UNIVERSIDADE Ð COIMBRA

David J.G. Marques, RD51 Mini-week, 4-6 December 2018

DEVELOPMENT OF A DUAL-POLARITY ION DRIFT CHAMBER &
STUDY OF ION TRANSPORT PROPERTIES IN NE-CF4 MIXTURES

David J.G. Marques, M.A.G. Santos, **A.F.V. Cortez**, R. Veenhof,
P. Colas, P.N.B. Neves, F.P. Santos, C.A.N. Conde, F.I.G.M. Borges

LIP

Physics Department

University of Coimbra

Coimbra, Portugal

December 2018

E-mail: davidmarques_12@hotmail.com and andre.cortez@coimbra.lip.pt

Contents

Introduction and motivation

Ion Mobility Spectroscopy

Technique that aims at identifying ionized molecules in a gas based on their mobility in a carrier buffer gas.

Time projection Chamber

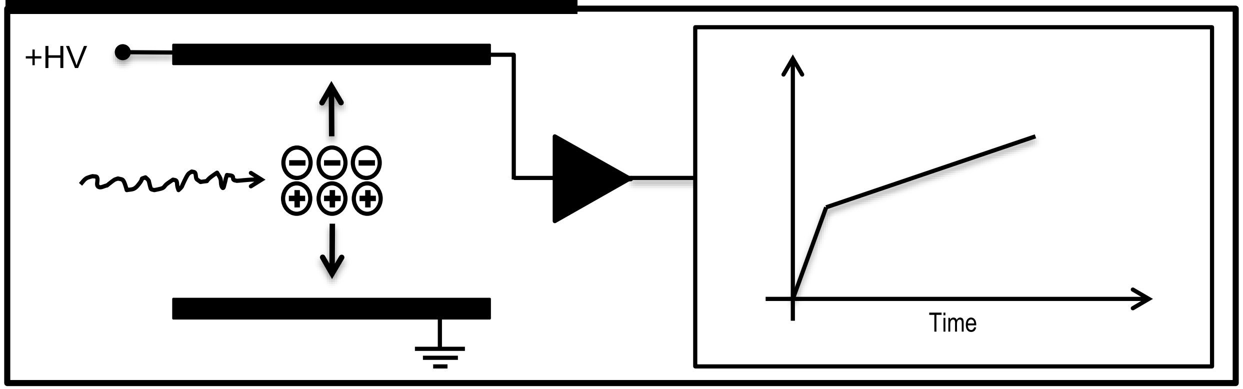
- ✓ Powerful tool in high energy and nuclear physics.
- ✓ Future Linear Collider TPC (LCTPC)

Negative Ion Time Projection Chamber

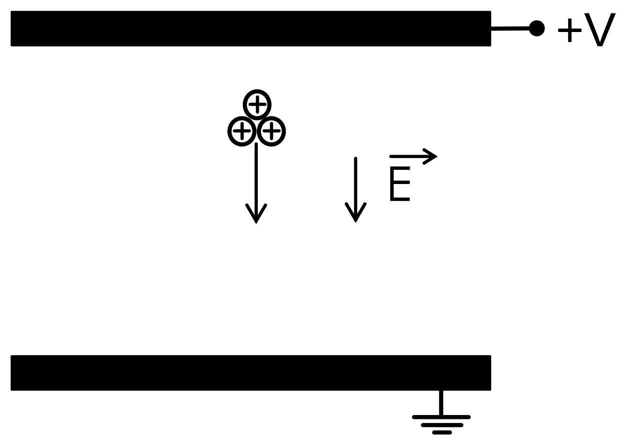
Rare event physics searches
- Neutrinoless beta decay (0νββ)
- Dark matter (WIMPs)

Astrophysics
- Polarimetry

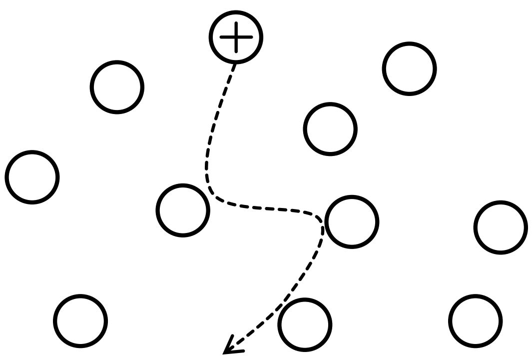
Gaseous Radiation Detectors



Theoretical Background



Microscopically...



Drift velocity

$$v_d = KE$$

E - Electric Field
K - Ion Mobility

Reduced Mobility

$$K_0 = KN/N_0$$

N – Gas number density
N_0–Loschmidt Number

Langevin Limit

$$K_0 = 13.88\left(\frac{1}{\alpha\mu}\right)^{\frac{1}{2}}$$

μ – ion-neutral reduced mass
α – neutral polarizability

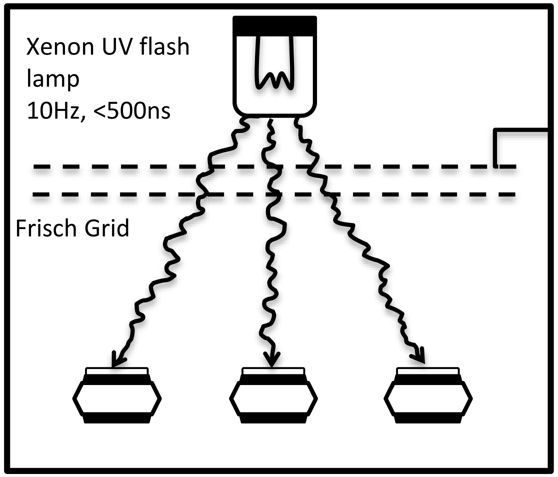
Blanc's Law

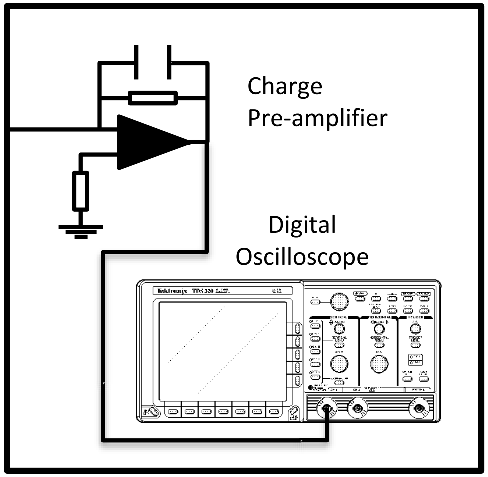
$$\frac{1}{K_{0mix}} = \frac{f_1}{K_{0g1}} + \frac{f_2}{K_{0g2}}$$

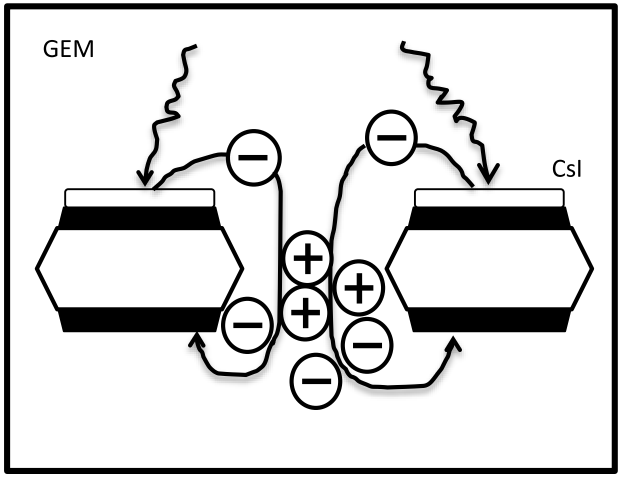
f_1,f_2– molar fraction of gas 1, 2
K_{0g1},K_{0g2} – ion mobility in the gas 1 and gas 2

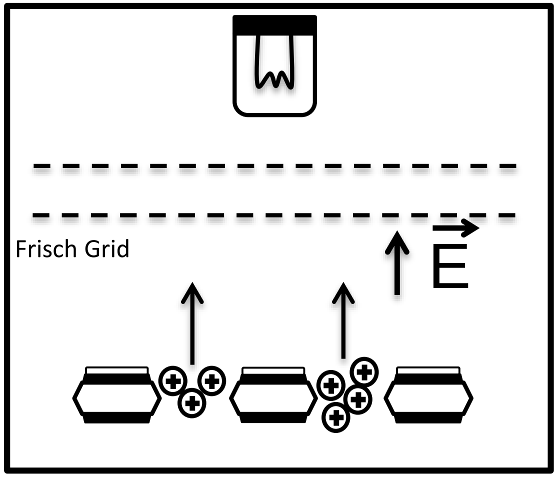
Experimental system and techniques

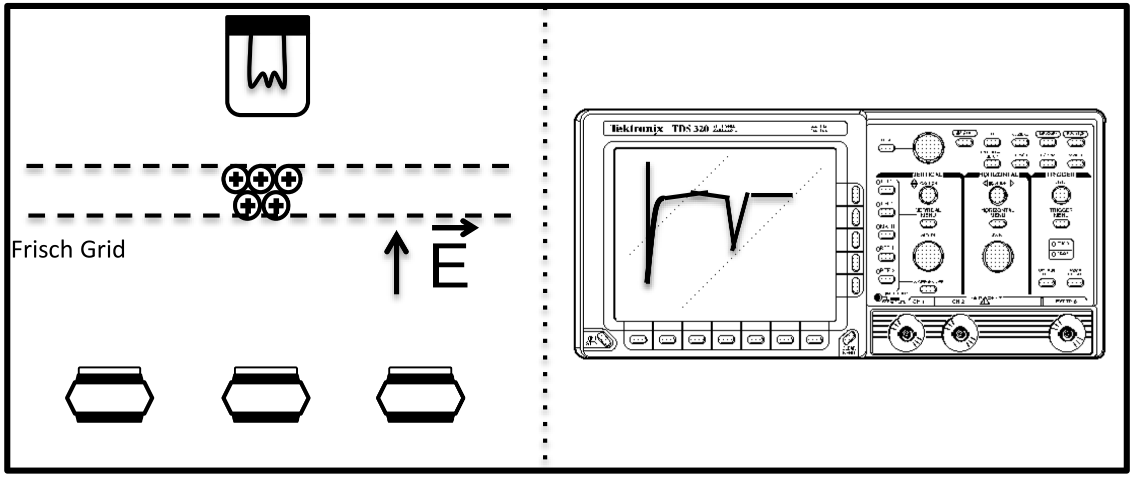
P.N.B. Neves *et al.* 2009

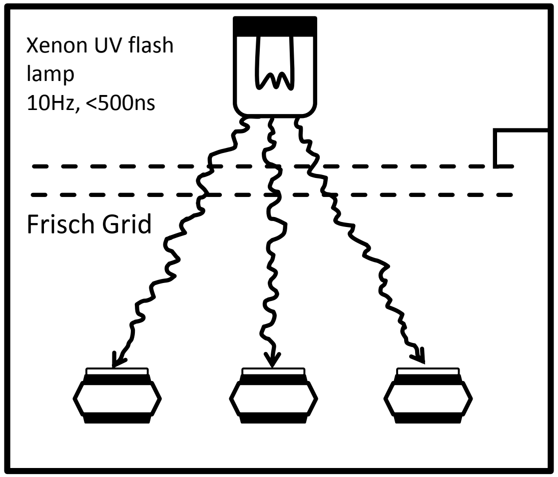


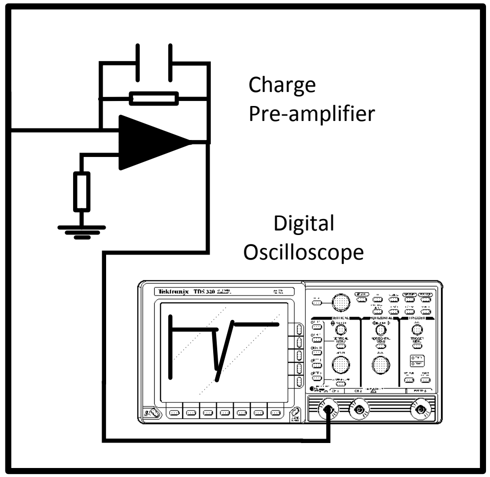












After the signal and the background were recorded…

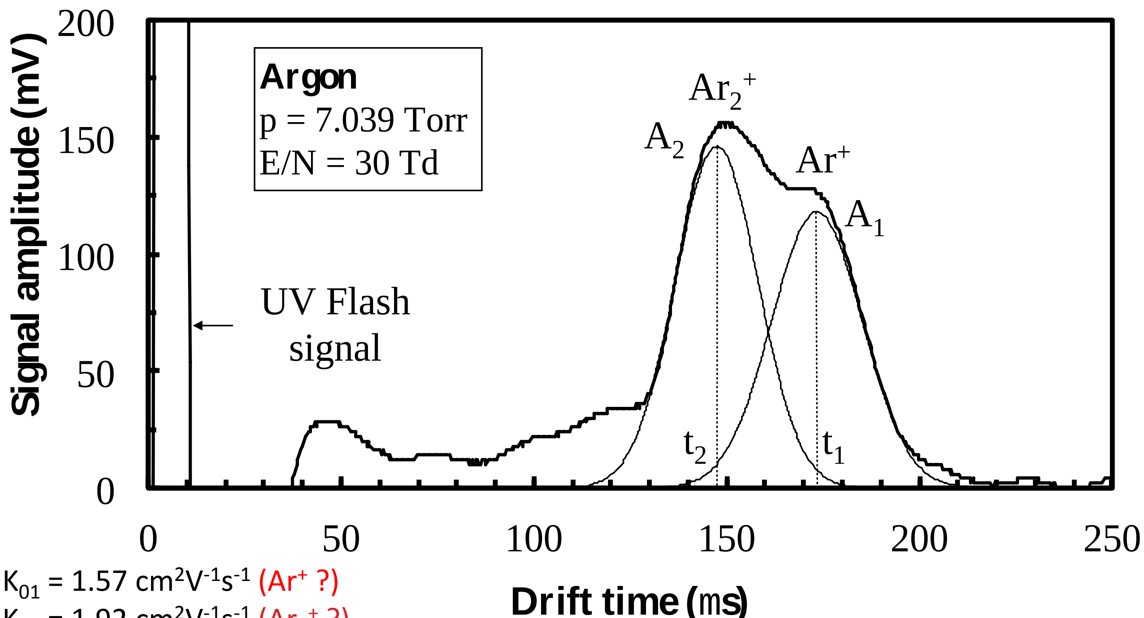
- Subtract the background to the signal
- Identify possible peaks
- Fit Gaussian curves to the spectrum obtained

peaks centroids

⬇

average drift time of the ion's distribution (t_{drift})

$$v_d = \frac{x_{drift}}{t_{drift}} \Rightarrow K = \frac{v_d}{E}$$



K_{01} = 1.57 $cm^2V^{-1}s^{-1}$ (Ar^+ ?)
K_{02} = 1.92 $cm^2V^{-1}s^{-1}$ (Ar_2^+ ?)

(A review on) Ion mobility in pure Ne and CF4

Ion mobility in pure Ne

- One peak (below 8 Td) - Ne_2^+
- Two peaks present (between 8 and 12 Td)
- One peak (above 12 Td) - Ne^+

Appearance Energies

Ne^+ 21.56 eV

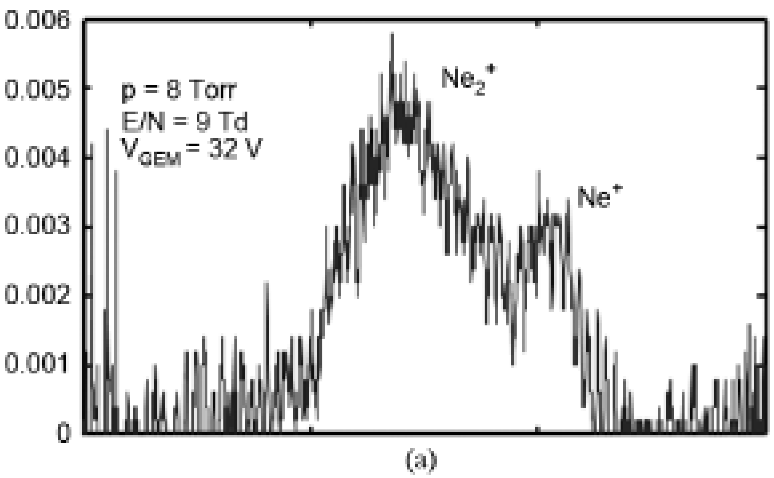
Reactions:

$Ne^+ + 2Ne \rightarrow Ne_2^+ + Ne$

$Ne^+ + Ne \rightarrow Ne + Ne^+$

$K_{01} \sim 4.4\ cm^2V^{-1}s^{-1}$ **Ne^+**

$K_{02} \sim 6.2\ cm^2V^{-1}s^{-1}$ **Ne_2^+**



P.N.B. Neves *et al.* 2011

Ion mobility in pure CF4

- One peak present

Appearance Energies

CF_3^+	15.0 eV
CF_2^+	19.0 eV
CF^+	22.3 eV
F^+	23.1 eV

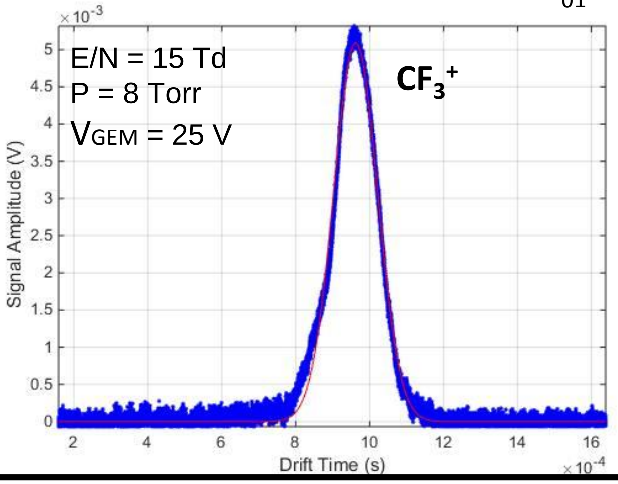
Reactions:

$CF_3^+ + 2CF_4 \rightarrow CF_3^+.(CF_4) + CF_4$

Possibility of Cluster Formation

(Pressure dependent)

$K_{01} \sim 1.10\ cm^2V^{-1}s^{-1}$ **CF_3^+**



M.A.G. Santos *et al.* 2018

Ion mobility in Ne-CF4

(Charge Transfer Reaction)

$Ne^+ + CF_4 \rightarrow CF_3^+ + Ne + F$

Prevents the formation of Ne^+.

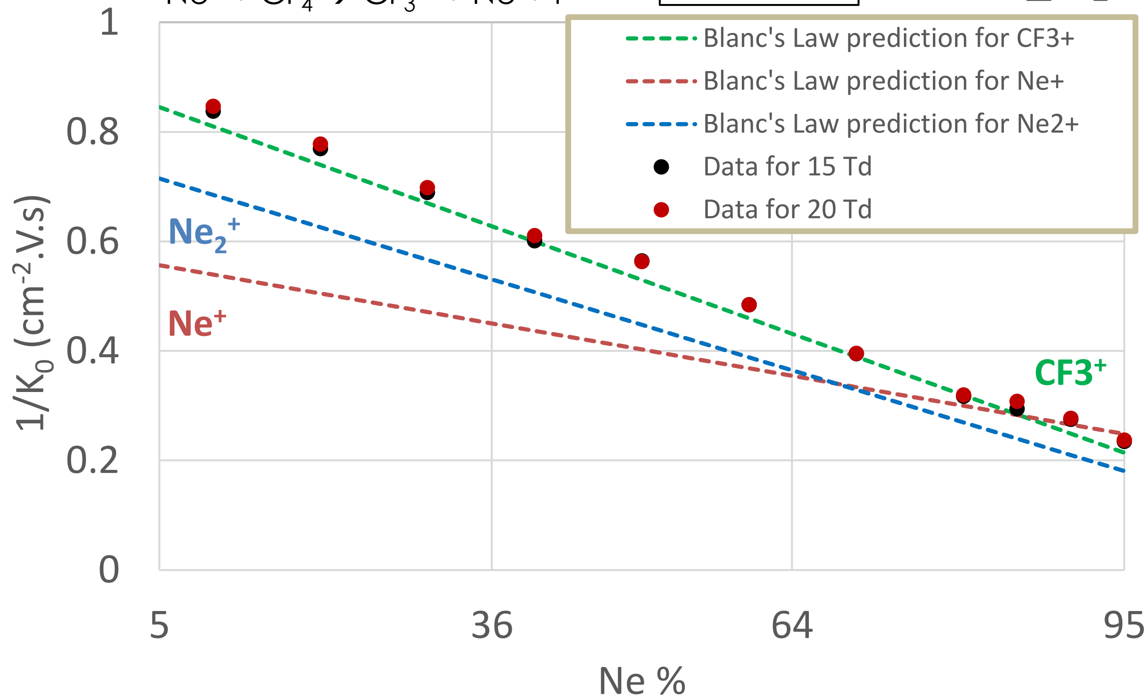
Ions move slower with the presence of CF4.

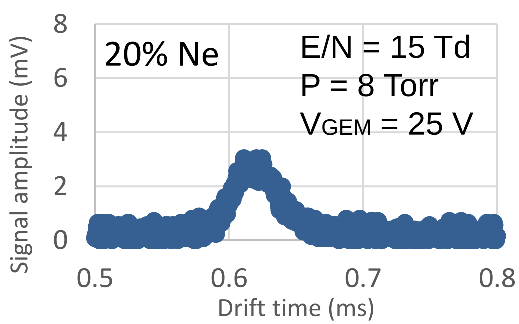
Behaviour well described by Blanc's law and Langevin theory. Amplitude rises until 90% of Ne

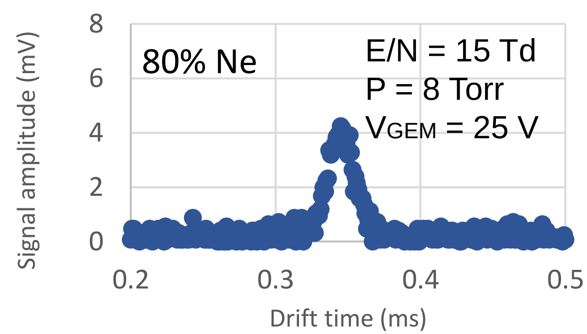
- Cross section.
- Presence of CF4 in mixtures with Ne leads to the same ion as in pure CF4.

Only one peak for 15 Td

Increasing pressure may lead to the **formation** of **cluster** (about **10% slower** than CF3+)





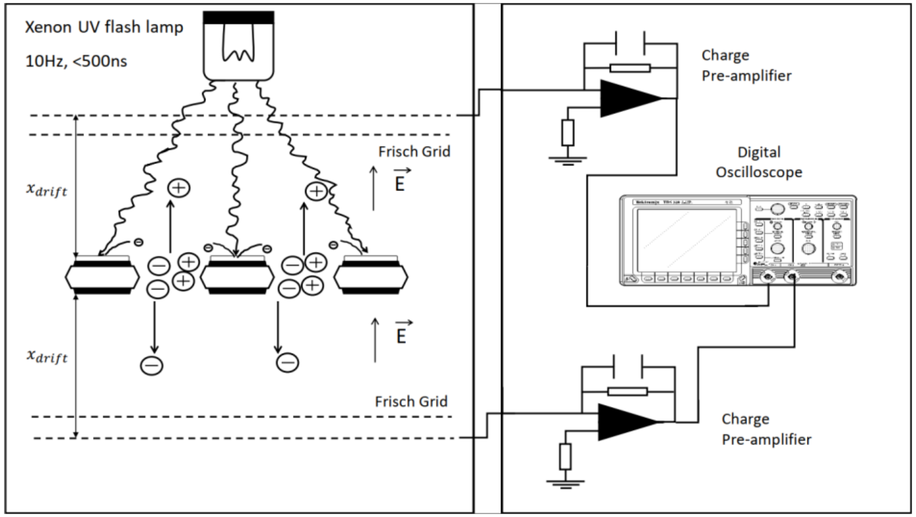


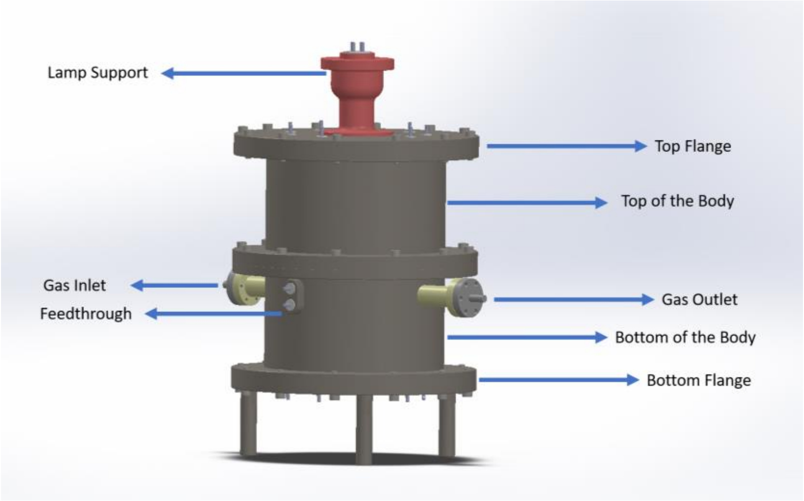
DP-IDC: Working principle and design proposal

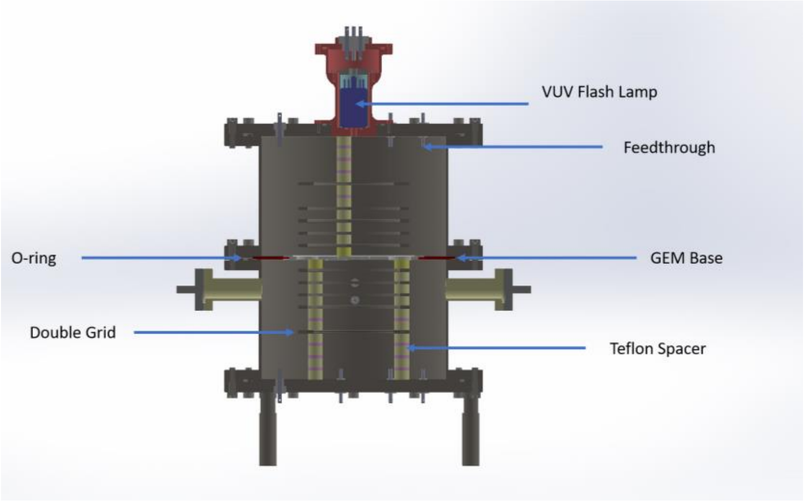
Dual **P**olarity – **I**on **D**rift **C**hamber

Allows to:

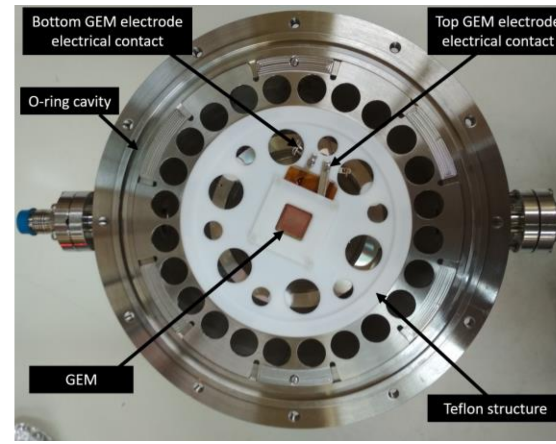
- ✓ study the transport properties of negative ions in gases, in addiction to the study of positive ions;
- ✓ vary the drift distance.

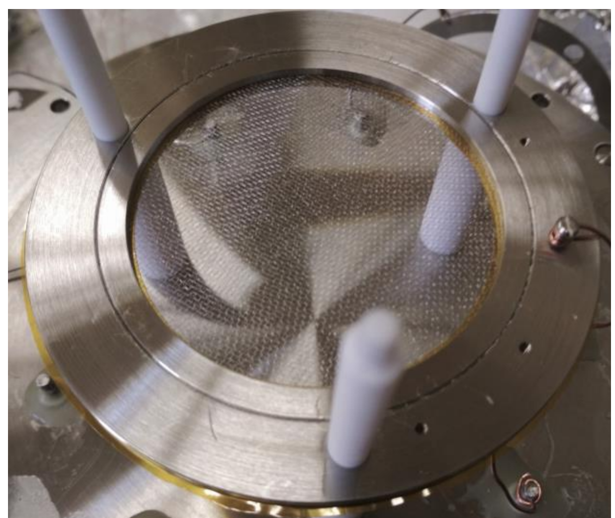


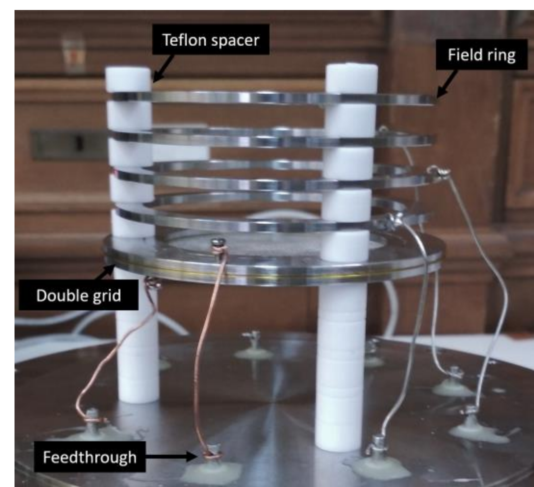




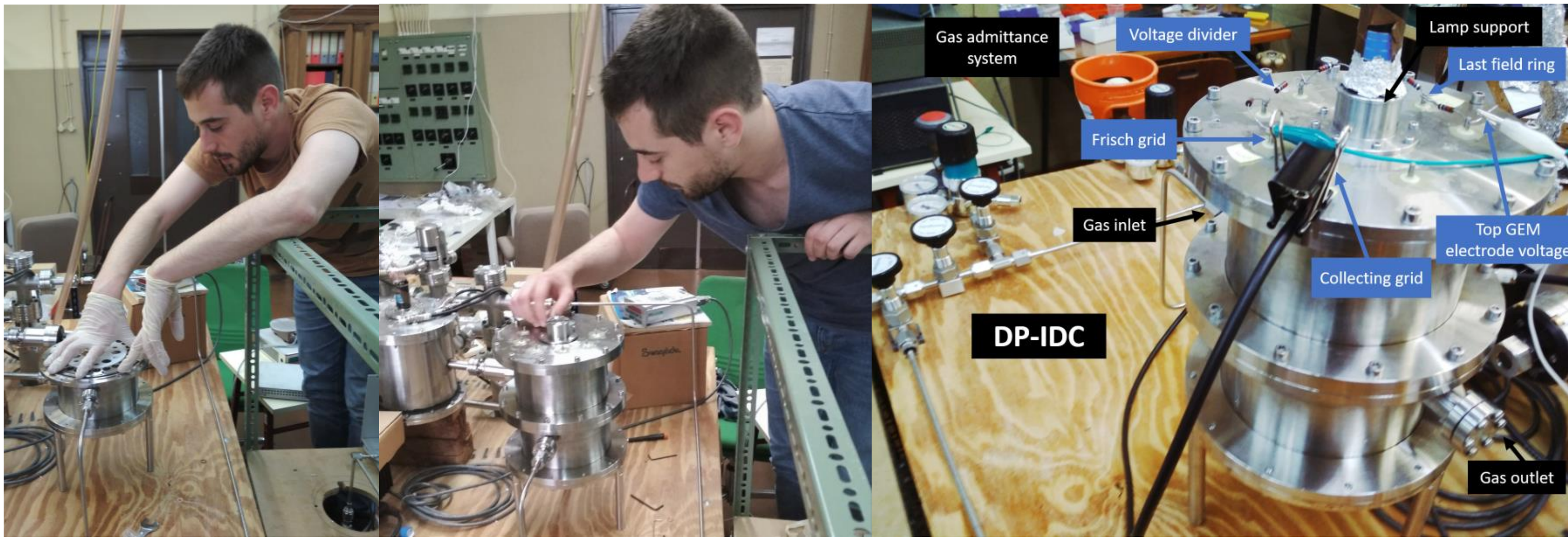
DP-IDC: Components, preliminary tests and system proposal



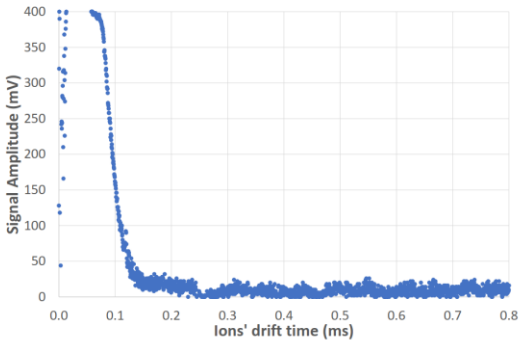




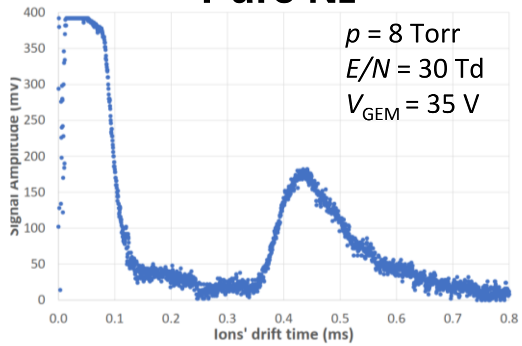
DP-IDC: Assembly

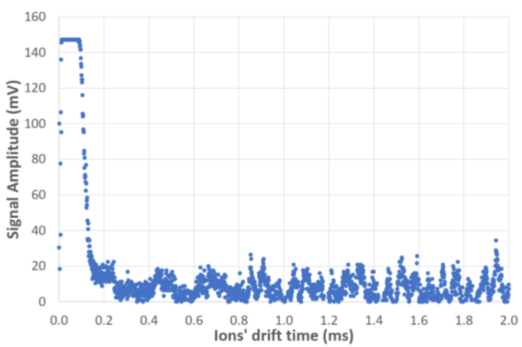


DP-IDC: First results

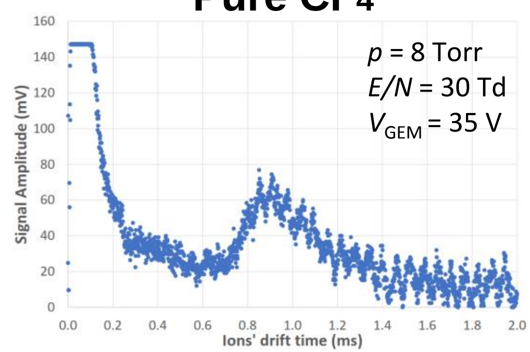


Pure N2





Pure CF4



1. One peak clearly visible in both spectra, as expected. A long tail and two smaller peaks are also visible.
2. Measured mobility about 40% lower than in previous work.

- No noticeable signal for:
  - *V*GEM = 25 V & *E*/*N* < 30 Td
  - *V*GEM = 35 V & *E*/*N* < 20 Td
- High and unstable electrical noise (6-10 mV).
- Lamp pulse 200 time wider than expected.

Solutions:

- reducing the length of the cables between the pre-amplifier and the collection feedthrough by
- insuring a stable and single ground across the detector.

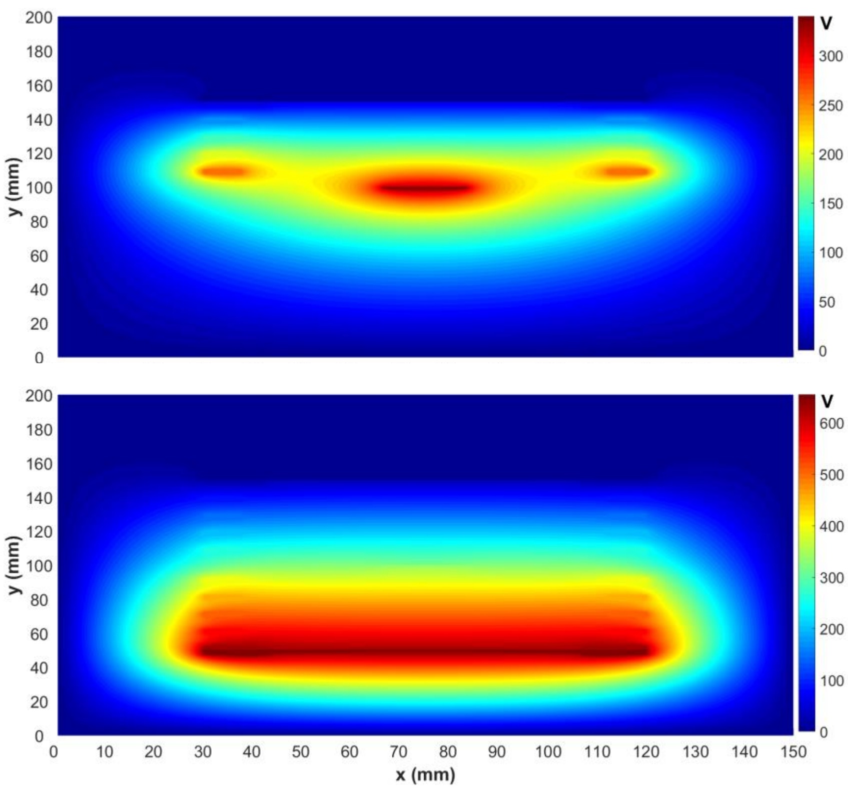
*Test gases chosen both by their availability and their known mobility lower than the upper limit of the mobility possible to be measured.

**Tests will follow in the next couple of months to solve these issues.

David J.G. Marques, RD51 Mini-week, 4-6 December 2018

DP-IDC: Limitations

Electric field



- Variations on the mobility of about 23% in half biased mode and of 2% in full biased modes;
- Can lead to lose of signal in half biased mode due to diffusion.

Residual gas

Due to outgassing, to the gas non-purity and minimum residual vacuum.
In the present installation:
Conductance < 0.012 l/s ⟶ Residual vacuum > 4.89 $\times$ 10^{-3} Torr

Lamp induced

Frequency of the pulses	0.1 s	Max. Mob. 0.012 $cm^2V^{-1}s^{-1}$
Expected pulse duration	0.5 μs	Theor. Min. Mob. 2481 $cm^2V^{-1}s^{-1}$
Experimental pulse duration	0.1 ms	Exp. Min. Mob. 12.4 $cm^2V^{-1}s^{-1}$

Teflon spacers

Mean thermal expansion of Teflon and thermal expansion coefficients at a given temperature vary a lot in the range of thermal temperatures leading to variations of the order of 0.1 mm in the drift distance.
*Also, explains why the first double grid prototype failed.

Conclusions

On the ion mobility

- The ion mobility in various mixtures of interest.
- The mobility values are consistent with the theoretical ones given by Blanc's law using Langevin's theory, following CF3+ ions.
- At **higher pressures**, the distribution of the final ions may differ, however these accurate ion mobility measurements have been consistently in accordance with the ones obtained at higher pressures (**Kalkan et al. 2015**).

On the DP-IDC

- The DP-IDC was designed, constructed, preliminarily tested and assembled **successfully**;
- First tested revealed **poor accuracy but good precision**;
- Still some **problems should be addressed**, specially in what concerns the uniformity of the electric field.

Future work

- Pursuit the investigation on the mobility of ions in different gas mixtures of interest for TPCs and NITPCs:

$Ne\text{-}iC_4H_{10}$	$SF_6\text{-}CH_4$
$Xe\text{-}iC_4H_{10}$	$SF_6\text{-}C_2H_6$
	$CS_2\text{-}CH_4$
SF_6	$CS_2\text{-}C_2H_6$
CS_2	
O_2	$Xe\text{-}SF_6$
N_2O	$Xe\text{-}CS_2$
CH_3NO_2	$CO_2\text{-}CH_3NO_2$

$Ne\text{-}CO_2\text{-}CH_3NO_2$

Thank you!

GEM Voltage

- Maximum energy gained by electrons.
- Primary ions possible to be formed.

Rg (pure)

$Rg + e \rightarrow Rg^{+} + 2e$

Possible Reactions

Ions formed through reactions of the primary ions with neutral atoms or molecules from the medium.

Reaction Time

Used to calculate the mobility of an ion in a gas mixture.

$$\tau = \frac{1}{kN}$$

- Identification the possible ions present.

Universal decay law

Used to calculate the variation of the concentration of a specific ion in a mixture.

$$Rg + Rg^{+} \xrightarrow{k} X^{+} + Y$$

$$\frac{[Rg^{+}]}{[Rg^{+}]_0} = e^{-\frac{t}{\tau}}$$

$$\frac{[X^{+}]}{[X^{+}]_0} = 1 - \frac{[Rg^{+}]}{[Rg^{+}]_0}$$

- Identification the possible ions present.

Select Most Probable Ions

Langevin Limit

To determine the mobility of an ion within a gas (not the parent).

$$K_p = 13.88\left(\frac{1}{\alpha\mu}\right)^{\frac{1}{2}}$$

m – reduced mass
a – neutral polarizability

Theoretical Mobility Values

Experimental Ion Mobility Values

Mobility of an ion within his parent gas (if known).

Blanc's Law

Used to calculate the mobility of an ion in a gas mixture.

$$\frac{1}{K_{0mix}} = \frac{f_1}{K_{0g1}} + \frac{f_2}{K_{0g2}}$$

f_1 , f_2– molar fraction of gas 1 and 2