High Q^2 radiative corrections

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Outline

- Two-Photon-Exchange and GMn/GMp
- ESEPP with cut on electron/proton angle
- Blunden on TPE in e,e'p and e,e'n

Proton/Neutron difference

Radiative corrections for $(e,e'p)$ reactions at GeV energies

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$$\frac{d\sigma}{d^3k'd^3\omega} \sim |\mathcal{M}_{\rm ei}+\mathcal{M}_{\rm ef}+\mathcal{M}_{\rm pi}+\mathcal{M}_{\rm pf}|^2.$$

R. ENT *et al.*

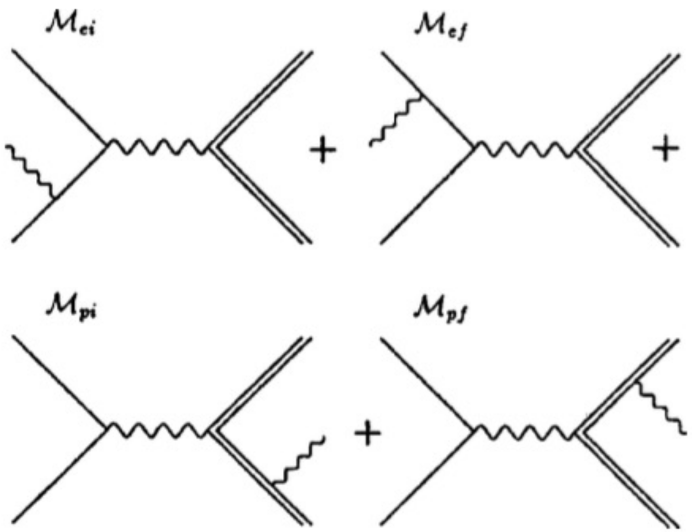

FIG. 2. Feynman diagrams contributing to first order bremsstrahlung radiation cross section.

Proton/Neutron difference

$$J_e^{\mu}(q) = e\bar{u}_e(k+q)\gamma^{\mu}u_e(k).$$

$$J_p^{\mu}(q) = -e\bar{u}_p(p+q)\Gamma^{\mu}(q)u_p(p). \tag{10}$$

The deviation of the proton from a point particle is described by

$$\Gamma^{\mu}(q) = F_1(q^2)\gamma^{\mu} + \frac{1}{2M}F_2(q^2)i\sigma^{\mu\nu}q_{\nu}, \tag{11}$$

Proton/Neutron difference

$$\mathcal{M}_{\mathrm{ef}} = i\bar{u}_e(k')e\gamma^\nu\varepsilon_\nu\left[\frac{i\gamma^\nu(k'_\nu+\omega_\nu)+m}{(k'+\omega)^2-m^2}\right]$$

$$\times\gamma^\mu u_e(k)\frac{e^2}{q_p^2-\mu^2}\bar{u}_p(p')\Gamma_\mu(q_p)u_p(p),$$

$$\mathcal{M}_{\mathrm{pi}} = i\bar{u}_p(p')\Gamma^\mu(q)\left[\frac{i\gamma^\nu(p_\nu-\omega_\nu)+M}{(p-\omega)^2-M^2}\right]$$

$$\times(-e)\Gamma^\nu(\omega)\varepsilon_\nu u_p(p)\frac{e^2}{q^2-\mu^2}\bar{u}_e(k')\gamma_\mu u_e(k),$$

$$\mathcal{M}_{\mathrm{pf}} = i\bar{u}_p(p')(-e)\Gamma^\nu(\omega)\varepsilon_\nu\left[\frac{i\gamma^\nu(p'_\nu+\omega_\nu)+M}{(p'+\omega)^2-M^2}\right]$$

$$\times\Gamma^\mu(q)u_p(p)\frac{e^2}{q^2-\mu^2}\bar{u}_e(k')\gamma_\mu u_e(k). \qquad (12)$$

The GMp12 experiment (E12-07-108)

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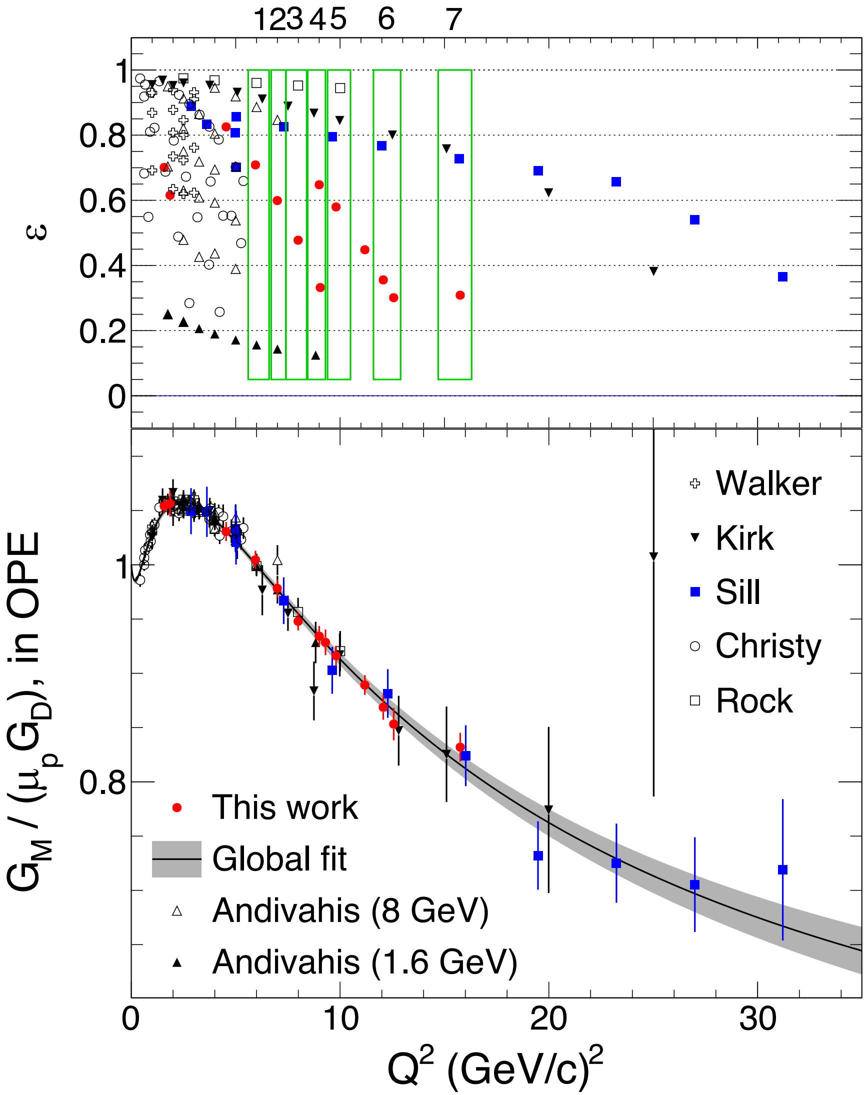

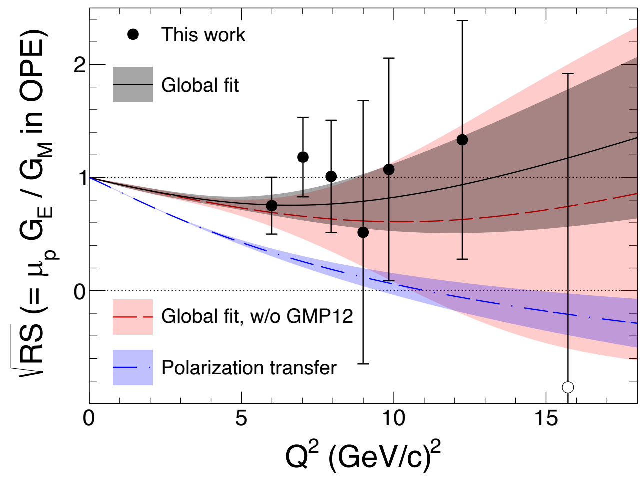

GMp12 fit:

$$G_M = \mu_p (1 + a_1 \tau)/(1 + b_1 \tau + b_2 \tau^2 + b_3 \tau^3),$$
$$\mathrm{RS} = 1 + c_1 \tau + c_2 \tau^2.$$

a_1	b_1	b_2	b_3	c_1	c_2
0.072(22)	10.73(11)	19.81(17)	4.75(65)	-0.46(12)	0.12(10)

courtesy of A. Gramolin and A. Puckett

ESEPP

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Reanalysis of Rosenbluth measurements of the proton form factors

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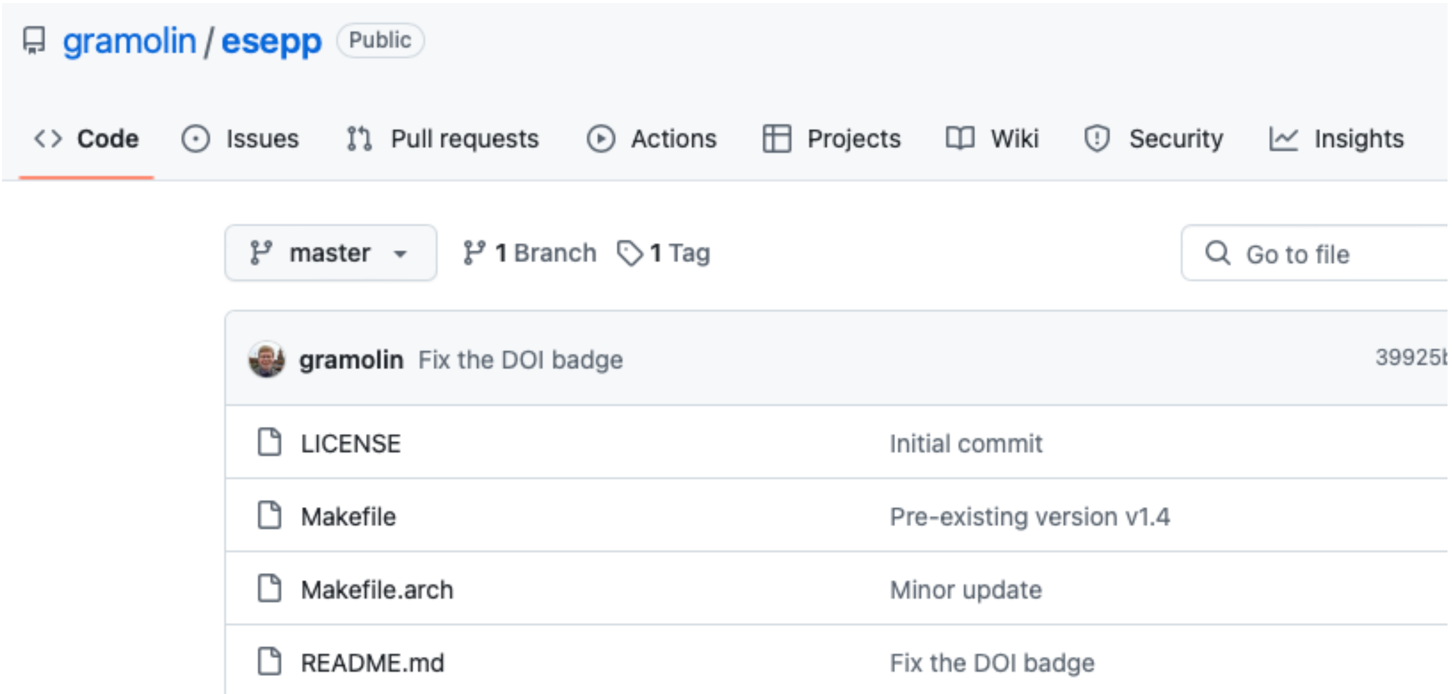
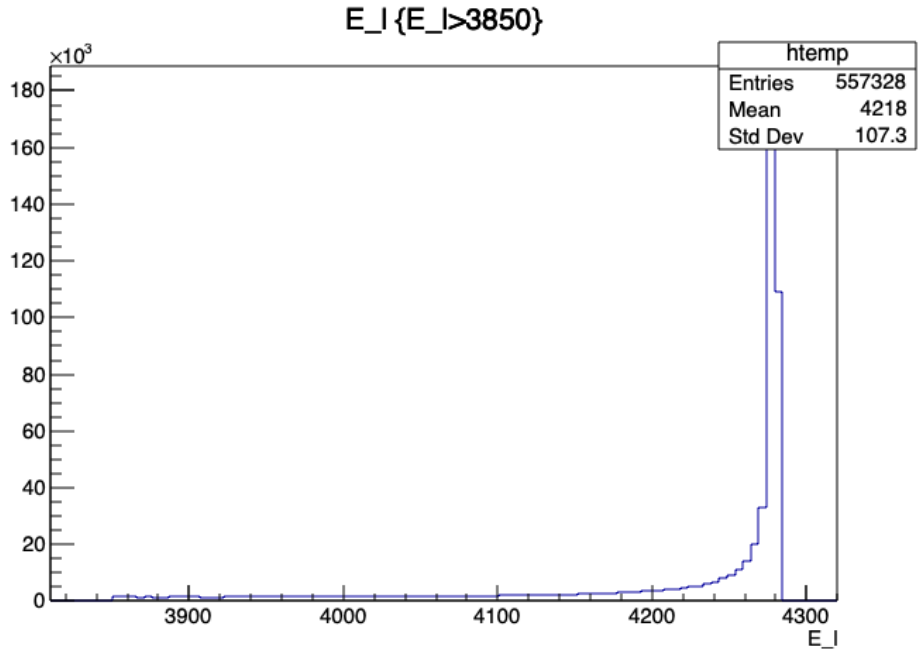


Result from ESEPP calculation



The example for:
E_0 = 10 GeV, 30 deg
Q^2 = 11 GeV^2

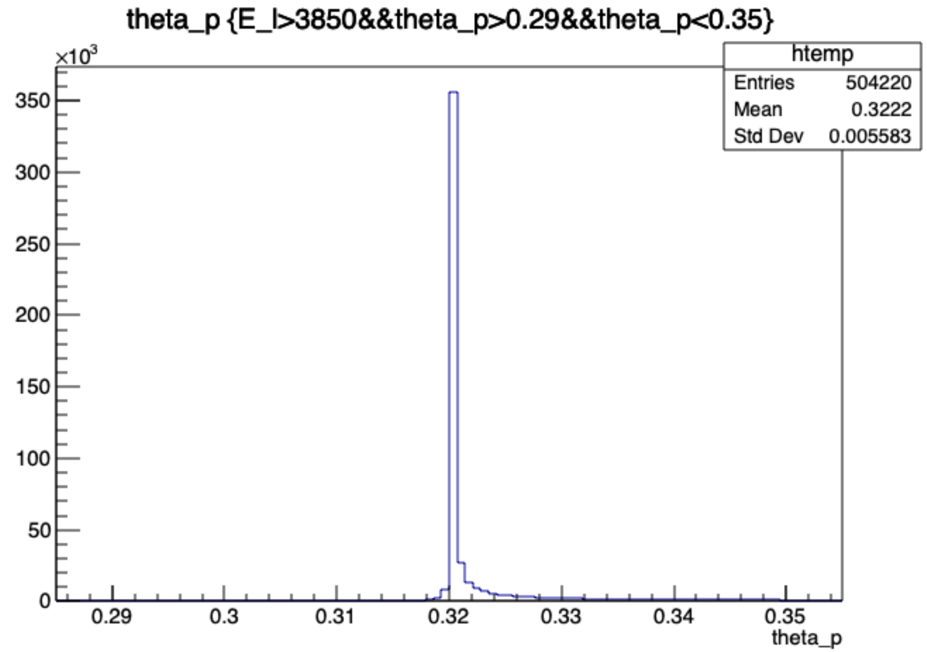
$E_{e'}$ > 90% of peak

$$N_{obs}^{e\text{-}n} = (1 -- 0.088) * N_{FFn}$$

$$N_{obs}^{e\text{-}p} = (1 + 0.020) * N_{FFp}$$

The GMn/GMp ratio is about
6% up from uncorrected values

Result from ESEPP calculation



The example for:
E_0 = 10 GeV, 30 deg
Q^2 = 11 GeV^2

$E_{e'}$ > 90% of peak

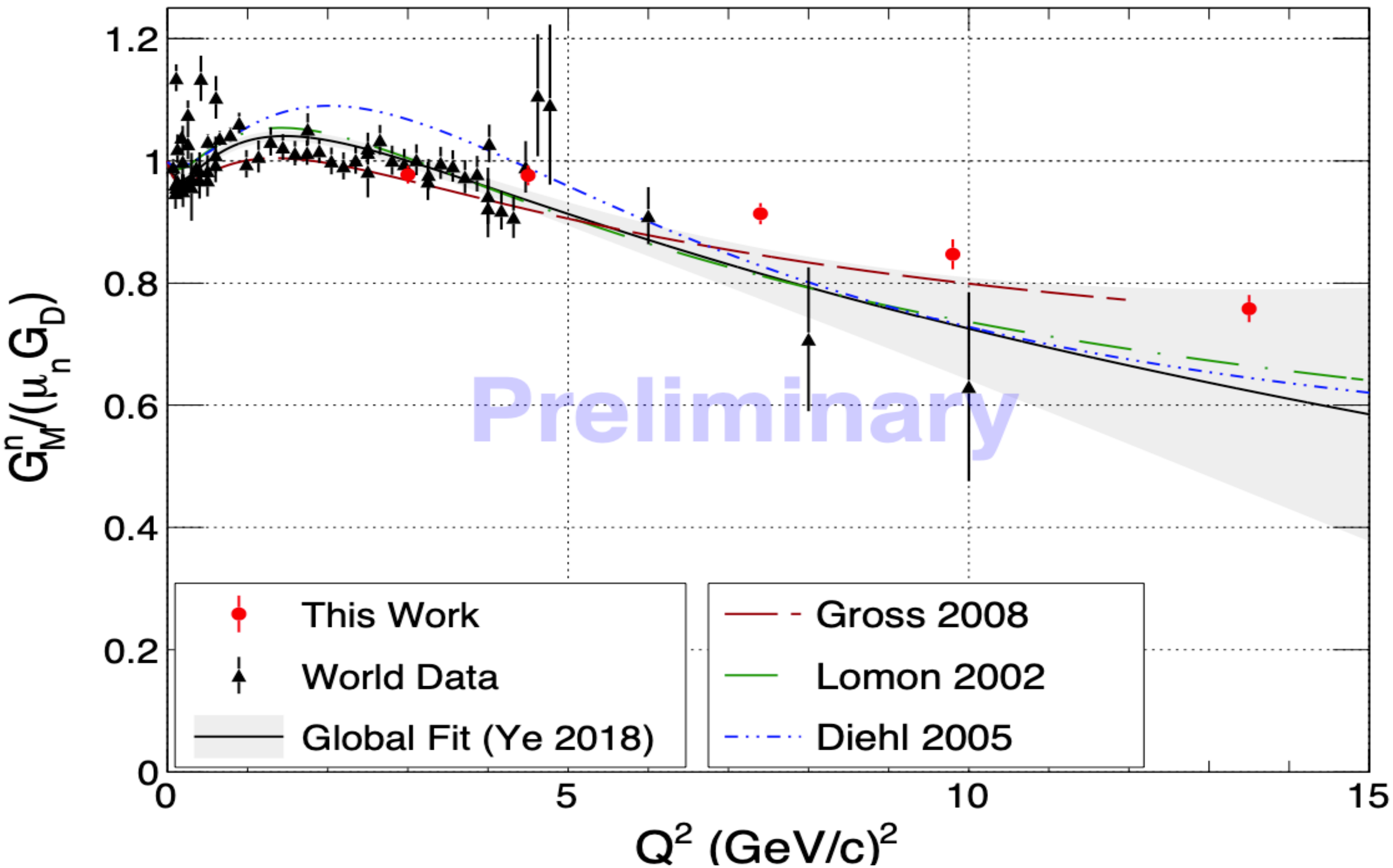
θ_p range = +/- 2 deg

$N_{obs}^{e\text{-}n} = (1 -- 0.207) * N_{FFn}$

$N_{obs}^{e\text{-}p} = (1 – 0.069) * N_{FFp}$

The GMn/GMp ratio is about
8% up from uncorrected values

SBS GMn in P.Datta thesis



interactions, meson exchange contributions, and radiative effects largely cancel out since they are nearly identical between neutron-tagged and proton-tagged events. This leaves the relative detec-

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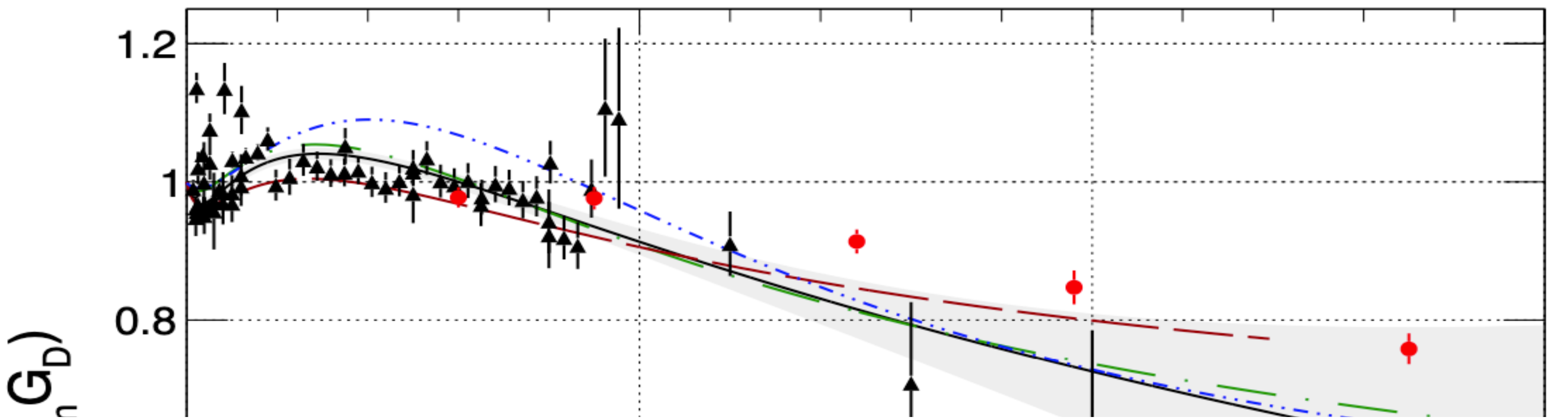


R, representing the en to ep Born cross-section ratio, is the most fundamental model-independent observable of the E12-09-019 experiment. It can be expressed using the Rosenbluth formula as follows:

$$R = \frac{\frac{\sigma_{\text{Mott}}}{\epsilon_n(1+\tau_n)}\left(\epsilon_n {G_E^n}^2 + \tau_n {G_M^n}^2\right)}{\frac{\sigma_{\text{Mott}}}{\epsilon_p(1+\tau_p)}\left(\epsilon_p {G_E^p}^2 + \tau_p {G_M^p}^2\right)} \tag{3.3}$$

This expression can be greatly simplified as the factors σ_{Mott}, ϵ, and τ are approximately the same for en and ep scattering.

Finally, by inverting Equation 3.3, G_M^n can be expressed in terms of R as:

$$G_M^n = -\left[\frac{1}{\tau_n}\frac{\epsilon_n(1+\tau_n)}{\epsilon_p(1+\tau_p)}\sigma_{Red}^p R - \frac{\epsilon_n}{\tau_n}{G_E^n}^2\right]^{\frac{1}{2}}, \tag{3.4}$$

Blunden TPE, PHYSICAL REVIEW C **72**, 034612 (2005)

$$\frac{d\sigma_0}{d\Omega} = \left(\frac{\alpha}{4Mq^2}\frac{E_3}{E_1}\right)^2 |\mathcal{M}_0|^2 = \sigma_{\mathrm{Mott}}\frac{\tau}{\varepsilon(1+\tau)}\sigma_R, \qquad (7)$$

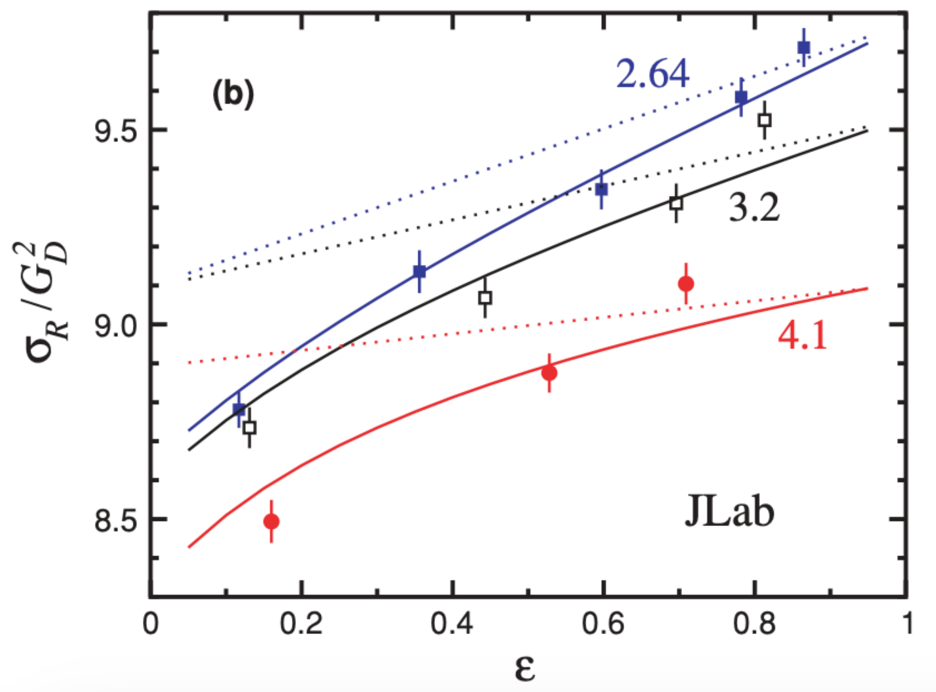
where σ_R is the reduced cross section given in Eq. (4), and the Mott cross section for the scattering from a point particle is

$$\sigma_{\mathrm{Mott}} = \frac{\alpha^2 E_3 \cos^2\frac{\theta}{2}}{4E_1^3 \sin^4\frac{\theta}{2}}, \qquad (8)$$

with E_1 and E_3 the initial and final electron energies and $\alpha = e^2/4\pi$ the electromagnetic fine structure constant. Including radiative corrections to order α, the elastic scattering cross section is modified as follows:

$$\frac{d\sigma_0}{d\Omega} \rightarrow \frac{d\sigma}{d\Omega}(1+\delta), \qquad (9)$$

Blunden TPE paper



The most notable difference with respect to the proton results is the sign and slope of the 2γ exchange correction. Namely, the magnitude of the correction $\delta^{\text{full}}(\varepsilon, Q^2)$ for the neutron is ~3 times smaller than for the proton. The reason for

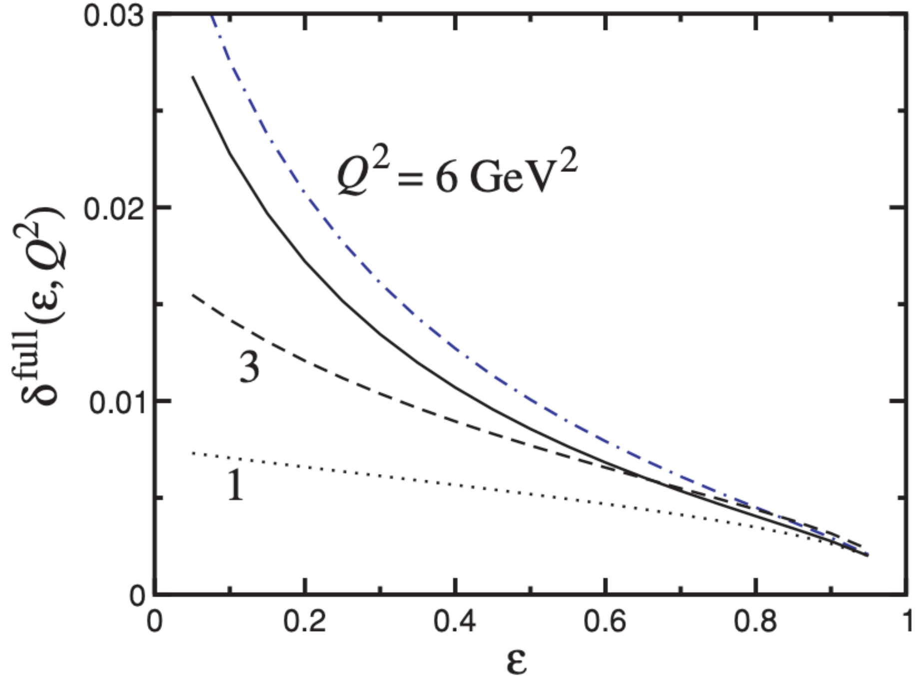
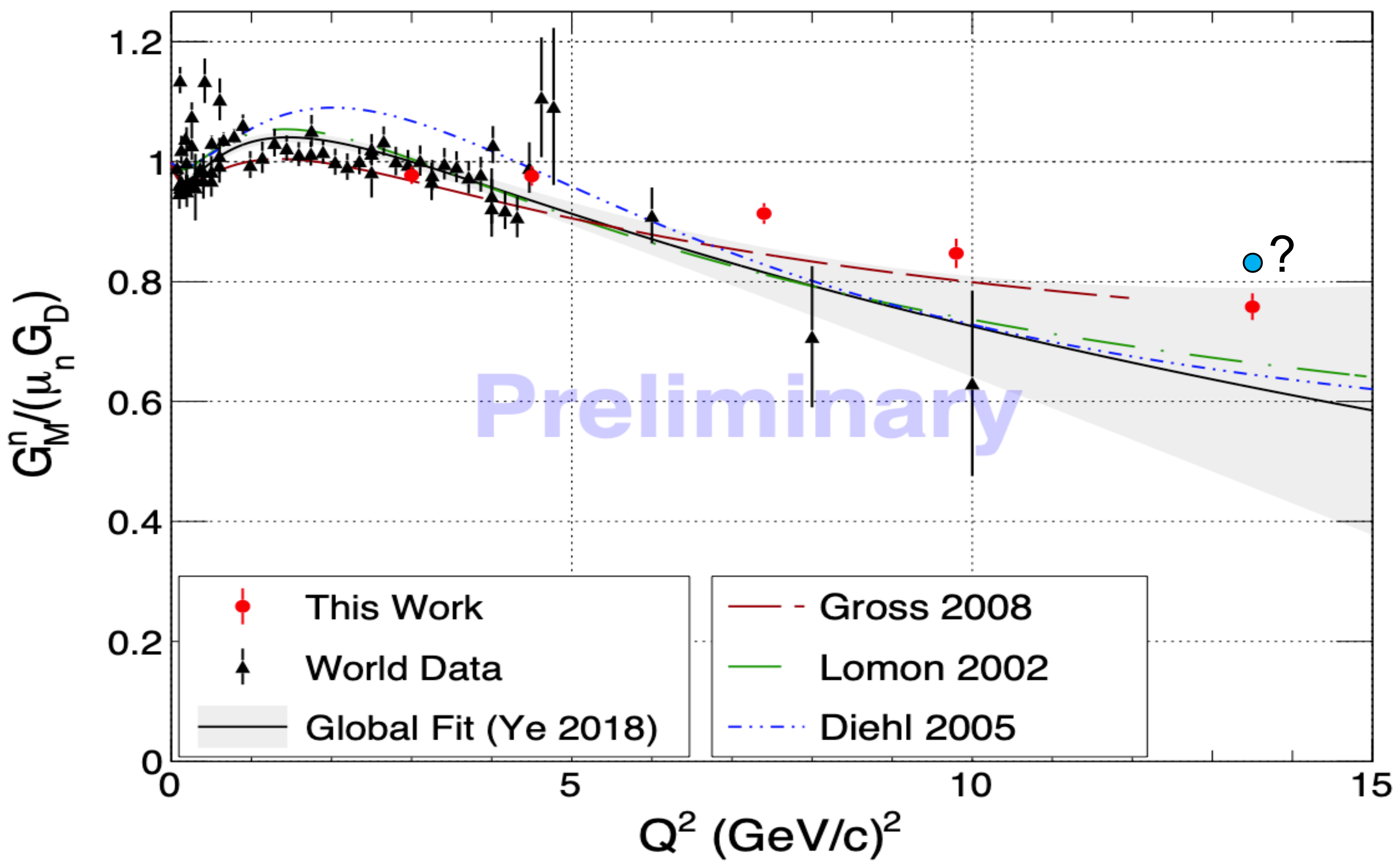


FIG. 12. (Color online) 2γ contribution to the unpolarized electron-neutron elastic scattering cross section, at $Q^2 = 1$ (dotted), 3 (dashed), and 6 GeV^2 (solid and dot-dashed). The dot-dashed curve corresponds to the form factor parametrization of Ref. [41], whereas the others are from Ref. [16] (as fitted by the parameters in Table I).

$\sigma_{e,e'n}/\ \sigma_{e,e'p}$ is down by ~ 2-3%; We need calculation for 13.5 GeV^2

SBS GMn in P.Datta thesis



Summary

- Difference of RadCor for e-p and e-n at high Q^2 could lead to change of the GMn/GMp by +7%

- Accurate measurement of the cross section at high Q^2 requires an update of the radiative correction