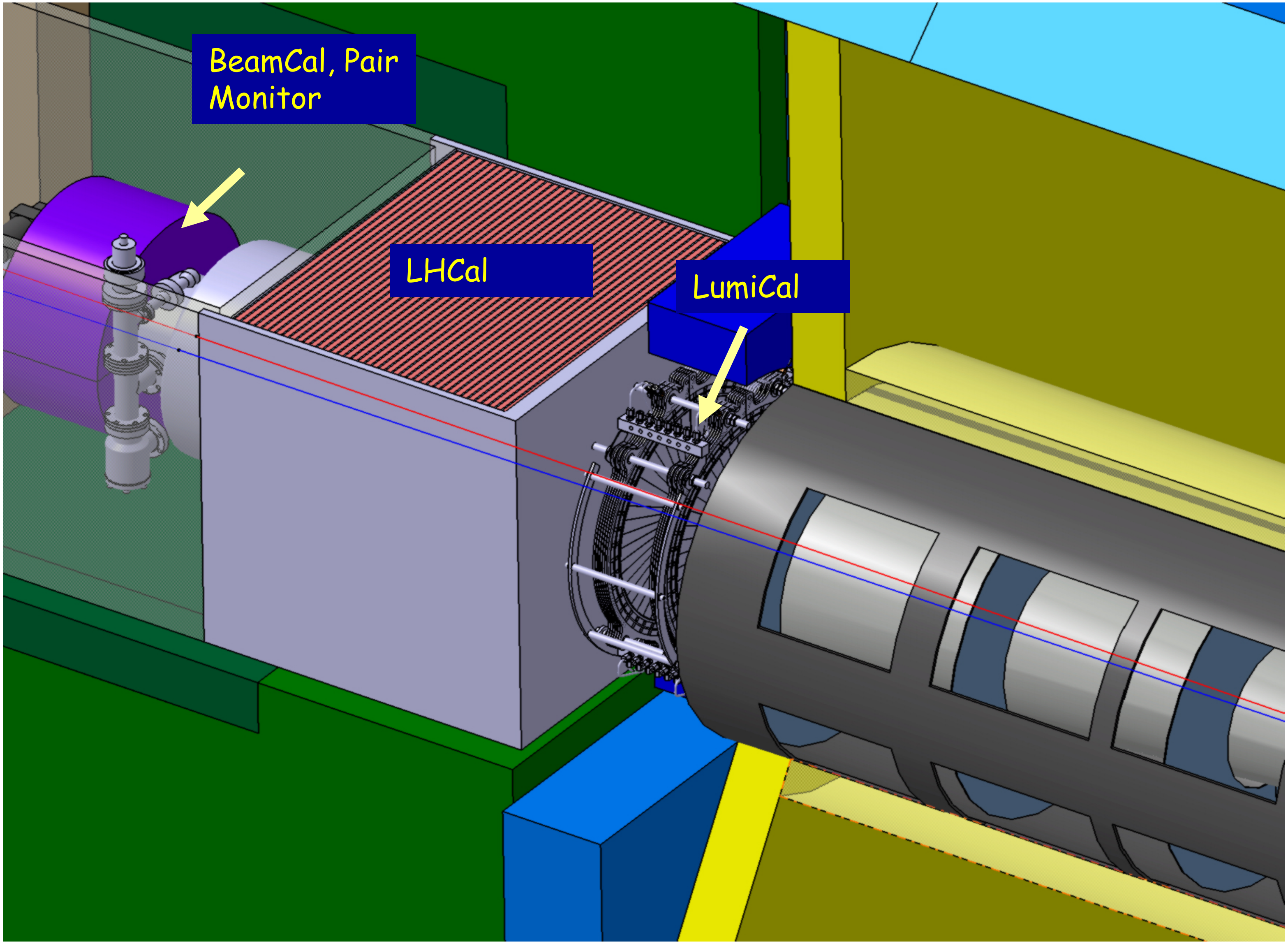
Large bandgap solid state sensors – some new developments

Sergej Schuwalow, DESY Zeuthen

On behalf of FCAL collaboration

Very Forward Region of the ILD Detector



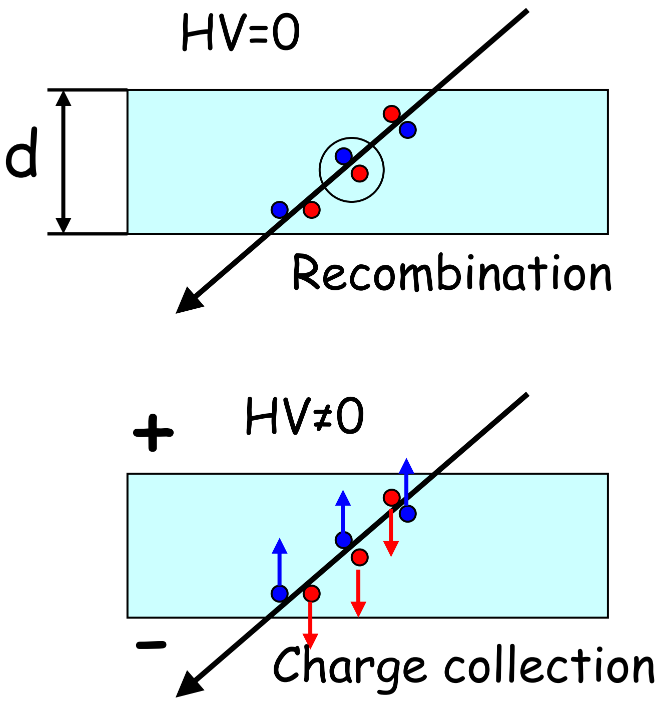
Content

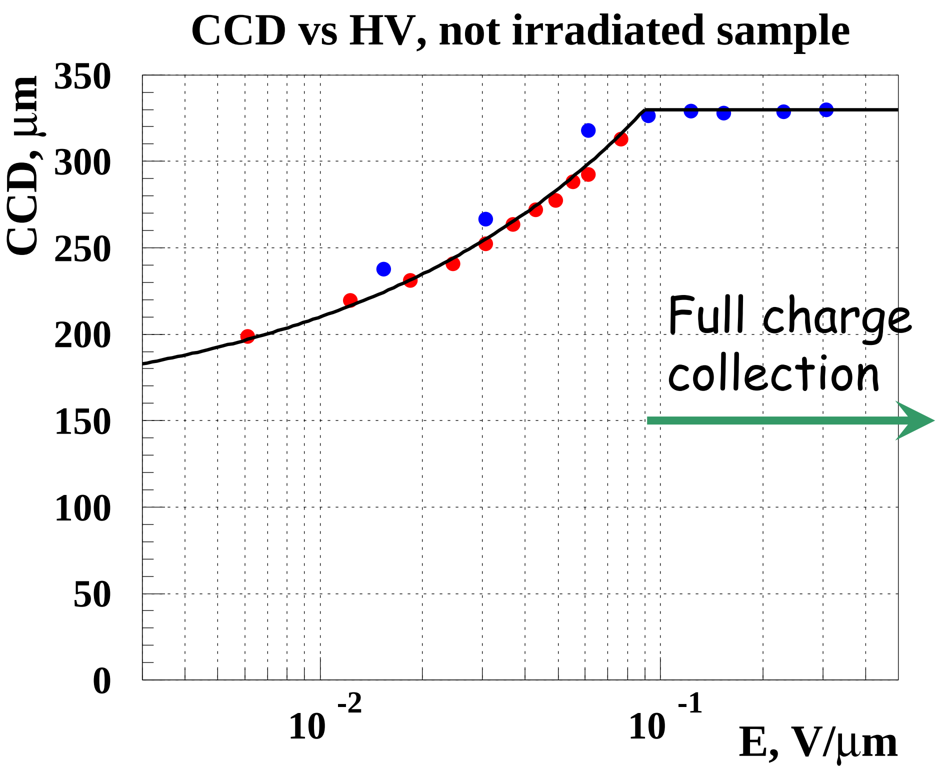
- Charge collection in the diamond detector
- Polarization effects
- CCD vs dose – test beam studies
- Beam pumping tests
- Measurements at PITZ, application at FLASH
- Sapphire and Quartz sensors – first results
- Summary

'Ideal' crystal charge collection

$CCE = Q_{collected}/Q_{produced}$ $CCD = CCE*d$

- Charge collection efficiency depends on E

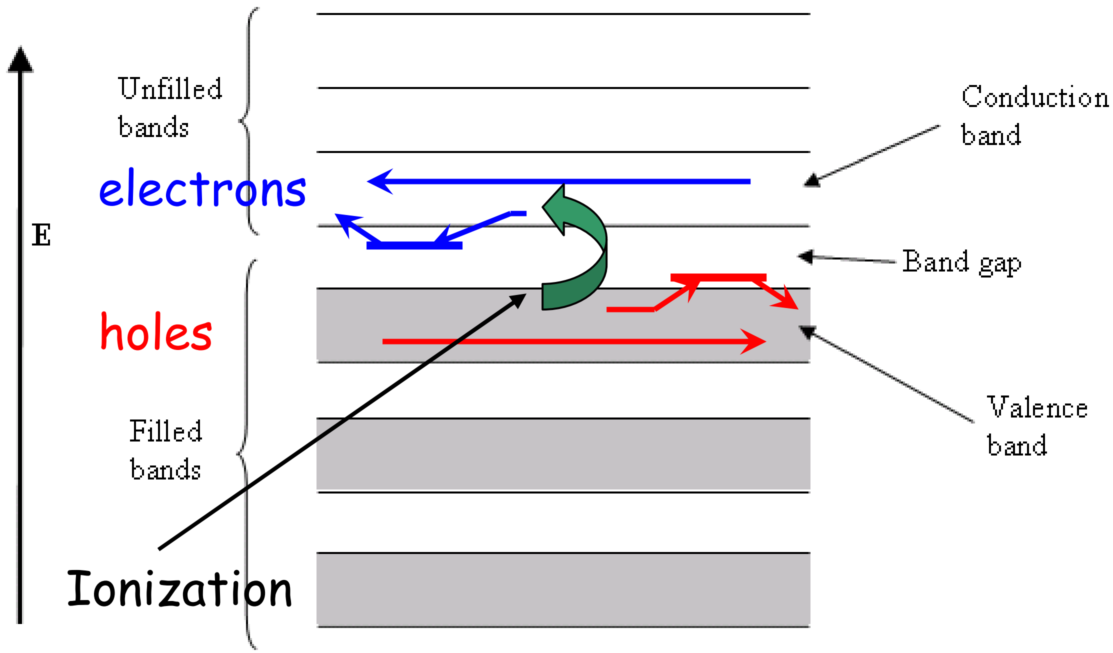




Radiation damaged crystal

- Radiation causes local damages of the lattice structure
- These local damages (traps) are able to capture free charge carriers and release them after some time

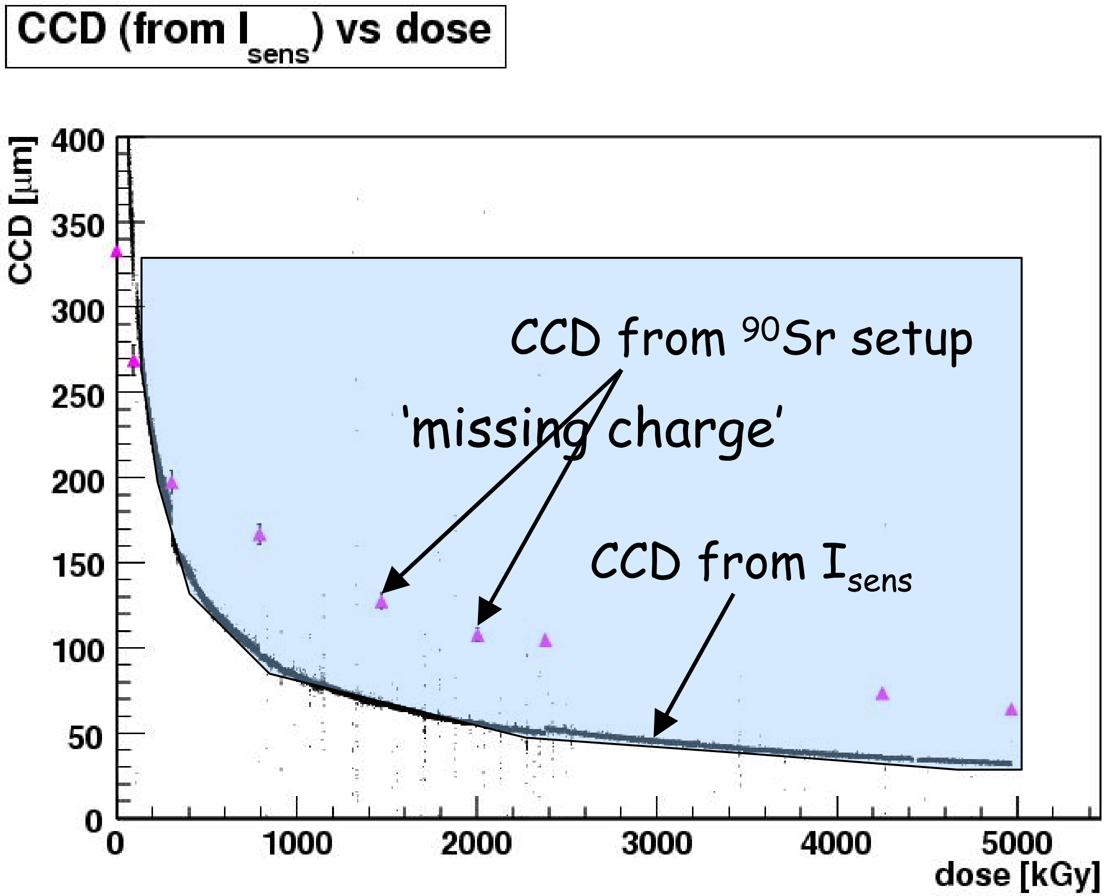
- Assumptions we are using:
- Trap density is uniform (bulk radiation damage)
- Traps are created independently (linearity vs dose)



Irradiation of scCVD Diamond

DALINAC, TU-Darmstadt June 2007

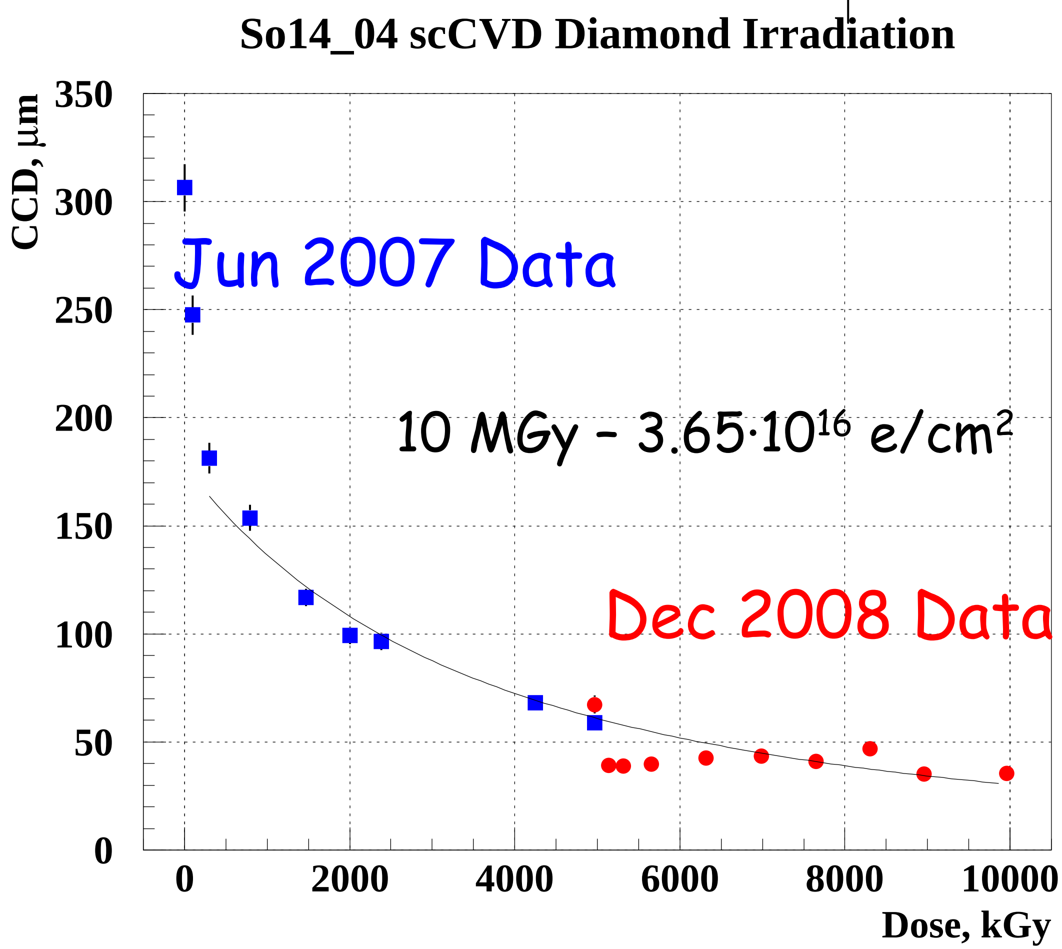
- After 5 MGy dose diamond detector is operational
- CCD is decreasing with the absorbed dose
- Generation of trapping centers due to irradiation
- Traps release?
- $CCD_{current}$ < CCD_{MIP}?
- Too high 'missing charge' ~N_{atoms} in the sample
- Pure trapping mechanism is contradictory
- Recombination is important
- Polarization?



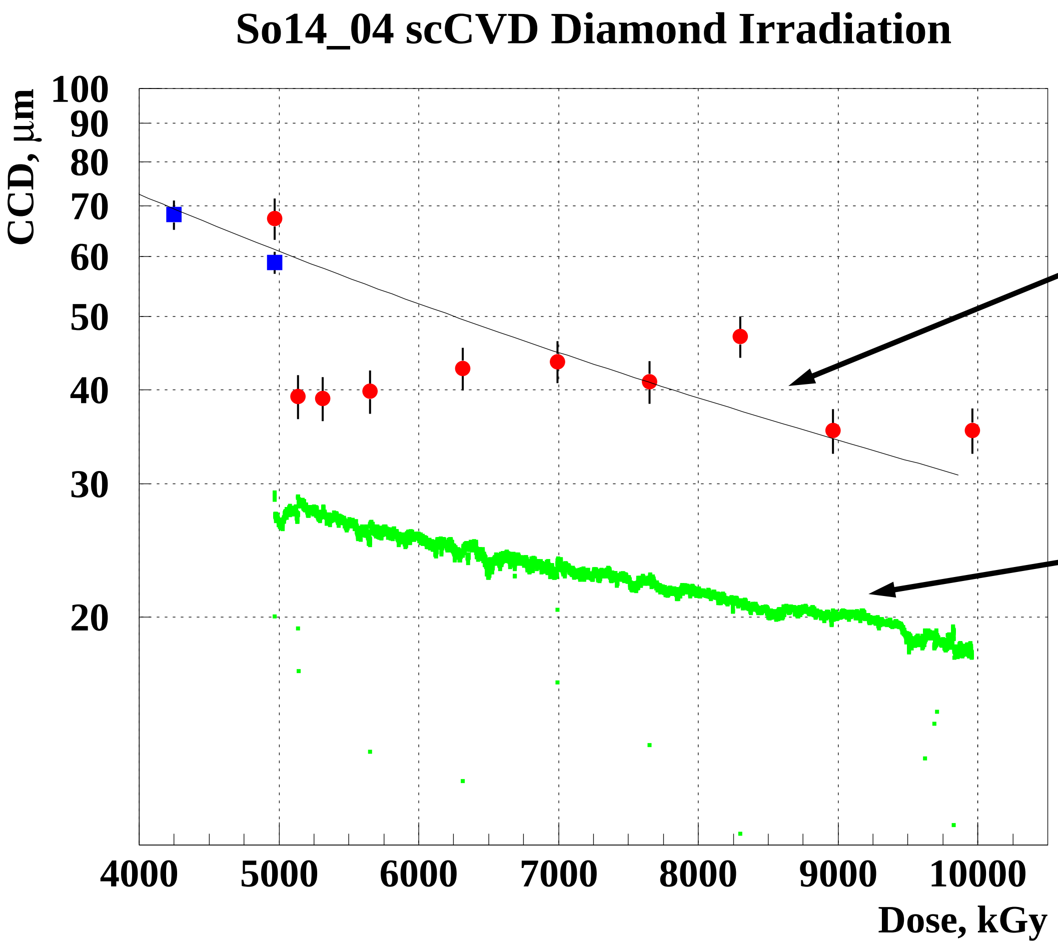
Irradiation of scCVD Diamond

Continued in December 2008

- No annealing!
- 1.5 years, a lot of tests with ^{90}Sr Source, UV-light, several TSC measurements
- After 10 MGy absorbed dose MIP signal is still detectable
- Leakage current is very small ~pA



CCD vs dose

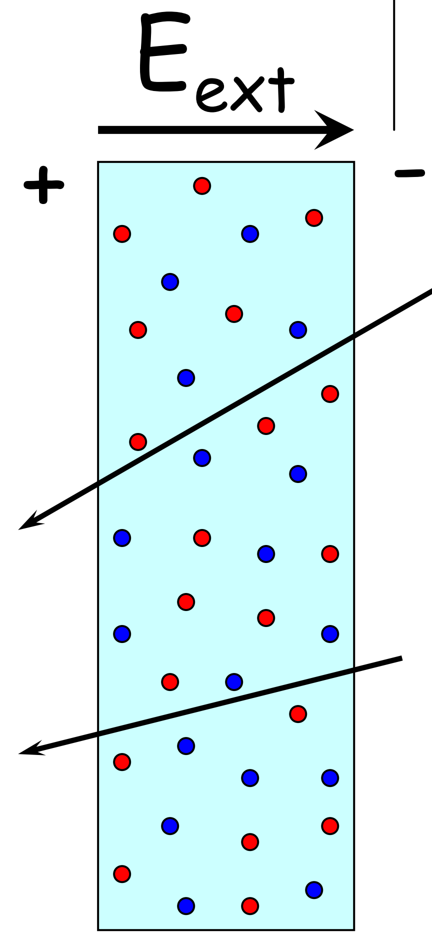


CCD from ^{90}Sr source setup

CCD derived from detector current measurements

Polarization origin

- Uniform generation of e-h pairs
- Asymmetry is introduced by the applied electric field
- Specific free charge carrier density is largest near detector edges
- Asymmetric trap filling according to charge carrier density
- Space charge creation in the bulk of the detector
- Compensation of the external field by space charge
- Polarization



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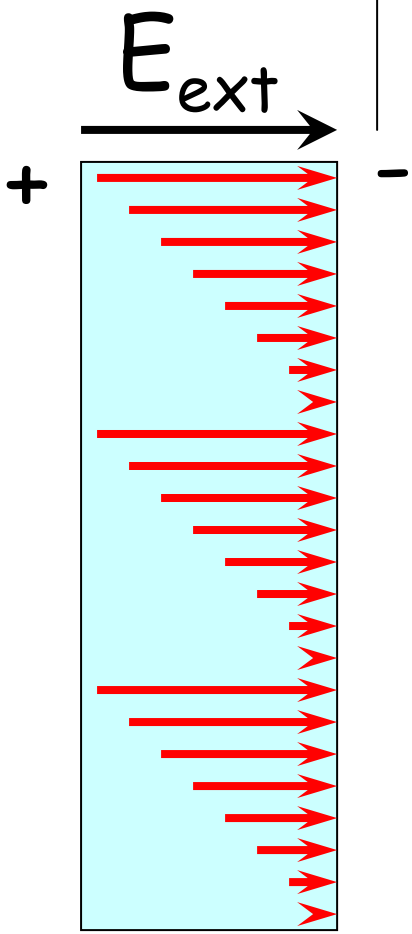

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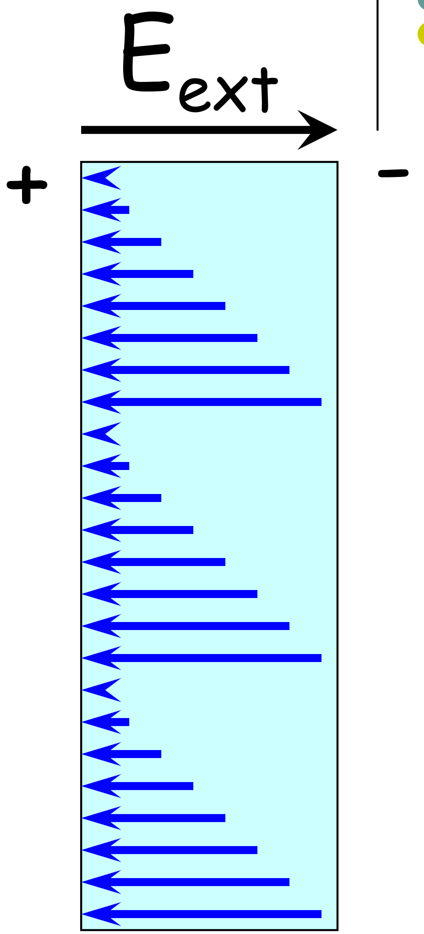

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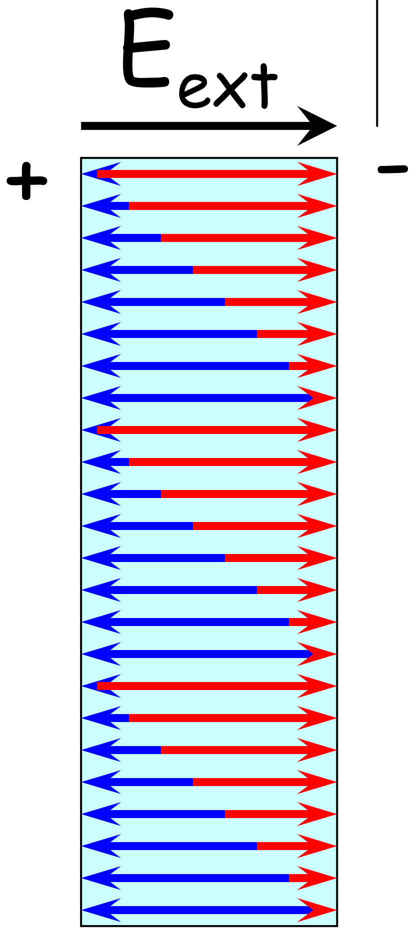

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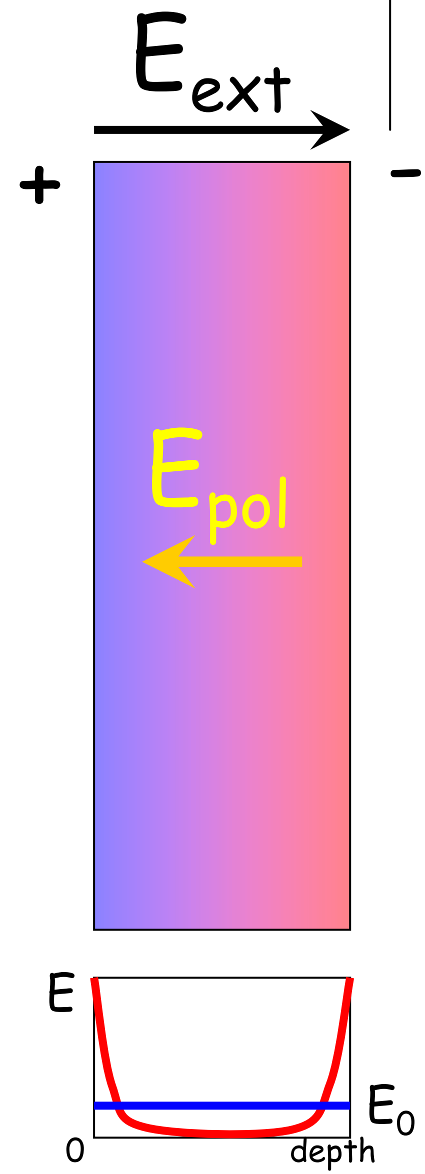
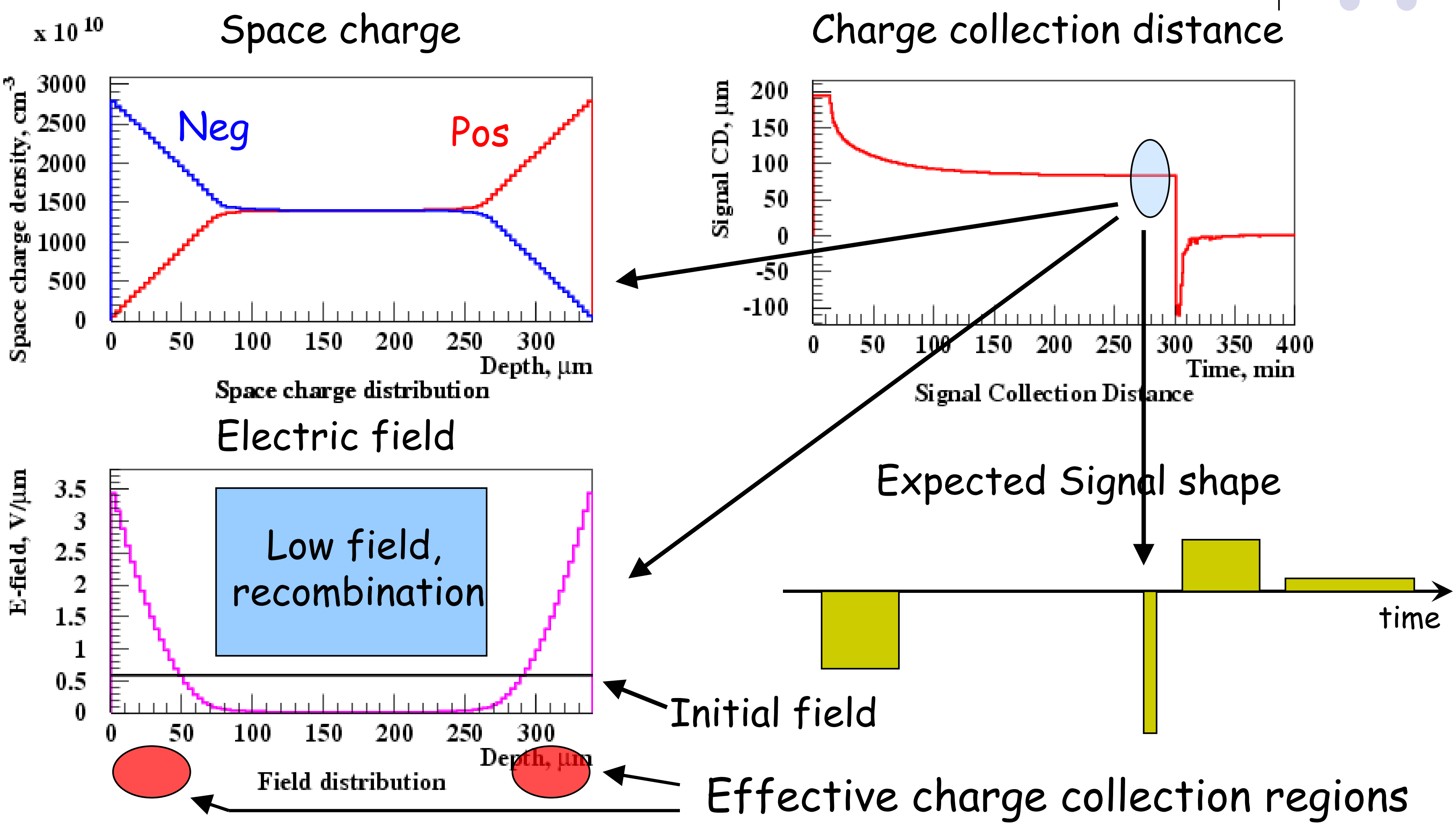


Model: 340 µm scCVD diamond after 5 MGy CCD time dependence



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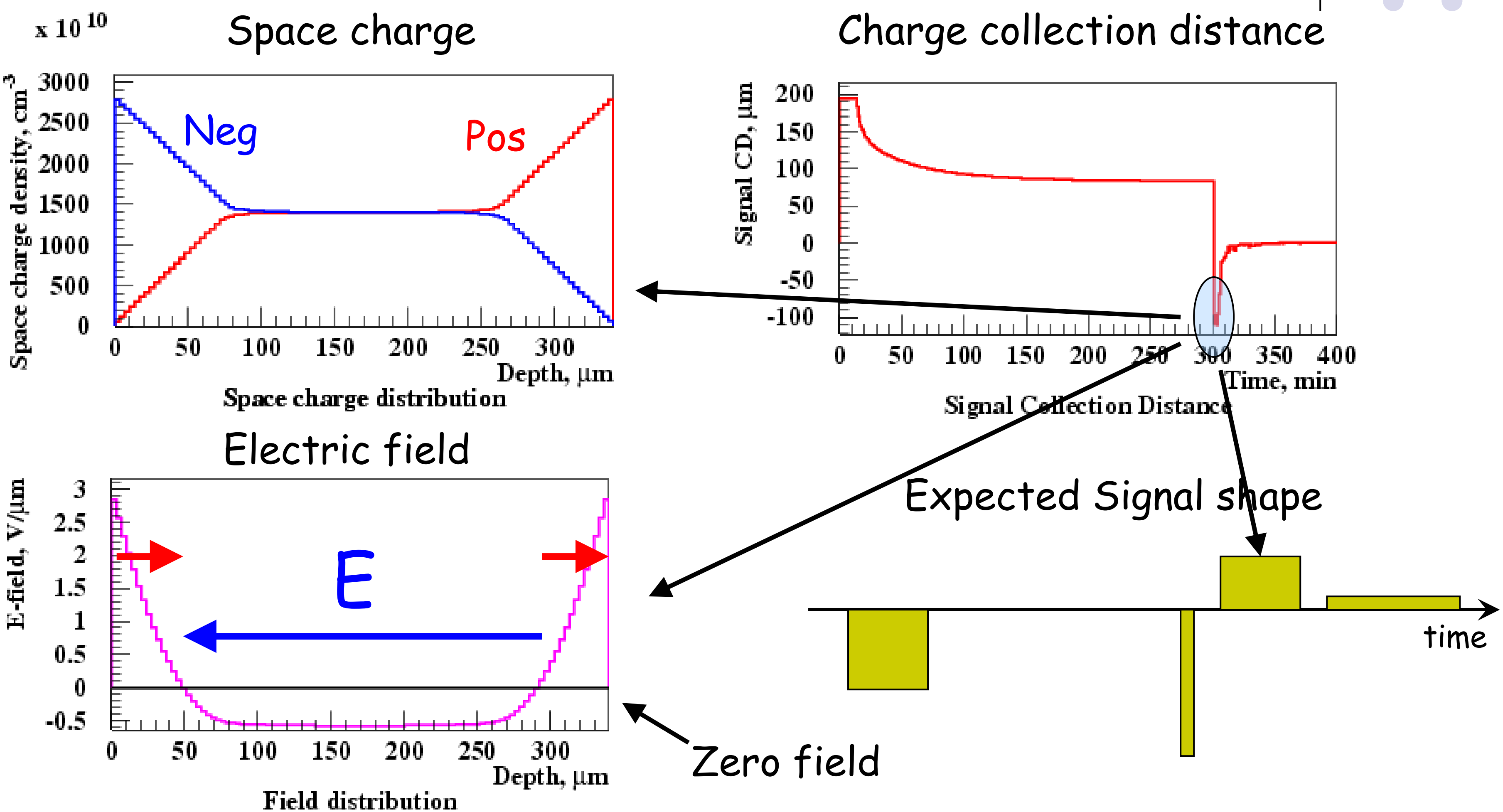

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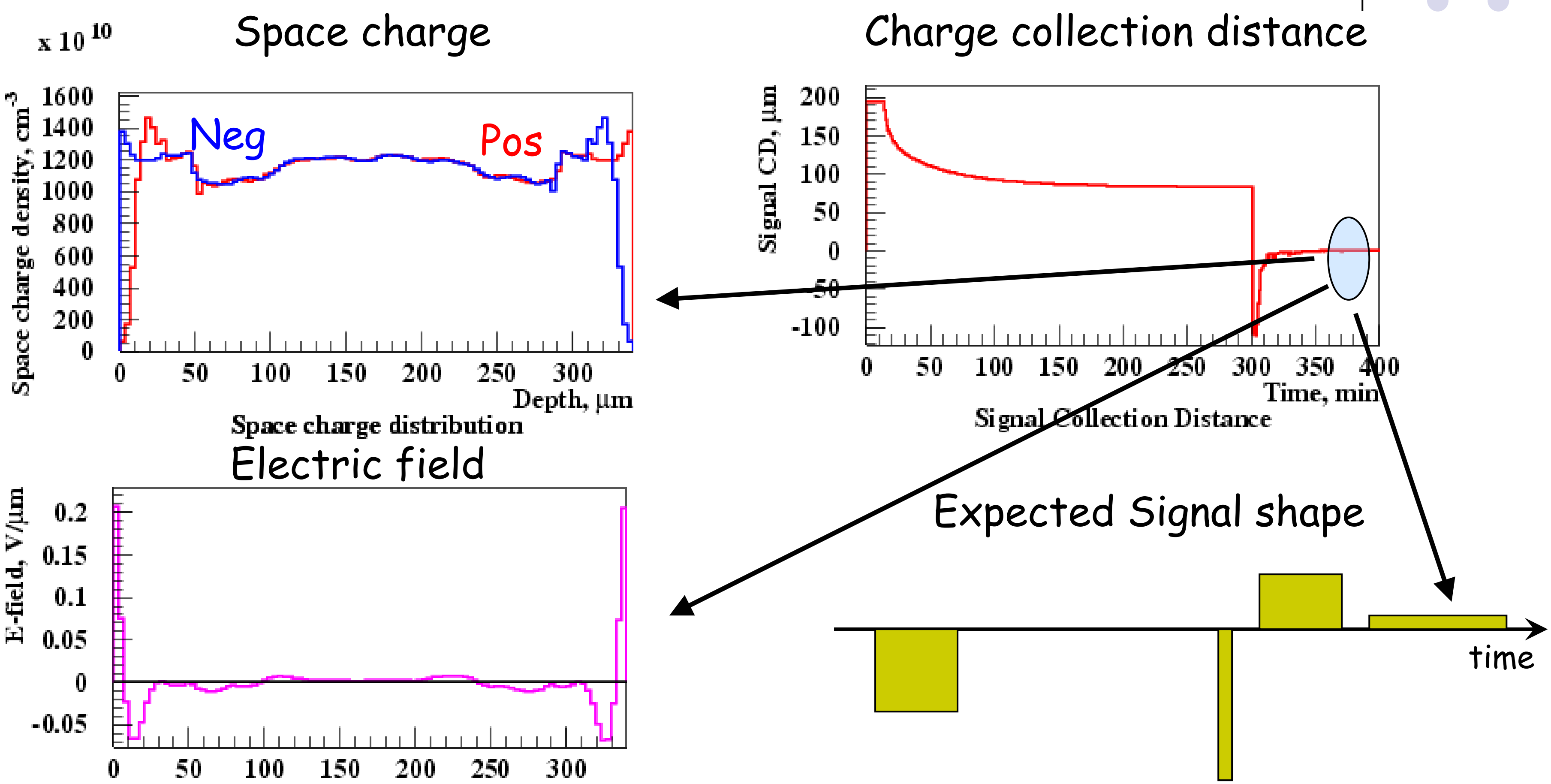
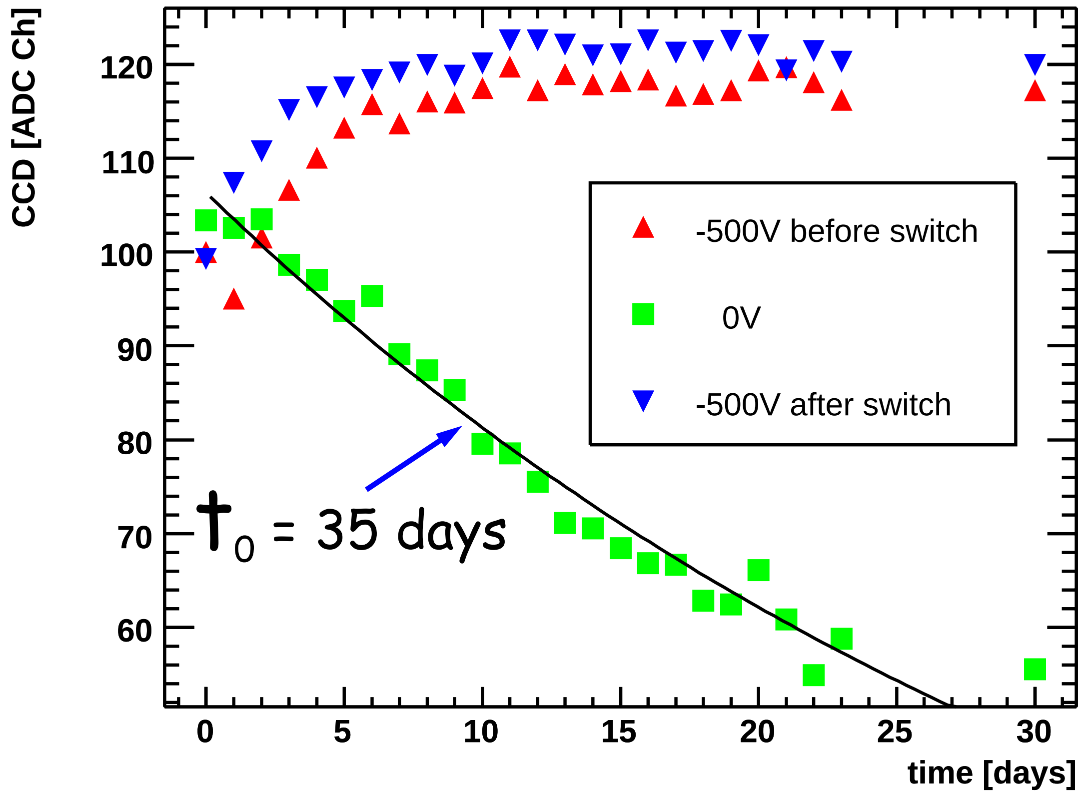


To be confirmed!

Long-term signal evolution

- Try to minimize an influence of the measurement onto the filled trap distribution
- Use the source only for short CCD evaluation runs
- Polarization is seen even after 1 month after the initial pumping – long living traps, possibility to fill all of them!

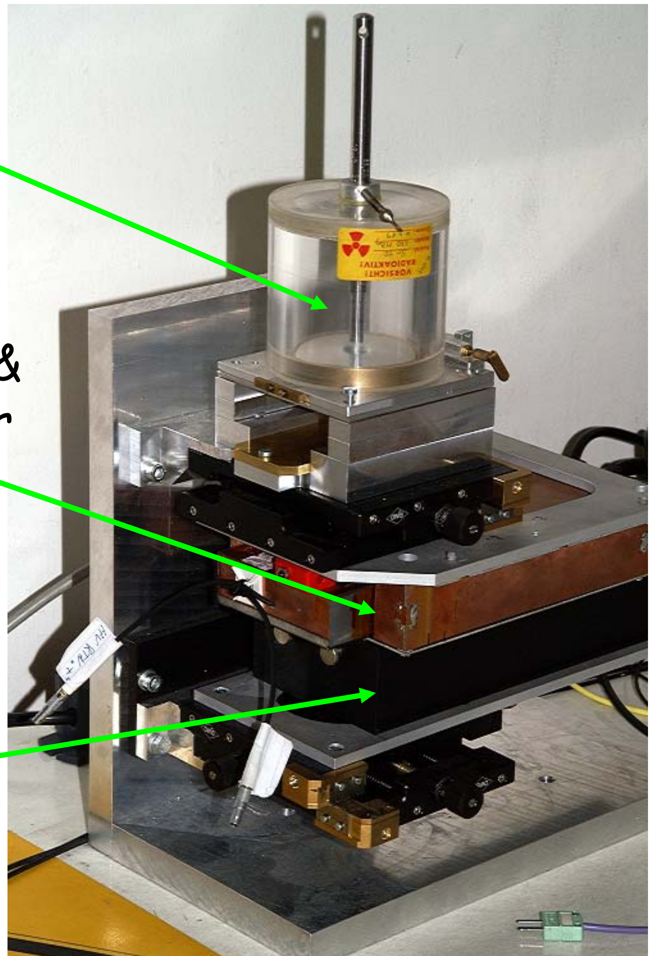


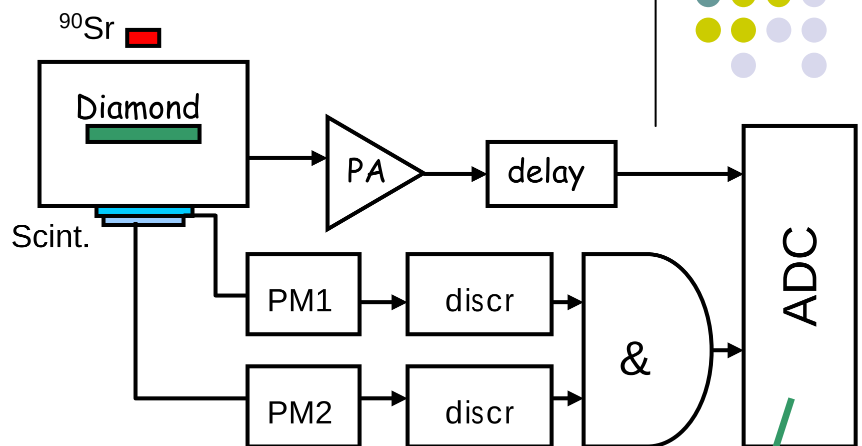
MIP Response of scCVD Diamond

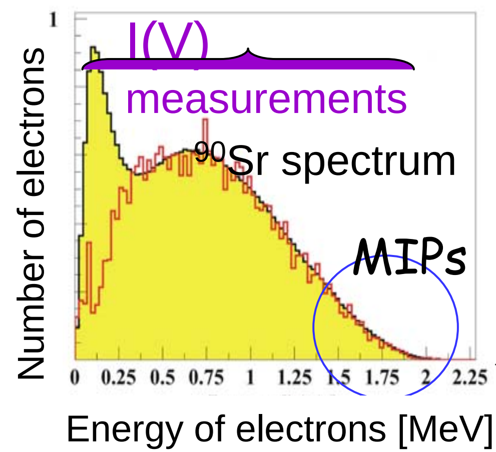
^{90}Sr Source

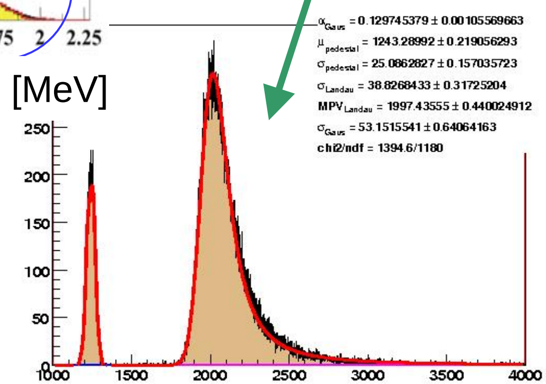
Sensor box &
Preamplifier

Trigger box



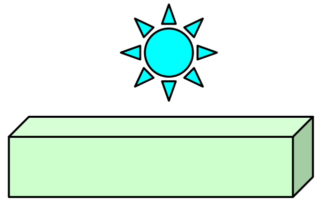




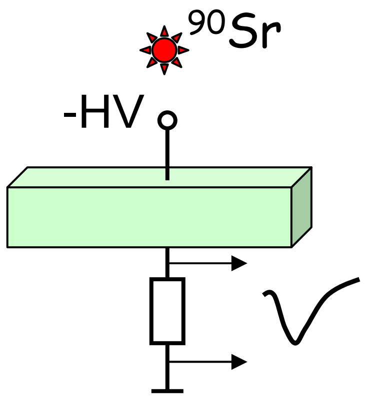


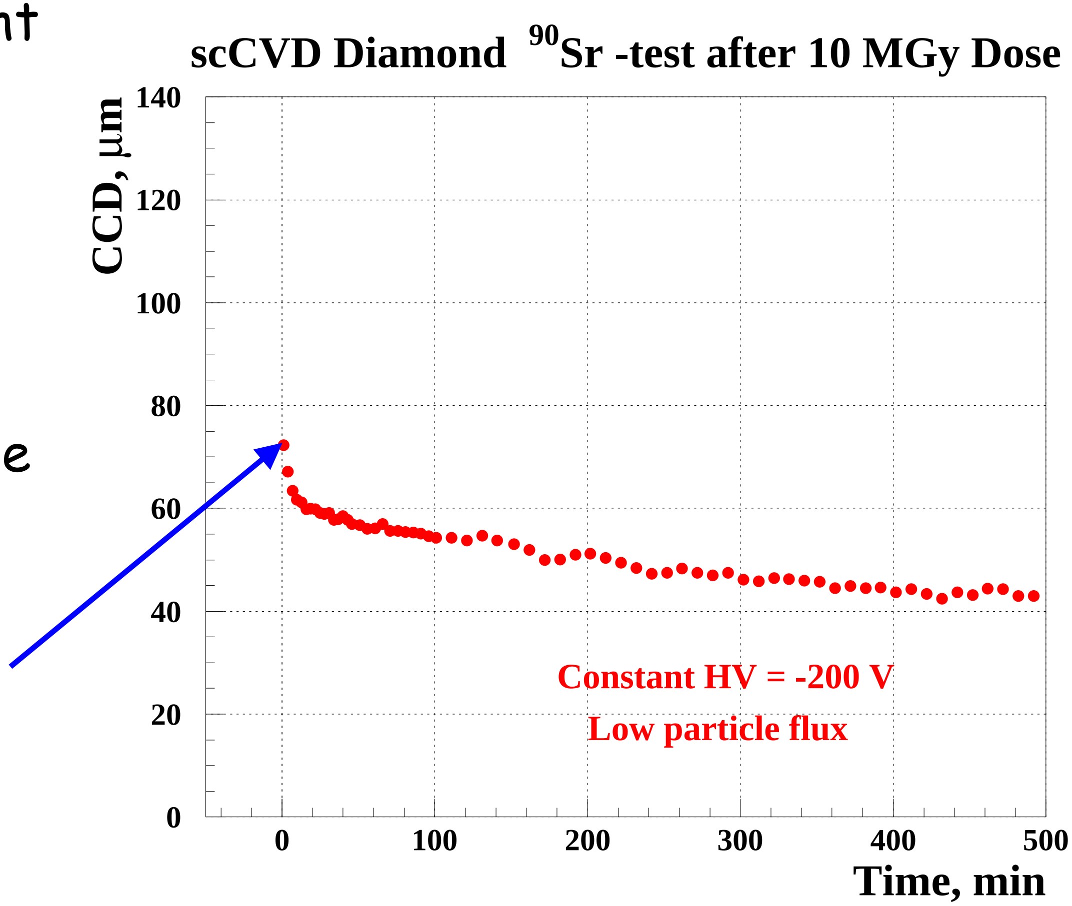
Damaged Sensor under ^{90}Sr Source: CCD vs time

Illuminate by UV-light to free all traps



Apply HV and source





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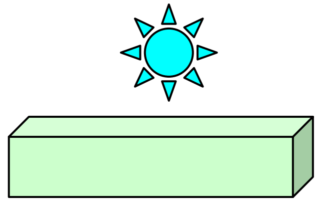

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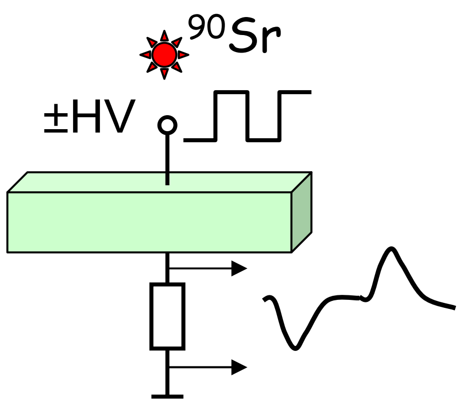

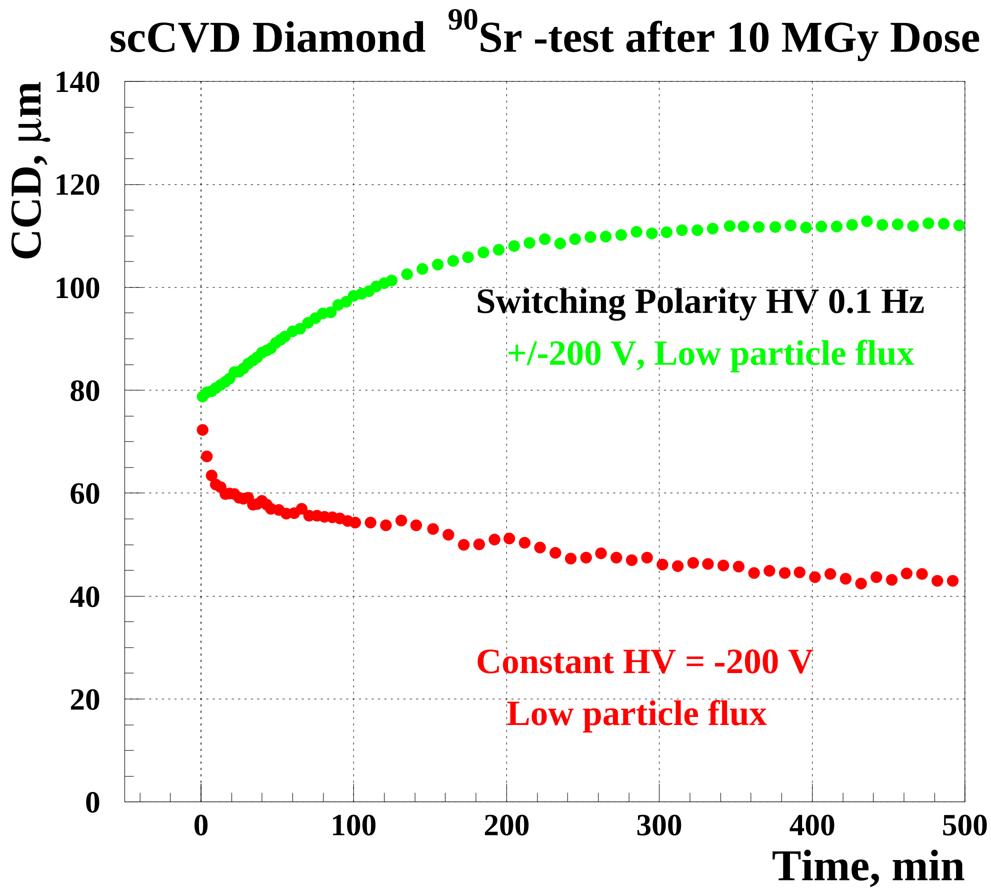

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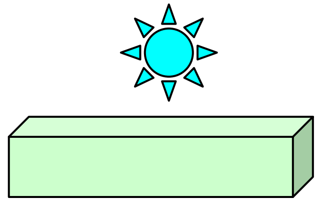

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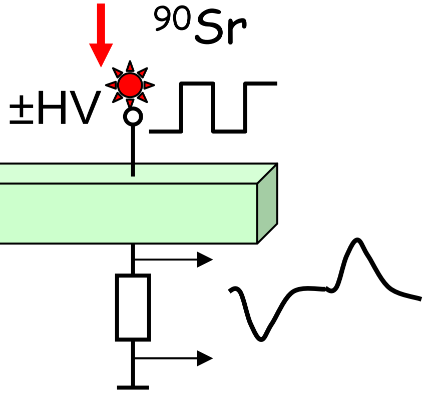

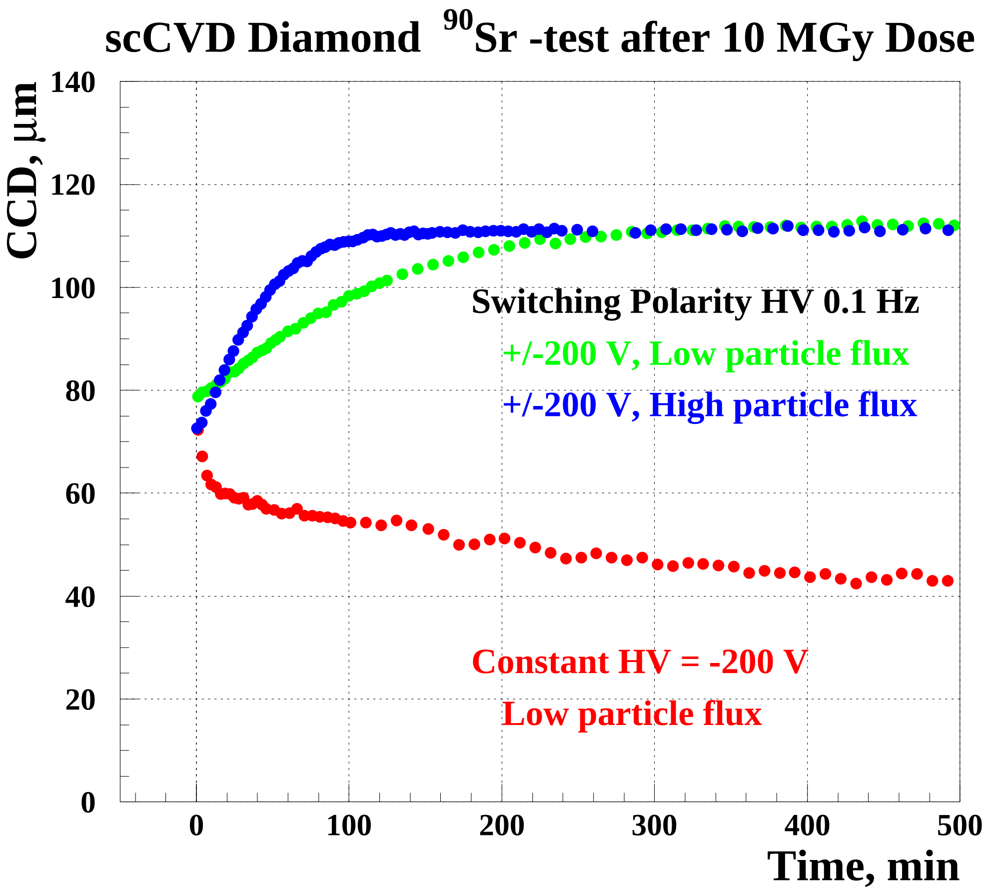

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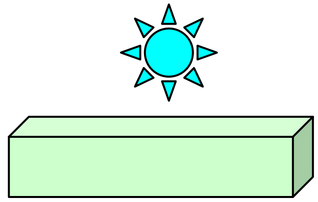

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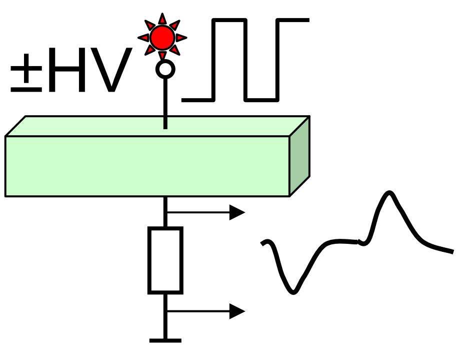
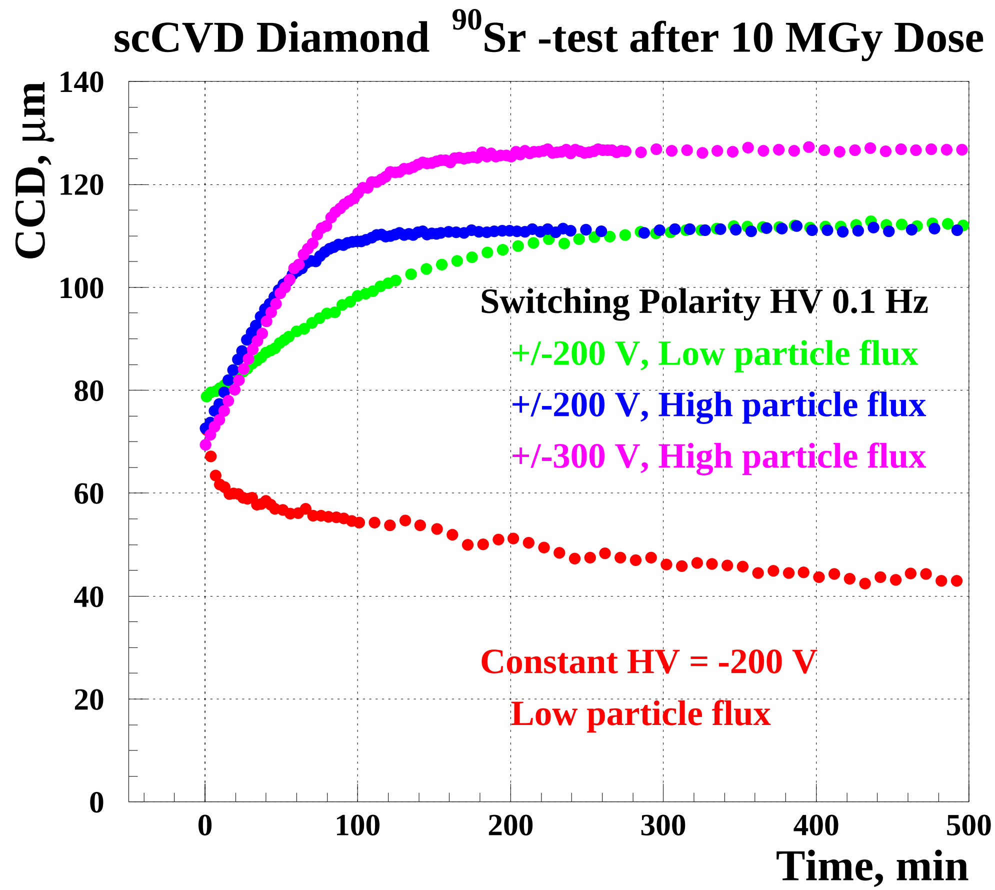
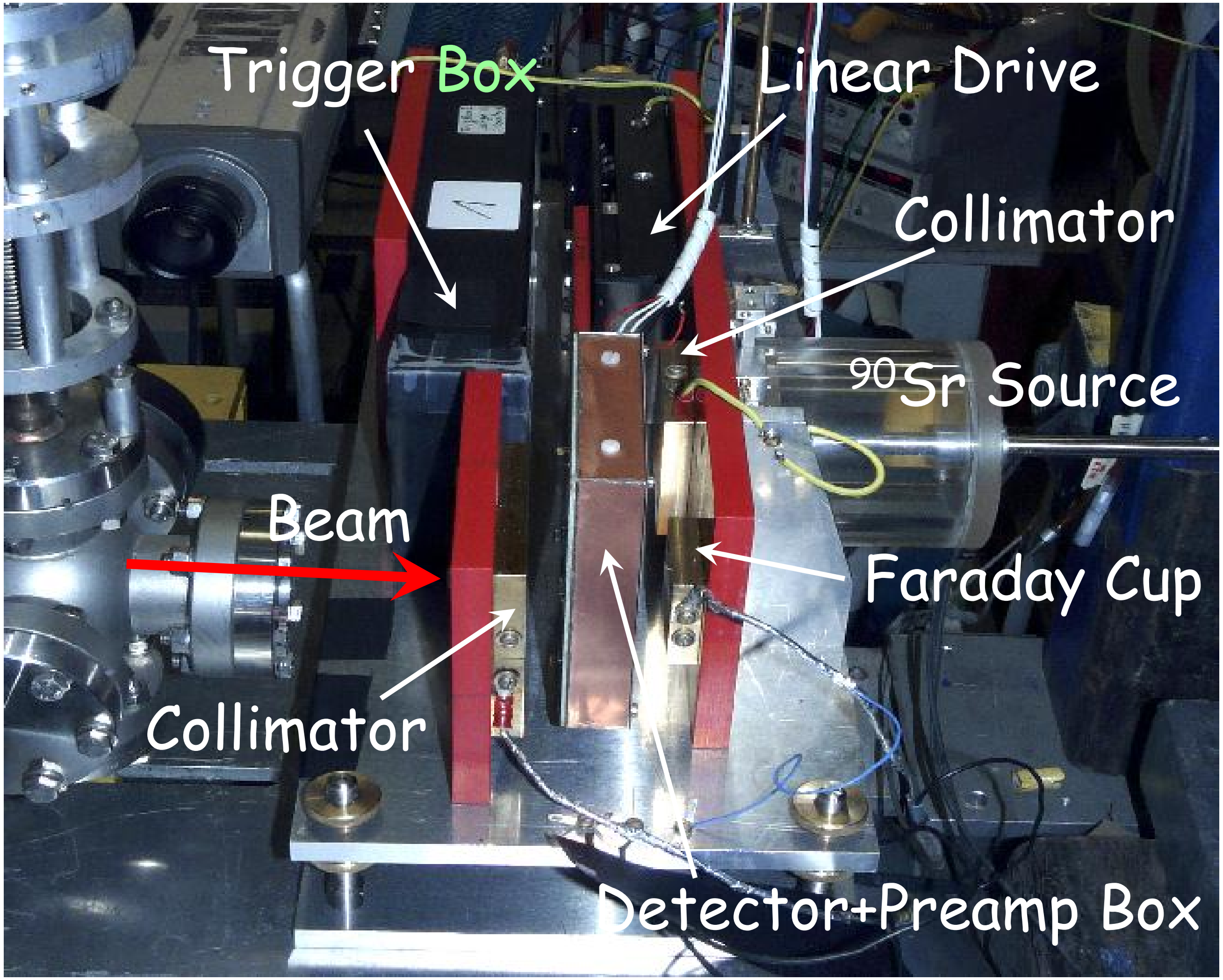




Short living traps

Beam Pumping Test



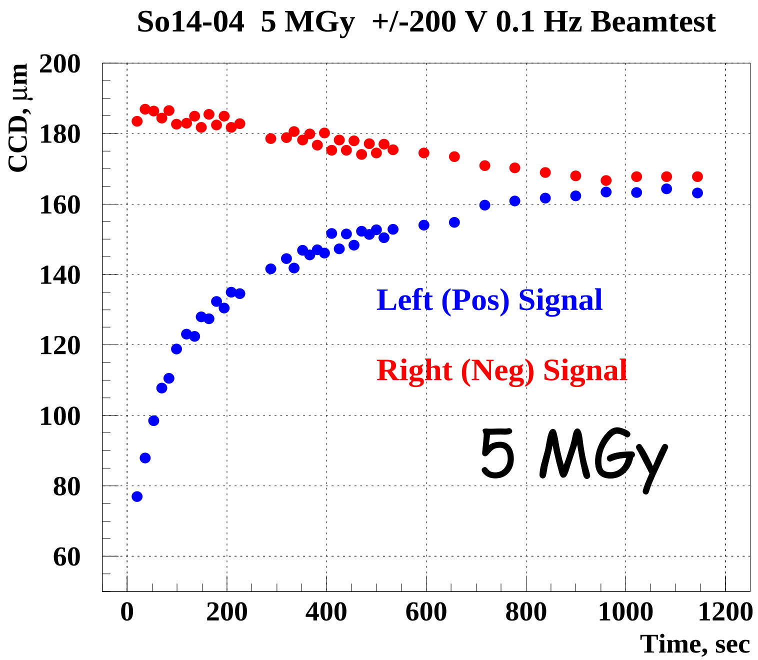
Use intensive beam to fill up short living traps

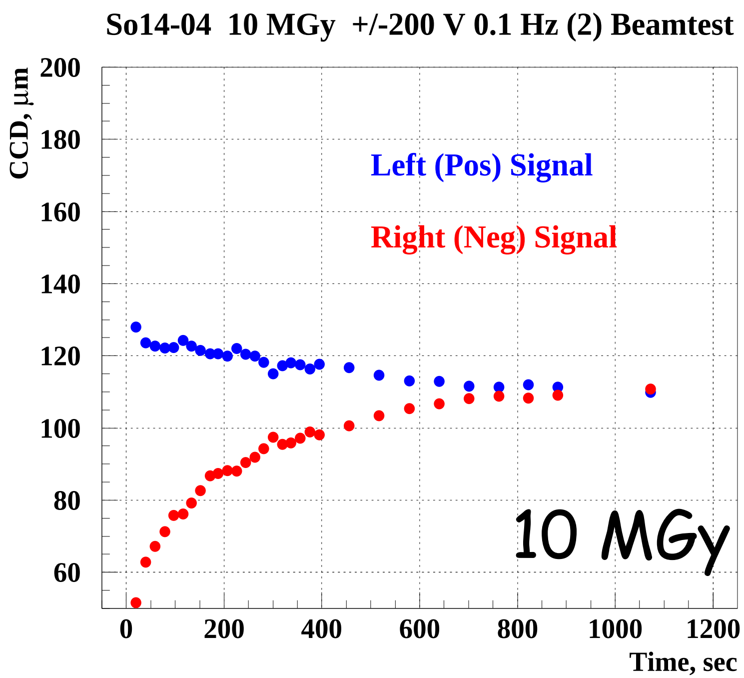
- Move (remotely) detector/preamp box to the low intensity ^{90}Sr line

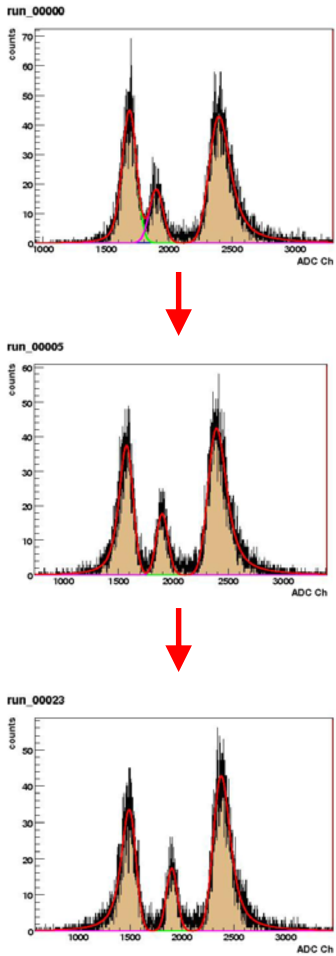
Measure signal evolution with time since beam-off

Beam Pumping Test

Dose rate ~ 100 x highest dose rate @ ILC detector





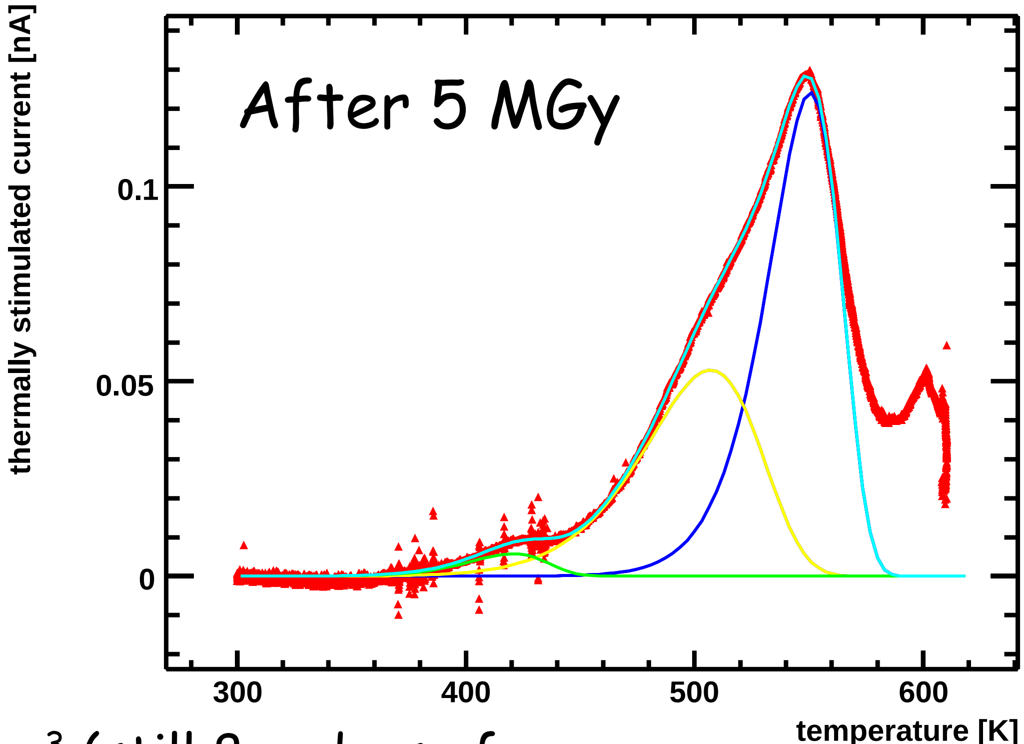


- Clear indication to the presence of fast decaying traps.
- Additional polarization due to shallow traps filling
- Faster trap release at higher bias voltage: “Poole-Frenkel”-like effect?

TSC measurements

At least 3 levels are visible:

	trap1	trap2	trap3
E_c-E_T [eV]	1.144 +0.002	0.851 +0.002	0.746 +0.006
n_T^0 [10^{14}cm^{-3}]	5.7	1.5	0.2

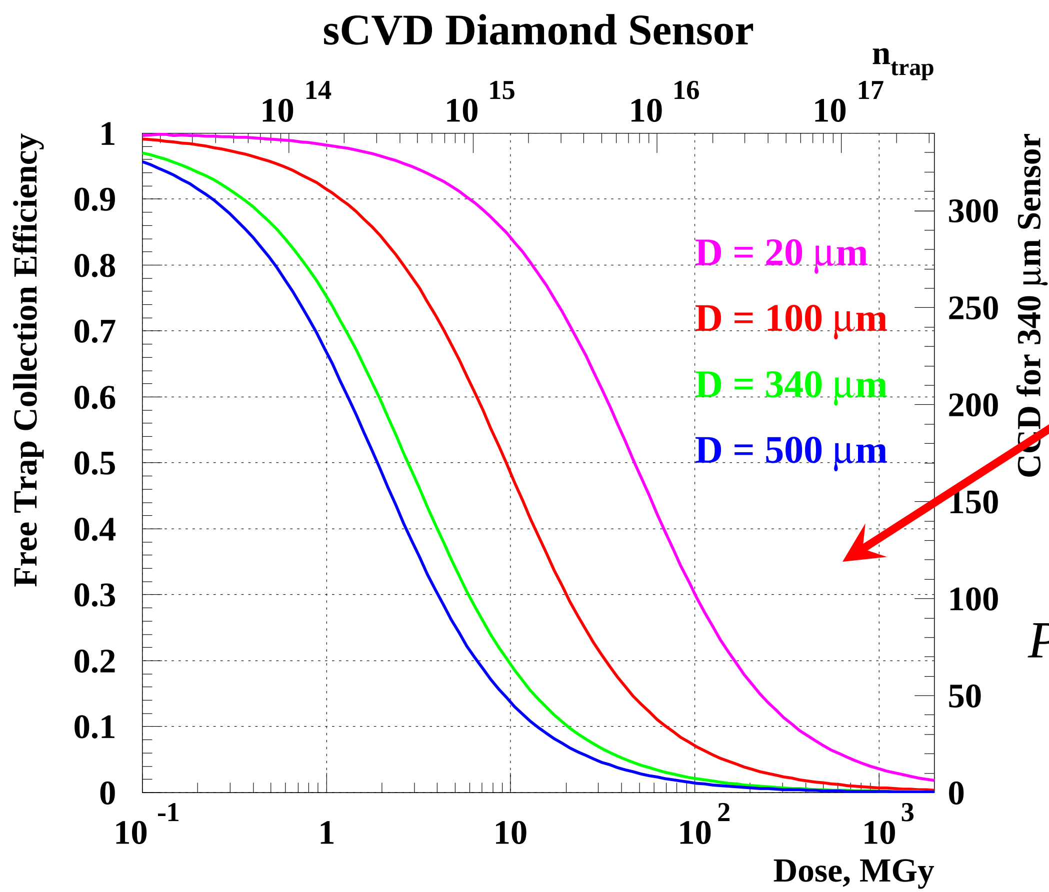


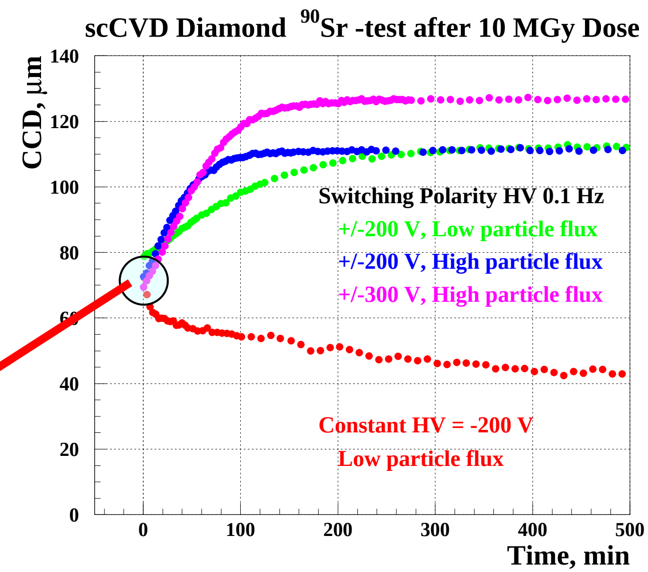
Trap concentration ~10^{14}-10^{15} cm^{-3} (still 8 orders of magnitude less than normal atom density)

CCD_0 vs Dose - free traps case

Are thin sensors more radiation hard?

Plan: irradiate thin (~100 μm) sensor at the test beam in Feb 2010





$$P_l = 1 - \exp\left(-\pi R_{trap}^2 \frac{l}{l_0} \frac{n_{empty}}{N} \right) = 1 - e^{-al}$$

$$CCE_0 = \frac{2}{aD}\left(1 - \frac{1 - e^{-aD}}{aD} \right)$$

Sapphire and Quartz Sensors

- Band-gap: Quartz 8.4 eV, Sapphire 9.9 eV (Diamond 5.5 eV, Si -1.12 eV)
- Single crystal, size 10x10x0.5 mm^3, cut 0001, available up to ~30 cm diameter wafers
- Producer: Crystal GmbH, Berlin
- Impurities: at some ppm level
- Metallization: 200 nm Al or 50/50/200 nm Al/Ti/Au, 4 pads 4x4 mm2 (1 pad 8x8 mm^2 backside) done @GSI
- First tests at the beam: TU-Darmstadt Dec 2008

Impurity analysis of Sapphire (Crystal GmbH data)

Element	Na	Si	Fe	Ca	Mg	Ni	Ti	Mn	Cu	Zr	Y
Impurity, ppm	8	2	5	5	1	<3	<1	3	<3	2	2

Sapphire radiation hardness

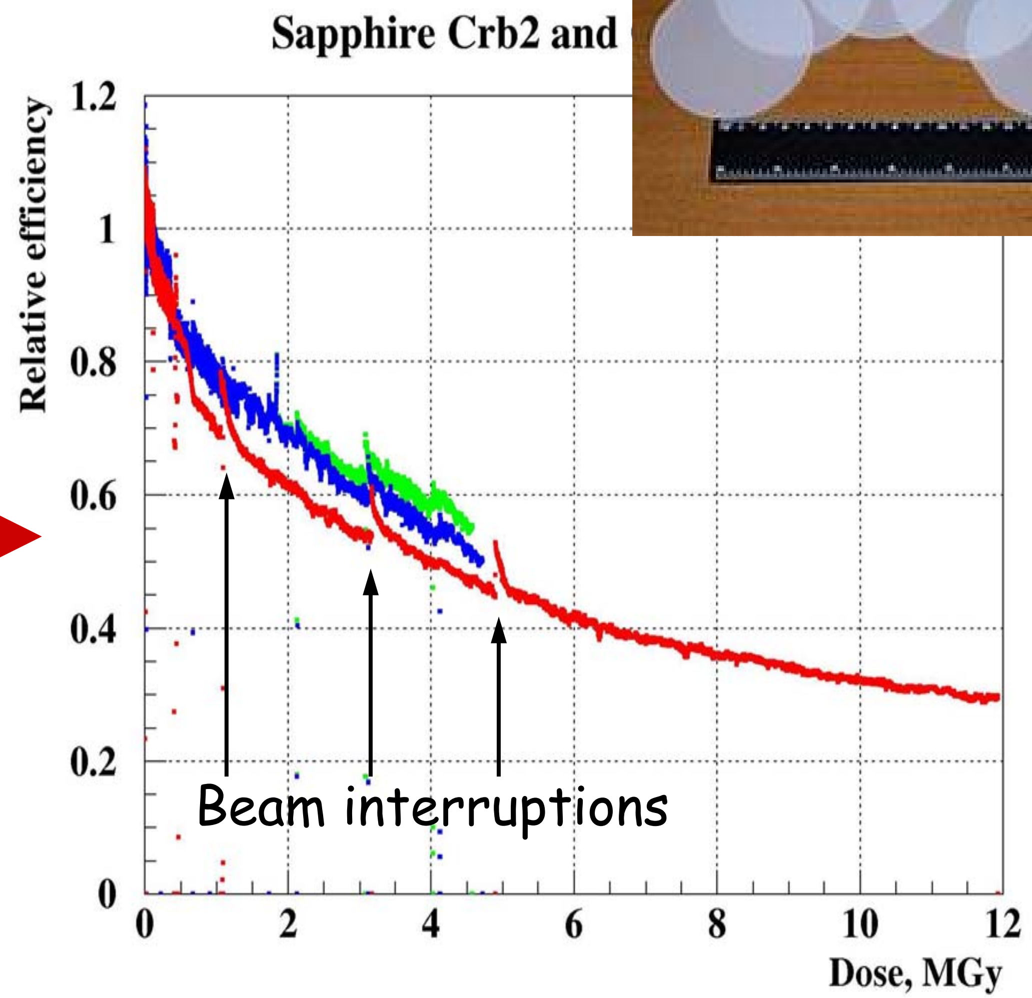
Single crystal, 1x1x0.05 cm^3

Metallization: Al 200 nm or

50/50/100 nm Al/Ti/Au,

TU-Darmstadt test beam

December 2008

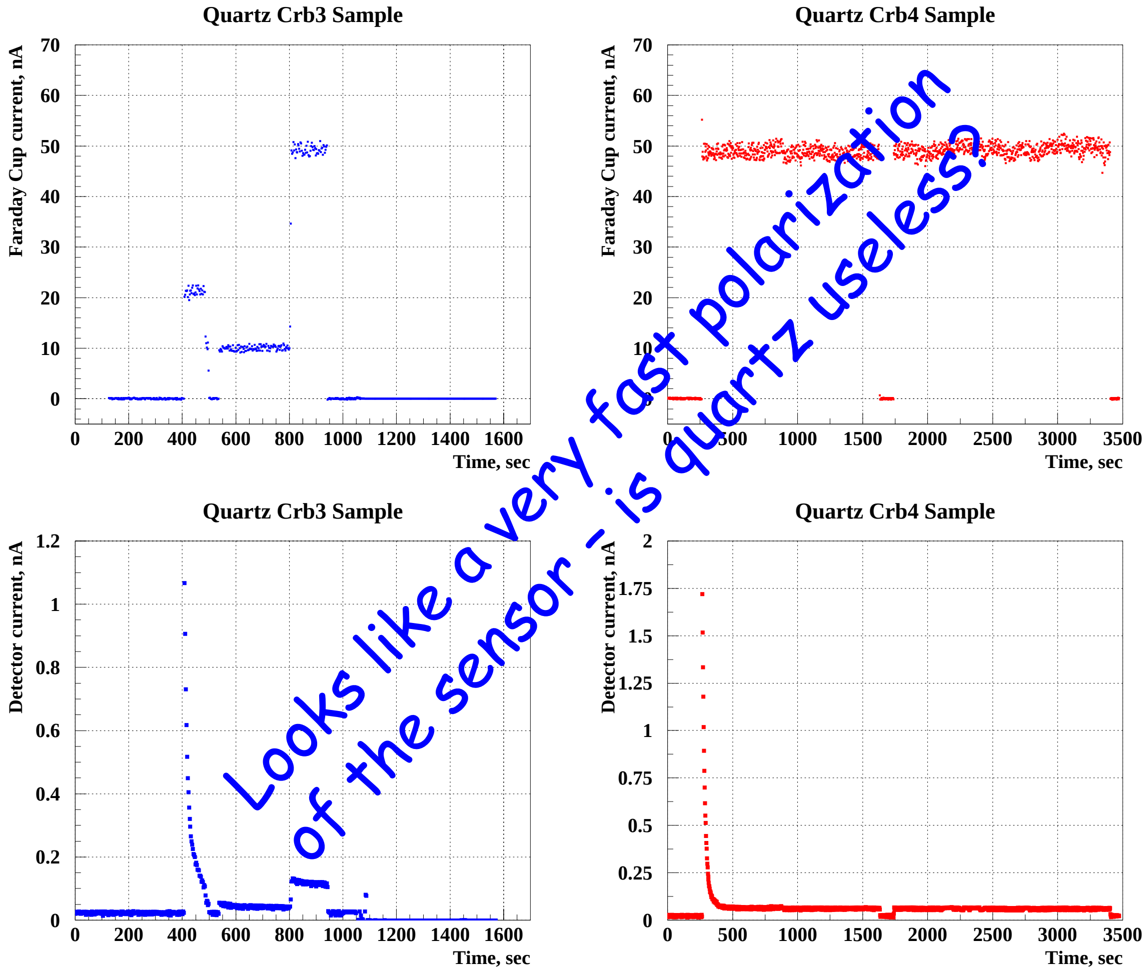


Ratio of the detector and Faraday cup currents

Initial charge collection efficiency: few % (purity?)

~ 30 % of the initial charge collection efficiency after 12 MGy

Quartz – raw data



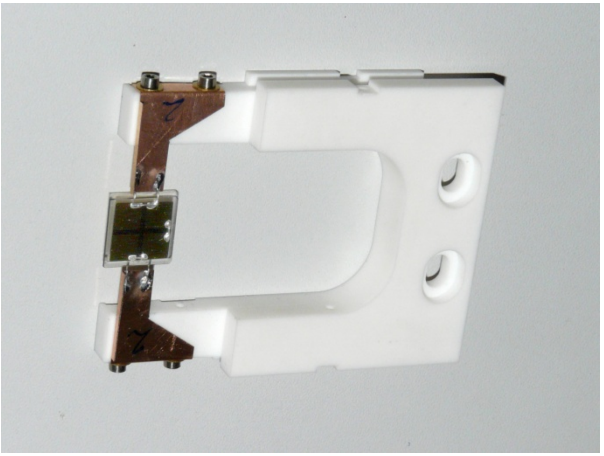
We need more clean material, impurity should be at the ppb level!

(Both for quartz and sapphore)

Test in PITZ

Electron beam, 14.5 MeV, bunches

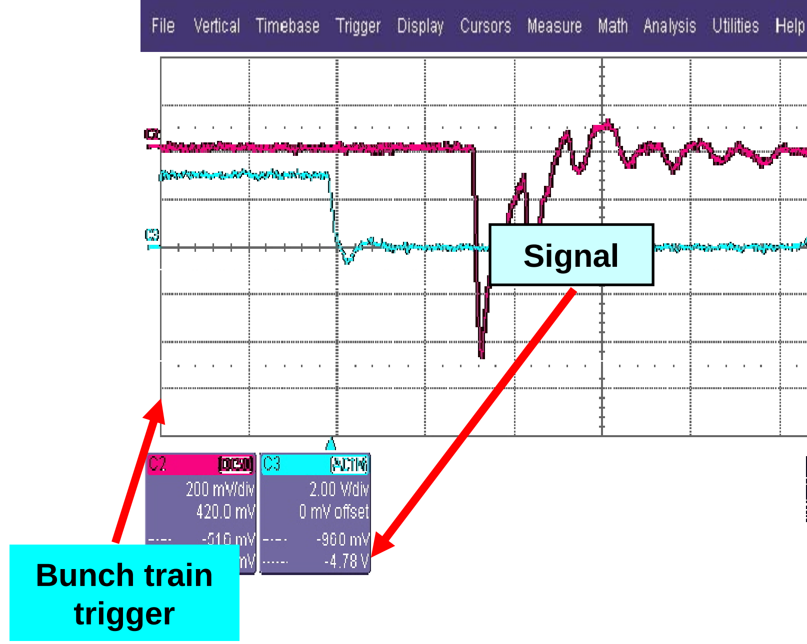
Diamond sensor was installed in the vacuum of the beam pipe

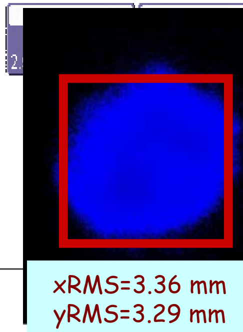


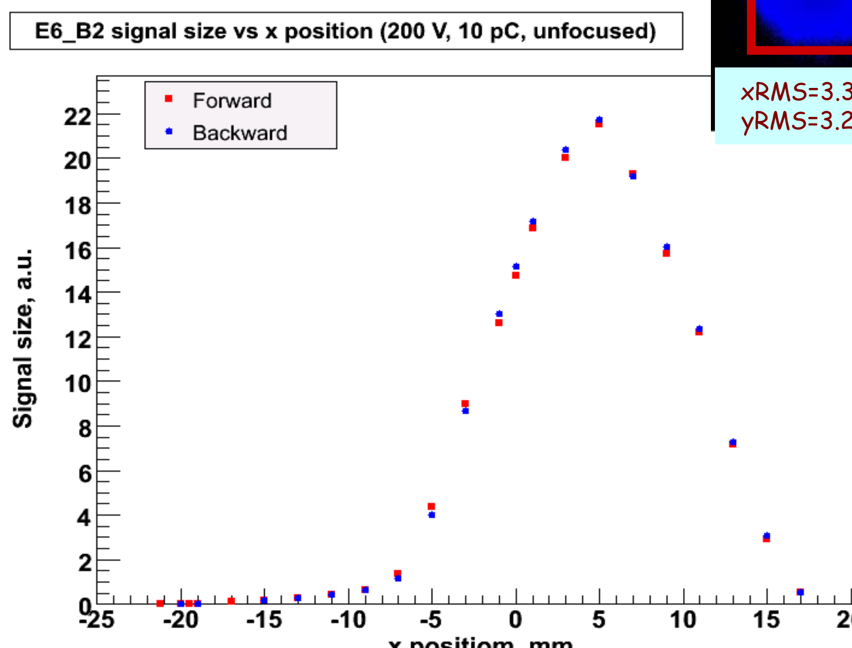
Moving the sensor through an electron beam.

Bunch charge 1 pC – 1 nC,
Beam spot: few mm²
Beam profile

EMI doesn't disturb operation



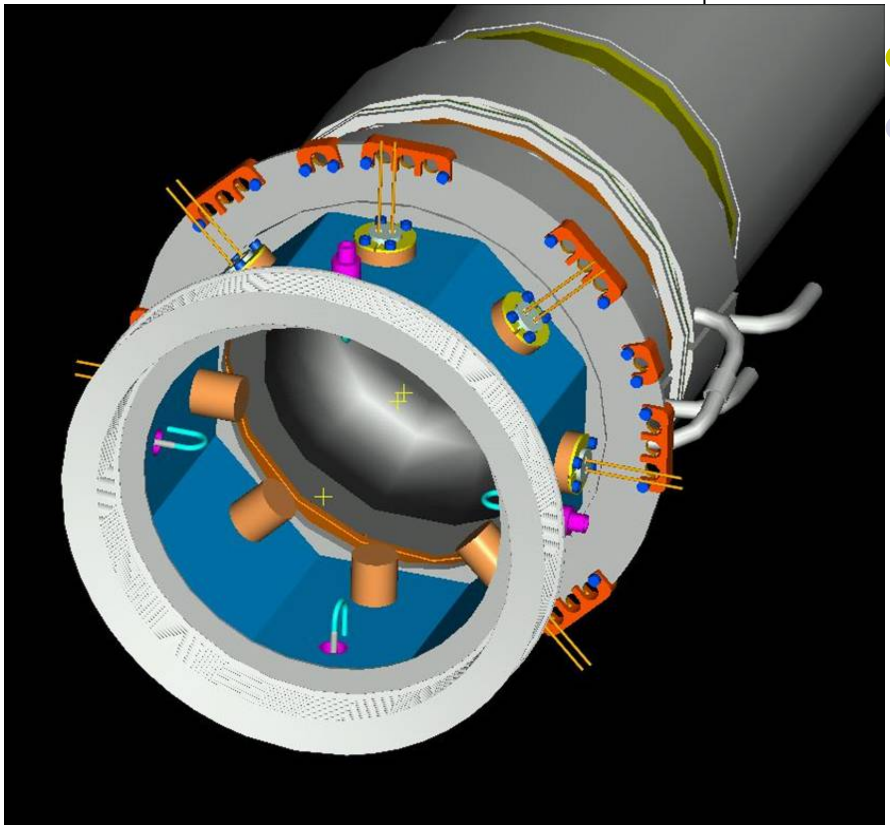


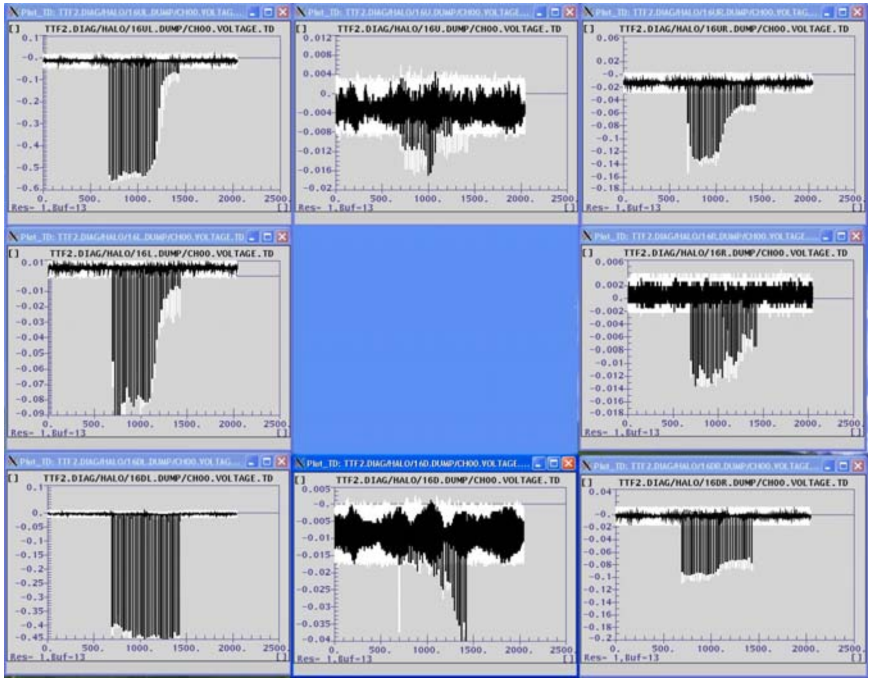


Application at FLASH

FCAL designed, constructed and installed a Beam-Condition Monitor at FLASH (4 diamond and 4 sapphire sensors

Operation in the "9 mA" run of FLASH was successful





Summary

- The performance of scCVD Diamond sensor was studied as a function of absorbed dose up to 10 MGy
- Strong polarization effects are observed in the radiation damaged scCVD Diamond detector
- Polarization significantly decreases the detector charge collection efficiency in addition to pure trapping mechanism
- Method of routinely switching bias HV polarity allows to suppress bulk polarization of long-living traps
- Beam pumping tests indicate that short-living traps are responsible for the residual detector inefficiency
- Sapphire and Quartz sensors were studied at the test beam
- Diamond sensor was studied at the PITZ facility (bunched beam)
- 8 Diamond and Sapphire sensors are installed at FLASH for beam dump diagnostic purposes

Thank you

Electric field calculations

Poisson Superfish program