



RÉPUBLIQUE
FRANÇAISE

*Liberté
Égalité
Fraternité*



ANIMMA

IRSN

INSTITUT DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

METHODOLOGY FOR AN EXPERIMENTAL DRIFT VELOCITY DETERMINATION USING A μ TPC. EXAMPLE IN A 700mBAR 95%He+5%CO₂ MIXTURE

Author: Thibaut VINCHON
Co-Author: Michael PETIT
IRSN/SDOS/LMDN

June 2023



LABORATOIRE
NATIONAL
DE MÉTROLOGIE
ET D'ESSAIS



The LMDN μ TPC

As an LNE associated laboratory, the LMDN is in charge of the neutron fluence distribution references and produces neutron reference fields (AMANDE monoenergetic fields, CEZANE AmBe and ^{252}Cf high fluence sources, ..)

μ TPC Objective : Primary measurement of the neutron fluence distribution in energy



IRSN-LNE-MIMAC = « μ TPC ». TPC = Time Projection Chamber

- Gaseous detector combining a drift chamber and a pixelized anode.

Neutron Flux

Accelerator or neutron source

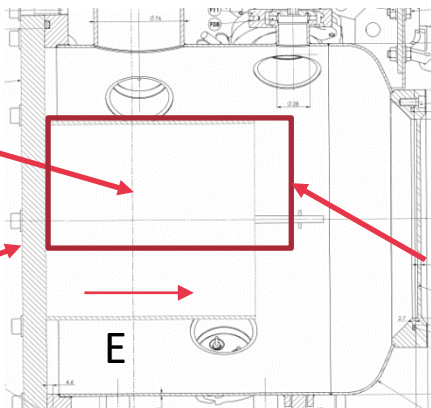


- (Gas, & stoichiometry) = f(measurement range)
 - ~ 50% C_4H_{10} + 50% CHF_3 (reaction (n,p), Energy < ~500 keV)
 - ~ 95% He + 5% CO_2 (reaction (n, α), Energy > ~500 keV)
 - + Tunable Pressure... (Pressure limit = 1.3bar(abs))



Detection volume = E field cage

pixelized anode



Full Cathode

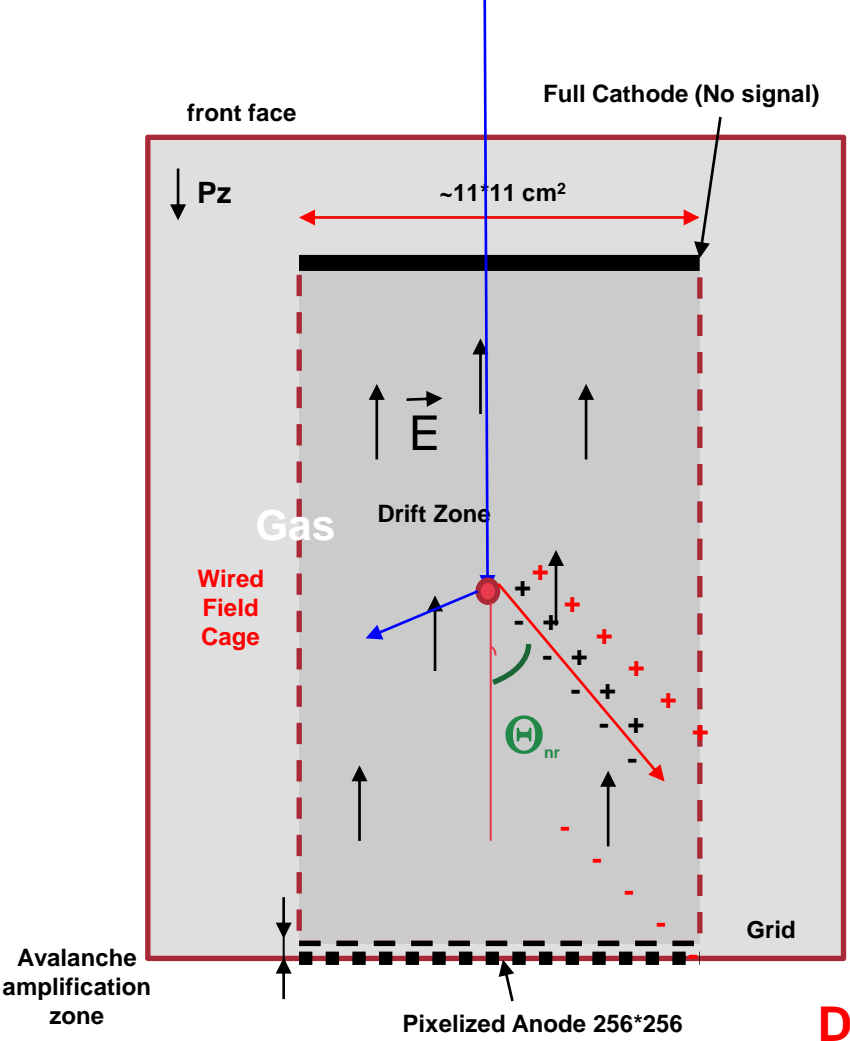


Section view

View of the detection part (anode and detection cage) on a picture of the μ TPC(opened)

μTPC working principle

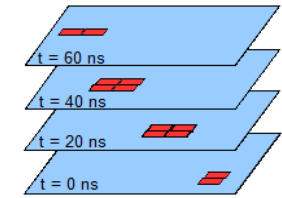
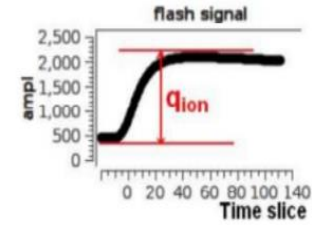
$$E_n = \frac{(m_n + m_r)^2}{4m_n m_r} \frac{E_r}{(\cos(\theta_{nr}))^2}$$



Event by event measurement

Observable quantities are:

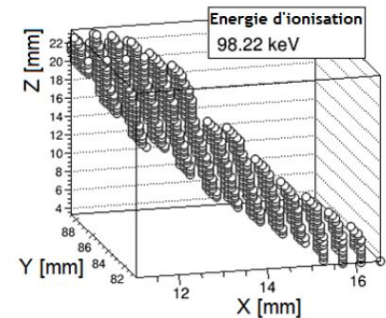
- $E_{\text{ionization}}$ deduced charge collection profile
- Serie of slice images at each ΔT
 $\Delta T = \text{sampling period} = 20\text{ns}$
 \Rightarrow anode provides only (X,Y)
 \Rightarrow 3rd coordinate computed using equation :



$$\Delta Z = \Delta T \cdot V_{\text{Drift}}$$

$$Z = \text{NbSlice} \cdot \Delta T \cdot V_{\text{Drift}}$$

Where V_{Drift} = Drift Velocity



One 3D electron cloud by collision event enabling to compute

- The track length
- The 3D vector of the track $\Rightarrow \cos(\theta_{nr}) = P_z$

Drift velocity = Key data to compute P_z and thus E_n

4 step process: relevant event selection based on inferred observables

Application to the 5 MeV field measured at the National Physics Laboratory (UK)

1) By Default cuts



2) Incompleted track cut

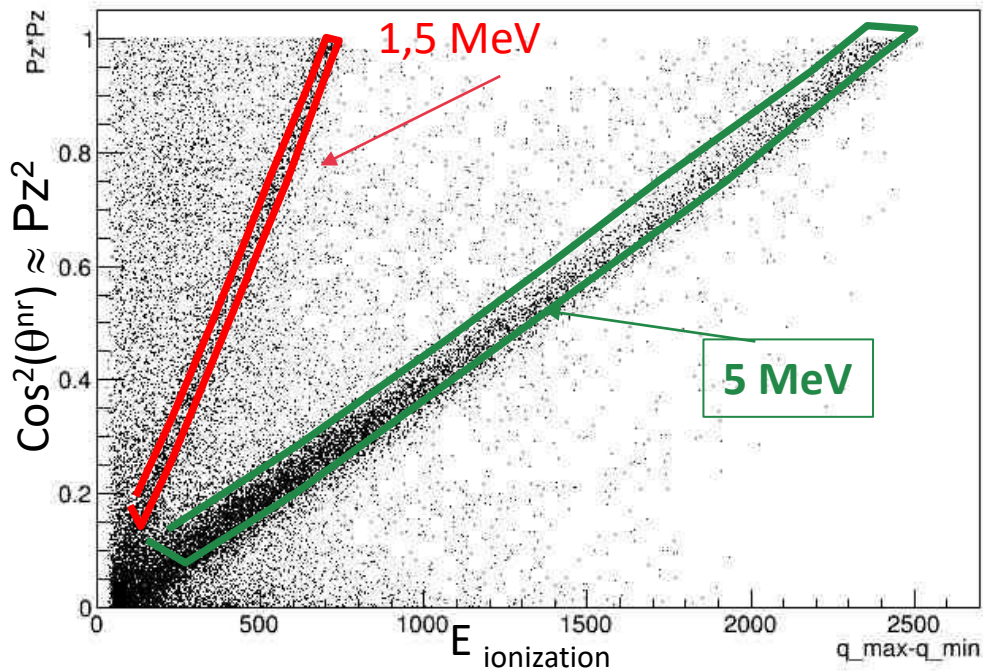


3) α recoil events selection (based on SRIM simulations)



Identification of the energy groups

Direct neutron selection



$$E_n = \frac{(m_n + m_r)^2}{4m_n m_r} \frac{E_r}{(\cos(\theta_{nr}))^2}$$

$$E_n \approx 25/16 * E_r / P_z^2$$

Theoretical linear dependence of P_z^2 and E_r for a given E_n

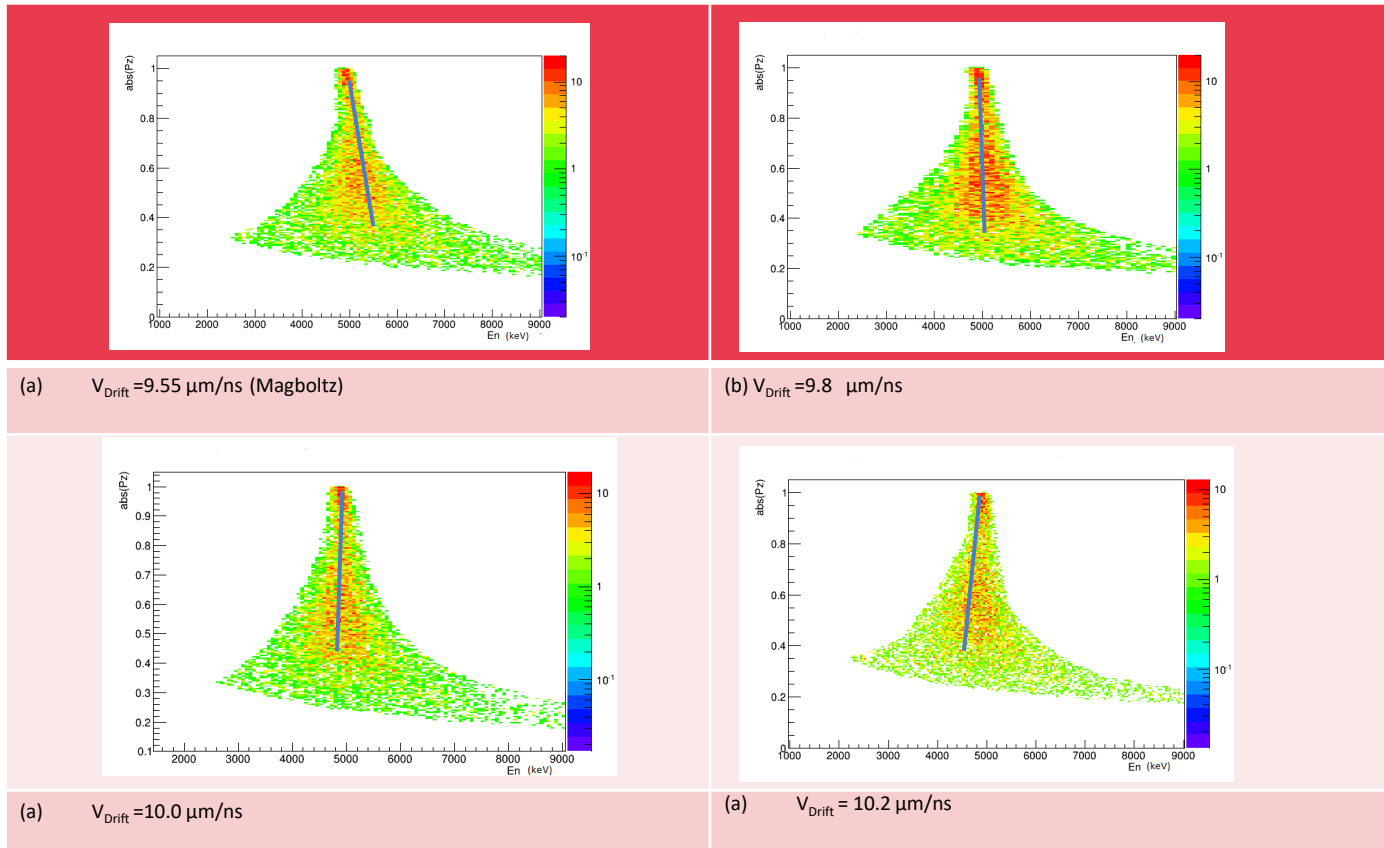
$$E_r = E_{\text{ionization}} / \text{IQF}_{\text{TRIM}}(E_{\text{ionization}})$$

4) On this bidimensional histogram, we select only the 5MeV branch (and/or the 1.5MeV branch)

Initial Drift velocity determination and further observations

Drift velocity can be simulated by MAGBOLTZ software which integrates the Boltzmann transport equation. MAGBOLTZ simulations were done for the μ TPC assuming a uniform electric field of ~ 156.5 V/cm in the gas mixture used \Rightarrow calculated drift velocity $= 9.55$ $\mu\text{m/ns}$.

Bidim. histograms of $(E_n, |P_z|)$ distribution obtained running the analysis code for different drift velocities V_{Drift}



In blue: visual estimations of average energy

\Rightarrow \nearrow as P_z \searrow for the Magboltz velocity estimation (i.e. 9.55 $\mu\text{m/ns}$)

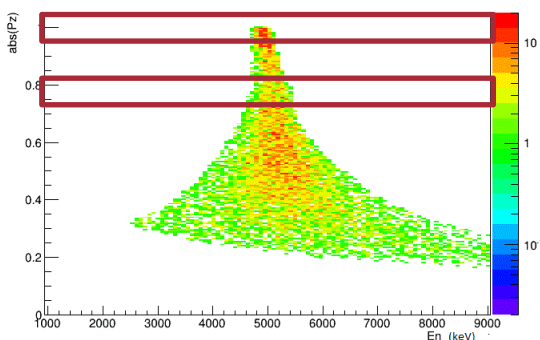
\Rightarrow when drift velocity is increased to 10 $\mu\text{m/ns}$, average E_n \searrow as P_z decreases

Strategy to deduce the optimal drift velocity ($V_{\text{Drift}}^{\text{Optimal}}$)

Physics determines that E_{mean} must be constant as a function of P_z . So the following quantitative approach can be applied :

For a set of V_{Drift} Values

Compute Bidimensional histograms of $(E_n, |P_z|)$



Start with $P_z^{\text{max}} = 1.0$

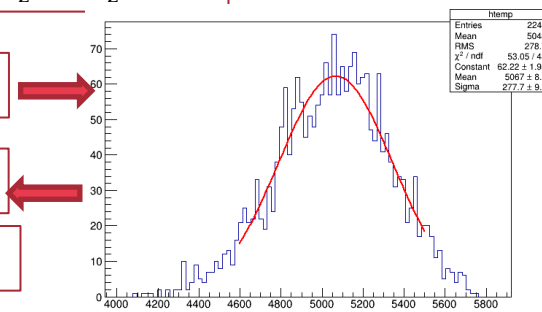
A) Mobile selection zone of $|P_z|$ as $[P_z^{\text{min}}, P_z^{\text{max}}]$ where P_z^{min} is adjusted by dichotomy to maintain a constant number of events in the zone

B) Compute P_z^{mean} for that adjusted selection zone $[P_z^{\text{min}}, P_z^{\text{max}}]$

C) Project this selection on E_n axis

D) Gaussian fit $\Rightarrow E_n^{\text{mean}}$ & its standard deviation

Change P_z^{max} and repeat steps A) to D)



\Rightarrow This repetition leads to a set of values $E_n^{\text{mean}} \pm \Delta E_n^{\text{mean}} = f(P_z^{\text{mean}})$ to plot

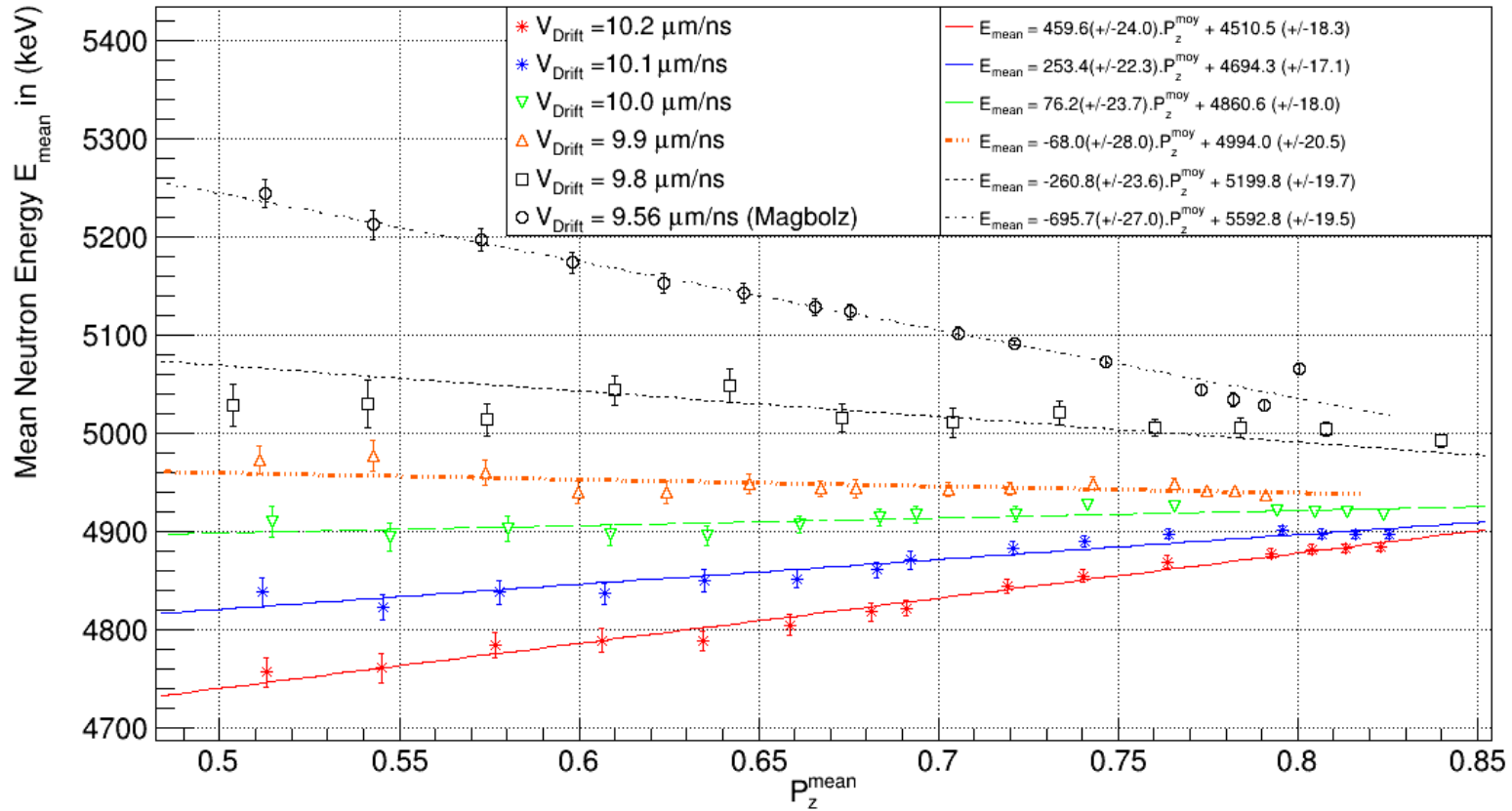
Linear fit taking into account ΔE_n^{mean} is performed

Leads to $\text{Slope}(V_{\text{Drift}}) \pm \Delta \text{Slope}(V_{\text{Drift}})$

Then $V_{\text{Drift}}^{\text{Optimal}}$ is deduced via the search for a zero slope

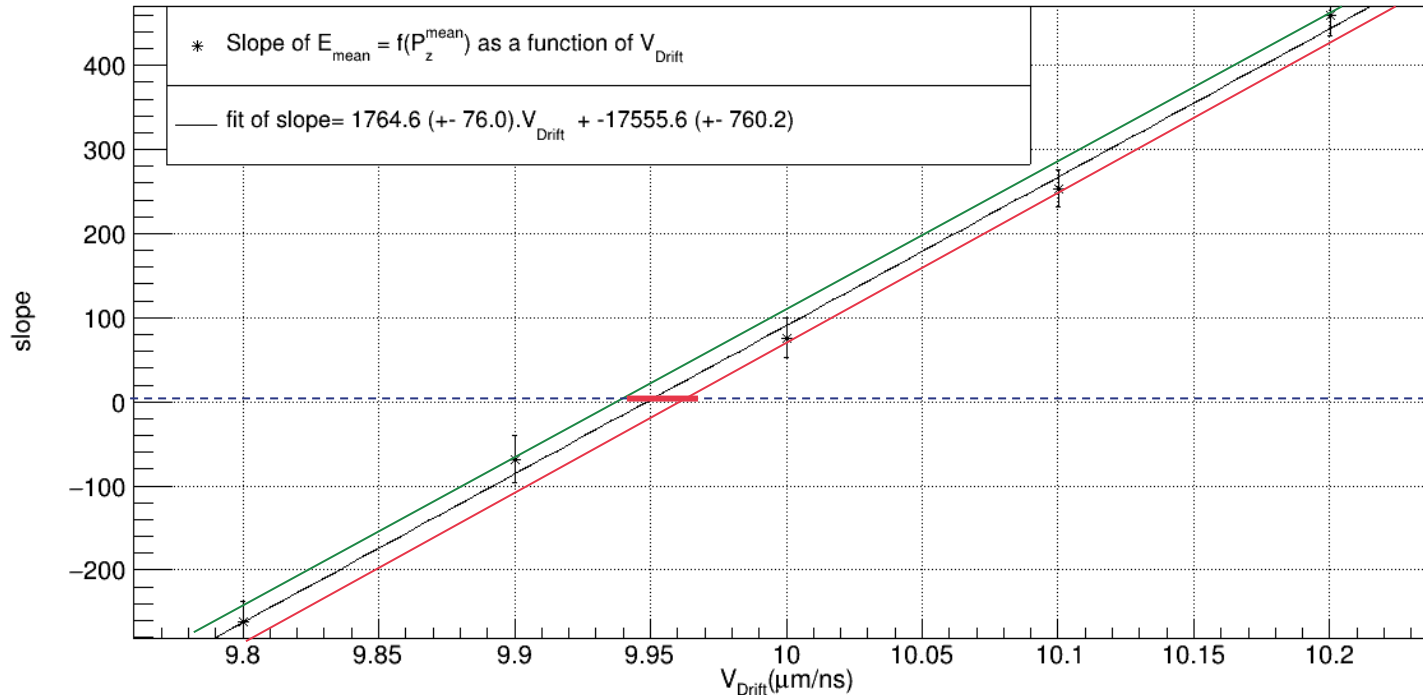
APPLICATION TO 5 MEV MONOENERGETIC NEUTRON FIELD - 1/2

Mean Neutron Energy E_{mean} as a function of P_z^{mean} for different drift velocities V_{Drift} for the 5MeV NPL reference field



APPLICATION TO THE NPL 5 MEV MONOENERGETIC NEUTRON FIELD - 2/2

Slope of E_{mean} as a function of V_{Drift} for the NPL 5MeV reference field



To quantify uncertainty, two fits:

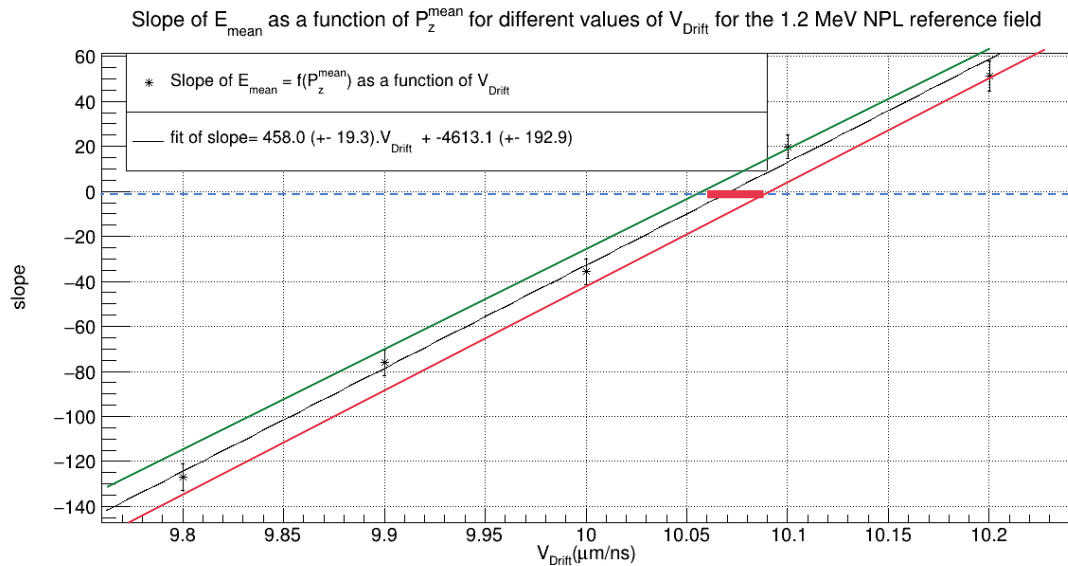
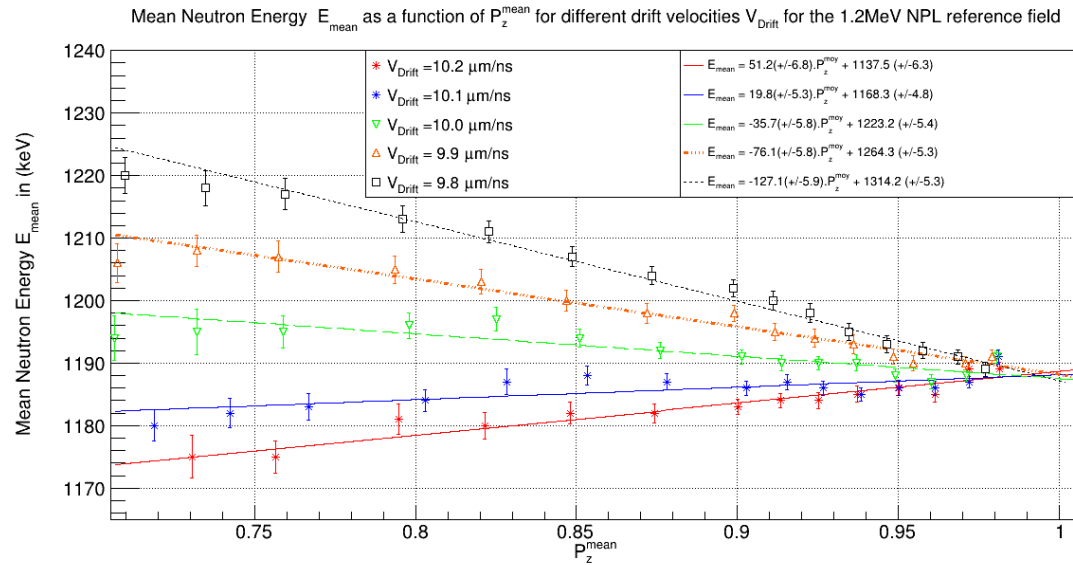
- With $(V_{\text{Drift}}, \text{Slope}(V_{\text{Drift}}) + \Delta\text{Slope}(V_{\text{Drift}}))$
- With $(V_{\text{Drift}}, \text{Slope}(V_{\text{Drift}}) - \Delta\text{Slope}(V_{\text{Drift}}))$



V_{Drift} is estimated to be in the range $[9.93-9.96] \mu\text{m/ns}$

Above $V_{\text{Drift}}^{\text{Magboltz}} = 9.55 \mu\text{m/ns}$

EXTENSION FOR THE NPL 1.2 MeV MONOENERGETIC NEUTRON FIELD



V_{Drift} is estimated to be in the range
[10.06-10.09] $\mu\text{m/ns}$

above $V_{\text{Drift}}^{\text{Magboltz}} = 9.55 \mu\text{m/ns}$

Discussion 1/2

The drift velocity in a (95% He + 5% CO₂) mixture was determined using two monoenergetic neutron fields (5 MeV and 1.2 MeV).

The results were compared with a simulation based on the MAGBOLTZ program.

Some differences between experimental estimations of V_{Drift} from both fields were observed:

- $V_{\text{Drift_opt}}(5 \text{ MeV})$ is between 9.93-9.96 $\mu\text{m/ns}$ so **+4.1%** relative to Magboltz (9.55 $\mu\text{m/ns}$)
- $V_{\text{Drift_opt}}(1.2 \text{ MeV})$ is between 10.06-10.09 $\mu\text{m/ns}$ so **+5.3%** relative to Magboltz

The sensitivity analysis at the nominal operating point was performed using Magboltz

(95%He/HV_{Drift} = 2770V/700 mbar(a)/20°C):

- A. Stoichiometry sensitivity was +/- 1.2% for a 1% variation in ⁴He ,
- B. HV sensitivity per Volt was less than 0.05%.
- C. Pressure sensitivity per mbar was less than 0.3%.
- D. Temperature sensitivity per °C was less than 0.3%.



Cumulated
uncertainty of
0.3%

Discussion 2/2

- $V_{\text{Drift_opt}}(5 \text{ MeV})$ is at **+4.1%** relative to Magboltz ($9.55 \mu\text{m/ns}$)
 - $V_{\text{Drift_opt}}(1.2 \text{ MeV})$ is at **+5.3%** relative to Magboltz
-
- The gap of 1.2% between the two estimations could not be attributed only to variations in the experimental conditions between the two measurements (limited at around 0.3%).
 - A possible explanation for this gap could stem from the assumption, in the Magboltz simulation, of a uniform electric field. Indeed, simulations previously carried out using a different gas mixture have demonstrated that there was a deformation of the electric field near the grid.
 - As the tracks in 5 MeV field are longer, one can postulate a slight difference in the influence of this deformation on the tracks in the drift cage.
 - Another explanation could come from the use of an Ionization Quenching Factor (IQF) curve computed using TRIM software. Indeed, some measurements were done at the AMANDE facility that led us to believe that the TRIM software, as it is designed, underestimates the IQF.
 - We tested the application of a preliminary IQF curve to the V_{Drift} determination process: This led to an additional increase in the drift velocity.

Conclusion

Drift velocity in a μ TPC is a key parameter to reconstruct the tracks of charged particles. The experimental determination of drift velocities can be done using the scattering properties of neutrons

Main conclusions:

⇒ The Magboltz estimation appears to be an underestimation

⇒ Additional /complementary measurements are needed to provide a consolidated estimation



RÉPUBLIQUE
FRANÇAISE

*Liberté
Égalité
Fraternité*



ANIMMA

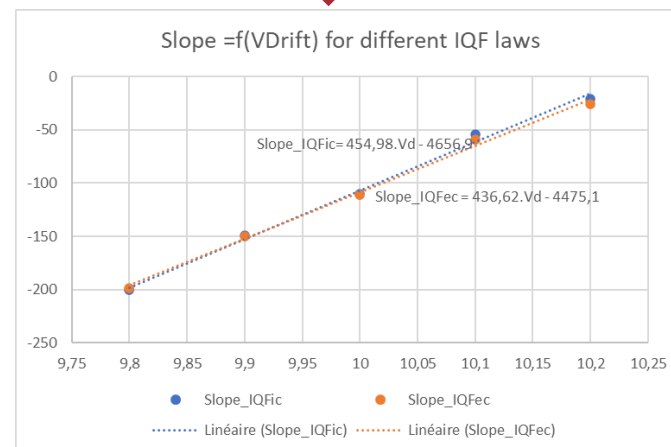
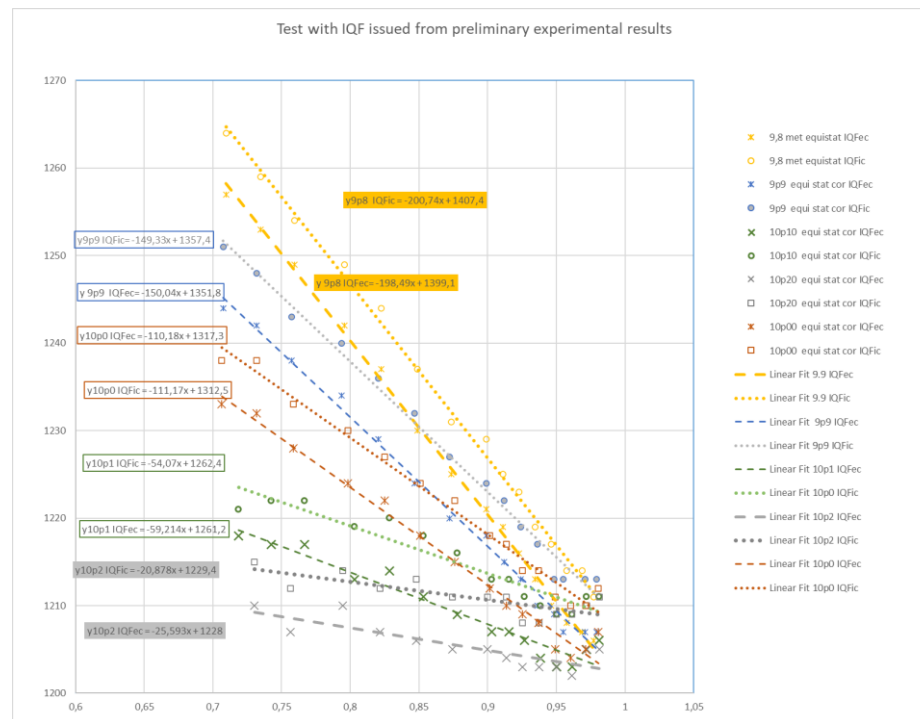
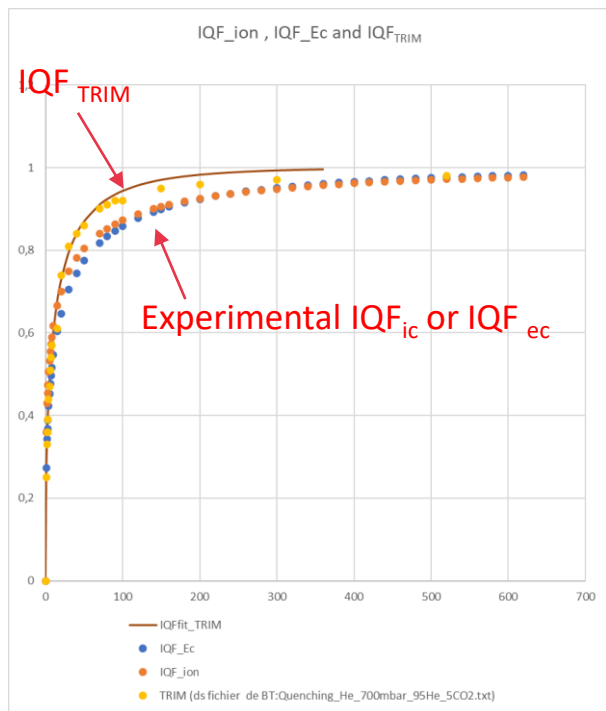
IRSN

INSTITUT DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

THANK YOU FOR YOUR ATTENTION

ANY QUESTION?

IQF law impact on V_{Drift} determination



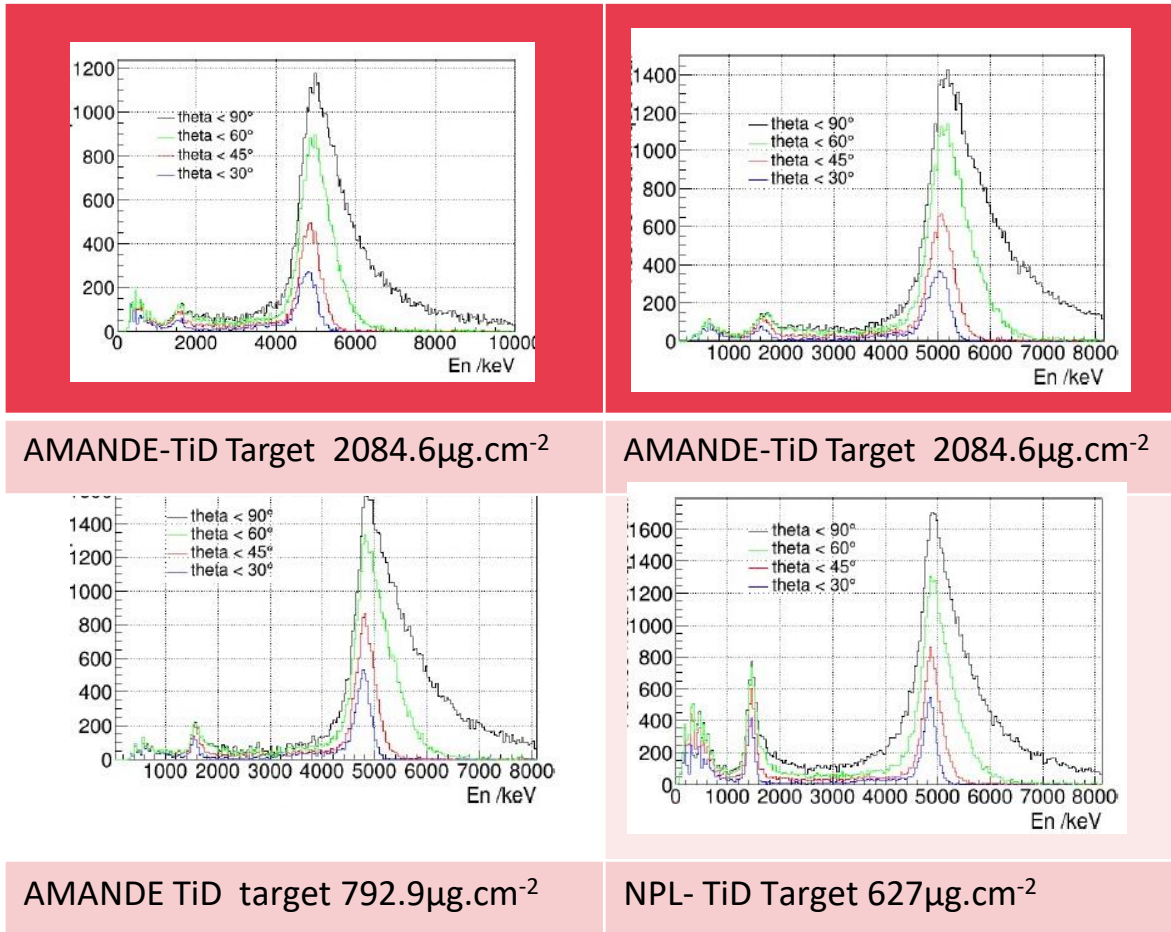
Extrapolation to Zero



| | slope | offset | (-)/offset/slo | Vd_slope0 |
|-------|--------|---------|----------------|-----------|
| IQFic | 454,98 | -4659,9 | 10,2419887 | 10,24 |
| IQFec | 436,62 | -4475,1 | 10,249416 | 10,25 |

Explanation of a second branch for the NPL 5 MeV field

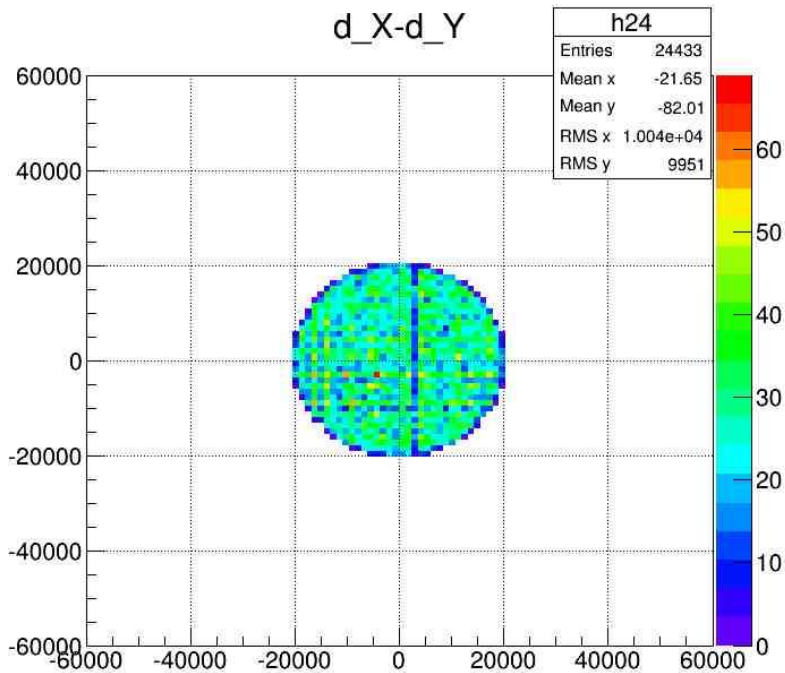
=> cannot be due to alphas induced by (n,α) in the detector since there would not be a perfect correlation between θ et $E_{\text{ionization}}$ as observed on $P_z^2 :: E_{\text{ionization}}$ bidim



Incident deuteron energy = $f(\text{Target thickness}) = 1.84 \text{ MeV}$ for a $792.9 \mu\text{g} \cdot \text{cm}^{-2}$ target .
 Interaction of deuterons of 1.84 MeV & production of 1.5 MeV neutron via the $^{12}\text{C}(d,n)^{13}\text{N}$ reaction
 Effect already observed for deuteron energies above 4 MeV (Varignon et al.).

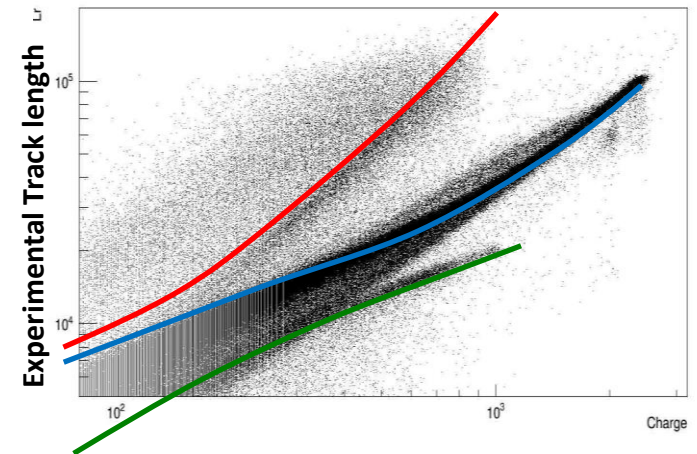
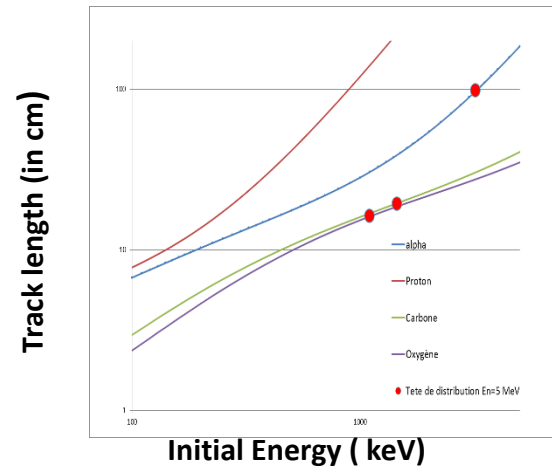
More details on the 4 step process: relevant event selection based on inferred observables

- 1- detection threshold cut
- 2- Minimum number of slices =3



- 1) Selection of the track start coordinates in a 2cm diameter cylinder

SRIM simulation data



- 2) Selection of the region associated with Alpha (⁴He)