Synthetic diamonds for heavy-ion therapy dosimetry

Monika Rębisz

Bernd Voss

Outline

Why CVD diamonds?

Motivation & Aim

Online monitoring → High-speed single-particle beam monitor

Offline monitoring → **T**hermo-**L**uminescent **D**etector

Detectors, Electronics and Equipment

Principles of operation

In-beam tests - results and discussion

Summary and Outlook

Why CVD Diamond? – Beam Monitor Concepts

- High drift velocity + short charge lifetime
  - short pulses (ns) ‘’rise time & duration’’
  - good time resolution for high-speed counting

- „Simple“ operation because of broad 5.5 eV band
  - gap no cooling or pn junction is needed

- Radiation hard ~10^{15} particles/cm^2

- Carbon low Z=6
  - beam quality preserved
  - biocompatible

- Actual size possible up to 12 cm ø wafers (nanoCVD larger size possible)

Motivation & Aim

Online monitoring High-speed single-particle beam monitor

Avoid the need for daily calibration of the gaseous monitor detector in terms of 'particles per monitor unit'

Measure intensity & structure of the extracted beam by **counting individual particles** close to the **GHz/channel**-range

Offline monitoring Thermoluminescent diamond detector

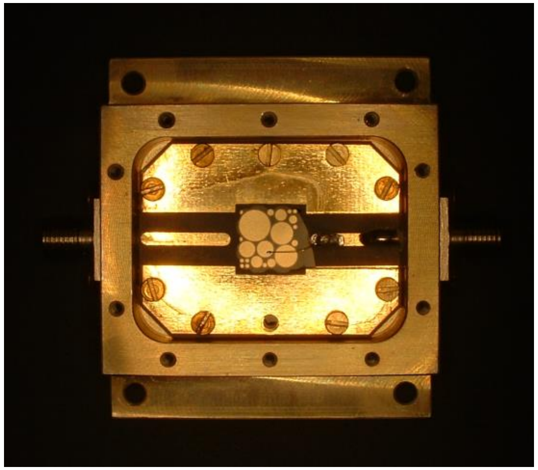
Dose verification after irradiation

Mostly outside the beam (Dose ≈ 0) → very sensitive material needed

Standard TLD material (**LiF**) shows low efficiency to HI - **fast local saturation**
→ CVD better candidate?

Detectors & Parameters

Sample name	Size [mm²]	Thickness [μm]	# Pad	Pad size [mm²]
B	20 × 20	95	16	17.64
D1	10 × 10	100	21	2.01
D2	10 × 10	100	21	8.04
S6	10 × 10	500	1	63.6
L3	10 × 10	124	1	63.6
NCD	~ 1.2	60	21	4.15



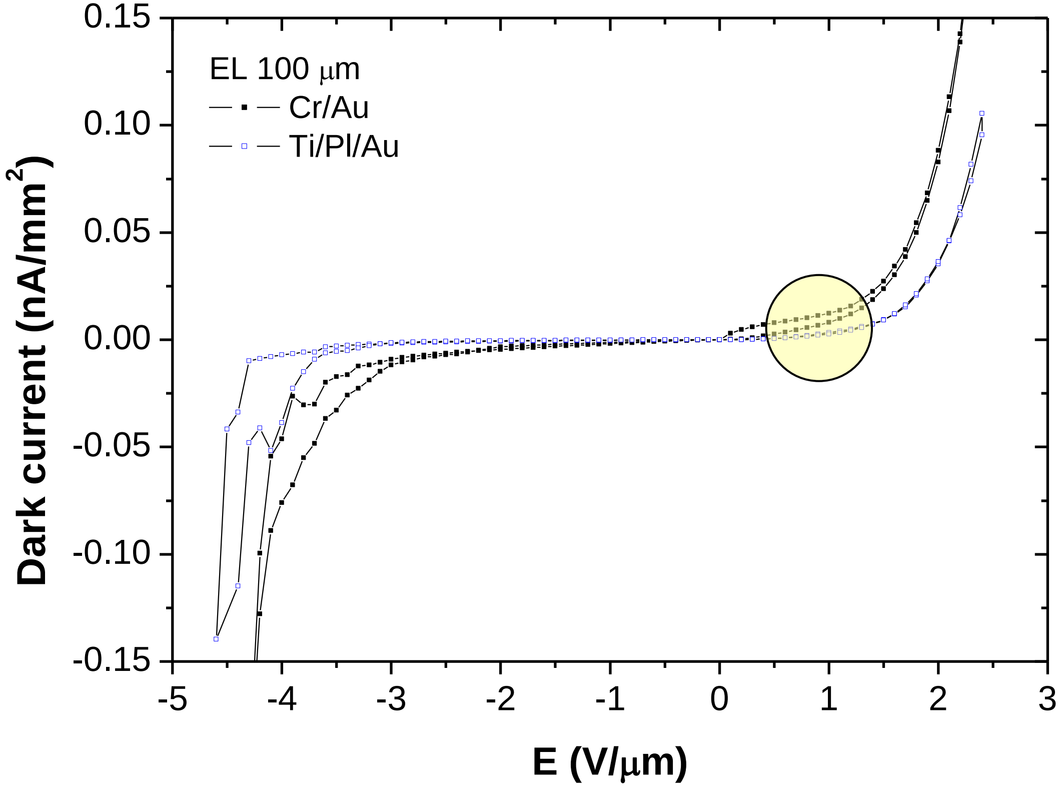
Pixel area: 0,2 – 16 mm^2

Sample name	Size [mm²]	Thickness [μm]	Producer
TM	3.6 × 3.6	385	e6
PC	3.6 × 3.6	359	e6
OP	3.6 × 3.6	355	e6
EL	3.6 × 3.6	370	e6
BEL	3.1 × 3.1	560	LUC Belgium
HPHT1	10.38	255	IMP Russia
HPHT2	7.84	359	IMP Russia
HPHT3	6.63	230	IMP Russia

Detectors & Parameters

I-V characteristics (D1 , D2)

Electric field = 1V/µm



What about fast read-out electronics?

Already existing fast "commercial" electronics:

DBA – Diamond Broad-Band Amplifier → designed specially for diamond at GSI

- Various types : DBA II; III ; IV
- Low noise, remote controlled gain for DBA III and IV
- Analogue output signal,
- Band width 2.3 - 2.1 GHz

☺ Quite good for heavy ion (high signal) beam monitoring
☹ Only single channel read-out
☹ Pick-up noise relatively high

Development of new fast multi-channel electronics:

NINO card → prototype designed for ToF ALICE project,

- Differential read-out of 24 channels per card
- Digital signal

Modifications:

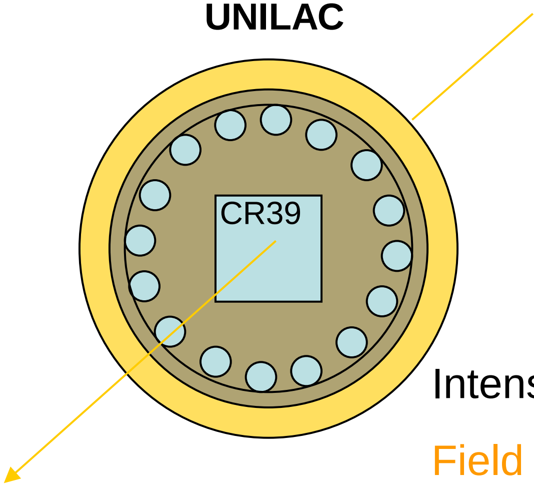
☺ Differential input → elimination of pickup noise
- Further modification in progress

Experiments & Beam Parameters

<table>
<tr><th></th><th colspan="2">SIS</th><th colspan="2">UNILAC</th></tr>
<tr><td>Energy</td><td>80-430 MeV/u</td><td rowspan="2">^{12}C
Therapeutic conditions –
Scanning beam</td><td>11,4 MeV/u</td><td rowspan="2">^{12}C, 10.2 MeV/u
^{48}Ca, 8.3 MeV/u
^{54}Cr, 7.6 MeV/u
^{152}Sm, 5.8 MeV/u
…
…</td></tr>
<tr><td>Beam size</td><td>4 -10 mm (FWHM)
3 × 3 cm^2
10 × 10 cm^2</td><td>45 mm Ø</td></tr>
<tr><td>Intensity</td><td colspan="2">10^6 -10^8 ions/second
2.8×10^4 -2.6×10^7 ions/cm^2</td><td colspan="2">10^4-10^5 ions/second/mm^2</td></tr>
<tr><td>Operation</td><td colspan="2">Transmission mode</td><td colspan="2">Stopping mode</td></tr>
<tr><td>Aims</td><td colspan="4">Feasibility test</td></tr>
<tr><td>DBA</td><td colspan="2">Reduce pickup noise</td><td colspan="2">bipolar</td></tr>
<tr><td>NINO</td><td colspan="2">1.test unipolar</td><td colspan="2">bipolar</td></tr>
</table>

Setup

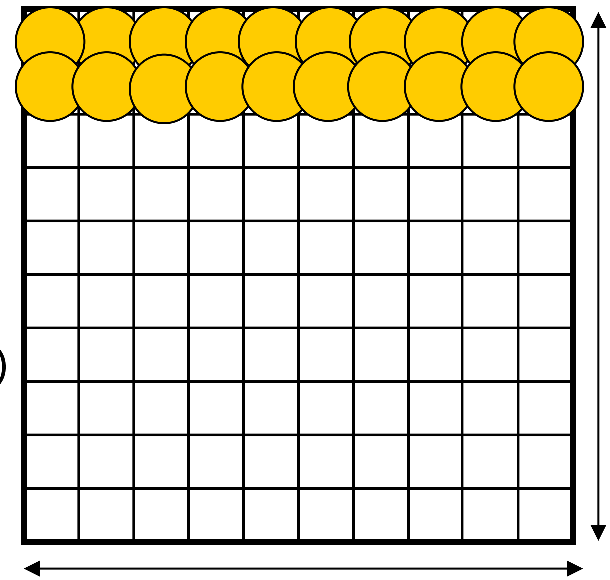
UNILAC



Intensity = const (x,y)

Field = 16 cm^2

SIS

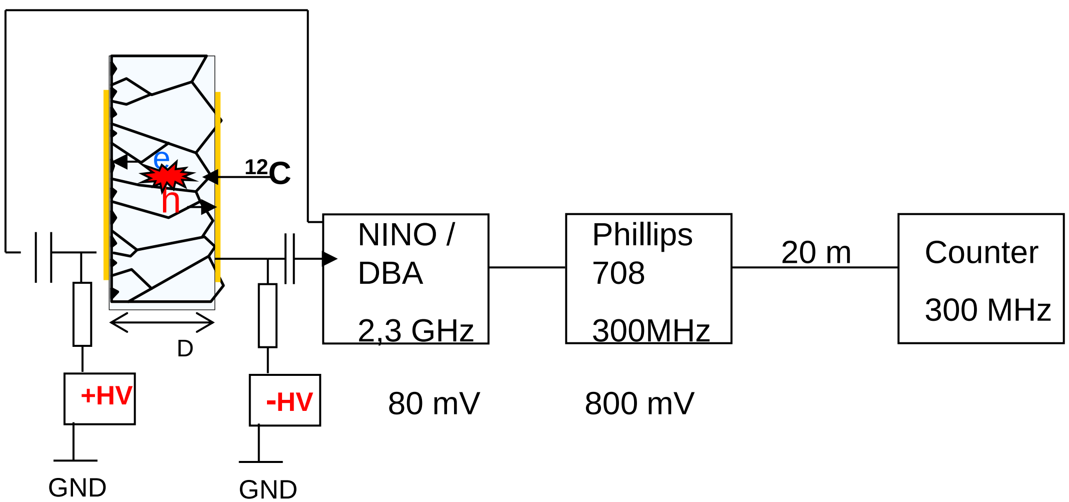


Intensity ≠ const

Field = 9 cm^2

256 irradiation points

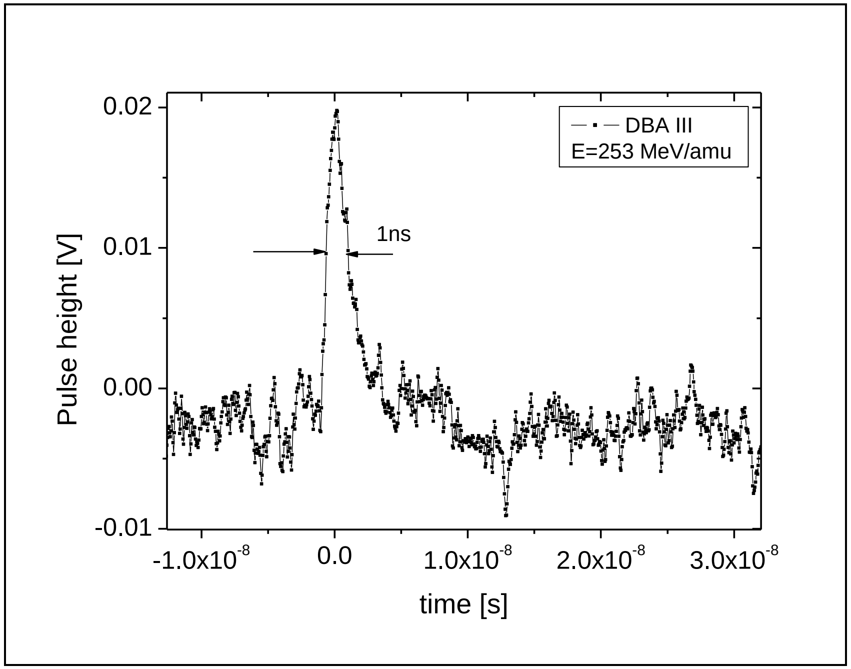
Ø 2,2 – 8,8 mm

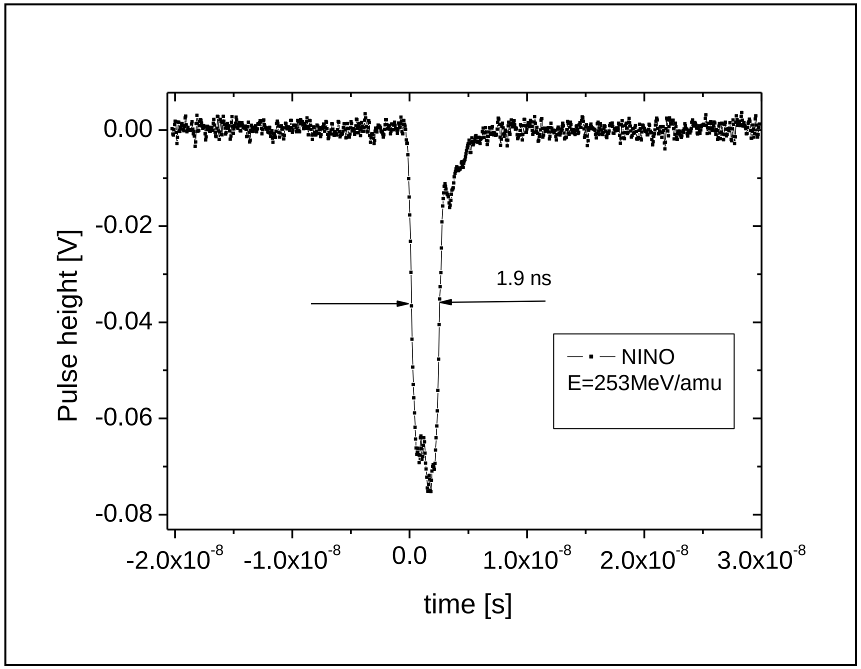


Results

16 Pixel detector 150µm ^{12}C E=253 MeV/u SIS

1st beam time – set-up of first electronics with unipolar readout





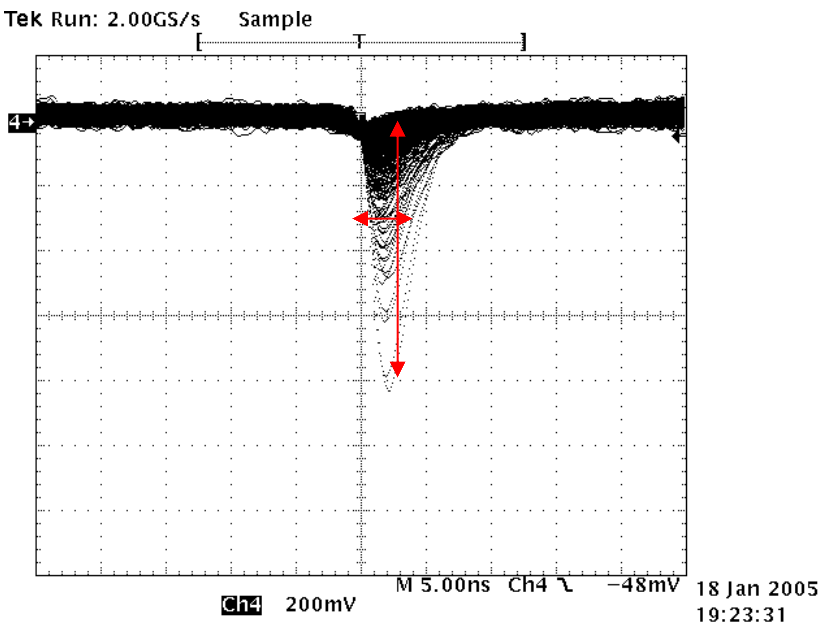
High pick-up noise with DBA III, better for NINO (even with unipolar input)

Results

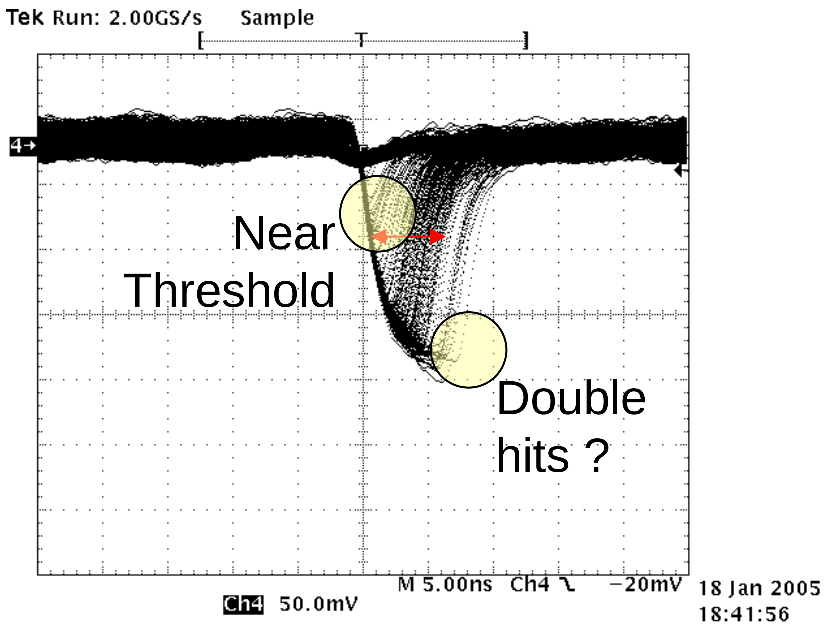
16 Pixel detector 150µm ^{48}Ca E=8,3 MeV/u UNILAC

Single shots, unipolar read-out

DBA IV



NINO

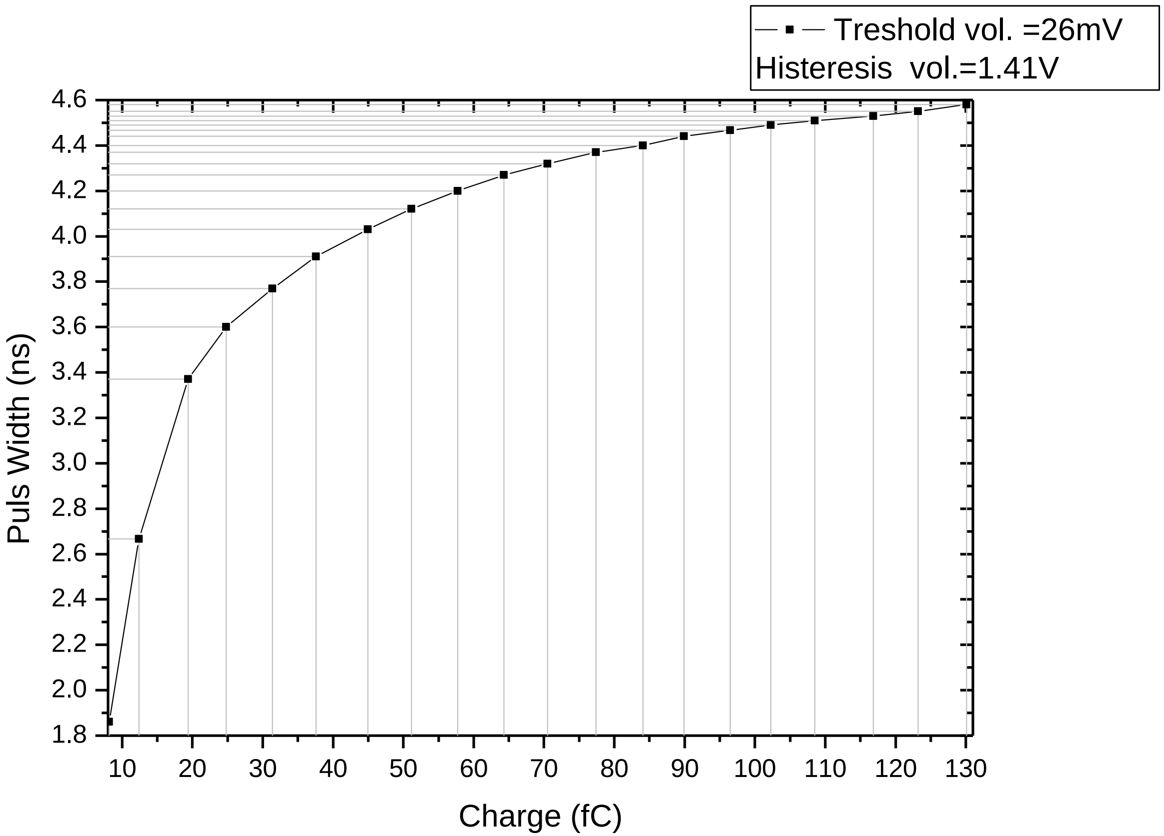


Pulse area ~ Q_C

Pulse with ~ Q_C

Results

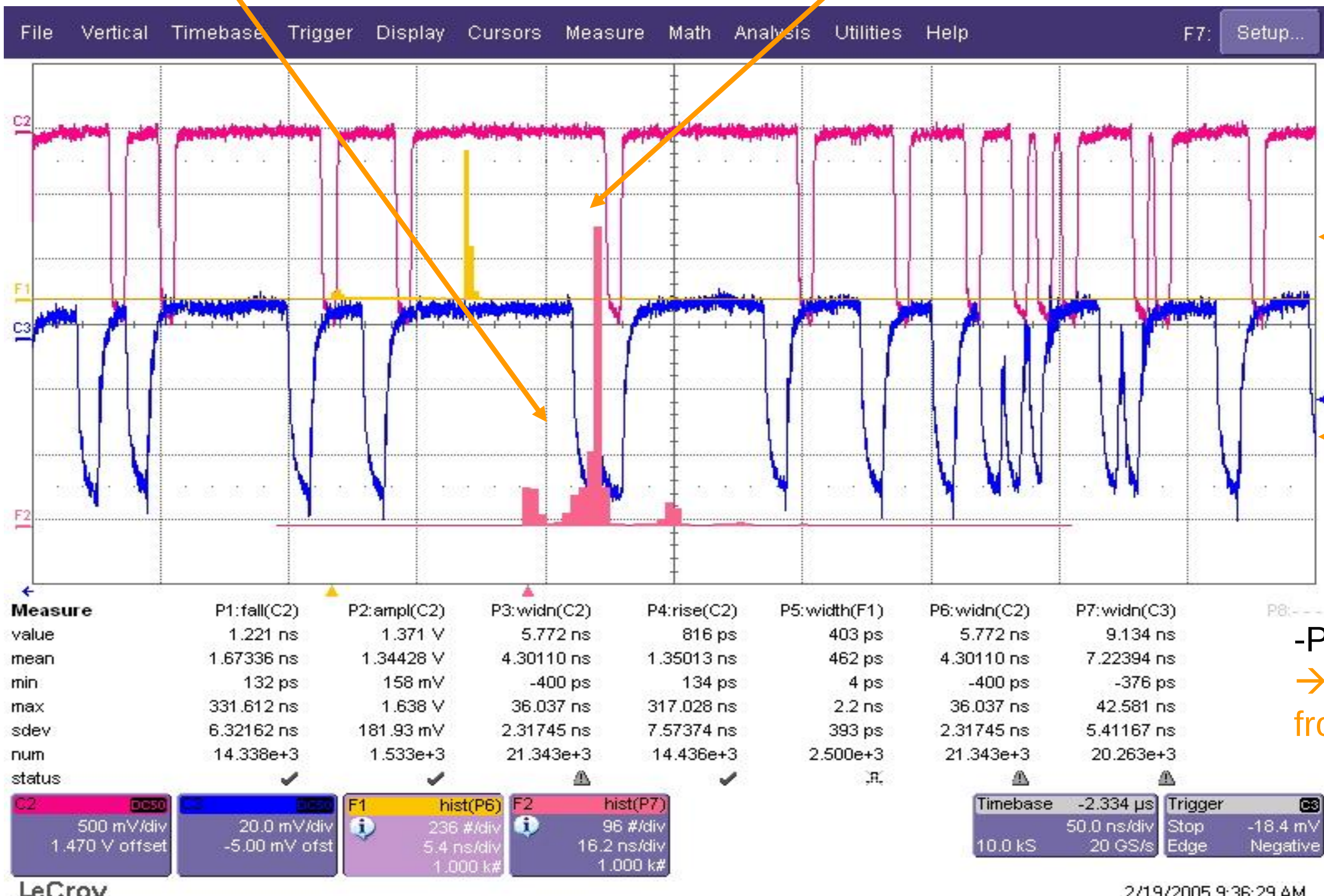
Pulse width – charge dependency for adapted NINO



Results

1 Pixel L3-GSI 124µm ^{12}C E=10,2 MeV/u UNILAC

Double pulse width **Only 1 pulse is counted** **→ Pileup problem**



NINO card

Digital signal after Philips 708 discriminator

Original signal

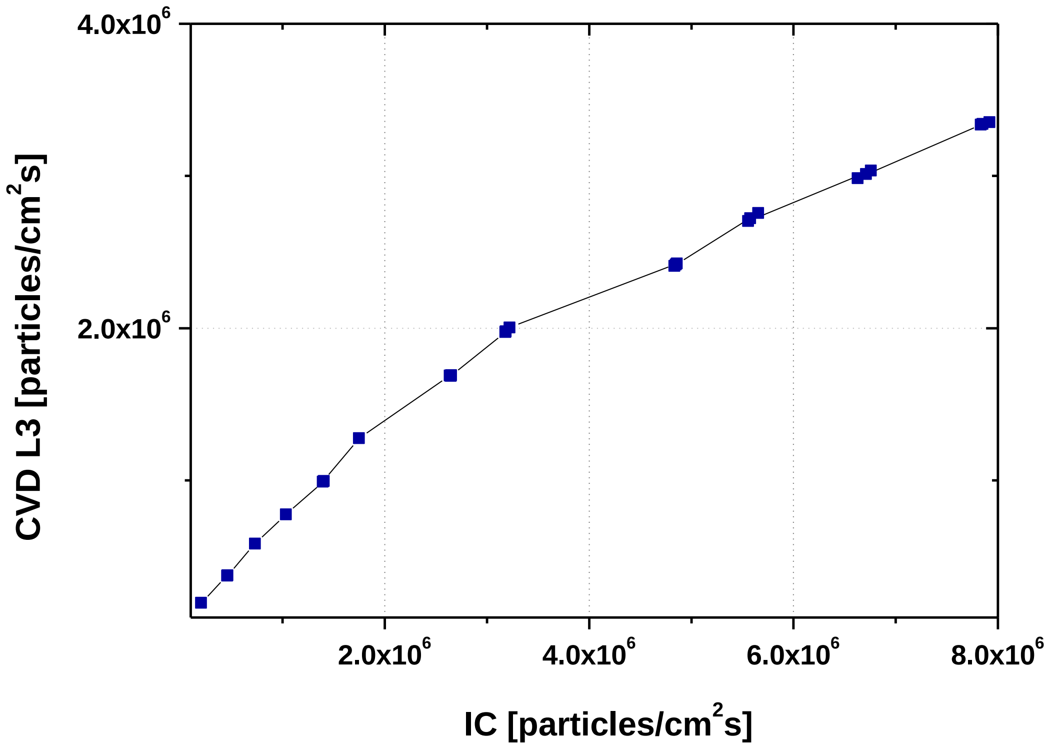
Th=30mV

-Pulse splitter used

→½ original signal from NINO

Results

1 Pixel L3-GSI 124µm ^{12}C E=10,2 MeV/u UNILAC



NINO card

30 mV threshold

Phillips 708

300 MHz discriminator

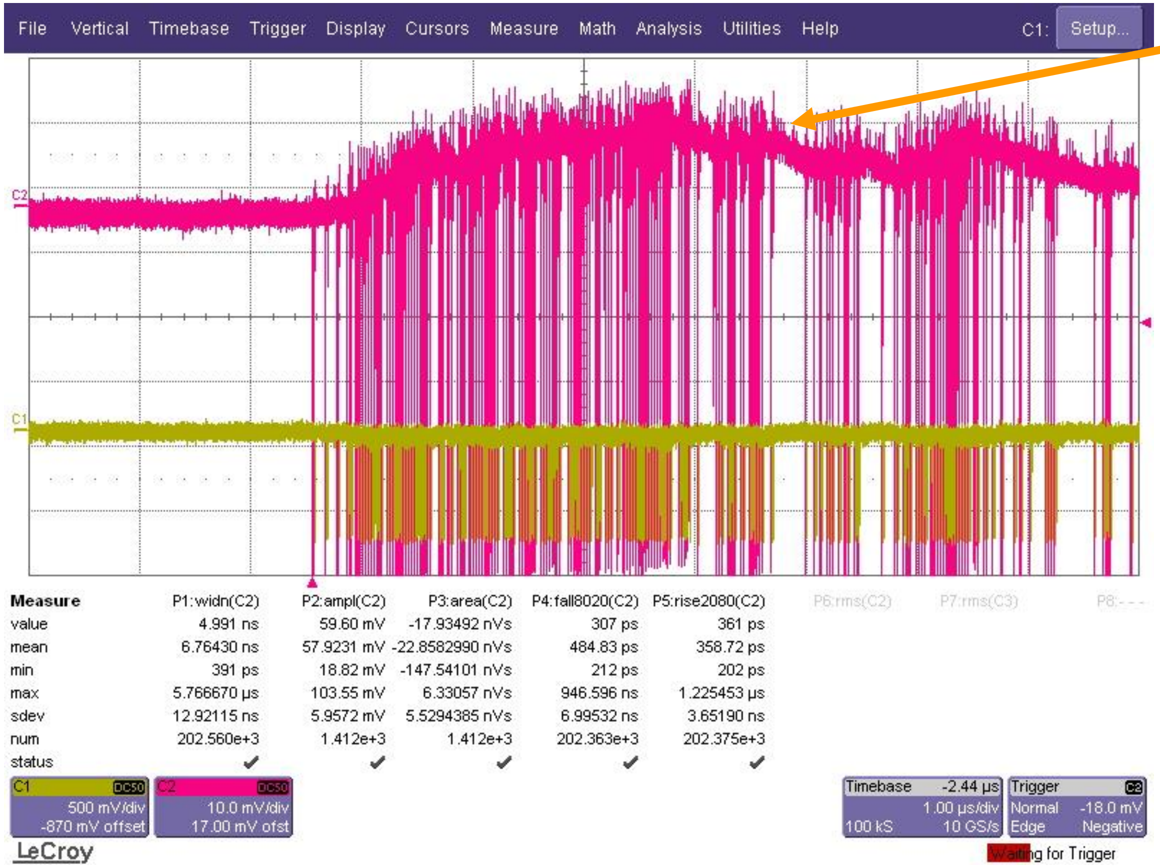
30 mV threshold

→ Too large pixel

→ Multi hits

Results

Single Pixel detector L3 GSI 124µm ^{152}Sm E=5,8 MeV/u UNILAC



Moving baseline

→ Loss of counting rate (?)

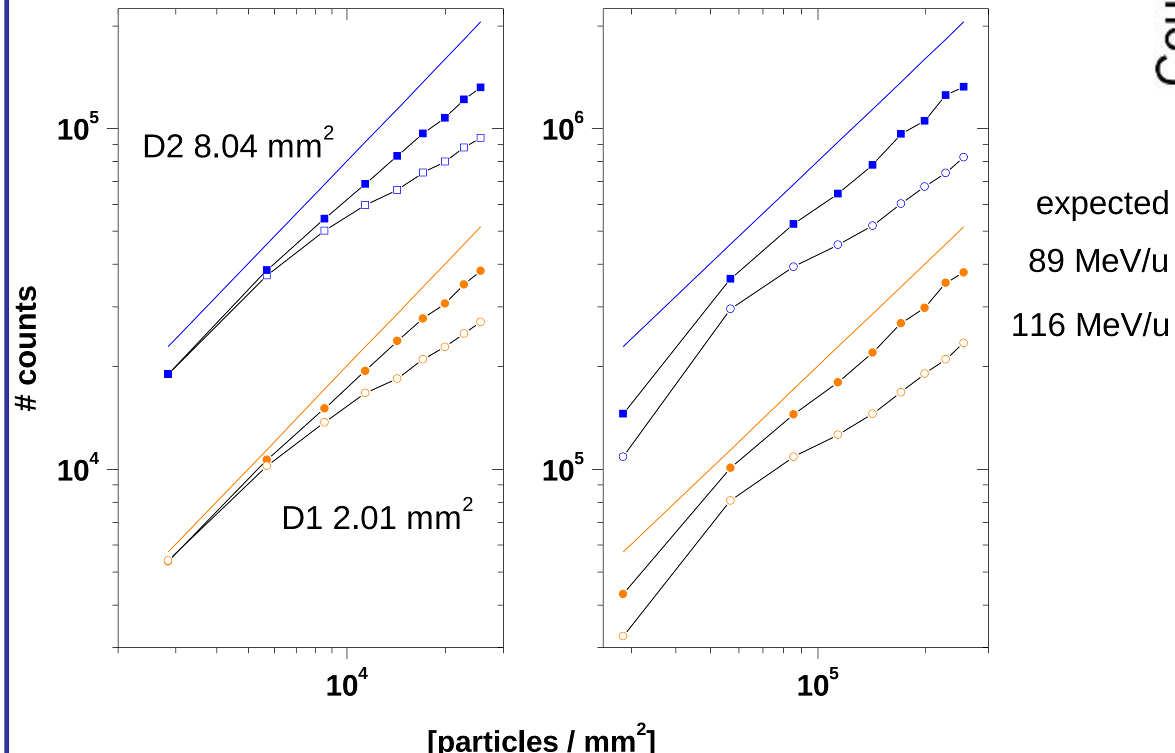
→ Baseline restorage needed

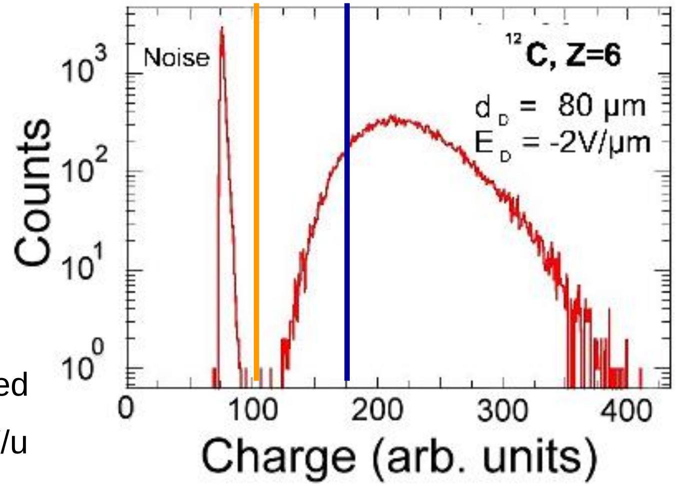
Discriminator Threshold

Trigger Threshold

Results

Pixel detectors D1, D2 100µm ^{12}C E=80-430 MeV/u SIS



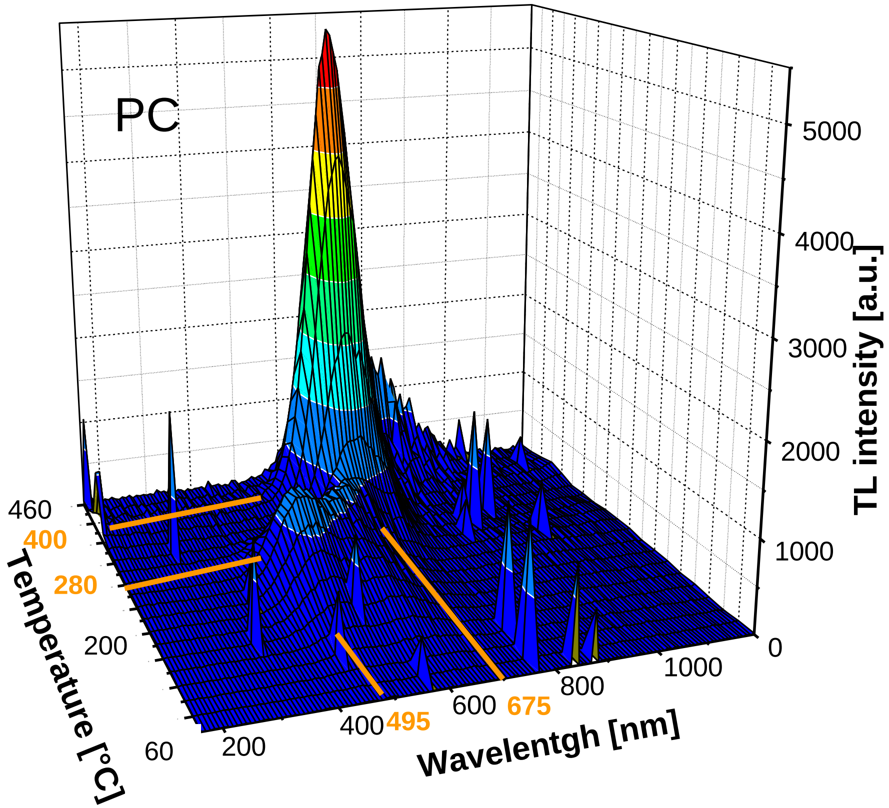


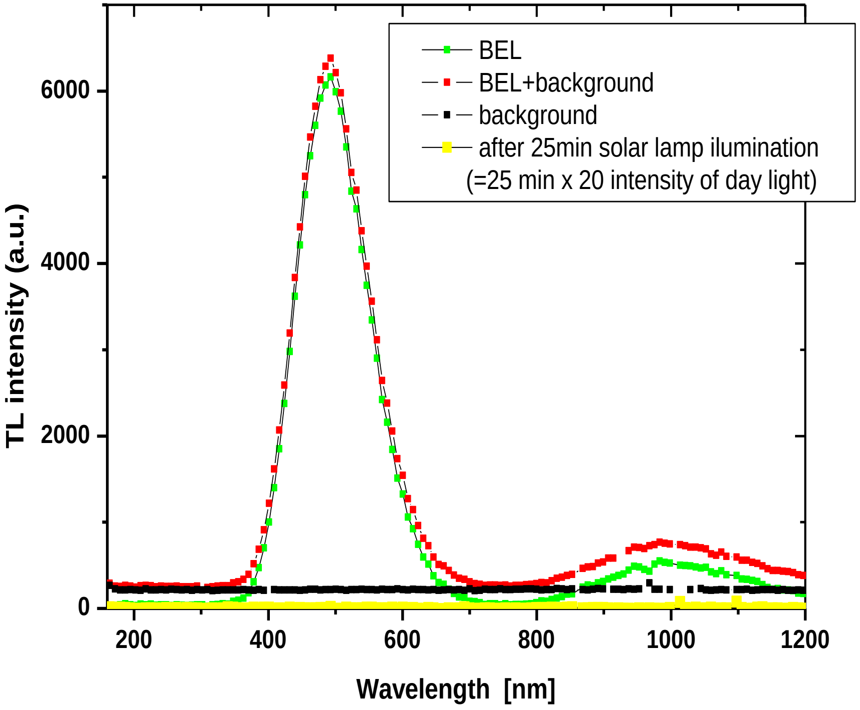
→ Missing counting efficiency due to electronics

Optical measurements

Emission spectra of IMO and PC samples after 1.2 kGy X-ray irradiation

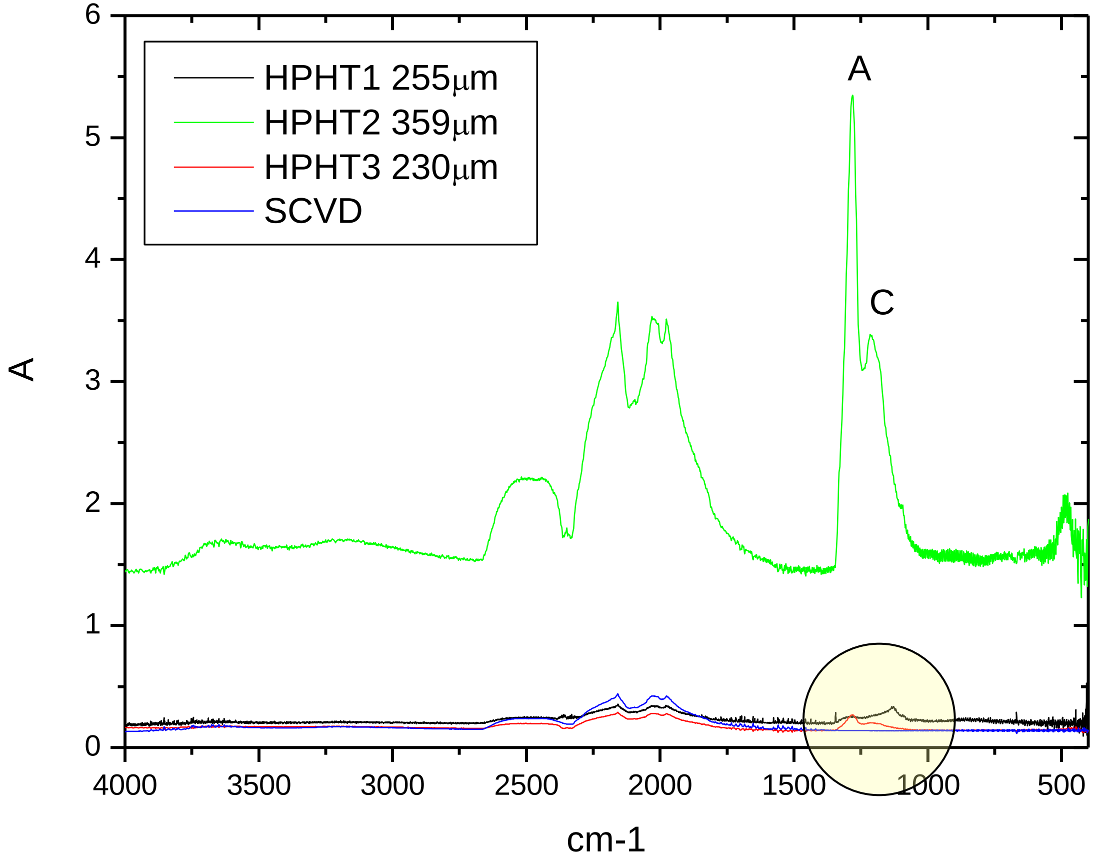
HR= 2 °C / sec





Optical measurements

IR absorption spectra of 3 different HPHT samples



Optical measurements

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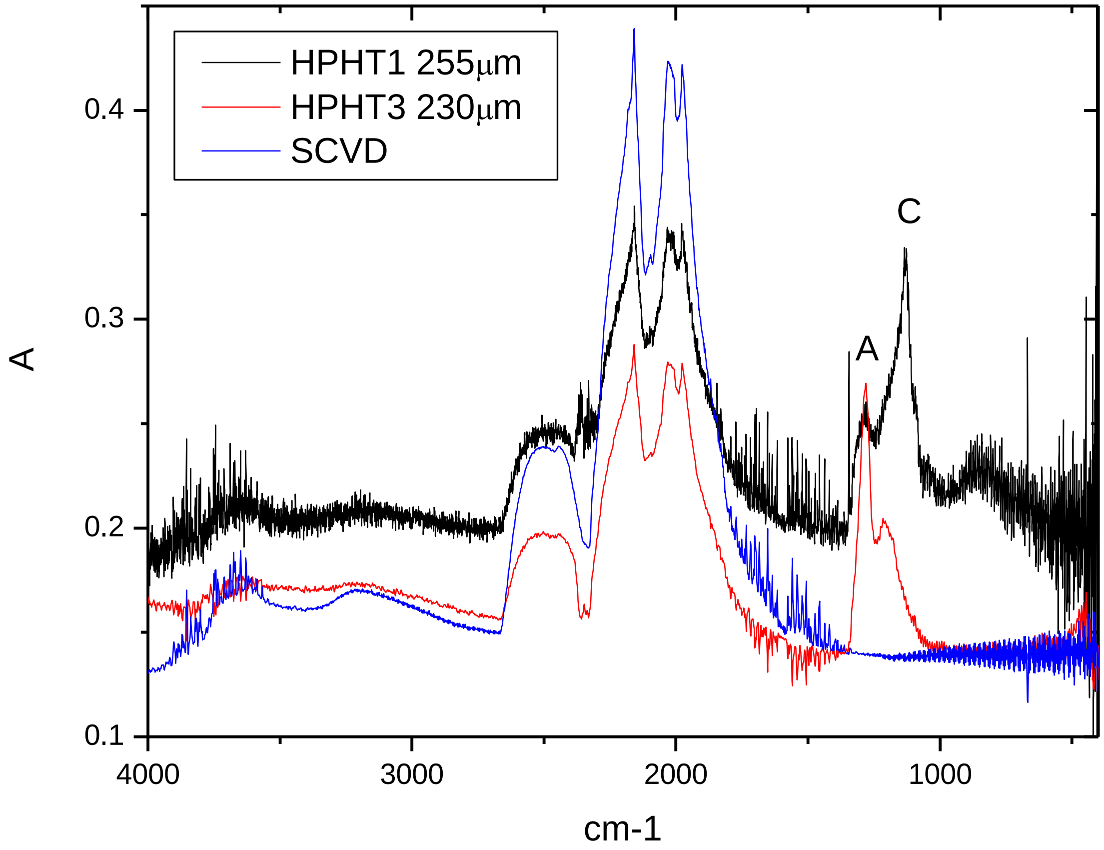


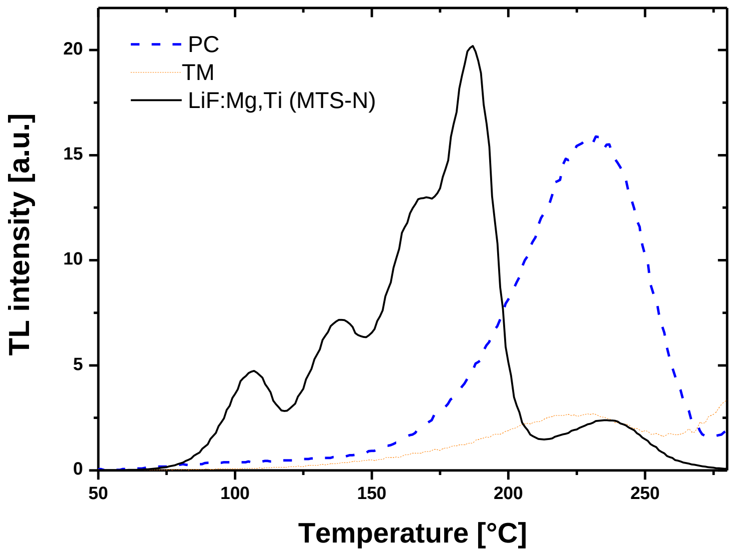
→ Nitrogen pairs “A” dominant in TL

→ SCVD not useful for TL

Offline monitoring - TLD

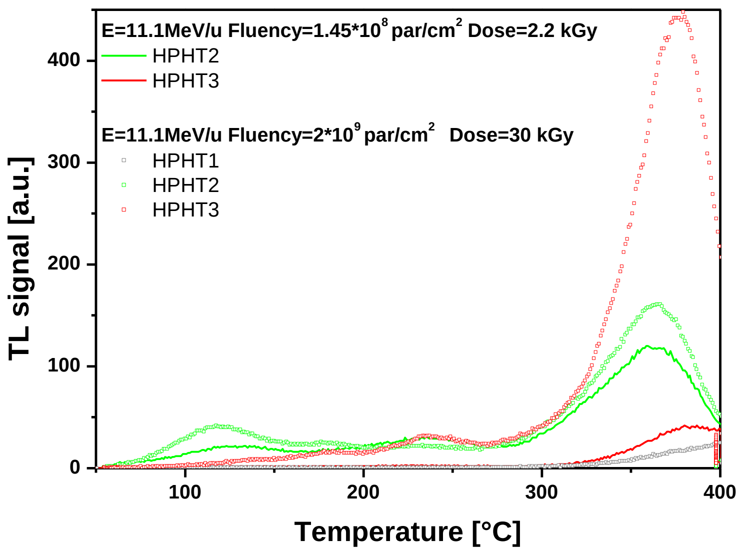
Typical TL glow curves

irradiation with C ions (350MeV/u)
Dose up to 2 Gy



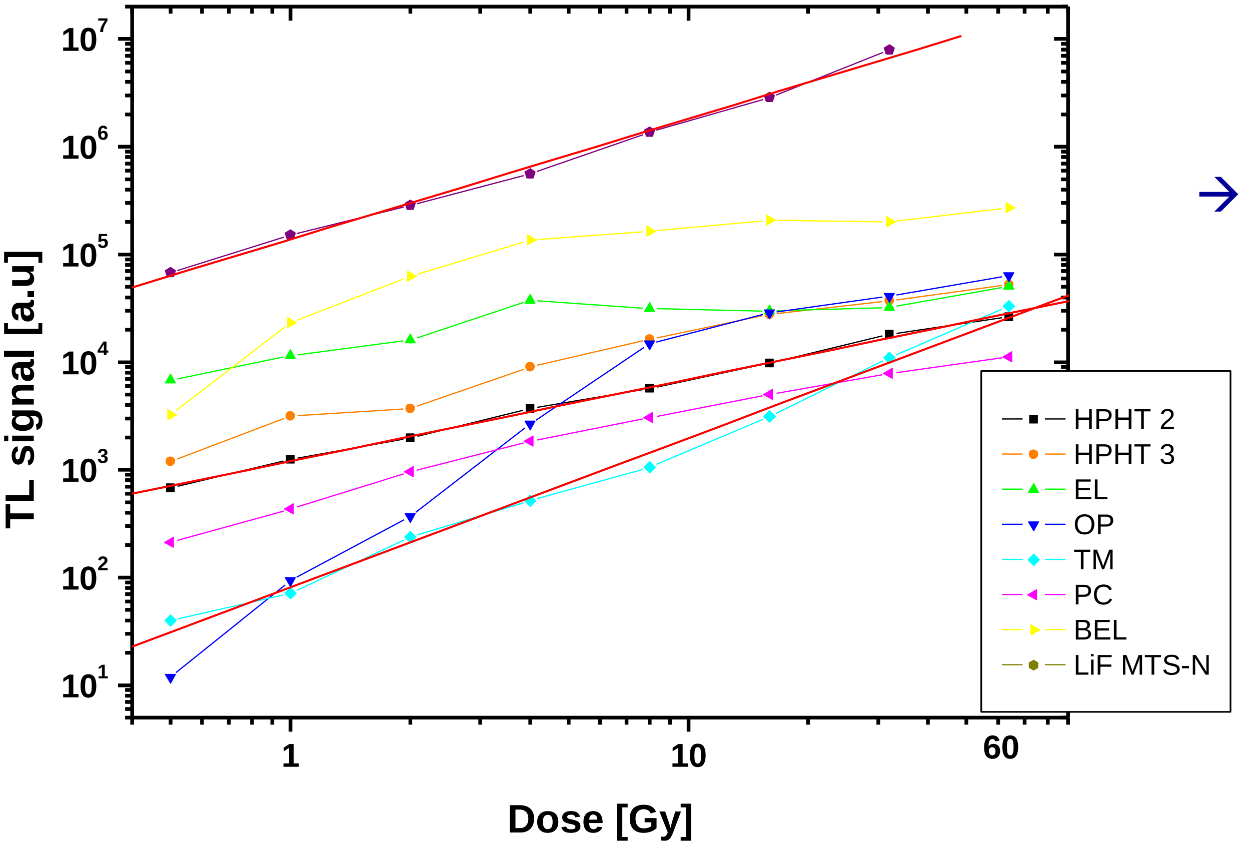
3 HPHT diamond detectors

irradiation with Au ions (11.4MeV/u)
dose 2.2 kGy and 30 kGy



Offline monitoring - TLD

Linearity test with X-rays



→Good up to **60 Gy**

TM, **PC**, **HPHT**

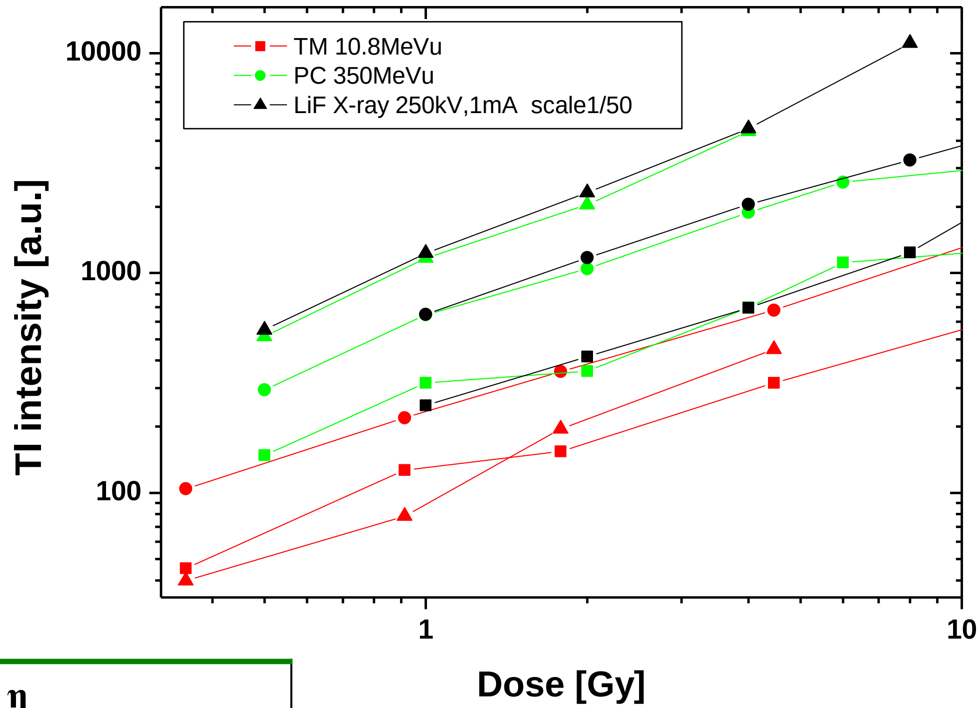
Offline monitoring - TLD

Efficiency of pCVD diamonds and LiF (MTS-N) detector for different species and energy regimes

Efficiency

The efficiency η was derived according to equation (1) where TLHI and TLX are the integral light sum of detectors irradiated with heavy ions (HI) and X-rays (X) respectively.

$$\eta \equiv \frac{(TL_{HI} / D)}{(TL_X / D)} \cdot 100\%$$



	Efficiency η	
Sample type	**350 MeV/u**	**11.4 MeV/u**
PC	100%	32%
TM	100%	41%
LiF (MTS-N)	100%	9%

! Efficiency of TL diamond detectors to HI better than for standard TLD material

Summary & Outlook (online)

- Various poly-CVD diamond detectors tested
- First results on NanoCrystalineDiamond sample

- Various ion spezies & energies used
- Fast single channel & muliti-channel electronics tested

- Achieved promising results for online beam-diagnostics for HI

- double hits (UNILAC) → more & smaller pixels
- Results depending on detector quality → investigation on detector 'grade', preparation, contacts
- electronics noise limits resolution → bipolar readout (NINO) necessary, work on DBA
- best choice: SC CVD membrane < 100µm, 200 × 200 mm²

Summary & Outlook (offline)

- Various poly-CVD and HPHT diamond detectors tested
- Different ion spezies & energies used
- Readout done with commercial equipment → optimization of annealing- & readout-parameters & procedure necessary

- Achieved very promising results for offline beam-diagnostics for all measured HI

  - Efficiency higher than for LiF
  - Linearity up to 60 Gy → detailed investigations on dose- & dose-rate dependency necessary
  - Results depending on detector quality → investigation on different batches & 'grades' necessary
  - Results scatters in one batch → dependency on history, annealing needed
  - Best results with material grade PC and TM → more investigation with different ion species end energies
  → investigation of mixed field conditions

TSC investigation planed