

Test-beam results for BeamCal and LumiCal sensor planes

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On behalf of the FCAL collaboration.



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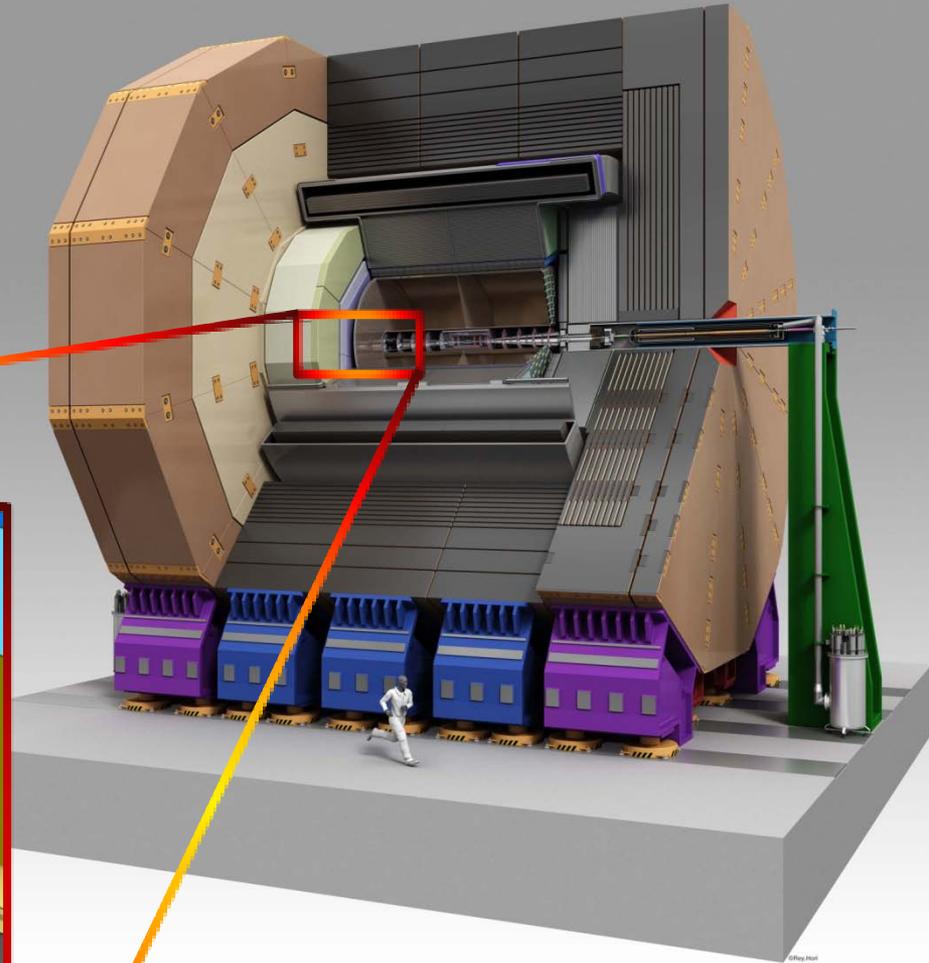
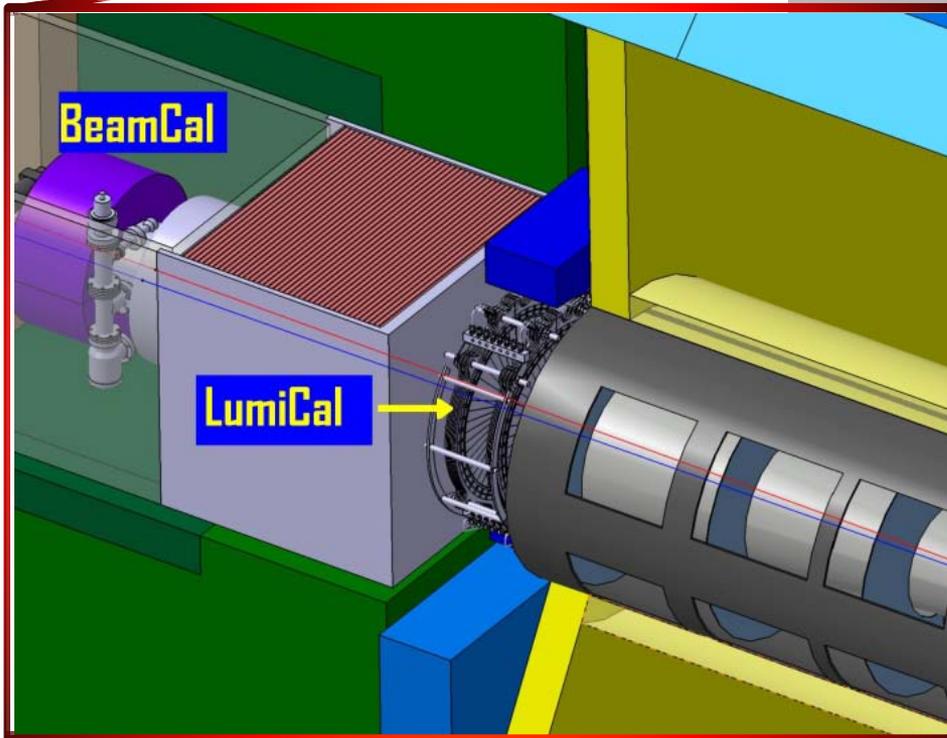
Introduction

During 2010 and 2011 the FCAL collaboration performed three beam tests. These were the first tests of the LumiCal silicon- and the BeamCal GaAs-sensors prototypes equipped with a full readout chain. The readout chain included sensors, fan-outs, dedicated front-end electronics and, during the 2011 beam-tests, also a newly-designed 10-bit pipeline ADC was included.

This talk will describe some new results from sensor characterisation measurements, the beam tests setup and performance results. These include spectrum and correlation analysis, combinations between sensor information and position-reconstruction and the development of electromagnetic showers in the tungsten absorber.

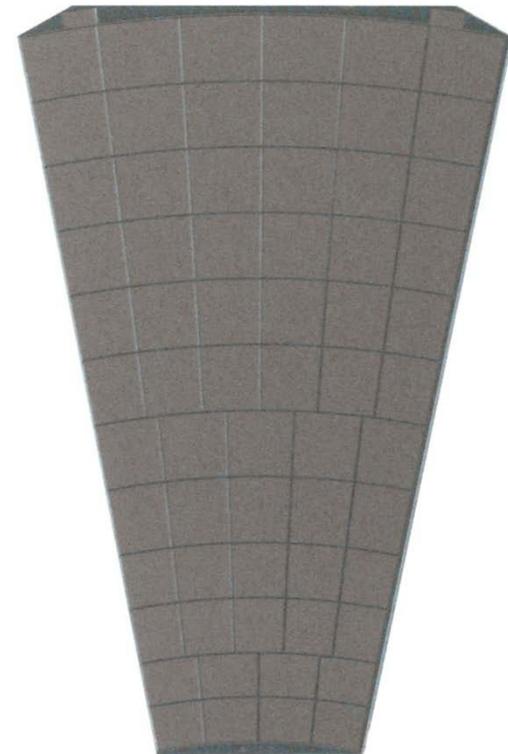
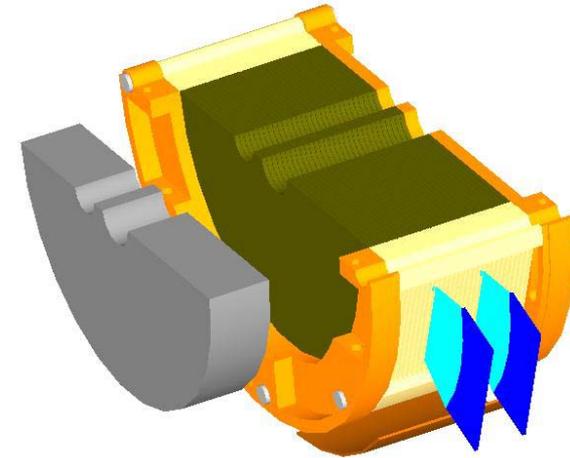
FCAL

In both detector concepts (ILD, SiD) of the future linear collider, two specialized compact calorimeters are foreseen in the very forward region, LumiCal for the precise measurement of the luminosity and BeamCal for a fast estimate of the luminosity and for the control of beam parameters.



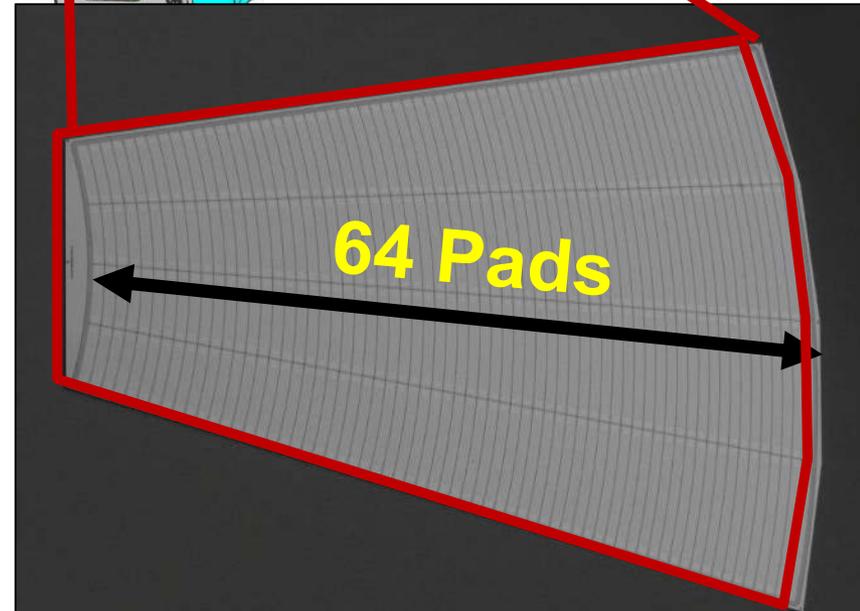
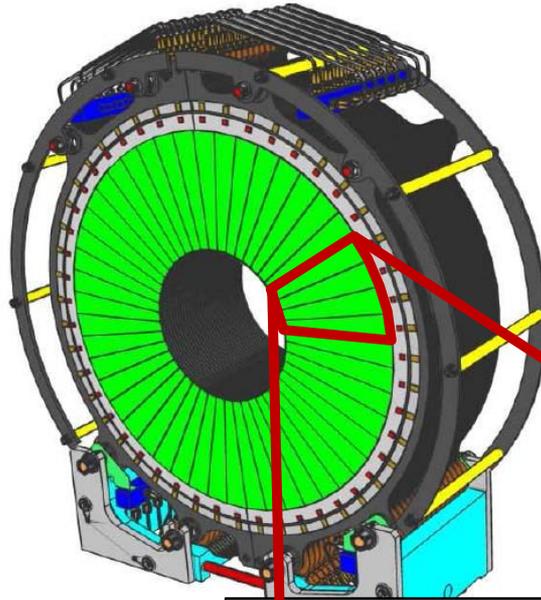
BeamCal sensor prototype

- GaAs Sensor Prototypes were produced at Tomsk State University.
- Doped with chromium and have high resistivity.
- Nickel metallization.
- 500 μm thick.
- The sensors have 12 radial rings and between 4-6 pads in a ring.
- 2 different sensor geometry are tested, constant pads size and ring dependent.
- A total of 87/64 pads in 1 sensor that covers $45^\circ / 22.5^\circ$.



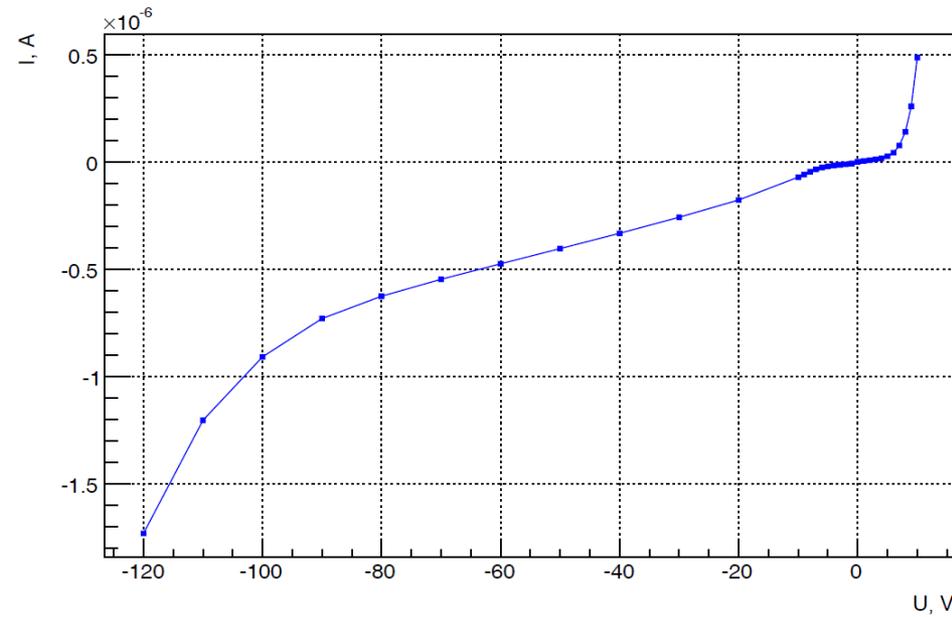
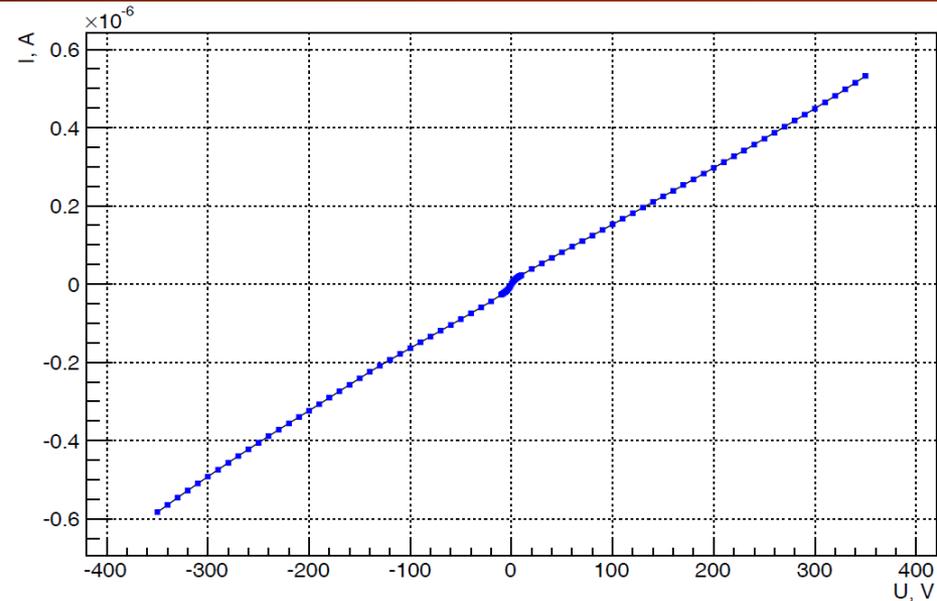
LumiCal sensor prototype

- Each layer has 48 sectors in the azimuth direction, and 64 pads (rings) in the radial one.
- A silicon-sensor prototype was produced by Hamamatsu from 320 μm thick 6" wafer, high resistivity n-type silicon
- The sensor prototype has 4 sectors (30° azimuthally) and 3 guard rings.



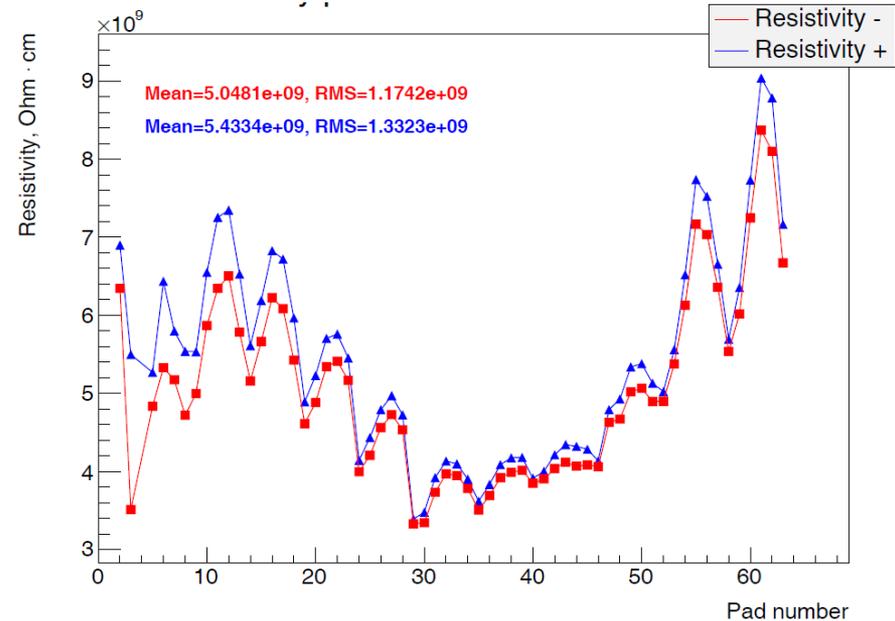
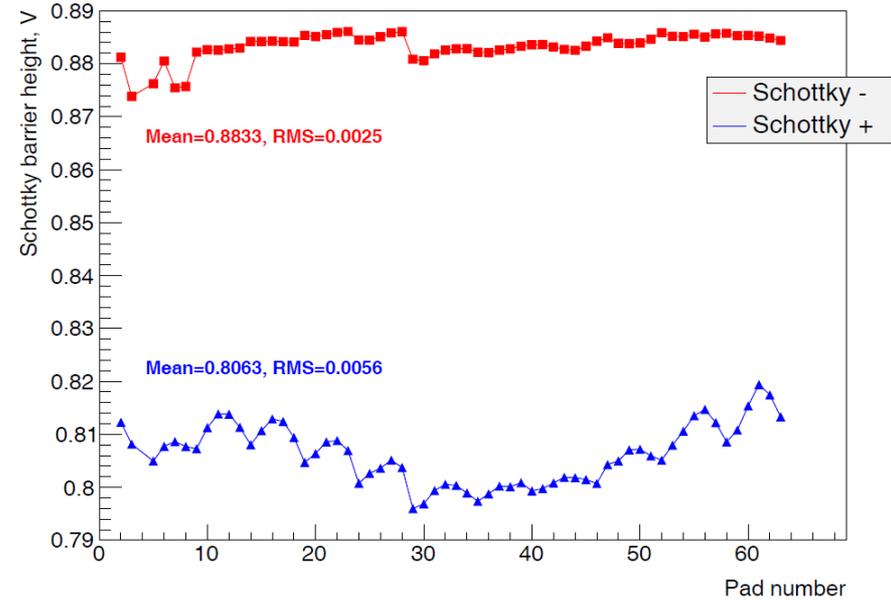
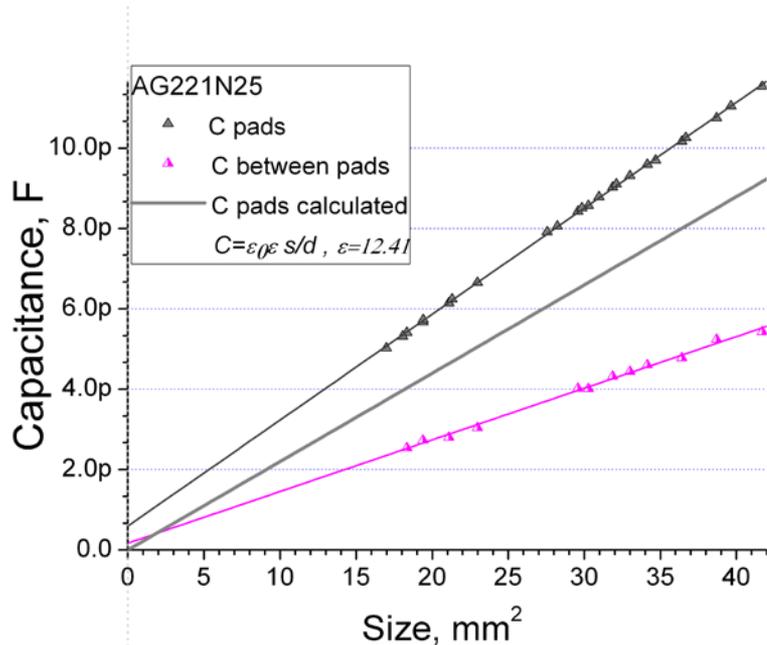
BeamCal sensor characteristics

- During October 2013, a new batch of wafers was tested.
- Test included the measurement of guard ring and pad current and capacitance, and aimed at finding defects.
- Outside of the $\pm 10\text{V}$ range, the pad current is linear in voltage and resistivity can be extracted.
- From the non linear area, the Schottky barrier height can be extracted.
- Some sensors had pads with an unusual behavior, probably metallization defects.



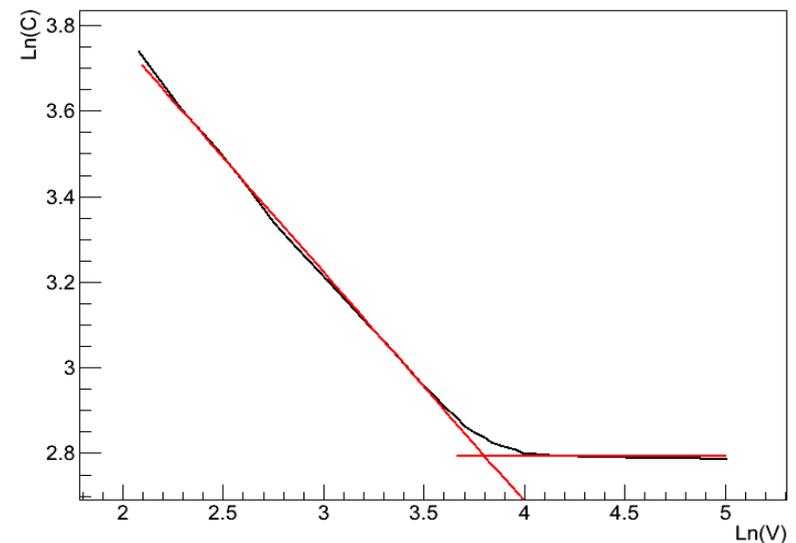
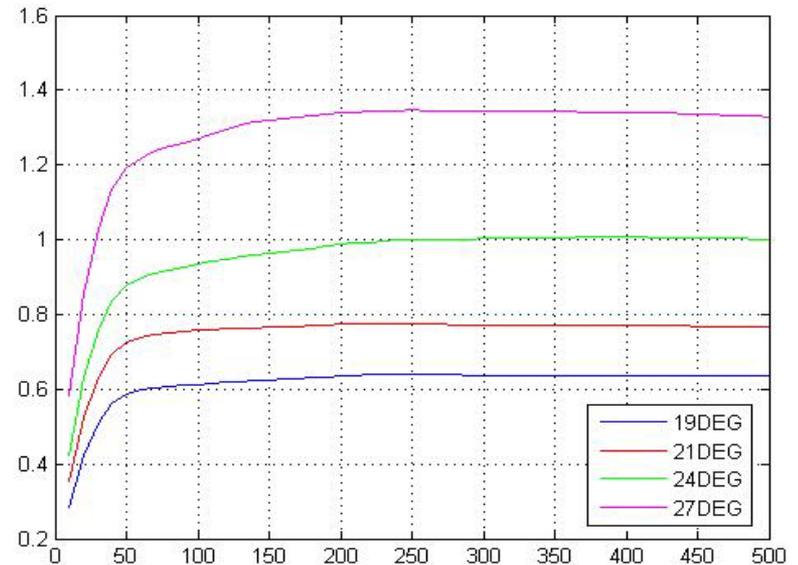
BeamCal sensor characteristics

Measured IV behavior, resistivity and Schottky barrier height are consistent with previous results and theoretical calculations.



LumiCal sensor characteristics

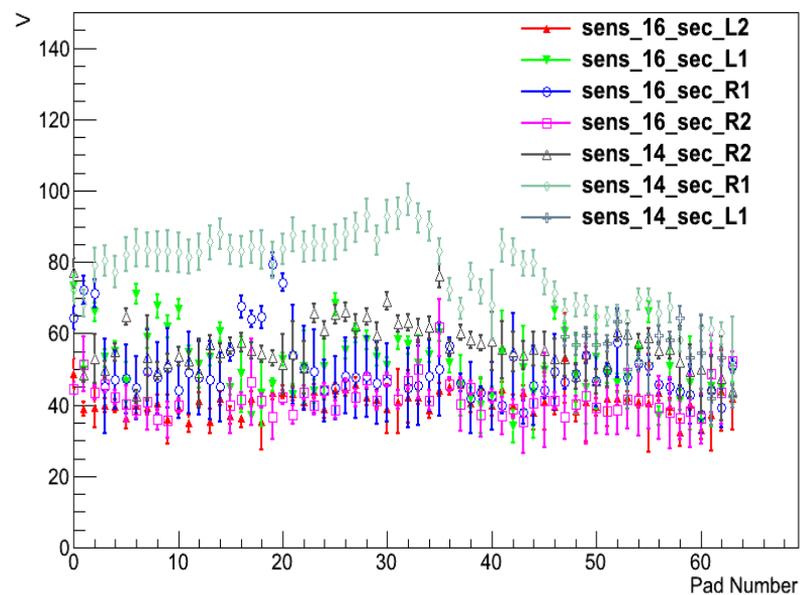
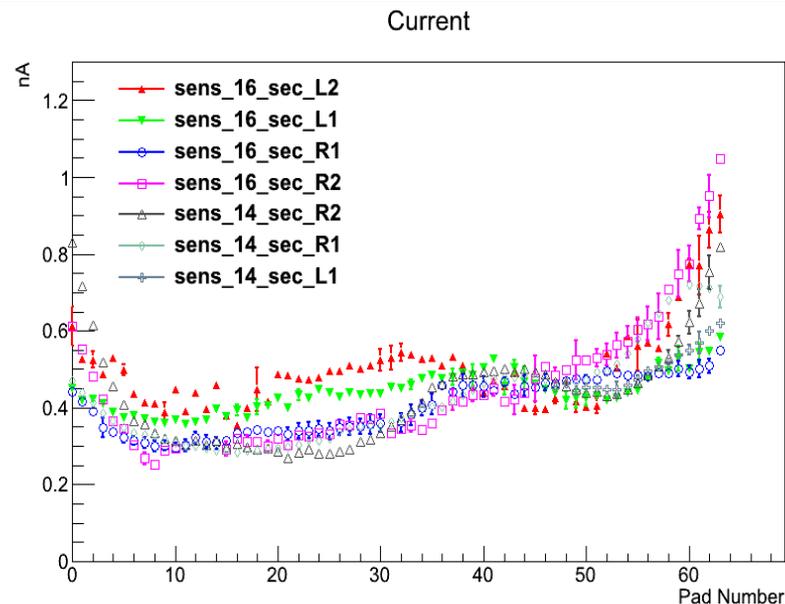
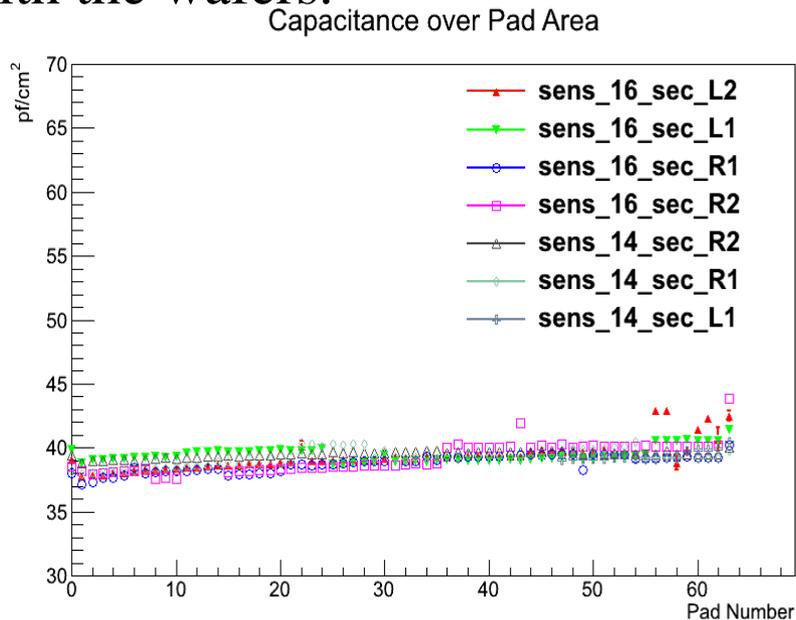
- During the last several months, a new extensive test was started for the LumiCal silicon sensors.
- The tests include the current and capacitance as a function of voltage measurements.
- Current measurements have the structure of a reverse diode and a strong dependence on temperature.
- From capacitance measurements the depletion voltage and sensor uniformity can be extracted.



LumiCal sensor characteristics

In general, all measurements are in agreement with the past results and theoretical expectations.

Large statistic measurements of pads give us a nice picture of sensors behavior and uniformity and show some unexplained results associated with the wafers.

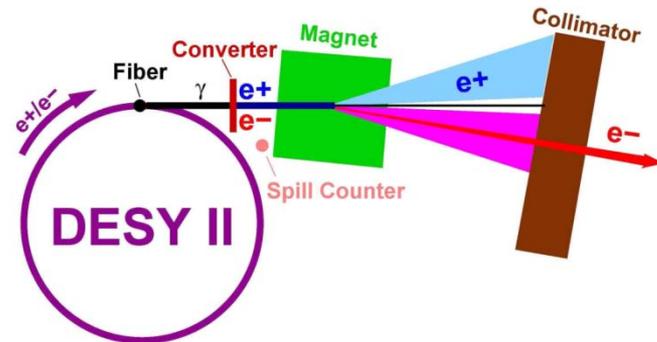
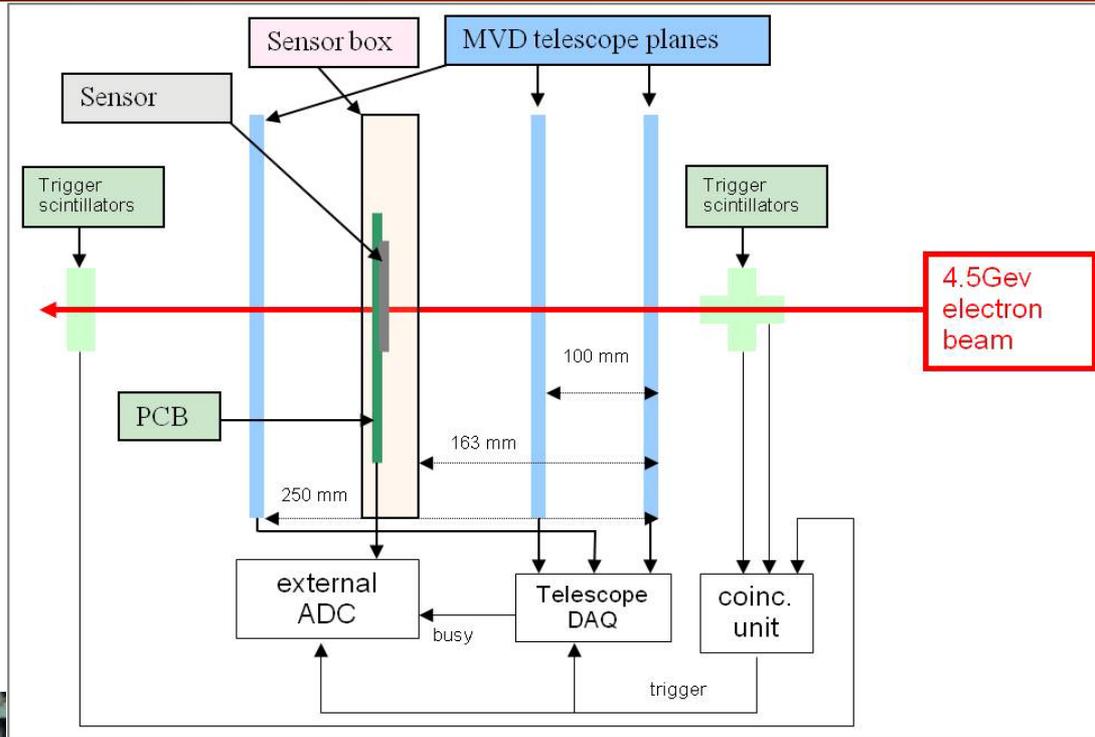


Beam test set-up

Beam tests took place in beam line 22 of DESY II ring in Hamburg with several (2-4.5) GeV electrons. Measurements are the combination of our sensors, ZEUS MVD Telescope for position reconstruction

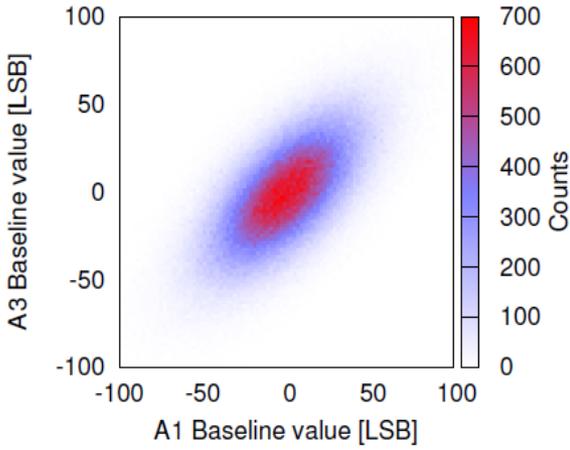
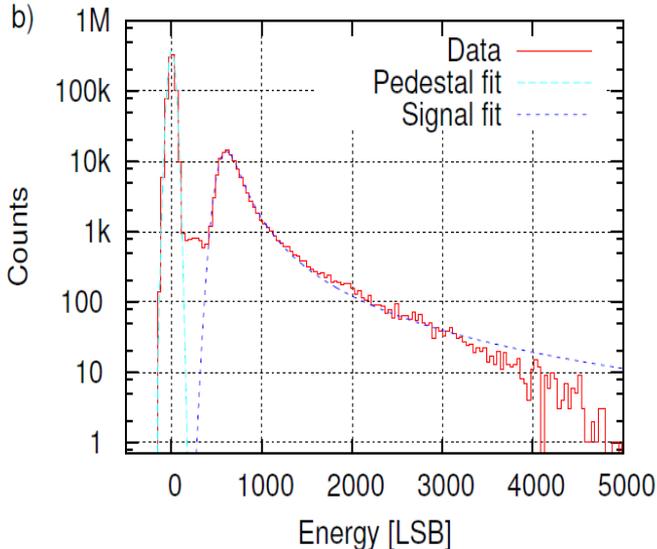
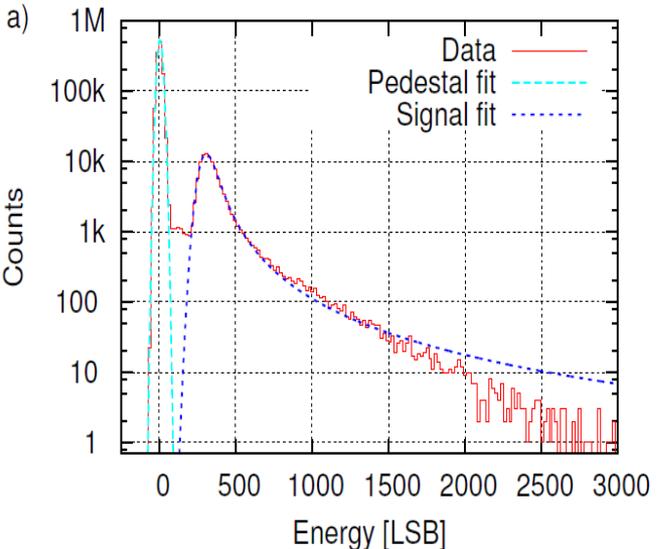
DAQ :

- 2010 - two systems (v1724 / v1721 external ADC + Telescope) + veto mechanism.
- 2011 - EUDAQ + TLU (unique trigger).



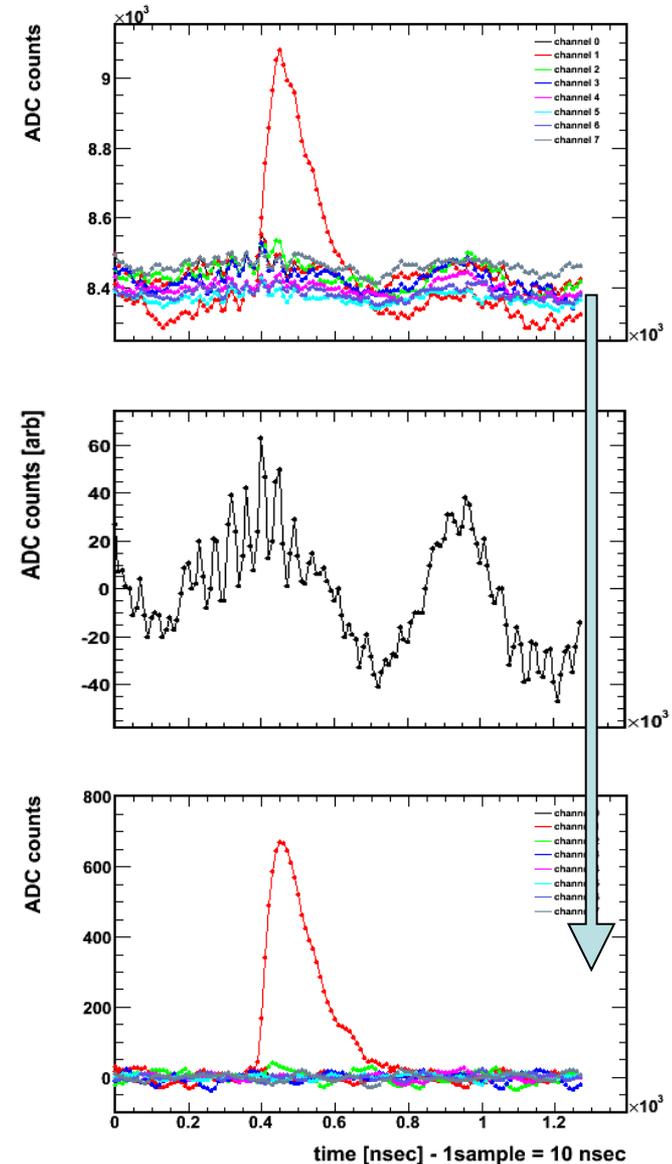
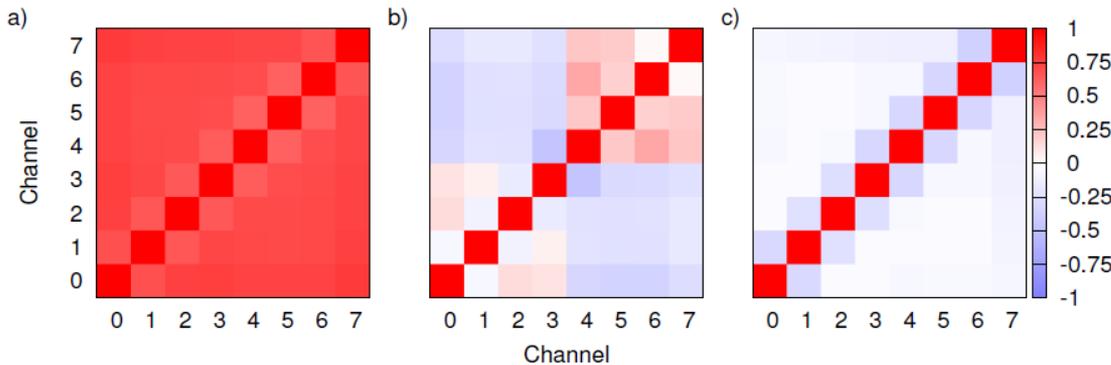
2010 test results (1)

- In the 2010 test, an analog detector module was tested.
- The module included : sensor, fan-out, front-end ASICs, power supply, biasing circuits and line drivers.
- Read out of only 8 channels.
- ASICs have 2 types of feedback loop, active feedback (MOS) – passive feedback (R_f), gain difference \sim order of 2 .
- Energy deposition spectrum built from pulse height analysis and fit nicely to a convolution of a Landau distribution and a Gaussian.
- Uniform gain between channels (\sim 2%).
- Good SNR for both LumiCal and BeamCal .
- High correlation factor between all channels.



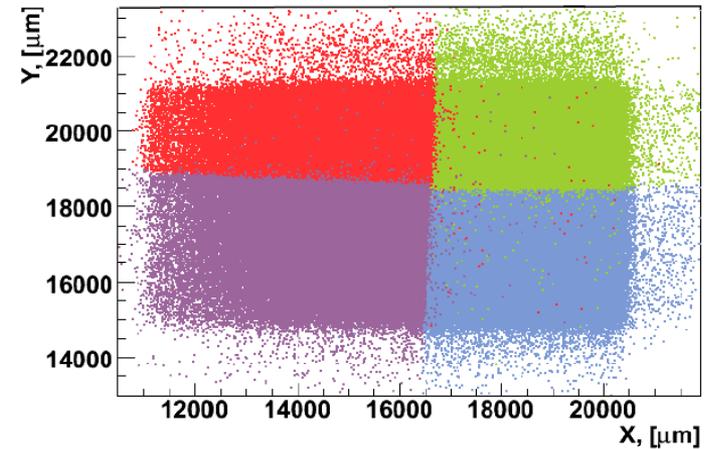
2010 test results (2)

- High correlation factor between channel is a result of a common mode noise, CMN.
- First the CMN needs to be extracted from all channels under threshold.
- Then CMN can be subtracted from all channels.
- Base-line temperature dependence and different channels gain need to be taken into account.

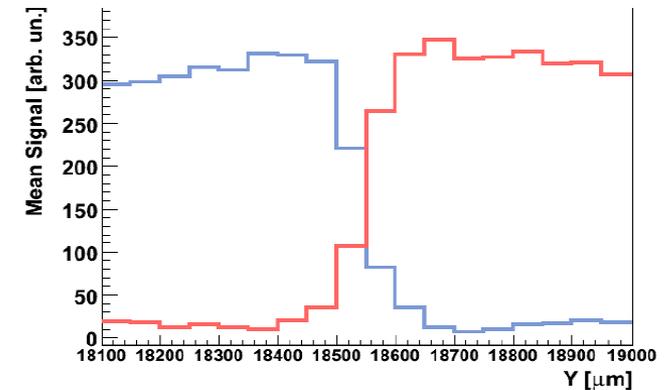
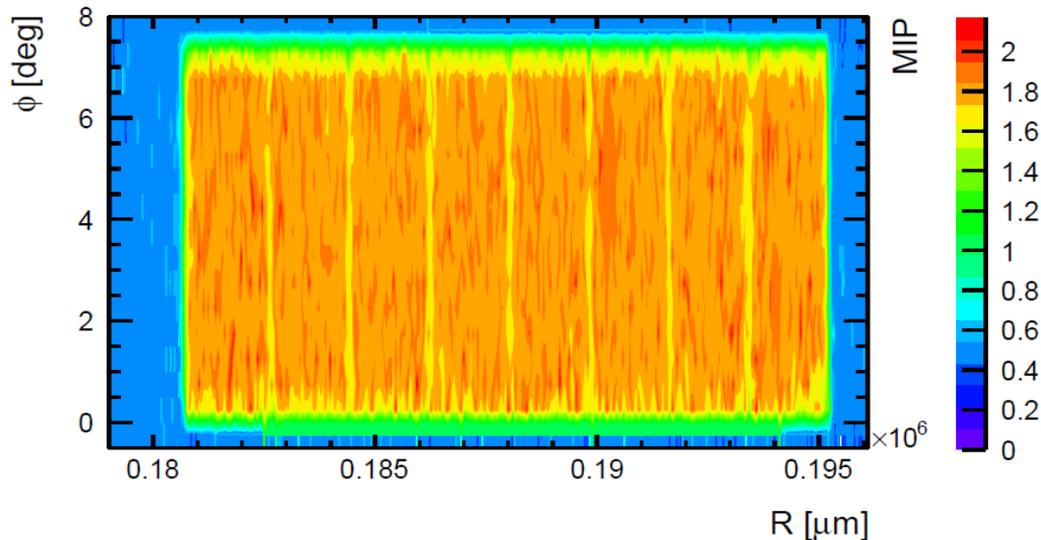


2010 test results (3)

- Using a track fit from the MVD telescope the impact position on the sensor is reconstructed.
- Uniformity – drop of 10% - 15% in CCE between pads.
- Detection efficiency just under 100%.
- The effect of charge sharing between pads is clear.

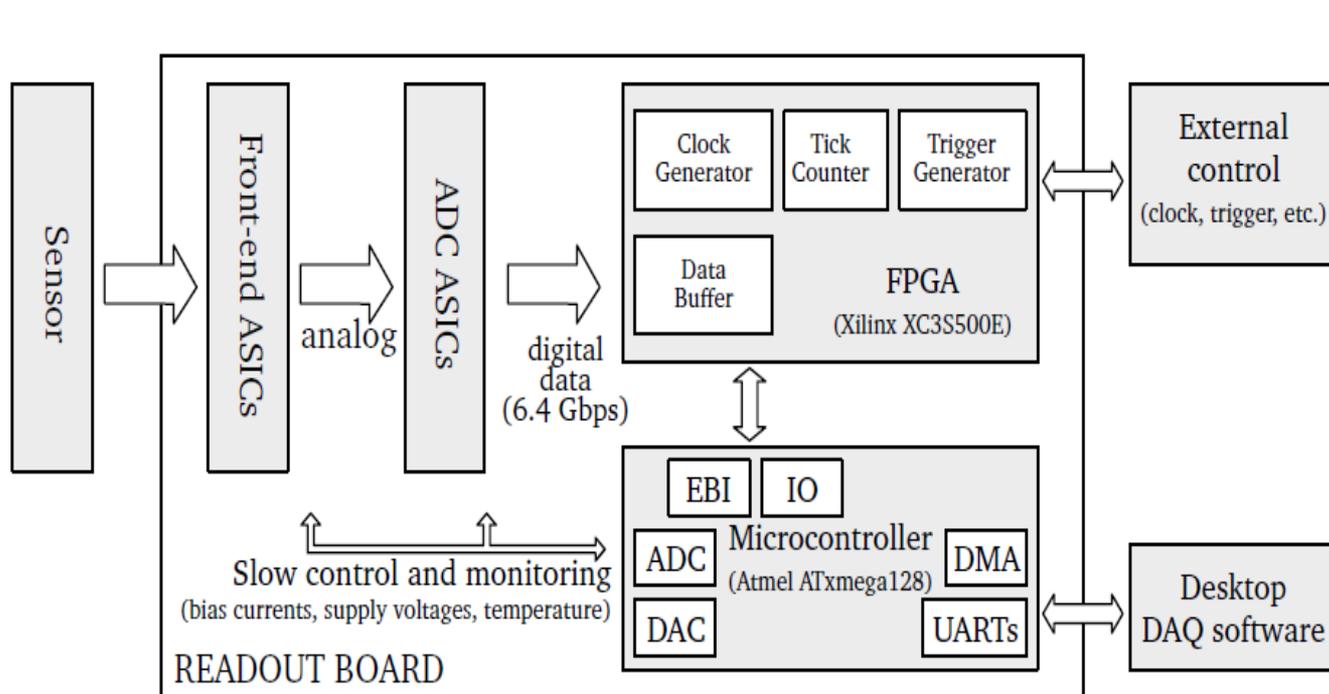


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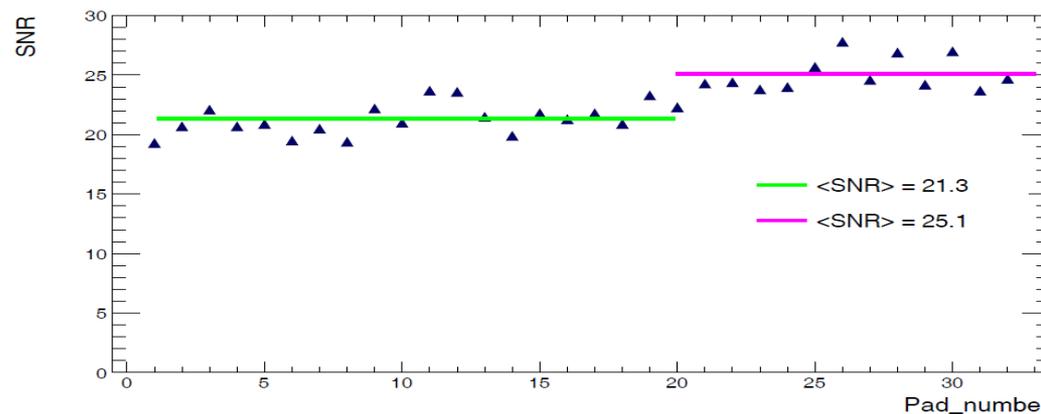
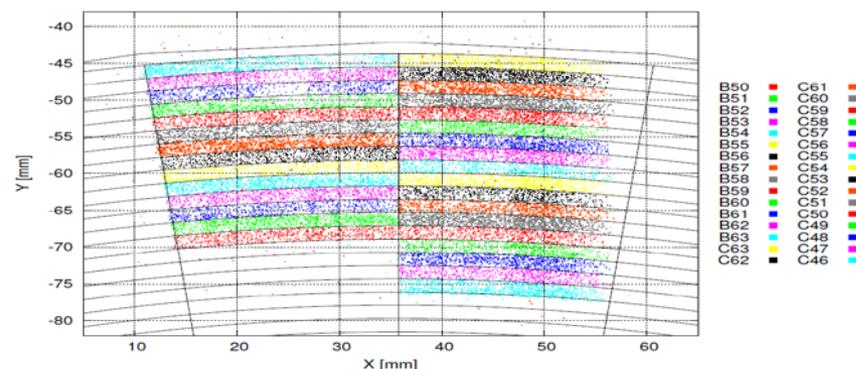
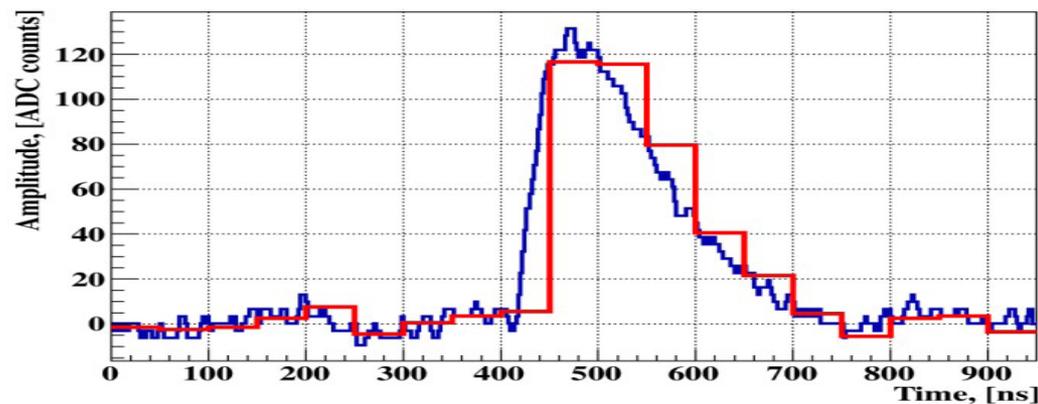
2011 tests (1)

- In the 2011 tests the complete detector module equipped with first level DAQ was tested.
- Include the operation of the complete readout chain: Si-sensor, kapton fan-out, front-end electronic and multichannel 10-bit pipeline ADC ASIC controlled by FPGA based data concentrator.
- The complete module has 4 multi channels chips with 8 channels each.
- Data was collected in two modes : synchronous (ILC mode) and asynchronous (test beam mode) with beam.



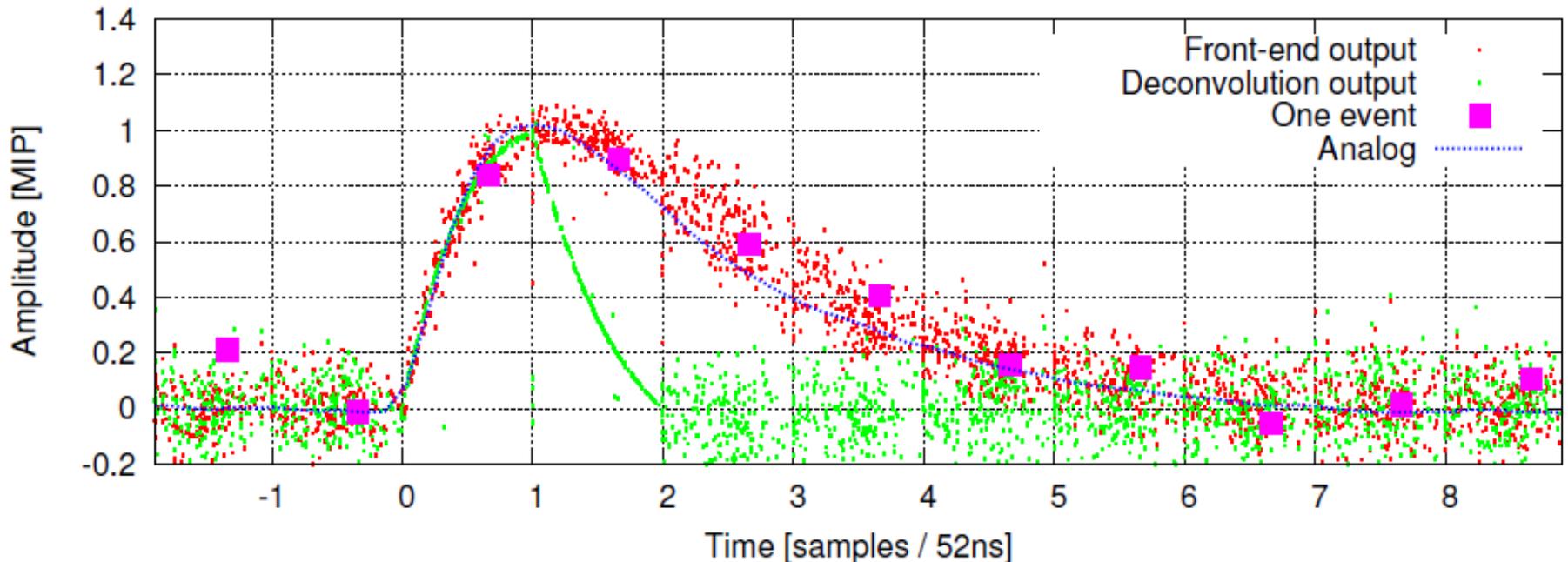
2011 tests (2)

- Similar measurements as in the 2010 test have been performed with the complete detector module in the 2011 one.
- BeamCal results was used to compare between external ADC and ADC in the ASICs.
- The main changes in the 2011 beam test were in the number of channels (32), ADC resolution (10-bit instead of 14/8-bit).
- The main results are the sensor uniformity and homogeneity response – like in the SNR case.



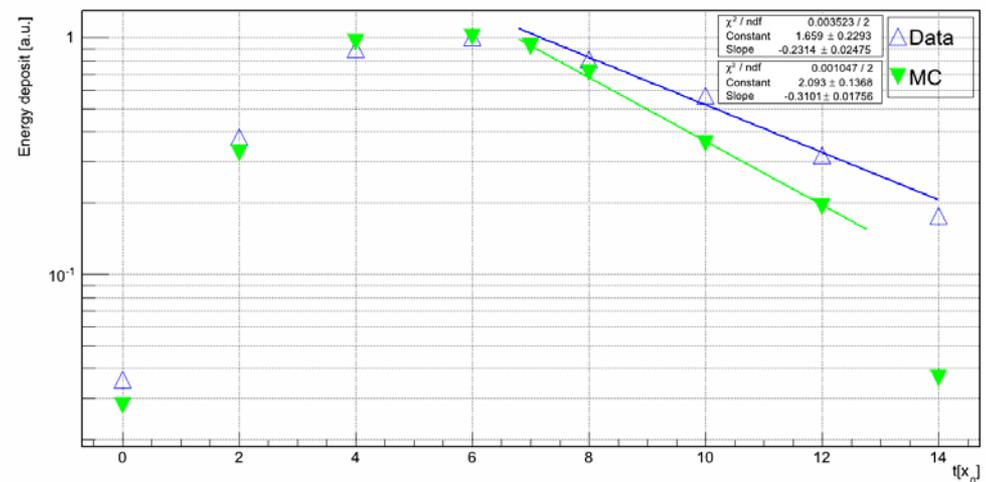
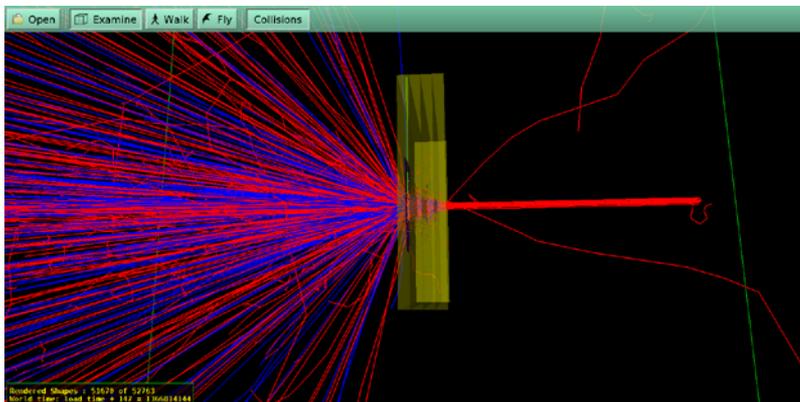
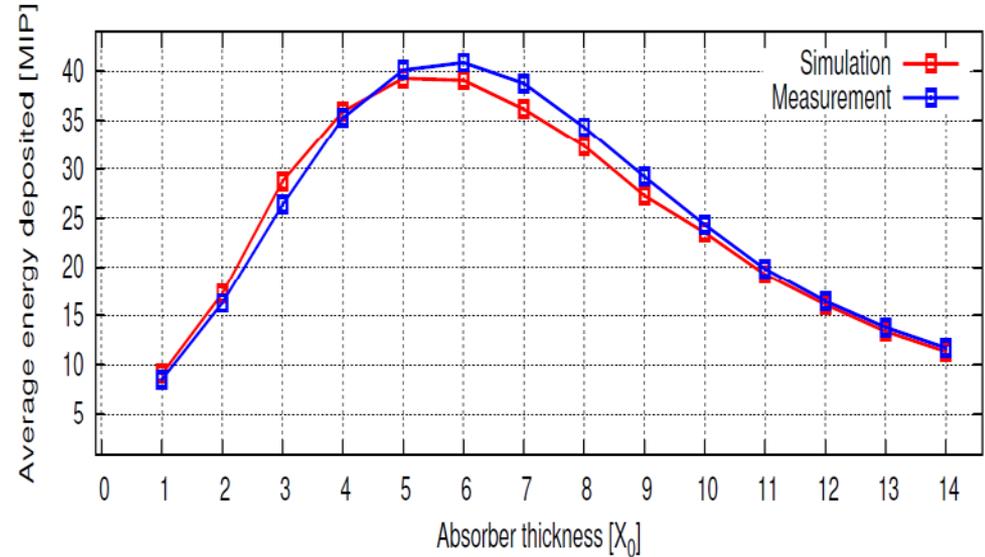
Readout with deconvolution

- As a preparation for high speed readout required in CLIC environment, the deconvolution method has been tested in the offline analysis.
- When using deconvolution, processed events can be precisely time-aligned and the exact amplitude and position can be determined.
- Deconvolution results was successfully compared to the other method.
- The measurements with an electron beam reproduce very well the results obtained in lab with a laser.



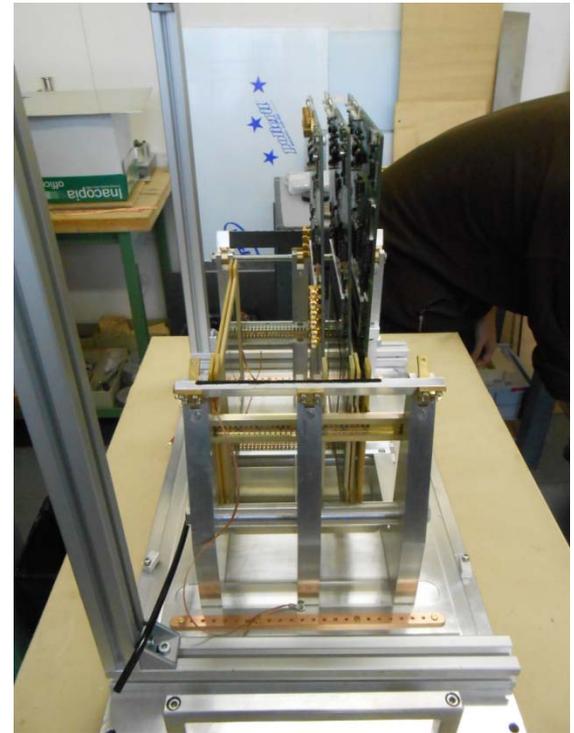
Shower development

- Several data runs were taken with tungsten absorber of different thickness in front of the sensor .
- Only statistical parameters can be analyzed.
- A MC simulation with GEANT4 was used to compare with the test results.
- Shower maximum observed after six radiation lengths and the agreement with MC is found to be reasonable.



Multi - layer prototype

- The difference between the results and MC simulations can be improved in the next beam test.
- In the next beam test we will use for the first time a dedicated rigid structure for precise alignment of sensor and absorber planes, that will act as a prototype calorimeter for both LumiCal and BeamCal.



Summary

- Sensor characteristics are well consistent with previous results and theoretical calculations.
- Operation of the FCAL complete detector module with complete readout chain was successfully verified under beam tests conditions.
- Good performance results have been obtained from the beam test campaign:
 - Good SNR .
 - Sensor Uniformity and Detection efficiency.
 - Low level cross-talk.
- Advance readout and analysis technique were tested.
- The response of the detector to shower development has been studied.
- In the near future the beam test will evolve to a prototype beam test with several sensor planes to simulate a full sector of the LumiCal detector.
- All results will be summarized in a dedicated paper in the near future.

Thank you!