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 improve/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

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

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

corrects for nuclear effects

the denominator is the precisely-known proton cross section.

Where:

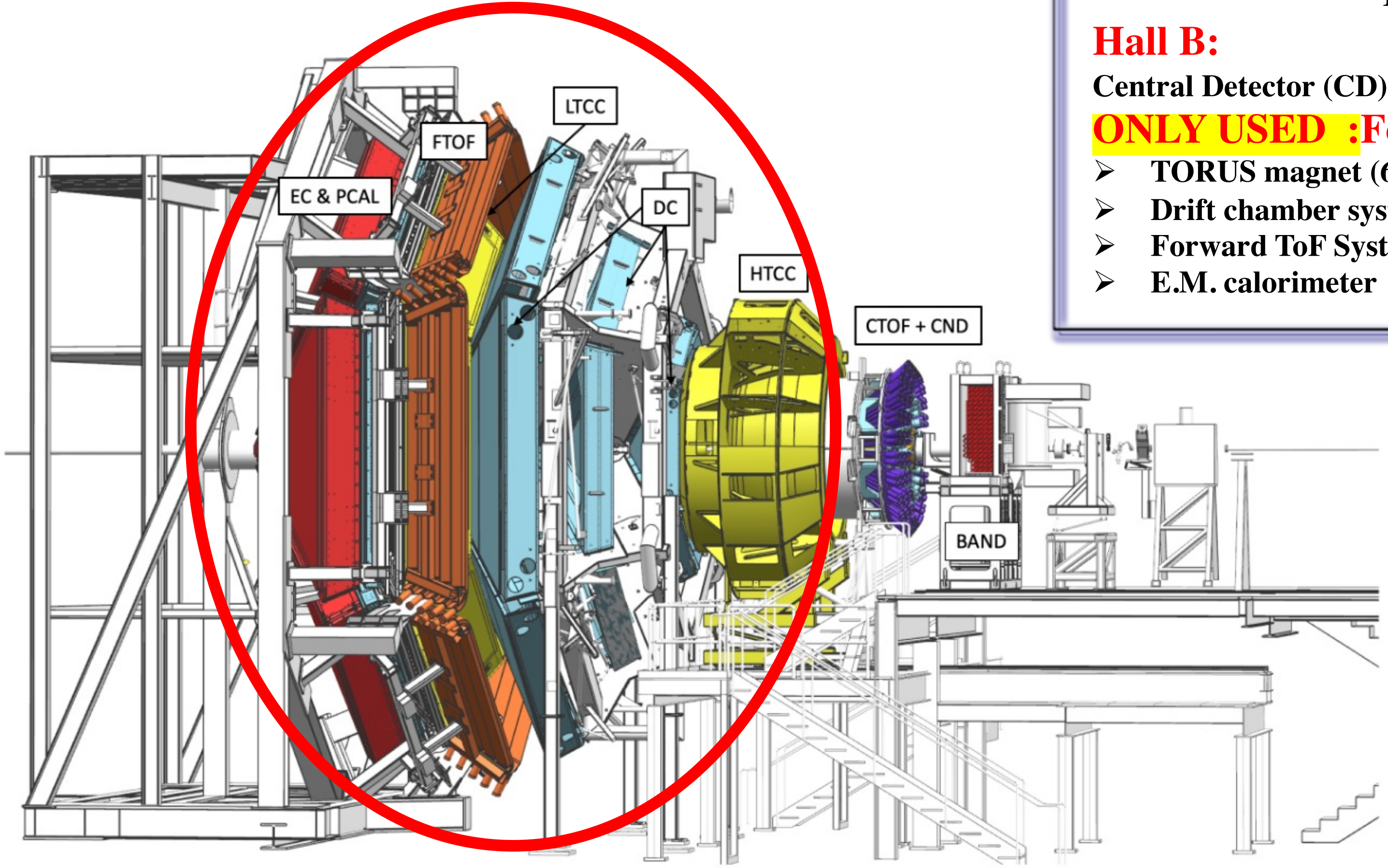
$$\sigma_{Mott} = \frac{\alpha^2 E' \cos^2(\frac{\theta_e}{2})}{4E^3 \sin^4(\frac{\theta_e}{2})}\ ,\quad \tau = \frac{Q^2}{4\,M_{p,n}^2}\ ,\quad Q^2 = 4EE'\sin^2\left(\frac{\theta_e}{2}\right)\ ,\ \epsilon = \left[1 + 2(1+\tau)\tan^2(\frac{\theta_e}{2})\right]^{-1}$$

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

Extracting G_M^n requires knowledge of other EEFFs

CLAS12 Detectors and Data Set

FD



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.

Preliminary Neutron detection efficiency (NDE) results

Determine the neutron detection efficiency (NDE) by using:

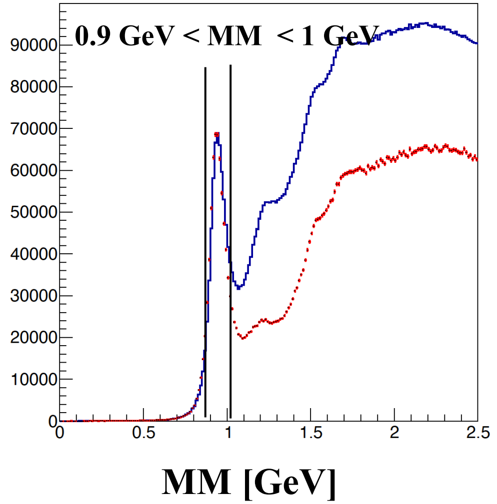
$$e\,p \rightarrow e'\,\pi^{+}(n)$$

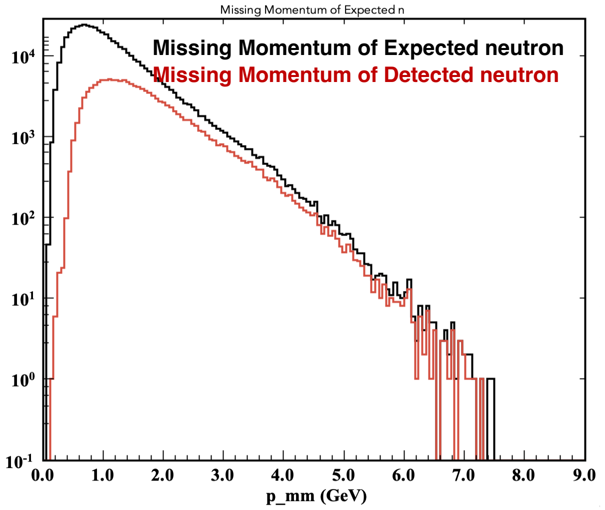
Select $e'\,\pi^{+}$ final state with no other charged particles

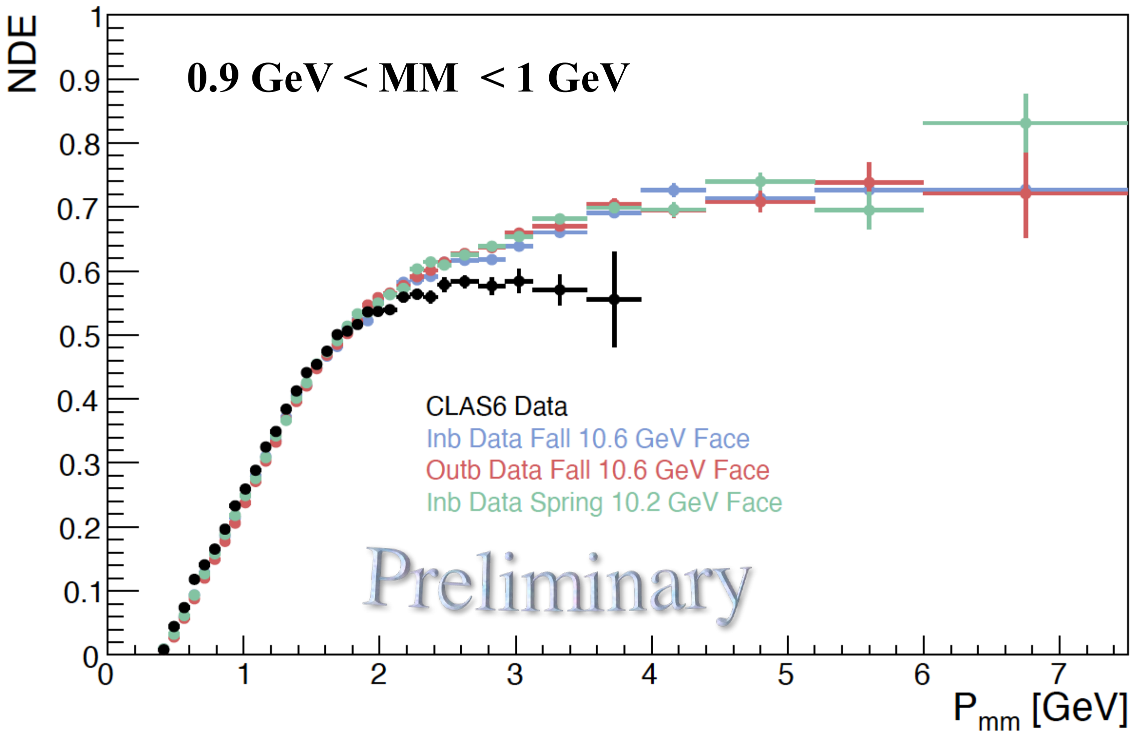
$$NDE = \frac{H(e,e'\pi^{+}n)}{H(e,e'\pi^{+})n}$$

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

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



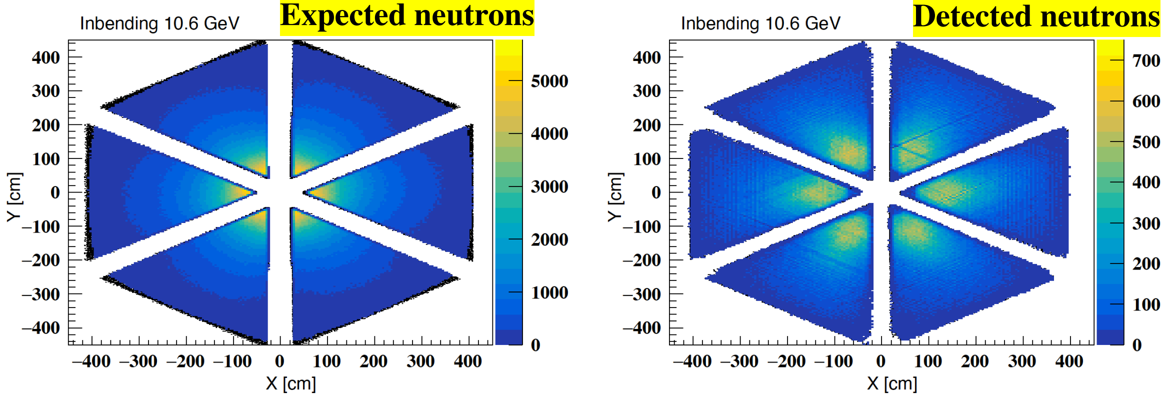


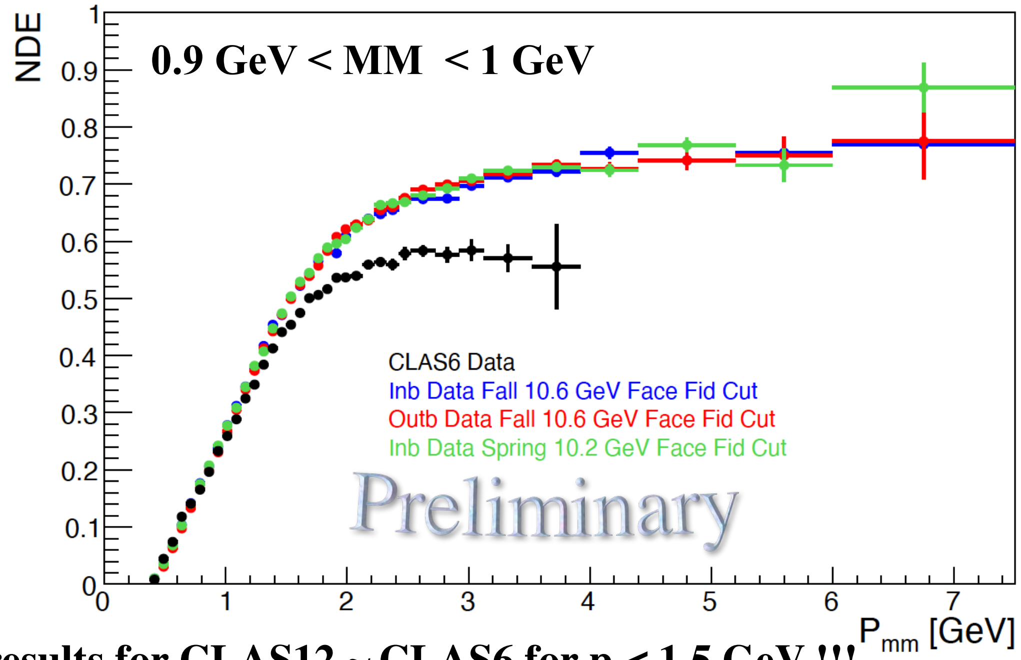


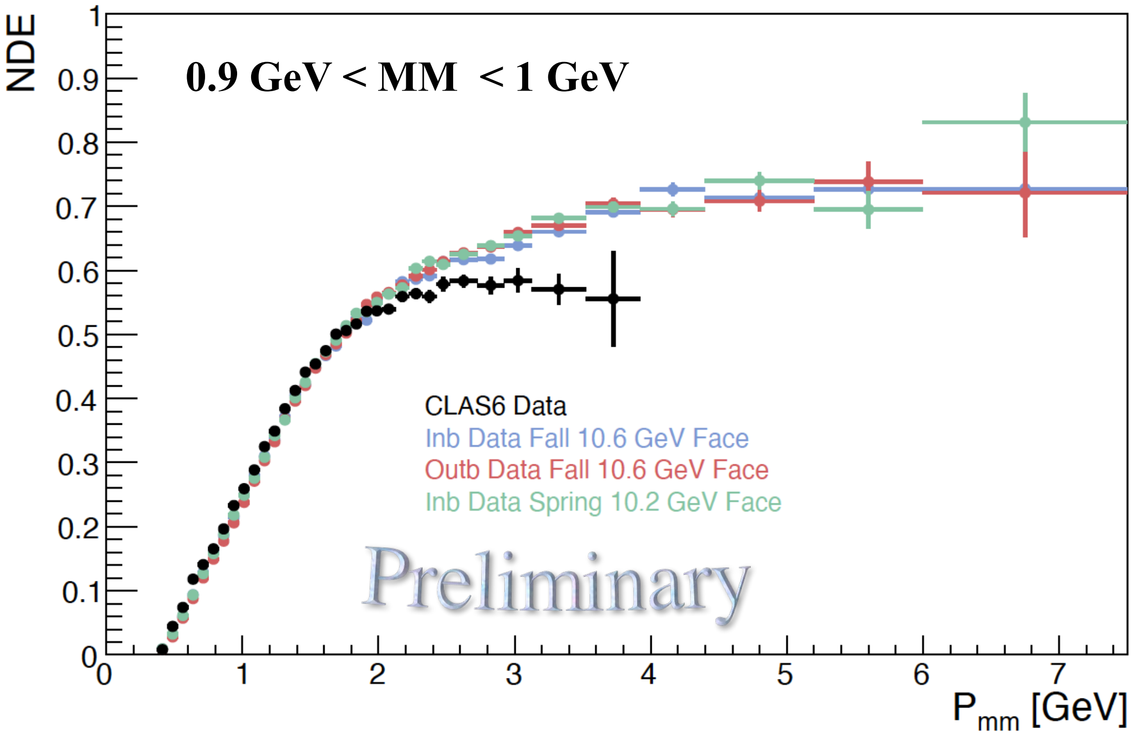
NDE results for CLAS12 ~ CLAS6 for p < 2 GeV !!!

Preliminary Neutron detection efficiency (NDE) results

PCAL/ECAL Hit Position Y vs. X







NDE results for CLAS12 ~ CLAS6 for p < 1.5 GeV !!!

Fiducial Cut Based on Cole Smith Code:

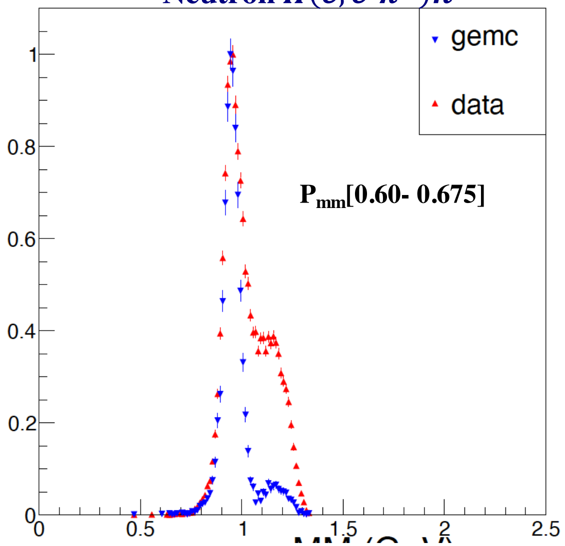
```
public boolean neutronFiduc(int opt, float cx, float cy) {
    float off = 0.52f;
    if(opt==1) return (cx>0.07 && Math.sqrt((cx+off)*(cx+off)+cy*cy)<(0.52+off) && Math.abs(cy)<0.57*(cx-0.07));
    if(opt==2) return Math.sqrt((cx-0.35)*(cx-0.35)+cy*cy)<0.1;
    return false;
}
```

Comparison of MC and Data for NDE

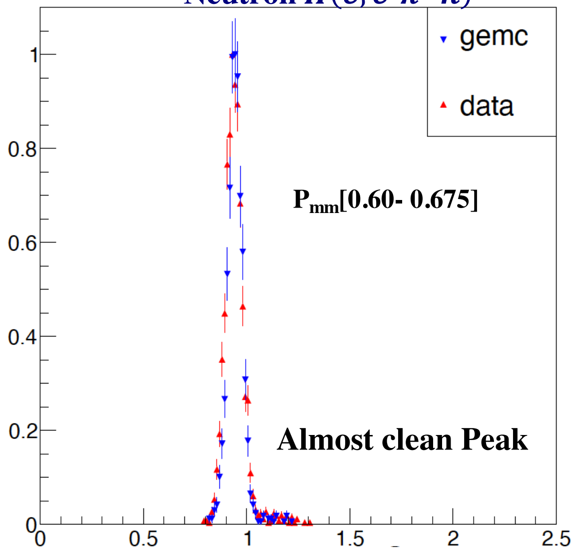
Why $NDE_{sim} > NDE_{data}$?

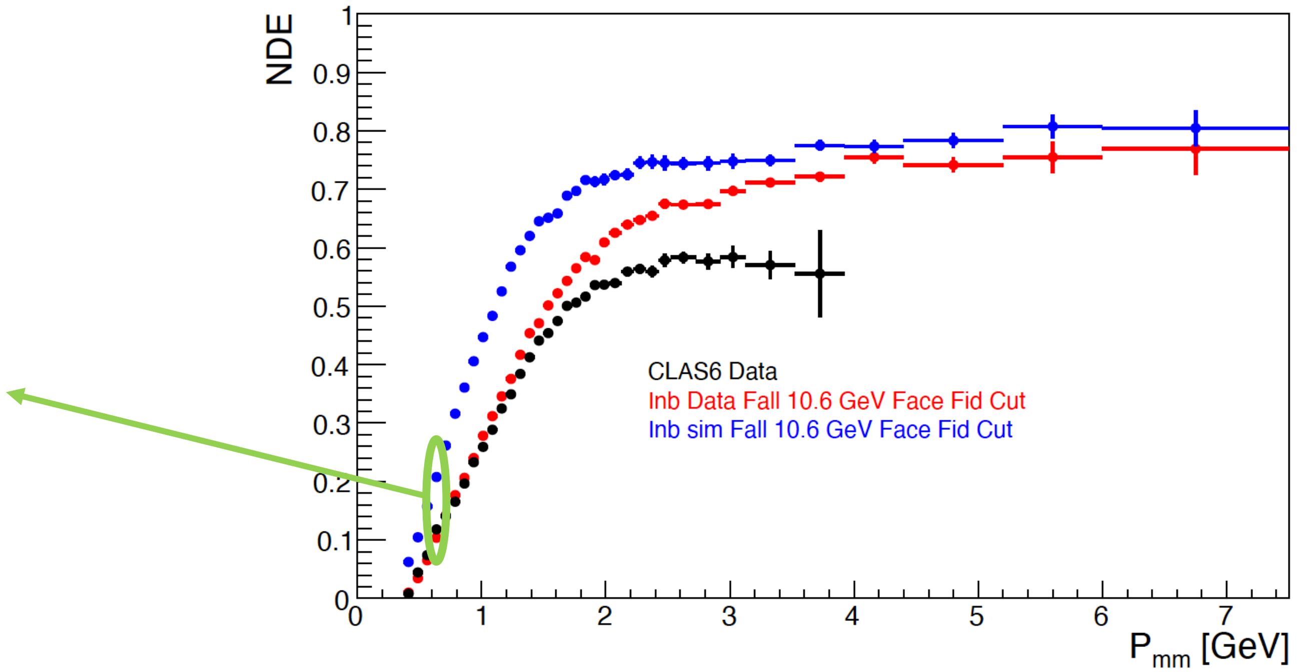
– an enhanced efficiency denominator due to backgrounds inside MM?

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

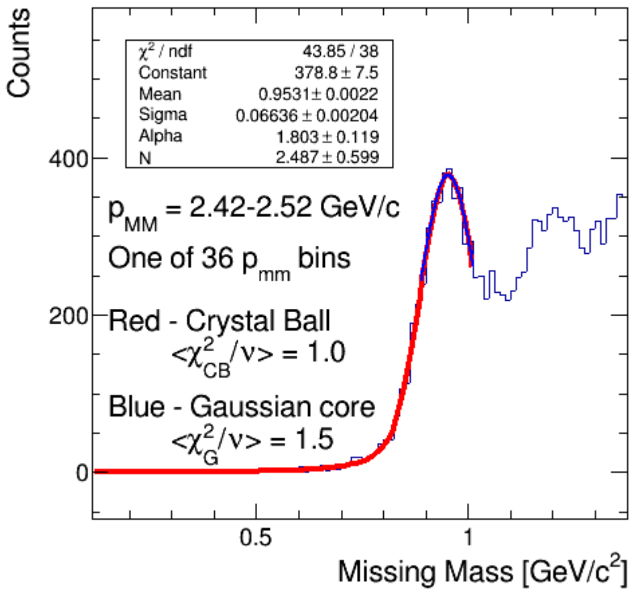


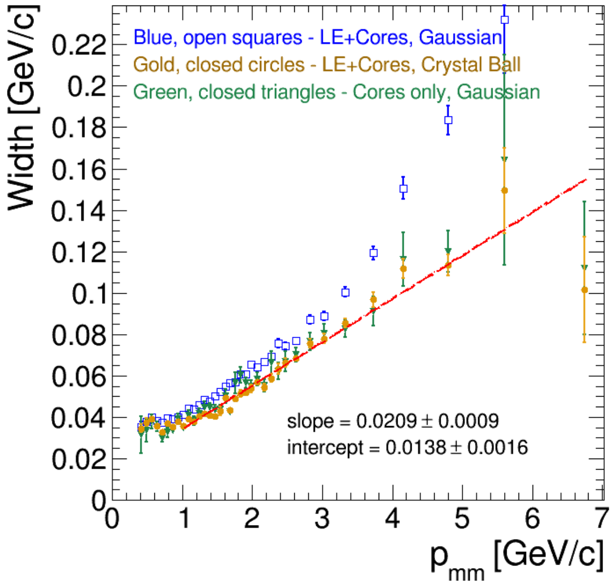
Missing Mass of detected Neutron $H(e,e'\pi^+n)$





Methods to Improve/Validate NDE





- Fit missing mass distributions in missing momentum p_{mm} bins to extract neutron yield. Start with detected neutrons.
- Gaussian fit to cores establishes a baseline. See blue curve top figure. Average χ^2/ν ~1.5 for all p_{mm} bins.
- Extend fits to Missing Mass = 0. Degrades the fit, average χ^2/ν ~3.5.
- Try Crystal Ball function - Gaussian core with an inverse power law tail. (J.E.Gaiser, SLAC-R-255 (1982), p. 178)
- Crystal Ball average χ^2/ν ~1.0 for all p_{mm} bins. See top figure.
- Crystal Ball parameters vary smoothly and agree with Gaussian core. Bottom figure shows width of peak.
- Next: add background at high p_{mm} and then go to expected neutron distributions.

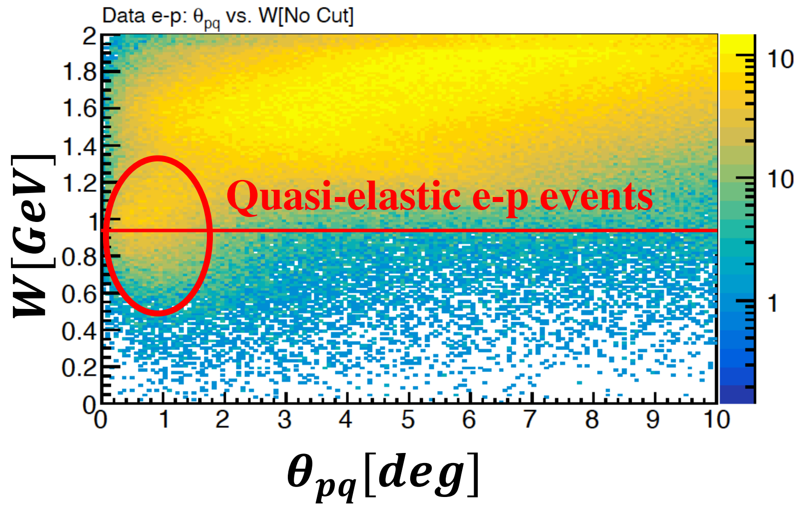
$D(e,e'p)$ Selection

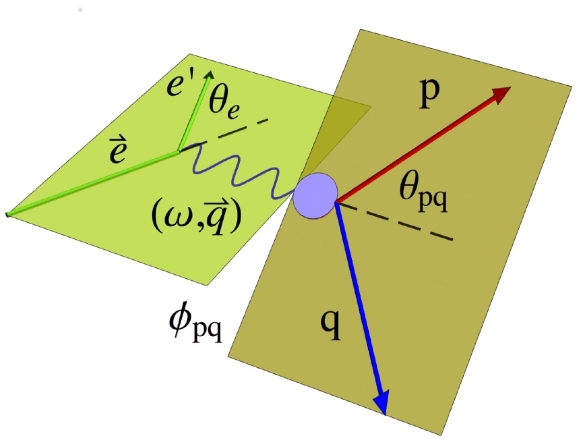
$$R = \frac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\frac{d\sigma}{d\Omega}(D(e,e'p))}$$

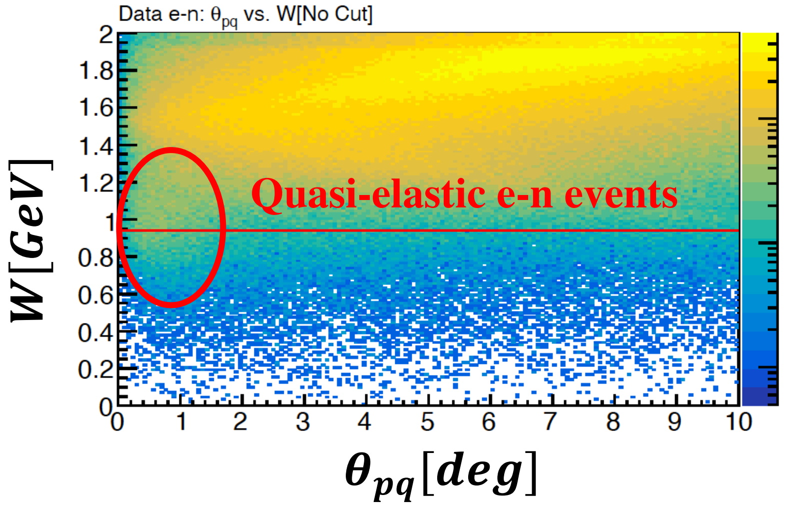
$D(e,e'n)$ Selection

- Select two tracks, one electron in FD and one proton in PCAL/ECAL

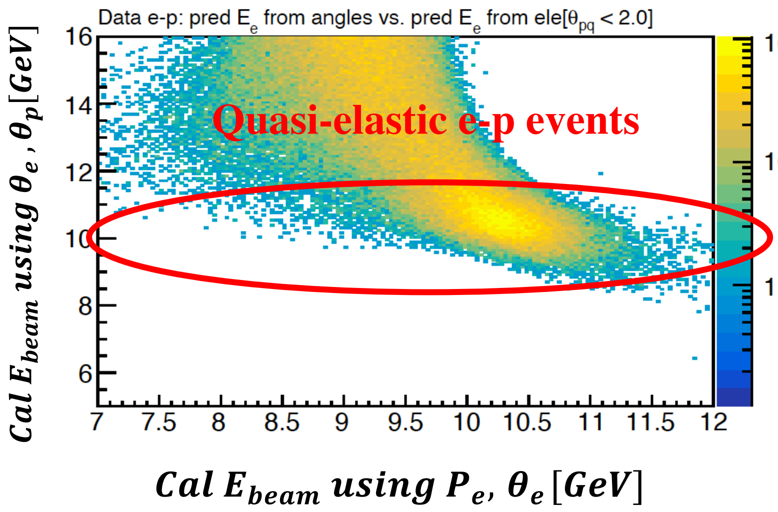
- Select one tracks, one electron in FD







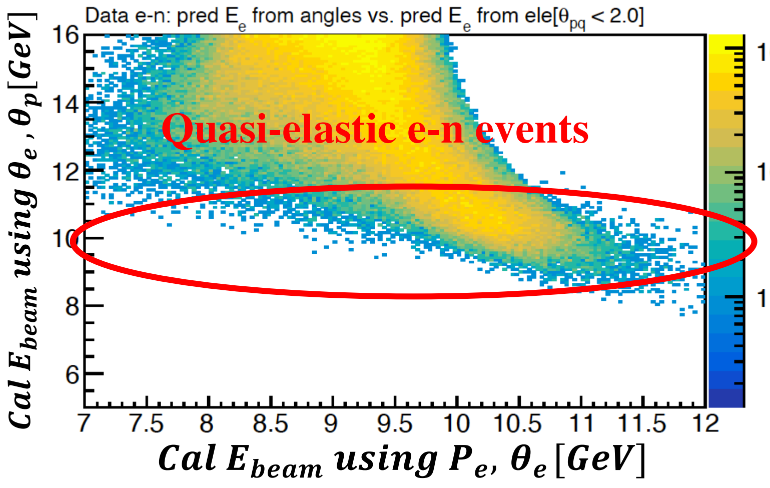
θ_{pq}: The angle between the transferred 3-momentum $\vec{q}$ and the momentum $\vec{P}_N$ of the detected nucleon.



Calculated E_{beam} in 2 diff way:

1-Using only measured P_e, θ_e

2- Using only measured θ_e, θ_p



CLAS-NOTE-02-008

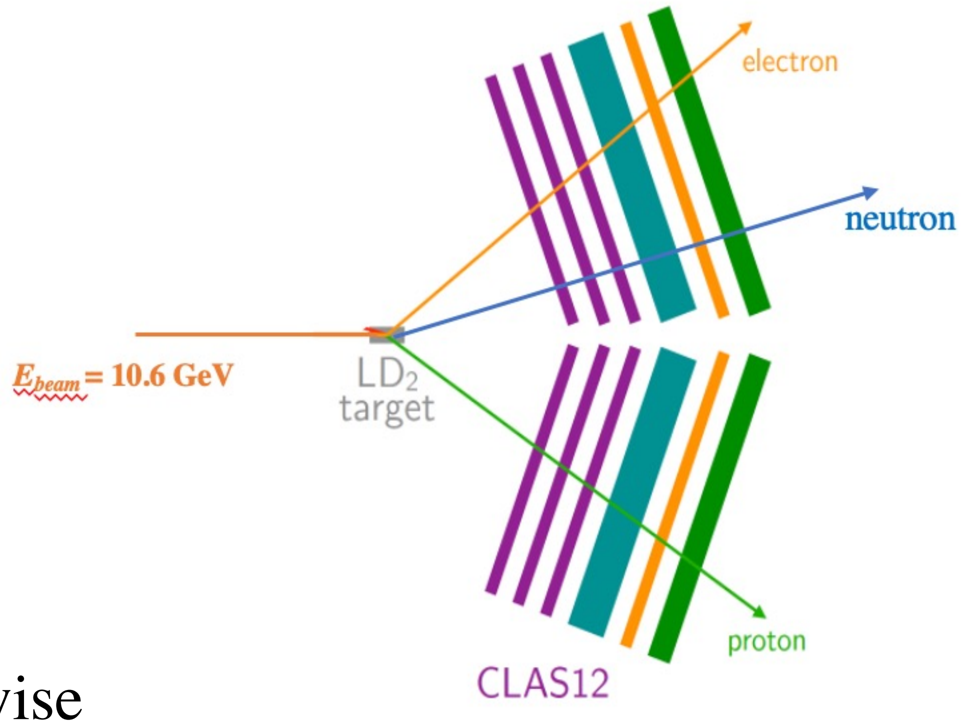
Acceptance Matching

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

Swim the predicted neutron and proton tracks through CLAS12.

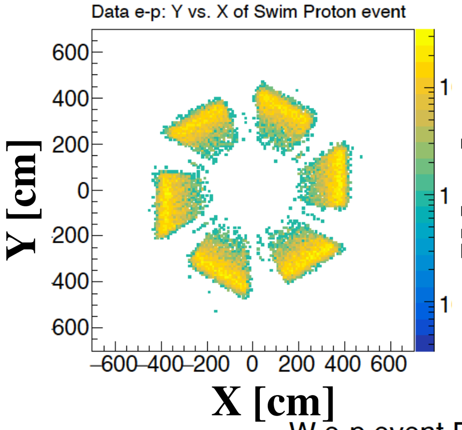
Check that both hadron tracks strike the fiducial volume of CLAS12.

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

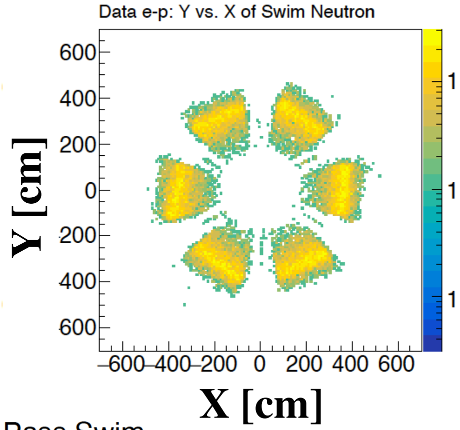


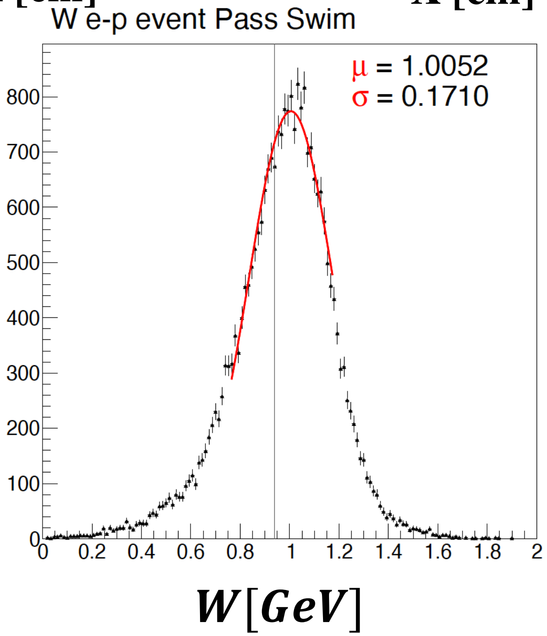
$D(e,e'p)$ Selection

Swimming the **predicted proton**



Swimming the **predicted neutron**

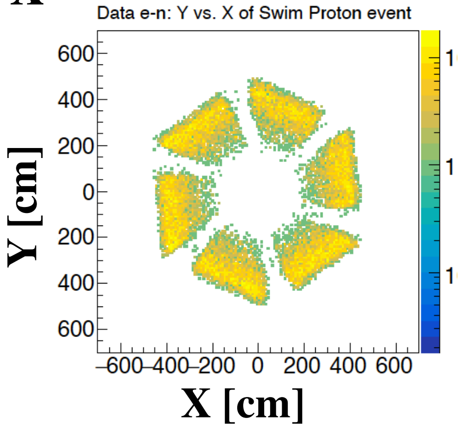




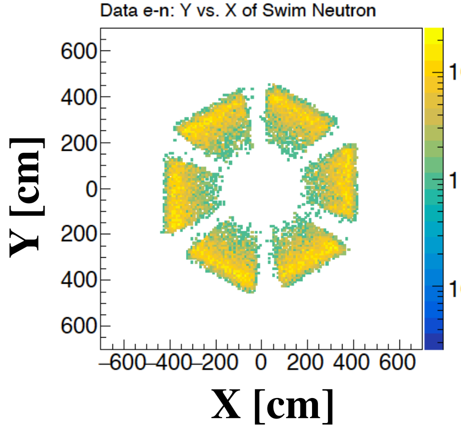
PCAL/ECAL Hit Position Y vs. X

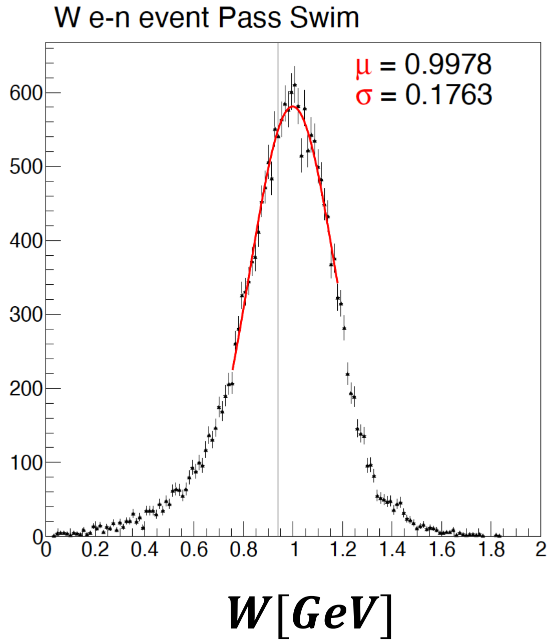
$D(e,e'n)$ Selection

Swimming the **predicted proton**



Swimming the **predicted neutron**

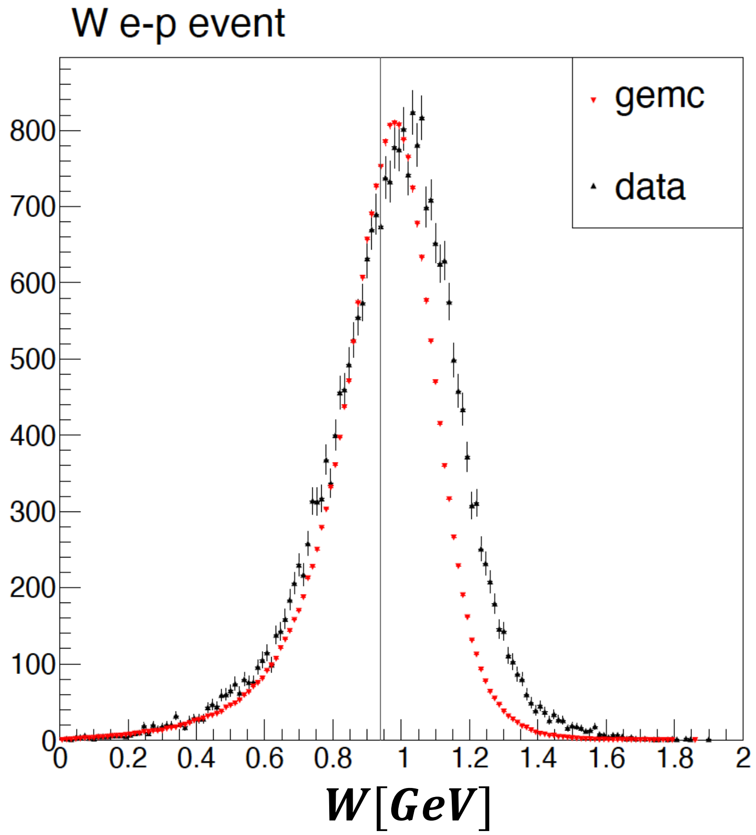




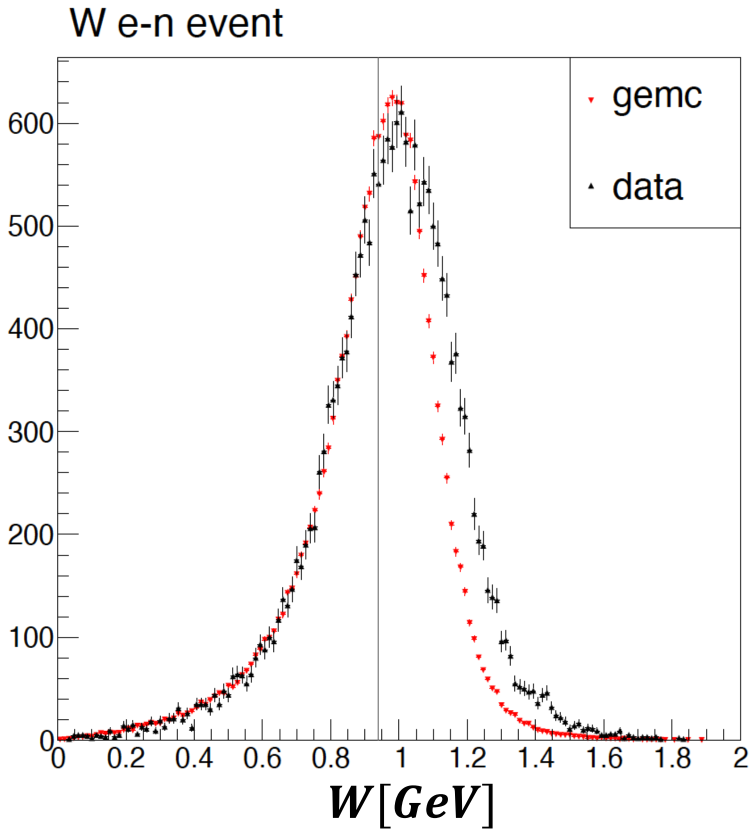
Both quasi-elastic $D(e,e'p)$ and $D(e,e'n)$ ~ same width.
Need to apply energy loss correction.

$D(e,e'p)$ 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.

What Next

In progress:

Neutron detection efficiency (NDE):

- Modeling NDE Data to improve/validate our method.

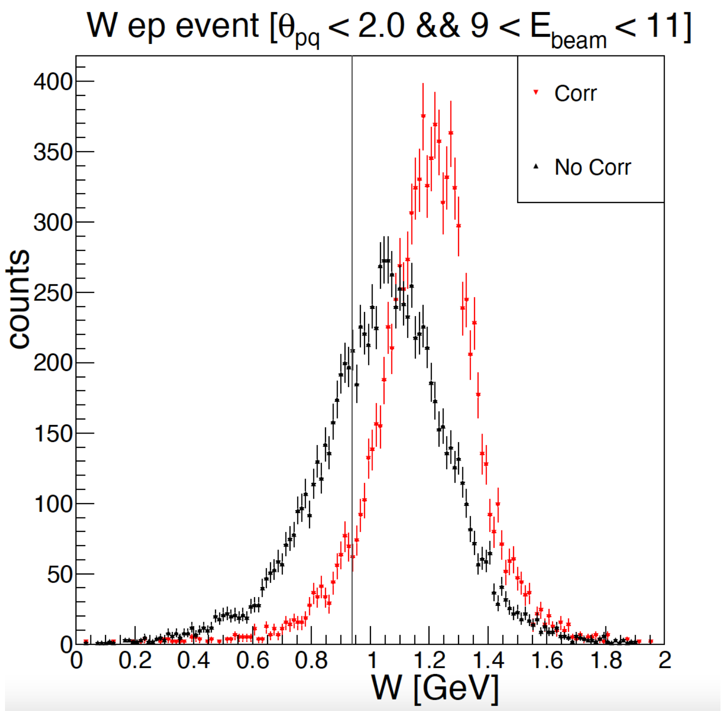
Work on Some Corrections G_M^n as :

- Energy loss corrections.
- Fermi motion corrections.
- Radiative corrections.
- Calculate the Ratio , $R = \dfrac{\frac{d\sigma}{d\Omega}(D(e,e'n))}{\frac{d\sigma}{d\Omega}(D(e,e'p))}$

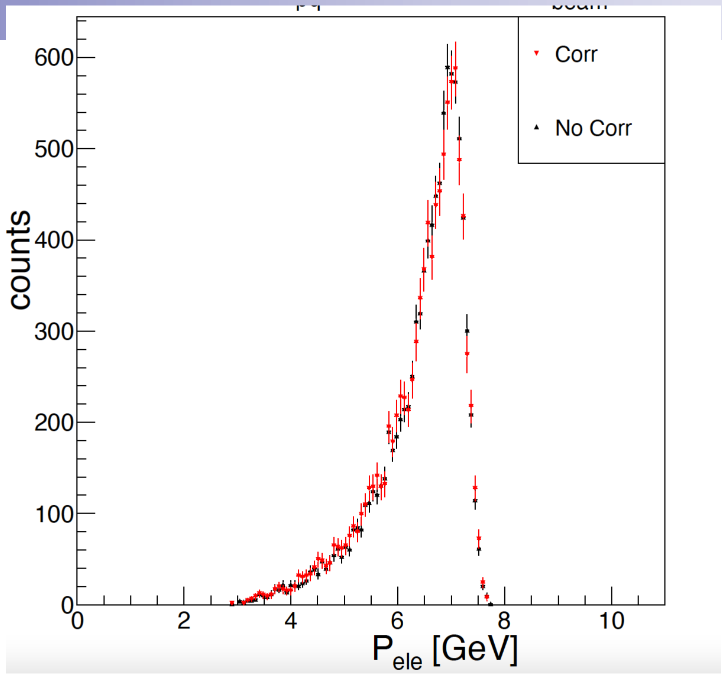
Next:

Study proton detection efficiency on Calorimeter.

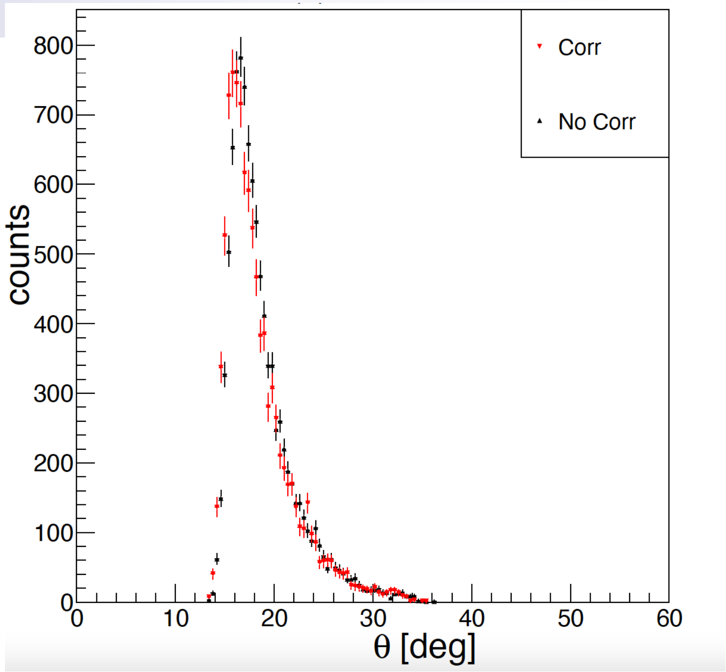
Thank you ..



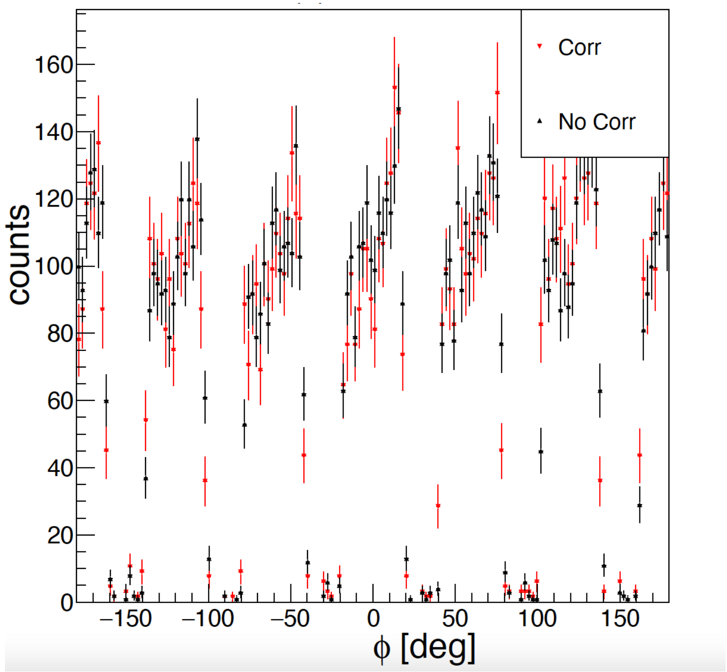
W ep event [$\theta_{pq} < 2.0$ && $9 < E_{beam} < 11$]
Corr
No Corr
counts
W [GeV]



Corr
No Corr
counts
P_{ele} [GeV]



Corr
No Corr
counts
θ [deg]



Corr
No Corr
counts
ϕ [deg]