ions in the LC-TPC

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outline

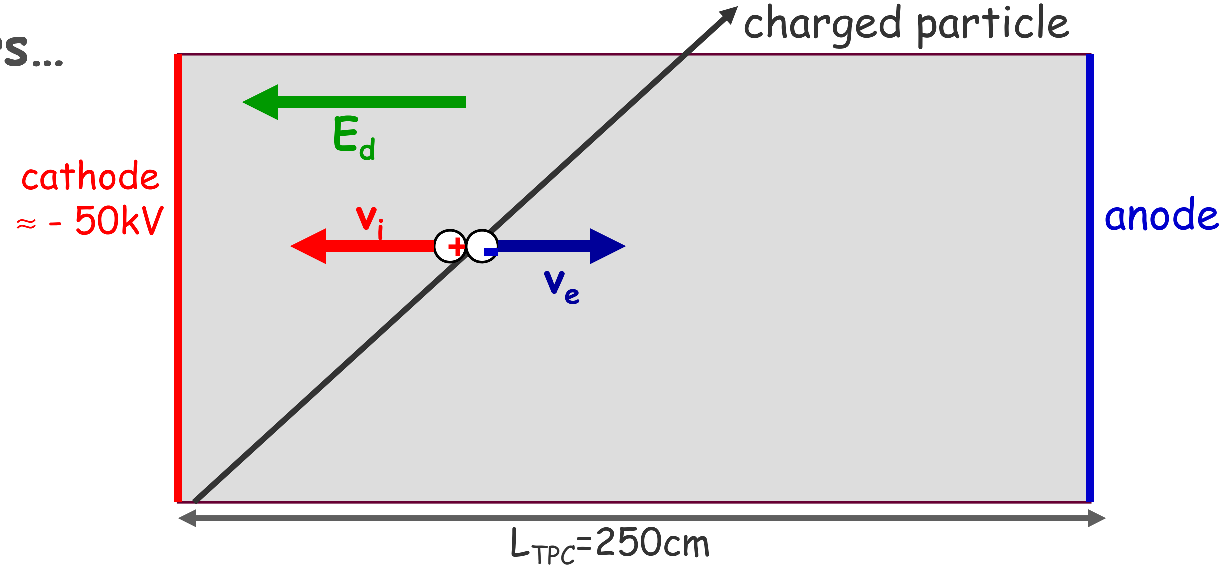
- introduction: what is the problem with the ions in the TPC?
- primary ions
- secondary ions and gating
- conclusion

**most of this was presented in my talk at the TPC Jamboree, Aachen, March 14-16th, 2007*

**sorry, when I prepared this talk a few days ago,
I did not know exactly what I would have to cover…
I am supposed to talk about the "gas possibilities"**

ions in the LC-TPC (intro)

a few numbers…



- electron:
  drift velocity ~ 5-8 cm/µs @200V/cm
  mobility ~ **30-40000** cm²/(Vxs)
  (max.) collection time ~ **50µs**

"typical values"

- ion:
  mobility ~ **2cm²/(Vxs)** in a "classical mixture" **Ar-CH4/CF4/isobutane/CO2**
  (max.) collection time ~ **600ms@200V/cm**
  typical displacement between 2 trains **d~80cm**
  displacement during one train **~ 4mm**
  displacement during electron drift time **<~ 40µm =negligible**

→ electrons see ions at rest during their drift to the anode

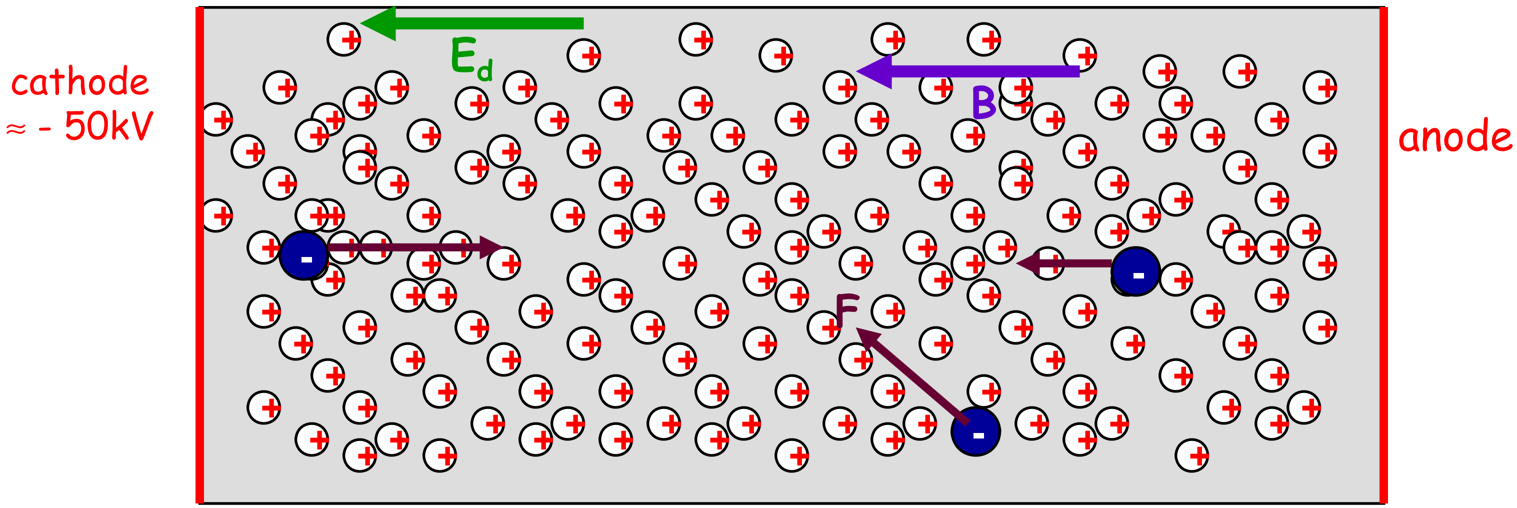
ions in the LC-TPC (intro)

what is the problem with the ions?

- due to their **low mobility** ions will stay for a long time in the drift volume
- electrons drifting will be attracted by the electric field of each ion causing **electric field distortions** and **ExB** effects
- two kinds of ions:
  from **primary** ionisation
  from **multiplication** in the MPGD (secondary)

what can we do against ions?

ions in the LC-TPC (primary ions)



primary ionisation

- non-uniform **feeding** of the whole volume
- ions **at rest** for a drifting electron
- creates **an attractive non-uniform local force** $\vec{F}_{ion}$ on an electron

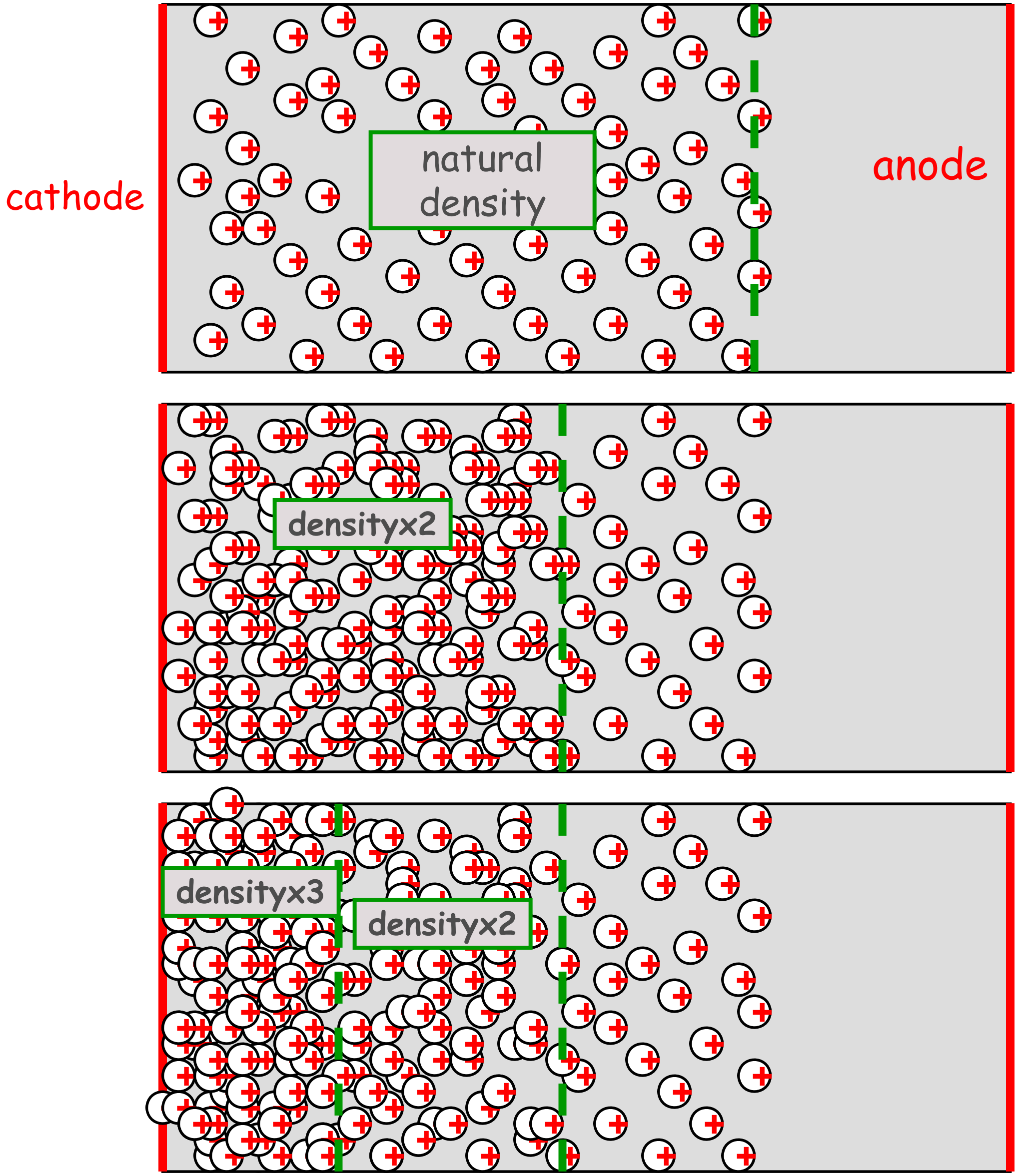
$\vec{F}_{ion} = -q.\vec{E}_{ion} = (1/4\pi\varepsilon_0).q^2 \sum_{ions}(1/r^3).\vec{r}$

- E_{ion} **to be added to the drift field** E_d → **E distortion**
- E_{ion} **generates an ExB effect**

can we survive?
what can we do against ions?

ions in the LC-TPC (primary ions)

distribution of primary ions in the TPC volume



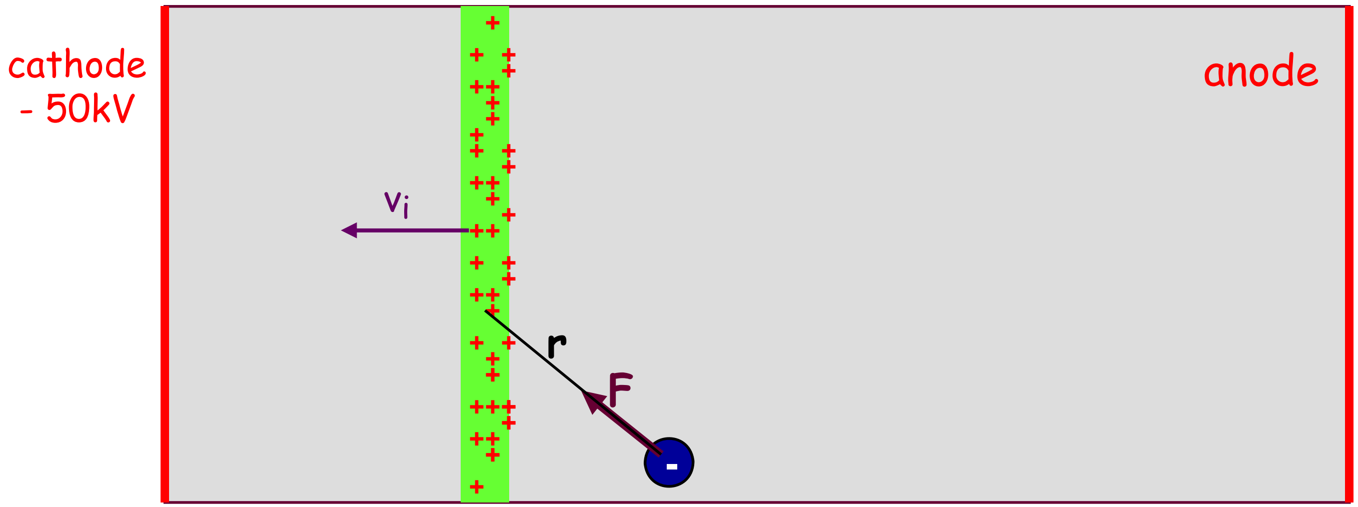
begining of train # +1 (+ 200 ms)

begining of train #+2 (+400ms)

stationnary state: more ions close to the cathode plane

begining of train # +3 (+600ms)

ions in the LC-TPC (secondary ions)



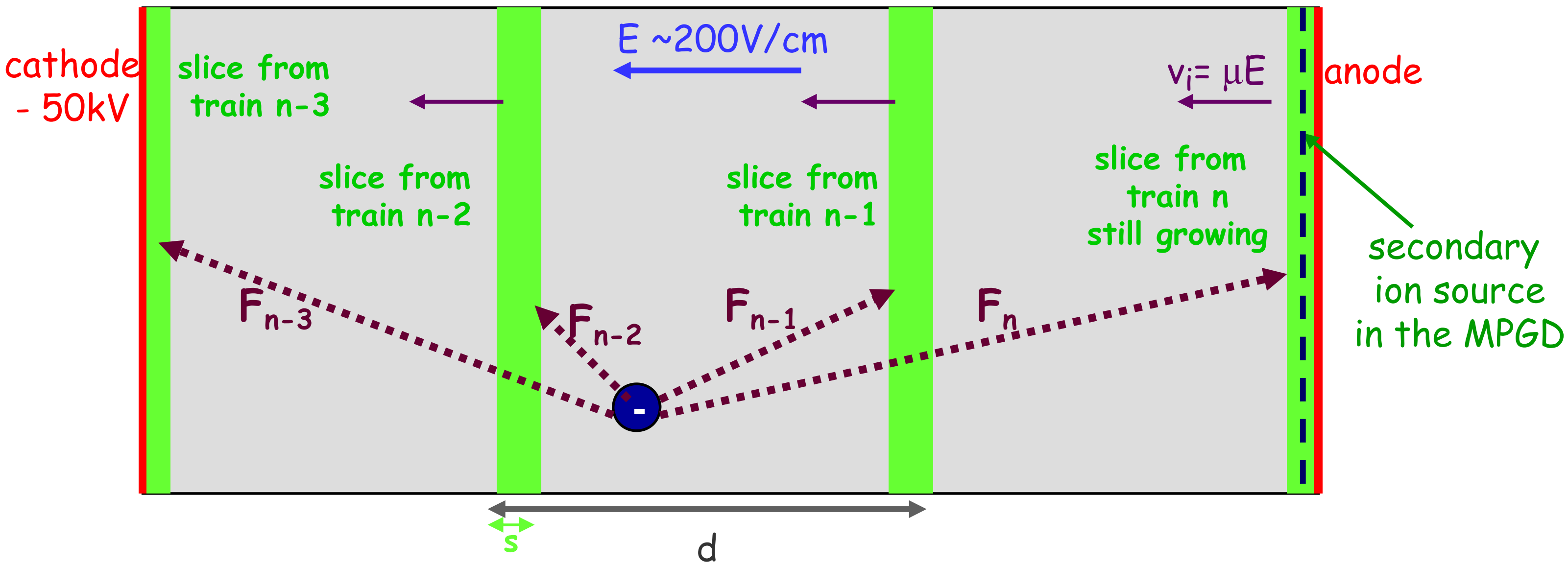
secondary ionisation

- produced all during the train by **avalanches** in the MPGD region
- each train **generates a small slice of ions, at rest** for an electron (v_i << v_e)
  slice size s= $v_i.\delta t$ (δt =1ms) ≈ **a few mm**.
- total secondary ion population N_s of the slice:
  $N_s = N_p \times (G-1) \times \beta$ (N_p= primary ionisation, G=gain, β=ion feedback)
  for a MPGD: G=1000-5000, $\beta=2\text{-}10\times10^{-3}$ -> $N_s \approx 2\text{-}10 \times N_p$ → **lower G, lower β ?**
  but with much more density: $\rho_s \approx (Ns/Np) \times 200 \times \rho_i \approx 10^3 \times \rho_p$
- each slice creates **an attractive force $\vec{F}$** on a drifting electron $\vec{F} = (1/4\pi\varepsilon_0)q^2\, \Sigma(1/r^3).\vec{r}$

→ **electric field distortion + ExB** effects
→ **differences with primary ions:**

- **a few times more ions**
- **ions distributed into a few slices: is it (very) different?**

ions in the LC-TPC (secondary ions)



what is the situation during a train of bunches (1ms) ?

→ **a slice of ions** is growing from the secondary ions source in the MPGD device

→ **a few more slices** (~3-4) are still in the TPC volume, at rest and generated by the previous trains, and equally spaced (~80cm)

→ **a primary electron** created in the TPC volume will experiment **the electric fields** created by each of the ion slices

→ it will experiment also the electric field generated by all **primary ions** created since the beginning of the train

ions in the LC-TPC (how to remove them?)

what can we do against ions in the TPC design?

I will not tell anything about **background optimisation**, we will have to deal with…

I exclude some "exotic" solutions: **increase E to 1kV/cm** in order to clean ions between two consecutive trains, or **decrease the TPC ½-length to ~80cm**!

We have to **estimate the primary electron/ion** density from the expected background and calculate the effects

- on the **TPC occupancy**
- and on the drifting electrons (**distortions and ExB**).

Also we have to think about **solutions to lower** (suppress) **the effect of ions**.

As mentioned by Takeshi, if we cannot survive with primary ions, we can stop now working…

what are the **possible solutions?**

1. **clean** (all) **ions between 2 trains** (200ms)
   criterium: ion drift velocity > 1200 cm/s
2. gate (secondary) **ions after each bunch train**

ions in the LC-TPC (how to decrease/remove them?)

solution	effect	advantages	disadvantages
(H-free gas)	↘ n background	+++	constraints on the gas (1)
clean the ions v_i>1200cm/s mobility>4-5cm^2/(V.s) + E>250-300 V/cm		+++ no more sec. ions 2x less primary ions	--- high constraints on the gas(2) --- too much high voltage
gate the ions classical wire gate MPGD	suppress sec. ions no effect on prim.	+++	ExB effect? (3) e transparency? (4)

a few words on (1), (2)
(3) ????
(4) covered by Akira Sugiyama

ions in the LC-TPC (how to decrease/remove them?)

1. use a H-free gas mixture

the idea is to replace classical quencher (for example 10-20%CH_4) by a **gas without H** in order to avoid **n-p collisions** (high cross section and very ionising p) from **n background**.
CO_2 is interesting, but **very slow**, and **large transv. diff.** at large magnetic field.
CF_4 in addition to Argon is promising:
- **high drift velocity at low field** (~ 8cm/μs at 200V/cm for 3-4% CF_4)
- **low transverse diffusion** **D_t=20μ/√cm@200V/cm** and 4T (ωτ≈15-20)
- **no attachment** (at least with Micromegas)
- but it seems not to quench enough → addition of a very small amount of **iso-C_4H_{10}** (1-2%).

except that this mixture is not completely **H-free** this addition does not degrade (very much) the gas properties in terms of:

- **gain** (higher)
- **drift velocity**
- **transverse diffusion**

ions in the LC-TPC (how to decrease/remove them?)

2. how to have high mobility ions?

the criterion is to have for ions **a drift velocity** as high as **1200 cm/s** (instead of **~400**) since we don't want probably have a **drift field greater than 250-300V/cm** this leads to an **ion mobility > 4-5 cm2/(V.s).**

the 1rst point on the gas is that when an ion is created, **it transfers very quickly its charge to the lower ionisation potential molecule**:
for example in an Ar-CH_4 mixing $Ar^+ \rightarrow CH_4^+$ and only those ions will move

but it doesn't change a lot the drift properties, which seem to be **dominated by the dominant gas (Argon in that case).**
gas mixtures follow the Blanc's law **(additivity if 1/μ)**

is it possible **to avoid Argon** in the ILC-TPC?

ions in the LC-TPC

from my talk at the TPC Jamboree,Aachen, March 14-16th, 2007

- how to **increase** μ by a factor 3 ?

  for Ar, $\mu \approx$ 2cm²/(V.s), for lighter gases the mobility is higher:

  for Ne $\mu \approx$ 3-4,

  for He μ_{He+}=10, but we have measured less than 5 at Saclay in 2002

  Blanc's law for additivity of $1/\mu$: $1/\mu = \Sigma(\varepsilon_i/\mu_i)$

  we can imagine to add to Ar (a lot of) Ne or He

  BUT v_e is smaller for mixtures with these gases, and max. at higher E_d

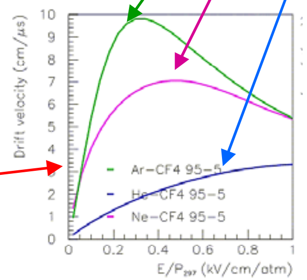
  so three disadvantages at the same time:

  - less ionisation, so less spatial and dE/dx resolution,
  - $\omega\tau$ smaller ex. 5%CF4@4T $\omega\tau$=16 (Ar), 7(Ne), 1(He)

    dramatic for the spatial resolution
  - larger HV on the cathode

Ar Ne He

$\omega\tau$= 16 7 1



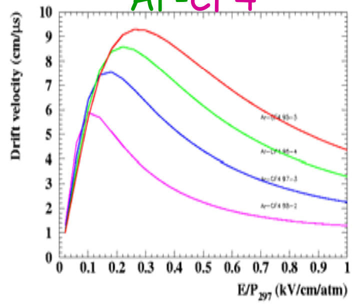
I think that the maximum we can gain is a factor 1.5 to 2, not 3-4

→ **conclusion:** the TPC is at least 1.5 times too long for the 200ms time between trains

do we need to measure ion mobilities?

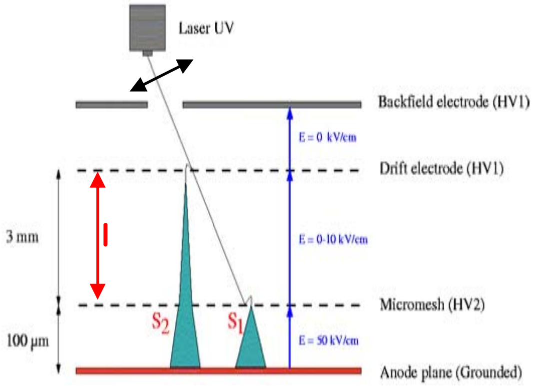
probably YES, especially if we want to put an appropriate **gating device**.

Ar-CF4

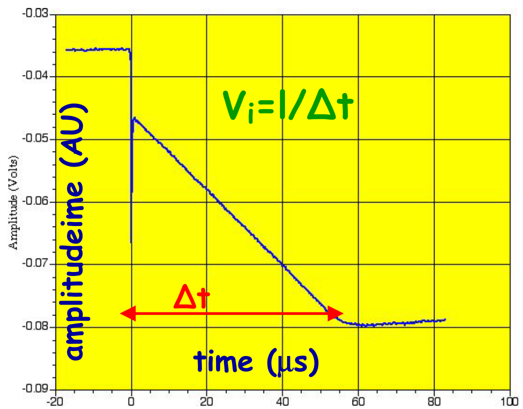


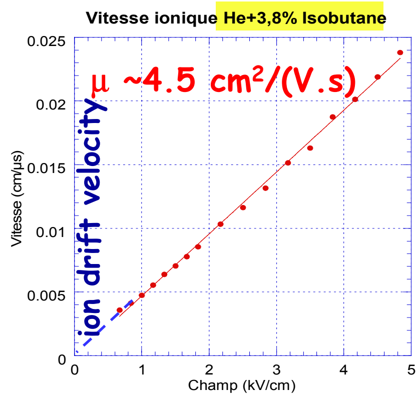
ions in the LC-TPC

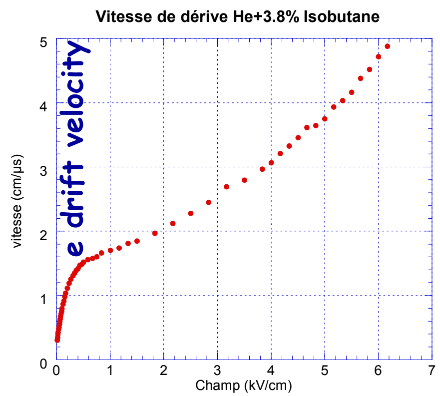
how to measure ion mobility?

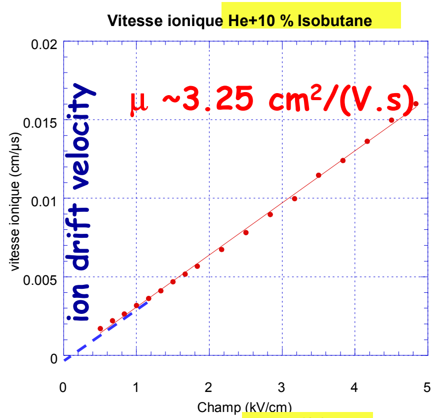


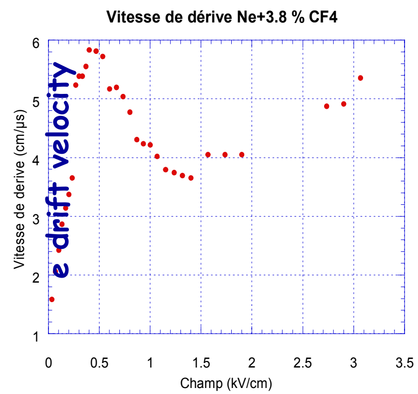
very simple device already used at Saclay
for e drift velocity measurement
P. Colas, et al., NIMA478(215)2002.
(results on ions not published)

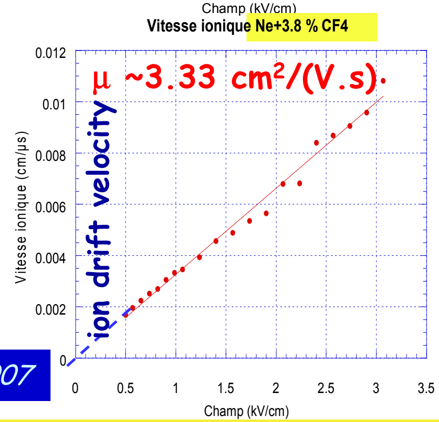


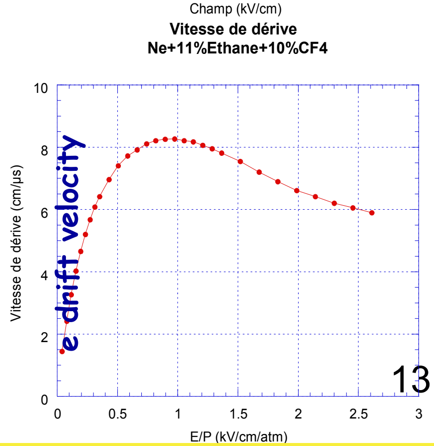












from my talk at the TPC Jamboree,Aachen, March 14-16th, 2007

ions in the LC-TPC

ion mobility measurements

Measurements of electron drift velocities and positive ion mobilities for gases containing CF_4 II

T. Yamashita, H. Kurashige, M.M. Morii, T.T. Nakamura, T. Nomura, N. Sasao and K. Shibata
Department of Physics, Kyoto University, Kyoto 606, Japan

Y. Fukushima, Y. Ikegami, H. Kobayashi and T. Taniguchi
National Laboratory for High Energy Physics, Ibaraki 305, Japan

Nuclear Instruments and Methods in Physics Research A317 (1992) 213–220

extrapolation for
Ar-3%CF_4-2%iso
$1/\mu \approx 0.5$ (V.s/cm²)

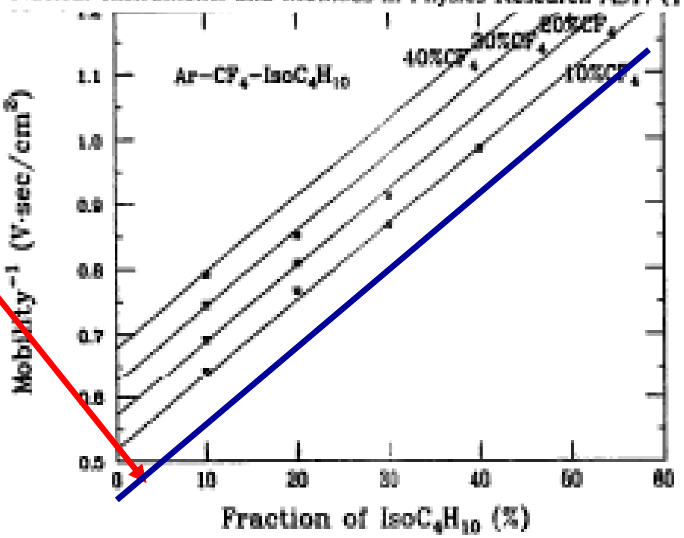


Fig. 13. Inverse mobility of positive ions as a function of the iso-C_4H_{10} fraction for gas mixtures of Ar + CF_4 + iso-C_4H_{10}. Solid lines indicate fitted results with Blanc's law.

also measurements by D. Schutz, G. Charpak, F. Sauli, J. Phys. Appliquée, 12(67)1977
«mobilities of pos. ions in some gas mixtures…»: $\mu_{Ar} \approx 2 cm^2/(V \times s)$

from my talk at the TPC Jamboree,Aachen, March 14-16th, 2007

ions in the LC-TPC

conclusion

primary ionisation

if we cannot reduce the background from the machine,

nothing to do except to

- **collect ions « quickly »** in order to decrease its density in the TPC
- **optimize the gas** in order to reduce the effects of the **n background**

→ need to do more simulations (calculations) on the distortions induced by these ions.
→ need for more work on the ion mobility in various gas mixtures
(S. Biaggi says that nobody knows how to calculate ion mobilities…)

secondary ionisation

- probably **impossible to collect** secondary ions on the cathode before 200 ms
- do we need a **gating device**?
  if Ns ≈ Ni, may be not, except if the high density secondary ions slice is a problem,
  if Ns large, probably yes we have to gate secondary ions,
- simulations (and/ore calculations/experiments) of the **distortions** induced on electron drift (**with B**) are needed,
- **ion mobility** measurements are probably needed for gate optimization (location in z)
- more work and thinking on **gating devices**:
  a gate should be **transparent** to electrons,
  should not induce (too much) **distortions** and **ExB** effects
  should be optimized for a given **gas mixture**

… more work to be done!

ions in the LC-TPC

how to estimate ion density in the TPC from occupancy?

- difficult exercise, may be an answer from Adrian Vogel simulations very soon…
- depends also on background, gas choice (neutrons), gain, ion feedback…

fast calculation yesterday evening, assuming:

- numbers from Adrian for the hits
- gain G=5000
- ion backflow $\beta=2\times10^{-3}$
- ion mobility $2 cm^2/(V.s)$
- $v_e=8 cm/\mu s$
- E_{drift} = 200V/cm and R=120cm, L_{TPC}=240cm
- 10^9 voxels in the TPC

extra slide

1. TPC occupancy

the max. drift time for electrons is 60µs, corresponding to ~200 bunches
from Adrian, there are ~4×10^5 "hits" during this time in the TPC.
I assume that a hit will occupies after diffusion ~20 voxels
-> $20\times4\times10^5 = 8\times10^6$ voxels "occupied"
-> occupancy ~ 1%

2. ion density

- I assume **very arbitrarily** that 1 hit => 100 electrons released
- total number of electrons producing ions during 600ms= 3 trains (time for ions to be collected by the cathode):
  $N_e=4\times10^5\times100\times(3300/200)\times3 \sim 2\times10^9$ … and the same number of primary ions,
- total number of secondary ions: $N_i = N_e \times G \times \beta = 2\times10^9\times5\times10^3\times2\times10^{-3} \sim 2\times10^{10}$ for 3 ion slices.
- total charge per slice $Q=0.7\times10^{10}\times1.6\times10^{-19}$ = 1 nC
- slice volume, with s=4mm: $V\sim1.7\times10^4$cm3
- charge density in the slice $\rho=Q/V \sim 60\ fC/cm^3$ ($6 fC/cm^3$ if $G=1/\beta$)

is it a problem for an electron crossing this «wall» of ions????