# Design and Performance Studies of the Luminometers for Future Linear Collider Experiments

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**[on behalf of the FCAL Collaboration]**

19th International Balkan Workshop on Applied Physics and Materials Science
16 - 19 July 2019 Constanta, ROMANIA

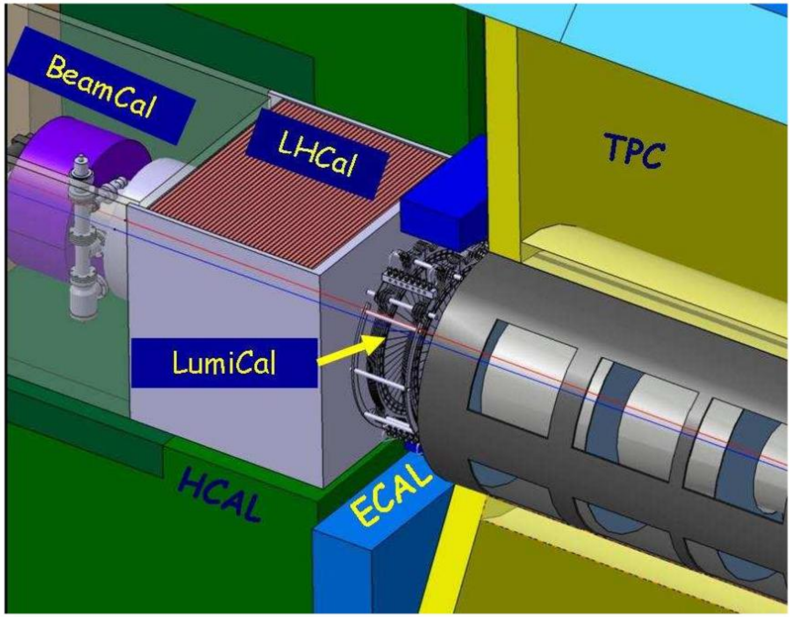
# Overview

- Forward region in LC Experiments
- Thin LumiCal module design
- LumiCal prototype performance in beam-test
  - Beam-test setup
  - Results
- Conclusions and Future Steps

# Forward region in LC Experiments

Goals:

- High precision integrated luminosity measurement;
- Instant luminosity measurement;
- Fast feedback for beam monitoring and tuning;
- Search for a new particles.




**The very forward region of the ILD detector.**

The **LumiCal** is a Si-W electromagnetic sampling calorimeter designed to:

- measure the luminosity with a precision of $10^{-3}$ at ILC and $10^{-2}$ at CLIC;
- covers polar angles range between 31 and 77 mrad.

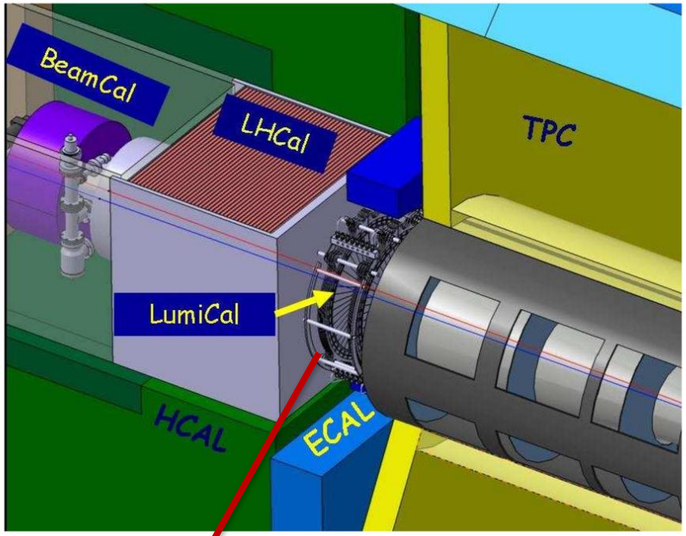
The **BeamCal** is a similar electromagnetic sampling calorimeter, with tungsten absorber but **radiation hard sensors** (GaAs, CVD diamond). It designed for three major purposes:

- Improving the hermicity of the detector to covering polar angles range between **5 and 40 mrad** *;*
- Instant luminosity measurements;
- Beam tuning.

The **LHCAL** extends the coverage of the calorimeter to the polar angle range of **LumiCal** and **ECAL,** and provides additional forward coverage inside the **HCAL** endcap.

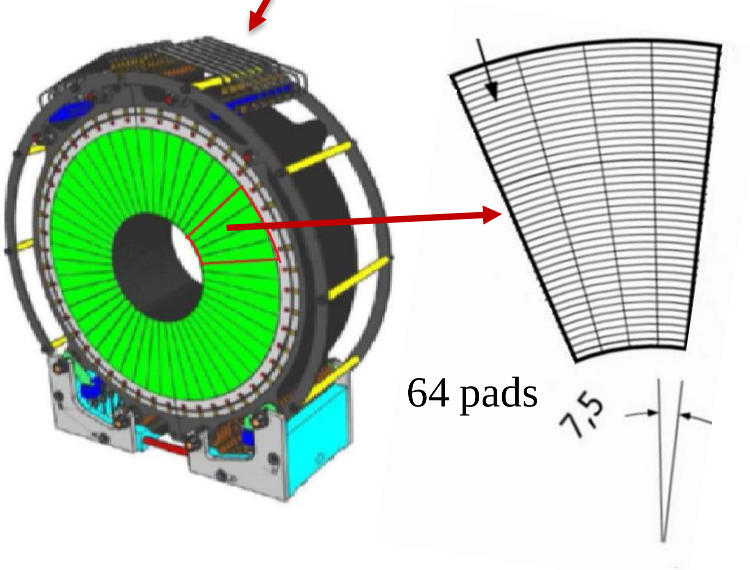
# Forward region in LC Experiments

- The **LumiCal** is a Si-W electromagnetic sampling calorimeter;
- 30 W absorber layers at ILC (40 at CLIC) interspersed with very thin detector planes;
- Fiducial volume between 41 mrad to 67 mrad;
- Compactness for transverse size of shower around 1 cm.

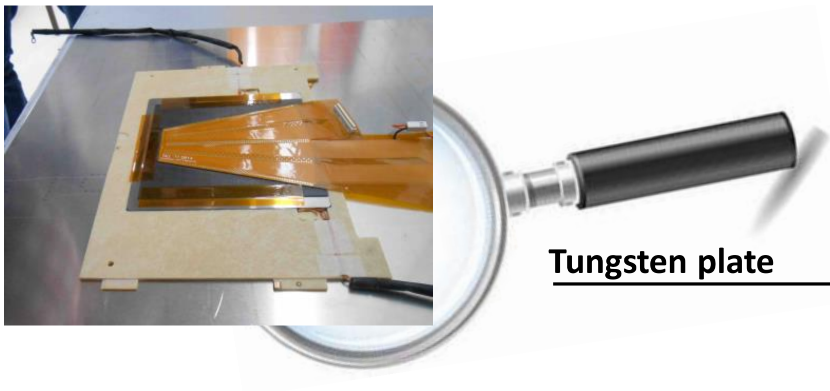


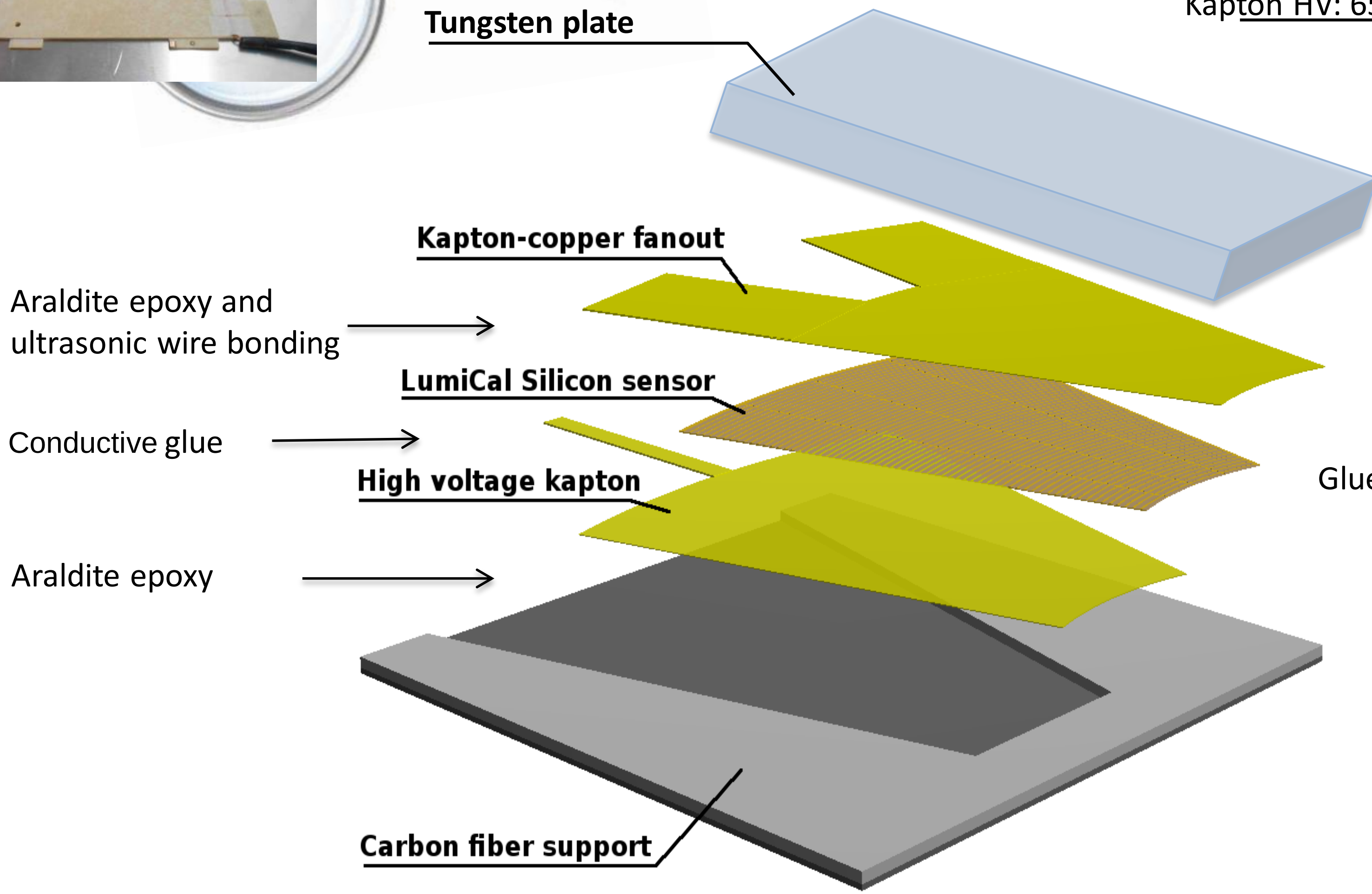

The silicon sensor prototype was produced by Hamamatsu in the technology based on:

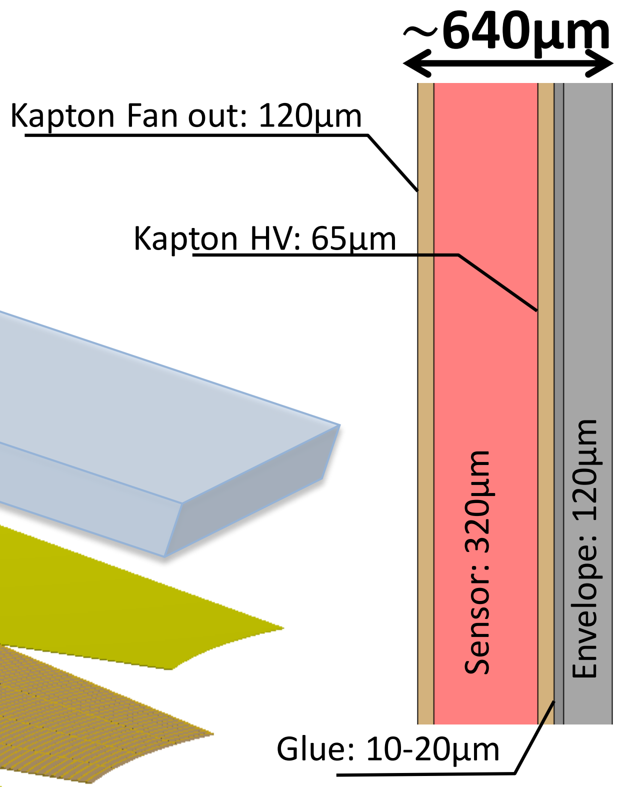
- 6-inch wafer;
- 320 μm thickness;
- 4 azimuthal sectors in one tile, each 7.5 degrees;
- Radially segmented – 64 pads with 1.8 mm pitch;
- 12 tiles makes full azimuthal coverage.



# Thin LumiCal Module



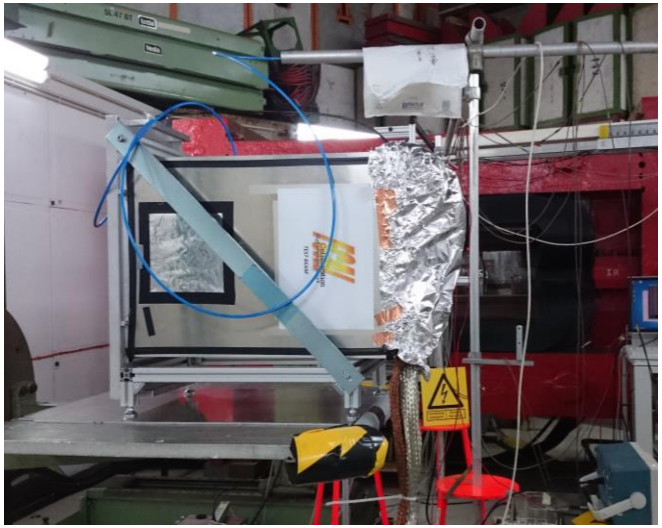


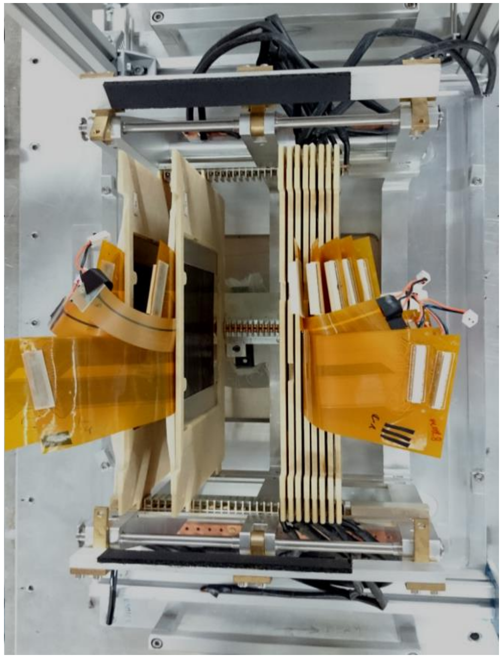



# Beam-test set-up

## Beam-test infrastructure @ DESY:

- Electrons **1 – 5 GeV energy**;
- Data taken in **August 2016** at 21 beam line area;
- **EUDET** telescope – 6 MIMOSA planes;
- **Dipole magnet** 1 – 13 kGs for e/γ separation;
- **DAQ framework** provided:
  - EUDAQ (software);
  - Trigger Logic Unit (hardware);
- **DUT (LumiCal multi-layer prototype)**

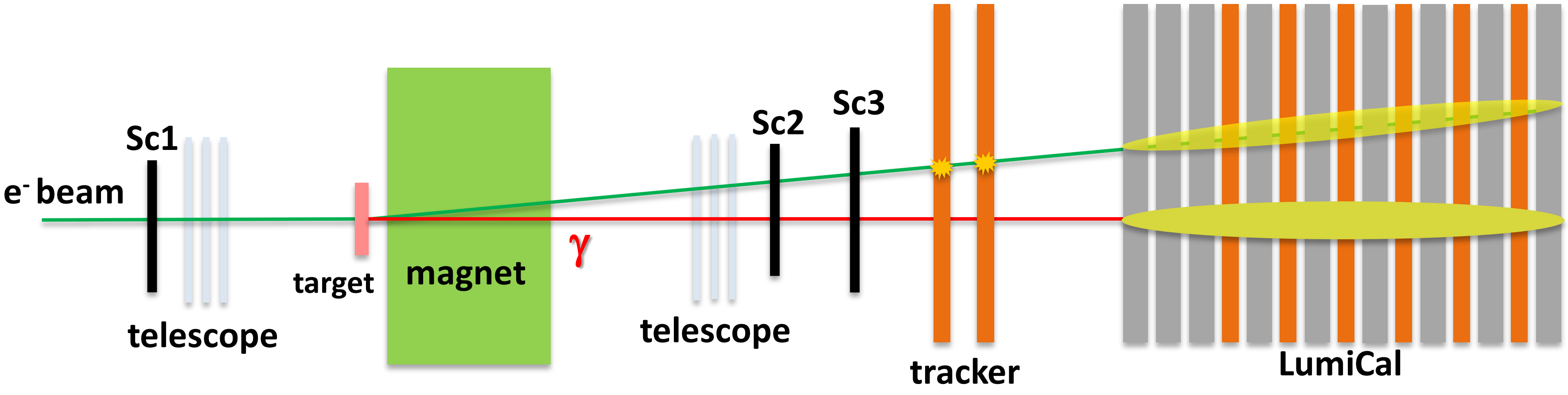




## Goals:

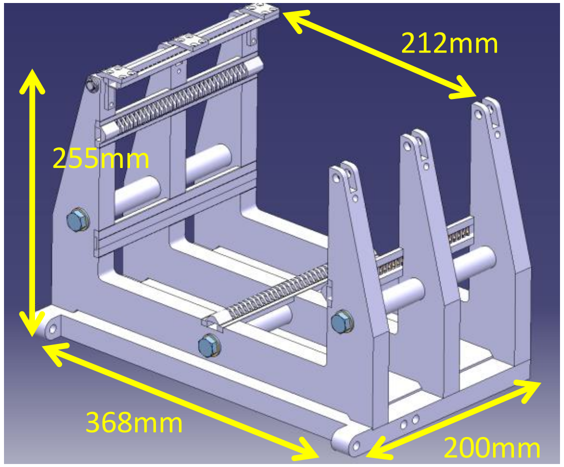
- Measurement of the shower position reconstruction;
- Measurement of the longitudinal shower development;
- Measurement of the transverse shower development;
- Measurement of Molière radius;
- e/γ identification with tracking detector in front of LumiCal;

# Beam-test set-up

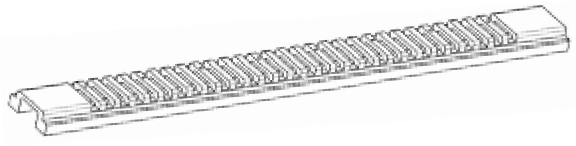



## DUT (LumiCal multi-layer prototype):

- First **submilimiter LumiCal** detector module **(~ 640 µm)**;
- 8 silicon sensors with **256 equipped channels**;
- Silicon sensor – **320 µm** thick;
- FEB: **APV-25 chip** based;
- 2 silicon sensors plane used as tracker;
- **Si sensors** of calorimeter part always separated by **one absorber layer**;



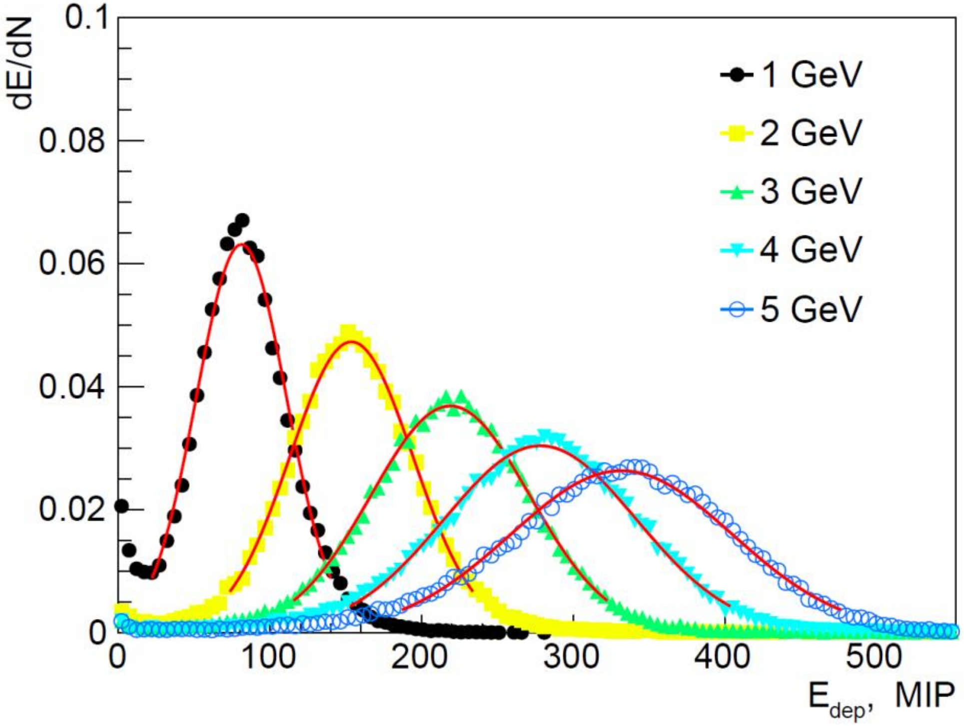

*Mechanical structure developed by CERN.*



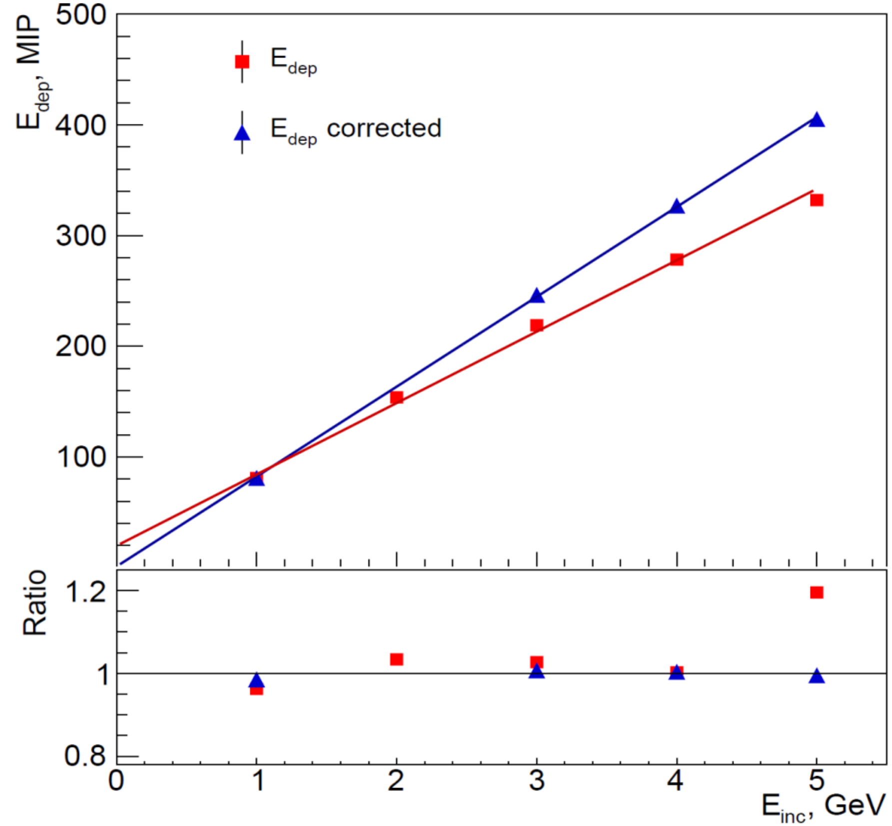
*30 slots comb positioning the detector layers.*

# Results

Energy deposited in calorimeter for different e$^-$ energy




*Energy deposited distribution in LumiCal prototype for different beam energy - fitted with Gaussian distribution function.*




*Average total energy deposited in LumiCal prototype as a function of beam energy before (red) and after (blue) APV25 front-end chip calibration. The lower part shows the ratio of the $E_{dep}$ to the straight line.*

# Results – transverse electromagnetic shower

- The function used to describe the average transverse energy profile of the shower is:

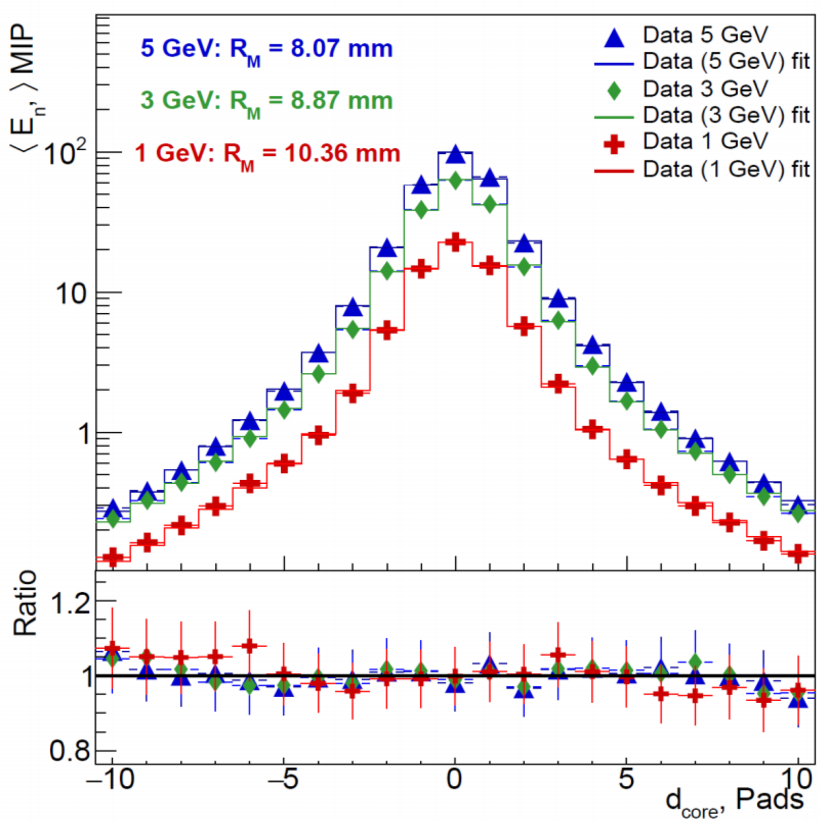
$$F_E(r) = A_C e^{-\left(\frac{r}{R_C}\right)^2} + A_T \frac{2r^{\alpha} R_T^2}{\left(r^2 + R_T^2\right)^2}$$

where: *r* is the distance from the shower center; $A_C$; $A_T$; $R_C$; $R_T$; $\alpha$ are the fit parameters.

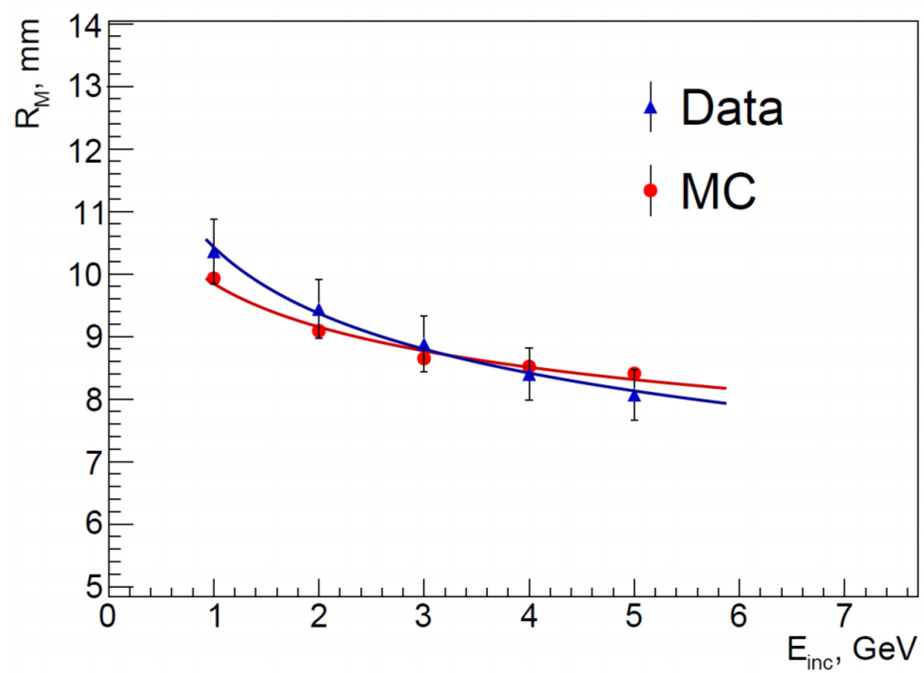
- The fitting range corresponds to the area connected to readout.
- The function $F_E(r)$ can be reconstructed using the test-beam data and the MC simulation.
- The Molière radius, $R_M$, is a characteristic constant of a material. By definition, it is the radius of a cylinder with axis coinciding with the shower axis, containing on average 90% of the energy deposition of the shower.
- The Molière radius, $R_M$, can be found from the equation:

$$0.9 = \int_0^{2\pi} d\varphi \int_0^{R_M} F_E(r)\, r dr$$

# Results – transverse electromagnetic shower




*Average transverse shower profile for 1, 3 and 5GeV electrons in data and ratio between data and the fitted functions.*




*The effective Moliere radius as a function of the electron energy for data (blue) and simulation (red).*

**Important results:**

- **Effective Molière radius for data: (8.1 ± 0.3) mm**
- **Effective Molière radius for MC simulation: (8.4 ± 0.1) mm**

# Conclusions and Future Steps

- Thin LumiCal module with submillimeter thickness was developed and produced. Its geometry meets requirements of LumiCal conceptual design.
- The measured longitudinal and transverse shower shapes are described well by GEANT4 simulations.
- The LumiCal prototype demonstrates good linear response to the beam of 1 GeV – 5 GeV.
- The results on effective Molière radius calculation give $R_{\mathcal{M}}$ around 8.1 ± 0.1mm for 5 GeV $e^-$ and are in good agreement with MC simulations.
- Major components developed by **FCAL Collaboration** can be operated as a system in the future **LC experiments.**
- Next beam-test at DESY-II in autumn 2019 will be done with a calorimeter fully equipped with sensor planes and using the readout with FLAME to demonstrate that the design specifications in spatial and energy resolution will be matched.

# THANK YOU FOR YOUR ATTENTION

# Acknowledgements:

This activity was partially supported by the Romanian UEFISCDI agency under 18PCCDI 2018 project, the Romanian Space Agency, R&D projects 160/2017 and 168/2017 and by the European Union Horizon 2020 Research and Innovation programme under Grant Agreement no.654168 (AIDA-2020).