Investigation of the properties of diamond radiation detectors

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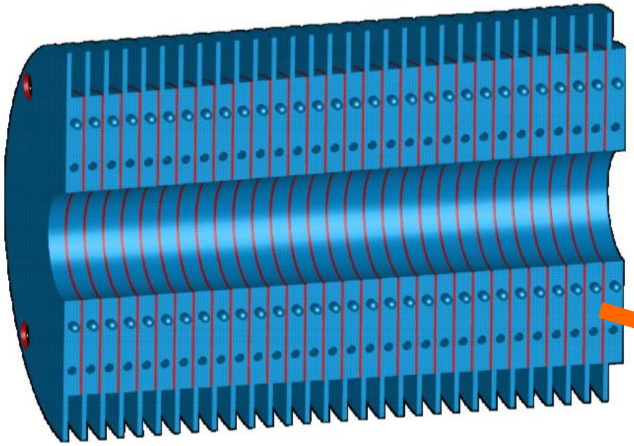
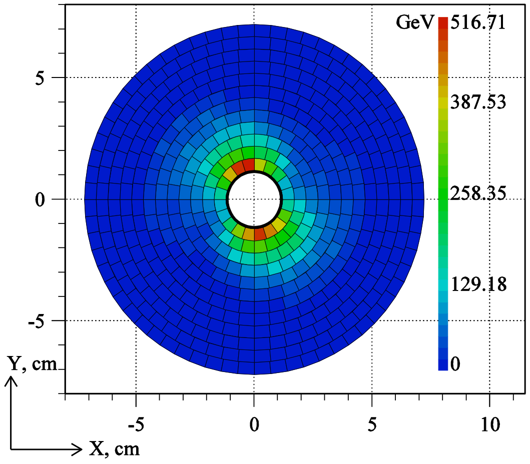
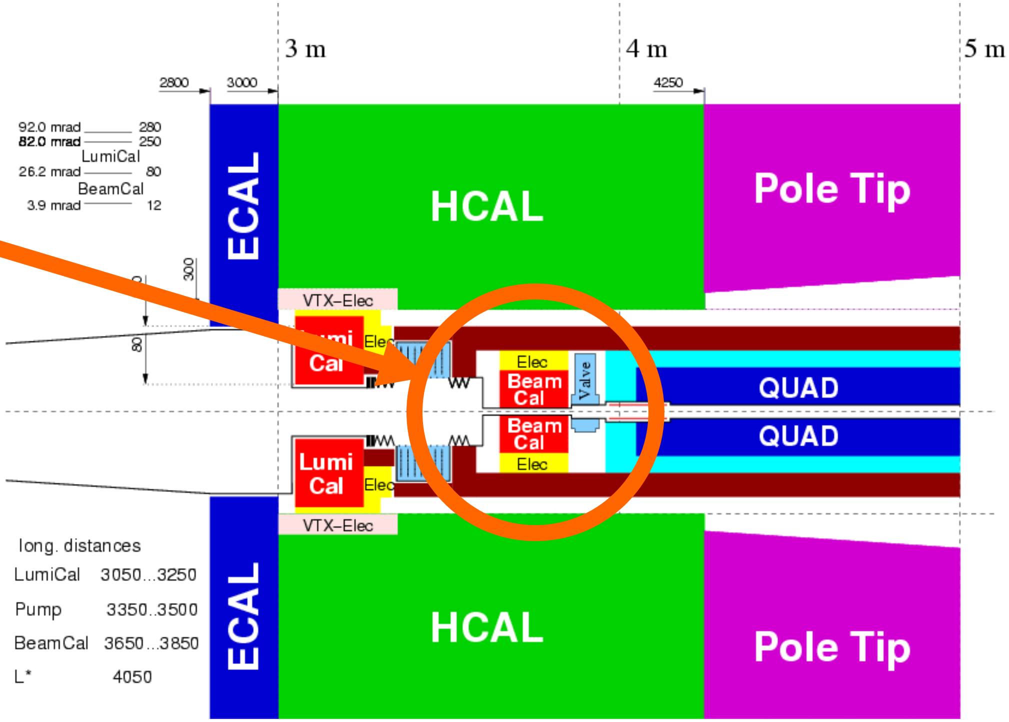
Possible Applications



Sampling diamond-tungsten calorimeter



ILC Detector forward calorimeter



long. distances	
LumiCal	3050...3250
Pump	3350..3500
BeamCal	3650...3850
L*	4050

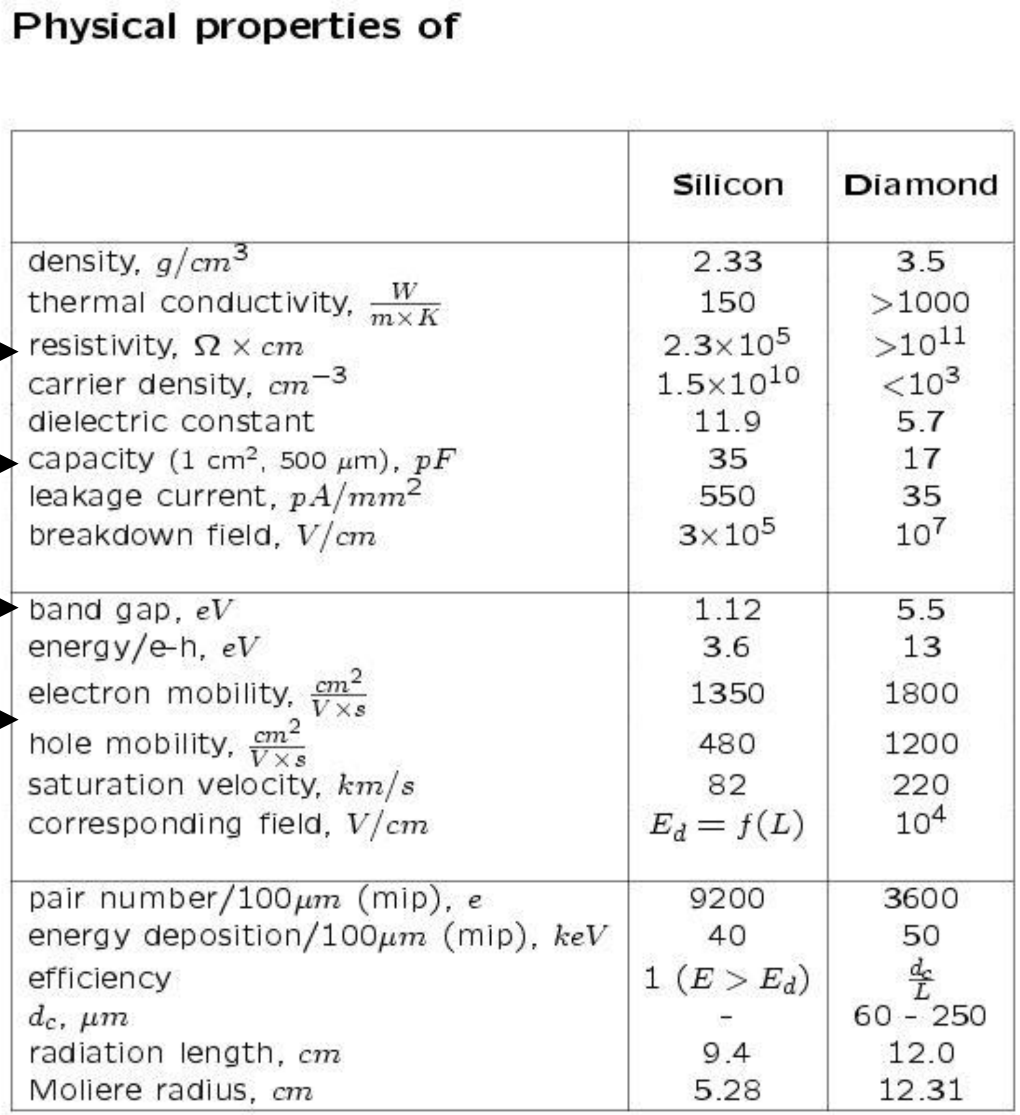
Expected dose from beamstrahlung is about 10 MGy per year

Diamond as detector

Diamond have very
high radiation hardness
(doses up to 10 MGy)

This makes diamond very
promising material for the
next generation colliders

It also have unique
properties, such as low
conductivity, high
thermoconductivity, wide
bandgap, chemical inertness



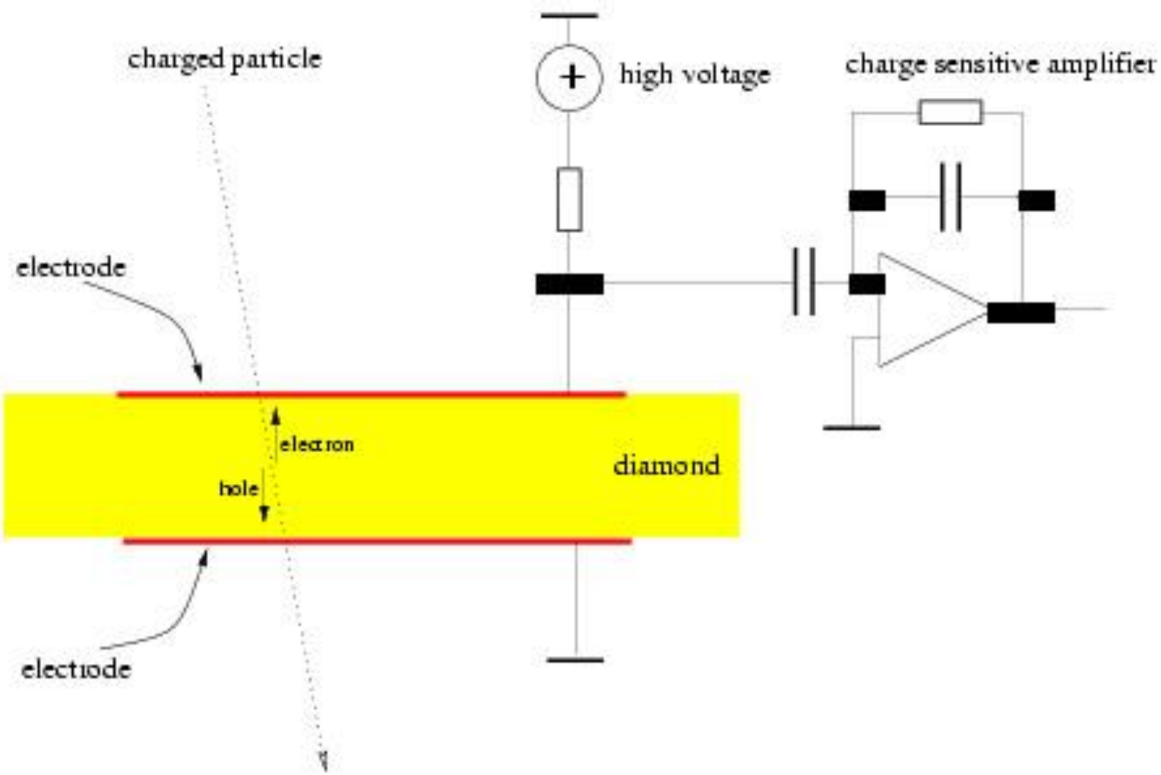
Physical properties of

	Silicon	Diamond
density, g/cm^3	2.33	3.5
thermal conductivity, $\frac{W}{m \times K}$	150	>1000
resistivity, $\Omega \times cm$	2.3×10^5	$>10^{11}$
carrier density, cm^{-3}	1.5×10^{10}	$<10^3$
dielectric constant	11.9	5.7
capacity (1 cm^2, 500 μm), pF	35	17
leakage current, pA/mm^2	550	35
breakdown field, V/cm	3×10^5	10^7
band gap, eV	1.12	5.5
energy/e-h, eV	3.6	13
electron mobility, $\frac{cm^2}{V \times s}$	1350	1800
hole mobility, $\frac{cm^2}{V \times s}$	480	1200
saturation velocity, km/s	82	220
corresponding field, V/cm	$E_d = f(L)$	10^4
pair number/100μm (mip), e	9200	3600
energy deposition/100μm (mip), keV	40	50
efficiency	$1\ (E > E_d)$	$\frac{d_c}{L}$
d_c, μm	-	60 - 250
radiation length, cm	9.4	12.0
Moliere radius, cm	5.28	12.31

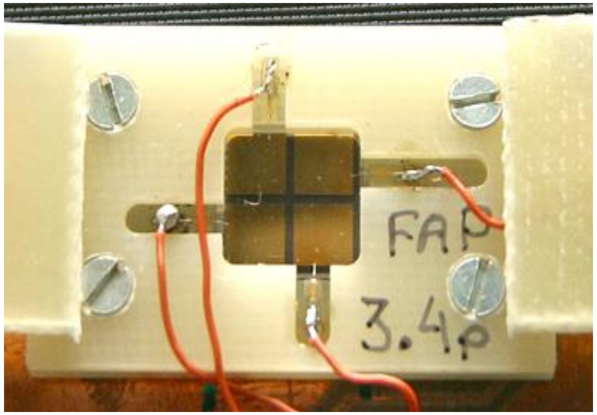
Detection mechanism

Diamond works as a solid state ionization chamber

Charge carriers, generated by ionizing particle move in an external electric field and induce charge on the surface electrodes



This charge is detected by a charge-sensitive preamplifier



The sapmles

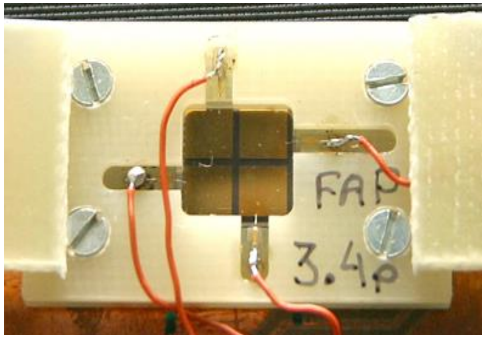
Chemical vapor deposited (CVD) polycrystalline samples:

A large selection of samples from Fraunhofer IAF, Freiburg

12x12 mm plates with thickness 200 - 700 μm

Metallization: 10 nm Ti + 400nm Au

1 pad or 4 pad segmentation



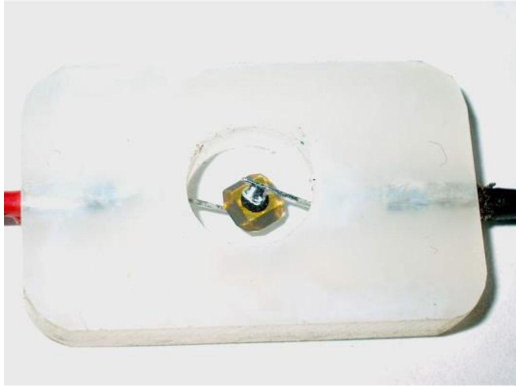
2 samples from Element Six (former De Beers Industrial Diamonds)

HPHT synthetic monocrystalline samples:

From ADAMAS BSU

Typical size 4x4 mm, thickness 300 - 600 μm

Metallization: **Fe-Ni with B ion implantation**



1 sample of natural monocrystalline diamond

Charge collection distance

Performance of diamond as particle detector is usually characterized by charge collection efficency ε or distance (CCD)

Efficency is given by $\boldsymbol{\varepsilon = Q_{meas}/Q_{ind}}$

where Q_{meas} is measured charge and Q_{ind} - total charge generated

Charge collection distance equals $\mathbf{CCD = \boldsymbol{\varepsilon} * d}$

where d is the thickness of the sample

CCD could be considered as separation between charge carrier pair before trapping

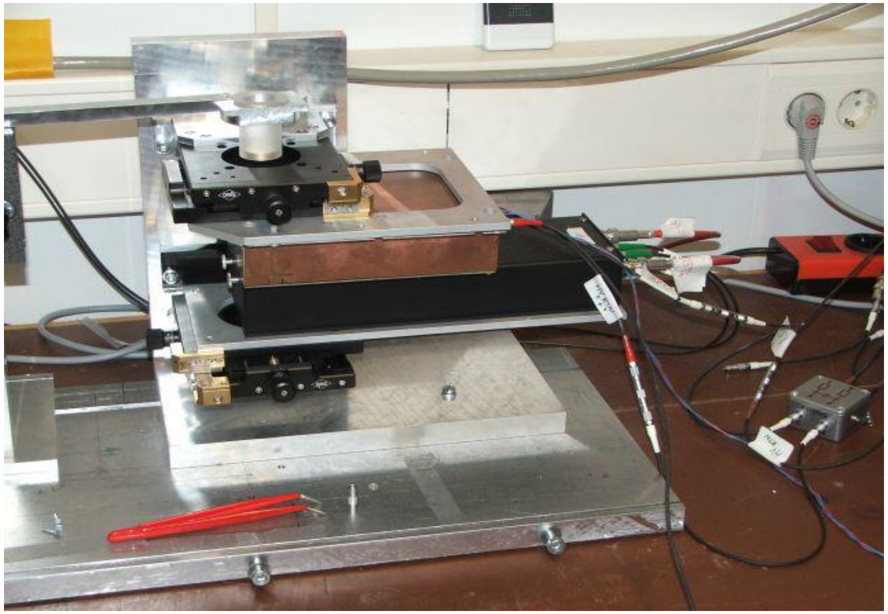
CCD Measurement

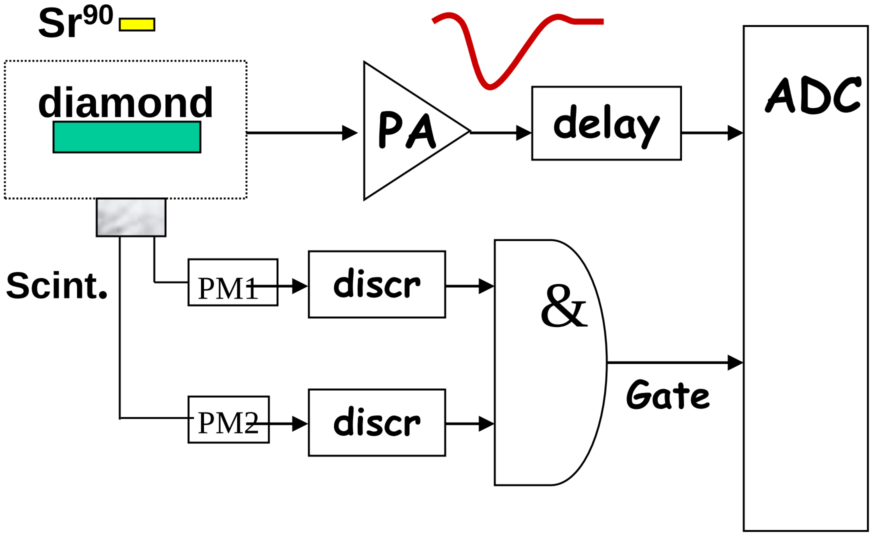
To measure CCD we need to know the exact amount of charge carriers generated

But we know that a MIP generates about 36 e^{-}-h pairs per 1 μm pathlength in diamond

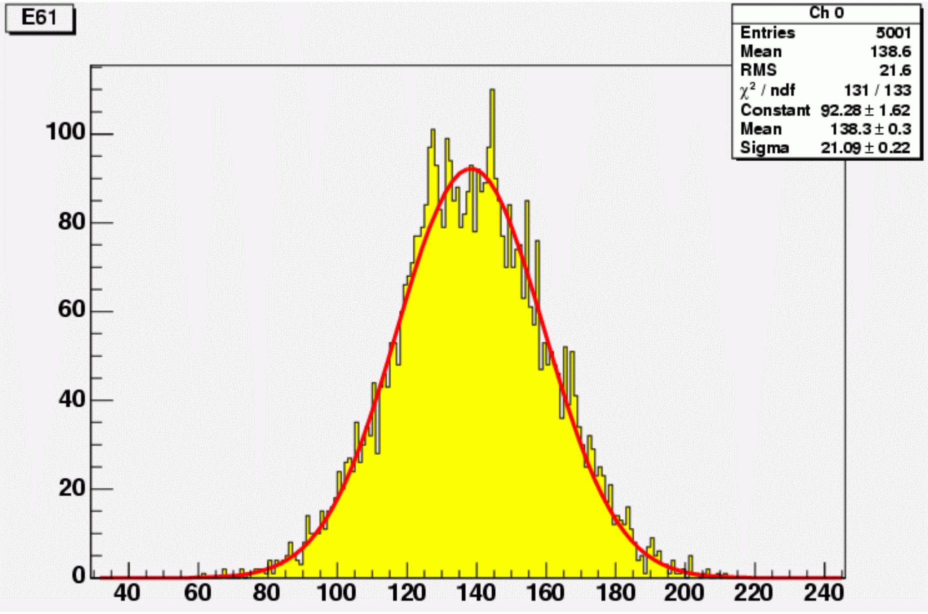
In this case CCD = $\mathbf{Q}_{\mathbf{meas}}/36$

Scintillator allows triggering only from particles which could be considered MIPS

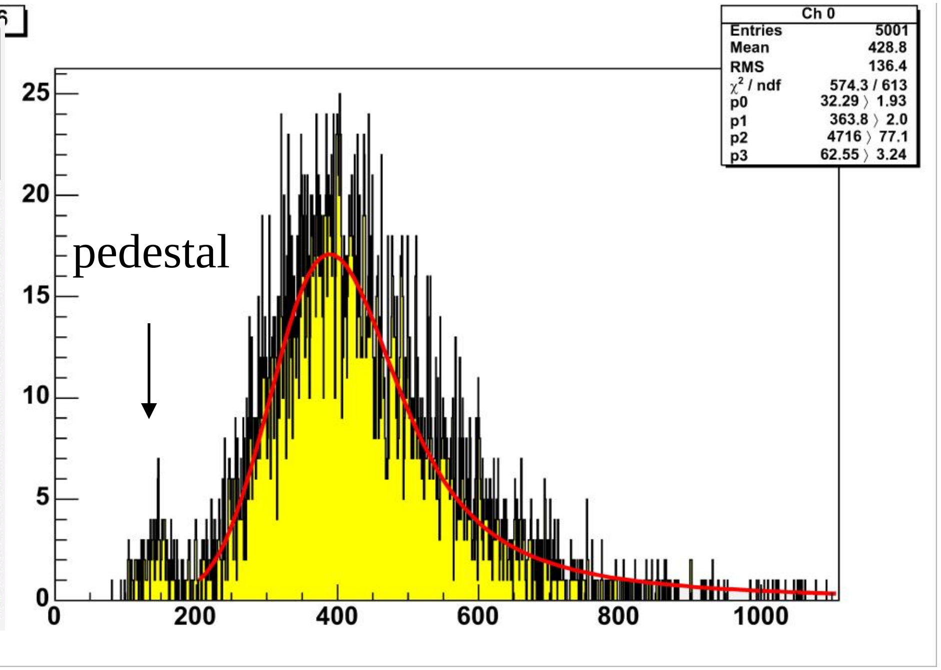




CCD Measurement



Pedestal (random trigger)



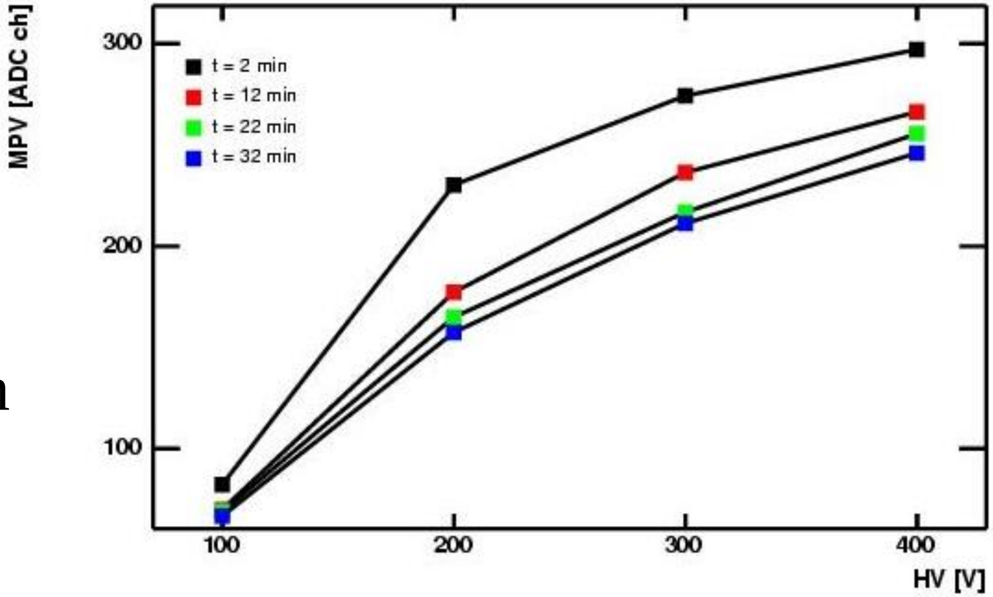
Signal (MIP trigger)

Signal charge value could be calculated from this pair of spectra by subtracting pedestal and multiplying by charge/ADC channel value from calibration.

CCD vs HV and time

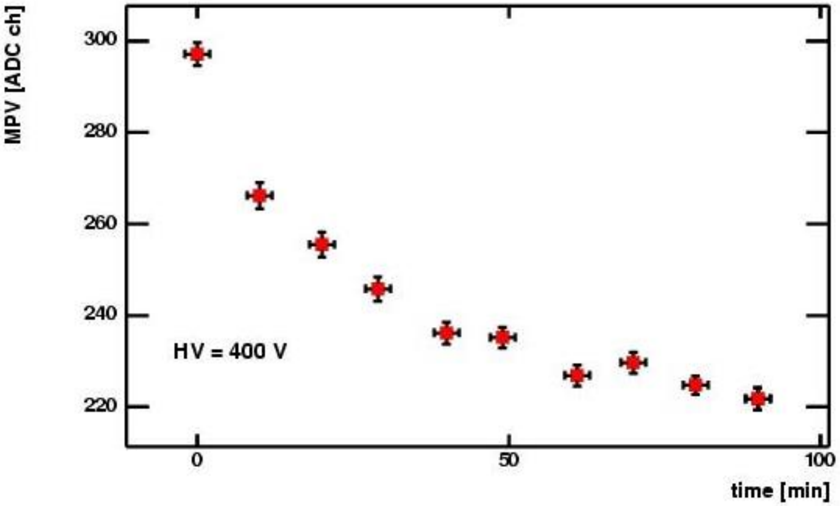
Charge collection distance depends on bias voltage applied to the sample

Saturation is observed at field strength of about 1V/μm

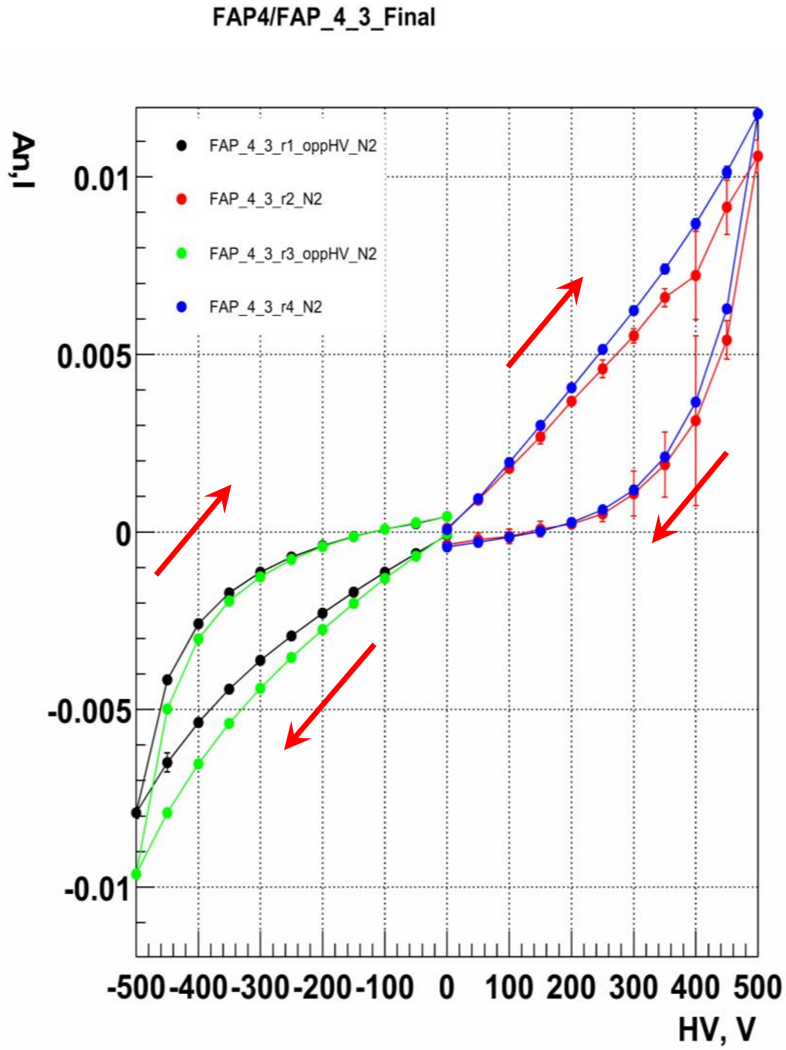


There is also dependence of CCD on time with HV on

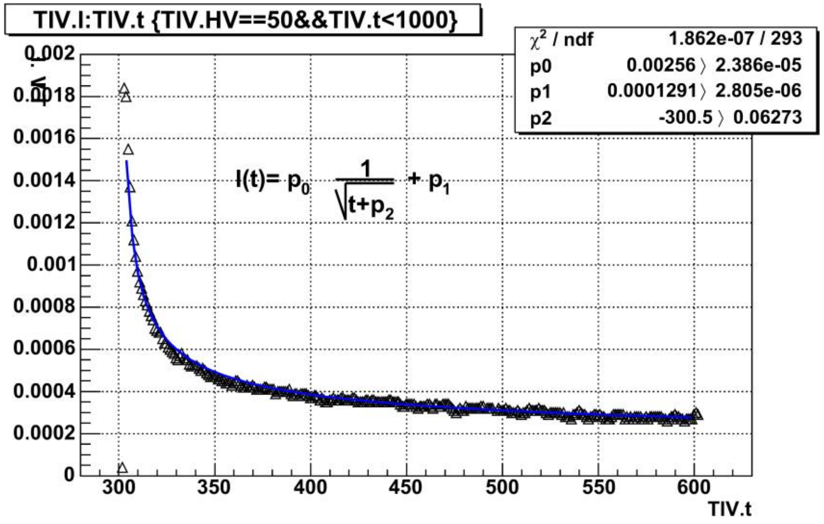
This is probably due to some kind of space-charge effect from trapped charge carriers



IV Measurement



Most of the samples show ohmic behavior and very high resistance in the order of 10^{13}-10^{14} ohm

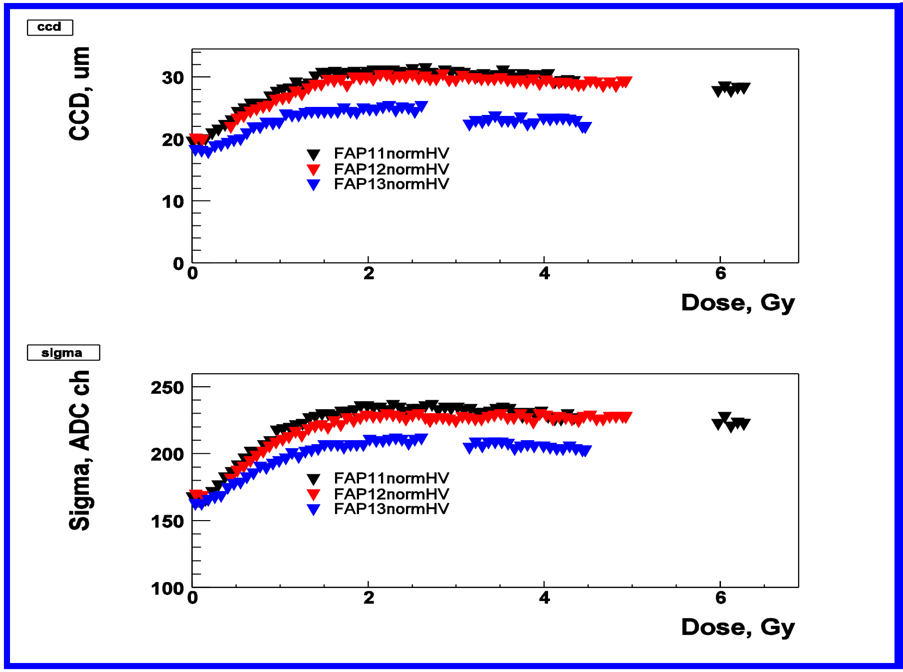


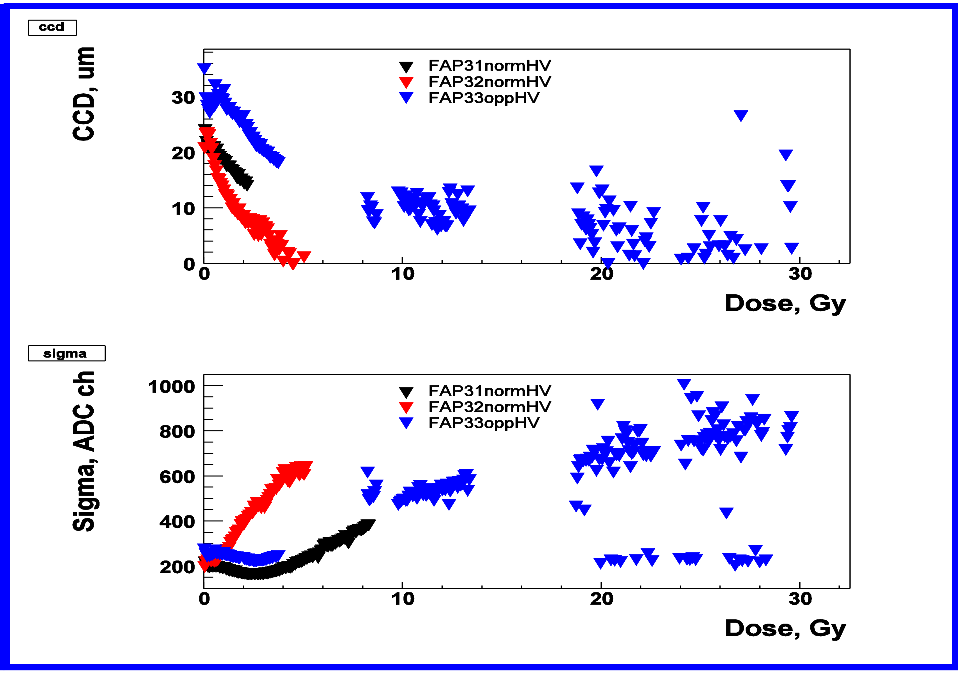
Settling time of the current is in the order of 100 s. Hysteresis is probably due to polarisation.

CCD vs Dose

Diamond is stable under irradiation with doses up to 10 MGy

But in the process of irradiation detector properties could change





Most of the samples show similar behavior
CDD is rising with the dose by approx. 10-20%
and then stabilises

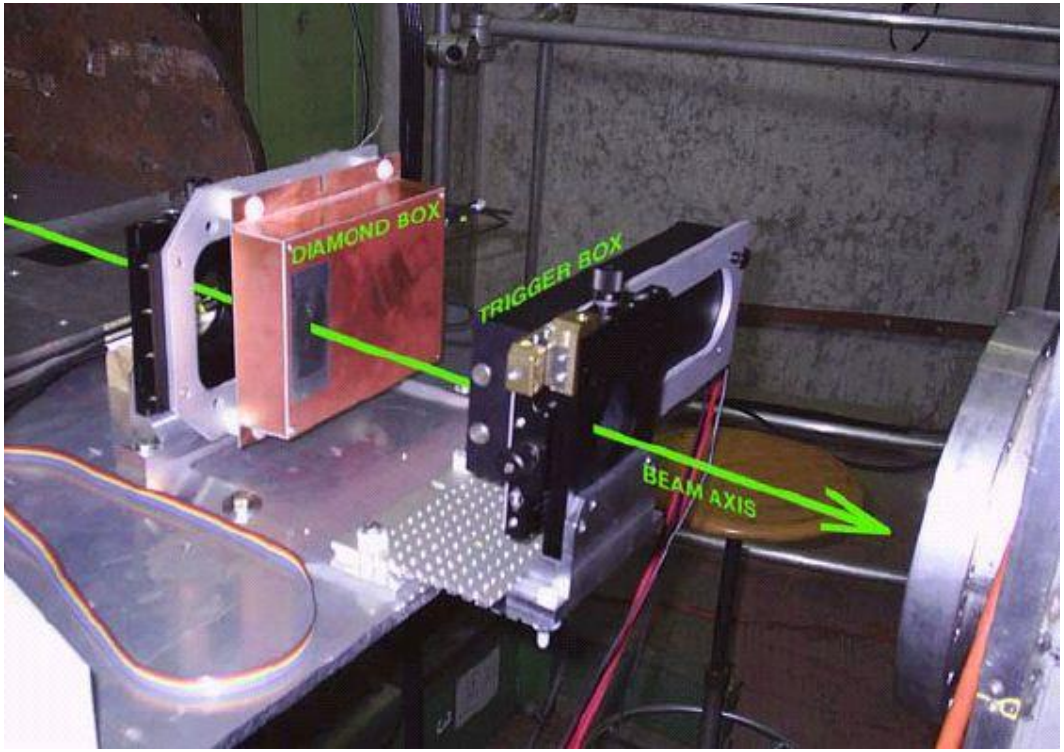
But some sapmles show complete
degradation of signal and sharp rise
of the current under irradiation

Linearity

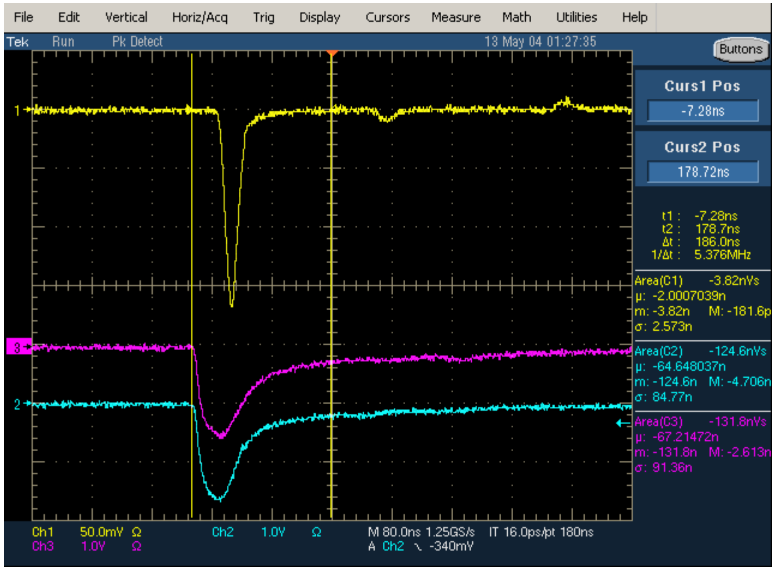
- A linear behavior over high dynamic range is required for the calorimetry application.
- We have checked this at a beamtest at CERN

Setup consists of a box with diamond and preamplifier and scintillator trigger box

Incident hadronic beam with approx. 4 GeV energy and intensity
from $10^5 - 10^6$ / s
up to $10^5 - 10^7$ / 10ns



Linearity



```
Curs1 Pos
-7.28ns
Curs2 Pos
178.72ns

t1 :   -7.28ns
t2 :   178.7ns
Δt :   186.0ns
1/Δt : 5.376MHz

Area(C1)     -3.82nVs
μ: -2.0007039n
m: -3.82n    M: -181.6p
σ: 2.573n

Area(C2)     -124.6nVs
μ: -64.648037n
m: -124.6n   M: -4.706n
σ: 84.77n

Area(C3)     -131.8nVs
μ: -67.21472n
m: -131.8n   M: -2.613n
σ: 91.36n

Ch1   50.0mV  Ω      Ch2   1.0V   Ω      M 80.0ns 1.25GS/s   IT 16.0ps/pt 180ns
Ch3   1.0V    Ω                          A Ch2 ↘ -340mV
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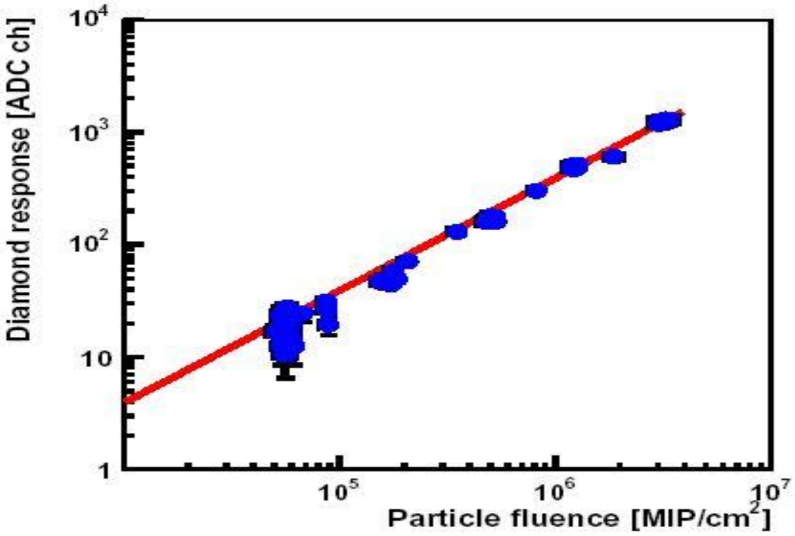
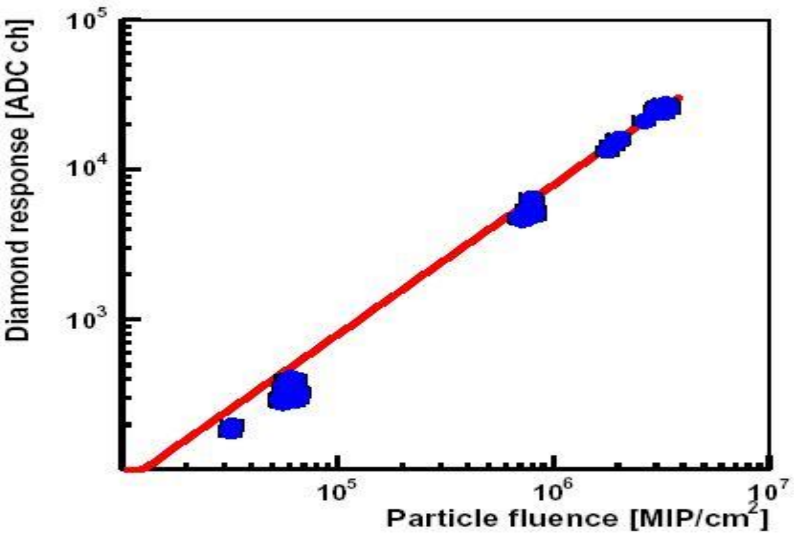
Signal at high intensity clearly visible w/o preamplifier

Good linearity for two samples over the dynamic range of 10^2





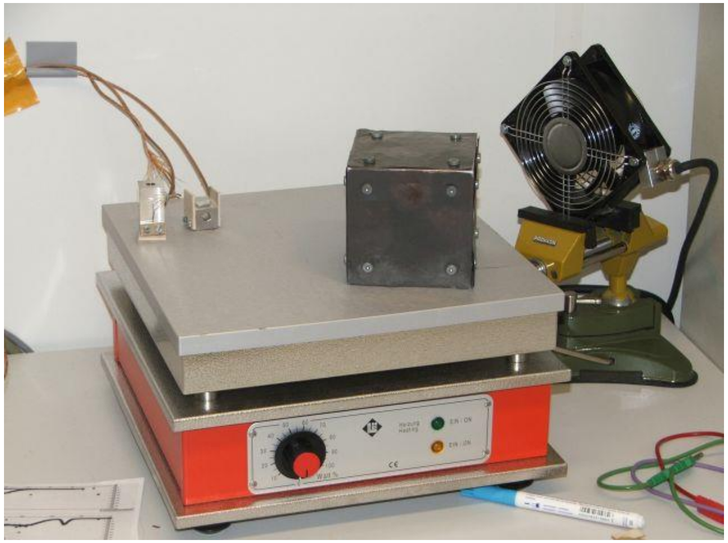
Trapping

- Trapping of the charge carriers is the main cause of low CCD.
- Traps could be impurities, defects and other irregularities of crystalline structure.
- Filling of traps produces space charge in the crystal and could give rise to polarisation effects
- If we have several trapping levels with different activation energy, density and cross section, the dynamics of trapping will be really weird.
- On the other hand filling of deep traps leads to “pumping effect”

TSC measurements

- TSC means thermally stimulated currents
- The idea is that if we have charge carrier trapping in the diamond at room temperature, then heating the sample up could free trapped charge carriers and produce detectable current. The current peak position vs temperature gives the idea about energy levels of traps.

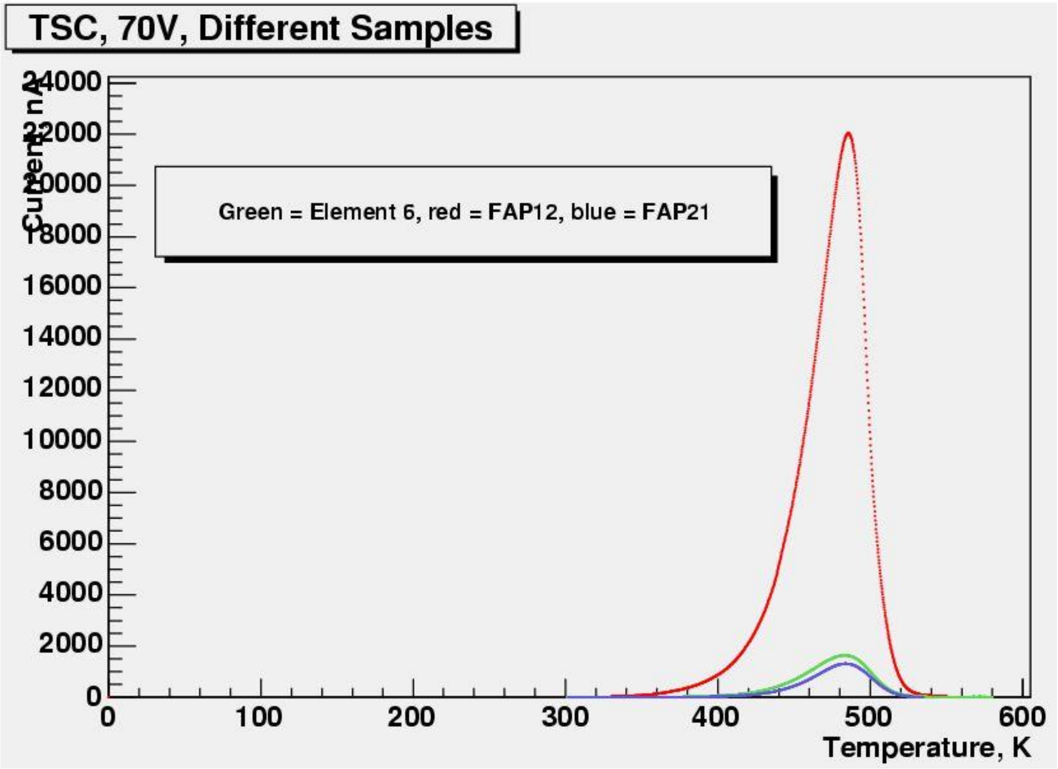
Setup consists of heating plate electronic thermometer with thermopair, HV supply and picoammeter



TSC measurements

- TSC data for different diamonds

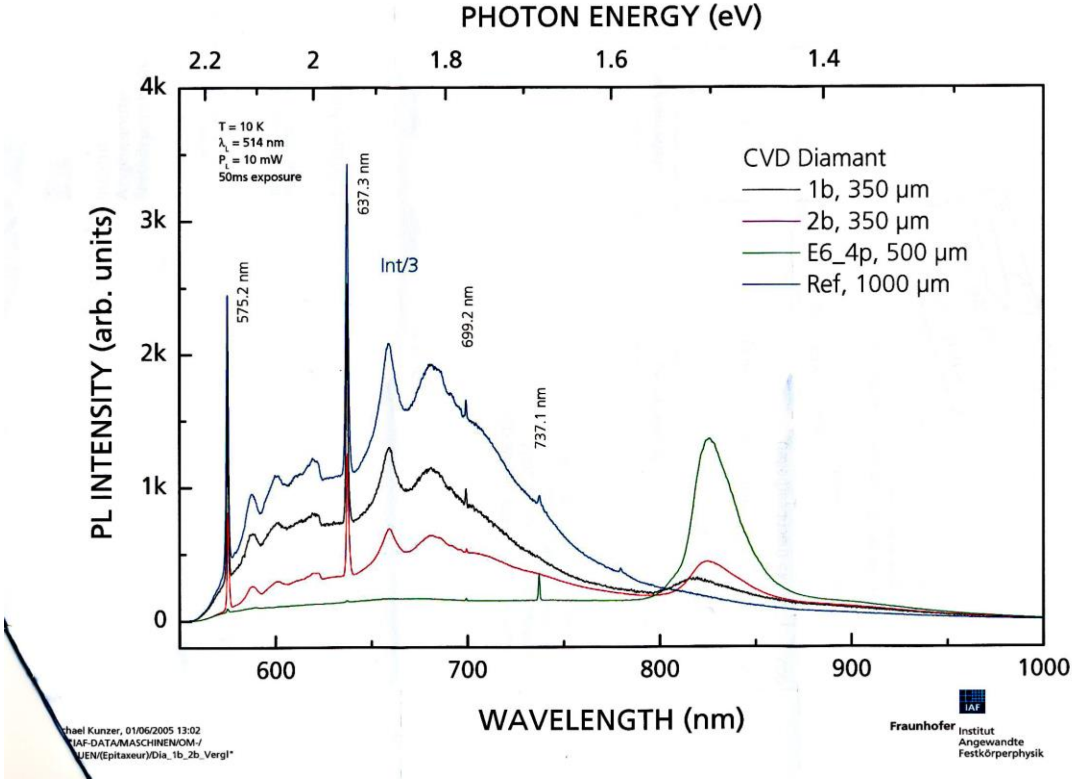
Peak position corresponds to energy of about 0,8-1 eV

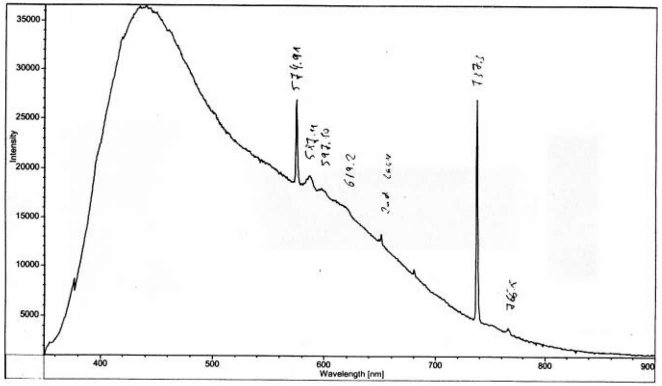


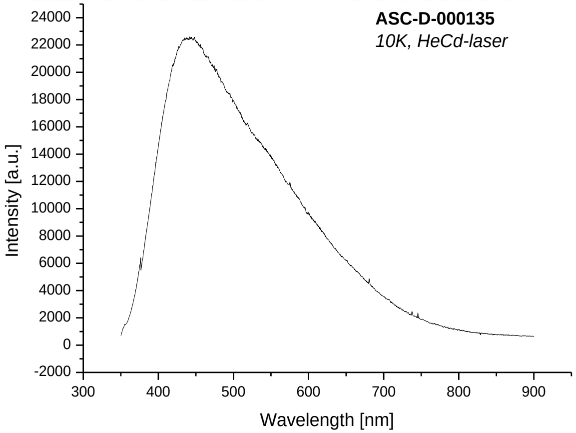
TSC “resets” sample, but the shape is similar for different samples

PL Spectra

- Photoluminescence spectra of different samples

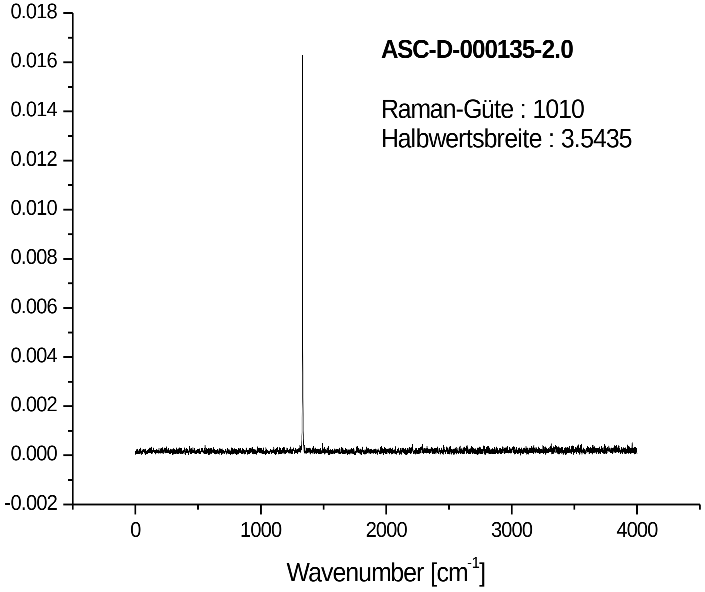


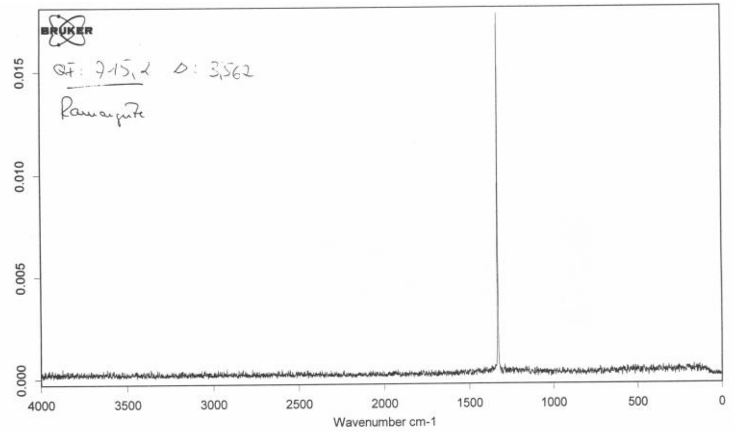


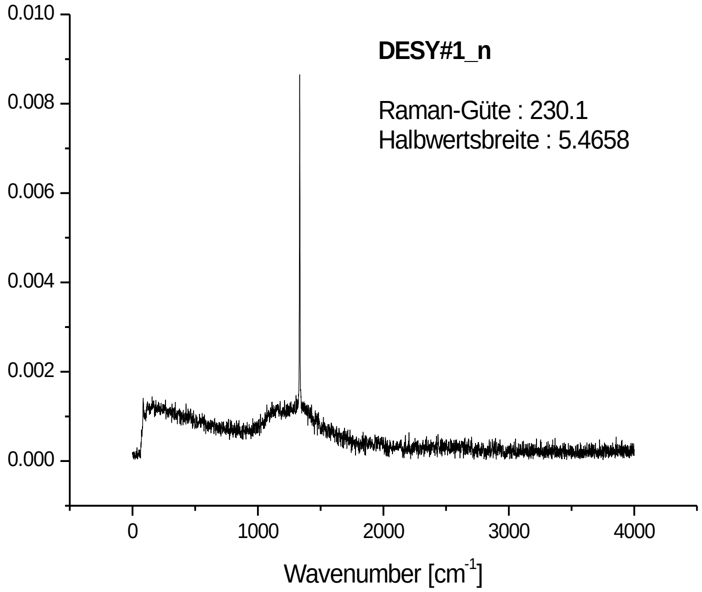


There seems to be a correlation between detector properties and PL

Raman Spectra







Conclusion

Diamond sensors work and we have results both from CVD and synthetic monocrystalline diamonds.

The sensors have good radiation hardness and linear response.

But the CCD vs time behavior and dependence of CCD on dose complicates use of diamond sensors in calorimetry.

In the present state diamond sensors already could be used for beam monitoring.

Future work

- Need to establish close contact with manufacturer, find a method to characterize samples (TL, raman?) and get interpretetion from the material scientists
- Further study of the influence of metallization and surface treatment is needed
- A study of radiation hardness with large doses is planned