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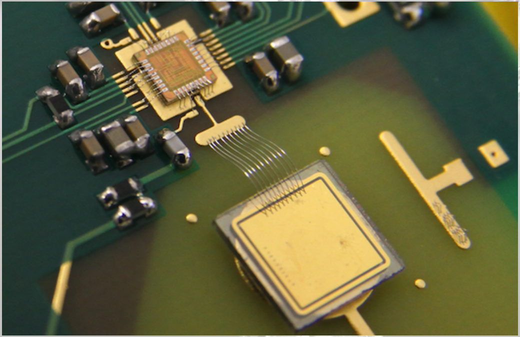

Analysis of CVD Diamond Pad Detectors

ETH Pixel/Diamond Meeting

Michael Reichmann

10th December 2018

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Introduction

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- diamond used as beam condition monitors at LHC
- diamond as future material for tracking detectors in high radiation areas

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- radiation tolerant
- isolating material
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PhD Topics

- Pad Detectors
- Pixel Detectors (Analysis)
- 3D Pixel Detectors (Analysis)
- High Resolution Studies

Introduction

- diamond used as beam condition monitors at LHC
- diamond as future material for tracking detectors in high radiation areas

Properties

- radiation tolerant
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PhD Topics

- **Pad Detectors** → investigate behaviour at different particle rates
- Pixel Detectors (Analysis)
- 3D Pixel Detectors (Analysis)
- High Resolution Studies

Measurements

- several beam test starting from May 2015

Name	**Nick**	**Type**	**Irradiation** [n/cm^2]
S129	S129	scCVD	0
II6-78$^{*\diamond}$	poly A	pCVD	0
II6-79$^{\diamond+}$	poly B	pCVD	0
II6-81$^{\diamond}$	poly D	pCVD	$1 \cdot 10^{14}$
II6-94	94	pCVD	0
II6-95	95	pCVD	$5 \cdot 10^{14}$
II6-97	97	pCVD	$0 \sim 3.5 \cdot 10^{15}$
II6-B2	B2	pCVD	$0 \sim 8 \cdot 10^{15}$
II6-H8	H8	pCVD	0

Table: Measured diamonds.

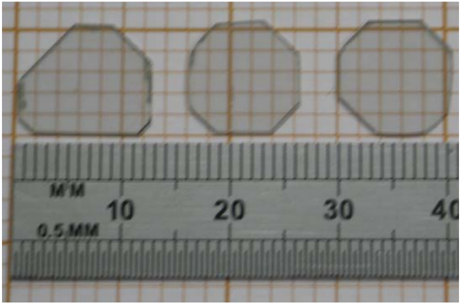
* only measured in May 2015 (bad timing)

$^{\diamond}$ processed by II6 with surface issues

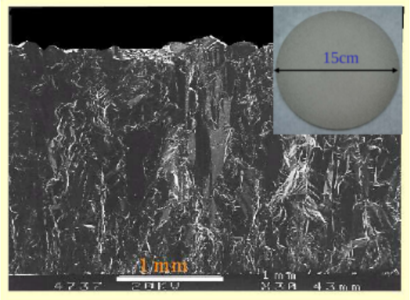
$^{+}$ reprocessed at OSU

Diamond Types

- diamonds artificially grown with chemical vapour deposition (CVD)
- investigation of two different diamond types:



(a) single-crystalline CVD



(b) poly-crystalline CVD (courtesy of E6)

- only small sizes ($\sim 0.25\,\text{cm}^2$)
- large wafers ($5 \sim 6'' \varnothing$)
- pCVD signals smaller than scCVD (1:2) in planar configuration

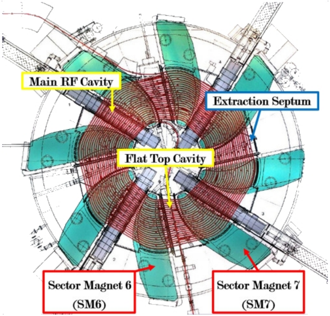
Section 2

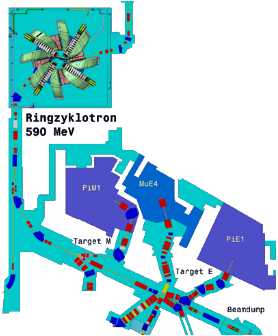
Test Site

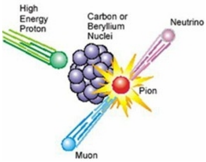

SCHWEISSWERK BÜLACH AG

Test Site

- High Intensity Proton Accelerator (HIPA) at PSI (Cyclotron) → beam line PiM1
- clean positive pion beam ($\sim$98 % π^+) with momentum of 260 MeV/c
  - ¾ smaller signals than at CERN! (120 GeV/c)
- **tunable particle fluxes from $\mathcal{O}\left(1\,\mathrm{kHz/cm^2}\right)$ to $\mathcal{O}\left(10\,\mathrm{MHz/cm^2}\right)$**
- **significant multiple scattering → worsens resolution**







Section 3

Setup

Setup

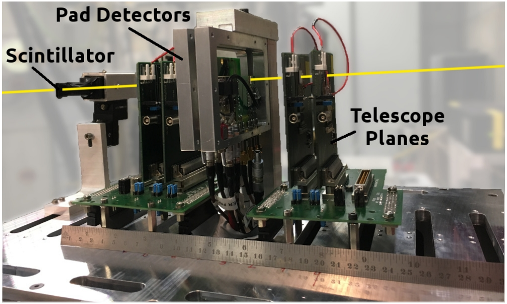
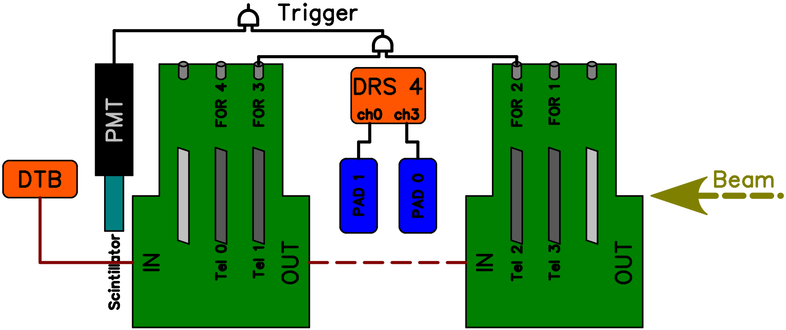


Figure: Modular Beam Telescope

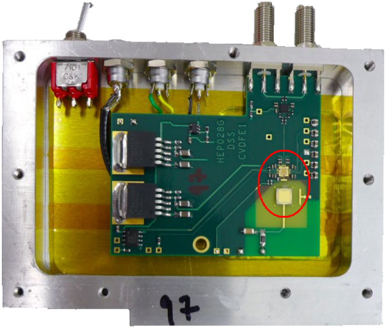
- 4 tracking planes $\rightarrow$ trigger (fast-OR) with adjustable effective area
- diamond pad detectors in between tracking planes
- low time precision of fast-OR trigger (25 ns)
- fast scintillator for precise trigger timing $\rightarrow \mathcal{O}(1\,\mathrm{ns})$

Schematic Setup

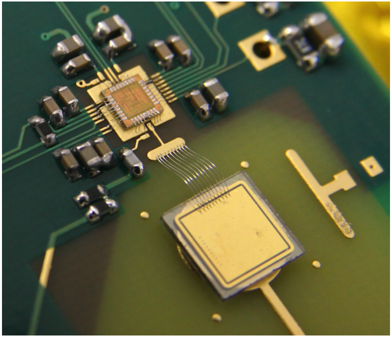


- PSI DRS4 Evaluation Board as digitiser for the pad waveforms
- Digital Test Board (DTB) and pXar software for the telescope readout
- global trigger: using coincidence of FOR 2 and FOR 3 + scintillator signal
- using custom built Trigger Unit (TU) to handle all the trigger logic

Pad Detectors



(a) Detector Box



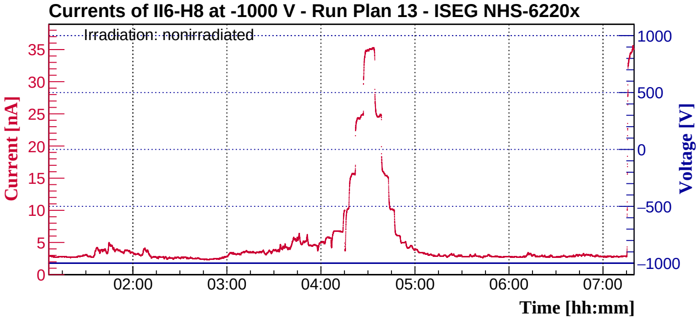
(b) Pad Detector with Amplifier

- building the detector: cleaning, photo-lithography and Cr-Au metallisation
- gluing to PCBs in custom built amplifier boxes
- connecting to low gain, fast amplifier with $\mathcal{O}(5\,\mathrm{ns})$ rise time

Section 4

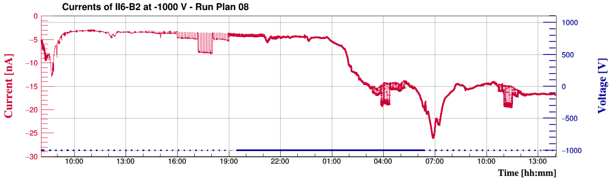
Measured Currents

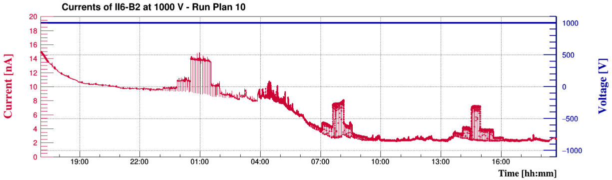
II6-H8



- typical rate scans for up to ∼30 h with rates up to ∼20 MHz/cm^2
- beam induced current clearly visible
- low leakage currents (<10 nA) at 2 V/μm

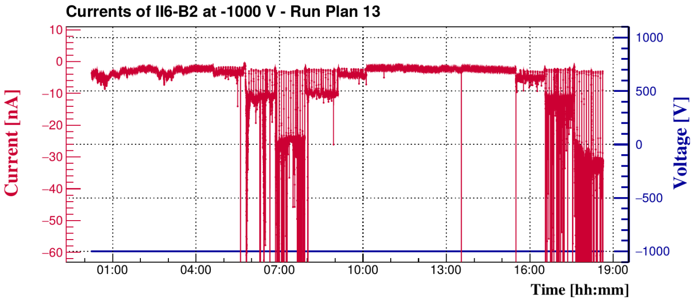
II6-B2





- also observe slowly changing base lines

II6-B2

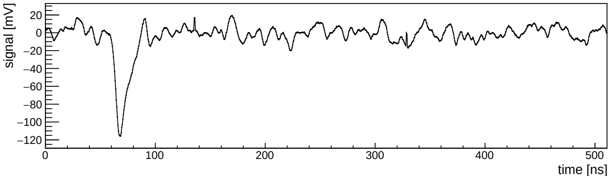


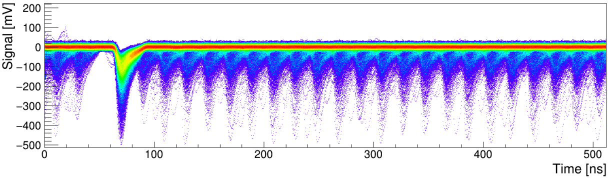
- also observe slowly changing base lines
- high spikes and erratic currents (mainly at high fluxes)

Section 5

Analysis

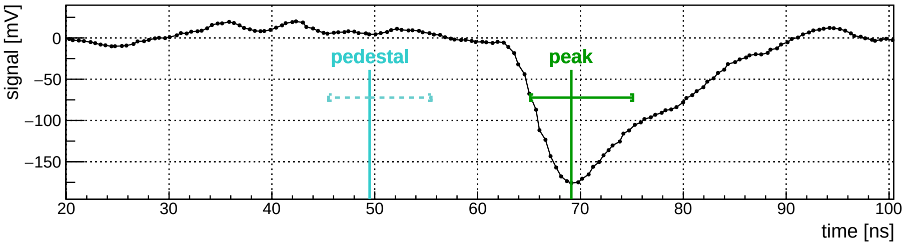
Waveforms





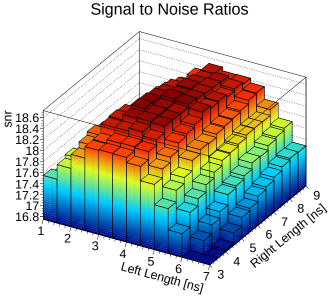
- most frequent peak (@ $\sim$70 ns) $\rightarrow$ signal from triggered particle
- other peaks from other bunches $\rightarrow$ resolve bunch spacing of PSI beam: $\sim$19.8 ns
- signals in pre-signal bunch forbidden $\rightarrow$ noise extraction

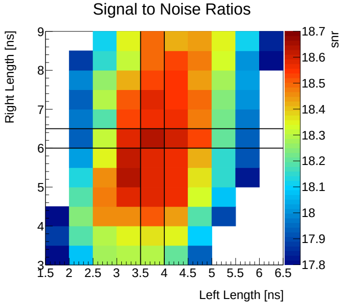
Signal Definition & Calculation



- perform DRS4 timing correction (circular buffer with varying cell size: (0.5 ± 0.3) ns)
- define signal region: $\sim \pm 10$ ns around peak of the triggered signal $\rightarrow$ [60 ns, 80 ns]
- signal: finding the peak in the signal region and integrate around it [−4 ns, 6 ns]
- pedestal: same integral in the centre of the pre-trigger bunch $\rightarrow$ [40 ns, 60 ns]

Signal To Noise Ratio





- left length = integration width to the left of the peak position
- optimise SNR by scanning the integral width in both directions
- maximum values around the FWHM of the peak
- wide plateau around the maximum

Event Cuts

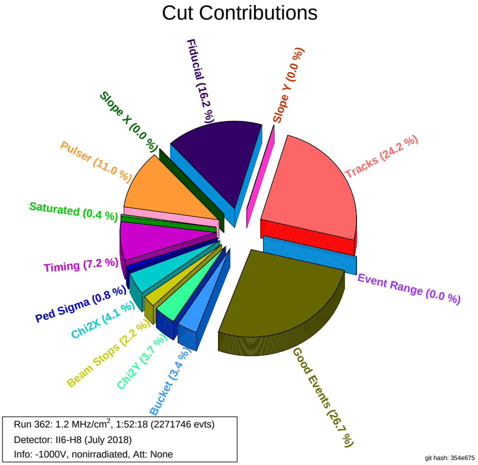
- separate pedestal and signal

Exclude Events:

- saturated
- pulser
- incomplete tracks
- wrong peak timing
- outside fiducial region
- during beam interruption

Also cuts on:

- track χ^2 in x- and y-direction
- track angle
- pedestal sigma

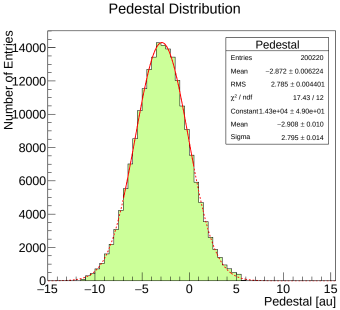


- after all cuts usually ∼25 % event left

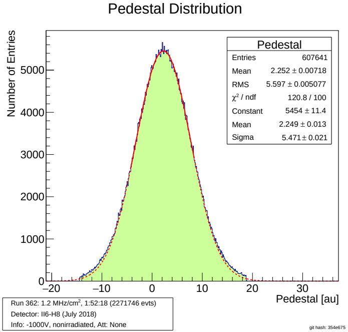
Section 6

Results

Noise Distributions high rate



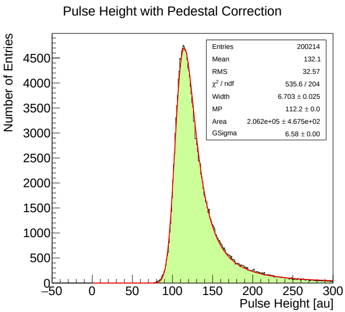
(a) scCVD (6 dB attenuation)



(b) pCVD

- noise distribution agrees well with Gaussian even at high rates
- extract noise by taking the sigma of the Gaussian fit
- noise very similar for scCVD and pCVD diamond

Signal Distributions high rate



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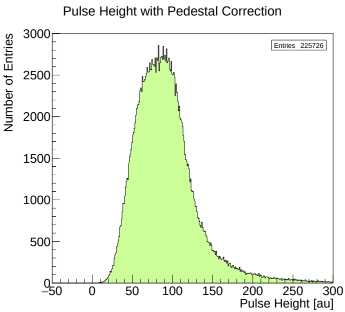
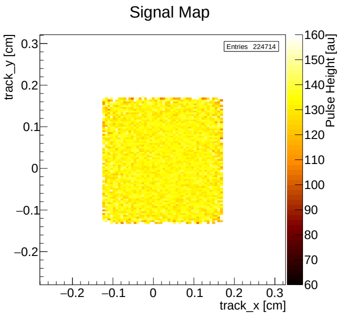


(b) pCVD

- correction by the mean of the noise (baseline offset)
- pCVD signal smaller and wider (less uniform)
- FWHM/MPV:
  - sCVD: $\sim$0.3
  - pCVD: $\sim$1.0

Signal Maps



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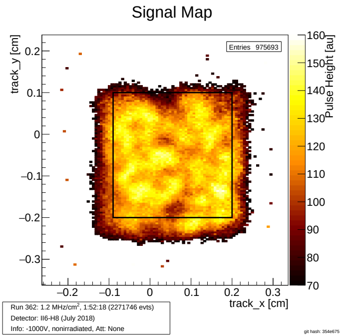
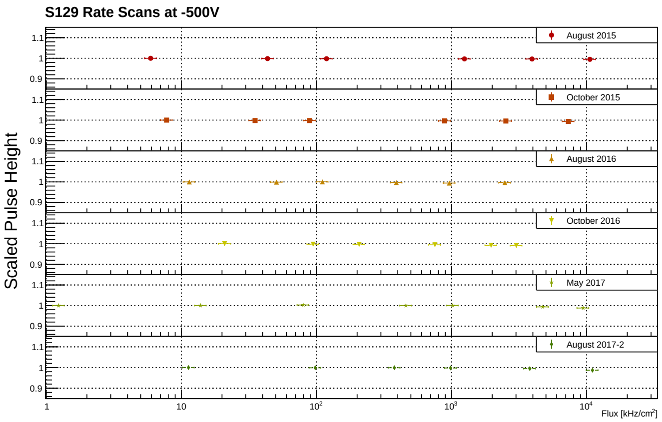


(b) pCVD

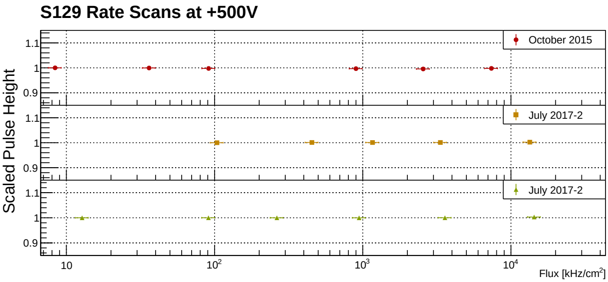
- flat signal distribution in scCVD
- signal response depending on region in the pCVD

Rate Studies in Non-Irradiated scCVD



- lowest rate point scaled to 1
- scCVD diamond shows now rate dependence within the measurement precision
- noise stays constant

Rate Studies in Non-Irradiated scCVD



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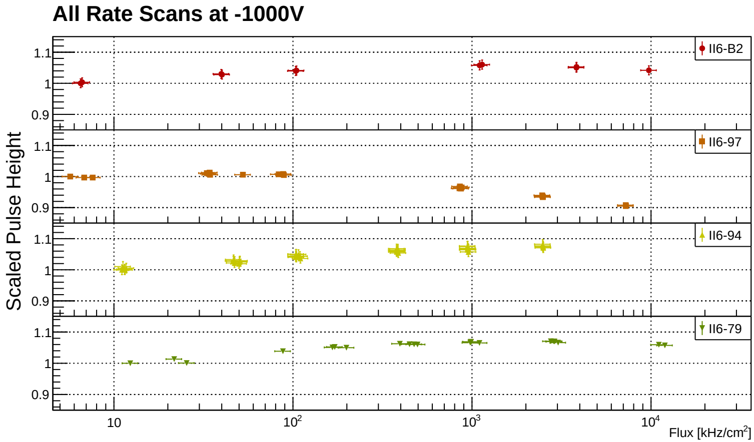
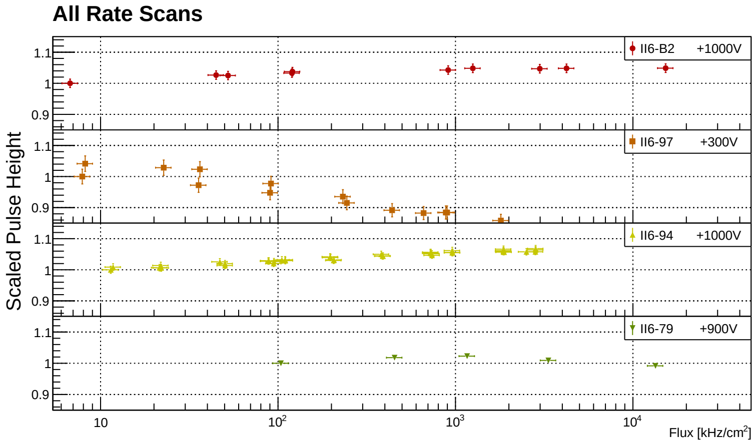
pCVD - Non-Irradiated



- lowest rate point scaled to 1
- all non-irradiated pCVD diamonds have slight rate dependence
- behaviour very similar for both positive and negative bias voltage
- II6-97 did not hold +1000 V

pCVD - Non-Irradiated



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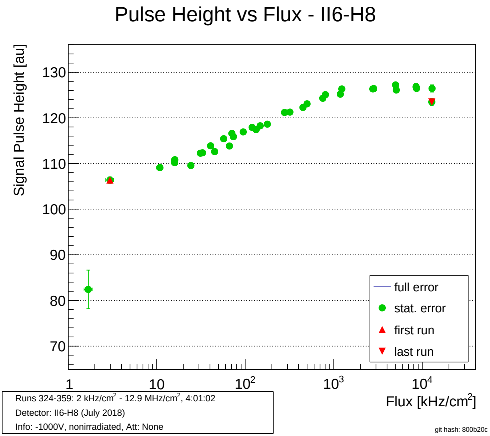
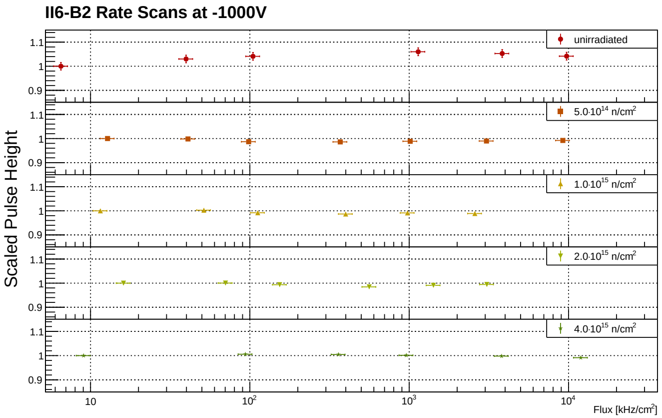
Detailed Study of Rate Dependence



- largest dependence found so far
- very continuous and reproducible behaviour
- only very weak theories for this behaviour → try to model it

Rate Studies in Irradiated pCVD



- lowest rate point scaled to 1
- pulse height very stable after irradiation
- noise stays the same

Section 7

Conclusion

Conclusion

- built beam test setup to characterise the rate behaviour of diamond pad detectors
- pCVD diamond show non-uniformities of the signal depending on the position in the diamond
- nonirradiated scCVD show no rate dependence
- up to 20 % rate dependence for non-irradiated pCVD
  - unknown origin, maybe surface contaminations during production
- all detectors with irradiated pCVD diamond sensors have a rate dependence below 2 % up to a flux of 20 MHz/cm^2


Del Fin