The Very Forward Region of the ILC Detectors

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FCAL Collaboration

Lecture Series of JAI, Oxford
Thursday 15/11/2007

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The FCAL Collaboration

14 Institutes from 10 countries:

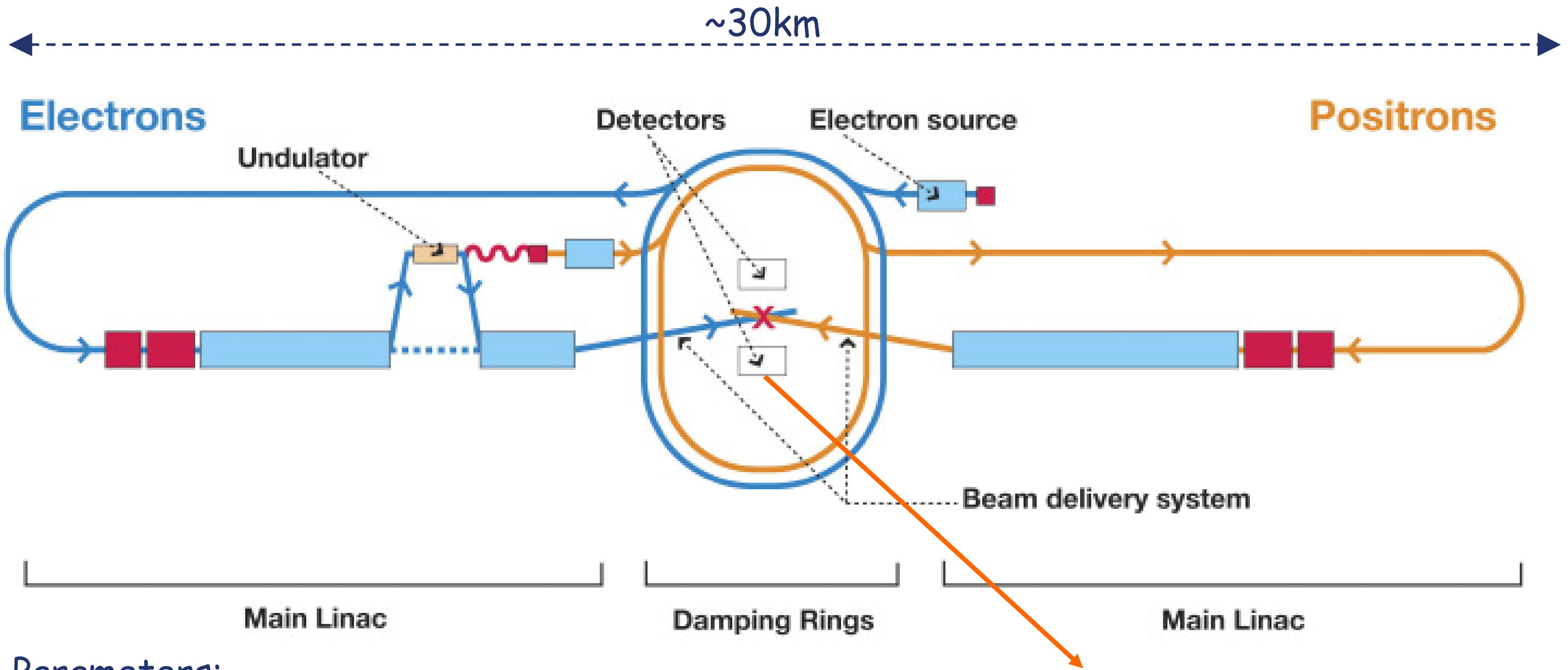
- **Academy of Science, Prague**
- **AGH University of Science and Technology, Krakow**
- **Brookhaven National Lab, Upton**
- **DESY**
- **Institute of Nuclear Physics, PAS, Krakow**
- **Joint Institute Nuclear Research, Dubna**
- **Laboratoire de l Accélérateur Linéaire, Orsay**
- **National Center 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 and Stanford University**

Supported by:
- EUROTeV,
- EUDET,
- NoRHDIA
- INTAS
- DOE
- ISF
- Fital

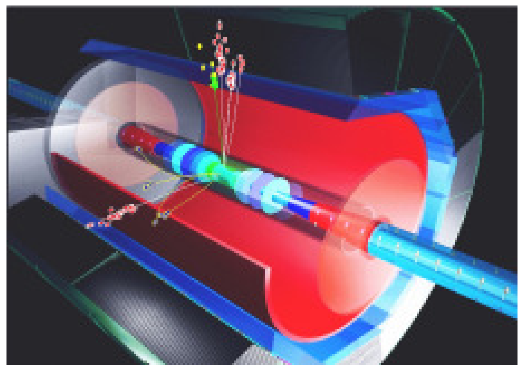
http://www-zeuthen.desy.de/ILC/fcal/

The International Linear Collider

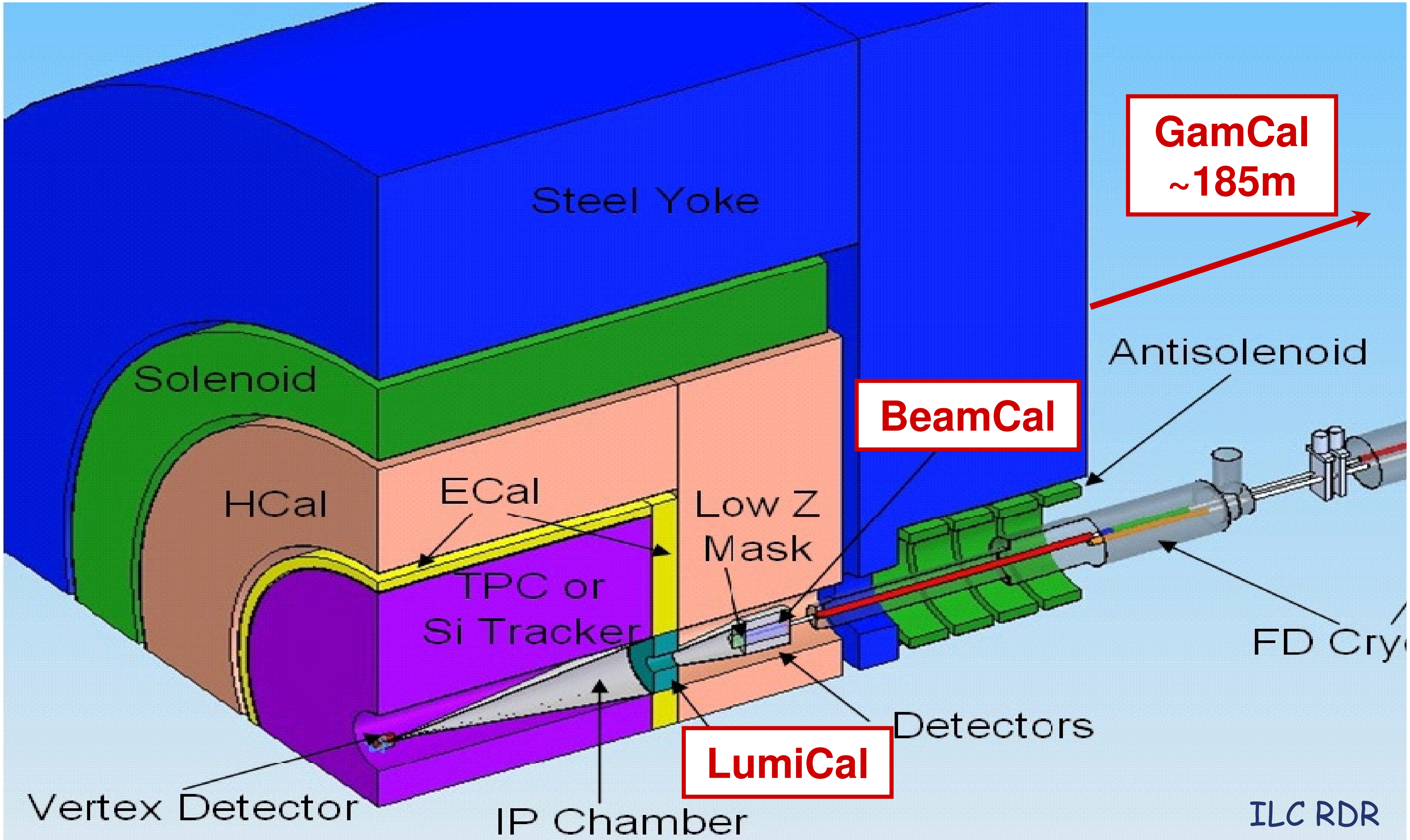


Parameters:

500 GeV (1 TeV upgrade possible)
2×10^{34} cm^{-2}sec^{-1}
electron polarization ~80 %
positron polarization ~30 % (60 %)
beam sizes: $\sigma_x \approx 600$nm, $\sigma_y \approx 6$nm, $\sigma_z = 300\mu$m

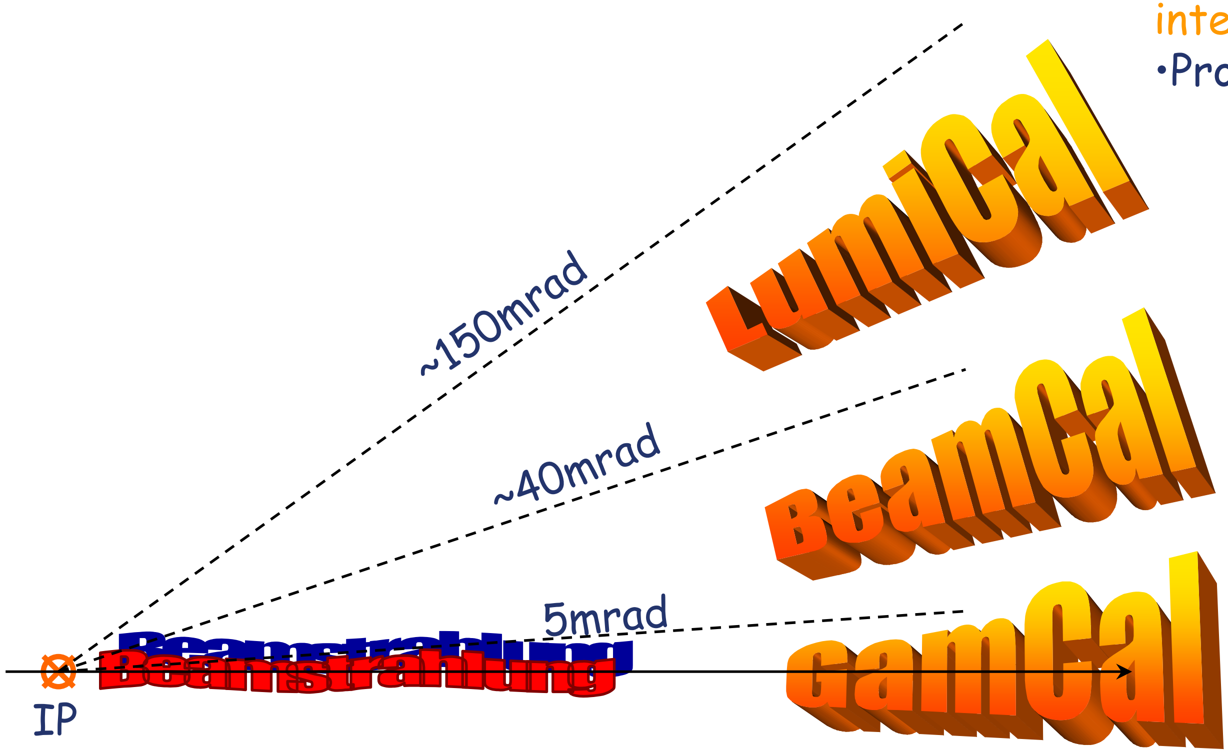


Design of the Forward Region



Tasks of the Forward Region

ECal and Very Forward Tracker acceptance region.



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

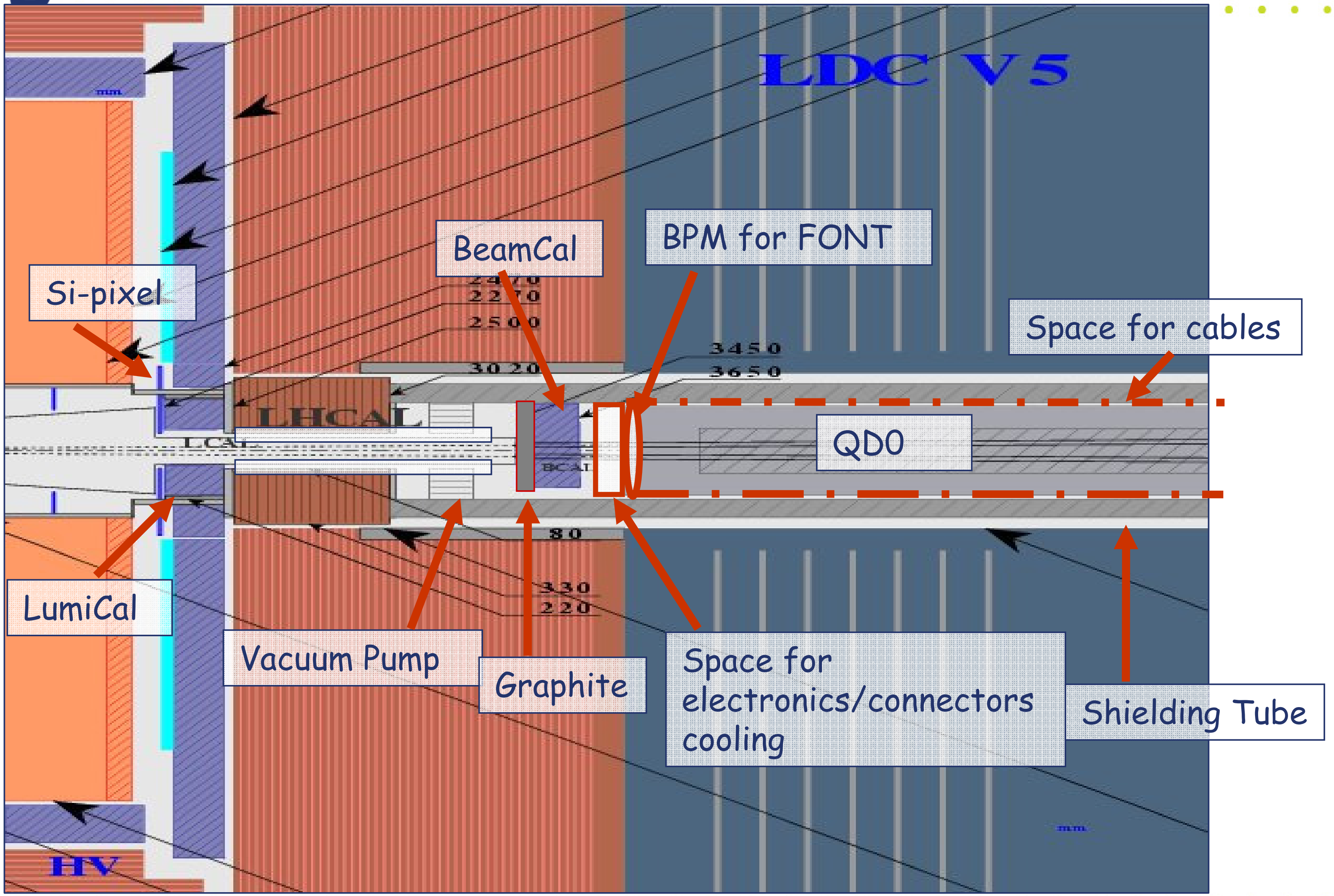
- Provide 2-photon veto
- Serve the beamdiagnostics using beamstrahlung pairs

- Serve the beamdiagnostics using beamstrahlung photons

Challenges:

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

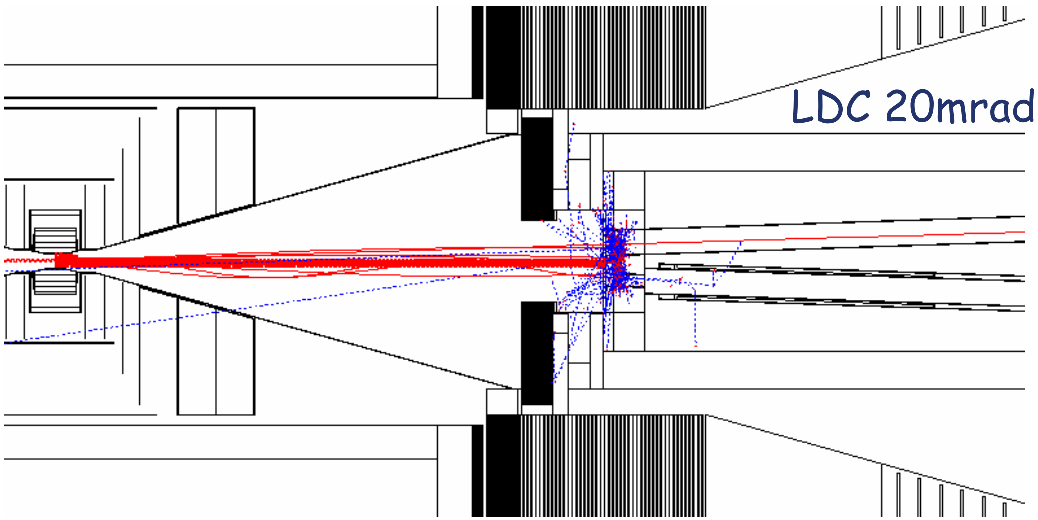
Forward Region (LDC)



Forward Region Overview

- The FCAL Collaboration develops the Very Forward Detectors: LumiCal, BeamCal and GamCal.
- Due to the small bunch size σ_x~650nm, σ_y~5.7 nm and the high bunch charge, N x 10^{10}/bunch, beamstrahlung becomes important at the ILC.
- The geometry has to be carefully optimized to minimize background due to the beamstrahlung pairs.

	LDC			SID		
	R_{Inner}	R_{Outer}	Z_{Pos}	R_{Inner}	R_{Outer}	Z_{Pos}
	mm	mm	mm	mm	mm	mm
LumiCal	80	350	2270	60	200	1800
BeamCal	20	165	3550	16	110	3000
GamCal	-	-	~185m	-	-	~185m



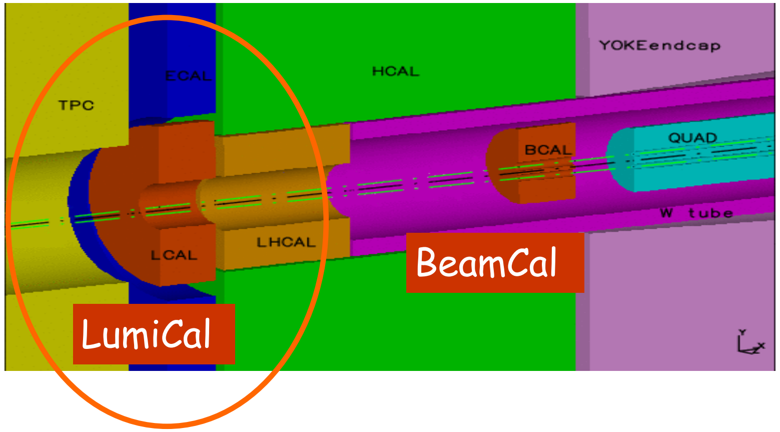
The LumiCal

Precise Measurement of the ILC's luminosity

Precise Measurement of the Luminosity

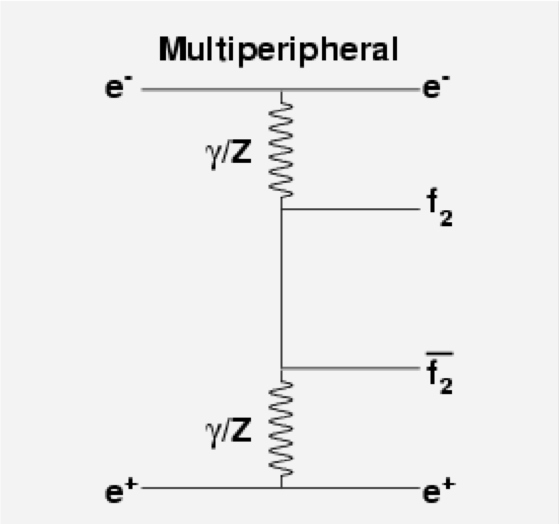
- Required precision is:

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

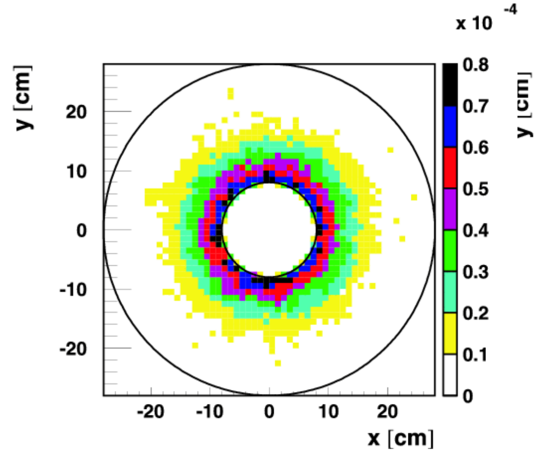


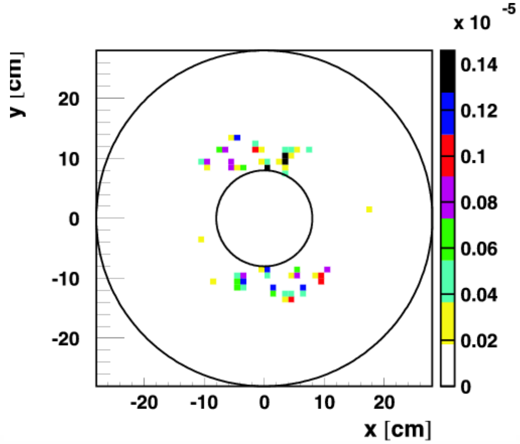
- Bhabha scattering ee->ee(γ) is the gauge process:
  - **Count Bhabha events in a well known acceptance region => $L = N/\sigma$**
  - **High statistics at low angles => $N_{Bhabha} \sim 1/\theta^3$**
  - **Well known electromagnetic process (LEP: 10^{-3}): the current limit on the theoretical cross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

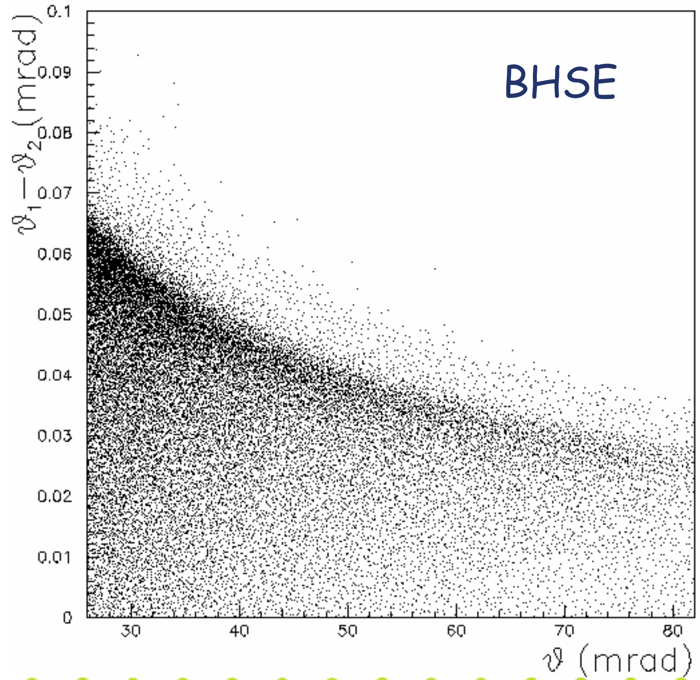
Physics Background and Beam-Beam Effect



2-photon rejection





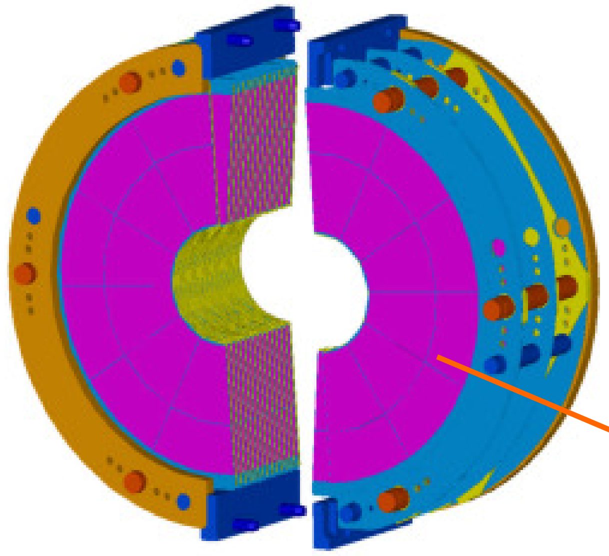


- 2-photon events are the main background.
- We determined an efficient set of cuts to reduce the background to the level of 10^{-4}.
- The Bhabha Suppression Effect (BHSE) is due to the EM deflection and energy loss by beamstrahlung of the Bhabhas. Correction needs precise knowledge of beam parameters.

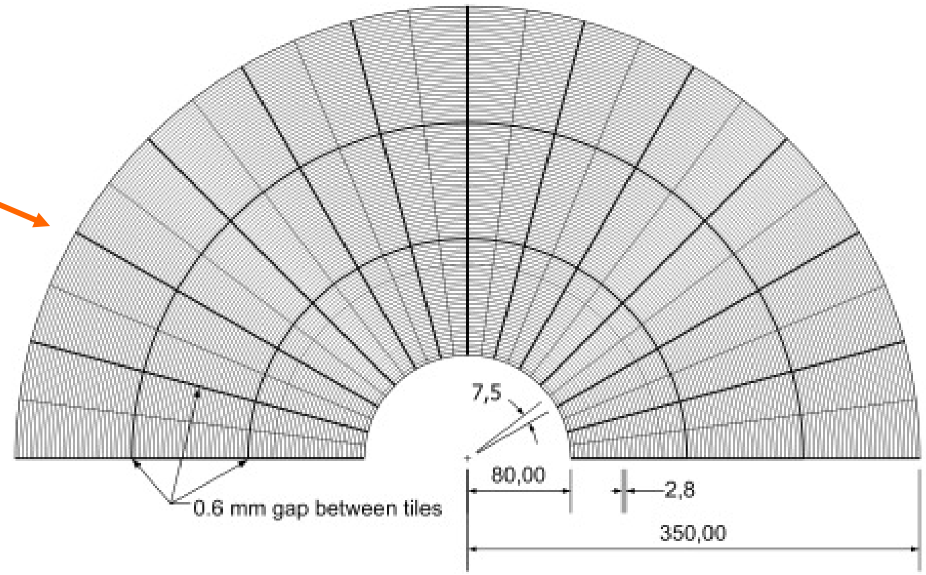
C.Rimbault et al. JINST 2:09001.2007

LumiCal Design

Si/W sandwich calorimeter,
2 half barrels, 30-40 layers
laser position monitoring system



Single detector layer
48 azimuthal sectors,
each sector subdivided into radial
pads of about 1 mrad

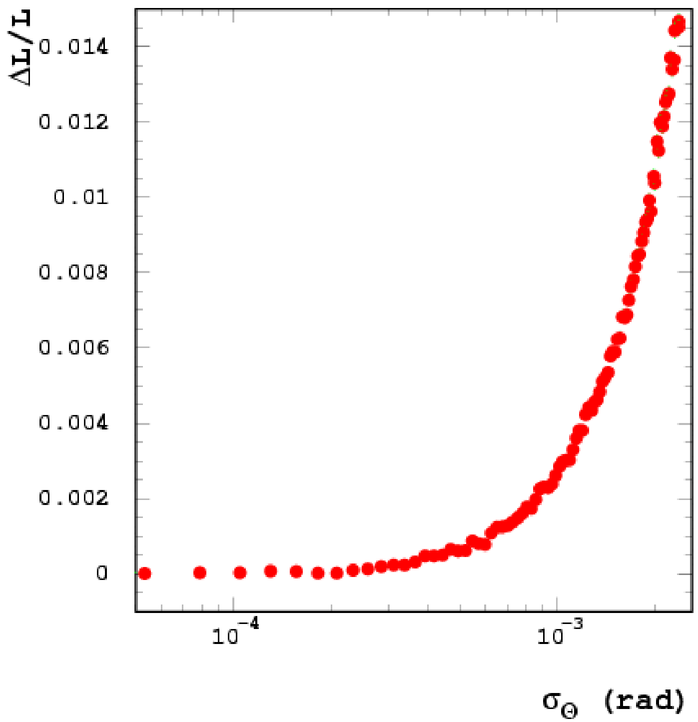


Each layer consists of
3.5mm tungsten absorber,
300μm silicon sensor and readout.

Requirements on the Mechanical Precision

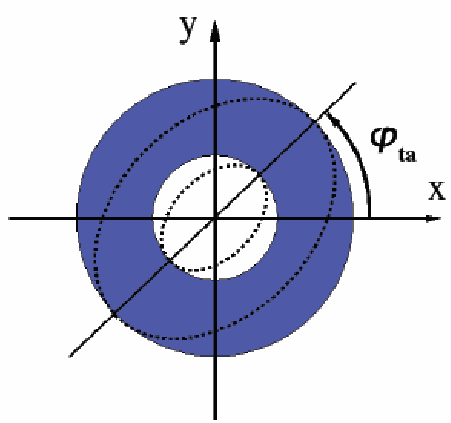
MC simulations of LumiCal:

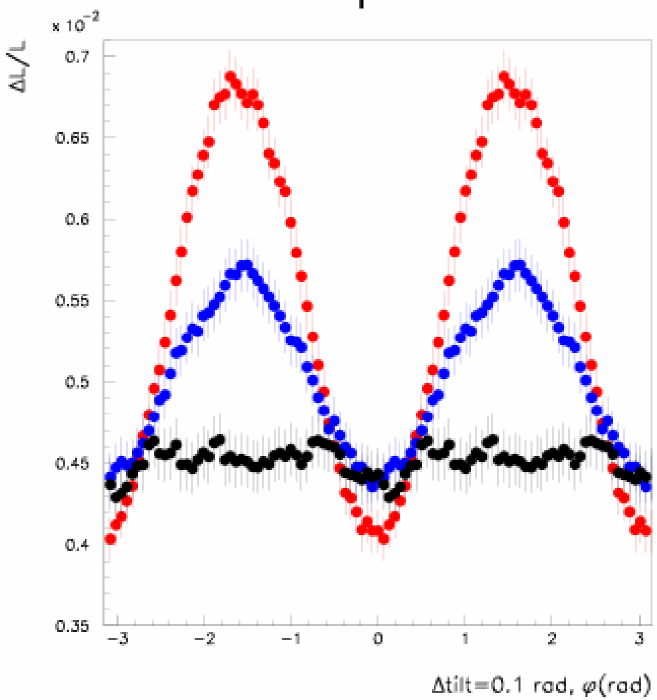
Derive requirements on design, segmentation, mechanical precision and impact of different magnetic field/crossing angles.



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

LumiCal: Systematics

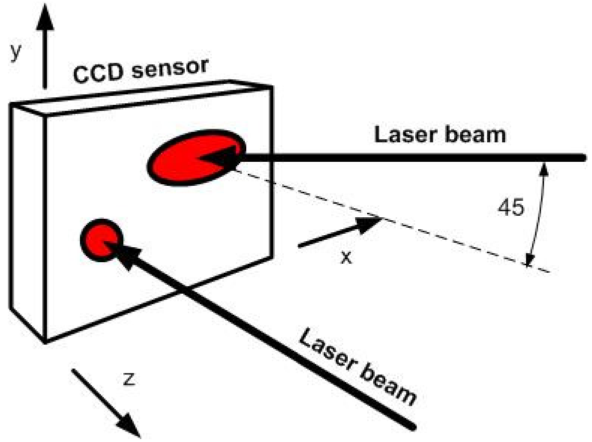




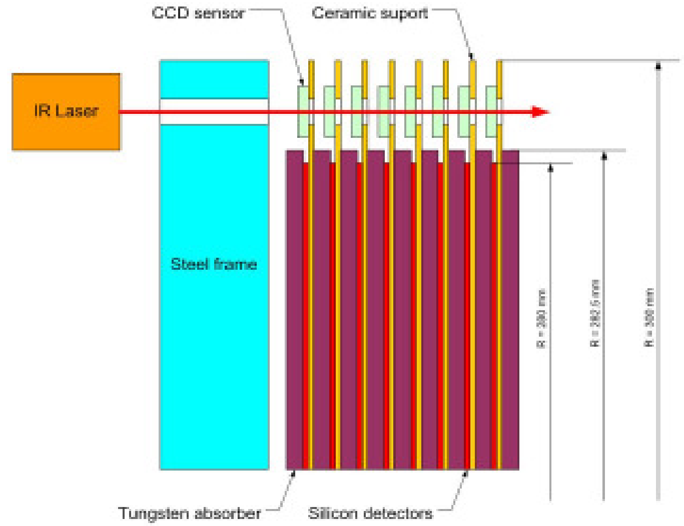
- ● Headon, 14,20 mrad X-angle outgoing beam
- ● 14 mrad X-angle detector axis
- ● 20 mrad X-angle detector axis

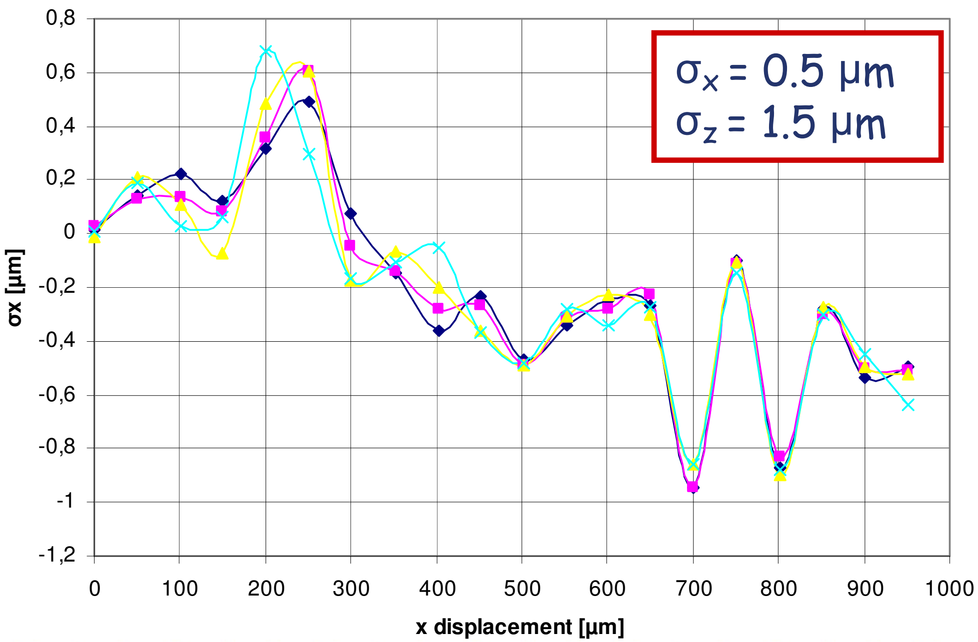
Recommendation:
place LumiCal around outgoing beam and tilt it accordingly.

Laser Alignment System



Two laser beams allow to measure displacements in xyz.





Temperature stability is an issue.
Observed changes of about 1µm/K.

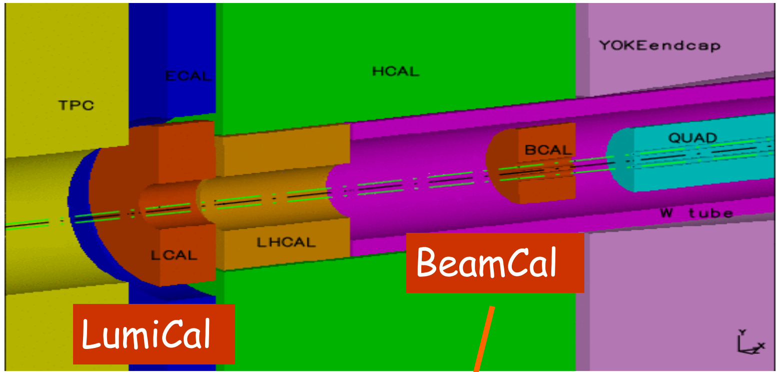
Integration study for the LAS started.

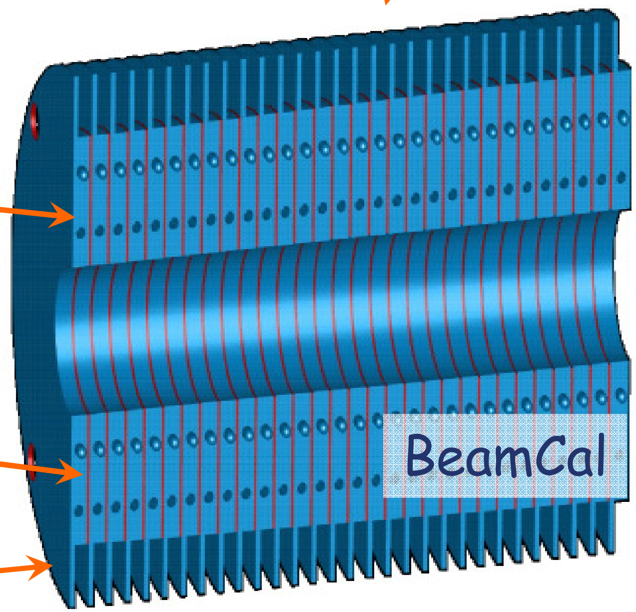
The BeamCal

Particle Veto at Lowest Polar Angles

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 ~45 mrad
  - Moliére radius $R_M \approx$ 1cm
  - Segmentation between 0.5 and 0.8 x R_M





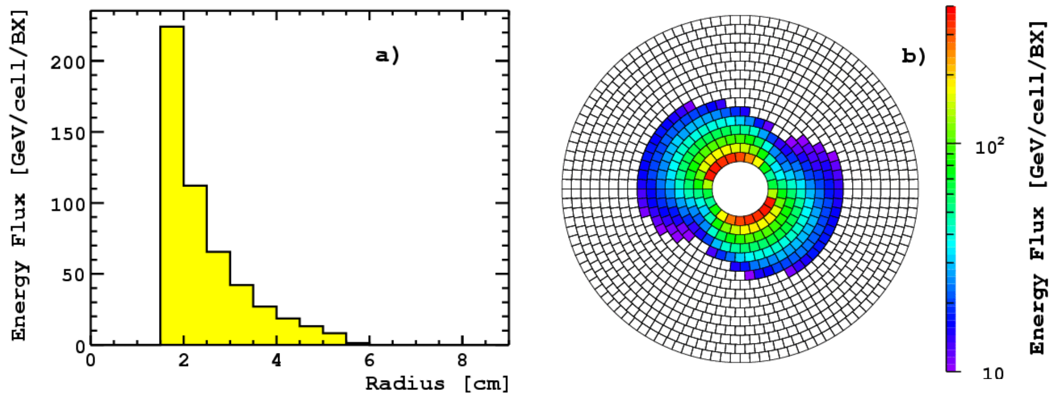
W absorber layers

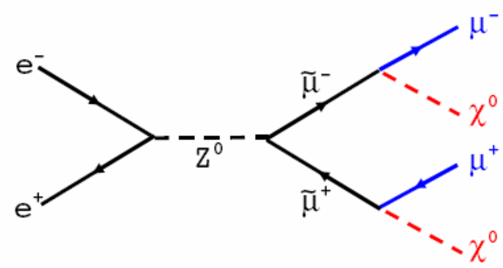
Radiation hard sensors with thin readout planes

Space for readout electronics

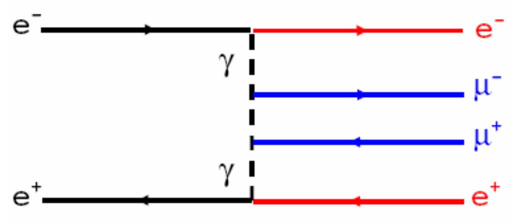
BeamCal Challenges

- 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, providing a 'beamstrahlung pair' information to the feedback system.





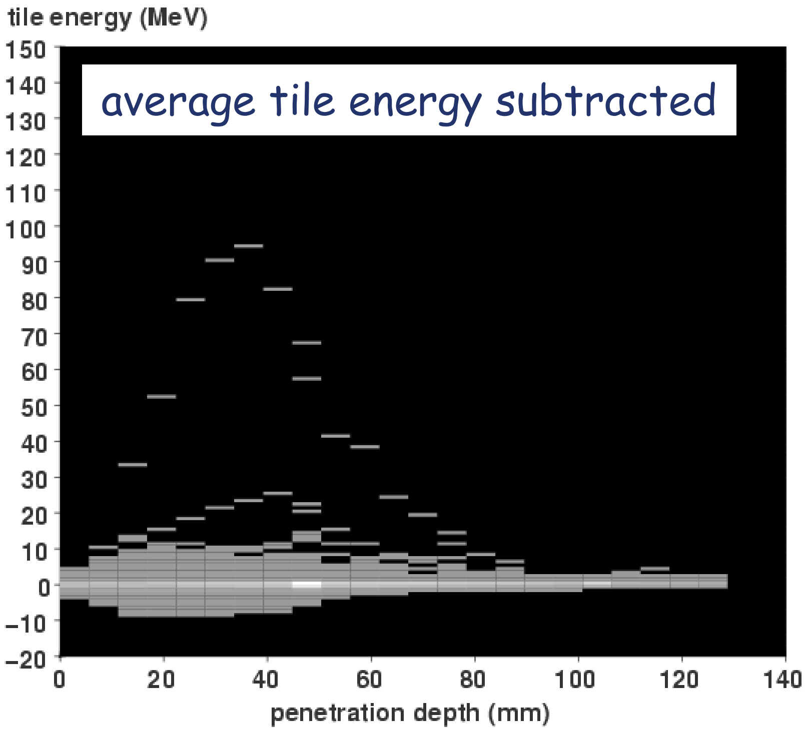
Physics signal:
e.g. SUSY smuon production

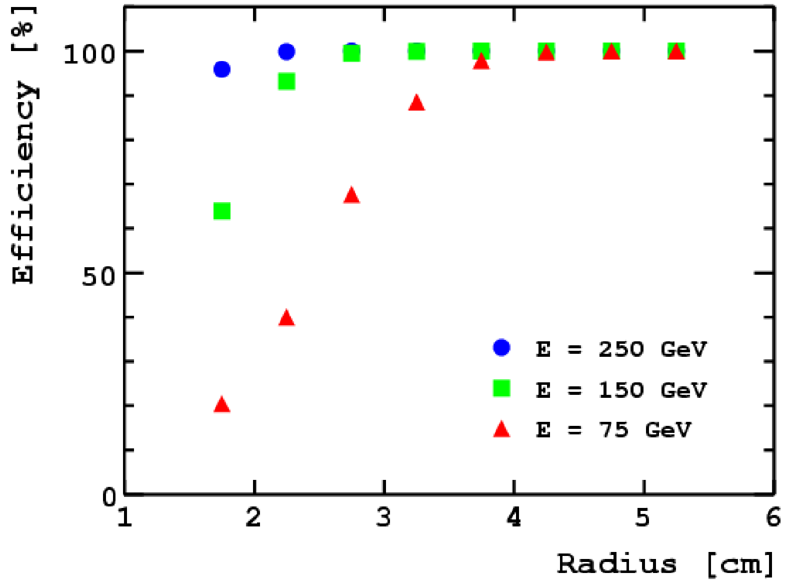


Background signal:
2-photon event, may fake the upper signal if the electron is not detected.

Particle Veto

Subracted Tile Energy



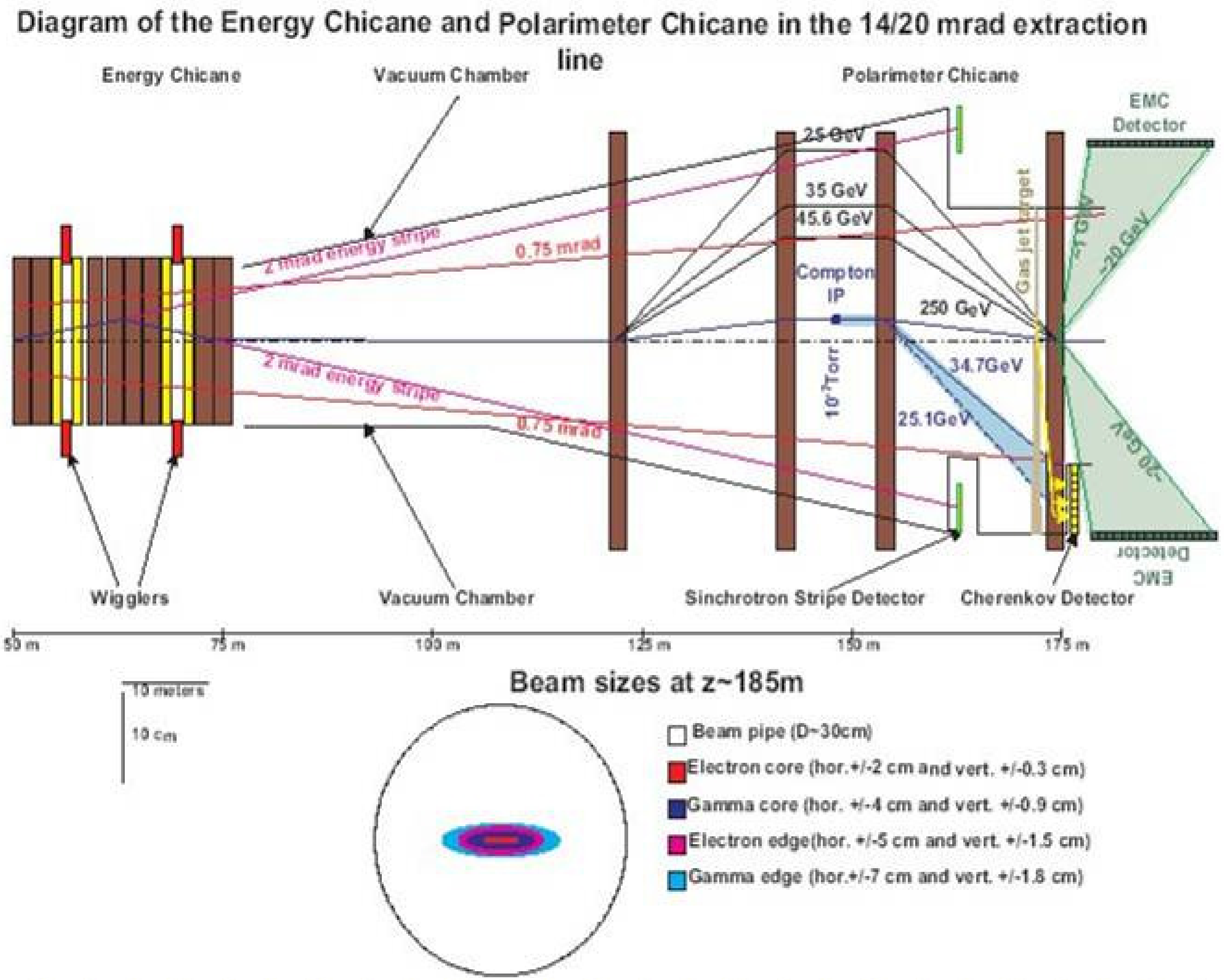


- We developed algorithms to efficiently veto single high energetic particles down to lowest polar angles.
- We investigated the impact of different layouts, cell sizes, etc..
- We need radiation hard sensors with a large dynamic range $O(10^4)$.

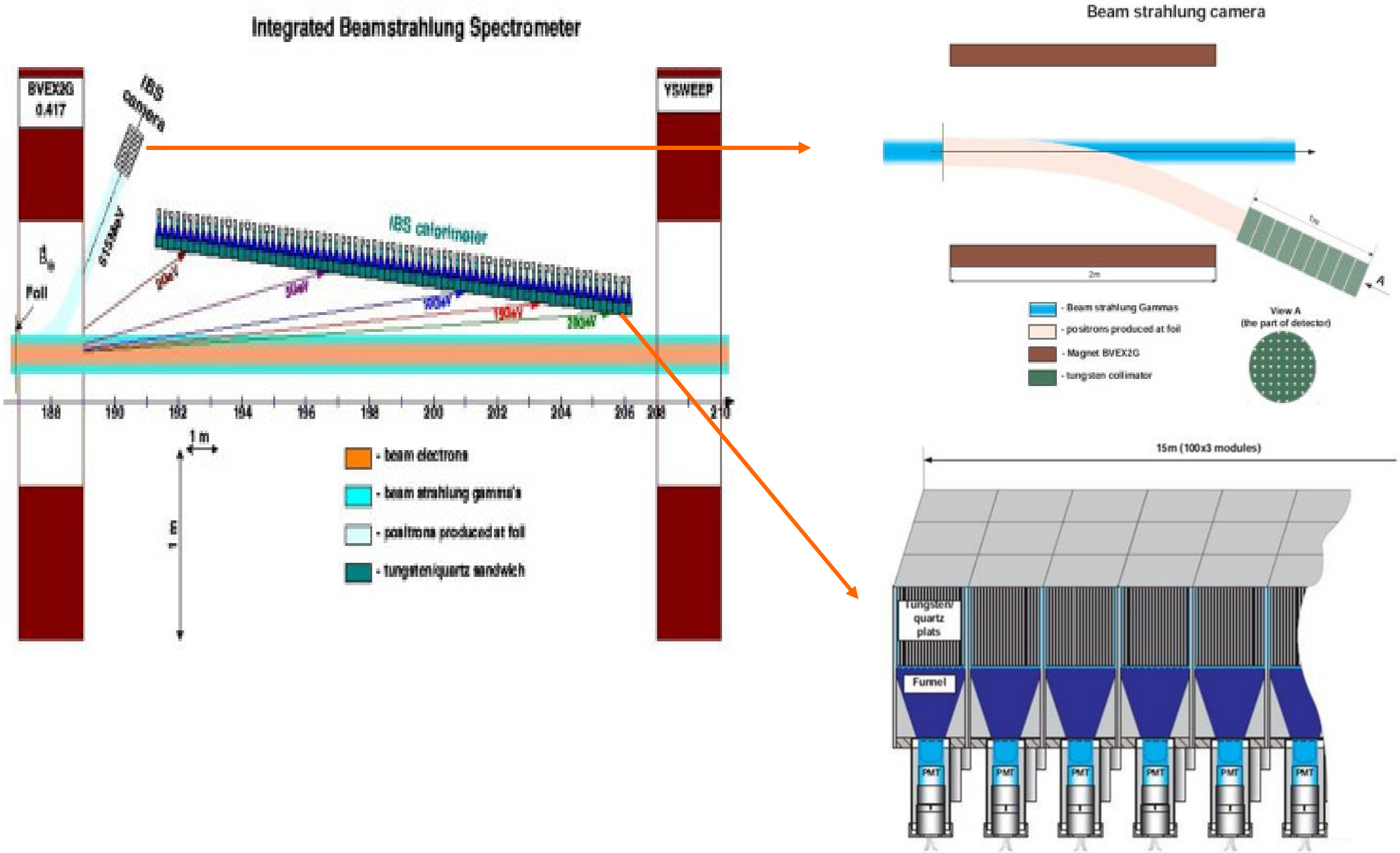
GamCal

Measuring Beamstrahlung Photons

GamCal Design



GamCal Design (cont.)



Beamdiagnostics

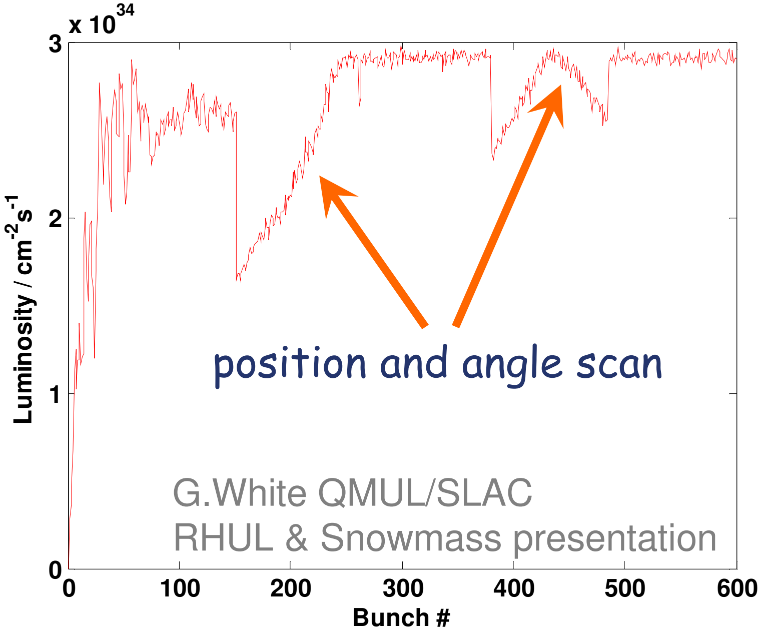
Using BeamCal and GamCal

Beamdiagnostics

- Obtain as much information about the collision as possible.
- BeamCal measures the energy of pairs originating from beamstrahlung.
- GamCal will measure the energy of the beamstrahlung photons.

1. Investigate correlation to learn how we can improve the beamdiagnostics and
2. Define a signal proportional to the luminosity which can be fed to the feedback system in real time and with a low latency.

Simulation of the Fast Feedback System of the ILC.

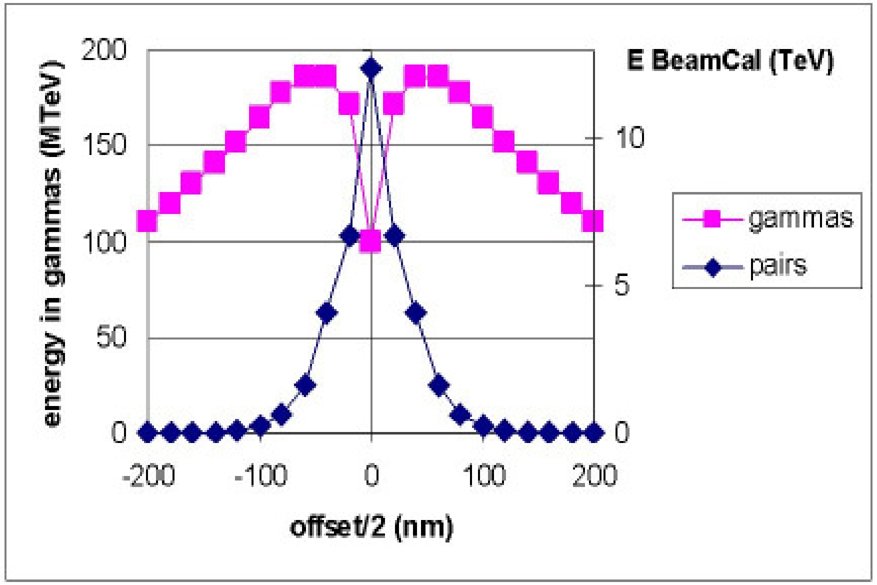


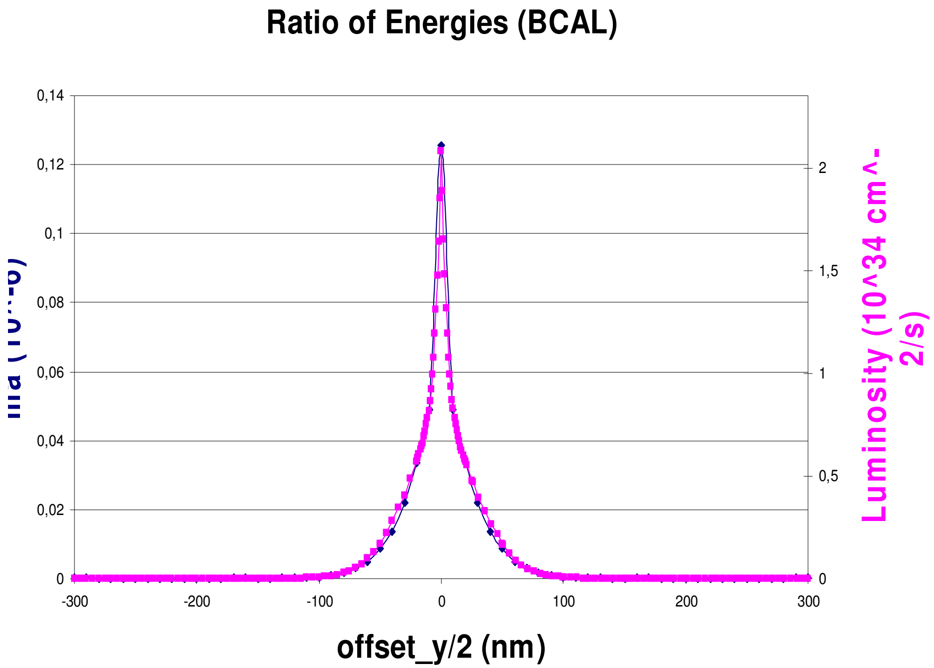
1. Standard procedure (using BPMs)
2. Include pair signal (N) as additional input to the system

Increase of luminosity of 10 - 15%

Include GamCal Information

Vertical offset





complementary information from

1. total photon energy vs vertical offset
2. BeamCal pair energy vs vertical offset

ratio of E_{pairs}/E_{gam} vs vertical offset is proportional to the luminosity

similar behaviour for vertical angle, vertical waist shift …

Studies by M.Ohlerich

Advanced Beamdiagnostics

- What else can we learn about the collision?
- Use the beamstrahlung pair and photon signal to determine and improve the accelerator parameters.

  - **The spatial distribution of the energy deposition from beamstrahlung pairs contains a lot of information about the collision.**
  - **Use a** fast **algorithm to extract beam parameters like:**

beam sizes (σ_x, σ_y and σ_z)
emittances (ε_x and ε_y)
offsets (Δ_x and Δ_y)
waist shifts (w_x and w_y)
angles and rotation (α_h, α_v and φ)
Particles per bunch (N_b)

Concepts of the Beamstrahlung Analysis

Simulate Collision
with **Guineapig**
1.) nominal parameter set
2.) with variation of a specific beam parameter
(e.g. σ_x, σ_y, σ_z, $\Delta\sigma_x$, $\Delta\sigma_y$, $\Delta\sigma_z$)
G.White: 2nd order dependencies

Produce photon/pair output
ASCII File

A.Sapronov: BeCaS1.0

Run full GEANT4 simulation
BeCaS and calculate energy deposition per cell
(geometry and magnetic field dependent)

include beamstrahlung photons ($E_{\gamma,total}$)

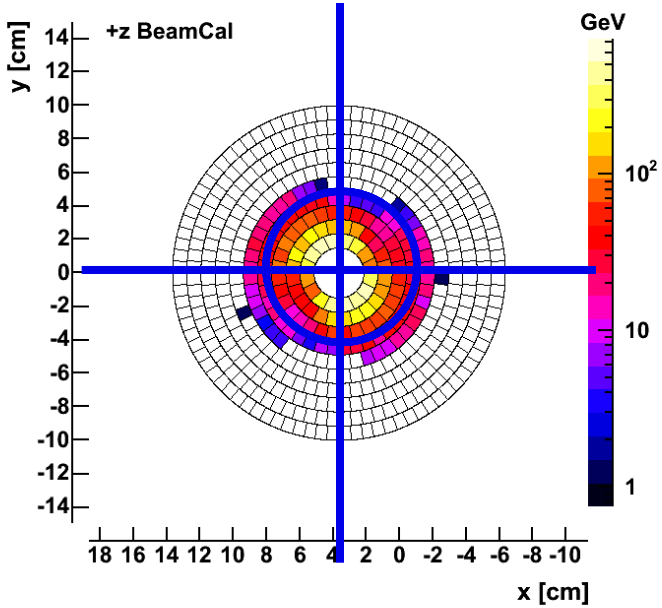
LC-DET-2005-003
Diagnostics of Colliding Bunches from Pair Production and Beam Strahlung at the IP
Achim Stahl

Calculate Observables and write summary file

Do the parameter reconstruction using
1.) linear approximation (Moore Penrose Inversion Method)
2.) using fits to describe non linear dependencies

Moore Penrose Method

$$\left(\text{Observables}\right) = \left(\text{Observables}\right)_{nom} + \left(\text{Taylor Matrix}\right)\left(\Delta\, \text{BeamPar}^{*}\right)$$



- observables:
  - total energy
  - first radial moment
  - inv. radial moment
  - l/r, u/d, diag asymmetries
  - E(ring ≥ 4) / Etot
  - E / N
  - phi moment
  - inv. phi moment
  - f/b asymmetries
  - total photon energy (extern)

- beam parameters (diff and av)
  - bunch sizes
  - emittances
  - beam offsets
  - waist shifts
  - bunch rotations
  - profile rotations
  - number of particles

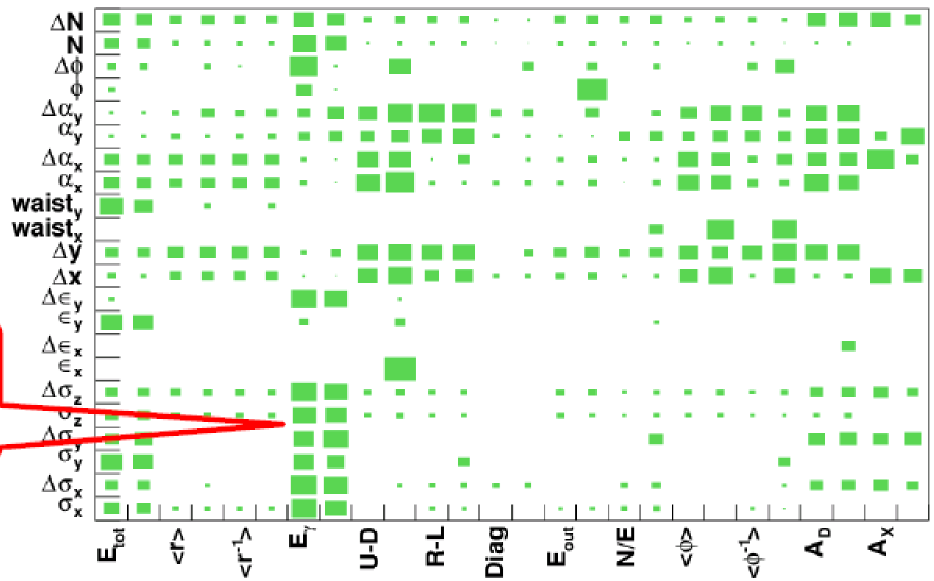
Beam Parameter Reconstruction

Single parameter reconstruction using whole calorimeter data

			2mrad (old)		20mrad DID		20mrad DID + Ephot		14mrad antiDID + Ephot	
BP	Unit	Nom.	μ	σ	μ	σ	μ	σ	μ	σ
σ_z	μm	300	300.75	**4.56**	307.98	**4.72**	299.80	**1.69**	301.09	**1.65**
ε_x	10^{-6}m rad	10	11.99	**7.61**	-	**-**	-	**-**	9.94	**2.16**
Δx	nm	0	4.77	**14.24**	4.55	**8.14**	4.57	**8.13**	-3.84	**11.80**
α_x	rad	0	0.002	**0.016**	0.010	**0.025**	-0.001	**0.025**	-0.071	**0.017.**

High significance of information from gammas for bunch sizes reconstruction.

A.Sapronov



Photon energy can be provided by GamCal.

EUROTeV-Report-2007-006
Ch. Grah, A. Sapronov

FCAL R&D

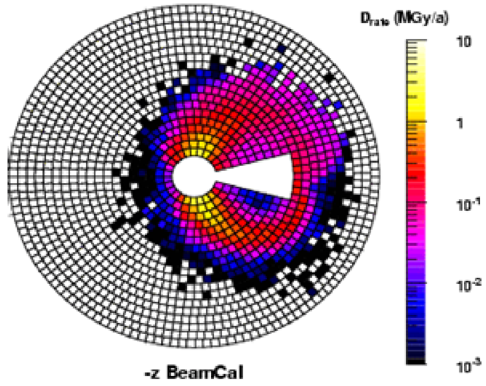
Radiation Hard Sensors and Readout Electronics

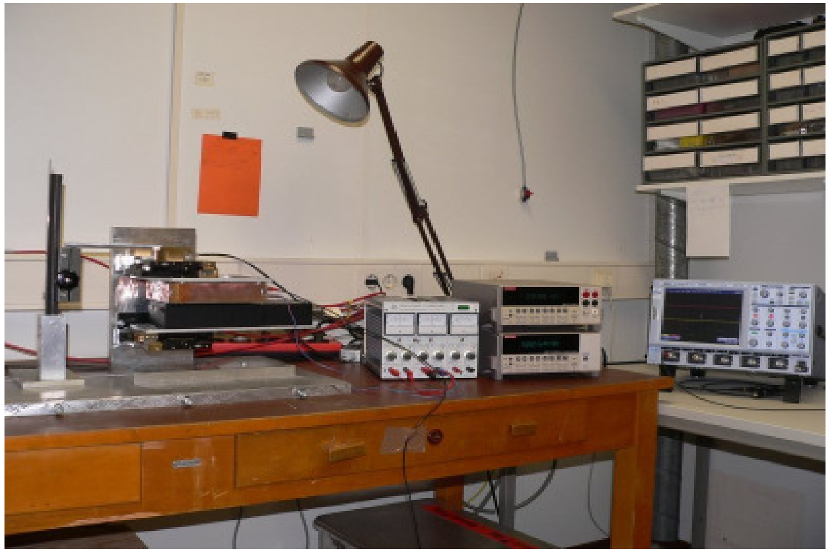
Radiation Hard Sensor Materials

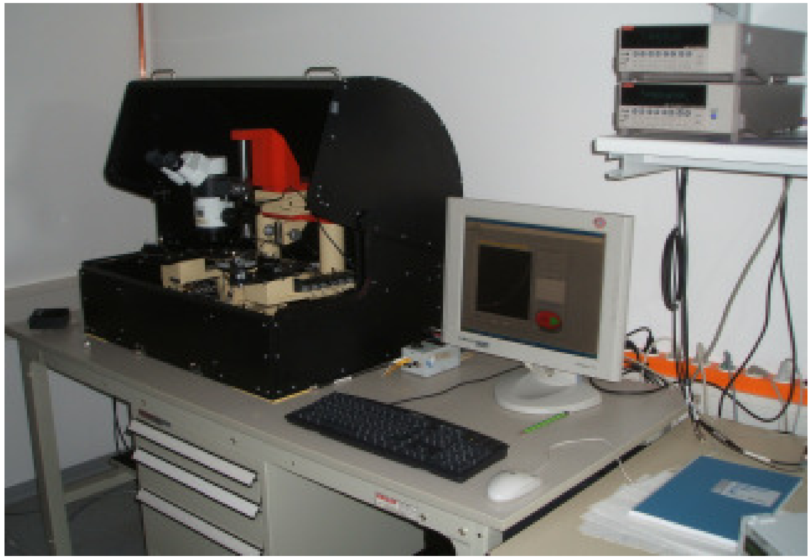
- BeamCal: high energy deposition from low energetic pairs from beamstrahlung.

- We perform different characterizing laboratory measurements (I-V, C-V, MIP response, low dose irradiation) as well as test beam measurements.

≈ 5 MGy/a

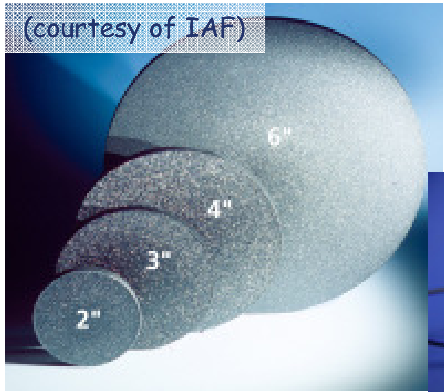




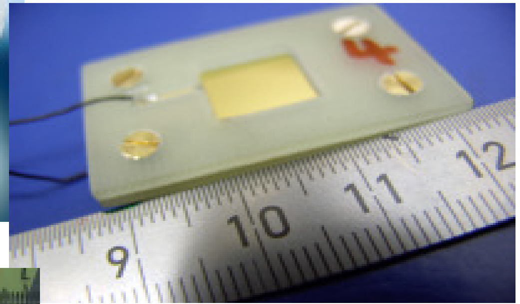


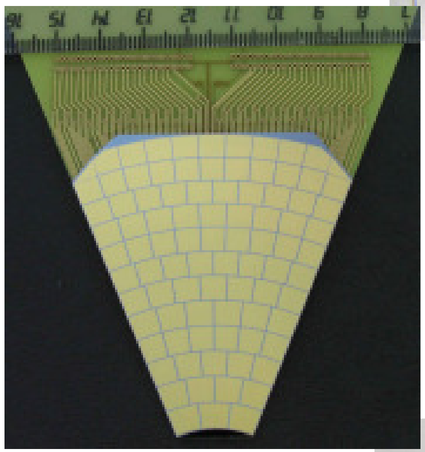
Materials under Investigation

- pCVD diamonds:
  - radiation hardness under investigation (e.g. LHC pixel detectors)
  - advantageous properties like: high mobility, low ε_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
- SC CVD diamonds:
  - available in sizes of mm^2

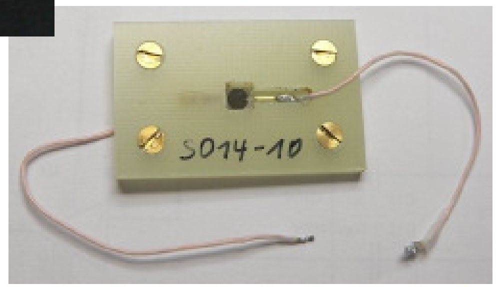


polycrystalline CVD diamond





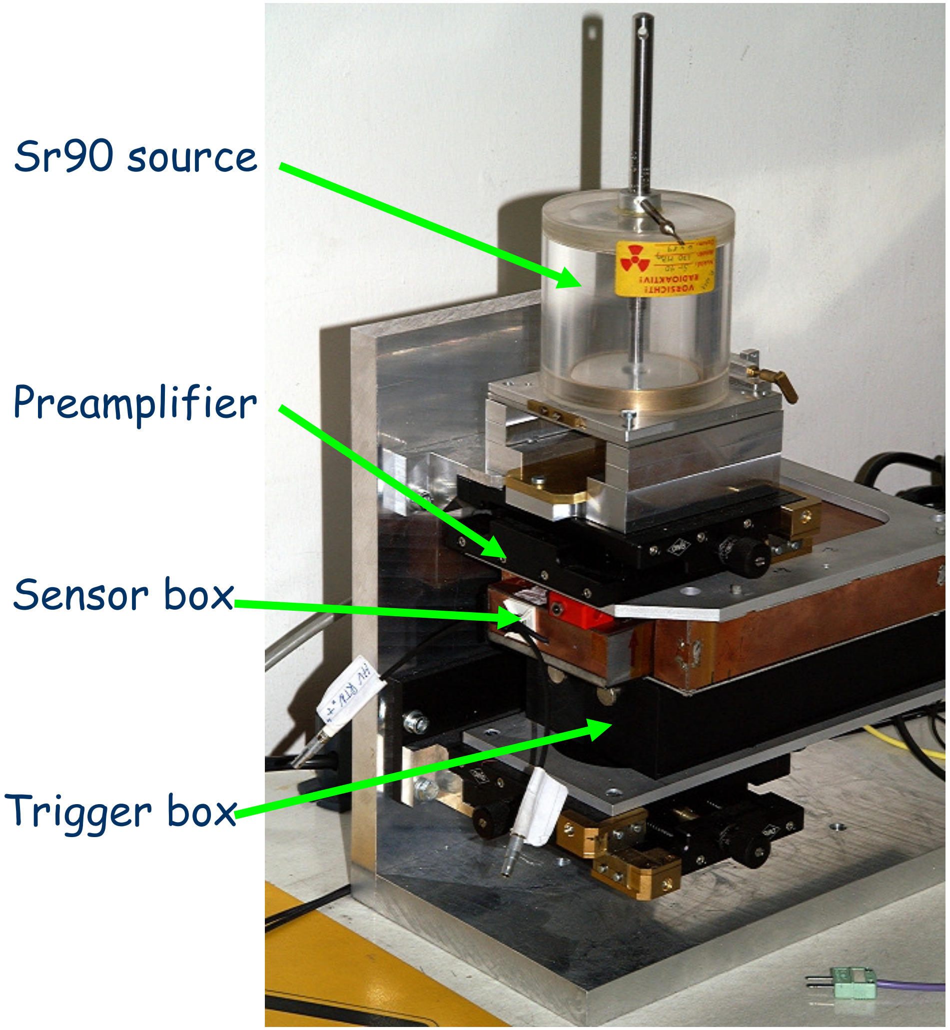
GaAs

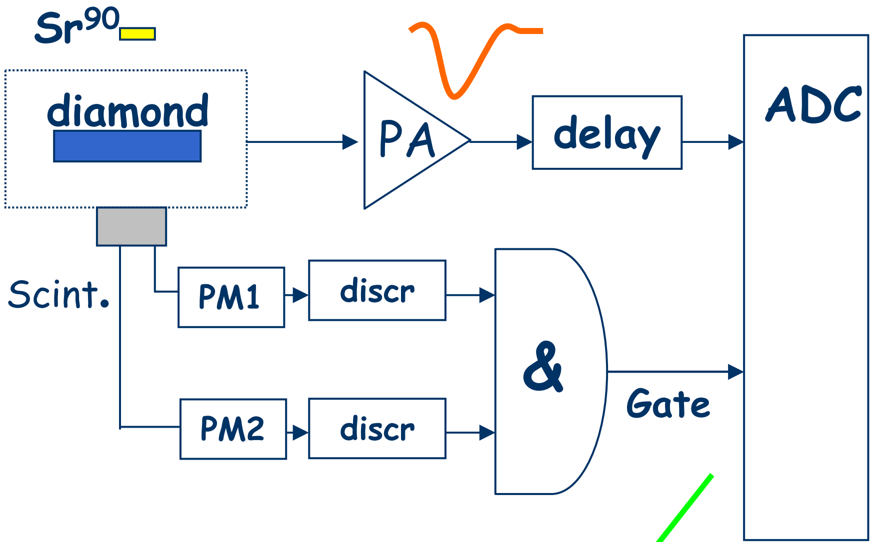


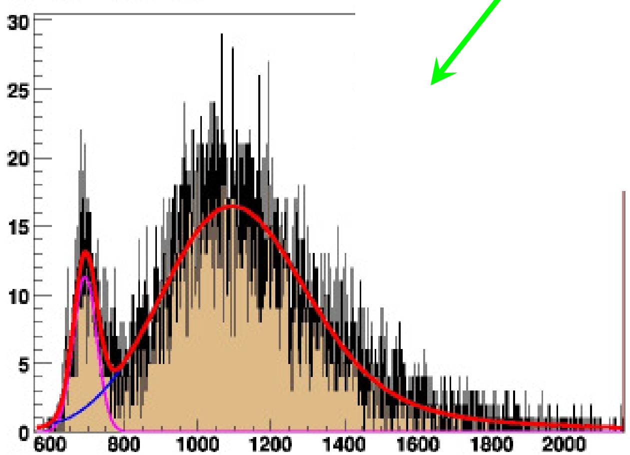
Single crystal CVD diamond

CVD: Chemical Vapor Deposition

MiP Response of pCVD Diamond



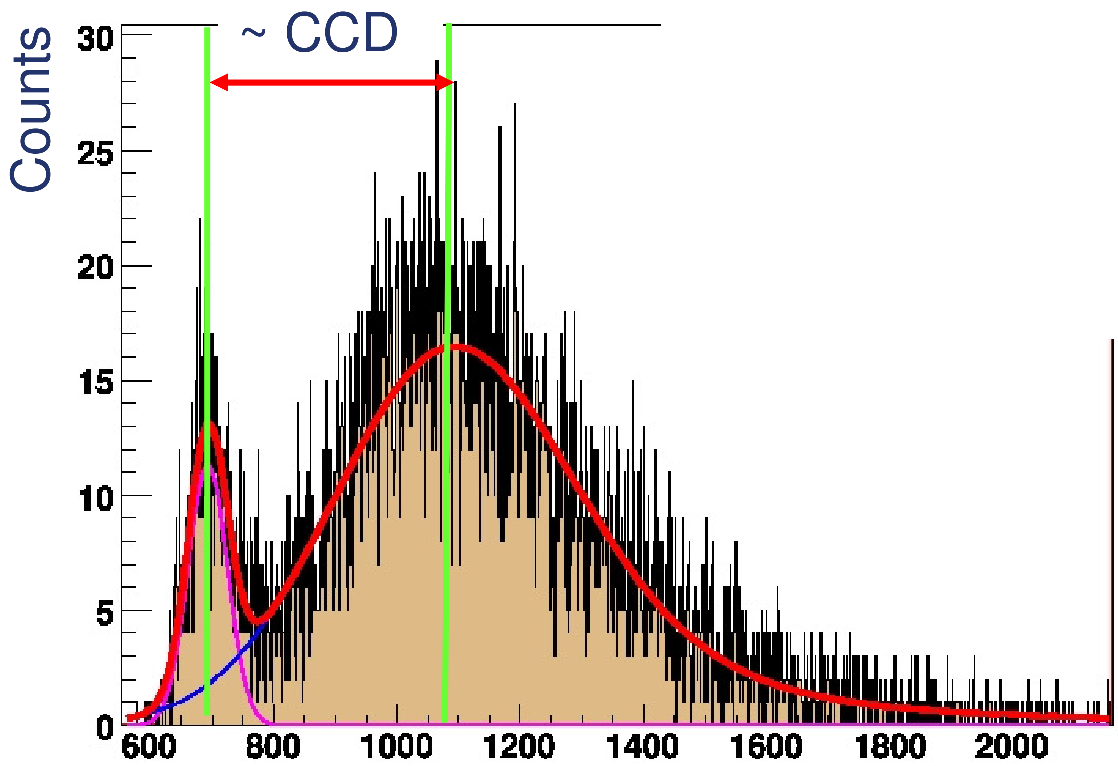




typical spectrum of an E6 sensor

CCD Measurement

CCD = *Charge Collection Distance*
= mean drift distance of the charge carriers
= charge collection efficiency x thickness

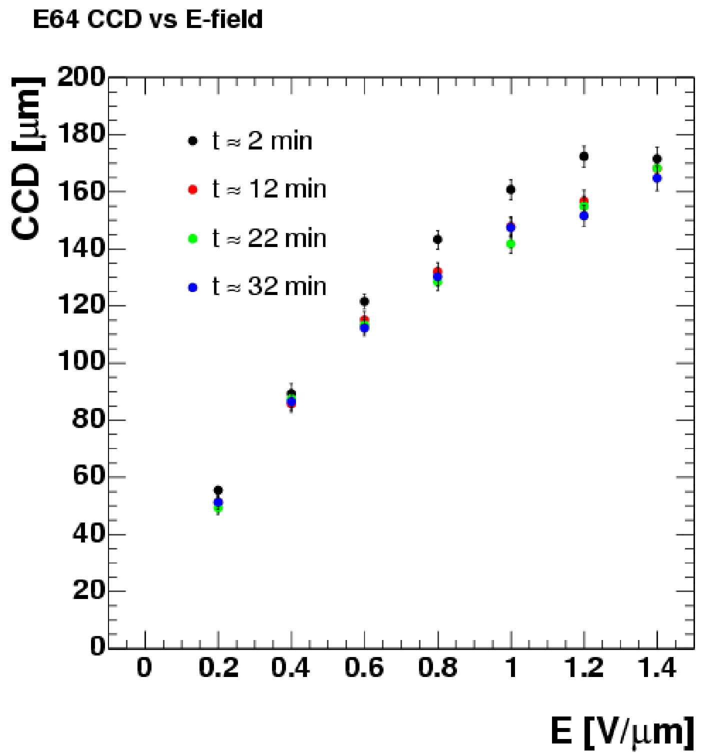


ADC Channels ~ charge

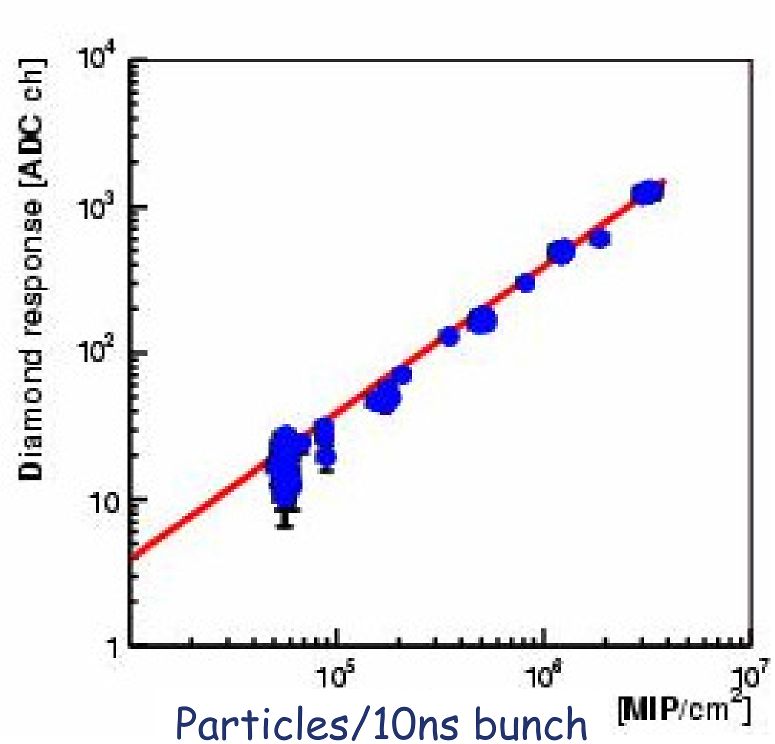
Investigation of Sensors

polycrystalline CVD Diamond

response vs electric field



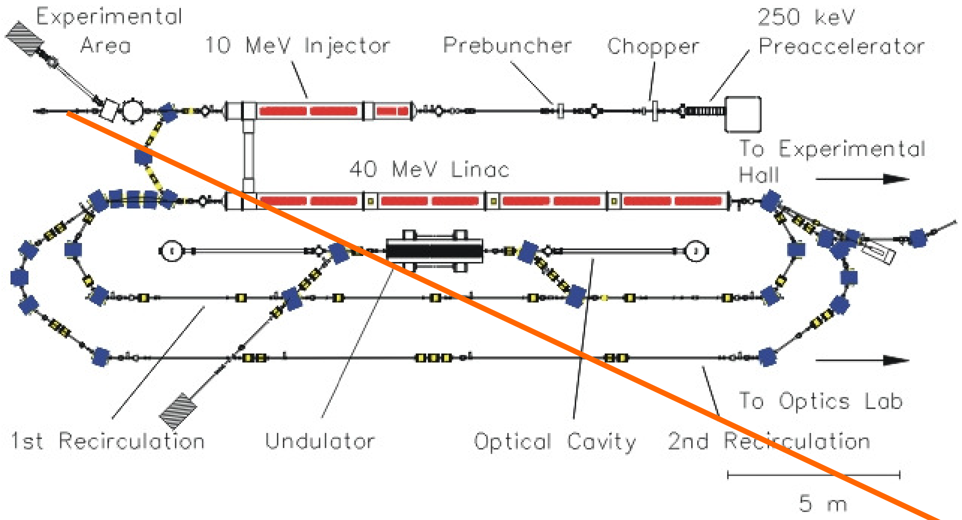
response vs particle fluence

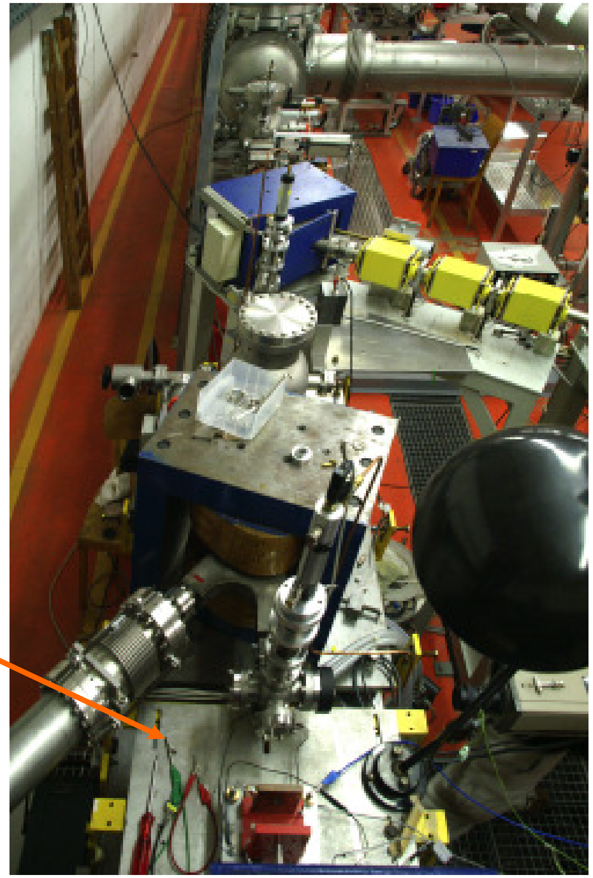


Particles/10ns bunch

High Dose Irradiation

Superconducting DArmstadt LINear ACcelerator
Technical University of Darmstadt

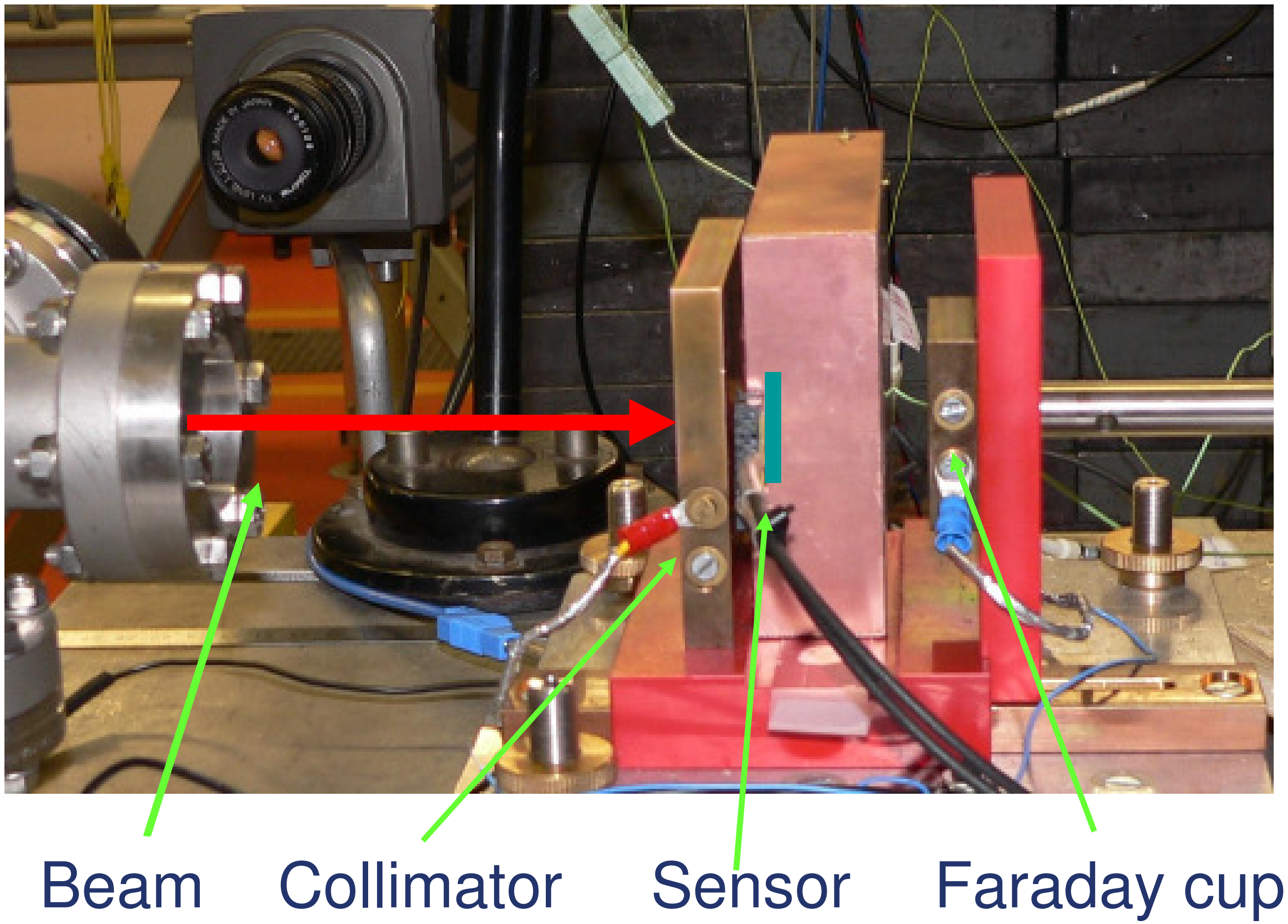




- Irradiation up to several MGy:
  10 ± 0.015 MeV electrons and beam currents from 10 to 50 nA
  (corresponding to 60 to 300 kGy/h.)
- Keeping the sensor under bias permanently.
- This is a much higher dose rate compared to the application at the ILC (~1 kGy/h)

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

Test Beam Setup

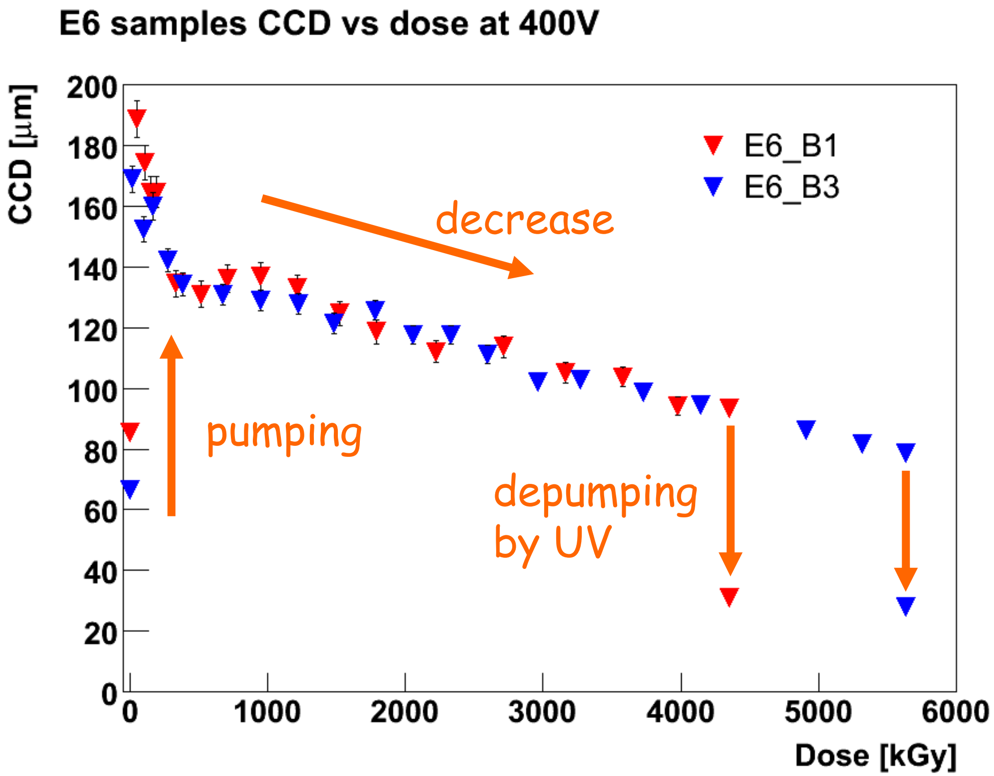


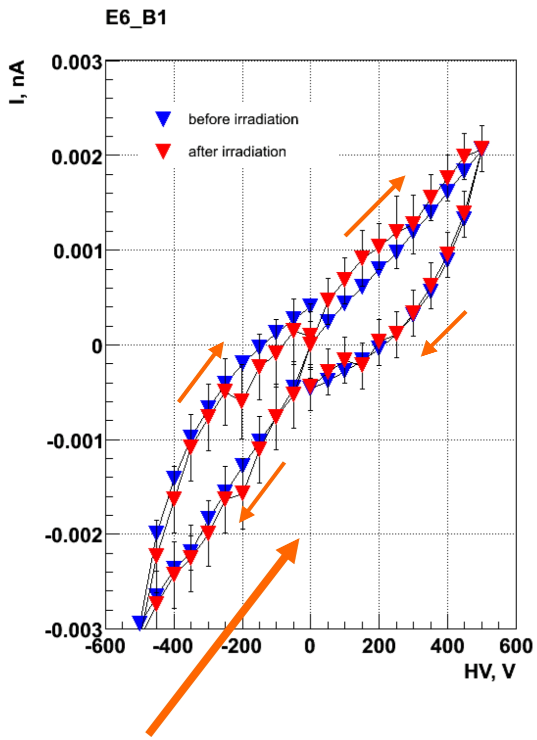
Beam current is measured using the Faraday cup.

Together with correction factors from a GEANT4 simulation we determine the absorbed dose with an error of less than 10%.

After absorbing 5-6 MGy:

CVD diamonds still operational.

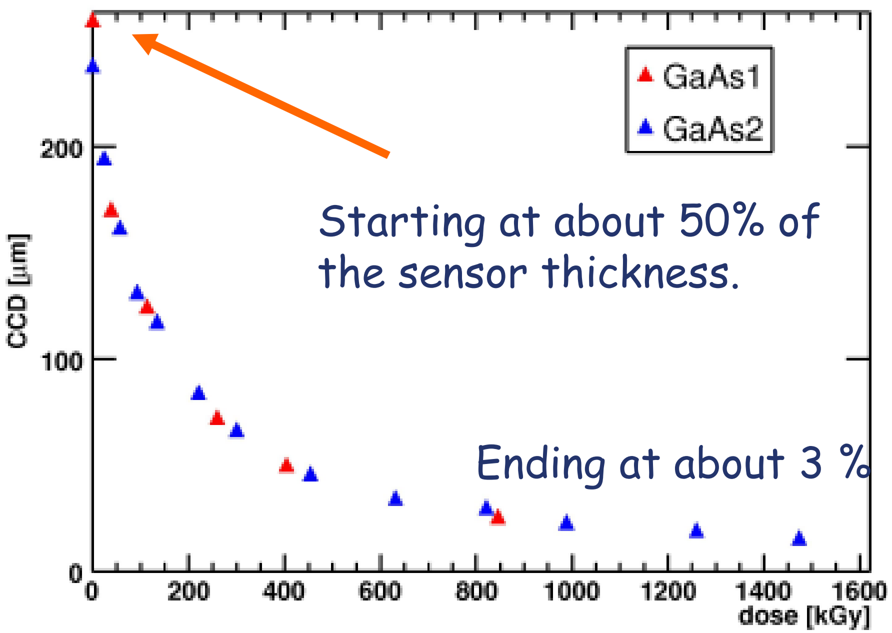


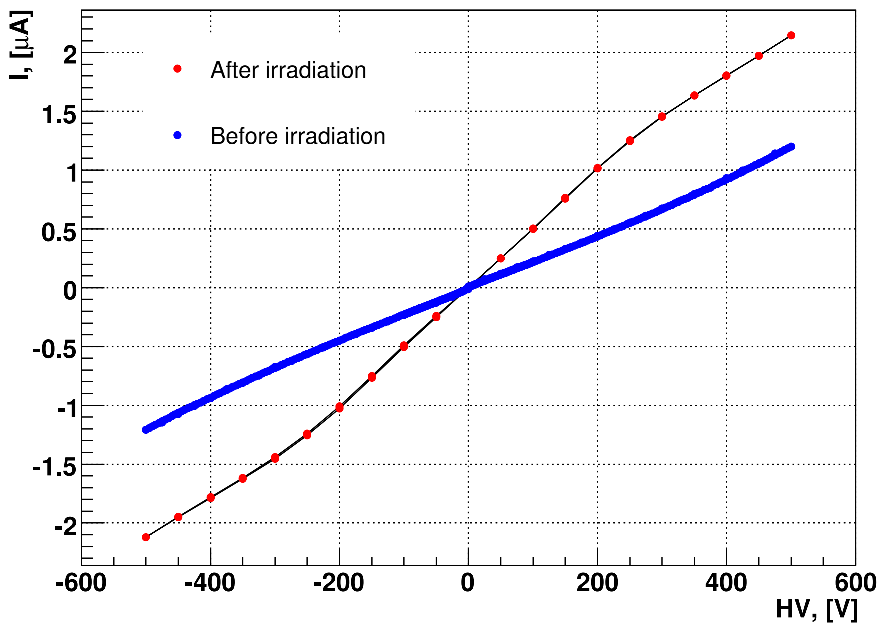


- ➢ Very low leakage currents (~pA) after the irradiation.
- ➢ Decrease of the charge collection distance.
- ➢ Generation of trapping centers due to irradiation.

Irradiation of GaAs

Irradiated one individual pad of each prototype to about 1 – 1.5 MGy.





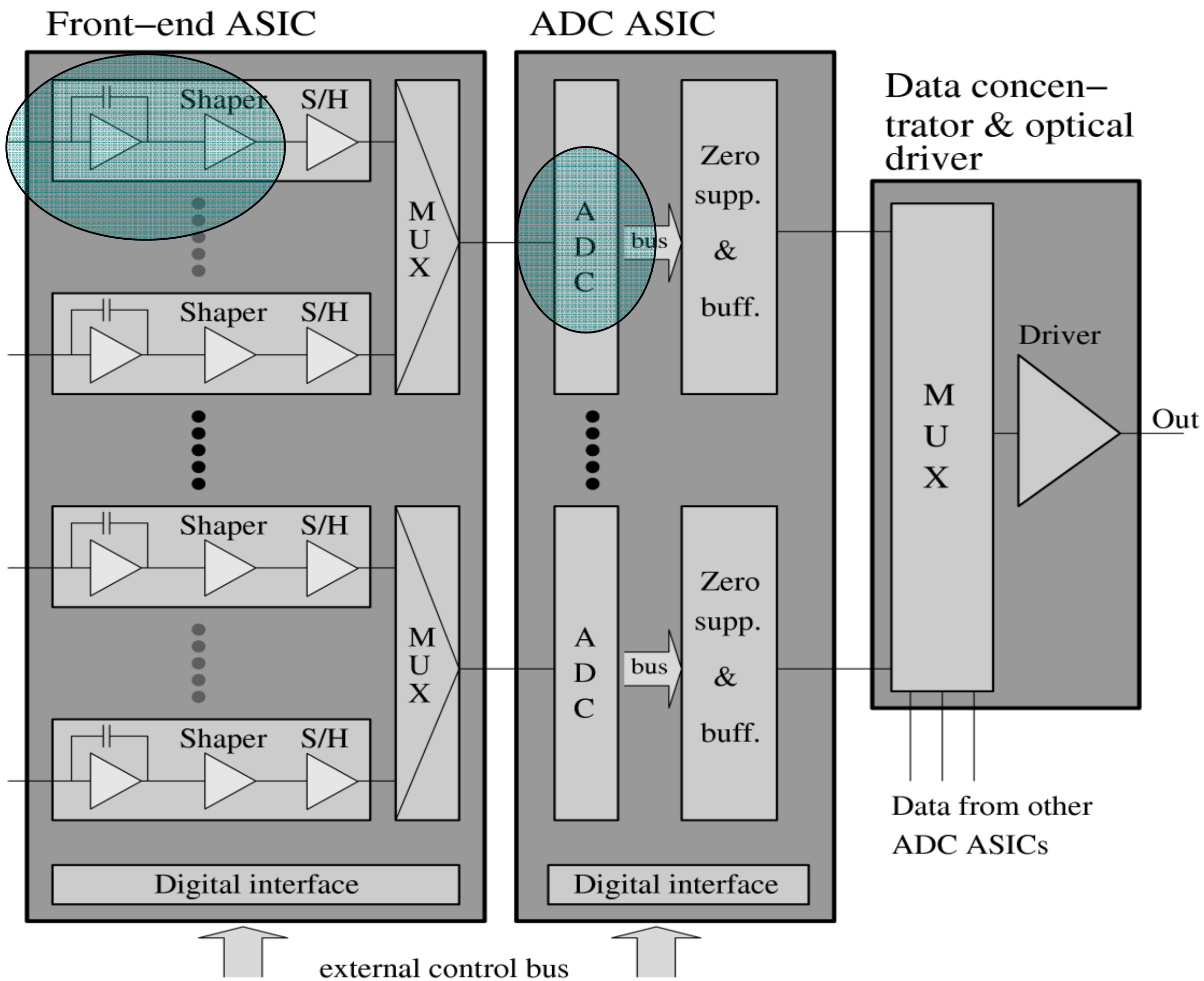
CCD vs Dose

IV before and after irradiation
Increase by about 2

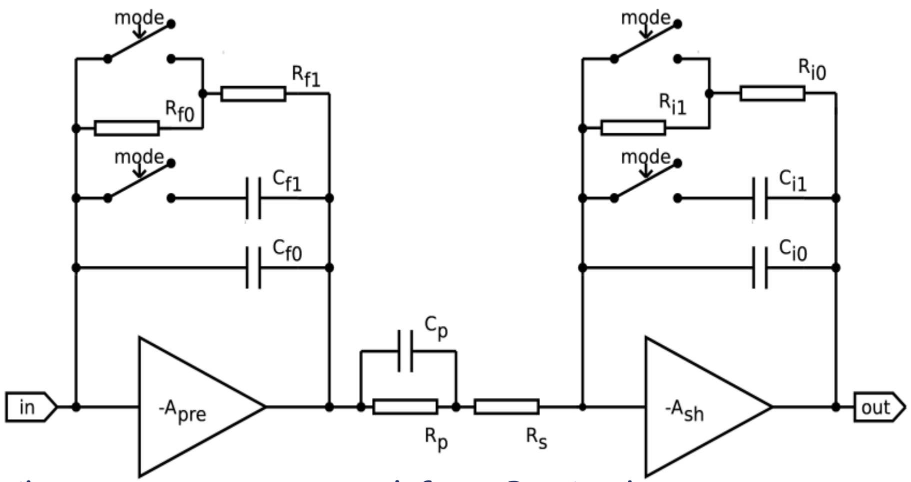
Proc. of the IEEE NSS07
in preparation

LumiCal Readout Architecture

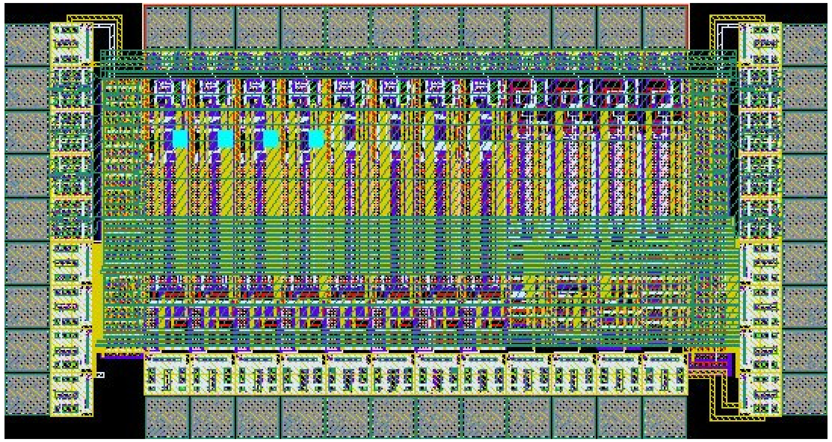
- Front-end ASIC will contain 32-64 dual gain channels
- An ADC will serve ~8(1?) front-end channels
- First prototypes in AMS 0.35 μm



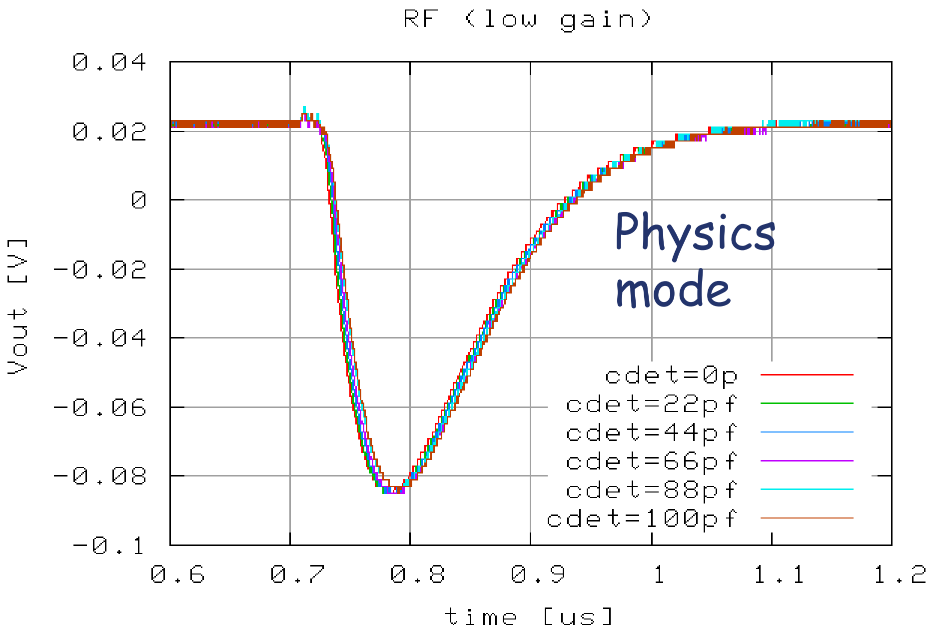
Front-end Design & Tests



Charge sensitive amplifier+PZC+Shaper



ASIC (few channels) submitted june 2007

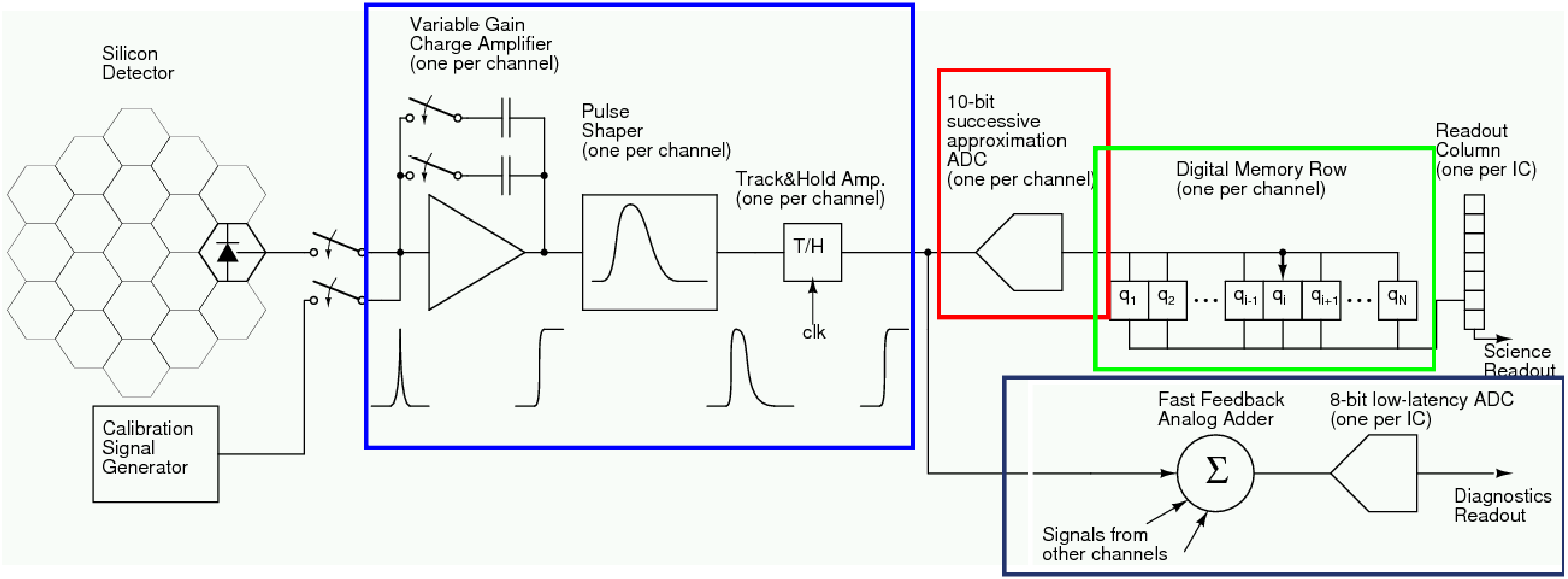


BeamCal Electronics

- 32 channels per chip
- High occupancy, all data is read out at 10 bits for science purposes;
- Low latency output, sum of all channels is read out after each bx at 8 bits for beam diagnosis (fast feedback)
- Prototype in 0.18-μm TSMC CMOS technology

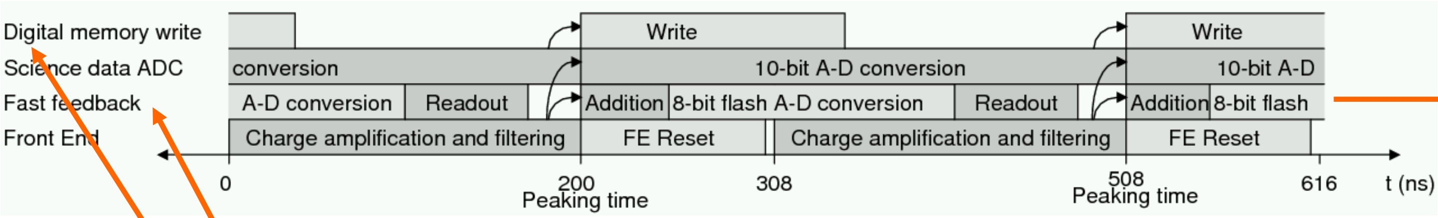
April 2007:	High level design complete
July 2007:	Charge amplifier designed
October 2007:	Filter designed

BeamCal Electronics Operation



- 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

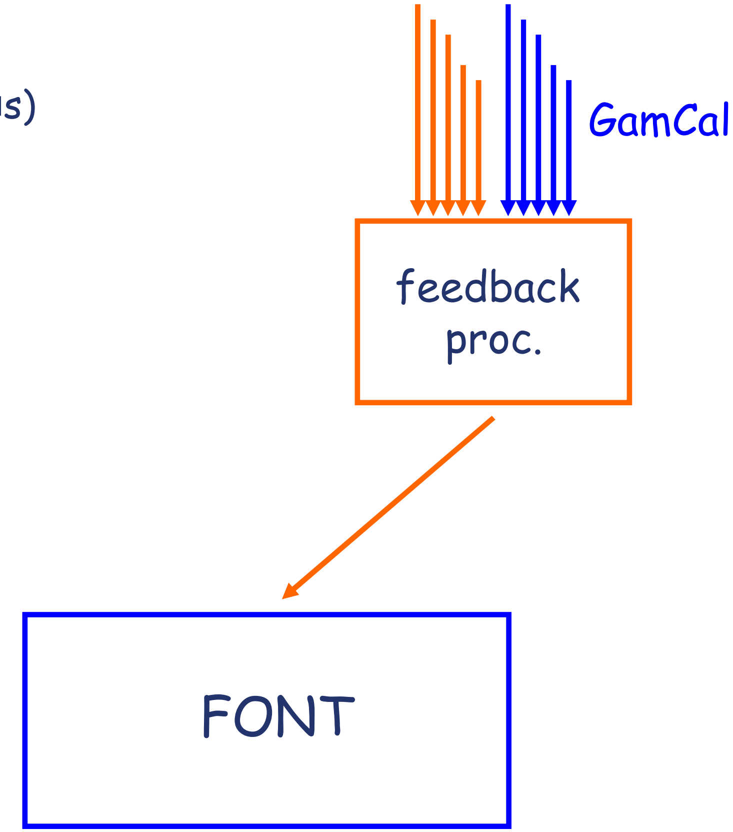
Timing and Architecture



~ 50 signals
per layer of BeamCal

Readout in real time and with low latency (~1 μs)

Readout between bunch trains



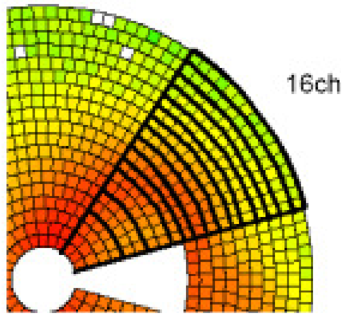
Need one more level in the readout architecture for the interface to FONT.

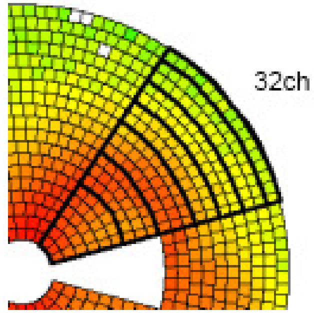
Q: How much can be handled by the FONT system itself?

Data Reduction

Scenarios of data reduction for the reconstruction of beam parameters:

- use not all layers (6th layer)
- use 32/16 channel clusters
- digitized information





			full details		digitized		16 channels		32 channels	
BP	Unit	Nom.	μ	σ	μ	σ	μ	σ	μ	σ
σ_x	μm	655	653.72	**1.29**	653.84	**1.35**	653.97	**1.30**	654.04	**1.27**
$\Delta\sigma_x$	μm	0.	-1.72	**2.01**	-1.87	**2.08**	-1.65	**2.01**	-1.65	**2.02**
ε_x	10^{-6}m rad	10	10.18	**2.62**	9.71	**2.62**	10.18	**2.62**	10.18	**2.62**
Δx	nm	0	-5.35	**11.51**	-9.82	**12.63**	-7.26	**9.80**	-7.78	**9.76**

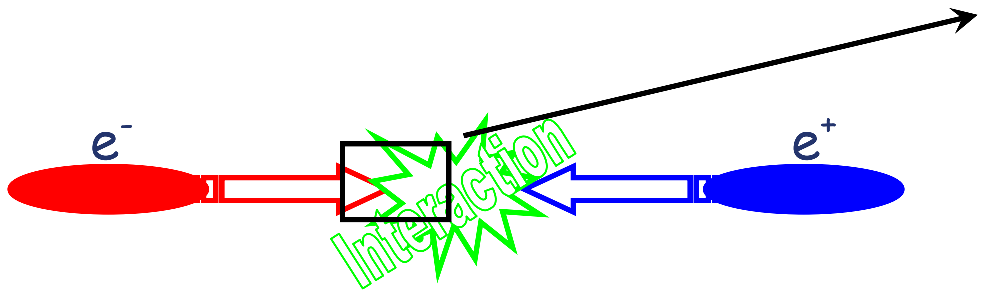
Summary

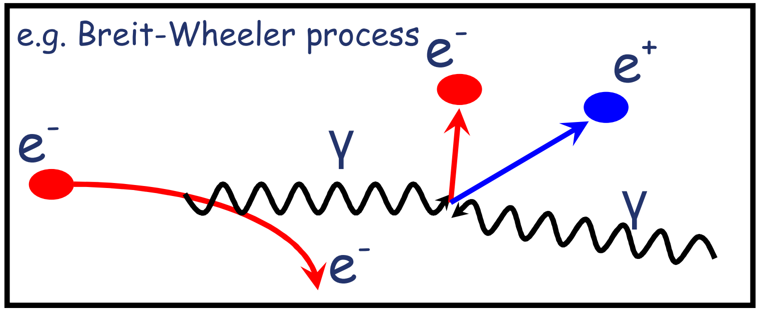
- The FCAL Collaboration develops the detectors in the very forward region of the ILC independent of a detector concept.
- MC simulations allowed to develop a very clear understanding of the physics background, beam-beam effects and the requirements on positioning and precision.
- Precision and position monitoring is essential for the LumiCal. Radiation hard sensors are of crucial importance for the BeamCal.
- BeamCal and GamCal are able to provide valuable information about the collision. The BeamCal electronics is designed to provide a fast feedback signal to FONT.
- We have an intensive R&D activity on radiation hard sensors. We investigate CVD diamond, GaAs, SiC and start to investigate radiation hard Si.

Backup

The Challenges for BeamCal

Creation of beamstrahlung at the ILC





- e+e- pairs from beamstrahlung are deflected into the BeamCal
- 15000 e^+e^- per BX

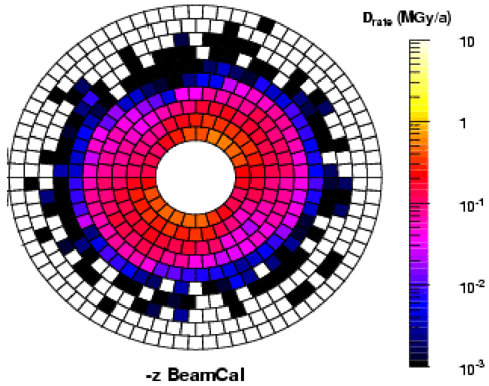
  => 10 – 20 TeV total energy dep.

- **~ 10 MGy per year** strongly dependent on the beam and magnetic field configuration

  => radiation hard sensors

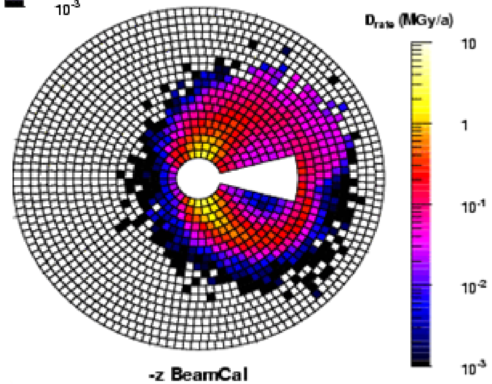
- Detect the signature of single high energetic particles on top of the background.

  => high dynamic range/linearity



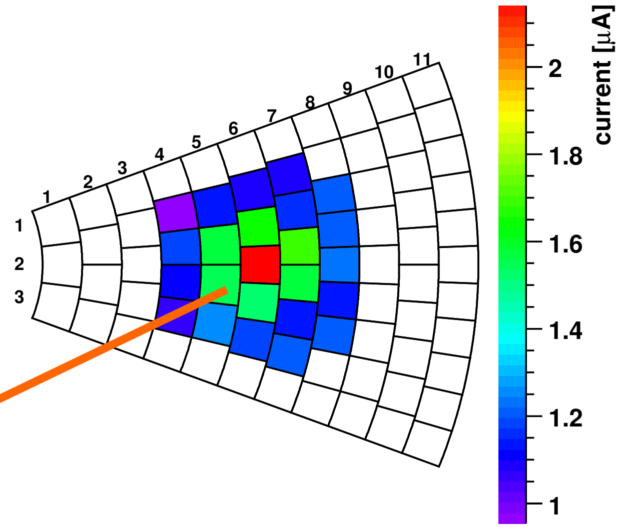
≈ 1 MGy/a

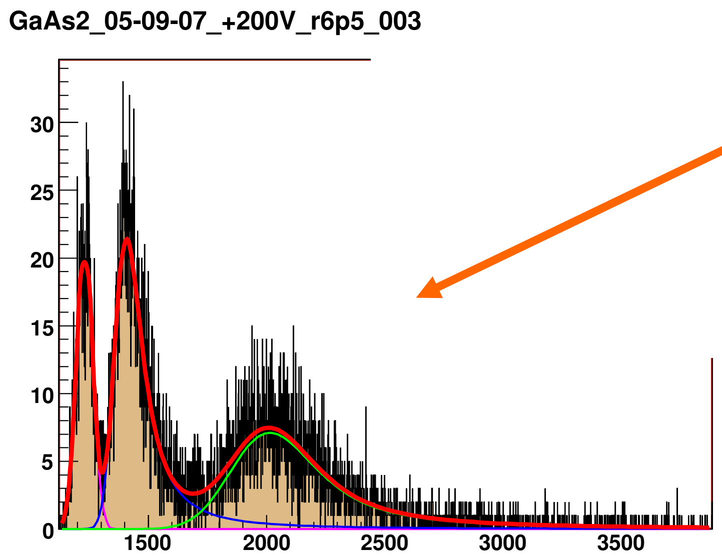
≈ 5 MGy/a



GaAs after Irradiation

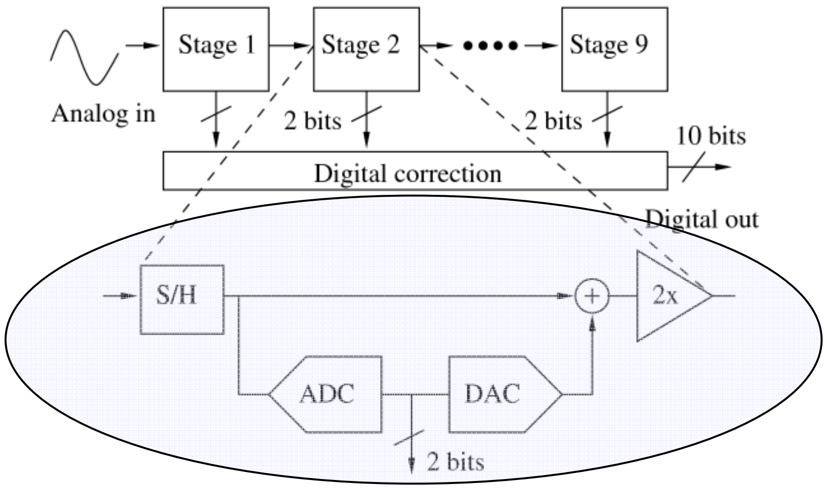
Leakage currents increase by about a factor of 2...but this time it is in the μA range.

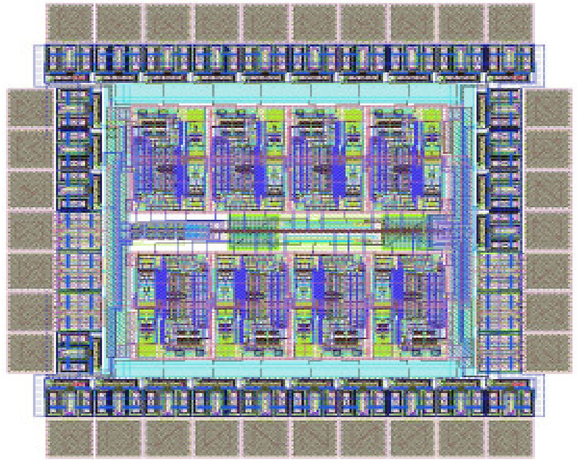


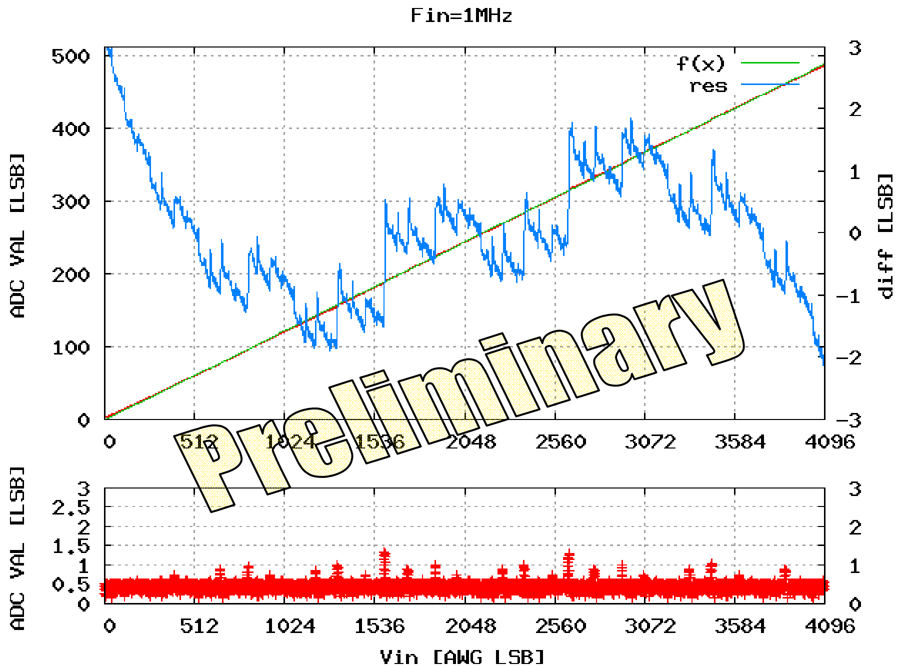


Partially irradiated pads show two very distinct signal peaks.
High: signal from not irradiated area
Low: signal after ~1.5 MGy

Pipeline ADC Design







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

BeamCal Electronics Operation

Timing diagram: between pulse trains