

Studien zu Gaseigenschaften in InGrid-basierten Röntgendetektoren

DPG Frühjahrstagung 2014 Mainz

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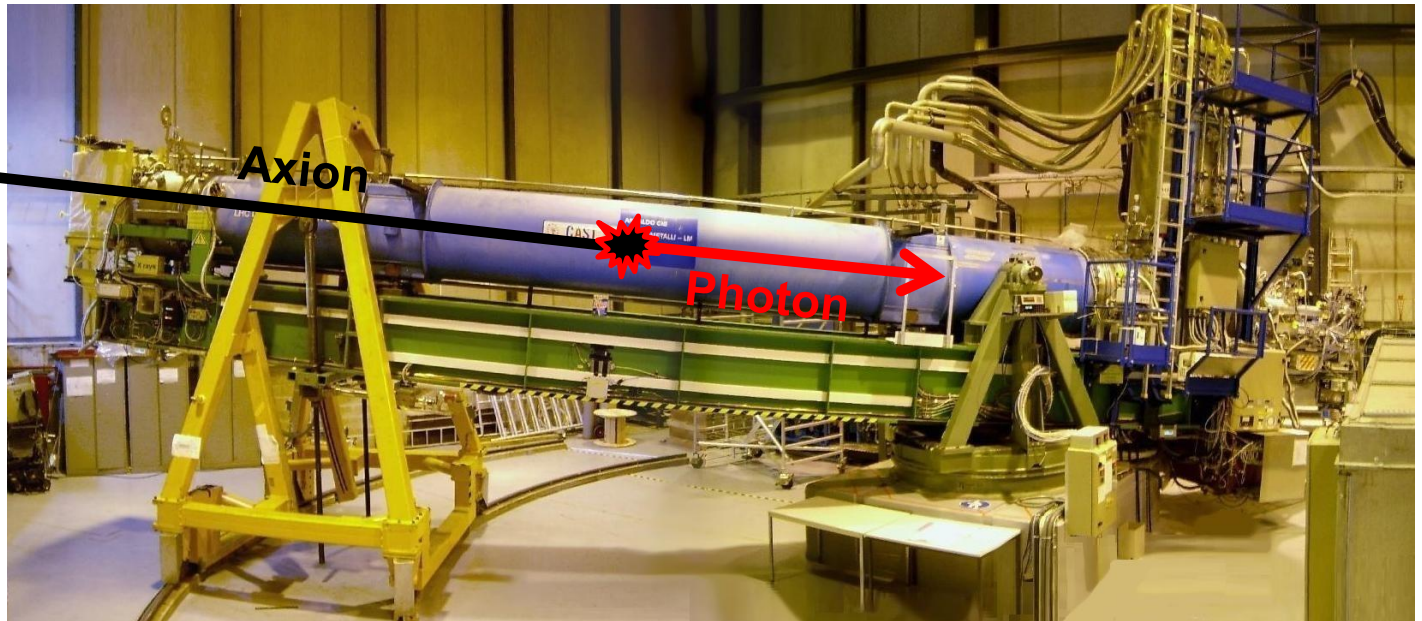
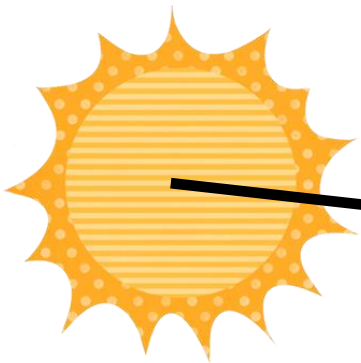
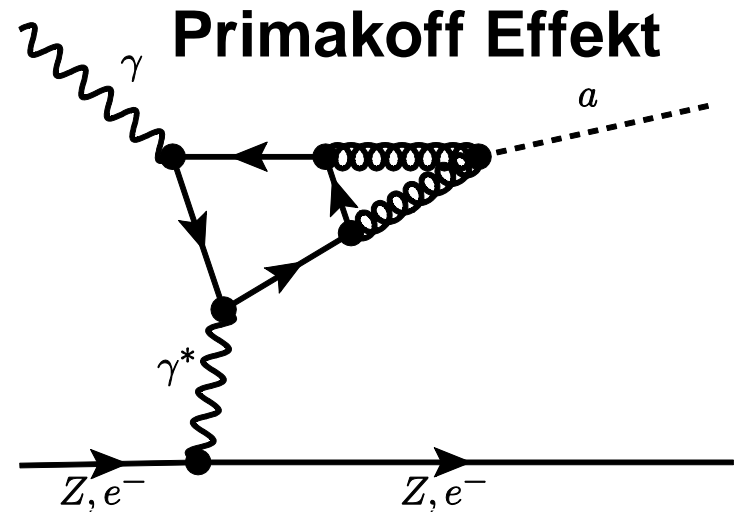
24.03.2014

Cern Axion Solar Telescope

- Quantenchromodynamik erlaubt CP -Verletzung,
- Bisher CP -Verletzung unbeobachtet
- Einführen der Peccei-Quinn Symmetrie löst dieses sog. starke CP -Problem
- Damit einhergehend: Einführung Axion:
 - Neutral, leicht, langlebig
 - Koppelt an Gluonen
 - Kandidat für dunkle Materie

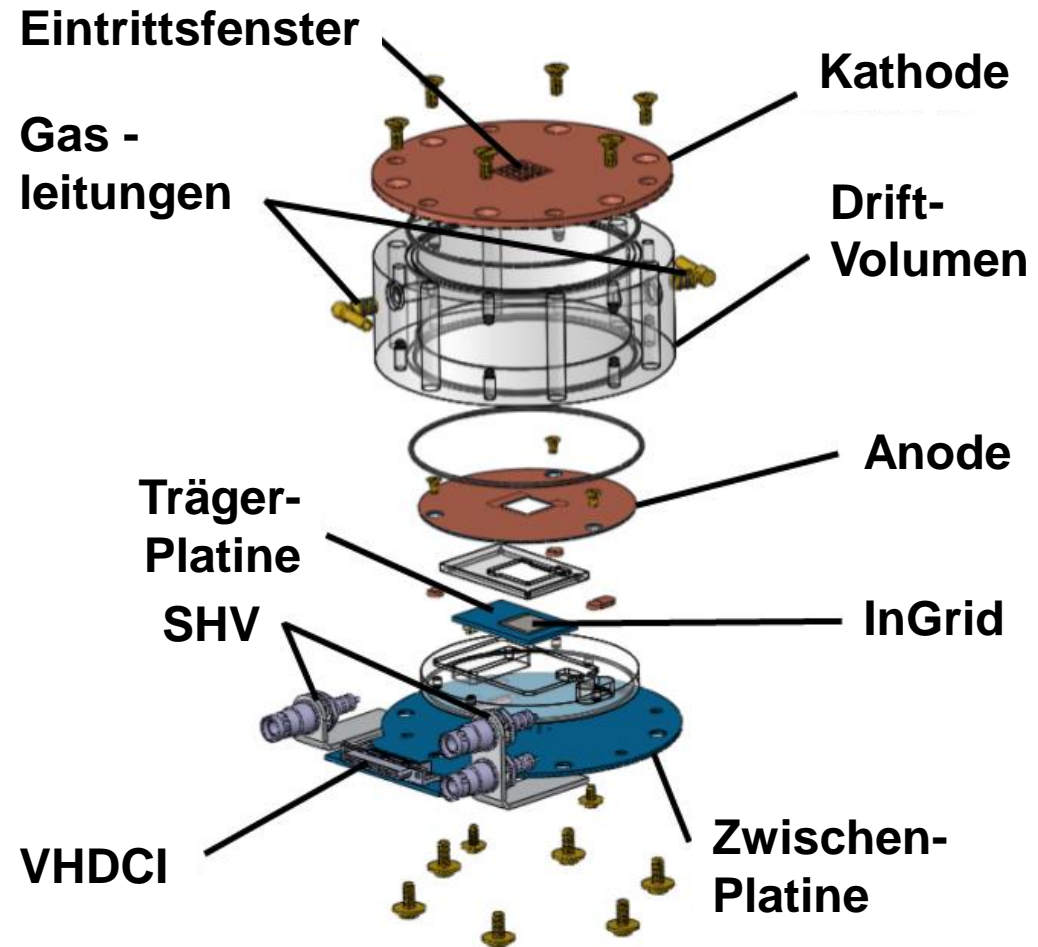
CERN Axion Solar Telescope

- Produziert in der Sonne via Primakoff Effekt
- Rekonversion via inversen Primakoff Effekt

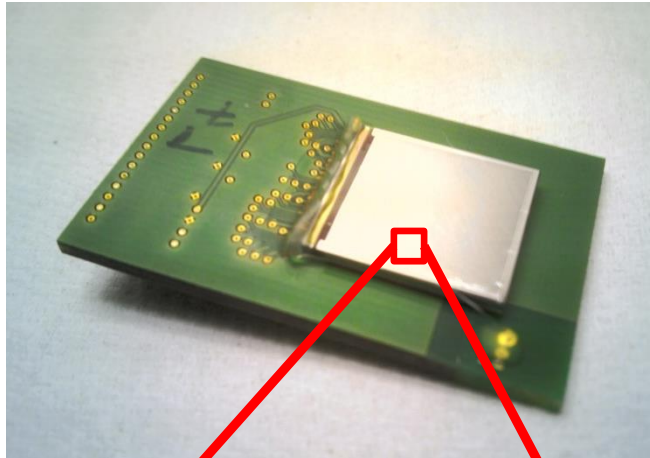


Versuchsanordnung – Der Röntgendetektor

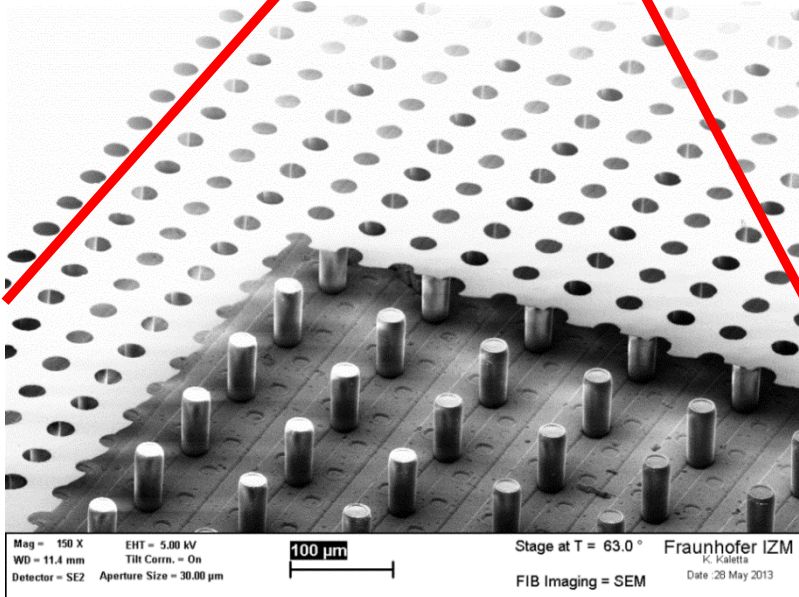
- Gasgefüllter Detektor entwickelt von C. Krieger
- Basiert auf CAST Micromegas
- 3 cm Drift-Distanz
- Kombination von pixelierter Auslese & integrierter Gasverstärkung



Versuchsanordnung – Timepix & InGrid

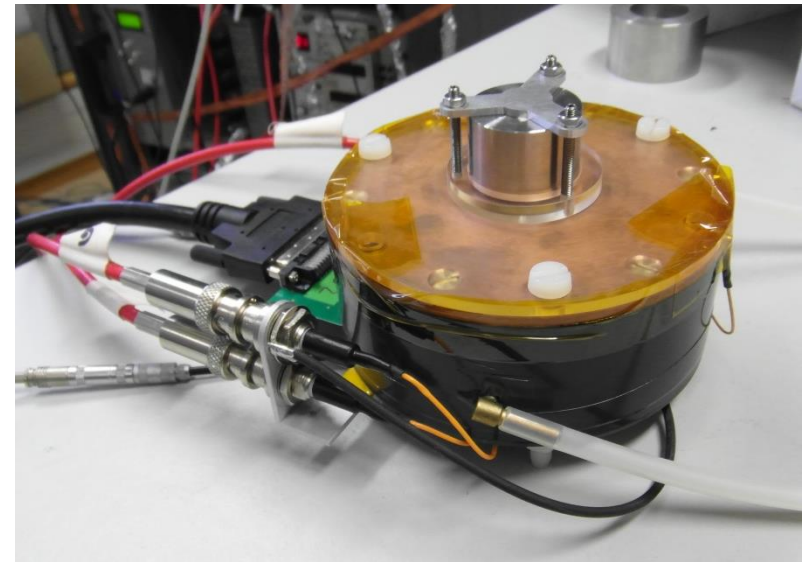


- 256 × 256 Pixel zu je 55 × 55 μm^2
- Gesamtfläche von 1.4 × 1.4 cm^2
- „Time over threshold“ (ToT) oder „time of arrival“ (ToA) Messungen



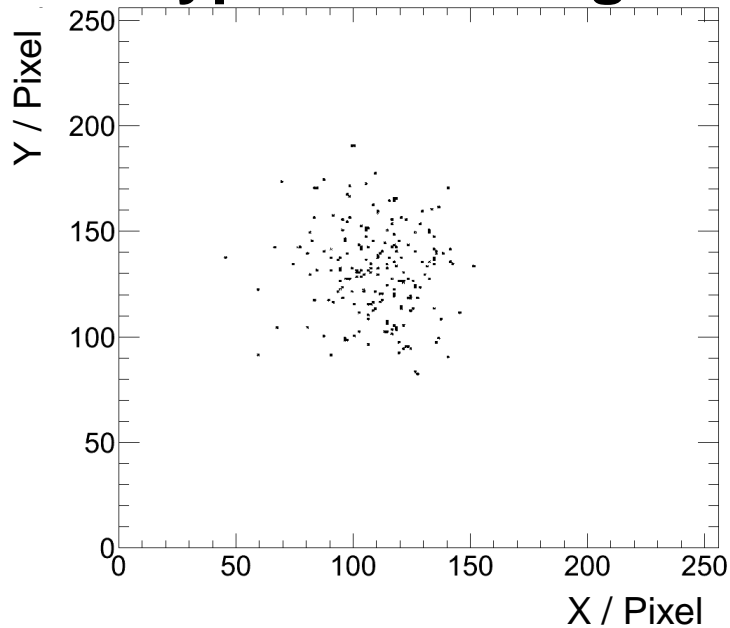
Versuchsanordnung

- ^{55}Fe -Quelle
- Ar/ $i\text{C}_4\text{H}_{10}$ Gasgemische
- FPGA basiertes Auslesesystem, entwickelt von M. Lupberger (**T 33.2**)
- Ladungskalibration mittels externer Testpulse möglich

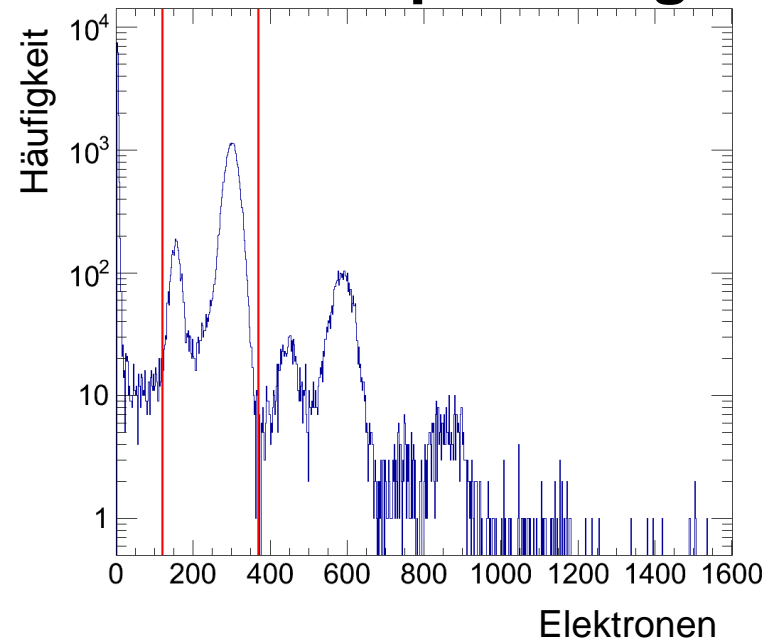


Datenaufbereitung

Typisches Ereignis

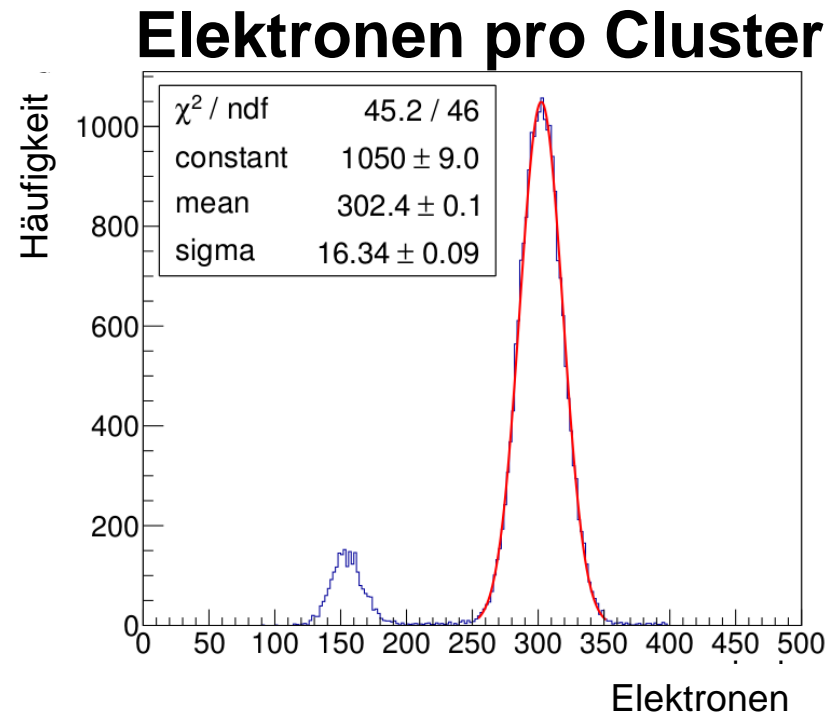


Elektronen pro Ereignis



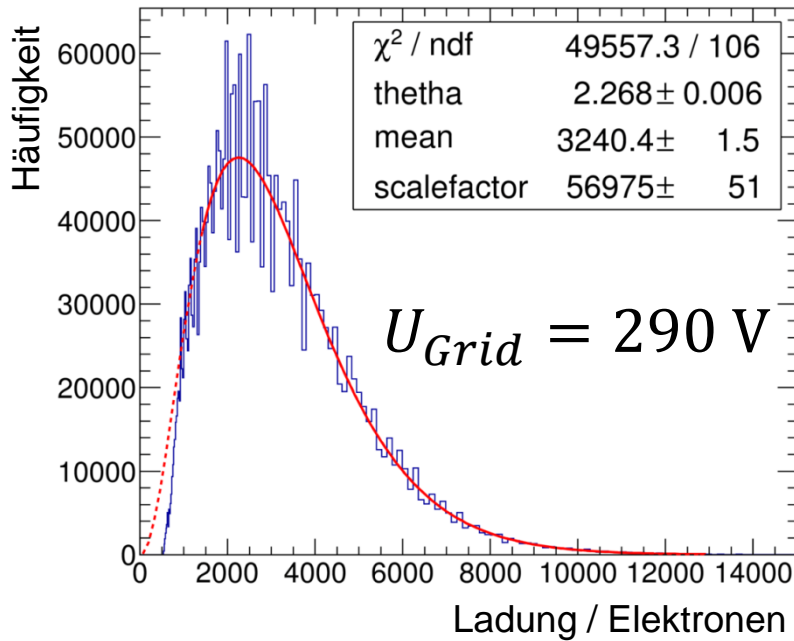
Datenaufbereitung

- Spektrum klar erkennbar
- $N_{exp.} = \frac{E}{W} \approx 222$
- $N_D \approx 302$
- Wieso $N_D > N_{exp.}$?

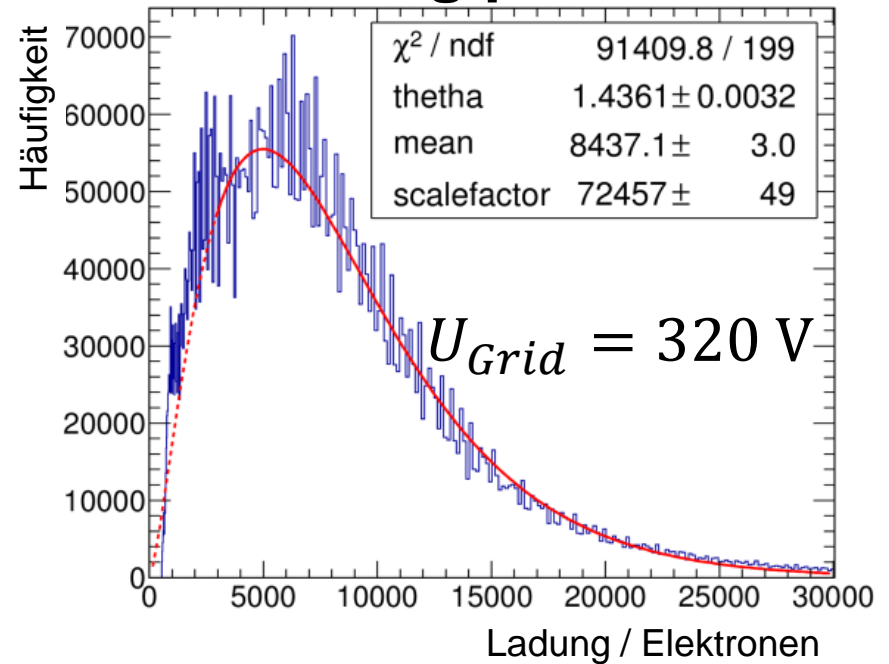


Ladungsaustausch – Die Polya-Verteilung

Ladung pro Pixel



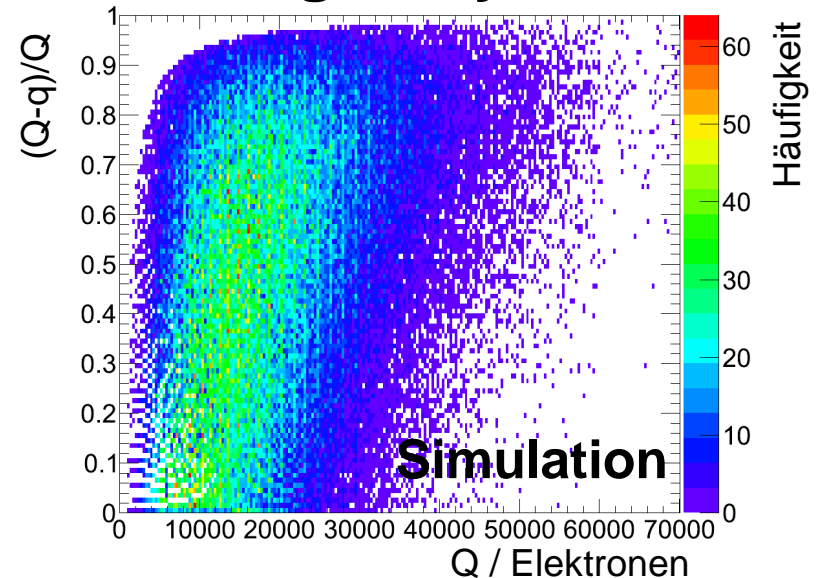
Ladung pro Pixel



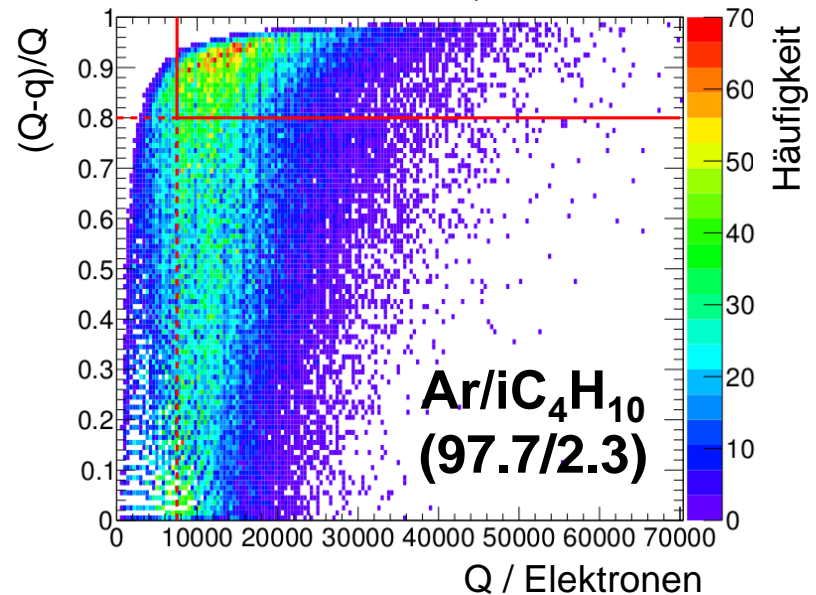
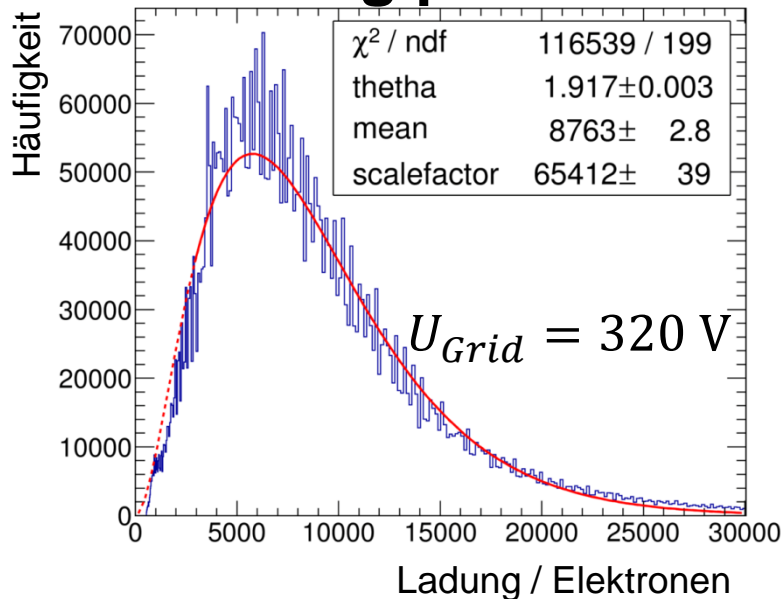
Ladungsaustausch - Korrektur

- Ladungsfluss zu benachbarten Pixeln
- Bevorzugte Paarung von Treffern mit hoher und niedriger Ladung

Ladungs-Asymmetrie

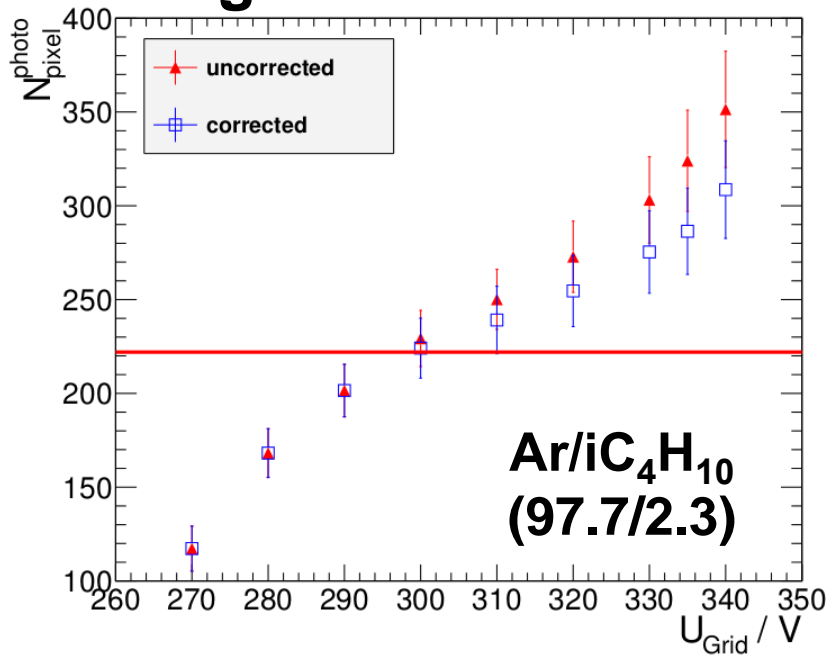


Ladung pro Pixel

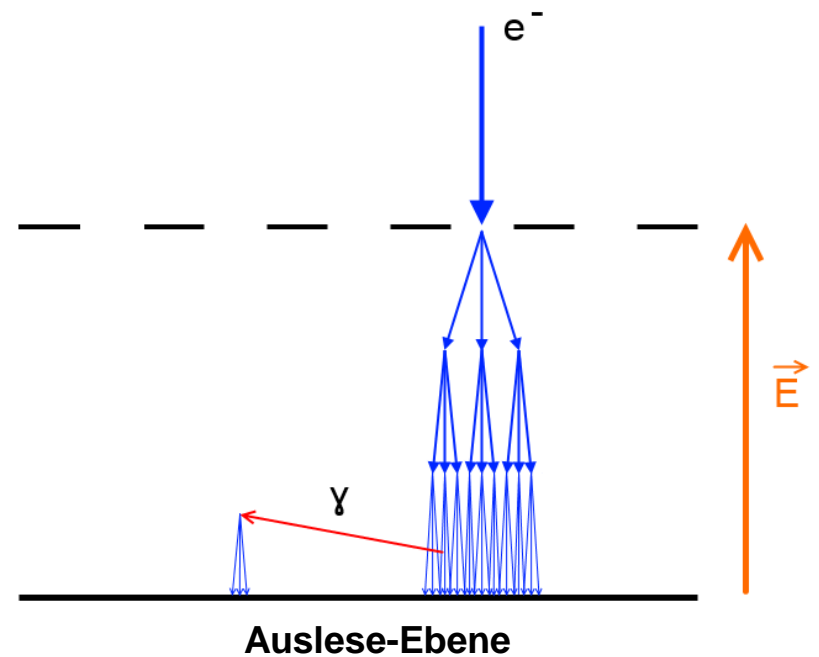


Ladungsaustausch - Korrektur

Lage der Photolinie

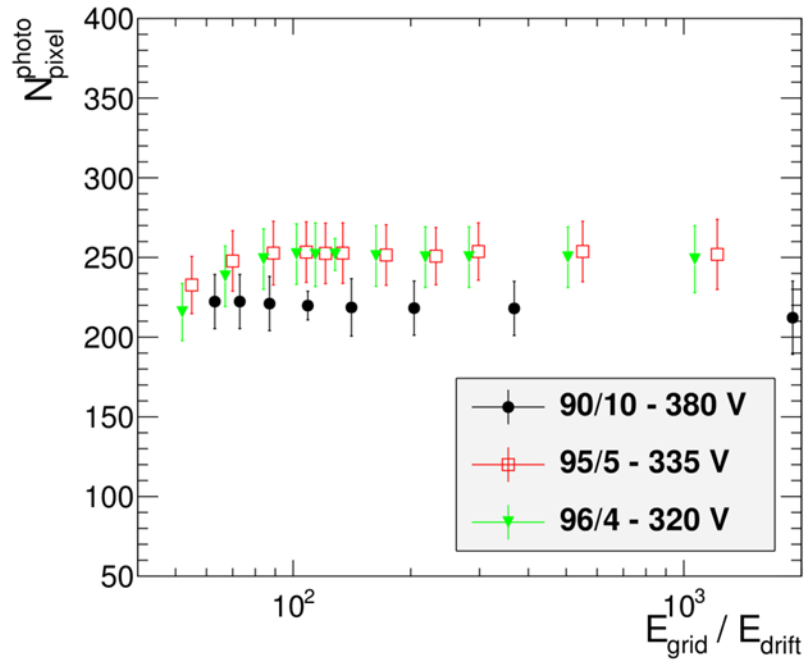


Sekundäre Lawinen

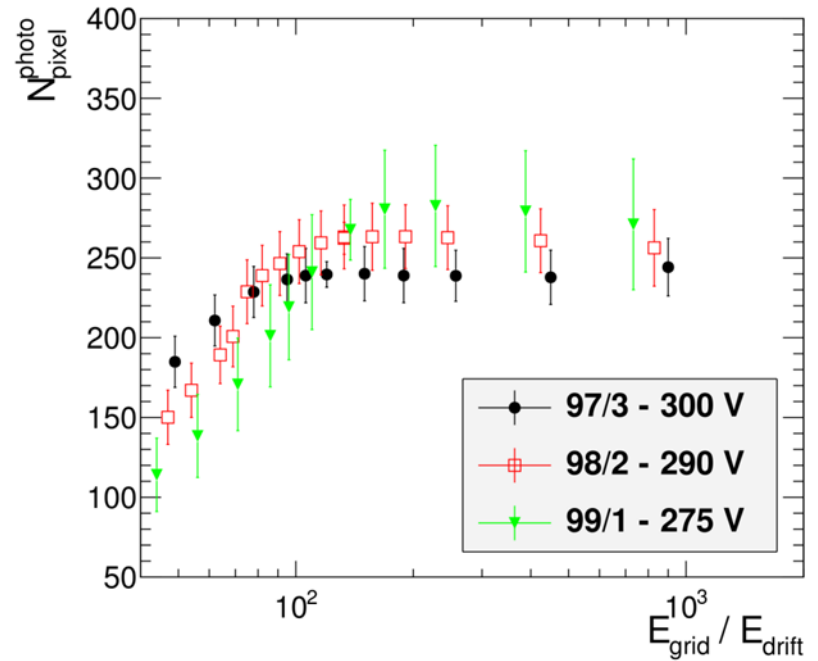


Effizienz

Variation Driftfeld

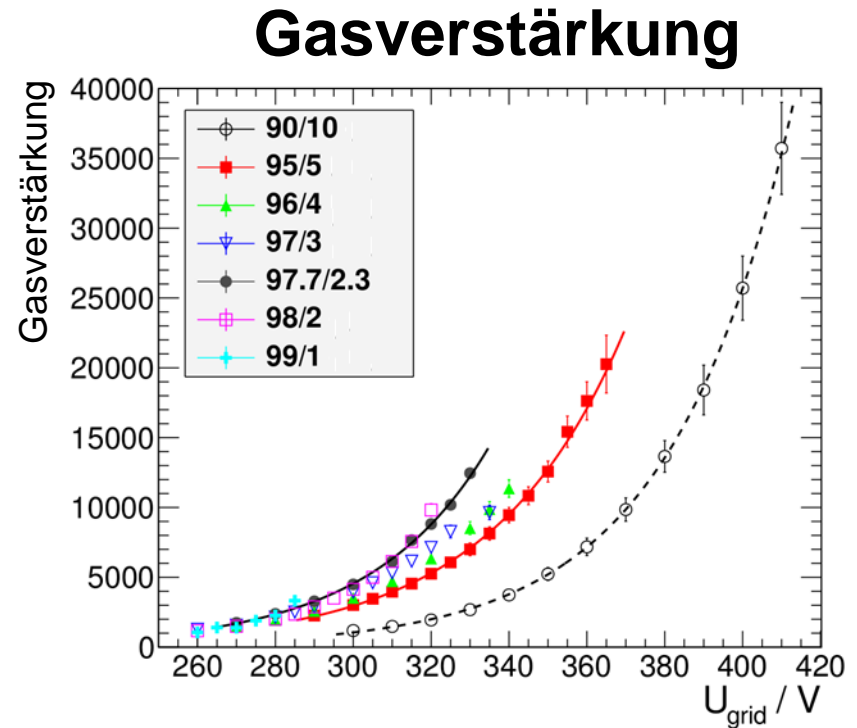


Variation Driftfeld



Gasverstärkungseigenschaften

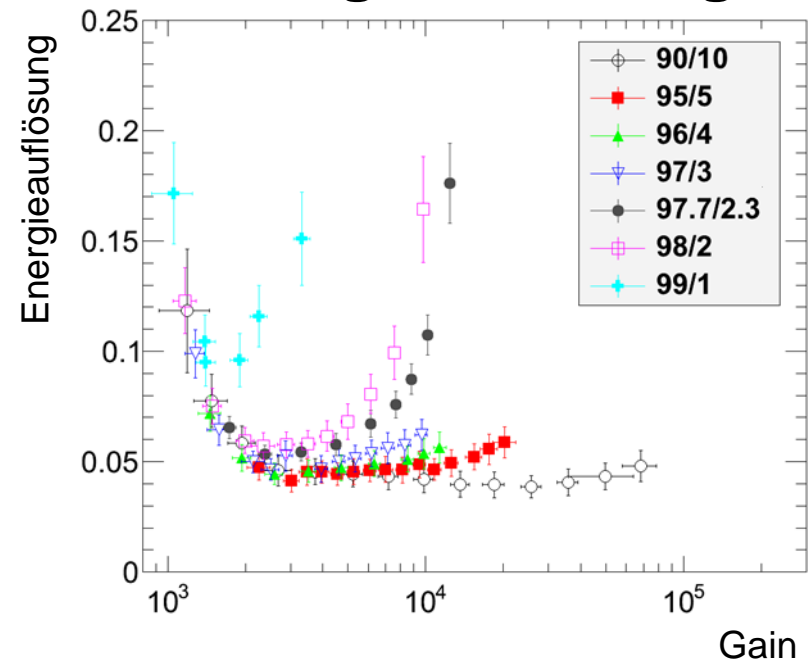
- Exponentielle Abhängigkeit von U_{Grid}
- Bei gegebenem U_{Grid} ist Gasverstärkung kleiner für mehr Isobutan
- Maximale Gasverstärkung ist größer für mehr Isobutan



Gasverstärkungseigenschaften – Energieauflösung

- $R = \sigma_D / N_D$
- R weist ein Minimum auf
- R ist besser für mehr Quencher
- $R_{meas} = F \frac{\sigma}{\sqrt{N}}$
- $F_{(90/10)} = 0.3338 \pm 0.0008$
- Bekannte Werte für Argon $\sim 0.25 - 0.35$

Energieauflösung



Ar/iC ₄ H ₁₀	U_{grid} / V	E_{grid} / E_{drift}	R
90/10	380	368	3.85% \pm 0.06%
95/5	335	134	4.38% \pm 0.05%
96/4	320	163	4.76% \pm 0.06%
97/3	300	257	4.60% \pm 0.05%
97.7/2.3	280	96	5.33% \pm 0.04%
98/2	290	133	5.40% \pm 0.06%
99/1	275	169	9.02% \pm 0.10%

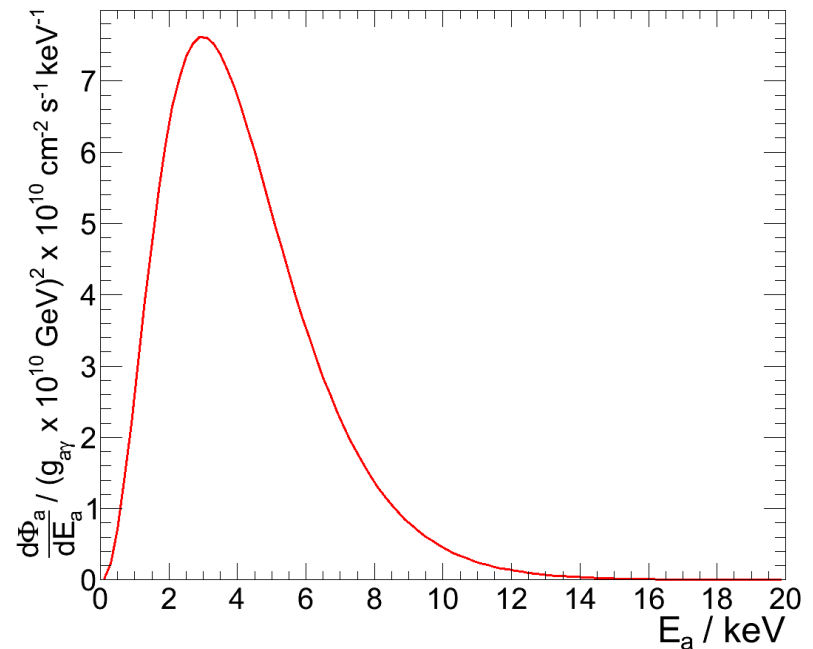
Zusammenfassung

- Energieauflösungen von bis zu 3.85 ± 0.06 %
- Ladungsaustausch konnte identifiziert und (teilweise) korrigiert werden
- Arbeitspunkt für Röntgendetektor in verschiedenen Gasgemischen wurde bestimmt
- Detektor bereit für Einsatz am CERN Axion Solar Telescope

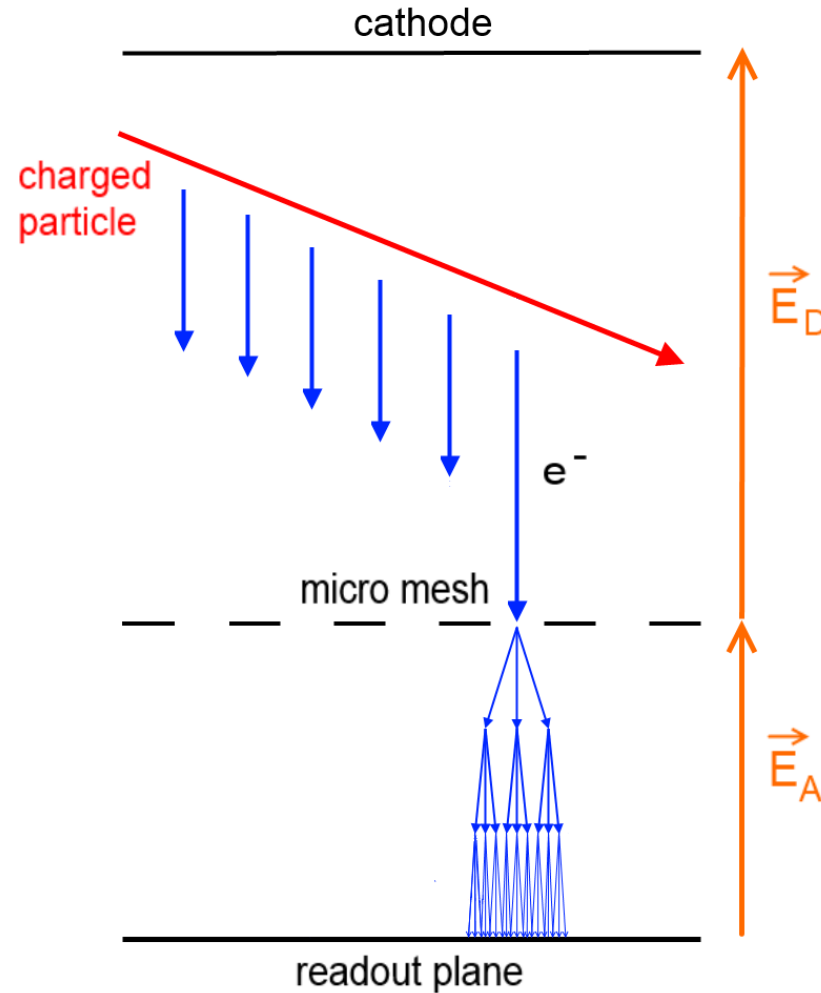
CERN Axion Solar Telescope – Requirements on a detector

- Sensitive in the soft X-ray regime
- Good rejection of background and noise
- Highest efficiency at low rates

Expected solar axion flux



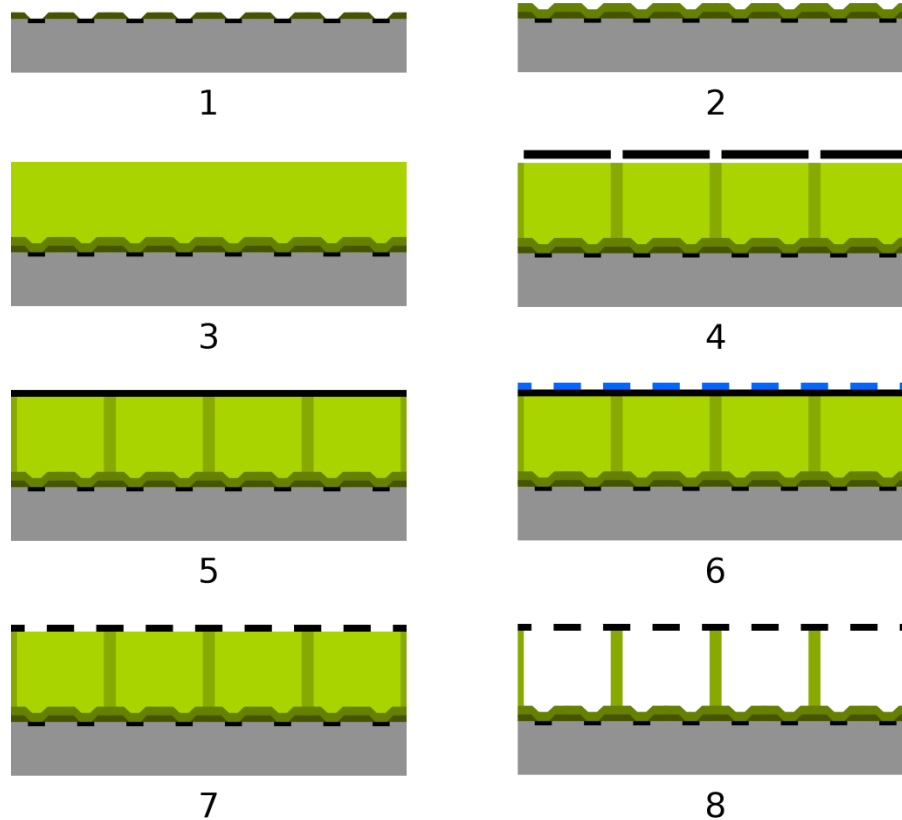
Experimental setup – Micromegas



Experimental setup – Expectations

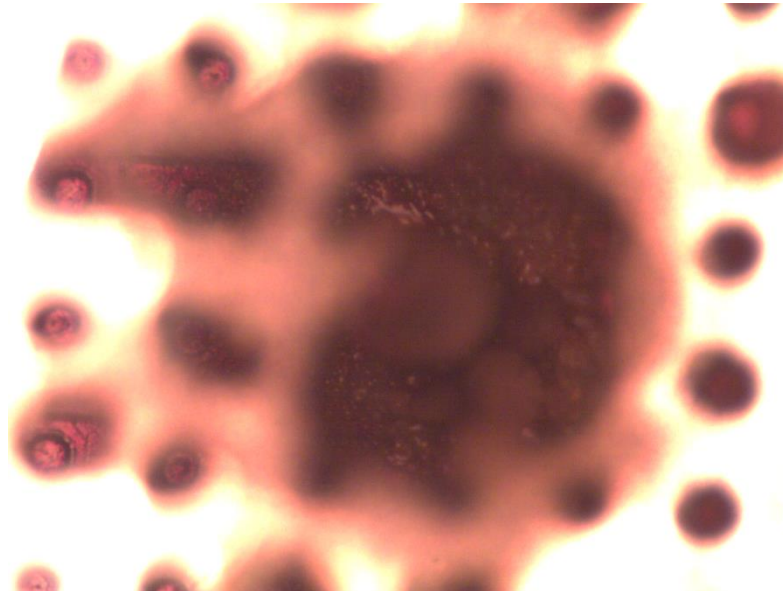
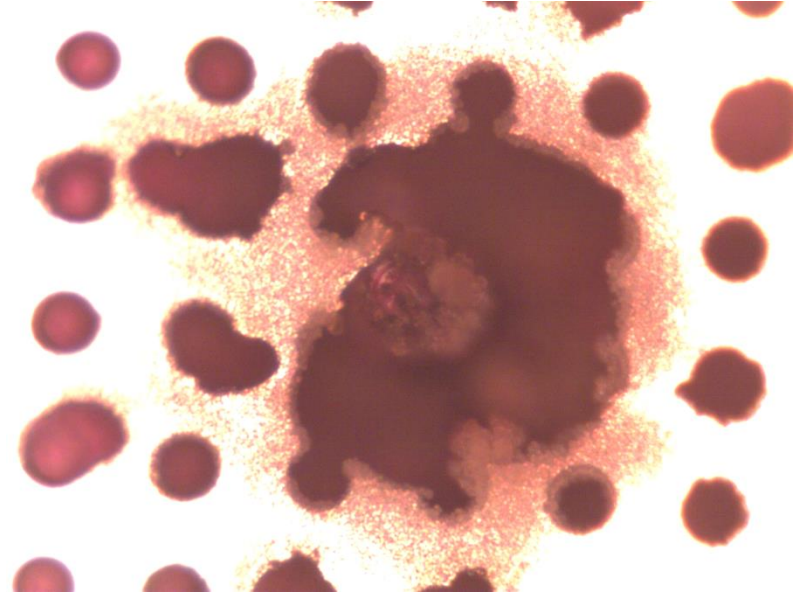
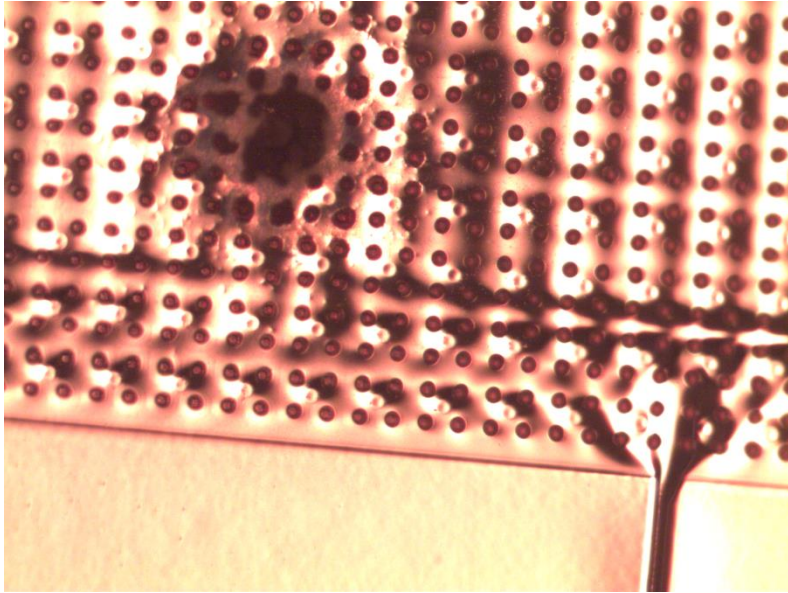
- ^{55}Fe decays via electron capture
- Emits photons at 5.9 keV and 6.4 keV
- 6.4 keV filtered out by a Cr-foil
- Two lines expected from the 5.9 keV photons:
 - 5.755 keV: the photo peak
 - 2.689 keV: the escape peak
- Mean ionization energy in argon is 26 eV
 - 222 electrons in the photo peak
 - 103 electrons in the escape peak

InGrid production

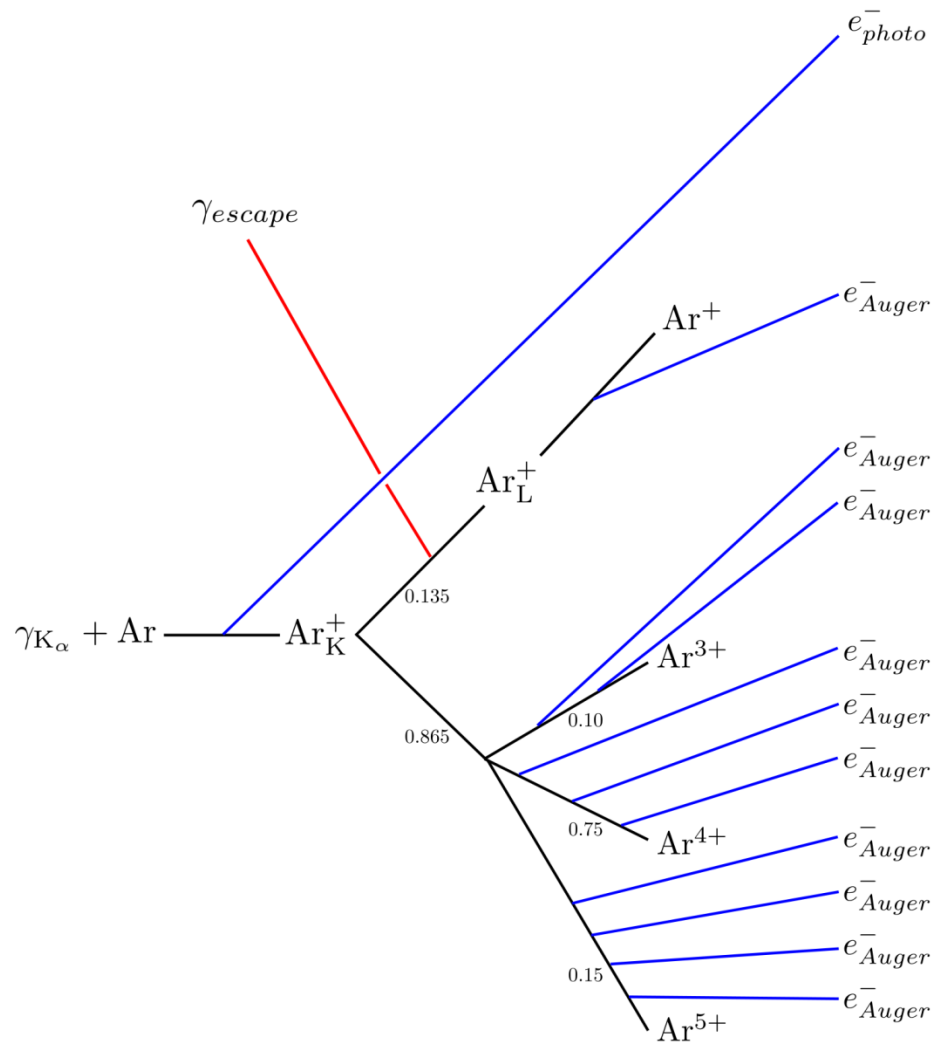


- Substrate
- Metal
- Passivation layer
- Protective layer silicon nitride
- Negative photoresist SU-8
- Exposed SU-8

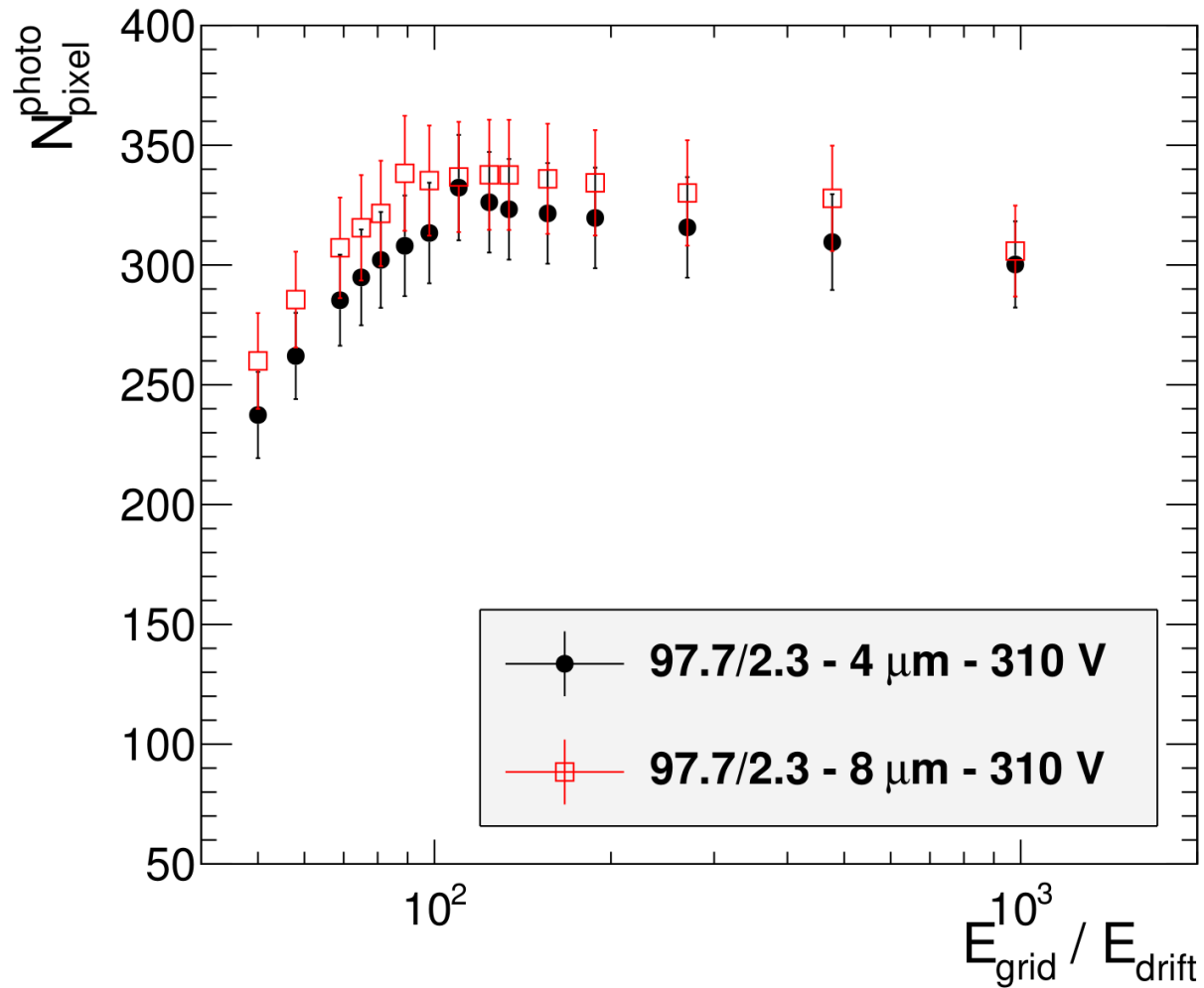
Damaged InGrid



Development of ^{55}Fe spectrum

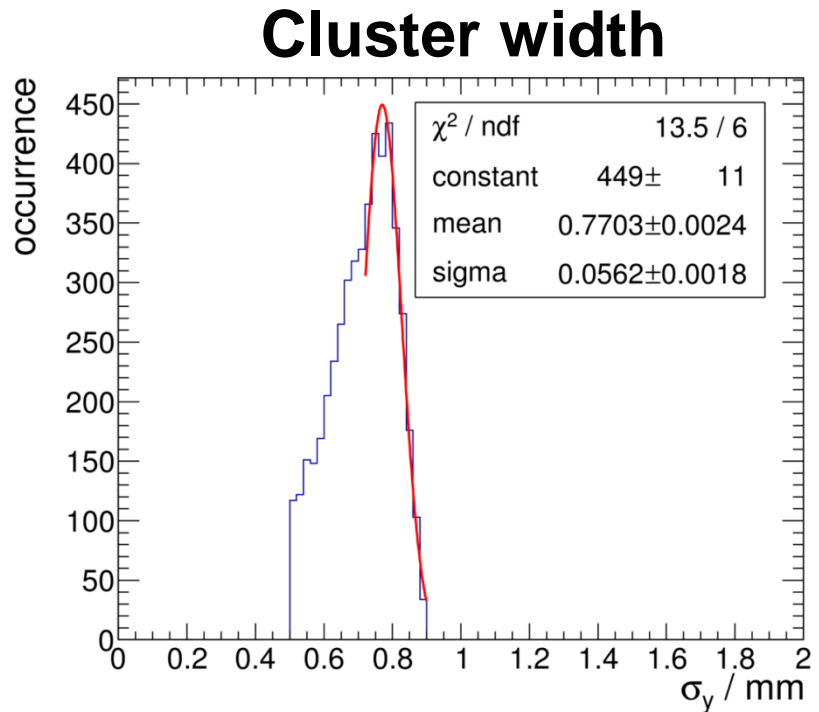


Collection efficiency



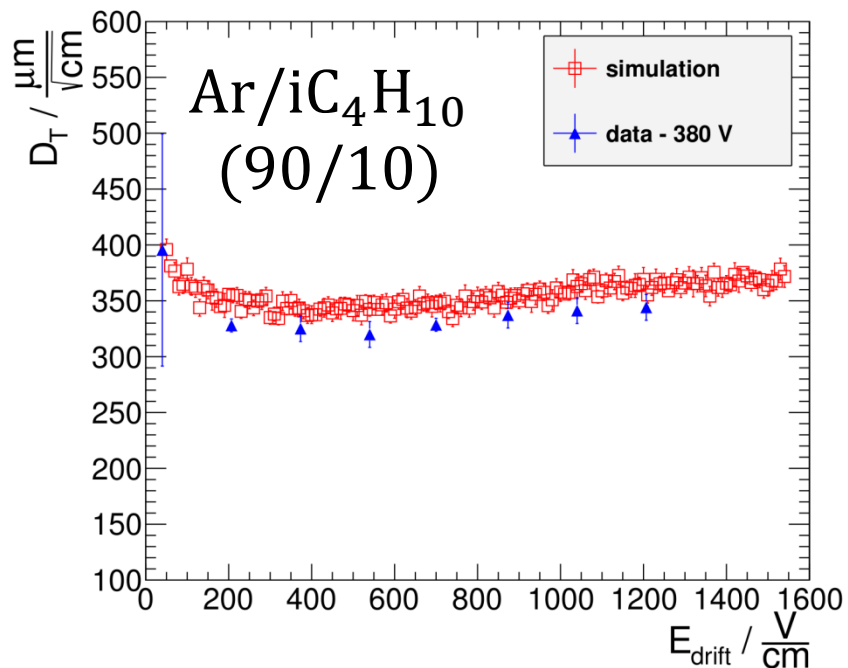
Field studies – Diffusion

- $D_T = \frac{\sigma_y}{\sqrt{z}}$
- Maximum width achieved for maximum drift distance
- Assume $z = 3$ cm
- σ_y from fit

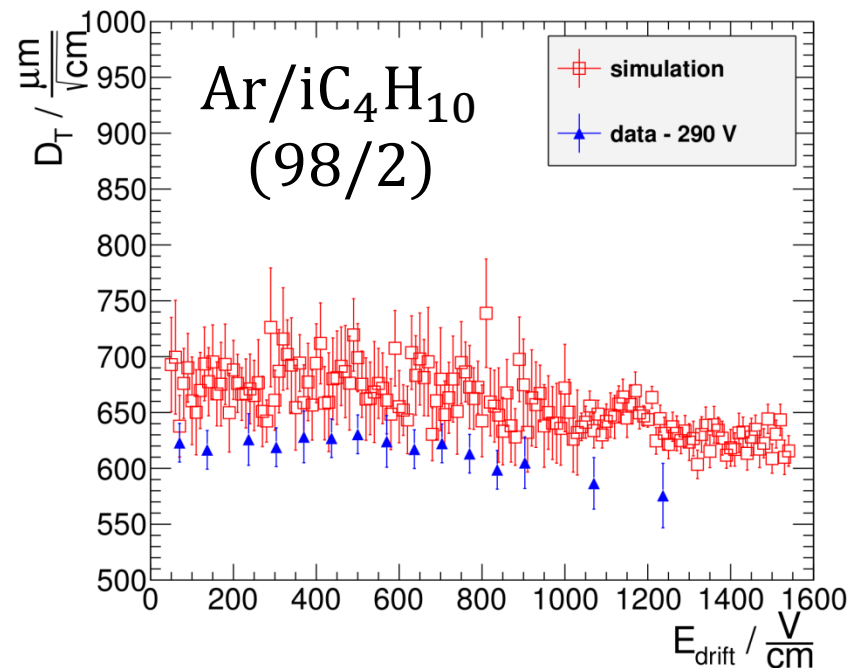


Field studies – Diffusion

Diffusion constant



Diffusion constant

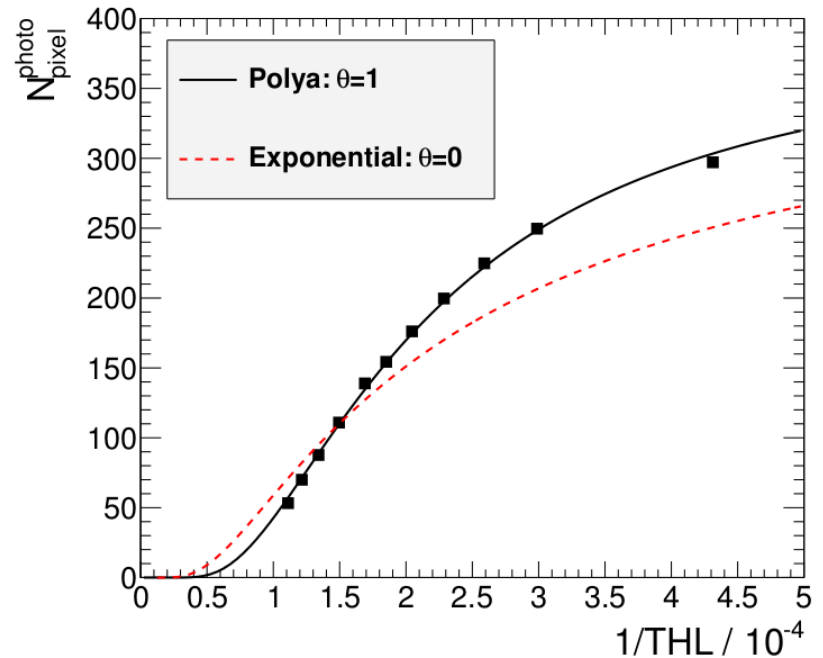


Detection efficiency

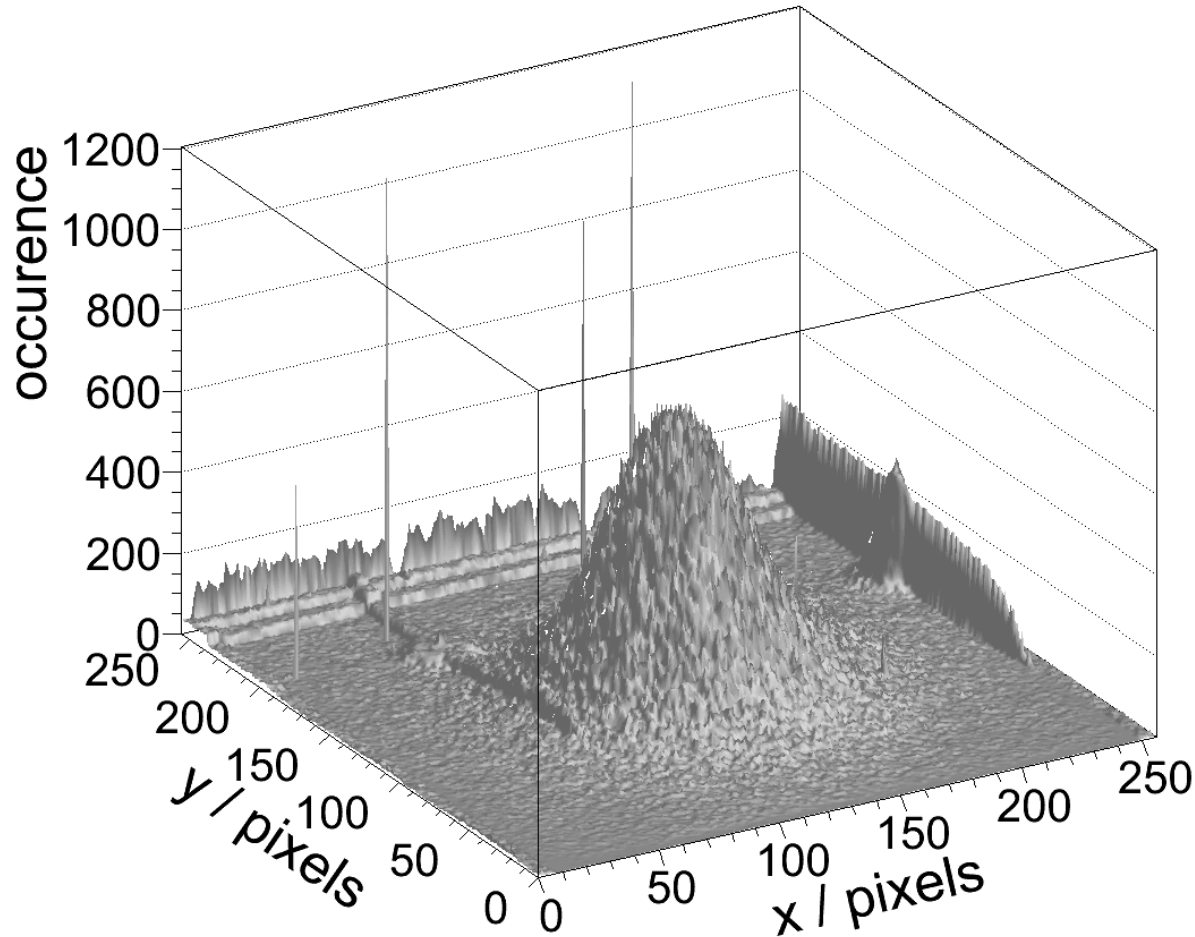
$$\delta = \int_t^\infty \frac{1}{\langle Q \rangle} \frac{(\theta + 1)^{\theta+1}}{\Gamma(\theta + 1)} \left(\frac{Q}{\langle Q \rangle} \right)^\theta \exp\left(-(\theta + 1) \frac{Q}{\langle Q \rangle}\right) dQ$$

$$\delta = (1 + 2t/\langle Q \rangle) \exp\left(-\frac{2t}{\langle Q \rangle}\right)$$

$$\delta = \exp\left(-\frac{t}{\langle Q \rangle}\right)$$

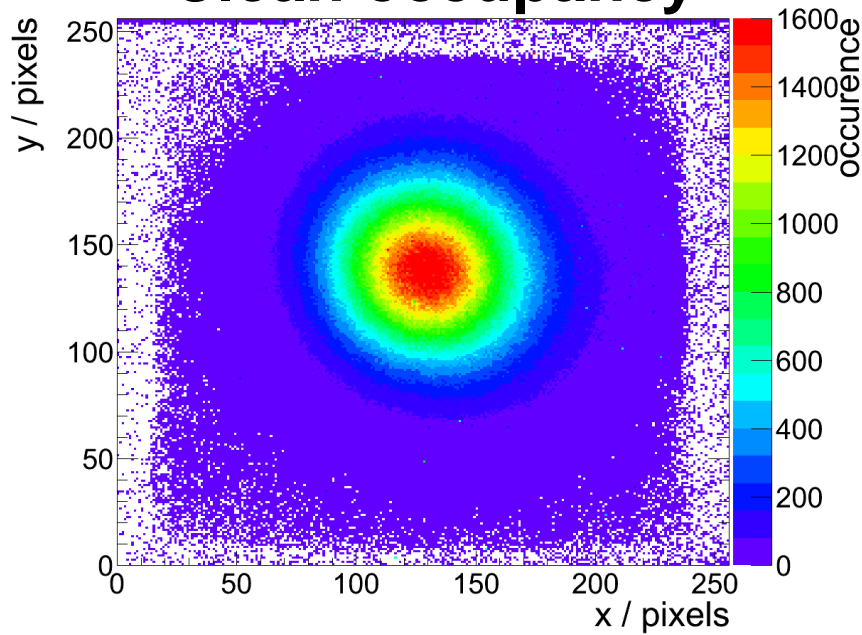


Data preparation – Cleaning

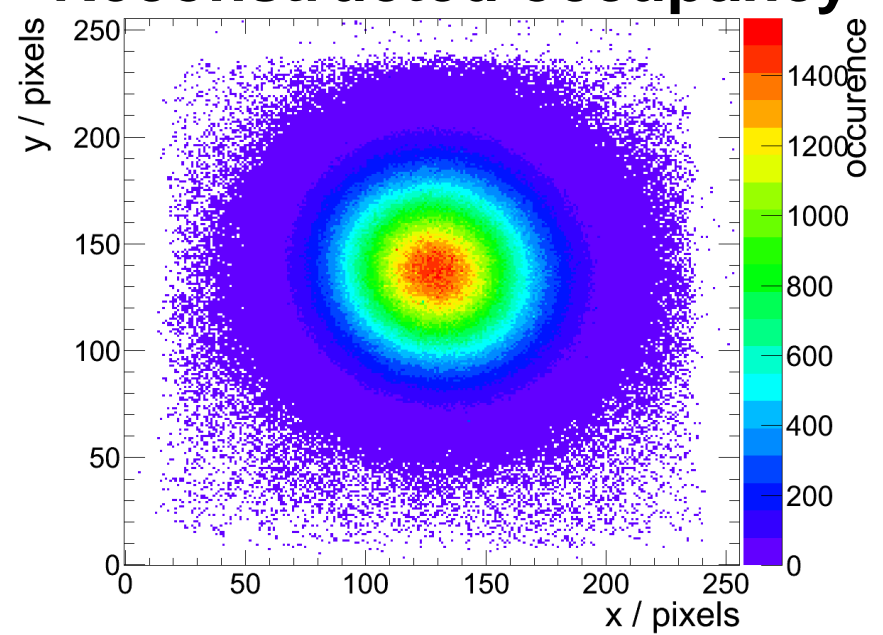


Data preparation – Reconstruction

Clean occupancy



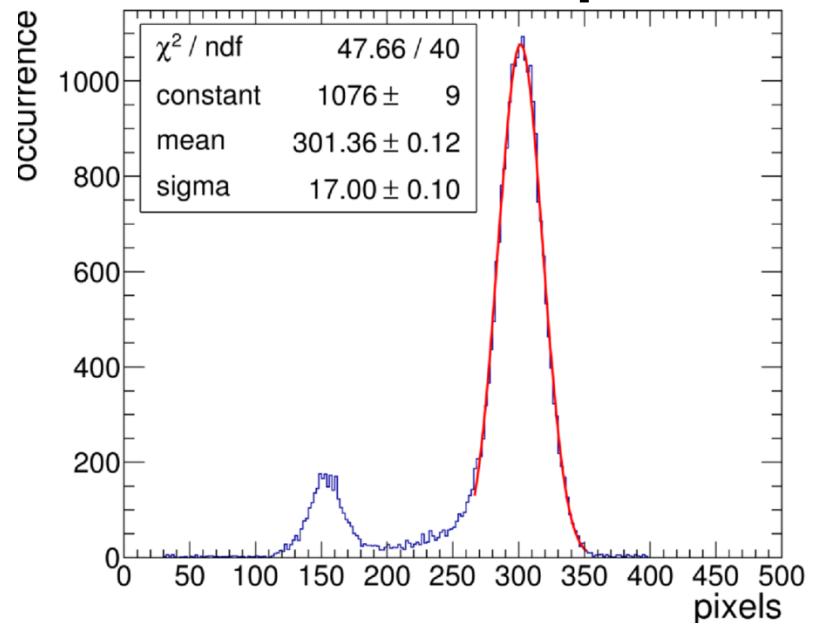
Reconstructed occupancy



Data preparation – Cut application

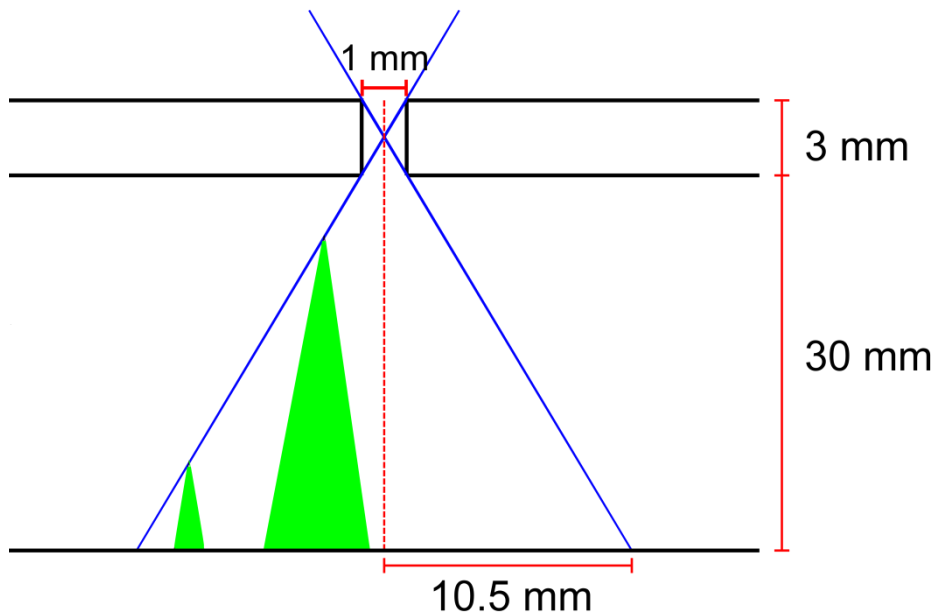
- ^{55}Fe spectrum already visible
- Photo peak deviates from Gaussian on the left edge
- This hints at events with insufficient diffusion

Reconstructed spectrum

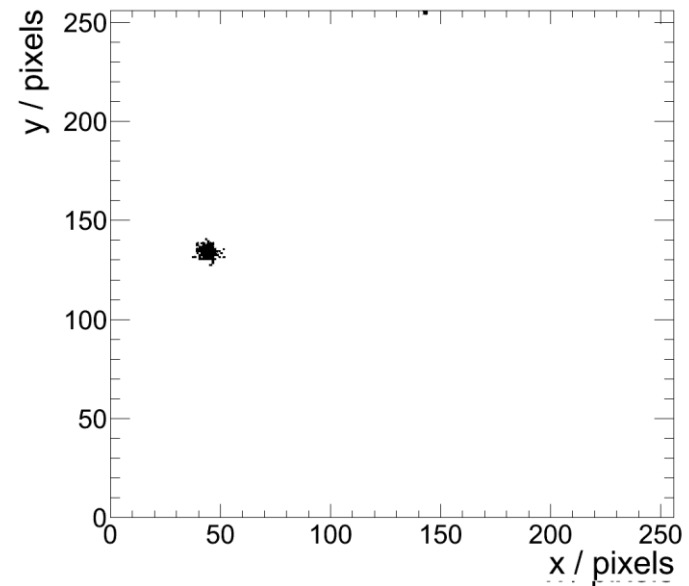


Data preparation – Cut application

Detector geometry

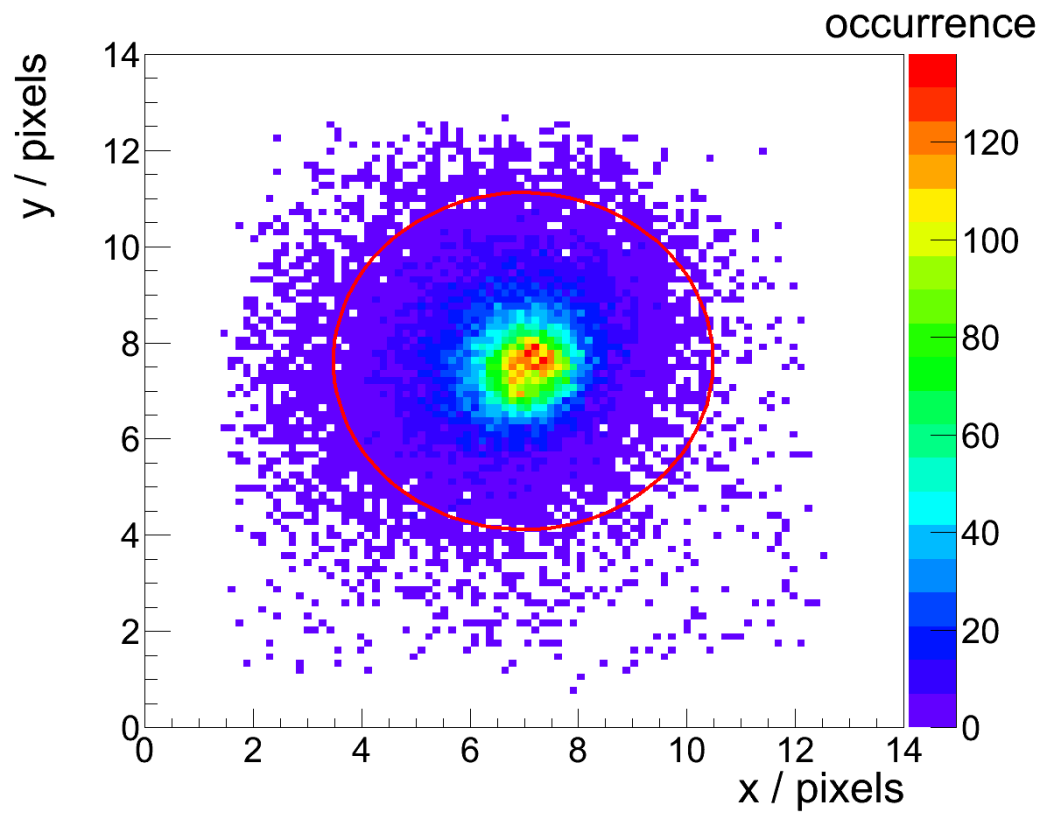


Example of insufficient diffusion



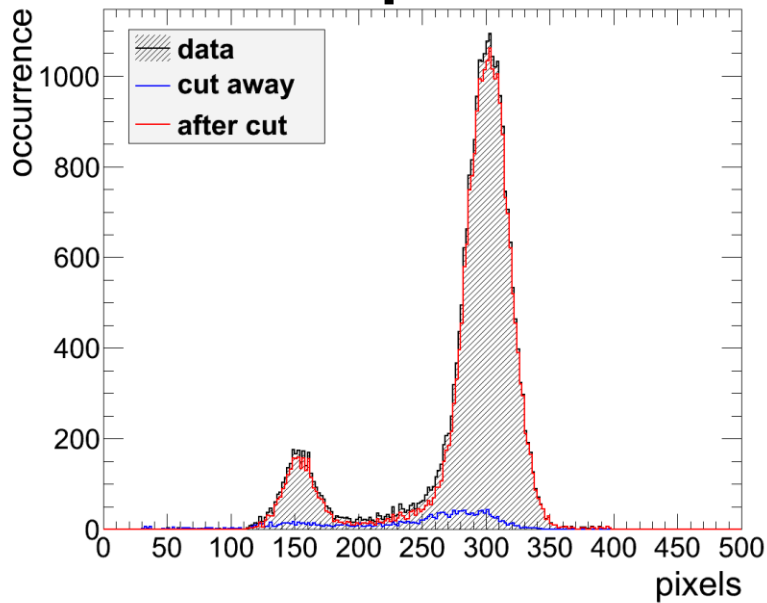
Data preparation – Cut application

Cut on center positions

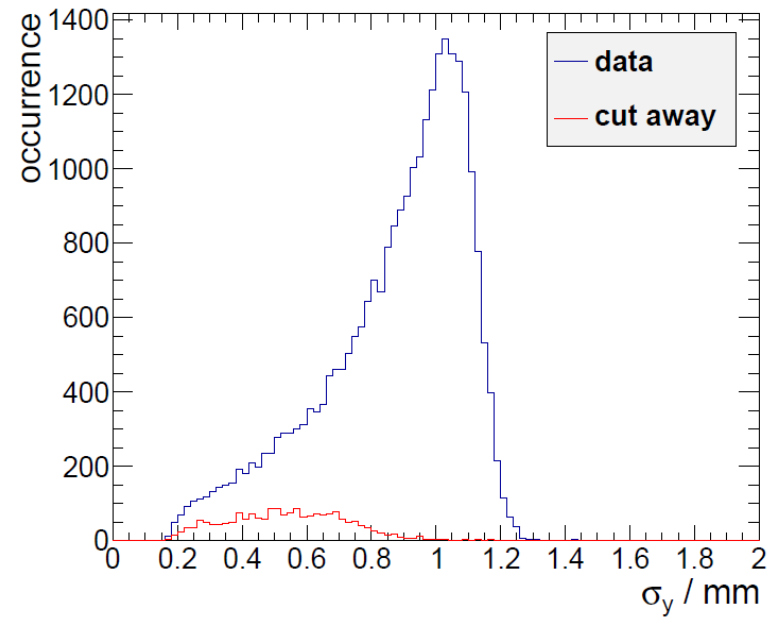


Data preparation – Cut application

Pixel spectrum

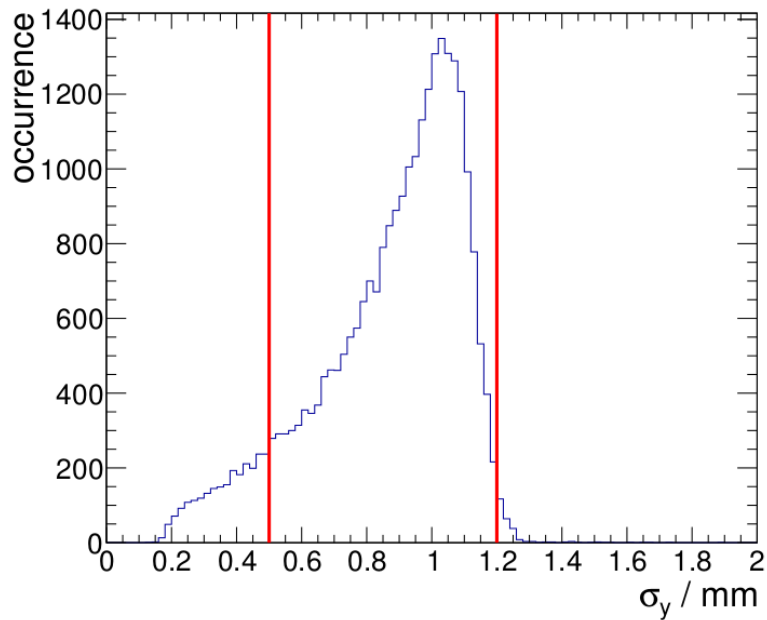


Cluster width

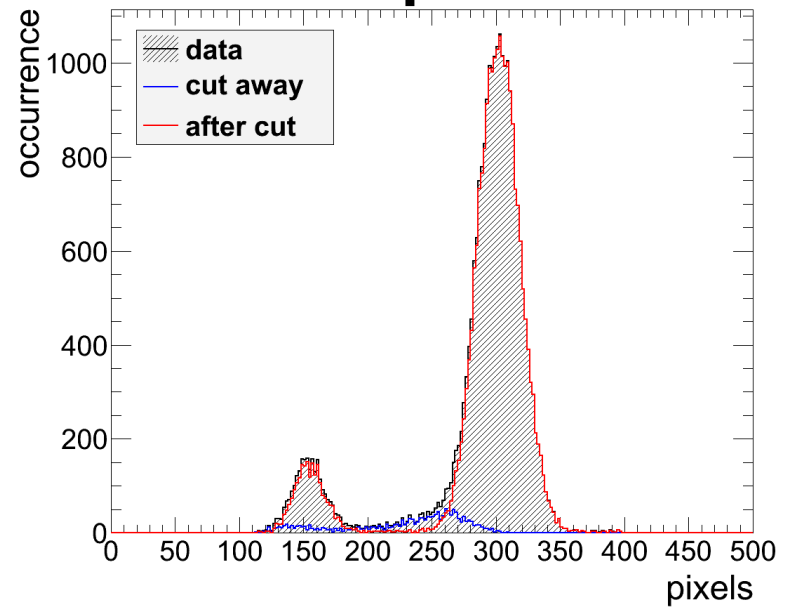


Data preparation – Cut application

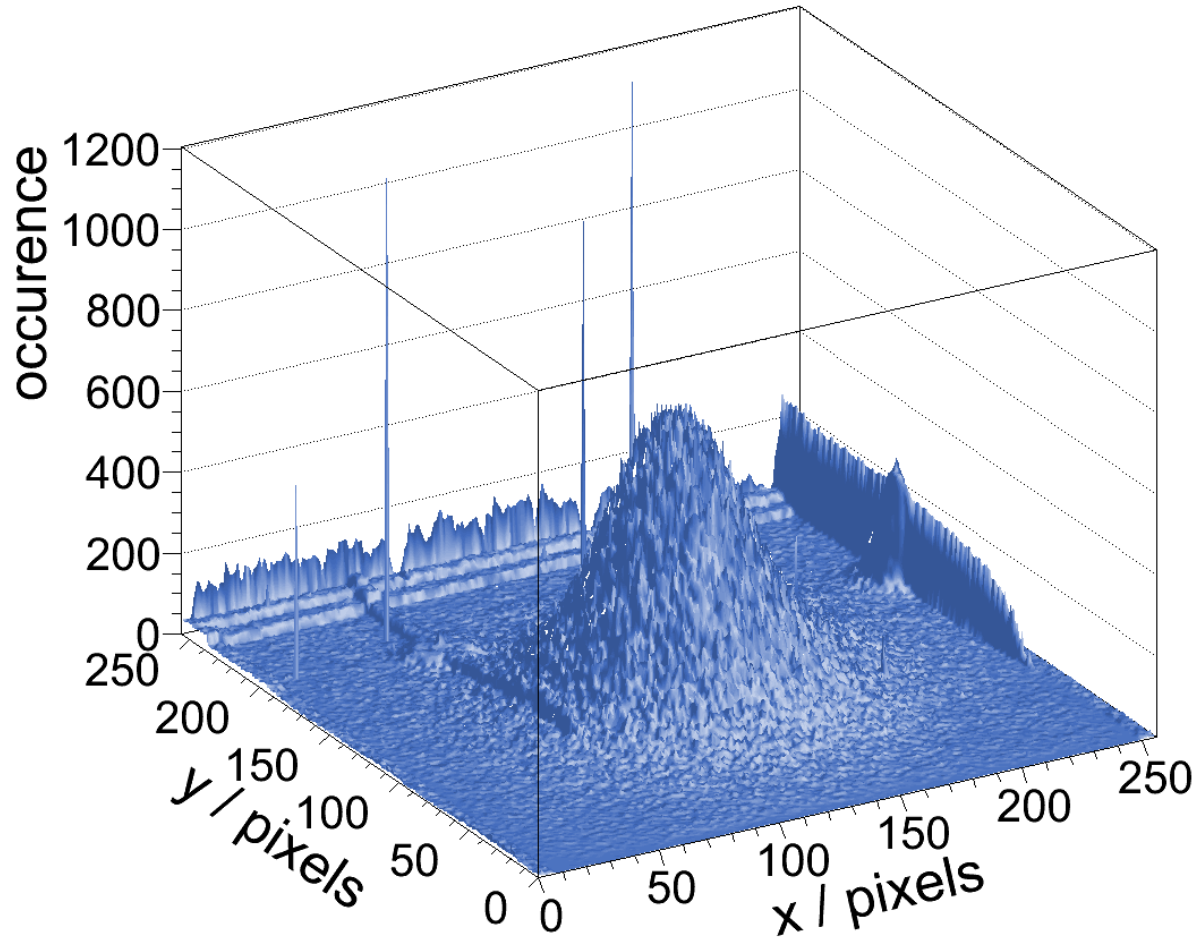
Cut on cluster width



Pixel spectrum

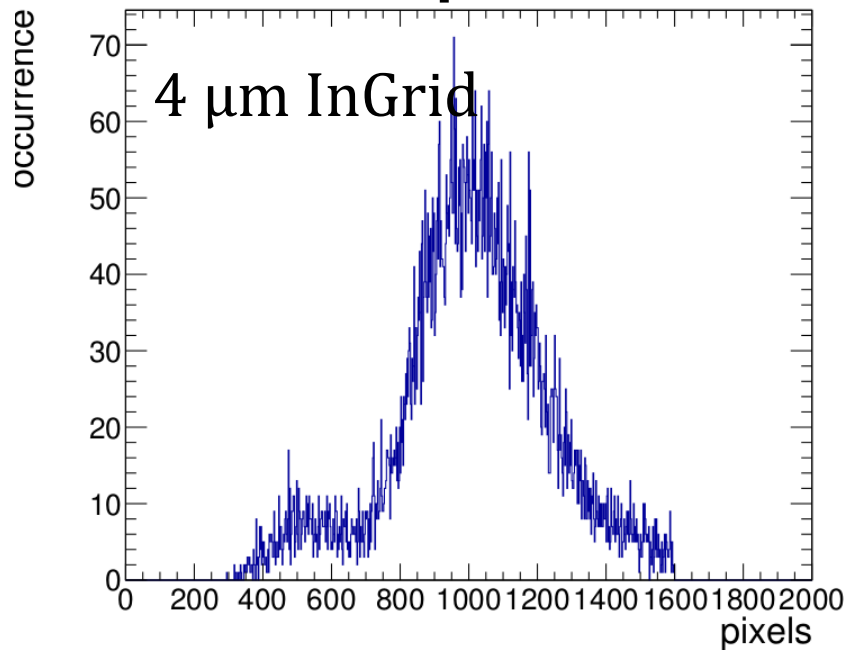


Data preparation – Cleaning

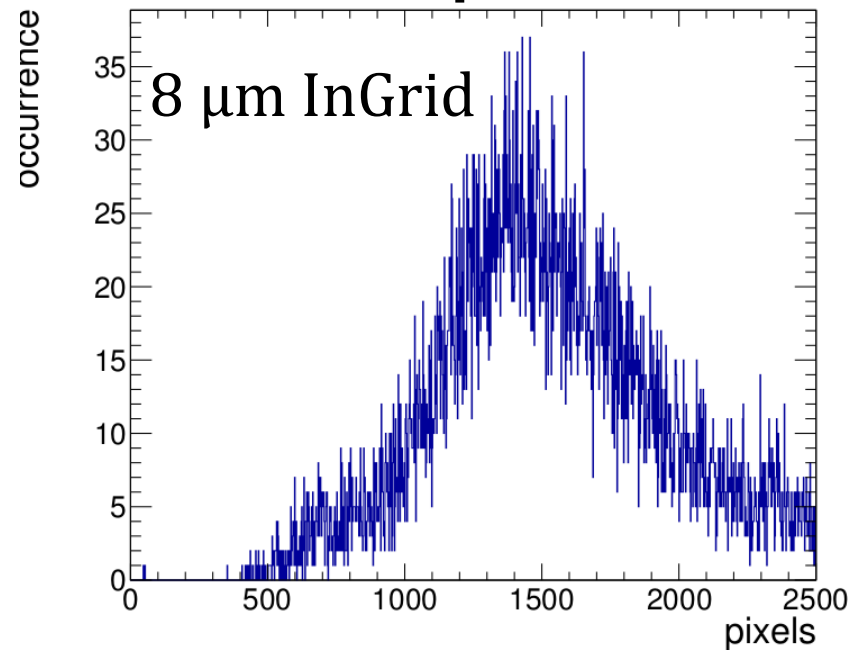


Ladungsaustausch – Einfluss der Schutzschicht

Pixel spectrum

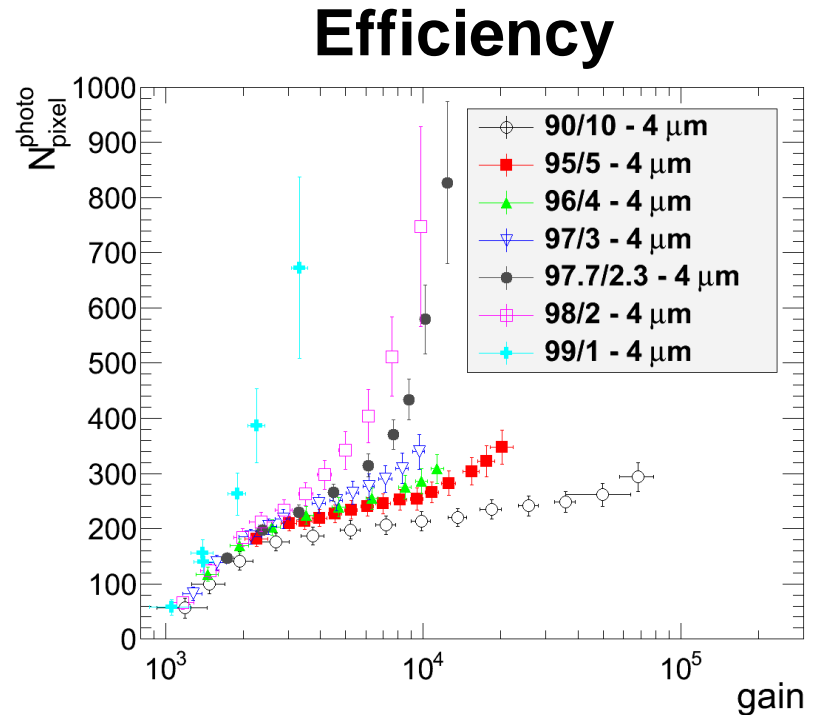


Pixel spectrum



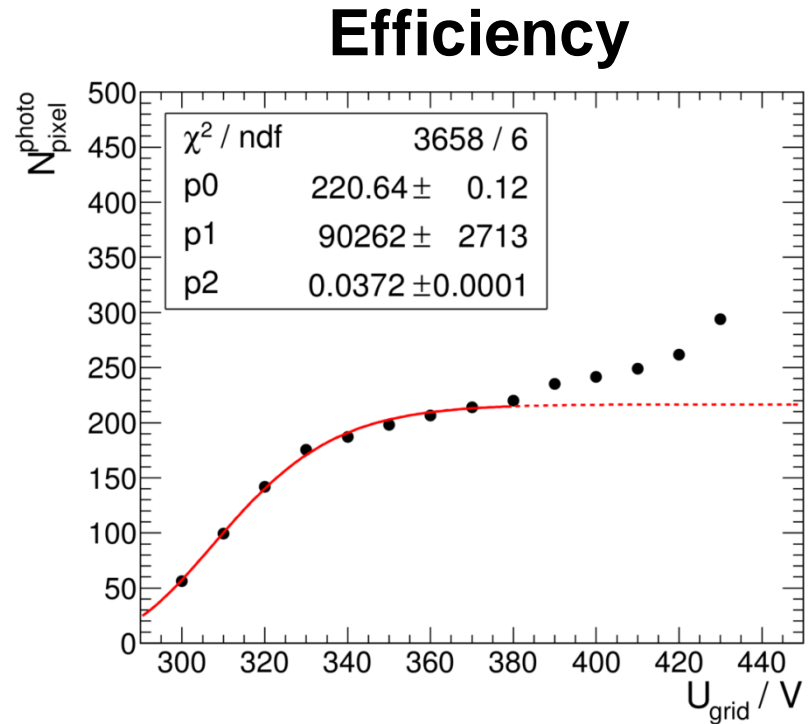
Amplification properties – Gas gain

- Number of detected electrons N_D depends on the gas gain
- Charge sharing effects are ‘under control’ for high quencher fractions



Amplification properties – Detection efficiency

- Fit function can be derived from the Polya function
- p_0 determines the number of electrons that reached the amplification stage



Amplification properties – Detection efficiency

Ar/iC ₄ H ₁₀	N_{pixel}^{photo}	p_0	δ
90/10	219.80 ± 0.09	220.64 ± 0.12	0.9962 ± 0.0007
95/5	253.48 ± 0.09	273.5 ± 0.6	0.9368 ± 0.0021
96/4	251.91 ± 0.10	271.7 ± 0.4	0.9272 ± 0.0014
97/3	239.63 ± 0.08	279.40 ± 0.30	0.8577 ± 0.0010
97.7/2.3	278.20 ± 0.09	325.0 ± 0.4	0.8560 ± 0.0011
98/2	262.27 ± 0.10	353.3 ± 0.5	0.7423 ± 0.0011

$N_P^{Theo} \approx 222 \rightarrow$ high collection efficiency

Amplification properties – Mean ionization energy

Ar/iC ₄ H ₁₀	N_D	W / eV	W_{theo} / eV
90/10	219.80 ± 0.09	26.182 ± 0.010	25.7
95/5	253.48 ± 0.09	22.704 ± 0.008	25.85
96/4	251.91 ± 0.10	22.845 ± 0.009	25.88
97/3	239.63 ± 0.08	24.016 ± 0.008	25.91
97.7/2.3	278.20 ± 0.09	20.687 ± 0.007	25.93
98/2	262.27 ± 0.10	21.943 ± 0.008	25.94

$$W = 5755 \text{ eV}/N_D$$