Beam test of a compact LumiCal prototype

CLIC Detector and Physics Collaboration Meeting

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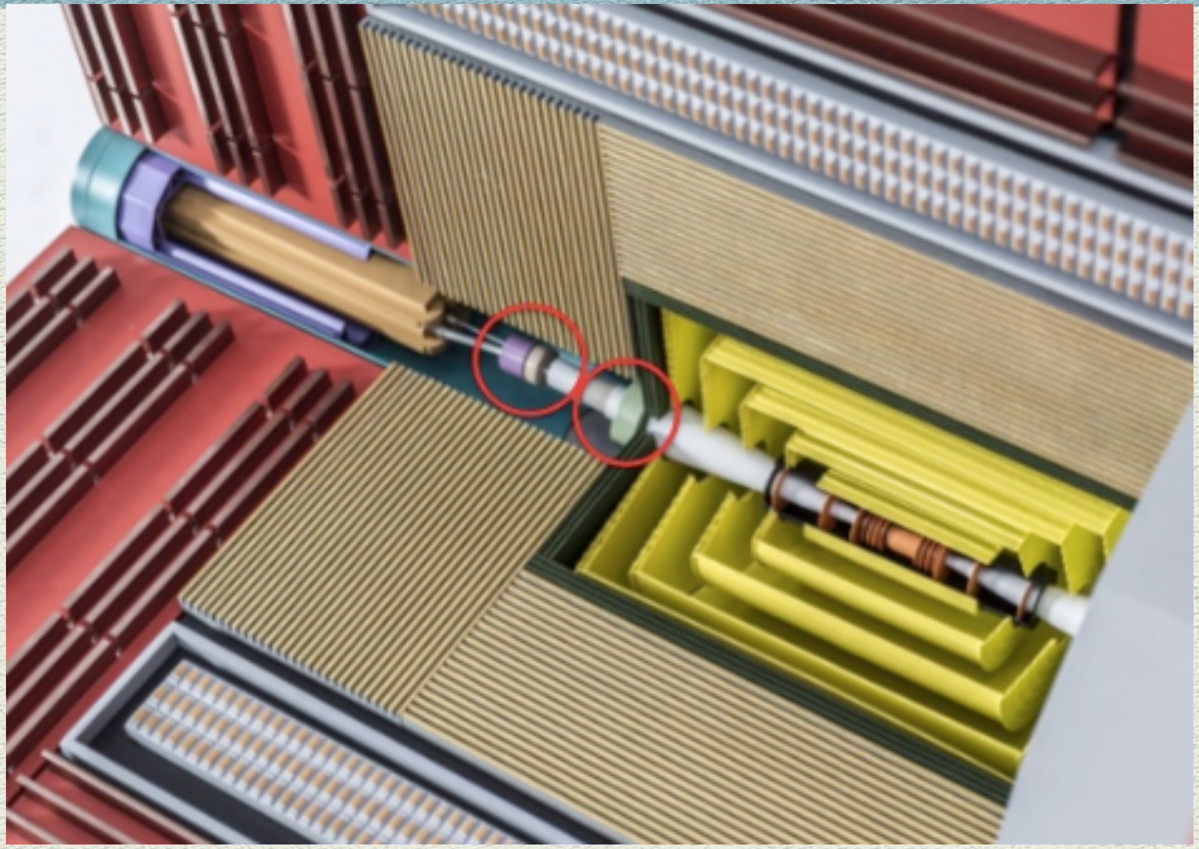
Outline

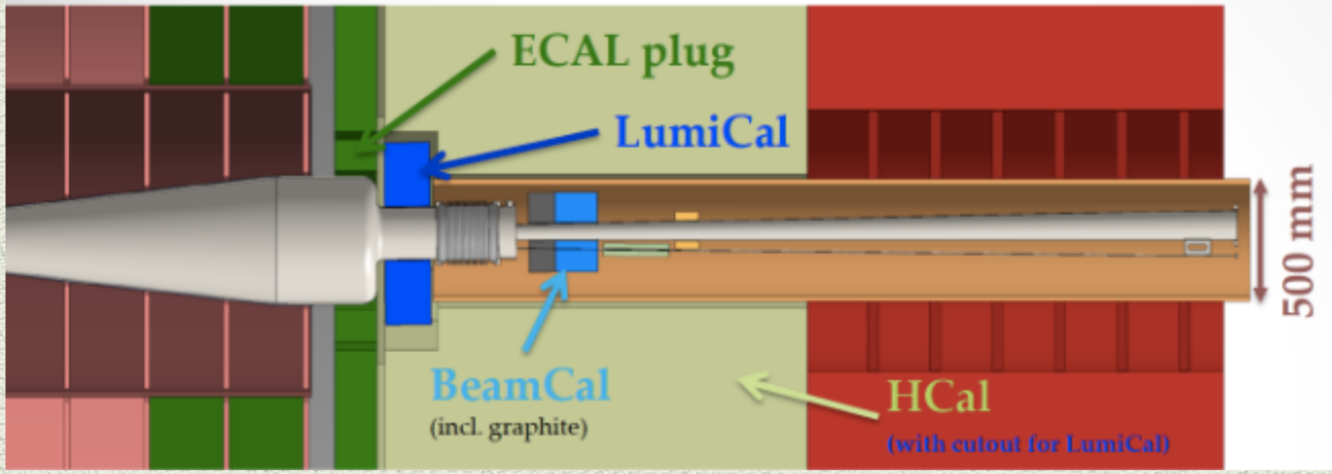
- ✤Motivation
- LumiCal calorimeter in CLIC experiment
  - Luminosity measurement
  - Detector module development
  - LumiCal prototype
- LumiCal simulations & test beam results
  - Beam test configuration and goals
  - Electromagnetic Shower Study in Longitudinal Direction
  - Electromagnetic Shower Study in Transverse Plane
  - MR preliminary results
- ✤Summary

LumiCal in CLIC Experiment

- **Goals:**
  - Precise integrated luminosity measurements;
  - Extend a calorimetric coverage to small polar angles.
  - Important for physics studies in high rapidity region.

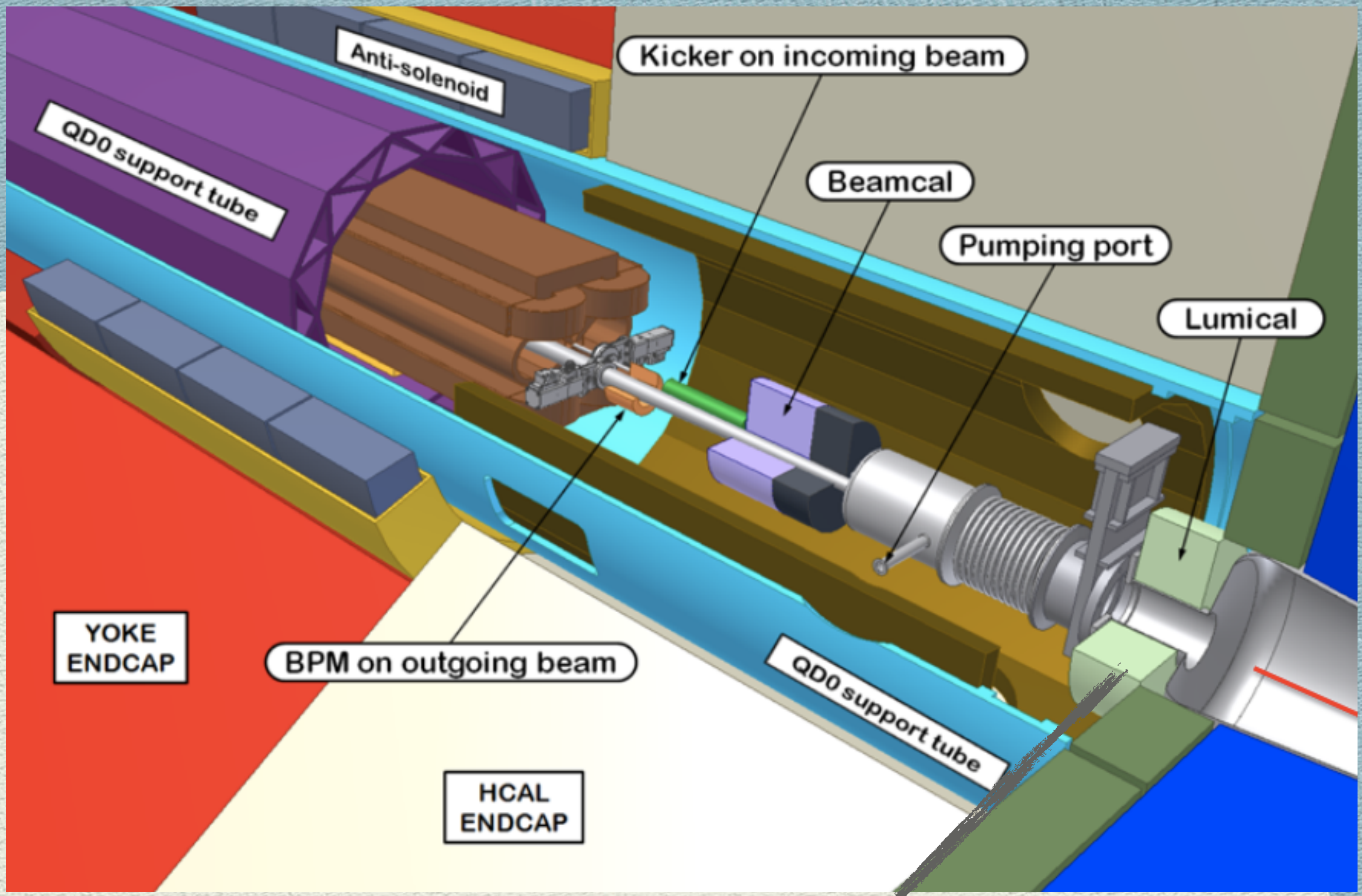


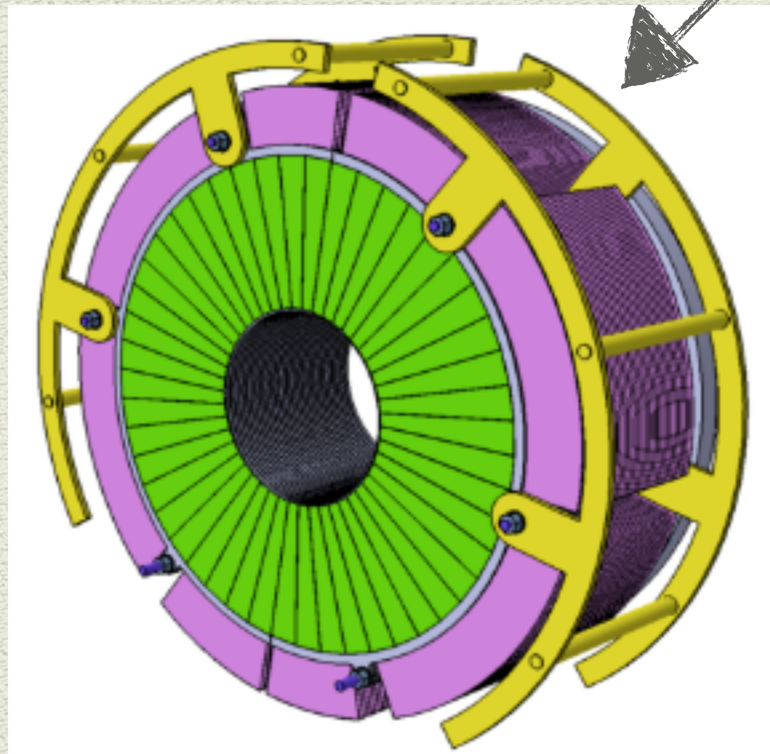
- **LumiCal Location:**
  - Two tungsten-silicon calorimeters placed symmetrically on both sides of the interaction point;
  - Positioned in circular hole of ECAL



LumiCal

LumiCal is a Si-W electromagnetic sandwich calorimeter





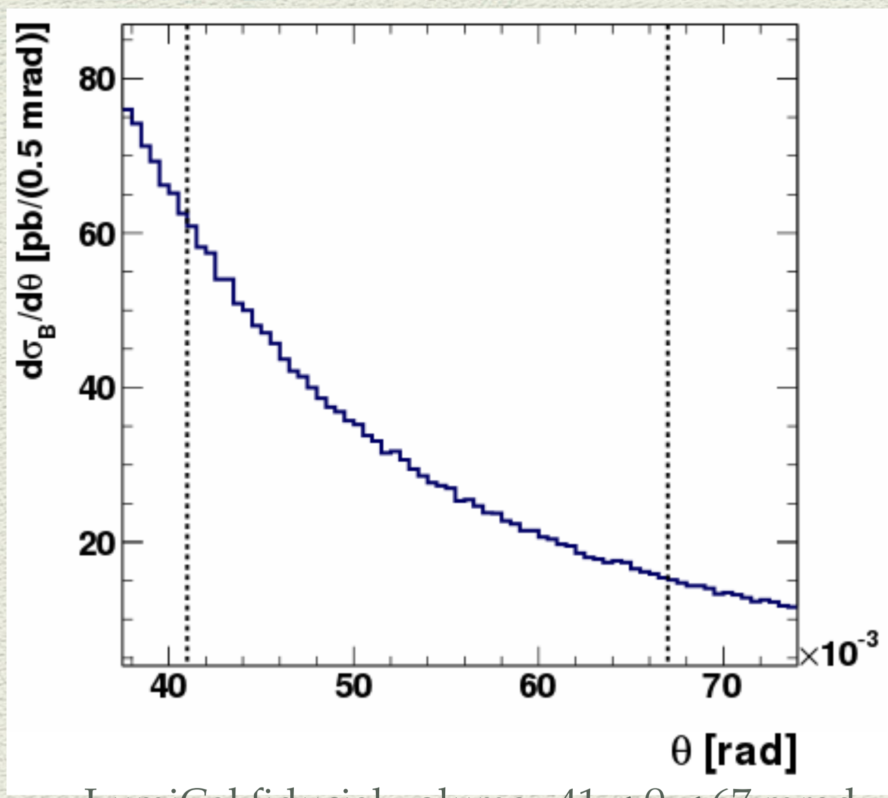
- Challenging requirements on geometrical compactness
- Each calorimeter consists of 40 layers of 3.5 mm (1X0) thick tungsten absorbers and silicon sensors placed in a 1 mm gap between absorber plates;
- 320 μm Si sensor with radial and azimuthal segmentation.

Luminosity measurement

- The luminosity can be 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 fiducial volume: 41 < θ < 67 mrad

The cross section of the Bhabha process can be precisely calculated.

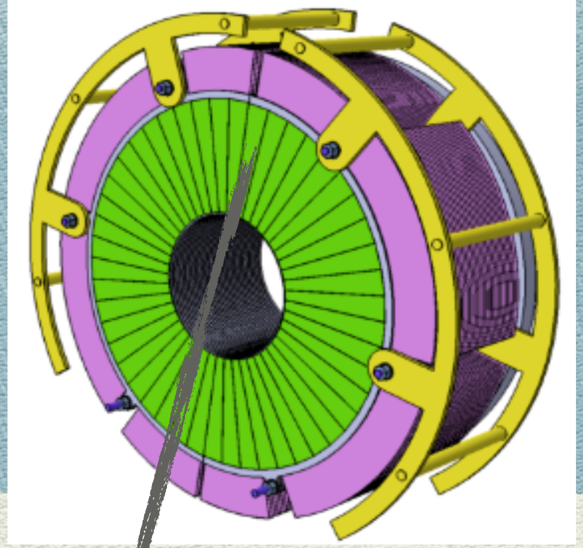
In leading order:

$$\frac{d\sigma_B}{d\theta} = \frac{2\pi\alpha_{em}^2}{s}\frac{\sin\theta}{\sin^4(\theta/2)} \approx \frac{32\pi\alpha_{em}^2}{s}\frac{1}{\theta^3},$$

the approximation holds at small θ.

α is the fine-structure constant, s - center-of-mass energy squared.

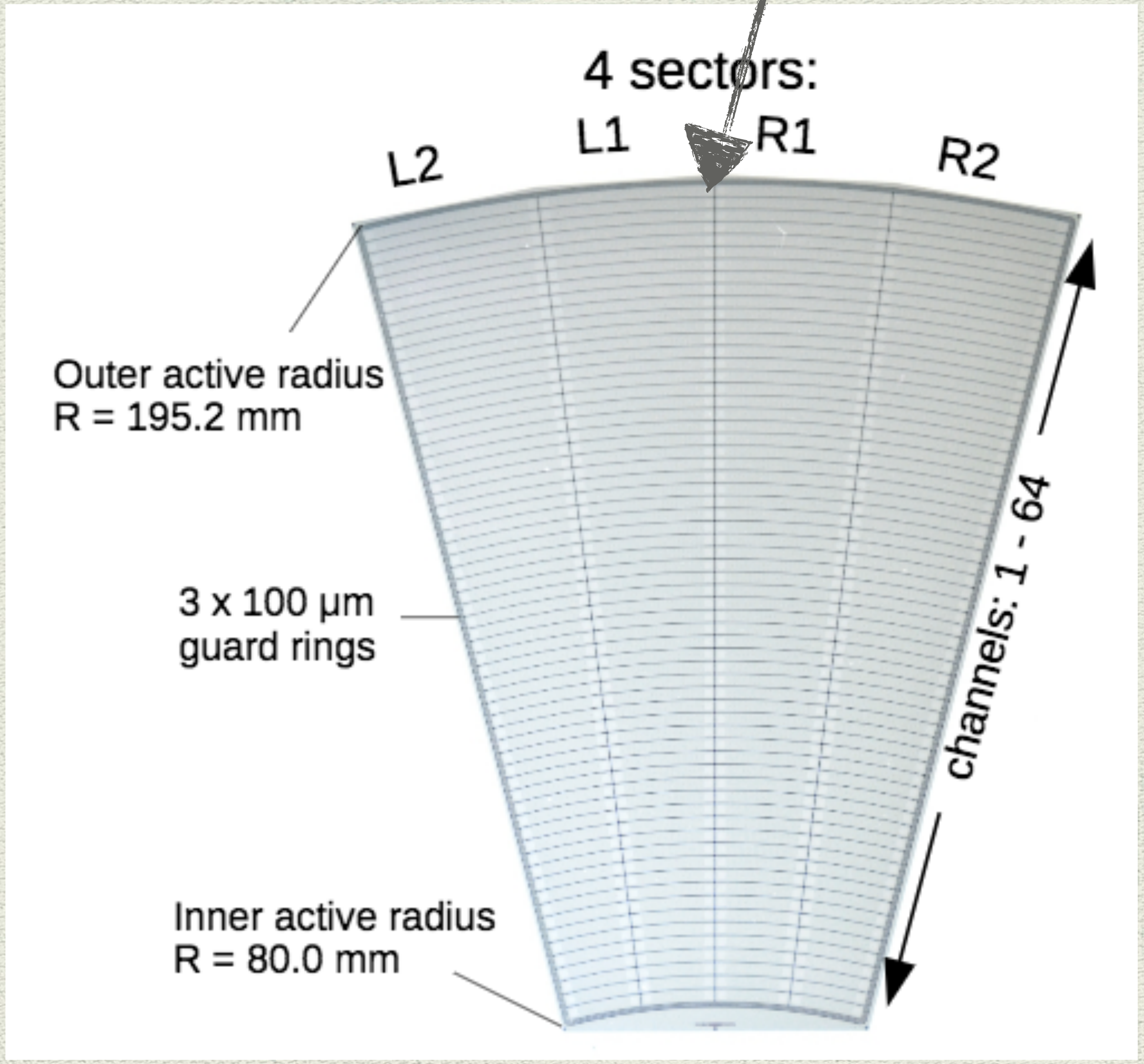
LumiCal silicon sensor



A silicon-sensor prototype was produced by Hamamatsu :

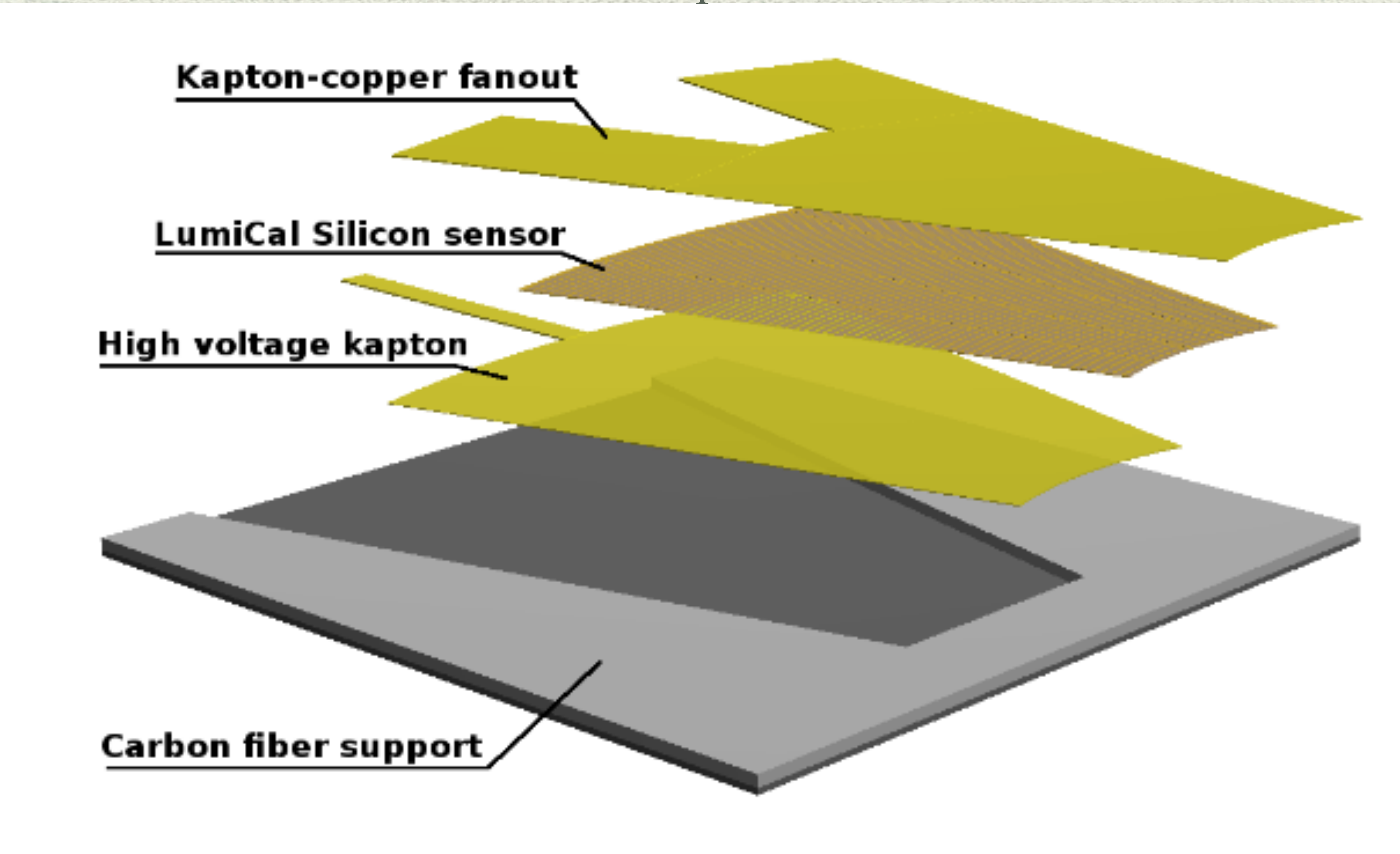
- thickness 320μm.
- DC coupled with read-out electronics.
- p^+ implants in n^- type bulk.
- 64 radial pads, pitch 1.8 mm.
- 4 azimuthal sectors in one tile, each 7.5°.

- 12 tiles make full azimuthal coverage.



Thin LumiCal module assembly.

- To meet LumiCal design performance the sensor module thickness was reduced to less than 1 mm - size of gap between absorbers.
- Front-end chip APV25: Designed for CMS silicon microstrip detectors (used for Belle II SVT)
- Front-end electronics could be placed outside the active volume.



Layer	Thickness
Fan-out	120
Adhesive	10
Si sensor	320
Adhesive	15
HV Kapton	70
Adhesive	15
Support	100
Total:	650 μm

TB 2016 campaign

- **The Beam Test Goal is to test the performance of the compact LumiCal prototype to meet the requirements on geometrical compactness:**
    - Detector modules performance: noise, saturation, S/N, etc;
    - Energy response to e- beam of 1 – 5 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.
- The data collected during the beam-test of 2016 have been preliminary analyzed and compared with results of Geant4 applications.

The results were discussed both at S&A and TAU WG meetings. Ongoing study of the shower development in transverse plane:

– the developed for TB2014 fitting method was applied to calculate Molière radius $R_{\mathscr{M}}$ for TB2016 data

2016 Test Beam Configuration

Sc1, Sc2 and Sc3 are scintillator counters; T1, T2 – three pixel detector planes; Tg – the copper target for bremsstrahlung photon production.

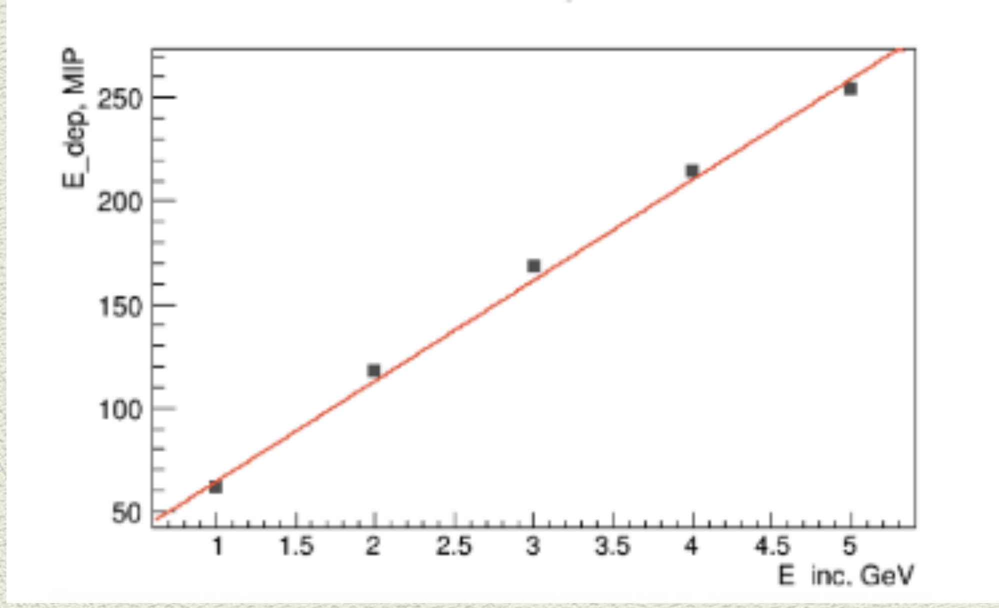
- 8 full (256 channels) thin layers (> 2k channels);
- 2 used as a tracker / tagger for e/γ separation;
- 6 as calorimeter (3 - 8 X0) with 1 mm gap;
- DAQ : SRS system, designed by RD51 collaboration;
- EUDET / AIDA beam Telescope : 6 planes with MIMOSA chip;

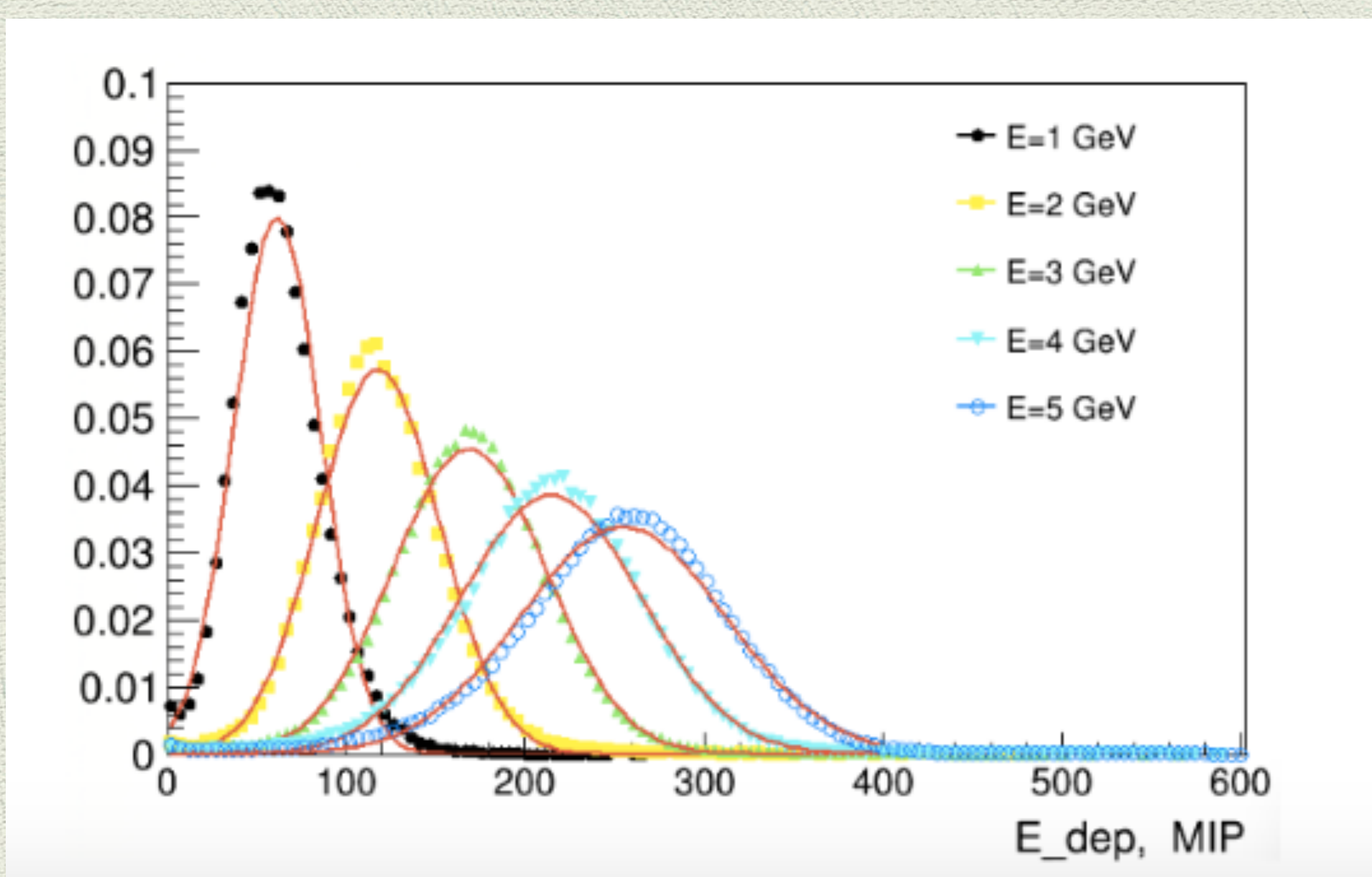
DESY test beam facilities:

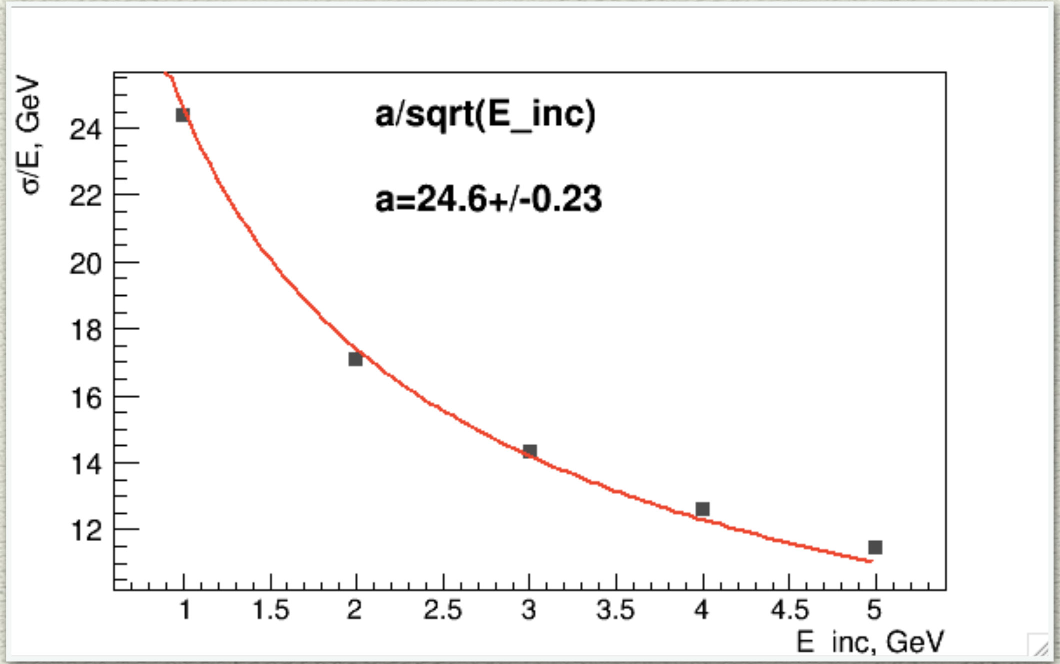
- Electron beam 1 – 5 GeV;
- Dipole magnet 1 – 13 kGs;

LumiCal Energy Response

LumiCal response to electron beam with E= 1-5 GeV when running with charge divider

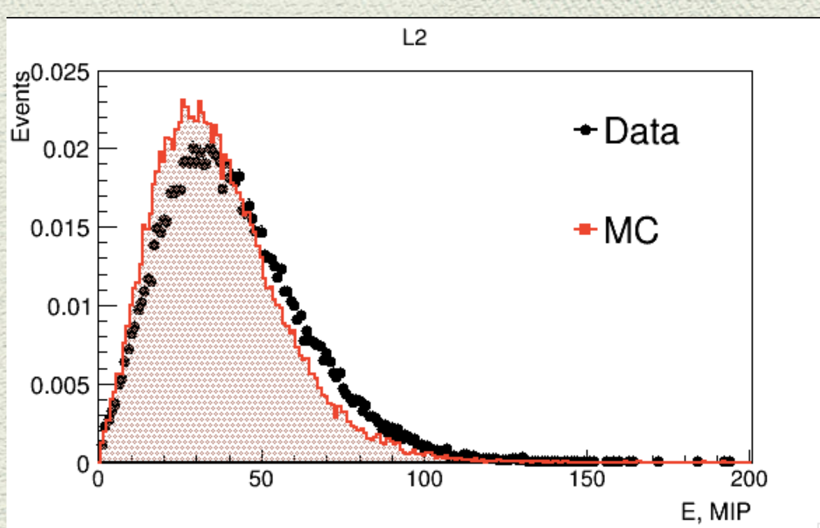


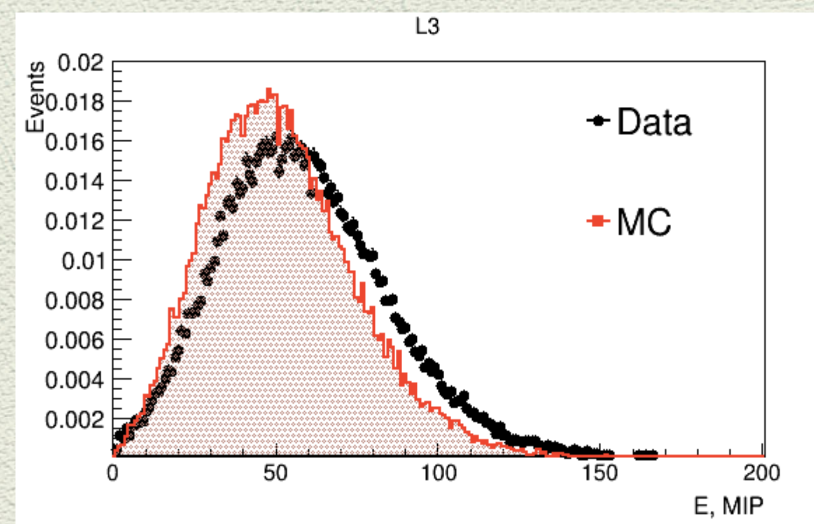




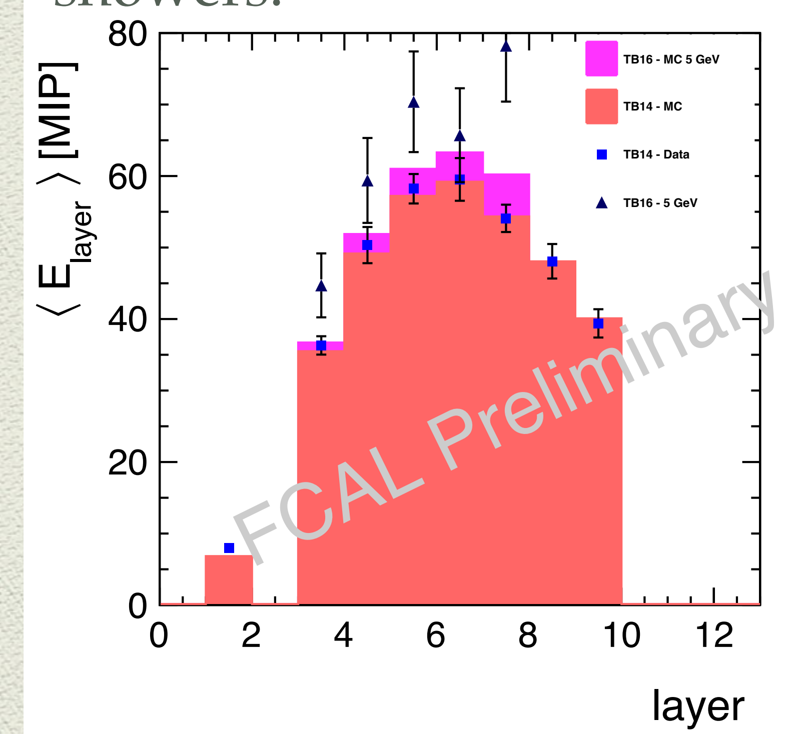
Shower development

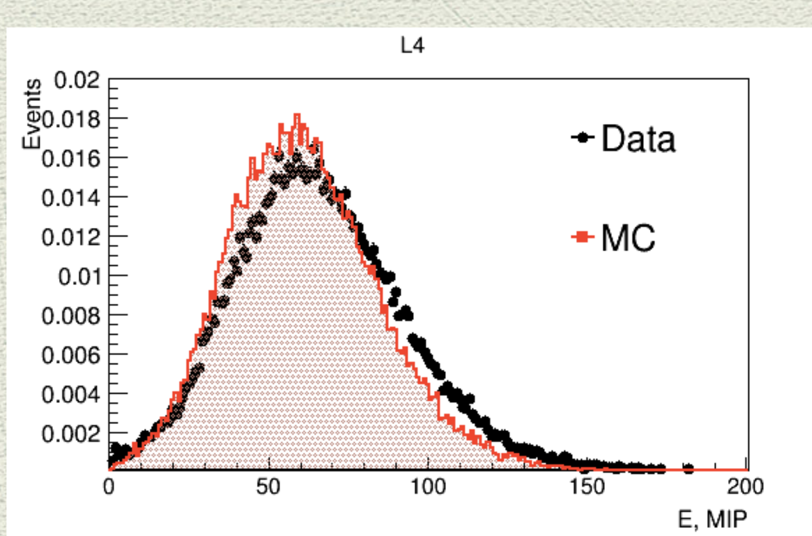
To examine the longitudinal development of the electromagnetic shower, the distribution of the sum of the deposited energy per layer, was compared with predictions of GEANT4 Monte Carlo simulations.

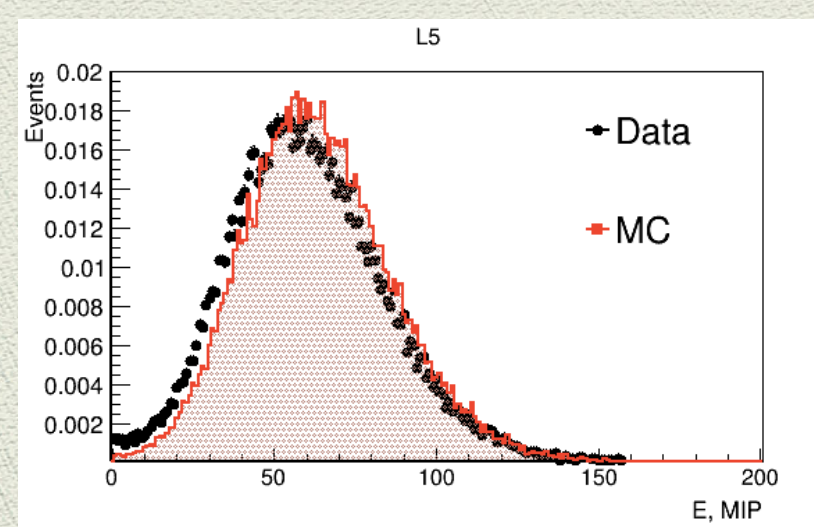




The average energy deposits per layer as a function of the number of absorber layers represents the longitudinal development of electron showers.





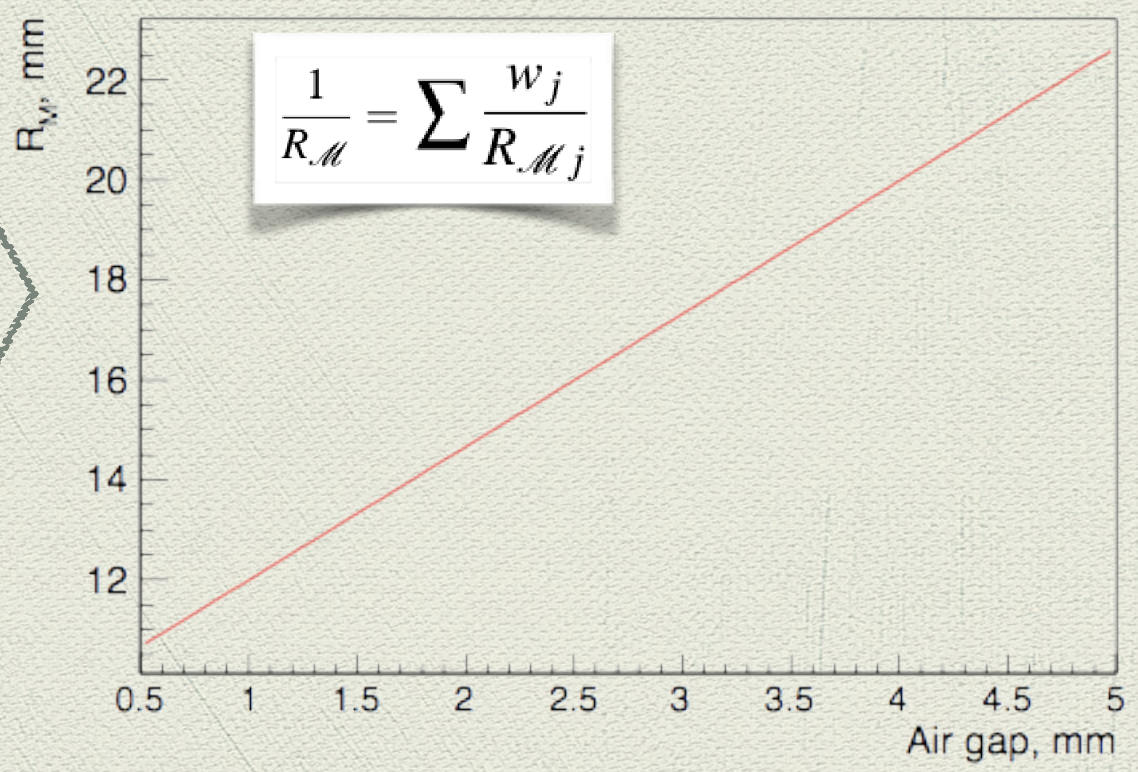


Work in progress..

Molière radius - motivation

- A major design aim of LumiCal is its compact structure.
- One aspect is to limit the development of the electromagnetic showers in the transverse direction and increase the fiducial volume of the calorimeter.
- Position resolution and separation of near-by showers depend on the Molière radius.
- The importance of the gap size between absorber layers in the calorimeter design on the Molière radius

$R_{\mathcal{M}}$ as function of the air gap between 3.5 mm thick tungsten plates



Reducing air gap from 4.5 mm to 1 mm gives

$R_{\mathcal{M}}$: 21 mm -> 12 mm

Shower Study in Transverse Plane

The sensor geometry doesn't allow direct measuring of transverse shower development

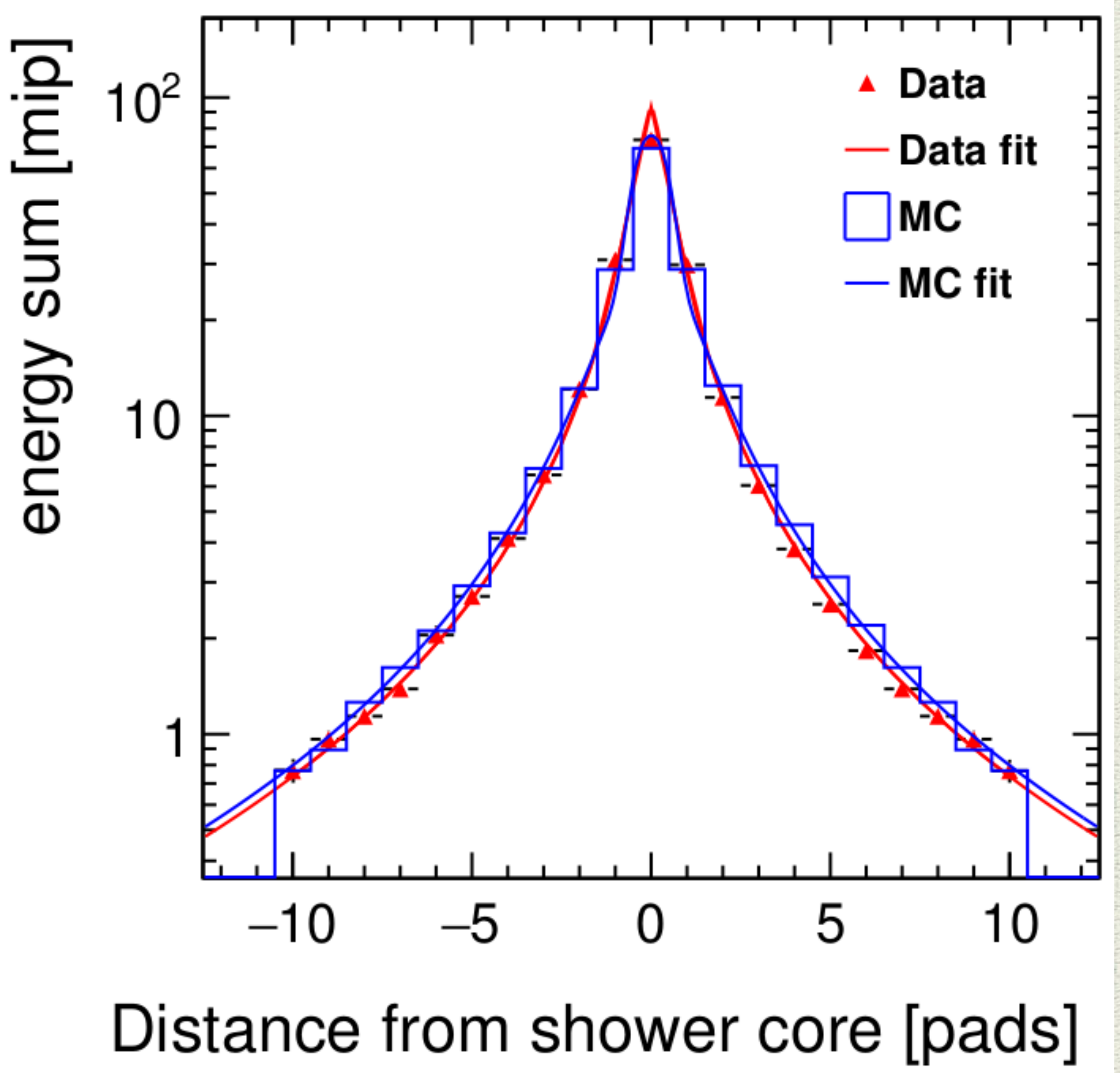
- Transverse shower profile is approximated as

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

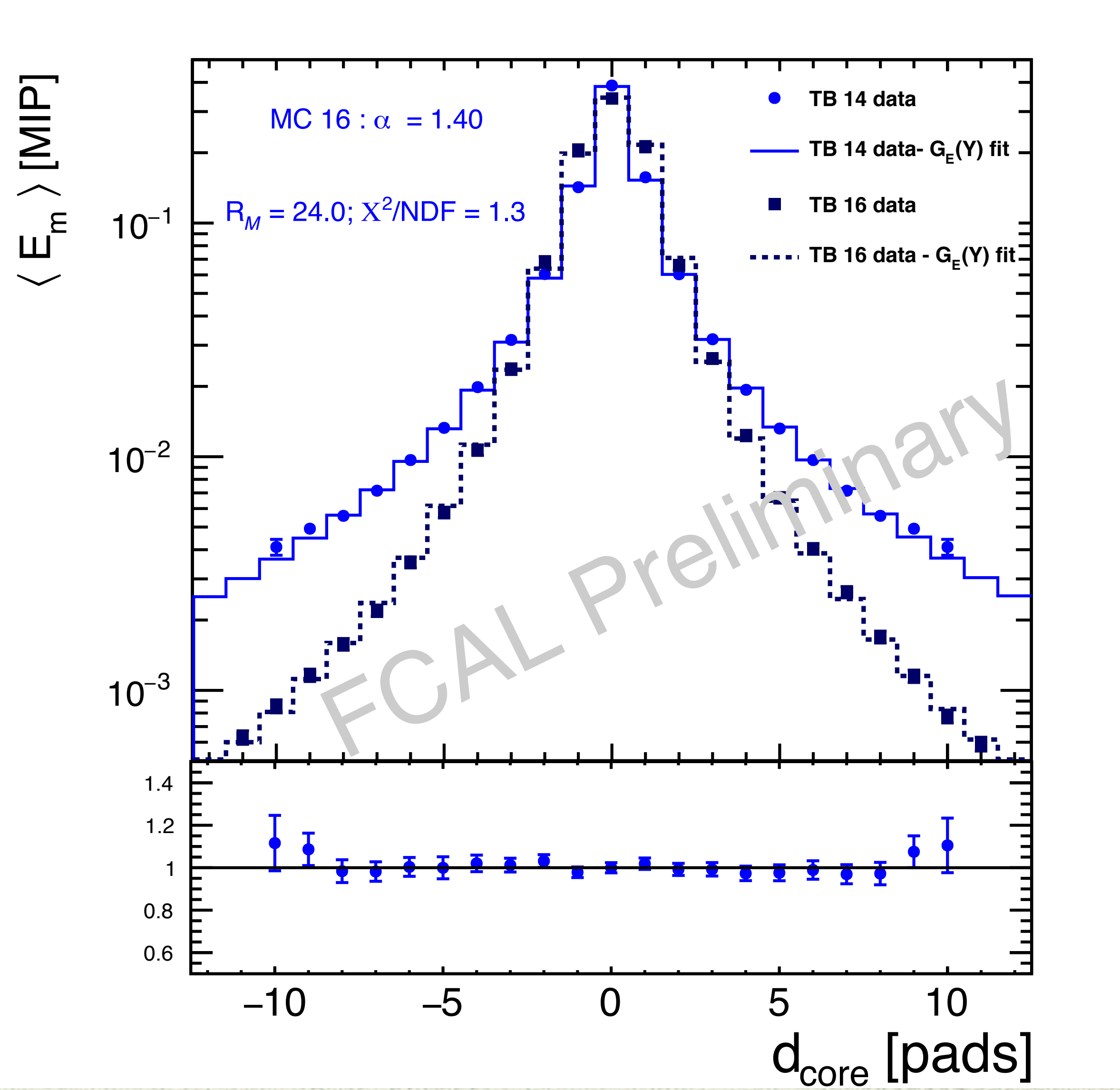
r – the distance from the shower center;
AC, AT, RC, RT – fit parameters.

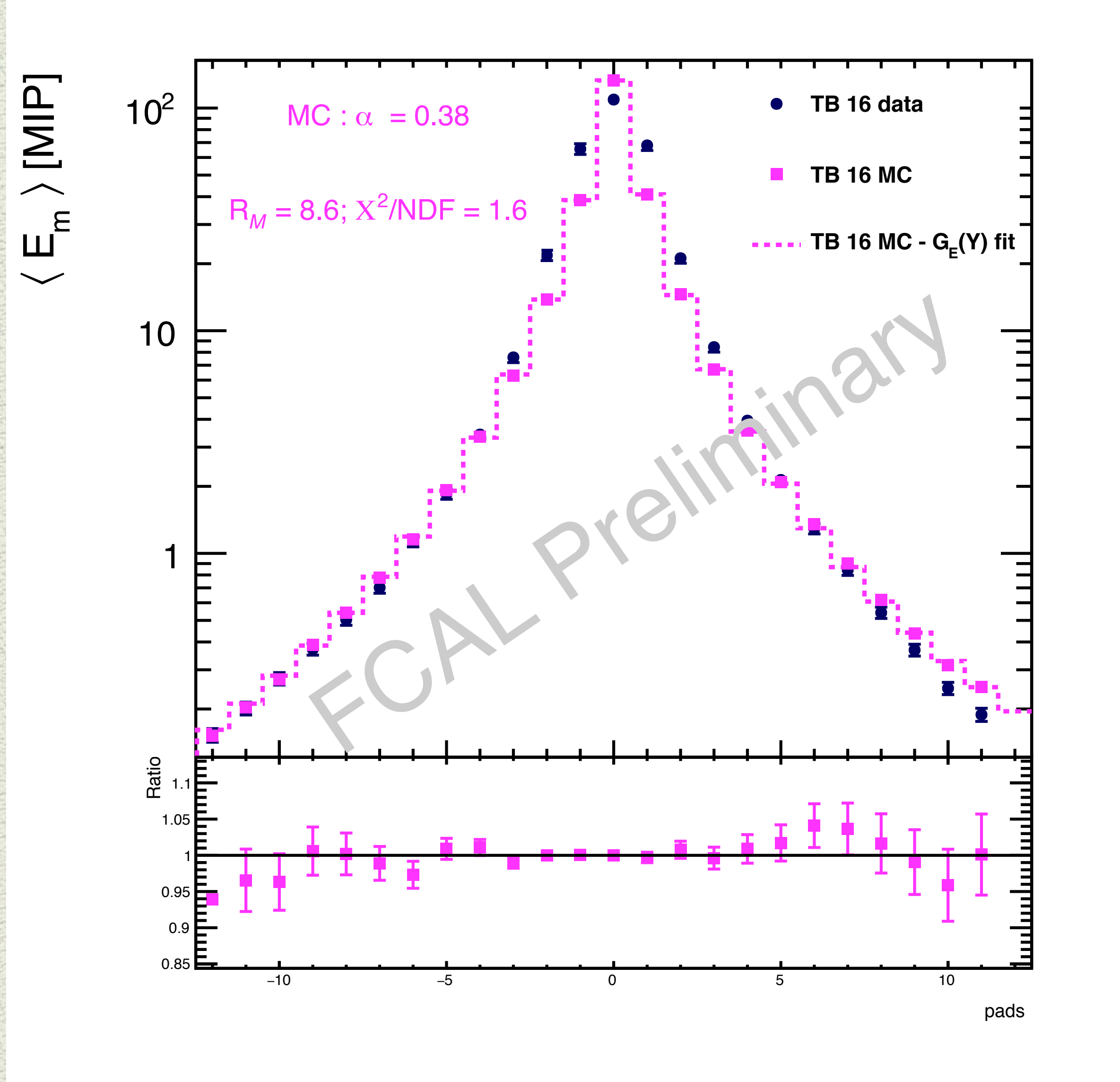
Molière radius $R_{\mathcal{M}}$ can be found from the equation:

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



Preliminary results





Summary

- Thin LumiCal modules with sub-millimeter thickness were developed and successfully produced. The LumiCal prototype with the thin modules and existing mechanical structure was assembled and tested with beam. It corresponds to the requirements of the future linear collider detector.
- The LumiCal prototype showed good performance during the beam test. Data have been successfully collected and their offline analysis is going on.
- The development of the transverse electromagnetic shower is measured and found to be in agreement with MC simulations from the 2014 test beam.
- The preliminary results on Molière radius calculation are in agreement with MC simulations

Thank you for your attention!

Backup

Future electron-positron projects

- **ILC – International Linear Collider**
  - e+e- linear collider, c.m. energy: 500 GeV w/ possibility to upgrade to 1 TeV;
  - superconducting niobium cavities, 31.5 MV/m;
  - supposed to be hosted by Japan in the Kitakami highland.
- **CLIC - The Compact Linear Collider**
  - high-luminosity linear e+e- collider under development at CERN with c.m. energy: 380–3000 GeV;
  - based on a novel two-beam acceleration technique. 100 MV/m has been reached in the CLIC test facility.
- **FCC-ee - Future Circular Collider**
  - – 80–100 km ring in Geneva area with e+e- collider,
  - – 90–350 GeV, very high lumi. Intermediate step before hadrons;
  - – Kick-off meeting on February 2014.

Thin LumiCal Mechanical Prototypes

Total assembly thickness:
- less then 900 µm for carbon fiber
- less then 800 µm for 3d printing

Carbon fiber module significantly more rigid

Procedure was destructive for wire bonding connections.