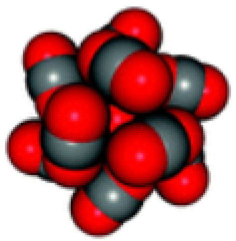
Exploring Size Variation of Ionic Clusters in Gas Detectors: A Comparative Analysis of Ar-CO_2 and Ne-CO_2 Gas Mixtures



Yalçın KALKAN

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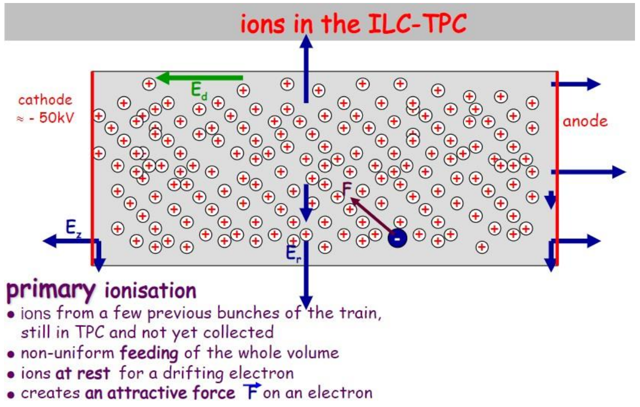
Motivation

- The ions, generated in the proportional multiplication process
- Atomic or molecular ions react with the carrier gas to form molecular ions and cluster ions.
- Measurements of ion mobility in most common used mixtures show that the ions are heavy, hence slow so signal induced the ion motion are altered.
- There they build up a space charge cloud
- Still, simulation programs still do not take ions into account.

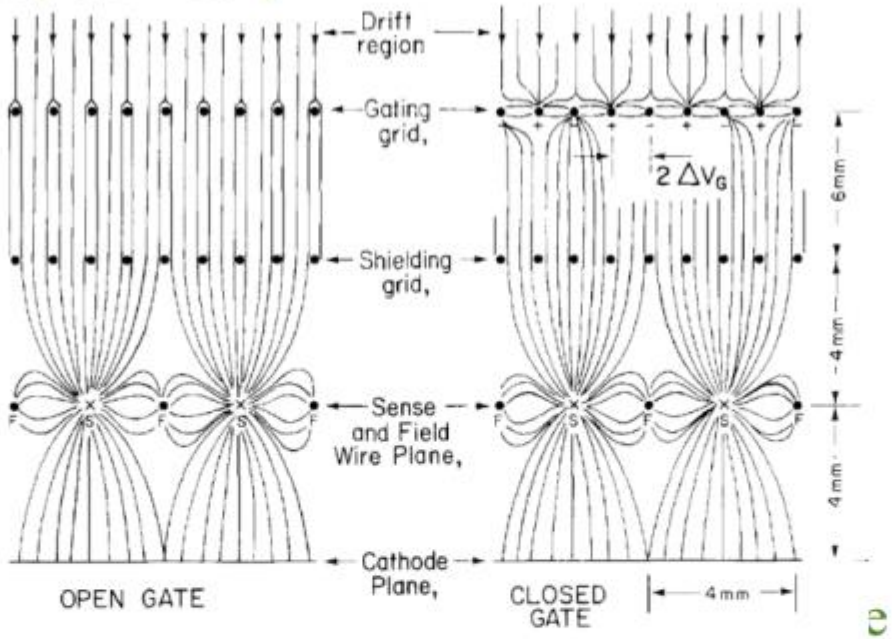


[Y. Kalkan et al, "Cluster ions in gas-based detectors", JINST 10 P07004, 2015.]
[Y. Kaya et al, "Protonated water clusters in TPC's", NIMA 824, 2016.]

Solution Attempts

- Gated TPC

[Peter Némethy et al, 1983, “Gated Time Projection Chamber”, Nuclear Instruments and Methods in Physics Research, 212, Issues 1–3,273-280.]



- The Grids

[C.K. Hargrove, “The Time Projection Chamber … e Proceedings 108, 1 (1984)]

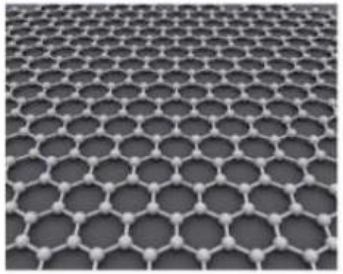
Solution Attempts

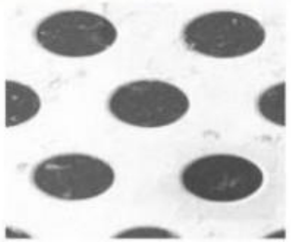
MM-THGEM with inner Graphene electrode

Franchino et al., NIMA 824 (2016) 571-574

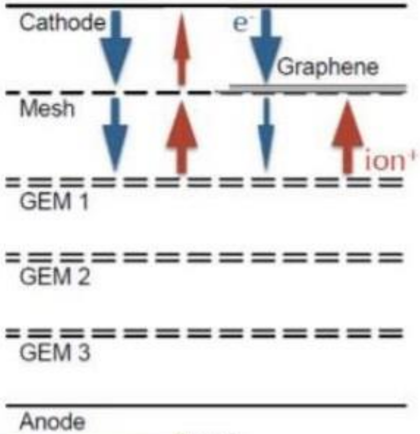
RESNATI **ION BLOCKING w GRAPHENE ON GEM**

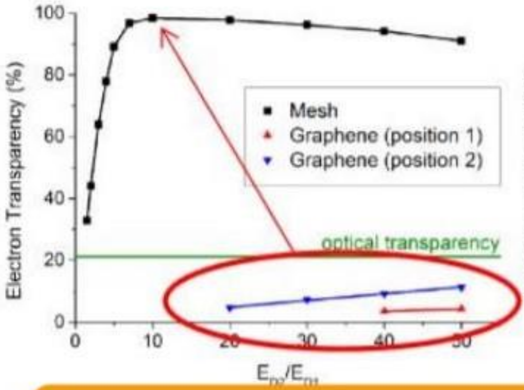
Graphene on "GEM"

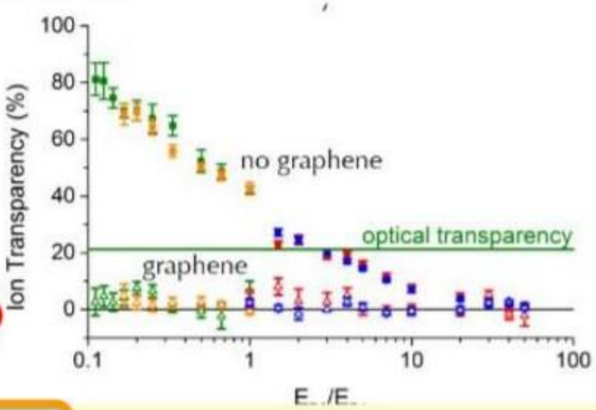


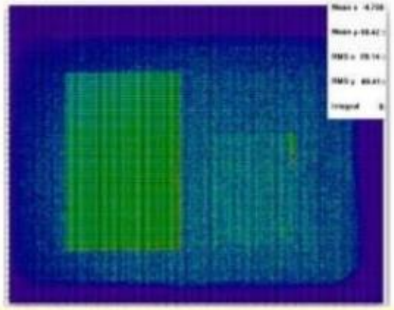


Graphene: opaque to ions and
UNDER SOME CONDITIONS:
transparent to electrons





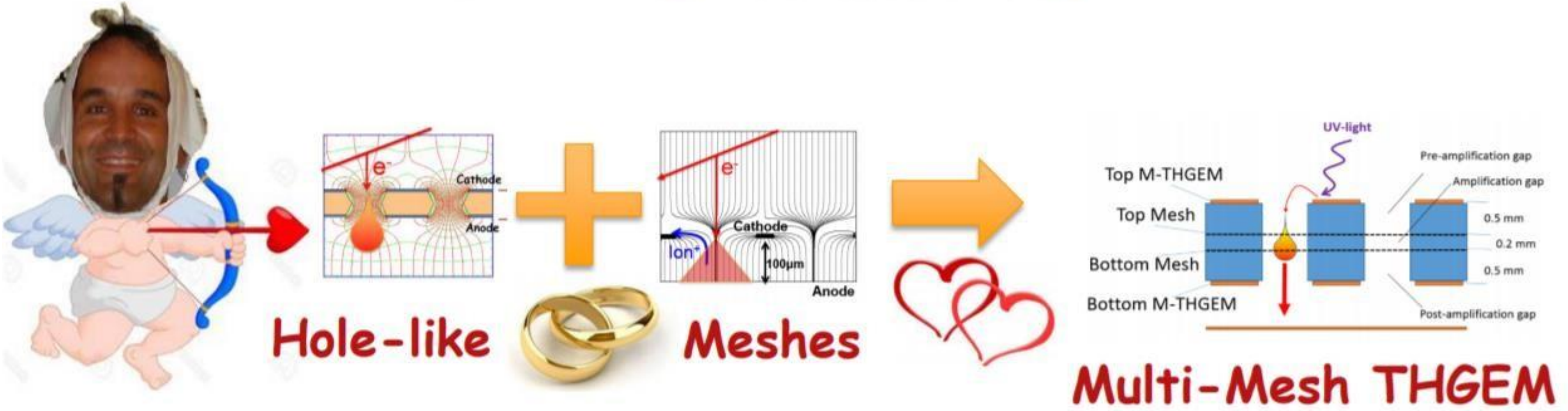




Coating GEM w GRAPHENE: need to increase e- Energy > 10kV/cm. Did not succeed to transmit e- via 3-layer Graphene. Literature: yet unclear (to our community) "directions"

Solution Attempts

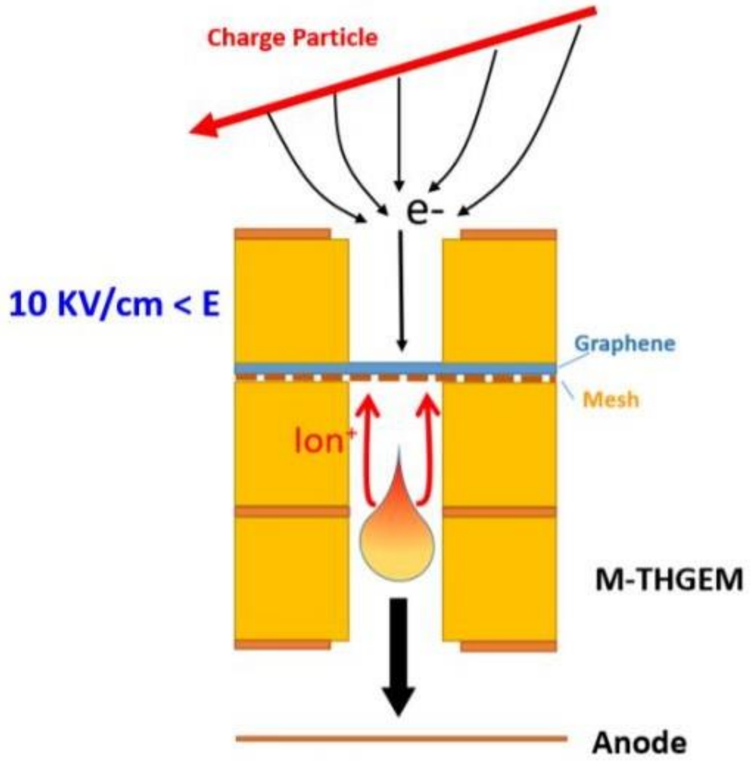
Hybrid: GEM-GEM-MicroMegas



[M. Cortesi, 2019, “Development of new MPGD structures for nuclear physics applications, MPGD19 La Rochelle, France]

Solution Attempts

MM-THGEM with inner Graphene electrode



The idea:

sandwich a layer graphene inside the MM-THGEM transparent to the drifting electrons and opaque to ions to suppress the IBF!

-) Hole-type structure
→ e- collection
-) first stage MM-THGEM first stage
→ pre-amplification and mechanical support for the graphene
-) last stages M-THGEM
→ gas avalanche process

Parameters to be estimated:

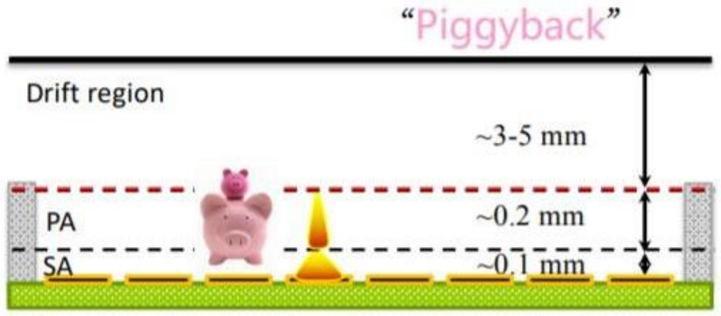
-) Electrons/ions transparency vs gain/bias configuration
-) Homogeneity of the graphene
-) Mechanical Robustness and stability
-) Aging (radiation-induced damages)
-) Production techniques
-) IBF reduction (including cascade geometries)
-) Multi-layer THGEM and possible different configurations
(intermediate layers between different electrodes)

[M. Cortesi, 2019, “Development of new MPGD structures for nuclear physics applications, MPGD19 La Rochelle, France]

Solution Attempts

DMM Design

- DMM: Double Micro-Mesh gaseous structure
  - Hole-type → mesh-type : to strongly reduce IBF
  - Double mesh: cascading avalanche for high gain

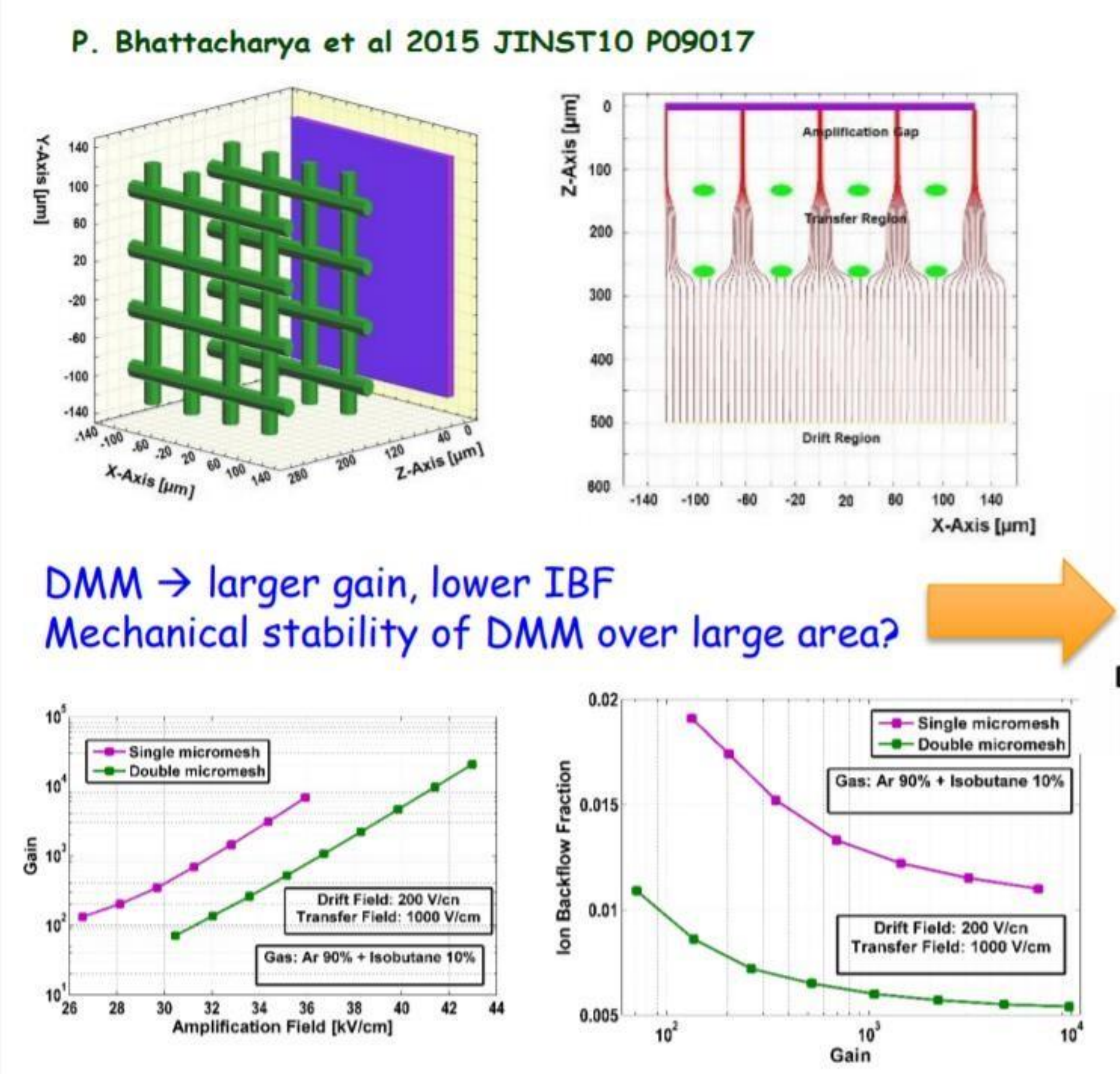


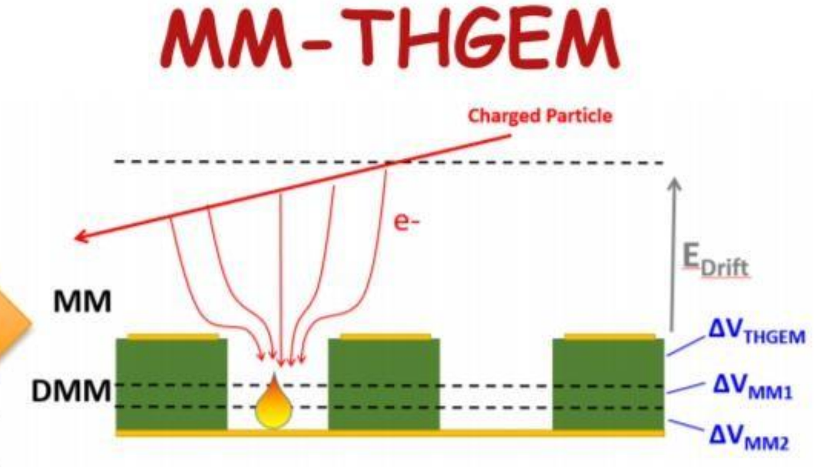
Stacked two meshes

- Gap between the stacked meshes: 200-300um, serving as pre-amplification (PA)
- Gap between the bottom mesh and anode: 50-100um as secondary amplification (SA)
- Allows to achieve very high gain, and yet significantly reduce ion back-flow.

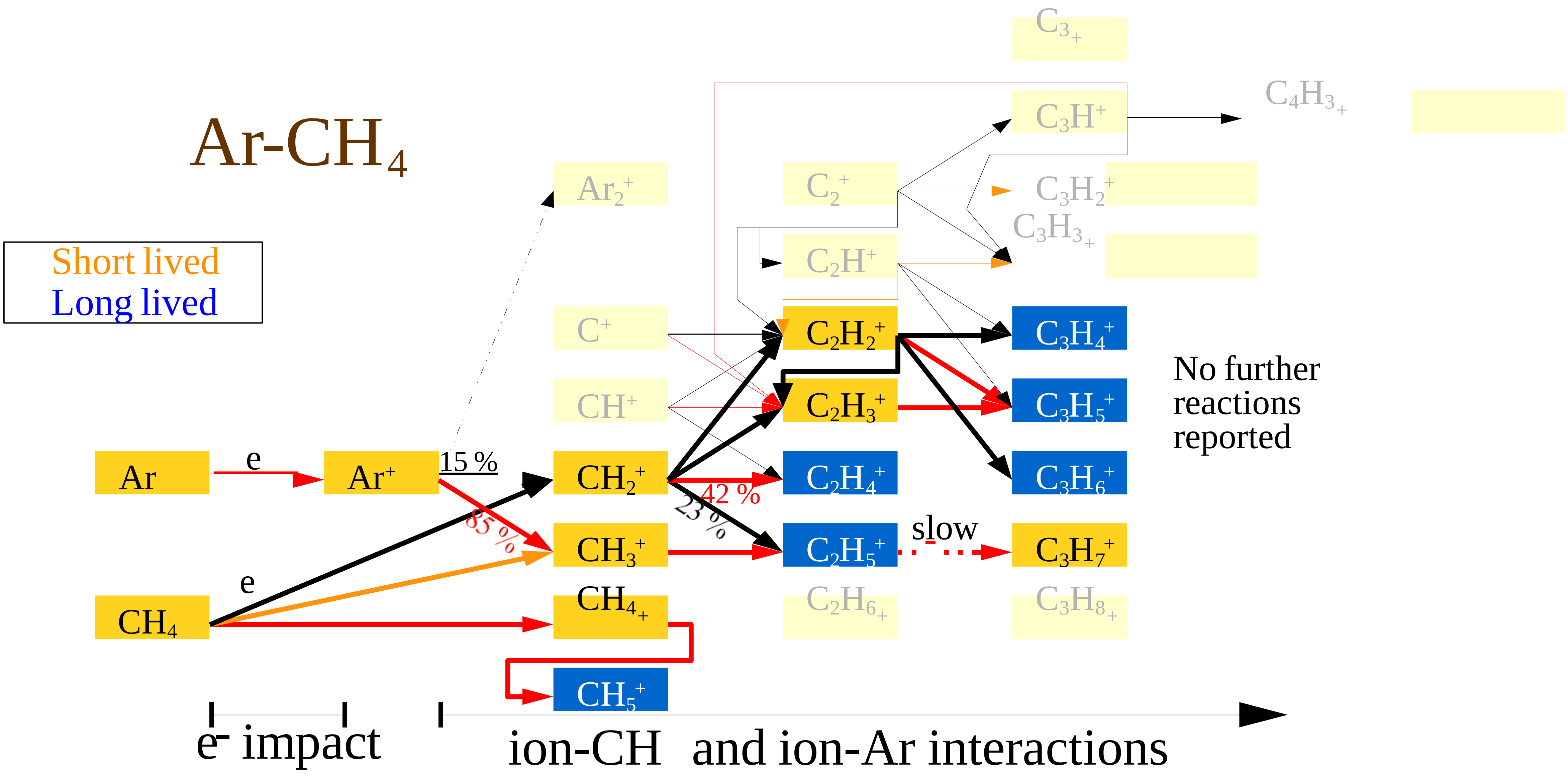
[L. Jianbei, 2019, “A high-gain and low ion-backflow DMM gaseous structure, MPGD19 La Rochelle, France]

Solution Attempts





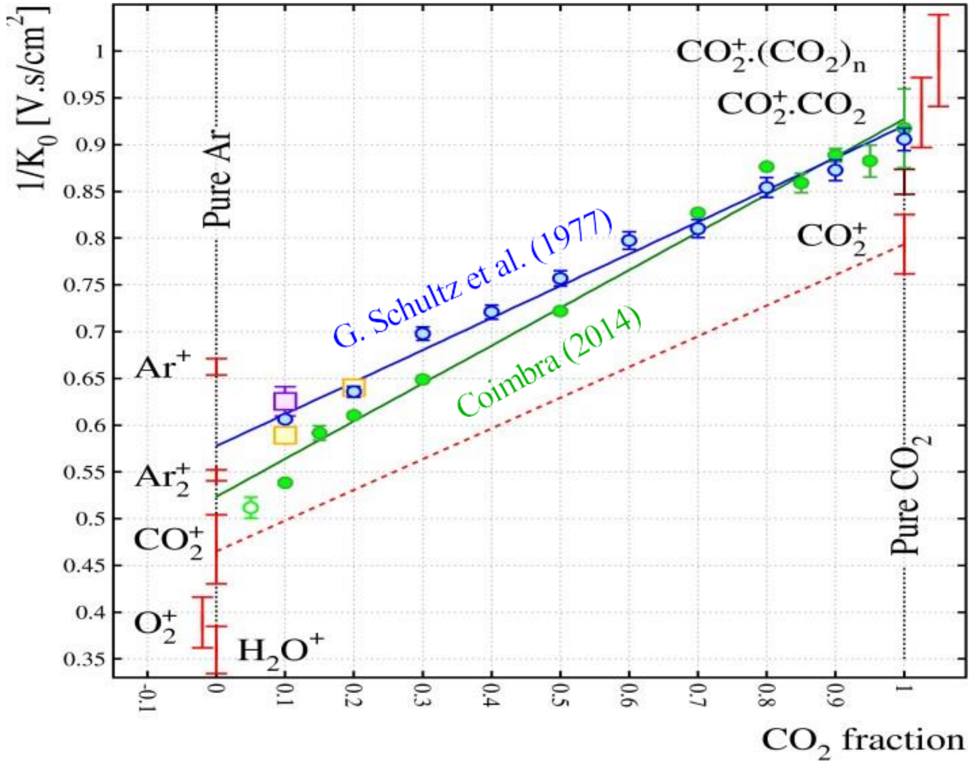
Ar-CH_4

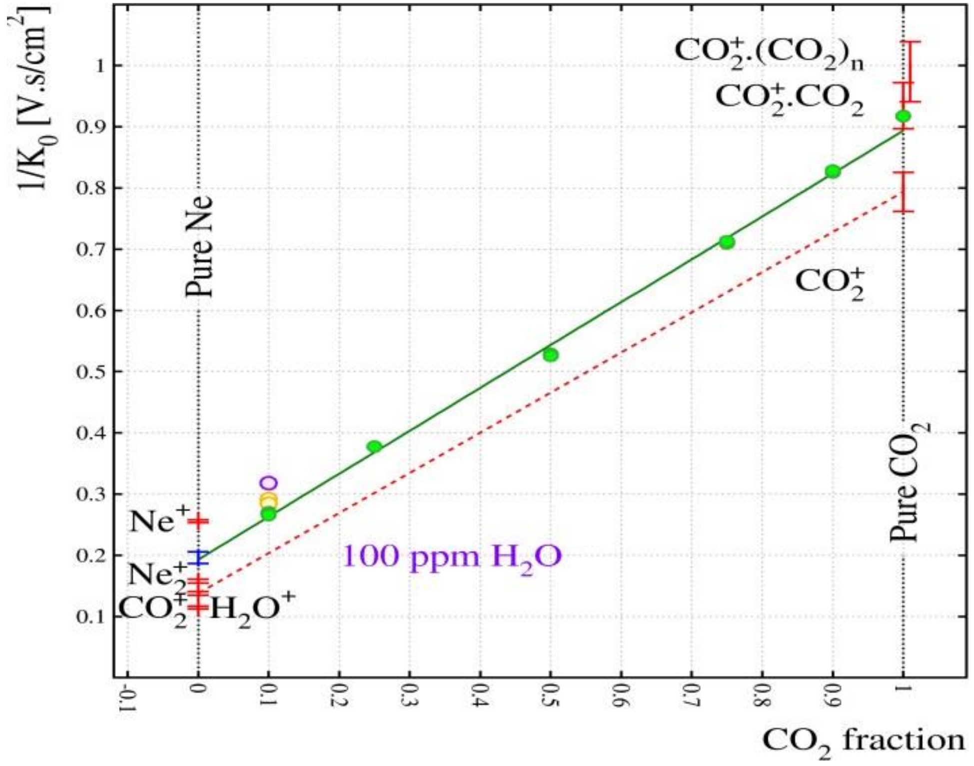


[Prepared by Rob Veenhof]

Ions drifting in Ar-CO_2 and Ne-CO_2

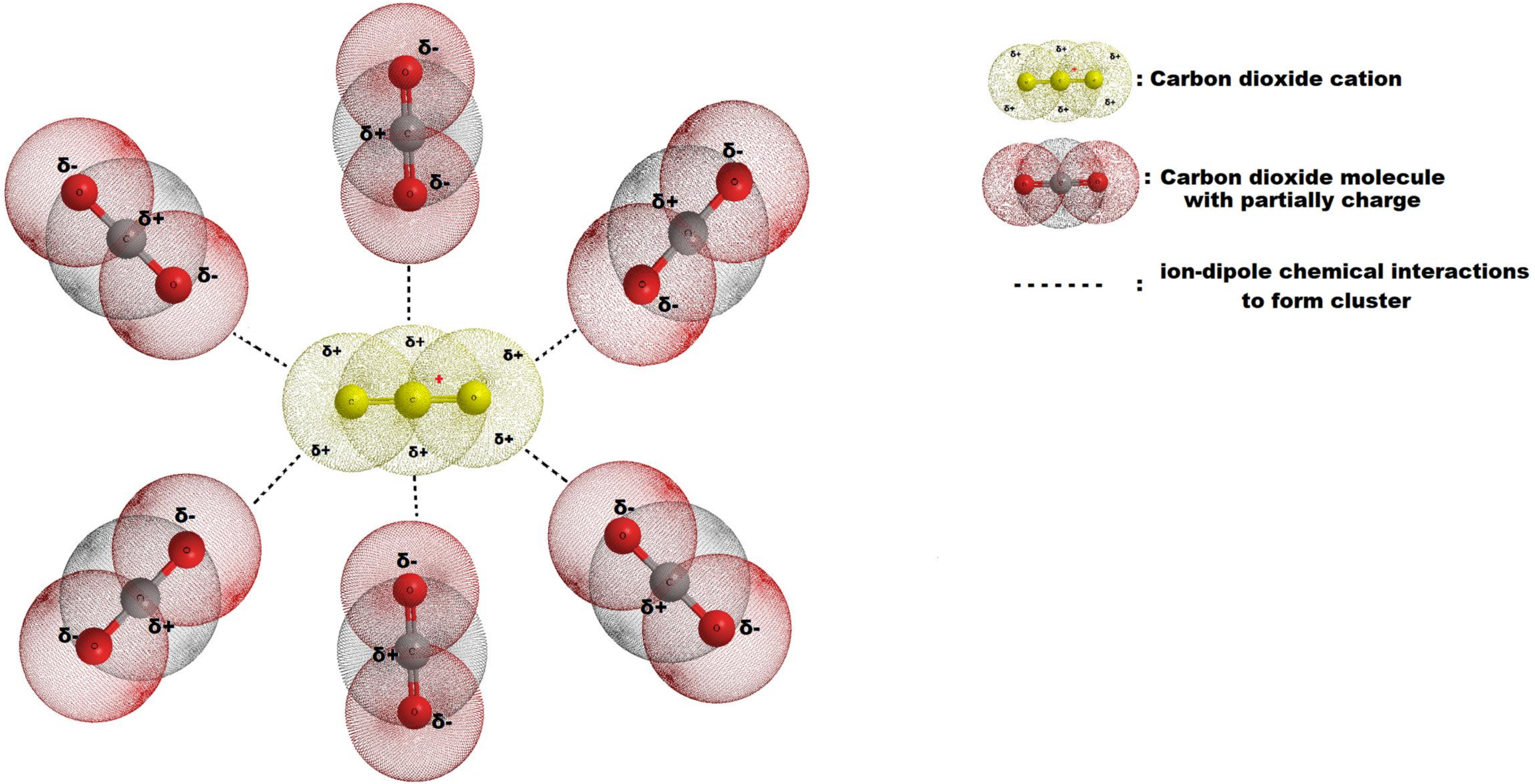
- Little Ar^+, Ne^+, CO_2^+ but $CO_2^+ \bullet (CO_2)_n$





Clustering reactions involving CO_2

- Ar^+: charge exchange, $\tau \approx 0.85$ ns
  - $Ar^+ + CO_2 \rightarrow Ar + CO_2^+$
- Ne^+: charge transfer in 2steps, $\tau \approx 8$ ns
  - $Ne^+ + CO_2 \rightarrow Ne + CO^+ + O$
  - $CO^+ + CO_2 \rightarrow CO + CO_2^+$
- CO_2: 3body association, $\tau = 0.72$ ns (faster if Ar helps)
  - $CO_2^+ + 2CO_2 \rightarrow CO_2^+ \bullet CO_2 + CO_2$
- [For 10 % CO_2, atmospheric pressure, room temperature]


δ-
δ+
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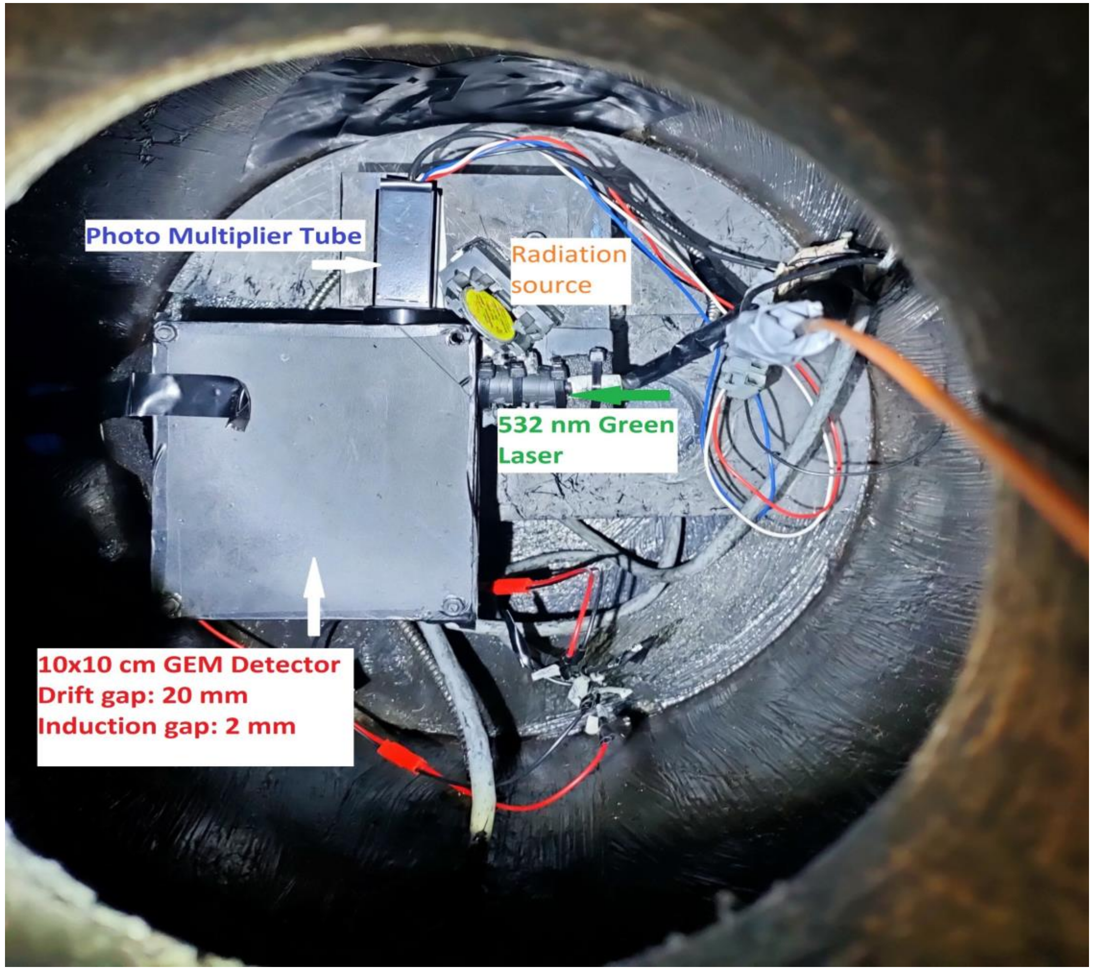
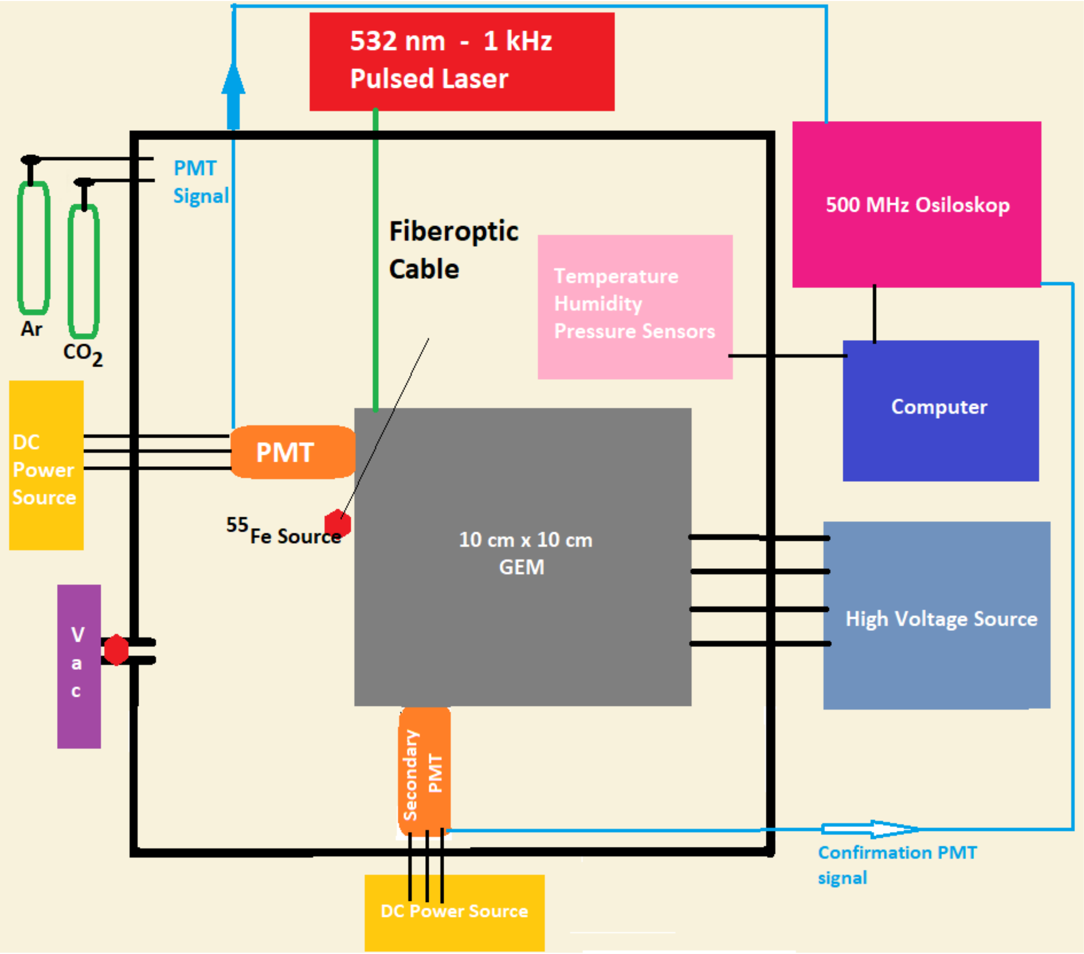
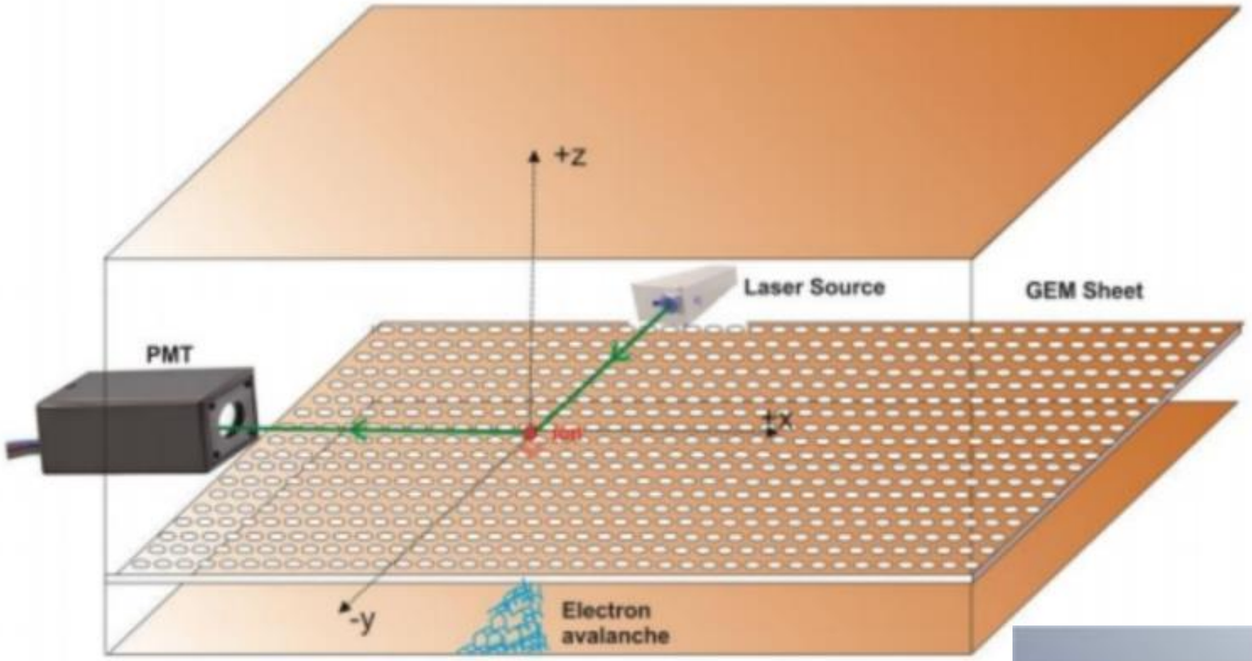
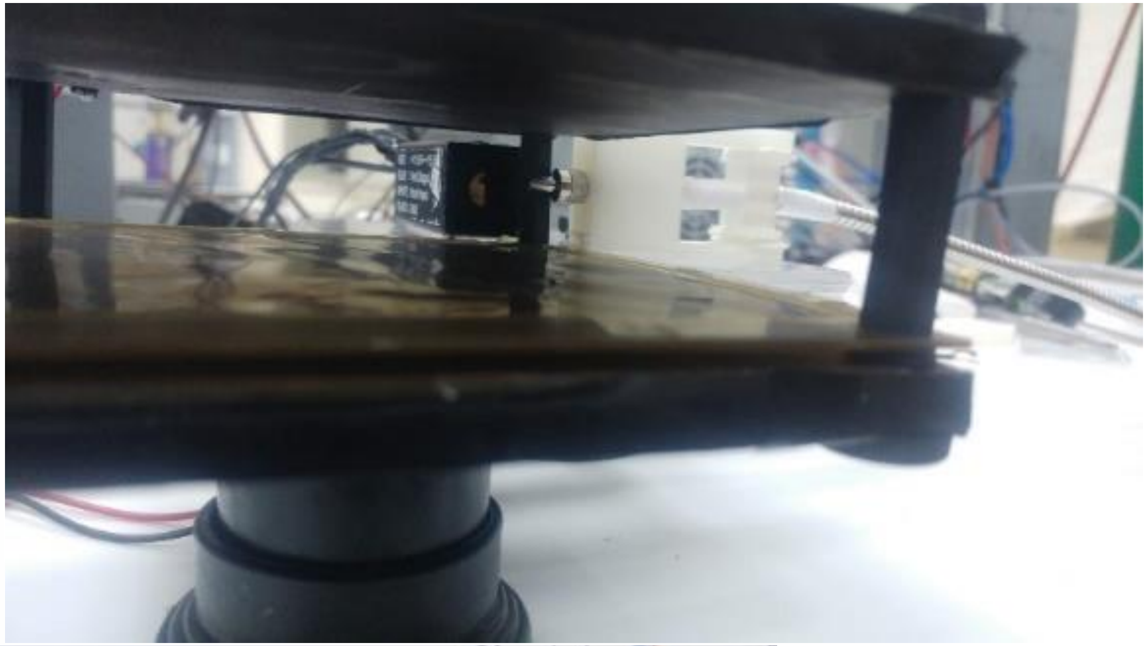
: Carbon dioxide cation
: Carbon dioxide molecule
with partially charge
: ion-dipole chemical interactions
to form cluster

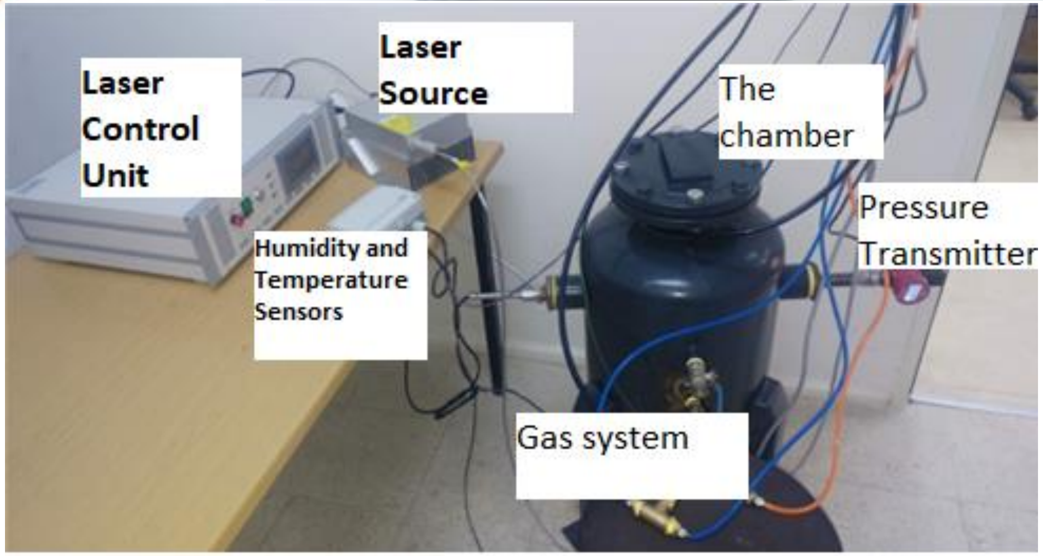
Experimental Setup



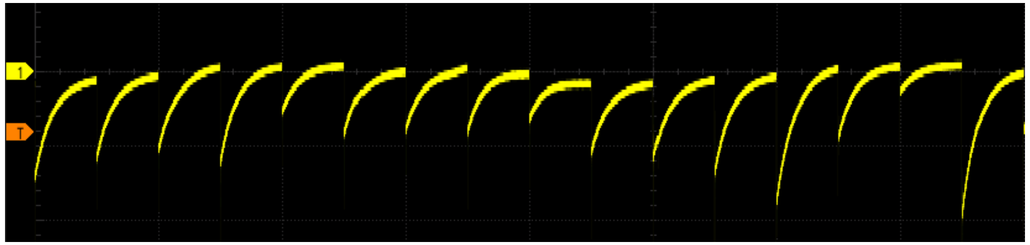



+z
Laser Source
GEM Sheet
PMT
+x
-y
Electron avalanche



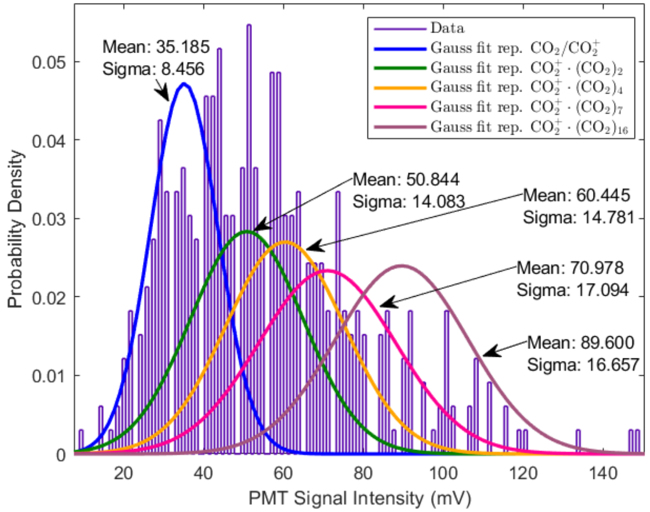

Laser Control Unit
Laser Source
The chamber
Pressure Transmitter
Humidity and Temperature Sensors
Gas system

Data Analysis



Distribution Fitter

Akaike's Information Criterion (AIC) Technique



Particle	Size (pm)	Signal (mV)
Ar/Ar^+	376	27
CO_2/CO_2^+	474	35
$CO_2^+ \cdot (CO_2)$	596	44
$CO_2^+ \cdot (CO_2)_2$	681	51
$CO_2^+ \cdot (CO_2)_3$	749	56
$CO_2^+ \cdot (CO_2)_4$	813	60
$CO_2^+ \cdot (CO_2)_5$	856	63
$CO_2^+ \cdot (CO_2)_6$	901	67
$CO_2^+ \cdot (CO_2)_7$	941	70
$CO_2^+ \cdot (CO_2)_{10}$	1046	78
$CO_2^+ \cdot (CO_2)_{12}$	1105	82
$CO_2^+ \cdot (CO_2)_{16}$	1207	90
H_2O	275	20

[https://www.mathworks.com/help/ident/ref/idmodel.aic.html]

for pure Ar

Gas mixture	Pressure (Atm)	Mean value of Gauss fit (mV) (Sigma value)	Detected particle
Pure Ar	1	27.381 (7.235) 45.03 (6.83)	Ar/Ar^+ Ar dimers
	2	27.649 (5.557) 49.01 (10.487)	Ar/Ar^+ Ar dimers
	3	27.833 (5.425) 48.398 (9.496)	Ar/Ar^+ Ar dimers
	4	26.571 (8.504) 41.677 (7.782)	Ar/Ar^+ Ar dimers
	5	26.764 (6.799) 44.324 (9.885)	Ar/Ar^+ Ar dimers

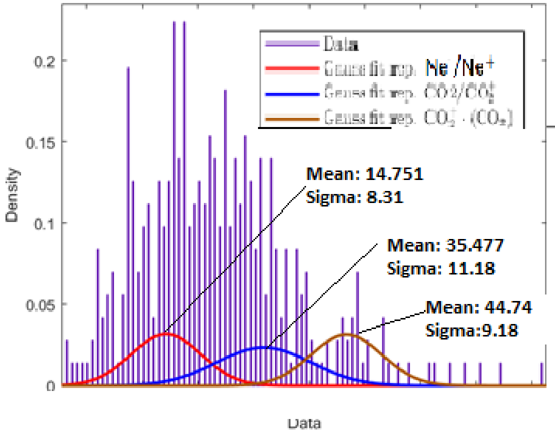
for %25 Ar

Gas mixture	Pressure (Atm)	Mean value of Gauss fit (mV) (Sigma value)	Detected particle
25% Ar-75% CO_2	1	27.646 (7.039) 35.74 (10.272) 44.414 (9.032) 56.926 (10.369)	Ar/Ar^+ CO_2/CO_2^+ $CO_2^+ \cdot (CO_2)$ $CO_2^+ \cdot (CO_2)_3$
	2	27.050 (7.285) 35.840 (10.097) 44.040 (8.825) 60.224 (10.997)	Ar/Ar^+ CO_2/CO_2^+ $CO_2^+ \cdot (CO_2)$ $CO_2^+ \cdot (CO_2)_4$
	3	35.102 (9.674) 44.31 (9.334) 63.368 (10.965)	CO_2/CO_2^+ $CO_2^+ \cdot (CO_2)$ $CO_2^+ \cdot (CO_2)_5$
	4	27.786 (7.846) 44.711 (8.605) 63.521 (10.98)	Ar/Ar^+ $CO_2^+ \cdot (CO_2)$ $CO_2^+ \cdot (CO_2)_5$
	5	27.542 (9.776) 35.337 (11.504) 44.483 (6.052)	Ar/Ar^+ CO_2/CO_2^+ $CO_2^+ \cdot (CO_2)$

for pure CO_2

Gas mixture	Pressure (Atm)	Mean value of Gauss fit (mV) (Sigma value)	Detected particle
Pure CO_2	1	35.758 (9.350) 44.497 (5.056) 51.296 (7.44) 56.268 (7.095) 60.901 (7.719)	CO_2/CO_2^+ $CO_2^+ \cdot (CO_2)$ $CO_2^+ \cdot (CO_2)_2$ $CO_2^+ \cdot (CO_2)_3$ $CO_2^+ \cdot (CO_2)_4$
	2	35.185 (8.456) 50.844 (14.083) 60.445 (14.781) 70.978 (17.094) 89.6 (16.657)	CO_2/CO_2^+ $CO_2^+ \cdot (CO_2)_2$ $CO_2^+ \cdot (CO_2)_4$ $CO_2^+ \cdot (CO_2)_7$ $CO_2^+ \cdot (CO_2)_{16}$
	3	44.44 (8.78) 51.119 (8.684) 56.017 (15.646) 67.61 (9.981) 78.413 (17.910)	$CO_2^+ \cdot (CO_2)$ $CO_2^+ \cdot (CO_2)_2$ $CO_2^+ \cdot (CO_2)_3$ $CO_2^+ \cdot (CO_2)_6$ $CO_2^+ \cdot (CO_2)_{16}$
	4	35.175 (9.26) 44.142 (10.692) 51.467 (12.0) 70.547 (15.294)	CO_2/CO_2^+ $CO_2^+ \cdot (CO_2)$ $CO_2^+ \cdot (CO_2)_2$ $CO_2^+ \cdot (CO_2)_7$
	5	44.926 (8.69) 56.32 (13.058) 67.239 (16.61) 82.281 (15.181)	$CO_2^+ \cdot (CO_2)$ $CO_2^+ \cdot (CO_2)_3$ $CO_2^+ \cdot (CO_2)_6$ $CO_2^+ \cdot (CO_2)_{12}$

for %25 Ne



Conclusion

- Characterization of cluster ions is essential for an effective solution
- Rayleigh Scattering technique is usefull to estimate the cluster size in gas detectors.
- Neon is less aggresive to forming the cluster ions.
- Pressure has a role onto the clustering mechanism in gaseous detectors.

Thank You !

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