Charge Collection Studies for HV-MAPS

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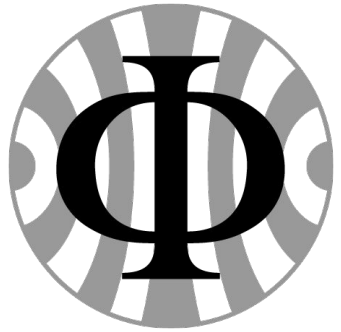
Ruben Kolb

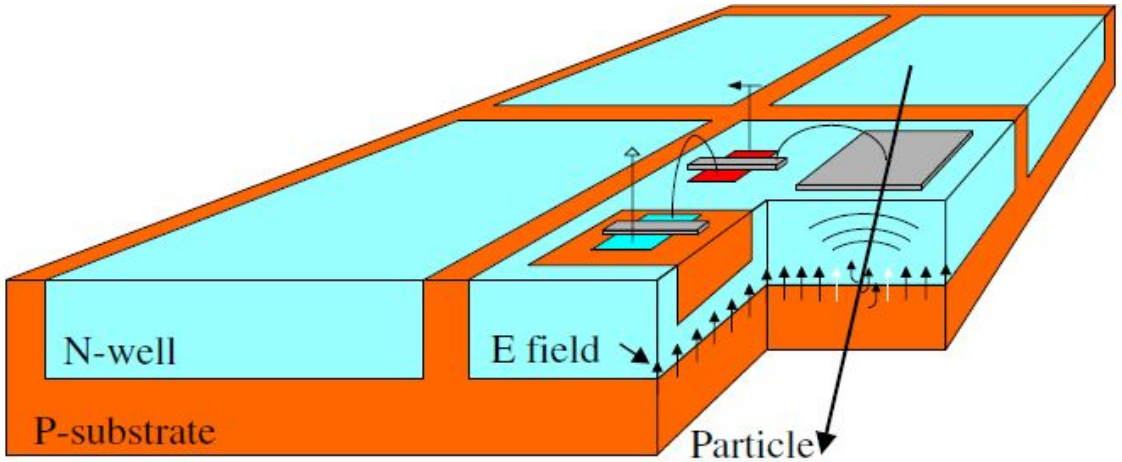
On Behalf of the HD HV-MAPS Collaboration

Physikalisches Institut Heidelberg



High Voltage - Monolithic Active Pixel Sensors (HV-MAPS)

- Monolithic: Readout and active volume on same chip



[I.Peric, P. Fischer et al., NIM A 582 (2007) 876]

Characteristics:

- Diode realised as deep n-well in p-substrate reversly biased up to -140 V

→ $w \propto \sqrt{\rho U}$

- Fast charge collection via drift in depleted volume

Charge Deposition and Collection in HV-MAPS

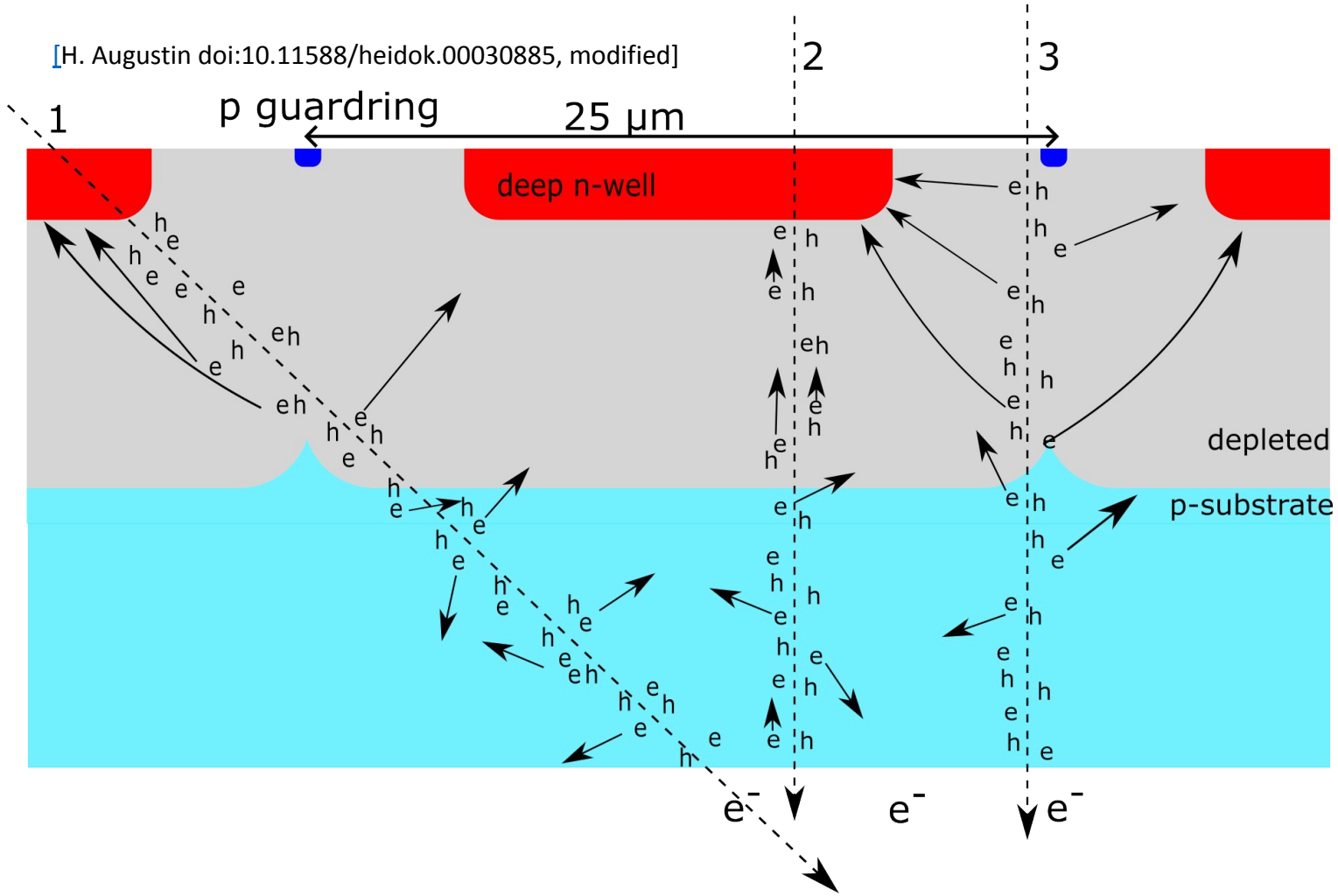
- Fast charge in depleted volume collected via drift
- Diffusion in non depleted volume

Time [ns]	Gaussian spread σ [µm]
500	62 ± 2.4
750	75 ± 3
1000	87 ± 3

→How large is the contribution from diffusion?

→Main observables: ToT, cluster size

[H. Augustin doi:10.11588/heidok.00030885, modified]



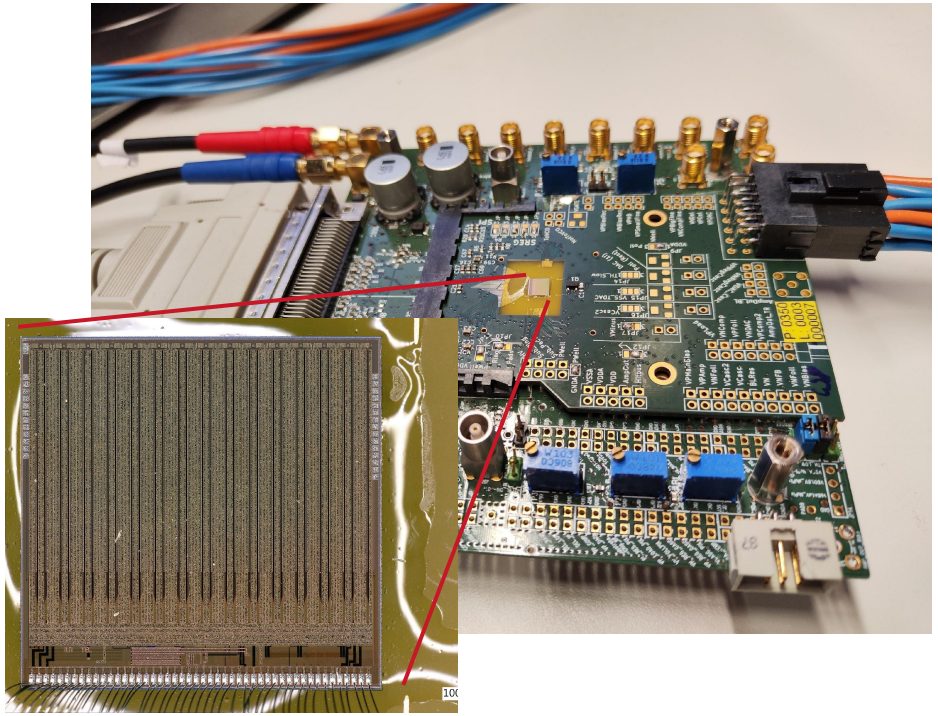
Fick's law: $\frac{dQ}{dx}(\vec{x},t) = \frac{1}{8(\pi D t)^{\frac{3}{2}}} \int Q_0(\vec{x}) e^{-\frac{(\vec{x}-\vec{x}')^2}{4Dt}} d\vec{x} \rightarrow \sigma = \sqrt{2Dt}$

TelePix1 (Run2021 V2)

- Small scale (5×5 mm²) R&D sensor
- In-pixel electronics contain amplifier and CMOS comparator
- Measurement Idea:

Compare observables at same HV & configuration for different thicknesses

⟶ Following results focus on:
d = 50 µm, 100 µm; ρ = 370 Ωcm

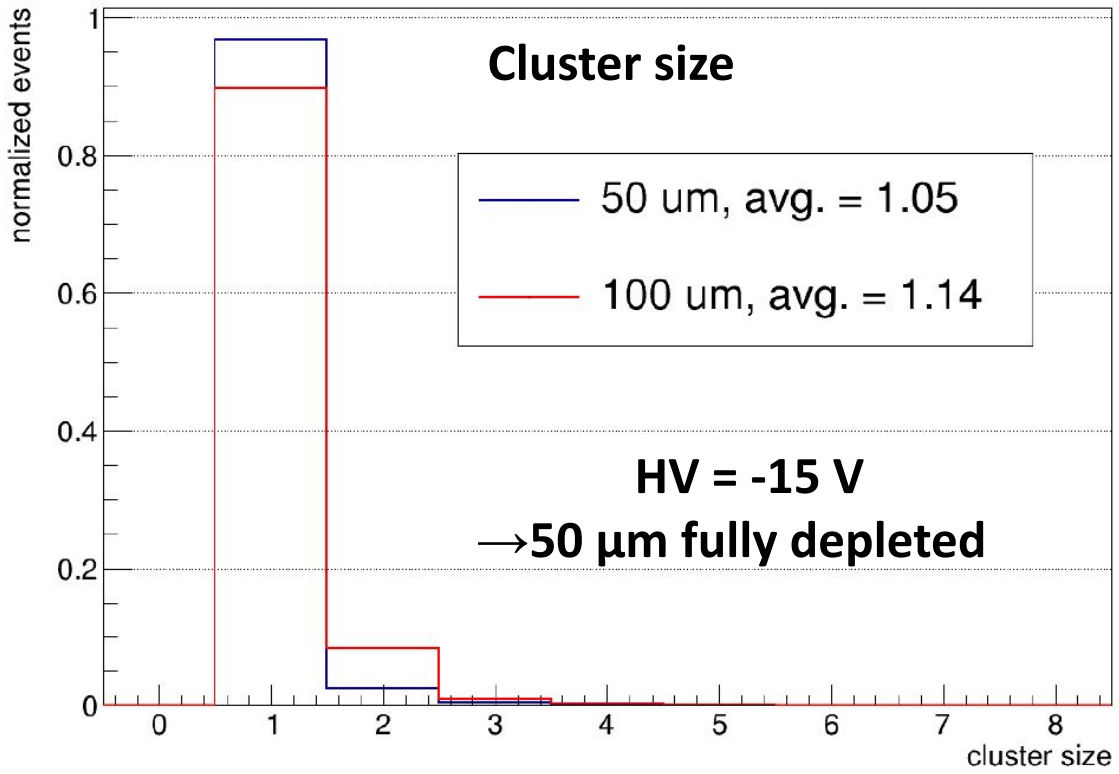


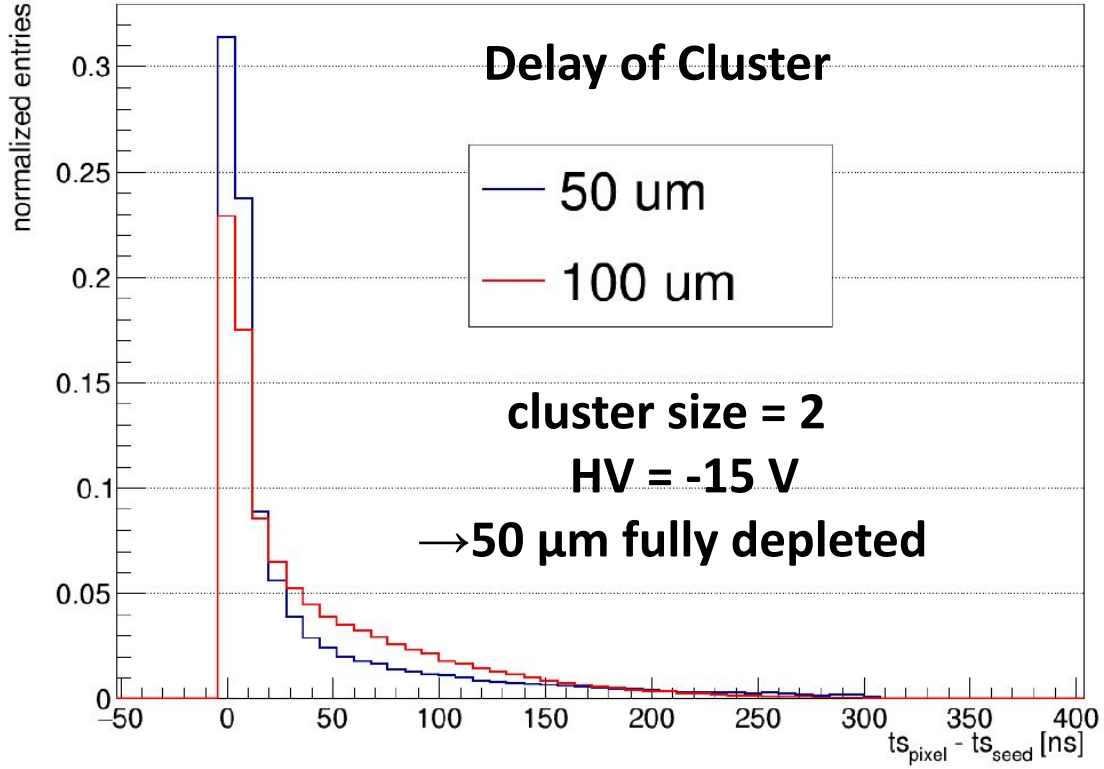
Substrate [Ωcm]	20, **370**, ~8000
Thickness [µm]	**50**, **100**, 300, 600
Matrix [Pixel]	29x124
Pixel size [µm²]	165x25
Sensor size [mm²]	5x5

Cluster Size Study @ DESY

- Higher average cluster size with undepleted material
- Second Pixel in the cluster shows a more pronounced tail towards larger delays

  →Diffusion is a slow process

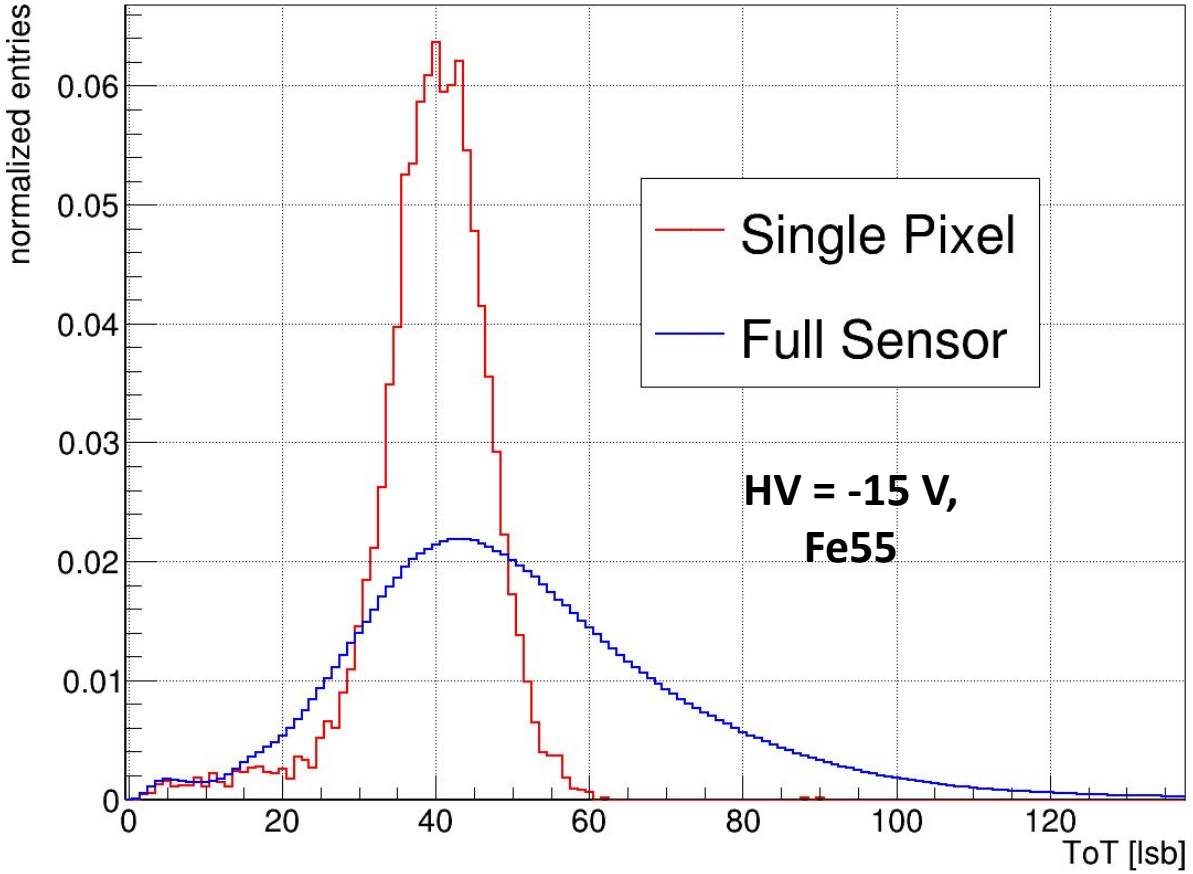




Pixel to Pixel ToT Variations

- Fe55: Monoenergetic x-ray source 5.9 keV → creates ~1634 e-h pairs
  →Similar pixel response expected

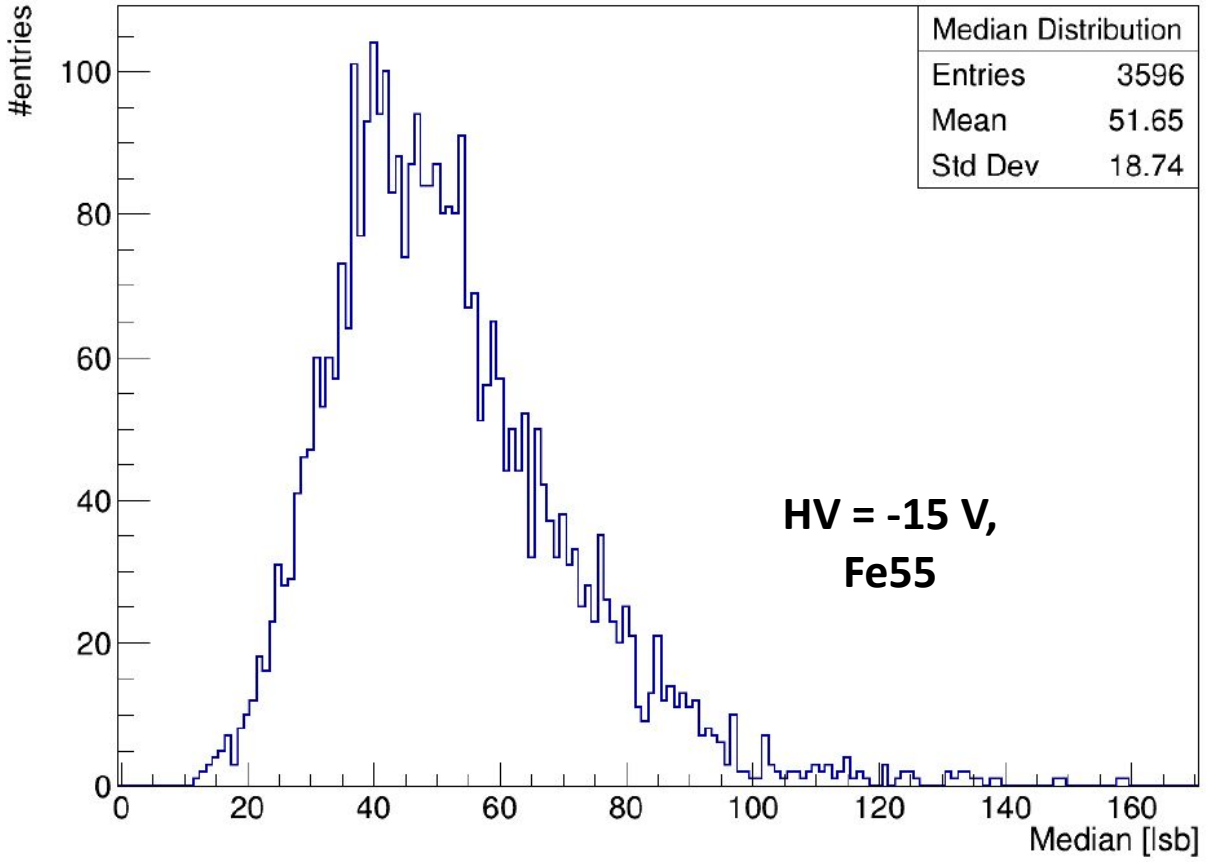
- Full sensor ToT has large FWHM



Pixel to Pixel ToT Variations

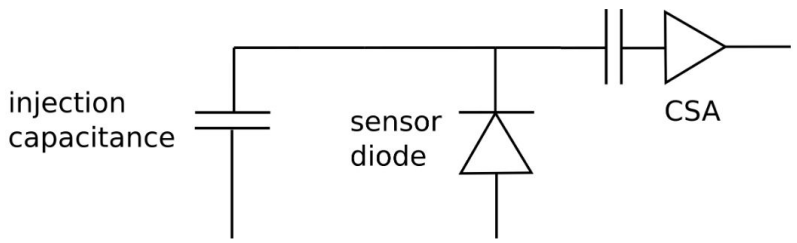
- Fe55: Monoenergetic x-ray source 5.9 keV → creates ~1634 e-h pairs
  →Similar pixel response expected

- Full sensor ToT has large FWHM
- Large variation in pixel median
  ToT for Fe55 source is observed
  →Variation from Chip to Chip
  →Calibration necessary

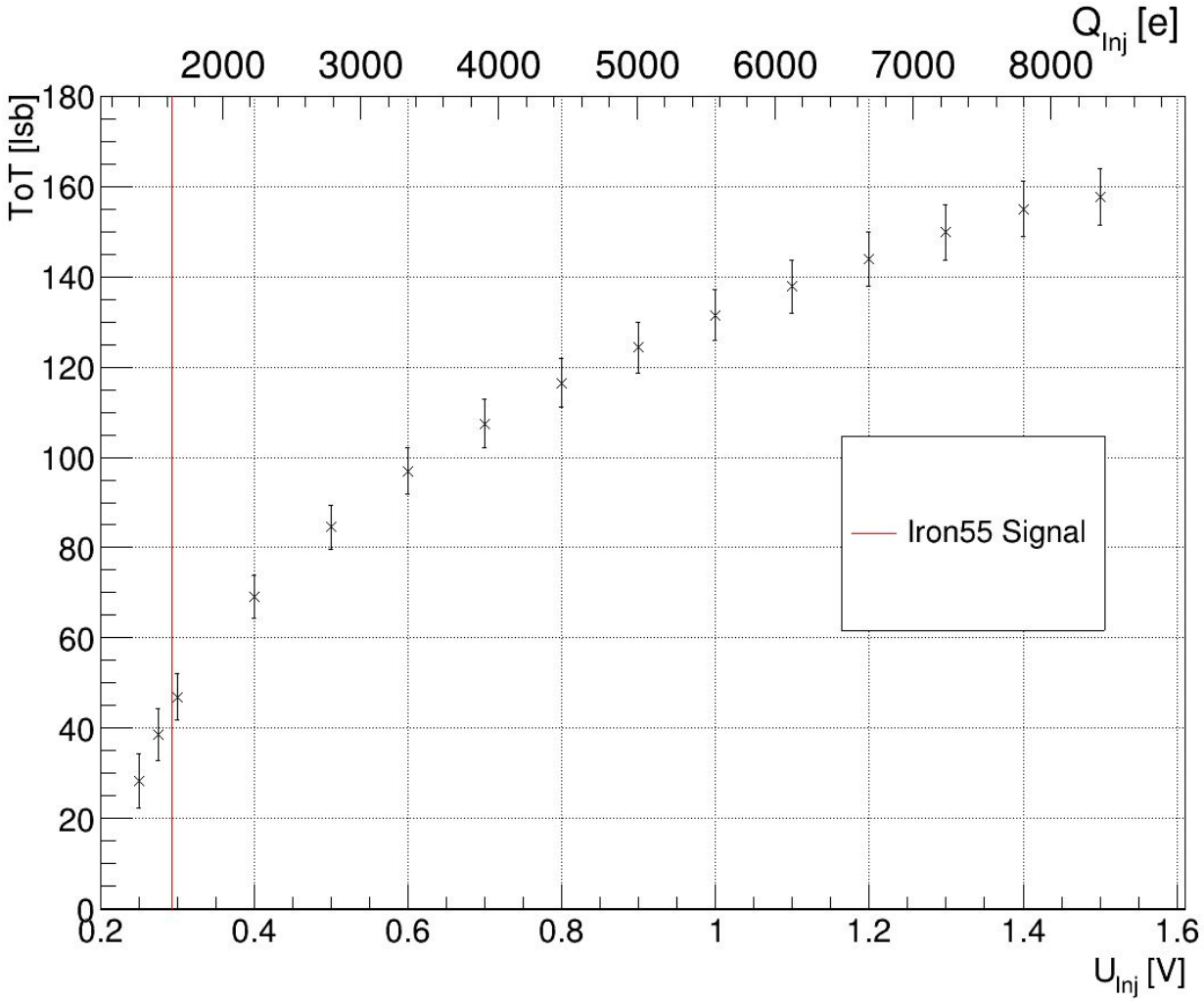


Amplifier Behavior

- Use of injection circuit: $Q_{\mathrm{Inj}} = U_{\mathrm{Inj}} \cdot C_{\mathrm{Inj}}$
  → reliable, artificial signal source



- Injection study conducted with a **single** pixel
  →Logarithmic amplifier response (empirical)
- Non-linear calibration needed



Calibration Method

https://doi.org/10.1088/1748-0221/16/03/P03008

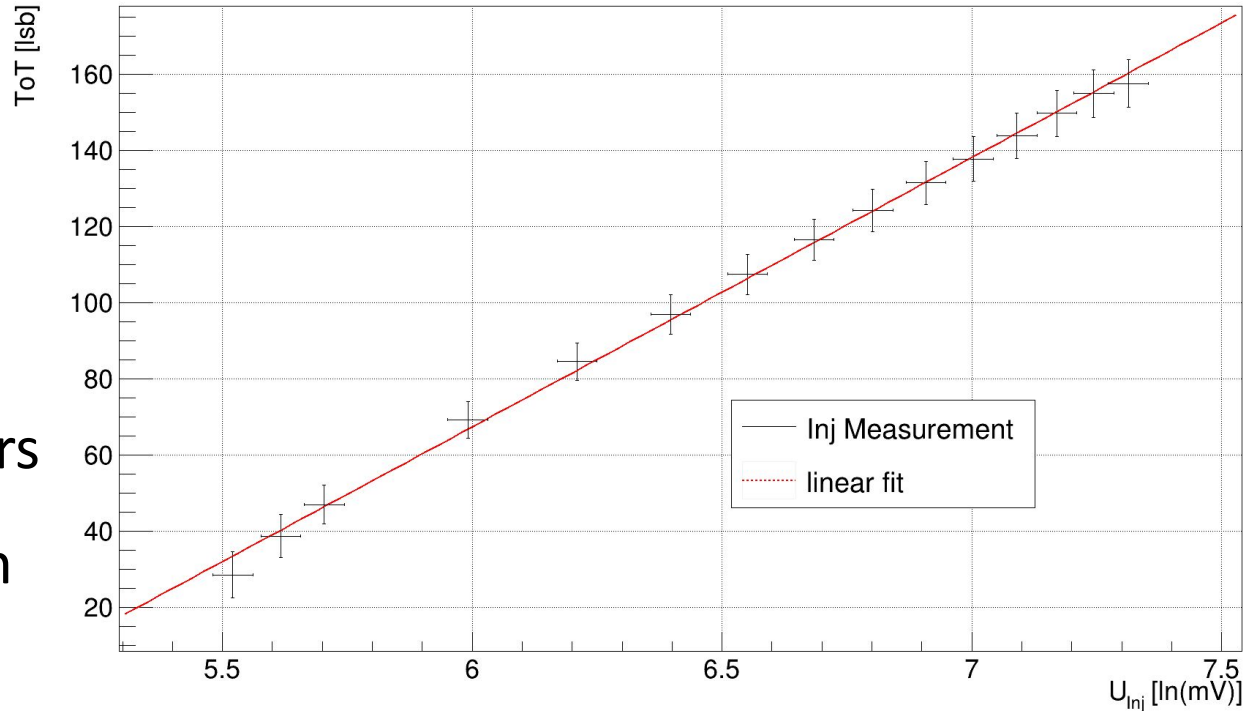
- Calibration in Corryvreckan ⟶ two new modules developed
- Analysis on per pixel level
- Exponential calibration function

$$C = 1634e^{-} * \exp(a * (ToT - ToT_{\mathrm{Fe}}))$$

with a: fit gradient , C: collected charge

⟶Achieves electron calibration for sensors

⟶Allows for sensor to sensor comparison

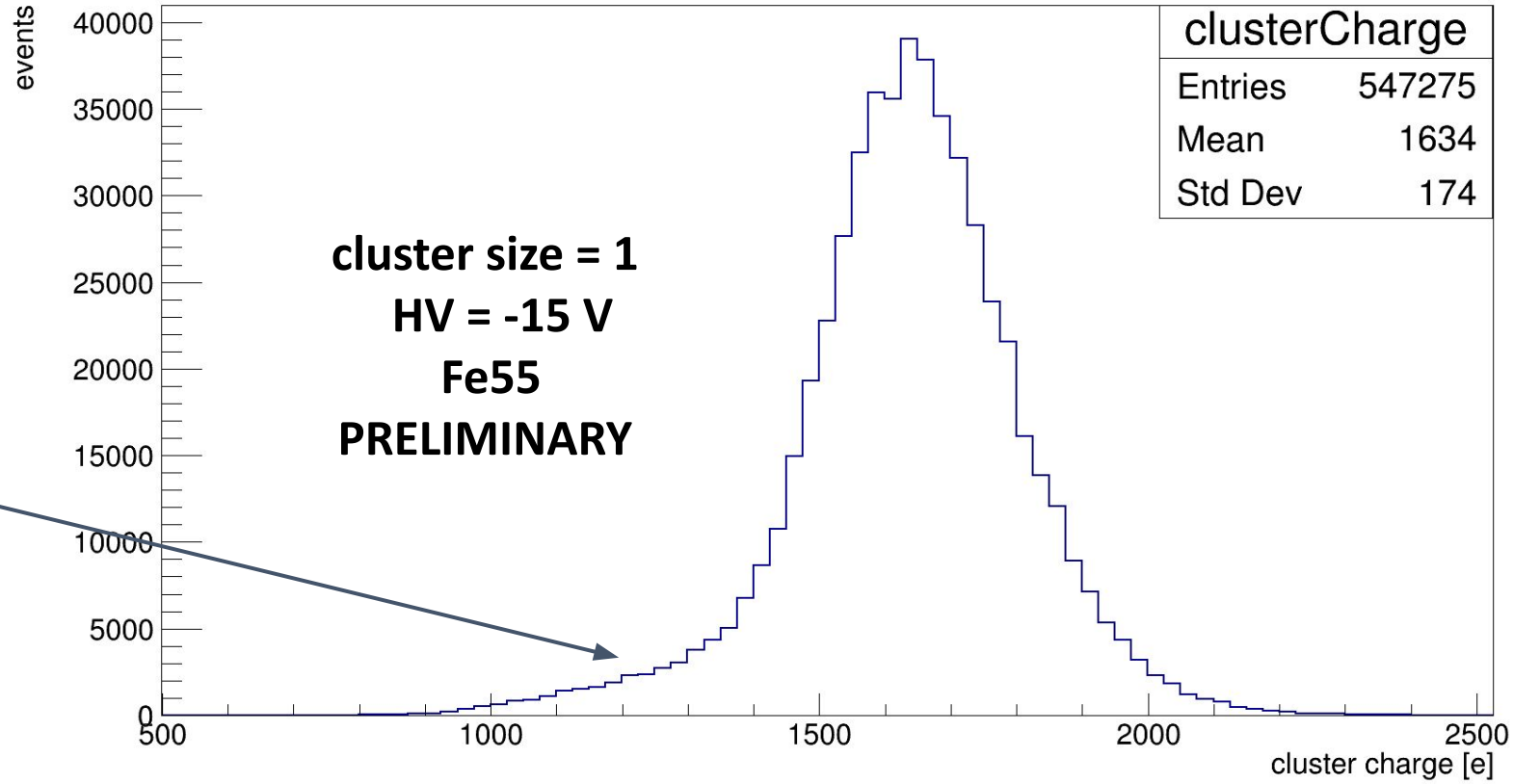


Calibration of Fe55

- Subset of 100 pixels
- Core of the distribution has Gaussian shape and mean 1634 electrons

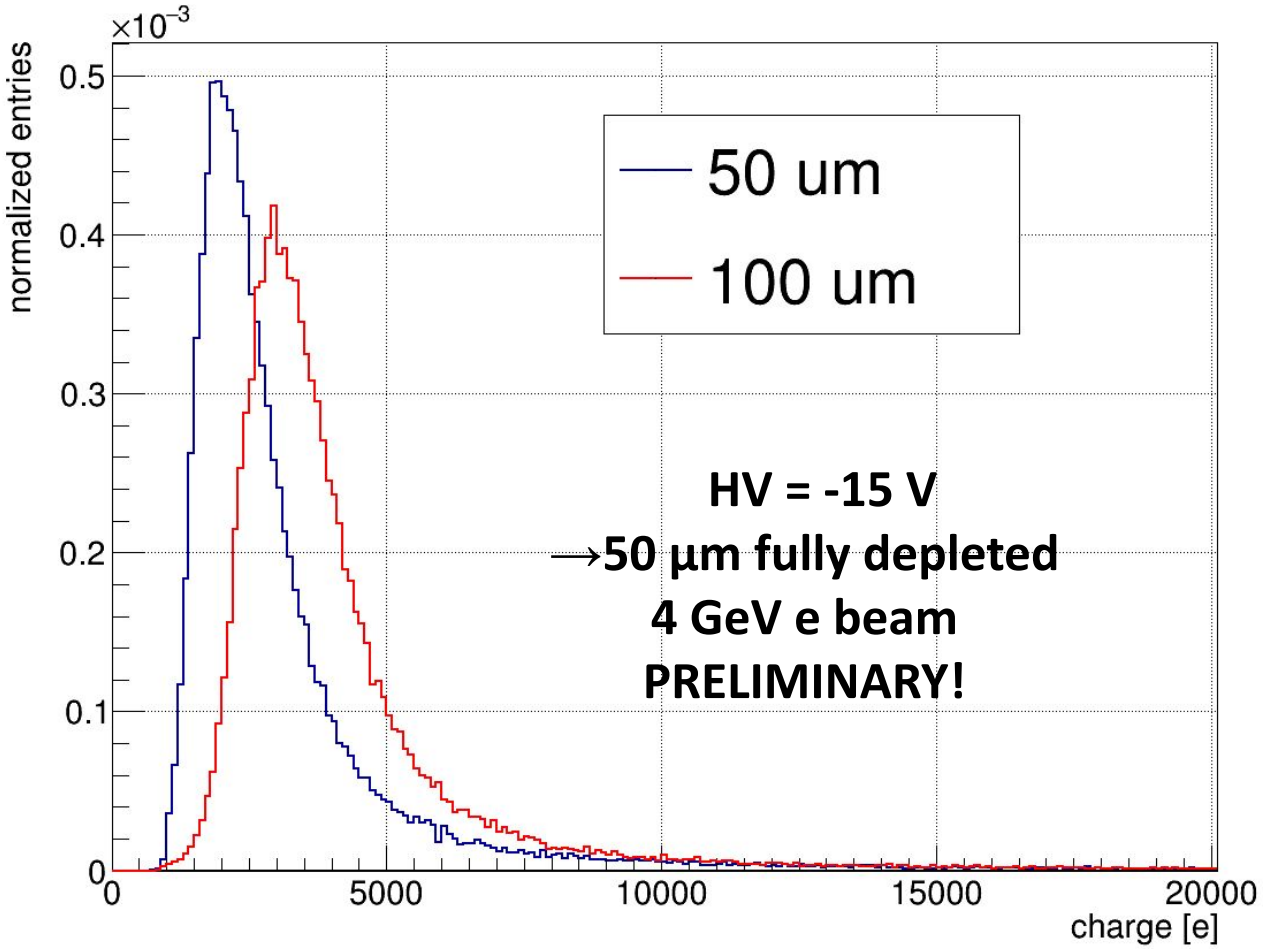
- Tail towards small charge collections

  →charge sharing



Calibrated ToT Studies @ DESY

- Subset of 100 Pixels
- Clear separation of charge spectra
- Mean electron collection:
  3349 e (50 µm) 4259 e (100 um)
- Expectation from Berger-Seltzer for drift only: 3300 e

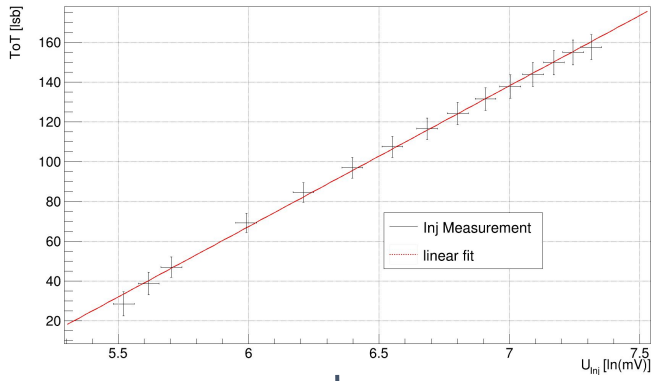


Conclusion & Outlook

Conclusion:

- Larger avg. cluster sizes with undepleted volume & delay of cluster
- ~30% more collected charge in thicker sensor

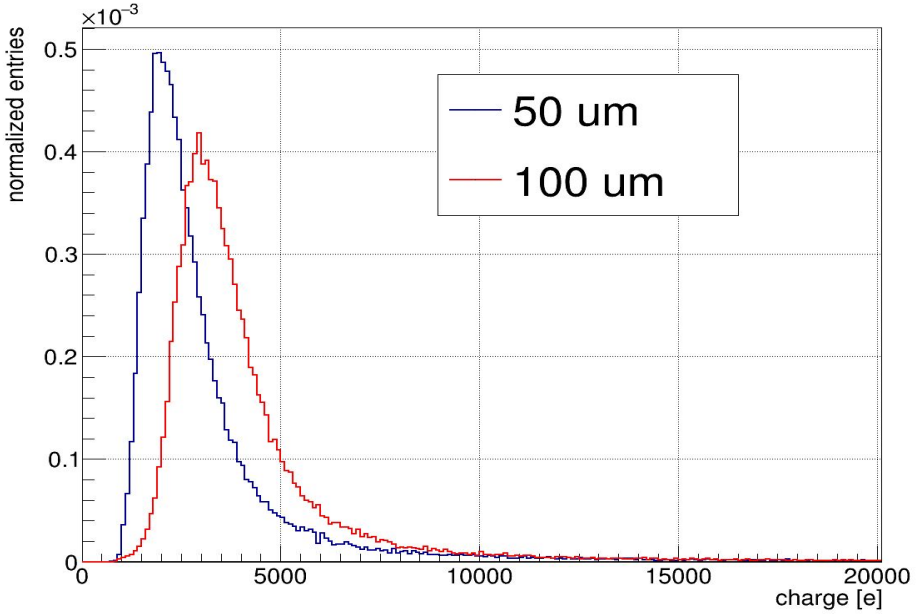
⟶ Significant contribution of diffusion to the signal is observed!



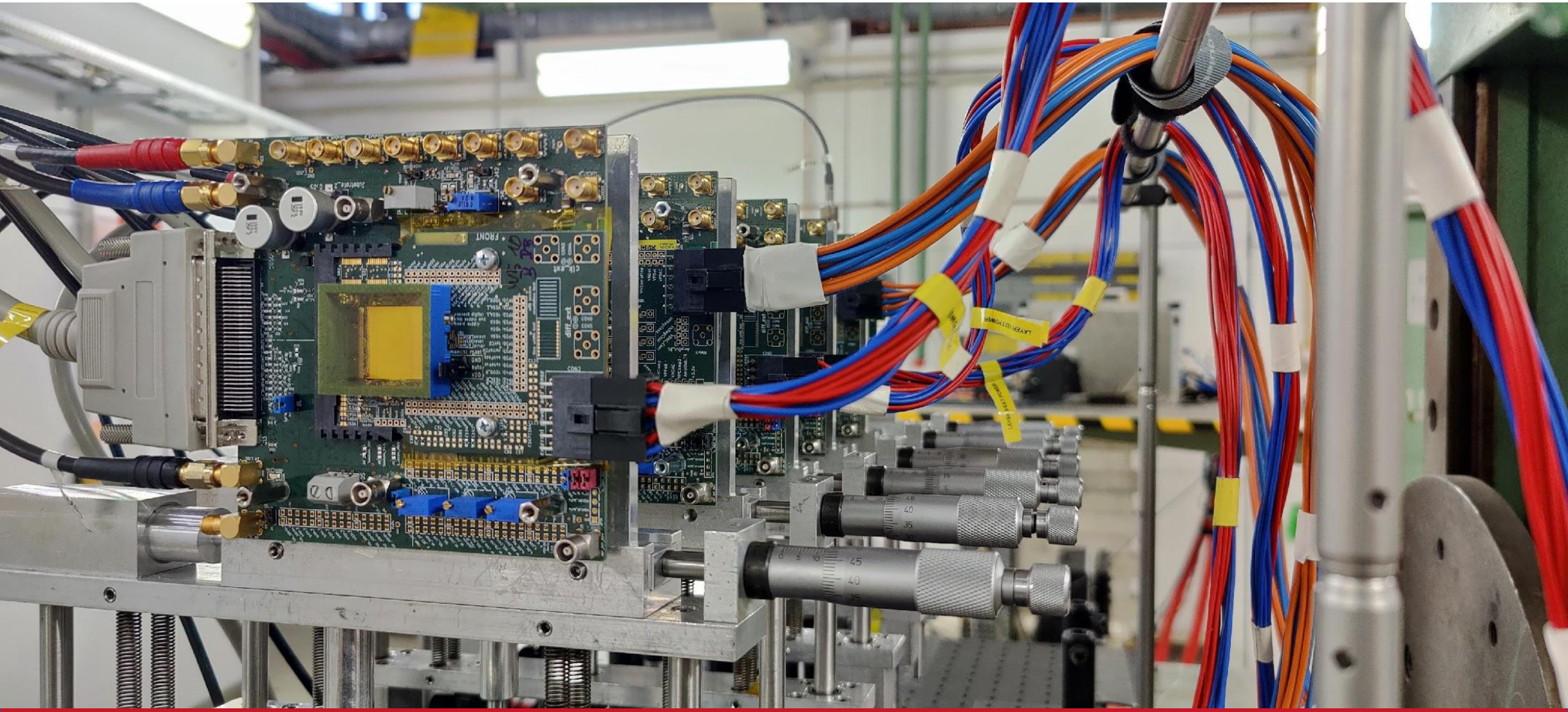
$$1615e^{-} * exp(a * (ToT - ToT_{\mathrm{Fe}}))$$

Outlook:

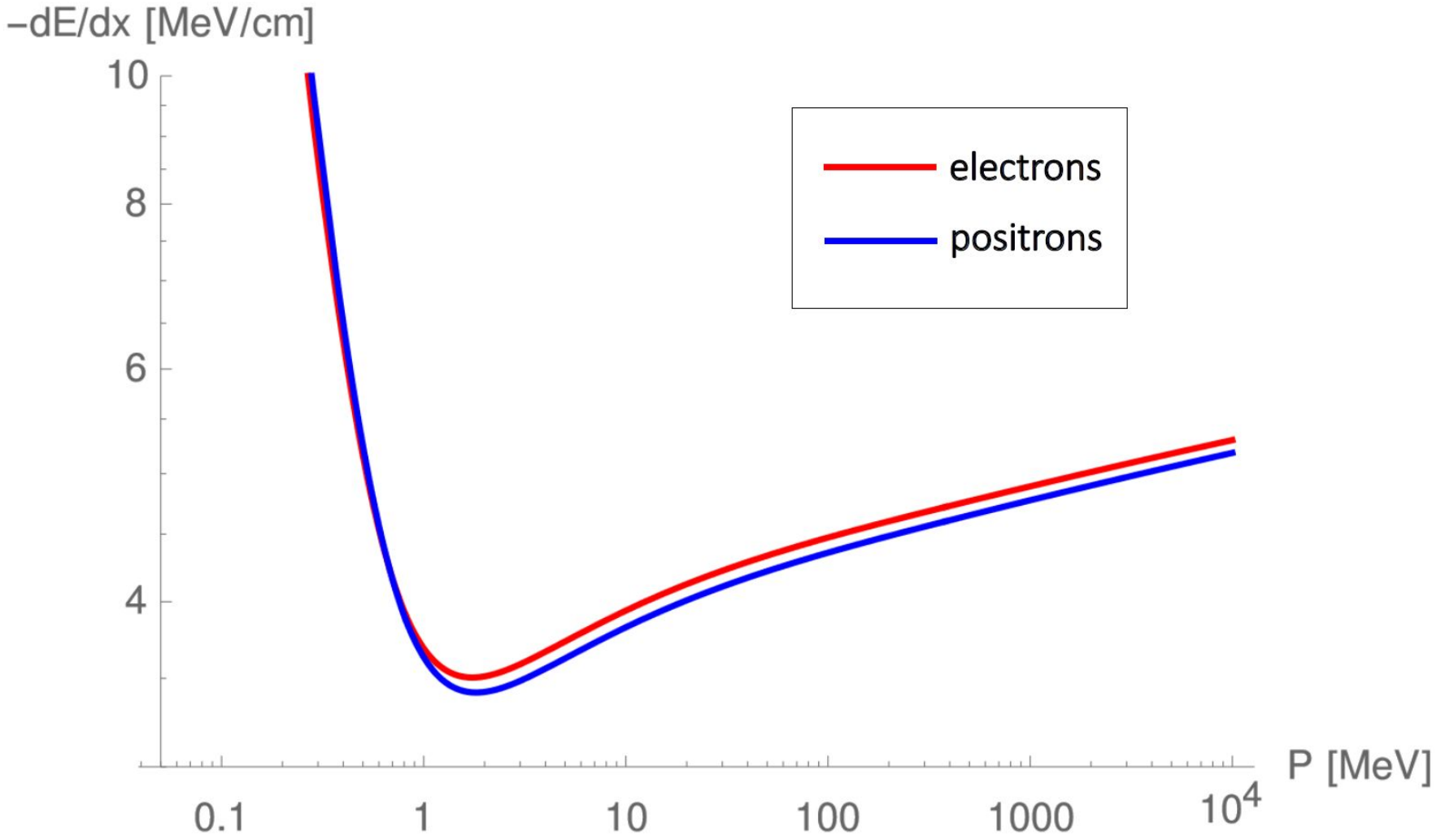
- Calibration for full sensor
- Allpix² Simulation



Questions?

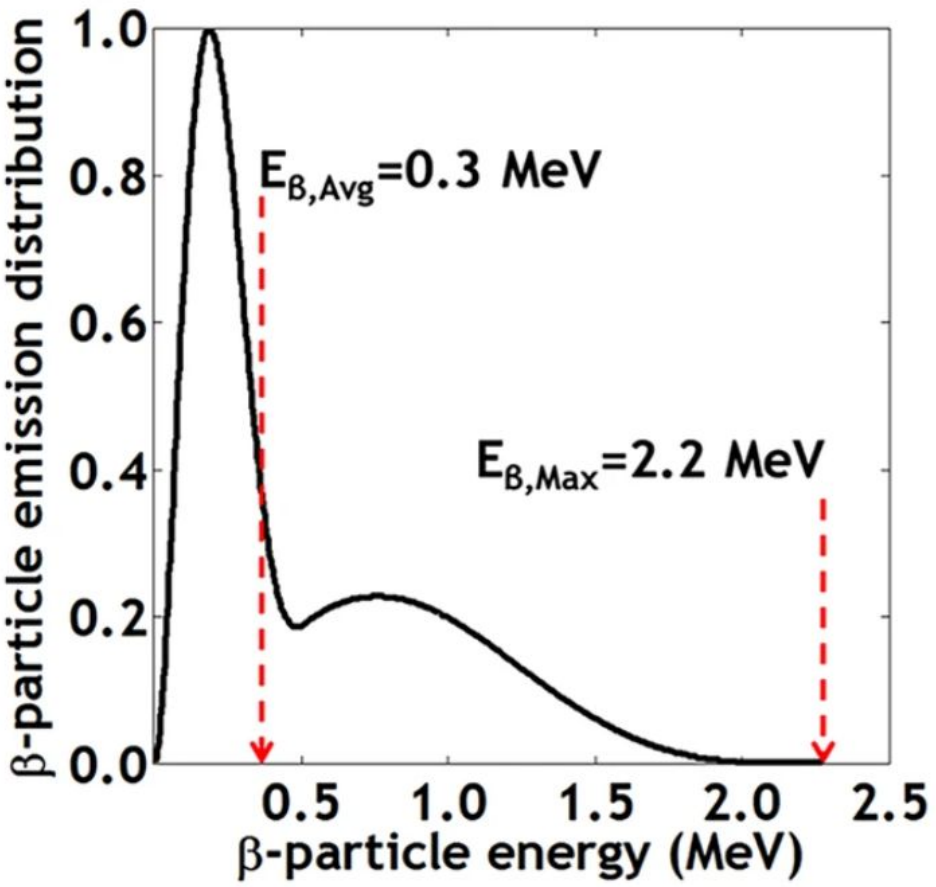


Berger-Seltzer



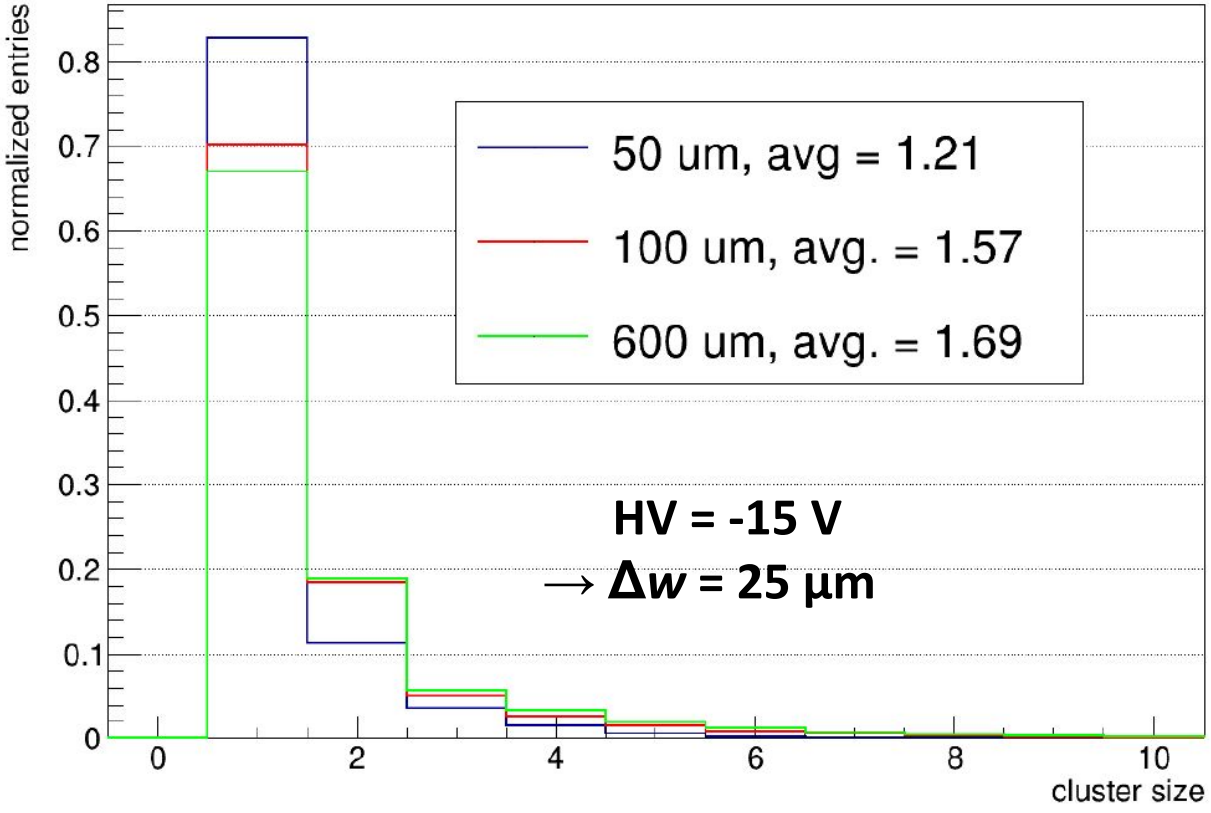
Sr90 calculated spectrum

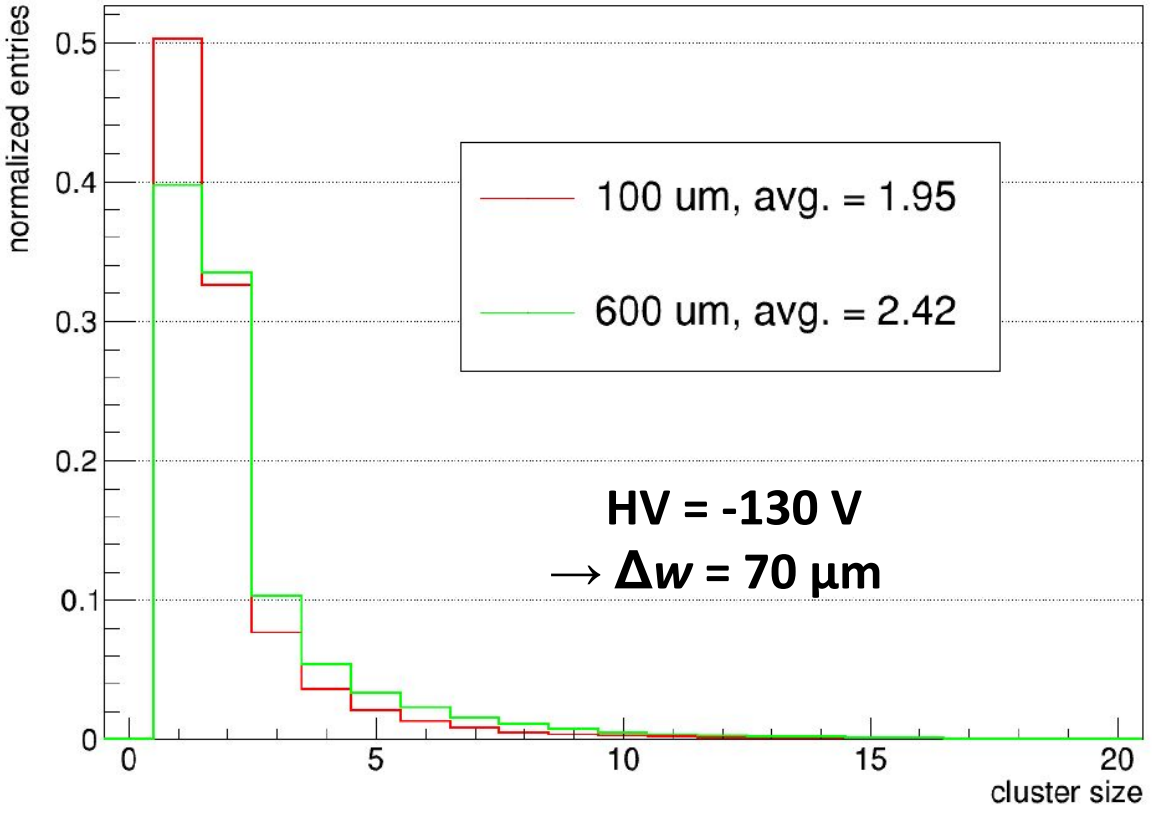
- Low energy electrons do not reach the detector
  → Most probable energy: 0.8 MeV



Cluster size studies Sr90

- Average cluster size increases with thickness
- For large diffusion volumina a constant offset in cluster size is observed

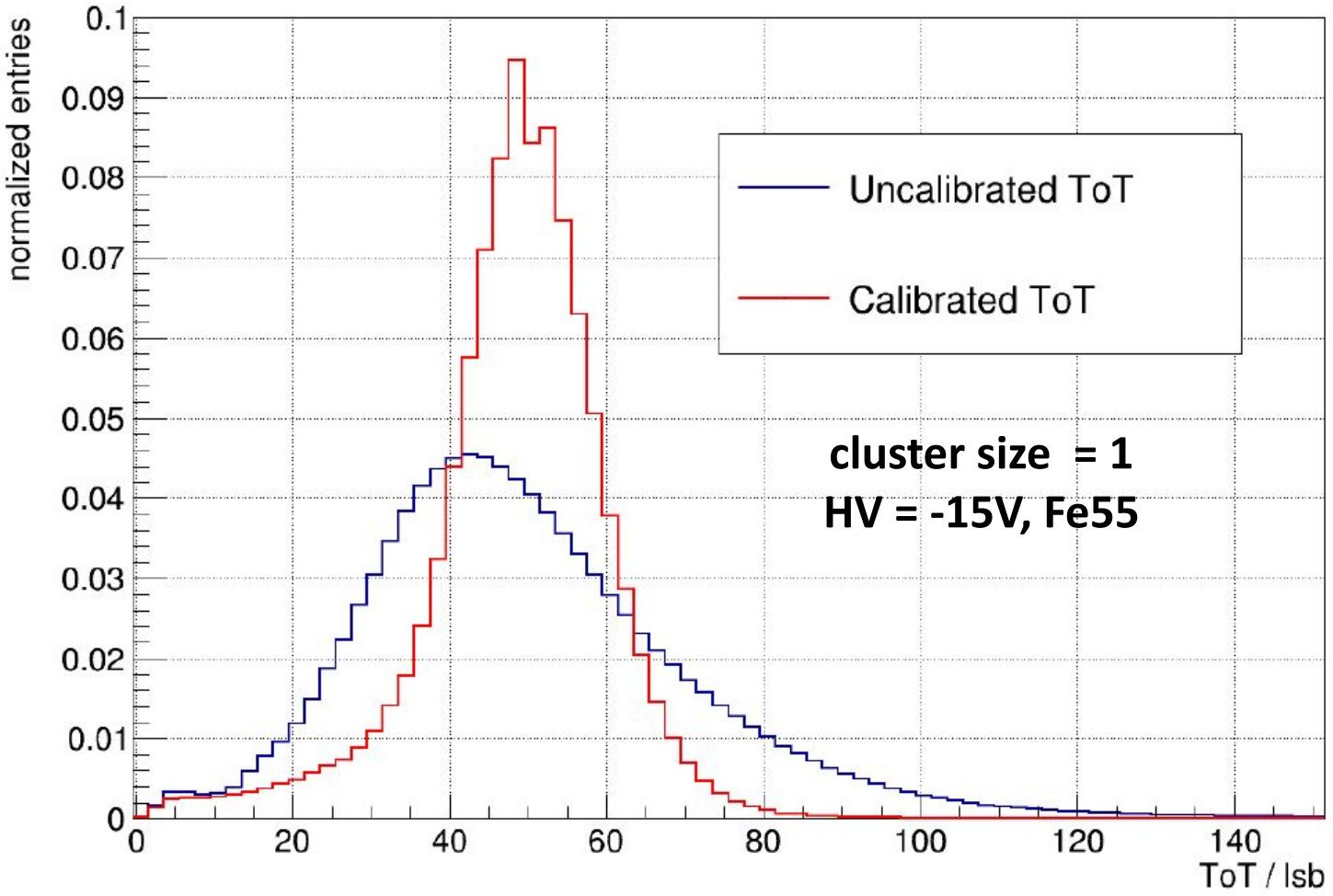




Quality Control of Calibration

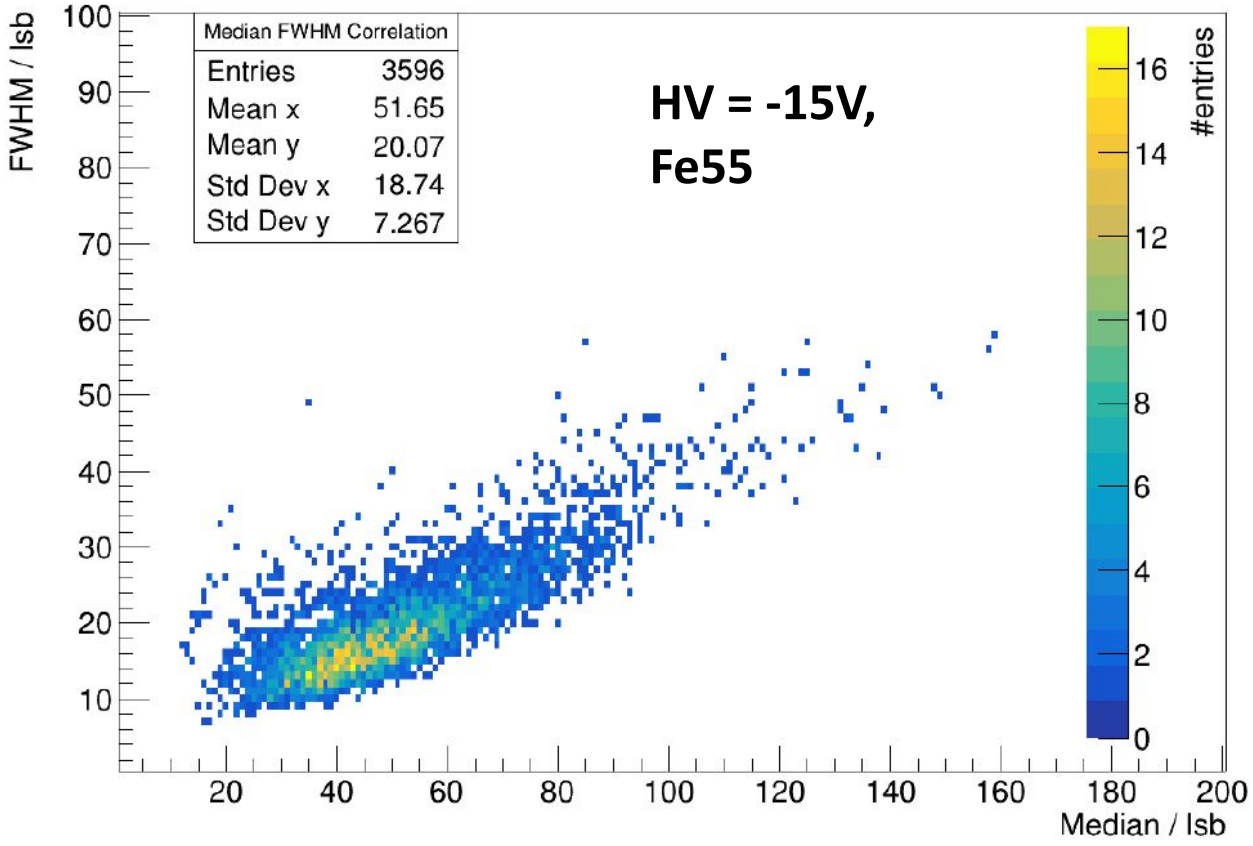
- Calibration achieves significant reduction of FWHM close to single pixel FWHM
- Tail to lower ToT is present

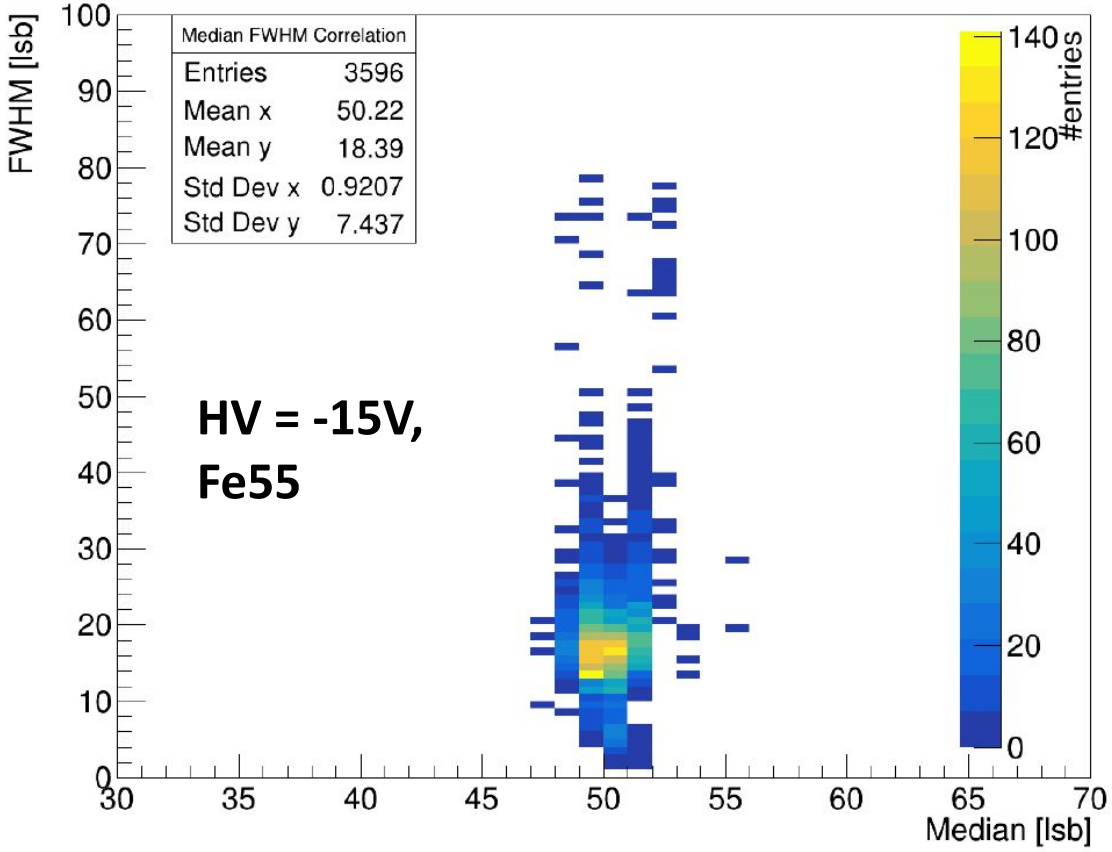
→Charge sharing



Quality Control of Calibration

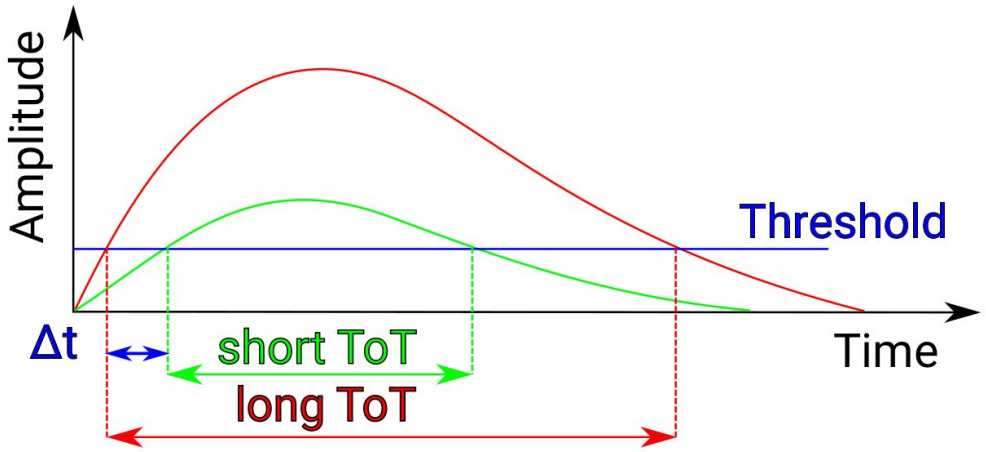
- Correlation between FWHM/Median before and after calibration
- Calibration achieves more uniform Fe55 response





Measurement Setup

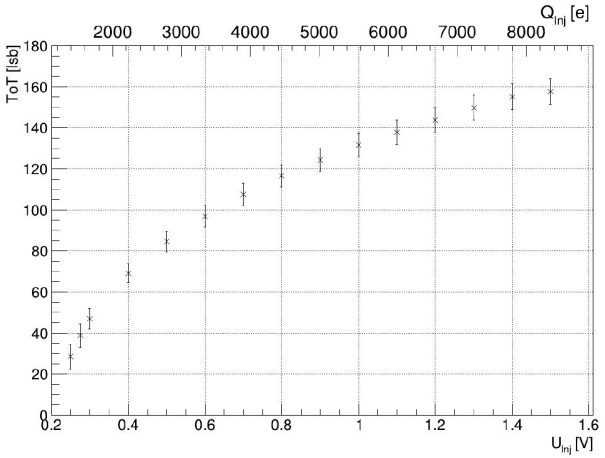
- Study charge collection by varying HV with various signal sources
- Compare **ToT** & Cluster size of DUTs at **same configuration** & **HV**



- $^{90}\mathrm{Sr}$: 2.28 MeV e^- source → continous spectrum
- $^{55}\mathrm{Fe}$: Monochromatic x-ray source 5.9 keV
- Testbeam@DESY: 4 GeV electrons

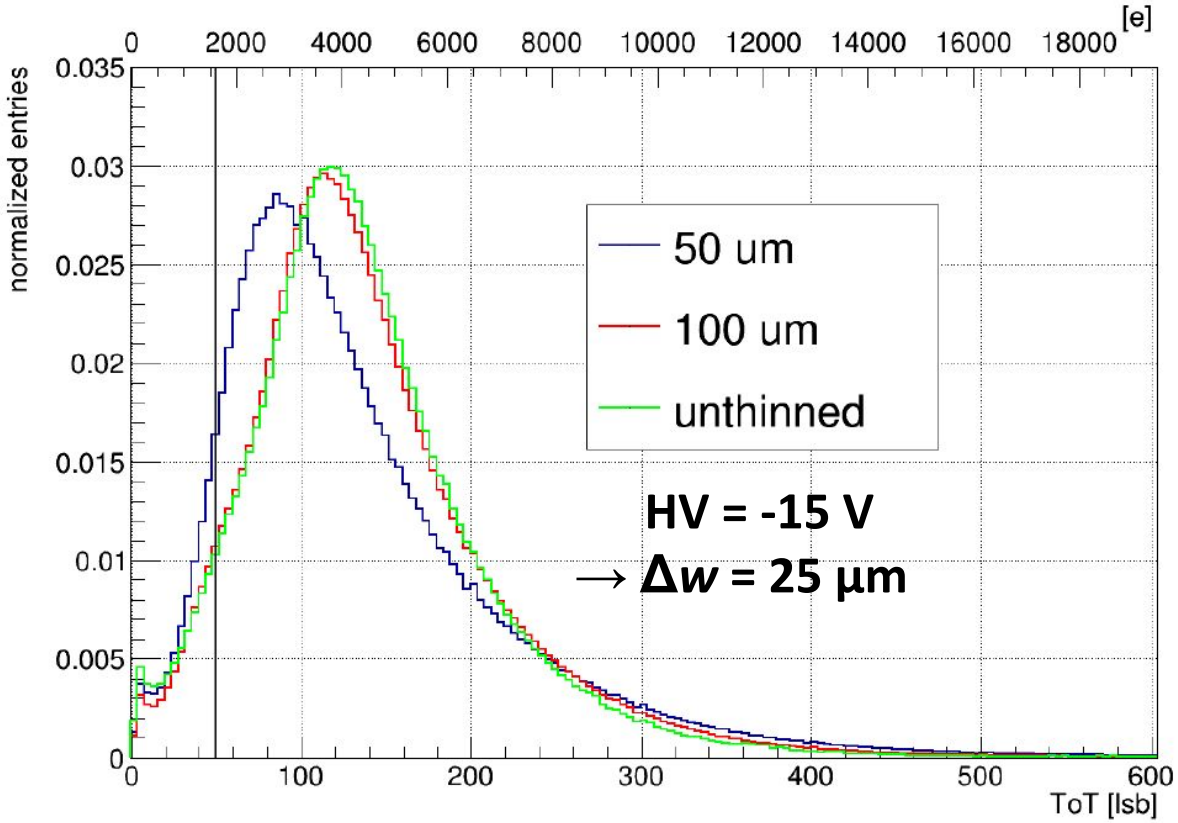
→Following results focus on:
d=50 µm, 100 µm, 600 µm $\rho = 370\ \Omega\mathrm{cm}$

Calibrated ToT studies Sr90



- Sr90: β^- decay ⟶ continuous spectrum up to 2.28 MeV
  ⟶ MPV ~ 0.8 MeV ⟶~2600 e^- from drift

- Both thicker sensors have larger ToT
  ⟶significantly more charge collection



only estimated!

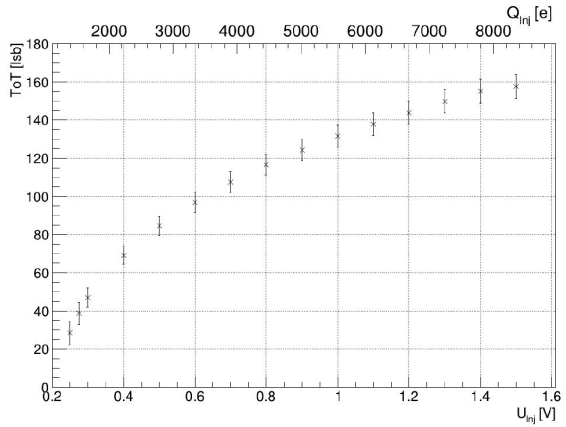
Chip Thickness	e^- from drift	e^- (^{55}Fe Calibration)	e^- (Injection Gauging)
50 µm	2600	2750	2750
100 µm	2600	3650	4300
unthinned	2600	3750	4450

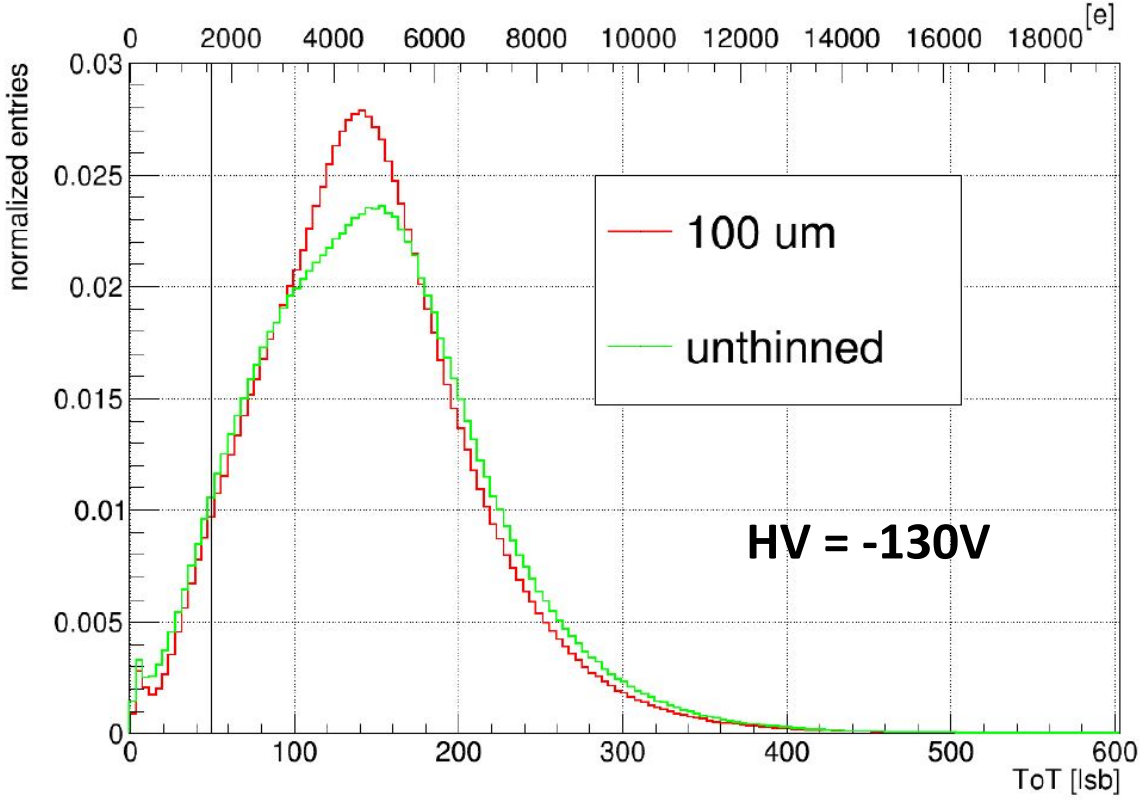
Calibrated ToT studies Sr90

- Large shoulder for unthinned sensor
- Huge amount of charge collected

  →Linear Calibration not applicable
- Injection Calibration problematic as well

→Higher energetic x-ray sources needed





Preliminary!

Chip Thickness	e⁻ from drift	e⁻ (^{55}Fe Calibration)	e⁻ (Injection Gauging)
100 µm	6700	3900	6400
unthinned	6700	4800	-