Instrumentation of the very Forward Region of a Linear Collider Detector

Wolfgang Lohmann

DESY (Zeuthen)

- Report from the FCAL workshop in Prague (April 16)
- Some results from SLAC (N. Graf and T Maruyama)

The very Forward Calorimeter Collaboration

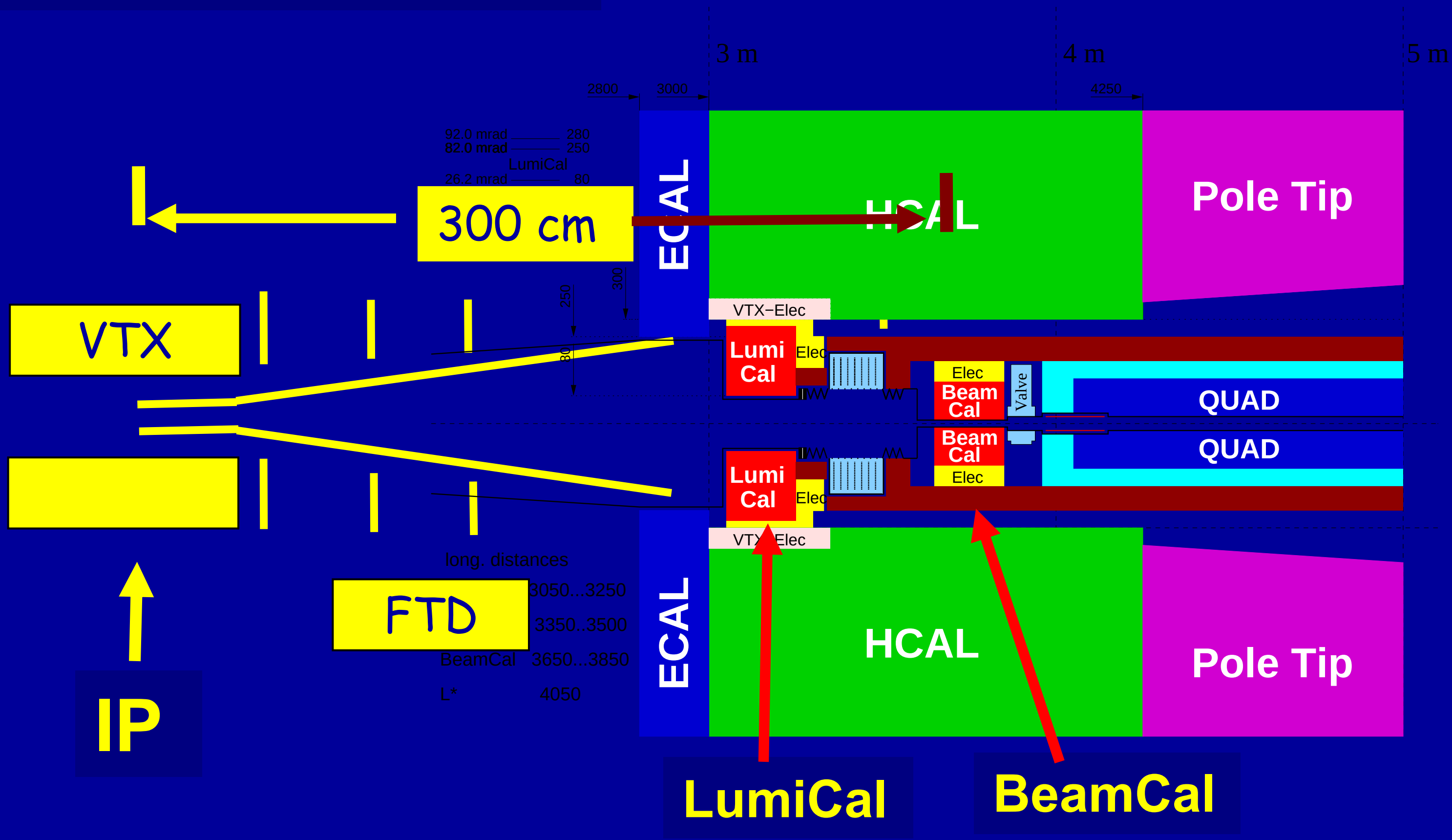
Recent meeting in Prague, April 16.

see: PRC R&D 01/02

Functions of the very Forward Detectors

- Measurement of the Luminosity (LumiCal)
- Fast Beam Diagnostics (BeamCal)
- Shielding of the inner Detector
- Detection of Electrons and Photons at very low angle – extend hermiticity

L* = 3m



• Measurement of the Luminosity

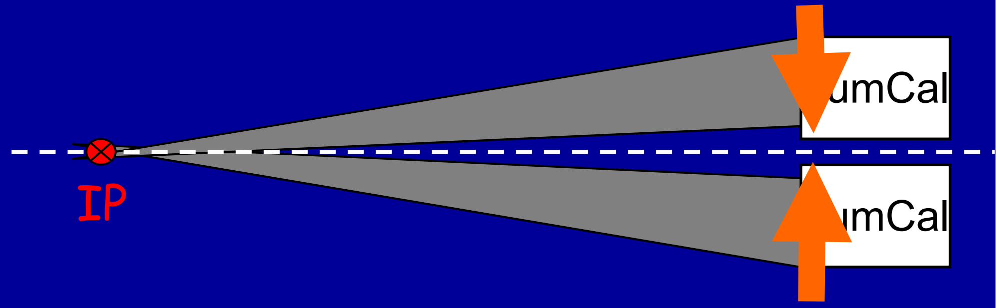
Gauge Process: $e^+e^- \longrightarrow e^+e^- (\gamma)$

Goal: 10^{-4} **Precision** (LEP: $3.4 \otimes 10^{-4}$ exp.; $5.4 \otimes 10^{-4}$ theor.)

Physics Case: σ_Z for Giga-Z , Two Fermion Cross Sections at high Energy, Threshold Scans

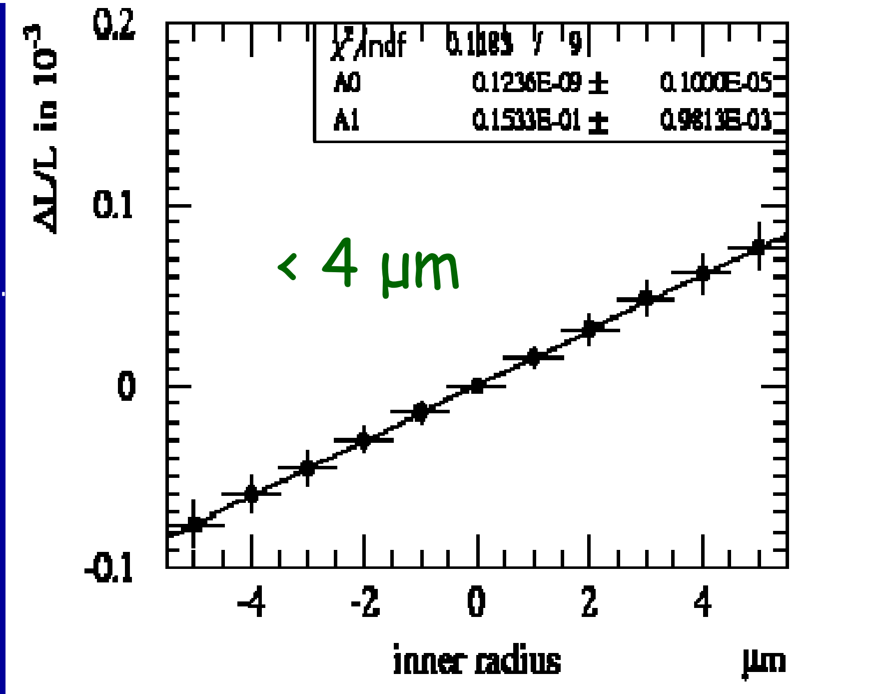
- **Technology: Si-W Sandwich Calorimeter**
- **MC Simulations** → Optimisation of shape and segmantation
- **Alignment with Laser Beams**
- **Close contacts to Theorists (Cracow, DESY)**

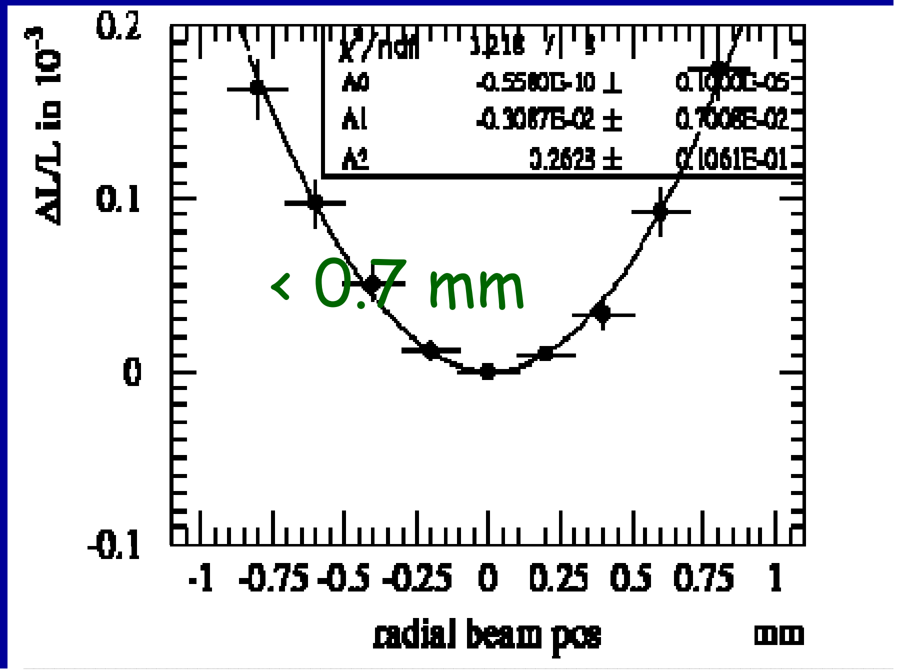
•Measurement of the Luminosity



Requirements on Alignment and mechanical Precision (rough Estimate)

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





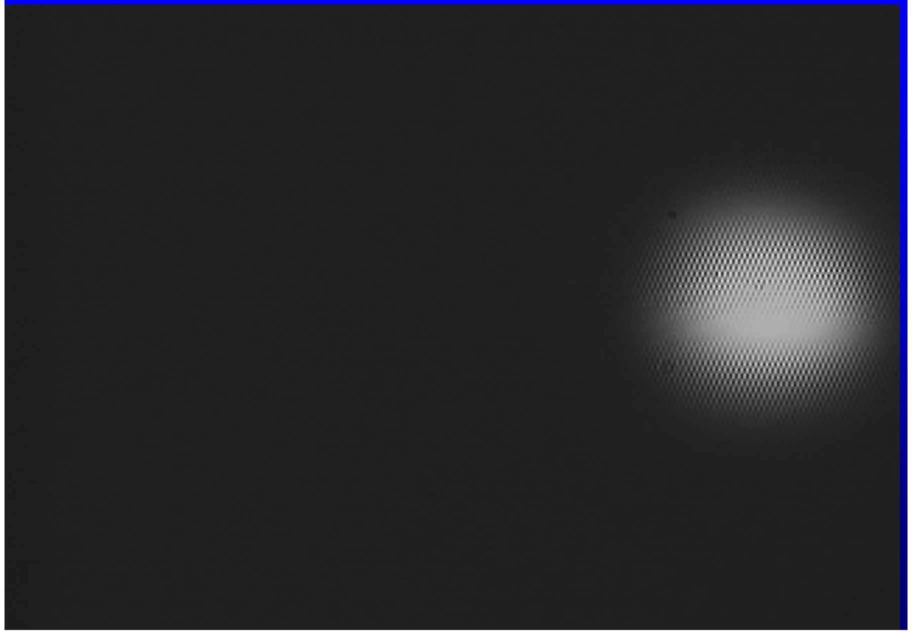
•Measurement of the Luminosity

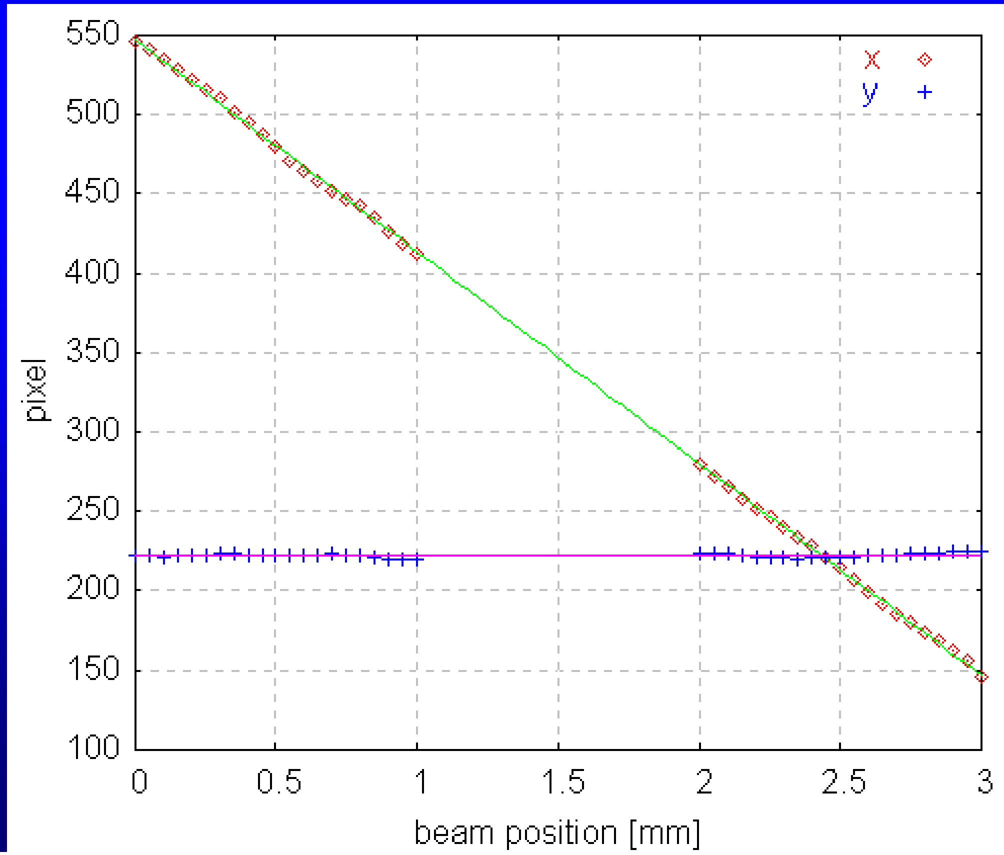
Laser Alignment System

Jagiellonian Univ. Cracow
Photonics Group

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

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





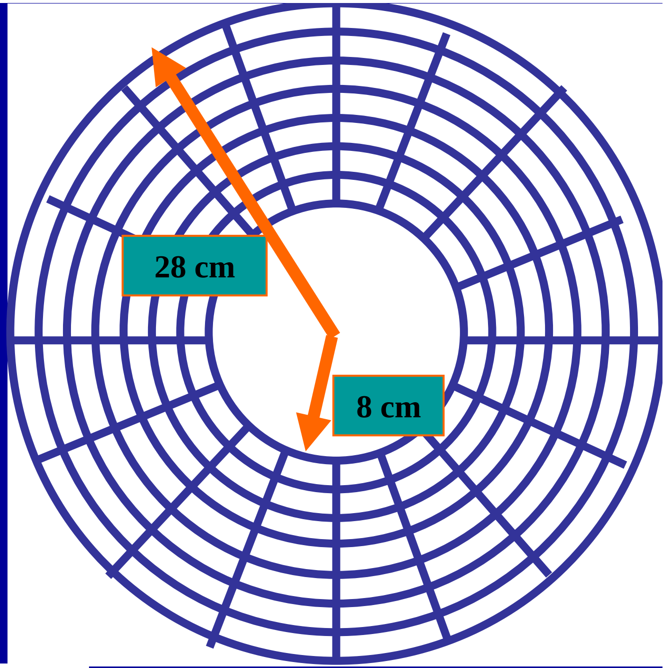
•Measurement of the Luminosity

$e^+e^- \longrightarrow e^+e^- (\gamma)$ Simulations with BHWIDE

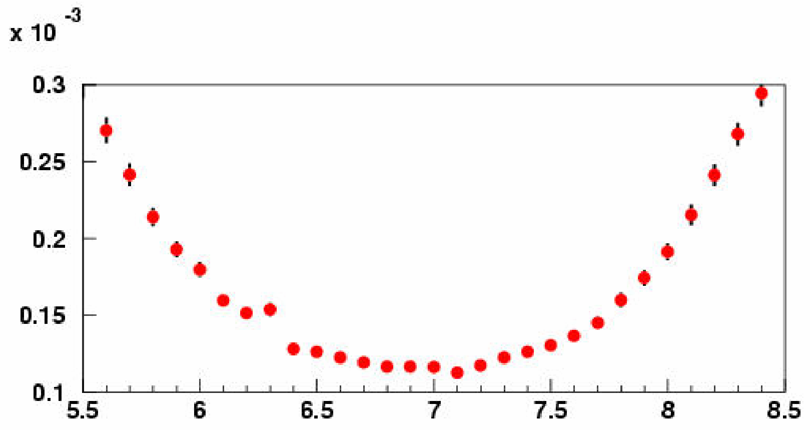
15 cylinders * 24 sectors * 30 rings = 10800 cells

$$< X >= \frac{\sum X_i W_i}{\sum W_i}$$

$$W_i = \max\{0, [const(E_{beam}) + \ln(\frac{E_i}{E_T})]\}$$

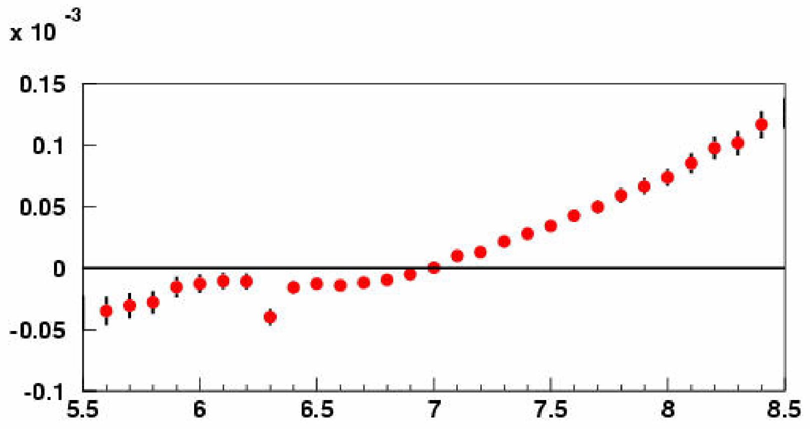


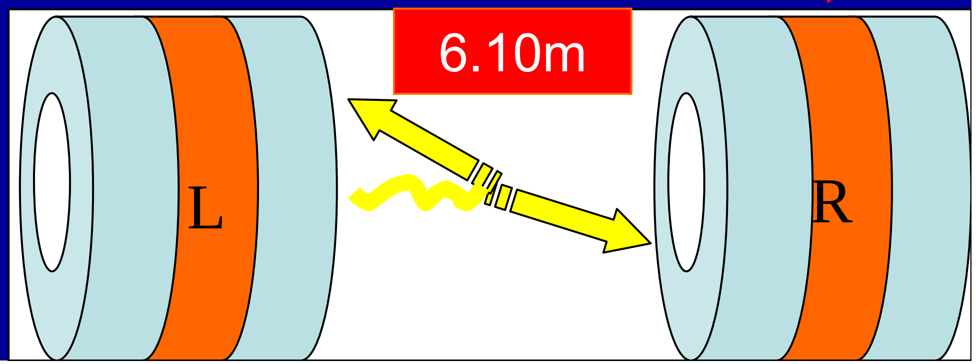
$\sigma(\theta)(rad)$



Rings

$\theta_{rec} - \theta_{gen} (rad)$

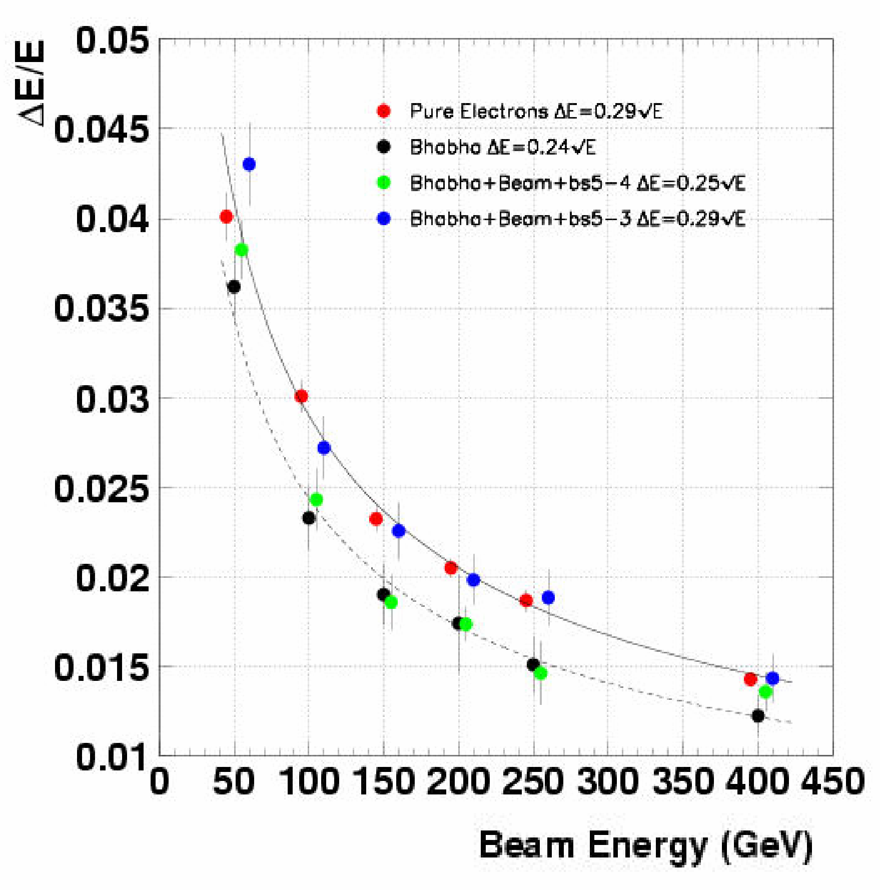


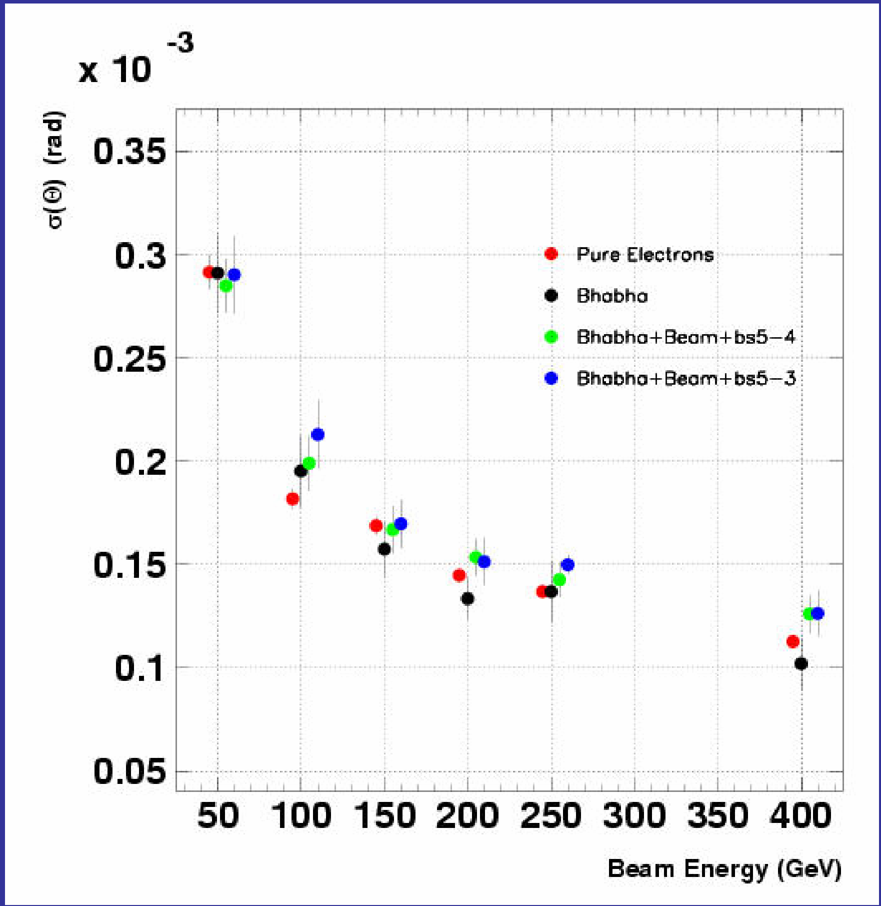


Energy and Angular resolution

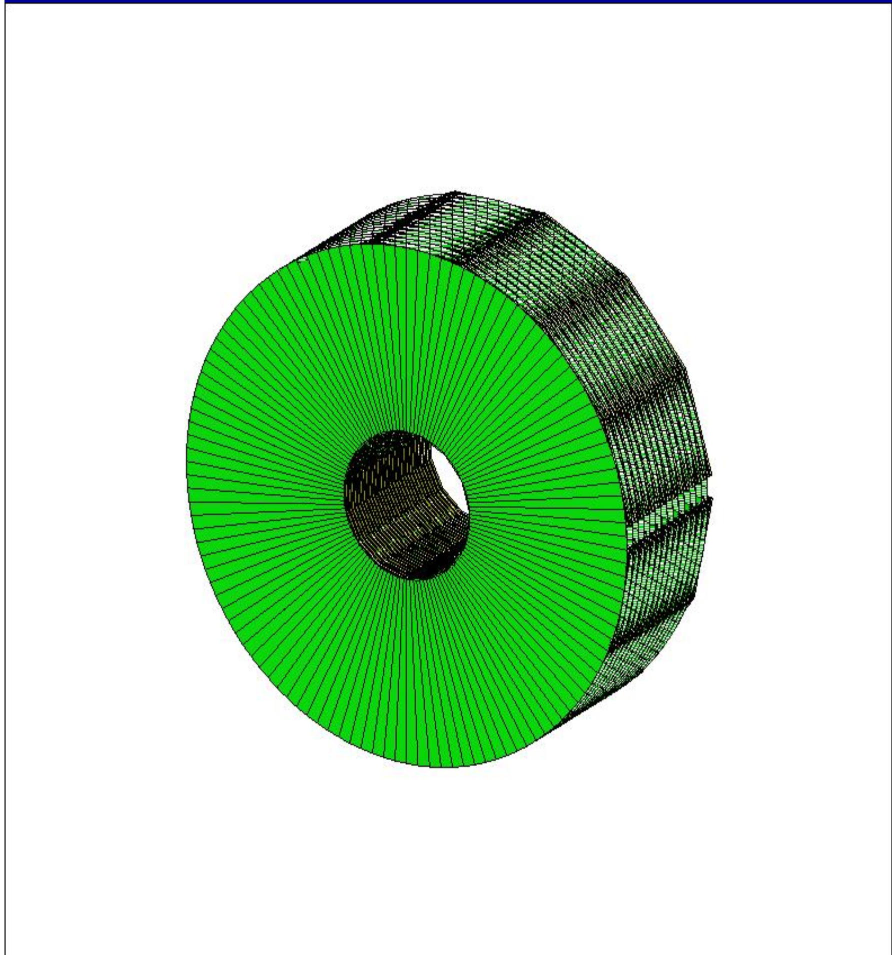
Simulation: Bhwide(Bhabha)+CIRCE(Beamstrahlung)+beamspred

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

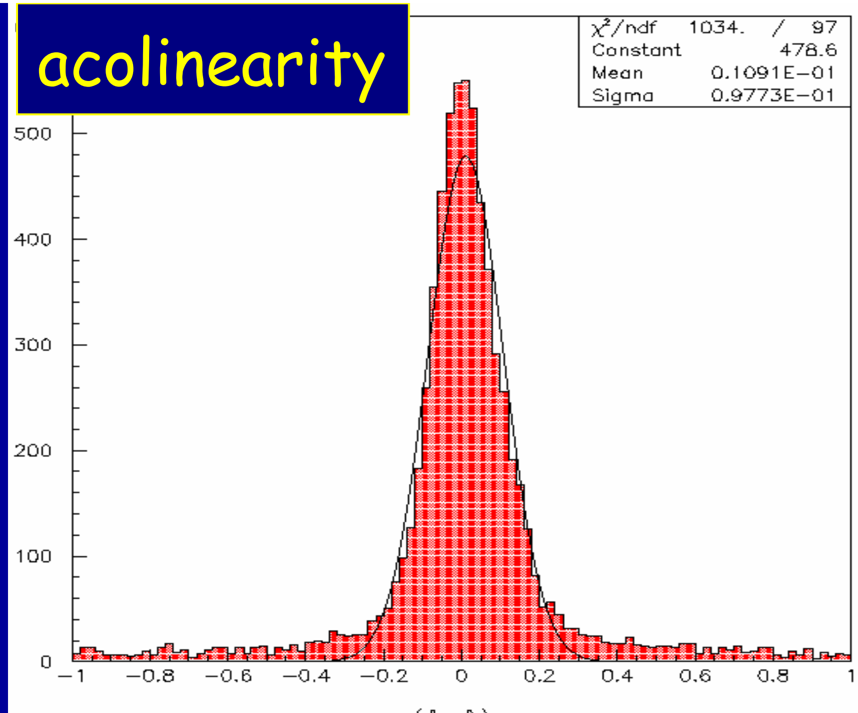




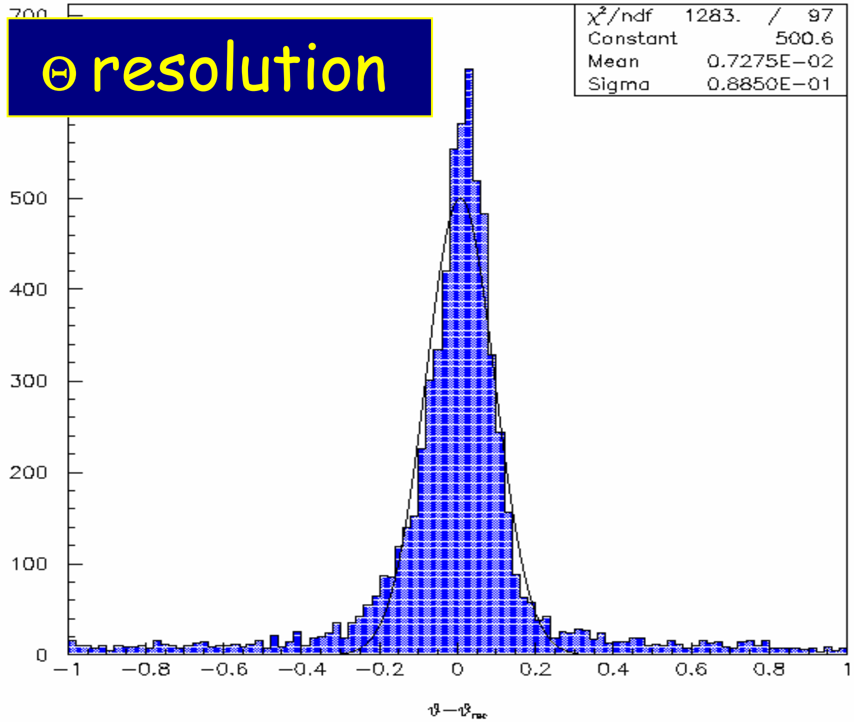
Stripped LumiCal



acolinearity

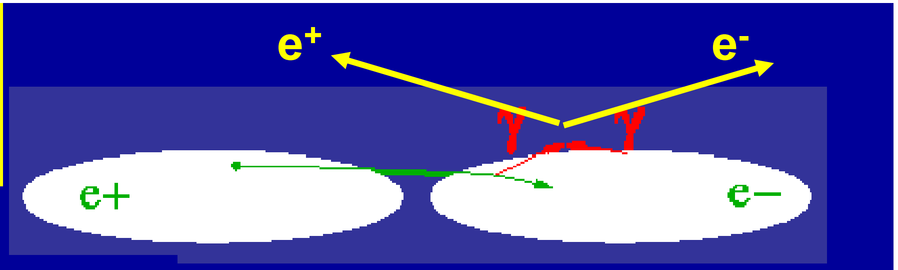


Θ resolution

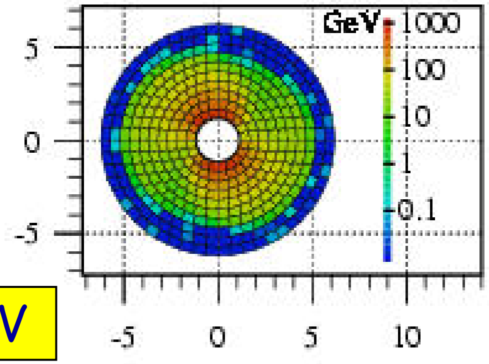


Some systematics in Θ Reconstruction !

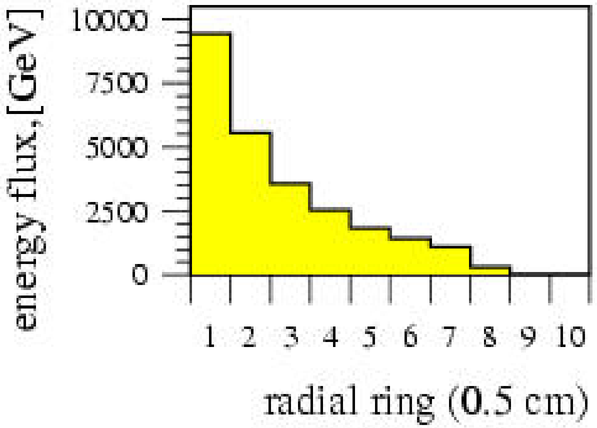
•Fast Beam Diagnostics (BeamCal)



- e^+e^- pairs from beamstrahlung are deflected into the LCAL
- 15000 e^+e^- per BX ⟶ 10 – 20 TeV
- 10 MGy per year ⟶ Rad. hard sensors



GeV



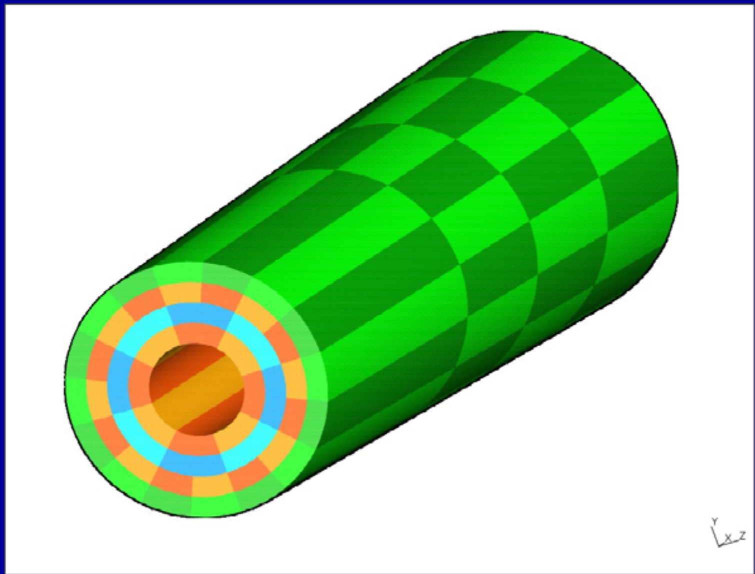
Technologies: Diamond-W Sandwich

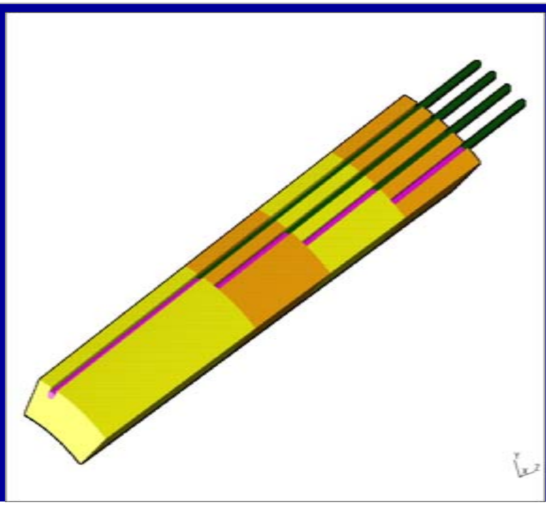
Scintillator crystals

Gas ionisation chamber

Schematic views

Heavy crystals

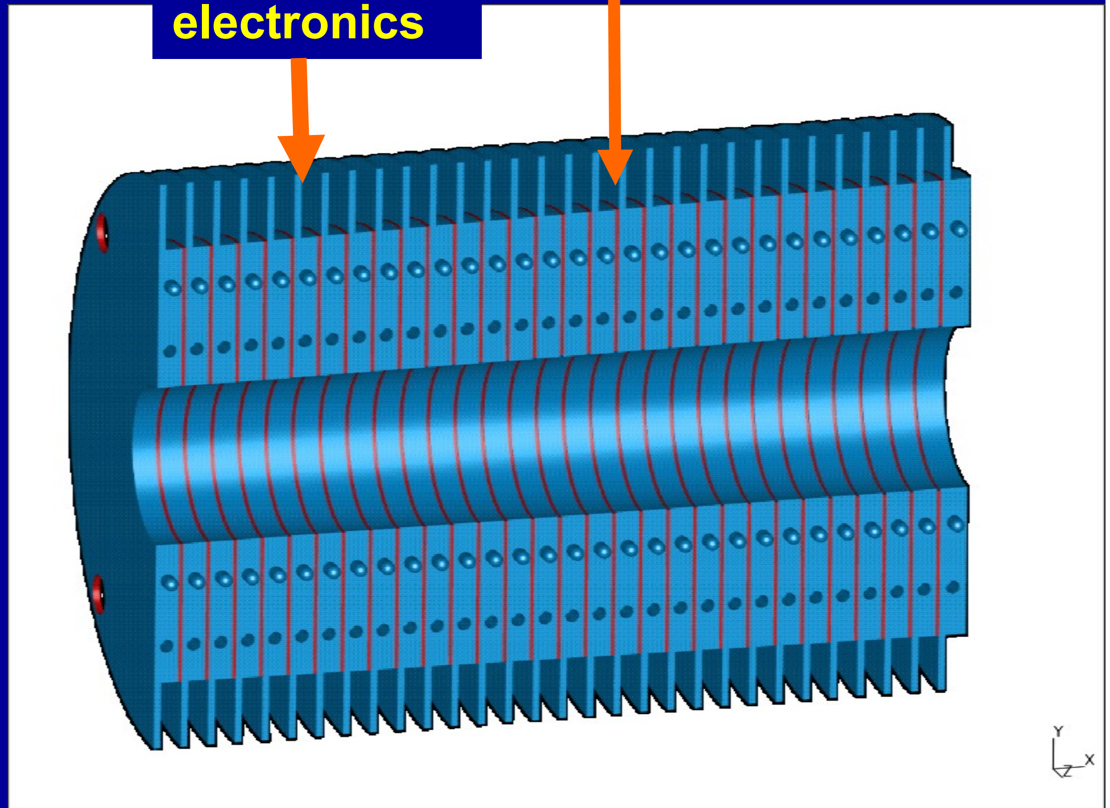




W-Diamond sandwich

Space for electronics

sensor

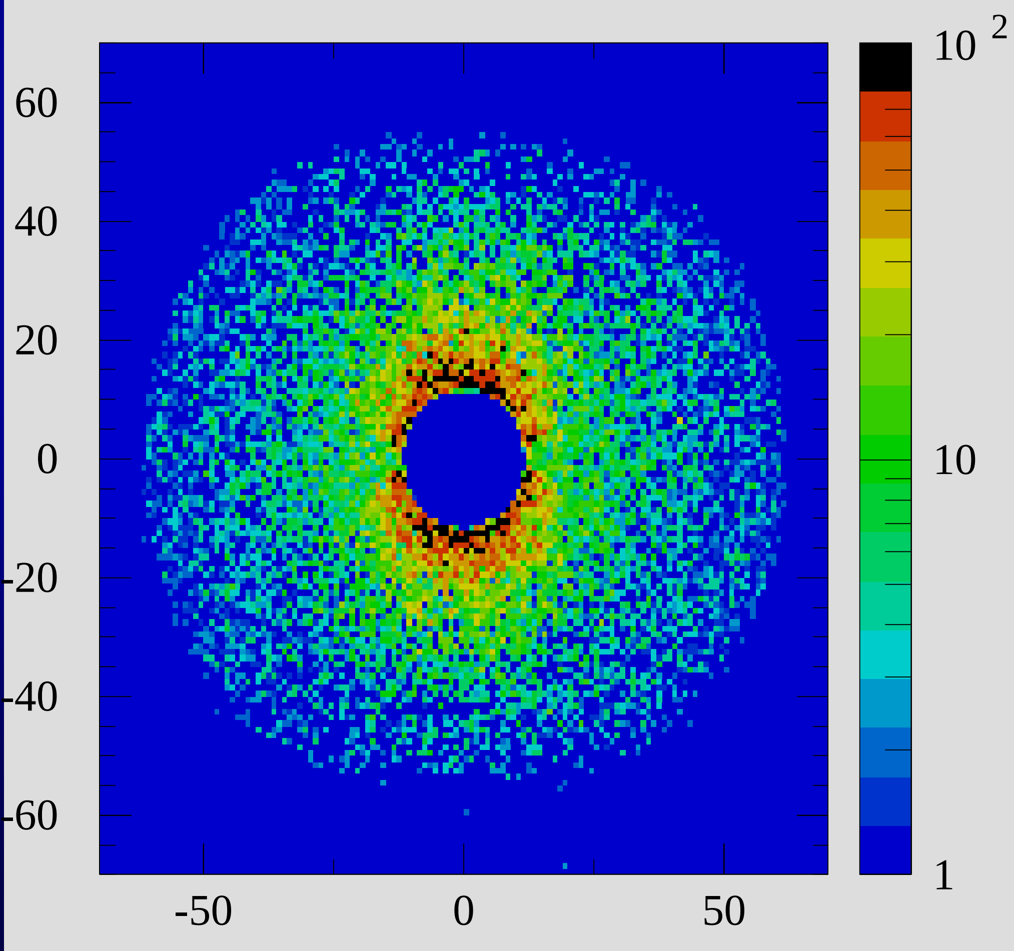


•Fast Beam Diagnostics (BeamCal)

Observables

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

- first radial moment
- first moment in 1/r
- thrust value
- total energy
- angular spread
- E(ring ≥ 4) / E_{tot}
- (A + D) – (B + C)
- (A + B) – (C + D)
- E / N



forward / backward calorimeter

• Fast Beam Diagnostics (BeamCal)

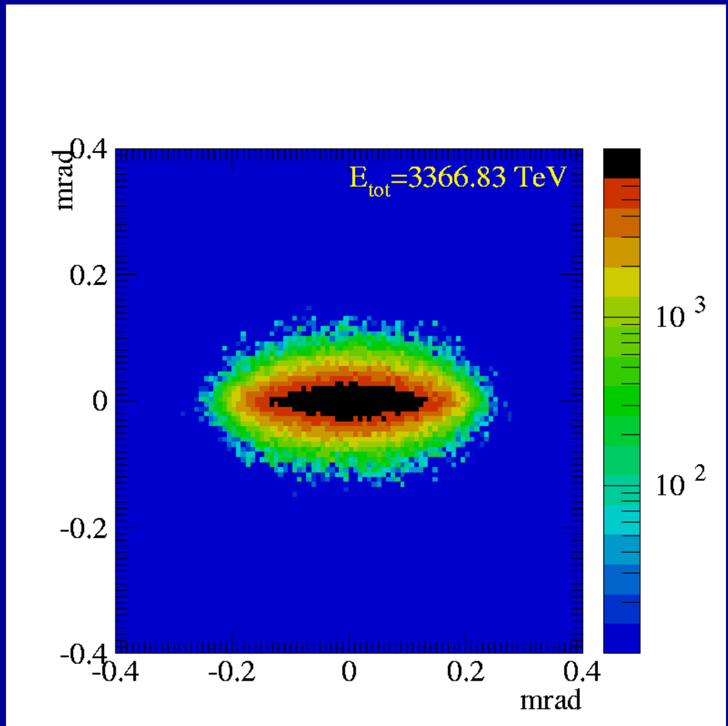
detector: realistic segmentation, ideal resolution
single parameter analysis, bunch by bunch resolution

	nominal	uncertainty.	Beam Diag.
Bunch width x Ave. Diff.	553 nm	1.5 2.1	~ 10 % ~ 10 %
Bunch width y Ave. Diff.	5.0 nm	0.2 0.5	Shintake Monitor
Bunch length z Ave. Diff.	300 µm	4.3 2.7	~ 10 % ~ 10 %
Emittance in x Ave. Diff.	10.0 mm mrad	--- 0.7	? ?
Emittance in y Ave. Diff.	0.03 mm mrad	0.001 0.002	? ?
Beam offset in x Beam offset in y	0 0	6 0.4	5 nm 0.1 nm
Horizontal waist shift Vertical waist shift	0 µm 360 µm	--- 24	None None

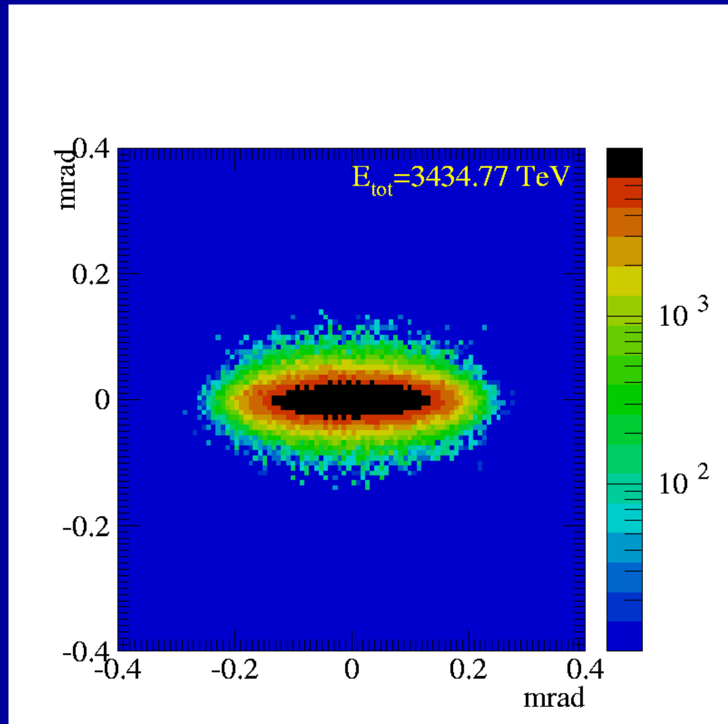
Multi Parameter Analysis

σ_x	$\Delta\sigma_x$	σ_y	$\Delta\sigma_y$	σ_z	$\Delta\sigma_z$
0.3 %	0.4 %	3.4 %	9.5 %	1.4 %	0.8 %
0.3 %	0.4 %	3.5 %	11 %	1.5 %	0.9 %
0.9 %	1.0 %	11 %	24 %		
		5.7 %	24 %	1.6 %	1.9 %
1.8 %	1.1 %	16 %	27 %	3.2 %	2.1 %

First Look at Photons



nominal setting
(550 nm x 5 nm)



σ_x = 650 nm
σ_y = 30 nm

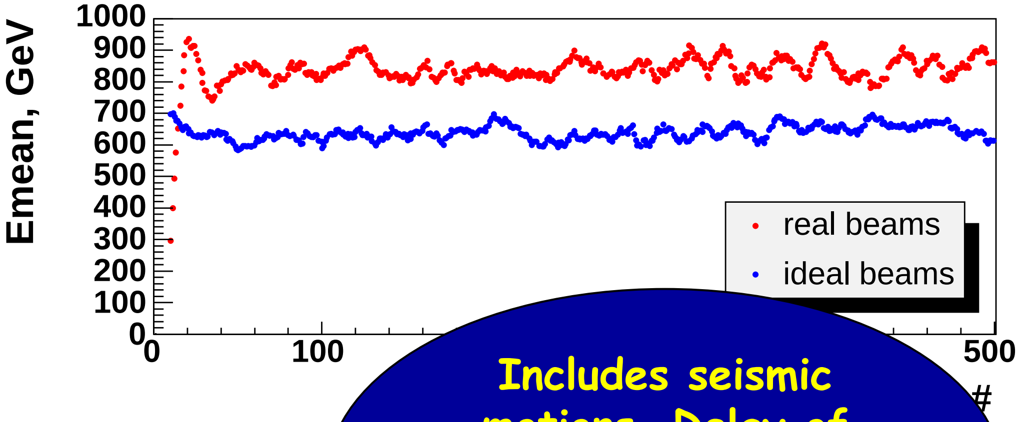
•Detection of Electrons and Photons

Realistic beam simulation

$\sqrt{s}$ = 500 GeV

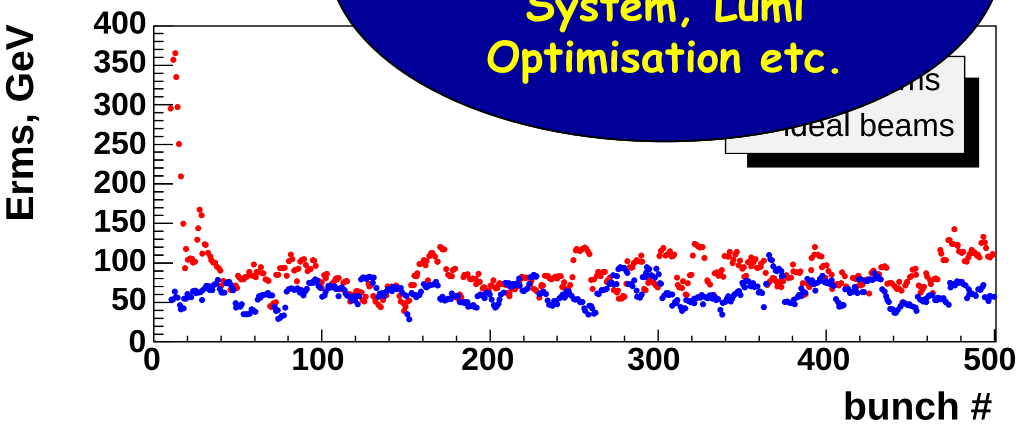
Efficiency to identify energetic electrons and photons (E > 200 GeV)

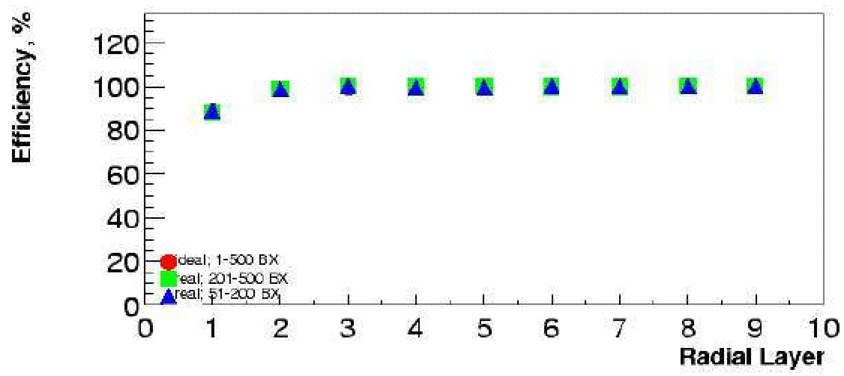
mean energy in particular cell (high BG near BP)



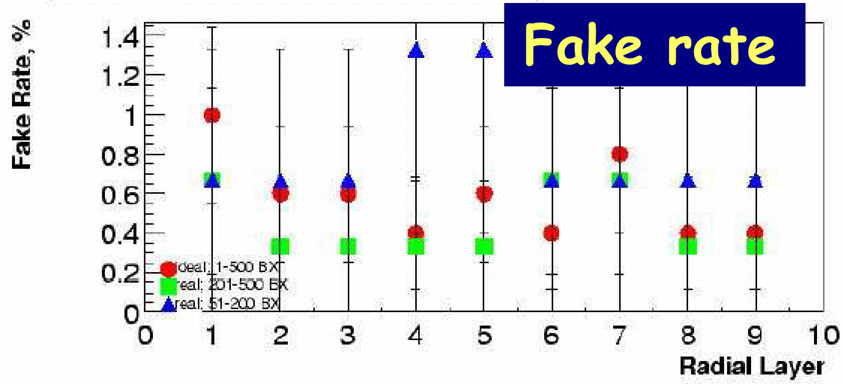
Includes seismic motions, Delay of Beam Feedback System, Lumi Optimisation etc.

energy RMS in p

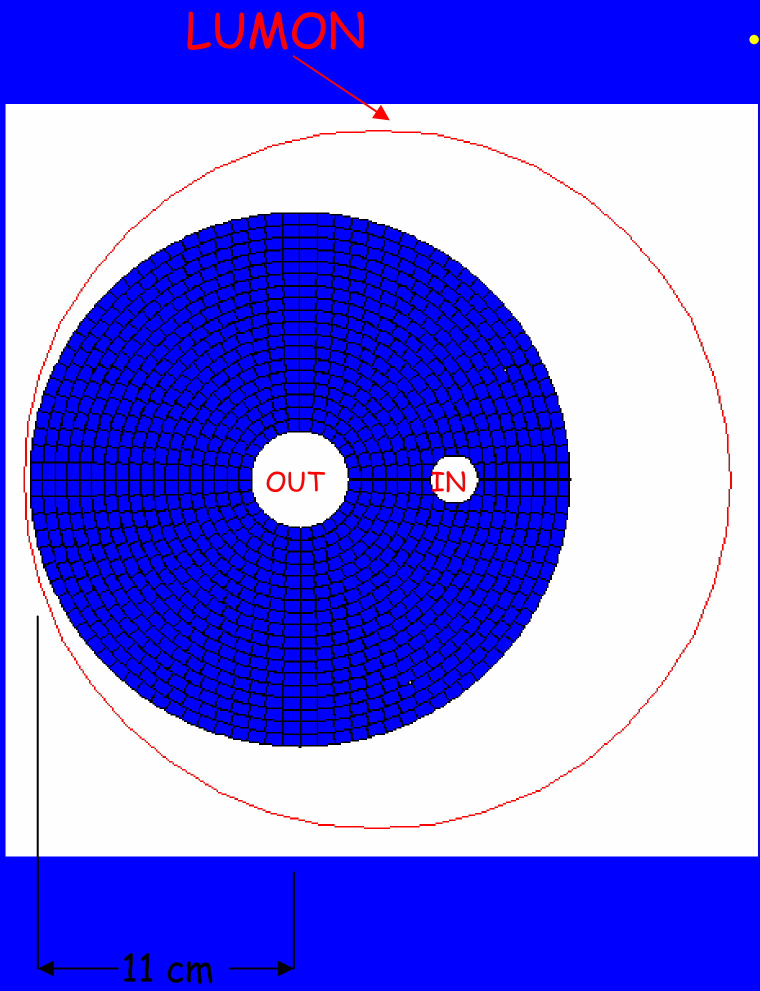




Fake rate



High Energy Electron Detection in NLC LUMON
N. Graf and T. Maruyama (SLAC)

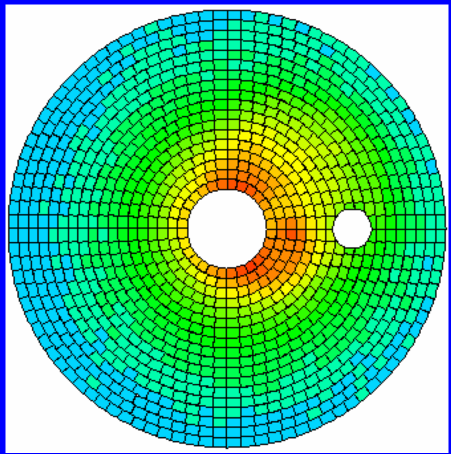


- Beampipe radius: IN 1 cm, OUT 2 cm
- Detector:
  - 50 layers of 0.2 cm W + 0.03 cm Si
  - Zeuthen R-ϕ segmentation

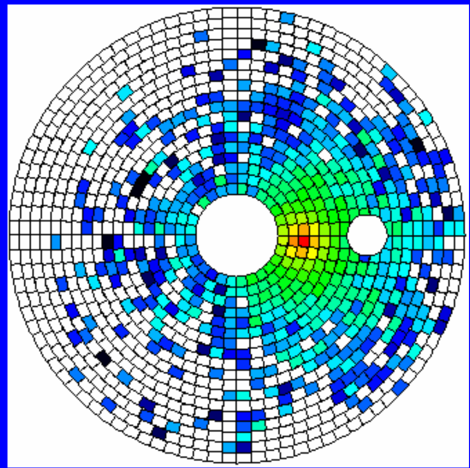
- Generate 330 bunches of pair backgrounds.
- Pick 10 BX randomly and calculate average BG in each cell, $\langle E \rangle_{background}$
- Pick one BX background and generate one high energy electron.
- $E_{BG} + E_{electron} - \langle E \rangle_{background}$, in each cell
- Apply electron finder.

High Energy Electron Detection

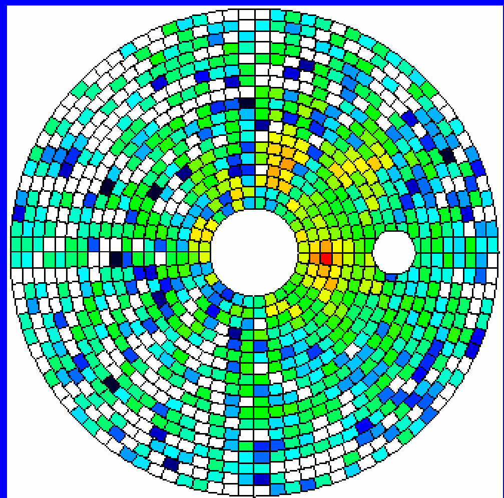
Pair Background

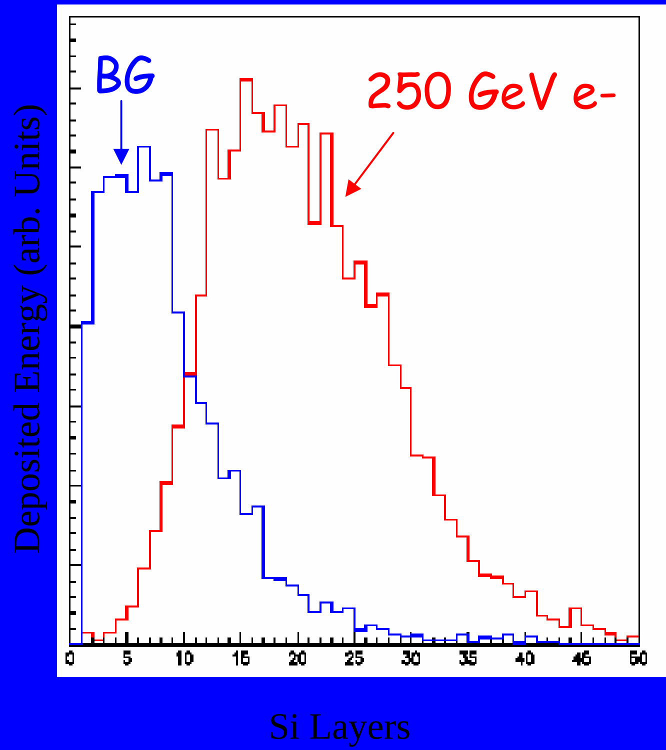


250 GeV Electron



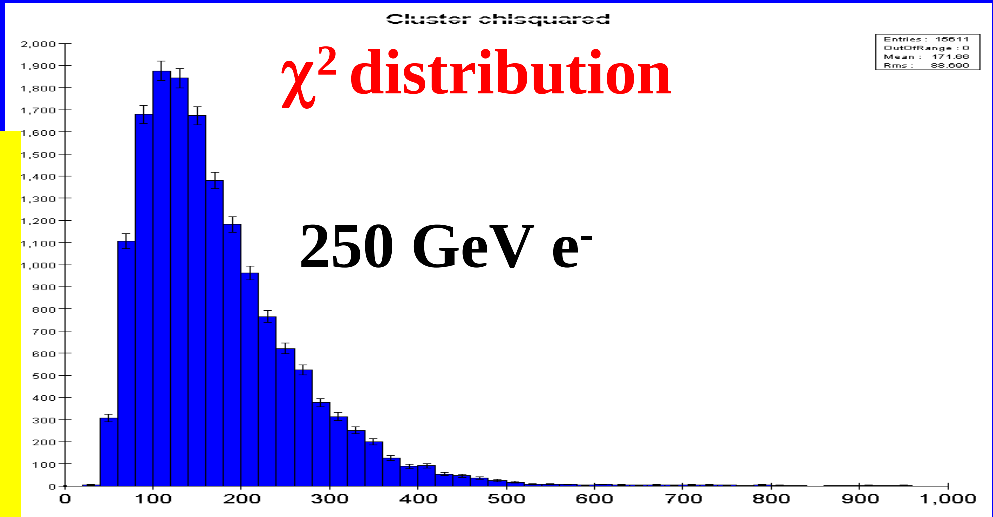
$E_{bg} + E_{electron} - \langle E_{bg} \rangle$

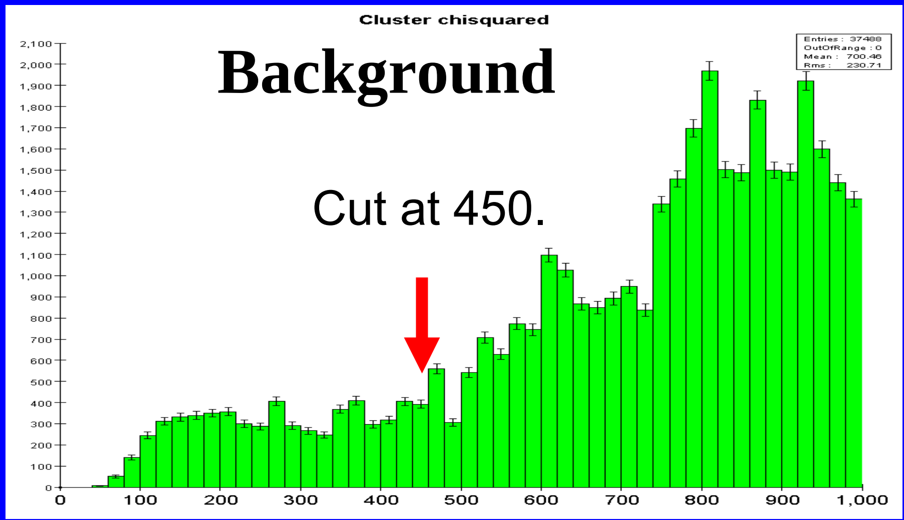




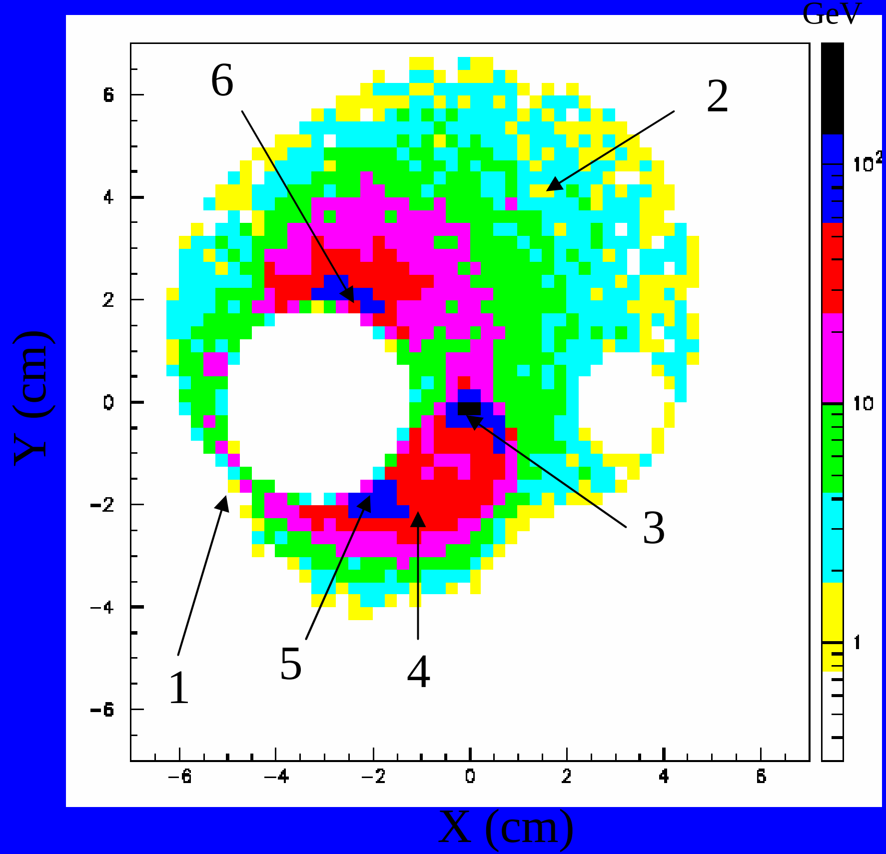
Electron finder

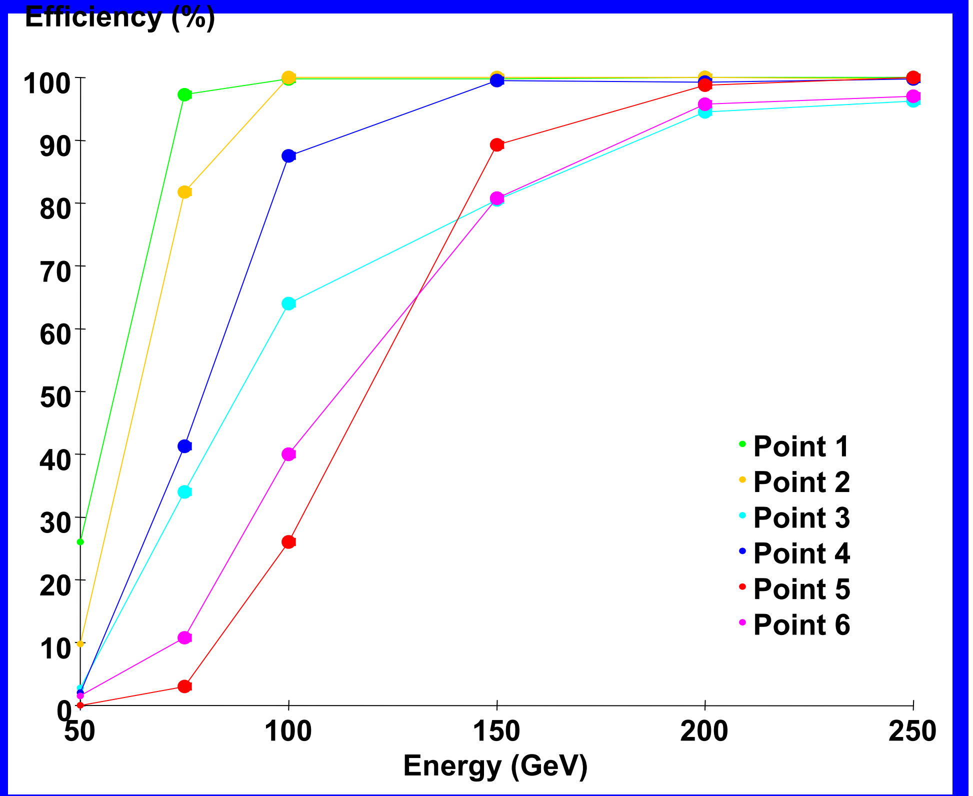
- Use first several layers as shield.
- Use towers past layer 10 as seeds for a fixed-cone algorithm to cluster cells.
  - physical size of shower doesn’t change
  - simplifies geometry handling
  - single pass through the data
- Cuts on cluster width and longitudinal shower χ^2.





Electron Detection Efficiency





Background Pileup

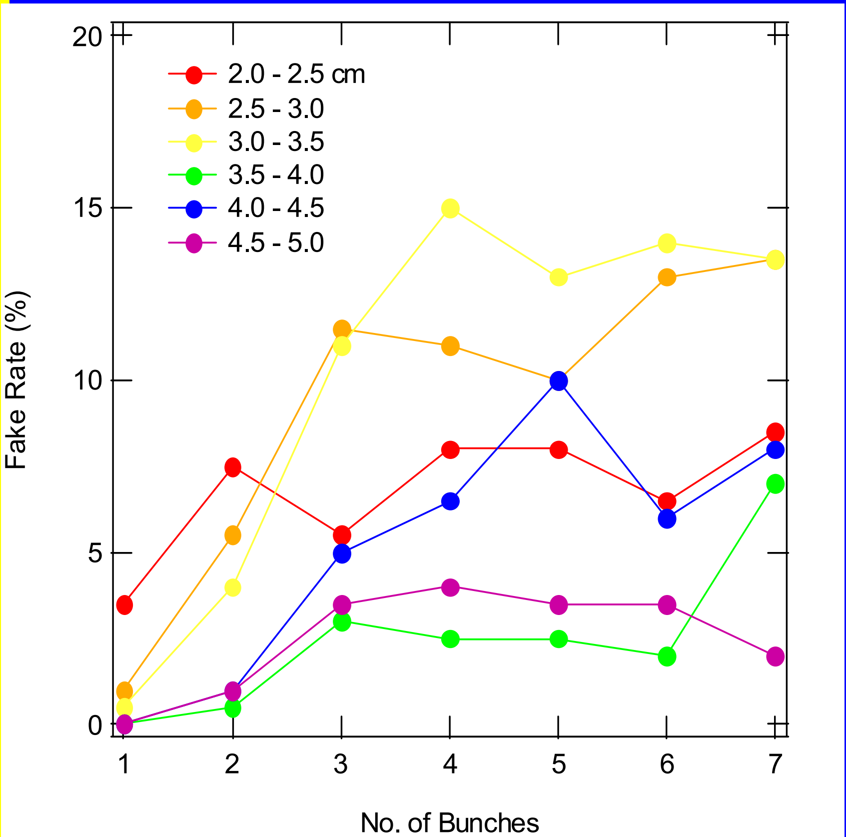
What happens if we do not have single bunch time resolution?

The detection efficiency does not degrade quickly, but the fake rake increases.

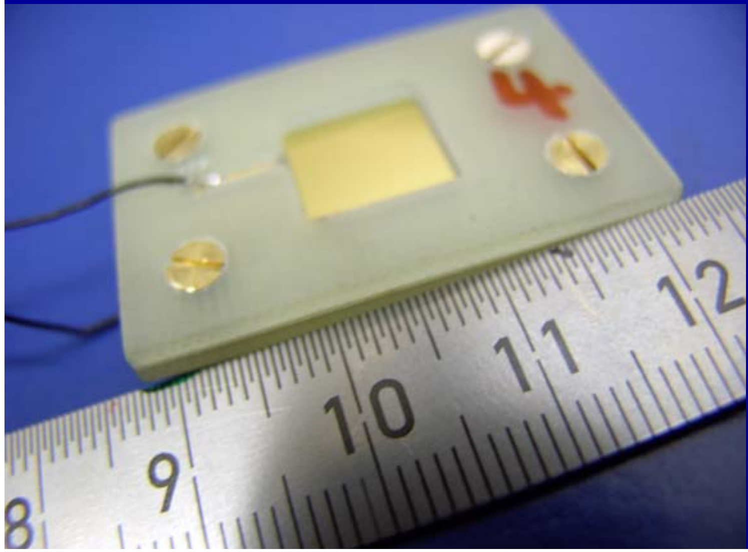
Fake rate (all cluster energies):

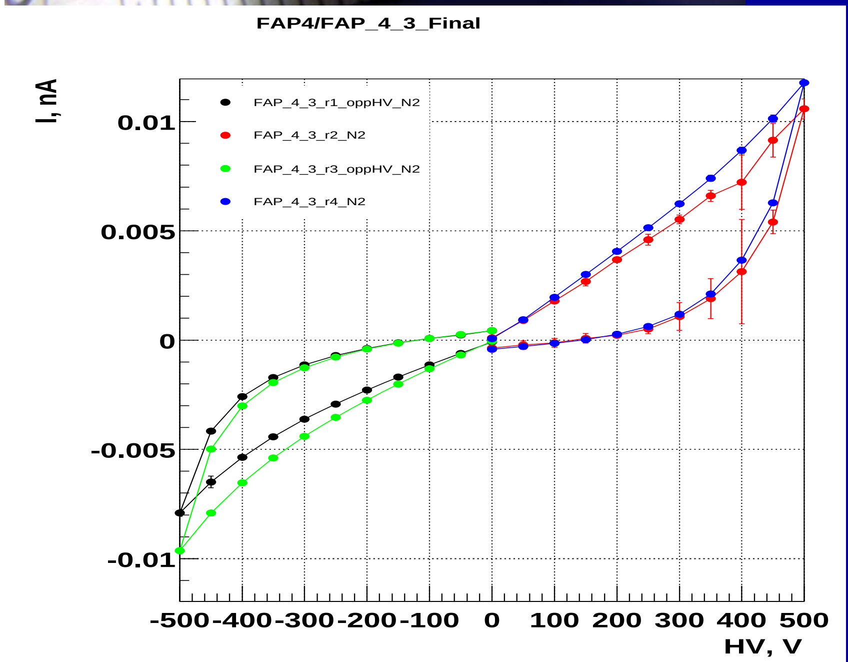
1 bx	5%
2	20
3	40
4	47

Fakes are concentrated in hotspots, not uniform in phi. Expect rejection to improve with further study.



Sensor prototyping, Diamonds





Different surface treatments :

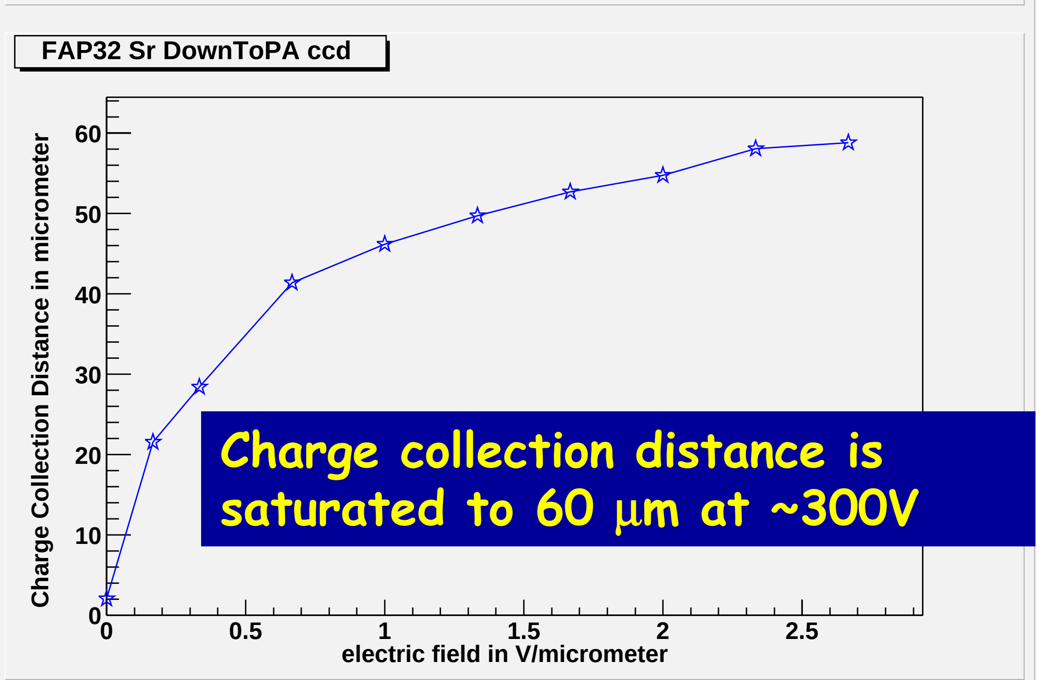
- **#1 – substrate side polished; 300 um**
- **#2 – cut substrate; 200 um**
- **#3 – growth side polished; 300 um**
- **#4 – both sides polished; 300 um**

Diamond; Size: 12x12 mm ^{2}

Metallisation: 10 nm Ti + 400nm Au

Current (I) dependence on the voltage (V)

Ohmic behavior for 'ramping up/down', hysteresis

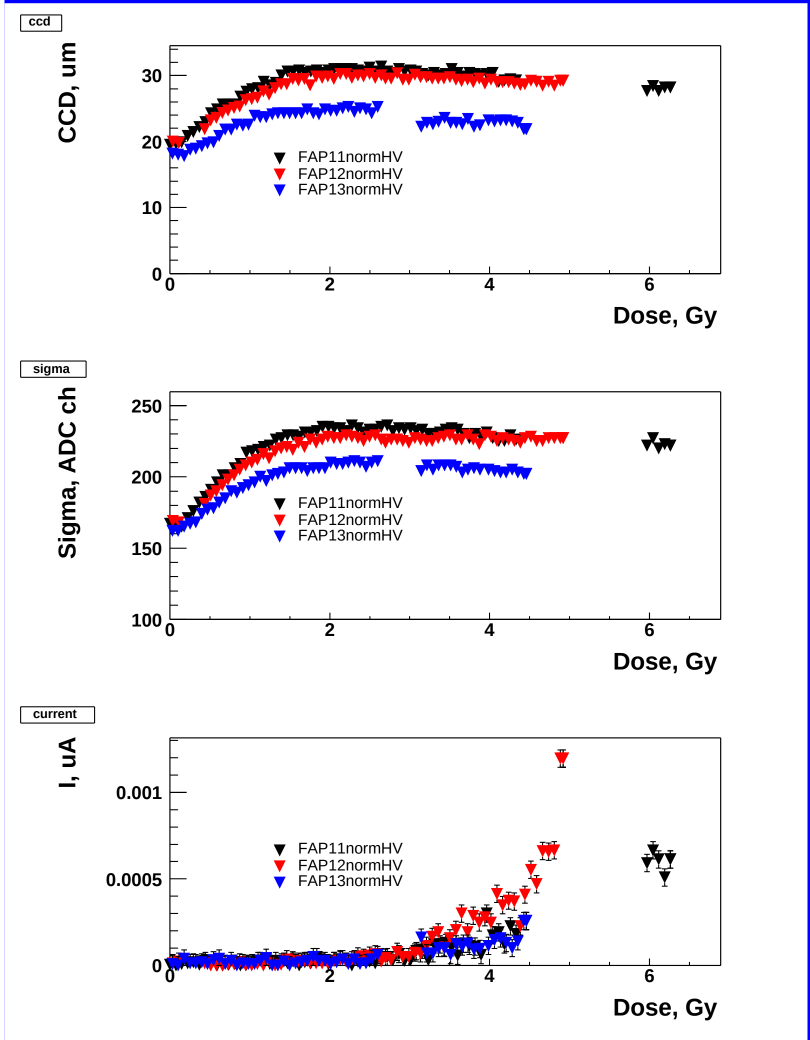


Charge collection distance is saturated to 60 μm at ~300V

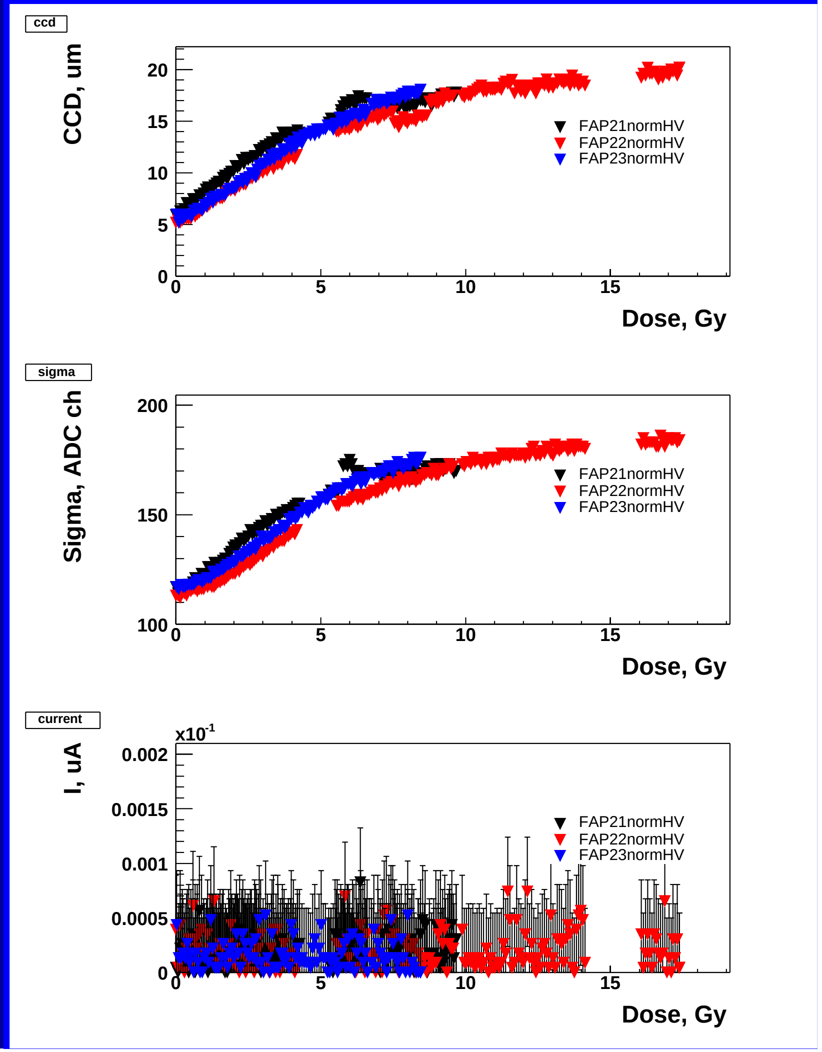
Sensor prototyping, Diamonds

Charge Collection distance vs. dose

#1 – substrate side polished; 300 um

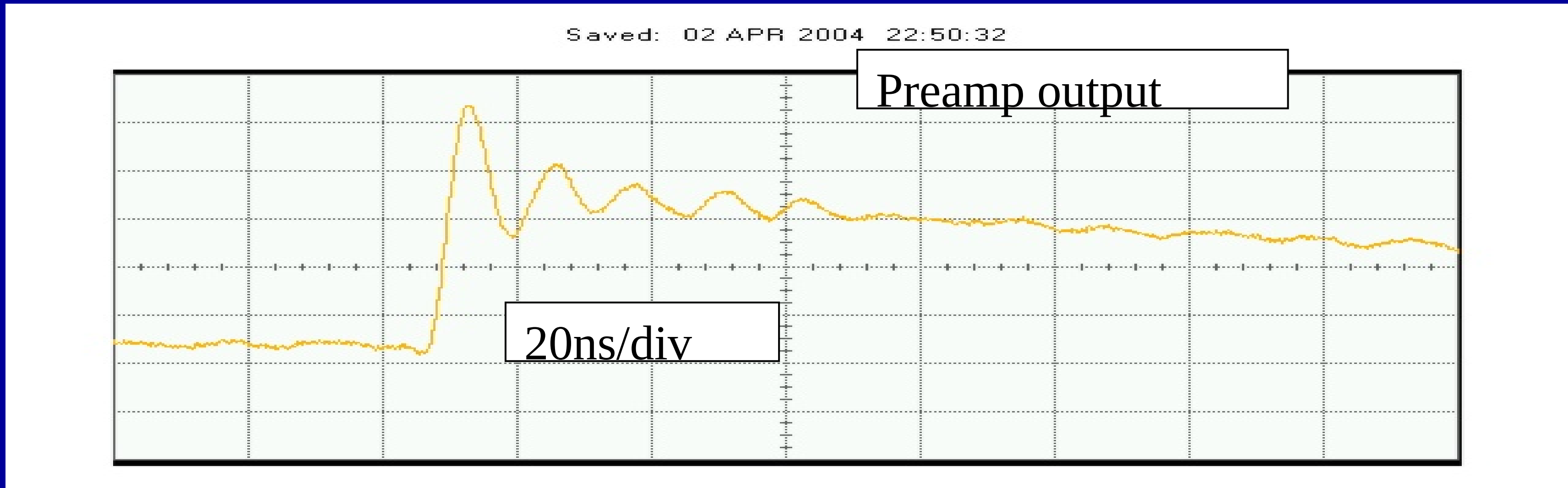


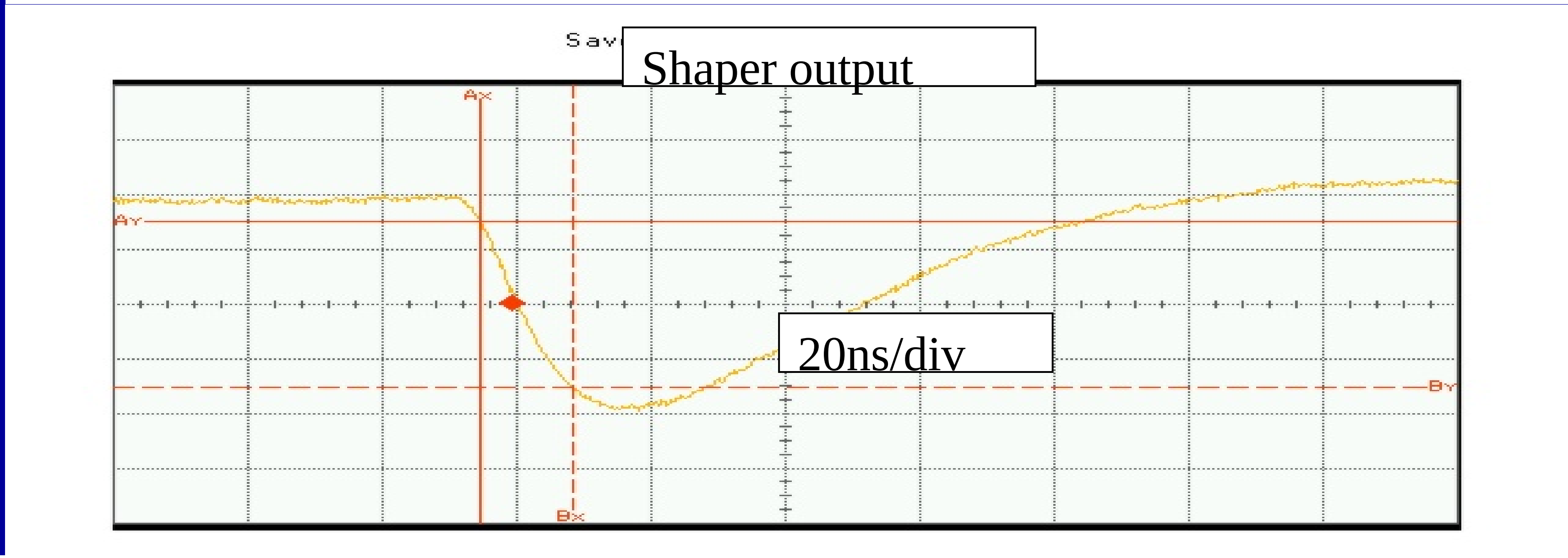
#2 – cut substrate; 200 um



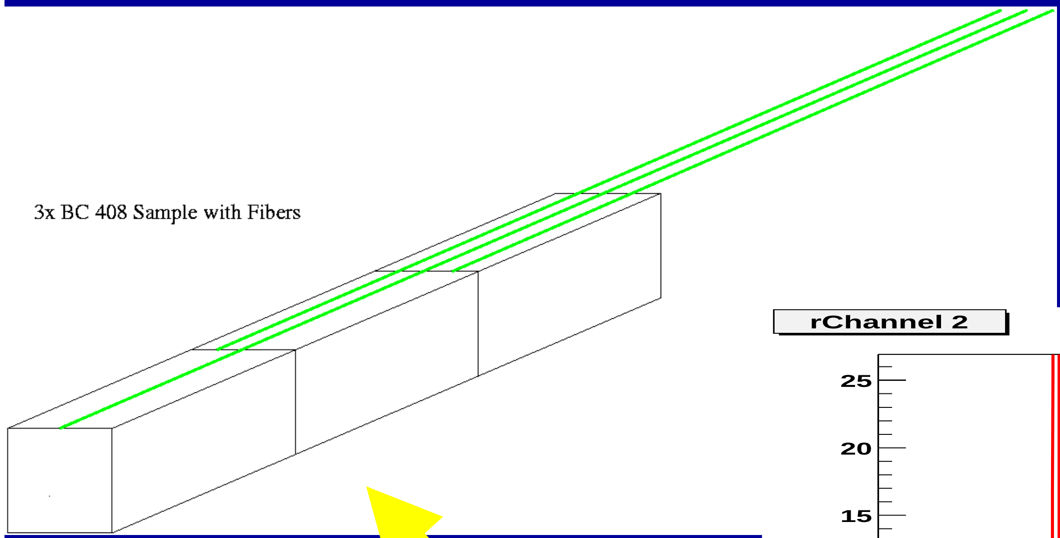
Preamplifier Characteristics

Oscillograms of Tetrod-BJT Amplifier



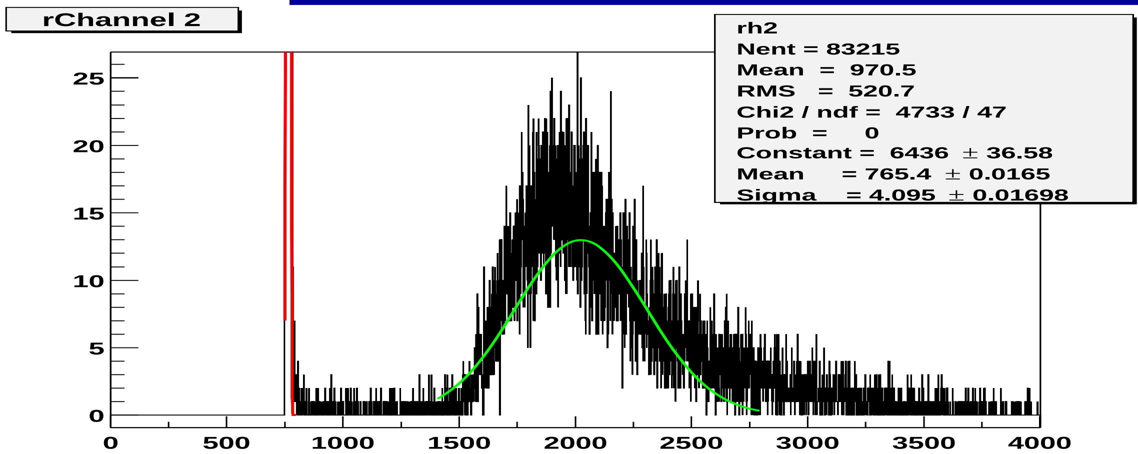


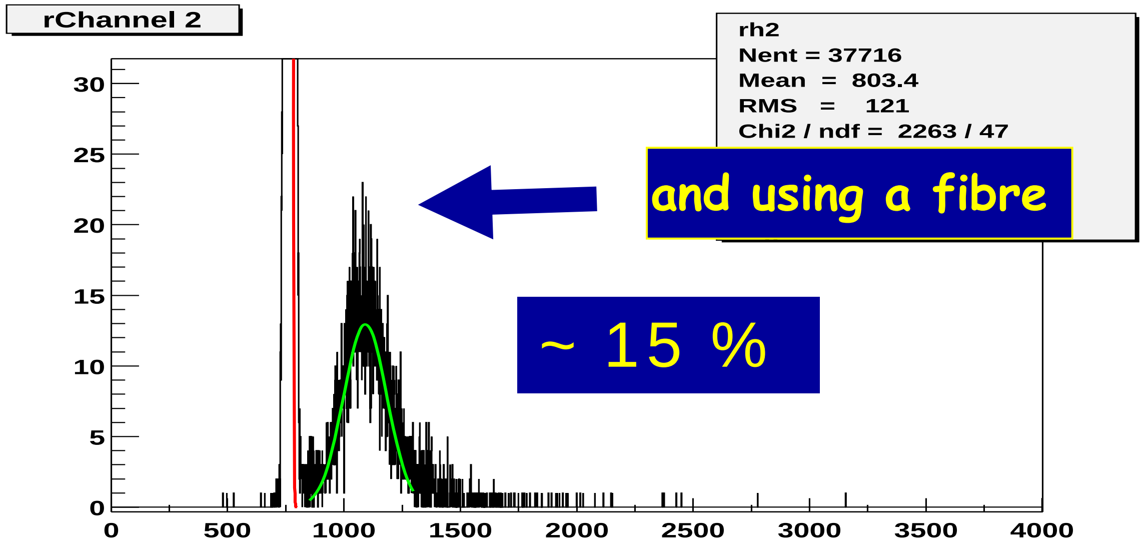
Sensor prototyping, Crystals



Plastic scintilator

Light Yield from direct coupling



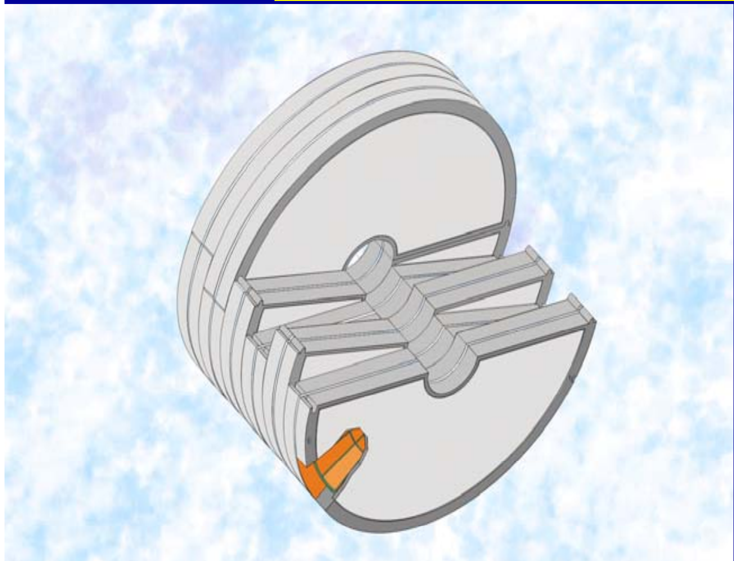


and using a fibre

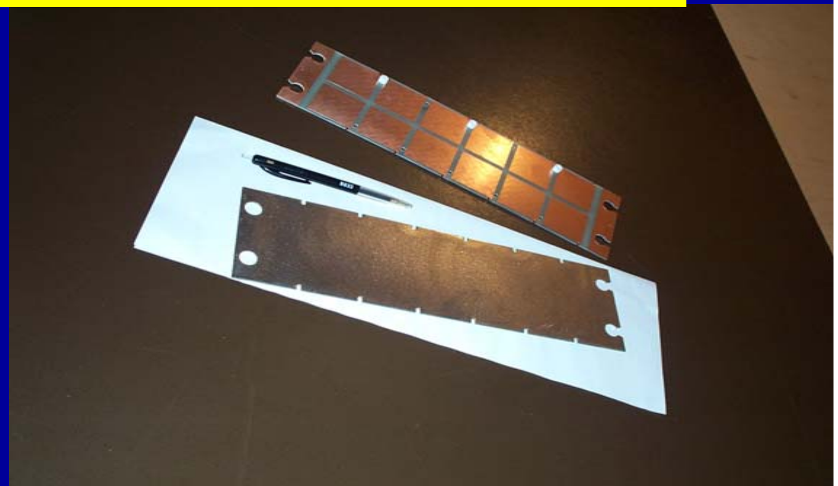
~ 15 %

Study with heavy crystals (Cerenkov light) is going on

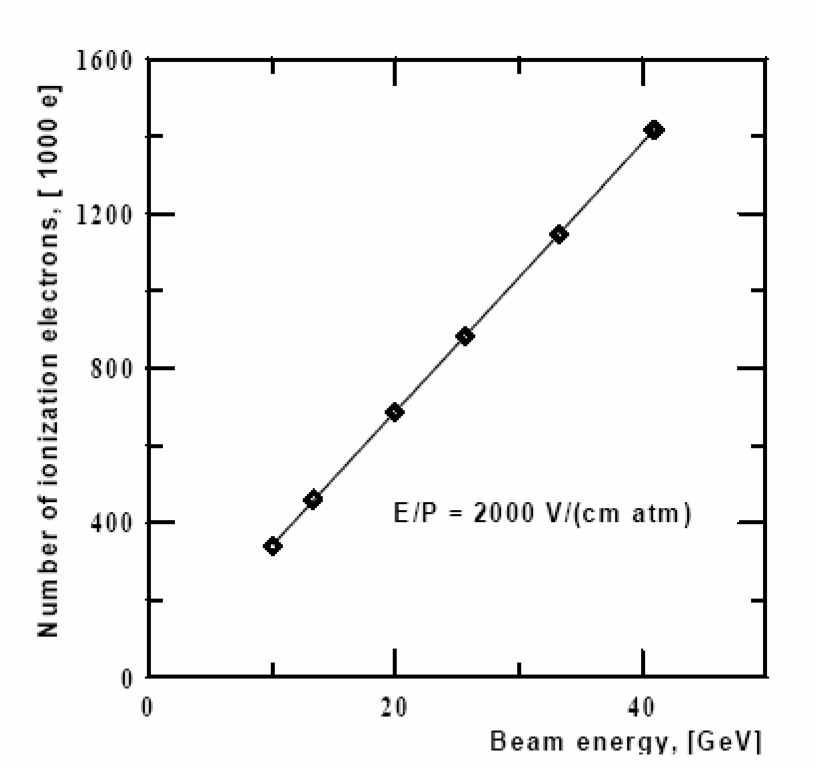
Sensor prototyping, C_3F_8 Gas Ionisation Chamber



Pads for charge collection

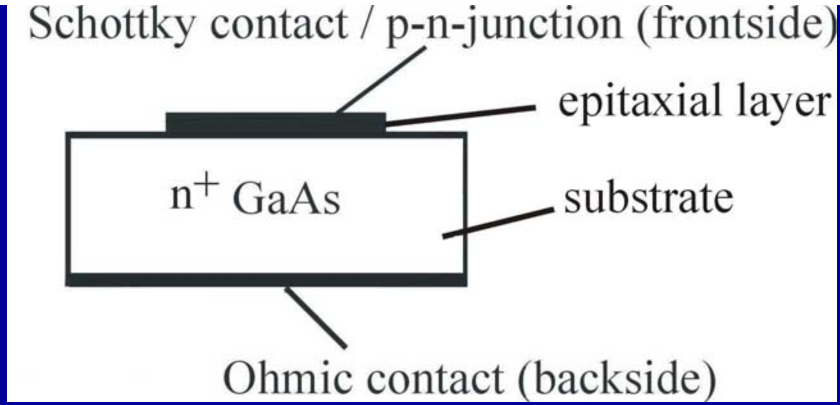


Beam Test, e^- beam, 10-40 GeV (IHEP)

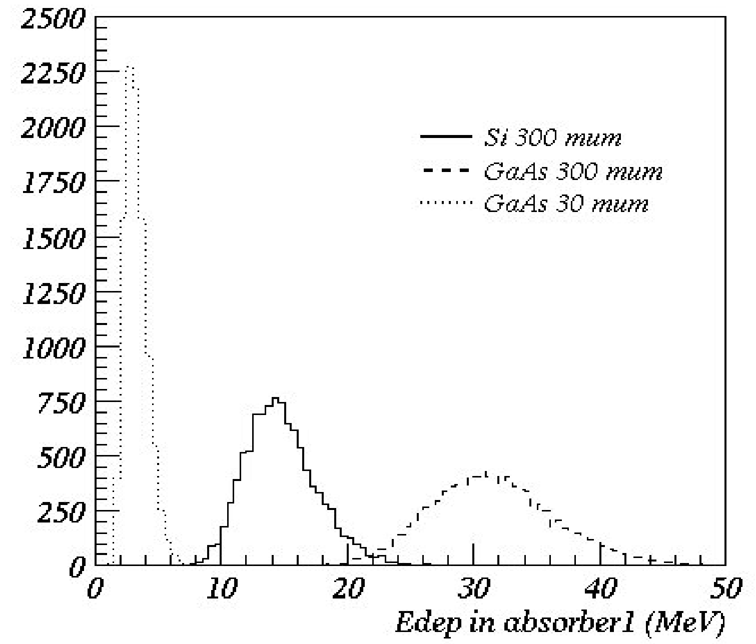


Pressure vessel

Offers for GaAs



LPI group Lebedev Physical Institute, Moscow

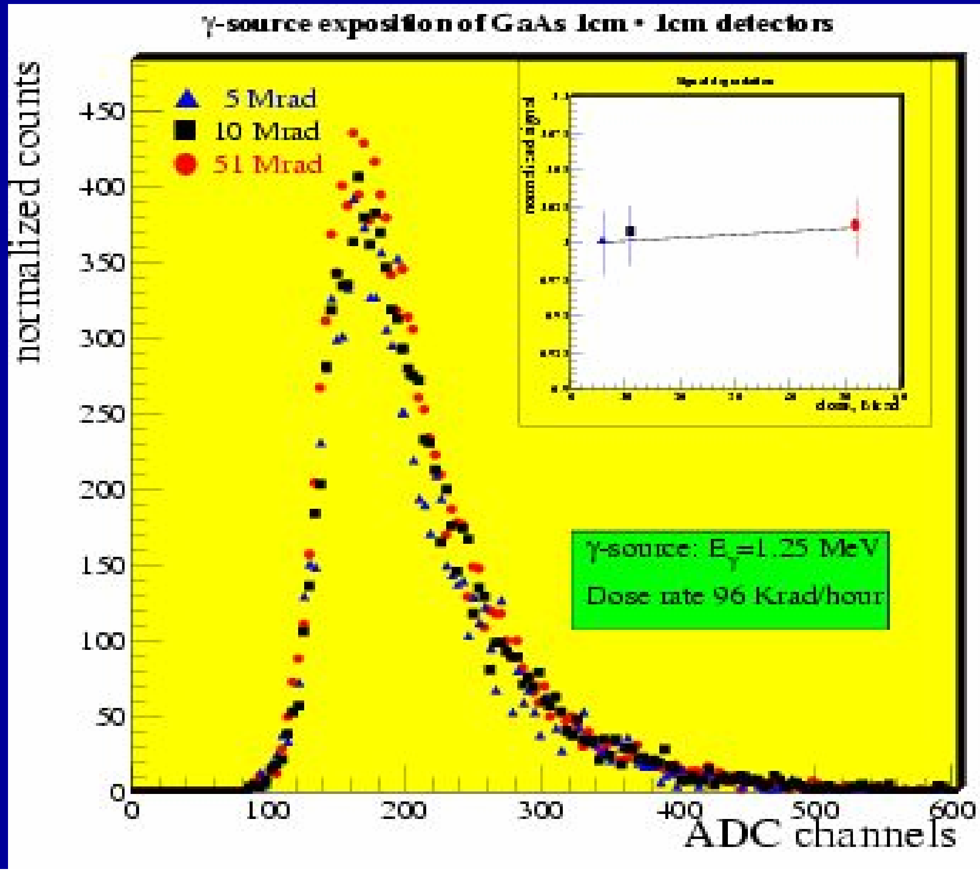


IHEP, Protvino

NCPHEP, Minsk

SIPT, Tomsk

ICBP, Puschino



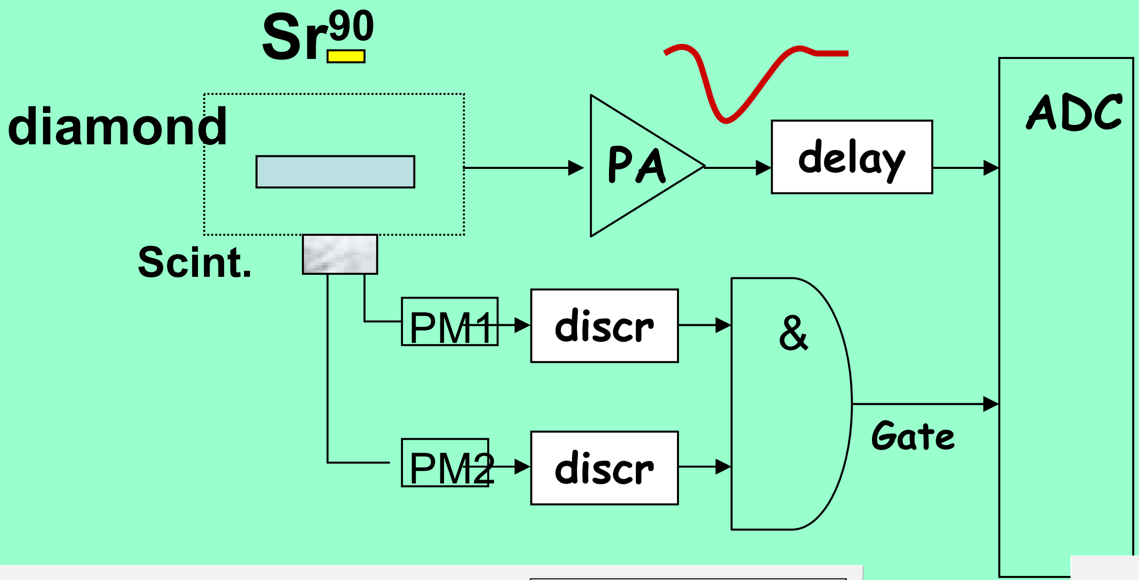
Summary

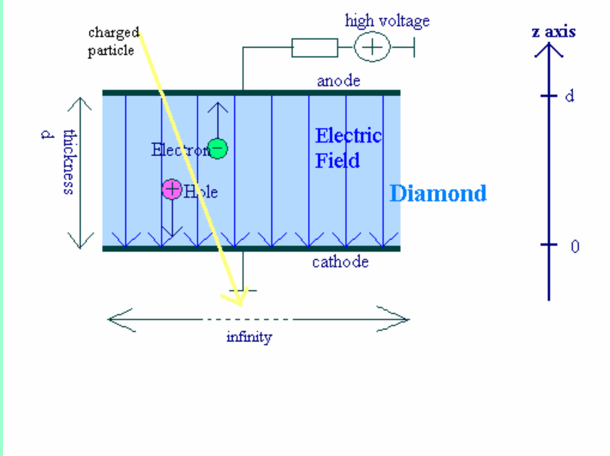
- MC Simulations to optimise the Design of the forward calorimeters are progressing
- Different Detector Technologies for BeamCal are under study
- BeamCal has a great potential for fast beam diagnostics
- Tests with Sensor Prototypes and preamplifier have been started
- After about one year we will present a Design
- The goal is to start after with the construction and test of a prototype

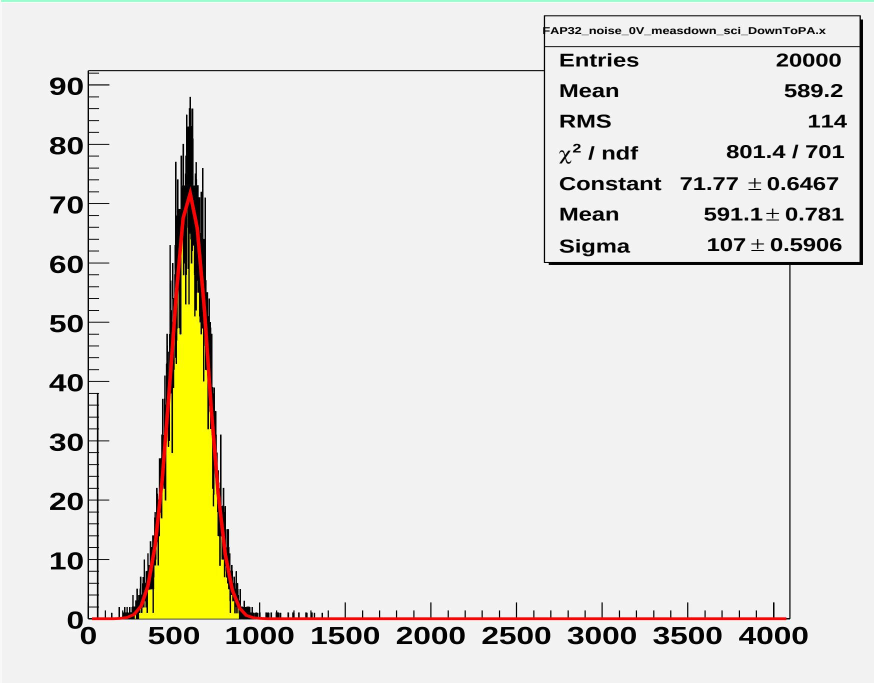
Charge collection distance measurements

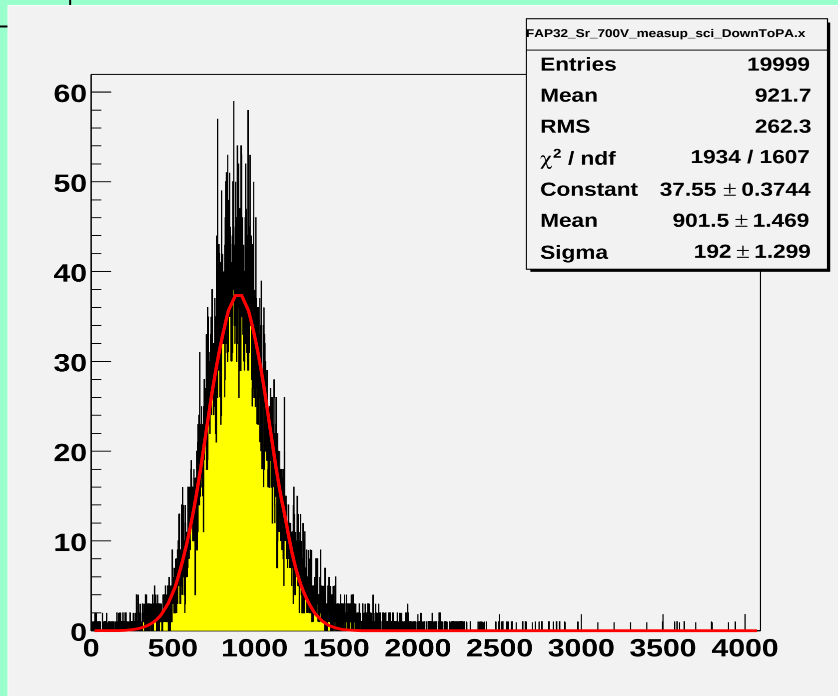
$$Q_{meas.} = Q_{created} \times ccd / L$$

Using electrons from a Sr^{90} source (mips)







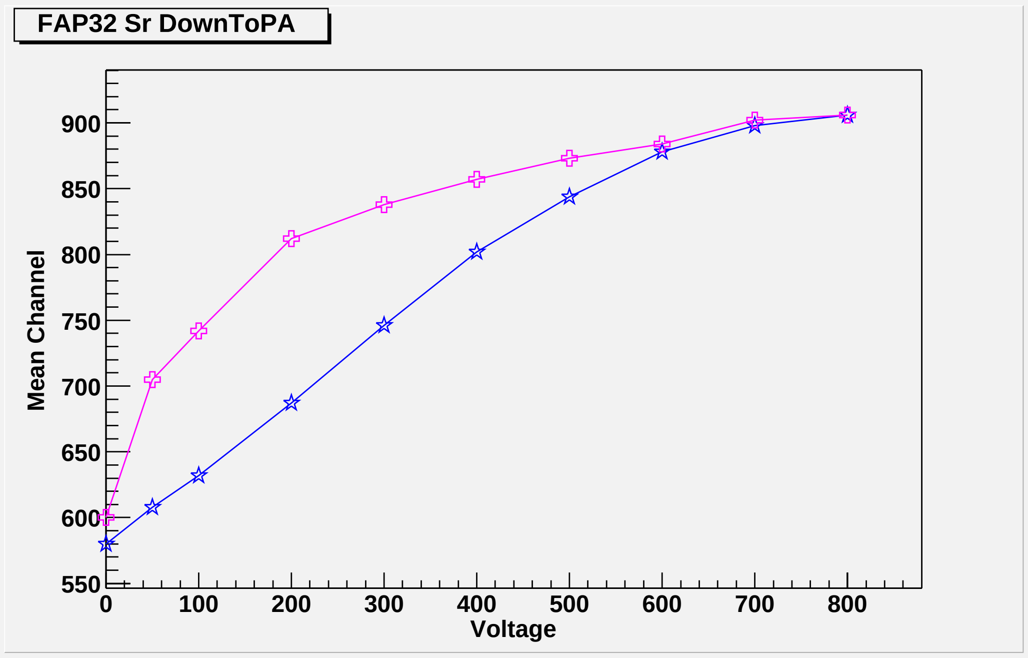


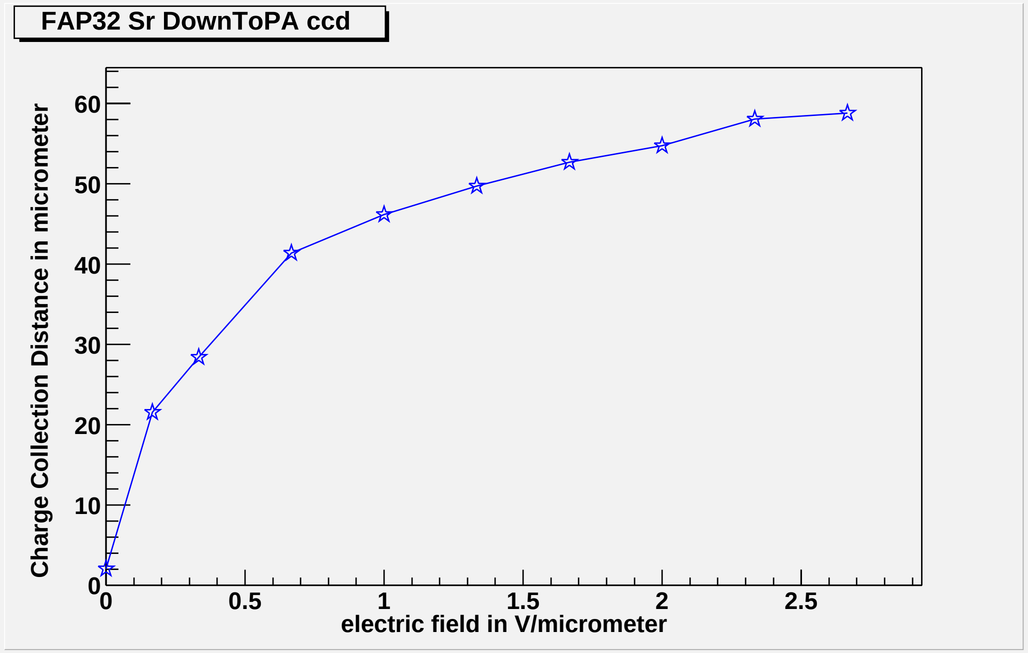
Charge collection distance measurements

The sensors are not irradiated

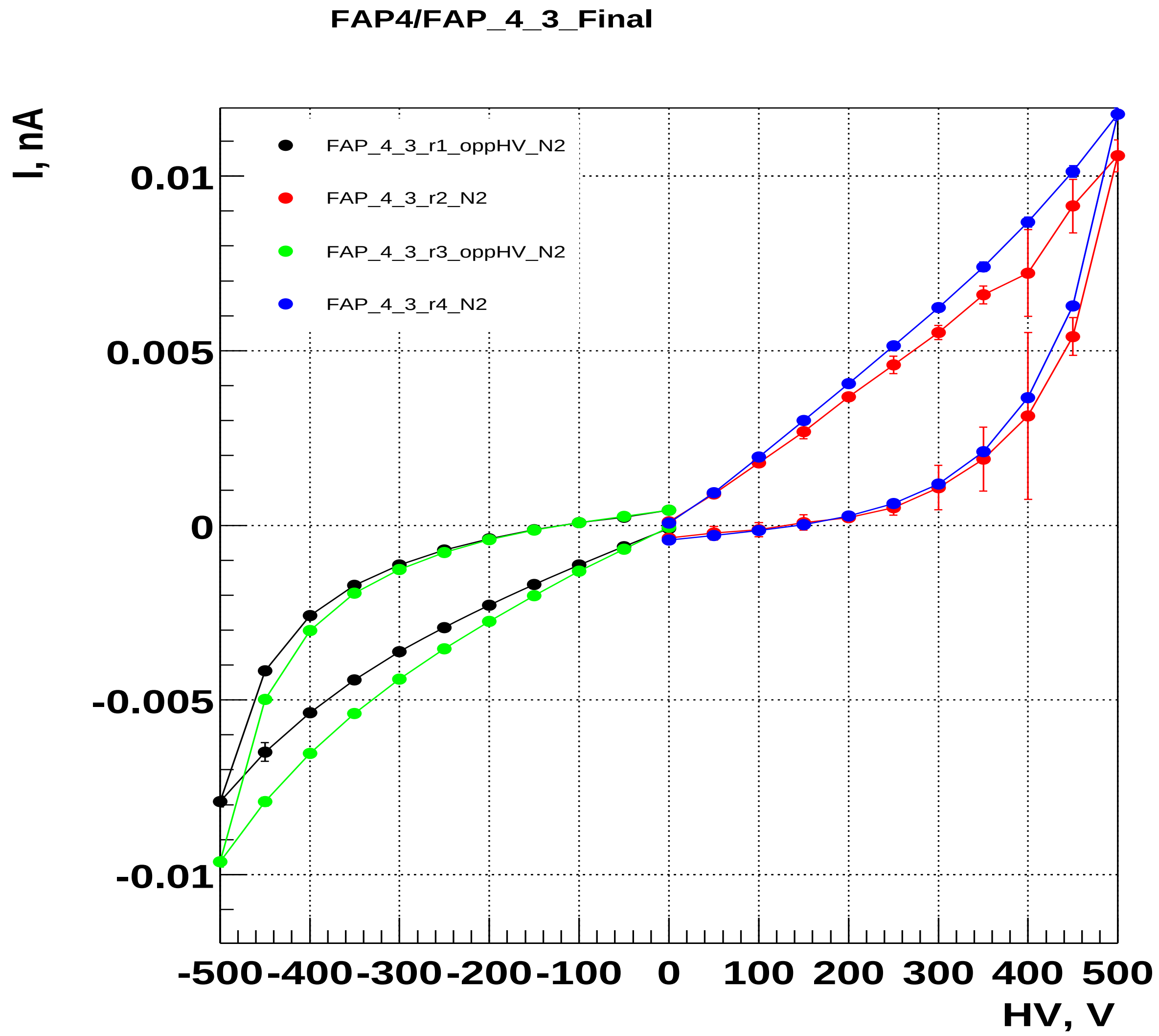
Upper curve is ramping up HV, Lower ramping down.

Charge collection distance is saturated to 50 µm at ~300V





Sensor prototyping and lab tests



Current (I) dependence on the voltage (V)

Ohmic behavior for 'ramping up/down', hysteresis

Resistance in the order of 100 TOhm

Current decays with time
After 24 h nearly 1/2

•Detection of Electrons and Photons

• essential parameters:

Small Molière radius

High granularity

Longitudinal segmentation

• Two photon event rejection

$e^+e^- \longrightarrow e^+e^- \mu^+\mu^-$

(Severe background for particle searches)

• Electromagnetic fakes

1% from physics 2% from fluctuations