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Ion mobility studies for the ILC experiment

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  - Basic Concepts
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    - Ar-CF4,
    - Ar-CH4
    - CF4-CH4
    - Ar-CH4-CF4
- Conclusions and Future Work

Objective...

- *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.

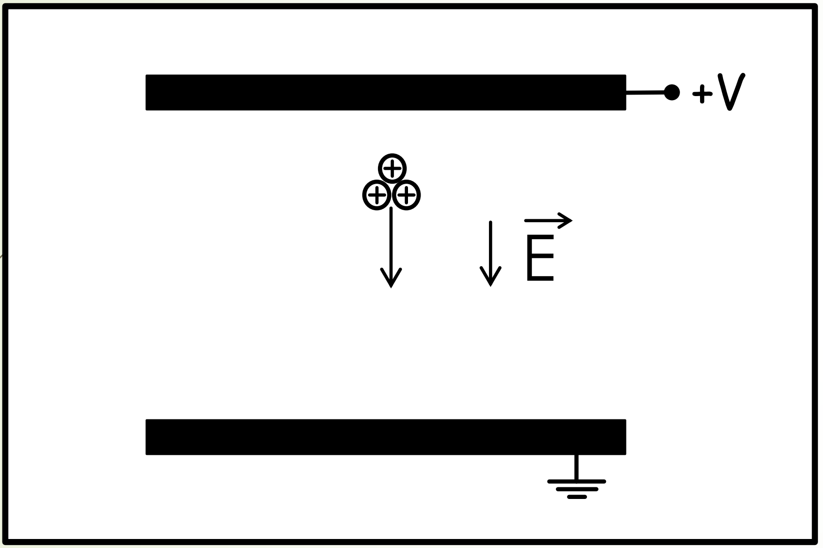
To stop the ions with a 'gating device' and dimension the gap between the gating device it is important to know the thickness of the ion disk.

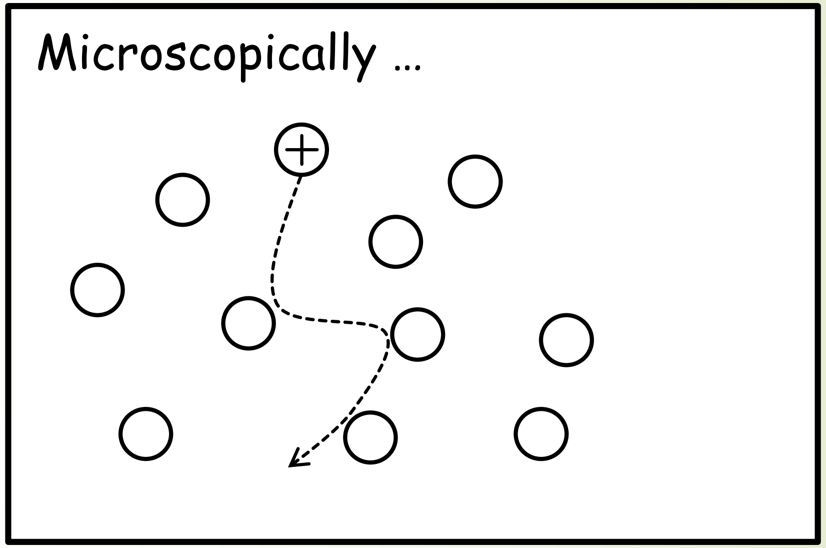
...Present Status

- First results with Ar-CF4 (to be published).
- New detector developed (dual-polarity drift chamber), will help to study the effect of negative ions simultaneously.

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

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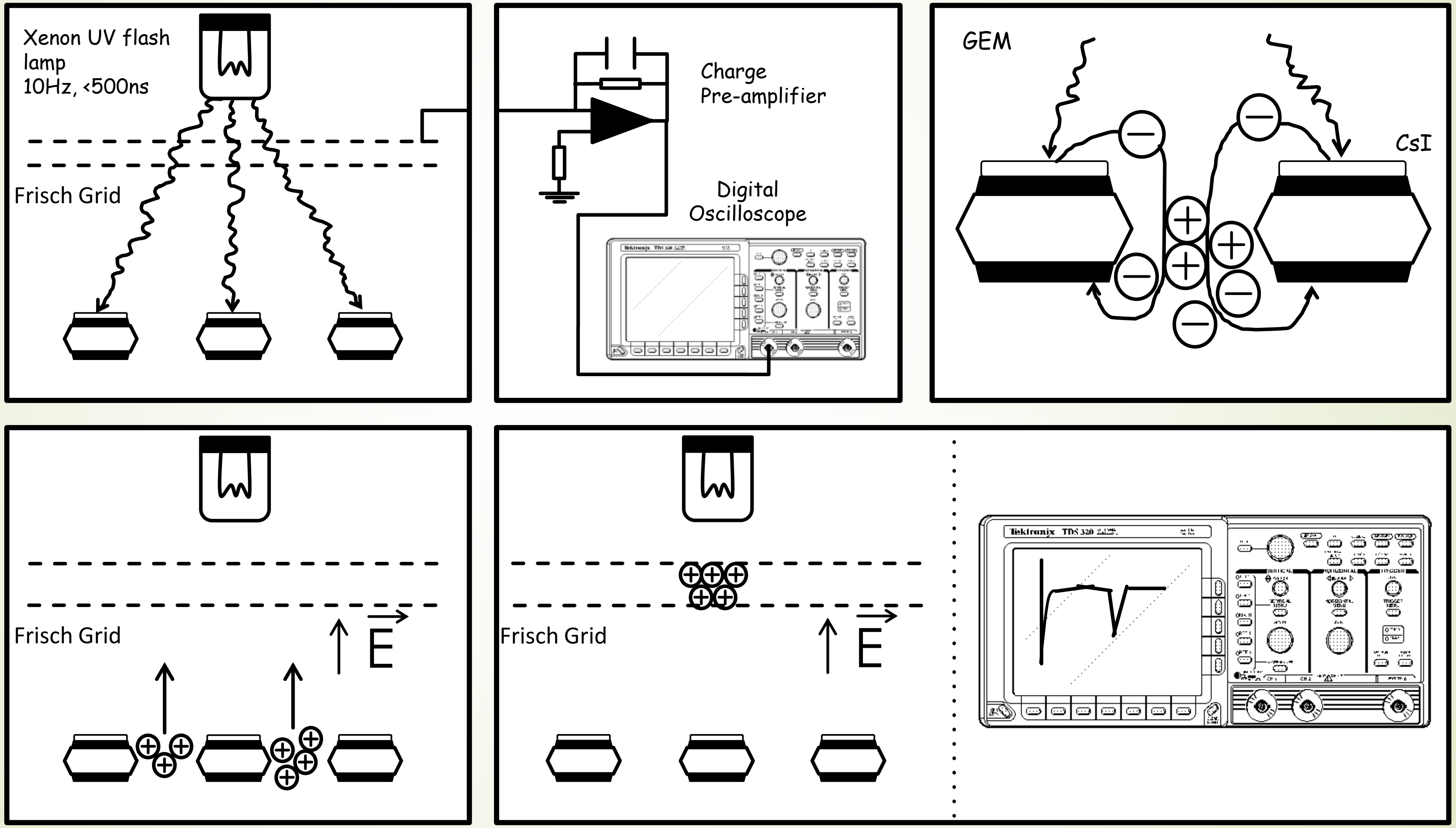
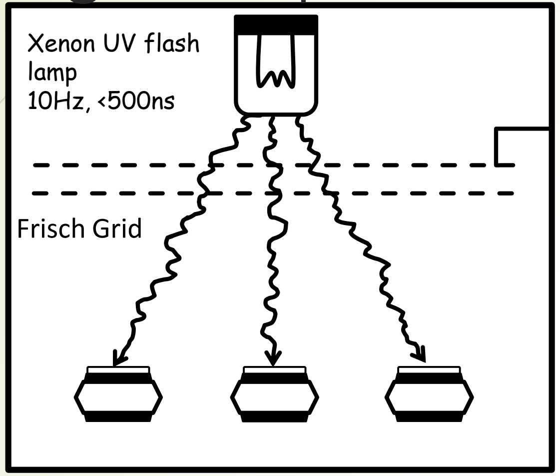
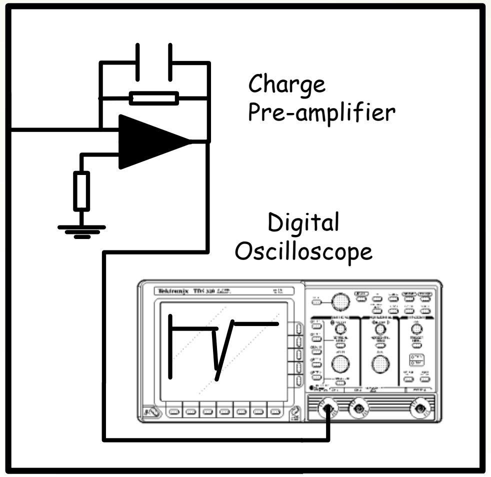
Experimental Setup and Working Principle

(Neves, Conde and Távora, 2007)



Experimental Setup and Working Principle





After the signal and the background were recorded…

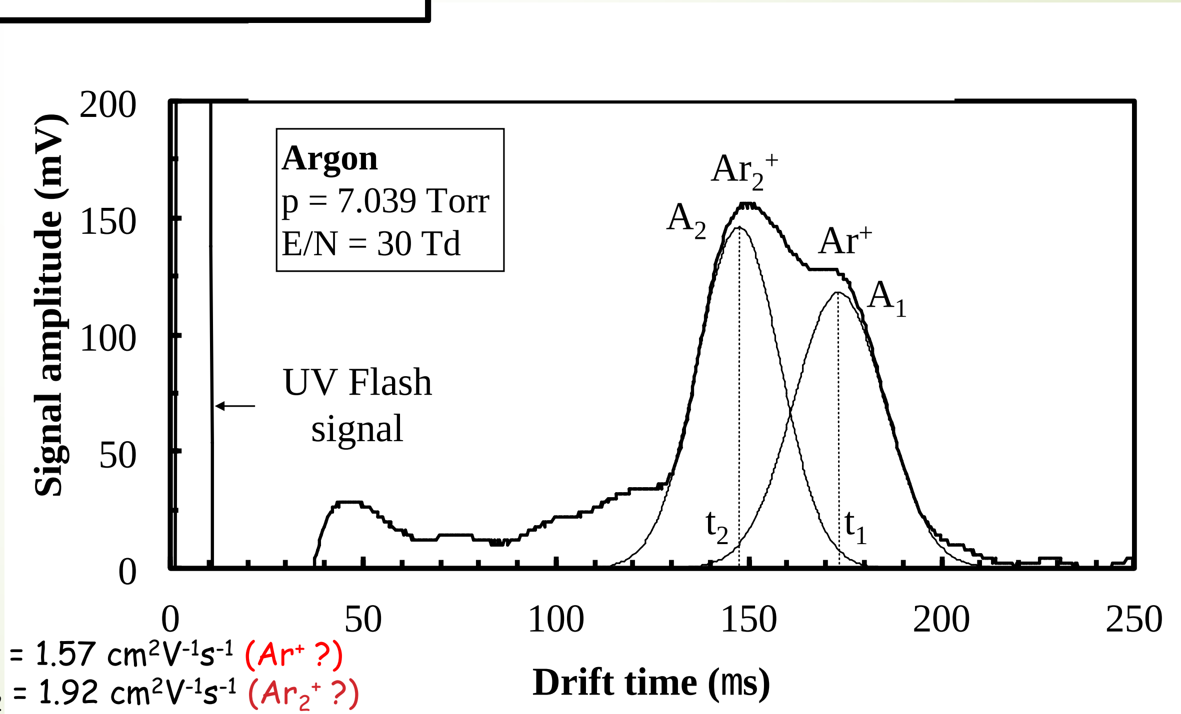
- Subtract the background to the signal
- Identify possible peaks
- Fit Gaussian curves to the spectrum obtained

peaks centroids

⬇

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

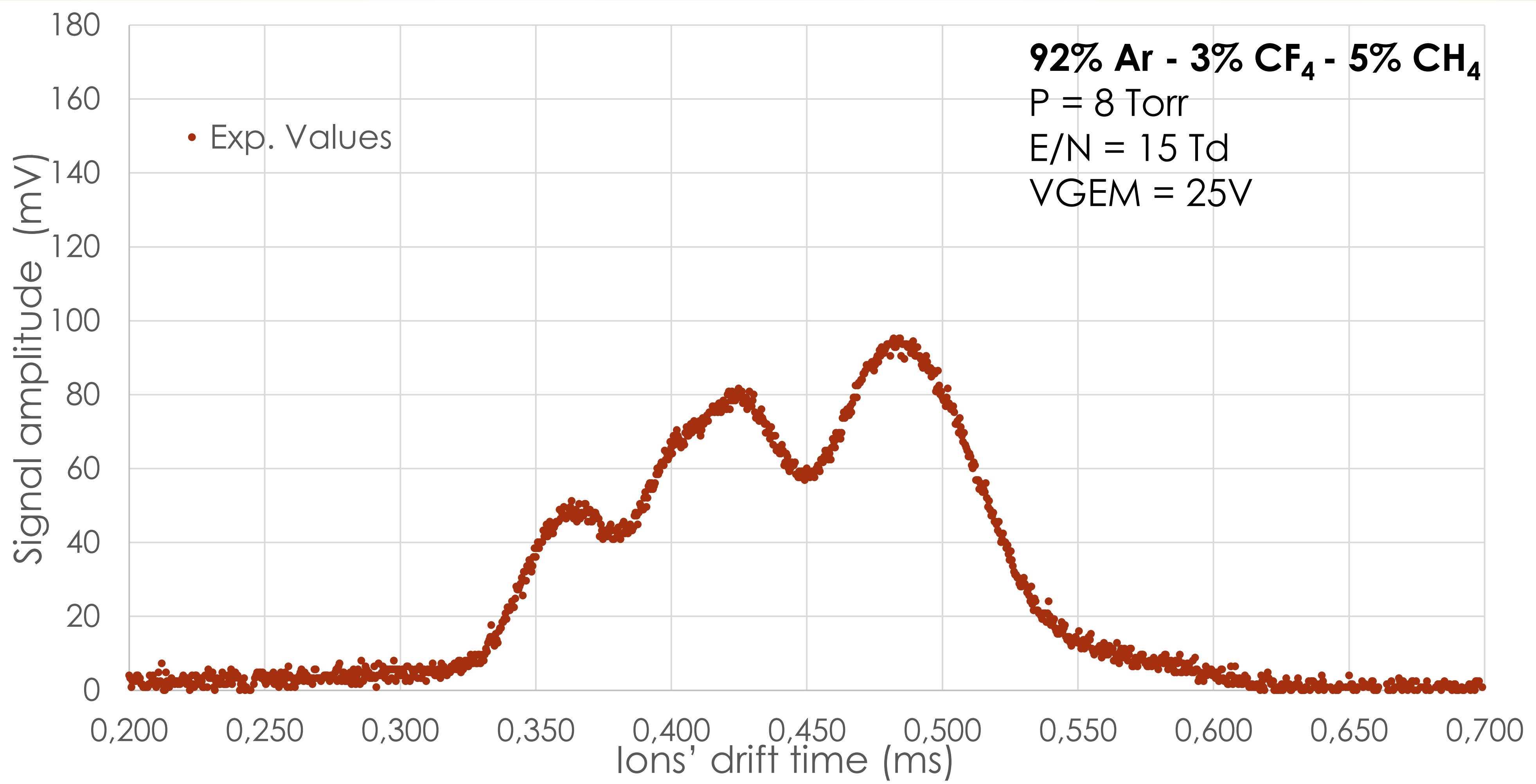
$$v_d = \frac{x_{drift}}{t_{drift}} \quad \Rightarrow \quad K = \frac{v_d}{E}$$



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

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

Ion Identification: $Ar\text{-}CF_4\text{-}CH_4$



Which ions are we observing?

Experimental Results: Ar

Appearance Energies

Ar^+ 15.76 eV

IONIZATION

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

Above threshold 15.76 eV

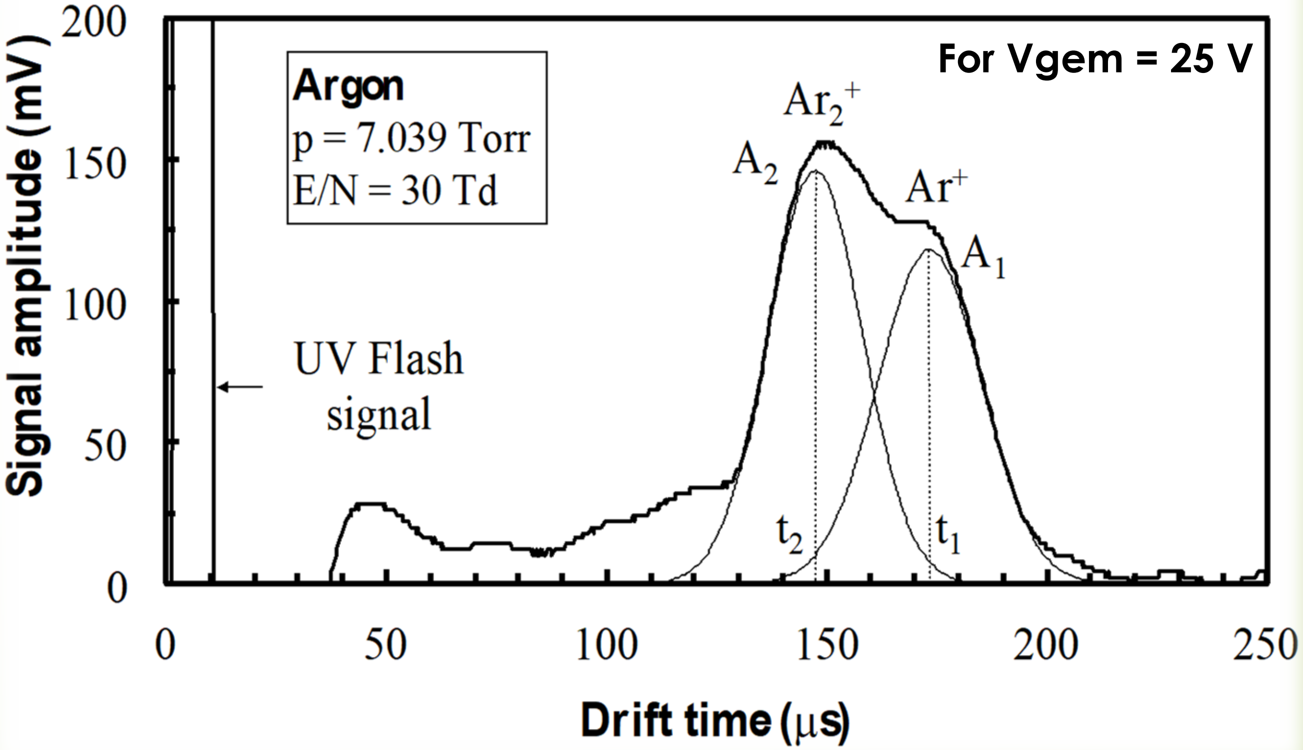
REACTIONS

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

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

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

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



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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

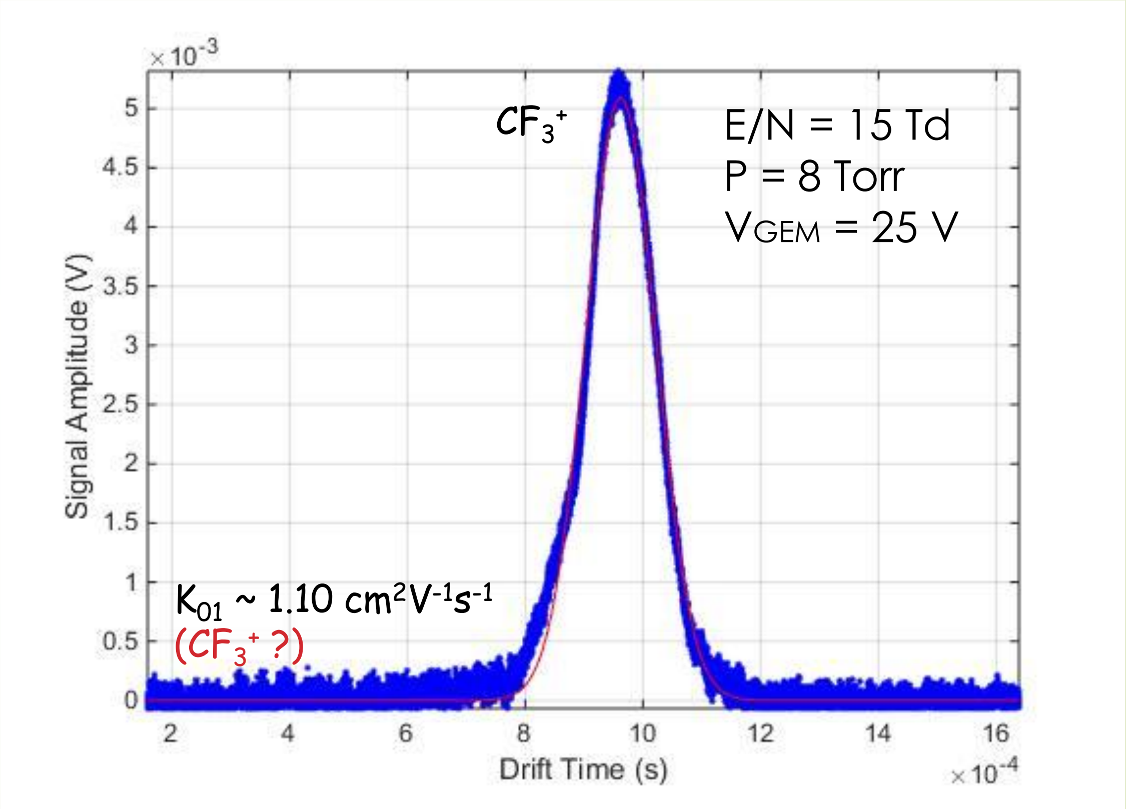
$CF_4 + e \rightarrow CF_3^+ + F + 2e$ | **above threshold 15 eV**

Reaction	*	
$CF_4 + e \rightarrow CF_3^+ + F + 2e$	96.1 %	**about 25 eV**
$\rightarrow CF_2^+ + F_2 + 2e$	3.6 %	
$\rightarrow CF^+ + F_2 + F + 2e$	0.16 %	
$\rightarrow F^+ + CF_3 + 2e$	0.07 %	
$\rightarrow C^+ + 2F_2 + 2e$	0.07 %	

REACTIONS

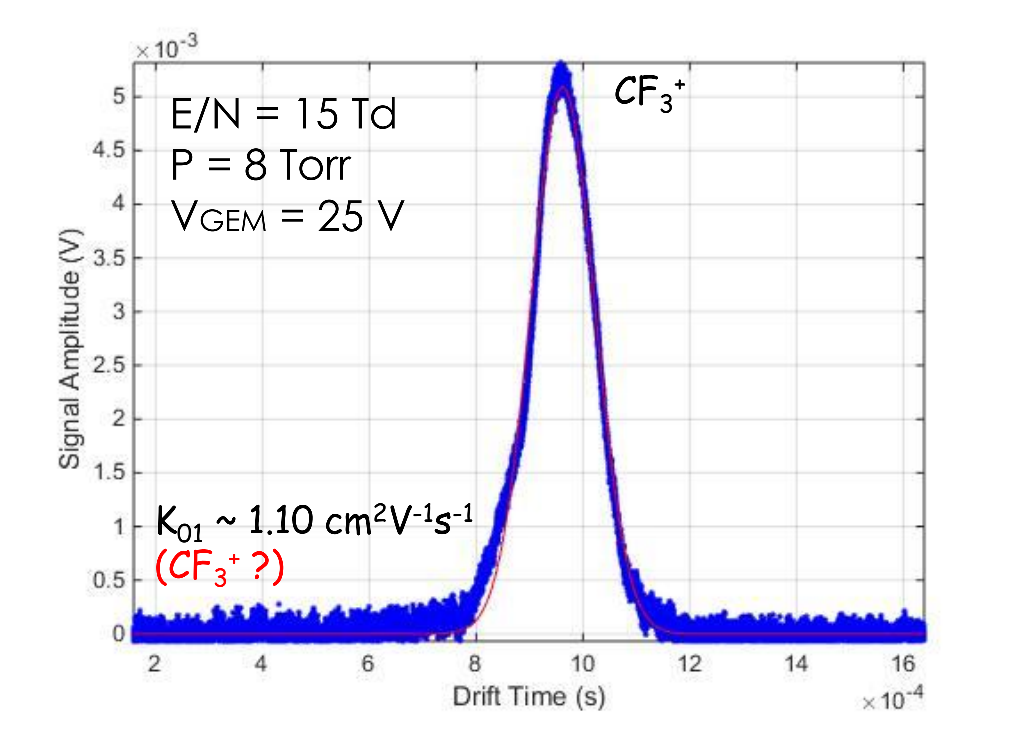
$CF_3^+ + 2CF_4 \rightarrow CF_3^+.(CF_3)$

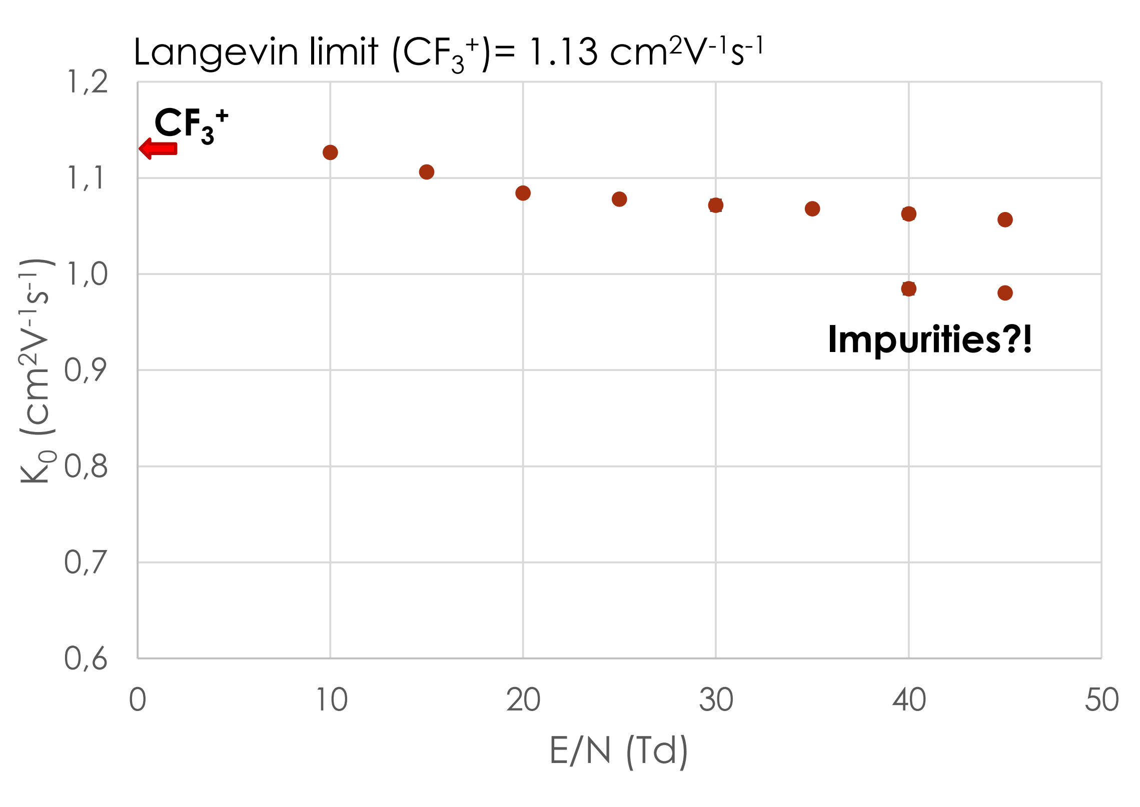
Possibility of Cluster Formation
(Pressure dependent)



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

Experimental Results: CF_4





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 $cm^2V^{-1}s^{-1}$

Cluster Formation

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

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

0.9% error

Experimental Results: CH_4

Appearance Energies

CH_4^+	13.0 eV
CH_3^+	14.2 eV
CH_2^+	15.2 eV
CH^+	24.1 eV
H^+	18.0 eV
H_2^+	20.2 eV

IONIZATION

$CH_4 + e \rightarrow CH_4^+ + 2e$	56.54 %*
$\rightarrow CH_3^+ + H^- + e$	40.46 %
$\rightarrow CH_3^+ + H_2 + 2e$	2.45 %
$\rightarrow CH_2^+ + H^- + H_2 + e$	0.32 %
$\rightarrow H^+ + \ldots$	0.03%
$\rightarrow H_2^+ + \ldots.$	
$\rightarrow CH^+ + \ldots.$	0.2%

about 25 eV

REACTIONS

$CH_4 + CH_4^+ \rightarrow CH_5^+ + CH_3$

$CH_4 + CH_3^+ \rightarrow C_2H_5^+ + H_2$

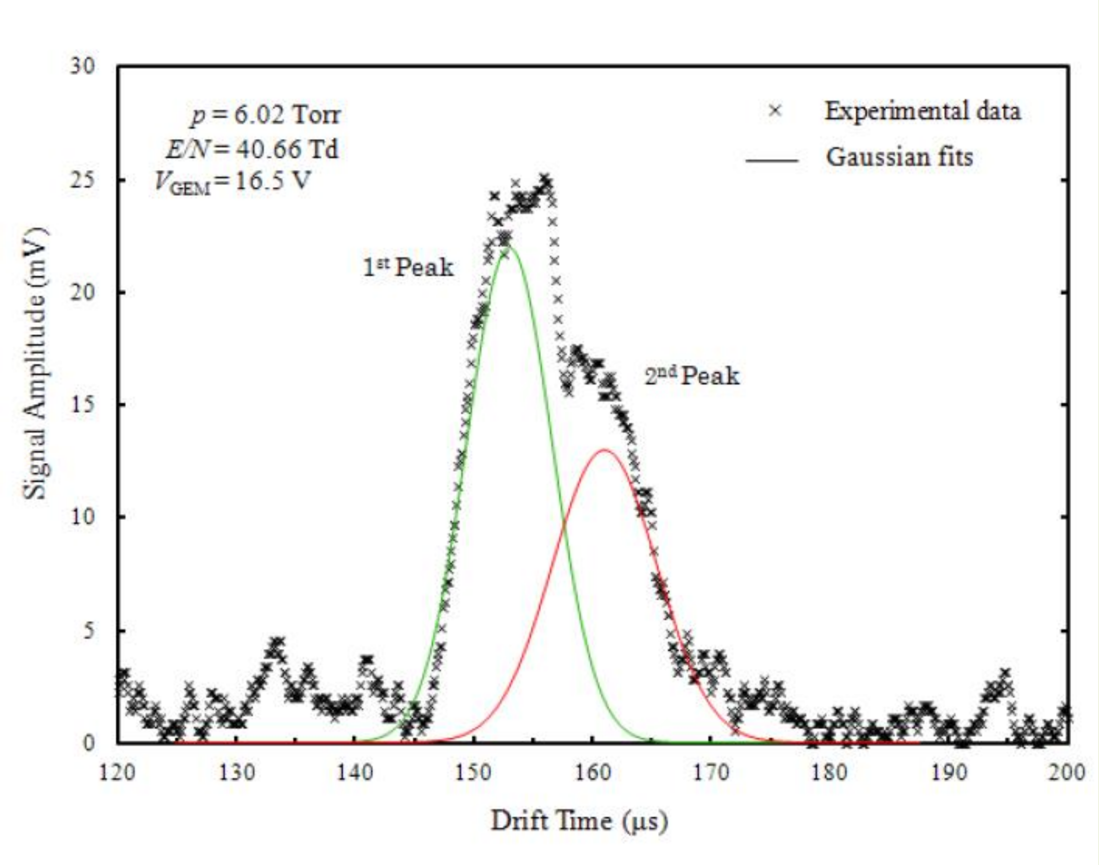
$CH_4 + CH_2^+ \rightarrow C_2H_2^+ + H_2$
$\rightarrow C_2H_3^+ + H_2$
$\rightarrow C_2H_4^+ + H_2$
$\rightarrow C_2H_5^+ + H$

$\rightarrow$

$CH4 + C_2H_5^+ \rightarrow C_3H_7^+ + H_2$

$CH4 + C_2H_3^+ \rightarrow C_3H_5^+ + H_2$

$CH4 + C_3H_2^+ \rightarrow C_3H_4^+ + H_2$
$\rightarrow C_3H_4^+ + H_2$



(Trindade 2012)

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

Let’s now move to the binary gas mixtures:

$Ar-CF_4$

$Ar-CH_4$ → **$Ar-CF_4-CH_4$**

CF_4-CH_4

Experimental Results: Ar-CF_4

Ions move faster with the presence of Ar.

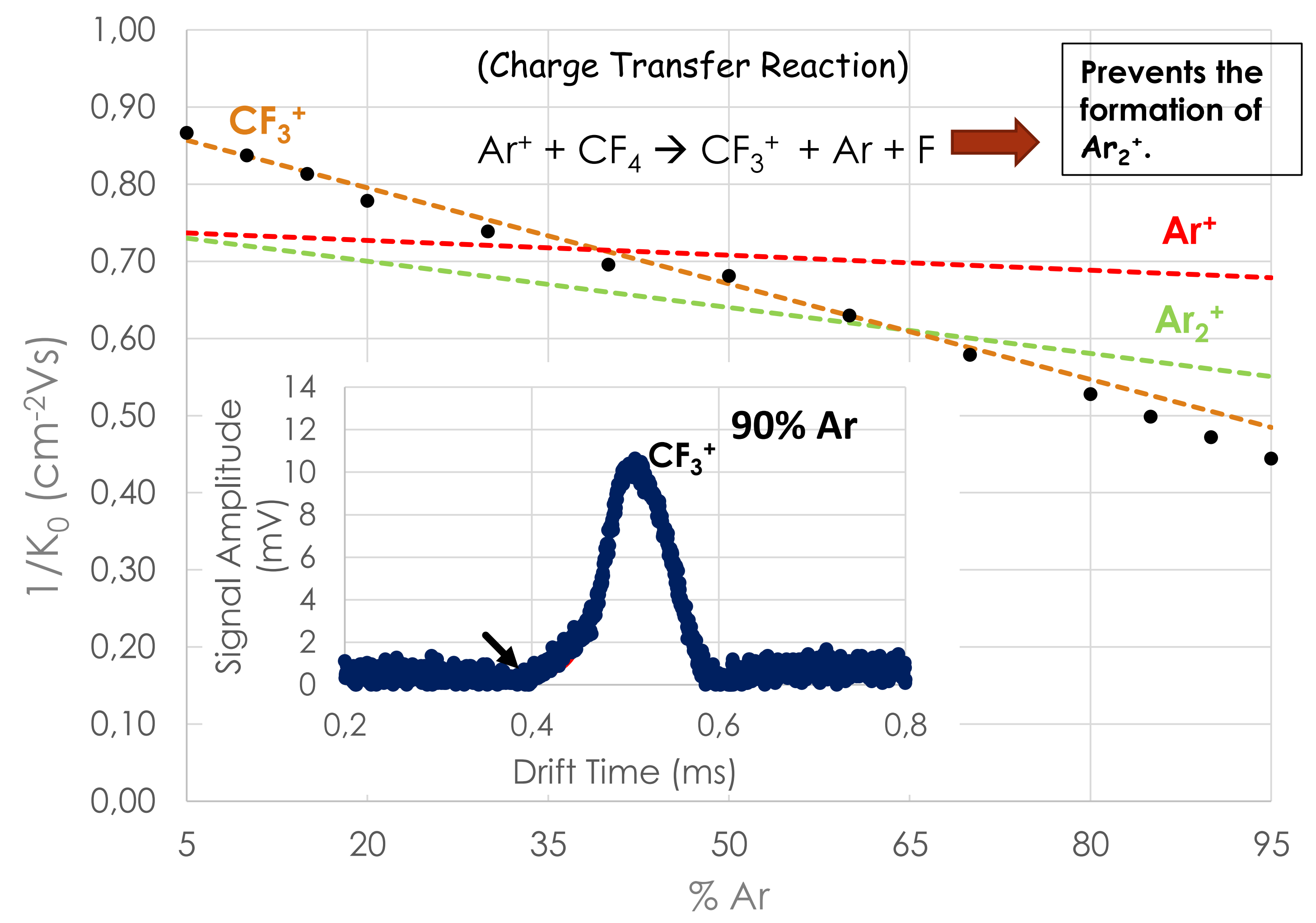
Behaviour well described by Blanc's law and Langevin theory.

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-CH_4

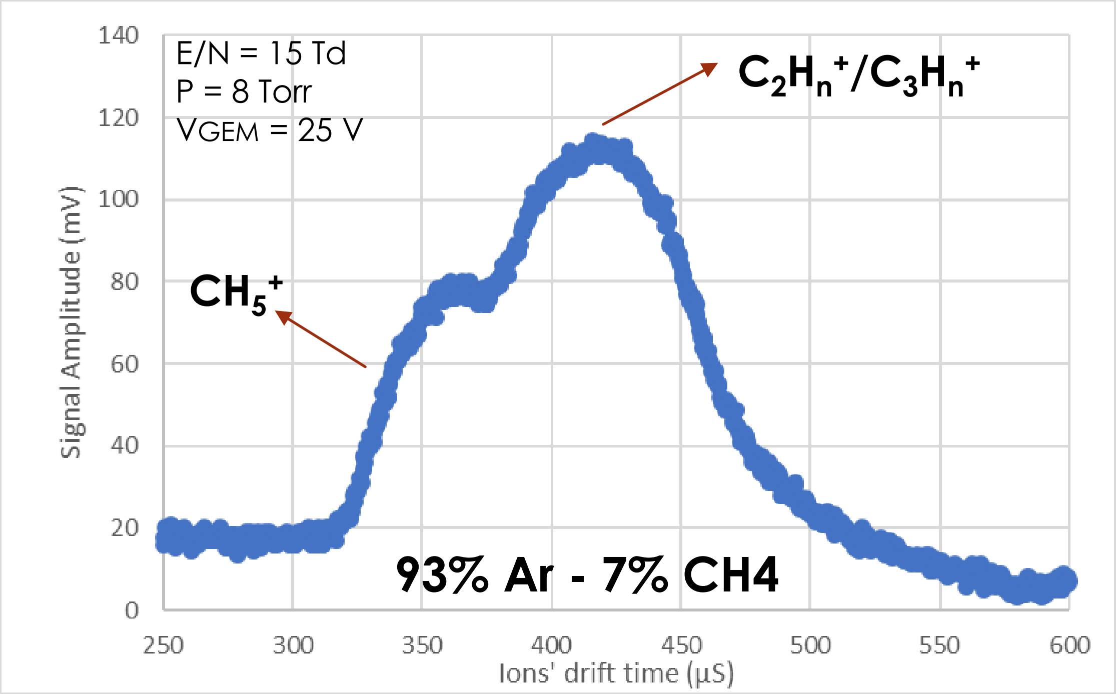
Ions move faster with the presence of Ar up to 95% of Ar. → Seems to stabilize

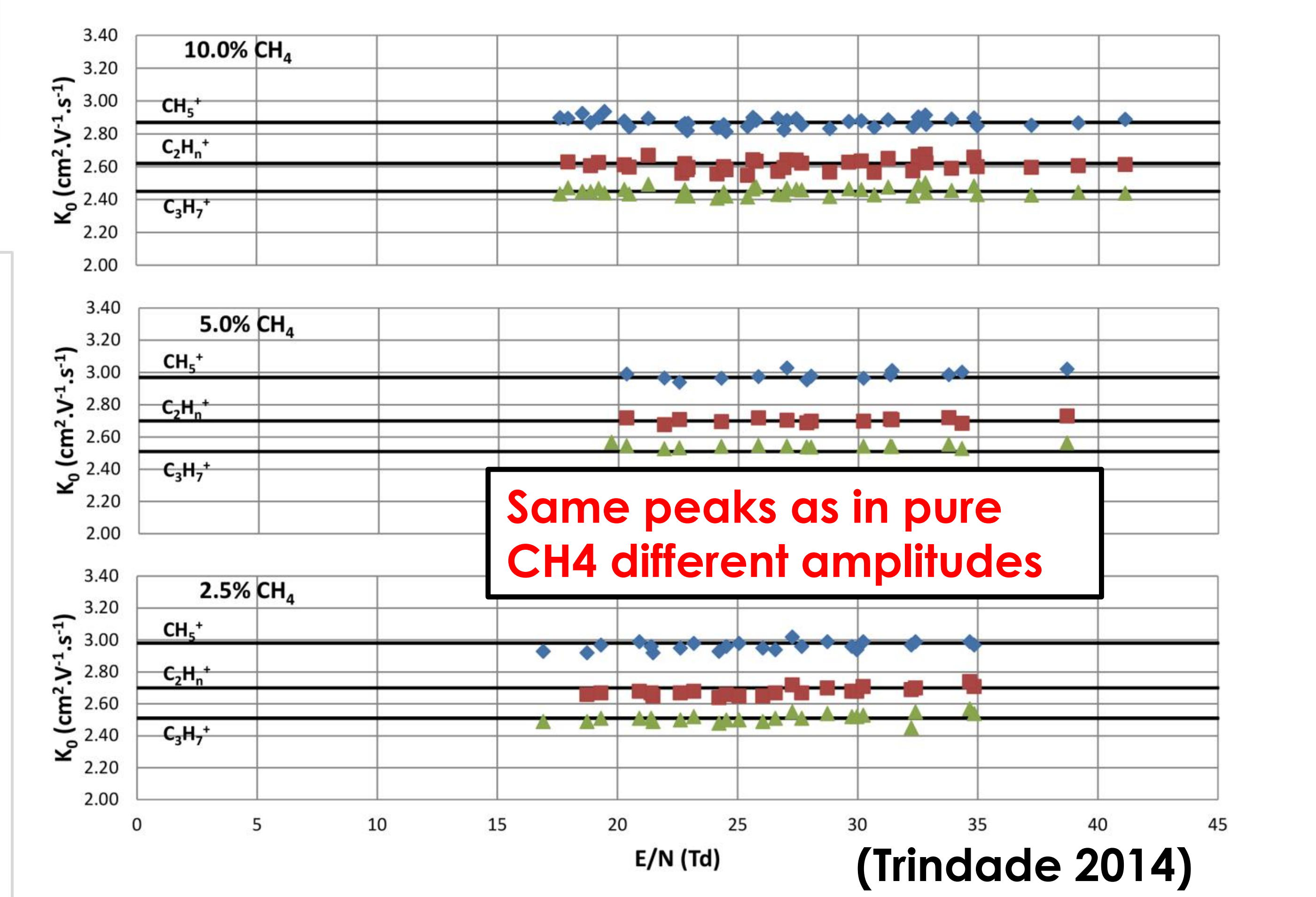
(Charge Transfer Reaction)

$Ar^+ + CH_4 \rightarrow CH_4$ products

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

Amplitude rises until 90% of Ar





(Trindade 2014)

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Experimental Results: CF_4-CH_4

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

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

Amplitude decreases with increasing **concentration of CF4**

- **One peak** below **25%** of CF4.

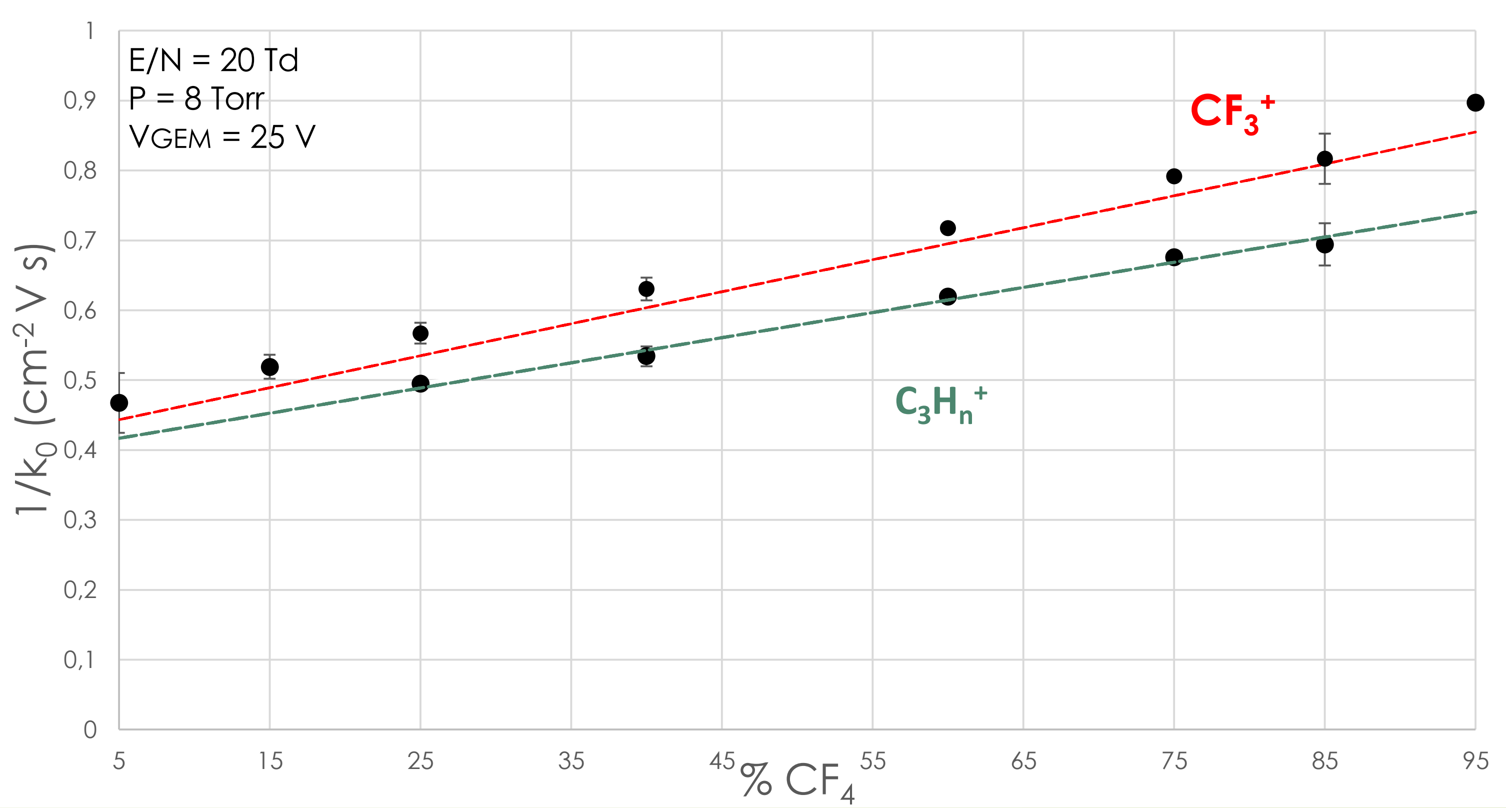
↓

Two different ions (CF3+ and C3Hn+)

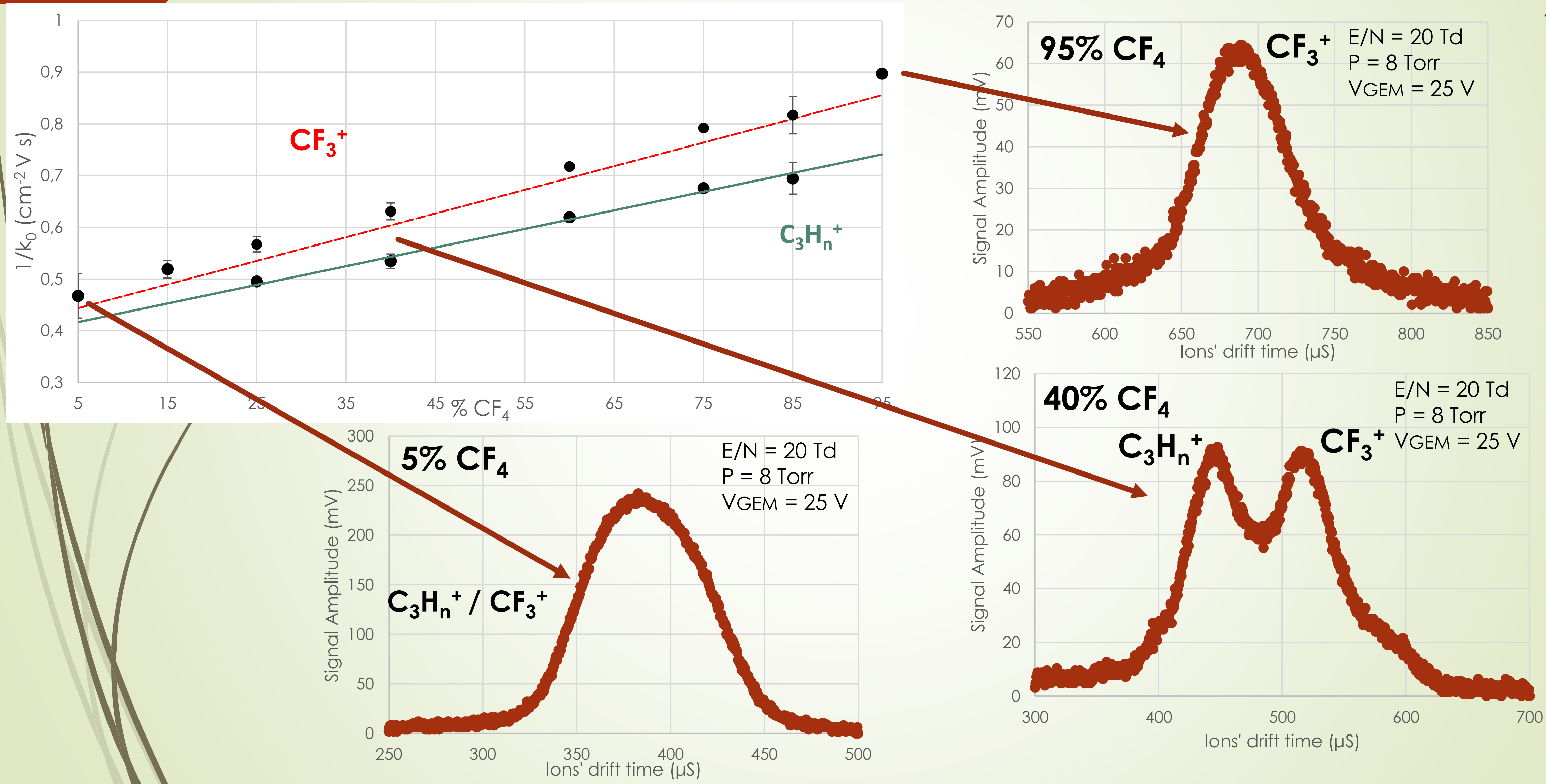
- **Two peaks** clearly identified for 20 Td **between 25% and 85%** of CF4
- **One peak** above **85%** (CF3+)

Charge Transfer Reactions

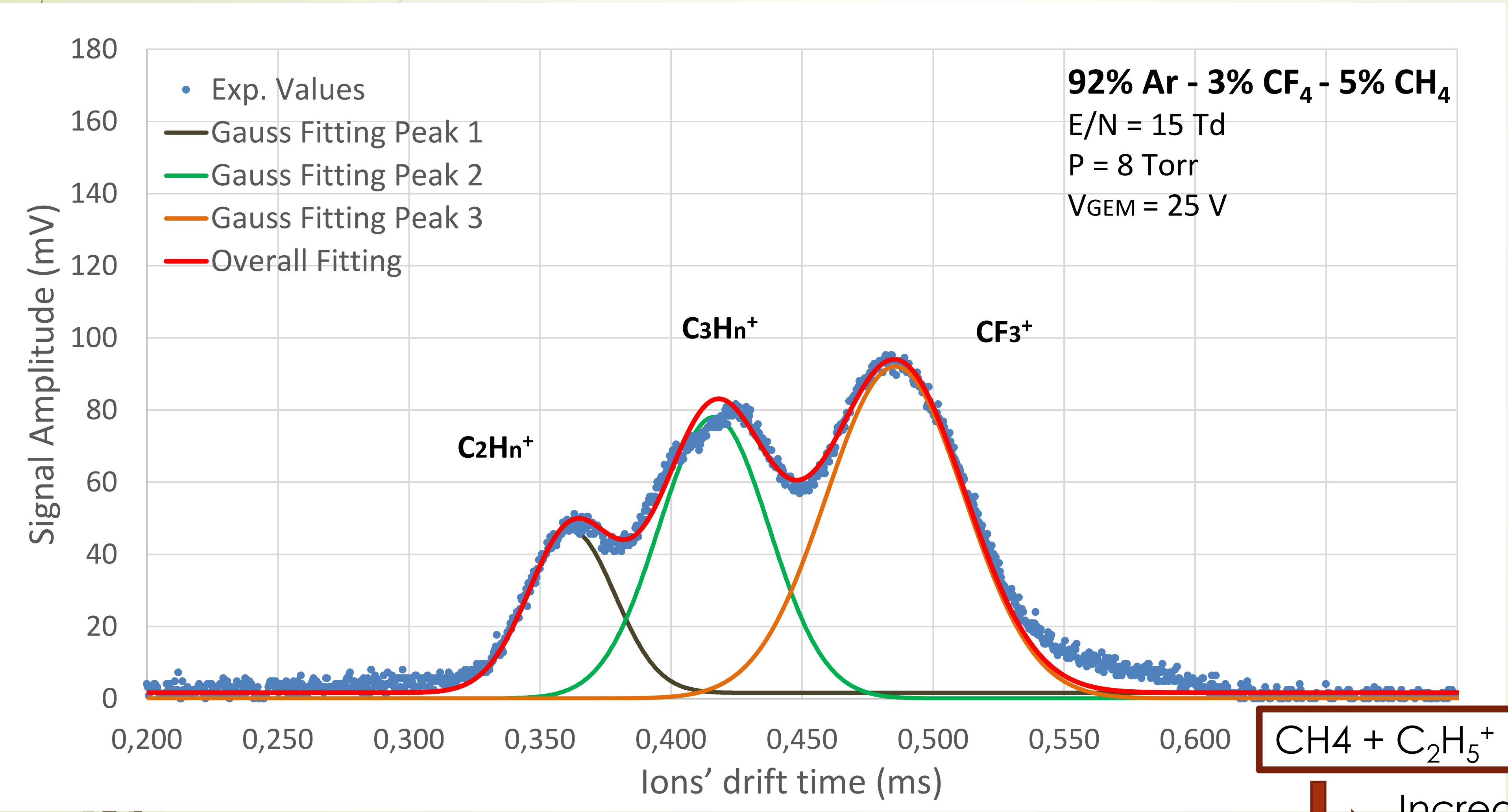
$CH_3^+ + CF_4 \rightarrow CF_3^+ + CH_3F$
$CH_5^+ + CF_4 \rightarrow CF_3^+ + CH_4 + HF$
$CH_2^+ + CF_4 \rightarrow CF_3^+ + CH_2F$
$C_2H_2^+ + CF_4 \rightarrow CF_3^+ + C_2H_2F$



Experimental Results: CF_4-CH_4



Experimental results: Ar-CF_4-CH_4



Theor. Values

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

K_{C2HN+} ~ 3.12

K_{C3HN+} ~ 2.40

K_{CF3+} ~ 2.15

~4.5%

Exp. Values

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

K_{01} ~ 2.95±0.02

K_{02} ~ 2.55±0.02

K_{03} ~ 2.19±0.01

$CH4 + C_2H_5^+ \rightarrow C_3H_7^+ + H_2$

Increases the mobility of C3H7+

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*

- Optimization of the detector:
  - *Negative Ion Drift Chamber* →
  - *Variable Drift Distance*

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

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

↓

Theoretical Mobility Values

→

Experimental Ion Mobility

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.

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

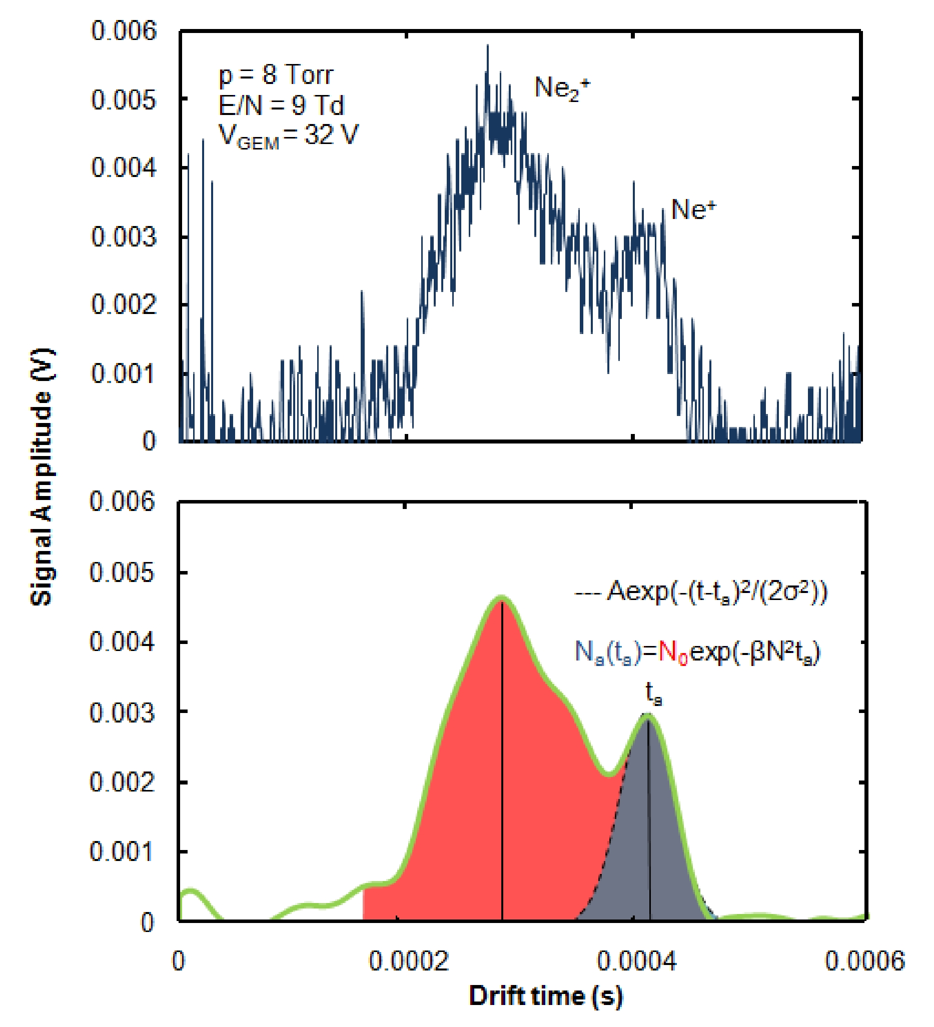
f_1 , f_2 – molar fraction of gas 1 and 2

↓

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.

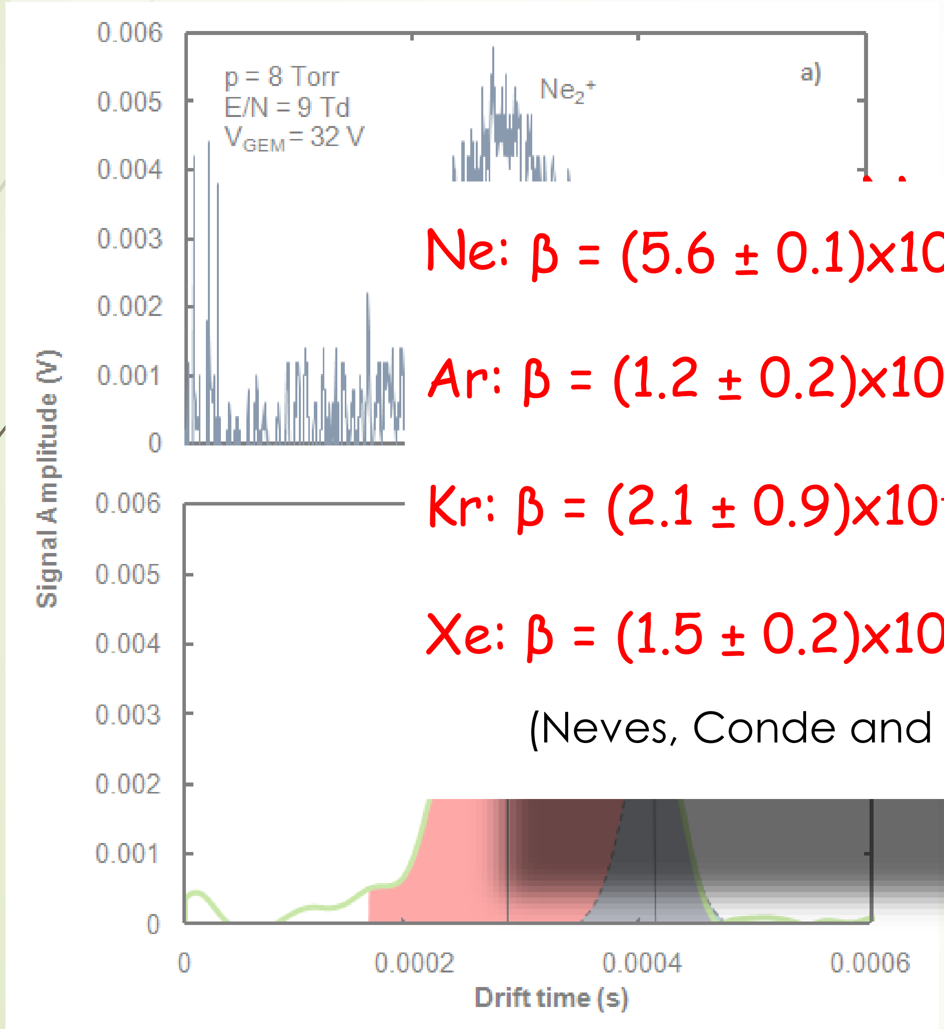
[Rg+](0) is proportional to the total area.

Depends on:

- Temperature

Results: Reaction rate

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



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

…Rg]^2

…p($-\beta N^2$)

…nal to the area …ussian.

…nal to the total area.

Ne: $\beta = (5.6 \pm 0.1) \times 10^{-32}\ cm^6 s^{-1}$

Ar: $\beta = (1.2 \pm 0.2) \times 10^{-31}\ cm^6 s^{-1}$

Kr: $\beta = (2.1 \pm 0.9) \times 10^{-31}\ cm^6 s^{-1}$

Xe: $\beta = (1.5 \pm 0.2) \times 10^{-31}\ cm^6 s^{-1}$

(Neves, Conde and Távora, 2010)

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.

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