Overview of FCAL Activities

Oleksandr Borysov
Tel Aviv University

On behalf of the FCAL collaboration

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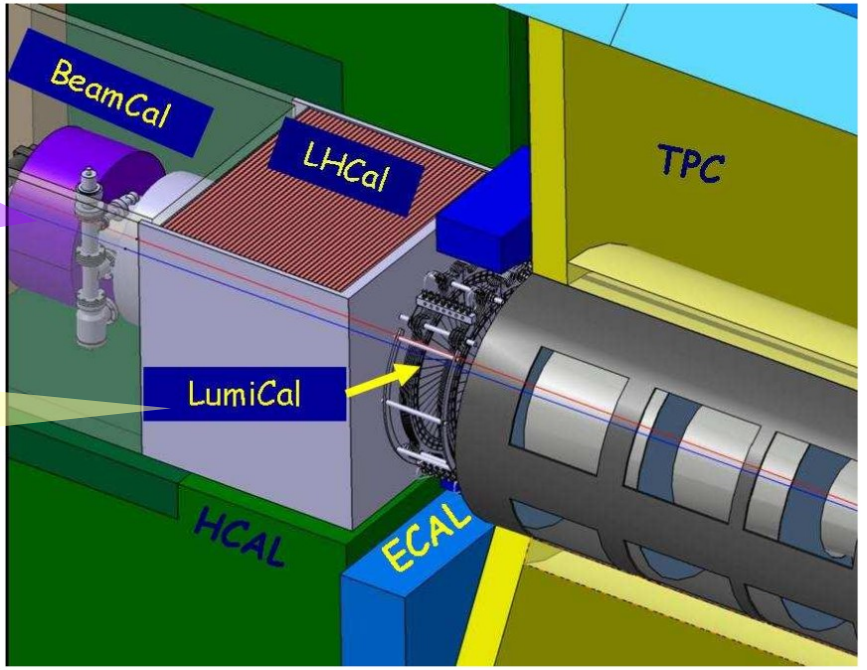
Overview

- Instrumentation of the forward regions in linear collider experiments
- LumiCal calorimeter:
  - Luminosity measurement;
  - Detector module development;
  - Infrastructure for LumiCal prototype beam test.
- BeamCal calorimeter:
  - Beam parameters and single electron reconstruction.
- Summary and plans

Instrumentation of the forward region

Goals:

- Instant luminosity measurement;
- Provide information for beam tuning;
- Precise integrated luminosity measurement;
- Extend a calorimetric coverage to small polar angles. Important for physics analysis.



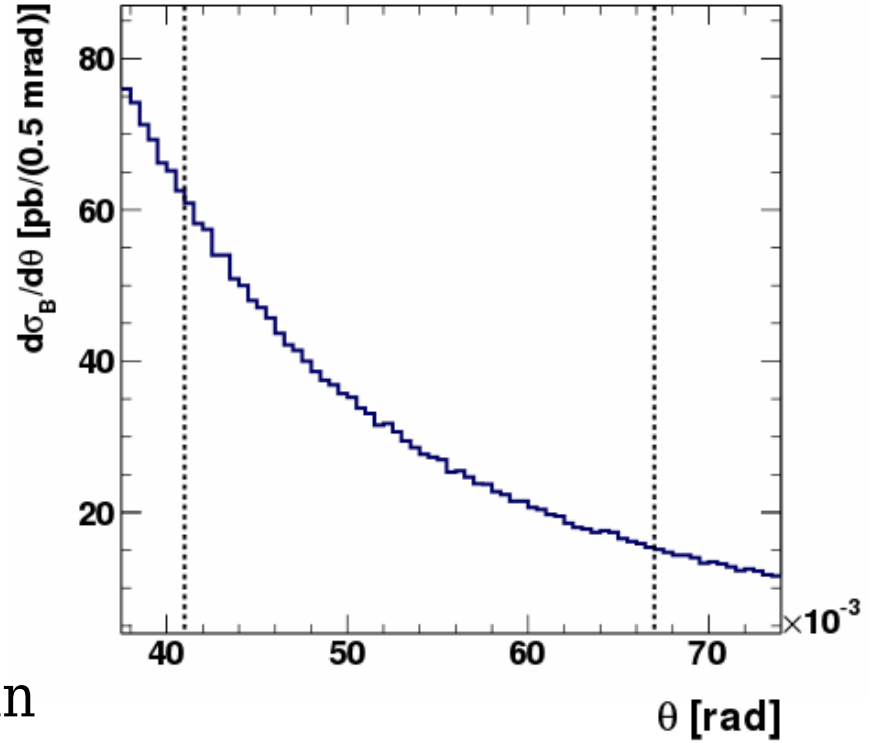
LumiCal: two tungsten-silicon calorimeters placed symmetrically on both sides of the interaction point at a distance of ~2.5 m.

Each calorimeter consists of 30 layers of 3.5 mm thick tungsten plates 1 mm apart interleaved with silicon sensors.

BeamCal: similar construction, with tungsten absorber but radiation hard sensors (GaAs, CVD diamond).

Luminosity measurement with LumiCal

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.

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 geometry

Uncertainty in luminosity measurement depends on the polar angle bias $\Delta\theta$ and minimum polar angle θ_{min} as:

$$\left(\frac{\Delta L}{L}\right)_{rec} \approx 2\frac{\Delta\theta}{\theta_{min}}$$

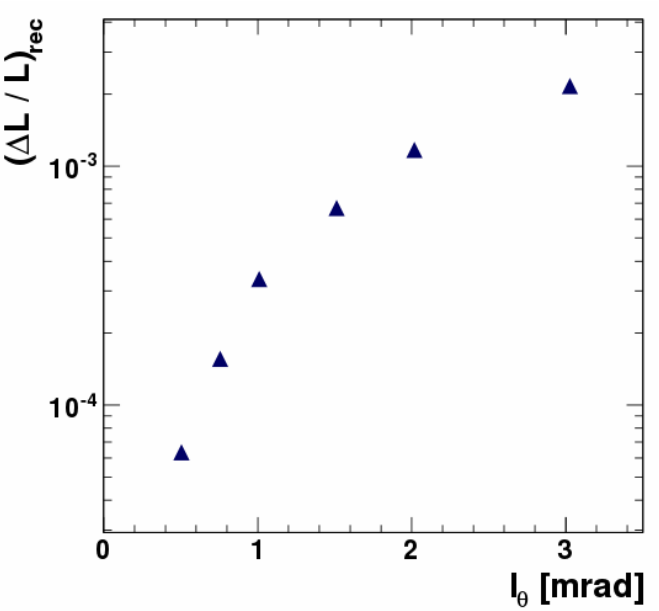
$\Delta\theta$ depends on polar angular pad size I_θ.

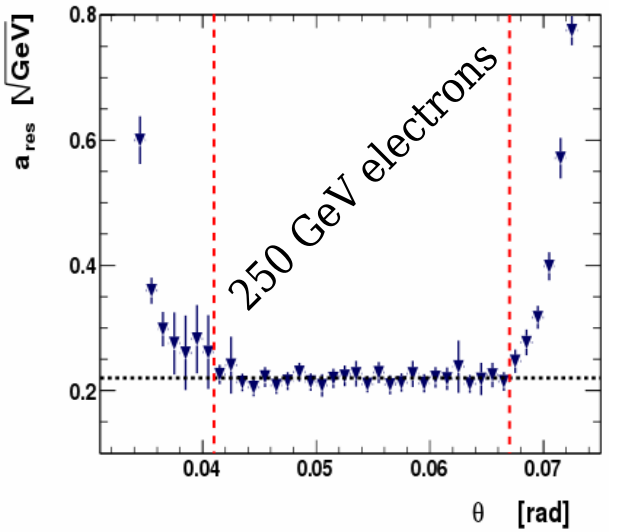
For I_θ=0.8 mrad, $\Delta L/L = 1.6\cdot10^{-4}$.

Energy resolution: $$\frac{\sigma_E}{E} = \frac{a_{res}}{\sqrt{E_{beam}\,(GeV)}},$$

LumiCal fiducial volume: 41 < θ < 67 mrad

$a_{res} = (0.21\mp0.02)\ \sqrt{GeV}$.

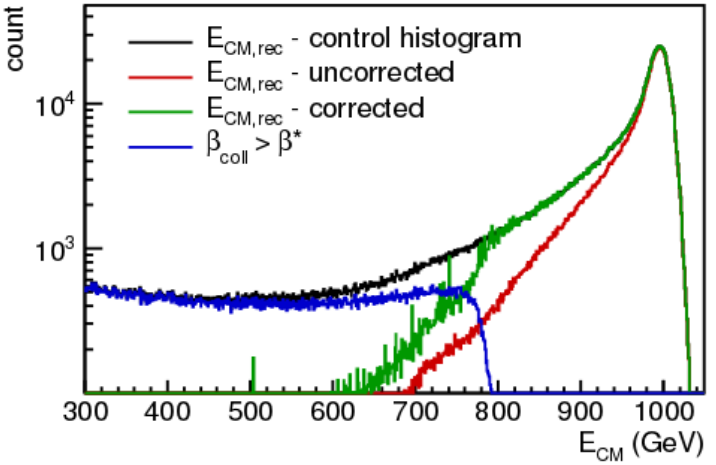




Systematic effects

- Pinch-effect and beamstrahlung;
- Background from four-fermion production;
- Resolution and scale of the electron energy measurement;
- Beam polarization

Estimated systematic uncertainty at $\sqrt{s}$ = 500 GeV.

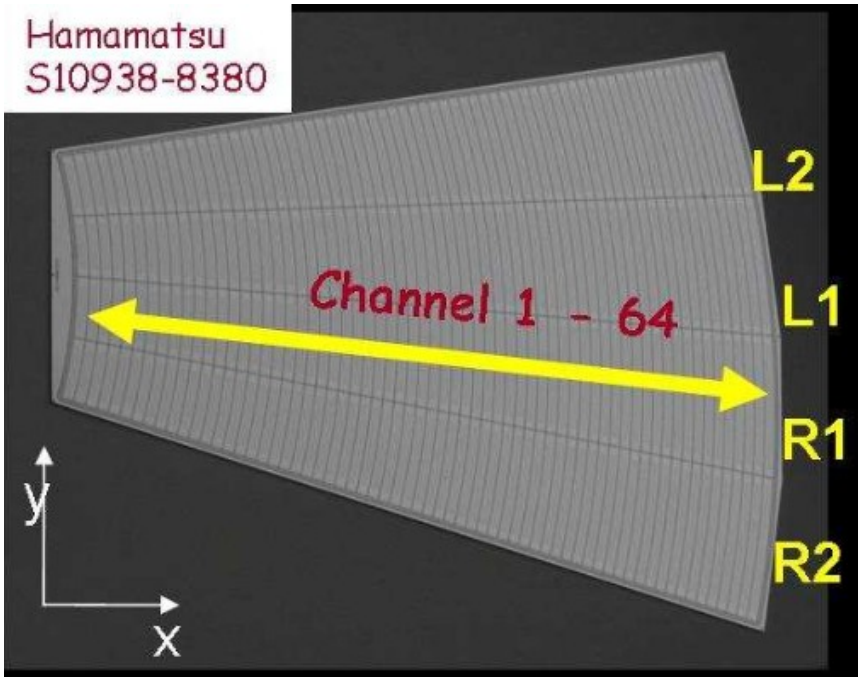


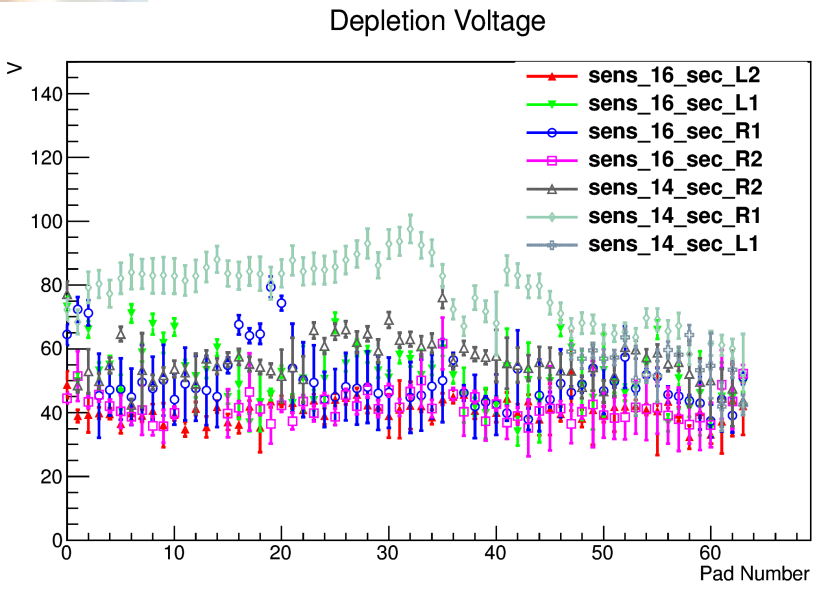
Lumi spectrum with event by event correction

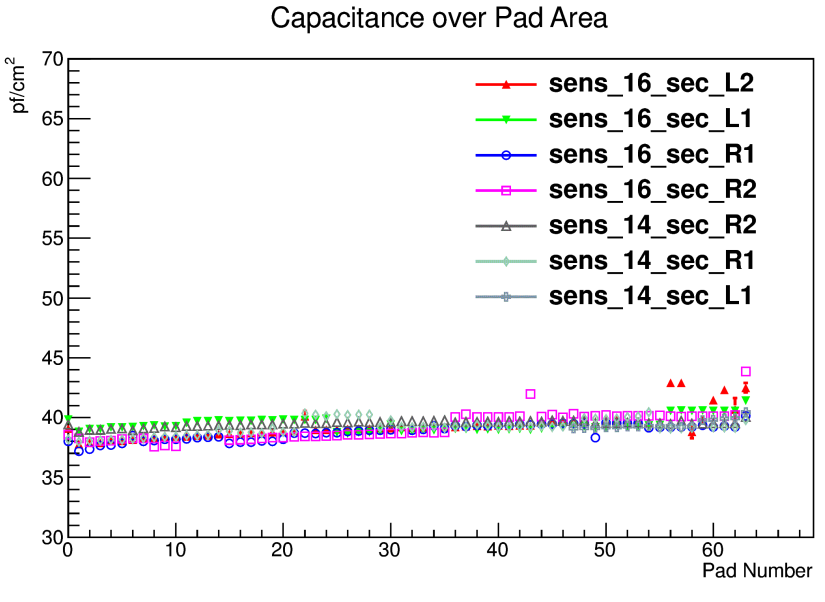
Source	Value	Uncertainty	Luminosity Uncertainty
σ_θ	2.2×10^{-2}	100%	1.6×10^{-4}
Δ_θ	3.2×10^{-3}	100%	1.6×10^{-4}
a_{res}	0.21	15%	10^{-4}
luminosity spectrum			10^{-3}
bunch sizes σ_x, σ_z,	655 nm, 300 μm	5%	1.5×10^{-3}
two photon events	2.3×10^{-3}	40%	0.9×10^{-3}
energy scale	400 MeV	100%	10^{-3}
polarisation, e^-, e^+	0.8, 0.6	0.0025	1.9×10^{-4}
total uncertainty			2.3×10^{-3}

LumiCal sensor

- Silicon sensor
- thickness 320 μm
- DC coupling with read-out electronics
- p^+ implants in n material
- radial pad pitch 1.8 mm
- Azimuthal pitch 7.5°



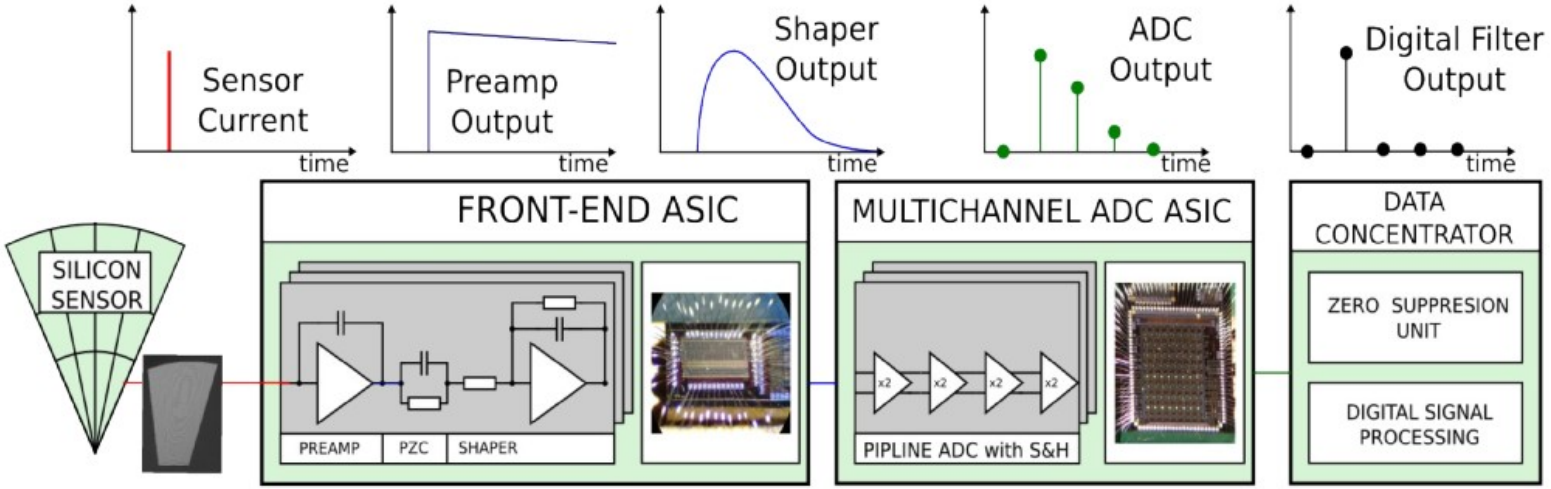




New Front-end in CMOS 130 nm

Existing readout based on 0.35µm ASIC:

- 8 channel front-end (preamp, shaper T_{peak} ~ 60 ns, ~9 mW/channel);
- 8 channel pipeline ADC, Tsmp ≤ 25 MS/s, ~1.2 mW/MHz;
- FPGA based data concentrator and further readout.



Front-end peak power consumption dropped to ~1.5 mW/channel

SAR ADC architecture,
peak power ~1 mW @ 40 MHz
(for 0.35 µm, would be > 40 mW)

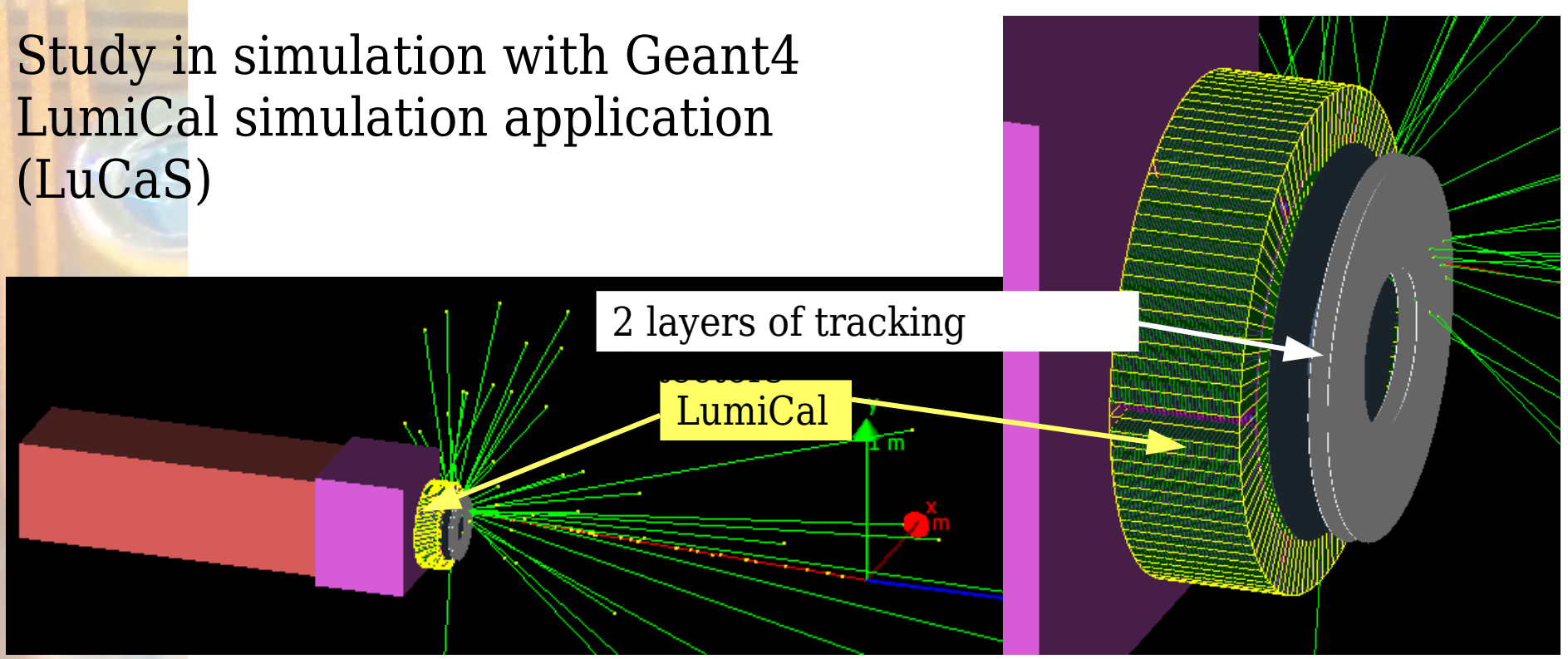
For the next readout generation a very low power, radiation resistant, ASICs are being developed in CMOS 130 nm.

See the talk by Angel Abusleme in Detector:Calorimetry session.

Tracking Detector in Front of LumiCal

- Improve polar angle measurement accuracy – important for precise luminosity evaluation;
- Provide information for better LumiCal sensors alignment;
- Provide more information to enable e/γ identification, important for various physics study.

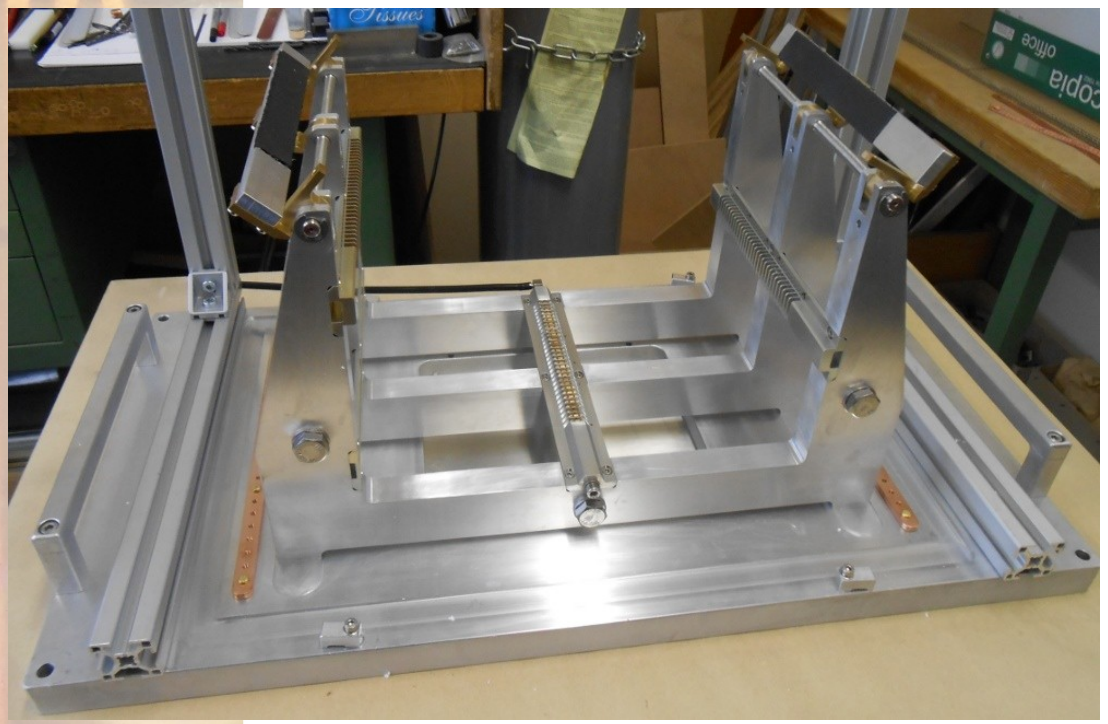
Study in simulation with Geant4 LumiCal simulation application (LuCaS)

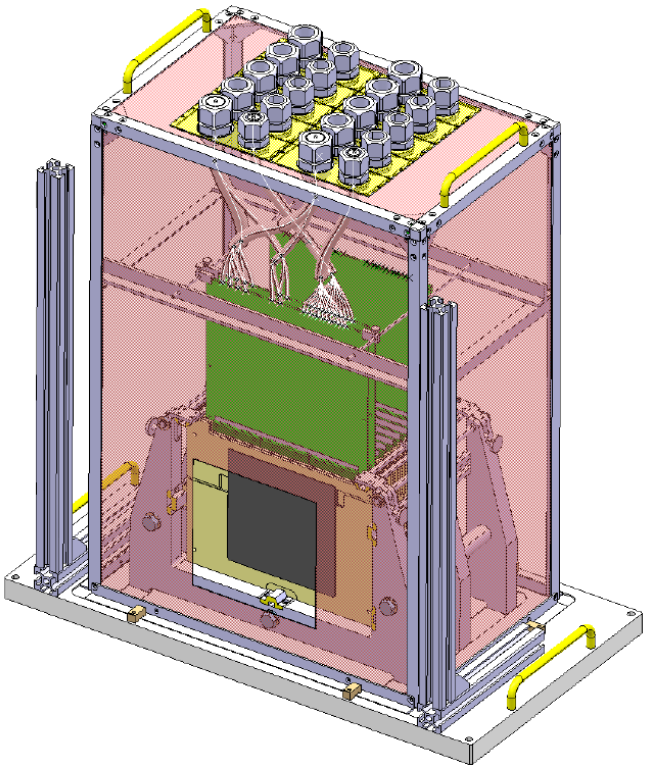


Mechanical Structure for Calorimeter Prototypes

Mechanical structure for tungsten-based calorimeter tests has been designed and manufactured:

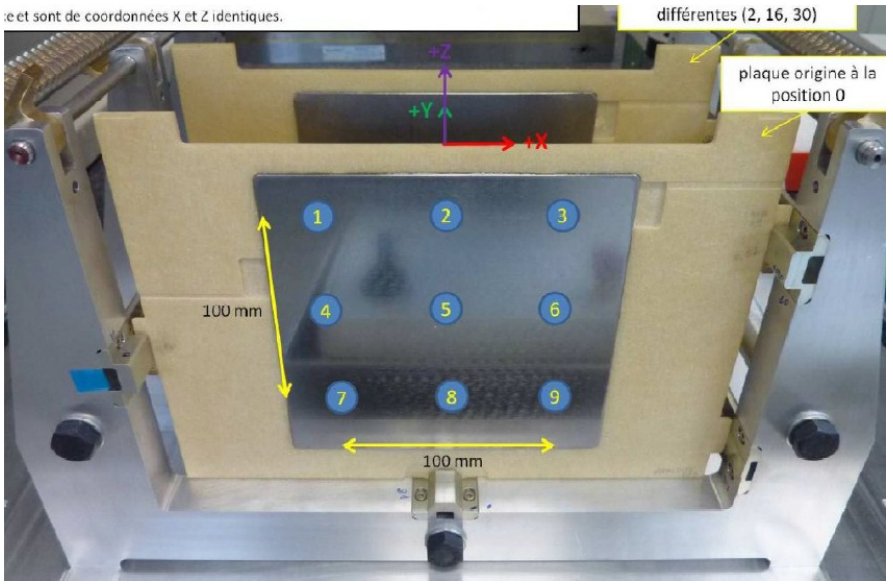
- capable of holding up to 30 tungsten plates and detector modules;
- Equipped with electronic cards and service lines supporting systems;
- Covered by light-tight shielding box.





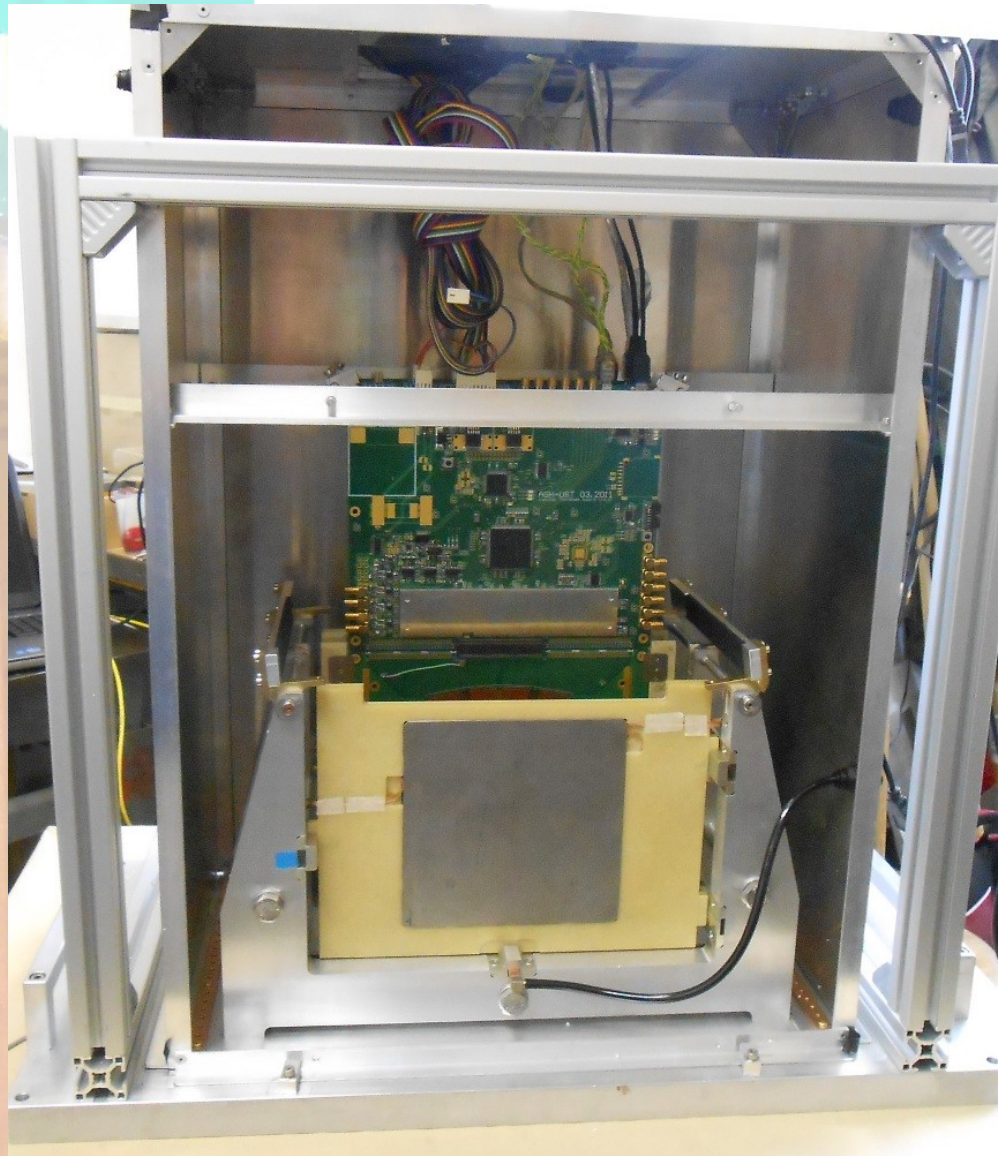
Frame Geometry Validation

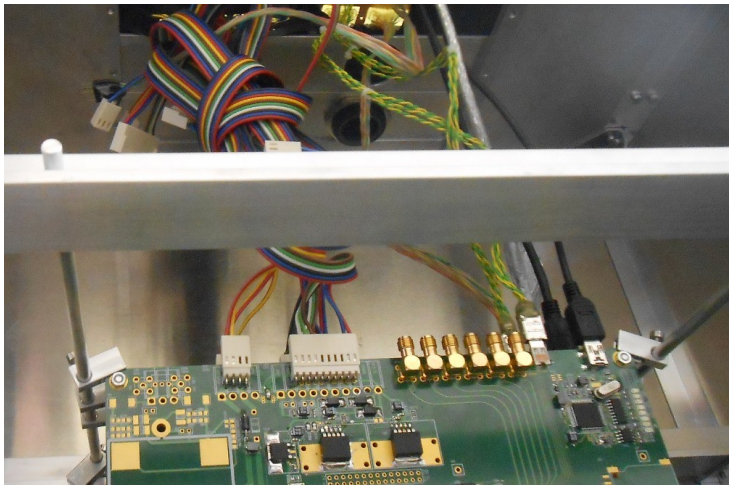
- 9 points were probed with a 3D coordinate measuring machine;
- Distance from point-to-point of different plates was measured.

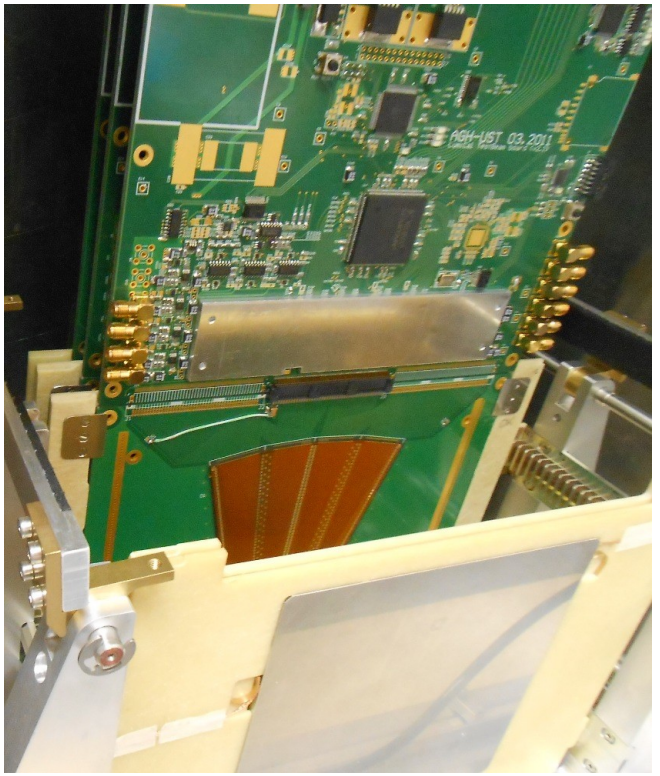


- 9 configurations have been tested with 2 tungsten plates;
- 4 configurations have been tested with 5 tungsten plates;
- Vertical and horizontal orientations were tested;
- More then 50 measurements were done which correspond to more then 900 probes.
- The accuracy of geometrical parameters was found to be better then 50 μm.

FCAL test beam infrastructure

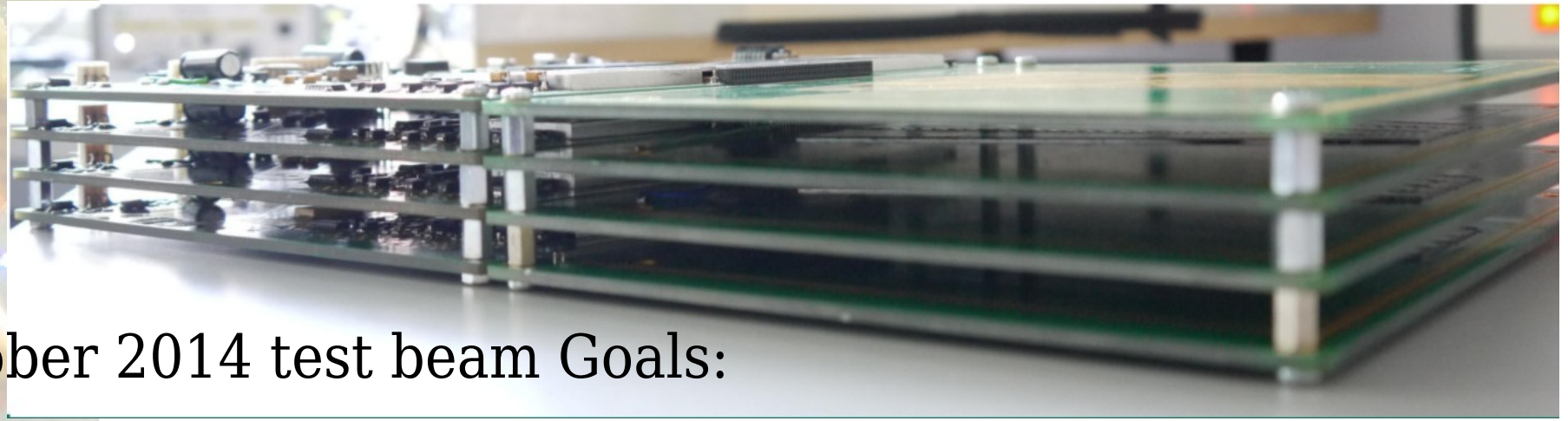






Beam Test of LumiCal Prototype

- Four LumiCal modules have been assembled.
- They were tested in AGH-UST (Krakow) to work together;
- Read out boards were modified to reduce the noise.



October 2014 test beam Goals:

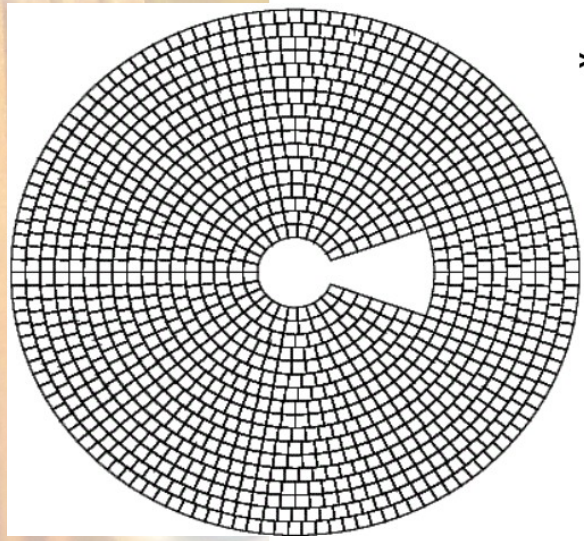
- Tests of the prototype with four detector modules working together;
- Study electromagnetic shower development in a precise and well known structure and compare it with MC;
- Test and improve reconstruction algorithm and particle tagging;
- Measure energy resolution and polar angle reconstruction precision.

BeamCal performance simulation

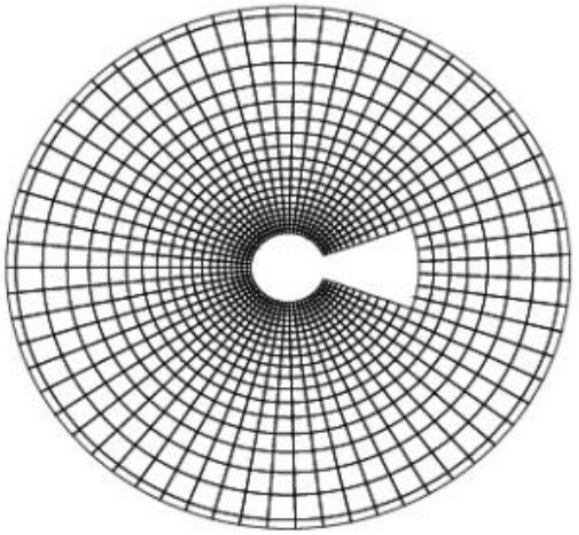
- The information about the collisions on a bunch-by-bunch basis is important to achieve the best possible conditions during the collisions.
- Beams interaction results in beamstrahlung photons radiation;
- Fraction of beamstrahlung photons convert into incoherent e^+e^- pairs;
- Energy depositions from these pairs in BeamCal can be used for fast beam parameter reconstruction and instant luminosity measurement.

Single high energy electron reconstruction in BeamCal

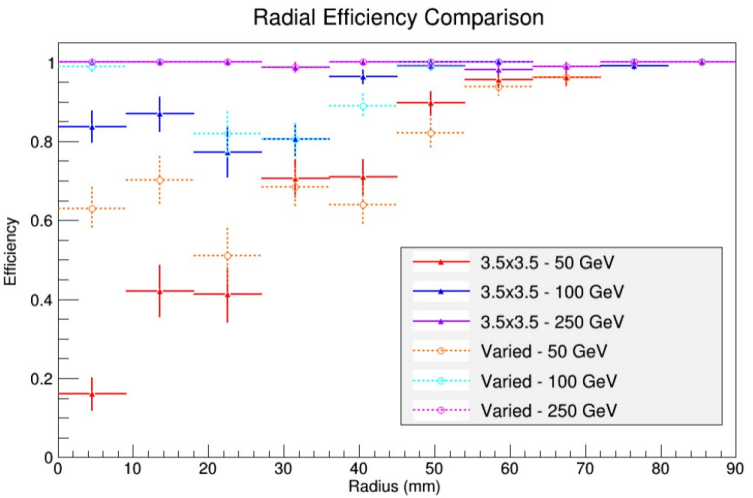
- Ongoing work on reconstruction algorithm and detector segmentation optimization.
- Background generated with Guinea-Pig
- Energy deposition simulated with BeCaS – Geant4 application.



Proportional Segment.



Uniform Segment.

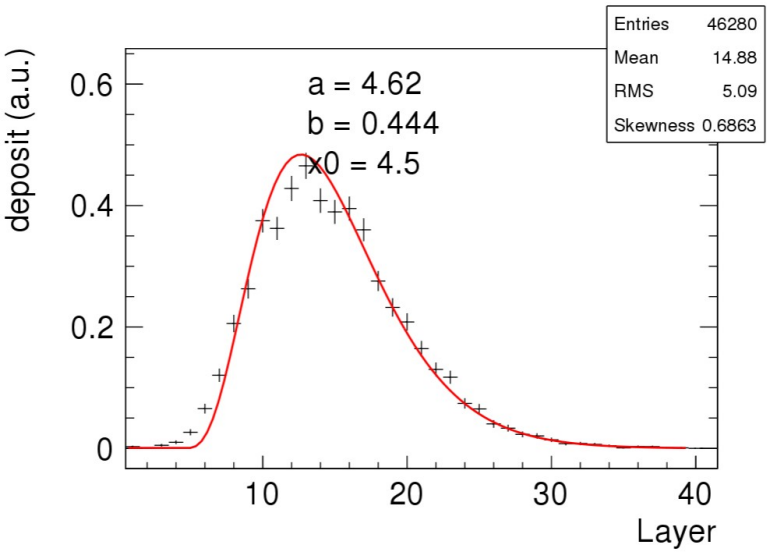


With different segmentation cell size.

More on this is in Lucia's Bortko talk in Detector:Calorimetry session

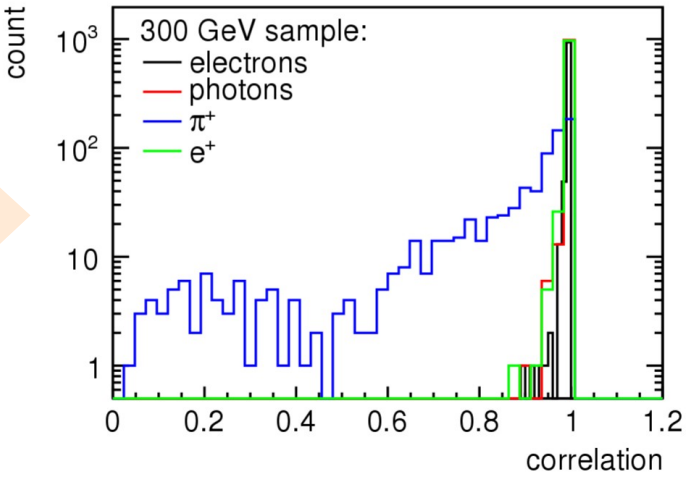
EM and Hadronic Showers Identification

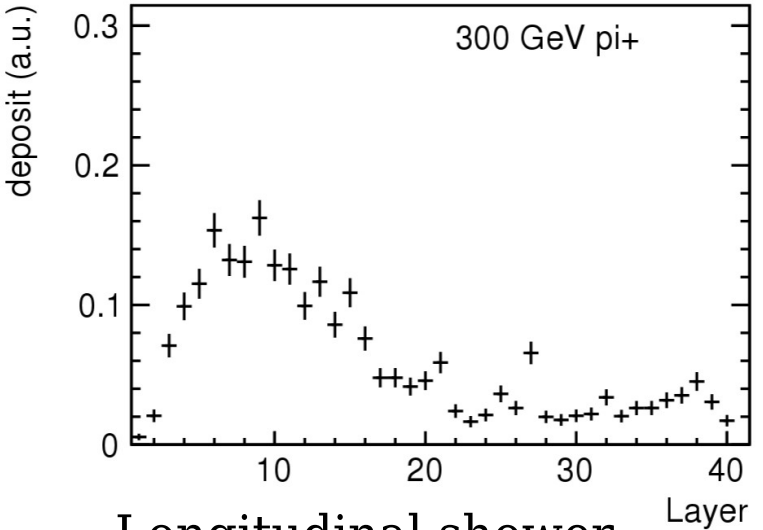
Longitudinal shape of EM shower is well approximated with Gamma distribution with two parameters: a and b.



Correlation coefficient between EM shower (h) pattern and measured shower (f)

$$\rho_{max}(h,f) = \frac{\sum_{i=1}^{N_h} h_i f_i(x^*_{start})}{\sqrt{\sum_{i=1}^{N_h} h_i^2}\sqrt{\sum_{i=1}^{N_h} f_i^2}}$$

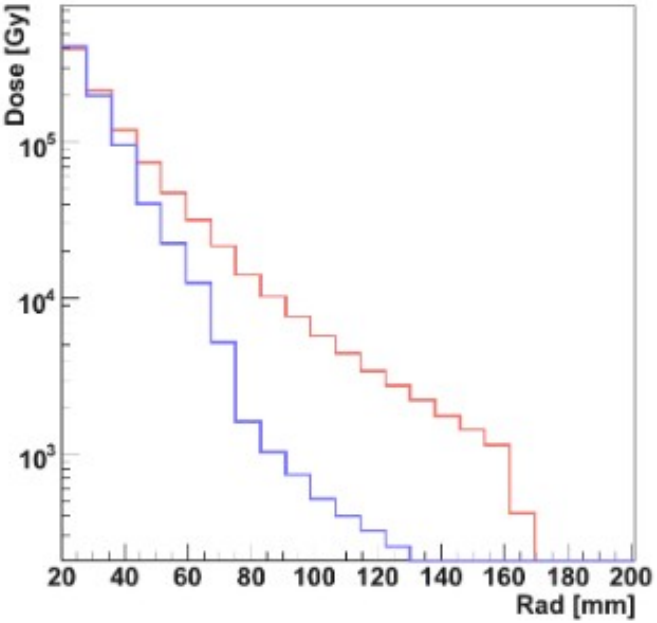




Longitudinal shower shape in BeamCal

BeamCal radiation load

- Radiation dose was estimated using BeCaS.
- The highest dose is in the layer 6; for small radius it is about 1 MGy per year for one single pad.



Dose per year as a function of BeamCal radius of the 6th layer. Blue/red - different set of beam parameters.

Different sensors were studied:

- GaAs sensor;
- Polycrystalline CVD diamond;
- Single crystal sapphire:
  - the prototype for MIP detection was studied at 5 GeV electron beam at DESY in January 2014.

Summary

- In the present conceptual design LumiCal and BeamCal detectors can provide luminosity measurements with precision required for physics analysis in linear collider experiments. But if the beam conditions change (e.g. L*) redesign will be required.
- Improvements can still be made in the integration of LumiCal in ECAL.
- Investigation of the performance of LumiCal in combination with tracking detector is in progress.
- There are 4 assembled LumiCal modules, plenty of tungstan absorber plates and mechanical frame ready for calorimeter prototype beam test.
- The paper summarizing the results from 2010 to 2012 beam tests of fully assembled modules is in final preparation. The performance of the modules matches the requirements.
- Development of the next generation of readout chips and detector modules for LumiCal and BeamCal are in progress.

Thanks for your attention!