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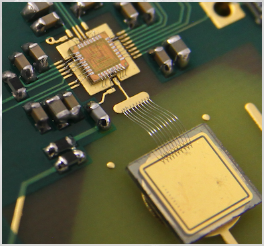

Summary of the Signal Dependence of Diamond Pad Detectors on Incident Particle Flux

RD42 Meeting

Michael Reichmann

9th April 2018

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Section 1

Introduction

Motivation

- innermost layers $\rightarrow$ highest radiation damage
- current detector is designed to survive $\sim$12 month in High-Luminosity LHC
- completely new regime of particle flux $\mathcal{O}\left(\mathrm{GHz/cm^2}\right)$
- $\rightarrow$ **R/D for more radiation tolerant detector designs and/or materials**

Motivation

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Diamond as Detector Material:

- advantageous properties
  - radiation tolerant
  - isolating material
  - high charge carrier mobility

Motivation

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Diamond as Detector Material:

- advantageous properties
  - radiation tolerant
  - isolating material
  - high charge carrier mobility
- investigation of the rate effect in various detector designs:
  - **pad $\rightarrow$ full diamond as single cell readout of the whole signal $\rightarrow$ shown here**
  - pixel $\rightarrow$ diamond sensors on state-of-the-art pixel chips
  - 3D $\rightarrow$ pixel detector with clever design to reduce drift distance

Measured Diamonds as Pad Detectors

- several beam test campaigns starting from May 2015
- measured diamonds:

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	1×10^{14}
II6-94	94	pCVD	0
II6-95	95	pCVD	5×10^{14}
II6-97	97	pCVD	0 to 3.5×10^{15}
II6-B2	B2	pCVD	0 to 4×10^{15}

* only measured in May 2015 (bad timing)

$^\diamond$ processed by II6 with surface issues

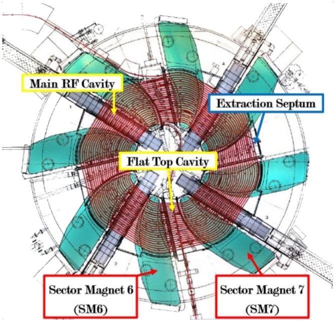
$^+$ reprocessed at OSU

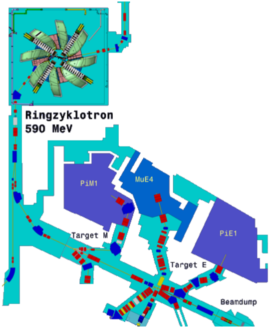
Section 2

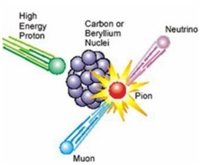
Test Site & Setup

Test Site

- High Intensity Proton Accelerator (HIPA) at PSI
- beam line PiM1
- positive pions (π^+) with momentum of 260 MeV/c
- tunable particle fluxes from $\mathcal{O}\left(1\,\mathrm{kHz/cm^2}\right)$ to $\mathcal{O}\left(10\,\mathrm{MHz/cm^2}\right)$







Setup

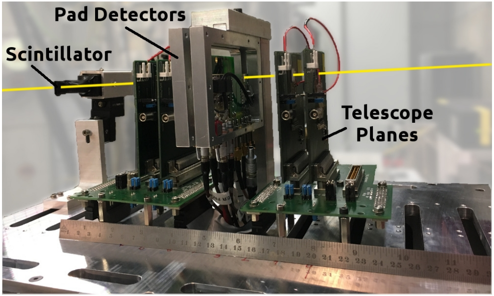
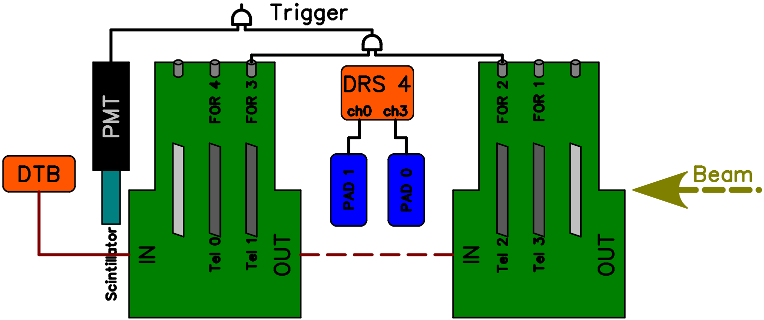


Figure: Modular Beam Telescope

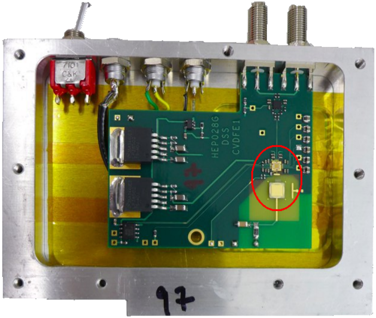
- 4 tracking planes → trigger (fast-OR) with adjustable effective area
- diamond pad detectors in between tracking planes
- low time precision of fast-OR trigger
- fast scintillator for precise trigger timing → $\mathcal{O}\,(1\,\text{ns})$

Schematic Setup

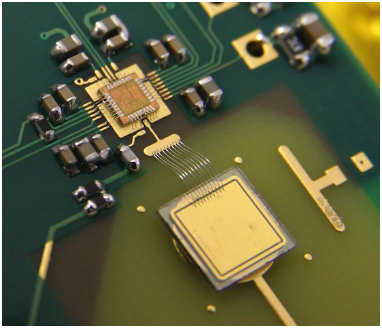


- PSI DRS4 Evaluation Board as digitiser for the pad waveforms
- Digital Test Board (DTB) and pXar software for the telescope readout
- global trigger: using coincidence of FOR 2 and FOR 3 + scintillator signal

Pad Detectors



(a) Detector Box



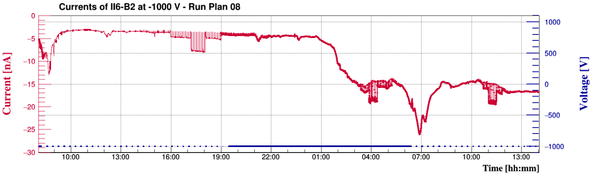
(b) Pad Detector with Amplifier

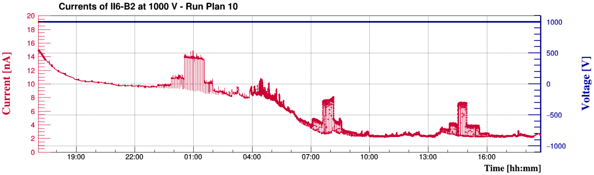
- building the detector: cleaning, photo-lithography and Cr-Au metallisation
- gluing to PCBs in custom built amplifier boxes
- connecting to low gain, fast amplifier with $\mathcal{O}\,(5\,\mathrm{ns})$ rise time

Section 3

Leakage Currents

pCVD Currents





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

pCVD Currents

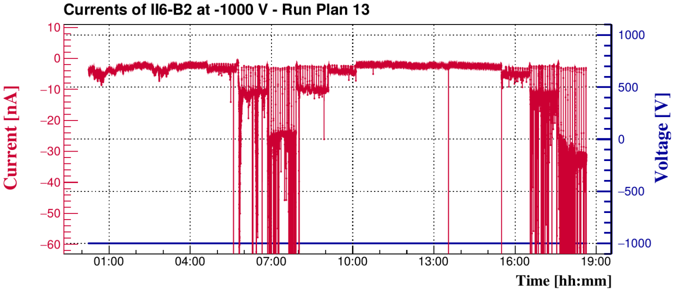


Figure: non-irradiated

- sometimes erratic behaviour at low irradiation
- current stabilises with irradiation steps
- beam induced current scales with pulse height

pCVD Currents

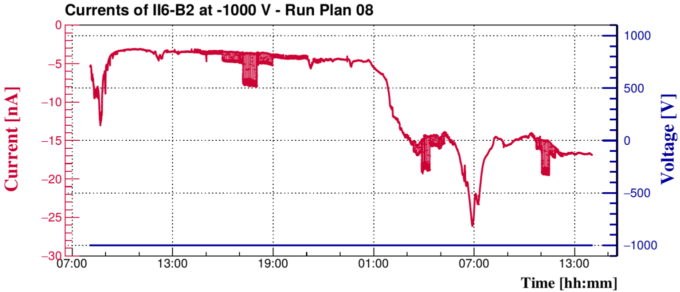


Figure: $5 \times 10^{14}\,\mathrm{n/cm^2}$

- sometimes erratic behaviour at low irradiation
- current stabilises with irradiation steps
- beam induced current scales with pulse height

pCVD Currents

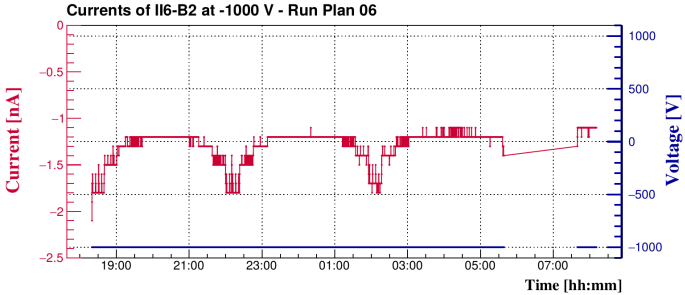


Figure: 2×10^{15} n/cm^2

- sometimes erratic behaviour at low irradiation
- current stabilises with irradiation steps
- beam induced current scales with pulse height

pCVD Currents

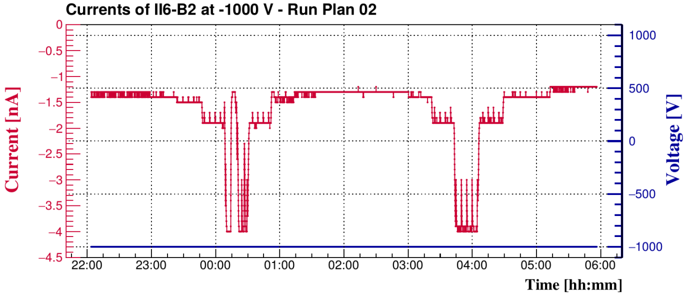
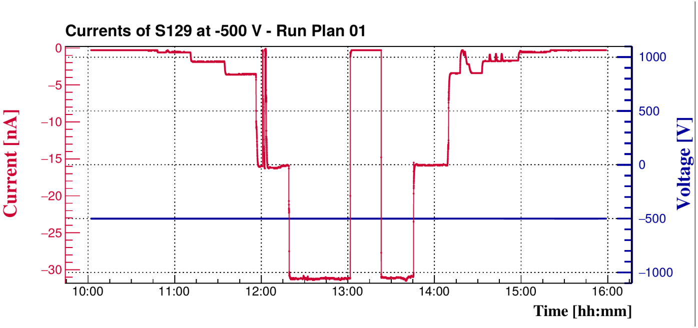


Figure: $4 \times 10^{15}\ \mathrm{n/cm^2}$

- sometimes erratic behaviour at low irradiation
- current stabilises with irradiation steps
- beam induced current scales with pulse height

scCVD Currents

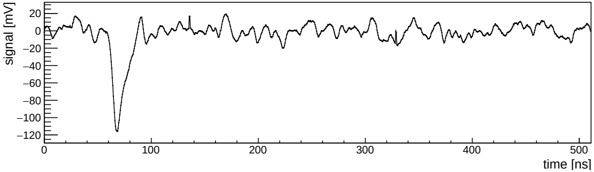


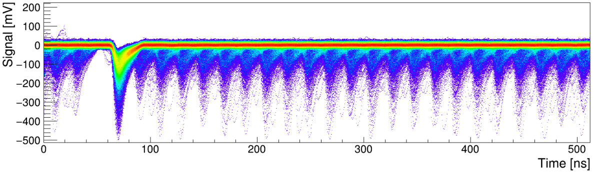
- scCVD diamond very stable at both polarities
- low leakage currents

Section 4

Analysis

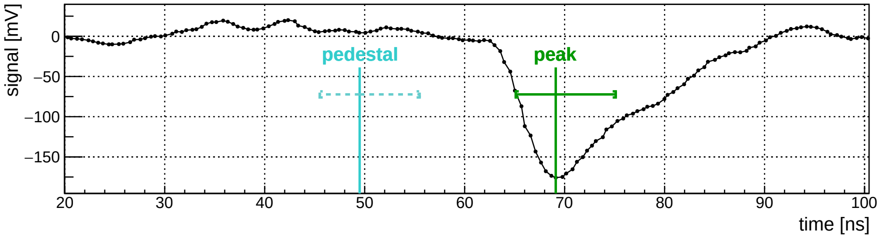
Waveforms





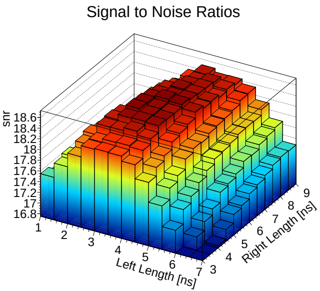
- most frequent peak (~70 ns): signal from triggered particle
- other peaks originate from particle of other bunches
- resolve bunch spacing of PSI beam: ~19.8 ns
- signals in in pre-signal bunch forbidden → noise extraction

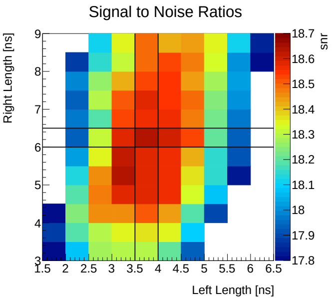
Signal Definition & Calculation



- define signal region: $\sim \pm 10\,\mathrm{ns}$ 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: integrate with same length (10 ns) in the centre of the pre-trigger bunch [40 ns, 60 ns]

Signal To Noise Ratio



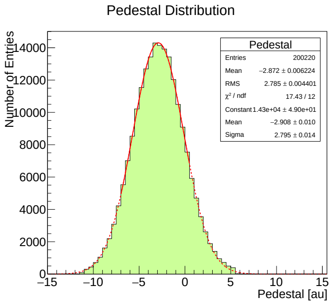


- optimise SNR by scanning the integral width in both directions
- flat plateau around the the FWHM of the waveform peak

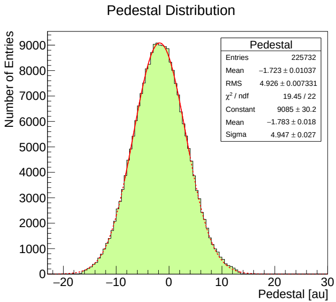
Section 5

Results

Pedestal Distributions at ∼10 MHz/cm^2



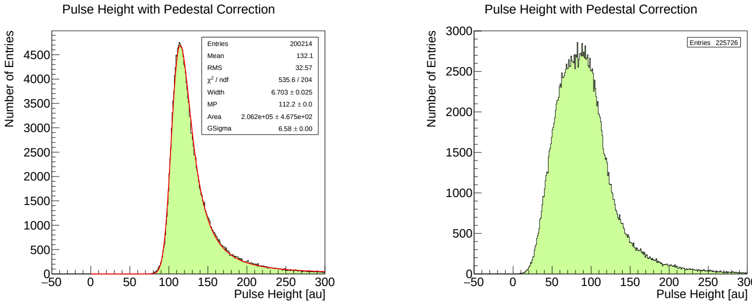
(a) scCVD with 6 dB attenuation



(b) pCVD

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

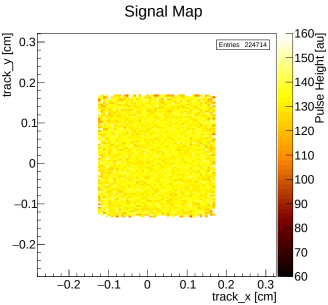
Signal Distributions at $\sim$10 MHz/cm^2



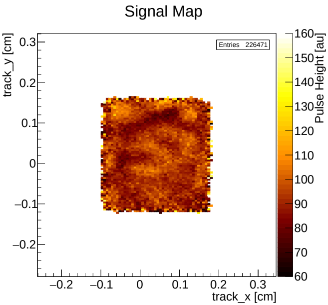
(a) scCVD with 6 dB attenuation (b) pCVD

- event based correction by the mean of the noise (baseline offset)
- pCVD signal smaller and smeared by different regions in the diamond
- FWHM/MPV:
  - scCVD: $\sim$0.3
  - pCVD: $\sim$1

Signal Maps



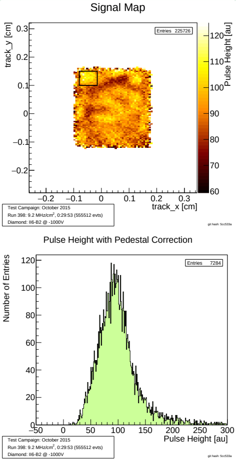
(a) scCVD with 6 dB attenuation

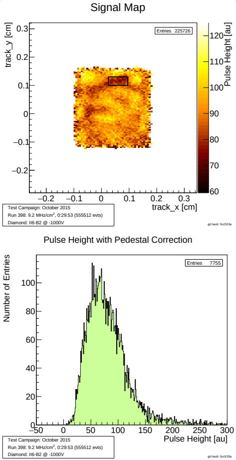


(b) pCVD

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

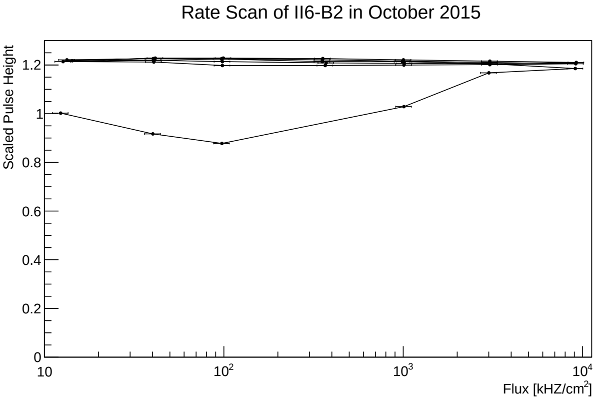
Signal Regions





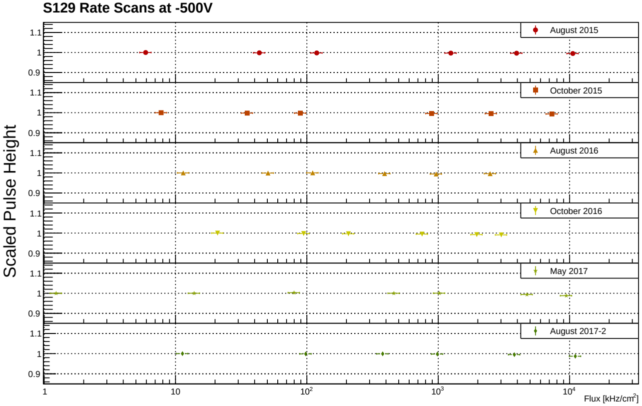
- Landau gets narrower for high region (FWHM/MPV: $\sim$1.5)
- stays similar for low region (FWHM/MPV: $\sim$0.85)

Rate Studies



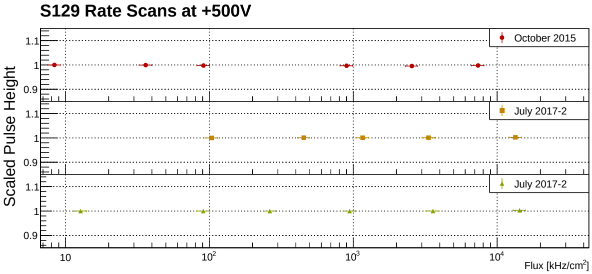
- systematically checking several up and down scans
- pumping required in the beginning to reach stable pulse height
- random scans to rule out systematic effects of the up/down scan

Rate Studies in Non-Irradiated scCVD



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

Rate Studies in Non-Irradiated scCVD



- lowest rate point scaled to 1
- scCVD diamond shows now rate dependence within the measurement precision
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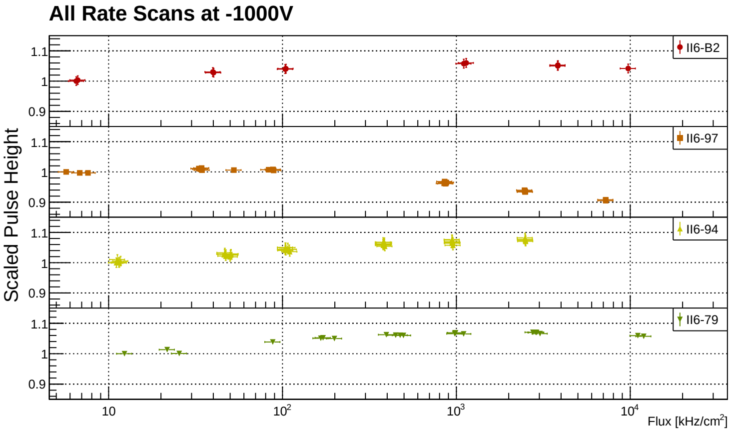
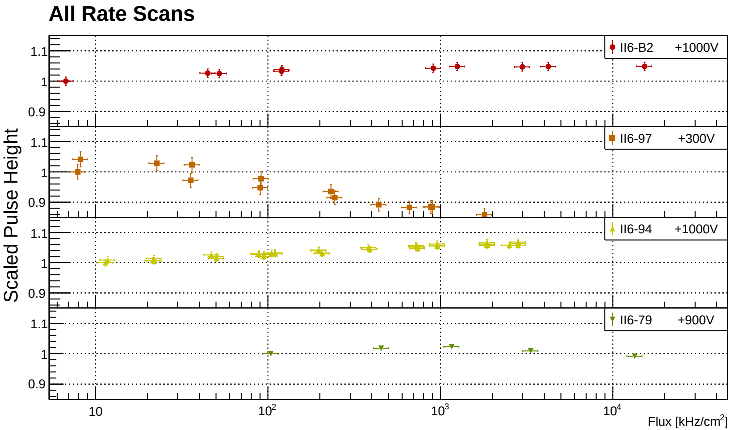
pCVD - Unirradiated Negative



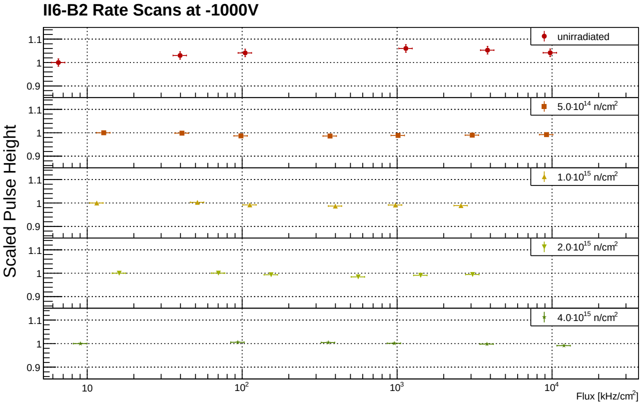
- all unirradiated poly have slight rate dependence with similar behaviour
- first up/down scan usually with lower pulse height → pumping
- → excluding first first up/down scan

pCVD - Unirradiated Positive



- II6-97 does not hold higher voltage
- longer pumping at lower voltage?
- all other diamonds behave very similar for both positive and negative bias

Rate Studies in Irradiated pCVD



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

Section 6

Conclusion

Conclusion

- built beam test setup to characterise the rate behaviour of diamond pad detectors
- pCVD diamond show non-uniformity of the signal depending on the position in the diamond
- nonirradiated scCVD shows no rate dependence
- all detectors with irradiated pCVD diamond sensors have a rate dependence below 2 % up to a flux of $20\,\mathrm{MHz/cm^2}$

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