Recent results from FCAL beam tests

Ivan Smiljanic, Ivanka Bozovic Jelisavcic
VINCA Institute of Nuclear Sciences, Belgrade, SERBIA
- on behalf of the FCAL Collaboration -

Overview

- Introduction
  - Test-beam setup in 2016 and 2019
- Test-beam results with ultra-thin detector planes
  - Shower position reconstruction
  - Longitudinal and transverse shower development
  - Effective Moliere radius
  - Test-beam 2019 preliminary results
  - Test-beam 2020
- Towards the compact calorimeter prototype
- Summary

Eur. Phys. J. C (2019) 79:579
https://doi.org/10.1140/epjc/s10052-019-7077-9

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Performance and Molière radius measurements using a compact prototype of LumiCal in an electron test beam

H. Abramowicz[1], A. Abusleme[2], K. Afanaciev[3], Y. Benhammou[1], O. Borysov[1], M. Borysova[1,13], I. Bozovic-Jelisavcic[4], W. Daniluk[5], D. Dannheim[6], M. Demichev[7], K. Elsener[6], M. Firlej[8], E. Firu[9], T. Fiutowski[8], V. Ghenescu[9], M. Gostkin[7], M. Hempel[10,14], H. Henschel[10], M. Idzik[8], A. Ignatenko[3,15], A. Ishikawa[11], A. Joffe[1], G. Kacarevic[4], S. Kananov[1], O. Karacheban[10,14], W. Klempt[6], S. Kotov[7], J. Kotula[5], U. Kruchonak[7], Sz. Kulis[6], W. Lange[10], J. Leonard[10], T. Lesiak[5], A. Levy[1,a], I. Levy[1], L. Linssen[6], W. Lohmann[10,14], J. Moron[8], A. Moszczynski[5], A. T. Neagu[9], B. Pawlik[5], T. Preda[9], A. Sailer[6], B. Schumm[12], S. Schuwalow[10,16], E. Sicking[6], K. Swientek[8], B. Turbiarz[5], N. Vukasinovic[4], T. Wojton[5], H. Yamamoto[11], L. Zawiejski[5], I. S. Zgura[9], A. Zhemchugov[7]

[1] Raymond & Beverly Sackler School of Physics & Astronomy, Tel Aviv University, Tel Aviv, Israel
[2] Department of Electrical Engineering, Pontificia Universidad Catolica de Chile, Santiago, Chile
[3] NC PHEP, Belarusian State University, Minsk, Belarus
[4] Vinca Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
[5] IFJ PAN, 31342 Kraków, Poland
[6] CERN, Geneva, Switzerland
[7] JINR, Dubna, Russia
[8] Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Kraków, Poland
[9] ISS, Bucharest, Romania
[10] DESY, Zeuthen, Germany
[11] Tohoku University, Sendai, Japan
[12] University of California, Santa Cruz, USA
[13] Visitor from Institute for Nuclear Research NANU (KINR), Kyiv 03680, Ukraine
[14] Brandenburg University of Technology, Cottbus, Germany
[15] *Present address:* DESY, Zeuthen, Germany
[16] DESY, Hamburg, Germany

Received: 30 December 2018 / Accepted: 27 June 2019 / Published online: 10 July 2019

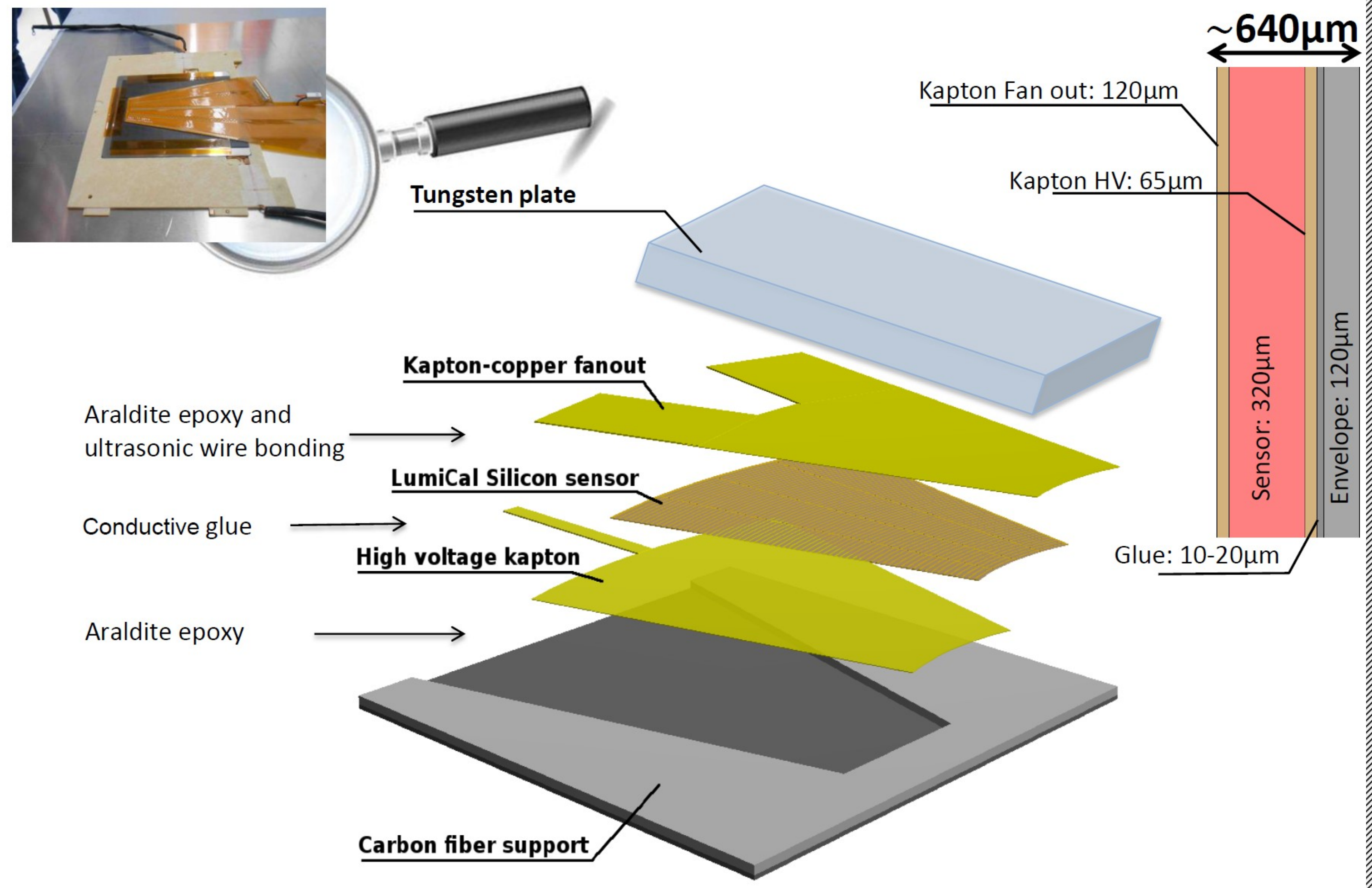
Abstract A new design of a detector plane of sub-millimetre thickness for an electromagnetic sampling

1 Introduction

Eur.Phys.J C (2019)79:579

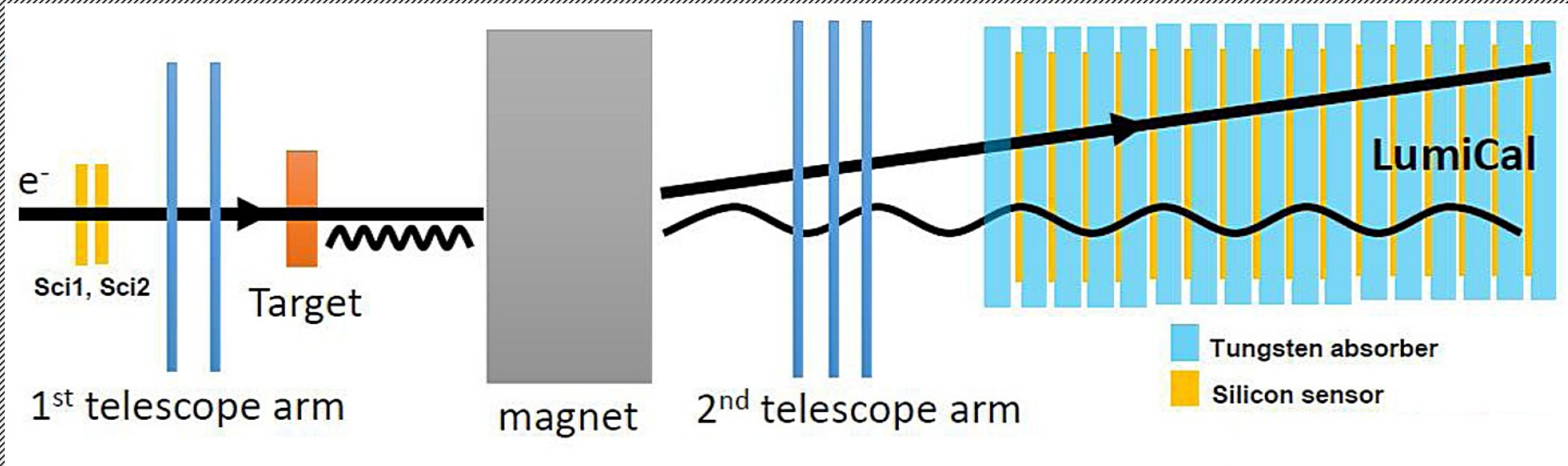
Test-beam with ultra-thin detector planes (1)

- Several test-beam campaigns
  - In 2014 with 4-plane calorimeter prototype
- The 2016 one with the ultra-thin detector planes <1mm
  - 8 detector planes
  - Ultrasonic wire-bonding (50-100 μm loop height)
- Aimed to test:
  - Performance of the compact calorimeter
  - Concept of the tracker+calorimeter for e/γ separation (ongoing)

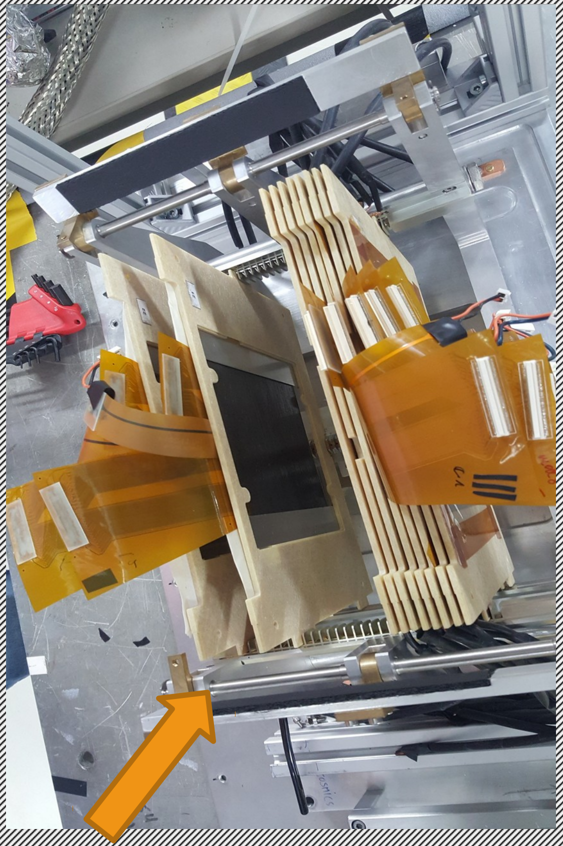


Test-beam with ultra-thin detector planes (2)

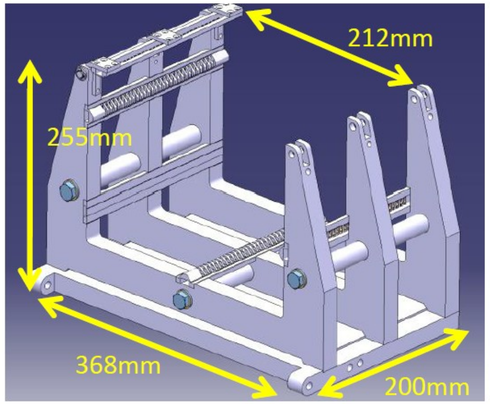
- The 2019 test beam with 1-6 GeV electron beam
  - ALPIDE telescope – 2 arms, 1st with 2 and 2nd with 3 layers
  - 90 μm thick W target
  - LumiCal – 16 Si sensor layers interspersed with W absorber layers
- Aimed to test:
  - Performance of the compact calorimeter
  - Concept of the tracker+calorimeter for e/γ separation
  - Multiple scattering



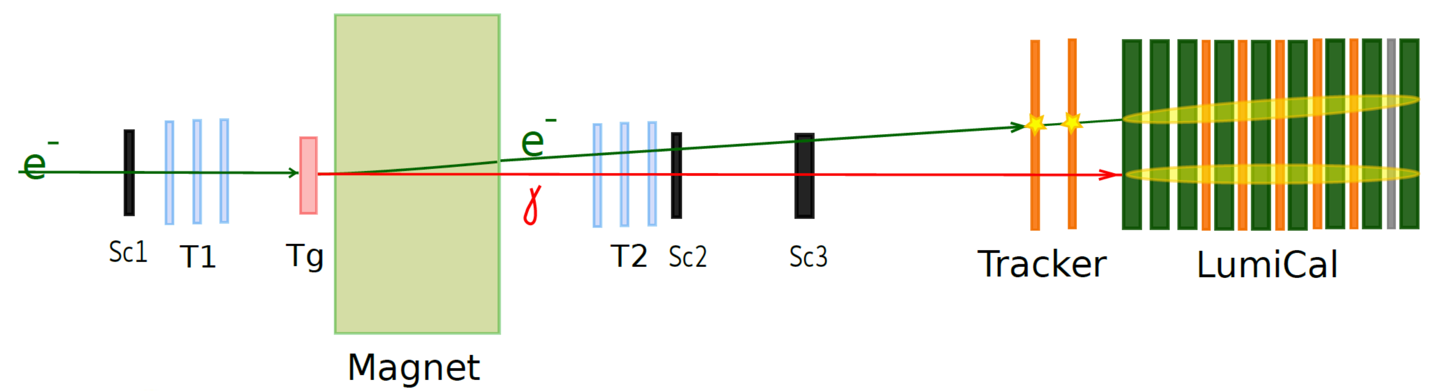
2016 - Test-beam setup



tracker planes

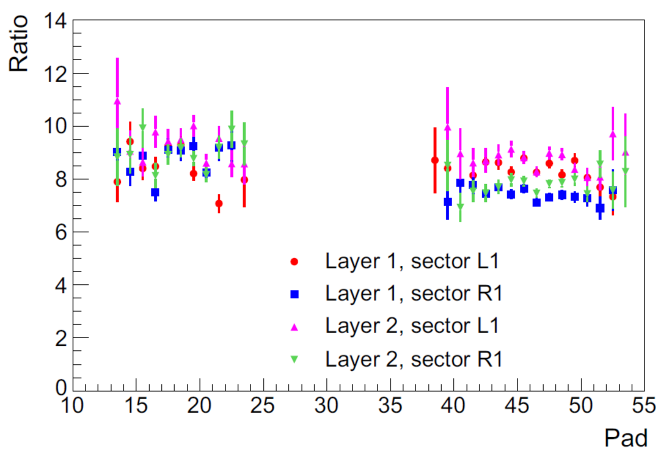


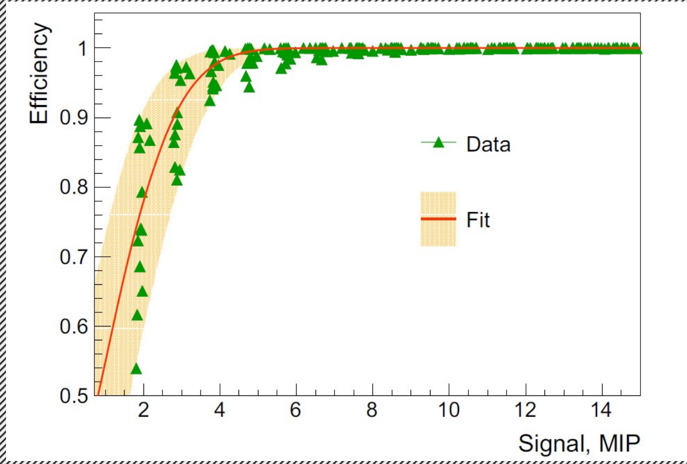
Mechanical structure developed by CERN

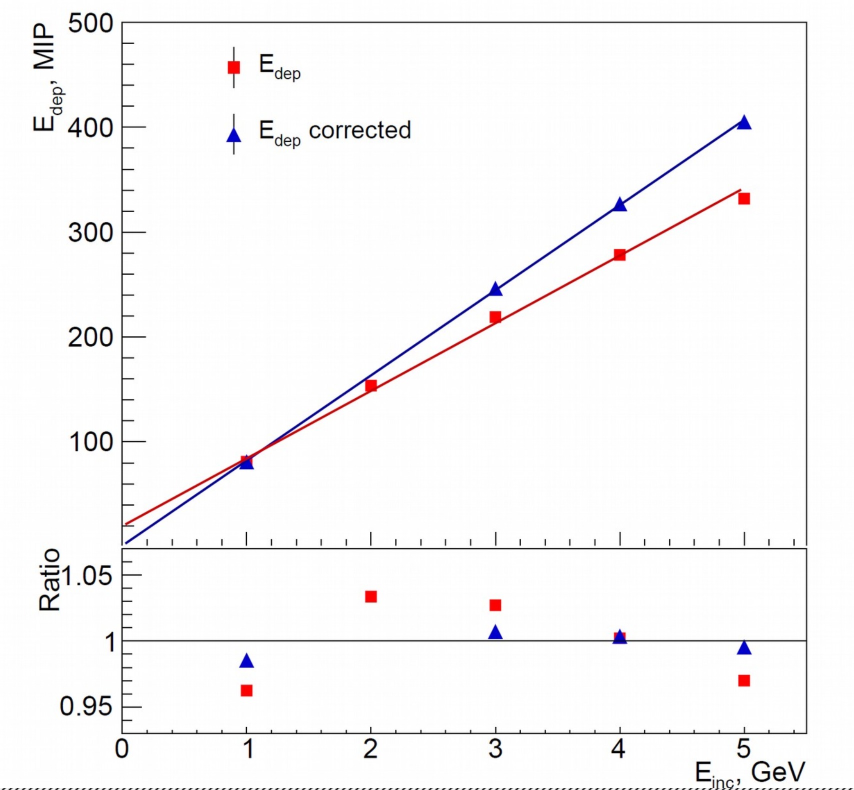


- DESY-II Synchrotron electron beam 1-5 GeV (beam size 5x5 mm2)
- T1, T2 Eudet telescopes each with 3 MIMOSA Si-pixel planes
- Sc1,2,3 scintillator trigger
- Tg copper target
- Dipole magnet -13 kGs for e/γ separation
- 8 detector planes (6 -LumiCal, 2-tracker)
- 128 read-out channels per plane
- 8 W absorber plates
- External electronics

2016 TB - Overall performance







- FE electronics performance (modified APV25 board):
  - Efficiency vs. signal size is used to correct (simulation) for signals with amplitude smaller than 10 MIPS (1MIP=88.5 keV)
  - Signal to noise ratio is (7-10) for most channels
- Detector response:
  - Excellent linearity (after leakage correction from simulation)

2016 TB - Measurement of the shower position

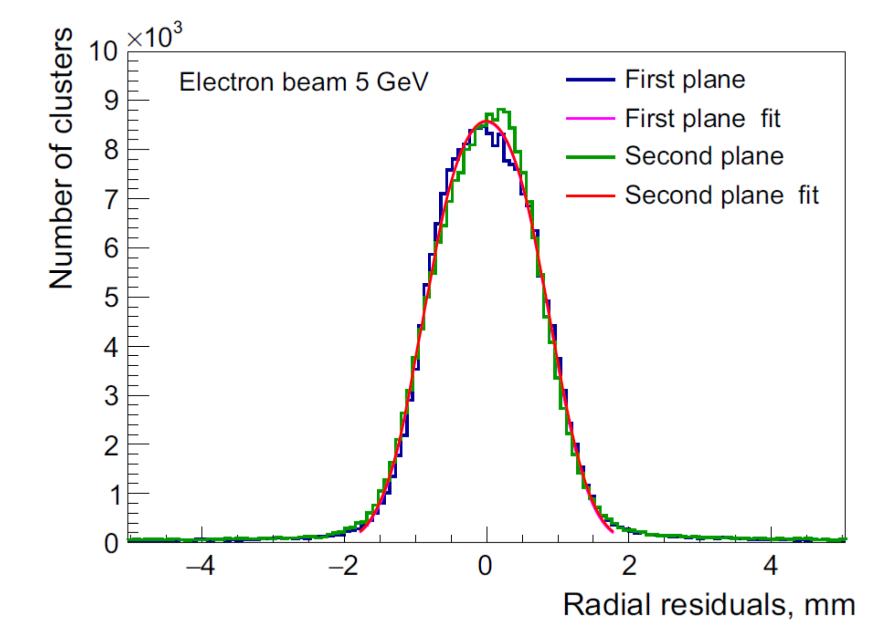
- Reconstruction of the shower radial position:

$$Y_c = \frac{\sum_m Y_m w_m}{\sum_m w_m},$$

  - Y_m - postion of the pad, *m* runs over all hit pads
  - W_m - logarithmic weight, $W_0=3.4=const.$ (obtained from simulation)

$$w_m = max\left\{0;\, W_0 + \ln\frac{E_m}{\sum_j E_j}\right\}$$

- Reconstruction is evaluated w.r.t. to the hit positions in tracker planes
- Resolution of (440±20) μm is found



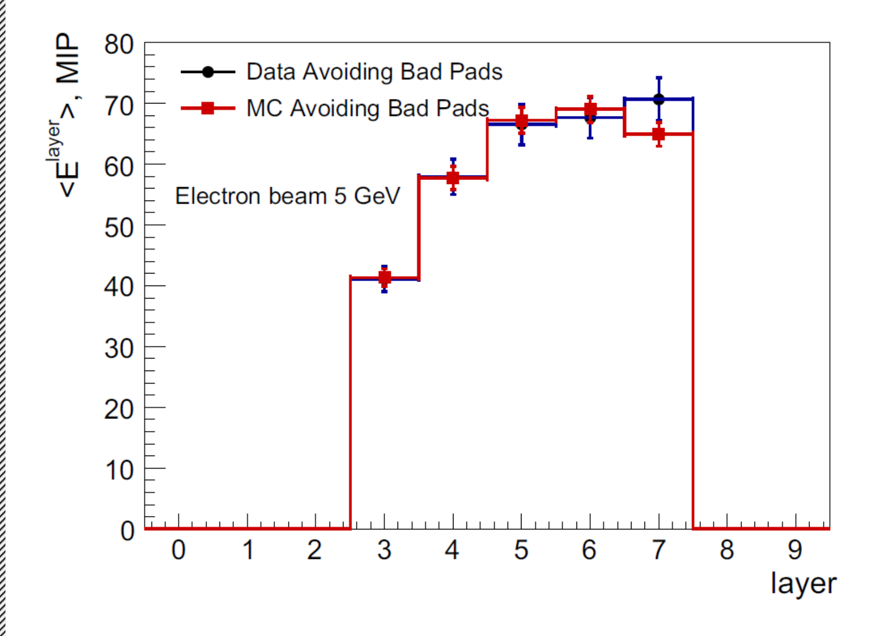
2016 TB - Longitudinal shower development

- Energy deposition per layer (averaged):

$$\langle E_l^{layer} \rangle = \sum_n \langle E_{nl}^{det} \rangle$$

  - Runs over radial pads *n* of the two instrumented central sectors

- Shower maximum at layer 7
- Good agreement between data and MC (within statistical uncertainties)



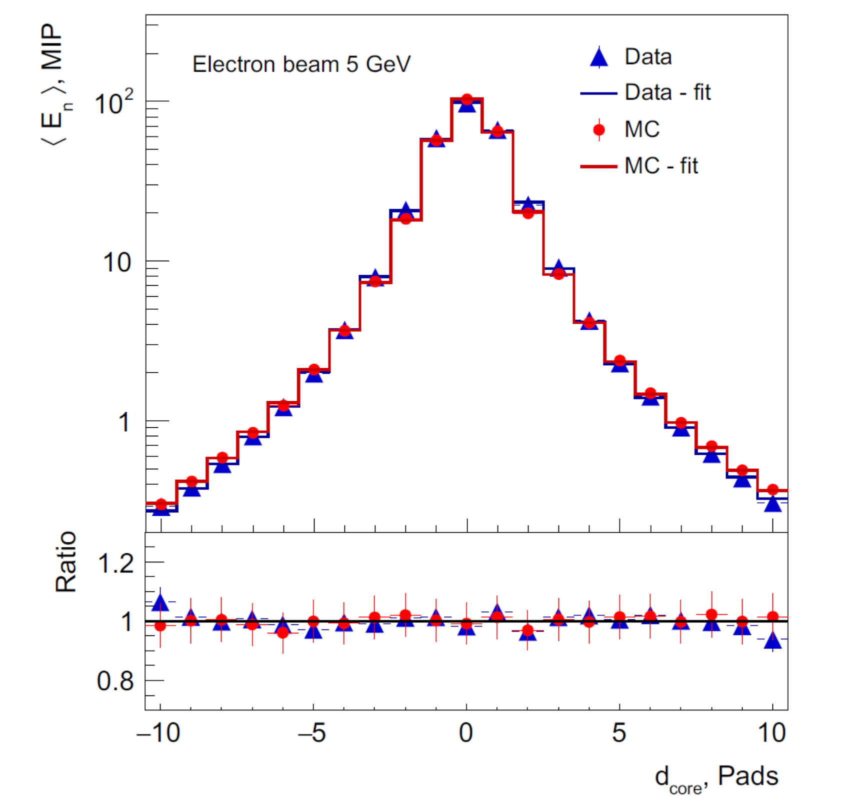
2016 TB - Transverse shower development

- Function used to describe (fit) the transverse profile:

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

  - Gaussian terms to describe shower core, Grindhammer-Peters term to describe the tail

- Very good agreement between data and Geant4 based MC

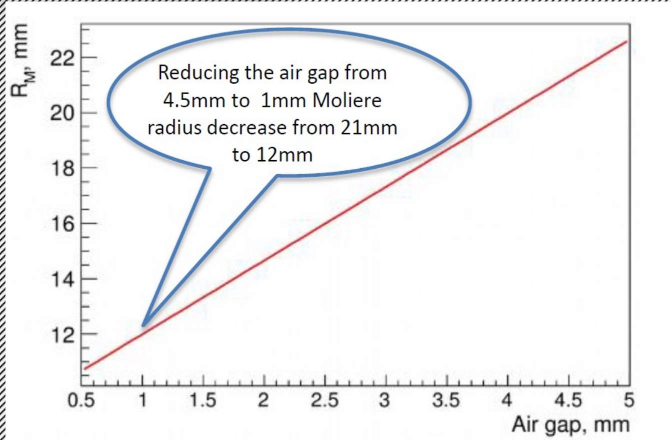


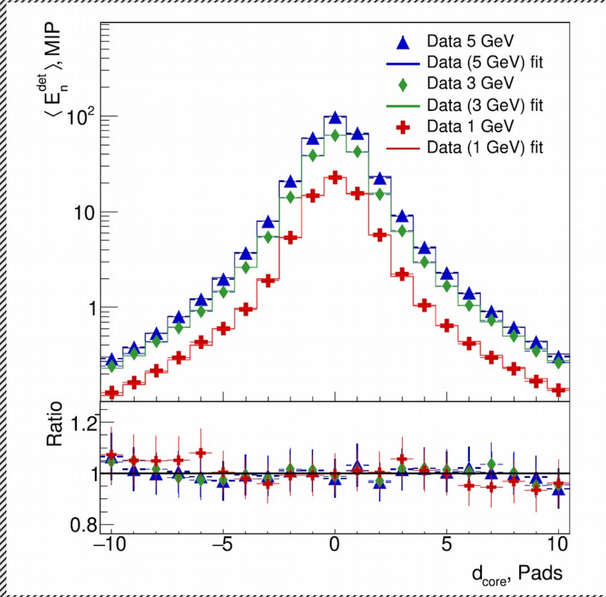
2016 TB - Effective Moliere radius

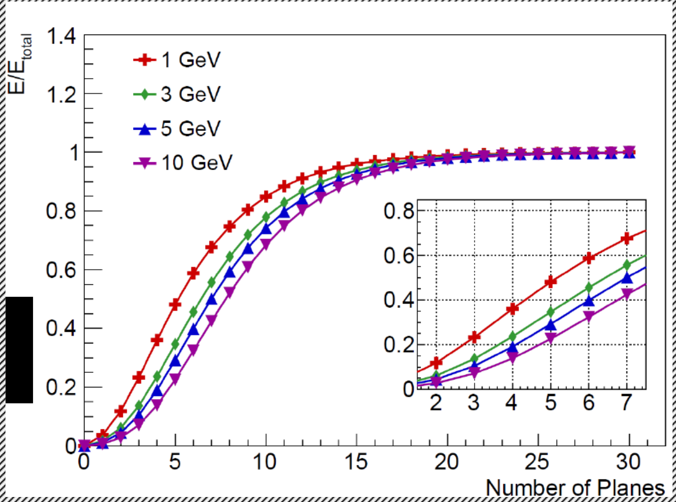
- For a prototype as a whole an *effective* Moliere radius R_M can be defined:

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

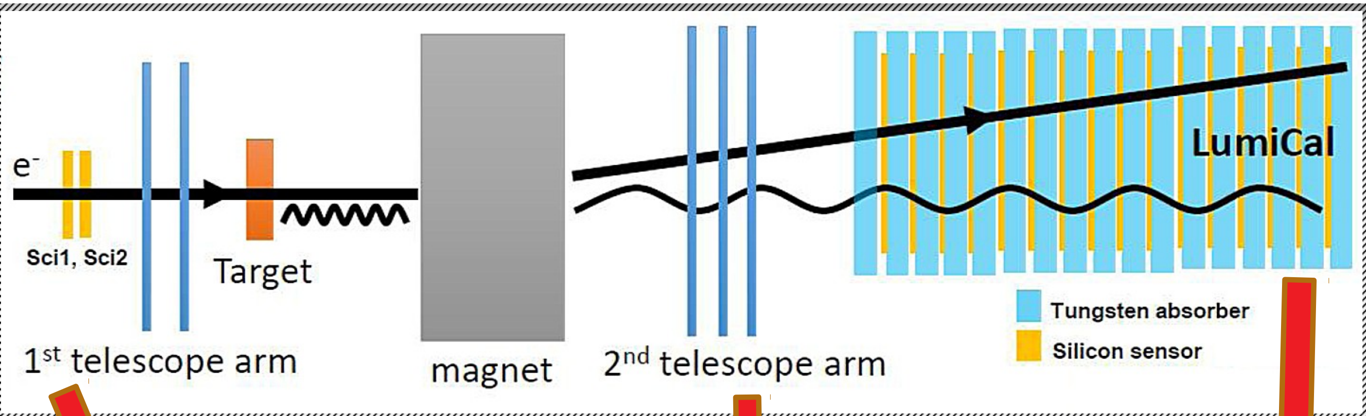
  - corresponding to the radial size within which 90% of a shower energy is contained
- Effective R_M depends a bit on electron energy due to the limited longitudinal coverage with existing number of sensor planes
- R_M also depends on the detector structure (i.e. air-gaps)
- With R_M=(8.1±0.1(stat.)±0.3(syst.))mm, feasibility of constructing a compact calorimeter is demonstrated
- Consistent with the ILC conceptual design

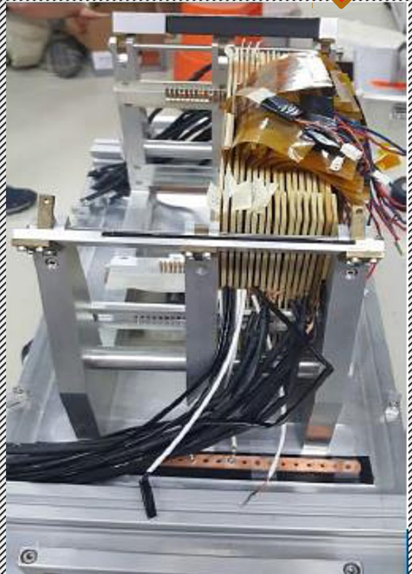






2019 - Test-beam setup

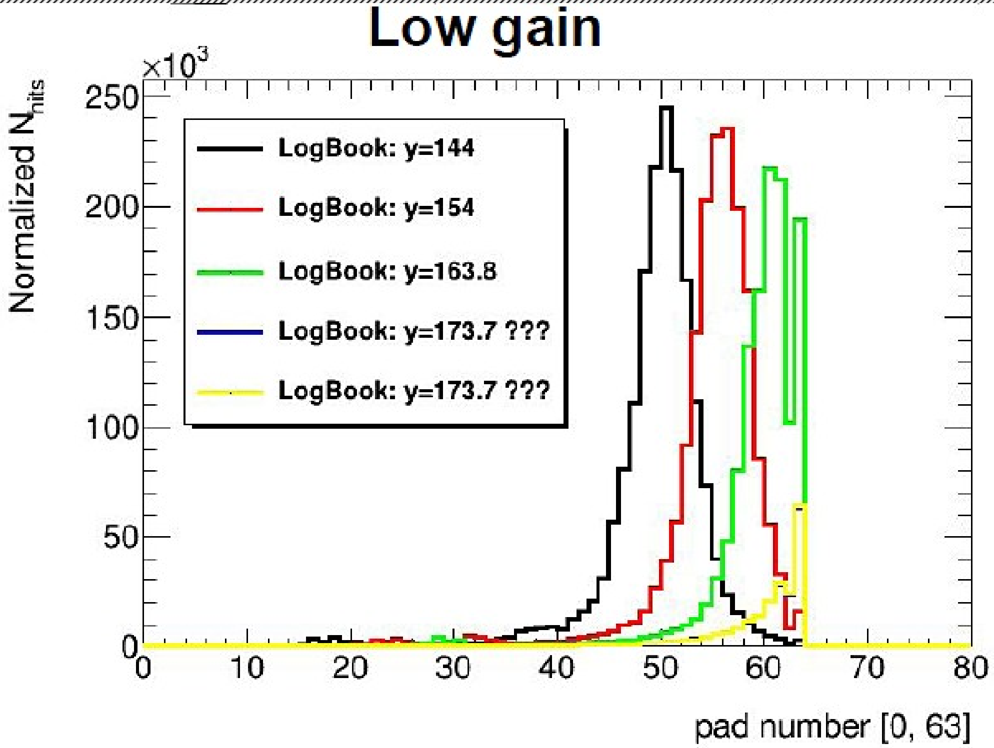


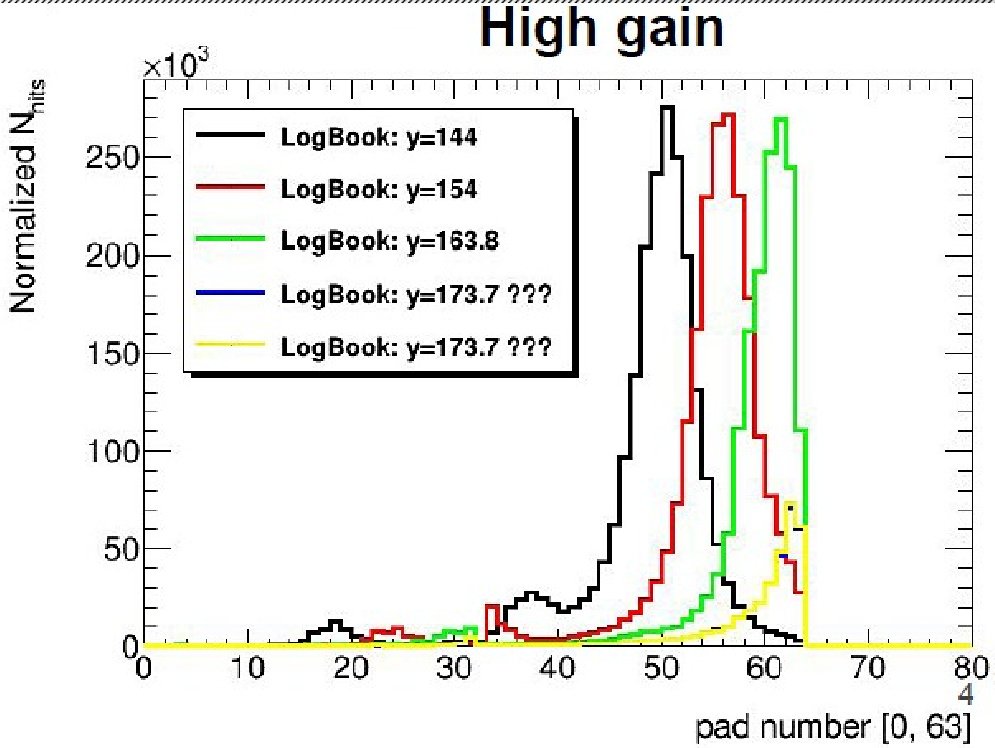


- The ALPIDE chip measures 15x30 mm and includes a matrix of 512x1024 pixel cells
- LumiCal plane consist of 256 pads, during the test beam only 128 pads were read-out using an APV-25 board
- 3 million events acquired in LumiCal

Work is ongoing on analysing November 2019 test beam data

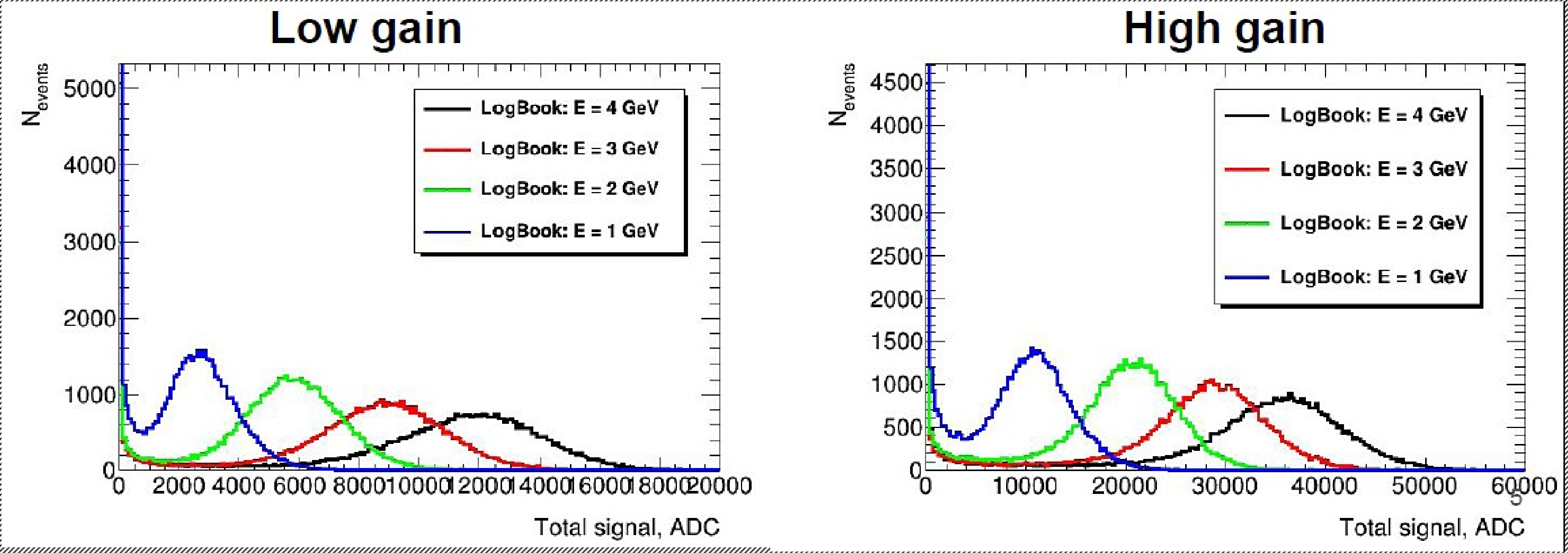
2019 - Test-beam preliminary results – position scan





- Position scan was performed by changing the calorimeter's position wrt the beam. It can be seen that the position change is well reflected by pad hits.

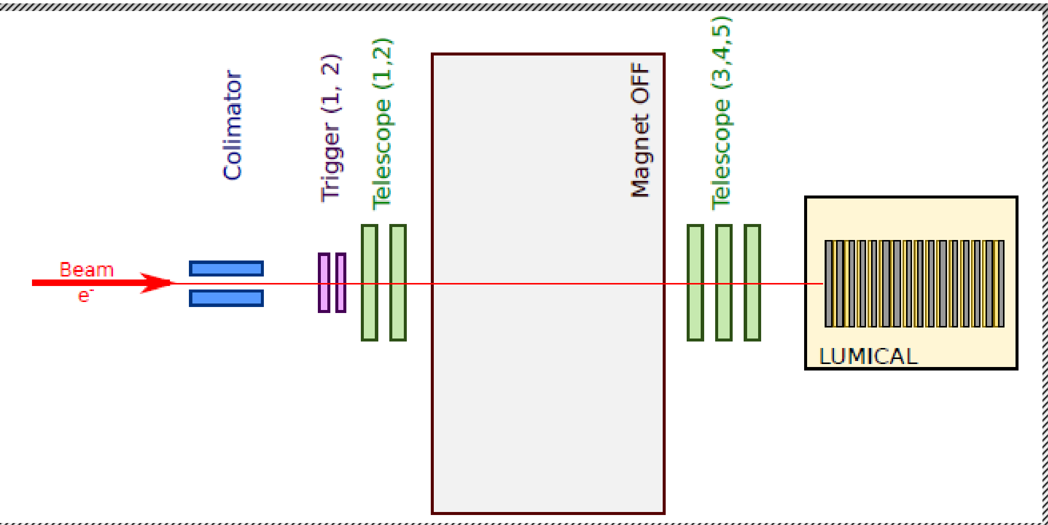
2019 - Test-beam preliminary results – energy scan

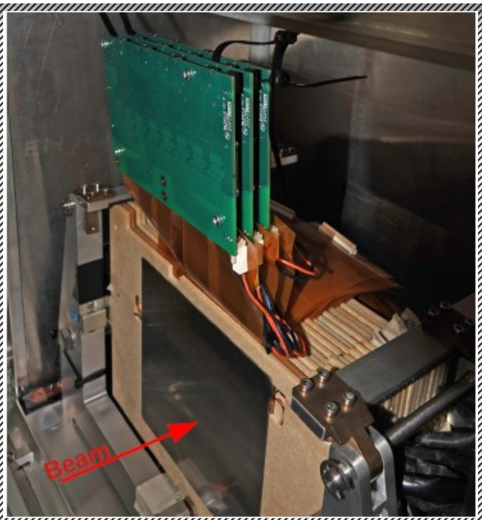


Special thanks to Mikhail Gostkin and Bohdan Dudar for TB2019 photographs and results presented here

- Energy scan was performed by changing the beam energy. It can be seen that the calorimeter can make a clear distinction between beams with different energies

2020 - Test-beam setup

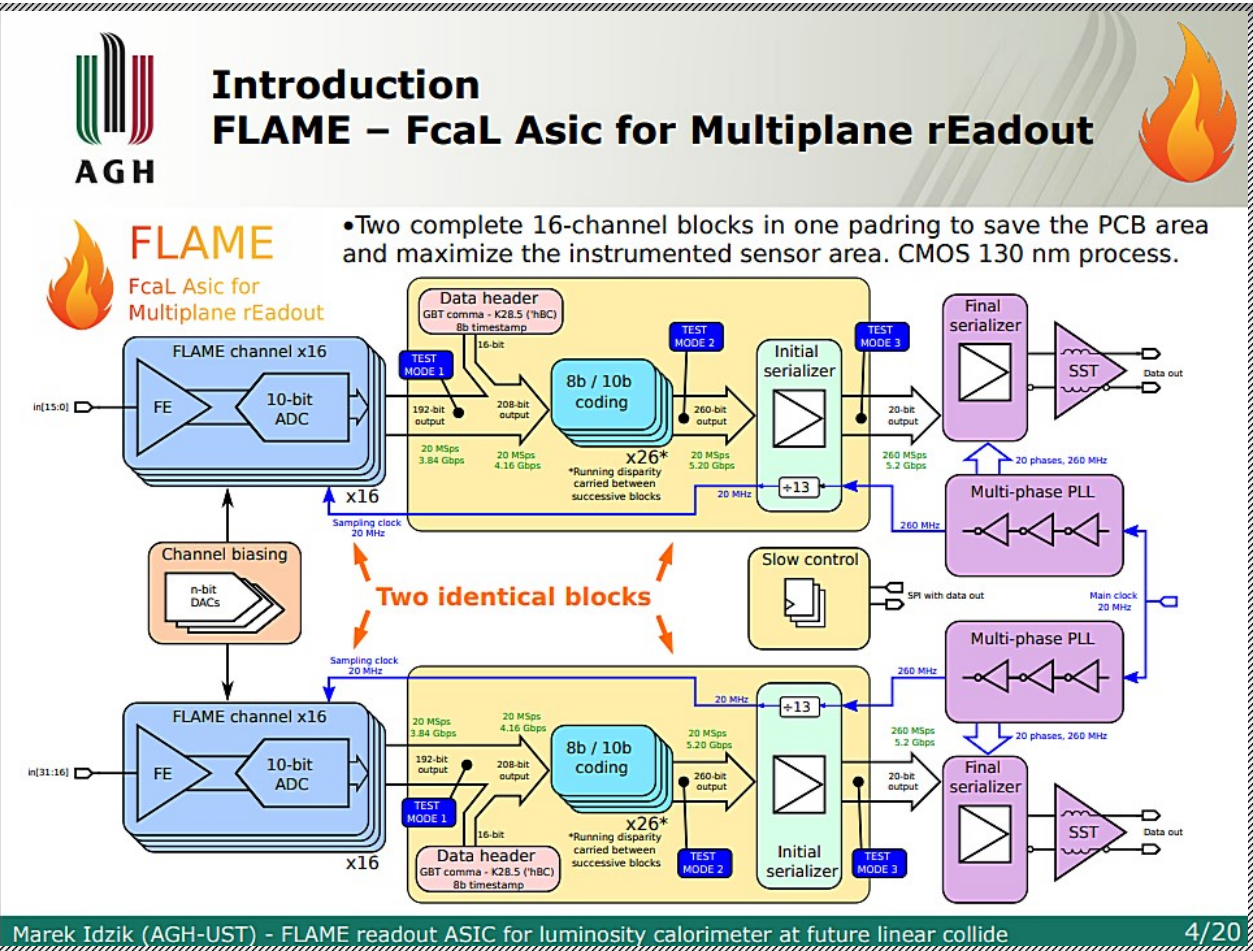




- Beam spot after the colimator ~5mm x 5mm
- Two scintilator triggers operating in coincidence mode
- 5 telescope planes – 2 before and 3 after the magnet
- Magnet switched OFF
- LumiCal placed on movable table
- LumiCal: 15 sensor layers glued to tungsten absorbers + additional tungsten layer in front of the stack
- LumiCal tilt is also examined

Work on analysing of March 2020 test beam data started

2020 – FLAME readout



- FLAME readout - project of 32-channel readout ASIC in CMOS 130nm, front-end & ADC in each channel, fast serialization and data transmission, all functionalities in a single ASIC
- 3 FLAME boards were ready for the test beam

Towards the compact calorimeter prototype

Ongoing analyses and efforts:

- Impact of the Si-tracker planes in front of the LumiCal
- Development of FE electronics with large input range/smaller signal
- Maximization of the instrumented sensor area

Experimental data (2020) with FLAME (FCAL ASIC for multiplane readout) - measurement of:

- Shower angular and energy resolution
- Moliere radius
- e/photon separation in multiplane test-beam setup

FCAL is taking unique data allowing development of expertise in compact calorimetry

Summary

- Compact calorimeters to instrument the very forward region of an e+e- collider are designed, simulated and prototyped by the FCAL Collaboration.
- Moliere radius of $R_M = 8.1 \pm 0.1 (stat.) \pm 0.3 (syst.)\ mm$, measured in the 2016 test-beam, demonstrates feasibility of such a compact calorimeter. For the first time in this effort, sub-millimeter detector planes are produced.
- Detector prototype exhibited linearity of response to 1-5 GeV electron test-beam.
- Measured shower reconstruction precision and longitudinal shower development are in agreement with MC expectation.
- Further steps lead into direction of development/production of FE electronics with large input range and maximization of the instrumented sensor area (FLAME), towards the final detector prototype.

Such a calorimeter is consistent with the conceptual design optimized for a high precision luminosity measurement at ILC and CLIC

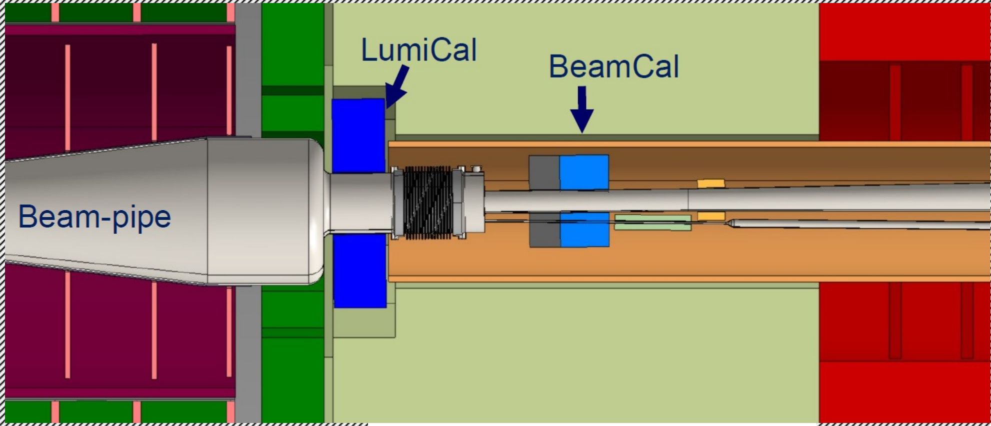
Thanks for your attention!

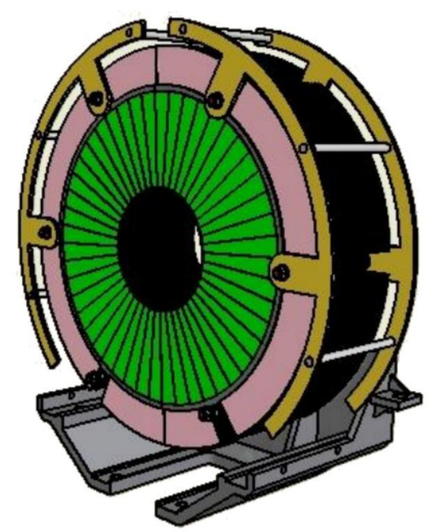
Backup

Motivation for forward calorimeters

- Luminosity measurement
  - Instantaneous - BeamCal
  - Beam-tuning (as a part of the fast-feedback system)- BeamCal
  - Integrated - LumiCal ($\delta L \sim 10^{-3}$)
- High-energy electron identification at low angles - all
  - Detector hermeticity (coverage < 5 mrad)
  - Physics studies (BSM, background suppression, etc.)
- Shielding the central tracker from the backscattered particles

[redacted]

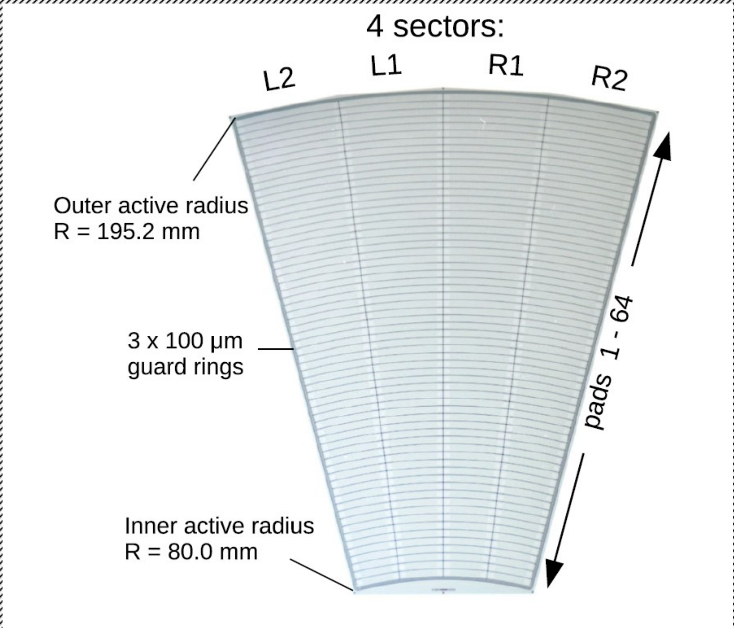




Design

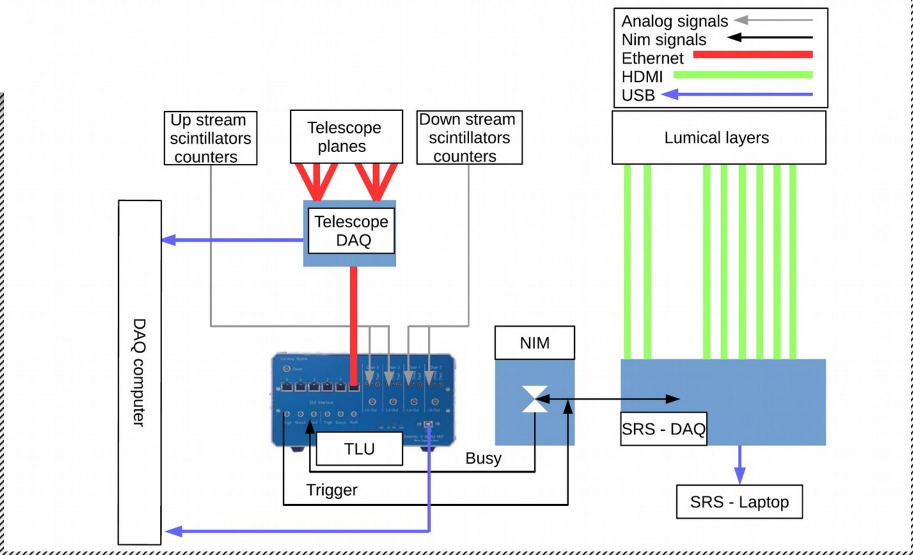
- Design
  - Cylindrical Silicon-Tungsten sandwich
  - 30-40 sensor/1 X_0 (3.5mm) absorber planes
  - 320 μm sensor thickness/1 mm gap
  - Radial segmentation: 64 pads with 1.8 mm pitch
  - Azimuthal segmentation: 48 sectors covering 7.5 deg each
  - FE electronics outside the calorimeter

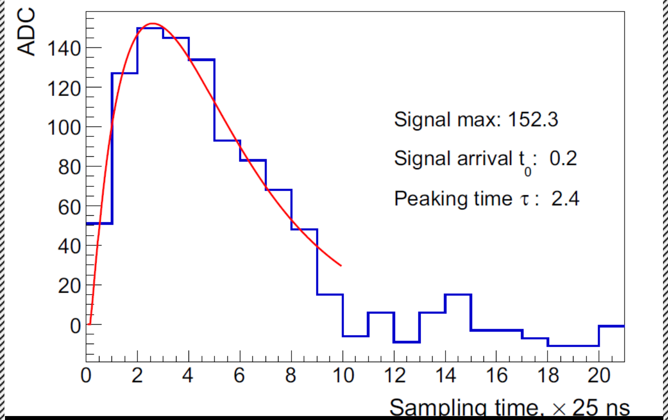
- Requirements
  - High mechanical precision (polar angle measurement, luminosity systematics)
  - Small Moliere radius (shower position and energy measurement in the presence of widely spread background)
  - Electron-photon discrimination
  - Radiation hardness, high occupancy (BeamCal, GaAs instead of Si in the baseline design)

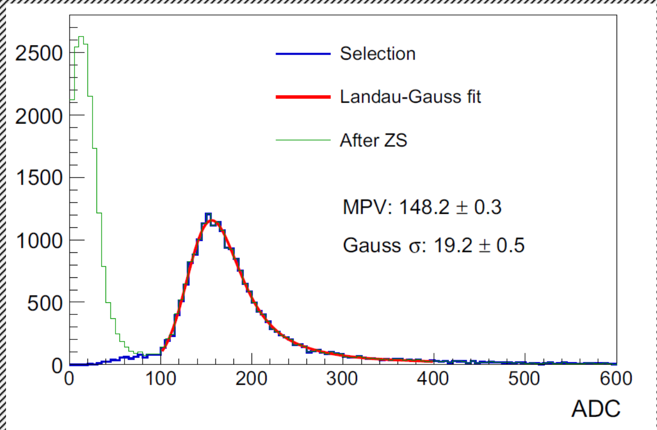


DAQ for the test-beam

- Scalable Readout System (SRS), based on APV25 front-end chip used for read-out:
  - 128 channels per detector plane
  - APV25 FE board applicable for signal >8 MIP
  - To correct for that, Capacitive Charge Divider connected to the APV input







Uncertainties of R_M

- Uncertainty of the measured efficiency of the signal identification ±0.16 mm
- Uncertainty of the particle impact position ±0.13mm
- Misalignment of detector planes ±0.08 mm
- Uncertainty due to bad channels ±0.14mm
- Noise uncertainty - negligible
- Calibration uncertainty of 5% for the APV read-out ±0.14mm