Oxygen and isopropyl alcohol as additives in drift chamber gas mixtures

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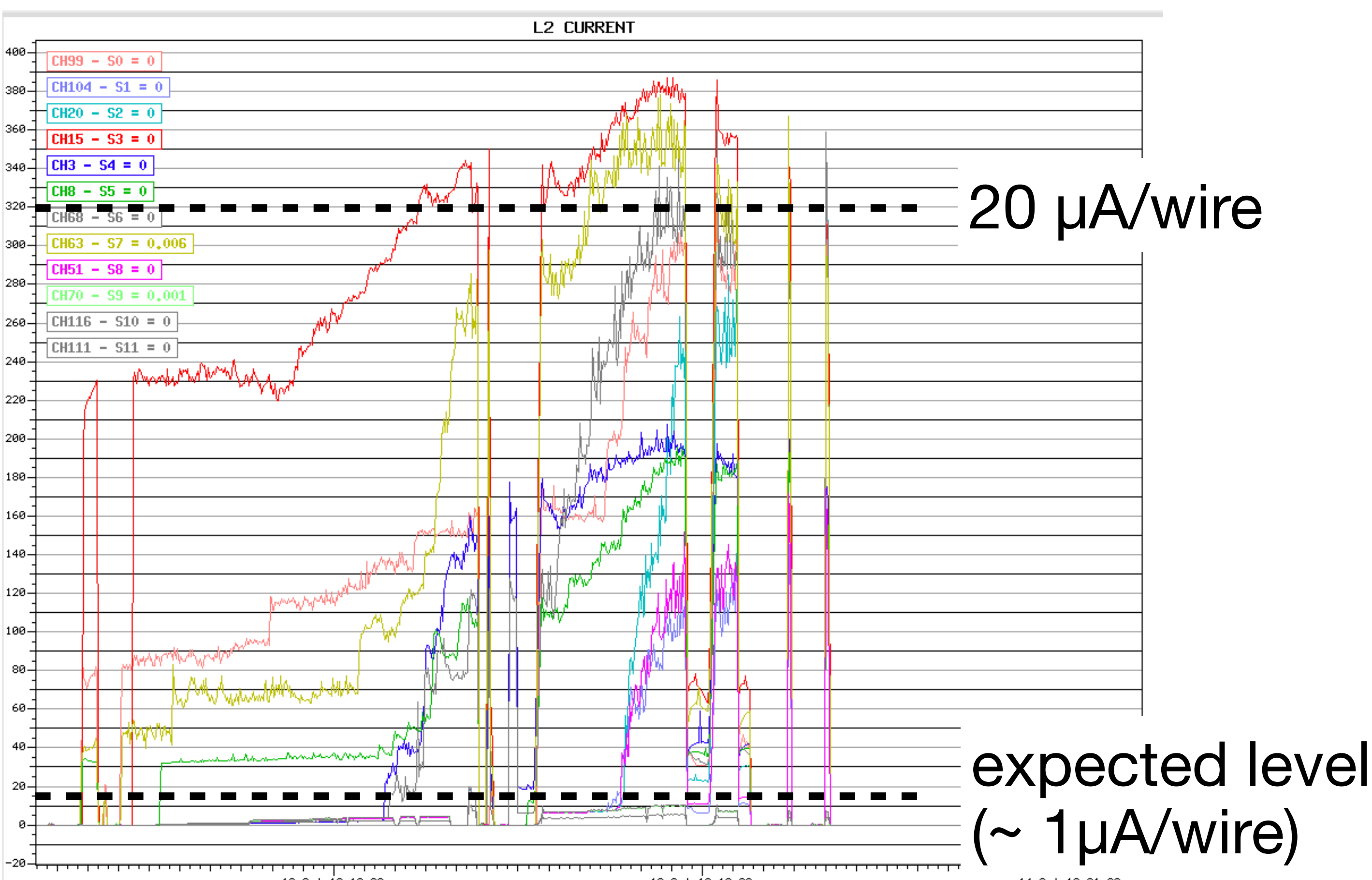
for the MEG II CDCH Group

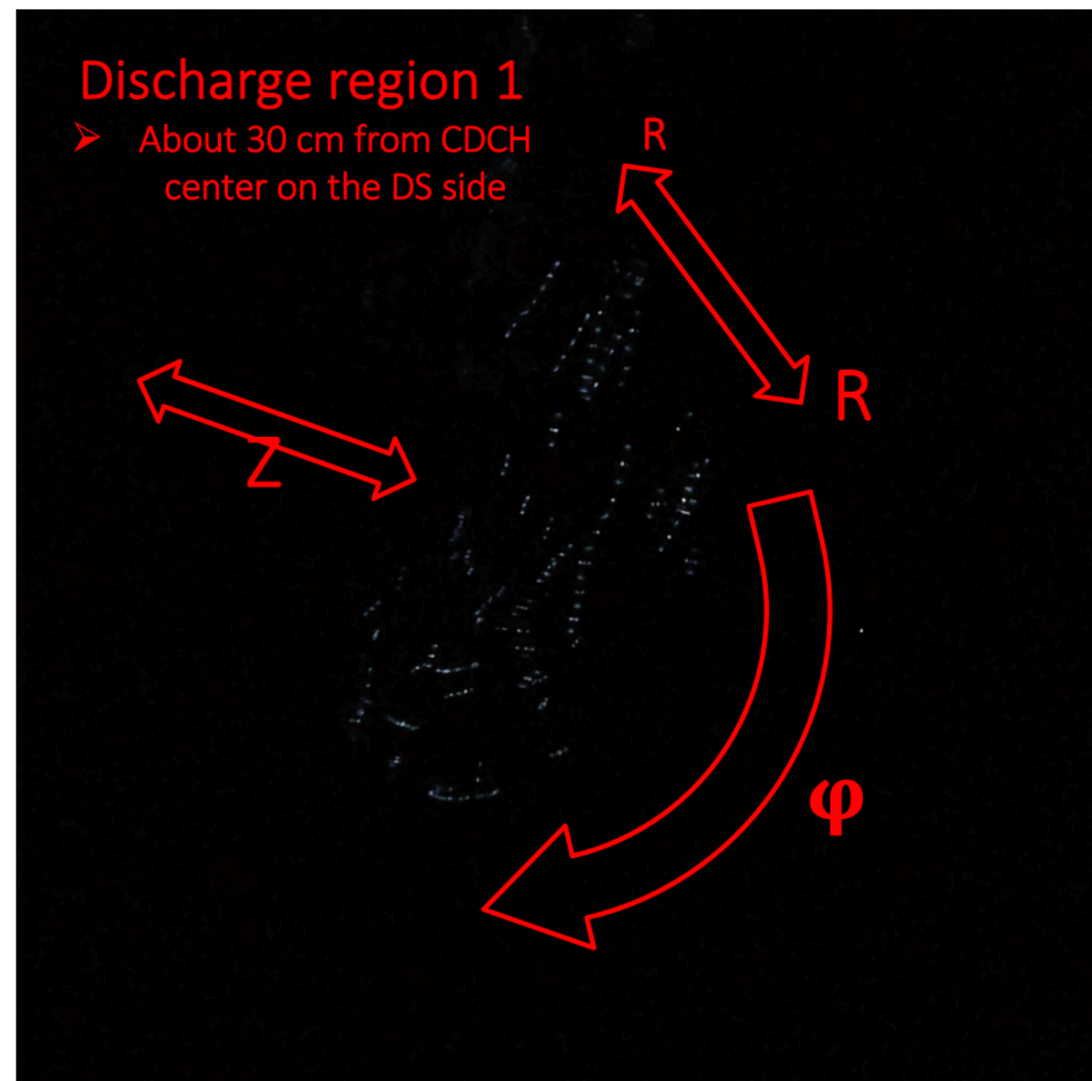
The MEG II Drift Chamber (CDCH)

- 9-layer cylindrical drift chamber with **He:Isobutane 90:10** mixture
- ∅20 μm gold-plated tungsten sense wires
- ∅40 μm and ∅50 μm silver-plated aluminum field and guard wires
- Full stereo geometry, ~ 7.5° stereo angle
- Cell size from 6.7x6.7 mm^2 to 8.7x8.7 mm^2

Operational issues

- After we started operating the CDCH under beam, we observed **large and unstable currents**
- Equipping the CDCH with a transparent external wall, we could observe sparks in some specific locations, where the wires look damaged
  - most probably, the combined result of a high-voltage accident at commissioning + a poor coating of the wires





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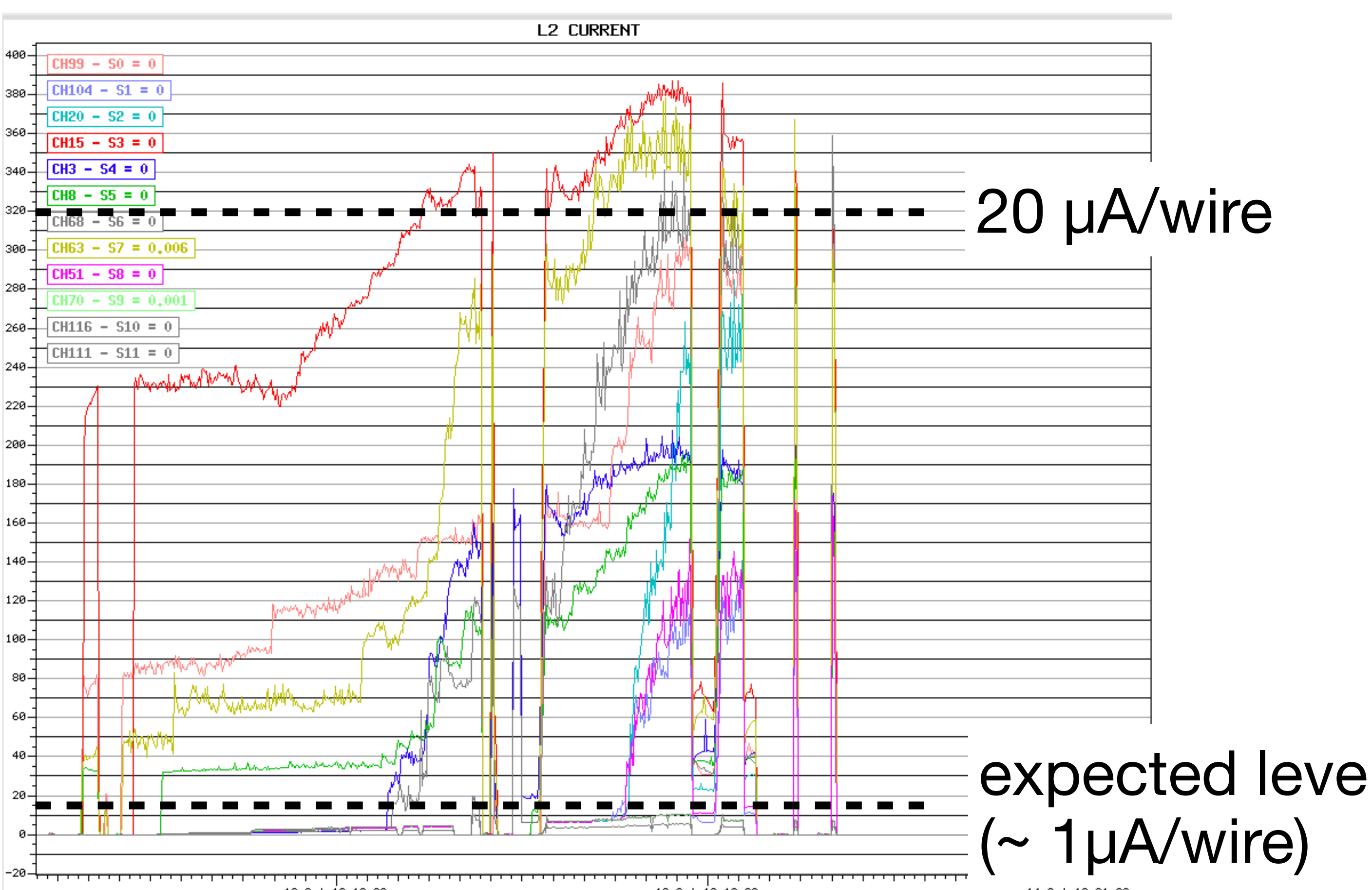
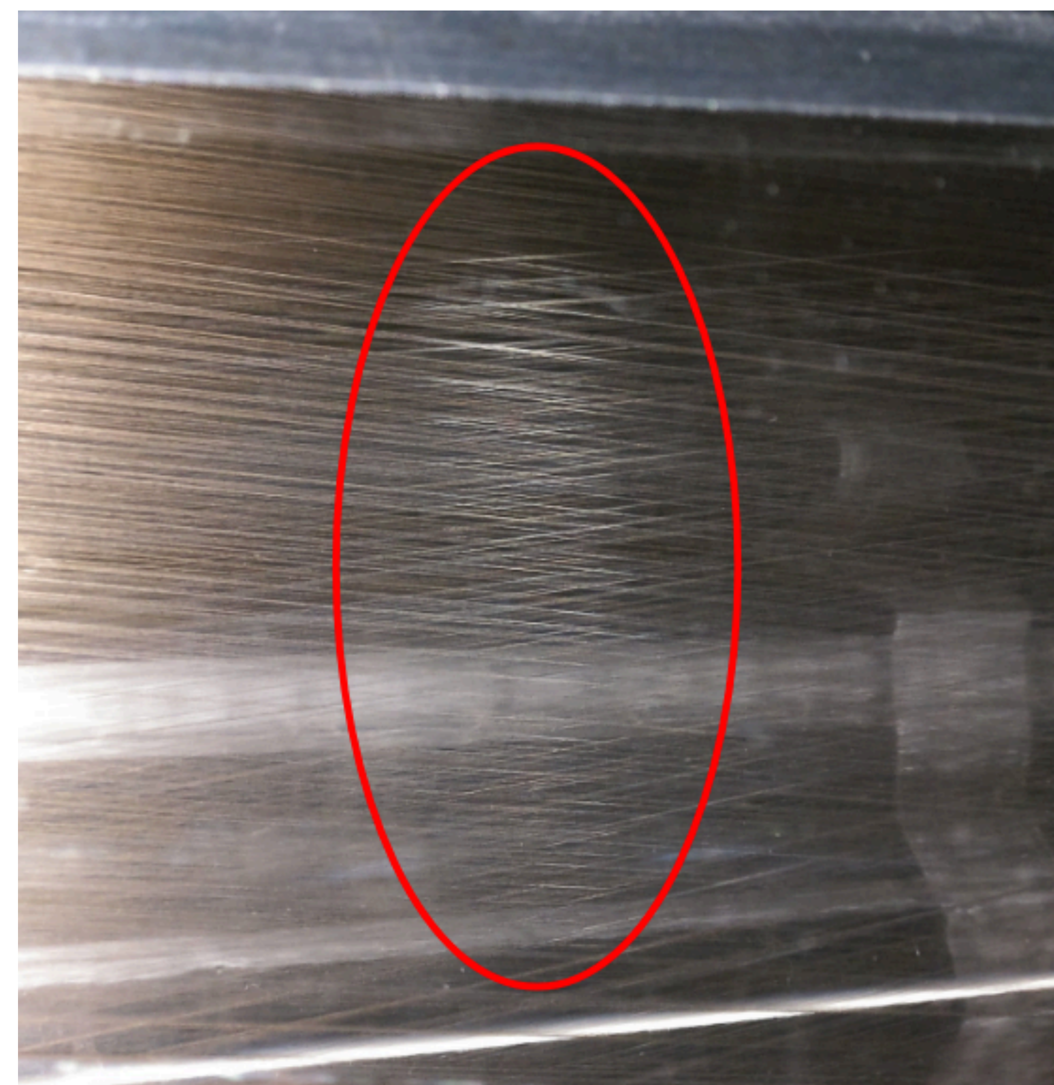




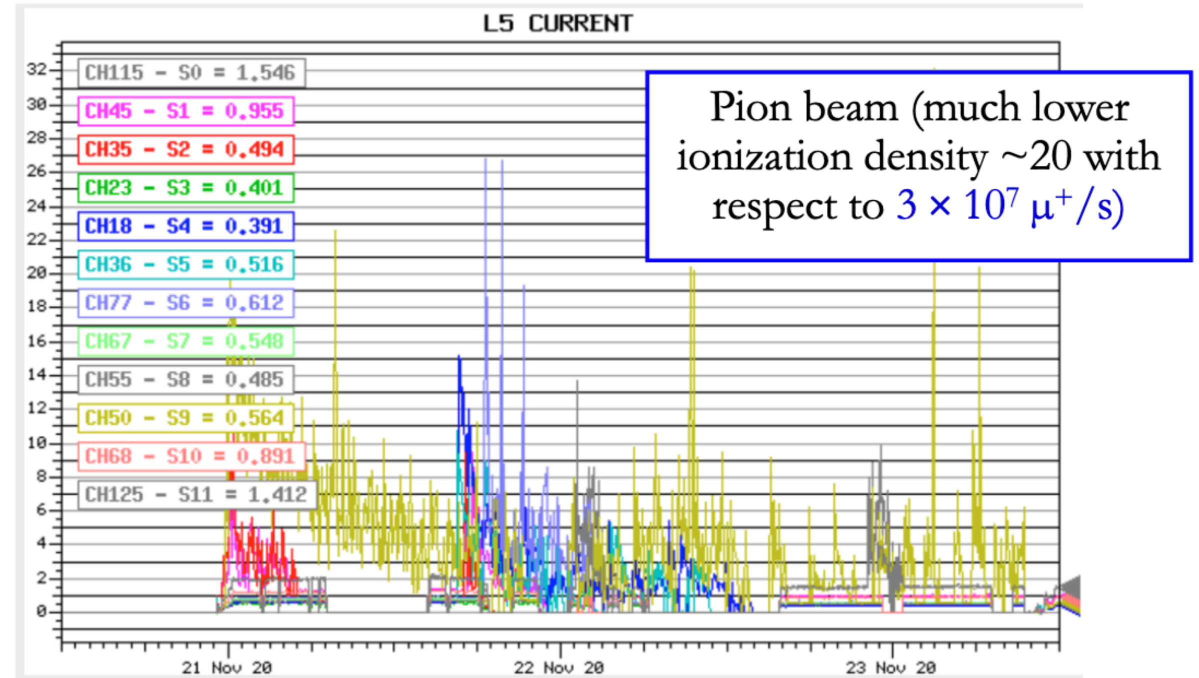
The MEG II magic mixture

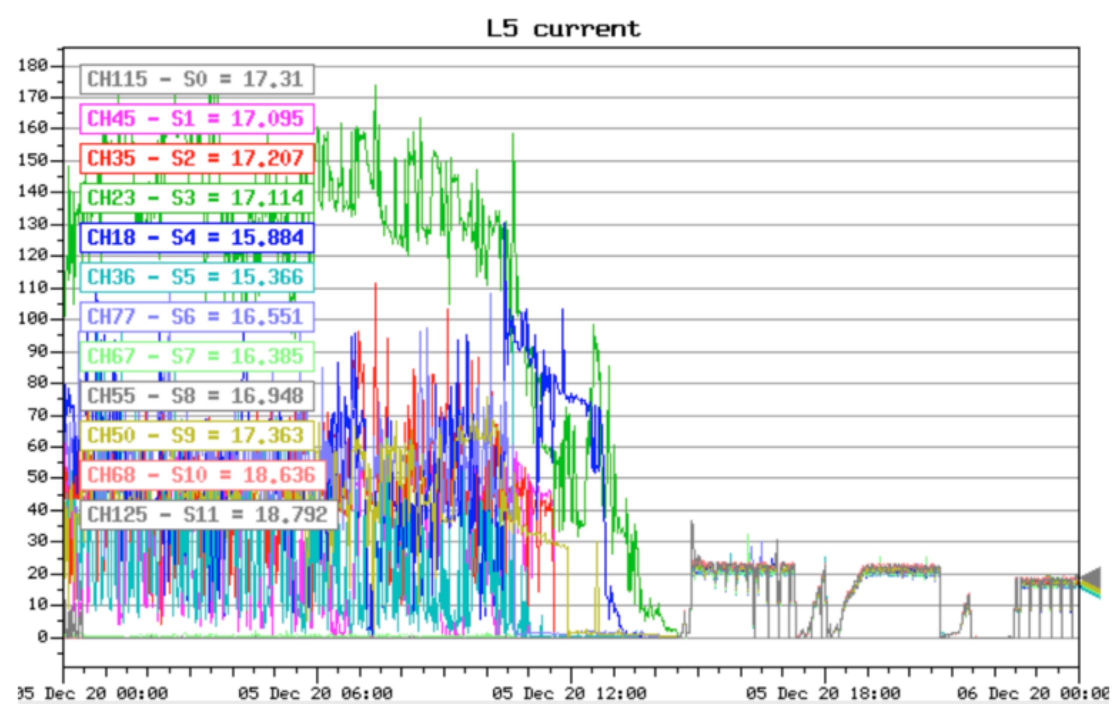
- After several attempts, we found that:

    1. the addition of a large **oxygen** concentration (up to 2%) with the chamber exposed to large ionization on beam, could reduce progressively the anomalous currents

    2. after this “conditioning” we could operate the chamber without anomalous currents, with **0.5% oxygen + 1-2% isopropyl alcohol** vapors

    3. after 4 years of data taking, we don’t have any sign of detector aging

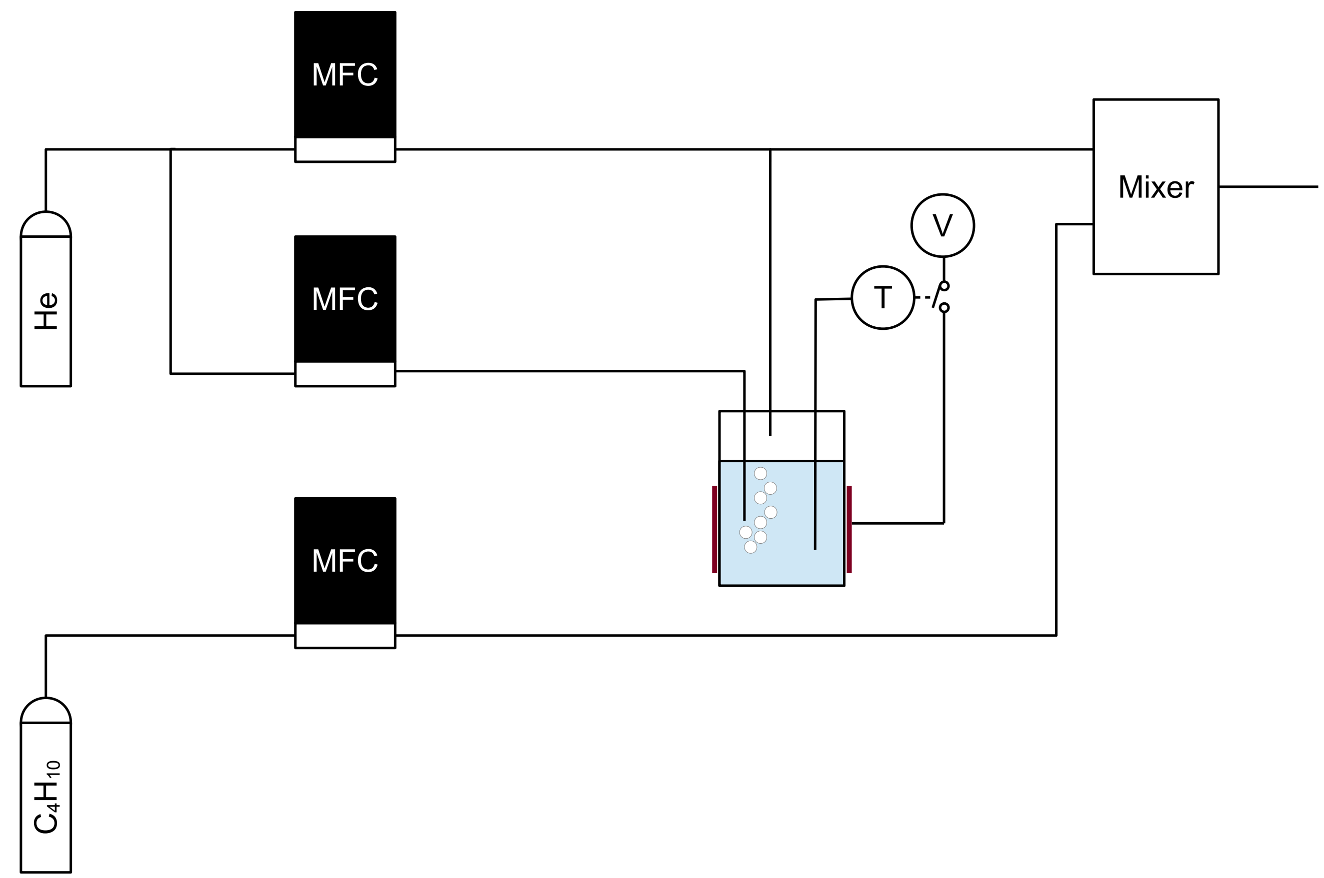




He	:	C_4H_{10}	:	isop. alcohol	:	O_2
87.9	:	9.8	:	1.84	:	0.5

Technical implementation

- Isopropyl alcohol is added at controlled concentration with the usual technique of **dilution of saturated flow from a thermally regulated bubbler**

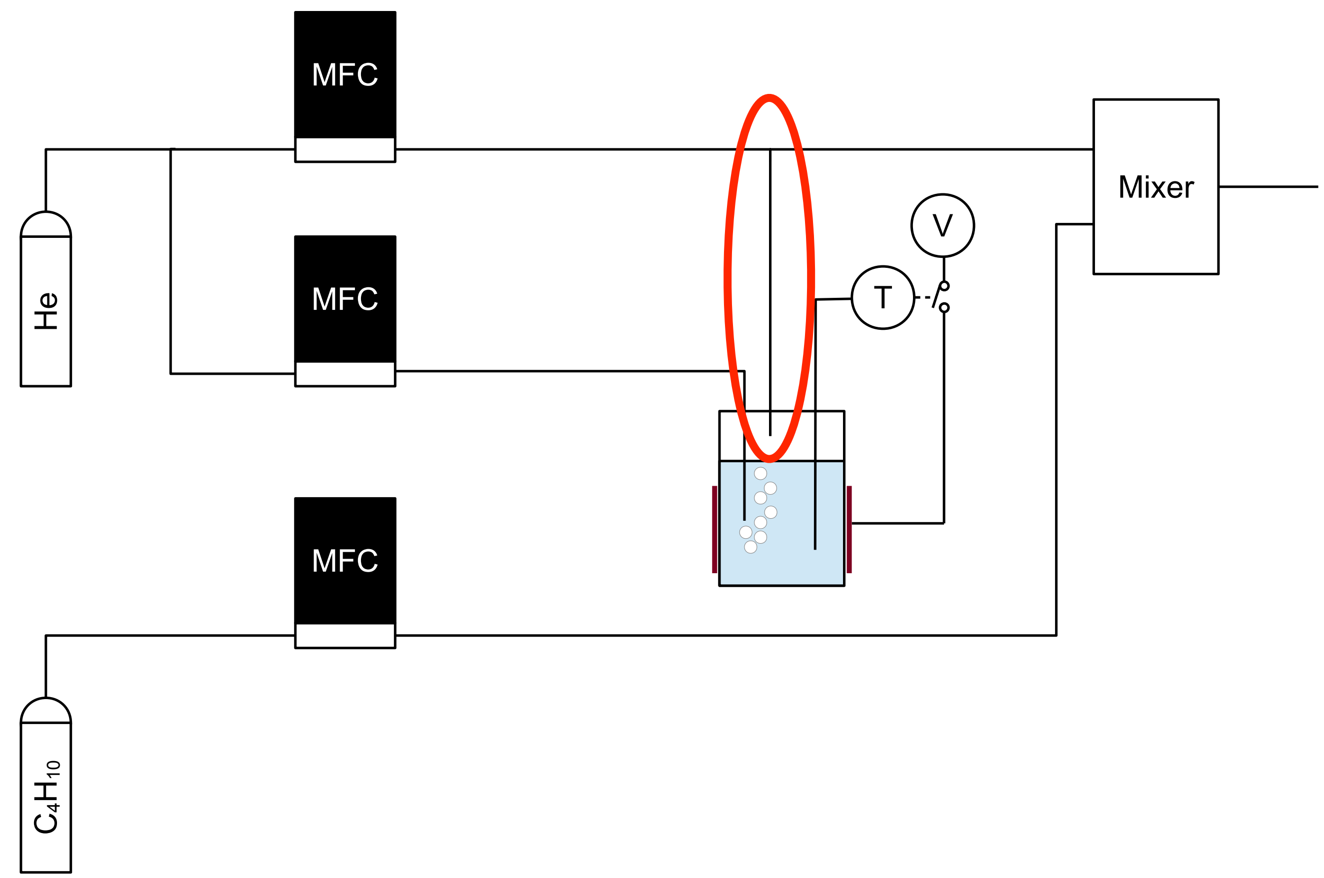


Technical implementation

- Isopropyl alcohol is added at controlled concentration with the usual technique of **dilution of saturated flow from a thermally regulated bubbler**

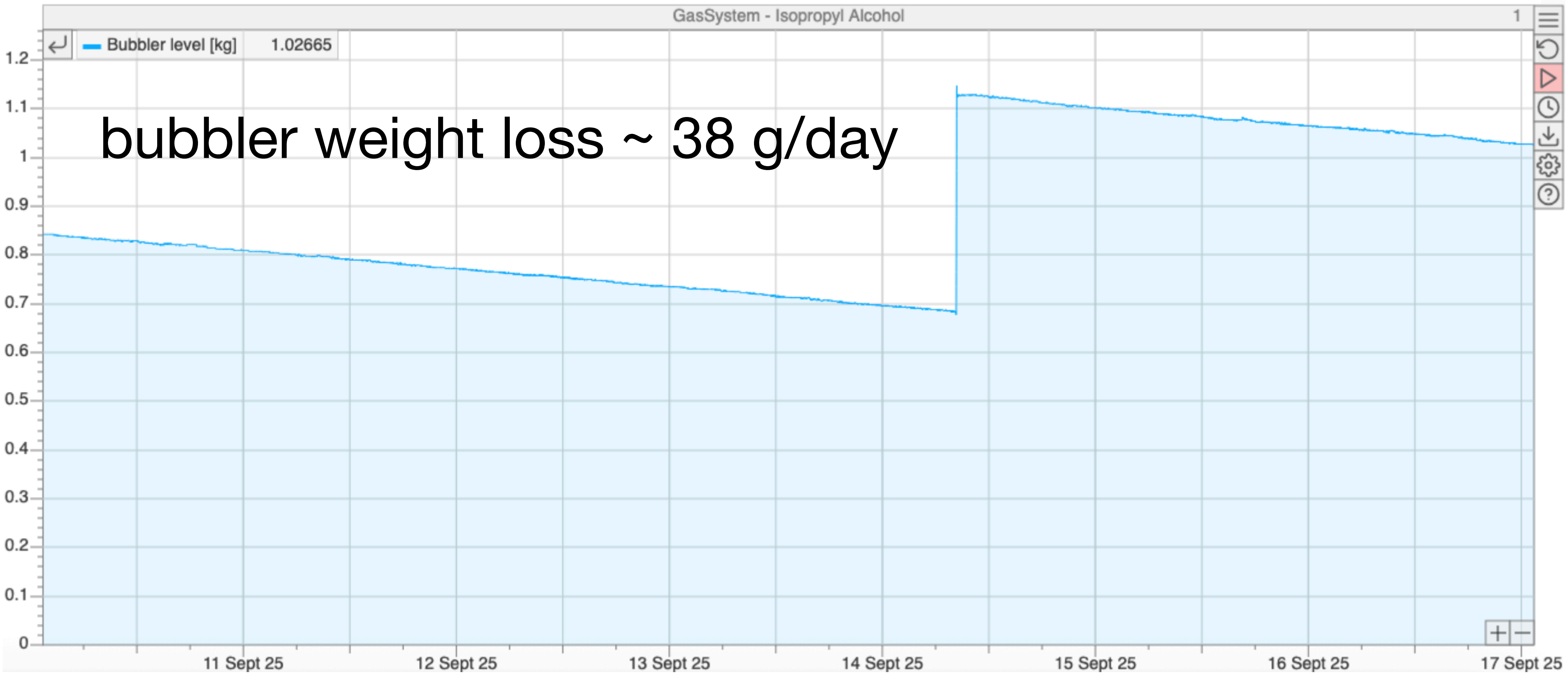
- Significant difficulties in keeping the concentration constant at varying ambient conditions:

  - even if the bubbler is thermally regulated, condensation can happen in piping!

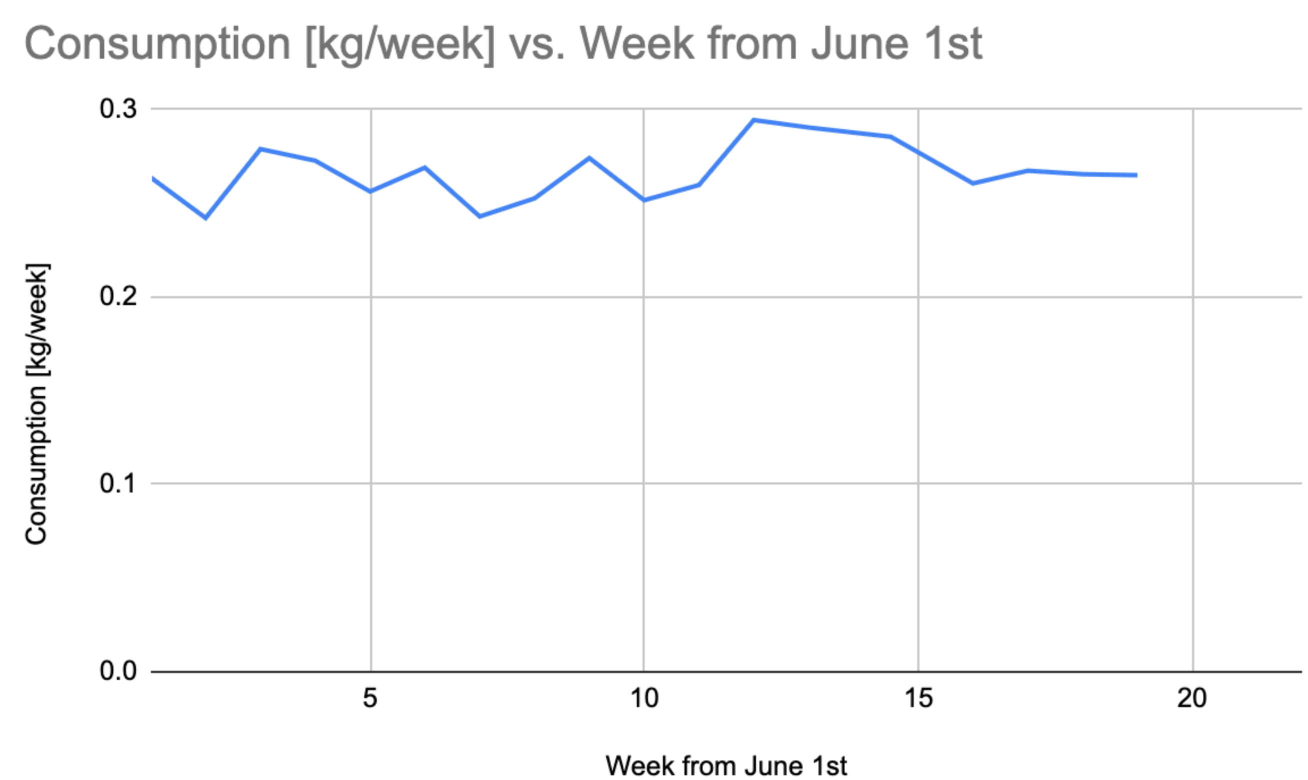


- The mixture is too complex to measure the alcohol concentration with simple analyzers (and we don't have a gas chromatograph)

  - effective alcohol concentration is extrapolated from the alcohol consumption (assuming no leak!)



- Weekly alcohol consumption during the 2023 run
  - concentration set point: 1.84%
  - avg. extrapolated alcohol concentration: 1.86%



A possible interpretation

- Operating with large currents and a high concentration of Oxygen (~ 2%) activates a plasma cleaning reaction on the wires
  - existing damages are fixed

Recovery of LHCb Detector Muon Chambers for Malter Effect Elimination

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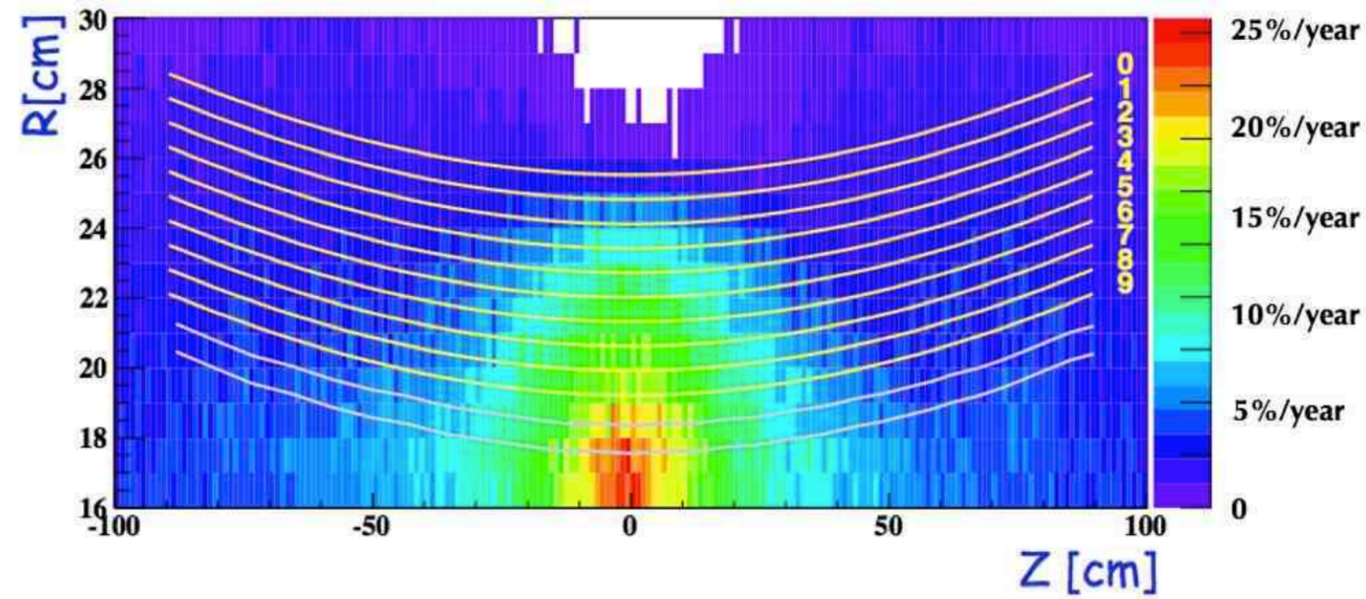
Abstract—A method is presented for restoring the performance of gas discharge detectors wherein a spontaneous self-sustaining current, i.e., Malter effect, occurs. A successful practical implementation of the method is demonstrated by the example of recovery of operability for multiwire proportional chambers used in the muon detector of the LHCb experiment carried out at the Large Hadron Collider. Four proportional chambers wherein Malter currents regularly occur during the experiment were subjected to high-voltage discharge training in the working gas mixture of 40% Ar + 55% CO_2 + 5% CF_4 with 2% of oxygen added. It is shown that, with addition of oxygen, the recovery of the proportional chambers occurs tens of times faster in compare to the training in the working gas mixture. The reconstructed chambers were installed in the LHCb muon detector and have been working in a collider beam experiment for more than two years already.

- Isopropyl alcohol has a role similar to water in other drift chambers
  - increase of wire surface conductivity —> reduction of charge accumulation —> reduction of Malter effect
- The immediate effect of low oxygen concentrations is not clear but, in the long term, it could suppress aging thanks to the neutralization of free radicals

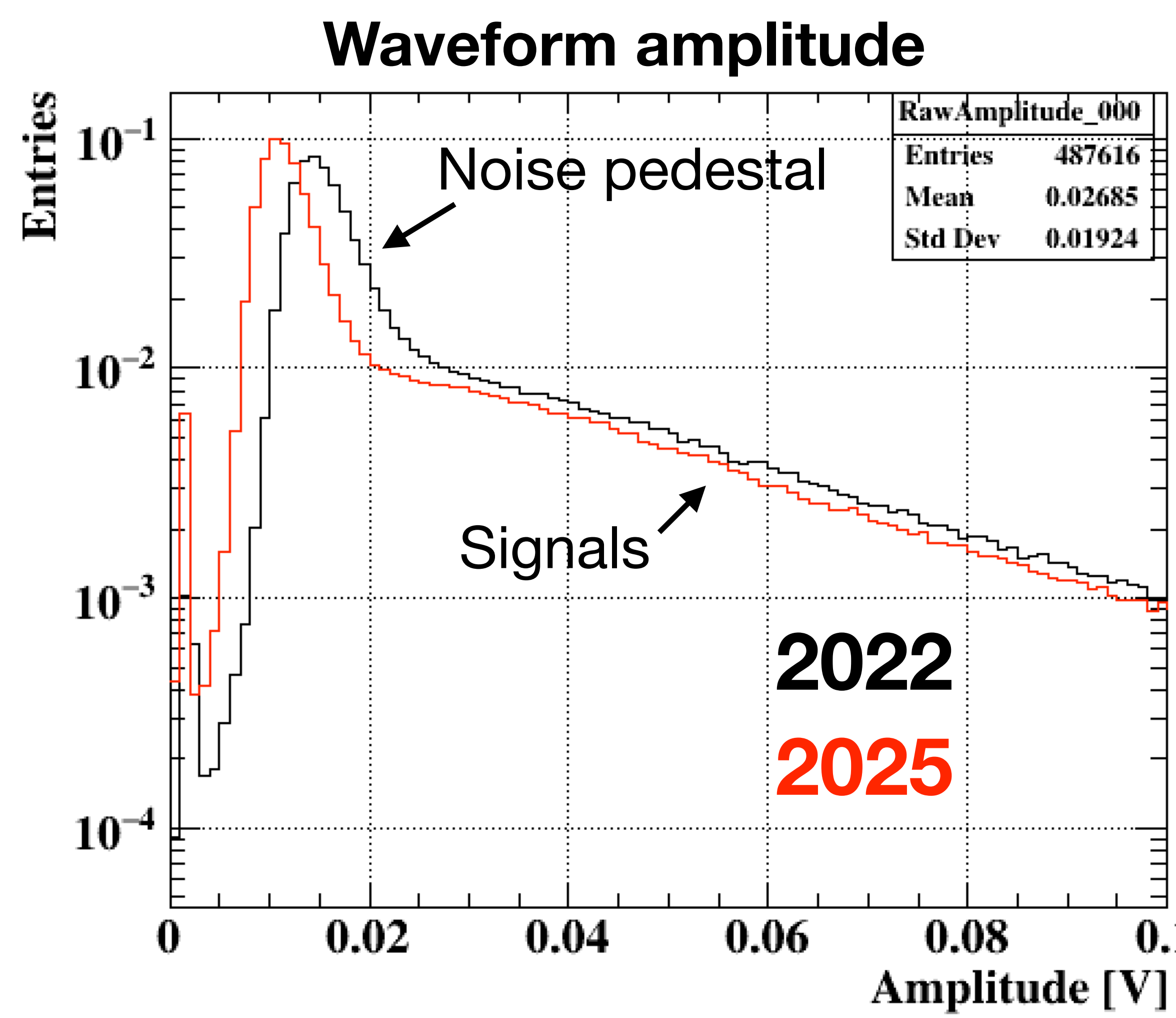
Expected and observed aging

- From measurements on prototypes with He:C_4H_{10}, we expected up to **25% gain loss per year** due to aging at 7 x 10^7 μ/s beam rate



- Though we are operating at lower rate (3-5 x 10^7 μ/s), we would still expect some observable effect

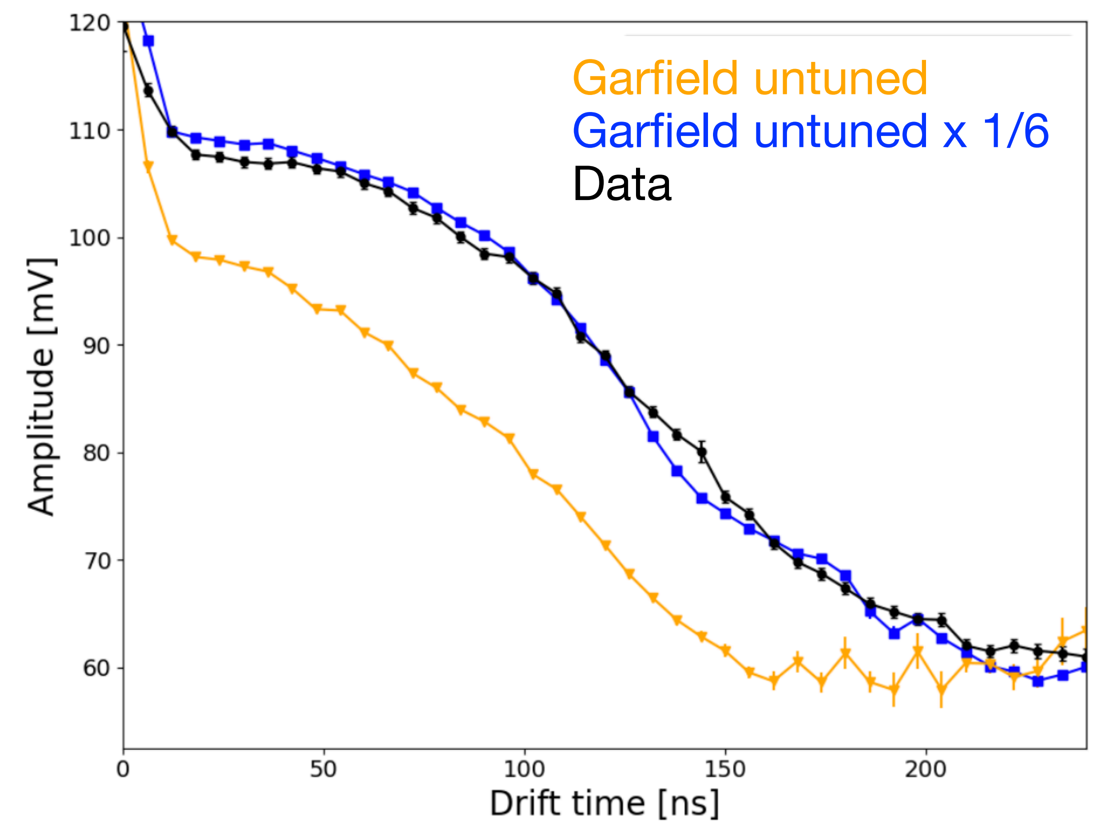
No sign of gain loss after years of run



The drawback of using oxygen

- Electron attachment to oxygen is potentially large, reducing the collected charge
    - if Garfield is not properly tuned to simulate the effect of attachment, its results discourage the addition of any relevant oxygen concentration (see F. Cei talk in the WG4 session)

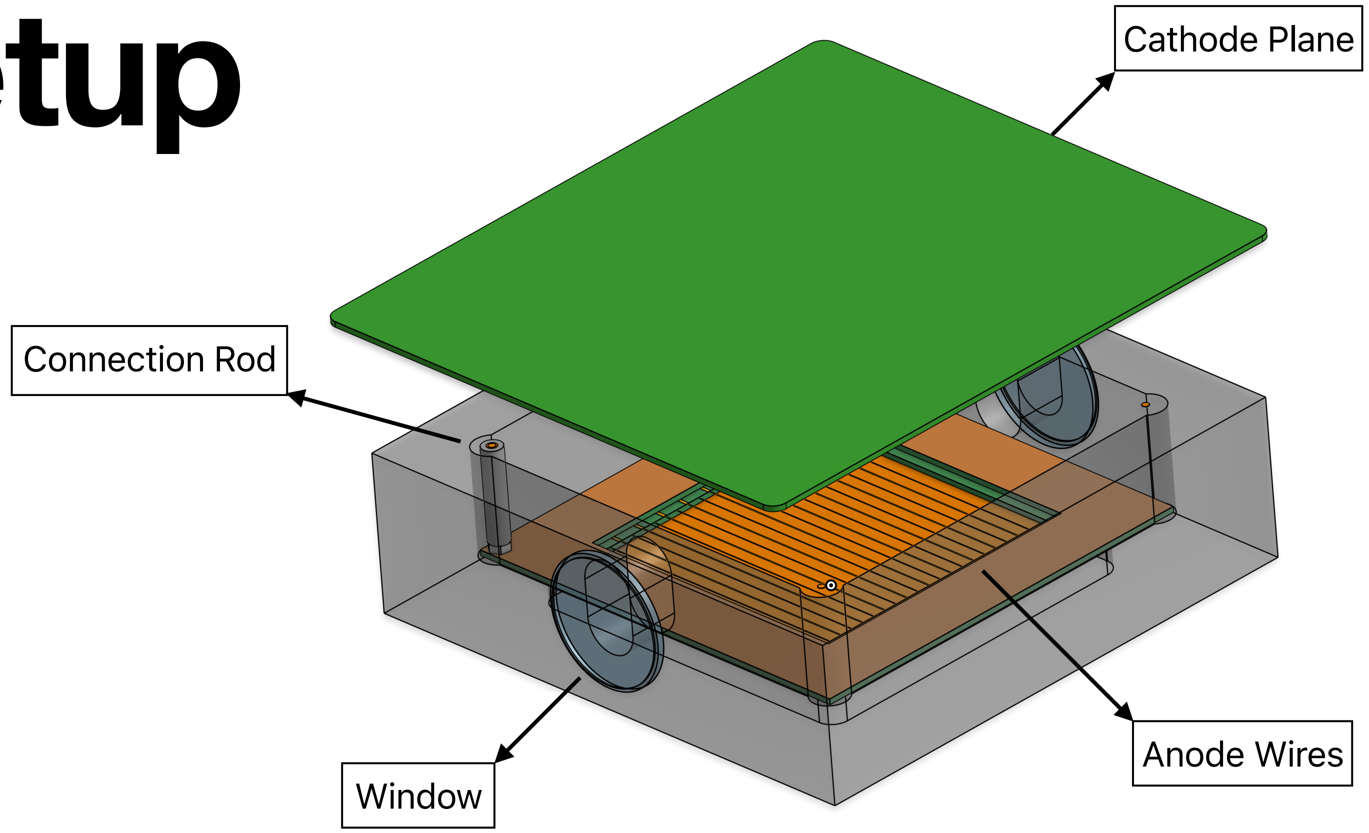
- Although we observe the impact of the attachment on our data, the signals are still large enough for our hit reconstruction
    - ~6 less attachment compared to the “untuned” Garfield results
    - no significant inefficiency ascribed to the attachment

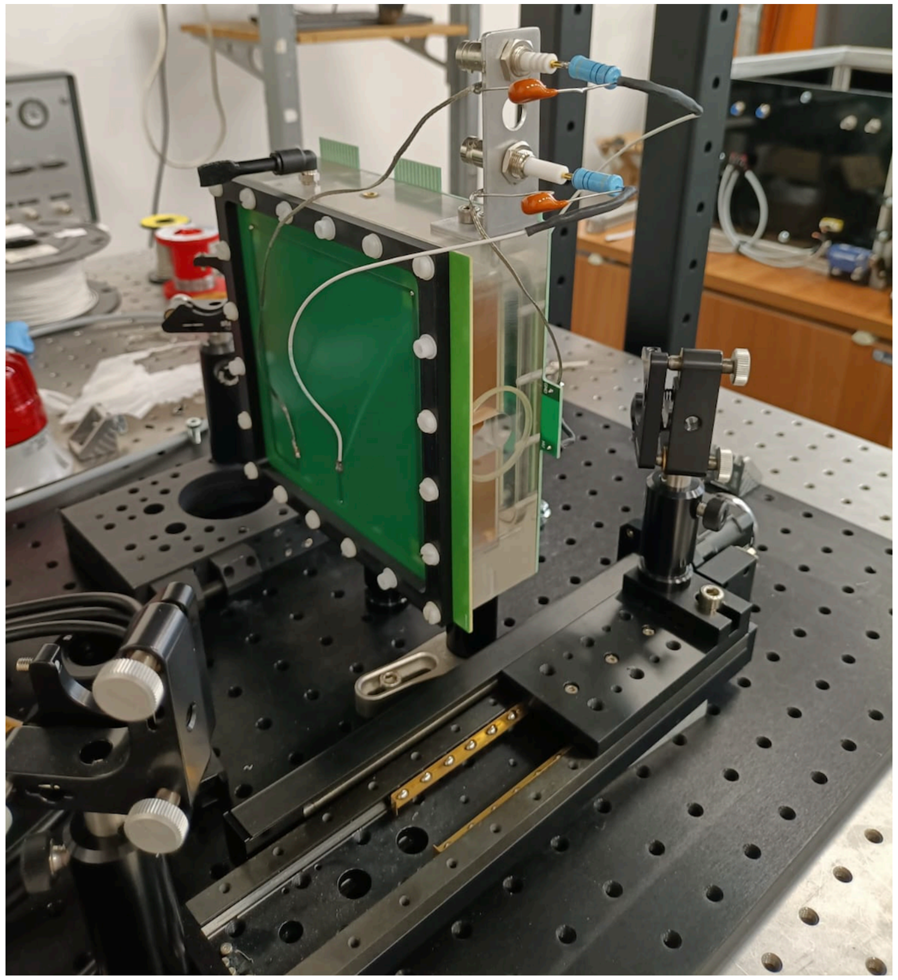


- To definitely asses the situation, we decided to perform an **experimental measurement of the attachment in the MEG II CDCH gas mixture**

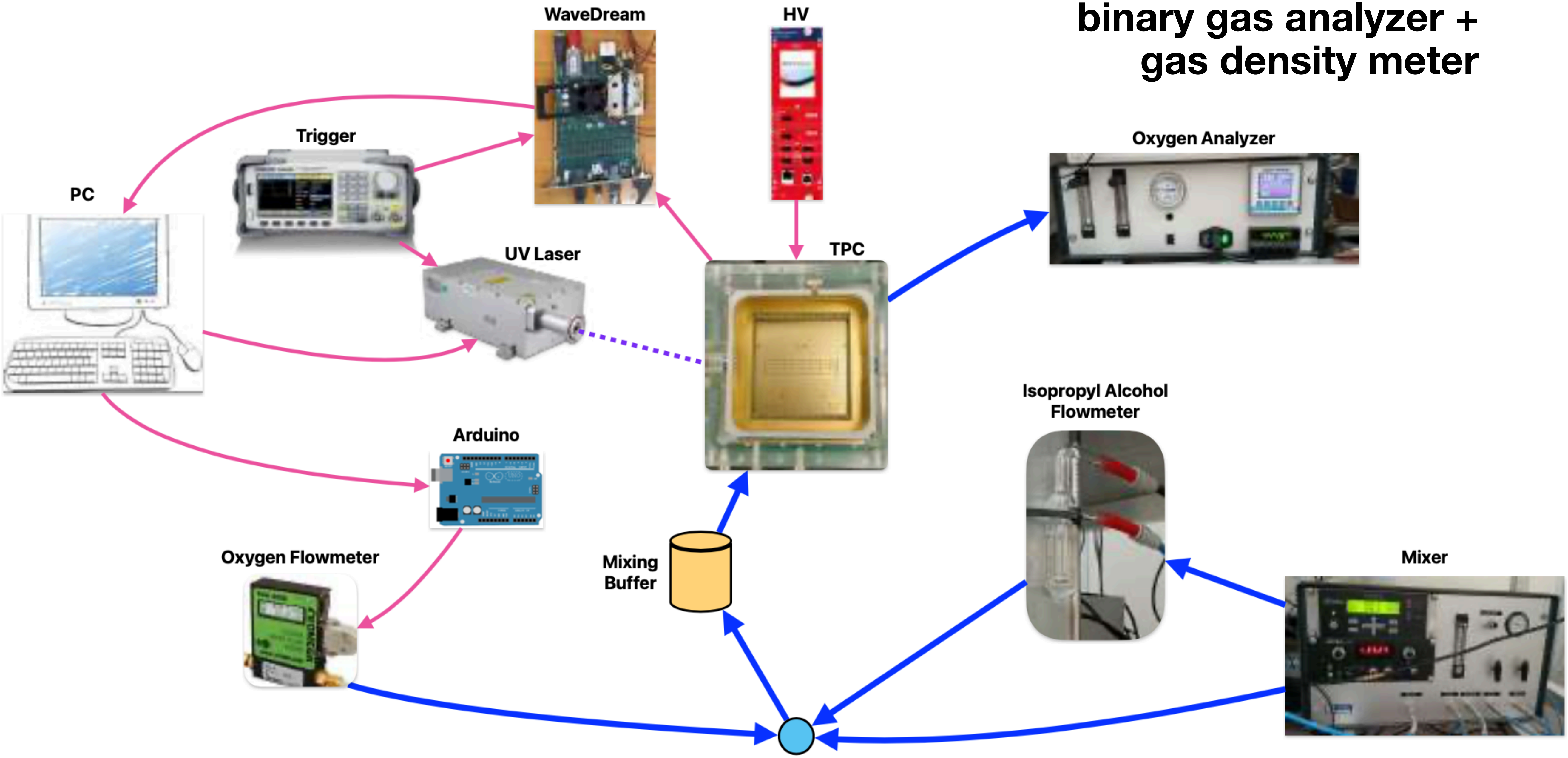
Experimental setup

- Small TPC with:
  - 3 cm drift
  - wire readout
  - CDCH frontend electronics
- Pulsed UV laser to produce ionization at a fixed drift distances from the readout
- Gas handling instrumentation and dedicated procedures to keep under control composition of the mixture
  - critical when operating with additives at very small concentrations





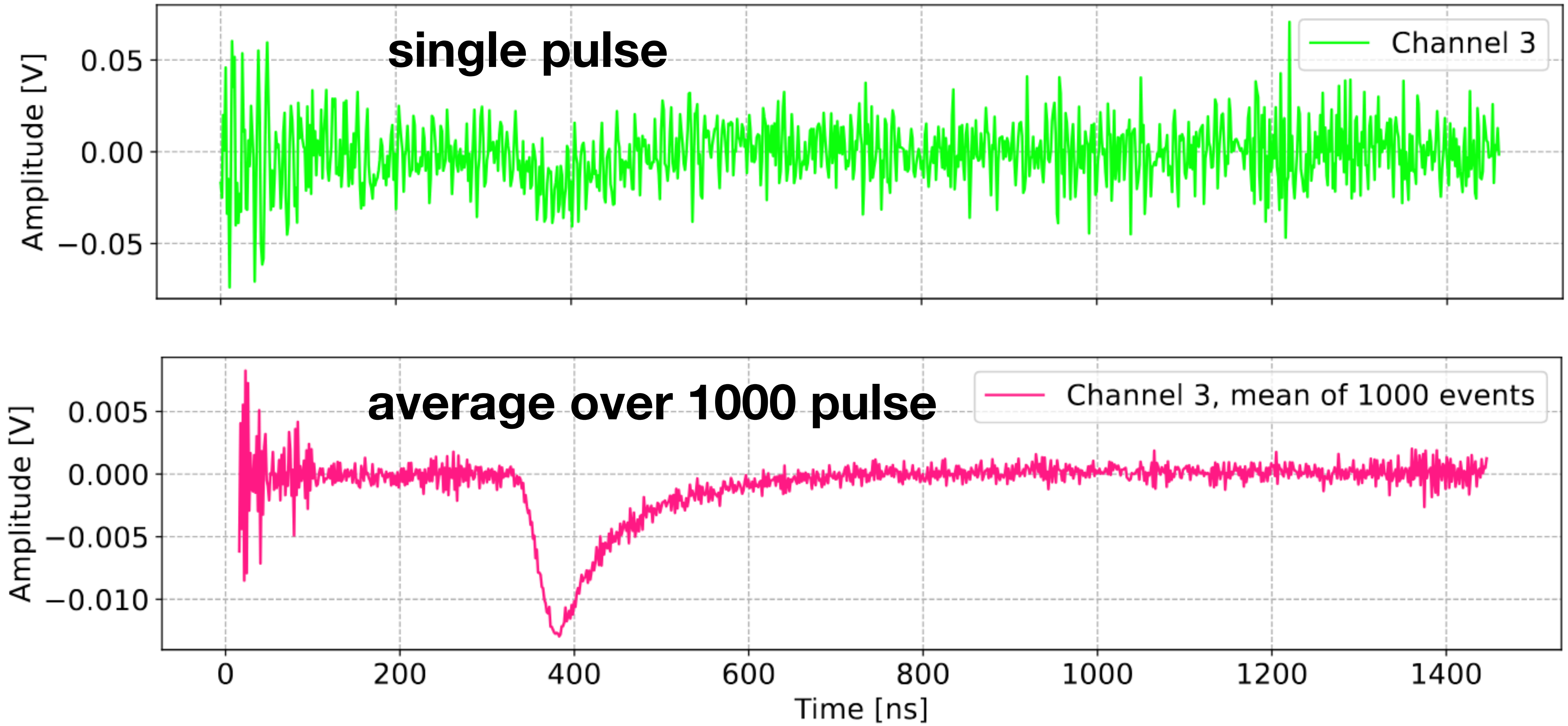
Oxygen analyzer + moisture analyzer + binary gas analyzer + gas density meter

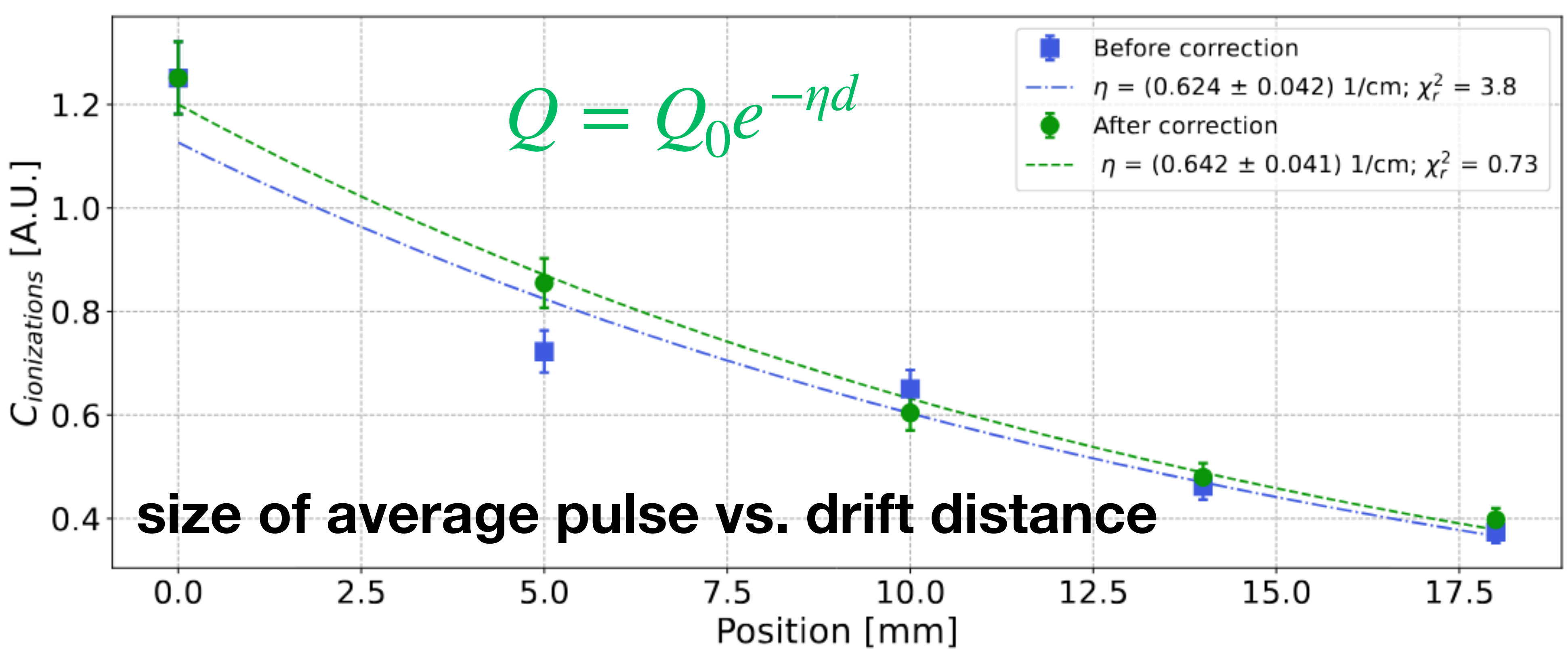


Mass flow controllers for precision gas mixing

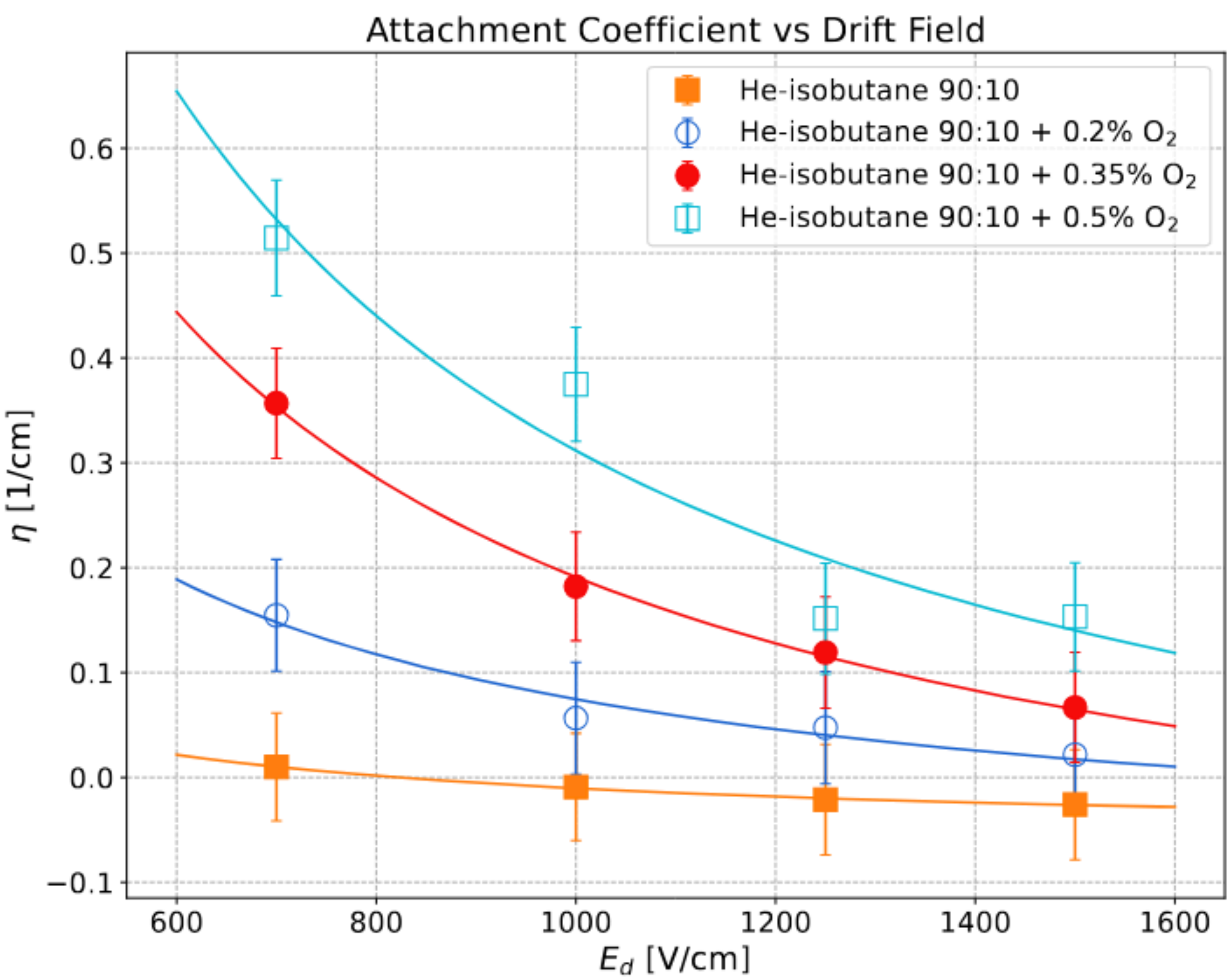
Experimental procedure

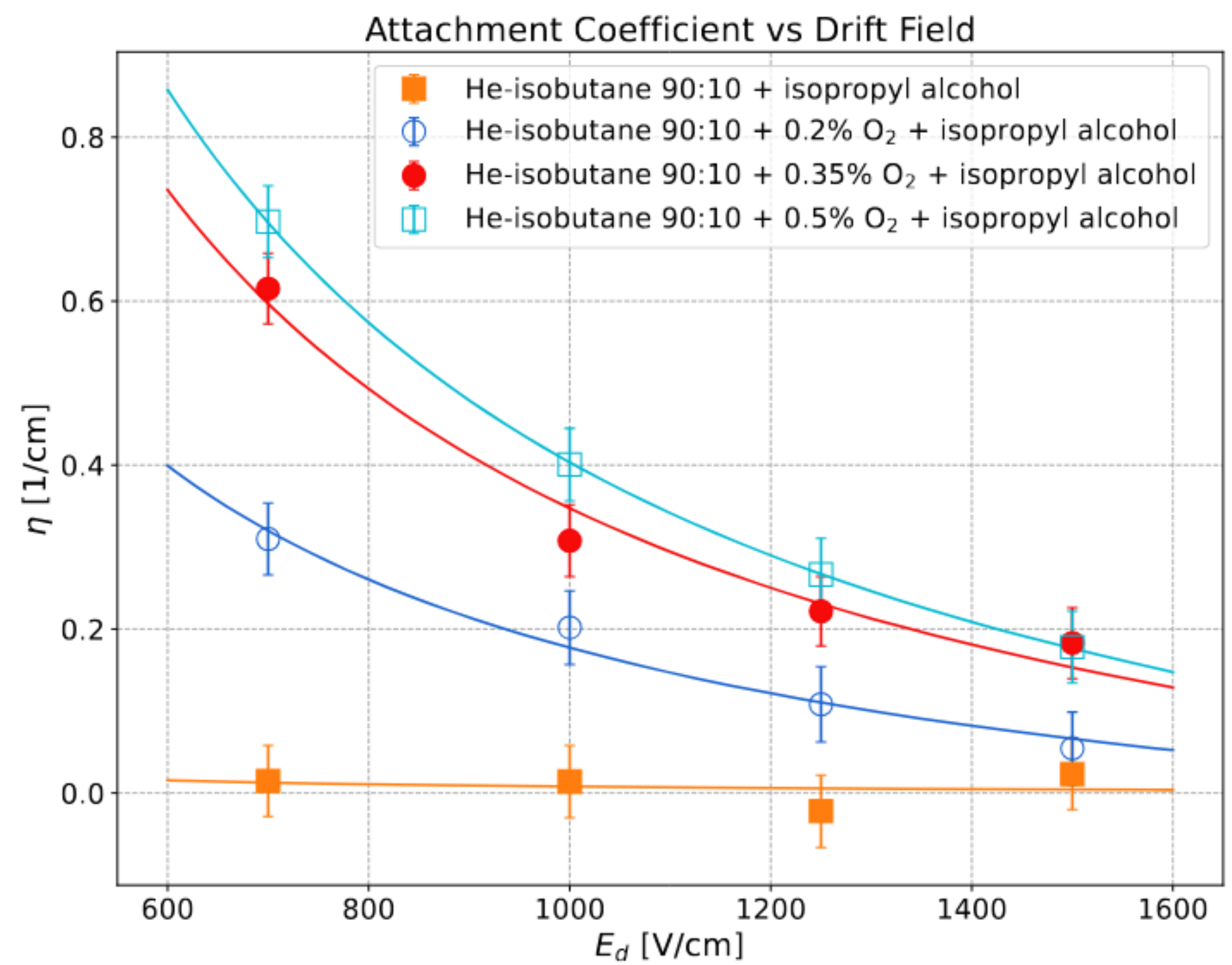
- The attachment is measured by studying the size of signals produced by a laser pulse as a function of the drift distance
- The intense laser beam (up to 100 μJ/pulse) can produce large ionization densities
    - with large signals (corresponding to dozens of ionization electrons) we observed non-linearities (saturation due to space charge)
- We need to operate with low enough gain and laser intensity to preserve the necessary linearity
    - with the MEG FE electronics and the imperfect EM shielding obtained in the lab, it results in a very small signal/noise ratio
    - countermeasures: common noise subtraction from a signal-free readout channel + analysis of average signals over O(1000) laser pulses instead of single-pulse events


single pulse
Channel 3
Amplitude [V]
0.05
0.00
−0.05
average over 1000 pulse
Channel 3, mean of 1000 events
0.005
0.000
−0.005
−0.010
0
200
400
600
800
1000
1200
1400
Time [ns]


$Q = Q_0 e^{-\eta d}$
Before correction
η = (0.624 ± 0.042) 1/cm; χ_r^2 = 3.8
After correction
η = (0.642 ± 0.041) 1/cm; χ_r^2 = 0.73
$C_{ionizations}$ [A.U.]
1.2
1.0
0.8
0.6
0.4
size of average pulse vs. drift distance
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
Position [mm]

Results





- Results in agreement with the rough expectations from MEG II data
  - ~6 less attachment compared to the untuned Garfield results
- See F. Cei talk in WG4 for a comparison with properly tuned Garfield simulations

Conclusions & Outlook

- The MEG II CDCH gas mixture, despite an unusually high oxygen concentration (0.5%), looks perfectly suitable for operating drift chambers with small (< 1 cm^2) drift cells

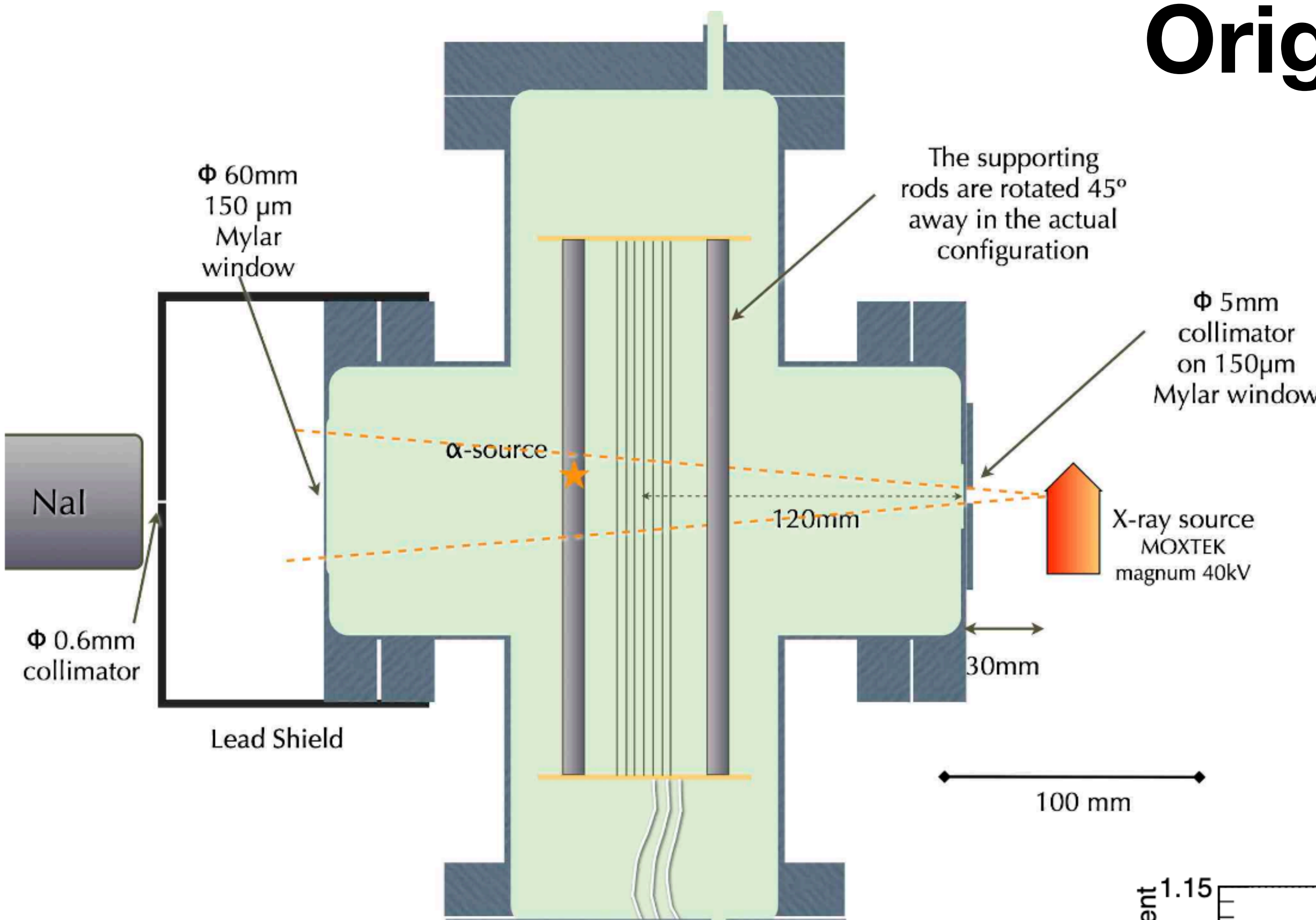
- Dedicated experimental measurements of the attachment in this mixture confirm the semi-quantitative observations made in the MEG II CDCH **- paper in preparation**

- After 4 years of run, no sign of aging in the detector

We are preparing a replica of the aging tests performed in the past, to see if the new mixture shows indeed an unusual anti-aging performance

- Our results could be of high relevance for both current (Belle II) and future (IDEA at FCC-ee) experiments using drift chambers for central tracking

Original aging test setup



X-rays from a 40 kV source on a single-cell prototype