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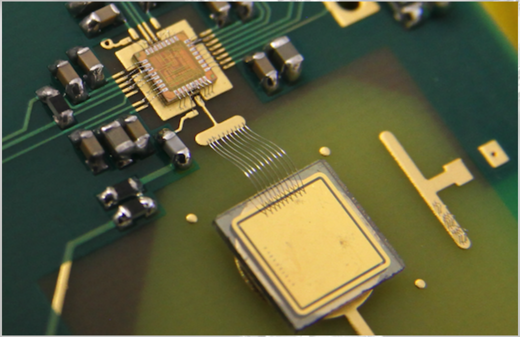

Analysis of CVD Diamond Pad Detectors

7th ADAMAS Workshop in Vienna

Michael Reichmann

14th December 2018

Table of Contents

Section 1

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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Properties

- radiation tolerant
- isolating material
- high charge carrier mobility

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Investigation of Rate Effects:

- Pad Detectors $\rightarrow$ whole diamond as single cell readout
- Pixel Detectors $\rightarrow$ diamond sensor on pixel readout chip
- 3D Pixel Detectors $\rightarrow$ 3D diamond detector on pixel readout chip

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- diamond as future material for tracking detectors in high radiation areas

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Investigation of Rate Effects:

- **Pad Detectors** $\rightarrow$ this talk
- Pixel Detectors
- 3D Pixel Detectors

Measurements

- several beam test starting from May 2015

Name	**Type**	**Irradiation** $[\mathrm{n/cm^2}]$
S1	scCVD	0
poly A	pCVD	0
poly B	pCVD	0
poly C	pCVD	$1 \cdot 10^{14}$
poly D	pCVD	0
poly E	pCVD	$5 \cdot 10^{14}$
poly F	pCVD	$0 \sim 3.5 \cdot 10^{15}$
poly G	pCVD	$0 \sim 8 \cdot 10^{15}$
poly H	pCVD	0

Table: Measured diamonds and irradiations.

- irradiation with thermal neutrons at Ljubljana
- irradiations in steps and always remeasured

Section 2

Test Site


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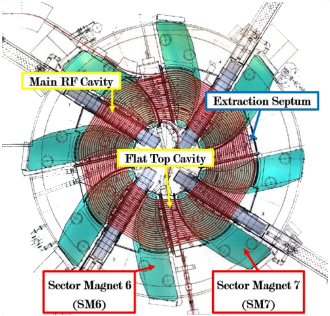
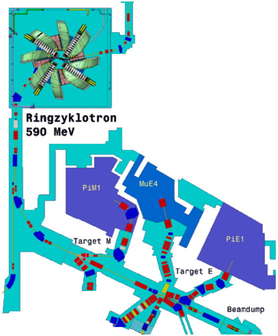
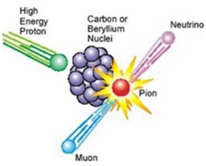
Test Site

- 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

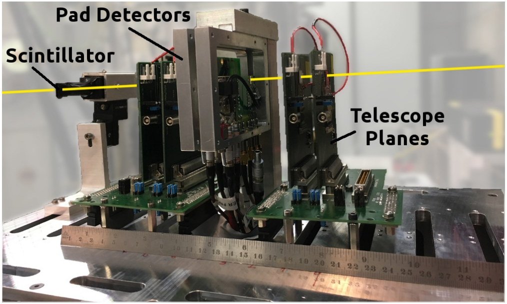
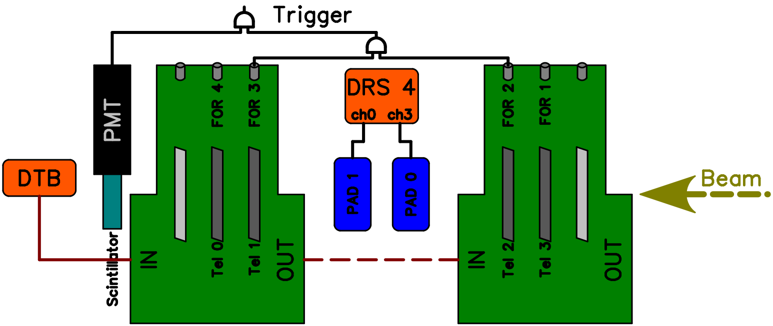


Figure: Modular Beam Telescope

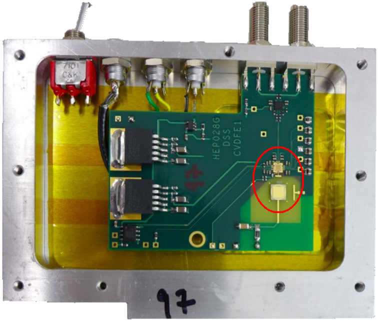
- 4 tracking planes $\rightarrow$ trigger (fast-OR) with adjustable effective area
- diamond pad detectors in between tracking planes
- low time precision of fast-OR trigger (25 ns)
- fast scintillator for precise trigger timing $\rightarrow$ $\mathcal{O}$ (1 ns)

Schematic Setup

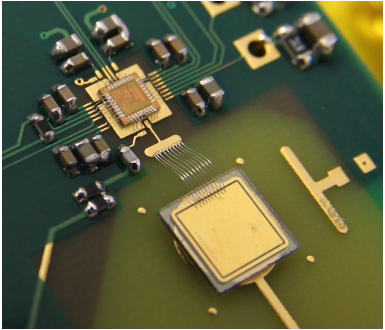


- PSI DRS4 Evaluation Board as digitiser for the pad waveforms
- Digital Test Board (DTB) and pXar software for the telescope readout
- global trigger: using coincidence of FOR 2 and FOR 3 + scintillator signal
- using custom built Trigger Unit (TU) to handle all the trigger logic

Pad Detectors



(a) Detector Box



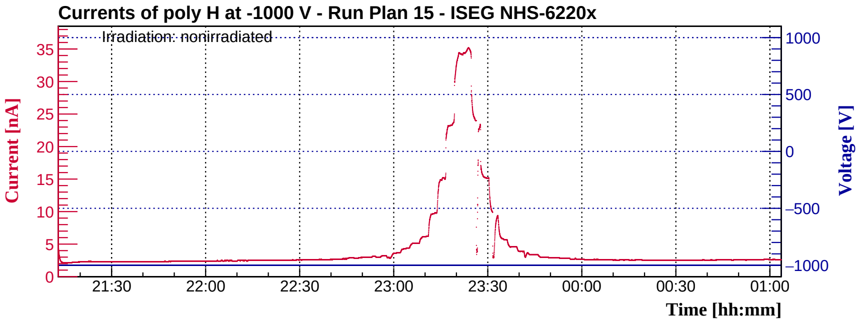
(b) Pad Detector with Amplifier

- 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

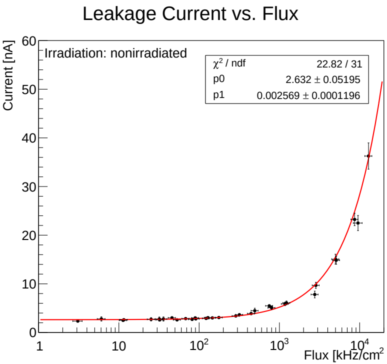
Measured Currents

Rate Scan



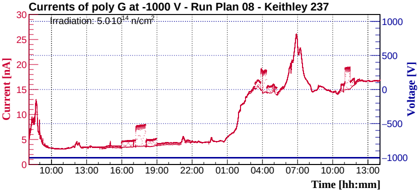
- typical rate scans for up to ∼30 h with rates up to ∼20 MHz/cm^2
- beam induced current clearly visible
- low leakage currents (<10 nA) at 2 V/μm

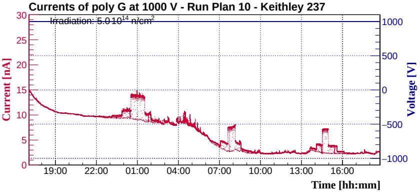
Current Vs. Flux



- beam induced current increases linearly with increasing flux
- interpolated leakage current: 2.63 nA

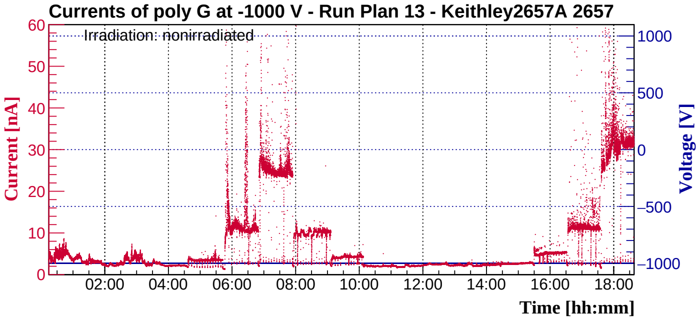
Unusual Behaviour





- also observe slowly changing base lines (2/10 scans)

Unusual Behaviour



- also observe slowly changing base lines (2/10 scans)
- high spikes and erratic currents (mainly at high fluxes, 1/10 scans → excluded from further analysis)

Section 5

Analysis

Waveforms

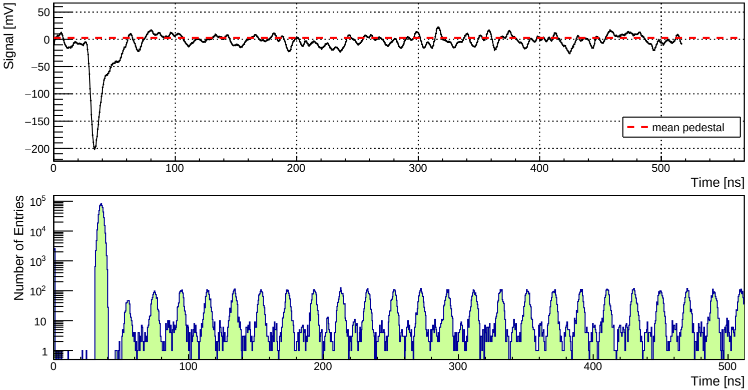
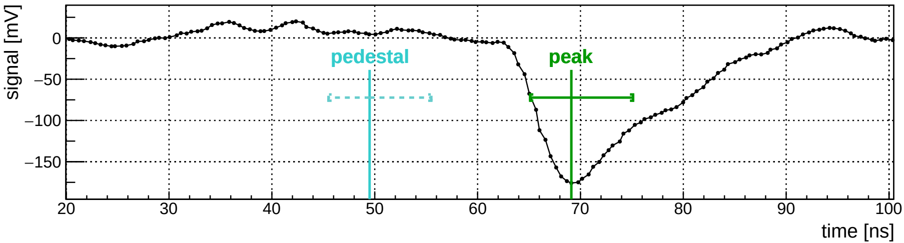


Figure: Peak timings.

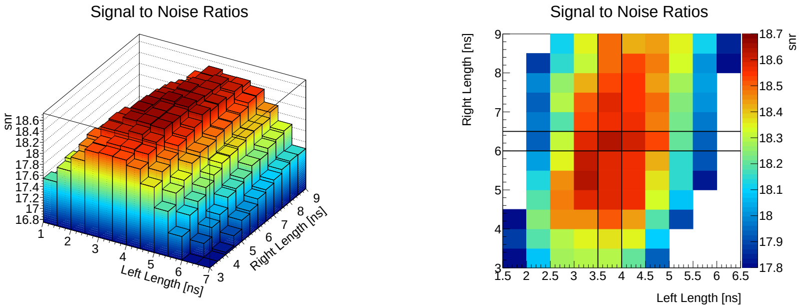
- most frequent peak (@ ∼35 ns) → signal from triggered particle
- other peaks from other bunches → resolve bunch spacing of PSI beam: ∼19.8 ns
- signals in pre-signal bunch forbidden → noise extraction

Signal Definition & Calculation



- perform DRS4 timing correction (circular buffer with varying cell size: $(0.5 \pm 0.3)\,\text{ns}$)
- define signal region: $\sim \pm 10\,\text{ns}$ 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

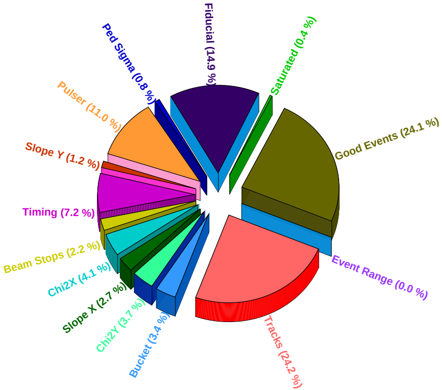
- separate pedestal and signal

Exclude Events:

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

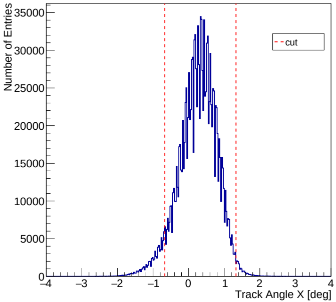
Also cuts on:

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

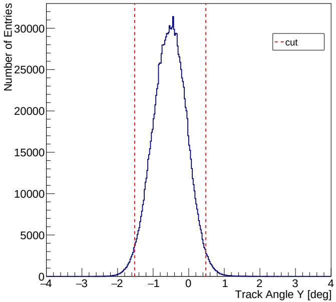


- after all cuts usually ∼25 % event left

Track Slope



(a) Track angle in X



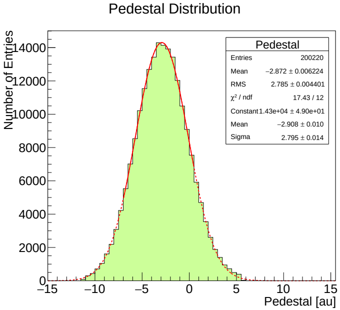
(b) Track angle in Y

- only take events with $\pm 1^\circ$ around the most probable slope
- slope has direct influence on the track length inside the sensor
- slope distribution slightly changes in every setup

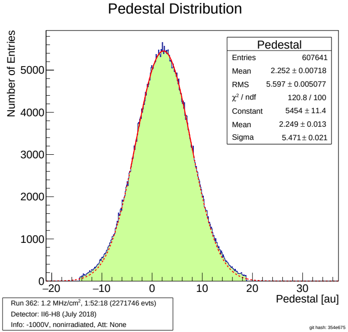
Section 6

Results

Noise Distributions high rate



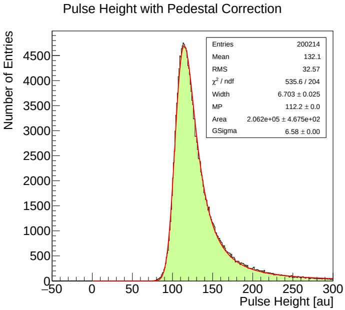
(a) scCVD (6 dB attenuation)



(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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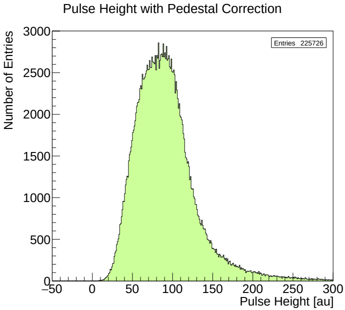
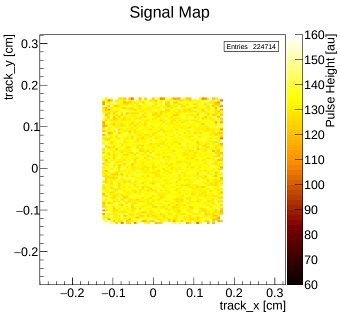


(b) pCVD

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

Signal Maps



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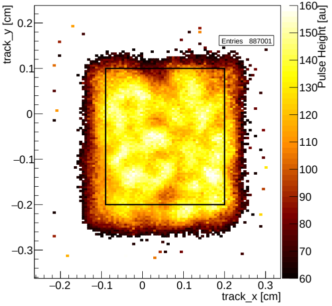
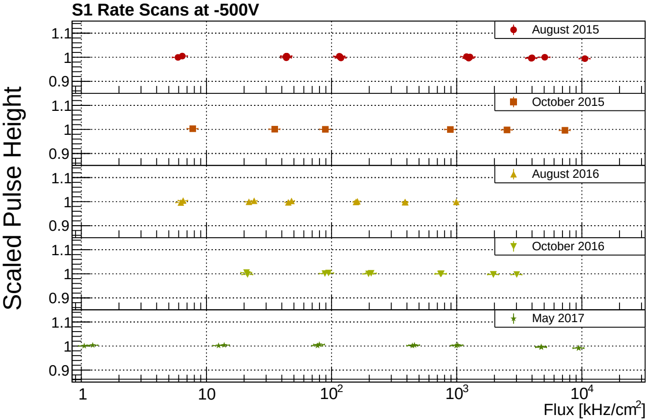


(b) pCVD

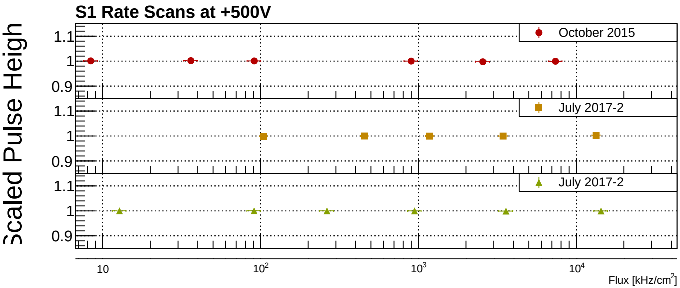
- uniform signal distribution in scCVD
- signal corresponding to wide Landau in pCVD

Rate Studies in Non-Irradiated scCVD



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

Rate Studies in Non-Irradiated scCVD



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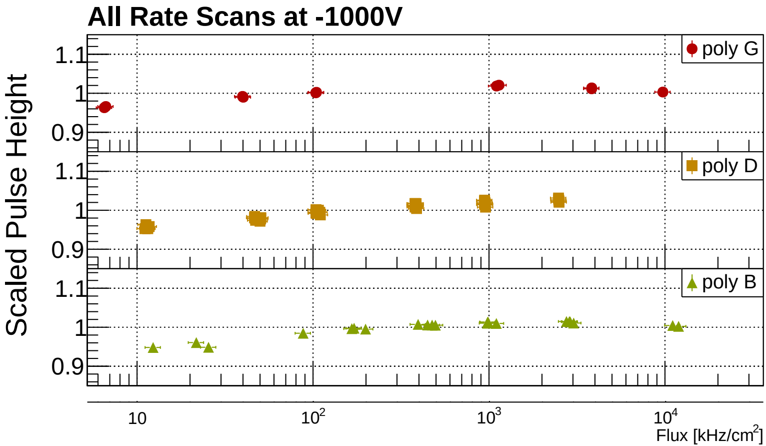
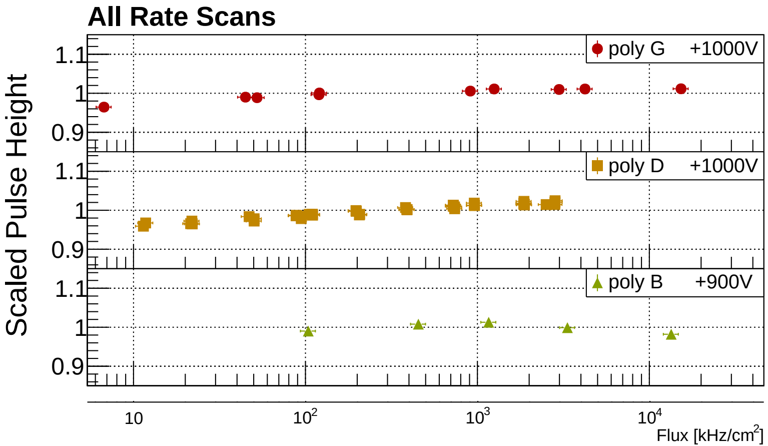
pCVD - Non-Irradiated



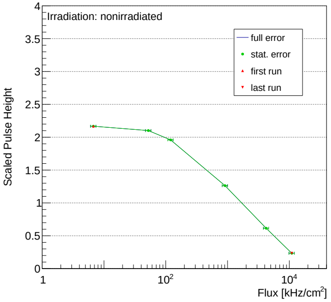
- rate scaled to the mean
- most non-irradiated pCVD diamonds have slight rate dependence ($<5\,\%$)
- behaviour very similar for both positive and negative bias voltage

pCVD - Non-Irradiated

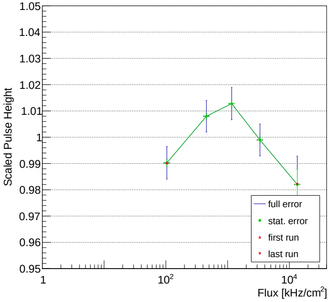


- rate scaled to the mean
- most non-irradiated pCVD diamonds have slight rate dependence (<5 %)
- behaviour very similar for both positive and negative bias voltage

A Special Case



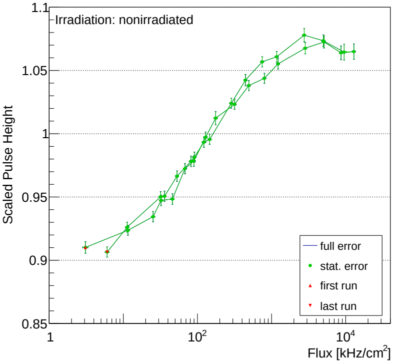
(a) First measurement.



(b) After reprocessing.

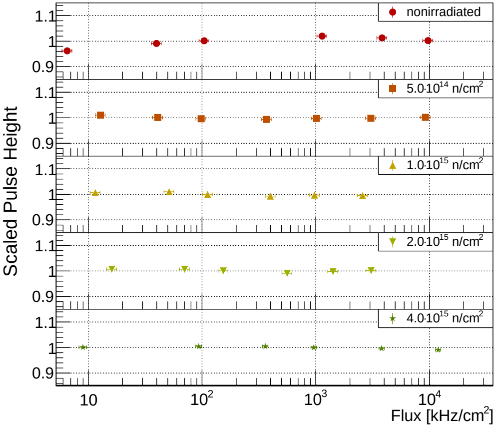
- very large rate dependence at the first measurement (>90 %)
- after reprocessing and surface cleaning with RIE very stable behaviour (∼2 %)
- possible to "fix" bad diamonds

Detailed Study of Rate Dependence



- largest increase of pulse height found so far
- all measurements very continuous and reproducible
- only very weak theories for this behaviour → try to model it
- try to fix by reprocessing

Rate Studies in Irradiated pCVD



- rate scaled to the mean
- 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
- most leakage currents $<10\,\mathrm{nA}$ and beam induced currents linear with flux
- pCVD diamond show non-uniformity according to wide landau of the signal depending on the position in the diamond
- nonirradiated scCVD show no rate dependence (large in irradiated)
- rate dependence for most non-irradiated pCVD $<5\,\%$
  - unknown origin, maybe surface contamination during production
  - possible to fix it for one sample $\rightarrow$ try to repeat it
- detectors with irradiated pCVD diamond sensors have a rate dependence below $\sim 2\,\%$ up to a flux of $20\,\mathrm{MHz/cm^2}$


Del Fin