





Measurement of the Neutron Magnetic Form Factor G_M^n at High Q^2 Using the Ratio Method on the Deuteron

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Why we need to measure G_M^n on a Neutron

- I. G_M^n : Fundamental quantity related to neutron magnetization.
- **II.** The form factors provide important constraints for GPDs:

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

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

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



RGB Data Set

Dataset used:

The RGB experiment ran on three different periods:

RGB Spring 2019 inbending:

1- $E_{beam} = 10.5986$ GeV: 117 production runs 2- $E_{beam} = 10.1998$ GeV: 106 production runs

RGB Fall 2019 outbending:

1- $E_{\text{beam}} = 10.4096 \text{ GeV}$: 97 production runs

RGB Spring 2020 inbending: 1- E_{beam} = 10.4096 GeV: 171 production runs

Quarter of the data were taken with a 10.6 GeV beam, another quarter at 10.2 GeV and the other half at 10.4 GeV

Monte-Carlo simulation

The generator used is QUEEG 'QUasi-Elastic EventGenerator'

Written by:

J.Lachniet and developed more by G.P. Gilfoyle **The Fermi-motion distribution :** is calculated with the Hulthen distribution **The generator produces either:** $ed \rightarrow e'n'(p)$ or $ed \rightarrow e'p'(n)$ events. Generating MC events with new gemc version 4.4.1/4.4.2 **Then reconstructed events with :** the same COATJAVA version 6.5.8 as the data.

> Generated && Simulated ~ 30 M events at 3 different beam energy



D(e, e'p) Selection

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

- Select two tracks, one electron in FD and one proton in FD
- Apply cut on W² < 4.0 && E_{beam} Calculated >9.8 GeV
- > Apply cut on θ_{pq} <1.5 to reduce inelastic contamination







E_{beam} = 10.1998 GeV

E_{beam} = 10.5986 GeV

 $E_{beam} = 10.4096 \text{ GeV}, Fall2019$



Acceptance Matching

Use the measured electron information to predict the trajectory of the associated 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.



R =

D(e, e'p) Selection Required proton hit FD

- Select two tracks, one electron in FD and one proton in FD \geq
- \triangleright Apply cut on W² < 4.0 && E_{beam} Calculated >9.8 GeV
- Apply cut on θ_{pq} <1.5 to reduce inelastic contamination \triangleright
- Normalize simulation to the measured counts \triangleright

Simulation **Real Data**

W² [Q² = 4 0- 4.5] FD [Beam > 9.8] Data Yield = 14312 +/- 119.633 Sim Yield = 194798 +/- 441.35 1600 1400 1200 W² [Q² = 5 5- 6.0] FD [Beam > 9.8] Data Yield = 8585 +/- 92.655 Sim Yield = 95165 +/- 308.48 $W^{2}[Q^{2} = 70 - 7.5] FD [Beam > 9.8]$ Data Yield = 2830 +/- 53.198 Sim Yield = 37668 +/- 194.08 W² [Q² = 85-9.0] FD [Beam > 9.8] Data Yield = 1026 +/- 32.031 Sim Vield = 33446 ±/- 182 88





Data Yield = 14477 +/- 120.320

Sim Yield = 136723 +/- 369.7

Data Yield = 5821 +/- 76.295

Data Yield = 2025 +/- 45.000

Data Yield = 1231 +/- 35.086

m Yield = 47162 +/- 217.16

n Yield = 43709 +/- 209.06

Yield = 71252 +/- 266.93

400 300 200

50 40 30

 $W^2 [Q^2 = 10]$

W² [Q² = 4 5-5.0] FD [Beam > 9.8]

W² [Q² = 6 0- 6.5] FD [Beam > 9.8]

 $W^2 [Q^2 = 75-8.0] FD [Beam > 9.8]$

 $W^{2}[Q^{2} = 9 - 10] FD [Beam > 9.8]$

All RGB Data Set

Acceptance Matching



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 G_M^n

D(e, e'p) Selection Required proton hit CAL

- Select two tracks, one electron in FD and one proton in FD
- Apply cut on W² < 4.0 && E_{beam} Calculated >9.8 GeV
- > Apply cut on θ_{pq} <1.5 to reduce inelastic contamination
- Normalize simulation to the measured counts

Simulation Real Data







W² [Q² = 4.5-5.0] CAL [Beam > 9.8]

W² [Q² = 6.0-6.5] CAL [Beam > 9.8]

 $W^2 [Q^2 = 7.5 - 8.0] CAL [Beam > 9.8]$

Bata Yield = 4149 +/- 64.413

Data Yield = 4982 +/- 70.583

Data Yield = 1967 +/- 44.351

- 10] CAL [Beam > 9.8]

Data Yield = 1207 +/- 34.742

im Yield = 46769 +/- 216.261

350

n Yield = 43174 +/- 207.784

im Yield = 63695 +/- 252.379

Yield = 20646 +/- 143.687

All RGB Data Set

W² [Q² = 5.0-5.5] CAL [Beam > 9.8]

W² [Q² = 6.5-7.0] CAL [Beam > 9.8]

 $W^{2}[Q^{2} = 8.0 - 8.5] CAL [Beam > 9.8]$

W² [Q² = 10 - 16] CAL [Beam > 9.8]

Data Yield = 4838 +/- 69.556

Data Yield = 3705 +/- 60.869

Sim Yield = 38232 +/- 195.53

Data Yield = 1358 +/- 36.851

Data Yield = 838 +/- 28.948

im Yield = 57734 +/- 240.279

Sim Yield = 31422 +/- 177.263

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Yield = 42081 +/- 205.13

Acceptance Matching



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 $W^{2}[Q^{2} = 9]$

 G_M^n

D(e, e'p) Selection Required proton hit CAL

No Acceptance Matching

- Select two tracks, one electron in FD and one proton in FD
- Apply cut on W² < 4.0 && E_{beam} Calculated >9.8 GeV
- \triangleright Apply cut on θ_{pq} <1.5 to reduce inelastic contamination
- Normalize simulation to the measured counts

Simulation Real Data

All RGB Data Set

Acceptance Matching



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 G_M^n

D(e, e'p) Selection Required proton hit CAL

- Select two tracks, one electron in FD and one proton in FD
- Apply cut on W² < 4.0 && E_{beam} Calculated >9.8 GeV
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- Normalize simulation to the measured counts

Simulation **Real Data**

No Acceptance Matching

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All RGB Data Set

Acceptance Matching



$\mathbf{D}(\mathbf{e}, \mathbf{e}'\mathbf{p})$ Selection Required proton hit CAL

- Select two tracks, one electron in FD and one proton in FD
- Apply cut on W² < 4.0 && E_{beam} Calculated >9.8 GeV
- \triangleright Apply cut on θ_{pq} <1.5 to reduce inelastic contamination
- Normalize simulation to the measured counts

Simulation Real Data

ta No Acceptance Matching

All RGB Data Set

Acceptance Matching



$\mathbf{D}(\mathbf{e}, \mathbf{e}'\mathbf{p})$ Selection Required proton hit CAL

- Select two tracks, one electron in FD and one proton in FD
- Apply cut on W² < 4.0 && E_{beam} Calculated >9.8 GeV
- \triangleright Apply cut on θ_{pq} <1.5 to reduce inelastic contamination
- Normalize simulation to the measured counts

Simulation Real Data No Acceptance Matching

All RGB Data Set

Acceptance Matching



D(e, e'p) Selection Required proton hit TOF

- Select two tracks, one electron in FD and one proton in FD \geq
- \triangleright Apply cut on W² < 4.0 && E_{beam} Calculated >9.8 GeV
- Apply cut on θ_{pq} <1.5 to reduce inelastic contamination \triangleright
- Normalize simulation to the measured counts \triangleright

Simulation **Real Data**

No Acceptance Matching

W² [Q² = 4.0-4.5] TOF [Beam > 9.8] W² [Q² = 4.5-5.0] TOF [Beam > 9.8] Data Yield = 14308 +/- 119.616 Sim Yield = 194790 +/- 441.35 1800 1600 1400 1200 1000 800 600 1500 W² [Q² = 5.5 - 6.0] TOF [Beam > 9.8] 1000 -800 -600 -400 -Data Yield = 8573 +/- 92.590 Sim Yield = 95121 +/- 308.41 W² [Q² = 7.0 - 7.5] TOF [Beam > 9.8] Data Yield = 2823 +/- 53.132 Sim Yield = 37631 +/- 193.987 200 150 W² [Q² = 8.5 - 9.0] TOF [Beam > 9.8] Data Yield = 1023 +/- 31.984 Sim Yield = 33412 +/- 182.789









2000

1000 800 600

1000 800 600

400

200 E

All RGB Data Set

Acceptance Matching

Data Yield = 14374 +/- 119.892

Sim Yield = 135268 +/- 367.78



W² [Q² = 8.5- 9.0] TOF Accp [Beam > 9.8]

Data Yield = 988 +/- 31.432

Sim Yield = 31842 +/- 178.443











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 G_M^n

What Next

Next:

- > Investigate quasi-elastic ep events D(e, e'p)
- > Simulate quasi-elastic en events D(e, e'n)
- > Select quasi-elastic en events D(e, e'n)
- $\succ \text{ Calculate the Ratio, } R = \frac{\frac{d\sigma}{d\Omega} (D(e, e'n))}{\frac{d\sigma}{d\Omega} (D(e, e'p))}$

Thank you ...