Tagged neutron DVCS mesurement at JLab

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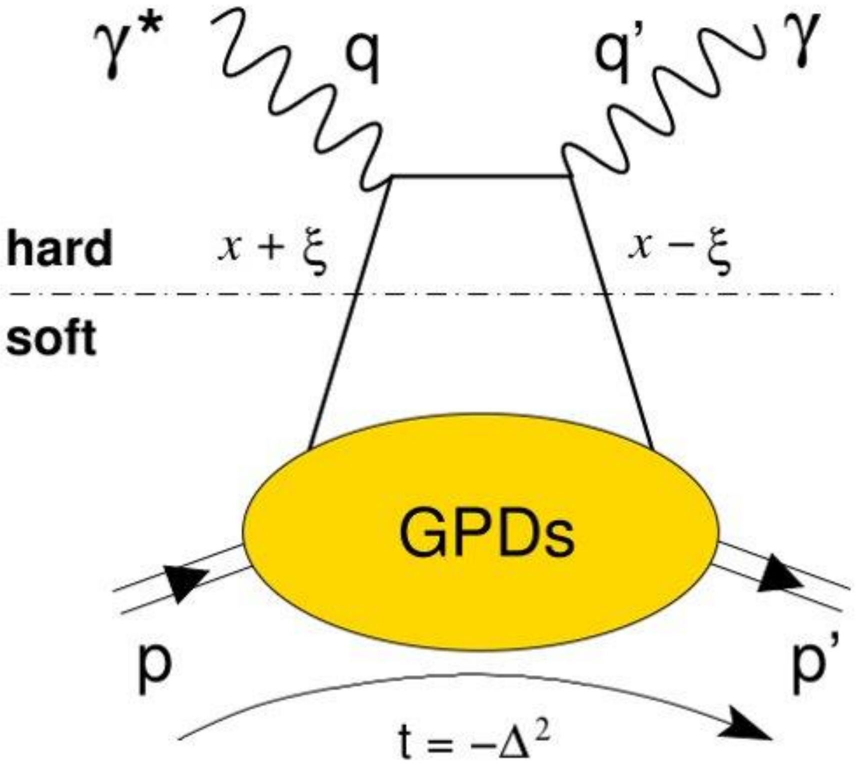
19/07/2023

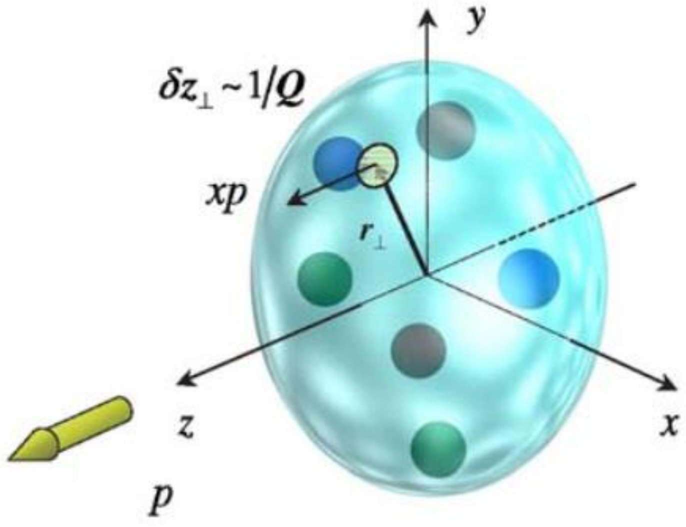
Short-Distance nuclear structure and PDFs ECT* workshop

Generalized partons distributions

- Generalized Parton Distributions (GPDs) :
  - *Non-perturbative functions.*
  - *Correlation of transverse position and longitudinal momentum of partons in the nucleon.*
  - *GPDs can be accessed through exclusive leptoproduction reactions*
  - *Impact parameter space, can interpreted as a distribution in the transverse plane of partons carrying a given longitudinal momentum.*
  - *4 GPDs for spin ½ particle →* $H, \widetilde{H}, E, \widetilde{E}$



Factorisation for $|t|/Q^2 \ll 1$



- *Link to FFs by integrating over x. Link to PDFs by the limit* $\xi \to 0$ *and* $t \to 0$.
- *Link to the Ji sum rule (Here GPDs H and E are essential).*
- *Nucleon internal structure: DVCS gives access to 4 complex GPDs-related quantities: Compton Form Factors CFF*
- *One measured observable: a specific combination of CFFs.*

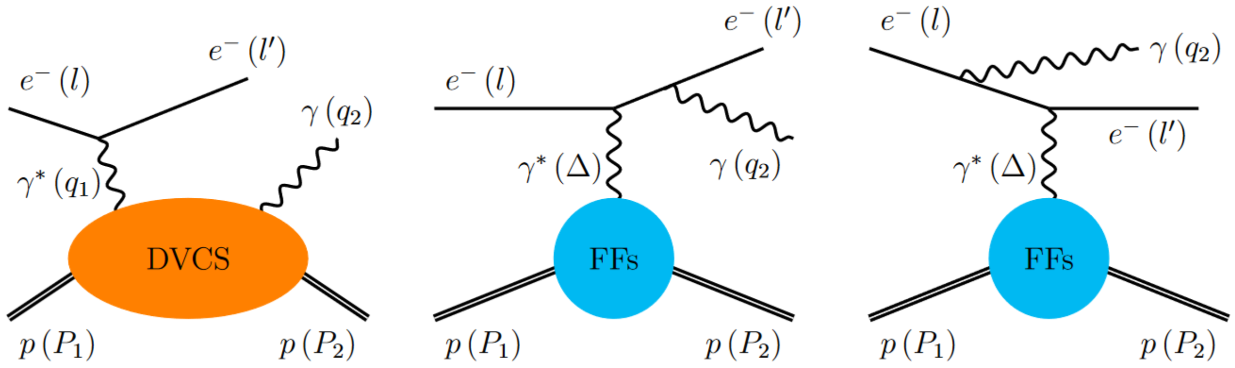
Accessing GPDs through neutron DVCS

Observable → beam spin asymmetry (BSA). The measurements on a neutron target will provide an important contribution to the extraction of the GPD :

$$A_{LU}^{\sin\phi} \propto \Im m \left[F_1 \mathcal{H} + \xi(F_1 + F_2)\tilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E} \right],$$

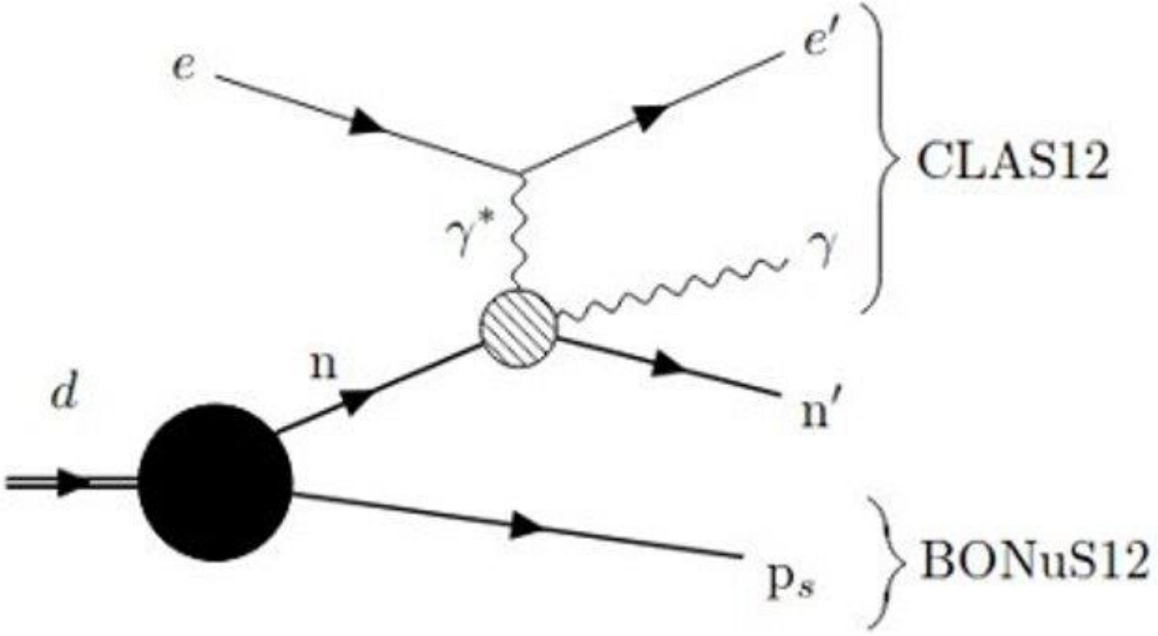
F1 small → 0

u, d cancel → 0



- Three types of measurement:
    - *Only the neutron, only the spectator proton, or both of them.*

- Missing high energy neutron → more uncertainty in exclusivity cuts.
- Why the neutron?
    - *Flavor separation, baseline for studies of nuclear modifications, determination of Ji sum rule.*

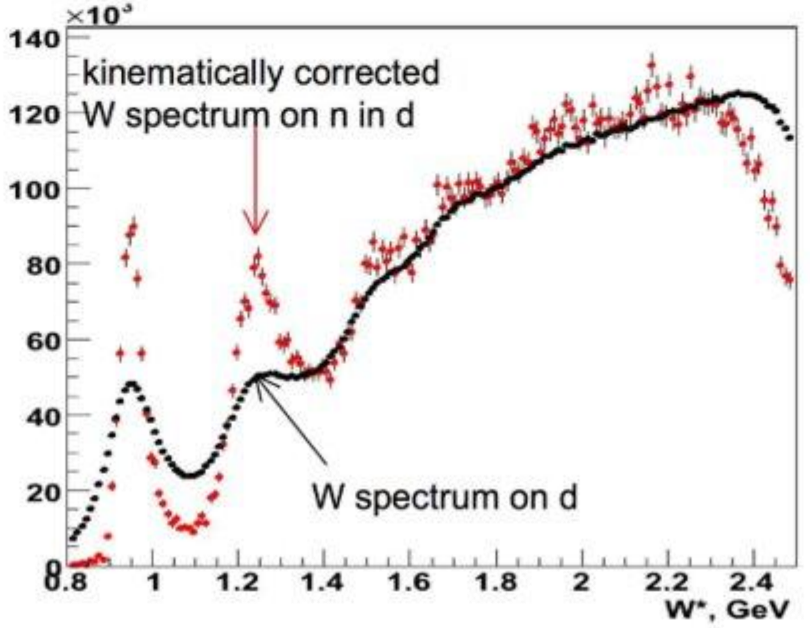


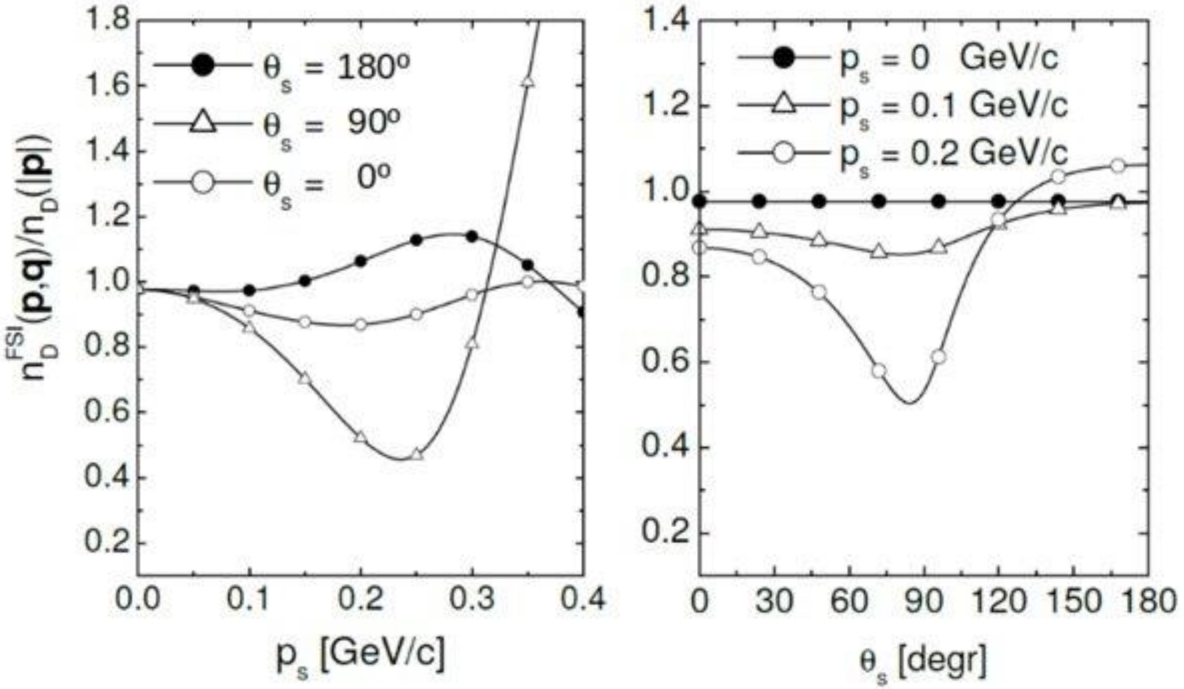
Tagged measurement

- "Tag" means we measure the non-interacting part (the spectator).

- Detection of the spectator proton :
  - *Detect low energy proton (0.05 to 0.2 GeV/c).*
  - *Initial neutron momentum can be inferred from the kinematic of the spectator proton.*

- Tagged measurements → Select nuclear configuration via spectator kinematics, allowing for differential study.
  - *Spectator kinematics allow to select different regions of interest for study.*
  - *On-shell extrapolation enables access to free nucleon structure.*
  - *At low recoil momentum and backward spectator angle, the FSIs are negligible.*
  - *Helping in the understanding of the nuclear effects.*





The BONuS12 experiment

- **Experimental configuration :**
  - *Baseline CLAS12 configuration. Forward ECAL, DC and TCC.*
  - *Where the central detector is replaced by a RTPC → BONuS12*
  - *Highly polarized electron beam.*
  - *Use here to detect electron and photon.*

- **Central Detector: BONuS12:**
  - *The Radial Time Projection Chamber.*
  - *Build to detect low proton and helium (between 0.05 to 0.2 GeV/c).*
  - *In our case, the spectator proton.*

- **BONuS12 experiment :**
  - *Data taken in summer of 2020.*
  - *3 beam energies : 10.4/10.3/10.2 GeV.*
  - *Beam polarization: 85%.*
  - *4 targets: Hydrogen, deuterium, Helium 4, and empty.*

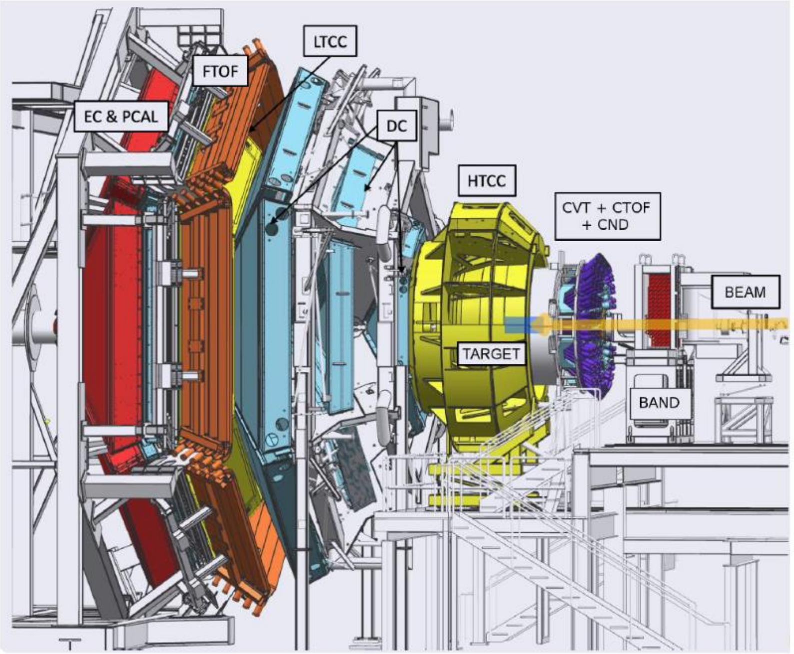
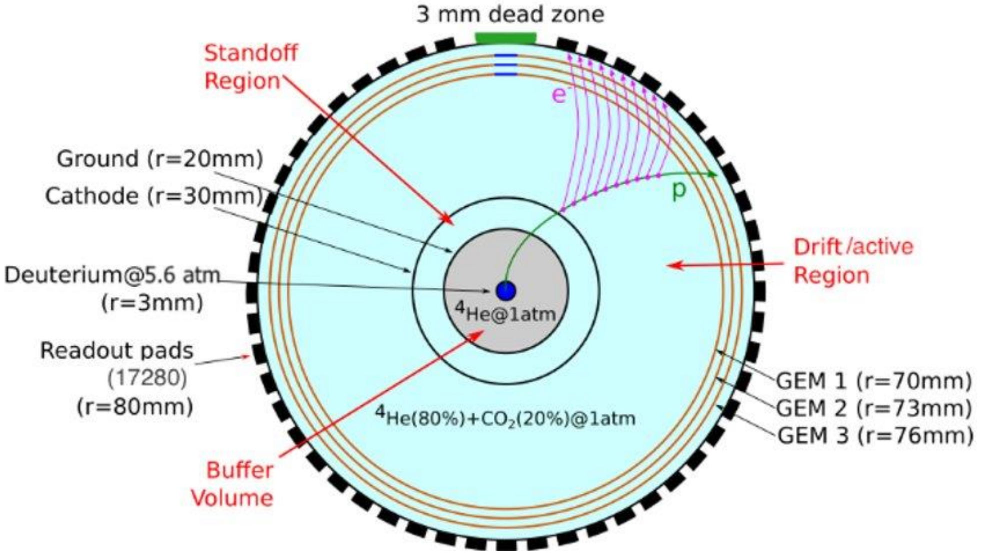


Figure in V. Burkert et al., Nucl.Instrum.Meth.A 959 (2020) 163419



Analysis : neutron DVCS with tagged proton

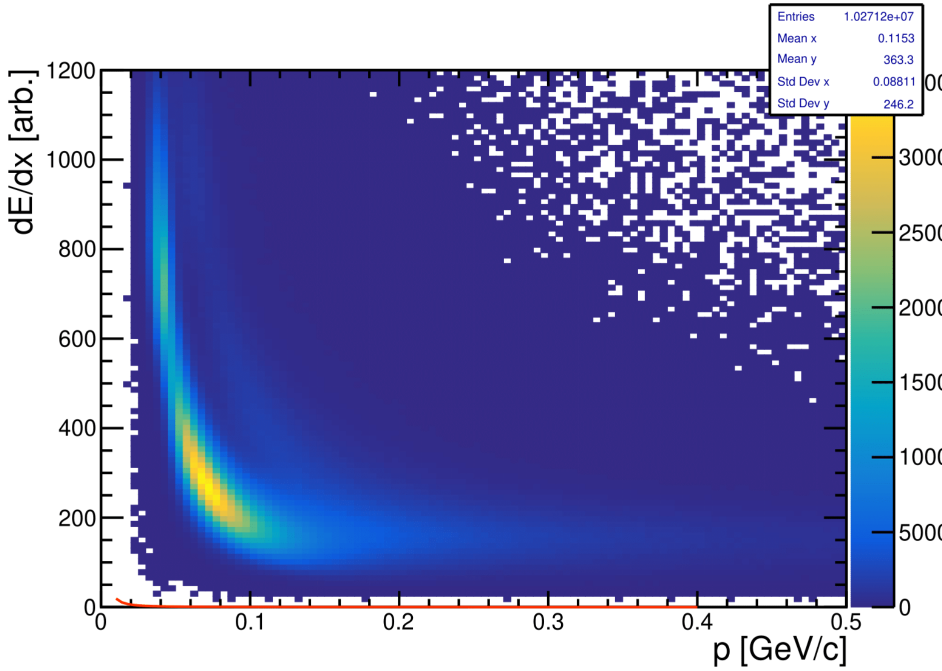
- **Goal : Tagged neutron DVCS on the valance region:**

$$e + d \rightarrow e' + \gamma + p_s + (n)$$

- Few things about the neutron DVCS analysis :
  - *A 10.4/10.3/10.2 GeV electron beam*
  - *With an average polarization of 83%*
  - *Scattering off an unpolarized gaseous deuterium target.*

- The exclusivity of the event is insured by:
  - *Electron detection, which is the trigger.*
  - *Photon detection, the most energetic is taken.*
  - *Neutron detection: Not detected.*
  - *Proton spectator detection: BONuS12 RTPC.*

- Spectator proton identification:
  - *Should be a low momentum proton (0.05 to 0.15 GeV/c).*
  - *Use dE/dx for identification*
  - *Use a multidimensional cut to remove the accidentals (on time and space).*



Without detecting the struck nucleon, t (transfert momentum) should be computed with the virtual and the real photon. Which is worse than the nucleon one due to energy reconstruction.

Analysis : neutron DVCS with tagged proton

- We compute the initial momentum of the neutron:

$$p_n = \left(-p_x^s, -p_y^s, -p_z^s, M_d - E_s\right)$$

- So we can compute the standard kinematics variables based on the momentum of the neutron (variable with a star DIS-like), or we can compute them based on a neutron at rest (for comparison with other DVCS analyses).

$$p_n = \left(-p_x^s, -p_y^s, -p_z^s, M_d - E_s\right)$$

$$y^\star = \frac{p_n \cdot q_{\gamma^*}}{p_n \cdot k_1}$$

$$W^{2\star} = \left(p_n + q_{\gamma^\star}\right)^2$$

$$t^\star = (p_n - p_n')^2$$

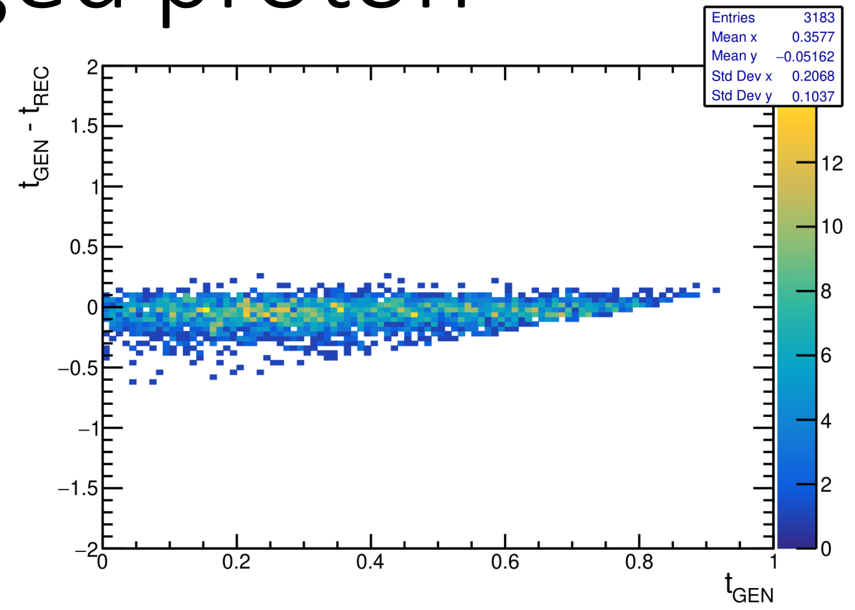
$$p_n = (0,0,0, M_n)$$

$$y = \frac{p_n \cdot q_{\gamma^*}}{p_n \cdot k_1}$$

$$W = \left(p_n + q_{\gamma^\star}\right)^2$$

$$t = (p_n - p_n')^2$$

Analysis : neutron DVCS with tagged proton

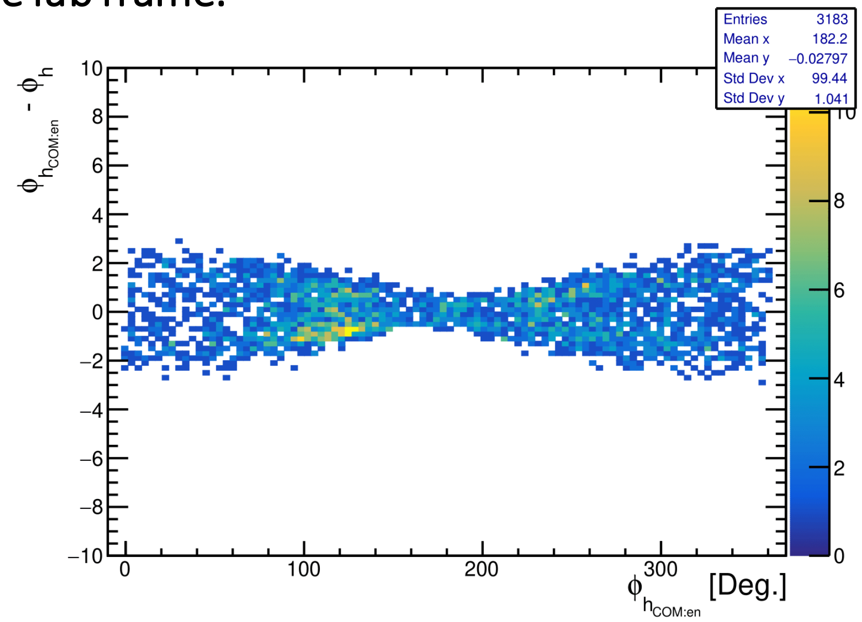


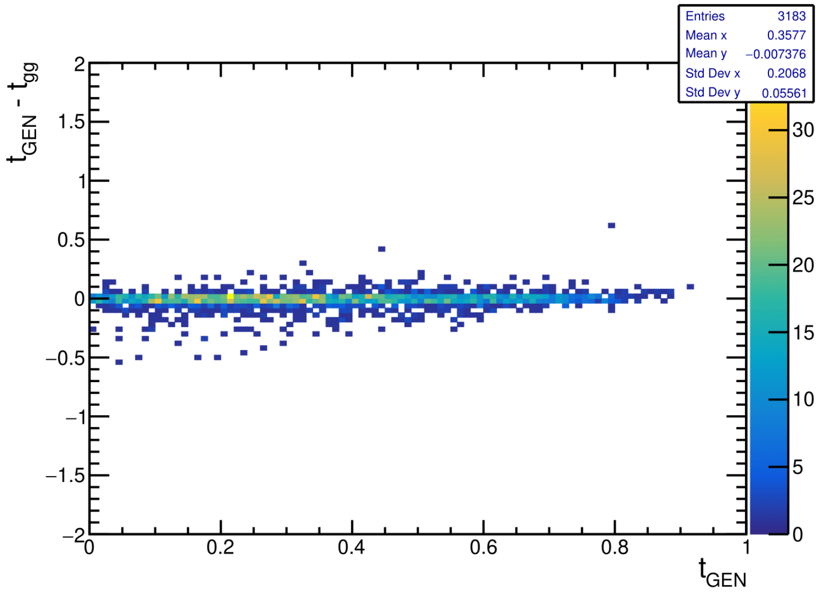
- We can't compute t with the initial and final neutron (not measured). Withe the energy of the outgoing photon we have a bad resolution. If we compute it for an exclusive process, then we don't need the energy of the outgoing photon only the angle:

- We cannot use it to select the DVCS event, but it can help the binning after.

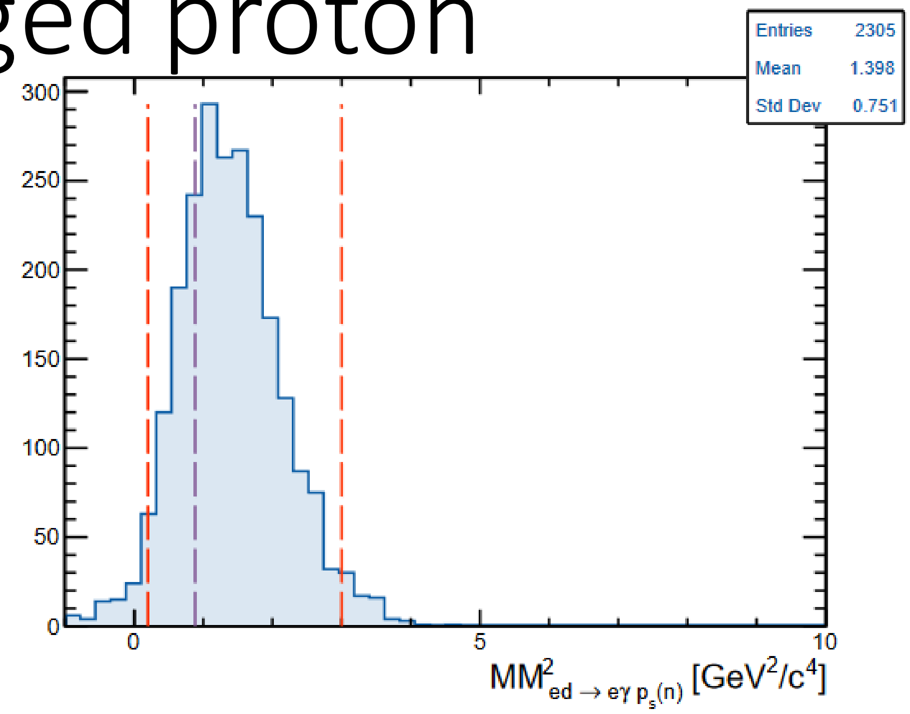
- φ_h is not frame invariant: compute it in the center of mass and give a different result than in the lab frame:

Only a few angle difference between them.





Analysis : neutron DVCS with tagged proton

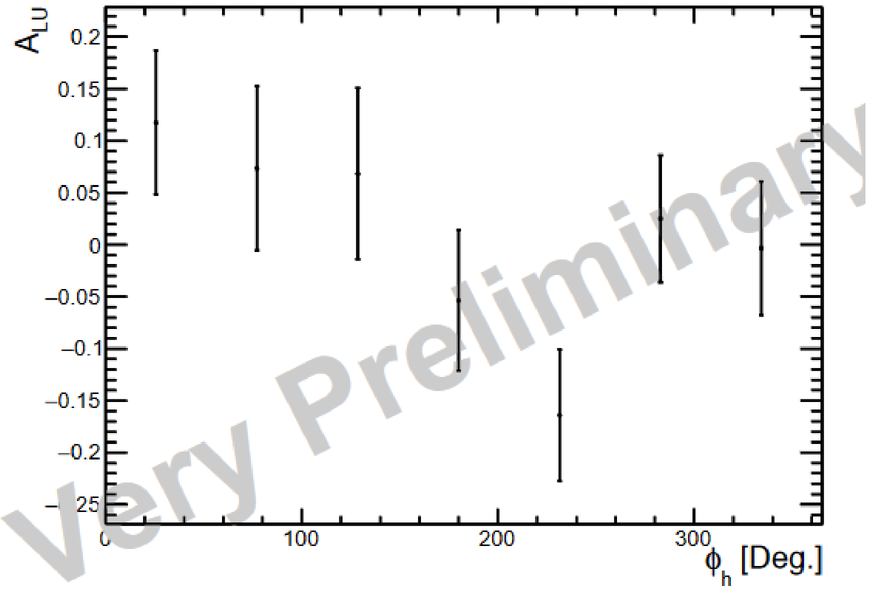


- Since we do not detect the struck nucleon (neutron), we only have access to a single exclusivity variable: the missing mass of the electron-photon system.

- We cannot calculate the usual variables :
  - *Missing mass : e d → e n γ X*
  - *Missing momentum : e d → e N γ X*
  - *Difference between two ways of calculating Φ and t: ΔΦ, Δt,*
  - *Cone angle between measured and reconstructed photon: ϑ(γ,X)*

- So the nDVCS final state is selected with the following exclusivity criteria, missing mass: e d → e γ X, we expect a pick at the square of the mass of the neutron.

- The asymmetry is integrate over ϕ_h (no binning).



π^0 analysis

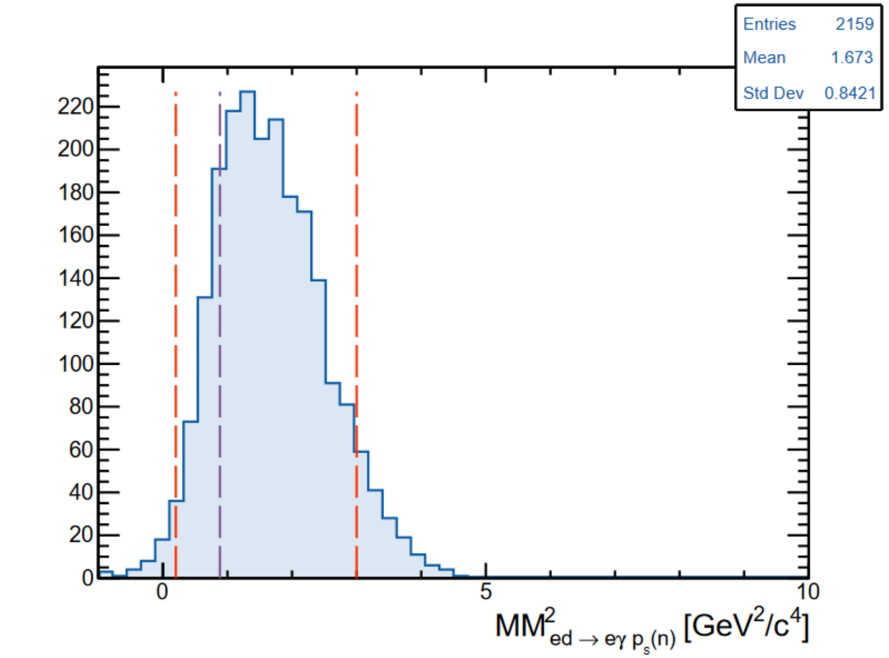
- Main background for DVCS (miss one photon emitted by the $\boldsymbol{\pi^0}$):

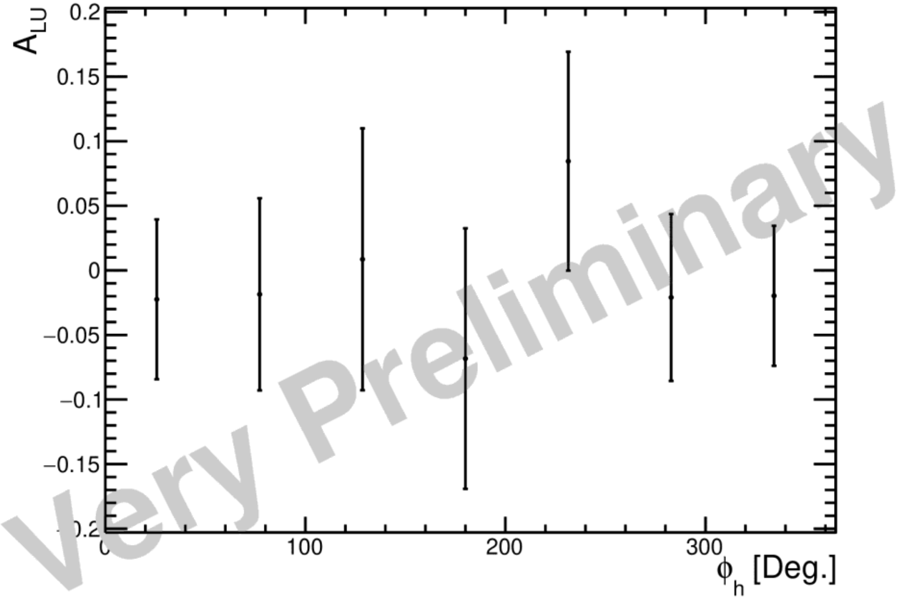
$$N_{en\gamma}^{True} = N_{en\gamma}^{Exp} - N_{en\pi^0(\gamma)'}^{Exp}$$

- Description of the method:
  - *Estimate the ratio of partially reconstructed eN π^0(1 photon) decay to fully reconstructed eN π^0 decays in MC*
  - *This is done for each kinematic bin to minimize MC model dependence*
  - *Multiply this ratio by the number of reconstructed eN π^0 in data to get the number of eN π^0(1 photon) in data*
  - *Subtract this number from DVCS reconstructed decays in data per each kinematical bin*

- Use simulation to compute : $\boldsymbol{N_{en\pi^0(\gamma)'}^{Exp} = \frac{N_{en\pi^0(\gamma)'}^{Sim}}{N_{en\pi^0(\gamma\gamma)'}^{Sim}} N_{en\pi^0(\gamma\gamma)'}^{Exp}}$.

- We need to extract the number of $\boldsymbol{\pi^0}$ events where we identify the two photons for that we use data.



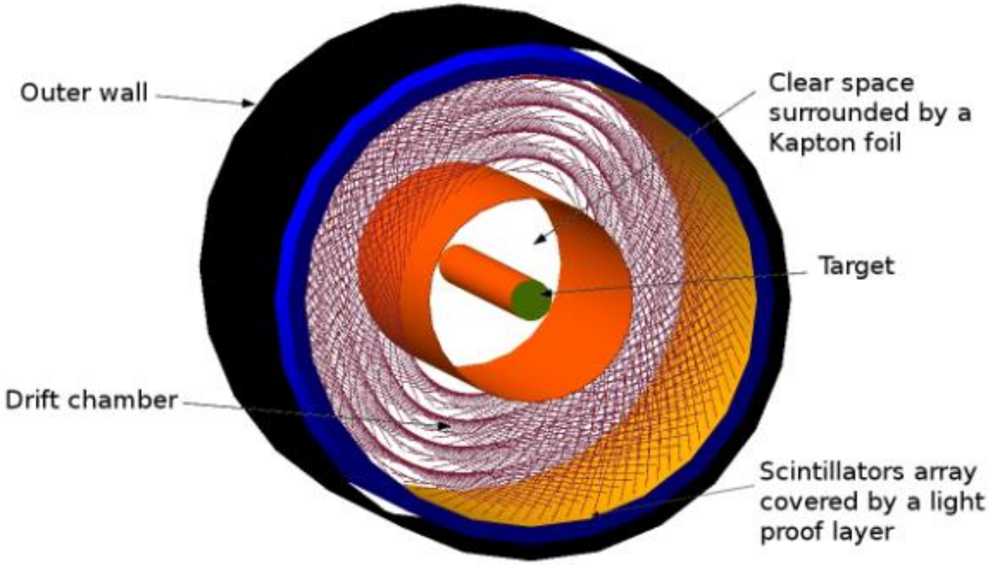


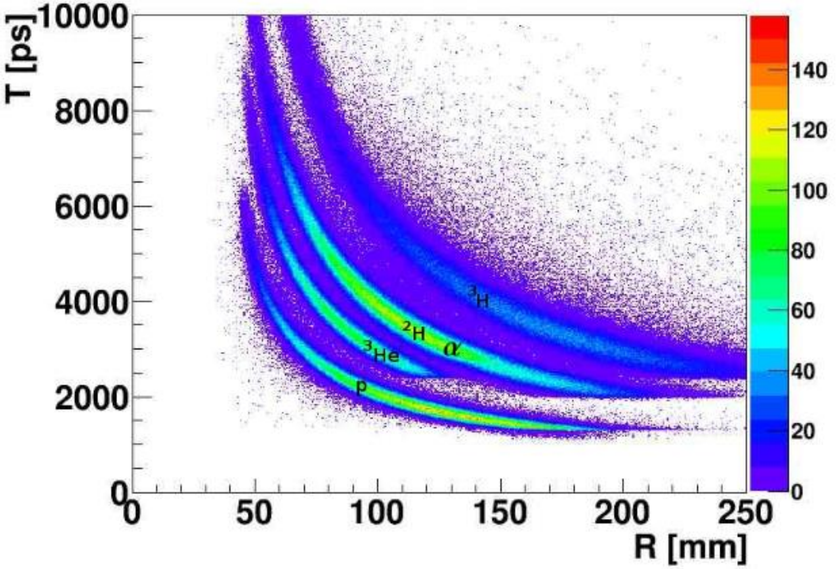
ALERT Detector

- A Low Energy Recoil Tracker consisting of two sub-systems:
  - *drift chamber.*
  - *scintillator hodoscope.*

- Build to detect low momentum particles → proton, deuterium, tritium, helium 3 and 4.
- Use dE/dx + timing resolution for PID.
- Track fitting: global helix fitter + Kalman filter with energy loss (important for low energy particles even in gas). Need particle identification → *two pass*

- Propose to measure bound p-DVCS/n-DVCS on helium 4 and quasi-free n-DVCS on deuterium (same analysis).
- Study also the GPDs on SRC pair through DVCS.



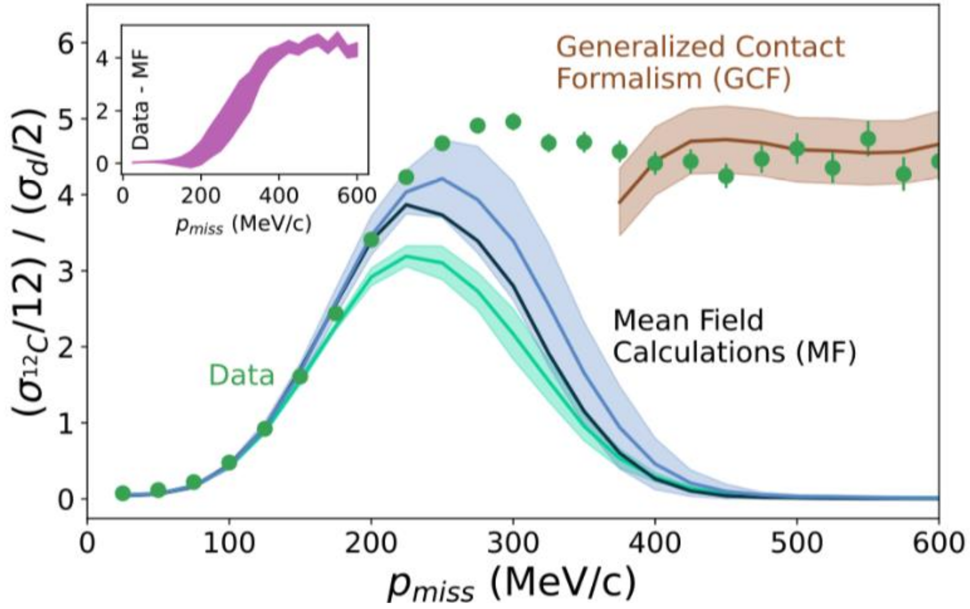


ALERT SRC Proposal

- Proposal by F. Hauenstein to Measuring Short-Range Correlation :
  - *Measuring the 4He(e, e'Xs)X reaction using 6.6 GeV electron beam.*
  - *Fully exclusive study of pn-SRC*

- Objectif:
  - *1. Test the basic assumption that the two body SRC pairs can be factorized from the residual nuclear system.*
  - *2. Study the transition from the single nucleons in a mean field (below fermi level) to SRC pairs above the fermi level.*

- Use CLAS12 + ALERT at JLAB.
- Reaction 4He(e,e'pds)n, 4He(e,e'ts)p, 4He(e,e') where the spectator are detected.



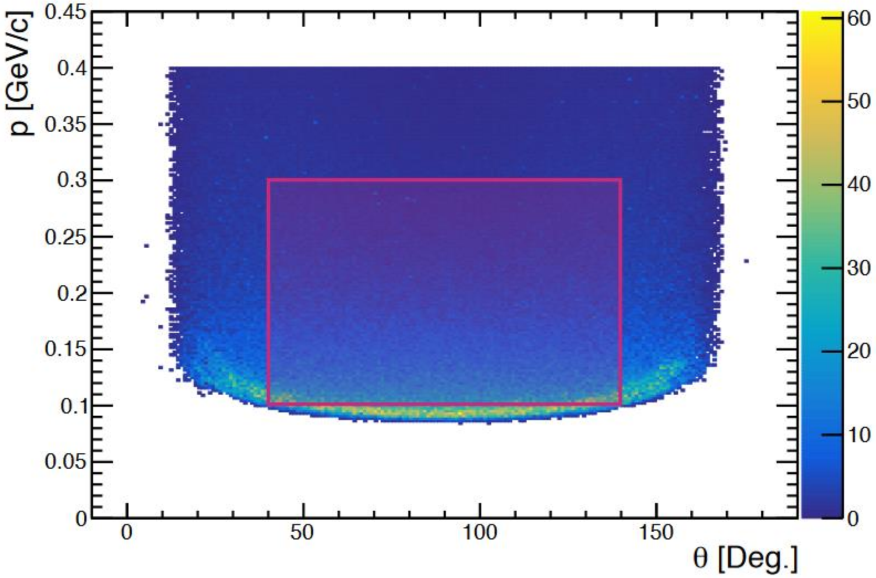


FIG. 15: Simulated deuteron acceptance in ALERT as a function of momentum and scattering angle. The colors indicate the total energy deposition of the

Conclusion

- GPDs are powerful tools to explore the structure of the nucleons and nuclei:
  - *Nucleon tomography, quark angular momentum, distribution of forces in the nucleon*
- Exclusive reactions can provide important information on nucleon structure:
  - *DVCS via the extraction of GPDs*
- First BSA measurement from neutron-DVCS with a tagged proton.

- On the analysis side :
  - *Objectif:*
    - *Beam spin asymmetry in 3 bin in t, Q^2, x_B on neutron in deuterium.*
  - *Done:*
    - *Extract a raw beam spin asymmetry for nDVCS with a tagged proton.*
    - *Reduce the background with a multi-dimensional background.*
  - *To do:*
    - *Use simulation to correct asymmetry from the acceptance.*
    - *Compute the accidental combinational background.*
    - *The background subtraction.*
    - *Both will be done by unfolding.*