# Forward Calorimetry: issues for LoI

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On behalf of the FCAL collaboration

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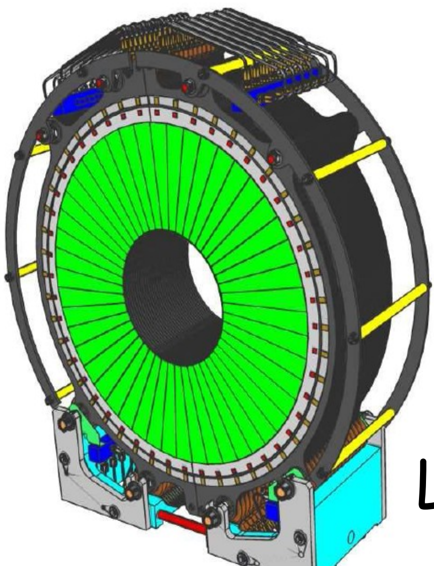
# Forward Calorimetry



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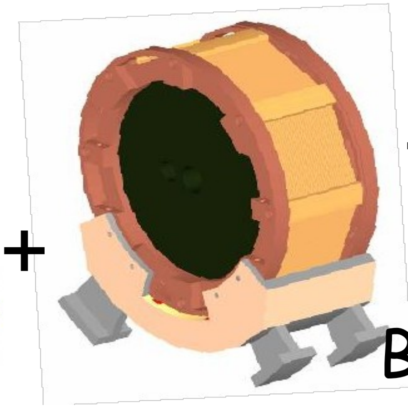
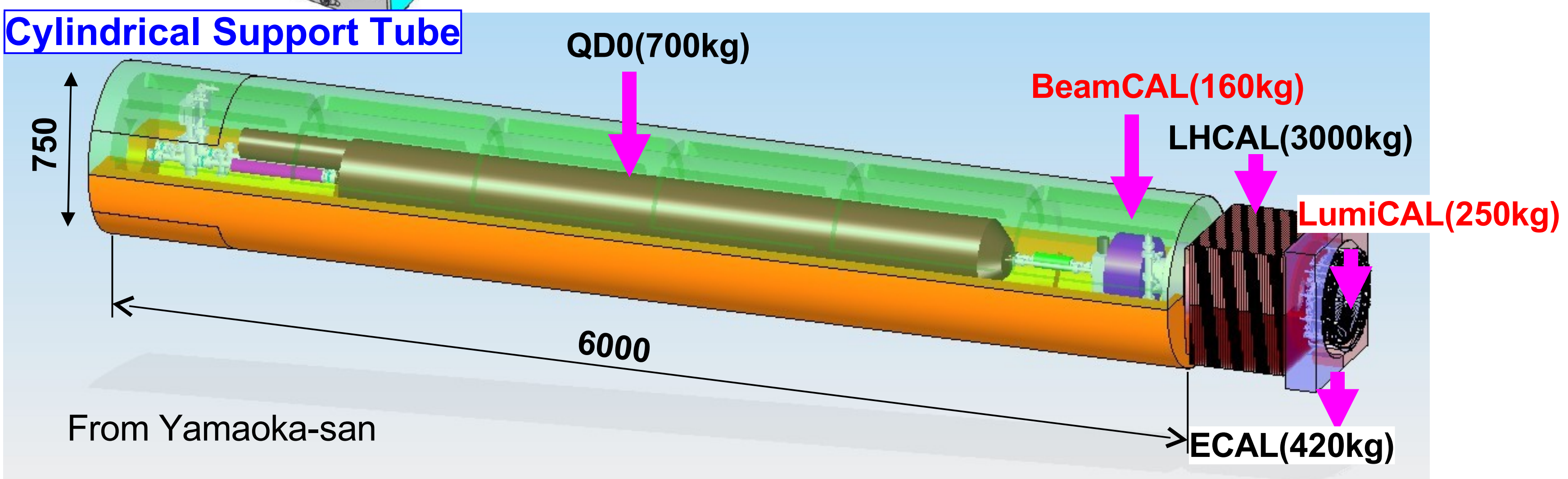


\+ GamCal (~185 m)
(fast readout)

BeamCal (rad. Hardness)
+Pair-monitor in front

LumiCal (precision)

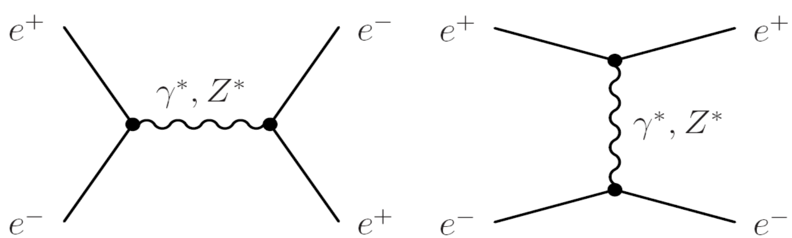


# LumiCal Performance Requirements

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)

- Measure luminosity by counting the number of Bhabha events ($N_B$):

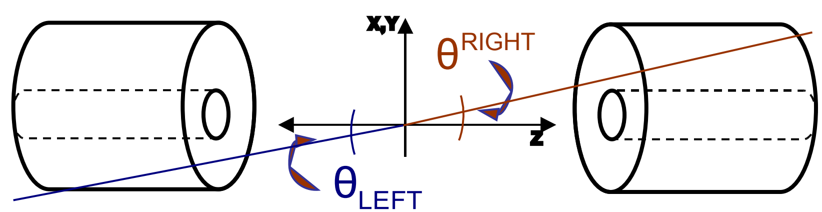



(a) s channel (b) t channel

$$\frac{d\sigma_B}{d\theta} \propto \frac{1}{\theta^3}$$

$$L = \frac{N_B}{\sigma_B}, \quad \frac{\Delta L}{L} = \frac{\Delta N_B}{N_B} = \left. \frac{N_{rec} - N_{gen}}{N_{gen}} \right|_{\theta_{min}}^{\theta_{max}}$$

**Compare angles & energy**

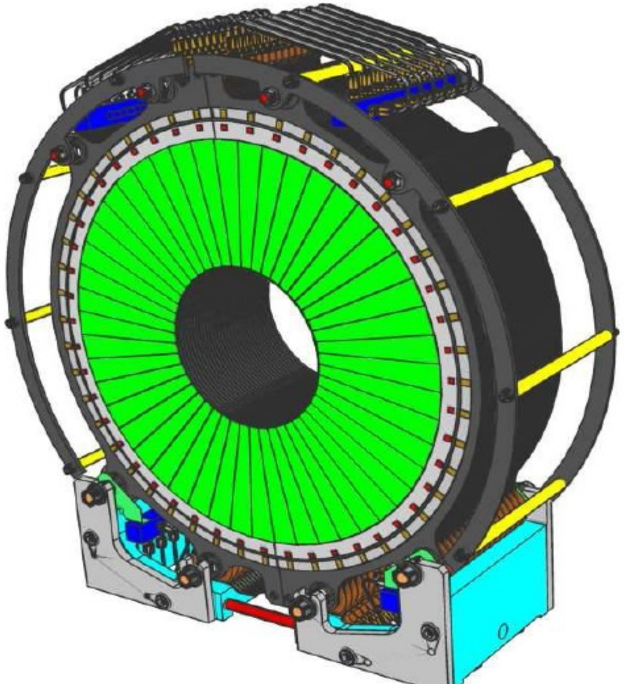


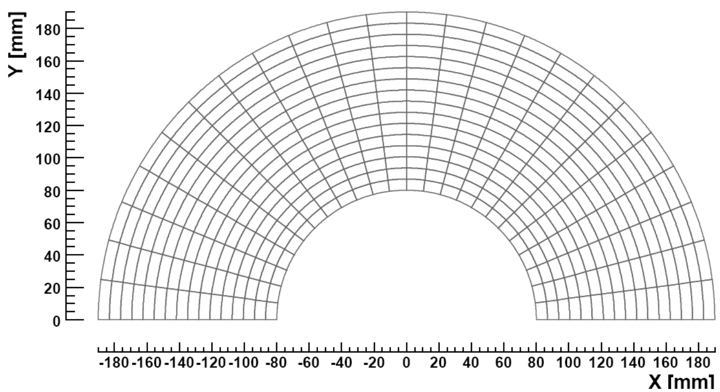

$\Delta\theta \equiv \theta_{RIGHT} - \theta_{LEFT}$

# LumiCal

- Compact, small Moliere radius
- 30 $X_0$ Si/W sampling calorimeter
- Layer thickness ~$X_0$ (3.5 mm W)
- Sensor thickness ~1 mm
- X/Y/Z = 15.9/0/±2270
- Weight ~200 kg
- Precise alignment, $t^0$ stabilization
- Rin/Rout (sensor) 80 mm/190 mm
- θ range 35.3 - 83.9 mrad,
  64 divisions 0.8 mrad
- 48 azimuthal divisions
- ~90K R/O channels

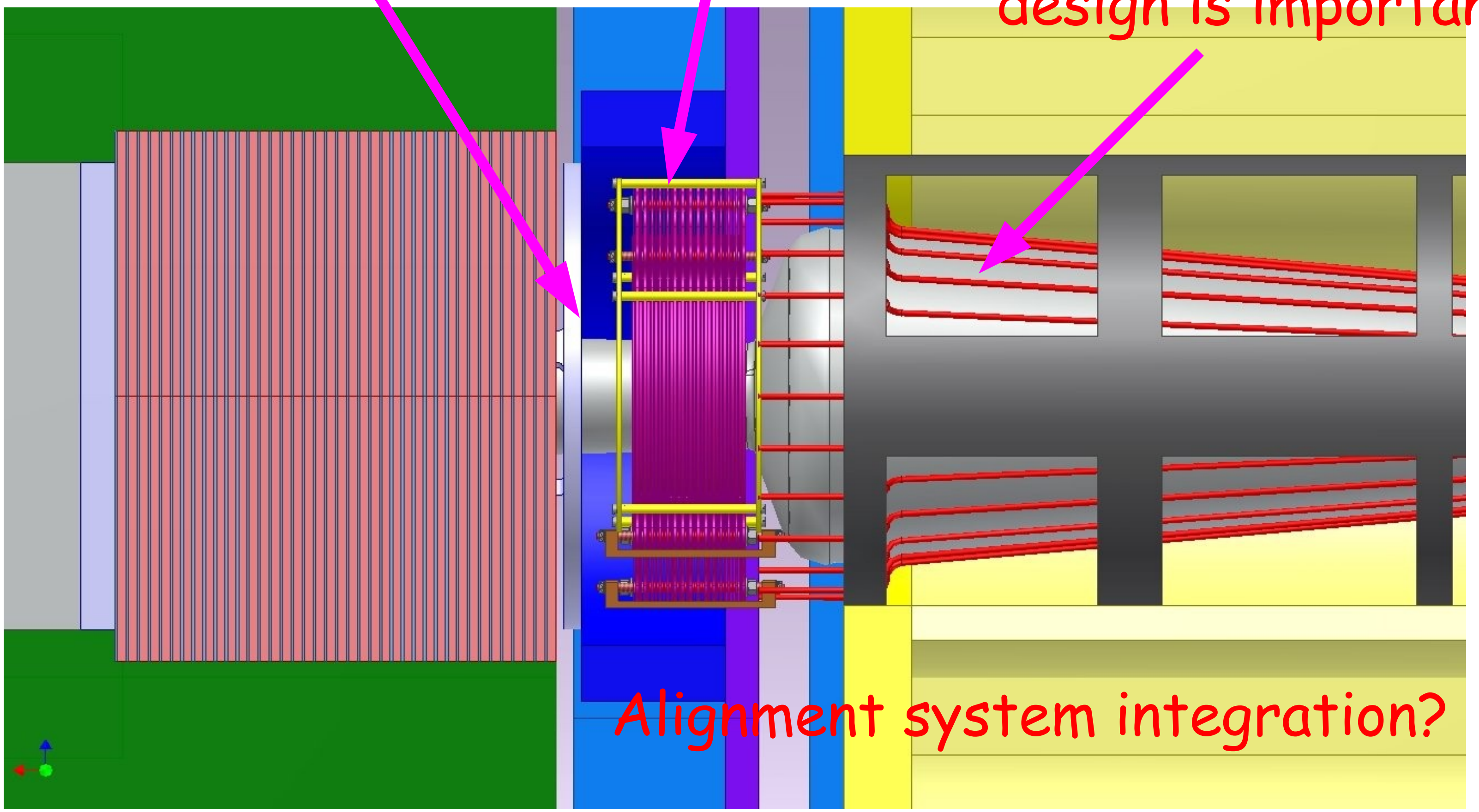
http://www-zeuthen.desy.de/ILC/fcal/





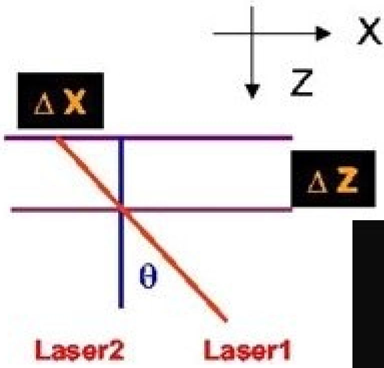

(every fourth radial segment is drawn)

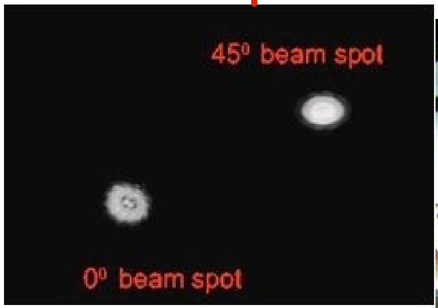
# LumiCal integration issues

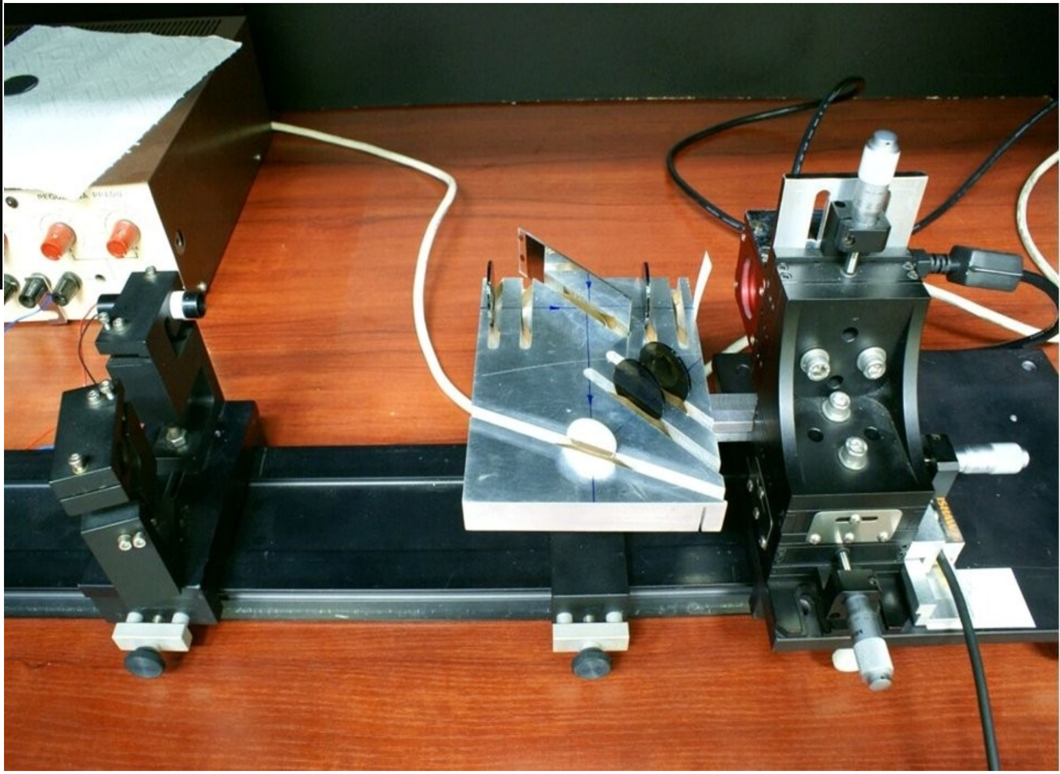


# LumiCal Laser Alignment System

Required accuracy: inner radius ~ μm level, distance between LumiCal's ~100 μm level. Temperature stabilization is mandatory.

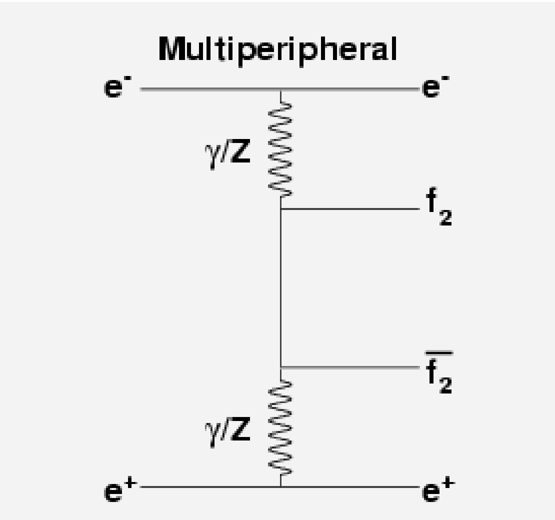


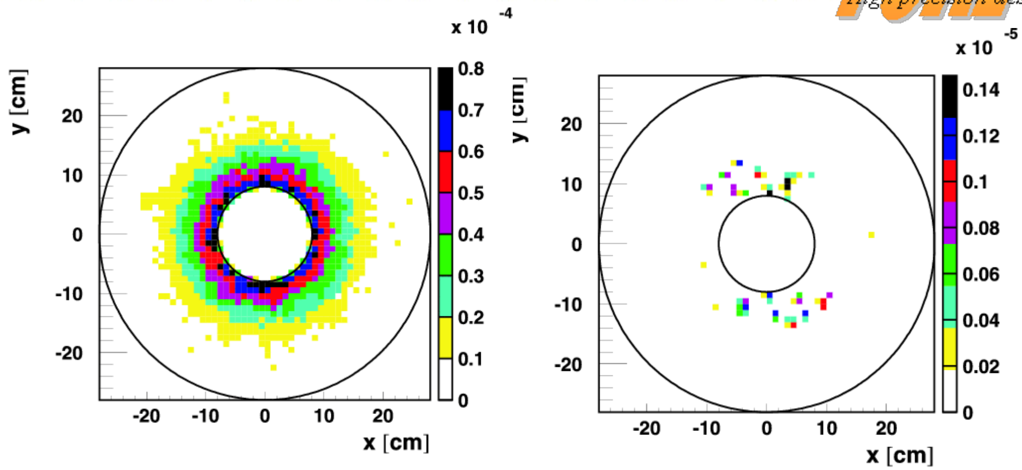



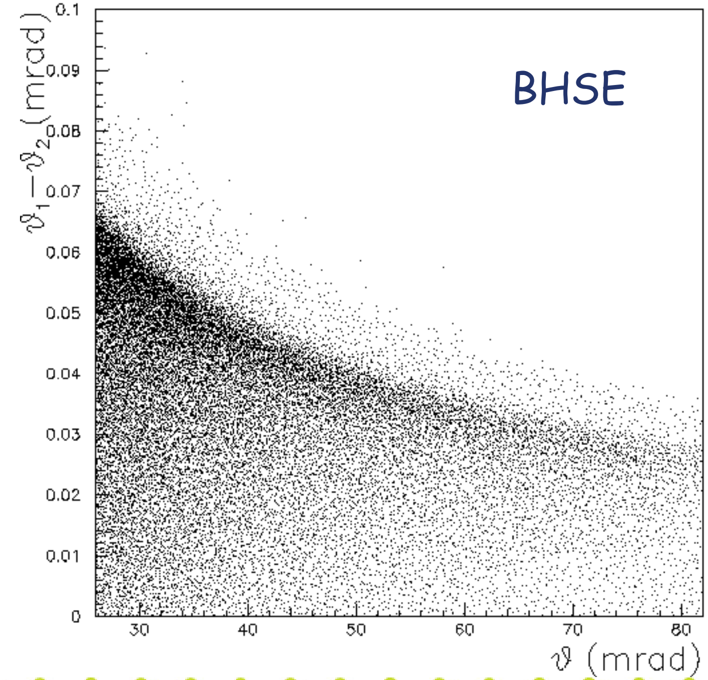
Lab tests: <μm accuracy achievable at short scale e.g. wrt beam pipe/BPM or QD0. LC1 - LC2 dist. is critical (Frequency Scanning Interferometry? - how to feed the laser beam?)

# Physics Background and Beam-Beam Effect




2-photon rejection



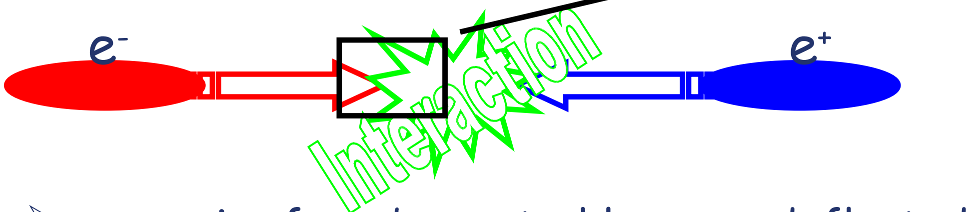



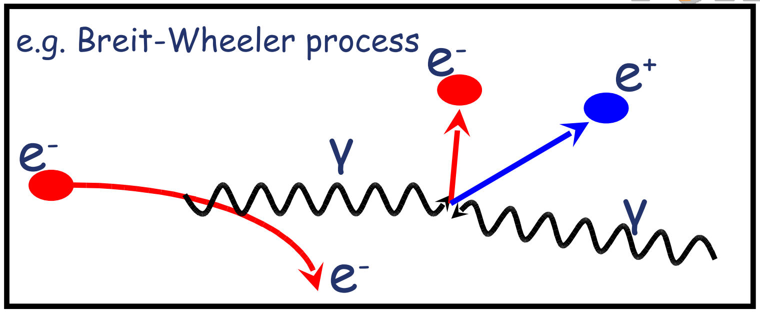

- 2-photon events are the main background.
- We determined an efficient set of cuts to reduce the background to the level of $10^{-4}$.
- The Bhabha Suppression Effect (BHSE) is due to the EM deflection and energy loss by beamstrahlung of the Bhabhas. Correction needs precise knowledge of beam parameters.

C.Rimbault et al. JINST 2:O9001.2007

# The Challenges for BeamCal

Creation of beamstrahlung at the ILC



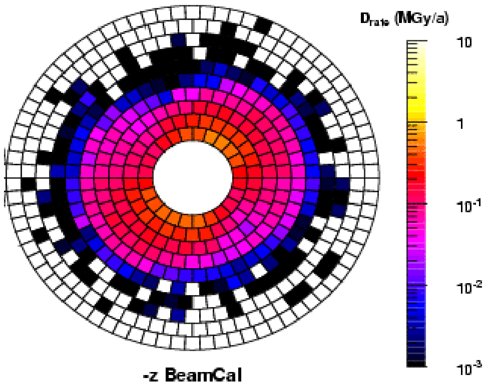




- e+e- pairs from beamstrahlung are deflected into the BeamCal
- 15000 $e^+e^-$ per BX

  => 10 – 20 TeV total energy dep.
- <u>**~ 10 MGy per year**</u> strongly dependent on the beam and magnetic field configuration

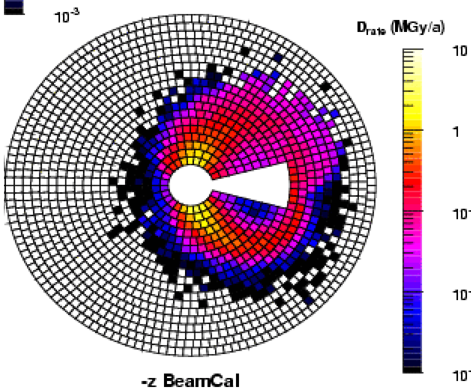
  => <u>radiation hard sensors</u>
- Detect the signature of single high energetic particles on top of the background.

  => <u>high dynamic range/linearity</u>

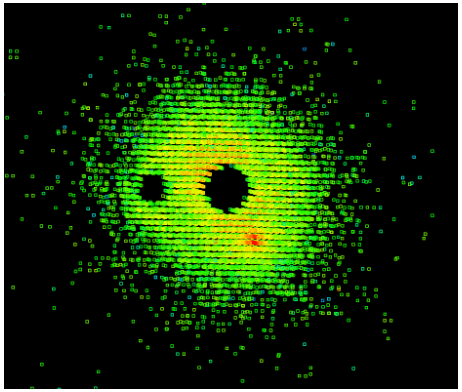


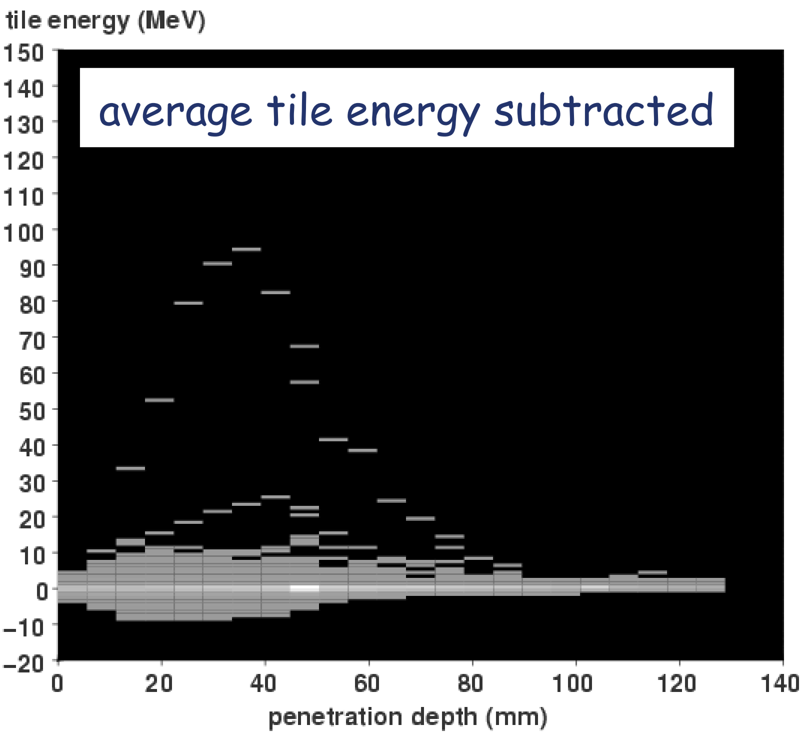

≈ 1 MGy/a

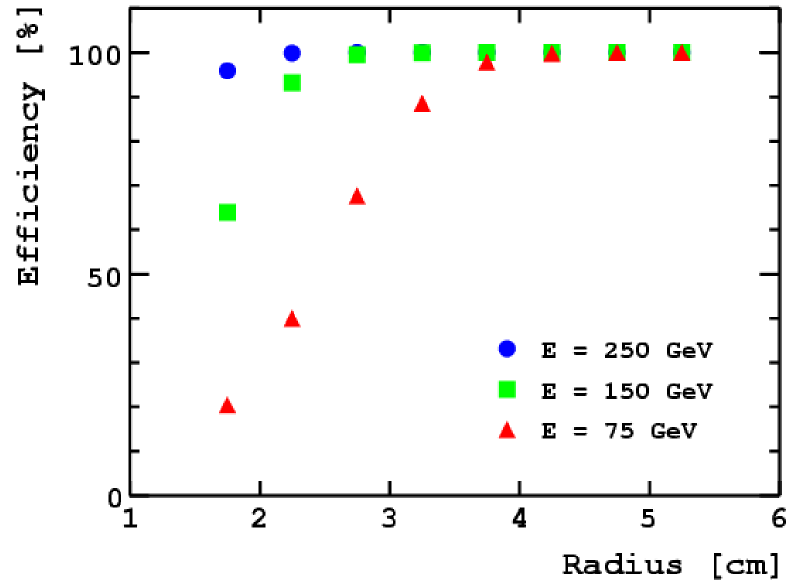
≈ 5 MGy/a



# Particle Veto





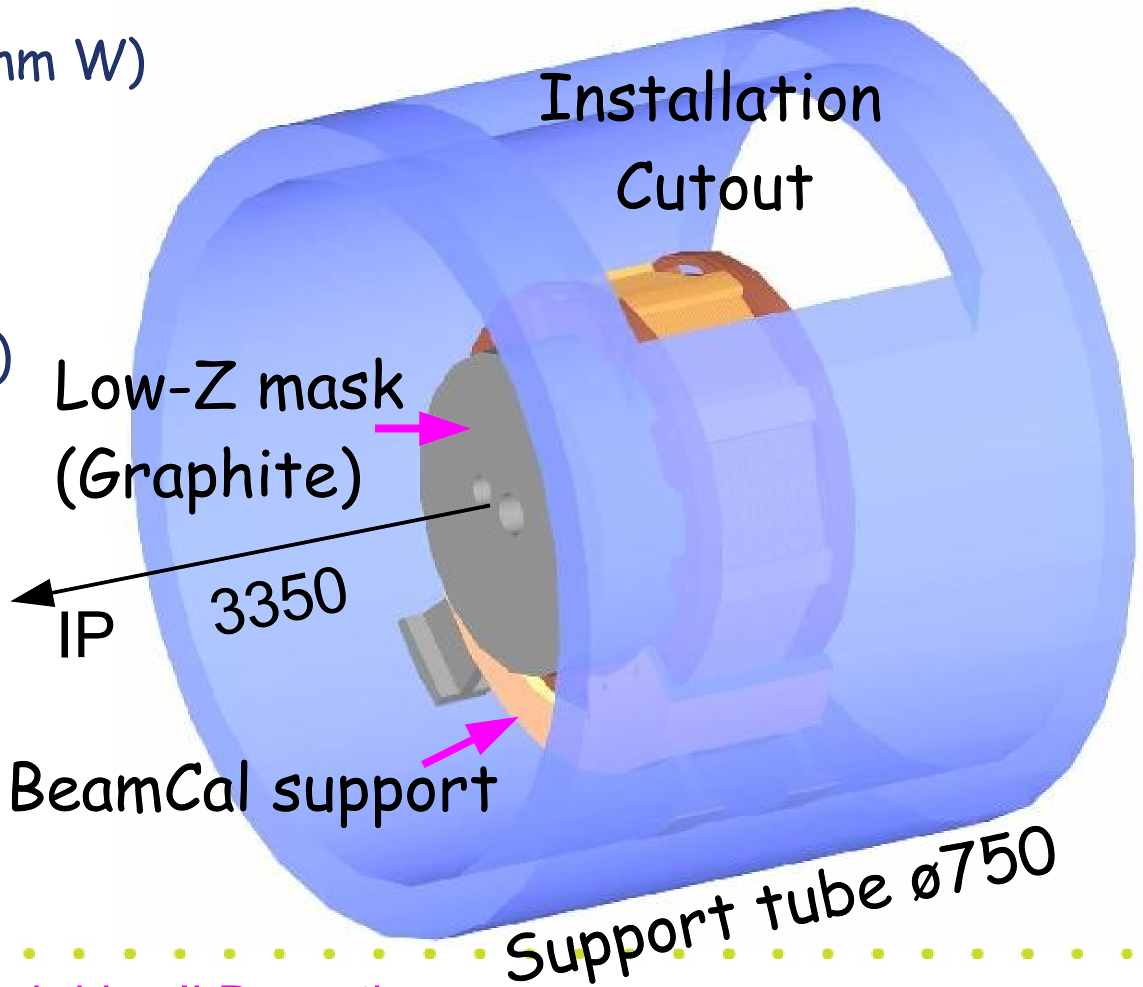




- We developed algorithms to efficiently veto single high energetic particles down to lowest polar angles.
- We investigated the impact of different layouts, cell sizes, etc..
- We need radiation hard sensors with a large dynamic range $O(10^4)$.

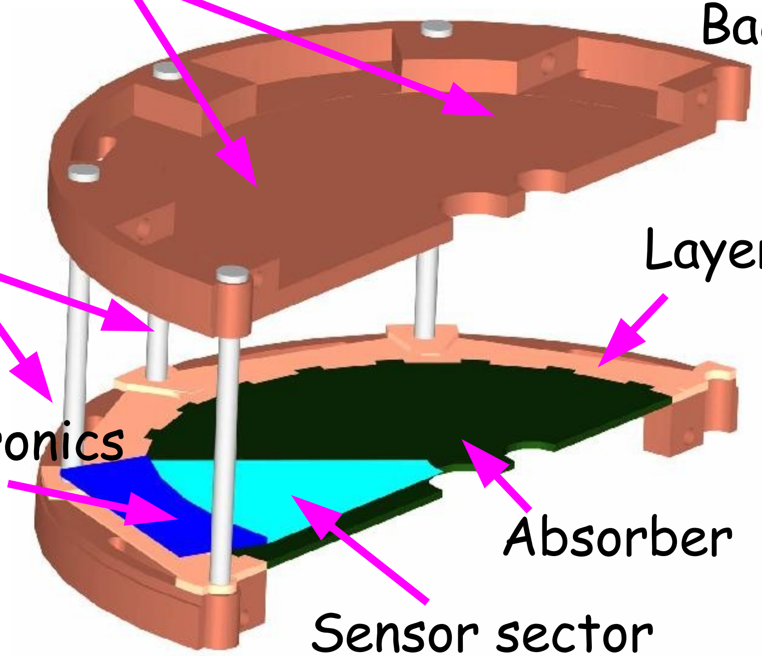
# BeamCal

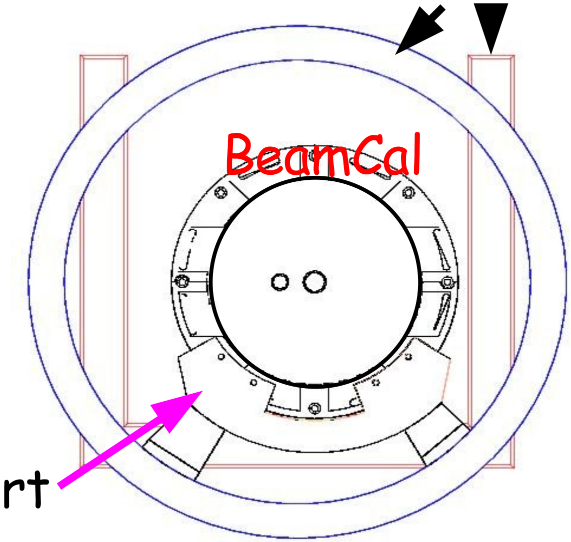
- Compact, smallest possible Moliere radius
- 30 $X_0$ ???/W sampling calorimeter
- Layer thickness ~$X_0$ (3.5 mm W)
- Sensor thickness ~0.5 mm
- X/Y/Z = 24.2/0/±3450
- Weight ~160 kg (+ support)
- 10 cm Graphite in front
- Rin (sensor) 20 mm
- Rout (sensor) 150 mm
- Rout (mech) 200 mm
- θ range 5.8 – 43.5 mrad
- ~40K R/O channels

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

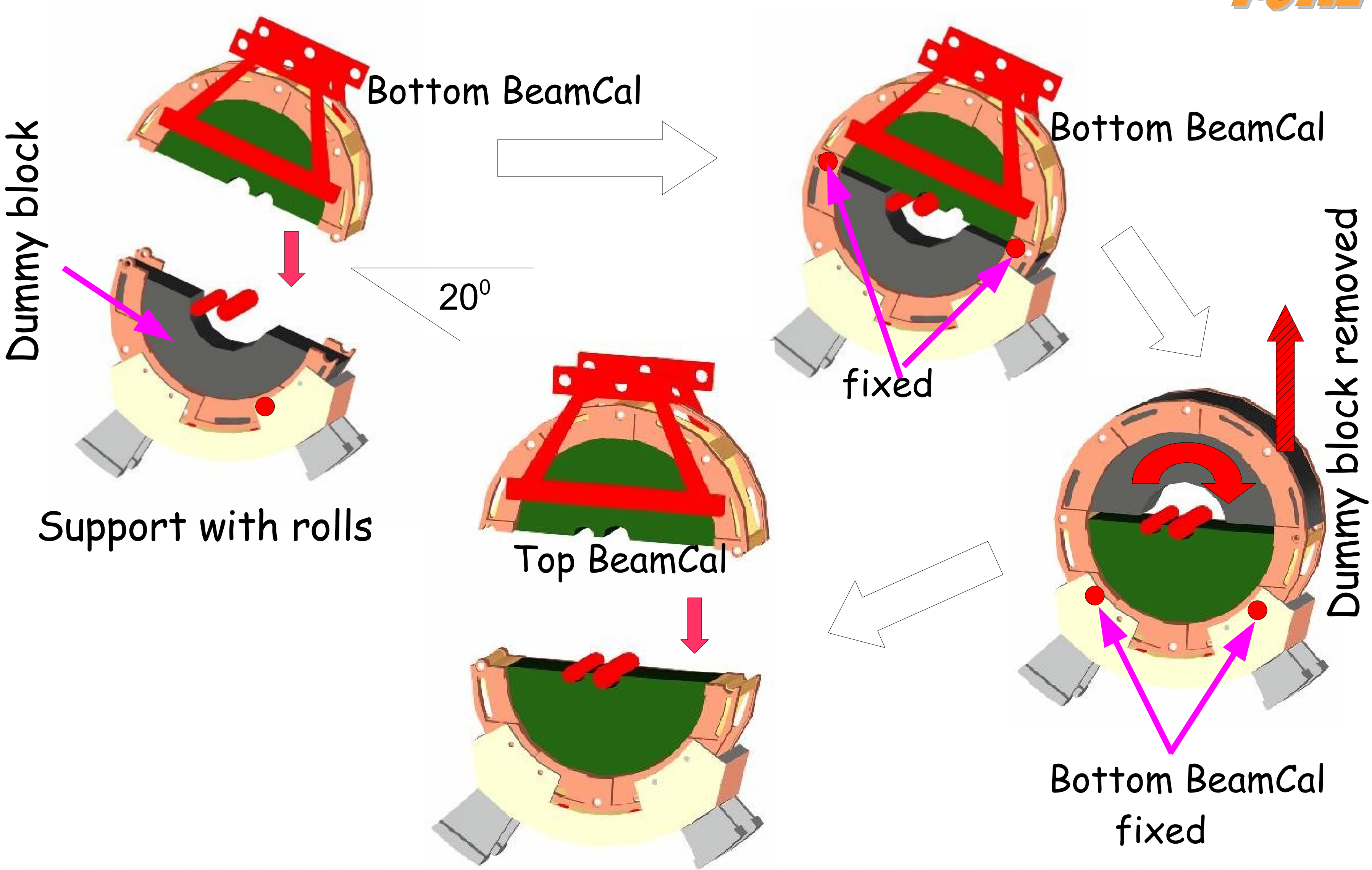


# BeamCal assembly



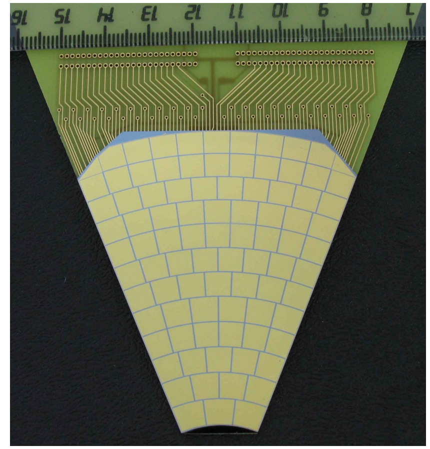
# BeamCal installation



# Sensor Materials under Investigation

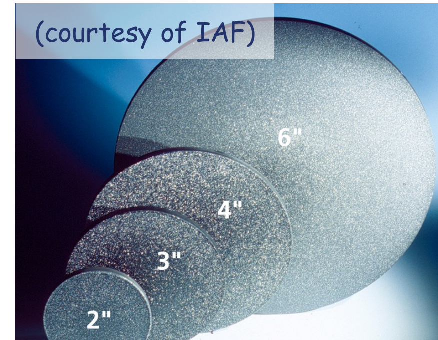
- GaAs (baseline):
  - semi-insulating GaAs, doped with Sn and compensated by Cr
  - produced by the Siberian Institute of Technology
  - available on (small) wafer scale
- pCVD diamonds:
  - radiation hardness under investigation (e.g. LHC pixel detectors)
  - high mobility, low $\varepsilon_R$ = 5.7, thermal conductivity availability on wafer scale
- SC CVD diamonds:
  - large and fast signal
  - available in sizes of few mm$^2$
- New: Sapphire, Quartz:
  - relatively cheap
  - available in large sizes (<12")

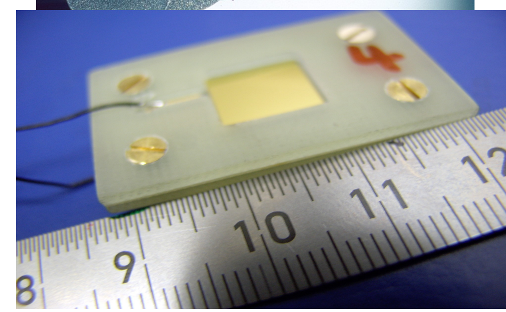
CVD = Chemical Vapor Deposition



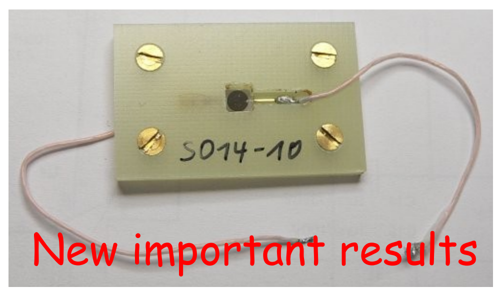
GaAs

polycrystalline CVD diamond



Single crystal CVD diamond




Sapphire

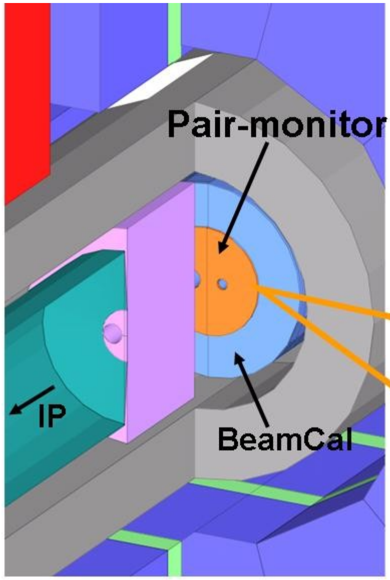
# Pair-monitor

Pair-monitor is the Silicon pixel sensor designed to measure the beam profile at the IP:

- beam size
- displacement and rotation of the beam
- the number of particles in the beam bunch

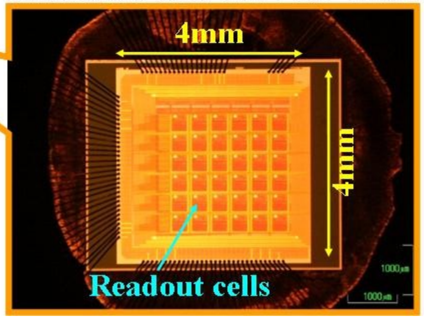
- $R_{out}$ (sensor) 100 mm
- Sensor thickness ~0.3 mm
- Tilt angle 7 mrad
- Pixel size 0.4 mm x 0.4 mm
- ~190K R/O channels
- Location: at the first layer of BeamCal

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

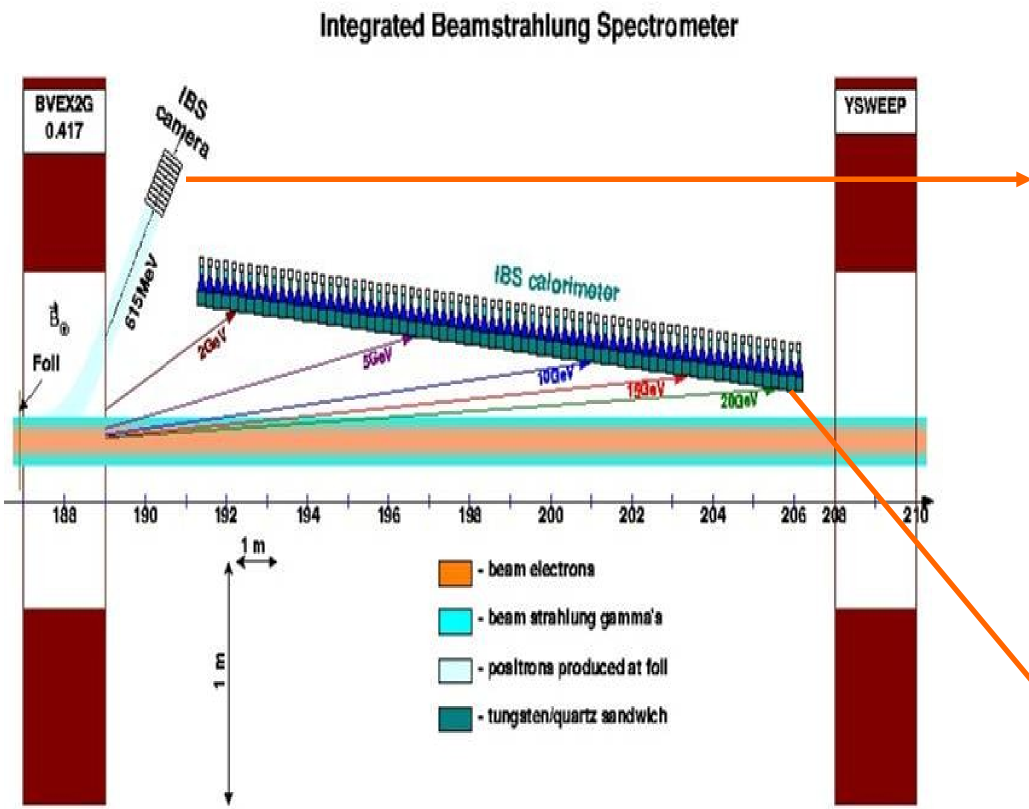


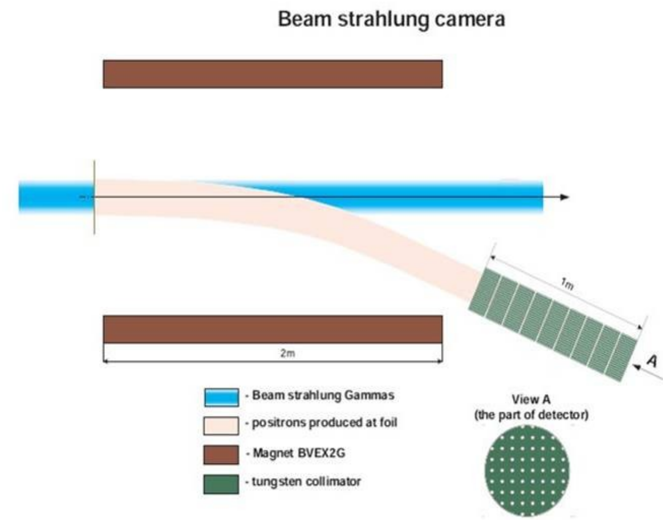

Tohoku University

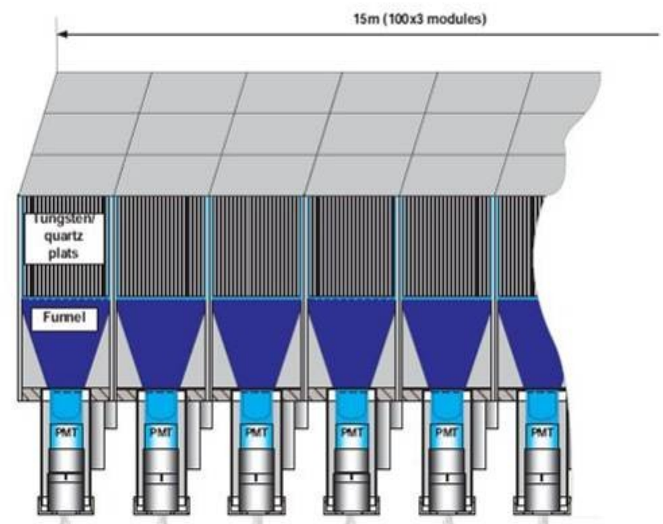
Readout ASIC for Pair-monitor



# GamCal Design




185 m from IP – practically no influence on the ILD design

Brookhaven National Lab/Upton/NY/USA

# Beampipe

**Parallel**

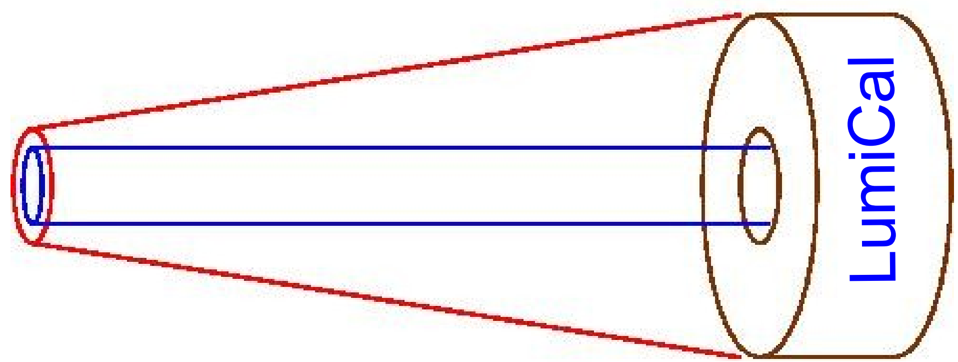
- Beryllium beampipe, with inner radius of 5.5mm, and outer radius of 6mm (the minimal radii for a 14 mrad crossing angle).

**Conical**

Vacuum?, HOM beam energy loss?

Two options were studied: conical (present design) and cylindrical versions. Systematic bias at the level of $10^{-4}$ is observed for the Be cylindrical beampipe. More studies are needed.

Even in the case of cylindrical beampipe some conical support structure is needed for cabling. Other option: conical beampipe and very thin perforated "inner" pipe – easy to pump, no high order RF modes.

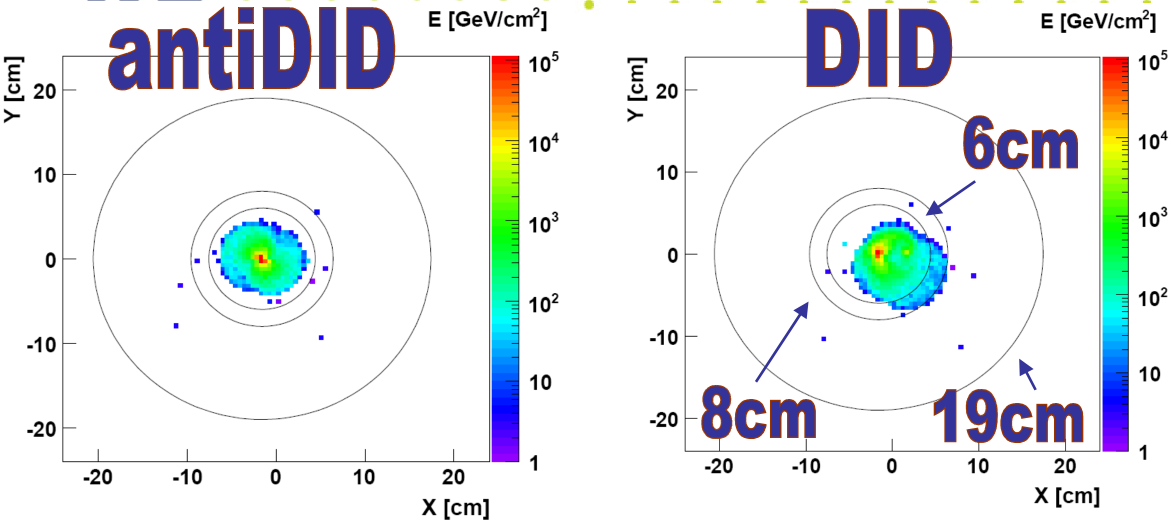


# Summary

- LumiCal: Design exists (the only option), sensor prototype ordered, Lumi-/BeamCal R/O elec. prototype under test.
- Laser alignment system – proof of principle OK, no detailed design yet (but important for the ILD inner region design!).
- BeamCal: Design exists, but no realistic solution for an extremely radiation hard sensor found. Many options are under test, GaAs is a baseline.
- Pair-monitor – design exists, combined Pair-monitor/BeamCal performance should be studied.
- GamCal is still at the design level (but no influence on ILD).
- Important ILD parameters: magnetic field configuration, beampipe design, limitation on beam-related background.
- No major changes are expected before LoI.

# Backup slides

# LumiCal Performance




- Beamstrahlung spectrum on the face of LumiCal (14 mrad crossing angle): For the antiDID case $R_{min}$ must be larger than 7cm.

$$a_{res} \approx 0.21 \sqrt{(\mathrm{GeV})}$$

$$\frac{d\sigma_B}{d\theta} = \frac{2\pi\alpha^2}{s}\frac{\sin\theta}{\sin^4(\theta/2)} \approx \frac{32\pi\alpha^2}{s}\frac{1}{\theta^3}$$

$$\int_{\theta_{min}}^{\theta_{max}} \frac{d\sigma_B}{d\theta} d\theta = 1.23 \text{ nb}$$

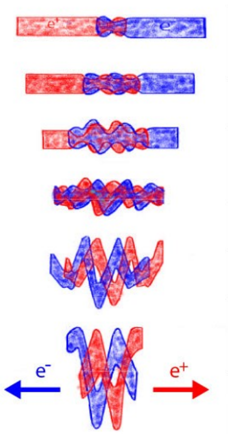
$$\left(\frac{\Delta\mathcal{L}}{\mathcal{L}}\right)_{rec} \approx 2\frac{\Delta\theta}{\theta_{min}} = 1.5\cdot 10^{-4}$$

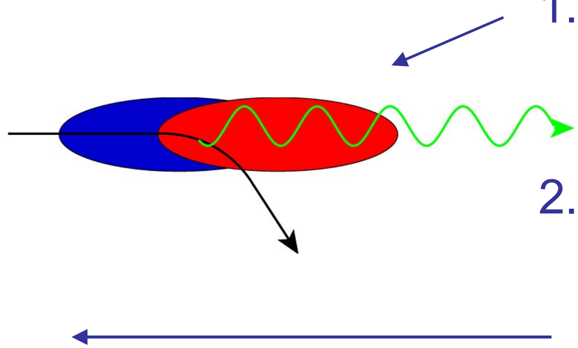
$$(\Delta\theta = 3.2\cdot 10^{-6} \text{ rad})$$

$$\left(\frac{\Delta\mathcal{L}}{\mathcal{L}}\right)_{stat} = \frac{\Delta N_B}{N_B} = \frac{\sqrt{N_B}}{N_B} = \frac{1}{\sqrt{N_B}} = 4\cdot 10^{-5}$$

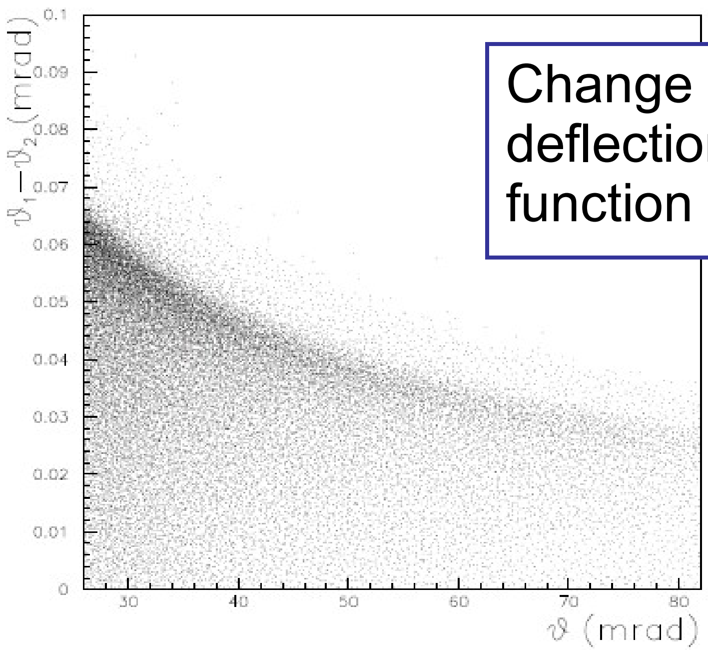
$$(500\ fb^{-1})$$

# Beam-Beam effects at the ILC



1. High beam-beam field (~kT) results in energy loss in the form of synchrotron radiation (beamstrahlung).
2. Bunches are deformed by electromagnetic attraction: each beam acting as a focusing lens on the other.




Change in the final state polar angle due to deflection by the opposite bunch, as a function of the production polar angle.

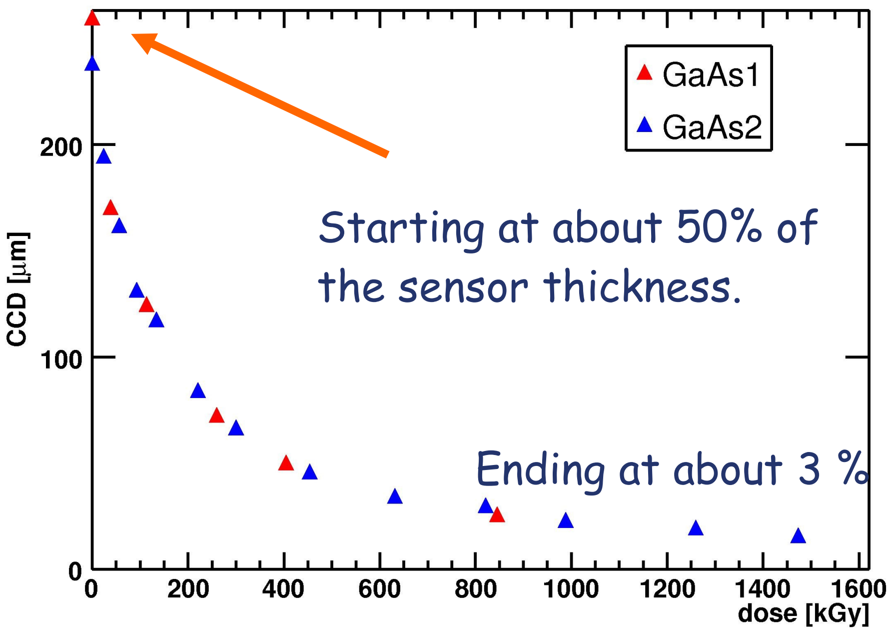
- Since the beamstrahlung emissions occur asymmetrically between e+ and $e^-$, the acolinearity is increased resulting in a bias in the counting rate.

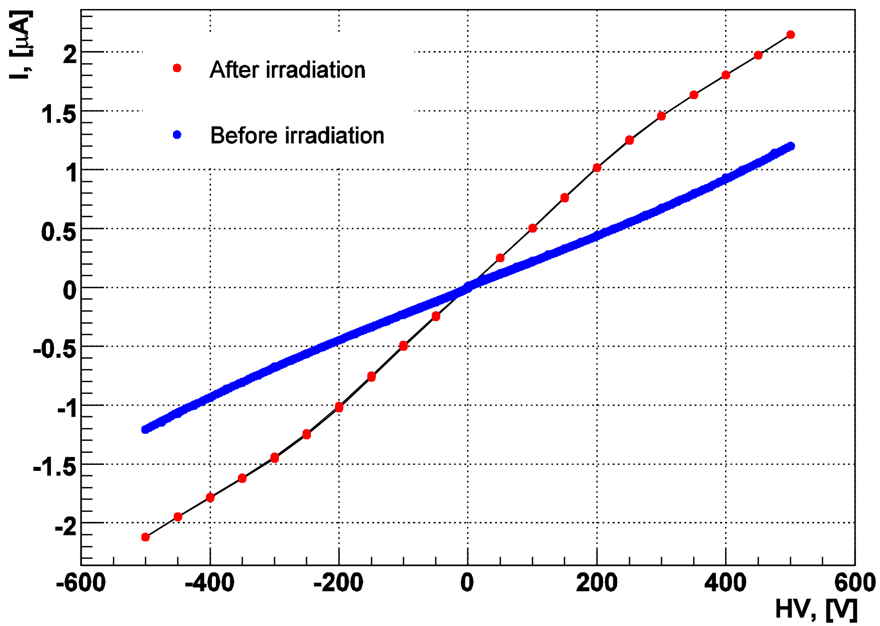
**"Impact of beam-beam effects on precision luminosity measurements at the ILC"**

– C. Rimbault et al. (http://www.iop.org/EJ/abstract/1748-0221/2/09/P09001/)

# Irradiation of GaAs

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



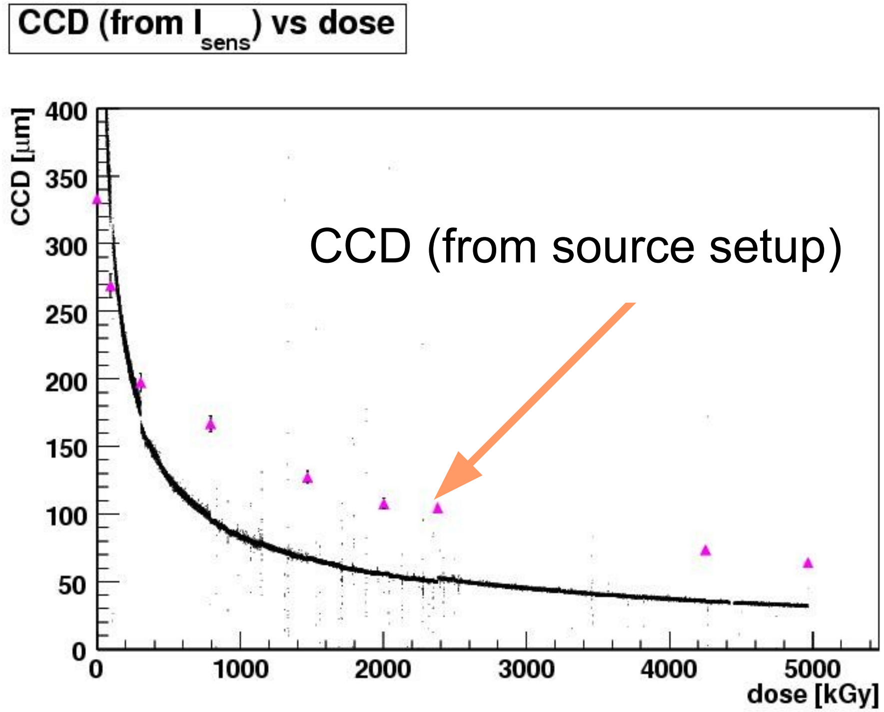

CCD vs Dose

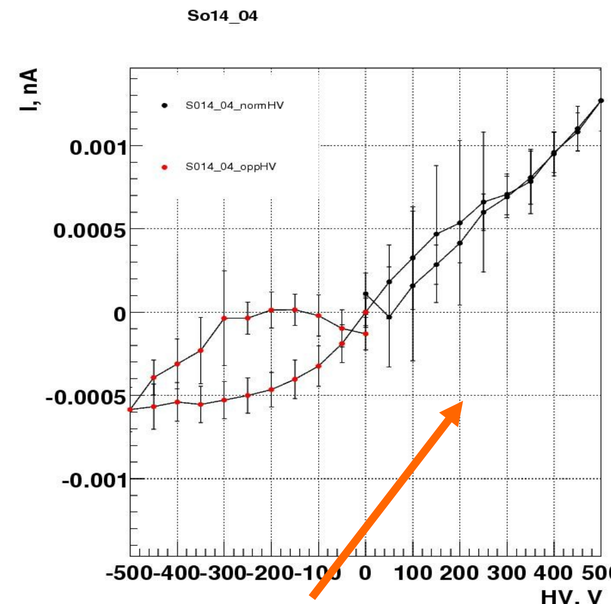
IV before and after irradiation
Increase by about 2

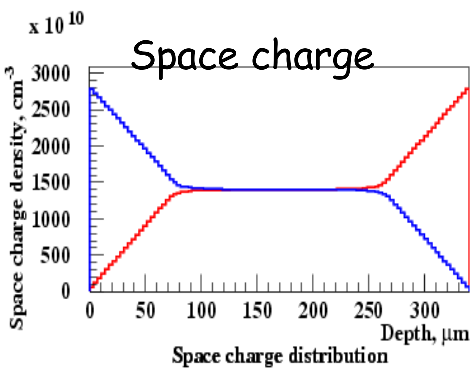
Proc. of the IEEE NSS07
in preparation

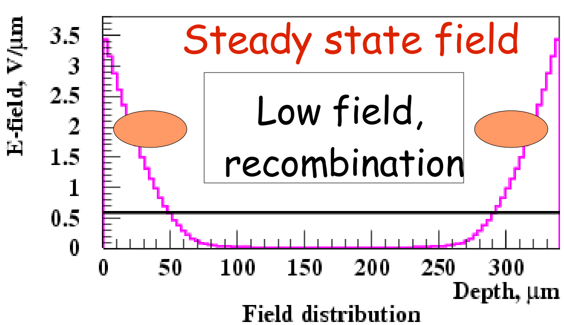
# Irradiation of single crystal CVD Diamond

## After absorbing 5 MGy: CVD diamonds still operational.




- Very low leakage currents (~pA) after the irradiation.
- Decrease of the charge collection distance with the dose.
- Generation of trapping centers due to irradiation. Traps release?
- Strong polarization effects !!!

# $^{90}$Sr setup: CCD time dependence



- Diamond sCVD sensor after 5 MGy

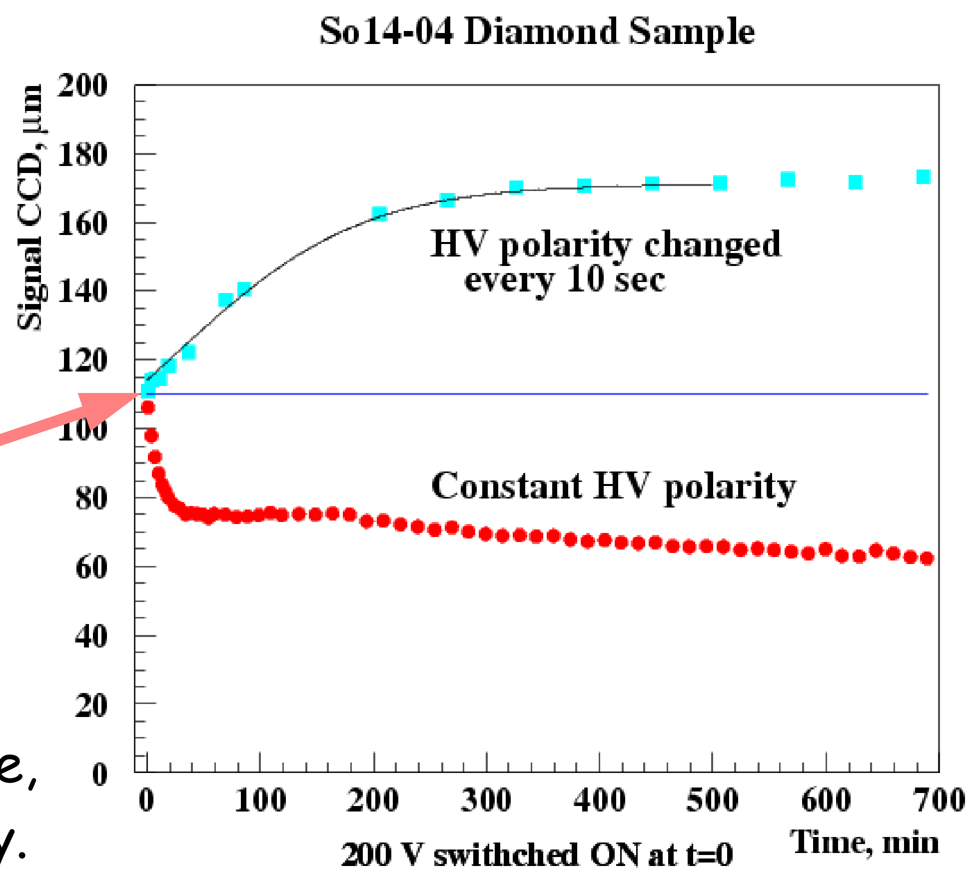
$$CCE_0 = \frac{2}{aD} \cdot \left(1 - \frac{1-\exp(-aD)}{aD}\right)$$

$$a = \frac{\pi R^2_{trap}}{l_0} \cdot \frac{n_{free}}{N}$$

CCD at t=0 allows to extract $n_{trap} R^2_{trap}$ value

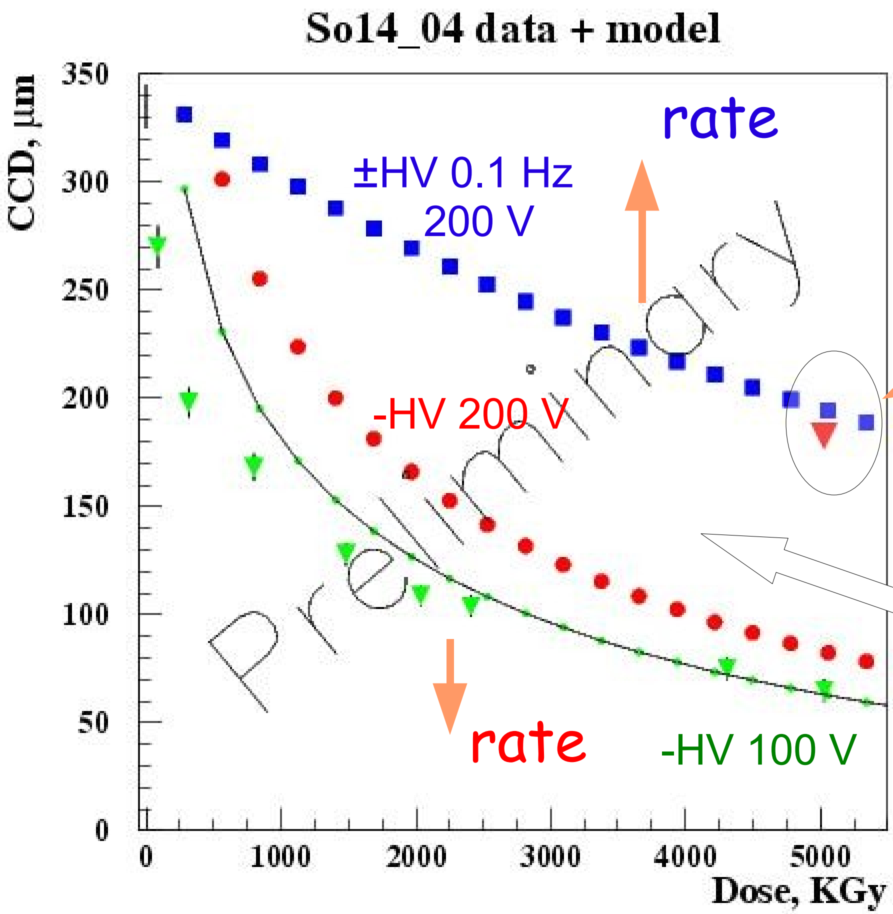
Steady state CCD is sensitive to $n_{trap}$, $T_0$ and signal rate

Curve shape depends on the rate, trap properties and trap density.

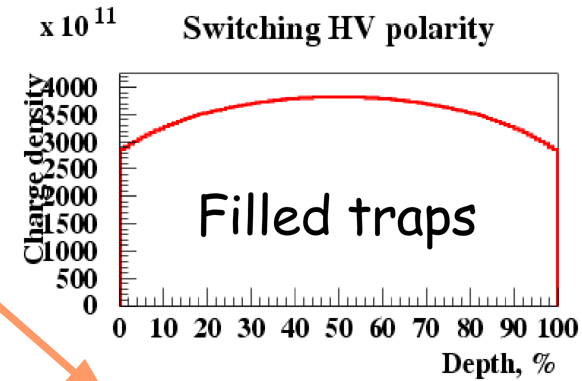


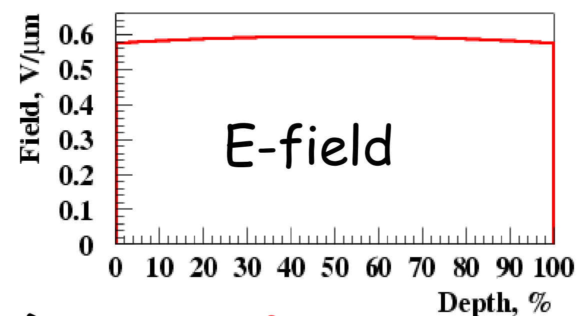
# Irradiated single crystal CVD Diamond

Regular change of HV polarity to avoid polarization: almost uniform E-field




cross-check




$n_{ntraps}$ = k Dose + $n_0$ ?

More experimental studies needed