PRÉPARATION DE L'EXPÉRIENCE ALERT À JLAB

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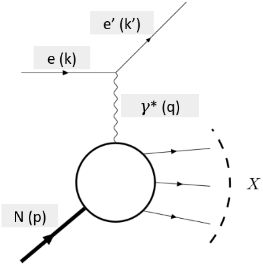
Outline

Deep inelastic scattering (DIS)

Physics motivation

- DIS of electrons to reveal nucleon structure



2 conditions :
– Virtuality
$Q^2 = -q^2 > M_N^2 \approx 1 GeV^2$
– Invariant mass
$W_X^2 = (p+q)^2 >> M_N^2$

- Cross section depends on two structure functions : $\mathcal{F}_{1,2}(x, Q^2)$:

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2 \cos^2\left(\frac{\theta}{2}\right)}{4E^2 \sin^4\left(\frac{\theta}{2}\right)} \left(\frac{\mathcal{F}_2(x, Q^2)}{\nu} + 2\frac{\mathcal{F}_1(x, Q^2)}{M_N} \tan^2\left(\frac{\theta}{2}\right) \right) \quad (1)$$

Parton distribution functions (PDFs)

Physics motivation

- $\mathcal{F}_{1,2}(x, Q^2)$ can expressed of PDFs

$$\mathcal{F}_1(x, Q^2) = \frac{1}{2} \sum_q e_q^2 f_q(x, Q^2) \tag{2}$$

$$\mathcal{F}_2(x, Q^2) = x \sum_q e_q^2 f_q(x, Q^2) \tag{3}$$

PDFs

They are mathematical functions of quark flavour q, momentum fraction x and Q^2 : $f_q(x, Q^2)$. They represent the probability of finding a quark of flavour q carrying a longitudinal momentum fraction x.

Parton distribution functions (PDFs)

Physics motivation

- Distribution of quarks inside a **proton**
- MMHT14 NNLO **fit** from world data

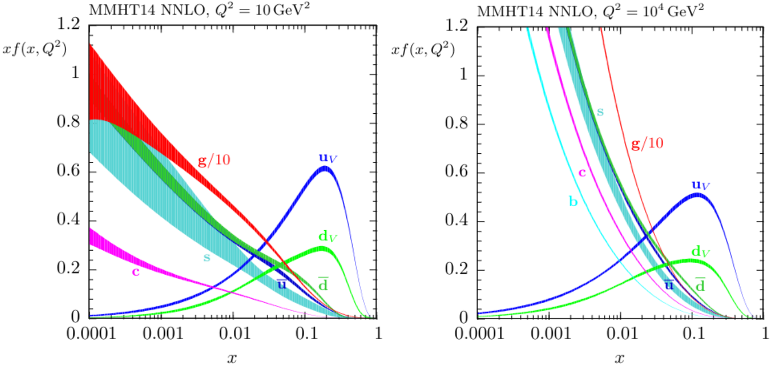


Figure 1: Distribution of quark inside protons. MMHT2014 NNLO PDFs at $Q^2 = 10$ GeV^2 and $Q^2 = 10^4$ GeV^2, with associated 68 % confidence-level uncertainty band. Source [1].

Generalised parton distributions (GPDs)

- Another set of structure functions
- Non pertubative theory : ~~pQCD~~

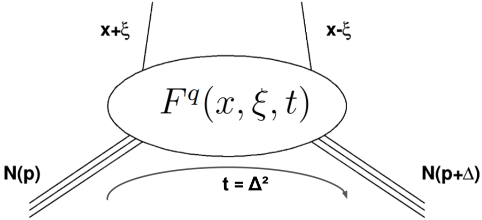


Figure 2: General representation of the GPDs of a nucleon represented by the triple line and noted N. Single lines can represent quarks or anti-quarks probed in the nucleon shown by the triple lines.

Generalised parton distributions (GPDs)

Physics motivation

- Encode the correlation between the charge distribution of quarks in the transverse plane and the longitudinal distribution of their momenta.
- 3D structure of nucleons

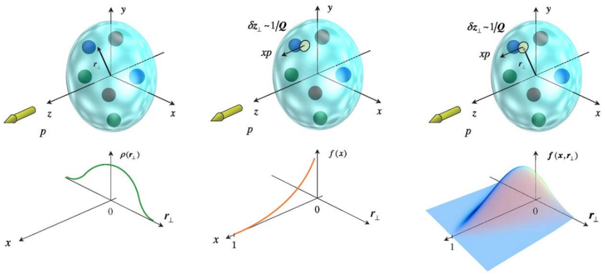


Figure 3: Illustration of form factors (left), parton distribution functions (center) as an hyperplane of generalized parton distributions (right). Source [2, p. 91]

EMC effect (open question)

Physics motivation

- Nucleon binding energy inside a nucleus (MeV) vs nucleon mass (GeV)
- Expectation : Parton distributions of bound nucleons inside a nucleus should be identical to the parton distributions of a collection of the same number of free nucleons.

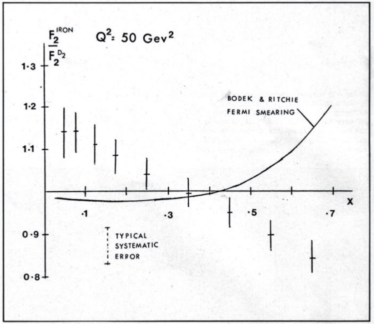
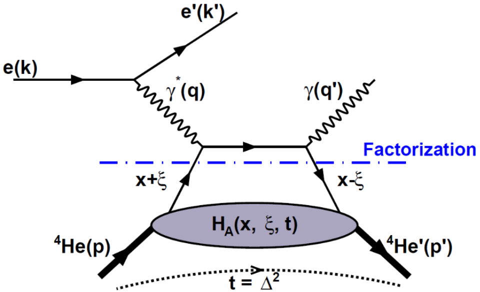


Figure 4: Ratio of the $\mathcal{F}_2^{IRON}(x, Q^2)$ structure function of iron over the $\mathcal{F}_2^{D_2}(x, Q^2)$ of deuterium, measured by the European Muon Collaboration (EMC). 1983. Source [3].

Deeply Virtual Compton Scattering (DVCS)

Proposed measurement

- Exclusive process to access GPDs
- Limit final state interactions (FSIs)
- Number of chiral-even GPDs of spin-s target : $(2s+1)^2$
- ^{4}He is a spin-0 nuclear target : only one GPD $H_A(x, \xi, t)$
- Measure beam spin asymmetry (BSA)



Tagged EMC

Proposed measurement

- Spectator mechanism or plane wave impulse approximation (PWIA)
- Measure cross section ratios as functions of kinematic variables of $A-1$ to challenge current theoretical models.

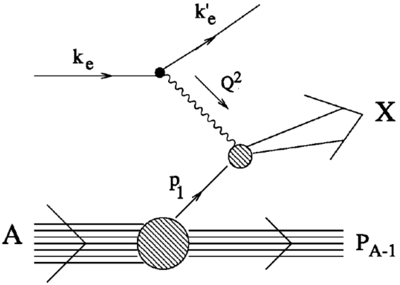
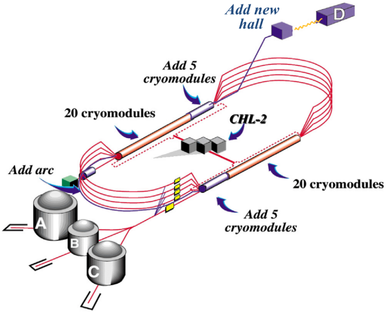


Figure 5: The process $A(e, e'(A-1))X$ within the impulse approximation.

CEBAF at Jefferson Lab

Experimental setup

- Continuous Electron Beam Accelerator Facility (CEBAF)



CLAS12

Experimental setup

- CEBAF Large Acceptance Spectrometer for operation at 12 GeV (CLAS12) in Hall-B

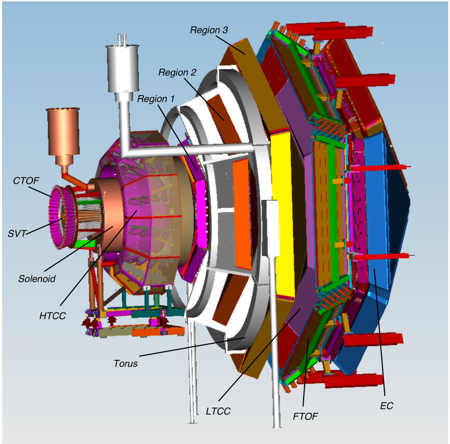
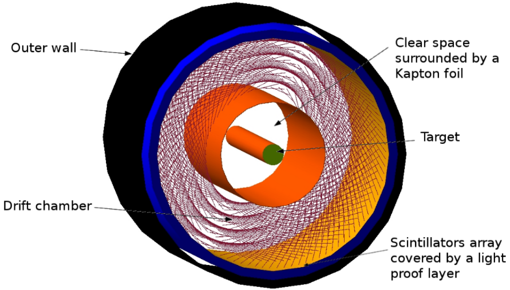


Figure 6: The CLAS12 spectrometer in Hall-B. The central detectors are contained in the solenoid magnet. The other detectors constituted the forward part of CLAS12. Source [4].

ALERT

Experimental setup

- Drift chamber (AHDC) + time-of-flight system (ATOF)
- Replaces SVT + BMT inside the solenoid magnet of CLAS12
- 3D view of the layout of the ALERT detector



ALERT

Experimental setup

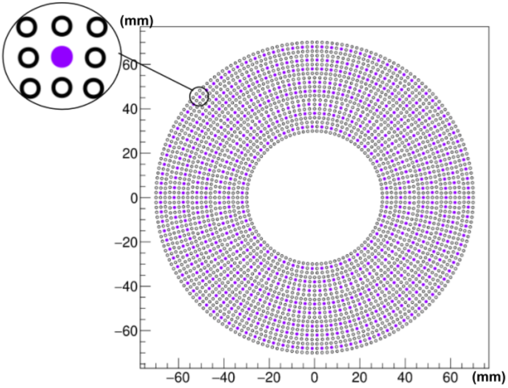
- Specific requirements for the particles to be detected by ALERT

Measurement	Particles detected	p range	θ range
Nuclear GPDs	^{4}He	$230 < p < 400$ MeV	$\pi/4 < \theta < \pi/2$ rad
Tagged EMC	p, ^{3}H, ^{3}He	As low as possible	As close to π as possible
Tagged DVCS	p, ^{3}H, ^{3}He	As low as possible	As close to π as possible

AHDC

Experimental setup

- Gaseous detector : He (80 %) + CO_2 (20 %)
- Tracking : 3026 wires distributed over 21 circular layers
- cell detection : 1 sense wire ● + 6 field wires ○
- Drift of electrons : potential difference between sense wires (+) and field wires (−)



AHDC

Experimental setup

- Wires orientation : either $-10°$ or $+10°$
- Determines z coordinate
- Gathered in 5 super-layers of 3 or 5 layers $(2 \times 3 + 3 \times 5)$

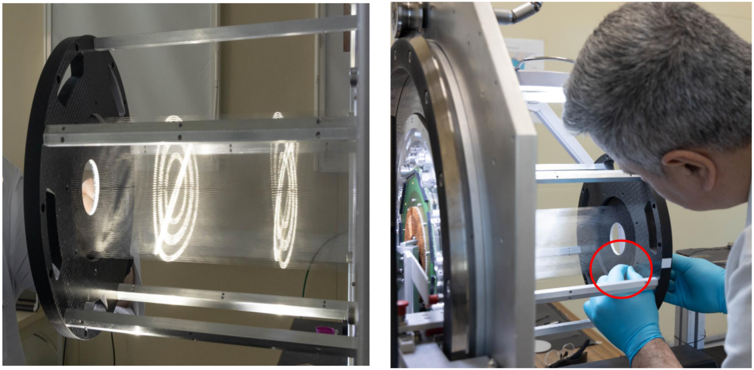


Figure 7: Picture of the drift chamber of ALERT taken on the premises of IJCLab.

ATOF

Experimental setup

- 2 layers of scintillators read by silicon photomultipliers (SiPM).
- t.o.f + track $\rightarrow$ particle identification

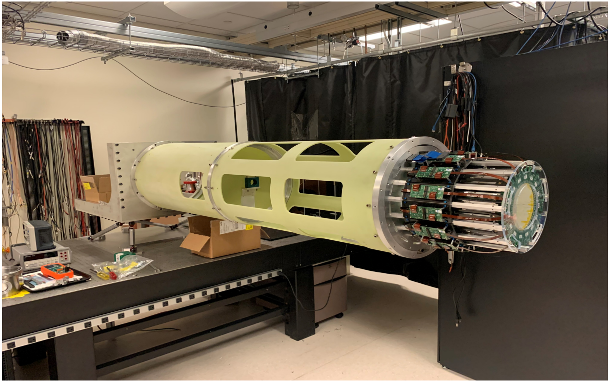


Figure 8: Picture of the time-of-flight system of ALERT taken on the premises of ANL. The ATOF is fixed at a cart tube.

ALERT simulation

- Presentation

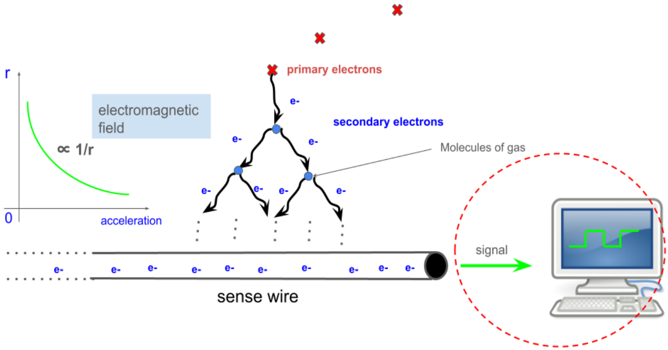


Figure 9: Mechanism that leads to the signal measured by the drift chamber of ALERT.

ALERT simulation

- Signal measured during the AHDC development
- Goal : reproduce this signal

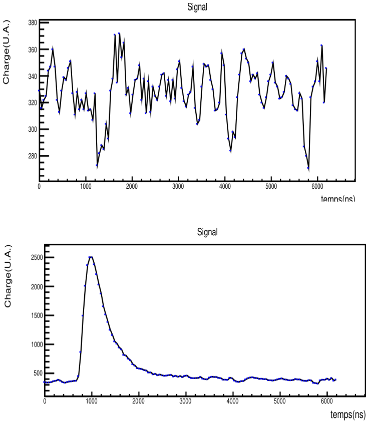


Figure 10: Signal measured on beam at ALTO by four sense wires during the passage of an α particle of 344 MeV/c.

Geant4 Monte-Carlo (GEMC)

ALERT simulation

- C++ framework
- User-friendly

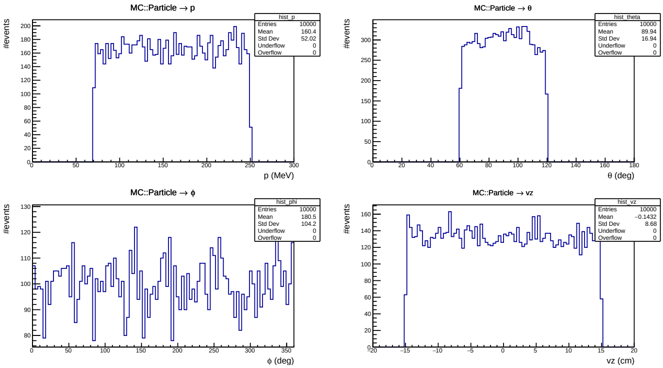


Figure 11: Momentum distribution of initial protons generated over ten thousands events in GEMC.

Event in GEMC

ALERT simulation

- Track composed of "steps"
- A step $\approx$ one of the multiples points calculated by Geant4
- Contains "delta" informations (e.g $\Delta E_{deposited}$), spatial coordinates, momentum, volume identifiers

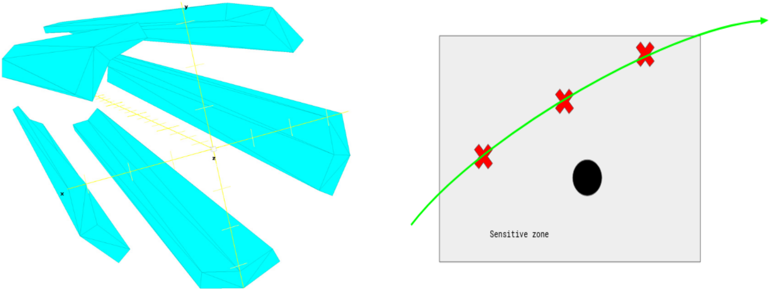


Figure 12: (Left) AHDC-like cells with exagerated concavity for easier visualisation. (Right) A set of steps (❌) calculated in the same detection cell. The green line represents the trajectory of a particle.

Event in GEMC

ALERT simulation

- `MHit` = set of steps with the same volume identifiers
- `MHit` content

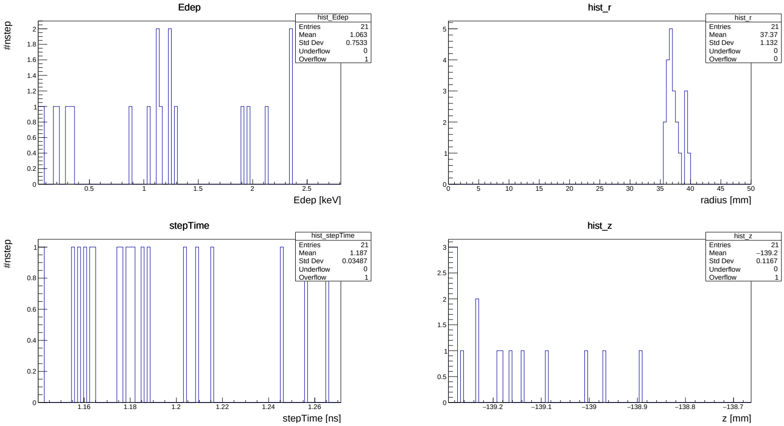
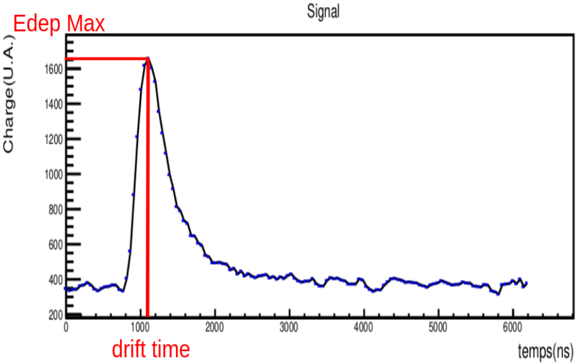


Figure 13: Distribution of energy deposited, `geant4` time, r position and z position of a particular MHit.

ALERT signal (reminder)

ALERT simulation

- Charge distribution vs time
- Electronics : charge distribution $\propto$ deposited energy
- We have $E_{deposited}$
- time ? Not yet ! (electronic resolution = 44 ns)



Drift time calculation

ALERT simulation

- Simulation of the drift of electrons
- Approximation : $D + \delta D \equiv t$
- Well : we have access to positions in simulation

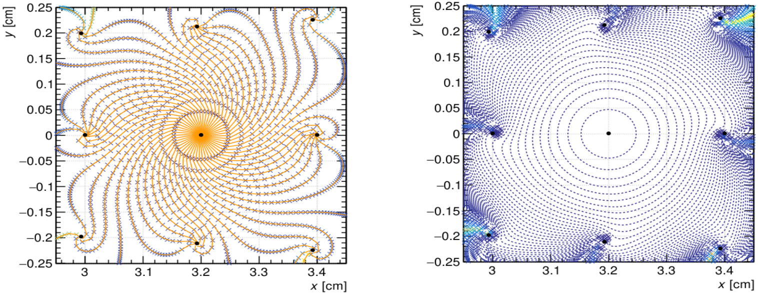
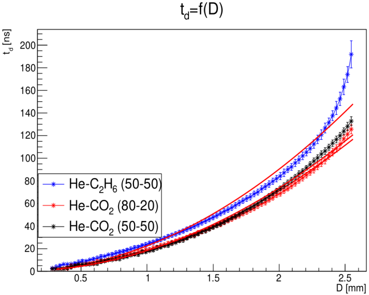


Figure 14: (Left) Drift trajectory of electrons in ALERT for a potential difference of 1.5 kV between the wires in a 5 T magnetic field. The sense wire is at the center and is surrounded by six field wires. (Right) The corresponding isochronous map. Two electrons generated on the same isochronous (closed curve) will reach the sense wire at the same time. Source [5, p. 64].

Drift time calculation

ALERT simulation

- Drift time vs distance



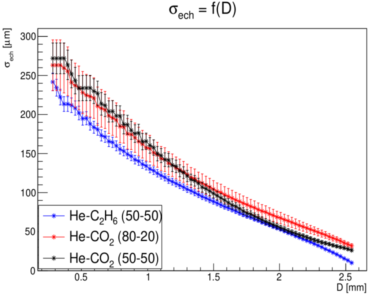
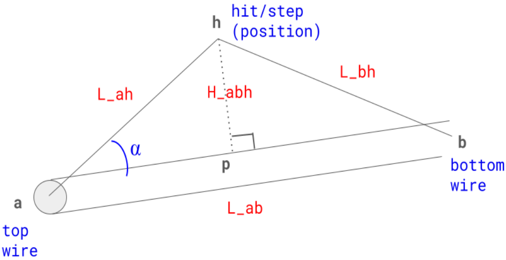


Figure 15: (Left) Drift time of primary electrons as a function their initial distance to the wire for various gaseous mixtures. The potential difference is still 1.5 kV, the drift chamber being in a 5 T magnetic field. (Right) Estimation of the spatial resolution of the detector as a function of the distance of the step. Source [5].

Drift time calculation

ALERT simulation

- Distance of closest approach (doca)



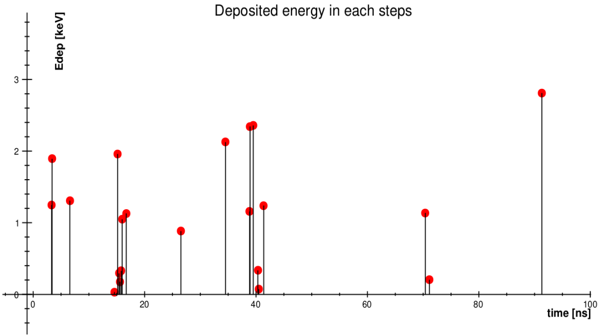
$$H_{abh} = AH\sin(\alpha) = AH\sqrt{1-\cos^2(\alpha)} \tag{4}$$

$$\cos(\alpha) = \left(L_{ah}^2 + L_{ab}^2 - L_{bh}^2\right) / \left(2 \cdot L_{ah} \cdot L_{ab}\right) \tag{5}$$

Drift time calculation

ALERT simulation

- Deposited energy in each steps as a function of time
- Look at the time windows
- Punctual distribution, not physical



Signal generation

ALERT simulation

- Punctual signal can be expressed as

$$\mathcal{S}_{punctual}(t) = \sum_s E_s \cdot \delta(t - t_s) \tag{6}$$

- Particularity

$$\int_{-\infty}^{+\infty} E_s \delta(t - t_s) = E_s \tag{7}$$

- Replace each $\delta(t)$ by a Landau distribution $\mathcal{L}(t, \sigma, \mu)$

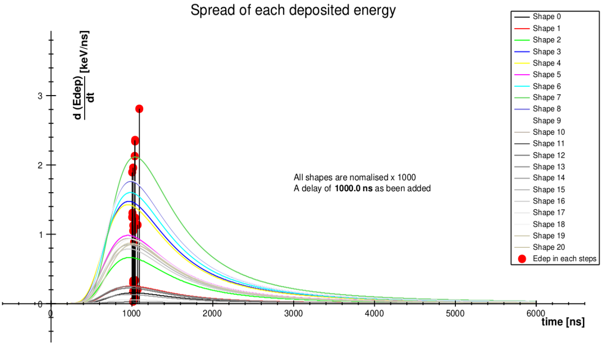
$$\mathcal{S}(t) = \sum_s E_s \cdot \mathcal{L}(t - t_0, \sigma, t_s) \tag{8}$$

where t_0 is a delay

Signal generation

ALERT simulation

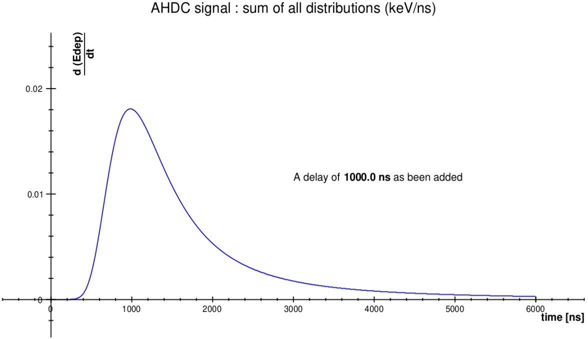
- Before summing all contributions



Signal generation

ALERT simulation

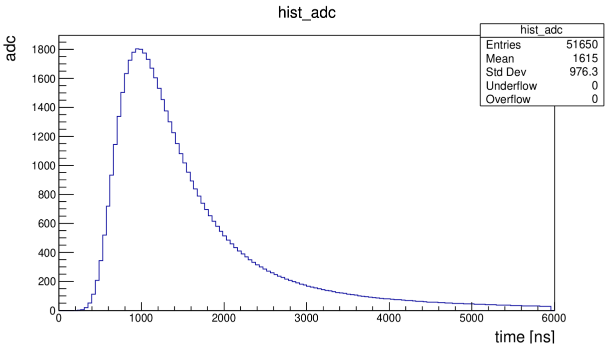
- After summing all contributions



Signal generation

ALERT simulation

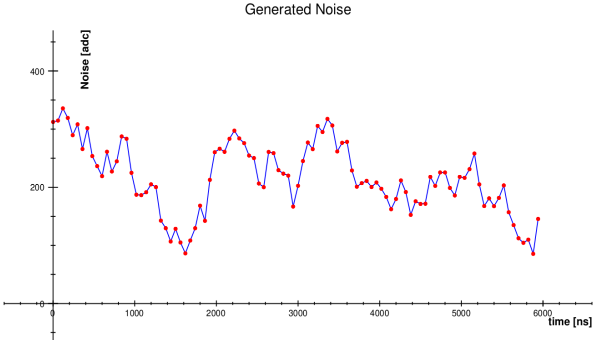
- Conversion keV/ns to ADC + sampling (44 ns)



Signal generation

ALERT simulation

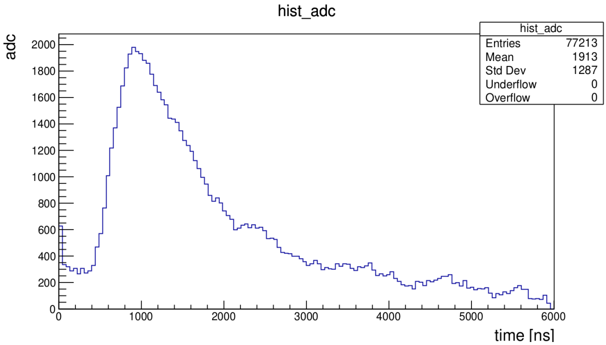
- Noise generation
- Current algorithm
  - X_0 is a draw of $\mathcal{N}(x_0, \delta x)$
  - for $i > 0$, X_i is a draw of $\mathcal{N}(X_{i-1}, \delta x)$



Signal generation

ALERT simulation

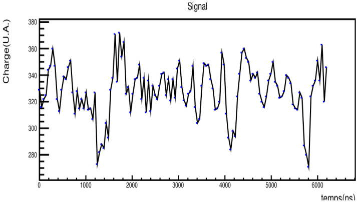
- Final result

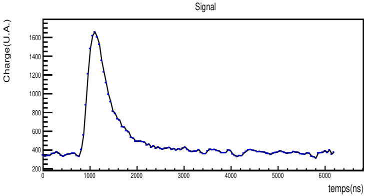


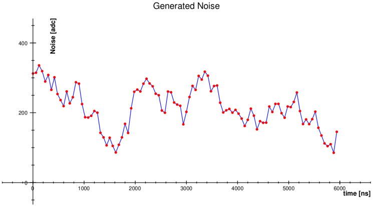
Signal generation

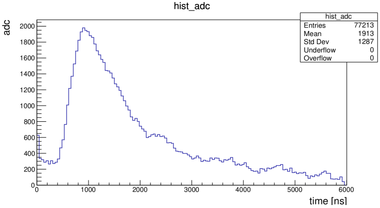
ALERT simulation

- Comparaison





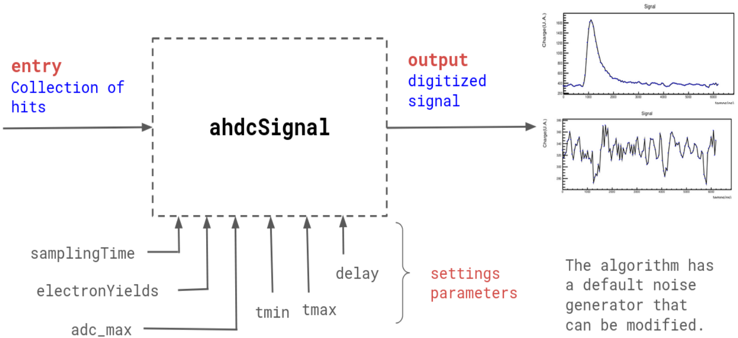




Signal generation

ALERT simulation

- Framework



Conclusion

- Conclusion
  - Bibliography
  - Simulation
- Outlook
  - Decoding
  - Reconstruction

References I

[1] L. A. Harland-Lang et al. "Parton distributions in the LHC era: MMHT 2014 PDFs". In: *arXiv* (2014). URL: https://arxiv.org/abs/1412.3989.

[2] A.V. Belitsky and A.V. Radyushkin. "Unraveling hadron structure with generalized parton distributions". In: *arXiv* (2005). URL: https://arxiv.org/abs/hep-ph/0504030.

[3] Douglas Higinbotham et al. "The EMC effect still puzzles after 30 years". In: *CERN Courier* (2013). URL: https://cerncourier.com/a/the-emc-effect-still-puzzles-after-30-years/.

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[5] Lucien CAUSSE. "Mise au point d'une chambre à dérive stéréo pour l'expérience ALERT au laboratoire Jefferson". PhD thesis. Particules, Hadrons, Energie et Noyau : Instrumentation, Imagerie, Cosmos et Simulation (PHENIICS), 2021. URL: https://theses.hal.science/tel-03613763v1.