université PARIS-SACLAY

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

Journées de Rencontres Jeunes Chercheur·se·s 2025

Experimental study of the strong interaction with the spectrometer ALERT and CLAS at JLab

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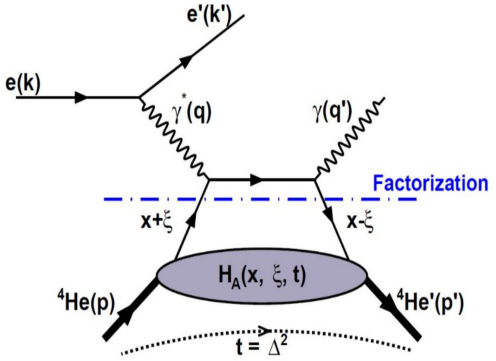
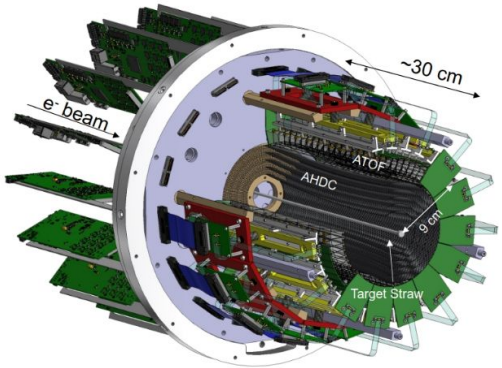
-- PhD student --

ALERT experiment

- ALERT is a hadronic physics experiment
  - Describe the nuclear structure in terms of quarks and gluons
  - Deeply Virtual Compton Scattering (DVCS) is the electroproduction of a real photon through the interaction with a nuclear target
  - DVCS gives access to the tomography of quarks inside the nucleus
- ALERT is also a new detector
  - It stands for ***A Low Energy Recoil Tagger***
  - It is composed of two sub-detectors
    - A Hyperbolic Drift Chamber (AHDC) → IJCLab (Orsay, France)
    - A Time-Of-Flight system (ATOF) → Argonne (Chicago, US)

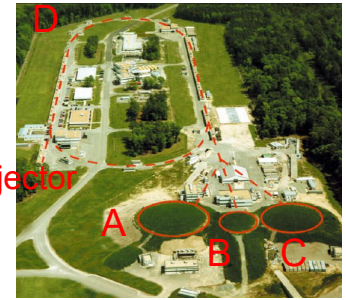


- AHDC
  - 3026 aluminium wires
  - 2 mm apart, distributed over 21 concentric layers
  - gas mixture He4 (80%) + CO_2 (20%)
  - 30 mm < R < 72 mm
  - ± 10° stereo angle for the z determination
  - track reconstruction
- ATOF
  - 2 plastic scintillator arrays read by SiPMs
  - Radius thickness : 2 mm and 3 cm
  - particle identification



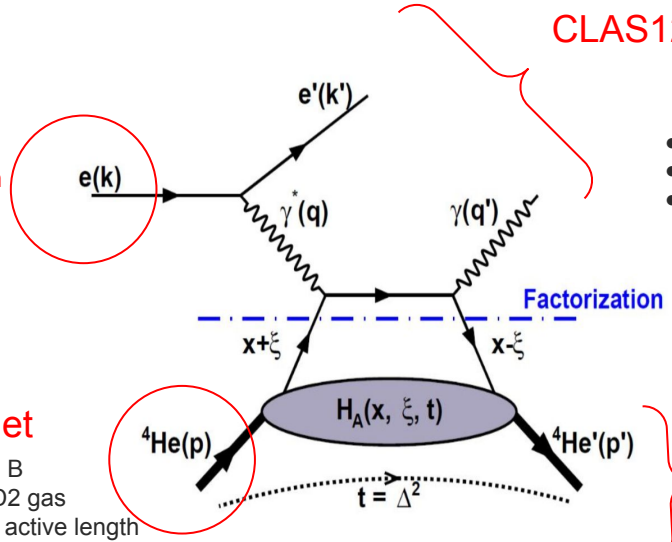
Experimental setup

- Jefferson Lab facilities are ideal for the physics program of ALERT
- ALERT is specially designed to detected ^{4}He and recoil fragments

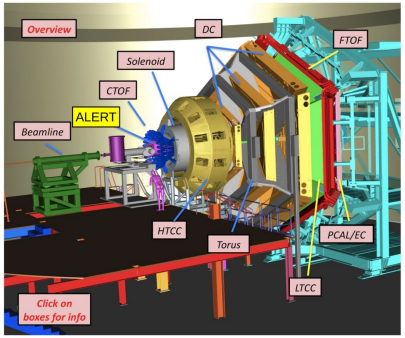


- Continuous Electron Beam Accelerator Facilities (CEBAF)
- CEBAF delivers spin polarized electron beam with energy up to 11 GeV

CEBAF
11 GeV
electron beam



CLAS12



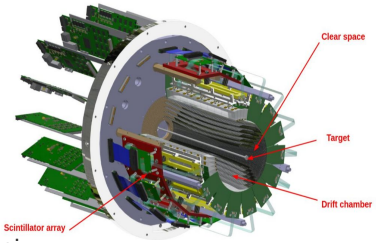
- CEBAF Large Acceptance Spectrometer (CLAS)
- Good detection of electrons and high energy photons
- Kinematics coverage
  - 3° < θ < 35° (forward part)
  - 35° < θ < 145° (central part)
  - 0° < φ < 360°

Target

- In Hall B
- He4, D2 gas
- 30 cm active length
- 6 mm diameter
- pressurized at 68 psig ~ 4.62 atm

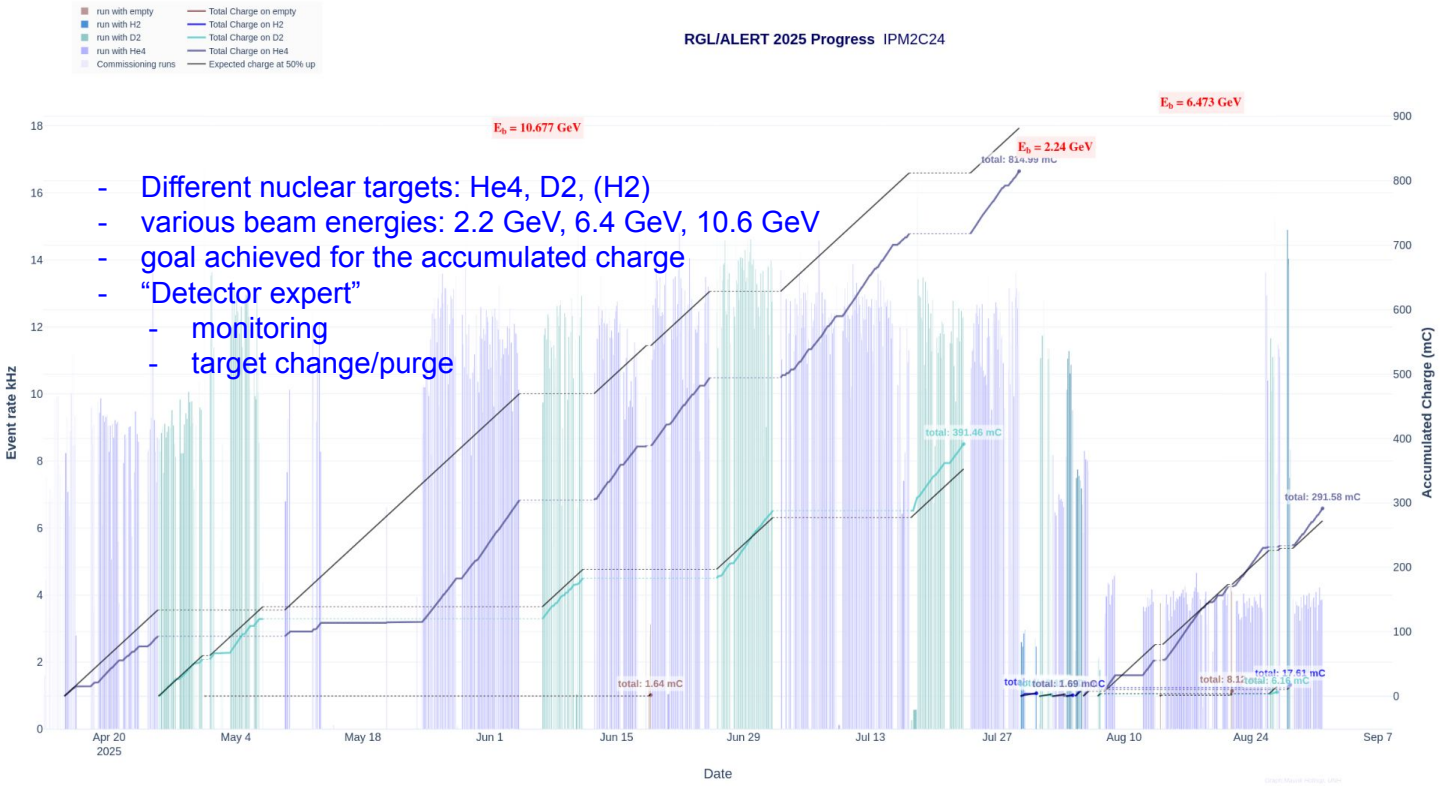
ALERT

- Detection of the recoil nuclei He^4, He^3, H^3, H^2, p



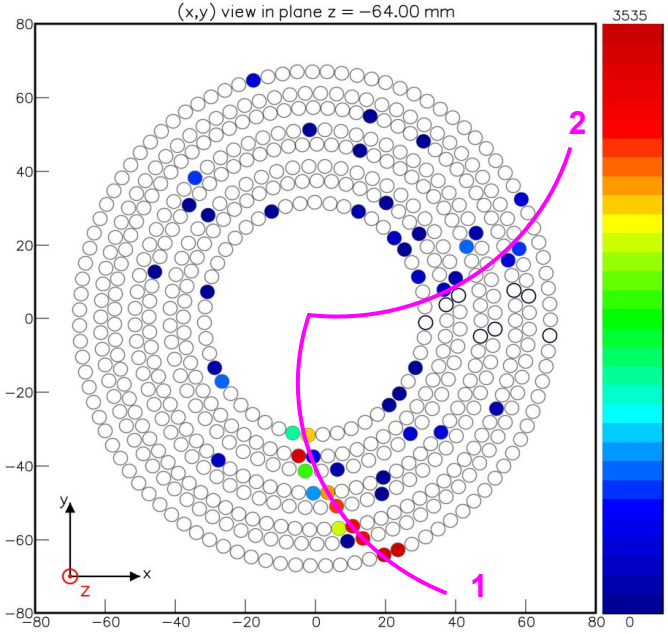
Run period

- Successful data taking from April 2025 to September 2025 (Newport News, Virginia, US)



- Different nuclear targets: He4, D2, (H2)
- various beam energies: 2.2 GeV, 6.4 GeV, 10.6 GeV
- goal achieved for the accumulated charge
- “Detector expert”
  - monitoring
  - target change/purge

♣ Overview



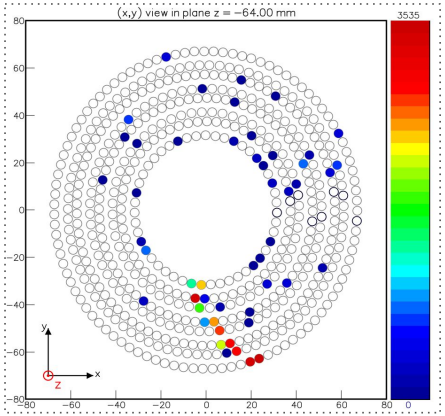
- Only the sense wires of the AHDC are represented
- The color scale shows the deposited energy

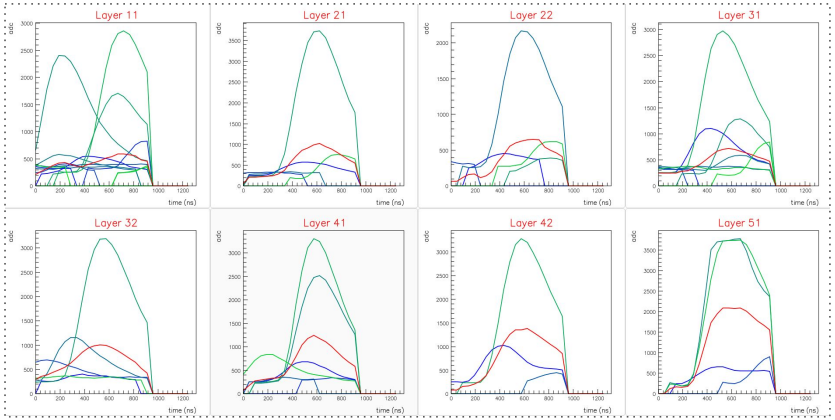
- This is an event in the AHDC at 2 GeV, on D2, 50 nA
- We have two tracks here !
  → 😲 what? how? maybe 1 ok, but 2 is difficult? why 1 is ok?
- Steps to reconstruct these tracks
  1. Clean the noisy hits (hit selection)
  2. Identity the groups of hits belonging to each given track (clusterization)
  3. Make a fit
     i. We need distances with respect to the wires
     ii. But from the wire signals, we can only extract times (AHDC is a Time Projection Chamber)
     iii. We should take into account the difference between the wires, so make corrections (t0 or time calibration)
     iv. We need to convert these times to distances (time2distance calibration)
     v. Do the fit (Helix fit + Kalman Filter)
- We can combine the tracking information (AHDC) with the timing information (ATOF) to get a PID

Reconstruction – Hit selection

- We have a lot of hit in the AHDC (> 20 % occupancy in the first layer)
- Most of them are noise and make the tracking difficult
- However, we identified clear patterns that can be used to get rid of them
  - At first, we extracted various informations from the signals: leadingEdgeTime, timeOverThreshold, amplitude, pedestal
  - Then we applied raw cuts, loaded from a CCDB, based on these informations (occupancy ~ 4 %)
  - However, we had a low ADC cut
    - it resulted to a low detection efficiency of the protons
  - Finally, we introduced a waveform classification (next slide) to prevent this low ADC cut

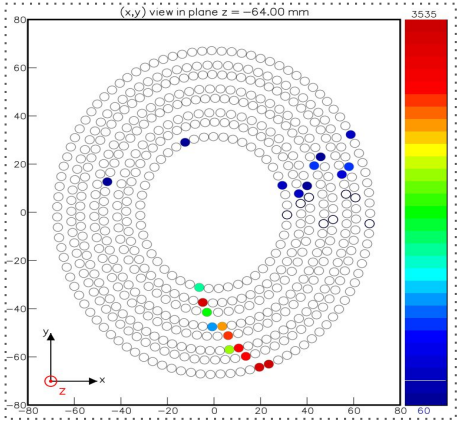
before





after

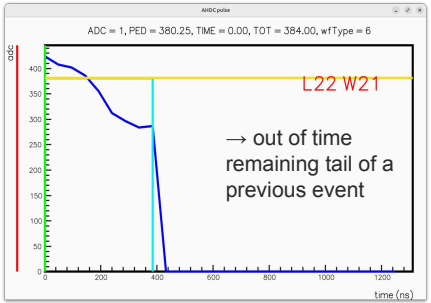
wfType <= 2 & non ADC cuts

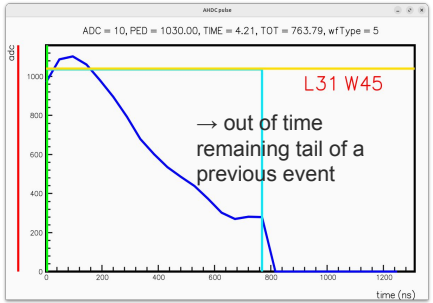


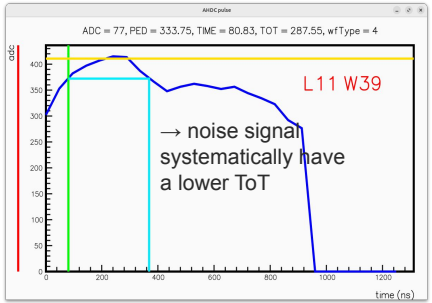
-- run 22712 on D2, current 50 nA --

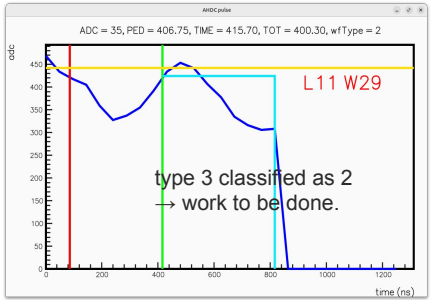
Reconstruction – Waveform classification

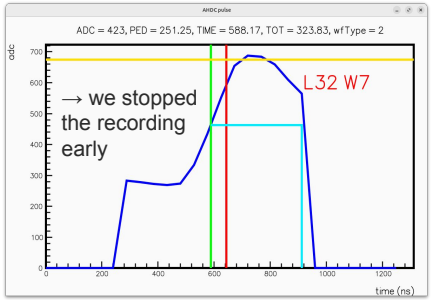
- Description
  - wfType 6 ⇒ too short (nsamples <= 10)
  - wfType 5 ⇒ decreasing baseline
  - wfType 4 ⇒ bad ToT (ToT < 300)
  - wfType 3 ⇒ pileUp (not done yet)
  - wfType 2 ⇒ bad trailingEdgeTime
  - wfType 1 ⇒ saturating
  - wfType 0 ⇒ OK
- We only use wfType <= 2 (and later wfType <= 3) because they have a good time reconstruction.

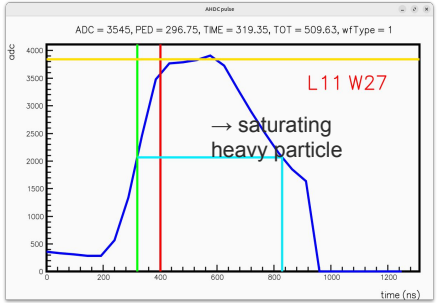


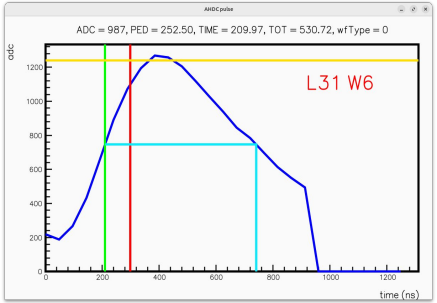












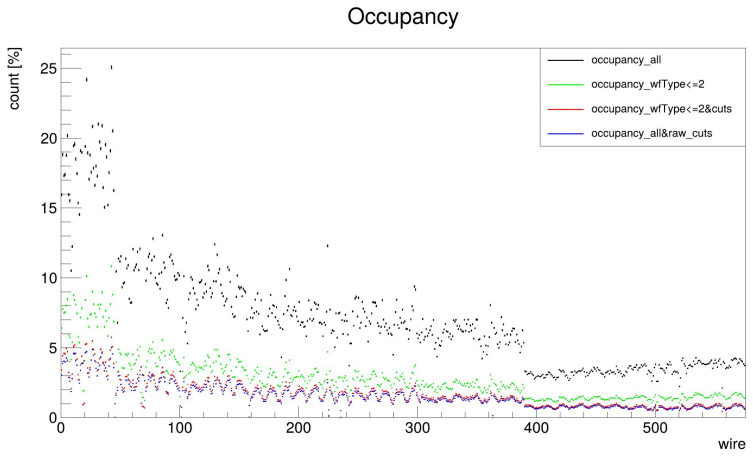
Reconstruction – Hit selection efficiency

- The table below resumes the performance of hit selection efficiency over the coatjava version.
  - Of course, the occupancy statistics depend on the beam current
  - We looked at the number of reconstructed elastic events to estimate the quality of our hit selection
  - We see that the raw cuts were very restrictive
  - The elastic detection efficiency increases almost by a factor 2
  - *This increase also benefits from the time calibration.

	ALL	rawCuts 13.0.1	wfTye <= 1 coat 13.3.0	wfTye <= 2 coat dev	wfTye <= 2 & cuts coat 13.4.0	wfType <= 2 & cuts (strong) coat dev
		time >= 200 time <= 500			time >= 0 time <= 340 *t0 substractred	time >= 0 time <= 340 *t0 substractred
		tot >= 350 tot <= 650			tot >= 300 tot <= 750	tot >= 340 tot <= 620
		ped >= 180 ped <= 360			ped >= 120 ped <= 350	ped >= 120 ped <= 350
					samples > 10	samples > 14
Occupancy on the 1st layer	40 %	6 %	4 %	15 %	8 %	5.5 %
nb elastics nb protons nb deuterons	–	9472 2485 3662	5725 921 3020	-	17882 4394 6757	12650 2343 5502

before (hidden ADC cut) *after

→ run 23003, beam current 200 nA



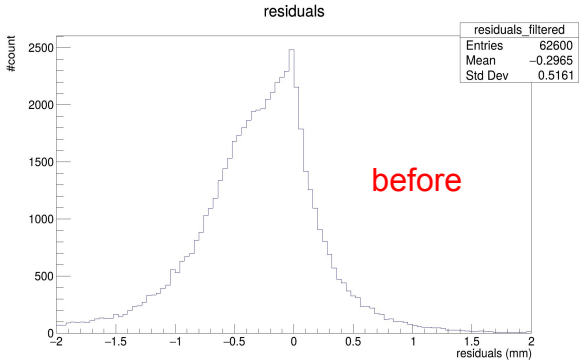
→ run 22712, beam current 50 nA

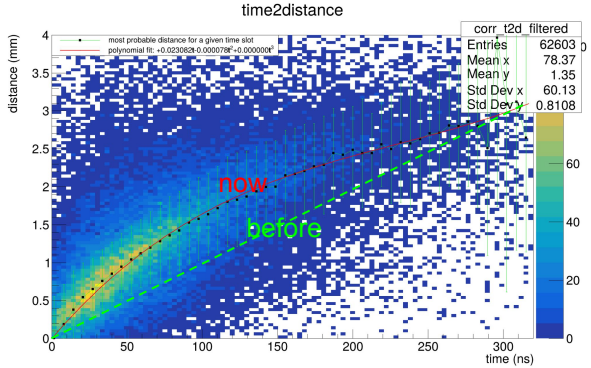
Calibration – time2distance

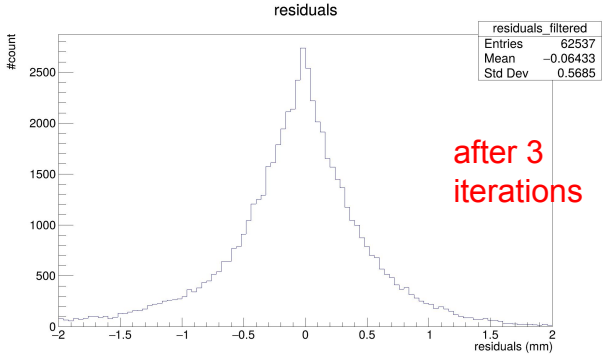
- We didn't have a calibration of the time2distance in real data
- The net result was that the residual distribution was systematically shift to one side
  - The distance in the ***time versus distance*** plot is the distance between the wire and the Kalman Filter track
  - The dashed green line represents the (non calibrated) time2distance used before the tracking
  - The smooth red line shows the real tendency of the time2distance
    - The polynomial coefficients of this fit are stored in a CCDB
    - When we re-run the reconstruction with this estimation of the time2distance, we obtained a better residual distribution

$$\text{residual} = \text{distance}_{\text{from time calibration}} - \text{distance}_{\text{from track fitting}}$$

Elastics data from run 22712 on D2



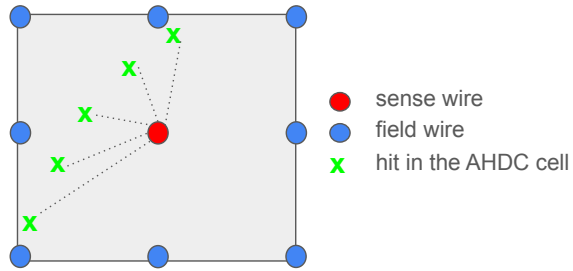


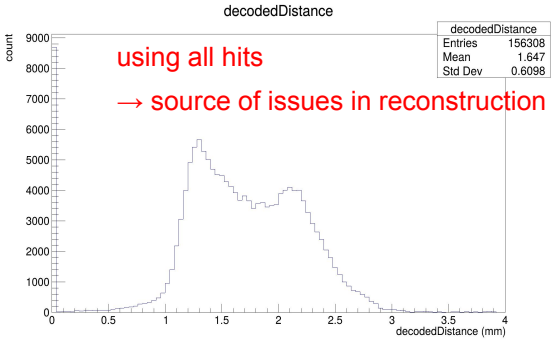


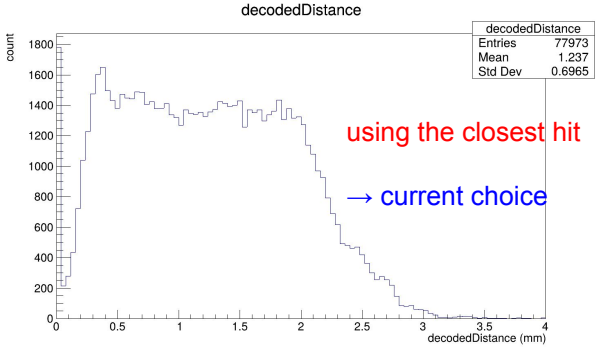
Simulation – Waveform digitization

- The track reconstruction for real data relies on a good calibration of the detector (time, time2distance, ADC calibrations)
- We need simulation to estimate the quality of our reconstruction software
- In order to use the exact same reconstruction code, we have to generate waveforms in simulation
  - In simulation, we have access to the real positions of the particle
  - We can determine the distance with respect to the sense wire
    - use the distances of all hits but weighted by their deposited energy, or
    - use the distance of the closest hit
  - Convert the distance to time (inverse of the time2distance)
  - Spread the deposited energy over the time → we get a waveform
  - We can now run the reconstruction

AHDC detection cell in Geant4

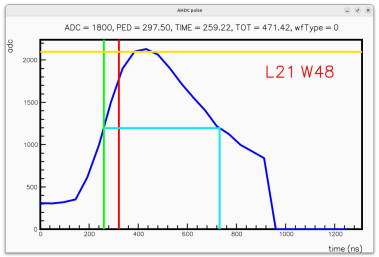


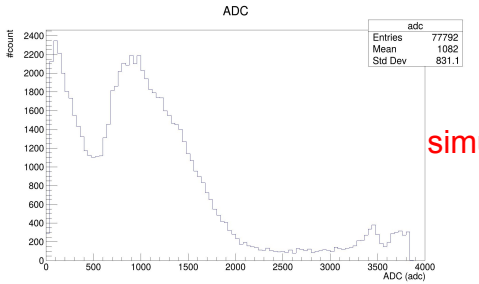




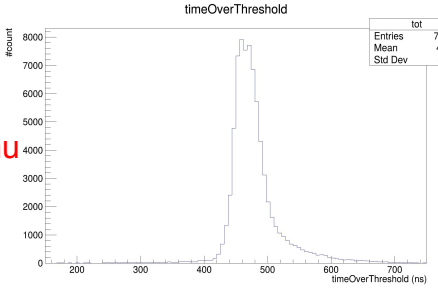
Simulation – Comparison with data

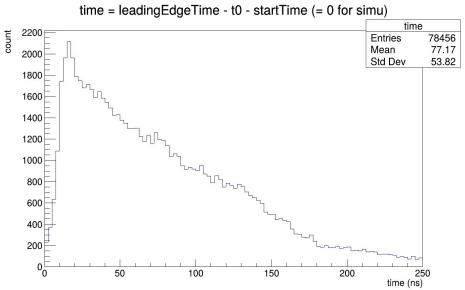
- We've compared deuteron signals from elastics data (run 22712, 2 GeV, D2) with simulation
  - **The distributions look very similar**
  - The ADC distribution presents two big peaks
  - The first one is noise, so bad reconstructed waveforms
  - The second one is characteristic of the detected particle
  - The separation between the two peaks is more clear in simulation
  - We have overestimated the noise in simulation
  - But we have not been able to spread the distributions as in real data (cf. ToT and the time distributions)
  - We should point that an ADC calibration for real data is being done by but it has not been included in this analysis. This calibration could improve the result.

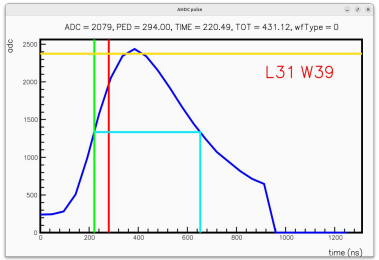


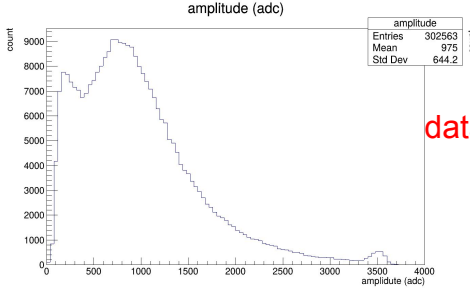


simu









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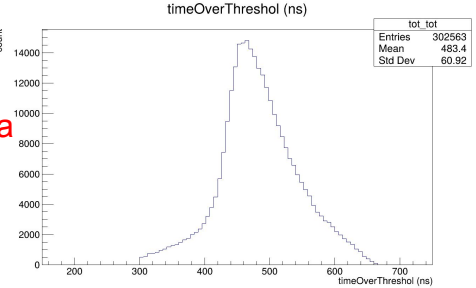
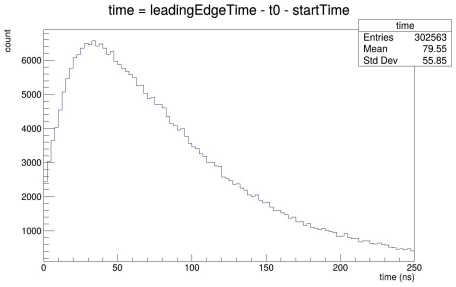
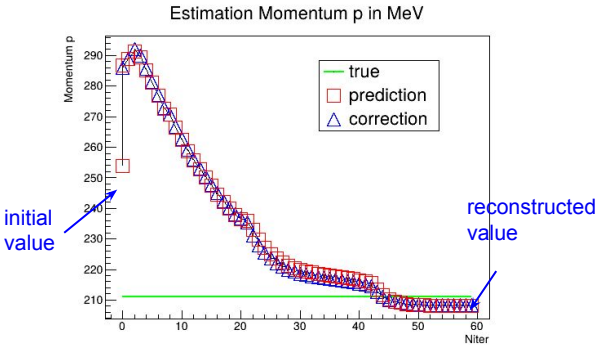


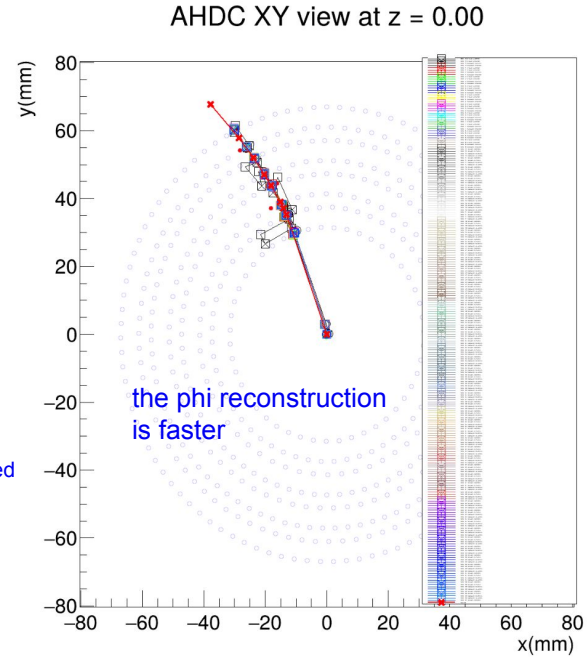


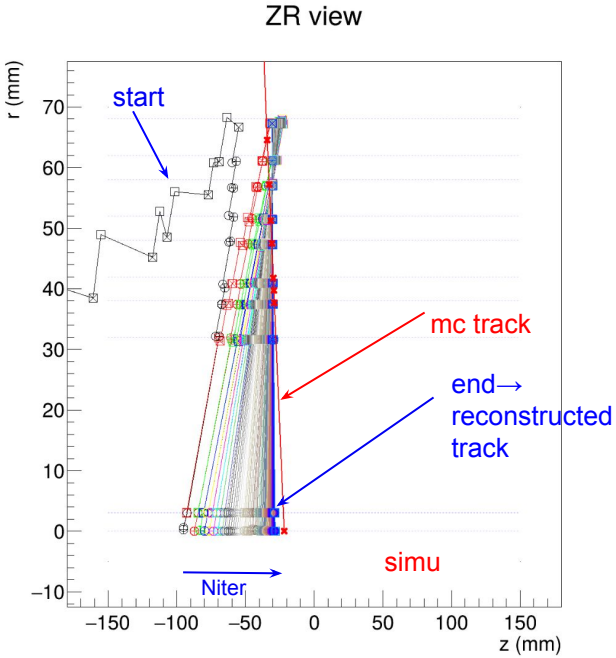
Reconstruction – Kalman Filter

- We use the Kalman Filter for the AHDC track reconstruction
- A lot of works remain to be done on the Kalman Filter but we can already see interesting things
- (Work in progress)

○ Here is the evolution the fit over the number of iterations (Niter)
○ This is simulation
○ The goal is to converge faster to the right values







Conclusion

- The ALERT experiment promises interesting results in nuclear physics
- It requires world-wide effort (CLAS collaboration)
- The data taking from April to September 2025 was a success
- Efforts are now mainly focused on the development of the reconstruction software and the calibration of the data
- On my side
  - I ensured the monitoring of the data during the run period
  - I have already performed a lot of work on the ALERT software, but it is far to be over
  - After the cooking of the data, I plan to study the DVCS on He-4

Quotation of the day

Life is a short and unique adventure.
Let's "be good, then"! (bigoudène)