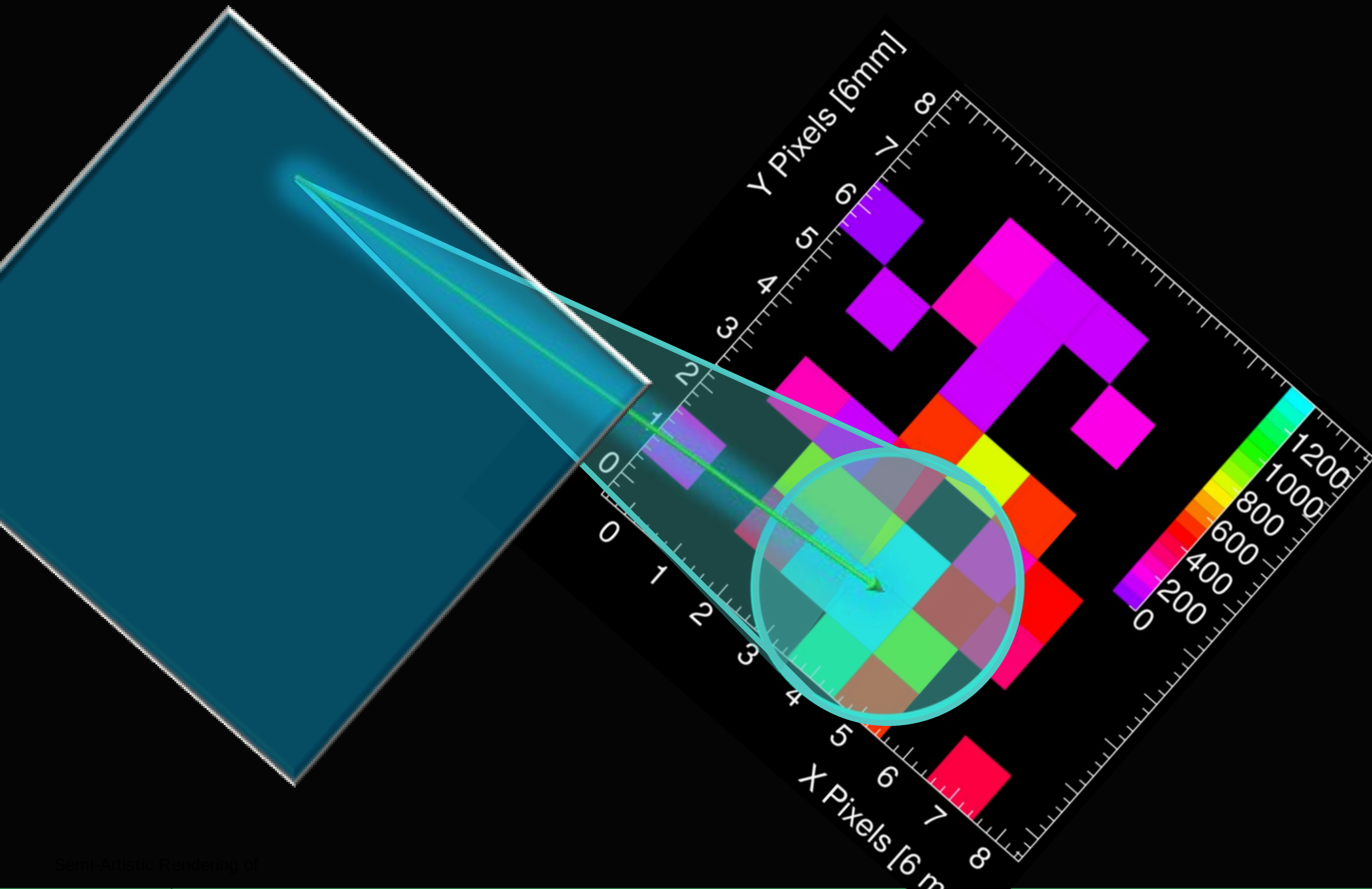
A Hitchhikers Guide to the Inversed RICH Micromegas



Joint Seminar 2022

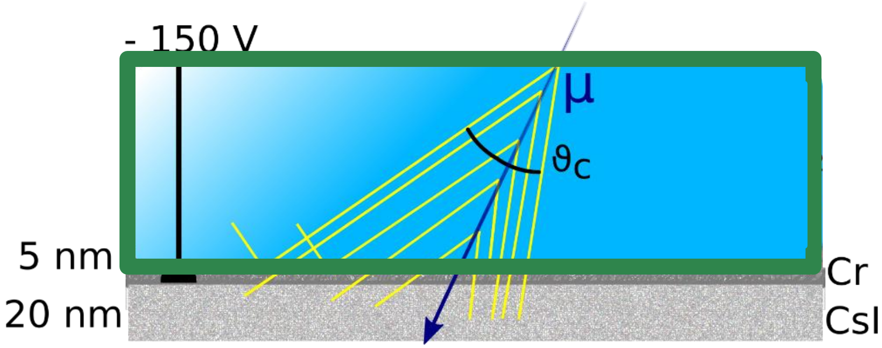
Maximilian Rinnagel

AG Biebel

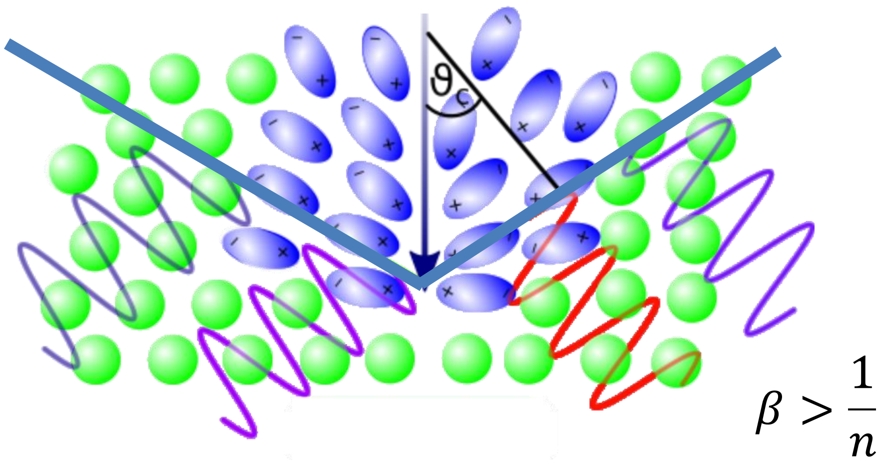
8th June 2022

LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Prelude: The Cherenkov Effect



On a microscopic level:



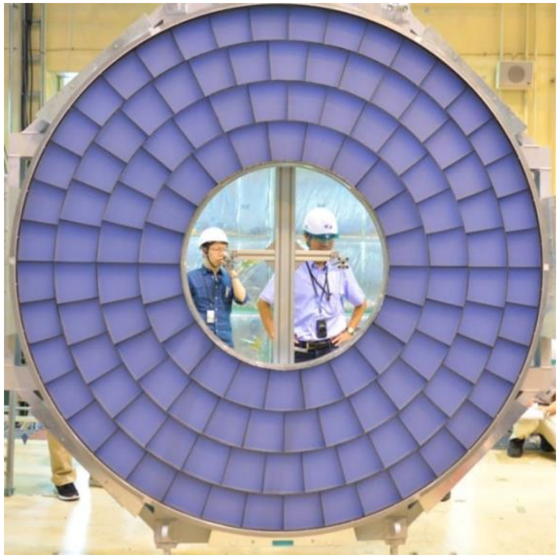
- Medium with refractive index $n(w) > 1$
- Traversing charged particle with $\beta = \frac{v}{c} > \frac{1}{n}$
- Polarisation of medium in a conic shape
- Photon emission due to constructive interference
- Emission angle dependent on photon frequency :

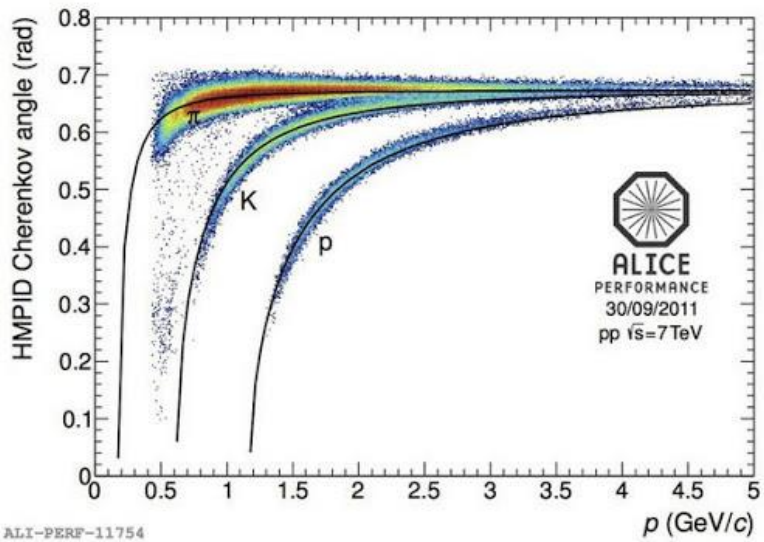
$$\cos\theta_C(\omega) = \left(\beta * n(\omega)\right)^{-1}$$

Particle Identification

BELLE II

ARICH





- Cherenkov Detectors established in large systems:

  HADES, BELLE II, LHCb, ALICE

  - Momentum determination p of charged particle q (magnetic field) via Lorentz Force curvature r

$$p = qBr$$

  - Determination of particle mass via Cherenkov angle measurement $m = \frac{p}{\beta\gamma}$

→ OUR GOAL:

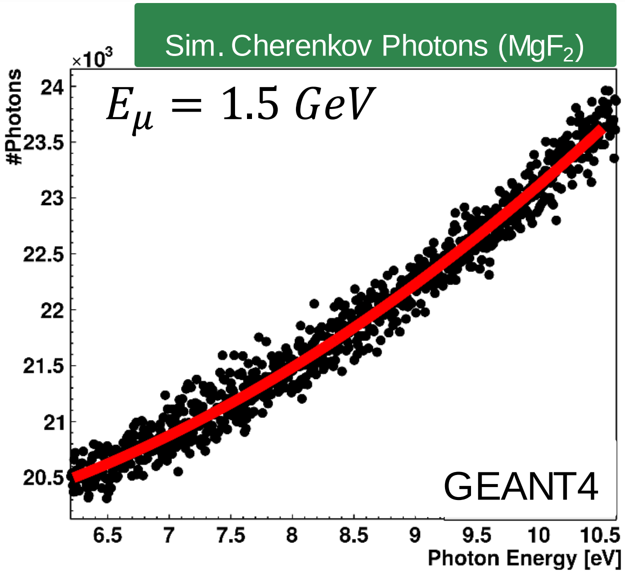
→ Momentum measurement via the Cherenkov effect (known particle e.g. cosmic μ)

→ Simultaneous position and momentum measurement

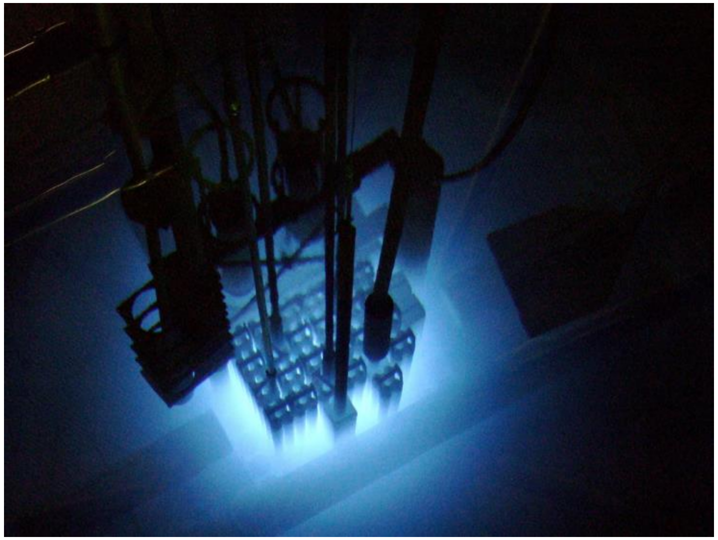
- Application: Beam Monitoring

  in Medical or High Energy Physics

Cherenkov Photon Yield



Cherenkov light in a reactor



Frank-Tamm formula

Number of photons per frequency $(d\omega)$

and unit length (dx) in the radiator :

$$\frac{d^2N}{d\omega dx} = \frac{q^2}{4\pi}\omega\alpha\underbrace{\left(1 - \frac{1}{n^2\beta^2}\right)}_{\sin\vartheta_c^{\ 2}}$$

- Continuous photon emission spectrum (Integrated):

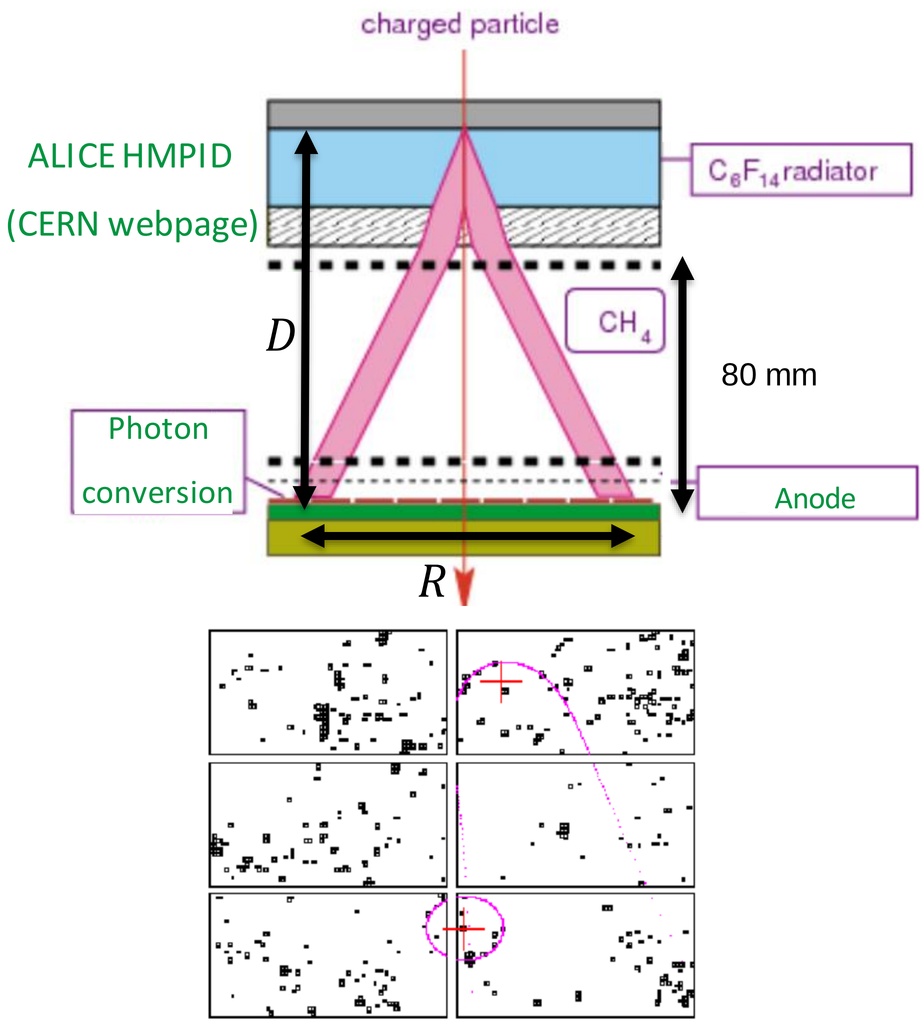
$$N_{ph} \sim n \cdot \beta \cdot \omega^2 \cdot d$$

→ Guidelines for Cherenkov medium (High yield N_{ph}):

- High radiator thickness d
- High refractive index of the radiator n
- Materials with far UV photon emission (large ω)

→ e.g. Fluoride crystals (MgF_2, LiF, CaF_2)

Typical Ring Imaging Cherenkov Detectors (RICH)



Pb-Pb event display

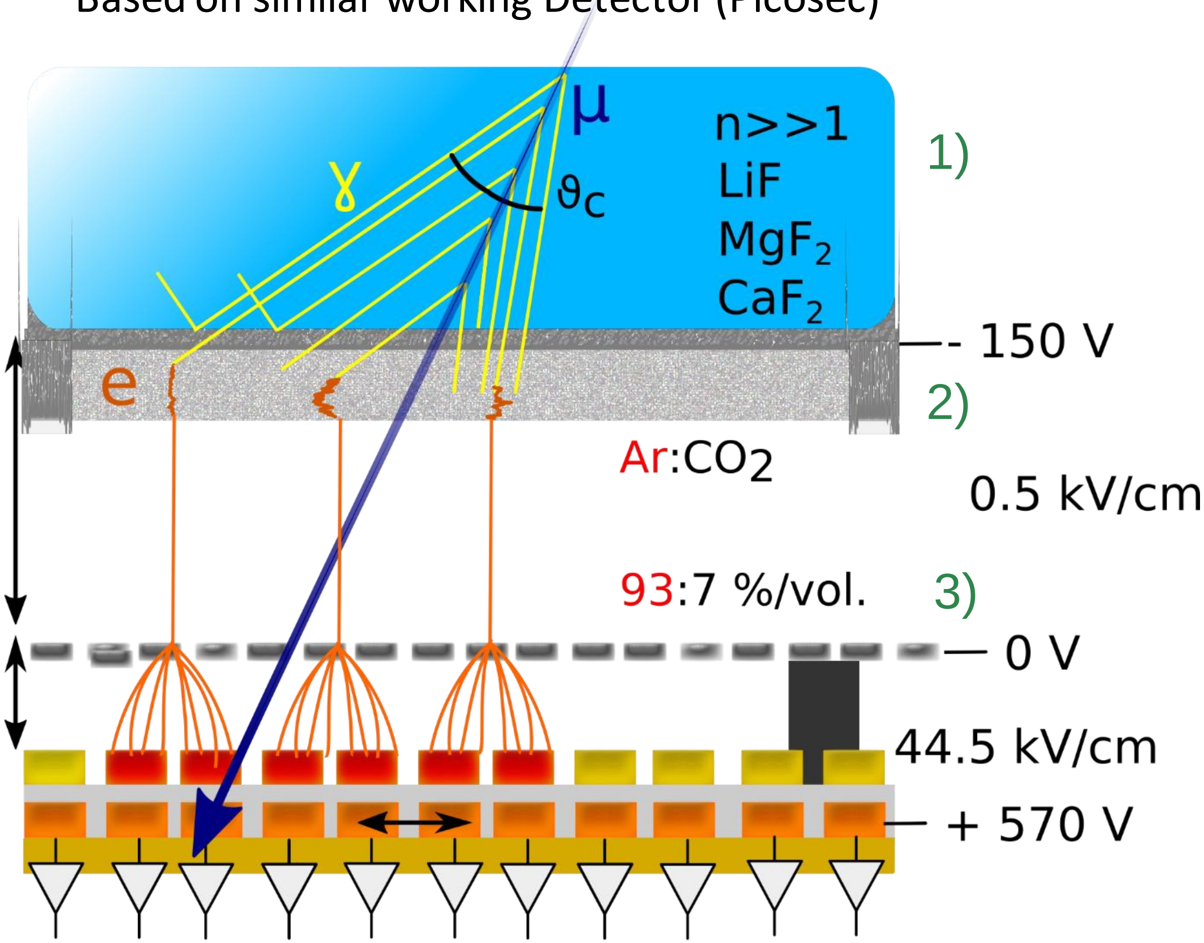
Example: HMPID of ALICE

- Consisting of a radiator, photon conversion layer, electron amplification stage
- Requirements:
  - Fine position sensitivity
  - Single Photon Resolution
- Determination of Ring diameter R

  → Cherenkov angle $\vartheta_c = \arctan(\frac{R/2}{D})$
- CHALLENGE: seperate signal from noise

Our Detector Schematic

Based on similar working Detector (Picosec)



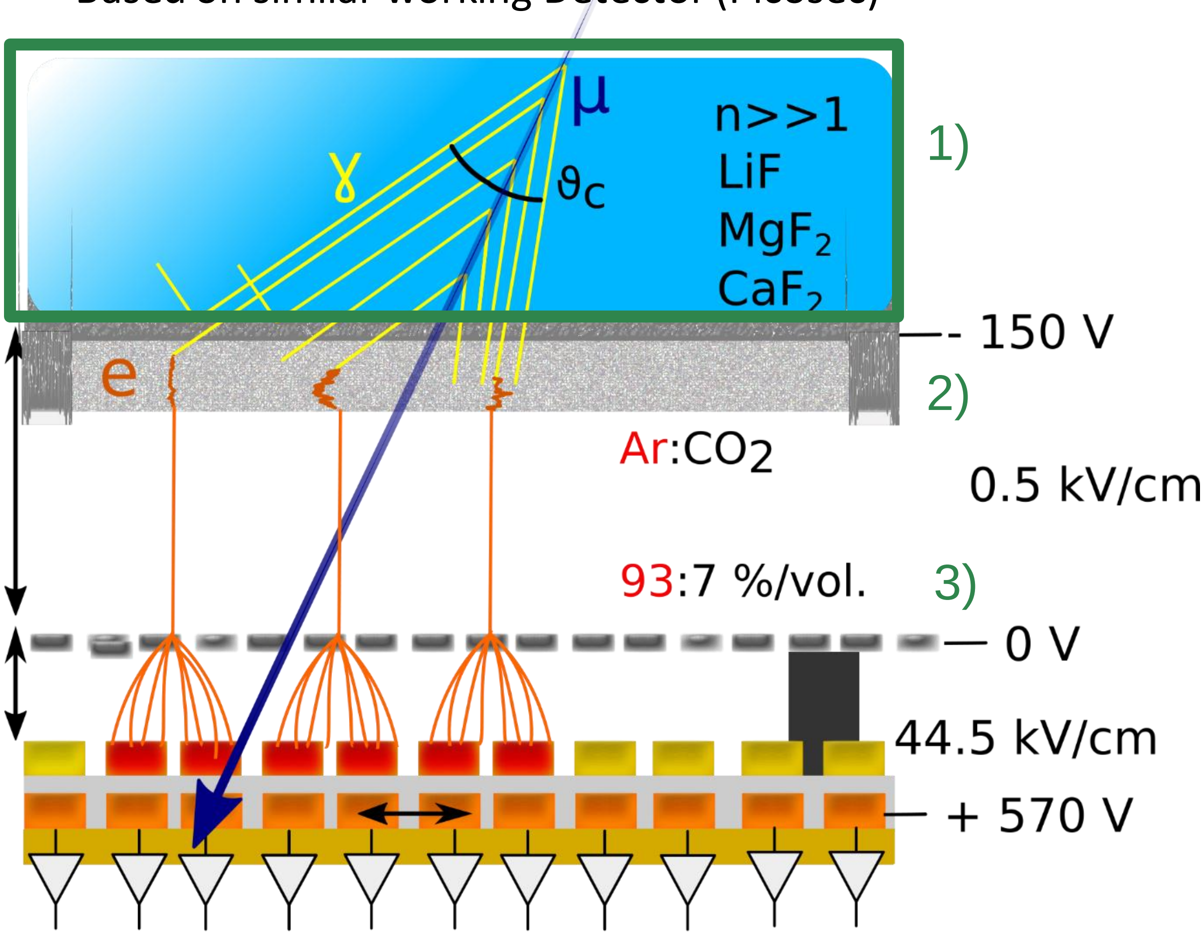
1) Photoemission (Cherenkov Radiator)

2) Photocathode (Cr + CsI)

3) Electron Amplification (Micromegas)

Detector Schematic: Cherenkov Radiator

Based on similar working Detector (Picosec)

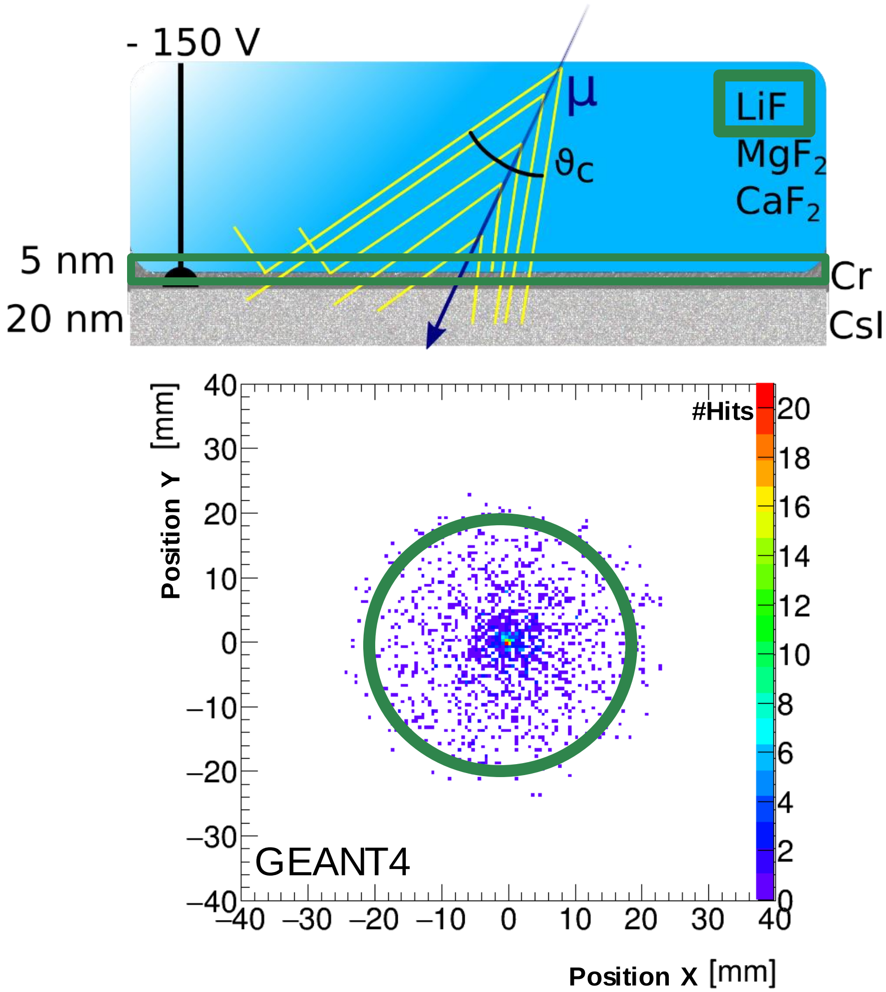


1) Photoemission (Cherenkov Radiator)

2) Photocathode (Cr + CsI)

3) Electron Amplification (Micromegas)

Sim: Cherenkov Photons inside the Radiator



Simulated photon position at the Cr layer

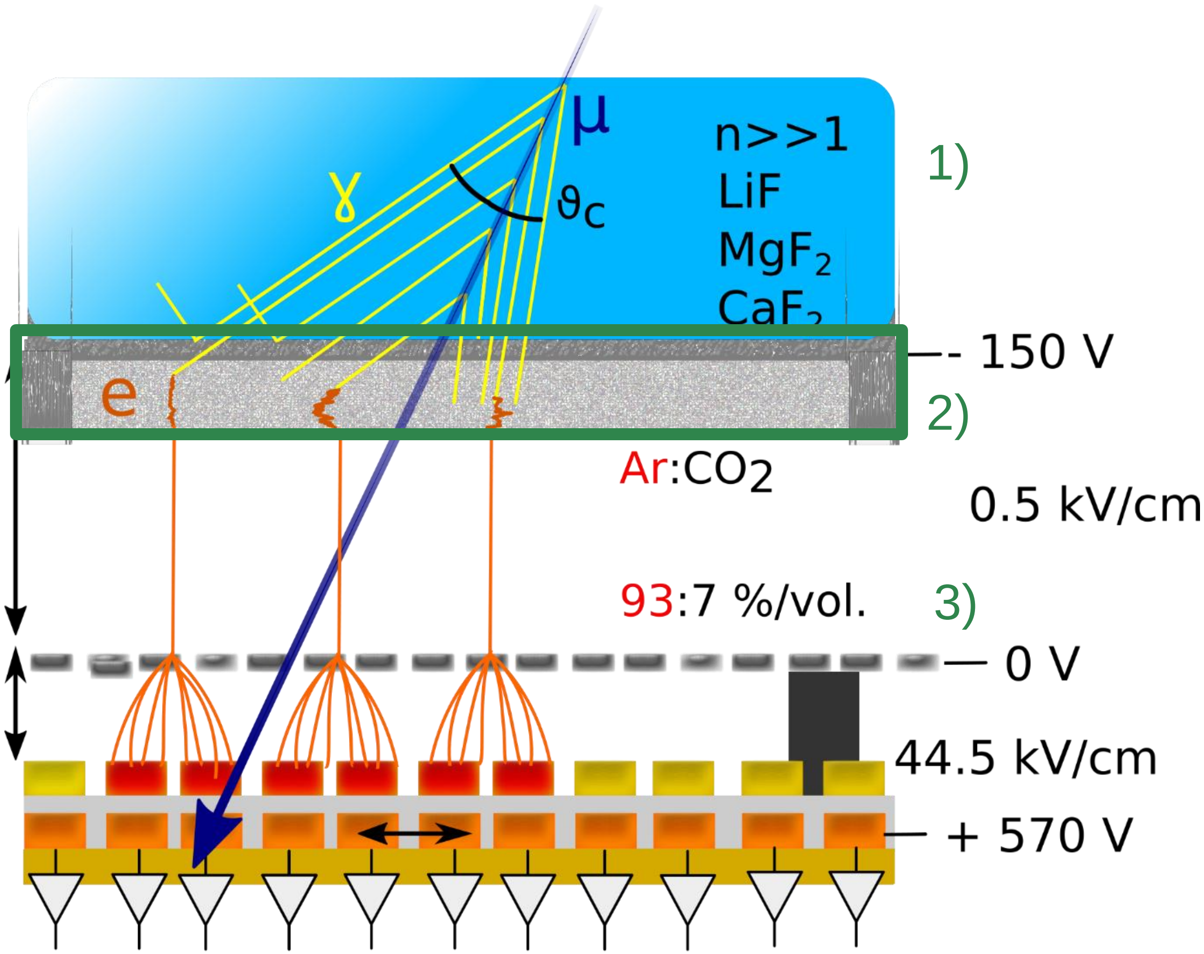
Simulation of Photons in LiF:

- Radiator: $n \sim 1.57; d = 20mm$
- Muon: $E_\mu = 1.5\ GeV$
- Simulated X-Y Position on bottom of the radiator

→ Cone Radius [perpendicular]: ~ 20mm

→ Creation of 1500 Cherenkov Photons

Detector Schematic: Photocathode



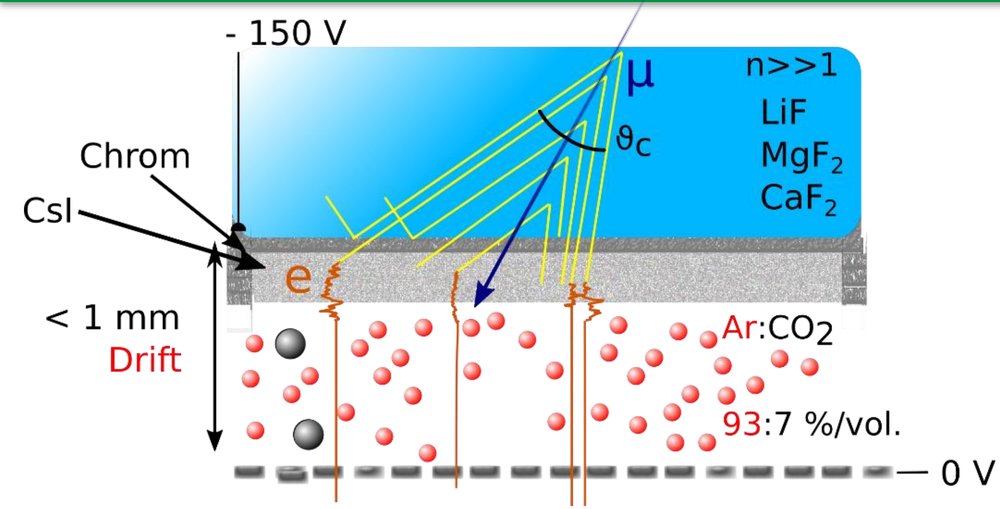
1) Photoemission (Cherenkov Radiator)

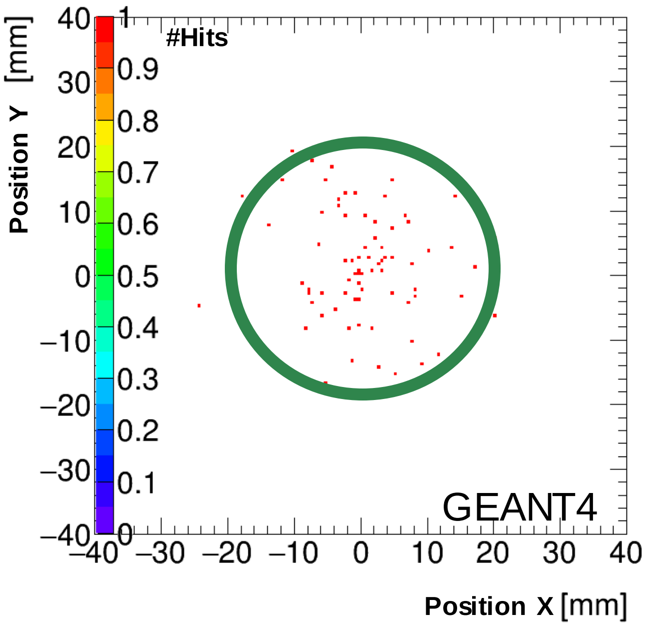
2) Photocathode (Cr + CsI)

3) Electron Amplification (Micromegas)

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Detector Schematic: Photocathode





Photocathode:

4nm Chromium (Cr) layer:

- Cr as sticky surface for conversion layer
- HV contacting and usage as cathode
- Reflection measured of 30% in agreement with literature

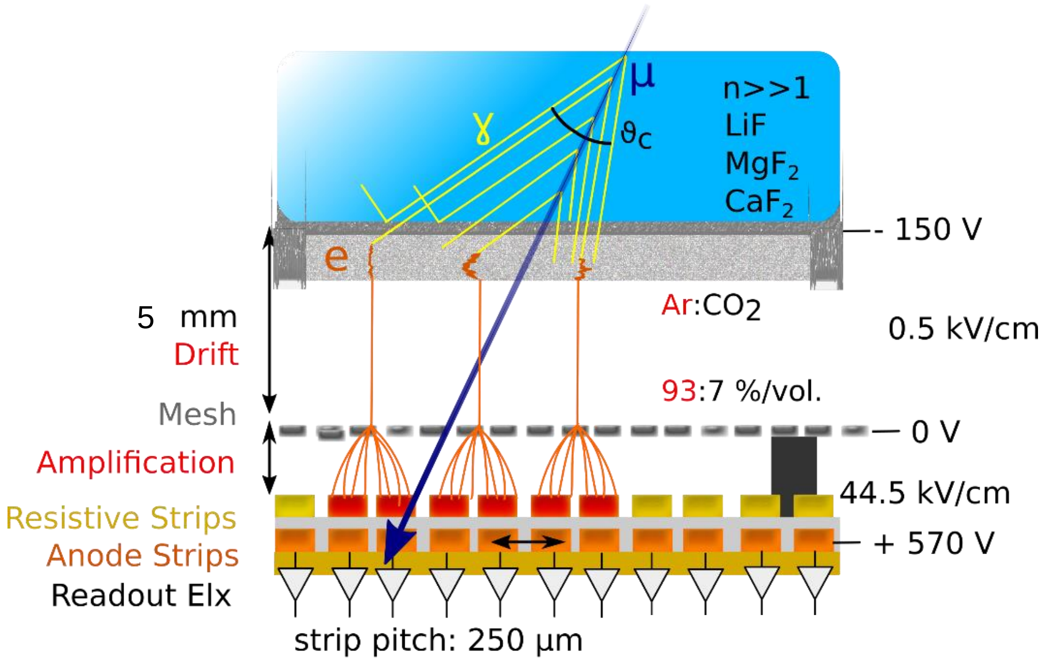
15nm Caesium Iodide (CsI) layer:

- Photoconversion via photo effect to e-
- e- elevated to the conduction band: $E_{gap} = 5.9\ eV$
- Mean QE of CsI: ~7% (range: $5.9 - 11.5\ eV$)

→ high overlap with LiF transmission region ☺

→ Conversion of 75 photo electrons

Detector Schematic: Micromegas (e- Amplification)



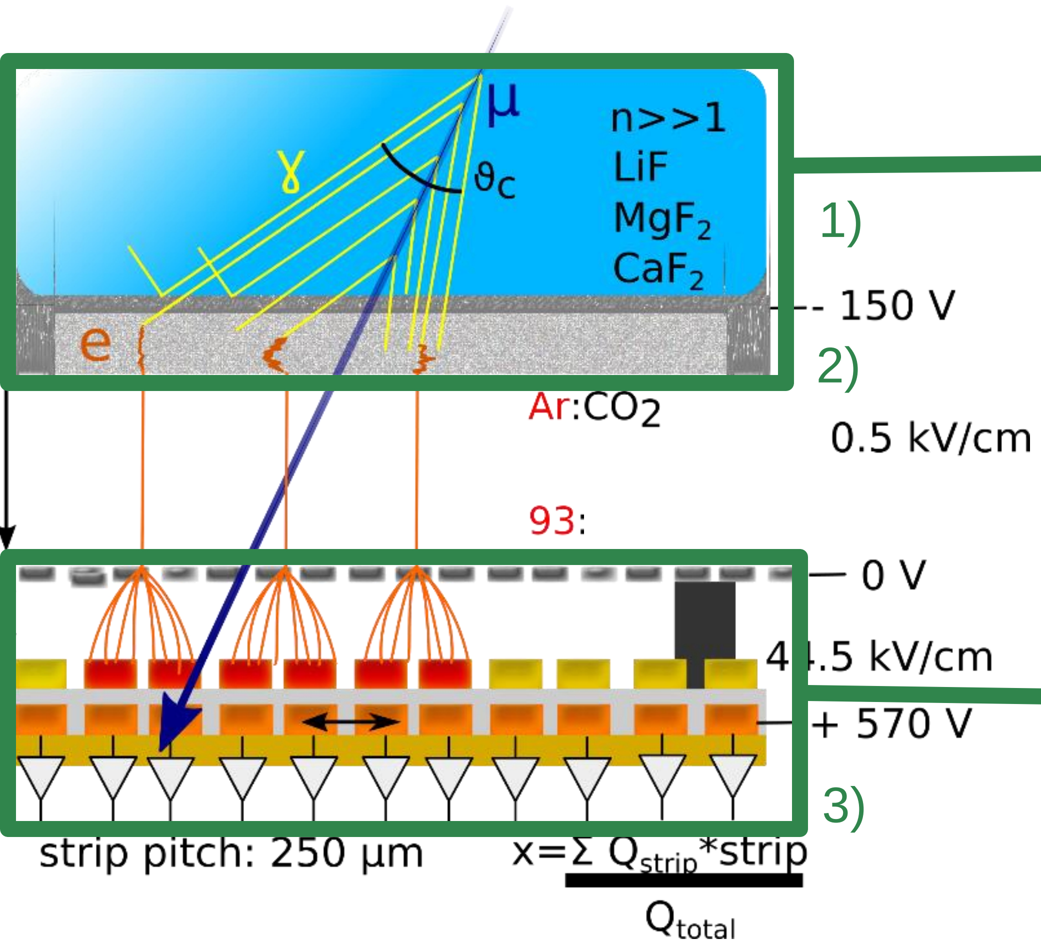
$$x = \frac{\sum_{strip} Q_{strip} * strip}{Q_{total}}$$

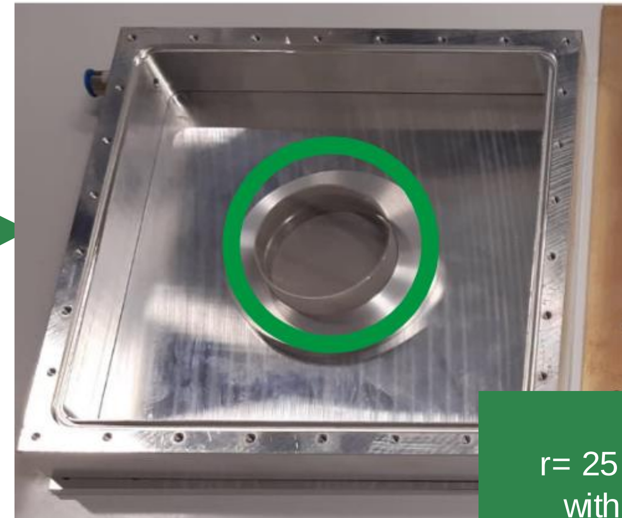
- Drift region:
  - Low electrical field (~ 600 V/cm)
  - Primary Ionziation of the gas by μ
  - Photo-e- & μe- drift towards a micro-mesh
- Micro-mesh: 0 V, e- funneled through holes
- Amplification region:
  - High electrical field (~ 50 kV/cm)
  - Multiplication of the initial electron by Townsend avalanches

→ Anode Strips:

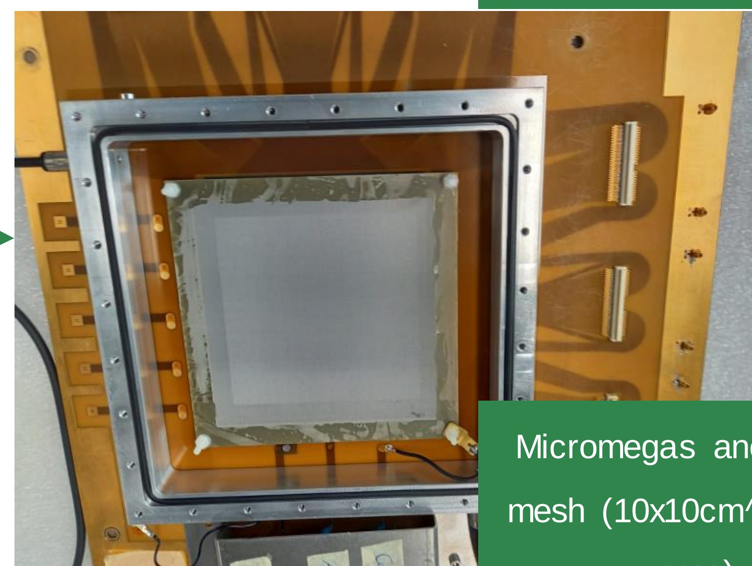
Position & Timing reconstruction with a segmented anode (2D strips readout)

Design: Electron Amplification (Micromegas)





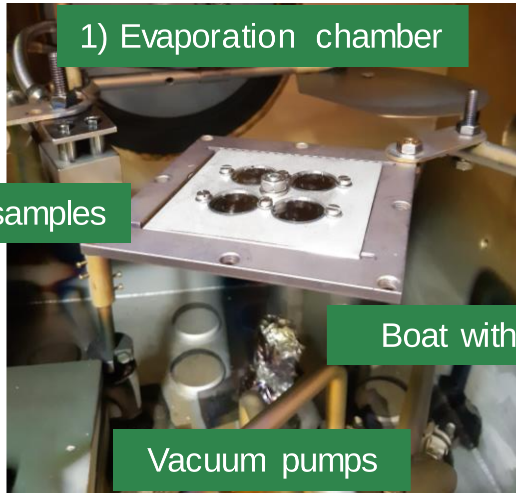
LiF
r= 25 mm, D=20 mm
with 4nm Cr layer



Micromegas anode with mesh (10x10cm^2 active area)

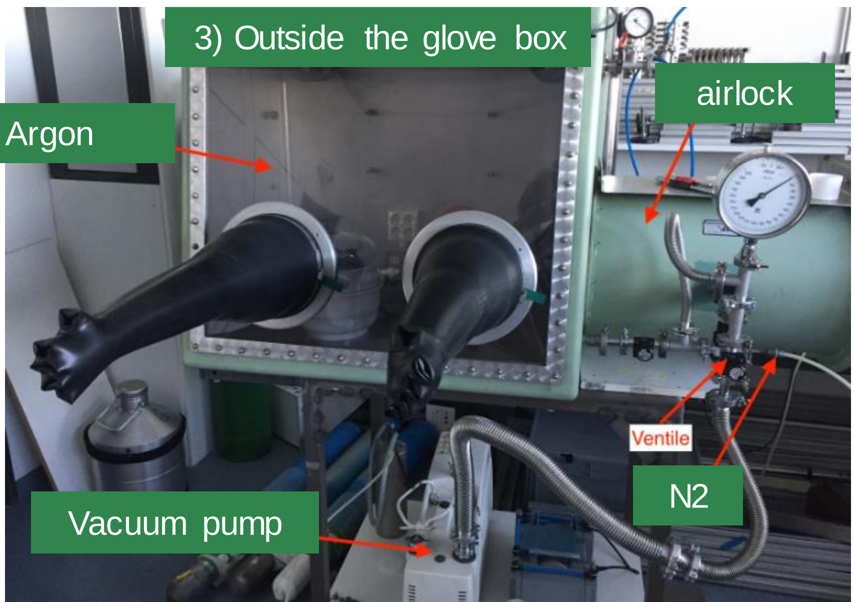
LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

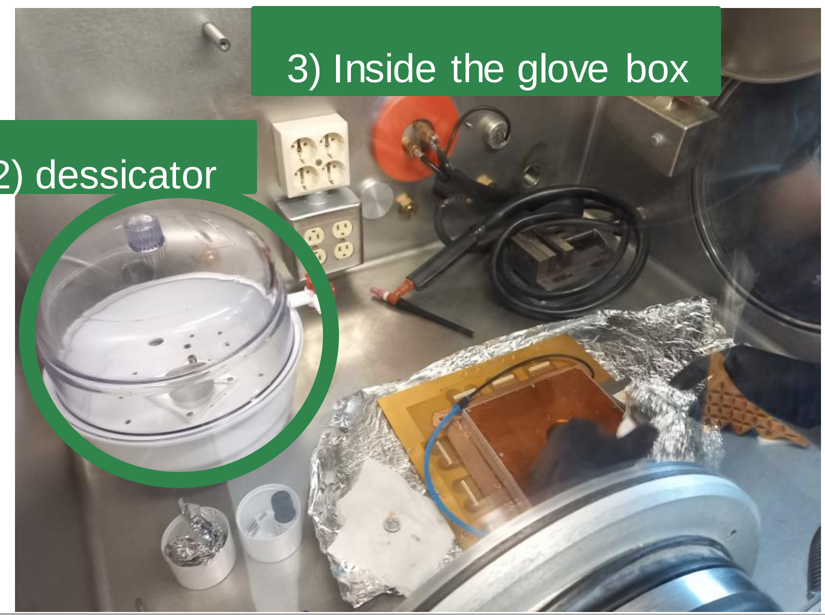
Photocathode Production



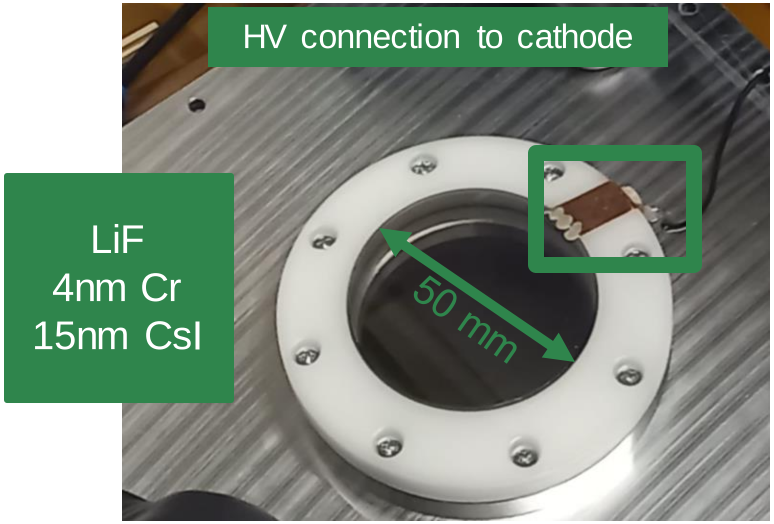
1. Evaporation in a vacuum chamber at TUM of Cr/CsI
2. Transportation of radiator in vacuum dessicator
3. Detector assembly in a glove box with Ar atmosphere

→ Required due to hygroscopic nature of CsI





Detector assembly

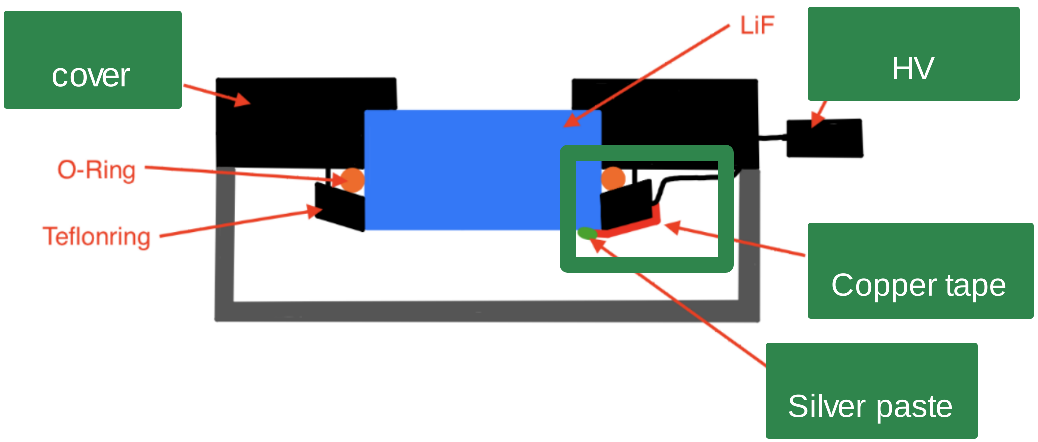


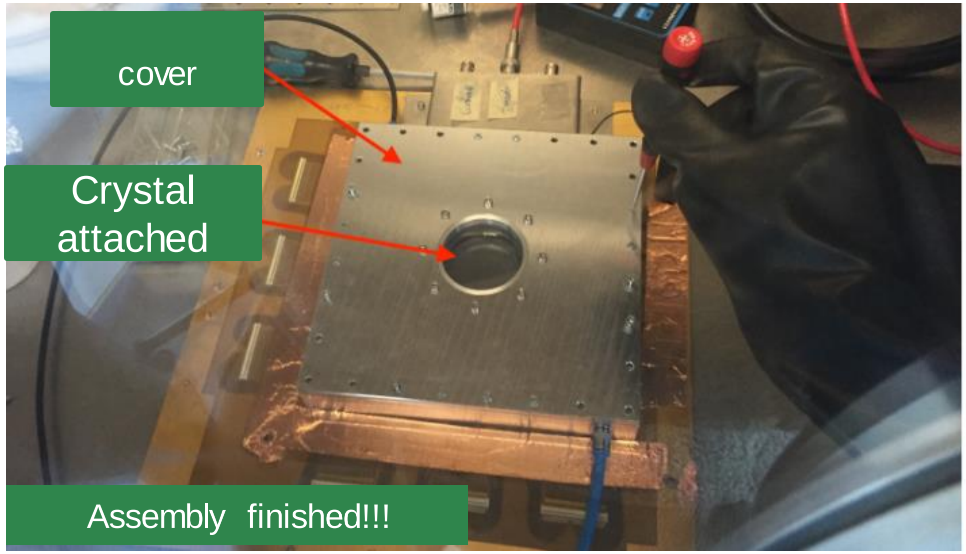
1. Contact between LiF Cr layer and HV Supply

   via a copper tape and silver paste

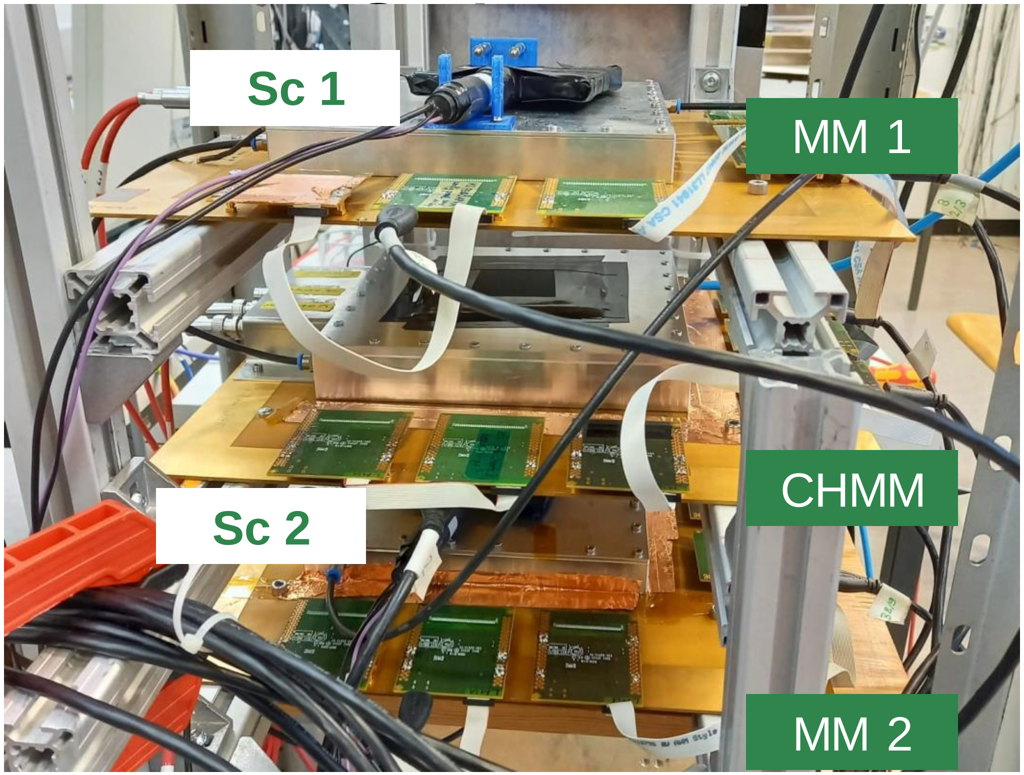
2. Gas frame on top of anode → We are finished!

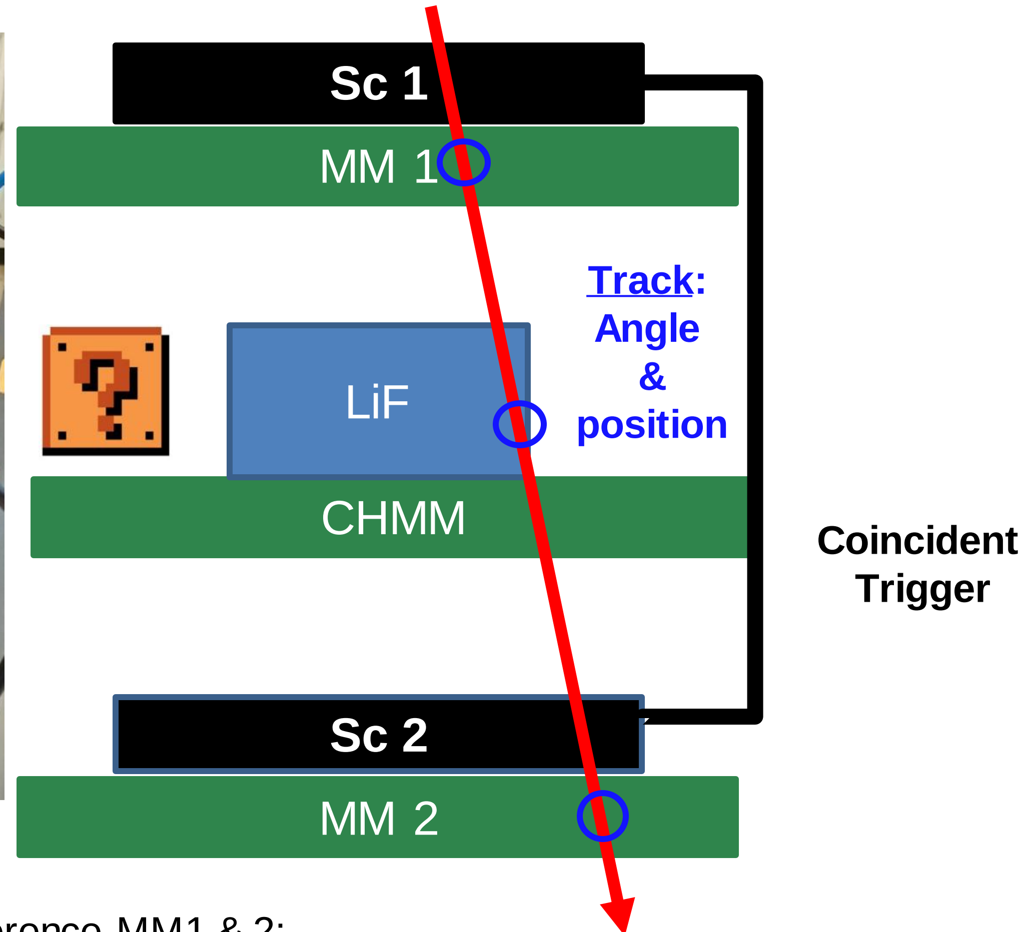
NOW its time for measurements





Measuring Cherenkov Cones in LiF



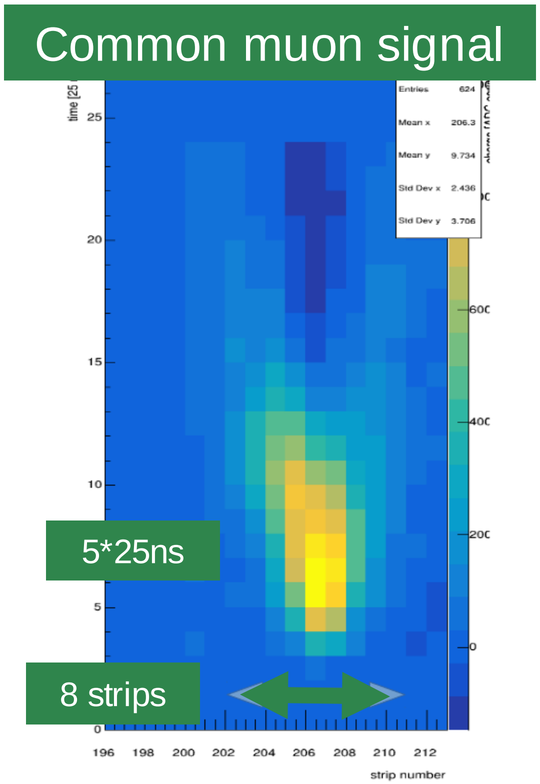


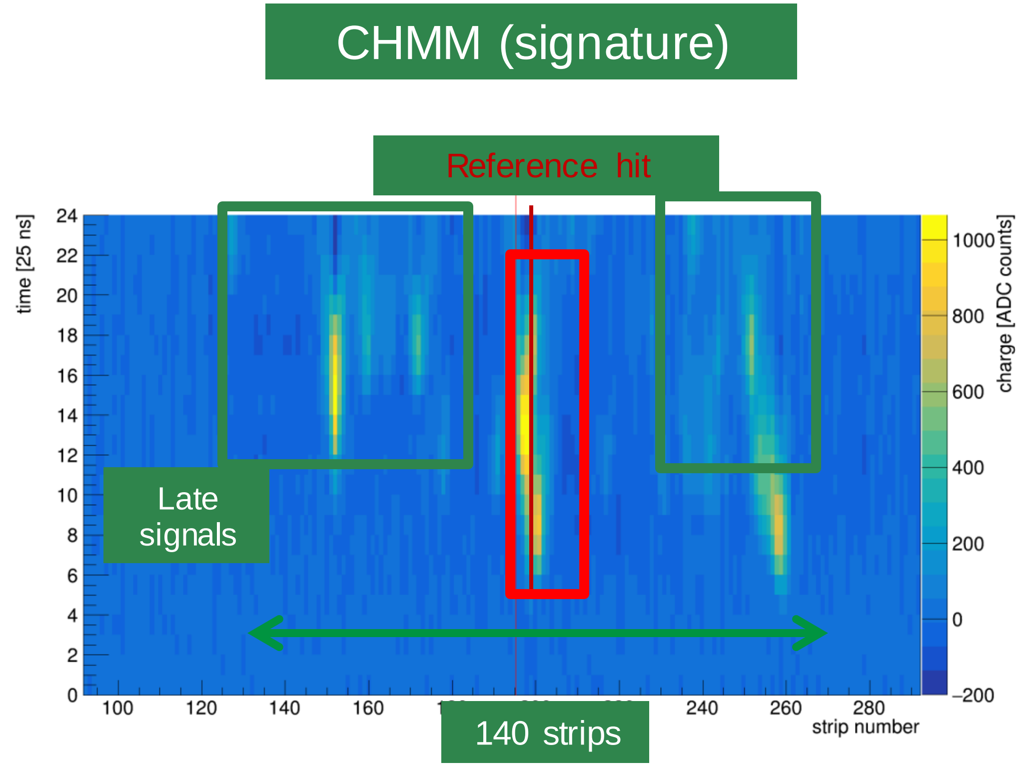
Track via Reference MM1 & 2:

Angle & hit position in CHMM (2D strip Micromegas)

→ **Compare angle & hit position with CHMM signal**

What about the Photons? (Signal shape)





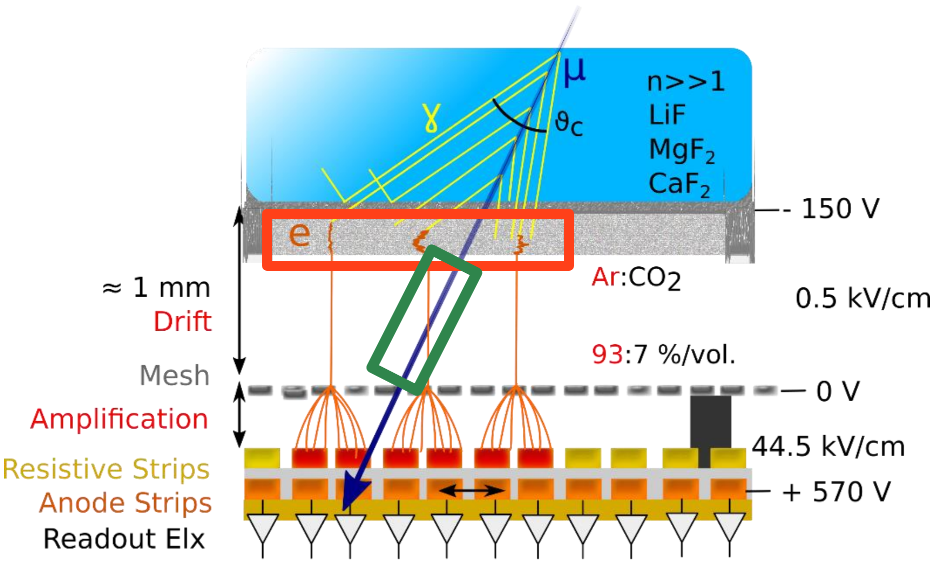
Muon signals („normal“ Micromegas (MM))

- Visible in Micromegas detector (also in Cherenkov MM)
- ~4-12 hit strips → 1-3mm broad (0.25 mm pitch)
- Duration: few time bins (5*25ns)

Typical Signature (Cherenkov MM):

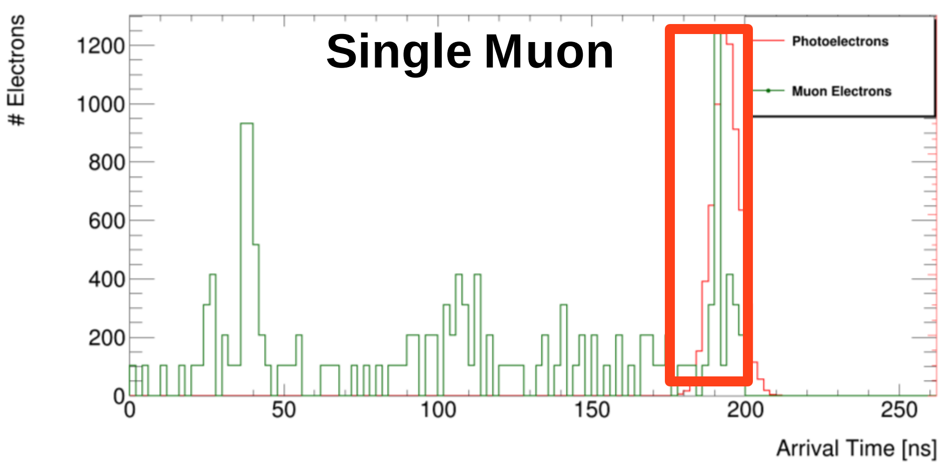
- Reference hit position determined by reference detectors
- Multiple cluster ~3-4 cm (~140 strips)
- muon cluster (prolonged) and late signals (hint @ photons)

Timing of the Muon- and Photoelectrons

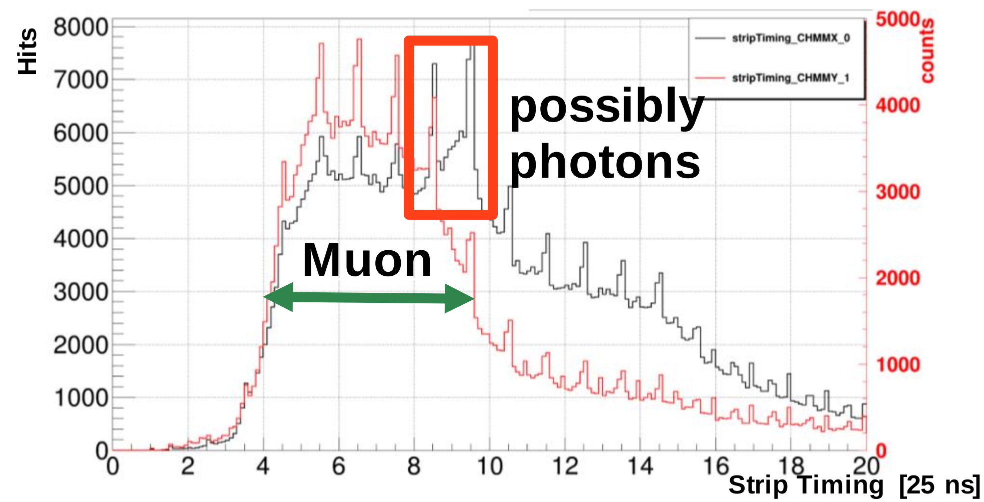


- Muon electrons are equally distributed on drift space
- Photoelectrons arriving ALL on the same time longest time to arrive
- Small photopeak in data possibly due to age of CsI

  → **Strong hint for Cherenkov photons ☺☺☺**



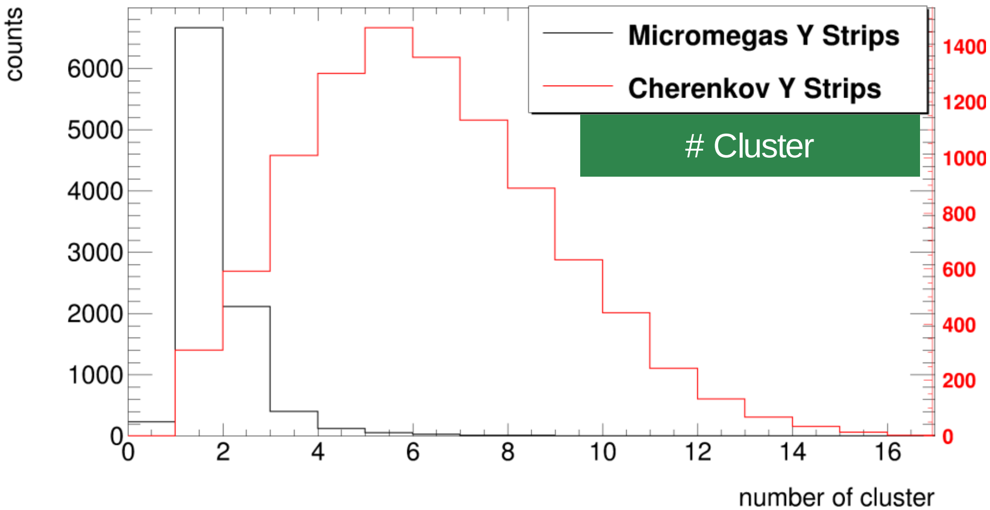
Garfield++



Electron arrival on strips (measured 50k muons)

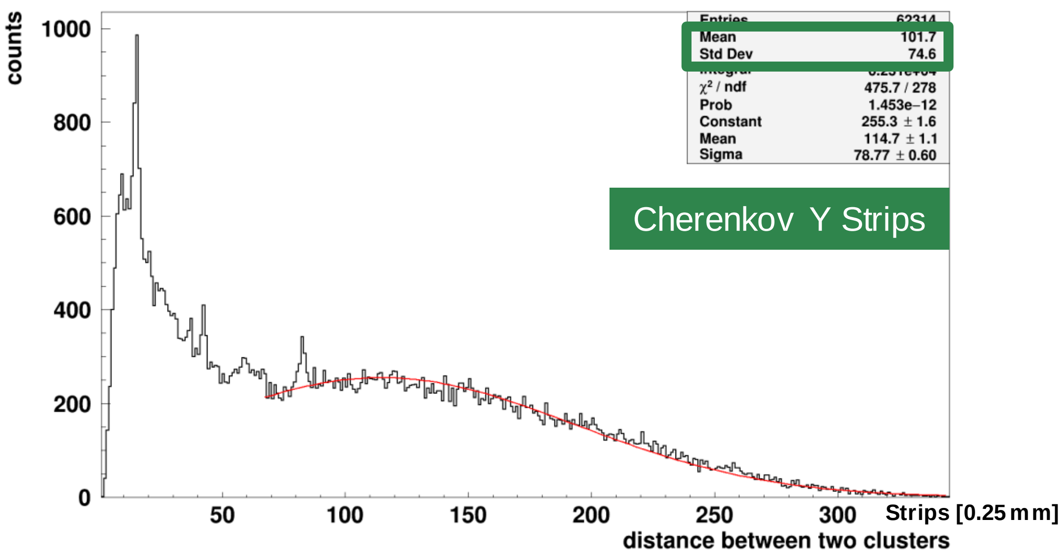
LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Position of secondary Cluster



Number of Cluster per Events

- Typical Micromegas: ~1.3 Cluster
  → Expected 1 cluster (likely noise)
- Multiple cluster in Cherenkov detector (5-9)
  → Possibly photon cluster

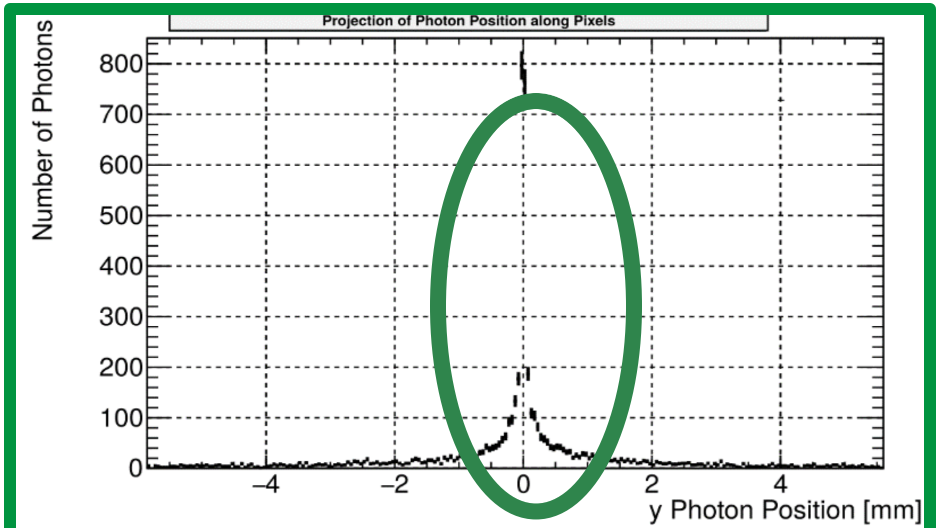


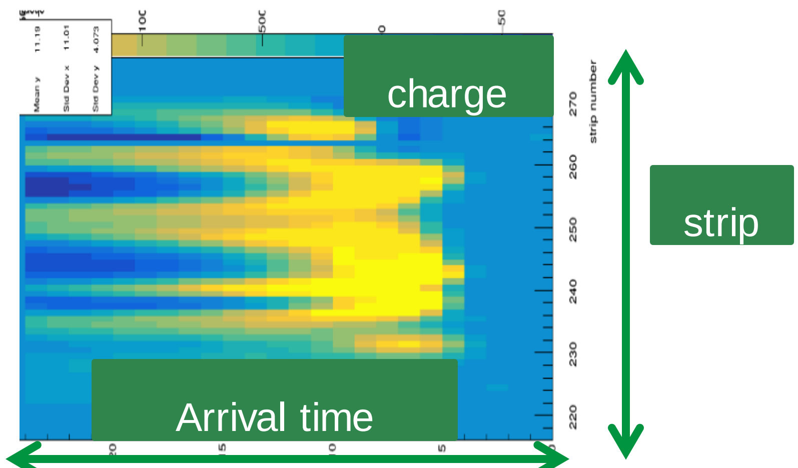
Distance between muon & 2ndary cluster

- Cherenkov Micromegas:
  - mean distance ~25 mm [many angle]
  → Very close to expectation for the Cherenkov radius (22 mm [0 deg]) ☺
  → More detailled investigation necessary

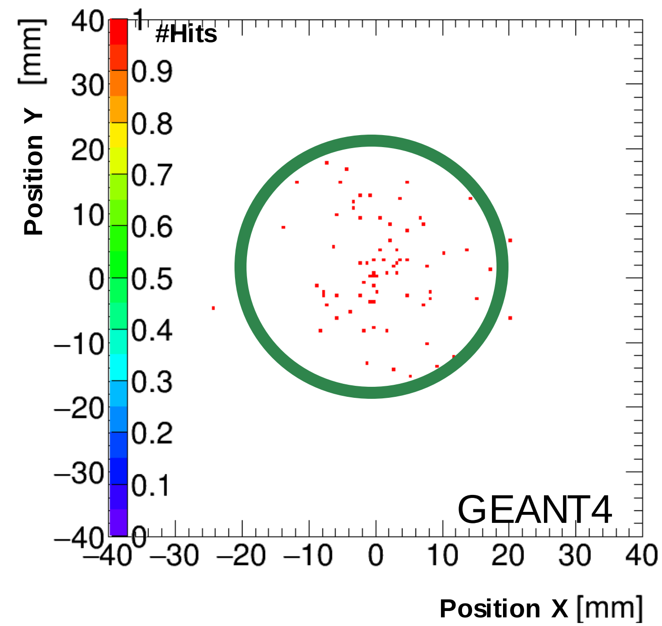
How can we extract the Cherenkov angle?

Two Separate 1D Information per event:





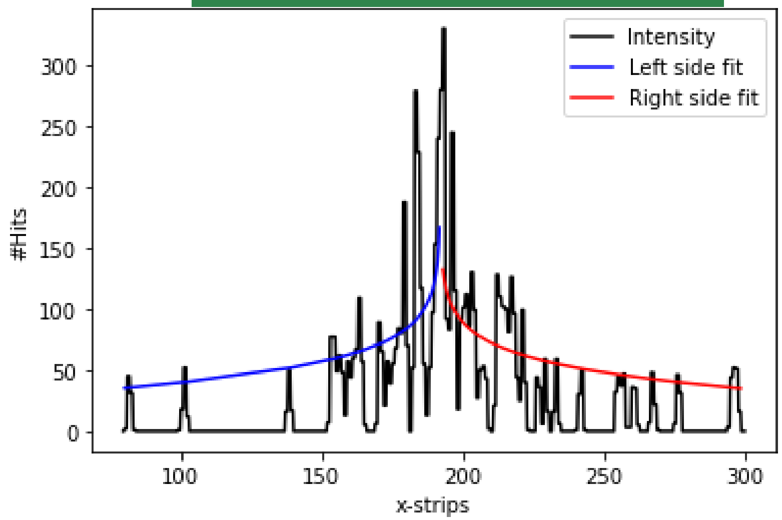
2D conic Cherenkov shape



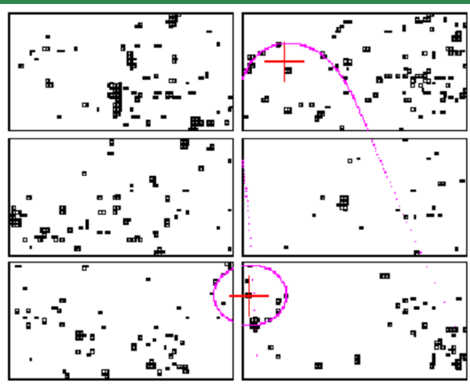
- Centre of Ellipse x_μ (muon hit position)
- Cherenkov Angle ϑ_c (radius R)
- Muon incident angle α_μ

Reconstruction Algorithms: Analytic Fit

1D Photon intensity (strips on detector, simulated)



Example: CHT (HMPID, ALICE)



Analytic Fit of the Photon Intensity (1D)

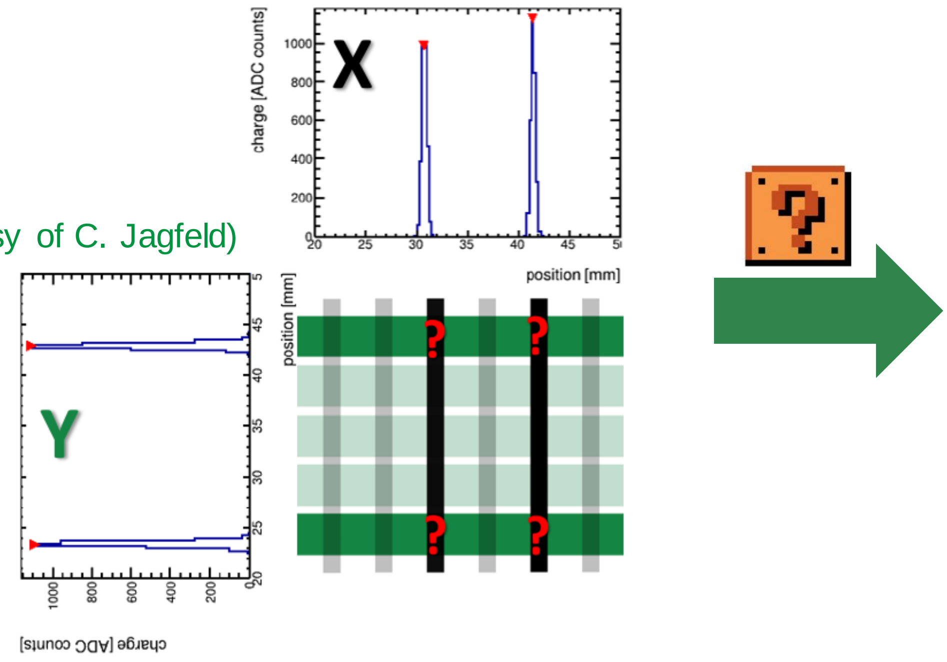
- Work in progress by Edis (first attempt)
- Determination of radius R, incident angle of the muon α_{μ}, Cherenkov angle ϑ_c
- Caveat: few data points (~70 photons)
- Alternative: Circular Hough Transform (CHT)
  - Finding intersection of circles in a parameter space

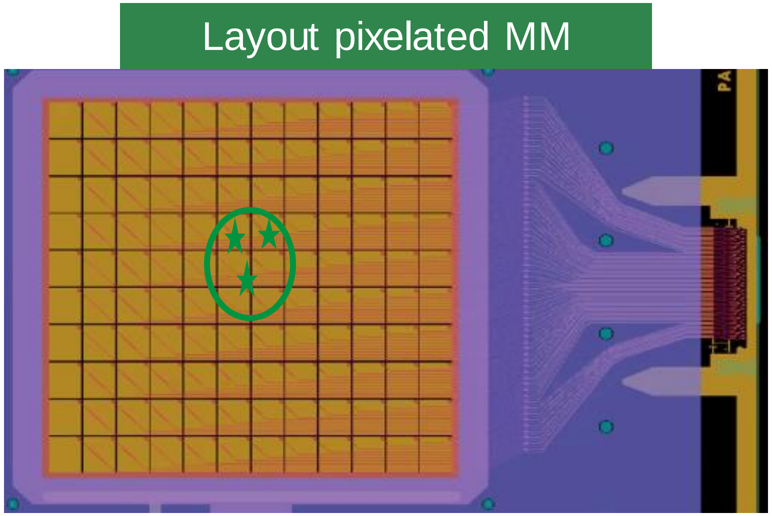
  → Circles in data determined

  → Caveat: 2x1D strip information ordered as (x,y)

Improvement: Segmented Anode

(courtesy of C. Jagfeld)





- Multiple Particles arriving at the same time

  → No unique 2D Position reconstruction possible

  ☹

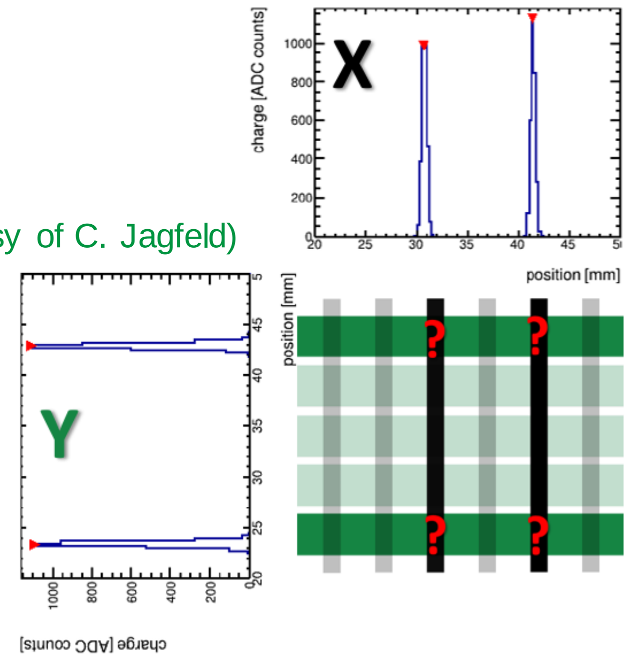
Pixel Micromegas Anode (Felix)

- Unique position for multiple particles
  - 1 mm pitch @ 10x10 cm^2

    → difficult mapping (10k electr. channels)
  - 10 x 10 mm Pixel: unprecise position

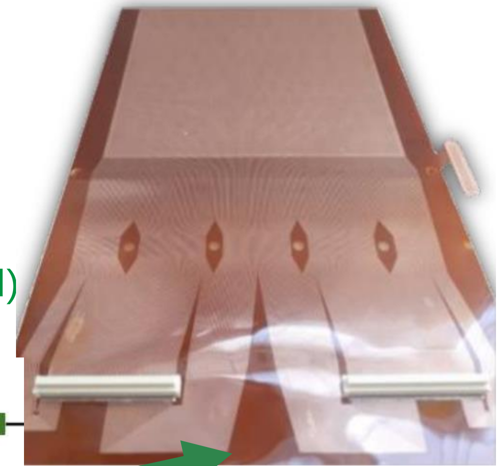
Improvement: Segmented Anode

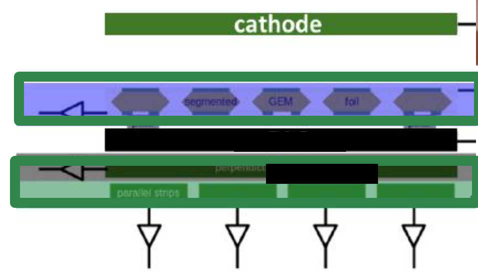
(courtesy of C. Jagfeld)



Segmented GEM foil

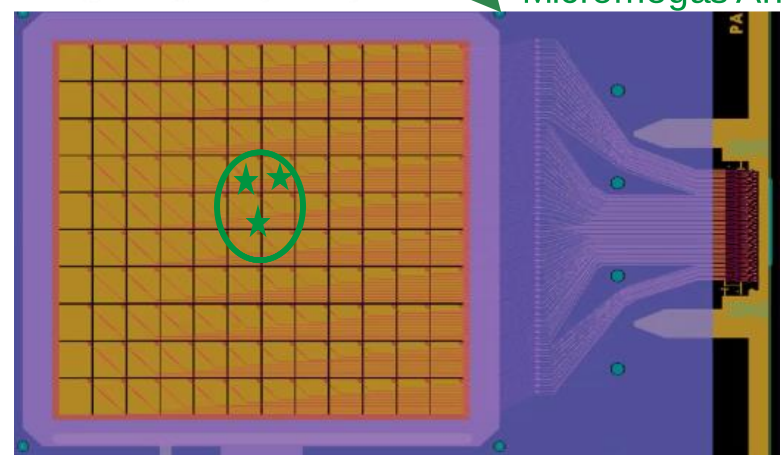
(courtesy of C. Jagfeld)





Layout pixelated

Micromegas Anode



- Combination with segmented GEM foil

  → (see Christoph‘s talk) ~ 50 um position resolution

  → xyv-readout will allow for direct reconstruction of Cherenkov clusters

Summary

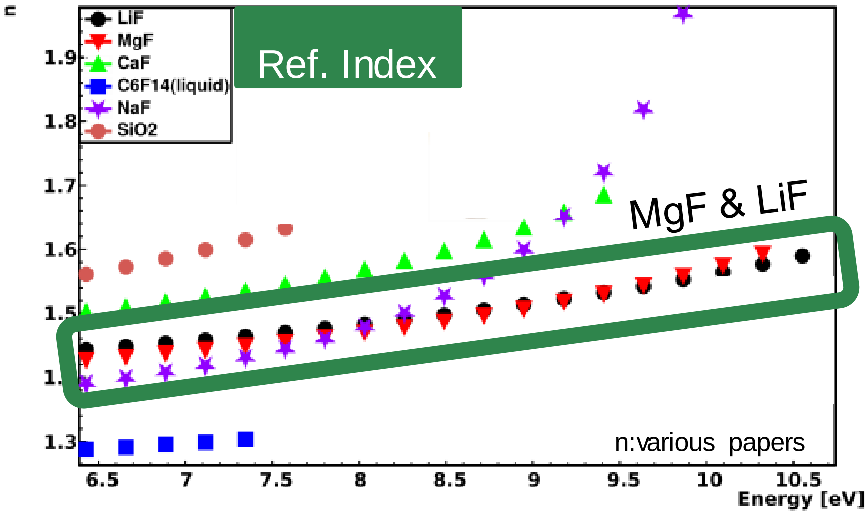
Thank YOU!

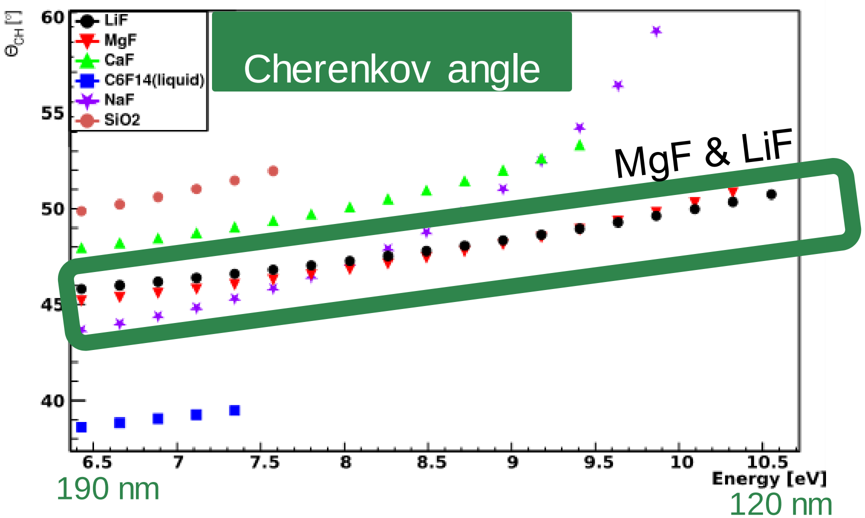
- **General design will allow for position and momentum reconstruction**
- **First prototype is functional:**
  - **Electrons can be extracted from the Cr cathode**
  - **Characteristic Photon signatures visible**
- **Next: second prototype using 100mm CaF2 crystal covering the whole active detector area**
- **Investigation of reconstruction algorithms (especially for strip readout; Edis)**
- **Pixel Readout will be advantageous (Felix Utsch) …**
- **… combining with xyv-Readout (Christophs talk) for an unambigous position determination of individual photons with a high spatial resolution**

Backup

Thank YOU!

Search for the Radiator



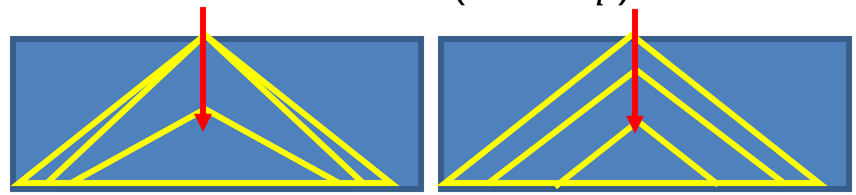


Variation of the Refractive Index

- $n = f(\omega)$ → larger Δn

  → Angle variance $\Delta\theta_c$ of created photons

  → Low desirable (lower Δp)



$\Delta\theta_c > 0$ $\Delta\theta_c = 0$

→ With high Δn hardly distinguishable

if angle or position of photons in radiator

- Transmission into far ultraviolet advantageous

  → increased photon yield

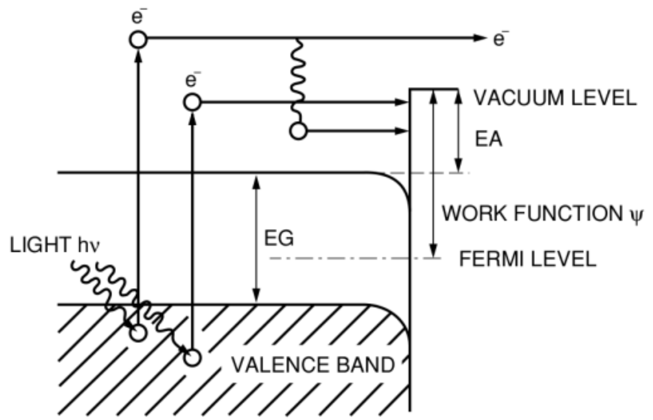
→ MgF & **LiF** $\Delta\theta_c \sim 3°$ are our candidates

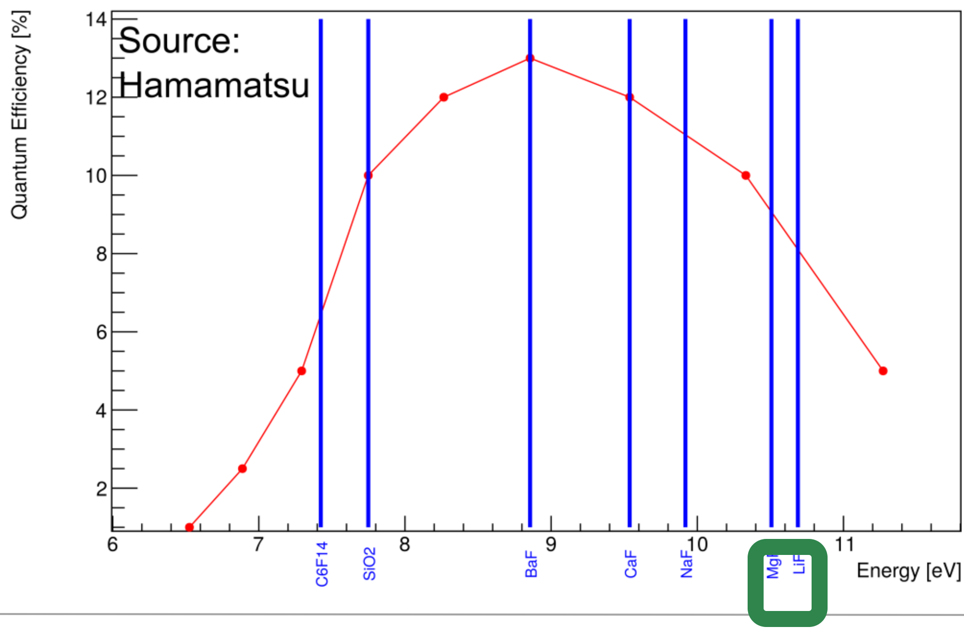
→ CaF also behaving nicely

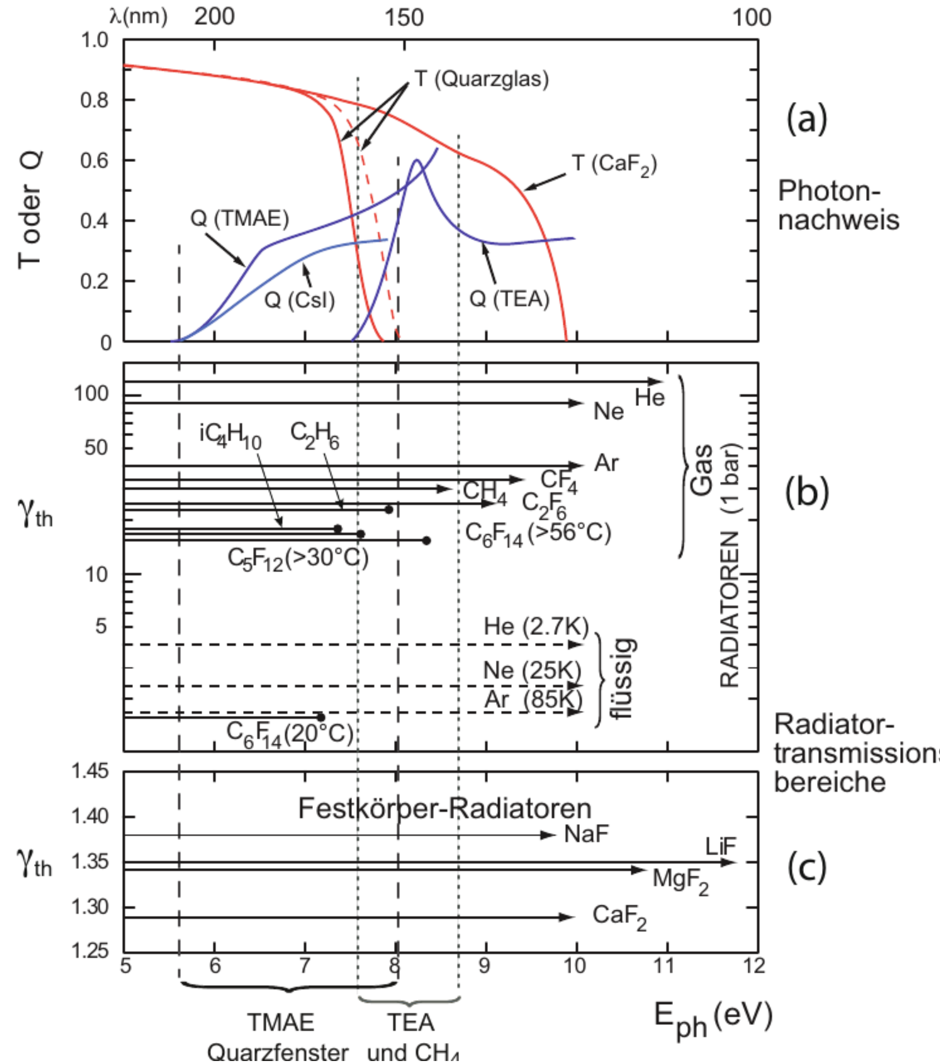
LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Working Principle: Photocathode

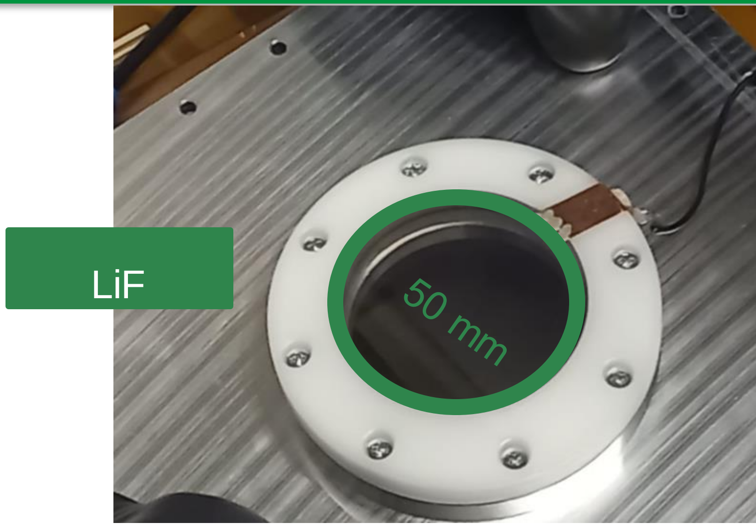
(1) ALKALI PHOTOCATHODE (source: Hamamatsu)

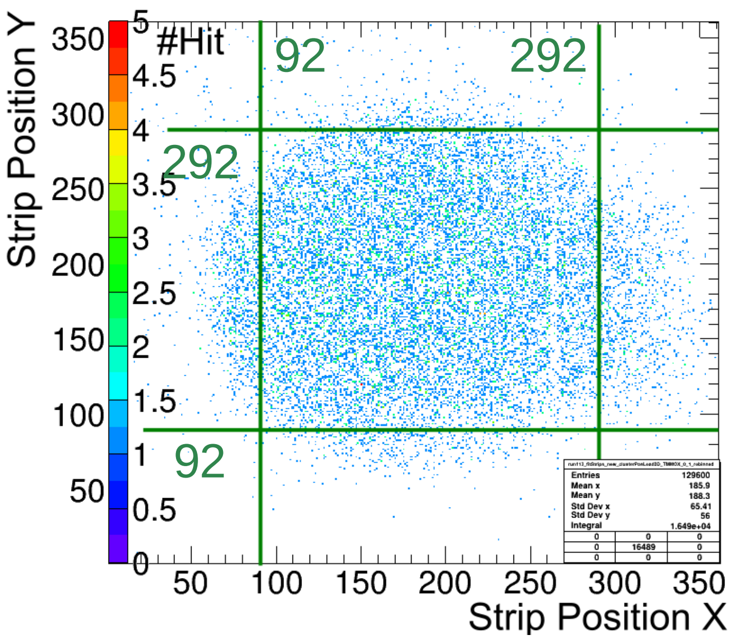






Test of the Cr adhesion layer





Measured Data with the prototype detector

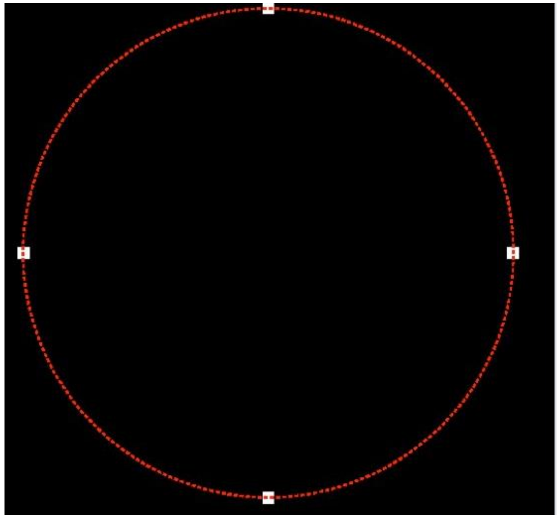
- Reconstruction of muons on the active detector area
- Expected strip (92 – 292) strips from s50mm radiator

  → Reconstruction of circular radiator shape

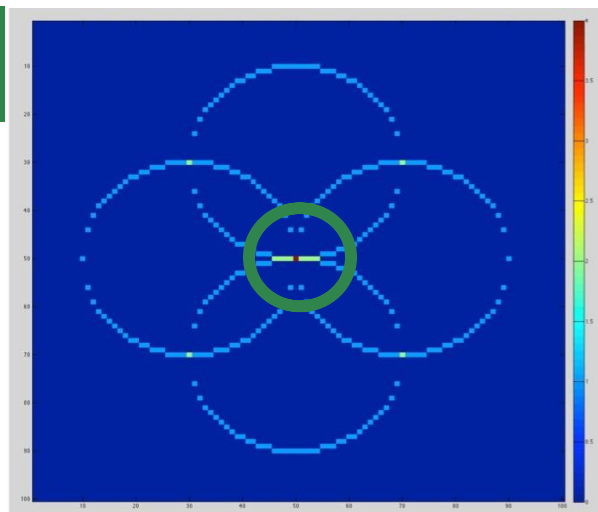
  → Chromium cathode part of the detector working ☺

Reconstruction Algorithms: Circular Hough Trafo

Input (4 point on circle, known radius)



Output (in parameter space)



Centre point of original circle

Source: Wikipedia

Future possibilty: Circular Hough Transform

- Points on circle with radius:

$$(x-a)^2 + (y-b)^2 = r^2$$

→ Transformation into parameter space (a, b, r)

- Determination of Radius R & centre of circle x_μ
- Robust to noise (used in ALICE, HADES)
- Caveat: 2x1D strip information has to be ordered

  as (x,y) before (or with) Hough Trafo

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN