RD51 Collaboration
Mini-week 20-23 February 2017 CERN

Ion mobility in Xe-CO2 mixtures: recent results

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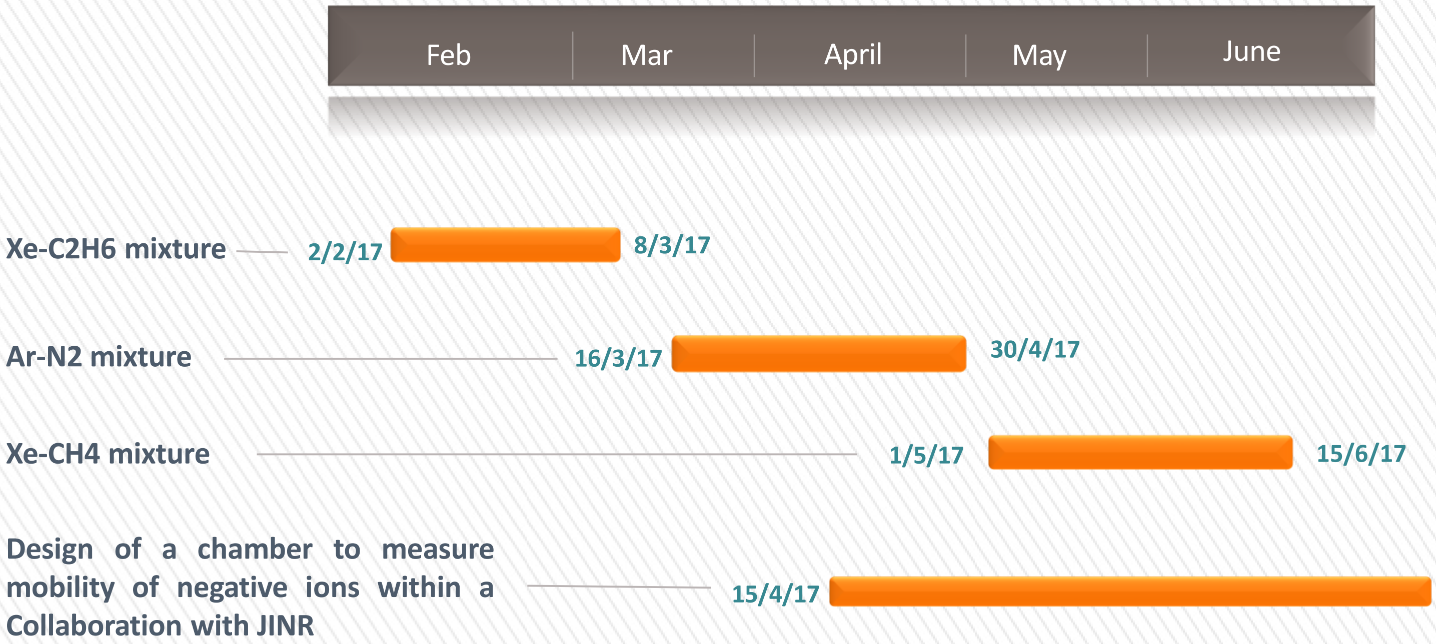
Chronogram



Feb
Mar
April
May
June
Xe-C2H6 mixture
2/2/17
8/3/17
Ar-N2 mixture
16/3/17
30/4/17
Xe-CH4 mixture
1/5/17
15/6/17
Design of a chamber to measure mobility of negative ions within a Collaboration with JINR
15/4/17

1 Basic Concepts

2 Experimental Setup and Working Principle

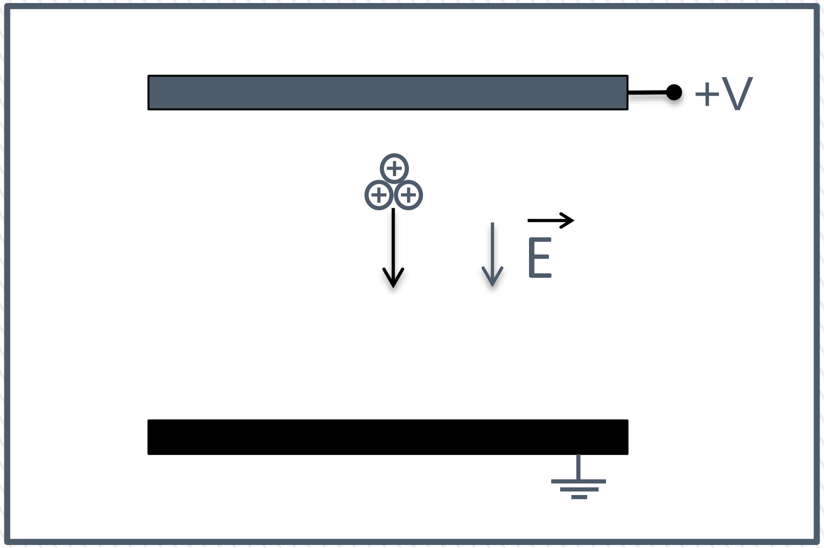
3 Ion Identification Process

4 Experimental results in:

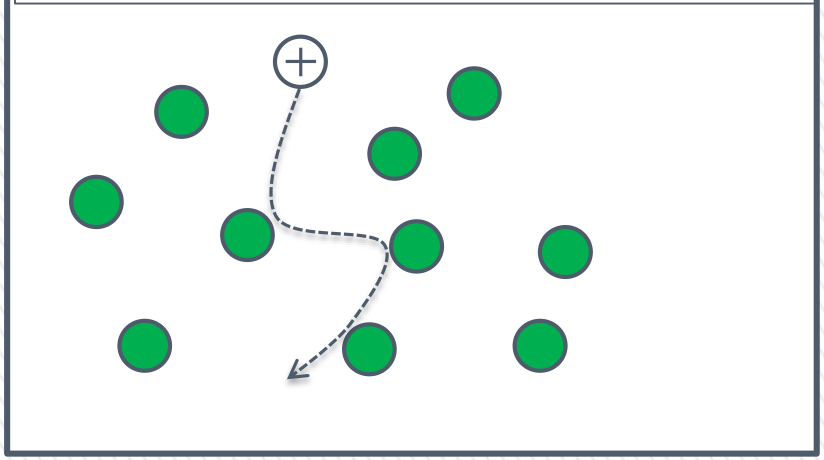
- a Xe, CO_2
- b Xe-CO_2

Basics

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

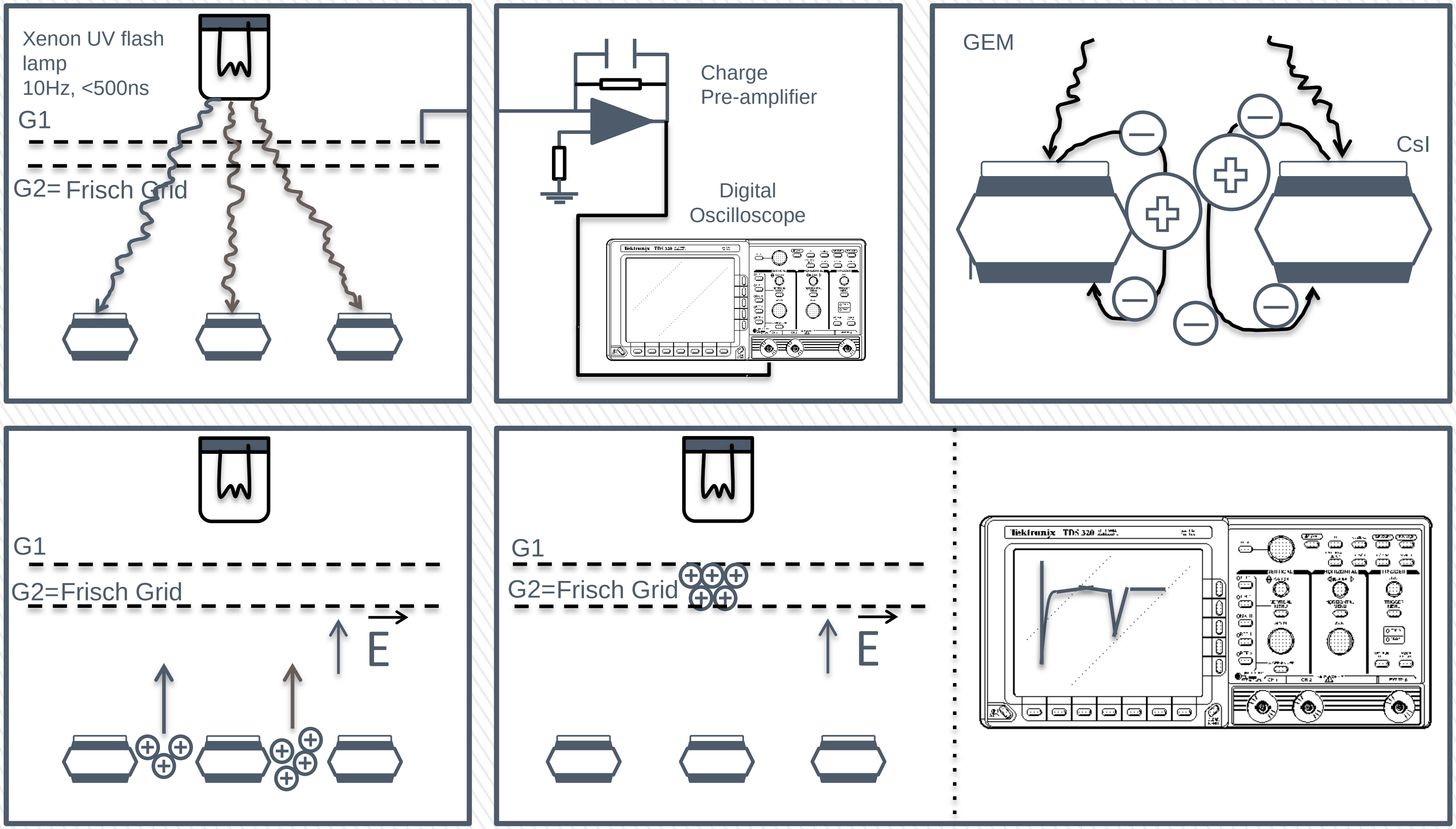
Blanc’s Law

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

f_1,f_2– molar fraction of gas 1, 2

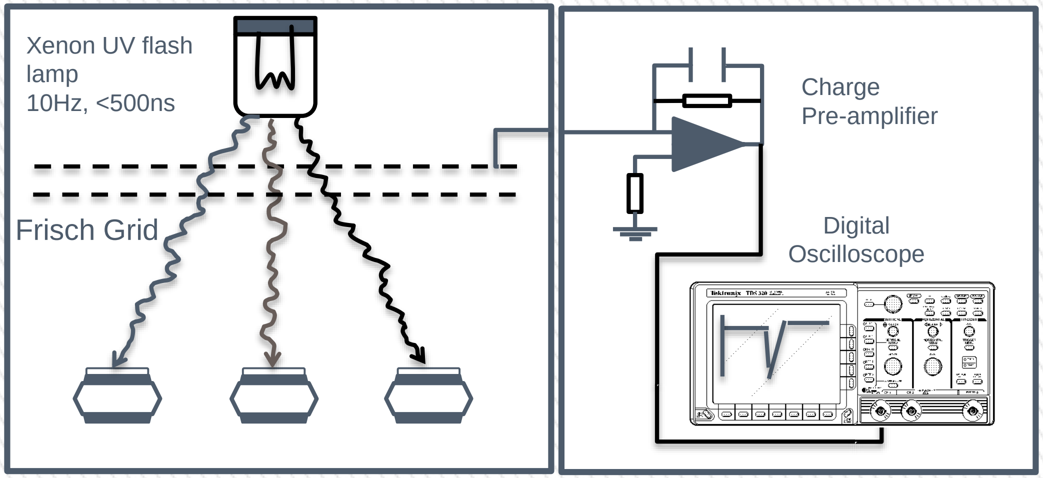
K_{0g1}, K_{0g2} – ion mobility in the gas 1 and 2

Experimental Setup and Working Principle



(Neves, Conde and Távora, 2007)

Experimental Setup and Working Principle



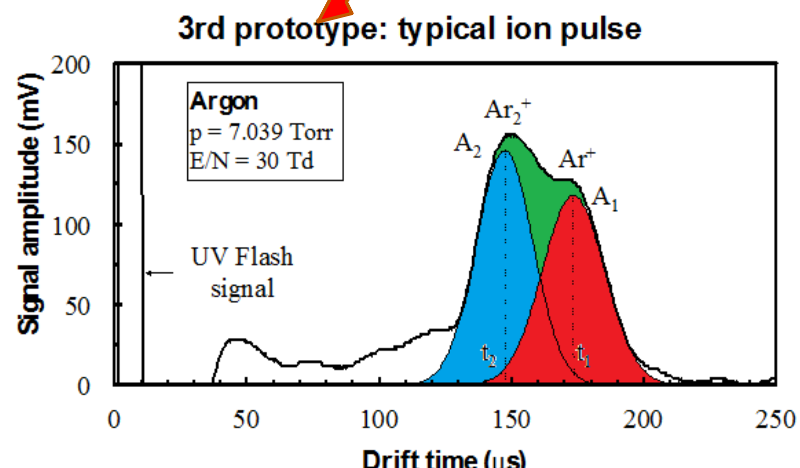
- Subtract the background to the signal
- Identify possible peaks
- Fit Gaussian curves to the peaks obtained

Peaks centroids

↓

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

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



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

Selection of Candidate ions

+

Calculation of expected mobility

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

↓

Comparison with experimental results

Theoretical Values = Experimental Values

Match?

Experimental Results: Xe

Ionization

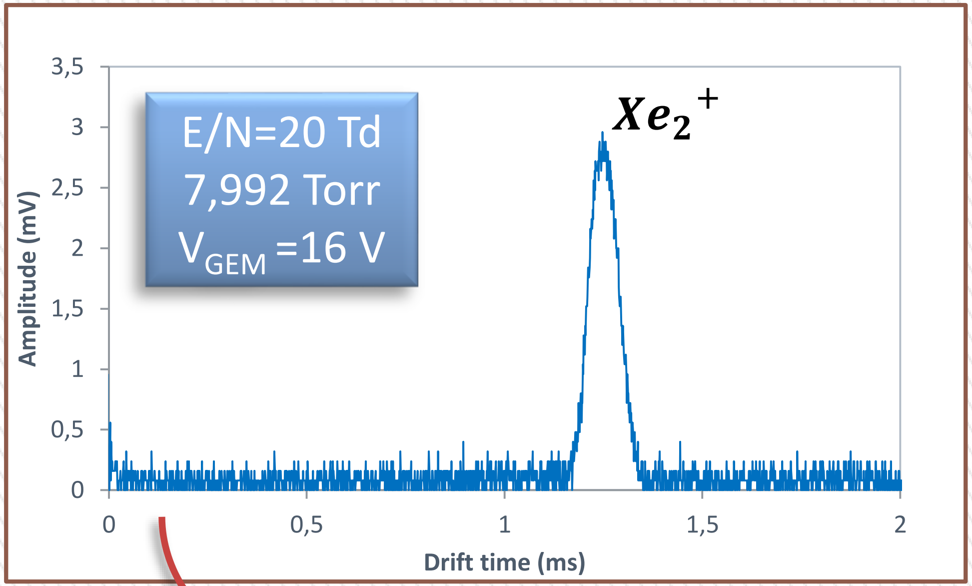
$Xe + e^- \rightarrow Xe^+ + 2e^-$

Above 12,1 eV

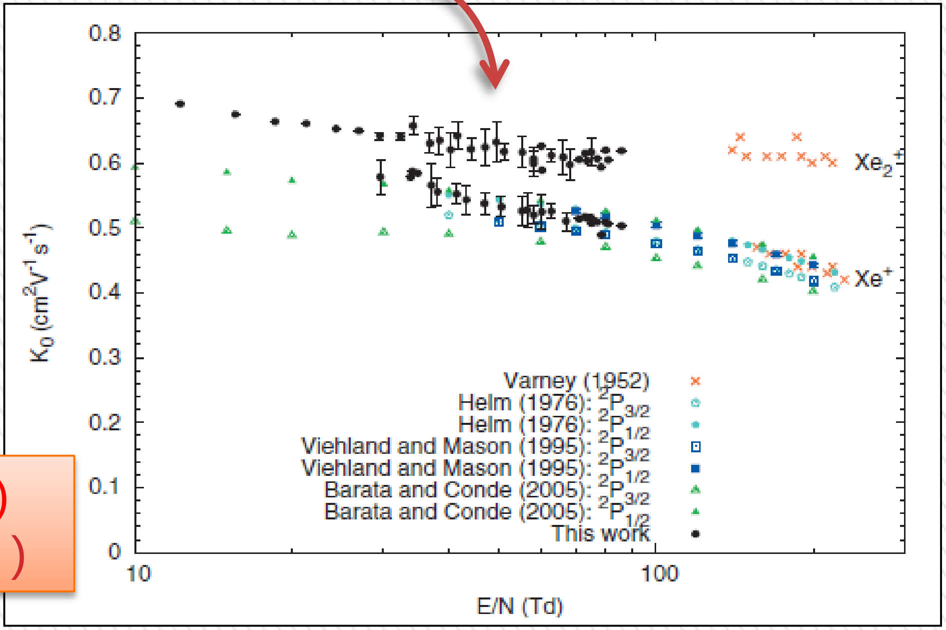
Secondary Reactions

$Xe^+ + 2Xe \rightarrow Xe_2^+ + Xe$

$Xe^+ + Xe \rightarrow Xe + Xe^+$



P.N.B.Neves, 2011, IEEE



$K_{01} = 0,58\ cm^2V^{-1}s^{-1}$ (Xe^+)

$K_{02} = 0,64\ cm^2V^{-1}s^{-1}$ (Xe_2^+)

Experimental Results: CO_2

Ionization

$CO_2 + e^- \rightarrow CO_2^+ + 2e^-$

Above 13.8 eV

above 19.5 eV

$CO_2 + e \rightarrow CO_2^+ + 2e^-$

$\rightarrow CO^+ + \frac{1}{2}O_2 + 2e^-$

$\rightarrow O^+ + CO + 2e^-$

Appearance Energies

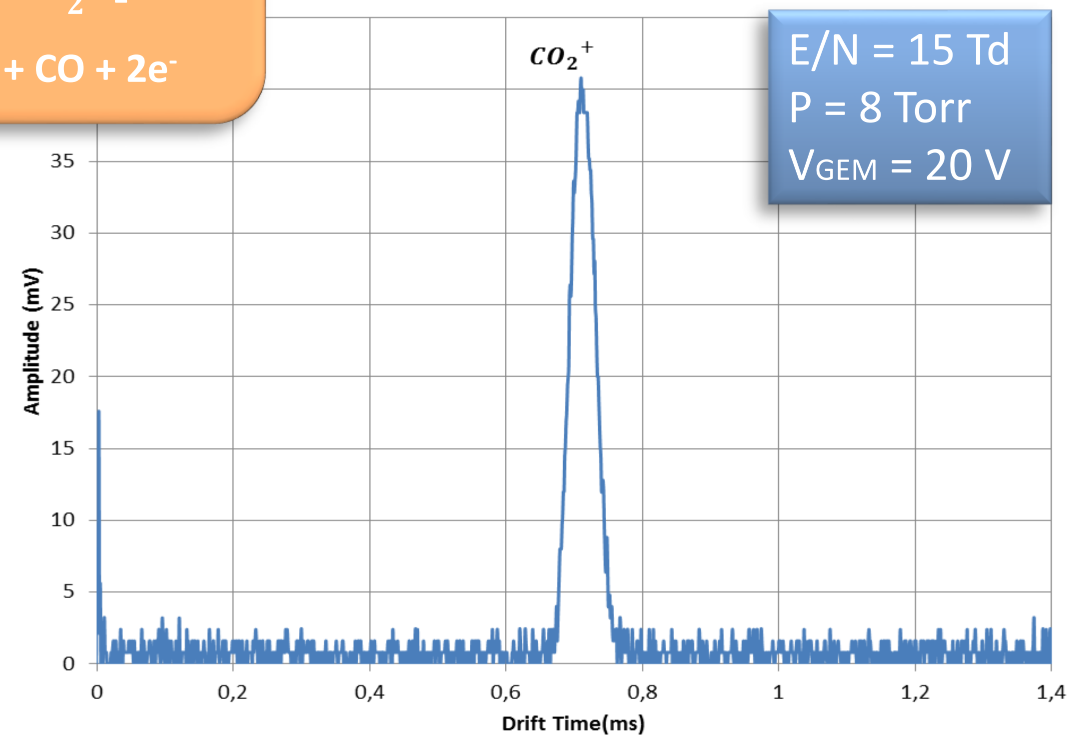
CO_2^+	13.8 eV
CO^+	19.5 eV
O^+	19.1 eV

Secondary Reactions

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

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

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



P.M.C.C. Encarnação, 2015, JINST

Experimental Results: CO_2

$K_{01} \sim 1.17\ cm^2V^{-1}s^{-1}$ **CO_2^+**

Good agreement with earlier reported works:

1. **W. T. Huntress et al. :** $1.23\ cm^2V^{-1}s^{-1}$
2. **G. Schultz et al. :** $1.09\ cm^2V^{-1}s^{-1}$

Langevin Formula

$1.82\ cm^2V^{-1}s^{-1}$

$\neq$

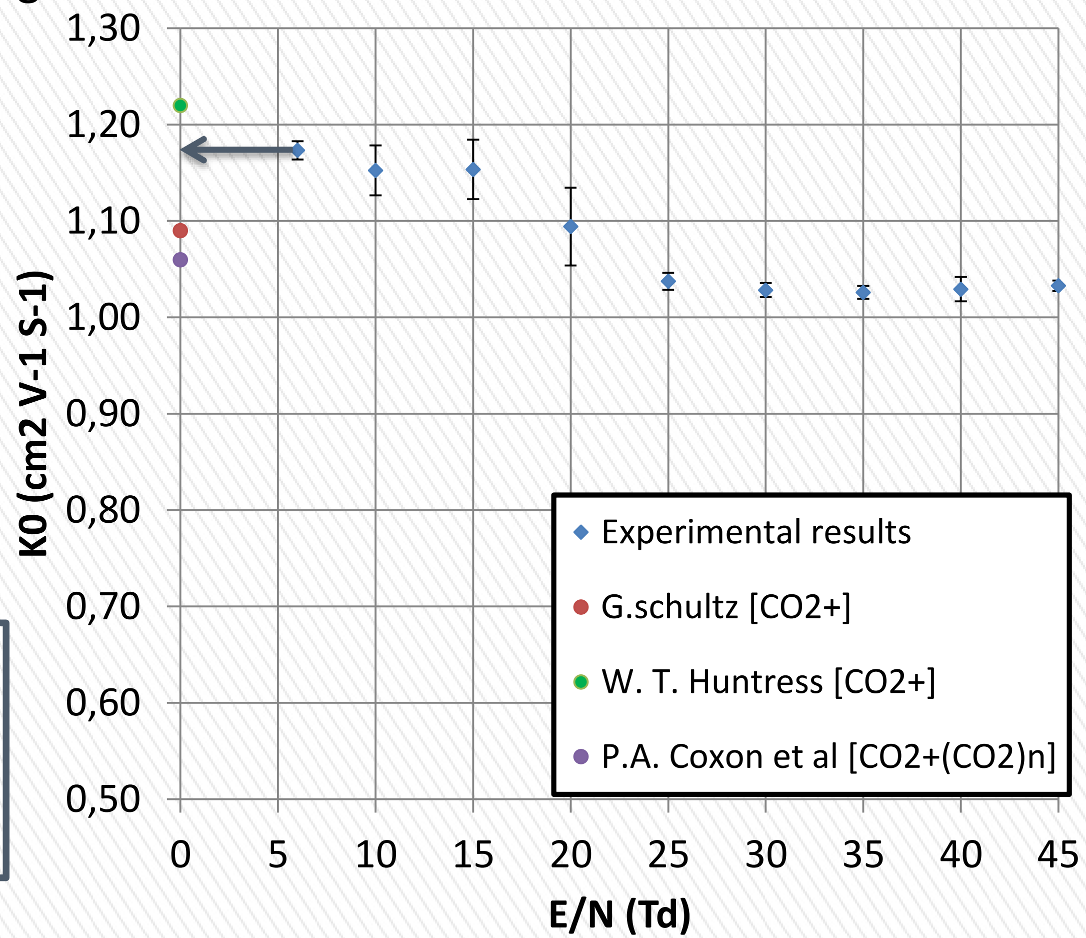
Extrapolated Value (E/N→0)

$1.17\ cm^2V^{-1}s^{-1}$

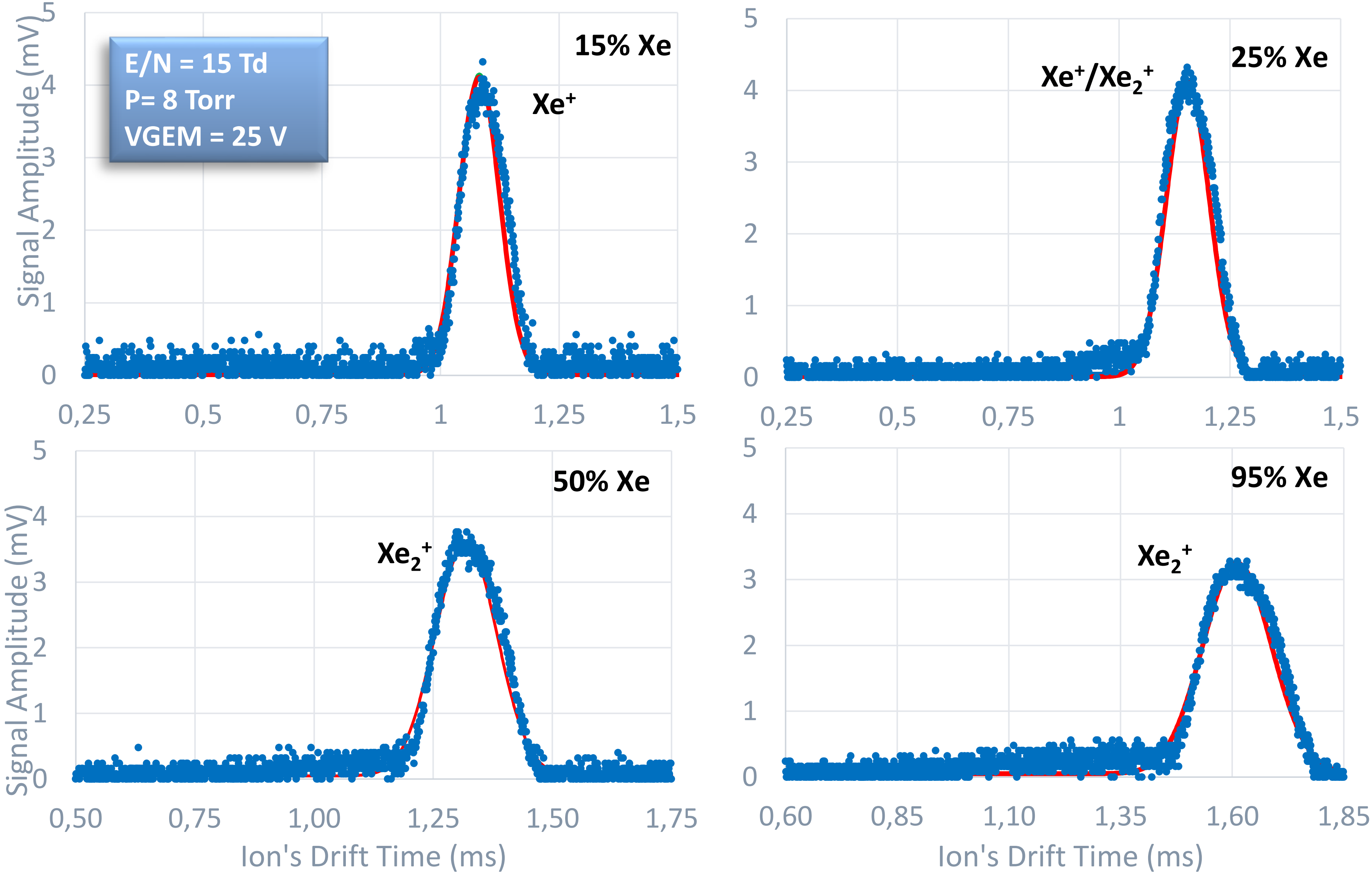
Charge Transfer Process

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

$$CO_2^+ + CO_2 + M \rightarrow CO_2.CO_2^+ + M$$



Experimental Results: $Xe\text{-}CO_2$



Experimental Results: Xe-CO_2

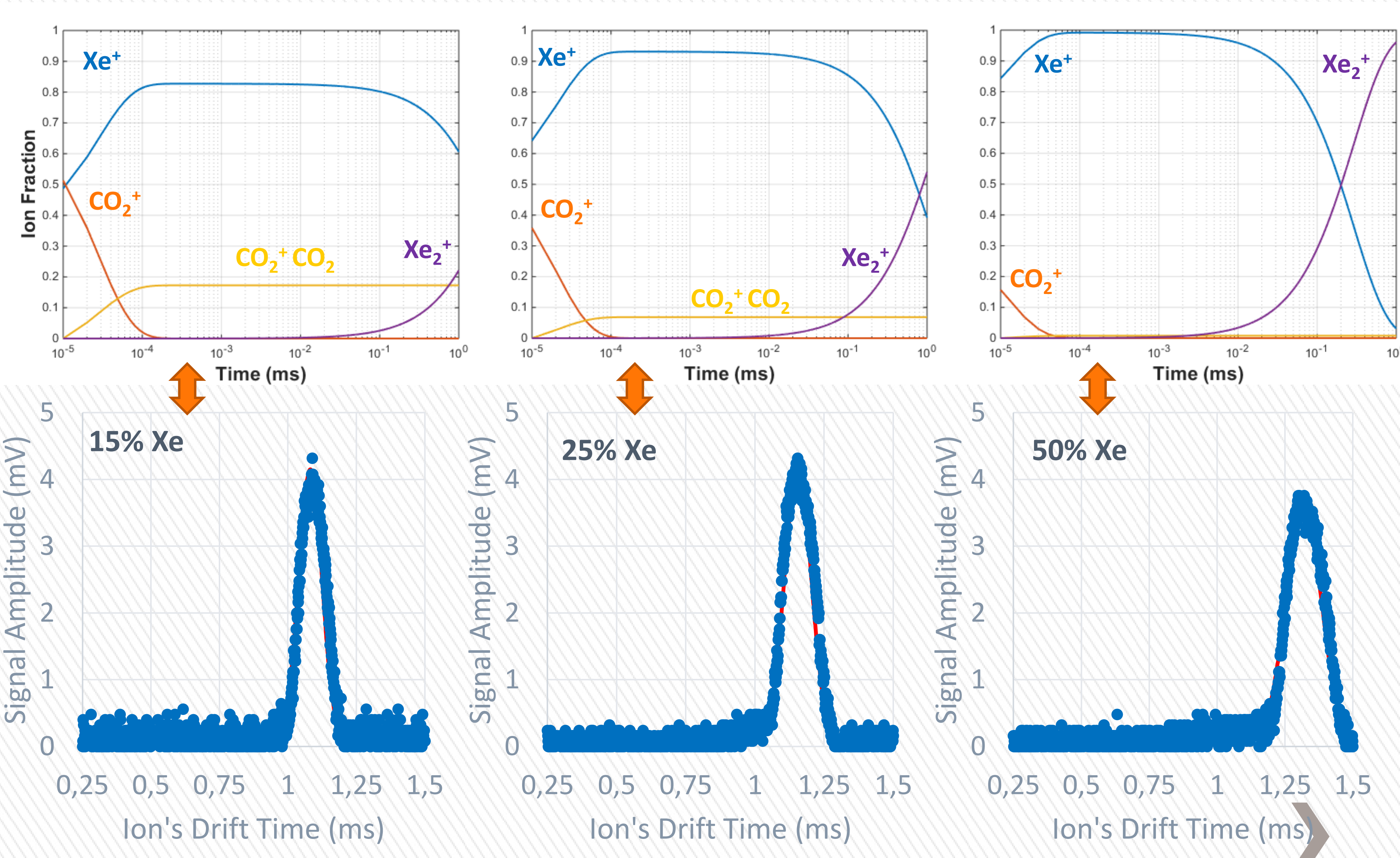
Direct Ionization	Cross Section (20 eV) (10^{-16} cm^2)	Final Ion
$CO_2 + e \rightarrow CO_2^+ + 2e$	0,452	CO_2^+
$Xe + e \rightarrow Xe^+ + 2e$	2,43	Xe^+

E/N = 20 Td
P= 8 Torr (95% Xe 5% CO_2)
VGEM = 25 V

Xe^+ predominant primary ion down to **15%** of Xe.

Secondary Reactions	Rate Constant $cm^3.s^{-1}$ or $cm^6.s^{-1}$	Final Ion
$CO_2^+ + Xe \rightarrow CO_2 + Xe^+$	6E-10	Xe^+
$Xe^+ + Xe \rightarrow Xe + Xe^+$	2,5E-10	Xe^+
$Xe^+ + 2Xe \rightarrow Xe_2^+ + Xe$	2E-31	Xe_2^+
$CO_2^+ + CO_2 + M \rightarrow CO_2.CO_2^+ + M$	2,1E-28	$CO_2CO_2^+$
$CO_2^+ + CO_2 \rightarrow CO_2 + CO_2^+$	3,7E-10	CO_2^+

Reactions Paths

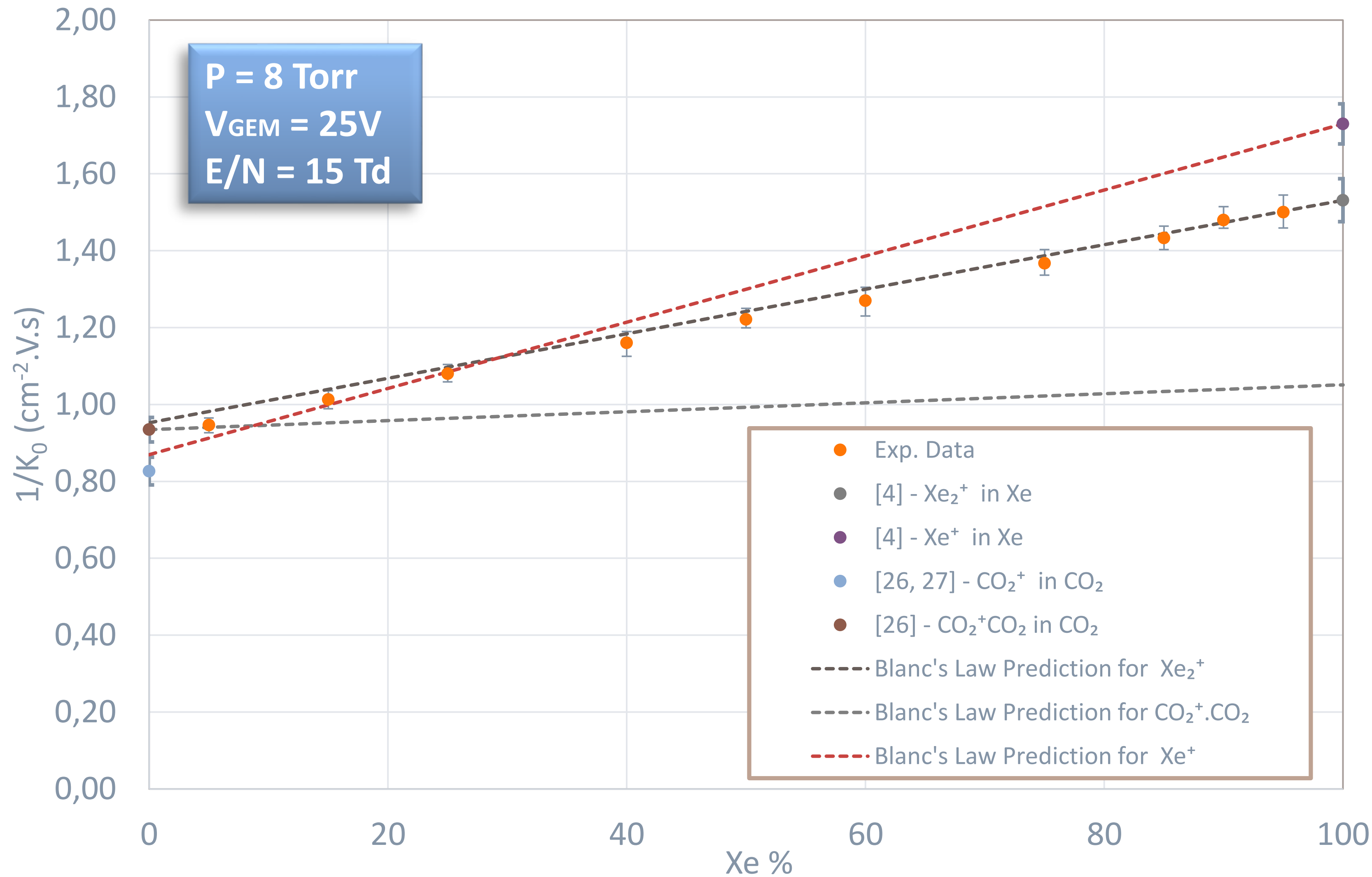


$K_{01} \sim 0,99\ cm^2V^{-1}s^{-1}$

$K_{01} \sim 0,93\ cm^2V^{-1}s^{-1}$

$K_{01} \sim 0,82\ cm^2V^{-1}s^{-1}$

Experimental Results: Xe-CO_2



Present Status and Future Work

- Pursuit the investigation of the mobility of ions in different gas mixtures of practical use (if you have any suggestions feel free to contact us).
    - In the scope of the RD51 common project submitted with GSI (Germany), Uludag Univ. (Turkey) and VECC (India).

Ne-N_2 (Published)
Ne-CO_2-N_2 (Presented in IEEE NSS Conference 2016 - Strasbourg)
Xe-CO_2 (Finished – Paper Submitted to JINST)
Xe-C_2H_6 (Ongoing with Preliminary Results)
Ar-N_2
Ar-CF_4 and Ar-CF_4-IsoButane

- Rate constant influence
- Study lighter ions (H_2)
- Water influence on the ion's mobility
- (...)

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

      (Already designed ready to be implemented – done by P. Encarnação)
    - *Measurement of the mobility of negative ions*

      (Just started the design of it within a Collaboration with JINR)

- A special thank to FCT-Fundação para a Ciência e Tecnologia for supporting this work through the National funds in the frame of the Project QREN n.4825, Rad for Life

and to

- CERN/RD51 Collaboration – Common Projects - 'Measurement and calculation of ion mobility of some gas mixtures of interest'. Participating institutions:

Variable Energy Cyclotron Centre

Thank you!

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.

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

f_1 , f_2 – molar fraction of gas 1 and 2

Mobility of an ion in a mixture

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.

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

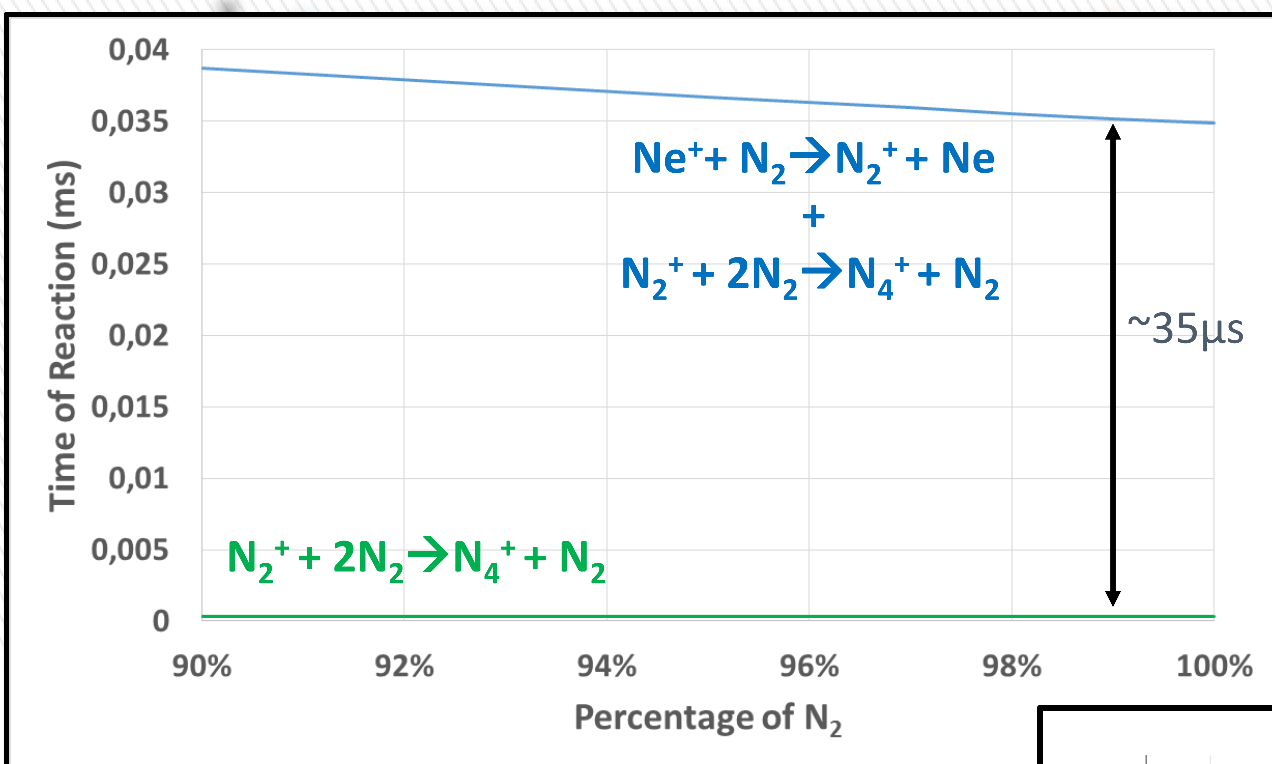
$$\frac{[Rg^+]}{[Rg^+]_0} = e^{-\frac{t}{\tau}}$$

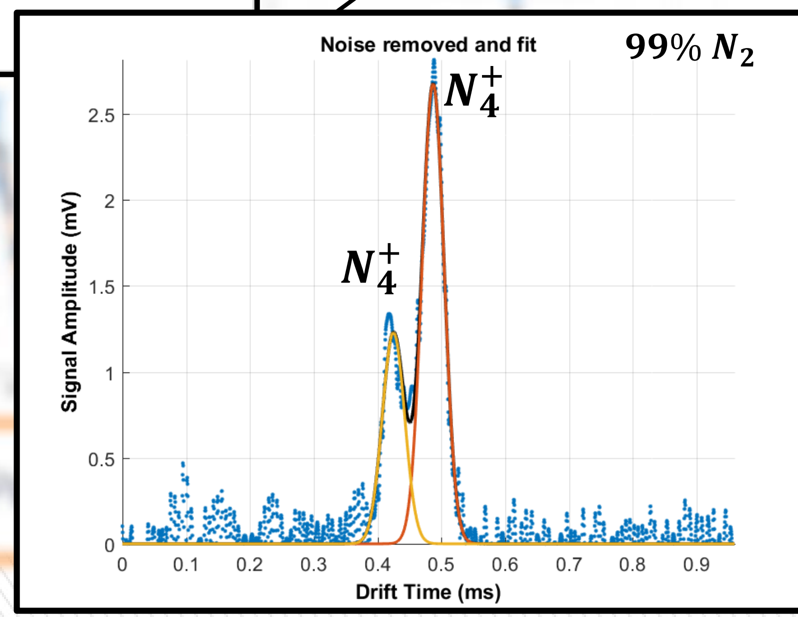
$$\frac{[X^+]}{[X^+]_0} = 1 - \frac{[Rg^+]}{[Rg^+]_0}$$

- Identification the possible ions present.

Select Most Probable Ions

Reactions Paths





Ion mobility results comparison