FCAL Collaboration: progress report on forward calorimeters for future electron-positron collider experiments

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On behalf of the FCAL collaboration

presented at LCWS21 | 2021|

Outline

- FCAL overview
  - BeamCal
  - LumiCal
- Tests of LumiCal prototype in the beam
  - 2016 TB
  - 2020 TB
- Conclusions

The FCAL Collaboration

The Research&Development and optimization of the very forward region for future e +e − colliders are performed in the last 15 years, by the FCAL Collaboration.
https://fcal.desy.de/

AGH University of science & technology, Krakow, Poland
CERN, Geneva, Switzerland
DESY, Germany IFJ PAN, PL-31342, Krakow, Polad
ISS, Bucharest, Romania
JINR, Dubna, Russia
National Research Tomsk State University NI TSU, TSU / Russia
NC PHEP, Belarusian State University, Minsk, Belarus
Pontificia Universidad Catolica de Chile, Santiago, Chile
Taras Shevchenko National University of Kiyv, Ukraine
Tel Aviv University, Tel Aviv, Israel
Tohoku University, Sendai, Japan
University of California, Santa Cruz, USA
Vinca Institute of Nuclear Sciences,
University of Belgrade, Serbia
IFIN-HH, Bucharest, Romania

FCAL is a worldwide collaboration with 15 institute.

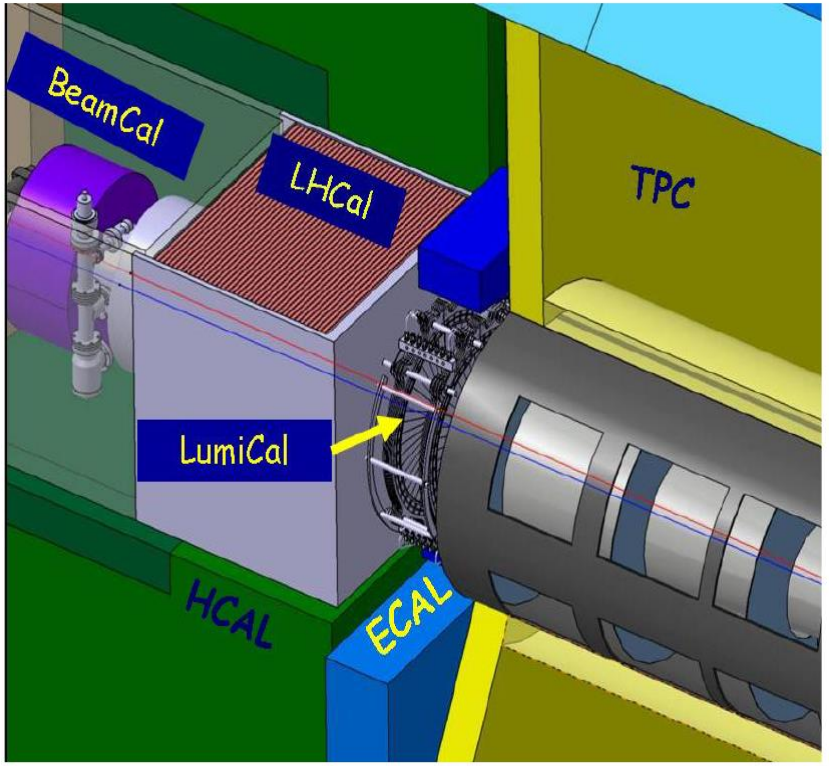
FCAL overview

FCAL main goals

- precise and fast luminosity measurement
- feedback for beam tuning

FCAL main activities

- optimisation of the design of the very forward region
  - detector technology development
  - MC simulation studies
- development of readout electronic
- performance tests of prototype detectors in the beam



The very forward region of the ILD detector.

Requirements:

- finely segmented and compact calorimeters (small Molière radius)
- mechanical precision (polar angle measurement)
- fast read out
- radiation hard sensors

Luminosity measurements

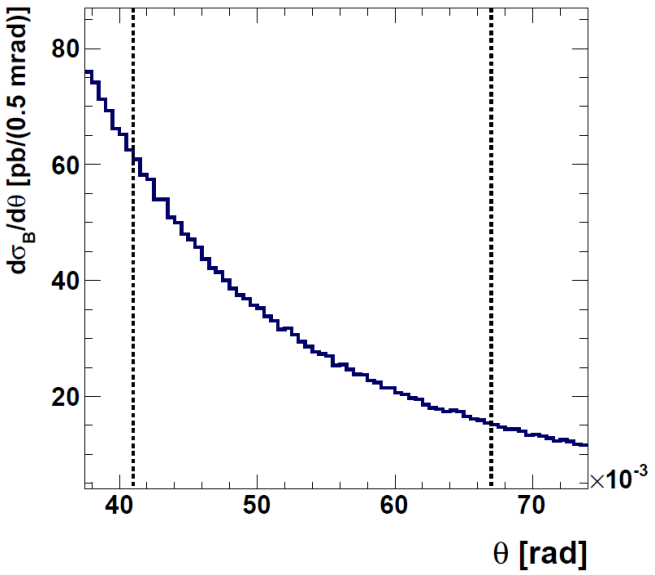
The luminosity at an e+e- collider can be measured by counting number of Bhabha events, N_B, in a certain polar angle range (θmin, θ max) of the elastically scattered electron.

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

σ_B integral of the differential cross section

Bhabha scattering at low polar angles can be calculated precisely .

The fiducial volume covers the angles between 41 mrad to 67 mrad (ILC).
Sensor segmentation is optimized for high precision of luminosity measurement.



LumiCal fiducial volume:
41 < θ < 67 mrad

The luminosity uncertainty for ILC is required to be better then 10^{-3}.

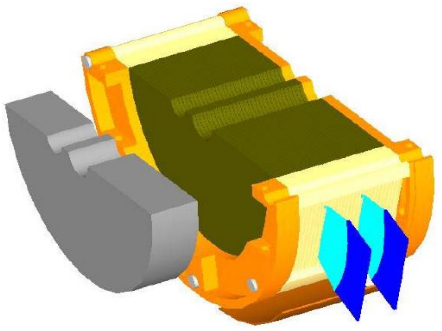
BeamCal

an electromagnetic sandwich calorimeter that uses Tungsten as absorber

covers polar angles between (5 − 40 mrad for ILC, 10 − 46 mrad for CLIC).

30/40 absorber interspersed with sensor layers

each sensor layer is segmented radially and azimuthally into pads.



A half-cylinder of BeamCal

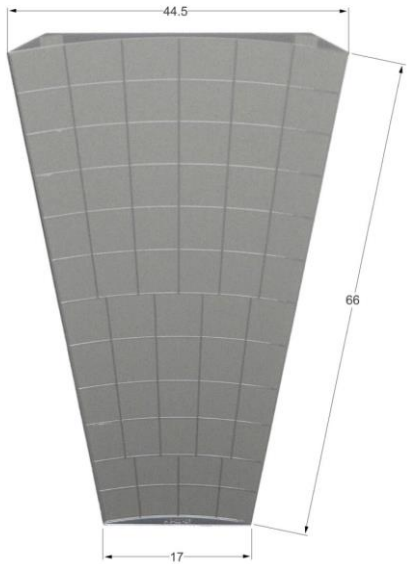
major purposes

- bunch-by-bunch luminosity measurement
- Improving the hermeticity of the ILC detector by providing electron and photon identification down to polar angles of a few mrad
- reducing the backscattering into the inner detector.
- beam diagnostics and tuning, when equipped with fast feedback electronics

BeamCal must be a very radiation hard sensor

Technologies under investigation:

- GaAs
- Sapphire



Baseline sensor: GaAs

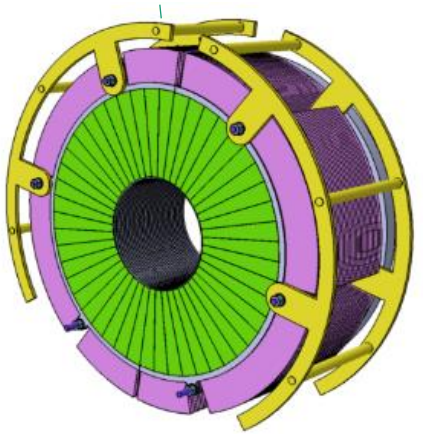
Dedicated ASIC is develop to provide fast feedback to the machine

LumiCal

Si-W sandwich calorimeter that covers the polar angles from 31 - 77 mrad

major purposes

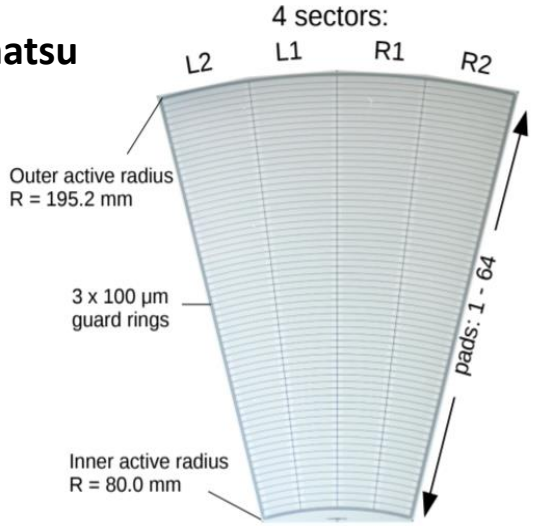
- Measuring the rate of Bhabha events at low angles.
- Improving the hermeticity of the ILC detector by providing electron and photon identification down to polar angles of a few mrad.
- Reducing background



The mechanical structure of LumiCal

Silicon pad sensor prototype is designed for ILD; produced by Hamamatsu

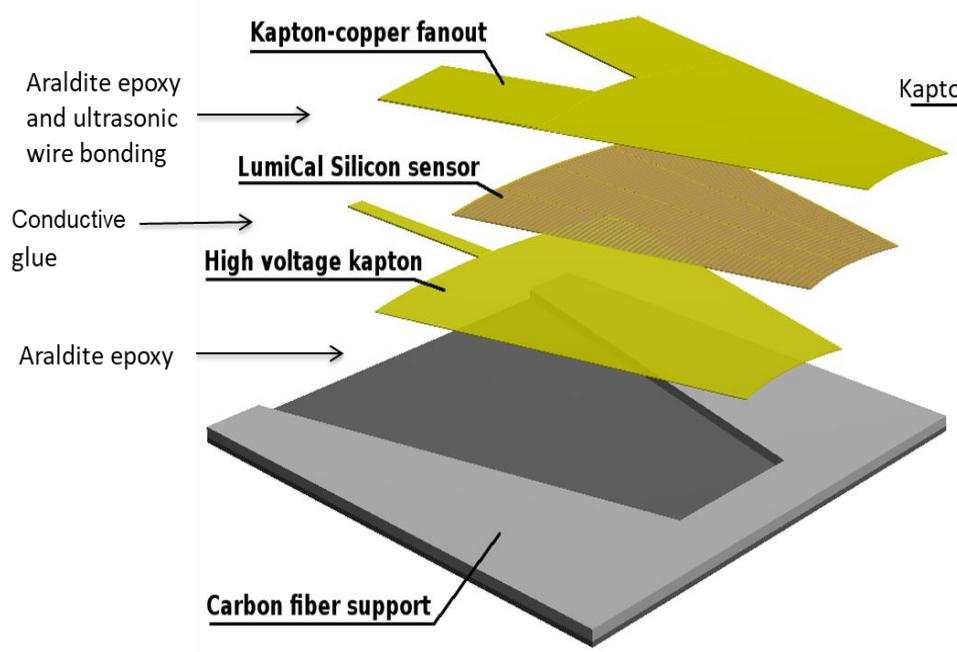
- ring segment of 30 degrees, 4 sectors of 7.5° each
- 64 radial pads, pitch 1.8 mm
- 11 cm long with an inner radius of 80 mm
- thickness 320 µm
- p+ implants in n-type bulk

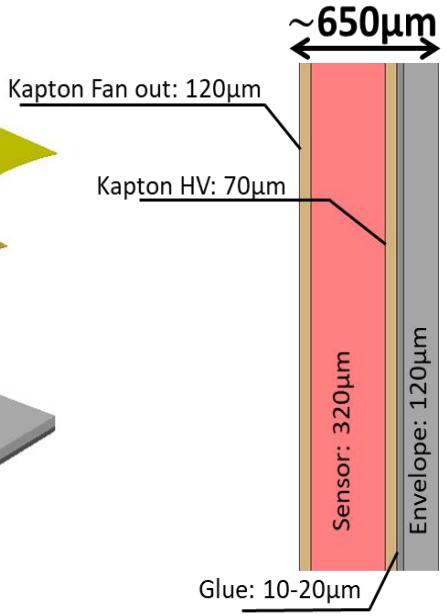


A prototype silicon sensor for LumiCal

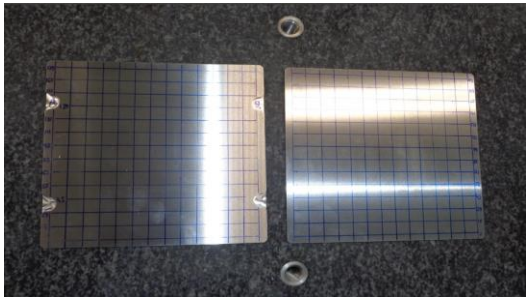
LumiCal thin prototype module

Compactness is an essential requirement to provide small Molière radius -> accurate shower position reconstruction





Detector plane assembly



W plates - dimensions 140 x 140 x 3.5 mm

Tungsten plates

W plates - alloy with 93 % tungsten, 5 % nickel and 2 % copper.

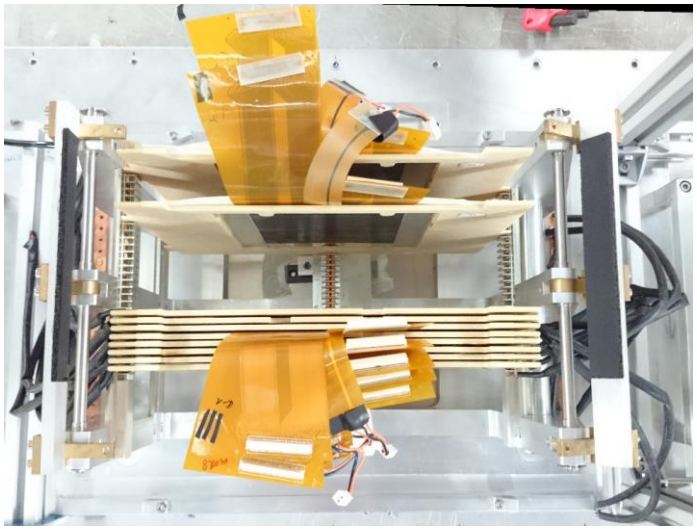
1 X_0, 3.5 mm thick.

flatness W plates is better than 30 μm.

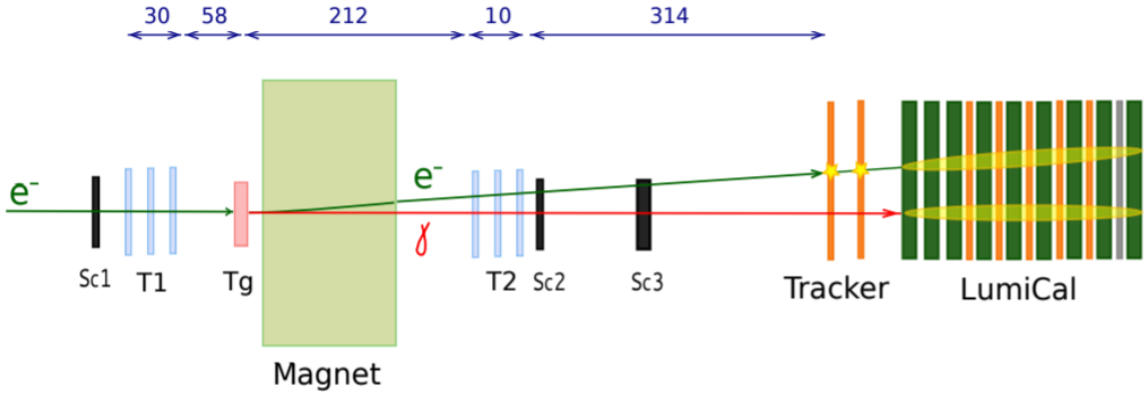
2016 TB - thin prototype module

The main goal was to study the performance of the ultra compact design

First Test of multi-layer compact design



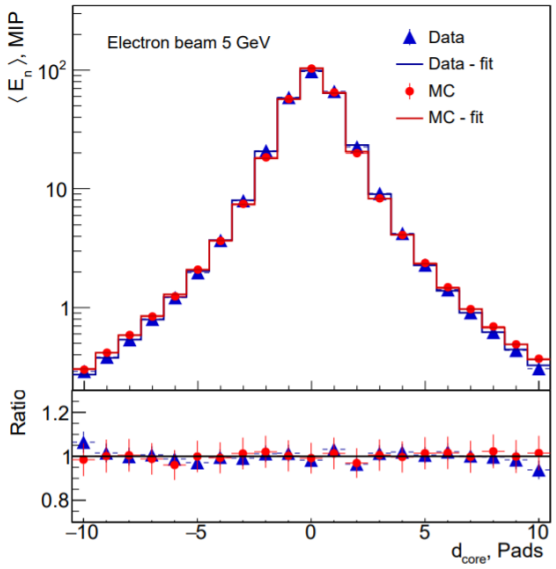
- 8 full (256 channels) LumiCal detector planes equipped with adapted APV25 readout
  - 2 used as a tracker / tagger for e/γ separation
    - 6 as calorimeter (3 - 8 X_0).
- 1 mm between tungsten plates
- Measured at DESY with 1-5 GeV electron
- EUDET / AIDA beam Telescope : 6 planes with MIMOSA chip



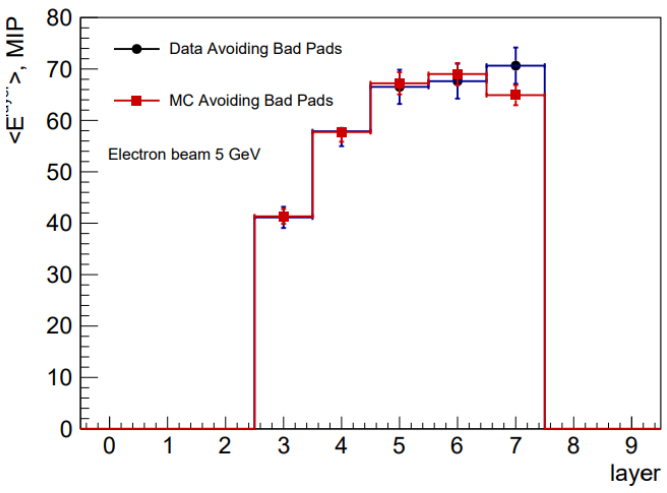
Sc1, Sc2 and Sc3 are scintillator counters; T1, T2 – three pixel detector planes; Tg – the copper target for bremsstrahlung photon production.

2016 Test beam– results at 5 GeV

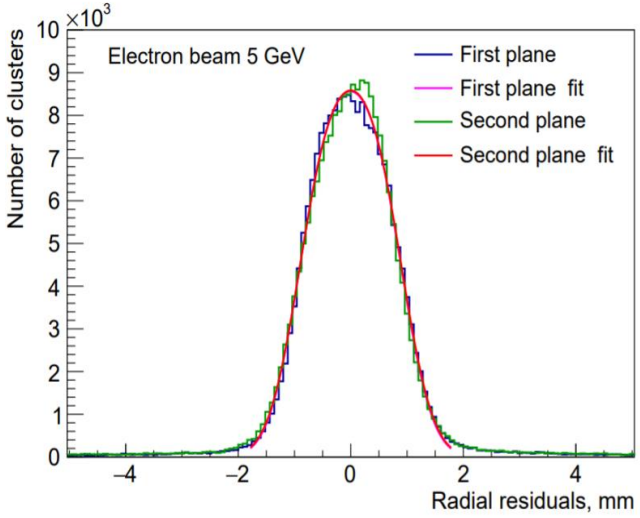
- The transverse and longitudinal shower profile were measured and found to be in excellent agreement with MC.
- The effective Molière radius is 8.1 ± 0.1 (stat) ± 0.3 (syst) mm
- The resolution of the shower position reconstruction was found to be 440 +/-20μm
- gamma / electron identification efficiency is better than 90%.



The shower transverse profile < *Em* >, as a function of d_{core} in units of pads. The ratio of the distributions to the fitted function, for the data and the MC



The longitudinal shower profile, comparison between data and MC. The distributions are obtained with a 5 GeV electron beam.



Distribution of residuals of the radial position measurements in the tracking planes and the calorimeter

Results were published at EUR.PHYS.J.C79(2019)NO.7,579

FLAME - Readout ASIC for LumiCal

Architecture of **F**ca**L** **A**sic for **M**ultiplane r**E**adout

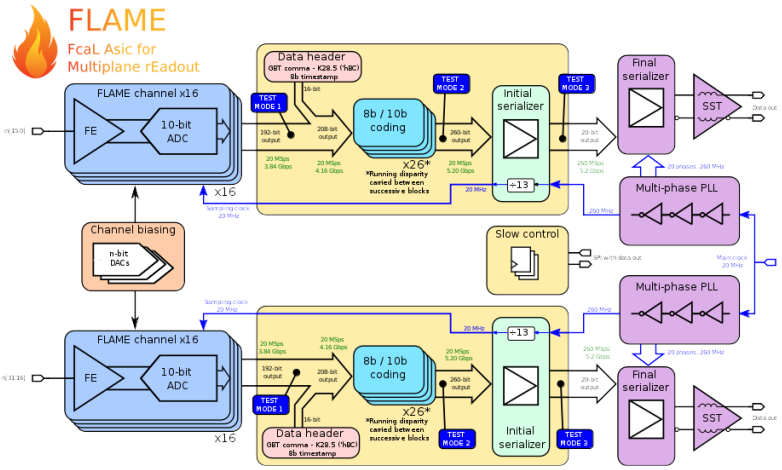
Complete readout ASIC integrating whole functionality (biasing, calibration, etc.)

32 mix-mode channels comprising:

- Variable gain front-end
- 10-bit SAR ADC with sampling rate up to 50 MSps
- Ultra low power consumption (Front-end + ADC)

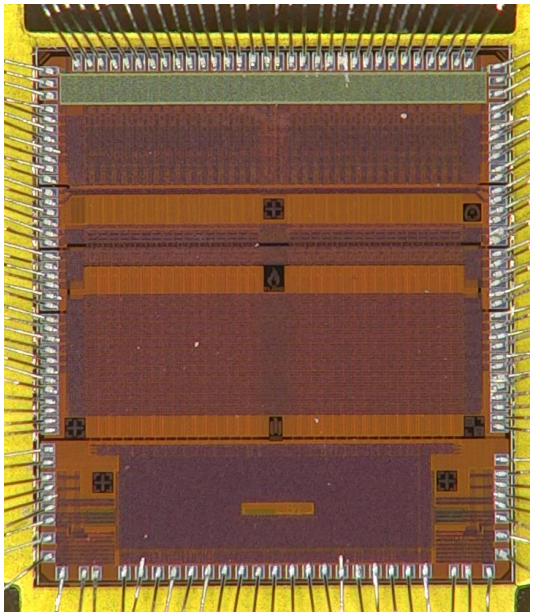
Multi-phase PLL based fast serializer (up to 8 Gbps)

Fast SST driver (up to 8 Gbps)



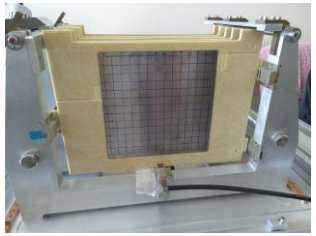
FLAME block diagram,

FLAME layout: the size is 3.7mm x 4.3mm

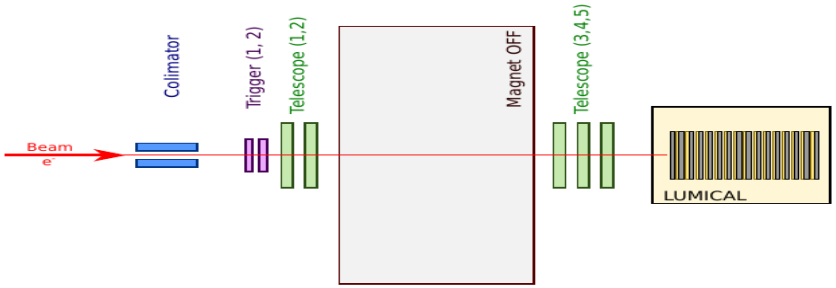


- Development of new readout ASIC for LumiCal – FLAME – is done
- Chip has been manufactured and assembled to PCB

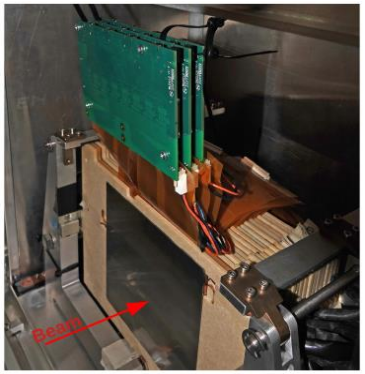
2020 TB – Full compact prototype calorimeter



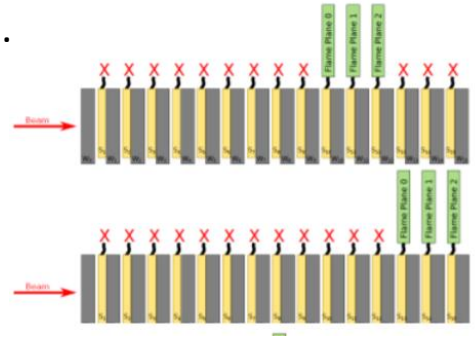
10 new tungsten absorber plates prepared, measured and assembled for the 2020 beam test campaign.



Geometry of the beam test setup

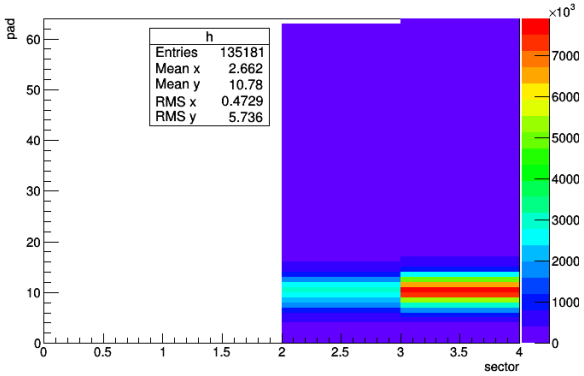


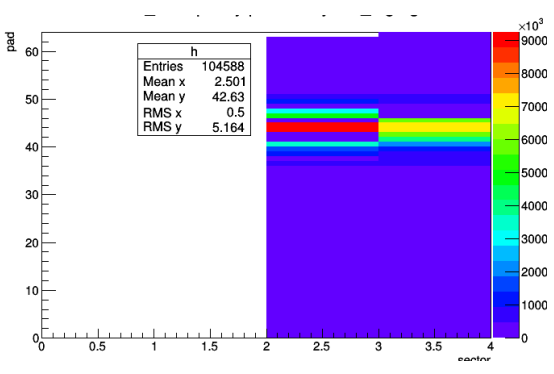
- 15 Lumical thin sensitive layers.
- Dual readout:
  - 3 planes equipped with FLAME dedicated LumiCal Readout
  - others - with double gain readout using APV25.
- Data were taken with different configurations.
- Energy and spatial resolution studies.
- Fiducial volume study.
- Polar angle bias study.
- Test electron/gamma response.

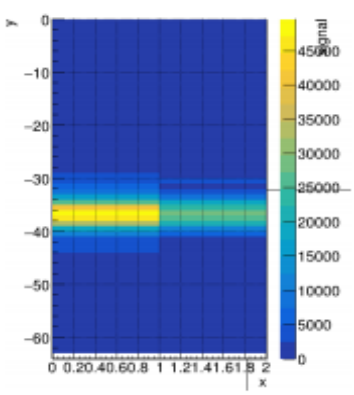


TB - different configurations

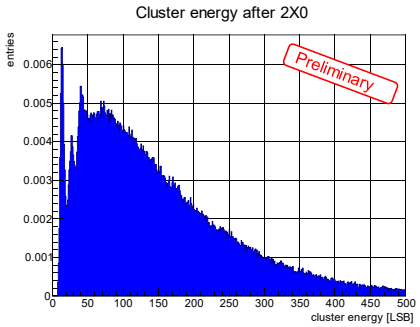
2020 Test beam– preliminary results

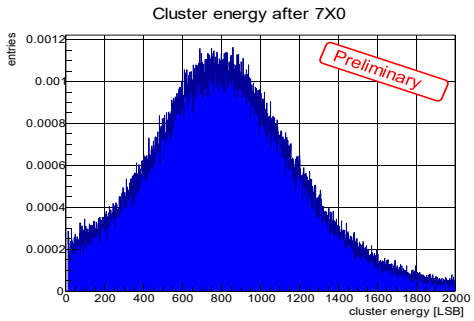


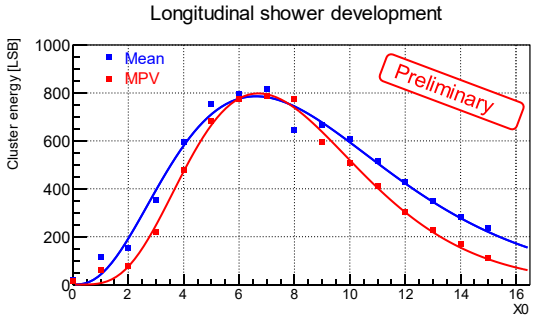




experimental data







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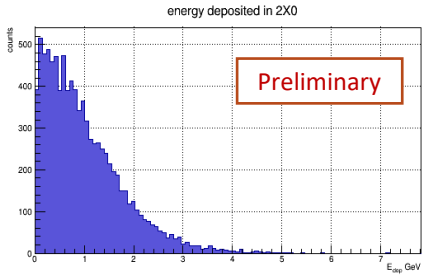

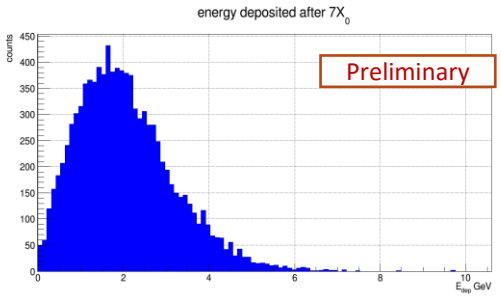

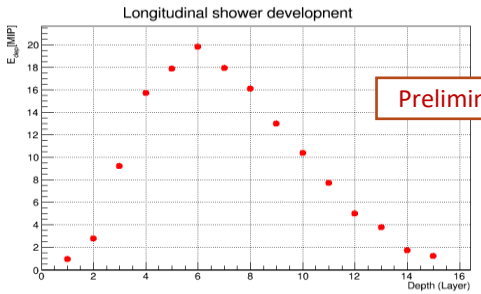

MC data

The data analysis is in progress.

Conclusions

- Major components developed by **FCAL Collaboration** can be operated as a system in the future **ILC experiments.**

- A prototype of a highly compact calorimeter was studied in test-beams at DESY
  - the measurement of the effective Molière radius (8 mm);
  - the measurement of the shower position reconstruction (440 µm resolution at 5 GeV)

- The LumiCal prototype with 15 thin modules and existing mechanical structure was assembled and tested in test beam at DESY with 1 – 5 GeV electrons;

- A dedicated readout ASIC for LumiCal –calls FLAME was used.

- Analysis of data and MC from the full compact calorimeter prototype test beam is ongoing.

- Technologies developed in FCAL are applied in other experiments, e.g. CMS, XFEL and considered for LUXE at DESY.

- Thank you for attention

Acknowledgements

This study was partly supported by the Romanian UEFISCDI agency under 18PCCDI/2018 project and grant no. 16N/2020. The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).