Forward Region Calorimetry

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for the FCAL Collaboration

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FCAL Collaboration

- University of Colorado, Boulder
- Brookhaven National Lab, Upton
- Yale University, New Haven
- Laboratoire de l Accélérateur Linéaire, Orsay
- Royal Holloway University, London
- AGH University, Krakow
- Institute of Nuclear Physics, PAN, Krakow
- DESY
- Joint Institute Nuclear Research, Dubna
- National Center of Particle & HEP, Minsk
- Academy of Science, Prague
- VINCA Inst. of Nuclear Sciences, Belgrade
- Tel Aviv University

- Cooperation with SLAC

Supported by:

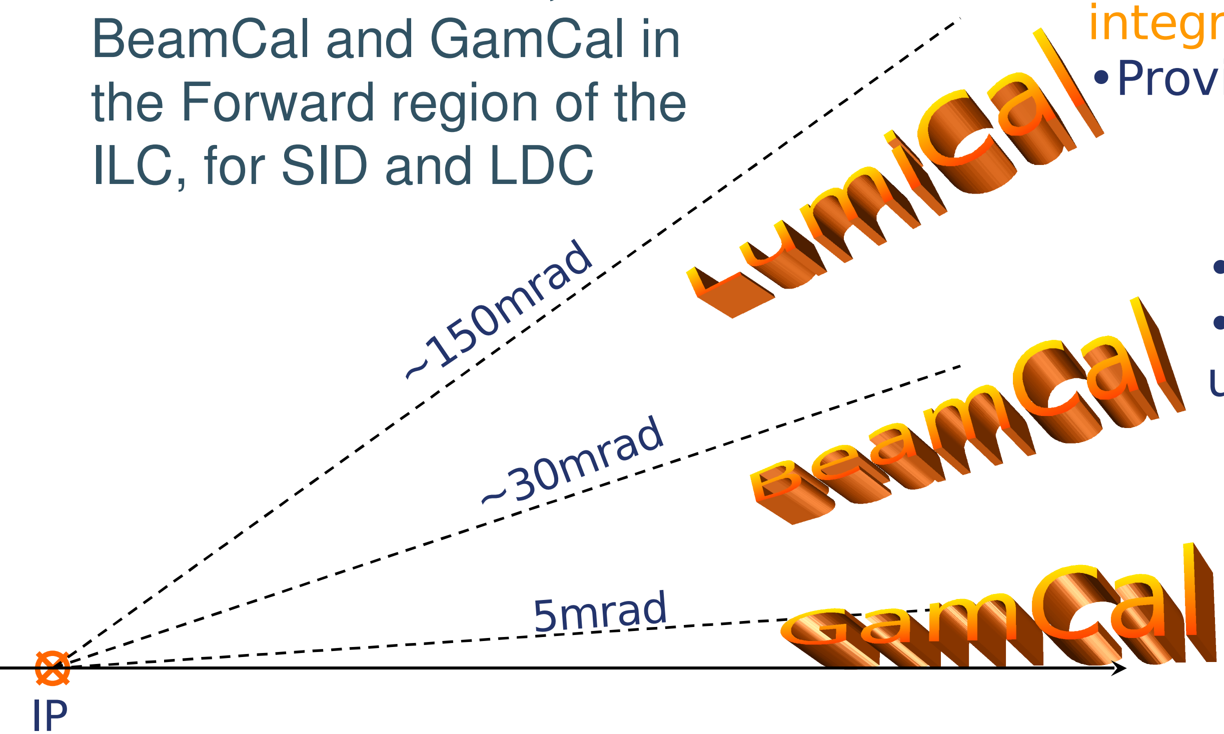
- EUROTeV,
- EUDET,
- NoRHDIA
- INTAS
- DOE

Outline

- Generel FCAL Overview
- FCAL Detectors: motivation, design concepts and simulations
  - LumiCal
  - BeamCal
  - GamCal
- FCAL integration
- Sensors R&D
- Readout Electronics R&D
- Summary

Tasks of Forward Region

- The FCAL Collaboration develops the Very Forward Detectors: LumiCal, BeamCal and GamCal in the Forward region of the ILC, for SID and LDC



LumiCal:
- Precise measurement of integrated luminosity ($\Delta L/L \geq 10^{-4}$)
- Provide 2-photon veto

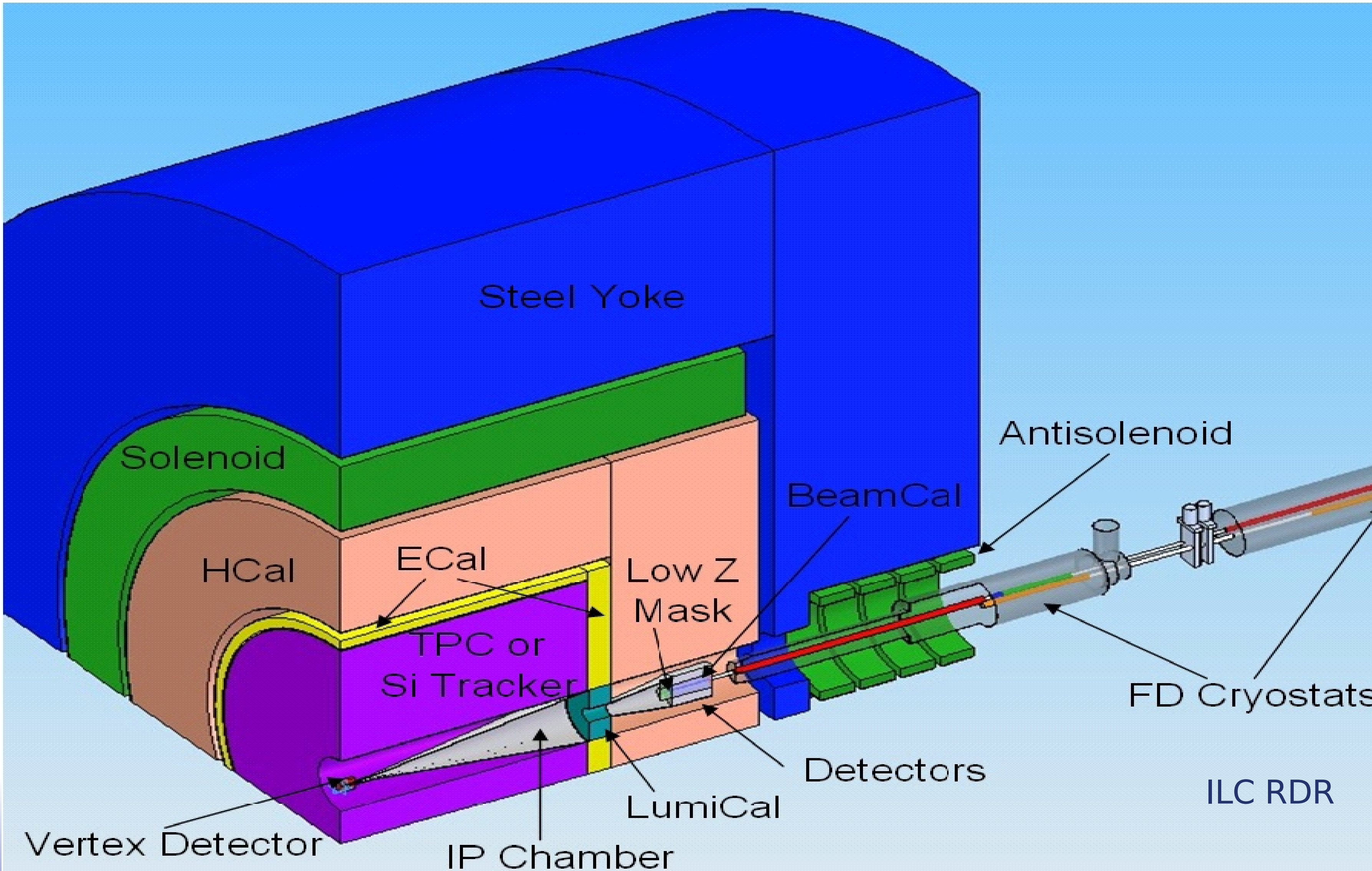
BeamCal:
- Provide 2-photon veto
- Serve beamdiagnostics using beamstrahlung pairs

GamCal:
- Serve beamdiagnostics using beamstrahlung photons

Challenges:

High precision, high occupancy, high radiation dose, fast read-out!

Forward Region Design



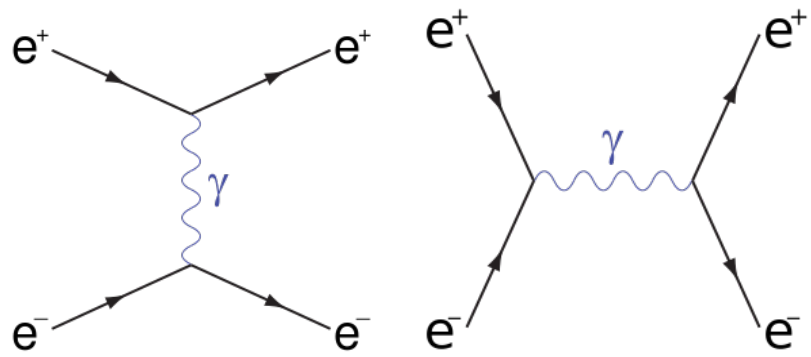
LumiCal -Precise Measurement of Luminosity

- Required precision is:

  $\Delta L/L \sim 10^{-4}$ (GigaZ 10^{9}/year)

  $\Delta L/L < 10^{-3}$ ($e^+e^- \rightarrow W^+W$ 10^{6}/year)

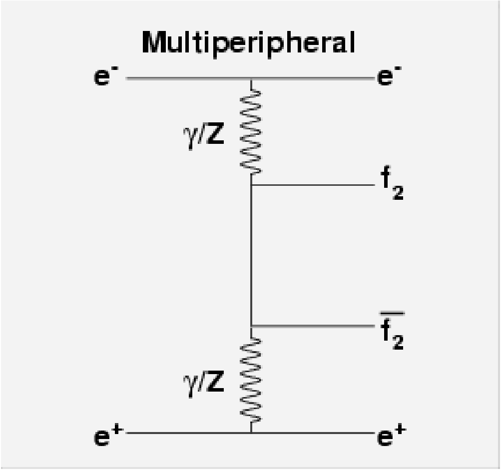
  $\Delta L/L < 10^{-3}$ ($e^+e^- \rightarrow q^+q^-$ 10^{6}/year)

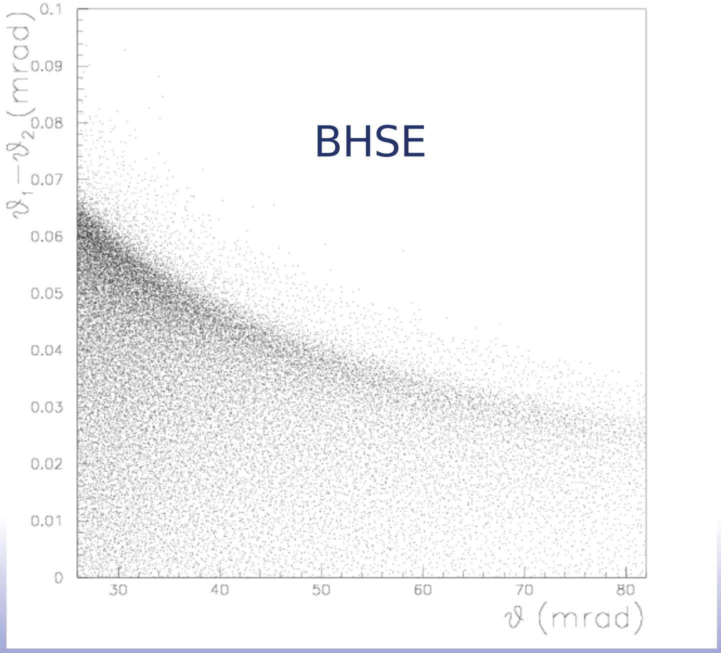


- Bhabha scattering ee-> ee(γ) is the gauge process:
  - Count Bhabha event in a well known accepctance region => $L = N/\sigma$
  - High statistics at low angles ($N_{Bhabha} \sim 1/\theta^3$) => need about 1 year of running at design luminosity
  - Well known electromagnetic process (LEP: 10^{-3}): the current limit on the theoretical cross section error is at ~5 10^{-4}.

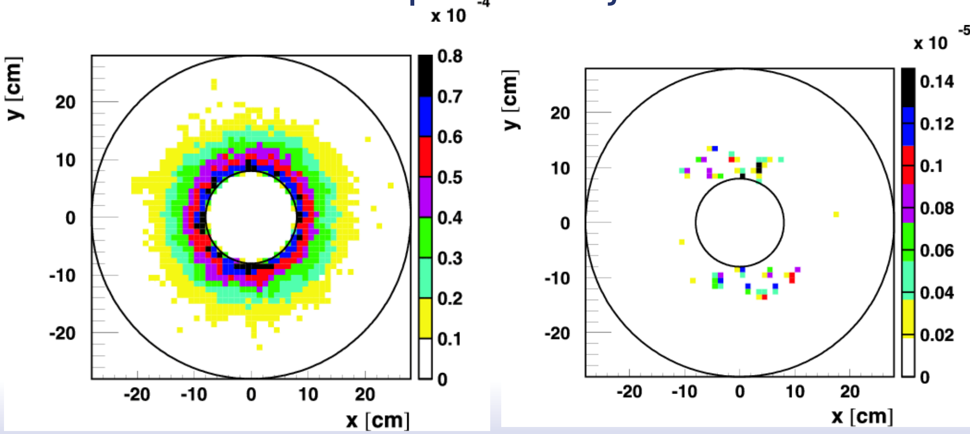
LumiCal: Physics Background and Beam-Beam Effect

- 2-photon events are the main background.
- We determined an efficient set of cuts to reduce the background to the level of 10^{-4}.
- Bhabha Suppression Effect is due to EM deflection and energy loss by beamstrahlung of Bhabhba's..



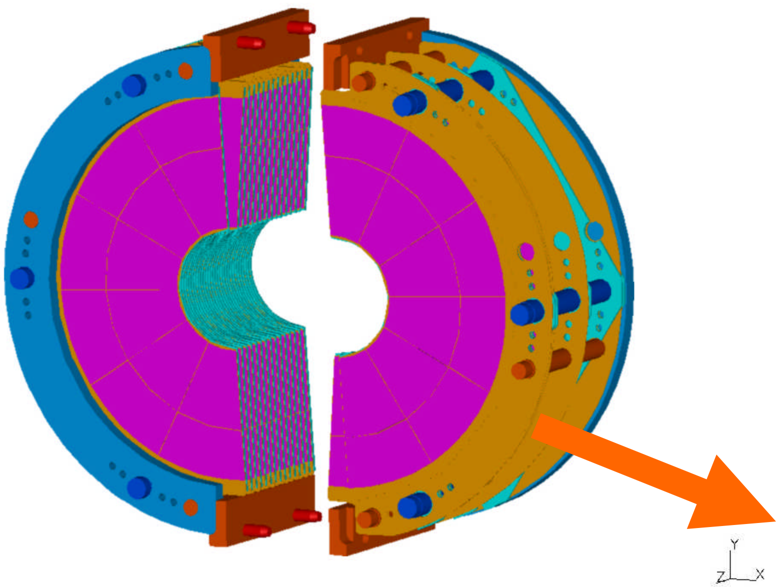


2-photon rejection

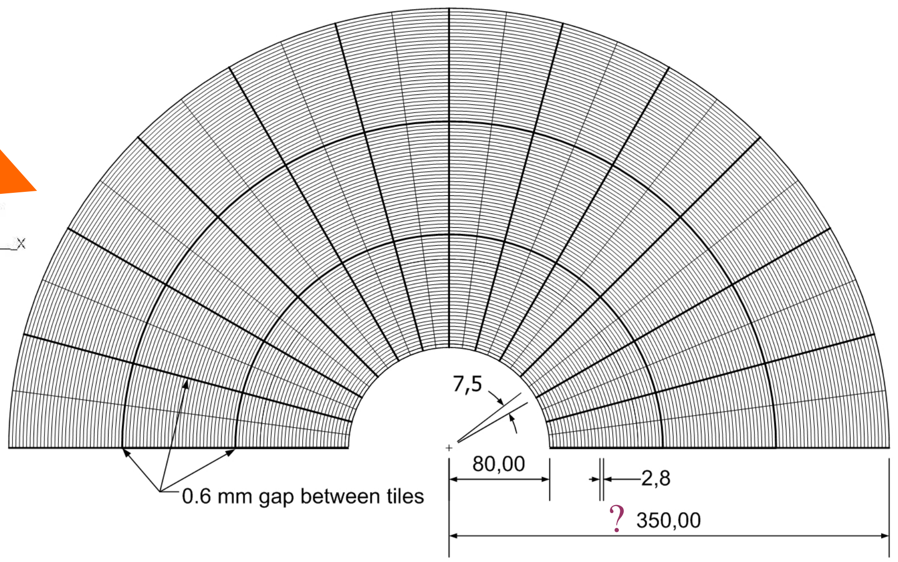


LumiCal Design

Si/W sandwich calorimeter,
2 half barrels, each 30-40 layers



Single detector layer
24 (48) azimuthal sectors,
each sector ~96 radial pads



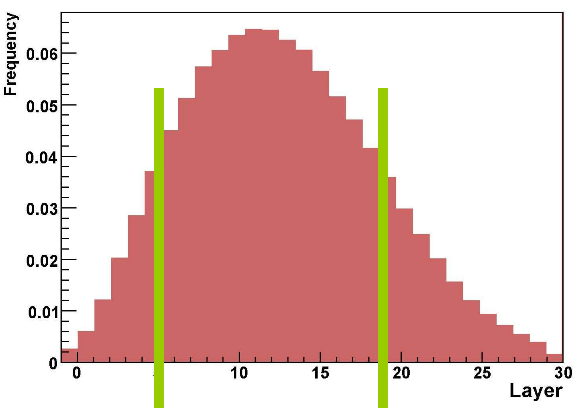
Half plane - 24 sectors, 96 cylinders (36 silicon tiles, 2304 pads)

Each layer consists of
0.35cm thick tungsten
and 300μm thick Si sensor

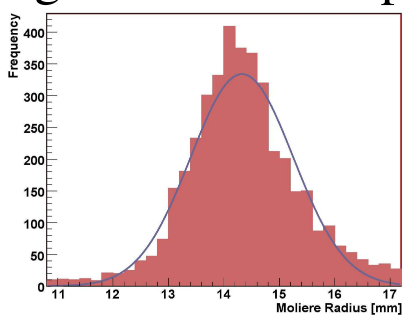
Clustering in LumiCal

1. Perform initial 2D “Nearest Neighbors” clustering in shower-peak layers.
2. Extrapolate “virtual cluster” CMs in non shower-peak layers, and build real clusters accordingly.
3. Build (global) 3D “super clusters” from all 2D layer clusters.
4. Check cluster properties (longitudinal development), and try to re-cluster.

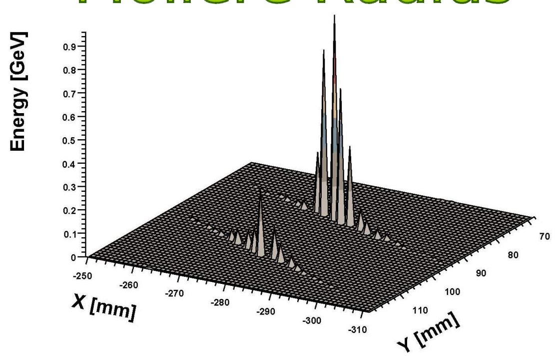
Shower-Peak



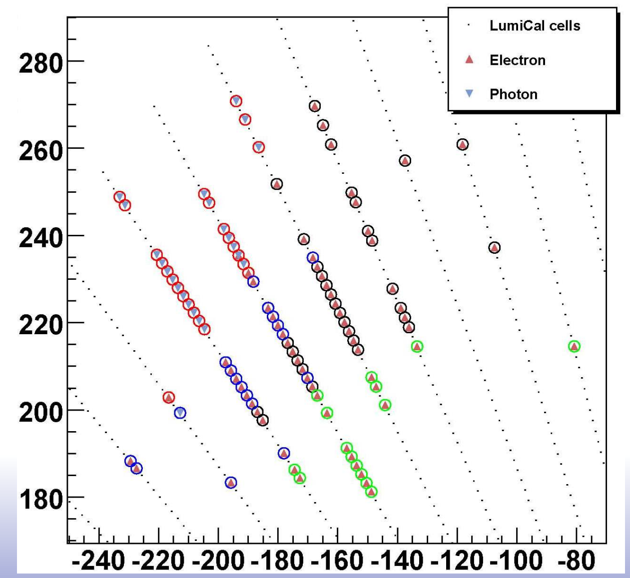
Number of hits per layer



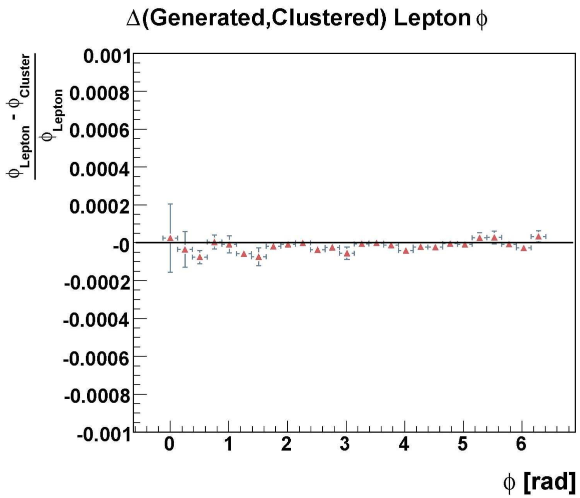
Moliere Radius

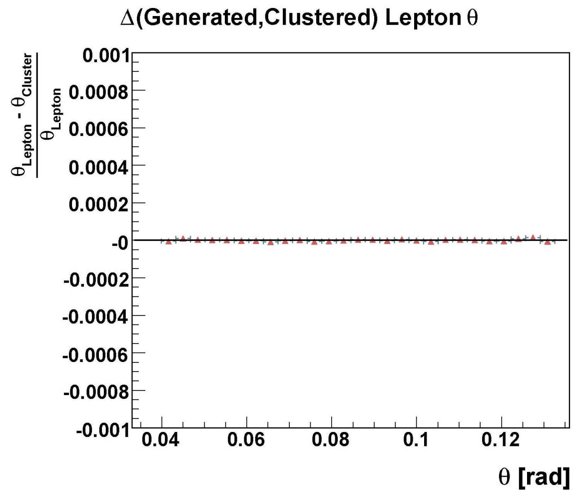


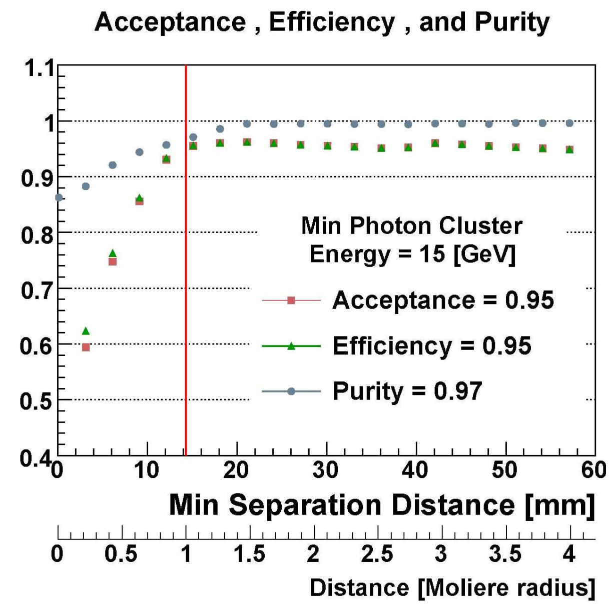
2D Clustering

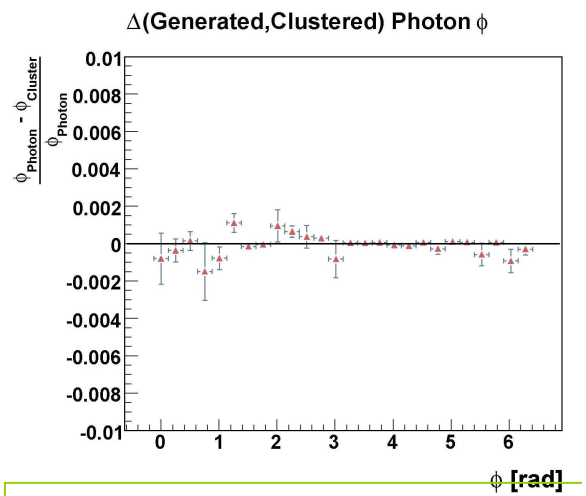


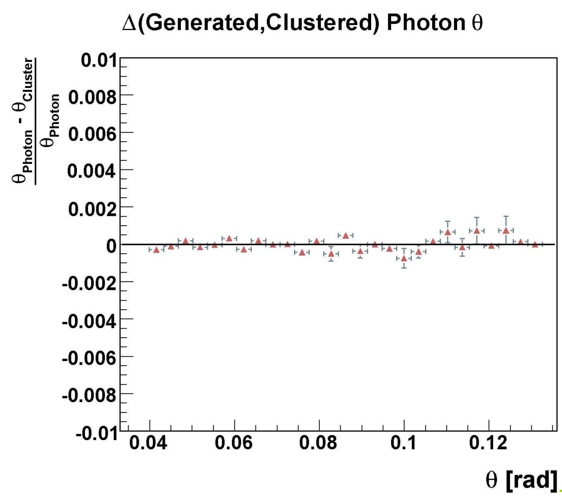
Cluster position reconstruction







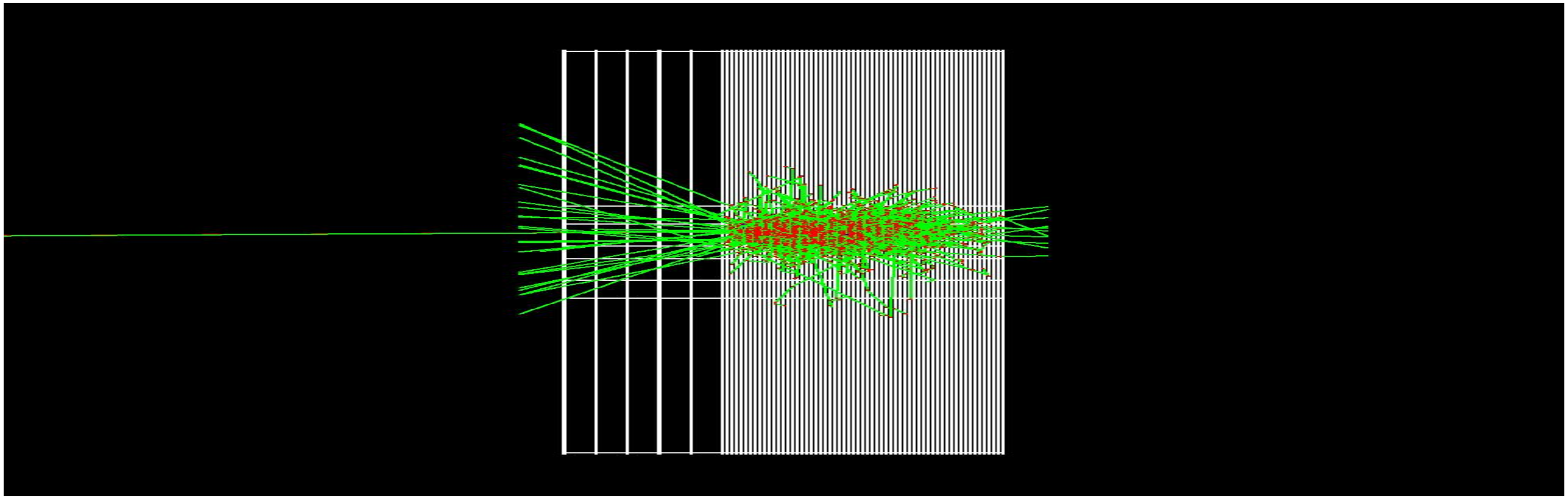




For Bhabha events with $\left(\sqrt{s} = 500\ [\mathrm{GeV}]\right)$:

Position reconstruction with error smaller than 0.1% for clusters which pass the acceptance cut of: (Separation distance > 1 Moliere radius) && (Energy > 15 GeV)

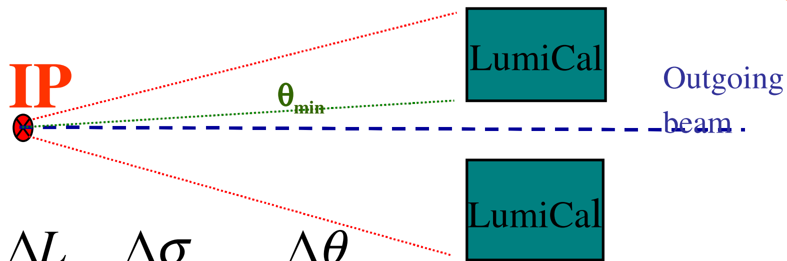
New LumiCal design concepts



- LumiCal is composed of two components: Silicon Tracker and a Calorimeter.
- In this design five silicon tracking layers are used, granulated into concentric strips.
- New reconstruction algorithm developed, combining Tracker and Calorimeter info.
- Above 90% efficiency of the tracker.
- First results:
  - Significant improvement in polar resolution (factor of 5 - 10).
  - Improvement in the polar bias (factor of 1.2 – 3).
- Design optimization study is ongoing (including a pixel tracker version).

LumiCal Position Aligment

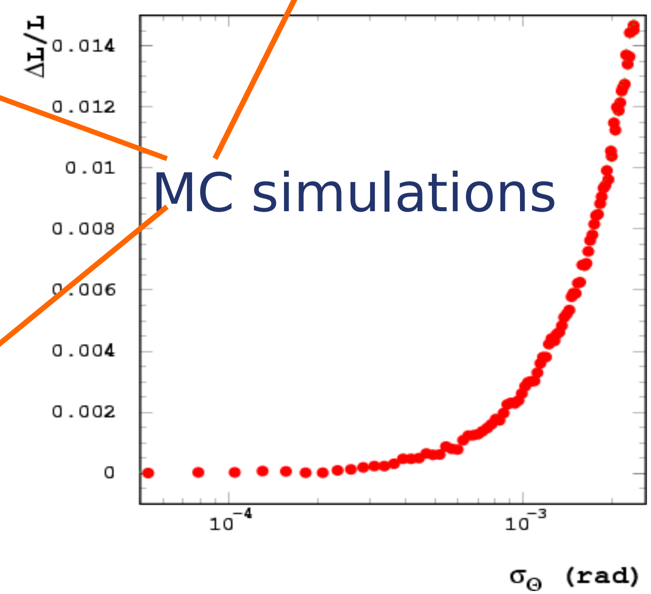
Single (L/R) LumiCal alignment



$$\frac{\Delta L}{L} = \frac{\Delta\sigma}{\sigma} \cong 2\frac{\Delta\theta}{\theta_{\min}}$$

LumiCal X, Y position with respect to the beam should be known with accuracy better than ~700 μm (optimal ~100 -200 μm) (LumiCal centered on outgoing beam)

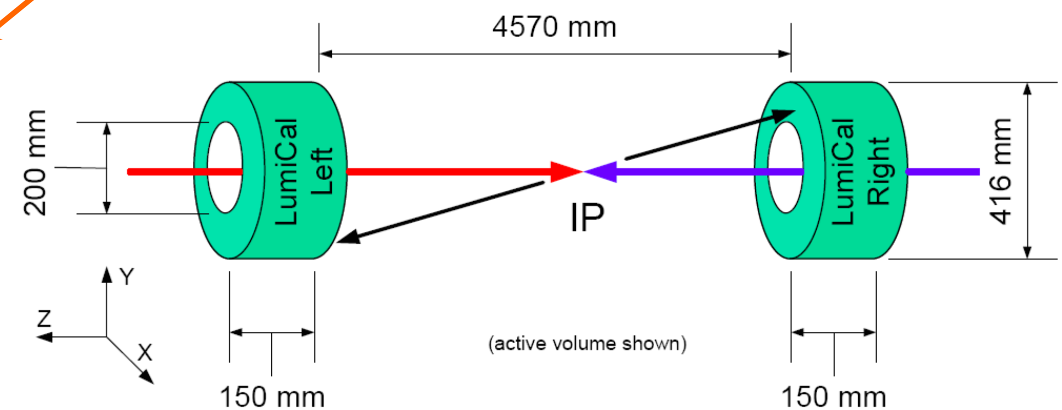
Inner radius accuracy ~ 4μm



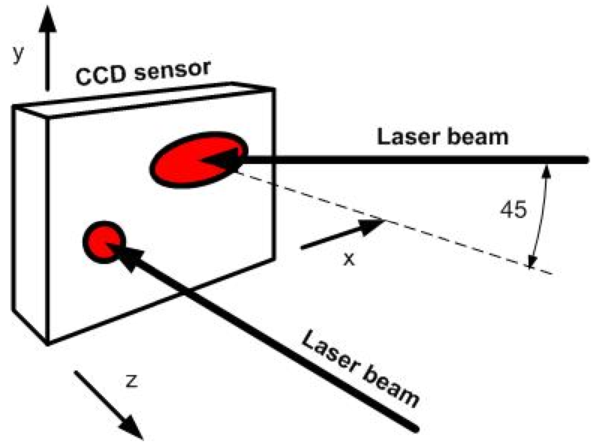
MC simulations

Two LumiCal's (L,R) alignment

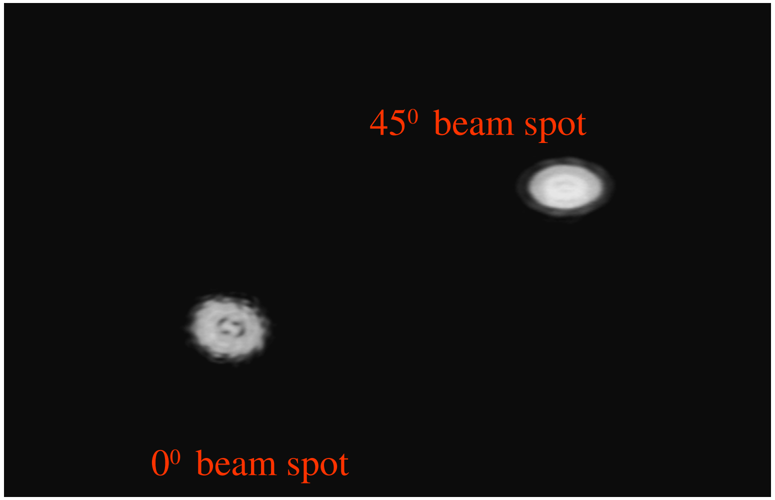
Requested accuracy on distance between two LumiCal's better than ~60 -100 μm (14 mrad crossing angle)

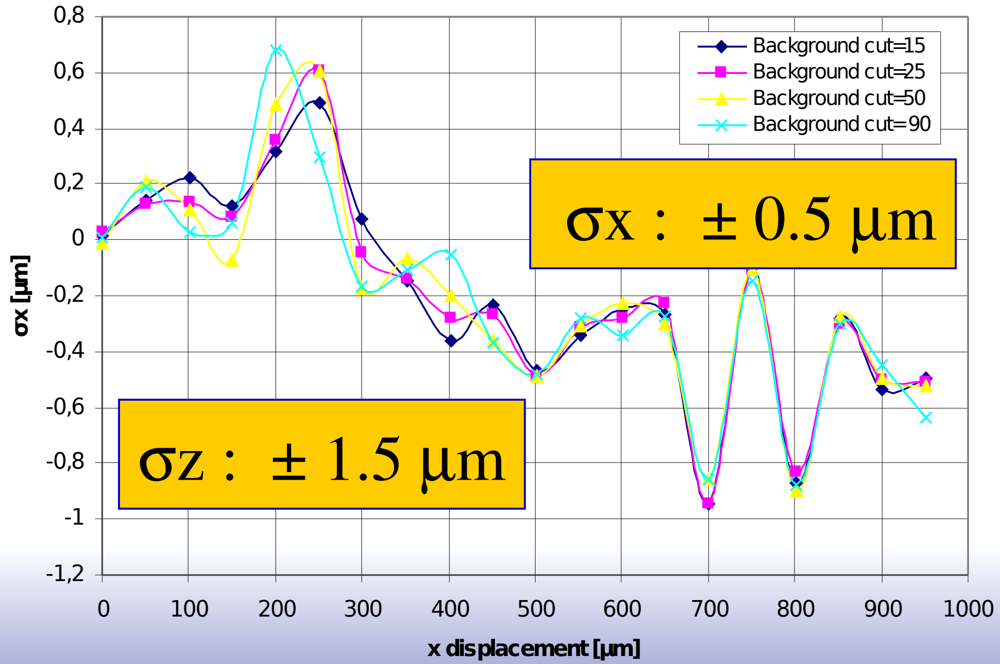


Laser Alignment System



Two laser beams (one perpendicular, second 45˚ to sensor plane) allow to measure XYZ translation in one sensor





σx : ± 0.5 μm

σz : ± 1.5 μm

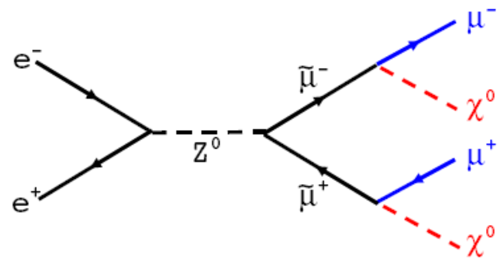
Temperature stability is an issue

Observed changes ~ 1 μm/1 ⁰C

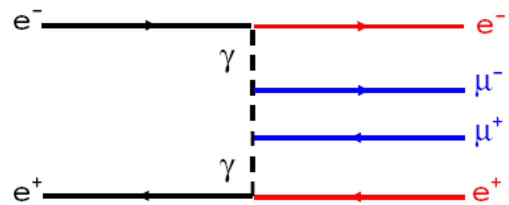
Works underway on integration of LAS into FCAL system

BeamCal Challenges

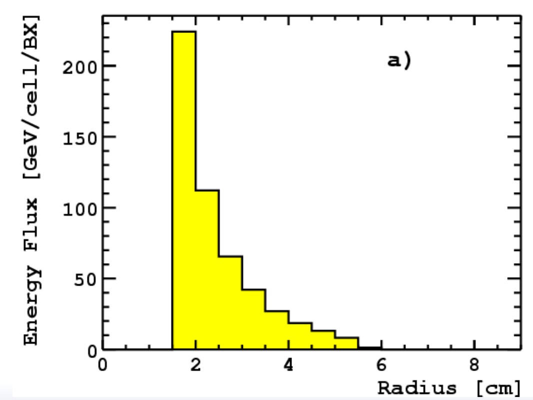
- BeamCal will extend the sensitive region to lowest polar angles.
- Challenge:
  Detect single high energetic particle on top of a background of 10^4 low energetic e^+e^- pairs.
- BeamCal serves also as part of the beam diagnostics system

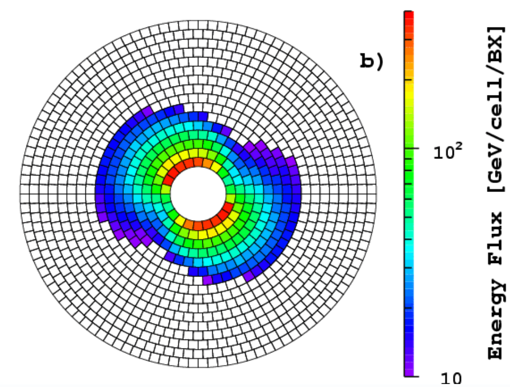


Physics signal:
e.g. SUSY smuon production



Background signal:
2-photon event, may fake the upper signal if the electron escapes.

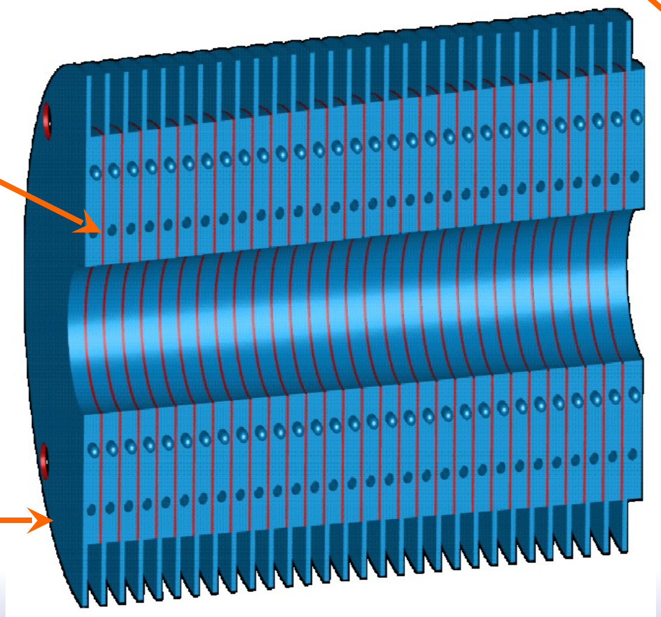




BeamCal Design

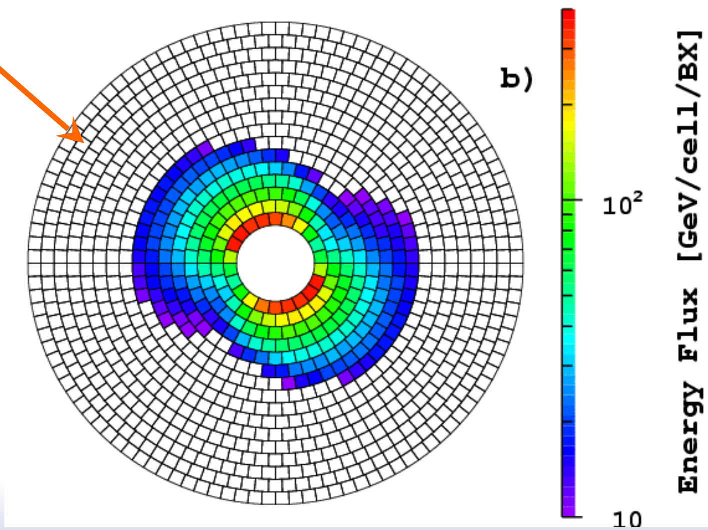
- Compact EM calorimeter with sandwich structure:
  - 30 layers of 1 X_0
    - o3.5mm W and 0.3mm sensor
  - Angular coverage from ~5mrad to ~28 mrad
  - Moliére radius $R_M \approx 1$cm
  - Segmentation between 0.5 and 0.8 x R_M

Radiation hard sensors



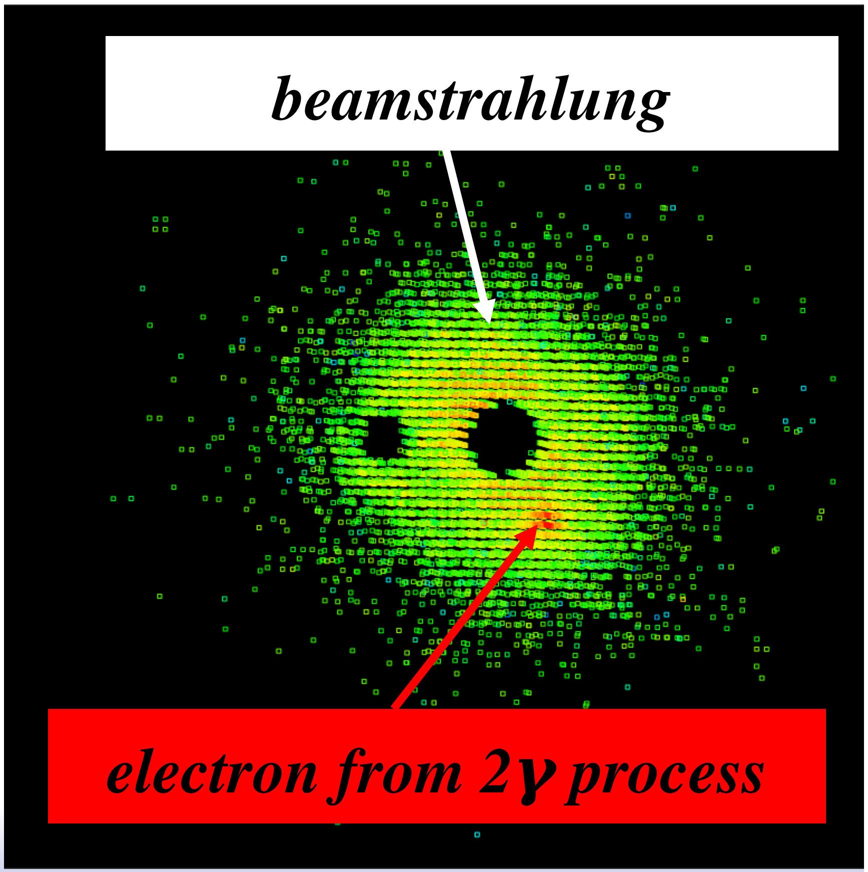
W absorber

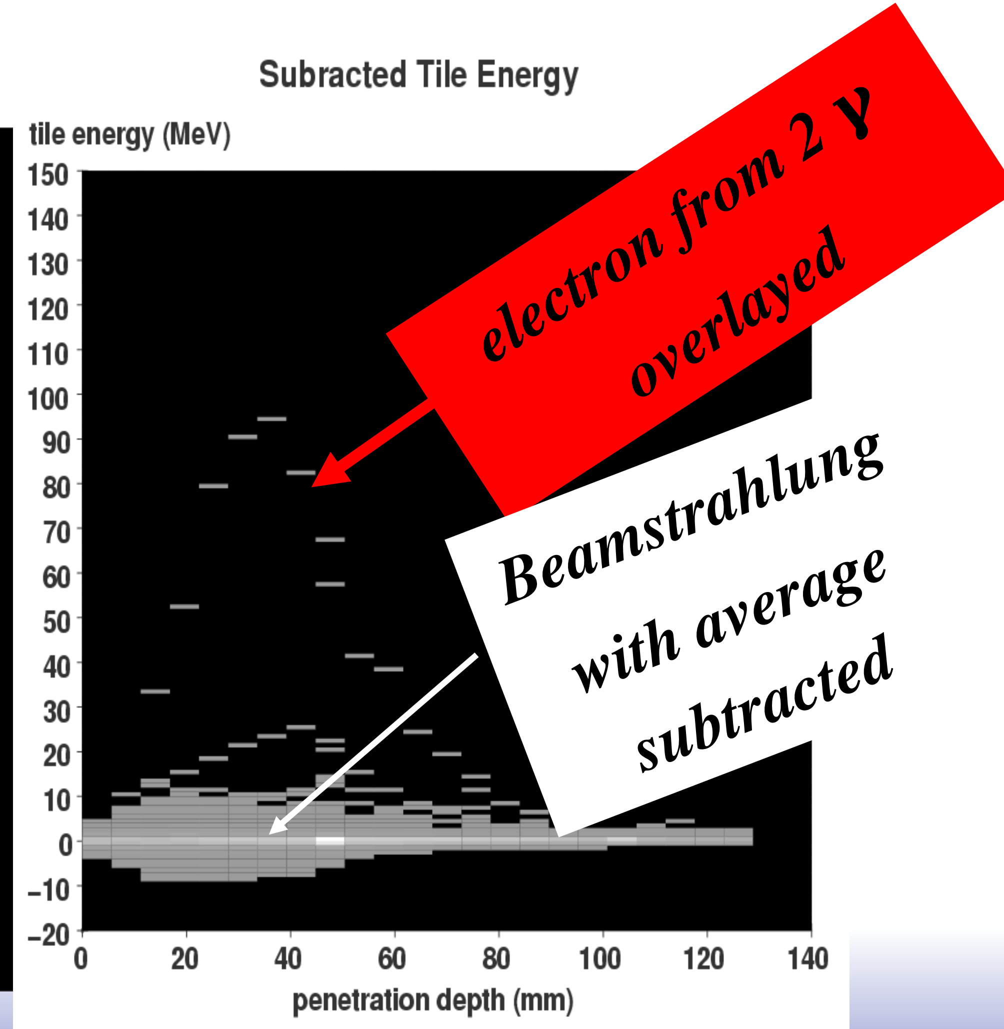
Single detector layer



BeamCal: Particle Veto

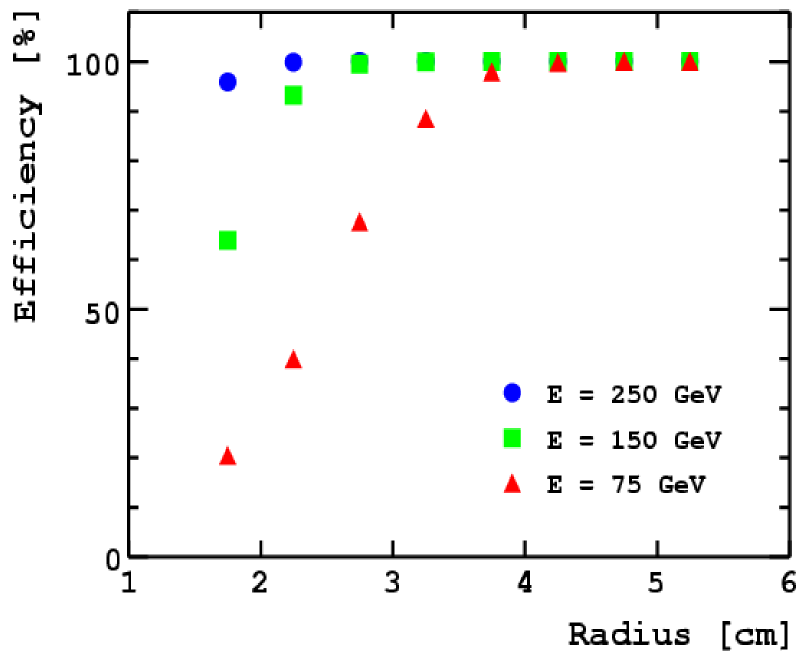
Head on view

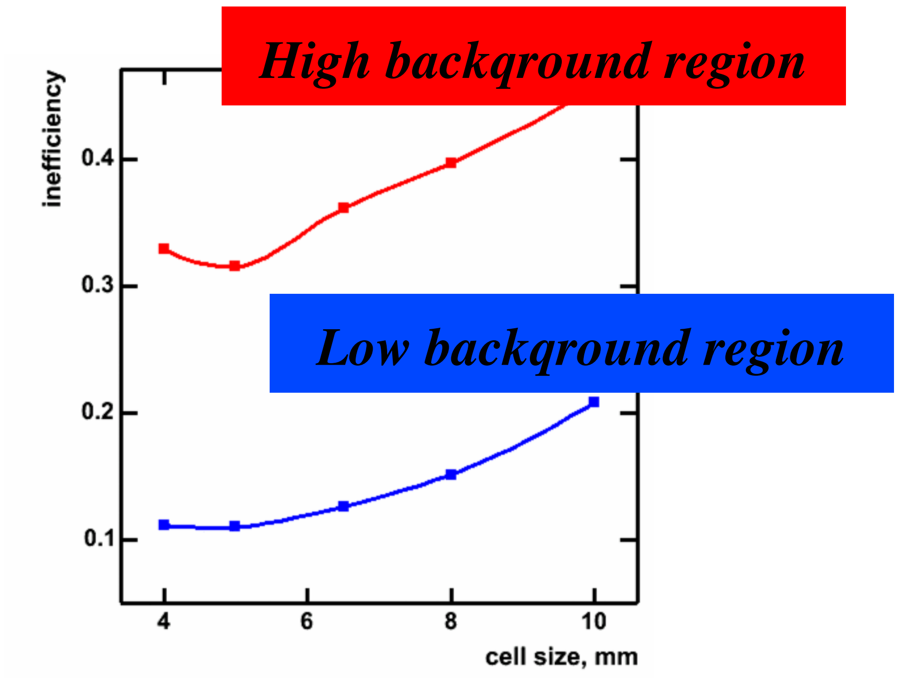




BeamCal: Veto Efficiency

Small crossing angle

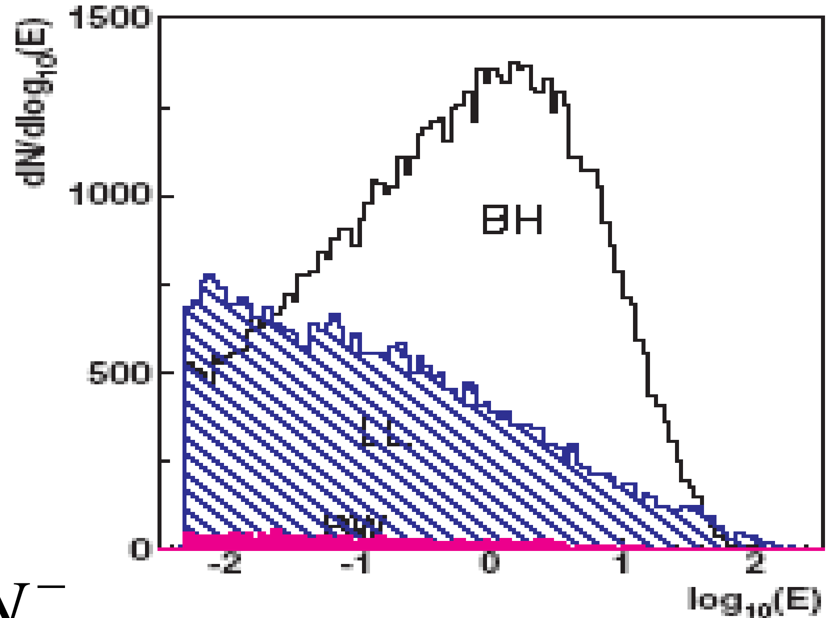




GamCal Motivation

- Measuring the beam-strahlung pairs and gammas provides robust complementary information
- Ratio of pairs to gammas is largely proportional to instantaneous luminosity

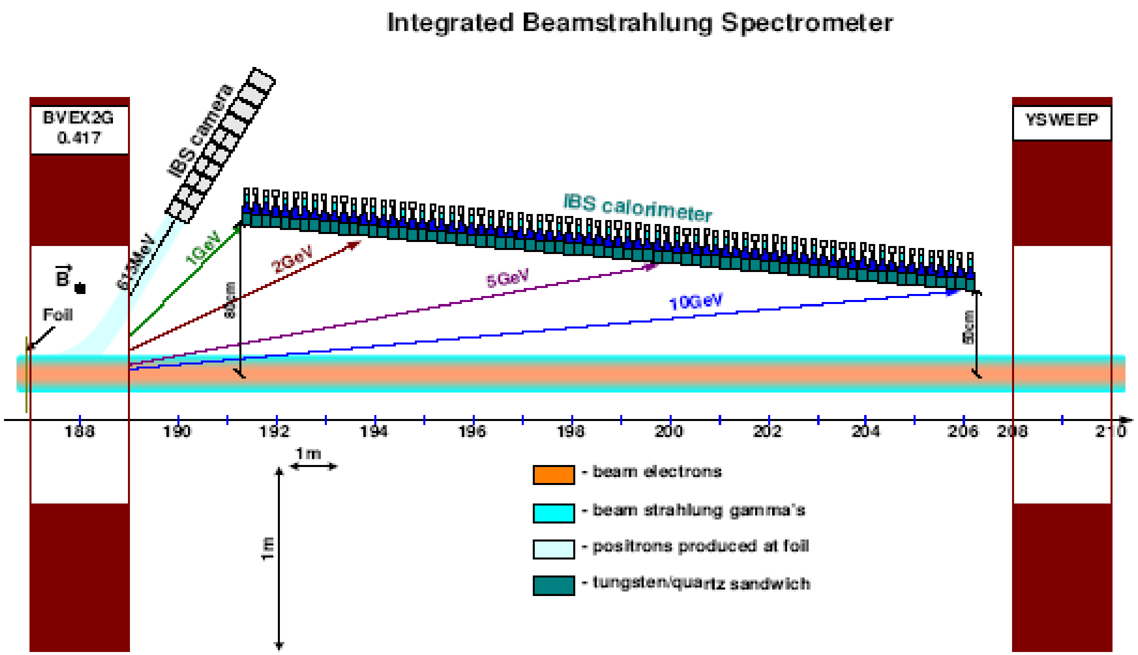
Bethe-Heitler: $\gamma e \rightarrow e\, e^{+} e^{-}$



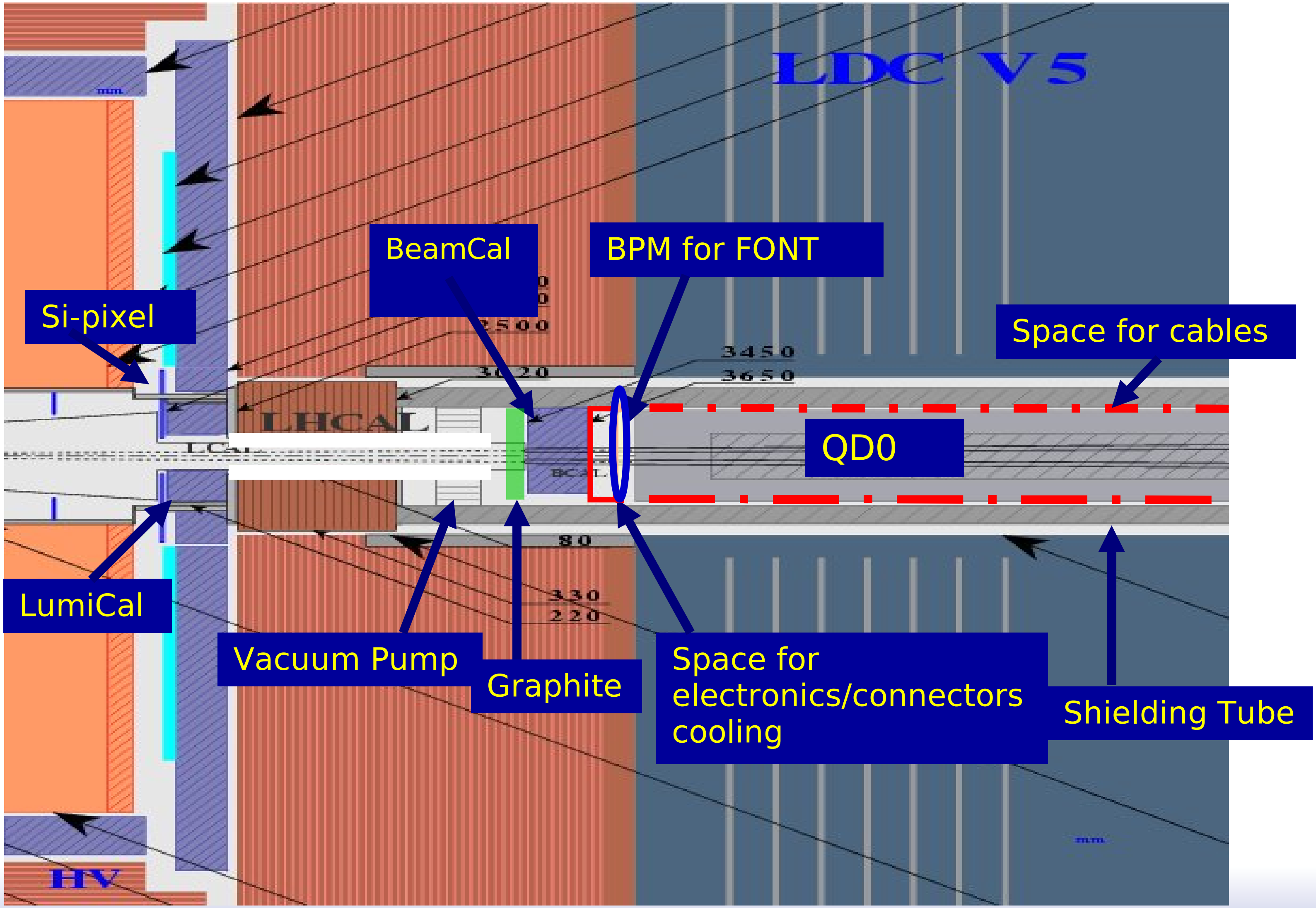
$$\frac{N_{ee}}{N_{\gamma}} \propto \frac{\sigma_{BH} N_e^o}{\sigma_x^o \sigma_y^o} \qquad L \propto \frac{N_o^+ N_o^-}{\sigma_x^o \sigma_y^o}$$

GamCal Design Concept

- 180m from interaction point
- 10^{-4} X_0 to convert beam-strahlung gammas into e^+e^- pairs
- Dipole magnet separates the pairs from beam electrons
- Calorimeters measure the 1-10 GeV positrons
- Design currently under study



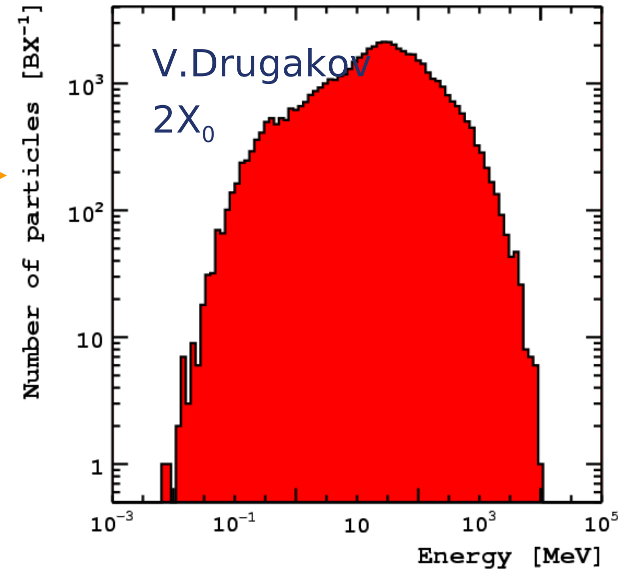
FCAL Integration



Works on FCAL mechanical integration in progress...

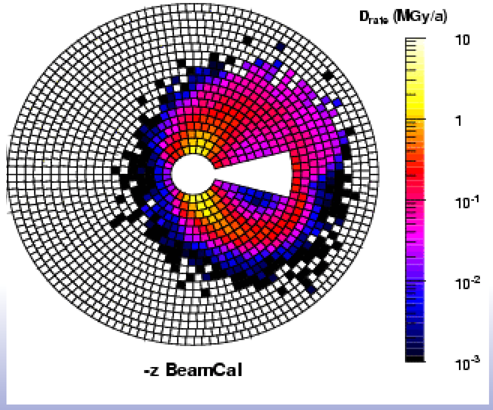
BeamCal: Radiation Hard Sensor Materials

- The load from low energetic pairs from beamstrahlung on the BeamCal will be very high, ~10^5 e^+e^- pairs, depositing about 10TeV per bunch crossing. **This corresponds to a dose of several MGy per year (several 100 Mrads per year !!!).**
- We consider several sensor materials:
  - CVD diamond sensors
  - GaAs sensors
  - SiC
  - radiation hard Si



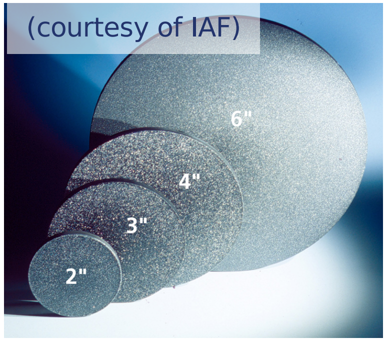
Particle Energy spectrum

≈ 5 MGy/a

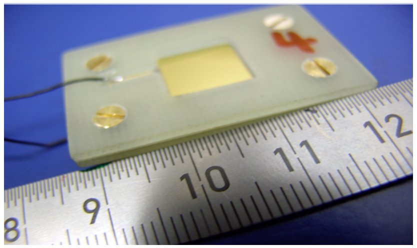


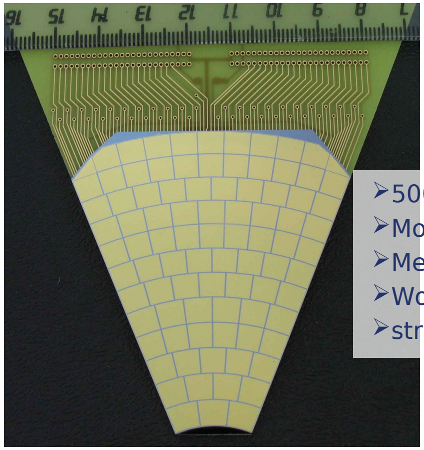
Materials under Investigation

- pCVD diamonds:
  - radiation hardness under investigation (e.g. LHC pixel detectors)
  - advantageous properties like: high mobility, low $\varepsilon_R = 5.7$, thermal conductivity
  - availability on wafer scale
- GaAs:
  - semi-insulating GaAs, doped with Sn and compensated by Cr
  - produced by the Siberian Institute of Technology
  - available on (small) wafer scale
- sCVD diamonds:
  - available in sizes of mm²
- Rad-hard Si (just starting)



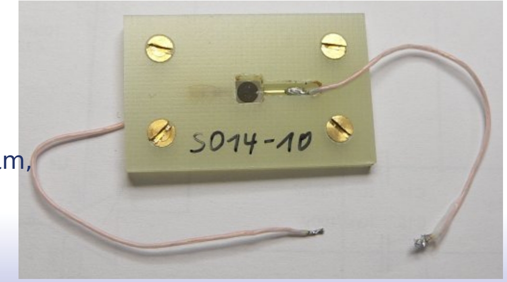
- Samples from two manufacturers:
  - Element Six$_{TM}$
  - Fraunhofer Institute for Applied Solid-State Physics – IAF
- 1 x 1 cm²
- 200-900 µm thick (typical thickness 300µm)
- Ti(/Pt)/Au metallization





- 500 µm thick detector, 87 5x5 mm pads
- Mounted on a 0.5 mm PCB with fanout
- Metallization is V (30 nm) + Au (1 µm)
- Works as a solid state ionization chamber
- structure is provided by metallization

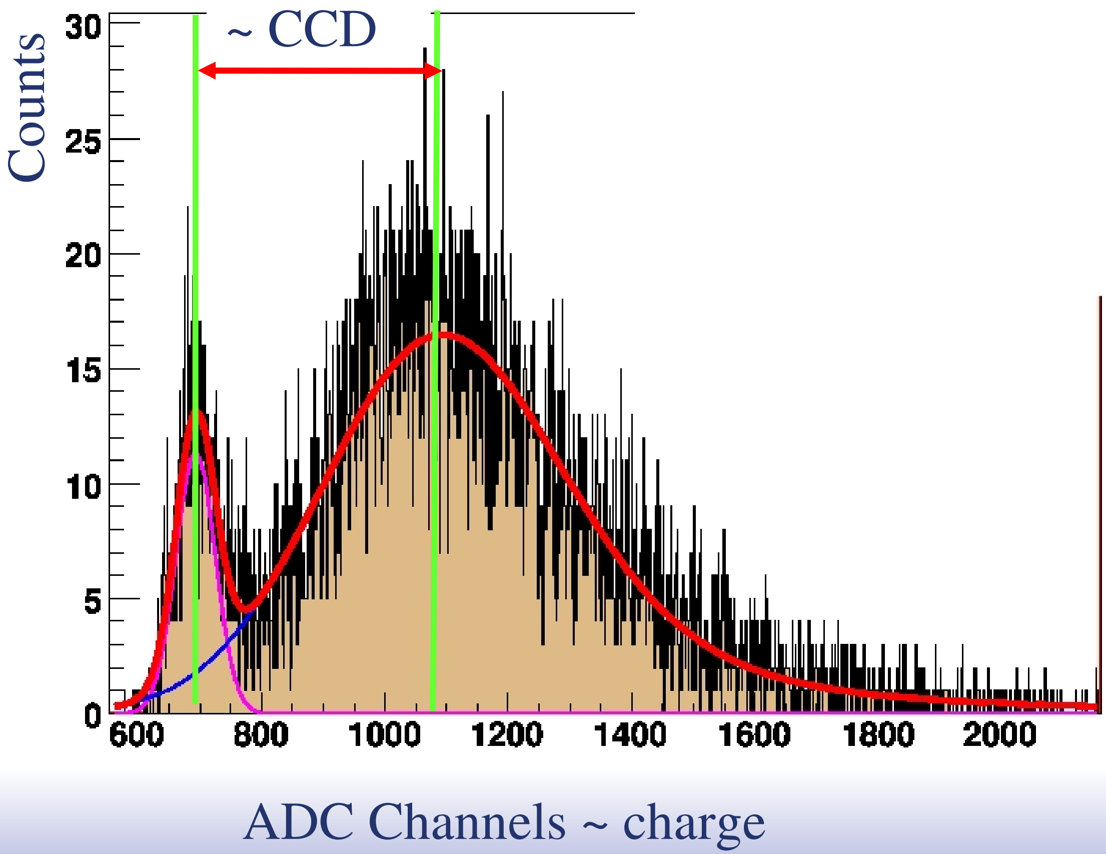
- scCVD diamond
- area 5x5 mm2, thickness 340 µm,
- metallization Ø3mm



CCD & other Measurements

CCD = *Charge Collection Distance*

= mean drift distance of the charge carriers = $Q_{meas}/Q_{induced}$ x thickness

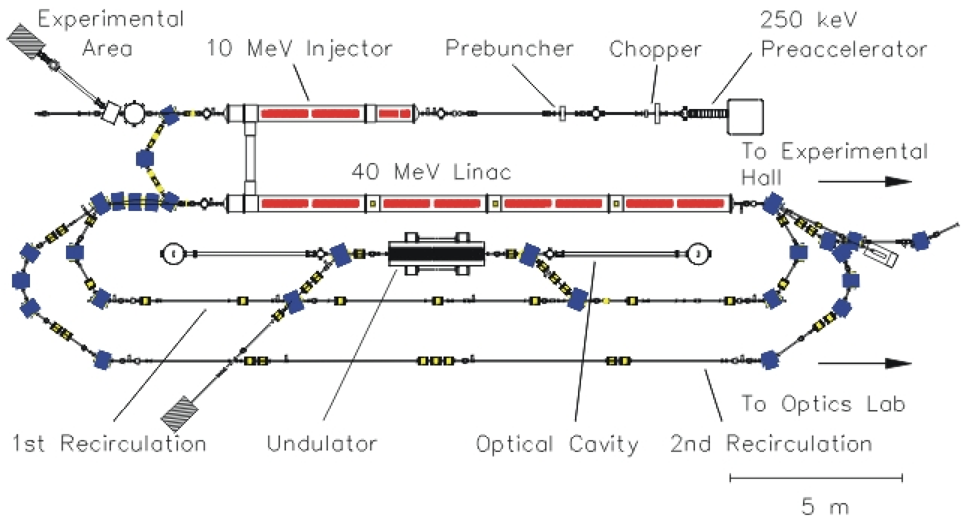


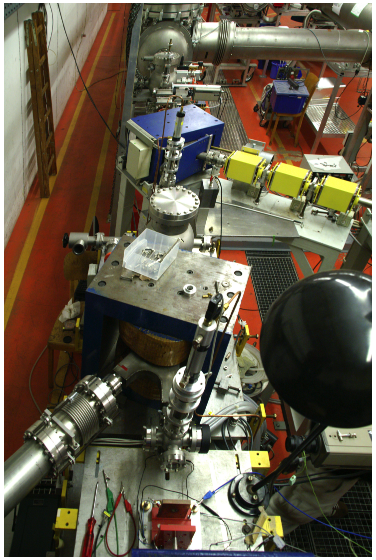
Other measurements showing sensor performance:

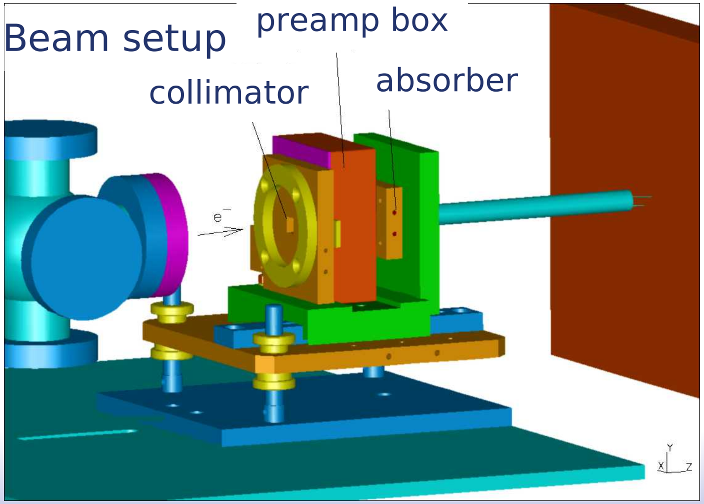
- Depletion voltage, from capacitance vs bias voltage measurement (C-V)
- Leakage current, measured as a function of bias voltage (I-V)

High Dose Irradiation

Superconducting DArmstadt LINear ACcelerator
Technical University of Darmstadt





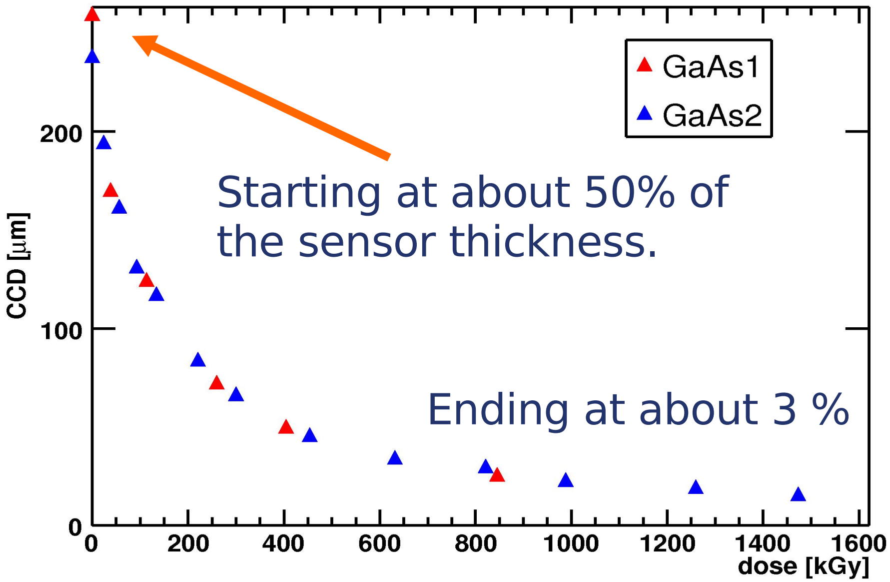


- Irradiation up to several MGy:
  10 ± 0.015 MeV and beam currents from 10 to 50 nA corresponding to 60 to 300 kGy/h.
- Keeping the sensor under bias permanently.
- This is a much higher dose rate compared to the application at the ILC (~1 kGy/h)

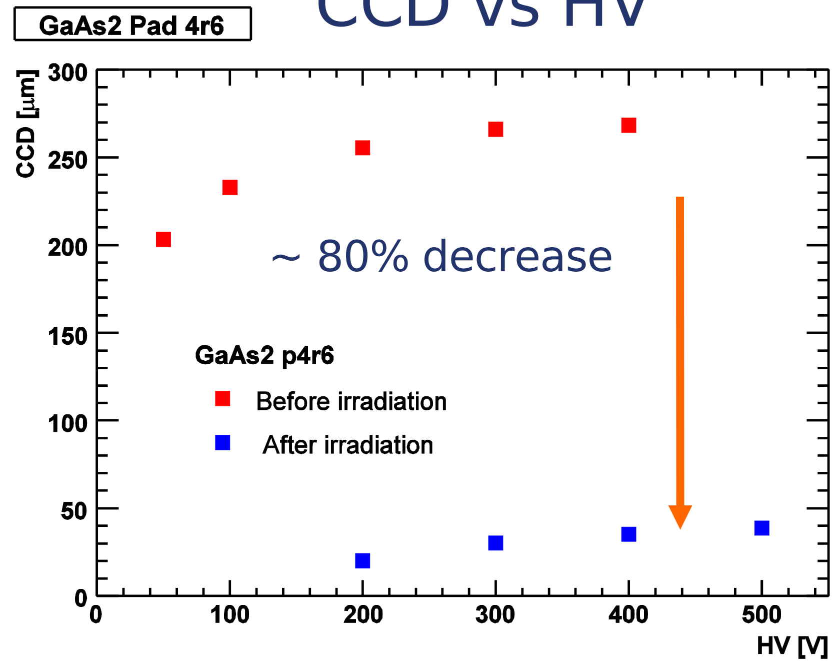
(1 MGy = 100 Mrad is deposited by about
4 x 10^{15} e^{-}/cm^{2})

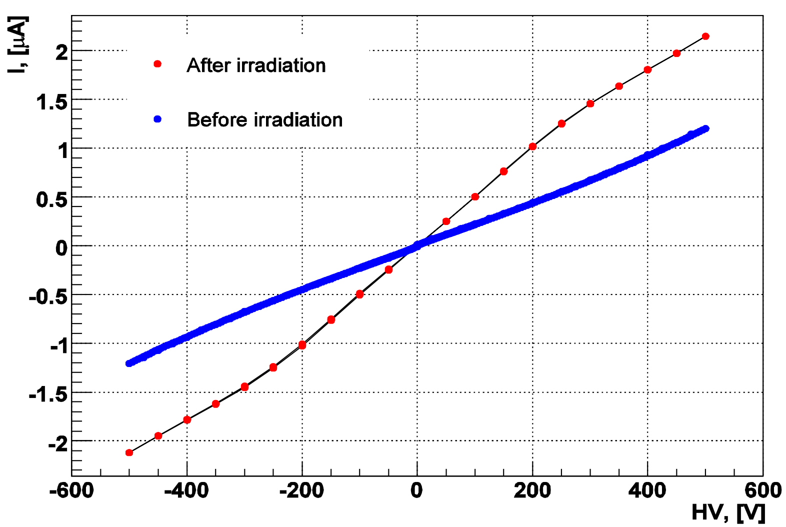
Irradiation of GaAs

CCD vs Dose



CCD vs HV



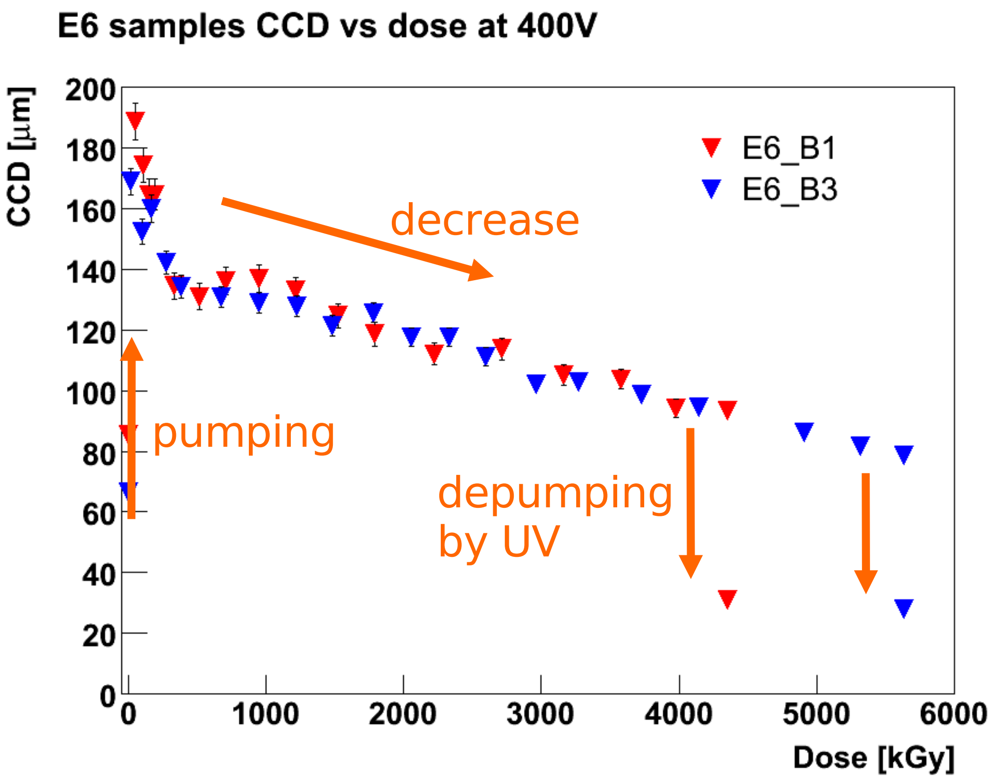


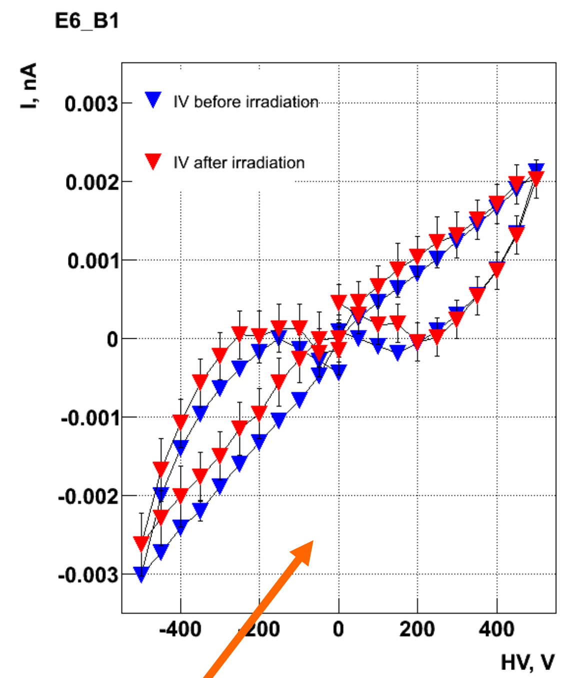
Leakage currents increase by about a factor of 2 but
it is in the μA range.

Polycrystalline CVD Diamond

After absorbing 5-6 MGy:

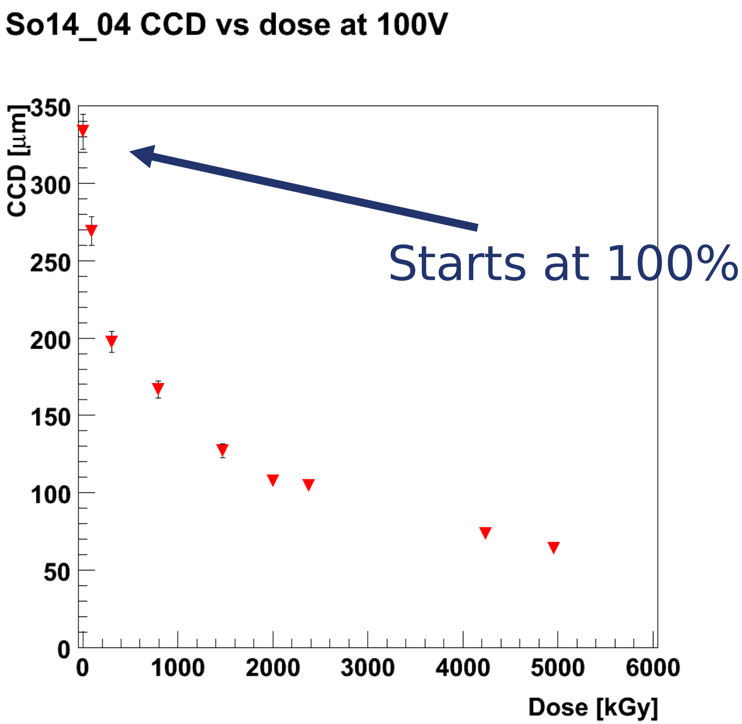
CVD diamonds still operational.

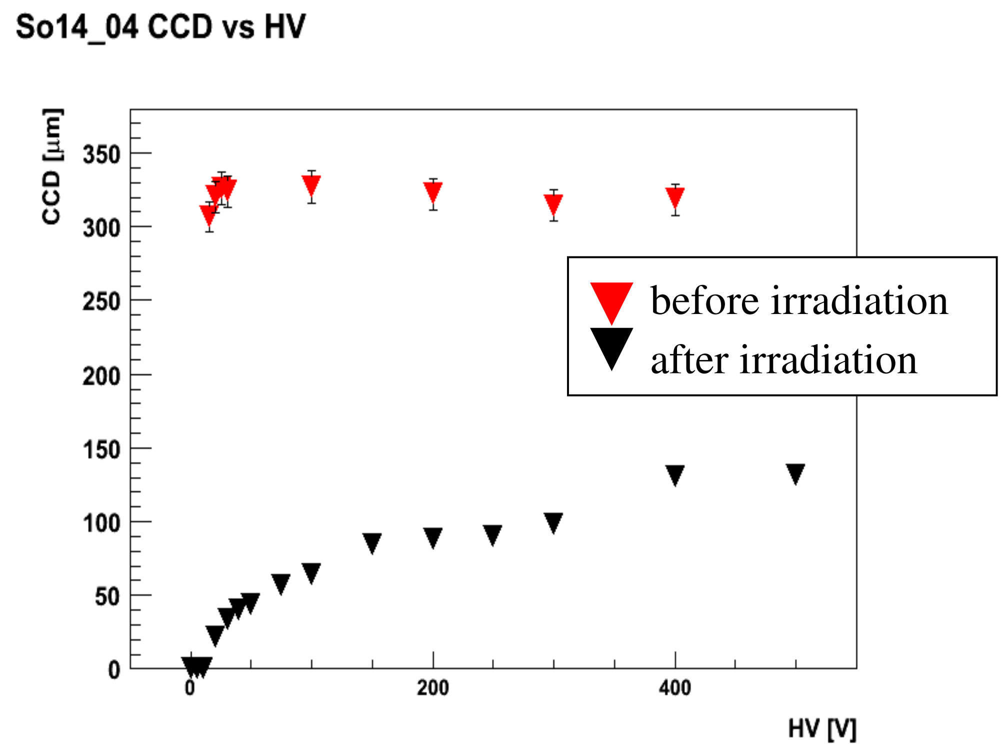




- Very low leakage currents (~pA)
- Decrease of CCD
- Generation of trapping centers

Single Crystal CVD Diamond



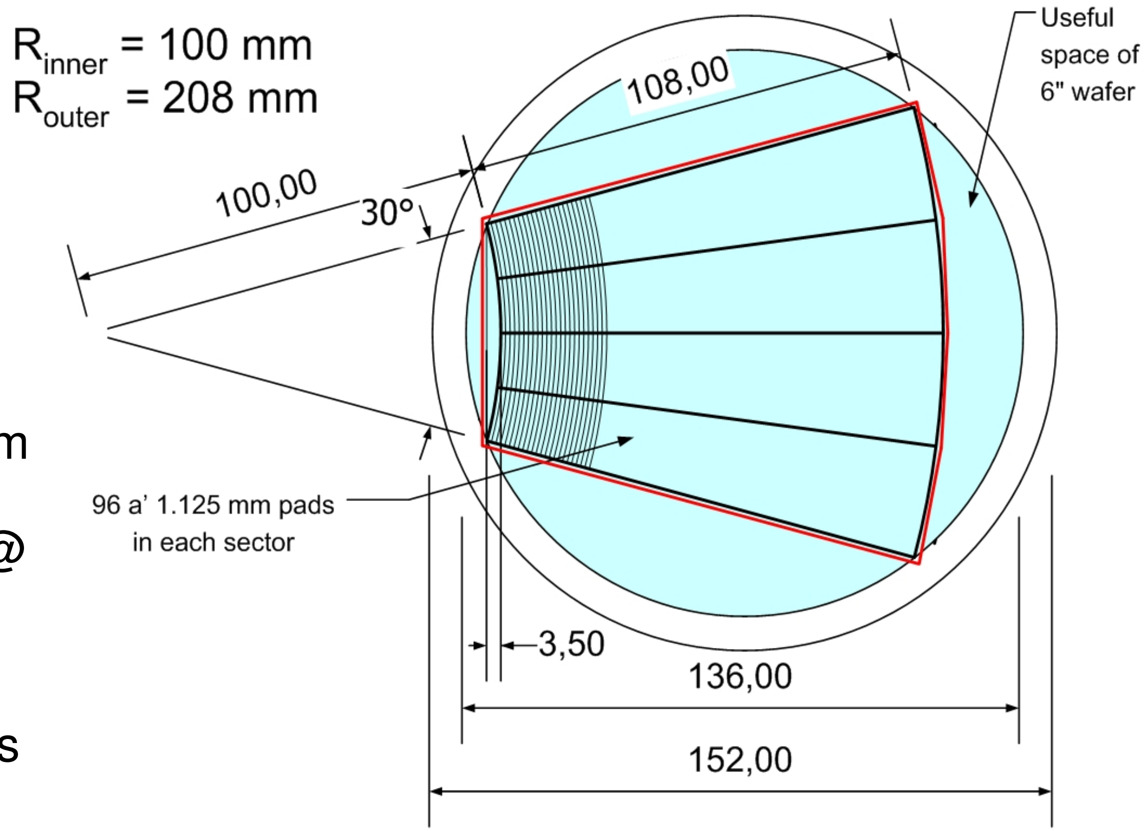


Reduction of measured signal, but still operating after 5 MGy.

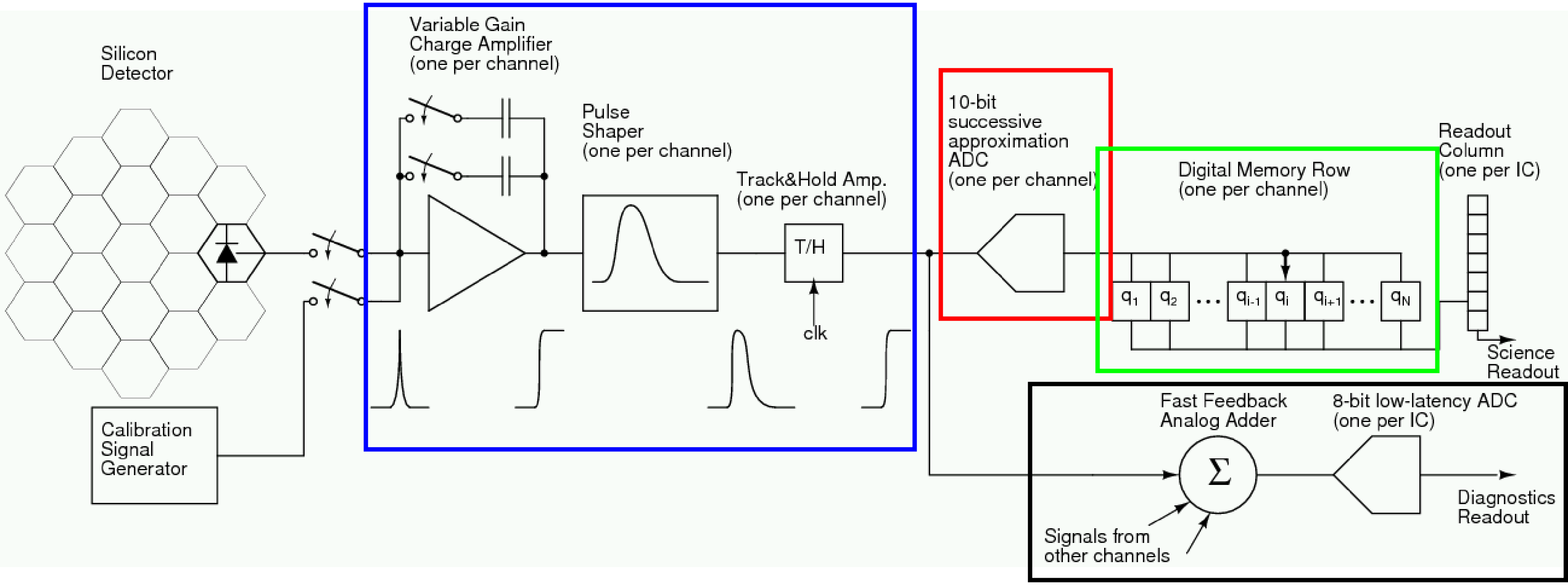
(~340µm thickness)

Sensors for LumiCal

- No radiation problem
- Standard silicon
- Possible candidade (Hamamatsu)
  - Si wafer thickness = 320 µm
  - Dark current ~ 10 nA/cm² @ 200 V
  - Time schedule = ~5 months
  - Costs of masks ~ 18600 €
  - Sensor cost ~ 930 €/pcs.
  - Prototypes in 2008

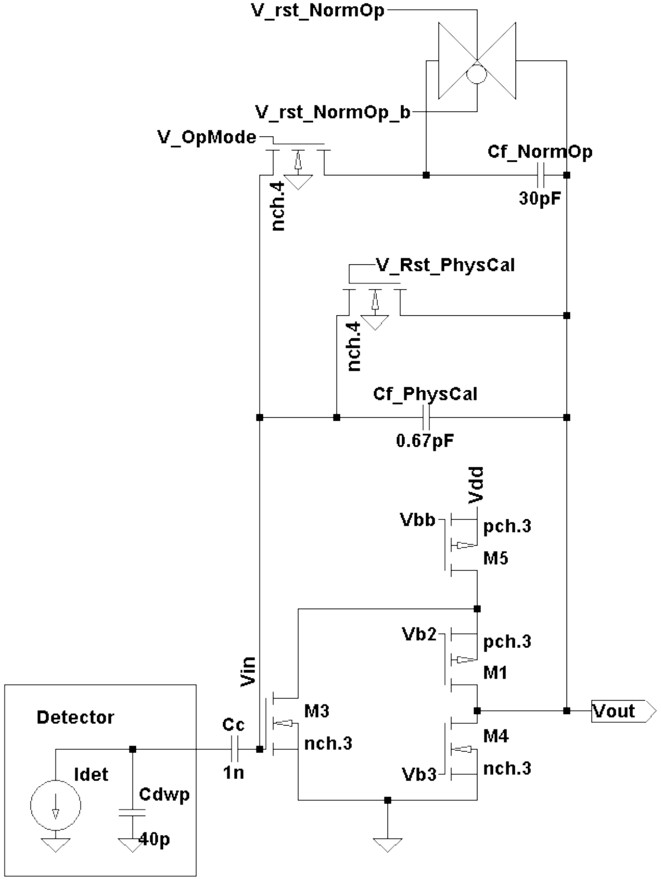


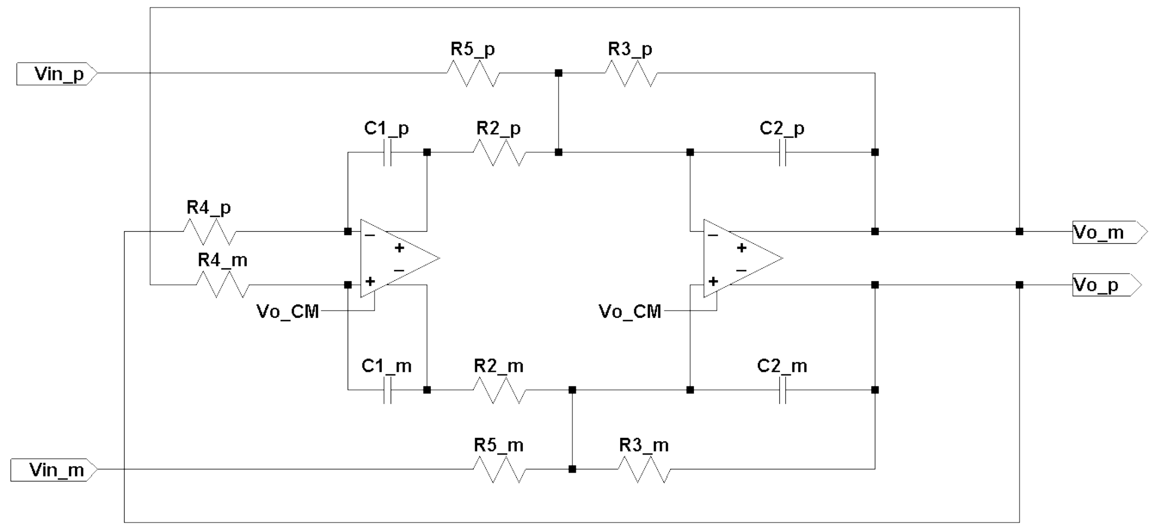
BeamCal readout electronics



- Dual-gain front-end electronics: charge amplifier, pulse shaper and T/H circuit
- Successive approximation ADC, one per channel
- Digital memory, 2820 (10 bits + parity) words per channel
- Analog addition of 32 channel outputs for fast feedback; low-latency ADC

Preamplifier & Shaper design





- Shaper – differential biquad filter

$$\frac{V_{o,d}}{V_{i,d}} = \frac{A_0 s \tau_p}{\left(1 + s\tau_p\right)^2}$$

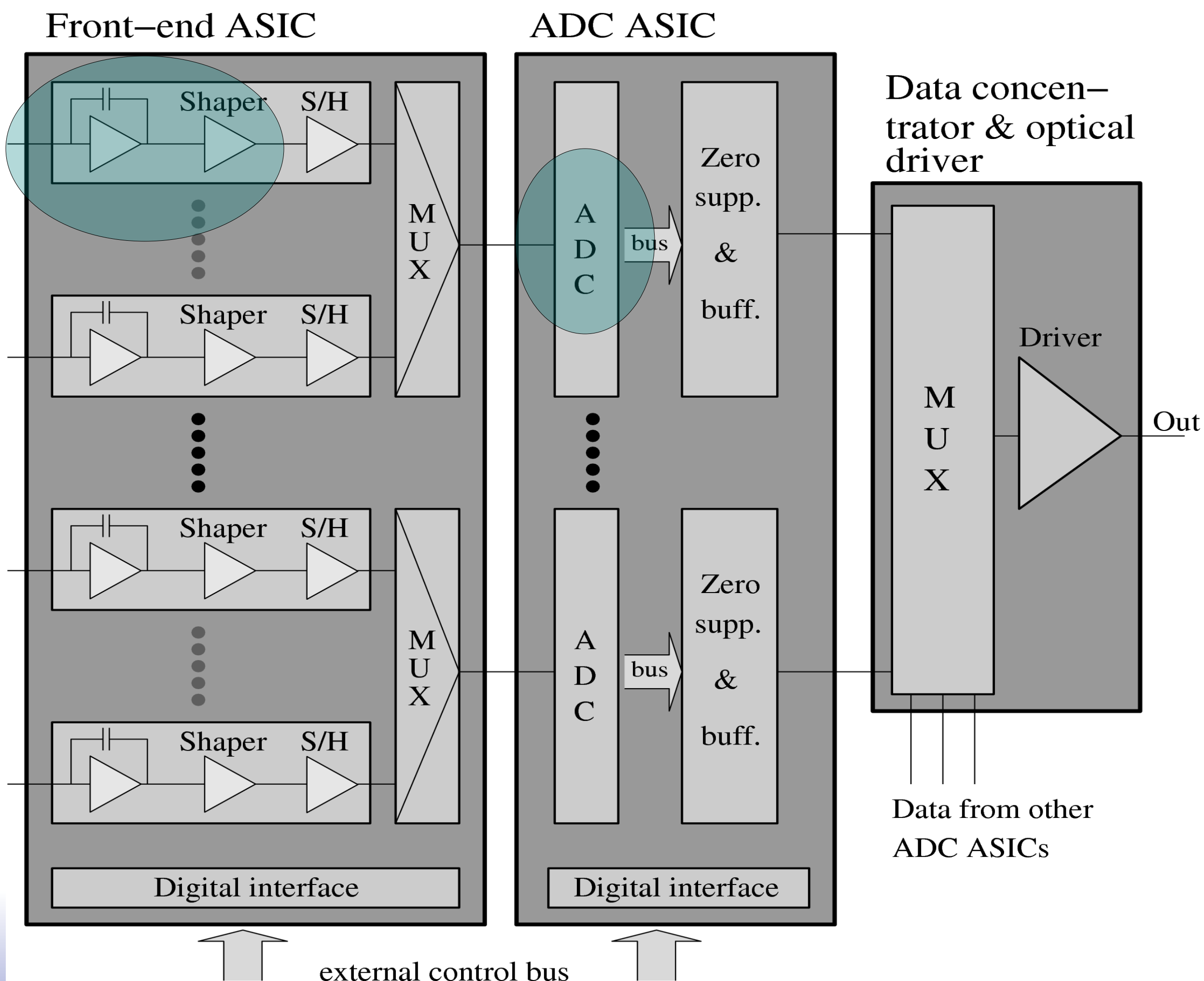
- Preamplifier – a voltage amplifier and capacitive feedback
- Two feedback capacitors for different gains

BeamCal electronics: Tentative schedule

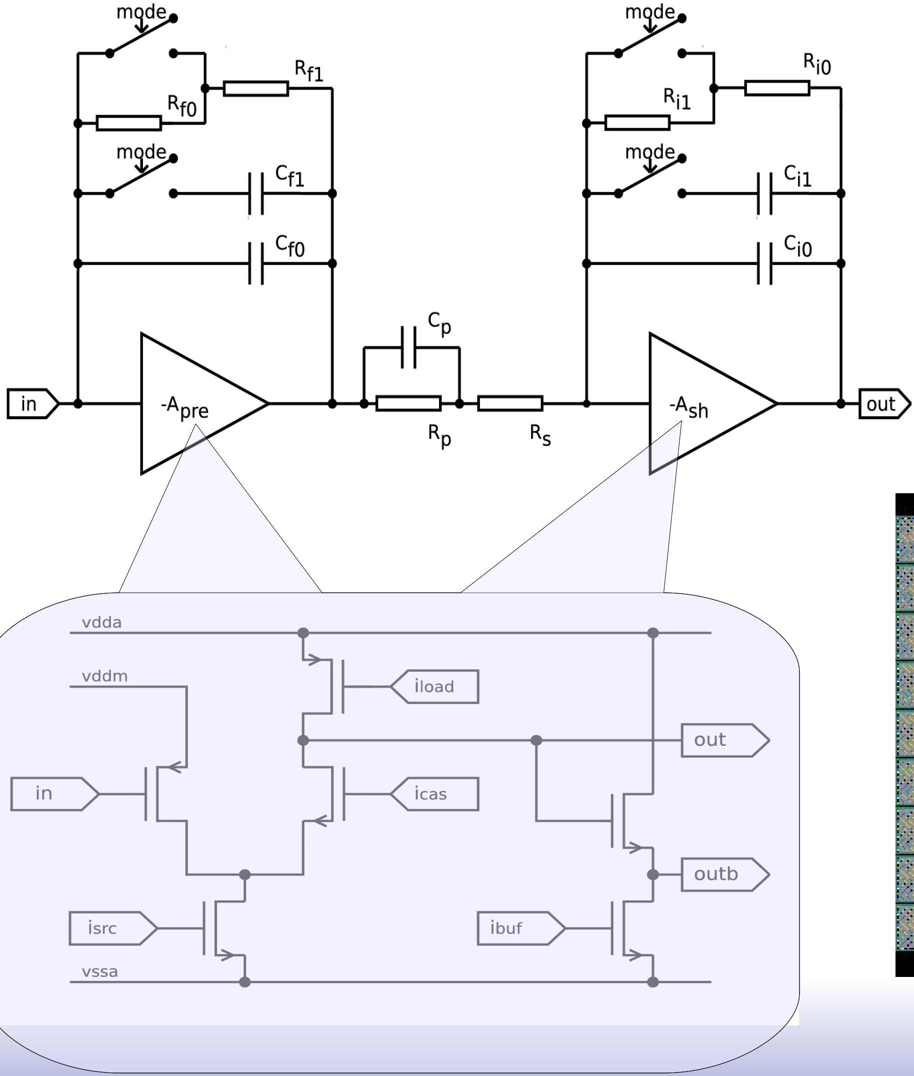
- April 2007: High level design complete
- July 2007: Charge amplifier designed
- October 2007: Filter designed
- January 2008: ADC designed
- February 2008: Memory designed
- March 2008: Fast feedback designed
- April 2008: Bias and supporting circuits
- July 2008: Circuit layout complete
- August 2008: Verification complete
- October 2008: Prototype ready
- January 2009: Prototype tests complete

LumiCal readout architecture

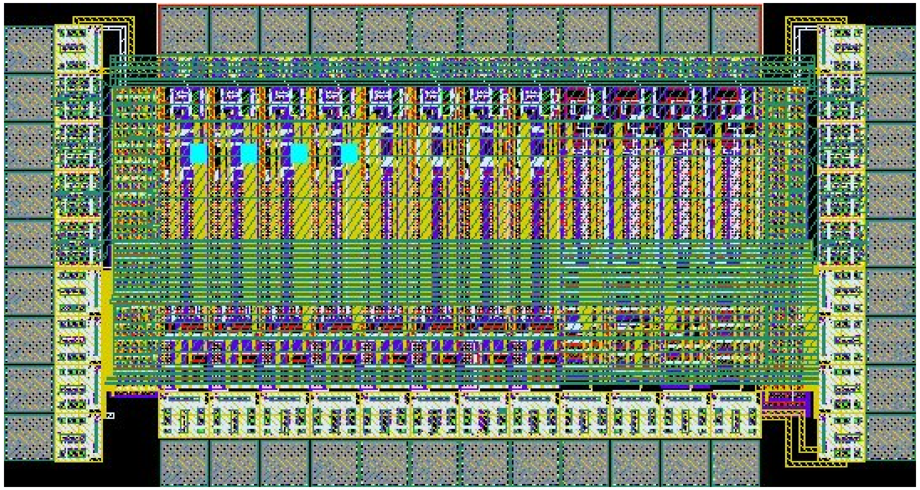
- Front-end ASIC will contain 32-64 dual gain channels
- An ADC will serve ~8(1?) front-end channels
- First prototypes in AMS 0.35 µm



Front-end electronics design

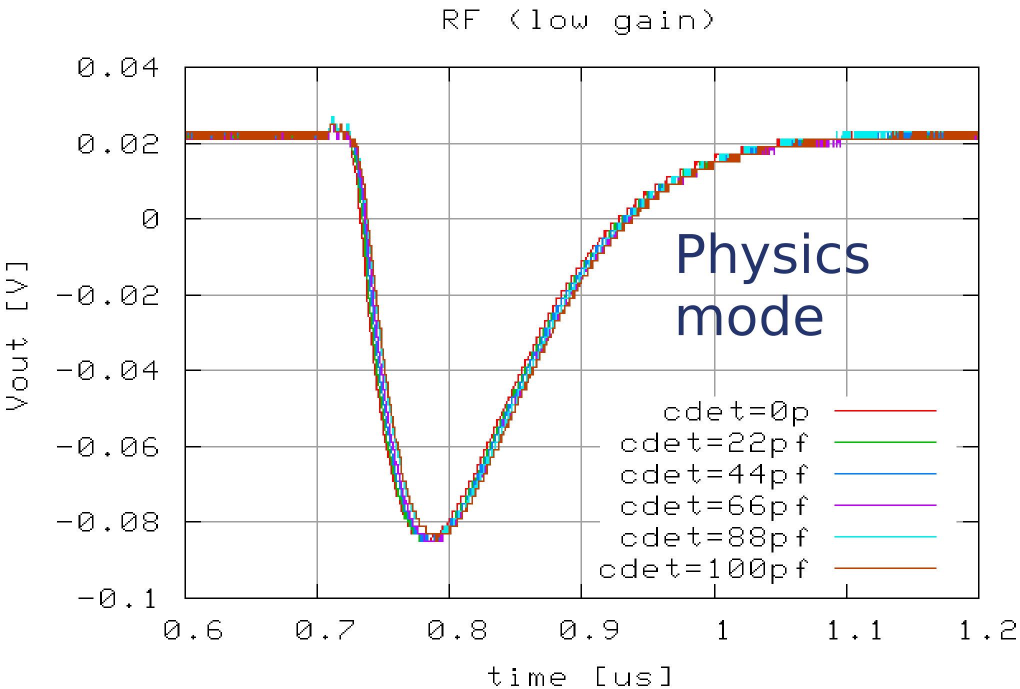


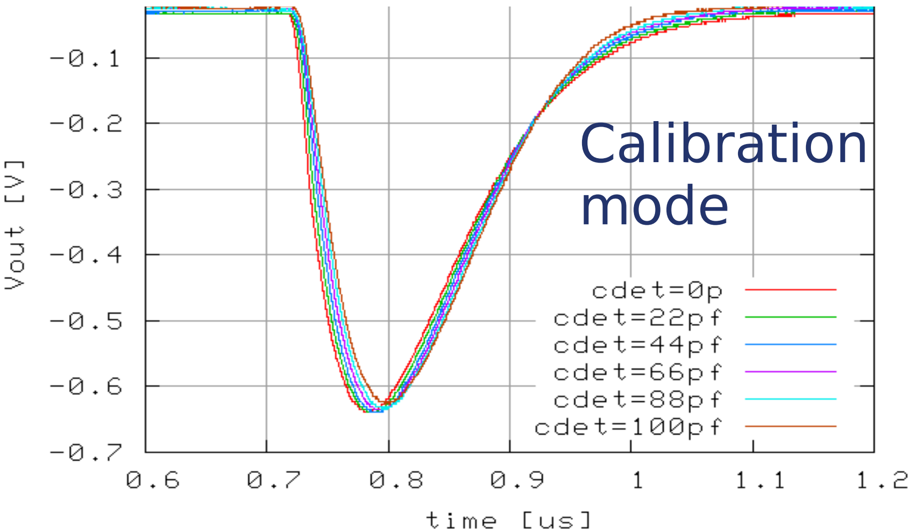
- Charge Sensitive Amplifier + PZC + CR-RC Shaper
- First few channel prototype ASIC submitted in june 2007

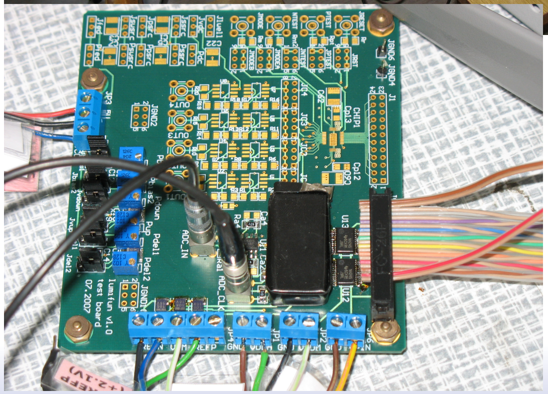


Front-end Layout

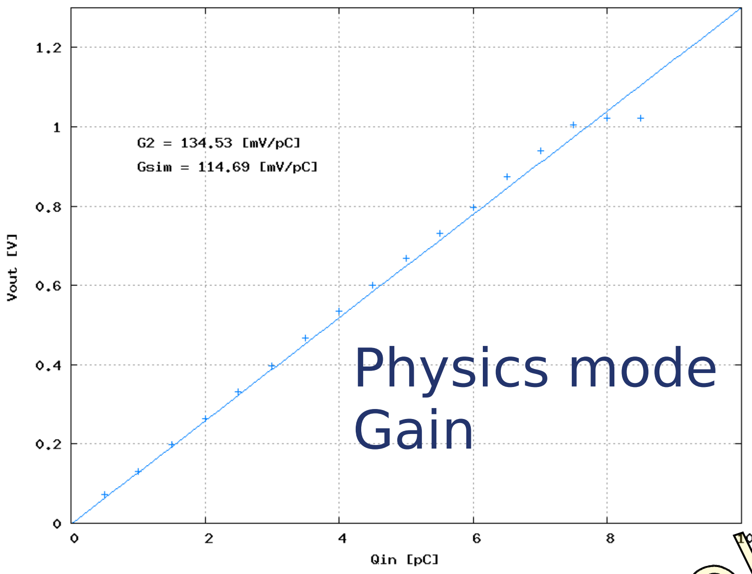
Front-end Tests

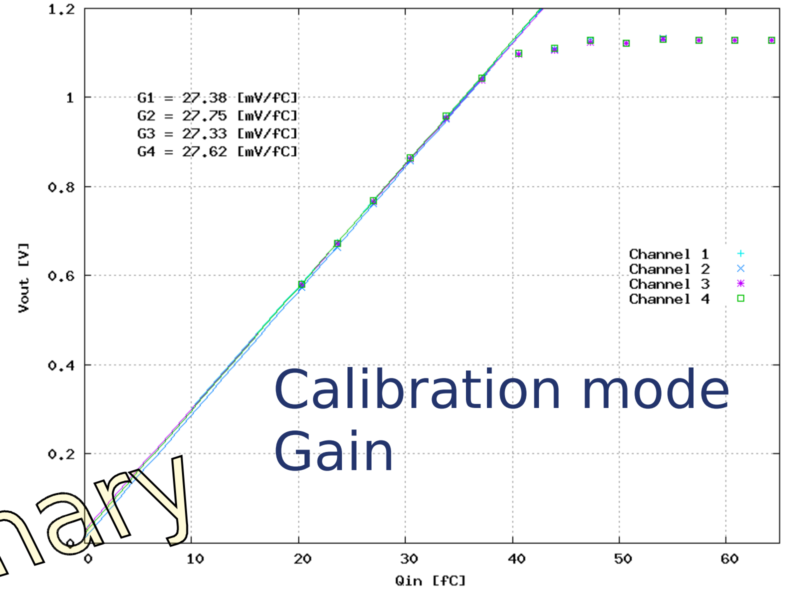




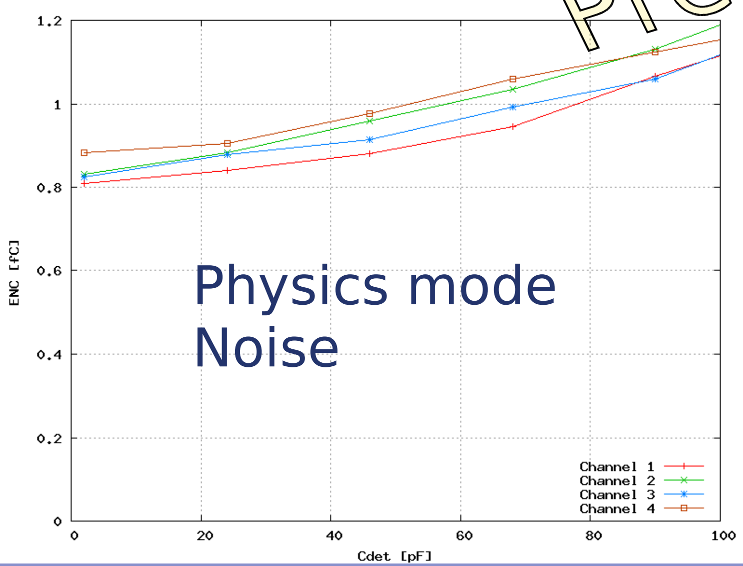


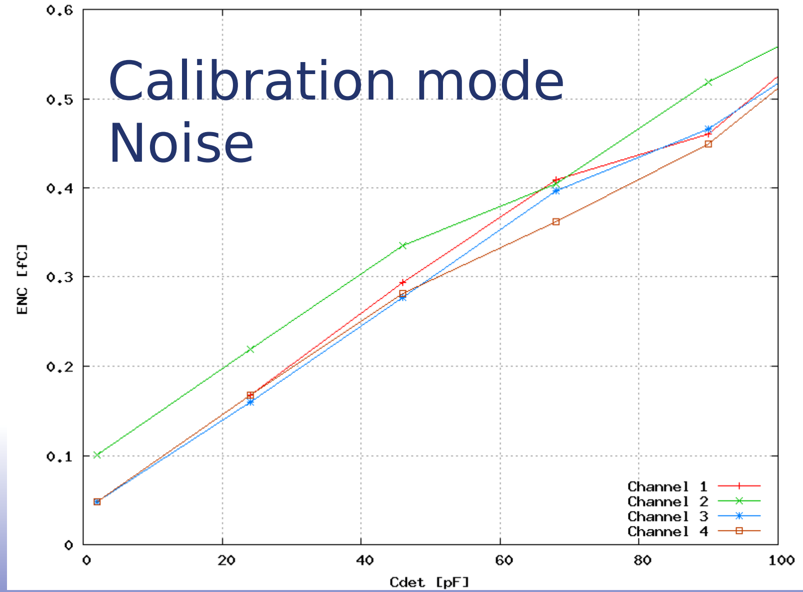
Front-end Measurements



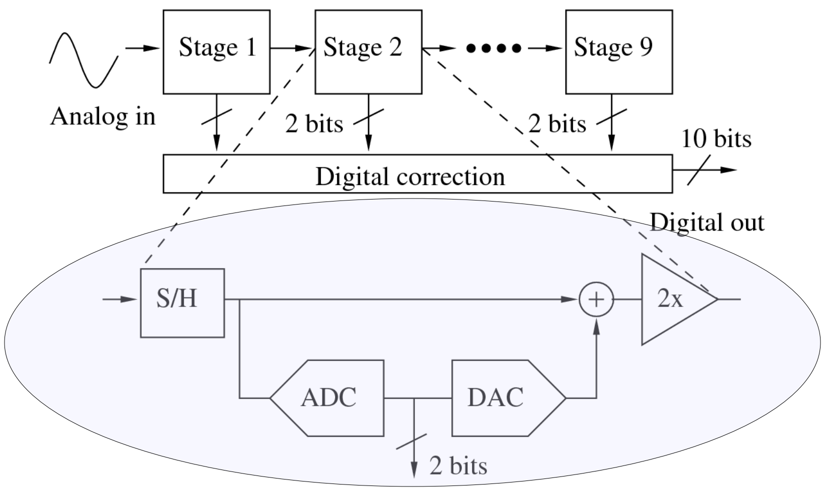


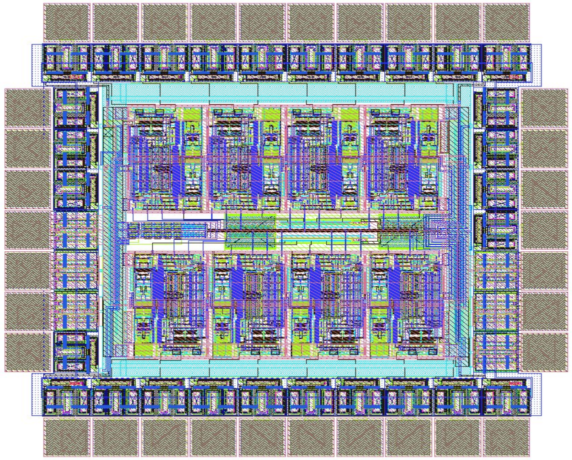
Preliminary

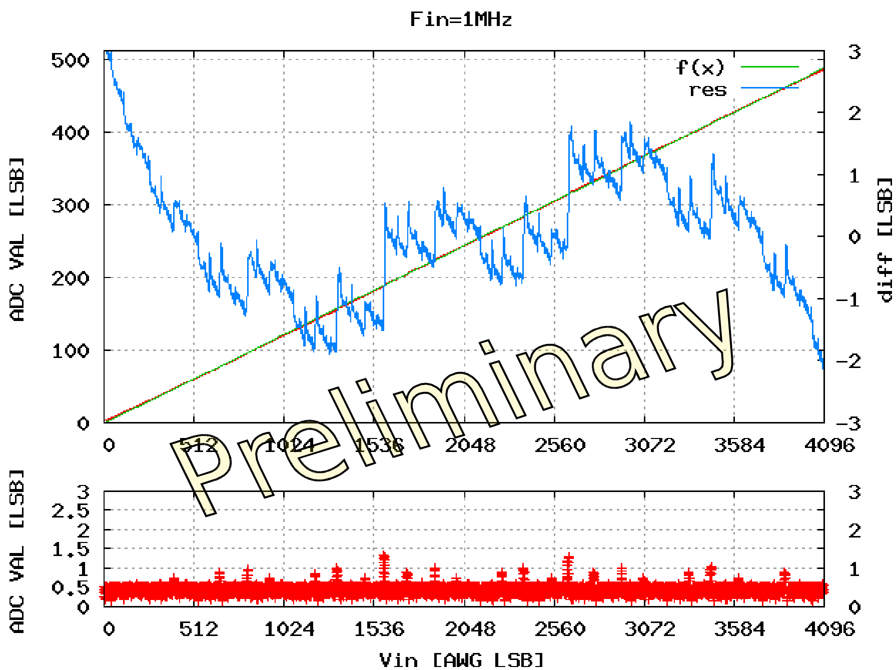




Pipeline ADC design







- 10 bit pipeline ADC
- 1.5 bit per stage
- Fully differential architecture
- Pipeline stages submitted in june 2007

Summary

- The FCAL Collaboration develops the detectors in the very forward region of ILC, independent of a detector concept.
- MC simulations allowed to develop a clear understanding of the physics background, beam-beam effects and the requirements on positioning and precision.
- An intensive R&D acticivity on BeamCal radiation hard sensors is underway. Possible candidades: pCVD diamond (expensive), sCVD (very expensive), rad-hard Si (just starting).
- The design of custom front-end electronics for BeamCal and LumiCal started this year, first prototypes of single components are produced and under test.
- A lot of work still to do...