Studying the Impact of Humidity on the Performance of MPGDs

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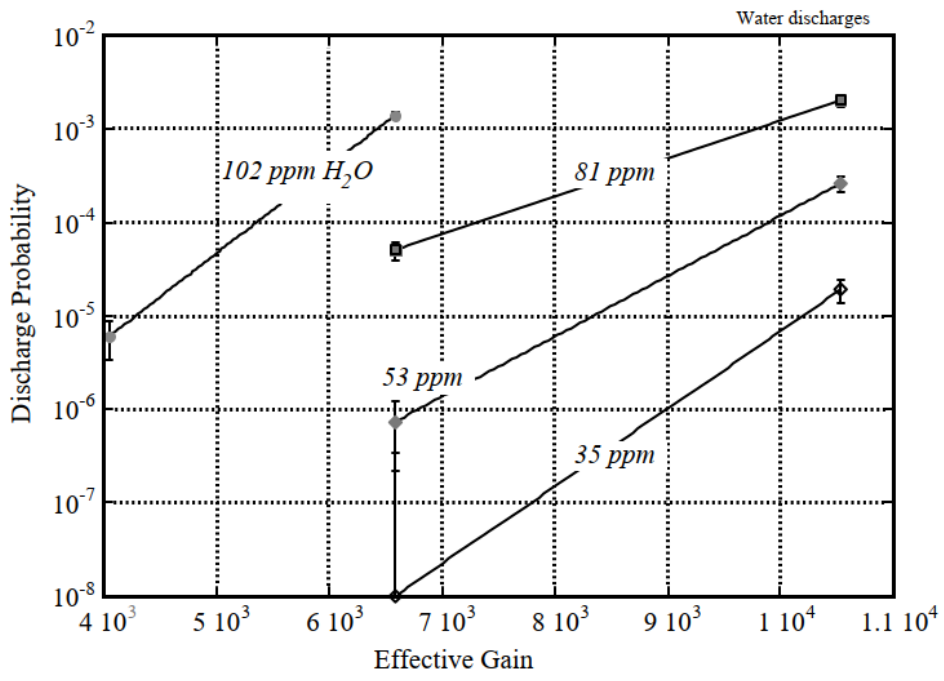
Humidity in MPGDs

- H_2O in gas is usually regarded as an unwanted contaminant
- Humidity in the gas can be favorable for the detector to, for example:
  - Mitigate aging effects[1]
  - Prevent glue used for detector components from drying out (e.g. ALICE TPC)
- Previous studies regarding the effects of adding humidity to the gas composition are not comprehensive
  - Especially no consensus has been reached concerning discharge stability

[1] M. Hohlmann et al. NIM-A 494 (2002) 179–193

Humidity in MPGDs

- The only (known to us) study of humidity influence on GEM stability in [F. Sauli et al. NIM-A 490 (2002) 177–203]
- Double GEM, Rn (gaseous) alpha source
- Detector in a nitrogen-filled plastic bag wrapper
- Water content varied by modifying gas in the wrapper or by extension of plastic tubing
- Dependency on humidity level observed
  - Origin of the effect unknown
  - Operational conditions should be strictly monitored



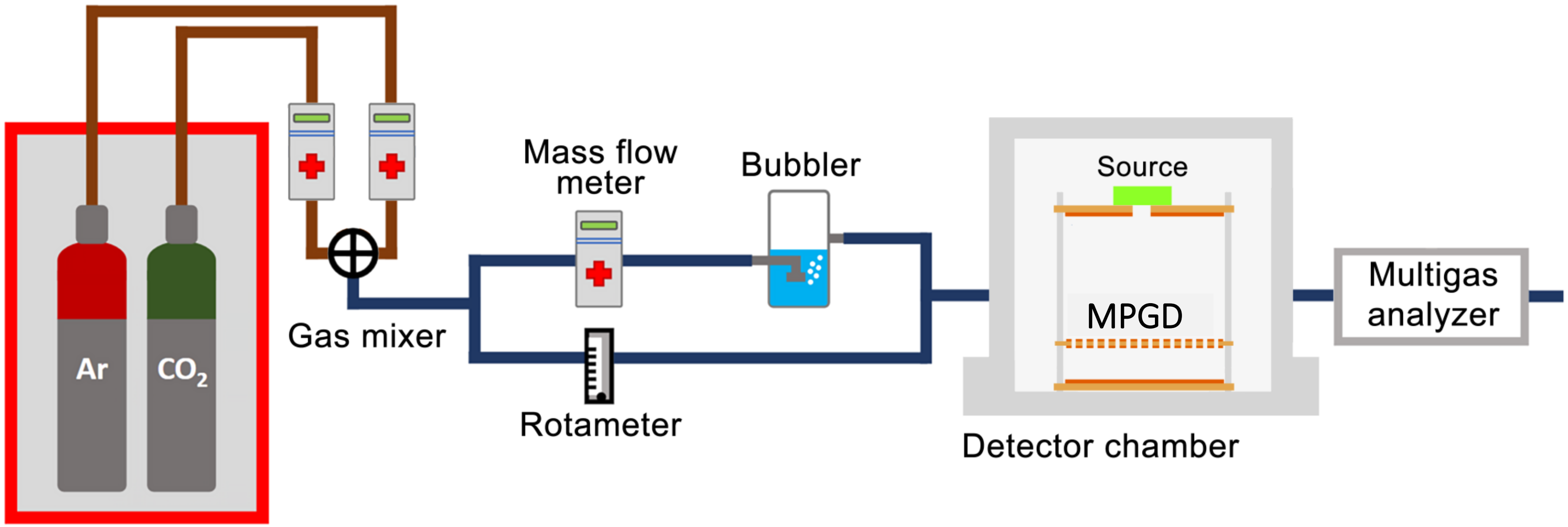
Humidity in MPGDs

"In terms of temperature and humidity research, these are representative: Dhali and Williams simulated the development process of nitrogen-positive flow in parallel plates [14]; Vitello simulated the development process of the negative flow of nitrogen in parallel plates [15]; Morrow and lowke simulated the development process of positive streamers in air [16]. For a uniform or slightly non-uniform field, air humidity has little effect on gap breakdown voltage [17]; for an extremely uneven field, most scholars believe that, under the influence of the electronegativity of water, the breakdown voltage increases slightly with the increase of humidity [18,19]. However, this is not entirely the case. Under some electrode structures, the breakdown voltage decreases with the increase of humidity [20,21]. Humidity has a significant effect on the discharge characteristics of an air gap under a non-uniform electric field, but there is no consistent conclusion about its influence law. Researchers at home and abroad have proposed corresponding humidity correction methods, curves and formulas [22,23] for the influence of humidity on air gap breakdown characteristics, and some have been accepted by the IEC standard [24] and by China's national standard [25]."

From the Introduction to
X. Ren et al. "Effect of Environmental Parameters on Streamer Discharge in Short Air Gap between Rod and Plate", Energies 15 (2022) 817

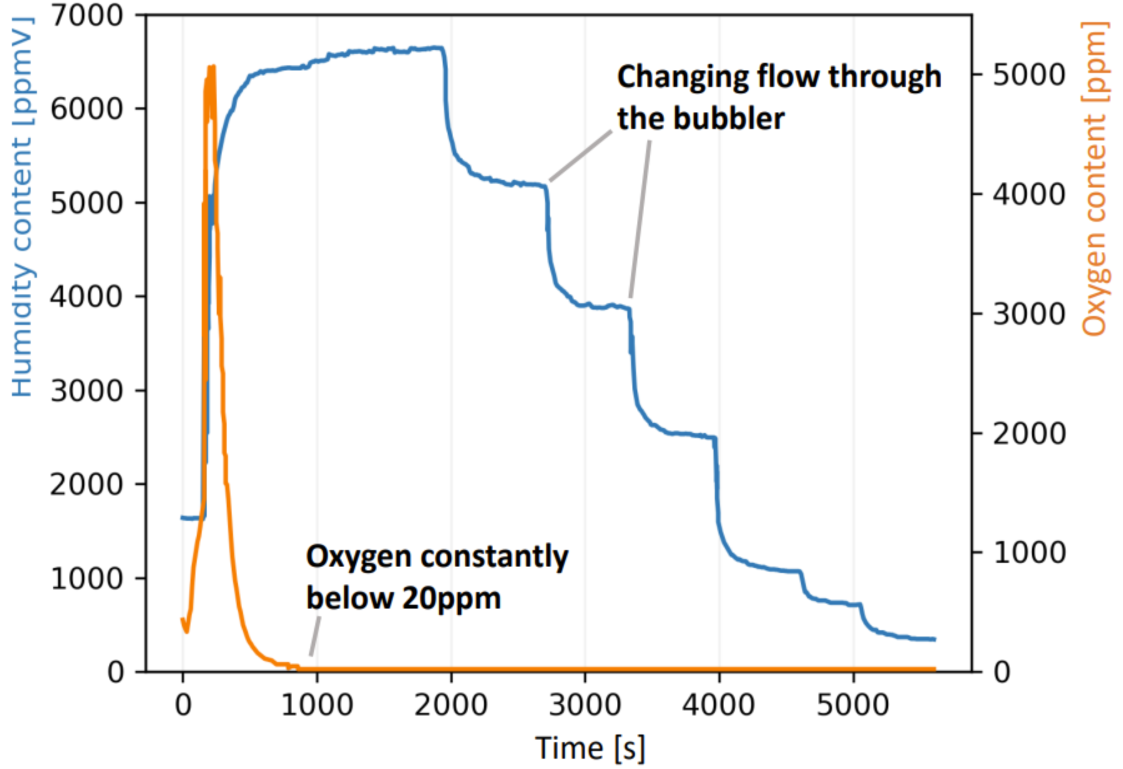
Experimental Setup

- We built a dedicated setup to introduce humidity to the gas mixture in a range of 0-4000 ppmV
- This is achieved by incorporating a water-filled bubbler* into the gas system, through which gas can be flushed at different rates

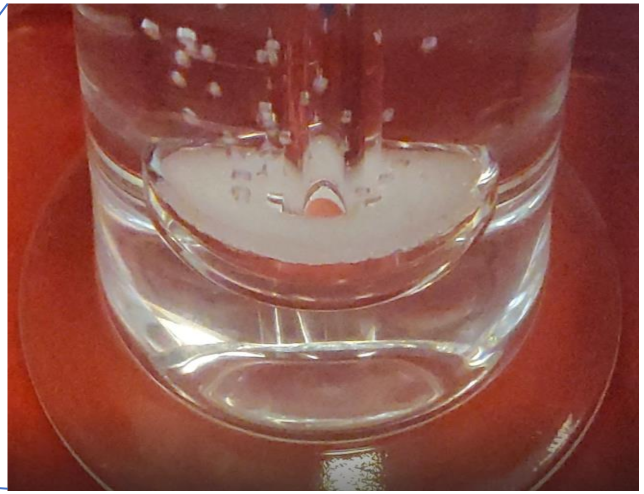


*We warmly thank Chilo Garabatos for many fruitful discussions on the gas system configuration

Experimental Setup



Test series/scan: Set a constant humidity level while keeping the oxygen content at a minimum

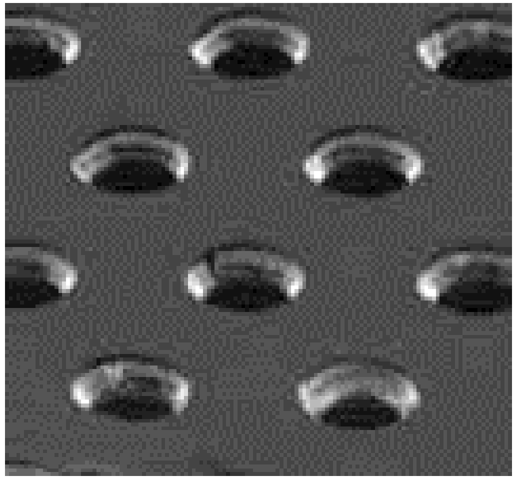


A close-up of the bubbler while flushing gas through it

Experimental Setup

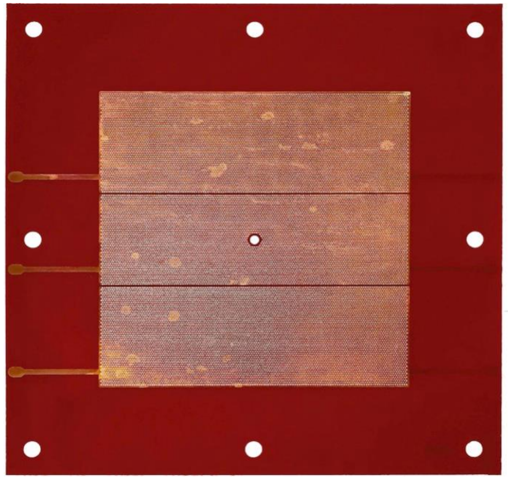
GEM

- Thickness: 60 µm
- Hole diameter: 50 µm (70 µm) inner (outer)
- Pitch: 140 µm (S), 280 µm (LP)



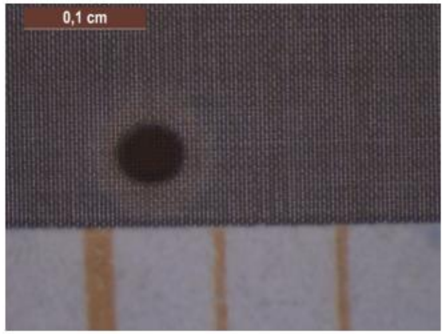
THGEM

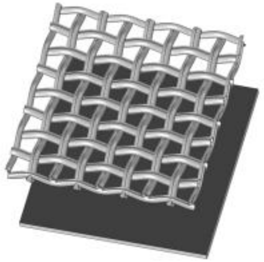
- Thickness: 470 µm
- Hole diameter: 400 µm (500 µm for edge holes)
- Pitch: 800 µm



Micromegas

- Wire distance: 22 µm
- Wire thickness: 13 µm
- Gap: 128 µm
- LPI: 730

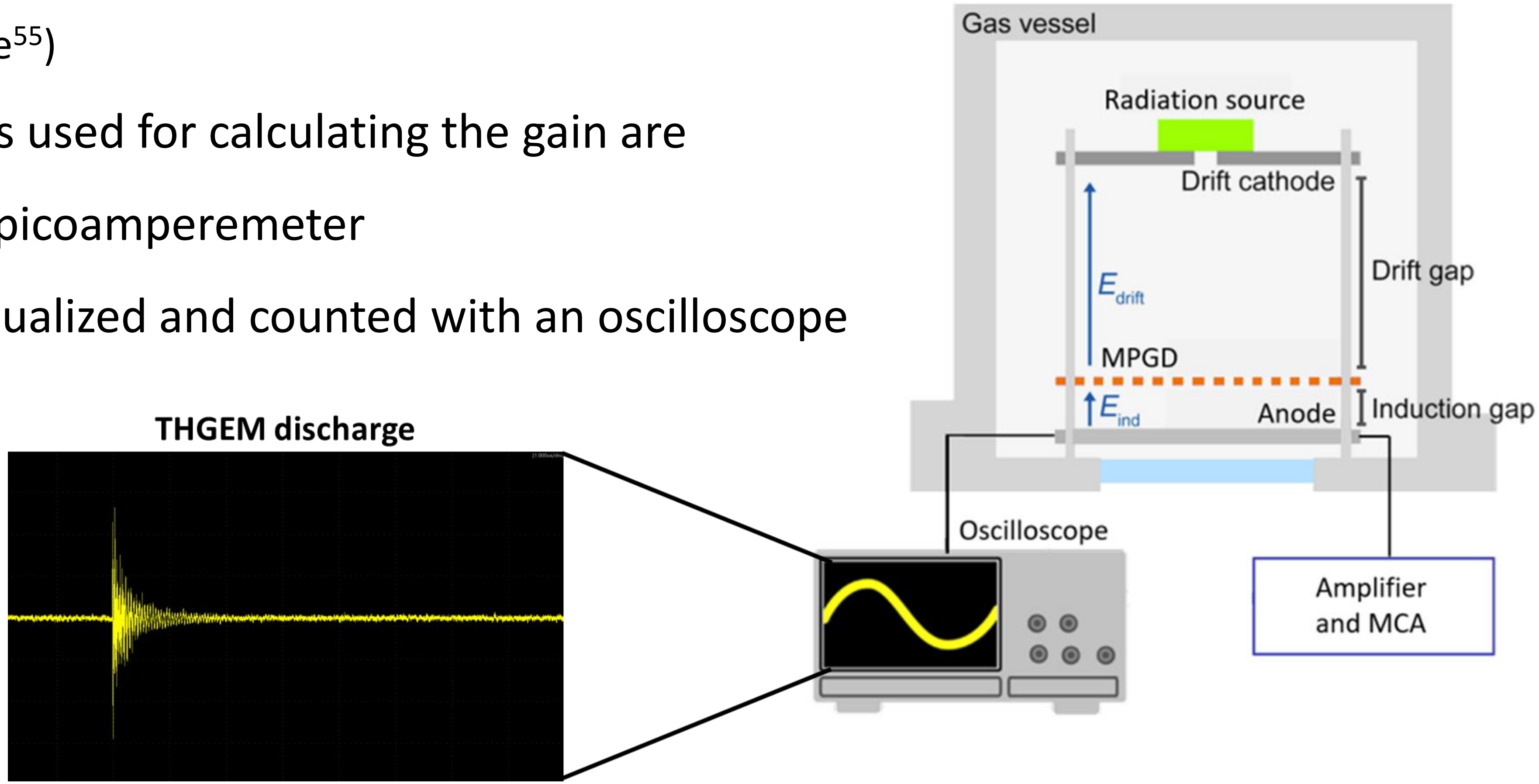




Experimental Setup

- Used sources:
  - Alpha emitter ($^{239}Pu+^{241}Am+^{244}Cm$)

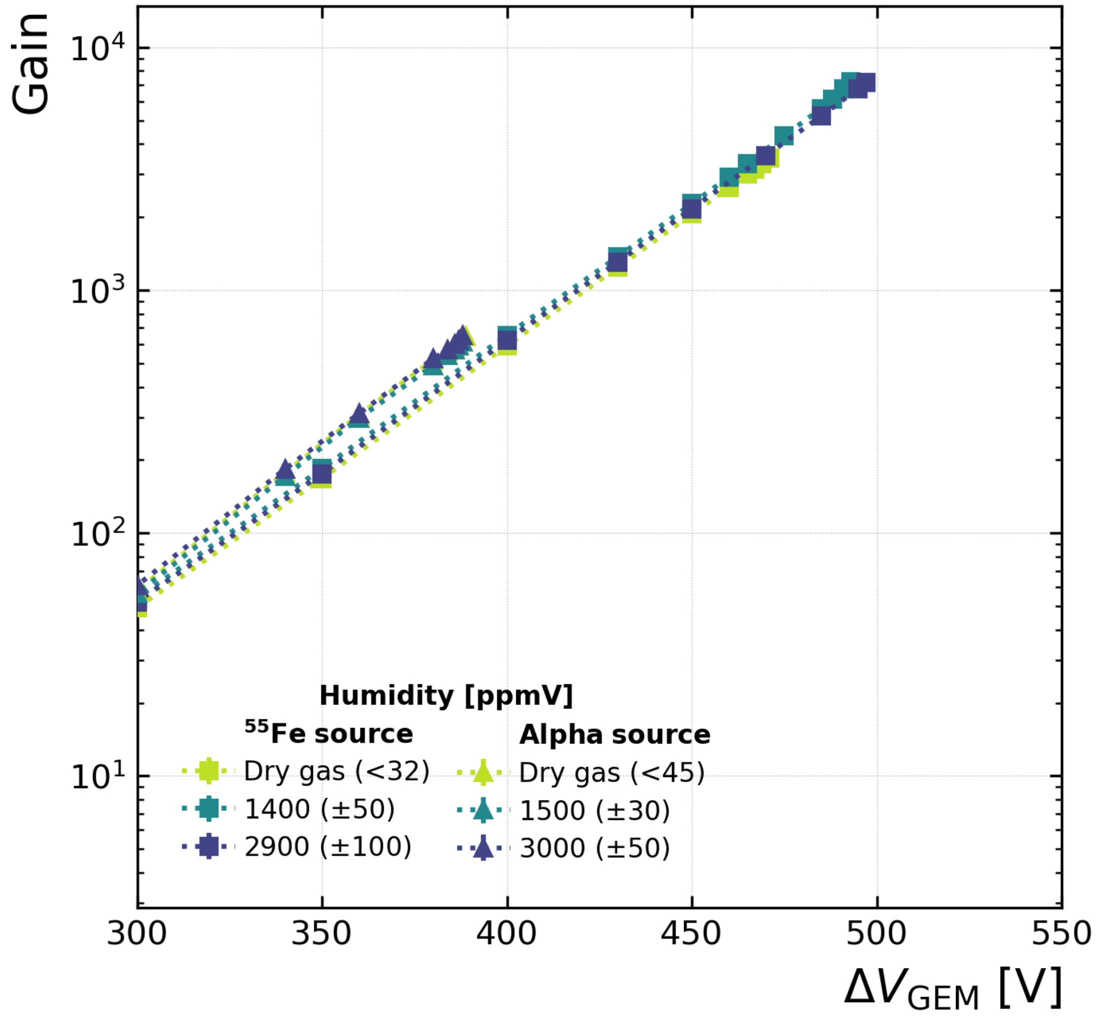
    Drift distance chosen to have Bragg peak close to the MPGD
  - X-Ray source (Fe^{55})
- Electrode currents used for calculating the gain are measured with a picoamperemeter
- Discharges are visualized and counted with an oscilloscope



Gain studies

- We measure the absolute gain as a function of the amplification voltage
- Gain = $I_{GEMbottom}/I_{primary}$
- No influence of humidity on the gain is observed → Townsend coefficient not affected

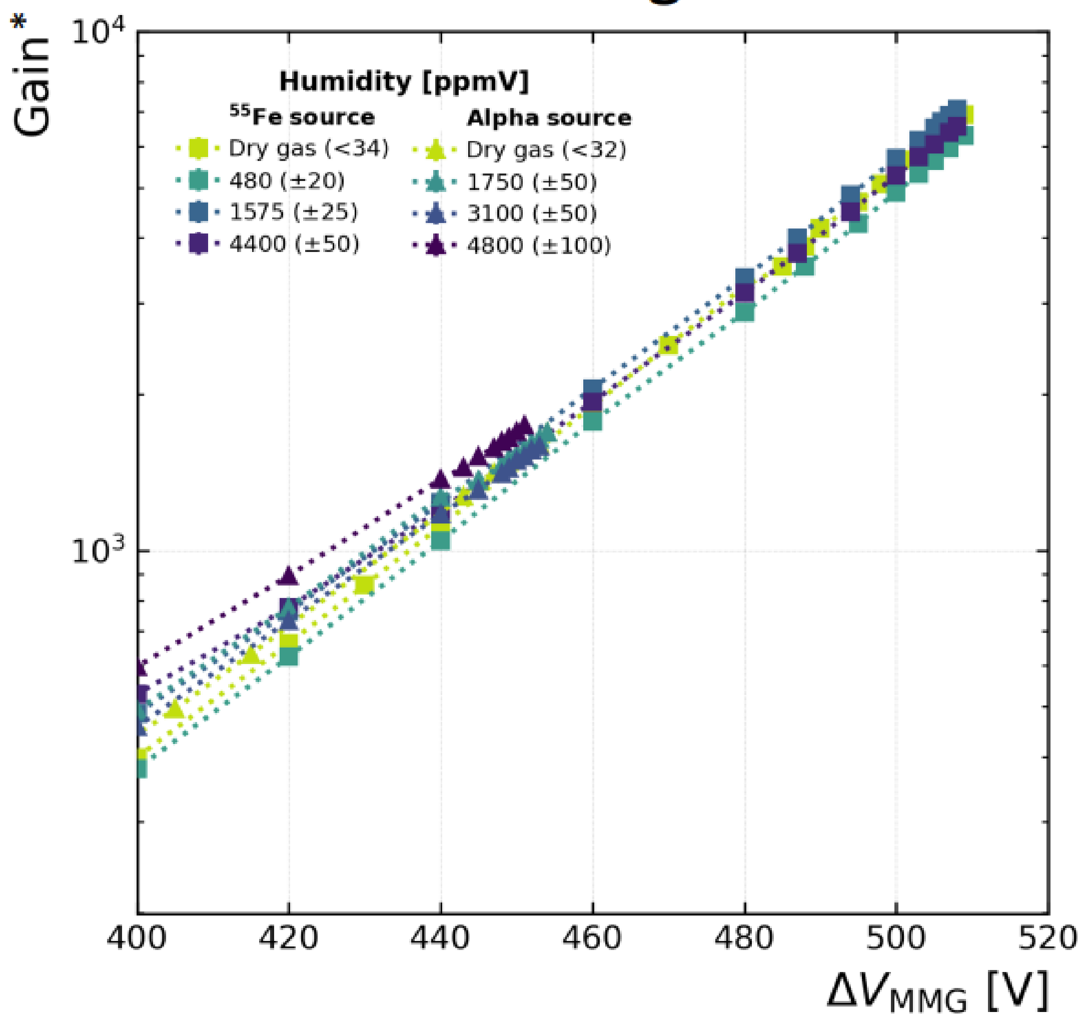
GEM(S)



Gain studies

- We measure the absolute gain as a function of the amplification voltage
- Gain = $I_{anode,readout}/I_{primary}$
- No influence of humidity on the gain is observed → Townsend coefficient not affected

Micromegas



*Gain corrected for electron transparency for the used drift field settings

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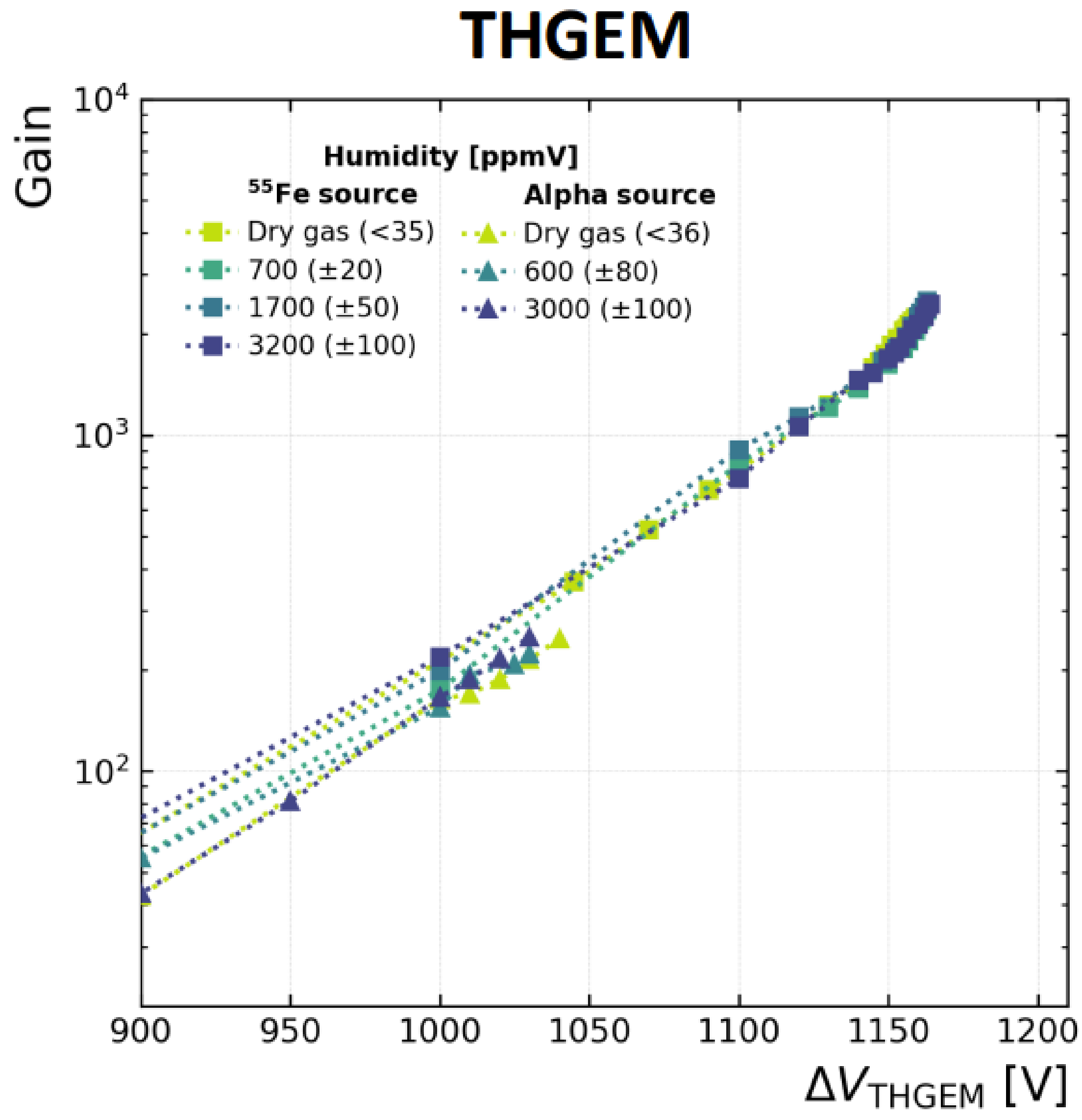

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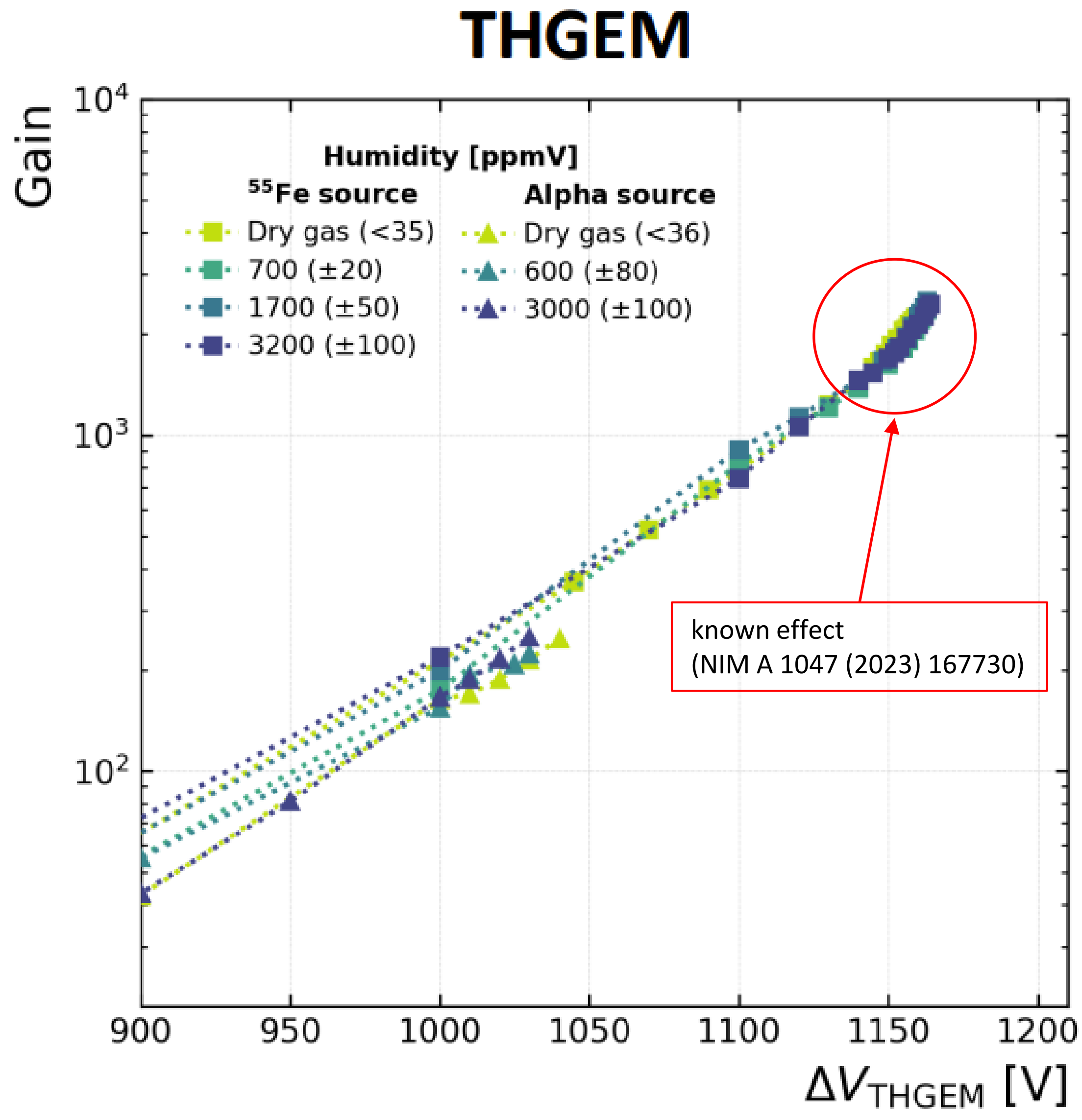


Other performance criteria

- **Energy resolution:**

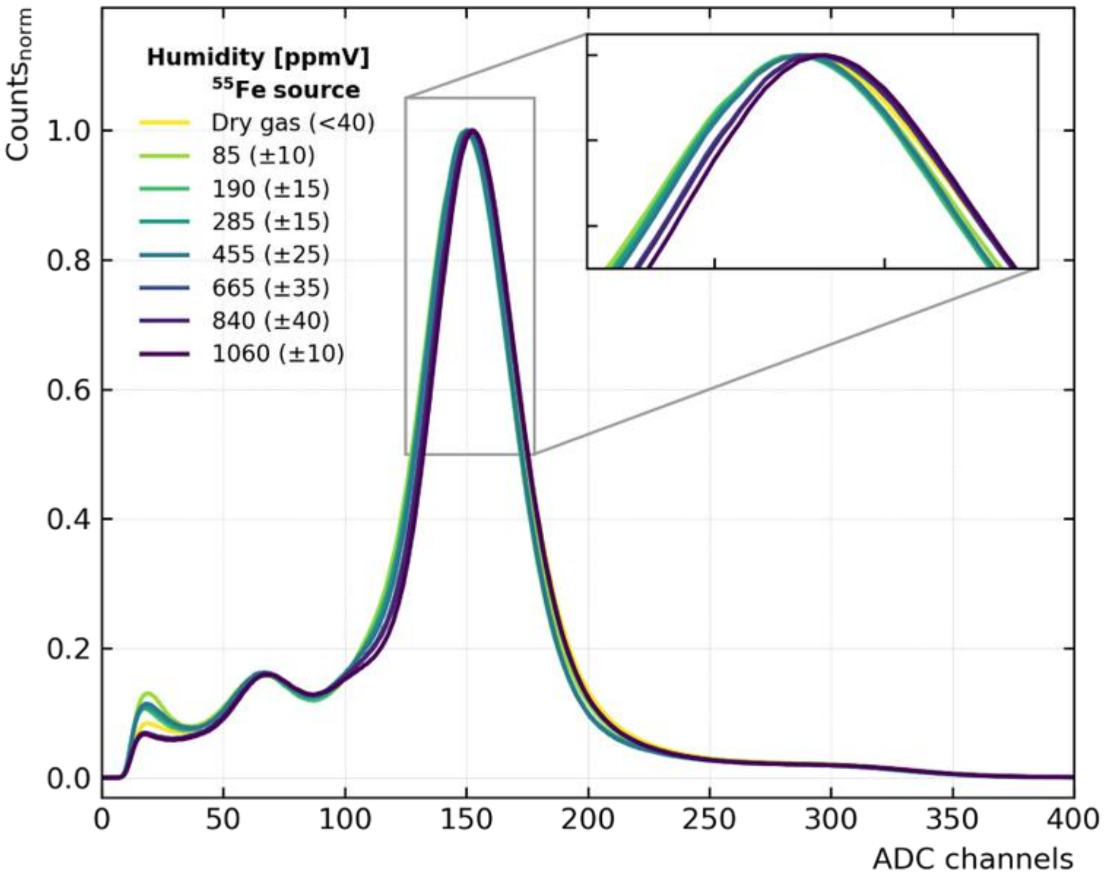
  - No significant effect of humidity on the energy resolution is observed within the given humidity range

  - Detailed evaluation of energy resolution ongoing

- **Charge-up effects:**

  No significant impact on characteristic time constants is observed for different humidity levels (similar results obtained in [1])

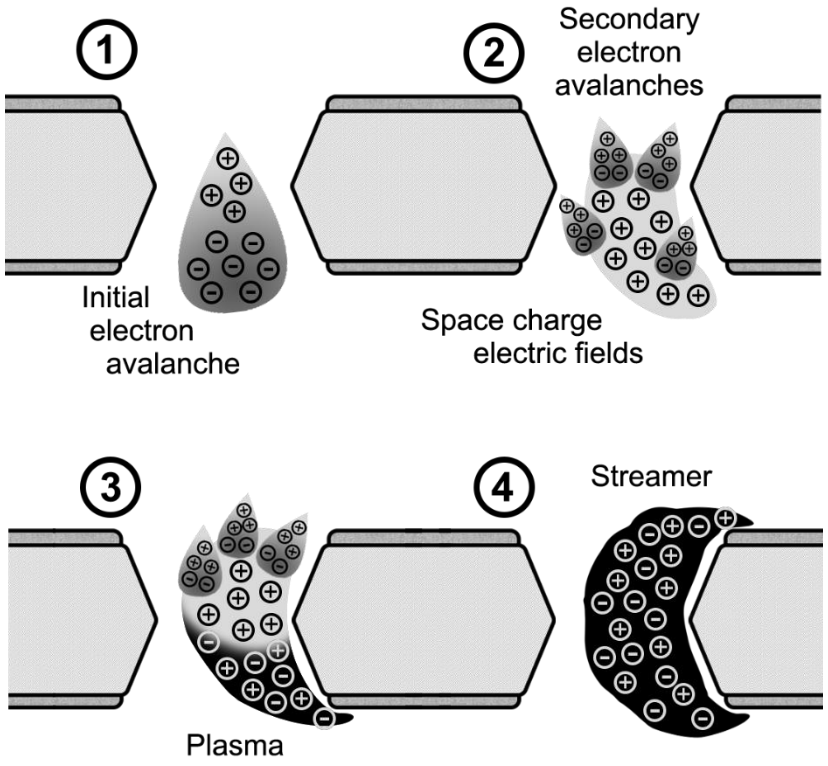
GEM Fe^{55} energy spectrum



[1] M. Shirajum, "Charging-up Behaviour of MicroPattern Gaseous Detectors", Master's thesis, University of Helsinki, 2020

Discharges in MPGDs

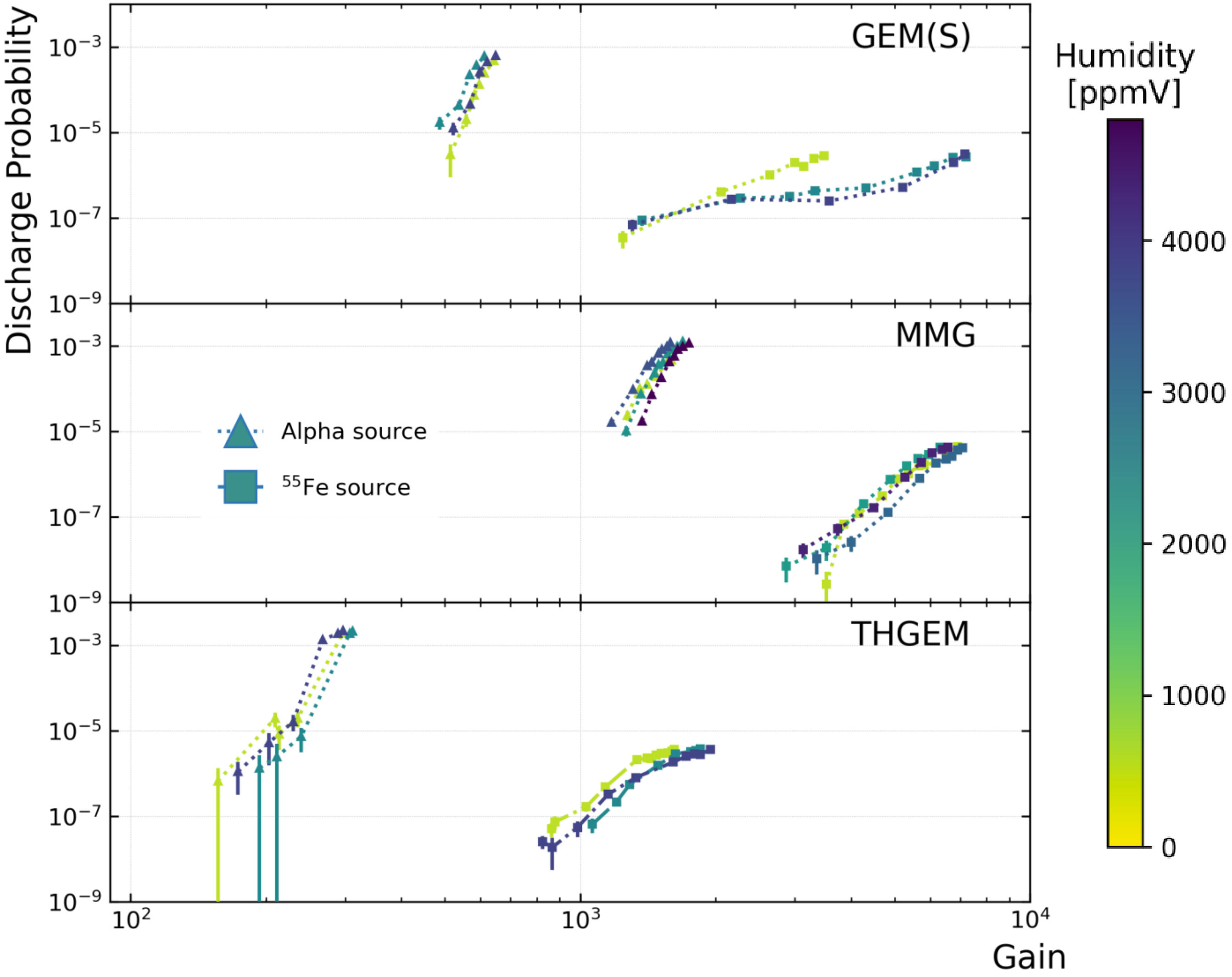
- Main source of discharges:
  - Exceeding the critical charge limit (typically 10^6-10^7 *e*) in the amplification region
  - Development of a streamer
  - Resulting in a spark between the electrodes, harmful to the detector
- Spurious discharges:
  - Appears even without the radiation source
  - Due to local field enhancement around electrode defects, sharp edges, etc.
  - These studies: only (spurious) spark discharges considered
- Influence of geometry, source, gas composition studied
  - Effect of humidity contamination inconclusive[1,2]



[1]F. Sauli et al. NIM-A 490 (2002) 177–203 [2]D. Xiao, Gas Discharge and Gas Insulation (2016)

Discharge studies

- We study the discharge probability as a function of gain
- No hierarchy observed with the alpha source
- Influence of humidity on discharge stability is only observed for the GEM operated at higher gains with the iron source



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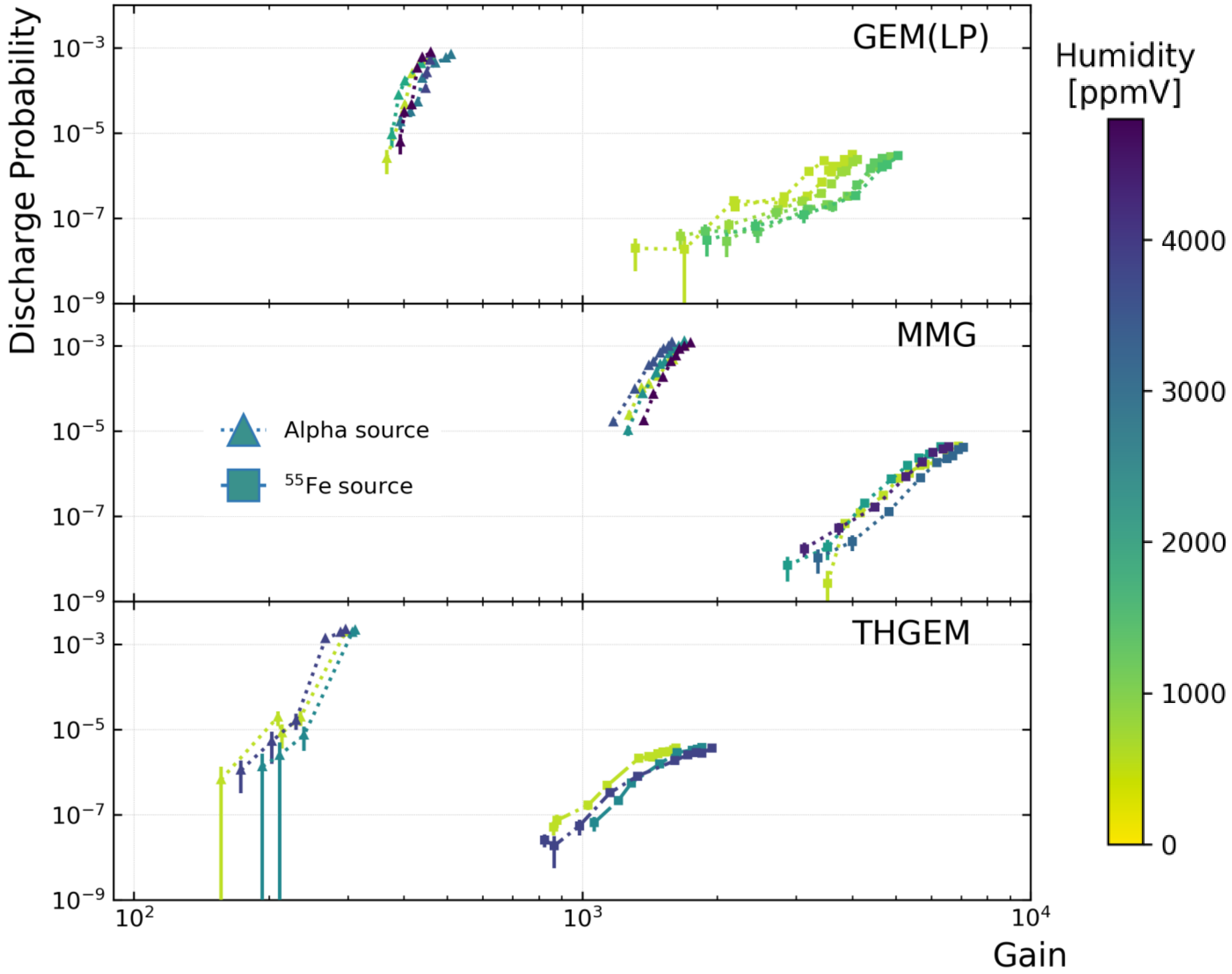
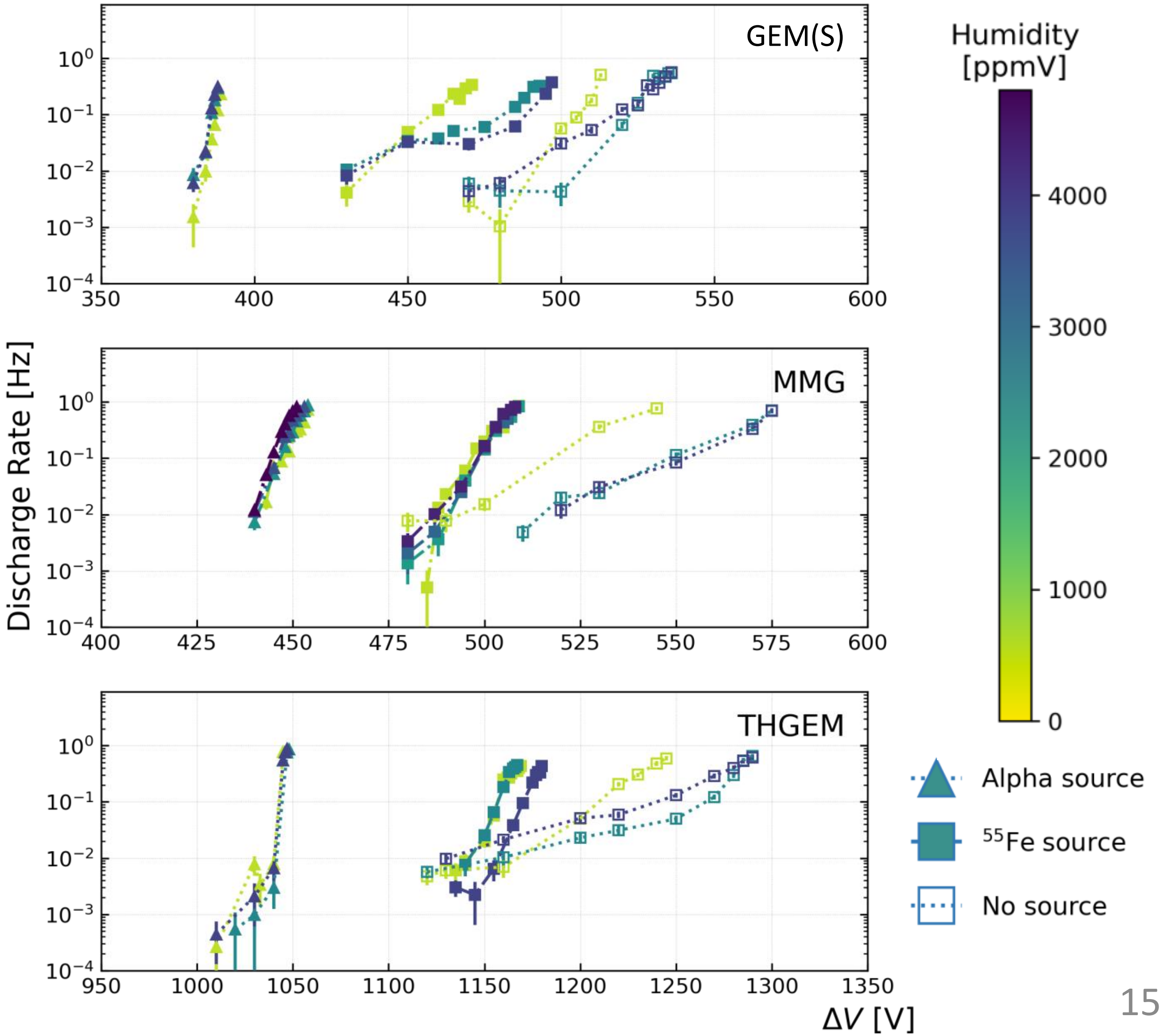


Discharge studies

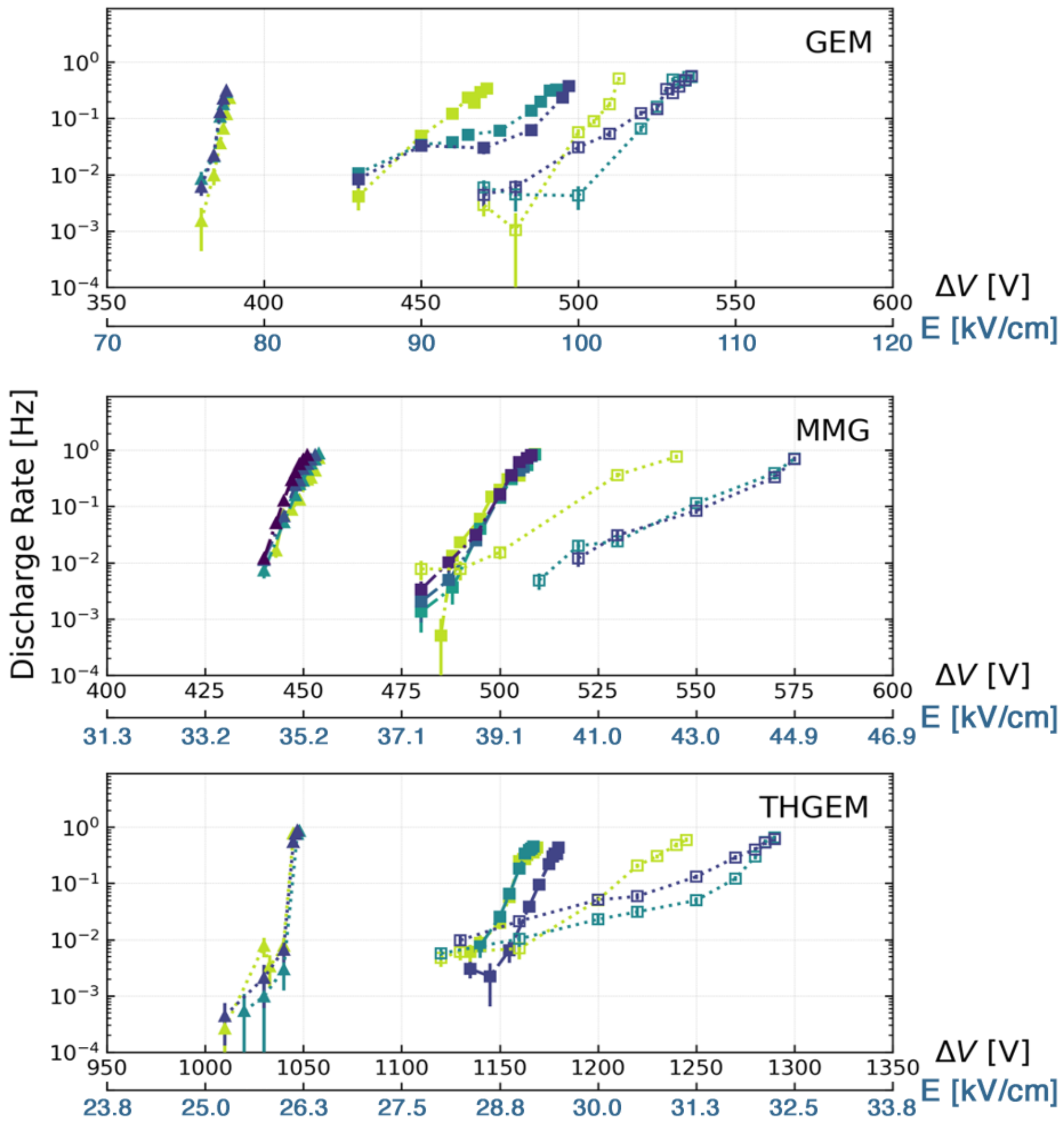
- We measure the rate of discharges without a radiation source in the detector chamber
- As expected, when operating the detector w/o a source, the discharges appear at much higher voltages/gains, where other effects play a role (defects, field emission, charge-up of insulating layers, etc.)
- We clearly observe higher discharge stability at the highest voltages when adding water vapor to the gas
- This suggests that humidity helps to reduce spurious discharges related to electrode defects or charging-up of the insulating layers



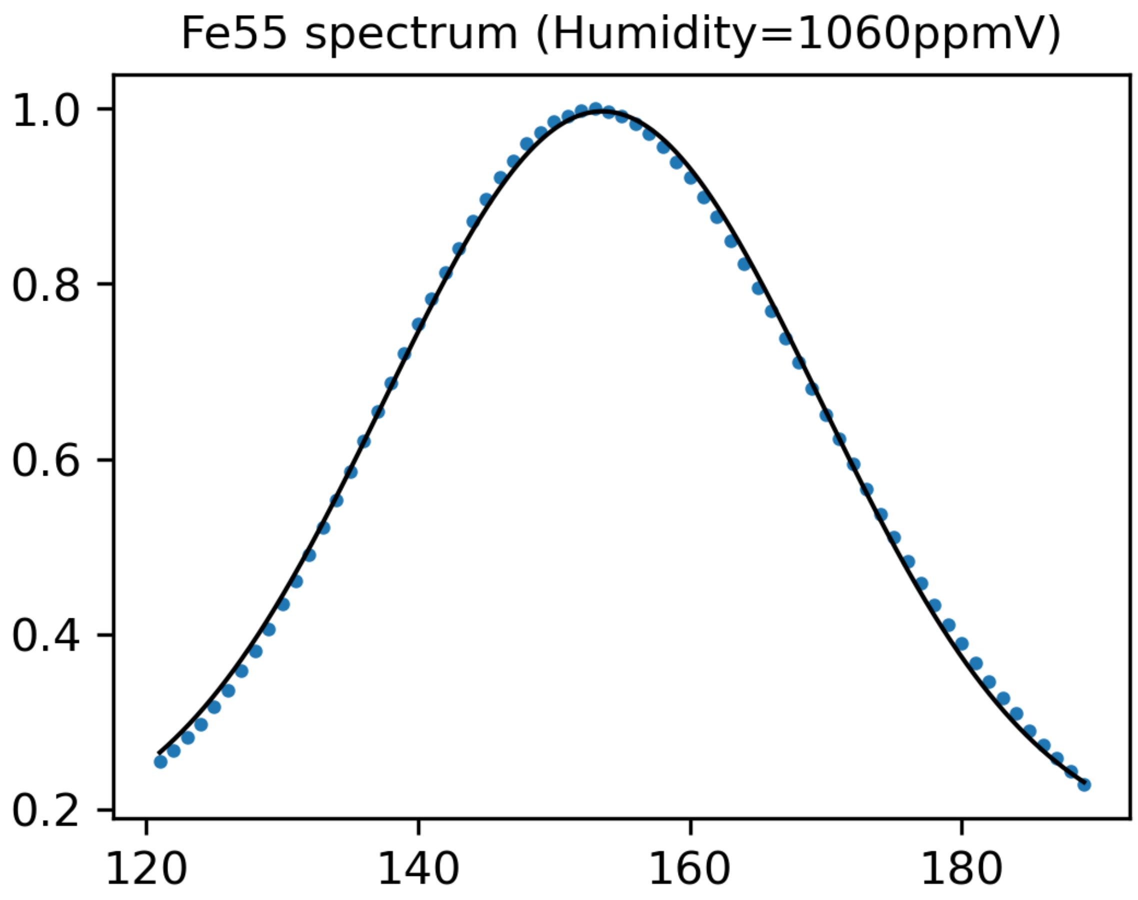
Summary & Outlook

- No deteriorating effects of humidity observed in the performance
  - In gain, energy resolution, and charge up
- Adding water vapor to the gas mixture improves the discharge stability at the highest fields
  - No influence of humidity on the critical charge limits of a given gas mixture is observed based on the alpha measurements
  - Reduction in the rate of spurious discharges related to electrode defects or charging-up of the insulating layers observed
- Further investigations with more MPGD structures ongoing
  - More comprehensive studies of effects on energy resolution and long-term charge up underway

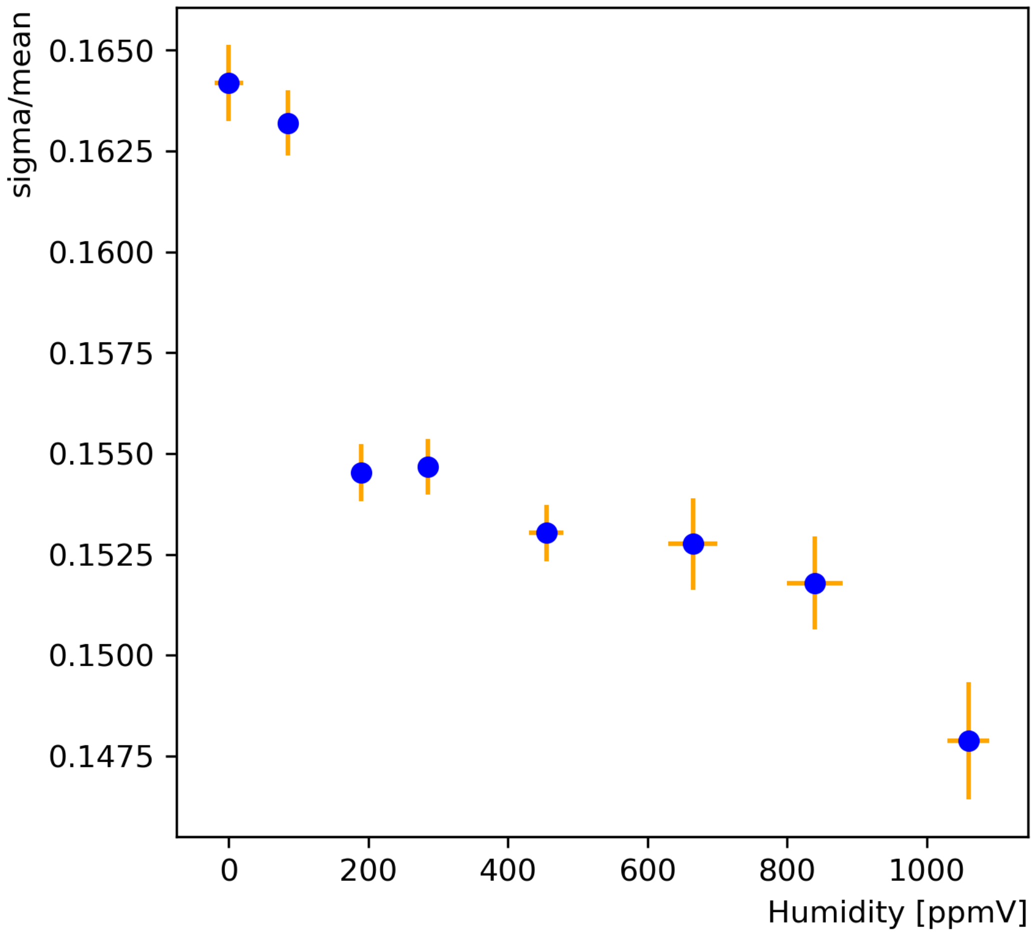
Backup



Backup

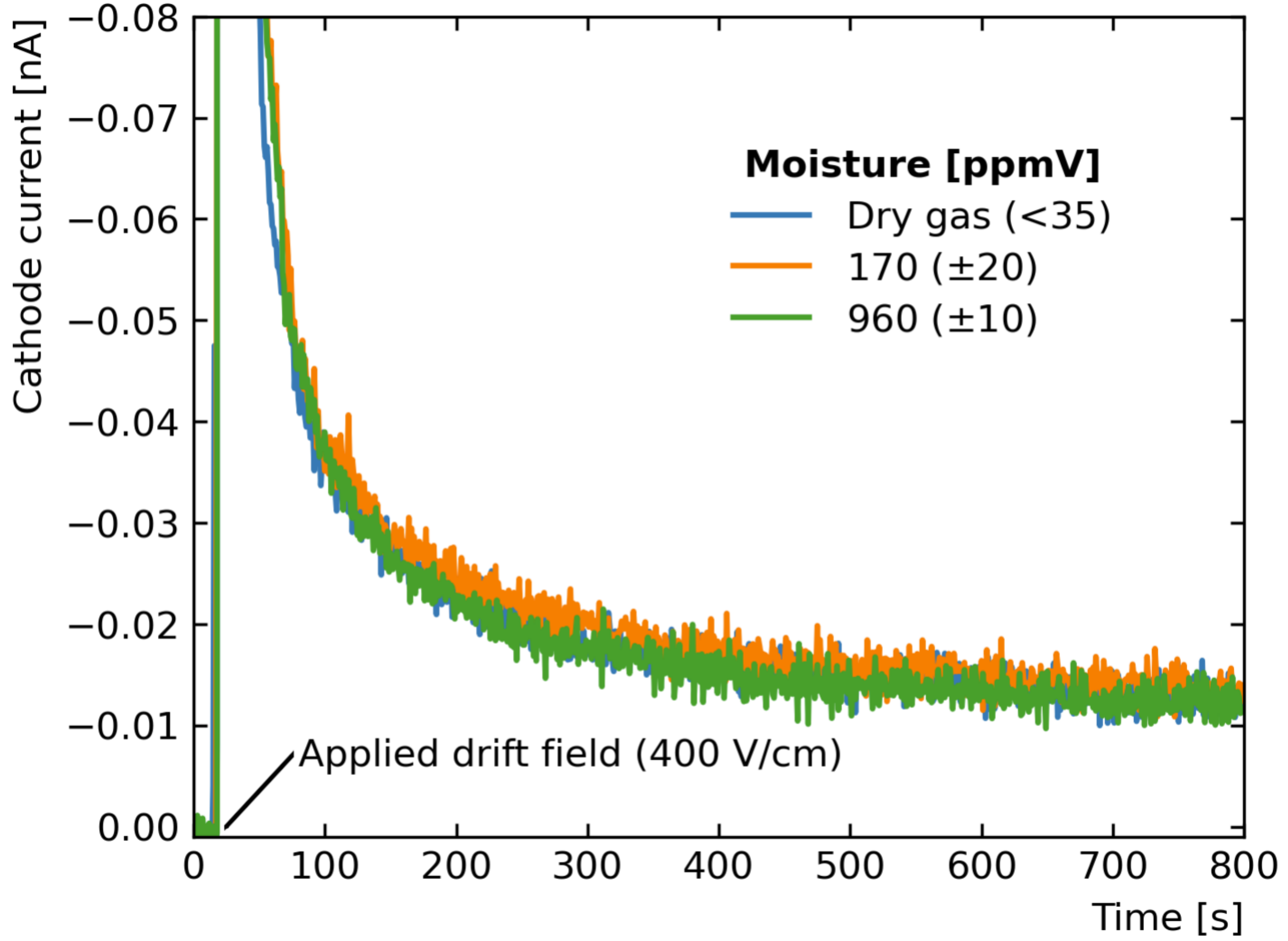

Fe55 spectrum (Humidity=1060ppmV)
1.0
0.8
0.6
0.4
0.2
120
140
160
180

Backup



sigma/mean
0.1650
0.1625
0.1600
0.1575
0.1550
0.1525
0.1500
0.1475
0
200
400
600
800
1000
Humidity [ppmV]

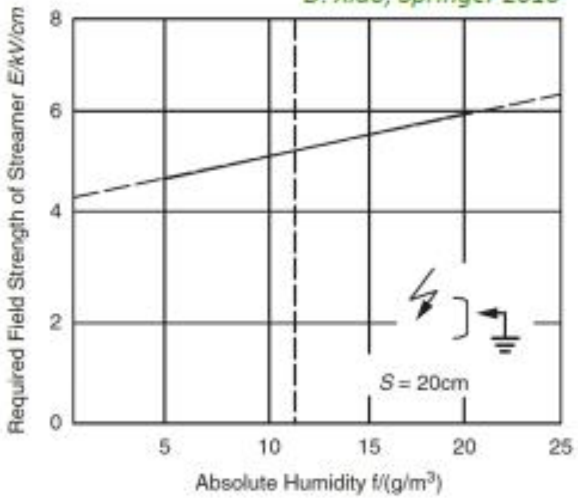
Backup


Moisture [ppmV]
Dry gas (<35)
170 (±20)
960 (±10)
Applied drift field (400 V/cm)
Cathode current [nA]
−0.08
−0.07
−0.06
−0.05
−0.04
−0.03
−0.02
−0.01
0.00
0
100
200
300
400
500
600
700
800
Time [s]

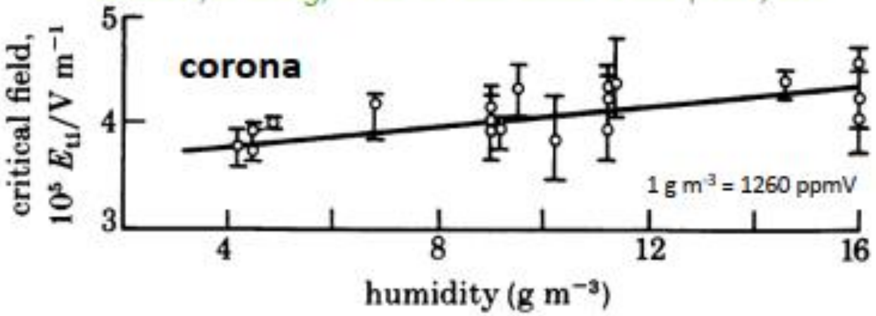
Status quo

- Recent R&D related to the Ultra HV transmission lines, and insulation of those.
- Humidity R&D related mainly to corona and streamer development in rod-plane air gaps
- Following D. Xiao, *"Gas discharge and gas insulation"*, Springer:
  - With the increase of the water content in air, the photon free path is shortened
  - No. charged particles produced in an avalanche will be reduced and the E-field of a streamer head will be weakened
  - In addition electronegative water molecules increase attachment
- Similar effects reported in other works on streamer propagation/breakdown, corona dev., etc.

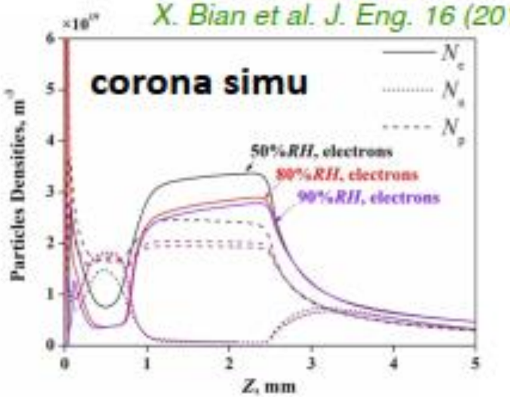
D. Xiao, Springer 2016

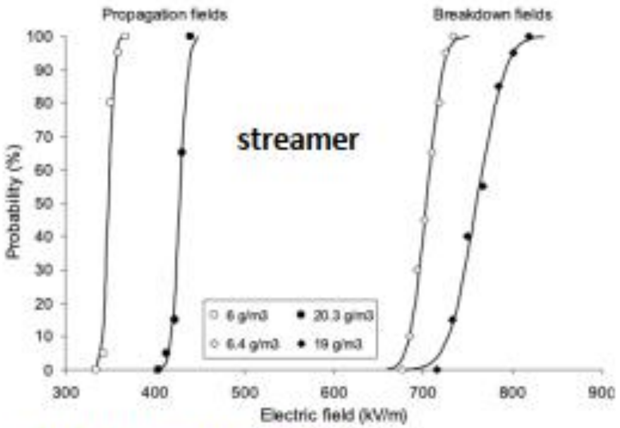


N. Allen, D. Dring, Proc. R. Soc. Lond. A 396 (1984) 281



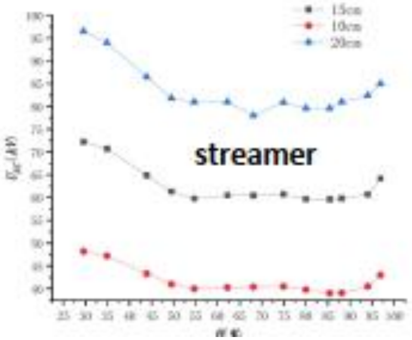
X. Bian et al. J. Eng. 16 (2019) 2869





P. N. Mikropoulos et al.
IEEE Trans. Dielectr. Electr. Insul. 15 (2008) 416

- But also opposite effects discussed



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