Neutron Magnetic Form Factor G_M^n Measurement at High Q^2 with CLAS12

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Overview

- Definition and Meaning of the Elastic Nucleon Form Factor
- Scientific Motivation
- The Ratio Method
- CLAS12 Detector
- Methods used to validate Neutron detection efficiency (NDE) results
- D$(e, e'p)$& D$(e, e'n)$ Selections
- Summary

Why we need to measure G_M^n

I. G_M^n : Fundamental quantity related to neutron magnetization.

II. The form factors provide important constraints for GPDs:

$$\int_{-1}^{1} dx H^q(x,\xi,Q^2) = F_1^q(Q^2) \quad and \quad \int_{-1}^{1} dx E^q(x,\xi,Q^2) = F_2^q(Q^2)$$

Where G_E and G_M Related to F_1 and F_2 *as* : $G_E(Q^2) = F_1(Q^2) - \tau\, F_2(Q^2) \quad and \quad G_M(Q^2) = F_1(Q^2) + F_2(Q^2)$

How Do We Measure G_M^n on a Neutron? Ratio Method on deuterium

The ratio of the free nucleon e-n to e-p cross sections in terms of the free nucleon form factors:

Requires a Precise Measurement of the Neutron Detection Efficiency (NDE)
$e\,p \rightarrow e'\,\pi^+(n)$

$$R = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\frac{d\sigma}{d\Omega}(D(e,e'p))} = a(Q^2)\,\frac{\sigma_{mott}^n \left(G_E^{n\,2} + \frac{\tau_n}{\varepsilon_n} G_M^{n\,2}\right)\left(\frac{1}{1+\tau_n}\right)}{\sigma_{mott}^p \left(G_E^{p\,2} + \frac{\tau_p}{\varepsilon_p} G_M^{p\,2}\right)\left(\frac{1}{1+\tau_p}\right)}$$

$a(Q^2)$: corrects for nuclear effects

the denominator is the precisely-known proton cross section.

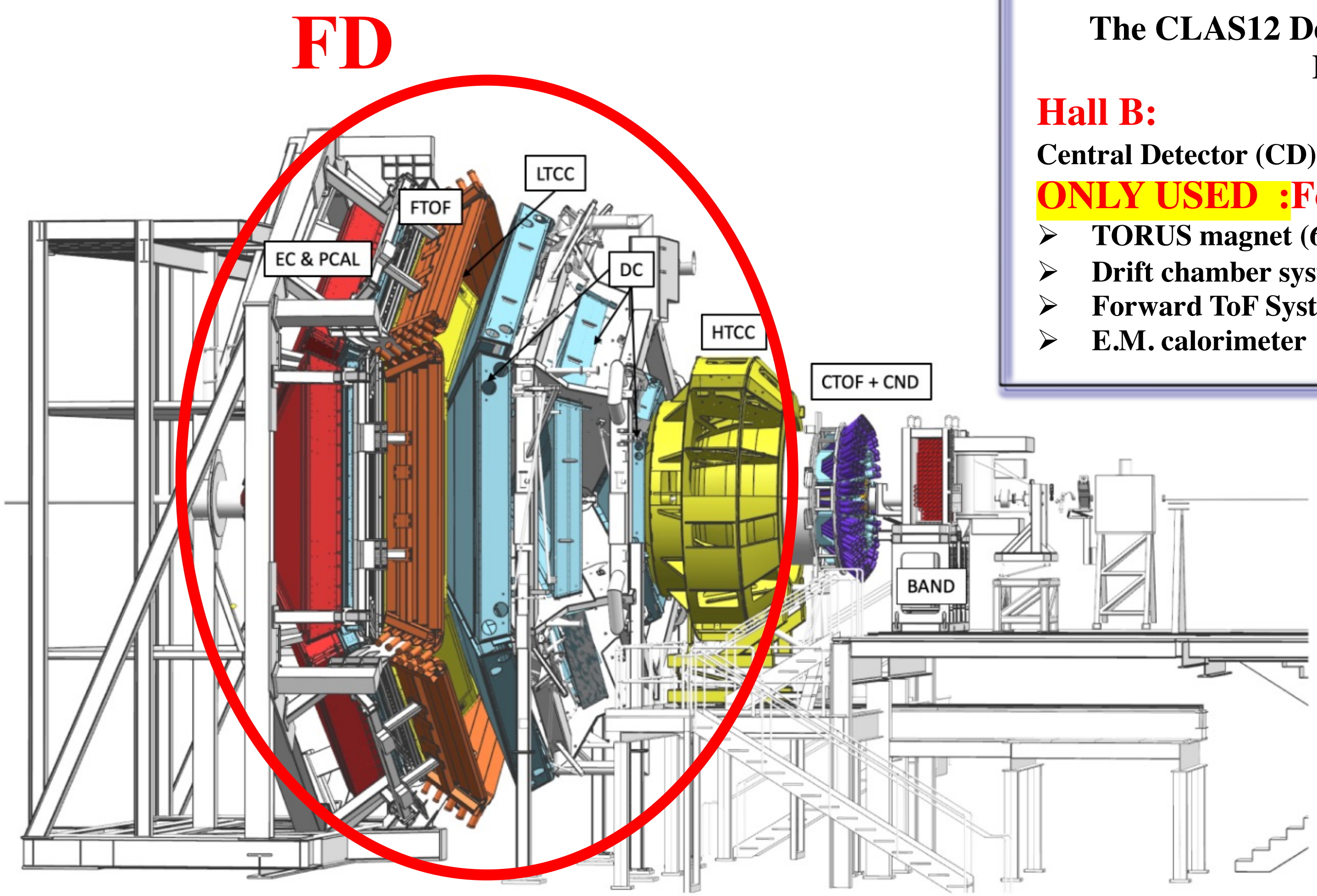
Where:

$$\sigma_{Mott} = \frac{\alpha^2 E' \cos^2(\frac{\theta_e}{2})}{4E^3 \sin^4(\frac{\theta_e}{2})}\ ,\quad \tau = \frac{Q^2}{4\,M_{p,n}^2}\ ,\quad Q^2 = 4EE'\sin^2\left(\frac{\theta_e}{2}\right)\ ,\ \epsilon = \left[1 + 2(1+\tau)\tan^2(\frac{\theta_e}{2})\right]^{-1}$$

$$G_M^n = \sqrt{\left[R_{corrected}\left(\frac{\sigma_{mott}^p}{\sigma_{mott}^n}\right)\left(\frac{1+\tau_n}{1+\tau_p}\right)\left(G_E^{p\,2} + \frac{\tau_p}{\varepsilon_p} G_M^{p\,2}\right) - G_E^{n\,2}\right]\frac{\epsilon_n}{\tau_n}}$$

Extracting G_M^n requires knowledge of other EEFFs

CLAS12 Detectors and Data Set



The CLAS12 Detector located in Hall B at Jefferson Laboratory, Virginia.

Hall B:

Central Detector (CD) and Forward Detector (FD)

ONLY USED :Forward Detector (FD):

- **TORUS magnet (6 coils)**
- **Drift chamber system**
- **Forward ToF System**
- **E.M. calorimeter**
- **HT Cherenkov Counter**
- **LT Cherenkov Counter**
- **Pre-shower calorimeter (PCAL)**

Data Set:

✓ **For NDE:**

Data was taken during Spring and Fall 2018 with E_{beam} = 10.6 GeV and Spring 2019 with E_{beam} = 10.2 GeV and Liquid hydrogen target.

✓ **For G_M^n :**

Data was taken with E_{beam} =10.6, 10.2 and 10.4 GeV and liquid deuterium target.

Measure Neutron Detection Efficiency (NDE)

Determine the neutron detection efficiency (NDE) by using:

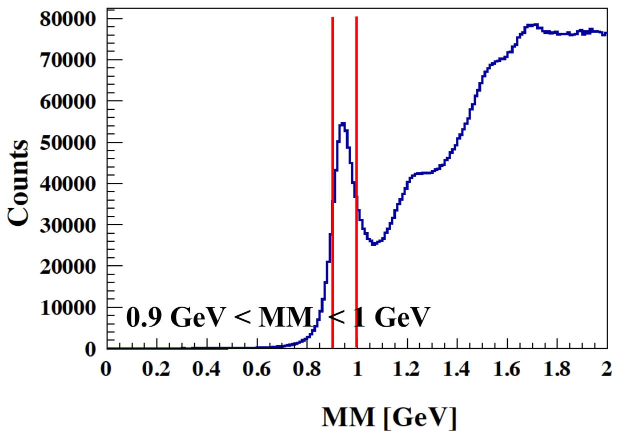
$$e\,p \rightarrow e'\,\pi^+(n)$$

Select $e'\,\pi^+$ final state with no other charged particles

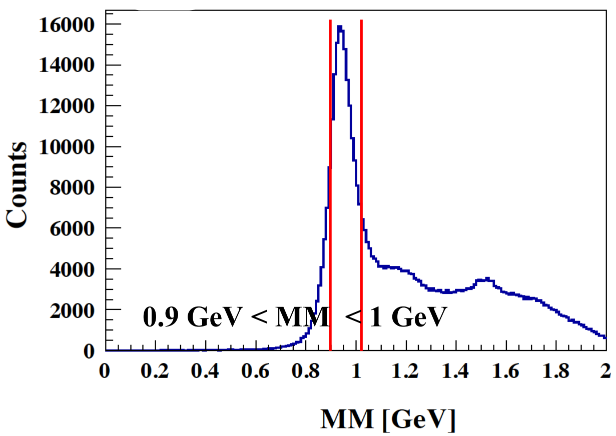
$$NDE = \frac{p(e,e'\pi^+n)}{p(e,e'\pi^+)n}$$

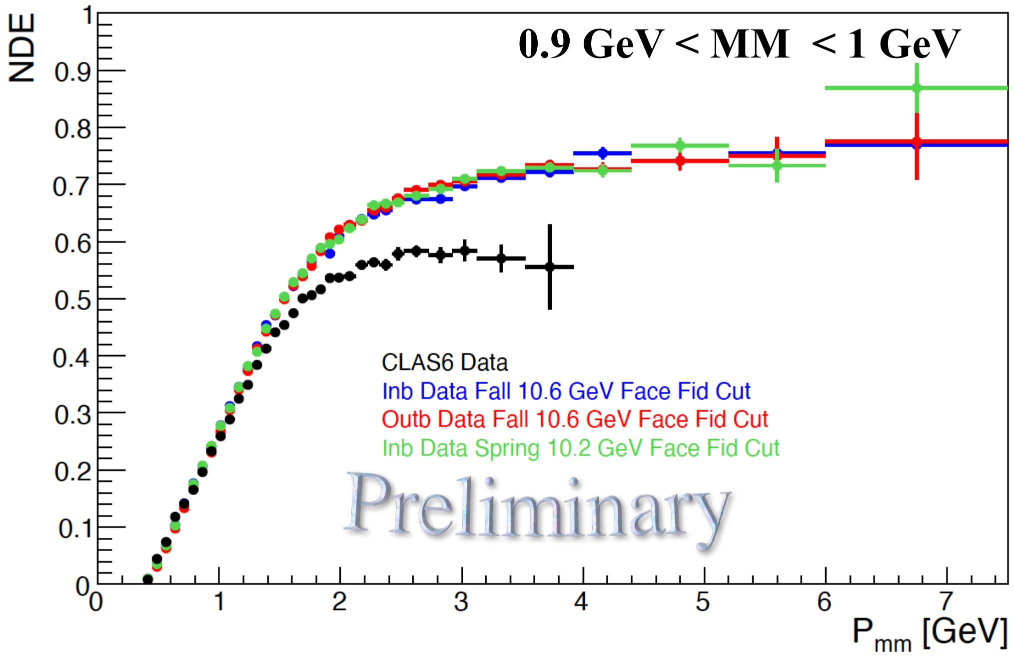
Expected Neutron = number of the neutron hit calorimeter
Detected neutron = number of the neutron measured in calorimeter

Missing Mass of expected Neutron $p(e,e'\pi^+n)$



Missing Mass of detected Neutron $p(e,e'\pi^+n)$

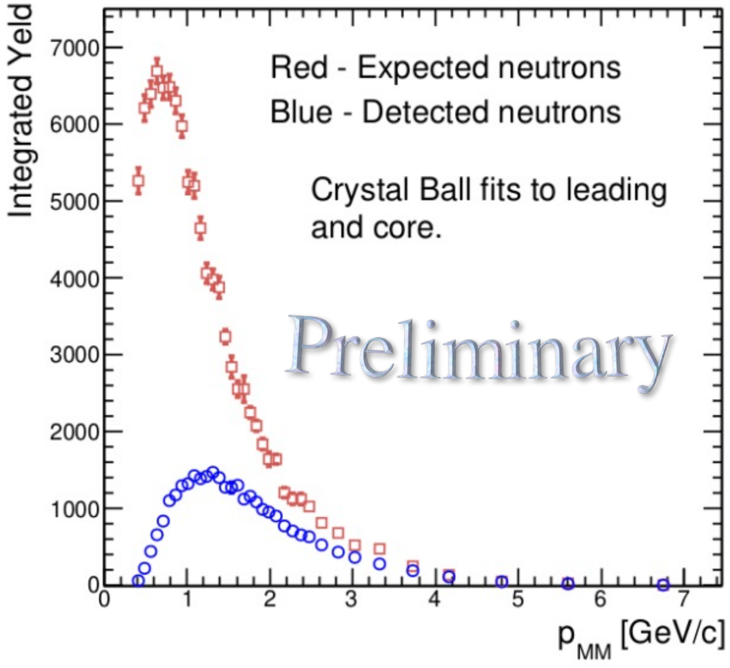


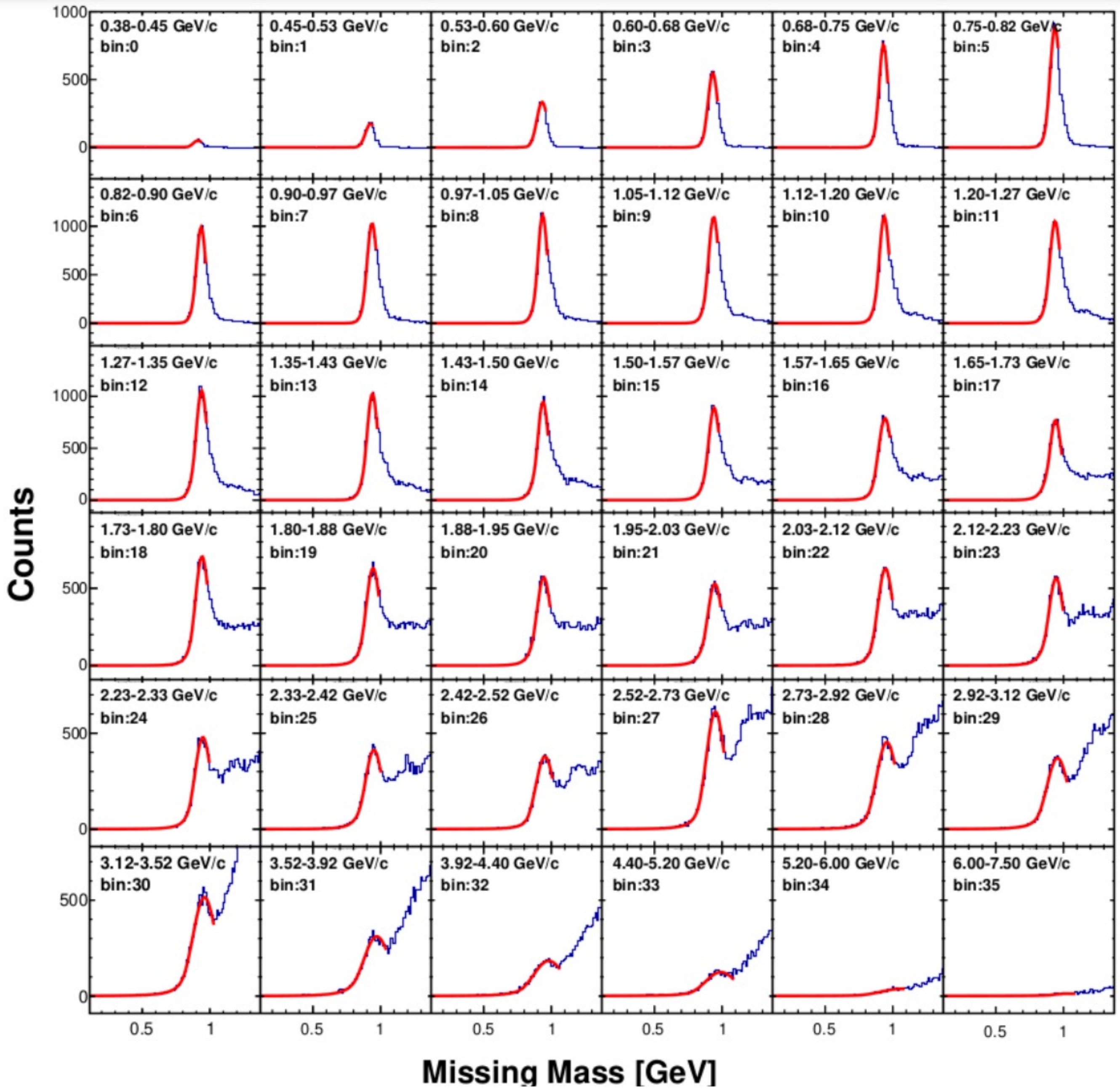


arXiv:0811.1716v2 [nucl-ex] 13 May 2009

Validate NDE Results

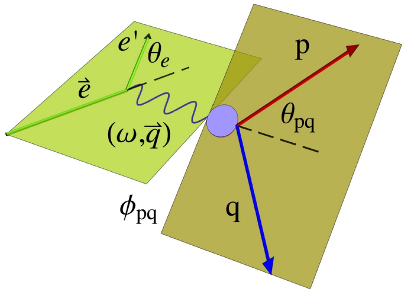
- Fit missing mass distributions in missing momentum p_{mm} bins to extract neutron yield.
- Use Crystal Ball function for both expected and detected neutrons.
- Take the ratio to get NDE.





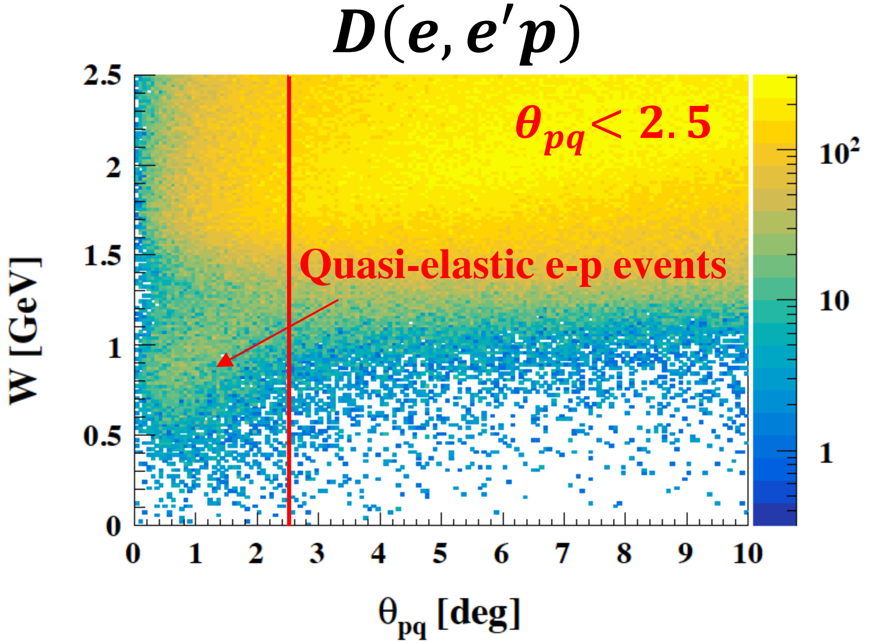
Measured G_M^n on a Neutron

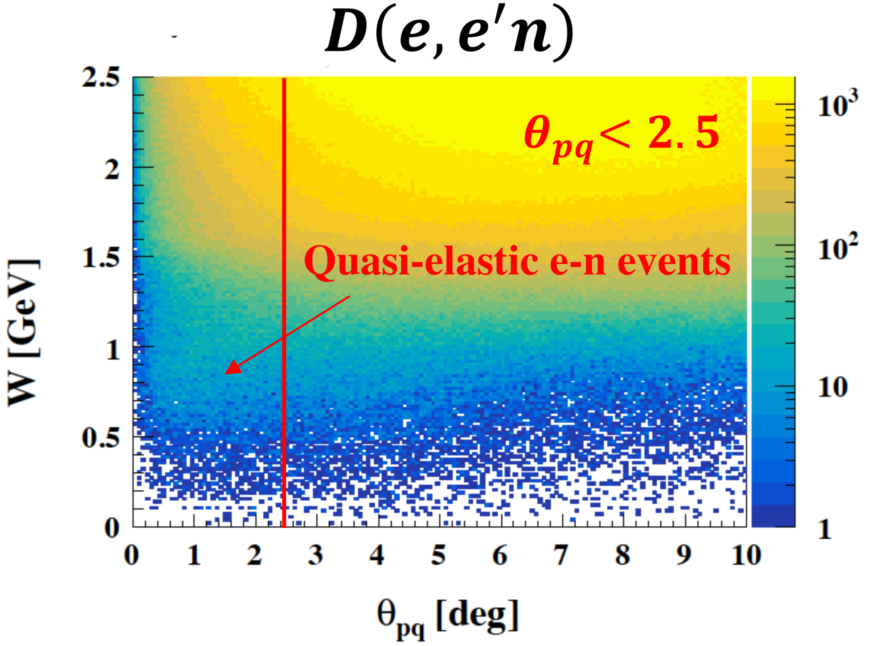
$$R = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\frac{d\sigma}{d\Omega}(D(e,e'p))}$$



Select quasi-elastic (QE) kinematics:

- using θ_{pq}: the angle between the 3-momentum transfer and the nucleon.
- Calculate E_{beam} in two different way:
  - Using measured P_e, θ_e
  - Using measured θ_e, θ_p
- Do acceptance matching to select events.





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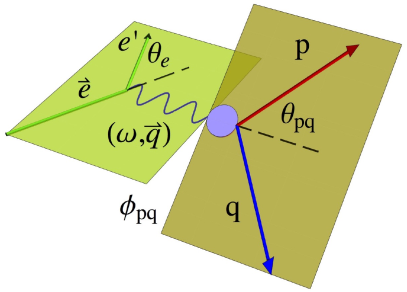

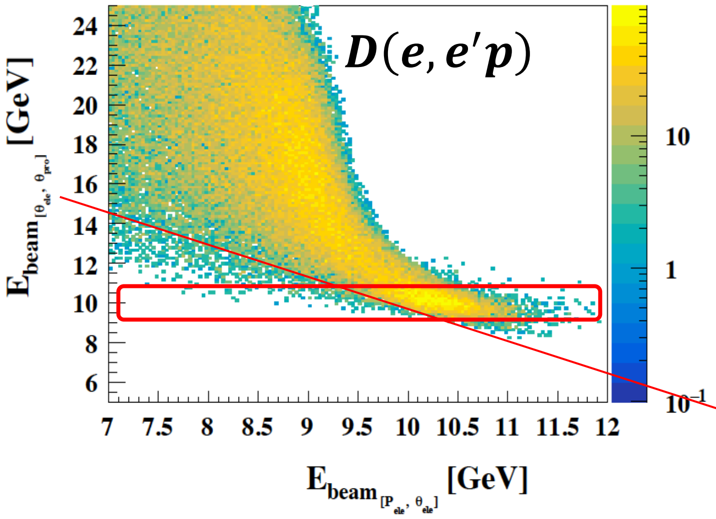

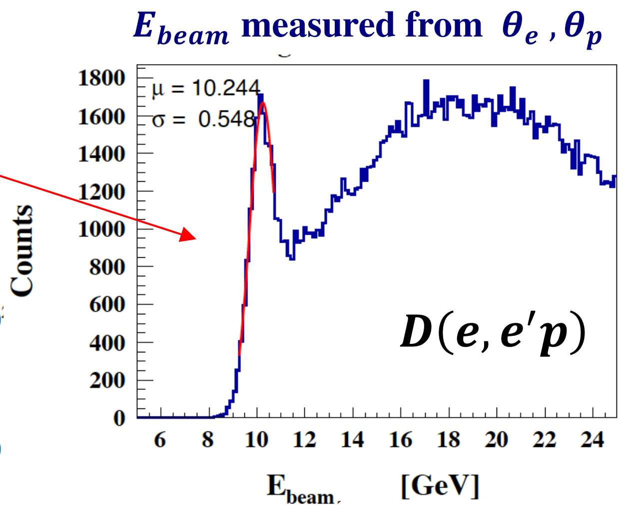

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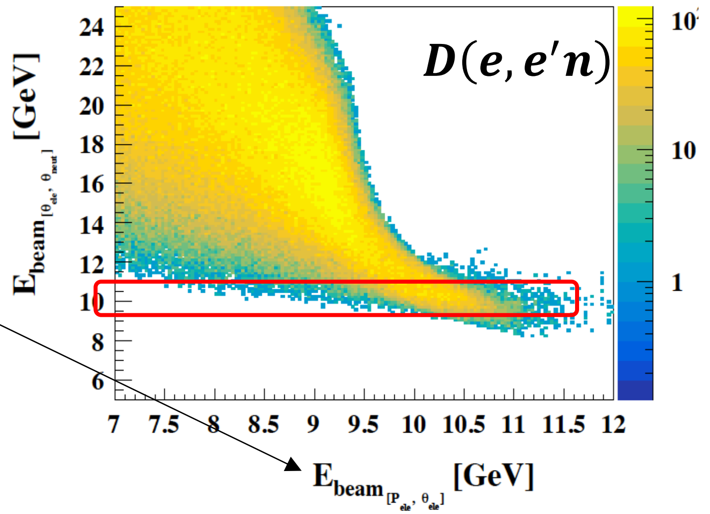


Acceptance Matching

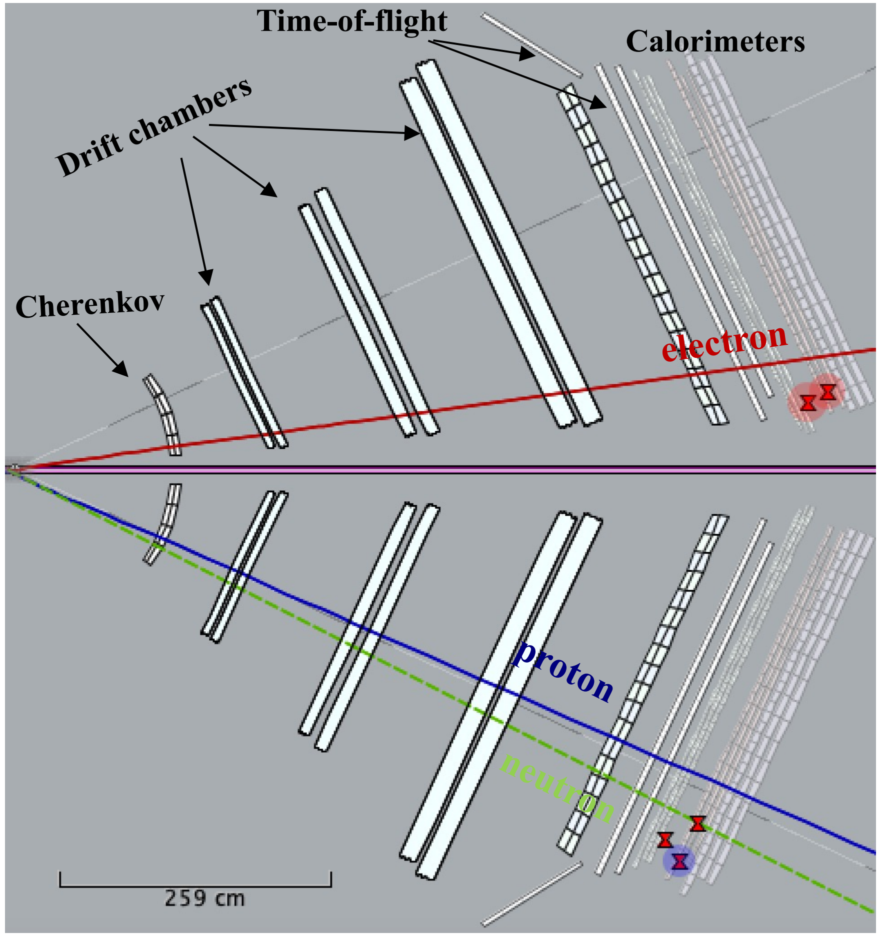
Use the measured electron information to predict the trajectory of the QE proton and neutron.

Swim the predicted neutron and proton tracks through CLAS12.

Check that both neutron and proton tracks strike the fiducial volume of CLAS12.

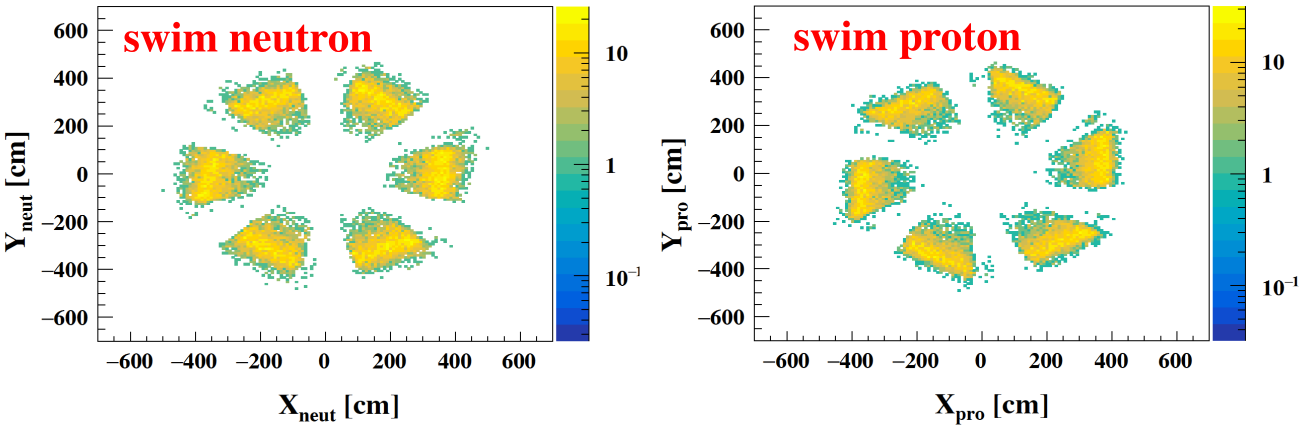
If both strike CLAS12 continue the analysis, otherwise throw it out.

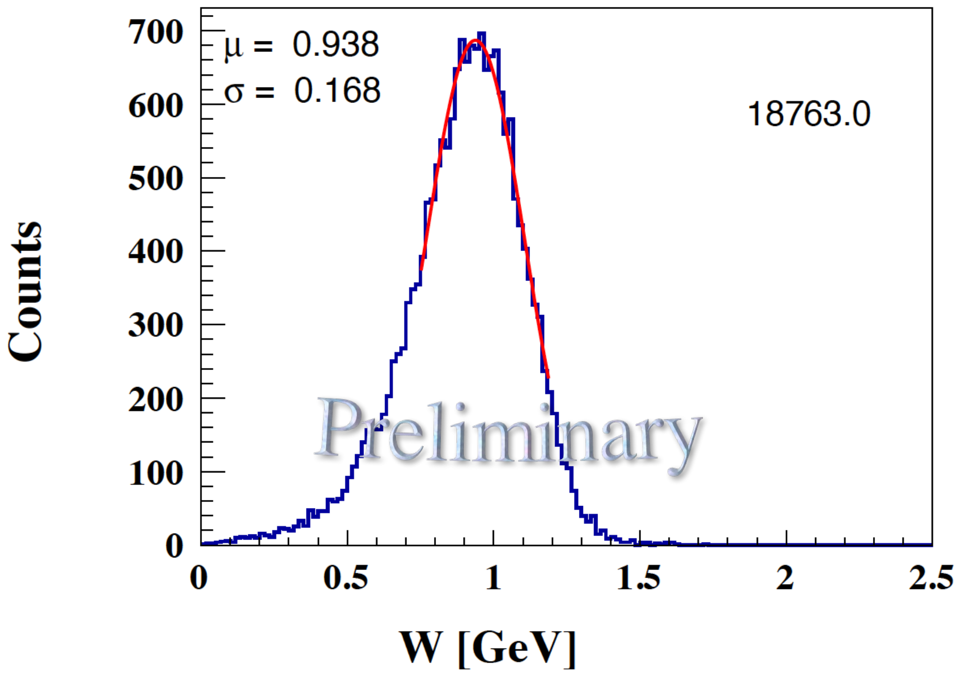
CLAS12 Detector



$D(e,e'p)$ Selection

Need to apply Fiducial Cut





$D(e,e'n)$ Selection

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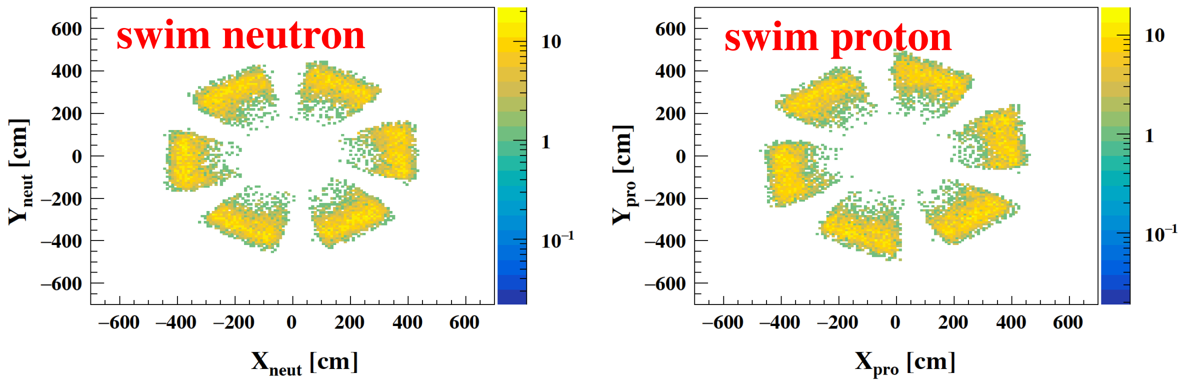
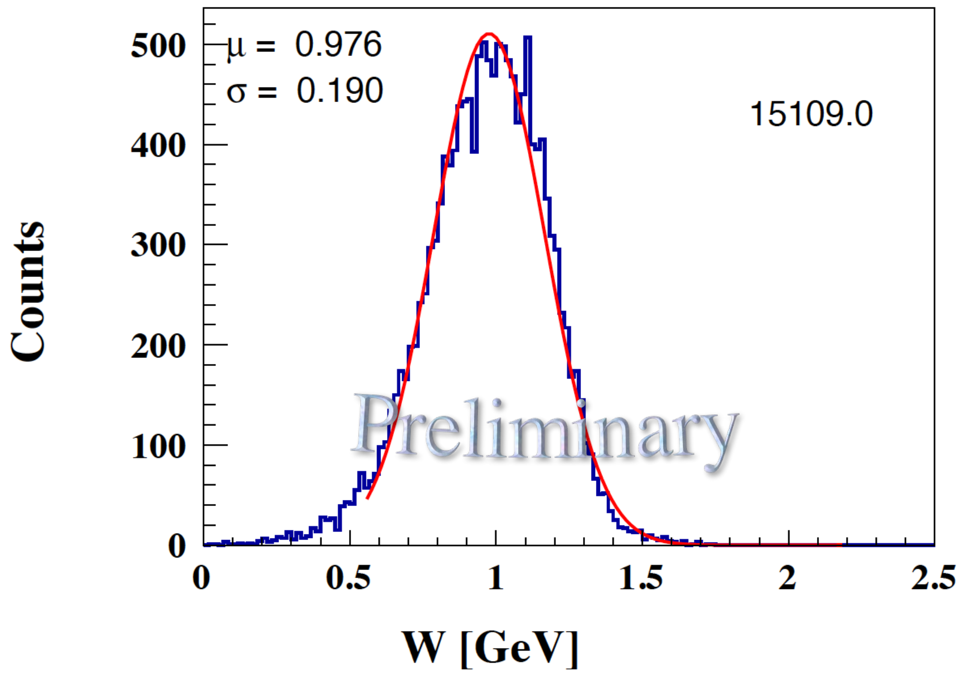




Conclusion and Outlook

Status:

- **Preliminary yields for quasi-elastic $D(e,e'p)$ & $D(e,e'n)$.**
- **NDE ~ 0.74 at the plateau (p_{mm} > 3.5 GeV) for two different magnetic field configurations with two different beam energies.**

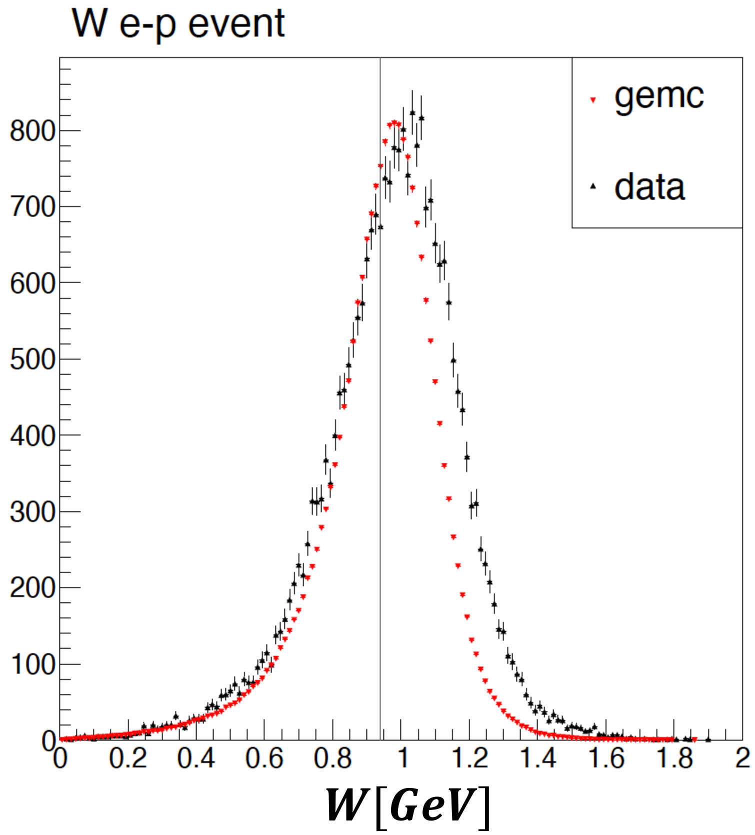
Future works :

- **Validating NDE results by fitting missing mass distributions in missing momentum p_{mm} bins.**
- **Improve and optimize quasi-elastic $D(e,e'p)$ & $D(e,e'n)$ Selection.**
- **Corrections: Fermi motion, radiative corrections, nuclear corrections.**

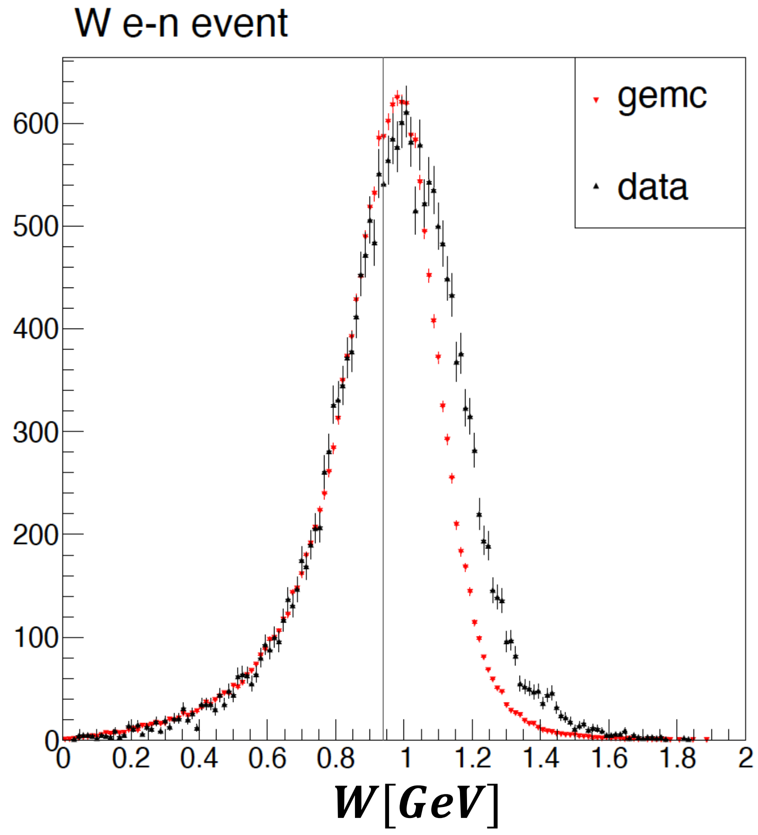
Thank you..

$D(e, e'p)$ Selection $D(e, e'n)$ Selection

Comparison of MC and Data to investigate quasi-elastic peaks.



Data wider than sim
Need to generate inelastic events to investigate quasi-elastic peaks



The generator used is QUEEG 'QUasi-Elastic EventGenerator'

QUEEG: A Monte Carlo Event Generator for Quasielastic Scattering on Deuterium, G.P. Gilfoyle , J.D. Lachniet , and O. Alam, CLAS-NOTE 2014-007, Sep 5, 2014.