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

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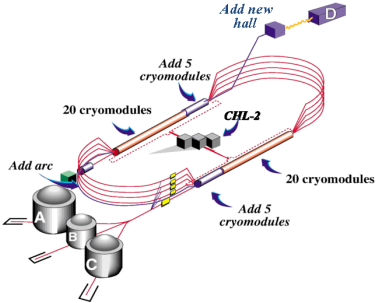
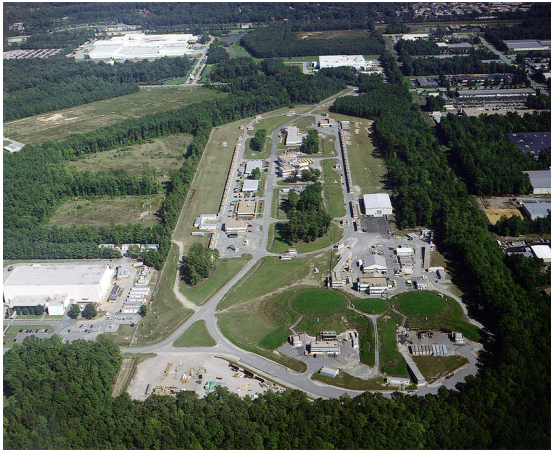
# Overview

1. Experiment
   - CLAS12 at Jefferson Laboratory
2. Theory
   - Generalised Parton Distributions
3. Motivation
   - Neutron Measurements
4. Detection
   - The Central Neutron Detector

# Jefferson Laboratory

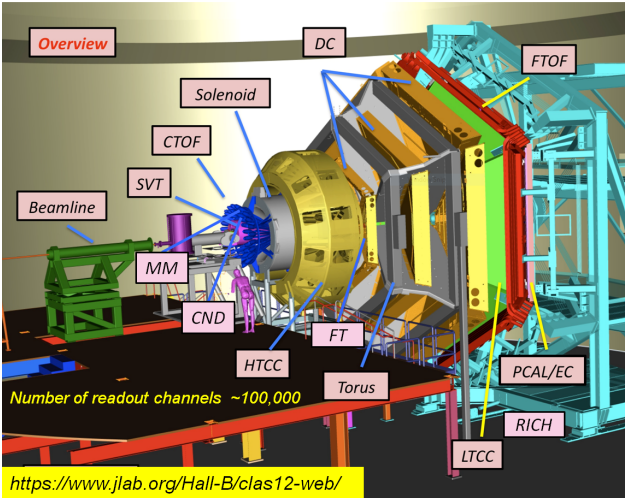
- Jefferson Laboratory in Virginia.
- Electron Synchrotron - CEBAF.
- **C**ontinuous **E**lectron **B**eam **A**ccelerator **F**acility.
- Four experimental halls.



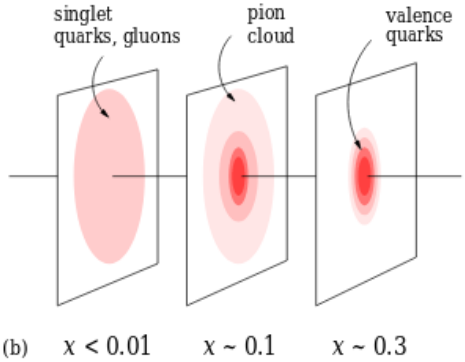
# CLAS 12

- **C**EBAF **L**arge **A**cceptance **S**pectrometer.
- 12 for 12GeV era of CEBAF.
- ∼11 GeV beam energy.
- Research in various fields including:
  - Hadron structure.
  - Hadron spectroscopy.
  - Beyond SM physics.



# Generalised Parton Distributions

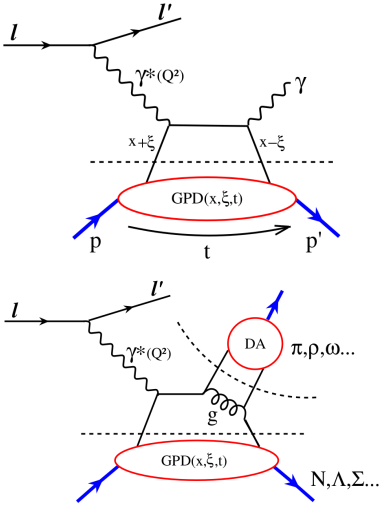
- GPDs describe spatial and momentum distributions of partons inside hadrons.
- Relate longitudinal momentum fraction of particles to their transverse position.
- Provide information on the composition of nucleon spin, and mechanical properties such as pressure.
- Enable 3D tomography of the nucleon.




*arXiv:0902.2018 [hep-ph]*

# Generalised Parton Distributions

- Extracted via measurements of exclusive processes:
  - **D**eeply **V**irtual **C**ompton **S**cattering
  - **D**eeply **V**irtual **M**eson **P**roduction.
- Interactions, under certain kinematic constraints, can be factorised into "hard" perturbative 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.
  - $\xi$: the skewness parameter.
  - $t$: squared four-momentum transferred to the target nucleon.



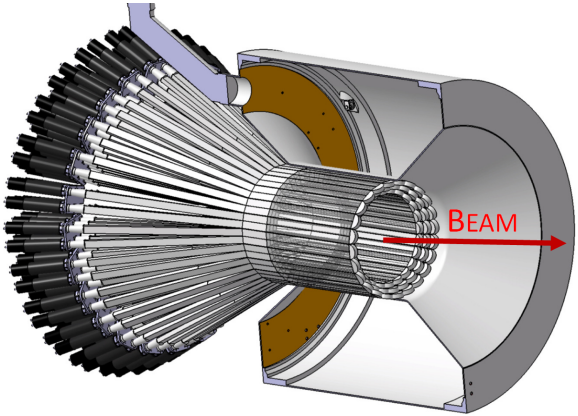

*arXiv:1612.03077 [hep-ph]*

# Why Measure Neutrons?

- 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.
- Accurate measurements on both proton and neutron targets would allow for flavour separation of GPDs:

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

# Central Neutron Detector




- 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.
- Kinematically, n-DVCS neutrons ejected at large angles.

# Detection

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

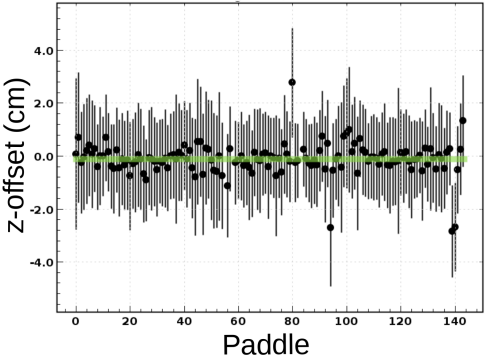
# Reconstruction


- Neutrals means no track! Position has to be extracted from timing information.
- 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.

$$z = \frac{1}{2} \cdot v_{eff} \cdot (t_{left} - t_{right}) \qquad t_{tof} \propto \frac{(t_{left} + t_{right})}{2} \qquad \beta = \frac{\ell_{path}}{t_{tof} \cdot c}$$

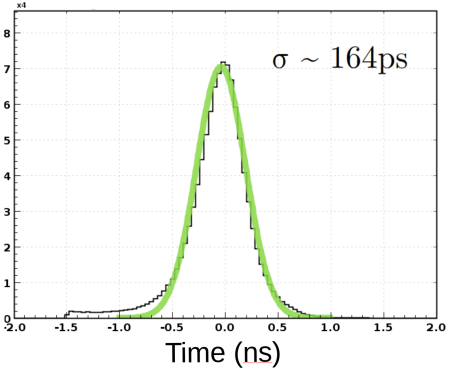
# Preliminary Performance

$z_{CND} - z_{CVT}$ (projected)




- Spatial reconstruction accurate
- Reconstructed position of $\pi^-$ particles compared to CVT track projections.

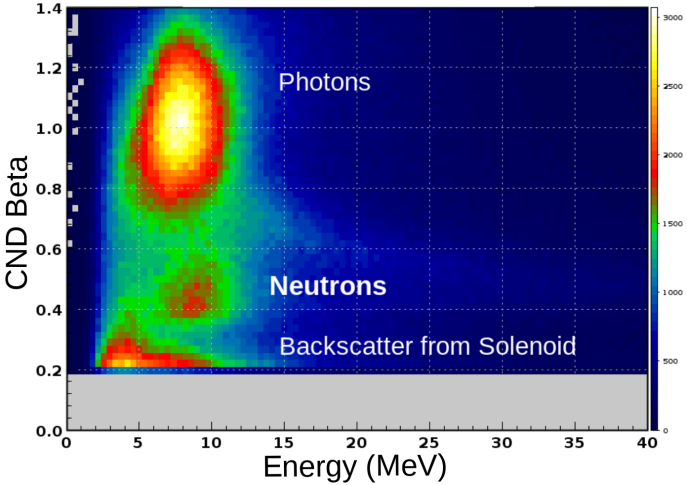
Integrated Vertex Time




- Timing resolution close to design goal of ∼150ps.

# Particle ID

- Neutral particles identified by a lack of track in Central Vertex Tracker (CVT) when a hit occurs in the CND.
- Neutrons separated from photons via a cut on $\beta$.
- Momentum can then be calculated for neutrons.



# Summary

- Data taking began this year - reconstruction underway.
- CND showing good timing and position resolution.
- Preliminary $\beta$ vs. p plots shows resolution of charged and neutral particles.
- Can resolve neutrons.
- Current challenges:
  - CVT track reconstruction efficiency of protons is currently lower than expected.
  - Protons without tracks are currently polluting neutron signal.
  - Work underway to determine means of vetoing protons from the neutron signal relying only on the CND and the CTOF.