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Ion Mobility in Ar-CF_4

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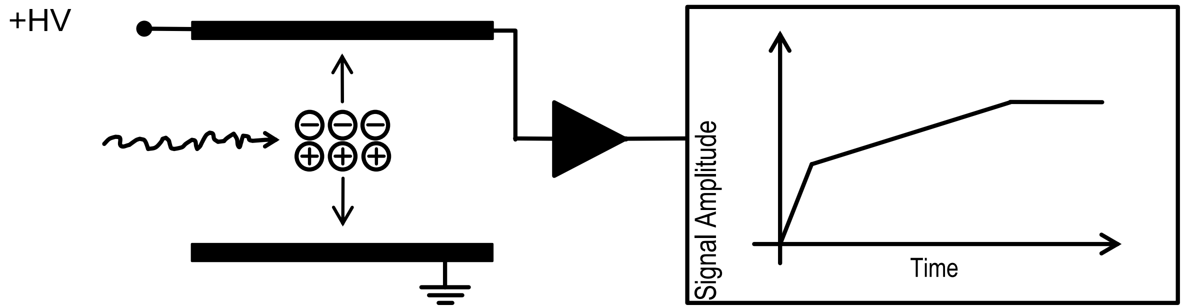
Why ion mobility is important...

Gaseous Radiation Detectors



Ion Mobility Spectrometry

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

High Energy Physics

NEXT experiment: HPXe TPC
$^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e$
K_0: Ba^{++}, Ba^{+}, Xe^{+}, Xe_2^{+}, …

Contents

Objectives

- *Systematically measure ion mobility in gaseous mixtures of interest*
  - *Ar-CO2*
  - *Ne-CO2*
  - *Ne-CO2-N2*
  - *Xe-CO2*
  - *Xe-N2*
  - *Xe-TMA*
  - *Ar-CF4-iC4H10*

Ar-CO2, Ne-CO2, Ne-CO2-N2 → **ALICE TPC**

Xe-CO2 → **ALICE** and **CBM TRDs**

Ar-CO2, Ne-CO2, Ne-CO2-N2, Xe-CO2 → **RD51 Collaboration/CERN**

Xe-N2, Xe-TMA → **NEXT Experiment** (Neutrino Experiment with a Xenon TPC)

Ar-CF4-iC4H10 → T2K mixture for **LCTPC** → Suggested by Jochen Kaminski and Paul Colas

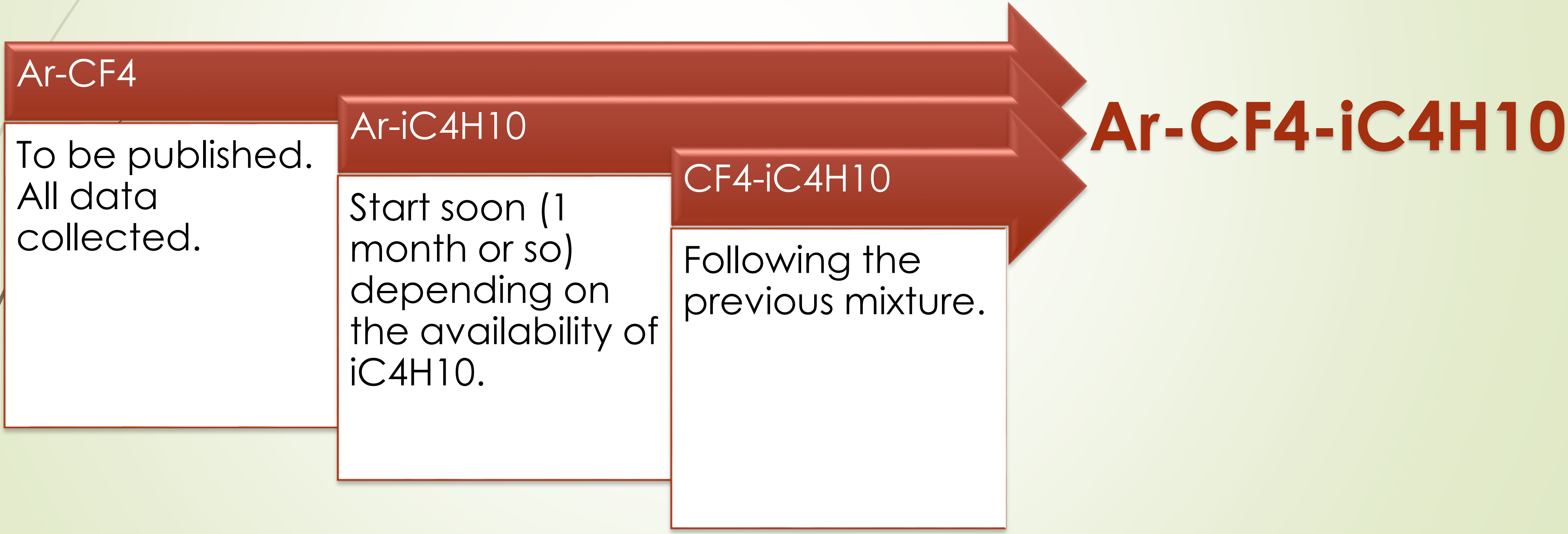
- *Simulation work within the mentioned gas mixtures and quantitative description of the measurements is possible (performed by Rob Veenhof's group).*

Why?

Scarce data available on ion mobility in mixtures relevant for the LCTPC, although measurements for other gases have been performed since long. → Timeline defined by the urgency of the LCTPC Project!

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.



Ar-CF4

To be published. All data collected.

Ar-iC4H10

Start soon (1 month or so) depending on the availability of iC4H10.

CF4-iC4H10

Following the previous mixture.

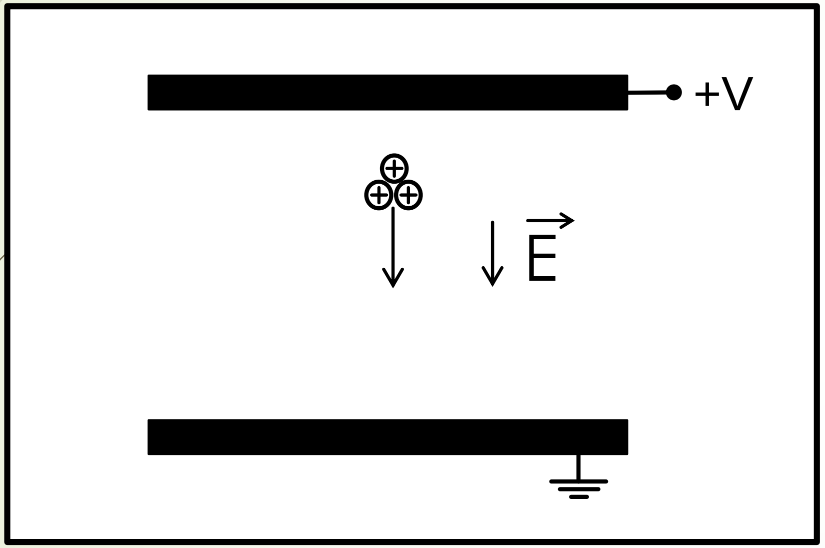
Ar-CF4-iC4H10

Ion Mobility Measurement at LIP Coimbra

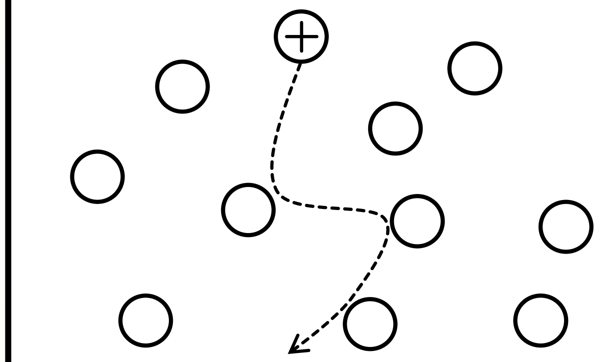
- Basic Concepts
- Experimental Setup and Working Principle
- Ion Identification Process
- Experimental results in:
    - Ar-CF4

Basic Concepts

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



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 – reduced mass
α – neutral polarizability

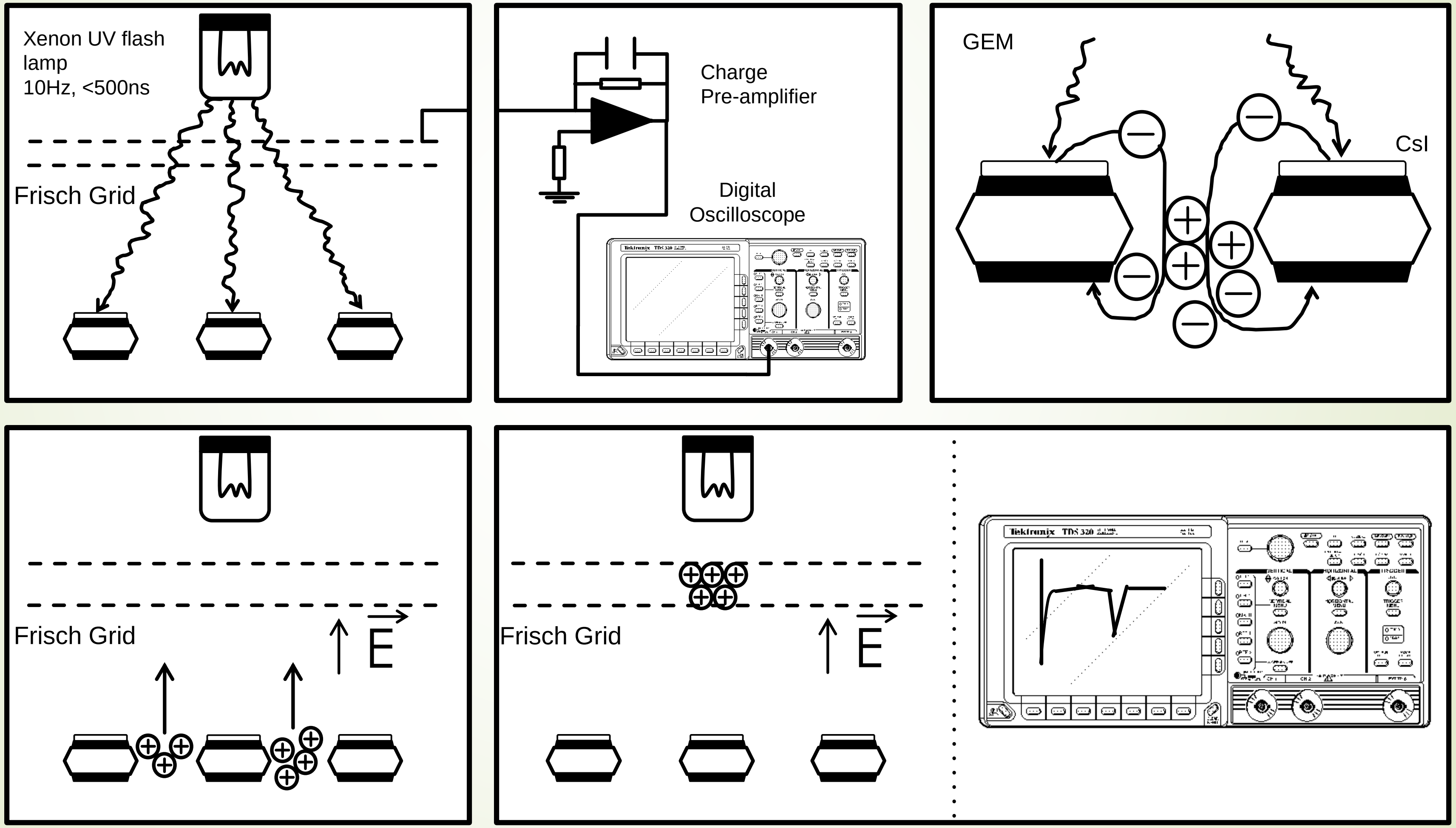
Blanc's Law

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

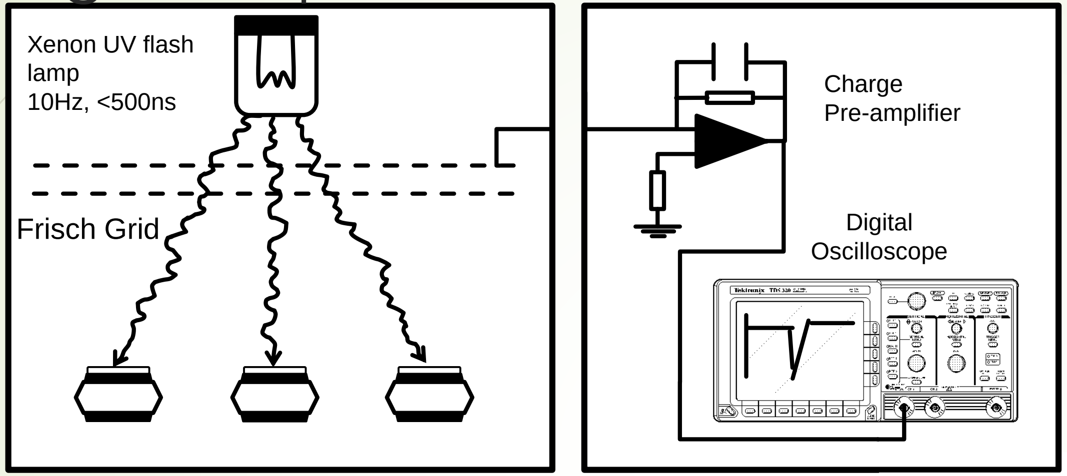
f_1,f_2– molar fraction of gas 1, 2
K_{0g1}, K_{0g2} – ion mobility in the gas 1 and gas 2

Experimental Setup and Working Principle

(Neves, Conde and Távora, 2007)



Experimental Setup and Working Principle



After the signal and the background were recorded…

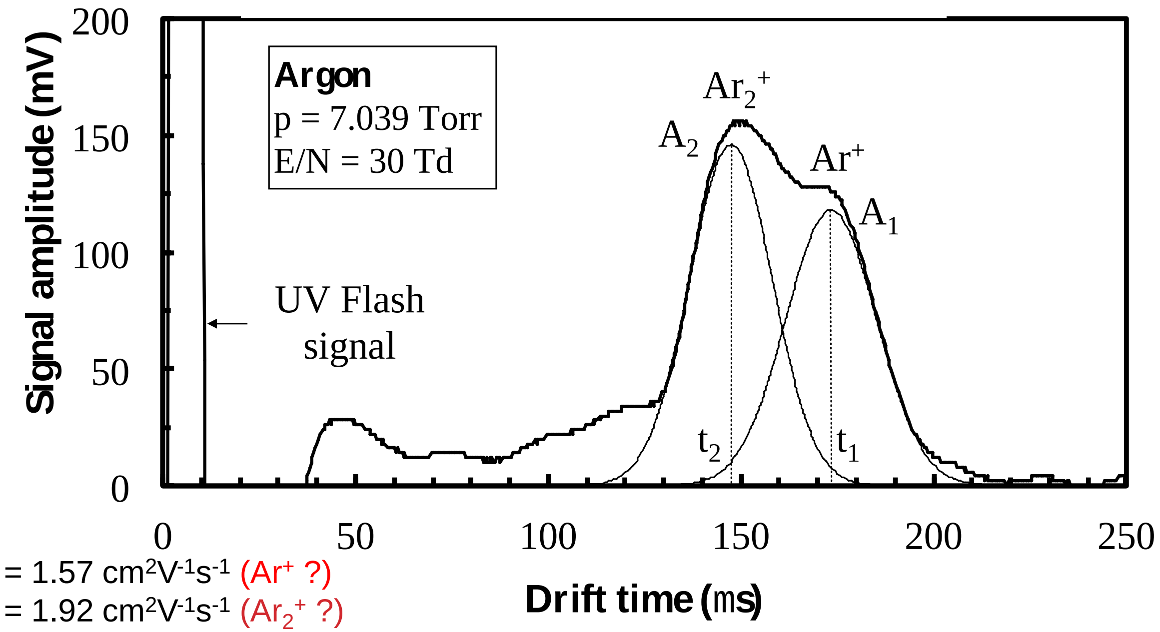
- Subtract the background to the signal
- Identify possible peaks
- Fit Gaussian curves to the spectrum obtained

peaks centroids

⬇

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

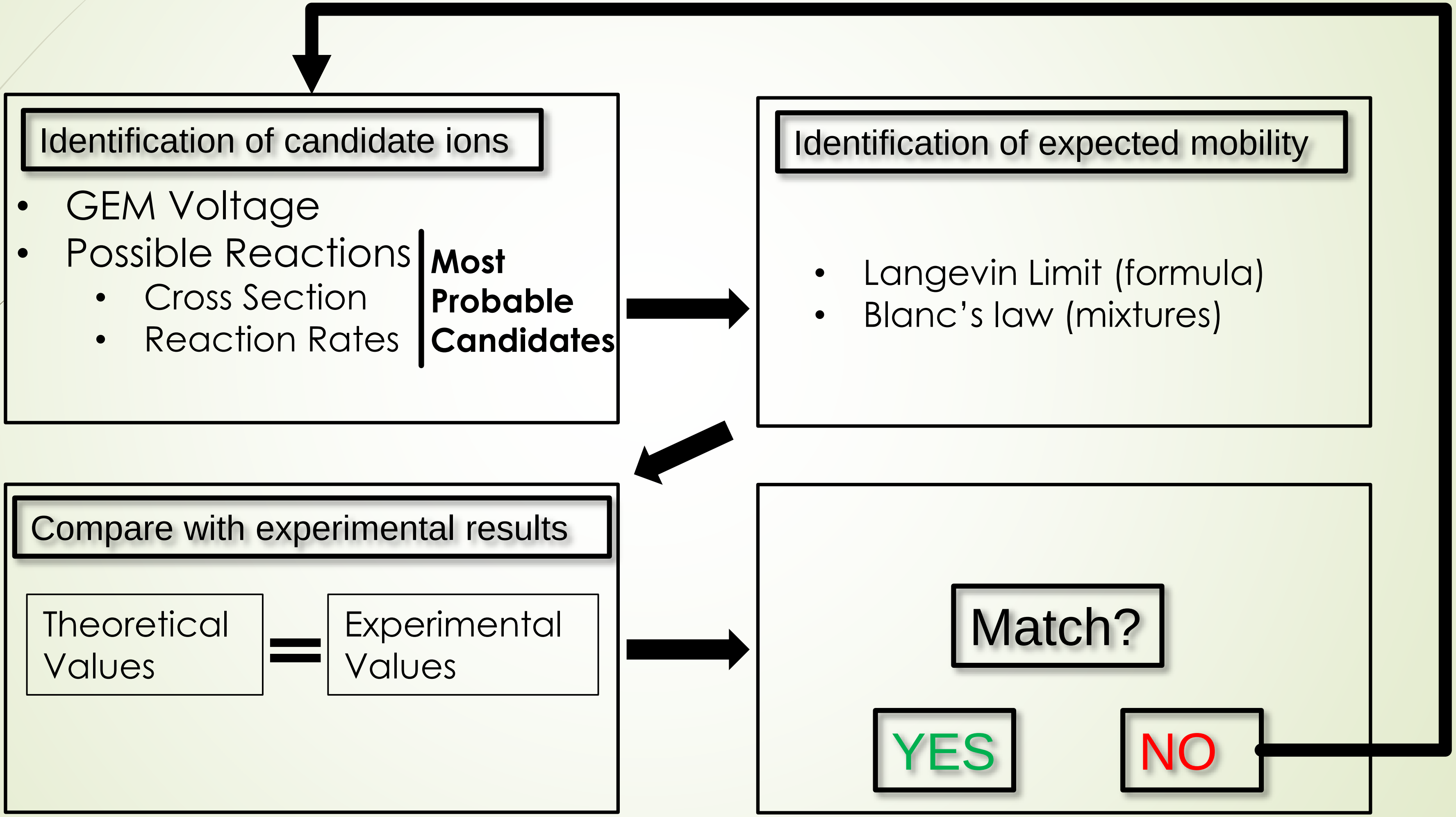
$$v_{\mathrm{d}} = \frac{x_{drift}}{t_{drift}} \Rightarrow K = \frac{v_{\mathrm{d}}}{E}$$



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

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

Ion Identification Process



Identification of candidate ions

- GEM Voltage
- Possible Reactions
  - Cross Section
  - Reaction Rates

Most Probable Candidates

Identification of expected mobility

- Langevin Limit (formula)
- Blanc's law (mixtures)

Compare with experimental results

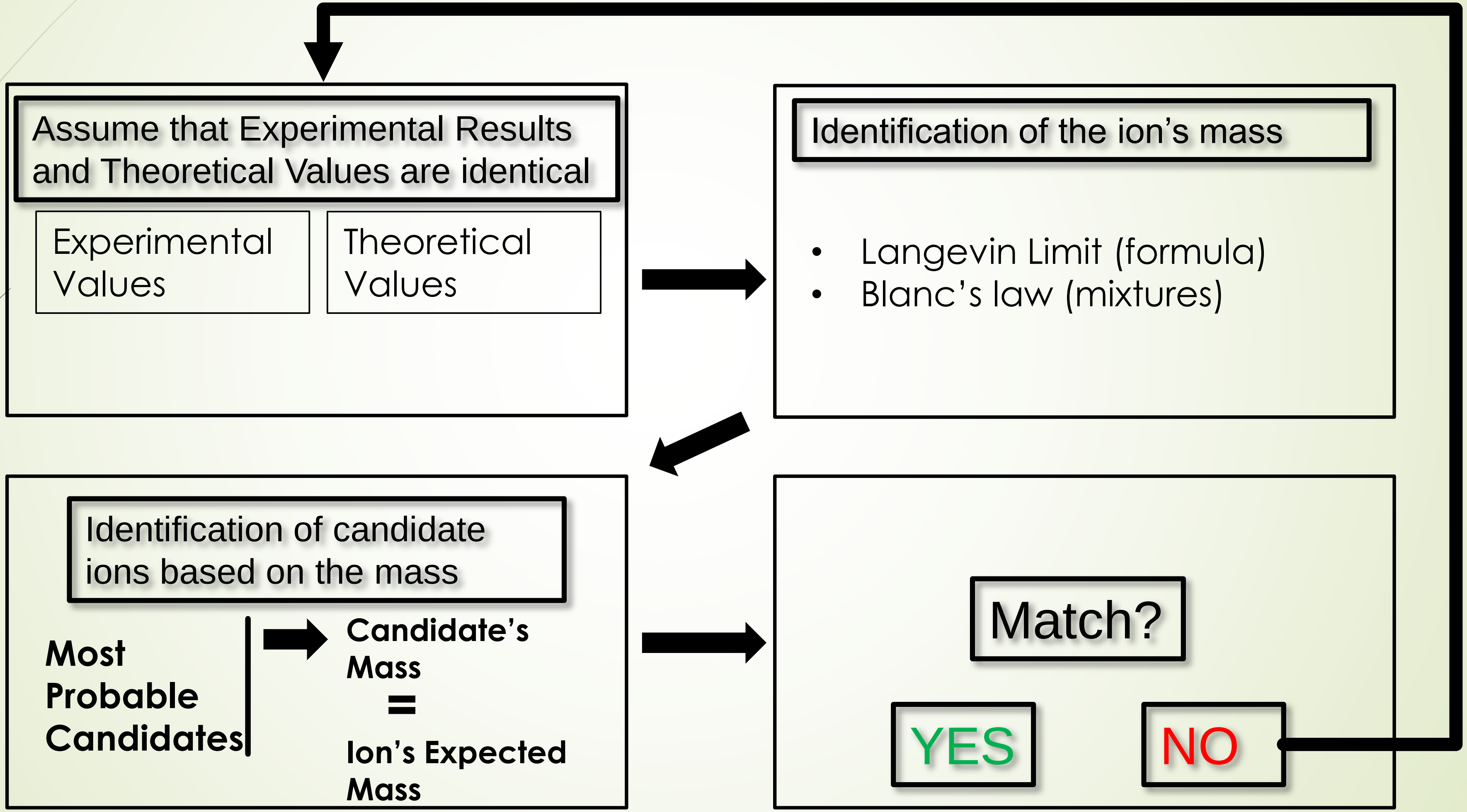
Theoretical Values = Experimental Values

Match?

YES

NO

Ion Identification Process



Assume that Experimental Results and Theoretical Values are identical

Experimental Values

Theoretical Values

Identification of the ion's mass

- Langevin Limit (formula)
- Blanc's law (mixtures)

Identification of candidate ions based on the mass

Most Probable Candidates

Candidate's Mass

=

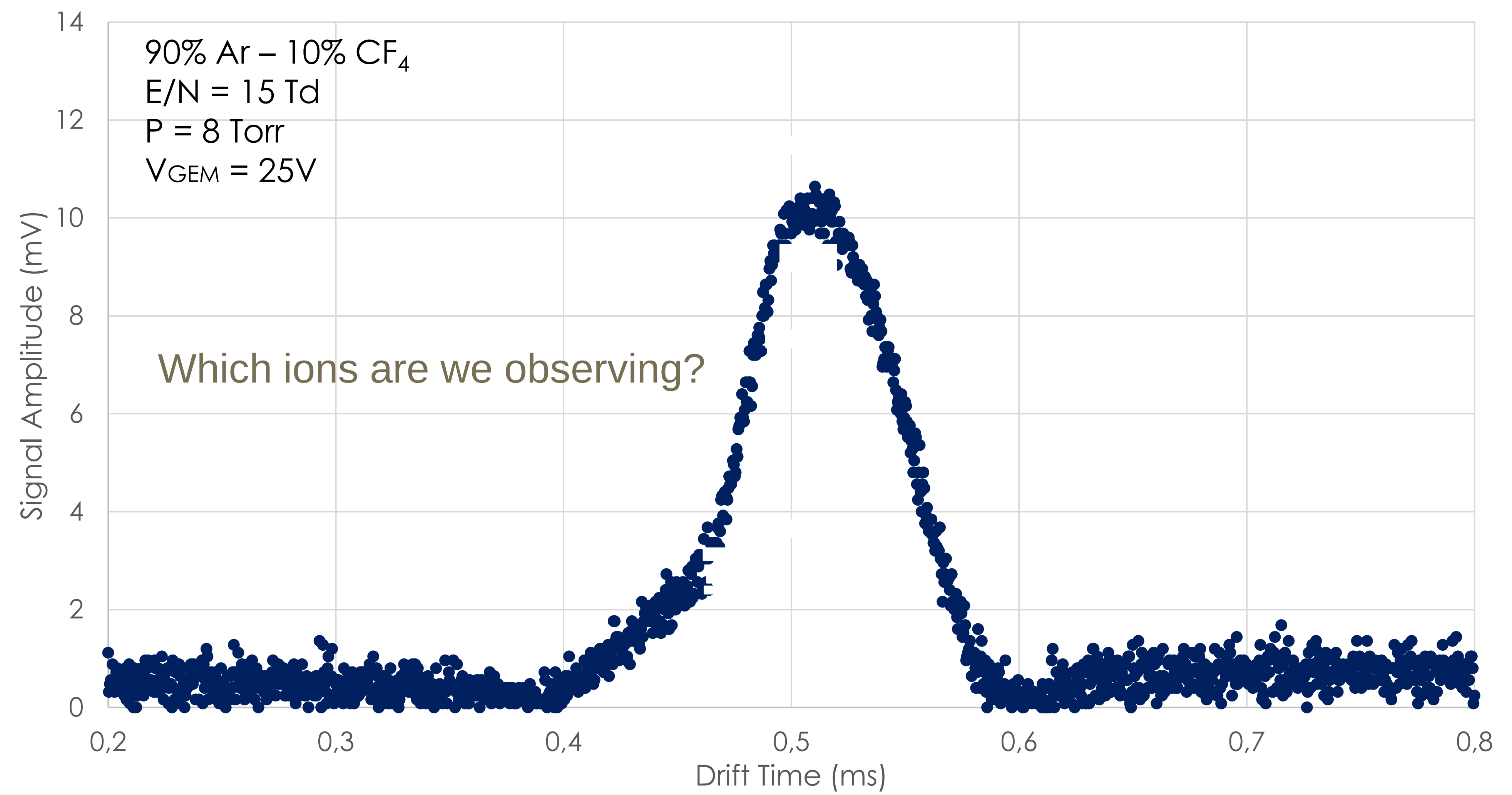
Ion's Expected Mass

Match?

YES

NO

Ion Identification: Ar-CF_4



90% Ar – 10% CF_4
E/N = 15 Td
P = 8 Torr
V_{GEM} = 25V

Which ions are we observing?

Experimental Results: Ar

Appearance Energies

Ar^+ 15.76 eV

IONIZATION

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

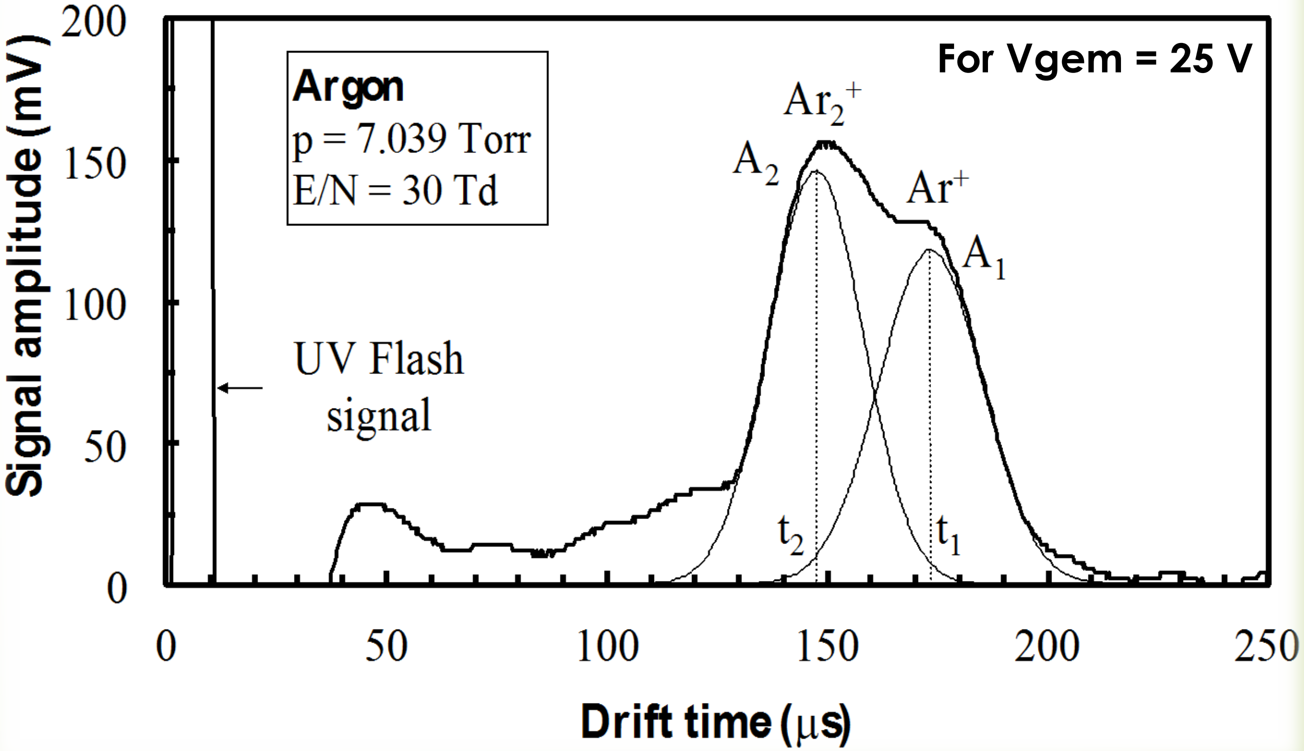
Above threshold 15.76 eV

REACTIONS

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

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

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

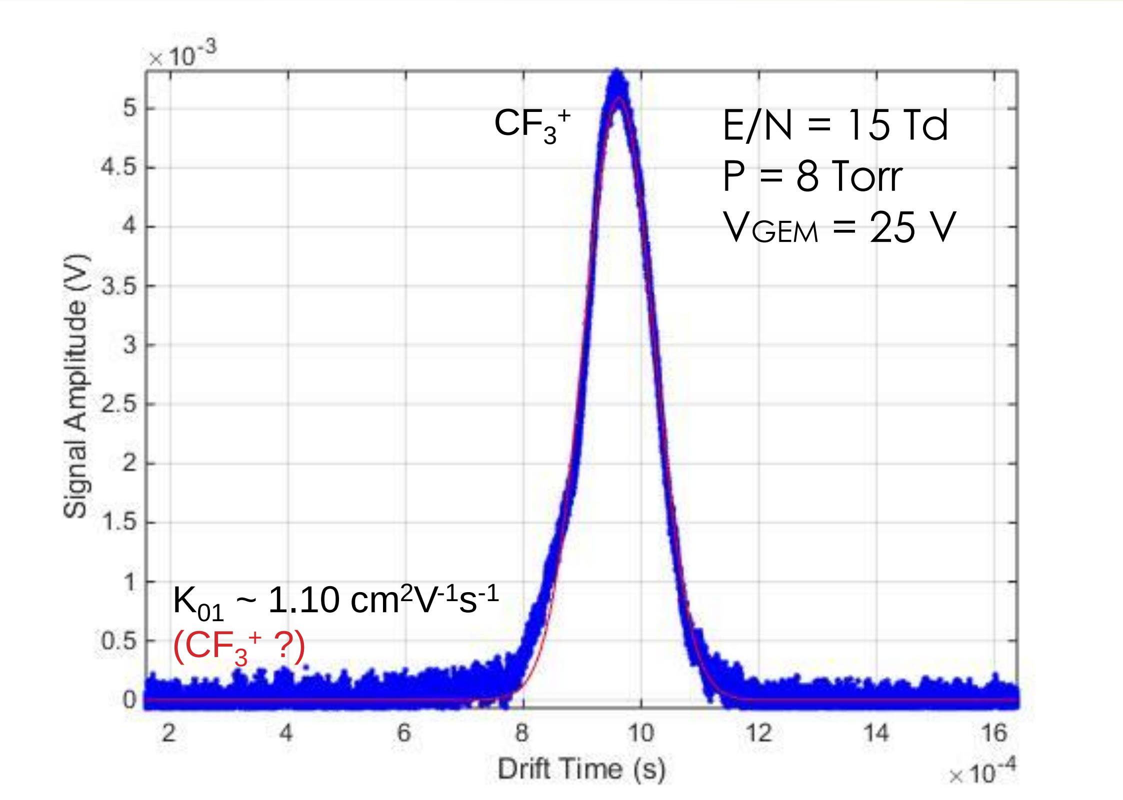
IONIZATION

$CF_4 + e \rightarrow CF_3^+ + F + 2e$

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 %
$\rightarrow F^+ + CF_3 + 2e$	0.07 %
$\rightarrow C^+ + 2F_2 + 2e$	0.07 %

about 25 eV



E/N = 15 Td
P = 8 Torr
VGEM = 25 V

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

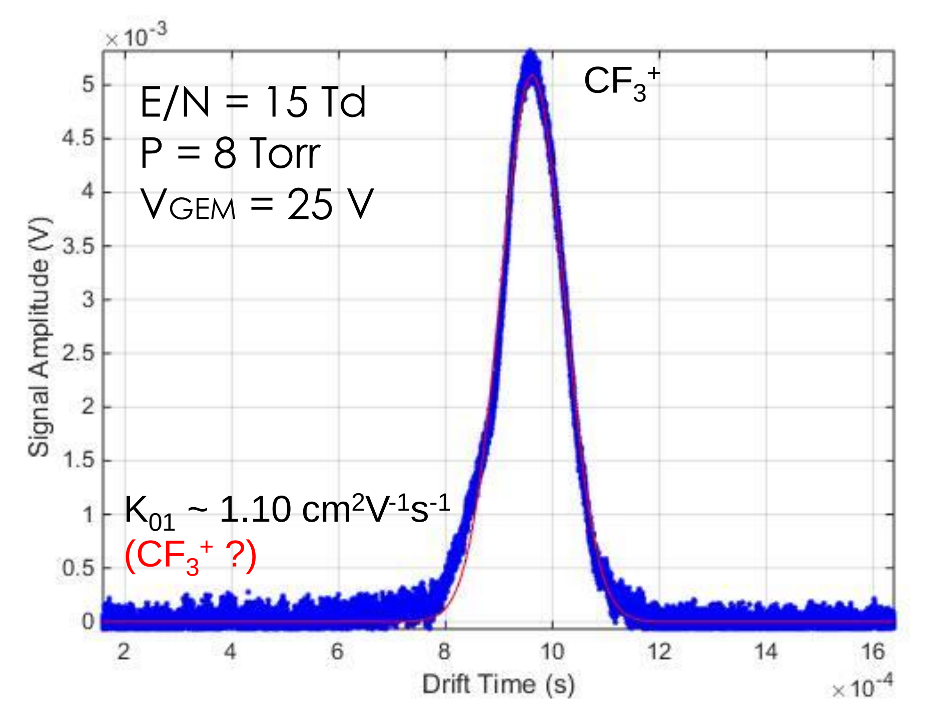
REACTIONS

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

Possibility of Cluster Formation
(Pressure dependent)

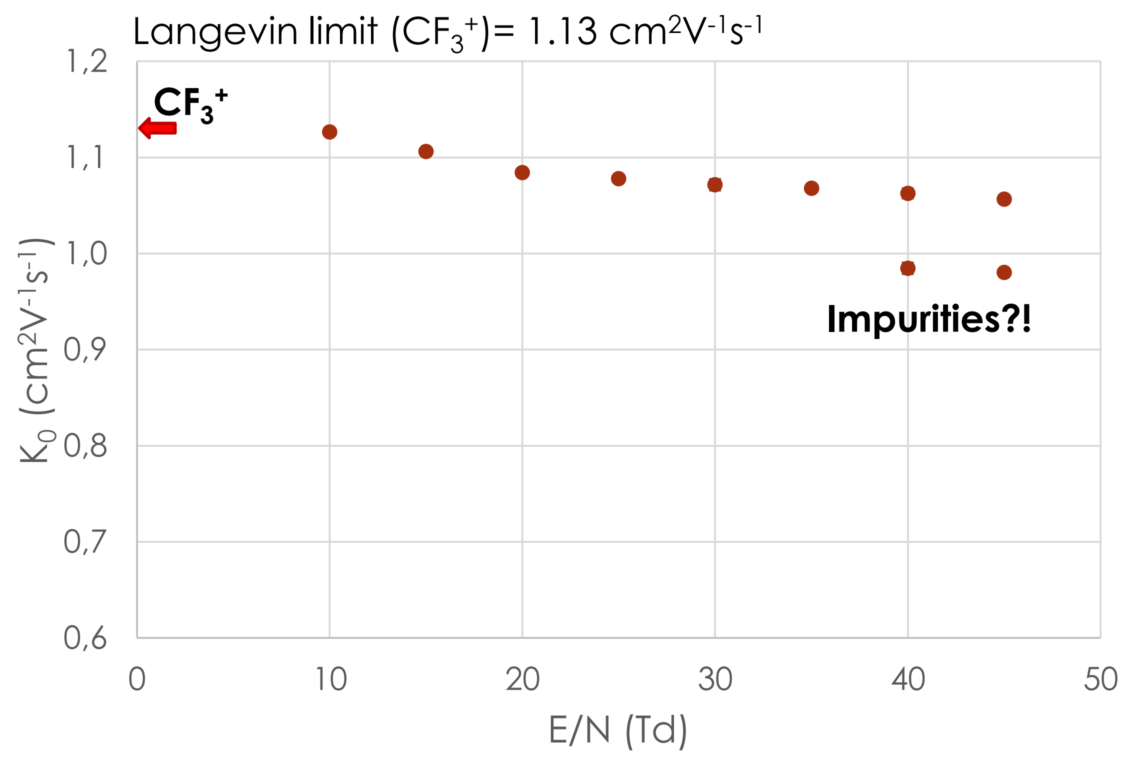
* values obtained from ionization cross sections for electron impact of 25 eV

Experimental Results: CF_4



E/N = 15 Td
P = 8 Torr
VGEM = 25 V

K_{01} ~ 1.10 $cm^2V^{-1}s^{-1}$
(CF_3^+ ?)



Langevin limit (CF_3^+)= 1.13 $cm^2V^{-1}s^{-1}$

Impurities?!

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

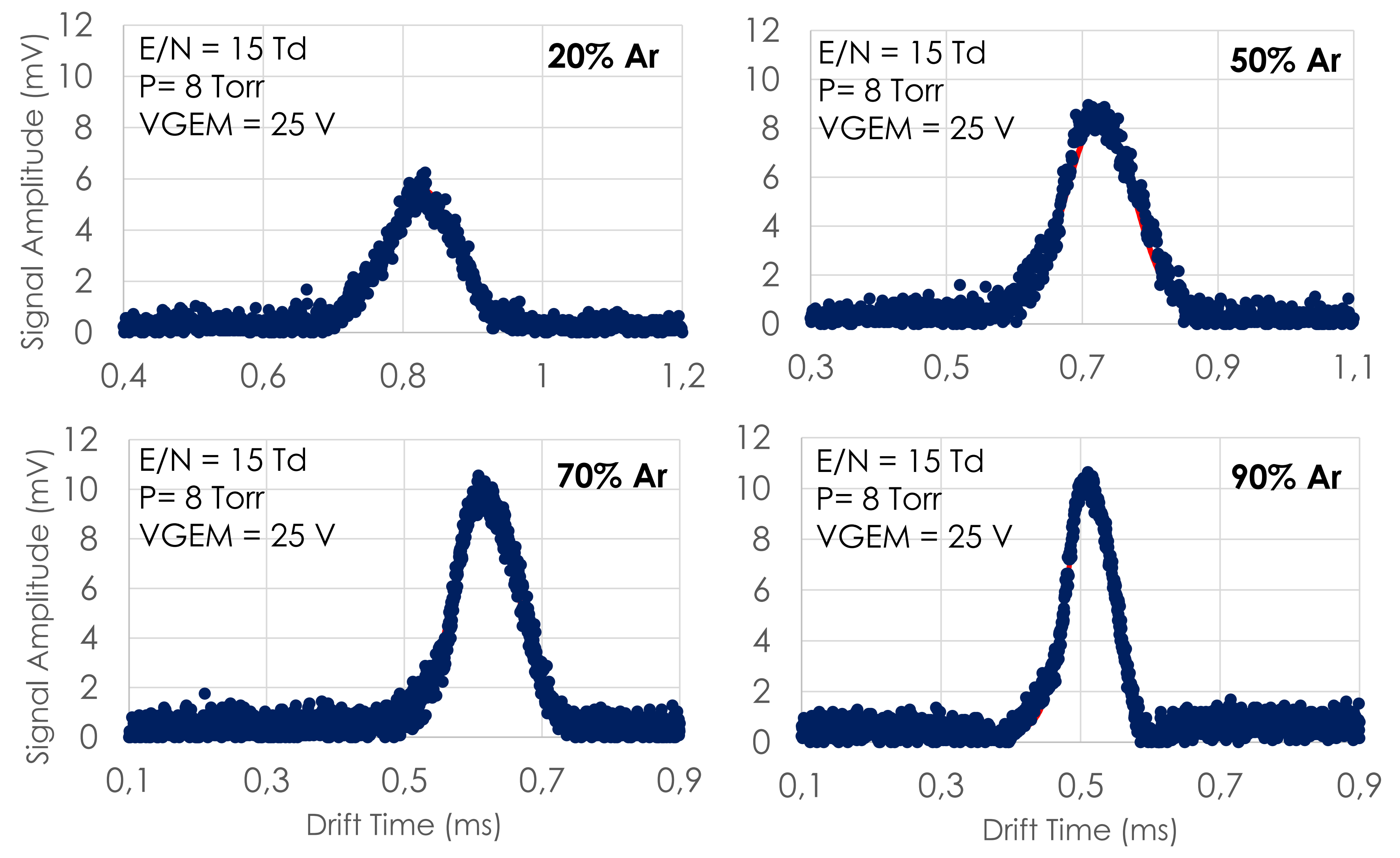
Cluster Formation

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

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

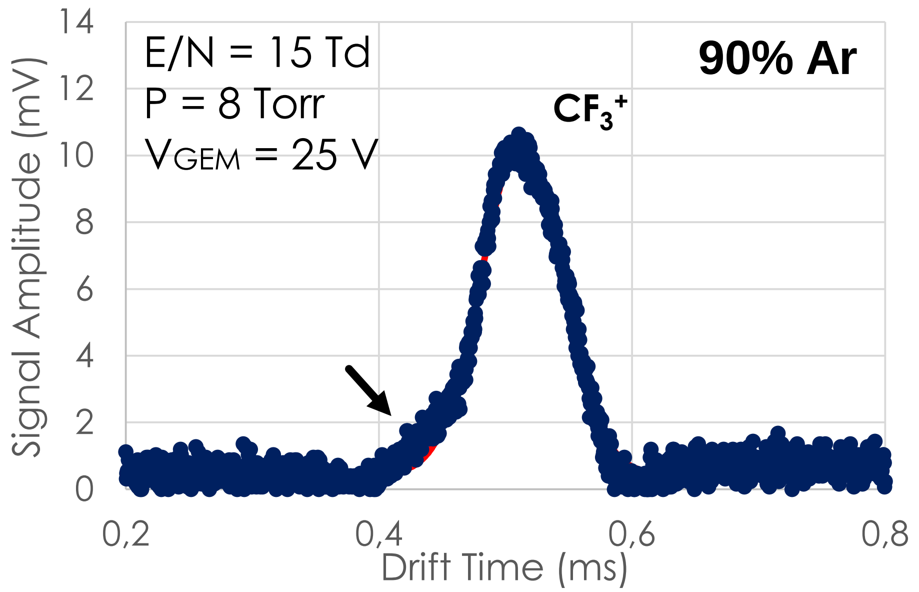
0.9% error

Experimental Results: Ar-CF_4



Experimental Results: Ar-CF4

Results



K_0 ~ 2.11 $cm^2V^{-1}s^{-1}$ (CF_3^+?)

Bump at the left (Impurities?!)

Discussion

(Charge Transfer Reaction)

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

Prevents the formation of Ar_2^+.

Same Ion Product

Match

Although the identification of the peak w/ higher K0 remains.

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

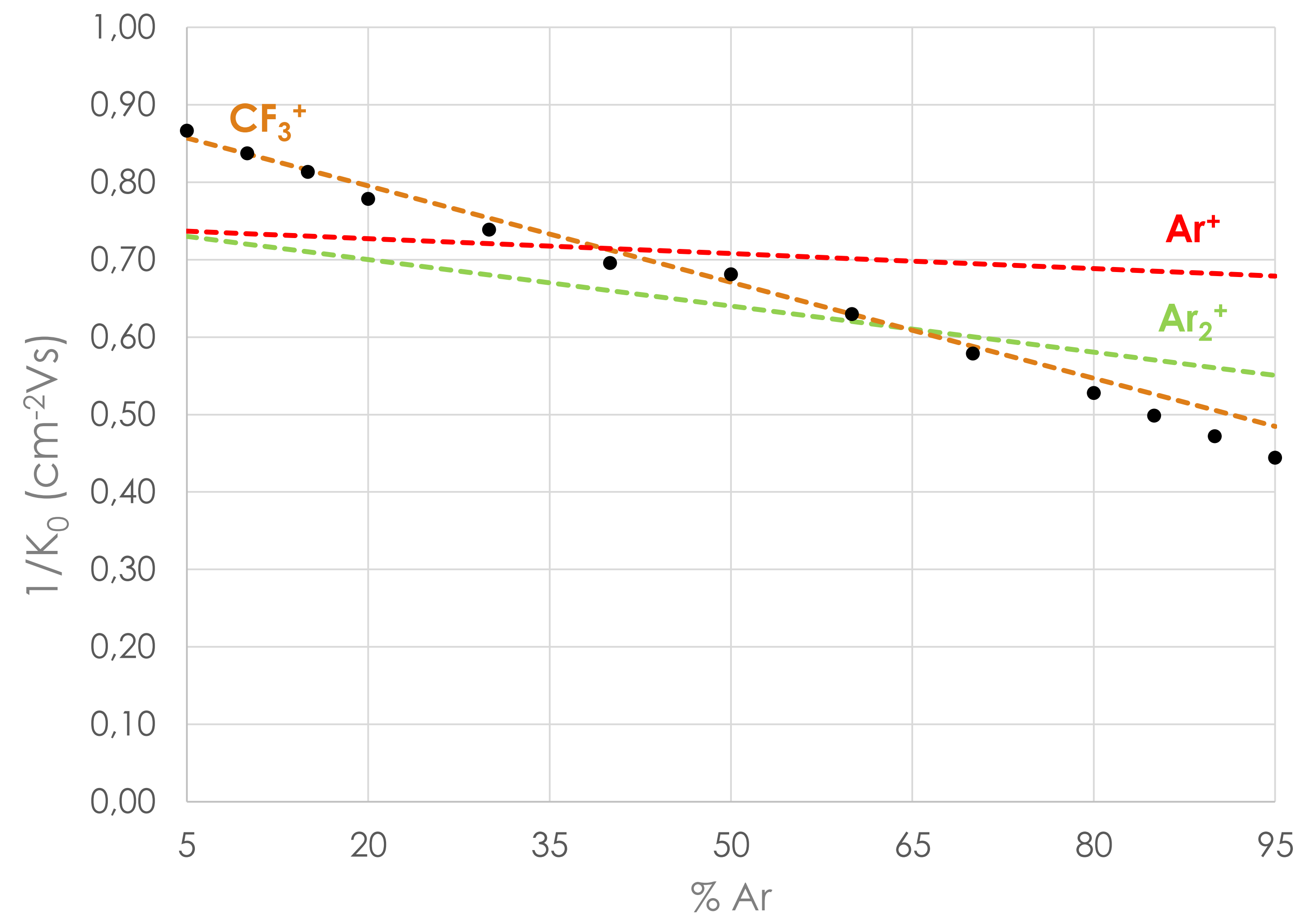
↓

- 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+)

Conclusions

Technique and Method

- This technique has allowed us to make ion mobility measurements in several gases, with the results in agreement with those obtained at higher pressures (see Cluster paper from Y. Kalkan).
- A GEM is used to produce the ions. The ions' initial position is known with great precision. The number and type of ions can be controlled by varying the GEM voltage.
- Although this technique doesn't provide direct identification of the ions, using a different method we were able to identify the group of ions present.
- Impurities effect has to be taken into consideration when analyzing the experimental results.

In the scope of this collaboration...

- First steps taken with interesting experimental results.
- Good perspectives for the future (Ar-CF4 results to be submitted soon) to which will follow Ar-iC4H10.

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)
- (...)

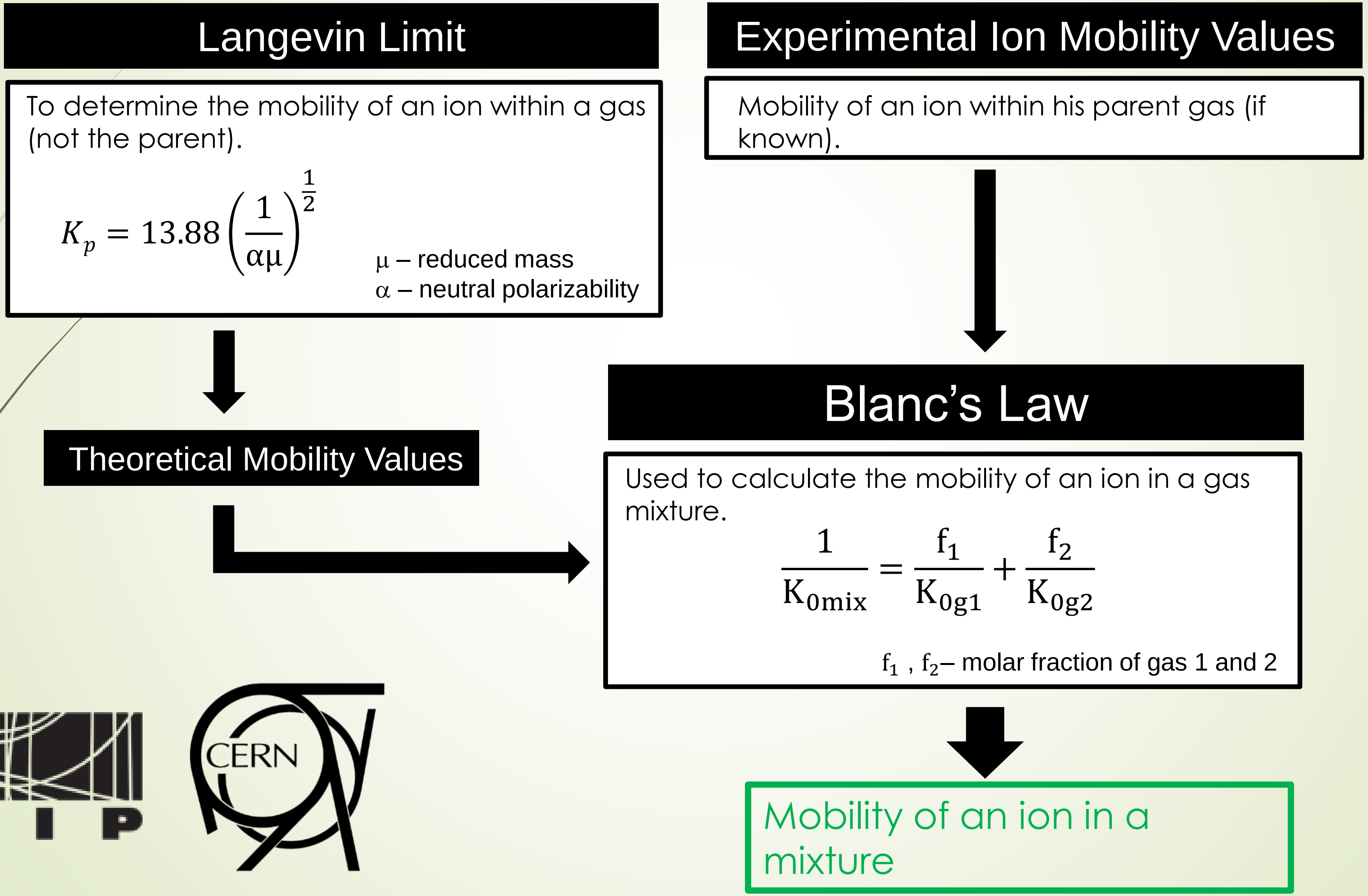
- Study of improved ion-neutral interaction models

Again a special thank you to Paul Colas and Jochen Kaminski for this opportunity...

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 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.

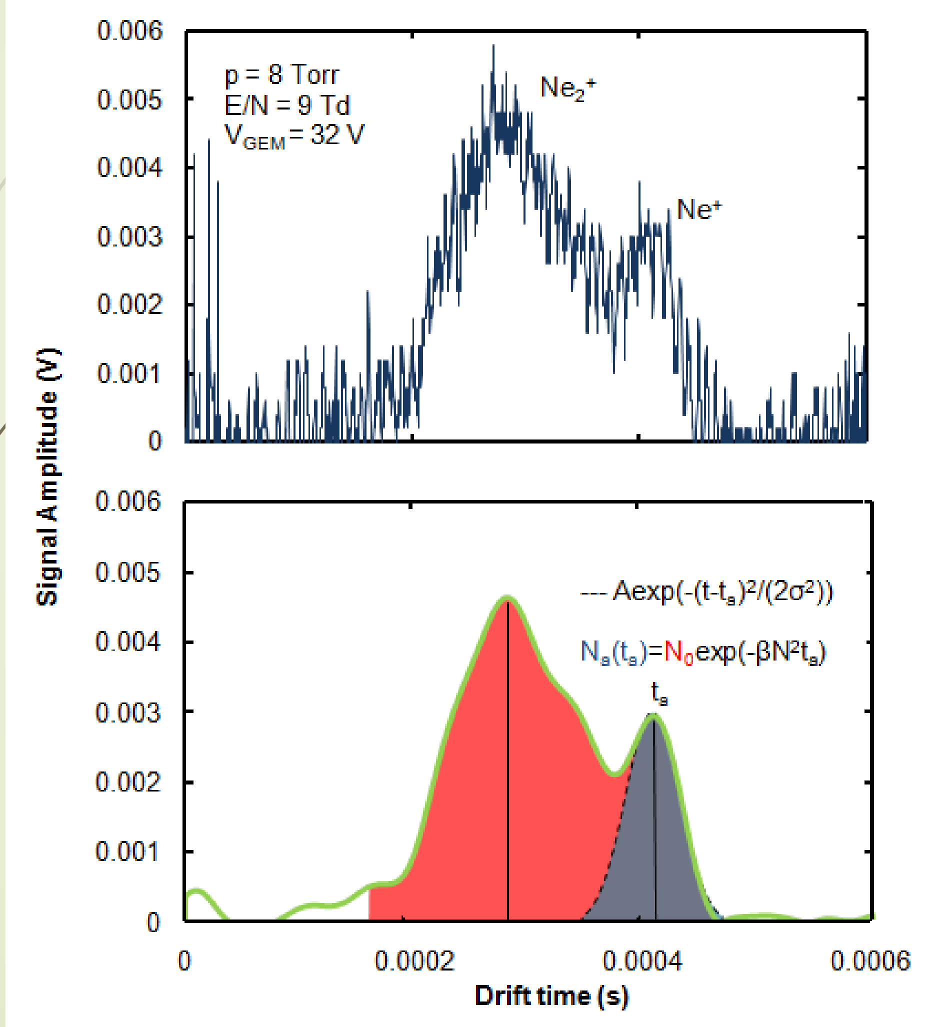
$$\frac{1}{\mathrm{K_{0mix}}} = \frac{\mathrm{f_1}}{\mathrm{K_{0g1}}} + \frac{\mathrm{f_2}}{\mathrm{K_{0g2}}}$$

$\mathrm{f_1}$, $\mathrm{f_2}$– molar fraction of gas 1 and 2

Mobility of an ion in a mixture

Reaction rate Measurements

$$Rg^+ + 2Rg \overset{\beta}{->} Rg_2^+ + Rg$$



$Rg^+ + 2Rg -> Rg_2^+ + Rg$

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

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

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

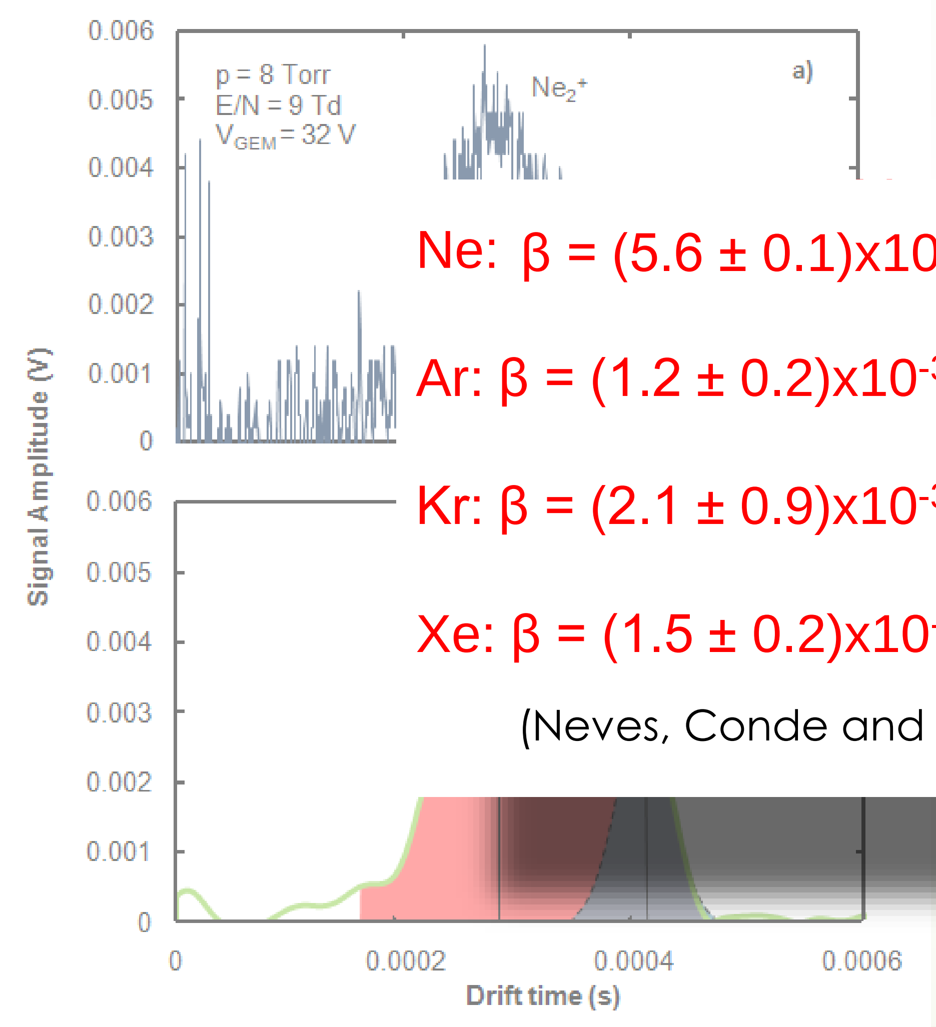
[Rg+](0) is proportional to the total area.

Depends on:

- Temperature

Results: Reaction rate

$$Rg^+ + 2Rg \overset{\beta}{->} Rg_2^+ + Rg$$



Ne: β = (5.6 ± 0.1)x10^{-32} cm^{6}s^{-1}

Ar: β = (1.2 ± 0.2)x10^{-31} cm^{6}s^{-1}

Kr: β = (2.1 ± 0.9)x10^{-31} cm^{6}s^{-1}

Xe: β = (1.5 ± 0.2)x10^{-31} cm^{6}s^{-1}

(Neves, Conde and Távora, 2010)

$Rg^+ + 2Rg -> Rg_2^+ + Rg$

g]^2

(-βN^2)

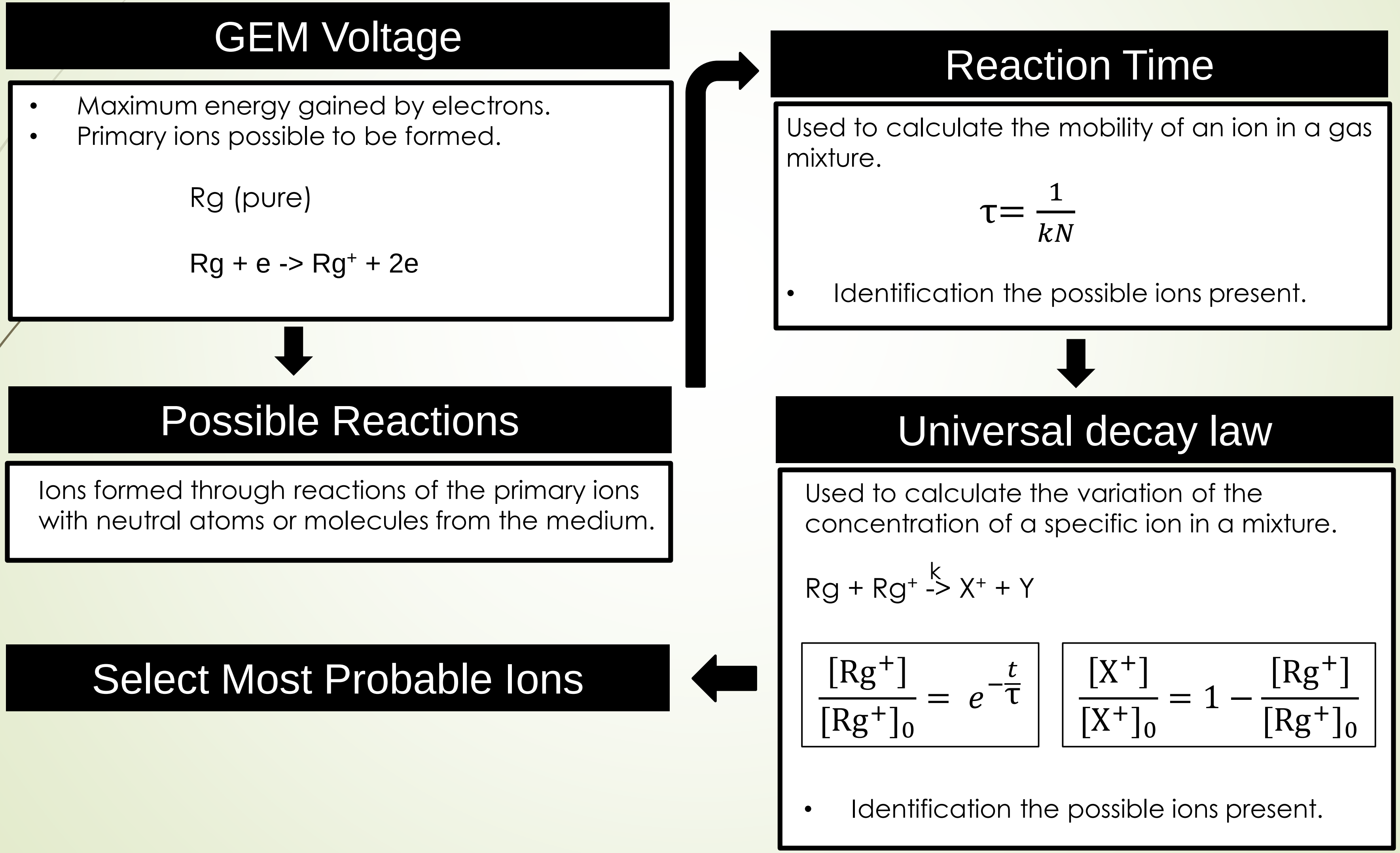
nal to the area

aussian.

ional to the

total area.

Candidate ions identification



GEM Voltage

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

Rg (pure)

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

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.

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

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

- Identification the possible ions present.

Possible Reactions

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

Select Most Probable Ions