nTPE+: Measurement of the Two-Photon Exchange in Electron-Neutron and Positron-Neutron Elastic Scattering

A Proposal to PAC53

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On behalf of the nTPE collaboration

PWG Meeting

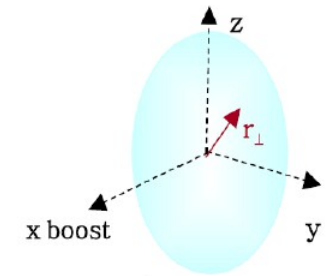
July 9th, 2025

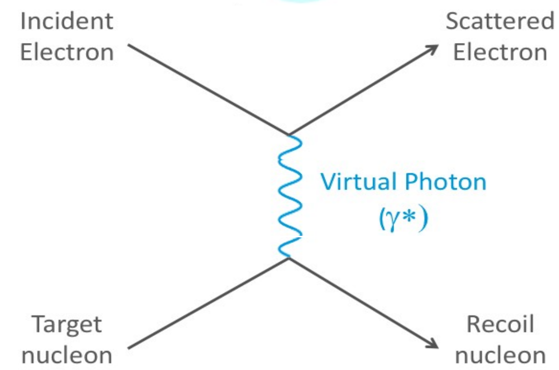
WILLIAM & MARY

CHARTERED 1693

Jefferson Lab

Elastic *e-N* scattering: Rosenbluth





- Space-like Form Factors ≡ charge distribution
- In the One-Photon Exchange (Born) approximation:

$$\left(\frac{d\sigma}{d\Omega}\right)_{eN\rightarrow eN} = \frac{\sigma_{Mott}}{\epsilon(1+\tau)}\left[\tau \underbrace{G_M^2(Q^2)}_{\text{Sachs magnetic FF squared}} + \epsilon \underbrace{G_E^2(Q^2)}_{\text{Sachs Electric FF squared}}\right]$$

with $\tau = Q^2/(4M_N)$

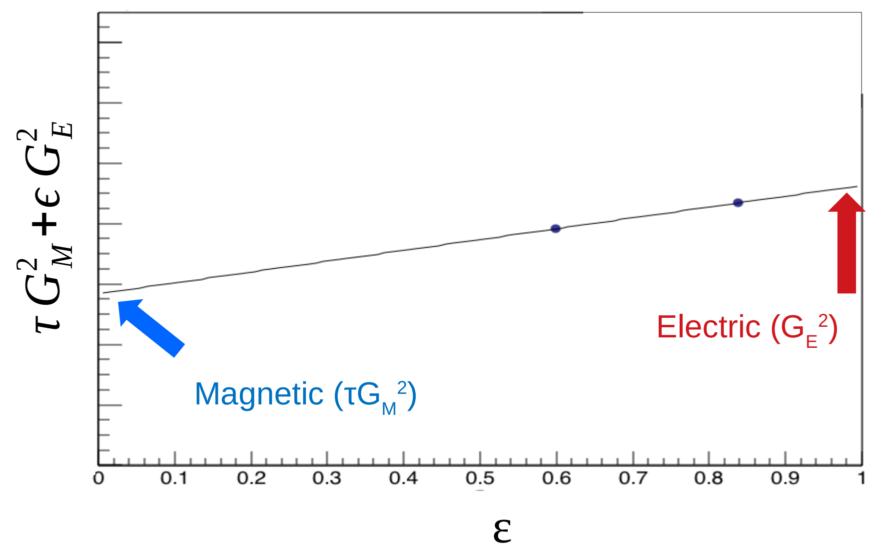
- Rosenbluth technique: separate G_M^2 and G_E^2 based

on the linear dependence in $\epsilon = \left[1+2(1+\tau)\tan^2(\theta/2)\right]^{-1}$ of

$$\sigma_r = (d\sigma/d\Omega)\cdot\epsilon(1+\tau)/\sigma_{Mott}$$
$$= \tau G_M^2(Q^2) + \epsilon\,\tau G_E^2(Q^2)$$
$$= \sigma_T + \epsilon\,\sigma_L$$

- Two or more measurements, same Q^2,

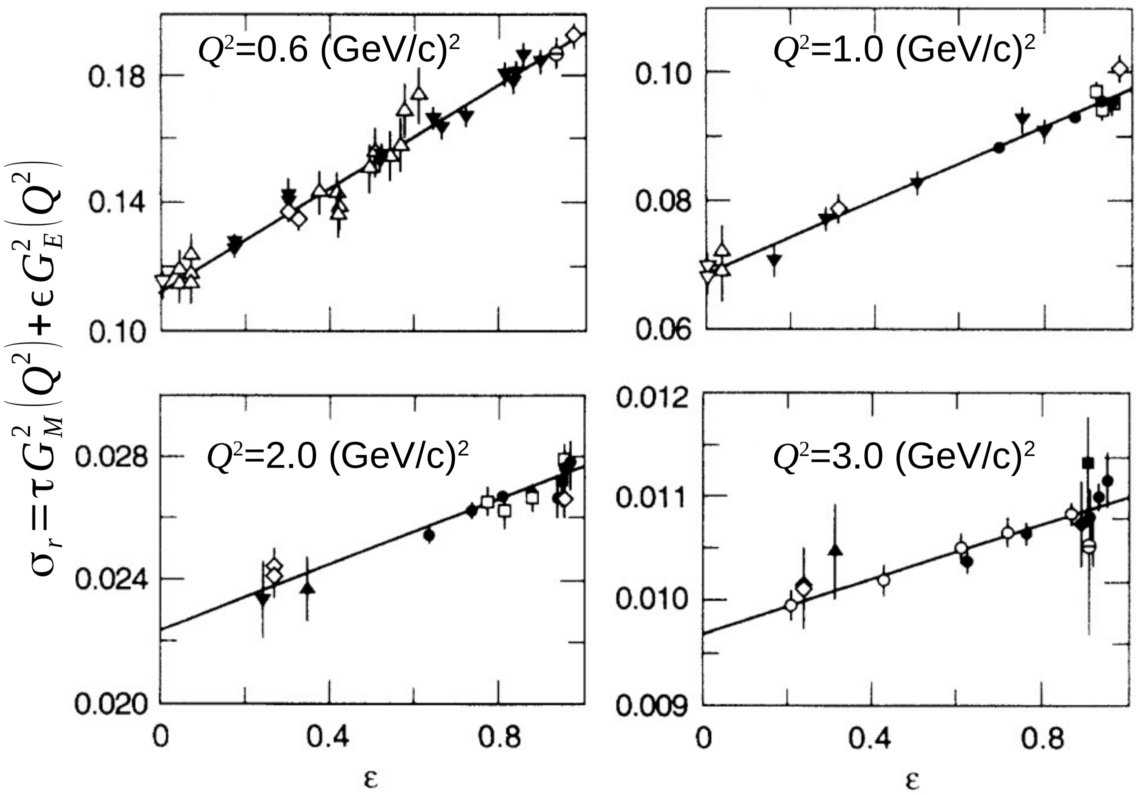
different E and θ (different ε)



Rosenbluth Measurements in e^-p Scattering

- Rosenbluth technique extensively used on the proton to extract G_E^p
- **Linearity in ε well tested up to $Q^2 \leq 3$ (GeV/c)^2**

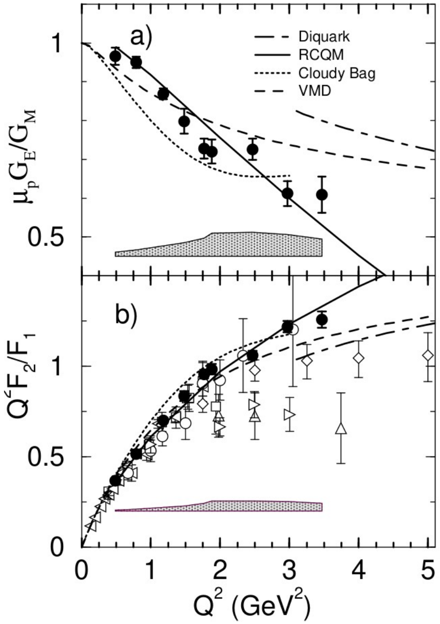
Walker et al. Phys. Rev. D49, 5671 (1994)



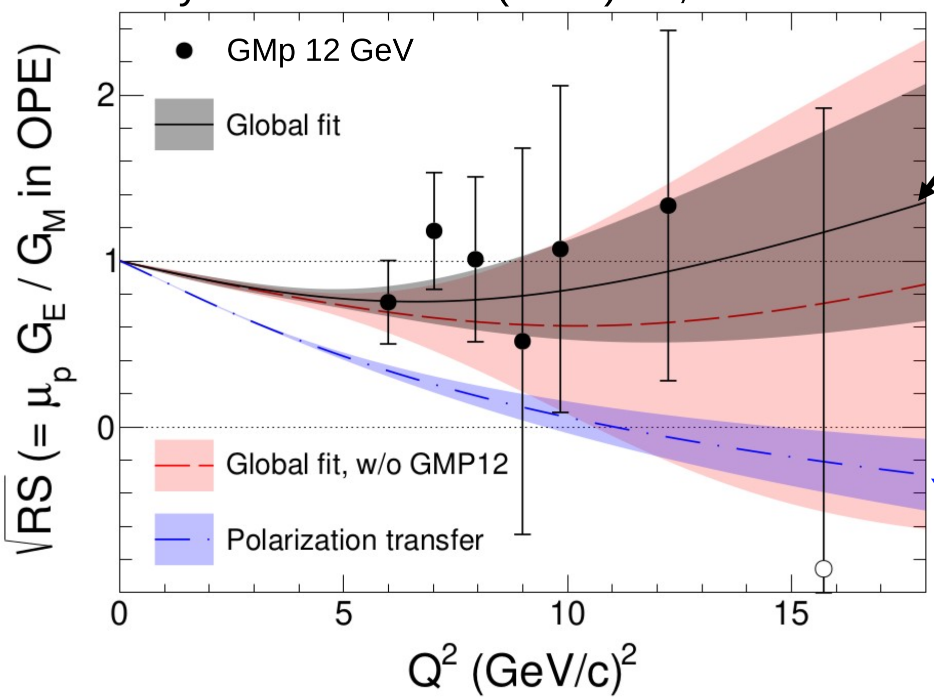
Global Fit on Rosenbluth Slope in $e^{-}p$ Scattering

- Until GEp-I at Jefferson Lab [Phys. Rev. Lett. 84, 1398 (2000)], OPE accepted to be a sufficient approximation
- ***Large*** **discrepancy** between Rosenbluth and polarization transfer (for measurements at $Q^2 \geq 2$ GeV^2);
- Missing contribution likely due to Two-Photon Exchange (TPE).

Phys. Rev. Lett. 84, 1398 (2000)



Phys.Rev.Lett. 128 (2022) 10, 102002



Global fit of high Q^2 Rosenbluth measurements

Latest JLab proton data at 12 GeV

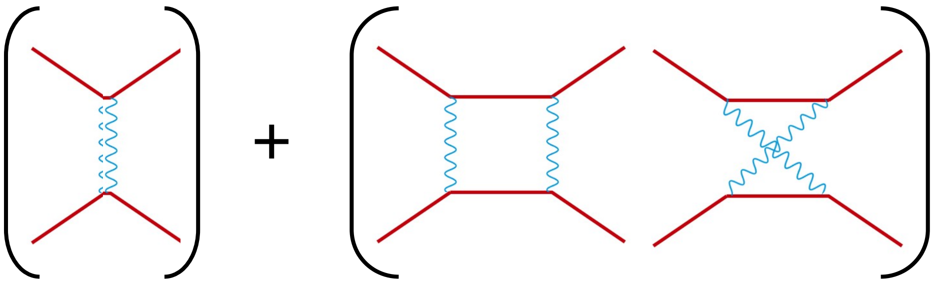
Global fit of polarization transfer measurements

Two-Photon Exchange with Positrons

- TPE in elastic e^+N scattering:
- Hard TPE amplitude interferes with OPE amplitude:

Lepton charge

$$\sigma_{eN} = |M_{1\gamma}|^2 \pm 2\,\Re e\left[M_{1\gamma} M_{2\gamma}\right]$$

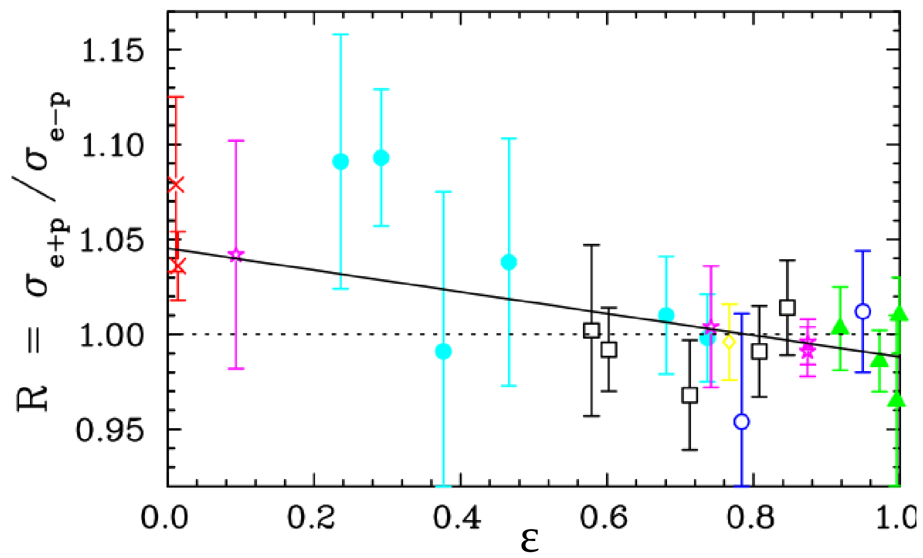


- Interference term depends on the lepton charge to the power 3:
  - TPE expected to be of same magnitude opposite sign in e^+N and e^-N;
  - measurement e^+N / e^-N => 2 TPE

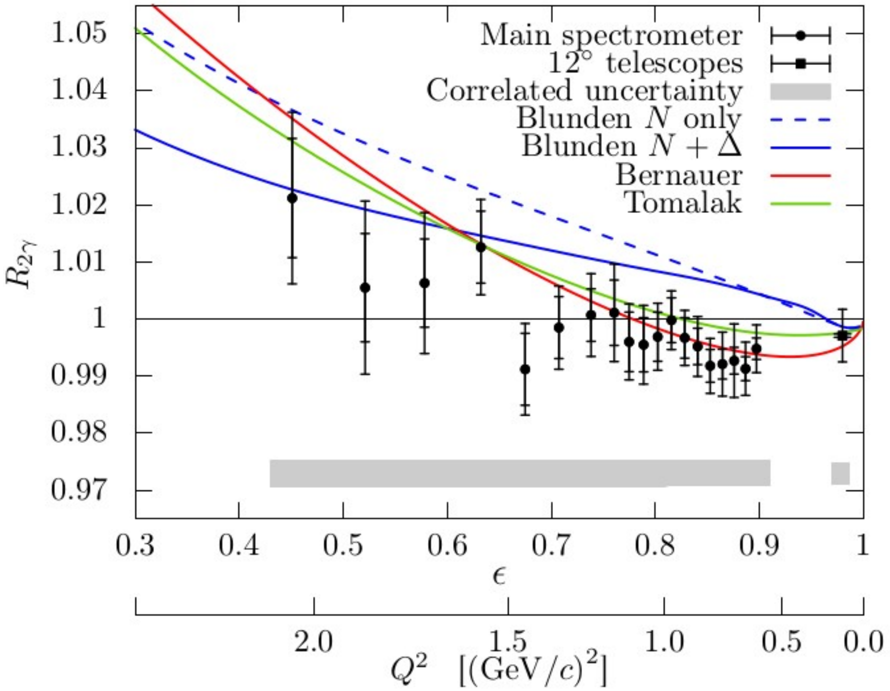
e^+p measurements

- Ratio of e^+p/e^-p measured in several experiments;
- Latest measurements in Olympus, with Q^2 up to 2 GeV^2:

Phys. Rev. C 69, 032201 (2004).526



Phys. Rev. Lett. 118, 092501 (2017)

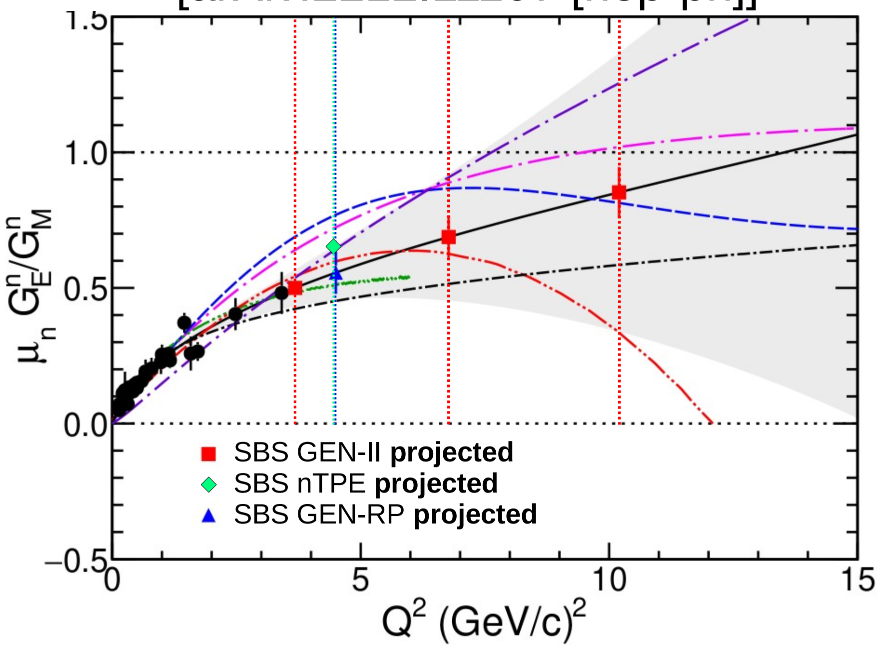


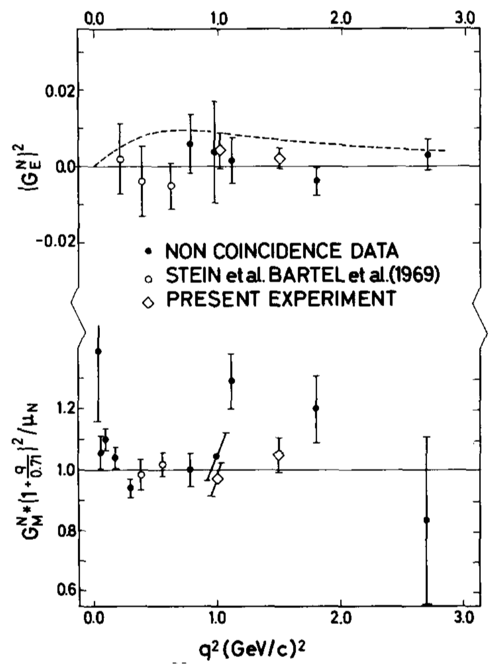
- ***Essentially inconclusive results***
- Note: Rosenbluth/polarization discrepancy not very significant at low Q^2

en Scattering Measurements

- Measurements of G_E^n:
  - Most data below Q^2 = 2 GeV^2;
  - All measurements beyond Q^2 = 3.5 GeV^2 from SBS (analysis underway);
  - Rosenbluth measurements on the neutron:
    - **old** (1960-70s), **low accuracy data** for Q^2 < 2.0 GeV^2
    - SBS nTPE (2022) at Q^2 = 4.5 GeV^2 (analysis underway)

[arXiv:2212.11107 [hep-ph]]

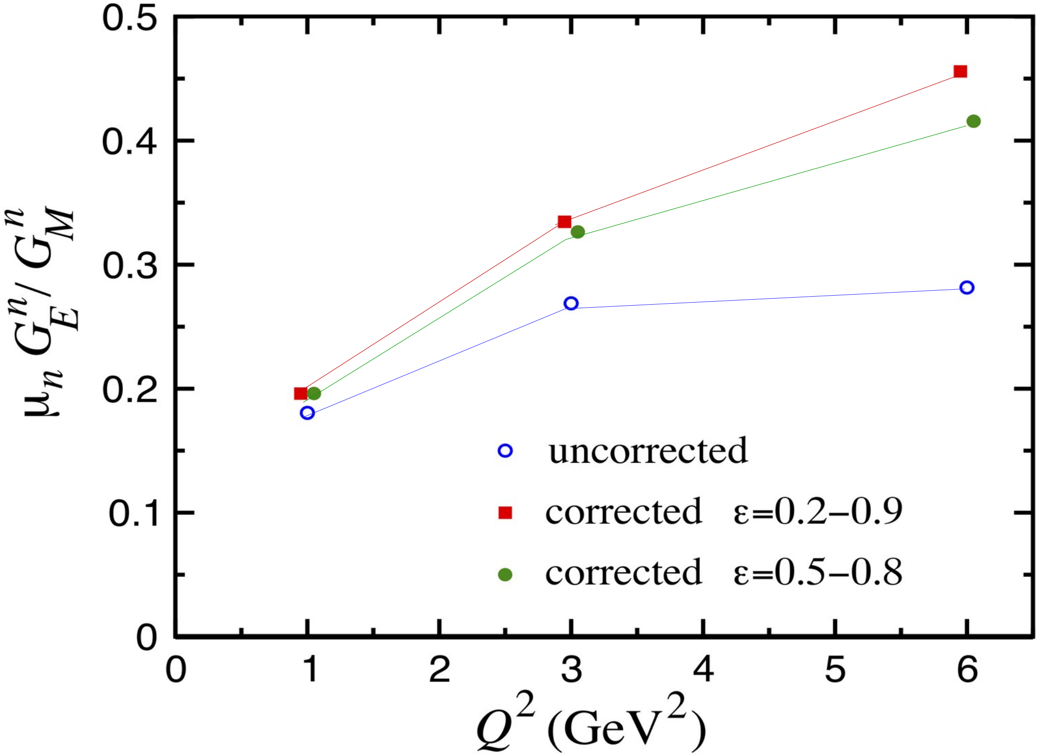




Bartel et al., Phys. Lett. 39B, 407 (1972)

Two-Photon Exchange in *en* Scattering

- Lack of "contradictory" measurements to evidence TPE in *en* scattering
- Predictions from Phys. Rev. C**72**, 034612 (2005) on *en* scattering:
  - small TPE contribution at Q^2 around 1 GeV^2;
  - significant at 3 GeV^2 and beyond;



Blunden, Melnitchouk and Tjon, Phys. Rev. C**72**, 034612 (2005)

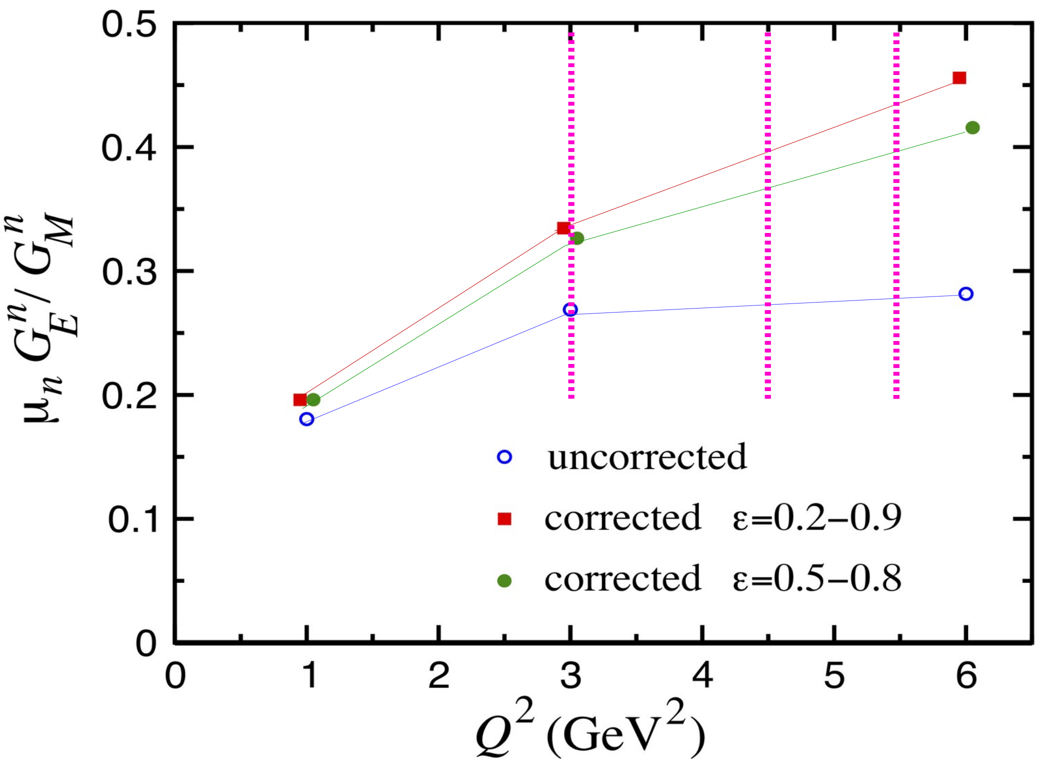
○ $\mu_n G_E^n/G_M^n$ from Mergell Meissner Drechsel parameterization of polarized data in Nucl. Phys. A596, 367 (1996)

■ $\mu_n G_E^n/G_M^n$ +TPE between ε = 0.2 and 0.9

● $\mu_n G_E^n/G_M^n$ +TPE between ε = 0.5 and 0.8

Two-Photon Exchange in *en* Scattering

- nTPE+: E.F. (contact), S. Alsalmi, P. Blunden, P.Datta, E. Wertz
  - **Followup of LOI12+24-008**: neutron TPE at Q^2 = 3 GeV^2, 4.5 GeV^2, 5.5 GeV^2
  - Direct measurement of nTPE via e^+n/e^-n ratio → *Suggested by LOI 2024 review*
  - Rosenbluth measurements of e^-n and e^+n cross section
  - => disentangle contribution of TPE in Rosenbluth/polarization discrepancies



Blunden, Melnitchouk and Tjon, Phys. Rev. C**72**, 034612 (2005)

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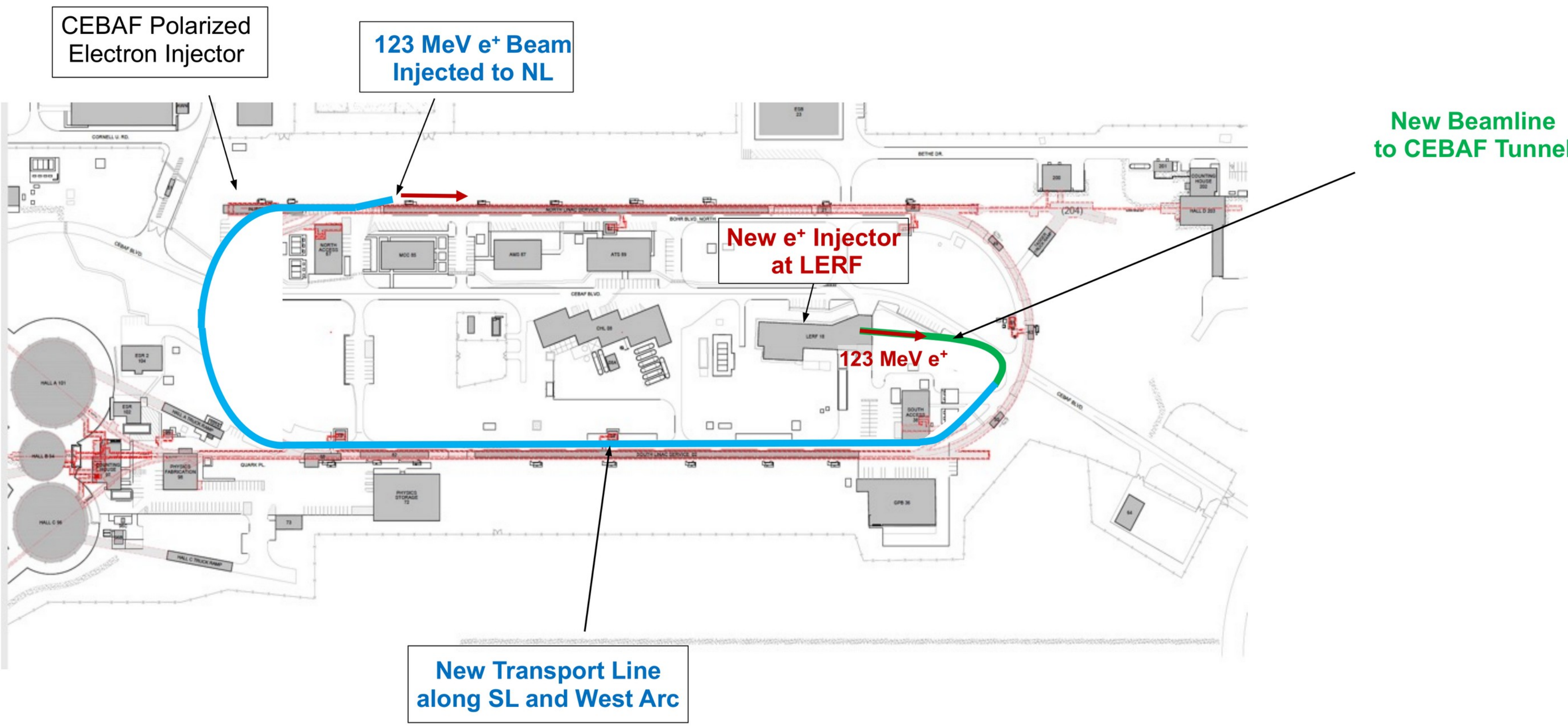
● $\mu_n G_E^n/G_M^n$ +TPE between ε = 0.5 and 0.8

nTPE+ with Jefferson Lab Positron Upgrade

- New injector to produce polarized positrons (and electrons)
- Promised specifications:
  - **1μA e^+ without polarization**;
  - 60nA with polarization;

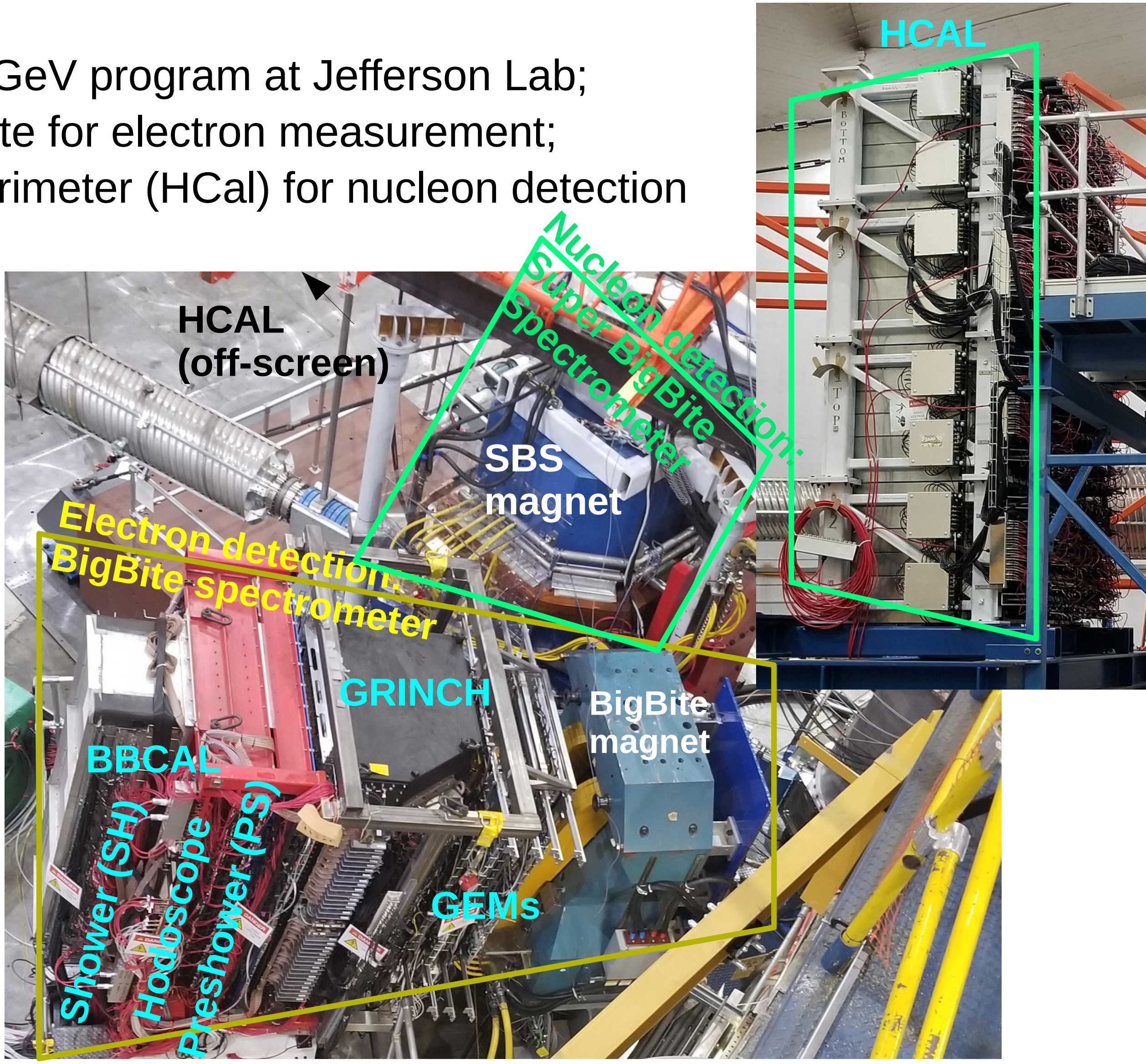


nTPE+ with Super BigBite Spectrometer

- **SBS:**
  - Major part of Hall A 12 GeV program at Jefferson Lab;
  - SBS coupled with Bigbite for electron measurement;
  - SBS uses Hadron Calorimeter (HCal) for nucleon detection / identification;

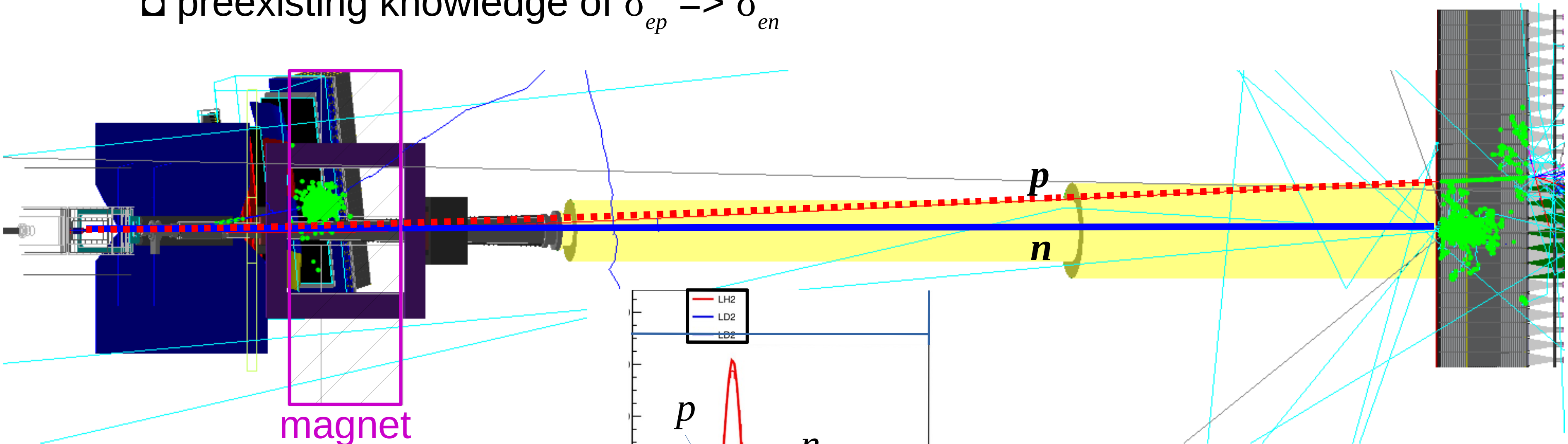
- **SBS form factor program**
  - GMN
  - *nTPE* (E12-20-010)
  - GEN
  - GEN-RP
  - GEP

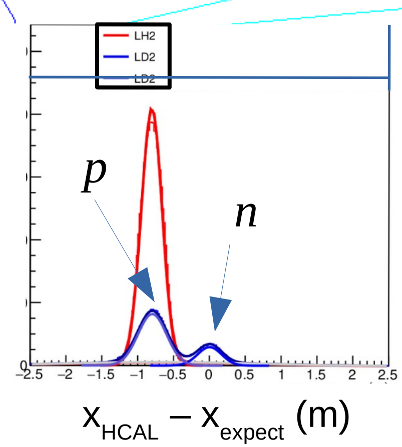
- Other Physics:
  - SIDIS
  - KLL
  - TDIS
  - nDVCS



Neutron Measurement with Durand Technique

- Established by Durand in Phys. Rev. 115, 1020 (1959).
- Used for SBS experiments GMN, nTPE (2020), **nTPE+**:
  - simultaneous *en*/*ep* measurement on D_2
  - Separation of *p* and *n* with magnet
  - σ_{en}/σ_{ep} with reduced systematics (cancellation of Fermi momentum,…)
  - preexisting knowledge of σ_{ep} => σ_{en}

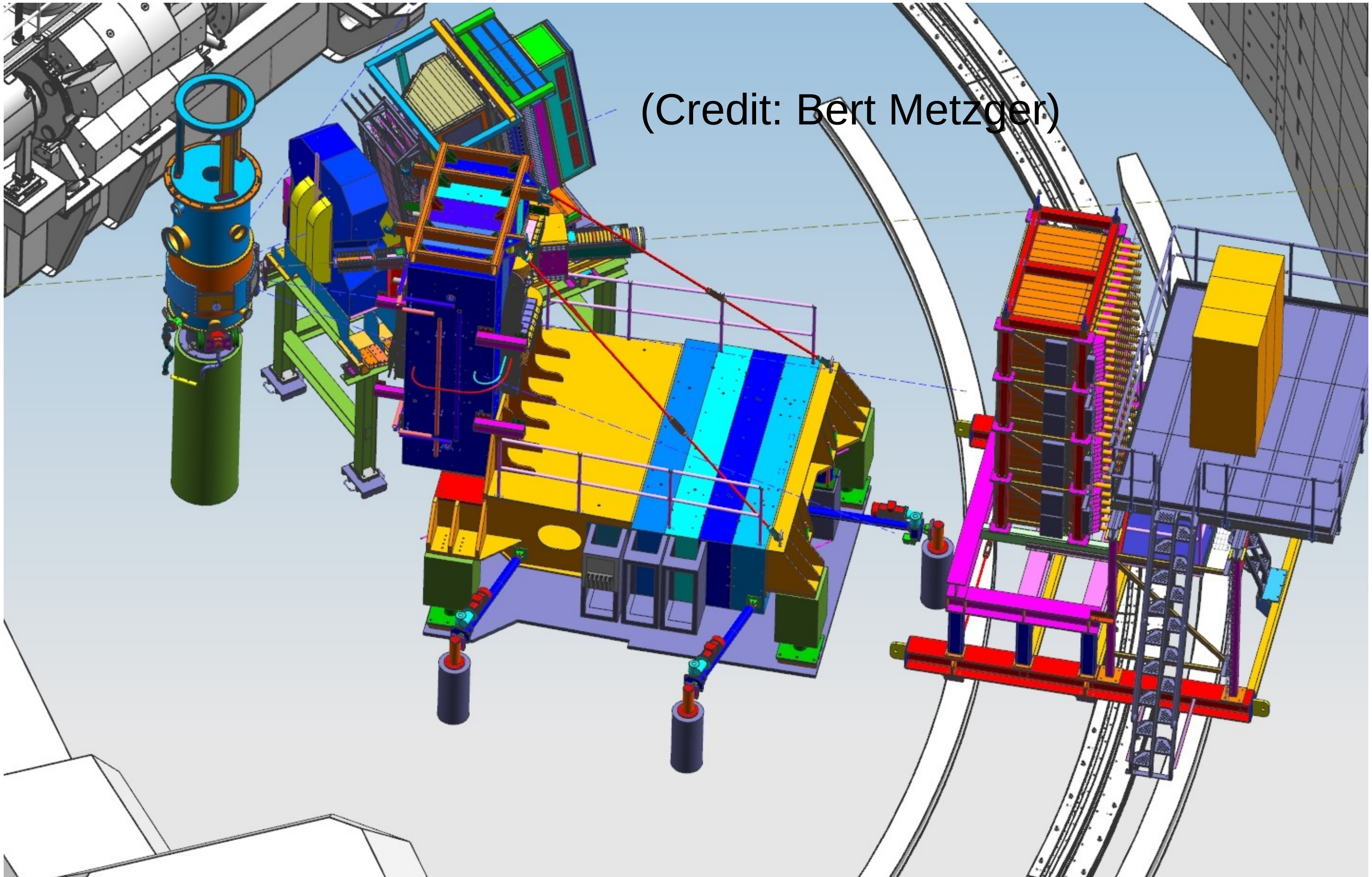




X_{HCAL}: reconstructed
x_{expect}: predicted from e^-

nTPE+ Kinematics

- NTPE+ will be proposed in **Hall C**:
  - SBS, BigBite and target installed downstream of pivot;
  - SBS, BigBite locations for our kinematics don't interfere with HMS/SHMS at their largest angles;



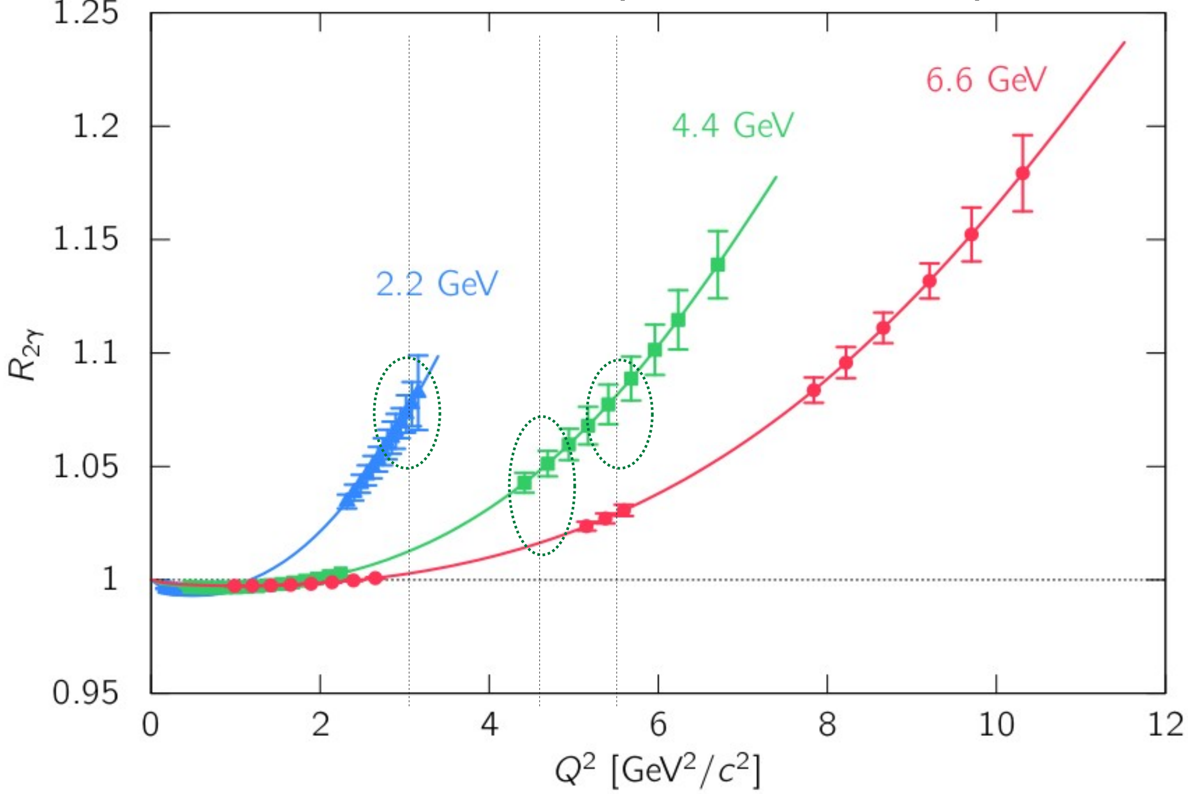
nTPE+ Kinematics

- NTPE+ will be proposed in **Hall C**:
  - SBS, BigBite and target installed downstream of pivot;
  - SBS, BigBite locations for our kinematics don't interfere with HMS/SHMS at their largest angles;
- Six kinematic settings:
  - each will run e^+, e^-, LD_2, LH_2;
    - **TAC recommendation**: use longer targets (30cm instead of 15cm);
  - Three settings at 2 pass, two settings at 3 pass, one setting at 1.5 pass.

Kinematic	e^+/e^- - I_{beam} (μA)	Q^2 (GeV/c)^2	E (GeV)	E$'$ (GeV)	θ_{BB} degrees	p' (GeV/c)	θ_{SBS} degrees	ϵ
1+/-	$e^{+/-}$ (1.0)	4.5	4.4	2.00	41.9	3.20	24.7	0.600
2+/-	$e^{+/-}$ (1.0)	4.5	6.6	4.20	23.3	3.20	31.2	0.838
3+/-	$e^{+/-}$ (1.0)	3.0	3.3	1.71	42.8	2.35	29.5	0.638
4+/-	$e^{+/-}$ (1.0)	3.0	4.4	2.81	28.5	2.35	34.7	0.808
5+/-	$e^{+/-}$ (1.0)	5.5	4.4	1.47	54.9	3.75	18.7	0.420
6+/-	$e^{+/-}$ (1.0)	5.5	6.6	3.67	27.6	3.76	26.9	0.764

nTPE+ Measurements: *e+/e-* ratios $R_{2\gamma}$

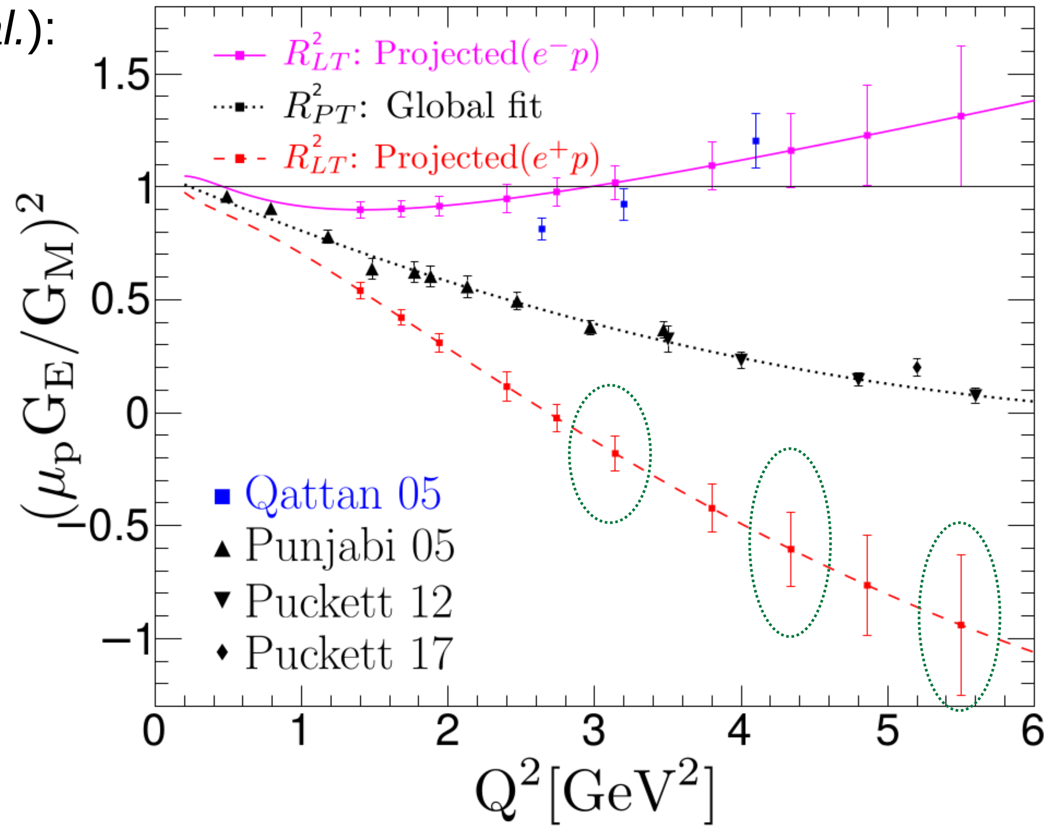
- $R^n_{2\gamma}$ measurement with Durand technique:
  - Measure $R_{n/p} = \sigma_{en}/\sigma_{ep}$ consecutively for positrons and electrons;
  - $\rho_{\pm} = \left(\frac{\sigma_{e^+n}}{\sigma_{e^+p}}\right) / \left(\frac{\sigma_{e^-n}}{\sigma_{e^-p}}\right) = R^n_{2\gamma}/R^p_{2\gamma}$ for **Q^2 = 3 GeV^2, 4.5 GeV^2, 5.5 GeV^2**
  - e^- data at same beam intensity as e^+ data (1μA)
  - $R^p_{2\gamma}$ sourced from PR12+23-008 (A. Schmidt *et al.*)



nTPE+ Measurements: Rosenbluth slopes S^n

- Rosenbluth measurement with Durand technique:
  - Measure $R_{n/p} = \sigma_{en}/\sigma_{ep}$ for both ε points;
  - $A = \frac{R_{n/p}^{\epsilon_1}}{R_{n/p}^{\epsilon_2}} \simeq \frac{1+\epsilon_2 S^p}{1+\epsilon_1 S^p} \times (1 + S^n \Delta\epsilon)$
  - Rosenbluth e^+p *up to Q^2 = 5.5 GeV^2* sourced from PR12+23-012

(M. Nycz *et al.*):



nTPE+ Systematics: GMn/nTPE Analysis

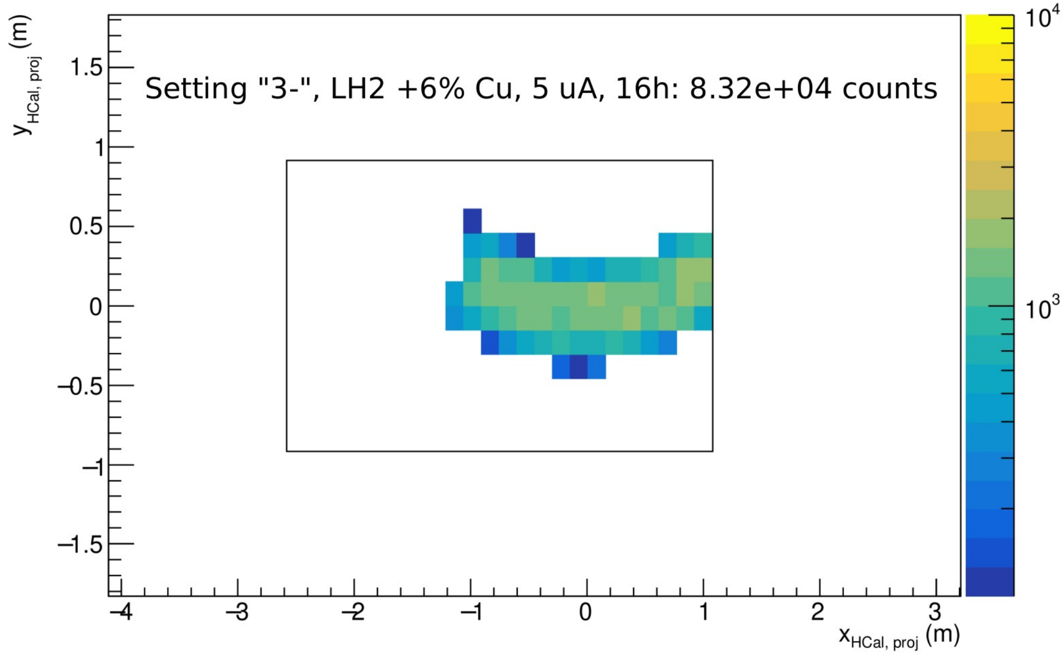
- Sources of systematics for $R_{n/p}$:
  - Preliminary estimation of systematics for GMn/nTPE analysis:
  - (*) => Divided by a factor 3 to account for possible improvements
  - Introduced factors of covariance for correlations between settings

Q^2 ((GeV/c)^2)	3.0	4.5	5.5	$\delta_{cov,\ e+/e-}$	$\delta_{cov,\ \epsilon_1/\epsilon_2}$
Radiative corrections*	0.77	1.11	1.26	+0.80	0.0
Inelastic contamination	0.33	0.75	0.84	+0.5	0.0
Nucleon detection efficiency*	0.7	0.7	0.7	+0.95	+0.5
Nucleon charge exchange in FSI	0.04	0.01	0.02	+0.95	0.0
Selection stability	0.16	0.15	0.40	+1.00	0.0
$\Delta R_{n/p}$	1.10	1.52	1.72	-	-
$\Delta\rho_\pm/\rho_\pm$	0.44	0.74	0.83	-	-
$\Delta A/A$	1.40	2.03	2.32	-	-

Neutron Detection Efficiency Measurement

- Neutron and protons detection efficiencies similar, but not identical;
  - Determine absolute detection efficiency for both protons and neutrons;

- *Explicit* beam request to measure $\gamma p \to \pi^+ n$ at "kinematic end-point":
  - π^+ measured by BigBite, n measured by HCal;
  - Strict kinematic selection to ensure $\gamma p \to \pi^+ n$ exclusivity;
  - LH_2 target with 6 % X_0 copper upstream to enhance photon production ;
  - Electron beam to increase luminosity;
  - Coverage of ~1/4 of HCal surface sufficient to determine neutron efficiency



nTPE+ Systematics: Uncertainties for $R_{2\gamma}$, S^n

- Systematics specific to $R_{2\gamma}{}^n$ and S^n:

$R_{2\gamma}{}^n$

Q^2 ((GeV/c)^2)	3.0	4.5	5.5
$\Delta\rho_\pm/\rho_\pm$ (stat)	0.28	0.25	0.58
$\Delta\rho_\pm/\rho_\pm$ (syst)	0.44	0.74	0.83
$\Delta R^p_{2\gamma}/R^p_{2\gamma}$ [13]	0.78	0.42	0.79
$\Delta R^n_{2\gamma}/R^n_{2\gamma}$ (syst)	0.93	0.89	1.28

S^n

Q^2((GeV/c)^2)	3.0 (e^-)	3.0 (e^+)	4.5 (e^-)	4.5 (e^+)	5.5 (e^-)	5.5 (e^+)
$\Delta A/A$ (stat, %)	0.32	0.32	0.40	0.40	0.58	0.58
$\Delta A/A$ (syst, %)	1.40	1.40	2.03	2.03	2.32	2.32
S^p [3, 14]	0.1056	-0.0267	0.0616	-0.0608	0.0478	-0.0773
ΔS^p [3, 14]	0.0160	0.0114	0.0165	0.0164	0.0170	0.0254
ΔS^n	0.100	0.096	0.103	0.103	0.087	0.094

[3] Phys.Rev.Lett. 128 (2022) 10, 102002
[13] A. Schmidt *et al.* PR12+23-008
[14] M. Nycz *et al.* PR12+23-012

nTPE+ Time Request

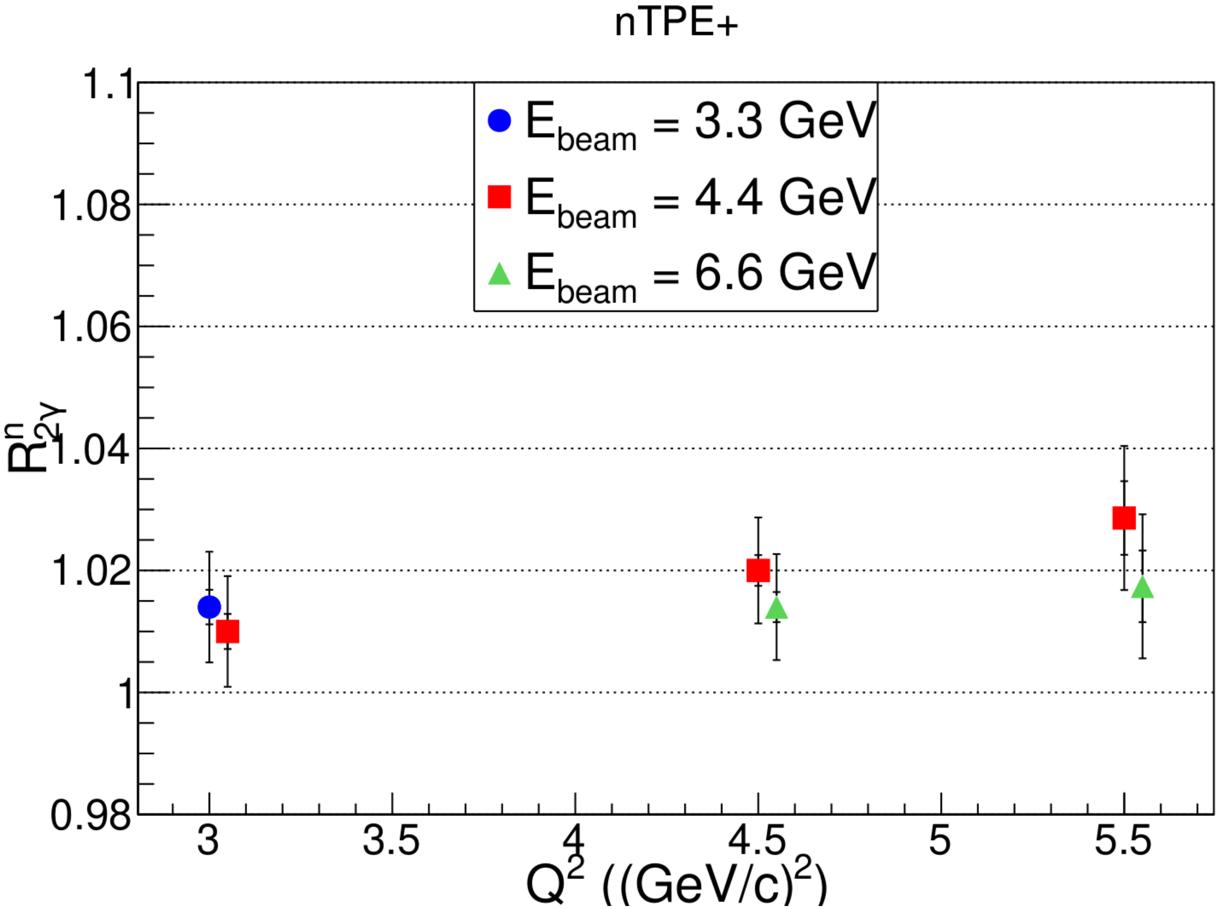
- **TAC recommendation**: use longer targets to maximize luminosity
- 6 kinematics with e+/e- LD2/LH2 30 cm (instead of 15 cm): **34.5 PAC days total**
  - *536 PAC hours (about 22 days) beam on target:*
  - 292 additional PAC hours (584 real hours) for setting changes:
    - ♦ 144 PAC hours (288 real hours) for 6 e^+/e^- changes;
    - ♦ 148 PAC hours (296 real hours) for 5 magnet angles and pass changes);

(including one week for pass change at 1.5 pass)

Kin	e^+ or e^-	E_{Beam} (pass) (GeV)	I_{Beam} μA	Q^2 $(\text{GeV/c})^2$	θ_{BB} / θ_{SBS} (degrees)	target	PAC (real) Time (hours)
Optics	e^-	4.4 (2)	10.0	3.0	28.5/34.7	C-foil	16
2-	e^-	4.4 (2)	1.0	3.0	28.5/34.7	LD2 30cm/LH2 30cm	8/8
Reconfiguration to positrons							24 (48) †
2+	e^+	4.4 (2)	1.0	3.0	28.5/34.7	LD2 30cm/LH2 30cm	8/8
BB/SBS magnet configuration change							16 (32)
3+	e^+	4.4 (2)	1.0	4.5	41.9/24.7	LD2 30cm/LH2 30cm	48/16
Reconfiguration to electrons							24 (48) †
NDE	e^-	4.4 (2)	10.0	4.5	41.9/24.7	LH2 30cm+6% Cu Rad	8
3-	e^-	4.4 (2)	1.0	4.5	41.9/24.7	LD2 30cm/LH2 30cm	48/8
BB/SBS magnet configuration change							16 (32)
5-	e^-	4.4 (2)	1.0	5.5	54.9/18.7	LD2 30cm/LH2 30cm	60/20
Reconfiguration to positrons							24 (48) †
5+	e^+	4.4 (2)	1.0	5.5	54.9/18.7	LD2 30cm/LH2 30cm	60/20
Pass change + BB/SBS magnet configuration change							16 (32)
4+	e^+	6.6 (3)	1.0	4.5	23.3/31.2	LD2 30cm/LH2 30cm	24/8
Reconfiguration to electrons							24 (48) †
4-	e^-	6.6 (3)	1.0	4.5	23.3/31.2	LD2 30cm/LH2 30cm	24/8
BB/SBS magnet configuration change							16 (32)
6-	e^-	6.6 (3)	1.0	5.5	27.6/26.9	LD2 30cm/LH2 30cm	18/6
Reconfiguration to positrons							24 (48) †
6+	e^+	6.6 (3)	1.0	5.5	27.6/26.9	LD2 30cm/LH2 30cm	18/6
Special Pass change (1.5 pass) + BB/SBS magnet configuration change							84 (168)
1+	e^+	3.3 (3*)	0.5	3.0	42.8/29.5	LD2 30cm/LH2 30cm	24/12
Reconfiguration to electrons							24 (48) †
1-	e^-	3.3 (1.5)	0.5	3.0	42.8/29.5	LD2 30cm/LH2 30cm	24/12
Optics	e^-	3.3 (1.5)	10.0	3.0	42.8/29.5	C-foil	16
Total beam							**536**
Total time request							**828 (1656)**

nTPE+ Projections

- $R^{n}_{2\gamma}$ for all 6 settings:
  - statistical uncertainty (inner bars);
  - statistical + systematics (outer bars);

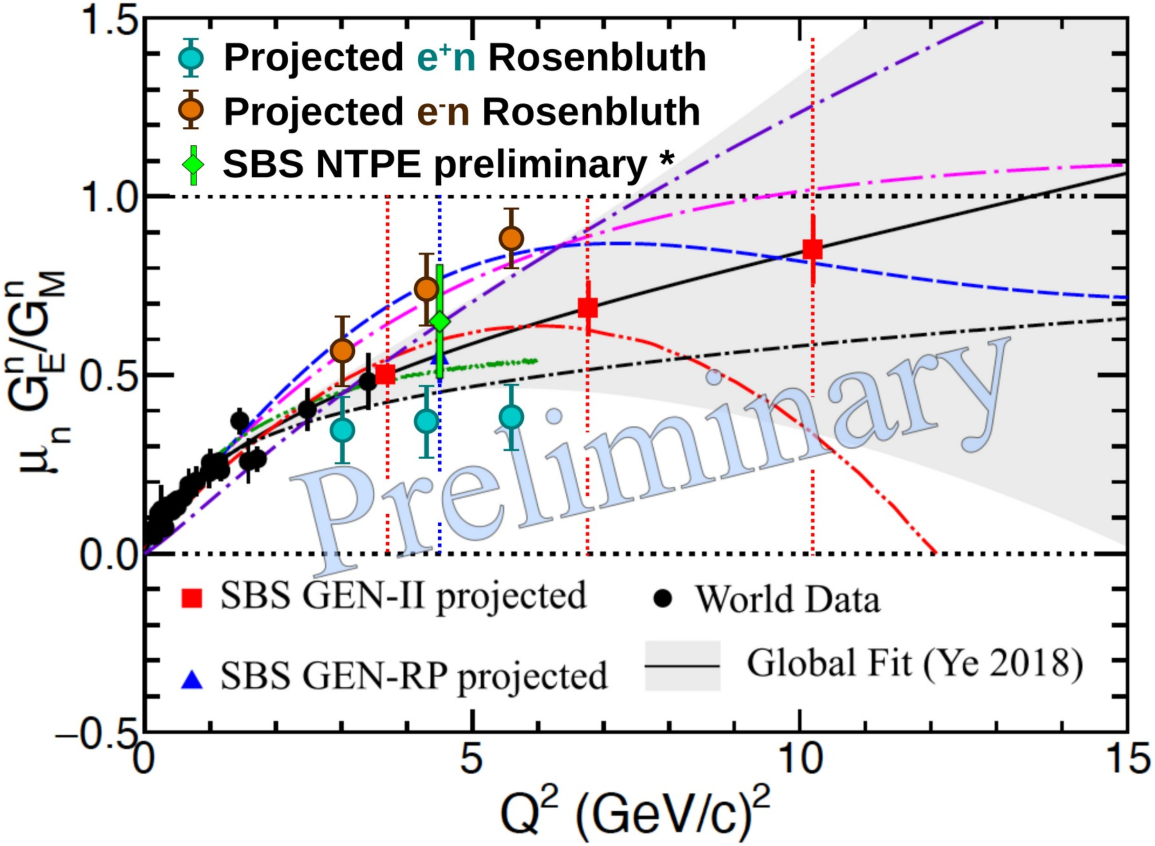


nTPE+ Projections

- Estimations of $e^{+}n$ and $e^{-}n$ Rosenbluth slopes
  - Superimposed on nTPE (2022) preliminary analysis by E. Wertz*

"A Measurement of the Neutron Electromagnetic Form Factor Ratio from a Rosenbluth Technique with Simultaneous Detection of Neutrons and Protons", Ph.D Thesis, William & Mary (July 2025).

  - $\mu_n\, G_E^n/G_M^n$ calculated from projected Rosenbluth slopes;
  - Other G_E^n measurements and projections are polarization data;



Summary

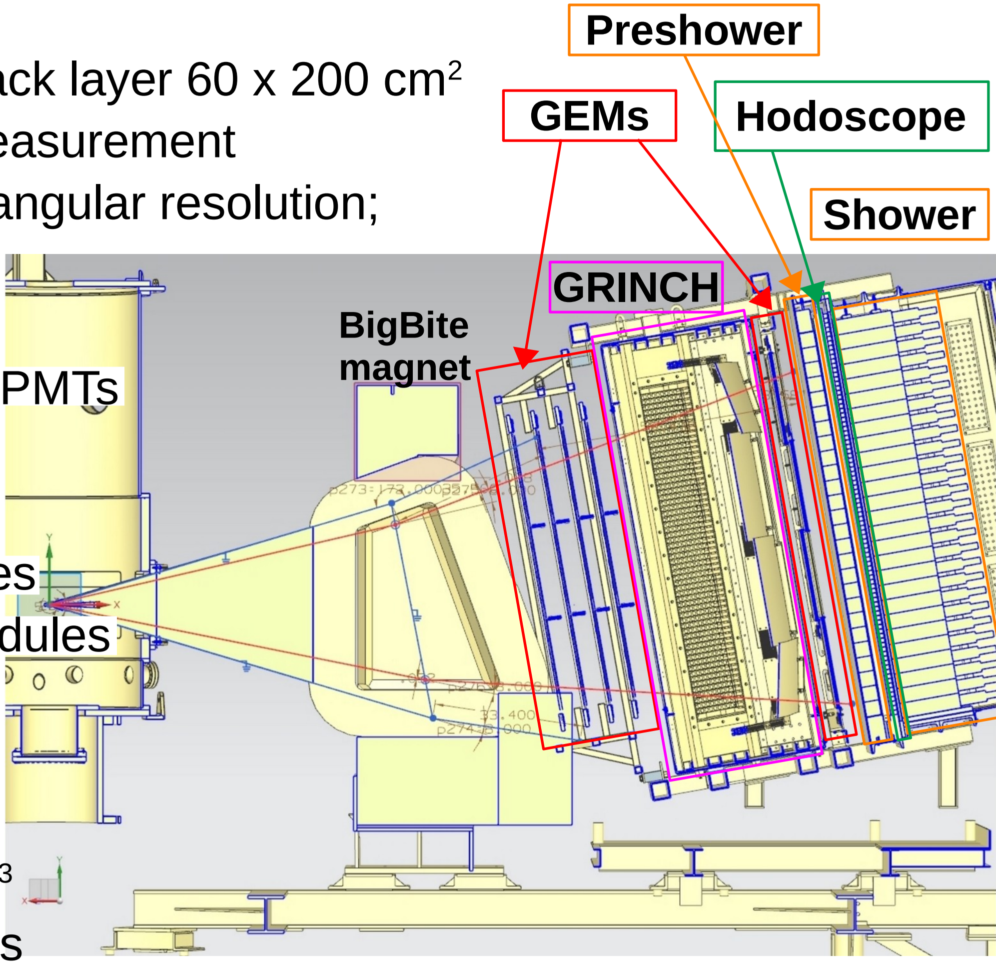
- nTPE+: unprecedented measurements on Two-Photon Exchange on Neutron:
  - Direct measurements of TPE in neutron with R^n_{2g}
  - Rosenbluth measurements for e^+n and e^-n:
    - both complementary *and* “contradictory” to existing G_E^n measurements**;**
  - complements current SBS Form Factors program;

- nTPE+ will benefit from the return of experience of the nTPE analysis
  - Extraction method worked out;
  - Systematics mostly under control;

Thank you for your attention !

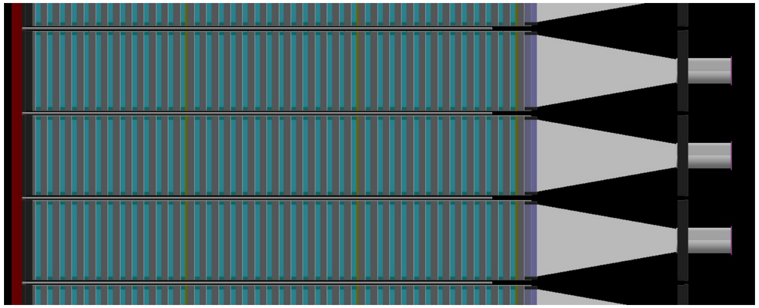
Super BigBite Spectrometer: BigBite

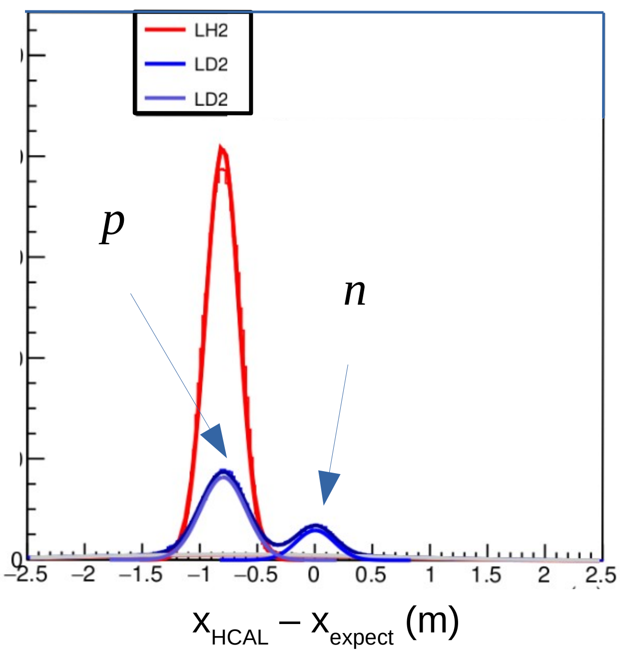
- Detector package tilted 10% behind dipole magnet
- **Function: Electron measurement;**
- Detector package:
  - GEMs:
    - 4 front layers 40 x 150 cm^2, 1 back layer 60 x 200 cm^2
    - momentum trivector + vertex measurement
    - 1% momentum resolution, 1mr angular resolution;
  - GRINCH:
    - C4F8 Cherenkov radiator
    - Cherenkov light readout by 510 PMTs
    - Electron ID ~98% Pion rejection
  - Calorimeter: (shower+preshower)
    - Shower: 7x27 lead glass modules
    - PreShower: 2x26 lead glass modules
    - Trigger
    - Electron ID/Pion rejection
  - Hodoscope:
    - 90 Scintillators 60 x 2.5 x2.5 cm^3
    - scintillators readout on both ends
    - Precision Timing: 500 ps resolution



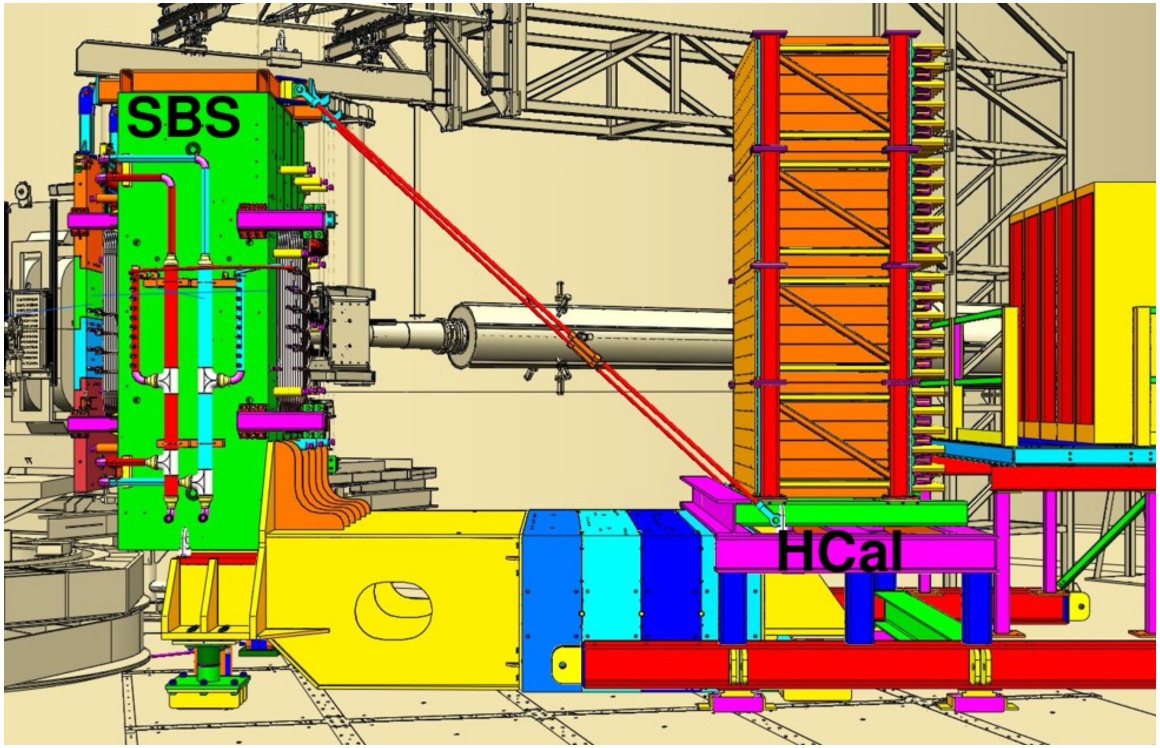
Super BigBite Spectrometer: HCal

- 12 x 24 iron/scintillator modules 15 x 15 * 90 cm^3
- **Function: Nucleon measurement:**
  - Position resolution ~5.5cm
  - Timing resolution (*ADC only*) ~1.5 ns
  - Energy resolution ~50 %
- **Nucleon identification (see next)**





X_{HCAL}: reconstructed
x_{expect}: predicted from e$^-$



nTPE+ Updated for 2025

Feedback for LOI-E12+24-008

- Reviewers recommends:
  - measuring ratios of cross sections $\left(\frac{\sigma_{e^+n}}{\sigma_{e^+p}}\right) / \left(\frac{\sigma_{e^-n}}{\sigma_{e^-p}}\right)$ at each ε point;
    - would provide $\delta^n_{TPE}(\varepsilon_2) - \delta^n_{TPE}(\varepsilon_1)$ and $\delta^p_{TPE}(\varepsilon_2) - \delta^p_{TPE}(\varepsilon_1)$
    - hydrogen data (e^+, e^-) needed to check systematics
    - *same nucleon footprint on* σ_{e+n}, $\sigma_{e\text{-}n}$ may reduce HCal systematics

- Reviewers concerned with:
  - difference of current between e^+ (1μA) and e^- (10μA) running;
    - Not so relevent for Rosenbluth measurements;
    - *becomes more important in* $\sigma_{e+n}/\sigma_{e\text{-}n}$

- Reviewers suggest another point at higher Q^2

Global Fit on Rosenbluth Slope in e^-p Scattering

- Note: Rosenbluth/polarization discrepancy not very significant at low Q^2

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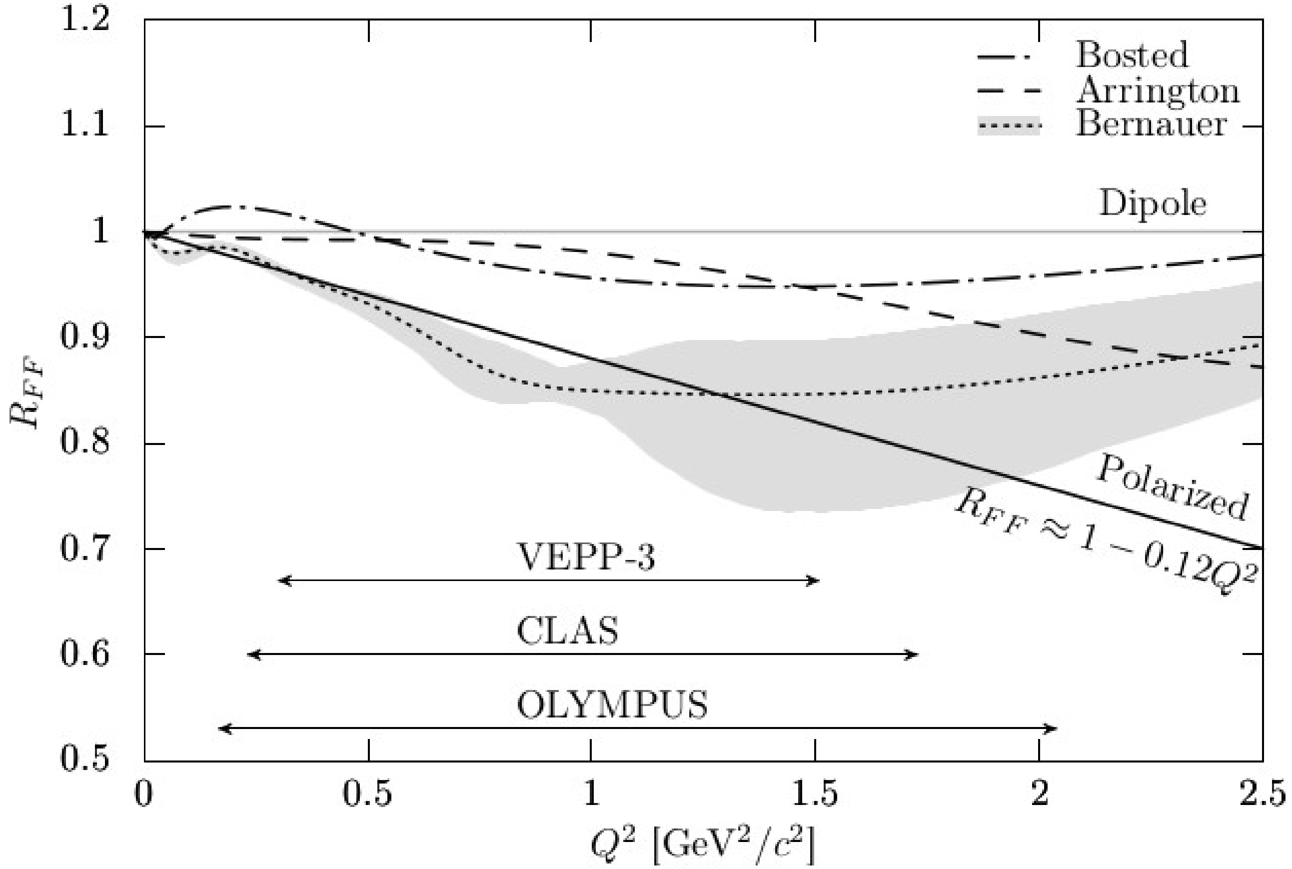


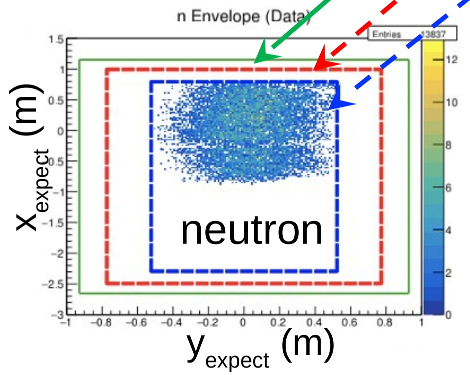
nTPE+ Systematics: GMn/nTPE Analysis

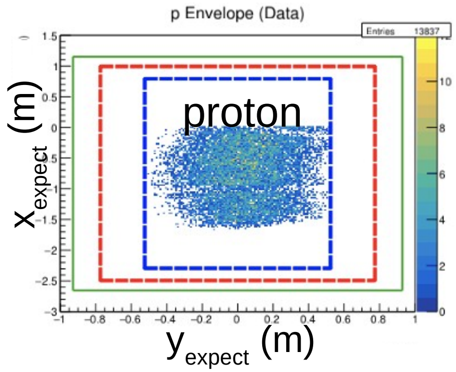
- Analysis: extraction of *n*/*p* ratios:

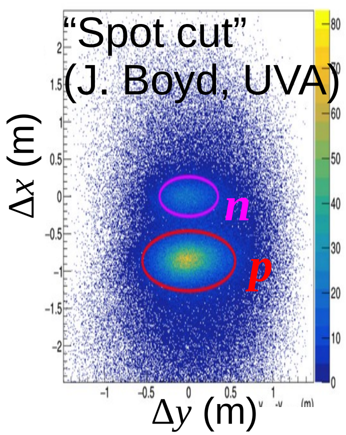
Elastic selection

Fiducial cut
(P. Datta, UConn/LBNL)

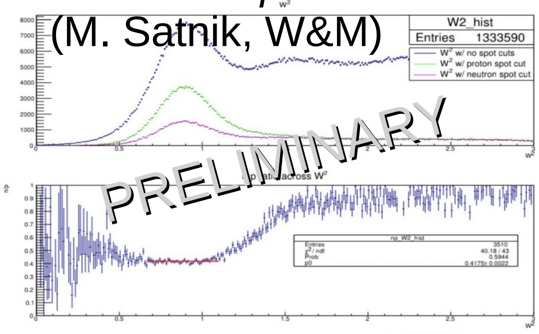
HCAL Boundary
Active Region
"Fiducial Cut"





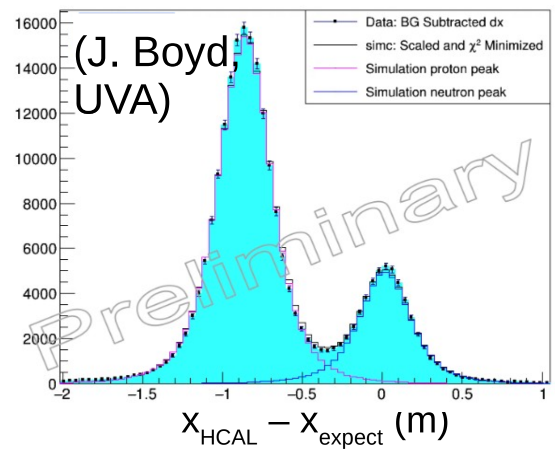


Selection optimization
(M. Satnik, W&M)



W^2 (GeV^2)

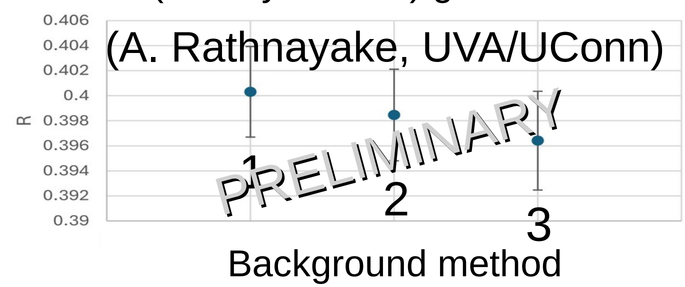
$N_n/N_p \rightarrow \sigma_n/\sigma_p$ correction with MC



x_{HCAL}: reconstructed
x_{expect}: predicted from e^-

Inelastic background subtraction

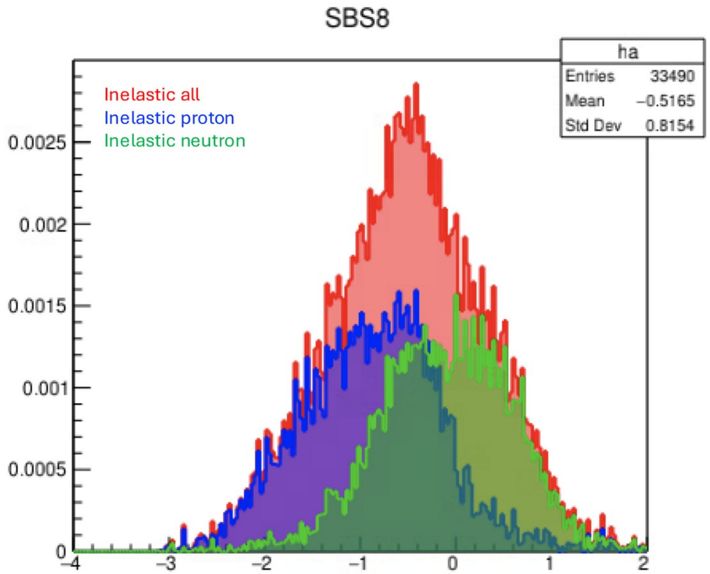
- 1: Combined fit *en*+*ep* +background of data Δx
- 2: Data background (HCal "antiselection");
- 3: MC (Christy-Bosted) generated background

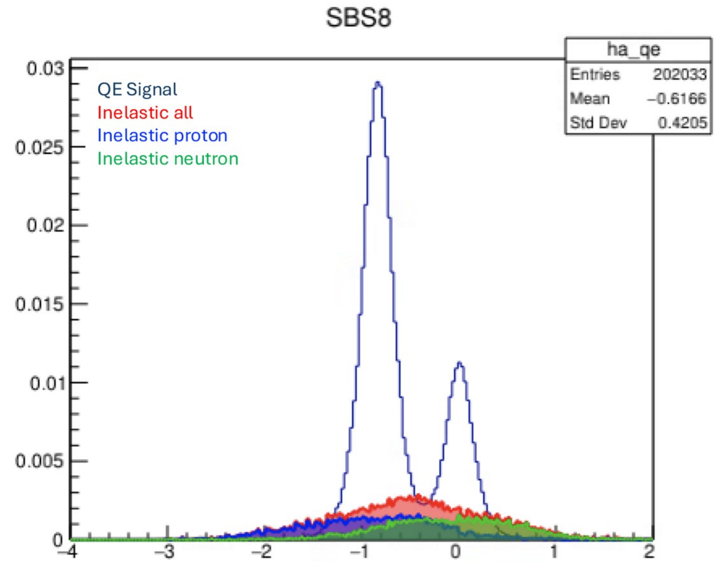


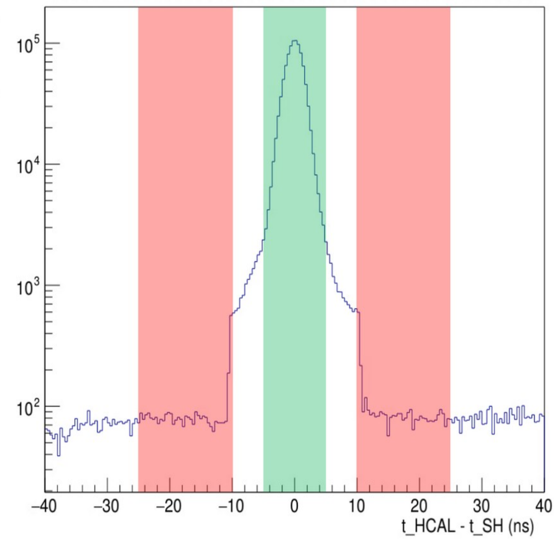
Background method

Systematic uncertainties: Inelastic contamination

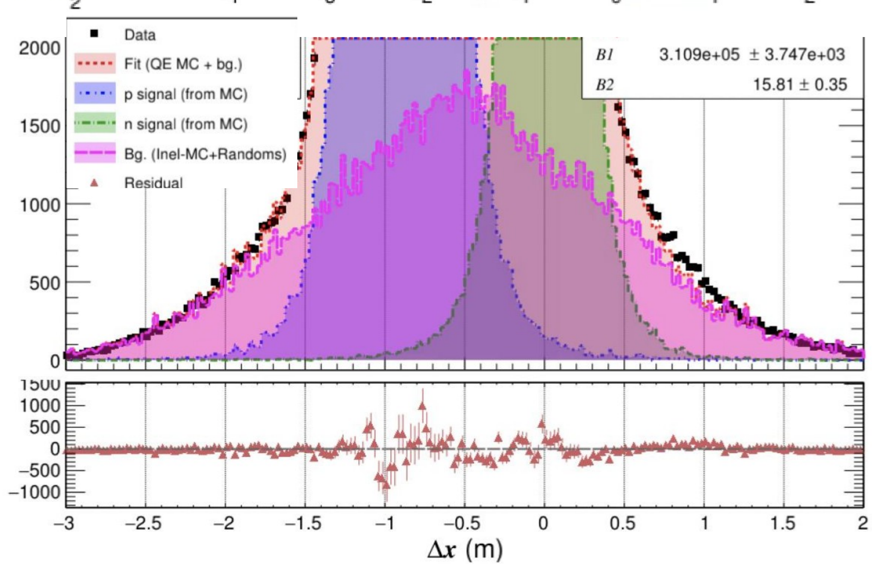
- Latest improvements on estimation of inelastic contamination:
  - Inelastic Monte Carlo combined with out-of-time events





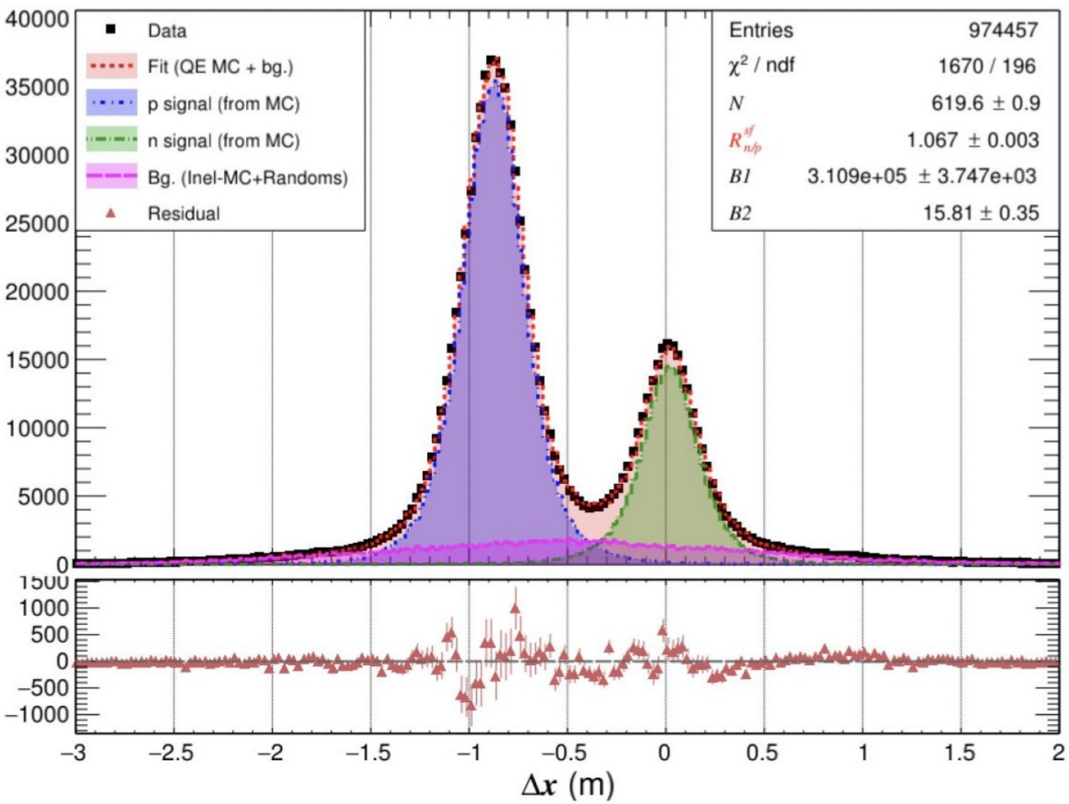


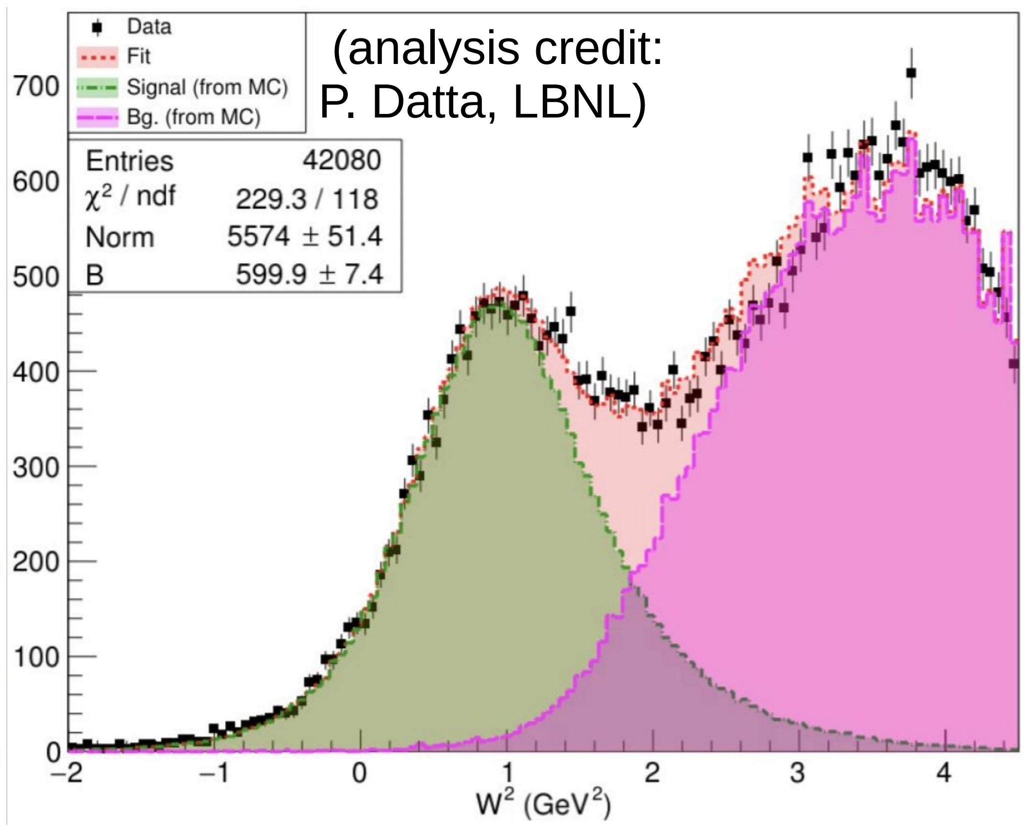
(analysis credit:
P. Datta, LBNL)



Systematic uncertainties: Inelastic contamination

- Latest improvements on estimation of inelastic contamination:
  - Inelastic Monte Carlo combined with out-of-time events
  - neutron/proton cross section ratio obtained with newest function compared with:
    - 2^{nd} and 4^{th} order polynomials, gaussian to fit inelastic background;
    - Δy side-band selection



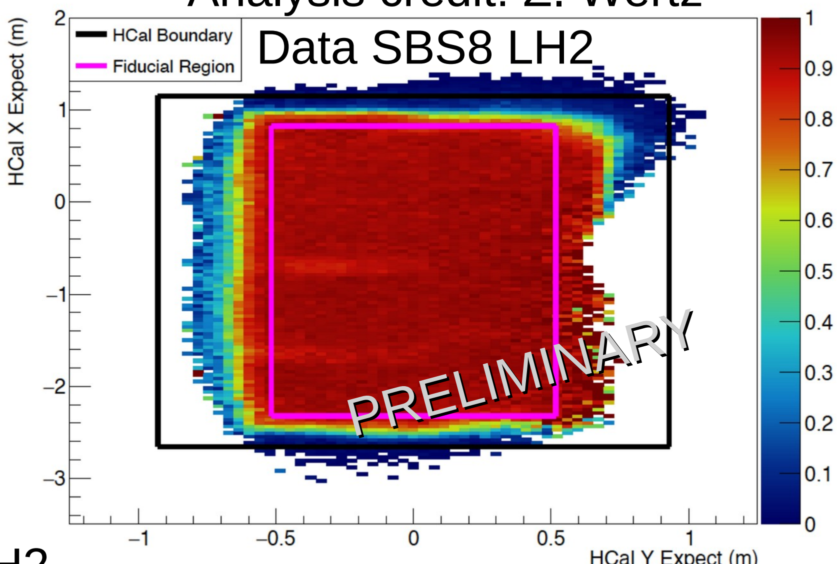


(analysis credit: P. Datta, LBNL)

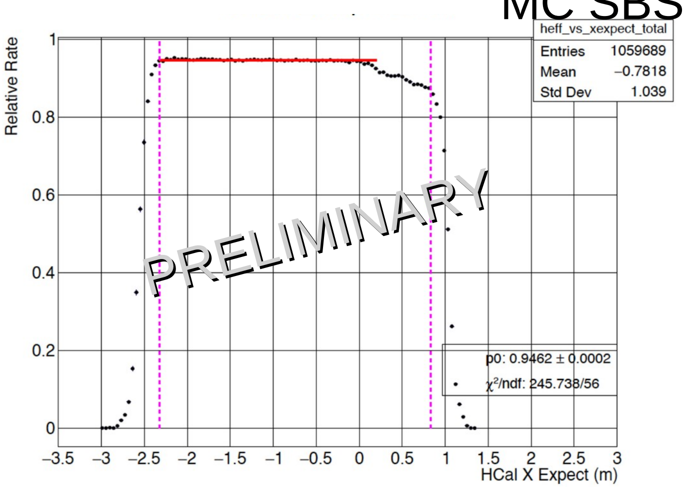
HCAL Non-Uniformity Corrections

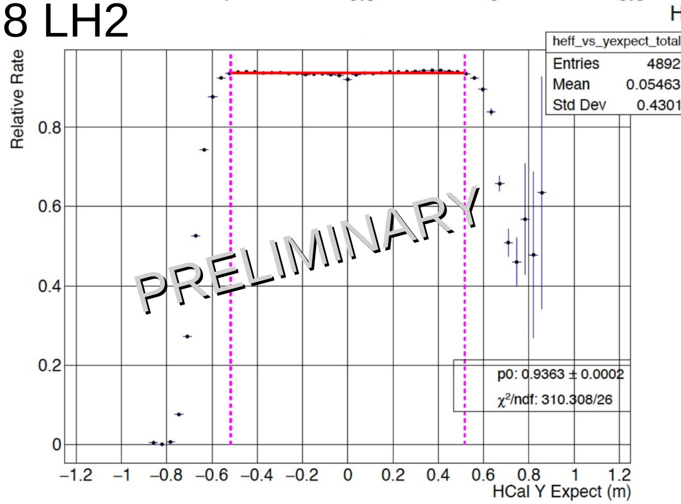
- Method to correct for HCal efficiency non-uniformity:
  - Reweight MC events with HCal non-uniformity map;
  - Map efficiency along x_{expect}, y_{expect};
  - Efficiency analysis for data, MC;
    - ♦ MC weight: η_{data}/η_{MC};
    - ♦ deployed in analysis;
  - Hurdle:
    - ♦ proton and neutron detection efficiency not equal a priori;

Analysis credit: Z. Wertz



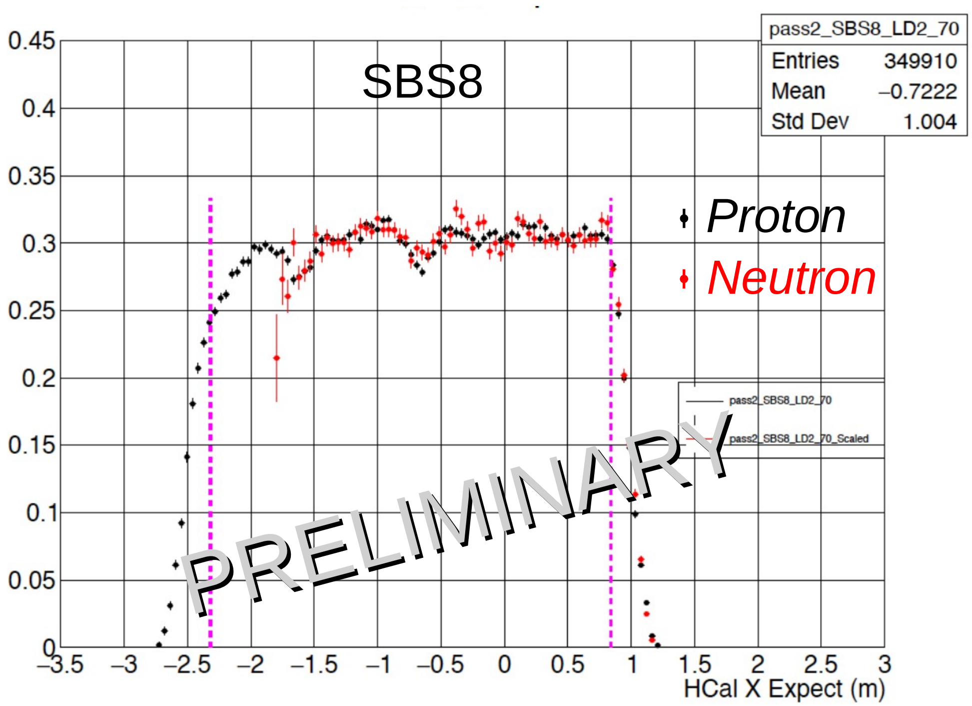
MC SBS8 LH2

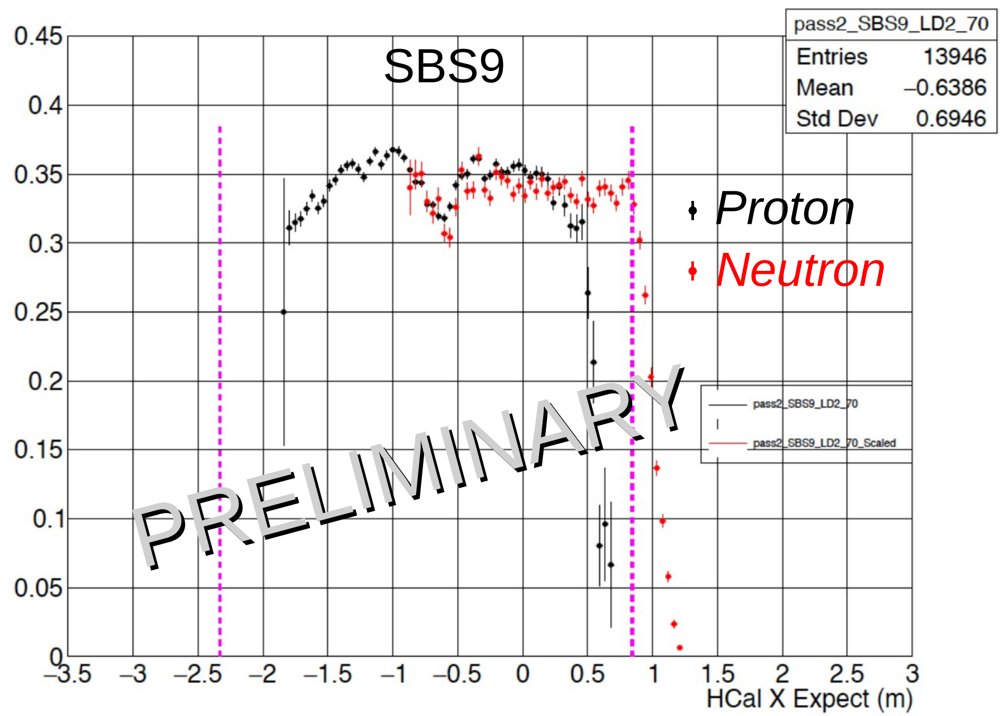




HCAL Non-Uniformity Corrections

- Reweight MC events with HCal non-uniformity map:
  - Analysis of all combined SBS8 LH2 settings for map efficiency:
  - *Neutron* efficiency drop comparable to *proton;*
  - Correction modifies σ_{en}/σ_{ep} by ~0.2 % (SBS8) and ~0.5 % (SBS9);
  - Other sources of systematics:
    - ♦ Lack of absolute neutron detection efficiency measurement;
    - ♦ Absolute proton detection efficiency uncertainty larger at high Q^2;



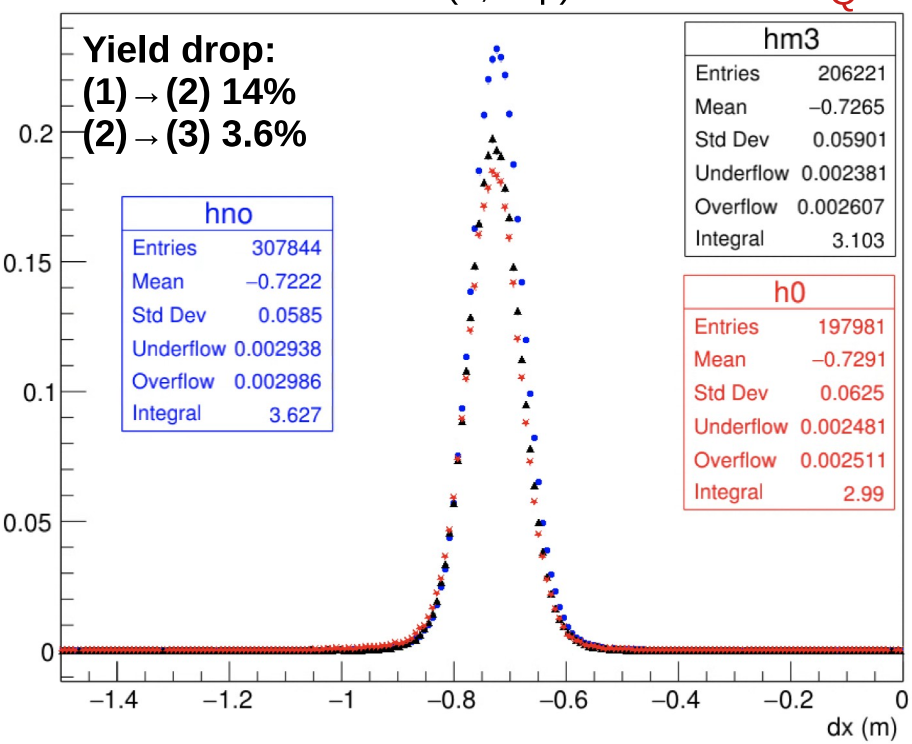


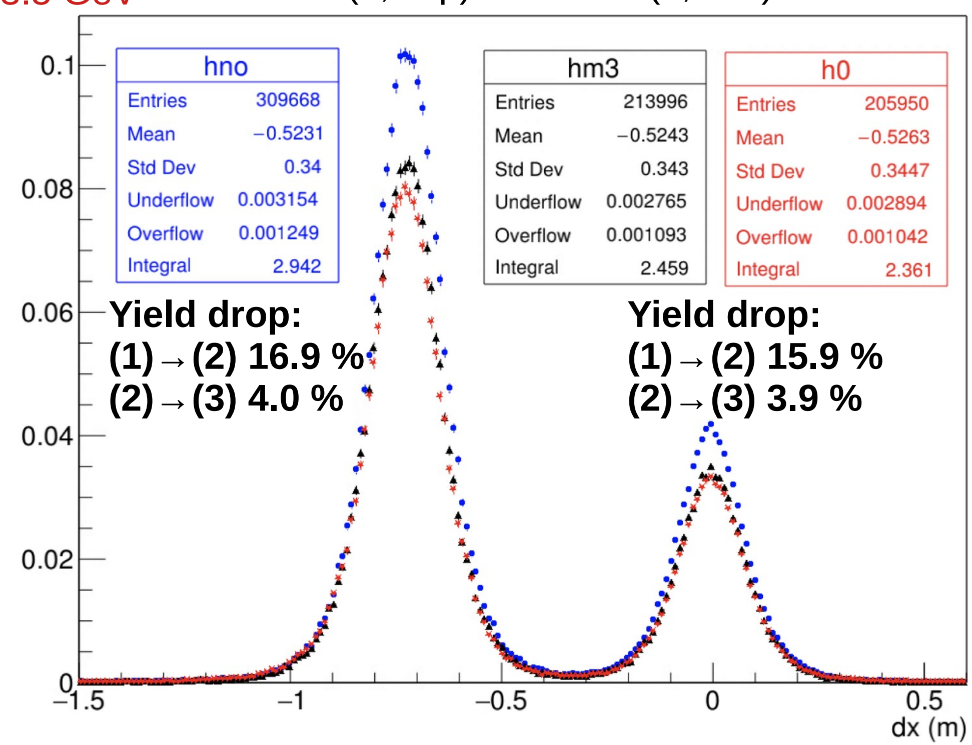
Analysis credit: E. Wertz

Systematic uncertainties: Radiative corrections

- Radiative corrections (analysis credit: P. Datta, LBNL):
  - SIMC events with the following configurations for radiative effects:
    - (1) - No radiative corrections i.e. none of the tails are radiated
    - (2) - One tail = 0 => All (e, e', and p) tails are radiated
    - (3) - One tail = -3 => All but p tails are radiated
  - SIMC events processed through g4sbs → libsbsdig → SBS-offline;
  - Properly weighted Δx distribution for all types of events with the same selection
  - Extract individual yields and then quantify the correction

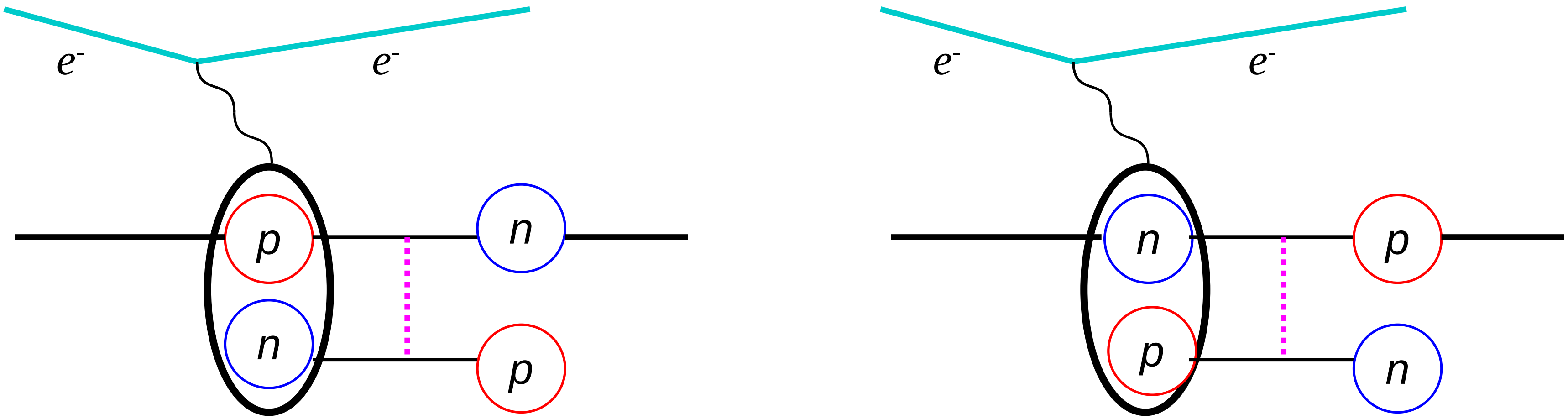
H(e, e' p) $Q^2 = 13.5\ \mathrm{GeV}^2$ D(e, e' p) + D(e, e' n)





Systematic uncertainties: FSI

- Final state interactions calculated by M. Sargsian:
  - calculations of final state charge exchange $ep \rightarrow en$ and $en \rightarrow ep$ on deuterium



  - Since D is symmetric, $ep \rightarrow en \equiv en \rightarrow ep$:
    - ratio $R_{n/p}$ basically not affected
    - uncertainty on ratio $R_{n/p}$ extremely small

Preliminary systematic uncertainties

- Systematics analysis credit: P. Datta (LBNL);
  - Improvement can be achieved for radiative corrections and nucleon detection efficiency

Table 2: Estimated contributions (in percent) to systematic error on R and $\frac{G_M^n}{\mu_n G_D}$.

	Error Sources	Q^2 (ϵ)				
		3 (0.72)	4.5 (0.51)	7.4 (0.46)	9.9 (0.50)	13.5 (0.41)
$\Delta(R)_{sys}$	Inelastic Cont.	0.33	0.75	0.84	0.75	2.67
	Nucleon Det. Effi.	2.00	2.01	2.01	2.02	2.02
	Radiative Corr.	2.31	3.32	3.77	3.87	5.47
	Cut Stability	0.16	0.15	0.40	0.67	0.60
	FSI	0.04	0.01	0.02	0.02	0.03
	Total	3.08	3.95	4.37	4.48	6.44
$\Delta(\frac{G_M^n}{\mu_n G_D})_{sys}$	Inelastic Cont.	0.17	0.38	0.42	0.37	1.34
	Nucleon Det. Effi.	1.00	1.00	1.01	1.01	1.01
	Radiative Corr.	1.16	1.66	1.88	1.94	2.73
	Cut Stability	0.03	0.07	0.20	0.33	0.30
	FSI	0.02	0.00	0.01	0.01	0.01
	σ^p_{Red}	0.82	0.92	1.35	1.52	1.33
	G_E^n	0.55	0.65	0.62	0.66	0.55
	Total	1.83	2.27	2.64	2.79	3.53