Charge Collection in HV-MAPS

Bundesministerium
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BTTB 12
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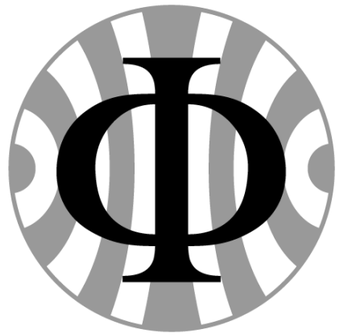
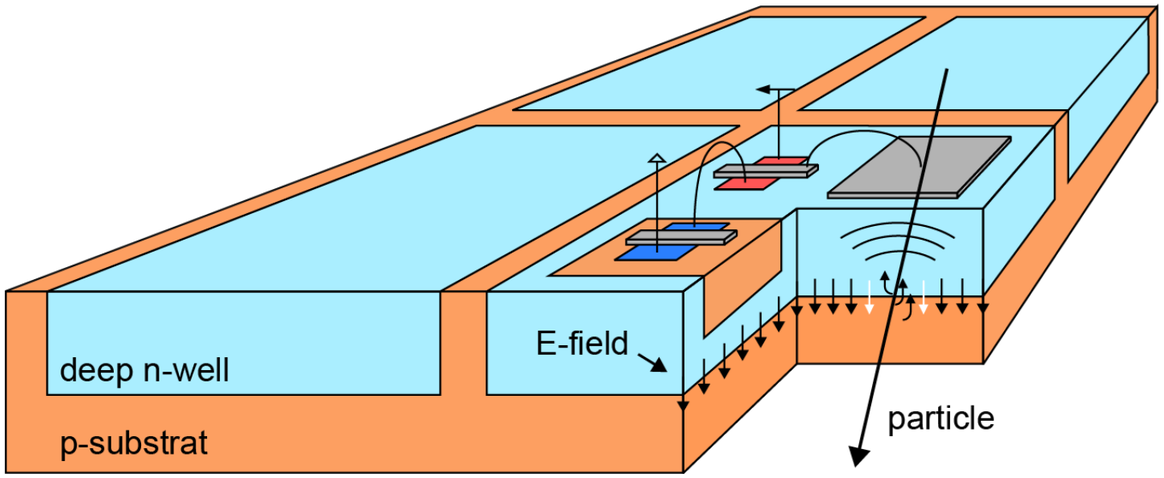


High Voltage - Monolithic Active Pixel Sensors (HV-MAPS)

Monolithic: Readout and active volume on same chip



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

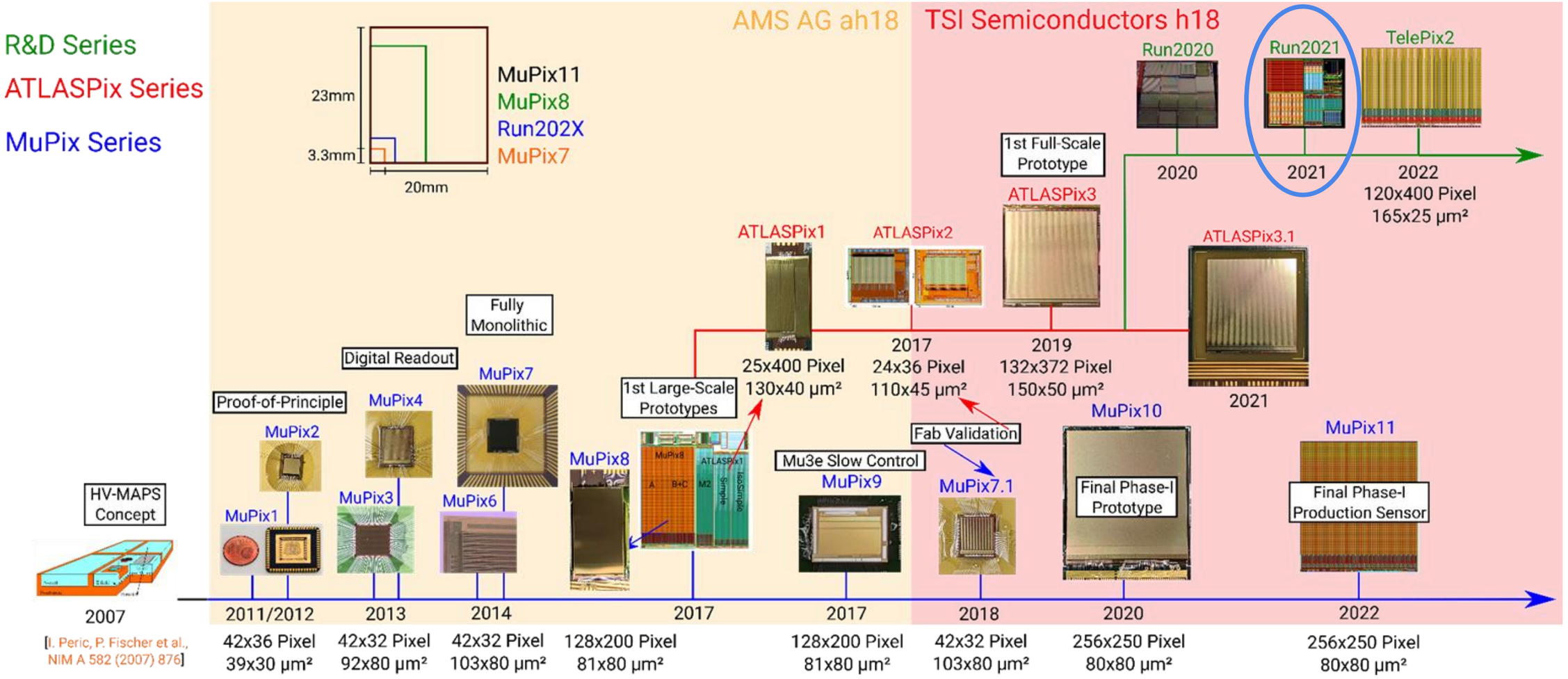
Characteristics:

- Reverse-biased diode realised as deep n-well in p-substrate

$$\text{Depletion depth} \propto \sqrt{\rho_{\text{substrate}} \cdot U_{\text{ext}}}$$

- Fast charge collection via drift in depleted volume
- Time over Threshold (ToT) information →charge equivalent

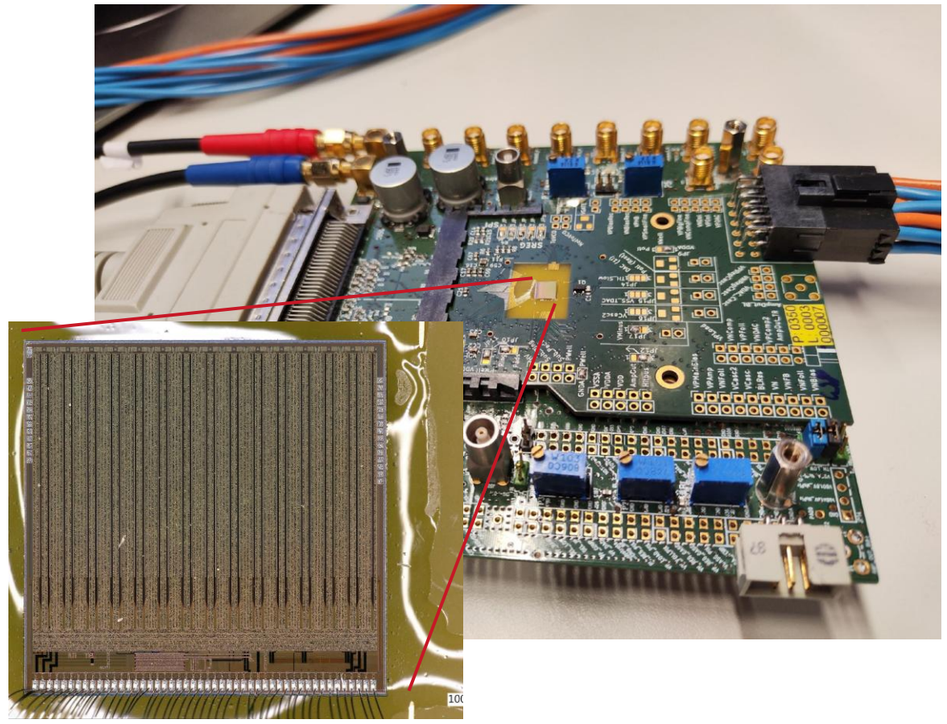
HV-MAPS Roadmap



[D. Immig, Straggling with Ultra-Thin HV-MAPS]

TelePix1 (Run2021 V2)

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



→ Following results focus on:
d = 50 µm, 100 µm, 740 µm; ρ = 370 Ωcm

Substrate [Ωcm]	20, **370** , > 5000
Thickness [µm]	**50**, **100**, 300, **740**
Matrix [Pixel]	29 x 124
Pixel Size [µm²]	165 x 25
Sensor size [mm²]	5 x 5

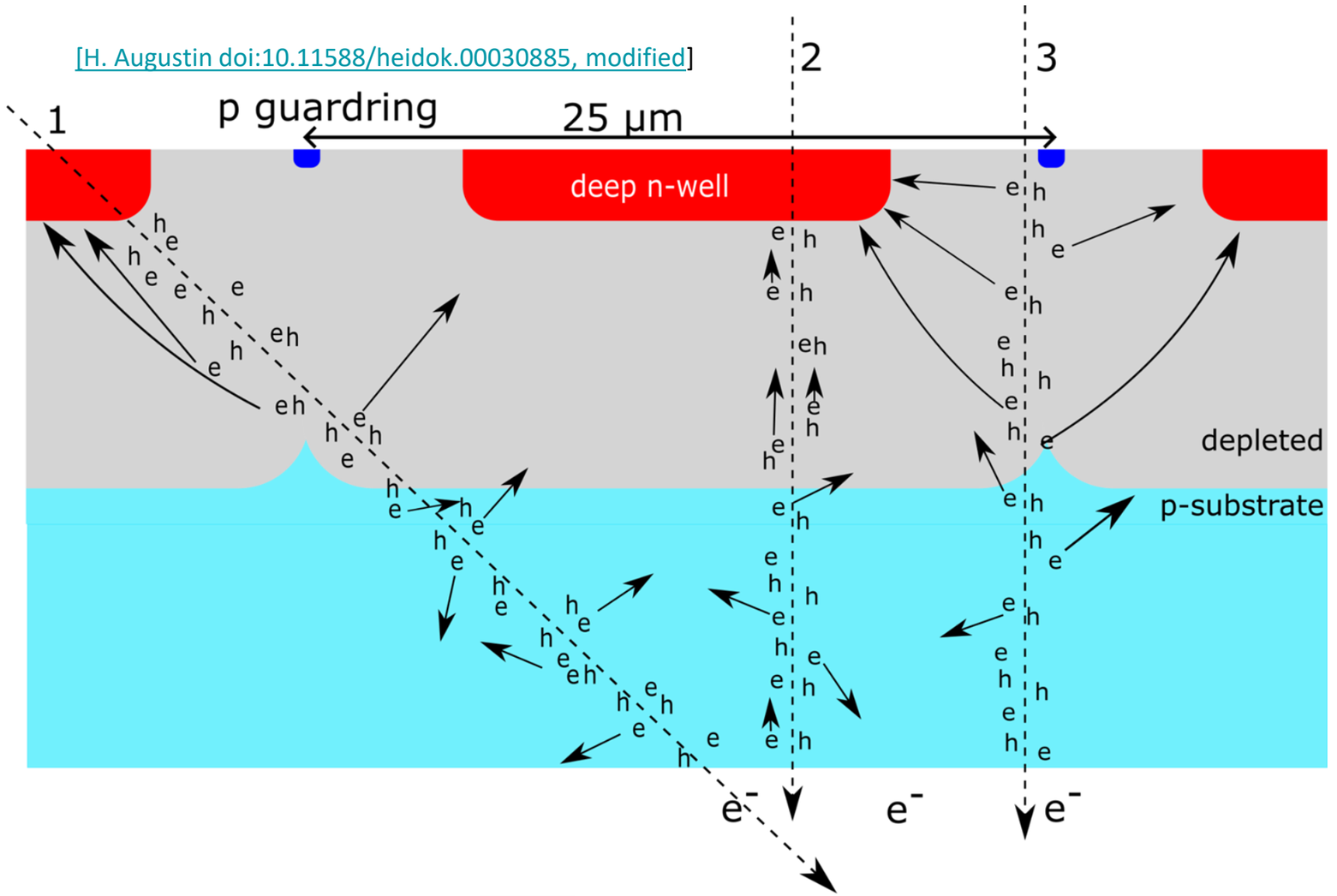
Charge Deposition and Collection in HV-MAPS

- HV applied on top, no back bias
- Fast charge collection ≤ O(ns) in depleted volume via drift
- Diffusion in undepleted volume

Time [ns]	Gaussian spread σ [µm]
500	61.2 ± 2.4
750	75 ± 3
1000	87 ± 3

➔ **How large is the contribution from diffusion?**

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



$$\sigma_{\text{diffusion}} = \sqrt{2Dt}, \quad D = (37.5 \pm 2.9)\,\text{cm}^2\text{s}^{-1}$$

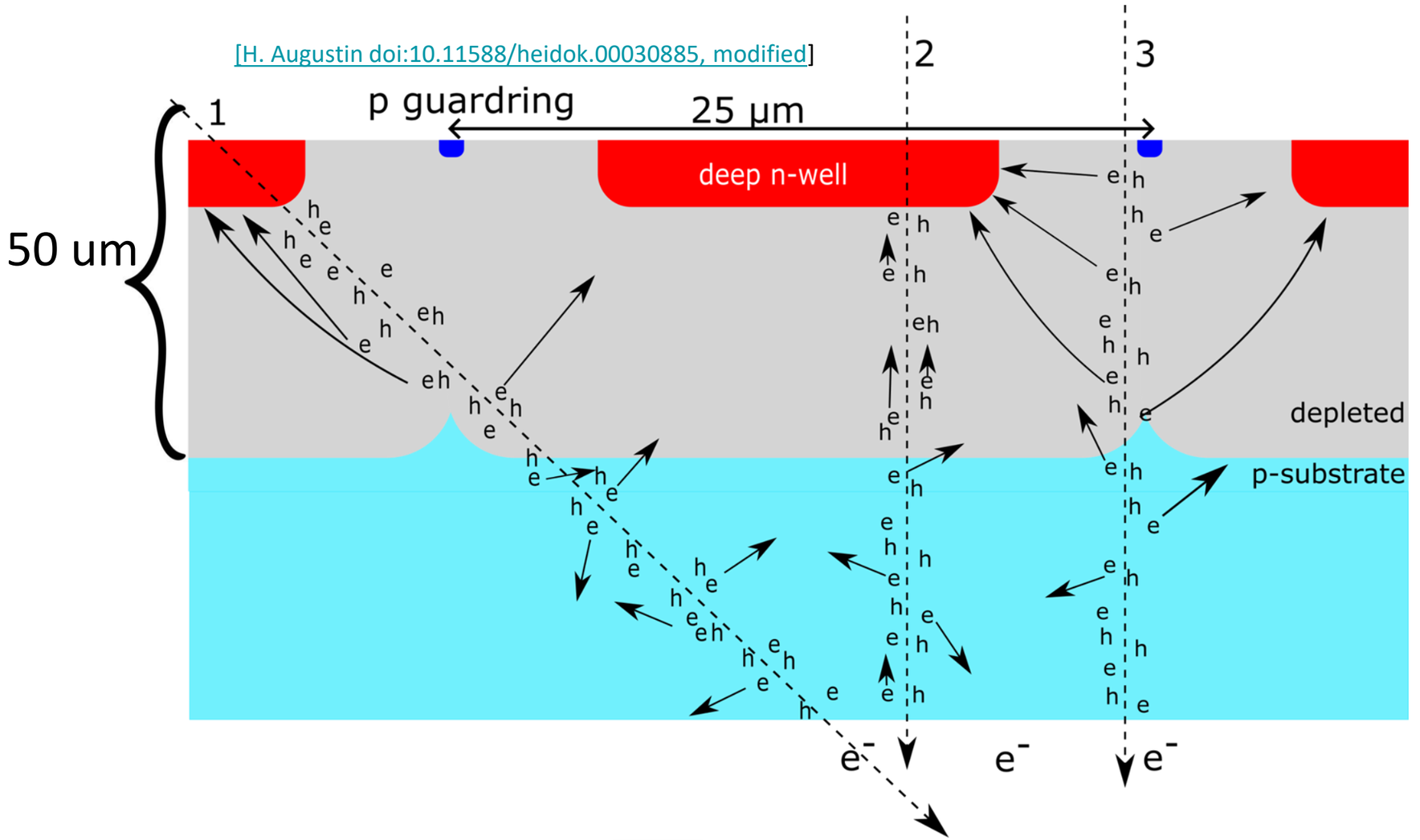
Charge Deposition and Collection in HV-MAPS

➔ **Main observables:**
ToT, cluster size

- Compare at same HV and configuration for different thicknesses

➔ 50 um, 100 um,
740 um (unthinned)

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

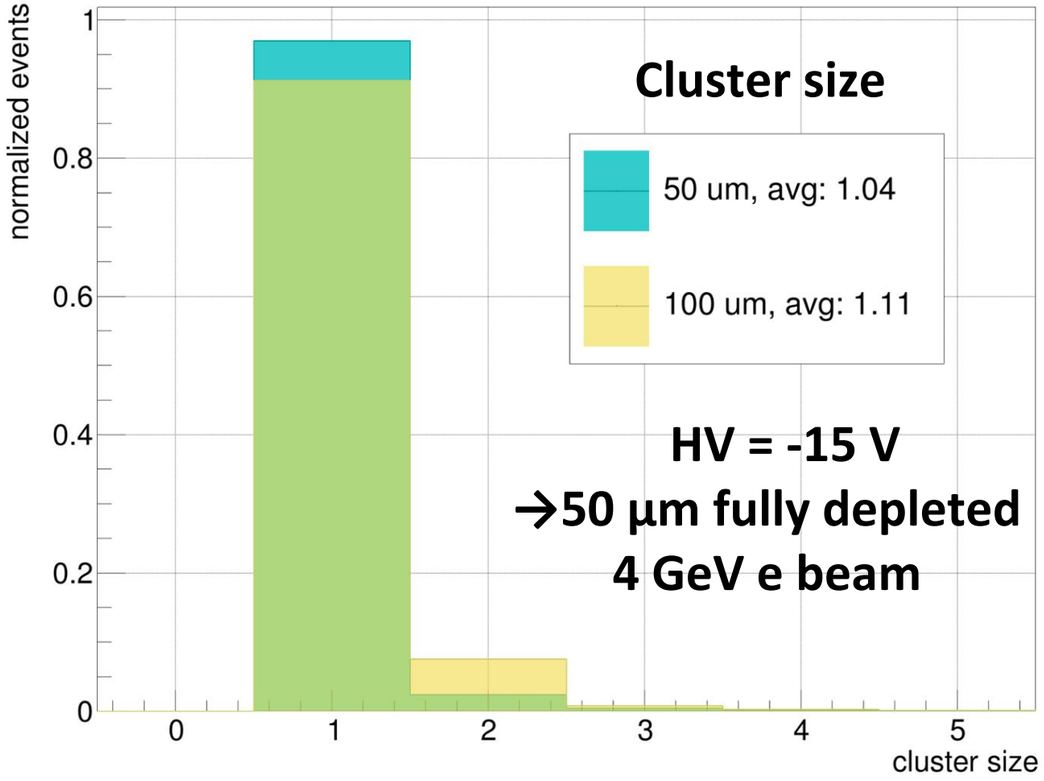


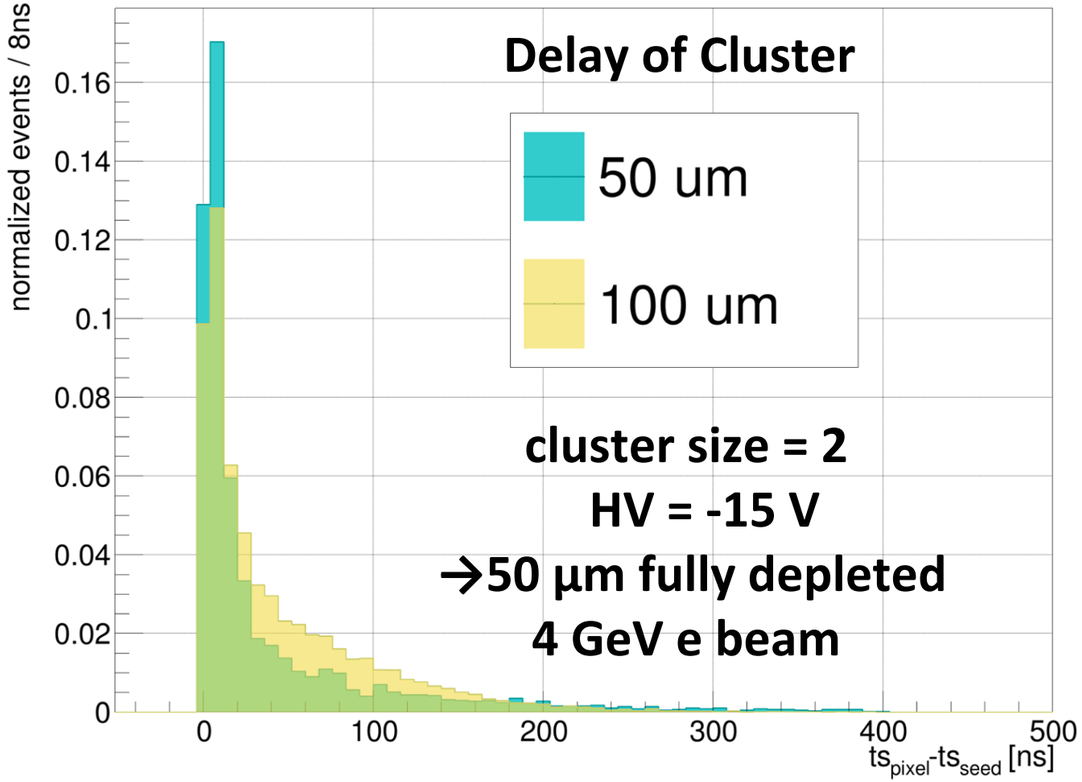
$$\sigma_{\text{diffusion}} = \sqrt{2Dt}, \quad D = (37.5 \pm 2.9)\,\text{cm}^2\text{s}^{-1}$$

Cluster Size Study @ DESY

- Cluster size increases with amount of undepleted substrate
- Second Pixel in the cluster shows larger delays

  ➔ Diffusion is a slower process than drift

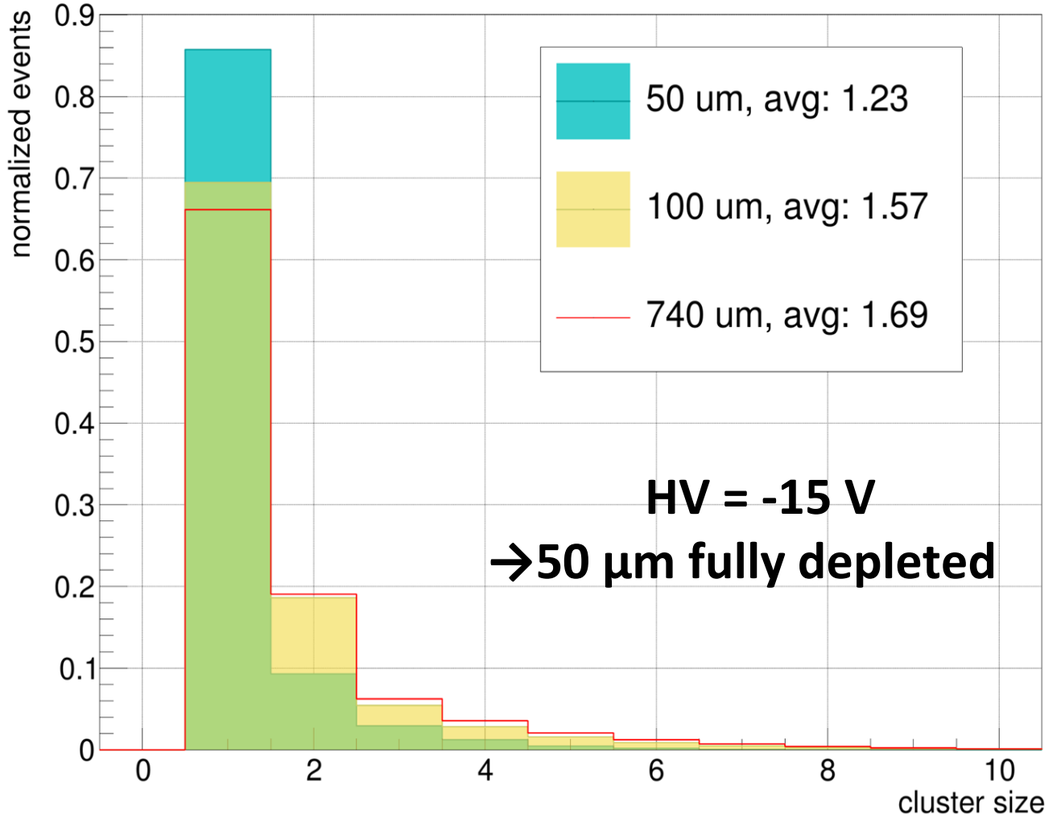


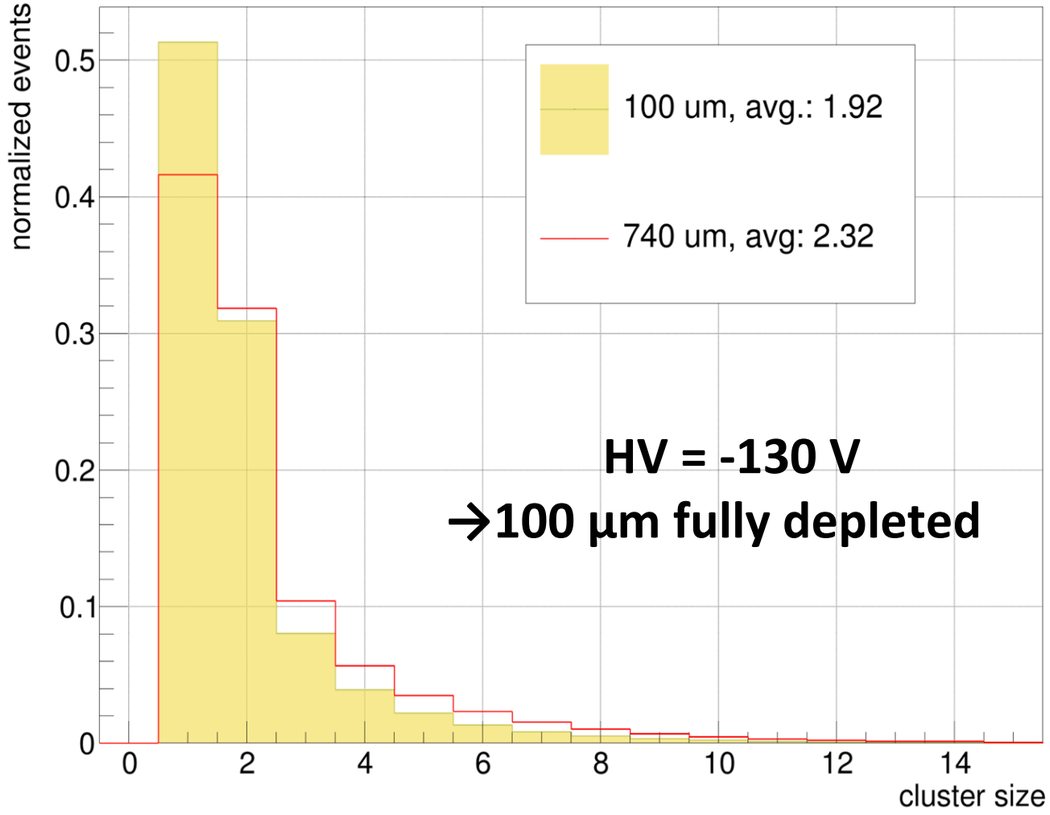


Cluster size study with Strontium-90

- > 600 µm of undepleted substrate → similar increase in cluster size

$$\sigma_{\text{diffusion}} \approx 60 \text{ um}$$





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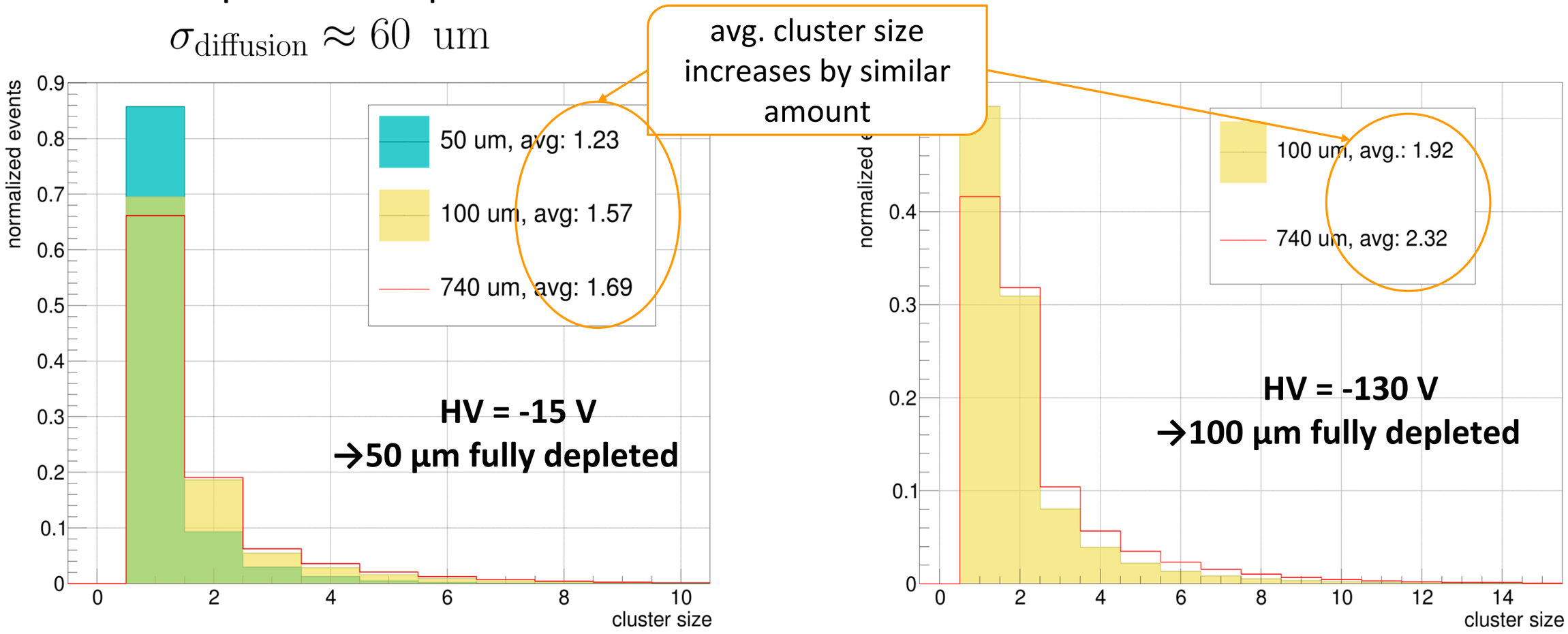
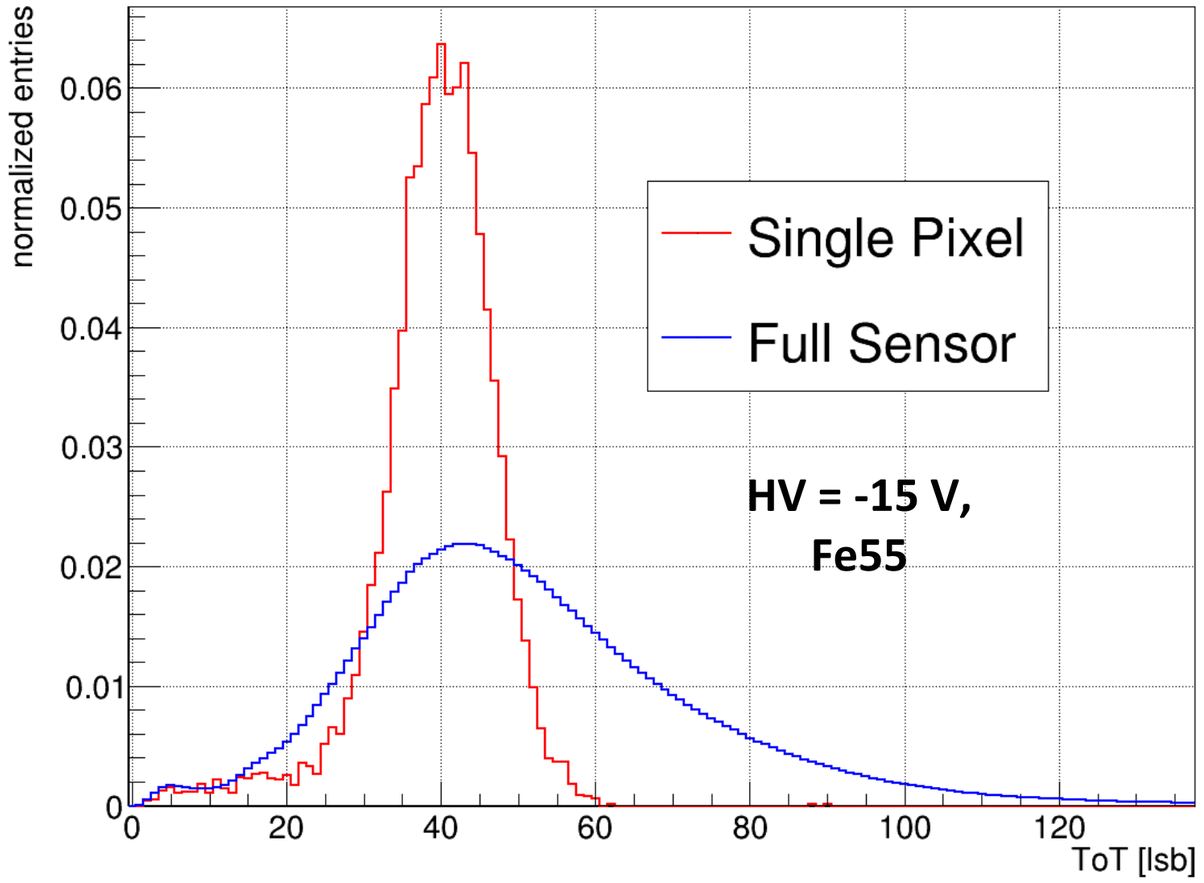


Pixel to Pixel ToT Variations

- Fe55: Monoenergetic x-ray source 5.9 keV
  - ➔ creates ~1634 e-h pairs[1]
  - ➔ Similar pixel response expected
- Full sensor ToT has large FWHM

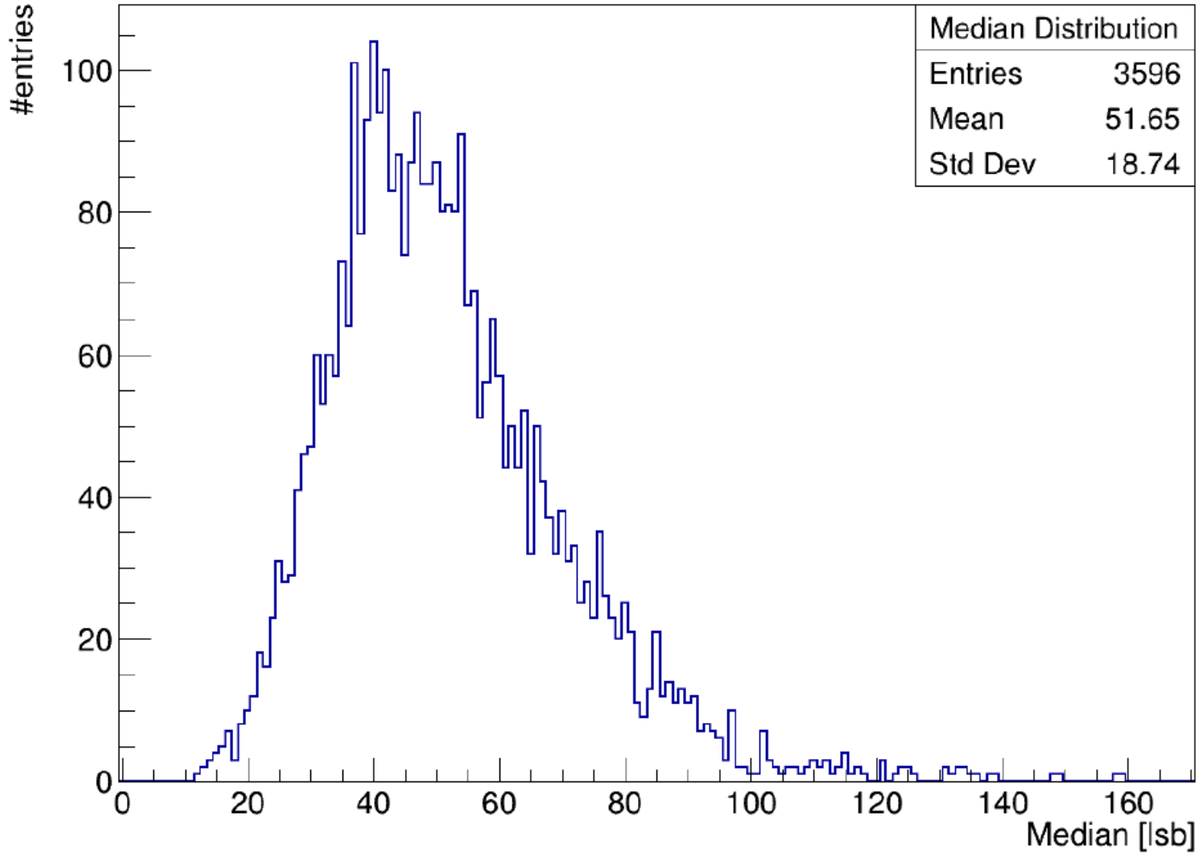


[1]e-h creation energy: W = 3.65 eV

Pixel to Pixel ToT Variations

- Fe55: Monoenergetic x-ray source 5.9 keV
  - ➔ creates ~1634 e-h pairs[1]
  - ➔ Similar pixel response expected

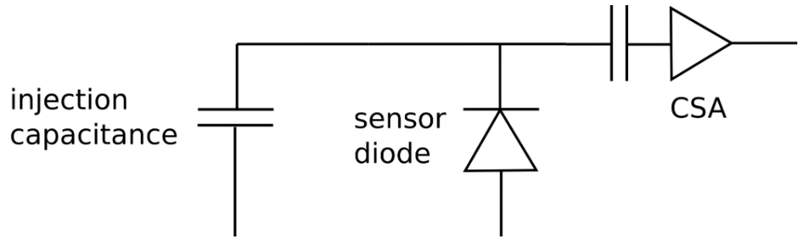
- Full sensor ToT has large FWHM
- Large variation in pixel median ToT for Fe55 source is observed
  - ➔ Variation from Chip to Chip
  - ➔ Calibration necessary

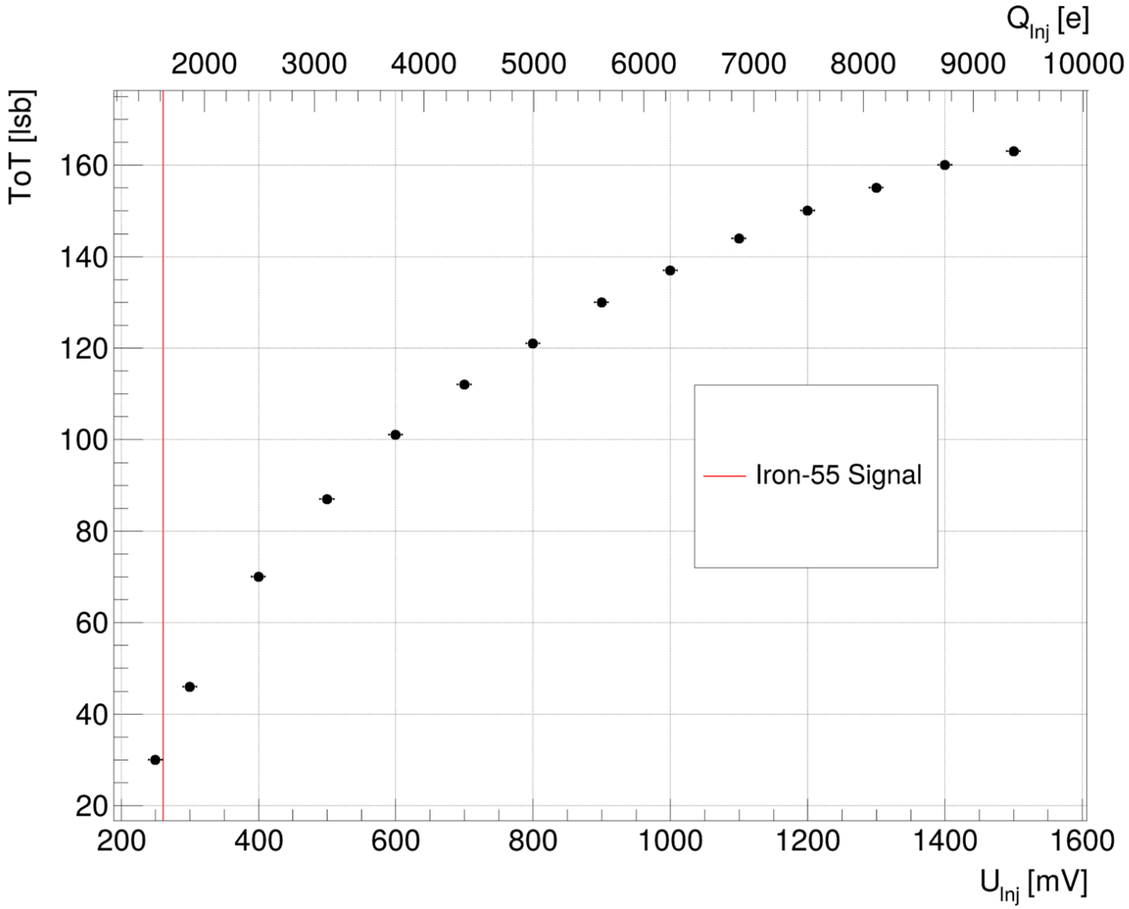


[1]e-h creation energy: W = 3.65 eV

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

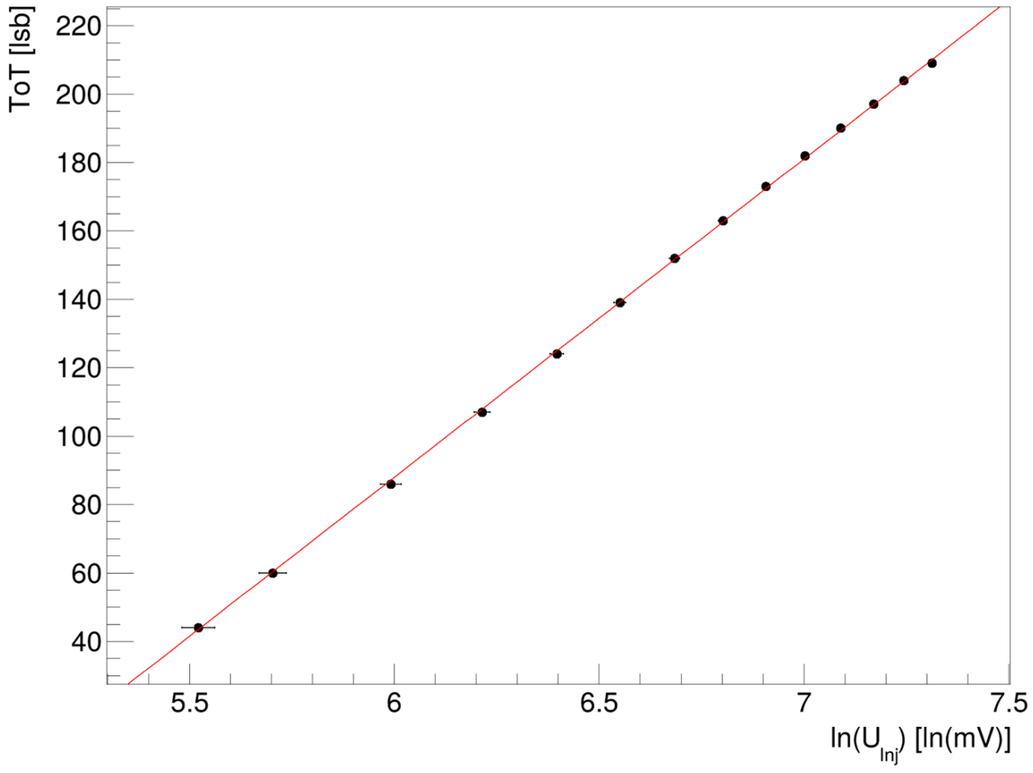
Calibration Method

D. Dannheim et al., “Corryvreckan: a modular 4D track reconstruction and analysis software for test beam data”

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

$$\mathrm{Charge} = 1634\,\mathrm{e} \cdot \exp(a(\mathrm{ToT} - \mathrm{ToT_{Fe}}))$$

- Uses gradient to achieve electron calibration of signal
- Allows for sensor to sensor comparison

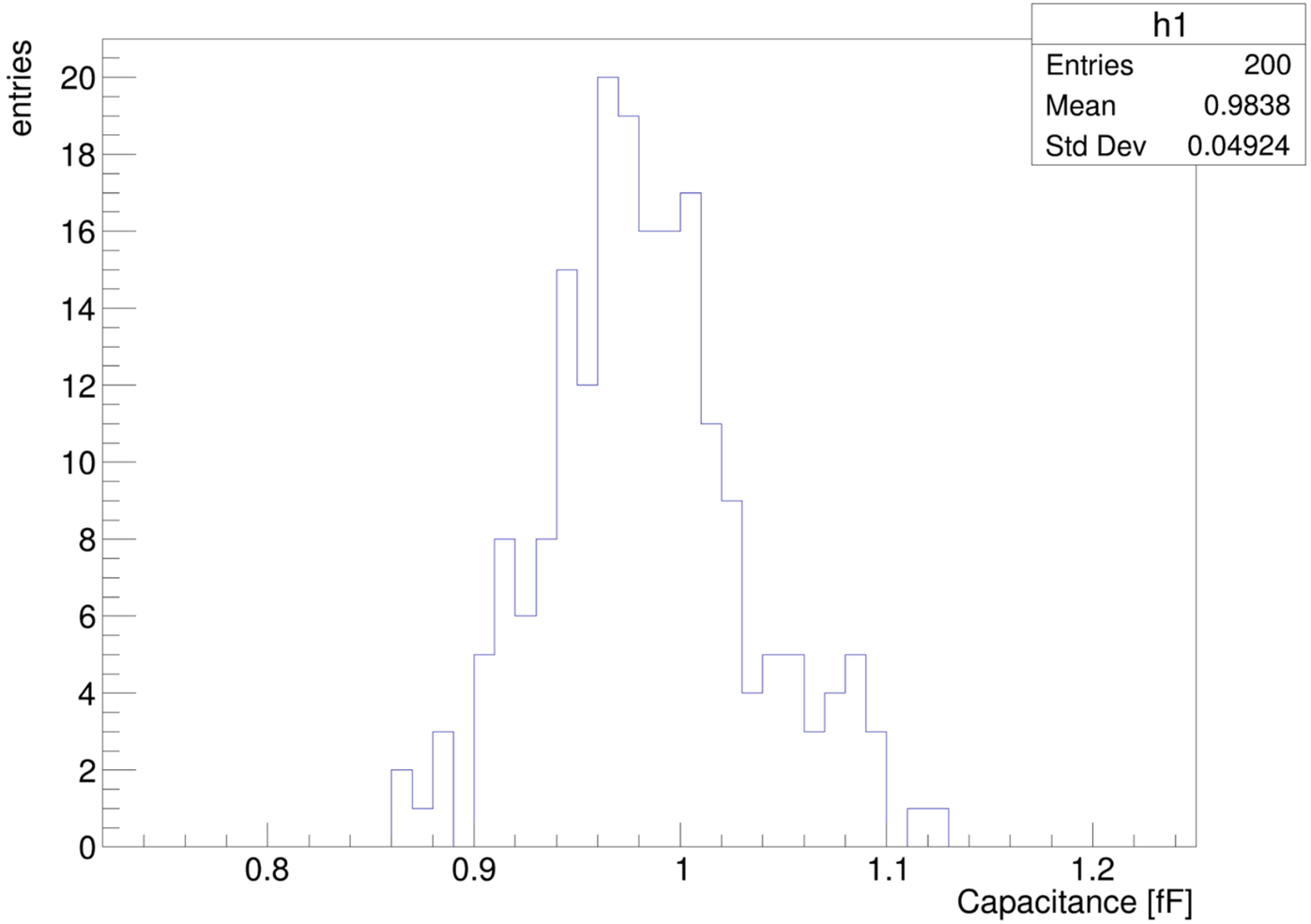


Cross-check: Injection Capacitance

- Subset of 200 Pixels
- Calculate $C_{\mathrm{Inj}} = \frac{Q_{\mathrm{Fe}}}{U_{\mathrm{Fe}}}$

➔ Design value: C_{Inj}= 1 fF

- Experimental capacitance matches design value very well

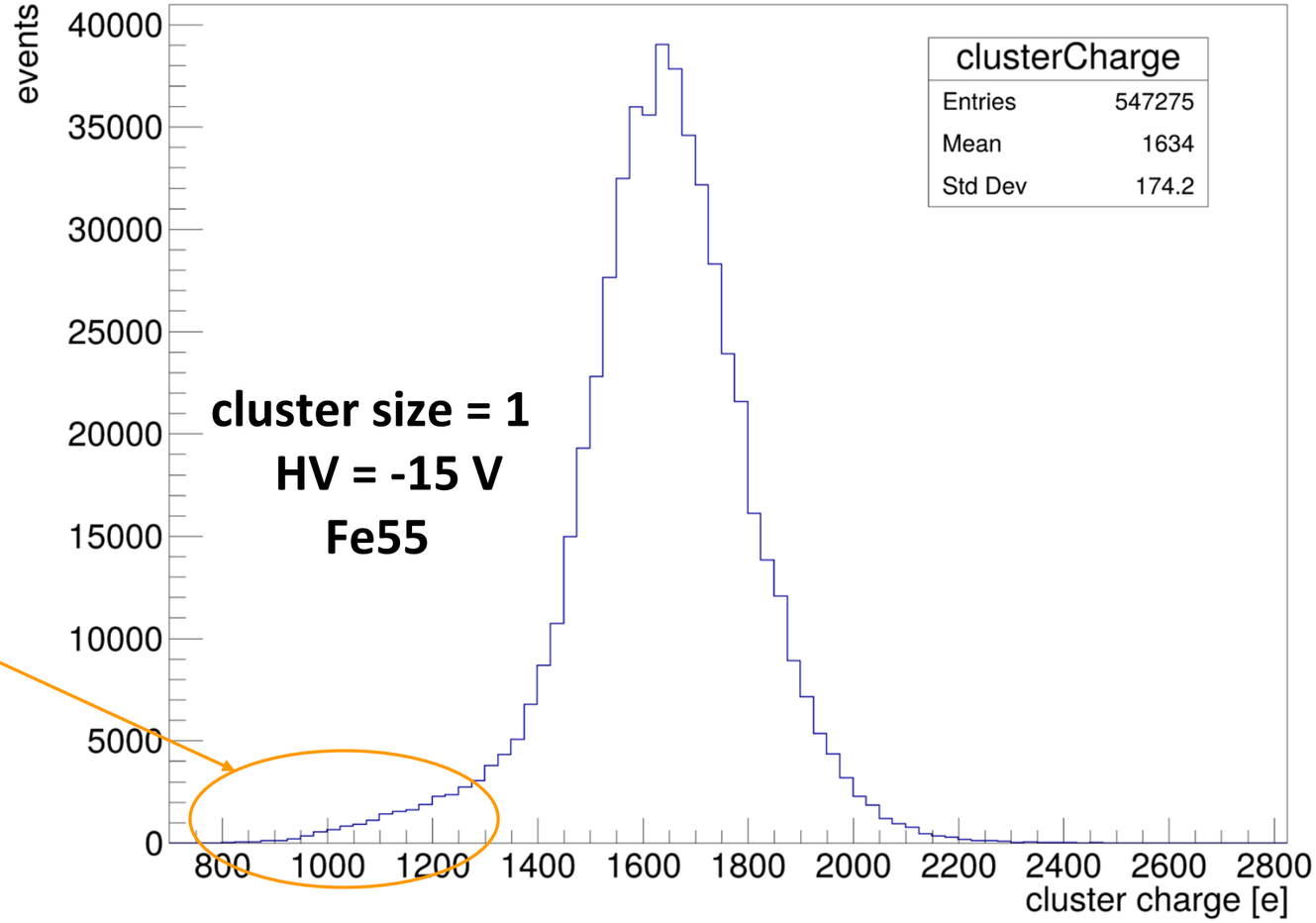


Calibration of Iron-55

- Subset of 200 pixels
- Core of the distribution has Gaussian shape and mean 1634 electrons

Tail towards small charge collections

➔ charge sharing



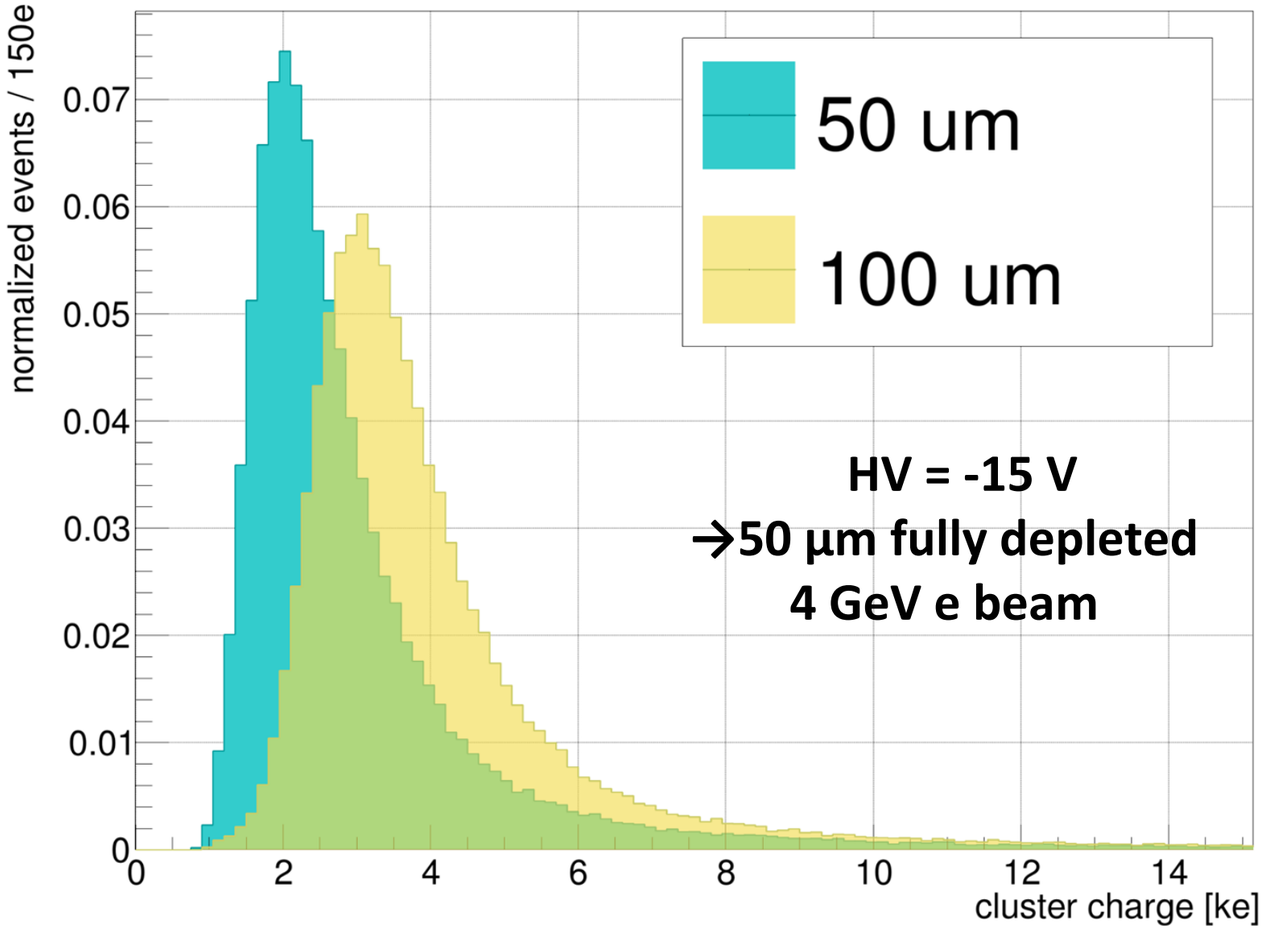
Calibrated ToT Studies @ DESY

- Subset of 200 Pixels
- Clear separation of charge spectra
- Mean electron collection:

  3386 e (50 µm) 4420 e (100 um)

➔ 30 % more charge collected

- MPV shifted by 1000 e

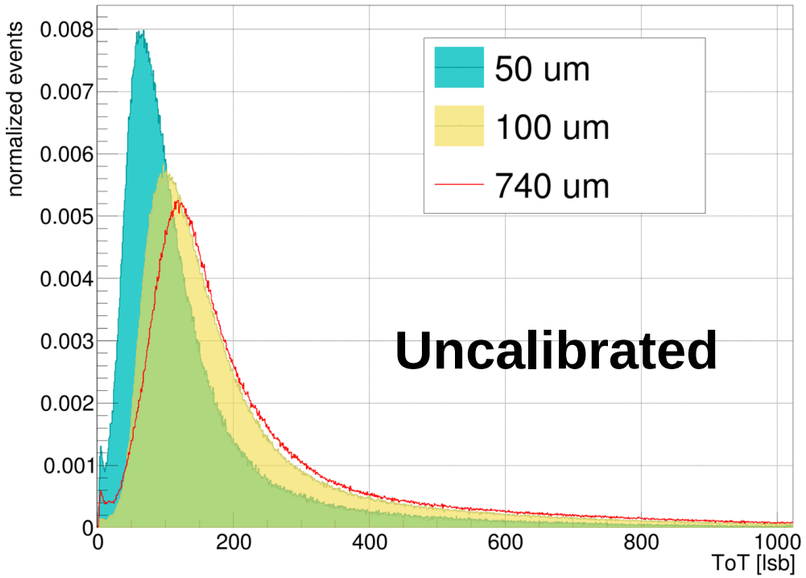


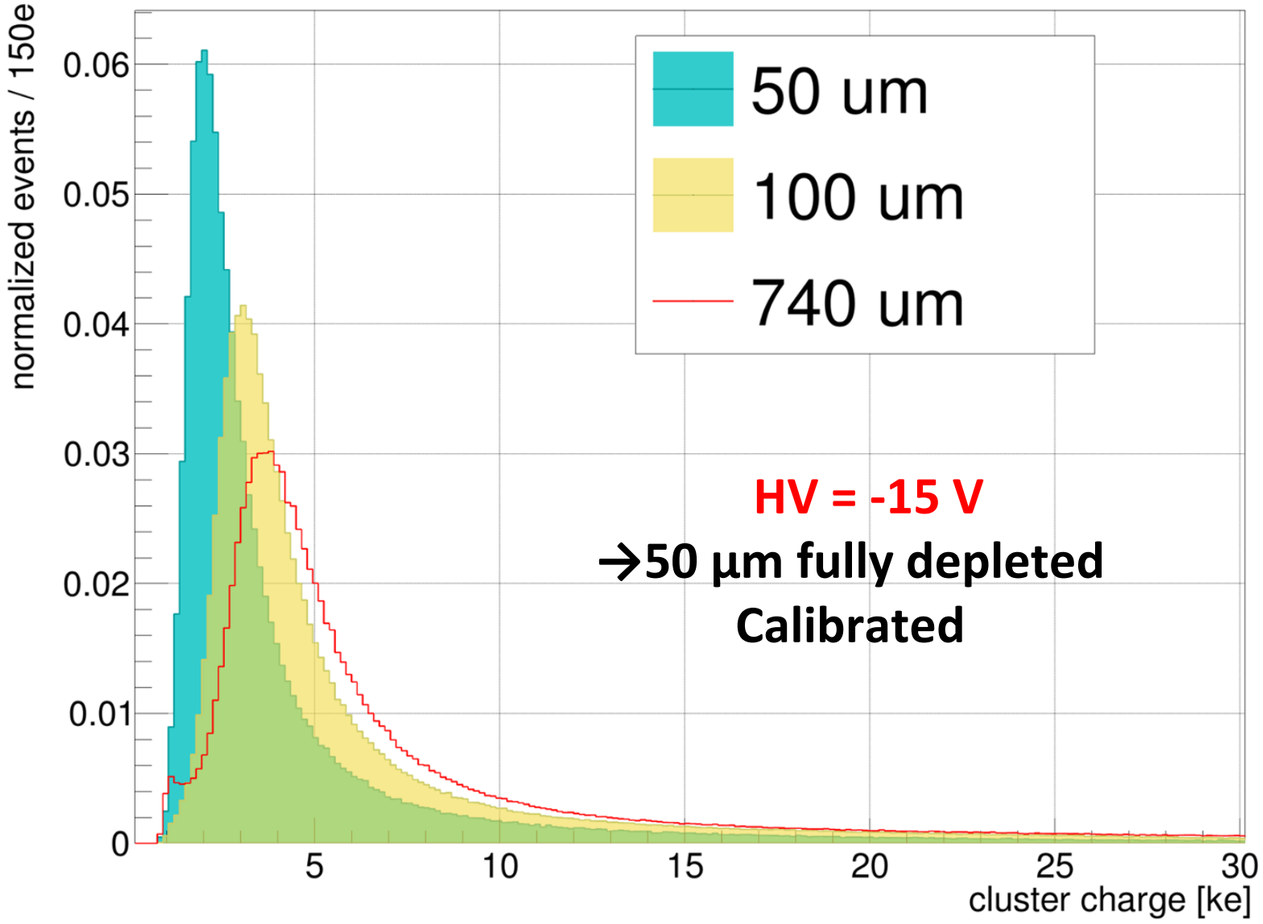
Strontium-90 Spectrum: -15 V Bias Voltage

- MPV of thick sensor shifted by O(2000 e)
- Larger FWHM for thicker sensor

➔ Diffusion increases the variation in collected charge

- Significant contribution from diffusion

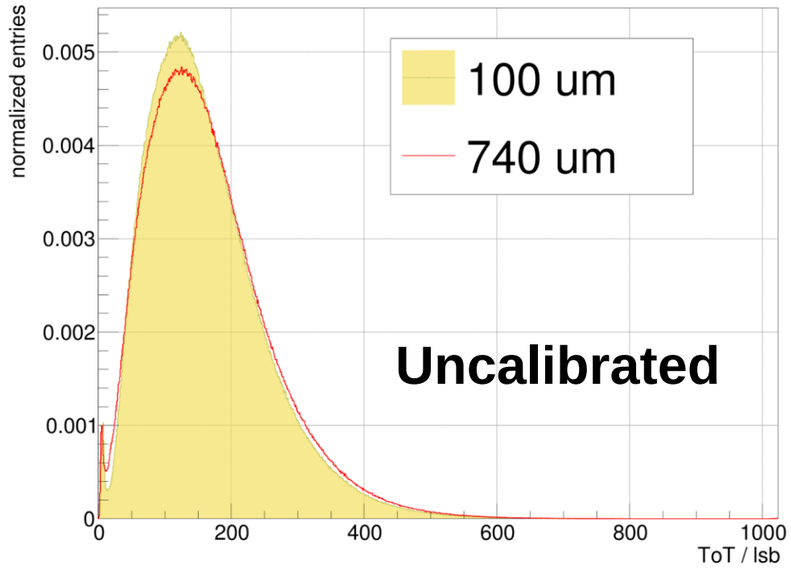


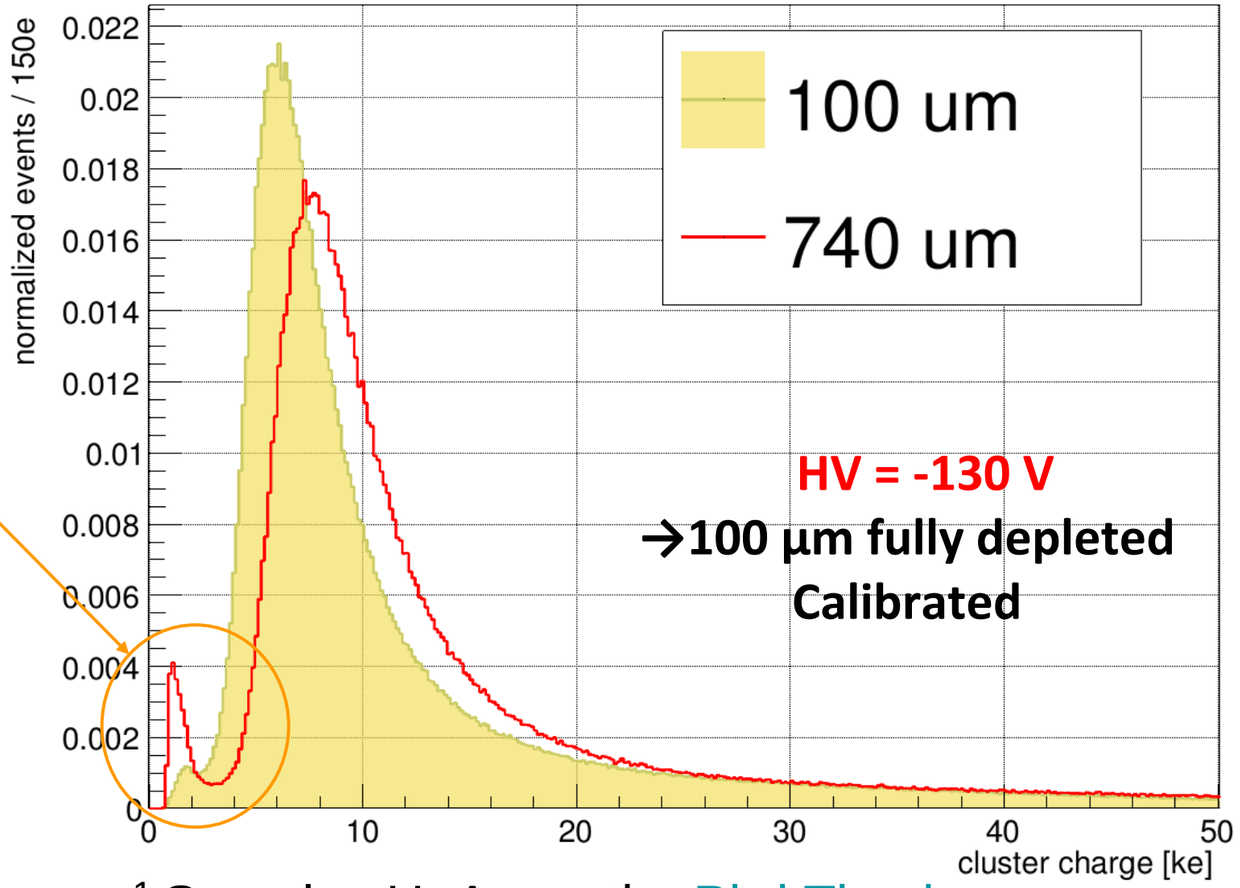


Strontium-90 Spectrum: -130 V Bias Voltage

- MPV of thick sensor shifted by O(2000 e)
- Diffusion leads to expected constant offset in charge collection

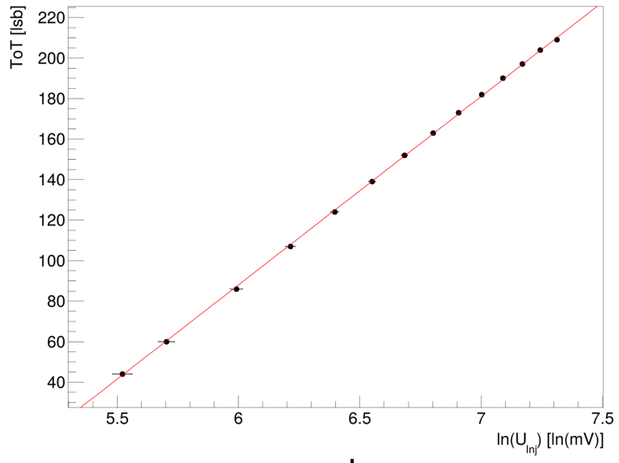
Signal Line Crosstalk observed [1]





[1] See also H. Augustin, Phd Thesis

Conclusion & Outlook

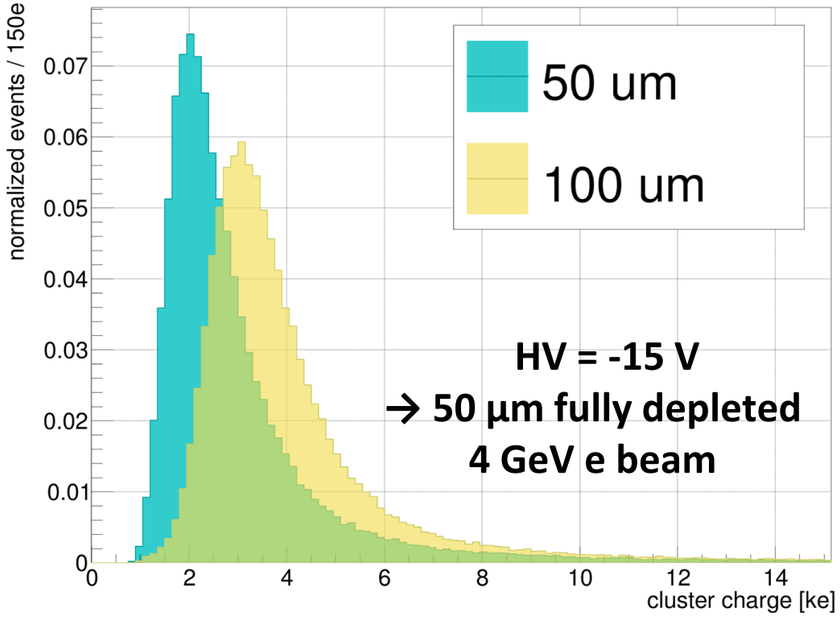


$$\text{Charge} = 1634\,\text{e} \cdot \exp(a(\text{ToT} - \text{ToT}_{\text{Fe}}))$$

Conclusion:

- Cluster size & delay in cluster increases with undepleted substrate
- 30% more collected charge in 100 µm sensor

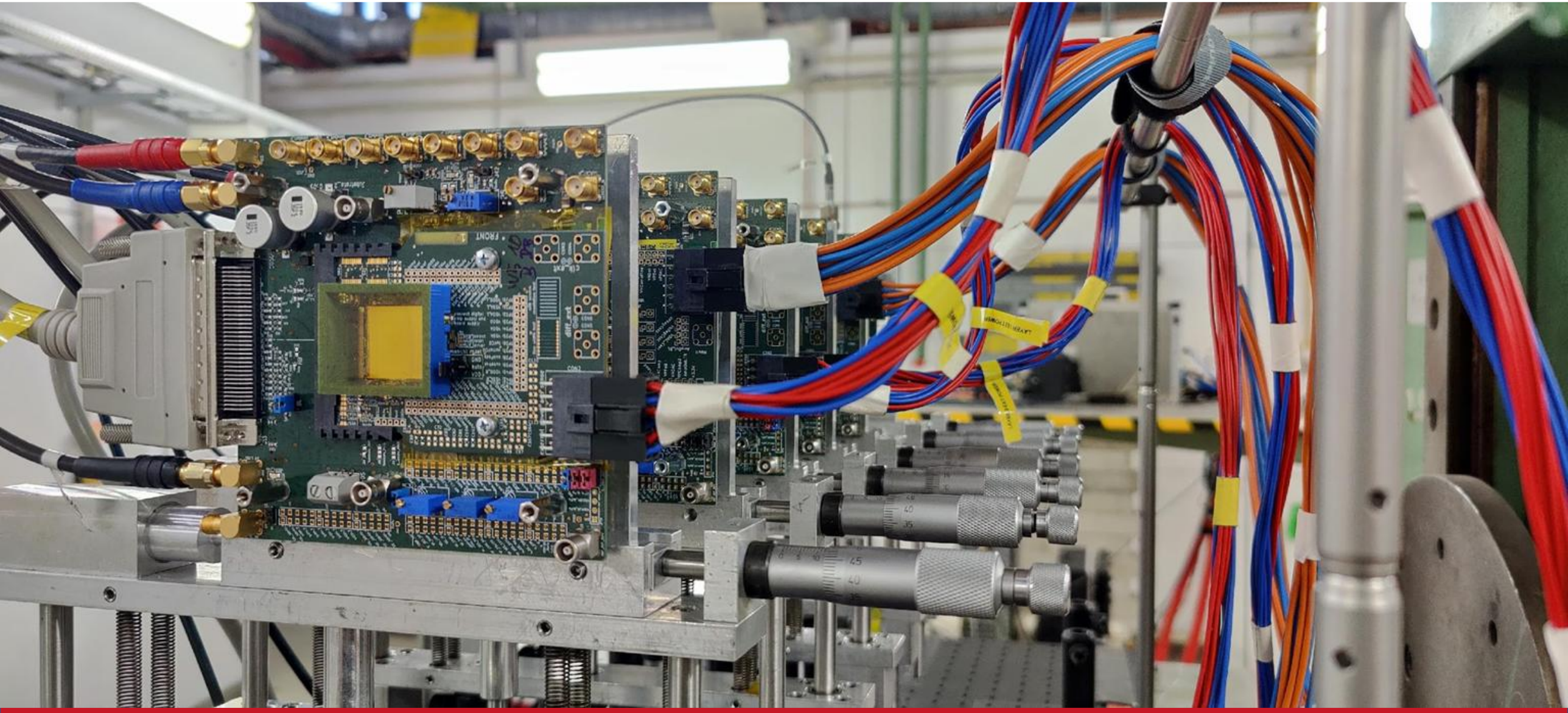
➔ Significant contribution of diffusion to the signal is observed!



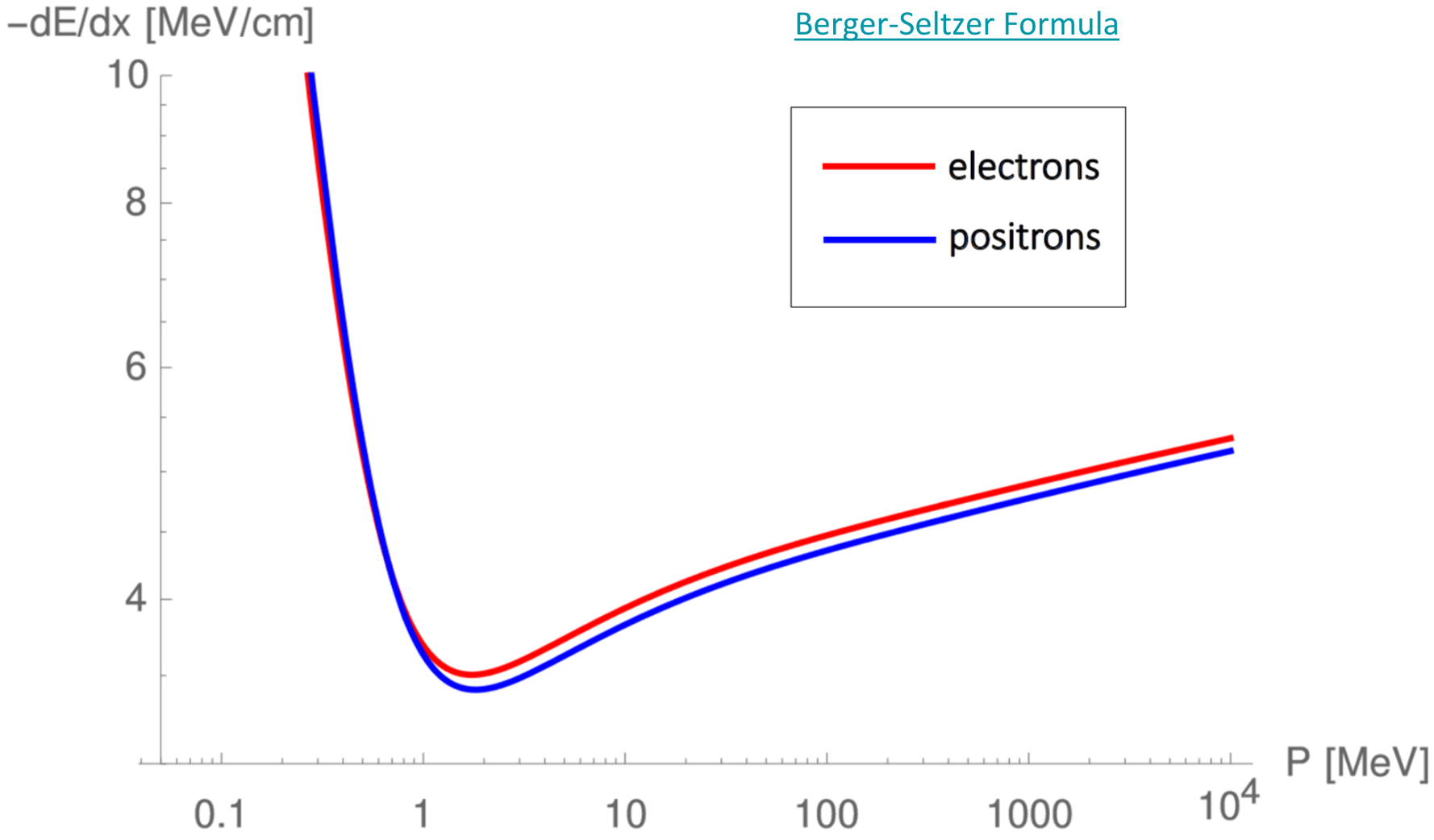
Next Steps:

- Calibration for full sensor
- Allpix² simulation to compare with measurements
- Prepare Corryvreckan pull request for *ChargeAnalyzer* & *ChargeCalibration* modules

Questions?



Berger-Seltzer Formula

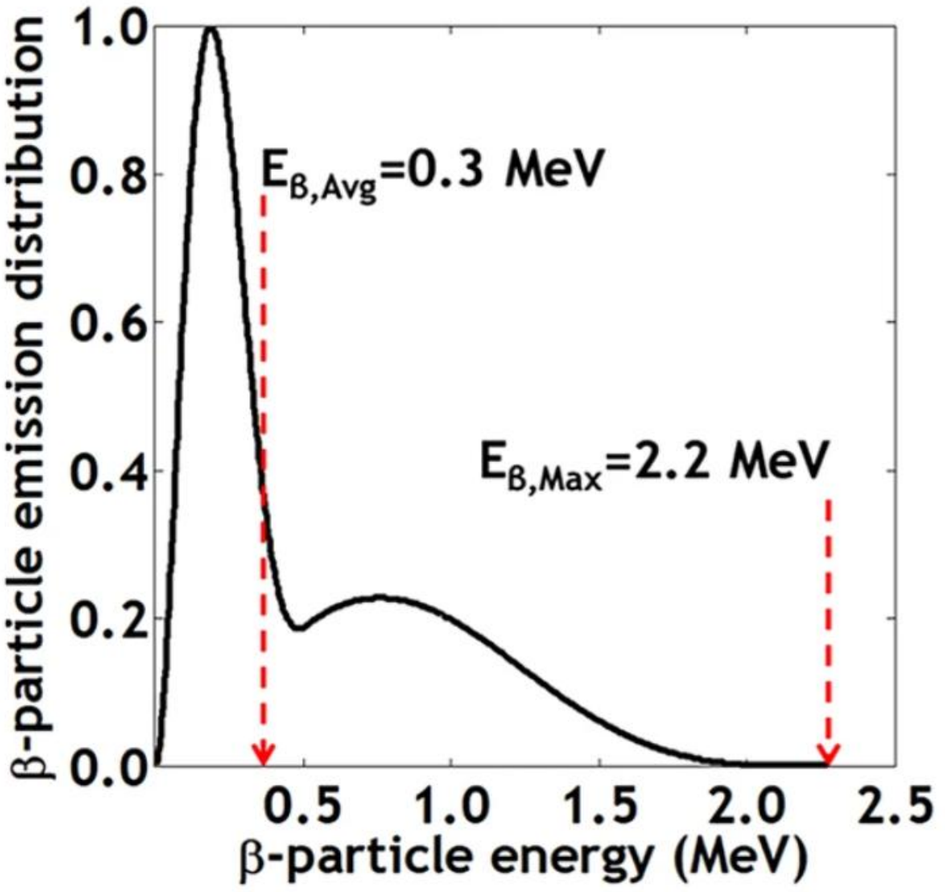


Berger-Seltzer Formula

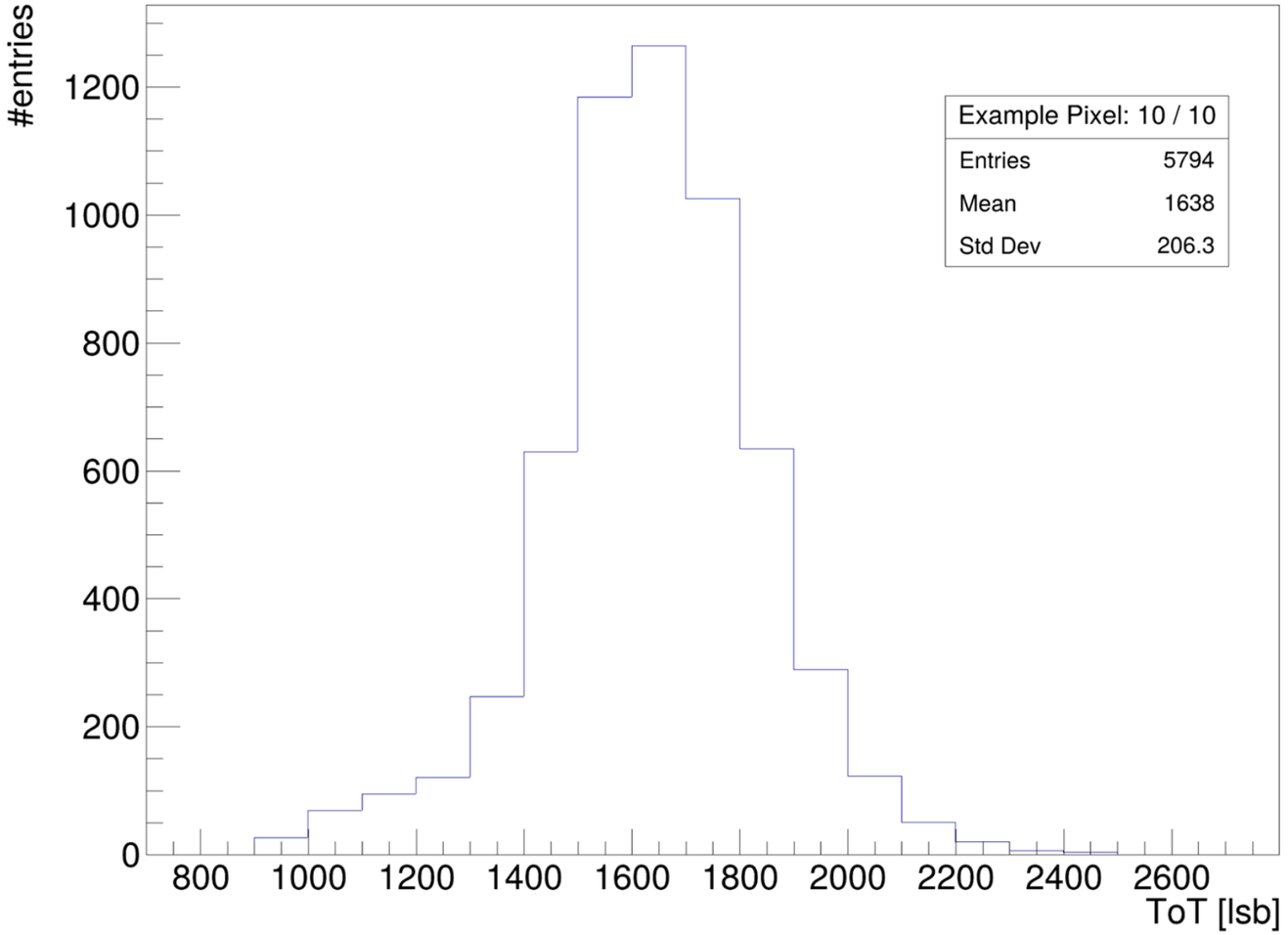
Strontium-90 Calculated Spectrum

- Low energy electrons do not reach the detector
- Additional shift of spectrum towards lower energies by energy loss in air

Calculated Strontium-90 & Yttrium-90 Spectrum



Calibration of Iron-55 - Single Pixel



Single pixel calibrated charge spectrum