Ionization quenching factor measurement at the COMIMAC facility

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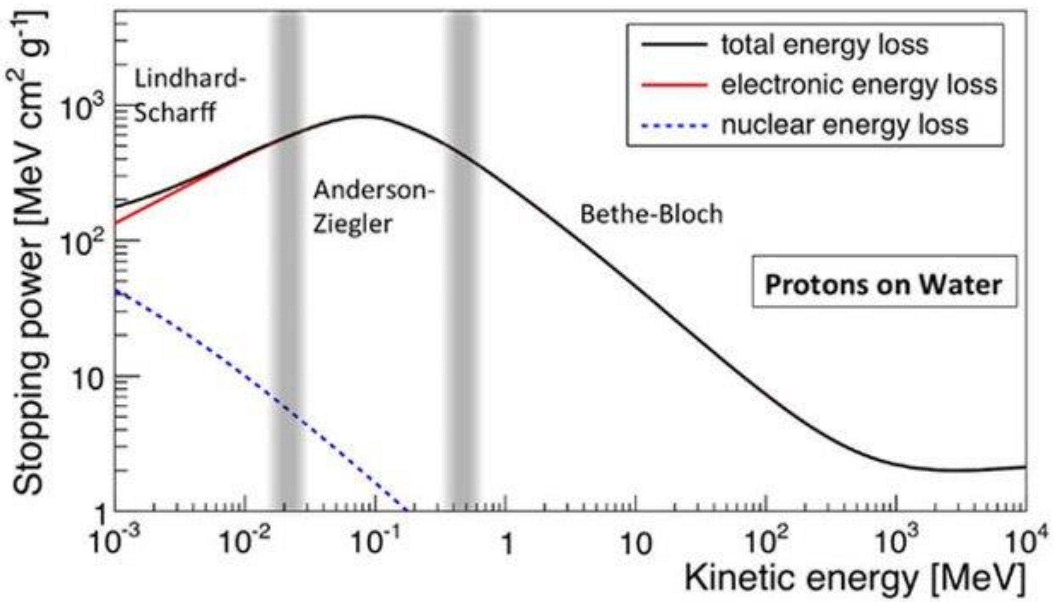
F. Di Giambattista, D. Marques

Ionization quenching factor (QF)

- Low energy (<100keV) nuclear reacoils (NR) lose a significant fraction of their energy through non-ionizing processes
- The QF is the fraction of energy lost to ionization (visible energy)

$$QF(E) = \frac{E_{ionization}}{E}$$

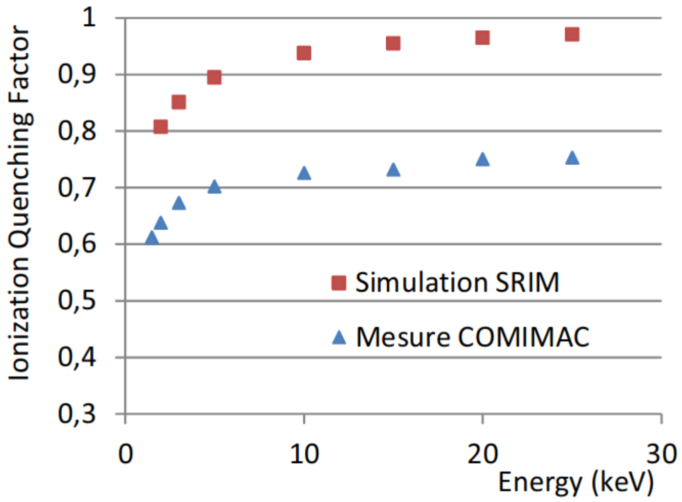
- The QF depends on the NR species (He, C or F), the gas ($HeCF_4$) and the NR kinetic energy
- A **precise knowledge of the QF** is of primary importance to reconstruct the true energy distribution of NR events in our detector



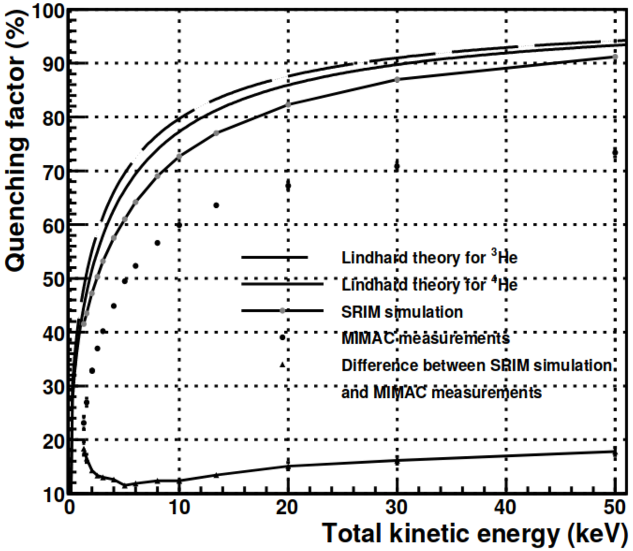
See J. Lindhard, V.Nielsen, M.Scharff, and P. V. Thomsen, Integral equations governing radiation effects, 1963

MC/data comparison

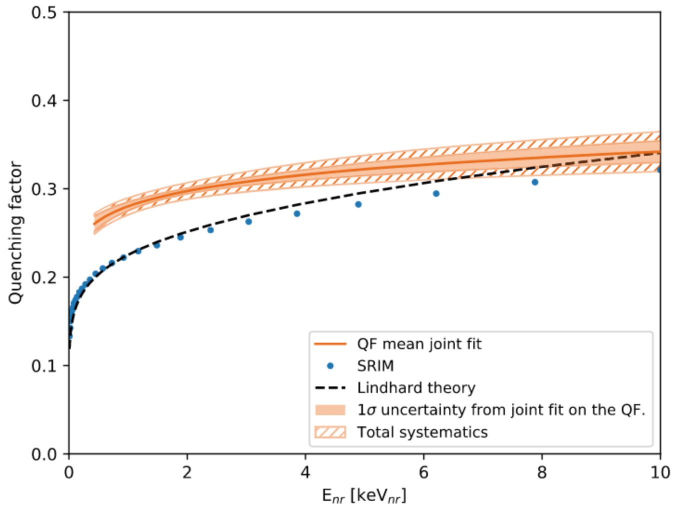
- Some comparisons between data and MC simulations were done in the past in different mixtures, and they all found some **discrepancy** between measurements and SRIM/Lindhard



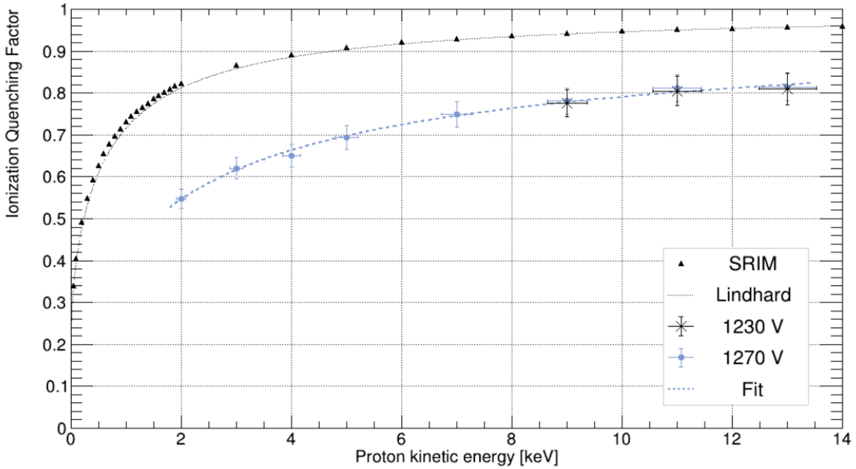
Protons in C_4H_{10}:CHF_3 (50:50),
doi: 10.1051/epjconf/201715301014



Helium in He:C_4H_{10} (95:5)
arXiv:0810.1137v1



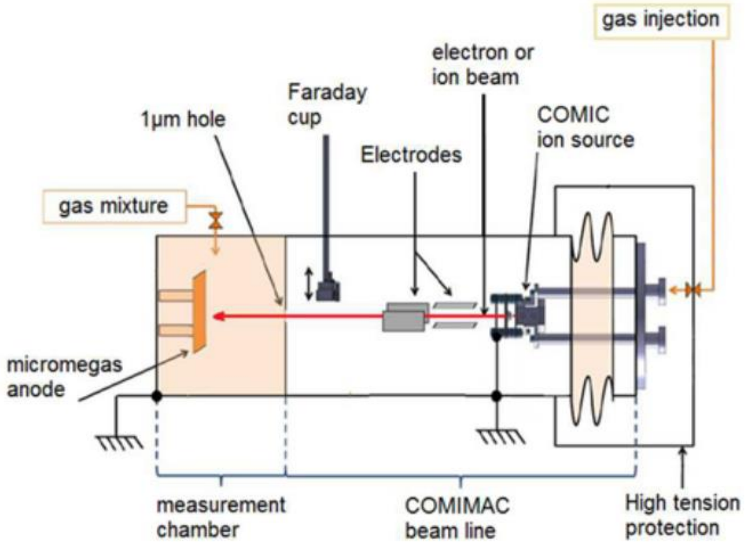
Neon in Ne:CH_4 (97:3)
PHYS. REV. D 105, 052004 (2022)

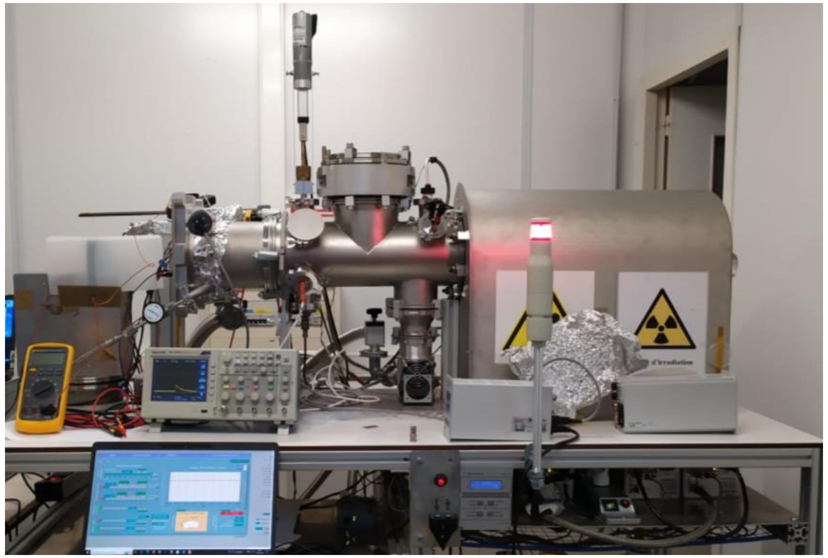


Protons is CH_4 , arXiv:2201.09566v1

The COMIMAC facility

- Laboratory of Subatomic Physics & Cosmology (LPSC), Grenoble, France
- Table-top ion and electron beams facility, beam energy from 1 keV up to 50 keV
- Plasma of mono-charged ions and electrons created and maintained in resonant cavity of COMIC ion source + extraction electrode + focusing electrodes
- Beam line at 10^{-5} mbar, beam current monitored through a Faraday cup
- Stainless steel cathode with 13 μm membrane, with central 1 μm hole, separates the beam line from the ionization chamber (at ~1 atm)
- 5 cm drift gap, Micromegas amplification, strips for 2D reconstruction
- Cost for 1 week of data taking: 6000€





Data taking

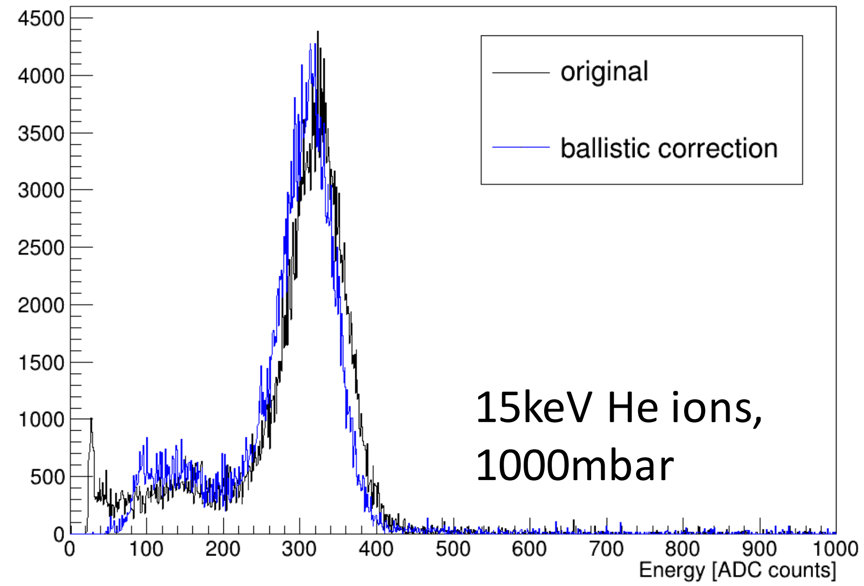
- Data taken from 25/10 to 27/10: 500mbar, 900mbar, 1000mbar
- Strategy:
  - **Optimization** of avalanche field (grid voltage) and collection field (cathode voltage), to maximize the gain and optimizing collection efficiency
  - **Calibration** run with electron beam, between ~1 keV and ~20 keV
  - **Ion run** with He gas in the source

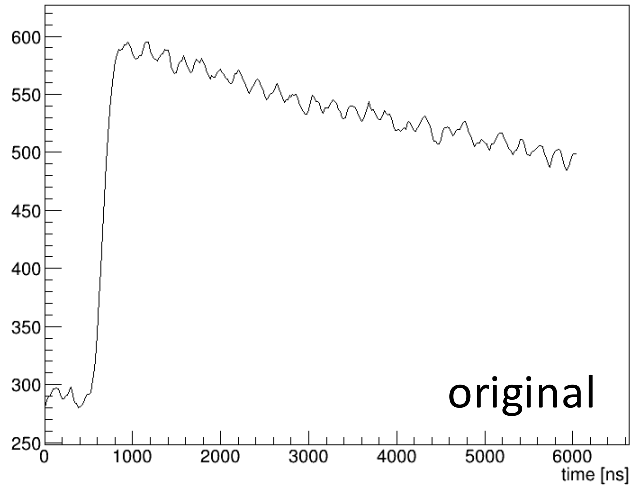
- Issues:
  - Ion source gas **contamination**, multiple peaks were visible (attributed to H^+, H_2^+, H_2O^+, N_2^+)
  - Focalization voltage, vertical and horizontal deflectors, and source rate **changed during the runs**, and it seemed to change the position of the peaks
  - Drift field could not be set to a value larger than 400 V/cm due to a limit of the cathode voltage
  - At low energy (<5 keV) we lose detection efficiency, and the peak position is overestimated (we lose the left tail of the gaussian distribution)

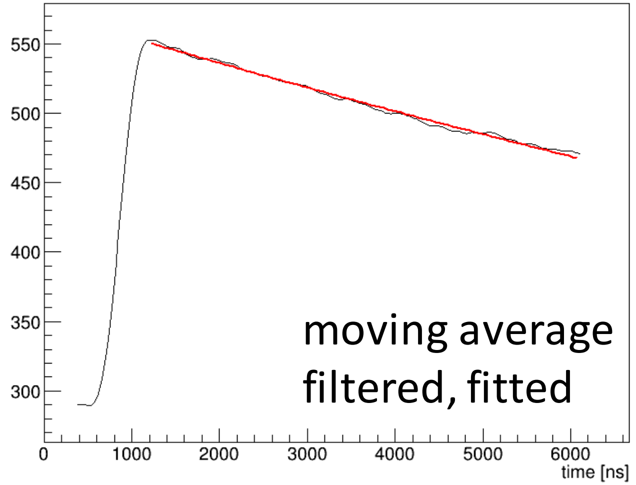
Data analysis

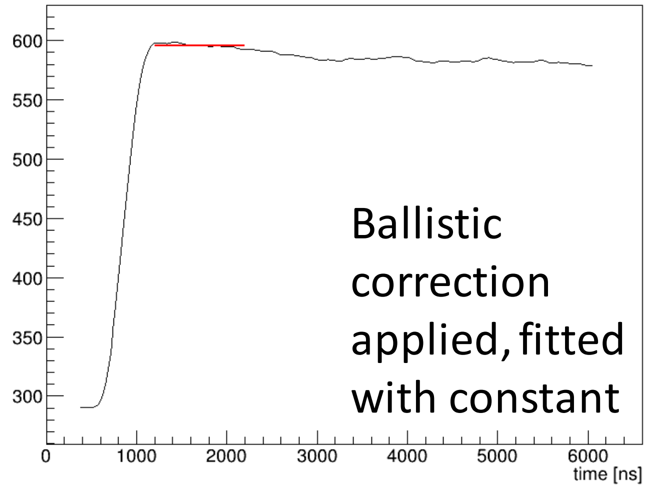
- Energy measured with charge-sensitive preamplifier that integrates the current induced on the grid, and it is digitised with a flash ADC
- **Ballistic correction** is applied to the signal to compensate the discharge of the CSP
- Signal is filtered, fitted with $Ae^{-t/tau}$ and then corrected

$$Q[t_i] = \begin{cases} F[t_i] & \text{, for i} = 1 \\ Q[t_{i-1}] + F[t_i] - F[t_{i-1}]\, e^{-\Delta T/\tau_D} & \text{, for i} > 1 \end{cases}$$



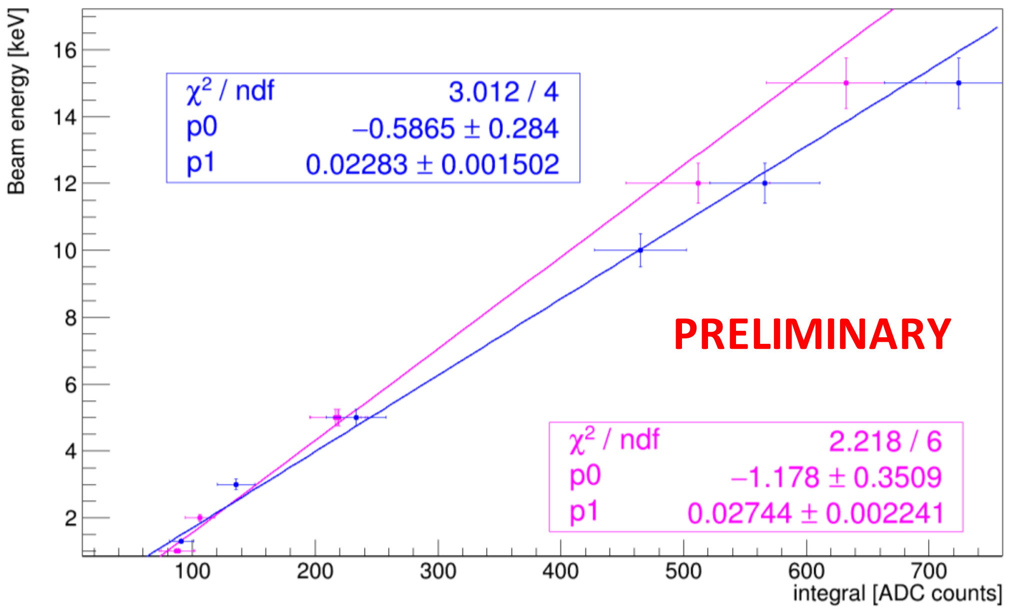


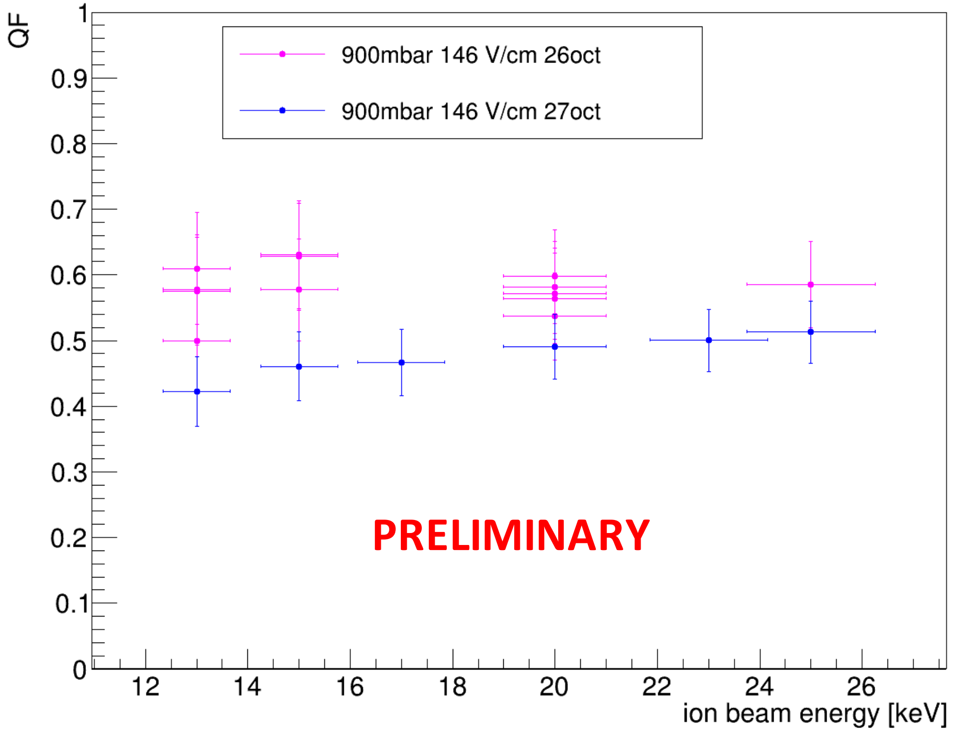




Data at 900mbar

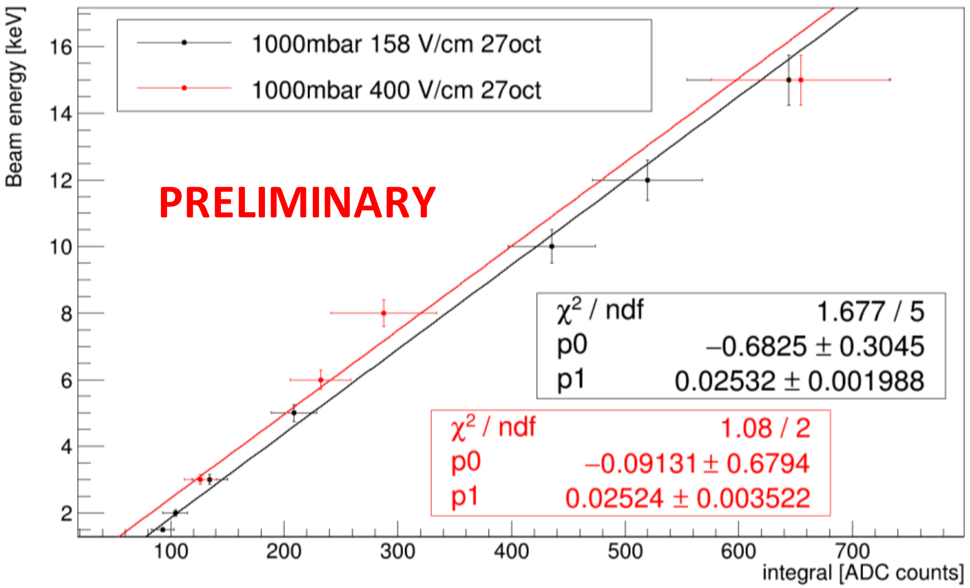
- On 26/10 there was still contamination and different parameters were changed mid-run
- We pumped the source gas all night, and on 27/10 we kept all beam parameters constant
- Results **not consistent** at same pressure and same drift field, QF seems shifted
- Data on the last day are more reliable

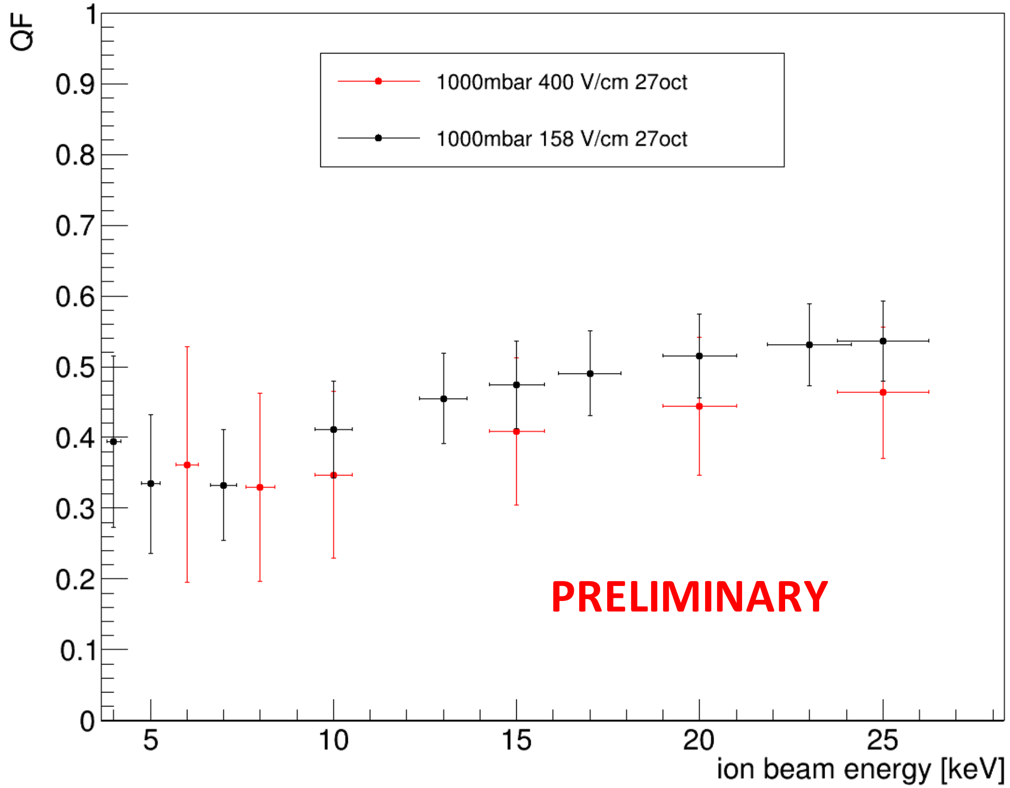




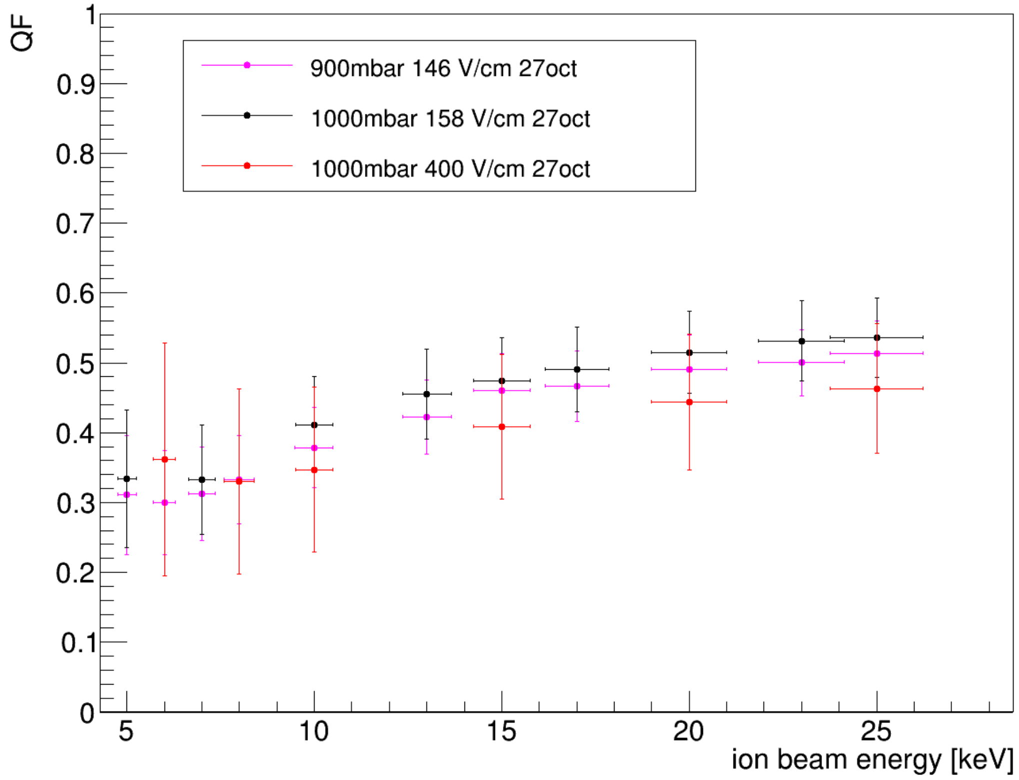
Data at 1000mbar

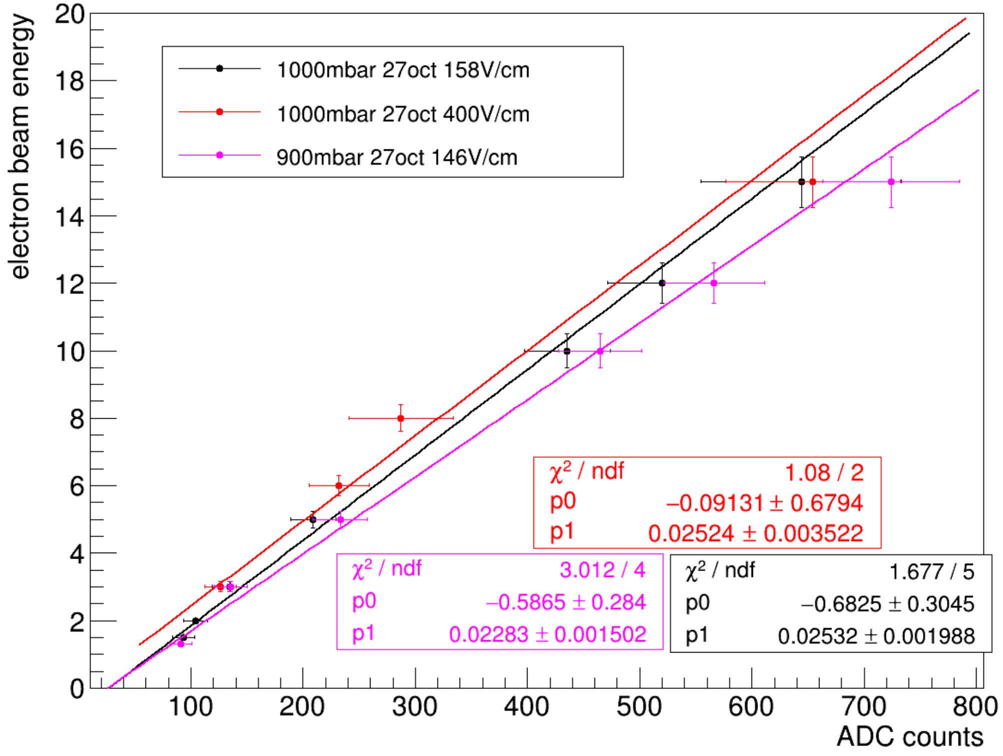
- Same pressure, different drift field
- Error estimation is preliminary; even if results are compatible, there seems to be a shift in the QF
  - Higher drift field → lower QF
  - Electrons don't seem affected as much as ions





Results summary

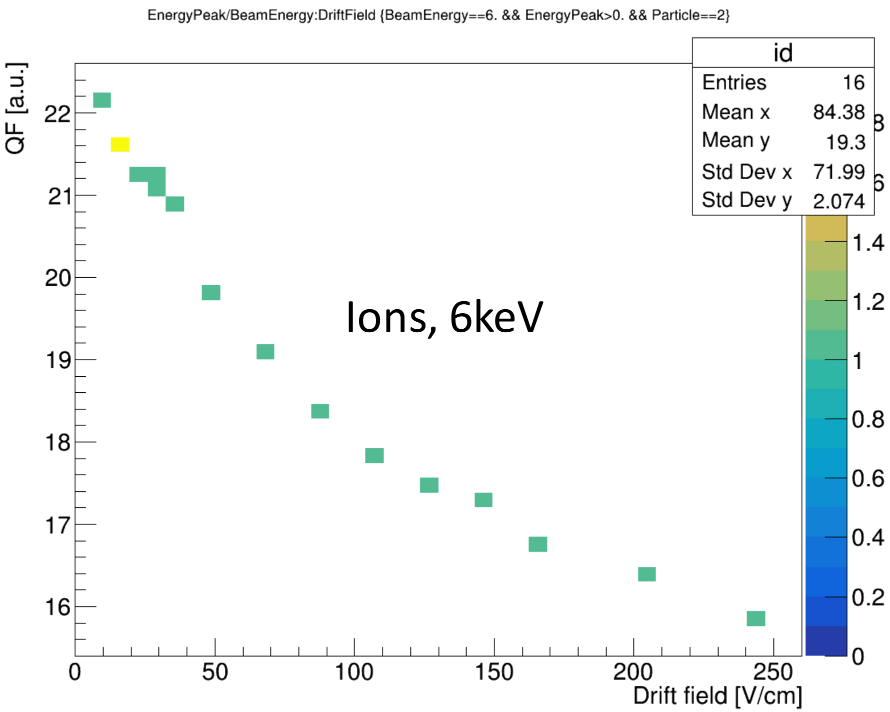


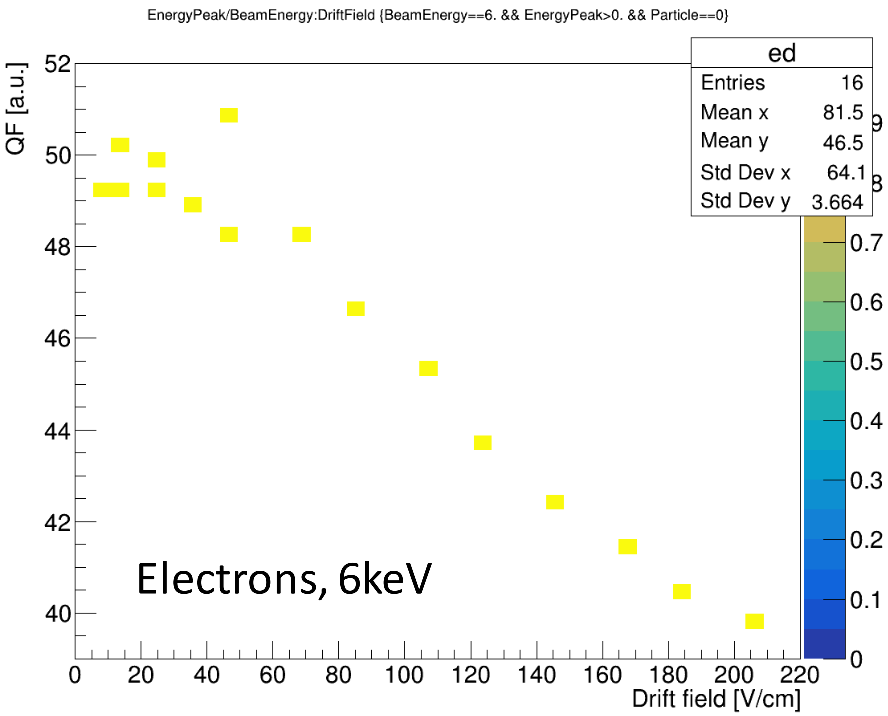


- Slight **dependance on drift field** is visible
- We need anyway more data, with full control on all parameters, and at our pressure of interest (900 mbar for LNGS)

New data at 900mbar

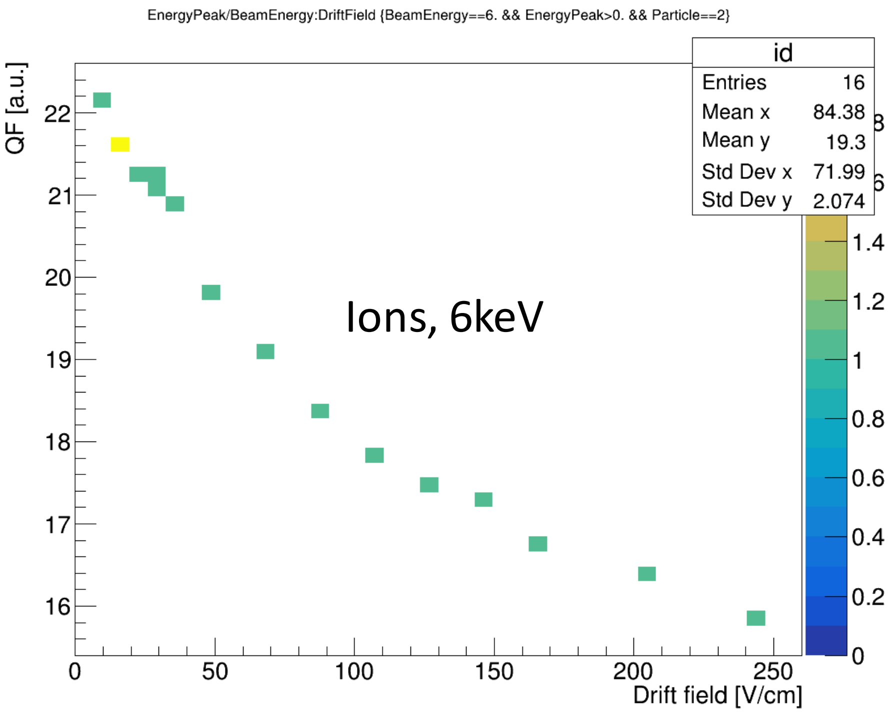
- Following our discussions, COMIMAC colleagues took **additional data** to explore the dependancies of the measured QF on the drift field and on the source rate
- *The measured energy increases with lower drift field and lower rate*

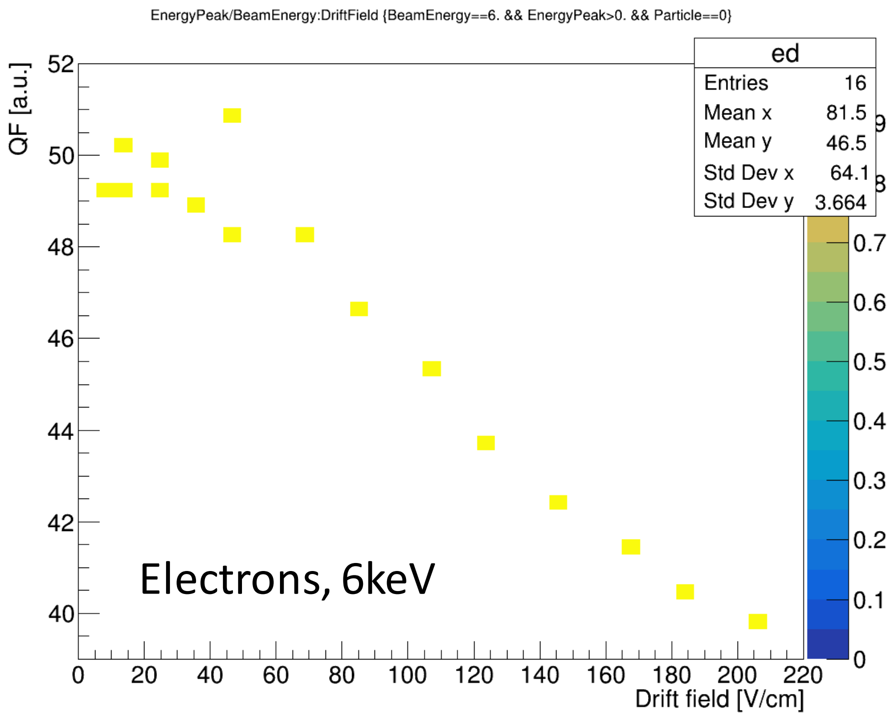




New data at 900mbar

- Ions and electrons are affected in a different way → it might be related to their different ionization density
- Hypothesis: **space charge effect** which effectively lowers the gain, and it is enhanced by higher drift fields
- If this is confirmed, higher drift fields are less suitable for very low energy applications

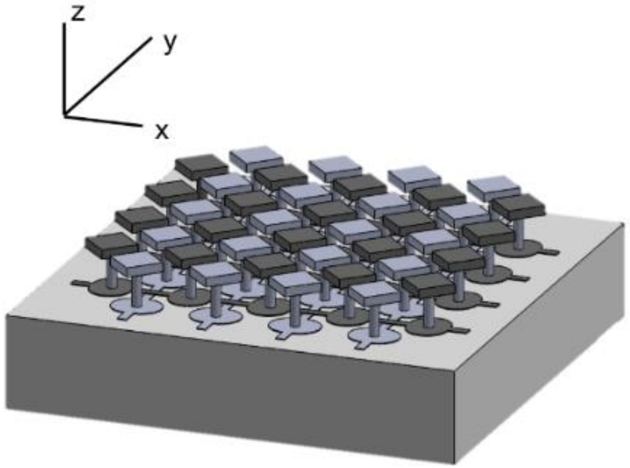


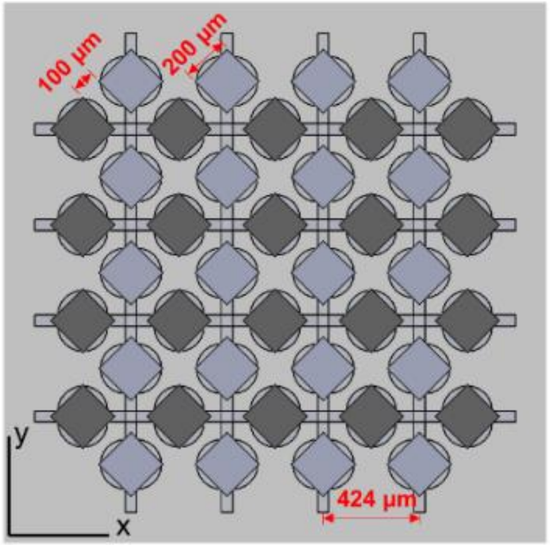


3D track reconstruction

- Pixelated anode 10.8×10.8 cm^2 with 256 strips in each direction
- 424 μm strip pitch (transverse resolution)
- A pixel is fired if the current is above a threshold defined previously as the instrinsic electronic noise of each strip (autocalibration)
- **X-Y binary information** (activated or not) - no current measurement
- Sampling at 50MHz, **2D image every 20 ns** timeslice
- **Z coordinate** determined from number of timeslices and drift velocity
- *Not really pixelated*: no actual coincidence in X-Y plane, just a set of X and Y strips fired → useful info are the barycenter (X_b,Y_b) and the transverse spread (σ_x, σ_y)

$$x^b(t_i) = \frac{1}{N}\sum_{j=0}^{N} x_j(t_i)$$





3D track reconstruction

- Some information on the length and shape of the track can be extracted
  - **Straight length** (3D distance between two extreme activated timeslices)

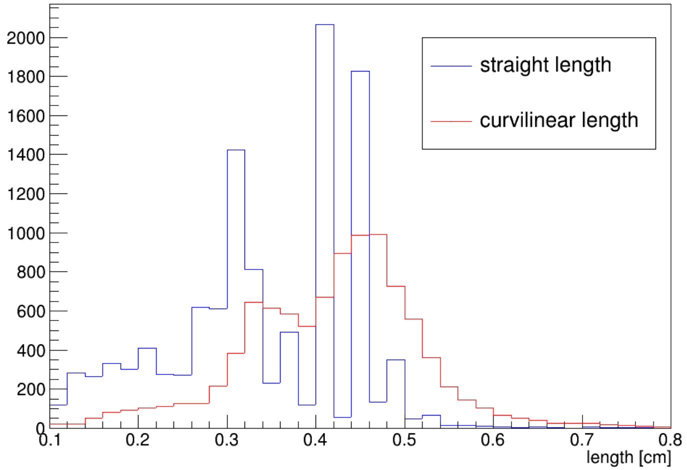
$$\mathrm{SL} = \sqrt{\left(x^b(t_{max}) - x^b(t_{min})\right)^2 + \left(y^b(t_{max}) - y^b(t_{min})\right)^2 + \left(\Delta Z(t_{max}) - \Delta Z(t_{min})\right)^2}$$

  - **Curvilinear length** (sum of 3D distances between barycenters)

$$\mathrm{CL} = \sum_{j=1}^{N} \sqrt{\left(x^b(t_j) - x^b(t_{j-1})\right)^2 + \left(y^b(t_j) - y^b(t_{j-1})\right)^2 + \left(\Delta Z(t_j) - \Delta Z(t_{j-1})\right)^2}$$

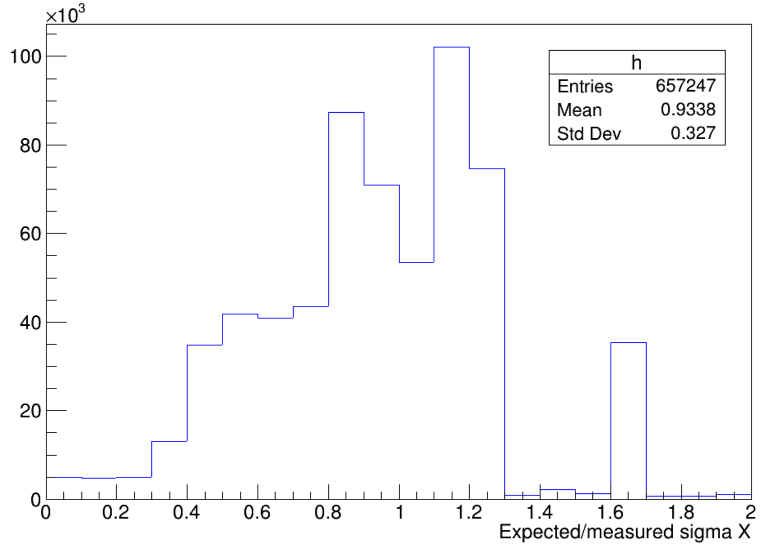
  - **Duration** (t_{max}-t_{min}, proportional to length in the Z direction through drift velocity)

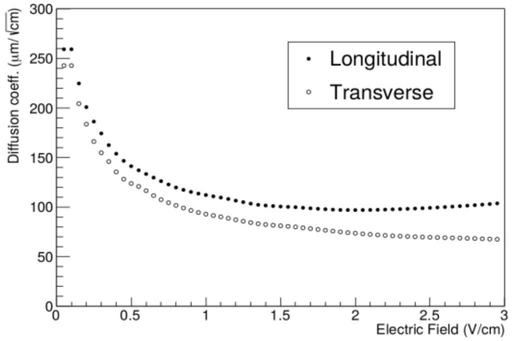
  - **Track width** from spread in X or Y direction, dominated by diffusion



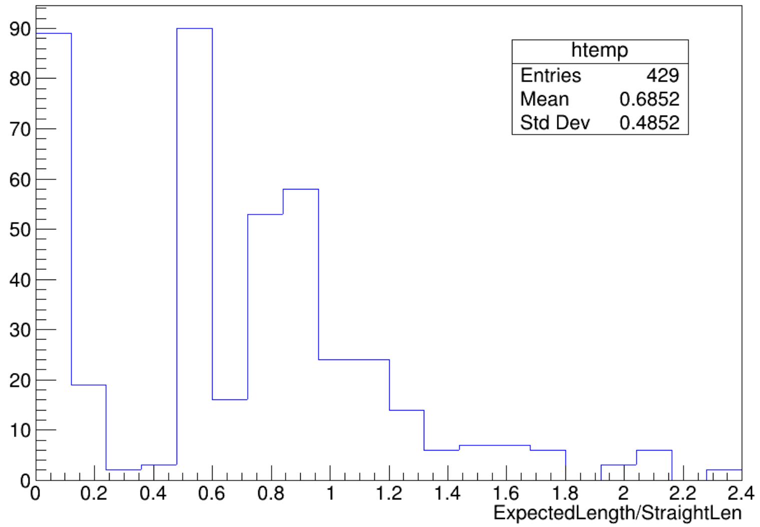
3D track reconstruction

Ratio between expected transverse diffusion and standard deviation of fired strips along X for He





Ratio between simulated range + 4*longitudinal diffusion and the measured straight length

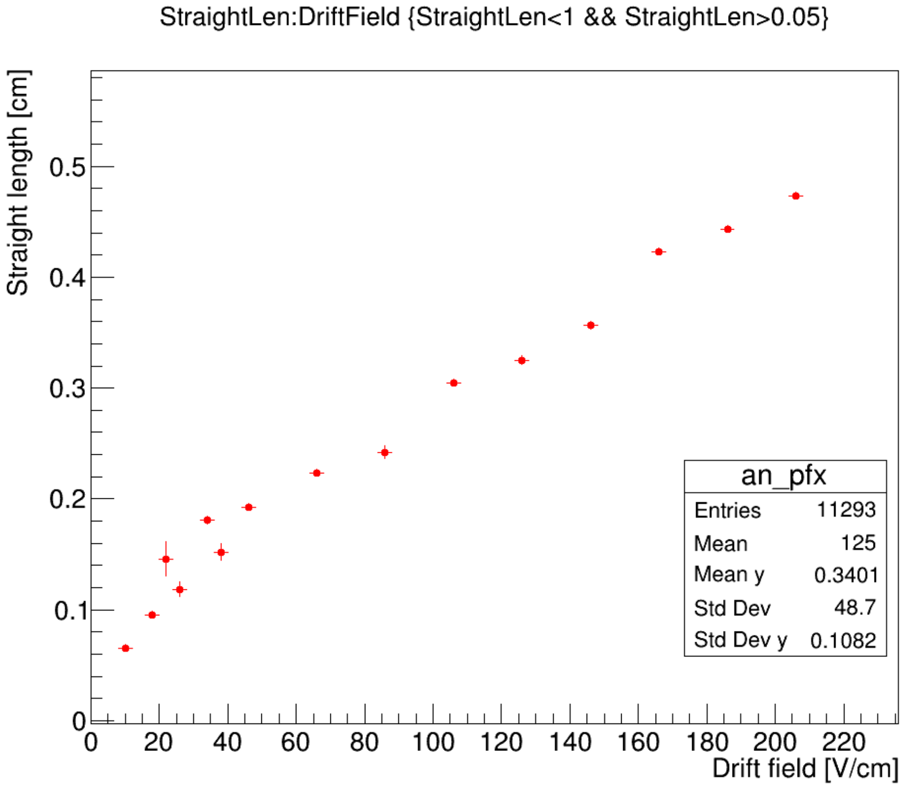


- The dimension of the track seems resonably consistent with the expected values based on diffusion and original track shape
- *Is few millimeters enough to justify this hypothetical space charge effect for 5 to 20 keV*?

Straight length vs drift field

- The track length increases with the drift field (opposite to what we would expect)
- The lower the field, the more spread the tracks are, so the ionization clusters are either recognised as different particles and/or part of the charge will be below threshold

Also the strip information is incomplete/unreliable and dependent on the drift field



Conclusions

- We faced different **issues** during the data taking, the effective amount and quality of data is not enough for our purposes
- The measured ionization energy **depends on the drift field** applied, both for electrons and ions
  - A similar dependance can be seen with the **rate** of particles in the beam, this suggests the presence of a space charge effect in the amplification region
  - *Is this consistent with what we see*?
  - A possible solution is to optimize the drift field to maximise the transparency of the grid for both electrons and ions; they found an optimal value of **32 V/cm** → much lower than what we need anyway!
- The COMIMAC setup functioning is not perfectly clear, we need to understand what (if any) reliable information we can retrieve
- Future plans:
  - We could **bring our setup** (MANGO-like) to COMIMAC, we are studying possible coupling
    - Drift field scan will be necessary to understand the dependance and extrapolate our working point
  - Using a **neutron source** (TUNL facility, arXiv:2109.01055v2) might be a better and reliable solution

→ see David's Talk!

Thank you for your attention!

Let's discuss! :)

QF SRIM simulation