Proposal to PAC48

Measurement of the two-photon exchange contribution to the electron-neutron elastic scattering cross section

On behalf of the spokespeople:

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SBS summer 2020 collaboration meeting

Full list of collaborators

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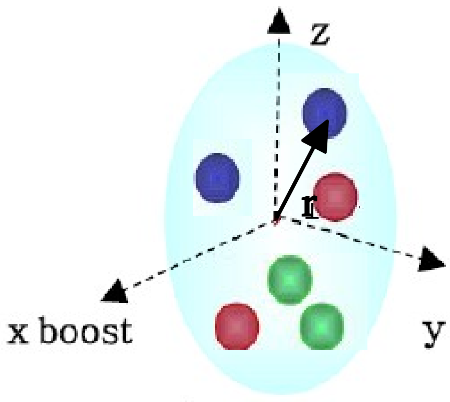
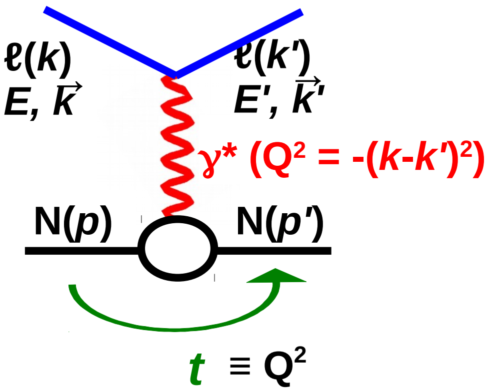
Physics motivation (1)

Form Factors:
Fourier transform of **nucleon charge density ;** Measured with **elastic eN scattering**





Nucleon: **2** form factors:
G_E, G_M (Sachs);
F^q_1, F^q_2 (Dirac, Pauli);

In one-photon exchange approximation

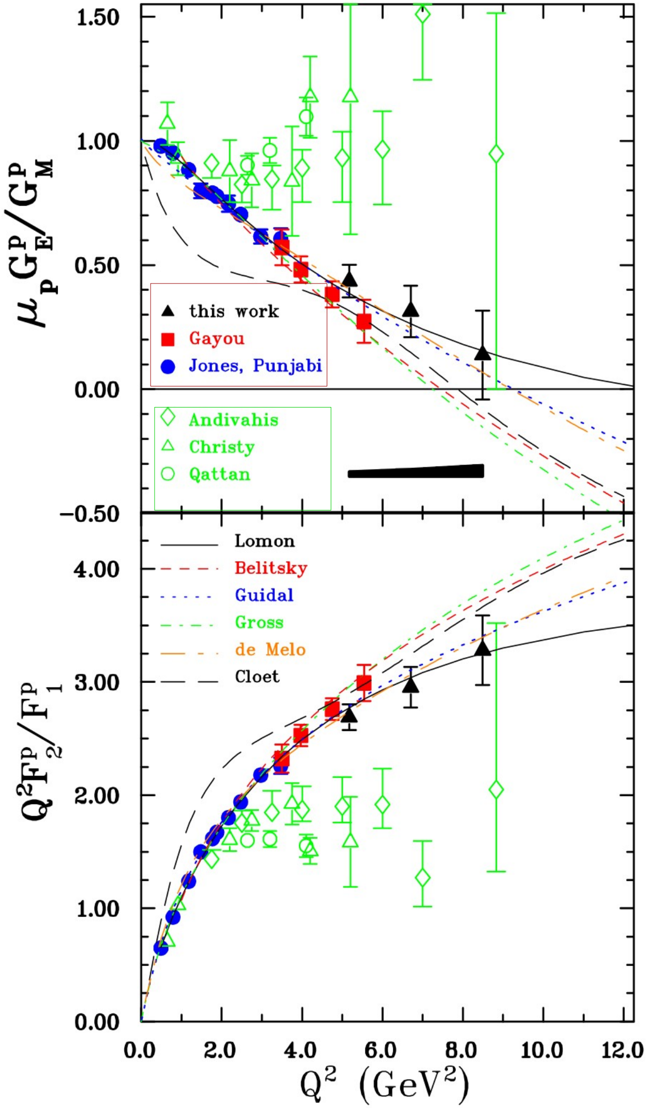
$$\left(\frac{d\sigma}{d\Omega}\right)_{eN\rightarrow eN} = \frac{\sigma_{Mott}}{\epsilon(1+\tau)} \left[\tau \cdot G_M^2(Q^2) + \epsilon \cdot G_E^2(Q^2)\right]$$

Physics motivation (2)

- **Two-Photon Exchange (TPE)** has an important effect on elastic *ep* scattering (G_E^p with double polarization vs Rosenbluth)
- ***Never* measured on neutron!**

=> Measurement of TPE on elastic *en* scattering at Q^2 = 4.5 GeV^2 with G_M^n setup

[Puckett *et. al.*: Phys. Rev. Lett. **104** (2010) 242301]



Technique (1)

Measurement of TPE on elastic *en* scattering at Q^2 = 4.5 GeV^2 *with G_M^n setup*

$$R_{corrected} = \boxed{f_{corr}} \times \boxed{\frac{N_{e,e'n}}{N_{e,e'p}}} = \boxed{\frac{\sigma^n_{Mott} \cdot (1+\tau_p)}{\sigma^p_{Mott} \cdot (1+\tau_n)}} \times \frac{\epsilon\sigma^n_L + \sigma^n_T}{\epsilon\sigma^p_L + \sigma^p_T}$$

f_{corr}: nuclear effects, effects of acceptance, etc

$= R_{Mott}$

Two measurements at same Q2, two beam energies (i.e. two values of ε):

$$R_{corrected,\epsilon_1} = R_{Mott,\epsilon_1} \times \frac{\epsilon_1\sigma^n_L + \sigma^n_T}{\epsilon_1\sigma^p_L + \sigma^p_T} \qquad R_{corrected,\epsilon_2} = R_{Mott,\epsilon_2} \times \frac{\epsilon_2\sigma^n_L + \sigma^n_T}{\epsilon_2\sigma^p_L + \sigma^p_T}$$

Ratio $A = R_{corrected,\epsilon_1} / R_{corrected,\epsilon_2}$

$$= B \times \frac{1+\epsilon_1 S^n_c}{1+\epsilon_2 S^n_c} \approx B \times (1 + \Delta\epsilon \cdot S^n_c),$$

with $B = \frac{1+\epsilon_1 S^p_c}{1+\epsilon_2 S^p_c}$ and $S^{n/p}_c = \frac{\sigma^{n/p}_L}{\sigma^{n/p}_T}$

=> $\boxed{S^p_c \simeq 0.107 \pm 0.010}$ at Q^2 = 4.5 GeV^2

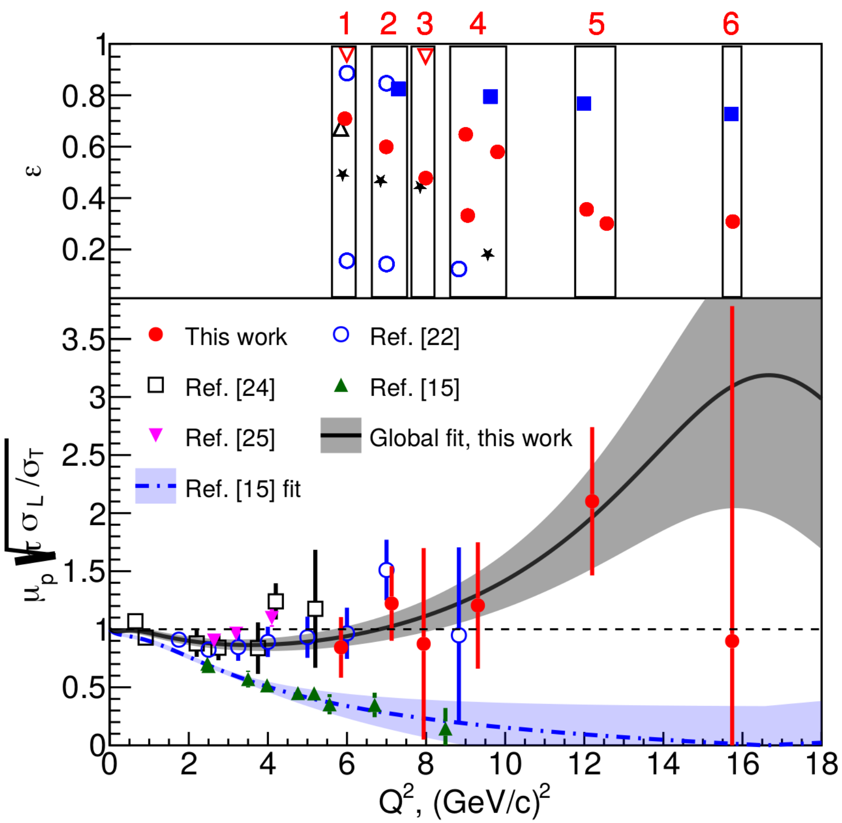


Figure from:
E. Christy *et al.*, “Two-photon exchange in electron-proton elastic scattering at large four-momentum transfer”

Technique (2)

$$S_c^n = \frac{A-B}{B\,\Delta\epsilon} \quad \text{and} \quad S_c^n = \frac{\sigma_L^n}{\sigma_T^n} = \frac{(G_E^n + nTPE)^2}{\tau G_M^2} \Rightarrow \boxed{\frac{(G_E^n + nTPE)^2}{\tau G_M^2} = \frac{A-B}{B\,\Delta\epsilon}}$$

$$A = R_{corrected,\epsilon_1} / R_{corrected,\epsilon_2}$$

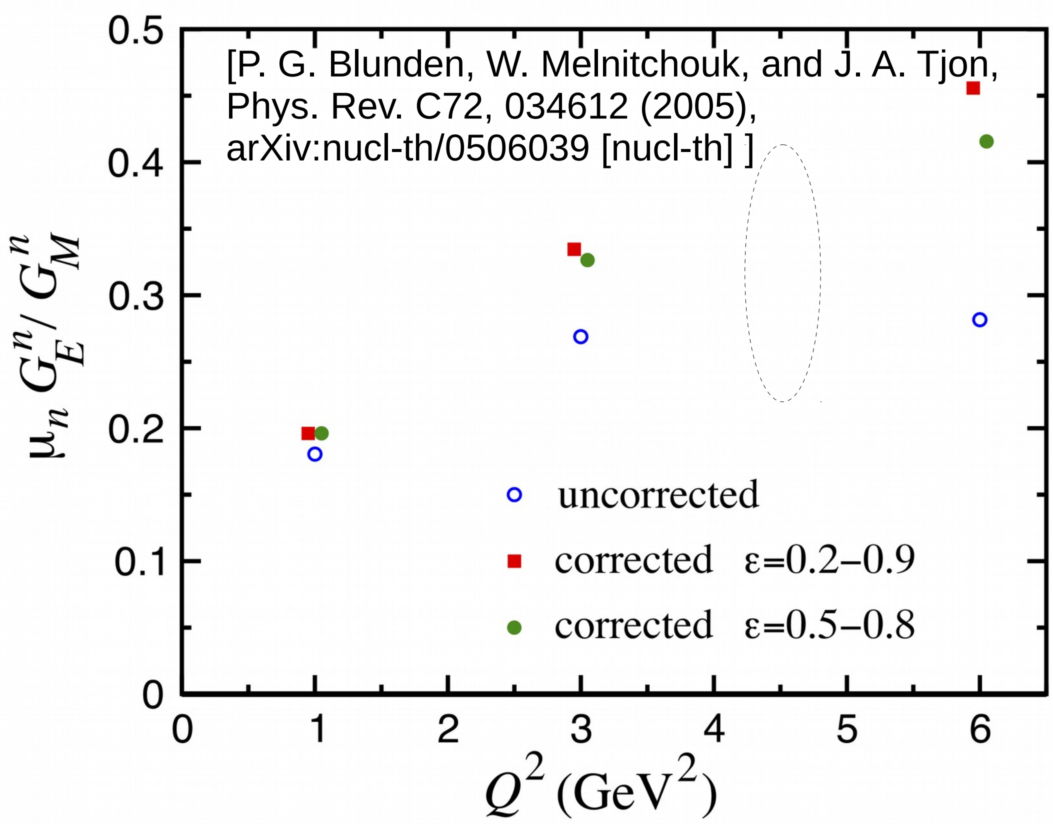
$$B = \frac{1+\epsilon_1 S_c^p}{1+\epsilon_2 S_c^p}$$

$$S_c^p \simeq 0.107 \pm 0.010$$

Knowing $\mu_n (G_E^n / G_M^n) = 0.55 \pm 0.05$

[V. Punjabi, C. F. Perdrisat, M. K. Jones, E. J. Brash, and C. E. Carlson, Eur. Phys. J. A51, 79 (2015), arXiv:1503.01452 [nucl-ex].]

and using prediction of Blunden, Melnitchouk, Tjon => **nTPE = 0.069 ± 0.012(syst)**

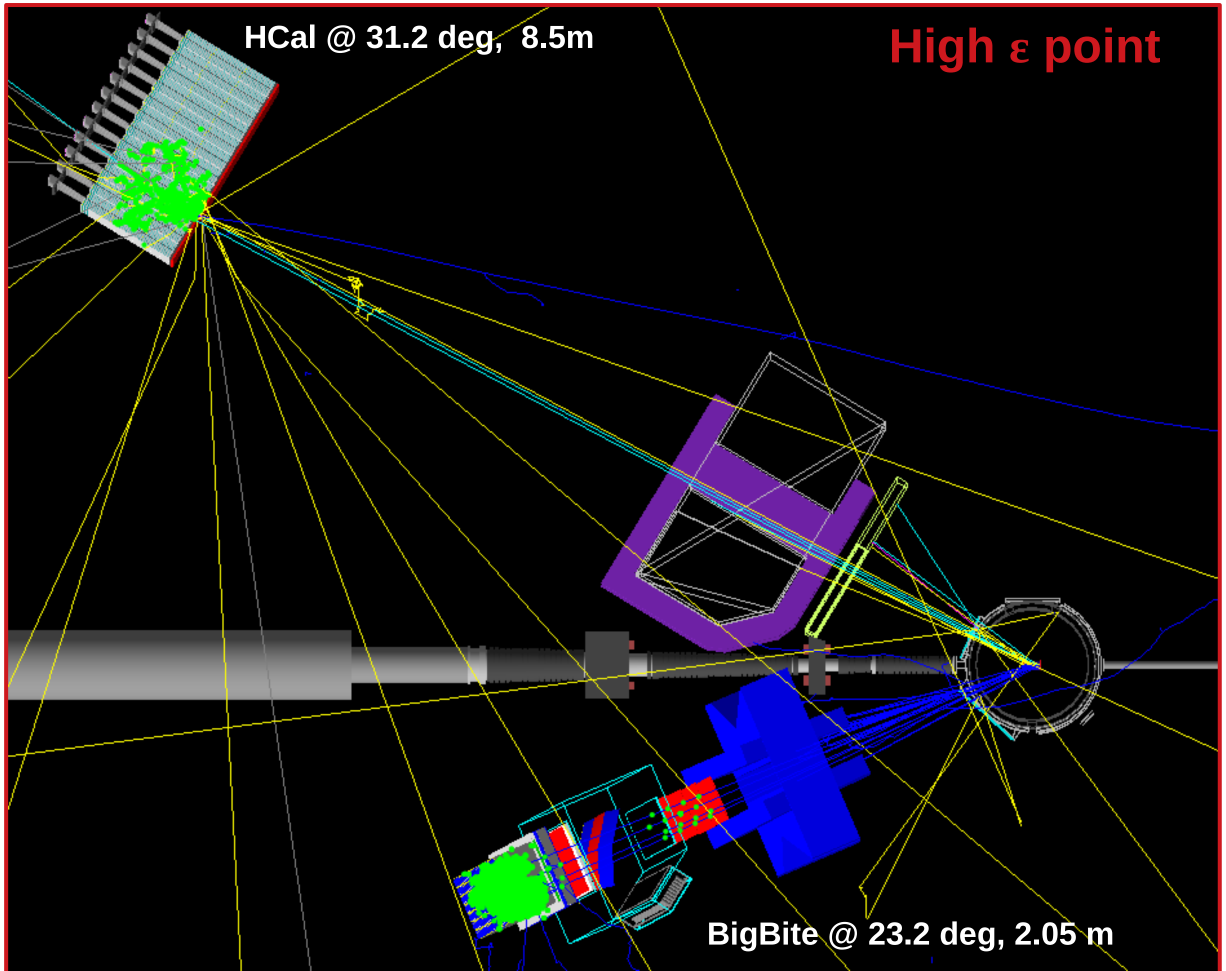


Experimental setup

* Same setup as G_M^n (BigBite+SBS/HCal)
* 2 ε settings at Q^2 = 4.5 GeV^2 :

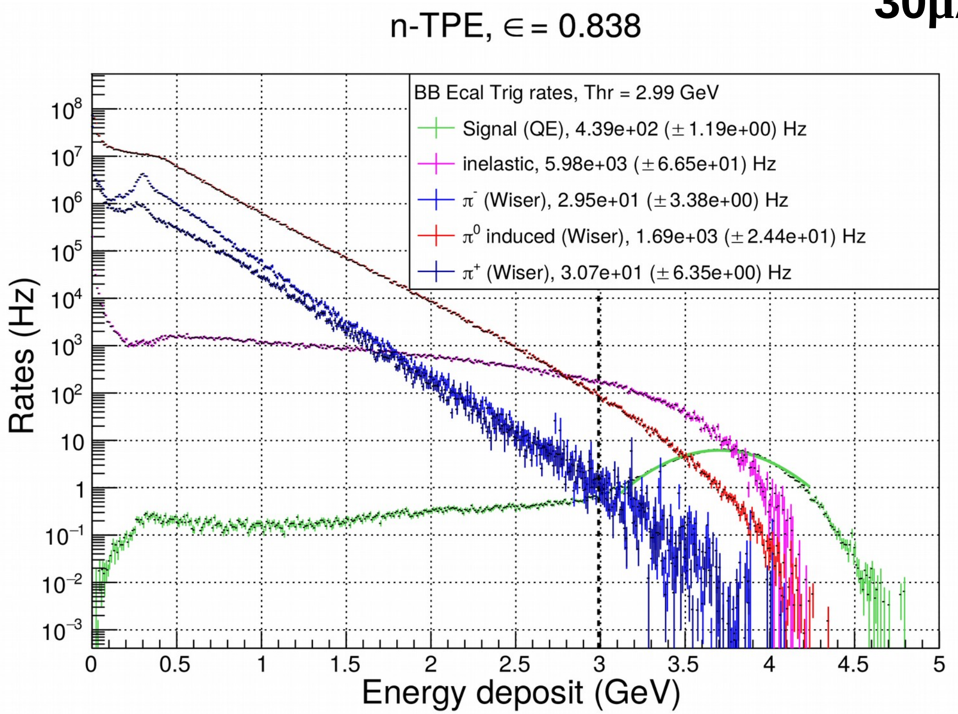
Point	Q^2 $(\text{GeV/c})^2$	E (GeV)	E′ (GeV)	θ_{BB} degrees	θ_{SBS} degrees	ϵ
1	4.5	4.4	2.0	41.88	24.67	0.599
2	4.5	6.6	4.2	23.23	31.2	0.838

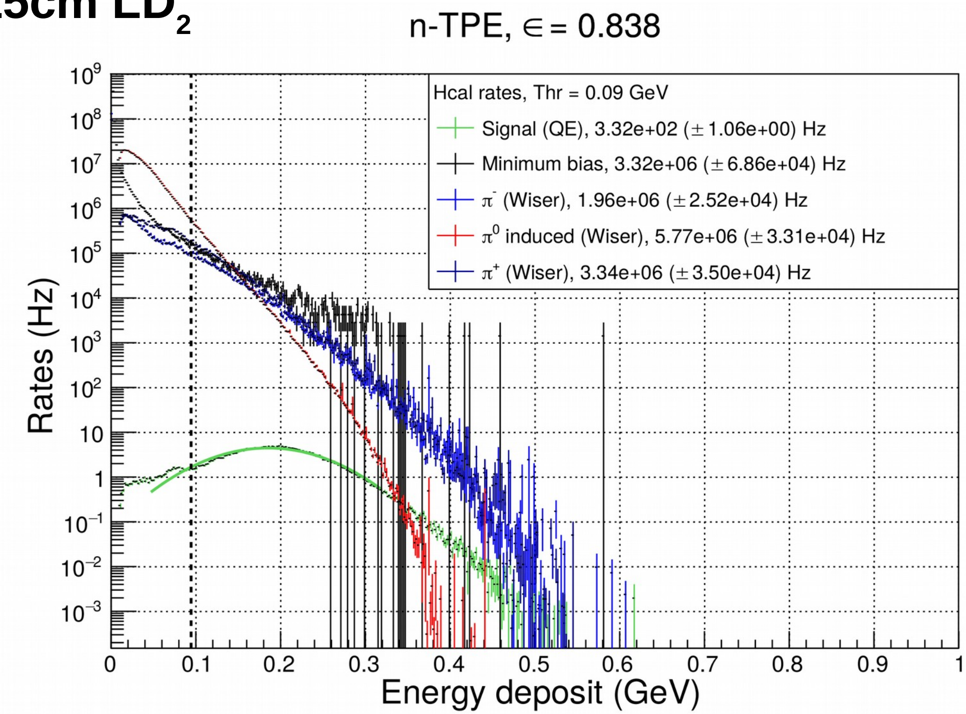
=> already existing GMn setting



Expected rates : background/trigger

30μA, 15cm LD_2





BigBite threshold: elastic peak – 2.5 σ

HCal threshold: setup to select 90 % of elastic peak

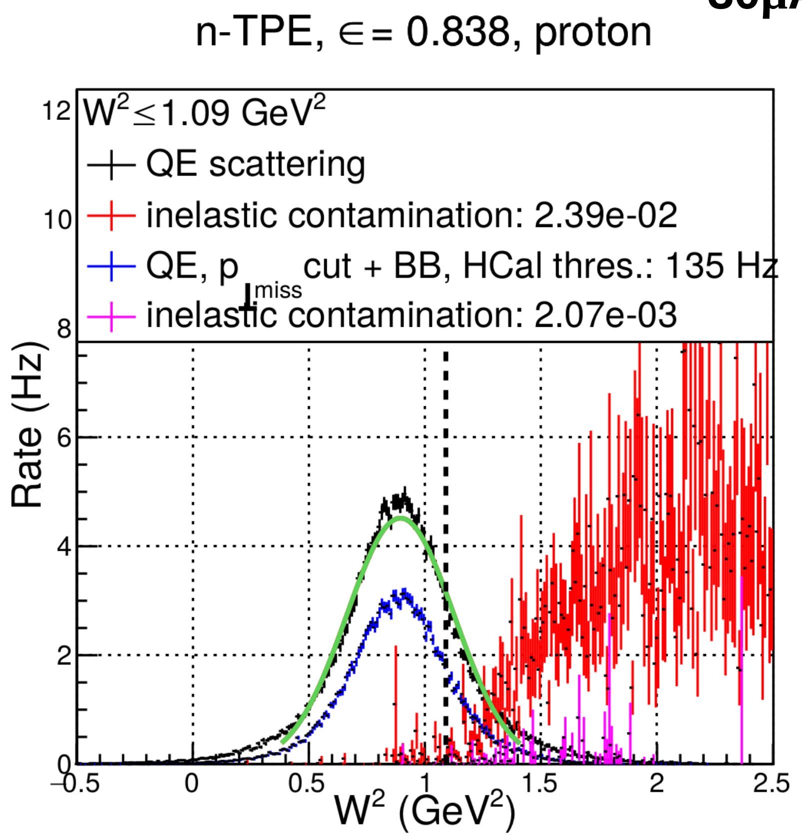
Point (ϵ)	1 (0.599)		2 (0.838)	
	BigBite rates (Hz)	HCal rates (Hz)	BigBite rates (Hz)	HCal rates (Hz)
Total (min. bias - HCal only)	1.37×10^4	1.22×10^7 / 3.39×10^6	8.17×10^3	1.11×10^7 / 3.32×10^6
Coincidence rate (with min. bias HCal)	5.01×10^3 1.39×10^3		2.72×10^3 8.14×10^2	

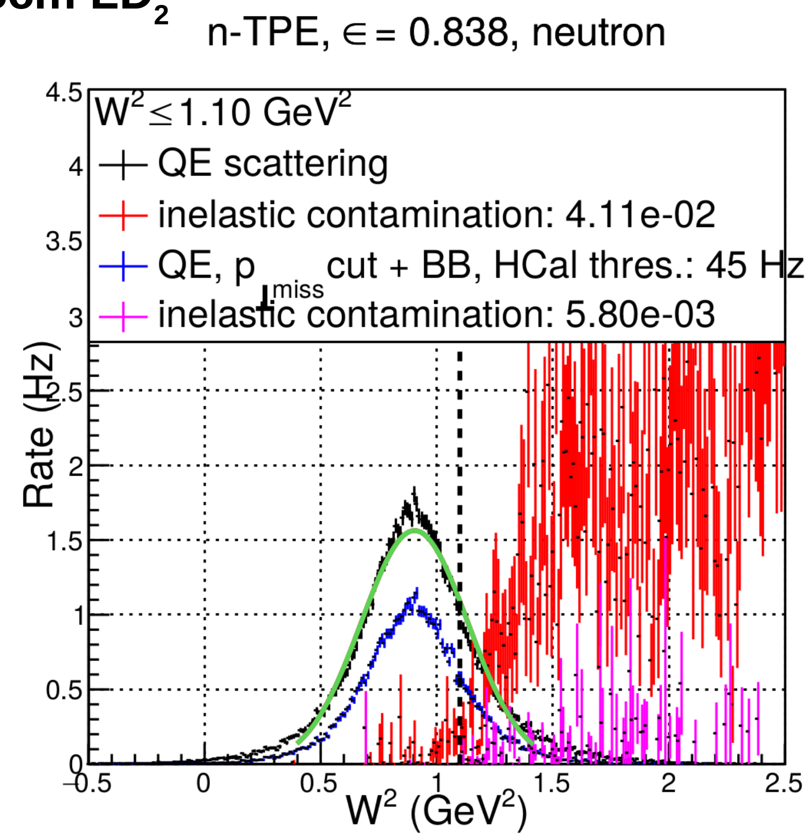
Consistent with calculations by P. Datta for G^M_n

Assuming minimum bias is correct : **trigger rates <2 KHz**

Expected rates: Quasi Elastic + inelastic contamination

30μA, 15cm LD_2





Statistics assuming 12 hours of data Inelastic contamination **<1%**

NB: $p_{\perp miss} =$

$$\sqrt{(q_x - p'_x)^2 + (q_y - p'_y)^2}$$

Point (ϵ)	N_{QE} (e-n)	N_{QE} (e-p)
1 (0.599)	9.07×10^5	2.55×10^6
2 (0.838)	1.94×10^6	5.83×10^6

Systematics

* Using similar en/ep ratio technique as GMn to obtain neutron form factors:
many sources of systematics uncertainties cancel out;
*** main source of systematic uncertainties comes from** S_c^p, $\mu_n(G_E^n/G_M^n)$

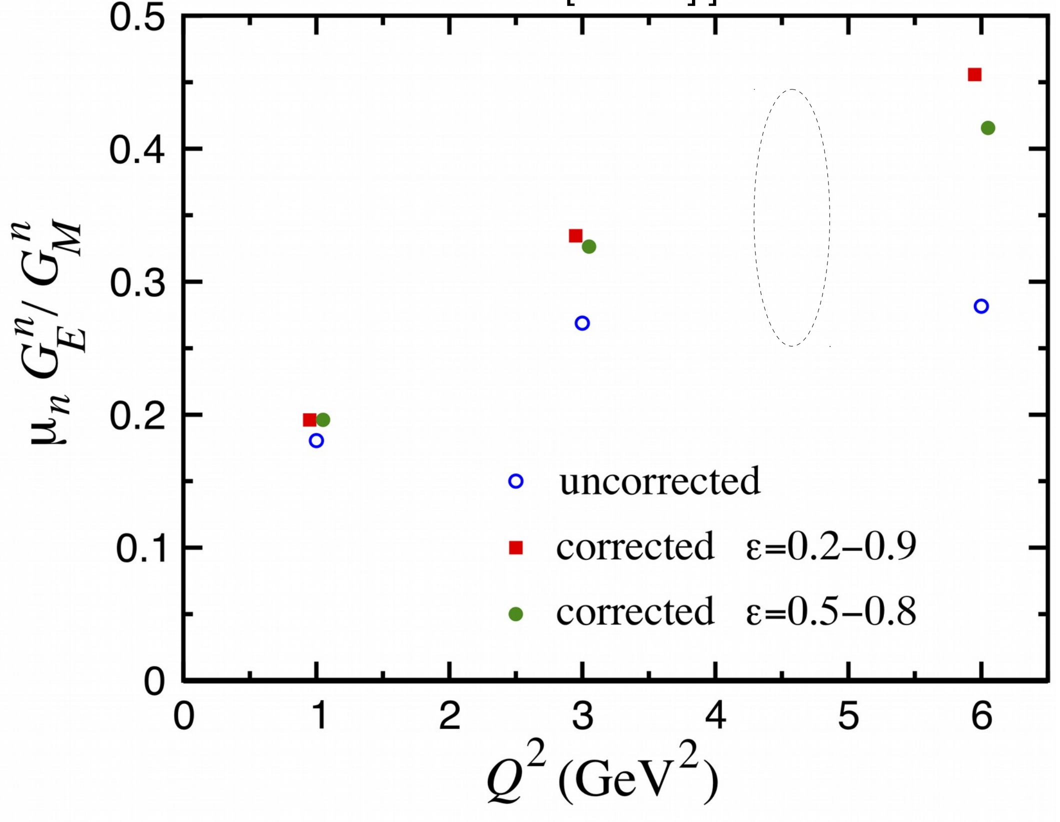
Kinematic (ϵ)	(1) 0.599	(2) 0.838
Acceptance losses	0.5 %	3.0 %
Inelastic contamination	0.9 %	0.6 %
Nucleon mis-identification*	0.6 %	
Syst. error on $R = f_{corr} \times N_{e,e'n}/N_{e,e'p}$ (Quadratic sum of the errors above)	1.3 %	3.1 %

Syst. error on p cross section ($S_c^p = \sigma_L^p/\sigma_T^p$)	± 0.01
Syst. error on n form factor ($\mu_n \mathrm{G}_E^n/\mathrm{G}_M^n$)	± 0.05
Syst. error on Rosenbluth slope (TPE)	±0.012

Expected results

Considering predictions of Blunden, Melnitchouk, and Tjon, [Phys. Rev. C72, 034612 (2005)]
Our measurement of nTPE will be **0.069 ± 0.012(syst) ± 0.010 (stat)**

[P. G. Blunden, W. Melnitchouk, and J. A. Tjon,
Phys. Rev. C72, 034612 (2005),
arXiv:nucl-th/0506039 [nucl-th]]



Beam time request

Task	Target	I_{exp}	time requested
Data taking (Prod.)	15 cm LD_2	30 μA	12 hours
Data taking (Syst.)	15 cm "Dummy"	30 μA	4 hours
Data taking (Prod.)	15 cm LD_2	15 μA	12 hours
Data taking (Syst.)	15 cm "Dummy"	15 μA	4 hours
Setting changes (BigBite move, beam pass change)			8 hours
Beam tune after beam pass change			8 hours
Total			**48 hours**

Insertion in existing schedule

Step #	task	Q^2 $(GeV/c)^2$	θ_{BB} / θ_{SBS} degrees	Beam GeV	Time hours	Tech work time (h)
4b (install GEn-RP)	GEn-RP		41.9 / 24.7	-	4	4
4c (GEn-RP)	Production	4.5	41.9 / 24.7	4.4	104 (calendar) (52 PAC hours)	
4d (remove GEn-RP)	GEn-RP		41.9 / 24.7	-	56	24
4e (GMn/nTPE low ϵ)	Production	4.5	41.9 / 24.7	4.4	64 (calendar) (32 PAC hours)	
5a (conf. change)	BB/SBS/HCal		32.5 / 31.1	-	32	16
5b (beam tune)	beam		32.5 / 31.1	4.4	4	
5c (GMn)	Production	3.5	32.5 / 31.1	4.4	64 (calender) (32 PAC hours)	
6a (pass change)	beam/BB		23.2 / 31.1	6.6	8	4
6b (beam tune)	beam		23.2 / 31.1	6.6	8	
6c see Table. X	Production	4.5	23.2 / 31.1	6.6	64 (calendar) (32 PAC hours)	
7a (conf. change)	BB/SBS/HCal		58.4 / 17.5		32	16
+ (pass change)	beam		58.4 / 17.5	4.4	during SBS move	
7b (beam tune)	beam	-	58.4 / 17.5	4.4	4	
7c	Production	5.7	58.4 / 17.5	4.4	50 (calendar) (25 PAC hours)	

Summary

*** No existing data on two-photon exchange contribution on elastic e-n**
=> Unique measurement;

*** Uses existing G_M^n setup *with no additional subsystem***

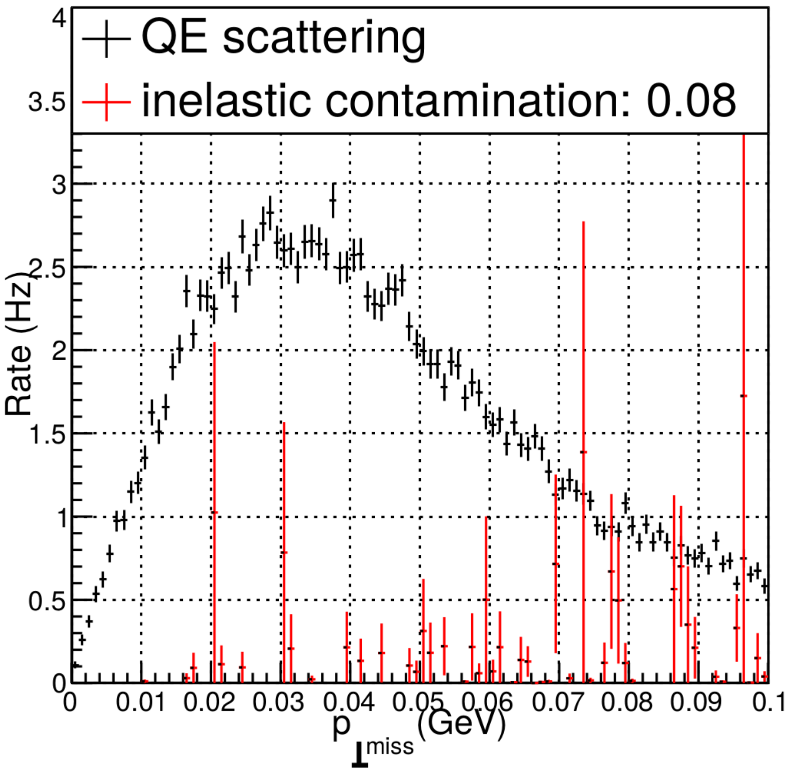
*** Can be inserted in the schedule *without SBS move***
=> reasonable time addition to the schedule

Backup

Expected rates: Quasi Elastic + inelastic contamination

$$p_{\perp\ miss} = \sqrt{(q_x - p'_x)^2 + (q_y - p'_y)^2}$$

n-TPE, ∈ = 0.838, proton



n-TPE, ∈ = 0.838, neutron