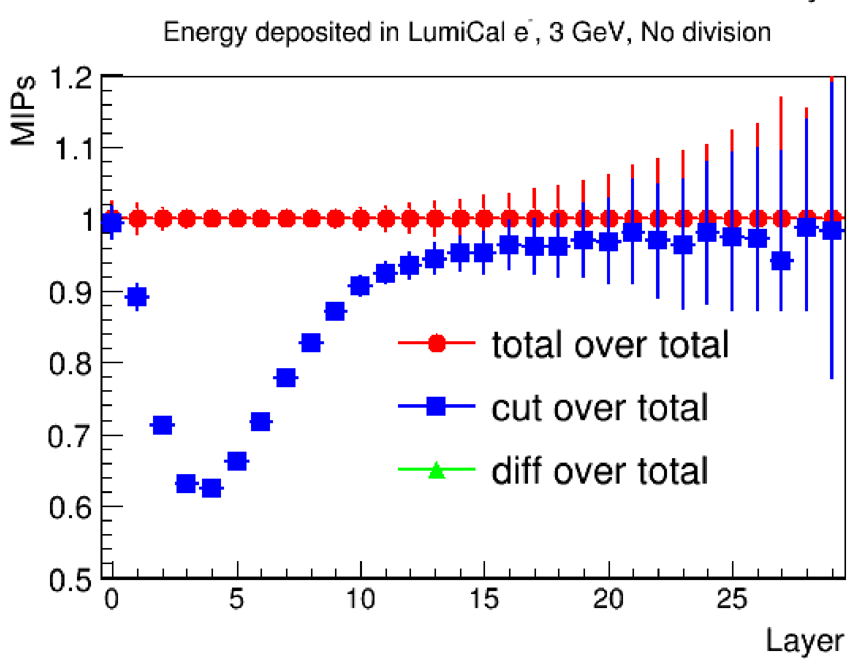
Energy deposition in sensor pad in layer 5

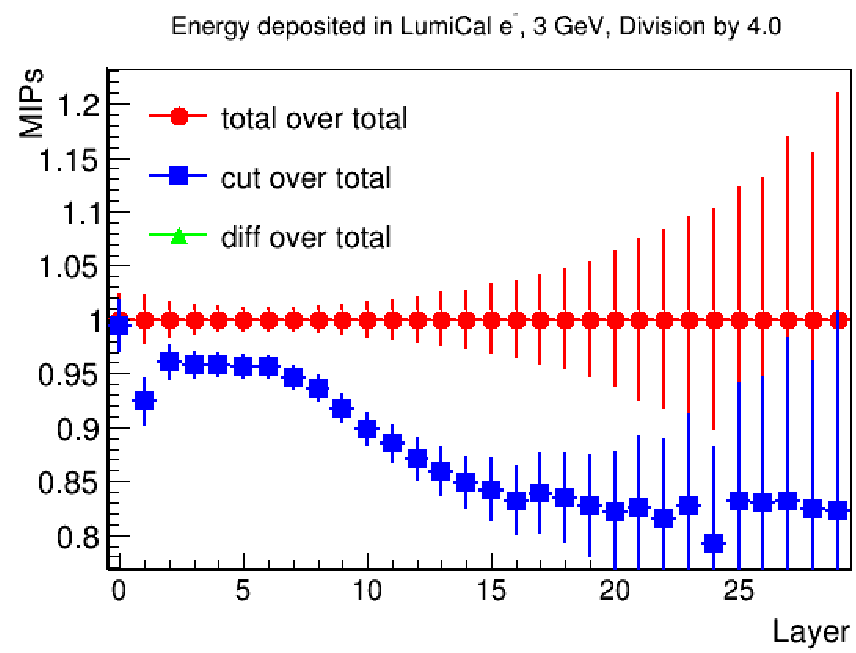


Different Dividers



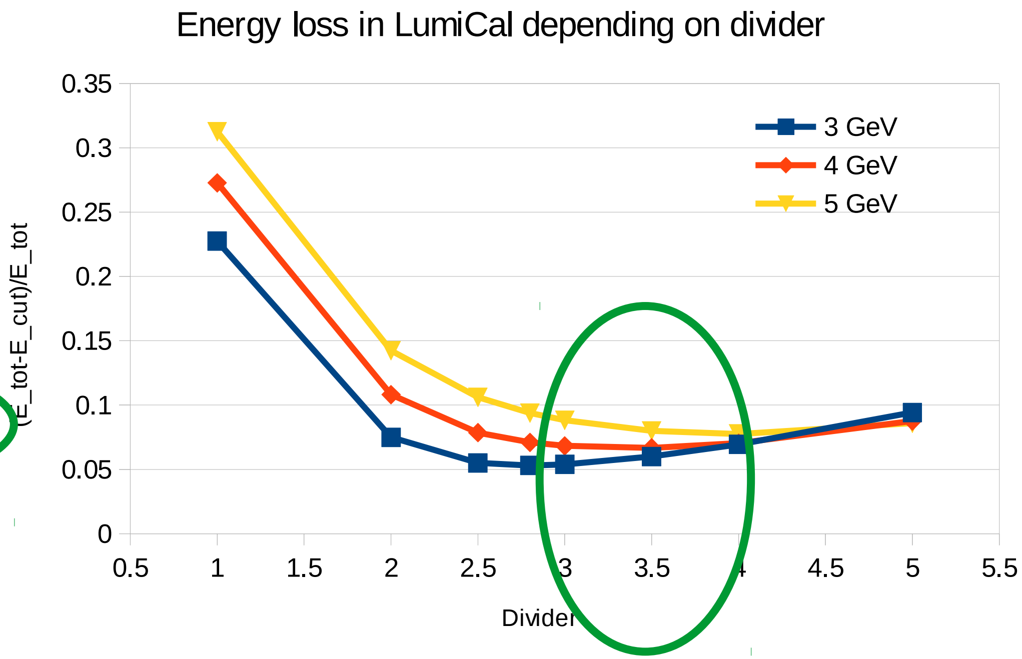






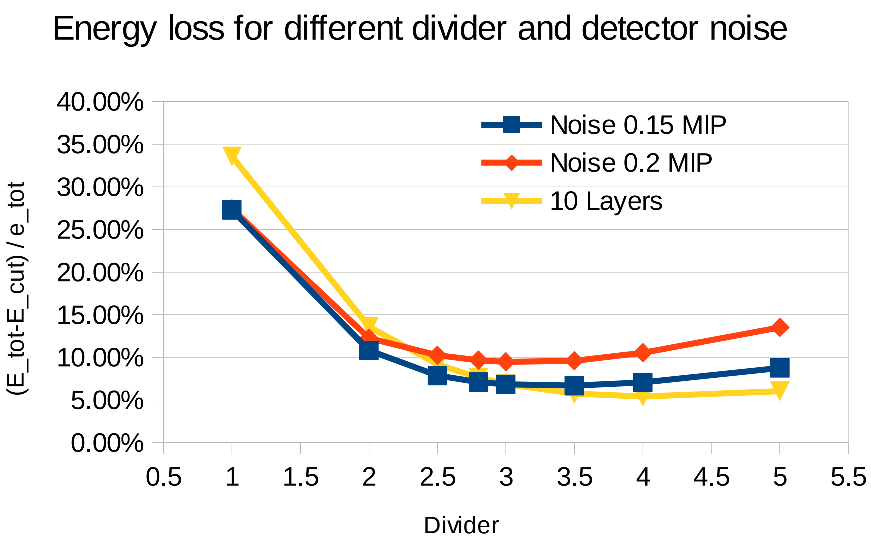
Lost Fraction for Different Beam Energy and Noise

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%



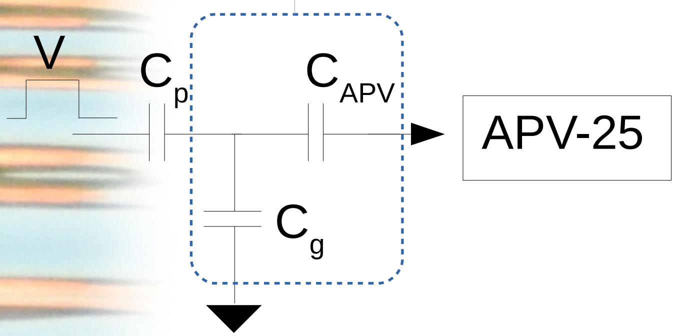
Affect of noise for 4 GeV beam and smaller number of layers (10)

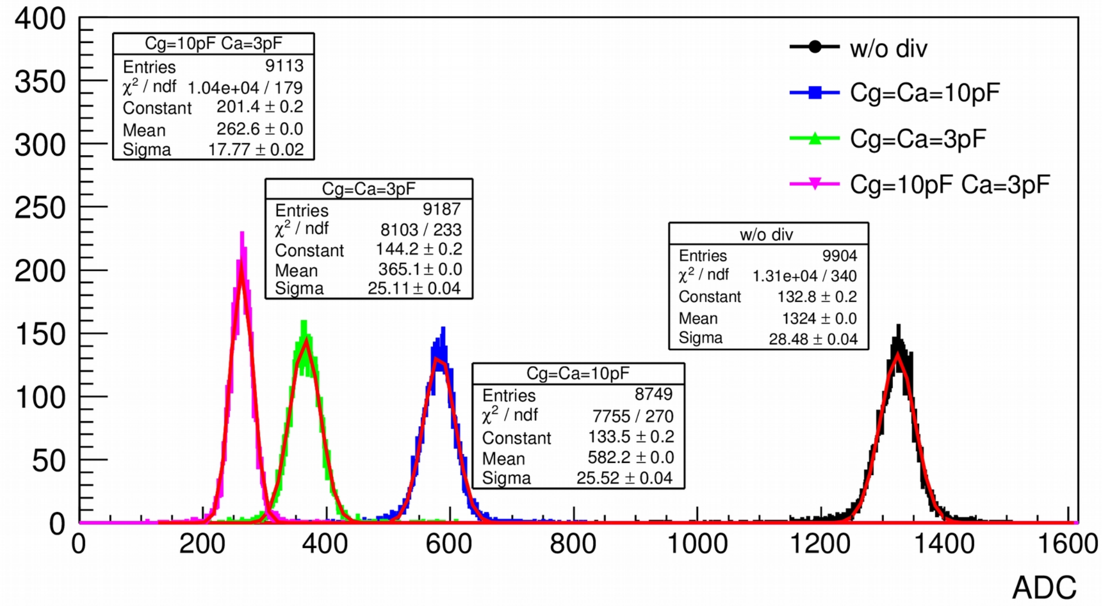
Divider	Noise 0.15 MIP	Noise 0.2 MIP	10 Layers
1	27.27%	27.42%	33.57%
2	10.81%	12.26%	13.60%
2.5	7.86%	10.24%	9.18%
2.8	7.10%	9.67%	7.61%
3	6.83%	9.48%	6.86%
3.5	6.68%	9.60%	5.74%
4	7.04%	10.55%	5.39%
5	8.75%	13.51%	6.03%



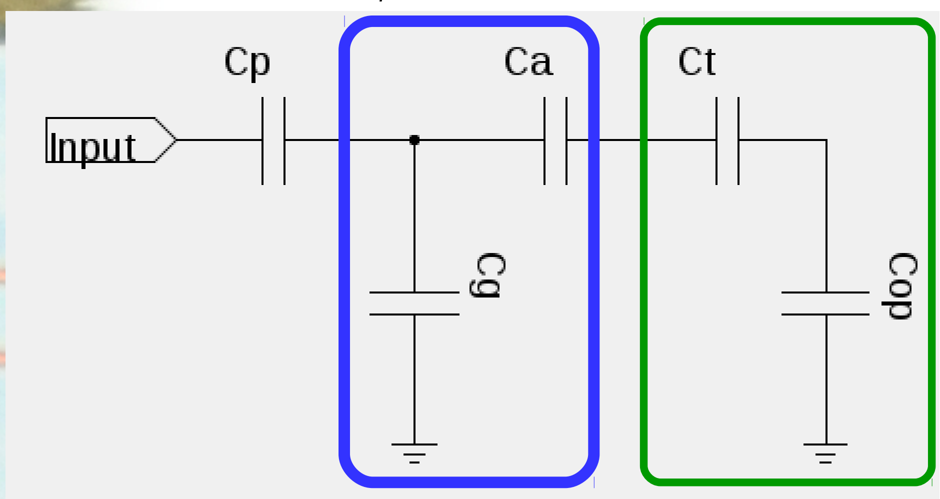
Divider Implementation Tests

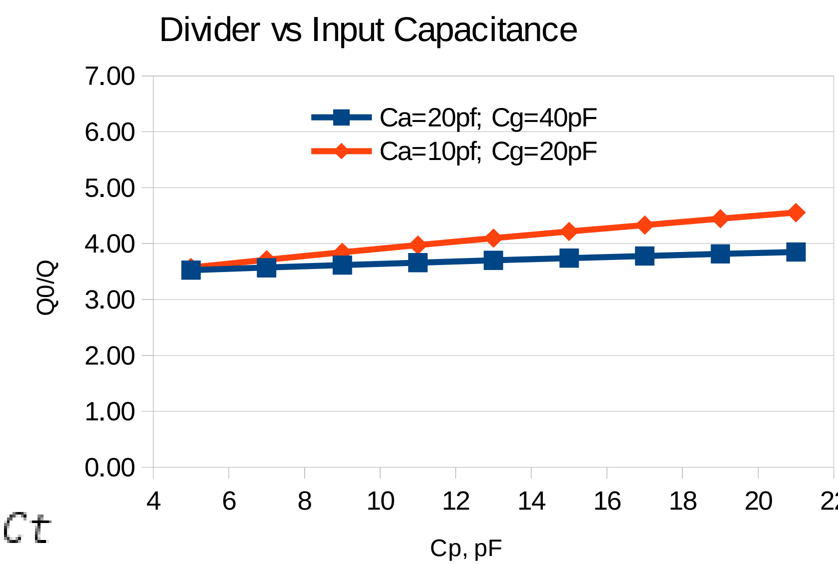
Can be implemented as a small PCB connected to LumiCal detector module and APV-25 board.





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

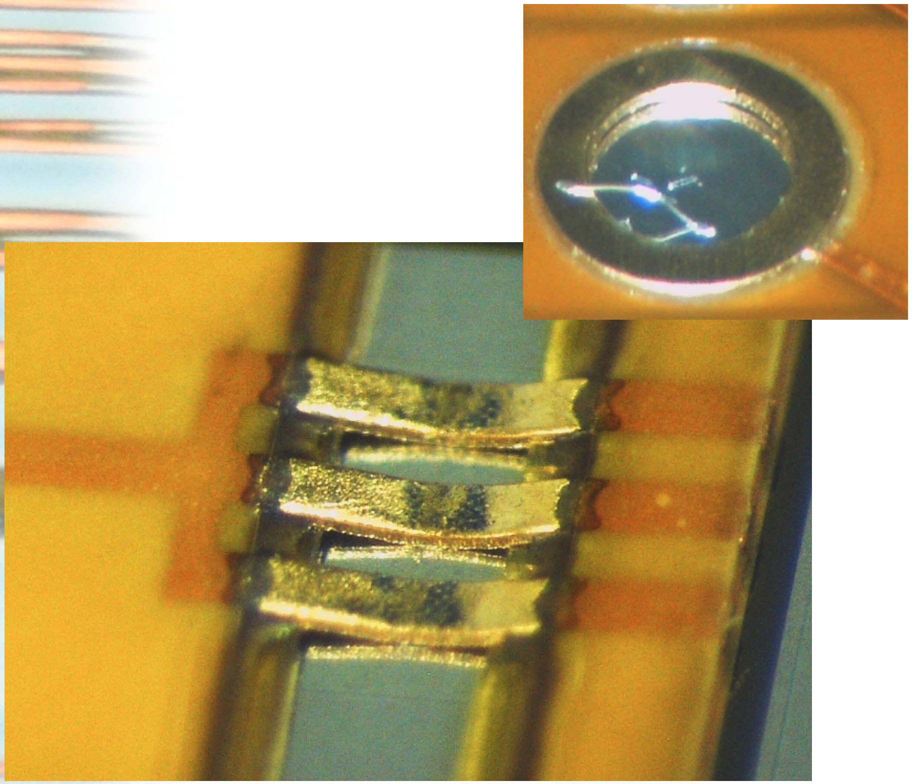


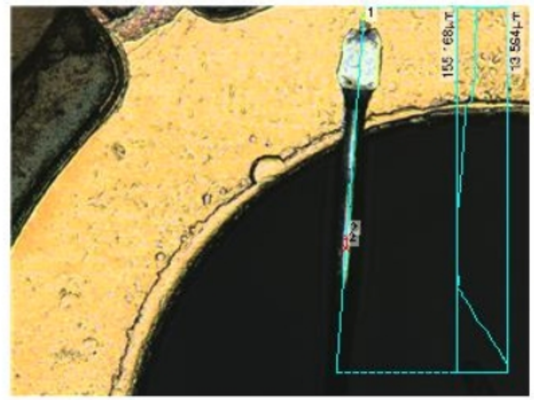


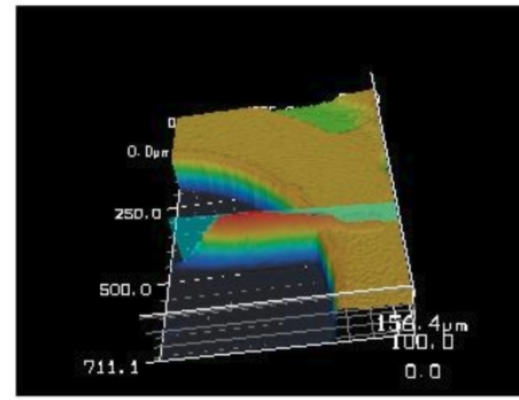
$$\frac{Q_0}{Q} = \frac{Ca\,Cg + Ca\,Cp + (Cp + Cg + Ca)\,Ct}{Ca\,Ct + Ca\,Cp}$$

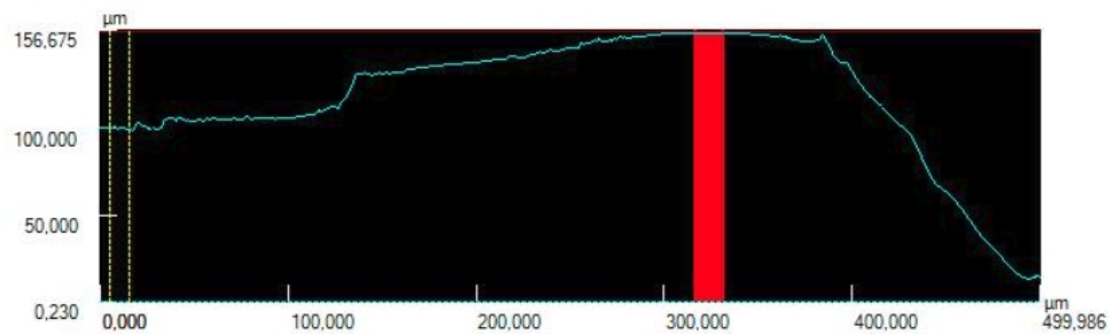
TAB Technology for Front-end Contact

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





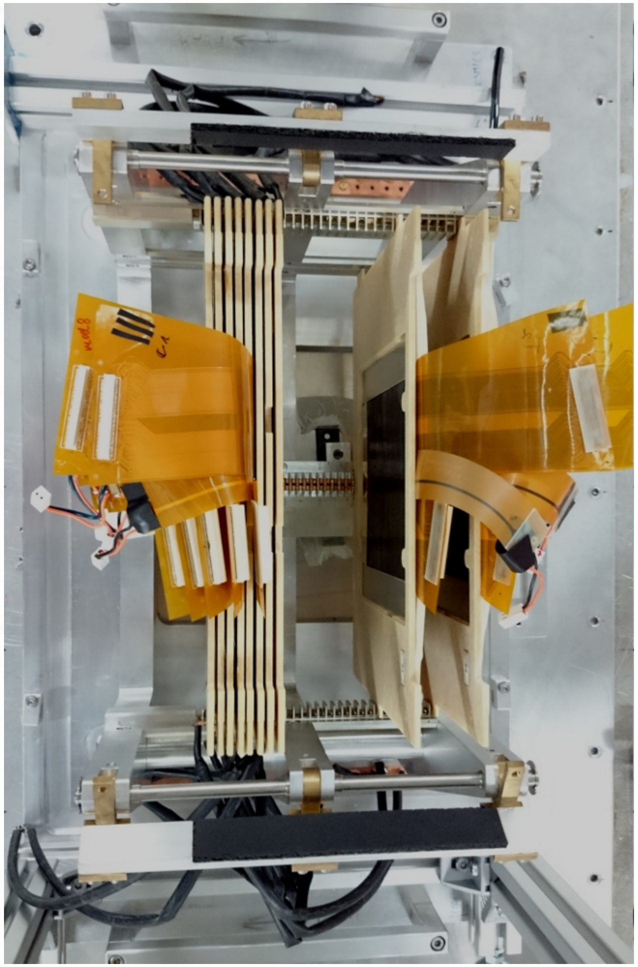


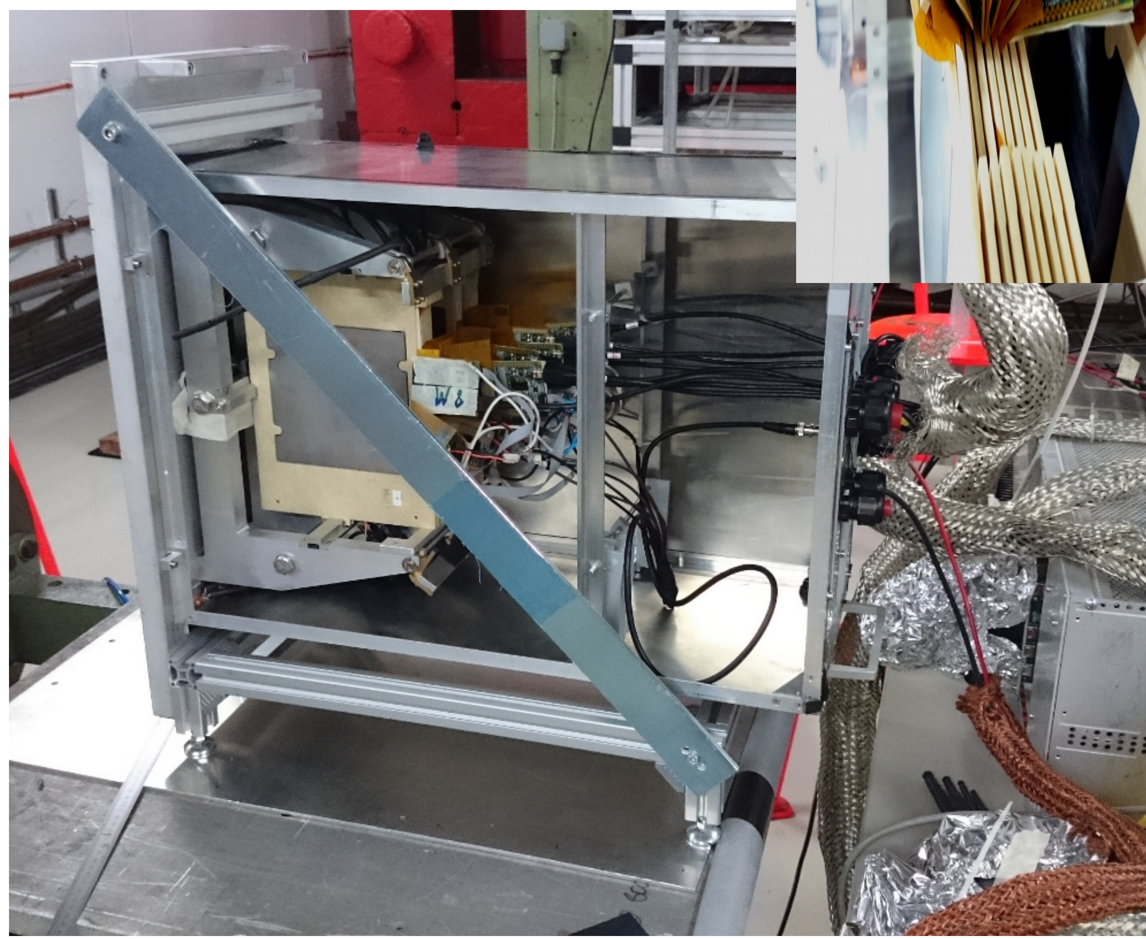


Single point Tape Automated Bonding (TAB):

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

LumiCal Setup





TB 2016 Workflow

- DESY TB21 beam line test facilities
- Dipole magnet up to 1.3 T
- e- or e+ beam up to 6 GeV
- Six planes of pixel sensors telescope (Eutelescope, DATURA) with resolution ~5 μm, 3 before and 3 after the magnet.

7 + 1 (TAB) LumiCal modules were readout using SRS and MMDAQ, about 2000 channels

Measurements to study energy response:

- Beam energies from 1 GeV to 6 GeV with 1 GeV step;
- Two different positions in LumiCal sensor;
- With and without charge divider;

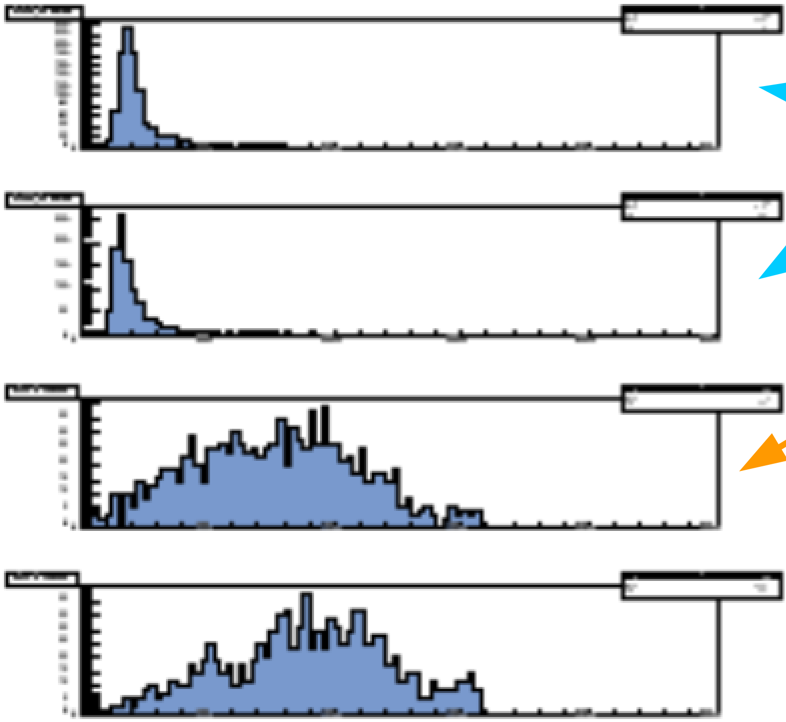
With all possible combinations

Study photon tagging capability:

- Photon generation with 1.5 mm and 2.5 mm thick Cu targets
- Different triggers for low (up to 2 GeV) and high (2 GeV – 5 GeV) energy photons.

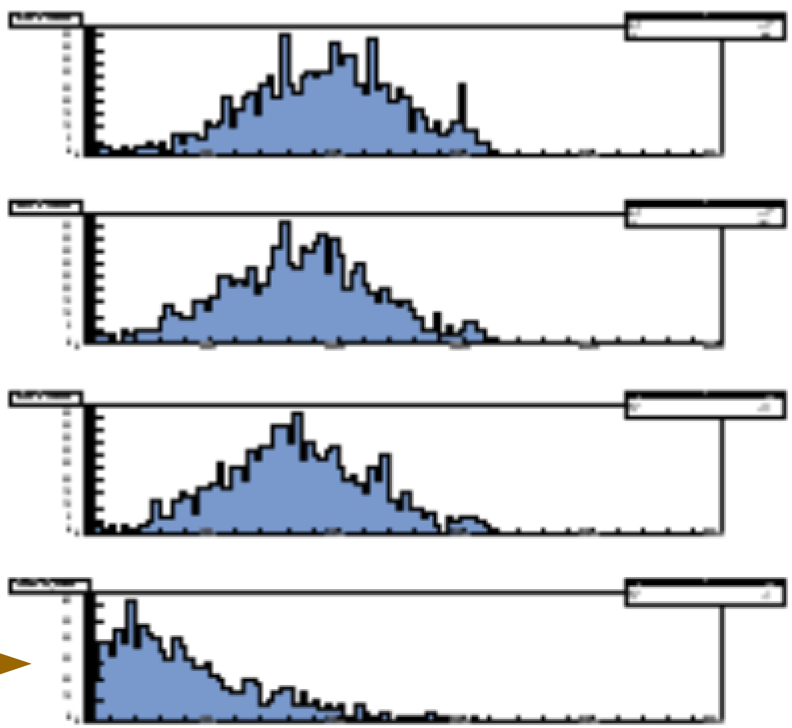
Energy Deposit in Sensitive Layers

MMDAQ online monitoring



Tracker layers

First sensor layer of calorimrter, installed after 3 layers of absorber($3X_0$)



Consecutive layers of the sensors are installed after each layer of absorber ($+1X_0$) in 1mm gap.

Sensor assembled using TAB technology, Not all pads were connected.

Summary

- Electromagnetic shower development in LumiCal 4-module prototype was studied using the beam test data. The paper is in final stage of preparation.
- Thin LumiCal modules with submillimeter thickness were developed and produced. The LumiCal prototype with the thin modules and existing mechanical structure was assembled and tested with beam. Data analysis is in progress.
- One LumiCal module prototype with TAB technologies has been produced and installed for 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 reducing the number of data from saturated channels.
- Data analysis is under way.

Thank you for your attention!