FCAL Status

Oleksandr Borysov
Tel Aviv University

On behalf of the FCAL collaboration

ALCW2015, Tsukuba
April 24, 2015

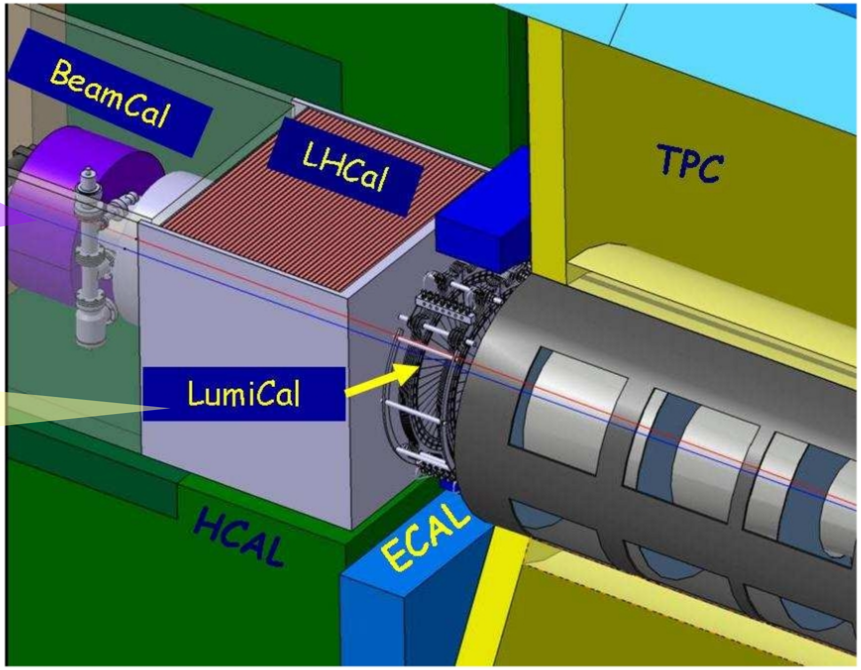
Overview

- Instrumentation of the forward regions in linear collider experiments
- First FCAL beam-test with multi-plane detector prototypes:
  - LumiCal module and beam test infrastructure;
  - Beam test setup;
  - Preliminary results.
- New design of LumiCal module
- BeamCal R&D
- LumiCal and BeamCal performance study in simulations
- Summary

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.

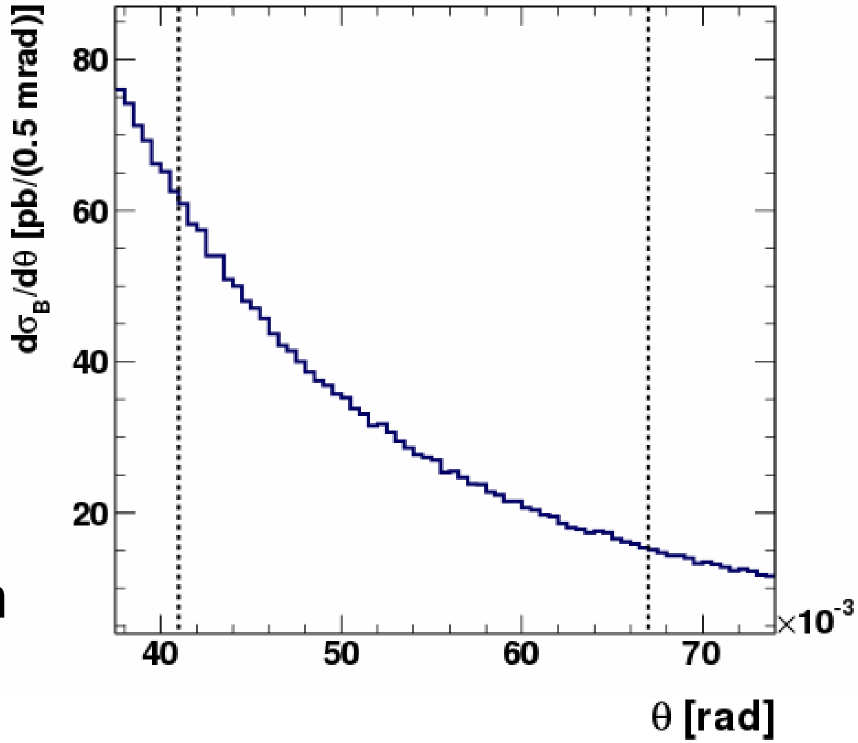
BeamCal: similar construction, with tungsten absorber but radiation hard sensors (GaAs, CVD diamond).

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.

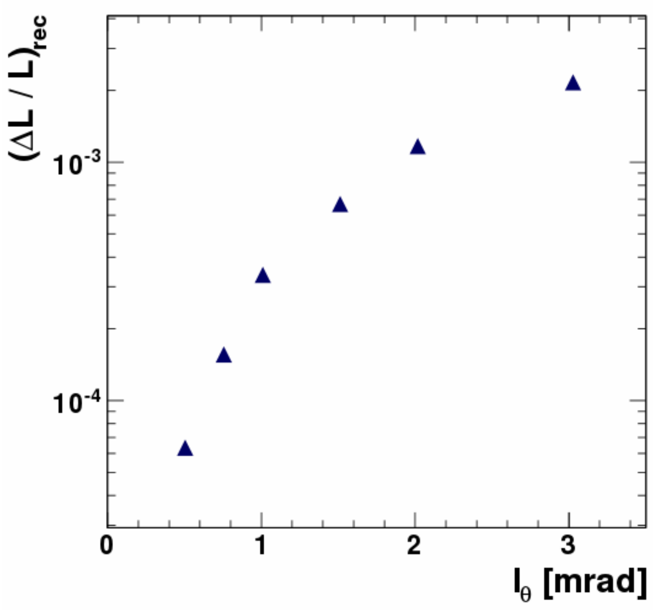
α is the fine-structure constant,
s - center-of-mass energy squared.

LumiCal geometry

Uncertainty in luminosity measurement depends on the polar angle bias Δθ and minimum polar angle θ_{min} as:

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

Δθ depends on polar angular pad size l_θ.



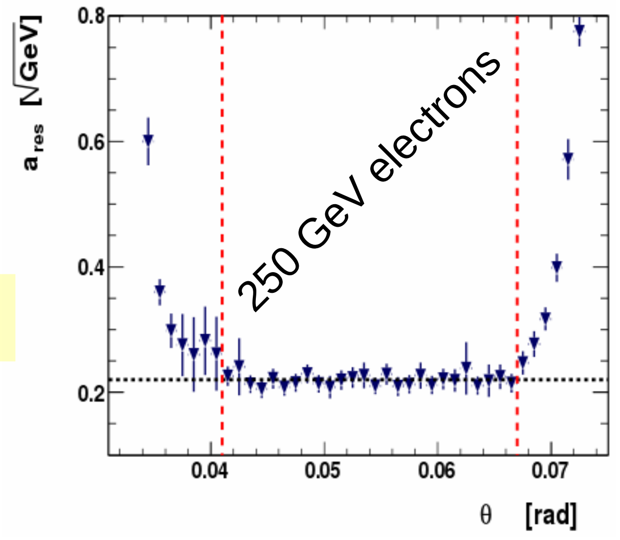
For $l_\theta = 0.8$ mrad, $\Delta L/L = 1.6\cdot10^{-4}$.

Energy resolution:

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

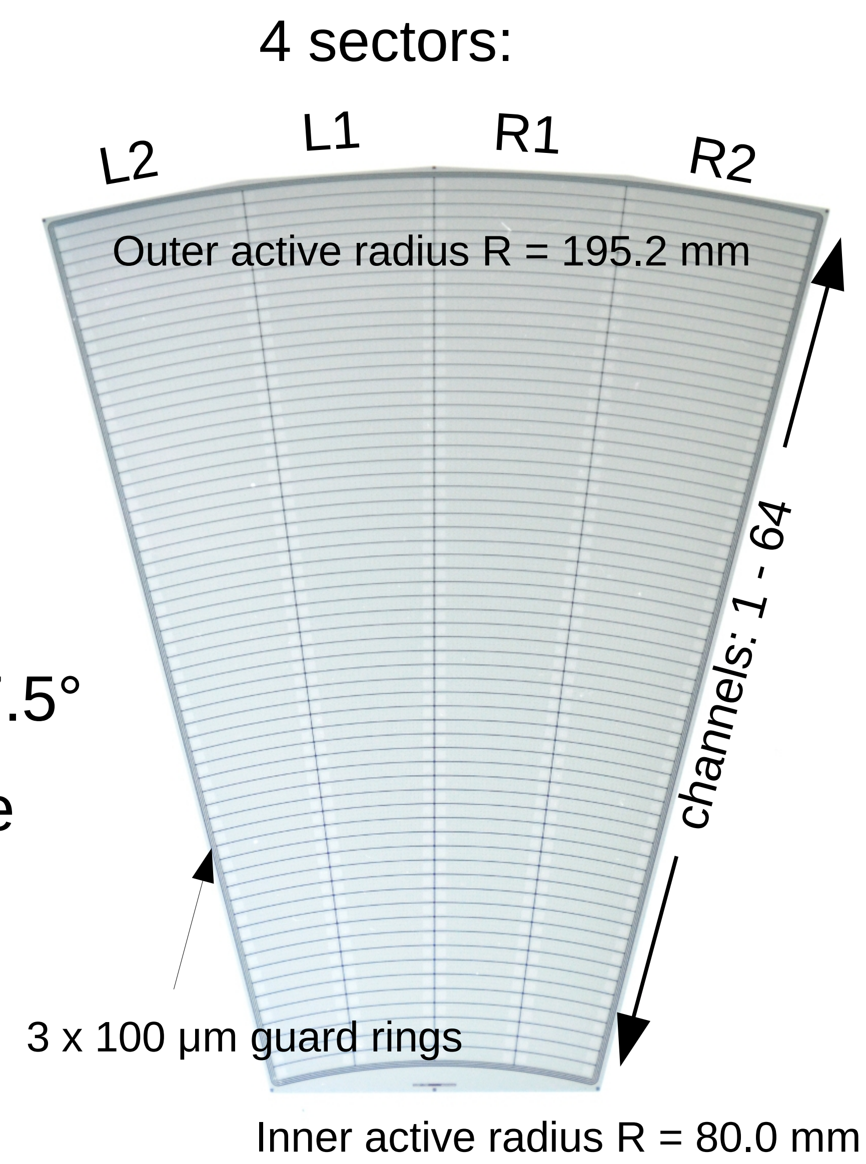
LumiCal fiducial volume: 41 < θ < 67 mrad

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



LumiCal Sensor

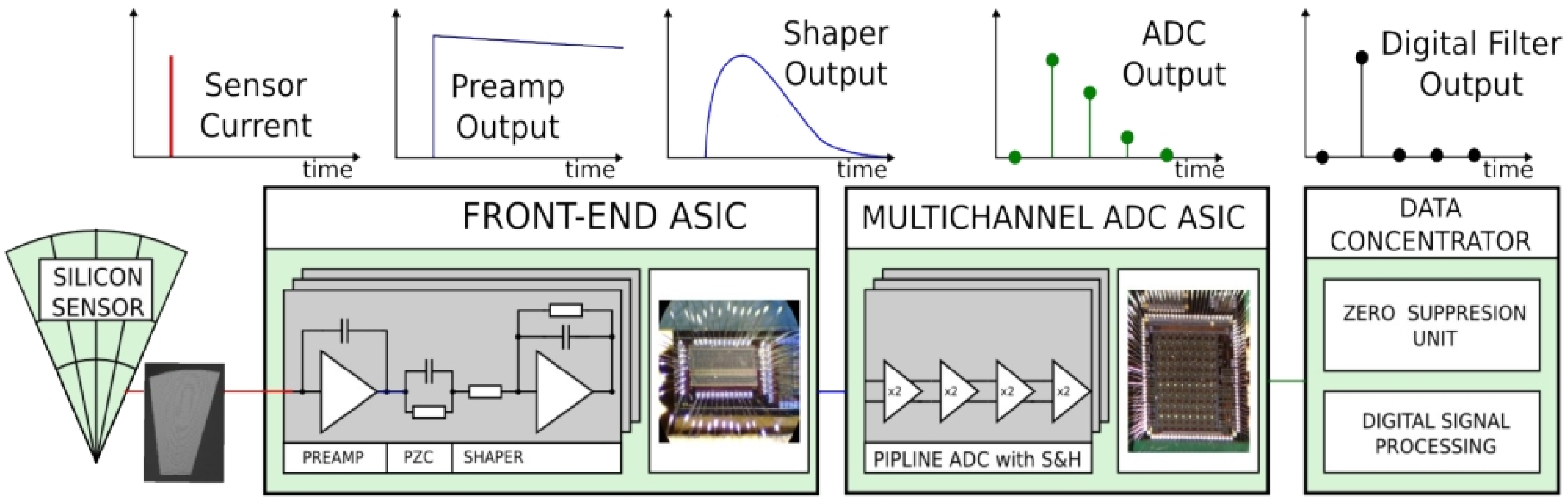
- Silicon sensor
- thickness 320 μm
- DC coupled with read-out electronics
- p+ implants in n-type bulk
- 64 radial pads, pitch 1.8 mm
- 4 azimuthal sectors in one tile, each 7.5°
- 12 tiles makes full azimuthal coverage
- 40 sensors were produced by Hamamatsu
- 5 modules were assembled



IFJ PAN, Cracow

LumiCal Readout Electronics

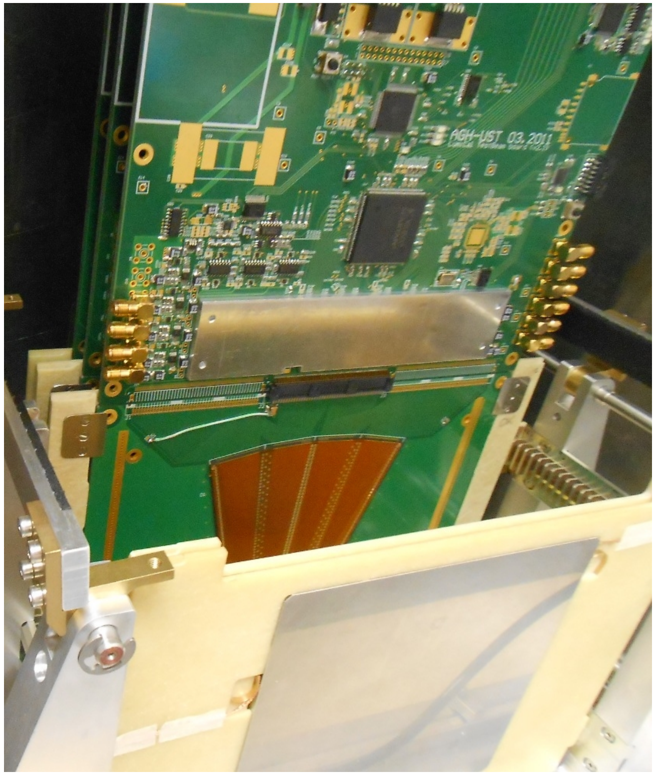
- Existing readout was developed in AGH-UST Cracow.
- It is a 32-channel readout system based on 8-channel front-end and ADC ASICs developed in AMS 0.35 µm.
- It has been used in test-beams in recent years.

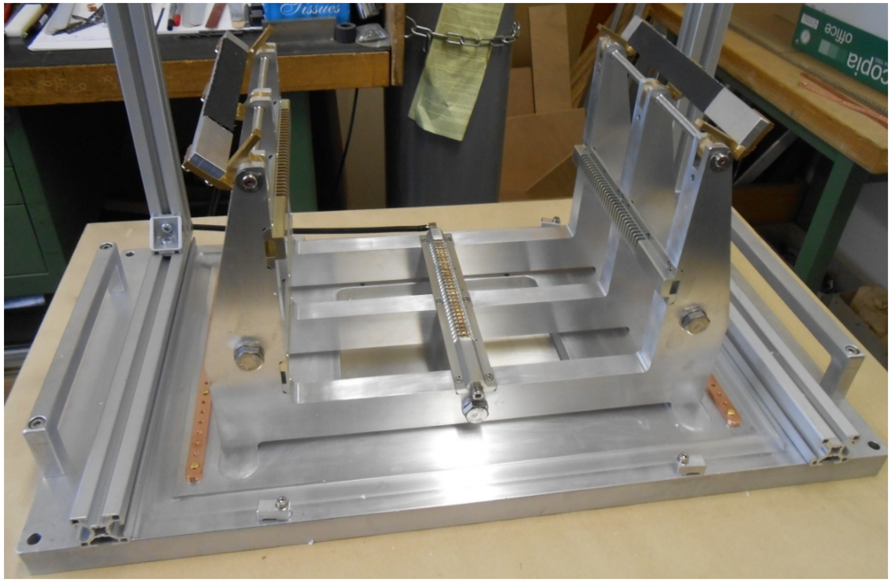


- 8 channel front-end (preamp, shaper T_{peak} ~ 60 ns, ~9 mW/channel, configurable gain);
- 8 channel pipeline ADC, Tsmp ≤ 25 MS/s, ~1.2 mW/MHz;
- FPGA based data concentrator and further readout.

FCAL test beam infrastructure

CERN

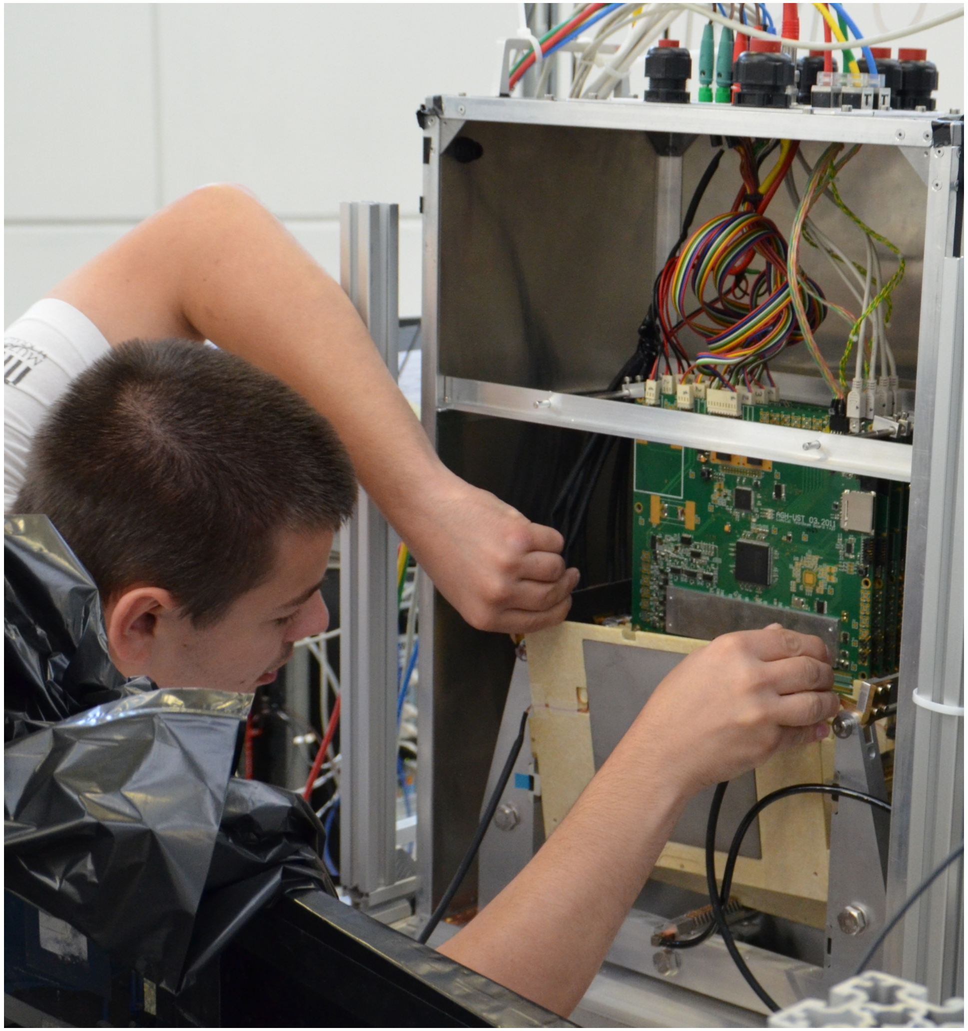




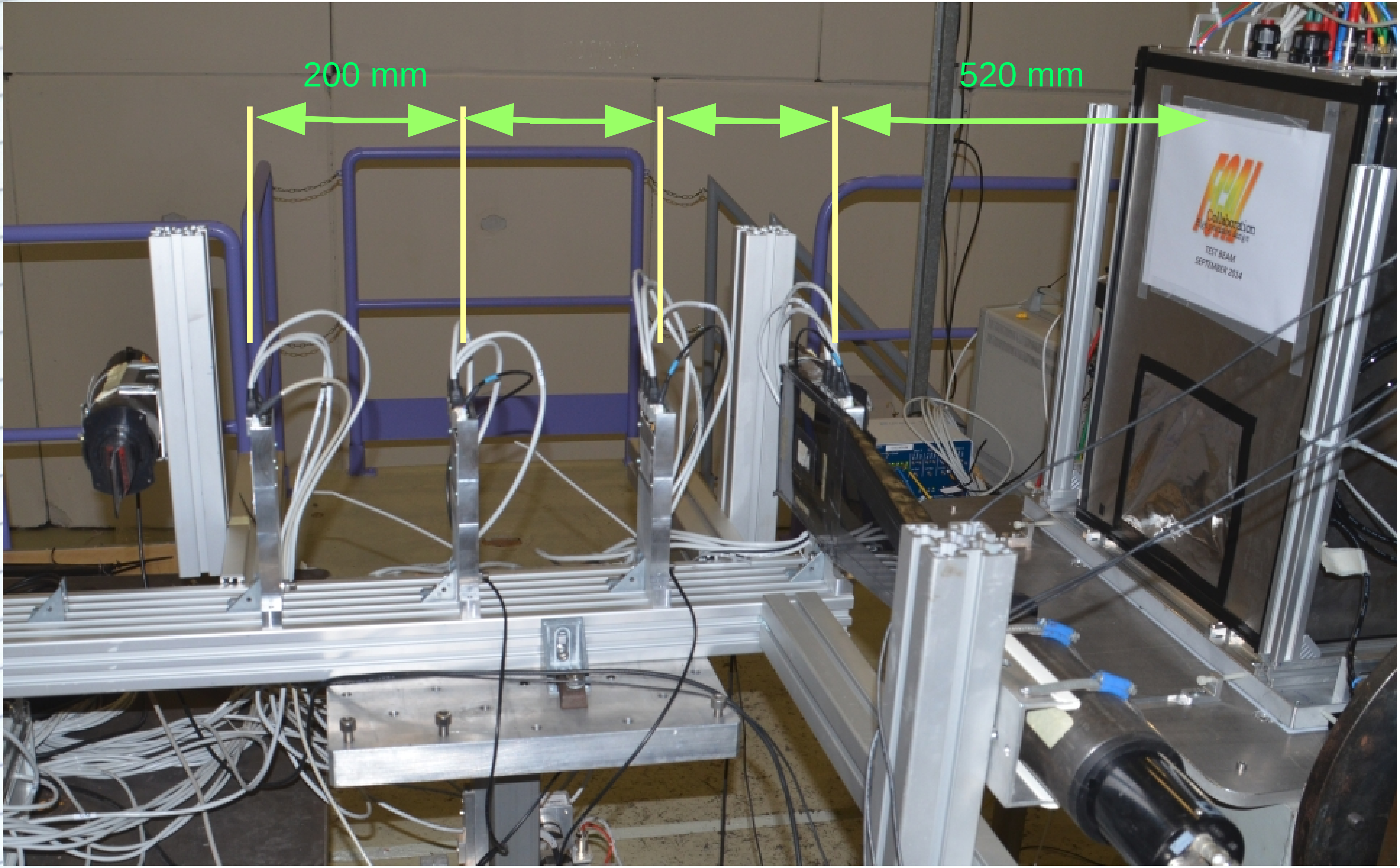
Test Beam Objectives

A good understanding of single plane performance of LumiCal and BeamCal detectors is shown in recent JINST publication (arXiv:1411.4431).

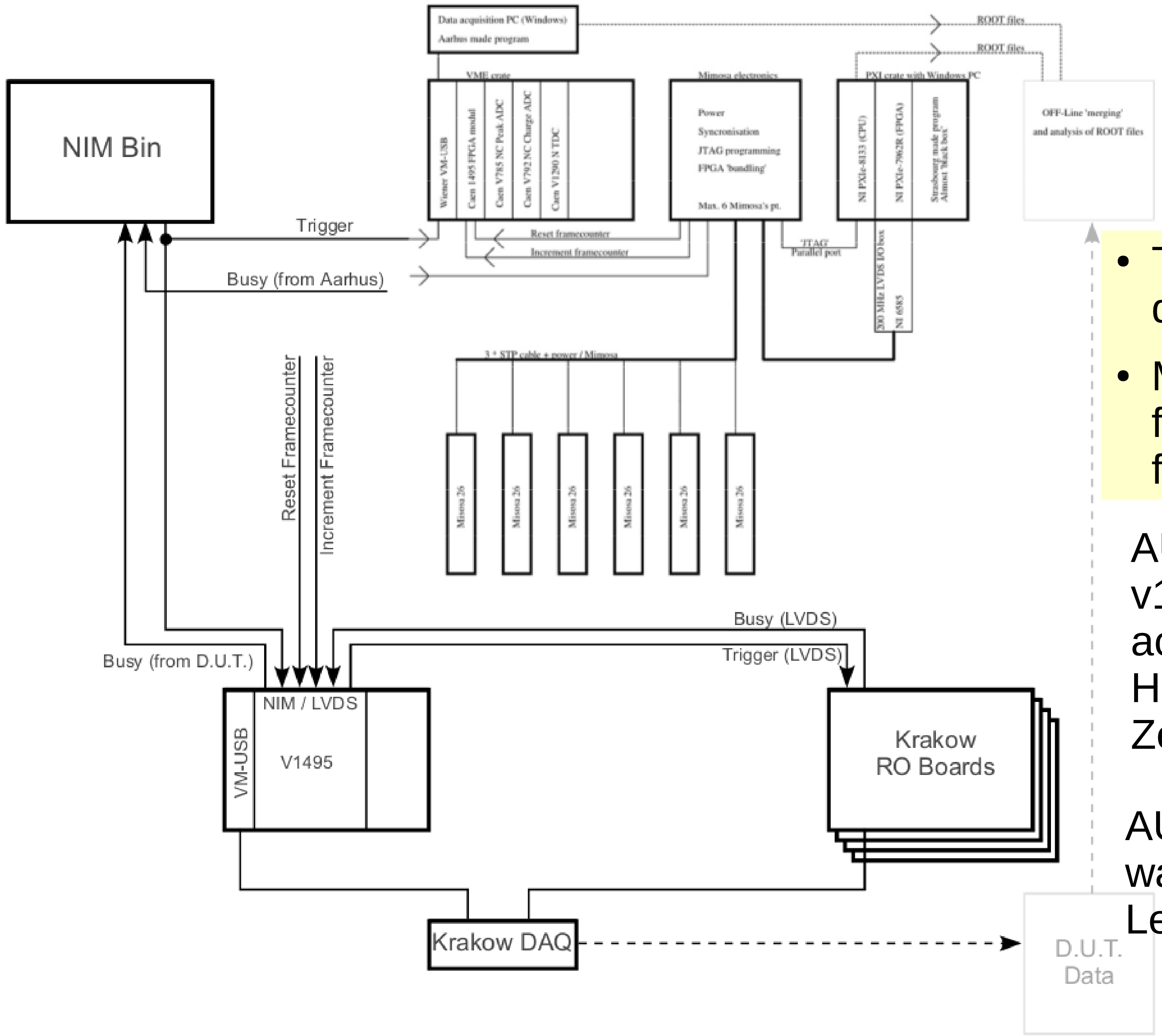
- Check for the first time multi-plane operation of the LumiCal prototype with 4 detector modules;
- Measure key parameters in multi-plane operation: baselines, noise, common-mode noise, signal-to-noise ratio, etc;
- Study the development of the electromagnetic shower in a precise and well known structure and compare with MC simulations.
- Check reconstruction algorithms on raw data and particle tagging (electrons and hadrons).
- Attempt to measure energy resolution and the precision of the polar angle reconstruction.



Telescope and LumiCal Layout



Combined LumiCal - Telescope System



- Two systems used different DAQ.
- MIMOSA hardware frame number was used for the synchronization.

AUX hardware based on v1495 I/O module accomplished by Hans Henschel, DESY Zeuthen group.

AUX software in EUDAQ was developed by Itamar Levy, TAU.

LumiCal Beam Test Configurations

Three different configurations for the LumiCal were used.

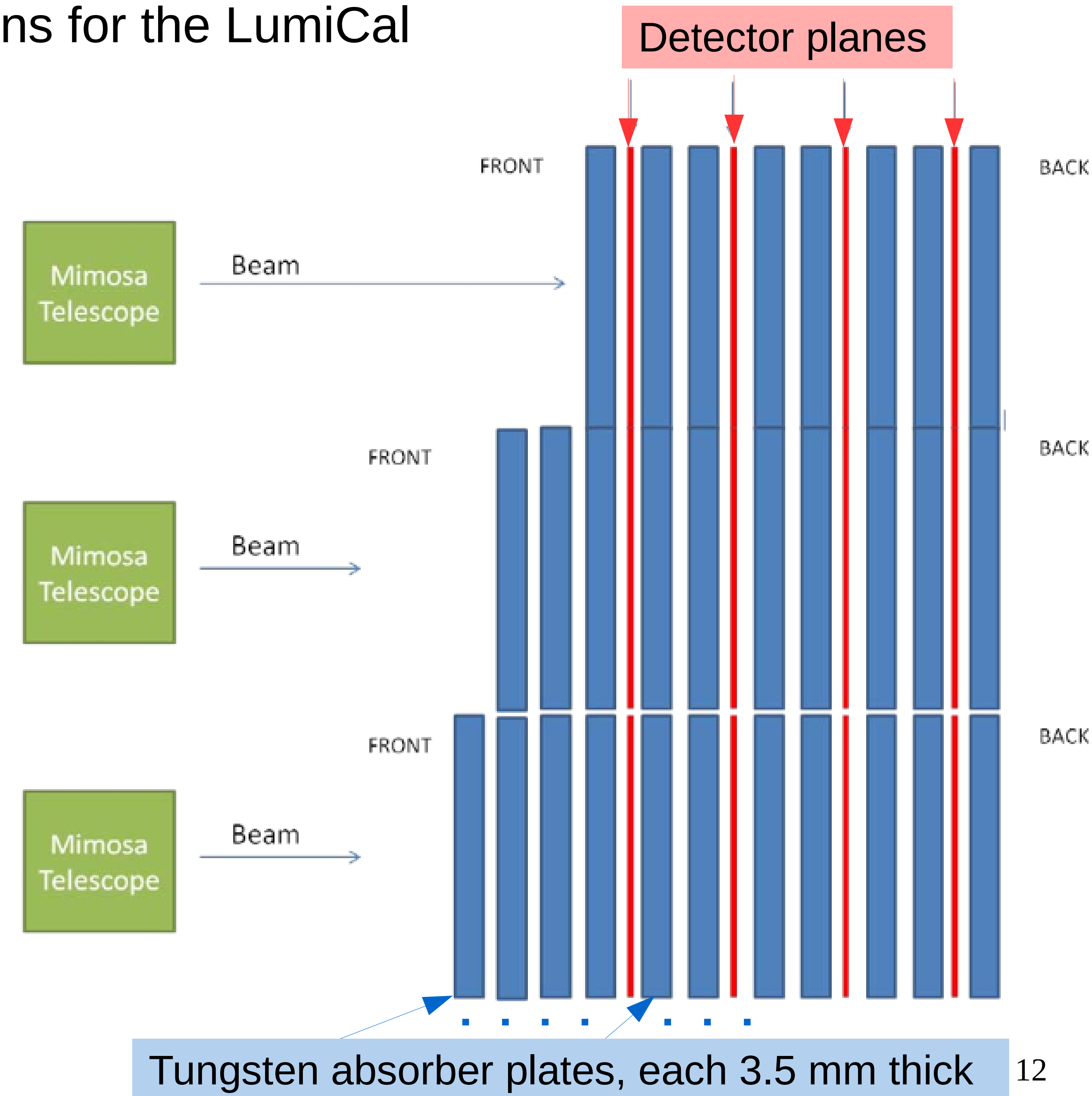
CERN PS beam at T9

5 GeV beam;

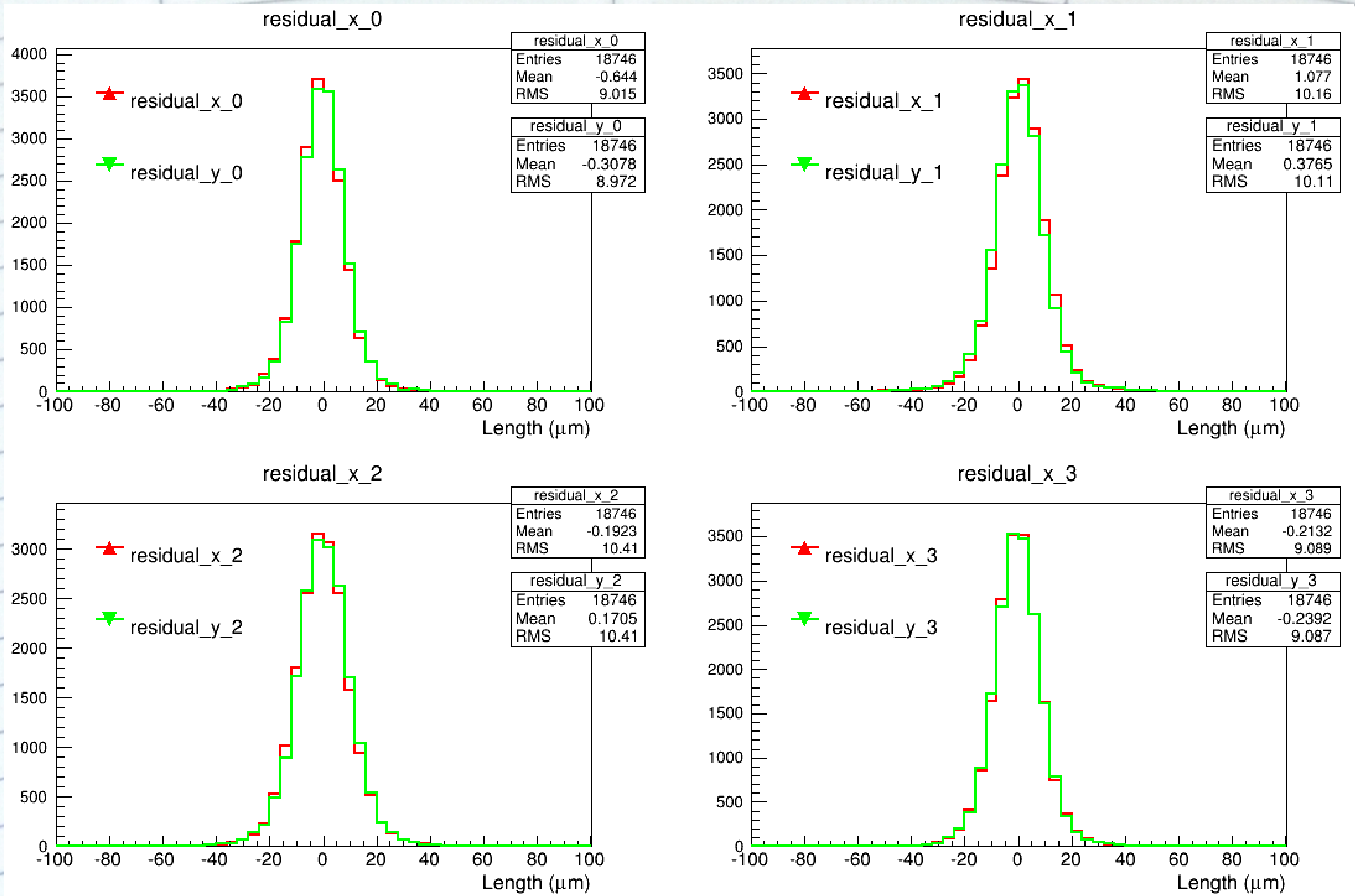
Trigger on:

- Electrons and muons;
- Hadrons.

For different configurations 55k-75k e^- events were collected.

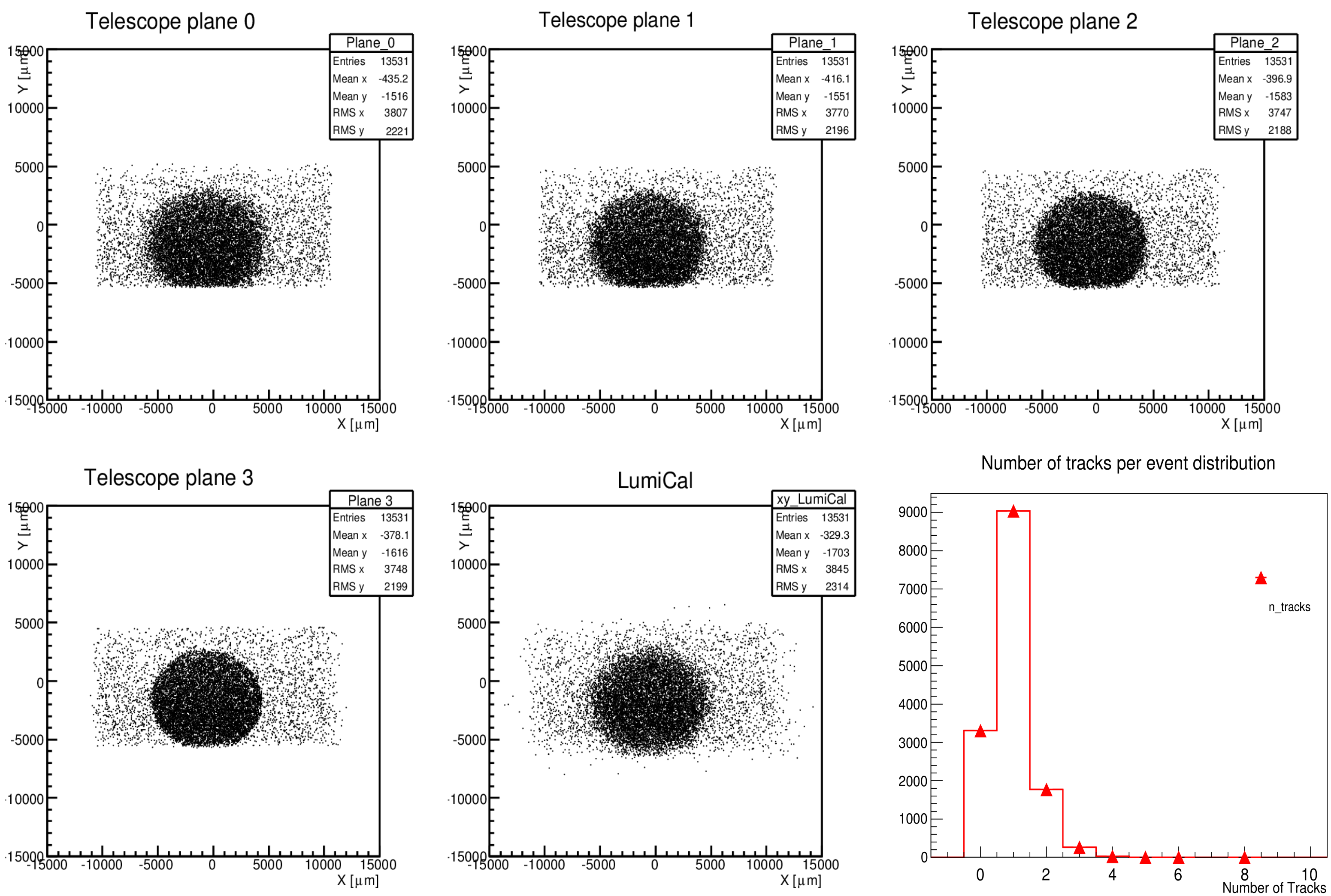


Telescope Position Resolution



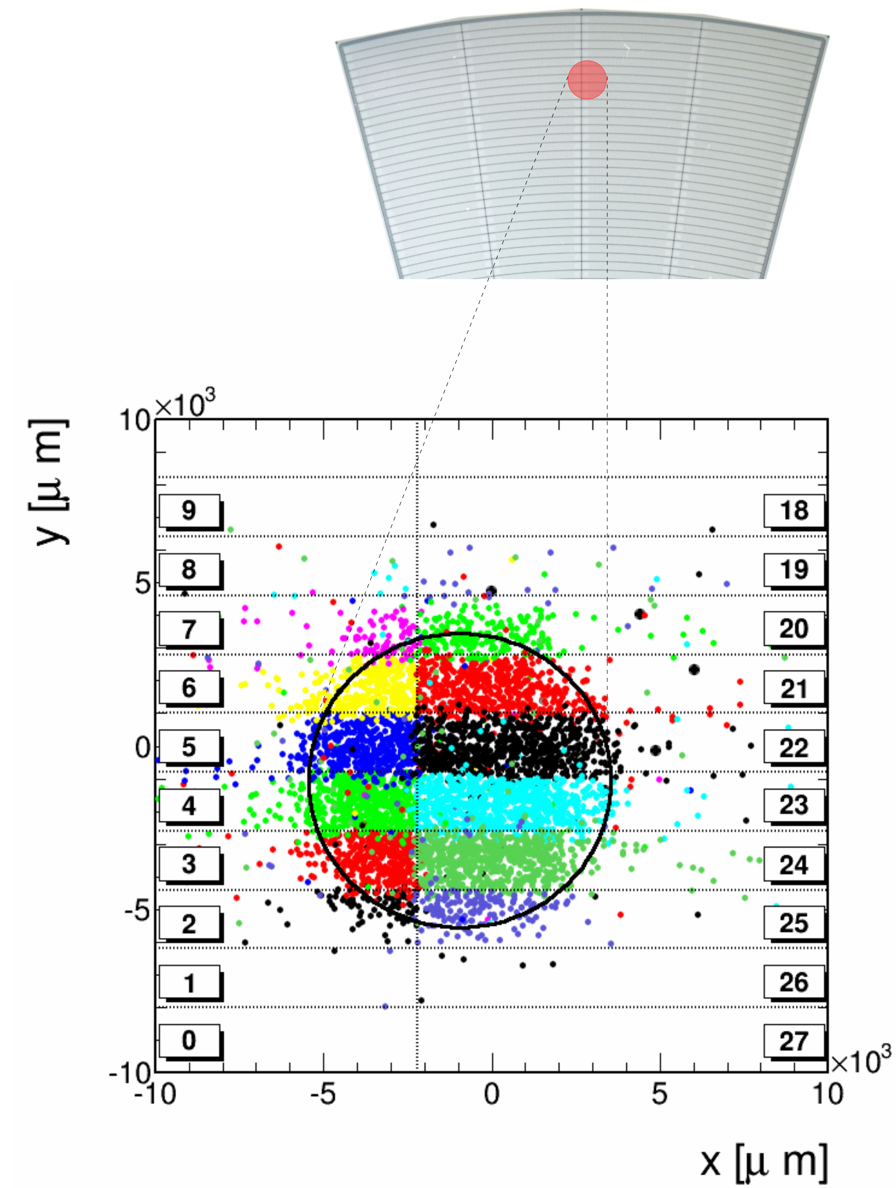
Occupancy in Telescope

- Telescope data are reconstructed using TAF (TAPI Analysis Framework, IPHC, Strasbourg), a bit modified to enable synchronization with LumiCal;
- Alignment and tracking based on software from telescope group of Aarhus University.

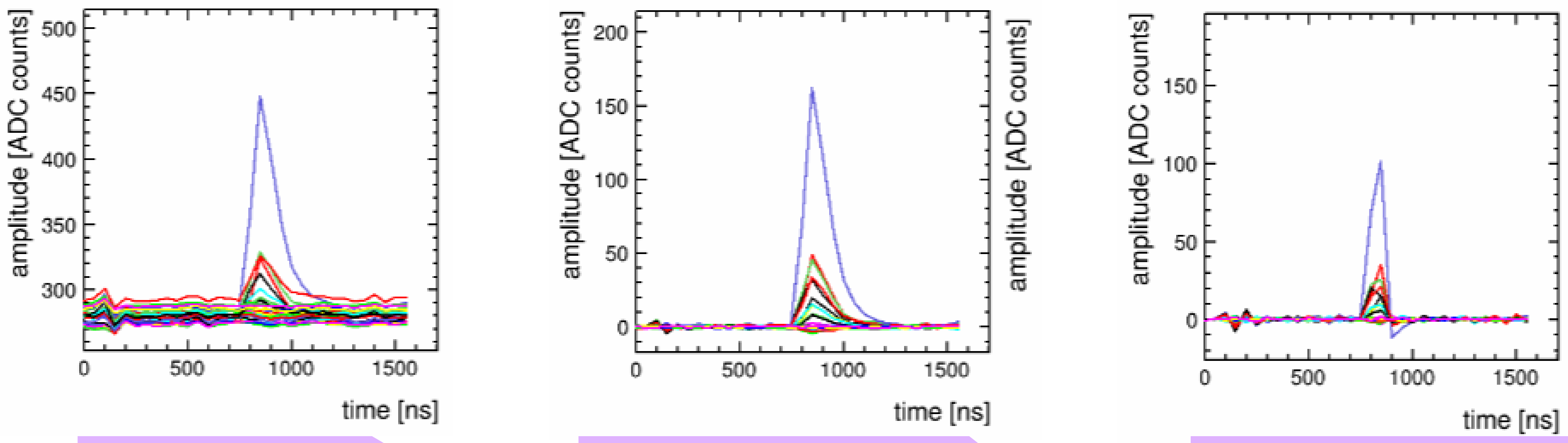


Test of LumiCal -Telescope Synchronization

- Extrapolation of the tracks reconstructed in the telescope to the first layer of LumiCal reproduces the round shape of the trigger scintillators.
- Position of the point is defined by the reconstruction of telescope data;
- Color of the point is defined by the channel which has a signal in corresponding event in LumiCal;
- The fact that this type of plot reproduce the pad structure of LumiCal sensor means that synchronization works successfully.

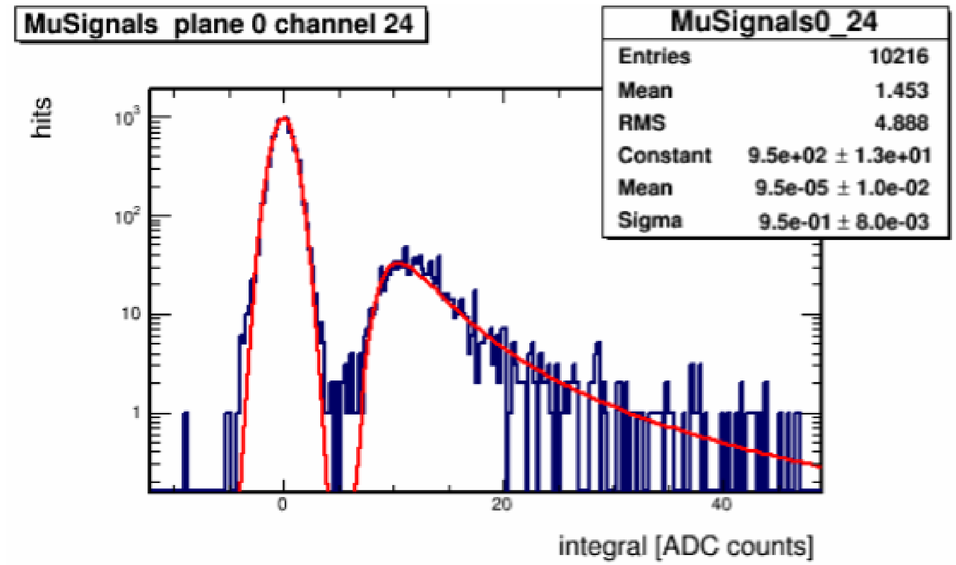


Signal Processing

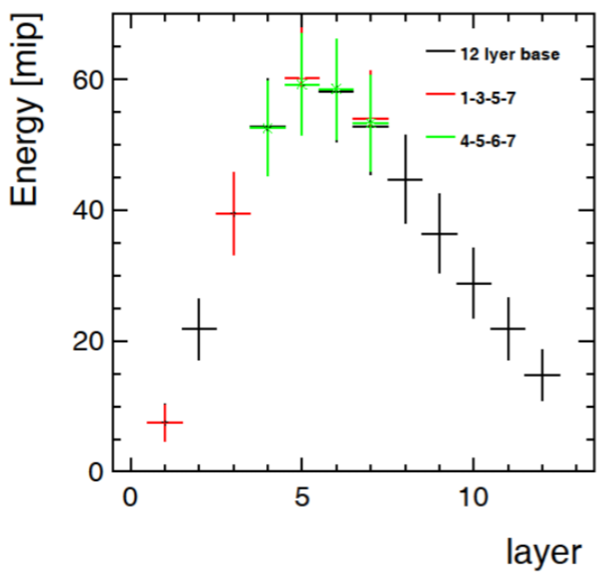


Raw data → Baseline and common mode noise correction → Deconvolution

- Gain results obtained in the lab using the same method (deconvolution) as data analysis;
- It was corrected using deposited energy distribution from muon events.

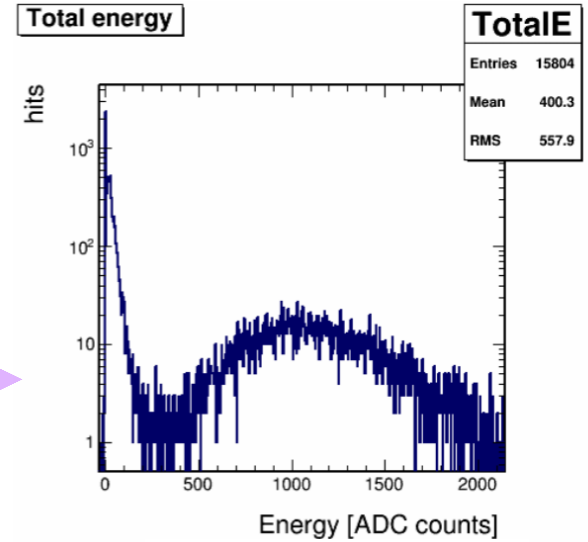


Deposited Energy and Shower Development

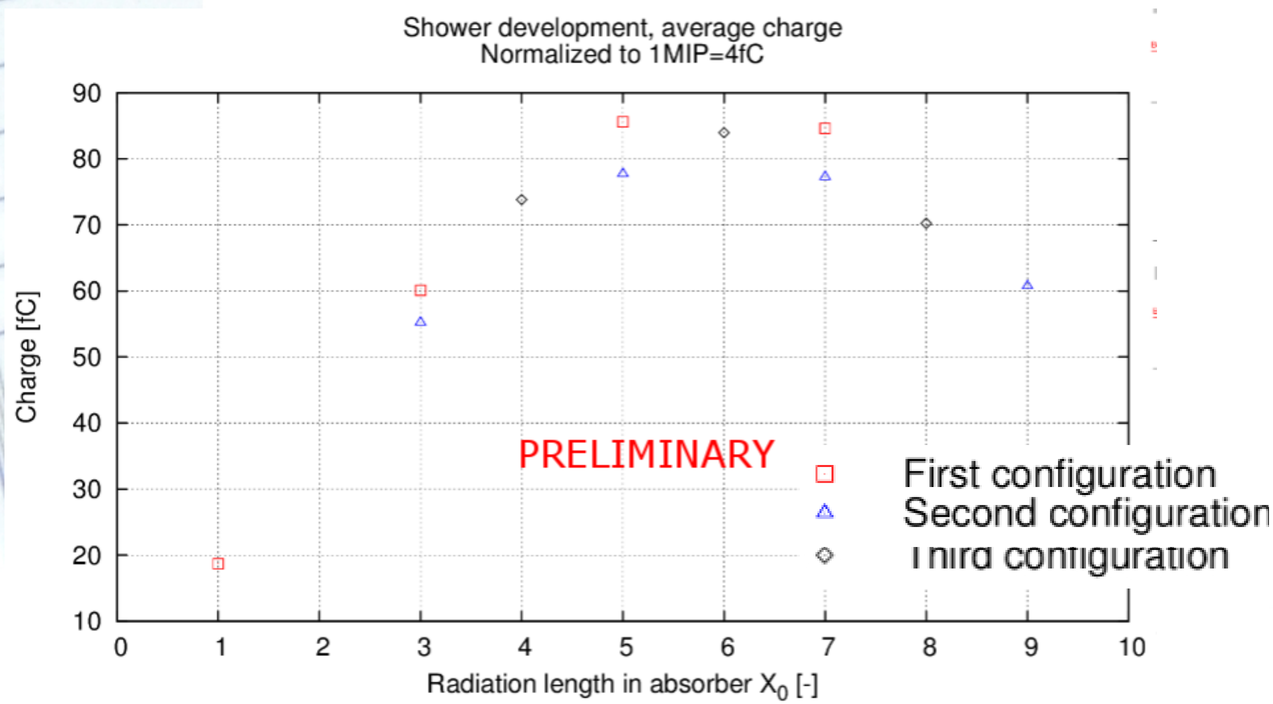


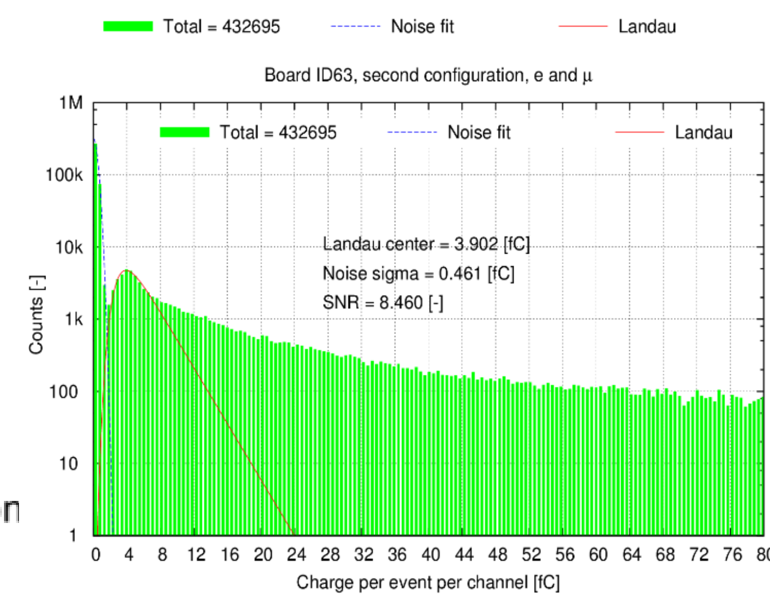
MC simulation

PRILIMINARY
BT data
reconstruction



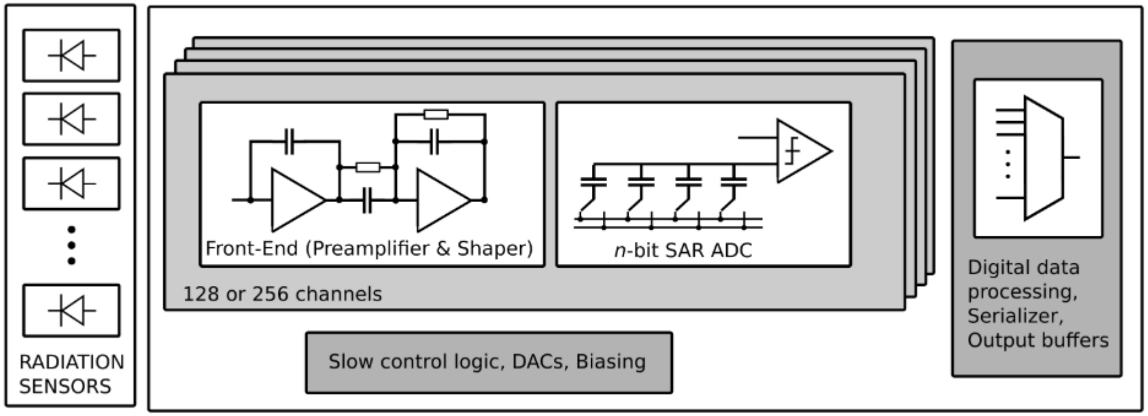
e^- & μ^- run data





BeamCal and LumiCal Electronics

LumiCal electronics R&D is conducted by AGH-UST Cracow;



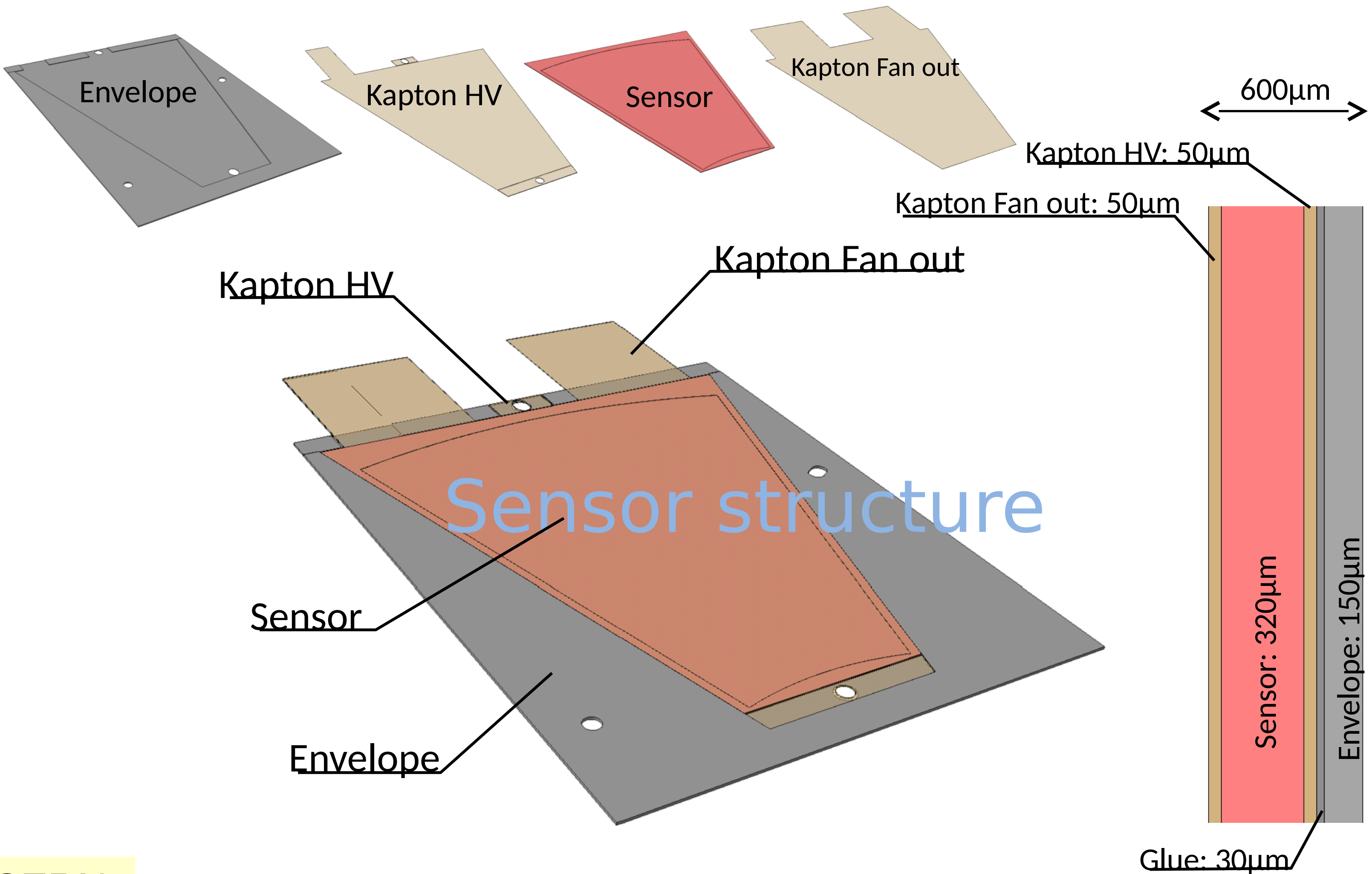
- New 10-bit SAR ADC ASIC has been designed, produced and tested. Excellent performance, 40 MS/s, power consumption <1 mW.
- Had to switch from IBM to TSMC (CMOS 130 nm) technology, many of chip components had to be redesigned.
- In 2015 plan to submit an ~8-channel CMOS 130 nm chip containing front-end, ADC, serialization, all biasing and digital control.

BeamCal electronics R&D in Pontificia Universidad Catolica de Chile:

- FE chip equipped with fast analog sum of several channels, to be used for the feedback to the machine.
- Existing chip (Bean V1.0): 3 charge amps, 4 x 10 bit, fully diff. SAR ADCs, 1 SC adder, 3 SC filters, etc.
- Design, fabrication and test of discrete-time signal processing filter to optimize SNR;
- Study the possibility to use nonlinear ADC to extend dynamic range.

New LumiCal Module Design

- Current LumiCal modules are based on 3.5 mm thick PCB.
- Compactness of LumiCal is essential requirement to provide small Molière radius and accurate shower position reconstruction.
- In current LumiCal conceptual design the space between absorbers is 1 mm!



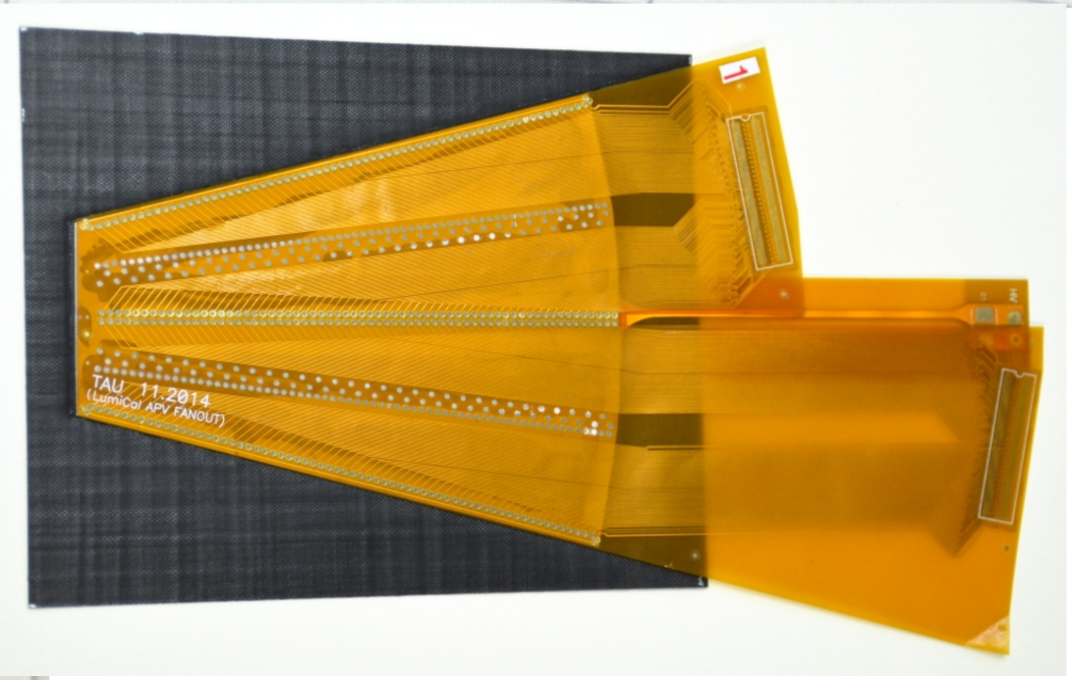
TAU, CERN

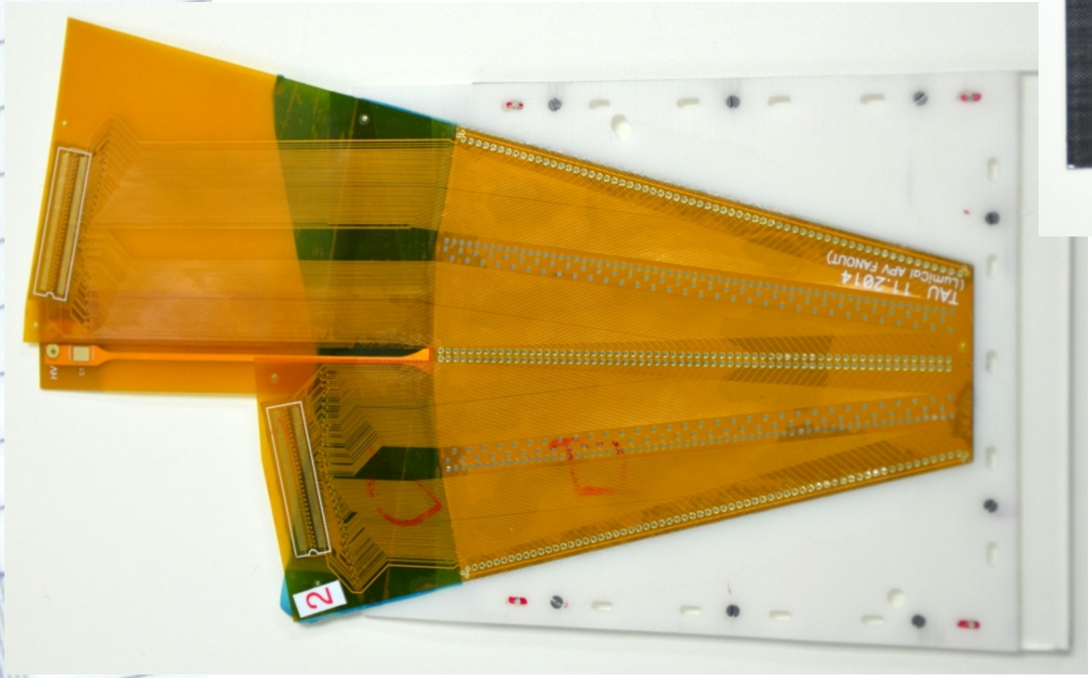
Thin LumiCal Mechanical Prototypes

Total assembly thickness:

- less than 900 μm for carbon fiber
- less than 800 μm for 3d printing

Carbon fiber module significantly more rigid.





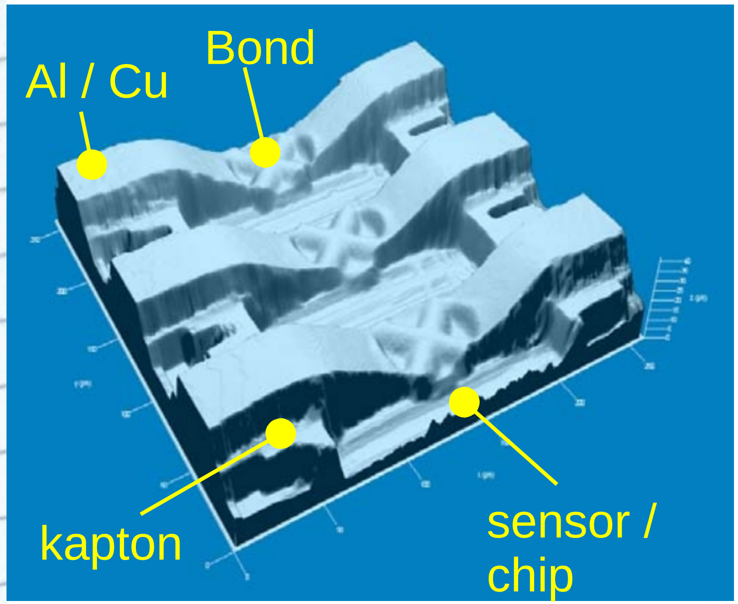
Procedure was destructive for wire bonding connections between sensor and fan-out!

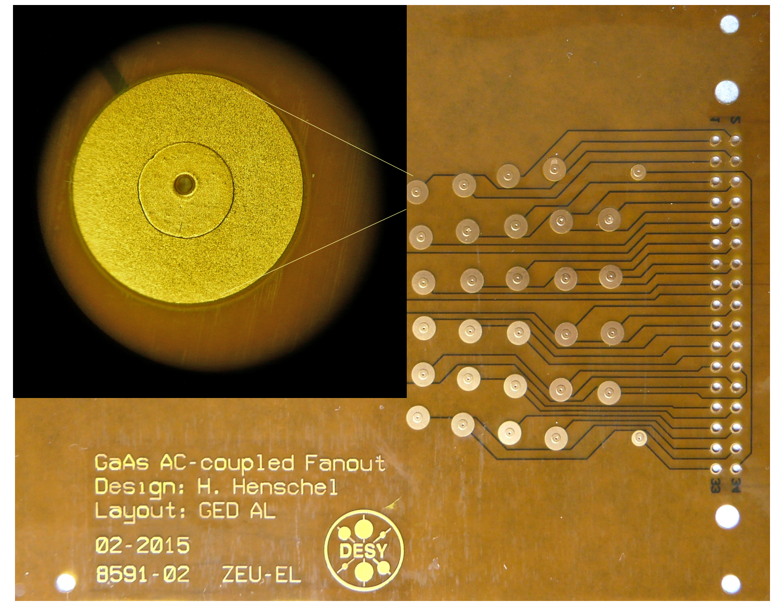
Next steps:

- Develop and produce carbon-fiber support with mounting on absorber frame;
- Modify accordingly the permaglass absorber frame;
- Assemble LumiCal module with silicon sensor.

Frontend Contact Technologies

Search for long-term stable contact between sensor and readout electronics which meets LumiCal and BeamCal geometrical (compactness) requirement





Single point Tape Automated Bonding (TAB):

- No wire loop;
- The bond can be covered by the glue for better protection;
- It is difficult to repair bonding defects;
- Work in progress in TAU.

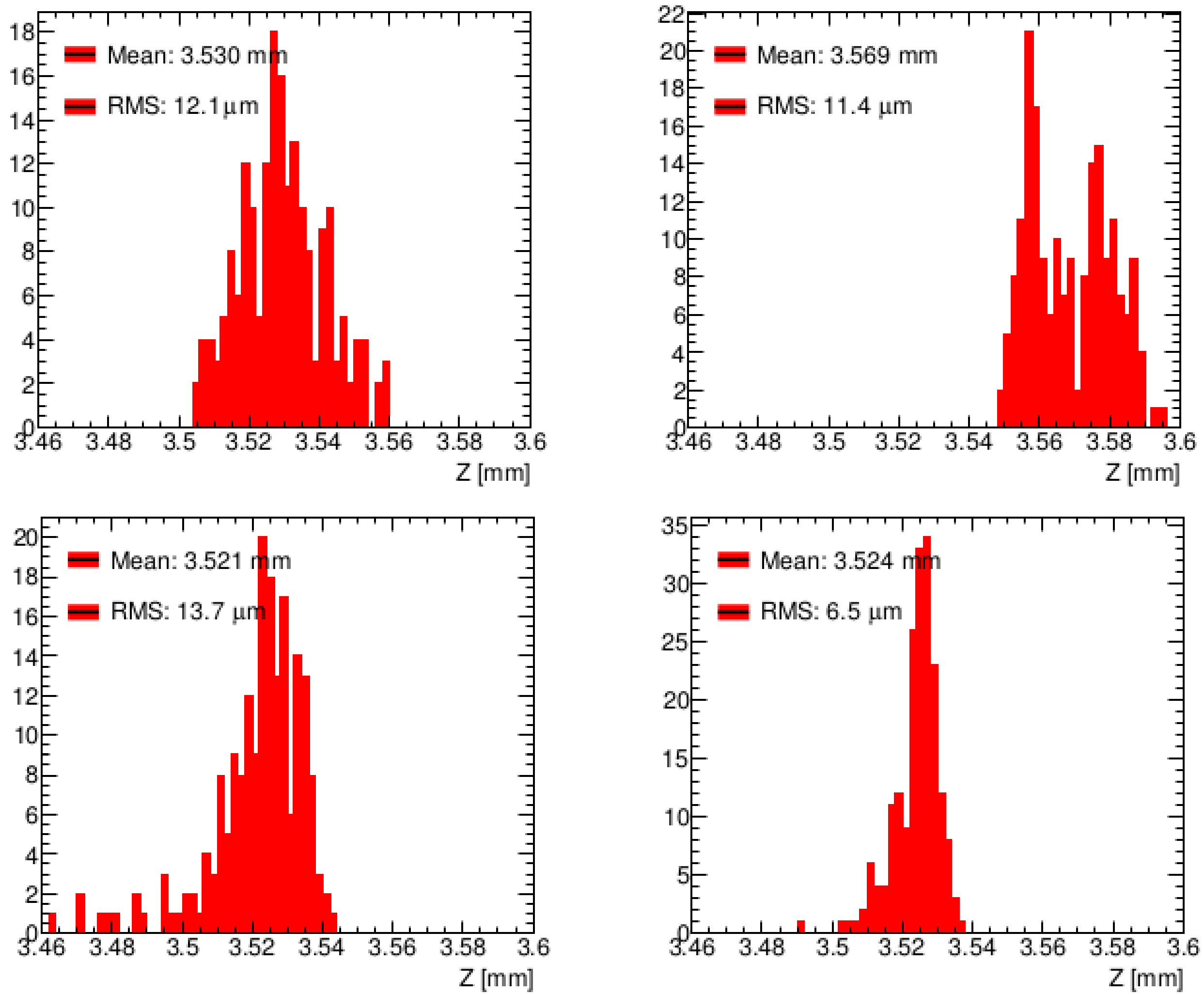
Spring Loaded Contact investigate in DESY Zeuthen:

- Sample production at GED company
- Contacts **NOT** spring loaded! Just embossed!
- Series of three measurements in two different clamps throughout two days
- NO fail! No degradation.

New Tungsten Absorber Plates

Four tungsten plates produced by two companies in Russian Federation were studied in JINR, Dubna.

- Thickness accuracy required for tungsten absorber plates is within 10 µm.
- Tungsten plates with 99.95% W is hard to process;
- Possible solution is to use alloy 95%W + 5%Cu which would significantly facilitate the mechanical processing.



Some of the plates are very close to the geometrical requirements.

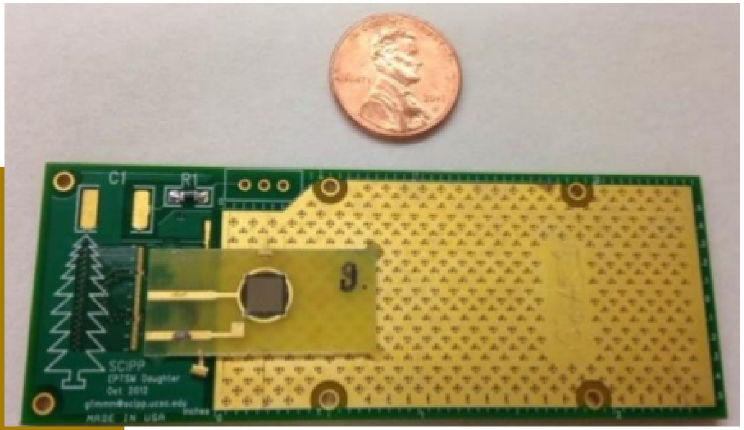
Electromagnetic Radiation Damage Study

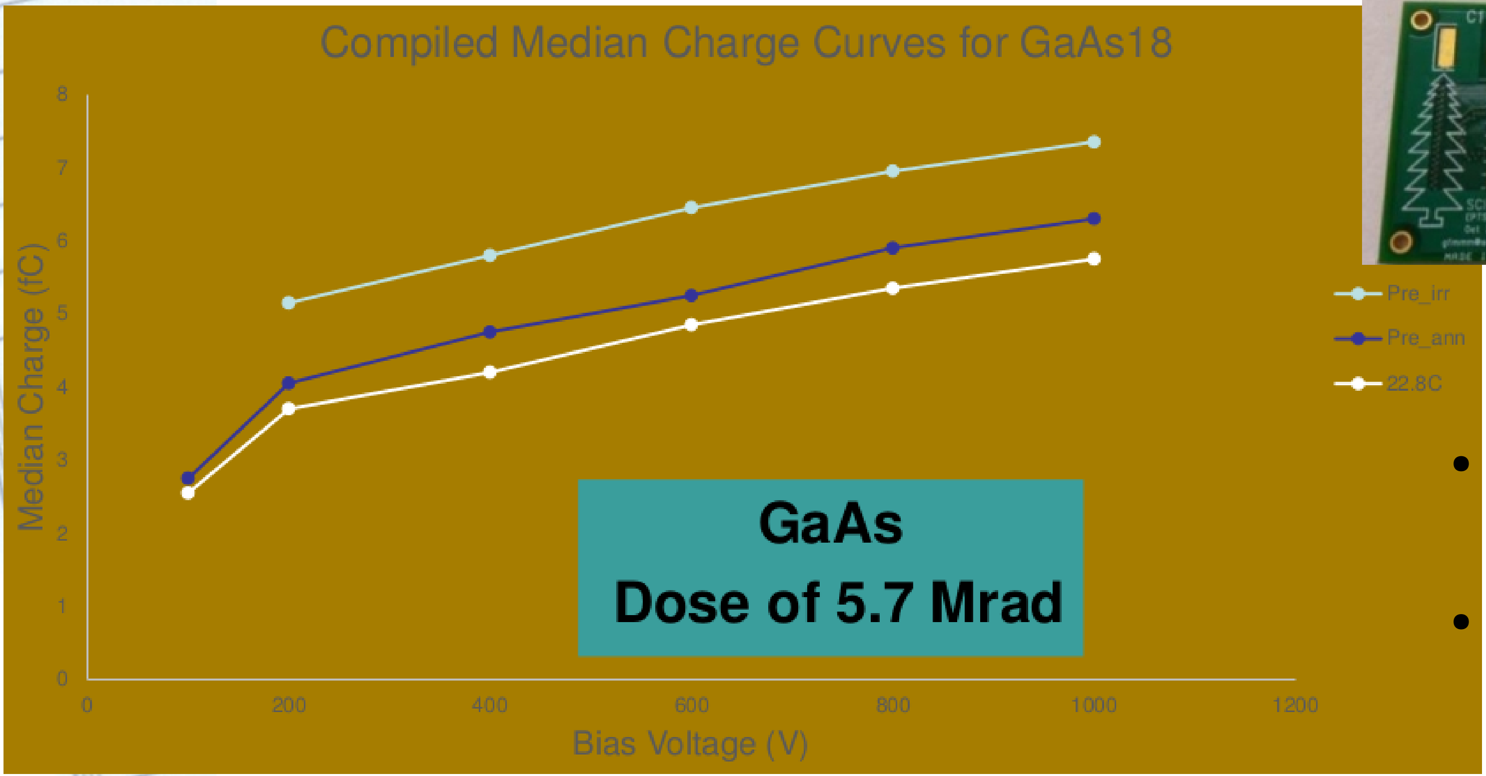
Studies carried out in University of California at Santa Cruz

- Ongoing study of different type of Si and GaAs sensors.
- In future: sapphire and Si carbide.

Recent results on GaAs pad sensors radiation damage study at SLAC T506.

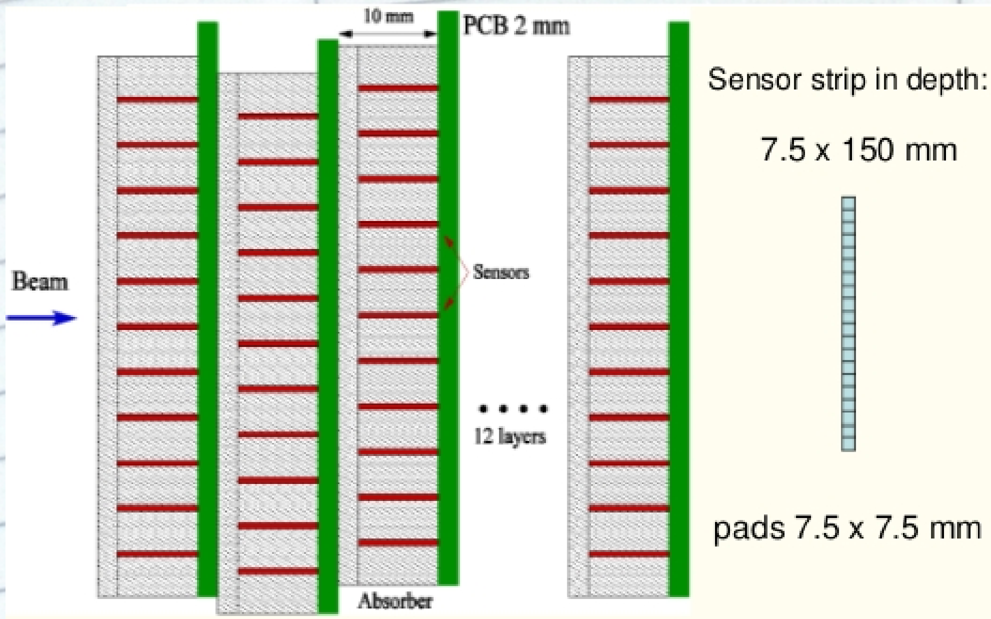
- Irradiated with 5.7 and 21.0 Mrad doses of electromagnetically-induced showers.
- Irradiation temperature 3°C; samples held and measured at -15°C.

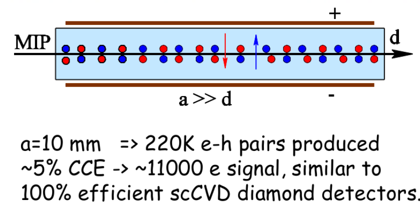


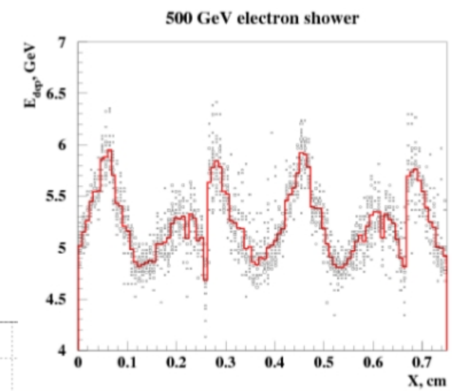


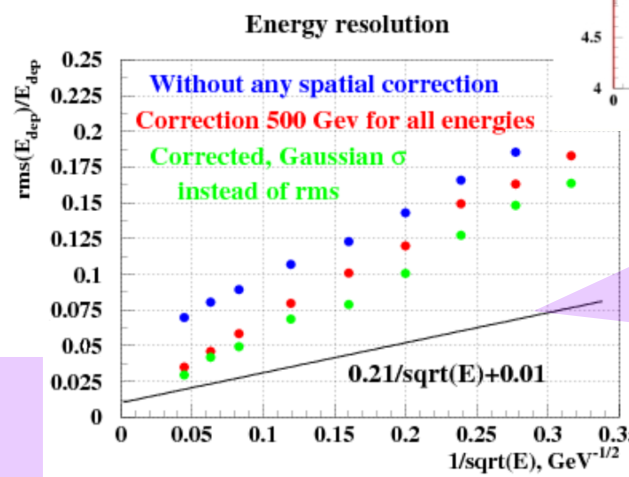
- 15-20% charge loss at 300 ns shaping.
- Seems to worsen with annealing.

Sapphire Calorimiter Prototype Design









Ideal case, without BG for baseline design

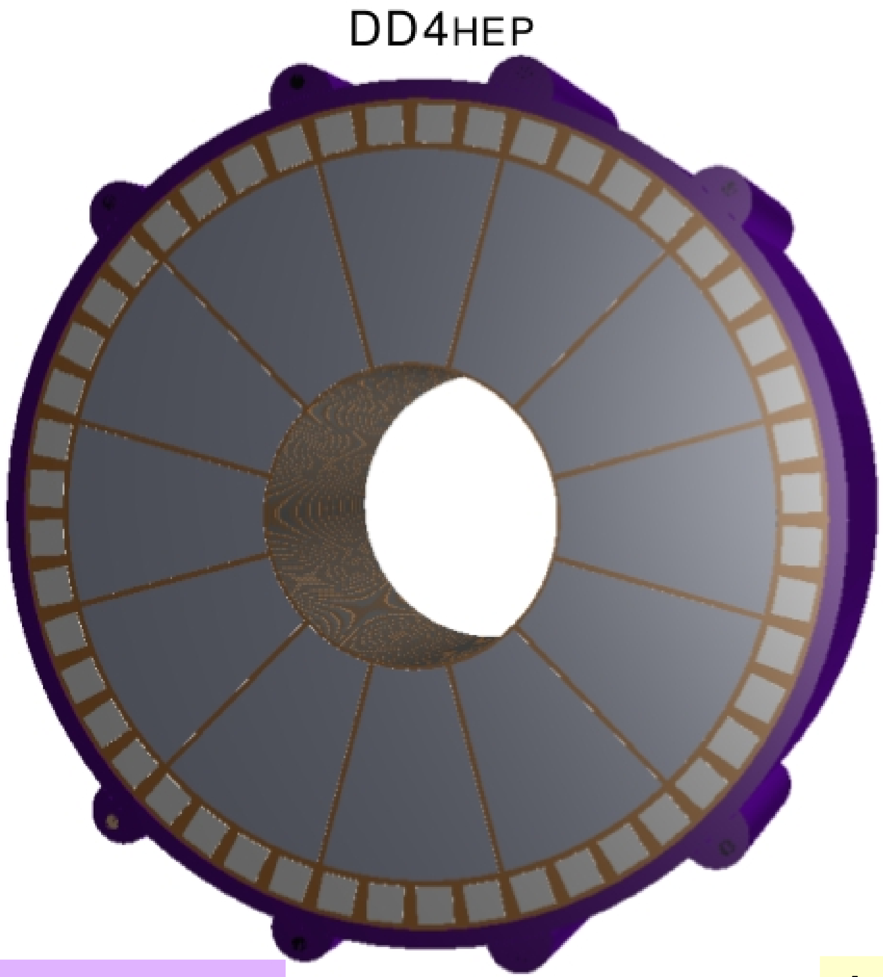
Performance can be improved by optimizing design and software

- Because of low CCE (~5%) for sapphire the new design allows to increase the response of the sensors to the MIPs, shifting calibration signal up in the “physical” working range, thus additional calibration mode is not needed anymore.
- Longitudinal and transverse sizes for both designs are kept the same
- Number of readout channels is 12000 for baseline design and 8880 for new one
- More space for electronics between layers, fanout PCB could be made using standard multilayer technology
- New sapphire sensors are investigated. They are very cheap! Very radiation resistant! and “small signal” down point is solved by turning sensors

DESY

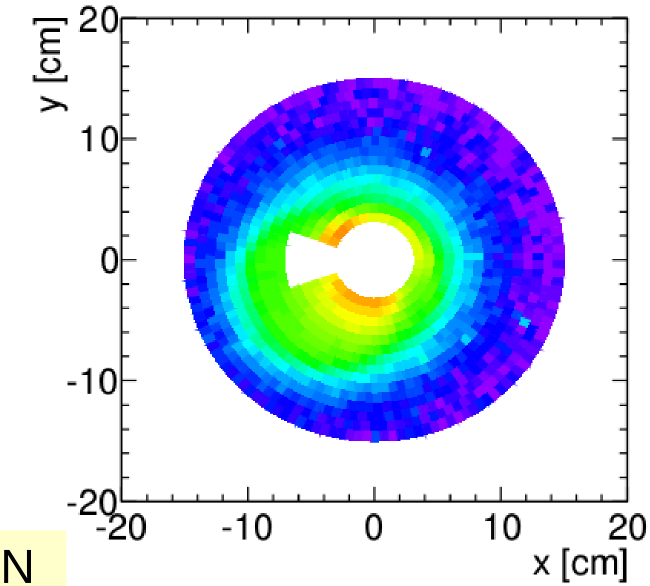
LumiCal and BeamCal in DD4Hep

- Simplified LumiCal geometry model completed;
- More detailed model still requires finalization.



- BeamCal geometry has been implemented in DD4Hep;
- Different type of segmentations can be easily implemented with DD4Hep geometry;
- Simulation parameters can be configured via python , XML, or CINT

Example of E_{dep} of incoherent pairs in the BeamCal of single bunch crossing of 3 TeV e^- for uniform segmentation.



M. Petric, CERN

A. Sailer, CERN

Physics Backgrounds in the FCAL

Uncertainty of Luminosity measurements and Electron tagging at ILC

Beamstrahlung effects:
- Energy loss -> Bhabha cross-section increases;
- Longitudinal boost -> Particles from very small regions reach the detector (with relatively low energy in the lab frame).

Simulation uses:
- WHIZARD 2.2;
- luminosity spectrum files from Guinea-Pig;
- ISR in the collinear approx., (no FSR).

Process	cross-section (nb)	Pileup prob.
Signal	1.39	3.6×10^{-3}
Single-hit Bhabha / BX	2.05	5.3×10^{-3}
Coplanar single-hit ($\Delta\phi < 6^\circ$) / BX	2.05	8.8×10^{-5}

Pileup adds 1 (or 2) extra electrons to the analyzed event -> confusion in reconstruction.

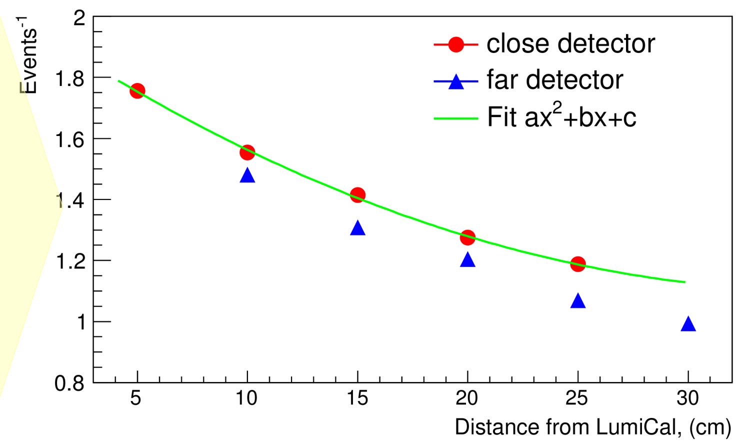
Preliminary calculations indicate that events with hadrons hitting the FCAL detectors are very rare, so that the distinction of hadrons at low angles (in FCAL or LHCAL) is not of great importance for the luminosity measurements and electron tagging.

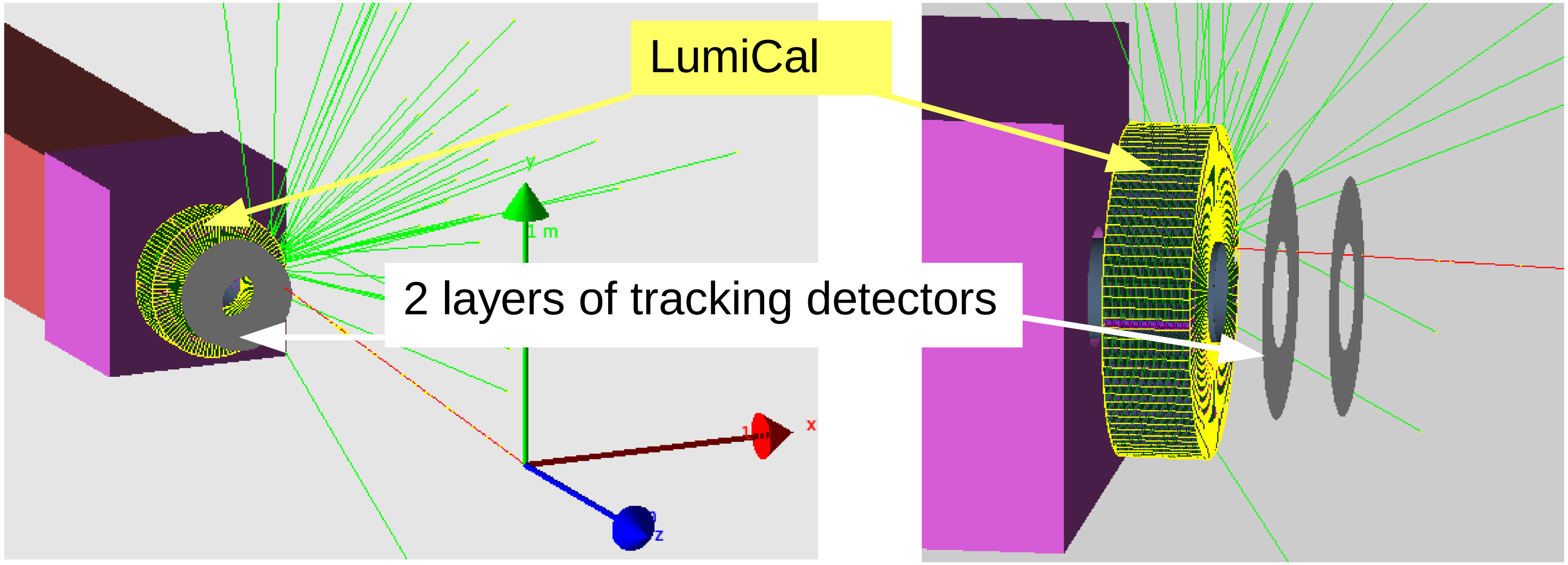
S. Lukić, Vinča Inst.

Tracking Detector in Front of LumiCal

- Improve polar and azimuthal angle measurement accuracy;
- LumiCal alignment;
- Provide more information to enable e/γ identification, important for various physics studies.

- Average event occupancy from back-scattered particles normalized on the number of primary is less then 2 at a distance of 5 cm from LumiCal.
- It decreases down to ~1 at 30 cm.
- The second layer has 5% - 10% less occupancy for the same distance from LumiCal.





Other Studies in FCAL

- UCSC/SCIPP group works on BeamCal reconstruction efficiency study including its z position dependence, effect of Anti-DID on backgrounds.
- IFJ PAN (Cracow) group studies a laser alignment system for the LumiCal position monitoring. The system is based on Frequency Scanning Interferometry (FSI) and Position Sensitive Detector (PSD) technologies which allow to measure absolute and relative position of LumiCal and its sensor planes.
- Study and development of the efficient BeamCal background parameterization (A. Sapronov, CERN).
- The BeamCal background change for the new L* = 4 m is studied
- Two students from Kiev Shevchenko University joined DESY group and started working on LHCAL.
- We plan to have a test beam at DESY on October 12–18, 2015 to collect more electron data for electromagnetic showers study in LumiCal and hopefully to check the performance of the new modules of submillimeter design.

Summary

- LumiCal 4-module prototype beam test demonstrated good performance of the system. Data analysis is in progress.
- New low power dedicated readout electronics for BeamCal and LumiCal is under development, and progressing well.
- Assembled mechanical prototypes of LumiCal modules matched submillimeter thickness requirements.
- Spring Loaded Contact and TAB technologies are investigated as a possible solution to connect fan-out to LumiCal and BeamCal sensors.
- Study of the possible BeamCal sensor materials and technology Si, GaAs, diamond, SiC continues.
- Simulation of the Forward Calorimeters almost ready to be done in DD4HEP. Magnetic field maps are missing.

Thank you for attention!