Channel calibration for the BCM1F beam test

Pascal Becht

DESY

Summer Student Programme
Final Report

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Luminosity overview

- Propotionality factor:

$$\frac{dN}{dt} = \mathscr{L}\sigma_{\text{process}}$$

$\frac{dN}{dt}$: Event rate, $\mathscr{L}$: Luminosity, σ_{process}: Cross section of specific process

Processes:

- Distinct physics event
- Primary pp collisions
- Hit in a luminosity detector

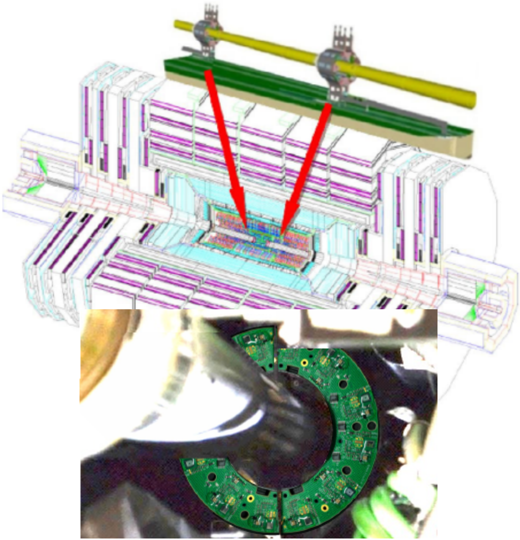
Luminosity needed for:

1) Accelerator performance optimisation
2) Physics cross section determination

Measurement:

- σ_{det} is known $\Rightarrow$ Measurement becomes a counting task

Fast Beam Condition Monitor (BCM1F)



Position of the BCM1F detector in the CMS experiment [1]

Where?

- Surrounds beam pipe on both sides
- Distance from IP: 1.8 m

What?

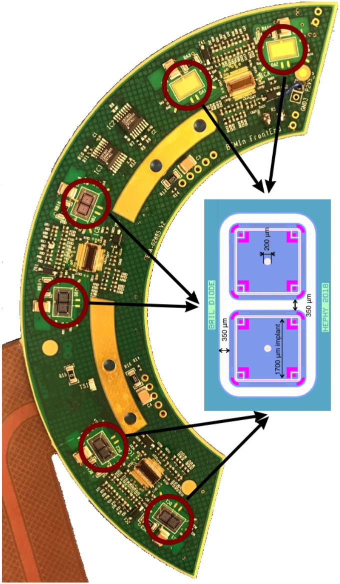
- 4 Printed Circuit Boards (PCB)

→ "C-shape"

→ Holds the sensors

→ Contains parts of front-end electronics

BCM1F Run 3 C-shape [1]



New requirements for Run 3:

- Increased particle flux

→ Rate capability

→ Radiation damage

Detector design:

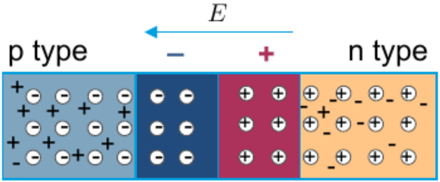
- 6 sensors per C-shape
- 2 silicon diodes (pads) per sensor
- New dedicated AC coupled sensors

  → Block leakage current

⇒ Need test beam to investigate detector performance

Reverse biased silicon diodes [2]

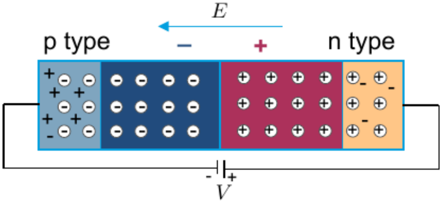
pn-junction:



- Electrons diffuse from n to p
- Neutralise with holes
- Electrical field builds up
- Drift from p to n until equilibrium
- Analogue for holes

⇒ Depletion zone

Reverse bias voltage applied:

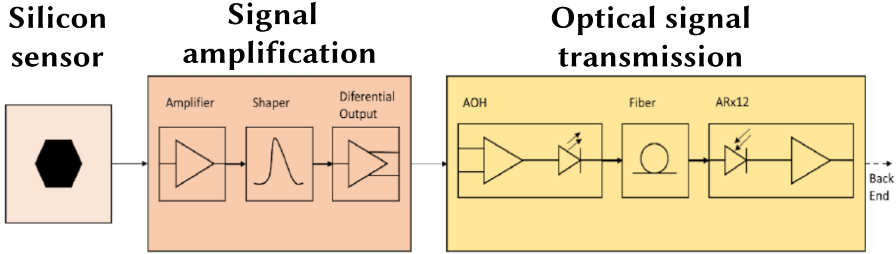


- Drift enhanced
- Equilibrium shifts

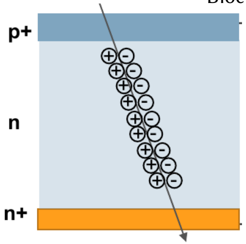
⇒ Depletion zone grows with applied voltage

Signal generation and readout chain

Signal generation and readout chain



Block diagram of the BCM1F front-end readout system [3]



Reverse bias silicon diode [2]

- Charged particle deposits energy:

→ Creation of electron-hole pairs

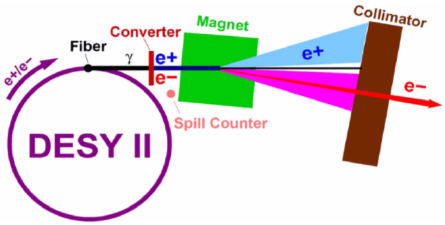
→ In Si: $\approx 78\ \frac{e}{\mu m}$ (MIP)

- Analog-Opto-Hybrids (AOH):

→ Laser:

Analog signals to optical signals

Test beam setup



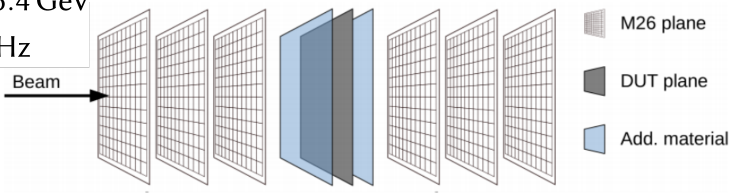
Sketch of the DESY II testbeam facility [3]

Experimental components:

- Device Under Test (DUT)
- 3 tracking planes before and after DUT
  - → Monitor test beam positions
  - → Confirm a detector hit
- CMS pixel detector as timing reference

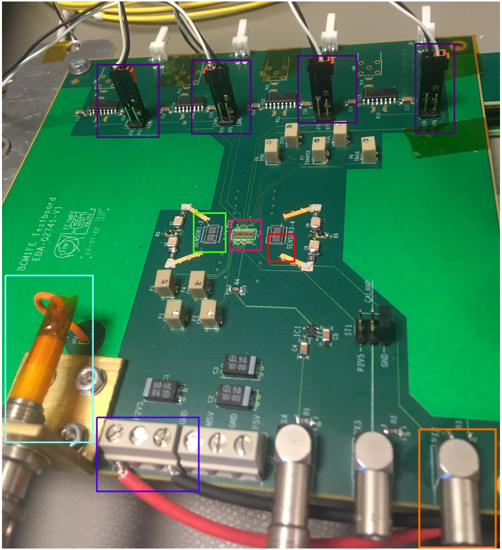
Used parameters:

- Energy: 5.4 GeV
- Rate: 80 Hz



Usual test beam setup [1]

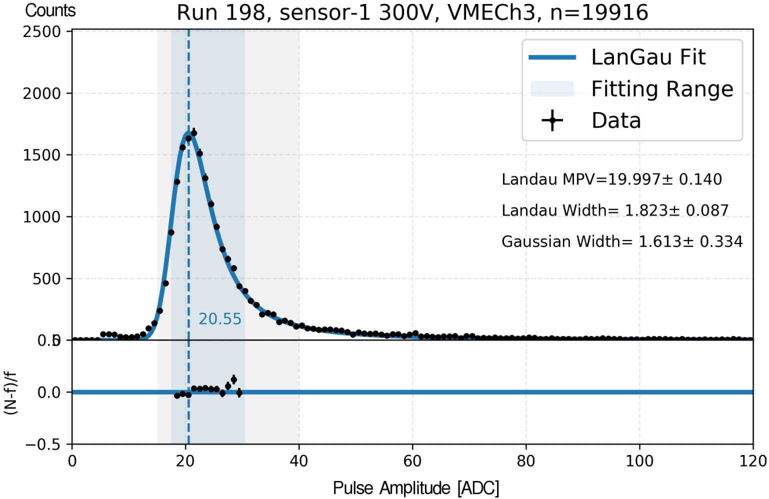
Device Under Test (DUT)



BCM1F testboard

- 1 sensor 200 µm
  - → Grounded guard ring
  - → Ch2, Ch3
- 1 sensor 300 µm
  - → Floating guard ring
  - → Ch0, Ch1
- Bias voltage: 300 V
- Supply voltage: 2.5 V
- ASIC
- To the AOHs
- External test pulse for calibration

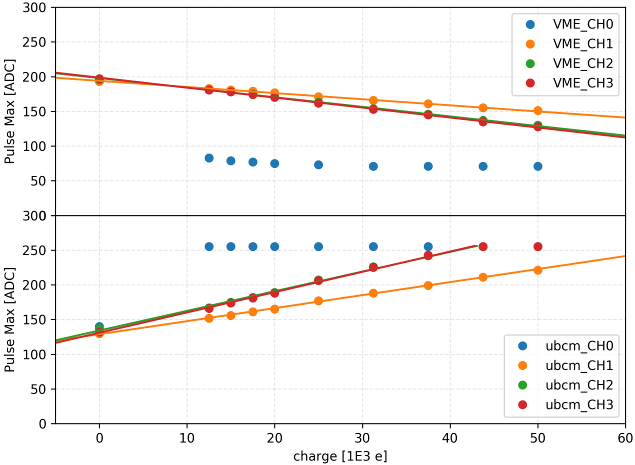
Exemplary pulse height spectrum [4]



- Pulse heights are in ADC counts

$\Rightarrow$ Need calibration (Relation between ADC values and charge)

Calibration procedure [4]



→ Inject test pulses of well defined charge/voltage

$$\text{charge}[e] = \frac{UC_{\text{cal}}}{e}$$

U: Test pulse voltage,

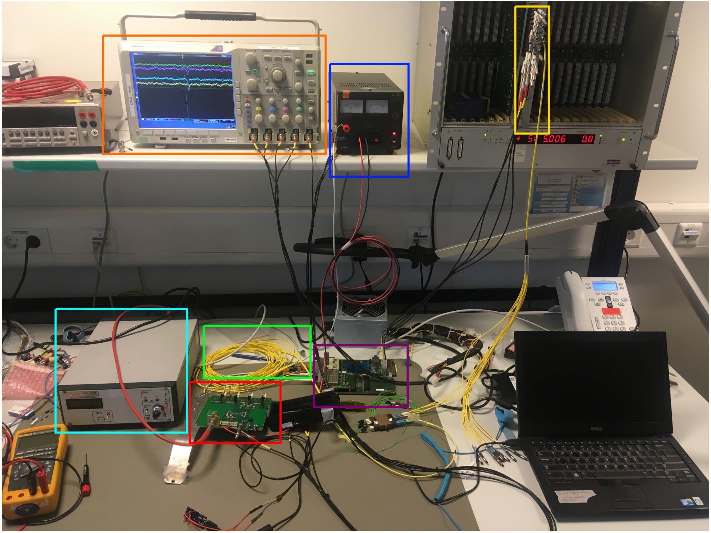
C_{cal}: Internal capacity for calibration

→ Scan through different test pulse heights

- Get calibration factors from linear fits

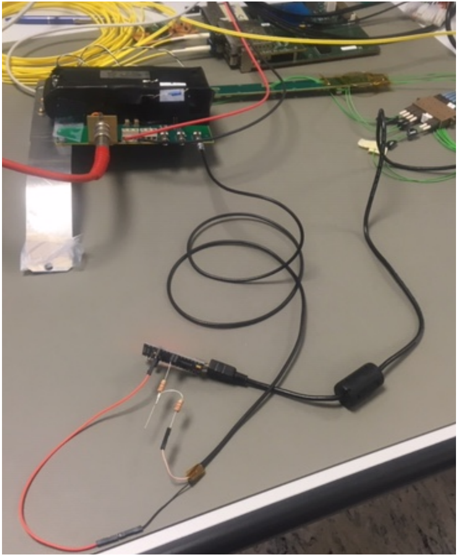
⇒ Cannot obtain a calibration factor for Ch0

Testboard setup in DESY E-Lab



- BCM1F testboard
- HV power supply
- Optical fibres
- Optical receiver
- Oscilloscope

External test pulse



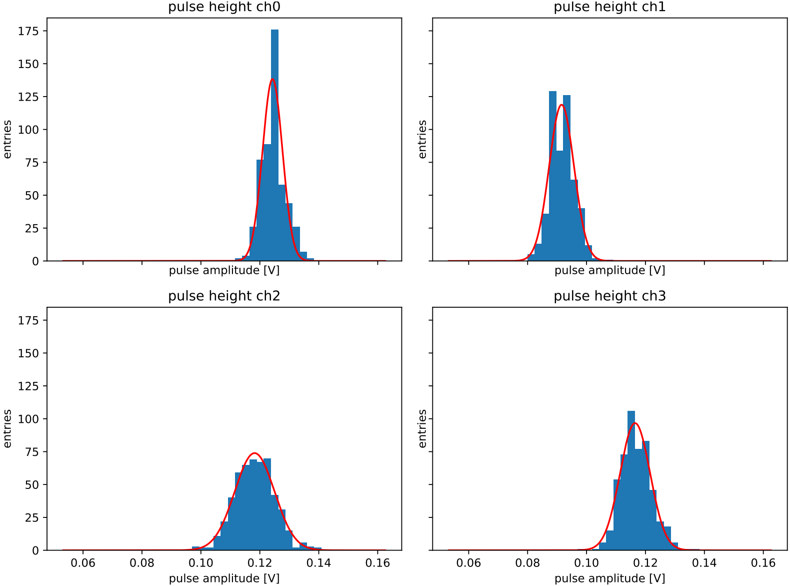
- Use Arduino as pulse generator
  - Rectangular pulse
  - Output voltage: 5 V

- Use voltage devider to lower signal

→ High pulse: 100 mV

→ Low pulse: 50 mV

Pulse height spectra (low pulse, 300V)



Data analysis

- Calibration factor k:

$$\text{charge } C\,[e] = k\,[e/\text{ADC}] \times \text{pulse amplitude } A\,[\text{ADC}]$$

- Individual k for each channel:

$$C = k_0 A_0$$
$$C = k_2 A_2$$

$\Rightarrow k_0 = k_2 \frac{A_2}{A_0}$ (also possible to use Ch3 as reference)

- Assumption: $\left(\frac{A_2}{A_0}\right)_{\text{tb}} = \left(\frac{A_2}{A_0}\right)_{\text{lab}} = \left(\frac{k_0}{k_2}\right)_{\text{tb}}$

Relative pulse heights

- Rescaled calibration factors relative to Ch2:

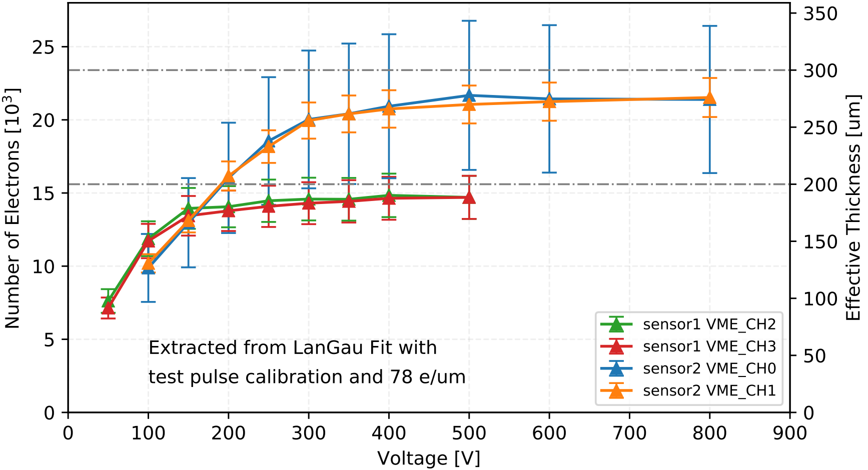
	VME Ch0	VME Ch1	VME Ch2	VME Ch3
testbeam:	none	1.57	1.00	0.96
rescaled:	0.95	1.29	1.00	1.02

- Same values for test beam and rescaling expected
- Use discrepancy in Ch1 for error estimation

$\Rightarrow$ Use rescaled calibration factor k_0

Recovered calibration factor Ch0

- Calibration error estimate: 10 %
- Additional error for Ch0: 20 %
- Fit error from Landau-Gauss-fit



⇒ Results for adjacent diodes are in agreement

Summary/Conclusion

- BCM1F detector design to meet the requirements of Run 3
  - $\rightarrow$ Stand increased particle rates/Luminosity
  - $\rightarrow$ High efficiency/stable operation
- Not possible to calibrate Ch0 in the test beam run
  - $\rightarrow$ ADC counts to charge conversion
- Restoration of k_0 successful
- Error estimation for charge collection results

Summary/Conclusion

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  - → ADC ...
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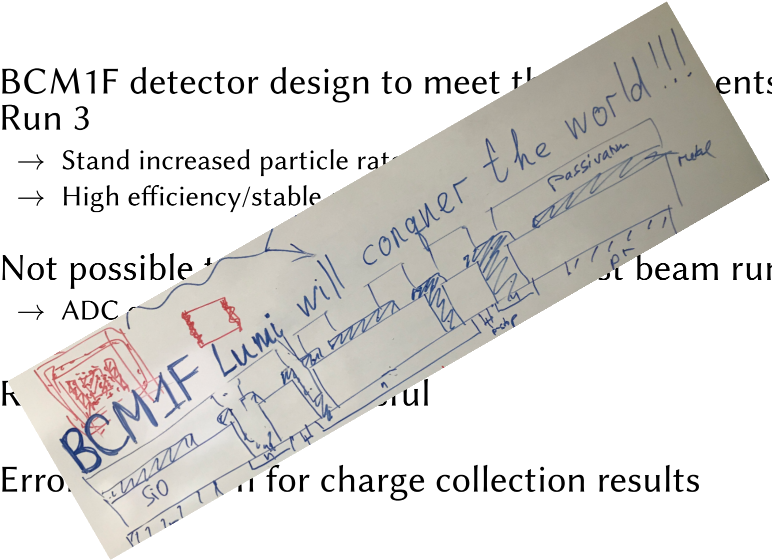
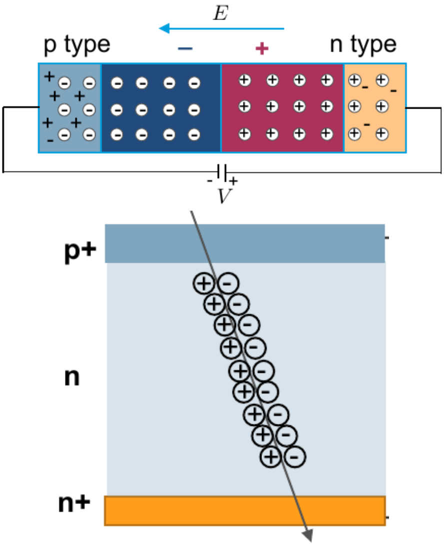


Backup slides

Signal creation in reverse biased Si diodes

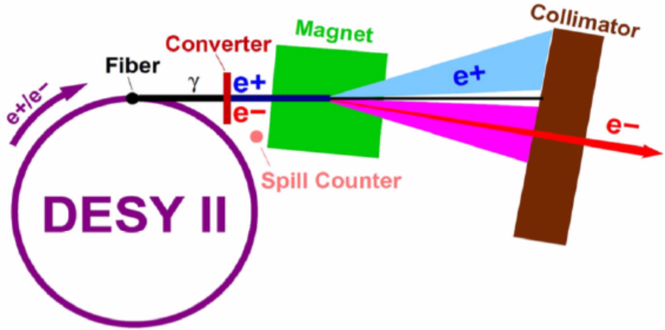


Reverse bias silicon diode [2]

1) Traversing charged particle deposits energy
   - → Creation of electron-hole pairs
   - → In Si: $\approx 78\ \frac{e}{\mu m}$ (MIP)
2) Charges separate in electrical field
3) Drift towards electrodes
4) Charge collection
5) Signal amplification
6) Signal transmission

Test beam area

- Investigate detector performance, validate Run 3 design
- Testbeam line 24



Sketch of the DESY II testbeam facility [3]

Used parameters:

- Energy: 5.4 GeV
- Rate: 80 Hz $\Rightarrow$ Rather low rate for the sake of higher energy

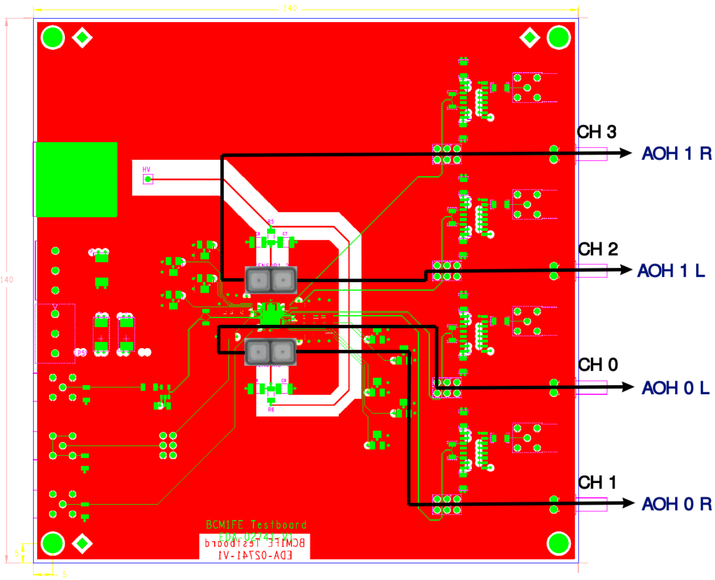
AOH configuration parameters

	E-Lab	Testbeam
Gain:	3	3
Bias:	30	?
HV [V]:	300 (0,50)	300

- Lasers on AOHs have largest uncertainty

$\rightarrow$ Channel to AOH mapping same as in the test beam!

Channel to AOH mapping



Recovered calibration factor Ch0

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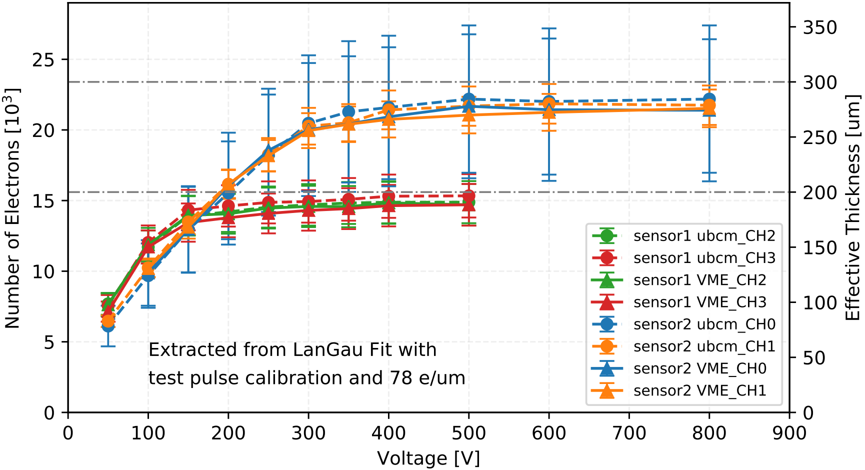
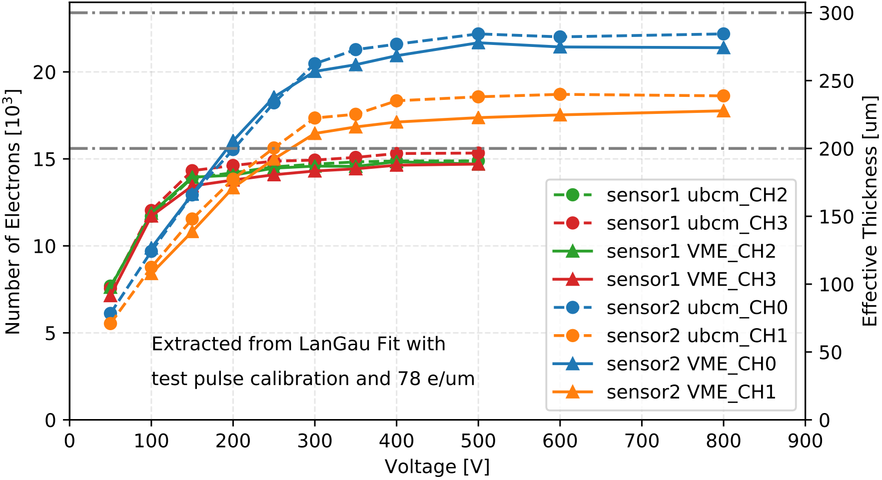


⇒ Results for adjacent diodes are in agreement

Recovered calibration factor Ch0, Ch1



⇒ Results for adjacent diodes are not in agreement

⇒ Estimate error of the rescaling method

References

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