

## Analysis of CVD Diamond Pad Detectors

7th ADAMAS Workshop in Vienna

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## 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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## Investigation of Rate Effects:

- Pad Detectors → whole diamond as single cell readout
- Pixel Detectors → diamond sensor on pixel readout chip
- 3D Pixel Detectors → 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** → this talk
- Pixel Detectors
- 3D Pixel Detectors

# Measurements

- several beam test starting from May 2015

Name	Nick	Type	Irradiation [n/cm <sup>2</sup> ]
S129	S129	scCVD	0
II6-78* <sup>◊</sup>	poly A	pCVD	0
II6-79 <sup>◊+</sup>	poly B	pCVD	0
II6-81 <sup>◊</sup>	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.

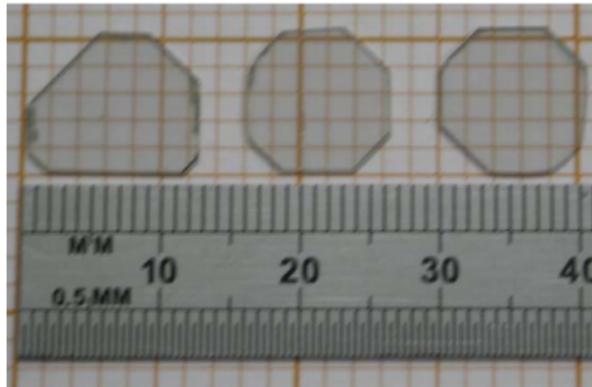
\* only measured in May 2015 (bad timing)

◊ processed by II6 with surface issues

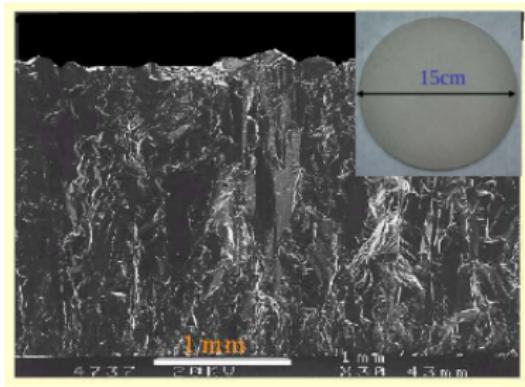
+ reprocessed at OSU

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

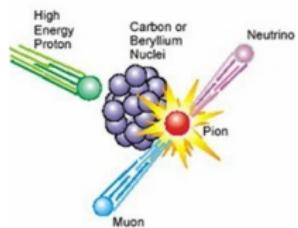
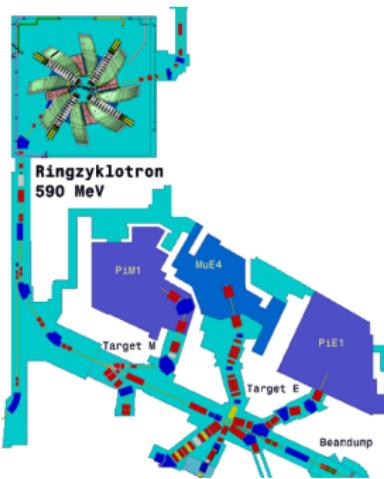
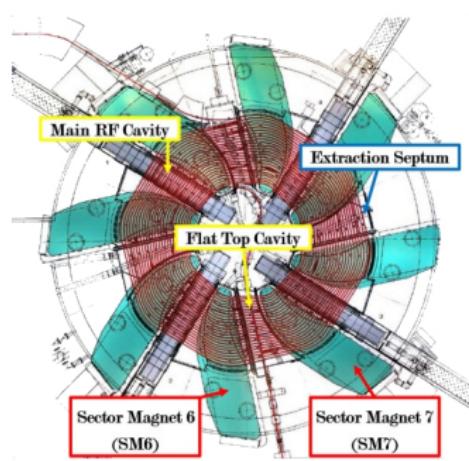
## Section 2

Test Site



# Test Site

- High Intensity Proton Accelerator (HIPA) at PSI (Cyclotron) → beam line PiM1
- clean positive pion beam ( $\sim 98\% \pi^+$ ) with momentum of 260 MeV/c
  - ▶  $\frac{3}{4}$  smaller signals than at CERN! (120 GeV/c)
- tunable particle fluxes from  $\mathcal{O}(1 \text{ kHz/cm}^2)$  to  $\mathcal{O}(10 \text{ MHz/cm}^2)$
- significant multiple scattering → worsens resolution



## Section 3

### Setup

# Setup

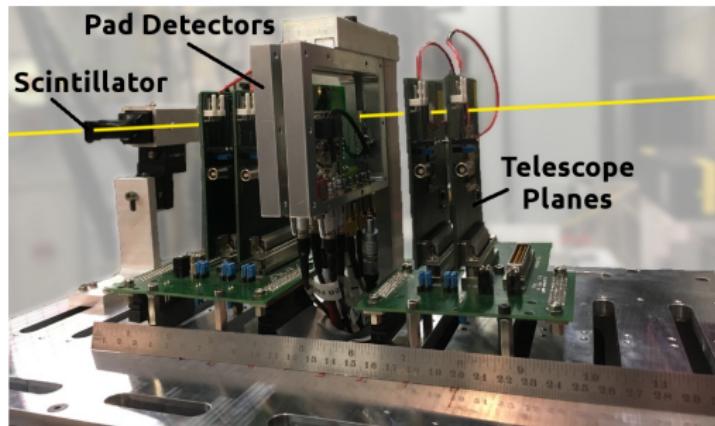
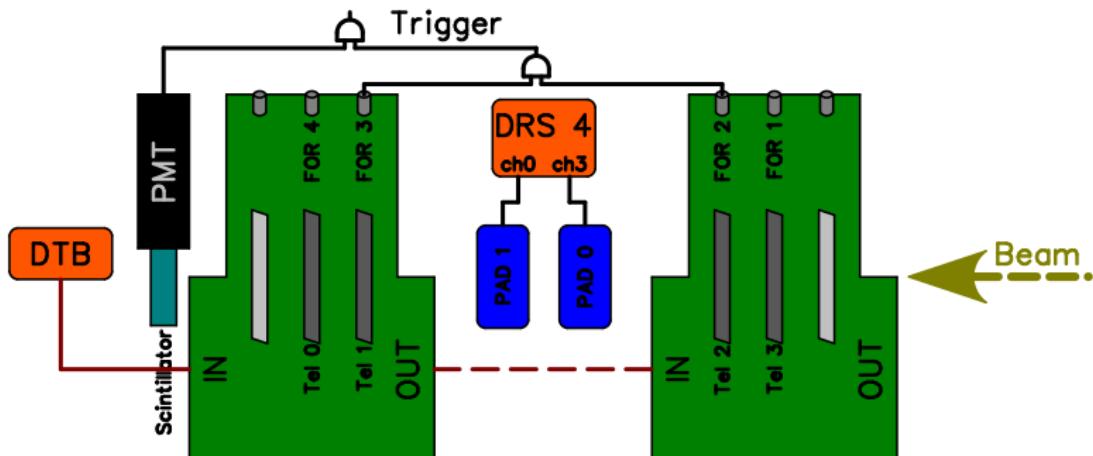


Figure: Modular Beam Telescope

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

## Schematic Setup

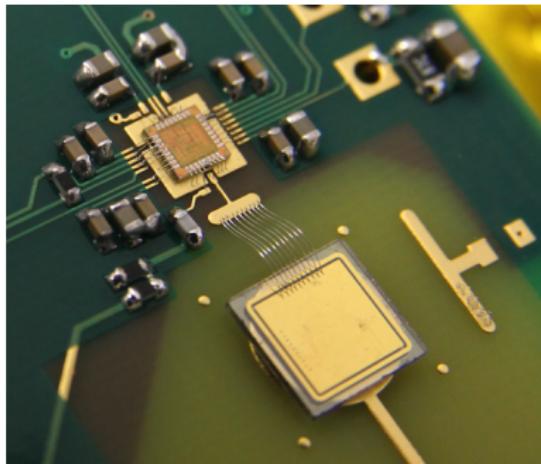


- PSI DRS4 Evaluation Board as digitiser for the pad waveforms
- Digital Test Board (DTB) and pXar software for the telescope readout
- global trigger: using coincidence of FOR 2 and FOR 3 + scintillator signal
- using custom built Trigger Unit (TU) to handle all the trigger logic

# Pad Detectors



(a) Detector Box



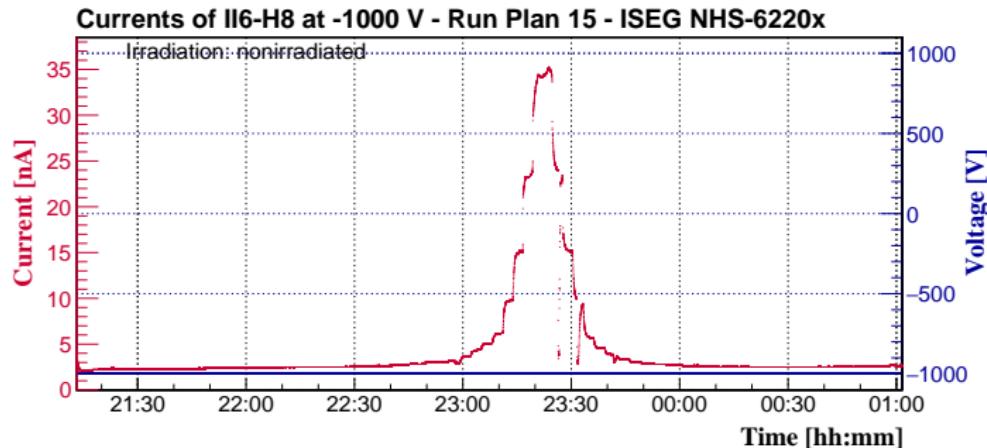
(b) Pad Detector with Amplifier

- 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  $\mathcal{O}(5\text{ ns})$  rise time

## Section 4

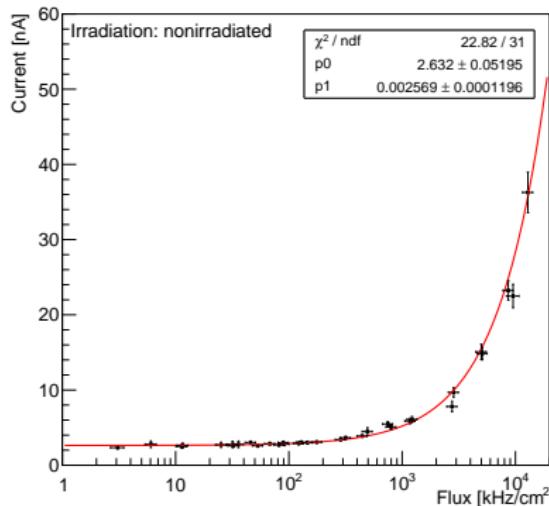
### Measured Currents

## Rate Scan



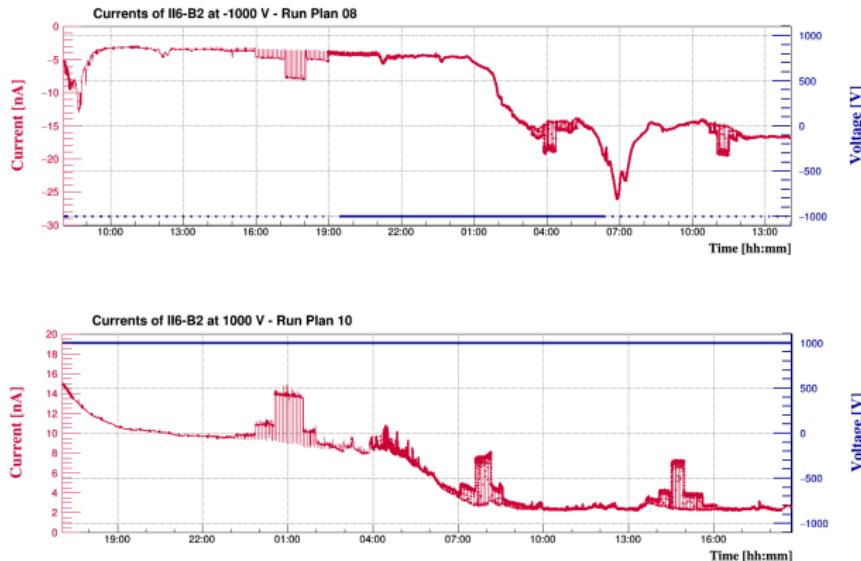
- typical rate scans for up to  $\sim 30$  h with rates up to  $\sim 20$  MHz/cm<sup>2</sup>
- beam induced current clearly visible
- low leakage currents ( $< 10$  nA) at 2 V/ $\mu$ m

## 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

## Unusual Behaviour



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

## Section 5

### Analysis

## Waveforms

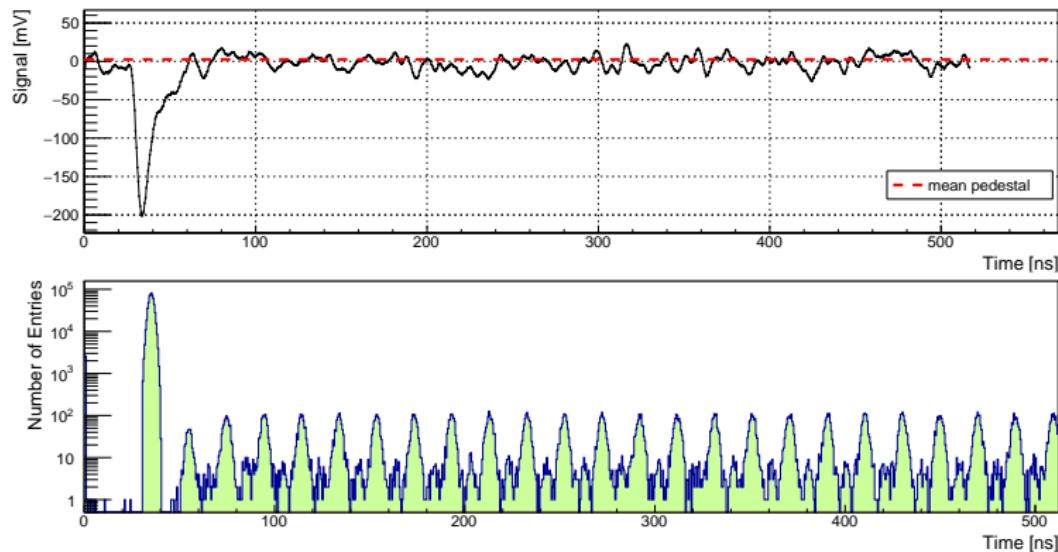
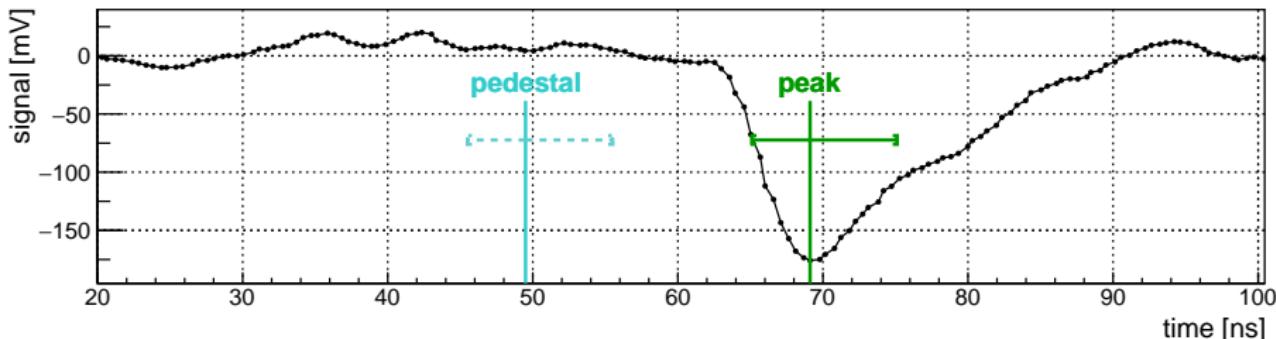


Figure: Peak timings.

- most frequent peak (@  $\sim 35$  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

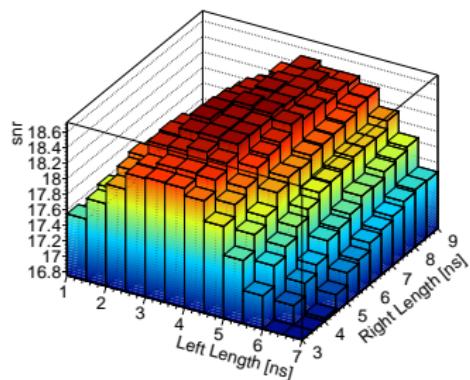
# Signal Definition & Calculation



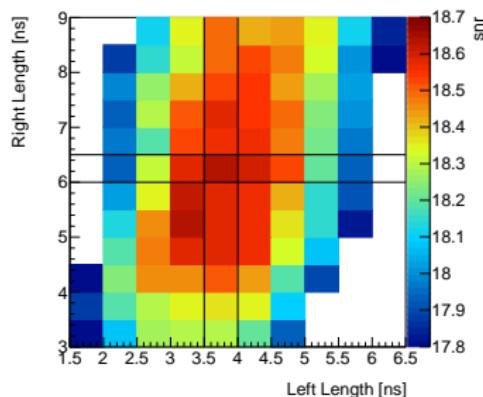
- perform DRS4 timing correction (circular buffer with varying cell size:  $(0.5 \pm 0.3)$  ns)
- define signal region:  $\sim \pm 10$  ns around peak of the triggered signal  $\rightarrow [60 \text{ ns}, 80 \text{ ns}]$
- signal: finding the peak in the signal region and integrate around it  $[-4 \text{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

# Signal To Noise Ratio

Signal to Noise Ratios



Signal to Noise Ratios



- 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

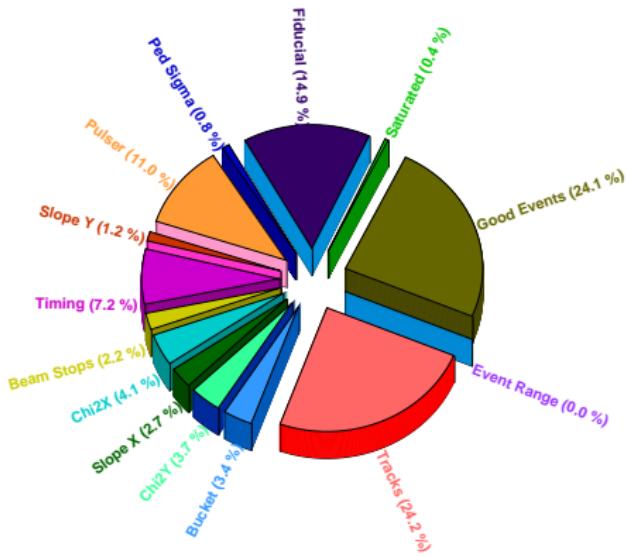
- separate pedestal and signal

## Exclude Events:

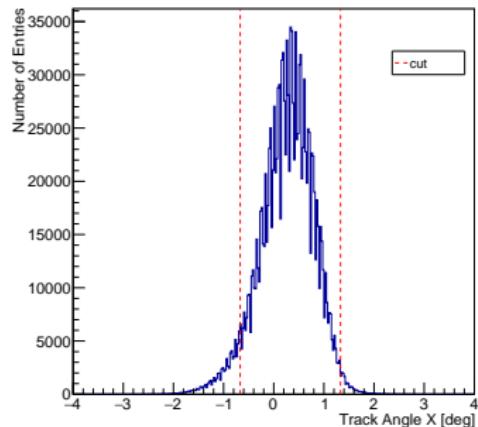
- saturated
- pulser
- incomplete tracks
- wrong peak timing
- outside fiducial region
- during beam interruption

## Also cuts on:

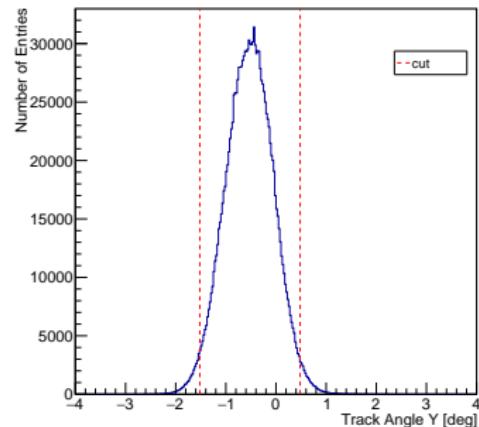
- track  $\chi^2$  in x- and y-direction
- track slope
- pedestal sigma
  
- after all cuts usually  $\sim 25\%$  event left



## Track Slope



(a) Track angle in X



(b) Track angle in Y

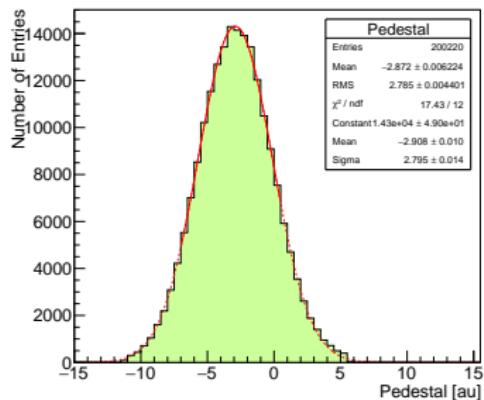
- only take events with  $\pm 1^\circ$  around the most probable slope
- slope has direct influence on the track length inside the sensor
- slope distribution slightly changes in every setup

## Section 6

### Results

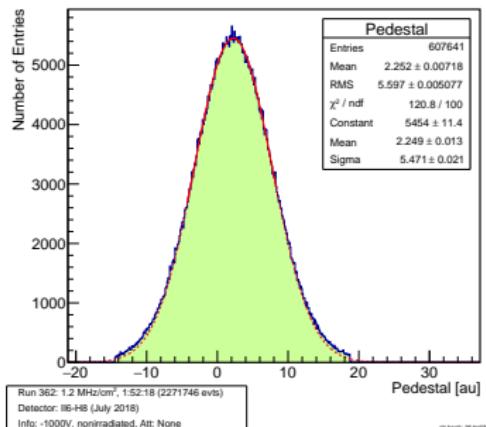
## Noise Distributions high rate

Pedestal Distribution



(a) scCVD (6 dB attenuation)

Pedestal Distribution

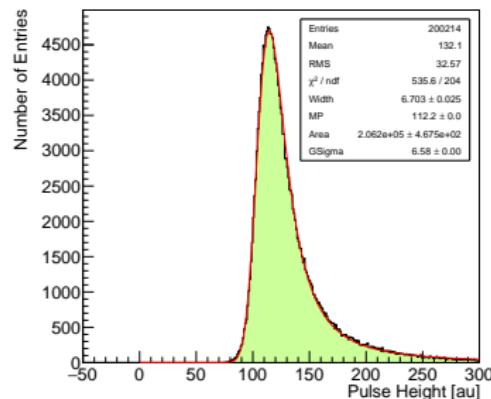


(b) pCVD

- 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

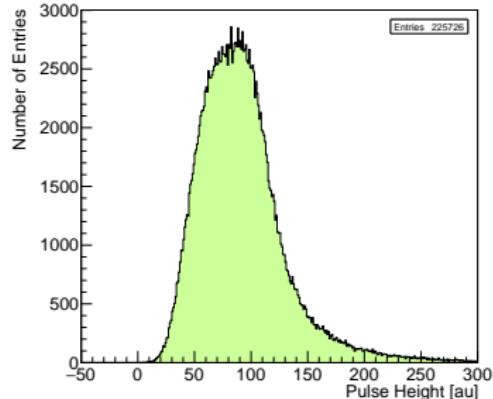
# Signal Distributions high rate

Pulse Height with Pedestal Correction



(a) scCVD (6 dB attenuation)

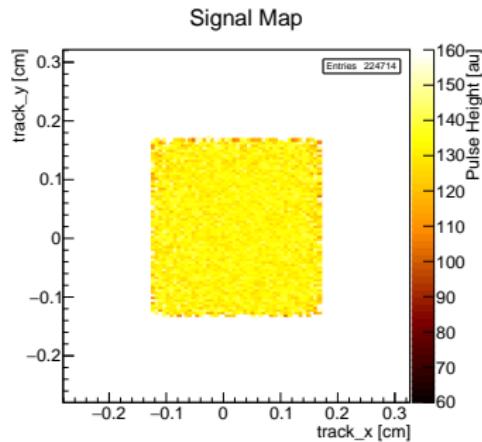
Pulse Height with Pedestal Correction



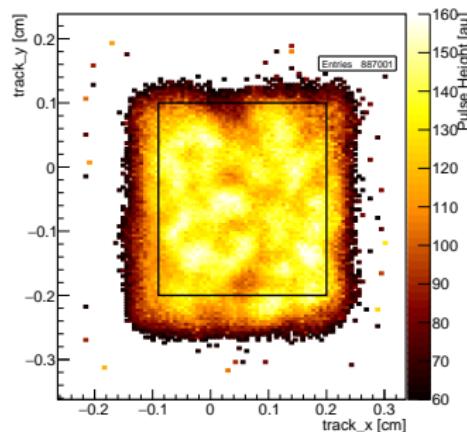
(b) pCVD

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

# Signal Maps



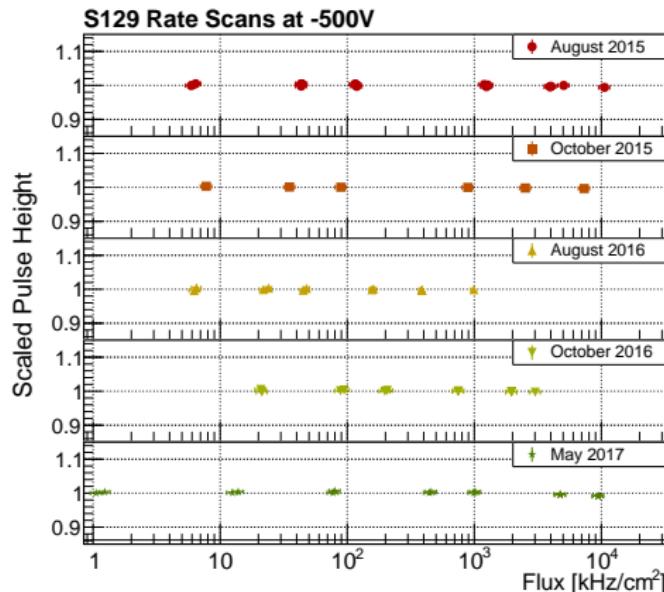
(a) scCVD (6 dB attenuation)



(b) pCVD

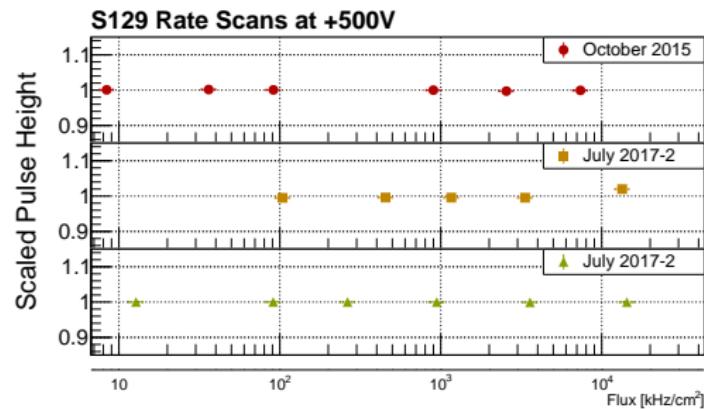
- flat signal distribution in scCVD
- signal response depending on region in the pCVD

## Rate Studies in Non-Irradiated scCVD



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

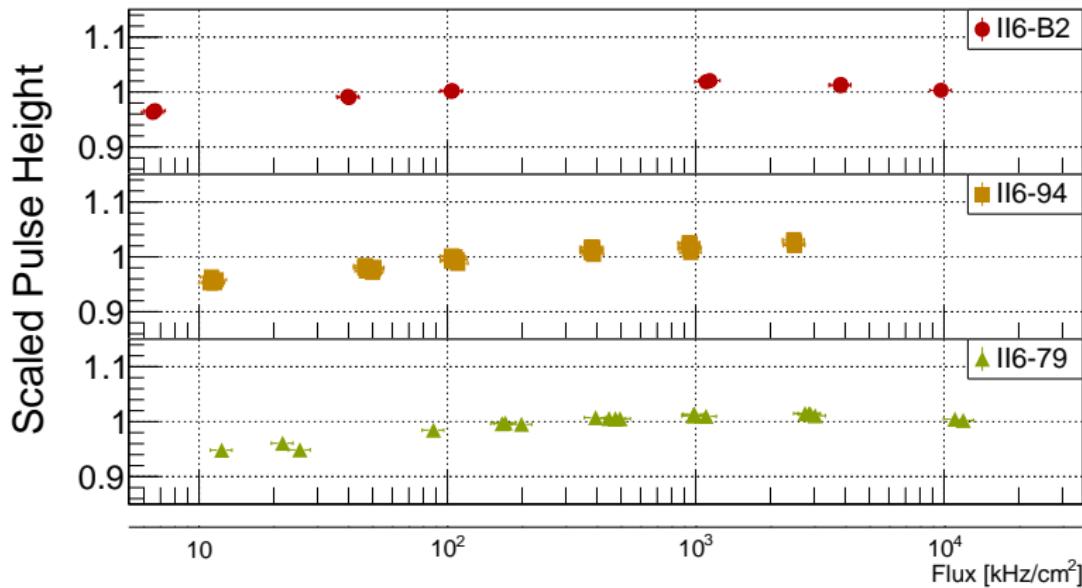
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## pCVD - Non-Irradiated

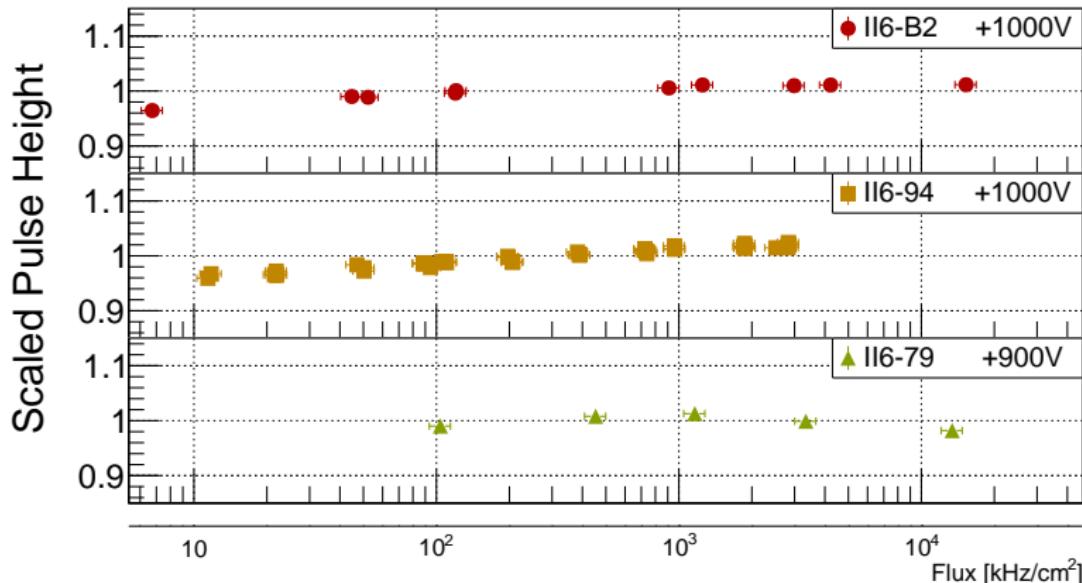
## All Rate Scans at -1000V



- rate scaled to the mean
- all non-irradiated pCVD diamonds have slight rate dependence
- behaviour very similar for both positive and negative bias voltage

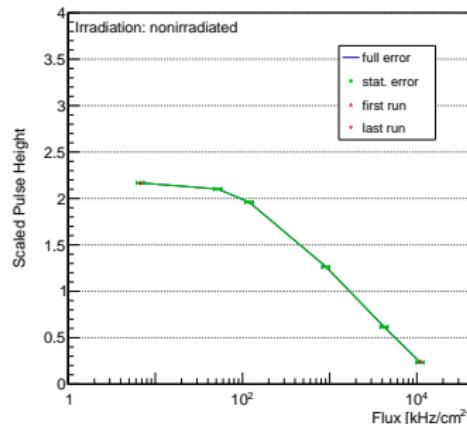
## pCVD - Non-Irradiated

## All Rate Scans

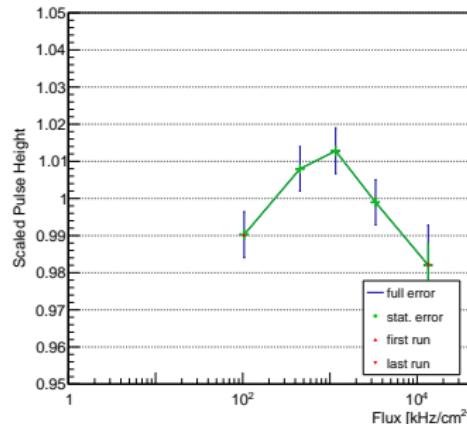


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# A Special Case



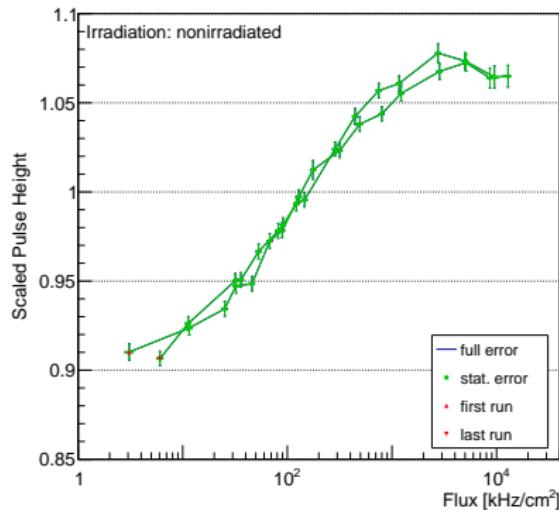
(a) First measurement.



(b) After reprocessing.

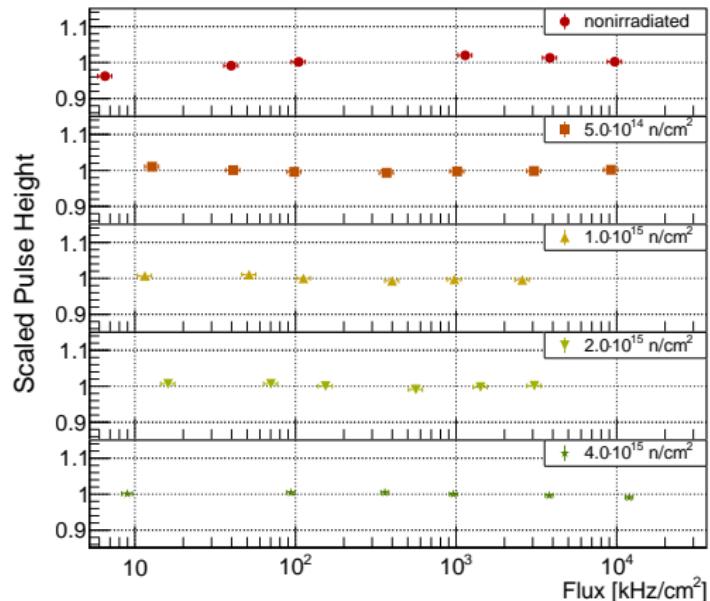
- very large rate dependence at the first measurement
- after reprocessing and surface cleaning with RIE very stable behaviour
- possible to “fix” bad diamonds

# 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
- 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
- pCVD diamond show non-uniformity of the signal depending on the position in the diamond
- nonirradiated scCVD show no rate dependence
- rate dependence for non-irradiated pCVD
  - ▶ unknown origin, maybe surface contamination during production
  - ▶ possible to fix it for one sample → try to repeat it
- detectors with irradiated pCVD diamond sensors have a rate dependence below ~2 % up to a flux of  $20 \text{ MHz}/\text{cm}^2$

# Del Fun

