Ion Mobility in Ar-CO_2

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Contents

Collaboration Project within RD51

Title: Measurement and calculation of ion mobility of some gas mixtures of interest

Participating Institutions

Darmstag - Germany	Coimbra - Portugal	Bursa - Turkey	Kolkata - India
GSI	LIP-Coimbra	Uludağ University	VECC

Contact Persons:

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Objectives

- *Systematic measure ion mobility in gaseous mixtures of interest*
  - *Ar-CO_2*
  - *Ne-CO_2*
  - *Ne-CO_2-N_2*
  - *Ar-CF_4*
  - *Ne-CF_4*

- *Simulation work within the mentioned gas mixtures and quantitative description of the measurements.*

Why?

Scarce data available on ion mobility in mixtures relevant for the ALICE TPC, although measurements for other gases have been performed since long.

→ Urgency to give feedback to the Alice TPC Project!

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Project Tasks

OUR COMMON PURPOSE

GSI

- *Develop a new detector and improve the large set of measurements done by VECC and LIP-Coimbra.*

LIP-Coimbra

- *Systematically measure ion mobility of mixtures such as Ar-CO_2, Ne-CO_2 and other gas mixtures at various concentration and electric fields around 400 V/cm.*

Uludağ Univ.

- *Adapt their simulation framework to the mentioned gas mixtures and aim at a quantitative description of the measurements.*

VECC

- *Improve ion mobility, extending the composition range, pressure and the electric field range.*

Collaboration Previous Achievements

- March 2014
  - First contacts.
- April 2014
  - GSI starts developing its ionization chamber
  - LIP-Coimbra starts with Ar-CO2 mixtures studies
  - Uludag Univ. starts with the simulation work
- May 2014
  - GSI concludes the ionization chamber
  - LIP-Coimbra achieve some preliminary results on Ar-CO2 mixtures studies
  - Uludag Univ. continues the simulation work
- June 2014
  - GSI starts testing the ionization chamber
  - LIP-Coimbra finishes the Ar-CO2 mixture studies
  - Uludag Univ. concludes the preliminary analysis for Ar-CO2 mixtures
  - …

Present Status

- GSI has the ionization chamber constructed, and is testing it.
- LIP-Coimbra is about to start with Ne-CO_2 mixtures.
- Uludağ Univ. has already started doing some simulation studies on the mentioned mixtures, Ar-CO_2 already completed.

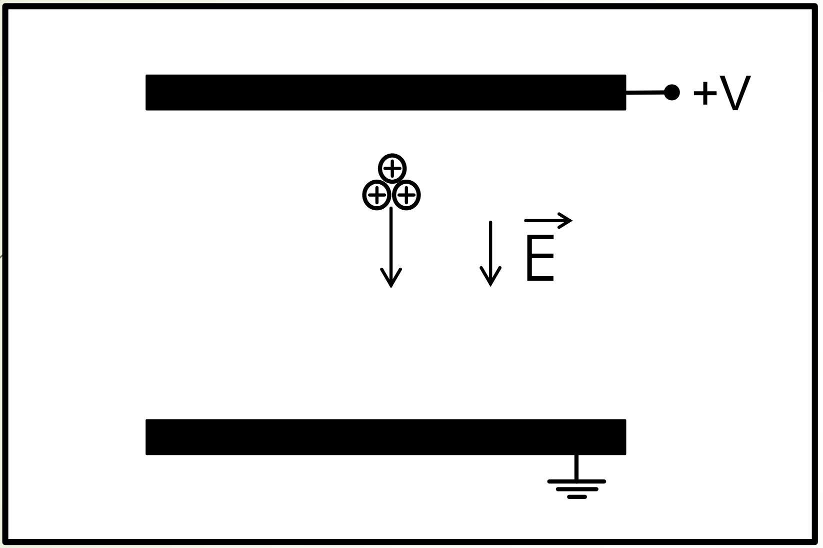
There's much yet to be done depending on financing...

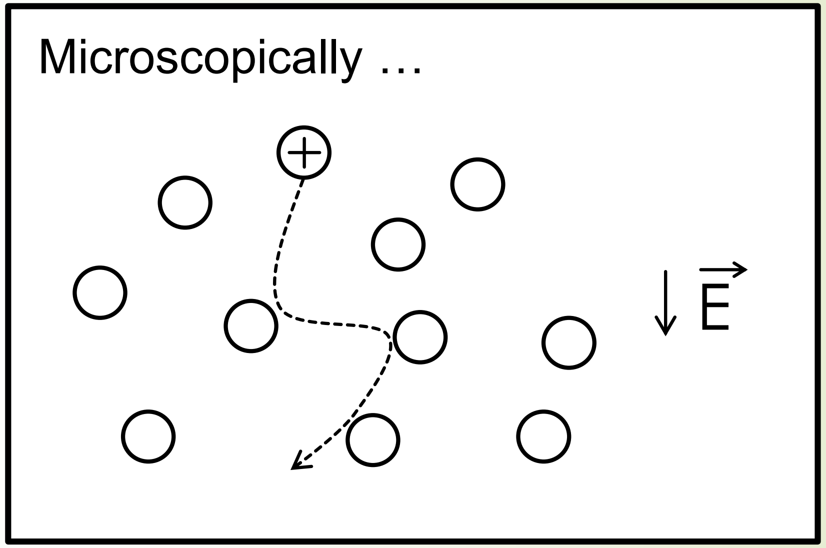
Ion Mobility Measurement at LIP Coimbra

- Basic Concepts
- Experimental Setup and Working Principle
- Ion Identification Process
- Experimental results in:
  - Ar-CO_2

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

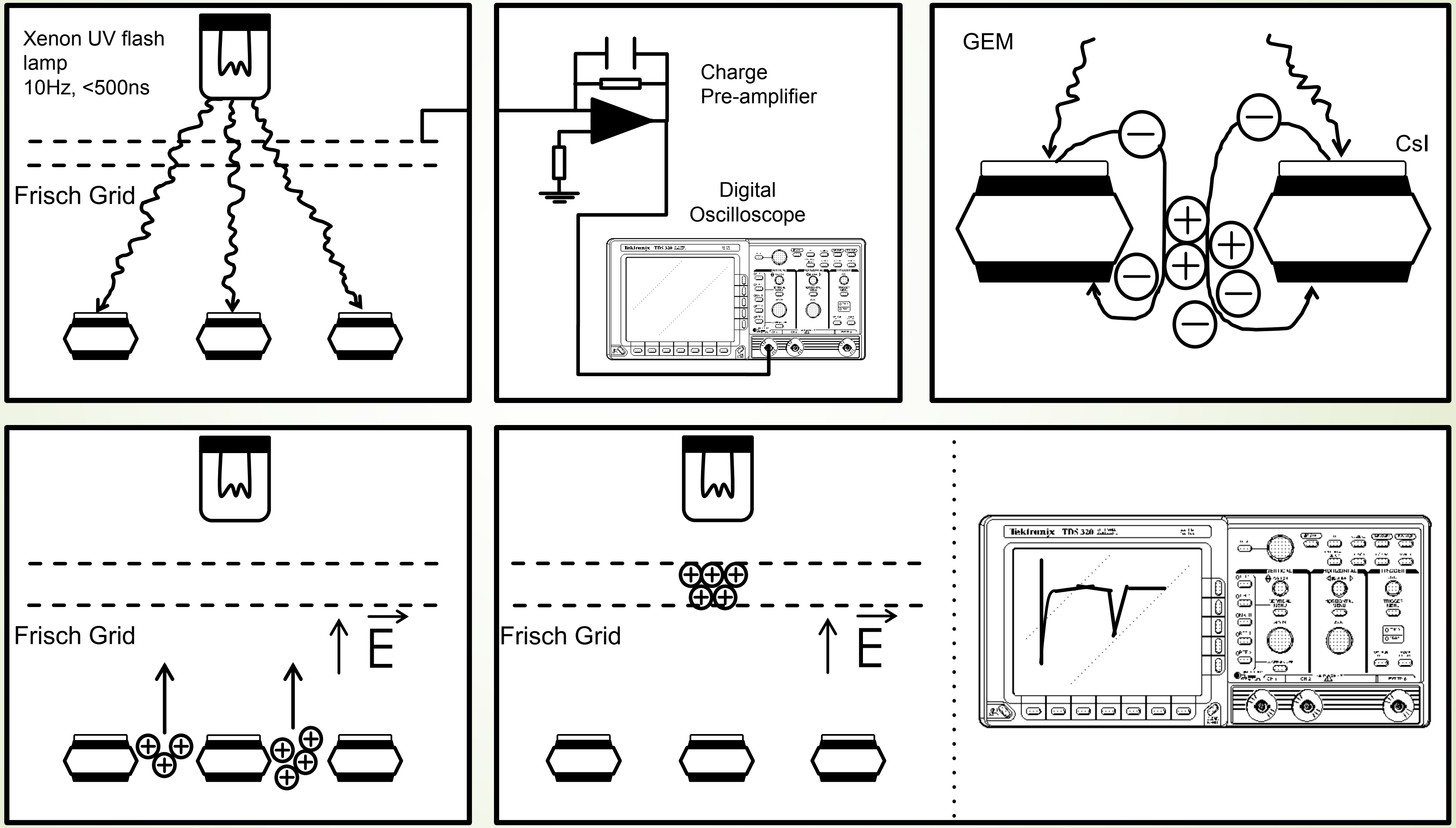
Blanc's Law

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

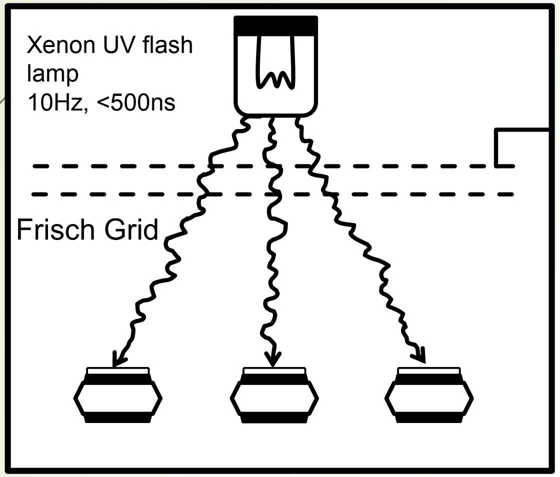
f_1, f_2 – molar fraction of gas 1, 2
K_{0g1}, K_{0g2} – ion mobility in the gas 1 and gas 2

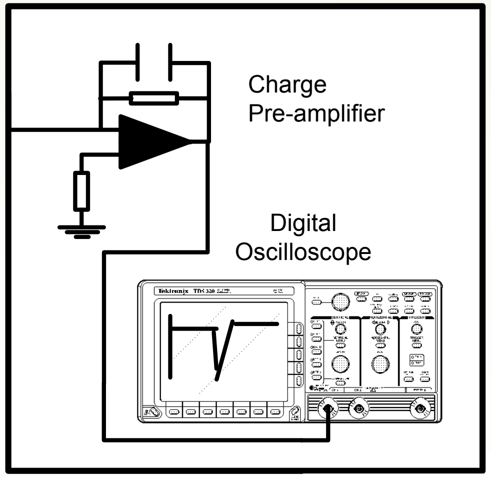
Experimental Setup and Working Principle

(Neves, Conde and Távora, 2007)



Experimental Setup and Working Principle





After the signal and the background were recorded…

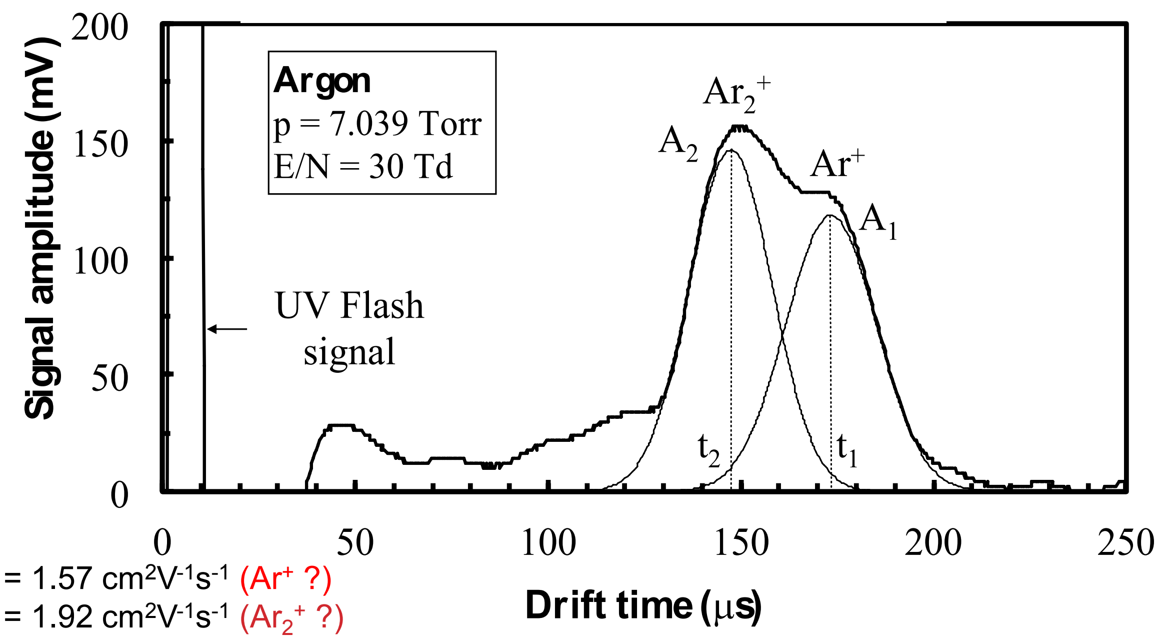
- Subtract the background to the signal
- Identify possible peaks
- Fit Gaussian curves to the spectrum obtained

peaks centroids

⬇

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

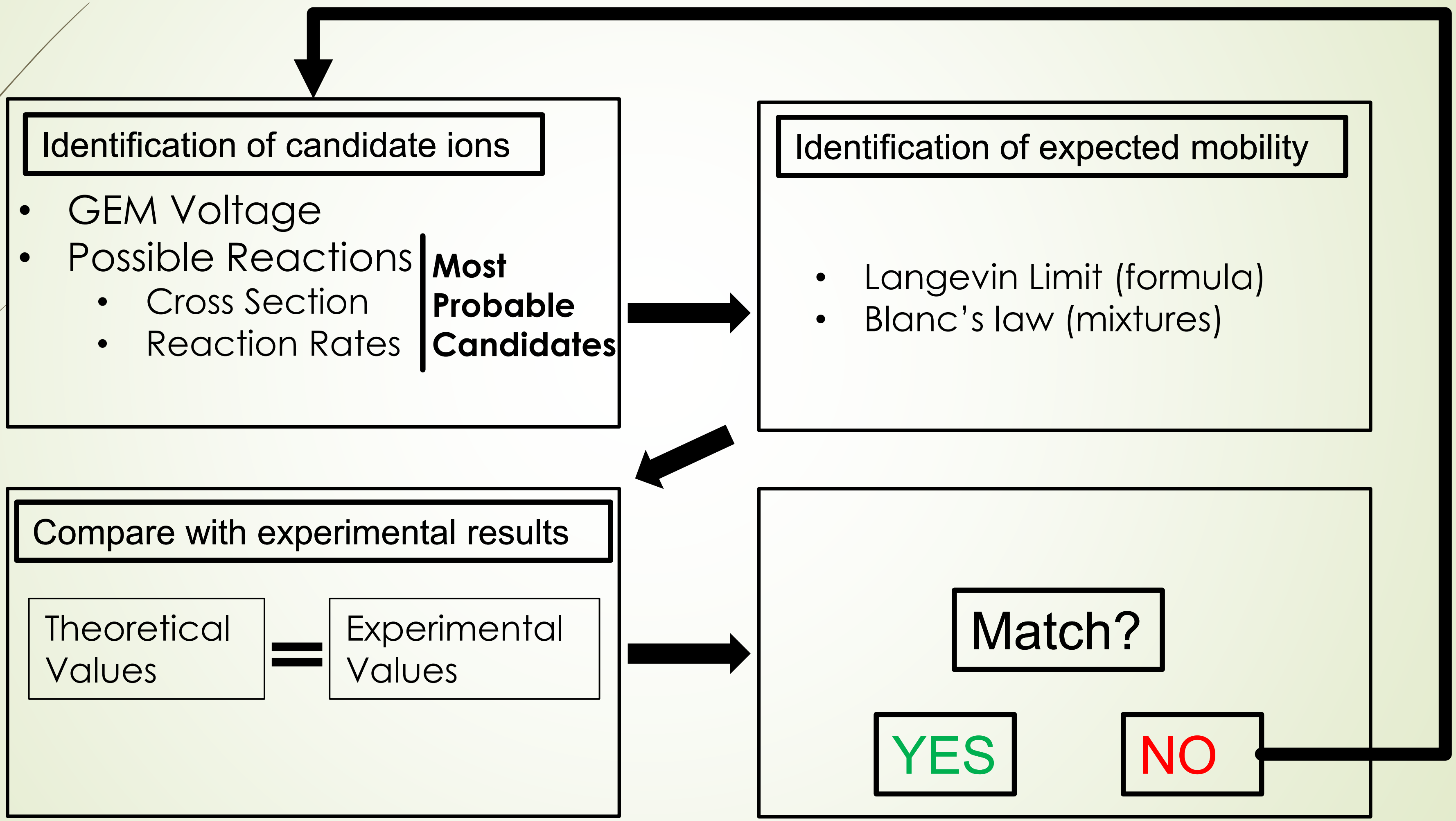
$$v_{\mathrm{d}} = \frac{x_{drift}}{t_{drift}} \rightarrow K = \frac{v_{\mathrm{d}}}{E}$$



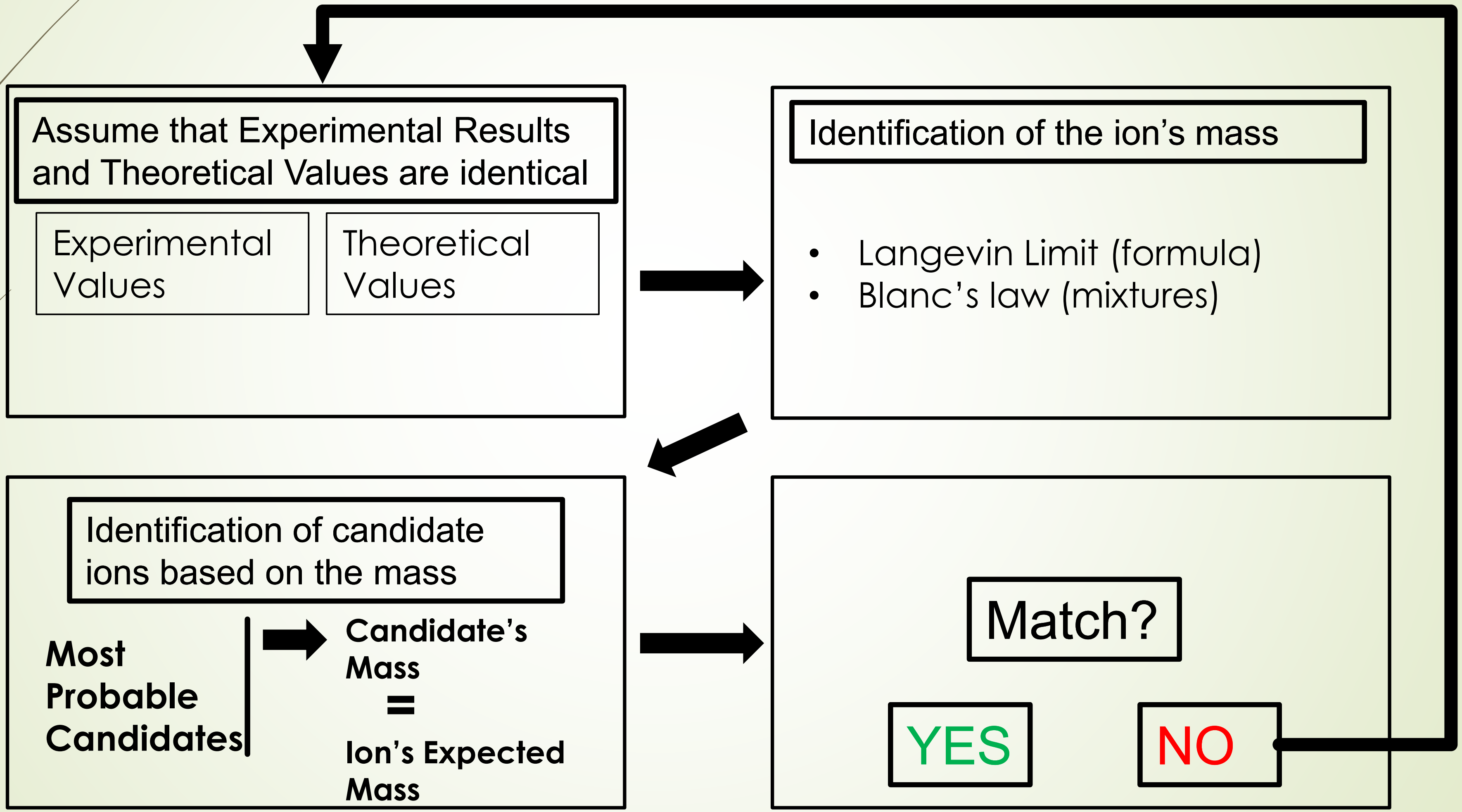
K_{01} = 1.57 $cm^2V^{-1}s^{-1}$ (Ar^+ ?)

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

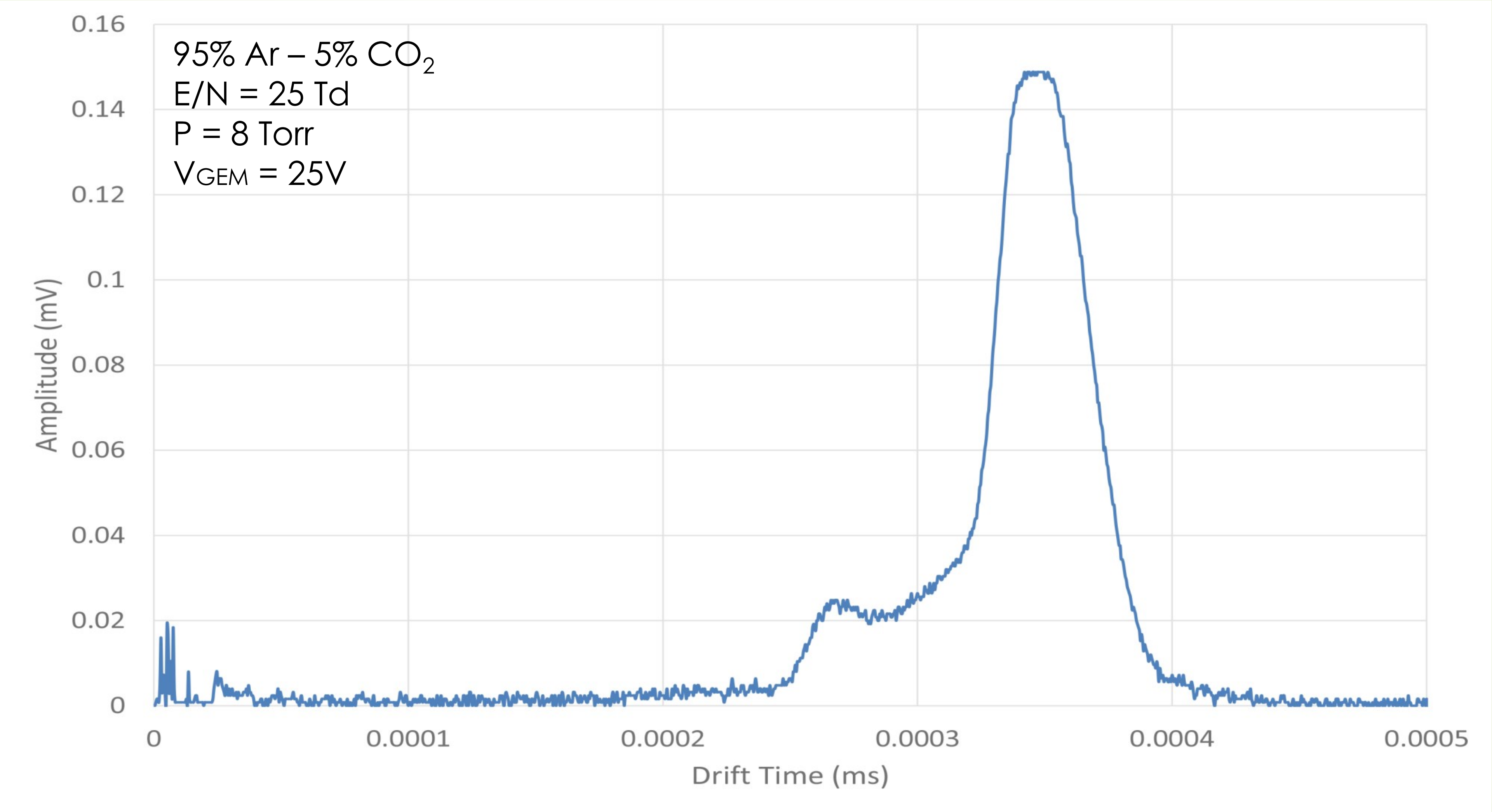
Ion Identification Process



Ion Identification Process



Ion Identification: Ar-CO_2



Which ions are we observing?

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Experimental Results: Ar

Appearance Energies

Ar^+ 15.76 eV

IONIZATION

Ar + e → Ar^+ + e

Above threshold 15.76 eV

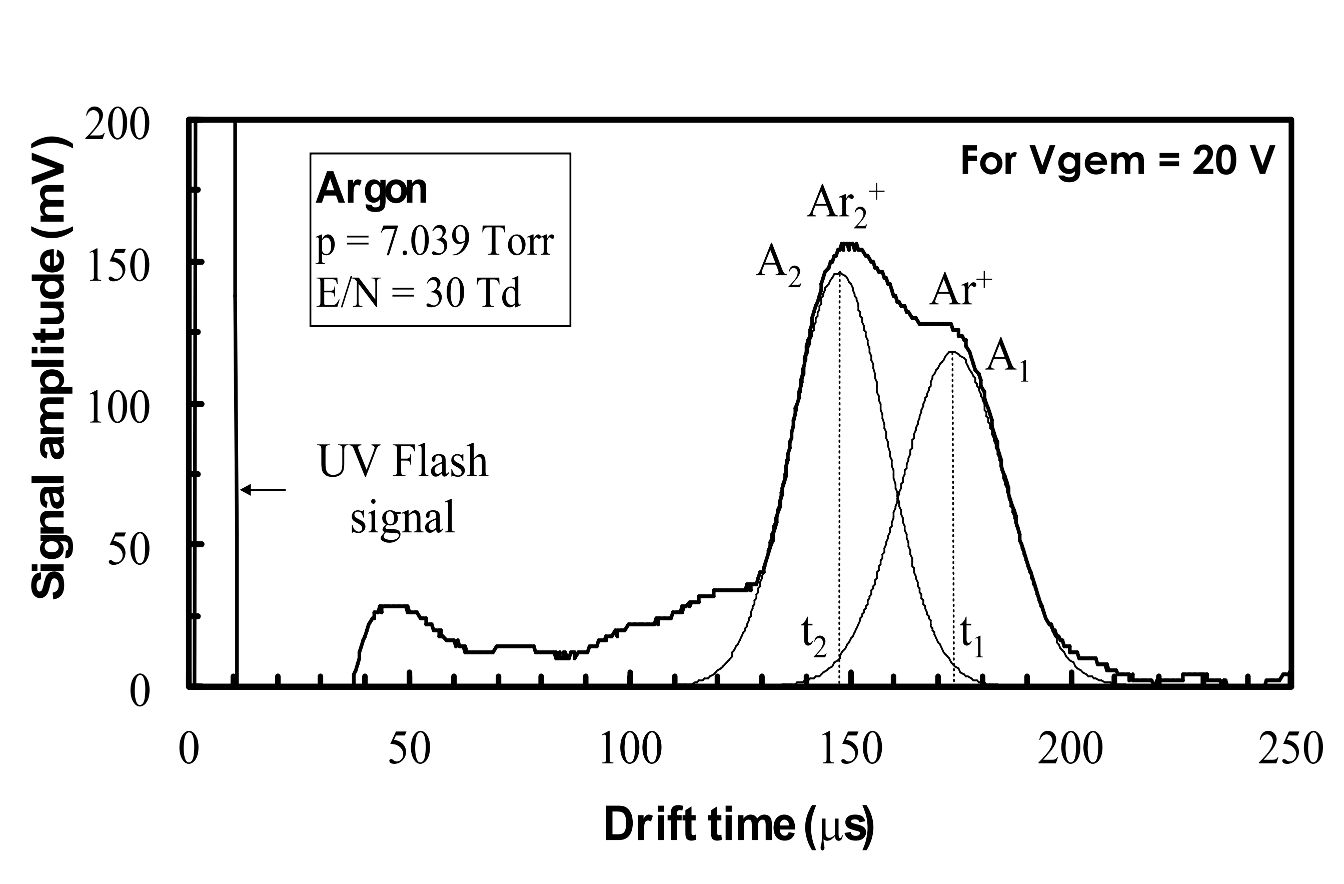
REACTIONS

Ar^+ + 2Ar → Ar_2^+ + Ar

Ar^+ + Ar → 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: CO2

Appearance Energies

CO_2^+	13.8 eV
CO^+	19.5 eV
O^+	19.1 eV

IONIZATION

$CO_2 + e \rightarrow CO_2^+ + e$ — **above threshold 13.8 eV**

$CO_2 + e \rightarrow CO_2^+ + e$ 84.7 %
$\rightarrow CO^+ + 1/2O_2 + e$ 3.7 %
$\rightarrow O^+ + CO + e$ 5.4 % *

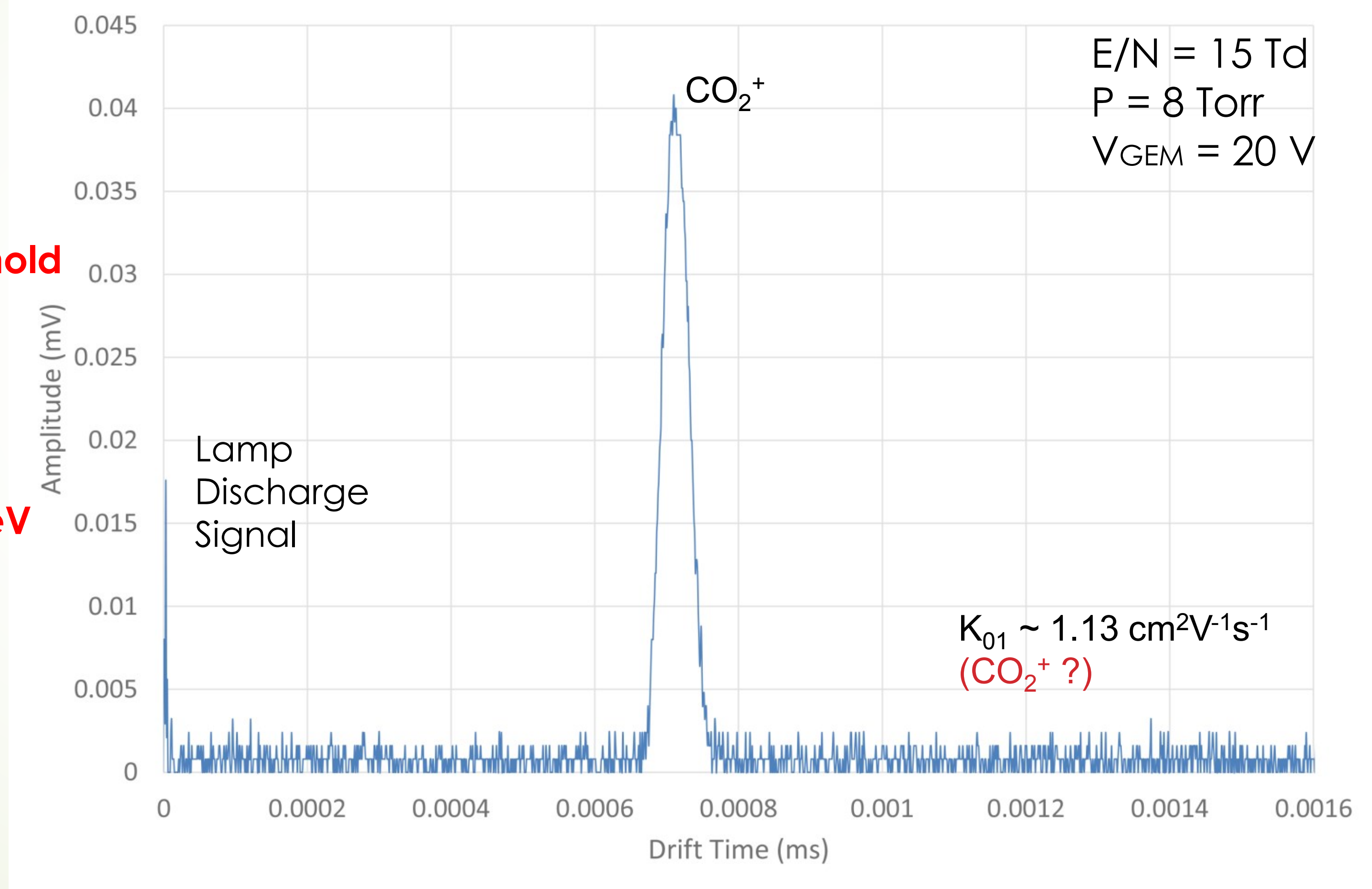
above 19.5 eV

REACTIONS

$CO_2^+ + CO_2 \rightarrow CO_2 + CO_2^+$

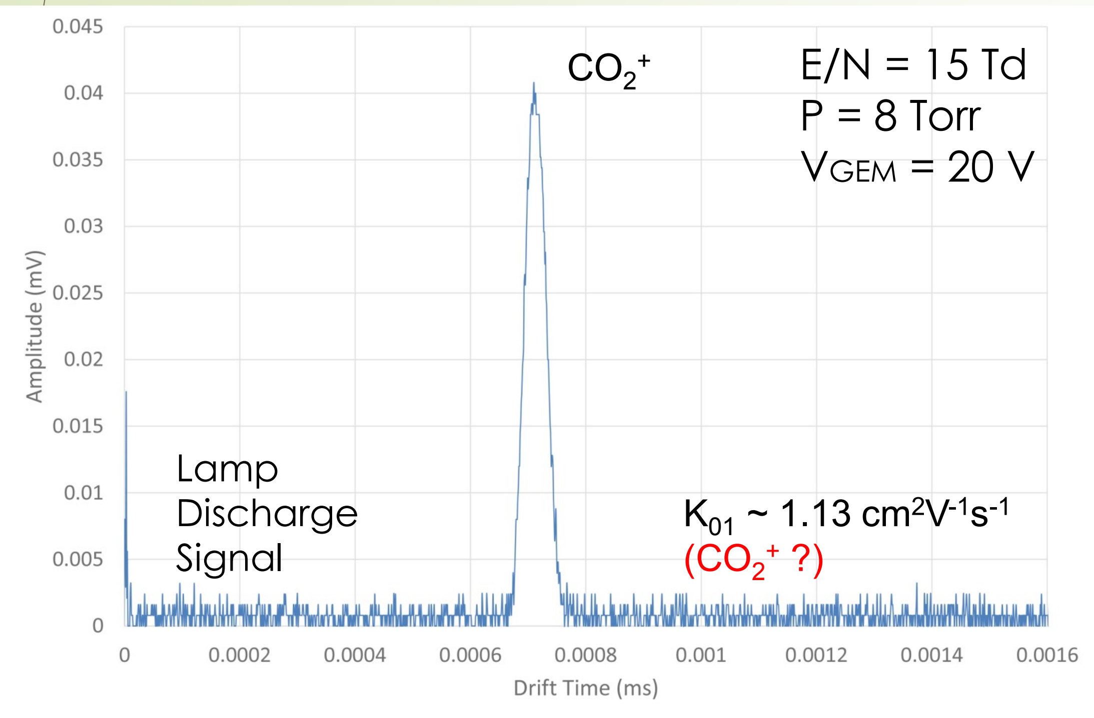
$CO^+ + CO_2 \rightarrow CO_2^+ + CO$

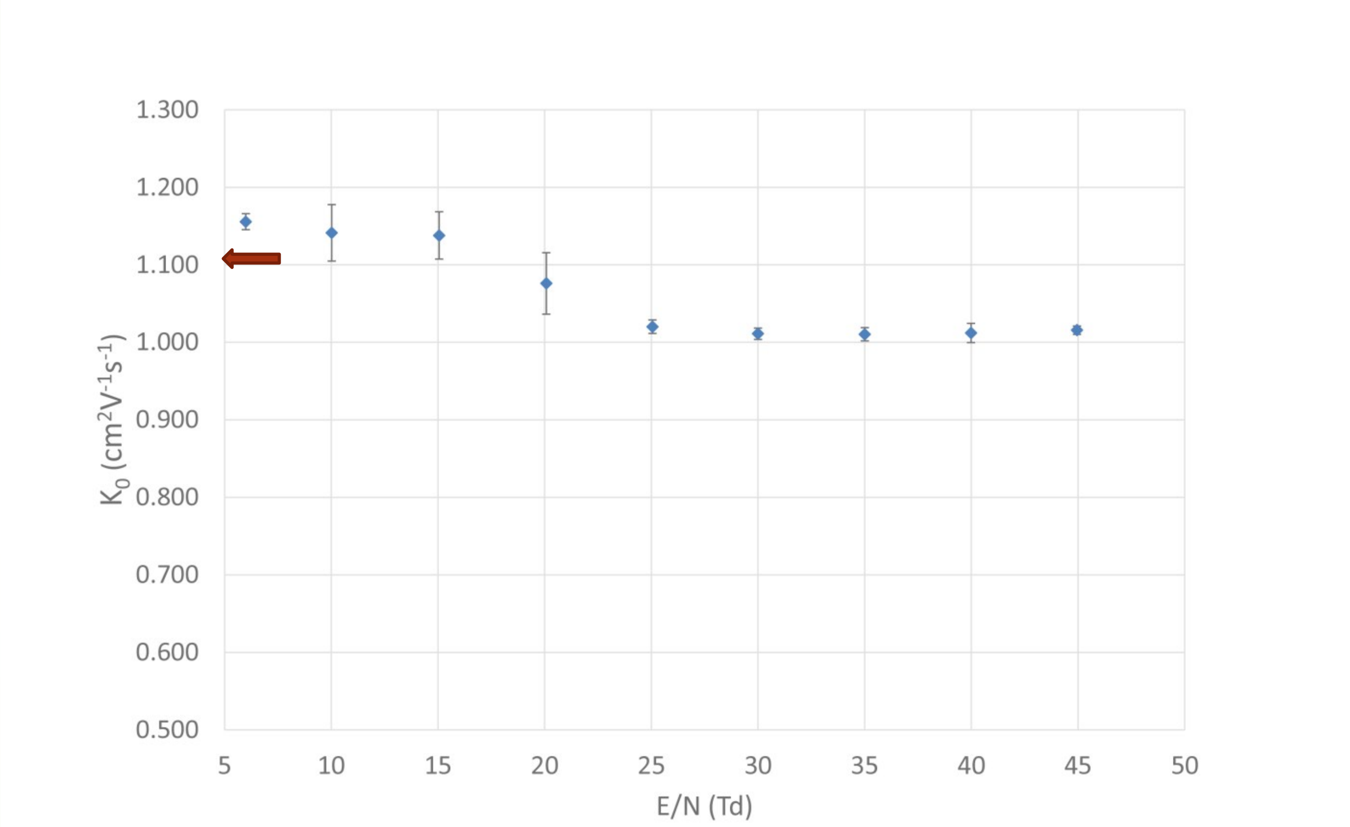
$O^+ + CO_2 \rightarrow O_2^+ + CO$



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

Experimental Results: CO_2





Good agreement with earlier reported work..

(Schultz, Charpak, Sauli 1977)

K_{01} ~ 1.09 $cm^2V^{-1}s^{-1}$
(CO_2^+ ?)

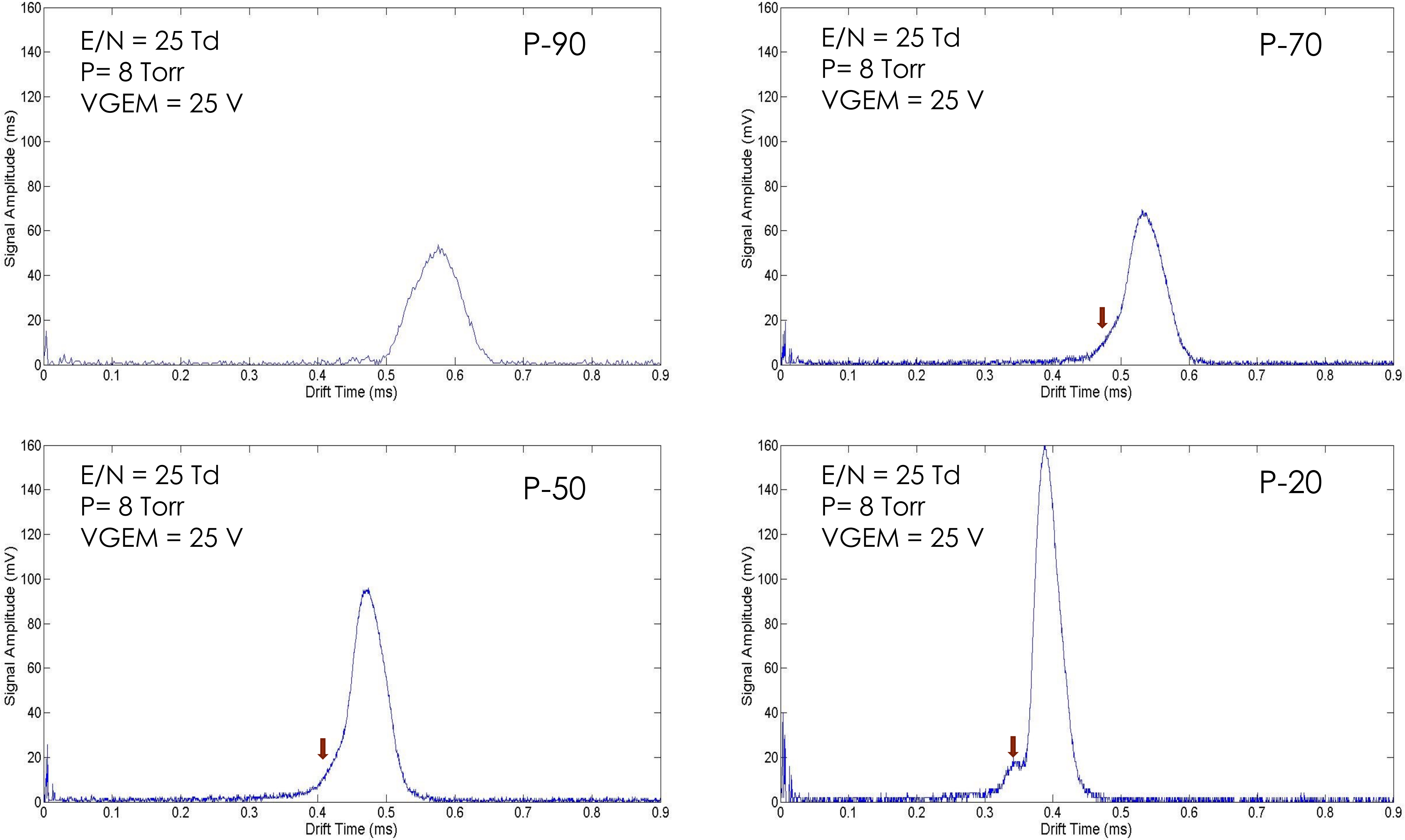
$\alpha = 2.63$ Å^3

Calc. Langevin Limit		Experimental value
1.81 $cm^2V^{-1}s^{-1}$	≠	1.16 $cm^2V^{-1}s^{-1}$

Charge Transfer Process

$CO_2^+ + CO_2 \rightarrow CO_2 + CO_2^+$

Experimental Results: Ar-CO_2



Experimental Results: Ar-CO_2

Ions move faster with the presence of Ar.

Amplitude rises until 80% of Ar

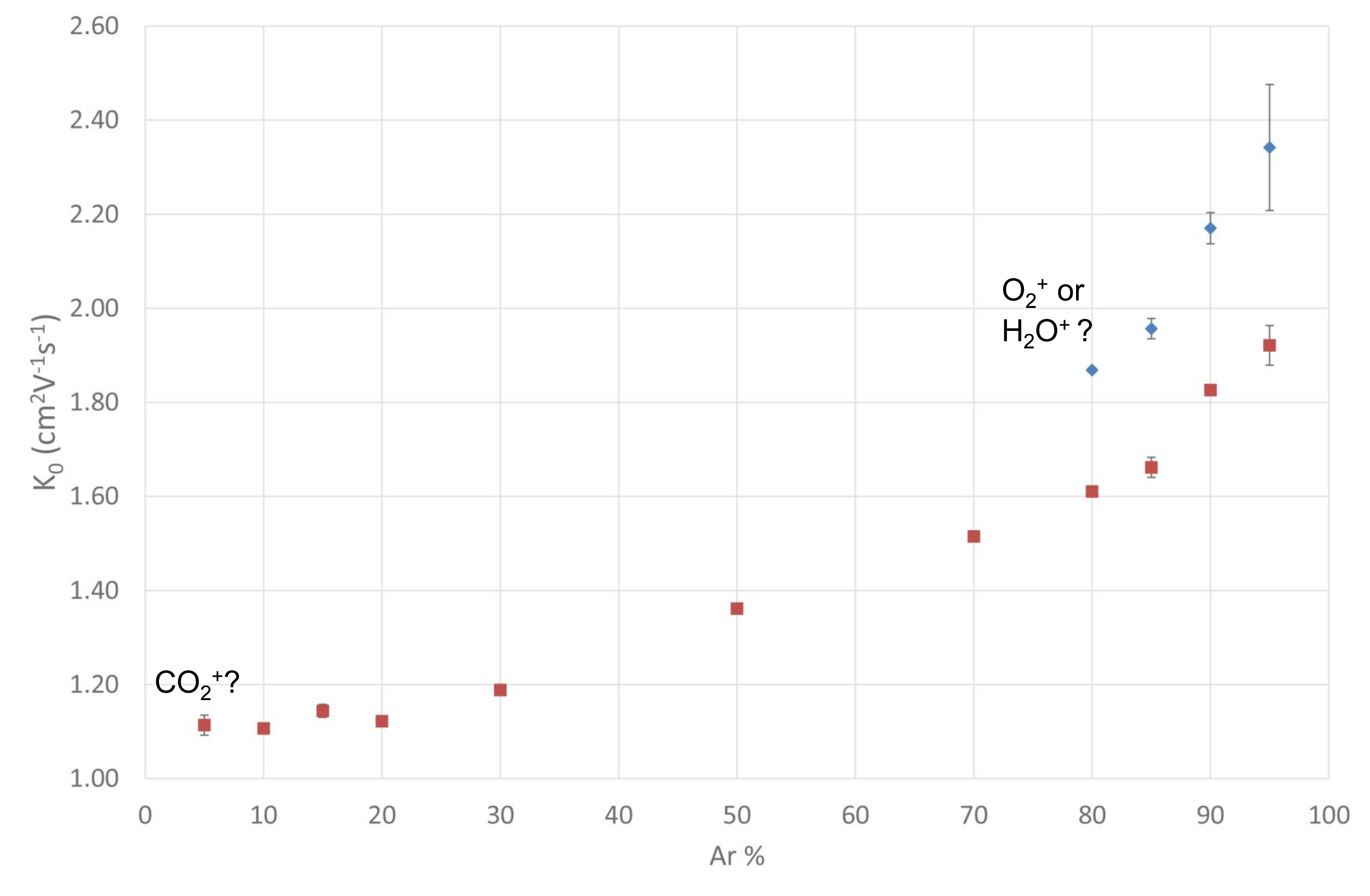
- Cross section.
- Presence of Ar limits the variety of possible ion products.

Appearance of a 2nd peak for:

Ar > 80%

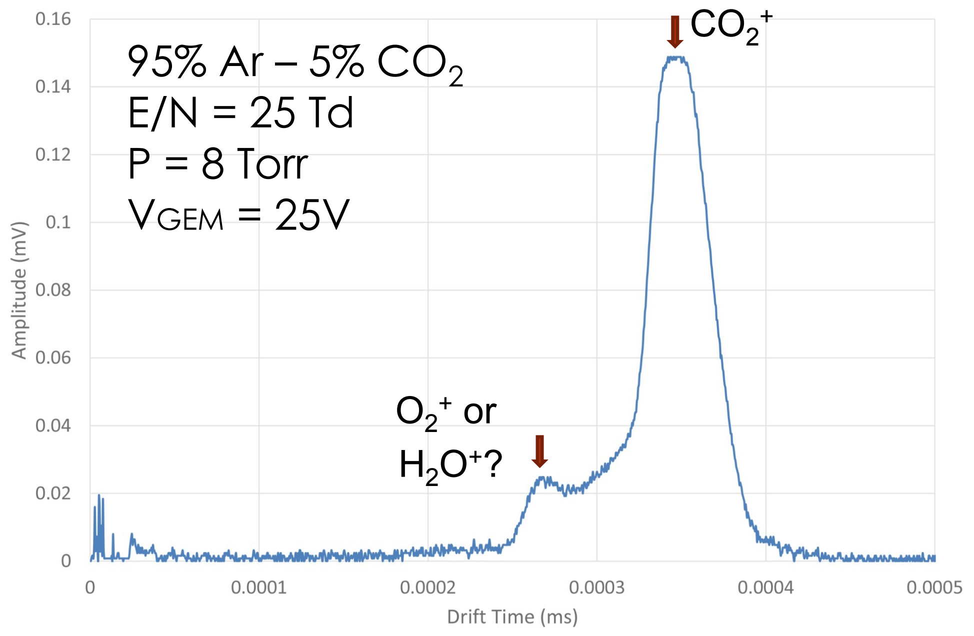
2nd peak maybe due to:

- O_2^+
- H_2O^+



Experimental Results: Ar-CO_2

Results



K_{02} ~ 1.98 $cm^2V^{-1}s^{-1}$ (CO_2^+?)
K_{01} ~ 2.35 $cm^2V^{-1}s^{-1}$ (O_2^+ or H_2O^+?)

Discussion

(Charge Transfer Reaction)

$Ar^+ + CO_2 \rightarrow CO_2^+ + Ar$

Prevents the formation of Ar_2^+.

↓

Same Ion Product

↓

Match

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

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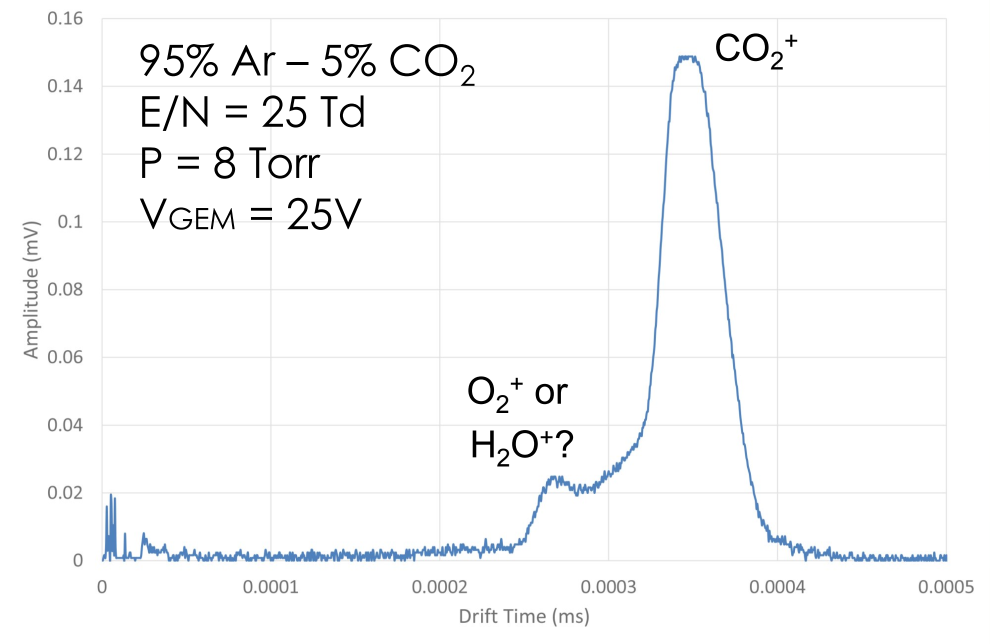
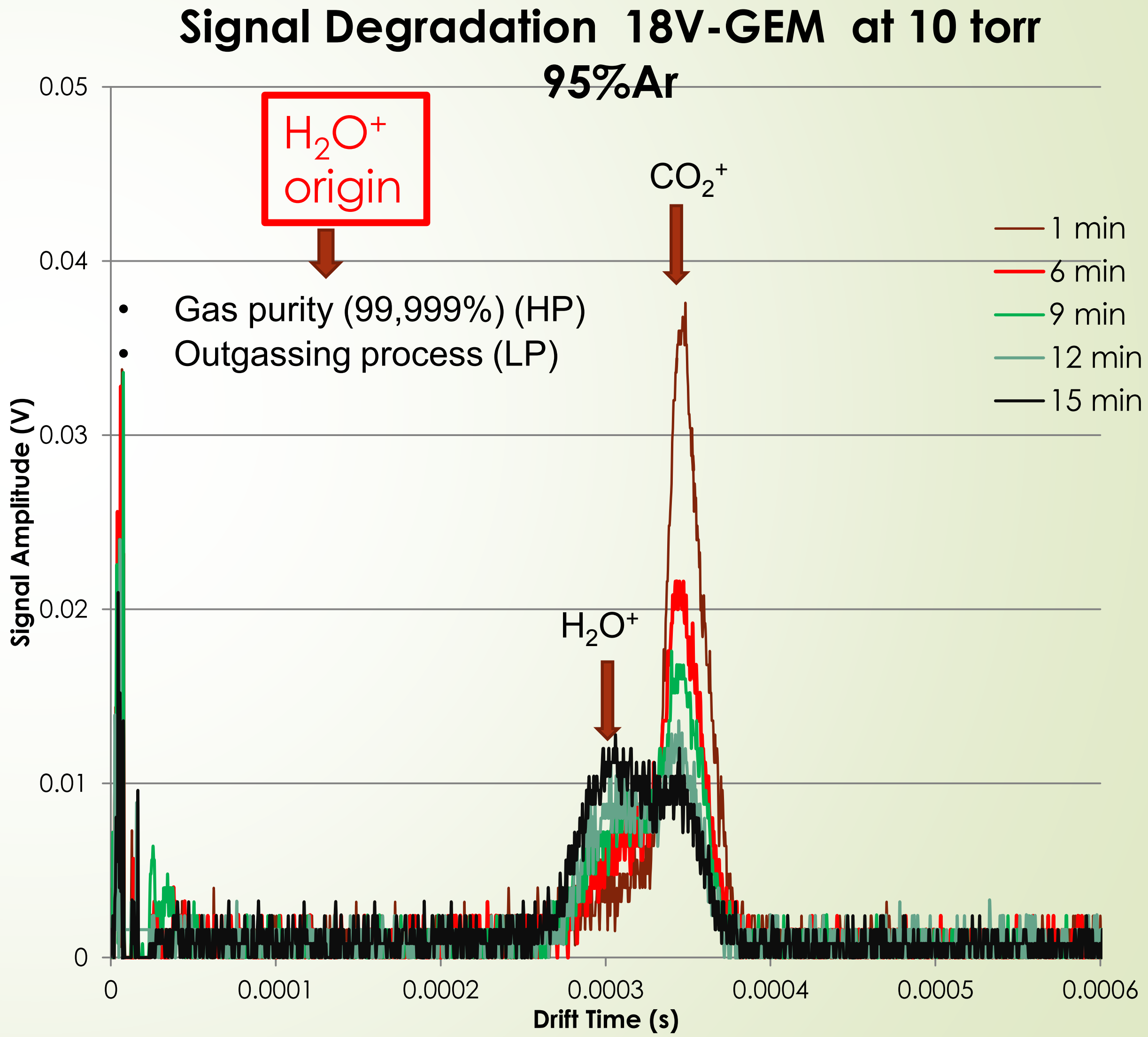
Experimental Results: Ar-CO_2

O_2^+ or H_2O^+ ?



- The small bump appears even for lower energies (18 eV).
- Even for 25 eV, Oxygen has a small probability to be formed

*only 5.4%



Conclusions

Technique and Method

- This technique has allowed us to make ion mobility measurements in several gases.
- 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.

Collaboration Project

- First steps taken with interesting experimental results.
- Good perspectives for the collaboration future (Ar-CO2 results to be published soon).

Future Work

- Pursuit the investigation on the mobility of ions in different gas mixtures of practical use:
  - *Ne-CO2*
  - *Ne-CO2-N2*
  - *Ar-CF4*
  - *Ne-CF4*

- Optimization of the detector:
  - *Variable Drift Distance*
  - *High Pressure*

  →
  - Rate constant influence
  - Study lighter ions (H2)
  - (...)

- Study of improved ion-neutral interaction models

CERN/FP/123613/2011 - Prof. Dr. João Barata

CERN/FP/116392/2010 - Prof. Dr. Rui Marques

- I would like to thank C.A.N. Conde, F.I.G.M. Borges, F.P. Santos, J.A.S. Barata, P.N.B. Neves, A.N.C. Garcia, A.M.F. Trindade , L.M.N. Távora, T.H.T.V. Dias, J. Escada, P. Encarnação, Tapan Nayak, Chilo Garabatos and Rob Veenhof for their contribution to this work.

Thank you!

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.

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

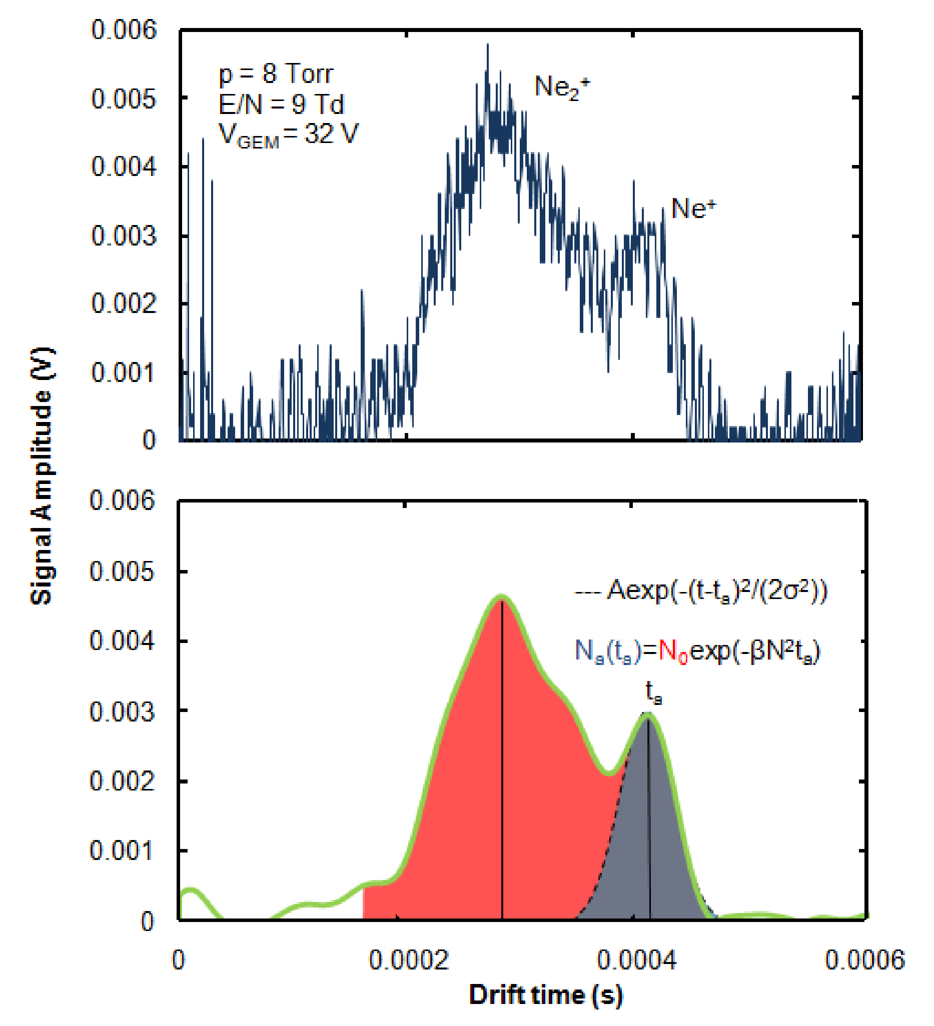
f_1 , f_2 – molar fraction of gas 1 and 2

↓

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:

- Temperatur
e

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)

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