Measurements of Penning transfer ratios

3rd DRD1 collaboration meeting

Stefan Roth, **Nick Thamm**

Online - 10.12.2024

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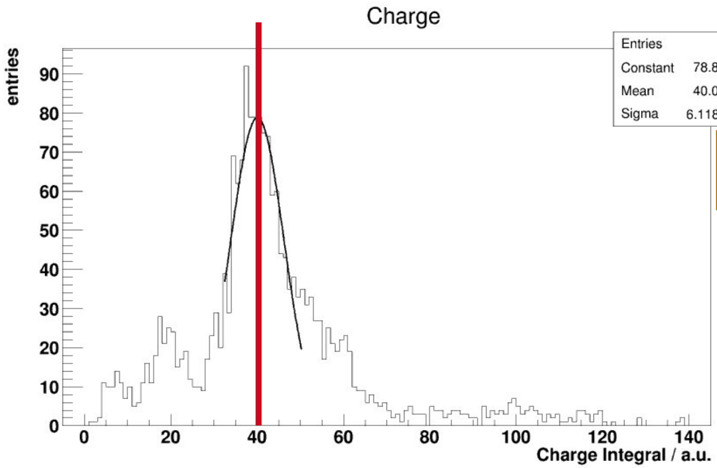
Gas Monitoring System @ ND280 / RWTH

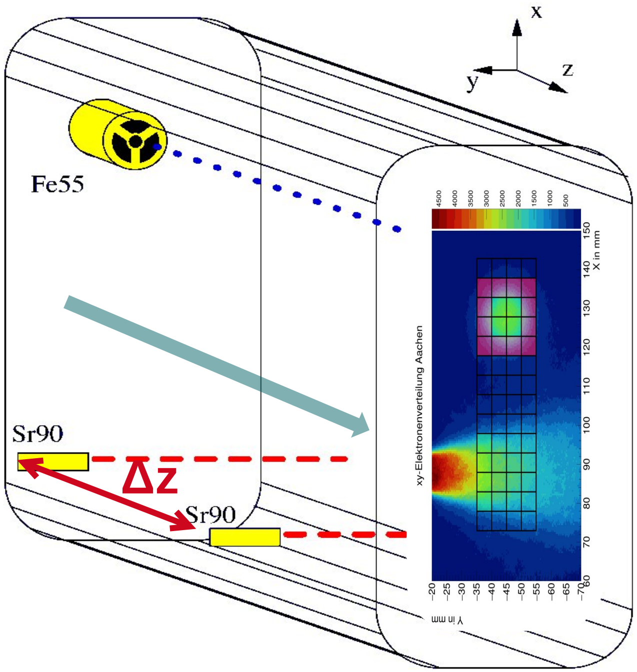
- Two identical chambers for supply and return gas
- Sequential measurement of drift velocity and gain

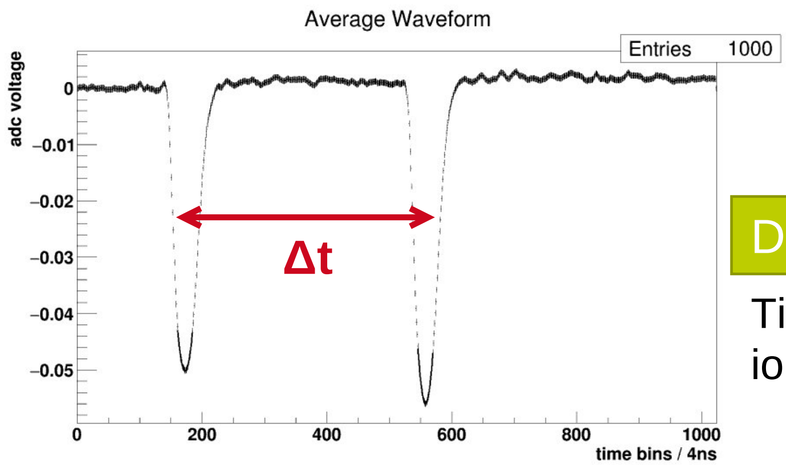


Gain Measurement

Detected charge from defined deposition

Only relative changes



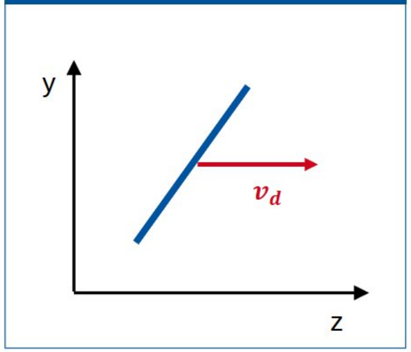


Drift Velocity

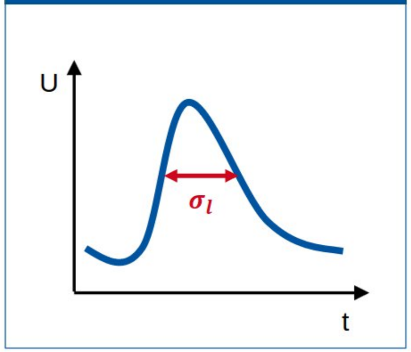
Time difference between ionization tracks of defined distance

Measurement quantities

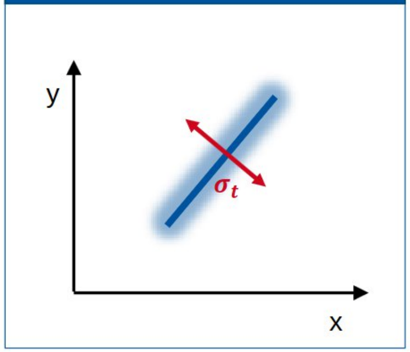
Drift Velocity:



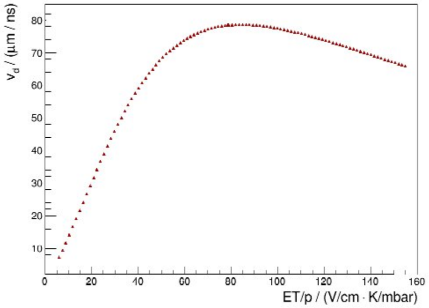
Longitudinal Diffusion:



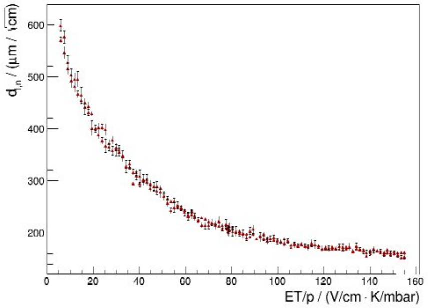
Transverse Diffusion:



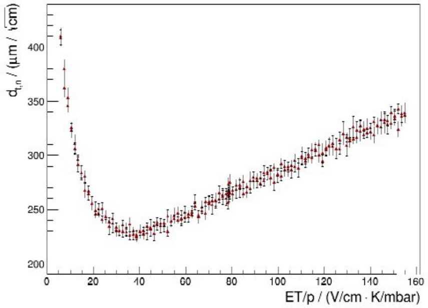
Drift Velocity



Longitudinal Diffusion

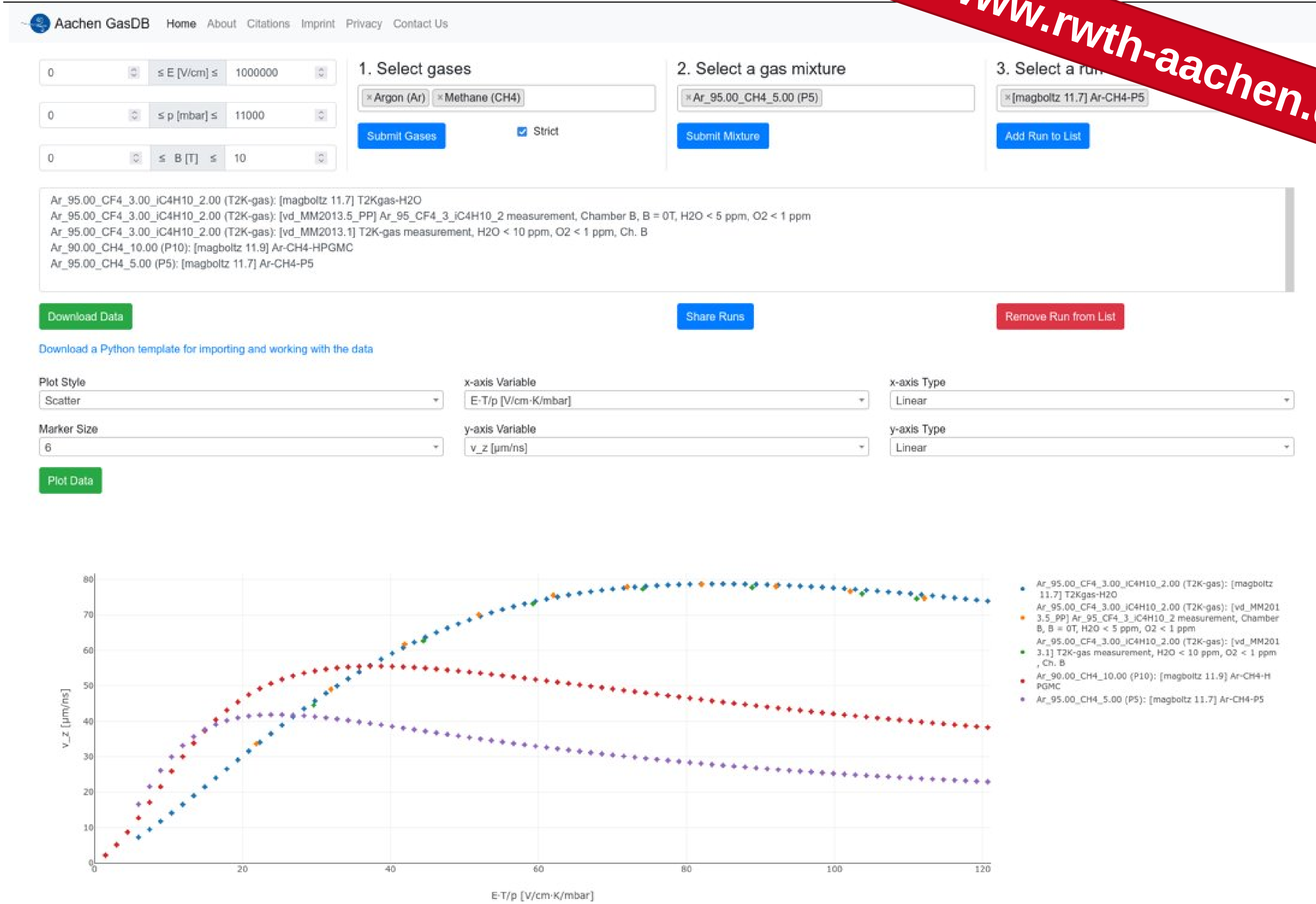


Transverse Diffusion



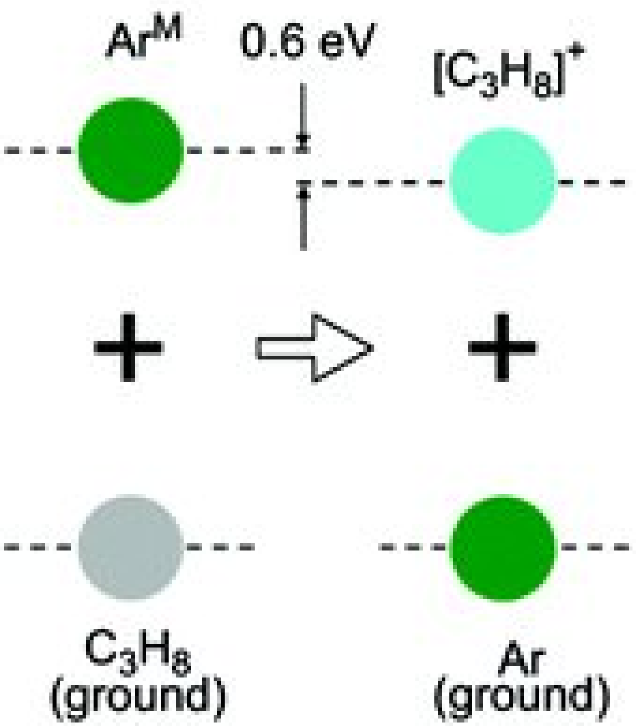
gasDB

https://www.rwth-aachen.de/gasdb



Penning effect

- Only occurs in gas-mixtures
  - Also due to contaminations
- Ionization levels of admixture lower than energy level of excited state
- Complicated due to various states:
  - Rotational
  - Vibrational
  - ...



https://doi.org/10.1039/C6AN01352J

Nick Thamm | thamm@physik.rwth-aachen.de

Gas mixtures / Penning / Jesse effect / Photon feedback / ...

Ionization: $P^{+} + A \rightarrow P^{+} + A^{+} + e^{-} + (n \cdot e^{-})$

Penning ionization: $A^{*} + B \rightarrow BA^{*} \rightarrow A + B^{+} + e^{-}$

Associative Penning ionization: $A^{*} + B \rightarrow BA^{*} \rightarrow BA^{+} + e^{-}$

Surface Penning ionization: $A^{*} + S \rightarrow A + S^{+} + e^{-}$
(Auger Deexcitation)

Jesse ionization: $A^{*} + B \rightarrow A + B + \gamma \rightarrow A + B^{+} + e^{-}$

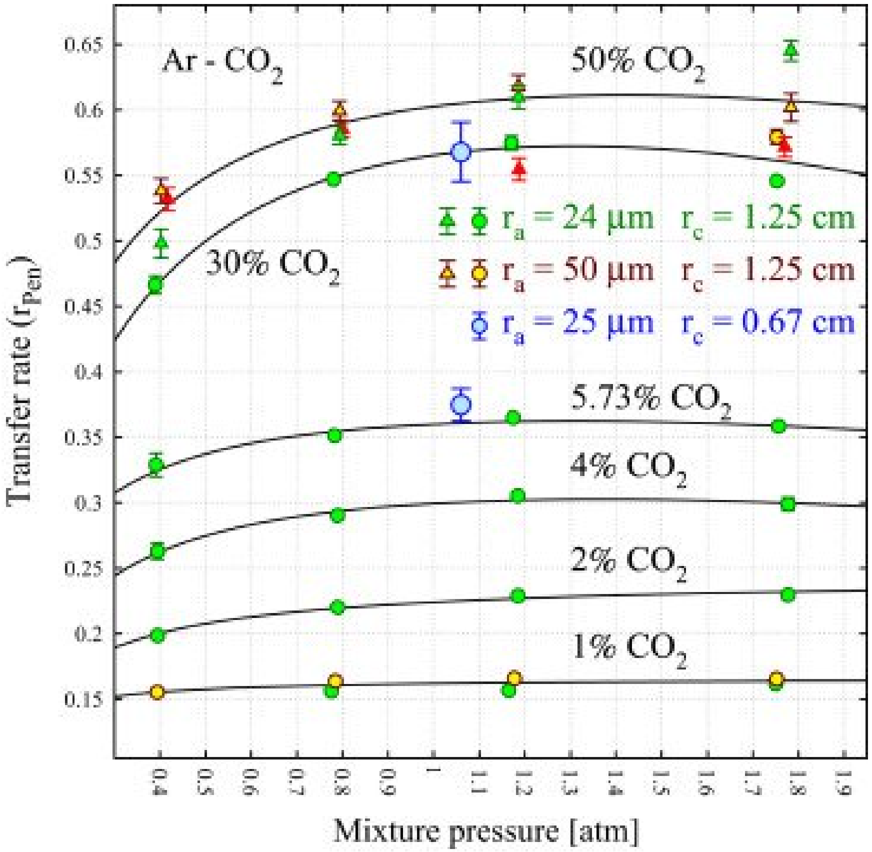
Surface Jesse ionization: $A^{*} + S \rightarrow A + S + \gamma \rightarrow A + S^{+} + e^{-}$
(Photon feedback)

Modified gas gain: $G = exp\int_{r_c}^{r_a} \alpha_{pen} E(r)dr = \frac{I}{I_0}$ $\qquad \alpha_{pen} = \alpha\left(1 + r_{pen}\frac{f^{exc}}{f^{ion}}\right)$

Detector effects: $G_T = G + \beta G^2 + \beta^2 G^3 + ... = \frac{G}{1 - \beta G}$

Penning effect

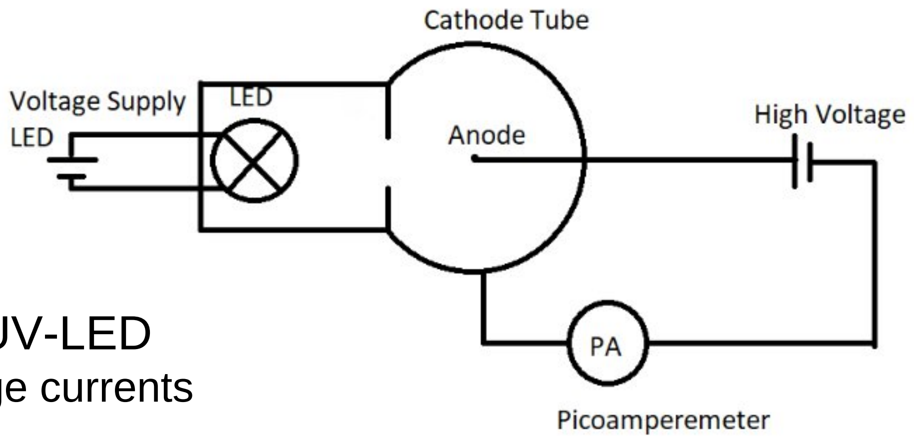
- Not predictable (as far as I know)
- Depends on:
  - Type of admixture
  - Amount of admixture
  - Pressure of gas
- Useful model for binary gas mixtures
- Could not yet find estimations for tertiary gas mixtures
  - T2K-gas
  - Tissue equivalent gases
  - ...



https://doi.org/10.1016/j.nima.2014.09.061

Plan to measure Townsend coefficient / Penning effect

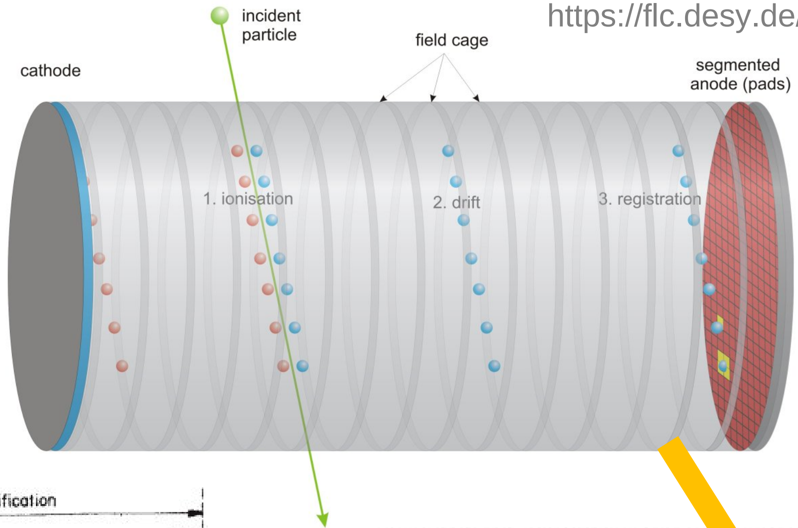
Measurement of first Townsend coefficient

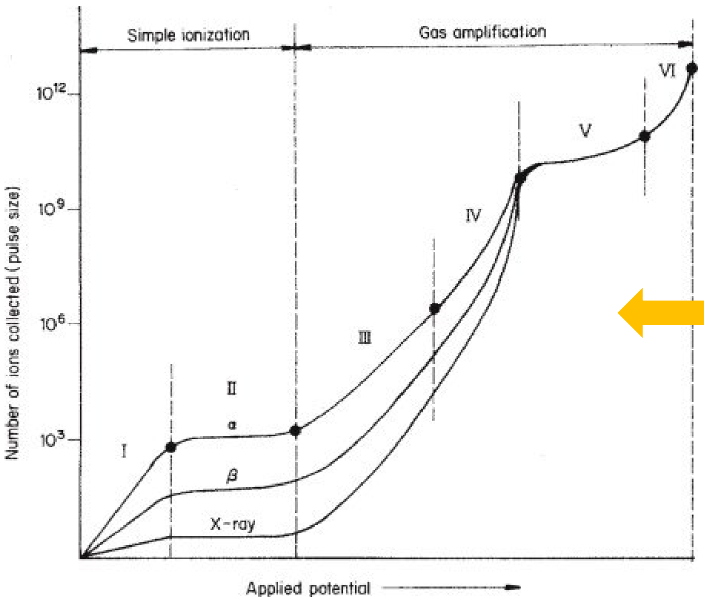


- Measure current through drift-tube
- Scan voltage from 0V to O(kV) to vary drift-field
- Induce current by photoeffect with UV-LED
  - Toggle LED to compensate for leakage currents
- Calculate from current to gas gain amplification
- Match gas gain to first Townsend coefficient
- Compare to simulation

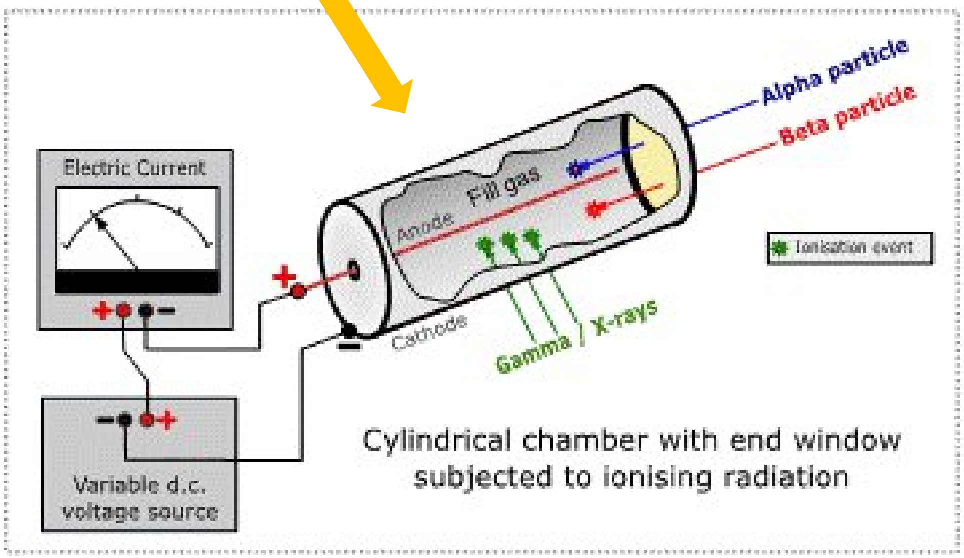
Gas ionization

https://flc.desy.de/tpc/basics/tpc/index_eng.html





https://doi.org/10.1016/B978-0-12-814397-1.00002-9



https://commons.wikimedia.org/wiki/File:Detector_regions.gif

Penning transfer ratios
Nick Thamm | thamm@physik.rwth-aachen.de
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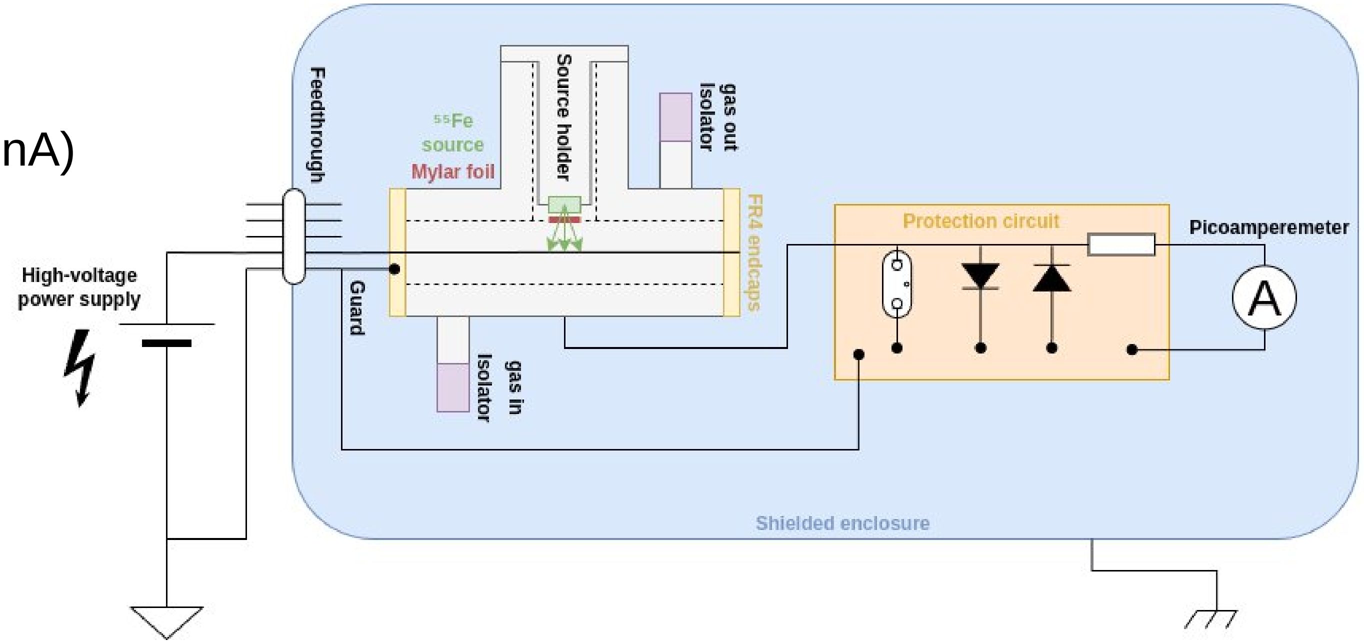
Measurement setup

- Guard ring to remove leakage current
- Enclosure to shield against external influences

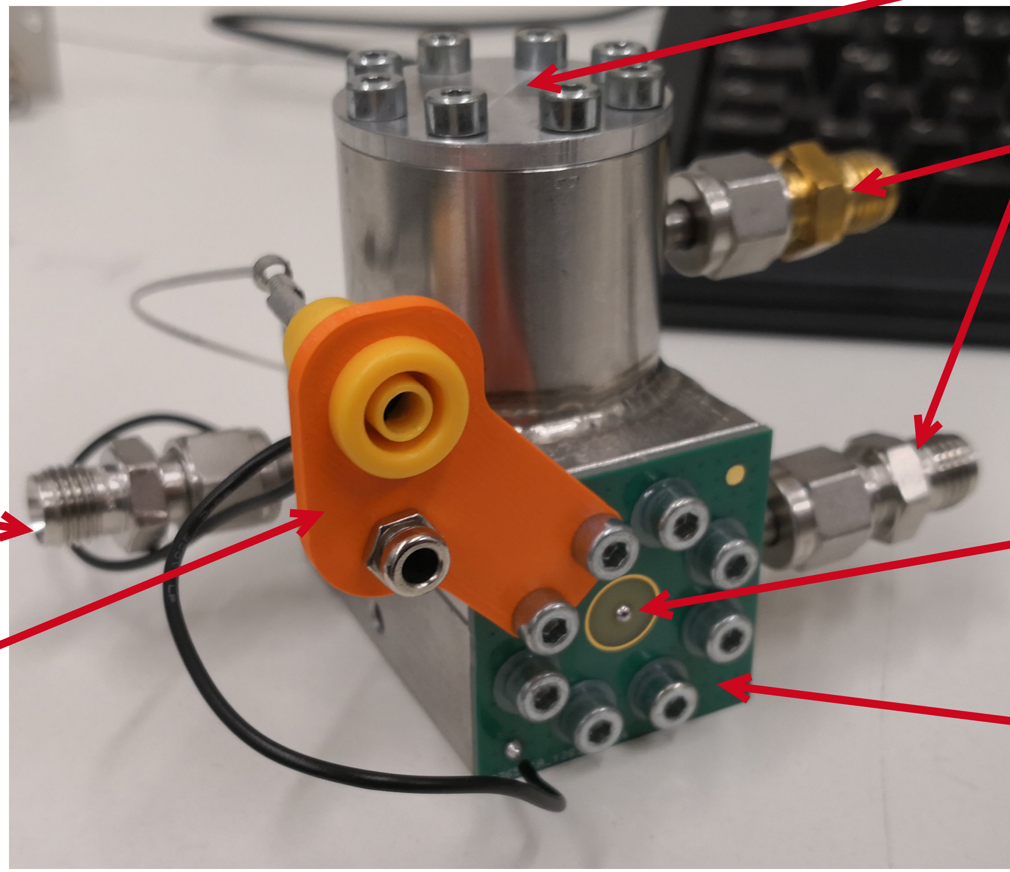
- Fe55 provides ionization
  - 370MBq activity
  - I0 ~ O(10pA)

- HV: 0-8000V
- P: 0-1.6bara
- I: 0-21mA (but <21nA)

- 6cm length
- 1cm diameter
- 25µm/80µm wire



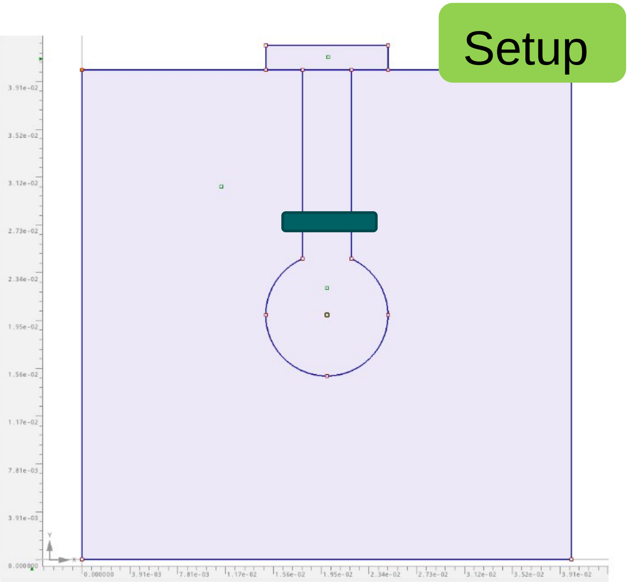
Measurement setup

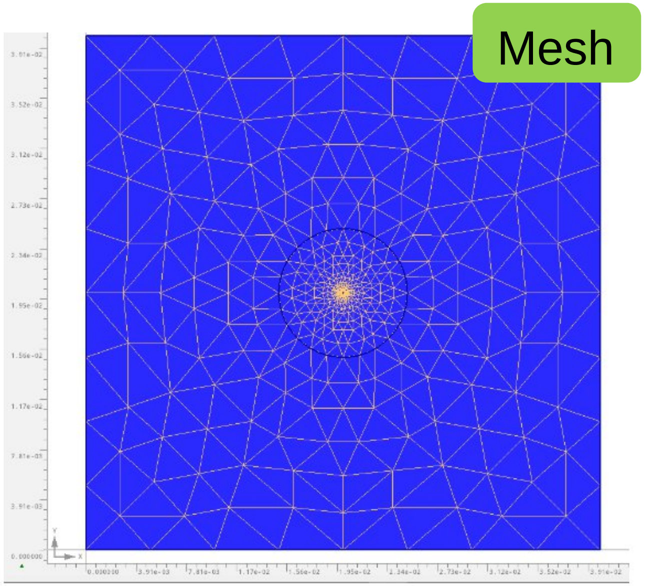


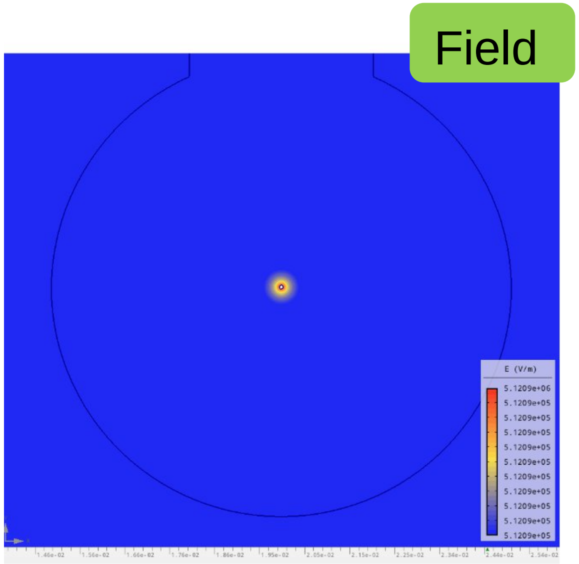
Measurement setup - Field simulation

- Electric field very sensitive to radius of diameters of setup
  - Most importantly wire-diameter!
- Source is inside of gas volume
- FEM simulation of setup crossection
  - Estimate effect of radiation window on field

$$S(r) = \frac{V}{p\, r\, \ln(r_c/r_a)}$$

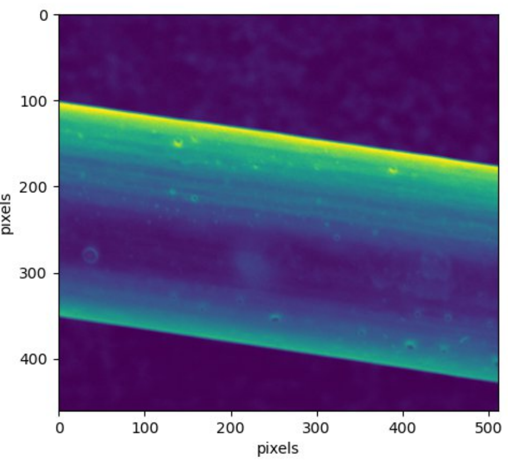


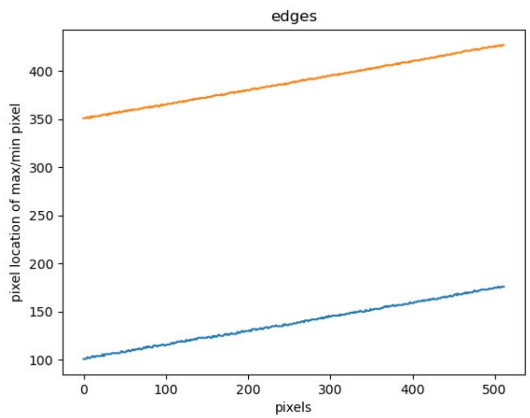


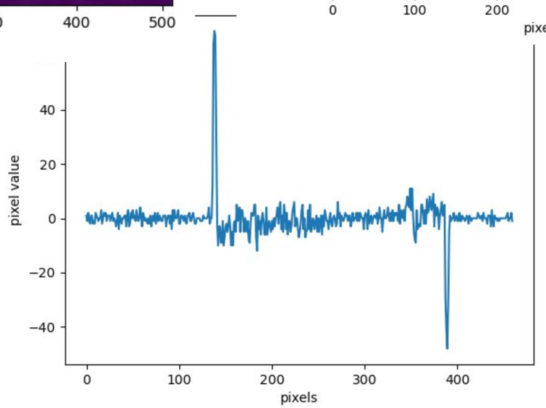


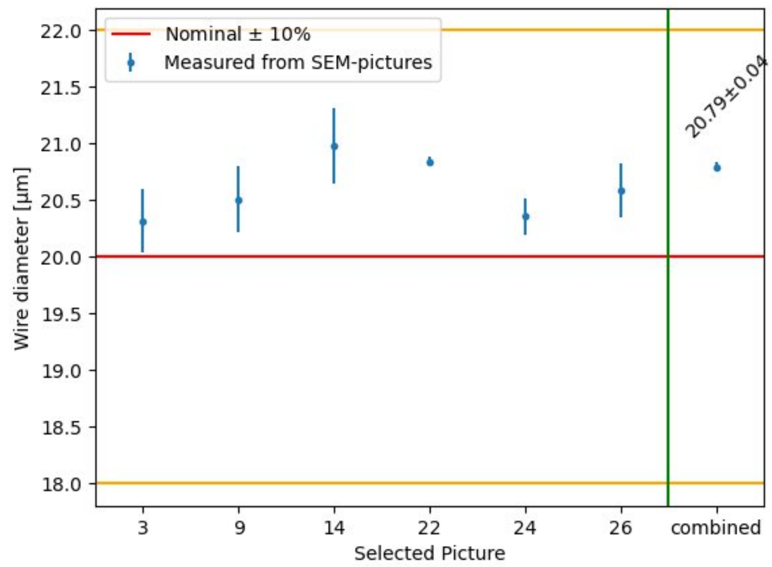
Wire diameter

- Need very precise knowledge of wire diameter
- Use scanning electron microscope images for measurement
  1. Load „clean“ image
  2. Find edges
  3. Determine distance between edges









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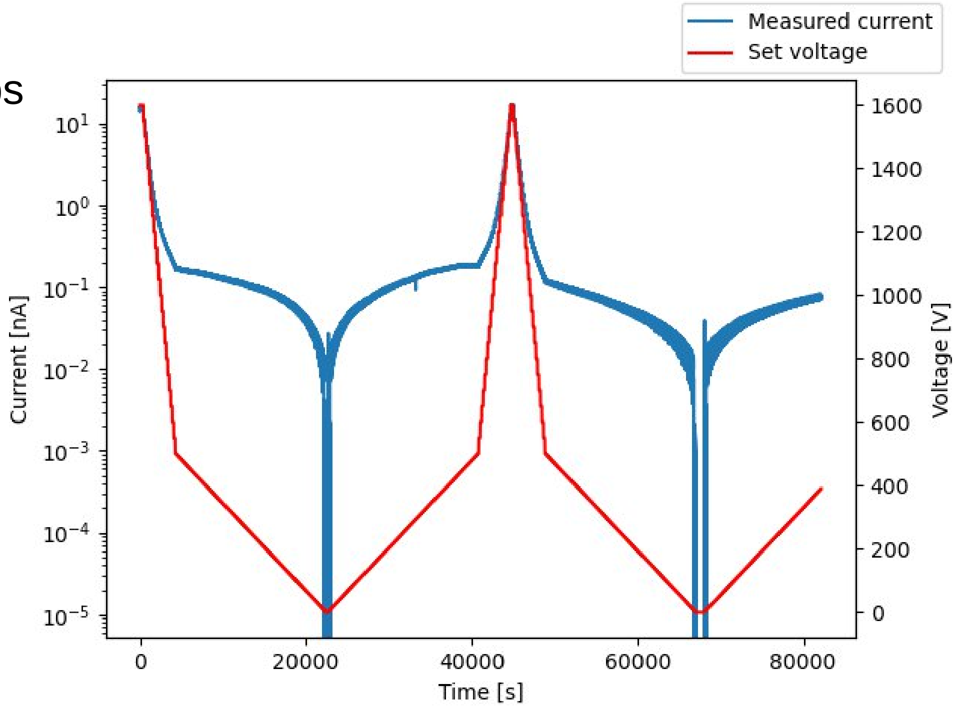
Measurement procedure

1. Prerequisites
    1. Flush gas for extended time periods
    2. Settle temperature

2. Measurement
    1. Ramp to voltage for gain
    2. Soak at high voltage for stabilization
    3. Ramp down voltages in intervals/steps
    4. Once at 0V, ramp up again in steps
    5. Repeat cycle X times

3. Go to step 1. with new gas

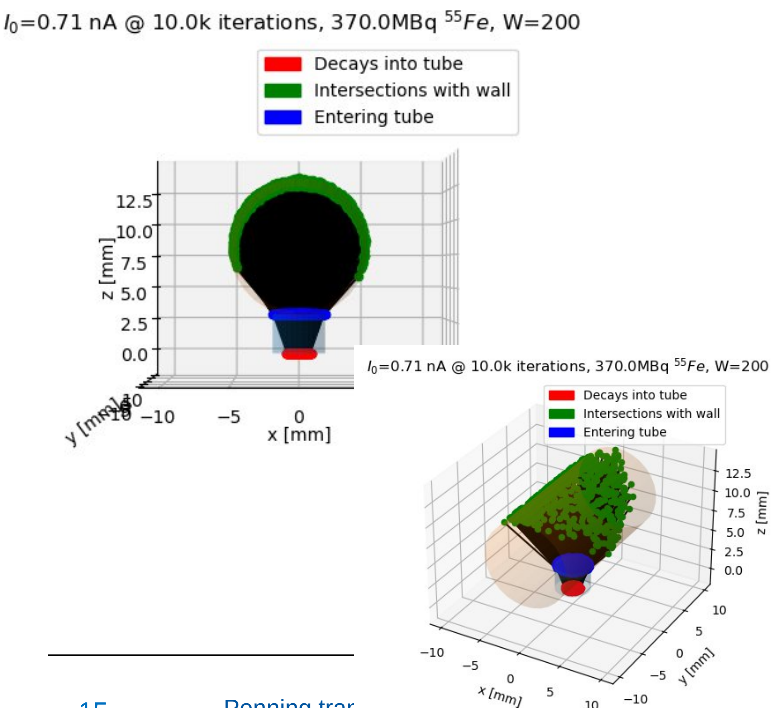


Estimating I0 (Simulation) - Irradiation simulation

- Estimate acceptance of detector:
  - Decays into tube solid angle
- Approximate number of interacting Fe55 photons
- Simulate amount of e- / interaction

G = I / I0

I0 = Activity * acceptance * W * (Fe55 int. probability) * e
= ~20pA



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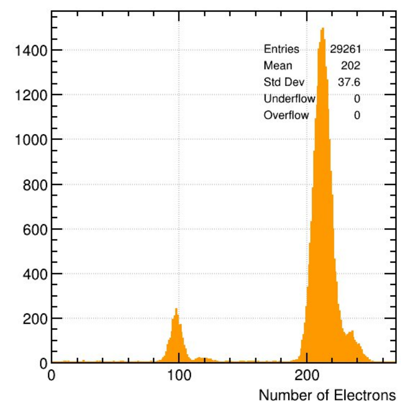

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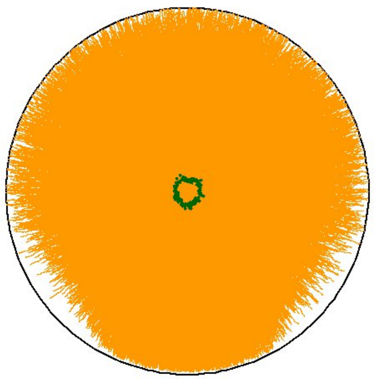


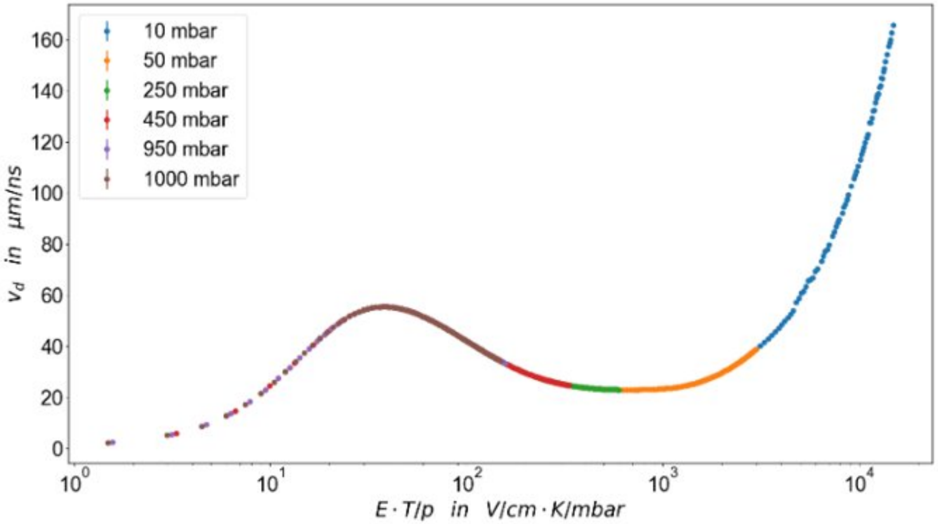
Simulation

- Magboltz / pyboltz
  - Programs to simulate electron transport in gas mixtures (monte-carlo)
    - Driftvelocity
    - Diffusion (longitudinal / transverse)
    - Gas gain (Townsend-coefficient / attachment)

  - https://magboltz.web.cern.ch/magboltz/
    - Actively maintained
    - Included into Garfield++
  - https://github.com/UTA-REST/PyBoltz
    - Not actively maintained?

- Custom scripts to run simulations in batch-mode on RWTH physics cluster

- Not possible to predict penning transfer



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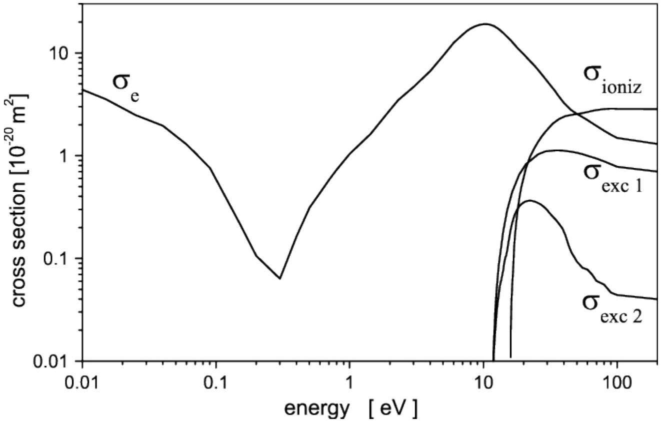
Simulation – Magboltz/Pyboltz

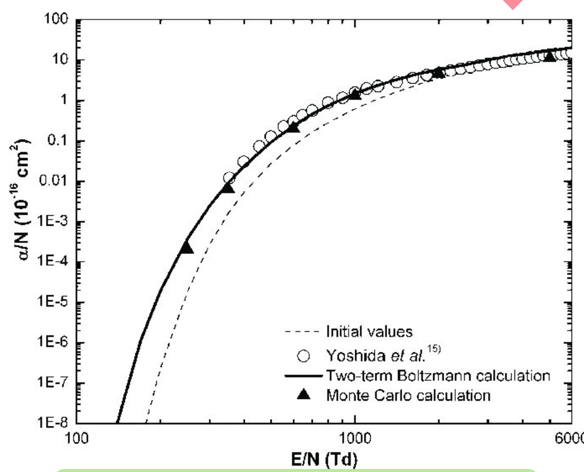
- Numerical simulation of electron swarm parameters



molecule cross-sections

https://doi.org/10.1088/0963-0252/16/1/S01

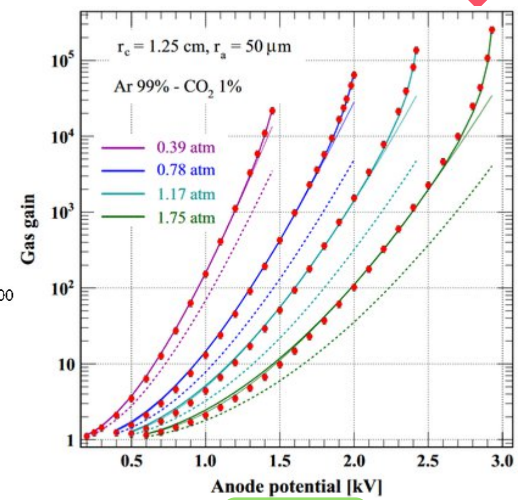
Frasier and Mathieson
(collision-by-collision simulations)



Townsend-coeffcient

https://doi.org/10.1143/JPSJ.81.064301

Numerical integration

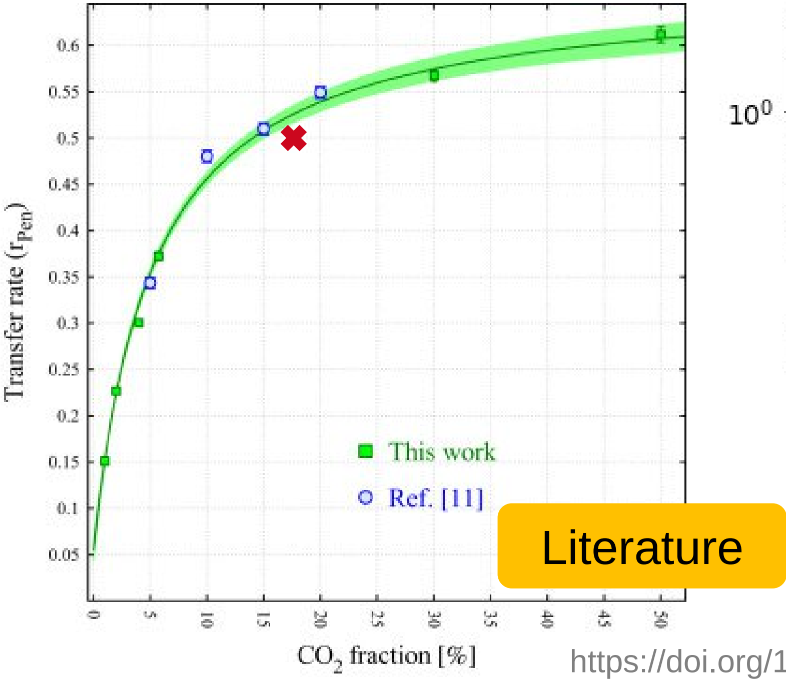


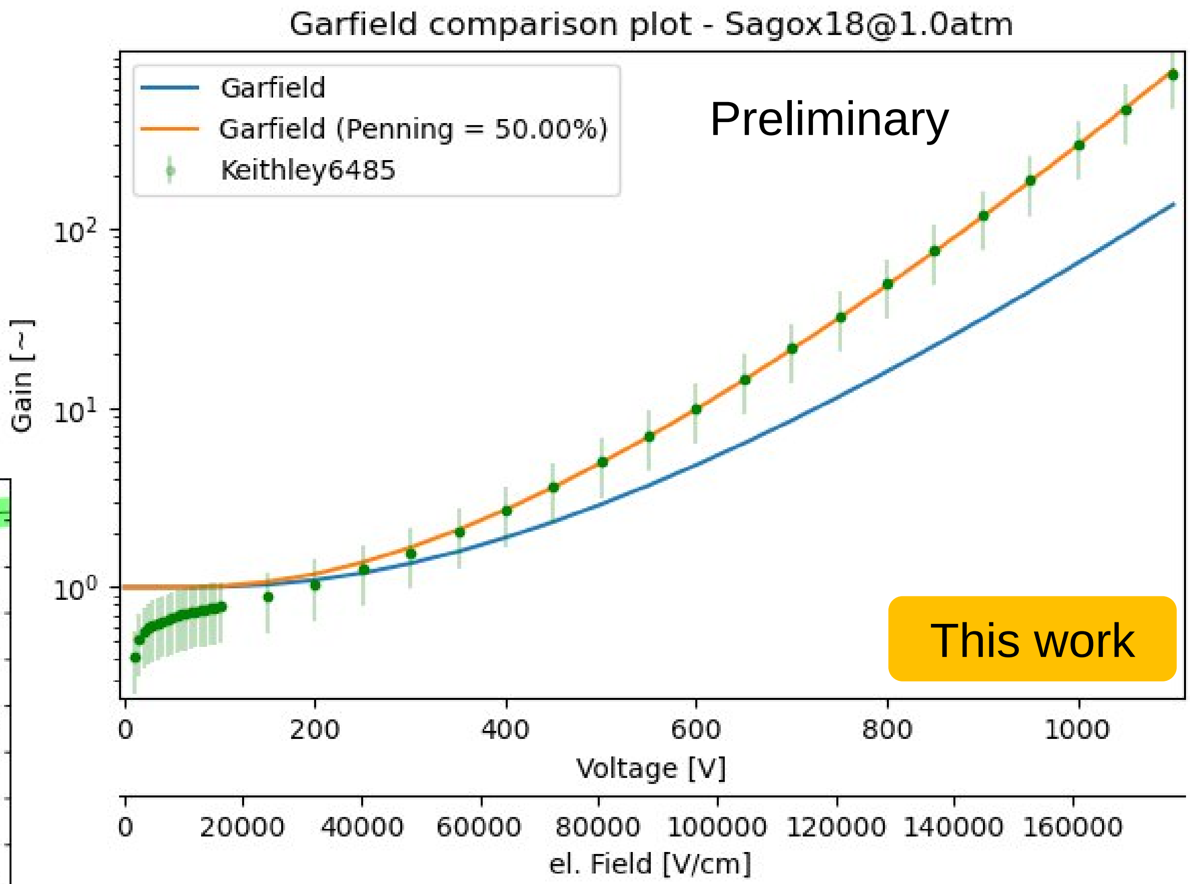
Gain

https://doi.org/10.1016/j.nima.2014.09.061

Modified gas gain: $G = exp\int_{r_c}^{r_a} \alpha_{pen}\, E(r)dr = \frac{I}{I_0}$

Measurement results





https://doi.org/10.1016/j.nima.2014.09.061

Conclusion and outlook

- Aachen gas database is a useful tool
  for operating and developing gaseous detectors
  - Results are traceable and publicly available

- New setup constructed to measure gas gain curves and qualify Penning effect transfer ratios

- First results agree with findings of other groups for various gases
  - P10
  - Sagox18
  - Pure CO2

Outlook

- Include UV-LED in future setup for better adjustability
  - Need to check interactions with uv radiation

- Try measurement on planar geometry or „in-situ“ on Micromegas detector

Thank you!