Présentation pour Comité de suivi individuel

Étude expérimentale de l'interaction forte avec les spectromètres CLAS et ALERT à Jefferson Lab

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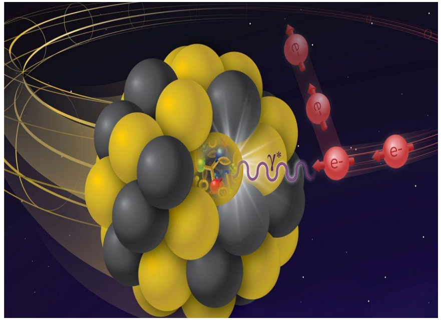
Outline

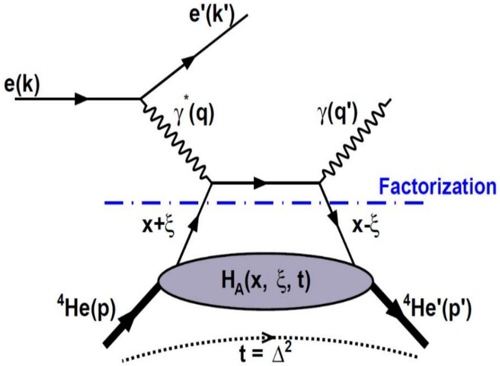
- Physics of interest
- ALERT experiment
- Work performed
  - Simulation (internship + thesis)
  - Reconstruction
  - Activities at JLab
- Conclusion/Perspectives

Deeply Virtual Compton Scattering (DVCS)

Probing the matter with an electron beam



- ♣ The DVCS is one of the various **physics process** studied to extract information about the nucleon/nuclear structure
  - ○ scale of interaction is $\lambda = 1/\sqrt{Q^2}$
- ♣ Electroproduction of a real photon : **$e + N \rightarrow e + N' + \gamma$**
  - ○ the virtual photon interacts with a quark inside a nucleon (inside a nucleus) without breaking the whole nucleus
- ♣ The DVCS highlights the **Generalized Parton Distributions**
  - ○ Mathematical functions of kinematics variables (x, ξ, t) emerging from **Quantum ChromoDynamics (QCD)**

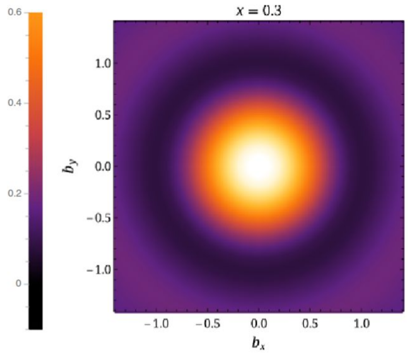


Generalized Parton Distributions* (GPDs)

- ♣ They encode the correlation between the transverse position and the longitudinal momentum distribution of the partons (i.e quarks or gluons)
- ♣ They encode various informations about the nucleon structure such as:

Nucleon Tomography

H.W. Lin, Phys. Rev. Lett. 127 (2021) 182001.



Contribution to the nucleon total spin

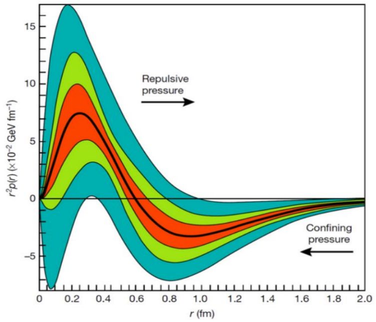
X. Ji, Phy.Rev.Lett.78,610(1997)

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta L + \Delta G$$

- Quark contribution is not the main contribution (30 %) ⟶ spin crisis
- Quark's orbital angular momentum is accessed through **GPDs**
- Gluon contribution

Access to Gravitational Form Factors

V. D. Burkert et al. Nature 557.7705 (2018): 396



- Mass/energy distribution inside the nucleon
- Forces distribution
- Nuclon radius
- Shear forces and pressure distribution

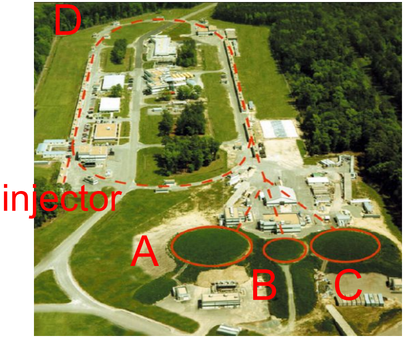
* Juan Sébastien ALVARADO GALEANO (his slide from CLAS collaboration meeting - July 2025)

Overview

- An experiment at **Jefferson Lab** to investigate the nuclear structure of He-4 and D2
- The physics program is very wide. It contains:
  - Measure of Deeply Virtual Compton Scattering on He-4
  - Measure of Deeply Virtual Meson Production on He-4
  - Short range correlation study
- The data taking was from early April 2025 to September 03, 2025
- ALERT is also a new detector. It stands for **A L**ow **E**nergy **R**ecoil **T**agger
- It is composed of **A H**yperbolic **D**rift **C**hamber **(AHDC)** and **A T**ime-**O**f-**F**light system **(ATOF)**
  - AHDC for track reconstruction
  - ATOF for particle identification

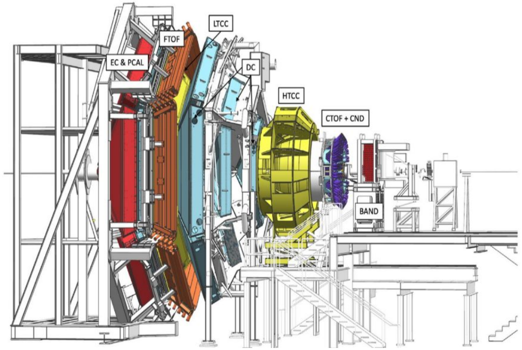
Experimental setup

- **Continuous Electron Beam Accelerator Facilities (CEBAF)**



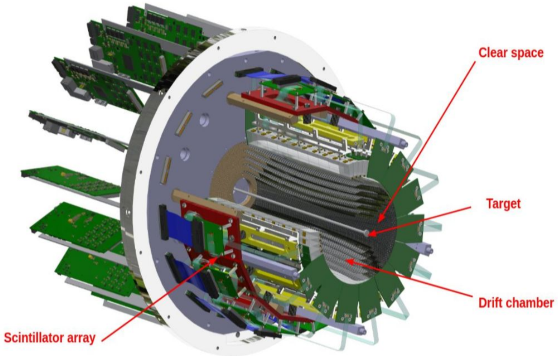
- CEBAF delivers **spin polarized electron** beam with energy up to **10.6 GeV**
- ALERT took place in **Hall B**

- **CEBAF Large Acceptance Spectrometer (CLAS)**



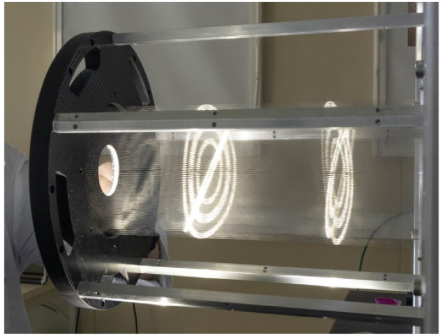
- CLAS provides a good detection of the scattered electrons and the production photons
- 3° < θ < 35° (forward part)
- 35° < θ < 145° (central part)
- 0° < φ < 360°

- **ALERT**



- Inside CLAS, very close to the beamline, surrounds the target
- Detects the **recoil nuclei**

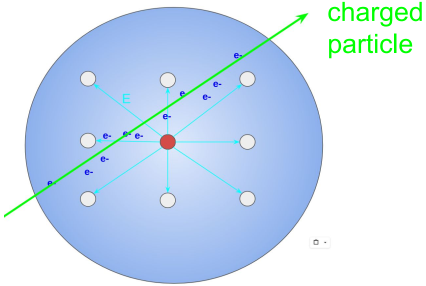
Drift chamber and signal generation



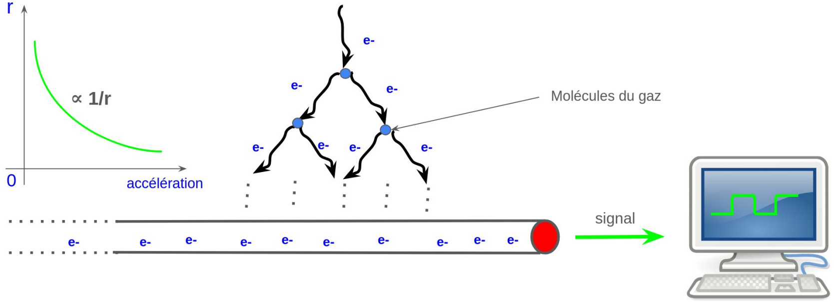
- ♣ The AHDC is a gaseous detector
  - Gas mixture : He-4 (80%) + CO_2 (20%)
  - 3026 aluminium wires organised in 21 concentric layers

AHDC detection cell

- 🔴 1 sense wire connected to the HV ~ 1400 V
- ⚪ 8 field wires connected to the LV



This disposition instaures an **electric field** that ensures the drift of the electrons generated by ionisation.

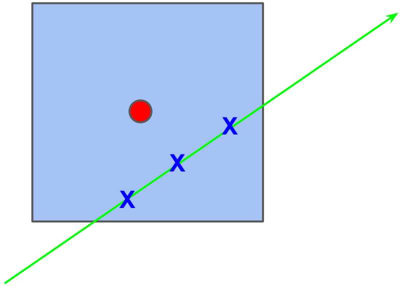


How can we generate this signal in simulation? 🤔

Work performed (simulation)

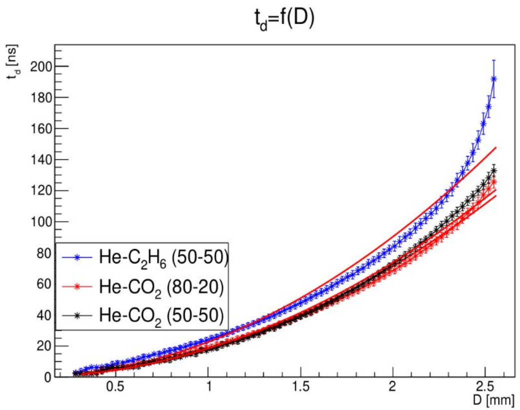
First approach (internship)

- The AHDC detection cell is a volume in the **Geant4** simulation
  - The discretisation results in a **collection of hits/steps**



- **X** represents a step, i.e a Geant4 object that contains information such as
  - position (x,y,z) and momentum (p_x,p_y,p_z)
  - deposited energy E

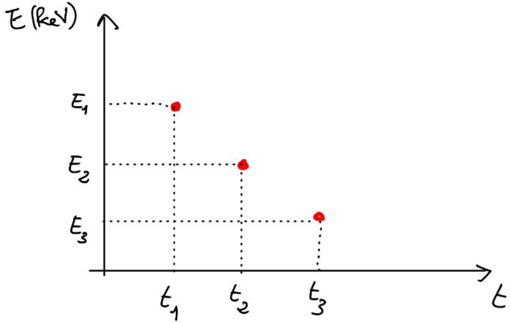
- During the development of the AHDC, here at IJCLab, Lucien CAUSSE determined a relation between the distance and drift time
  - a polynomial fit is **$f(x) = 7x + 7x^2 + 4x^3$**



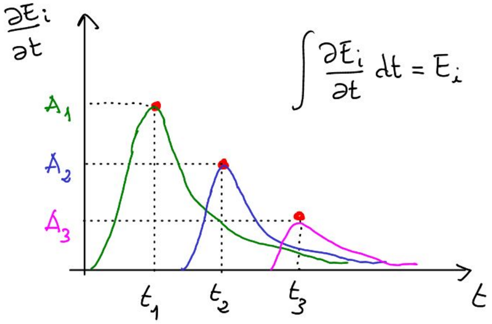
- We use this **distance2time** relation to compute drift times from step positions

First approach (internship)

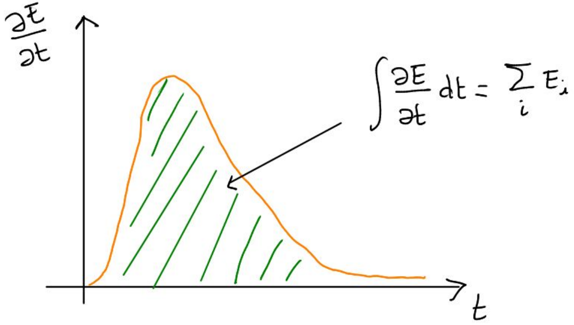
♣ We use this **distance2time** relation to compute drift times from step positions



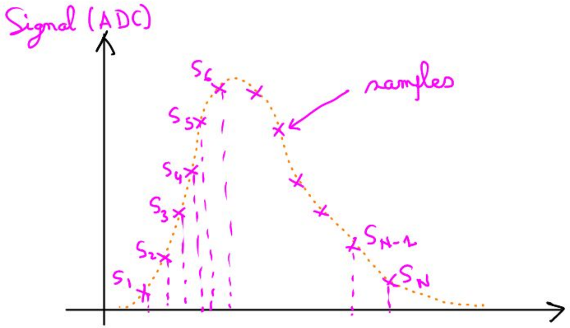
♣ We add an envelope to these punctual distributions (**Landau distribution**)



♣ The resultant is a complex signal



♣ The samples of this signal are recorded in the relevant data structure



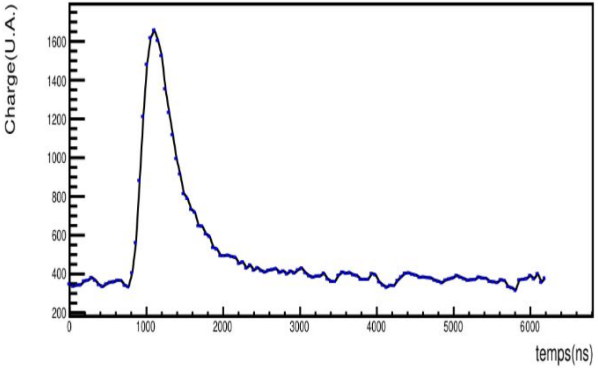
First approach (internship)

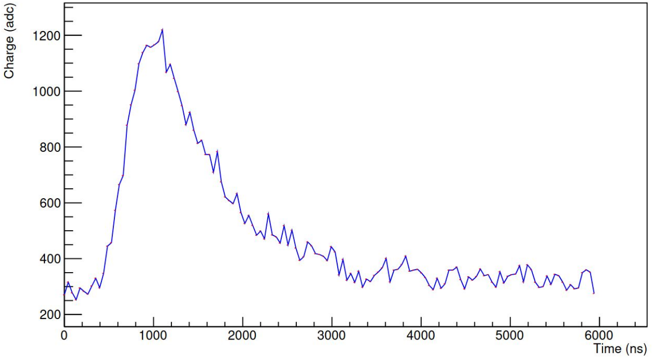
$$\mathcal{L} = \mathcal{L}_{(\mu,\sigma)}(t) \;;\; \mu \text{ is fixed by } t_i \quad \mu_i = t_i$$

- Here is a typical result from simulation
- This approach has several free parameters
  - the scale parameter σ of the Landau distribution
  - the eventual delay added to the resulting signal
  - the noise level
  - the proportionality factor that ensures the conversion to keV/ns to ADC
- These parameters have been choose to fit the signal measured by Lucien during his thesis

A measurement made at ALTO during the development of ALERT

Lucien CAUSSE 's thesis

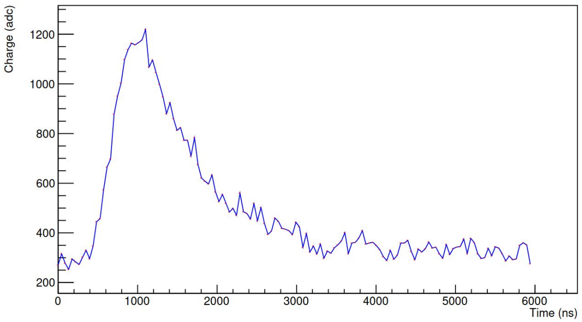




State of the simulation before the thesis

New problematics (thesis)

- ♣ In the previous state of simulation, the time window was about 6000 ns, hence 120 samples at 50 ns.
- ♣ An efficiency study, made during the commissioning of the experiment in April 2025, has shown a reduction of the **live time** with respect the increase of the number of samples.
  1. We have been constrained to reduce the number of samples at 30 then at 20.
  2. 20 samples cover only the first 1000 ns, i.e a very small part of the signal in simulation
  3. We have to make the simulation matching read data.

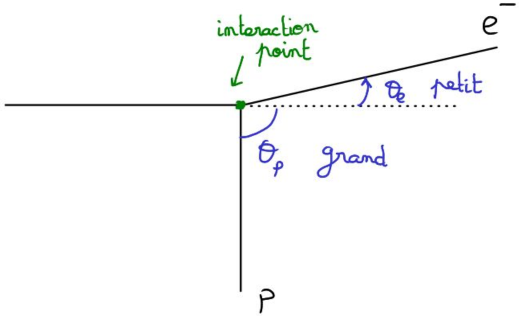


Work performed (simulation)

Elastics study

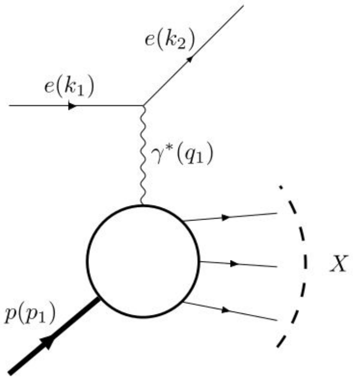
- To compare simulation and real data, we need to look at the same kind of events
  - e.g finding protons in real data and simulate them with the same kinematics
- How can we find protons if the reconstruction software (including its calibration) is not completed?
  - **looking at elastics events**
- All the kinematics quantities in an elastics interaction can be retrieved knowing the θ_e angle
  - Fortunately, CLAS has many years of service and can provide very detection of the scattered electron.

$$e + p \rightarrow e + p$$



Elastics study

- Data analysis
  - A run on Deuterium target (run 22712)
  - Reconstruct the missing mass **W²**



$$W^2 = (q_1 + p_1)^2 = M_p^2 + 2M_p\nu - Q^2$$

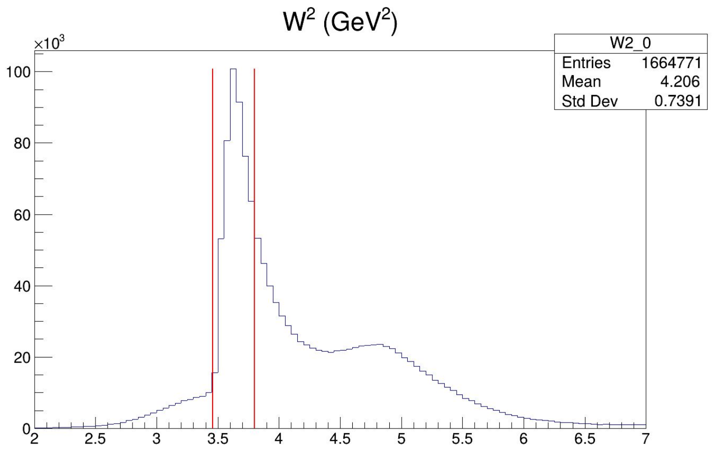
$$\nu = \frac{-q_1 \cdot p_1}{M_p} \overset{\text{lab}}{=} E_{k_1} - E_{k_2}$$

$$Q^2 = 4E_e E_{e'} \sin^2\left(\frac{\theta_{e'}}{2}\right)$$

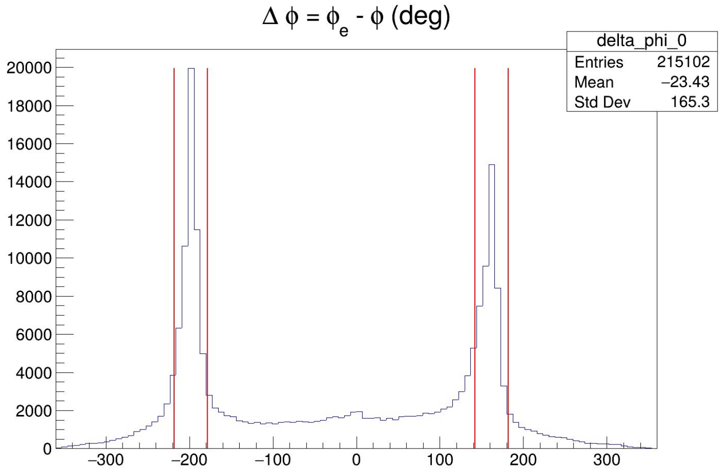
$$x_B = \frac{Q^2}{2p_1 \cdot q_1} \overset{\text{lab}}{=} \frac{Q^2}{2M_p\nu}$$

Elastics study

- Selection cuts
  - **W^2 cut** : the energy at rest of D2 i.e its mass is 1.875 GeV (and $1.875^2 = 3.51$)
  - For D2, we cannot separate elastics and quasi-elastics events
  - **$\Delta\phi$ cut** : for elastics event, the final states move back to back



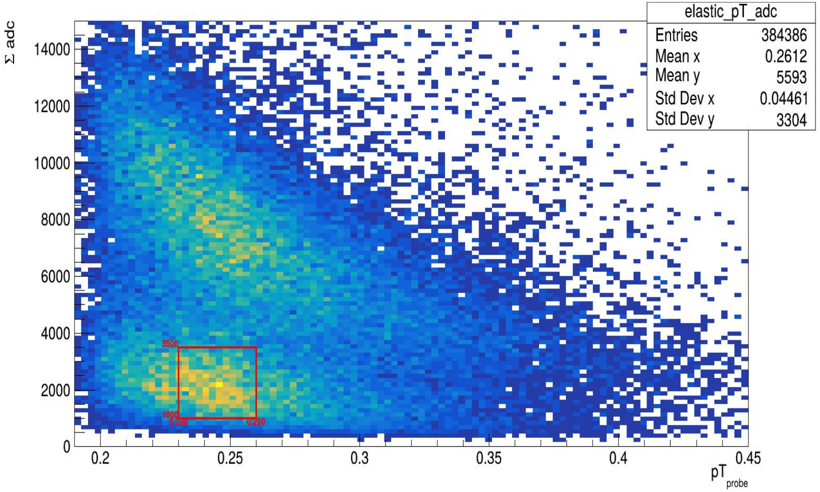
$3.46 < W2 < 3.8$ GeV², only electrons



$|\Delta\phi - \text{peak}| < 20$ deg

Elastics study

- Only for couples {electron, track} that satisfy the previous cuts, we plot the correlation between the deposited energy of the track versus the transverse momentum of the electron.
  - the points in the red rectangle are identified as proton
  - pT electron ⟷ theta electron ⟶ p, pT, theta, phi, vz of the track i.e proton



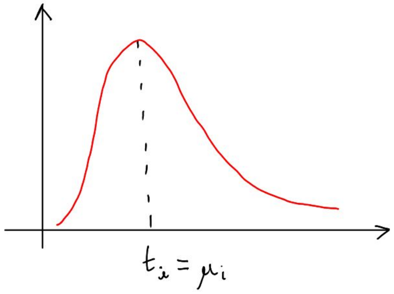
We know what we have to simulate!

Work performed (simulation)

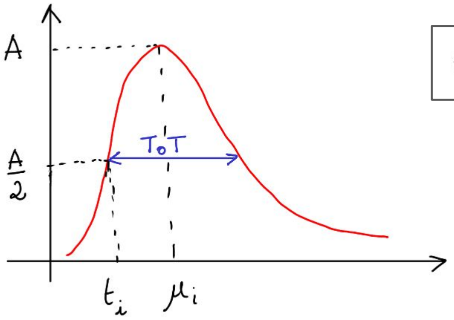
Current approach in simulation

- ♣ The **drift time** is now the time at half amplitude

before



now



$$t_i = \mu_i - 1.36\,\sigma$$

Landau's property

- ♣ After selecting good protons in real data and plotting the time over threshold (ToT) distribution of their signals, we can have a direct estimate of the **scale parameter *σ*** of the Landau distribution

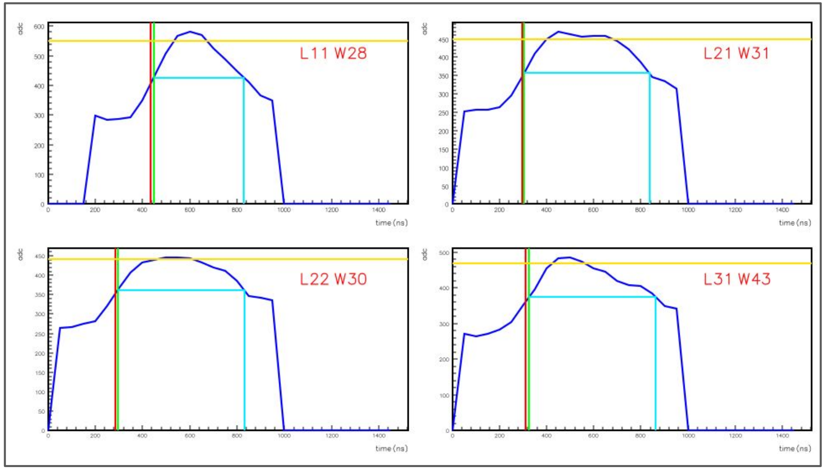
$$\sigma = \frac{FWHM}{4.107} = \frac{ToT}{4.017}$$

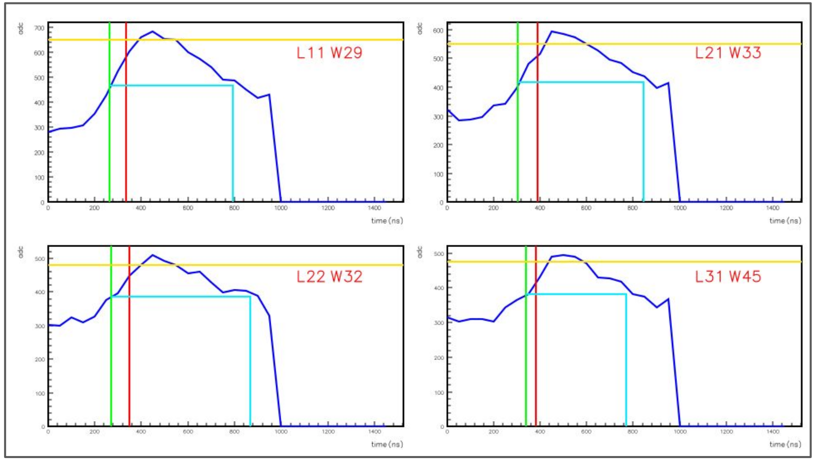
Landau's property

FWHM : Full Width at Half Magnitude

Current approach in simulation

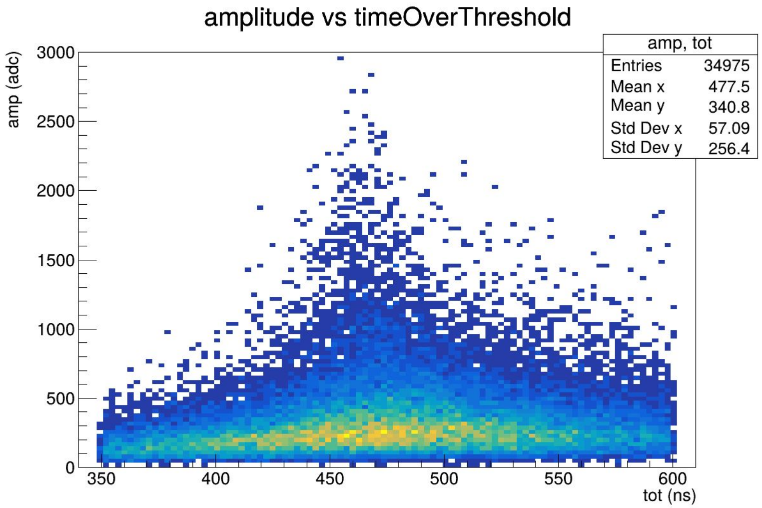
- The **delay parameter** is taken to be the time correction from calibration, i.e t0
  - t0 is loaded from the Calibration Constant DataBase (CCDB), even in simulation!
- The model of noise is still a normal distribution **N(300, 30)**
  - we can play with standard deviation to increase or not the level of noise
- **Results**: waveforms – data (left) vs simulation (right)

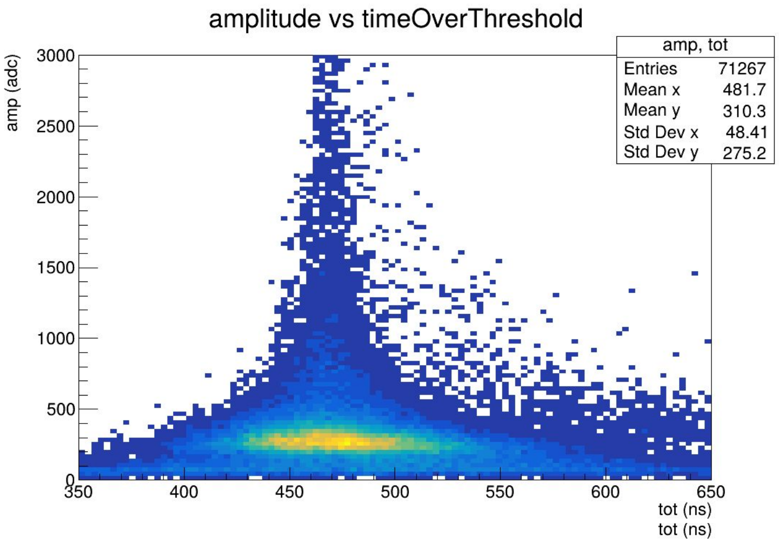




Current approach in simulation

♣ **Results**: quantitative comparison – data (left) vs simulation (right)





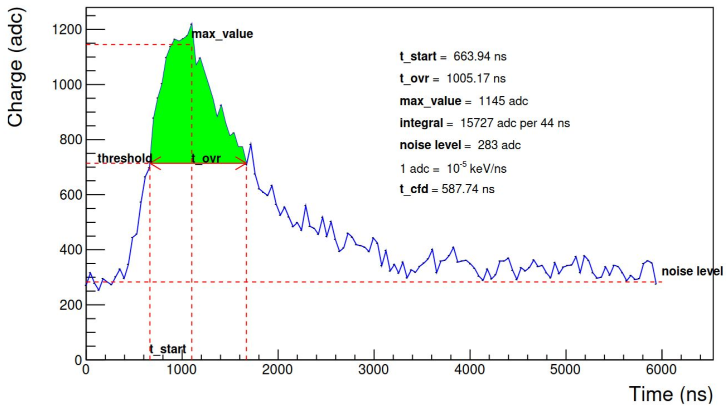
- We have a bias in real data because of the selection cuts that remove big deposited energy
- Real data are very disperse at very low amplitude ⇒ we suspect a bad time reconstruction at the decoding level (object of the next section)

Work performed (reconstruction)

Decoding

- The reconstruction is the processing part that goes from the decoding of raw data to the identification of particles

- For the drift chamber of ALERT, the decoding consists of the extraction of time and charge informations for the waveform
    - The initial code has been developed during the internship (in C++ and Java)
    - Small modifications have been done since then. E.g:
        - t_start renamed to leadingEdgeTime
        - noise_level renamed to to pedestal
        - t_ovr renamed to to timeOverThreshold
        - the integral is no longer the green area, it is the sum of samples after the noise reduction

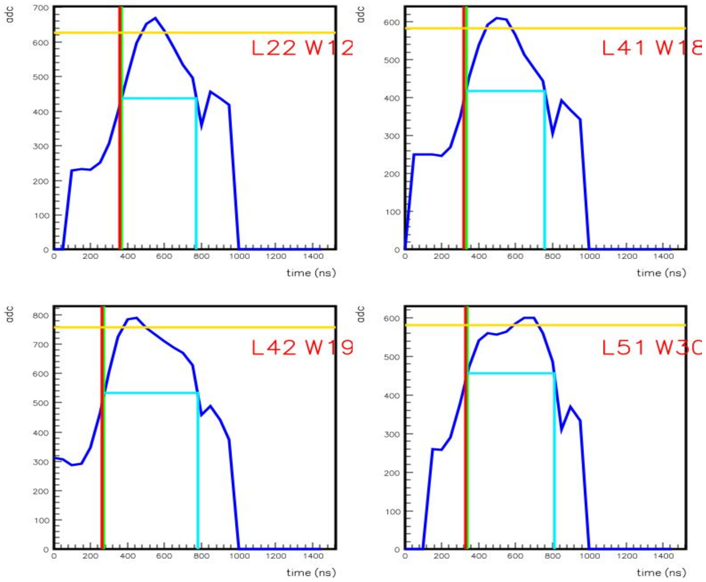


Decoding (some issues)

- The decoding work well for very big signals but sometimes fail for small signals

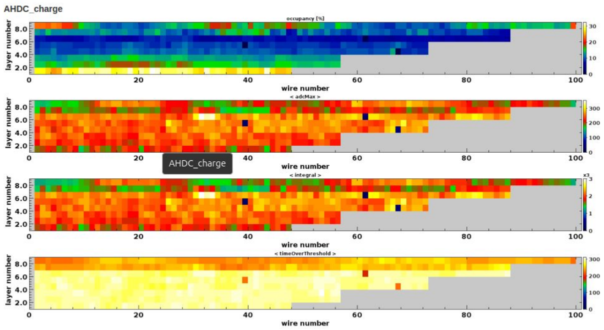
- Some convention used to determine the time don’t work very well when the noise level is big.

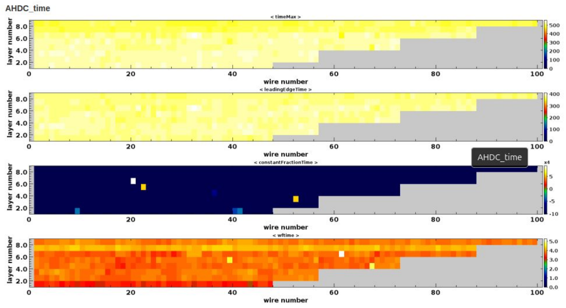
Signals from real data. The shape are relatively good except the decreasing peaks. We don’t have a direct explanation in that moment. But we see that what we the trailingEdgeTime (and so the timeOverThreshold) is not well reconstructed.

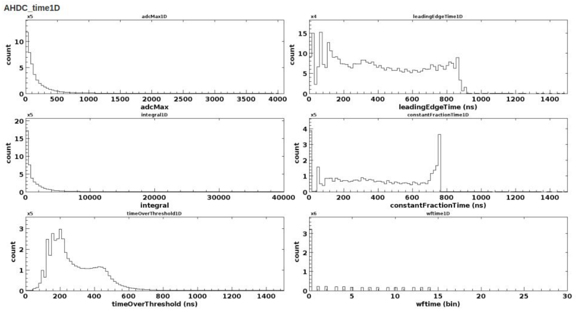


mon12

- ♣ The monitoring of the quality of the data is essential for data taking.
- ♣ I have added some monitoring plots in the live monitoring software of JLab/Hall B, i.e mon12
    - ○ Each square in the 2D histograms represent a sense wire
    - ○ The distributions correspond to the decoding outputs

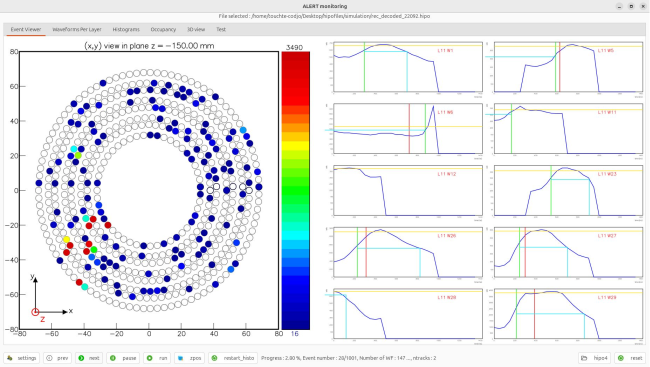


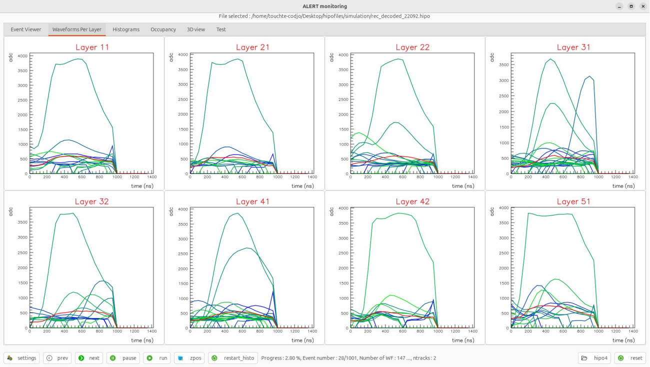


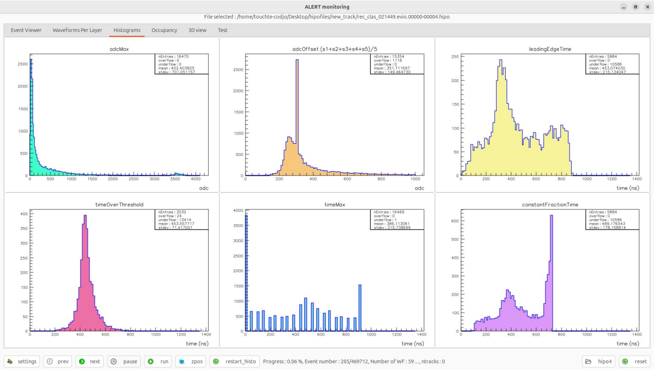


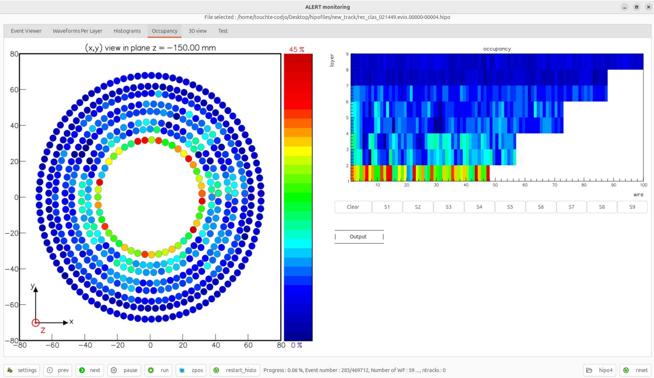
amon (ALERT monitoring)

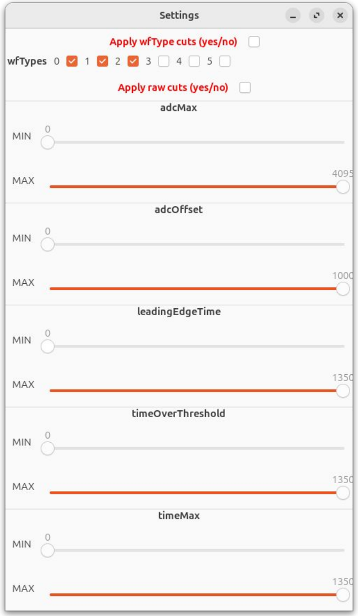
♥ From scratch in C++ using the GTK library





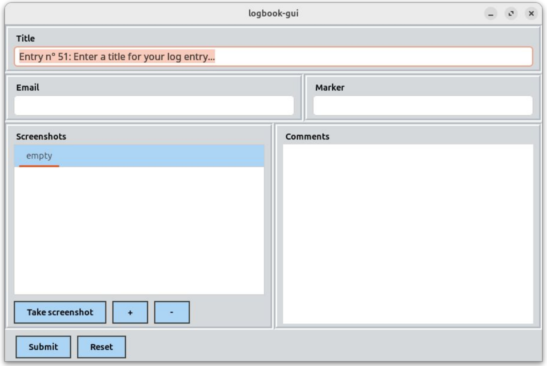




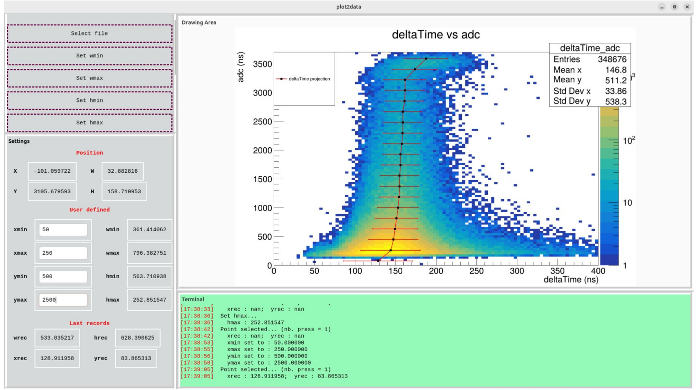


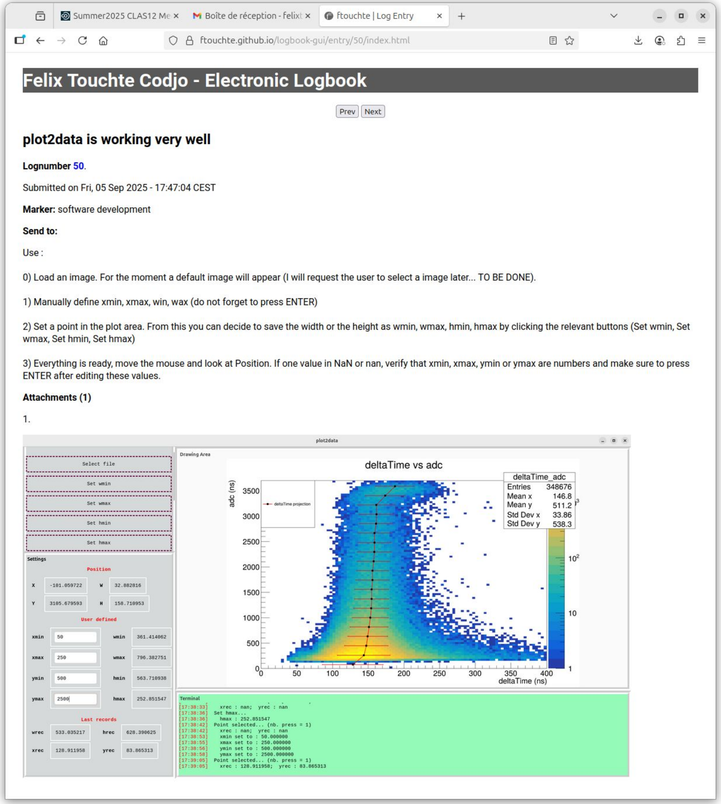
Work performed (Miscellaneous)

logbook-gui



plot2data

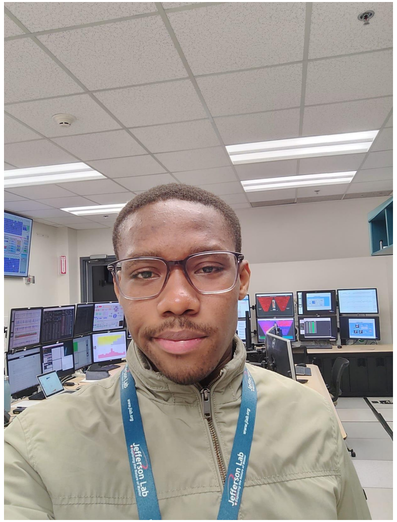




Activities in the US

From March 01, 2025 to July 12, 2025

Detector expert

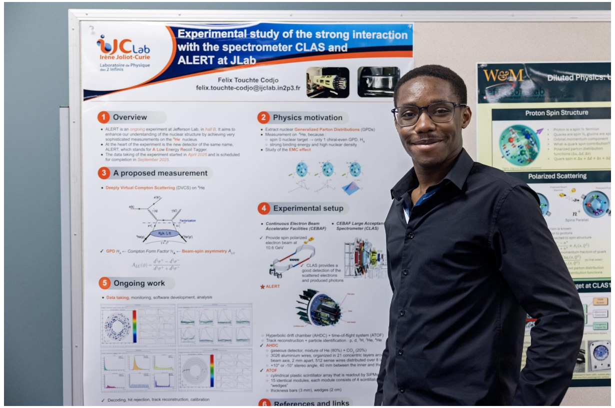


- AHDC expert
- Target expert (responsible of the target change every one or two weeks)
- Shift expert

Summer school (HUGS)

- A very good occasion to meet other students in my field.
- They all had a very good level. I have an idea of what I have to do to match their level.

Poster competition during JLab user group meeting



- Poster competition, my best picture at JLab
- Again, the other competitors were very good.
- I didn't win the competition. :-(

Conclusion and Perspectives

Conclusion

- ♣ A lot work in simulation
- ♣ A real physics analysis through the research of elastics event: my first one
- ♣ The decoding is not perfect
  - ○ Further progresses can be done with a good tracking reconstruction
- ♣ Not mentioned in the presentation but I had a teaching assignment at polytech Paris-Saclay (TP Object Oriented Programming, C++)

Perspectives

- ♣ Matching simulation and real data
- ♣ Data calibration
- ♣ Data analysis (DVCS on Helium-4)