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

Lamya Baashen

16/6/2023

Overview

- ✓ Ratio Method to extract G_M^n
- ✓ Datasets Used
- ✓ D$(e, e'p)$& D$(e, e'n)$ Selections
- ✓ Neutron Momentum Corrections
- ✓ Preliminary Ratio Results
- ✓ Next step

Measuring G_M^n:

G_M^n : Fundamental quantity related to neutron magnetization.

Use the ratio $\frac{D(e,e'n)}{D(e,e'p)}$ in quasi-elastic kinematics to extract G_M^n.

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

Where:

$$\sigma_{Mott} = \frac{\alpha^2 E' \cos^2(\frac{\theta_e}{2})}{4E^3 \sin^4(\frac{\theta_e}{2})}, \quad \tau = \frac{Q^2}{4\,M_{p,n}^2},$$

$$Q^2 = 4EE'\sin^2\left(\frac{\theta_e}{2}\right), \epsilon = \left[1 + 2(1+\tau)\tan^2(\frac{\theta_e}{2})\right]^{-1}$$

Solving for G_M^n:

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

Extracting G_M^n requires knowledge of other EEFFs

$$R_{cor} = f_{\text{NDE}}\, f_{\text{nuclear}}\, f_{\text{radiative}}\, f_{\text{fermi}}\, R$$

Data Set Used:

- ✓ **Analyzed each dataset separately.**
- ✓ **Excluded the out-bending dataset due to limited statistics.**

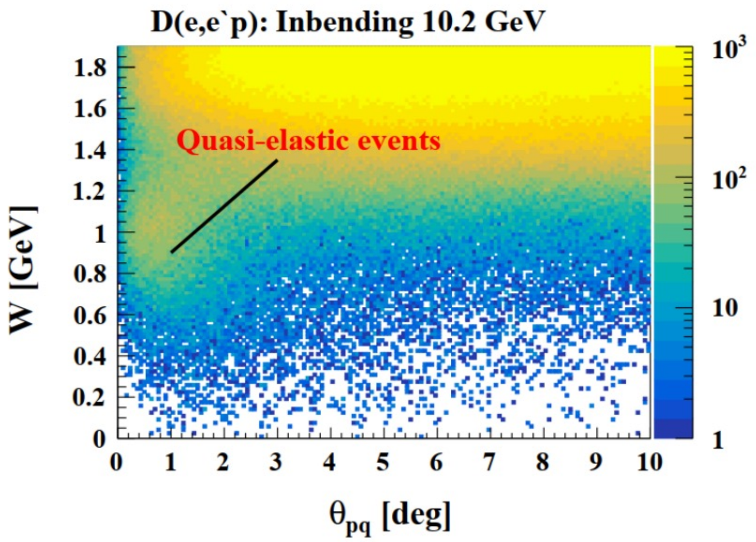
Exp. Detail	In-bending	Out-bending	In-bending
Run Period	Spring 2019	Fall 2019	Spring 2020
Run Range	6156 - 6603	11093 - 11300	11323 - 11571
Number of runs	117 runs 106 runs	97 runs	171 runs
Beam	10.6 GeV 10.2 GeV	10.4 GeV	10.4 GeV
Target	Unpolarized LD2	Unpolarized LD2	Unpolarized LD2
Current	35-50 nA	40 nA	35-50 nA
Torus Field	-1	+1/+1.008	-1
Solenoid Field	-1	-1	-1

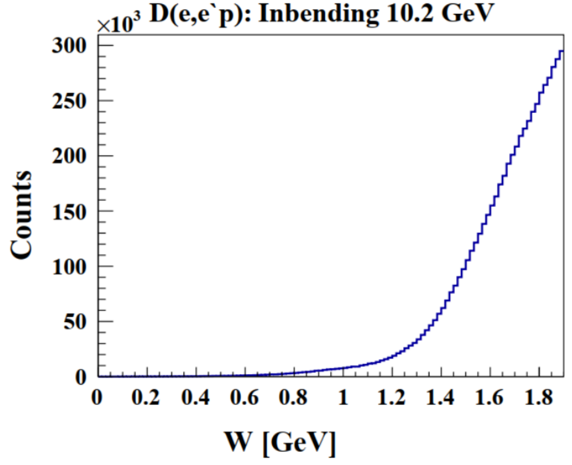
Table 4.1: RG-B run period conditions

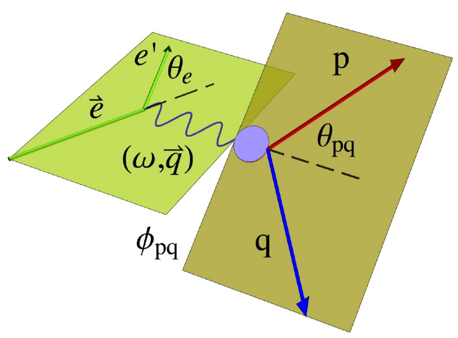
Quasi-elastic Selection

$D(e,e'p)$ Selection

- Select electron in FD and proton hit PCAL/ECAL



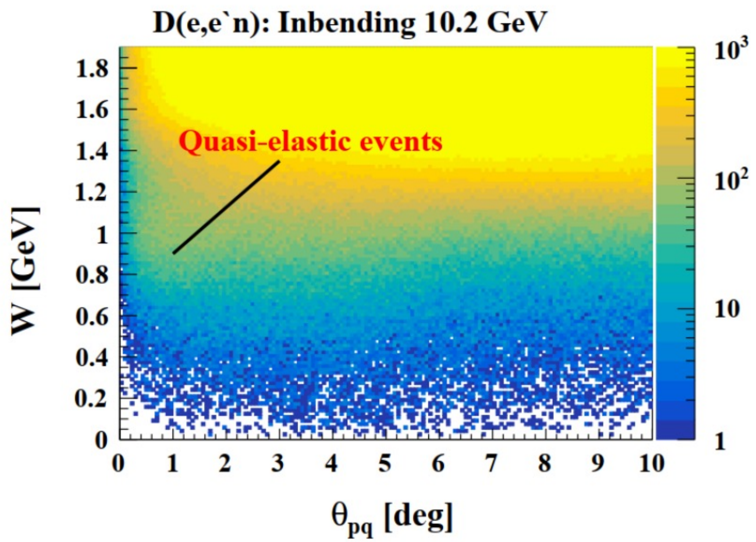


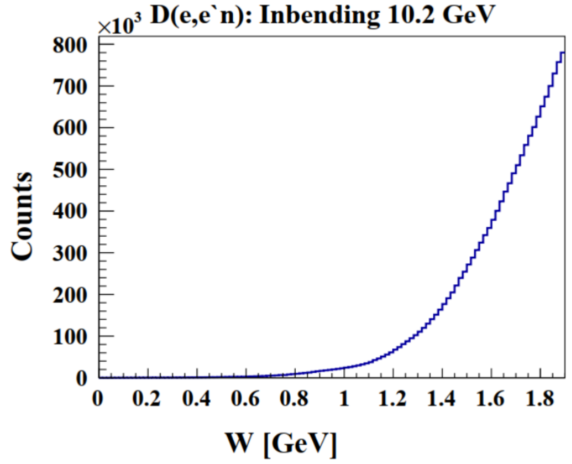


θ_{pq}: The angle between the transferred 3-momentum $\vec{q}$ and the momentum $\vec{P}_N$ of the detected nucleon.

$D(e,e'n)$ Selection

- Select electron in FD and neutral particle hit PCAL/ECAL





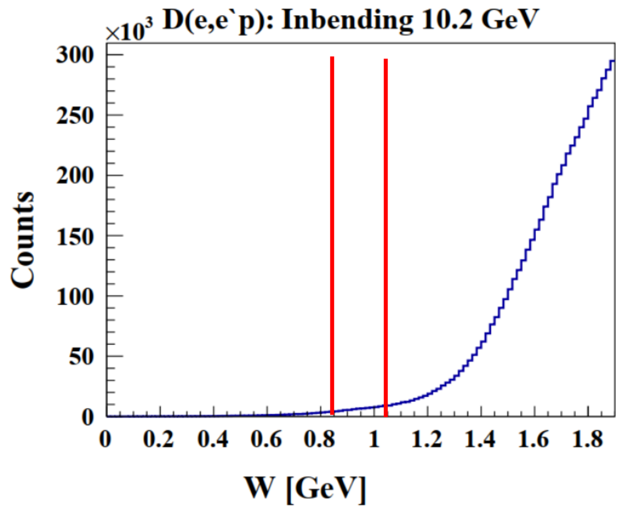
Quasi-elastic Selection

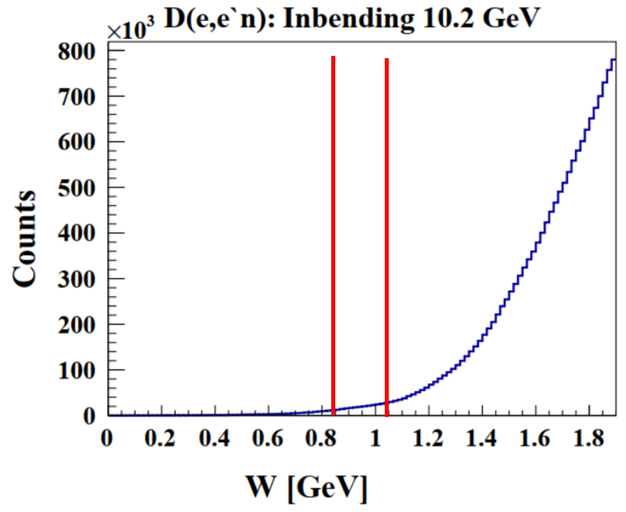
Cut applied

0.85 < W < 1.05

List of the cuts applied to select quasi-elastic events:

- ***Incident electron beam energy $E_{\text{beam}}^{\text{angles}}$ Cut***
- $\Delta\phi = \phi_N - \phi_e$ ***Cut***
- θ_{pq} ***Cut***
- ***Missing Energy Cut***





Quasi-elastic Selection

1- Incident electron beam energy cut

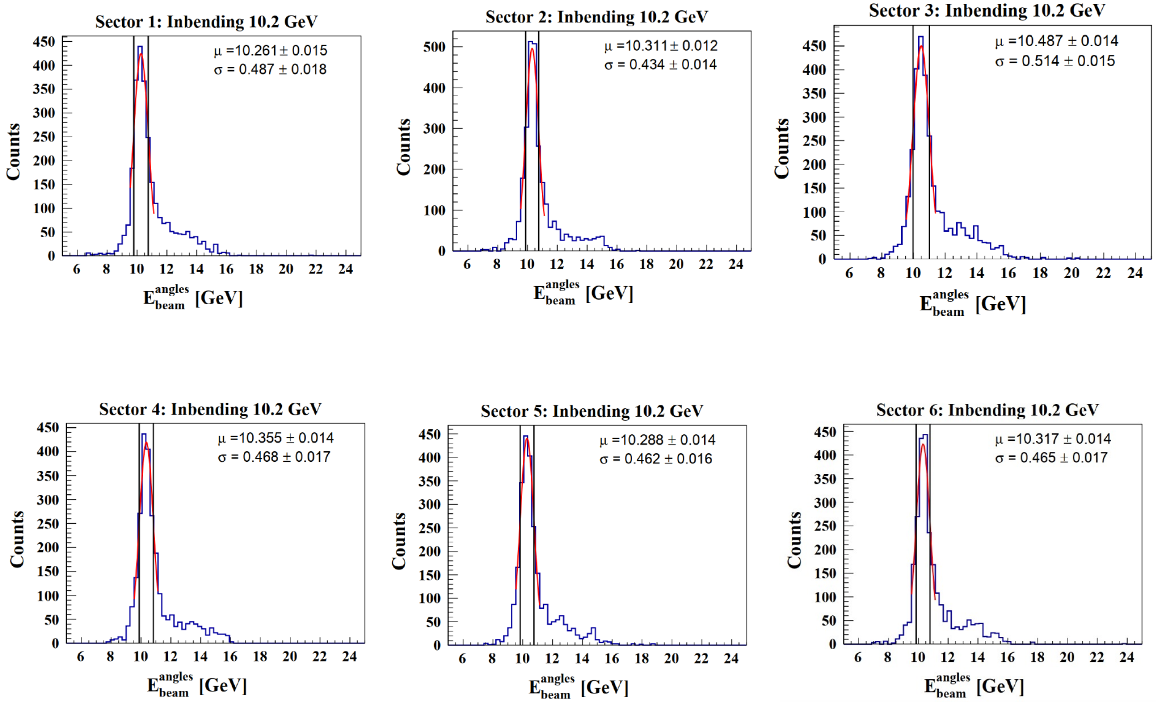
Cut applied

0.85 < W < 1.05

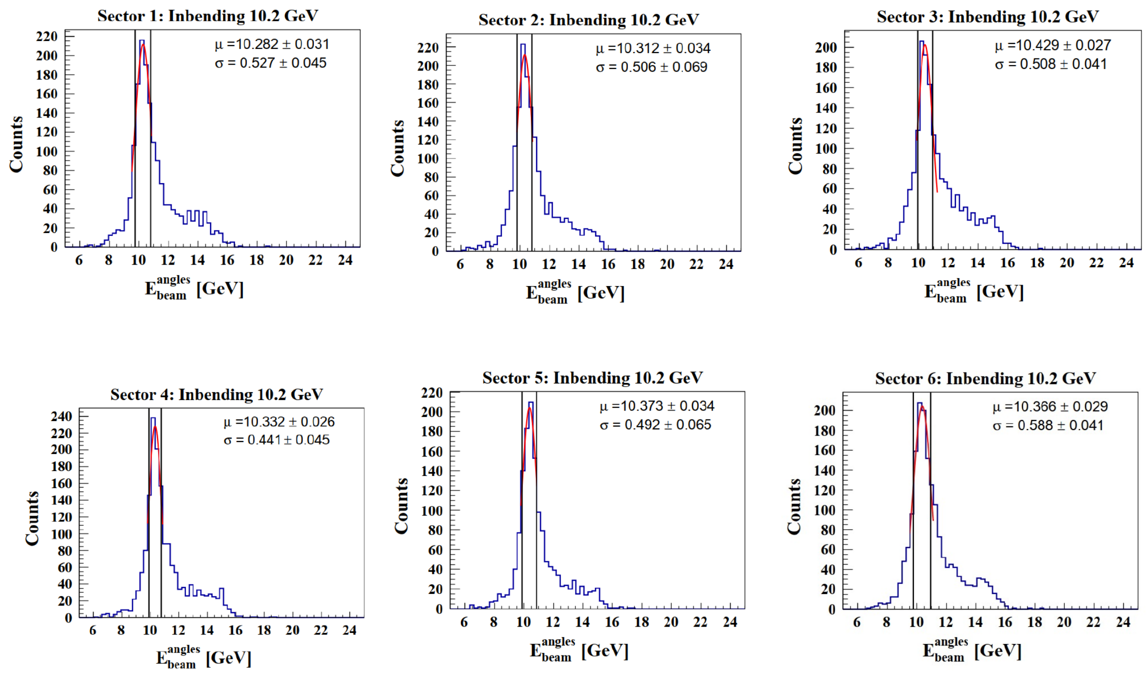
Calculated the incoming beam energy $E_{\text{beam}}^{\text{angles}}$ using θ_e, θ_N:

$$E_{\text{beam}}^{\text{angles}} = M_N \left(\frac{1}{tan\left(\frac{\theta_e}{2}\right)\tan(\theta_N)} - 1 \right)$$

$D(e, e'p)$ Selection



$D(e, e'n)$ Selection



Quasi-elastic Selection

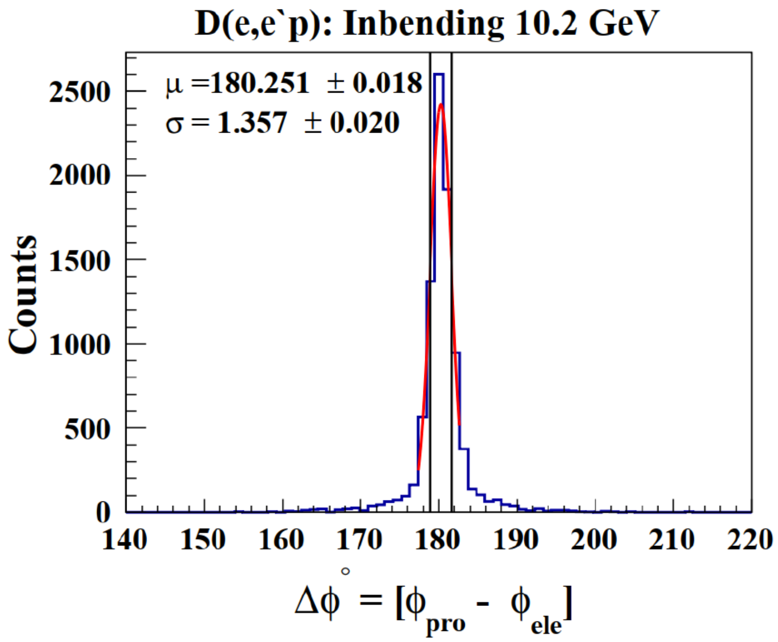
2- $\Delta\phi = \phi_N - \phi_e$ cut

Cut applied
$0.85 < W < 1.05$
$1\ \sigma\ E_{beam}^{angles}$

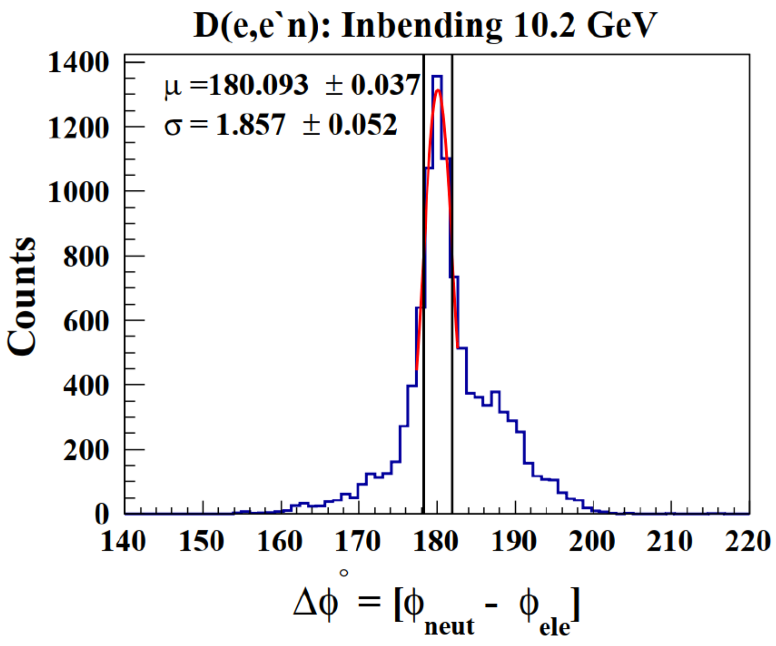
The difference in the lab azimuthal angle between the nucleon and the scattered electron

$$\Delta\phi = \phi_N - \phi_e$$

$D(e,e'p)$ Selection



$D(e,e'n)$ Selection



Quasi-elastic Selection

Cut applied

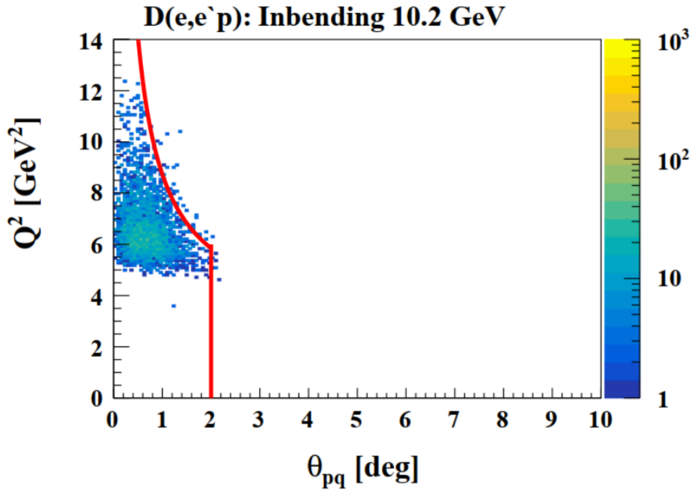
$0.85 < W < 1.05$

$1\ \sigma\ E_{beam}^{angles}$ cut

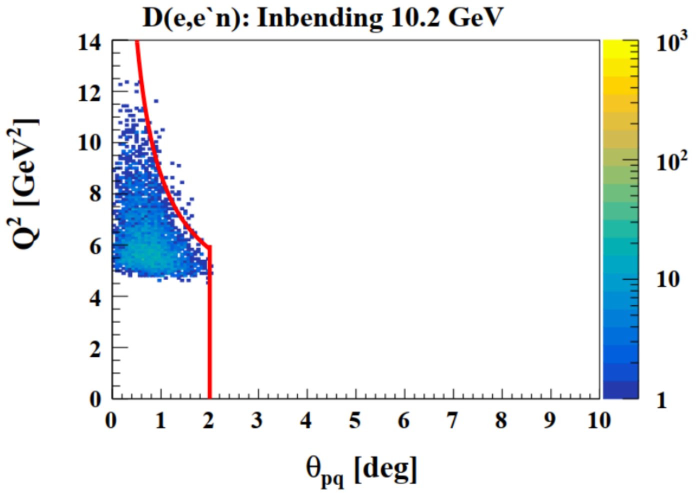
$1\ \sigma\ \Delta\phi$ cut

3- θ_{pq} *cut*

$D(e,e'p)$ Selection



$D(e,e'n)$ Selection



Quasi-elastic events depend on Q^2 value:

high Q^2 ⟶ Quasi-elastic events narrow

small Q^2 ⟶ Quasi-elastic events broader

To select quasi-elastic events while minimizing background contamination in the absence of the W cut, the function is introduced as follows:

$$f(\theta_{pq}) = 2.5204 + \frac{6.2127}{\theta_{pq}^{0.9003}}$$

Cut Used

$Q^2 < f(\theta_{pq})$

$\theta_{pq} < 2$

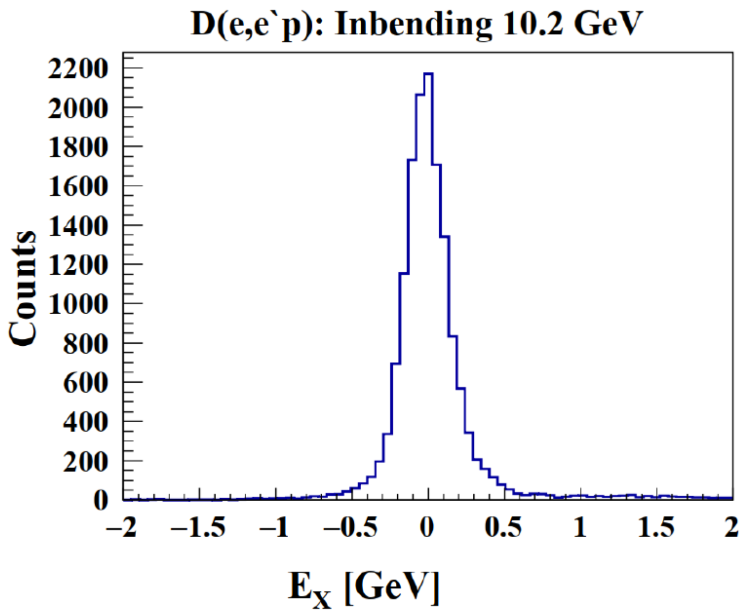
Quasi-elastic Selection

4-Missing Energy Cut

From the momentum conservation law the transverse momentum for quasi-elastic events are expected to be zero.

$$E_x = E_{beam} + E_N - E_{e'} - E_{N'}, \quad where \quad E = \sqrt{P^2 + m^2}$$

$D(e,e'p)$ Selection



Cut applied

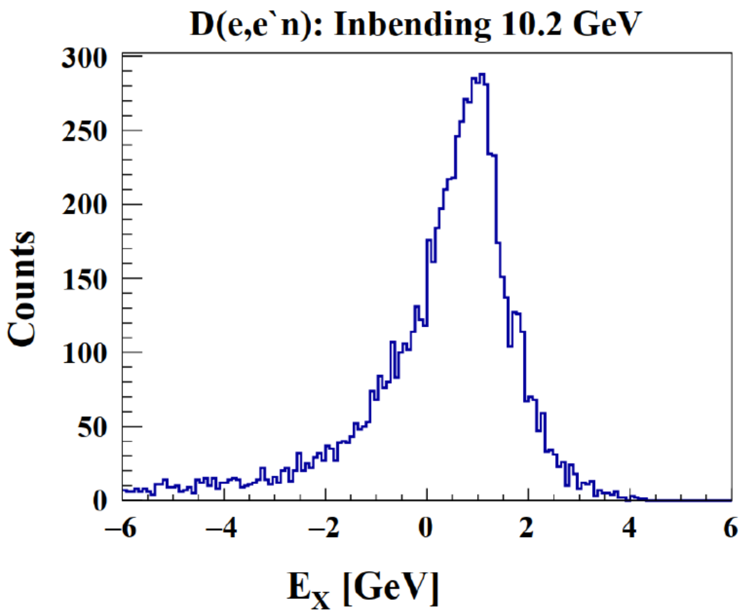
$1\ \sigma\ E_{beam}^{angles}$ cut

$1\ \sigma\ \Delta\phi$ cut

$Q^2 < f(\theta_{pq})$

$\theta_{pq} < 2$

$D(e,e'n)$ Selection



Neutron Momentum Correction

In order to correct the measured neutron momentum (P_{meas}) a calculated neutron momentum (P_{calc}) is used as a reference (accurate value)

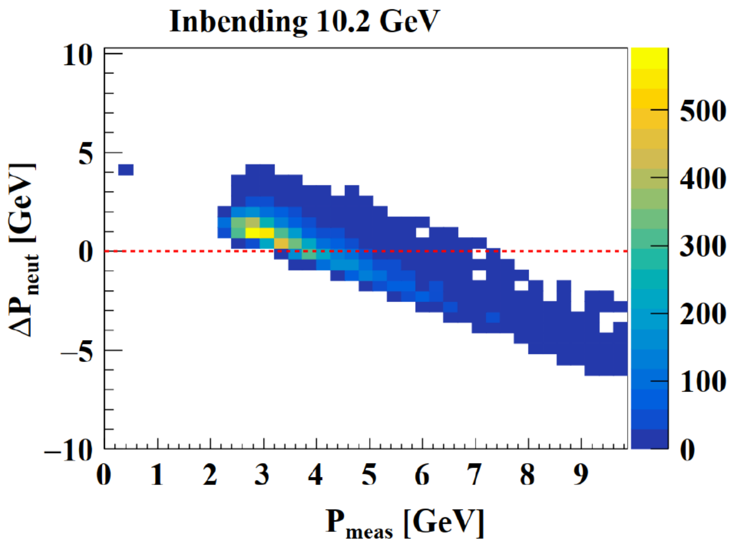
$$\Delta P_{neut} = p_{calc} - p_{meas}$$

The calculated neutron momentum is determined based on the known E_{beam} and the measured electron polar angle, assuming elastic scattering

$$P_{calc} = \sqrt{E_0^2 - 2\,E_0 * p_{ecal} * \cos\theta_e + p_{ecal}^2}\,, \qquad \text{where} \quad P_{ecal} = \frac{E_0}{1 + 2E_0 \sin^2(\frac{\theta_e}{2})/M_N}$$

The measured neutron momentum (P_{meas}) is determined using

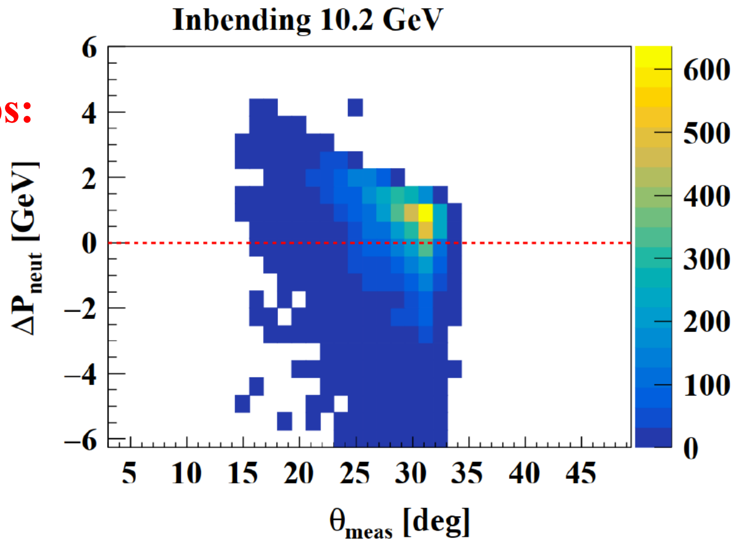
$$P_{meas} = \frac{m_n\,\beta_{neutral}}{\sqrt{1 - \beta_{neutral}^2}}\,, \qquad \text{where} \quad \beta_{neutral} = \frac{l_{n(REC)}}{c.(t_{n(REC)} - t_{st})}$$



The neutron momentum correction is made in two steps:

1- ΔP_{neut} vs. P_{meas}

2- ΔP_{neut} vs. θ_{meas}



Neutron Momentum Correction

1- ΔP_{neut} $vs.$ P_{meas}

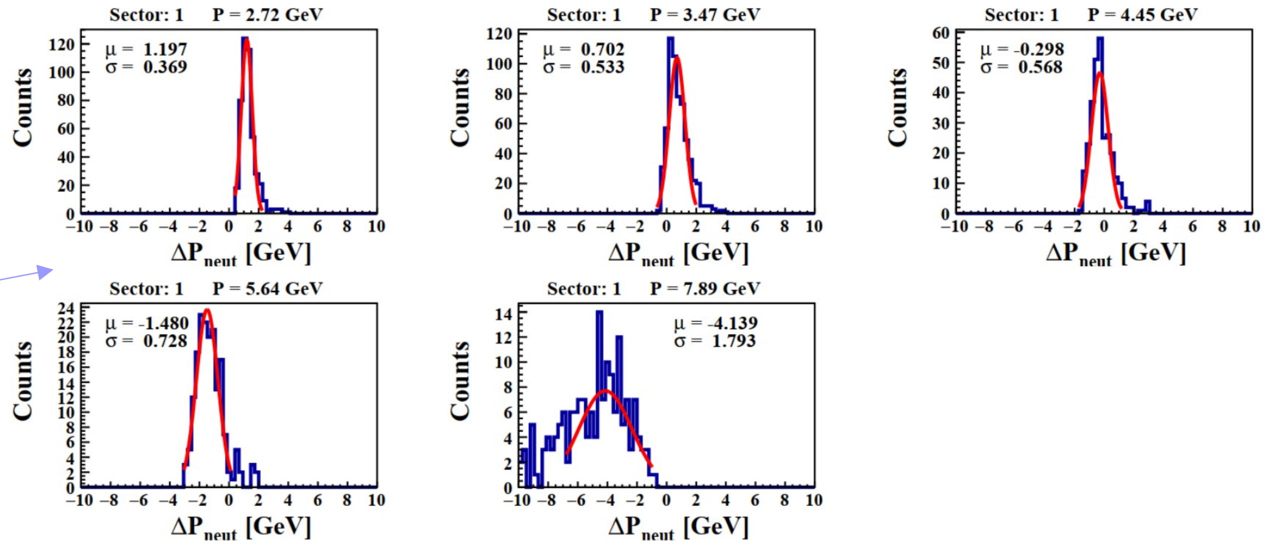
1- Correction done for each sector
2- Binning ΔP_{neut} in P_{meas}
3- Fitting ΔP_{neut} using Gauss
4- The mean of the Gauss is then fit by 1st order Poly:

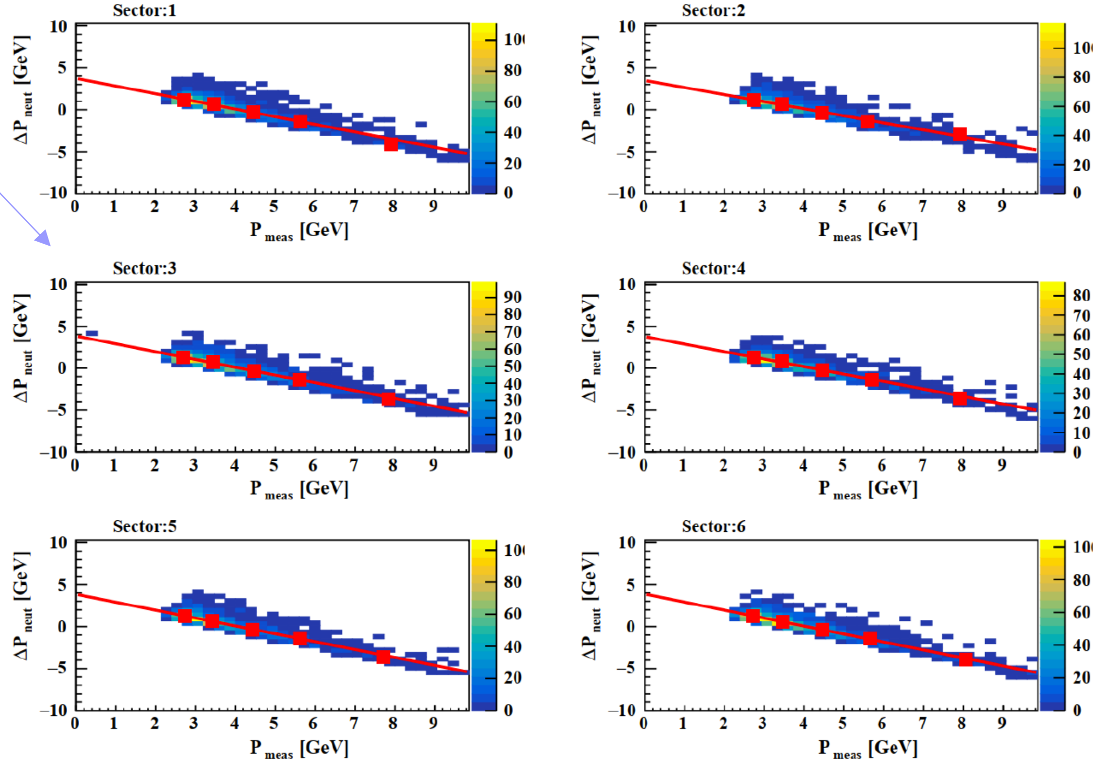
$$\mu_p = a_p + b_p \, P_{meas}$$

5- the momentum correction function

$$P_{Pcorr} = P_{meas} + \mu_p$$

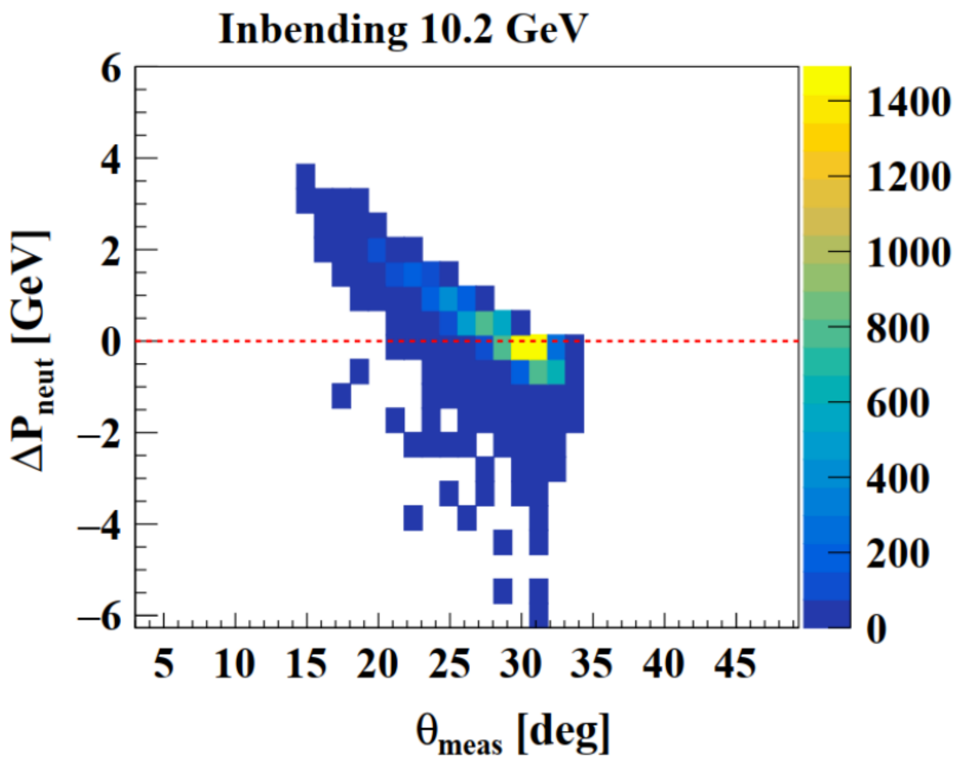
is then implemented with the parameters coming from fits.

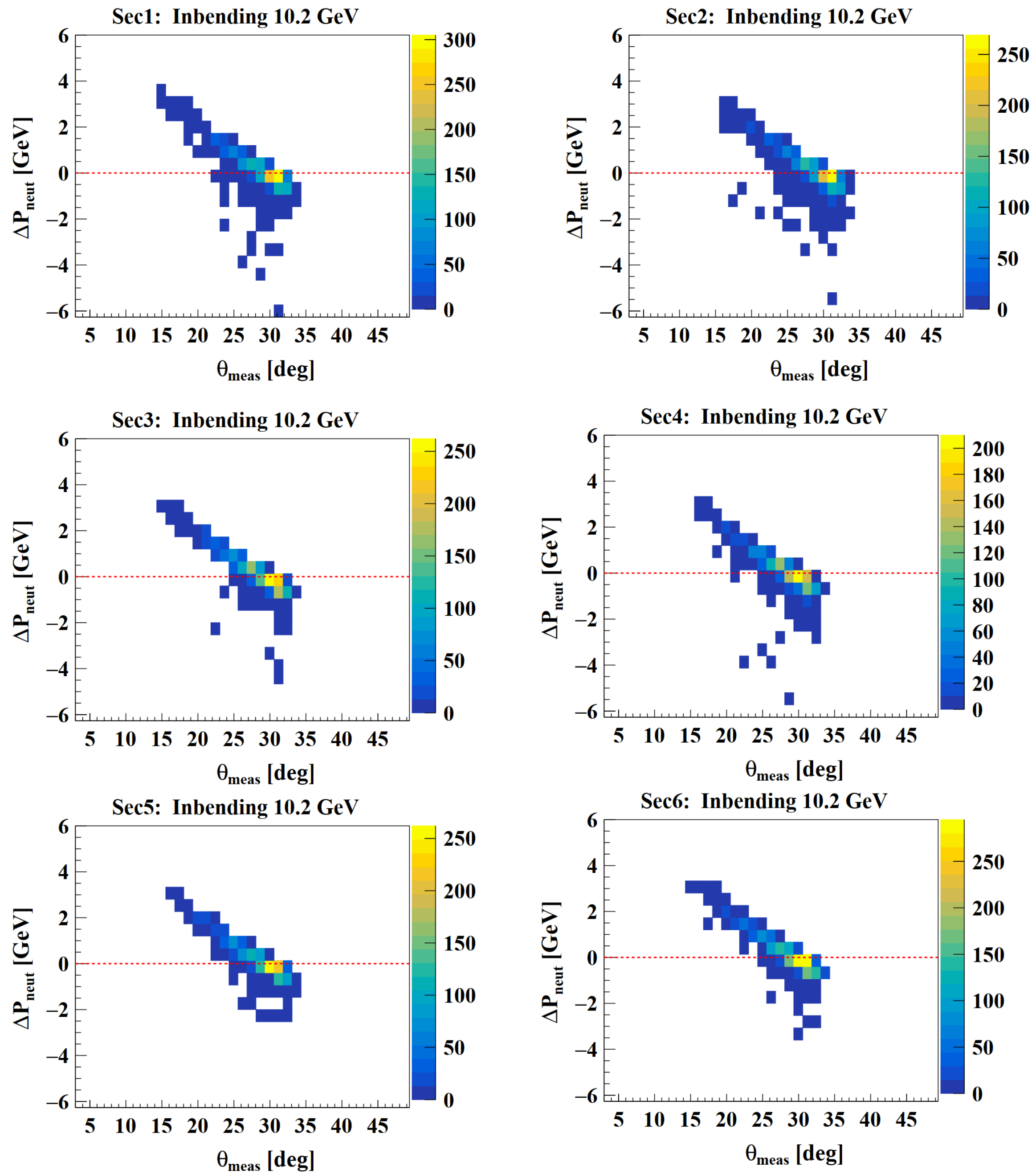




Neutron Momentum Correction

$2 - \Delta P_{neut}$ vs. θ_{meas}





Neutron Momentum Correction

$2 - \Delta P_{neut}\ vs.\ \theta_{meas}$

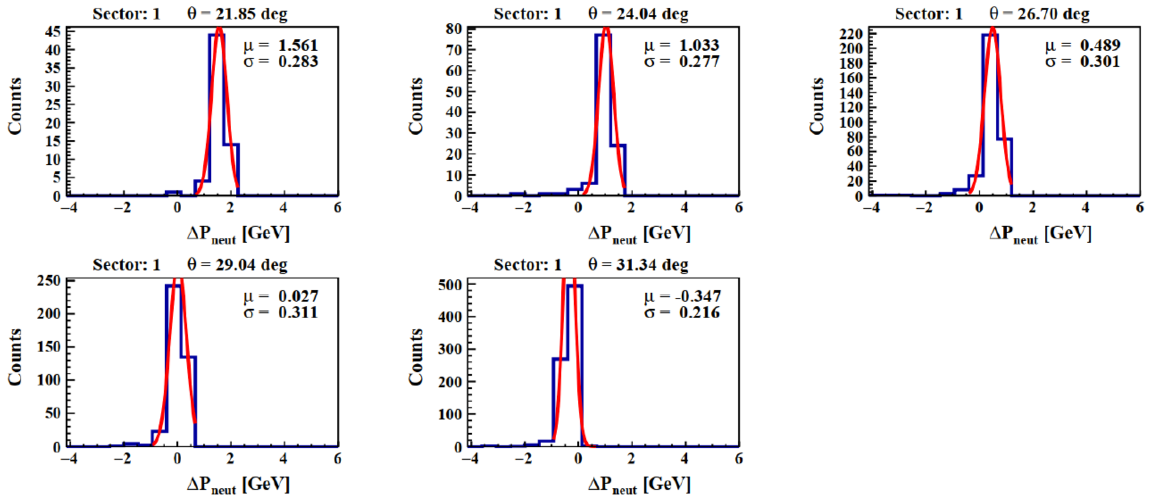
1- Correction done for each sector
2- Binning ΔP_{neut} in θ_{meas}
3- Fitting ΔP_{neut} using Gauss
4- The mean of the Gauss is then fit by 1st order Poly

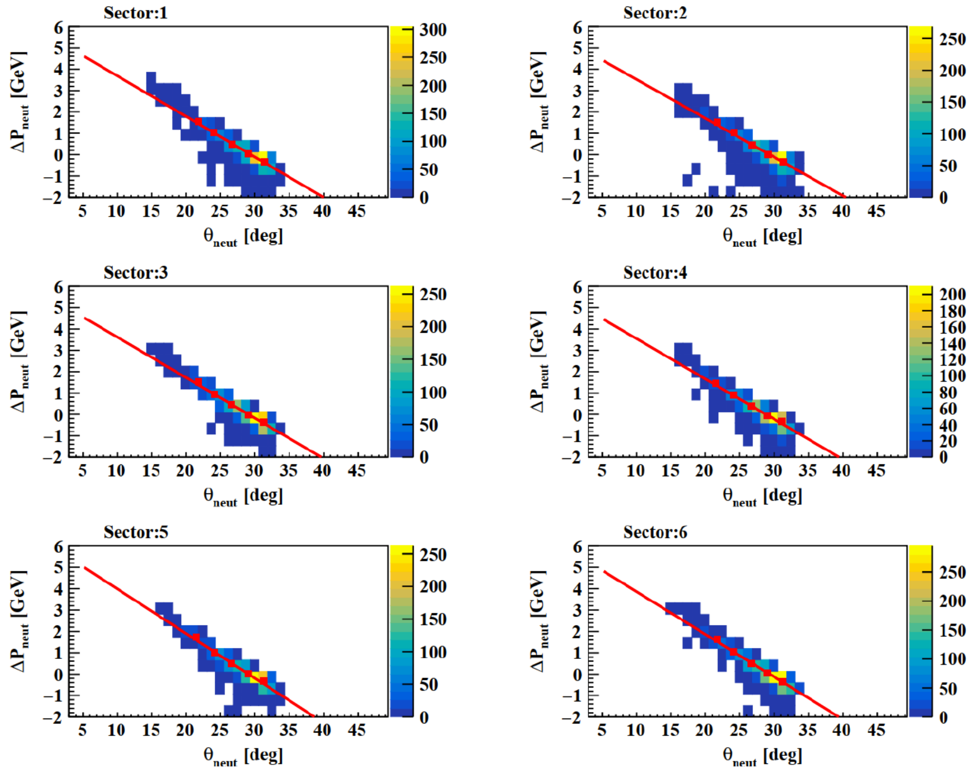
$$\mu_\theta = a_\theta + b_\theta\, \theta_{meas}$$

5- the momentum correction function

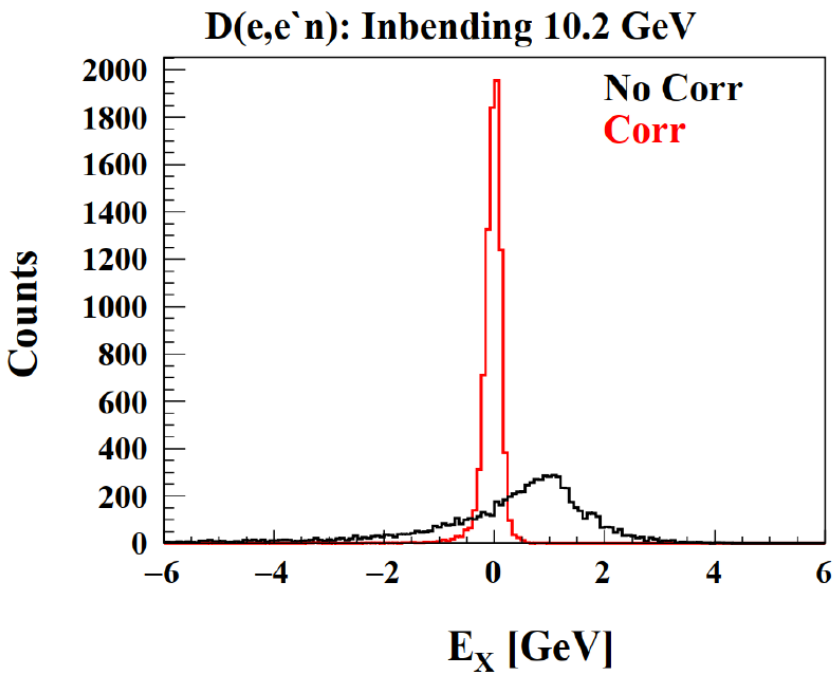
$$P_{\theta corr} = P_{meas} + \mu_\theta$$

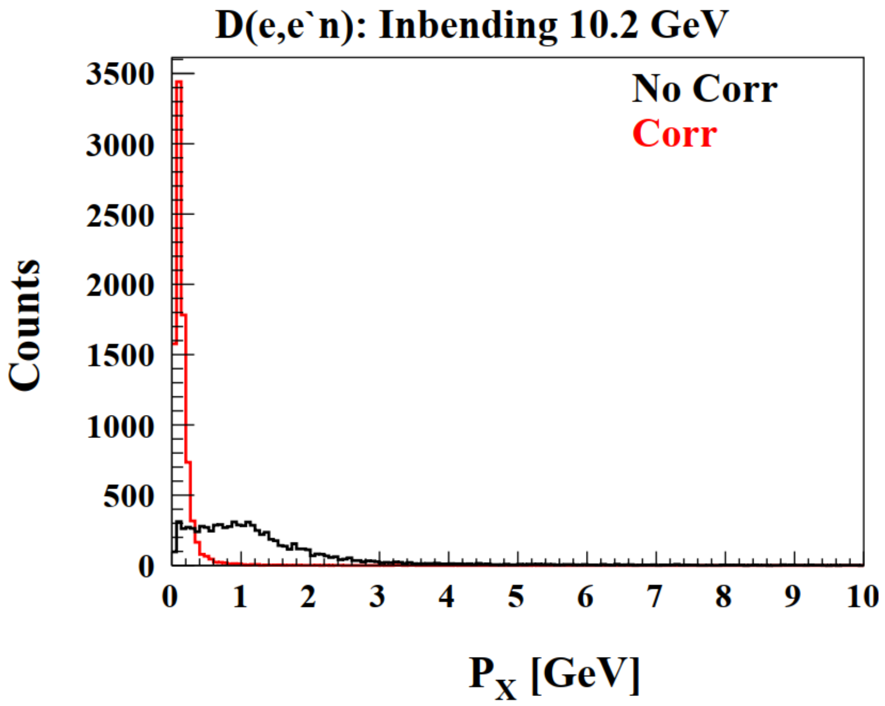
is then implemented With the parameters coming from fits.





Results of Correction





The corrections have led to clear improvements in both the resolutions and peak position of the missing energy distribution.

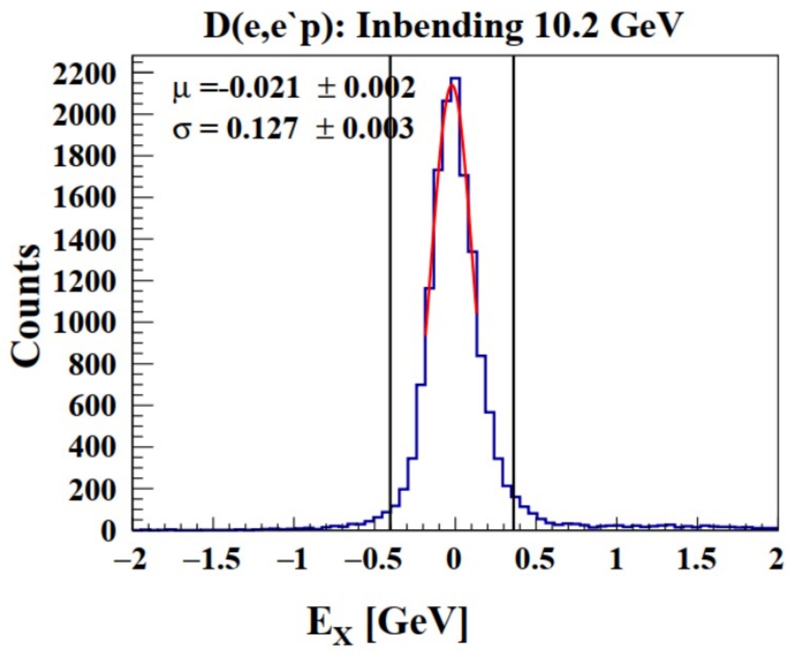
Quasi-elastic Selection

4-*Missing Energy Cut*

From the momentum conservation law the transverse momentum for quasi-elastic events are expected to be zero.

$$E_x = E_{beam} + E_N - E_{e'} - E_{N'}, \quad where \quad E = \sqrt{P^2 + m^2}$$

$D(e,e'p)$ Selection



Cut applied

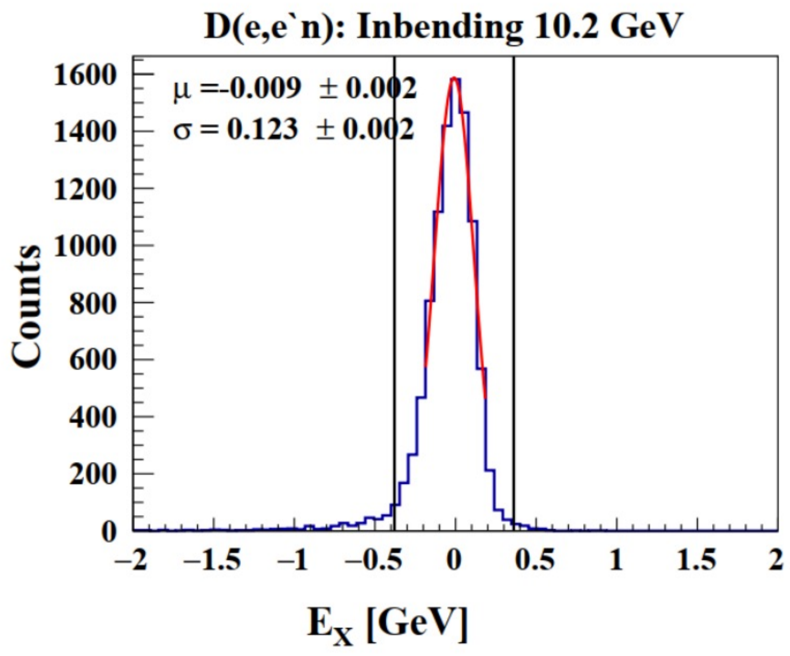
1 σ E_{beam}^{angles} cut

1 σ $\Delta\phi$ cut

$Q^2 < f(\theta_{pq})$

$\theta_{pq} < 2$

$D(e,e'n)$ Selection



Quasi-elastic Selection

The W distribution of $D(e,e'p)$ and $D(e,e'n)$ that satisfied

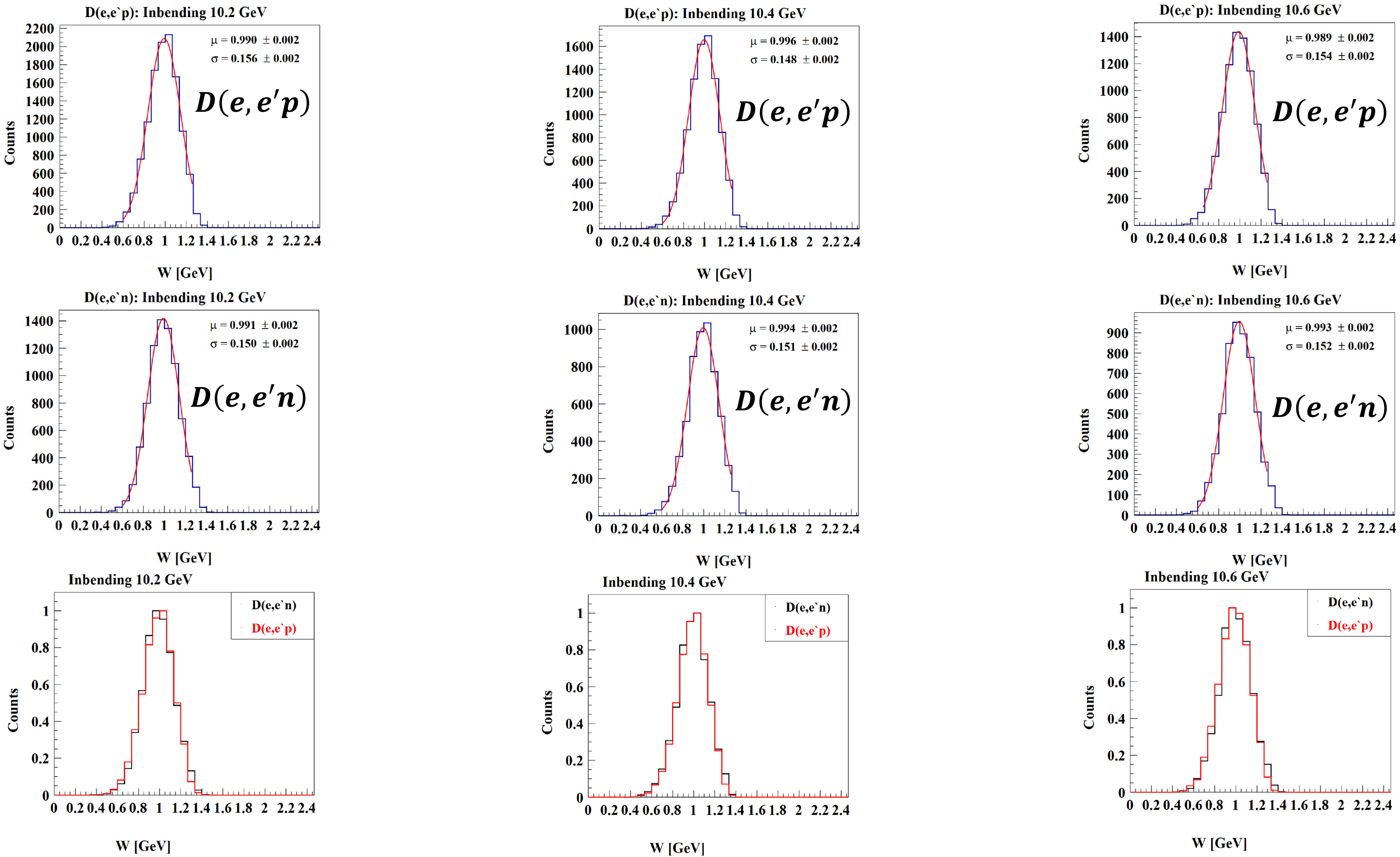
$1\ \sigma\ E_{beam}^{angles}$ cut

$1\ \sigma\ \Delta\phi$ cut

$Q^2 < f(\theta_{pq})$

$\theta_{pq} < 2$

$3\ \sigma\ E_x$



Acceptance Matching

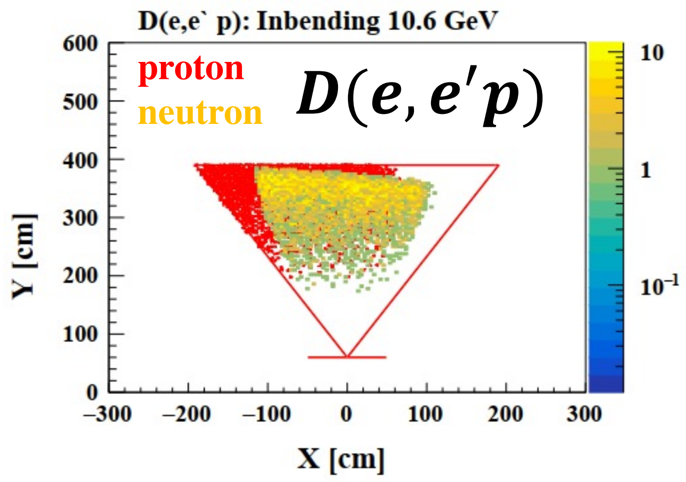
Using only the electron information, assume elastic scattering, predict the proton momentum, and swim it through CLAS12.

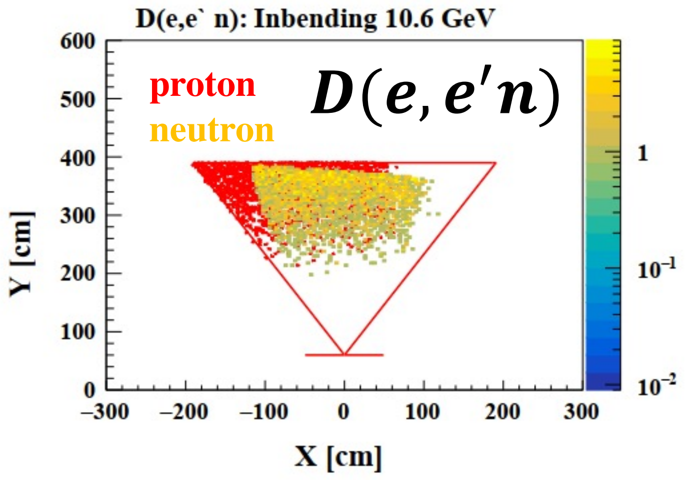
If the 'swum' proton track strikes the CLAS12 fiducial volume, continue. If it does not, then drop the event.

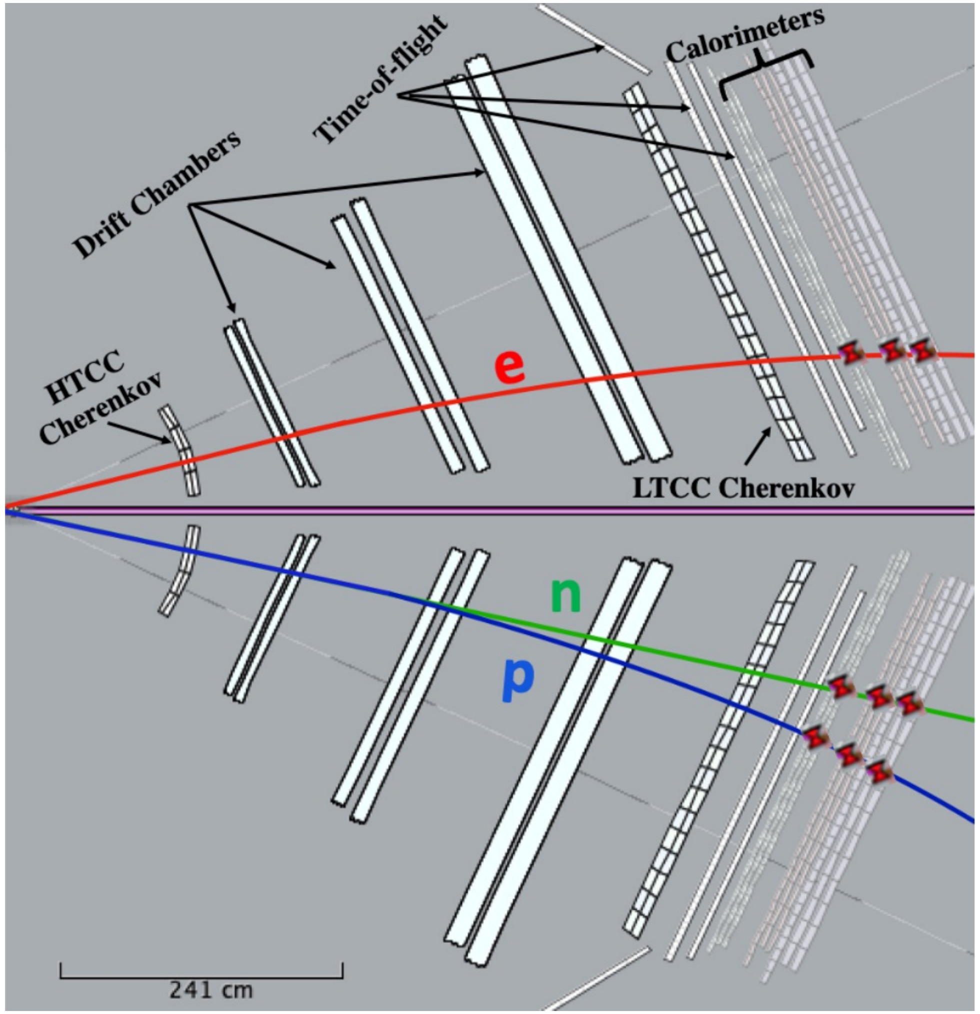
Using only the electron information, assume elastic scattering, predict the neutron momentum, and swim the neutron track through CLAS12.

If the 'swum' neutron track strikes the CLAS12 fiducial volume, continue. If it does not, then drop the event.

If both 'swum' tracks hit CLAS12, begin the nucleon analysis

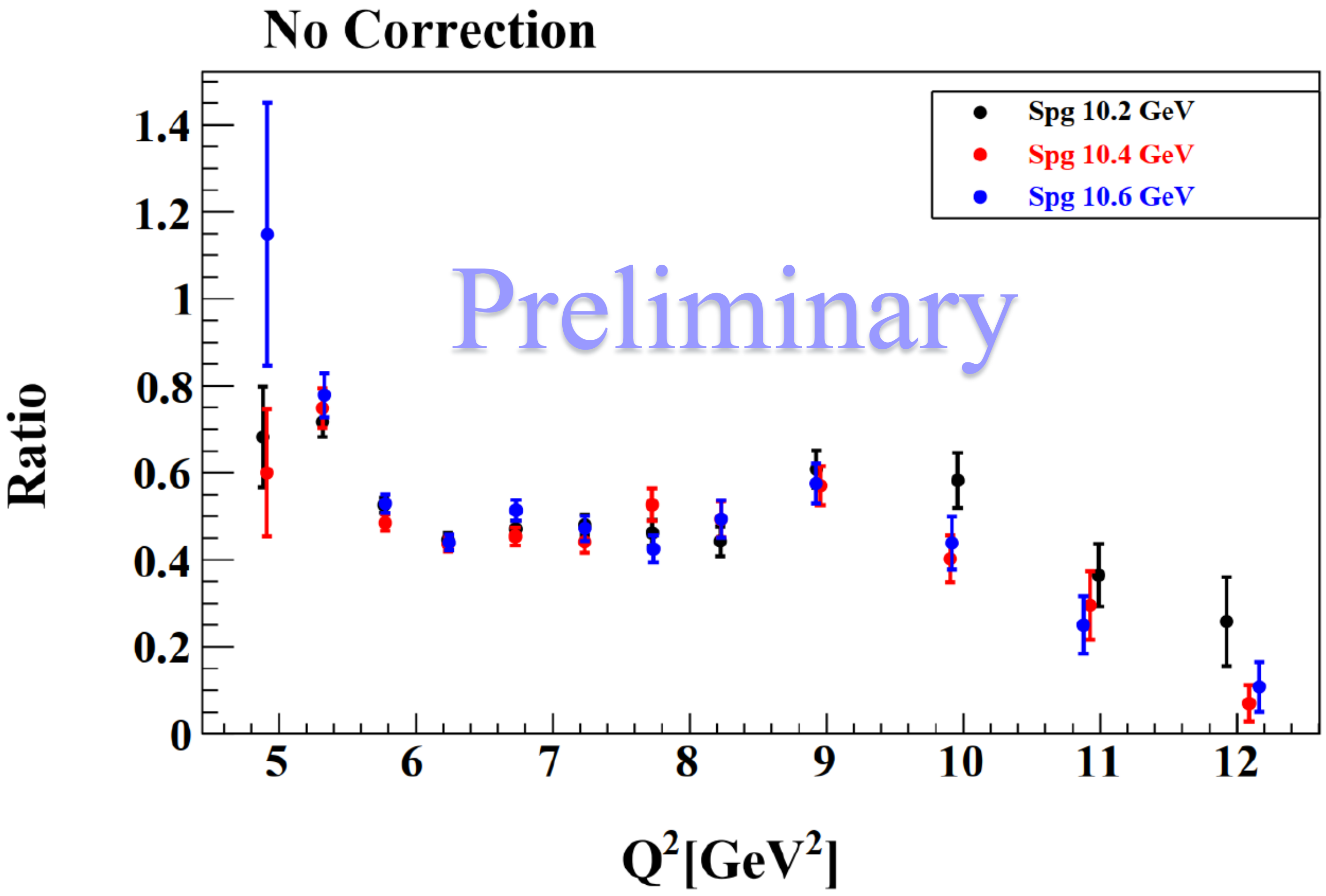






Ratio Result

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



What is Next

Applied the correction to the Ratio:

1- NDE Correction

2- Fermi Correction

3- Radiative Correction

4- Nuclear Correction

Calculate G_M^n:

Looking for the recent G_E^p, G_M^p *and* G_E^n parameterization

Thank you !!