Research and Development of an Inverted RICH Detector

DANIEL GREWE

AG BIEBEL

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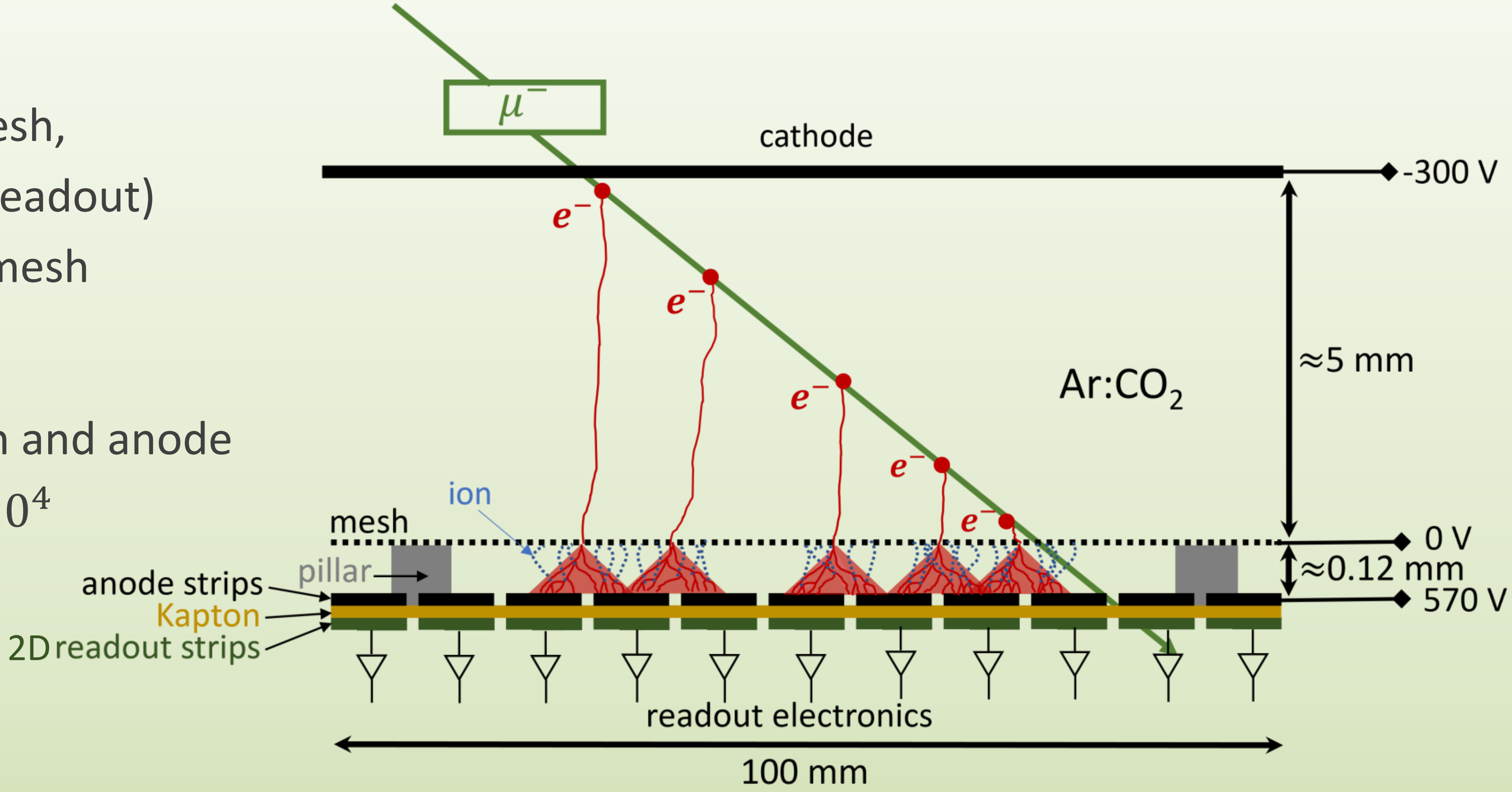
IMPRS

Bundesministerium für Bildung und Forschung

Working Principle of **MICROMEGAS** Detectors

- **MICRO ME**sh **GA**seous **S**tructure
- Planar structure (cathode, micro mesh, resistive anode, copper micro-strip readout)
- **Drift region** between cathode and mesh ($E_{\text{drift}} \approx 600\,\frac{\text{V}}{\text{cm}}$)
- **Amplification region** between mesh and anode ($E_{\text{ampl.}} \approx 47\,\frac{k\text{V}}{\text{cm}}$) → gas gain up to 10^4
- Spatial resolution $< 80\ \mu\text{m}$

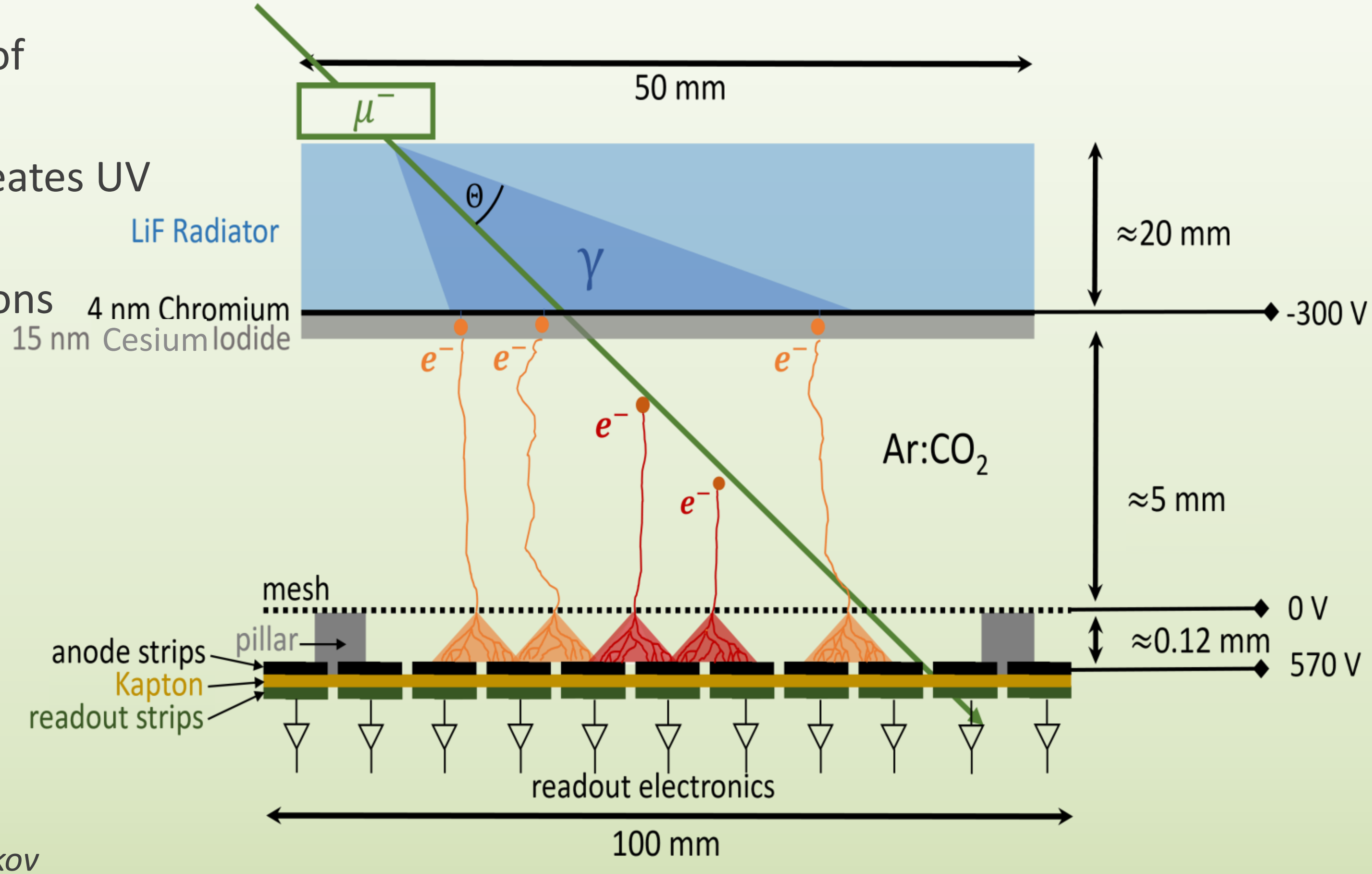


Working Principle of an **Inverted RICH** Detector

- **Purpose:** Momentum and Position reconstruction of charged particles
- **Cherenkov radiator**: relativistic charged particle creates UV photons
- **Photocathode**: conversion of UV photons to electrons
- **Drift region:** standard MM
- **Amplification region:** standard MM
- **Anode:** 2D strip readout

$\mu^{\pm}$→ measuring cherenkov angle → momentum

$$\cos\theta_C = \frac{c}{n \cdot v}, \ v \cdot n > c$$



Rinnagel, Maximilian; *Development of an Inverted Ring Imaging Cherenkov Micromegas;* August 2023

Separation of Photon and Muon Signals

Development of C++ analysis framework to reconstruct and separate Photon and Muon signals:

Signals are a Cluster of more than two strips:

Photon Cluster have:

- lower charge than μ^- signals (secondary cluster)
- photon signals arrive at:

$$t_{max} = \frac{d_{drift}}{v_{drift}}$$

- Δt between first and last responding strip small compared to μ^- signals

μ Cluster:

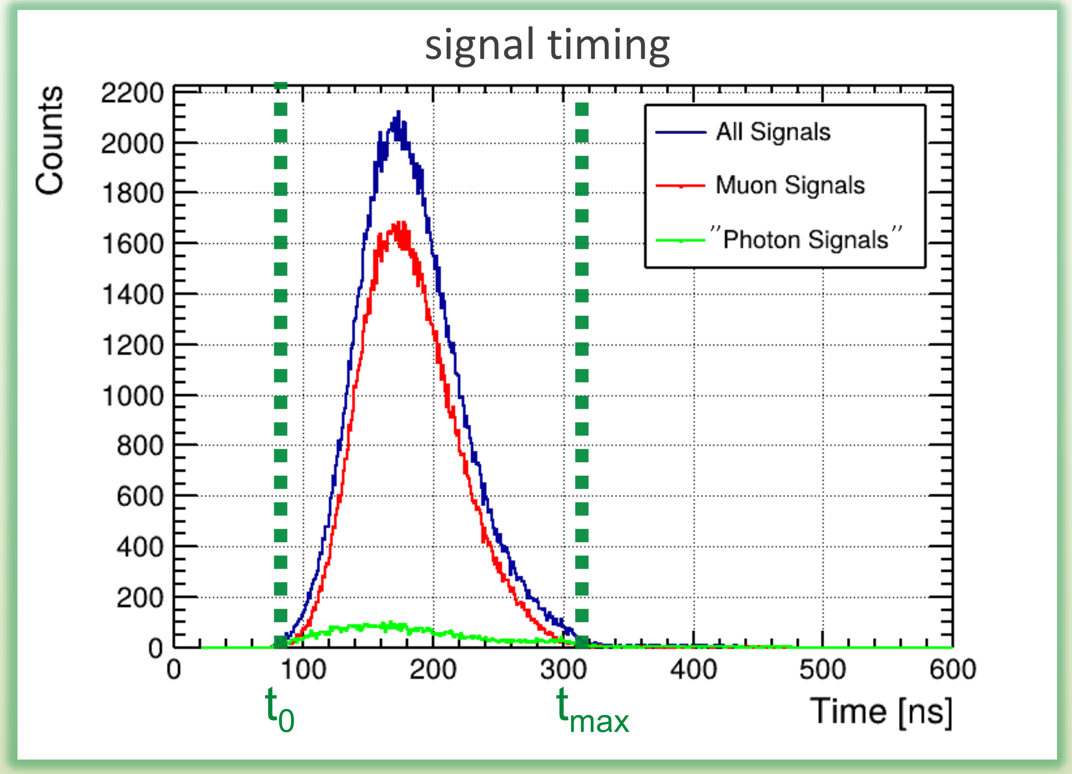
- arrive at t $\in [t_0, t_{max}]$
- Primary clusters

Cluster from Afterpulsing:

- lower charge than μ^- signals (secondary cluster)
- arrive at t $> t_{max}$

v_{drift} = 0.046 $\frac{mm}{ns}$ for Ar:CO_2 93:7 vol%

Measurements: CERN SPS H4 Beam Line 2023



Standard Micromegas:

- 1 cm drift
- No photon converter
- No cherenkov radiator
- Perpendicular incident 120 GEV μ^-

  → Gaussian distribution of signal timing

Measurements: CERN SPS H4 Beam Line 2023

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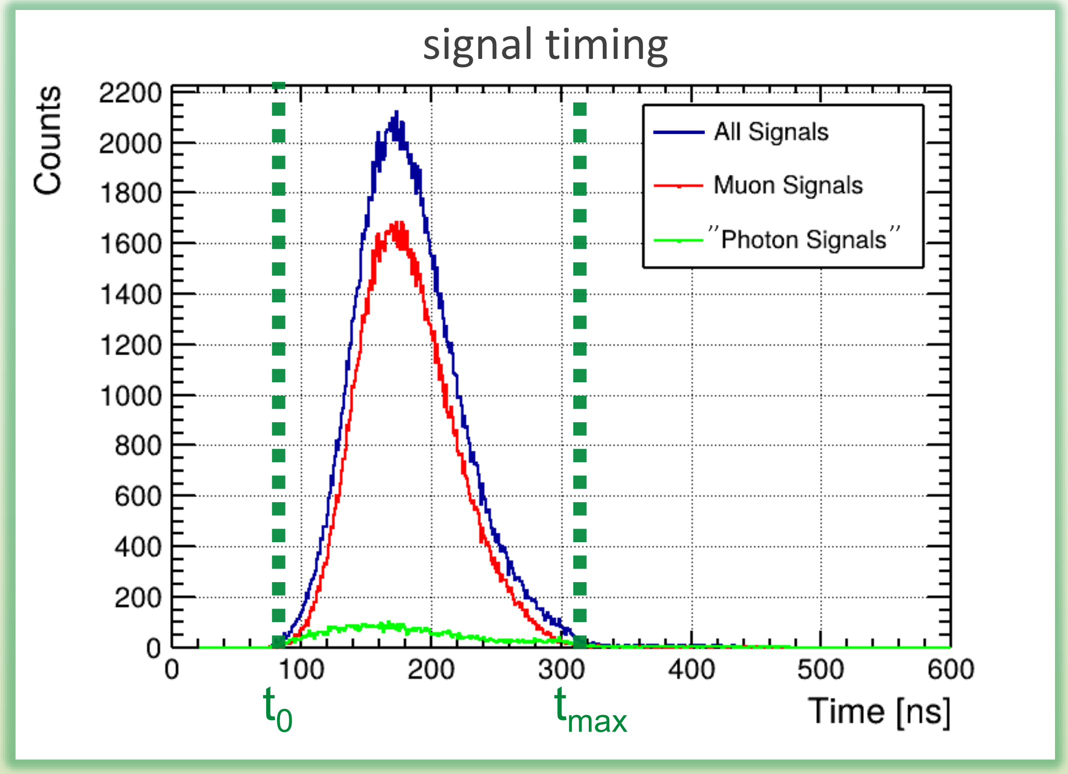
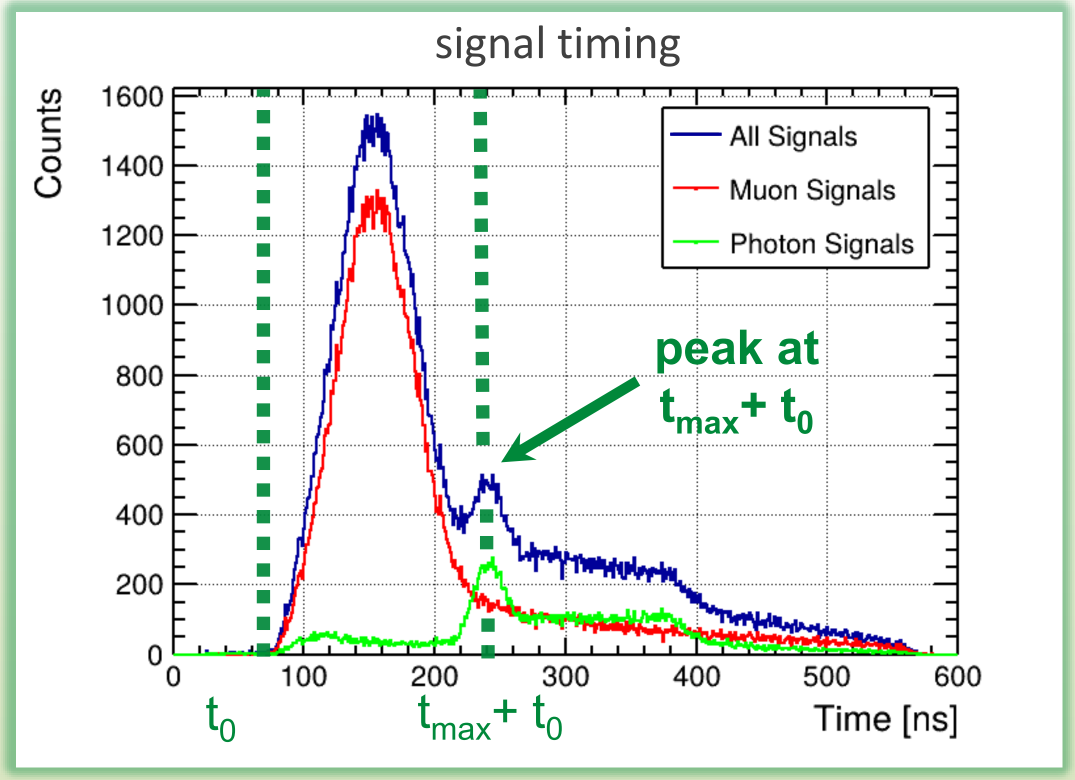
standard MICROMEGAS, 1 cm drift

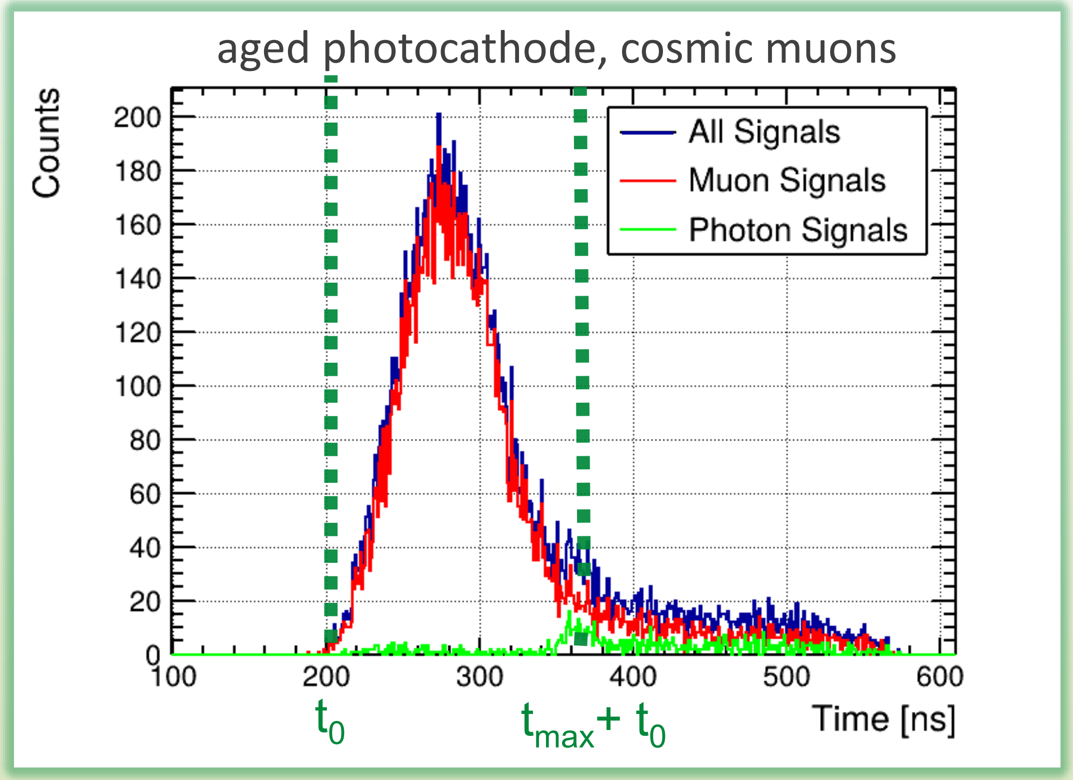


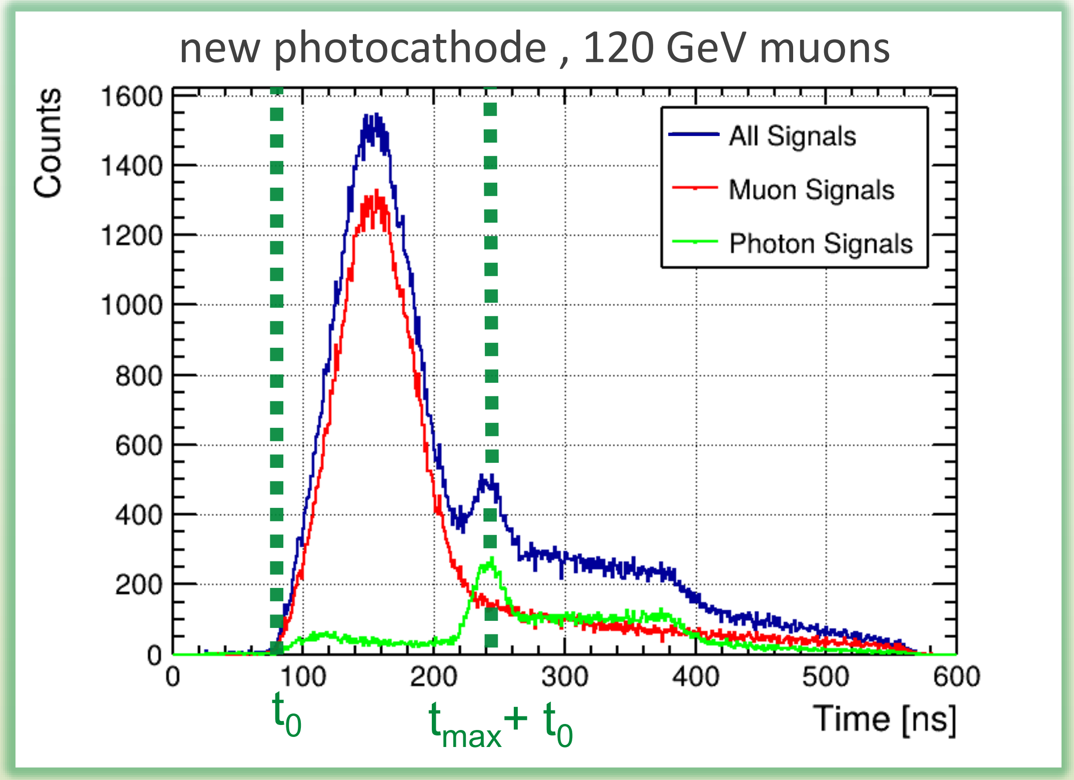
Inverted RICH, 0.6 cm drift



peak at t_{max} → **it is possible to detect Cherenkov photons !!!**

Aging of the CsI Photocathode





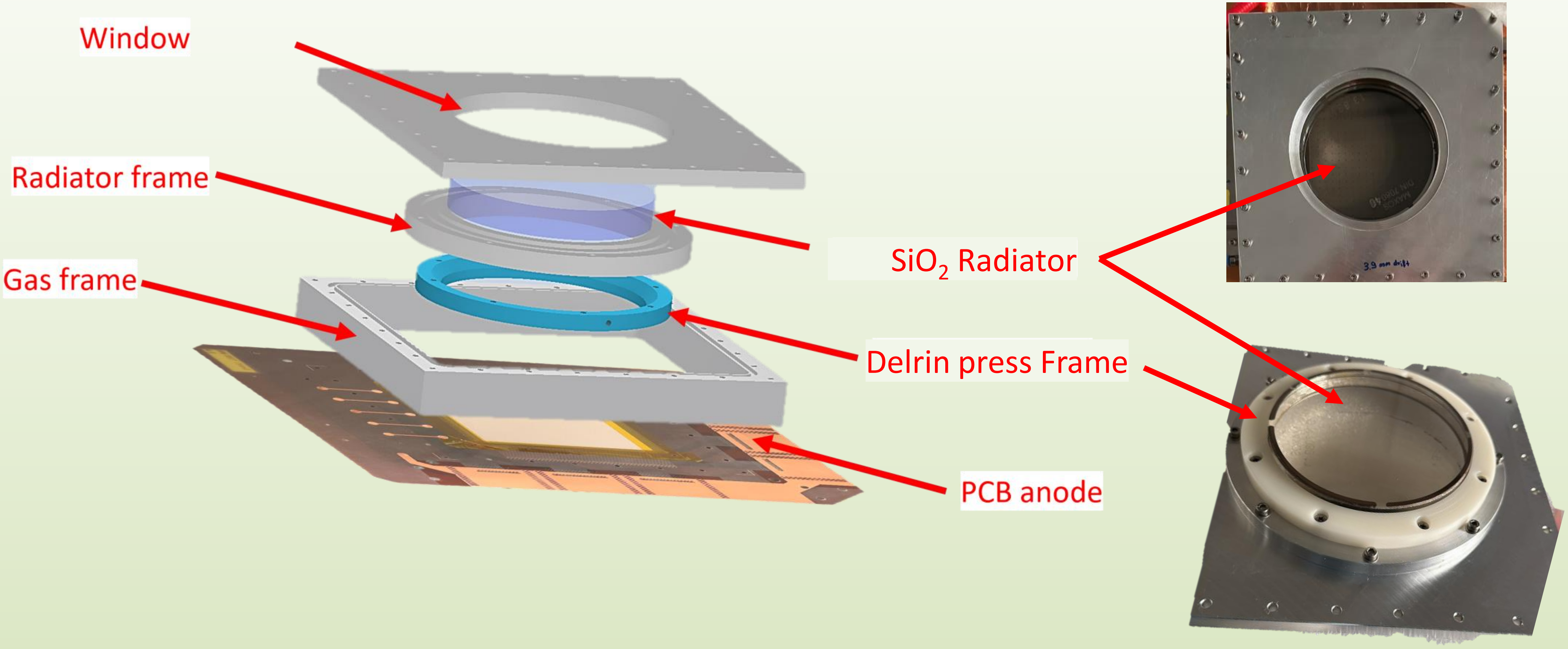
CsI vulnerable to humidity → aging of the photocathode

→ Cherenkov photons further reduced

Optimizing the Inverted RICH Detector

- **Investigating alternative photocathode materials**
  - High quantum efficiency
  - No aging
- **Investigating alternative different radiator materials**
  - Transparent for VUV photons
  - Low costs
- **testing new detector structures**
- **examination of various counting gas:**
  - Stability (no discharges)
  - High gas gain
  - Good timing resolution $\sigma(10\ ns)$
  - Good spatial resolution $\sigma(100\ \mu m)$
  - (Gas studies performed with a standard MM)

Alternative Photocathodes and Radiators

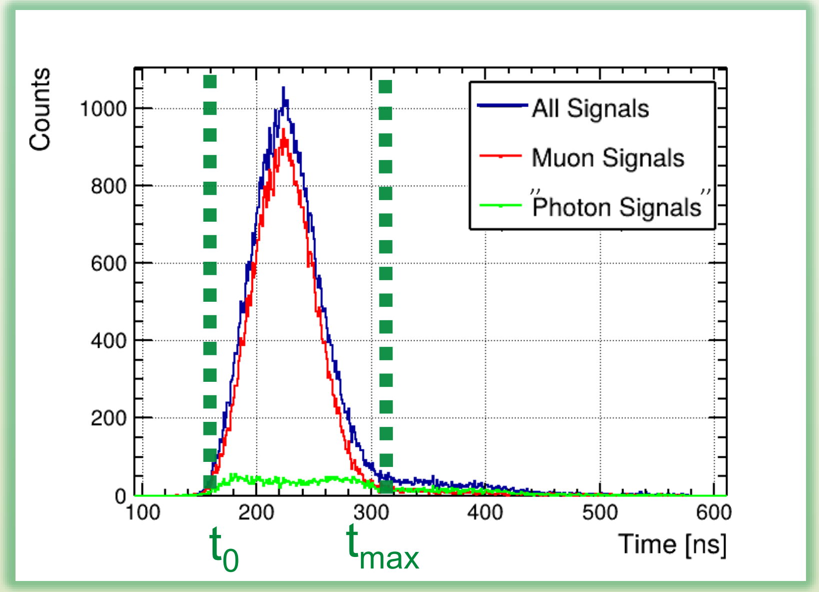


20 nm DLC
20 mm SiO_2 Radiator
3nm Cr

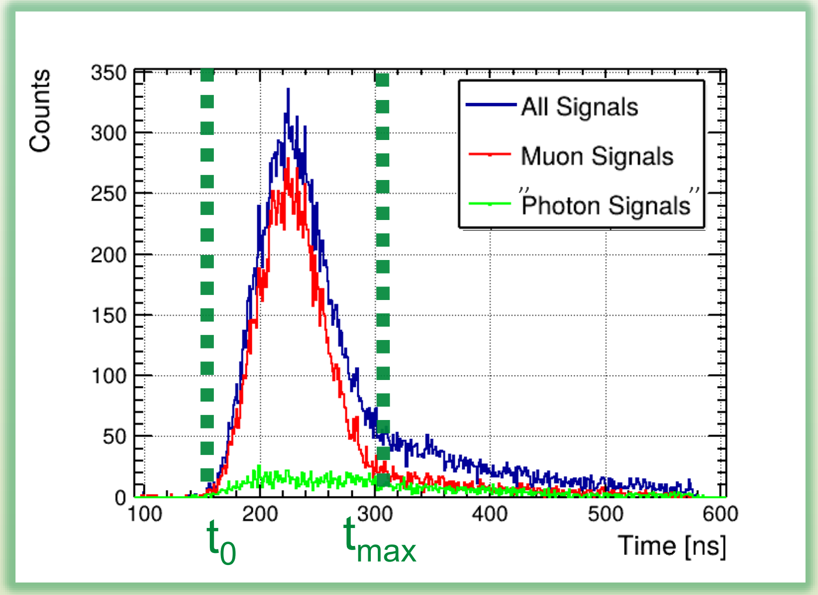
10 nm DLC
20 mm SiO_2 Radiator
3nm Ti

Characterization of DLC-Photocathode with Cosmic Muons

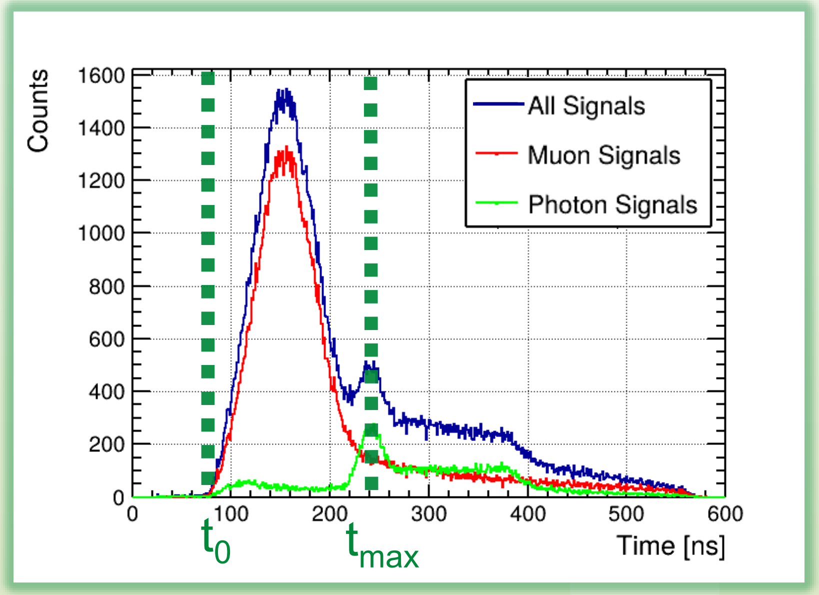
10 nm DLC
cosmic muons



20 nm DLC
cosmic muons

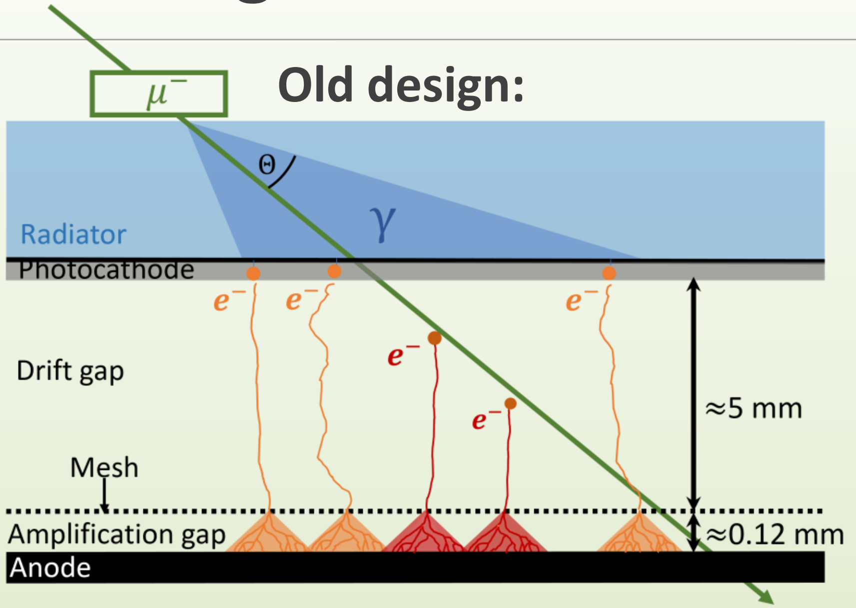


15 nm CsI
120 GeV muons



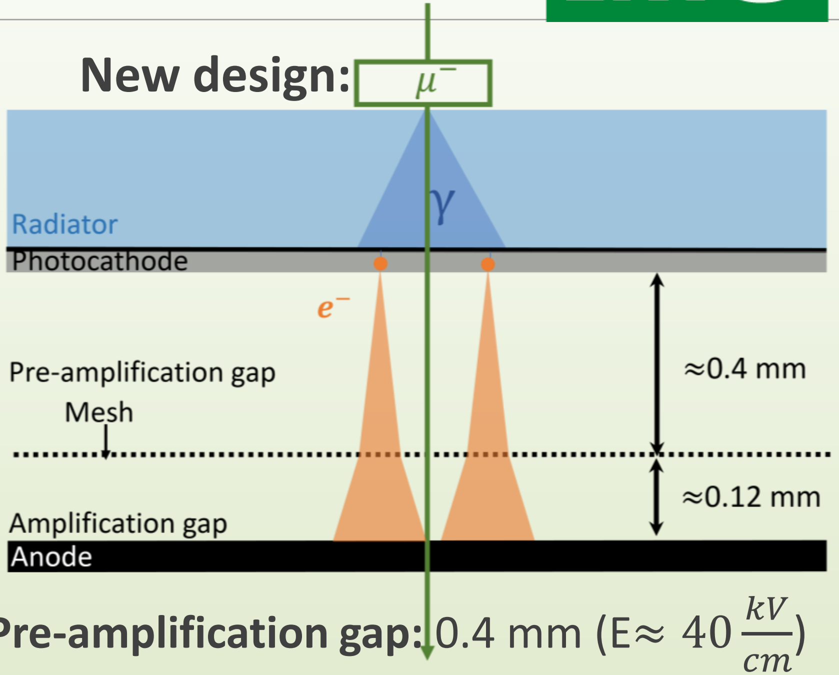
→ **No Cherenkov photons detected with DLC-Photocathodes**

Testing New Detector Structure



Drift Region: standard MM (E≈ $0.55 \frac{kV}{cm}$)

Amplification gap: standard MM (E≈ $50 \frac{kV}{cm}$)



Pre-amplification gap: 0.4 mm (E≈ $40 \frac{kV}{cm}$)

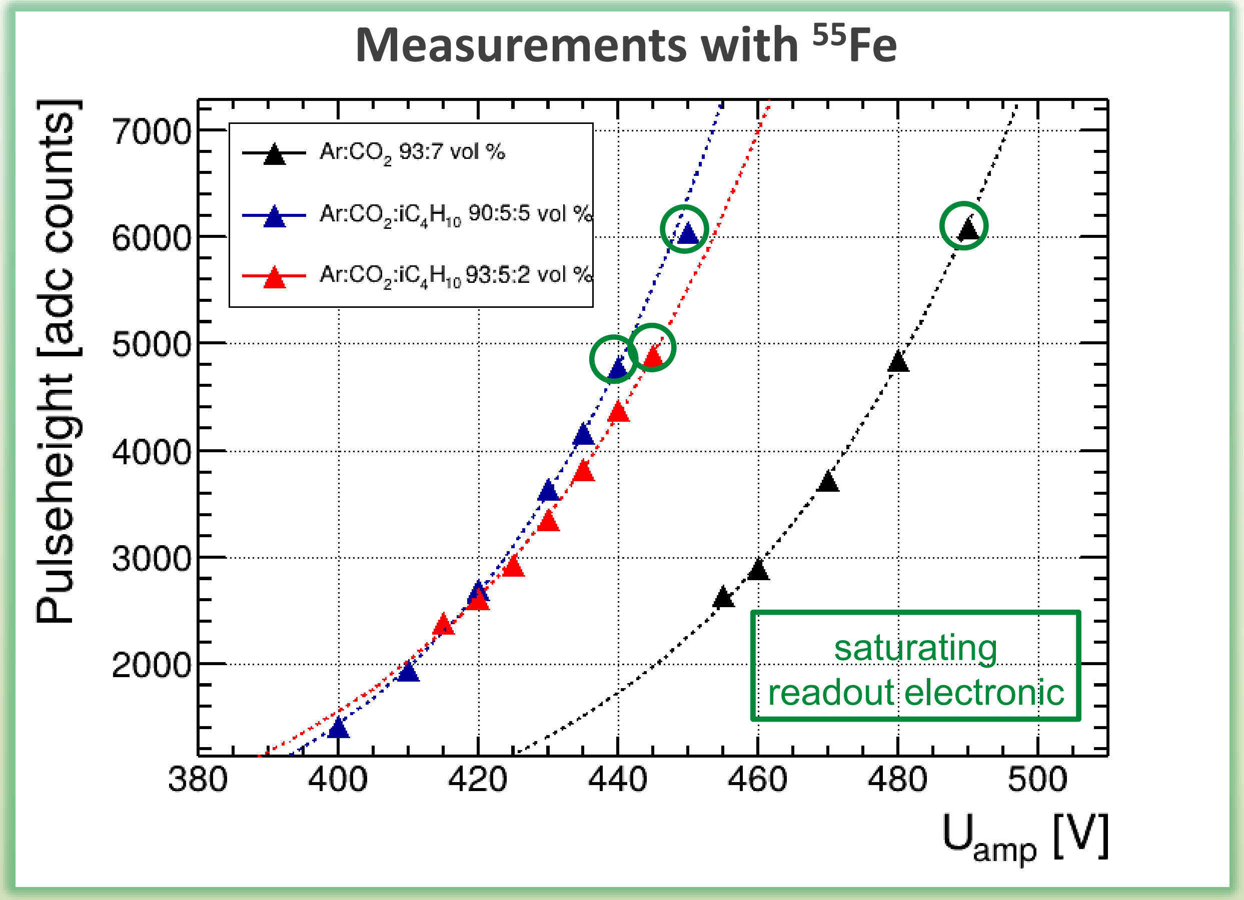
Amplification gap: 0.12mm (E≈ $25 \frac{kV}{cm}$)

→**higher field close to photocathode**

(to overcome work function)

→ **No Cherenkov photons detected but photons from an external light source can be detected**

Pulse Height Analysis

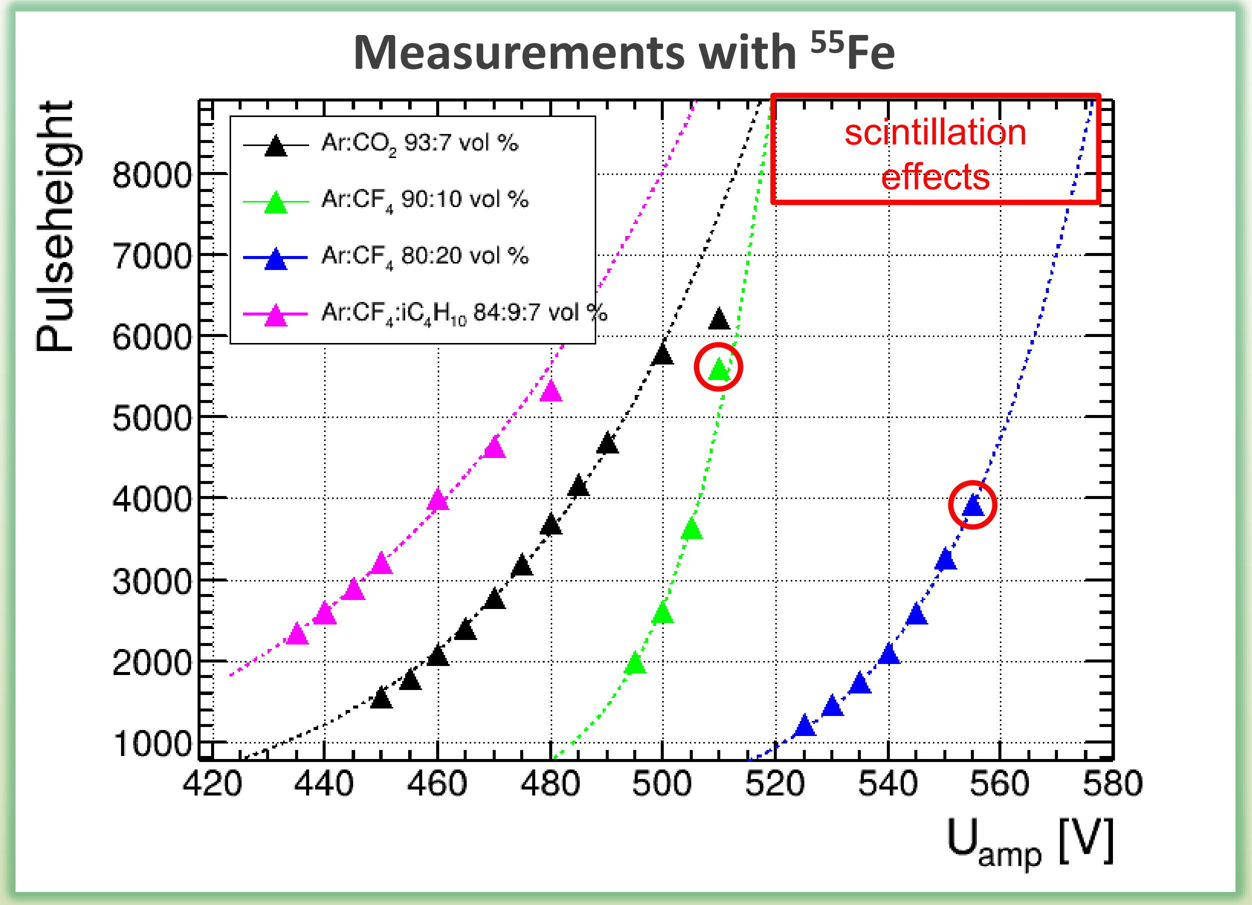


pulse height Q $\sim \exp\left[x\, A \frac{p}{T} \exp\left(-\frac{B}{E}\frac{p}{T}\right)\right]$

	Stable until
$Ar:CO_2:iC_4H_{10}$ 90:5:5 vol%	500-505 V
$Ar:CO_2:iC_4H_{10}$ 93:5:2 vol%	490-495 V
$Ar:CO_2$ 93:7 vol%	490-500 V

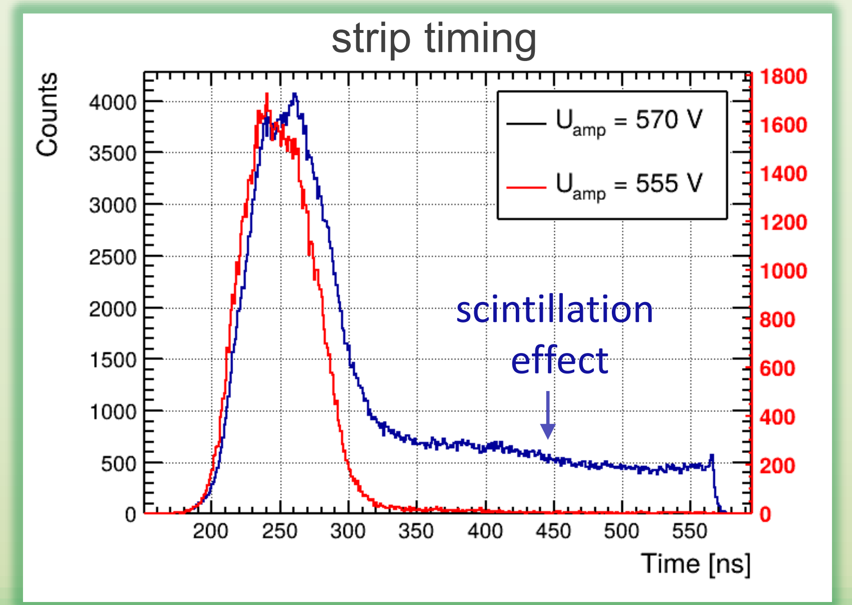
≈**3 times higher gas gains** with $Ar:CO_2:iC_4H_{10}$ 93:5:5 vol% compared to $Ar:CO_2$ 93:7 vol% before discharges ✓

Pulse Height Analysis

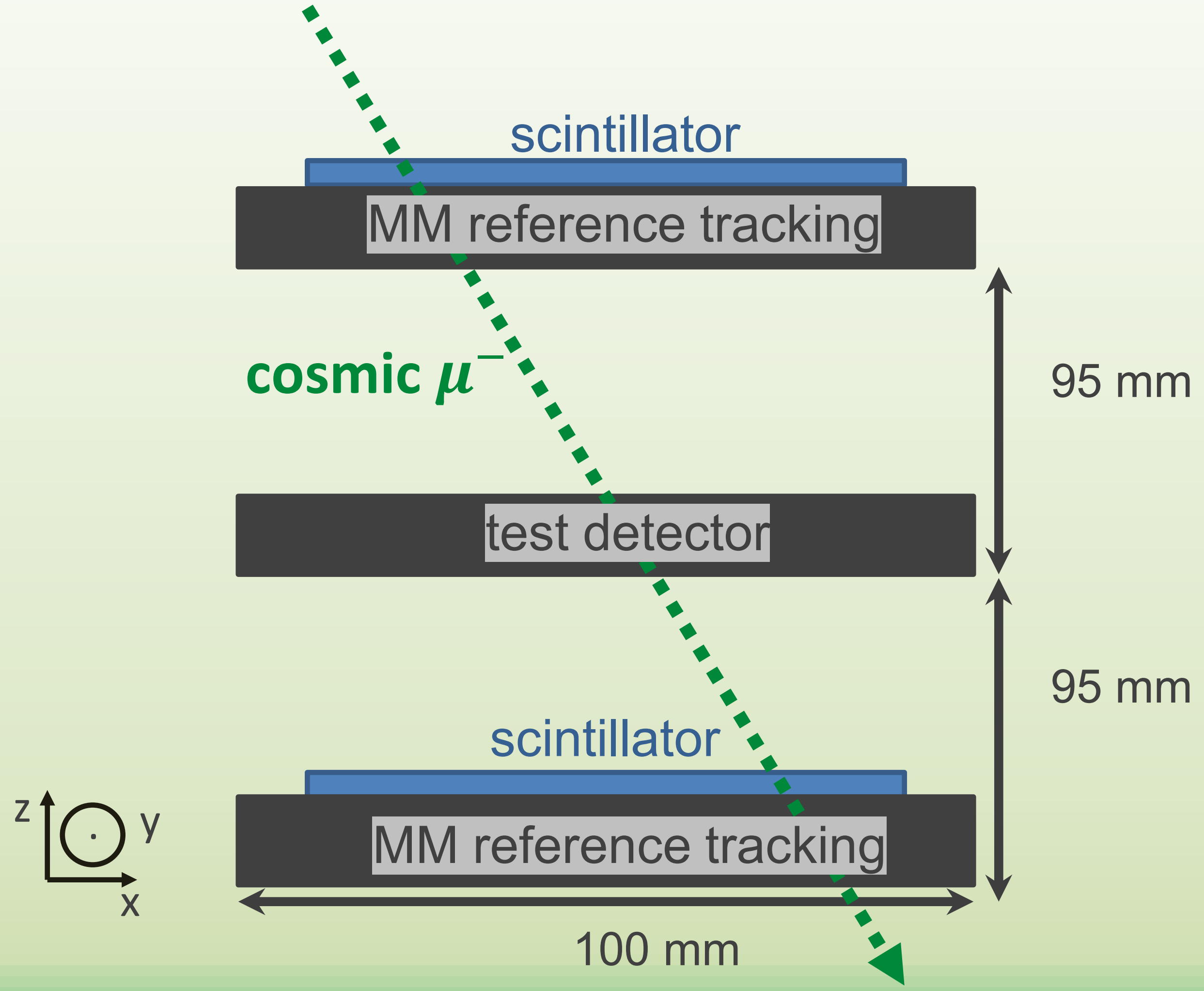


- highest gas gain with Ar:CF_4:iC_4H_{10}
- pulse height for Ar:CF_4 80:20 and Ar:CF_4 90:10 has a steeper than expected rise with U_{amp}
  → **scintillation of Ar:CF_4** → photons hit the cathode
  → photo electrons are amplified at high U_{amp}
  → large cluster size

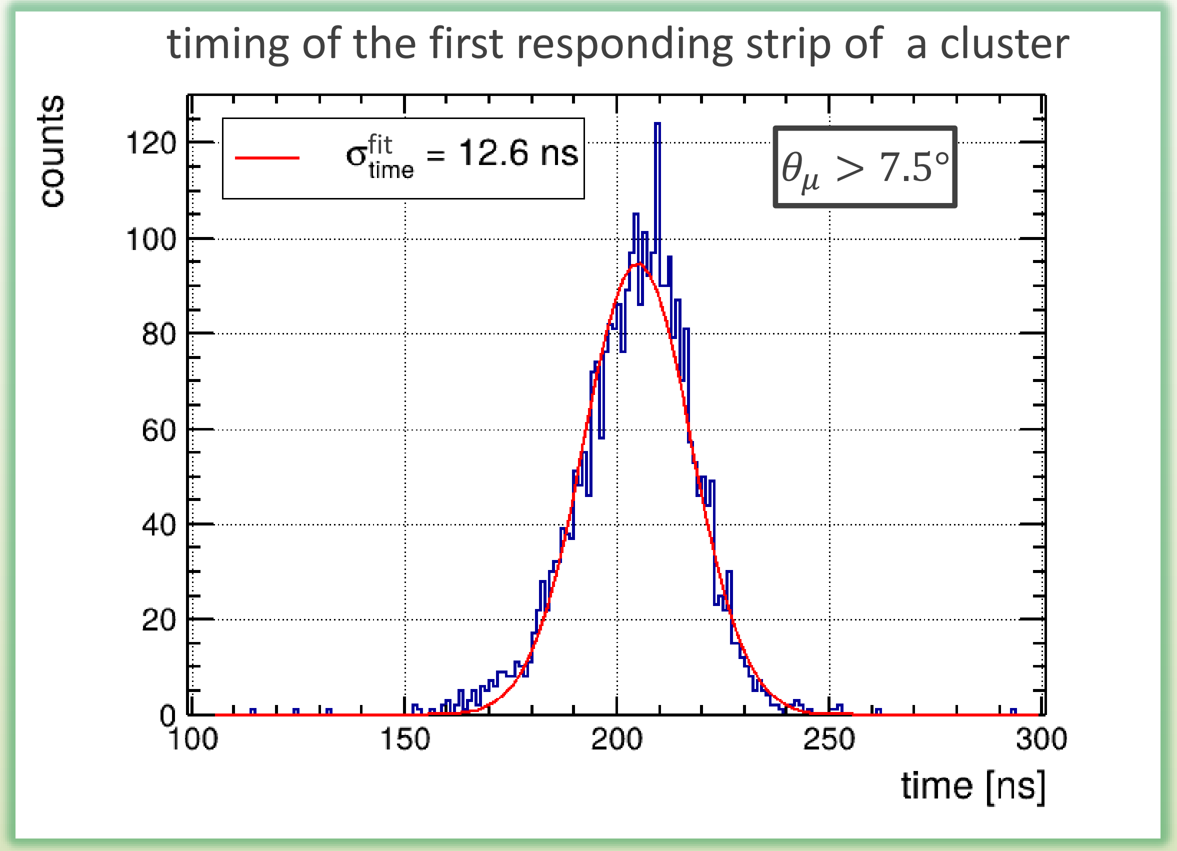
Measurements with Cosmic Muons:



Measurements with Cosmic Muons:

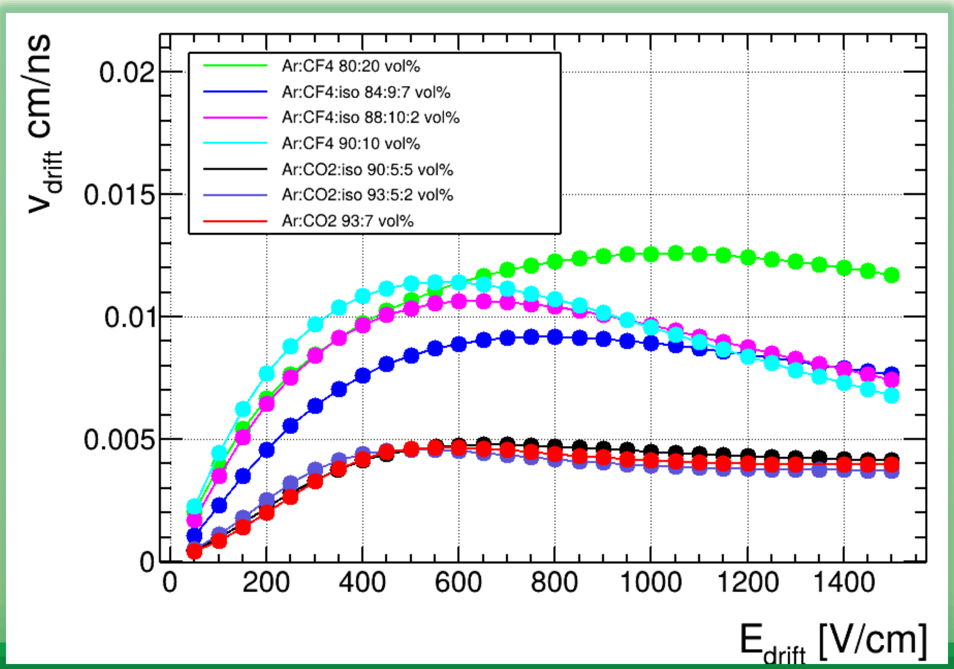


Examination of the Time Resolution

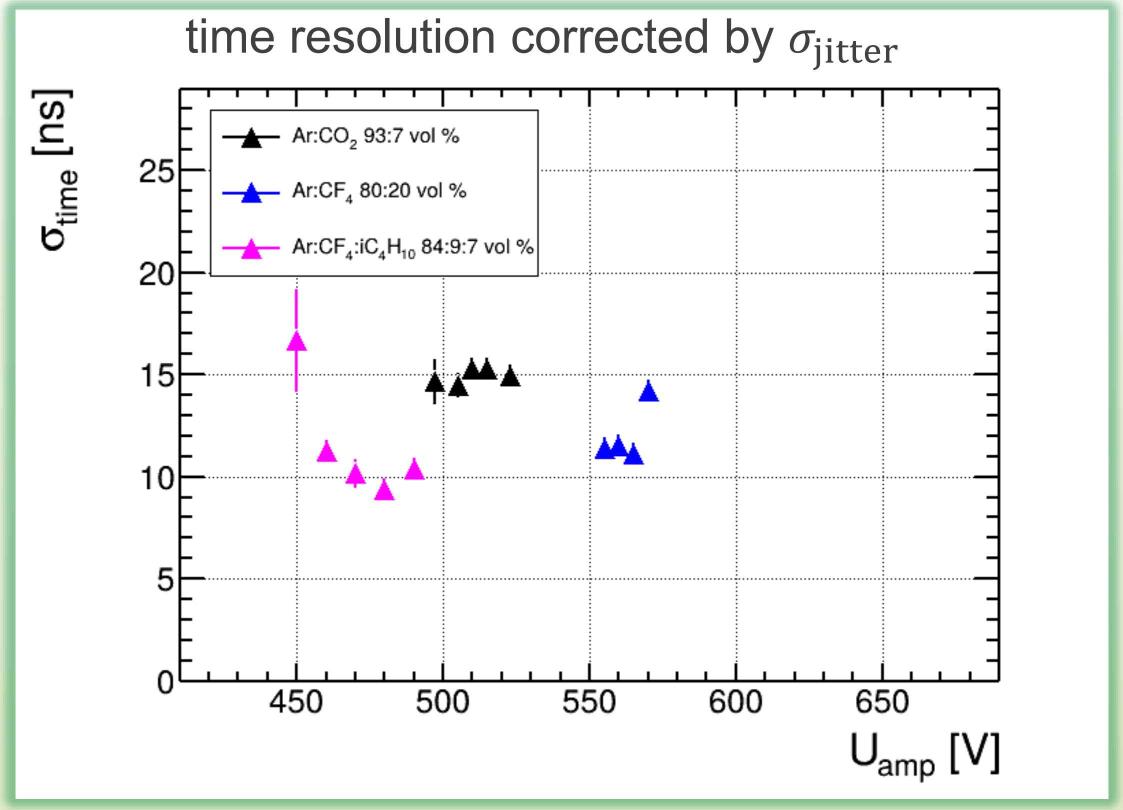


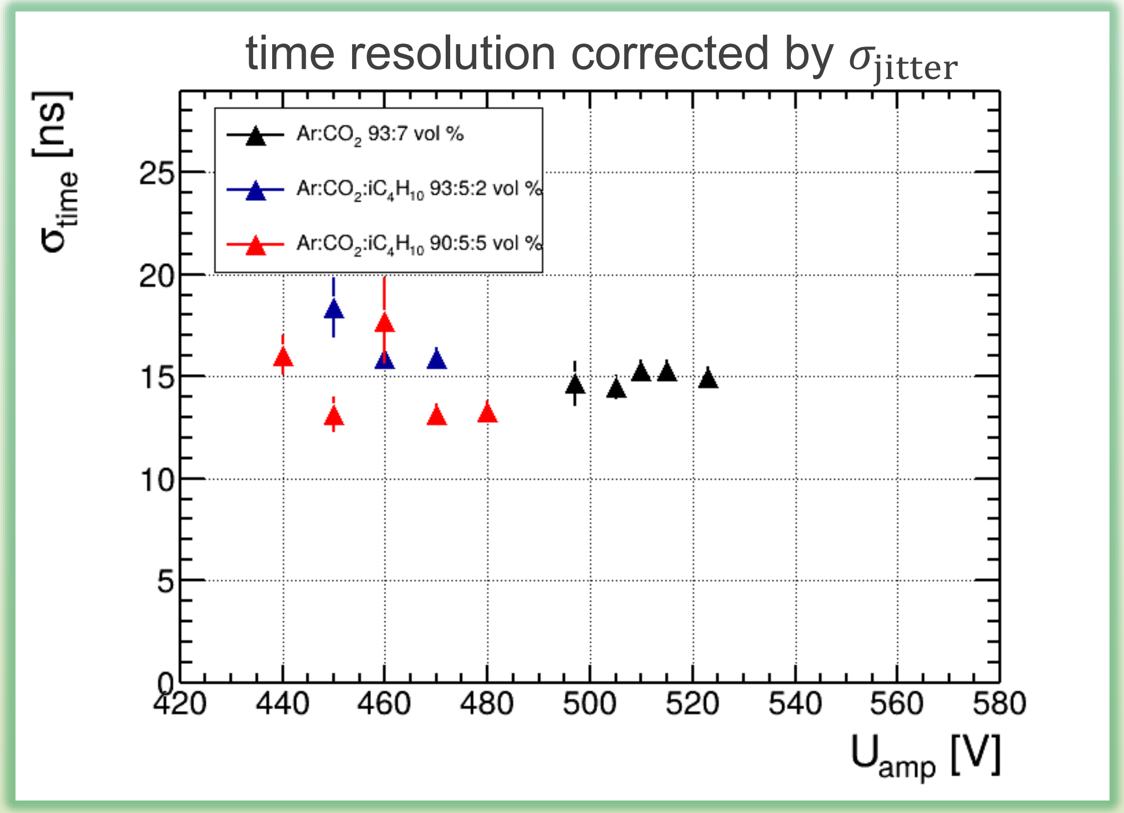
Drift Electrons Simulated with Garfield++, MAGBOLTZ

- σ of gaussian fit represents time resolution
- Time jitter of the trigger: $\sigma_{jitter} = \frac{25}{\sqrt{12}}$ ns
- $\sigma_{time} = \sqrt{{\sigma_{time}^{fit}}^2 - {\sigma_{jitter}}^2}$
- σ_{time} strongly depends on θ_μ
- Expect lower σ_{time} with high v_{drift}



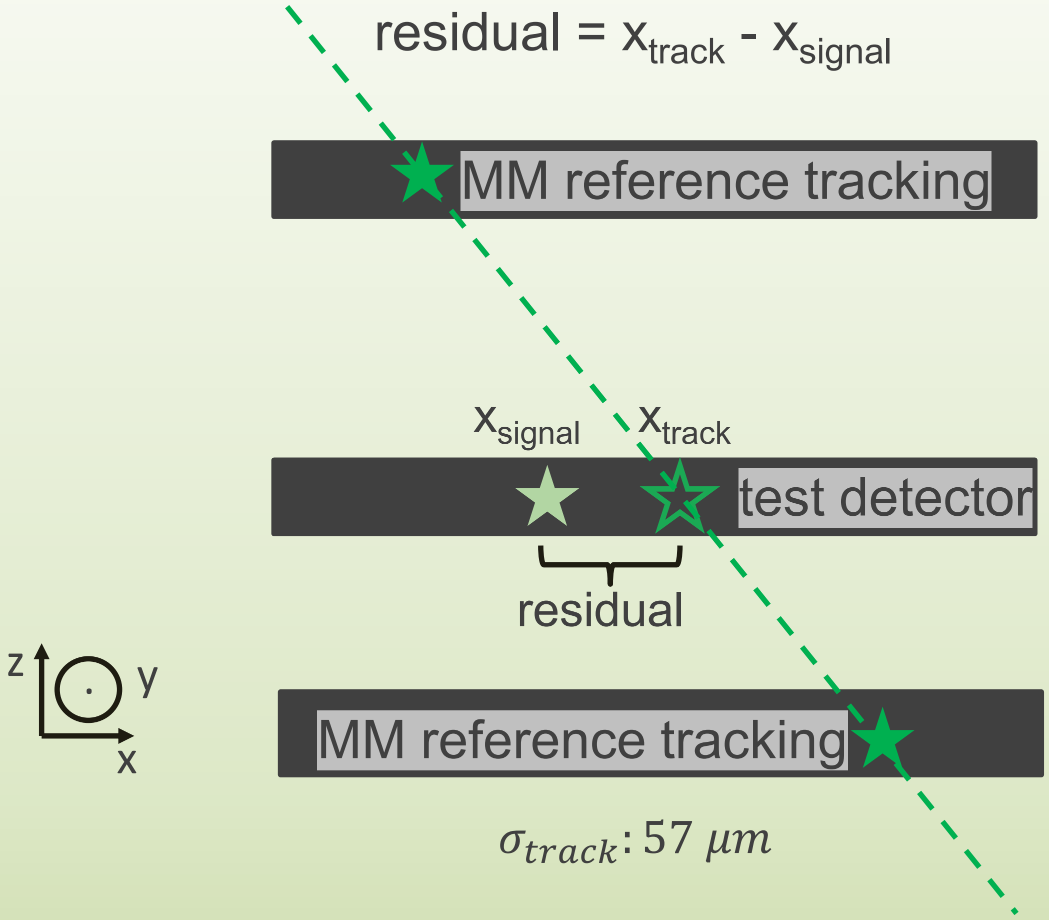
Examination of the Time Resolution



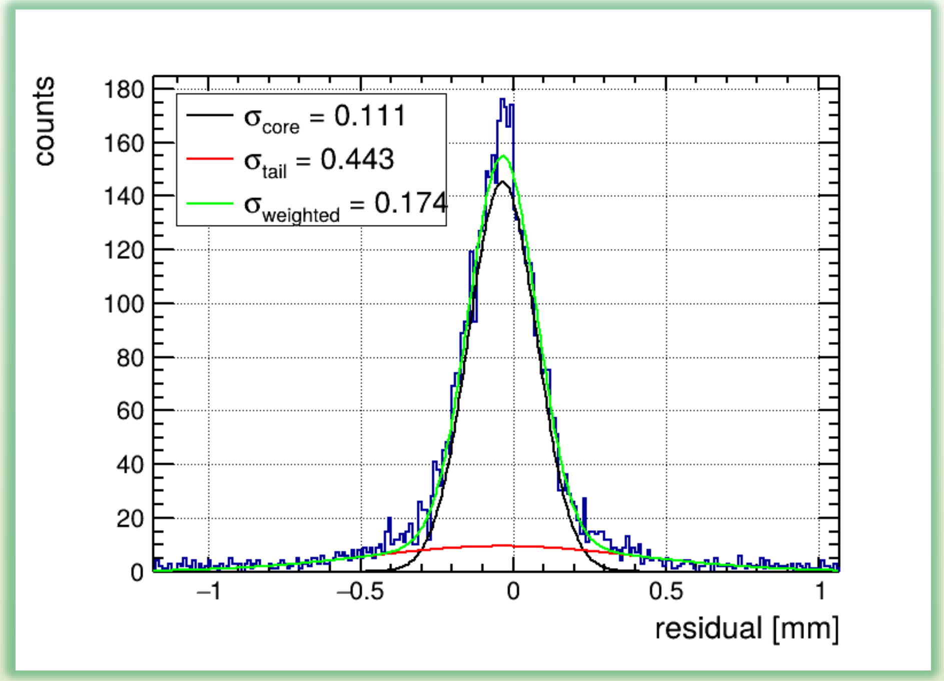


Ar:CF_4:iC_4H_{10} has the best
time resolution of $\sim$ 10 ns for $\theta_\mu > 7.5°$

Examination of the Spatial Resolution



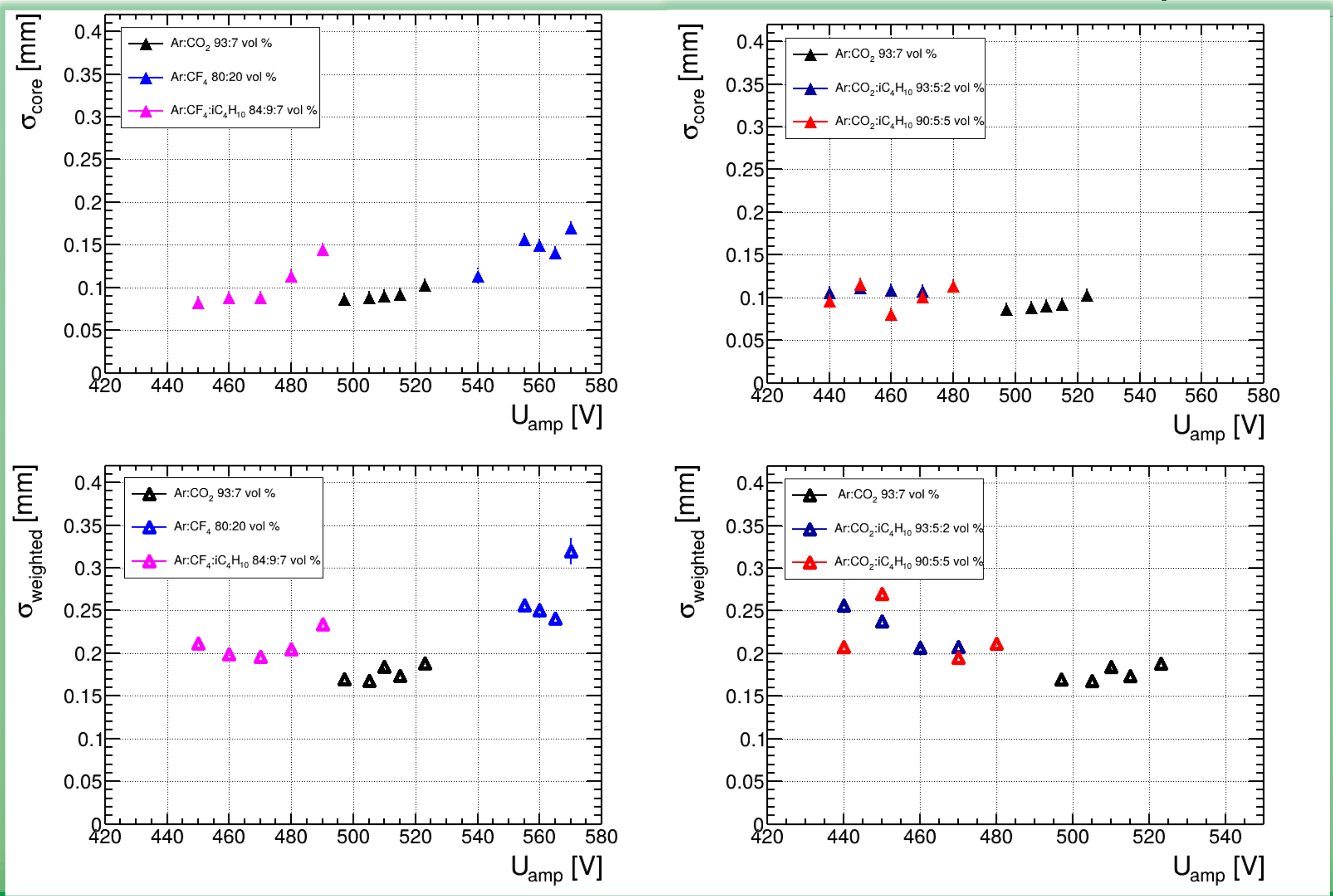
σ_{track}: 57 μm



double gaussian fit:

- σ_{core} : internal detector resolution
- σ_{tail} : broadening effects
  - multiple scattering
  - delta electrons
  - …

Spatial Resolution for $0 < |\theta_\mu| < 20°$



$\boldsymbol{\sigma_{core} < 90\ \mu m}$ for:

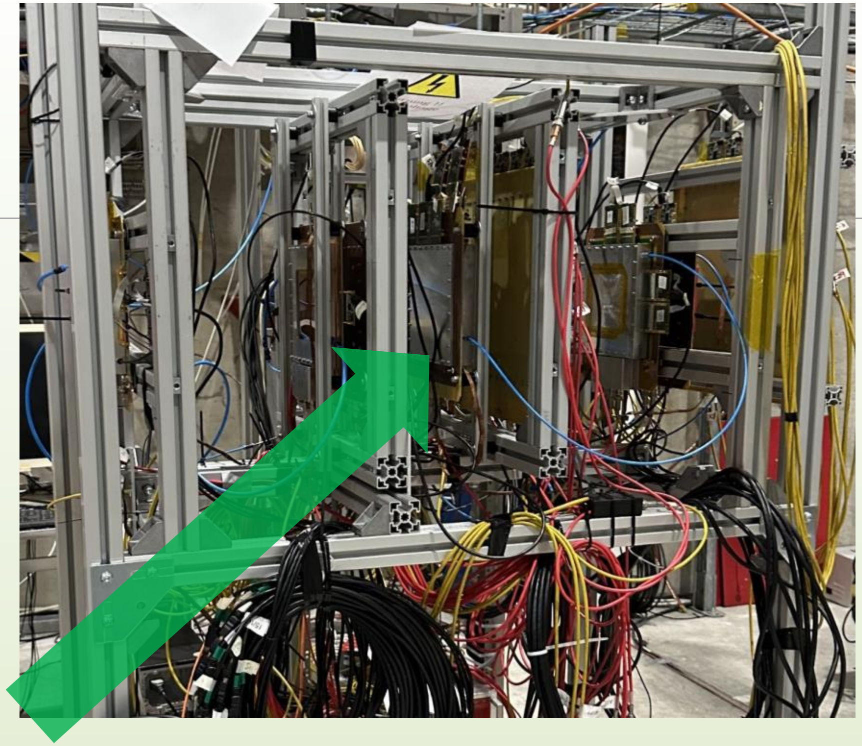
Ar:CF_4:iC_4H_{10}, Ar:CO_2 , Ar:CO_2 :iC_4H_{10}

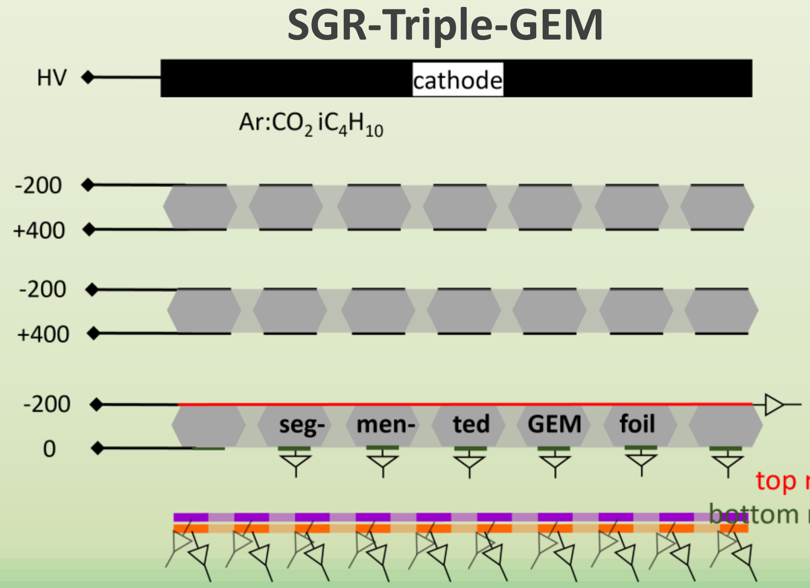
Summary

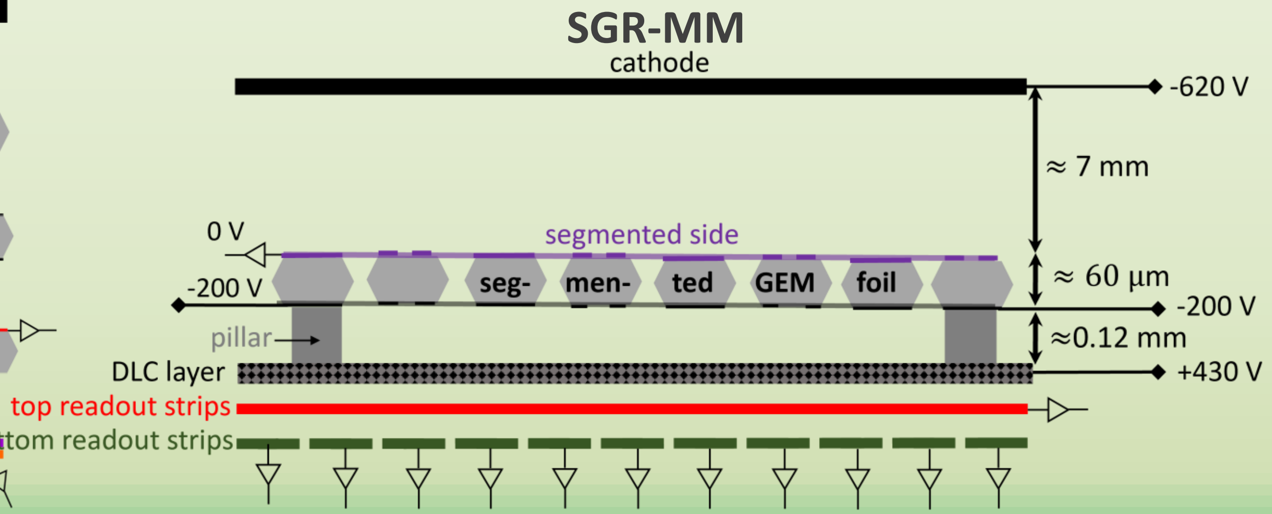
- Inverted RICH detector can create and detect Cherenkov photons
- $Ar:CO_2:iC_4H_{10}$ is a very promising counting gas due to
    - High gas gain
    - Stability
    - Good time resolution (<15 ns)
    - Good spatial resolution (<90 μm)
- CsI photocathode ages → investigation of DLC photocathodes with SiO_2 radiator
- No photon conversion in DLC photocathode observed → work function of the DLC photocathodes is too high
- Inverted RICH detector with pre-amplification field could detect photons from external light source

Outlook

- Characterization of MgF radiator with DLC (2 nm), Br_4C (5 nm) DLC Photocathodes at CERN SPS H4 Beam Line
- Testing new anode structures → 2-D Position reconstruction for multiple incident particles
  - SGR Micromegas and SGR Gem detector are currently tested with H4 beamline at CERN's SPS



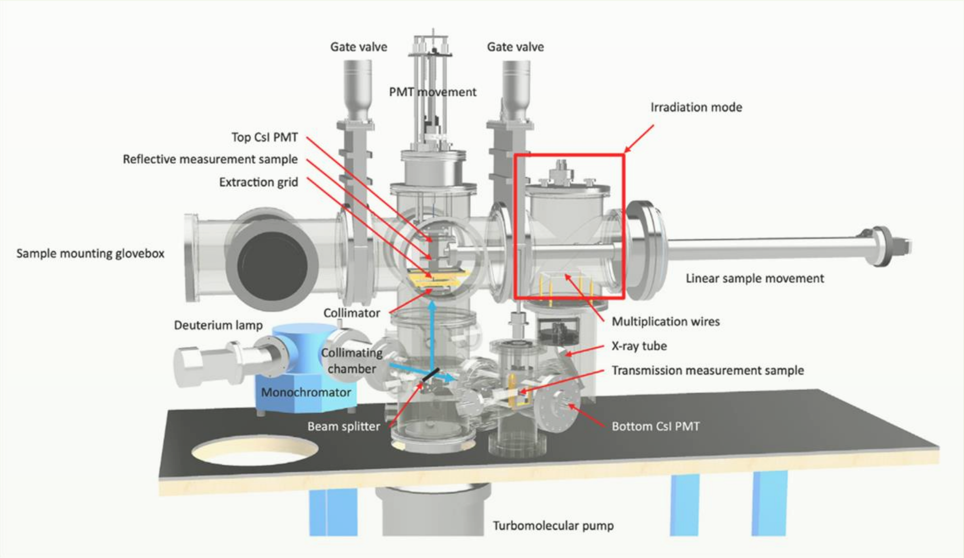




Backup

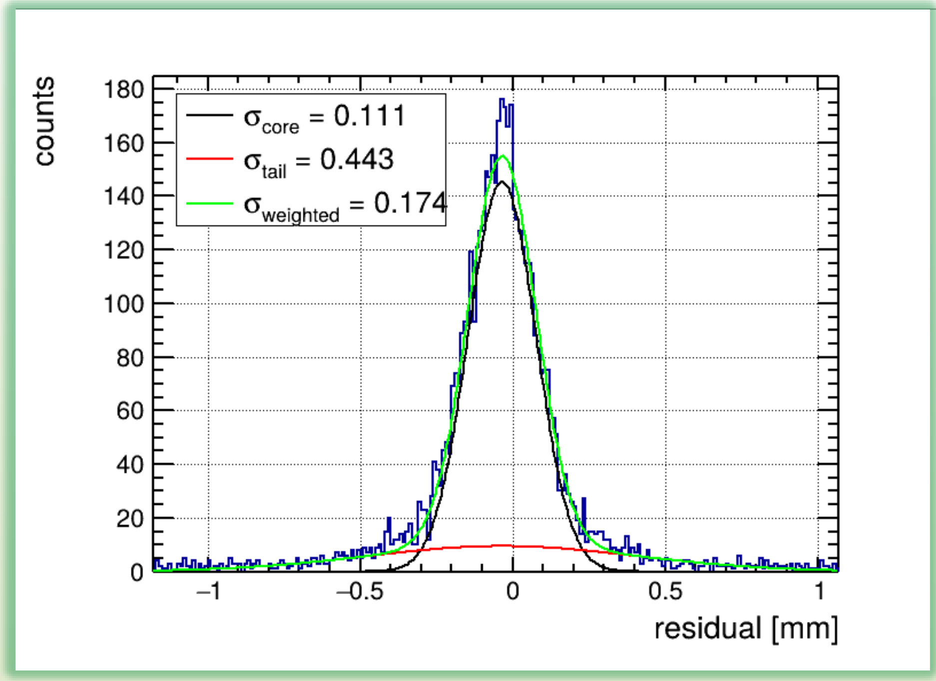
Outlook

- Characterization of MgF radiator with DLC (2 nm), Br_4C (5 nm) DLC Photocathodes at CERN SPS H4 Beam Line
- Testing new anode Structures → 2-D Position reconstruction for multiple incident particles
  - SGR Micromegas and SGR Gem detector are currently tested with H4 beamline at CERN's SPS
- Charakterization of MgF radiator with SiPMs
- Charakterization of DLC Photocathodes with the ASSET (A Small Sample Evaporation Test) setup



M. Lisowska, Photocathode Characterisation and Ageing Studies for Precise-Timing Gaseous Detectors (M.S. thesis),2021

Examination of the Spatial Resolution



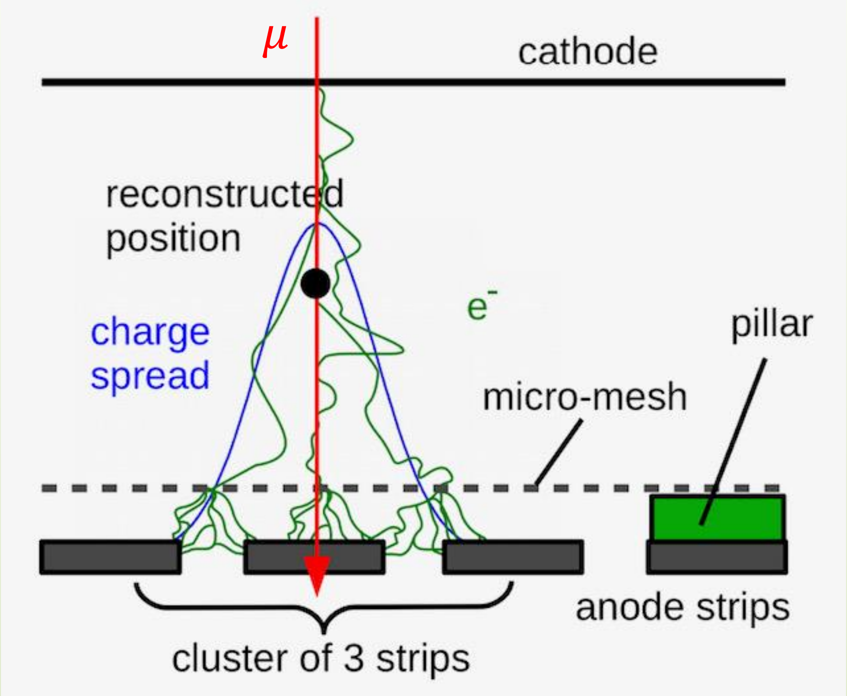
double gaussian fit:

- σ_{core} : internal detector resolution
- σ_{tail} : broadening effects
    - multiple scattering
    - delta electrons
    - …

$$\sigma_{weighted} = \frac{\sigma_{core} \cdot \int G_{core}(x)dx + \sigma_{tail} \cdot \int G_{tail}(x)dx}{\int G_{core}(x)dx + \int G_{tail}(x)dx}$$

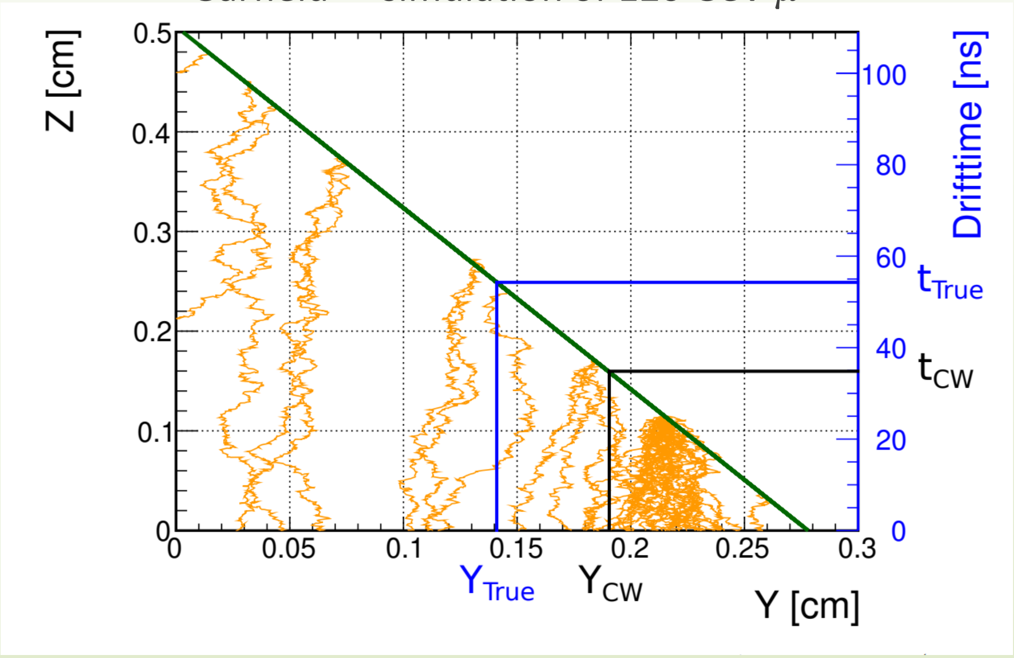
$$\sigma = \sqrt{\sigma^2_{weighted\,/\,core} - \sigma^2_{track}}$$

Position Reconstruction:



$$x_{\text{centroid}} = \frac{\sum_{\#strips\ in\ cluster} q_{strips} \cdot x_{strip}}{Q_{cluster}}$$

Garfield++ simulation of 120 GeV μ^-



inhomogeneous ionization by muons

Vogel,Fabian;Long-Term Irradiation Studies of Large-Area Micromegas Detectors for the ATLAS NSW Upgrade; December 2023;

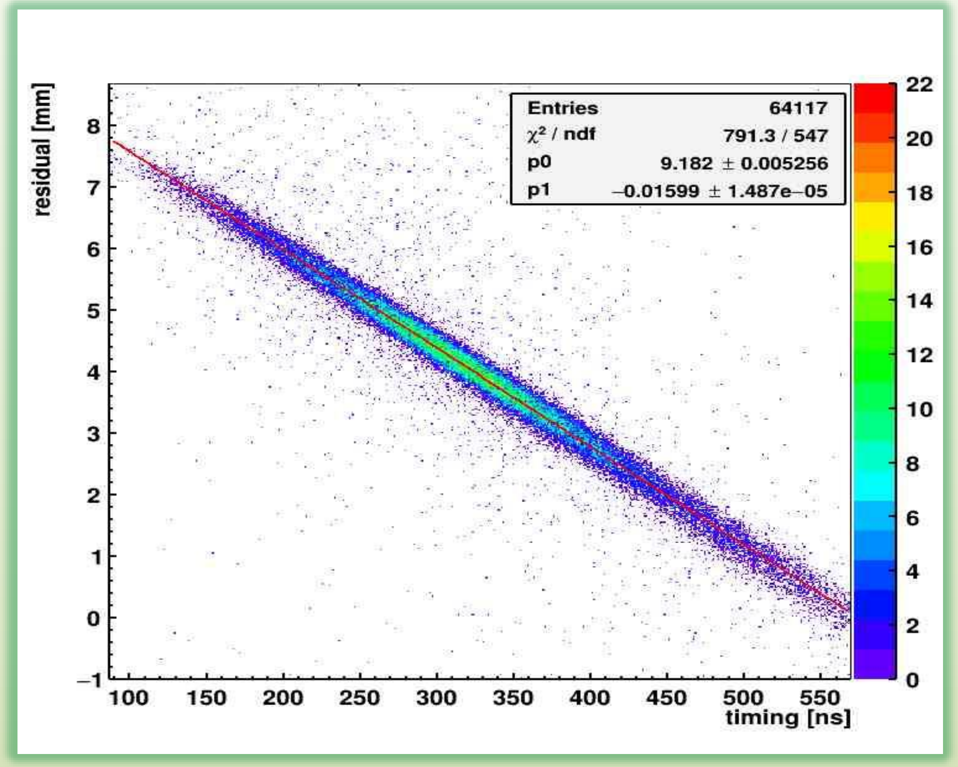
Time Corrected Centroid Methode

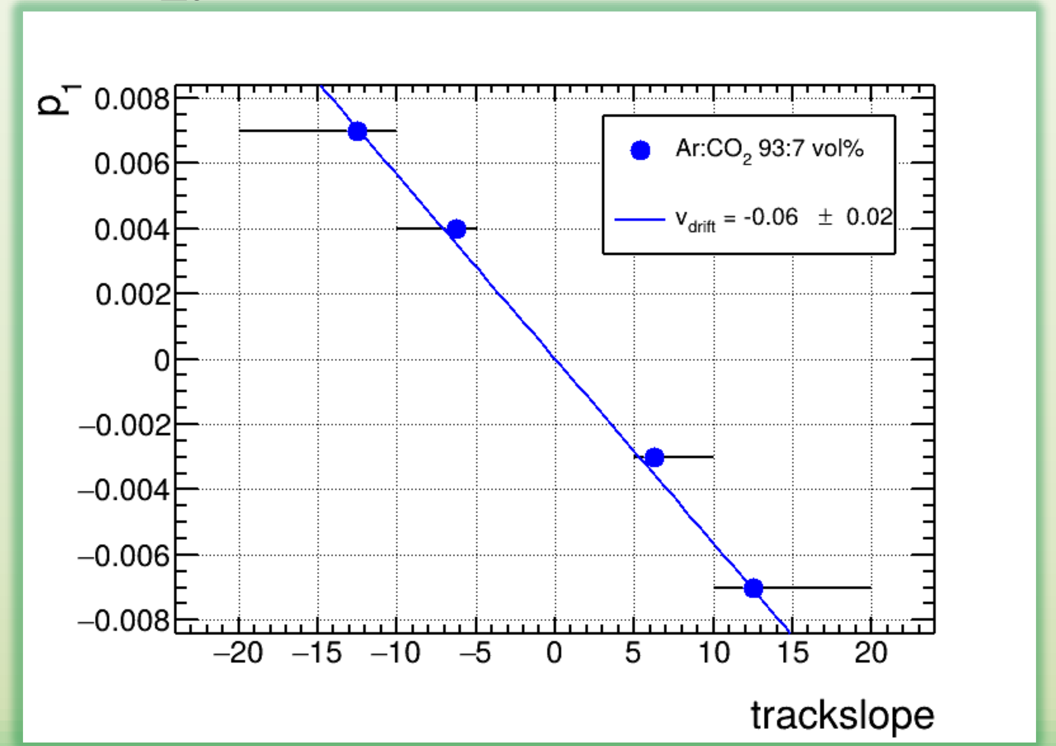
Correlation between charge weighted cluster time and charge weighted residual

$$t_c = \frac{\sum_{\#strips\ in\ cluster} q_{strips} \cdot t_{strip}}{Q_{cluster}} \rightarrow \boldsymbol{\Delta x = (t_{mid} - t_c) \cdot v_D \cdot tan(\theta_\mu)}$$

$$p_1 = \frac{\Delta x}{\Delta t} = v_D \cdot \tan(\theta_\mu)$$

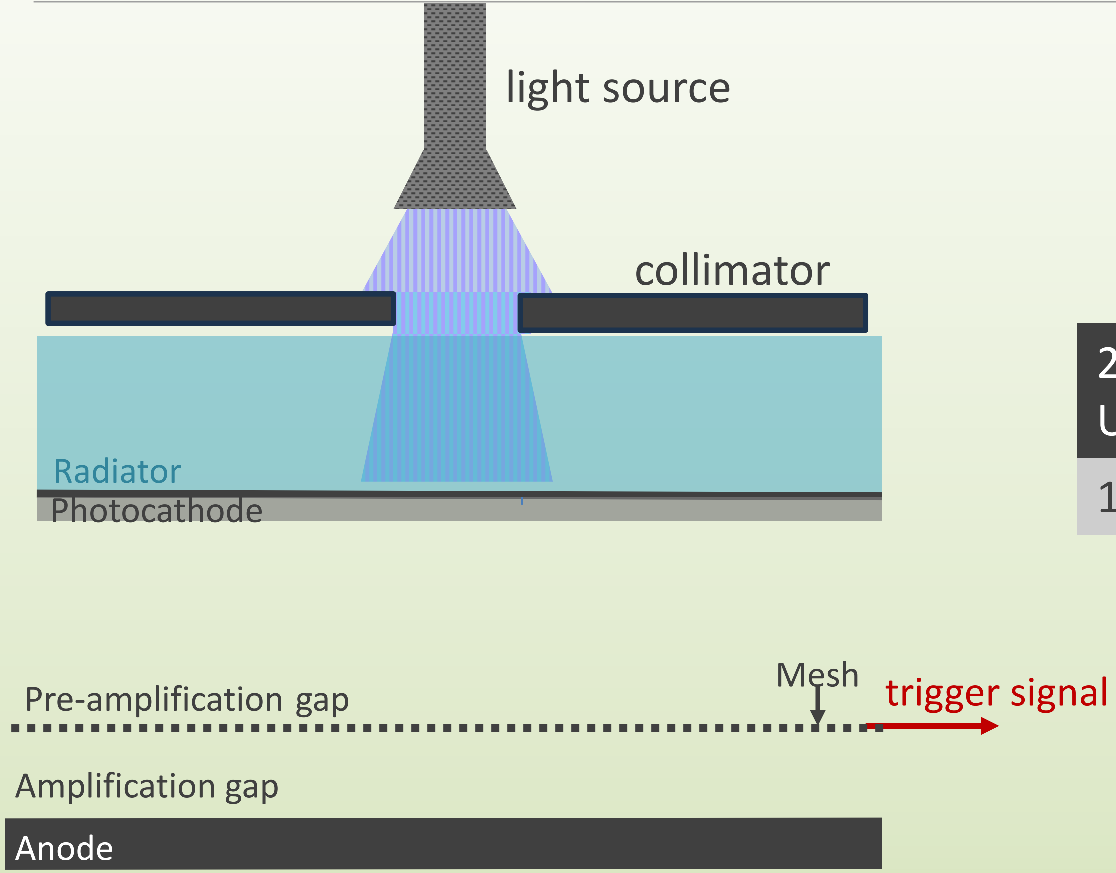
$v_D = 0.046 \frac{mm}{ns}$ for $Ar{:}CO_2$ 93:7 vol%





Method developed in:
Flierl,Bernhard; Particle Tracking with Micro-Pattern Gaseous Detectors; Mar 2018

External Light Source Measurements

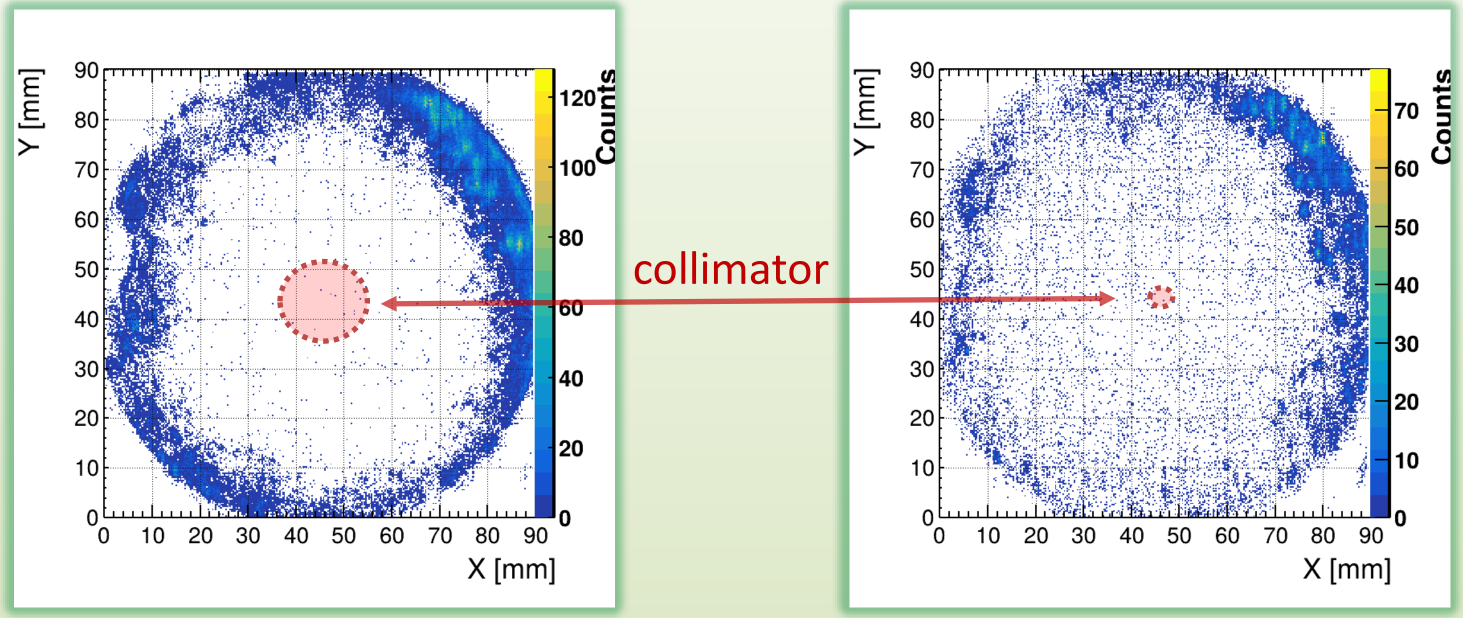


- UV light /Blue light/ no light onto radiator
- 2 cm / 3mm collimator used to hit center of the detector
- Signal of the mesh used for triggering

2cm collimator UV light	3 mm collimator Blue LED light	No light
100 Hz trigger-rate	10 Hz trigger-rate	1 Hz trigger-rate

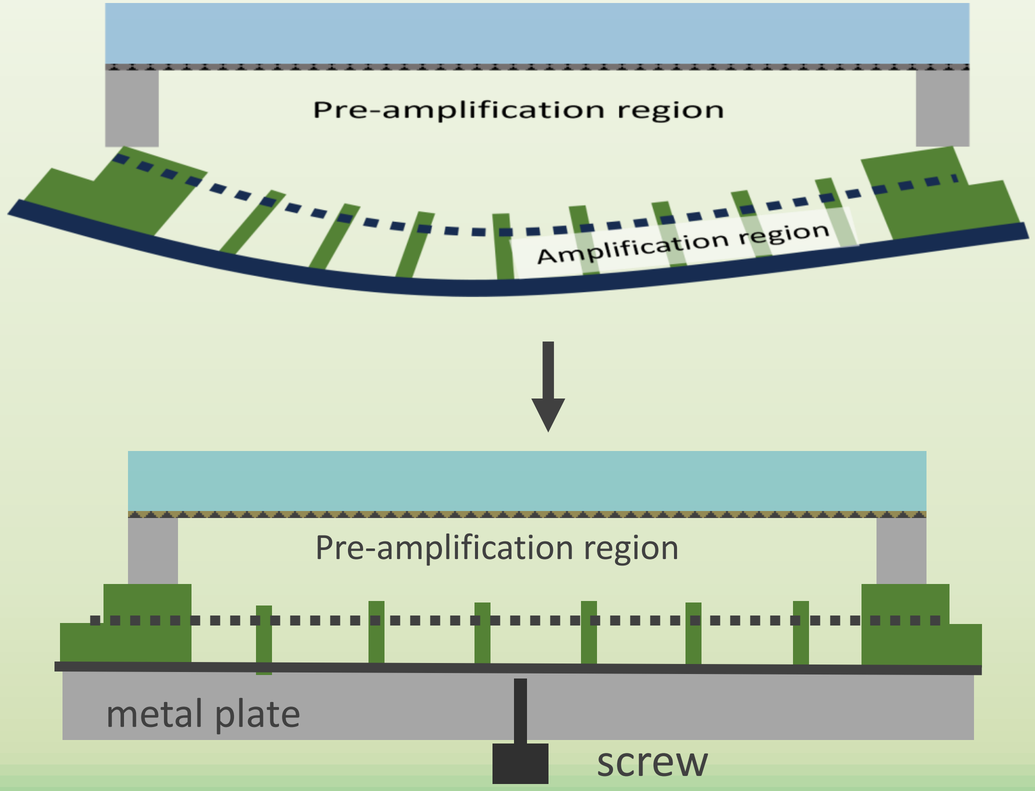
2D Hit-Position with External Light Source

2cm collimator UV	3 mm collimator LED
100 Hz trigger-rate	10 Hz trigger-rate

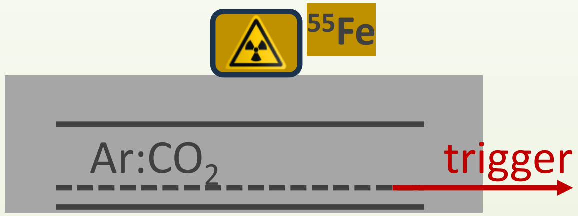


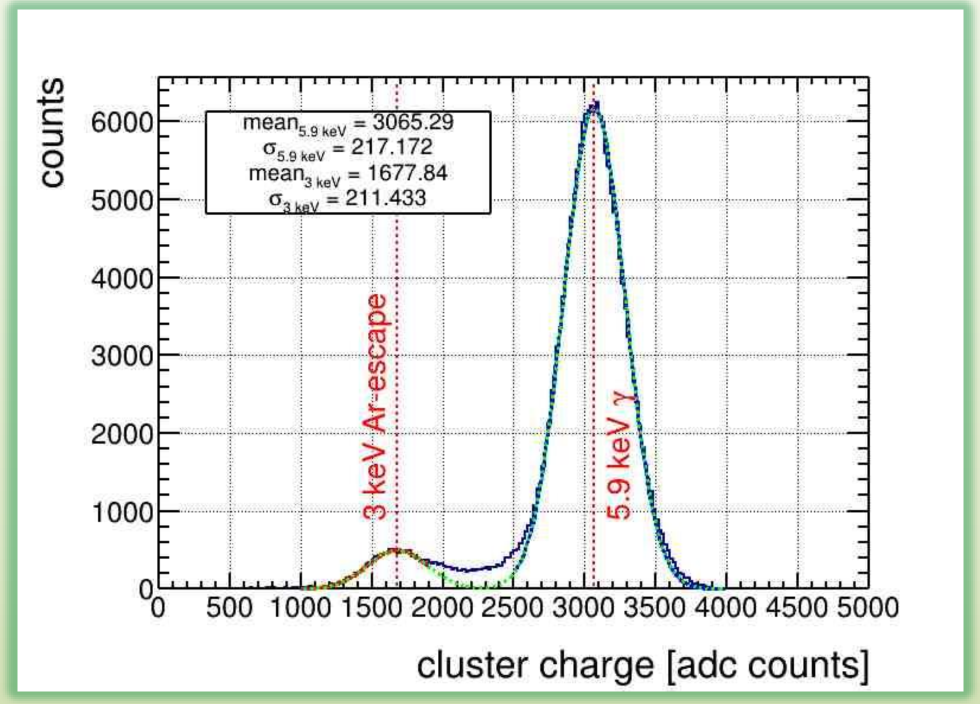
Light still reaches outer part of the photocathode due to reflection and scattering in the radiator

- Inhomogeneous pre-amplification field
- Conversion of photons only at the edge of the photocathode!



Energy Resolution (standard Micromegas)





$^{55}Fe + e^- \rightarrow\ ^{55}Mn^* \rightarrow\ ^{55}Mn + \gamma$

$E_{K\alpha}$ = 5.9 keV

If X-Ray displaces K-shell e^- fom Ar → e^- transition from L- to K-shell

If γ from e^- L- to K-shell transition leaves detector:

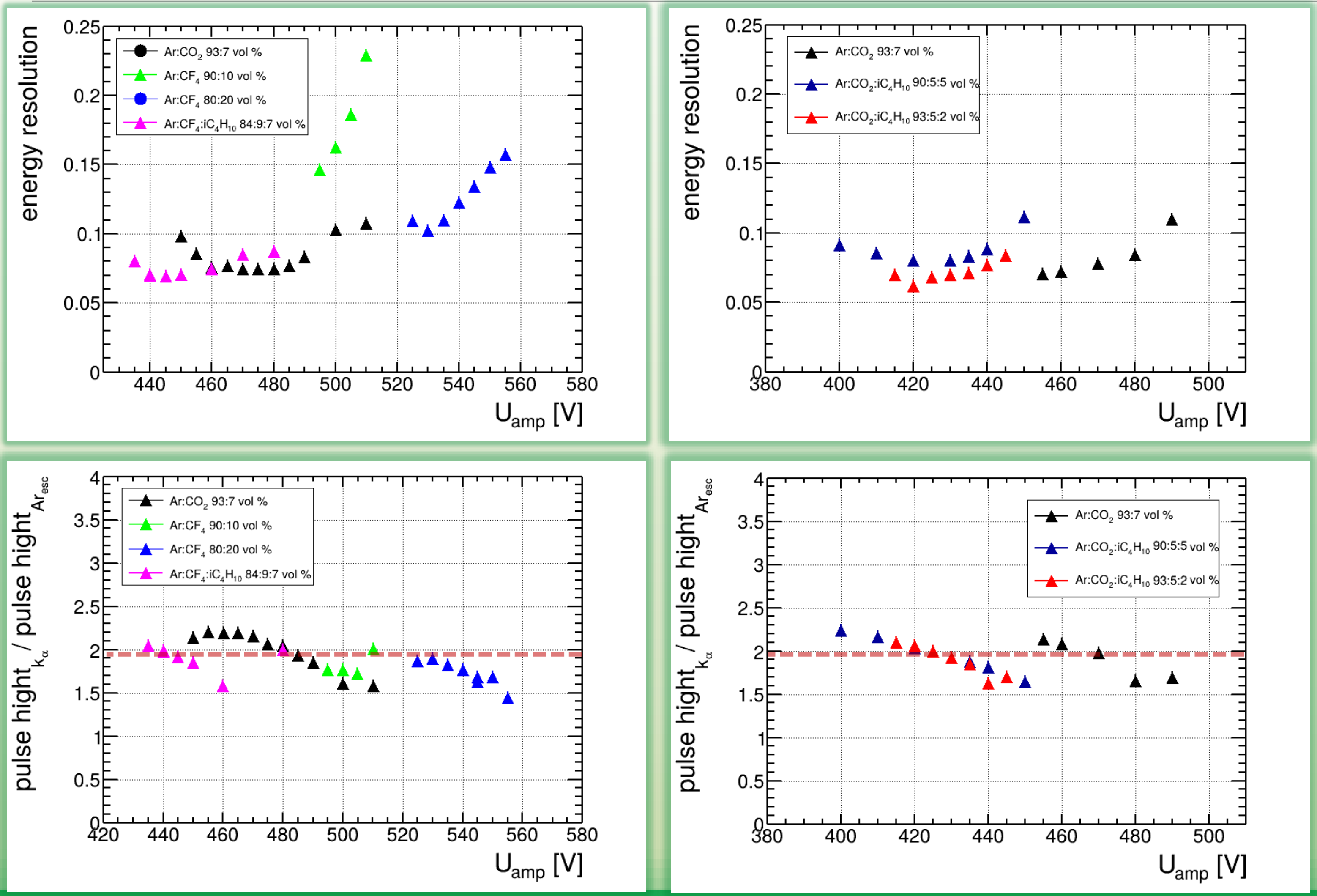
$E_{Ar\ esc}$ = 3 keV

Gaussian fit of K_α– and Ar escape-peak:

$$\text{energy resolution} := \frac{\sigma_{5.9\ keV}}{\text{mean}_{5.9\ keV}}$$

$$\frac{\text{mean}_{5.9\ keV}}{\text{mean}_{3\ keV}} \overset{!}{=} 1.97$$

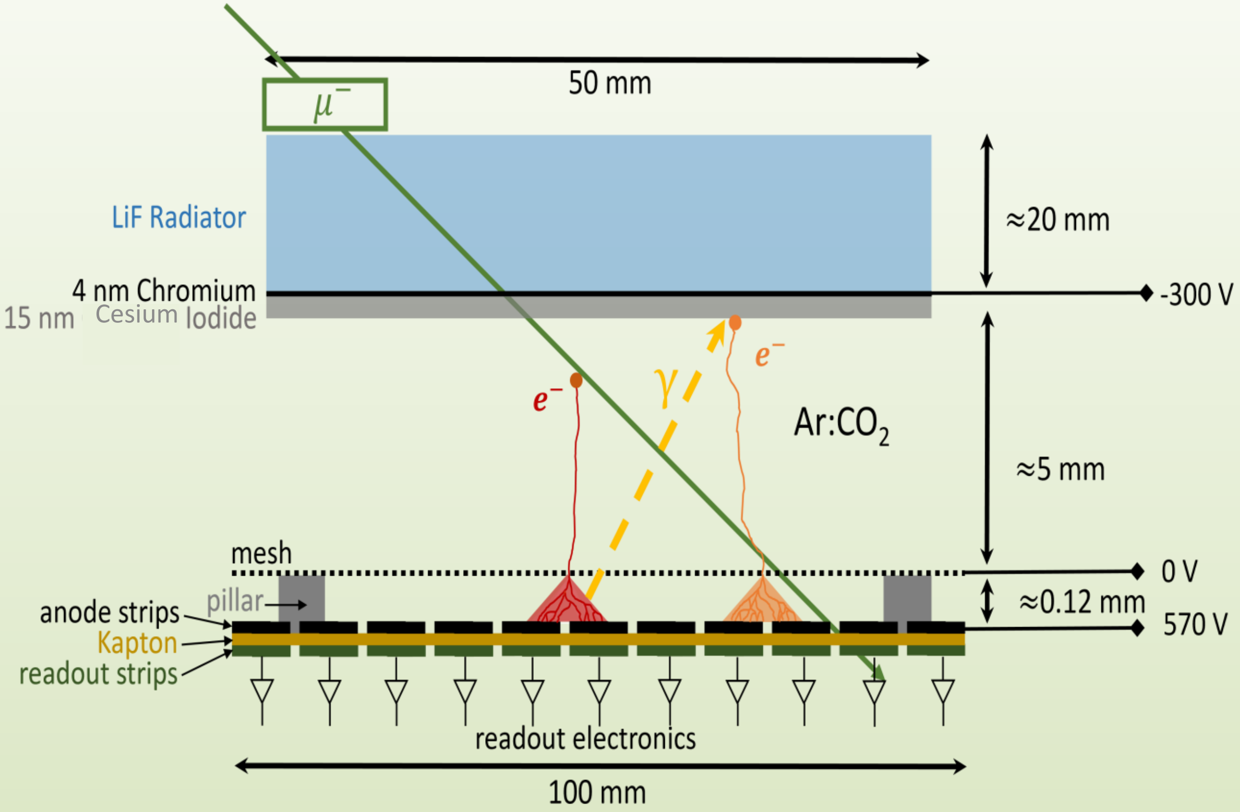
Energy Resolution (standard Micromegas)



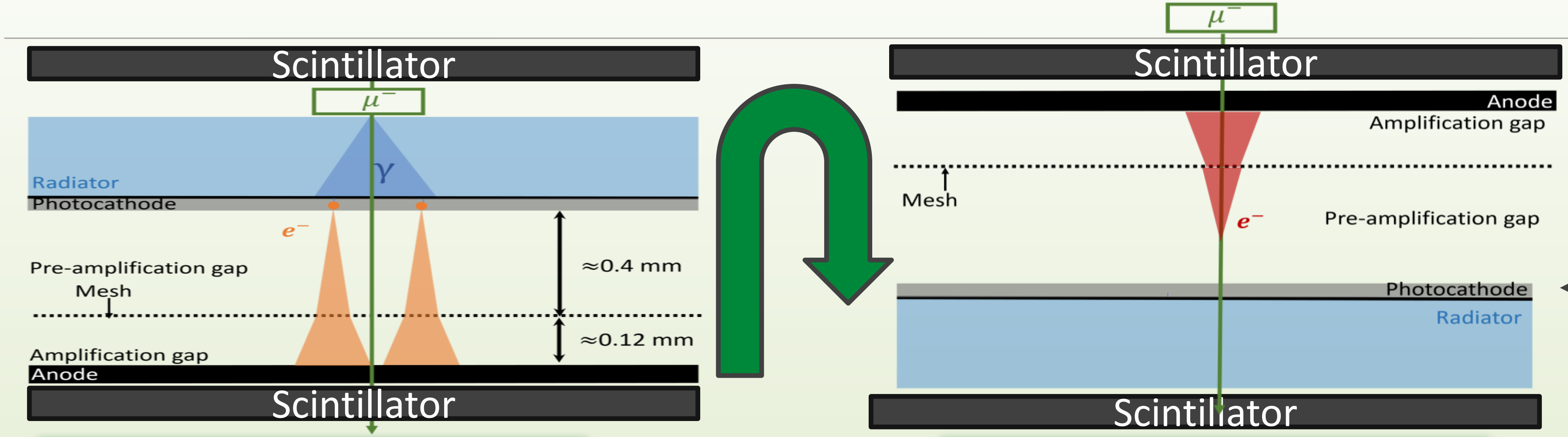
- Fe spectrum seen with all gas mixtures
- Best **energy resolution (<7%)** with $Ar:CO_2:iC_4H_{10}$ 90:5:5 vol%
- Significantly worse energy resolution:
  - $Ar:CF_4$ 90:10
  - $Ar:CF_4$ 80:20

Afterpulsing

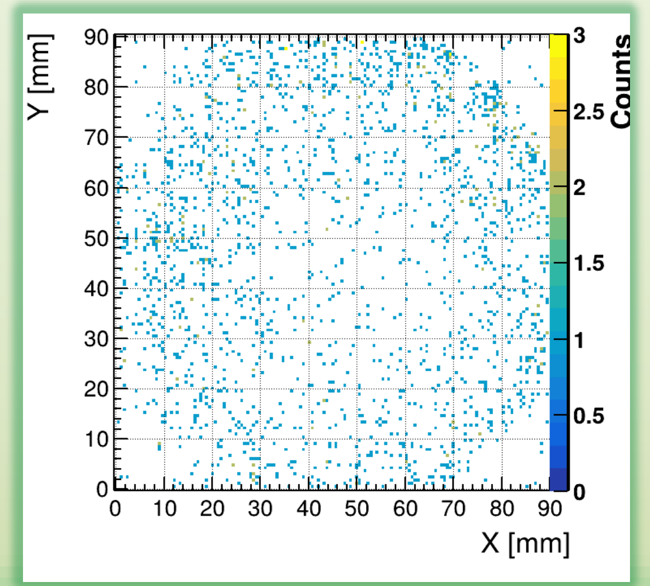
- Recombination of ions and electrons in amplification region
- Photon from recombination hits Photocathode
- Photon is converted into an electron and enters drift region
- Detection after maximum drift time
- Boxlike timing distribution expected

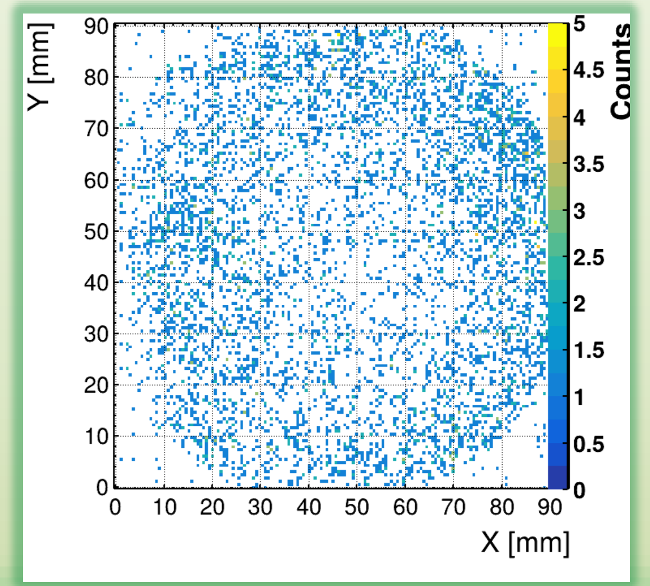


2D Hit-Position with Cosmic Muons



← No Cherenkov e^- expected

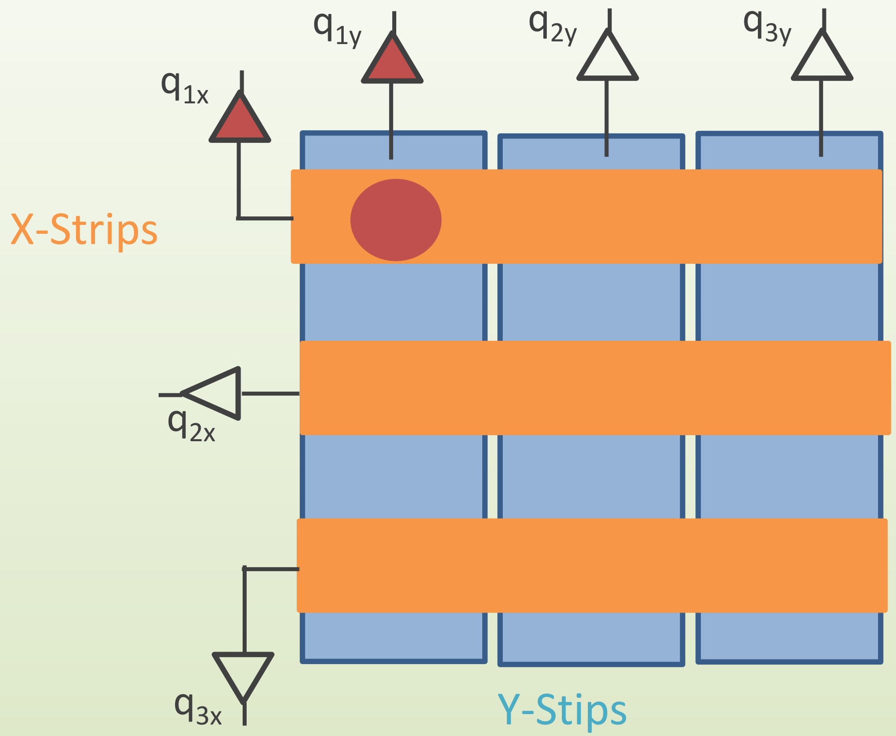


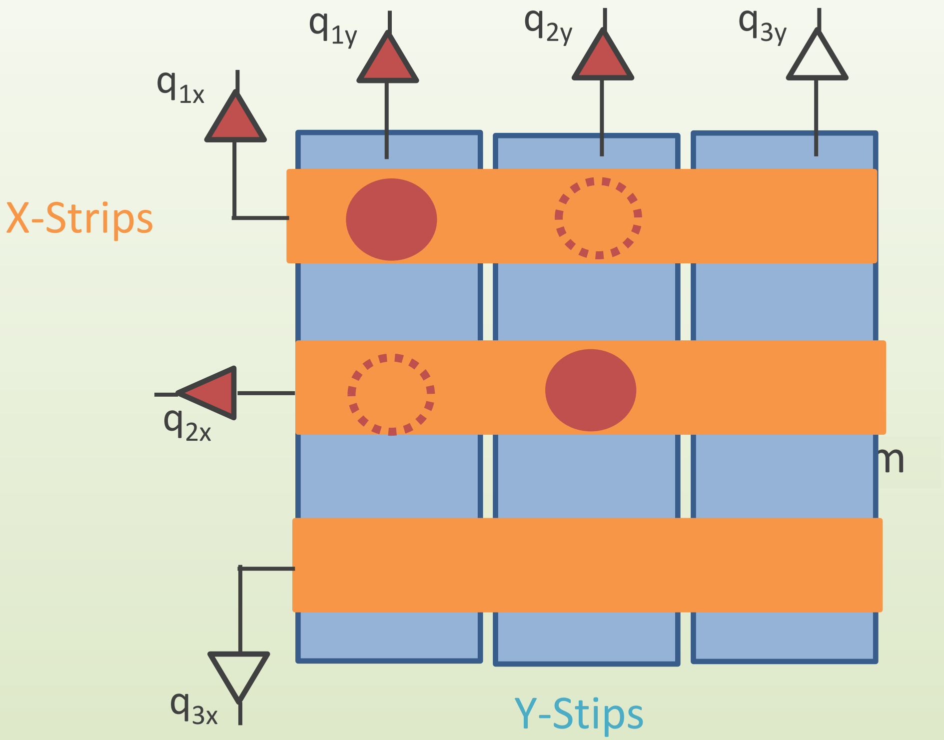


- Low efficiency in the middle of the detector
- No difference if the detector is turned upside down

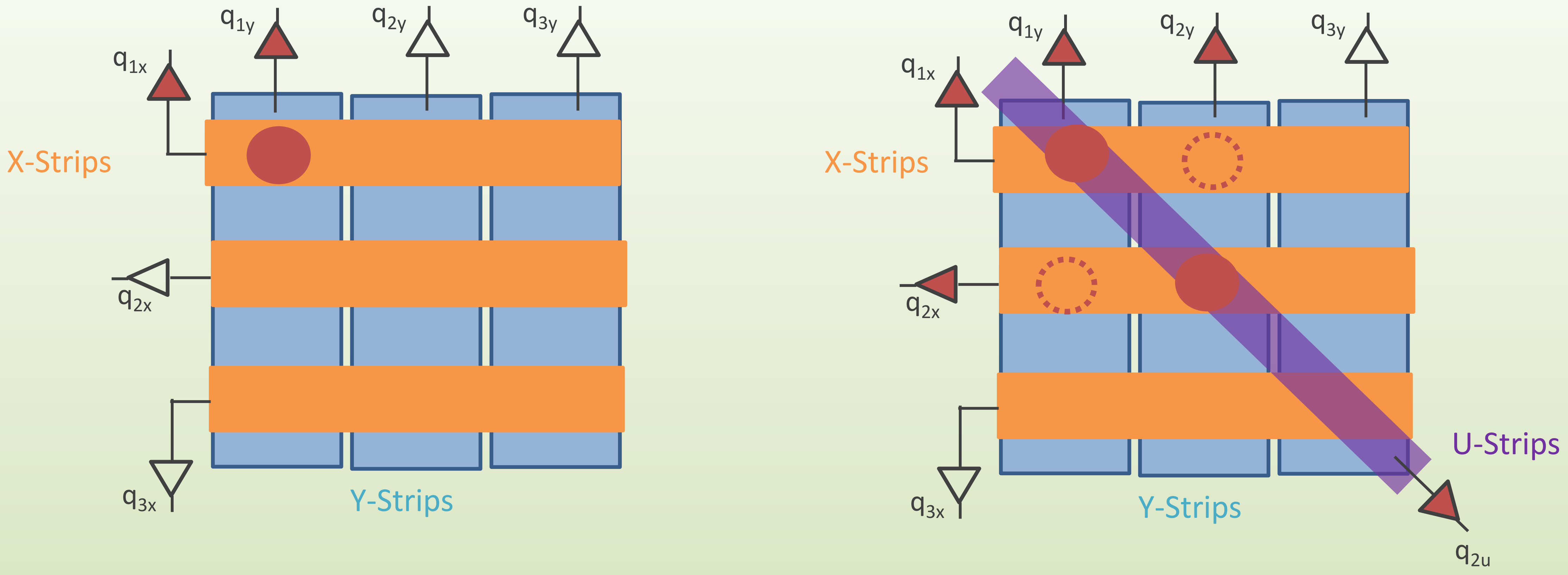
→ **No Cherenkov photons detected**

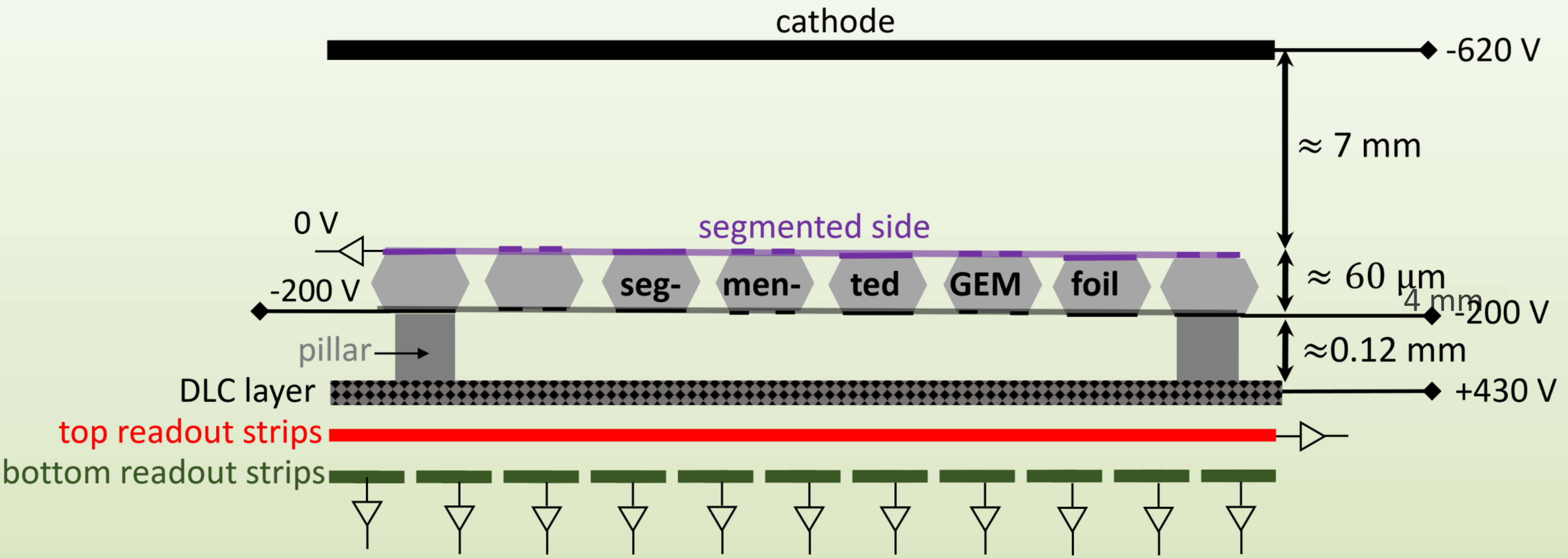
2-D Position Reconstruction for Multiple Incidetce Particles

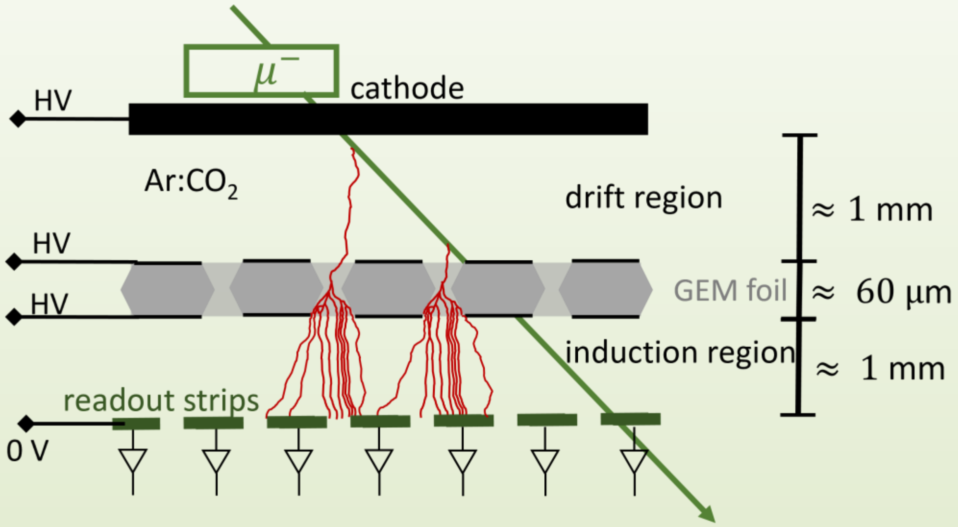




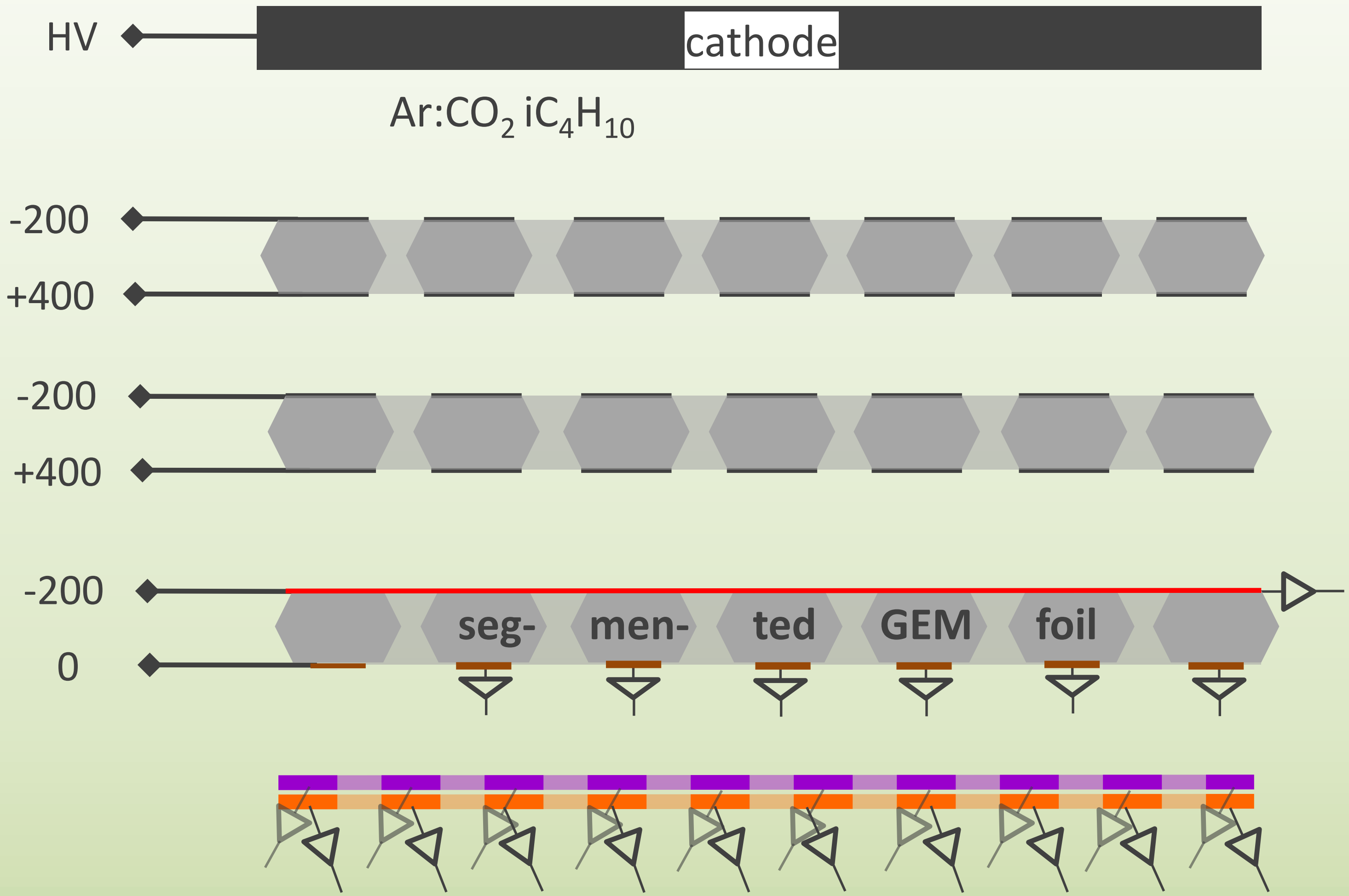
2-D Position Reconstruction for Multiple Incident Particles

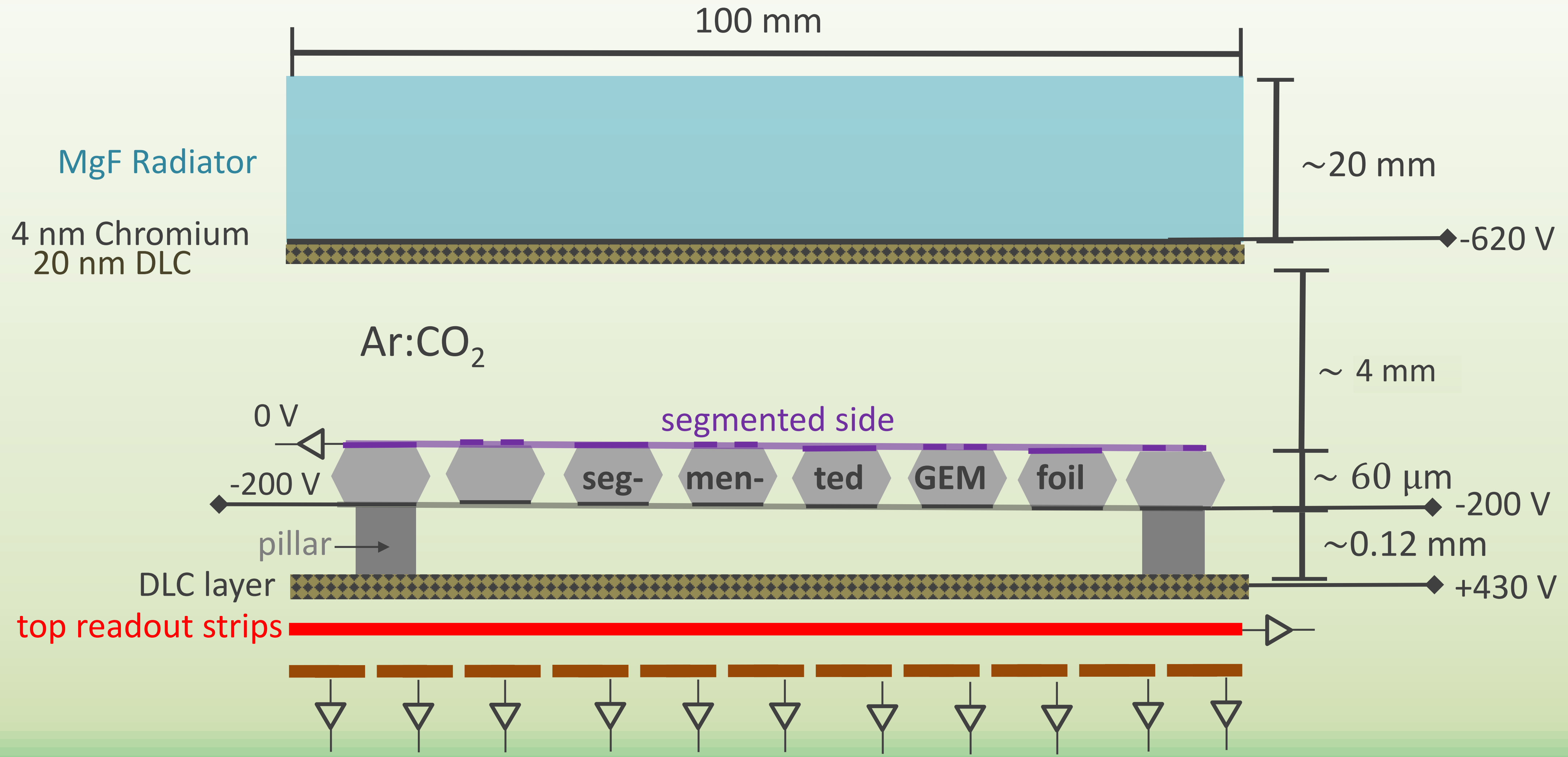



cathode
-620 V
≈ 7 mm
0 V
segmented side
-200 V
seg-
men-
ted
GEM
foil
≈ 60 µm
4 mm
-200 V
pillar
≈0.12 mm
DLC layer
+430 V
top readout strips
bottom readout strips

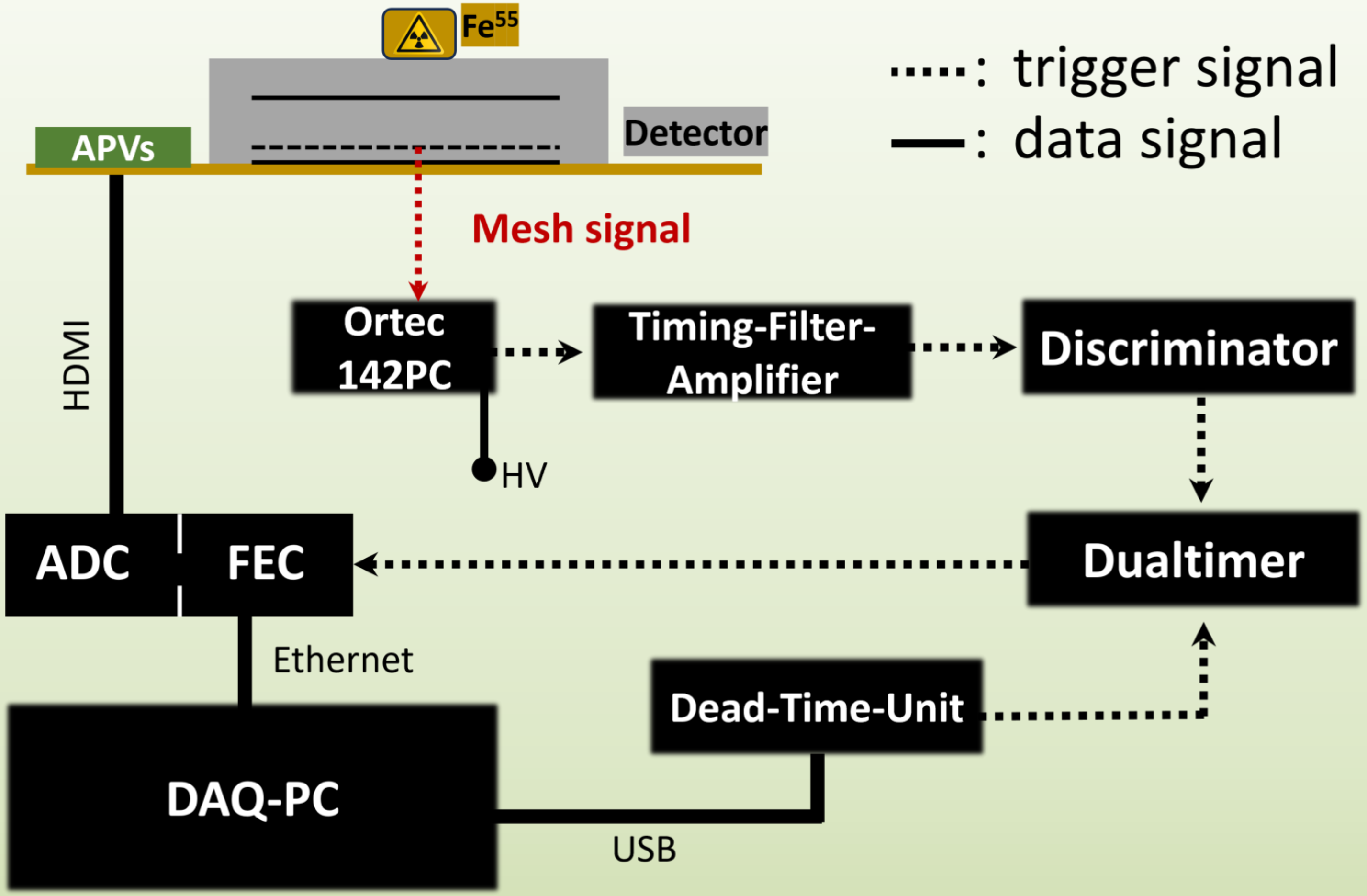


μ^-
cathode
HV
Ar:CO$_2$
drift region
$\approx$ 1 mm
HV
HV
GEM foil
$\approx$ 60 µm
induction region
$\approx$ 1 mm
readout strips
0 V

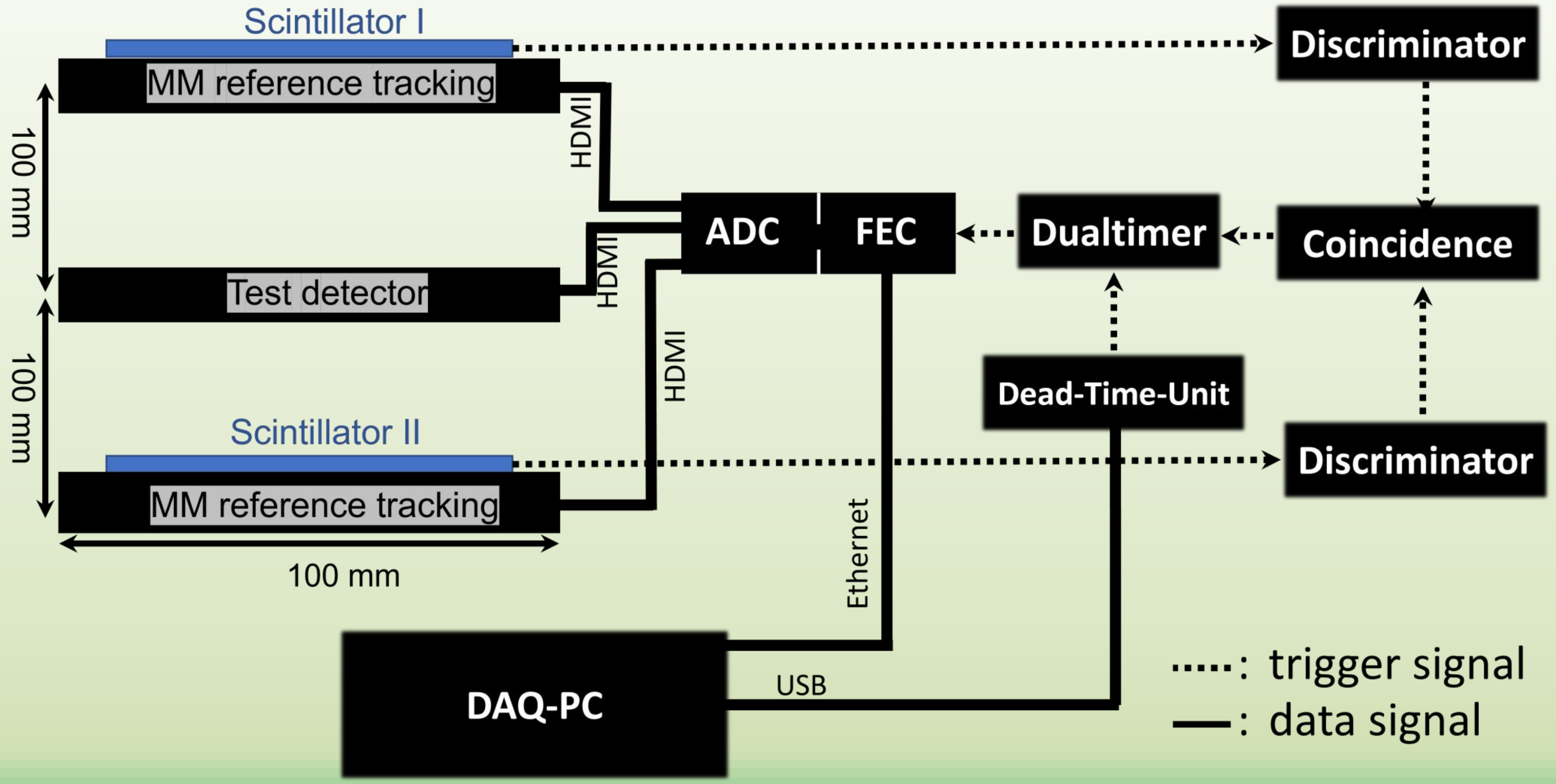

HV
cathode
Ar:CO_2 iC_4H_{10}
-200
+400
-200
+400
-200
0
seg-
men-
ted
GEM
foil


100 mm
MgF Radiator
~20 mm
4 nm Chromium
20 nm DLC
-620 V
Ar:CO_2
~ 4 mm
0 V
segmented side
-200 V
seg-
men-
ted
GEM
foil
~ 60 µm
-200 V
pillar
~0.12 mm
DLC layer
+430 V
top readout strips

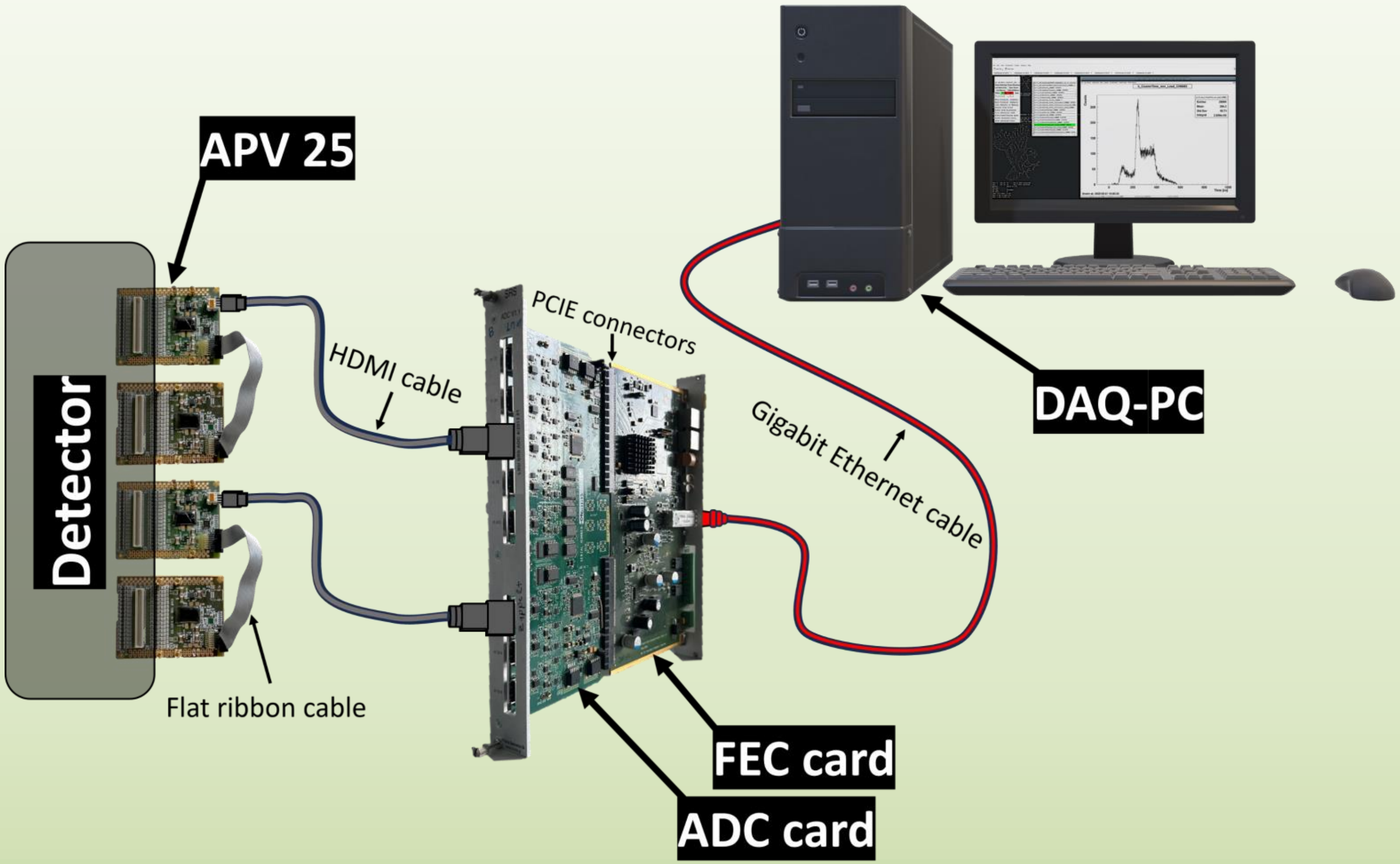
Measurements with Fe55:



Tracking with muons:



SRS


APV 25
Detector
HDMI cable
PCIE connectors
Flat ribbon cable
Gigabit Ethernet cable
DAQ-PC
FEC card
ADC card

Drift and Diffusion of Electrons Simulated with Garfield++, MAGBOLZ