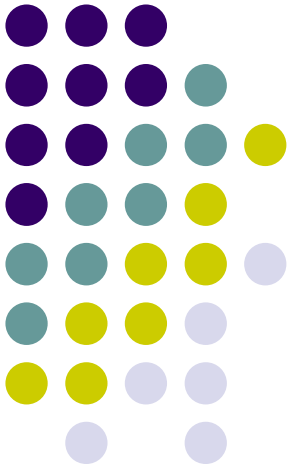
Polarization effects in the radiation damaged scCVD Diamond detectors

Sergej Schuwalow, DESY Zeuthen

On behalf of FCAL collaboration



Diamond properties

- Density 3.52 $g\ cm^{-3}$
- Dielectric constant 5.7
- Breakdown field $10^7\ V\ cm^{-1}$
- Resistivity $>10^{11}\ \Omega$ cm
- Band gap 5.5 eV
- Electron mobility 1800 (4500) $cm^2\ V^{-1}\ s^{-1}$
- Hole mobility 1200 (3800) $cm^2\ V^{-1}\ s^{-1}$
- Energy to create e-h pair 13.1 eV
- Average signal created 36 e μm^{-1}

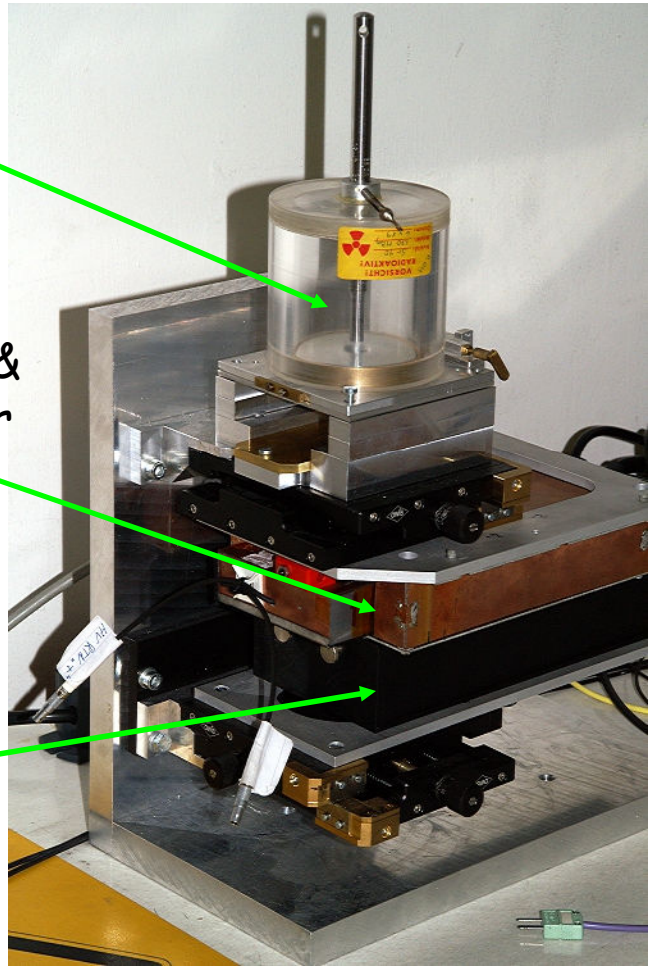
*High purity single crystal CVD diamond

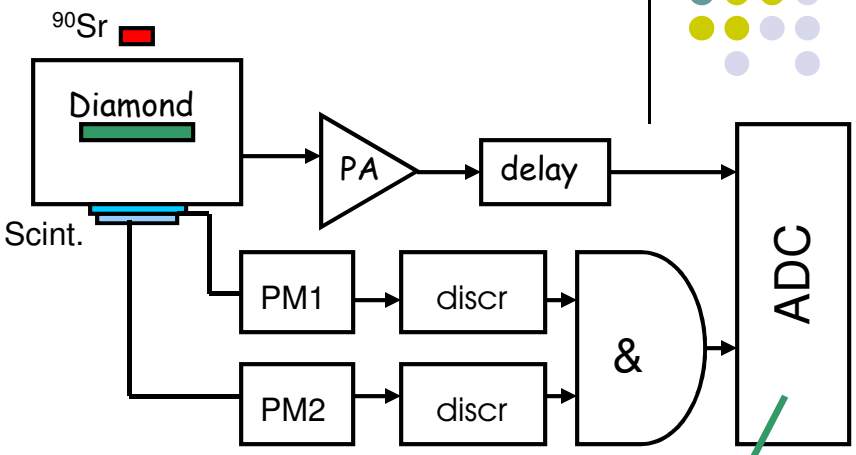
MIP Response of scCVD Diamond

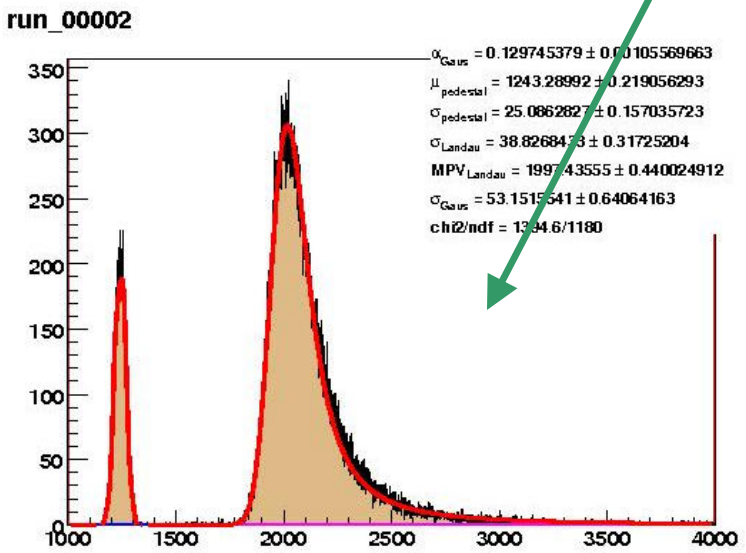
^{90}Sr Source

Sensor box & Preamplifier

Trigger box





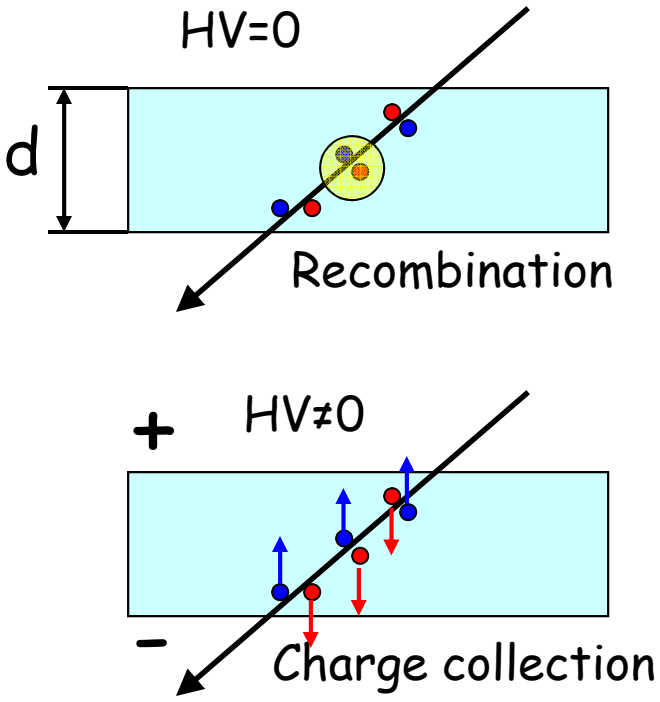


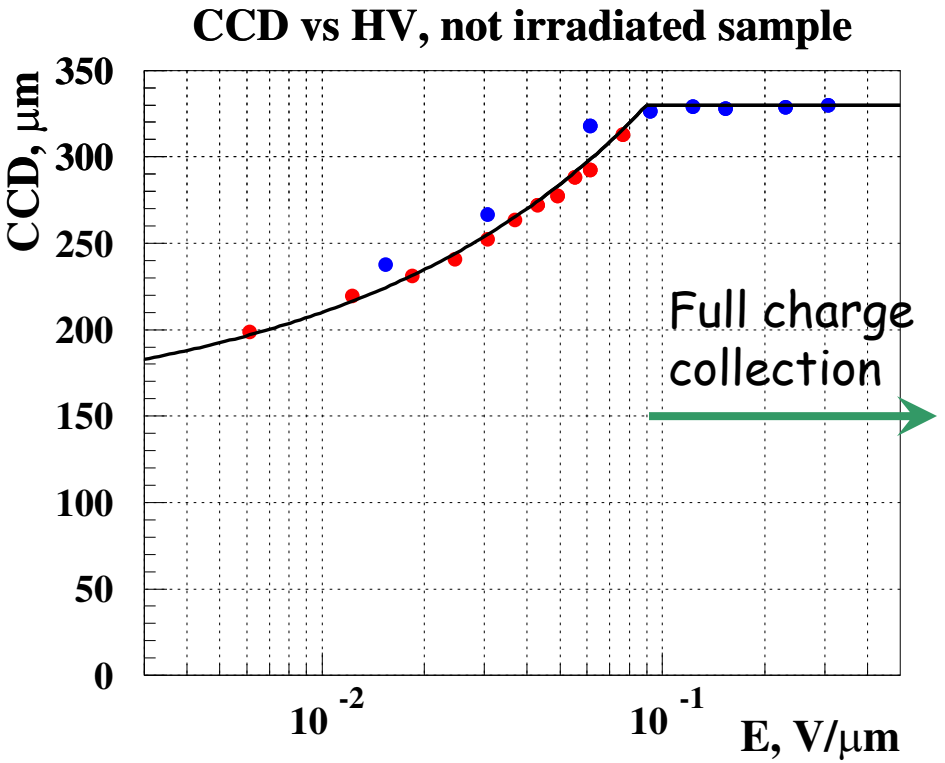
ADC spectrum

‘Ideal’ crystal charge collection

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

- Charge collection efficiency depends on E

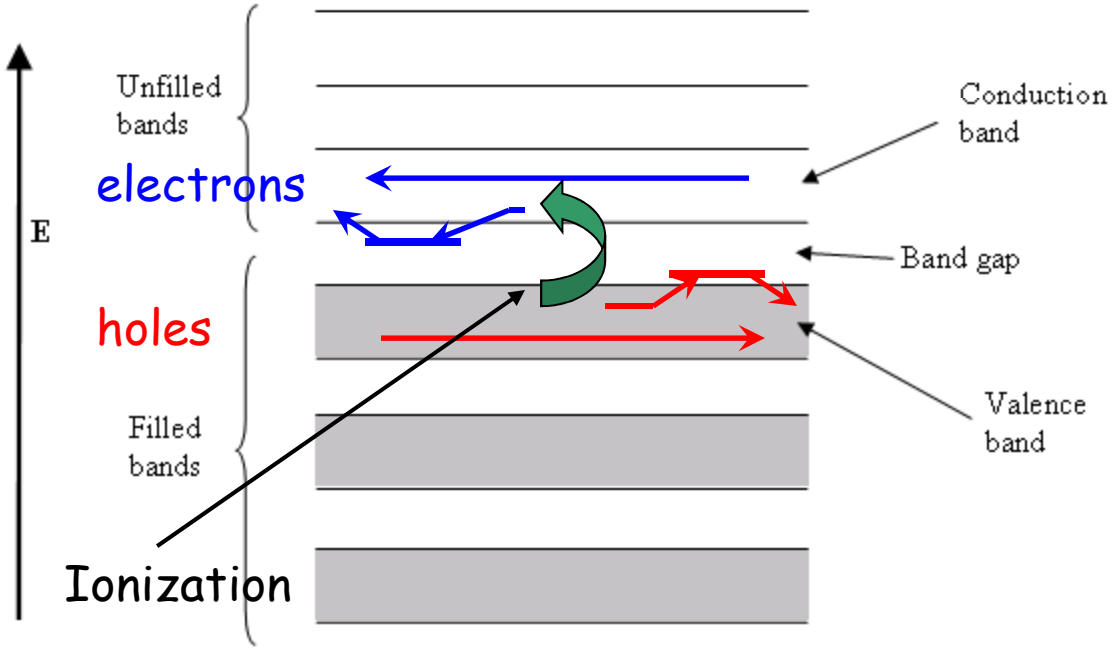




Radiation damaged crystal

- 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

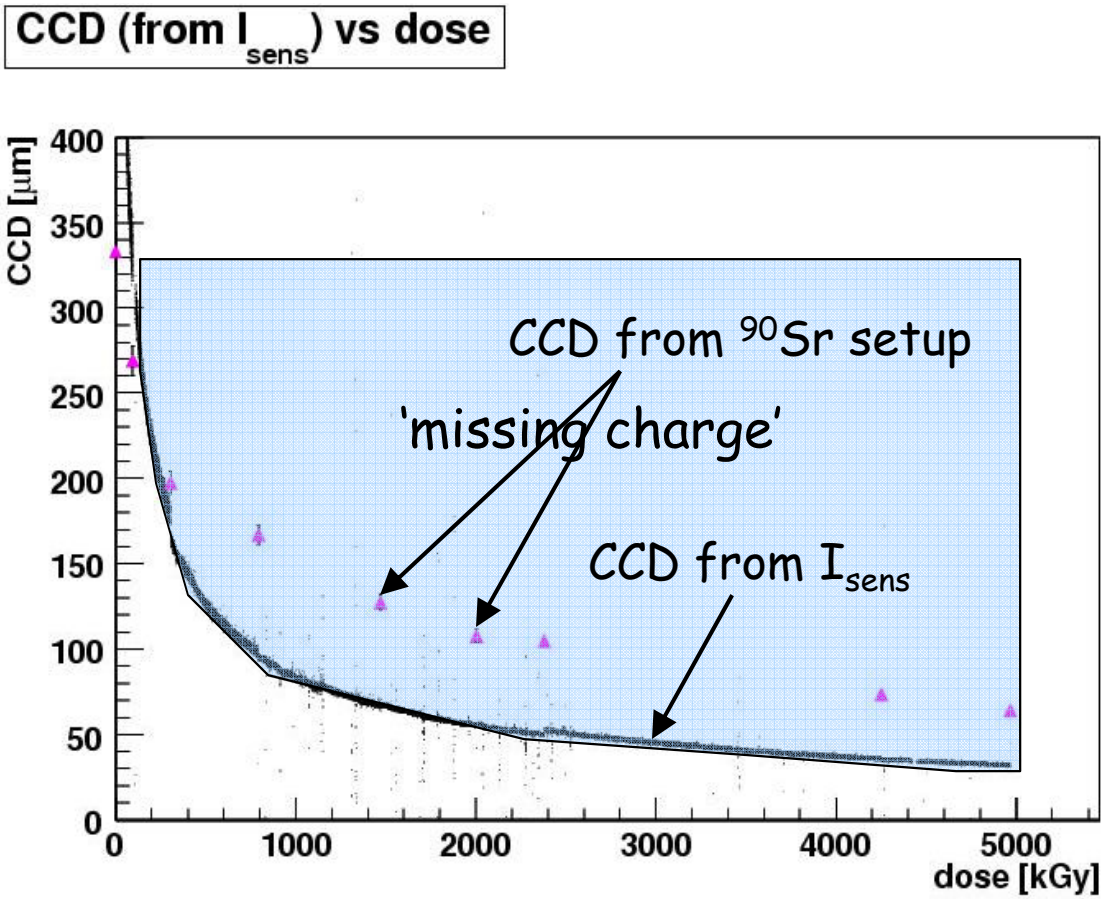
- Assumptions we are using:
- Trap density is uniform (bulk radiation damage)
- Traps are created independently (linearity vs dose)



Irradiation of scCVD Diamond

DALINAC, TU-Darmstadt June 2007

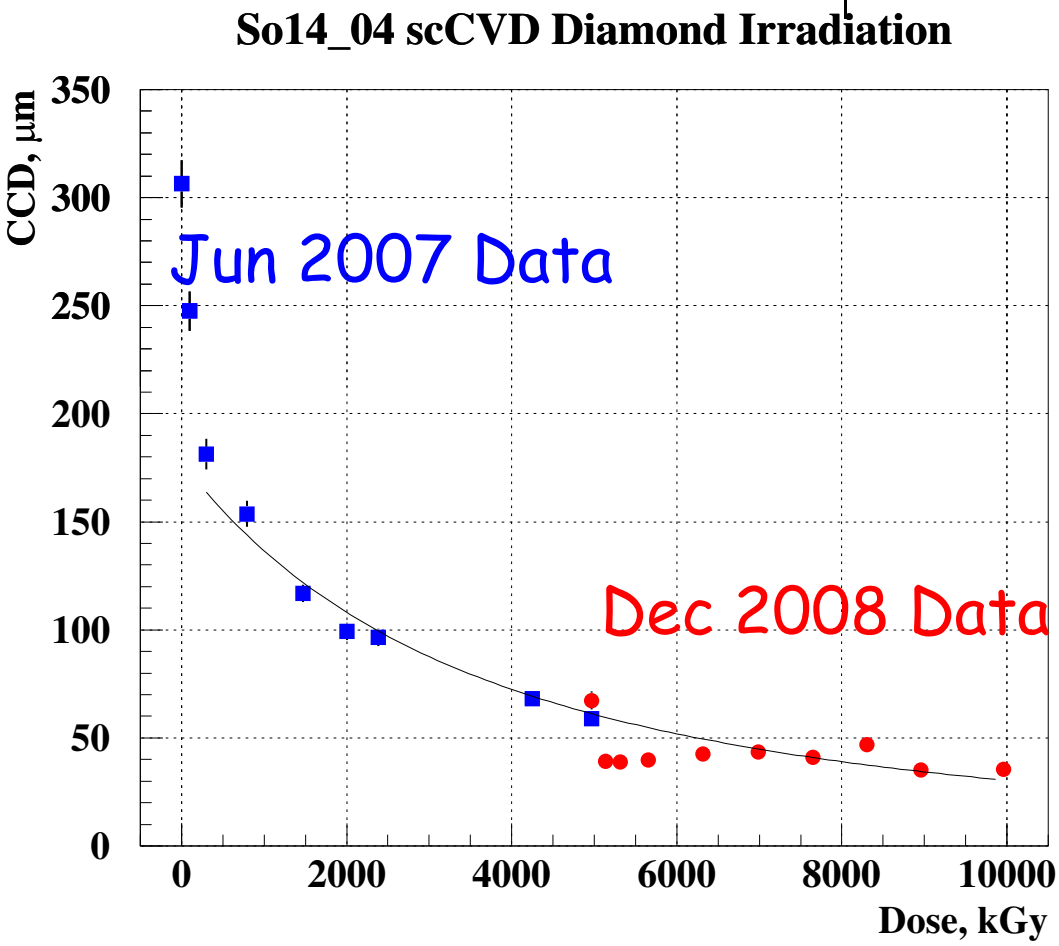
- After 5 MGy dose diamond detector is operational
- CCD is decreasing with the absorbed dose
- Generation of trapping centers due to irradiation
- Traps release?
- $CCD_{current} < CCD_{MIP}$?
- Too high 'missing charge' $\sim N_{atoms}$ in the sample
- Pure trapping mechanism is contradictory
- Recombination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



Irradiation of scCVD Diamond

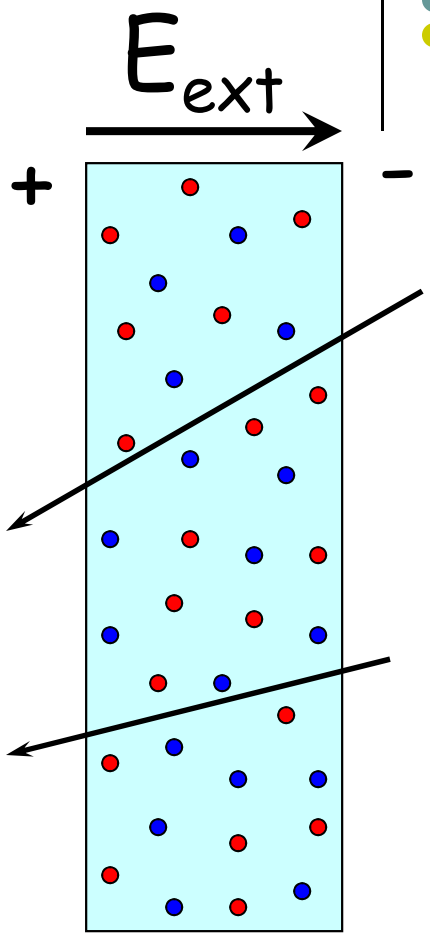
Continued in December 2008

- 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



Polarization origin

- Uniform generation of e-h pairs
- Asymmetry is introduced by the applied electric field



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
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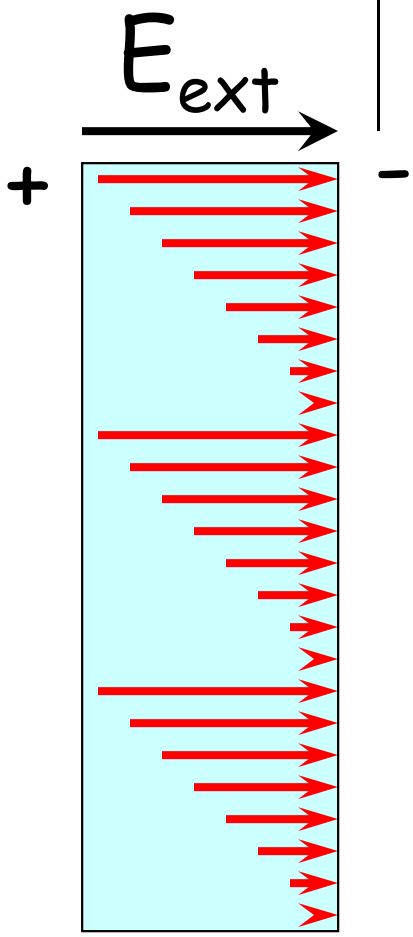

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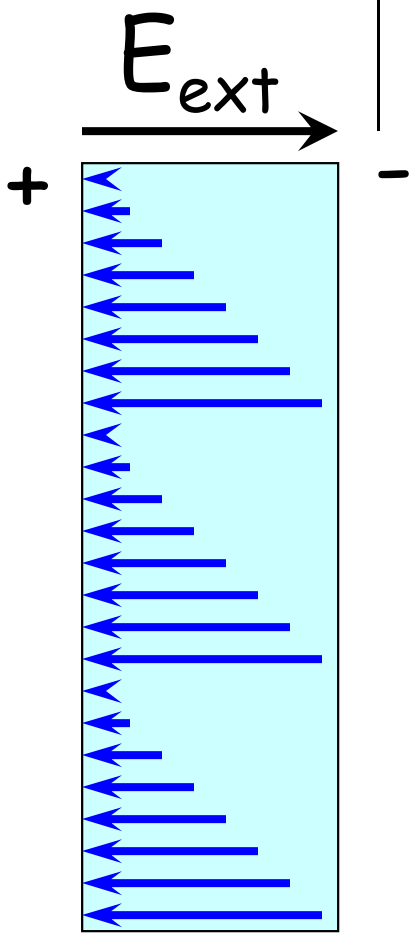

Polarization origin

- 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
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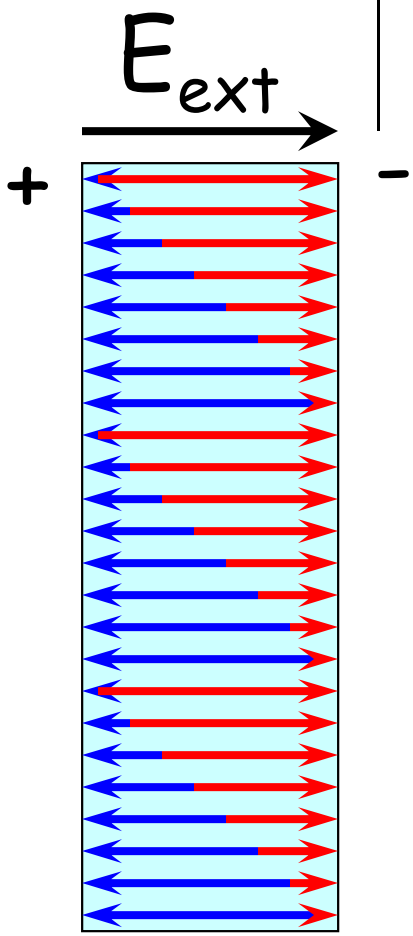
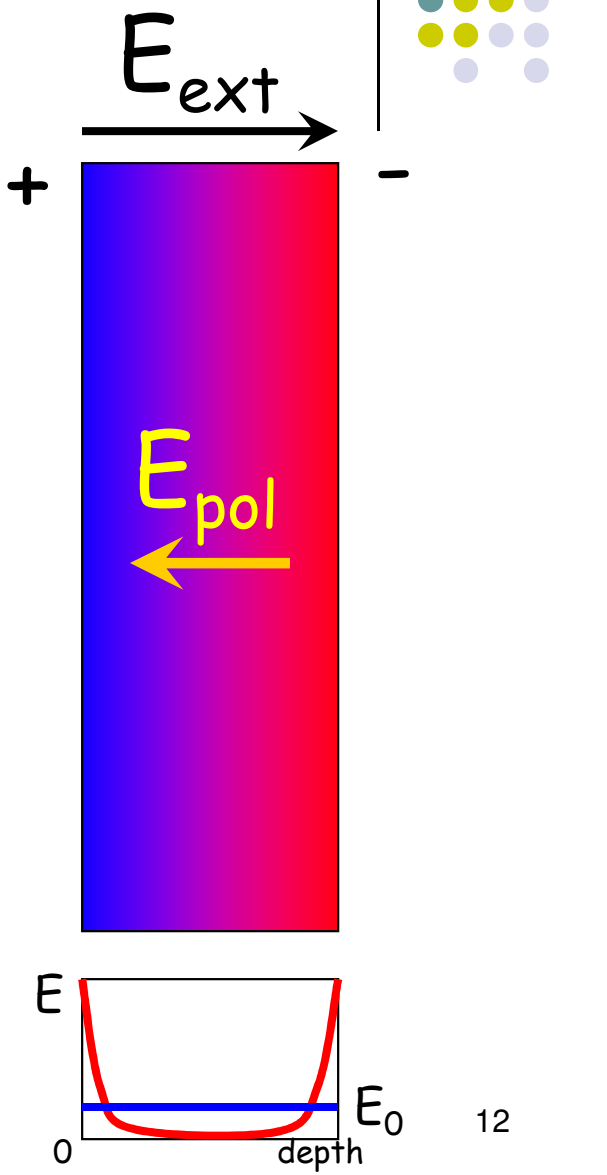
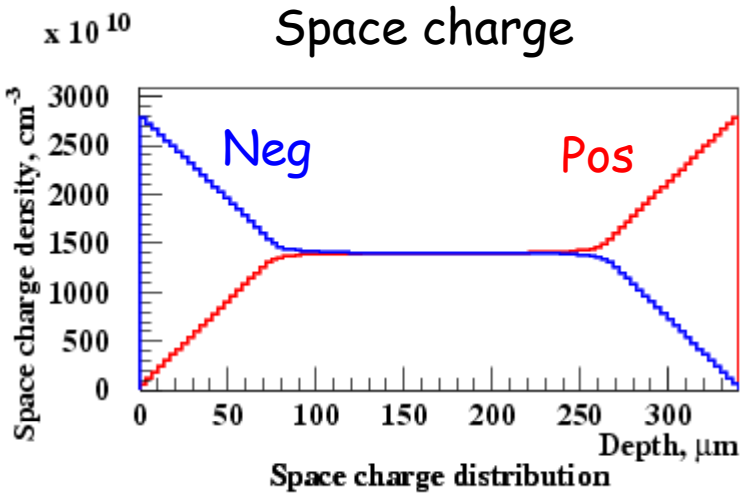


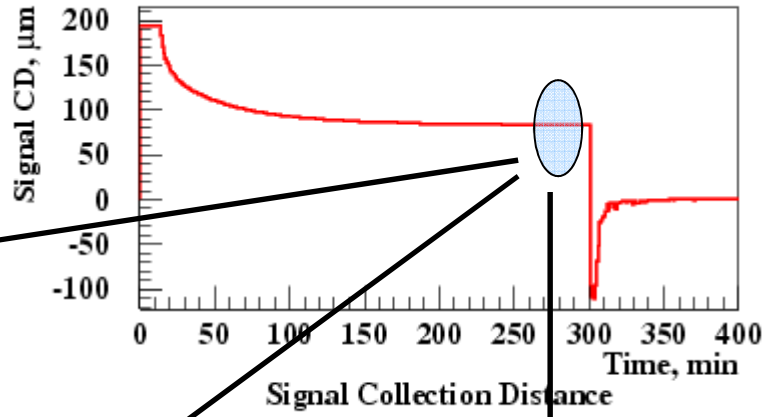
Polarization origin

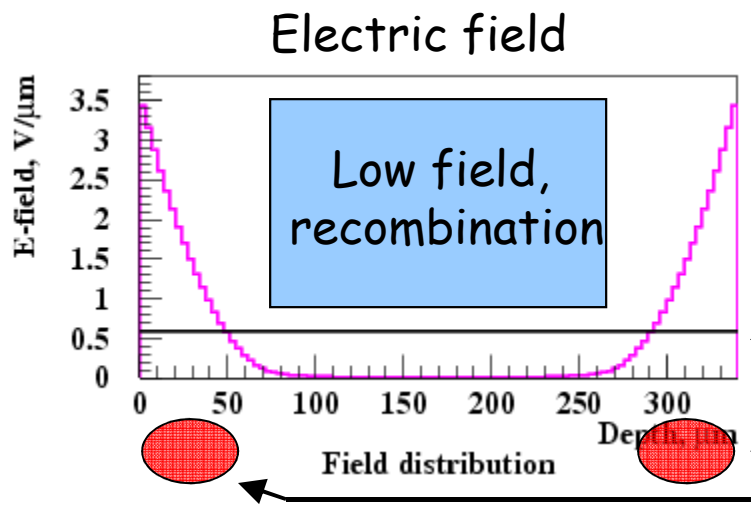
- Uniform generation of e-h pairs
- Asymmetry is introduced by the applied electric field
- Specific free charge carrier density is largest near detector edges
- Asymmetric trap filling according to charge carrier density
- Space charge creation in the bulk of the detector
- Compensation of the external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



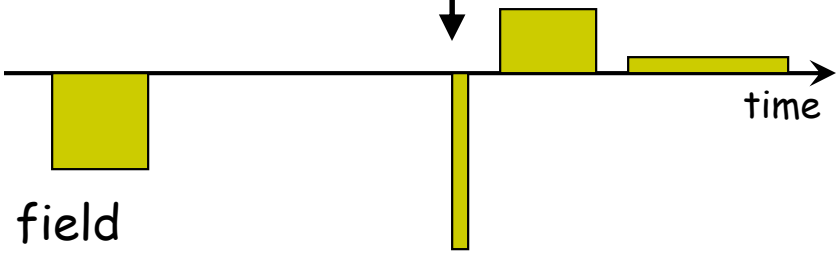
Model: 340 μm scCVD diamond after 5 MGy CCD time dependence







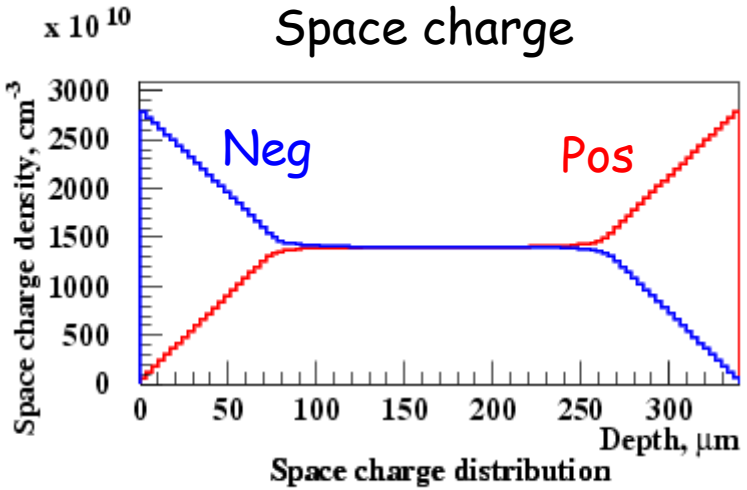
Expected Signal shape

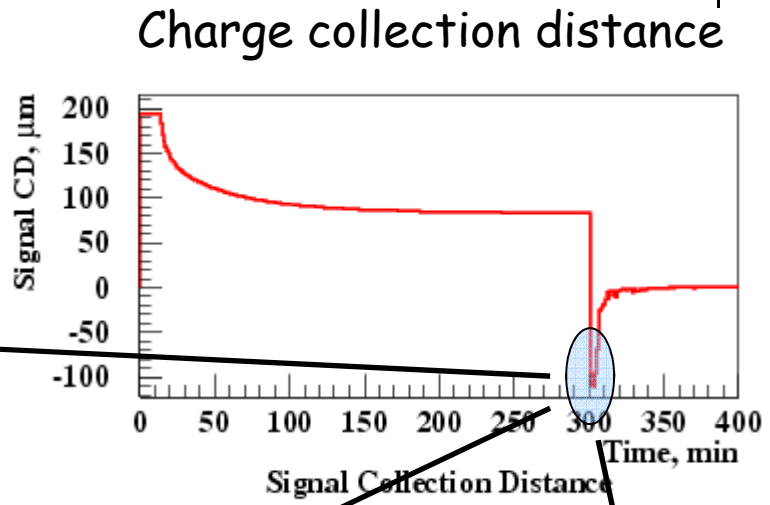


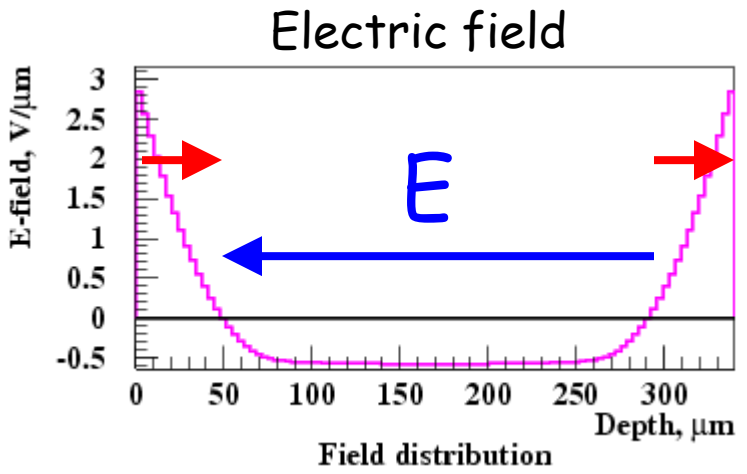
Initial field

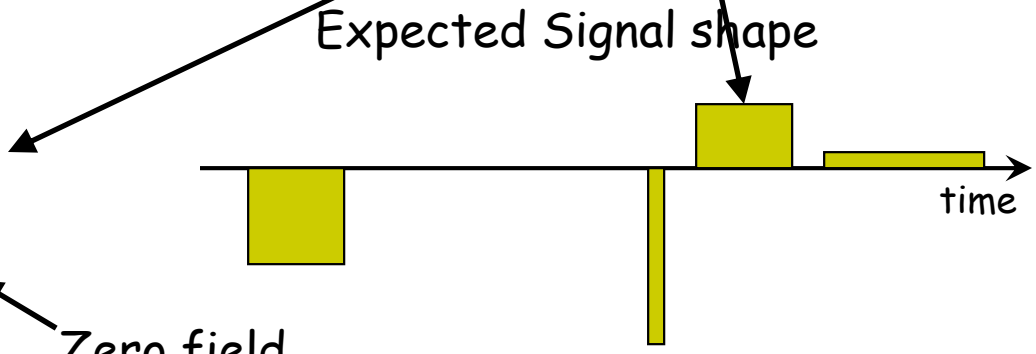
Effective charge collection regions

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



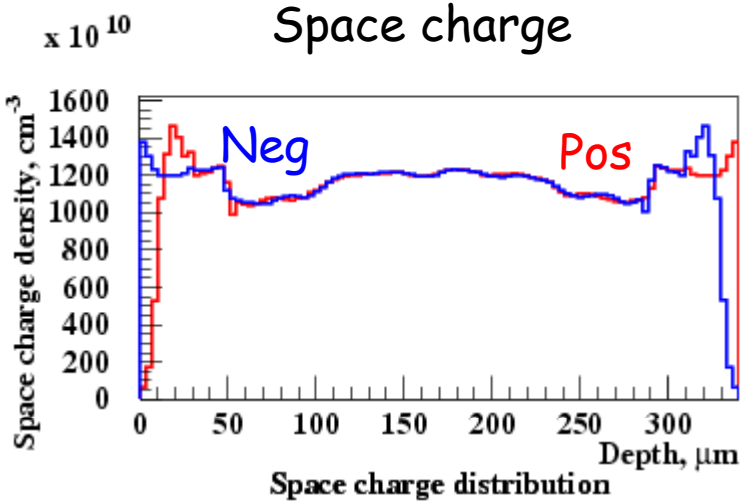


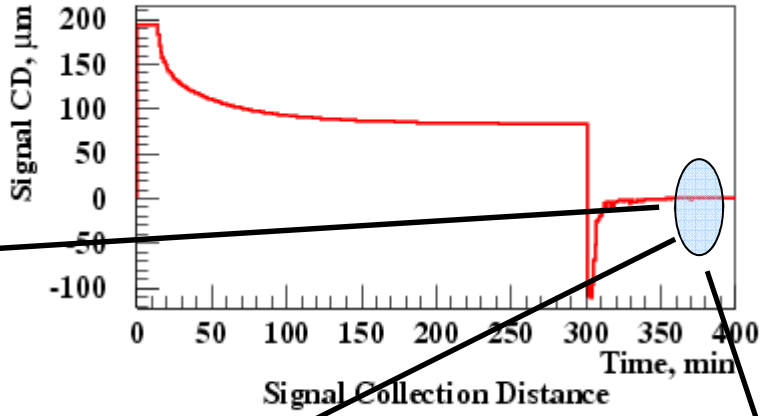


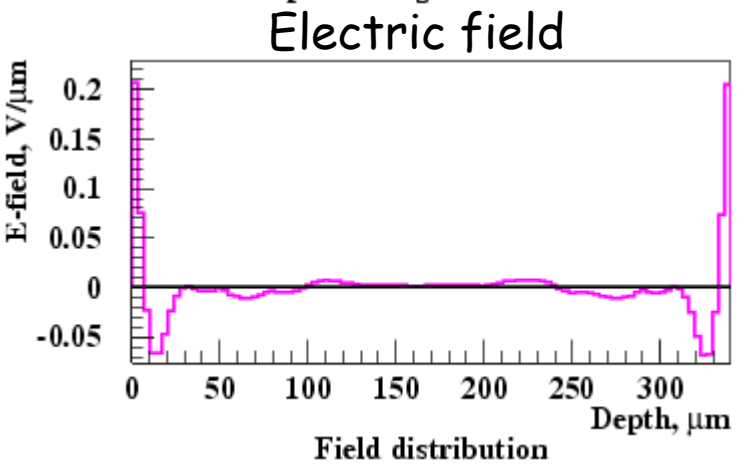


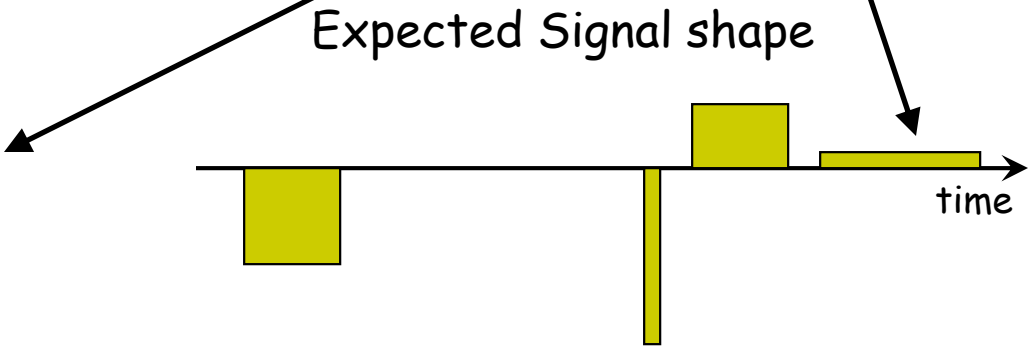
Zero field

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





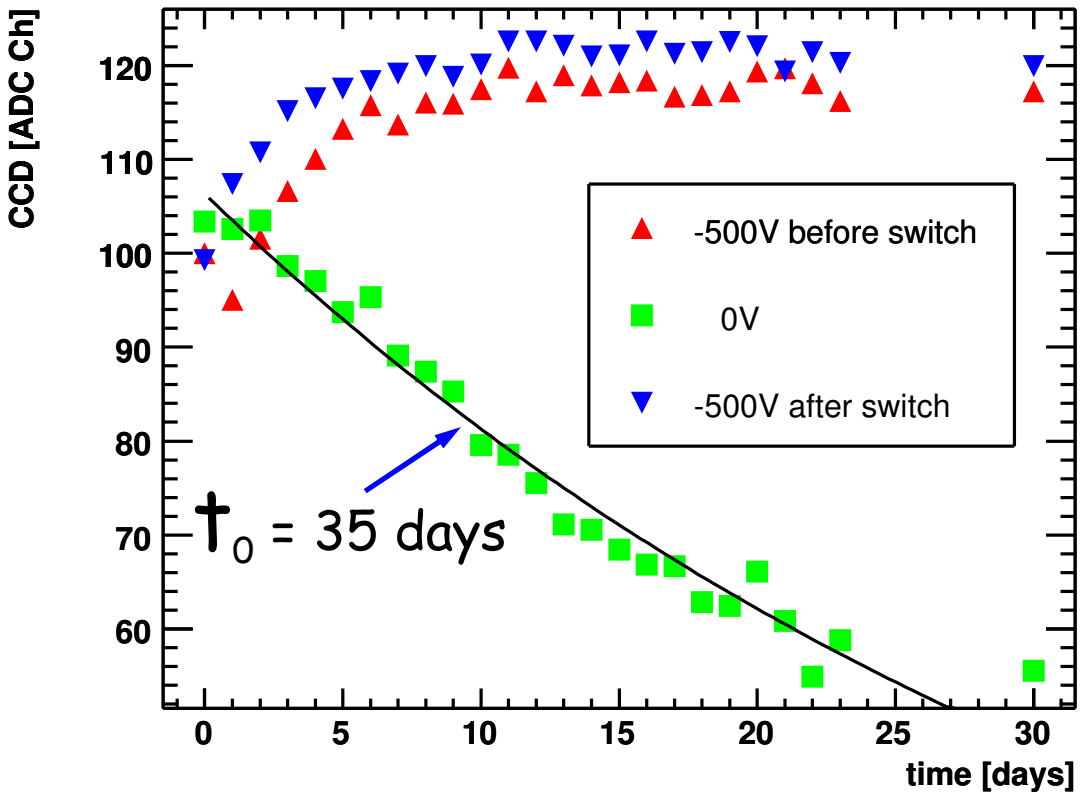




To be confirmed!

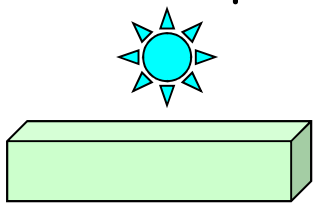
Long-term signal evolution

- 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!

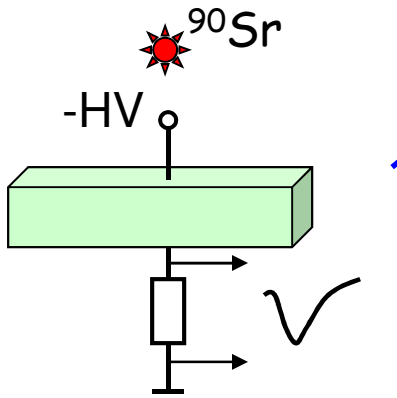


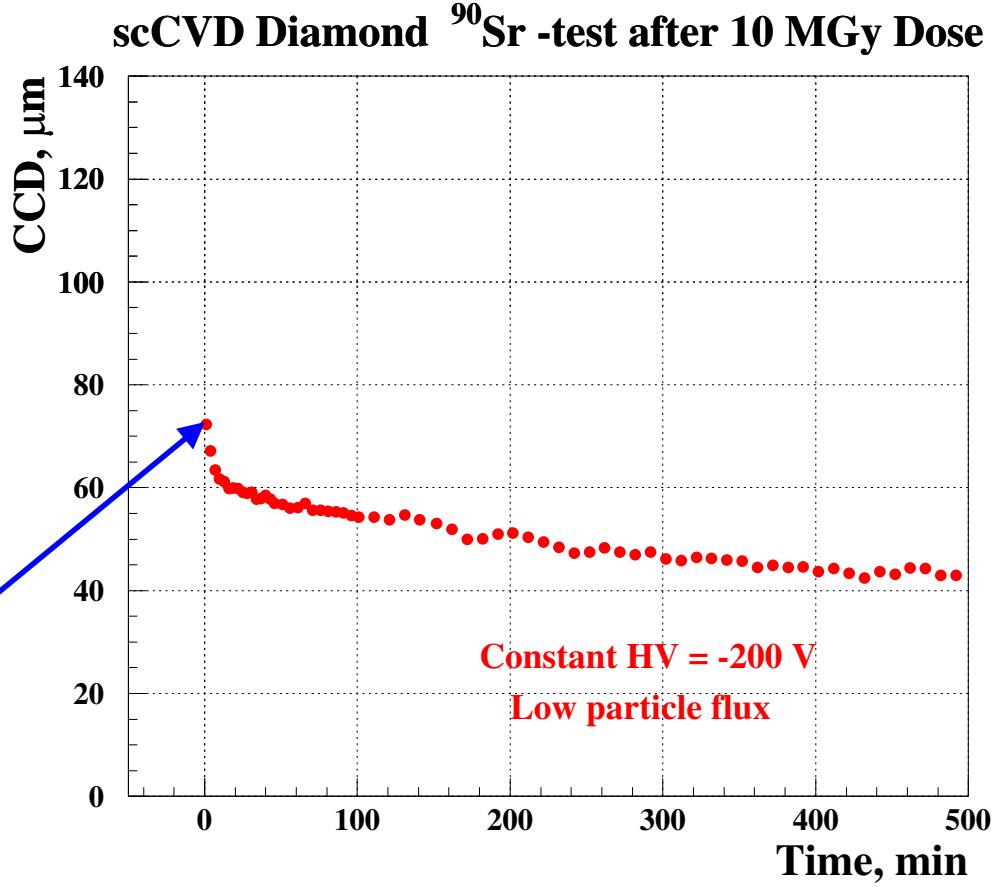
Damaged Sensor under ^{90}Sr Source: CCD vs time

Illuminate by UV-light to free all traps



Apply HV and source





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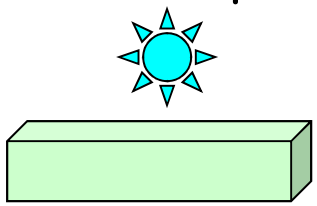

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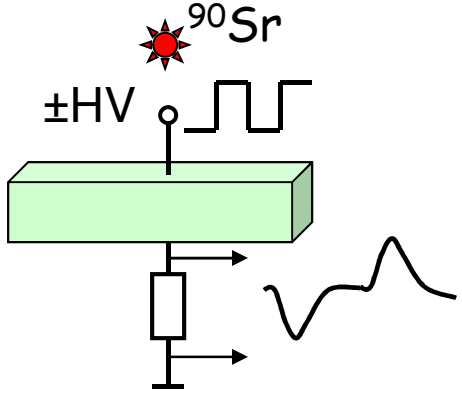

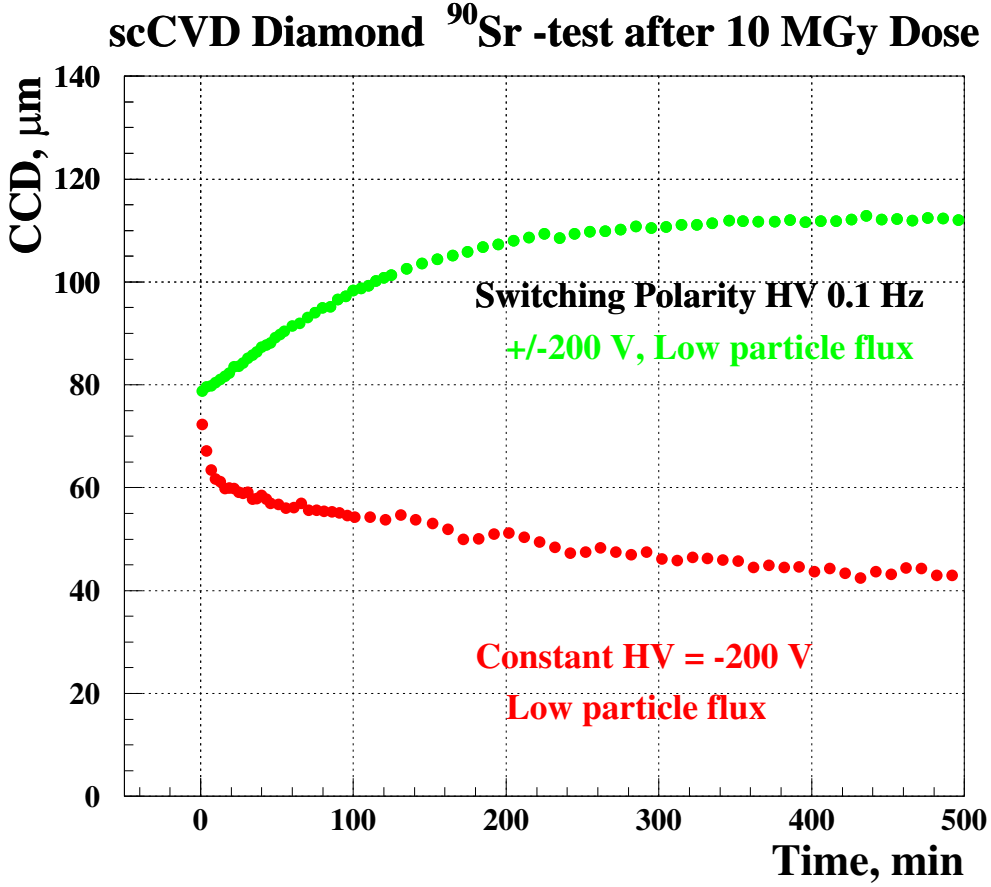

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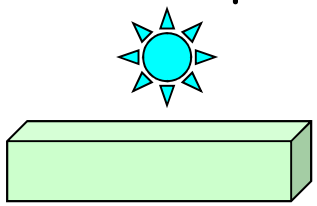

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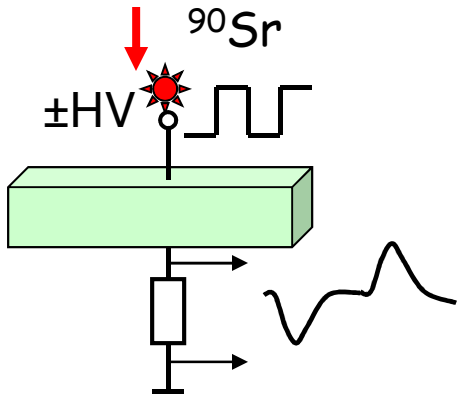
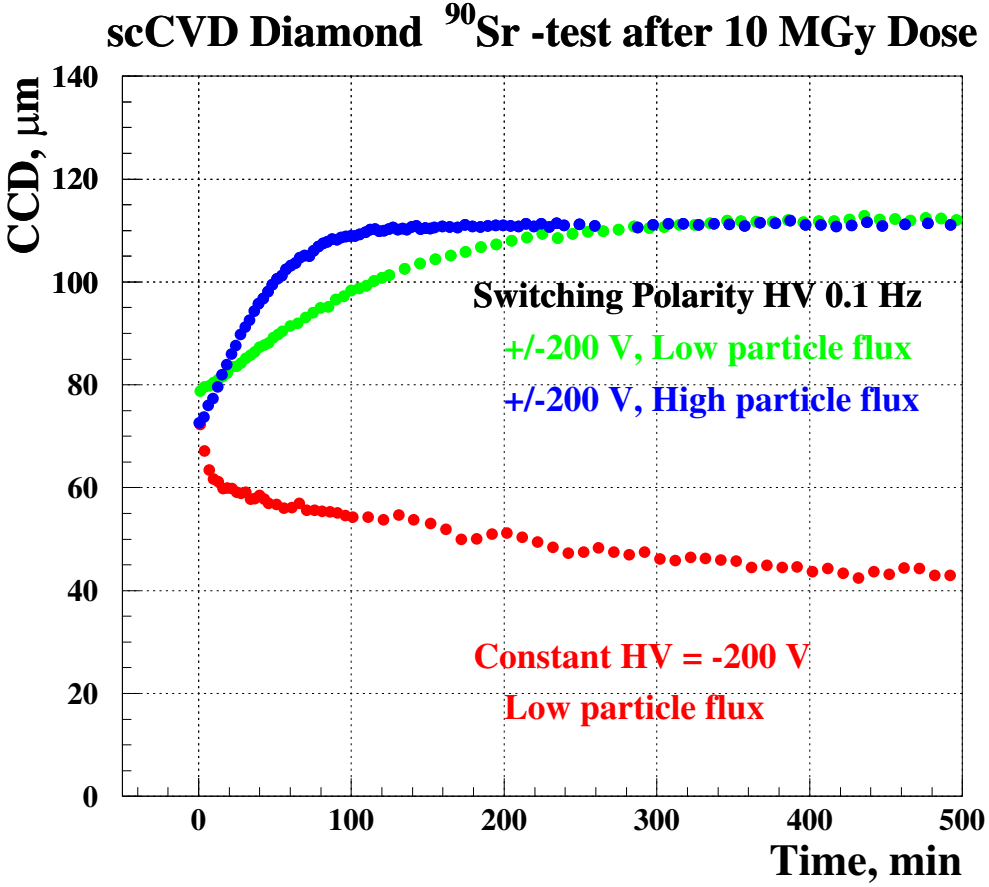
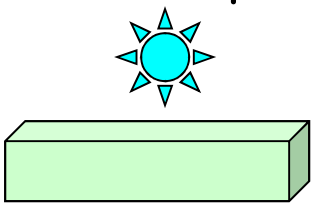




Damaged Sensor under ^{90}Sr Source: CCD vs time

Illuminate by UV-light to free all traps



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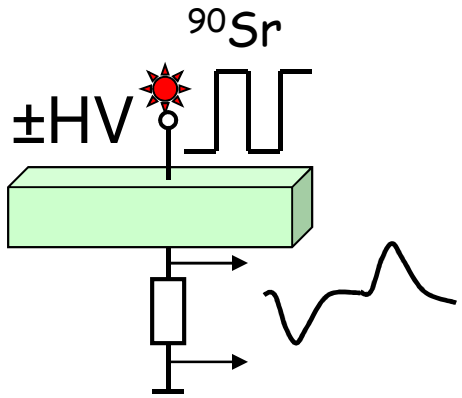
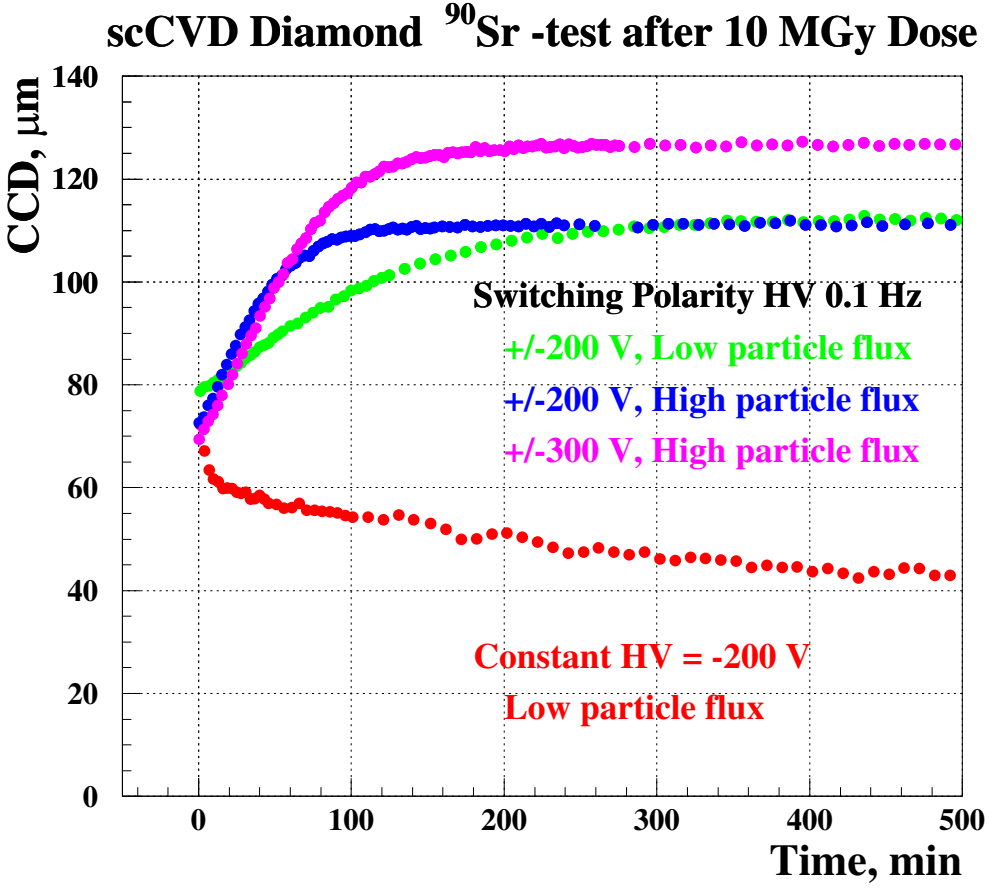
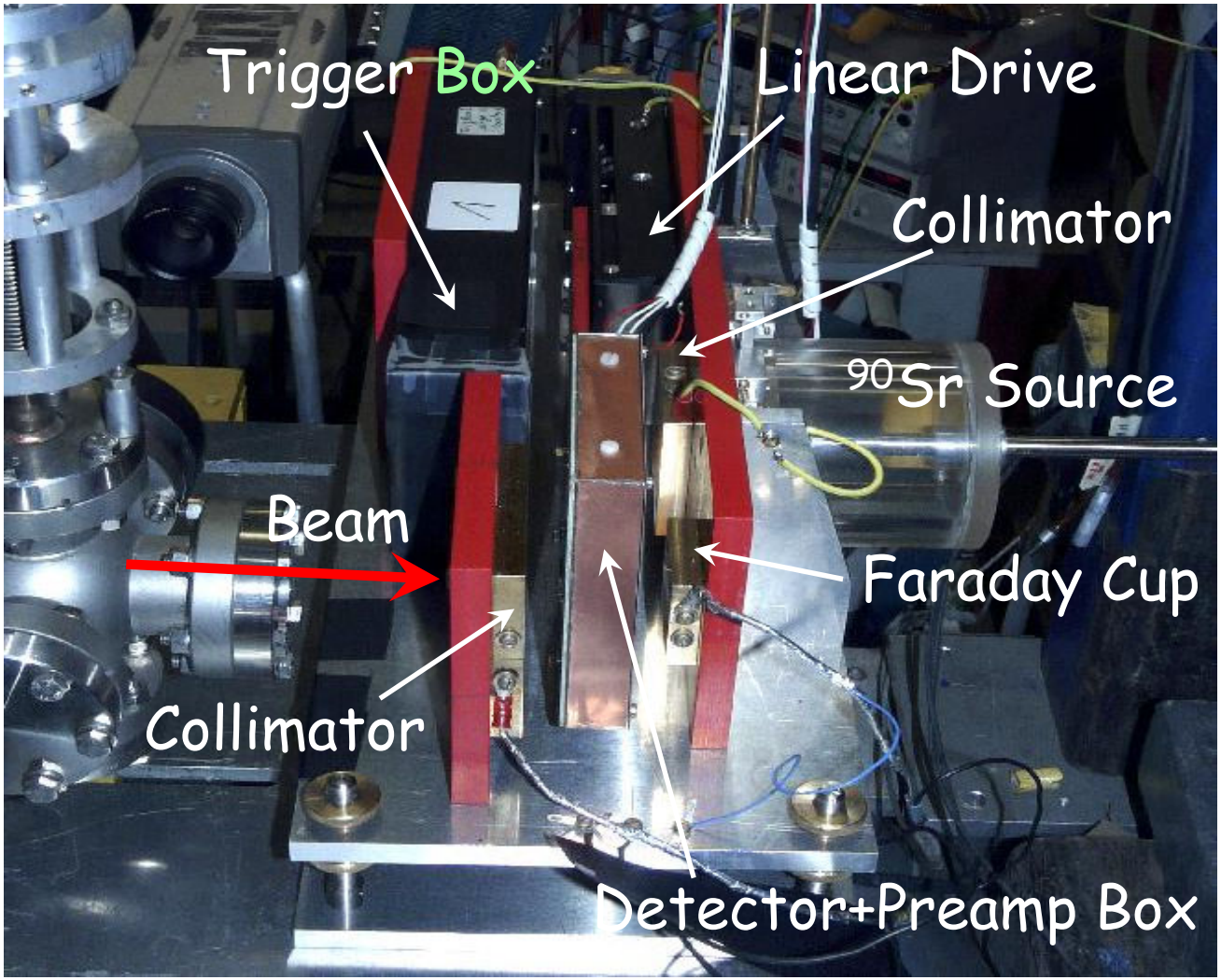




Short living traps

Beam Pumping Test



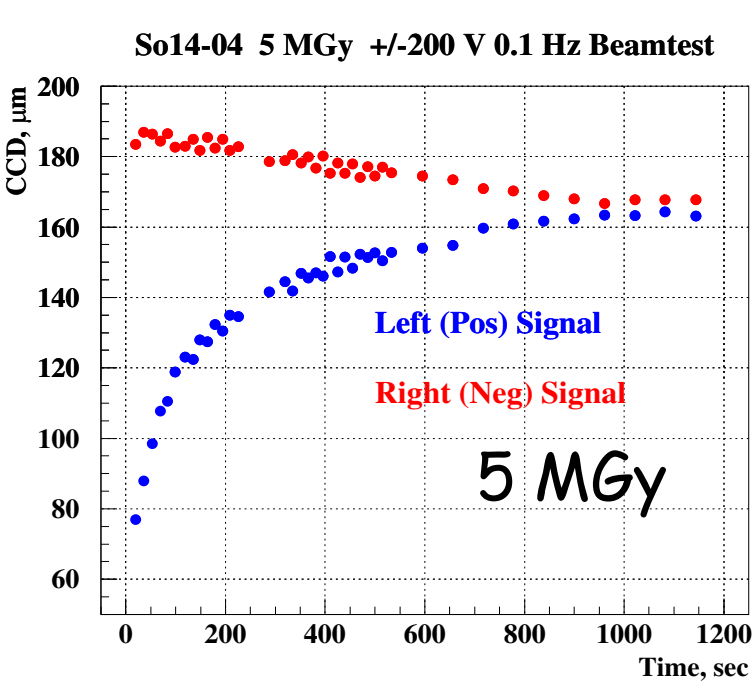
Use intensive beam to fill up short living traps

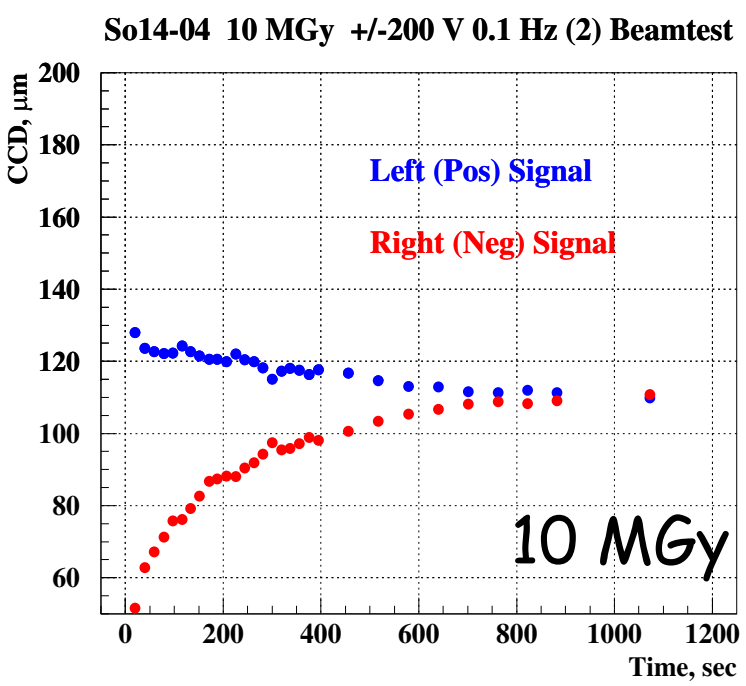
Move (remotely) detector/preamp box to the low intensity ^{90}Sr line

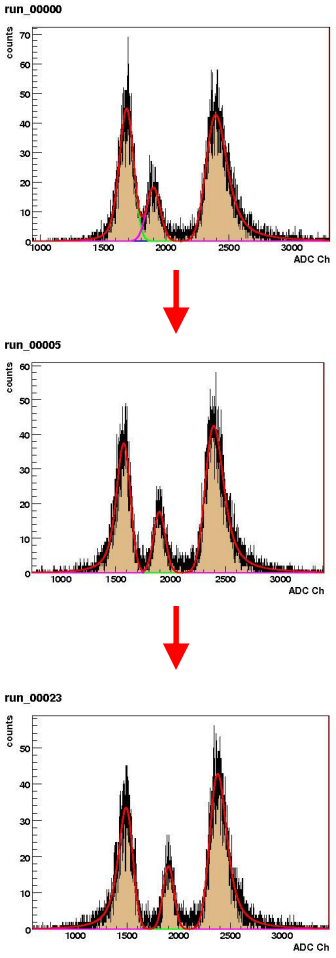
Measure signal evolution with time since beam-off

Beam Pumping Test

Dose rate ~ 100 x highest dose rate @ ILC detector





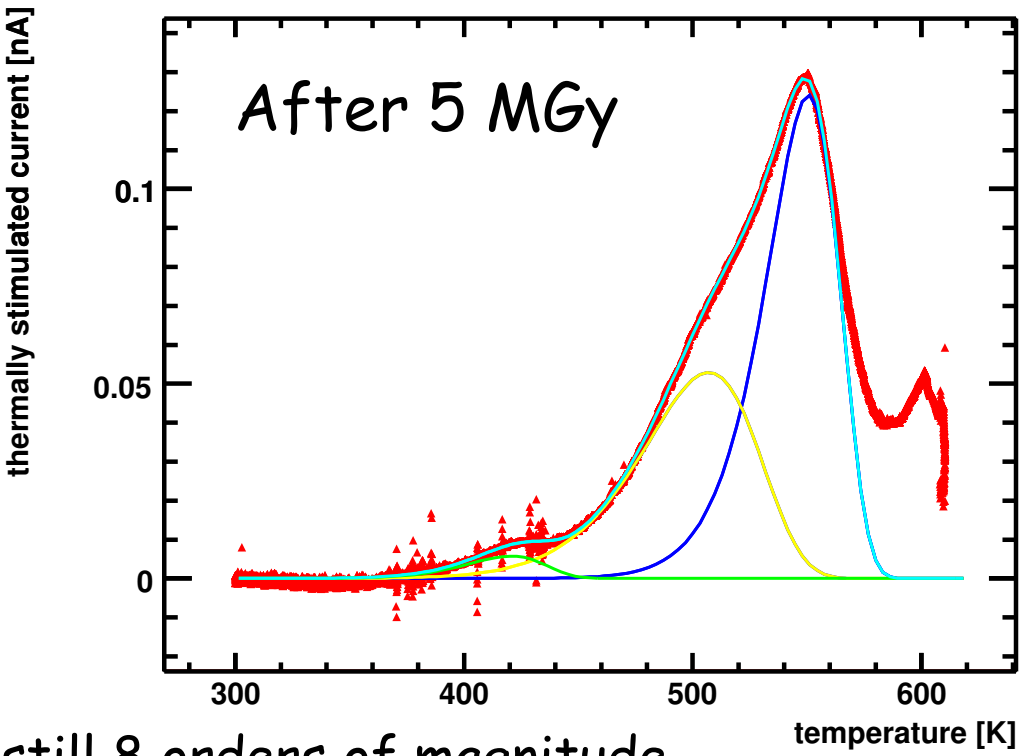


- Clear indication to the presence of fast decaying traps.
- Additional polarization due to shallow defects filling

TSC measurements

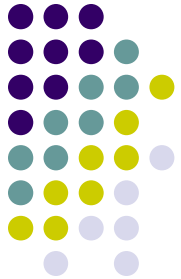
At least 3 levels are visible:

	trap1	trap2	trap3
$Ec-E_T$ [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

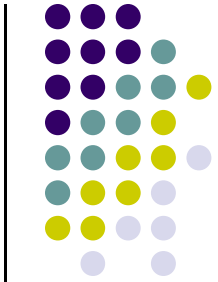


Trap concentration ~ 10^{15} cm^{-3} (still 8 orders of magnitude less than normal atom density)

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
- Polarizaton significantly decreases the detector charge collection efficiency in addition to pure trapping mechanism
- A simple model is developed in order to understand and describe observed phenomena
- Method of routinely switching bias HV polarity is proposed to suppress bulk polarization of long-living traps
- Beam pumping tests indicate that short-living traps are responsible for the residual detector inefficiency



Thank you