Measurement of the electron drift velocity for directional Dark Matter detectors

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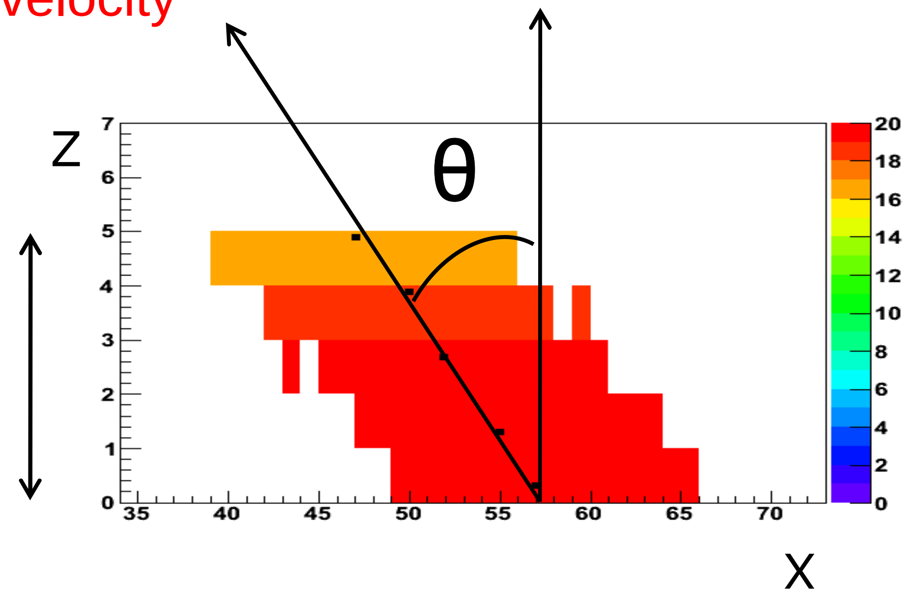
based on J. Billard *et al.*, arXiv:1305.2360 and J. Billard PhD Thesis

Drift velocity: introduction

3D Track reconstruction requires a precise knowledge of the electron drift velocity

$$\Delta Z = \Delta T \times V_d$$



→Magboltz simulations give good result for pure CF_4

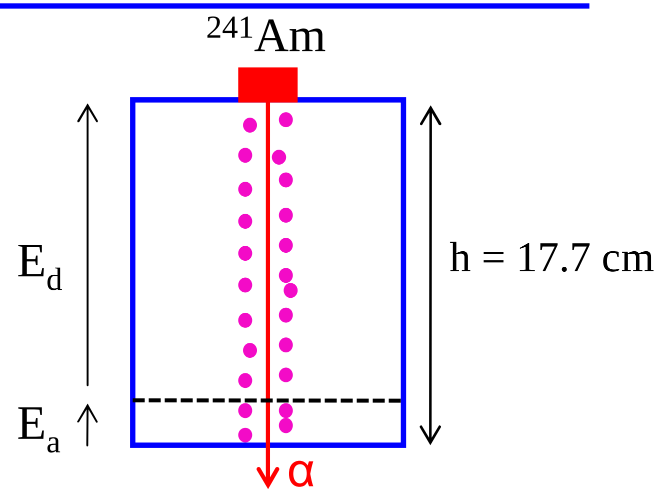
differences with real life gas mixture (impurities ?) ?

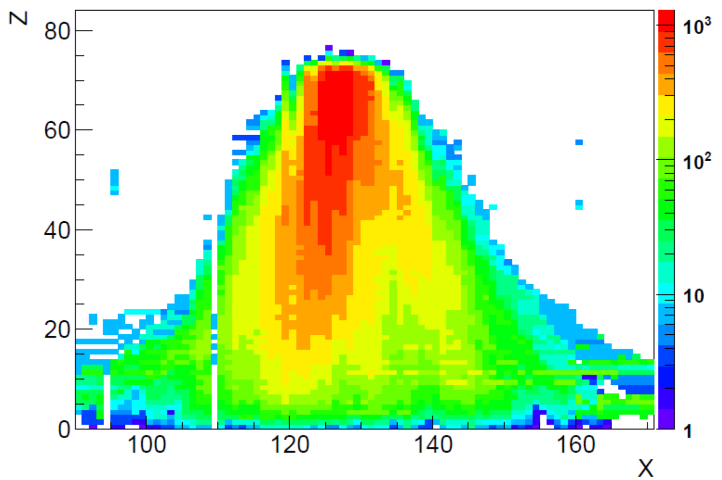
→Measure the electron drift velocity with our directional prototype

Drift velocity: Experimental setup

J. Billard *et al.*, arXiv:1305.2360

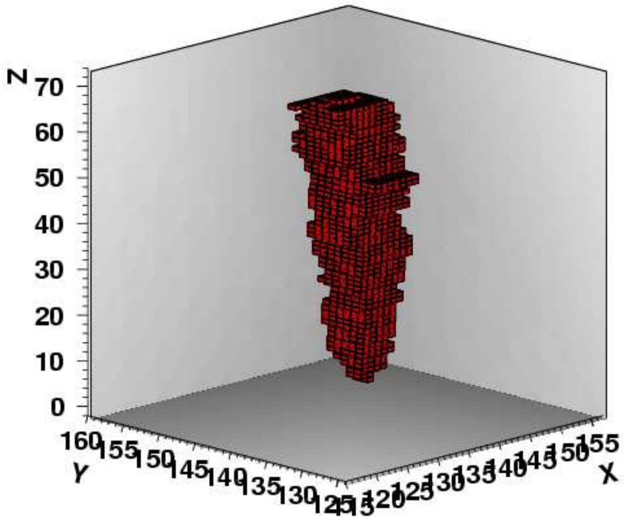
- Use of an 5.47 alpha source (^{241}Am)
- Alpha particles go through the entire drift chamber
- A starting and an ending point
- Measurement of the 3D tracks and charge profile





2D projections of 500 α tracks

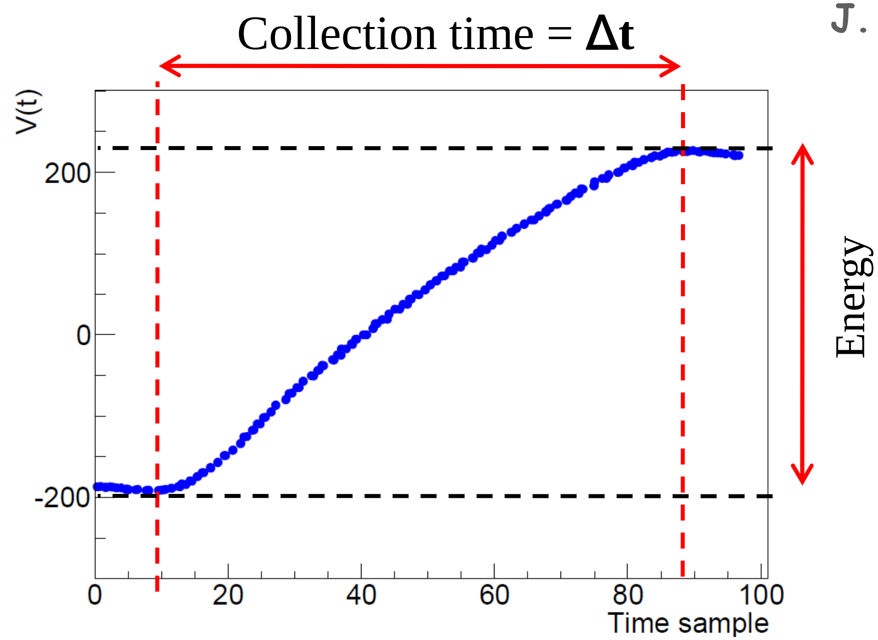
A pencil point-like source (5° opening angle)



3D reconstruction of one a track crossing the whole drift space

Drift velocity : Straightforward analysis

J. Billard *et al.*, arXiv:1305.2360



Drift length (17.7 cm)

$$v_d = \frac{d}{\Delta t_e}$$

Δt_e Time difference between α arrival time and last primary electrons

depends on readout time constants
→understimation of the drift velocity

Δt_c Time difference between first and last spatial coincidence

depends on amplification electric field (gain)

(Probability to have a spatial coincidence depends on the number of electrons)

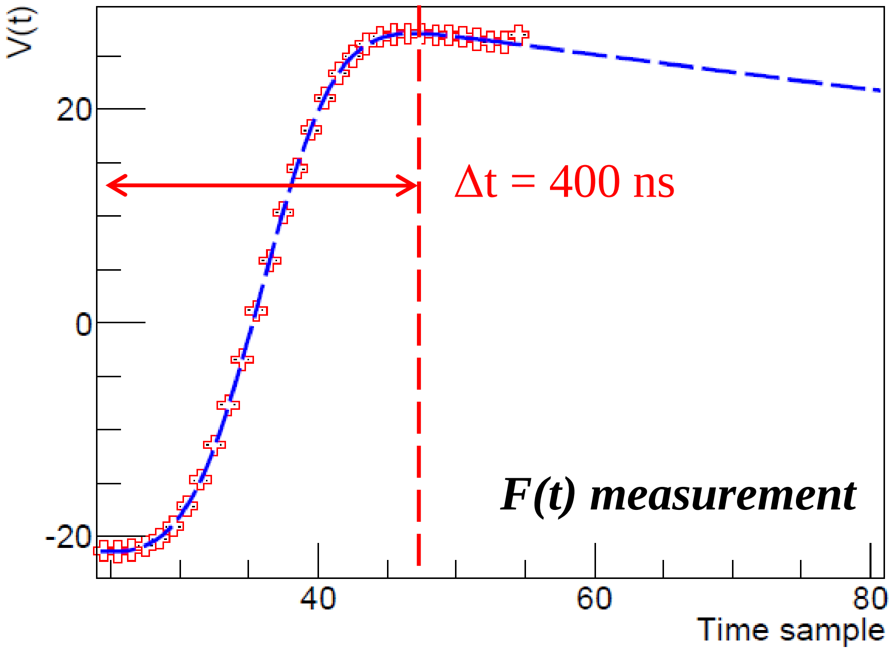
Drift velocity : Electronic signal modelisation (1)

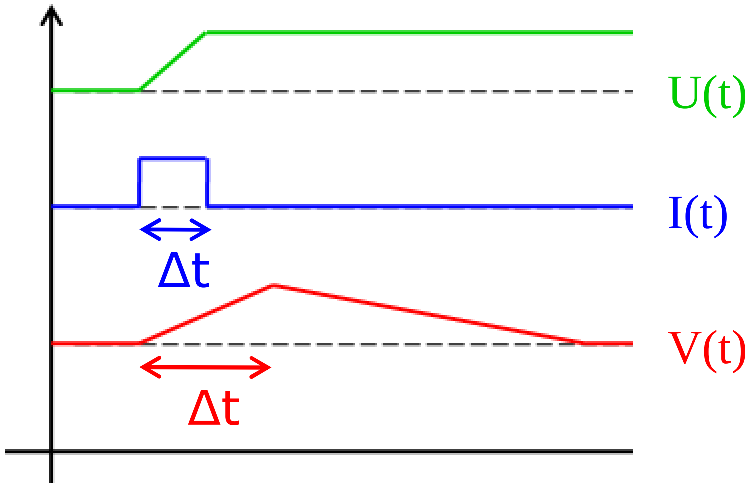
Measurement of the transfer function **F(t)**
of the charge preamp.

- Charge injection on the grid
- Voltage step injected through a capacitor C

$$I_{\rm ind}(t) = C\frac{dU(t)}{dt}$$

- When I(t) → δ(t) then **V(t) = F(t)** *(pulse response)*





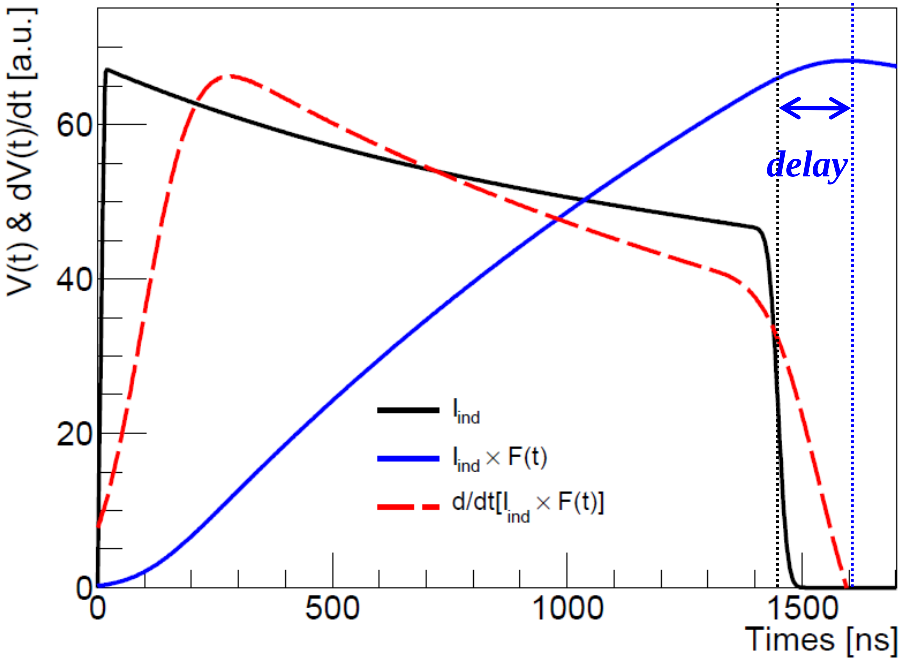
Possibility to measure the charge collection profile

Drift velocity : Electronic signal modelisation (2)

J. Billard *et al.*, arXiv:1305.2360

Modeling the signal output V(t):

$$V_{\rm th}(t) \propto \int\int\int \frac{dE}{dt}(t-\xi) \times Q_{\rm ion}(\xi-\tau) \times g_{\rm diff}(\tau-T) \times F(T)\, dT d\tau d\xi$$



- **Induced current on the grid:**
  - -dE/dZ => dE/dt
  - -Signal from ions
  - -Electrons diffusion
- **Calculation of V(t)**
  - **- Convolution product with F(t)**
- **Time derivative of V(t) => dV/dt(t)**

An important delay is induced!

V = h/Δt → biased

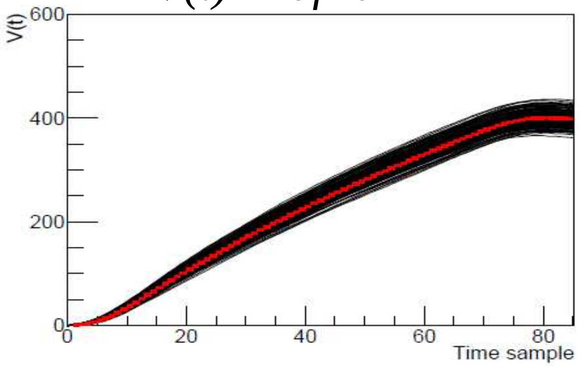
→ ***Likelihood approach***

Drift velocity: How to fit the data?

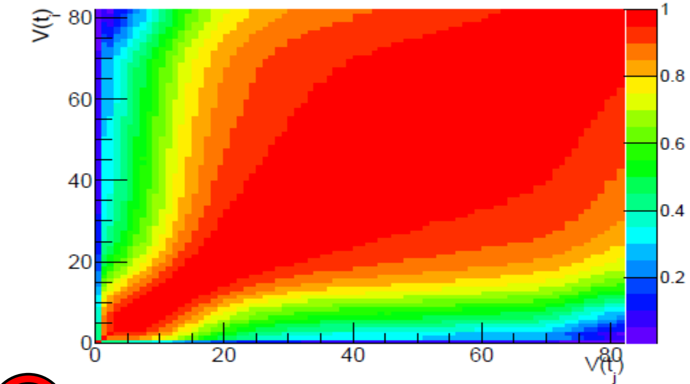
J. Billard *et al.*, arXiv:1305.2360

For each configuration, we measure ~ 500 alpha particles

V(t) Profile

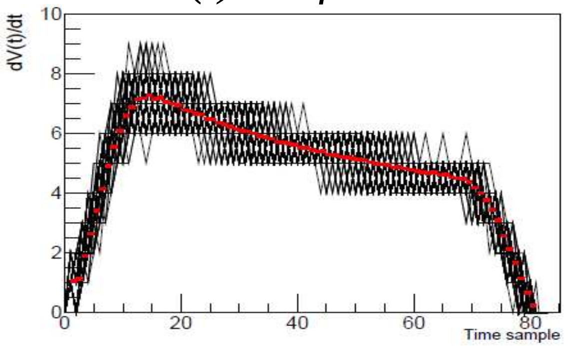


Strong correlations between $V(t_i)$

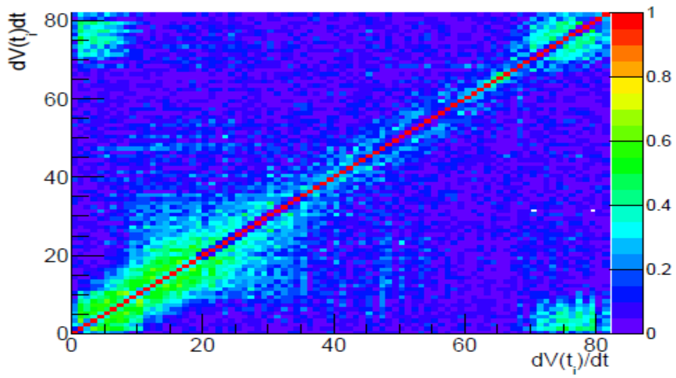


Correlation matrix is not diagonal

V'(t) Profile



Negligible correlations between $V'(t_i)$



Mean profile V'(t) is being adjust by the signal model $V'_{\text{th}}(t; v_d, v_{\text{ion}}, D_l)$

Drift velocity: The likelihood function

J. Billard *et al.*, arXiv:1305.2360

- We fit the time derivative of the charge collection V'(t):

$$\mathscr{L}(v_d, v_{\rm ion}, D_l, \delta t, A) = \exp\left(-\frac{1}{2}\sum_{i=1}^{N_t}\left[\frac{A \times V'_{\rm th}(t_i - \delta t; v_d, v_{\rm ion}, D_l) - \bar{V}'(t_i)}{\sigma_{\bar{V}'(t_i)}}\right]^2\right)$$

Free parameters :
- Electron drift velocity v_d
- Ion drift velocity $v_{d_{\rm ion}}$
- Longitudinal diffusion coefficient D_l
- *2 additional parameters : A (amplitude) and δt (delay)*

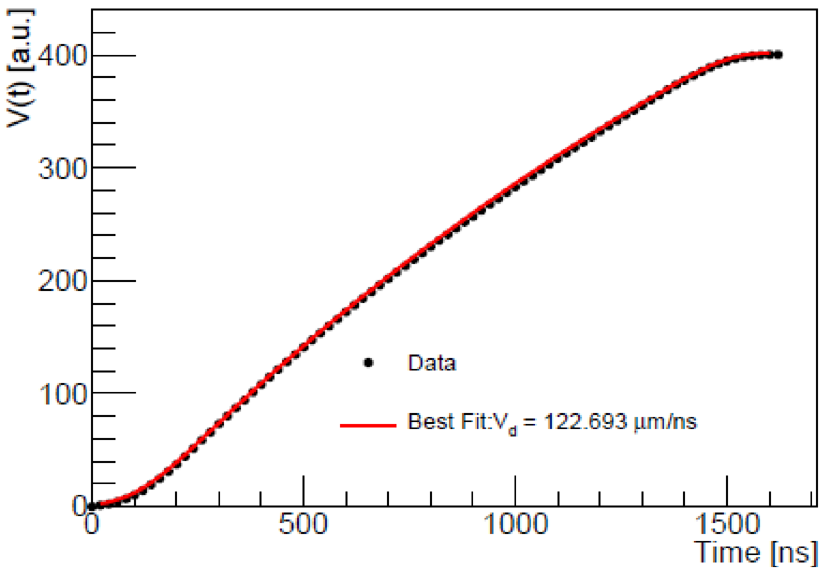
Drift velocity: Illustration

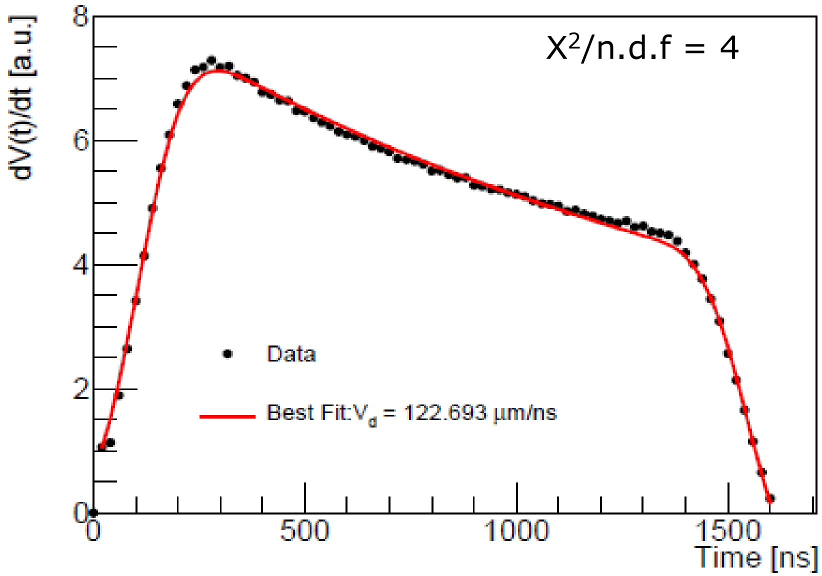
J. Billard *et al.*, arXiv:1305.2360

Consider the following case:

Pure CF_4 @ 50 mbar, E_d = 138 V/cm and E_a = 14.5 kV/cm

Maximisation of the likelihood function:





$$v_d = 122.7 \pm 0.14\ \mu\mathrm{m/ns} \quad (68\%\ \mathrm{C.L.})$$

- ***Good agreement between the data and the model!***
- ***Robust estimation of V_d***
- *Small deviations on V'(t) -> estimation of the falling time of F(t)*

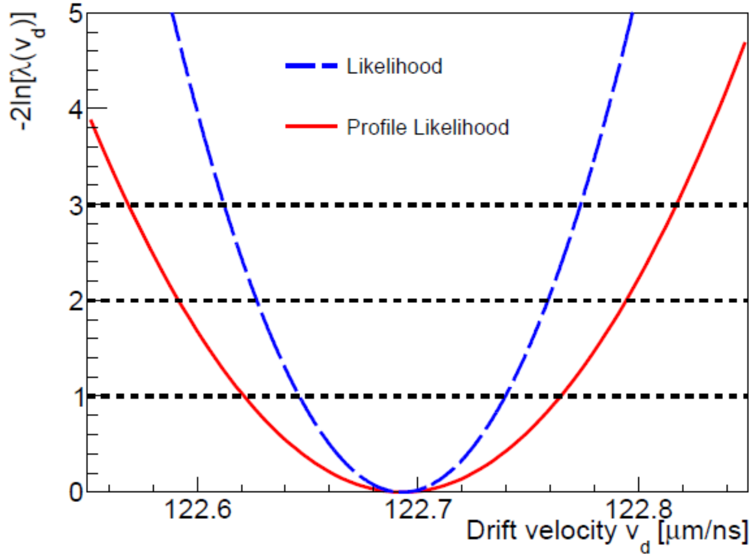
Drift velocity: Error bars and constraints

J. Billard *et al.*, arXiv:1305.2360

Estimation of the error bars using a **profile likelihood**
We used the profile likelihood ratio test statistic:

$$\lambda(v_d) = \frac{\mathscr{L}(v_d, \hat{\hat{v}}_{d_{\rm ion}}, \hat{\hat{D}}_l, \hat{\hat{\delta t}}, \hat{\hat{A}})}{\mathscr{L}(\hat{v}_d, \hat{v}_{d_{\rm ion}}, \hat{D}_l, \hat{\delta t}, \hat{A})}$$

@ 68% C.L., we solve: $$-2\ln[\lambda(\hat{v}_d \pm \sigma^{\pm}_{v_d})] = 1$$ *(follows a X^2 distribution with 1 d.o.f)*

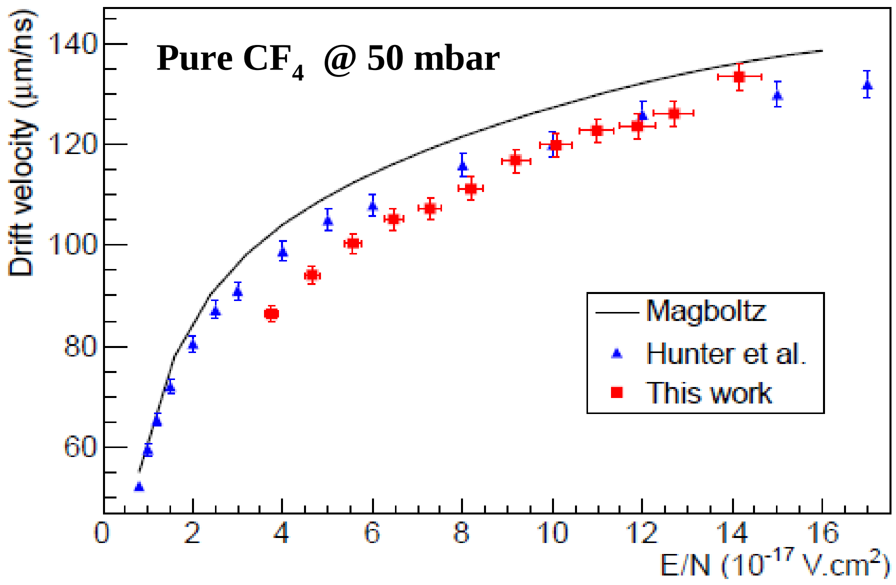


Precise measurement of V_d
(0.1% error)

$$v_d = 122.7 \pm 0.14\ \mu\text{m/ns} \quad (68\%\ \text{C.L.})$$

Drift velocity: result for pure CF_4

J. Billard *et al.*, arXiv:1305.2360



- Fair agreement (up to 10%) with the Magboltz simulation

→*Validation of the charge collection all along the drift chamber*

- Discrepancy highlights the need to measure the electron drift velocity with our own detector.

→to account for impurities in the gas mixture, electric field inhomogeneities…

→ Effective velocity

Drift velocity: result for CF_4+CHF_3

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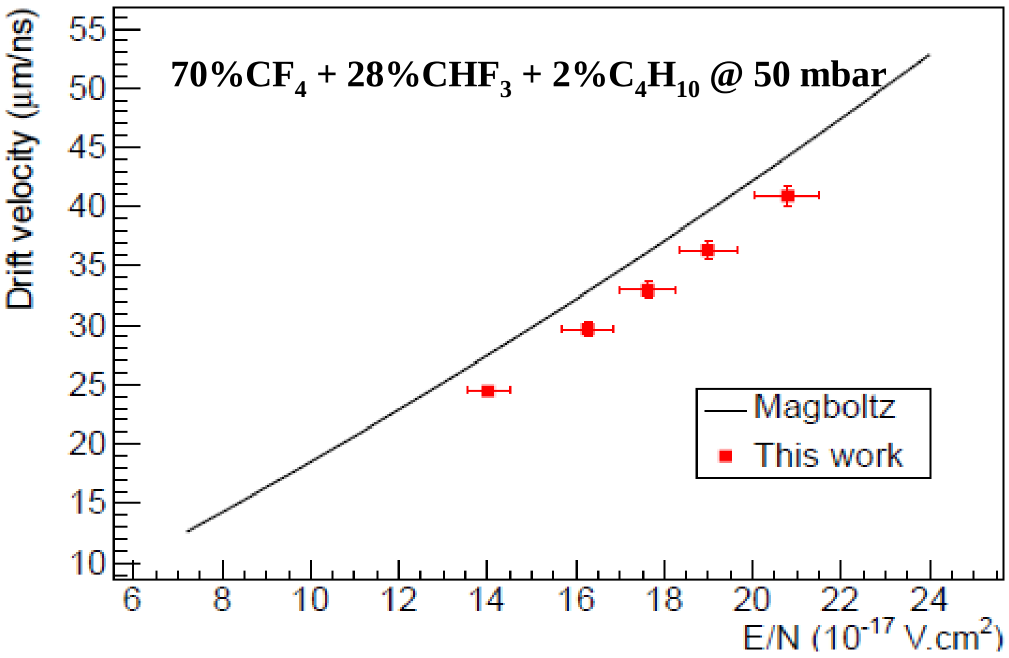
The addition of CHF_3 lowers the electron drift velocity while keeping a large Fluorine content



Good agreement with Magboltz

Conclusion

• A new measurement method of the electron drift velocity

- α source
- profile Likelihood analysis
- full modeling of the signal on the grid

->avoid bias due to electron diffusion, ion collection time and elec. readout

• In situ measurement of the effective electron drift velocity, accounting for

- Large drift distances
- Field inhomgeneities
- Impurities

• A golden gas mixture for MIMAC

$70\%CF_4 + 28\%CHF_3 + 2\%C_4H_{10}$ @ 50 mbar

-> low electron drift velocity & large Fluorine fraction