Forward Region Calorimetry

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for the FCAL Collaboration

DESY PRC Meeting 2007

Hamburg November 8th

FCAL Collaboration

High precision design

FCAL Collaboration

14 partners from 10 countries

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

- **Cooperation with SLAC**

Supported by:

- EUROTeV
- EUDET
- NoRHDIA
- INTAS
- DOE
- ISF

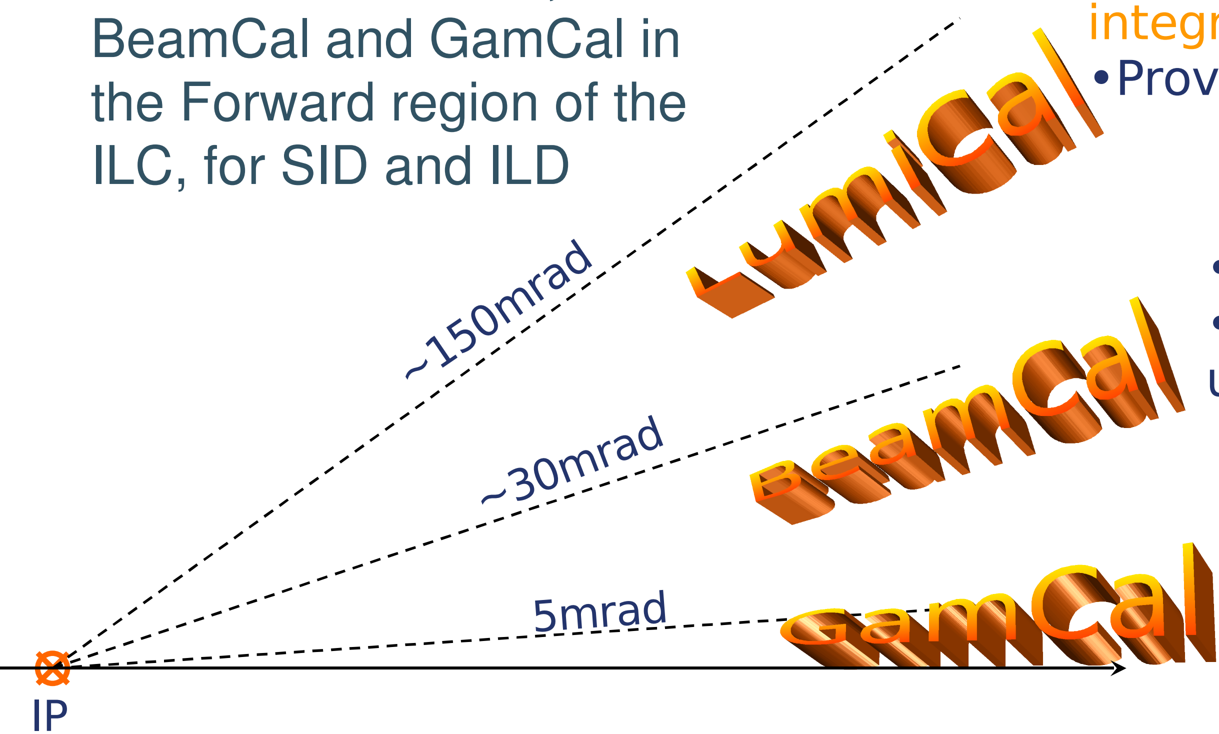
and National Founding Agencies

Outline

- General 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 ILD



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

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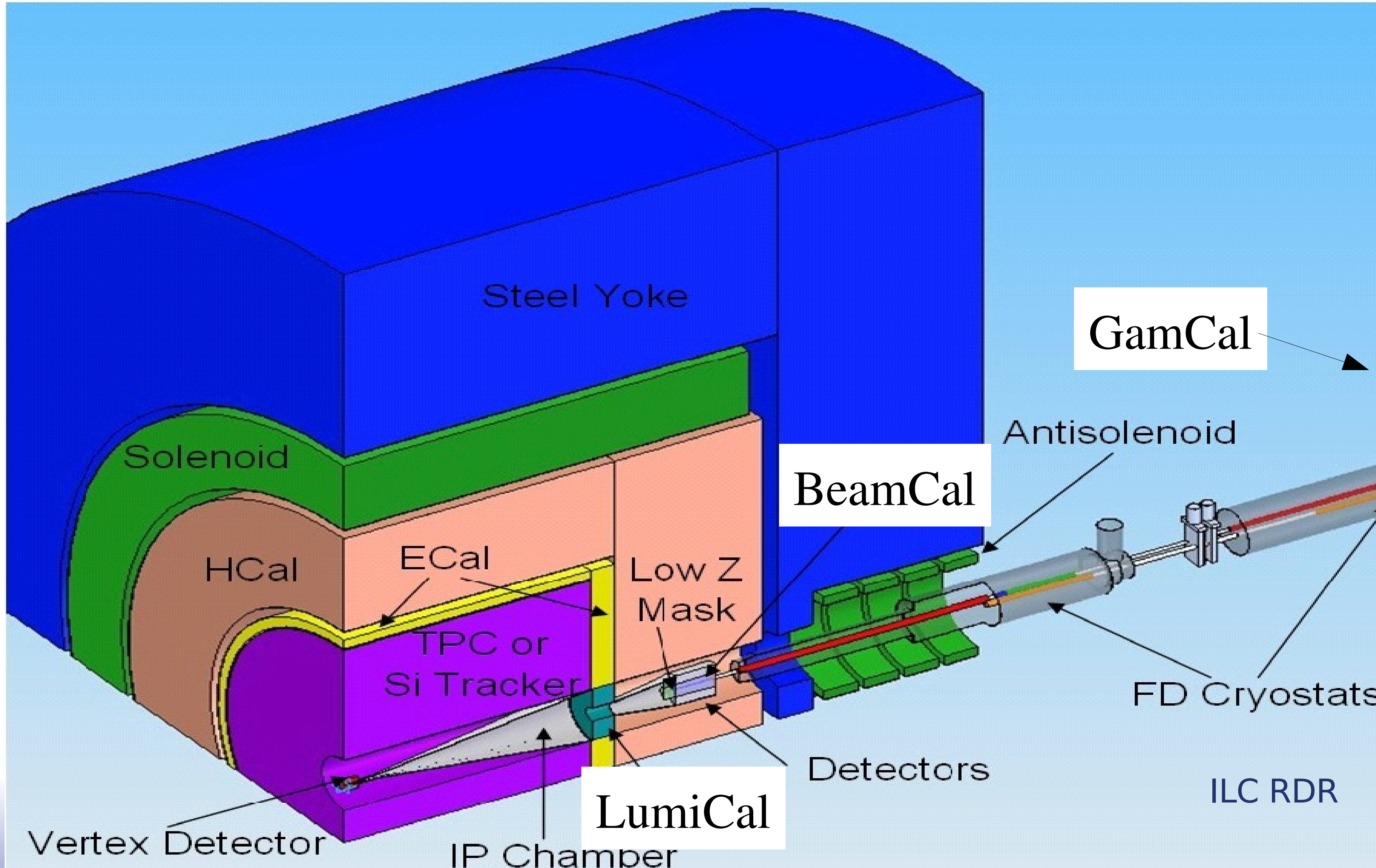
- Serve beamdiagnostics using beamstrahlung pairs

- Serve beamdiagnostics using beamstrahlung photons

<u>Challenges:</u>

<u>High precision, high occupancy, high radiation dose, fast read-out!</u>

Forward Region Design



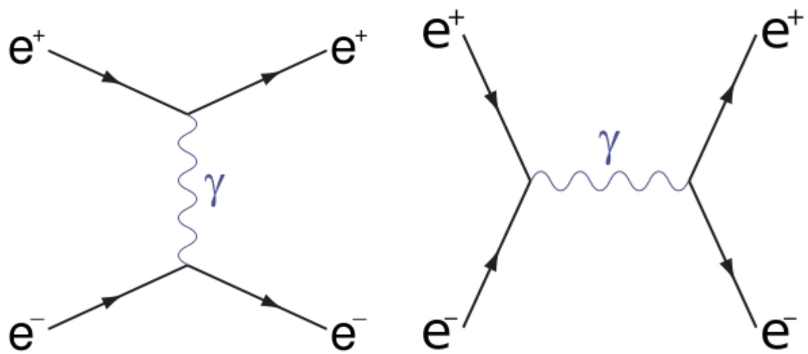
LumiCal -Precise Measurement of Luminosity

- 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)

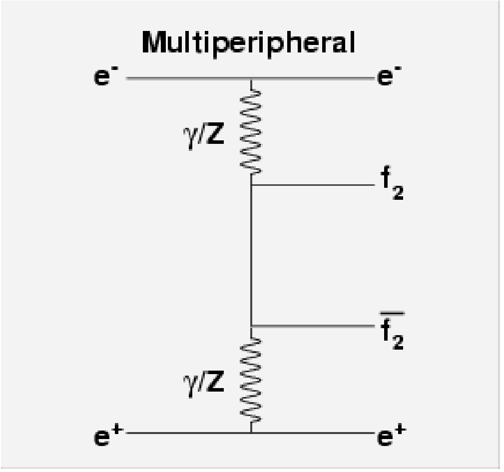
  $\Delta L/L < 10^{-3}$ ($e^+e^- \rightarrow q^+q^-$ 10^6/year)

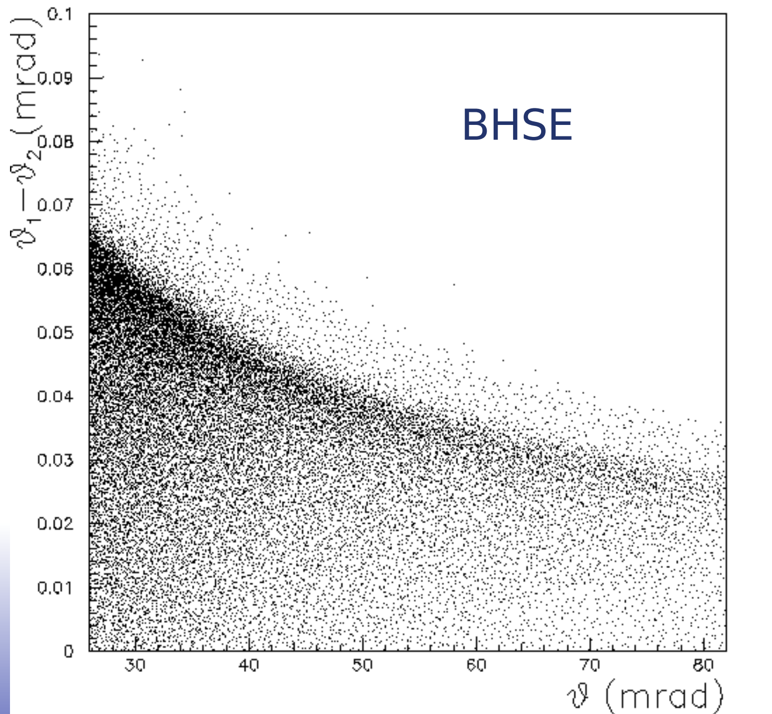


- Bhabha scattering ee-> ee(γ) is the gauge process:
  - Count Bhabha event in a well known acceptance region => $L = N/\sigma$
  - High statistics at low angles => $N_{Bhabha} \sim 1/\theta^3$
  - Well known electromagnetic process (LEP: 10^{-3}): the current limit on the theoretical cross section error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

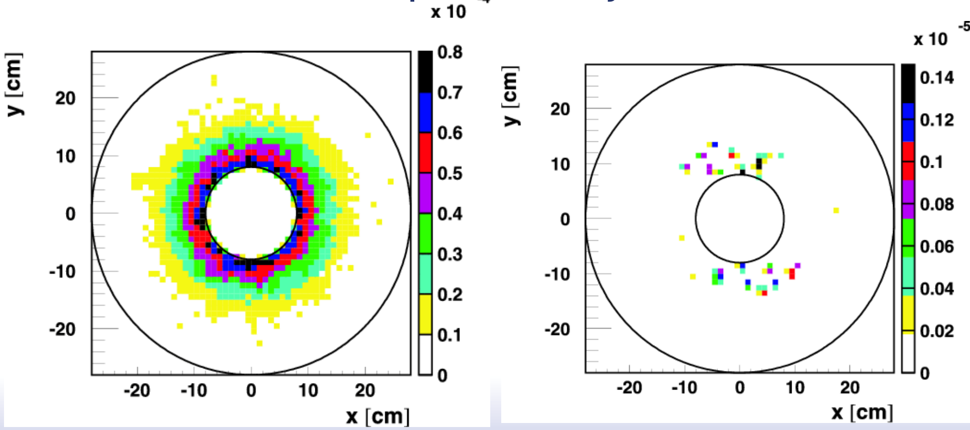
LumiCal: Physics Background and Beam-Beam Effect

- 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 (BHSE) is due to EM deflection and energy loss by beamstrahlung of Bhabhba's. Correction needs precise knowledge of beam parameters.



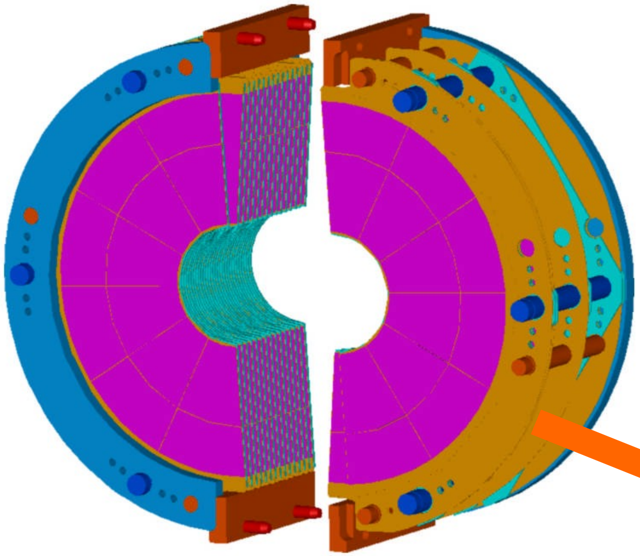


2-photon rejection

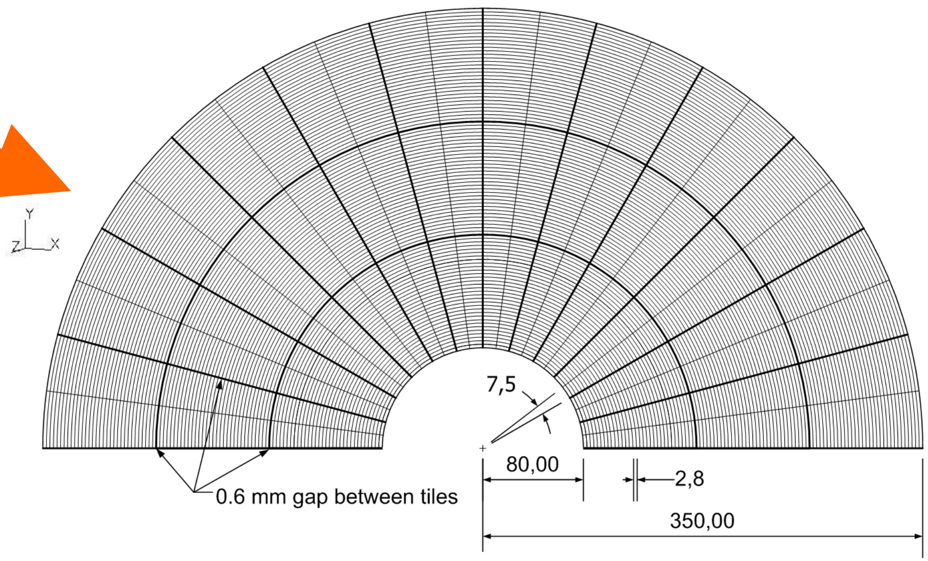


LumiCal Design

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



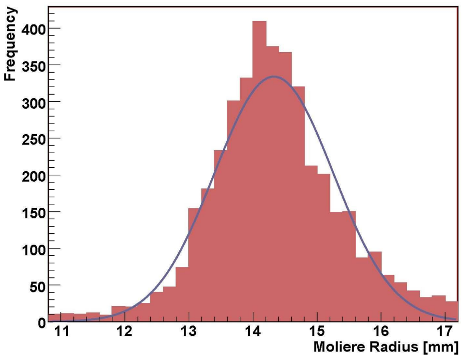
Single detector layer
48 azimuthal sectors,
each sector ~96 radial pads



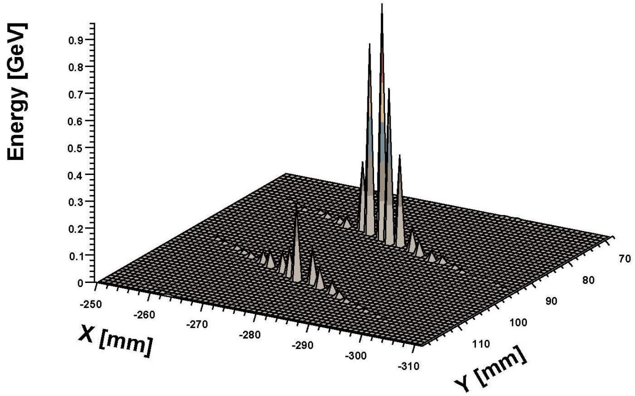
Each layer consists of
0.35cm thick tungsten
and 300μm thick Si sensor

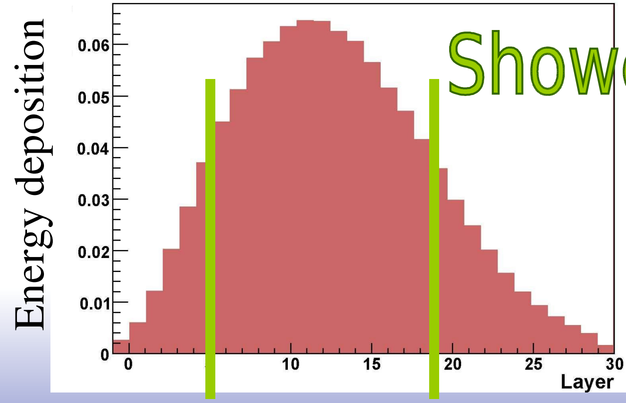
Clustering in LumiCal

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.



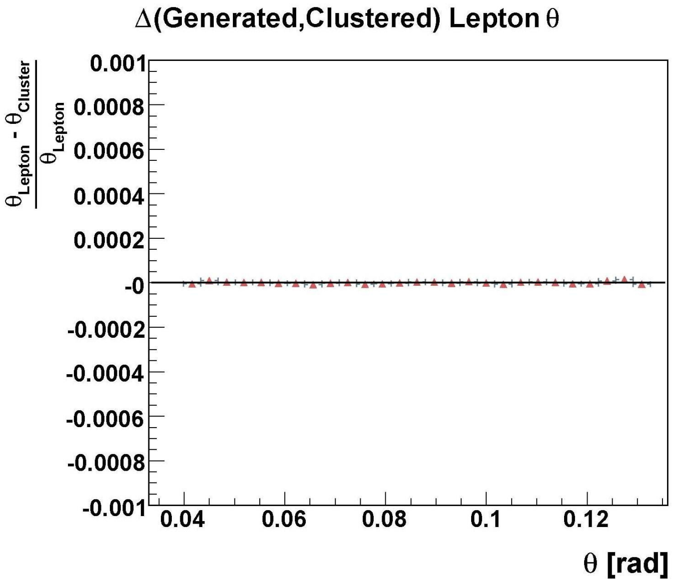
Moliere Radius

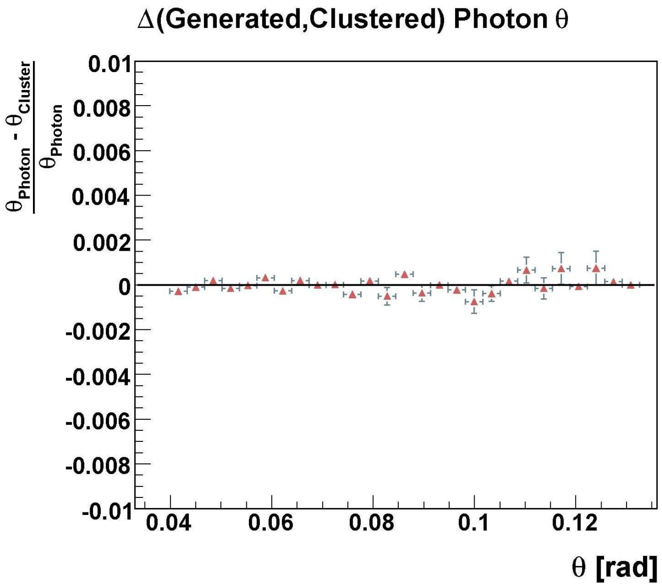




Number of hits per layer

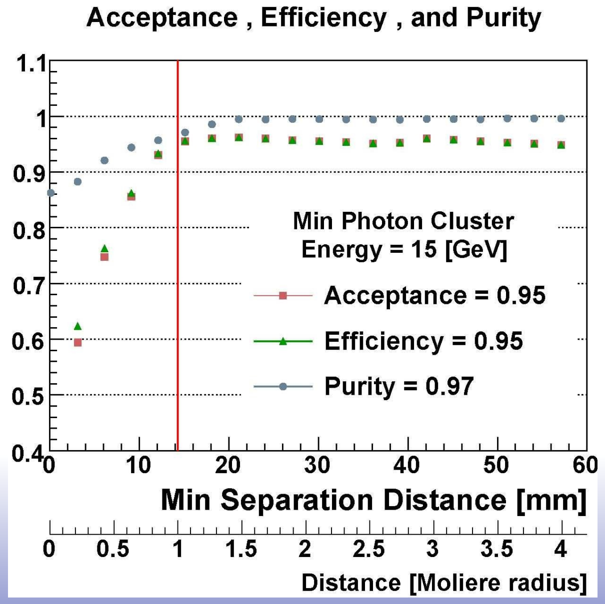
Cluster Position Reconstruction



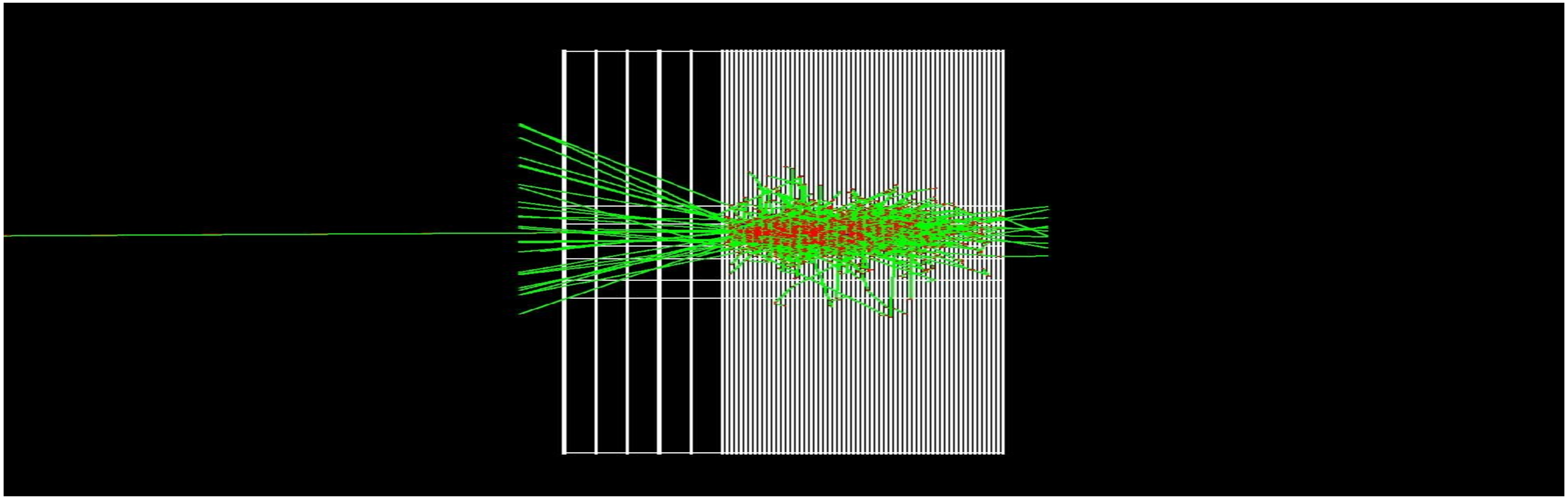


For Bhabha events with $\left(\sqrt{s} = 500 \text{ [GeV]}\right)$:

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



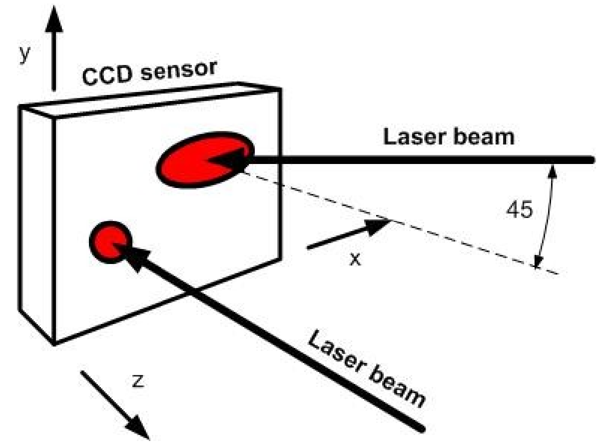
New LumiCal Design Concepts



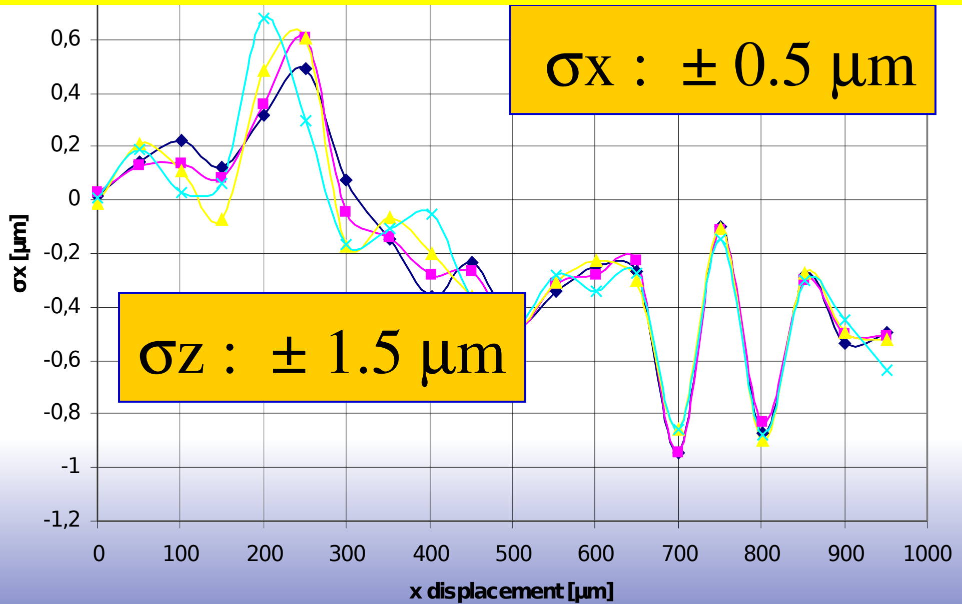
- LumiCal is composed of two components: Silicon Tracker and a Calorimeter.
- In this design five silicon tracking layers are used, granulated into concentric strips.
- New reconstruction algorithm developed, combining Tracker and Calorimeter info.
- First results:
  - Significant improvement in polar 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).

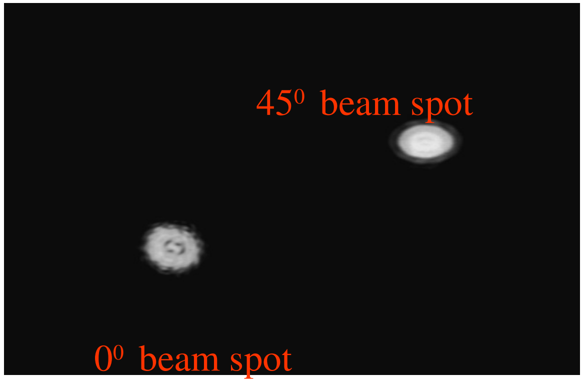
LumiCal Positioning & Laser Alignment

ΔL/L	1.0 10^{-4}
inner radius	4.2 μm
radial offset	640 μm
distance	300 μm



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





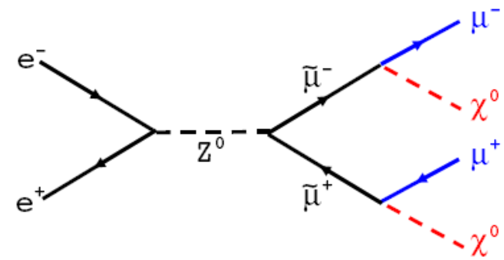
Temperature stability is an issue

Observed changes ~ 1 μm/1 ^{0}C

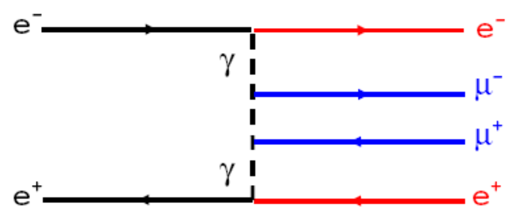
Work underway to integrate the LAS in the detectors

BeamCal Challenges

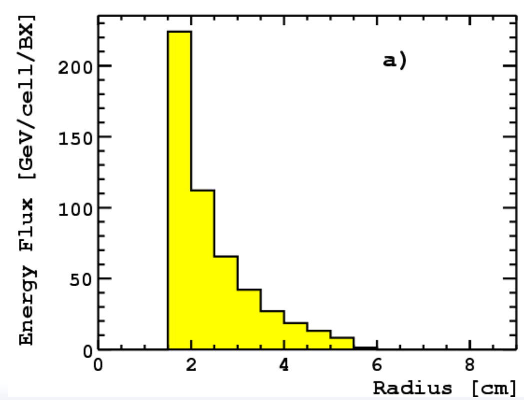
- BeamCal will extend the sensitive region to lowest polar angles.
- Challenge: Detect single high energetic particle on top of a background of 10^4 low energetic e^+e^- pairs.
- BeamCal serves also as part of the beam diagnostics system

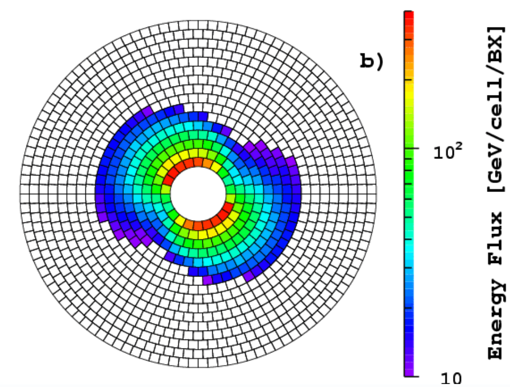


Physics signal:
e.g. SUSY smuon production



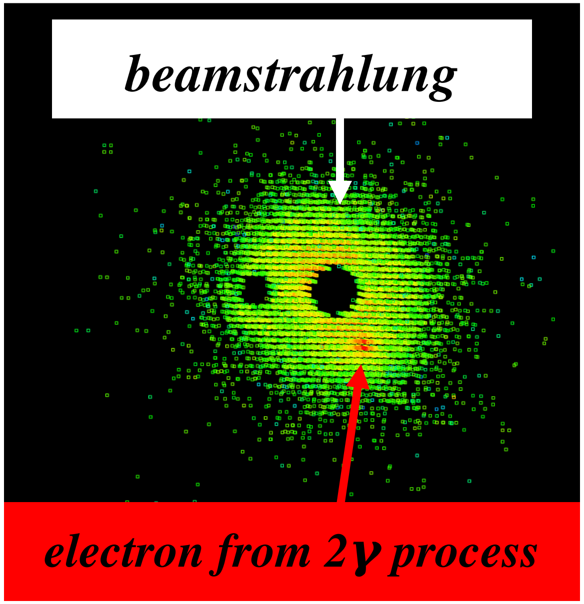
Background signal:
2-photon event, may fake the upper signal if the electron escapes.

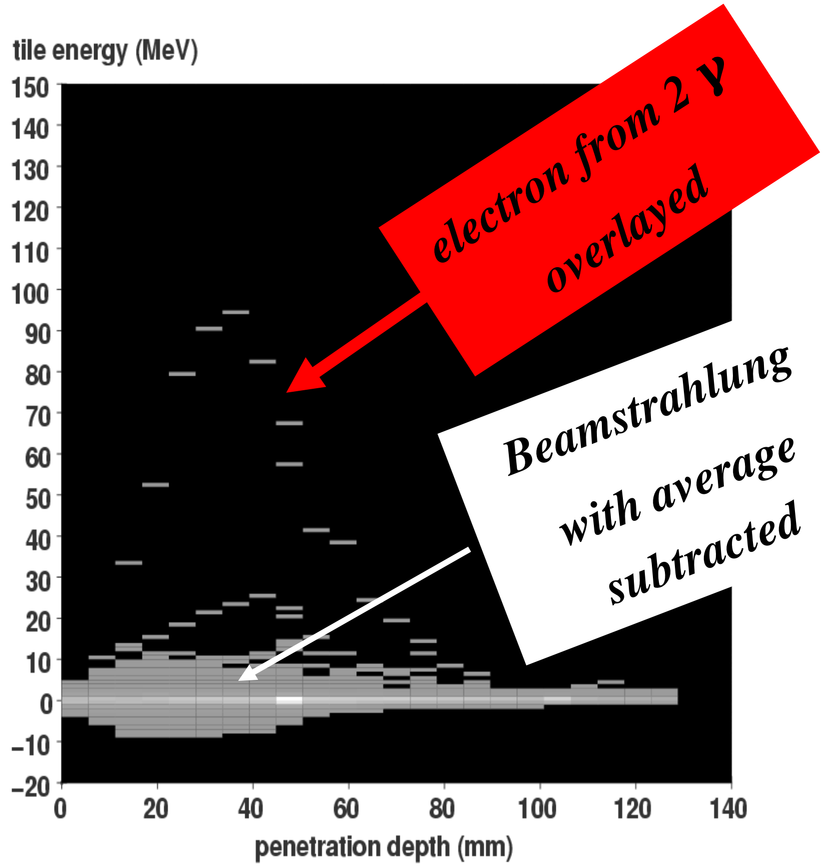


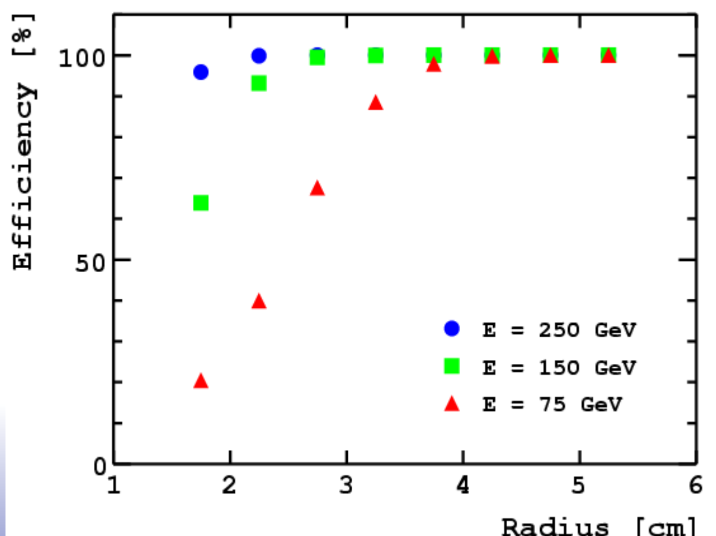


BeamCal design concept similar to LumiCal

BeamCal: Particle Veto



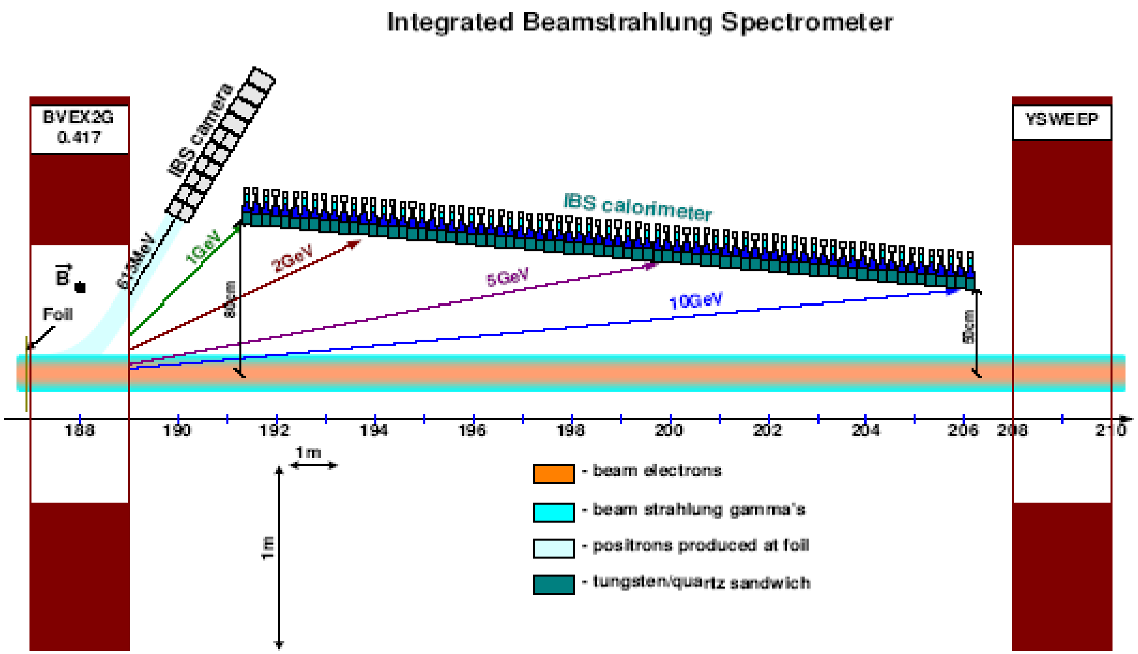




- Algorithms developed to efficiently veto single high energetic particles
- Radiation hard sensors with a large dynamic range O(10^4) needed

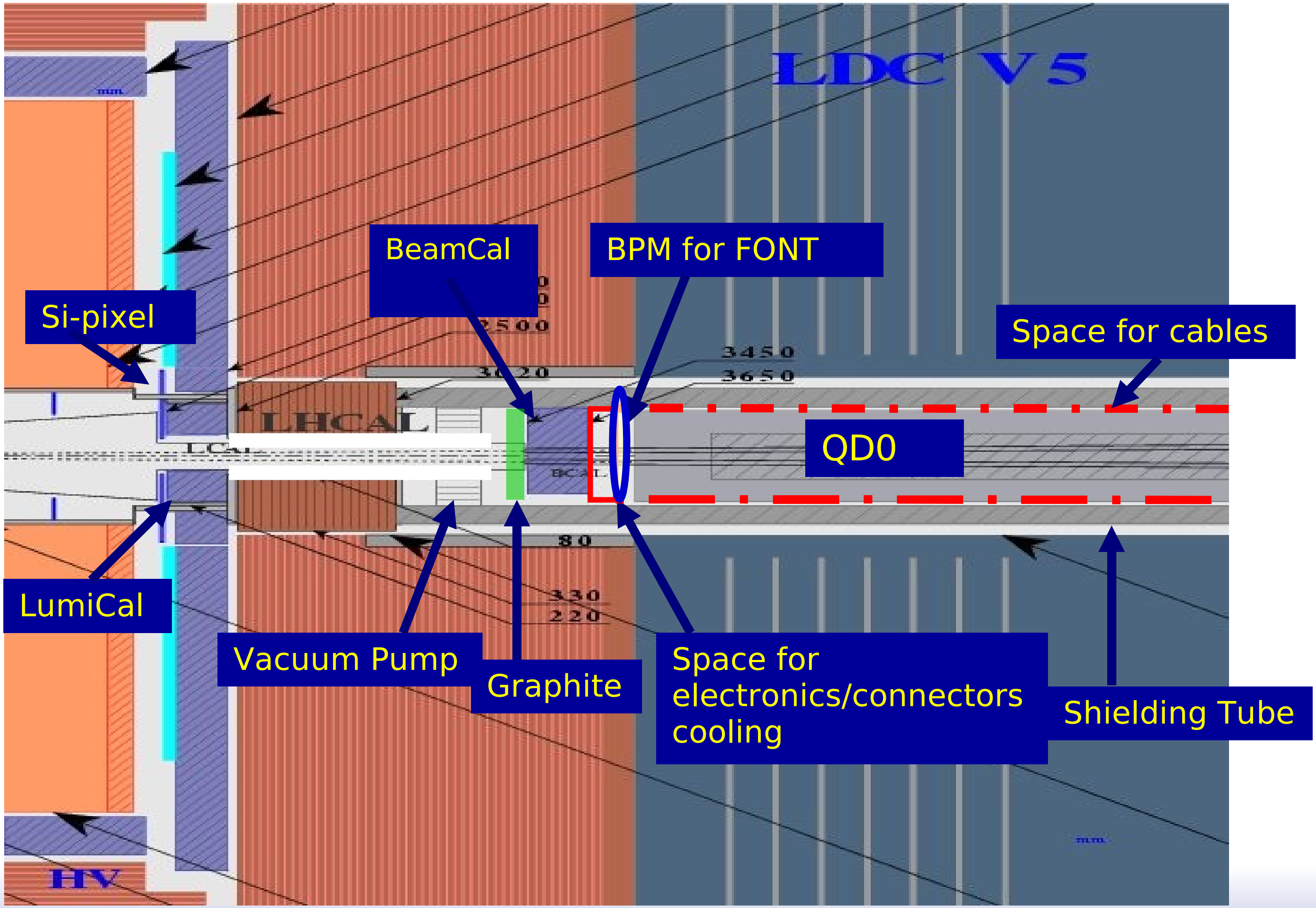
GamCal Motivation & Design Concept

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



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

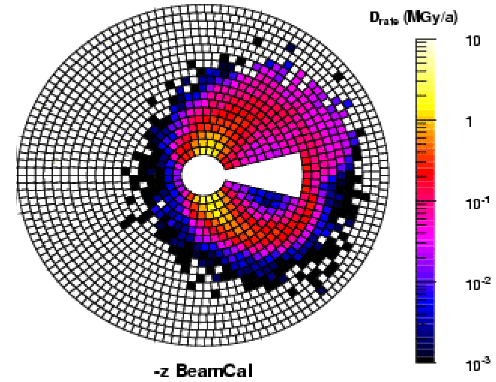
FCAL Integration



Work on FCAL mechanical integration in progress...

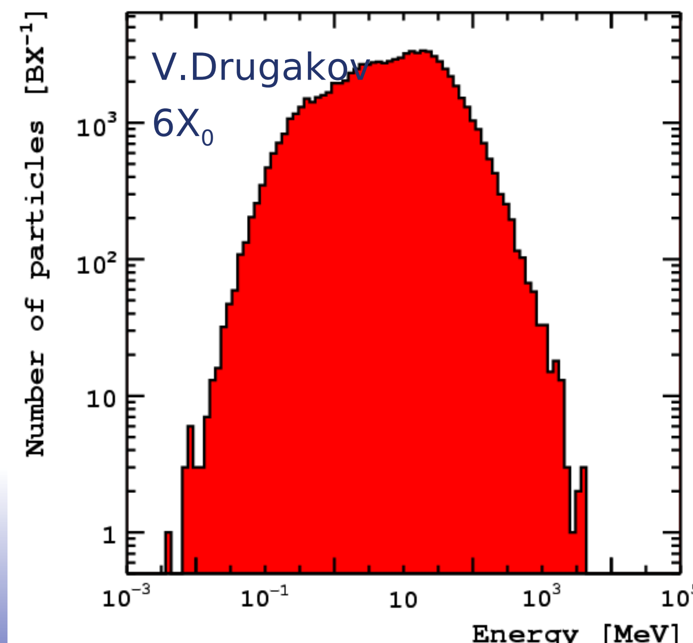
BeamCal: Radiation Hard Sensors

- Very high BeamCal load, ~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
  - radiation hard Si



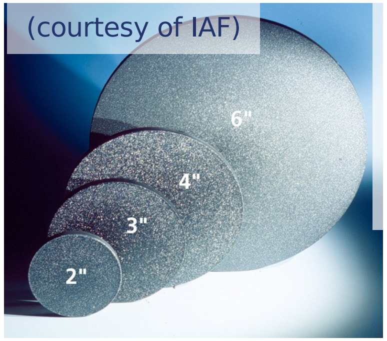
≈ 5 MGy/a

Particle Energy Spectrum

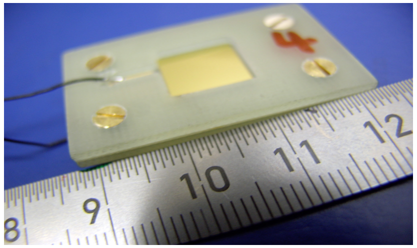


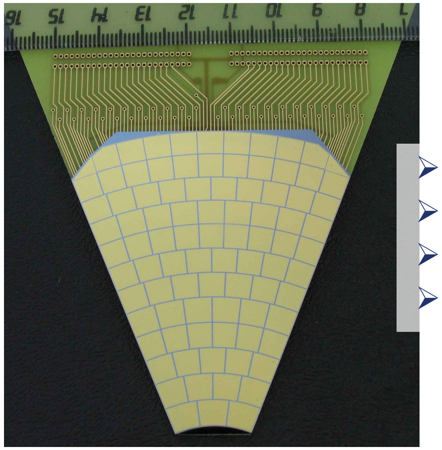
Materials under Investigation

- pCVD diamonds:
  - radiation hardness under investigation (e.g. LHC pixel detectors)
  - high mobility, low $\varepsilon_R = 5.7$, good 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)
  - DOFZ, CZ, MCZ, EPI,...



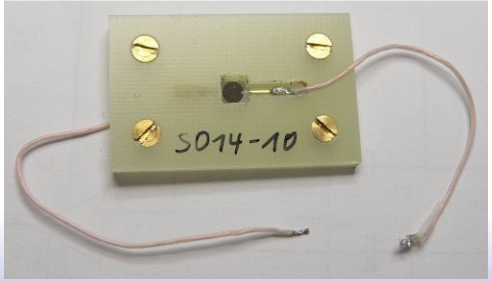
- Two manufacturers:
  - Element Six$_{TM}$
  - Fraunhofer Institute (IAF)
- 1 x 1 cm²
- 200-900 µm thick





- 500 µm thick detector
- 87 5x5 mm pads
- Mounted with fanout
- Solid state ionization chamber

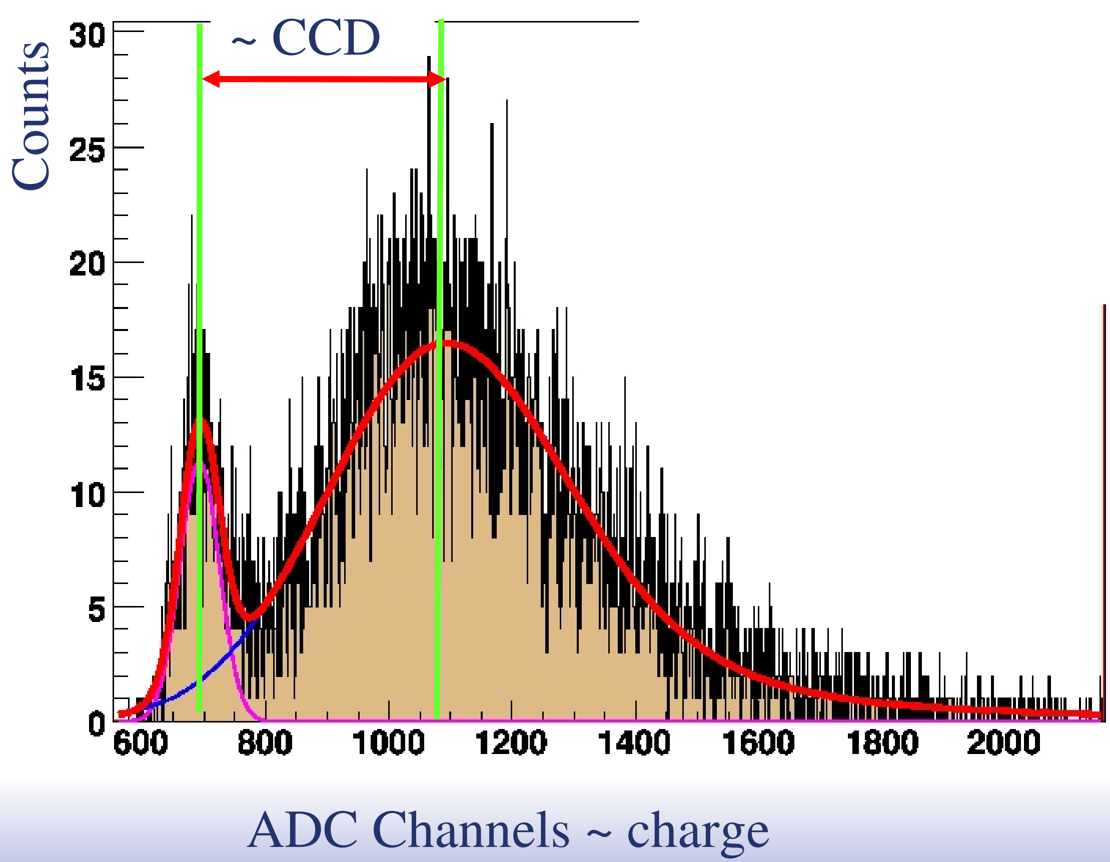
- sCVD diamond
- area 5x5 mm²,
- thickness 340 µm



CCD & other Measurements

CCD = *Charge Collection Distance*

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

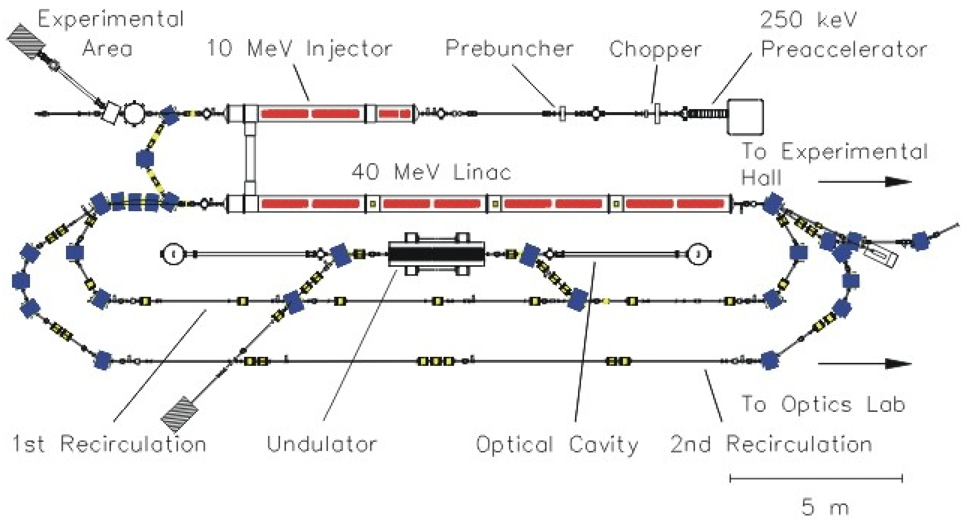


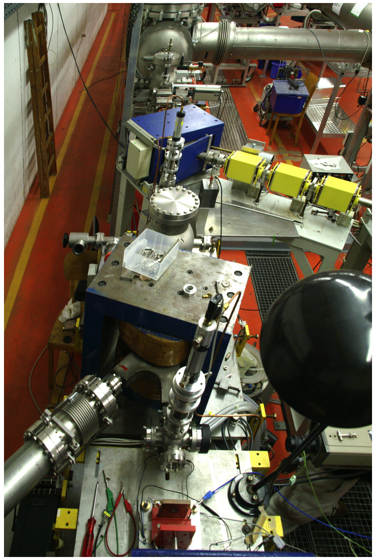
Other measurements showing sensor performance:

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

High Dose Irradiation

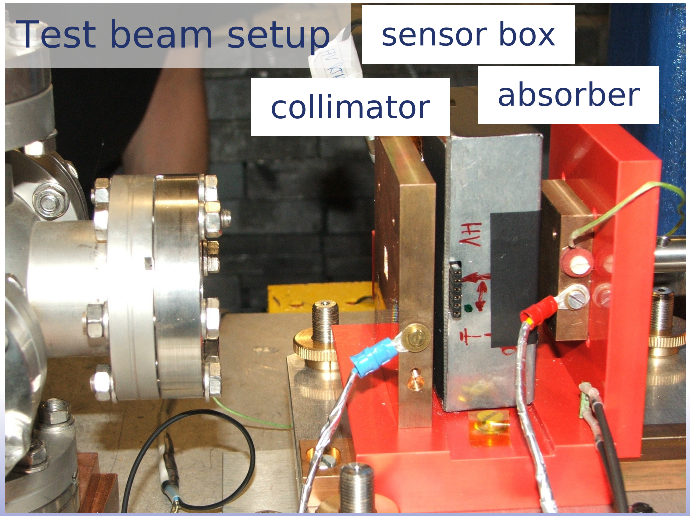
Superconducting DArmstadt LINear ACcelerator
Technical University of Darmstadt





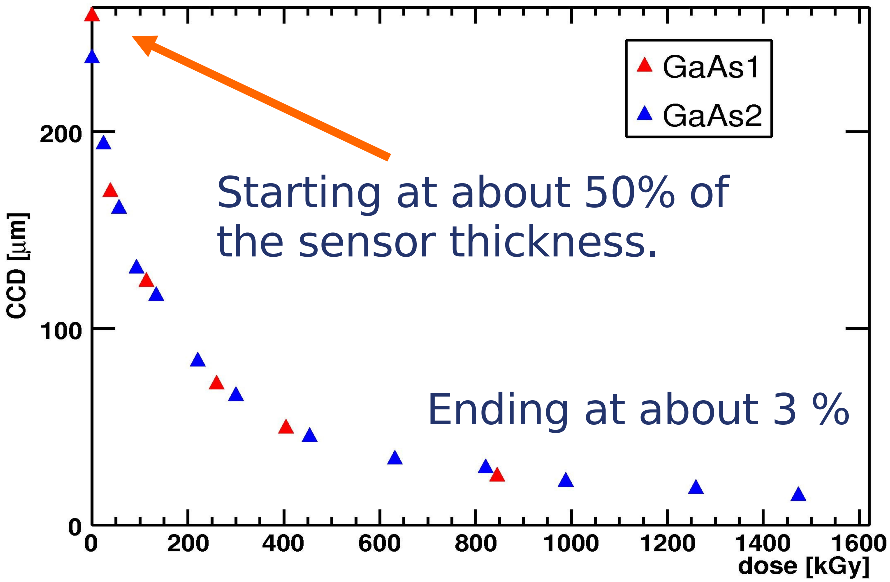
- Irradiation up to several MGy: 10 ± 0.015 MeV and beam currents from 10 to 50 nA corresponding to 60 to 300 kGy/h.
- Keeping the sensor under bias permanently.
- This is a much higher dose rate compared to the application at the ILC (~1 kGy/h)

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

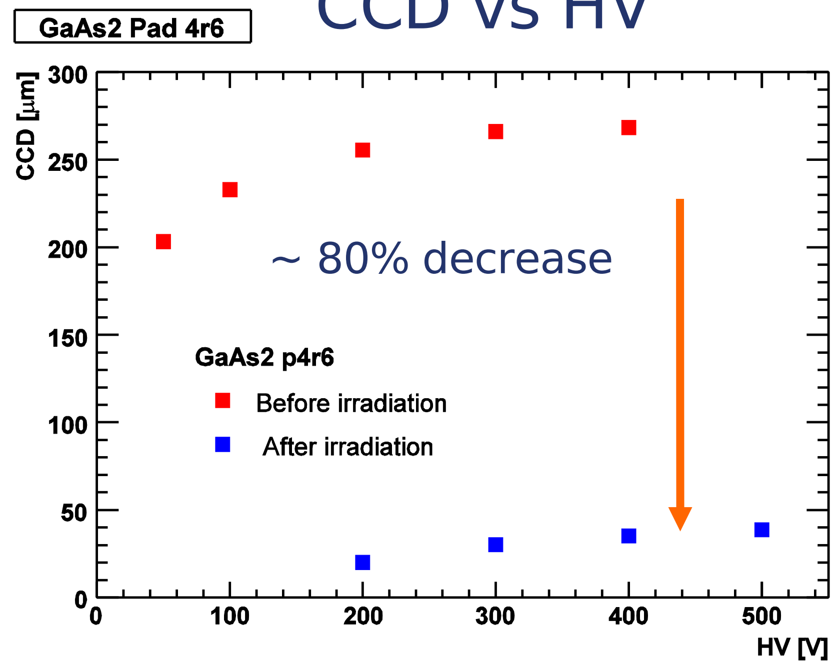


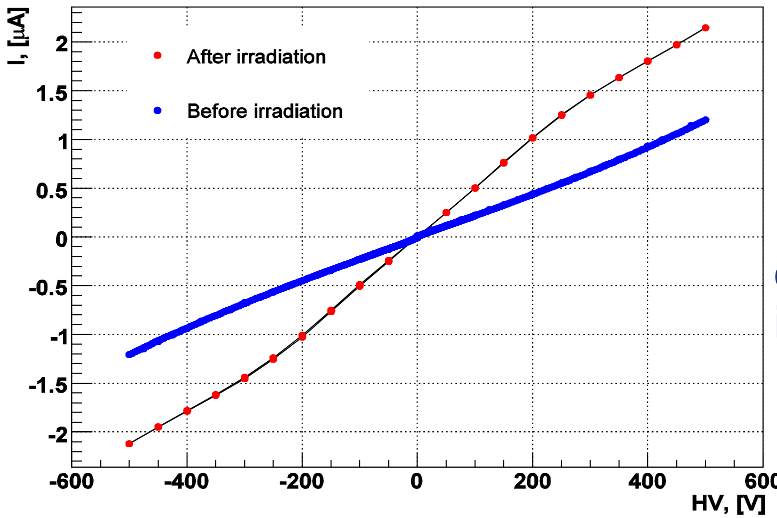
Irradiation of GaAs

CCD vs Dose



CCD vs HV



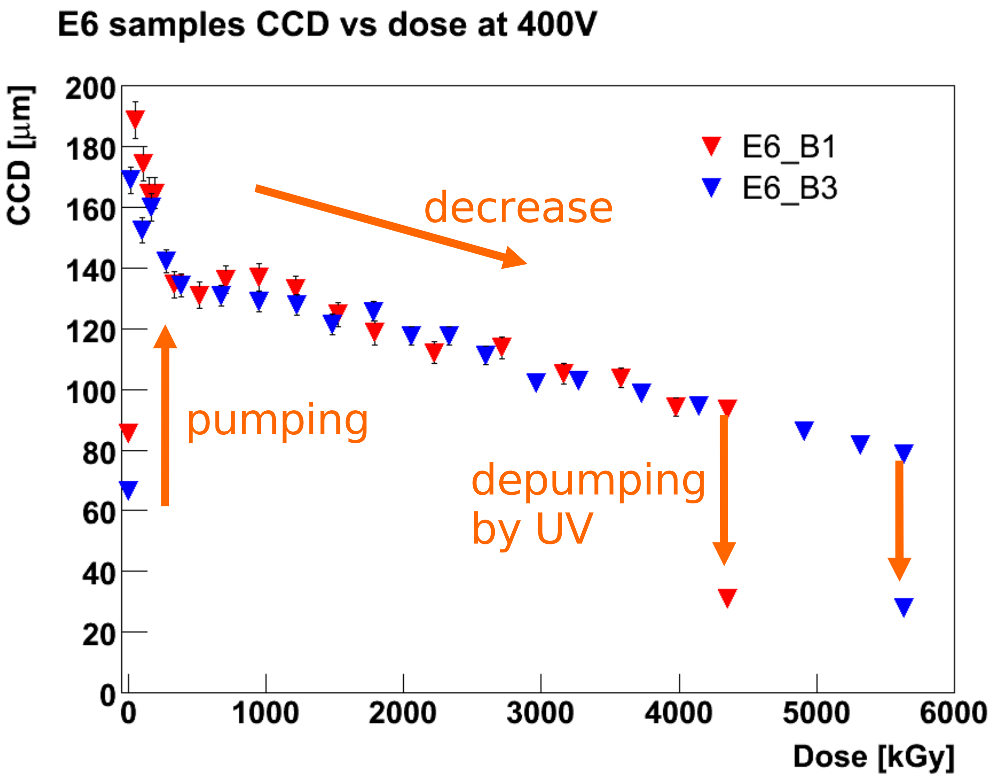


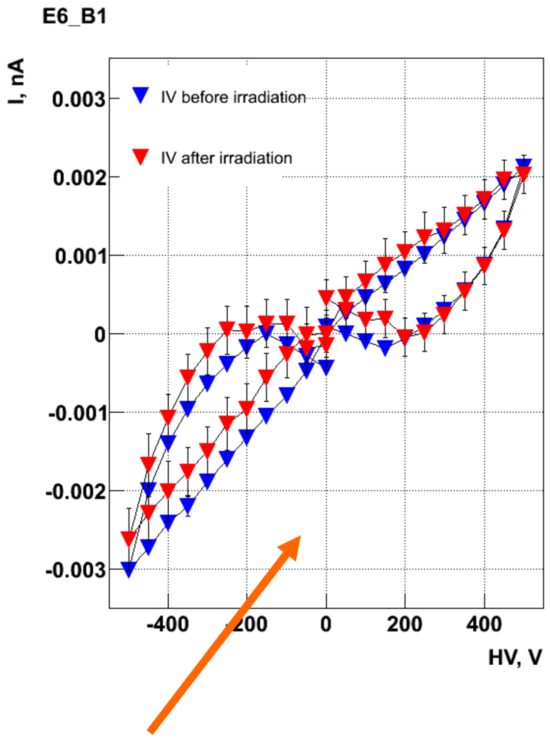
Leakage currents increased only by 2, but already in the µA range.

Polycrystalline CVD Diamond

After absorbing up to 6 MGy:

CVD diamonds still operational.



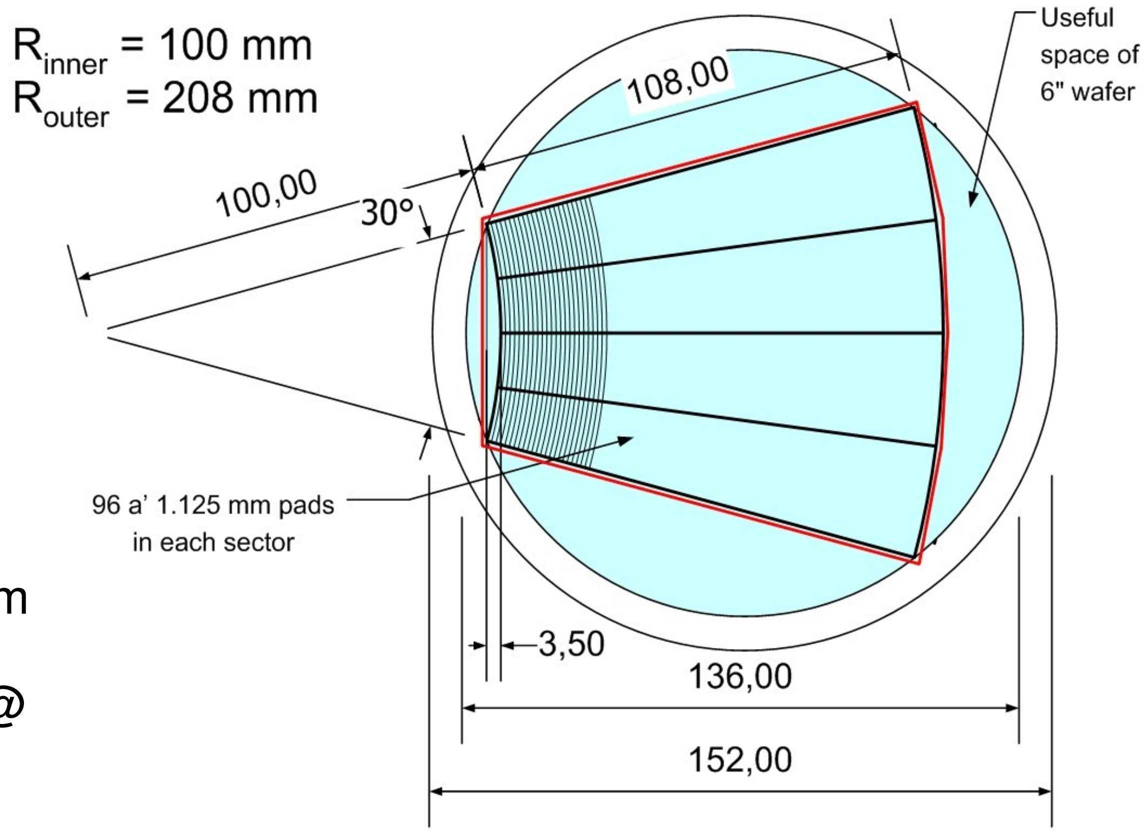


- Very low leakage currents (~pA)
- Decrease of CCD
- Generation of trapping centers

We have similar results also for single crystal CVD diamonds

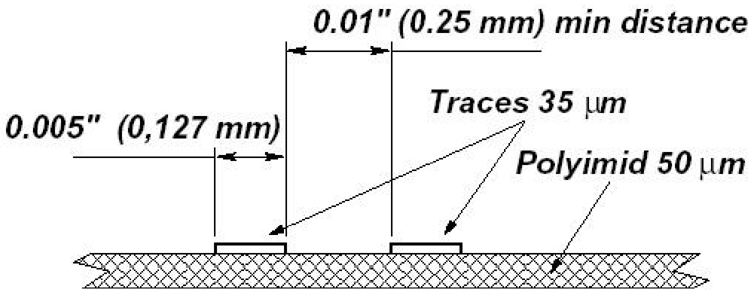
Sensors for LumiCal

- No radiation problem
  - (To be verified)
- Standard silicon
- Possible candidate (Hamamatsu)
  - Si wafer thickness = 320 µm
  - Dark current ~ 10 nA/cm² @ 200 V
  - Time schedule = ~5 months
  - Prototypes in 2008

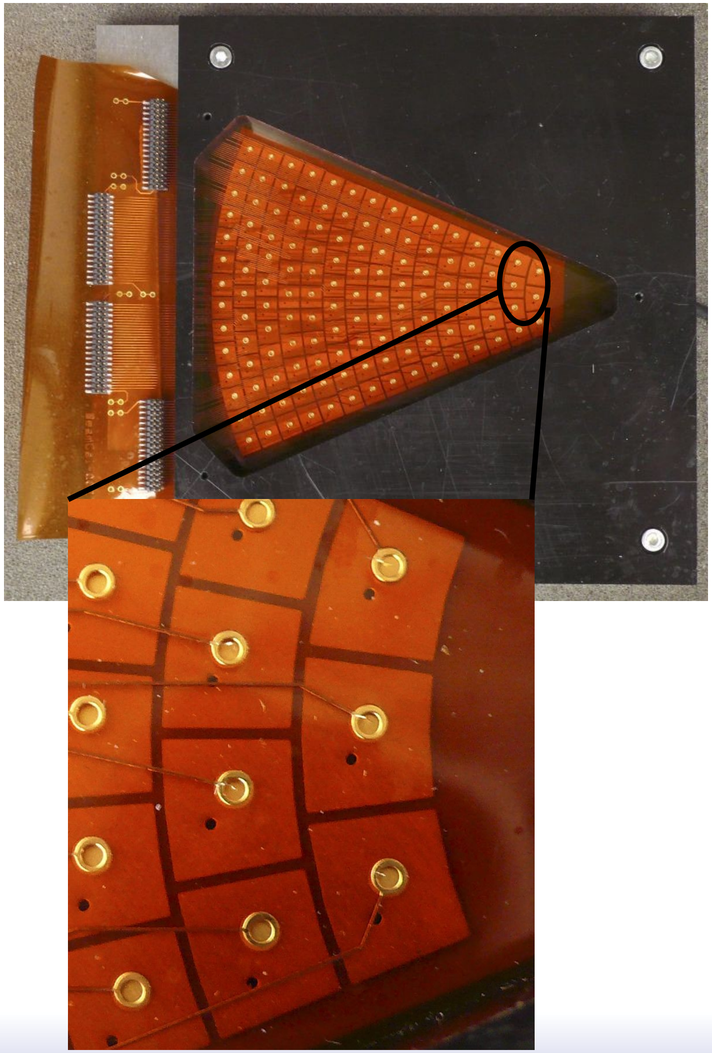


Between Sensor & Front-end

Both BeamCal and LumiCal will requires long (~10 cm) fanout structures, which may affect the detector performance

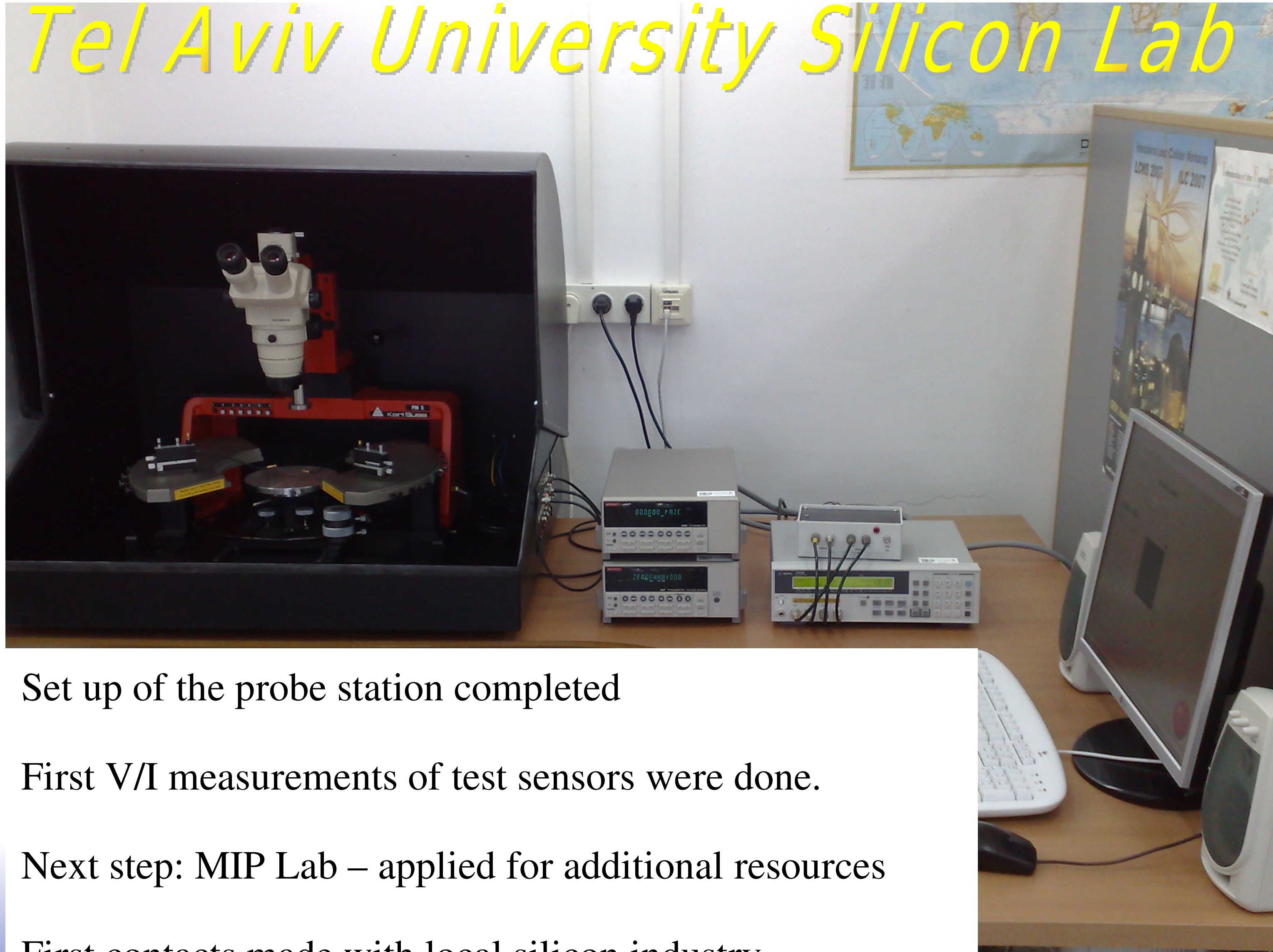


Design of test structures and their parameters measurements (e.g. crosstalk) for both detectors are underway



Readout structure prototype with metal pads bonded to capton readout

Development of Infrastructure



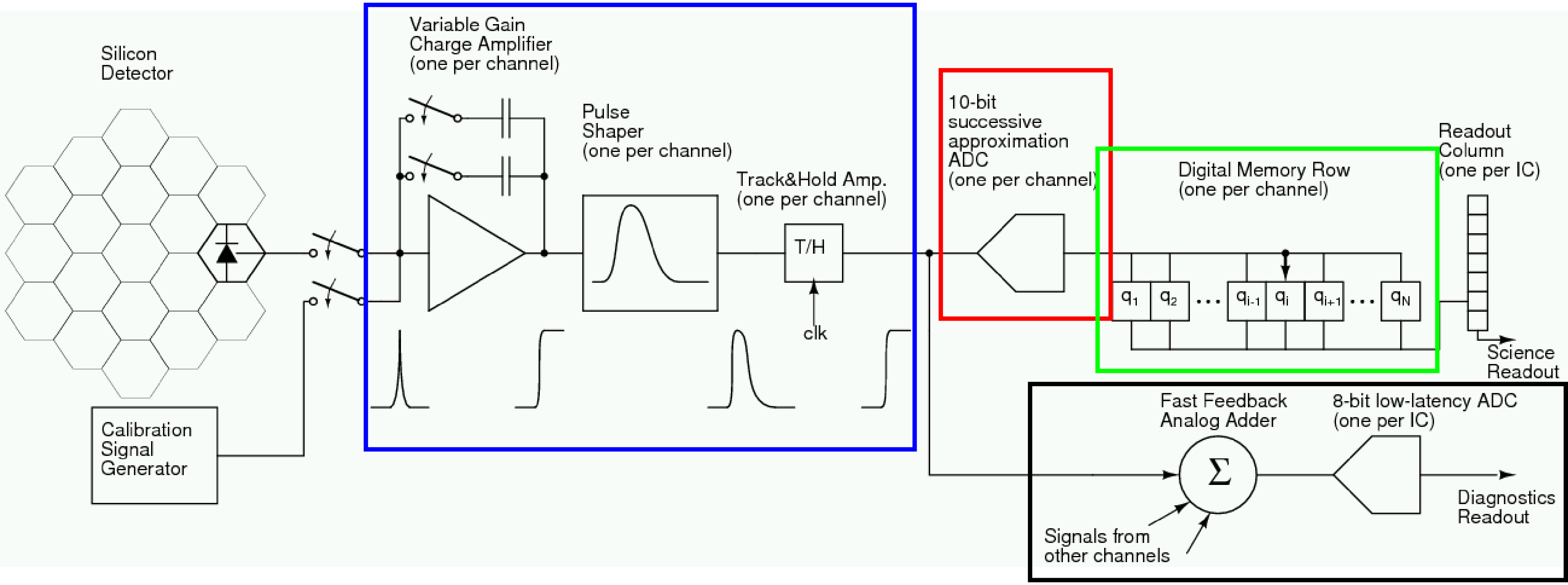
Set up of the probe station completed

First V/I measurements of test sensors were done.

Next step: MIP Lab – applied for additional resources

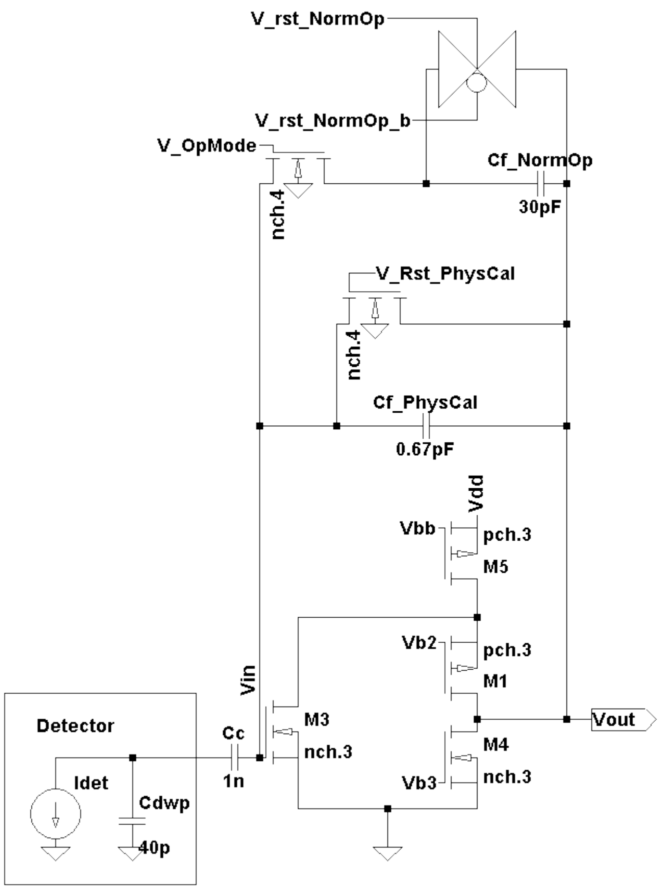
First contacts made with local silicon industry

BeamCal Readout Electronics

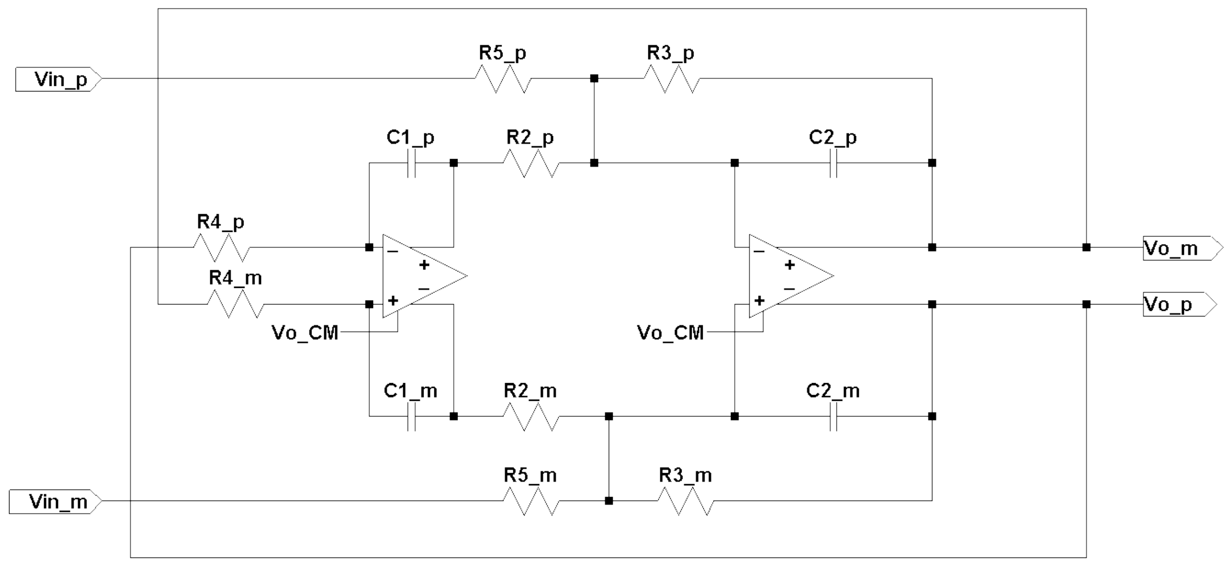


- Dual-gain front-end electronics: charge amplifier, pulse shaper and T/H circuit
- Successive approximation ADC, one per channel
- Digital memory, 2820 (10 bits + parity) words per channel
- Analog addition of 32 channel outputs for fast feedback; low-latency ADC

Preamplifier & Shaper Design



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



- Preamplifier – a voltage amplifier and capacitive feedback
- Shaper – differential biquad filter

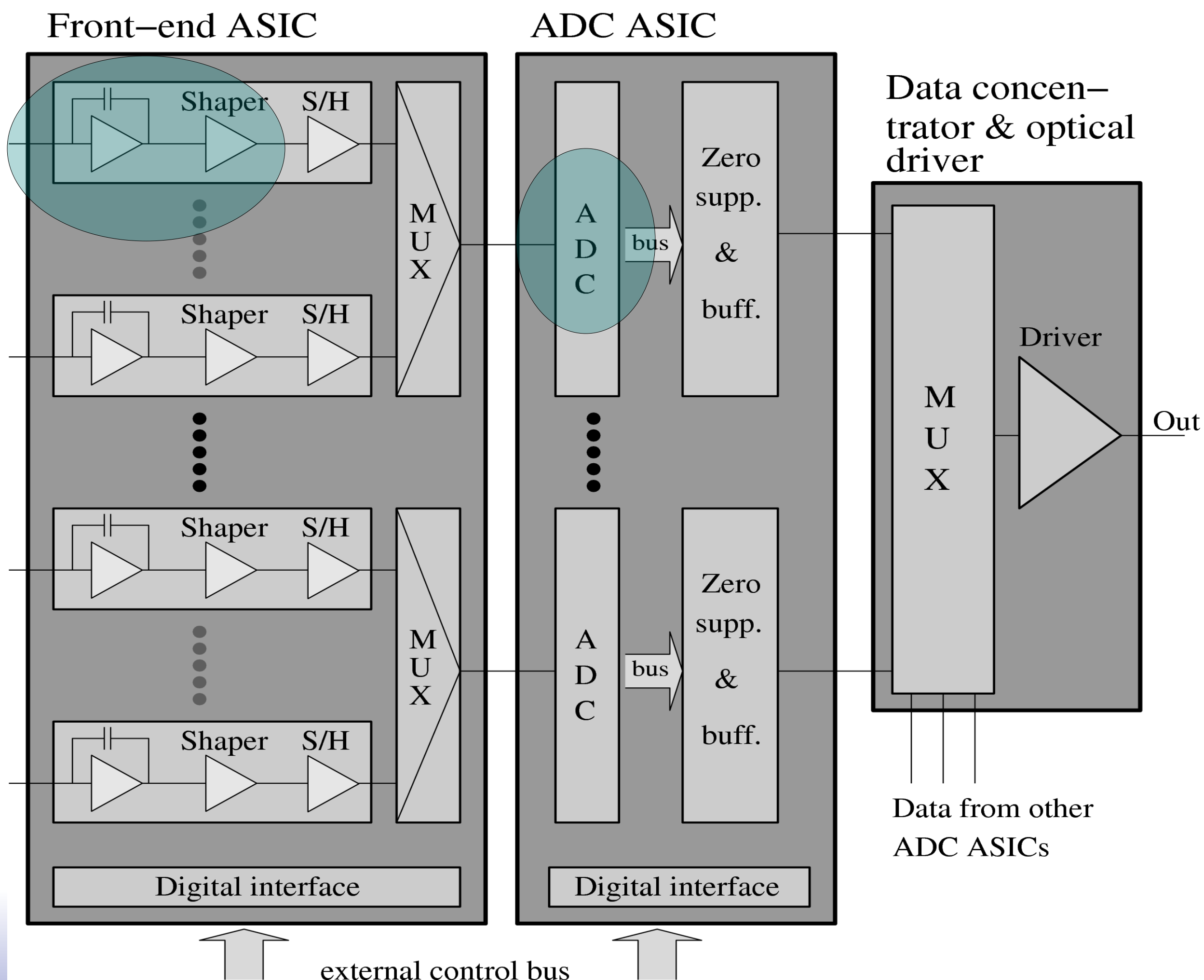
Prototype will be in 0.18μm TSMC CMOS technology, which is naturally radiation tolerant

BeamCal Electronics: Tentative Schedule

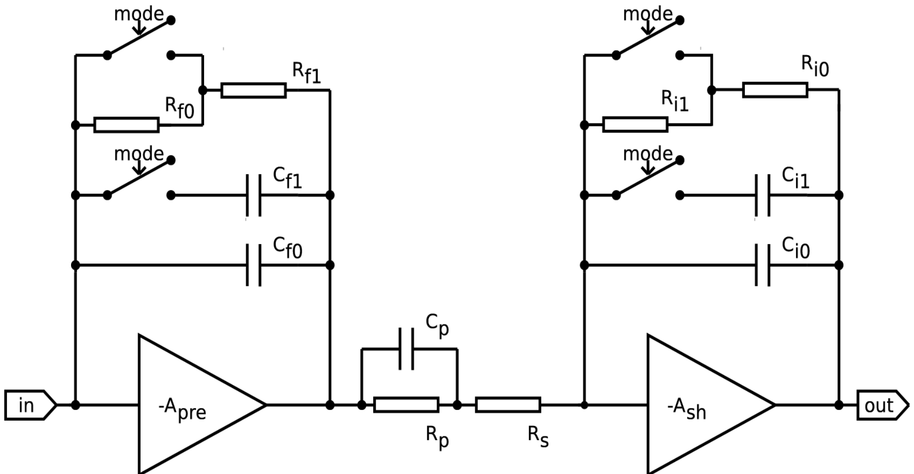
April 2007:	High level design complete
July 2007:	Charge amplifier designed
October 2007:	Filter designed
January 2008:	ADC designed
February 2008:	Memory designed
March 2008:	Fast feedback designed
April 2008:	Bias and supporting circuits
July 2008:	Circuit layout complete
August 2008:	Verification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

LumiCal Readout Architecture

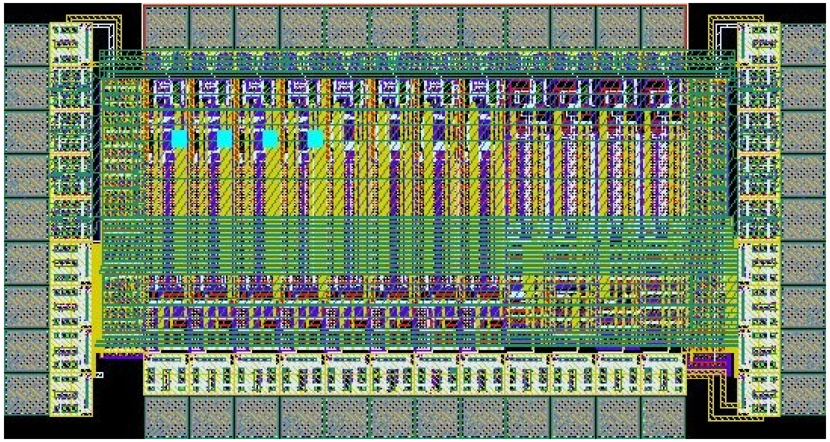
- Front-end ASIC will contain 32-64 dual gain channels
- An ADC will serve ~8(1?) front-end channels
- First prototypes in AMS 0.35 µm



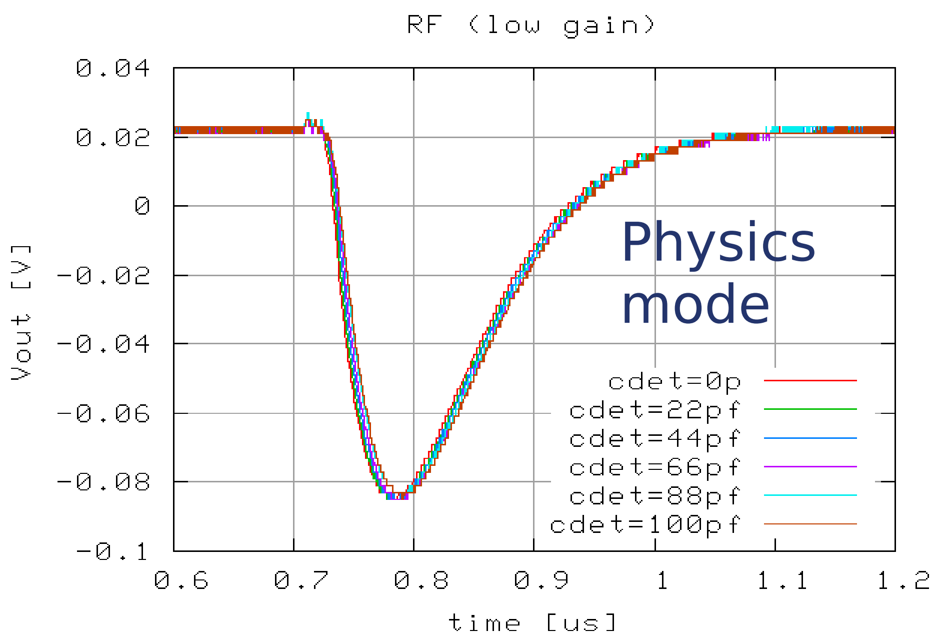
Front-end Design & Tests



Charge sensitive amplifier+PZC+Shaper

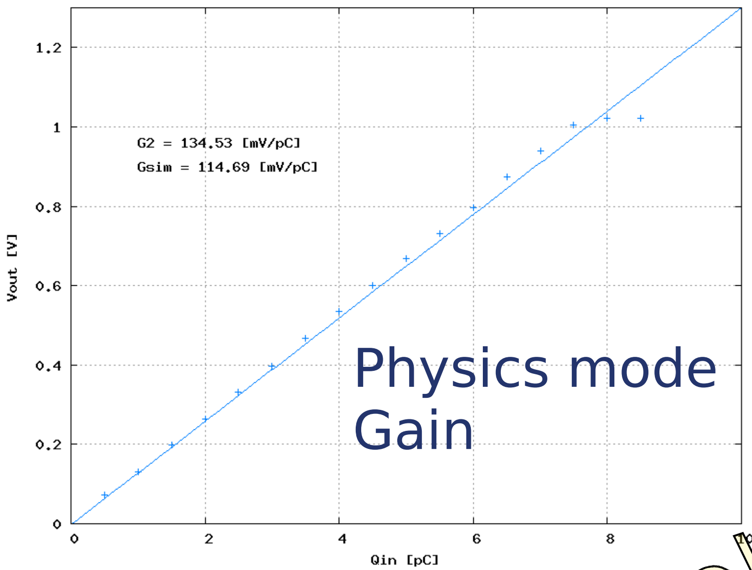


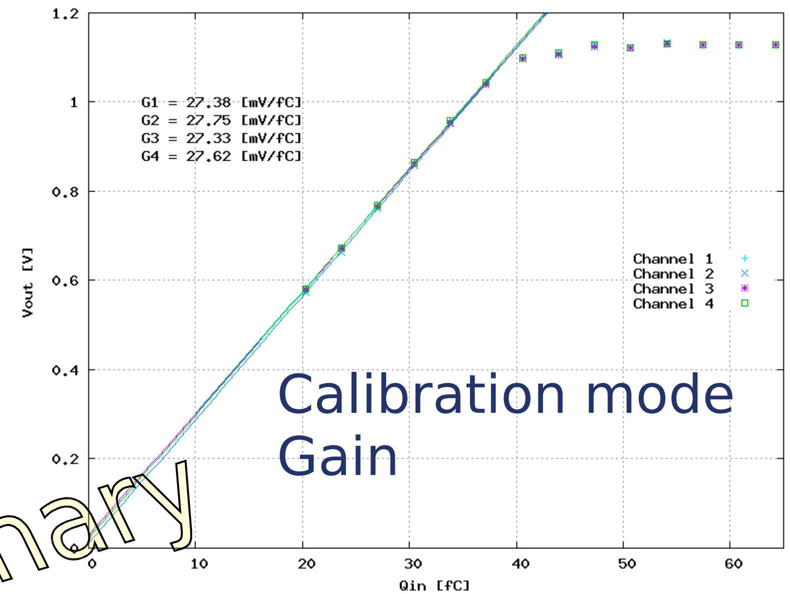
ASIC (few channels) submitted june 2007

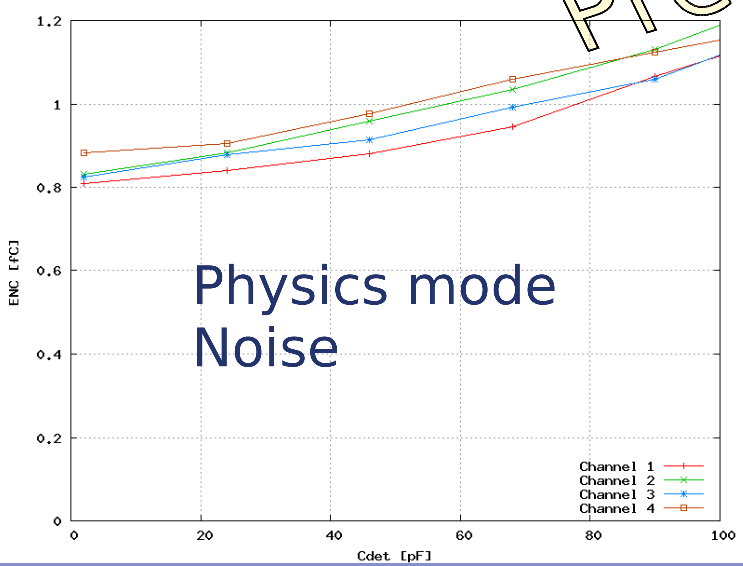


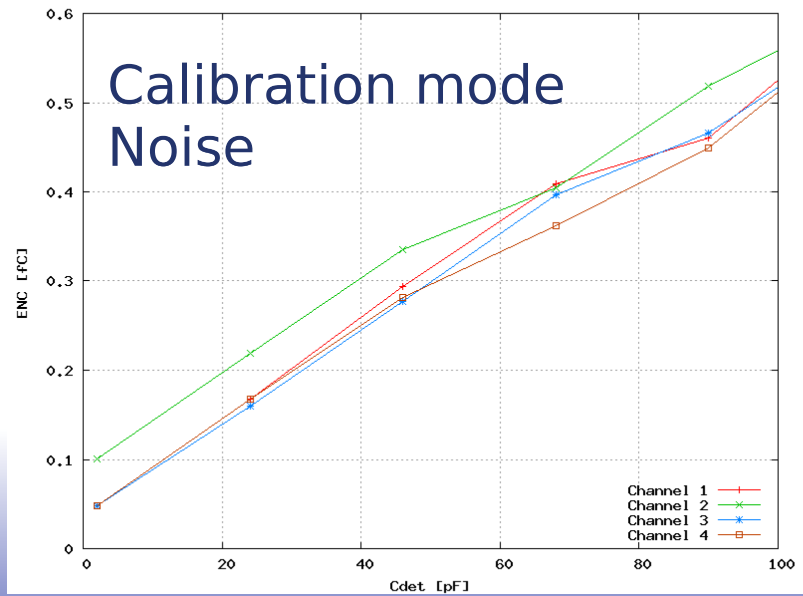
Front-end Measurements

Preliminary

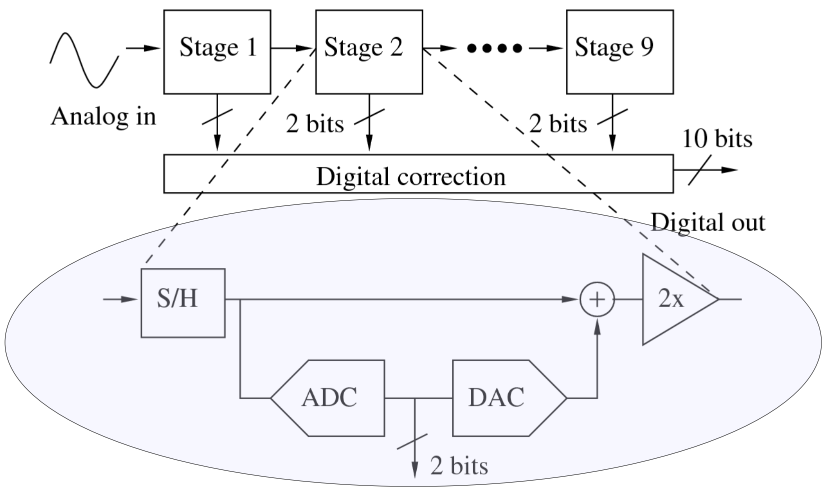


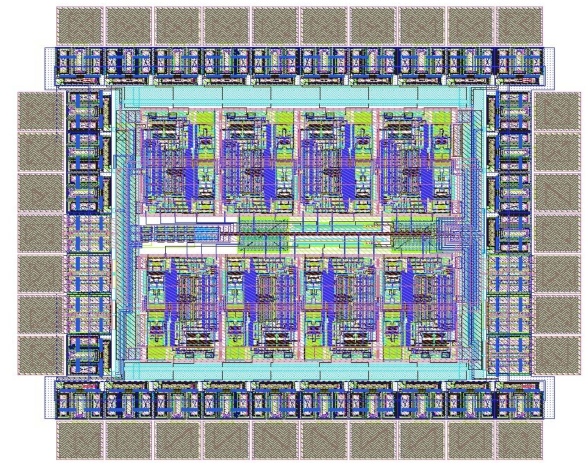


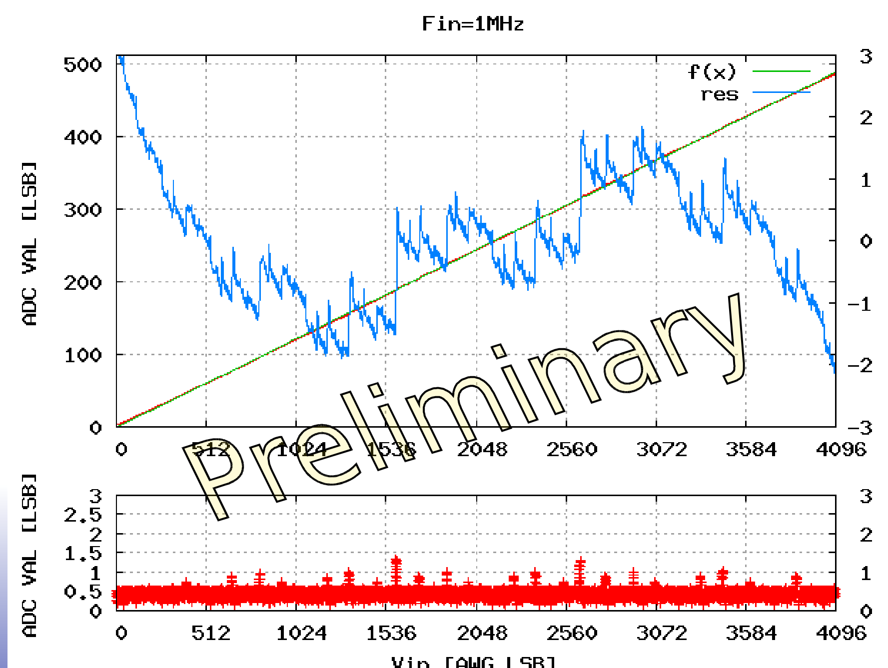




Pipeline ADC Design





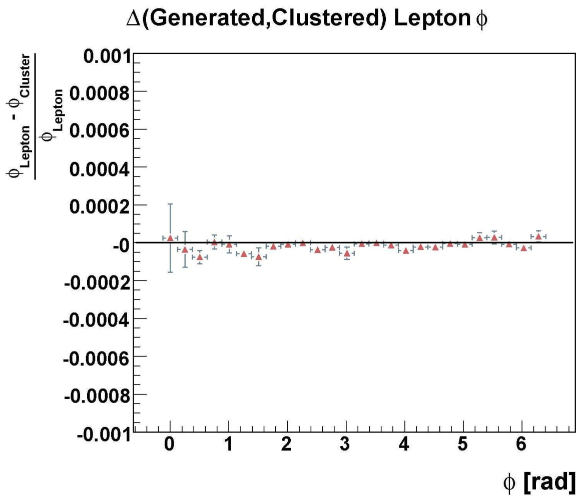


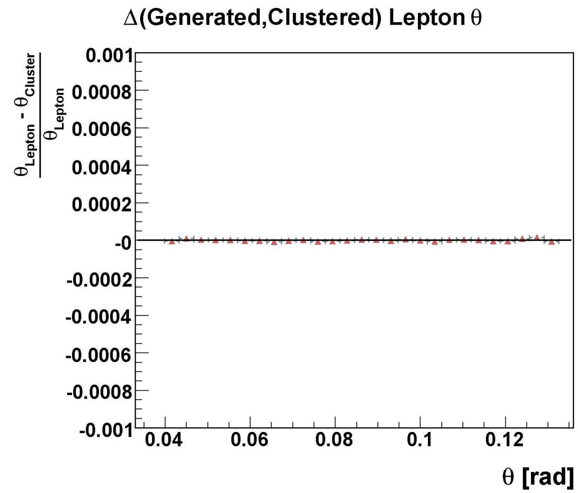
- 10 bit pipeline ADC
- 1.5 bit per stage
- Fully differential architecture
- Pipeline stages submitted in june 2007

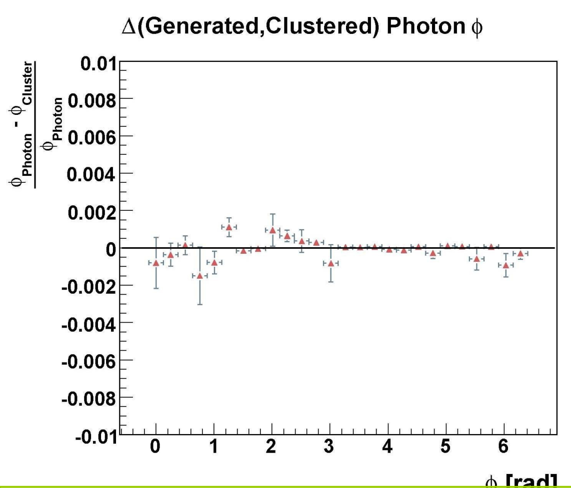
Summary

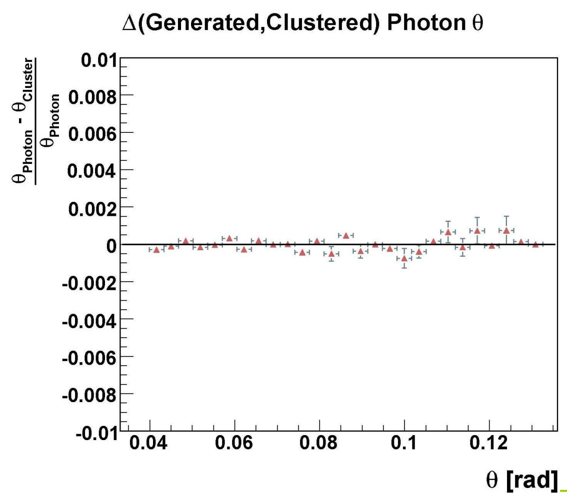
- The FCAL Collaboration develops the detectors in the very forward region of the ILC, independent of a detector concept.
- MC simulations for understanding of the physics background, beam-beam effects and the requirements on positioning and precision.
- An intensive R&D activity on BeamCal radiation hard sensors is underway. Possible candidates: pCVD diamond (expensive), Ga-As, 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 tests.
- A lot of challenges are still ahead.

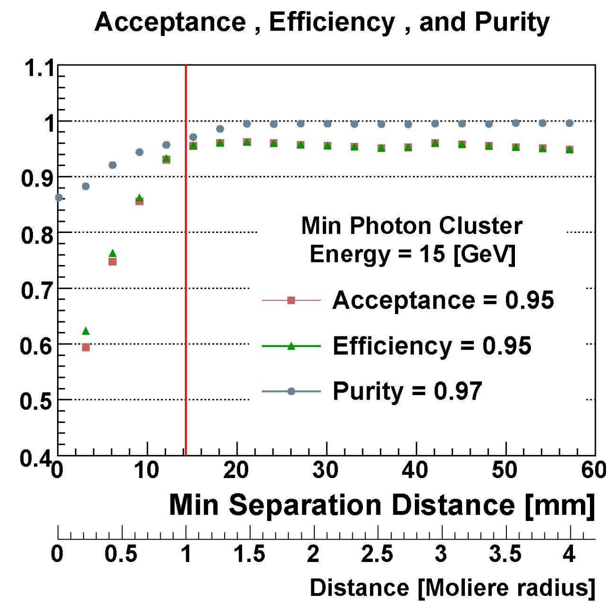
Cluster position reconstruction









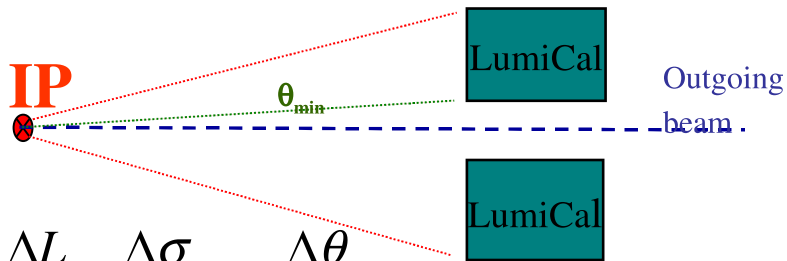


For Bhabha events with $\left(\sqrt{s} = 500\ [\mathrm{GeV}]\right)$:

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

LumiCal Positioning and Alignement

Single (L/R) LumiCal alignment



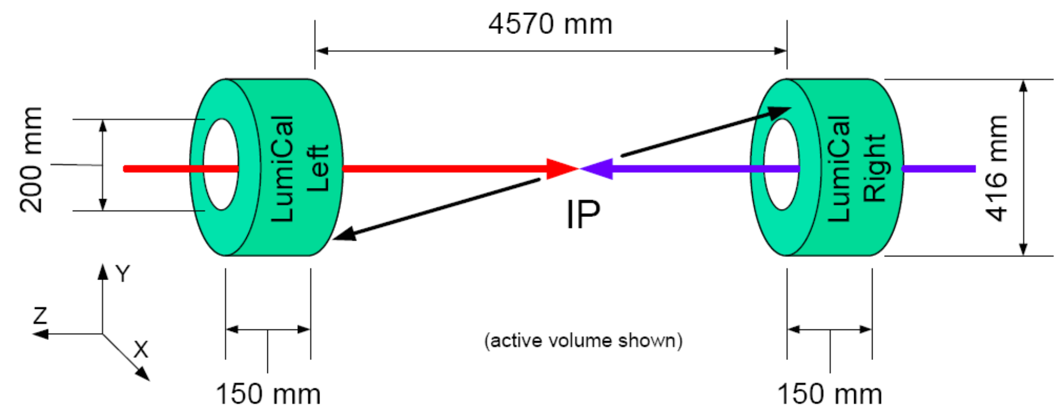
$$\frac{\Delta L}{L} = \frac{\Delta \sigma}{\sigma} \cong 2\frac{\Delta \theta}{\theta_{\min}}$$

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

Two LumiCal's (L,R) alignment

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

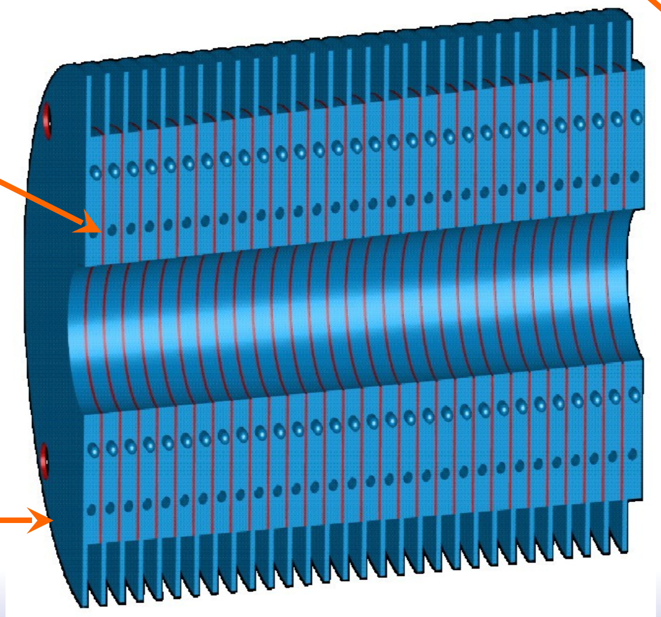


BeamCal Design

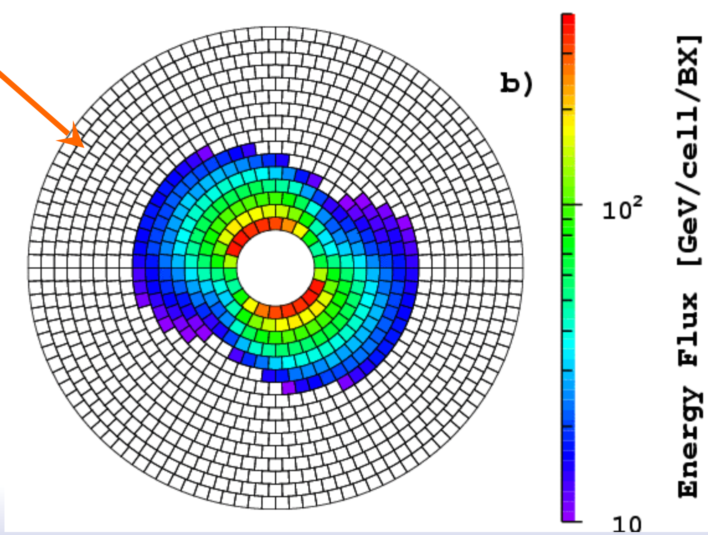
- Compact EM calorimeter with sandwich structure:
  - 30 layers of 1 X_0
    - 3.5mm W and 0.3mm sensor
  - Angular coverage from ~5mrad to ~28 mrad
  - Moliére radius $R_M \approx 1$cm
  - Segmentation between 0.5 and 0.8 x R_M

Radiation hard sensors

W absorber



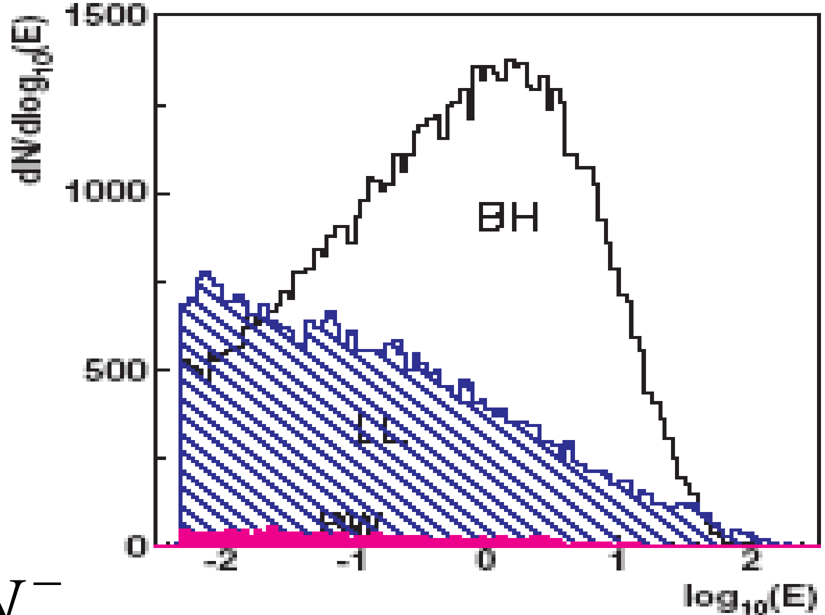
Single detector layer



GamCal Motivation

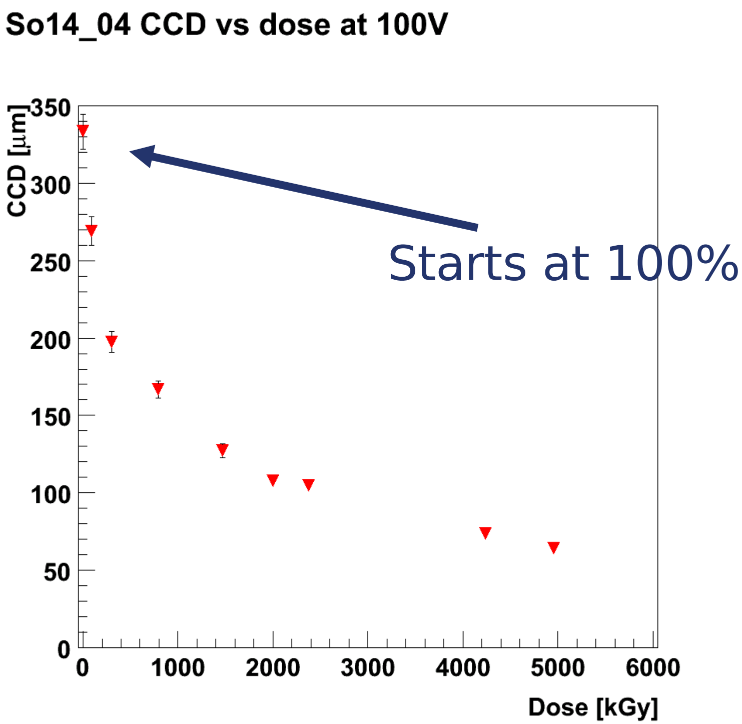
- Measuring the beam-strahlung pairs and gammas provides robust complementary information
- Ratio of pairs to gammas is largely proportional to instantaneous luminosity

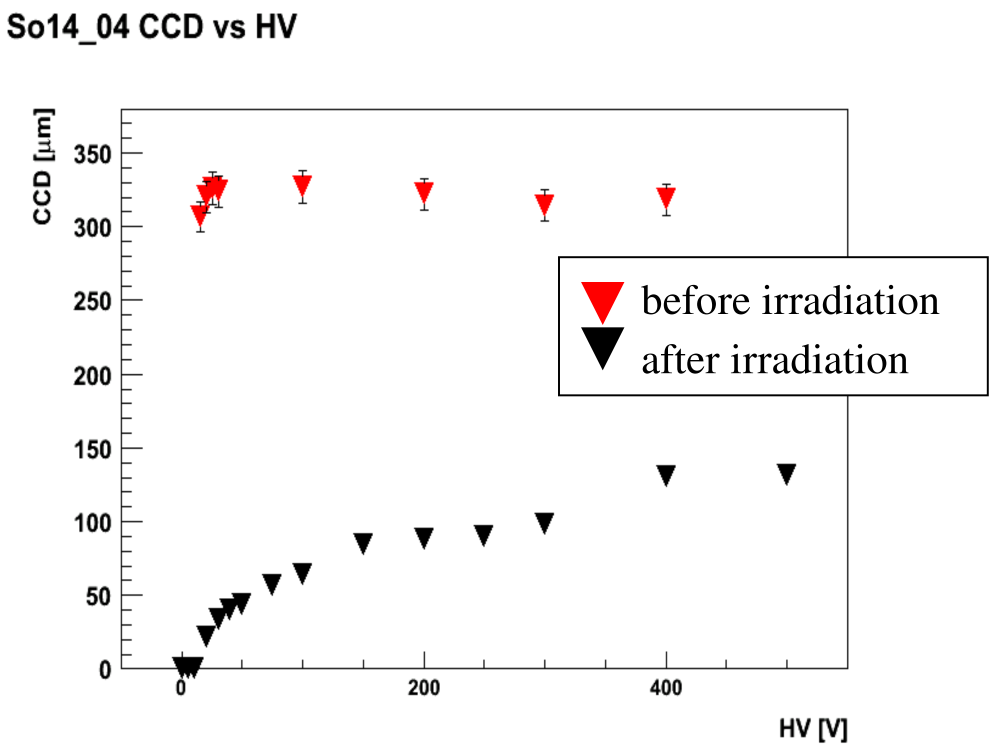
Bethe-Heitler: $\gamma e \rightarrow e\, e^{+}e^{-}$



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

Single Crystal CVD Diamond

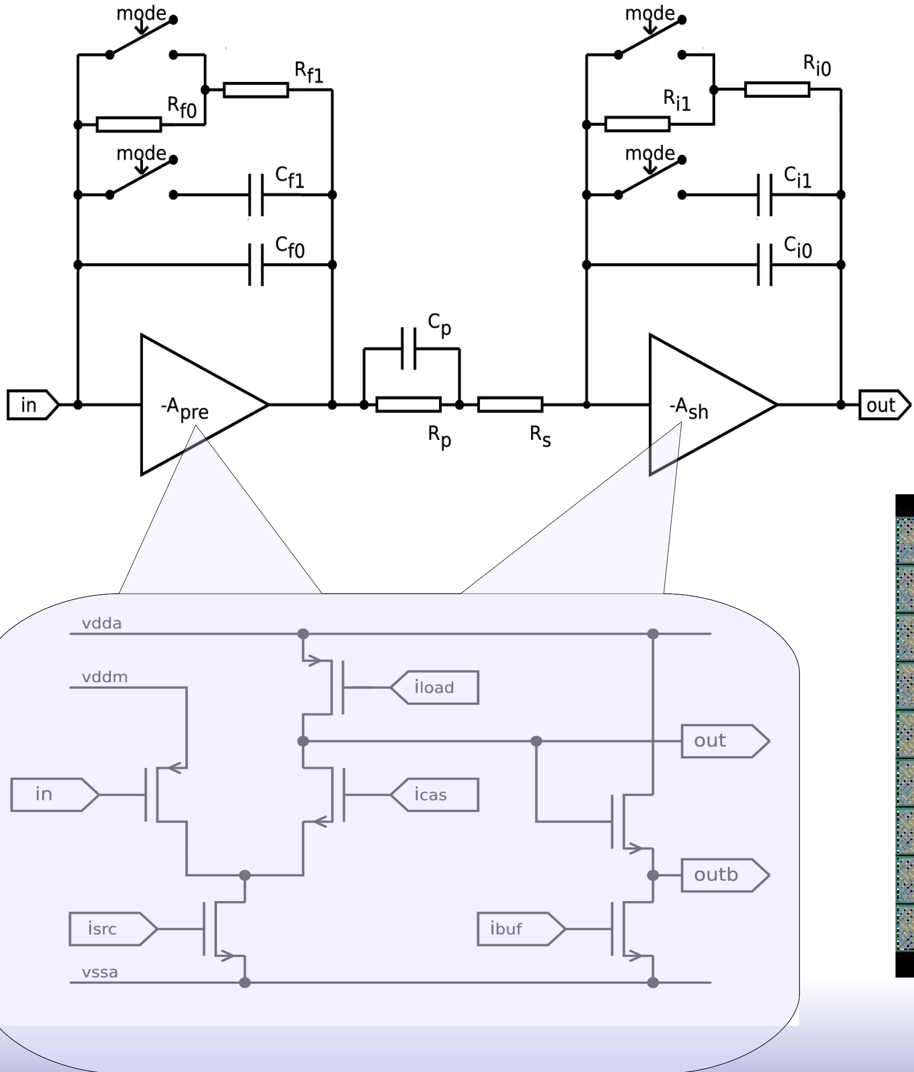




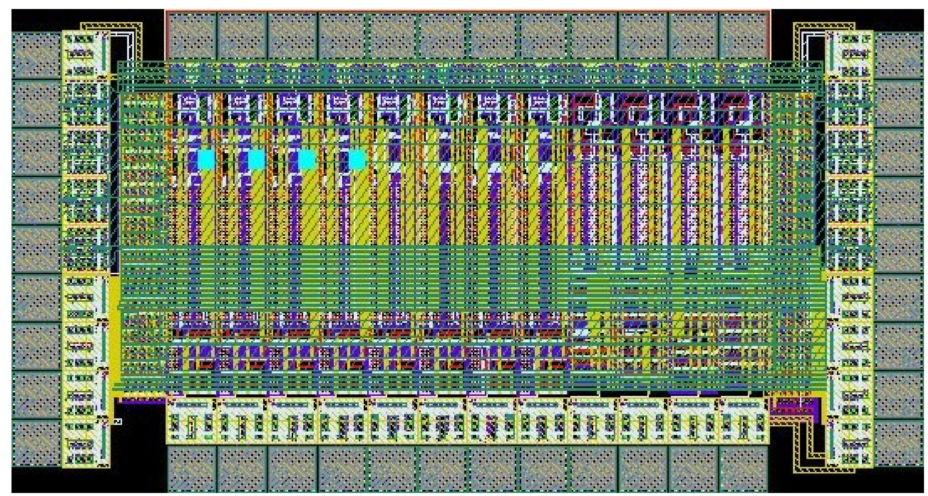
<u>Reduction of measured signal, but still operating after 5 MGy.</u>

(~340µm thickness)

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