Photon Detection in Micro-Pattern Gaseous Detectors

RU-A DAY 2023

12.10.2023

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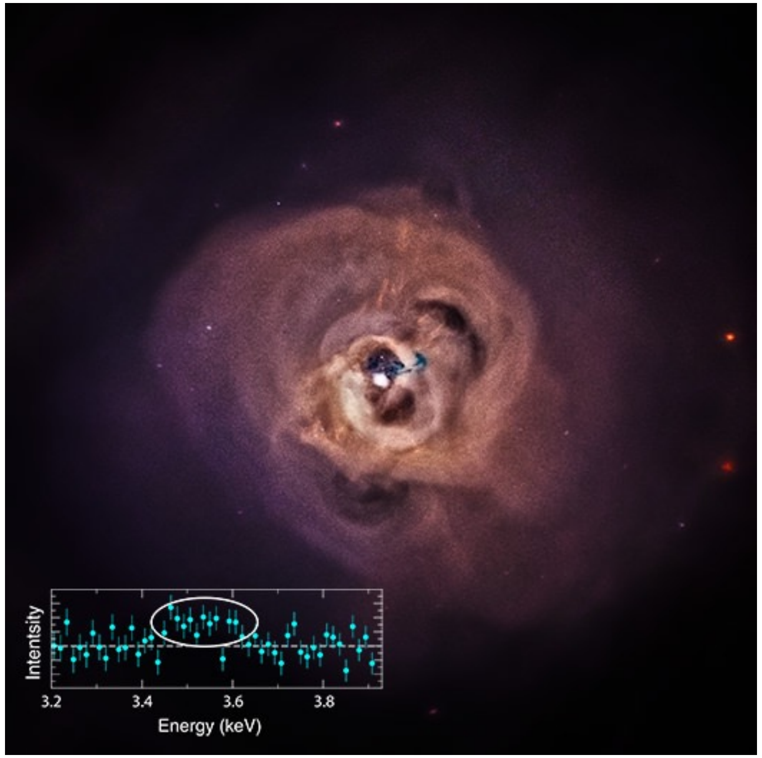
ORIGINS Excellence Cluster

Motivation

Photon detection applications

- Astrophysics
- Material Research
- Particle Physics

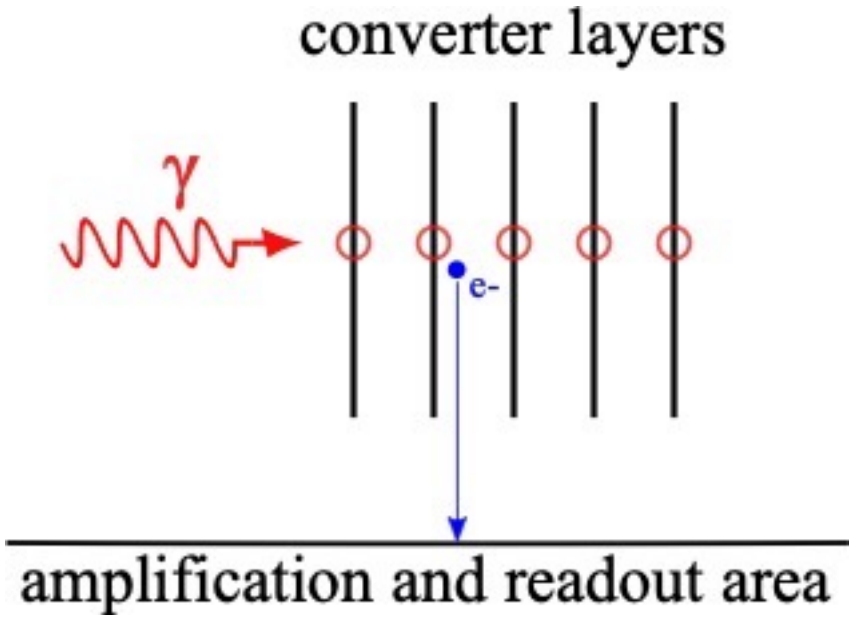


XMM Newton: X-ray signal coming from the Perseus galaxy cluster (from [1])

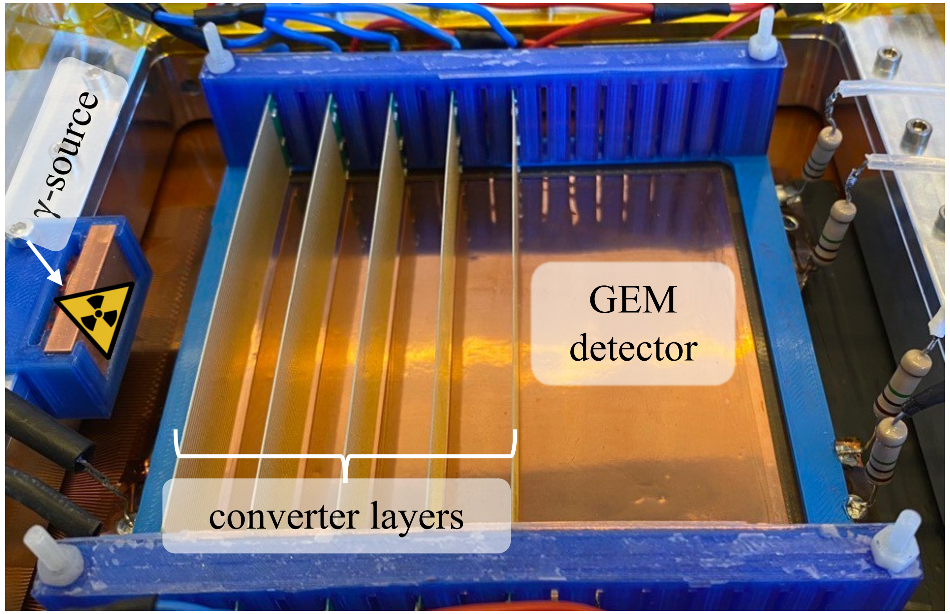
→ efficient photon detection with high spatial resolution
→ use of **Micro-Pattern Gaseous Detectors**

Motivation

- Micro-Pattern Gaseous Detector: extremely good spatial resolution and high-rate capability
- gas → low density → poor detection efficiency for photons → ρ(gas) << ρ(solid)
- idea: increase detection efficiency by **solid converter layers**



multiple converter layers

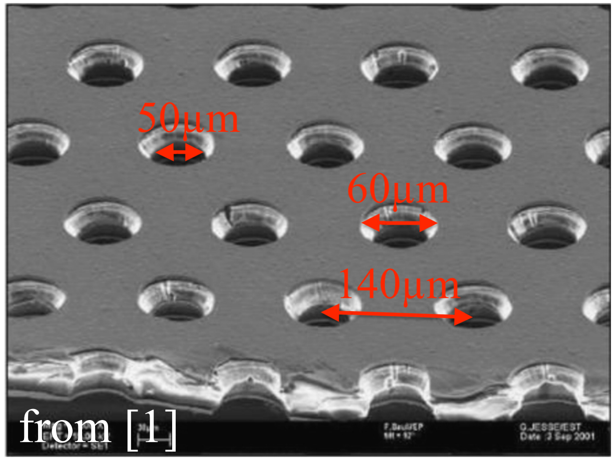


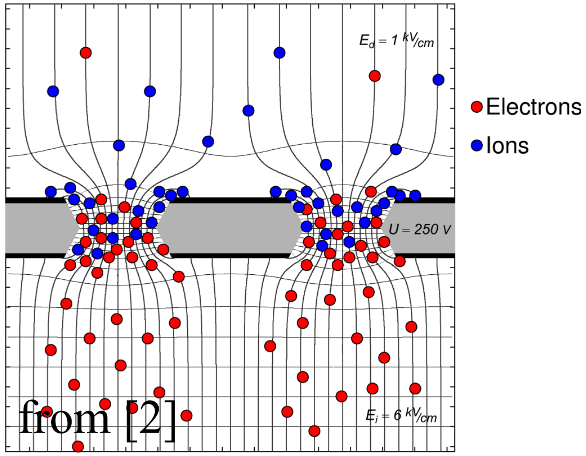
multiple converter layers in detector

The GEM Detector Principle

- **G**aseous **E**lectron **M**ultiplier

- amplification by GEM foils:





- copper plated Kapton foils

- electron amplification factor per foil: 20
  → 3 foils → $20^3 = 8000$

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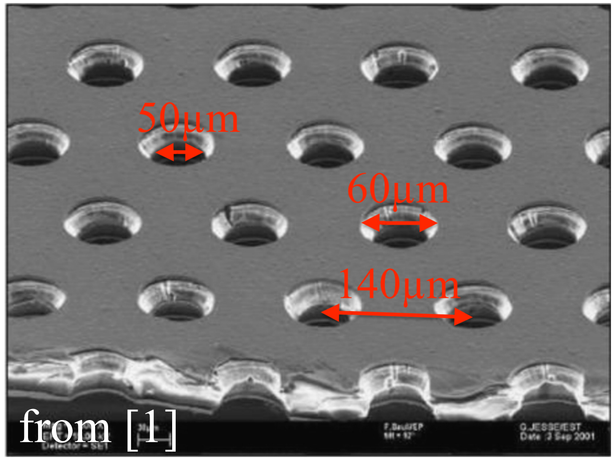

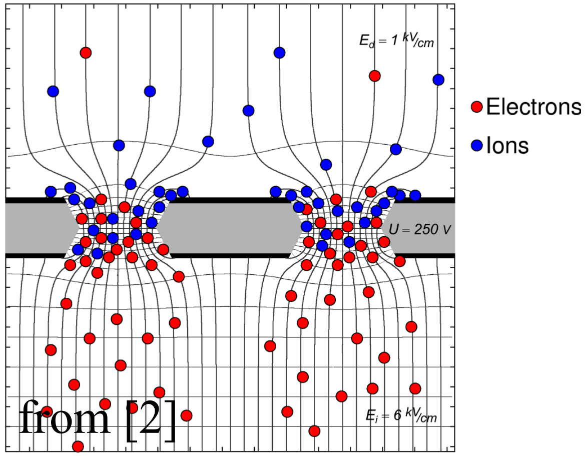

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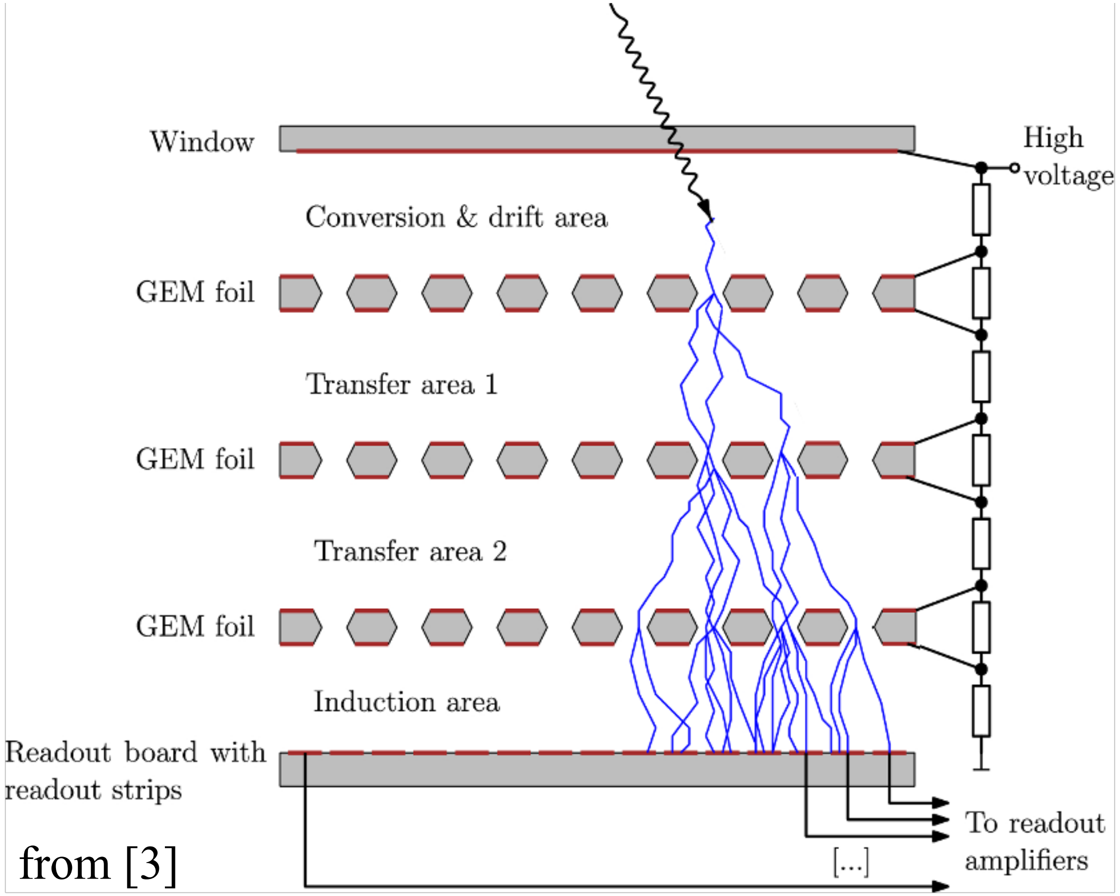
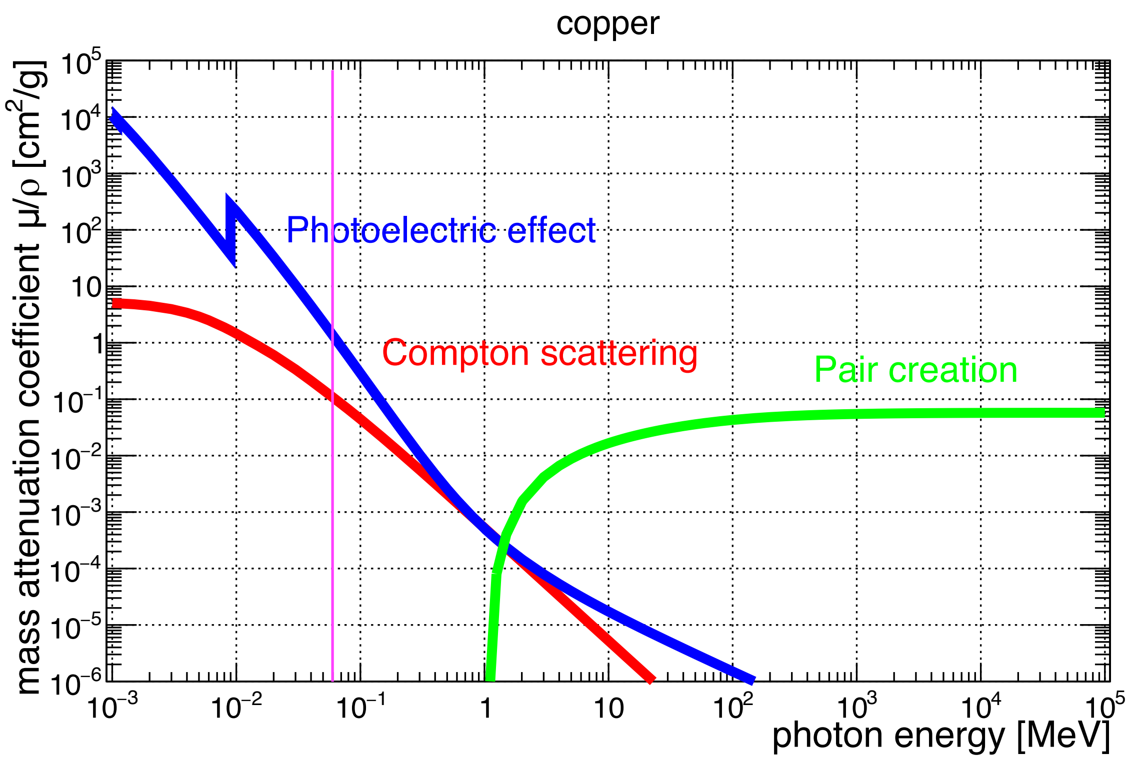


- advantages: → excellent spatial resolution (< 100 µm)
  → high-rate capability

Photon Detection Process



data from [4]

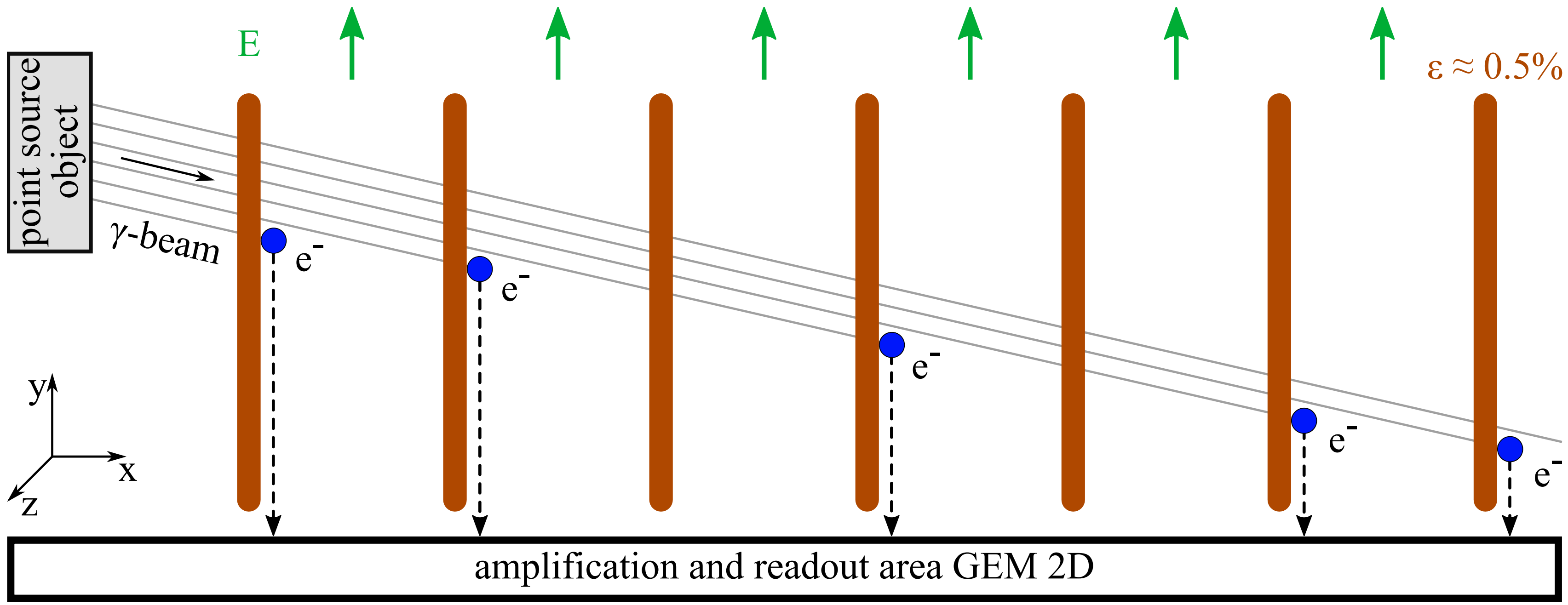
- first attempt: optimize detection for E_γ = 59.5 keV (Am241-source)
- solid copper layer enhances detection efficiency compared to pure argon due to:

  → higher mass attenuation coefficient
  $\mu(Ar) \approx 0.001\ cm^{-1}$
  $\mu(Cu) \approx 20\ cm^{-1}$

  → Photoelectric effect: $\sigma_{ph} \sim Z^5$

aim: enhance detection efficiency by **multiple** solid converter layers with high-Z coating

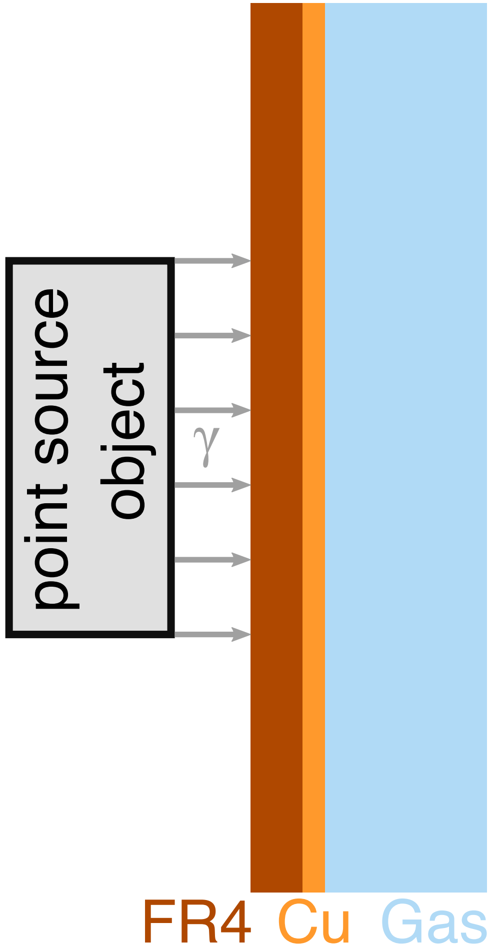
Perpendicular Layer Setup



Goals:

1. **high guidance efficiency** (optimized electric field)
2. **enable 3D position reconstruction** (adapted setup)
3. **high detection efficiency when using many layers, ε = 0.5 % per layer**
   → material optimization

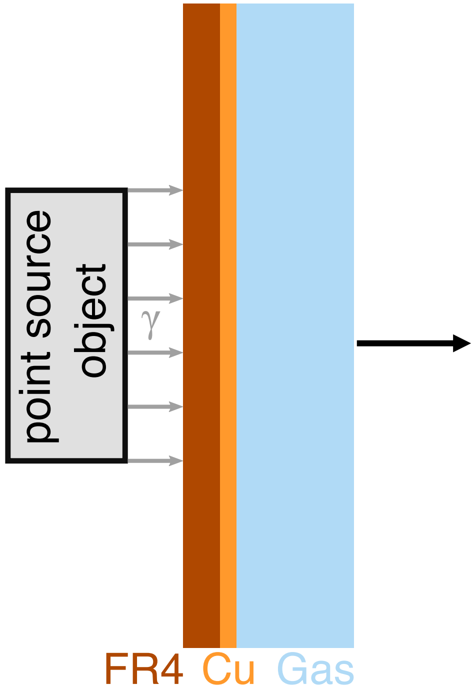
Simulation: Material Optimization

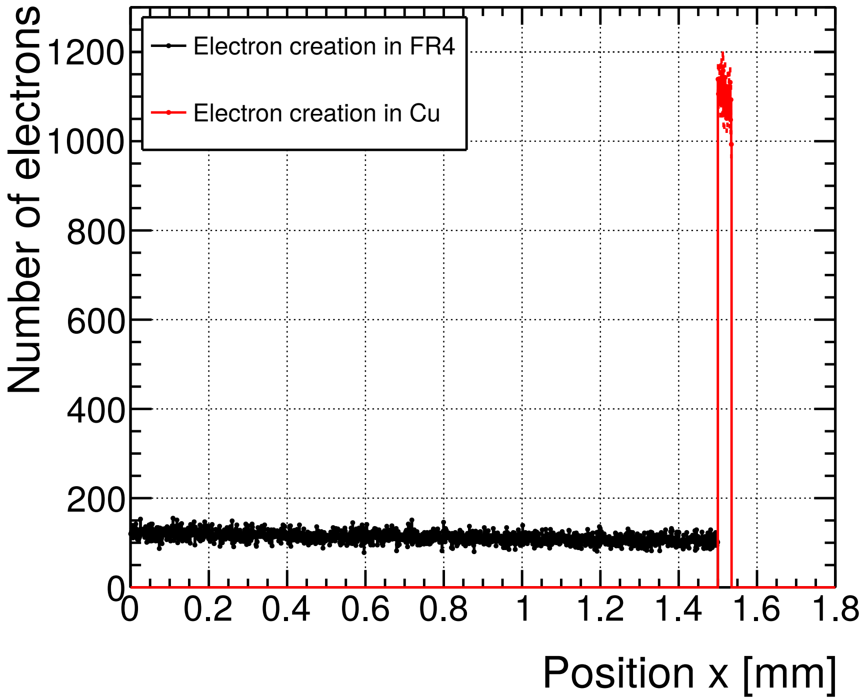


- Geant4 simulation: particle-matter interaction
- 59.5 keV photons
- converter layer: 1550 µm FR4, 35 µm Cu (industrial availaible) and 5 mm gas
- electrons created in interaction process

→ for detection electrons have to reach gas volume
→ optimization between creation and extraction

Electron Creation

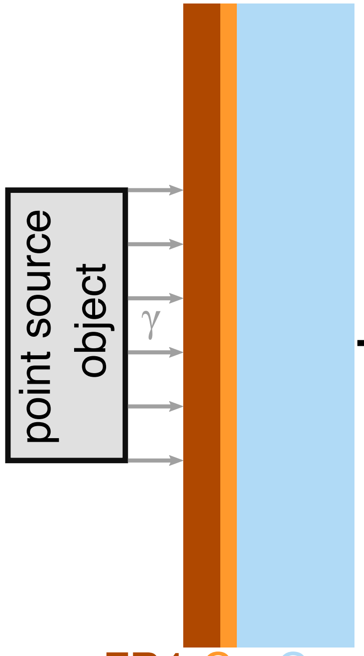




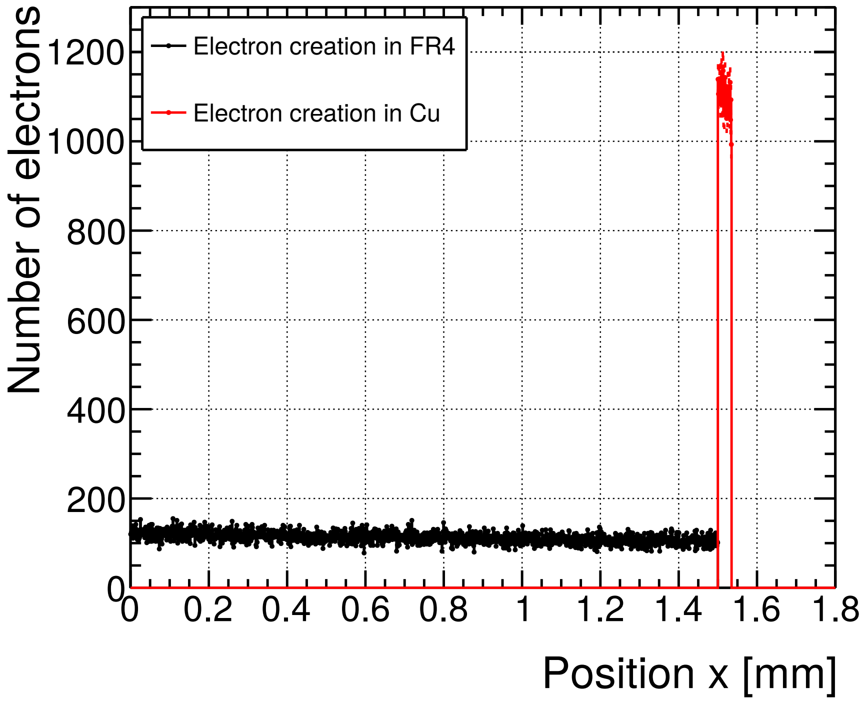
Simulation Setup

homogenous electron creation

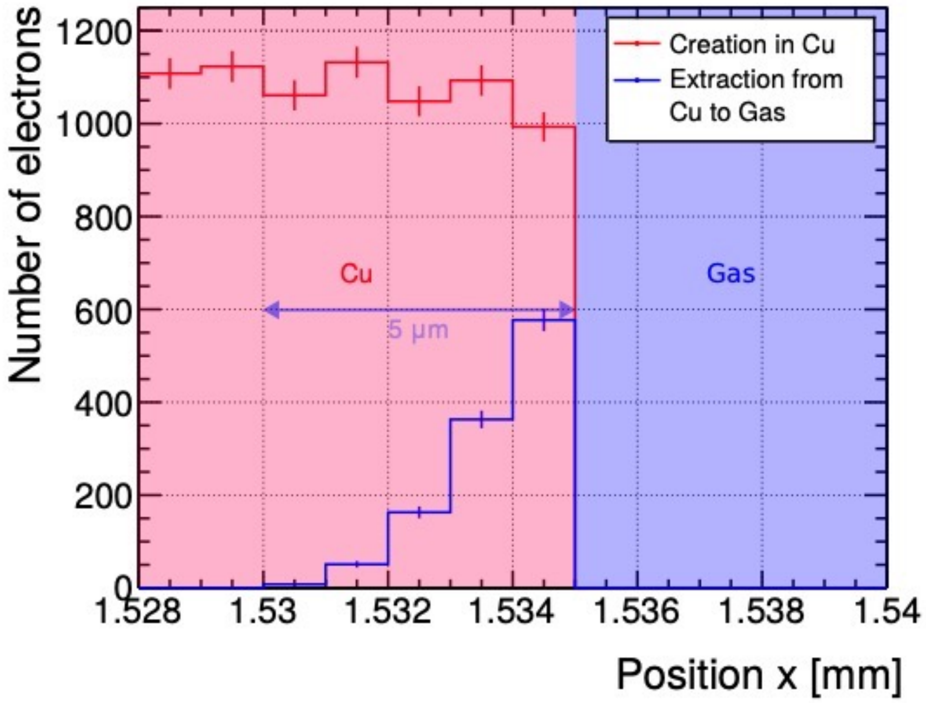
Electron Creation and Extraction



Simulation Setup

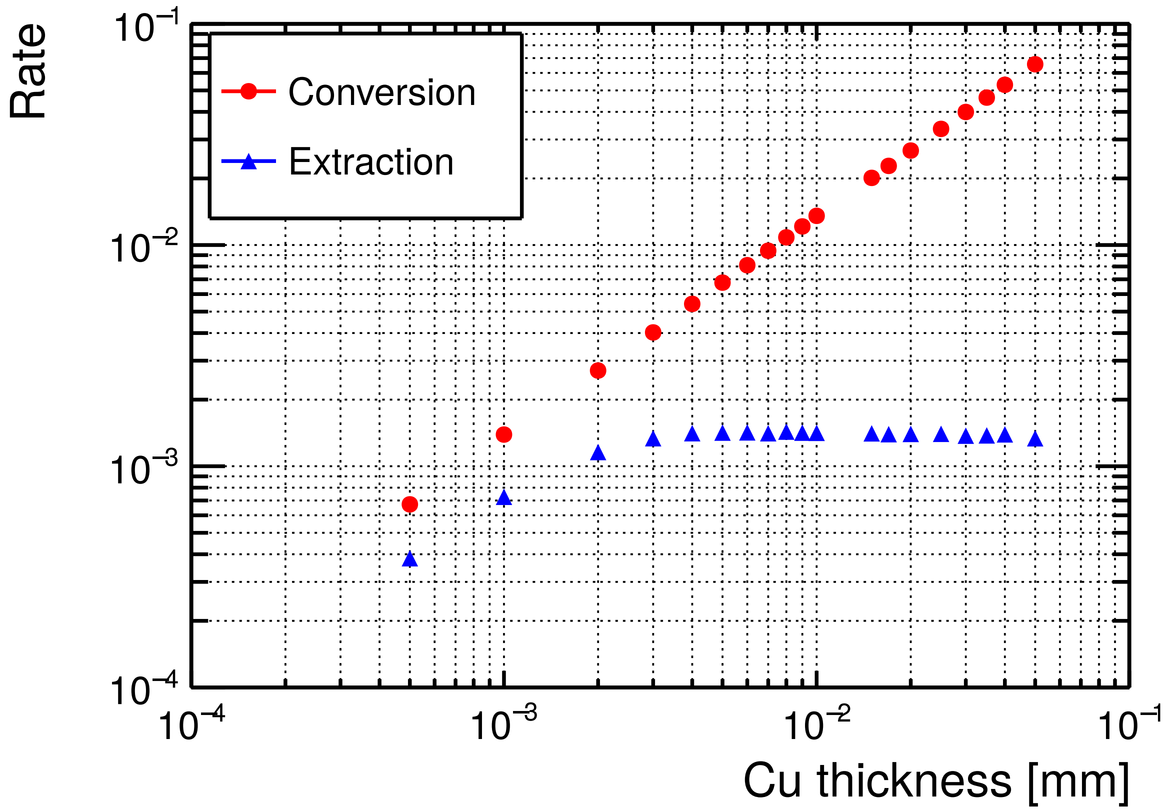


homogenous electron creation



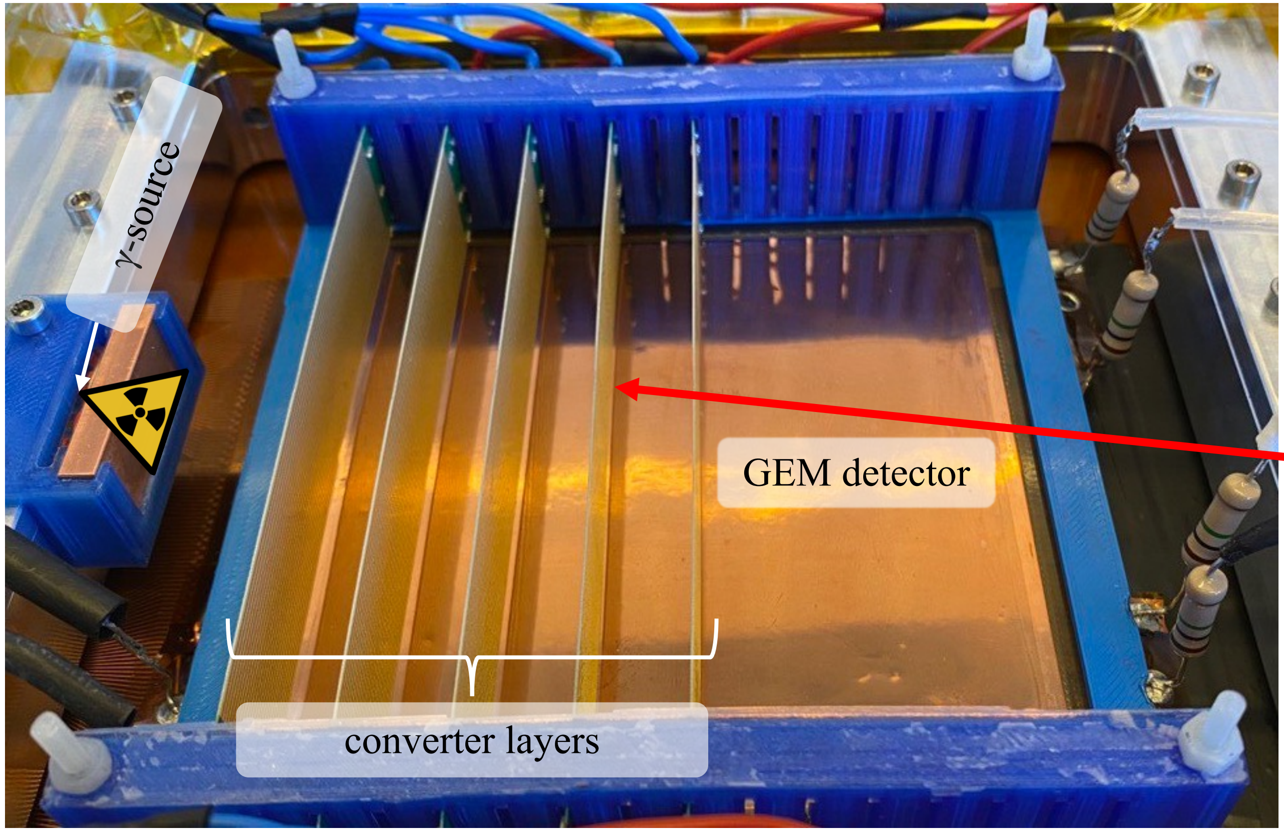
only electrons created in the last 5 μm in Cu can reach gas

Simulation: Material Optimization



- e^- creation rate increases with thickness
- e^- extraction rate saturates
- material optimization necessary:
  → **maximize number of extracted electrons**
  → **minimize unnecessary material**

Measurement Setup



Electron Guiding

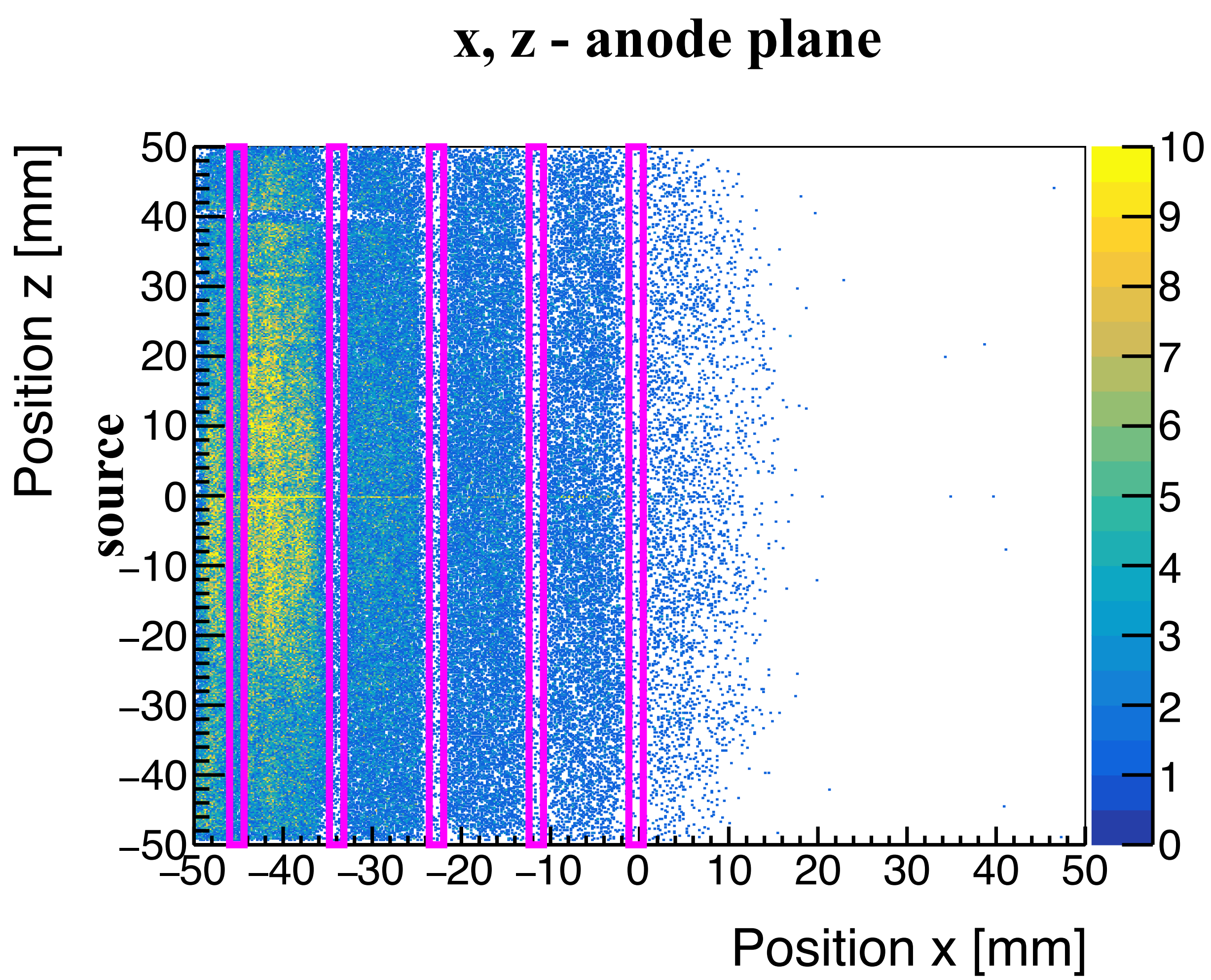
→ structured copper-plated layer with guiding E-field:

- copper strips on Printed Circuit Board (**PCB**)
- connected with resistors

→ positioning in detector

- **1550 µm FR4 and 35 µm Cu**
- 5 layers perpendicular arrangement

Measurement Results



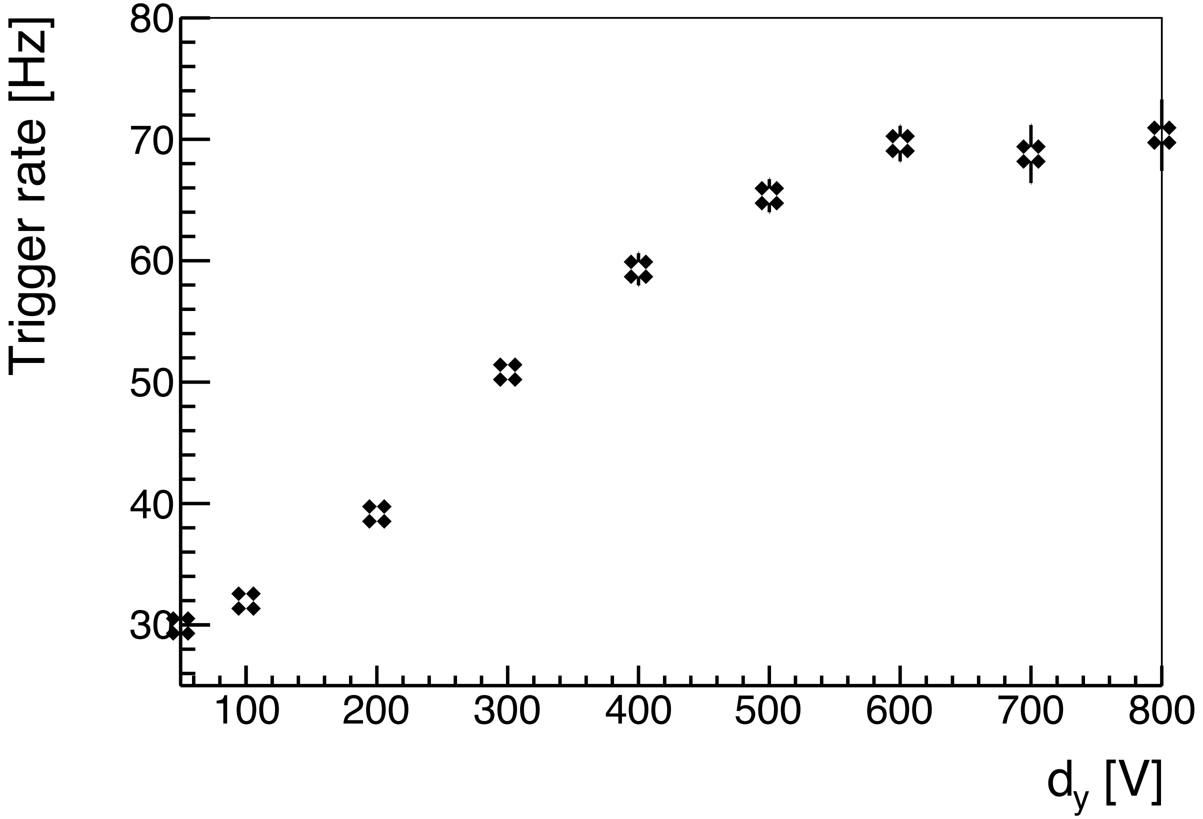
- irradiation with Am-241 (59.5 keV photons)
- d_y = 600 V
- pink boxes: assumed converter layer position
- only hits below converter layers

→ layer is working → electrons are guided down

- investigate

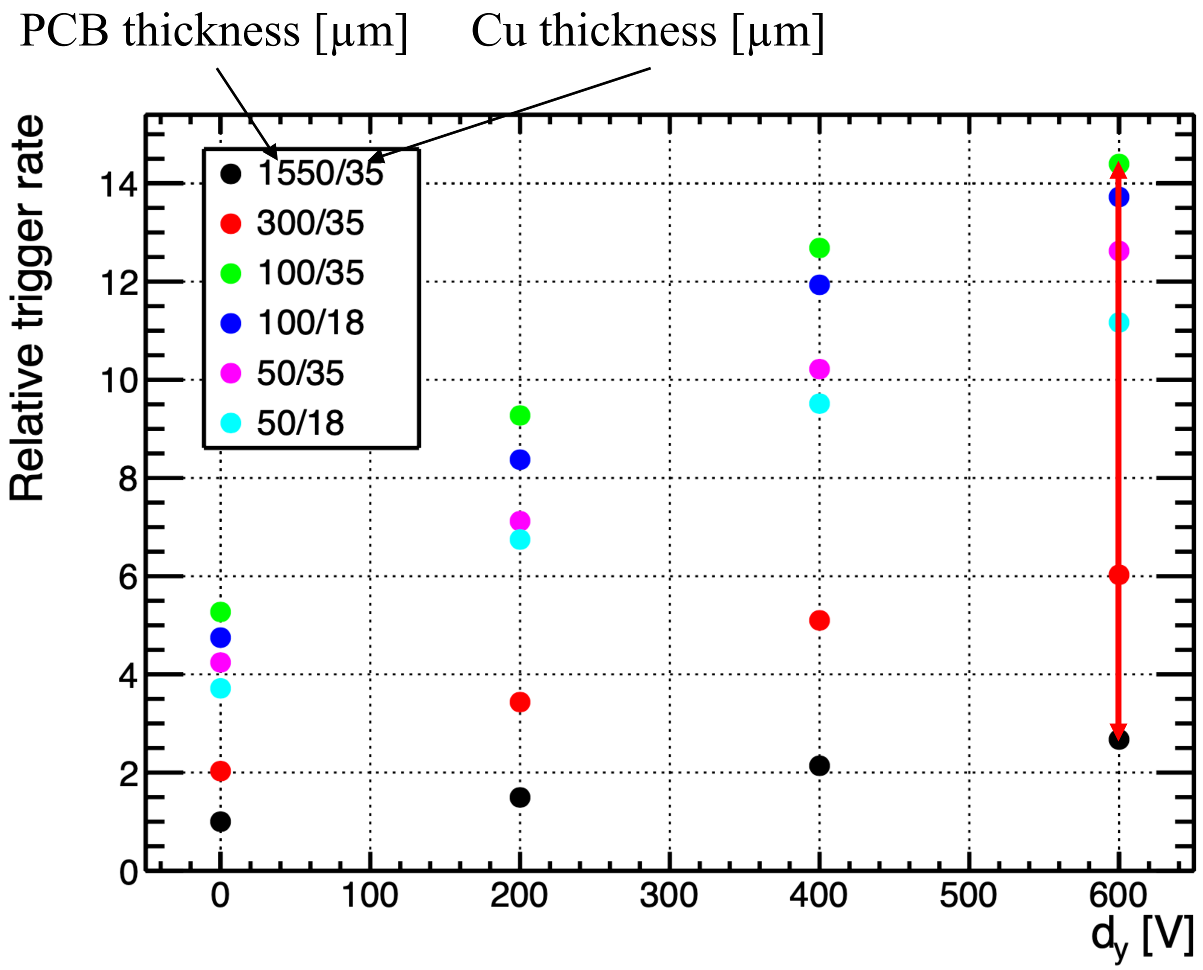
→ **influence of d_y**
→ **influence of layer thickness**

Measurement: Voltage Dependency



- irradiation with Am-241 (59.5 keV photons)
- 1550 μm FR4 and 35 μm Cu
- increasing d_y → higher trigger rate
- $d_y > 600$ V: saturation starts

Measurement: Layer Thicknesses

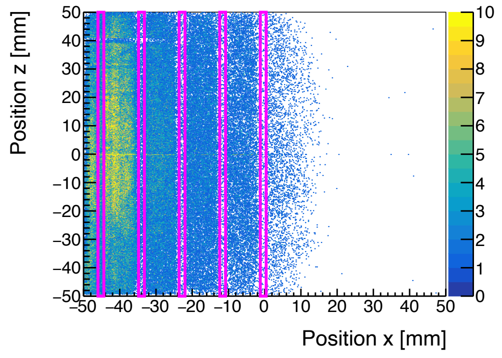


- irradiation with Am-241 (59.5 keV photons)
- normalization to 1550 μm FR4 layer, $d_y = 0$ V
- different **thicknesses** for PCB and Cu
- **PCB materials:**
  FR4: 1550 μm and 300 μm
  Kapton: 100 μm and 50 μm

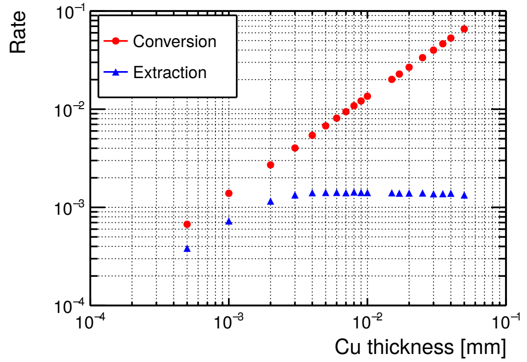
→ material optimization leads to improvement by a factor of 5

Summary and Outlook

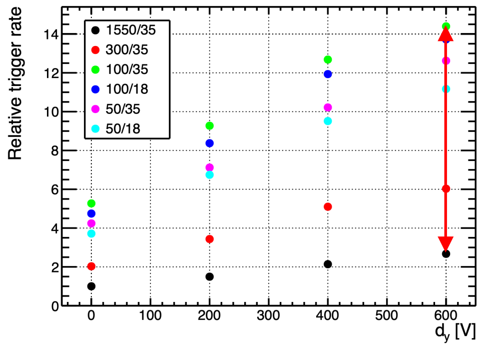
→ electron guiding with converter layers is working



→ material optimization necessary



→ improvement by factor 5 achievable using thin Kapton layers



Outlook

- improve agreement between simulation and measurement to understand physical processes
- achieve 3D-position reconstruction

Thank you for your attention!

Literature

[1]: Fabio Sauli. The gas electron multiplier (gem): Operating principles and appli- cations. Nuclear Instruments and Methods in Physics Research Section A: Ac- celerators, Spectrometers, Detectors and Associated Equipment, 805:2–24, 2016. https://doi.org/10.1016/j.nima.2015.07.060, [Online; Accessed: 5.10.2021]

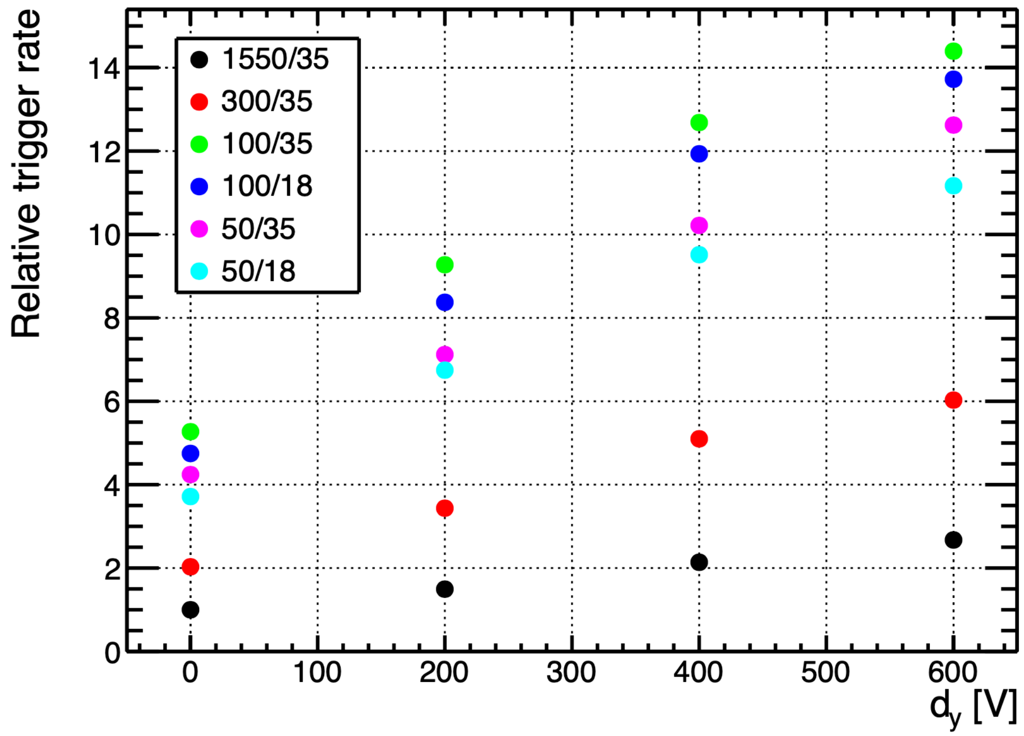
[2]: Deutsches Elektronen-Synchrotron DESY. FLC - Forschung mit Lepton Collidern – GEM Gas Electron Multipliers (GEMs), https://flc.desy.de/tpc/basics/gem/index_eng.html, [Online; Accessed: 5.10.2021]

[3]: Zabołotny, W.M., Kasprowicz, G., Poźniak, K. et al. FPGA and Embedded Systems Based Fast Data Acquisition and Processing for GEM Detectors. J Fusion Energ 38, 480–489 (2019) doi:10.1007/s10894-018-0181-2, https://doi.org/10.1007/s10894-018-0181-2, [Online; Accessed: 5.10.2021]

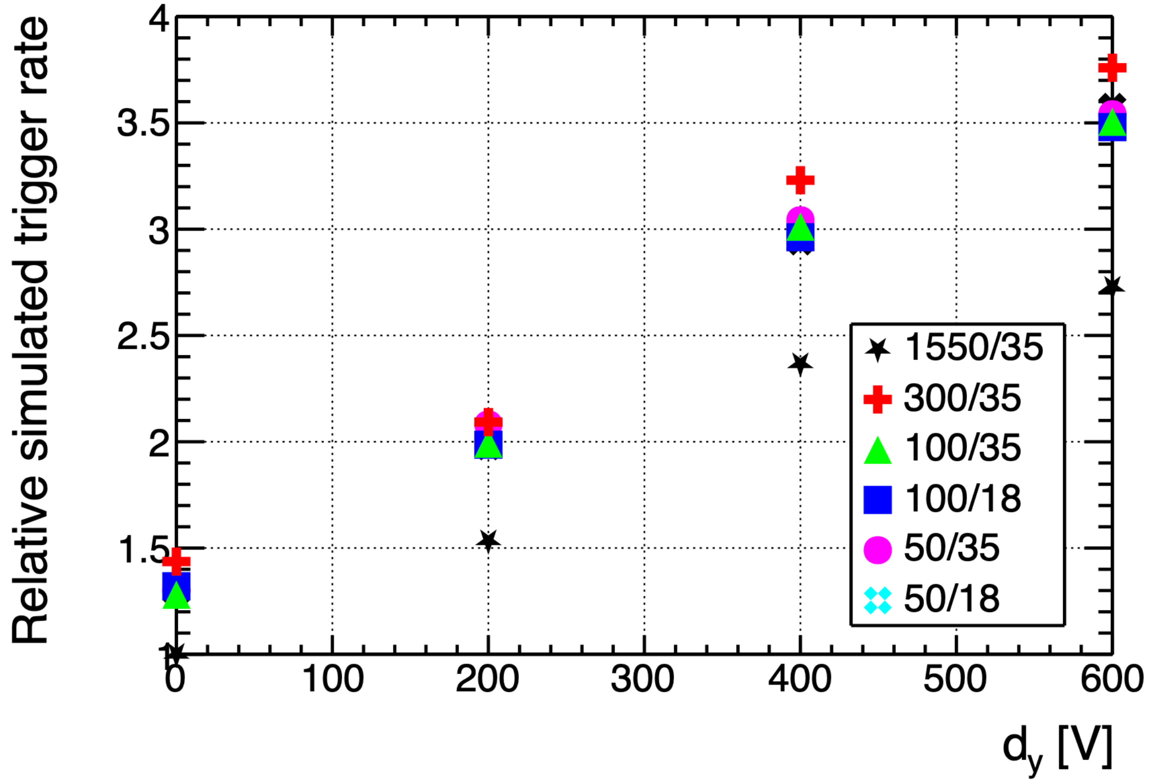
[4]: National Institute of Standards and Technology: XCOM: Photon Cross Sections Database. https://www.nist.gov/pml/xcom-photon-cross-sections-database, [Online, Accessed: 5.10.2021]

Comparison: Material Optimization

Measurement



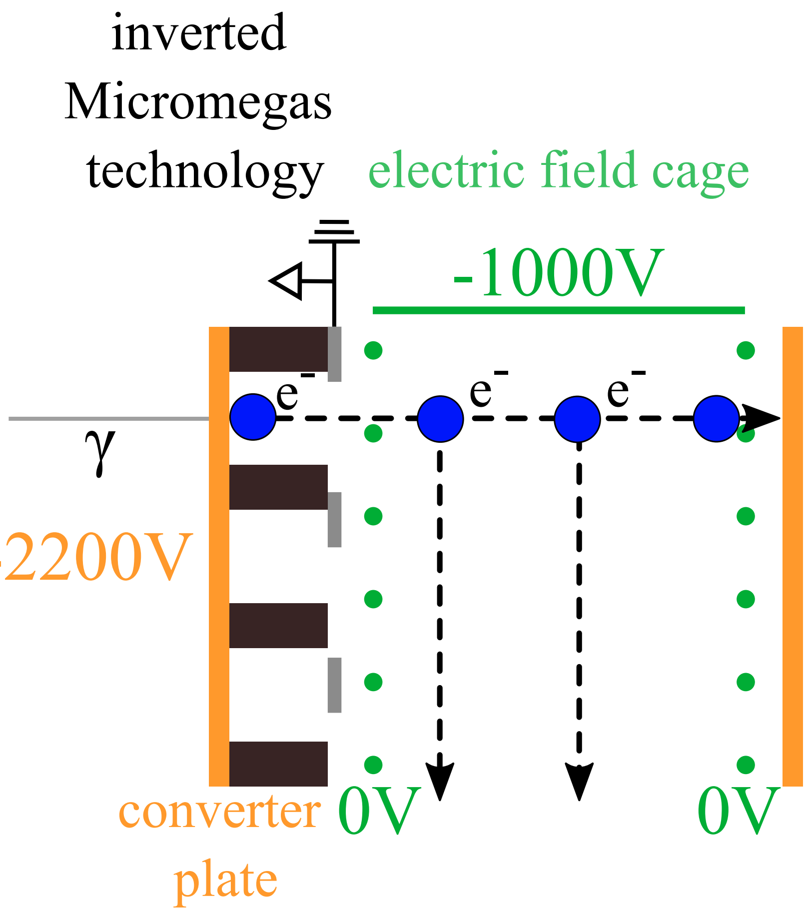
Simulation



- Simulation: particle-matter interaction (Geant4), electric fields (ANSYS), electron drift (Garfield++)
- only 1550 µm FR4 shows a different behaviour, all other layer types perform similar

→ **reason for difference in simulation and measurement still under investigation**

Appendix



→ photon conversion: 1e$^-$ → inverted Micromegas amplification: ≈10^5 e$^-$ → transparency: ≈ 10^2 e$^-$ → further ionization: ≈ 10^3 drift e$^-$

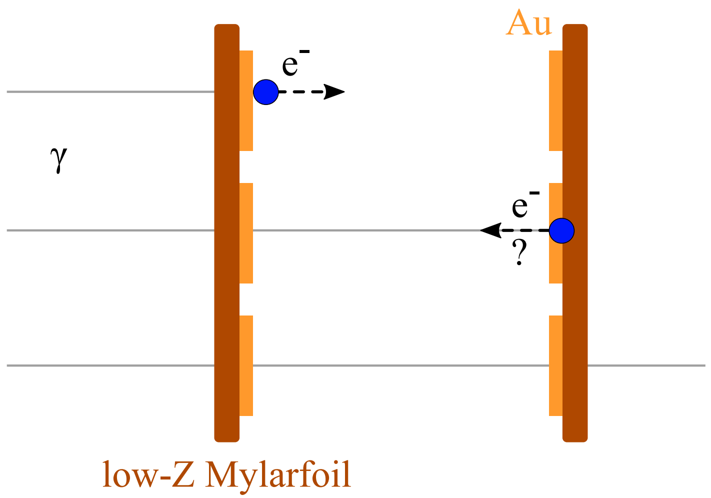
→ voltages and geometries have to be optimized

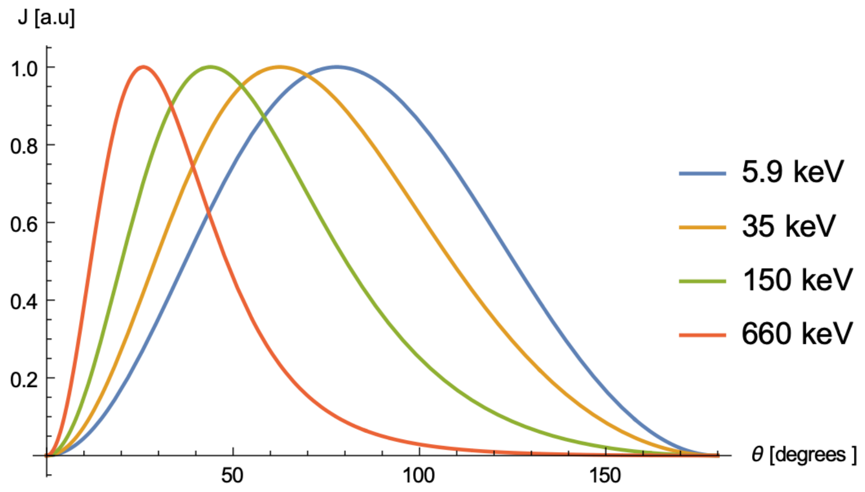
Appendix

Optimization of structured converter foils

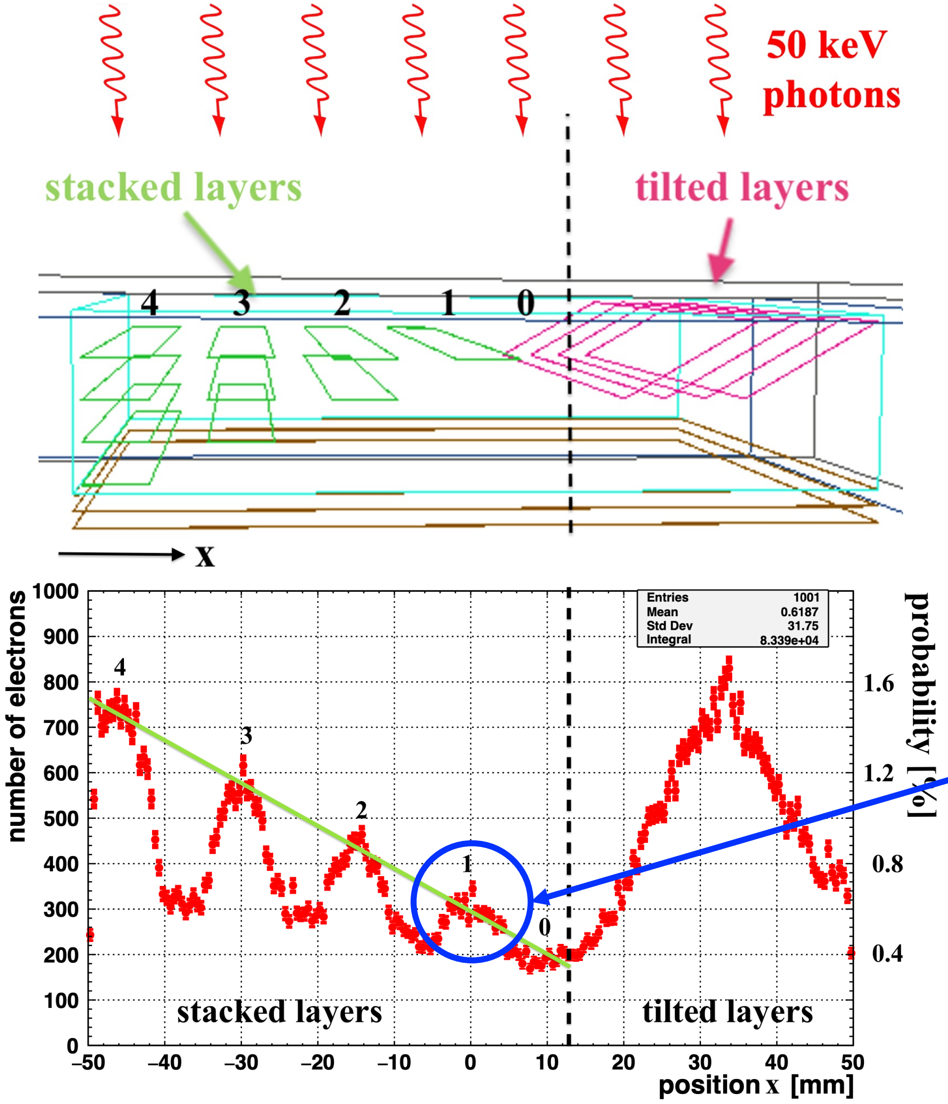
- coating, thickness, design
- minimization of dead material
- direction memory of photoelectric effect:

$$J(\theta,\beta) = A\cdot\beta^2\sin^2\theta\left(\frac{\sqrt{1-\beta^2}}{(1-\beta\cos\theta)^4} - \frac{1-\sqrt{1-\beta^2}}{2\sqrt{1-\beta^2}(1-\beta\cos\theta)^2} + \frac{2(1-\sqrt{1-\beta^2})}{4(1-\beta\cos\theta)(1-\beta\cos\theta)^3}\right)$$





Simulation: Photon Conversion Efficiency

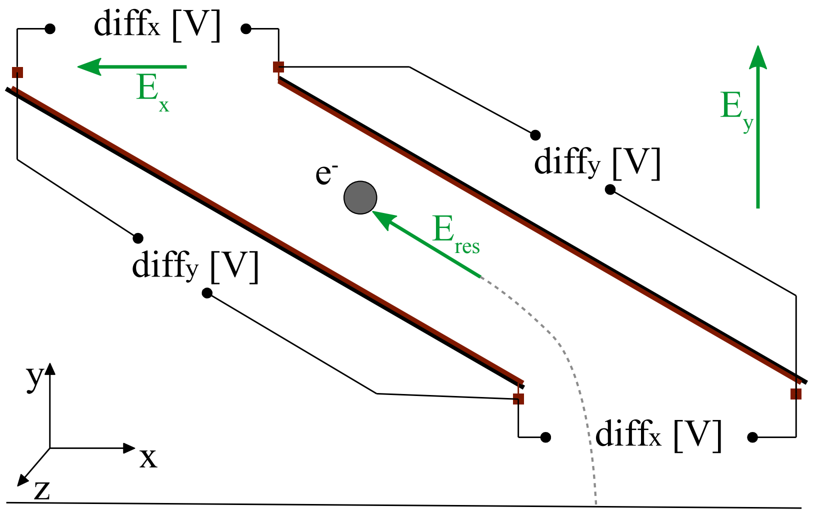


- on top of GEM foil: 0-4 stacked layers vs. 4 tilted layers
- 20 µm thick copper layers
- irradiation with 50 keV photons

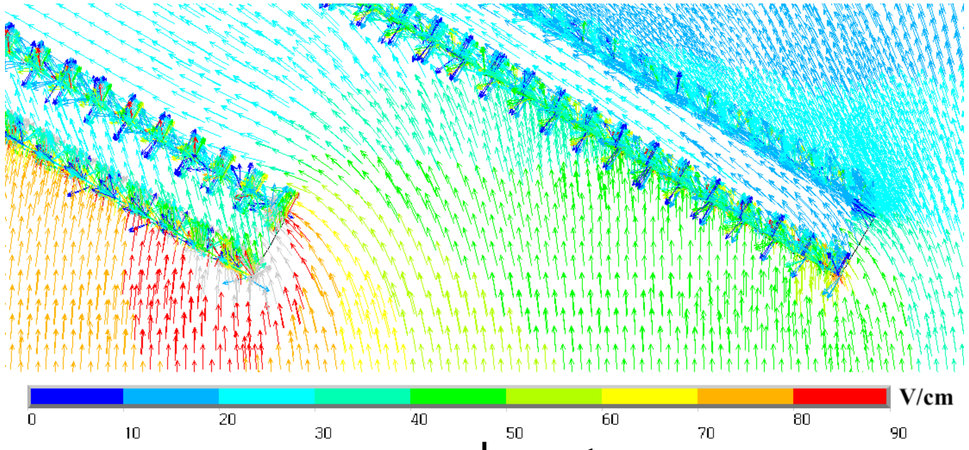
→ ε = 0.5 % per copper layer
20 layers → ε = 10 %

Simulation: Principle of Electron Guiding

Geometry: Tilted Converter Cathodes

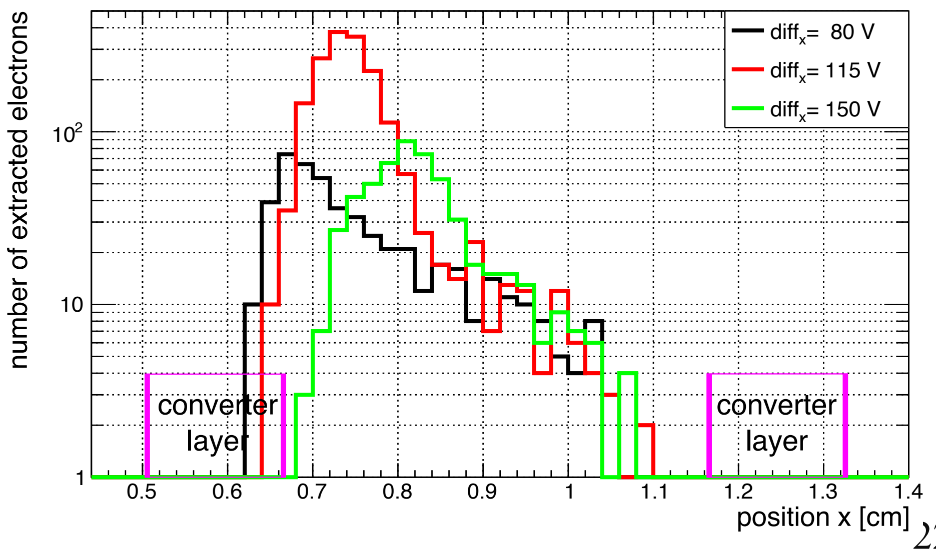


E-field →



↓ result

electron endpoint distribution below converter layers



- electron guiding by voltages $diff_x$ and $diff_y$
- electron drift direction described by electric field vectors
- voltage dependent electron extraction (on the right for $diff_y$ = 400 V)