Neutron Magnetic Form Factor at Q^2 = 16 and 18 $(GeV/c)^2$

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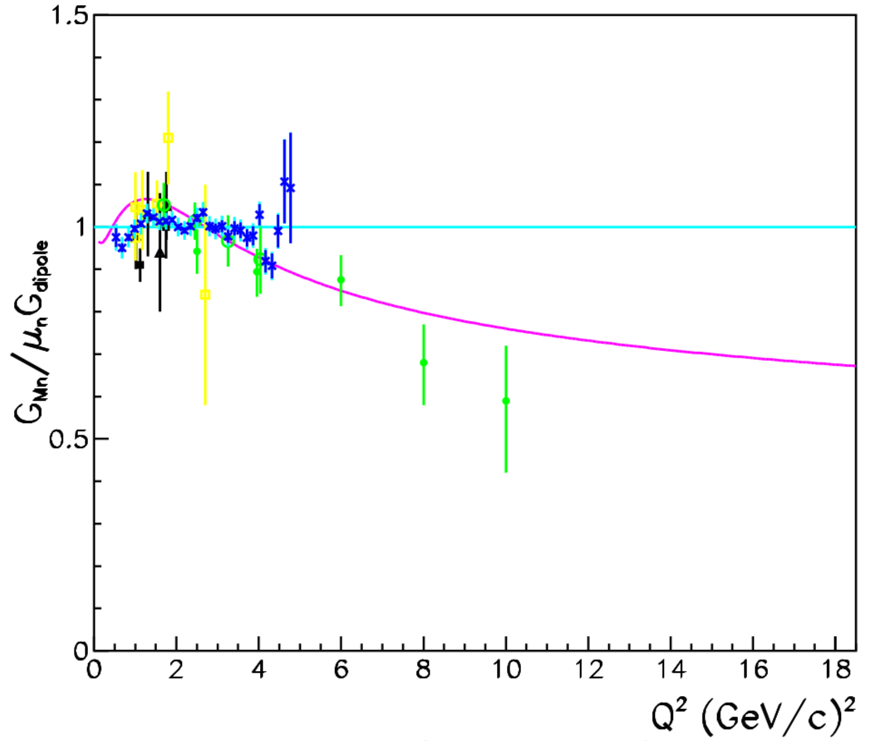
Hall C Winter Collaboration Meeting Jan 14, 2025

Introduction

- Elastic form factors probe the nucleons' four-current distributions, critical for understanding nucleon structure
- They are functions of the squared momentum transfer (Q^2) in a scattering process;

$$Q^2 = 4EE' sin^2\left(\frac{\theta_e}{2}\right)$$

- GMn is a measure of the distribution of magnetization inside the neutron



Existing GMn data [$Q^2 > 1$ (GeV/c)^2 range] plotted as ratio to scaled dipole approximation [1]

Previous Proposals

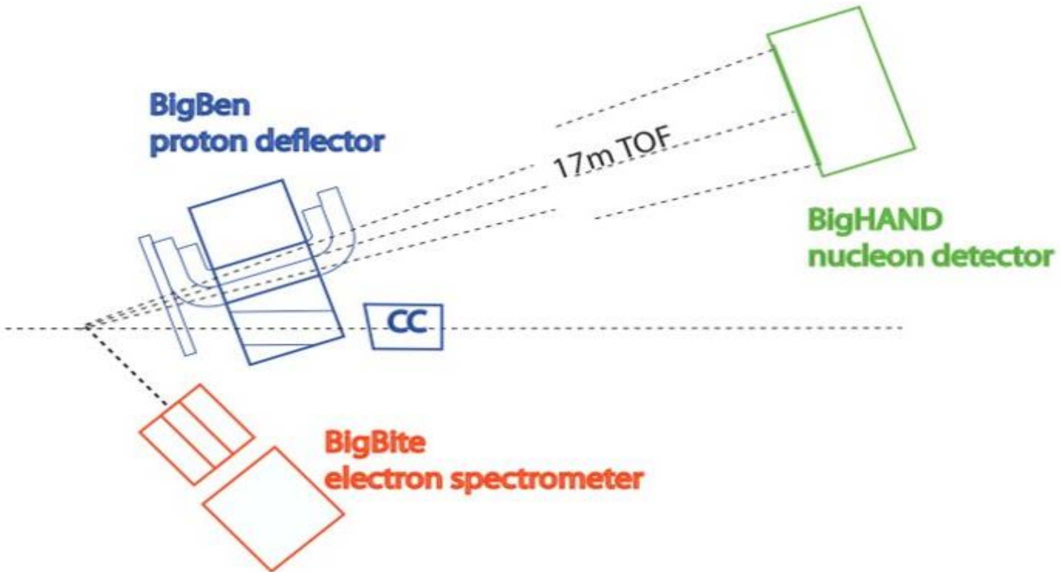
PR12-09-019

- **Spokespersons:**

  B. Quinn, B. Wojtsekhowski and R. Gilman

- Q^2 = **3.5**, **4.5**, **6.5**, **8.5**, **10.0**, **12.0**, **13.5**,

  16.0 and 18.0 $(GeV/c)^2$

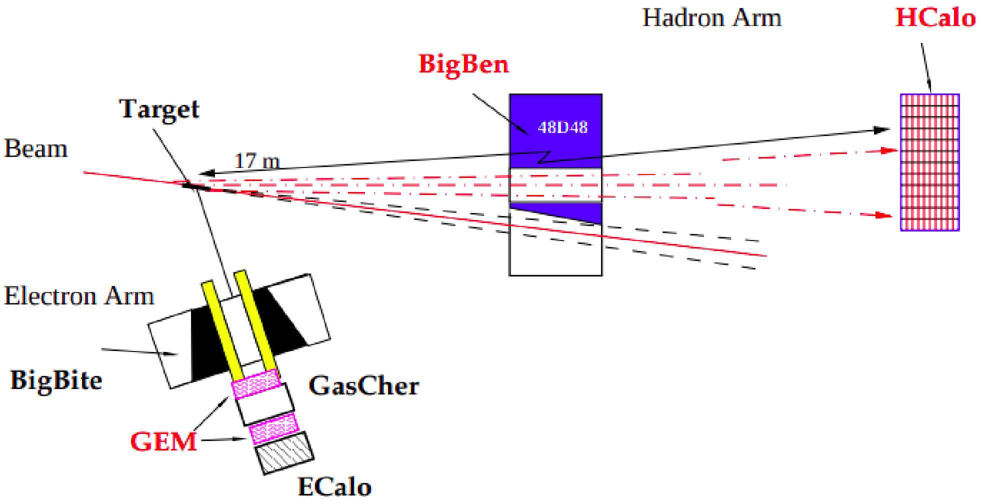


PR12-10-005

- **Spokespersons:**

  B. Quinn, B. Wojtsekhowski and R. Gilman

- Q^2 = **16.0 and 18.0** $(GeV/c)^2$



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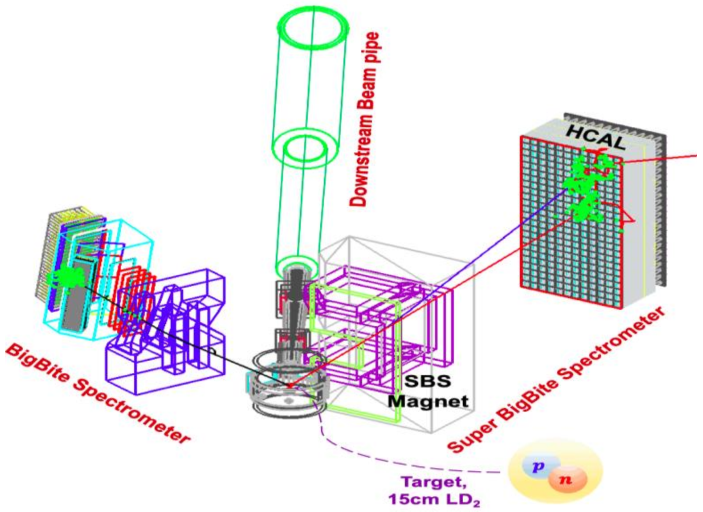
Bogdan Wojtsekhowski/JLab
Ron Gilman/Rutgers Univ.

Carnegie Mellon/ JLab/ Rutgers/ William and Mary/ Santa Maria/ Norfolk/ Glasgow/ Ljubljana/ Richmond/ Kharkov/ U.N.H./ N.C. Central/ Saint Mary's/ UVa/ Yerevan/ Florida International/ INFN/ Novosibirsk/ Tel Aviv/ Cal State/ MIT/ Edinburgh/ Temple

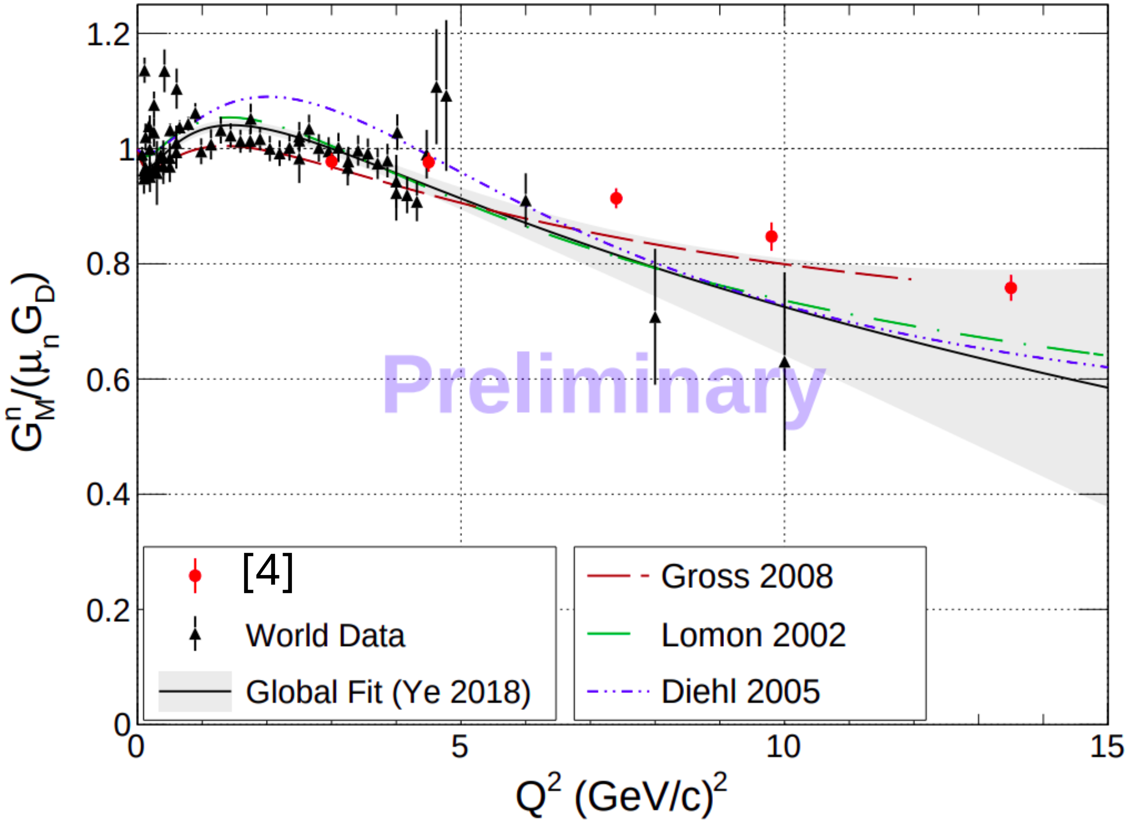
Previous Experiment

E12-09-019 (Oct 2021 to Feb 2022)

- 4.4 to 11 GeV electron beam energies on a liquid deuterium target
- hydrogen target was used for calibration of the detector system
- simultaneous measurement of two quasi-elastic processes for cross-sections ratio
- selection of the quasi-elastic process is based on the angular correlation between the momentum transfer and the momentum of the recoiling nucleon



Geant4 setup of SBS GMn experiment [3]



GMn world data and preliminary results of E12-09-019 measurements [4]

Cross Section

- cross section for scattering of electrons from a spin- 1/2 target in the one-photon approximation can be written as

$$\frac{d\sigma}{d\Omega} = \eta\frac{\sigma_{mott}}{1+\tau}\left((G_E)^2 + \frac{\tau}{\epsilon}(G_M)^2\right)$$

where

$$\eta = \left(1 + 2\frac{E}{M_N}\sin^2(\frac{\theta}{2})\right)^{-1}$$

$$\epsilon = \left(1 + \frac{q^2}{Q^2\tan^2(\frac{\theta}{2})}\right)^{-1}$$

$$\tau = \frac{Q^2}{4M_N^2}$$

G_E (Q^2) and G_M (Q^2) are the Sachs Electric and Magnetic form factors.

scaling approximation: $G_M^n \approx \mu_n G_D$ and $G_M^p \approx \mu_p G_D$

where $G_D = \frac{1}{(1+Q^2/0.71)^2}$ is the empirical Dipole parameterization of GEp

Technique

Ratio method:

- requires the measurement of both neutron-tagged, d(e, e' n), and proton-tagged, d(e, e' p), quasi-elastic scattering from the deuteron.
- the quasi-elastic scattering cross-section ratio:

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

R'' can be used to determine (with nuclear correction, ϵ_{nuc}) the elastic cross–sections ration R':

$$R' = \frac{\frac{d\sigma}{d\Omega}\left|n(e,e')\right.}{\frac{d\sigma}{d\Omega}\left|n(e,e')\right.} = \frac{R''}{1+\epsilon_{nuc}}$$

in terms of neutron form factors →

$$\frac{\eta\frac{\sigma_{Mott}}{1+\tau}\left((G_E^n)^2 + \frac{\tau}{\epsilon}(G_M^n)^2\right)}{\frac{d\sigma}{d\Omega}\left|p(e,e')\right.}$$

thus, GMn can be extracted through:

$$R = R' - \frac{\eta\frac{\sigma_{Mott}}{1+\tau}((G_E^n)^2}{\frac{d\sigma}{d\Omega}\left|p(e,e')\right.} = \frac{\eta\sigma_{Mott}\frac{\frac{\tau}{\epsilon}}{1+\tau}((G_M^n)^2}{\frac{d\sigma}{d\Omega}\left|p(e,e')\right.}$$

Technique: Benefit

- simultaneous detection of d(e, e ' p) and d(e, e ' n) gives the quasi-elastic scattering cross-section ratio

$$\Longrightarrow R'' = \frac{\frac{d\sigma}{d\Omega}\left|d(e, e^{'}n)\right.}{\frac{d\sigma}{d\Omega}\left|d(e, e^{'}p)\right.}$$

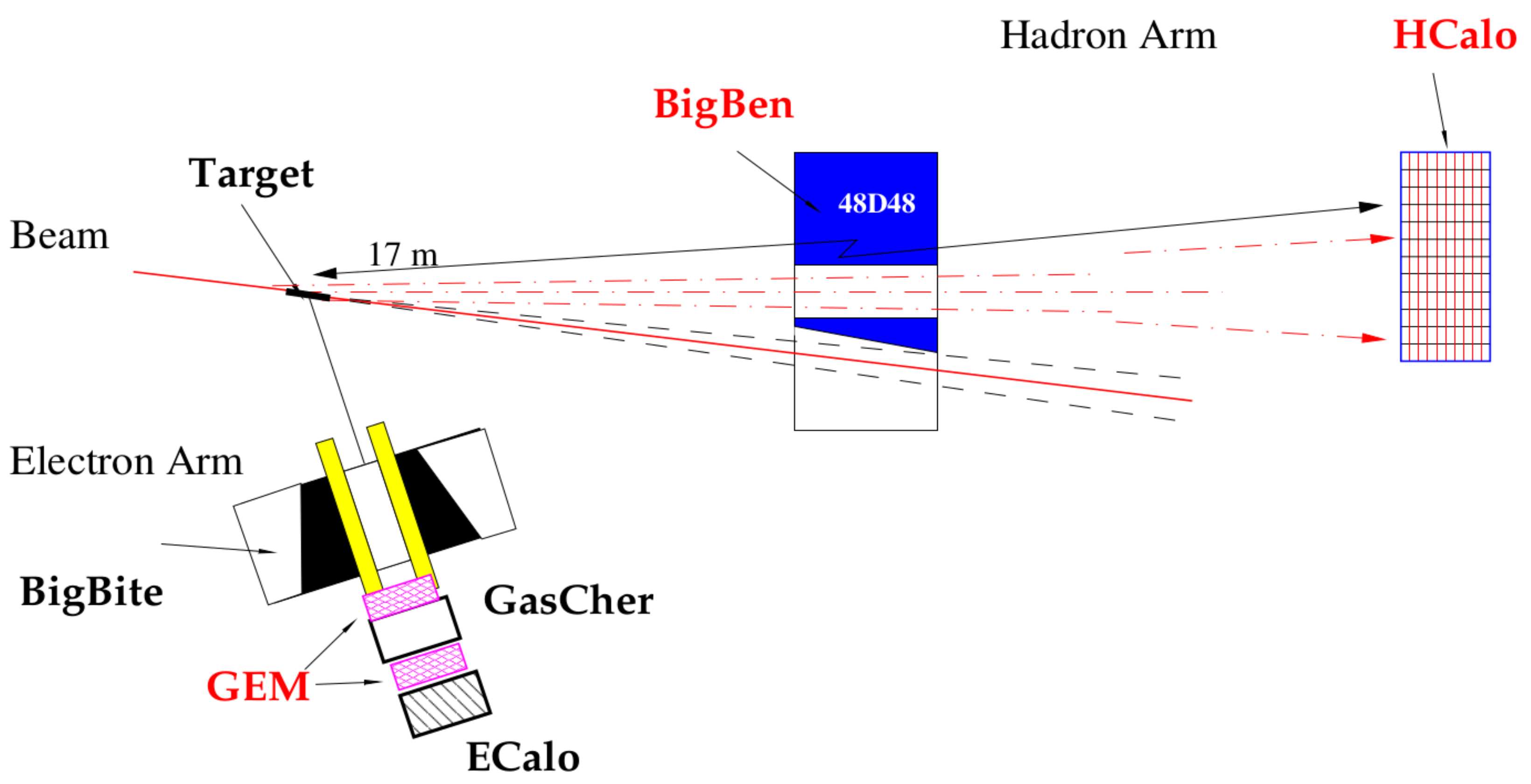
is insensitive to:

- target thickness
- target density
- beam current
- beam structure
- live time
- electron track reconstruction efficiency
- electron trigger efficiency
- electron trigger threshold

Proposed Kinematics

Q^2 $(GeV/c)^2$	E_{beam} (GeV)	θ_e	θ_N	E' (GeV)	P_N (GeV/c)
3.5	4.4	32.5°	31.1°	2.5	2.6
4.5	4.4	41.9°	24.7°	2.0	3.2
6.0	4.4	64.3°	15.6°	1.2	4.0
8.5	6.6	46.5°	16.2°	2.1	5.4
10.0	8.8	33.3°	17.9°	3.5	6.2
12.0	8.8	44.2°	13.3°	2.4	7.3
13.5	8.8	58.5°	9.8°	1.6	8.1
16.0	11.0	45.1°	10.7°	2.5	9.4
18.0	11.0	65.2°	7.0°	1.4	10.5

Apparatus



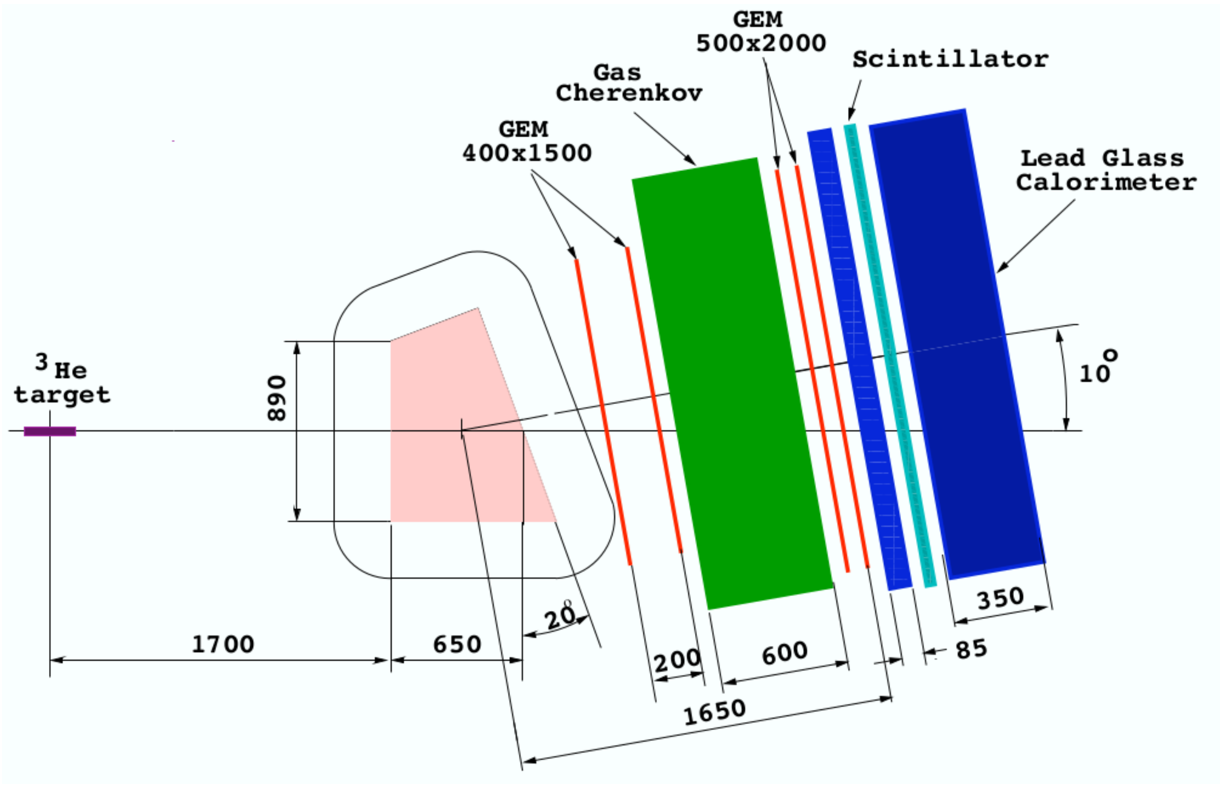
The dipole magnet "BigBen" will deflect protons for PID.

magnetically-shielded hole in the return iron will allow the unscattered beam to continue on to the beam dump.

Corrector coils (not shown) will compensate for any effect of residual magnetic field on the beamline.

schematic view of the apparatus is shown as configured for the higher Q^2 point

Apparatus: BigBite Electron arm

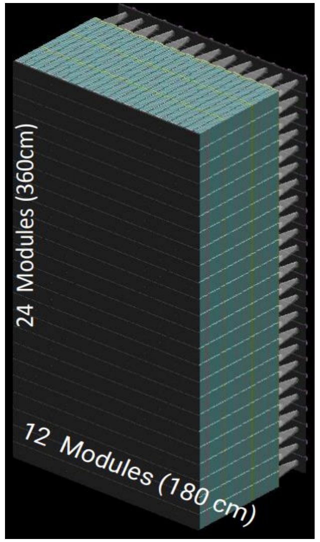


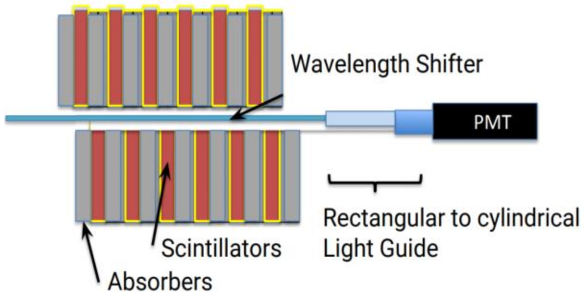
Instrumented with:
GEM planes from SBS
ECal from GEp(5)
Gas Cerenkov
Timing planes
Higher luminousity

BigBite spectrometer, configured for high momentum, high luminosity running.
Tracking is performed with GEM detectors and a gas Cerenkov counter is located between the detector packages (The target label refers to another experiment)

Apparatus: HCal

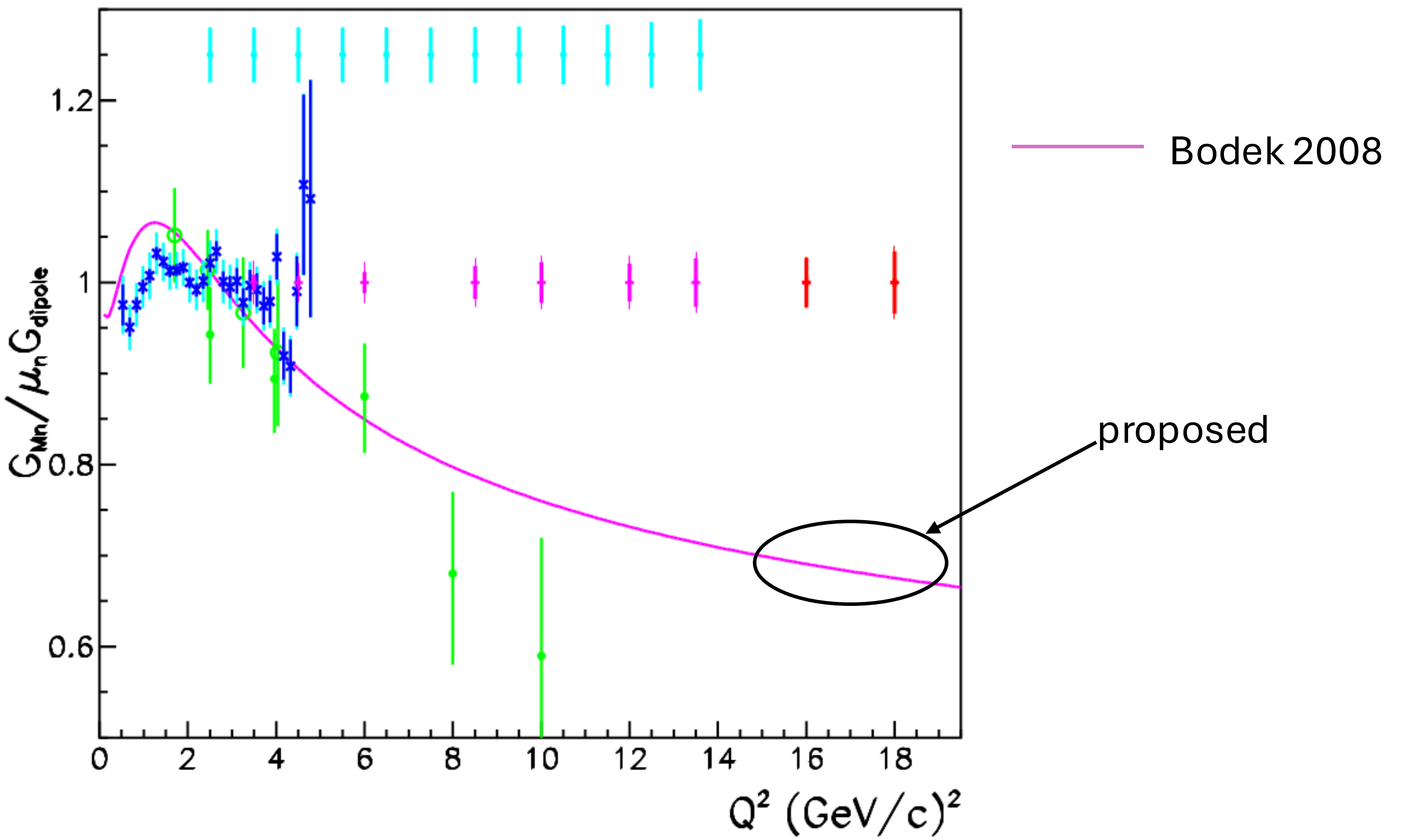
-segmented calorimeter detecting high energy nucleons
-288 modules (12x24 blocks of 15 x 15 x 100 cm^3)
-each module is made of 40 layers of iron absorbers alternating with scintillators
-light produced by the scintillator goes into a wavelength shifter at the center of the module
-the light then passes through the light guide and goes into PMTs.





SBS HCal in Hall A [5,6]

Projected Results



GMn data in the Q^2 range of the proposed measurement [1]

Summary

- Measure GMn up to 18 $(Gev/c)^2$
- Possible in the 12 GeV era
- Setup/equipment are similar to those used in the E12-09-019 experiment

Looking forward to future PAC submission…

References

[1] https://www.jlab.org/exp_prog/proposals/10/PR12-10-005.pdf

[2] https://www.jlab.org/exp_prog/proposals/09/PR12-09-019.pdf

[3] https://indico.jlab.org/event/529/contributions/10270/attachments/8180/11693/F%26C_MIT_gmn%26bbcal_2022.pdf

[4] https://ctdigitalarchive.org/node/3809291

[5] https://indico.jlab.org/event/721/contributions/13216/attachments/10055/14941/SBS_collaboration_HCAL_072023.pdf

[6] https://indico.jlab.org/event/878/contributions/15206/attachments/11686/18136/SBS_collaboration_HCAL_092024.pptx