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ALTERNATIVE GAS MIXTURES FOR LCTPC: Ar-CF4-C2H6

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- Present Status (Ion Diffusion and DP-IDC)
- Ion Mobility Measurement at LIP-Coimbra
  - Basic Concepts
  - Experimental Setup and Working Principle
  - Preliminary Results Ar-C2H6-CF4:
    - Ar-CF4,
    - Ar-C2H6
    - CF4-C2H6
    - Ar-C2H6-CF4
- Conclusions and Future Work

PRESENT STATUS: ION DIFFUSION STUDIES

- *Measure the diffusion coefficients and drift velocity of ions in gas mixtures of interest*

  will be specially important in the case of Negative Ion TPCs

Why?

To achieve optimal tracking capabilities the charge is transported by the negative ions.

Lower diffusion is obtained with ions, but as in the case of ion mobility relevant data is scarce.

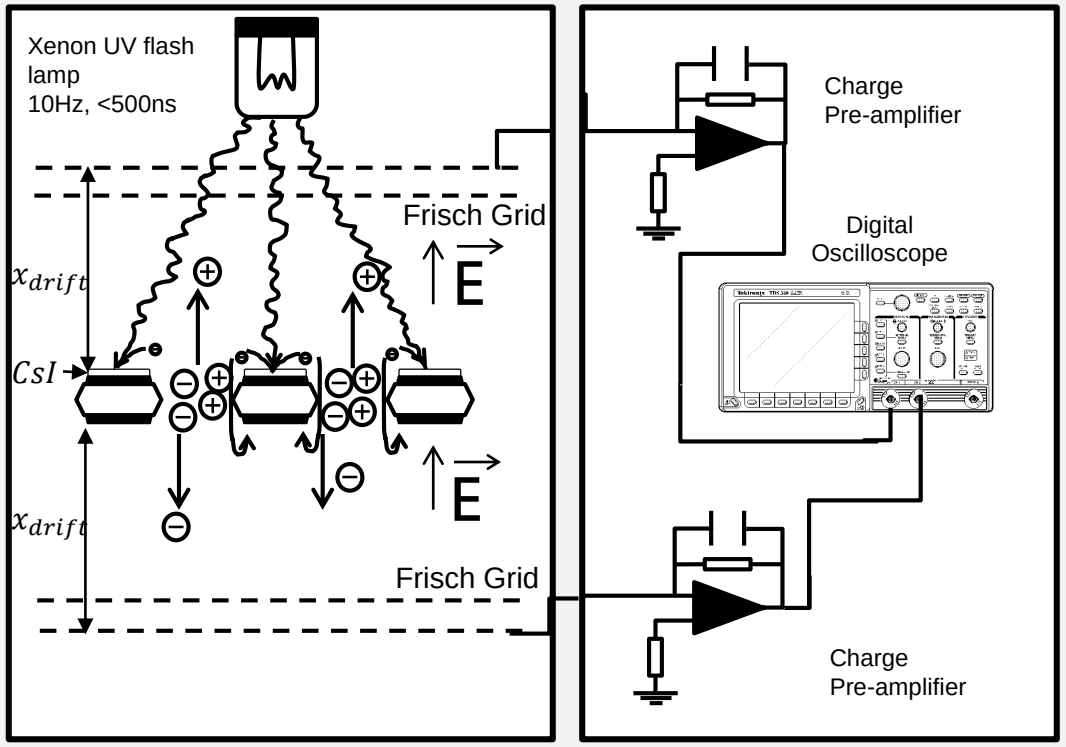
Essential for track reconstruction of events.

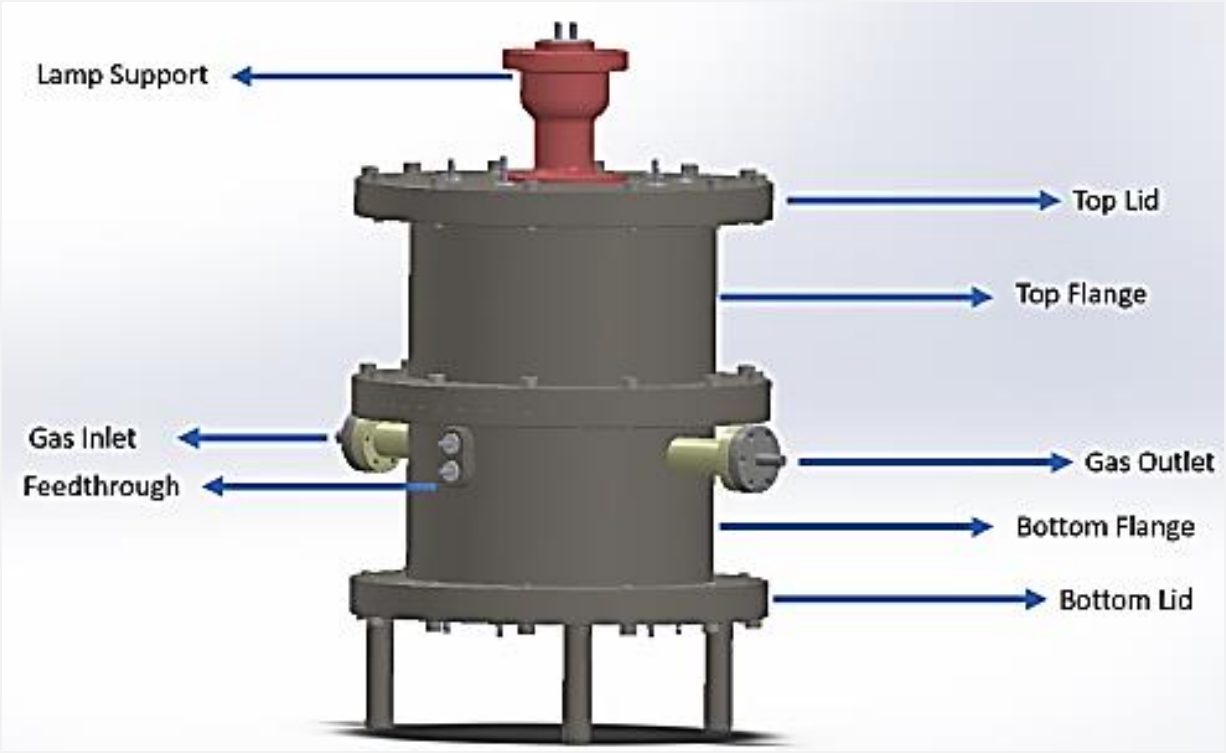
…Present Status

- **First contacts made** with **groups from RD51** with a general **good receptivity**.
- **System** is currently **being developed in Coimbra**, groups interested are more than welcome to join this effort.

PRESENT STATUS: DUAL POLARITY ION DRIFT CHAMBER

- *Systematically measure ion mobility in gaseous mixtures of interest for both TPCs and NITPCs.*





…Present Status

- New detector developed (dual-polarity drift chamber), will help to study the effect of negative and positive ions simultaneously.
- Detector already assembled.
- Integrity tests underway.

PRESENT STATUS: ION MOBILITY MEASUREMENTS

- *Systematically measure ion mobility in gaseous mixtures of interest*

Scarce data available on ion mobility of mixtures relevant for the LCTPC (Linear Collider TPC), although measurements for other gases have been performed since long.

Ar-CF4-iC4H10

Desired Characteristics

Look for the highest mobility ions to flush rapidly the TPC.

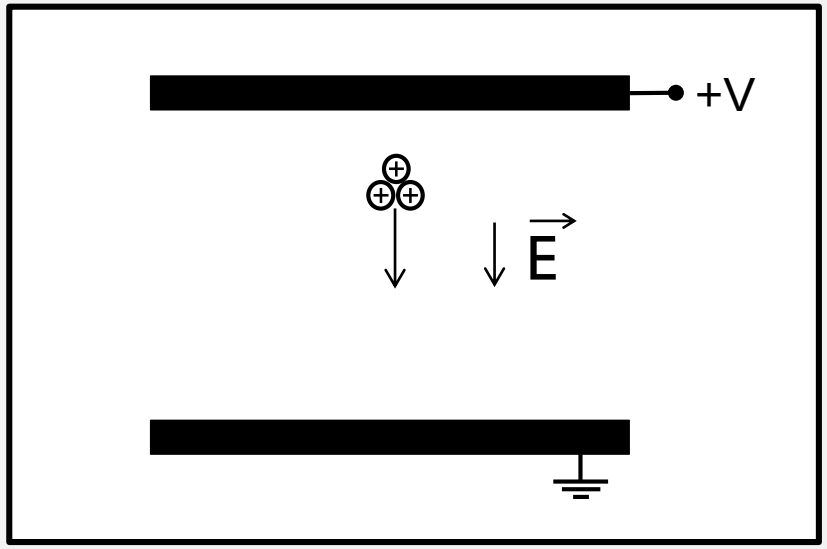
To stop the ions with a 'gating device' and dimension the gap between the gating device it is important to know the thickness of the ion disk.

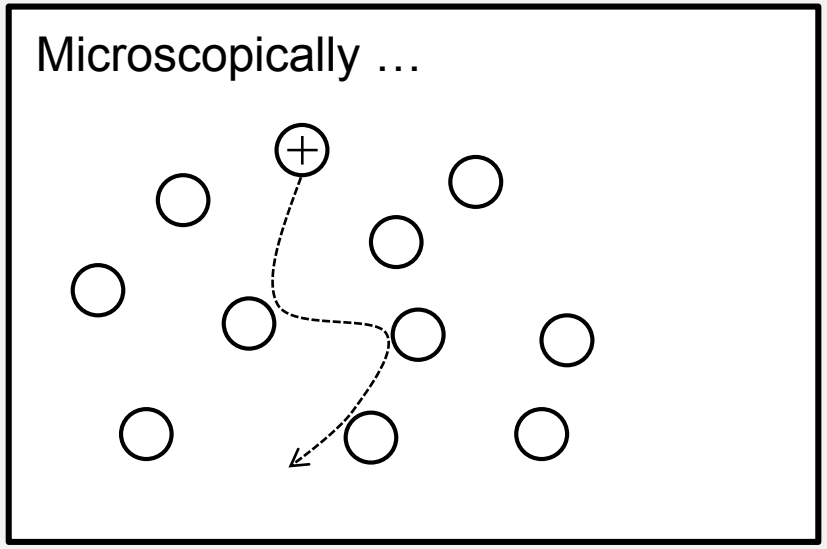
…Present Status

- All data with Ar-CF4 obtained, results to be published soon.
- Xe-CF4 data already taken with the results to be published as well.

BASIC CONCEPTS

- Let us consider a group of ions moving in a gaseous medium under the influence of a uniform electric field…





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 – reduced mass
α – neutral polarizability

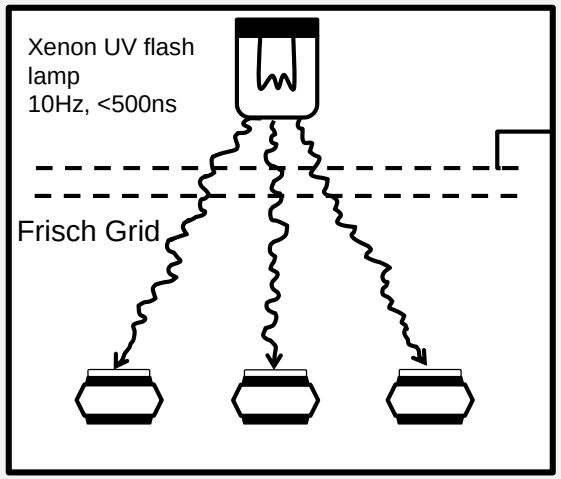
Blanc's Law

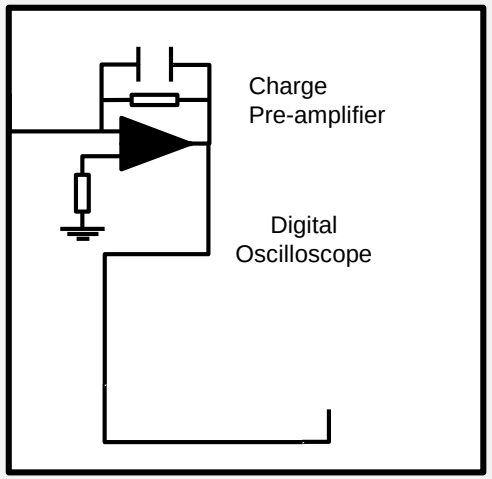
$$\frac{1}{K_{0mix}} = \frac{f_1}{K_{0g1}} + \frac{f_2}{K_{0g2}}$$

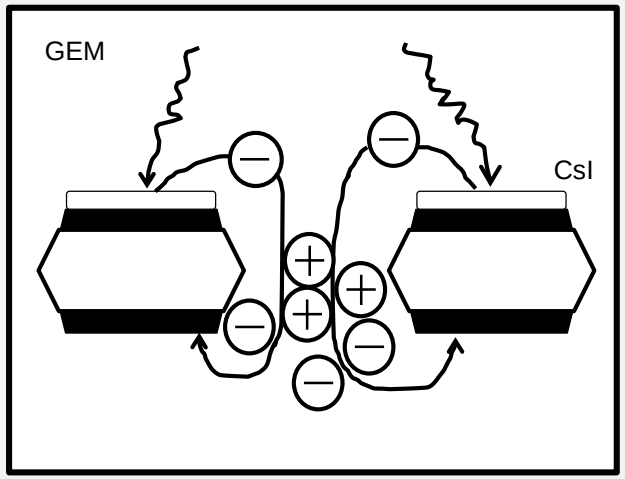
f_1, f_2– molar fraction of gas 1, 2
K_{0g1}, K_{0g2} – ion mobility in the gas 1 and gas 2

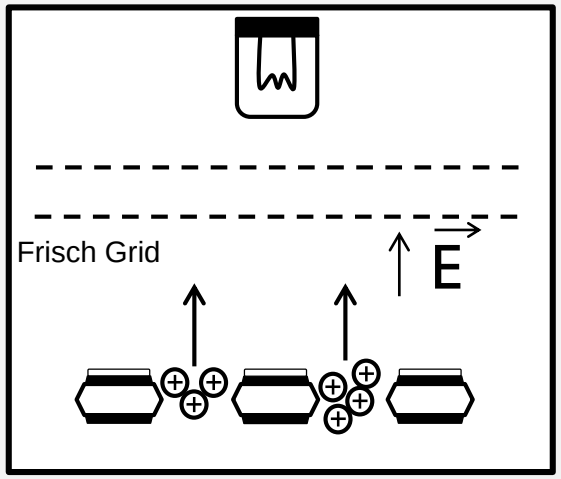
EXPERIMENTAL SETUP AND WORKING PRINCIPLE

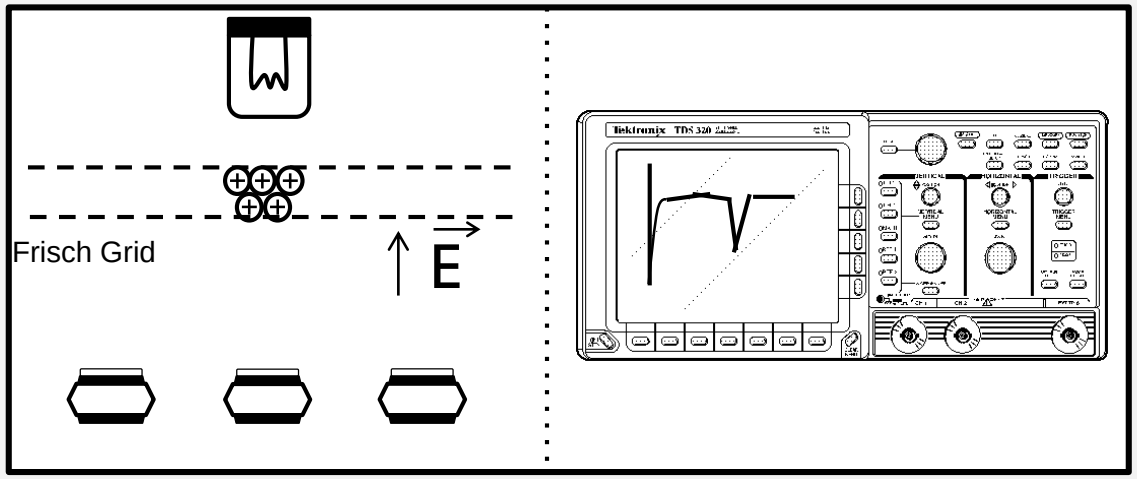
(Neves, Conde and Távora, 2007)



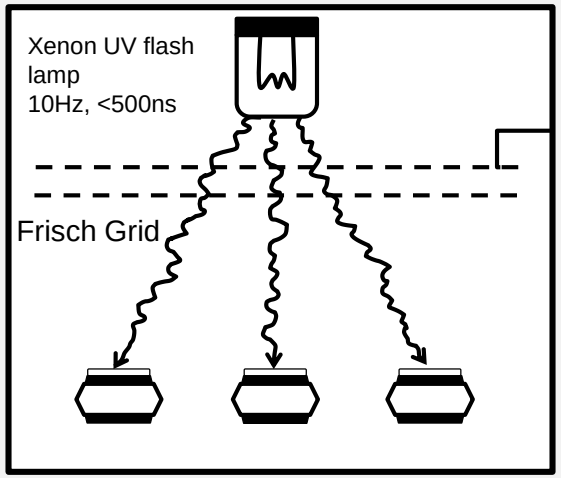


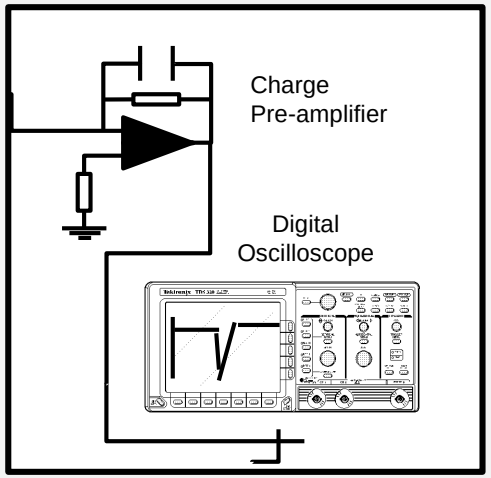






EXPERIMENTAL SETUP AND WORKING PRINCIPLE





After the signal and the background were recorded…

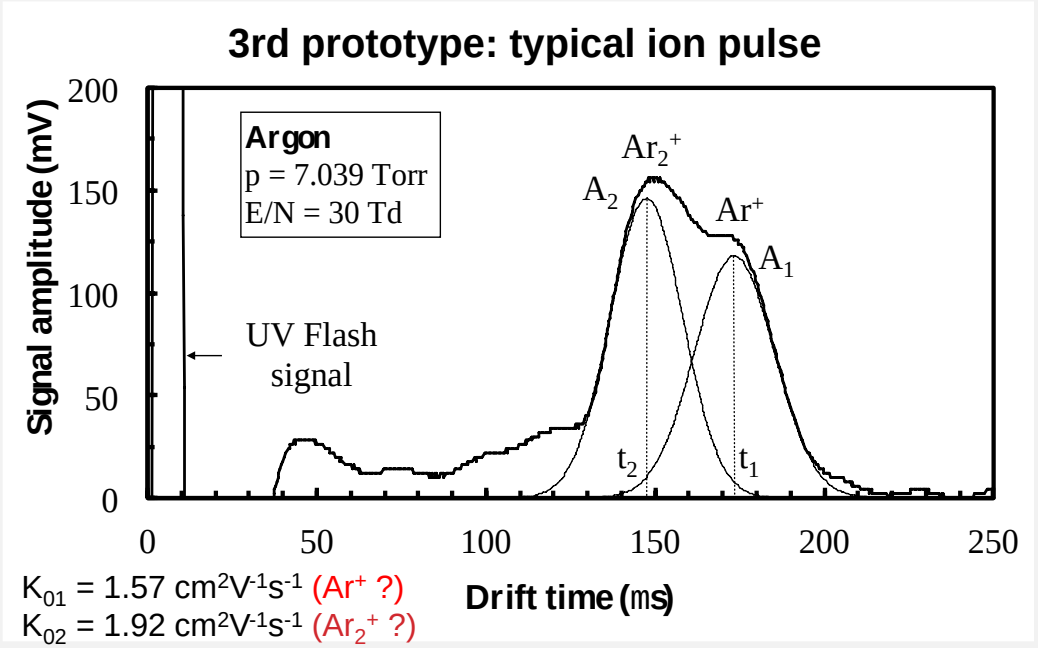
- Subtract the background to the signal
- Identify possible peaks
- Fit Gaussian curves to the spectrum obtained

peaks centroids

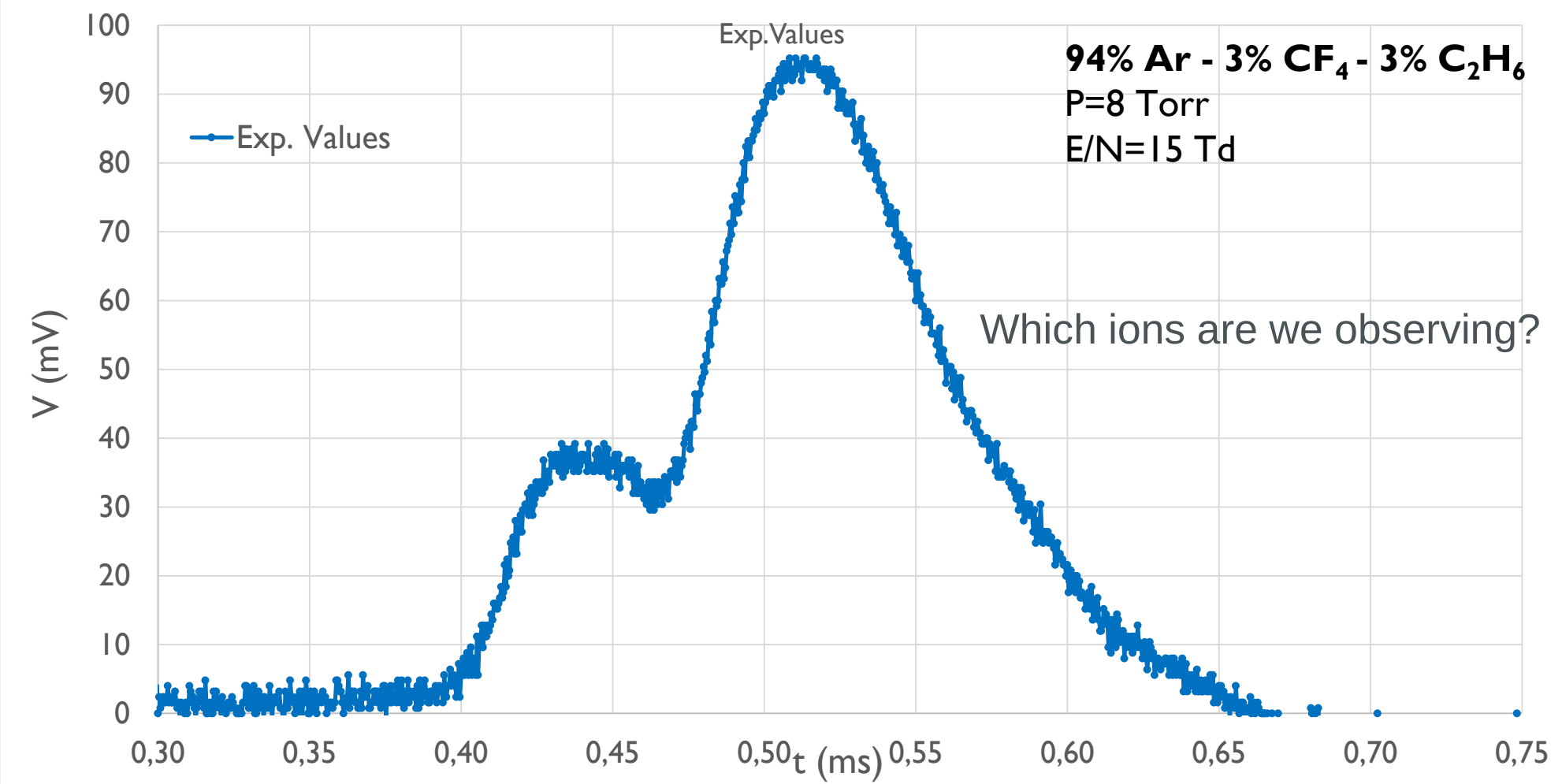
⬇

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

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



ION IDENTIFICATION: Ar-CF_4-C_2H_6



EXPERIMENTAL RESULTS: Ar

Appearance Energies

Ar^+ 15.76 eV

IONIZATION

$Ar + e \rightarrow Ar^+ + 2e$

Above threshold 15.76 eV

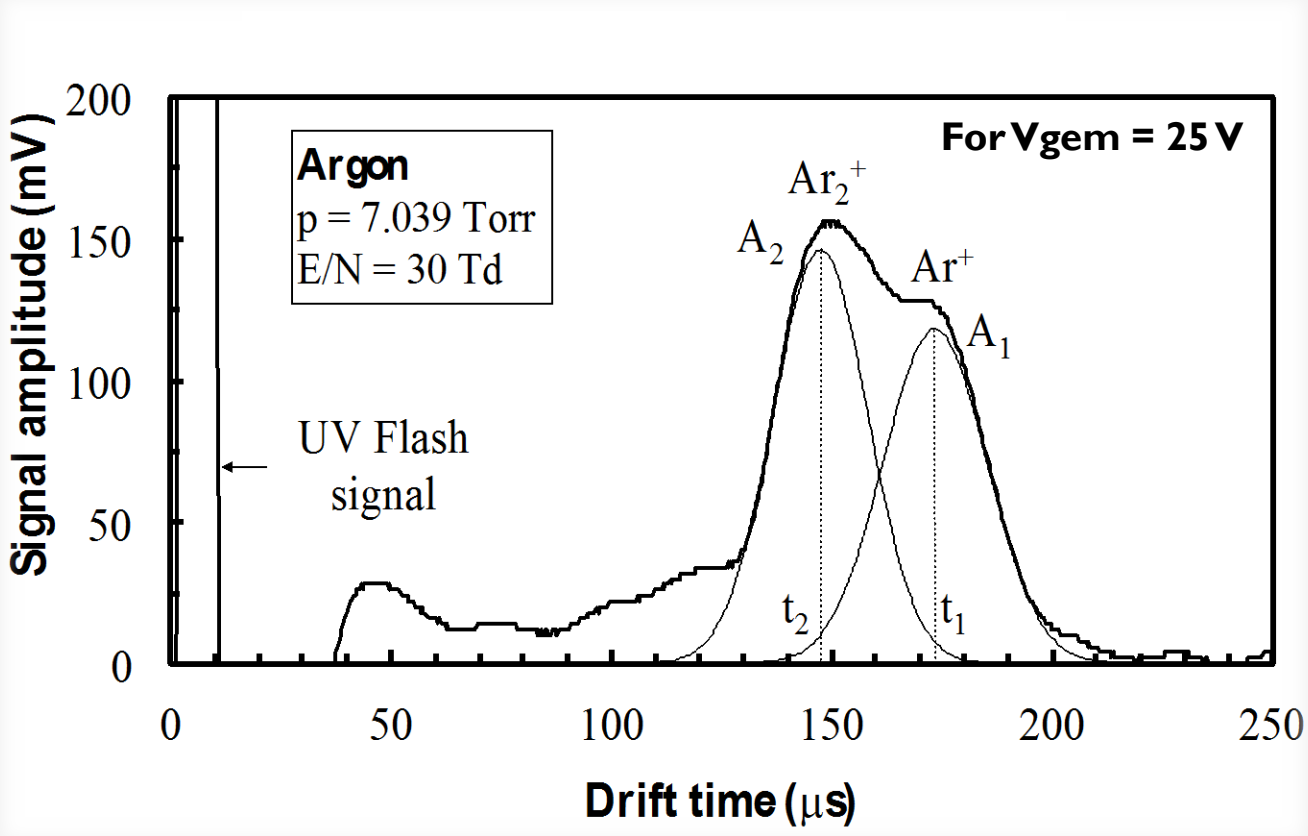
REACTIONS

$Ar^+ + 2Ar \rightarrow Ar_2^+ + Ar$

$Ar^+ + Ar \rightarrow Ar + Ar^+$

$K_{01} \sim 1.57\ cm^2V^{-1}s^{-1}$ (Ar^+ ?)

$K_{02} \sim 1.92\ cm^2V^{-1}s^{-1}$ (Ar_2^+ ?)



EXPERIMENTAL RESULTS: CF_4

Appearance Energies

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

IONIZATION

$CF_4 + e \rightarrow CF_3^+ + F + 2e$ | **above threshold 15 eV**

$CF_4 + e \rightarrow CF_3^+ + F + 2e$ 96.1 %*

$\rightarrow CF_2^+ + F_2 + 2e$ 3.6 %

$\rightarrow CF^+ + F_2 + F + 2e$ 0.16 %

0.07 %

$\rightarrow F^+ + CF_3 + 2e$ 0.07 %

$\rightarrow C^+ + 2F_2 + 2e$

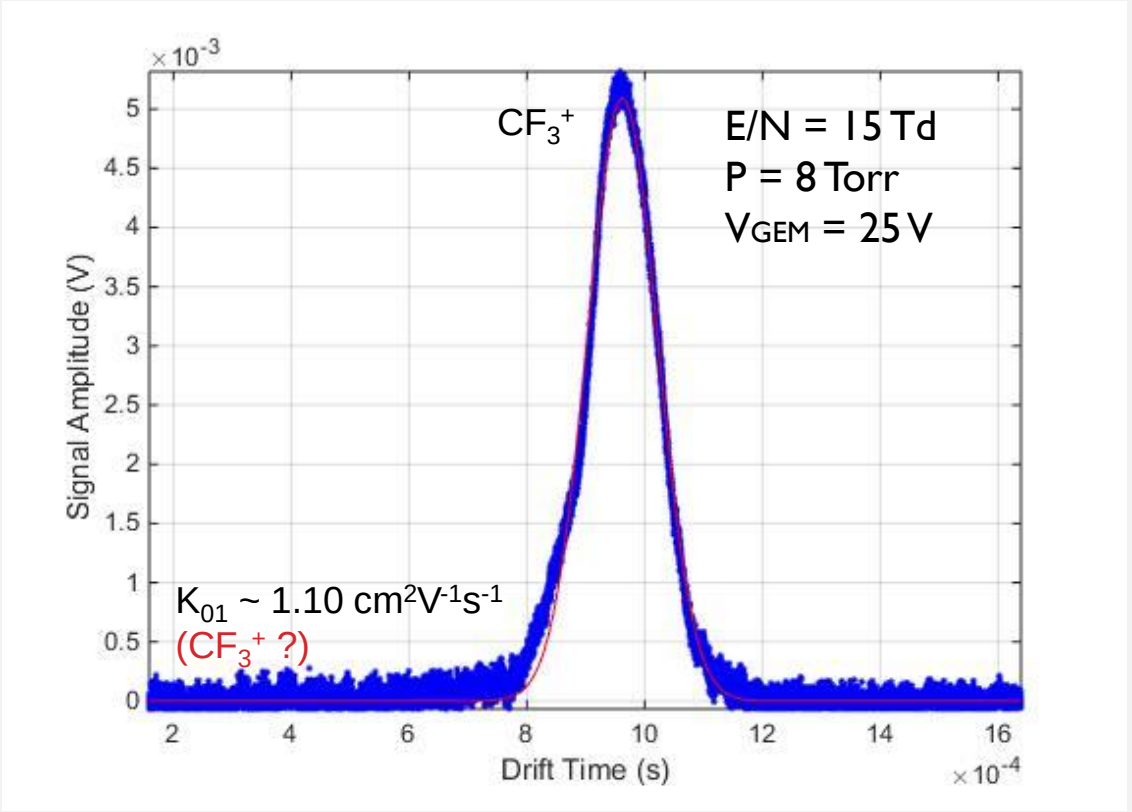
about 25 eV

REACTIONS

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

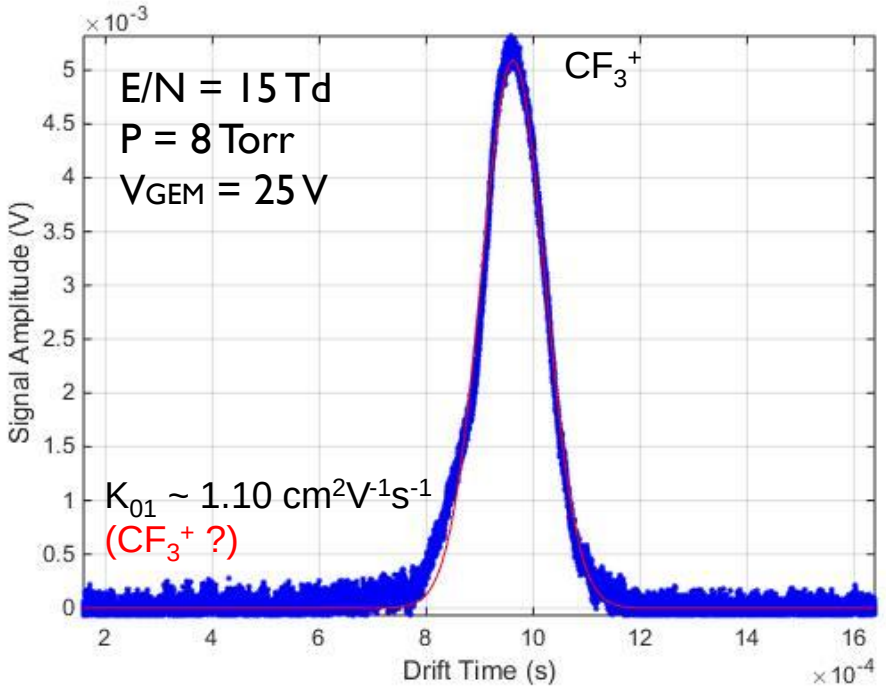
Possibility of Cluster Formation

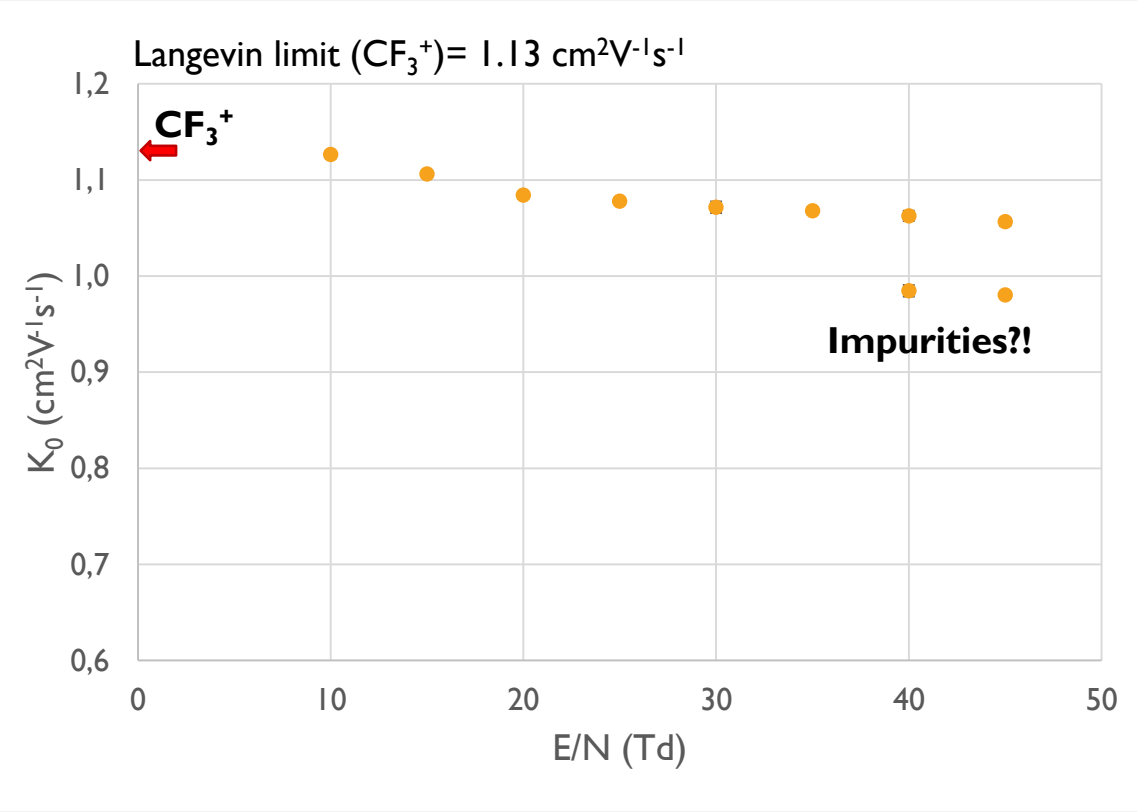
(Pressure dependent)



* values obtained from ionization cross sections for electron impact of 25 eV

EXPERIMENTAL RESULTS: CF4





Fair agreement with earlier reported work..

(Basurto, Urquijo 2002)

Experimental value		Calc. Langevin Limit
K_{01} ~ 0,96 $cm^2V^{-1}s^{-1}$ ($CF_3^+.CF_4$?)	⟺	0.92 $cm^2V^{-1}s^{-1}$

Calc. Langevin Limit		Experimental value
1.13 $cm^2V^{-1}s^{-1}$	~	1.12 $cm^2V^{-1}s^{-1}$

0.9% error

Cluster Formation

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

EXPERIMENTAL RESULTS: C_2H_6

Appearance Energies

CH_3^+	13.72 eV
$C_2H_2^+$	14.41 eV
$C_2H_3^+$	14.50 eV
$C_2H_4^+$	11.81 eV
$C_2H_5^+$	12.08 eV
$C_2H_6^+$	11.57 eV

IONIZATION

$C_2H_6 + e \rightarrow CH_3^+ + CH_3 + 2e$
$\rightarrow C_2H_2^+ + 2H_2 + 2e$
$\rightarrow C_2H_3^+ + H^- + H_2 + e$
$\rightarrow C_2H_4^+ + H_2 + 2e$
$\rightarrow C_2H_5^+ + H^- + e$
$\rightarrow C_2H_6^+ + 2e$

* 3 % 7 % 12 % 44 % 11 % 15 %

about 25 eV

REACTIONS

$C_2H_6 + \mathbf{CH_3^+} \rightarrow C_2H_5^+ + CH_4$
$\rightarrow C_3H_5^+ + 2H_2$
$\rightarrow C_3H_7^+ + H_2$

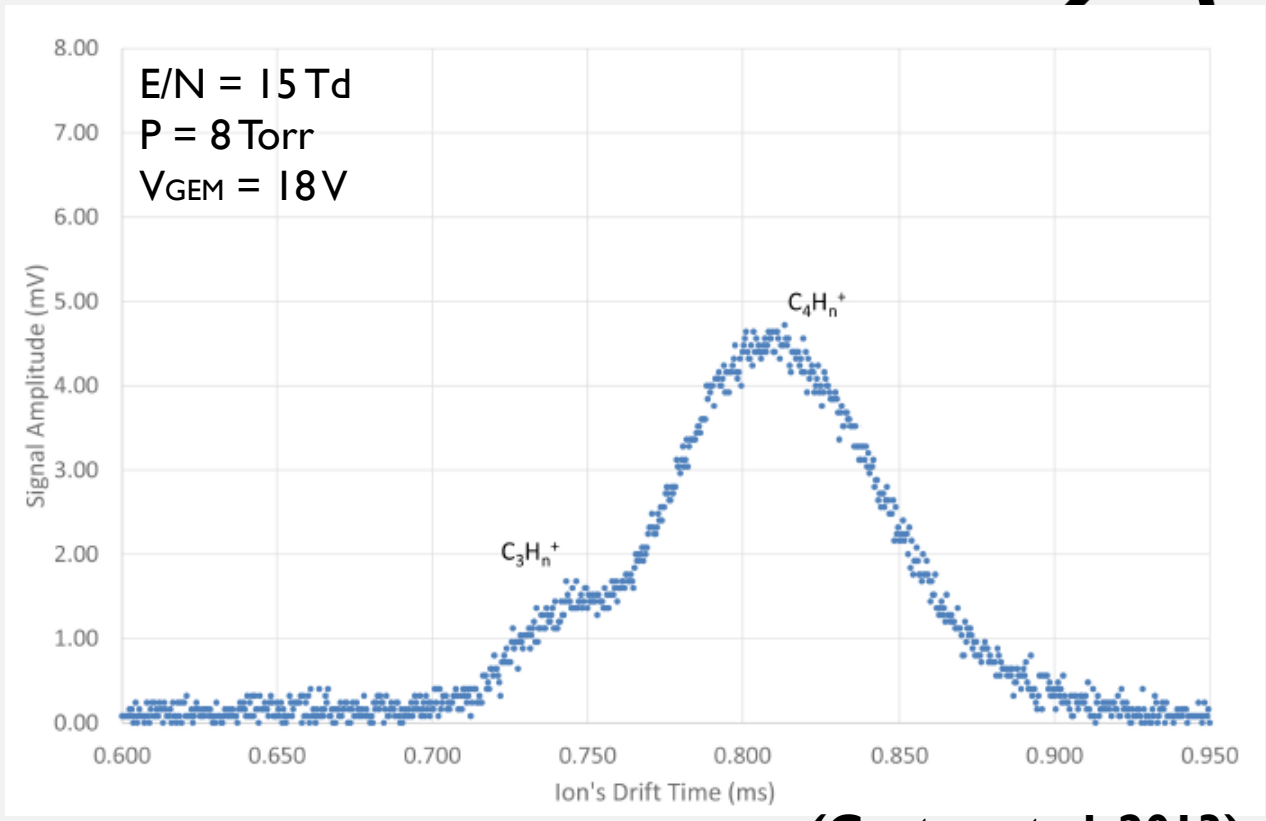
$C_2H_6 + \mathbf{C_2H_2^+} \rightarrow C_2H_4^+ + C_2H_4$
$\rightarrow C_2H_5^+ + C_2H_3$
$\rightarrow C_3H_3^+ + CH_3 + H_2$
$\rightarrow C_3H_5^+ + CH_3$
$\rightarrow C_4H_5^+ + H_2 + H$
$\rightarrow C_4H_7^+ + H$

$C_2H_6 + \mathbf{C_2H_3^+} \rightarrow C_2H_5^+ + C_2H_4$
$\rightarrow C_3H_5^+ + CH_4$
$\rightarrow C_4H_7^+ + CH_3$

$C_2H_6 + \mathbf{C_2H_4^+} \rightarrow C_3H_6^+ + CH_4$
$\rightarrow C_3H_7^+ + CH_3$

$C_2H_6 + \mathbf{C_2H_5^+} \rightarrow C_4H_9^+ + H_2$

$C_2H_6 + \mathbf{C_2H_6^+} \rightarrow C_3H_8^+ + CH_4$
$\rightarrow C_3H_9^+ + CH_3$



(Cortez et al. 2013)

Intermediate reaction
$C_2H_6 + \mathbf{C_2H_4^+} \rightarrow C_4H_{10}^+$

This results in two groups of ions a $C_3H_n^+$ and $C_4H_n^+$

* values obtained from ionization cross sections for electron impact of 25 eV

Let's now move to the binary gas mixtures:

$Ar\text{-}CF_4$

$Ar\text{-}C_2H_6$  **$Ar\text{-}CF_4\text{-}C_2H_6$**

$CF_4\text{-}C_2H_6$

EXPERIMENTAL RESULTS: Ar-CF4

Ions move faster with the presence of Ar.

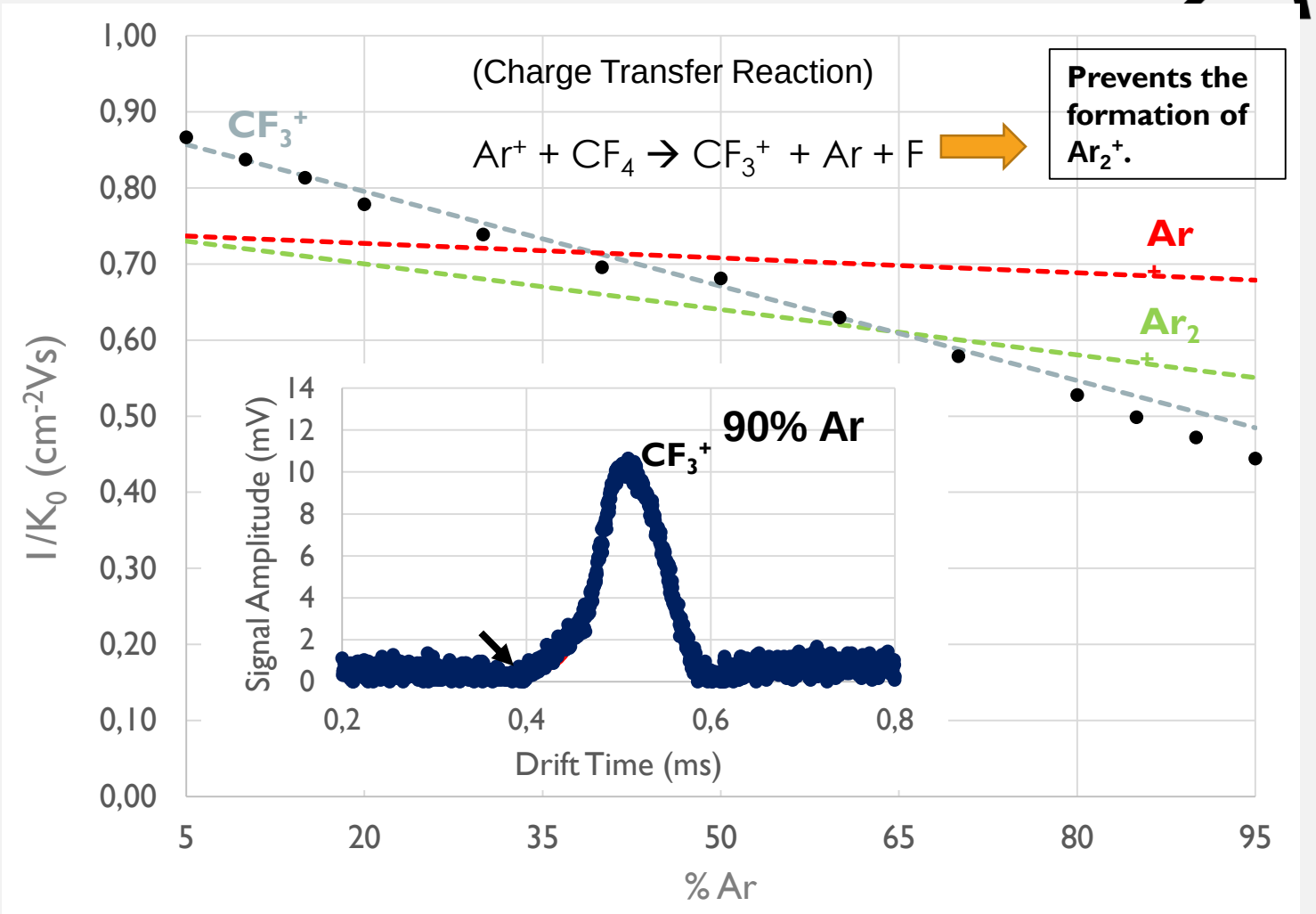
Behaviour well described by Blanc's law and Langevin theory.

Amplitude rises until 90% of Ar

- Cross section.
- Presence of Ar leads to the same ion as in pure CF4.

Only one peak for 15 Td
a bump appears for Ar > 80%

- Probably due to impurities.



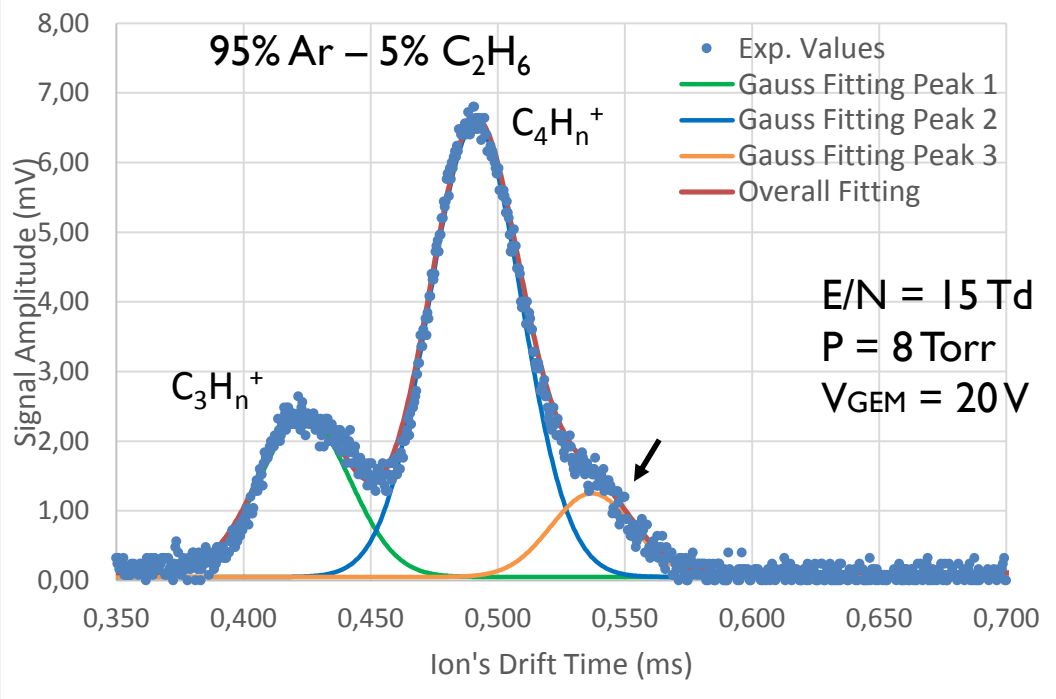
Increasing pressure may lead to the **formation** of **cluster** (**10% slower** than CF3+)

EXPERIMENTAL RESULTS: Ar-C_2H_6

Ions move **faster** and the signal **amplitude decreases** with the presence of **Ar**

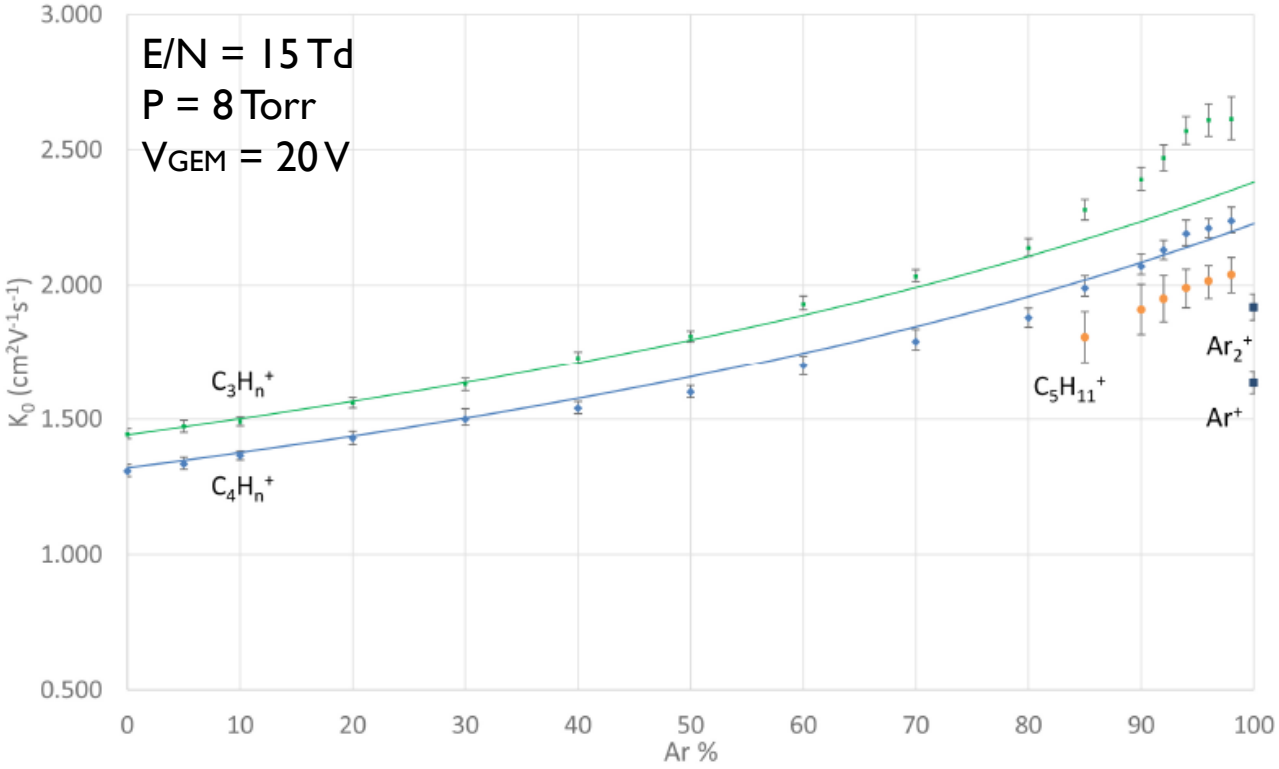
Behaviour **well described** by Blanc's law and Langevin theory **until 80%** of **Ar**

A **bump** appears **above 85%** of **Ar**



(Charge Transfer Reaction)

$Ar^+ + C_2H_6 \rightarrow$ products



(Cortez et al. 2013)

EXPERIMENTAL RESULTS: CF_4-C_2H_6

Ions move slower with the presence of **CF4**.

Behaviour **roughly described by Blanc's law and Langevin theory**

Amplitude decreases with increasing **concentration of CF4**

- **Two peaks throughout all mixtures**

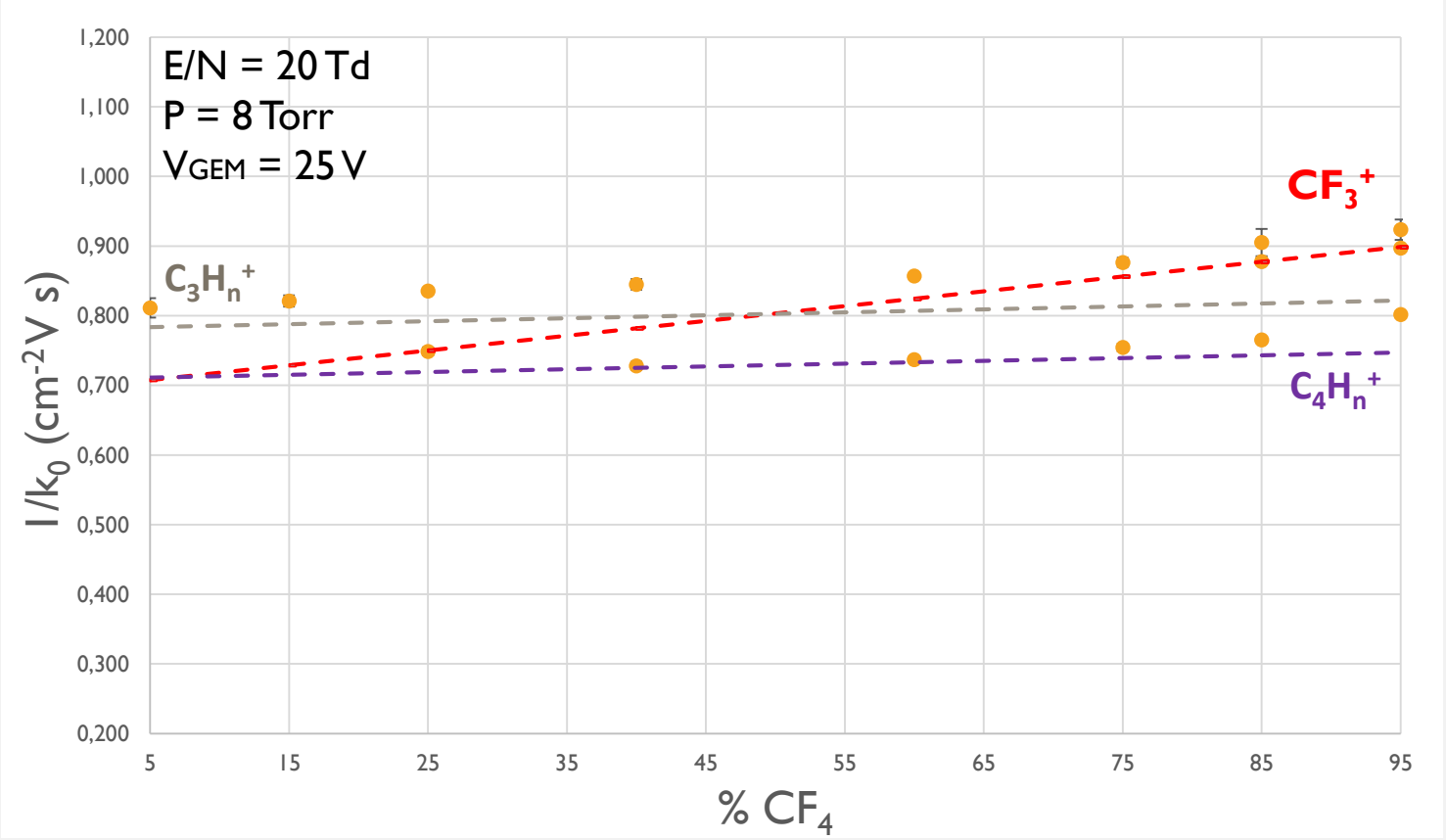
Two different ions (**C3Hn+** and **C4Hn+)**

- **One peak** (overlap) up to 15%
- **Two peaks** clearly identified for 20 Td **between 25% and 85%** of CF4
- A **third peak** appears for concentrations above **85%** of CF4

Charge Transfer Reactions

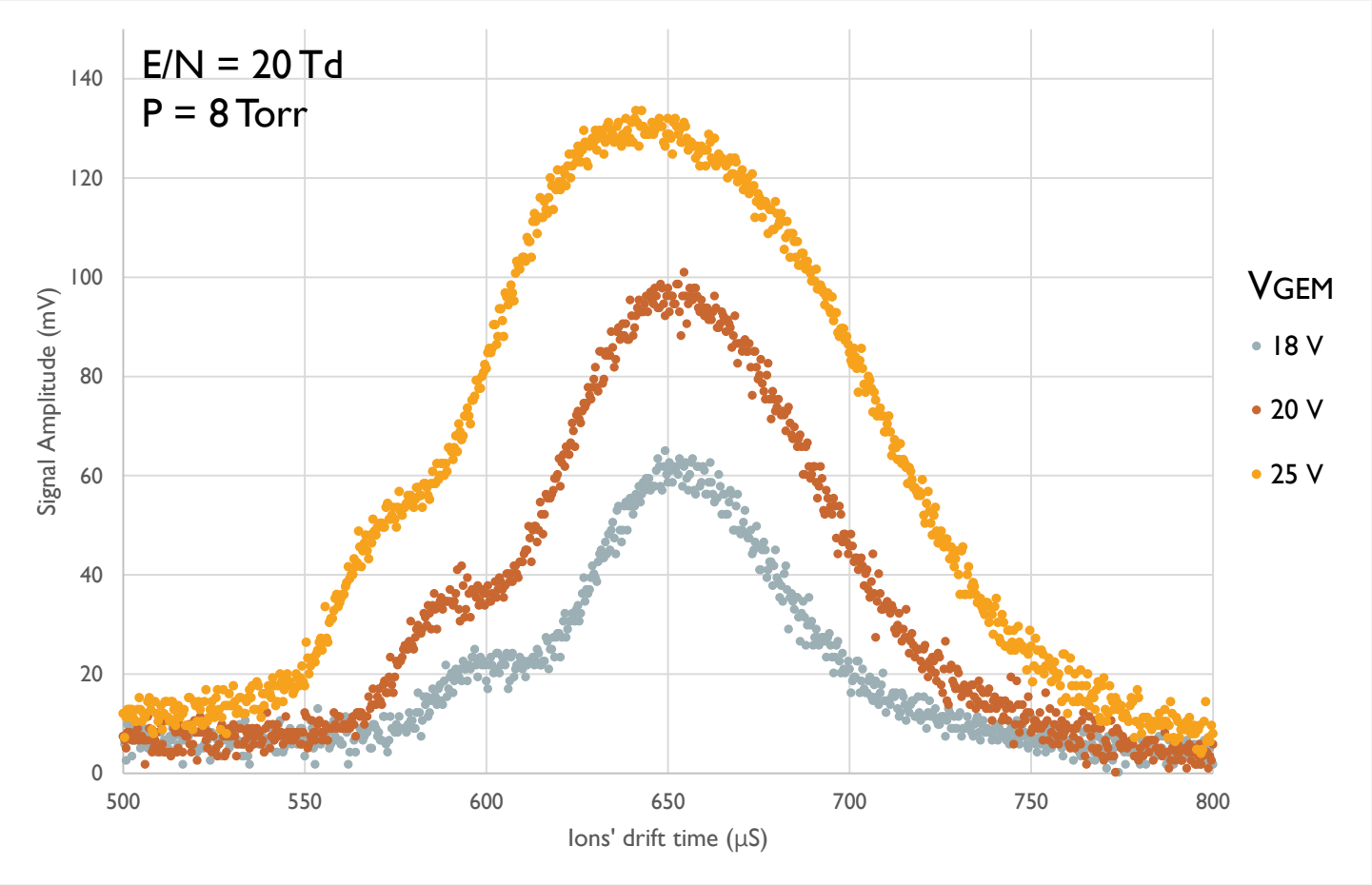
$CF_3^+ + C_2H_6 \rightarrow C_2H_5^+ + CF_3H$

$\rightarrow C_2H_6^+ + CF_3$



EXPERIMENTAL RESULTS: CF_4-C_2H_6

Why there is only one peak up to 15 % of CF4?



Increasing V_{GEM}

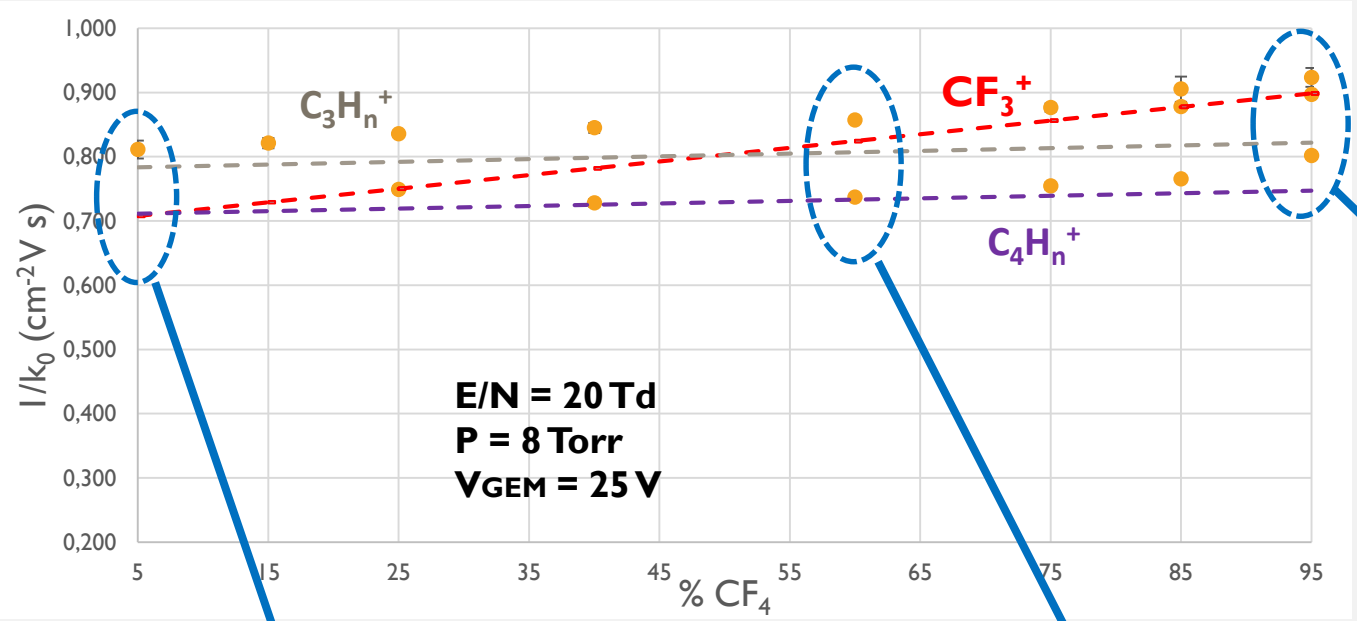
Increases the electric field inside the GEM holes

Increases the number of ions

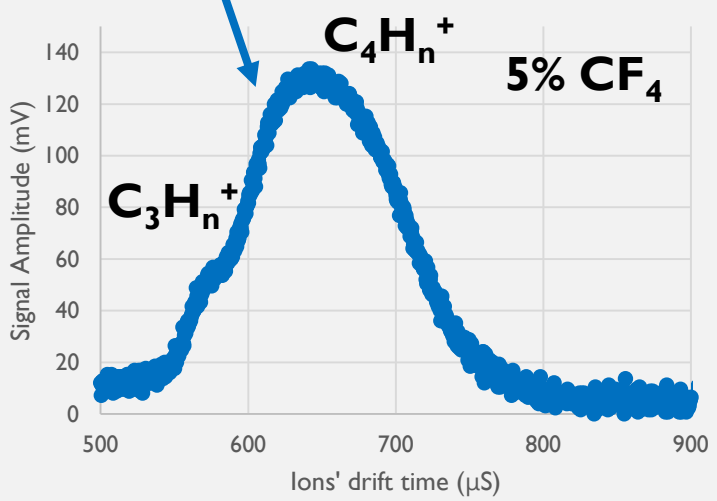
Increases space charge effects

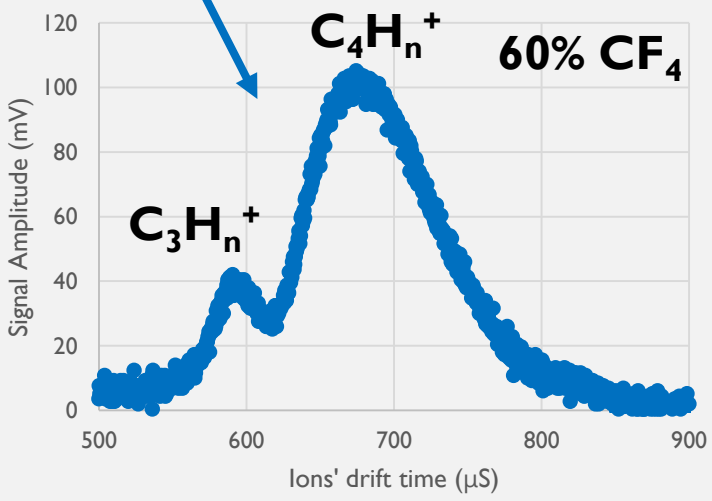
Leads to peak broadening

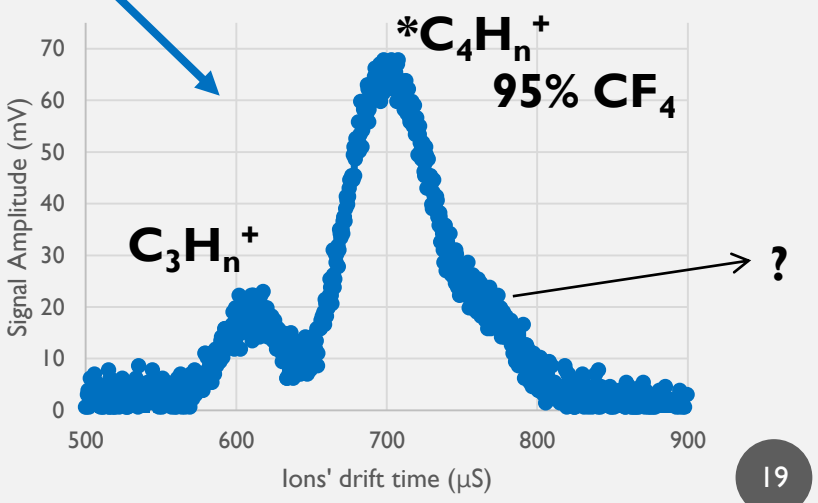
EXPERIMENTAL RESULTS: CF_4-C_2H_6



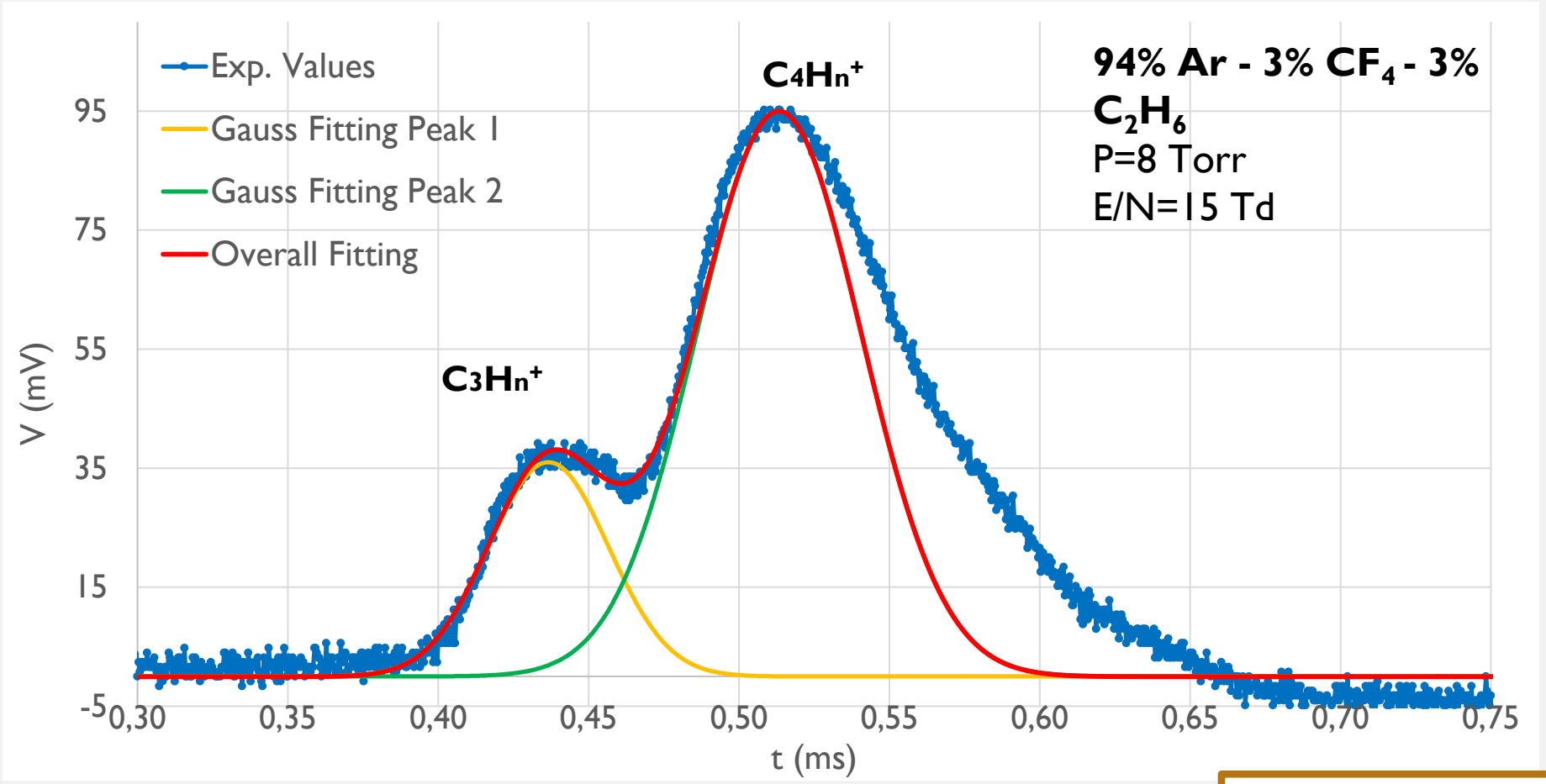
* The mobility is highly influenced by the predecessor ions







EXPERIMENTAL RESULTS: Ar-CF_4-C_2H_6



Theor. Values

($cm^2\ V^{-1}\ s^{-1}$)

K_{C3HN+} ~ 2.31

K_{C4HN+} ~ 2.15

Exp. Values ($cm^2\ V^{-1}\ s^{-1}$)	**Theor.**
K_{01} ~ 2.50±0.03	**8.4 %**
K_{02} ~ 2.07±0.02	**3.4 %**

$C_2H_6 + C_2H_4^+ \rightarrow C_3H_n^+ +$ products

Increases the mobility of C3Hn+

CONCLUSIONS AND FUTURE WORK

- Pursuit the investigation on the mobility of ions in different gas mixtures of practical use (if you have any suggestions feel free to contact us):
  - *Ar-iC4H10*
  - *CF4-iC4H10*
  - *Ar-CF4-iC4H10 (LCTPC objective)*
  - *Ne-CF4*

- First measurements with new detector:
  - *SF6 and mixtures of SF6 with additive gases of interest.*

With this new detector we expect to be able to:

- Study the rate constant influence
- Study lighter ions (H2)
- Negative ions (for NTPCs)
- (...)

Thank you for listening…

Questions?

Universidade de Coimbra

MIXING LANGEVIN LIMIT WITH BLANC'S LAW

Langevin Limit

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

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

μ – reduced mass
α – neutral polarizability

Experimental Ion Mobility Values

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

Theoretical Mobility Values

Blanc's Law

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

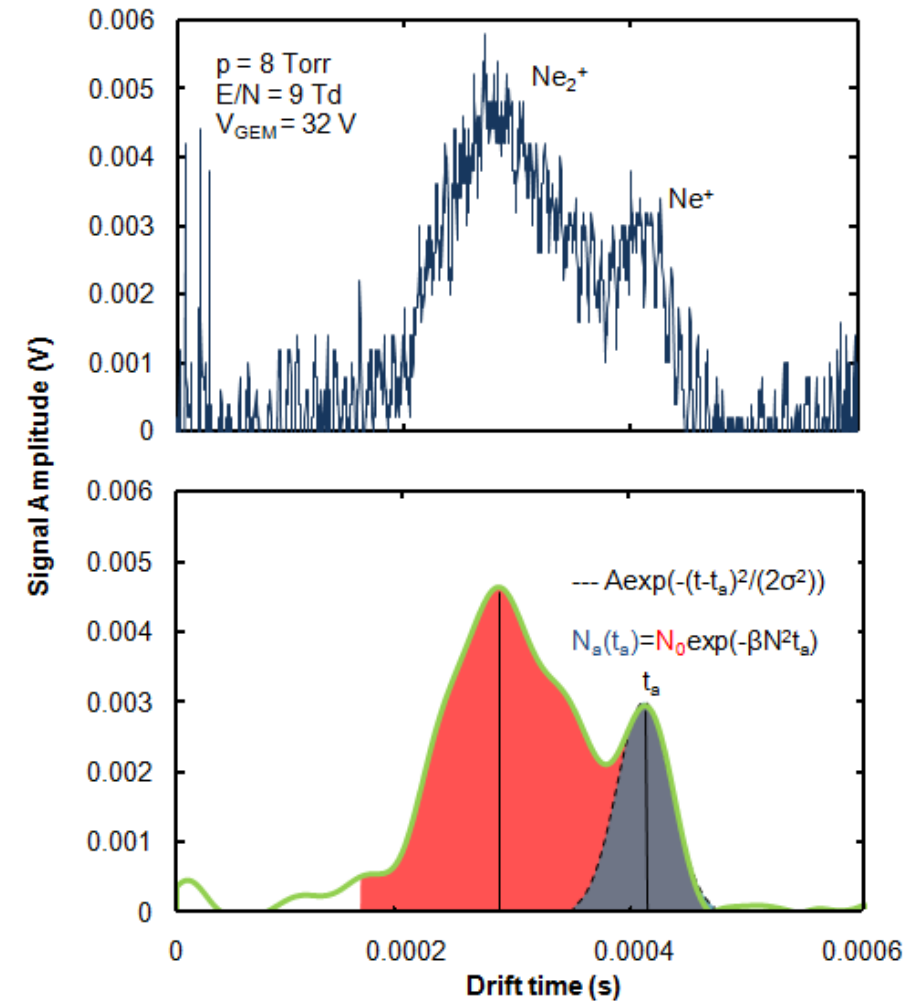
$$\frac{1}{K_{0mix}} = \frac{f_1}{K_{0g1}} + \frac{f_2}{K_{0g2}}$$

f_1 , f_2– molar fraction of gas 1 and 2

Mobility of an ion in a mixture

REACTION RATE MEASUREMENTS

$$Rg^+ + 2Rg \xrightarrow{\beta} Rg_2^+ + Rg$$



$Rg^+ + 2Rg \rightarrow Rg_2^+ + Rg$

$d[Rg^+]/dt = -\beta[Rg^+][Rg]^2$

$[Rg+](t)=[Rg+](0)\exp(-\beta N^2 t)$

$[Rg^+](t)$ is proportional to the area of the atomic ion gaussian.

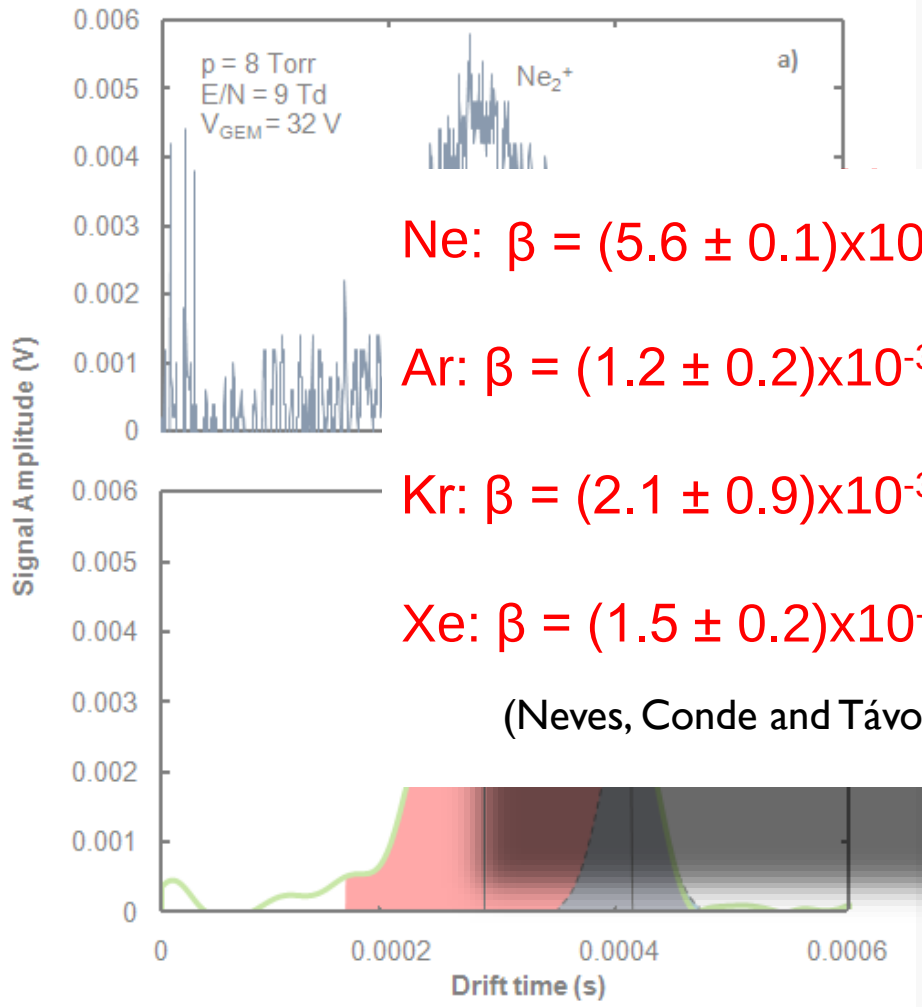
$[Rg+](0)$ is proportional to the total area.

Depends on:

- Temperature

RESULTS: REACTION RATE

$$Rg^+ + 2Rg \xrightarrow{\beta} Rg_2^+ + Rg$$



Ne: $\beta = (5.6 \pm 0.1)\times10^{-32}\ cm^6s^{-1}$

Ar: $\beta = (1.2 \pm 0.2)\times10^{-31}\ cm^6s^{-1}$

Kr: $\beta = (2.1 \pm 0.9)\times10^{-31}\ cm^6s^{-1}$

Xe: $\beta = (1.5 \pm 0.2)\times10^{-31}\ cm^6s^{-1}$

(Neves, Conde and Távora, 2010)

$Rg^+ + 2Rg \rightarrow Rg_2^+ + Rg$

$g]^2$

$(-\beta N^2)$

onal to the area
aussian.

ional to the
total area.

CANDIDATE IONS IDENTIFICATION

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.

Select Most Probable Ions

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.

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

$$\frac{[Rg^+]}{[Rg^+]_0} = e^{-\frac{t}{\tau}} \qquad \frac{[X^+]}{[X^+]_0} = 1 - \frac{[Rg^+]}{[Rg^+]_0}$$

- Identification the possible ions present.