Measurements of ion mobility in argon- and neon-based gas mixtures

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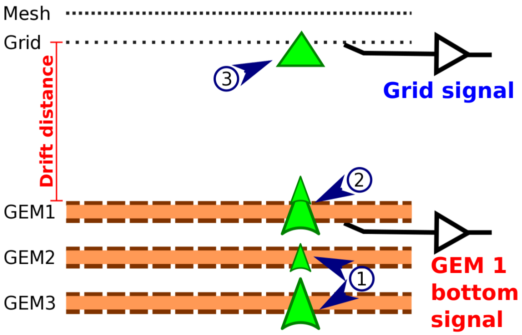
Motivation

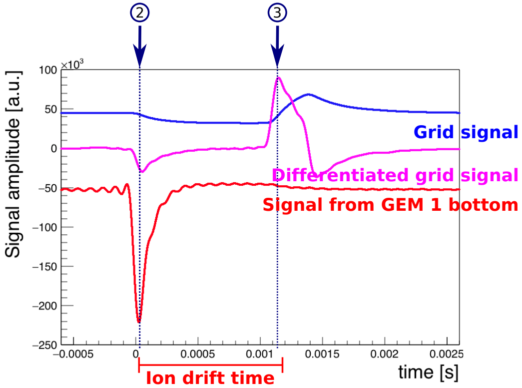
- Ions created in a gaseous detector have a considerable impact on the detector performance:
  - High rates of primary ionisations & Ion back flow (IBF) from the gas amplification $\rightarrow$ Ions build up of space charge in the drift volume
- Example: The upgraded ALICE Time Projection Chamber (TPC) @ LHC Run 3 (2020)
  - R&D efforts to prevent IBF
  - Correct for space charge due to the high rate of primary ionisations
  - Simulations needed to predict the space charge and to test the correction procedures

$$v_{\mathrm{Drift}} = K \cdot E$$

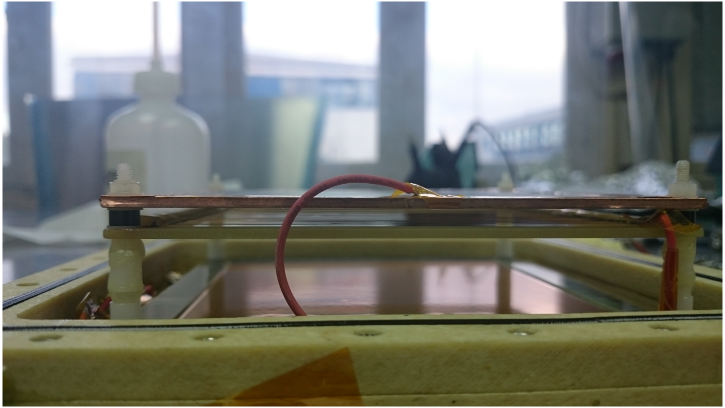
$\Rightarrow$ To simulate space charges the knowledge of the ion mobility K is necessary.

Measurement procedure and detector – 1/2





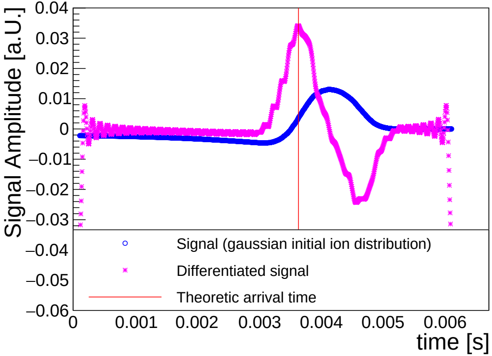
Measurement procedure and detector – 2/2



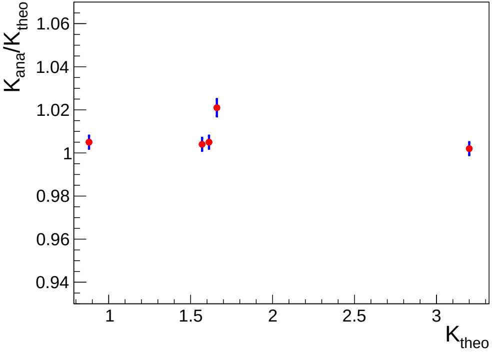
- Set-up operated at atmospheric pressure
- Measurements done in the **low field** region (hence $K \sim E$) and at reduced fields of $E_{\mathrm{D}}/N < 10\,\mathrm{Td}$
- Mixing of up to three different gases possible
- All HV-channels supplied from an individual power supply

Verification of the inflection-point method

Using Garfield[1] the ion drift in a similar geometry as in the measurement is simulated.



The derivative of the signal peaks at the expected arrival time. (Known from the input parameters of the simulation.)



Proof of method with a modelling of the induced ion signal – K_{ana}: result of an analysis; K_{theo}: simulation parameter

[1]R. Veenhof, *Garfield-simulation of gaseous detectors* (Cern Program Library W, 1984)

Measurement procedure

- At different E values: Record GEM1 bottom and wire-grid signal
- From these signals the drift time and hence the mobility K is extracted.
- Using the recorded temperature T and the pressure p, K_0 is calculated.

This is done for various gas mixtures of $\mathrm{Ar}\text{-}\mathrm{CO_2}$, $\mathrm{Ne}\text{-}\mathrm{CO_2}$ and $\mathrm{Ne}\text{-}\mathrm{CO_2}\text{-}\mathrm{N_2}$. (In this gases just $\mathrm{CO_2}$ ions drift[2].) Fitting a function according to Blanc's law[3] to the data of each gas mixture, gives the mobility in the pure gases.

Blanc's law

$$\frac{1}{\mu_{\mathrm{mix}}} = \sum_i \frac{f_{\mathrm{i}}}{\mu_{\mathrm{i}}}$$

Correction to K_0

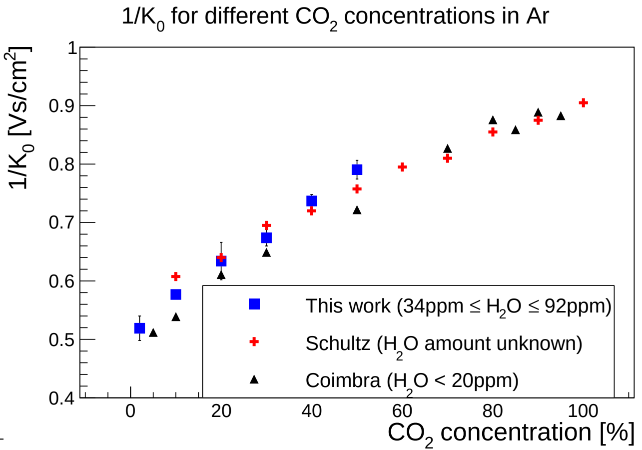
$$K_0 = K \times \frac{273.15\,\mathrm{K}}{T} \times \frac{p}{1\,\mathrm{atm}}$$

[2] Y. Kalkan et al.,*Cluster ions in gas-based detectors* (Journal of Instrumentation, IOP Publishing, 2015)
[3] M. A. Blanc, *Mobilité des Ions*, (J. Phys. Theor. Appl., 1908)

Ion mobility in different Ar-CO_2 mixtures

- Compared to the results of the Coimbra group our measurement seems to underestimate K_0.
- Fairly good agreement with Schultz et al. (similar measuring conditions)
- Fitting Blanc's law to the data yields:

	K_0
Ar	$(1.92 \pm 0.02)\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$
CO_2	$(0.95 \pm 0.02)\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$



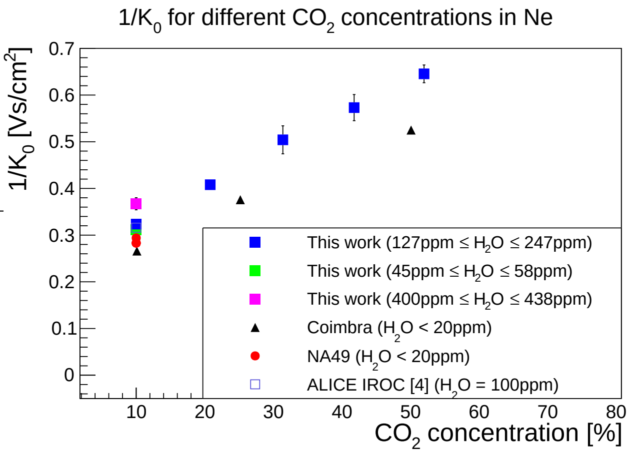
Results of other groups extracted from "**Encarnação et al.**, ***Experimental ion mobility measurements in Ar-CO2 mixtures*** **(Journal of Instrumentation, IOP Publishing, 2015)**" (Coimbra) and "**Y. Kalkan et al.**,***Cluster ions in gas-based detectors*** **(Journal of Instrumentation, IOP Publishing, 2015)**" (Schultz)

Ion mobility in different Ne-CO_2 mixtures

- K_0 smaller as compared to the Coimbra results
- Fitting Blanc's law to the data yields:

	K_0
Ne	$(4.04 \pm 0.05)\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$
CO_2	$(0.98 \pm 0.04)\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$

- K_0 in CO_2 agrees within 7 % with the Ar-CO_2 measurement $\Rightarrow$ Precision of the measurement
- Water has an influence on the mobility

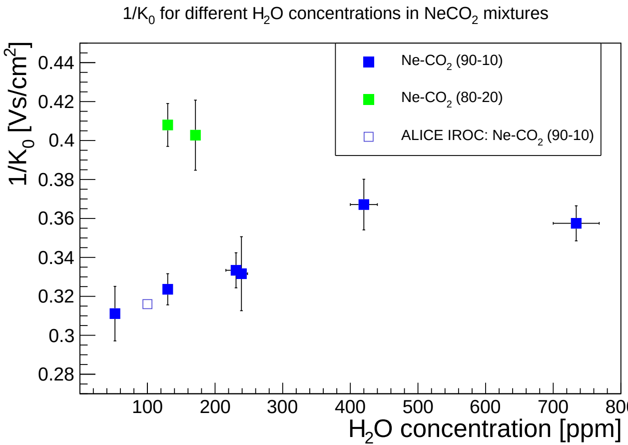


Results of other groups extracted from "**Y. Kalkan et al.,*Cluster ions in gas-based detectors* (Journal of Instrumentation, IOP Publishing, 2015)**" (Coimbra, NA49, ALICE IROC)

Influence of water on the ion mobility

In the $Ne\text{-}CO_2$ (90-10) the influence of water contaminations on the ion drift was studied:

- By changing the gas flow, the water content in the detector was changed.
- It was confirmed that H_2O has a significant influence on the mobility.
- For an increase of 100 ppm in water a decrease of by 5 % in K_0 was found. However at some point ($H_2O \geq 400$ ppm) the dependence levels off.



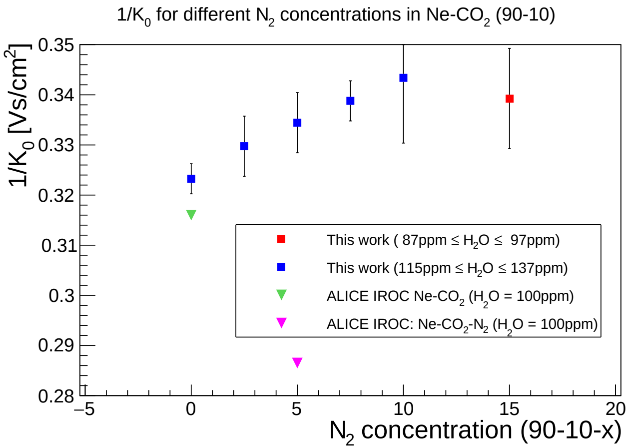
'ALICE IROC' data point extracted from "Y. Kalkan et al.,*Cluster ions in gas-based detectors* (Journal of Instrumentation, IOP Publishing, 2015)"

Influence of N_2 in Ne-CO_2 (90-10)

- To Ne-CO_2 (90-10) different amounts of N_2 were added.
- Fitting a modified 'Blanc's law' function to the data points yields:

	K_0
Ne	$(4.0 \pm 0.1)\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$
CO_2	$(1.0 \pm 0.3)\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$
N_2	$(1.8 \pm 0.1)\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$

- This is in good agreement with our previous results.



'ALICE IROC' results extracted from "Y. Kalkan et al.,*Cluster ions in gas-based detectors* (Journal of Instrumentation, IOP Publishing, 2015)"

Conclusions

- A set-up to measure the mobility of ions was built and successfully commissioned.
- With Garfield simulations it is shown that differentiation of the signal induced by ions on a wire grid allows to determinate the time ions arrive there.
- The mobilities measured in $Ar\text{-}CO_2$ were found to be consistent with previous publications. However, compared to results obtained by the Coimbra group, the measured mobilities are up to 20 % lower. Such a difference may be explained by different H_2O contents.
- The presence of water decreases the mobility in $Ne\text{-}CO_2$ (90-10) and (80-20) – an admixture of 100 ppm water leads to a decrease of 5 % in K_0.
- Measured mobilities in $cm^2\,V^{-1}\,s^{-1}$:

$K_0(CO_2)$ measured in	Ar	Ne	N_2	CO_2
$Ar\text{-}CO_2$	1.92 ± 0.02			0.95 ± 0.02
$Ne\text{-}CO_2$		4.04 ± 0.05		0.98 ± 0.04
$Ne\text{-}CO_2$ (90-10) N_2		4.0 ± 0.1	1.8 ± 0.1	1.0 ± 0.3

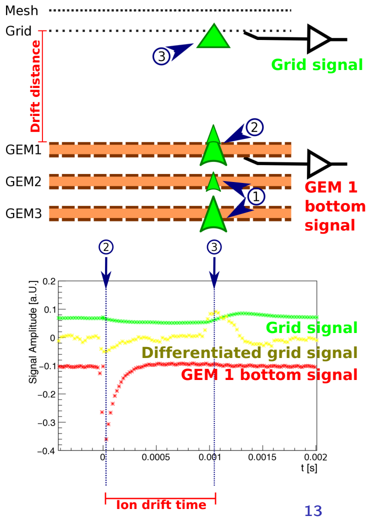
Backup

Measurement procedure explained

Starting from primary ionisations in the detector:

1. Ions from the gas amplification drift towards GEM1.
2. The GEM1 bottom signal serves as trigger – as it peaks the ions enter the drift volume.
3. During the movement of the ions through the drift volume, a signal on a wire grid is induced.
   As the ions pass through the grid the signal amplitude changes polarity. The inflection point of the ion signal serves as an indicator for the arrival time of the ions.

The time difference between the trigger signal and the inflection point is measured as the ion drift time.



Procedure with Garfield:

- Two dimensional simulations (coordinate in drift direction: z; x perpendicular to z)
- Create two random x values from an uniform distribution
- *Optional: Create two random z values from a distribution with mean $z = 0$*
- Place 10 ions along the track between the coordinates
- Drift the ions towards the cathode(s)
- Repeat this 300 times, average the obtained signals and normalise these to the signal of one ion

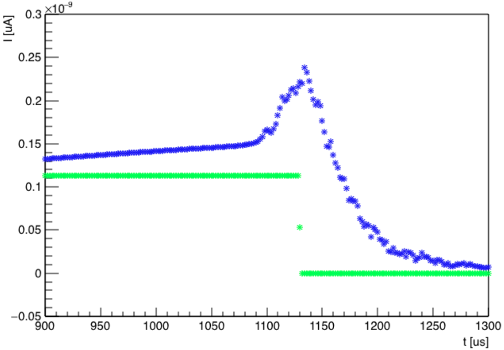
Caveats

- Diffusion not implemented
- Ion mobility an external parameter (to be set by the user)
- The performance of ion drift depends highly on the set parameters

Parallel plane geometry vs. one plane and an infinite grid

$$v = \mu E \quad \rightarrow \quad t = \frac{s(2\,\mathrm{cm})}{E(1000\,\mathrm{V\,cm^{-1}}) \times \mu(1.77\,\mathrm{cm^2\,V^{-1}\,s^{-1}})} = 1.13\,\mathrm{ms}$$

- Two parallel planes, signal readout at the cathode
- The cathode-plane was replaced with a wire-grid. (Gaussian distribution of ions in z implemented.)
- The peak arises because of ions getting accelerated and changing direction as they approach the grid
- Overall rising slope in the blue → Field not completely homogeneous anymore



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