Studying neutron structure at Jefferson Lab through electron scattering off the deuteron, using CLAS12 and the Central Neutron Detector

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Generalised Parton Distributions (GPDs)

- GPDs describe spatial and momentum distributions of partons inside hadrons.
  - Relate longitudinal momentum fraction of particles to their transverse position.
  - Provide information on the composition of nucleon spin, and mechanical properties such as pressure.
  - Enable 3D tomography of the nucleon.
- Interactions, under certain kinematic constraints, can be factorised into “hard” QED part and “soft” non-perturbative part which describes internal quark-gluon dynamics.
- Soft part defined by GPDs which depend on:
  - x: longitudinal momentum fraction of the interacting parton.
  - ξ: the skewness parameter.
  - t: squared four-momentum transferred to the target nucleon.
- Extracted via measurements of exclusive processes:
  - **D**eeply **V**irtual **C**ompton **S**cattering
  - **D**eeply **V**irtual **M**eson **P**roduction.
- Accurate measurements on both proton and neutron targets would allow for flavour separation of GPDs:

$$H^p(x,\xi,t) = \frac{4}{9}H^u + \frac{1}{9}H^d \qquad H^n(x,\xi,t) = \frac{1}{9}H^u + \frac{4}{9}H^d$$

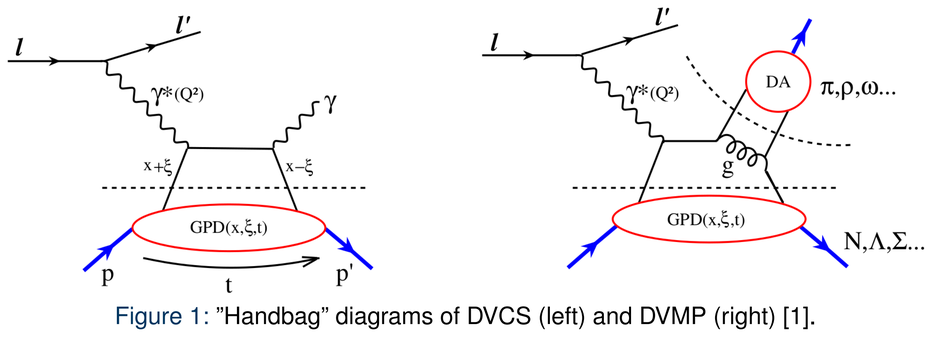

Figure 1: ”Handbag” diagrams of DVCS (left) and DVMP (right) [1].

CLAS12 Experiment

- Jefferson Laboratory in Virginia - **C**ontinuous **E**lectron **B**eam **A**ccelerator **F**acility.
- **C**EBAF **L**arge **A**cceptance **S**pectrometer - 11 GeV beam energy.
- A sophisticated detector suite including micromegas, scintillators, calorimeters, drift chambers and Cherenkov detectors.
- Research varying from studies of hadron structure, hadron spectroscopy, exotic hadrons and beyond.

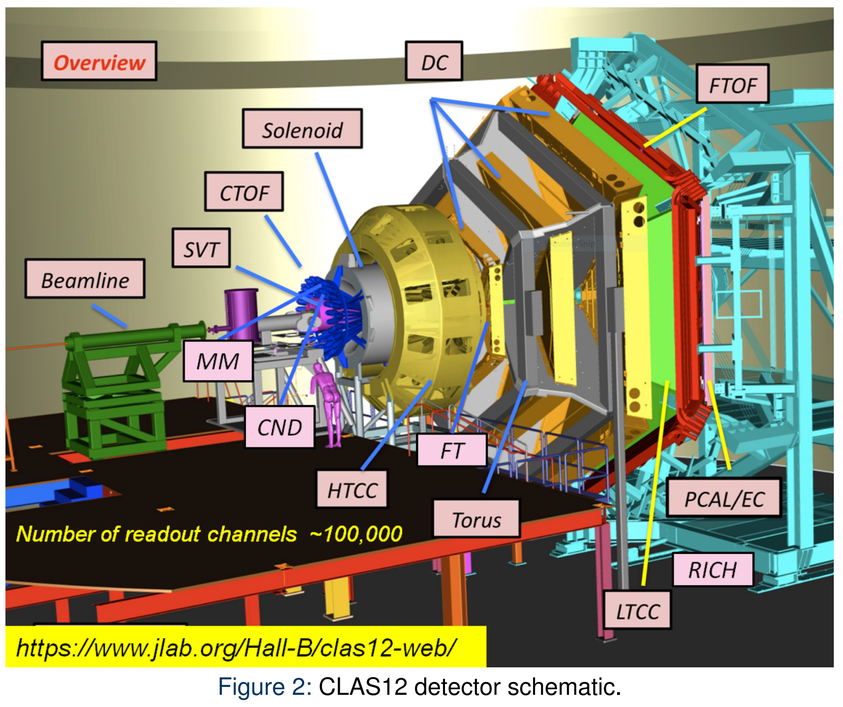

Figure 2: CLAS12 detector schematic.

Central Neutron Detector (CND)

- Until recently, largest body of work on measurements for GPD extraction has been with proton targets.
  - No free neutron target (must use deuterium).
  - Neutron cross-section smaller than proton cross-section.
  - Detection efficiency of neutrons is low.
- CND included in CLAS12 detector suite for the purpose of taking measurements on deuteron-target neutron-DVCS and DVMP [2].
- CND positioned just inside the central detector solenoid, forming the outer-most layer of the central detectors. Kinematically, n-DVCS neutrons ejected at large angles.
- Design:
  - Scintillating barrel detector.
  - Made up of 3 layers containing 24 sectors.
  - Each sector contains two paddles which are paired via a semicircular light-guide in the downstream direction.
  - Each paddle connected to a long light guide leading to Photo-Multiplier Tubes for read out in the upstream direction.

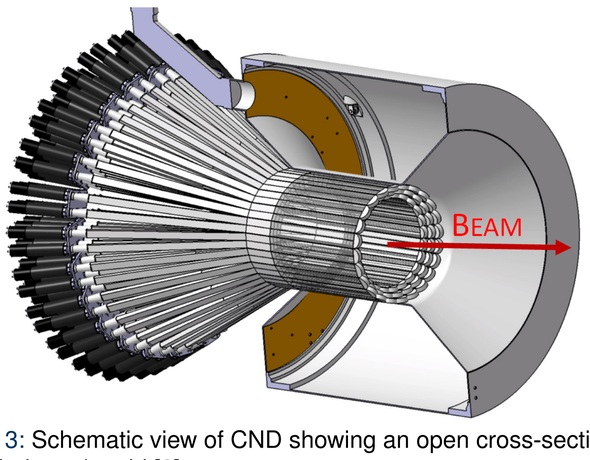

Figure 3: Schematic view of CND showing an open cross-section through the solenoid [2].

Reconstruction and PID

- Neutron detection relies upon strong-interactions with a proton in the scintillator paddles.
- Ejected proton causes scintillation within paddles.
- Neutron efficiency ∼10%.

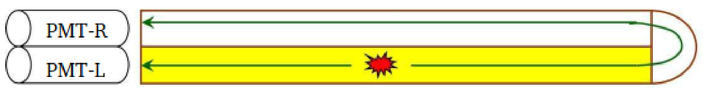

Figure 4: Illustration of a hit in a paddle of the CND [2]

- Scintillation light propagates in both directions giving signals in both PMTs.
- The signals are digitised into channels by an ADC. Integral of the ADC represents energy deposited in the scintillator.
- High-resolution timing information extracted from signals using Constant Fraction Discriminators and TDCs.
- Difference in time between paddles used to back-trace to the location of hit in the CND, while their average time is used to calculate the time of hit.

$$z = \frac{1}{2}\cdot v_{eff}\cdot(t_{left} - t_{right}) \qquad t \propto \frac{(t_{left} + t_{right})}{2}$$

- β is calculated from time of flight.
- Neutral particles identified by a lack of track in Central Vertex Tracker (CVT) when a hit occurs in the CND.
  - CVT includes **S**ilicon **V**ertex **T**racker and **M**icro**m**egas.
- Neutrons separated from photons via a cut on β.

Preliminary CND performance

- Spatial reconstruction accurate
  - Reconstructed position of charged reference particles compared to CVT track projections.
- Timing resolution close to design goal of $\sim$ 150ps.
- Good resolution of charged and neutral particles.

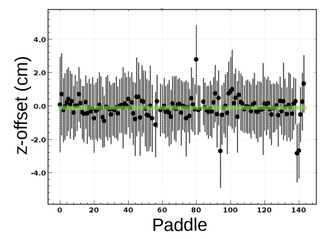

Figure 5: zCND - zCVT (projected)

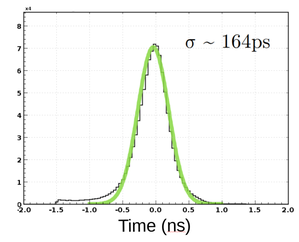

Figure 6: Integrated vertex-time

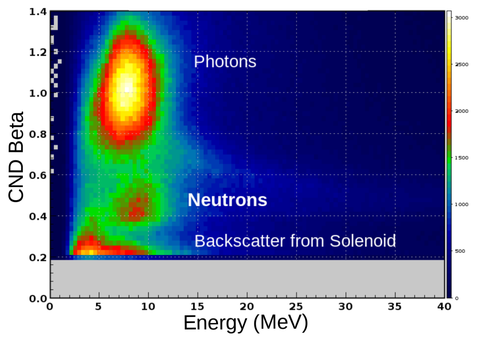

Figure 7: Plot of β vs.hit-energy for neutral particles.

- Current challenges:
  - CVT reconstruction efficiency of protons is currently lower than expected.
  - Therefore, protons without tracks are currently polluting neutron signal.
  - Work currently underway to determine means of vetoing protons from the neutron signal relying only on the CND and the **C**entral **T**ime **o**f **F**light detector, which is a single-layer scintillating barrel detector.)

References

[1] N. G. Stefanis *et al.*, “Nucleon tomography. What can we do better today than Rutherford 100 years ago?,” *The European Physical Journal Conferences*, vol. 137, 2016.
[2] S. Niccolai *et al.*, ”The central neutron detector for CLAS12”, *Nuclear Inst. and Methods in Physics Research A*, vol. 904, pp. 81-92, 2018.

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