FCAL Collaboration
High precision design

Universal Instrumentation of the Forward Region

DESY-PRC2006

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Jagellonian University, **Cracow**

University of **Colorado**

DESY

Joint Institute Nuclear Research **Dubna**

Royal Holloway **London**

National Center of Particle & HEP **Minsk**

Brookhaven **NY**

LAL **Orsay**

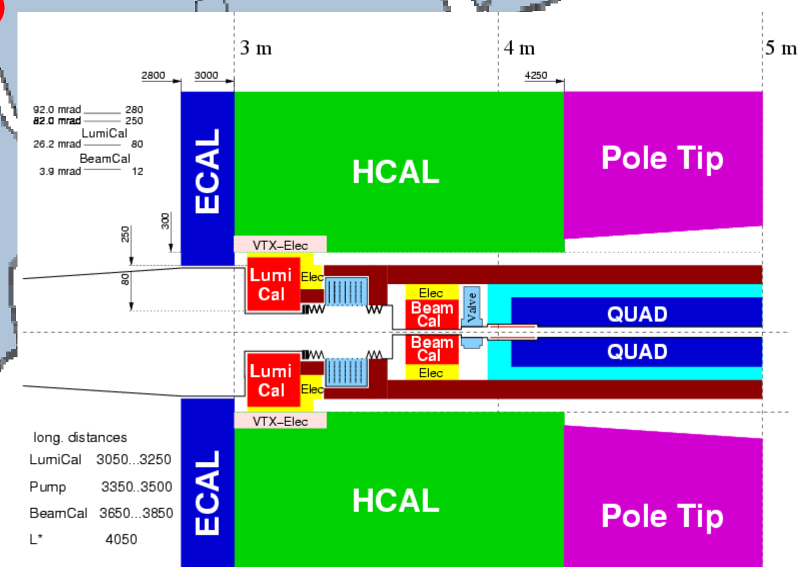
Prague Acad. of Science

Institute HEP **Protvino**

Tel Aviv University

Goals : design and construction of

- **Luminosity detector**
- **Beam monitor**
- **Photons calorimeter**



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FCAL Vision,

Goals & Challenges

Forward Calorimeters System

Independent system | **Extension of any ILC detector**

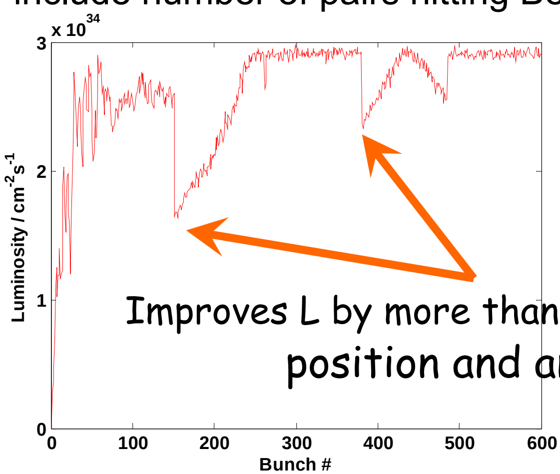
- Integrated **luminosity** measurement – High precision

  (**$e^+e^- \rightarrow w^+w^-$ ~10^6 events/year, $e^+e^- \rightarrow f^+f^-$ ~10^6 events/year, GigaZ ~10^9 events/year**)

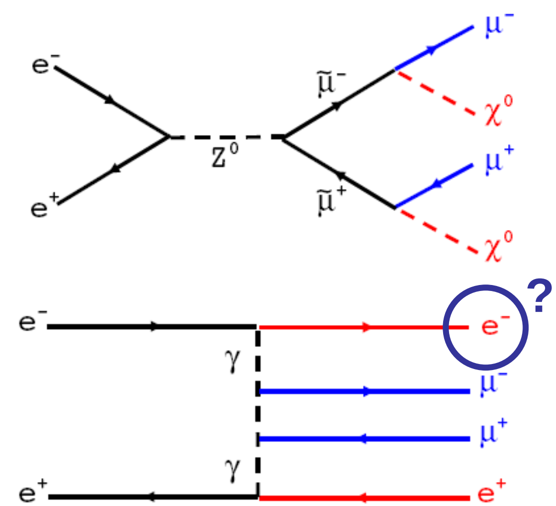
- Beam diagnostics with intra train luminosity feedback and optimization capabilities

The Collaboration plays a key role in the Machine Detector Interface

include number of pairs hitting BeamCal in the feedback system



Improves L by more than 12% (500GeV)!
position and angle scan



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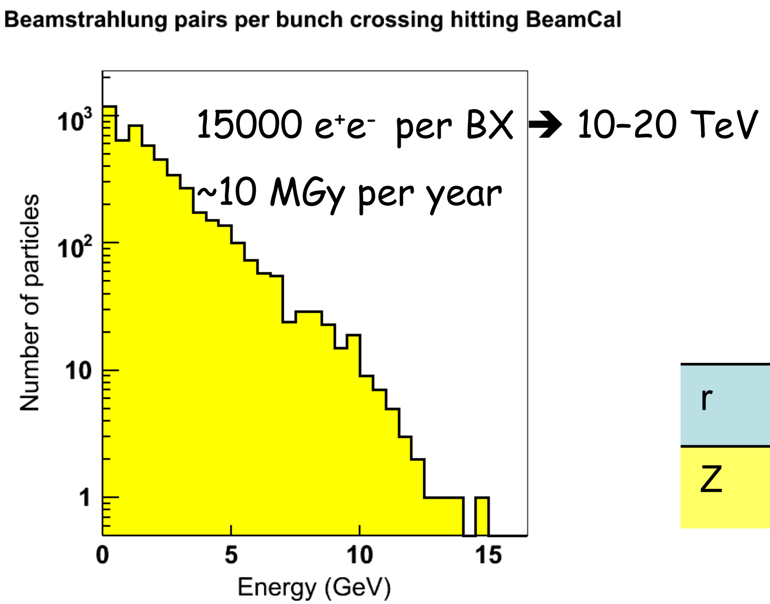
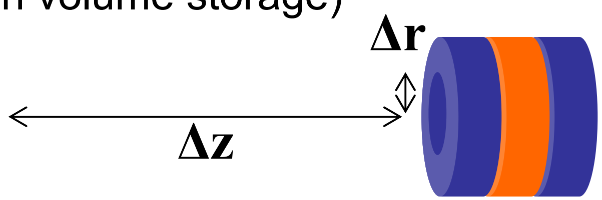
Challenges

Fast, simple and reliable machine monitoring ⟷ **Detector performance**

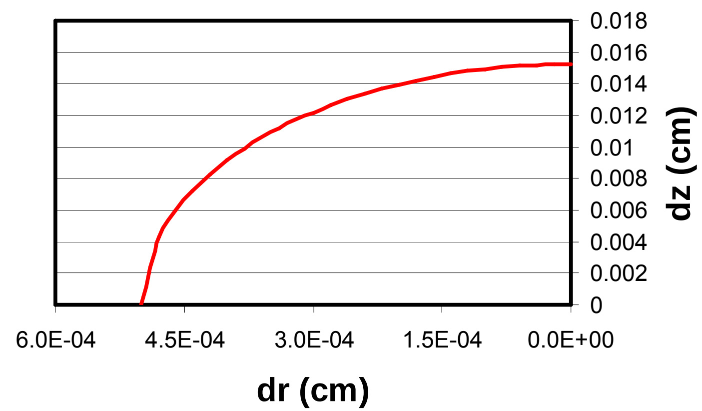
- High granularity and multi-channel (10^4)
- High precision alignment
- High occupancy – machine and physics backgrounds (efficient selection algorithms)
- High radiation environment (radiation hard sensors/electronics)
- Readout of every bunch (fast electronics, fast analyzes, high volume storage)





$\Delta L/L=10^{-4}$

	Align
r	~μm
Z	~100μm

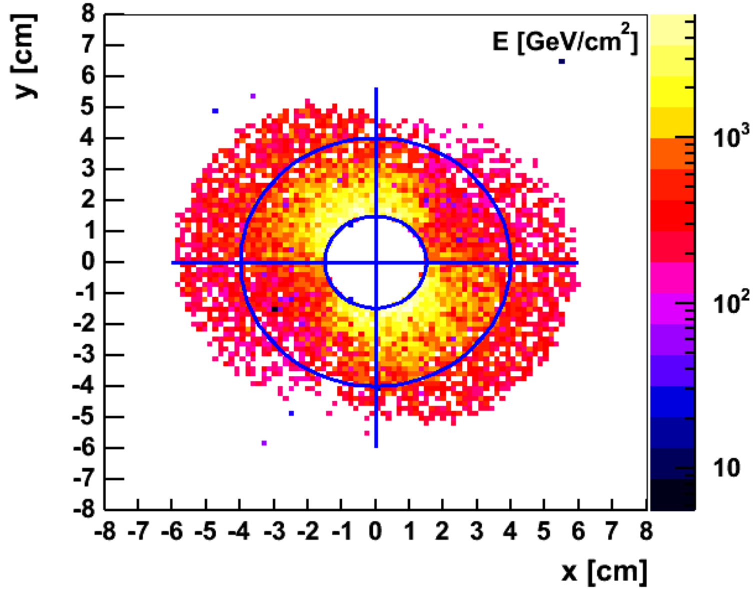


FCAL BeamCal

Beam diagnostics : BS Pairs

Observables (examples):

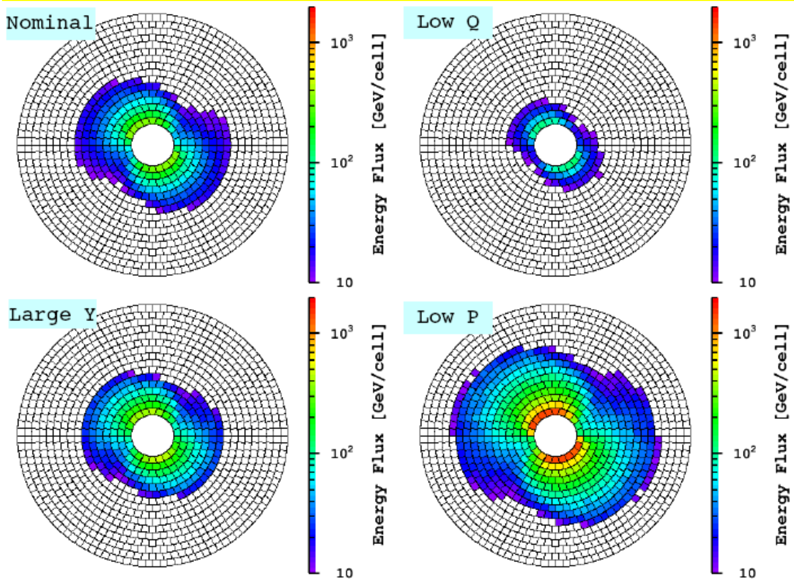
- total energy
- first radial moment
- left/right, up/down,
- forward/backward asymmetries



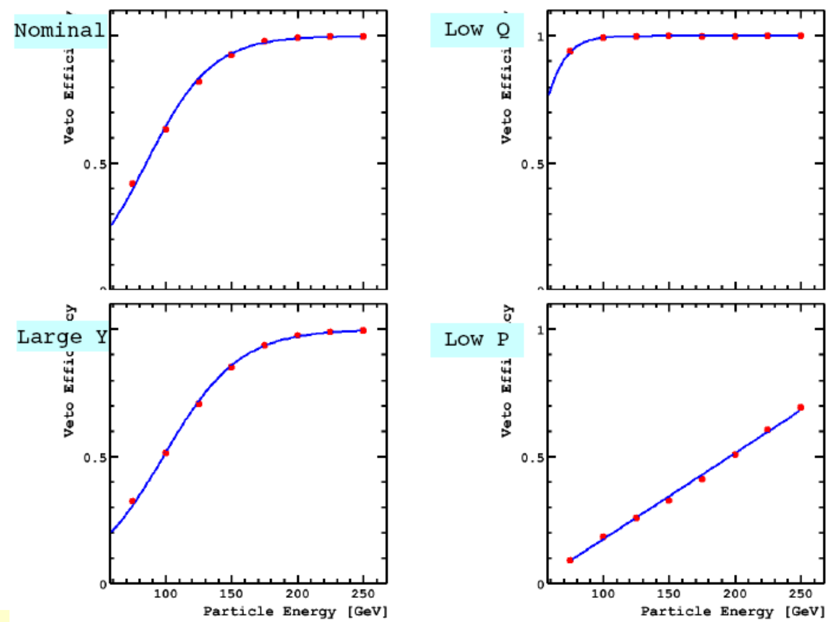
Quantity	Nominal Value	Precision		
		PRC04 Head-on (TESLA, different nom. value)	PRC06 2mrad	PRC06 20mrad
σx	655 nm	1.2	3.1	2.9
σy	5.7 nm	0.1	0.3	0.2
σz	300 μm	4.2	4.8	8.5

Electron detection - different accelerator parameters

Accelerator parameters

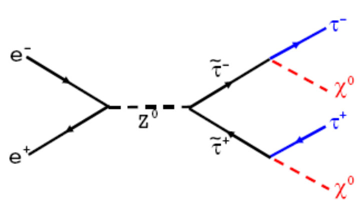


Results. Veto Efficiency



Nominal
Low Q – half Q, double Nb, shorter and smaller bunch
Large Y – longer, larger bunch
Low P – half Nb, shorter and smaller bunch

Number of unvetoed **2-photon events:**



L = $500 fb^{-1}$

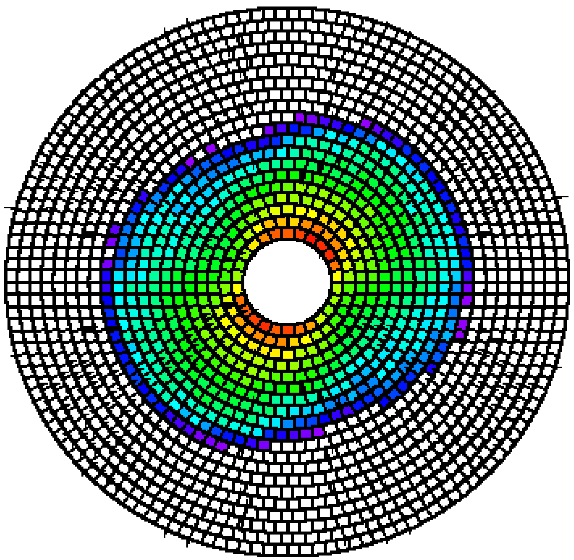
Number of **SUSY events** ~ 20

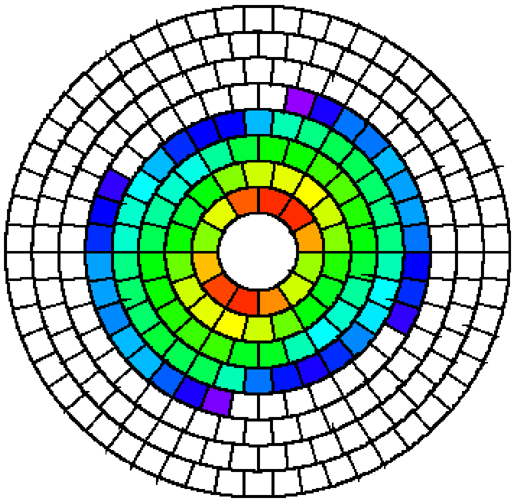
Veto Energy Cut, GeV	75	50
Nominal	45	5
Low Q	40	0.1
Large Y	50	9
Low P	364	321
Nominal, 20mrad	396	349

Optimization of cell size

4 mm

$N_{channels}$	~50,000



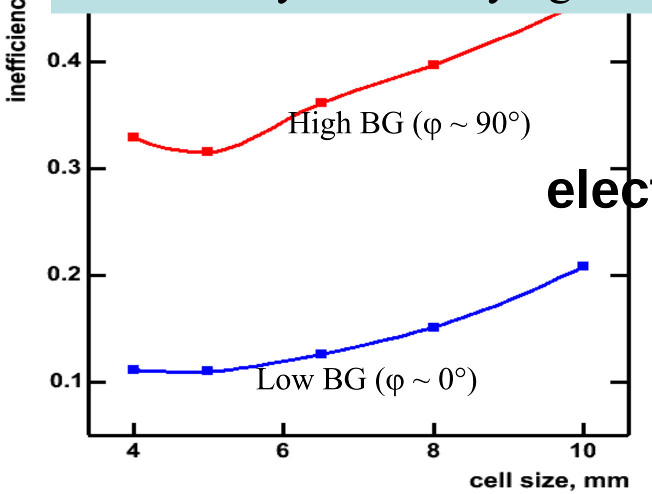


10 mm

$N_{channels}$	~8000

Lost particles for R < 55 mm

Inefficiency in identifying electrons

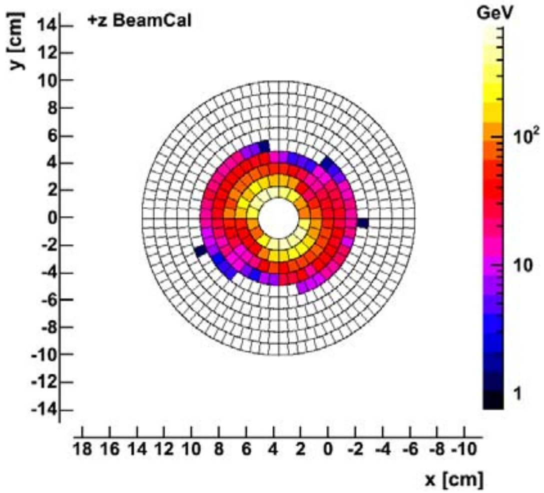


electrons 200 GeV

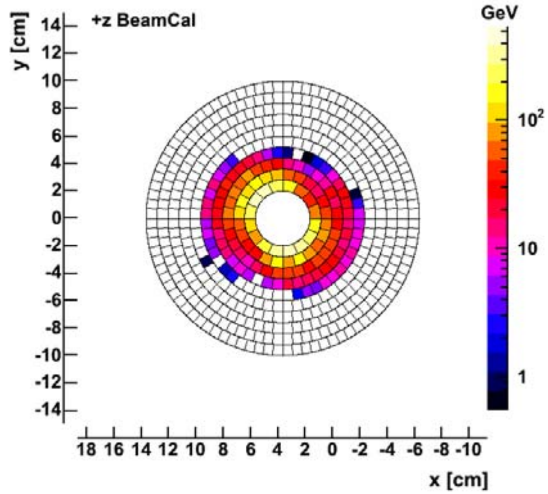
X-angle & magnetic field

Distribution of BeamStrahlung pairs

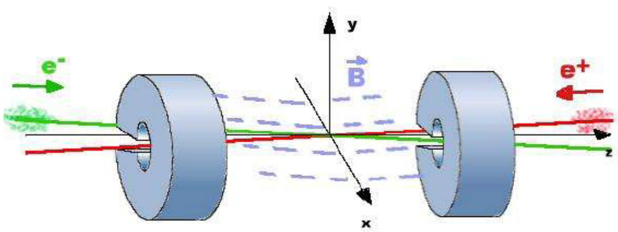
Head-on



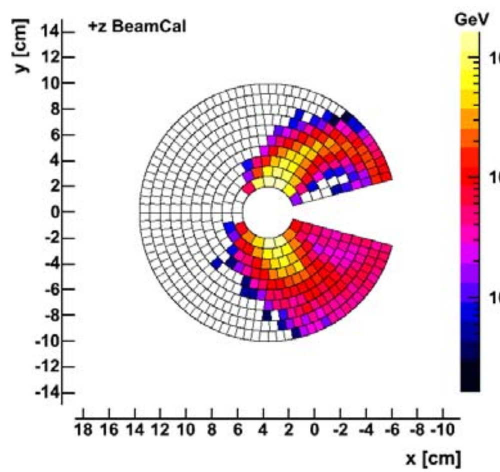
2 mrad



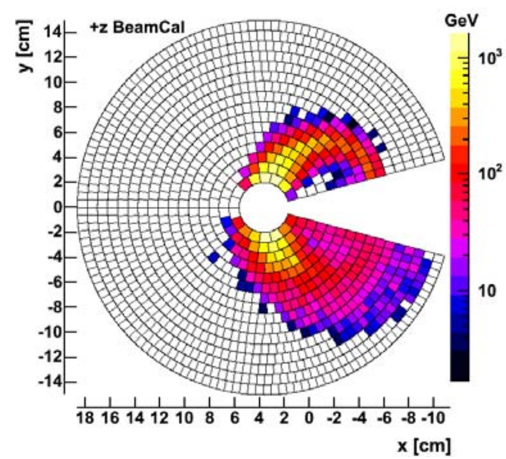
Detector Integrated Dipole



20 mrad, DID

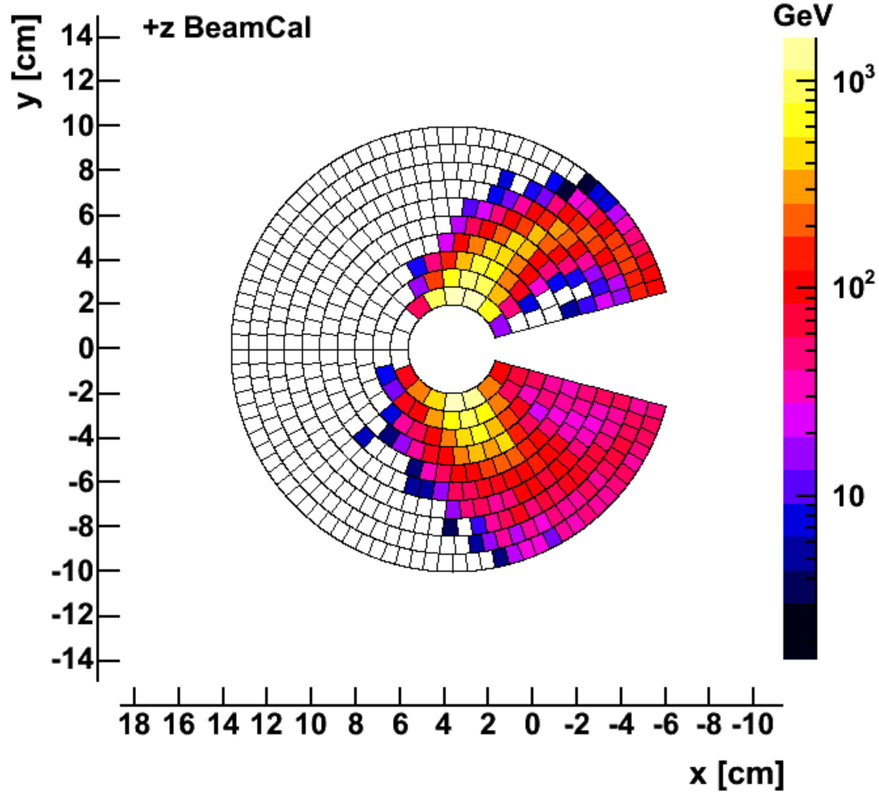


20 mrad, DID (extended Rmax)

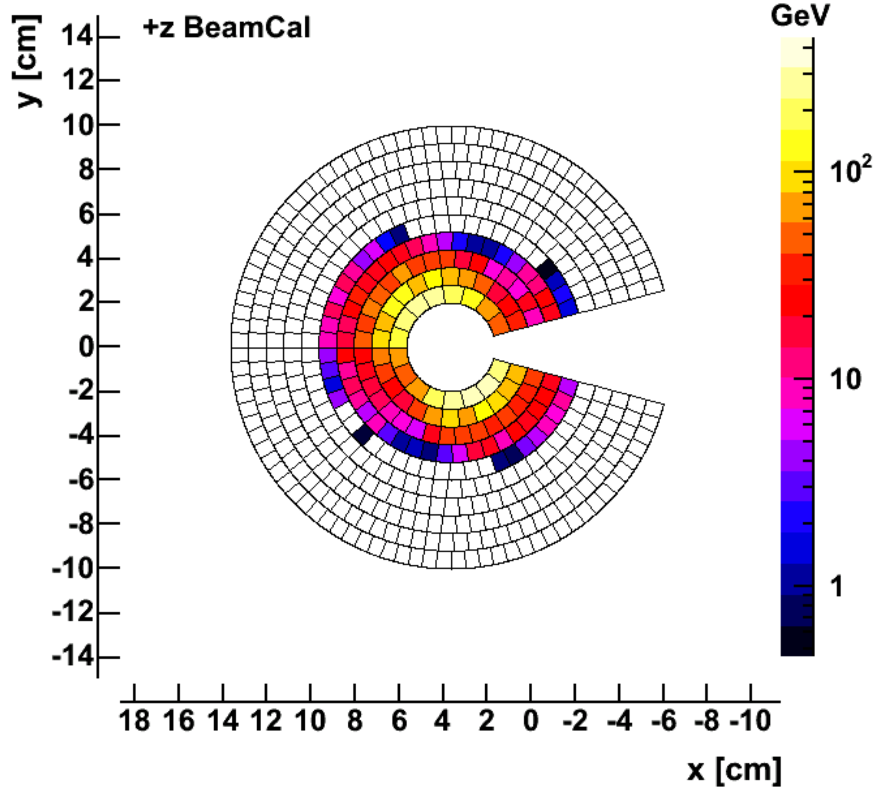


Anti DID

20 mrad, DID



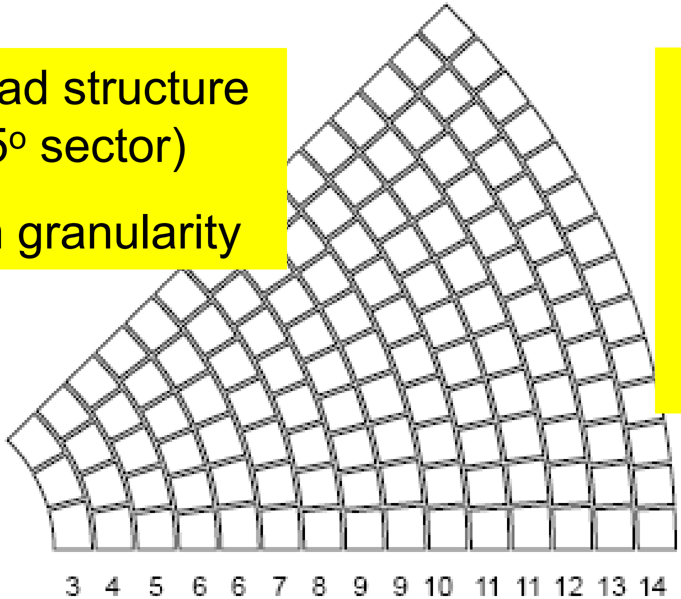
20 mrad, anti DID



BeamCal Present Understanding

128 pad structure
(45º sector)

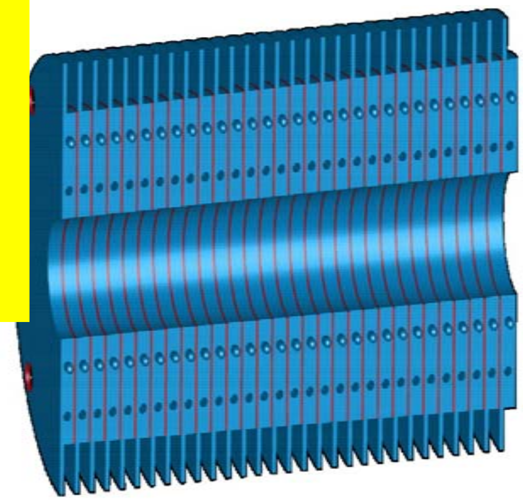
5 mm granularity



30 tungsten disks

~ 1 X_0 thick

0.5 mm thick sensors + flat readouts



Sensors options:

Silicon,

Diamond,

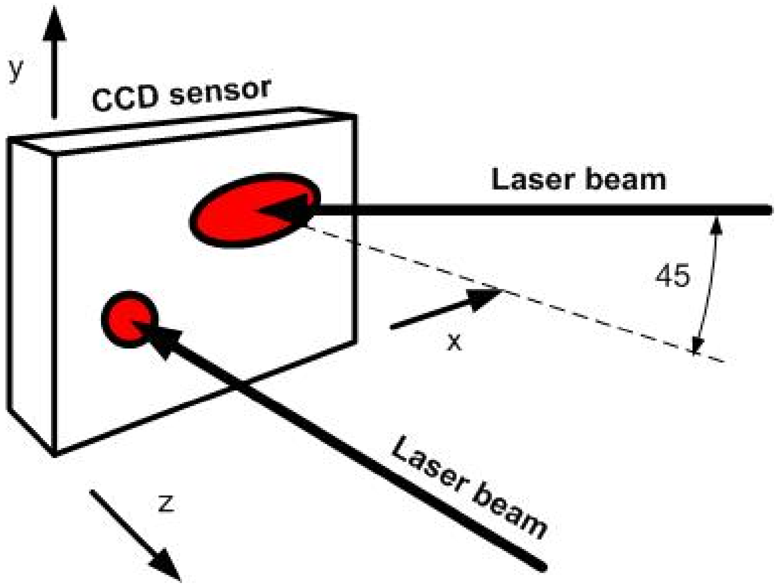
GaAs

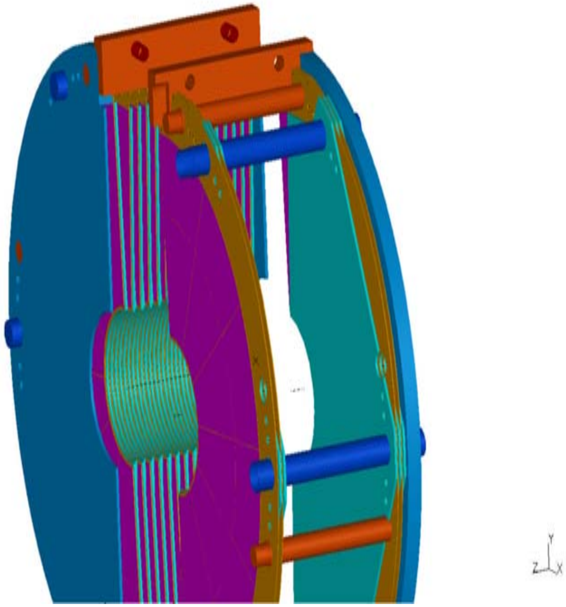
We consider a graphite layer in front of BeamCal to reduce backscattering to the inner detector

scheme	R_{in} [mm]	R_{out} [mm]	blind area
head-on	15	100	no
2 mrad	20	100	no
14 mrad	15/20	165	40°
20 mrad	15/20	165	30°

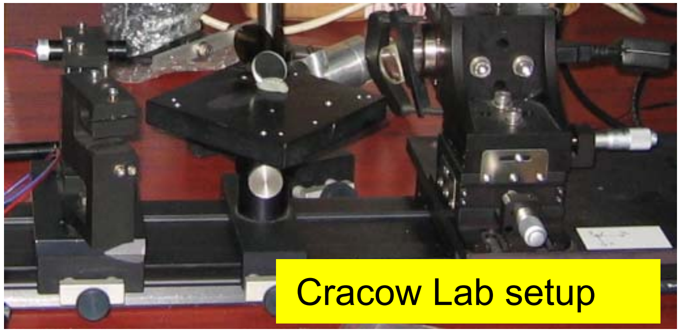
LumiCal

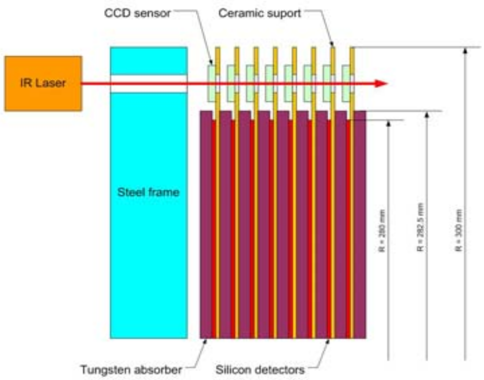
Mechanics and Position



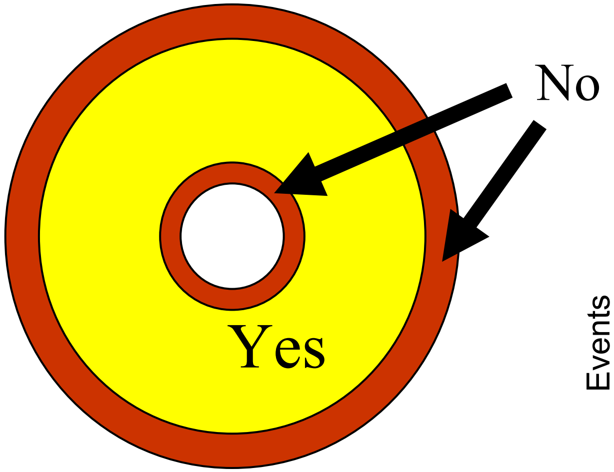


XYZ displacement mesurement

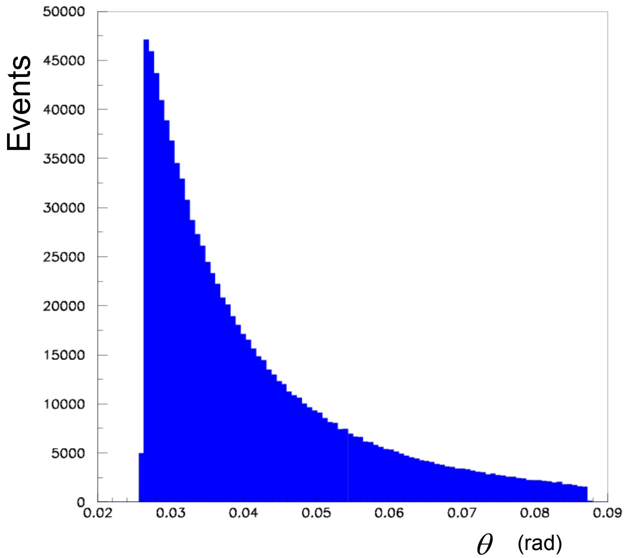


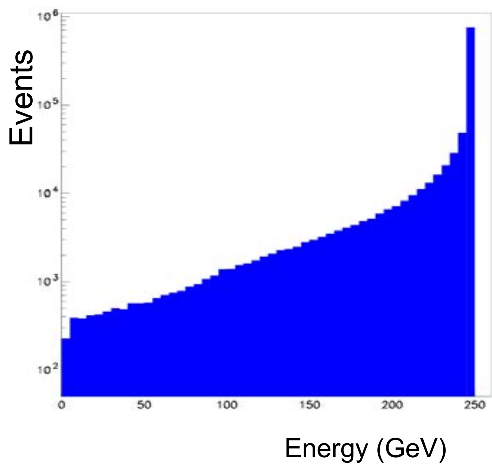


Counting Bhabha events



	Min	Max
R	~10 cm	~25 cm
θ	33 mrad	80 mrad





Requires also precision on the theoretical cross-section
Working with Zeuthen, Cracow, Katowice theory groups (two loop calculation)

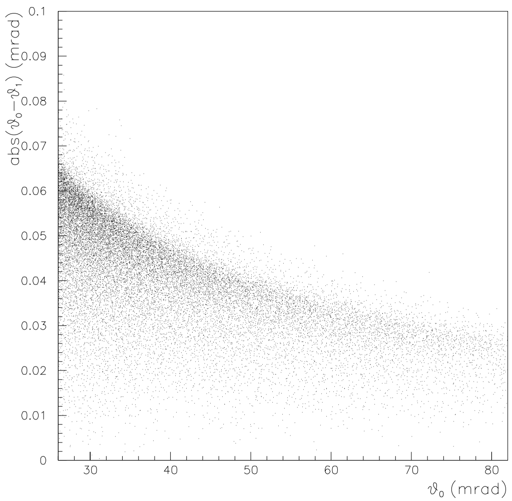
Polarised Bhabha

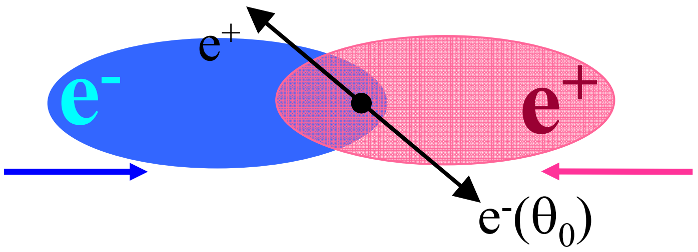
$$\sigma^{LL}_{EW}(P_-,P_+) = \frac{d\sigma^O_{EW}}{d\Omega}\left(1+\left(P_-{}^L - P_+{}^L\right)A^-_{LL} + P_-{}^L P_+{}^L A^{-+}_{LL}\right)$$

~2%

Bunch charge effect

Deflection of Bhabhas due to the field of the opposite beam





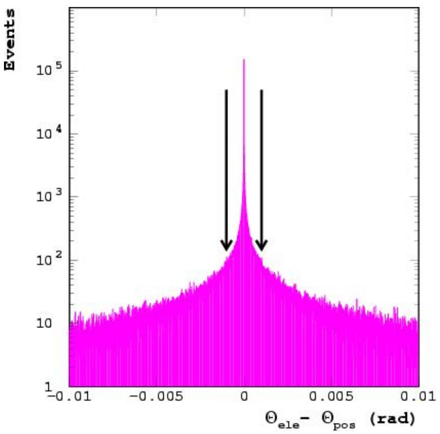
~0.5%

Four-lepton processes

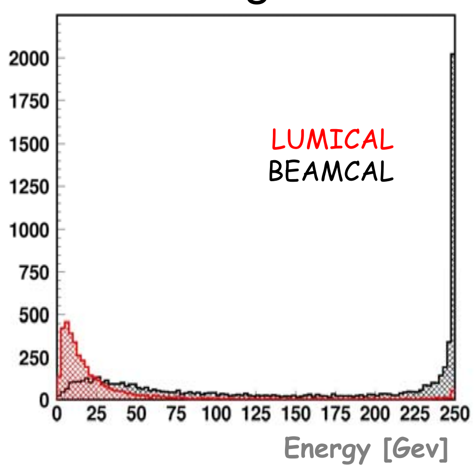
Simulation of $e^+e^- \rightarrow e^+e^-l^+l^-$ (l = e, μ, τ): **WHIZARD**

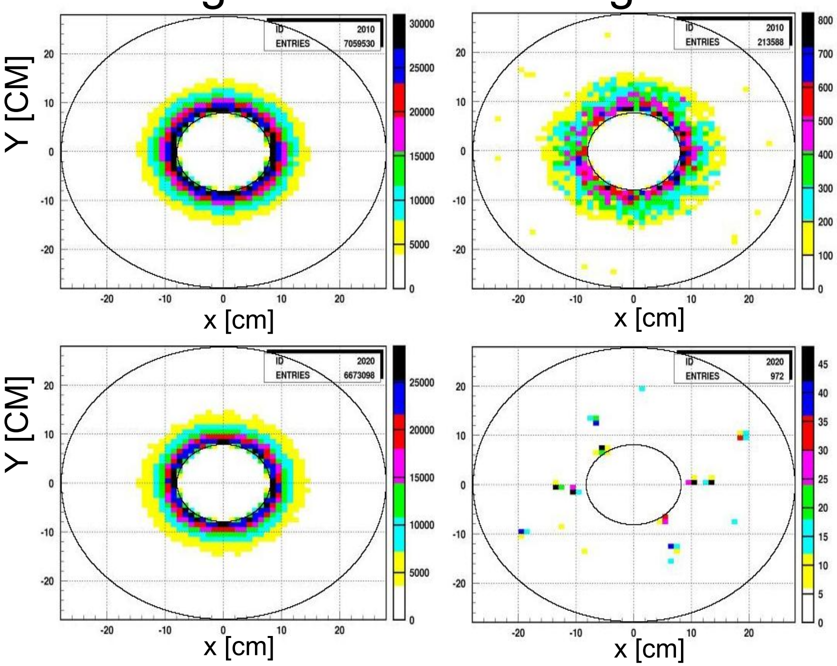
Bhabha scattering: **BHLUMI**

Event Selection: back to back



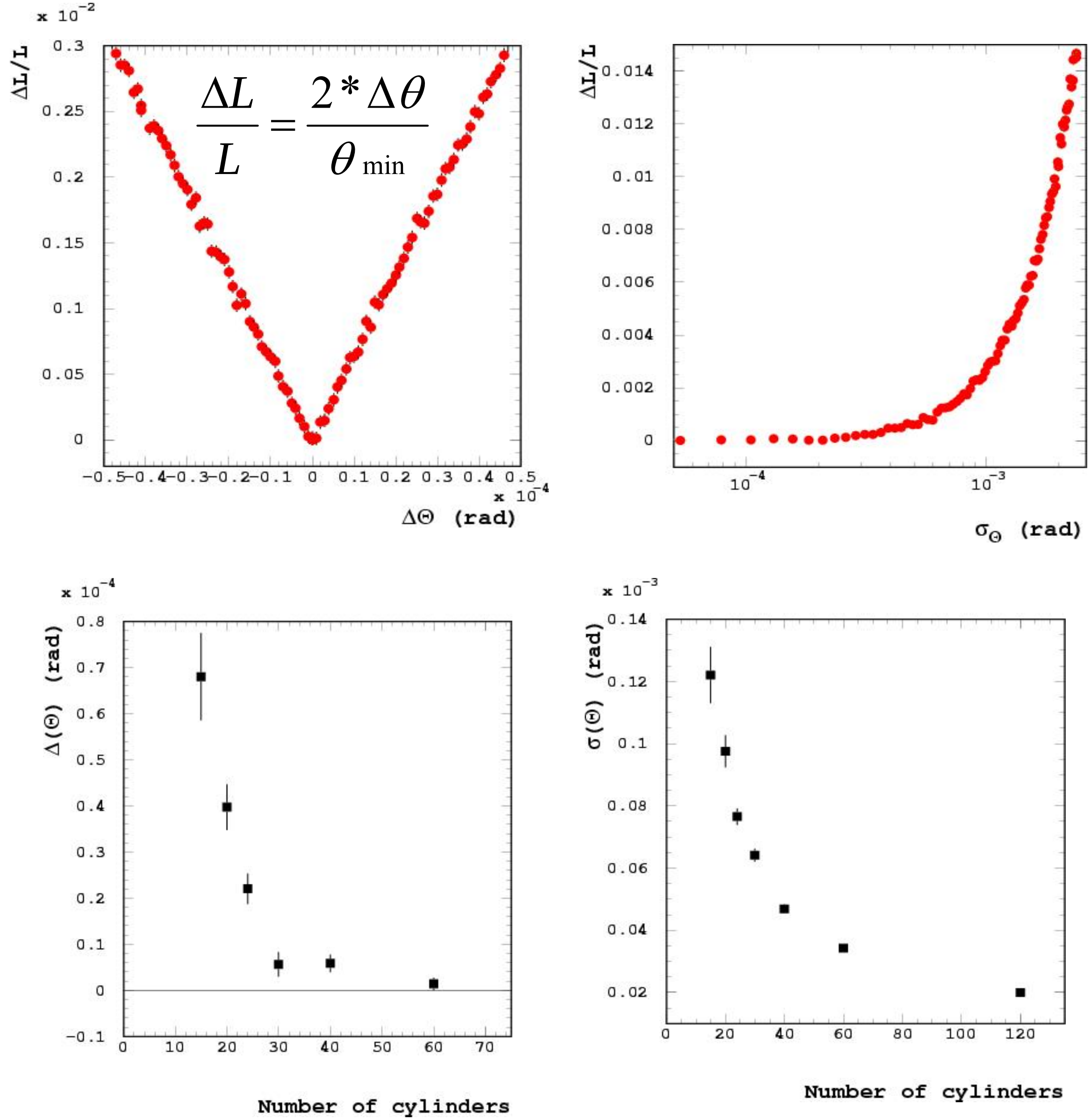
Background





Fast simulation

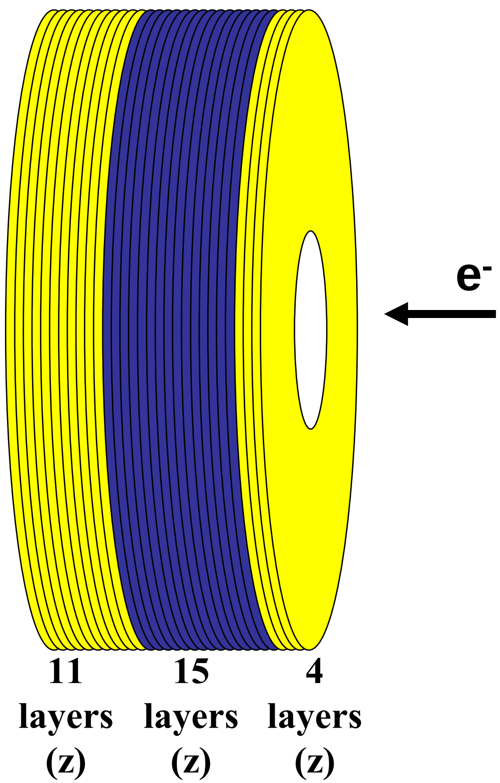
Optimization (Geant)



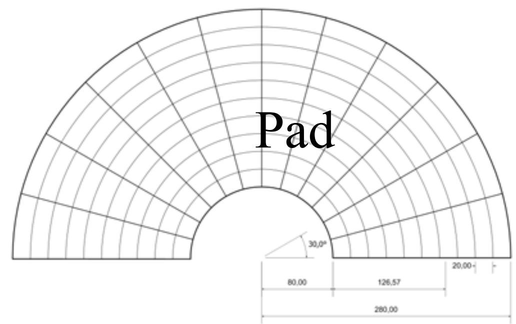
LumiCal Present Understanding

Maximum peak shower

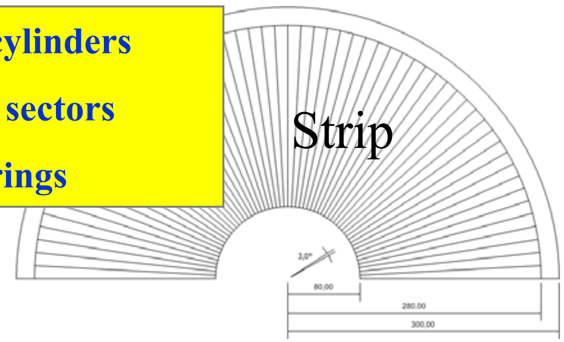
- 10 cylinders (θ)
- 60 cylinders (θ)



Every other ring:



64 cylinders
120 sectors
30 rings



Parameter	Pad Performance	Strip Performance
Energy resolution	25% $(\sqrt{GeV})$	25% $(\sqrt{GeV})$
θ resolution	3.5 * 10^{-5} rad	2.1 * 10^{-5} rad
ϕ resolution	10^{-2} rad	10^{-3} rad
$\Delta\ \theta$	~ 1.5 * 10^{-6} rad	~2.1* 10^{-7} rad
Electronics channels	25,200	3720 (with bonding sectors) 13,320 (without bonding)

New simulations results

Strip design - signal digitization

	analog	*8-bit ADC*
σ(θ) [rad]	**(3.11±0.01)×10^{-5}**	**(3.07±0.01)×10^{-5}**
Δθ/θ	**(2.1±0.3)×10^{-5}**	**(2.3±0.3)×10^{-5}**
σ(φ) [rad]	**(1.4±0.1)×10^{-3}**	**(1.4±0.1)×10^{-3}**

Digital Calorimeter

200 concentric rings

720 radial strips

14400 channels in each plane

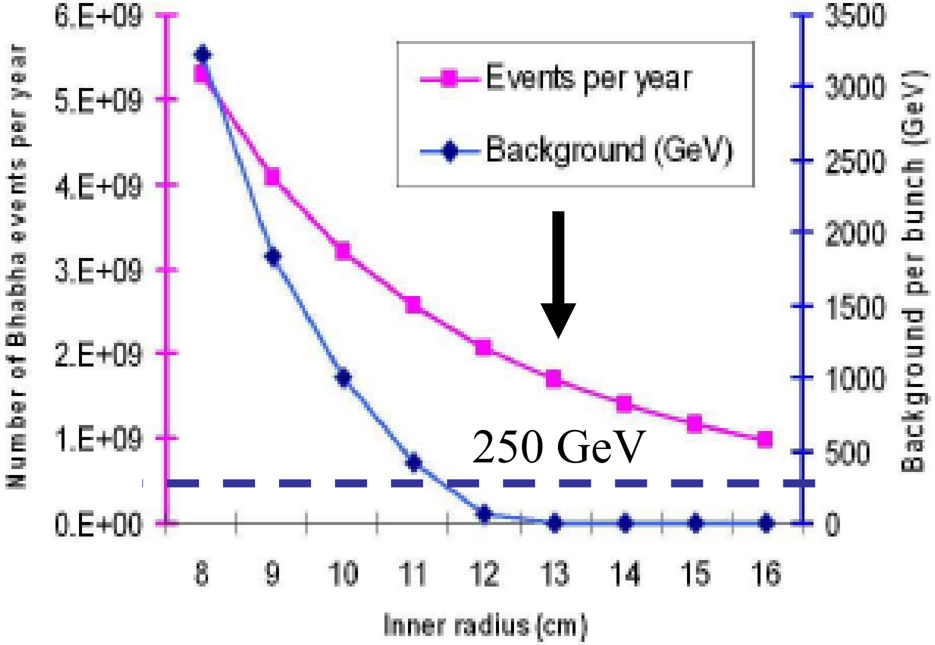
Promising performance results

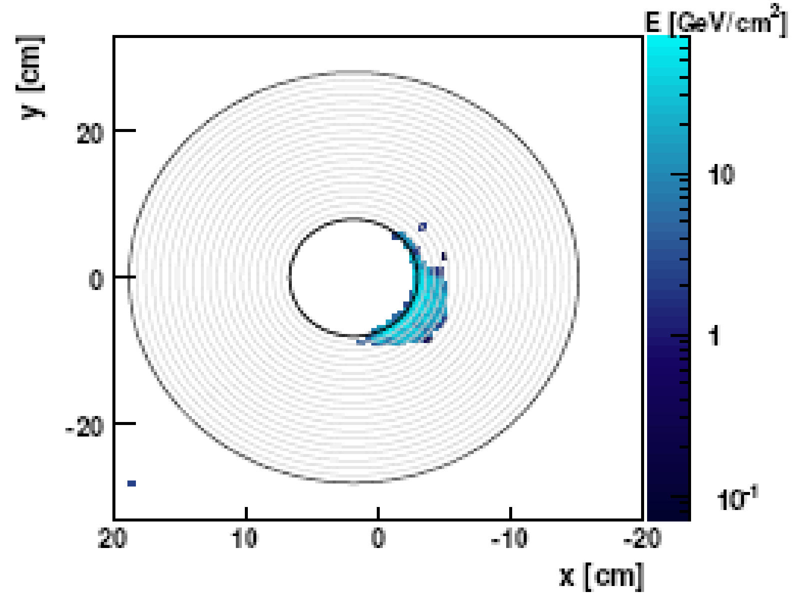
Needs further optimization

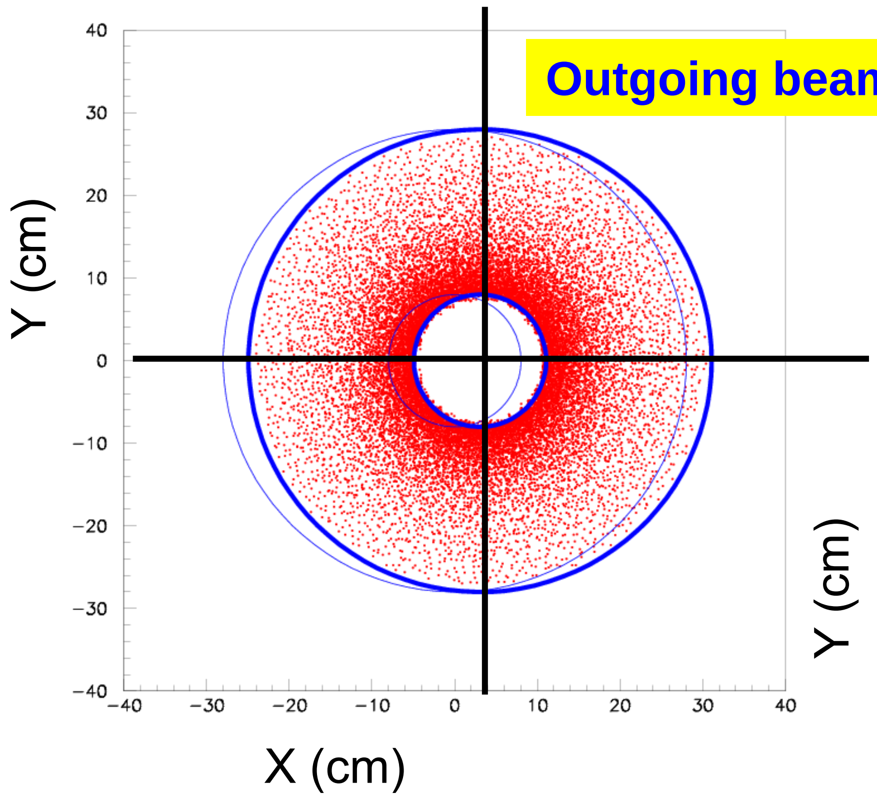
X- angle background

Beamstrahlung pair background

Outgoing beam
20 mrad, DID



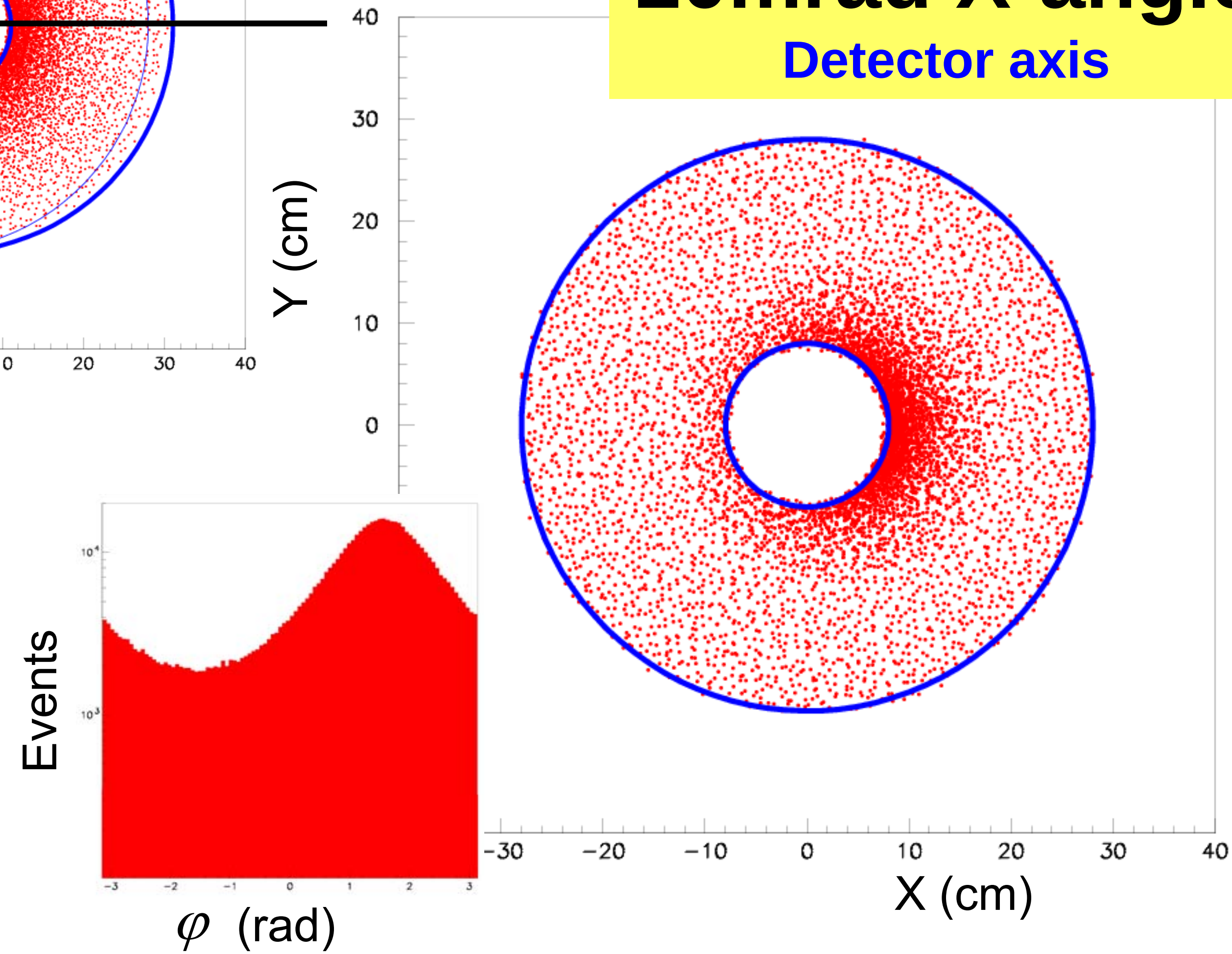


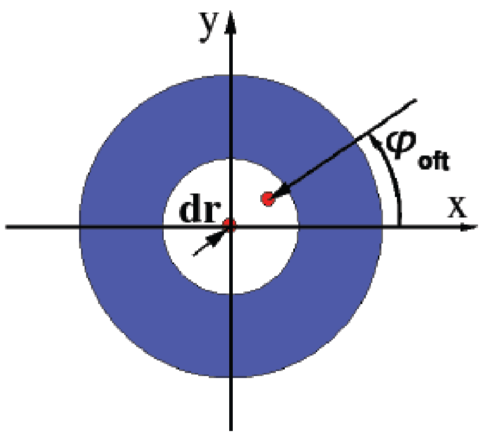


Bhabha Scattering

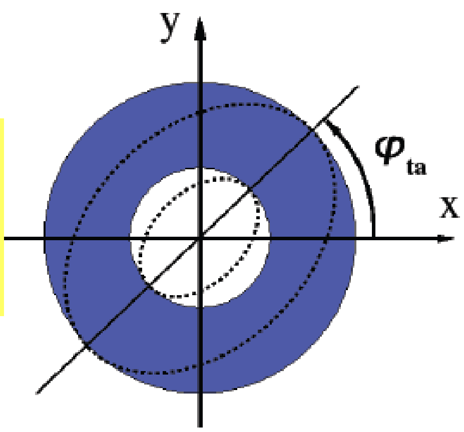
20mrad X-angle

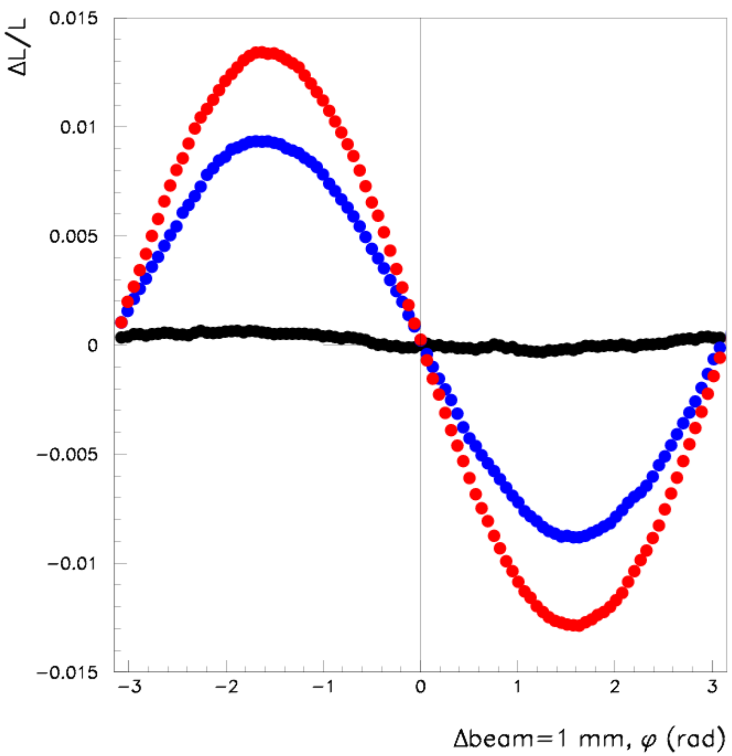
Detector axis

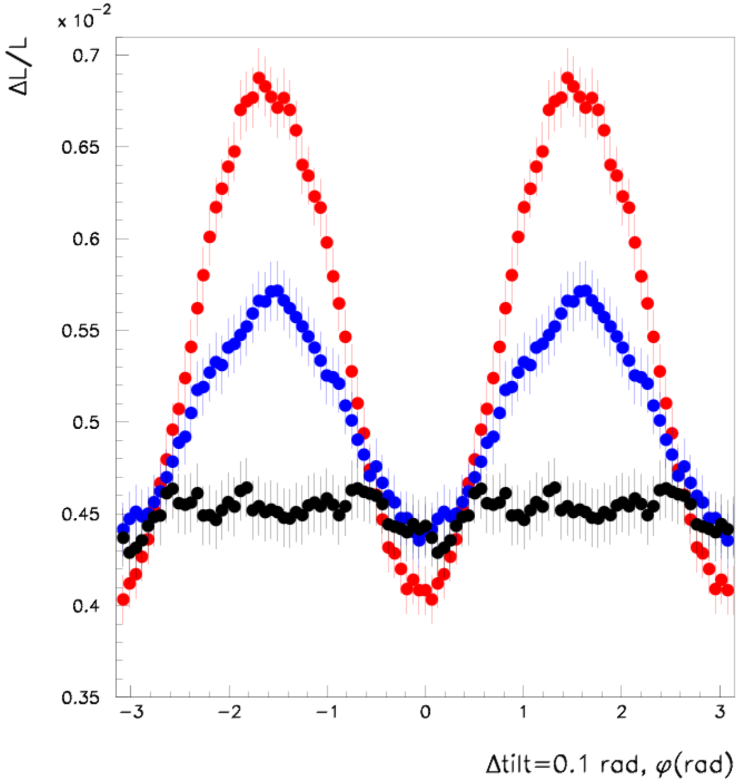




- Headon, 14,20 mrad X-angle outgoing beam
- 14 mrad X-angle detector axis
- 20 mrad X-angle detector axis



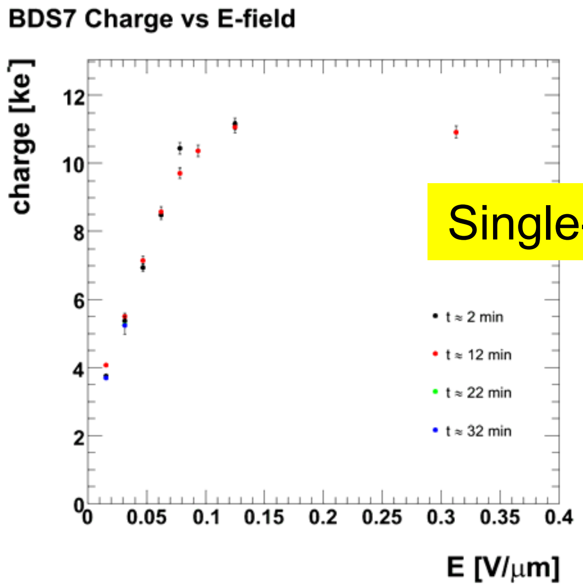




FCAL Sensors

Technology options

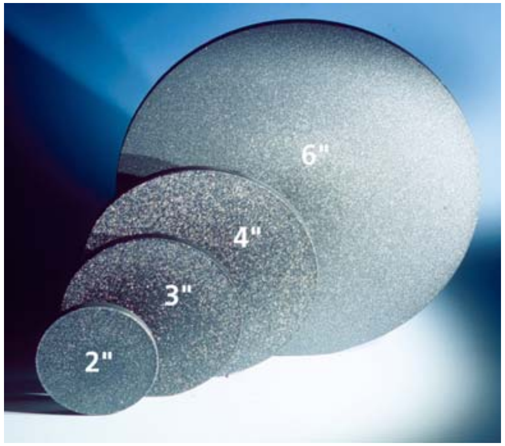
Diamond sensors



Single-crystal

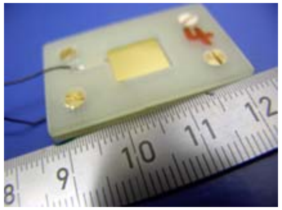
~10 MGy / year

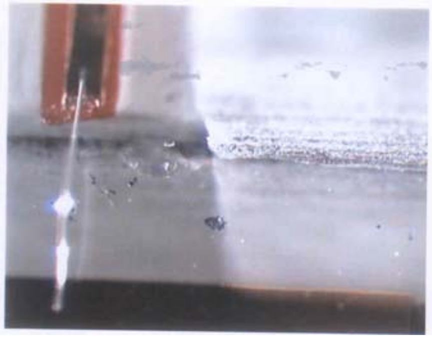
	Silicon	Diamond
Resistivity, W×cm	2.3×10^{5}	10^{13} - 10^{16}
Breakdown field, V/cm	3×10^{5}	10^{7}
Dielectric constant	11.9	5.7



Diamond samples (pCVD):

- Freiburg (FAP)
- GPI (Moscow)
- Element6 (De Beers)

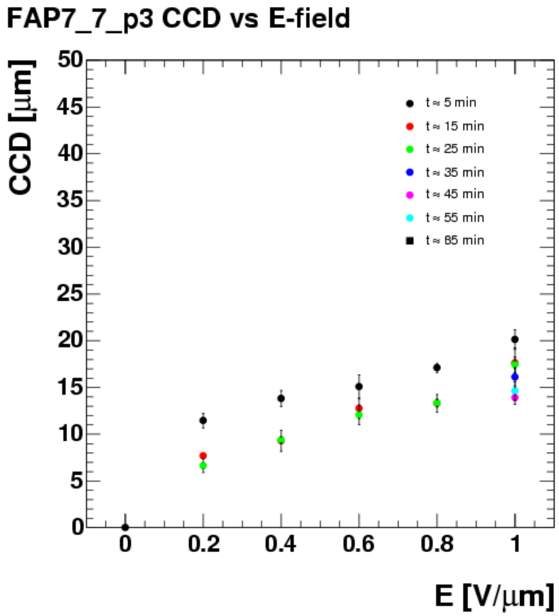




Some sensors show microcracks (and leakage)
The CCDs are between 0 and 150 µm
Some are stable under irradiation, other not.

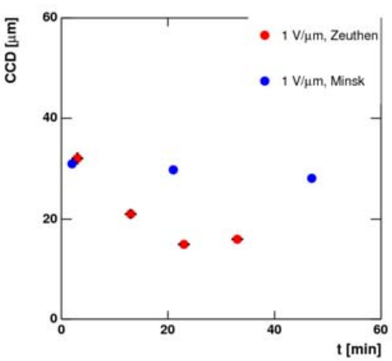
The search for a homogeneous reproducible sensor

Freiburg, FAP7

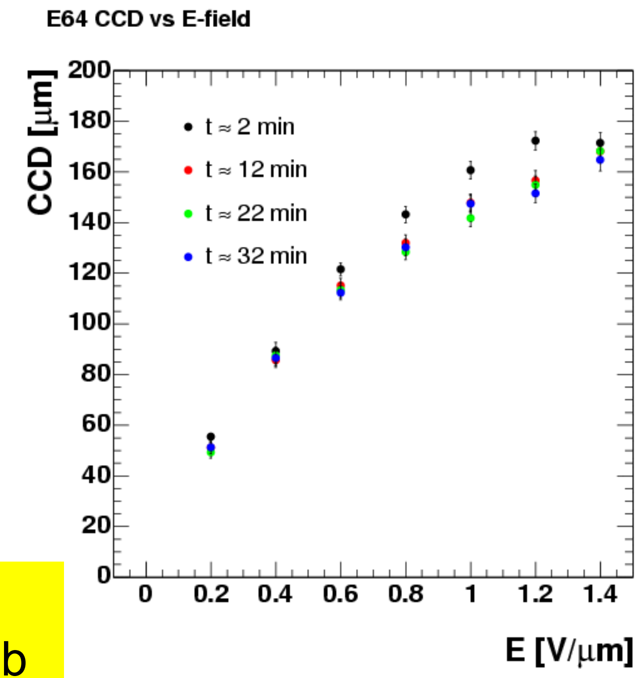


CCD performance of One FAP7 sample is poor, but a signal can still be extracted.

First results from Minsk lab



Element 6 – E6_4p



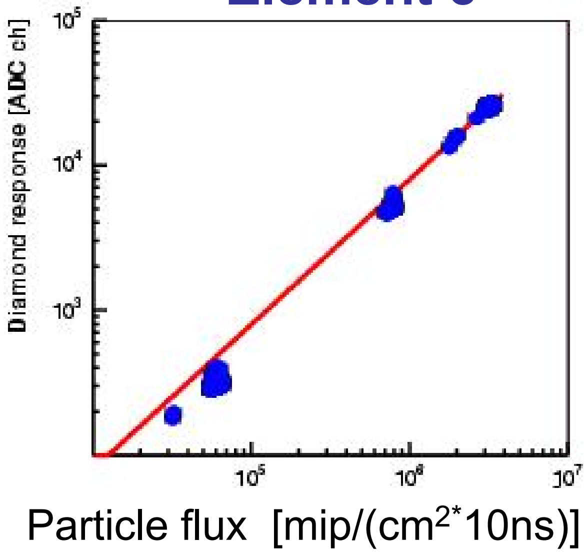
Element 6 shows good performance.
Stable under irradiation

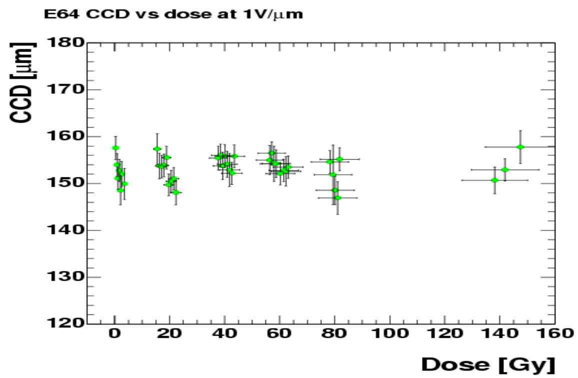
The search for a homogeneous reproducible sensor

Linearity over large dynamic rage

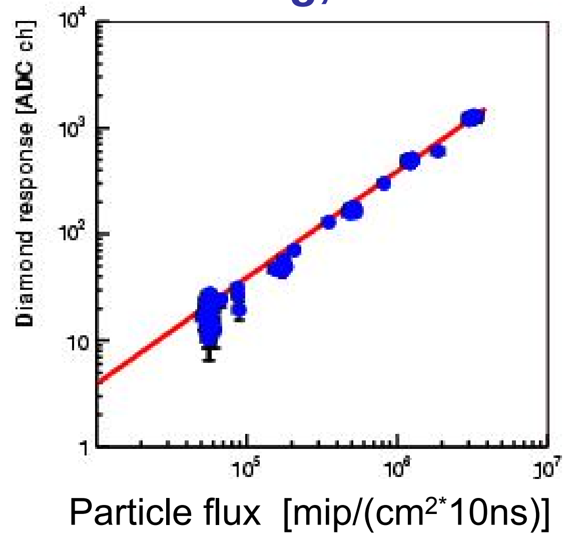
CERN PS Hadron beam – 3,5 GeV. fast extraction ~10^5-10^7 / ~10ns (Wide range intensities)

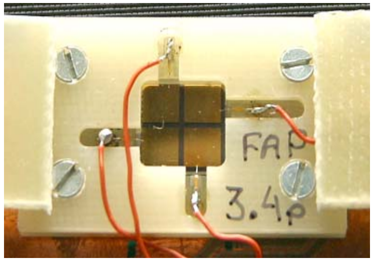
Element 6

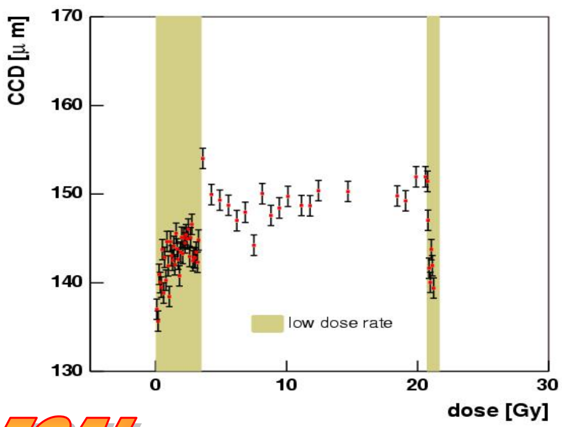


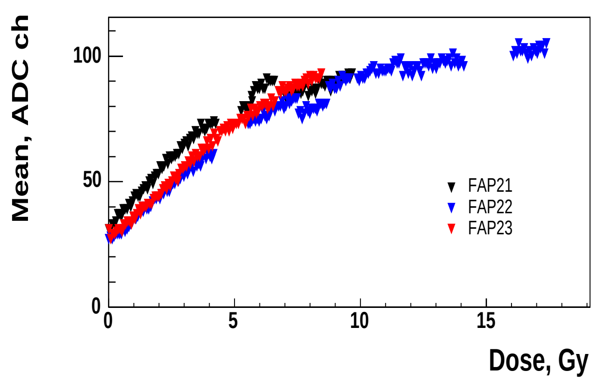


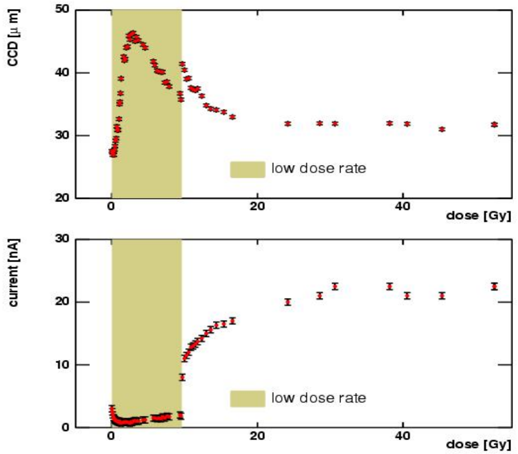
Freiburg, FAP22











FCAL Collaboration
High precision design

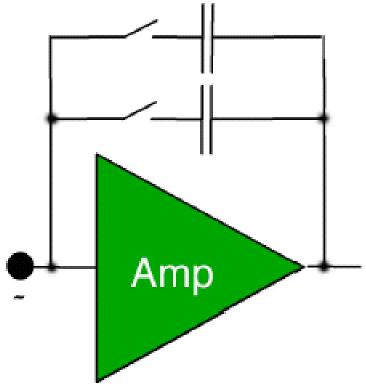
DESY-PRC2006

FCAL Readout electronics

Facing the challenges

- 5 bunch trains per second (5 Hz)
- 3000 bunches within one train

- One bunch every 300ns, 150ns possible
- Each bunch to be registered
- High dynamic range (better 1:10k)
- 8→12 bit ADC

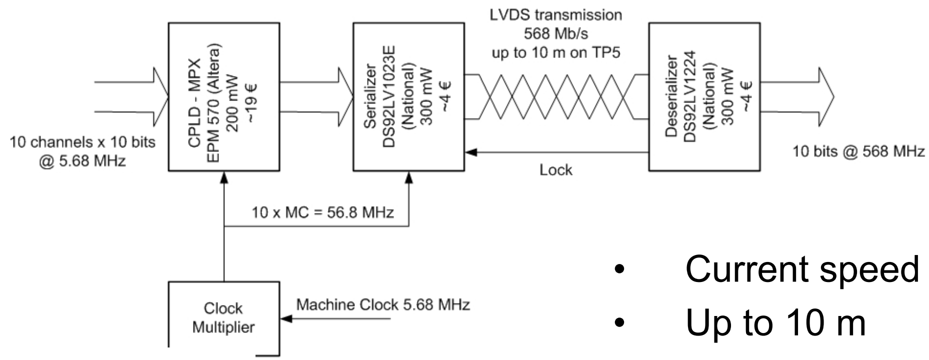


- Data per train ~1 Gb
  (transmission during train ~1 Tb/s, during break ~3 Gb/s)

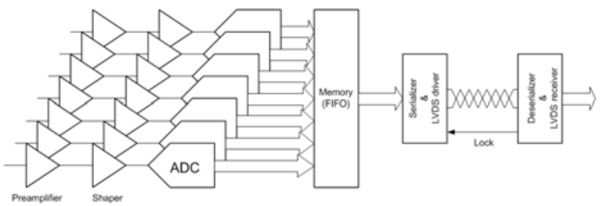
- Radiation hardness to be considered
- Compact detectors: low power little space for multi-channel electronics

Signal transmission

Digital Transmission LVDS link

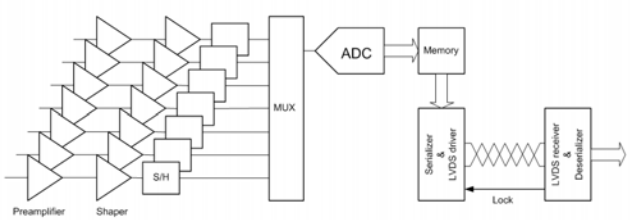


- Current speed – 0.6 Gb/s
- Up to 10 m



Parallel conversion – **BeamCal**

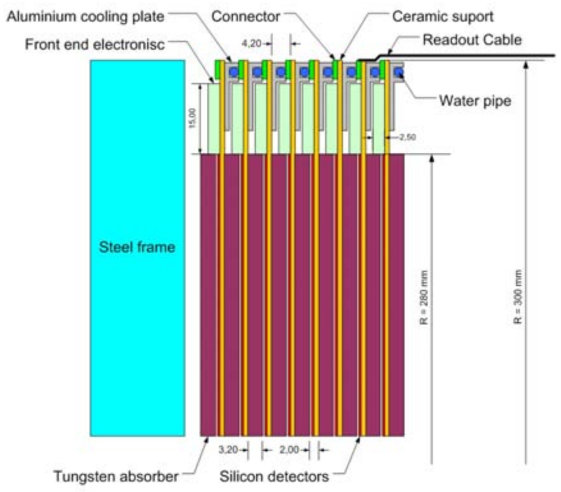
ADC in each channel – expensive, needs ‘Sample and Hold’ and consuming space on chip



Multiplexed ADC - **LumiCal**

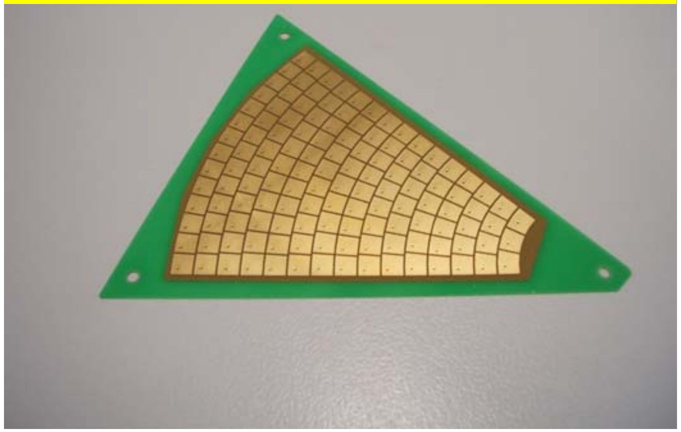
One ADC for a group of channels – cheaper, needs ‘Sample and Hold’, MUX and faster ADC

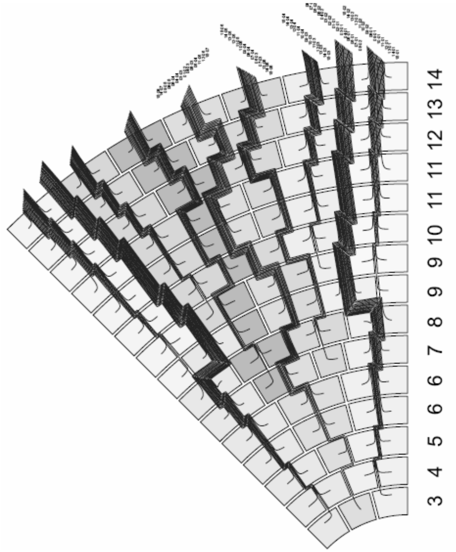
- *ADC to be included onboard (digital transmission)*
- *Optical fiber transmission – best rates*
- *Transmission between trains – only for LumiCal*
- *BeamCal readout simultaneously with bunches*

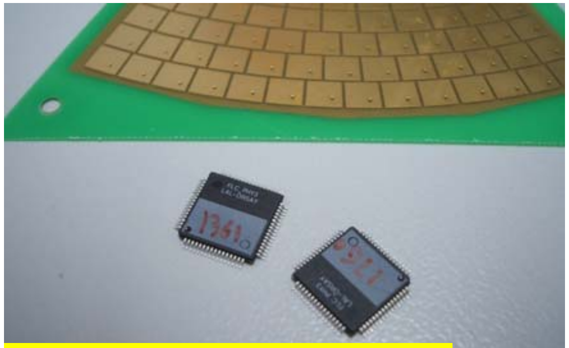


- *Strategy: Investigation of known systems, since we are limited with manpower / resources.*
- *Investigation of different types of preamps*
- *Feasibility studies of digitization*

BeamCal sensor test structure



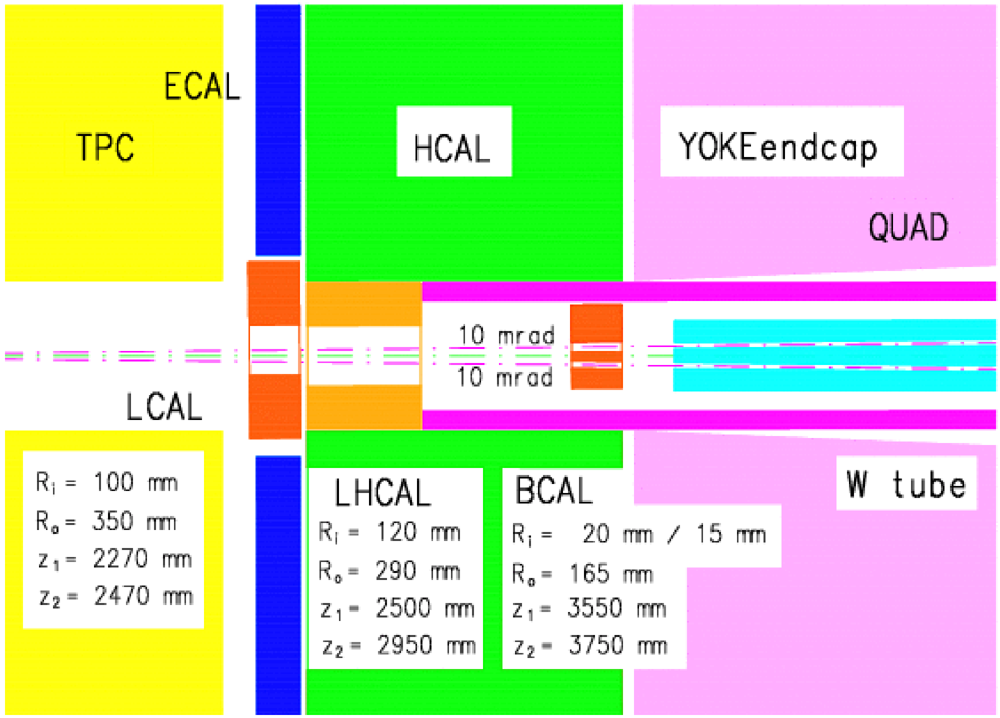


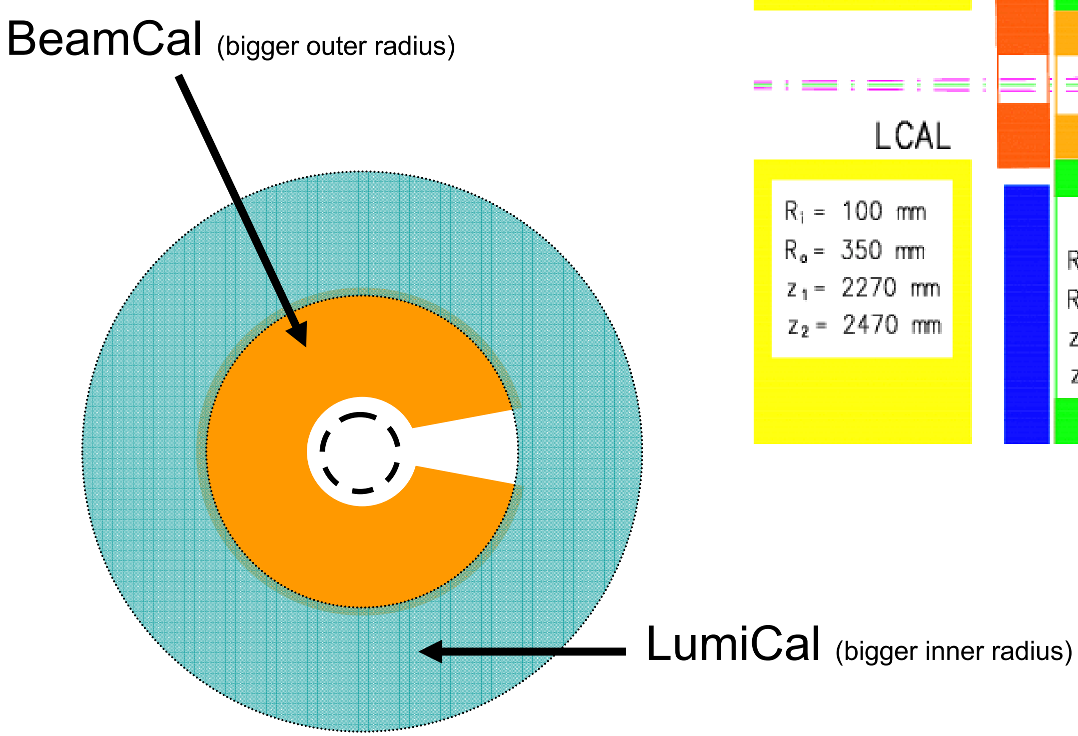


PHY3, Readout chip

Present Understanding
& Summary

20 mrad LDC


TPC
ECAL
HCAL
YOKEendcap
QUAD
10 mrad
10 mrad
LCAL
R_i = 100 mm
R_o = 350 mm
z_1 = 2270 mm
z_2 = 2470 mm
LHCAL
R_i = 120 mm
R_o = 290 mm
z_1 = 2500 mm
z_2 = 2950 mm
BCAL
R_i = 20 mm / 15 mm
R_o = 165 mm
z_1 = 3550 mm
z_2 = 3750 mm
W tube

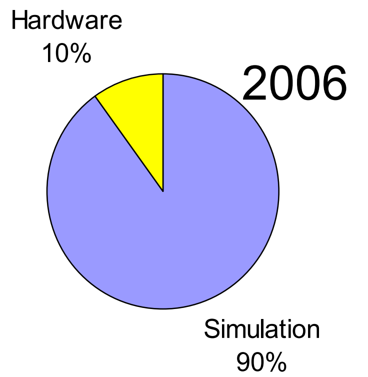

BeamCal (bigger outer radius)
LumiCal (bigger inner radius)

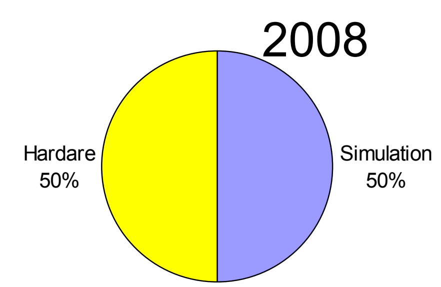
Since last PRC (1.5 years ago)…..

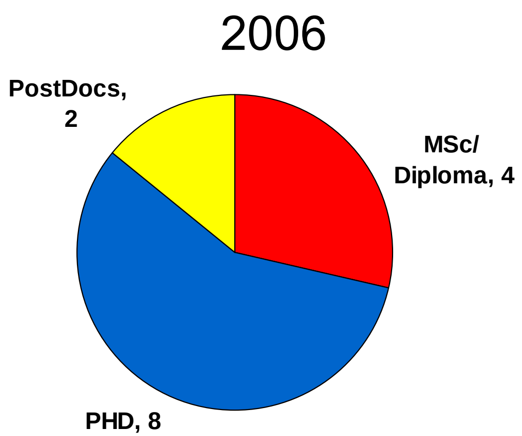
- Close working relations between the groups
- Most simulation milestones were addressed (ahead of schedule)
- Hardware milestones seems feasible - following original schedule
- 3 FCAL collaboration meeting:

  Zeuthen, Tel-Aviv, Cracow (~20 talks were given in each meeting)
- ~40 talks were given in big international meetings:

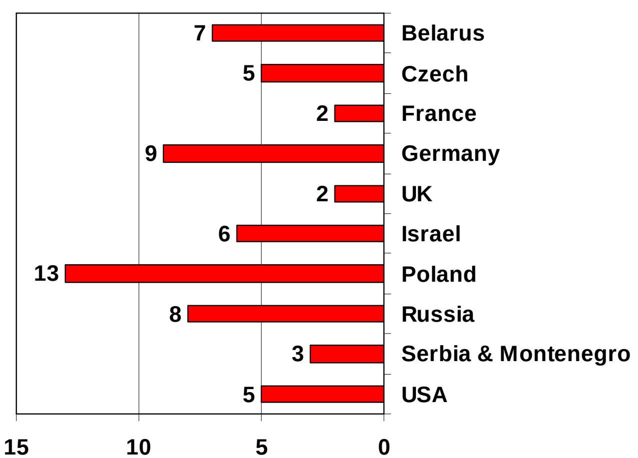
  (LCWS, ECFA, Snowmass, MDI …)
- 1 Ph.D. thesis, 2 M.Sc. thesis







People signing the 2006 PRC report (60)



R&D Milestones – Hardware

2006 2007 2008

Readout design concept for LumiCal and BeamCal

Operation and performance study of multi-channel preamplifiers of different architecture (ECAL and NC PHEP design)

Performance of several sensors types as function of the absorbed dose, up to MGy (Silicon, GaAs, pCVD diamonds)

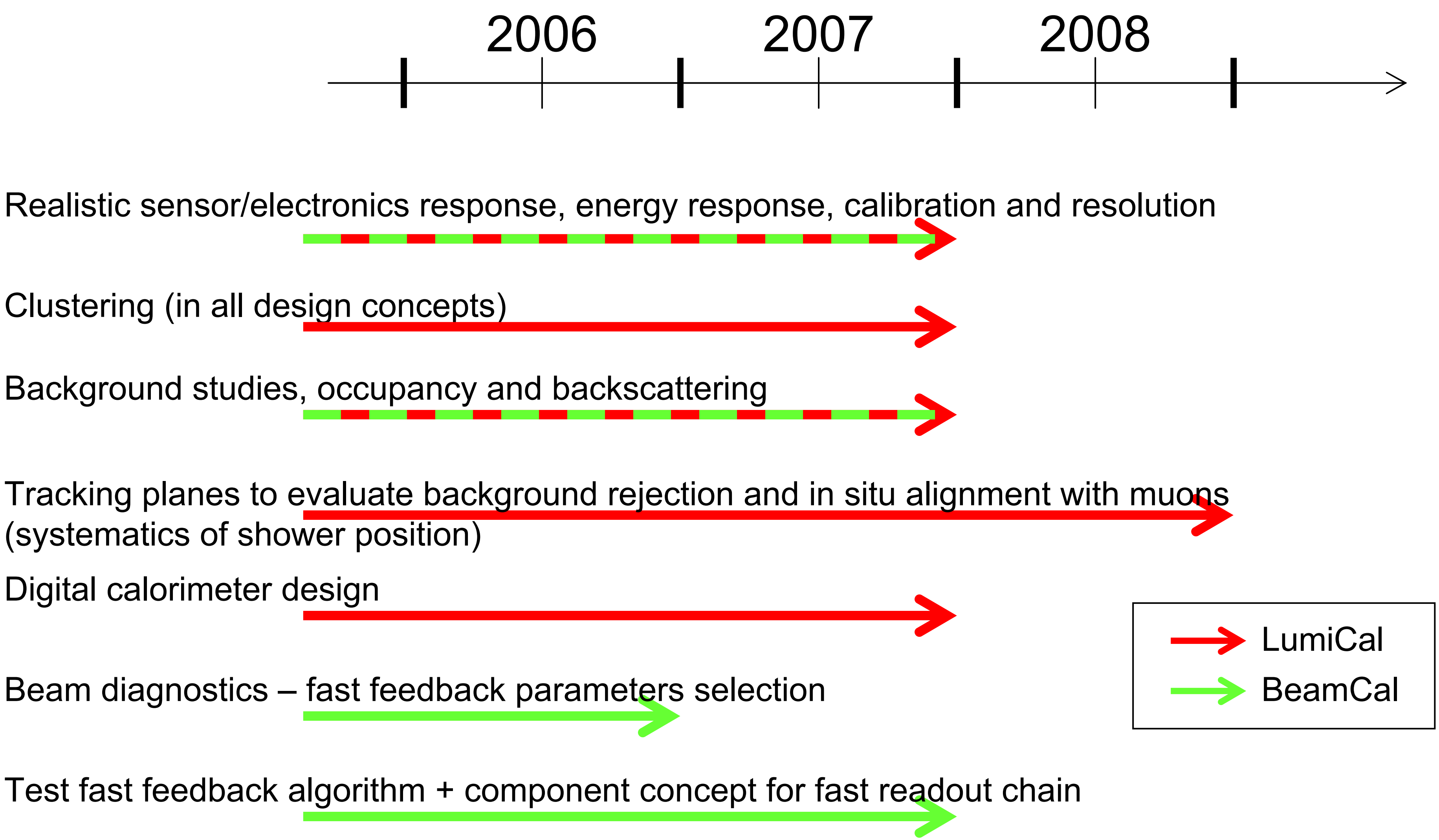
Design ultra-flat readout structure

Large area CVD diamonds with good homogeneity

Sensor plane positioning and position control with µm accuracy

Setup of a silicon testing lab in Israel + working relations with Israeli silicon industry

R&D Milestones – Simulations & Design



Cracow FCAL meeting, Feb 2006