AGH University of Science and Technology

Compact LumiCal prototype tests for future e+e- collider

Marek Idzik on behalf of the FCAL collaboration

Faculty of Physics and Applied Computer Science
AGH University of Science and Technology

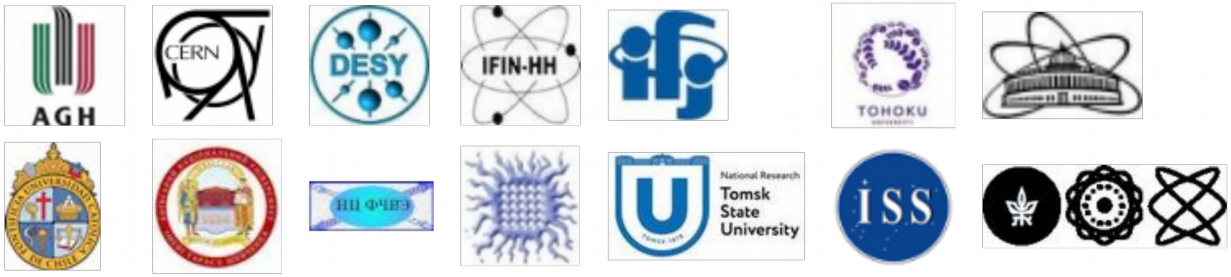
24-28 May 2021, International Conference TIPP 2021

Outline

- Introduction
  - FCAL, BeamCal, LumiCal
- Development of Compact LumiCal
  - Thin detector module, 2016 test-beam
- Development of dedicated readout for LumiCal
  - FLAME ASIC, FPGA back-end
- New LumiCal prototype in a beam
  - Setup&Results
- Summary

Introduction
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/

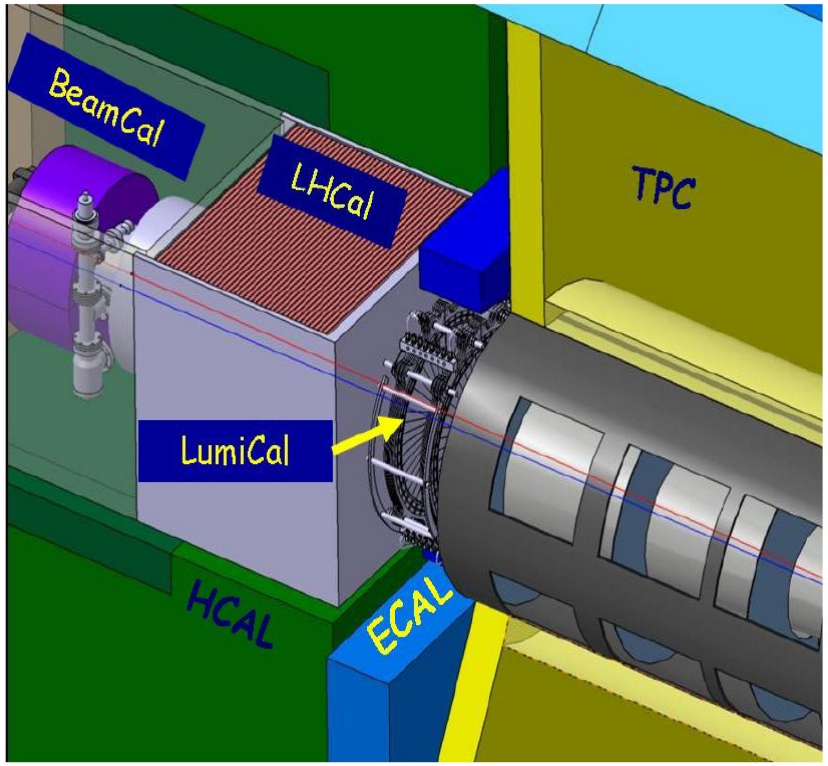


FCAL is a worldwide collaboration with 15 institutes

Introduction
FCAL Overview

FCAL main goals

- luminosity measurement
- feedback for beam tuning



The very forward region of the ILD detector.

FCAL main activities

- Detector technology development
- Detector optimization by MC simulations
- Performance tests of prototype detectors in the beam
- Development of readout electronics

Forward detector challanges

- Compact calorimeters (small Molière radius)
- Mechanical precision (polar angle measurement)
- Fast readout
- Radiation hard sensors

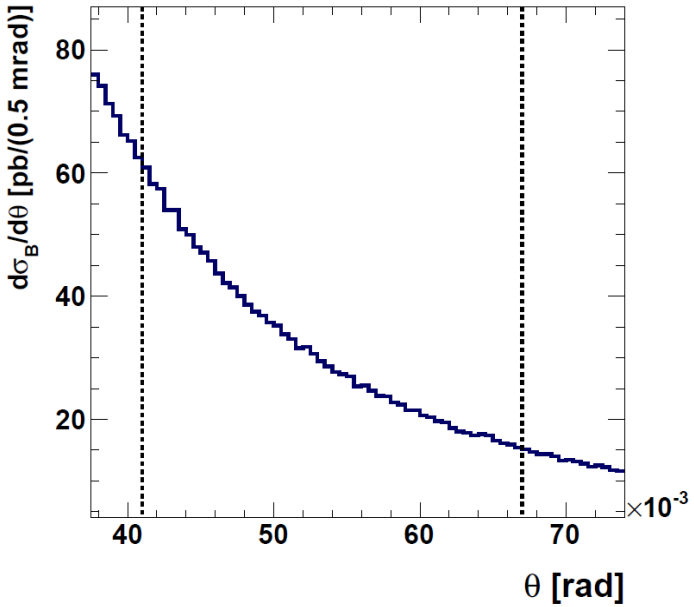
Introduction
Luminosity measurements

Precise cross-section measurement requires a precise luminosity measurement. The luminosity *L* at an e+e- collider can be measured by counting number of Bhabha events N_B, in a certain polar angle range (θ_{min}, θ_{max}) of the elastically scattered electron. Bhabha scattering is a well-known and theoretically-controlled process.

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

σ_B integral of the differential cross section

Sensor segmentation has to be optimized for better precision of luminosity measurement. The luminosity uncertainty for ILC is required to be better then 10^{-3} and for CLIC better than 10^{-2}.



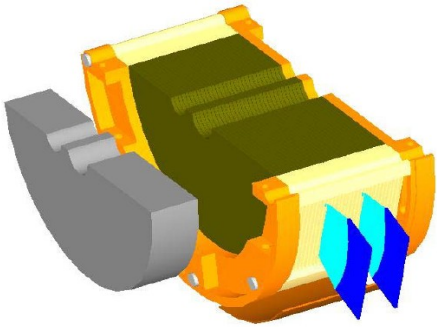
LumiCal (ILC) fiducial volume:
41 < θ < 67 mrad

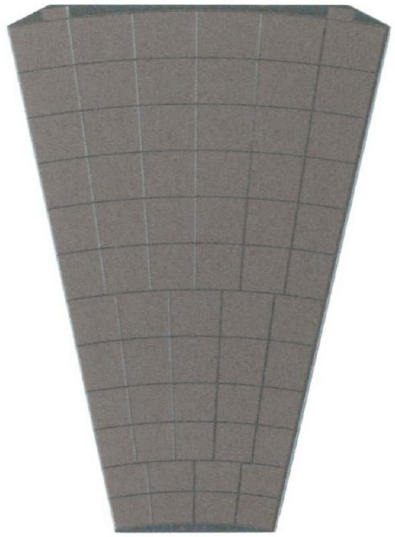
5

Introduction
BeamCal ?-W sandwich calorimeter

BeamCal main goals

- 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, using fast feedback electronics





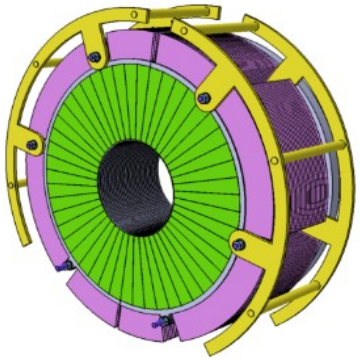
BeamCal sensors

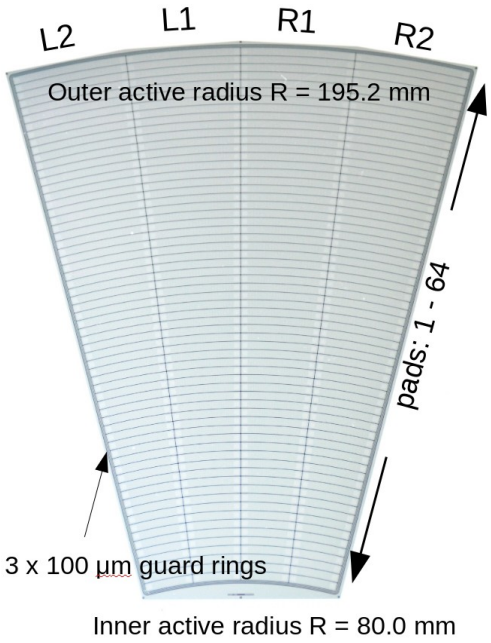
- Segmented radially and azimuthally into pads
- BeamCal must use a very radiation hard sensor
- Dedicated ASIC under development to cope with wide signal range and to provide fast feedback
- Few technologies are under investigation:
  - GaAs
  - CVD diamond
  - Sapphire

Introduction
LumiCal Si-W sandwich calorimeter

LumiCal main goals

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



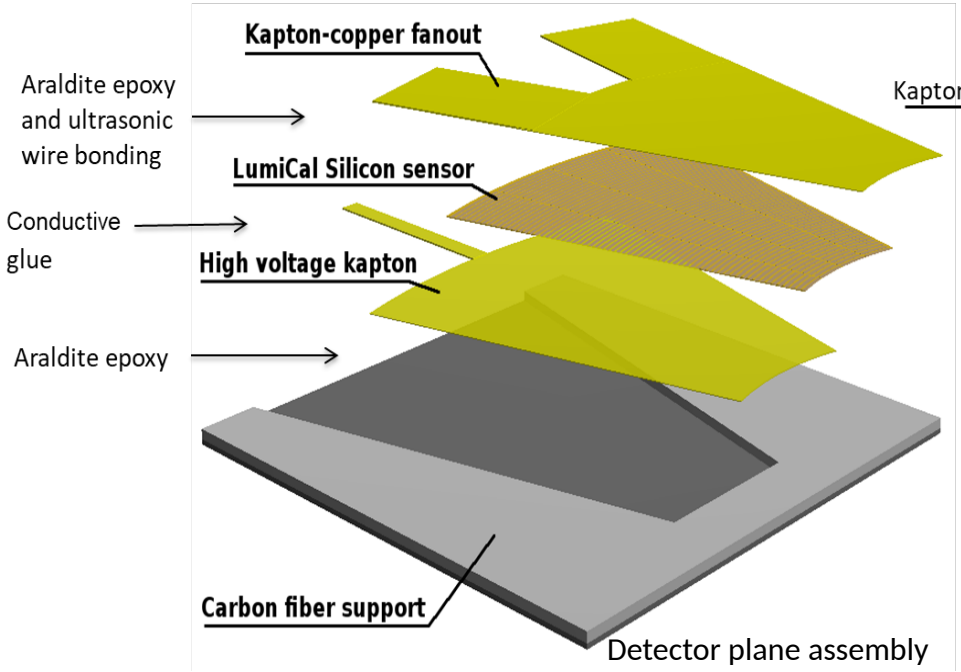


Silicon pad sensor prototype was designed for ILC (produced by Hamamatsu)

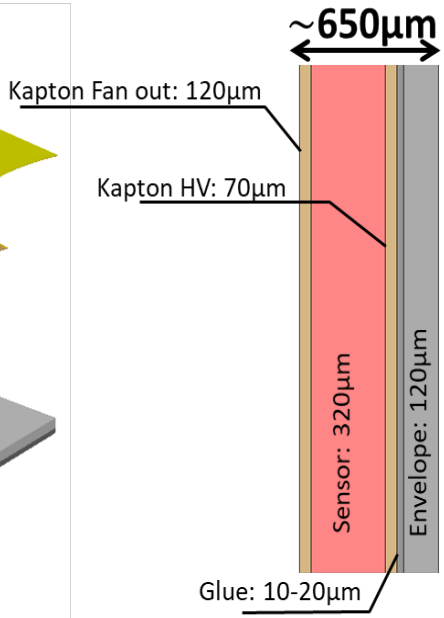
- ring segment of 30 degrees, 4 sectors of 7.5˚each
- 64 radial pads, pitch 1.8 mm
- 11 cm long with an inner radius of 80 mm
- thickness 320 µm
- p+ implants in n-type bulk

Development of Compact LumiCal
Prototype of thin detector module

Thin sensor module



Detector plane assembly



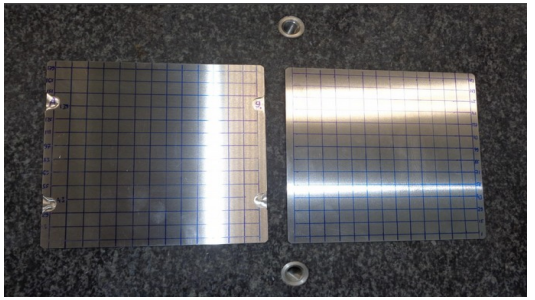
Compactness is essential to get small Molière radius

->

accurate shower position reconstruction

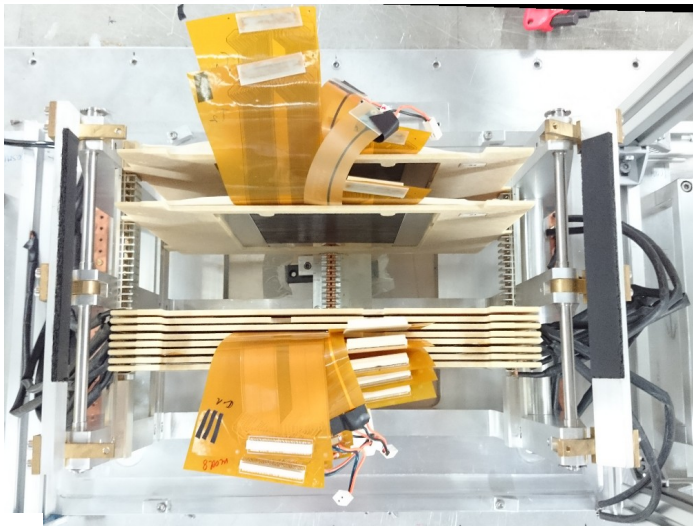
Absorber plates

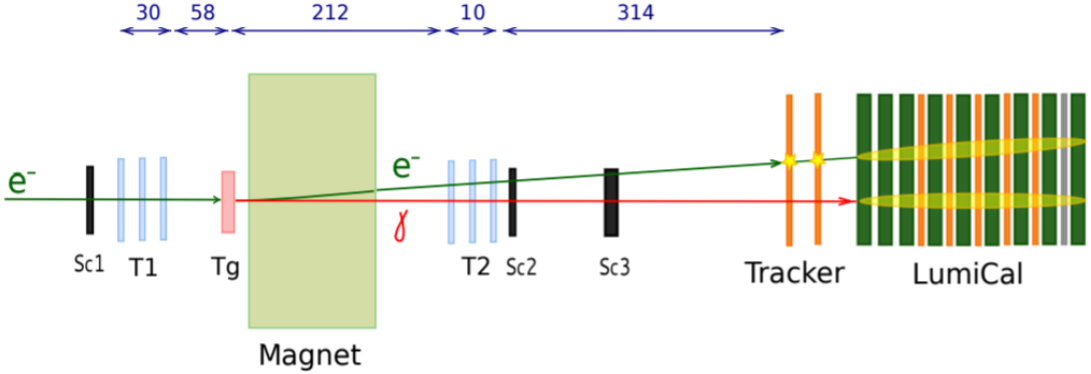
- W plates - alloy with 93 % tungsten, 5 % nickel and 2 % copper
- 1 X_0 – 3.5 mm thick
- Flatness of W plates is better than 30 μm

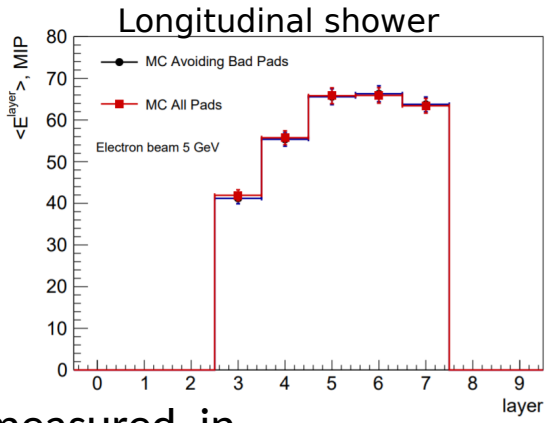

W plates - dimensions 140 x 140 x 3.5 mm

Development of Compact LumiCal
2016 test-beam of LumiCal prototype

- LumiCal prototype with 8 detector planes
  - 2 used as a tracker - tagger for e/γ separation
  - 6 used as calorimeter (3 - 8 X_0) with 1 mm gap
- Planes read by APV25 – dedicated chip for LumiCal not yet available
- 1 mm gap between tungsten plates
- Measured at DESY with 1-5 GeV electron

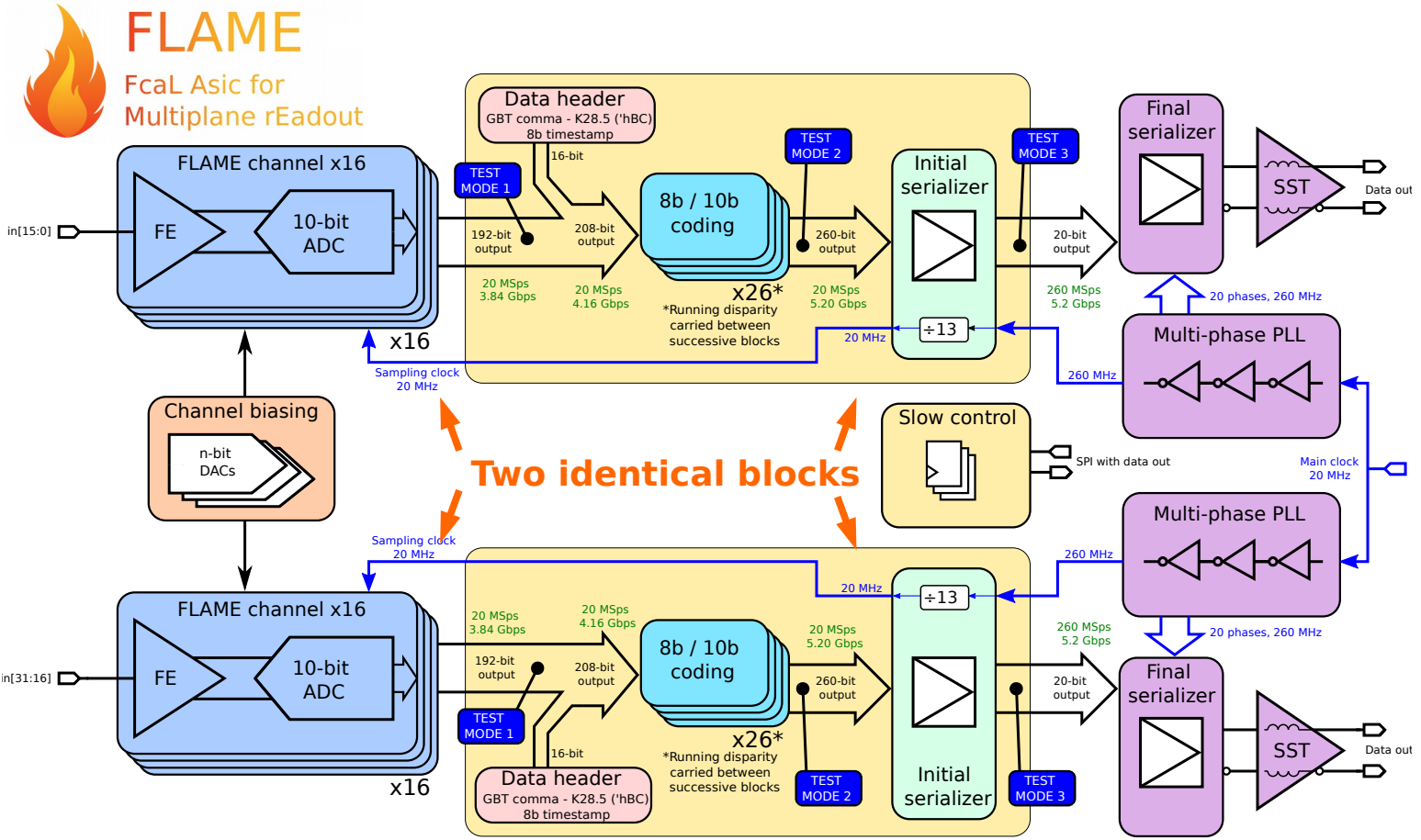






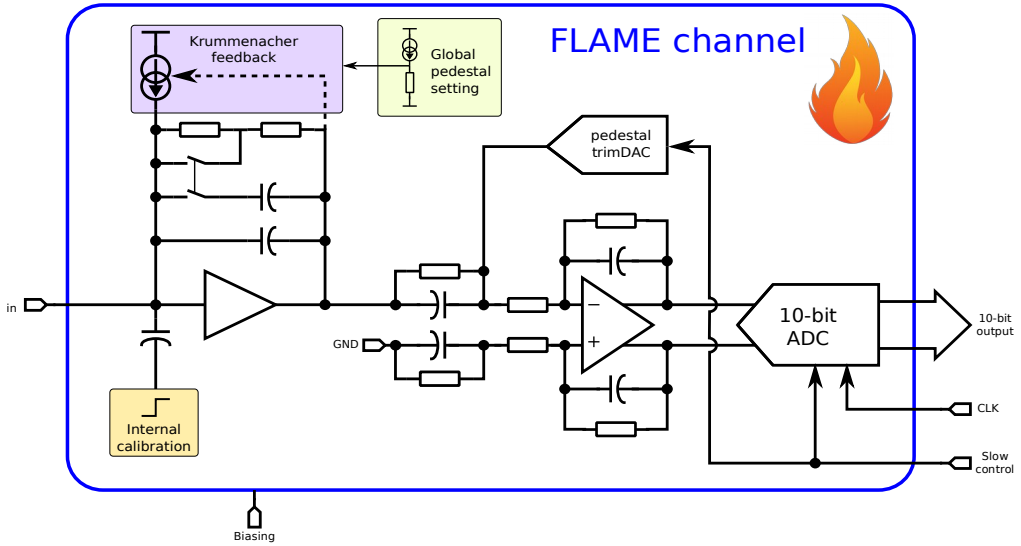
An effective Molière radius of 8.1 ± 0.1 (stat) ± 0.3 (syst) mm was measured, in excellent agreement with MC simulations (EUR.PHYS.J. C79(2019)NO.7,579)

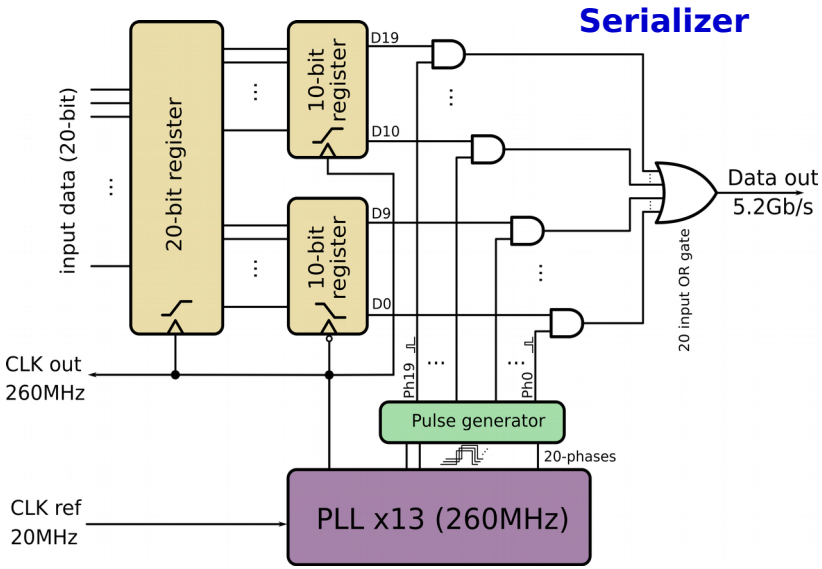
Development of dedicated LumiCal readout
FLAME ASIC Architecture



FLAME is a 32-channel ASIC, designed in CMOS 130 nm, containing FE+ADC in each channel, followed by high speed serializers and data transmission

Development of dedicated LumiCal readout FLAME - Single channel and Fast serializer



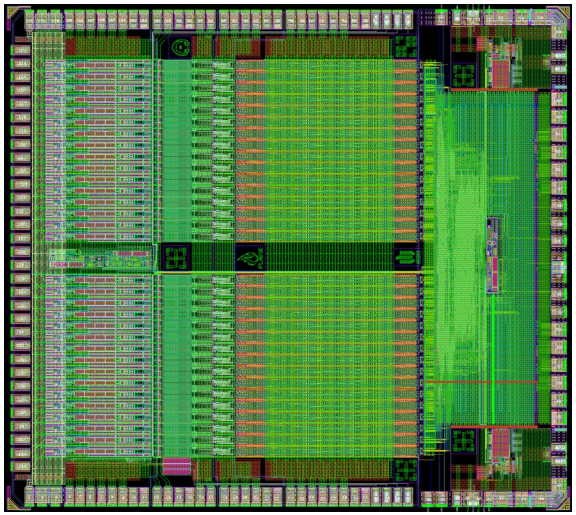


- Analogue front-end comprising:
  - Charge sensitive preamplifier with variable gain:
    - High gain – for MIP sensitivity
    - Low gain – for shower deposition (up to 6pC)
  - Differential CR-RC shaper – **for simple amplitude and time deconvolution** - with ~50ns peaking time
  - Internal calibration and pedestal trimDAC
  - Power consumption ~1mW
- 10-bit multichannel SAR ADC
  - Sampling rate 20 MS/s (Max 50 MS/s)
  - ENOB > 9.5, DNL, INL < 0.5 LSB
  - Ultra low power consumption (<0.5mW/channel@20MSps)

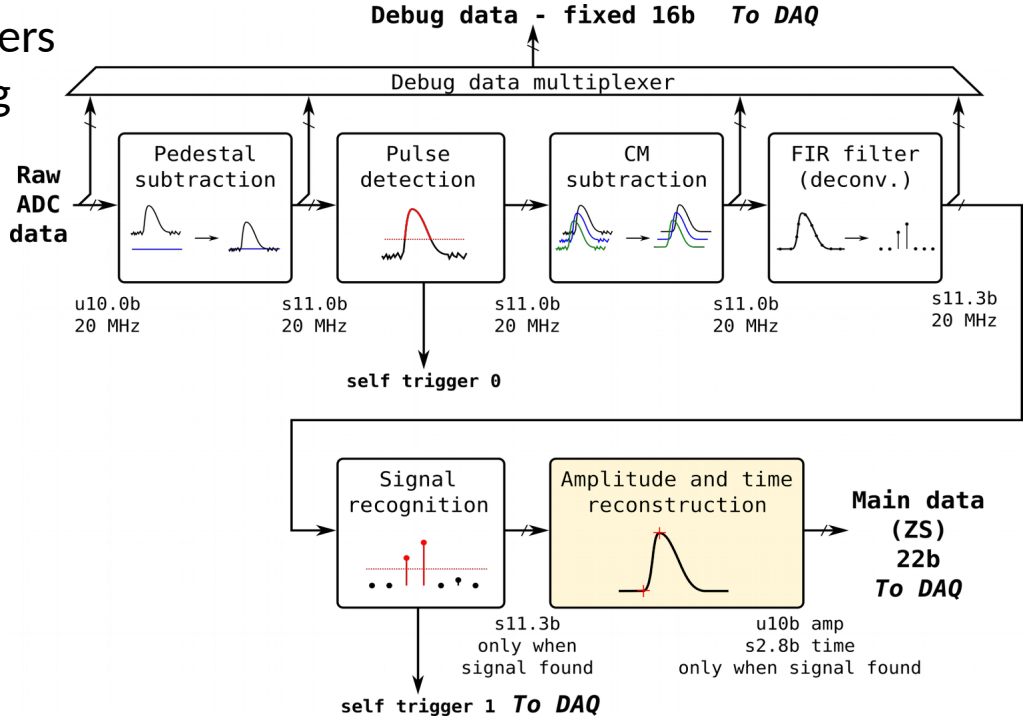
- Serialization based on 20 uniformly distributed phases of PLL clock
- PLL generates 260MHz clocks from 20MHz reference (x13)
- 5.2 Gb/s output data rate

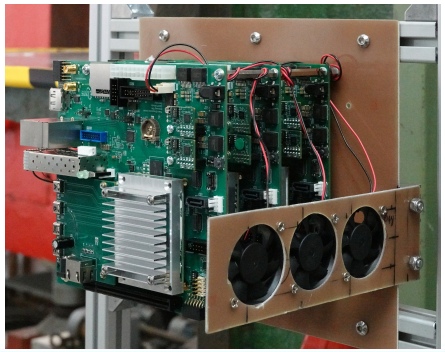
Development of dedicated LumiCal readout DSP online processing with FPGA back-end

FLAME serializers send data to GTH transceivers of Zynq UltraScale FPGA for online processing



FLAME size 3.7mm x 4.3mm

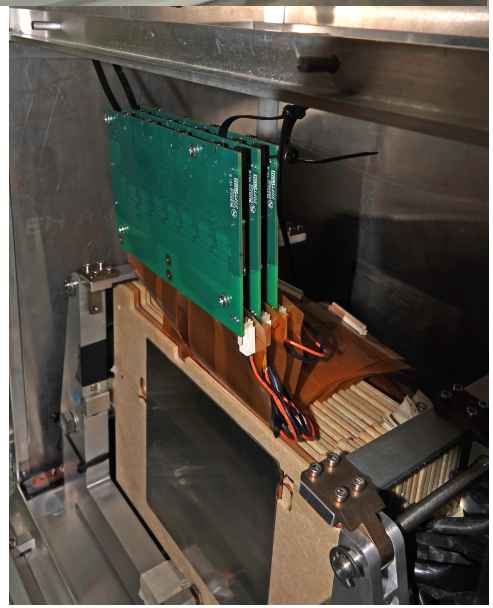


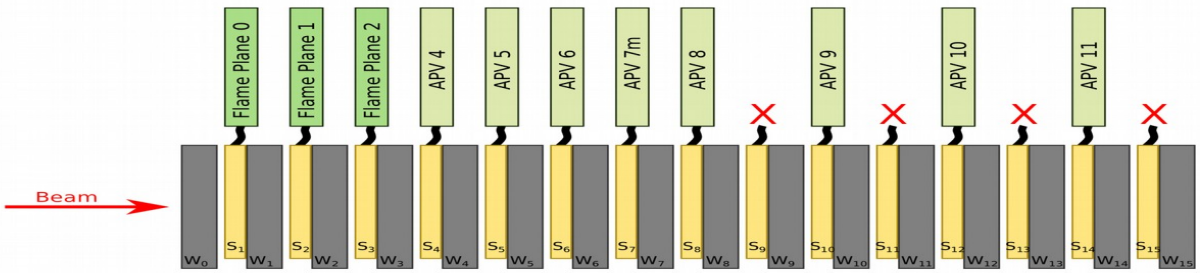


Reconstructed amplitude (10-bit) and time of arrival (~1 ns) information of detected pulses are sent to DAQ system

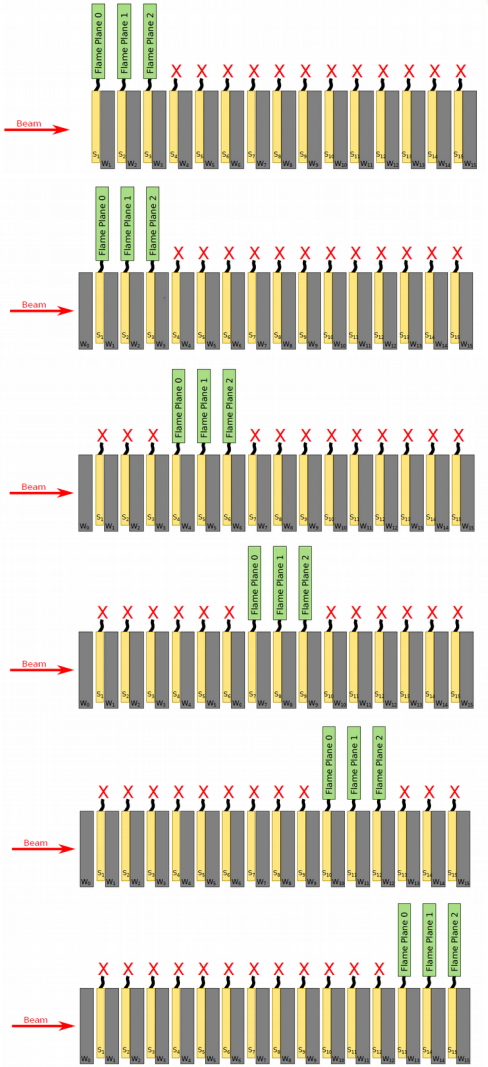
New LumiCal prototype in the beam
2020 Test-beam Setup

- Two weeks campaign on March 2020 at DESY
- Setup built of 16 Tungsten plates and silicon sensors
- Available readout:
  - 3 readout boards with FLAME chip
    First test-beam with FLAME readout !
  - 8 SRS readout boards with APV25 chip
- 5 ALPIDE planes for tracking
- Data acquired for:
  - different beam energies (1-5 GeV)
  - impact position scans
  - different incident angles
  - different readout board configuration (position in the stack)

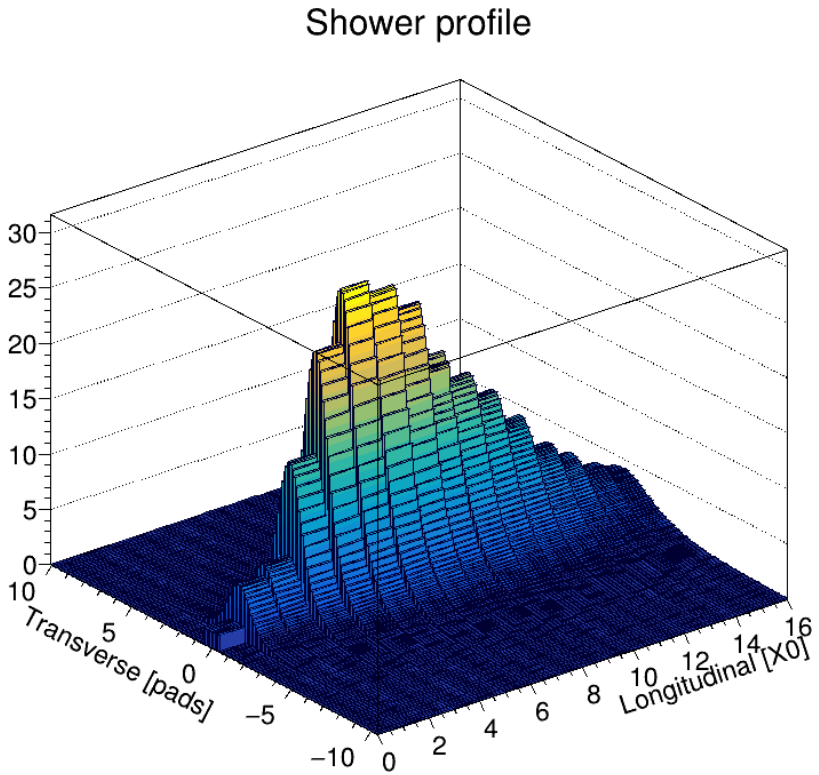




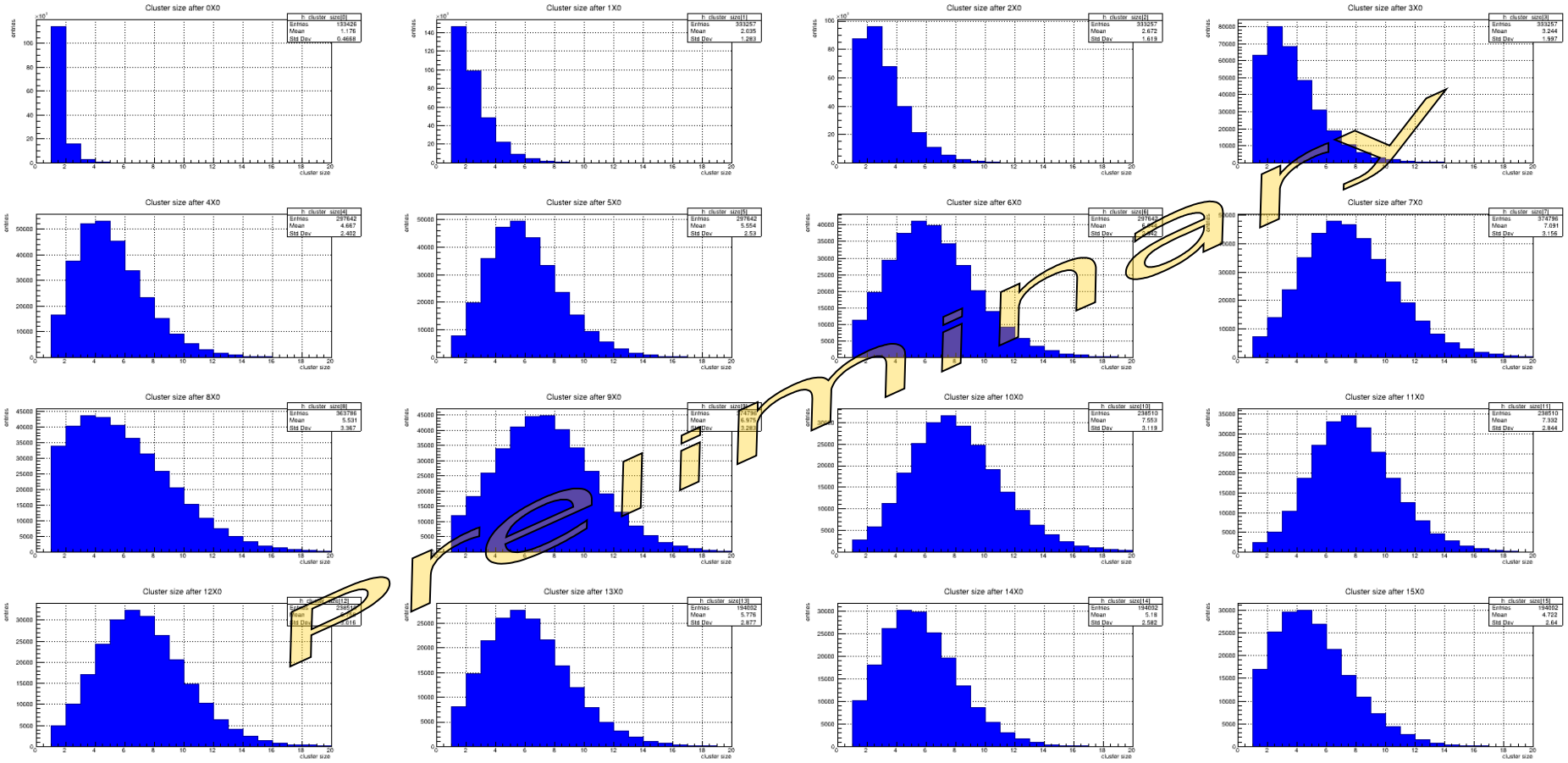
New LumiCal prototype in the beam
FLAME readout configurations



- To study the shower development in the entire calorimeter stack with only three FLAME boards, the boards were successively connected to the next sensor layers
- Shower development reconstruction in the whole stack was done offline by merging data from different configurations

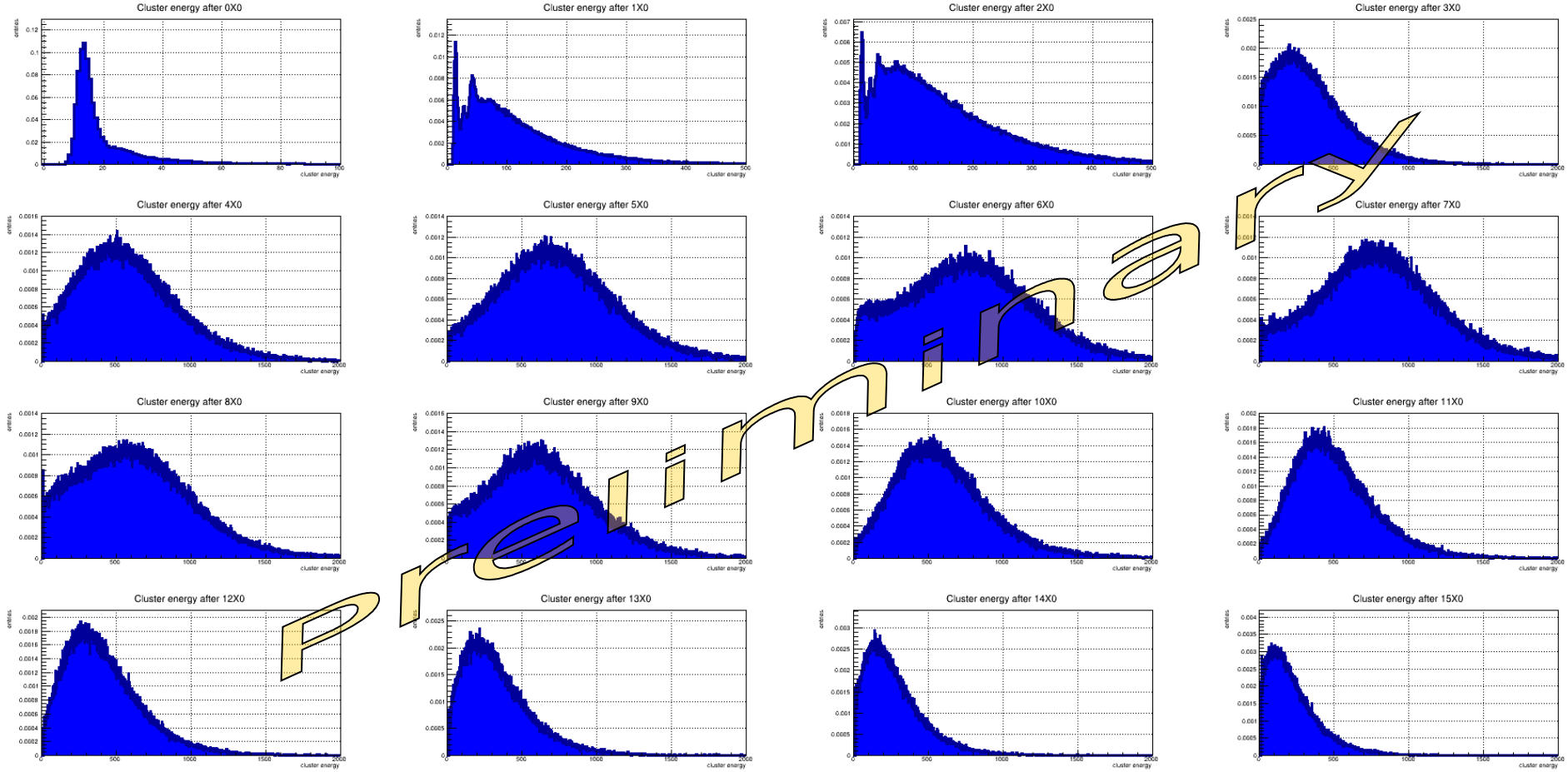


New LumiCal prototype in the beam
Cluster size at different radiation lengths



Cluster size for planes up to 15 radiation were measured

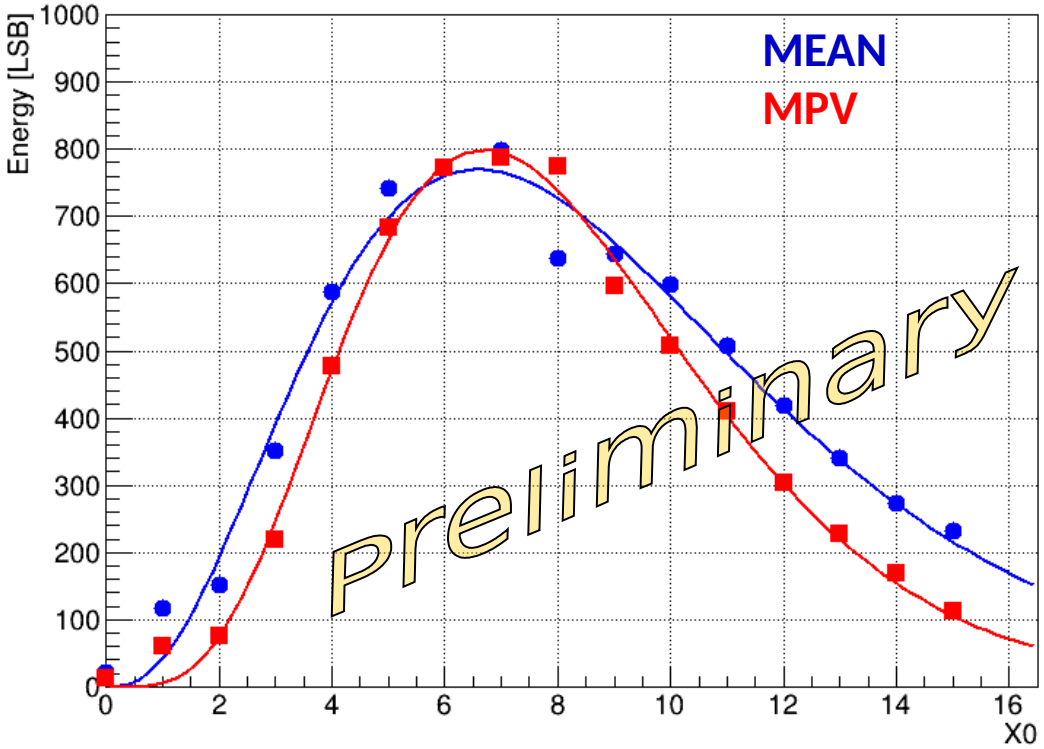
New LumiCal prototype in the beam
Cluster energy vs radiation length



Energy deposited up to 15 radiation lengths were measured. Some noise cuts still under tuning...

New LumiCal prototype in the beam
Longitudinal shower development

- The maximum energy deposition for 5 GeV electrons at around $7X_0$ as expected
- Analyses in progress:
  - Telescope information to be added...
  - Moliere radius calculations have been started...



Summary

- Prototype of Compact LumCal was developed
  - Thin sandwich calorimeter module with ~650um silicon detector and 3.5mm (1X0) tungsten absorber was developed
  - Dedicated FLAME readout ASIC together with FPGA back-end were developed
- Test-beam of new LumiCal prototype was done
  - The whole detector chain successfully verified on the beam
  - Many runs with different beam energies (1-5 GeV) and different LumiCal configurations were taken
  - First analysis of shower development gives very promising results...

Thank you for attention