Instrumentation of the Very Forward Region of a Linear Collider Detector

Univ. of Colorado, Boulder,
AGH Univ., INP & Jagiell.
Univ. Cracow,
JINR, Dubna,
NCPHEP, Minsk,
FZU, Prague,
IHEP, Protvino,
TAU, Tel Aviv,
DESY, Zeuthen

Wolfgang Lohmann

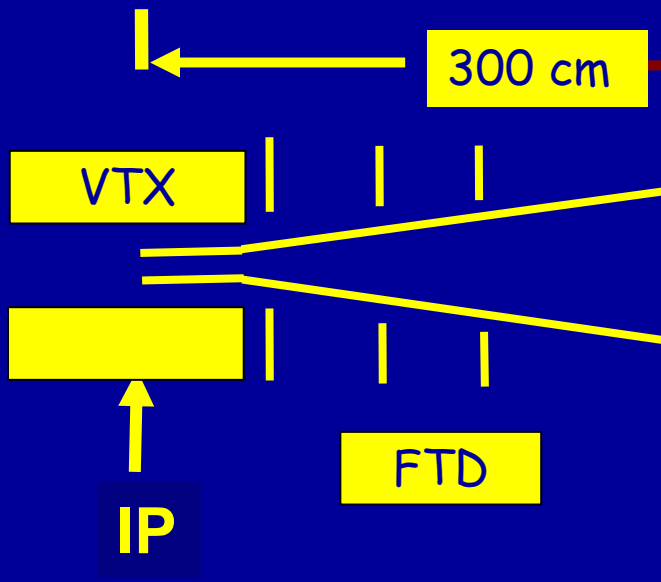
The Very Forward Calorimetry Collaboration

see: PRC R&D 01/02 (2002)

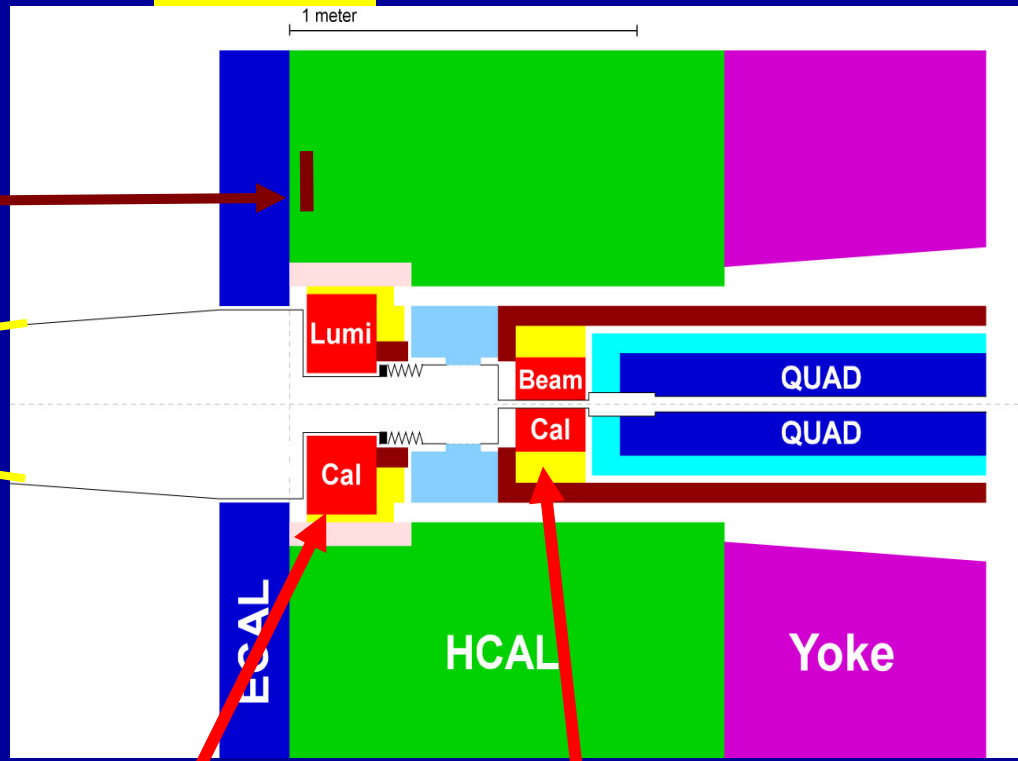
Functions of the very Forward Detectors

- Measurement of the Luminosity with precision $O(10^{-4})$
- Fast Beam Diagnostics
- Shielding of the inner Detector
- Detection of Electrons and Photons at very low angle – extend hermiticity

(Important for Searches)



L* = 4m



LumiCal:	$26 < \theta < 82$ mrad
BeamCal:	$4 < \theta < 28$ mrad
PhotoCal:	$100 < \theta < 400$ μrad

•Measurement of the Luminosity

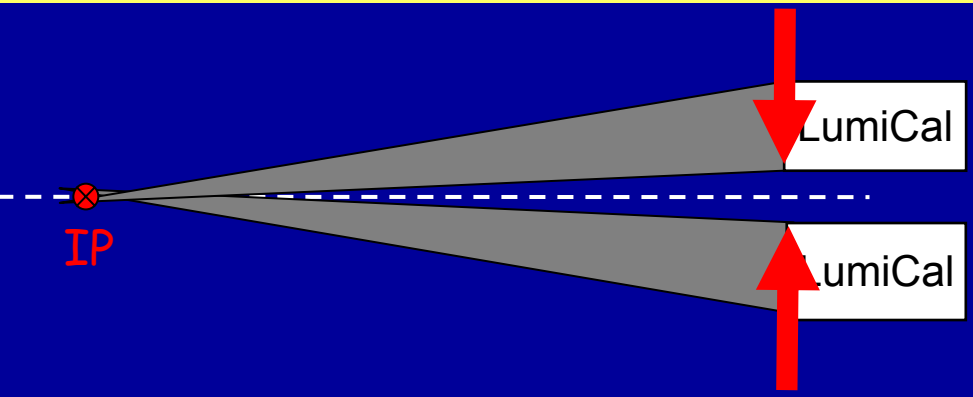
Gauge Process: $e^+e^- \longrightarrow e^+e^-(\gamma)$

Goal: 10^{-4} **Precision**

Physics Case: Giga-Z ,Two Fermion Cross Sections at High Energy, $e^+e^- \longrightarrow W^+W^-$

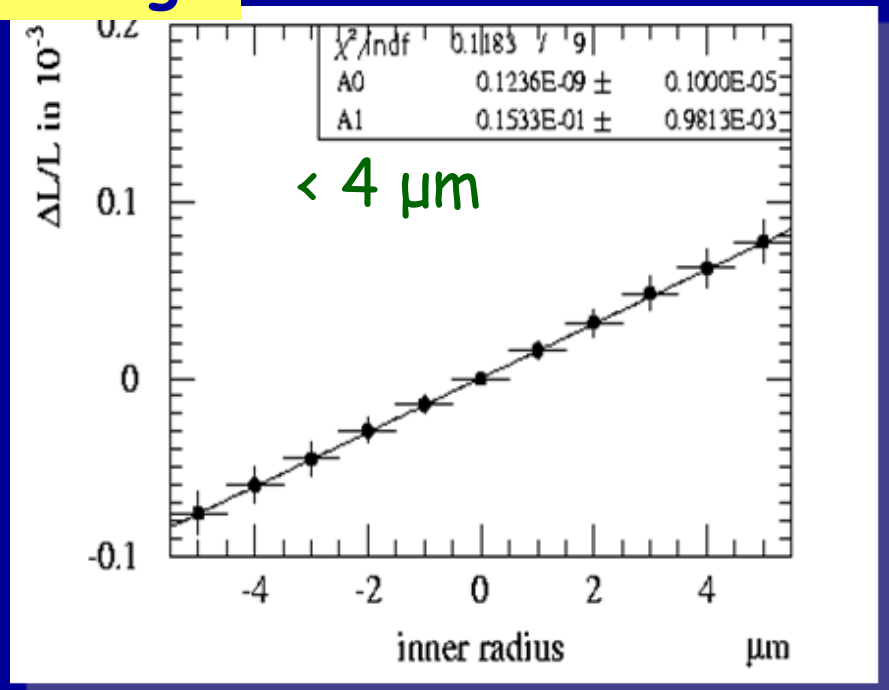
- Technology: Si-W Sandwich Calorimeter
- MC Simulations → Optimisation of Shape and Segmentation, Key Requirements on the Design
- Close contacts to Theorists (Cracow, Katowice, DESY)

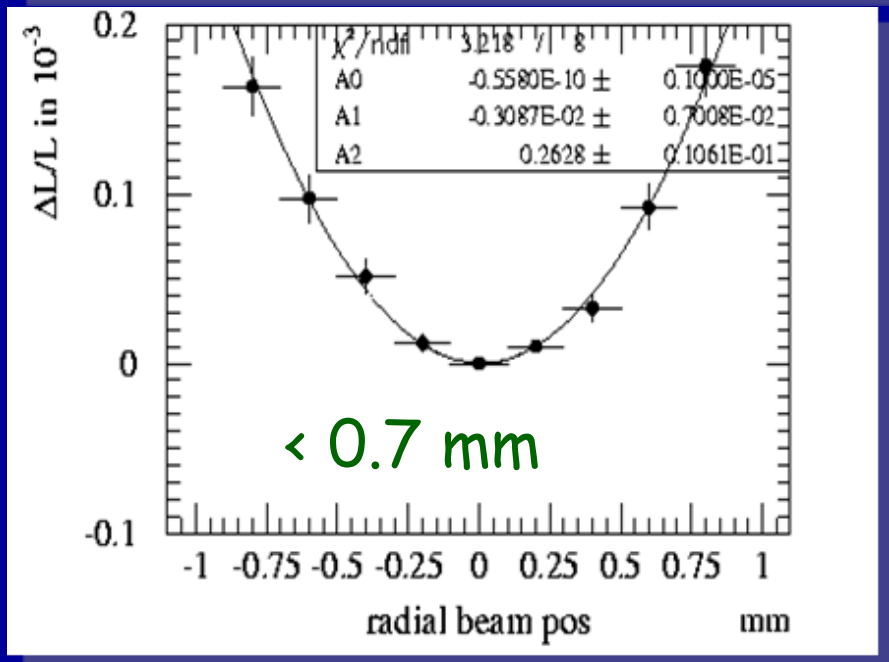
Requirements on the Mechanical Design



Requirements on
Alignment
and mechanical Precision
(rough Estimate)

Inner Radius of Cal.:	**< 1-4 µm**
Distance between Cals.:	**< 60 µm**
Radial beam position:	**< 0.7 mm**

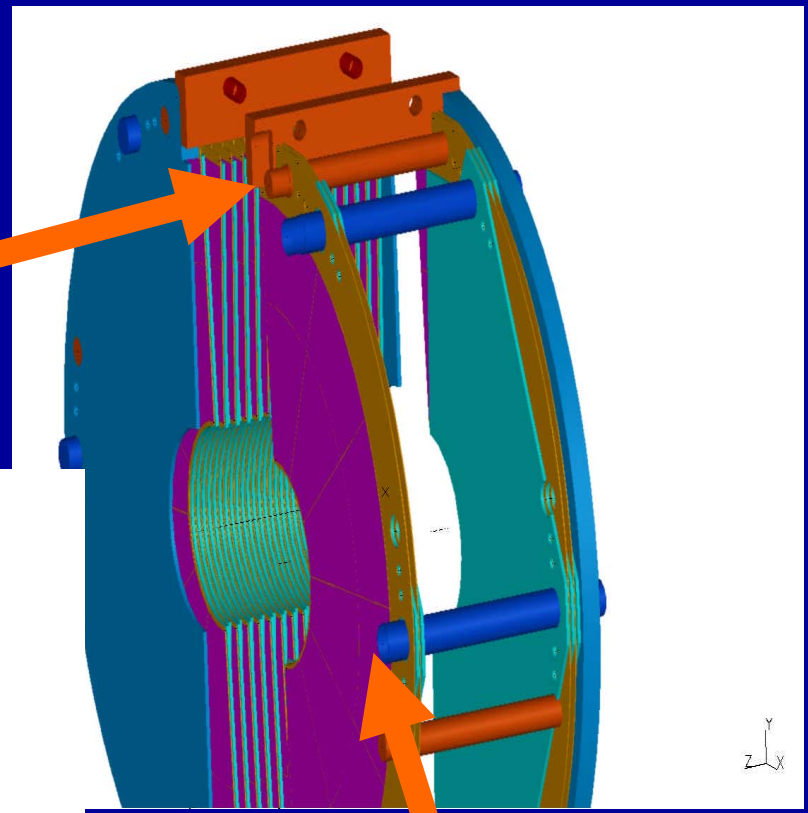


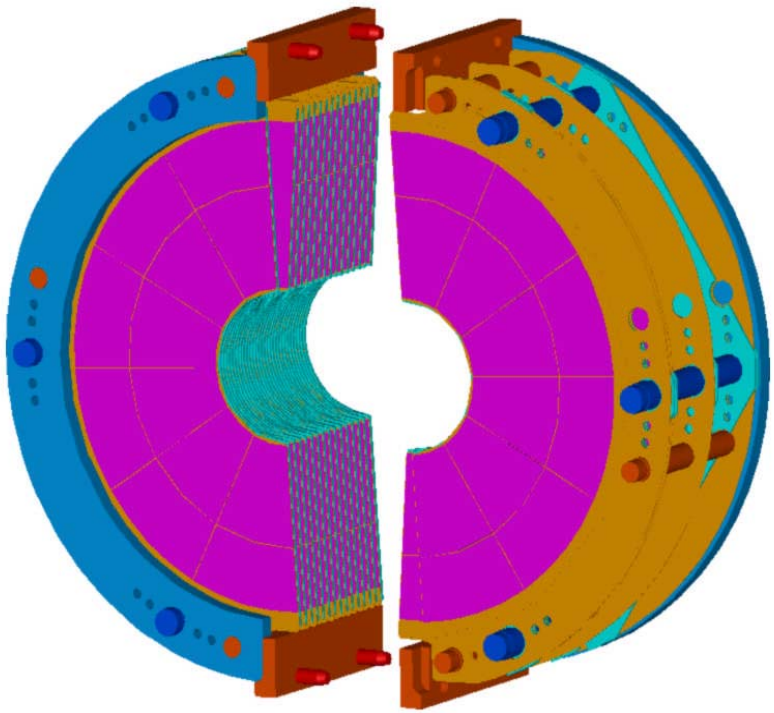


Concept for the Mechanical Frame

Decouple sensor frame from absorber frame

Sensor carriers





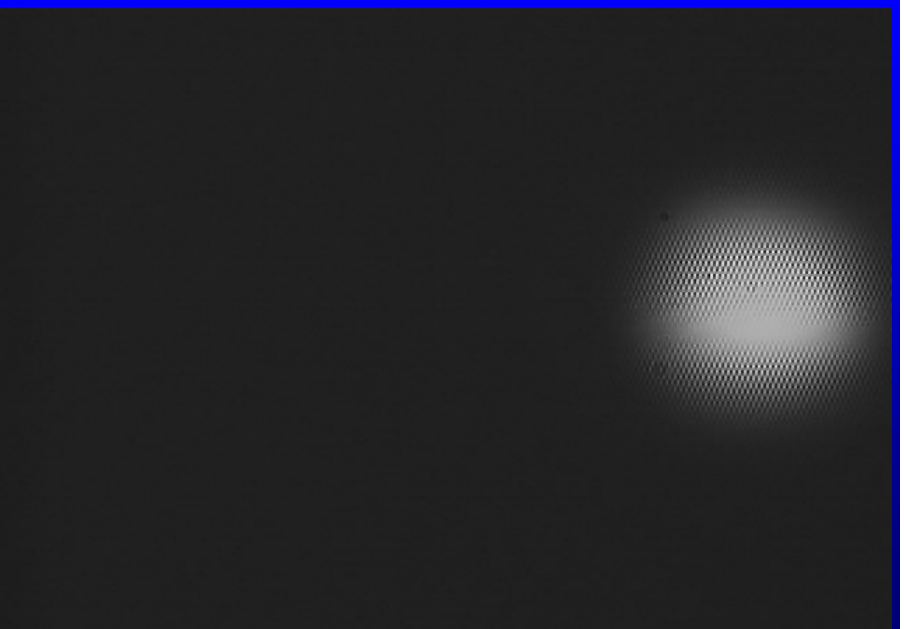
Absorber carriers

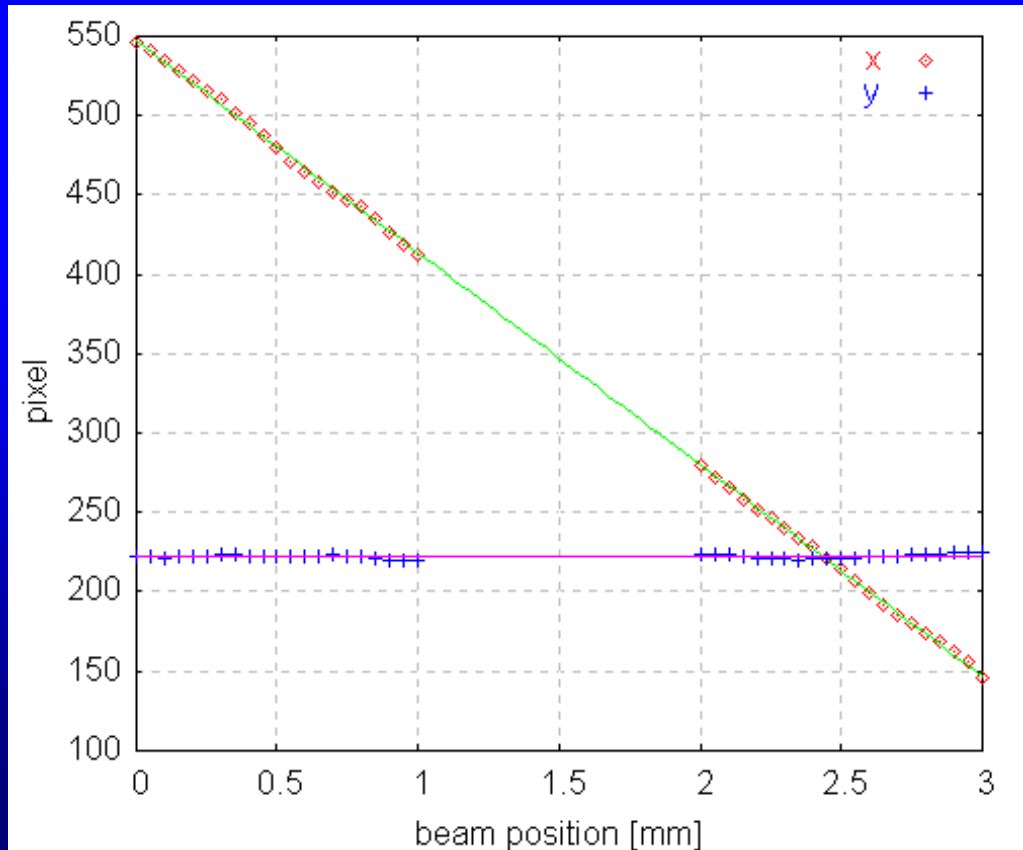
Laser Alignment Test

Jagiellonian Univ. Cracow
Photonics Group

- Simple CCD camera,
- He-Ne red laser,
- Laser translated in 50 μm steps

reconstruction of
the laser spot (x,y) position
on CCD camera



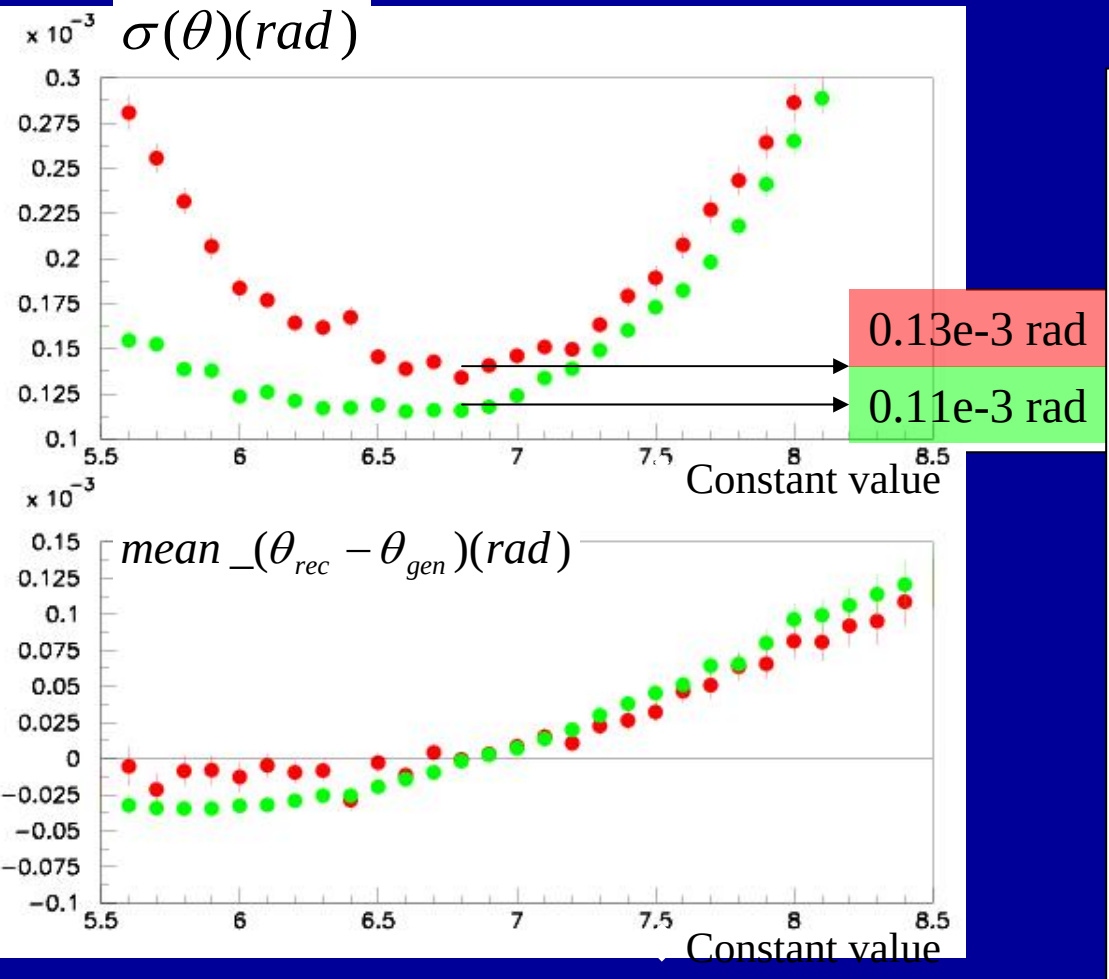


Performance Simulations for $e^+e^- \longrightarrow e^+e^-(\gamma)$

Simulation: Bhwide(Bhabha)+CIRCE(Beamstrahlung)+beamspread

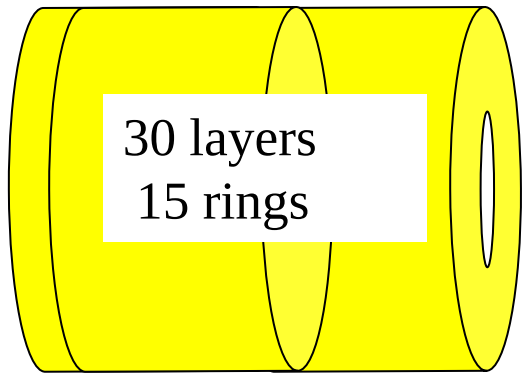
Event selection: acceptance, energy balance, azimuthal and angular symmetry.

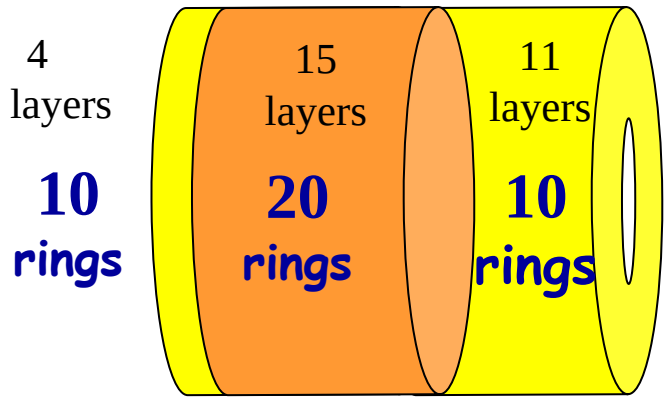
$$< X >= \frac{\sum X_i W_i}{\sum W_i} \qquad W_i = \max\{0, [const(E_{beam}) + \ln(\frac{E_i}{E_T})]\}$$



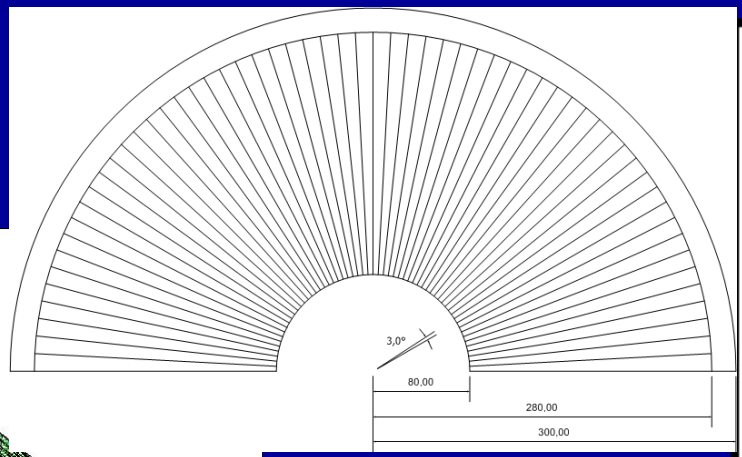
0.13e-3 rad

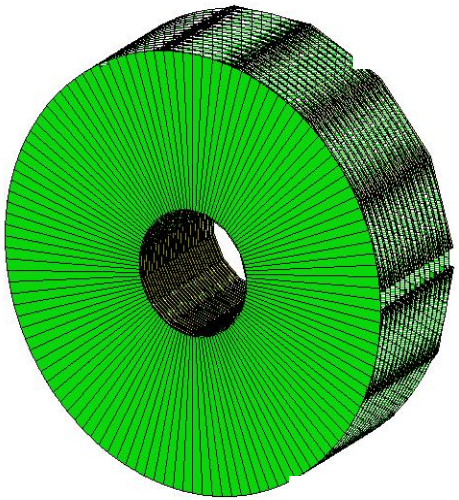
0.11e-3 rad

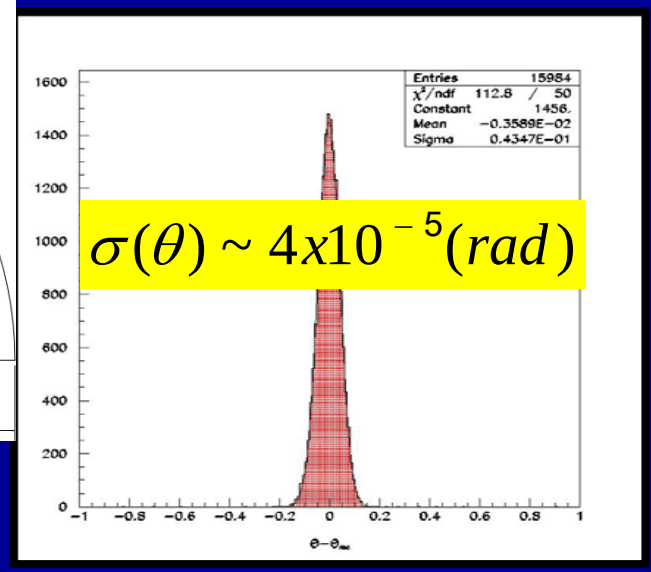


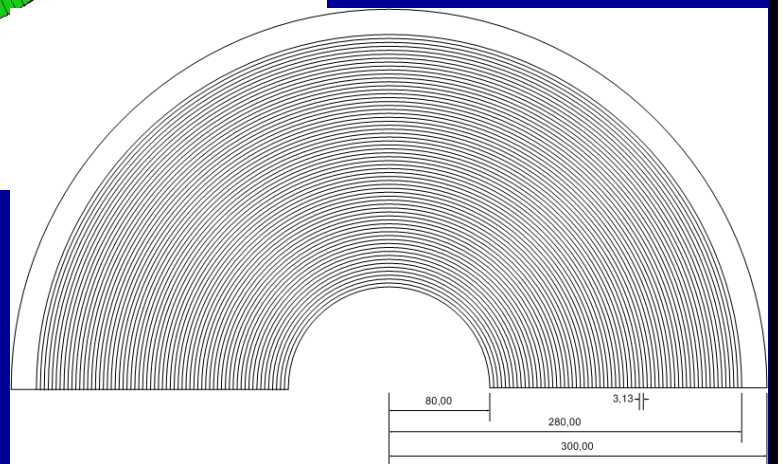


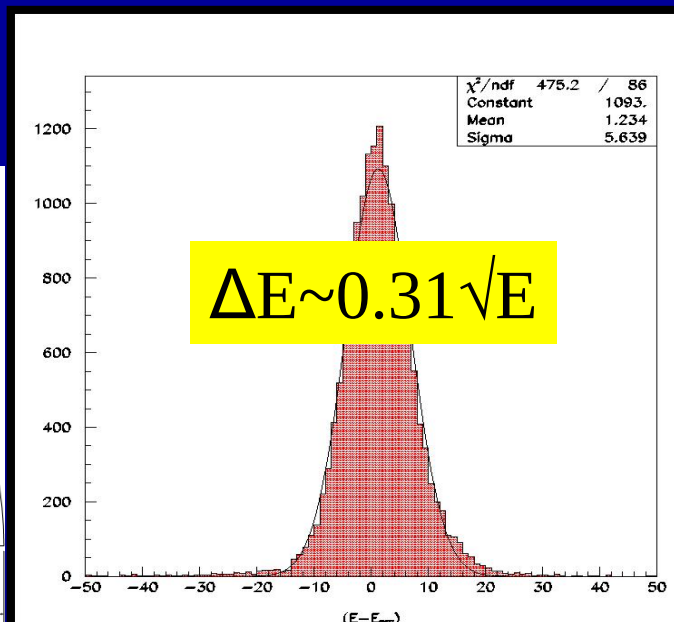
Determination of shower Coordinates
Strip version





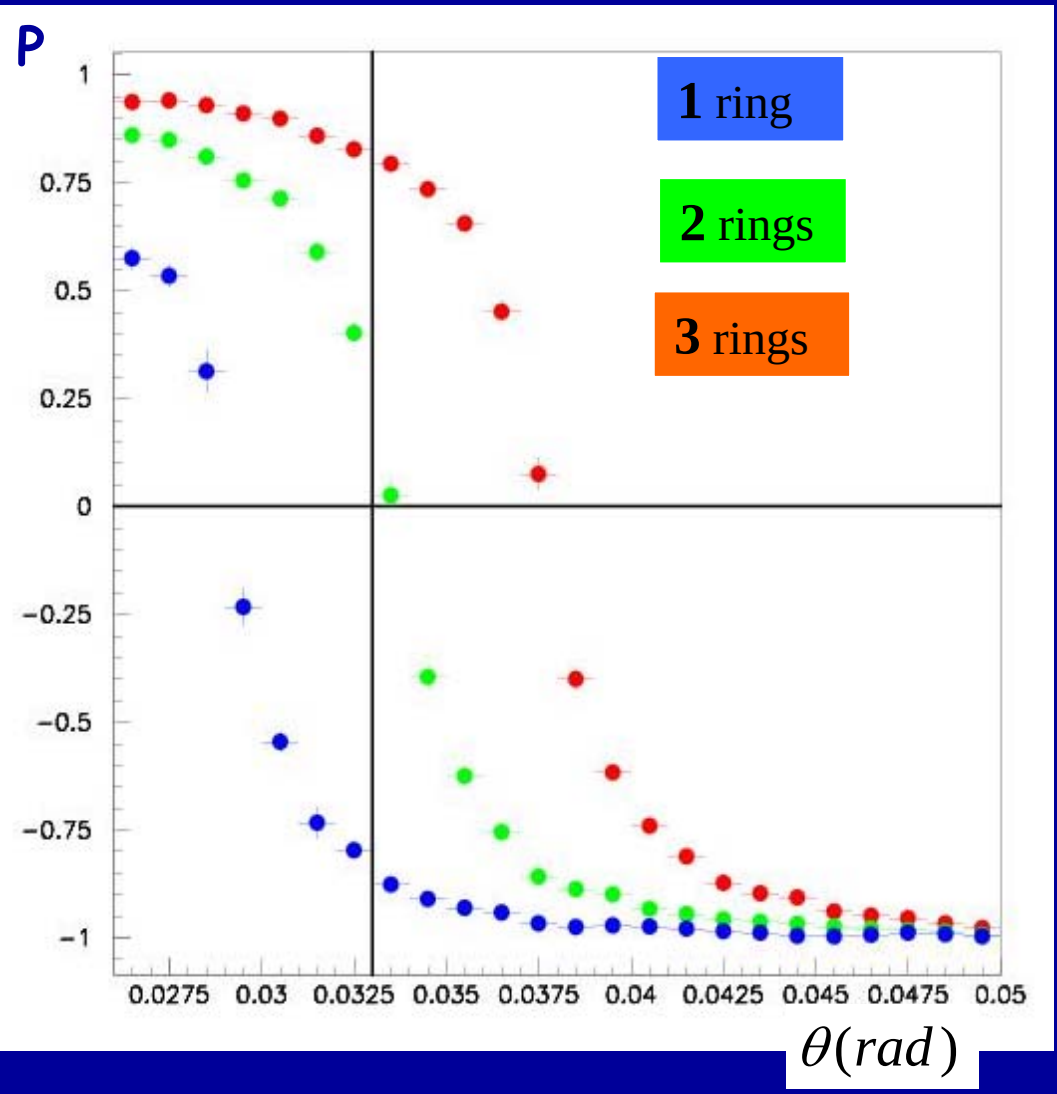


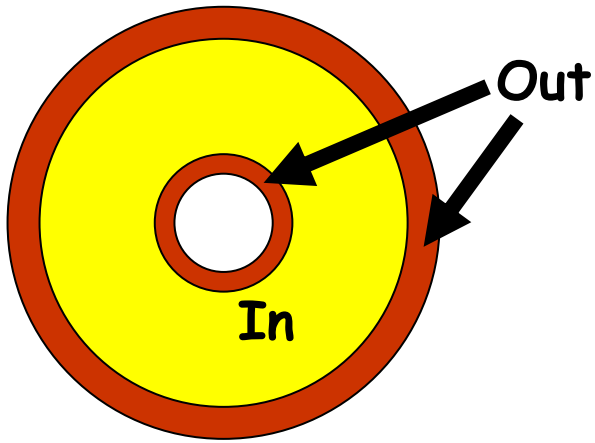


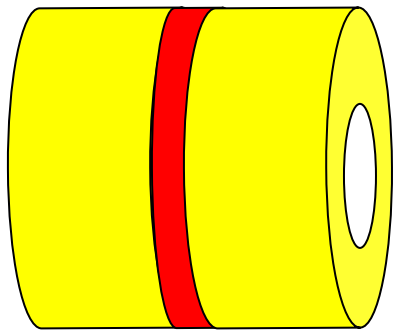


Determination of the Acceptance region

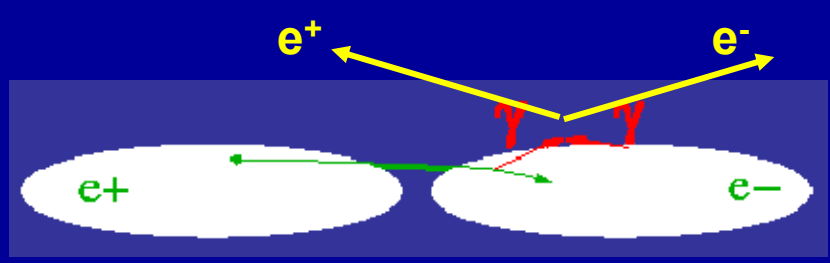
$$P = \frac{Eout-Ein}{Eout+Ein}$$



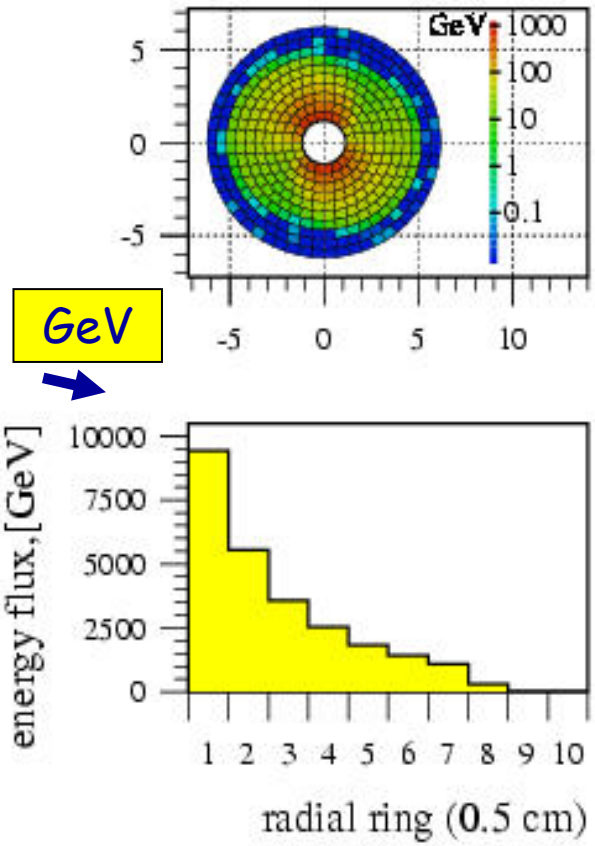




•Fast Beam Diagnostics



- e^+e^- Pairs from Beamstrahlung are deflected into the BeamCal
- 15000 e^+e^- per BX ⟶ 10 – 20 TeV
- 10 MGy per year ⟶ Rad. hard sensors
- direct Photons for θ < 200 μrad



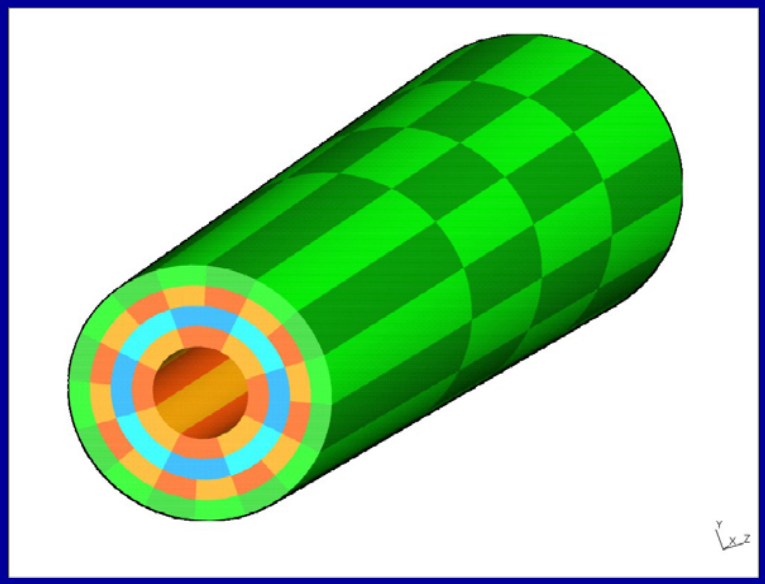
Technologies: Diamond-W Sandwich

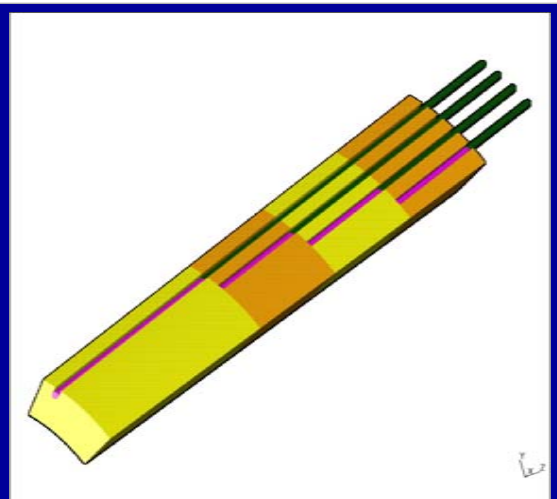
Scintillator Crystals

Gas Ionisation Chamber

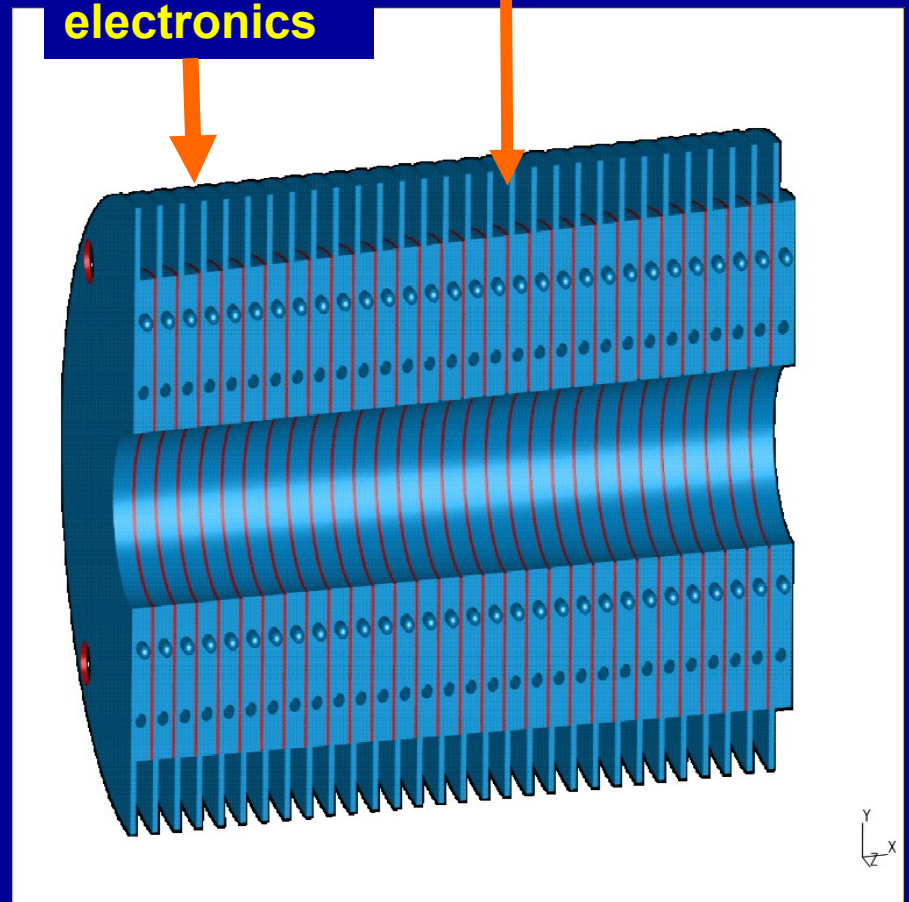
Schematic Views

Heavy crystals





W-Diamond sandwich



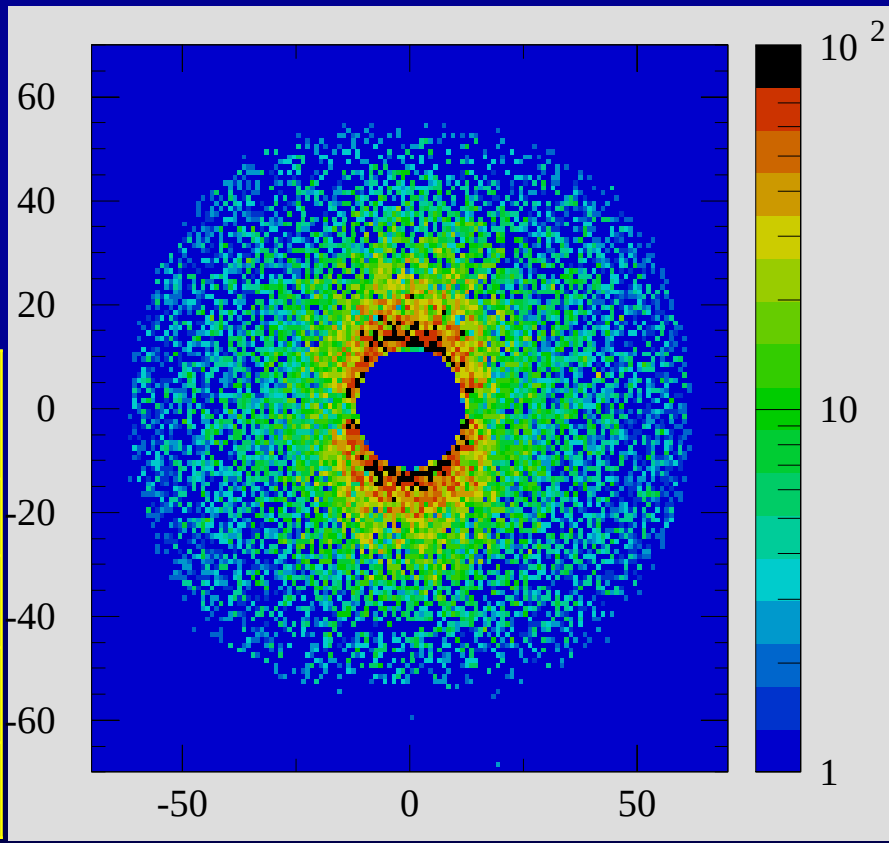
Beam Parameter Determination with BeamCal

Observables

detector: realistic segmentation, ideal resolution
single parameter analysis, bunch by bunch resolution

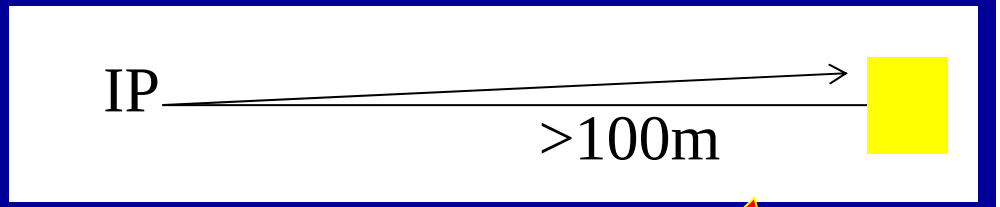
first radial moment
thrust value
total energy
angular spread
L/R, U/D F/B asymmetries

Quantity	Nominal Value	Precision
σx	553 nm	1.2 nm
σy	5.0 nm	0.1 nm
σz	300 μm	4.3 μm
Δy	0	0.4 nm

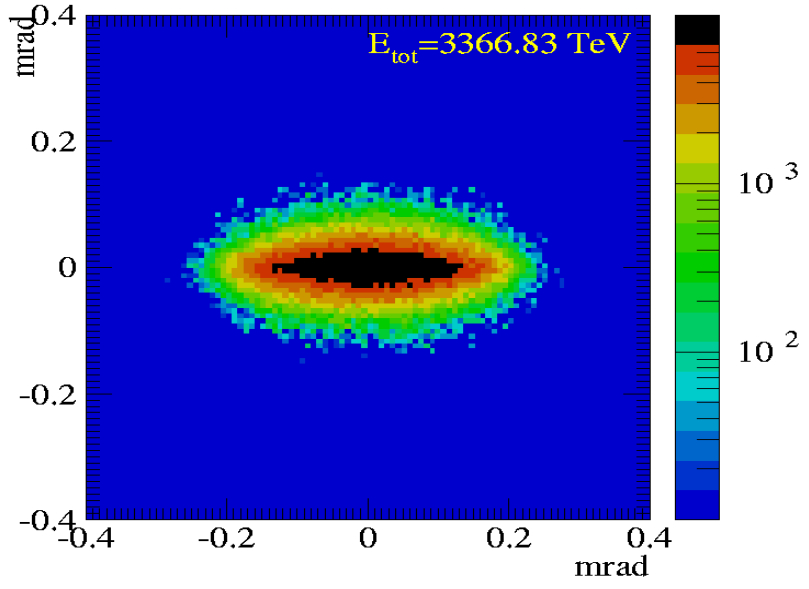


and with PhotoCal

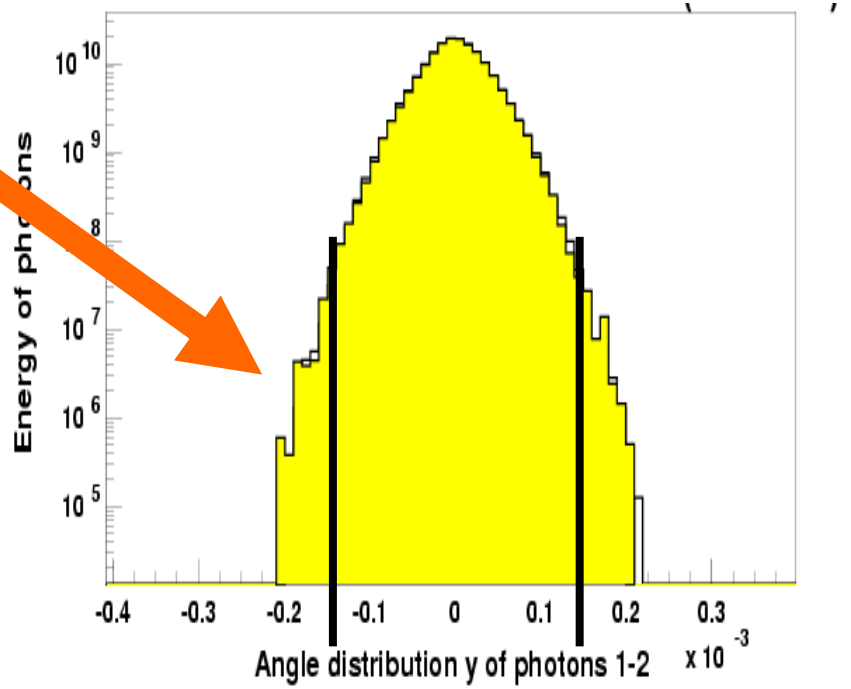
Photons from Beamstrahlung



Heavy gas ionisation Calorimeter



L/R, U/D F/B asymmetries of energy in the angular tails

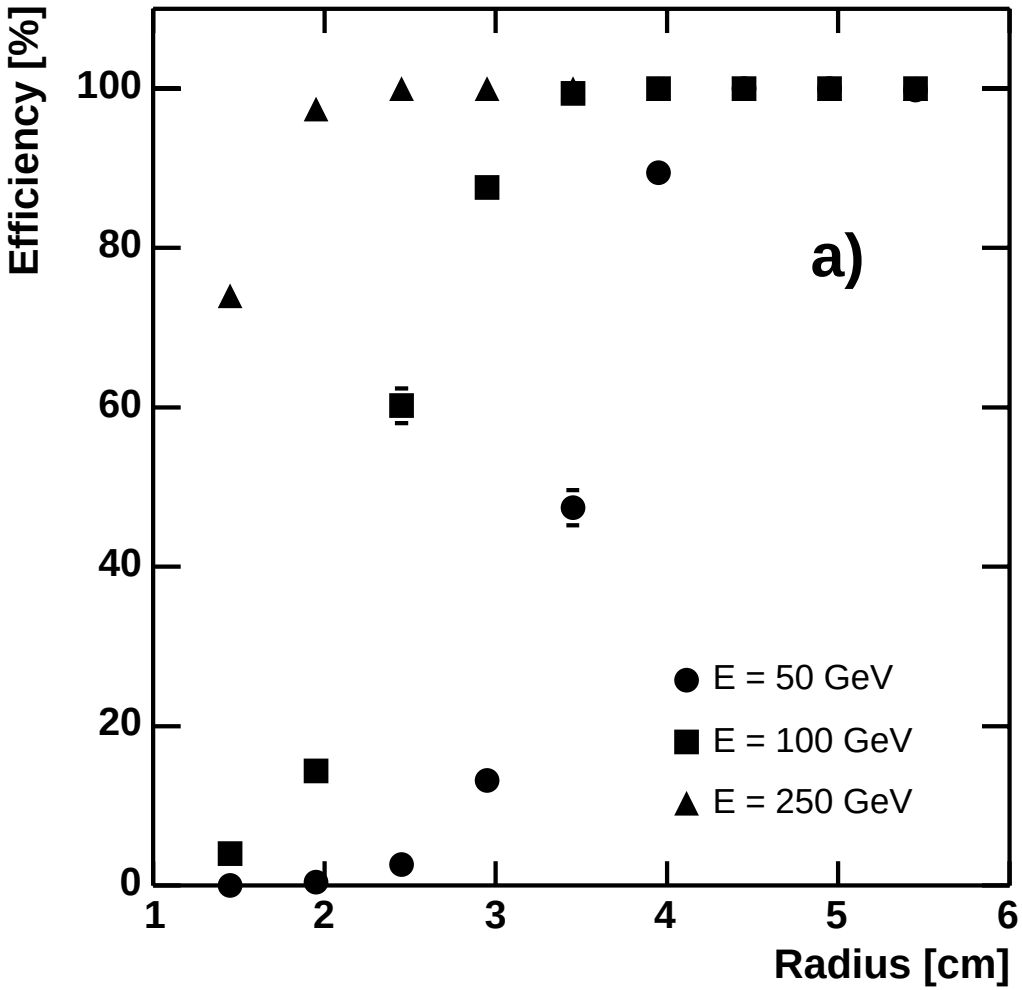


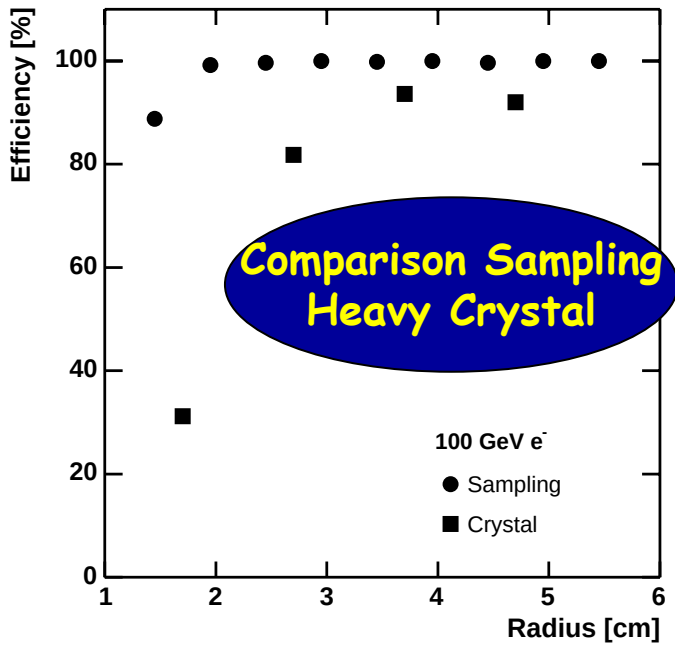
Quantity	Nominal Value	Precision
σx	553 nm	4.2 nm
σz	300 μm	7.5 μm
Δy	0	0.2 nm

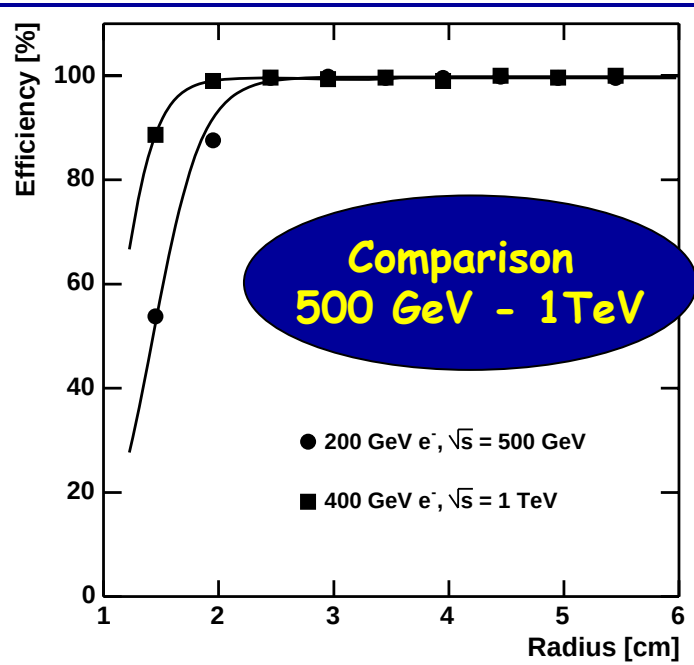
•Detection of High Energy Electrons and Photons

√s = 500 GeV

Single Electrons of 50, 100 and 250 GeV





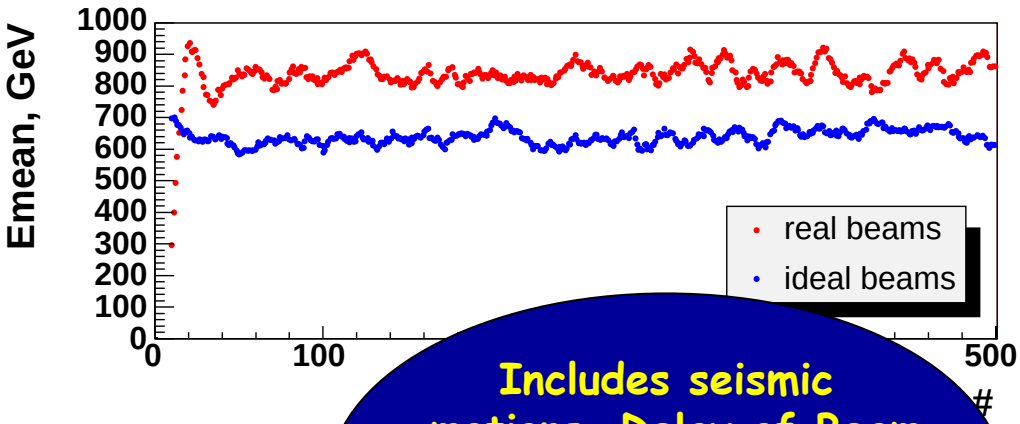


Realistic beam simulation

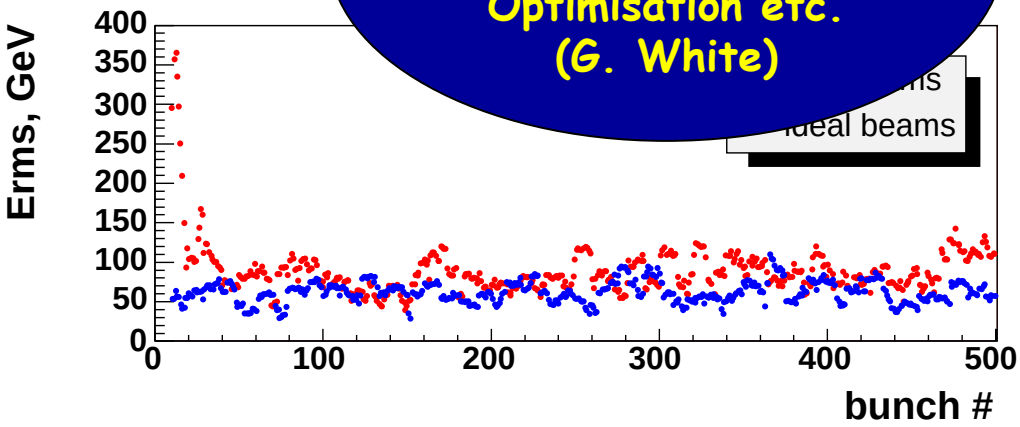
$\sqrt{s}$ = 500 GeV

Efficiency to identify energetic electrons and photons (E > 200 GeV)

mean energy in particular cell (high BG near BP)

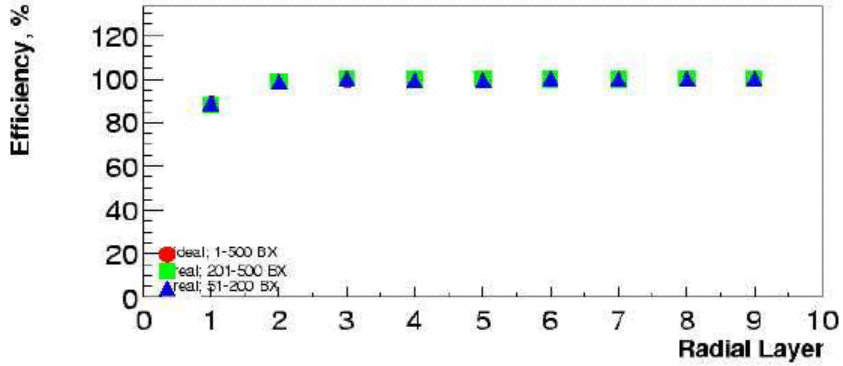


energy RMS in p

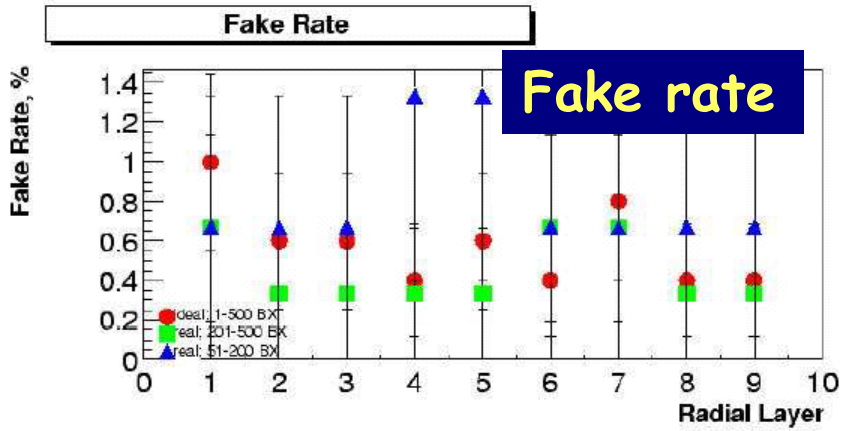


Includes seismic motions, Delay of Beam Feedback System, Lumi Optimisation etc. (G. White)

Efficiency



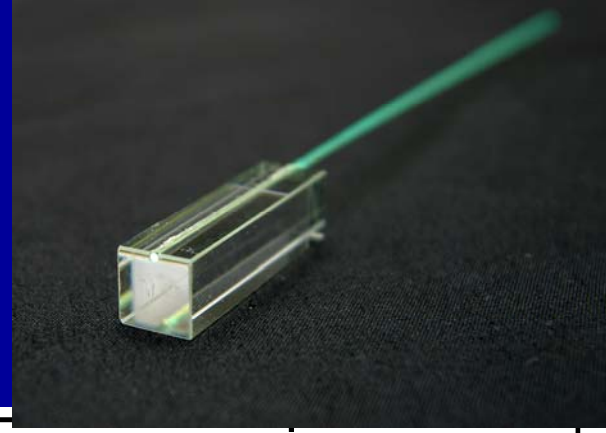
Fake Rate



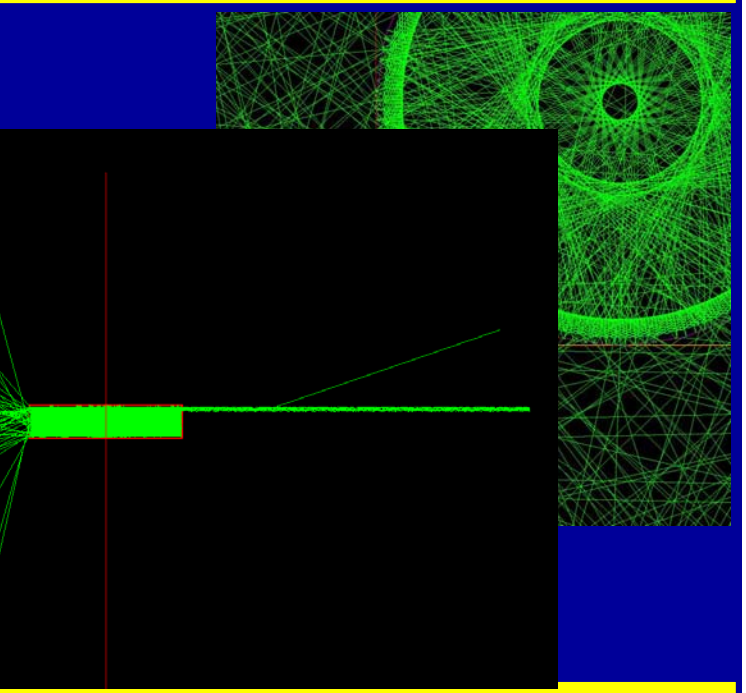
Fake rate

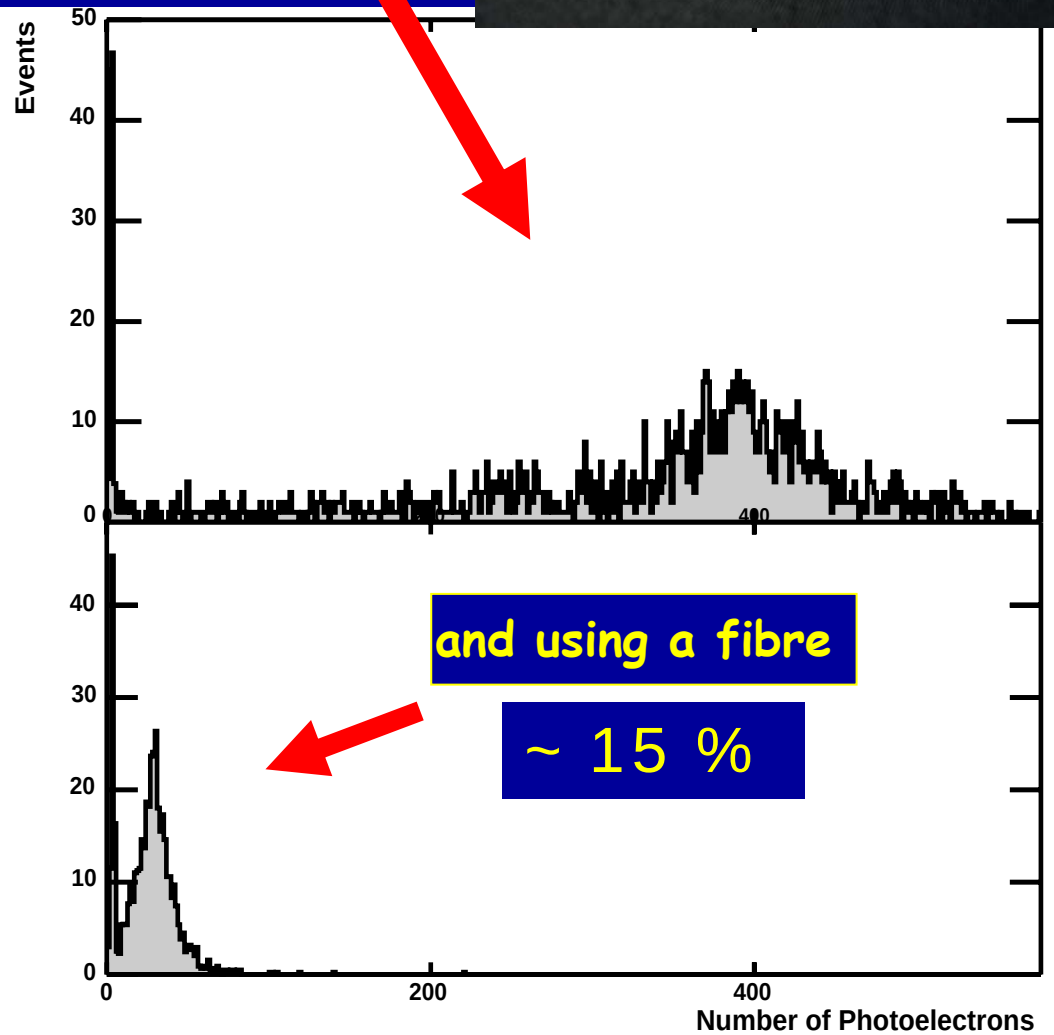
Sensor prototyping, Crystals

Light Yield from direct coupling



Compared with GEANT4 Simulation, good agreement



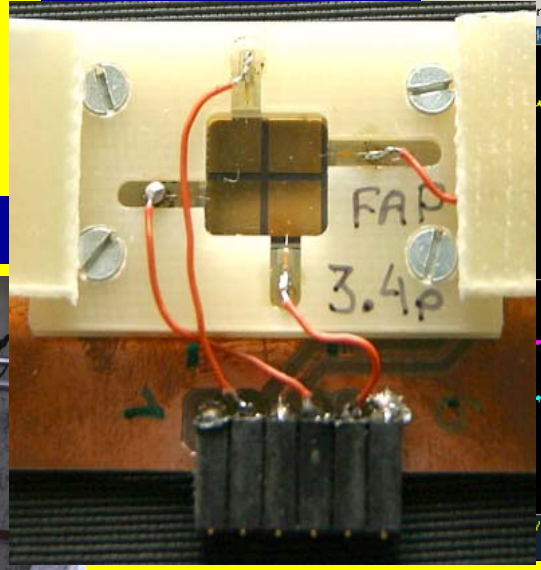


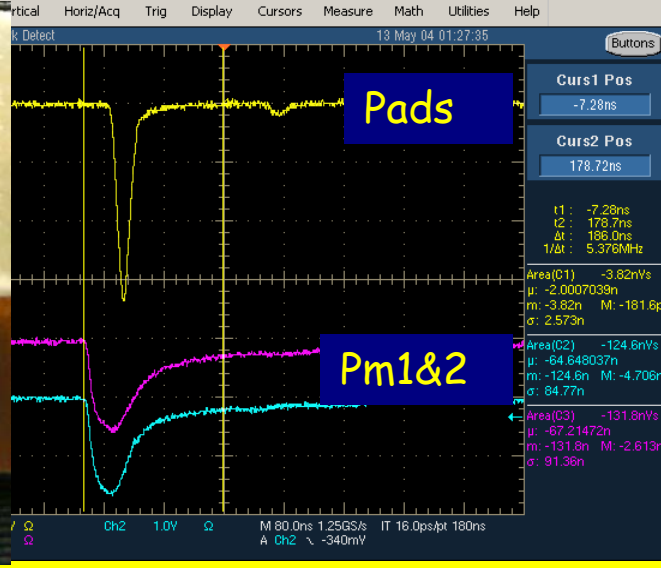
and using a fibre

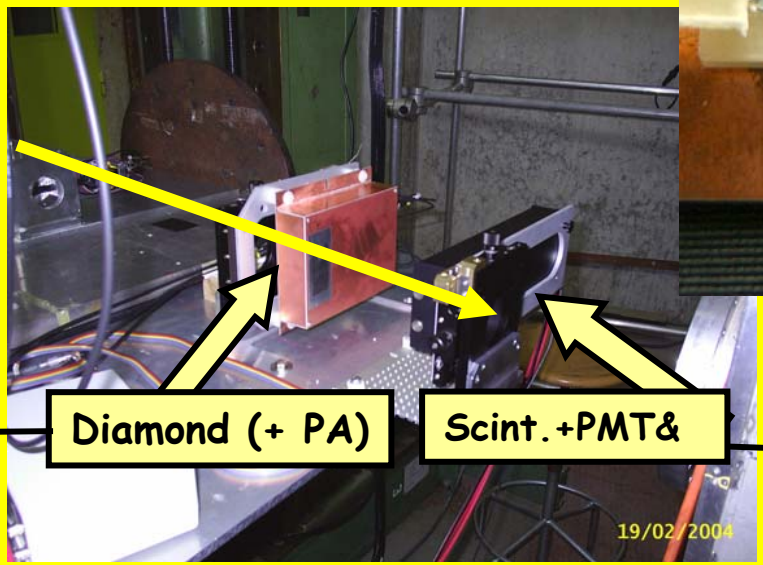
~ 15 %

Similar results for lead glass Crystals (Cerenkov light !)

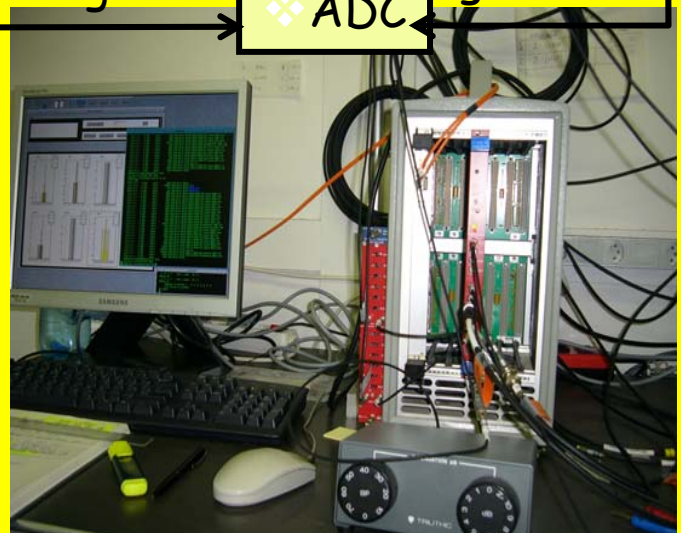
Sensor prototyping, Diamonds







signal ADC gate



May,August/2004 test beams

CERN PS Hadron beam – 3,5 GeV

2 operation modes:

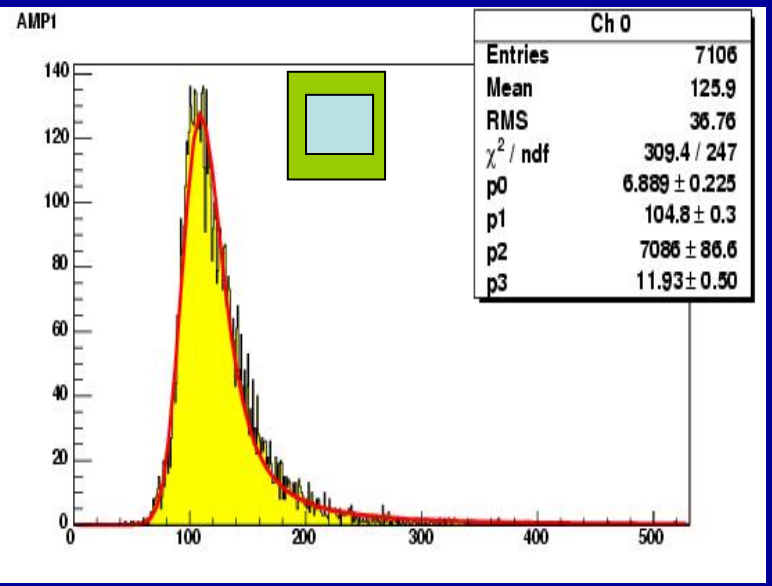
- Slow extraction ~10^{5}-10^{6} / s
- fast extraction ~10^{5}-10^{7} / ~10ns (Wide range intensities)

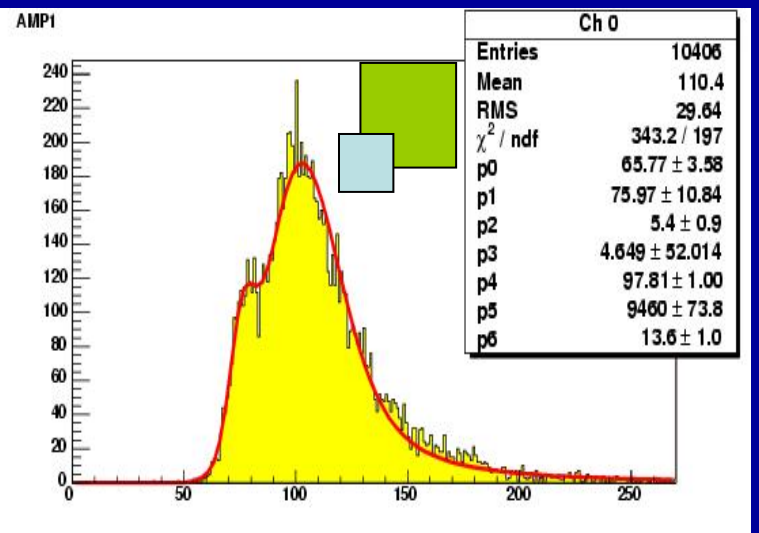
Diamond samples (CVD):

- Freiburg
- GPI (Moscow)
- Element6

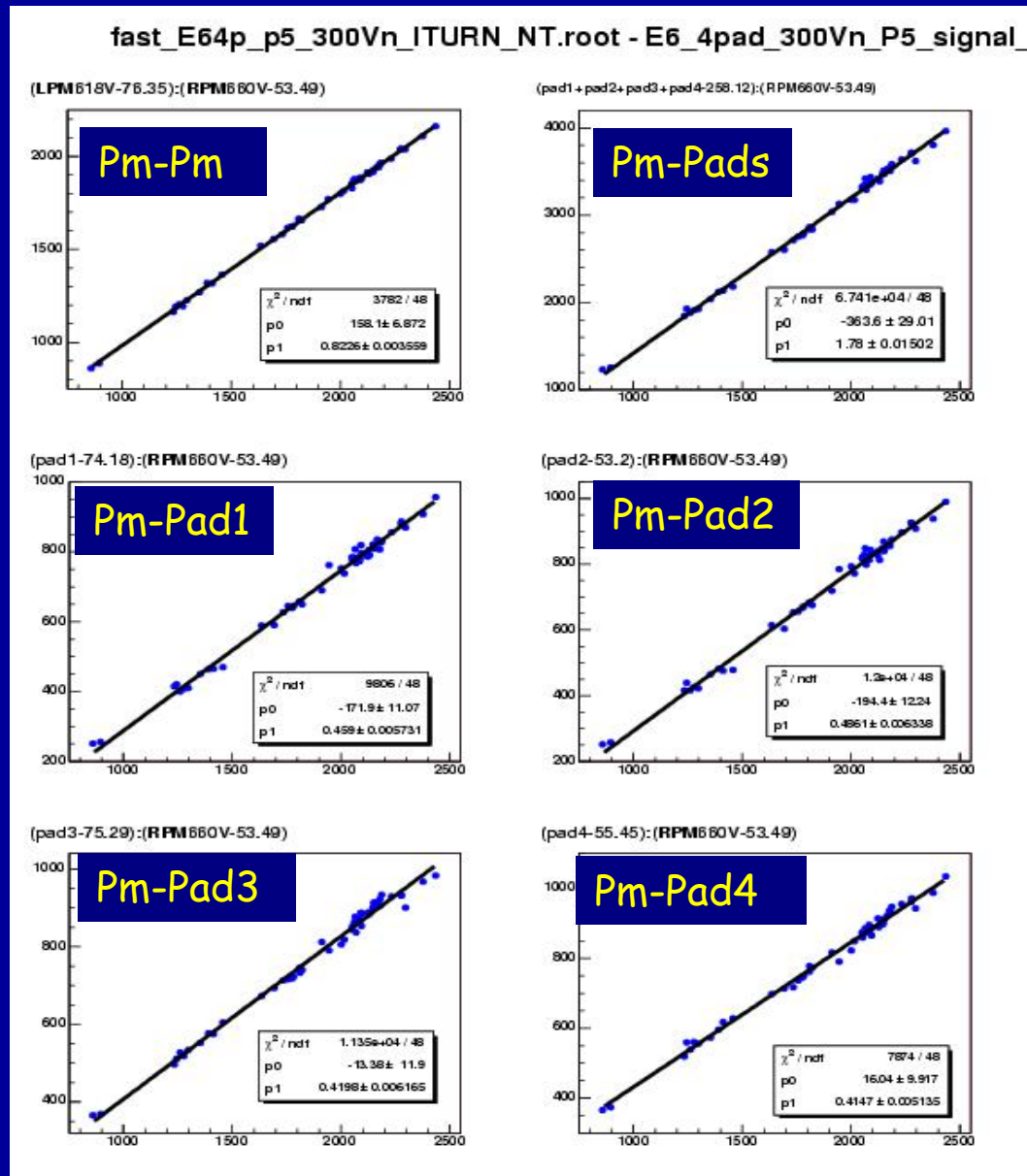
Diamond Sensor Performance

Response to mip

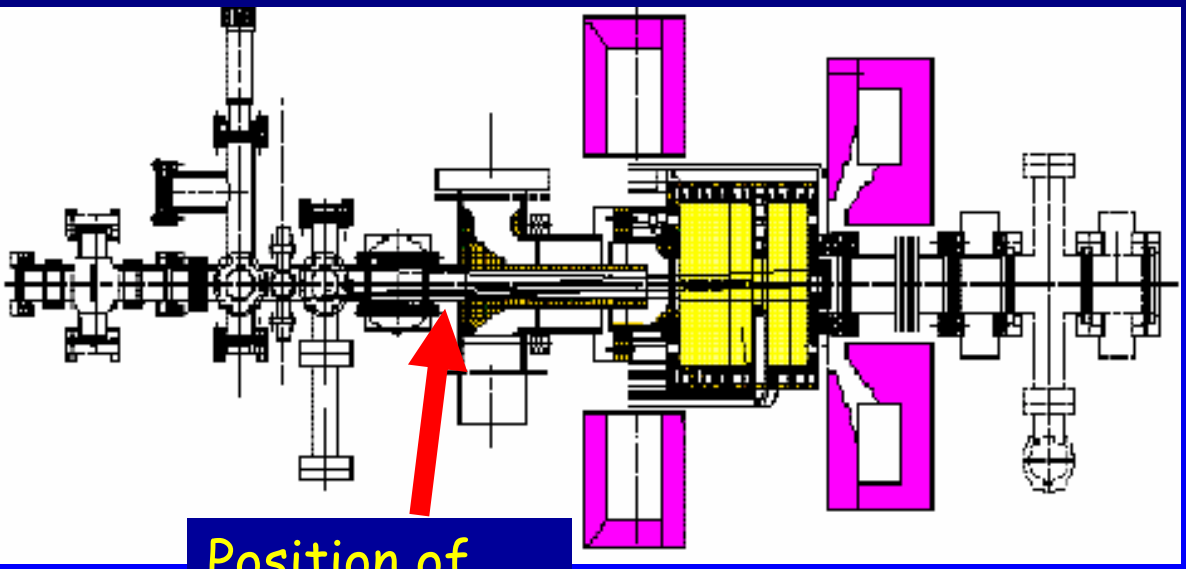




Linearity Studies with High Intensities



Application as beam halo monitor

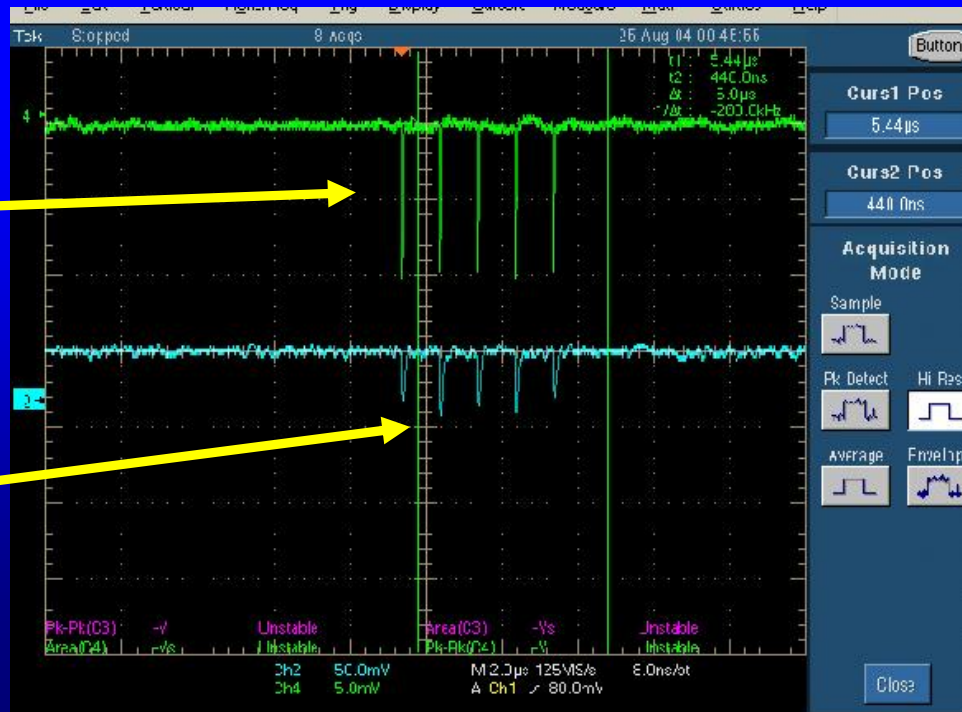


PITZ Facility at Zeuthen

Position of the Diamond

Laser Reference Pulse

Diamond Response (on top of dark current)

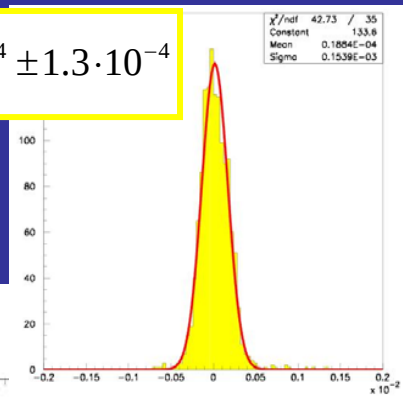


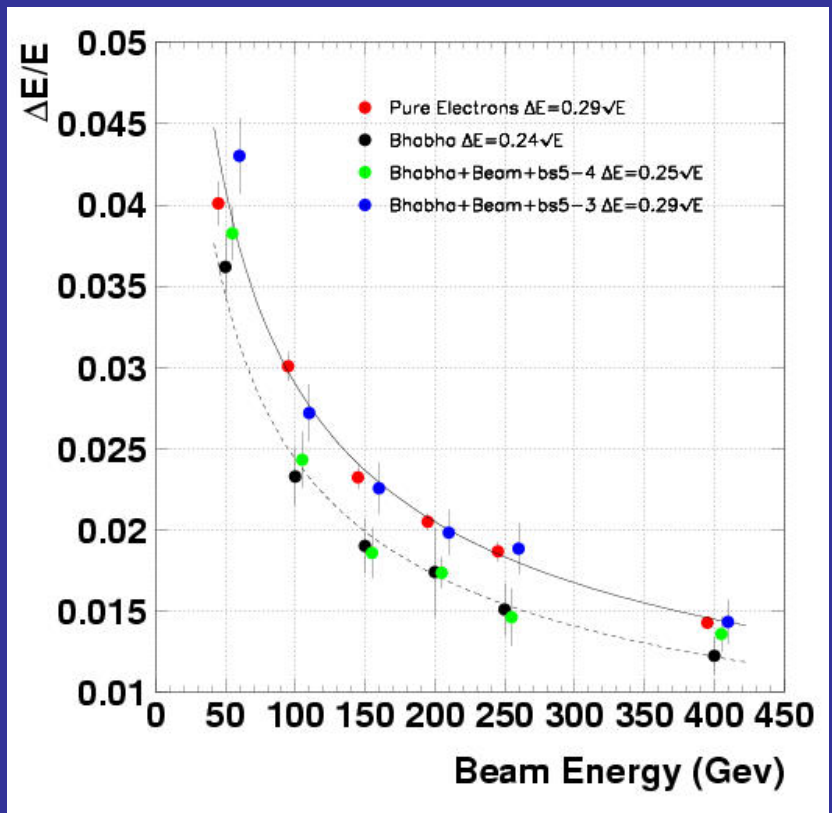
Summary

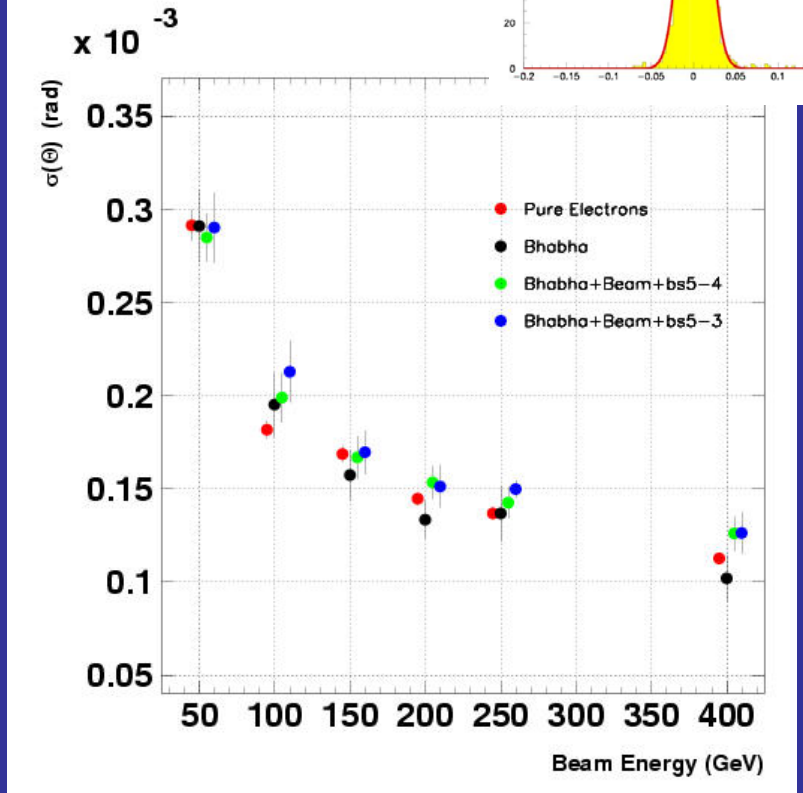
- We learned a lot ……
- We are motivated to continue
- LumiCal: More detailed Monte Carlo Studies on the bias in θ, Acceptance boundaries, two photon background;
  Mechanics Support, Laser Alignment, Sensors
  → Prototype in 3 years.
- BeamCal: MC to reduce segmentation, not performance, beam diagnostics;
  Feasibility Study for Large Area Diamond Sensors (Coll. with IAF) → Preparation of a Prototype
- PhotoCal: We are just at the beginning….

Energy and polar angle resolution, pad version

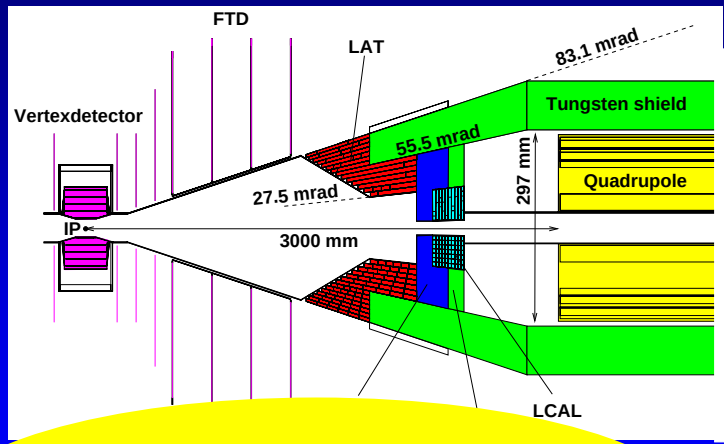
$$\frac{\Delta\theta}{\theta} = 5.7 \cdot 10^{-4} \pm 1.3 \cdot 10^{-4}$$

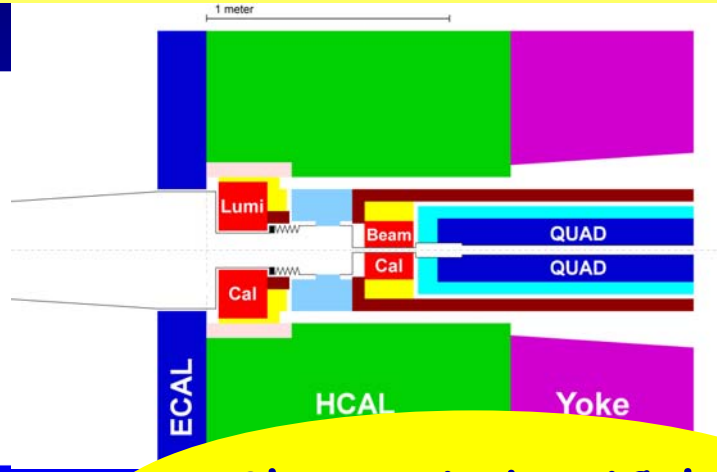






Shower LEAKAGE in old (TDR) and new LumiCal design

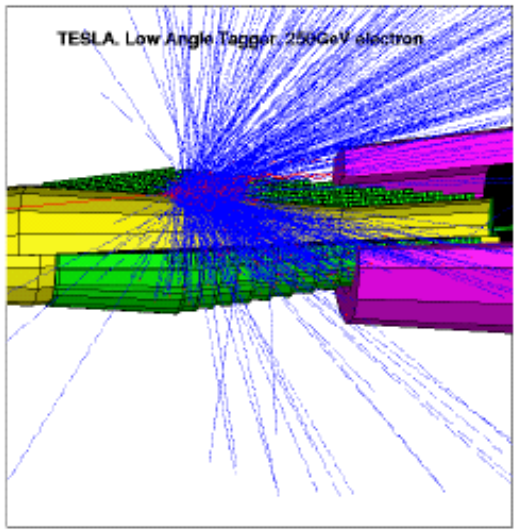




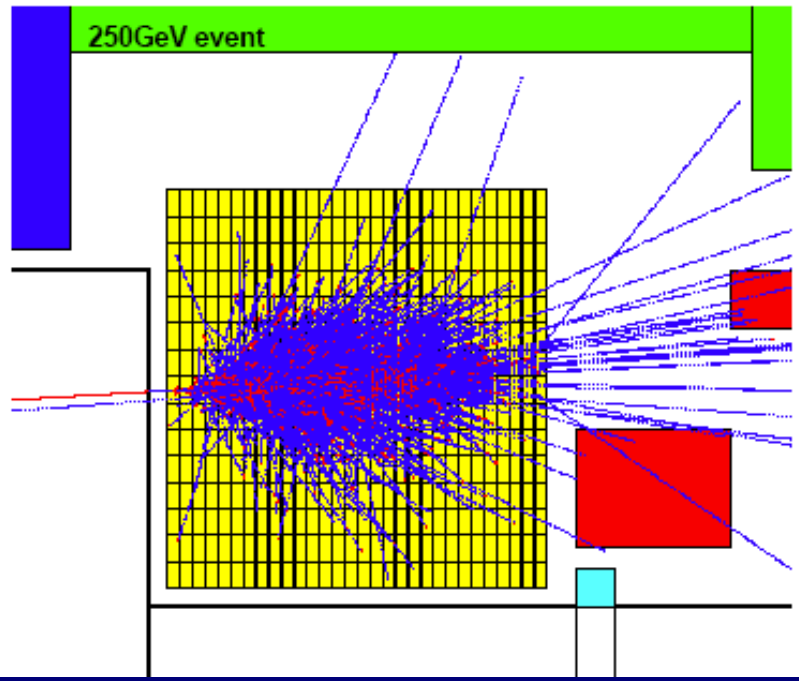
Shower in LAT (TDR design)

Shower in LumiCal (new design)

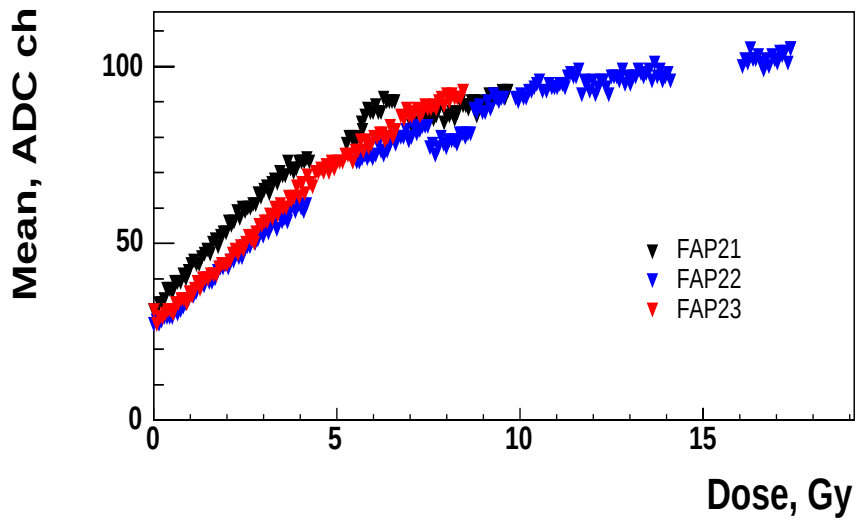
LAT shower example



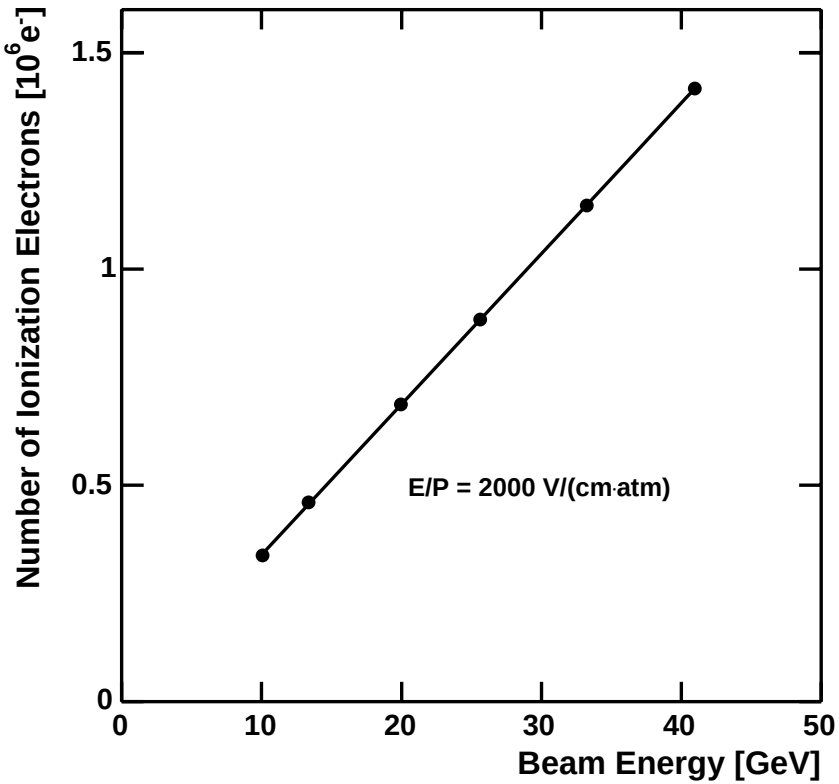
Only photons (blue) and electrons (red) over 5 MeV are displayed



Diamond performance as function of the absorbed dose



Linearity of a heavy gas calorimeter (IHEP testbeam)



Pile up effects

200 GeV Electrons Efficiency less then 90%