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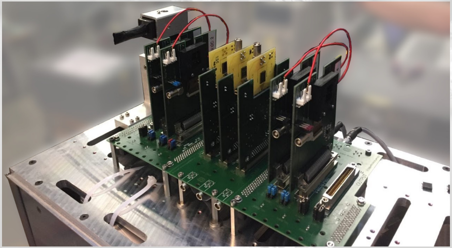

Beam Test Results of 3D Diamond Detectors on CMS Pixel Chips

RD42 Meeting

Michael Reichmann

9th April 2018

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Section 1

Introduction

Detectors

	II6-A2	**II6-B6**
manufacturer	II-VI Inc.	II-VI Inc.
diamond type	poly-crystal	poly-crystal
size	∼4 mm × 4 mm	∼4 mm × 4 mm
thickness	∼500 µm	∼500 µm
construction	summer 2016	summer 2017
3D drilling	Oxford	Oxford
3D cell size	**150 µm × 100 µm**	**50 µm × 50 µm**
columns	**20 × 30 (600)**	**60 × 62 (3720)**
pixel chip	PSI46digV2.1respin (CMS)	PSI46digV2.1respin (CMS)
pixel pitch	150 µm × 100 µm	150 µm × 100 µm
ganged cells	1 × 1	2 × 3 (6 cells)
bump & wire bonding	Princeton	Princeton

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- II6-A2 broke in October 2016 (chip malfunctioned)
- successful re-bonding to new chip in the spring 2017

Measurements

	Oct 2016	May 2017	Aug 2017-1	Aug 2017-2
II6-A2	✓	✓	✓	✗
II6-B6	✗	✗	✓	✓
rate scan	✓	✓	✓	✗
voltage scan	✓	✓	✓	✗
rise time scan	✗	✓	✓	✗
angle scan	✗	✗	✗	✓

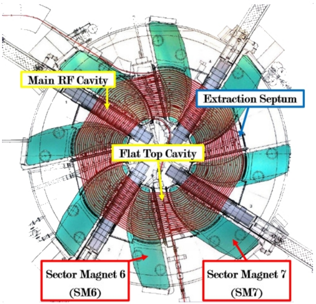
- rate scan: fixed voltage with periodical change in flux
- voltage scan: fixed flux with increasing or decreasing bias voltage
- rise time scan: change of amplifier rise time at fixed flux and voltage
- angle scan: change of incident angle at fixed flux and voltage

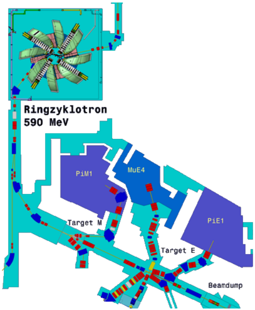
Section 2

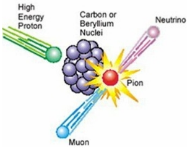
Test Site

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 $\mathcal{O}\left(10\,\mathrm{MHz/cm^2}\right)$**
- **significant multiple scattering → worsens resolution**



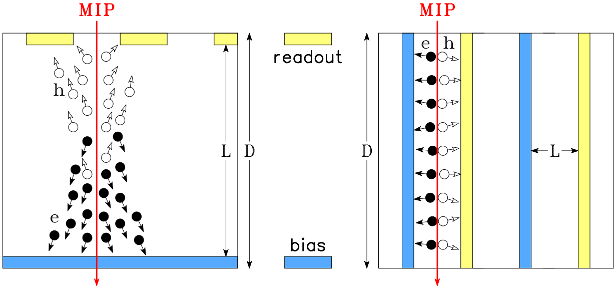




Section 3

3D Detector

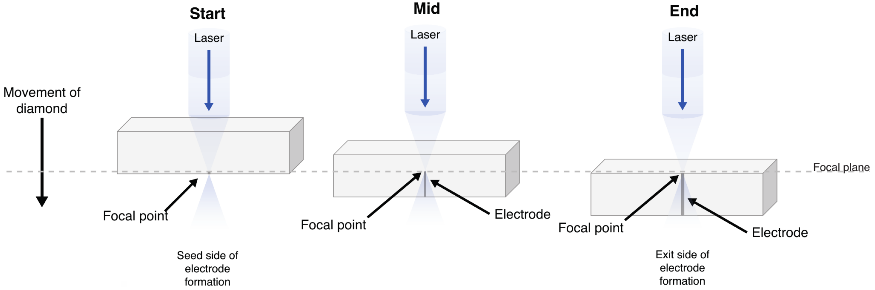
Detector Concept



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

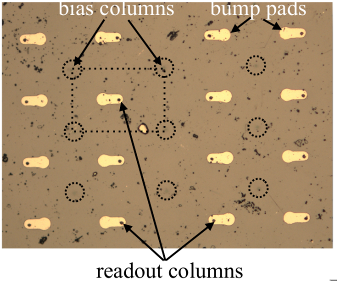
Laser drilling

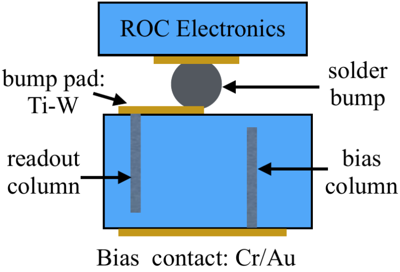
- cleaned and prepared for laser drilling (OSU)
- "drilling" columns with ∼15 µm gap to the surface using fs-laser (Oxford)
- convert diamond into resistive mixture of carbon phases (i.a. DLC, graphite)
- ≥99 % column yield using spatial light modulation (SLM) to correct for aberration



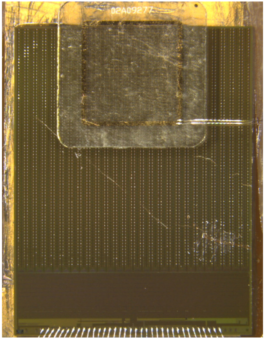
Metallisation & Bump Bonding

- connection to bias and readout with surface metallisation
  - cleaning and preparation for photo-lithography (OSU)
  - photo-lithography and metalisation of HV back plane (OSU)
  - photo-lithography and metalisation of pixel readout (Princeton)
  - bump and wire bonding at Princeton

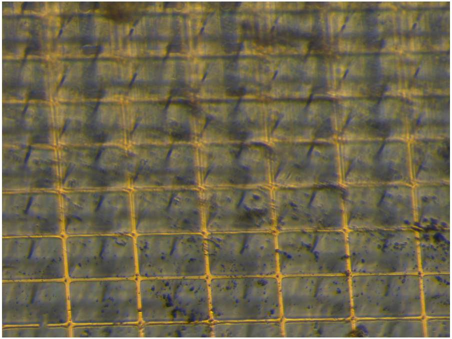




Fully Processed 3D Pixel Detector



(a) detector bonded on CMS pixel



(b) bias grid and columns

Section 4

Setup

Pixel Telescope

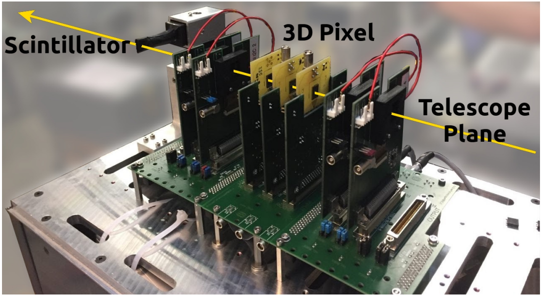
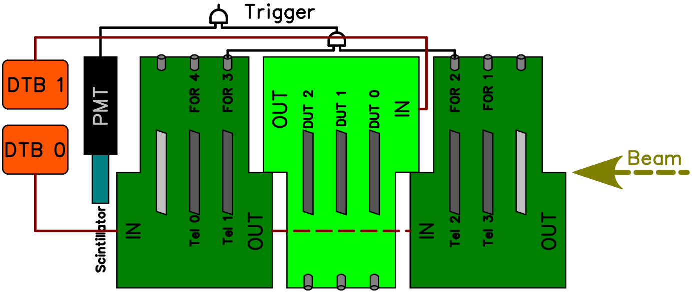


Figure: modular ETH beam telescope in pixel configuration

- 4 tracking planes with trigger (fast-OR) and 25 ns time precision
- up to 3 DUT planes (any digital pixel detector)
- scintillator for precise trigger timing → $\mathcal{O}(1\,\text{ns})$
- spatial resolution of ∼188 μm × 175 μm (multiple scattering)

Schematic Setup

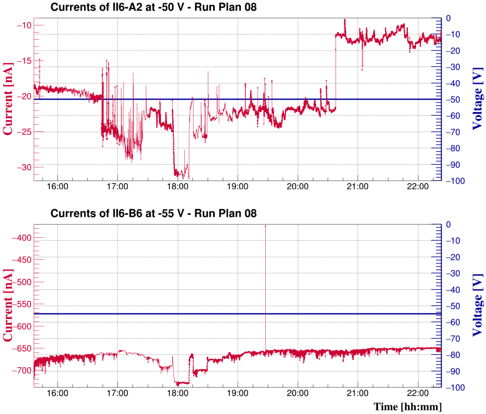


- independent telescope module as DUT (light green)
- Digital Test Board (DTB) and pXar software for the telescope readout
- global trigger as coincidence of fast-OR self trigger and scintillator signal
- EUDAQ as DAQ framework

Section 5

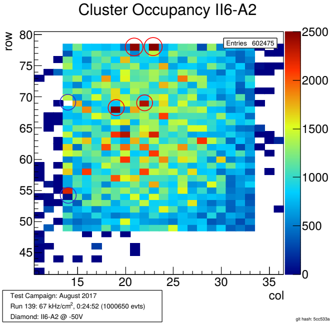
Analysis

Leakage Currents

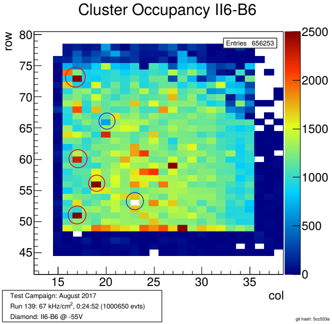


- beam induced currents visible around 6 p.m.
- both devices mainly stable
- high base line current in II6-B6

Raw Hit Maps



(a) II6-A2



(b) II6-B6

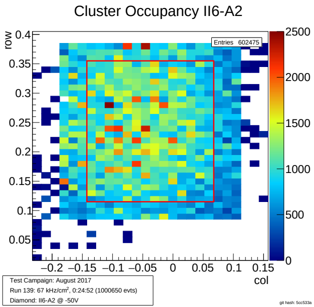
- pixel chips tuned to ∼1500 e threshold
- some **hot** and **dead** or **inefficient** pixels
- bad bump bonding in top right corner of II6-B6
- few hits in unbonded area (correlated to tracks)

General Cuts

- Event Range
  - discard first minute of the run $\rightarrow$ unstable beam conditions
- Beam Interruptions
  - beam sent to another area for 5 s every 5 min
  - exclude 5 s before and 15 s after the interruption
- Tracks
  - only events with exact one cluster in every tracking plane
- Track χ^2
  - exclude events with $\chi^2 > 90\,\%$ quartile separately in x- and y-direction
- Track Angle
  - exclude events with $\alpha > 2^\circ$ from mean angle
- R-Hit
  - discard events with distance of predicted hit position to cluster position $>90\,\%$ quartile

Fiducial Cut

- select suitable area of the diamond
  - no dead pixels
  - away from the border to unbonded pixels



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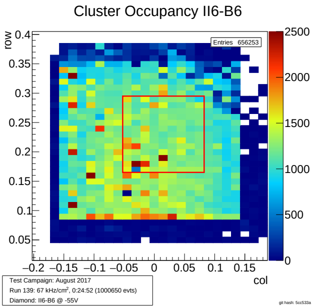
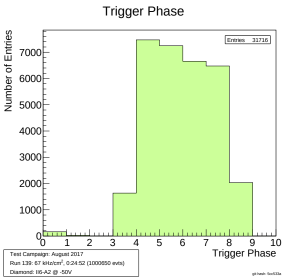


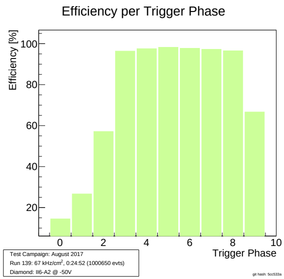
(b) II6-B6

Trigger Phase Cut

- Trigger Phase: select only efficient trigger phases (3-7)
  - time the trigger arrived at the DTB wrt. the 40 MHz clock
  - only certain range where trigger can arrive (due to trigger logic)
  - others are random hits and have to be excluded



(a) Distribution

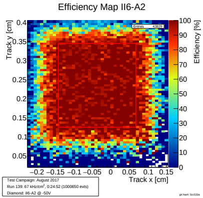


(b) Efficiency

Section 6

Results

Efficiency Maps



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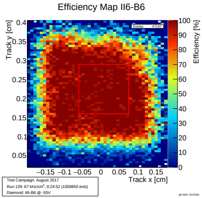
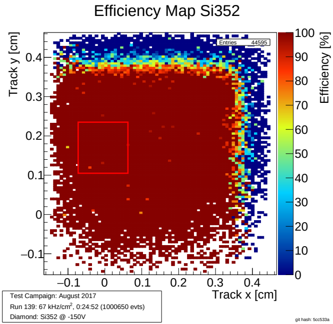


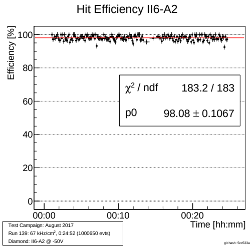
(b) II6-B6



(c) Silicon reference

- Efficiency = Number of hits in 3D per track passed through the DUT
- total trigger area from telescope bigger than 3D
- centre regions highly efficient

Efficiencies



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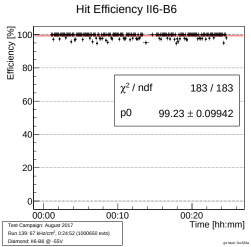
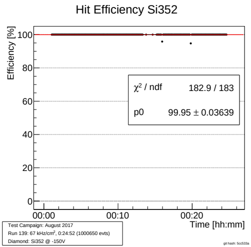


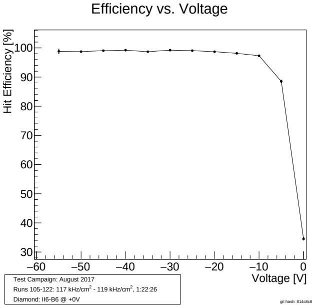
(b) II6-B6

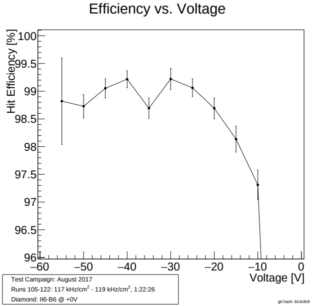


(c) Silicon reference

- efficiencies stable in time
- lower efficiency for 3D with big cell size
- silicon almost fully efficient

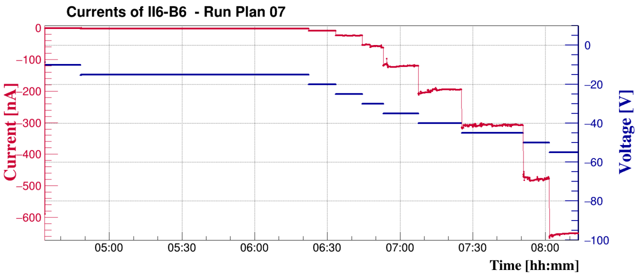
Efficiency vs Voltage





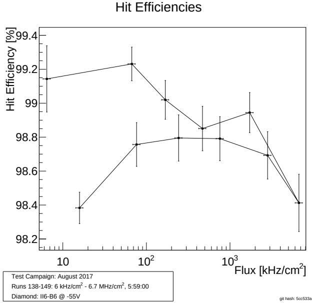
- already working with 0 V (just chip voltage)
- reaches highest efficiency already at -30 V
- drop at higher voltages probably due to single pixels with high currents

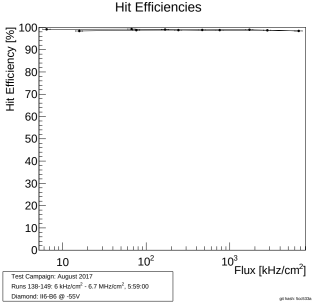
Leakage Current During Voltage Scan



- high leakage current stepwise increasing with voltage

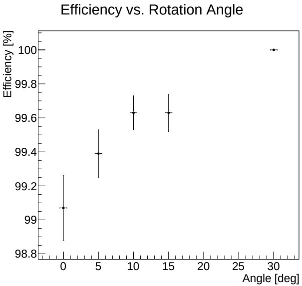
Efficiency vs Rate





- first run: top left point
- efficiency seems to slightly drop with rate and time
  - data-taking less stable at higher rates

Efficiency vs Tilting Angle



- very preliminary
- no good adaption of fiducial cut yet
- efficiency totally recovers

Section 7

Conclusion

Conclusion

- successfully built working 3D pixel device based on CMS-Pixel-Chips
  - small cell size of ($50\,\mu m \times 50\,\mu m$)
  - high column yield (2/600 dead pixels)
  - high efficiency (99.2 %)
  - efficiency recovers when tilting the detector wrt to the beam
- some open questions left
  - pulse height not fully understood
  - hits in unbonded areas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