Status and Goals for the FCAL

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On behalf of the FCAL collaboration

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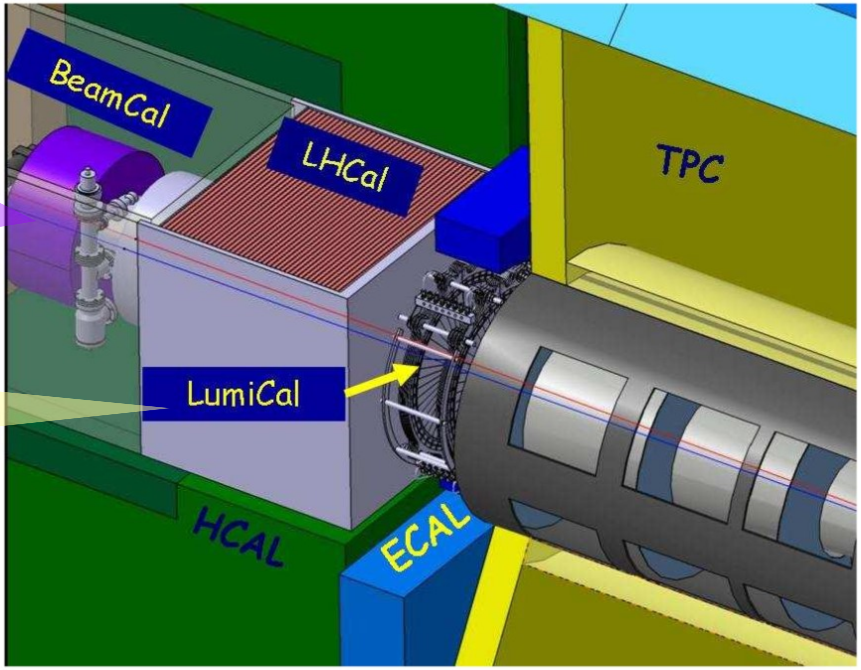
Overview

- Instrumentation of the forward regions in linear collider experiments
- LumiCal calorimeter:
  - Luminosity measurement;
  - Detector module development.
- BeamCal calorimeter:
  - Beam parameters reconstruction;
  - Single high energy electron detection;
  - Sensor development.
- 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.



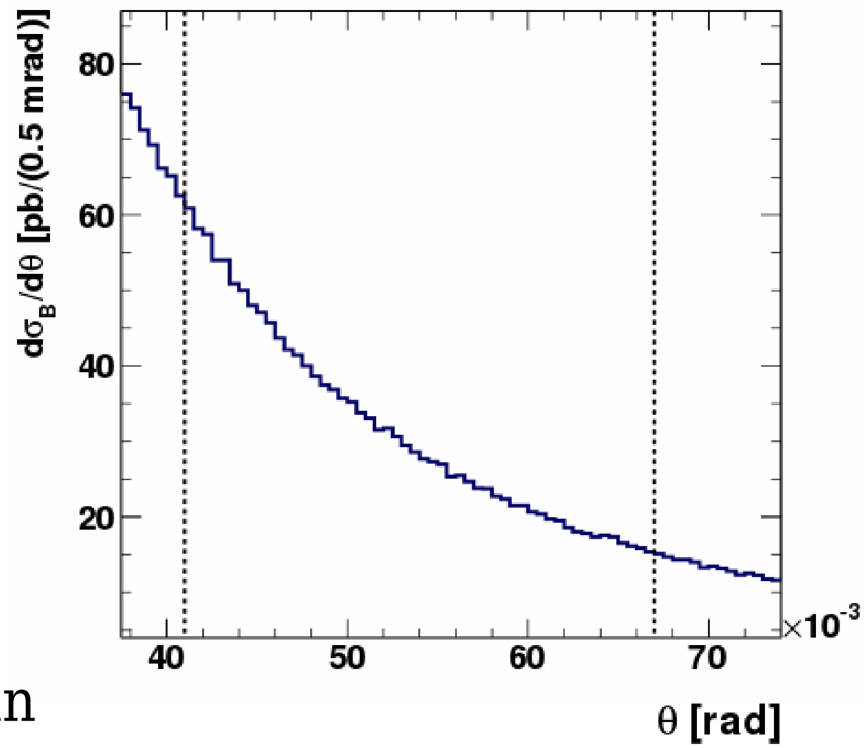
LumiCal: two tungsten-silicon calorimeters placed symmetrically on both sides of the interaction point at a distance of ~2.5 m.

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:

$$\frac{d\sigma_{\rm B}}{d\theta} = \frac{2\pi\alpha_{\rm em}^2}{s}\frac{\sin\theta}{\sin^4(\theta/2)} \approx \frac{32\pi\alpha_{\rm em}^2}{s}\frac{1}{\theta^3},$$

the approximation holds at small θ.

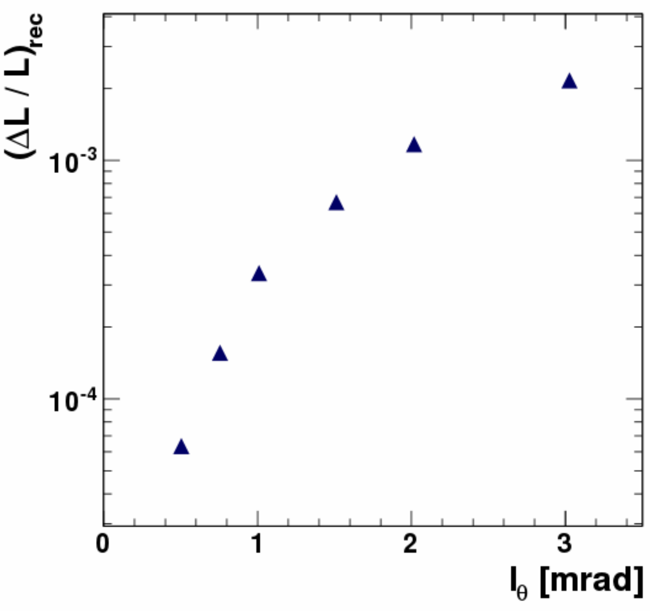
α is the fine-structure constant,
s - center-of-mass energy squared.

LumiCal geometry

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

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

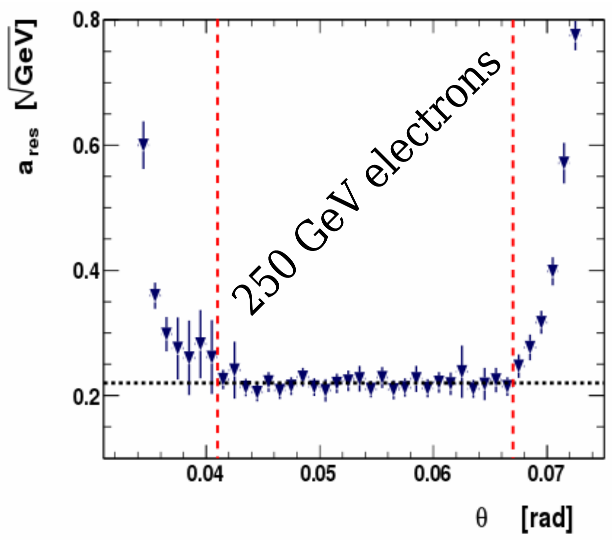
$\Delta\theta$ depends on polar angular pad size l_θ.



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

Energy resolution:

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

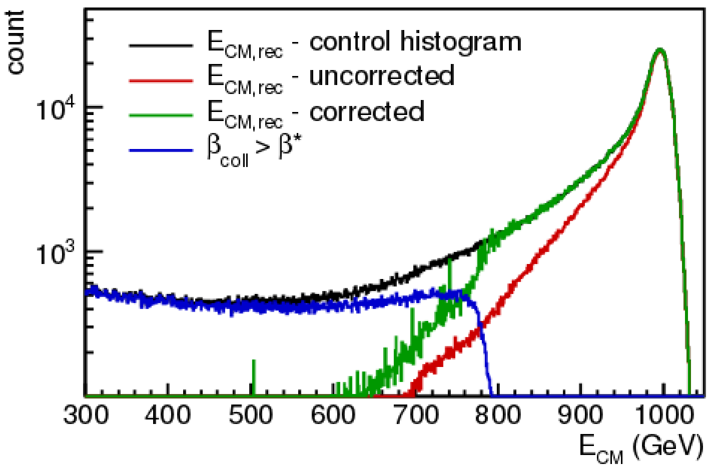


LumiCal fiducial volume: $41 < \theta < 67$ mrad

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

Systematic effects

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



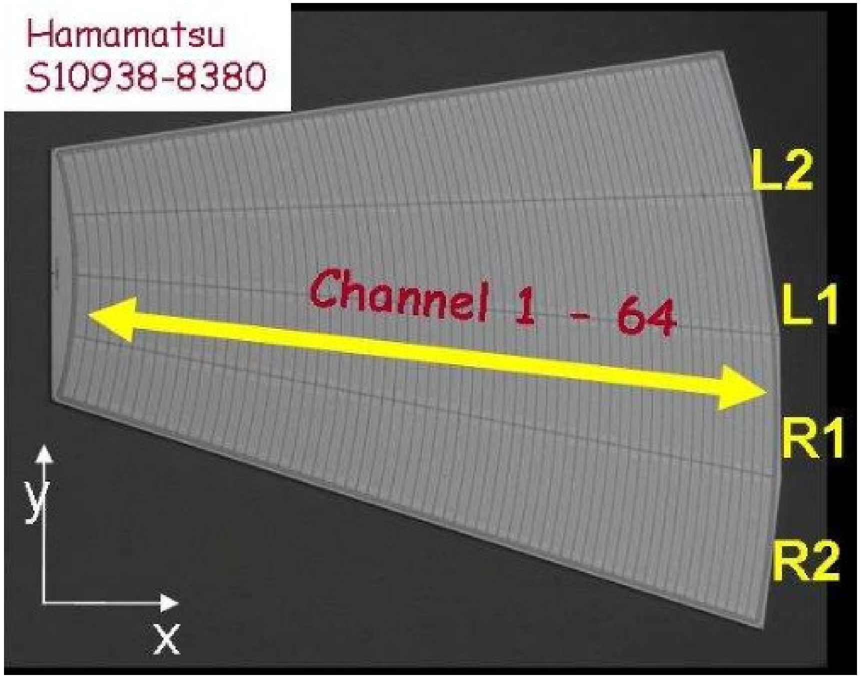
Lumi spectrum with event by event correction

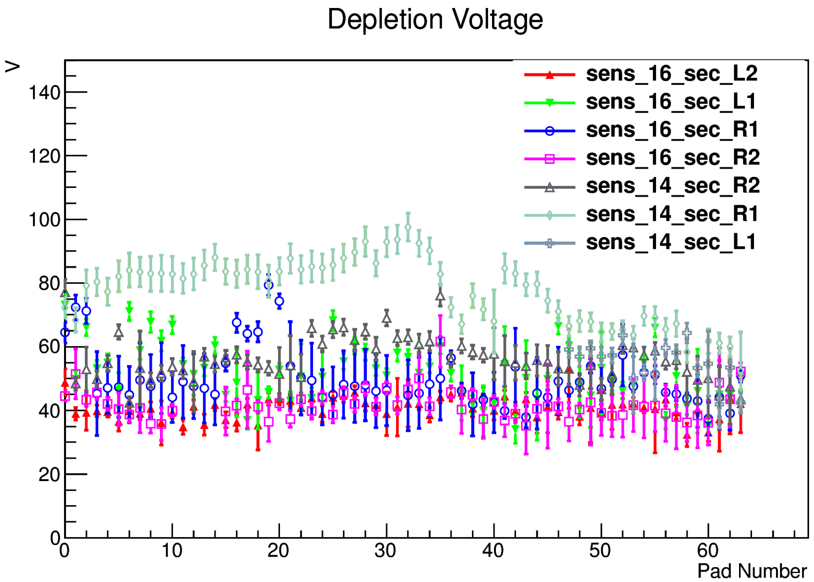
Estimated systematic uncertainty at $\sqrt{s}$ = 500 GeV.

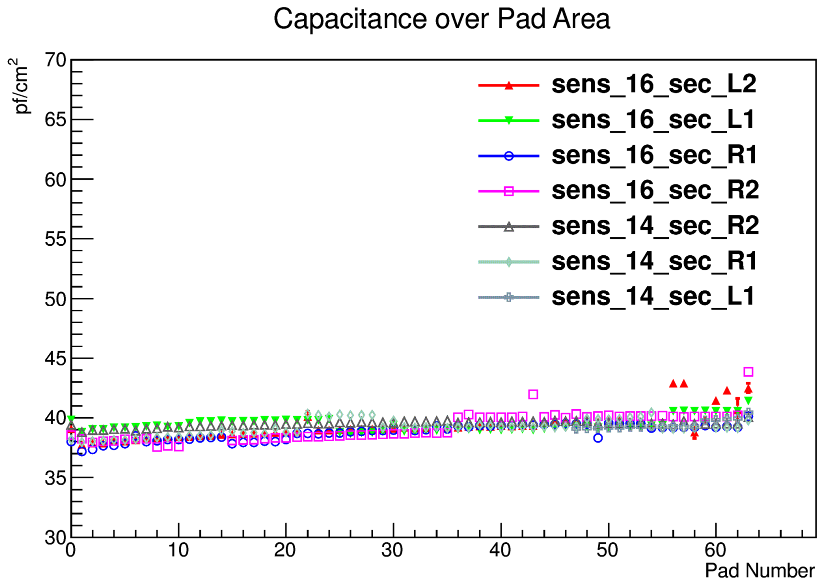
Source	Value	Uncertainty	Luminosity Uncertainty
σ_θ	2.2×10^{-2}	100%	1.6×10^{-4}
Δ_θ	3.2×10^{-3}	100%	1.6×10^{-4}
a_{res}	0.21	15%	10^{-4}
luminosity spectrum			10^{-3}
bunch sizes σ_x, σ_z,	655 nm, 300 μm	5%	1.5×10^{-3}
two photon events	2.3×10^{-3}	40%	0.9×10^{-3}
energy scale	400 MeV	100%	10^{-3}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

LumiCal sensor

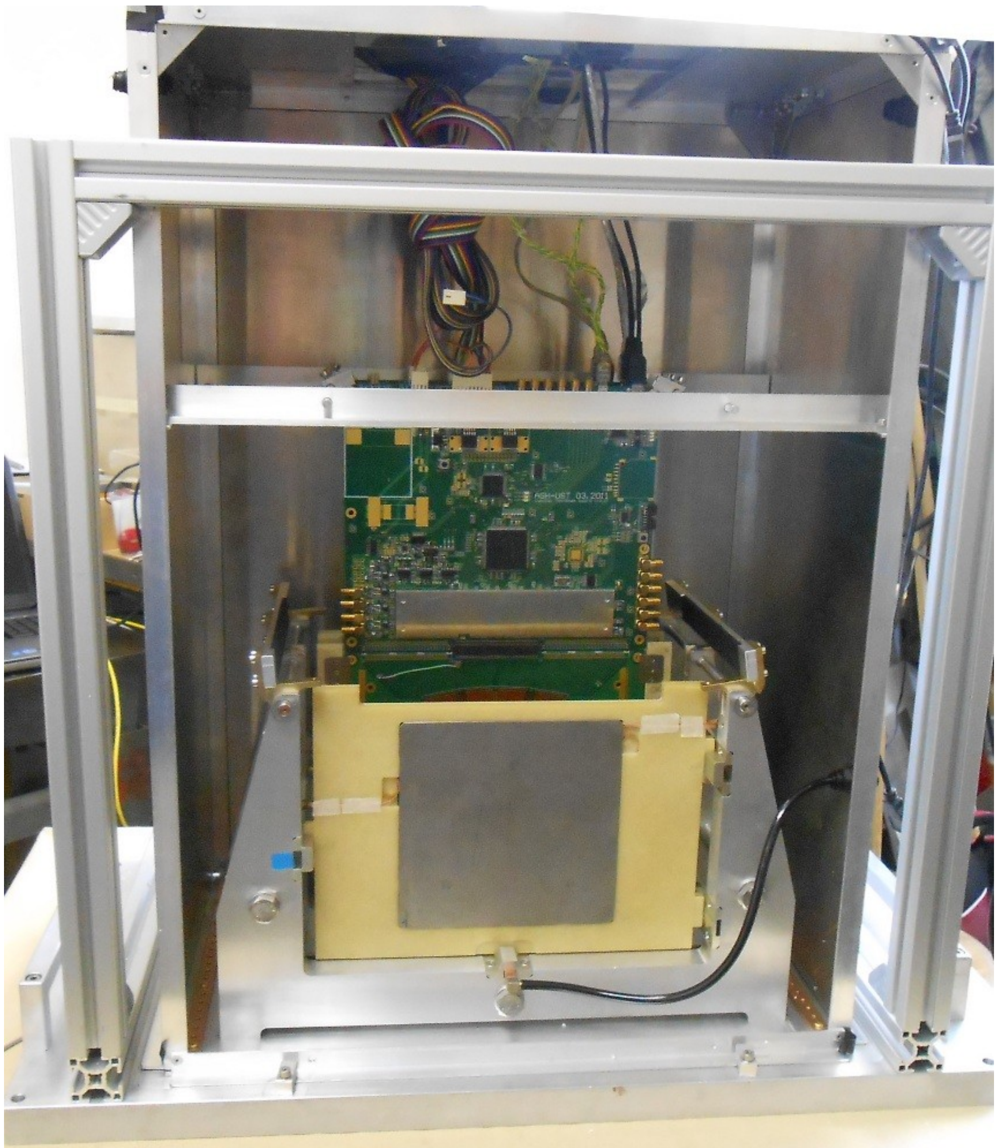
- Silicon sensor
- thickness 320 µm
- DC coupling with read-out electronics
- p^+ implants in n material
- pad pitch 1.8 mm

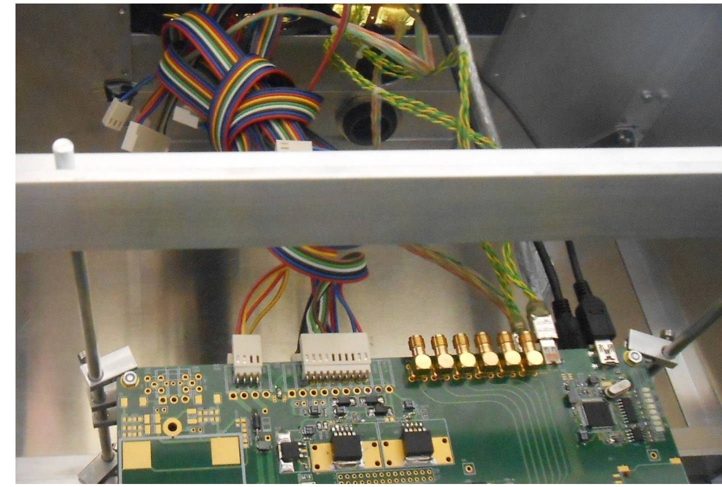


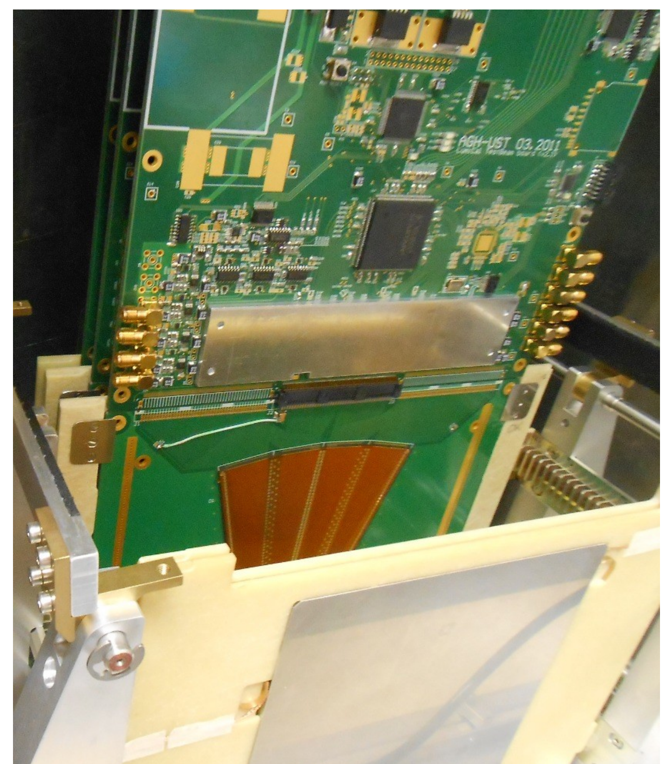




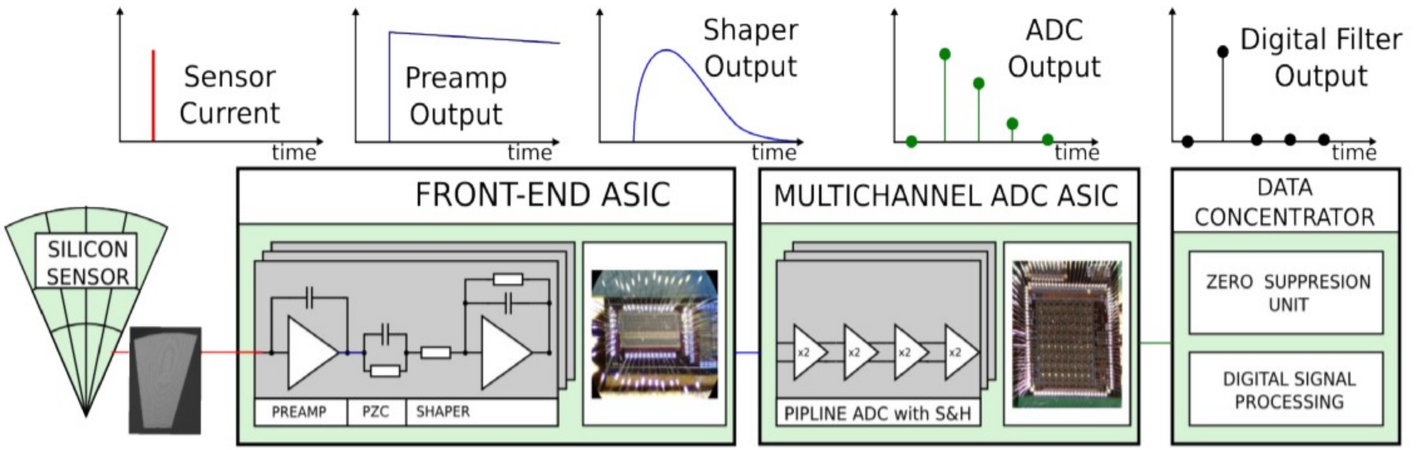
FCAL test beam infrastructure







Front-end electronics in CMOS 130 nm



Existing readout developed in CMOS AMS 0.35 µm comprises:

- 8 channel front-end ASIC (preamp, shaper Tpeak~60ns, ~9mW)
- 8 channel pipeline ADC ASIC, Tsmp<=25MS/s, ~1.2mW/MHz
- FPGA based data concentrator and further readout

New developments in IBM CMOS 130 nm:

- First prototype of front-end ASIC developed and under tests
- First prototypes of SAR ADC ASIC developed and under tests

Even Newer developments in TSMC CMOS 130 nm just started...

Laser alignment system

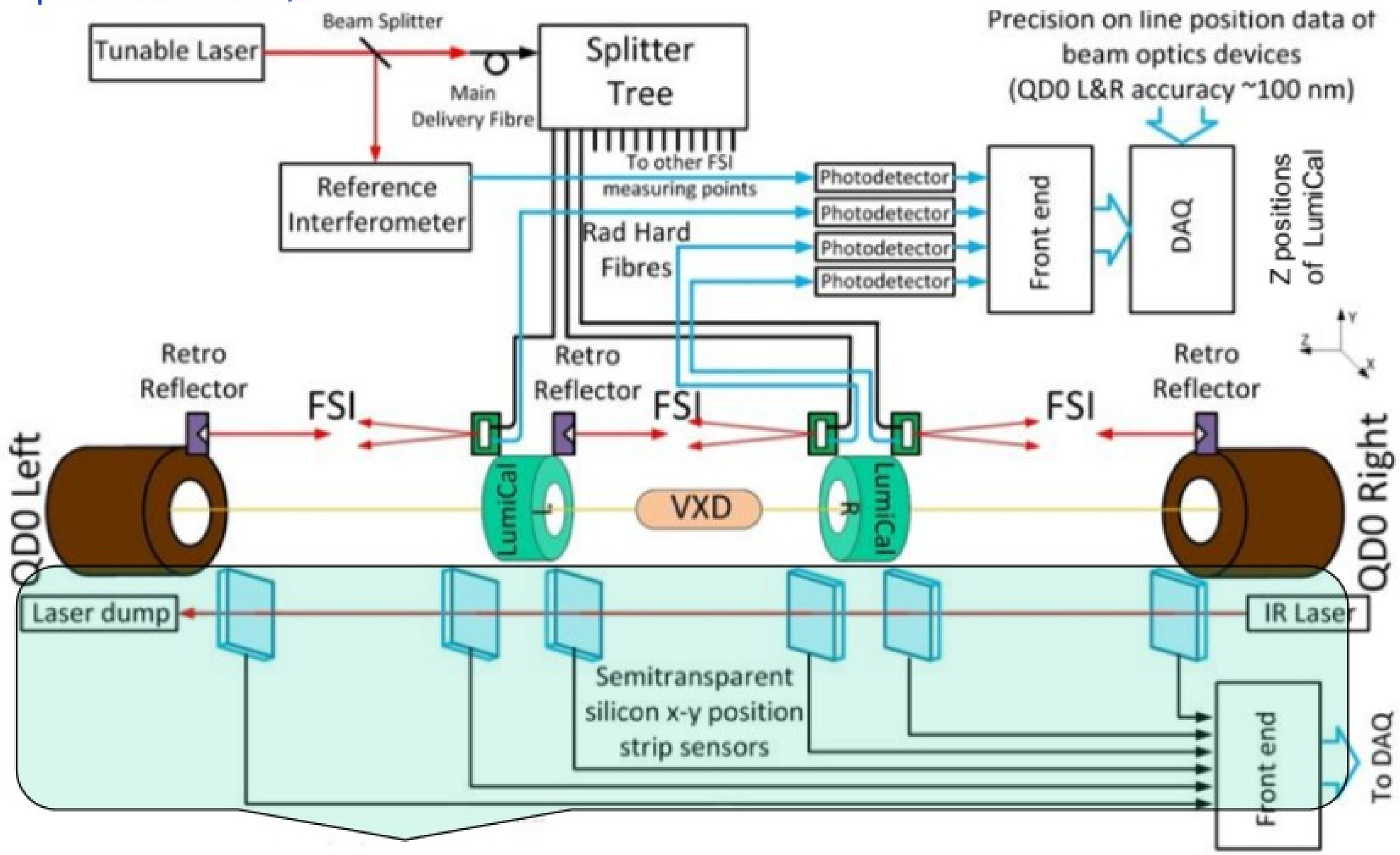
The alignmen system may include two components:

- IR laser + PSD system:

infra-red laser beam and semi-transparent position sensitive detectors

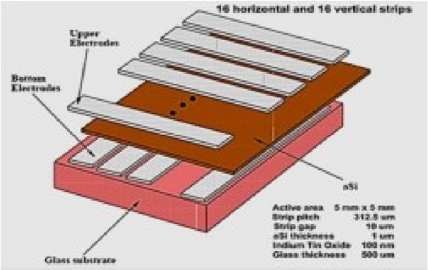
- FSI system:

tunable laser(s), beam splitters, isolator, Fabry-Perot interferometer, retroreflectors, fibers, collimators, photodetectors, lens



FSI - Frequency Scanning Interferometry

The absolute distance measurements between LumiCal's



IR Laser + PSD

Relative positions of LumiCal's and displacments of the internal Si layers

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.

Beam parameters

Assuming that bunches are ellipsoidal with Gaussian charge distribution, the following parameter are sufficient to define conditions upon collision:

- σ_x , σ_y , σ_z – bunch sizes in x, y and z;
- ε_x , ε_y – emittances in x and y;
- Δx, Δy – beam offsets in x and y;
- W_x, W_y – waist shifts, horizontal and vertical;
- α_x , α_y – bunch rotations in horizontal and vertical planes;
- φ – bunch rotation around the beam axis;
- N – number of particles per bunch.

The dependence of observables (*O*) derived from the energy deposited in BeamCal is approximated by first order Taylor series

$$O_m = \boldsymbol{M} \cdot (P_{act} - P_{nom}) + O_{nom}$$, *P* – above listed beam parameters

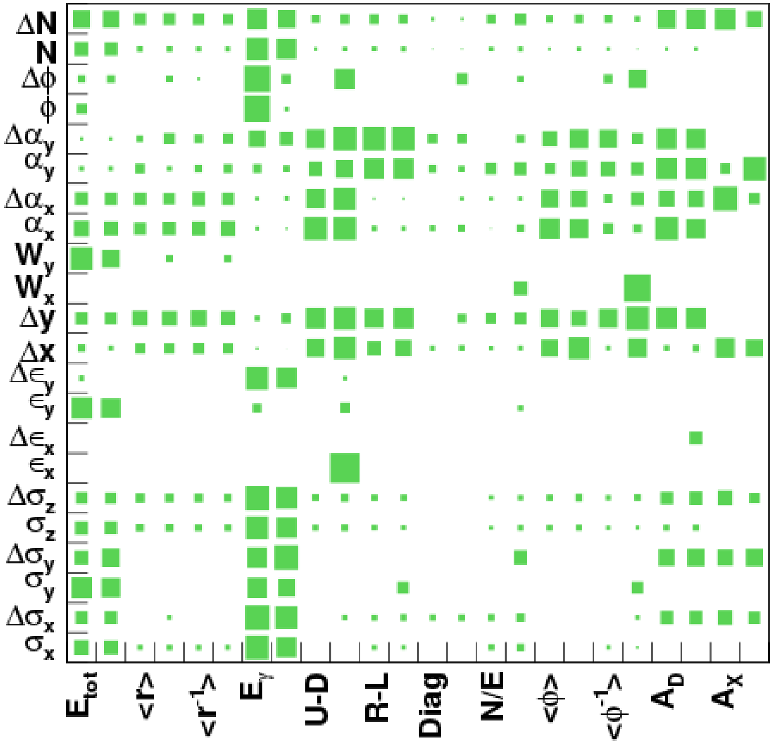
BeamCal observables

1. E_{tot} – total energy deposited in calorimeter;
2. <r> – first radial moment: $<r>=(\Sigma\, r_l E_l)/E_{tot}$;
3. <1/r> – inverse radius first moment, defined similar to above;
4. U-D – vertical energy imbalance;
5. R-L – horizontal energy imbalance;
6. R-L – diagonal energy imbalance;
7. N/E – total number of particles to E_{tot} ratio (counting detector required);
8. <φ> – first angular momentum;
9. A_{dir} – direct forward-backward asymmetry;
10. A_{xsd} – crossed forward-backward asymmetry;
11. E_{γ} – total energy of all beamstrahlung photons (requires GamCal).

- Taylor matrix is calculated by fitting the observables as a function of the beam parameters.
- Simulation: Guinea-Pig, Geant4.
- The Moore-Penrose inverse of the Taylor matrix was used to calculate the beam parameters from the observables.

Beam parameters reconstruction

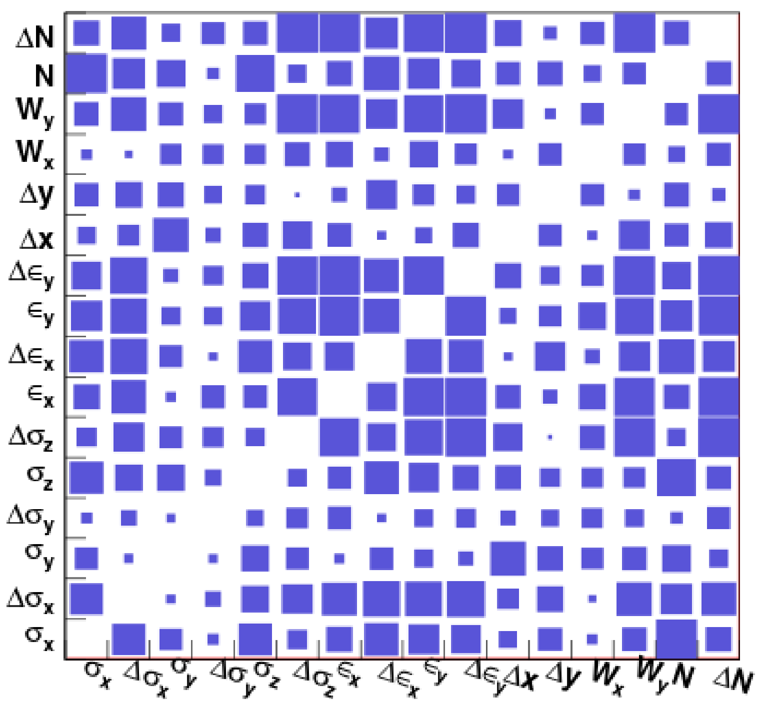
- Each single parameter can be reconstructed in this approach within the uncertainty in 14 mrad crossing angle geometry;
- The analysis has limited capabilities in multi-parameter reconstruction due to correlations between beam parameters;
- To cope with it one can use measurements from other tools to fix some parameters;
- Another approach is to combine correlated parameters into one quantity.

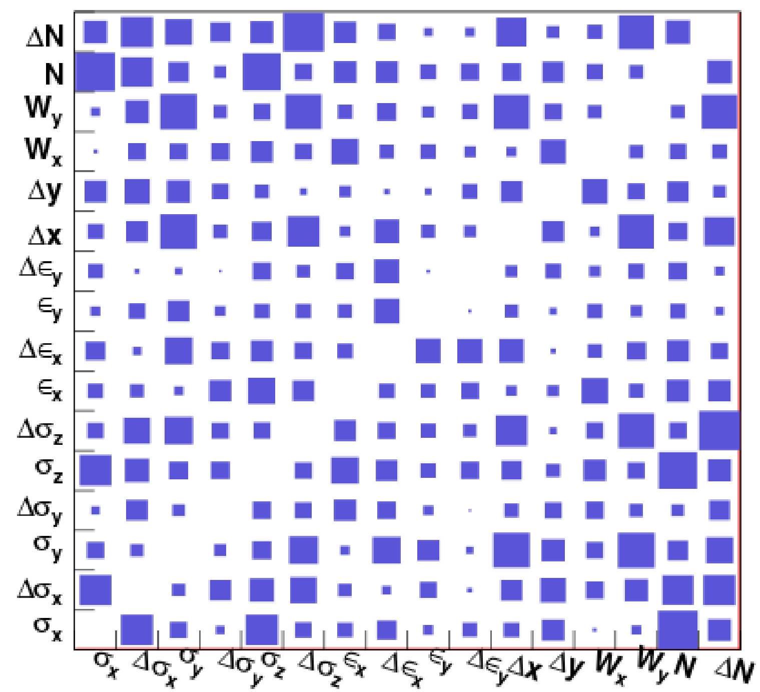


Significance of observables in the reconstruction of a beam parameter

Beam parameters correlations

- Plots show the correlation coefficients between the parameters which allow a relatively stable reconstruction;
- The bunch rotations are excluded as Moore-Penrose inversion fails.





Emittances were fixed.

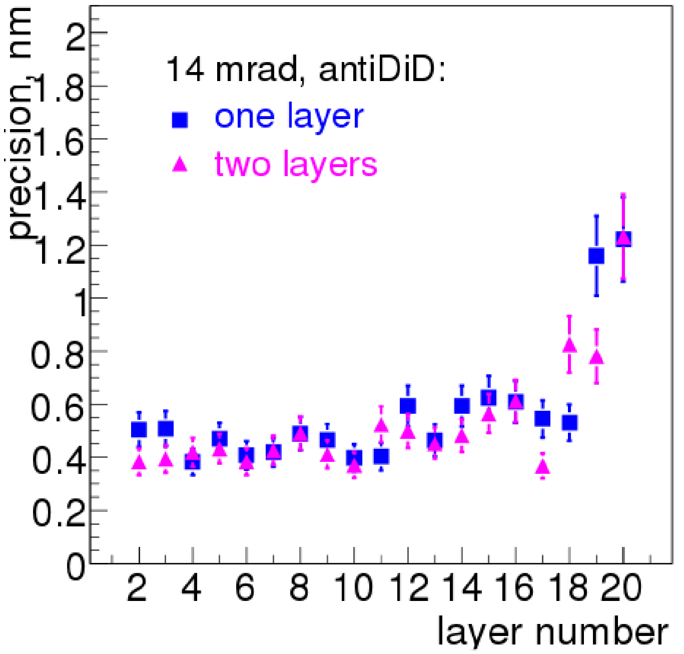
The size of the squares is proportional to correlation coefficient.

Read out optimization

To reduce the amount of primary data:

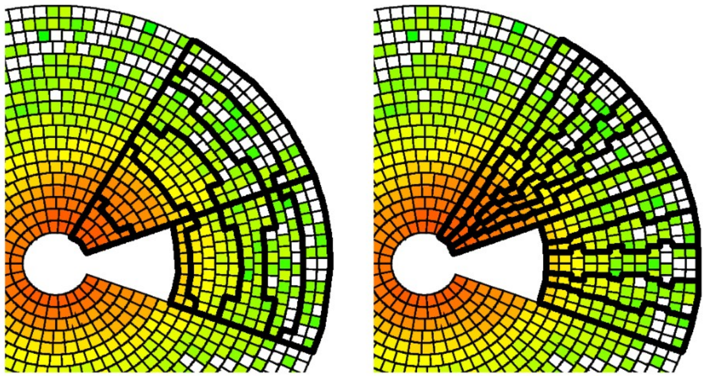
- choose a small number of most sensitive layers;
- merge pads into groups.

For the single parameter reconstruction 1-2 layers are sufficient to obtain a precision comparable to the full calorimeter



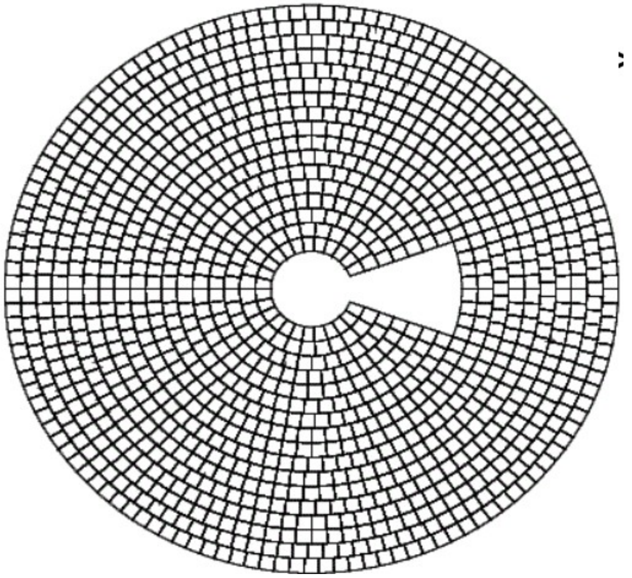
Resolution of the parameter σ_y as a function of the first read-out layer.

- Pads azimuthal and radial grouping;
- Radial is slightly better for the bunch sizes reconstruction.

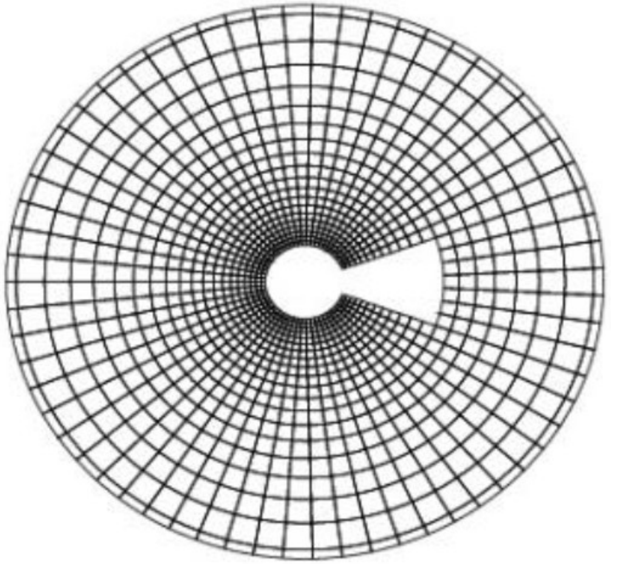


Single high energy electron reconstruction in BeamCal

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



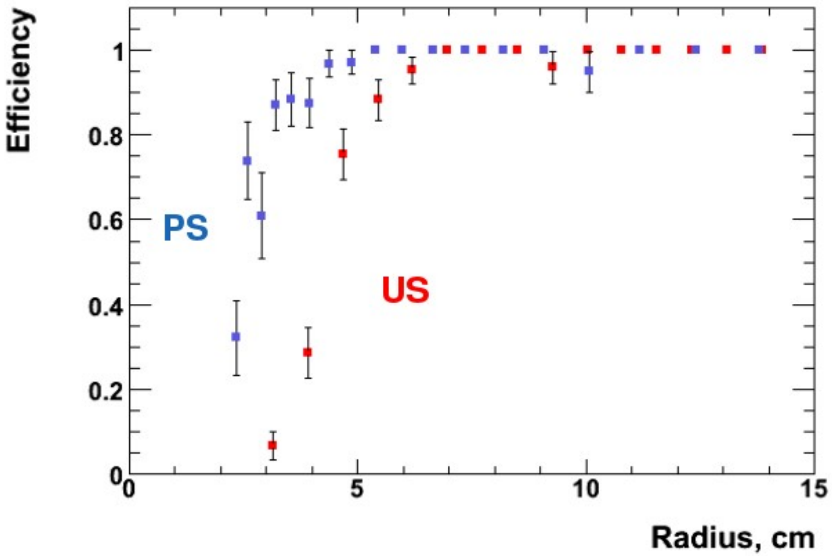
Proportional Segmentation (PS)

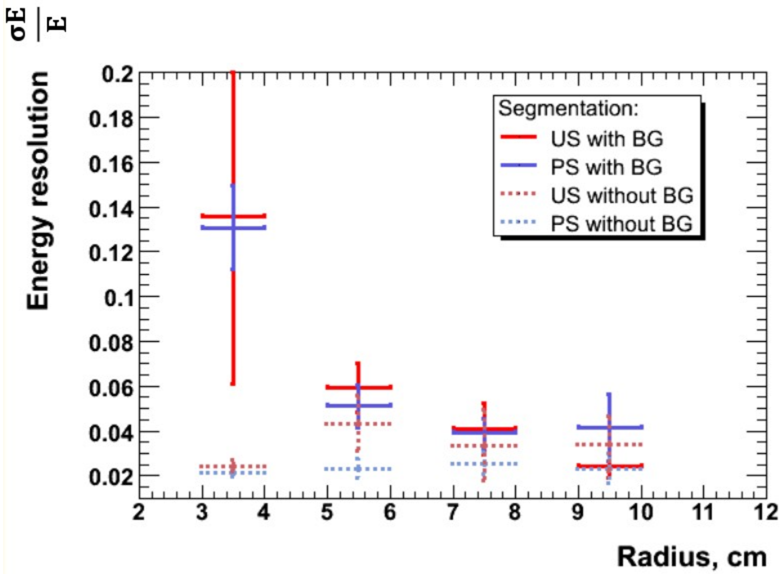


Uniform Segmentation (US)

Single high energy electron reconstruction in BeamCal

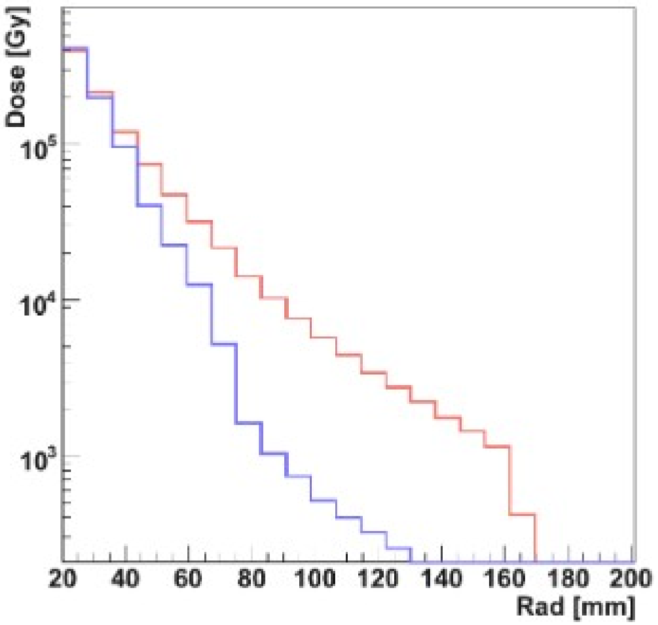
- The shower reconstruction efficiency for electrons with energies above 200 GeV is higher for proportional segmentation.
- For lower energy electrons the efficiencies are similar and showers cannot be reconstructed for R < 3-5 cm.





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.



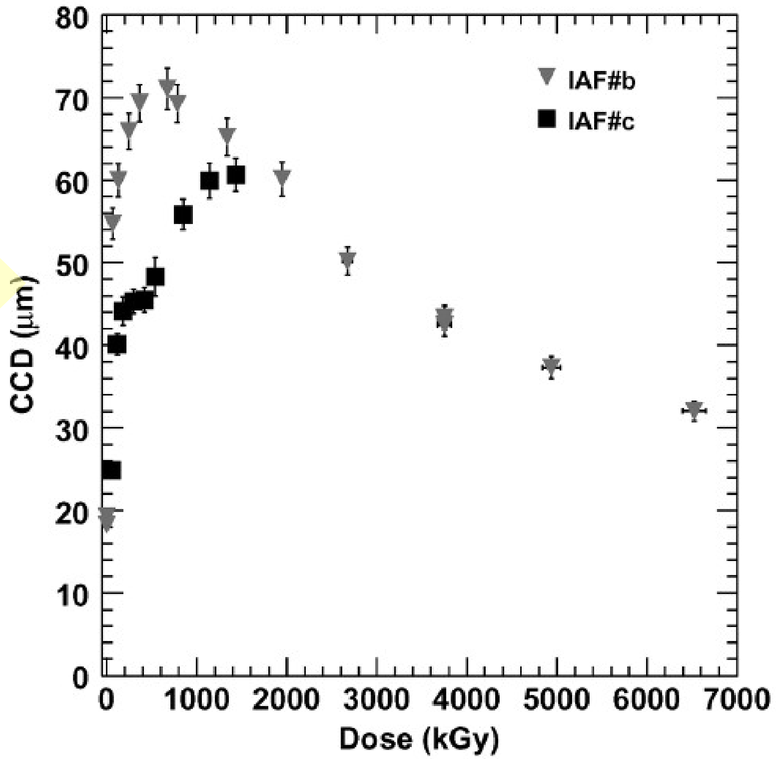
Dose per year as a function of BeamCal radius of the 6th layer. Blue/red - different set of beam parameters.

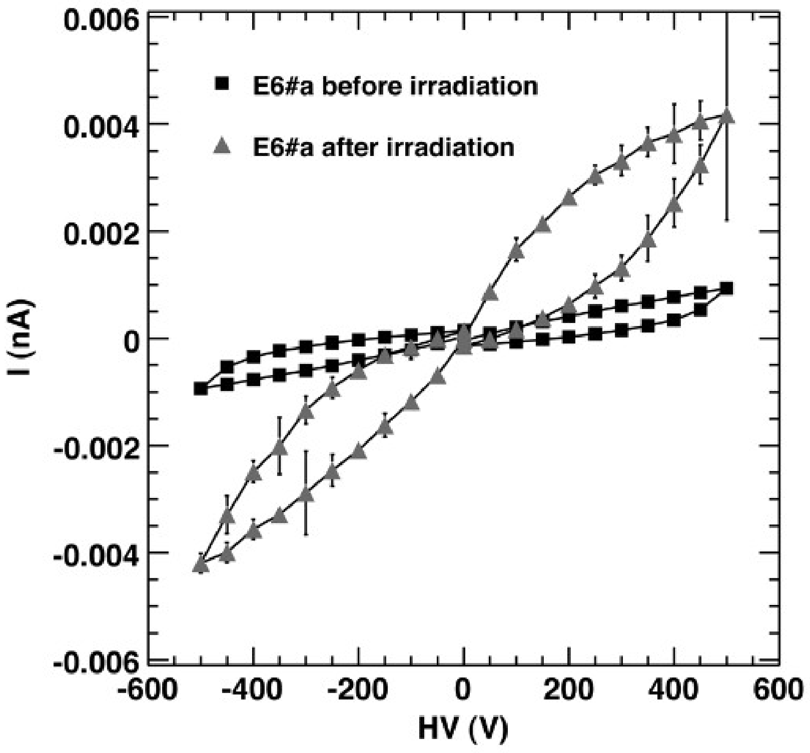
Different sensors were studied:

- 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.

Polycrystalline CVD diamond sensors

- Four 1 cm^2 CVD sensors were studied:
  - showed good linear response on particle flux.
  - Operational after 7 MGy, though the charge collecting efficiency decreased.





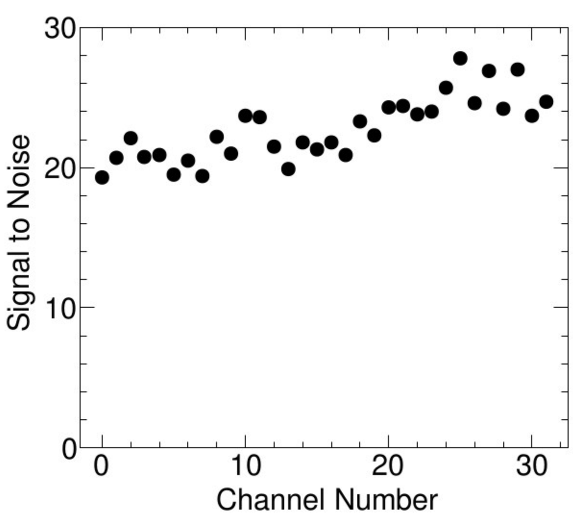
Current increased after the irradiation, but it remained withing few pA and is uncritical for operating the diamond as a sensor.

GaAs sensors

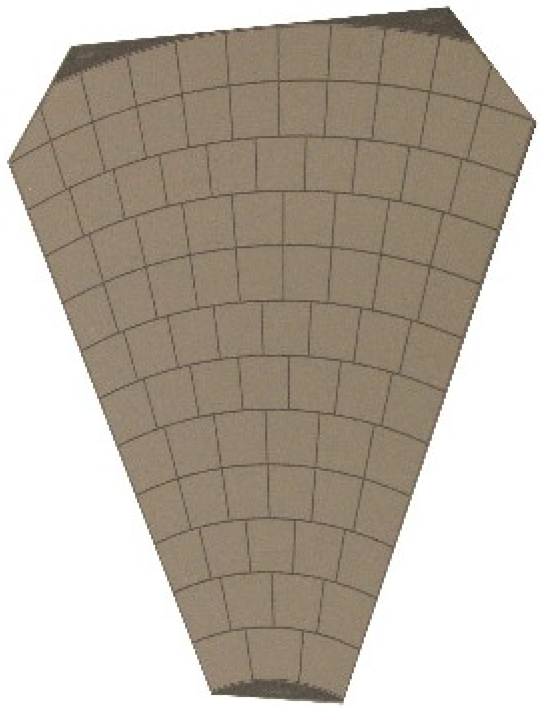
Two types of GaAs:Cr sensors 500 μm thick with different pad geometry were produced and studied both in the lab and in test-beam.

Different doping: Sn, Te:

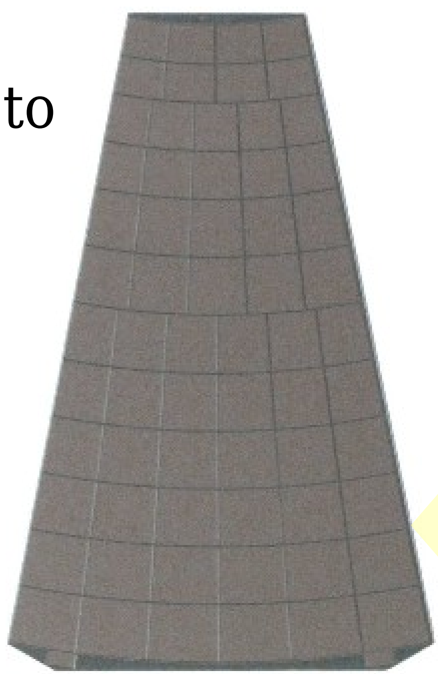
- Irradiated up to 1.2 MGy;
- The smallest decrease of CCE is for Sn;
- MIP reconstruction up to 600 kGy;
- Current: 200 nA at 50 V increased up to factor of 2 after 1.2 MGy.



Signal to noise ratio



Pads area: ~5x5 mm^2



Pads area depends on R

Plans

- Improvements can still be made in the integration of LumiCal in ECAL.
- Investigate the performance of LumiCal in combination with tracking detector:
  - Improve the accuracy of polar angle measurement;
  - Provide additional information for particles identification;
  - Improve LumiCal alignment.
- For LHCAL to measure hadrons behind LumiCal not much work has been done so far.
- If changes happen in beam parameters, like smaller L*, we will have to do new design work.
- Smaller L* means stronger focusing, leading to more beamstrahlung and hence more background, for LumiCal, and BeamCal.
- After a redesign of the detector geometry, all background estimates have to be repeated.

Summary

- In the present conceptual design LumiCal and BeamCal detectors can provide luminosity measurements with precision required for physics analysis in linear collider experiments.
- Beam tests study of the sensors and detector modules demonstrated their good performance.
- Development of the next generation of readout chips and electronic boards for LumiCal and BeamCal are in progress.
- Detector modules have to be improved to match mechanical constraint of final design.