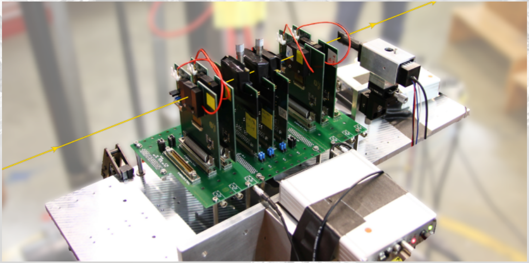
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

ETH Institute for Particle Physics



Overview of the PhD Project

ETH Group Meeting

Michael Reichmann

3rd July 2017

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Section 1

Introduction

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Time Line:

- 2015/02 – 2015/08: Master Thesis at IPP
- 2015/08 – 2016/01: Scientific assistant
- 2016/02 – today: PhD Student

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Projects:

- **Rate dependence of diamond as detector material**
  - commissioning, supervision and further development of the ETH beam telescope
  - pad detectors
  - pixel detectors
  - 3D detectors (pad & pixel)
  - supervision and organisation of beam tests
- **CMS Pixel Layer 1 $\rightarrow$ pROC**
  - Layer 1 software
  - high rate beam tests
  - L1 readout errors

Section 2

Motivation

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- innermost layers $\rightarrow$ highest radiation damage
- current detector is designed to survive $\sim$12 month in High-Luminosity LHC
- $\rightarrow$ **R/D for more radiation hard detector designs and/or materials**

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Diamond as Detector Material:

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

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- diamond pixel detectors in Pixel Luminosity Telescope (PLT) (installed 2010/2011)
- **signal dependence on incident particle rate observed!**

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- diamond pixel detectors in Pixel Luminosity Telescope (PLT) (installed 2010/2011)
- **signal dependence on incident particle rate observed!**

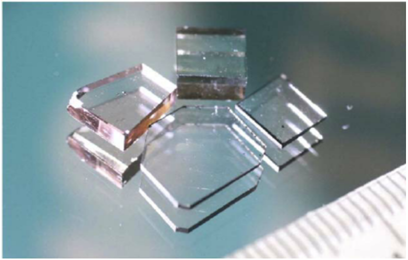
- investigation of the rate effect in various detector designs:
  - pad $\rightarrow$ full diamond as single cell readout of the whole signal
  - pixel $\rightarrow$ diamond sensor on CMS-Pixel Chips
  - 3D $\rightarrow$ pixel detector with clever design to reduce drift distance

Section 3

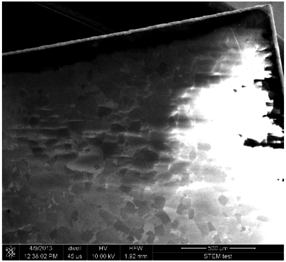
Diamond Types

Artificial Diamond Types

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



(a) single-crystalline CVD



(b) poly-crystalline CVD

- grown on existing diamond crystal
- only small sizes ($\sim$0.25 cm^2)
- larger signals than pCVD (5 : 3)

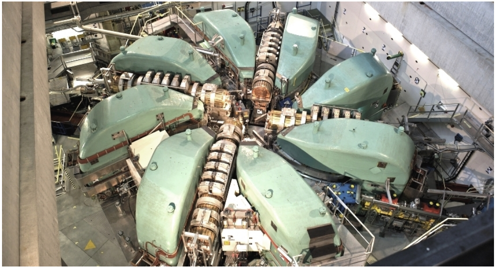
- grown on Si substrate with diamond powder
- large wafers (5″ to 6″ ⌀)
- non-uniformities and grains

Section 4

Test Site & Setup

Test Site

- High Intensity Proton Accelerator (HIPA) at PSI (Cyclotron)
- using beam line πM1 at Paul Scherrer Institute (PSI)
- 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

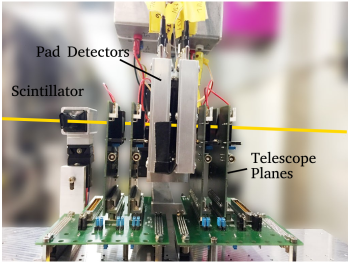
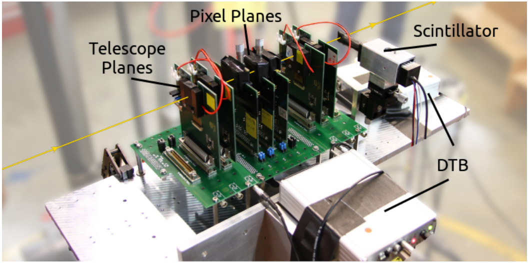


Figure: pad telescope

- modular ETH beam telescope $\rightarrow$ test apparatus for all detectors
- 4 tracking planes $\rightarrow$ trigger (fast-OR) with scalable area
- fast-OR clocked with 40 MHz $\rightarrow$ 25 ns time precision
- diamond detectors (DUTs) in between tracking planes
- scintillator for precise trigger timing $\rightarrow \mathcal{O}\,(1\,\mathrm{ns})$

Setup



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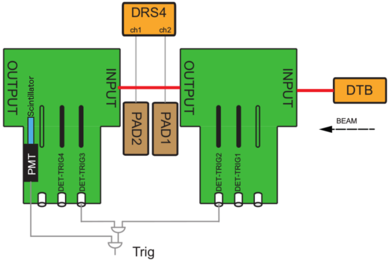


Figure: pad telescope

- PSI DRS4 Evaluation Board as digitizer for the pad waveforms
- Digital Test Board (DTB) and pXar software for the telescope readout
- global trigger as coincidence of fast-OR self trigger and scintillator signal
- EUDAQ as DAQ framework

Setup

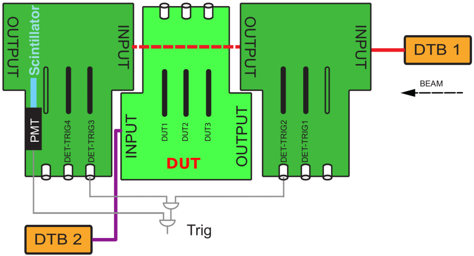


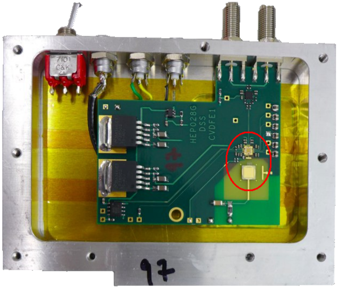
Figure: pixel telescope

- independent telescope module as DUT (light green)
- Digital Test Board (DTB) and pXar software for the telescope readout
- global trigger as coincidence of fast-OR self trigger and scintillator signal
- EUDAQ as DAQ framework

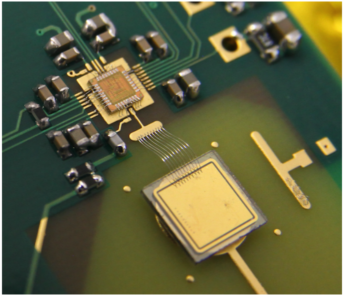
Section 5

Pad Detectors

Pad Detectors



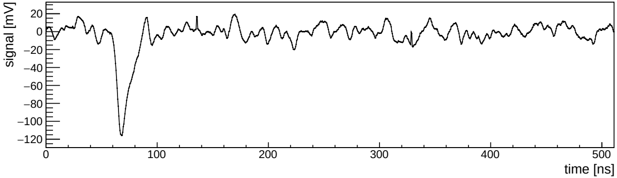
(a) fast amplifier box

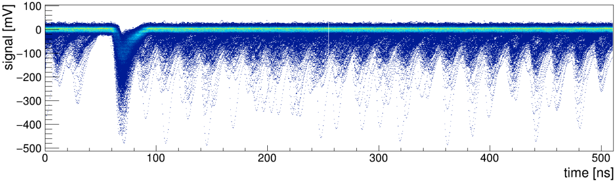


(b) diamond and fast amp

- diamonds in custom built amplifier boxes from Ohio State University (OSU)
- cleaning, photo-lithography and Cr-Au metallisation at OSU
- low gain, fast amplifier with $\mathcal{O}$ (ns) rise time

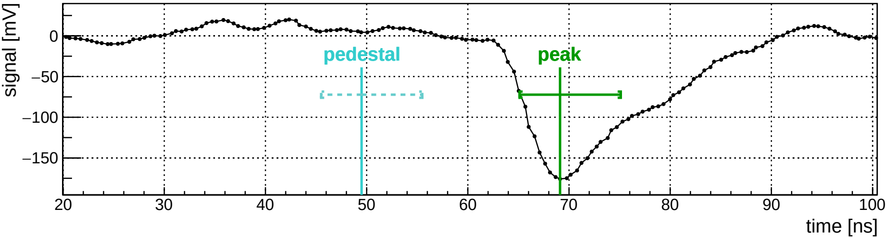
Waveforms





- most frequented peak ($\sim$70 ns): triggered signal
- other peaks originate from other buckets ($\rightarrow$ resolve beam structure of $\approx$19.7 ns)
- system does not allow signals in pre-signal bucket due to fastOR trigger deadtime

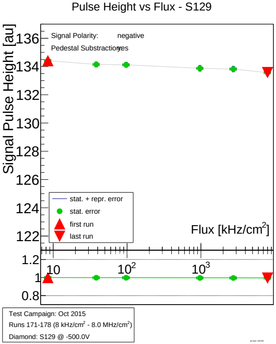
Pulse Height Calculation



- finding the peak in the signal region
- integrating the signal in time fixed asymmetric integral around peak
- optimising the integral width by highest SNR (Integral / Pedestal Sigma)

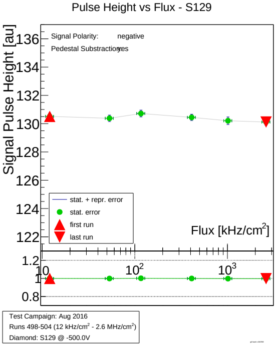
Non-Irradiated Single Crystal Diamond

October 2015



noise $\sigma \approx 2.6\,\mathrm{au}$

August 2016



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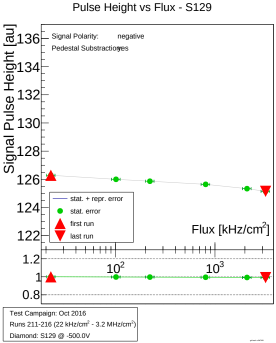
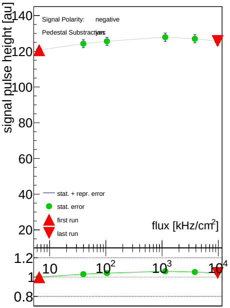


noise $\sigma \approx 2.6\,\mathrm{au}$

- measurements taken under the same conditions
- noise stays the same
- pulse height very stable

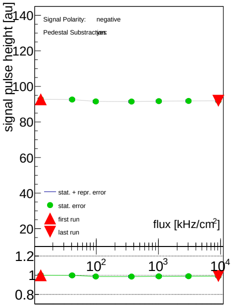
Poly Crystal Diamond

August 2016 - unirradiated



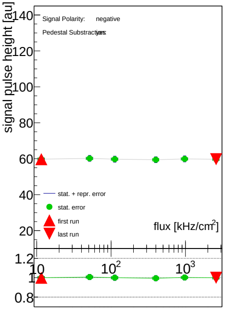
noise $\sigma \approx 4.9$ au

October 2015 - $5 \cdot 10^{14}$ n/cm^2



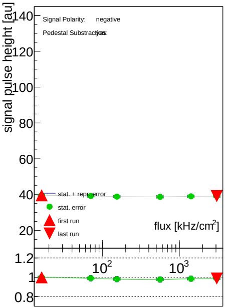
noise $\sigma \approx 4.9$ au

August 2016 - $1 \cdot 10^{15}$ n/cm^2



noise $\sigma \approx 4.9$ au

October 2016 - $2 \cdot 10^{15}$ n/cm^2



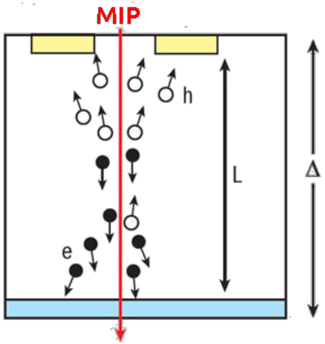
noise $\sigma \approx 4.9$ au

- pulse height very stable after irradiation
- noise stays the same

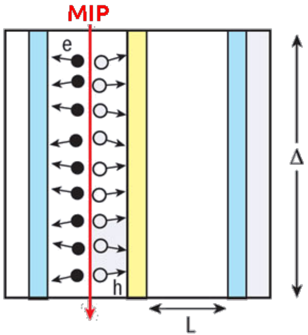
Section 6

3D Detectors

Detector Concept



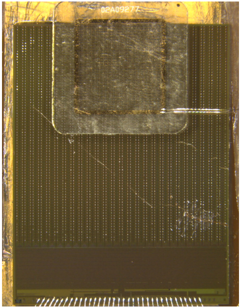
(a) planar detector



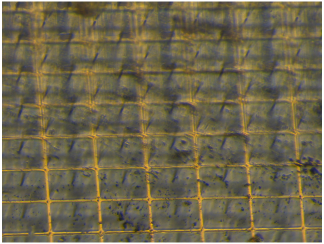
(b) 3D detector

- bias and readout electrode inside detector material
- same thickness $\Delta \rightarrow$ same amount of induced charge
- shorter drift distance L
- **increase collected charge in detectors with limited mean free path**

3D Detector



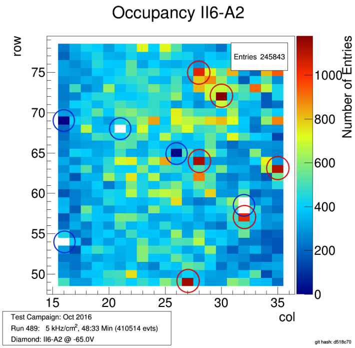
(a) detector bonded on CMS pixel



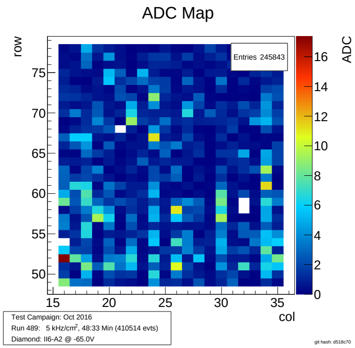
(b) bias grid and columns

- columns laser drilled → convert diamond into resistive mixture of carbon phases
- size of 4 mm × 4 mm
- thickness of 500 μm
- cell size of 150 μm × 100 μm → 20 cells × 30 cells

Raw Data



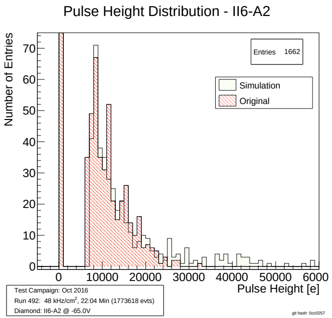
(a) raw hit map



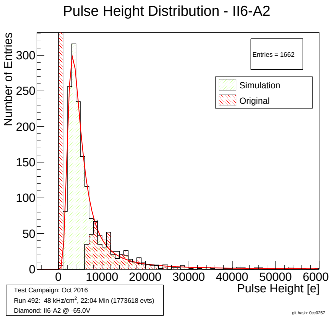
(b) raw adc map

- some hot (6) and dead (6) pixels in the detector (total 600 pixels)
- very low adc values (8 bit range) $\rightarrow$ most of the values are 0
- **mistuned chip induced loss of pulse height information**

Pulse Height Distribution



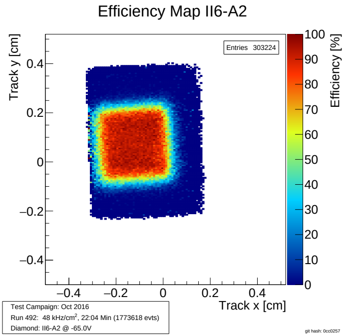
(a) simulation of Landau with threshold



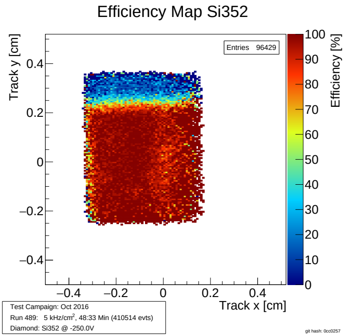
(b) full distribution with fit

- **mean of the full simulated distribution:** 6950 e
- lower than expected pulse height: $>$14 000 e $\rightarrow$ under investigation
- 1.8 % of the events beneath 1500 e (pixel threshold)

Efficiency Map



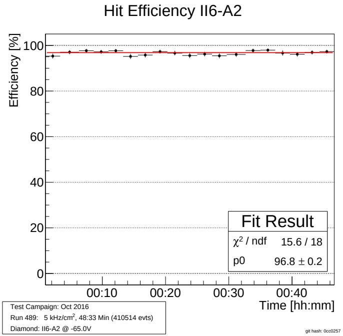
(a) II6-A2



(b) Si352 - reference

- percentage of valid hits at estimated hit position by tracking
- total area: unmasked area of the trigger planes
- central region highly efficient

Efficiency vs. Time



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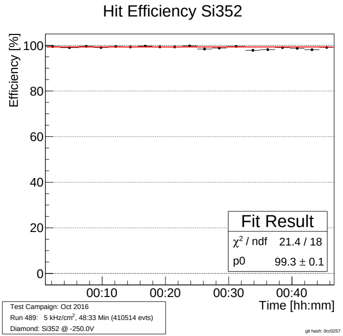

(b) Si352 - reference

- **mean efficiency of the II6-A2:** $\sim$97 %
- mean efficiency of the silicon reference: $\sim$99 %
- undetected hits likely below pixel threshold → agrees well with simulation

Section 7

Pixel Detectors

Pixel Detectors

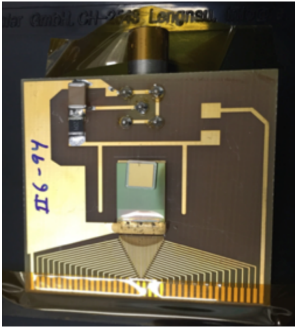

Figure: diamond sensor detector on CMS Pixel Chip

- cleaning, photo-lithography and Cr-Au metallisation at OSU and Princeton
- bump bonding at Princeton
- analysis very similar (easier) to 3D $\rightarrow$ ongoing

Section 8

Conclusion

Conclusion

- commissioned the ETH beam telescope
- designing new improved version of the telescope $\rightarrow$ soon to be tested
- pad analysis almost finished $\rightarrow$ paper soon
- started pixel analysis
- successfully measured the very first 3D diamond pixel detector
  - high detecting efficiency of $\sim$97 %
  - very high pixel yield (only 6/600 dead pixels)