Proposal PR12-12-011:

Measurements of $A_\parallel$ and $A_\perp$ to Extract G_E^n and G_M^n at $Q^2 = 1 - 2.6\ (\mathrm{GeV}/c)^2$ from the Inclusive $^3\overrightarrow{\mathrm{He}}(\vec{e},e')$ Reaction

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for the PR12-12-011 Collaboration

PAC 39 Meeting

June 21st, 2012

Motivation

- **Neutron** not understood to the same accuracy as the proton
  - No pure neutron target
  - **Indirect measurements** using appropriate targets: deuteron and/or ^3He

- High precision measurement will help pin down **theoretical treatments** on the extraction of the the neutron electromagnetic form factors from different nuclei (deuteron and ^3He) and different reaction channels **A(e,e')** and **A(e,e'n)**

- Theoretical models and parameterizations begin to diverge for $Q^2 > 1$ $(GeV/c)^2$

- Compared to the other form factors the precision on G_E^n is poorly constrained over the measured Q^2 range (**only three data points have a precision better than 10%**)

Extraction of G_E^n at Q^2= 0.98 (GeV/c)^2 by Measurements of $^3\overrightarrow{He}(\vec{e}, e')$

- G_E^n was extracted for the first time by inclusive polarized measurements from ^3He at Q^2 = 0.98 (GeV/c)^2
- Form the ratio of asymmetries for longitudinal and transverse target polarization; use the well known proton electromagnetic and the neutron magnetic form factors
- **Proton and neutron contributions calculated in PWIA**
- This technique agrees with previous measurements; uncertainty ~19% (limited by statistics in only a few shifts of data)
- **Note: M. Sargsian and G. Salme` are ready to support full model extractions of precision data**

^{3}He Inclusive Response Functions near the Quasi-elastic Peak in PWIA

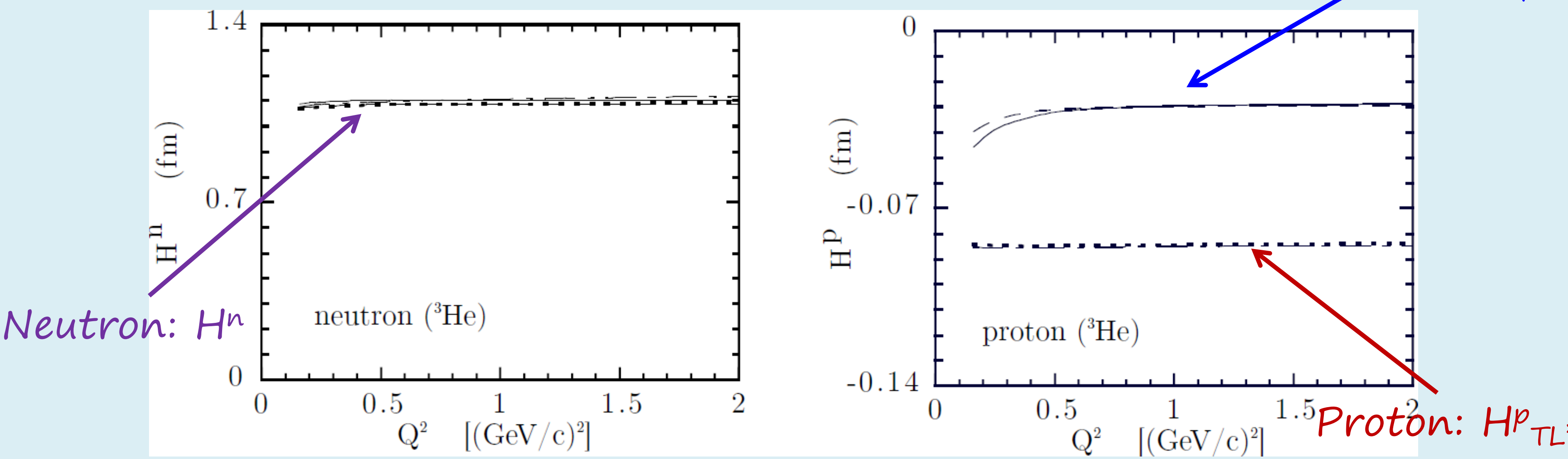
Transverse-longitudinal:

$$R^{^3He}_{TL'} = -\sqrt{2}[2G_E{}^p G_M{}^p H^p{}_{TL'} + G_E{}^n G_M{}^n H^n{}_{TL'}]$$

Transverse:

$$R^{^3He}_{T'} = \frac{Q^2}{2qM}[2(G_M{}^p)^2 H^p{}_{T'} + (G_M{}^n)^2 H^n{}_{T'}]$$

where *H*'s are calculated by momentum distribution and nucleon polarization in ^{3}He



A. Kievsky, E. Pace, G. Salme' and M. Viviani, PRC 56 (1997) 64

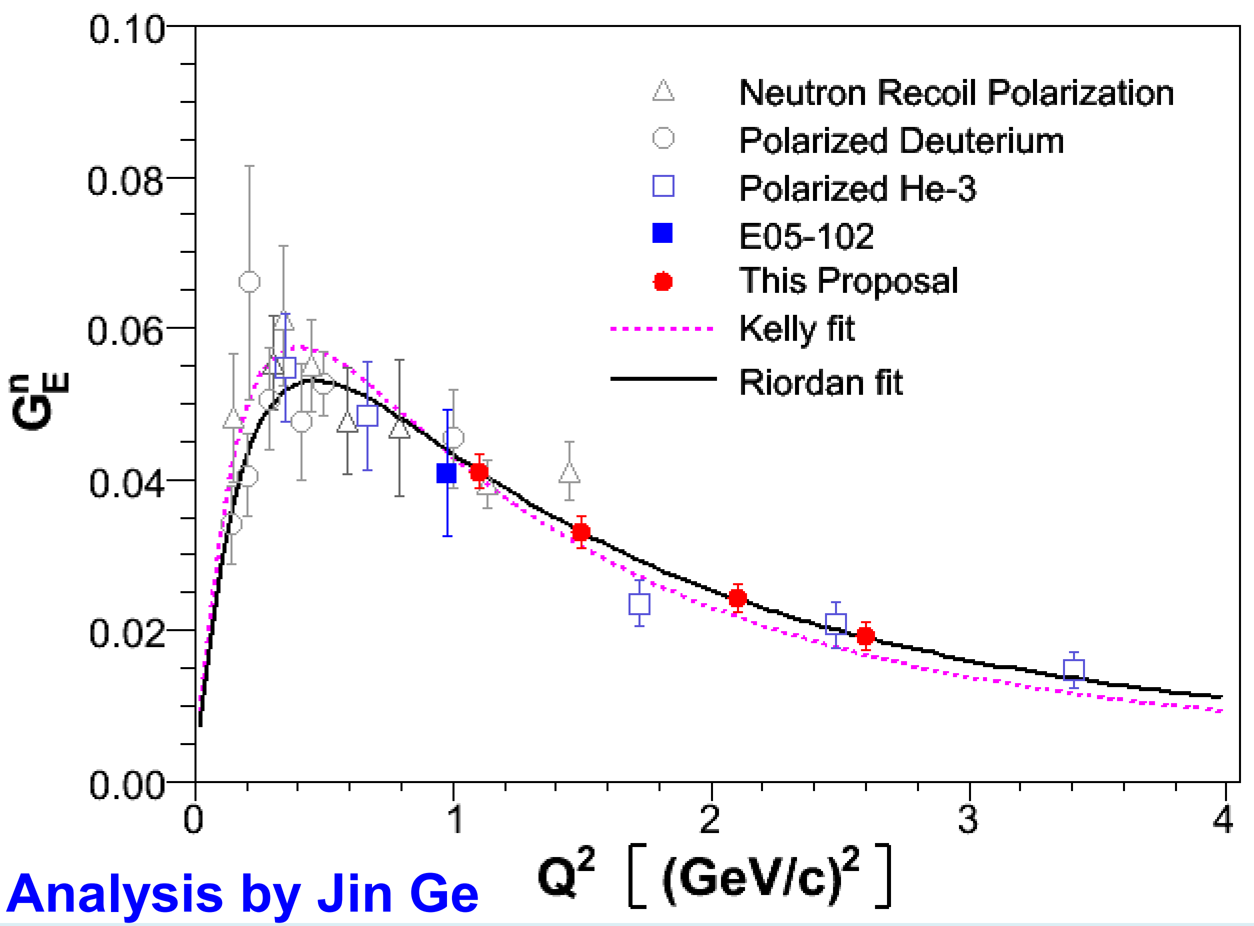
Ratio of Asymmetries as a Function of Form Factors

$$\frac{A_{TL'}}{A_{T'}} = \frac{v_{TL'}(-\sqrt{2}[2G_E{}^p G_M{}^p H^p{}_{TL'} + G_E{}^n G_M{}^n H^n{}_{TL'}])}{v_{T'}(\frac{Q^2}{2qM}[2(G_M{}^p)^2 H^p{}_{T'} + (G_M{}^n)^2 H^n{}_{T'}])}$$

- By measuring $A_{TL'}/A_{T'}$ and using G_E^p, G_M^n, and G_M^n as known parameters can one extract G_E^n

G_E^n from ^{3}He(e,e') at Q^2=0.98 (GeV/c)^2

with a few shifts of data



Analysis by Jin Ge

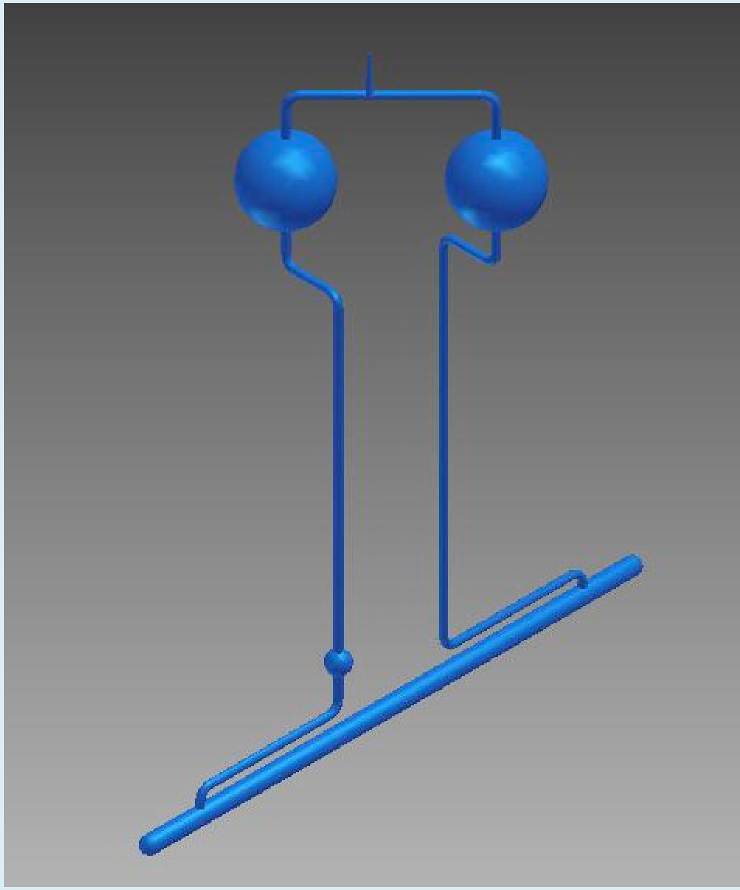
G_E^n/G_D = 0.234 ± 0.044 (stat) ± 0.011 (syst)

G_E^n = 0.0414 ± 0.0077 (stat) ± 0.0019 (syst)

Overview of Experiment

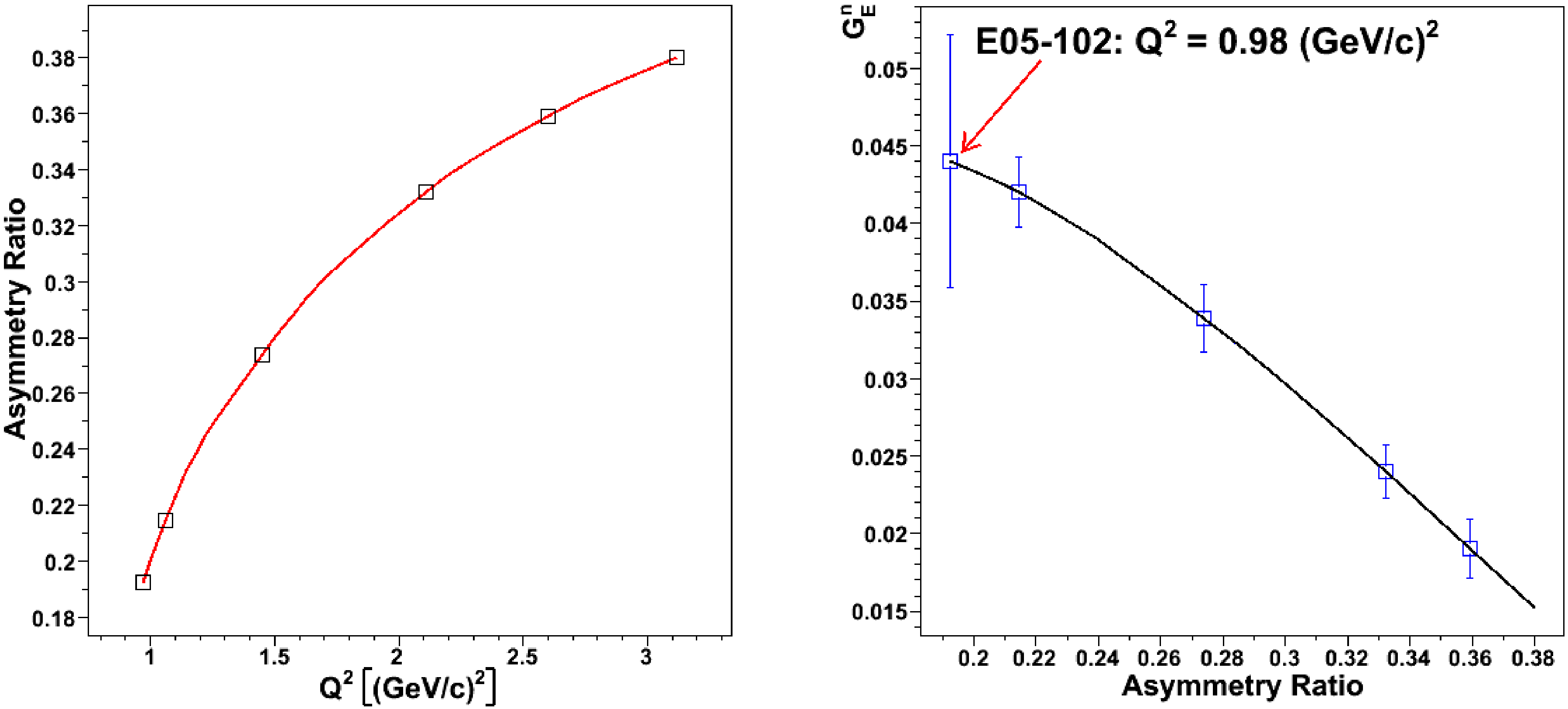
$$\overrightarrow{{}^{3}\mathrm{He}} + \vec{e} \rightarrow e' + X$$

- Measure inclusive double-polarized ^{3}He asymmetries
- Use the Hall C Super High Momentum Spectrometer (SHMS) to detect the scattered electrons at 6 and 8.5 degrees with 11 GeV beam
- Use the upgraded polarized ^{3}He target planned for the A_1^n (E12-06-110) and d_2^n (E12-06-121) experiments
- Considering to detect the knock-out proton in the High Momentum Spectrometer (HMS)



Form Factor Sensitivity to Asymmetry Ratio

$$A_{ratio} = \frac{A_{TL'}}{A_{T'}}$$

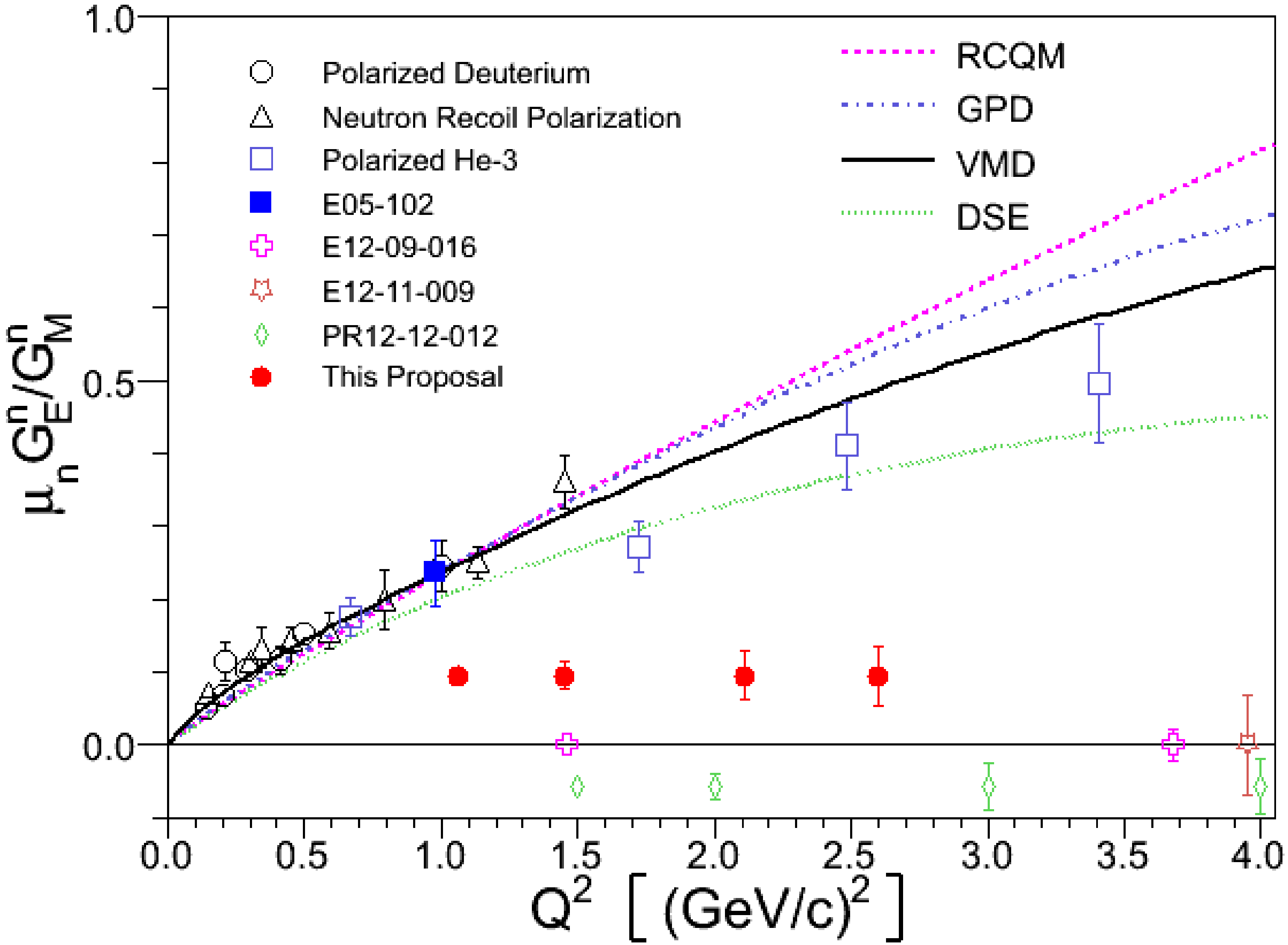


Kinematics and Rates

E_0 [GeV]	E' [GeV]	θ_{SHMS} [deg]	Range of θ_{lab} [deg]	Q^2 $(GeV/c)^2$	e^- rate [kHz]	$t_{\parallel}$ [hrs]	$t_{\perp}$ [hrs]	$\Delta A_{\parallel}$ $[\cdot 10^{-4}]$	$\Delta A_{\perp}$ $[\cdot 10^{-4}]$
11.0	10.437	6	5 – 6	1.057					
11.0	10.229	6	6 – 7	1.446	7.70	48	6	0.8	2.2
11.0	9.874	8.5	7.5 – 8.5	2.114					
11.0	9.612	8.5	8.5 – 9.5	2.604	0.37	240	36	1.6	4.1

- Utilize full capabilities of SHMS (**11 GeV forward angle**)
  - Take advantage of the **rate boost from σ_{Mott}**
  - Helps **minimize inelastic backgrounds**
- Estimated quasi-elastic counting rates for a 42-cm long target with 60% target polarization, 80% beam polarization at 60 μA
- Based on J. Arrington parameterization for G_E^p and G_M^p and CLAS data for G_M^n

Expected Results



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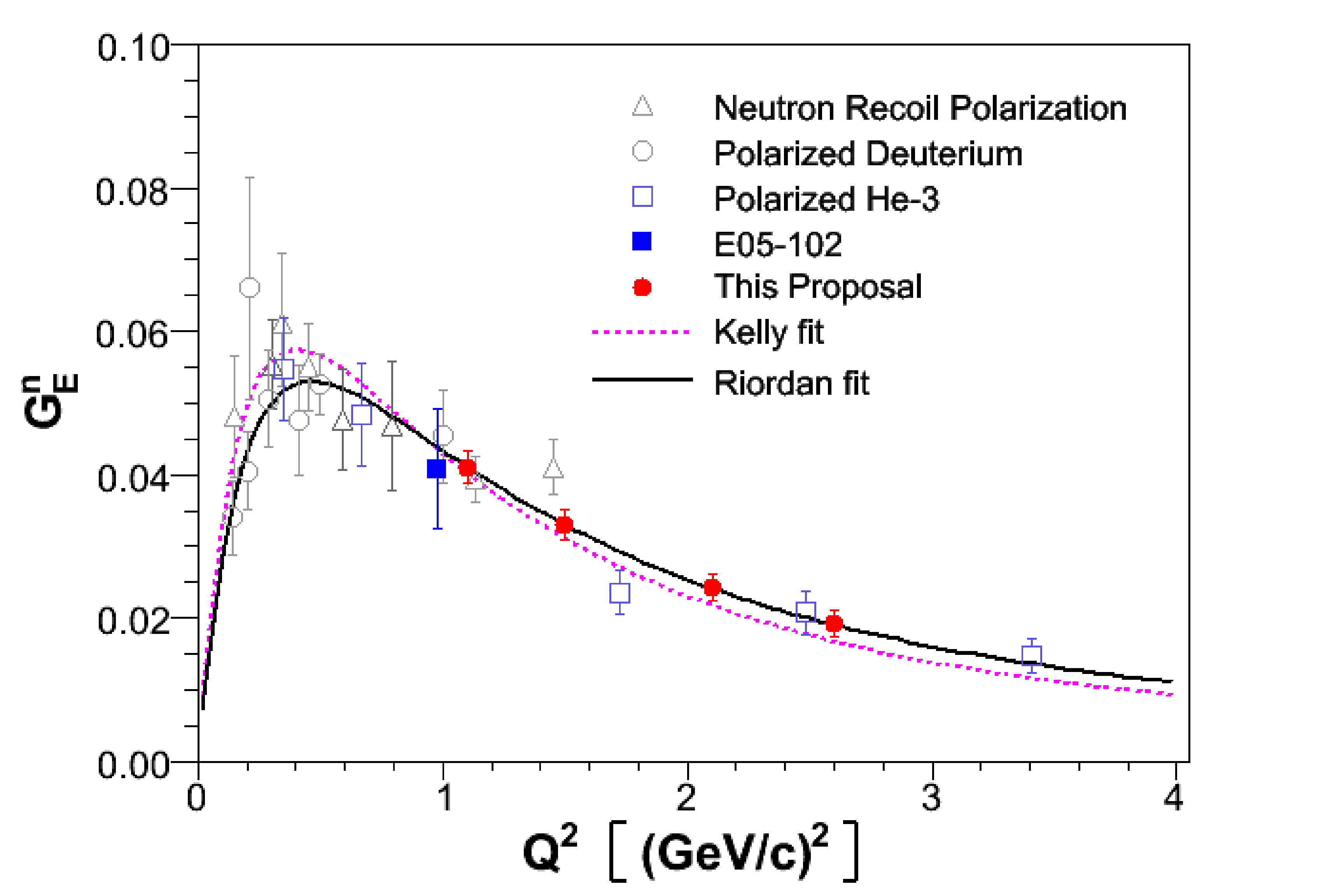
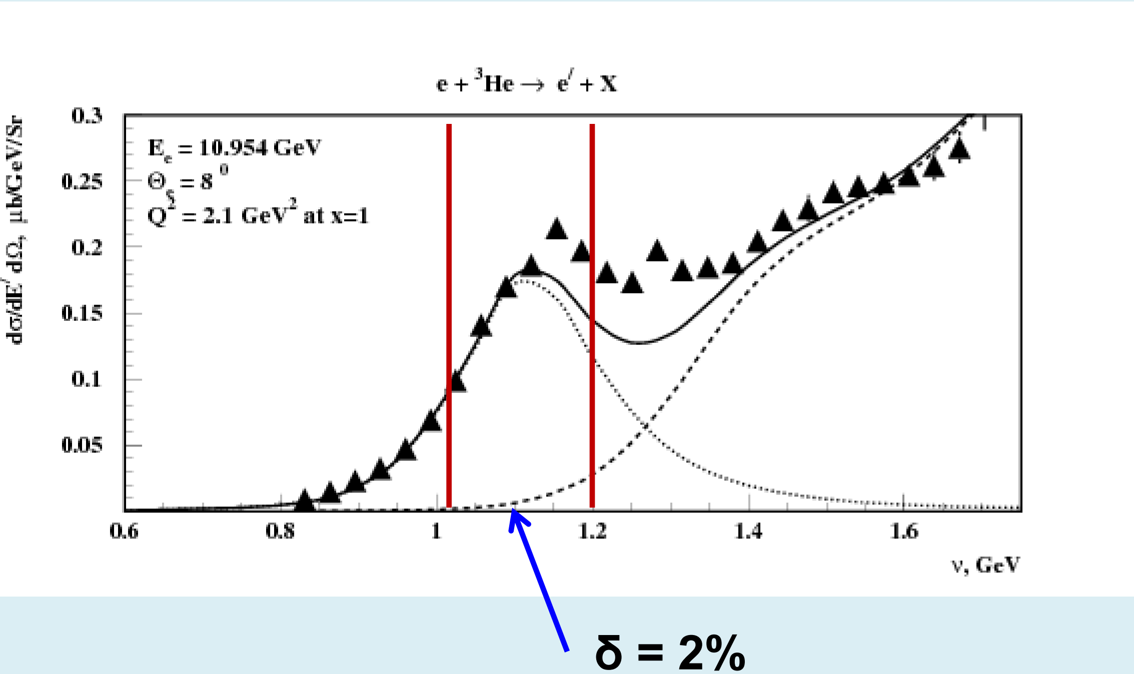


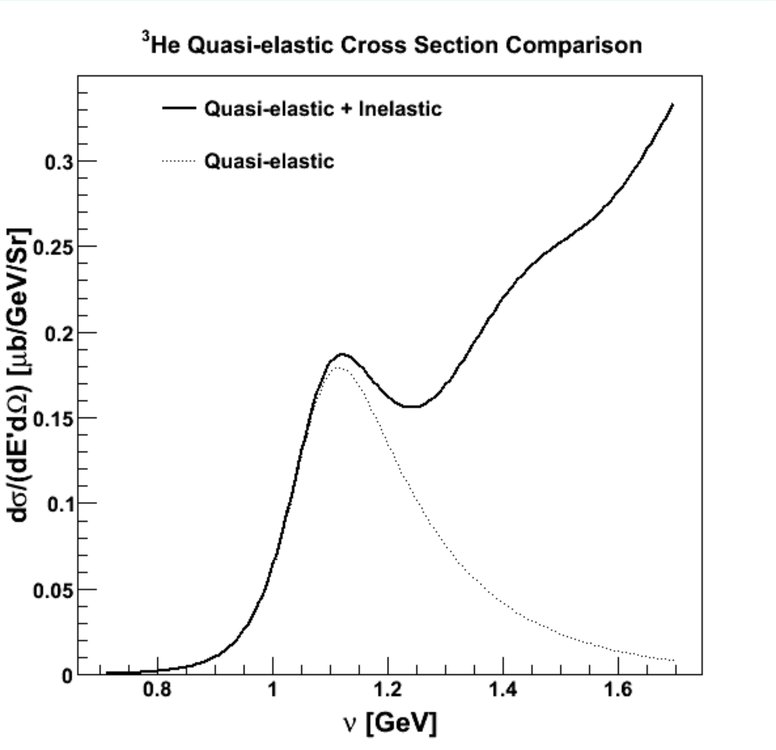
Concerns Raised by PAC 39 and TAC

- Polarized Inelastic background contamination
- Final State Interactions (FSI) and Meson Exchange Currents (MEC)
- Relativistic Effects

Inelastic Contamination

- Used the cross section models from Misak Sargsian and Peter Bosted (http://arxiv.org/abs/1203.2262)
- The two models agree well with each other at the top of the quasi-elastic peak with less than a 0.5% absolute difference





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- The two models agree well with each other at the top of the quasi-elastic peak with less than a 0.5% absolute difference
- By varying the momentum cut, the effect of the contamination can be studied with the data

Q^2 $(\mathrm{GeV/c})^2$	Contamination $x = 1$ [%]	Contamination (dp = 2%) [%]	Contamination (dp = 1.5%) [%]
1.06	0.3	0.7	0.4
1.45	1.5	3.0	1.7
2.11	4.6	8.8	4.9
2.60	7.8	11.9	6.8

Inelastic Contamination on Asymmetry

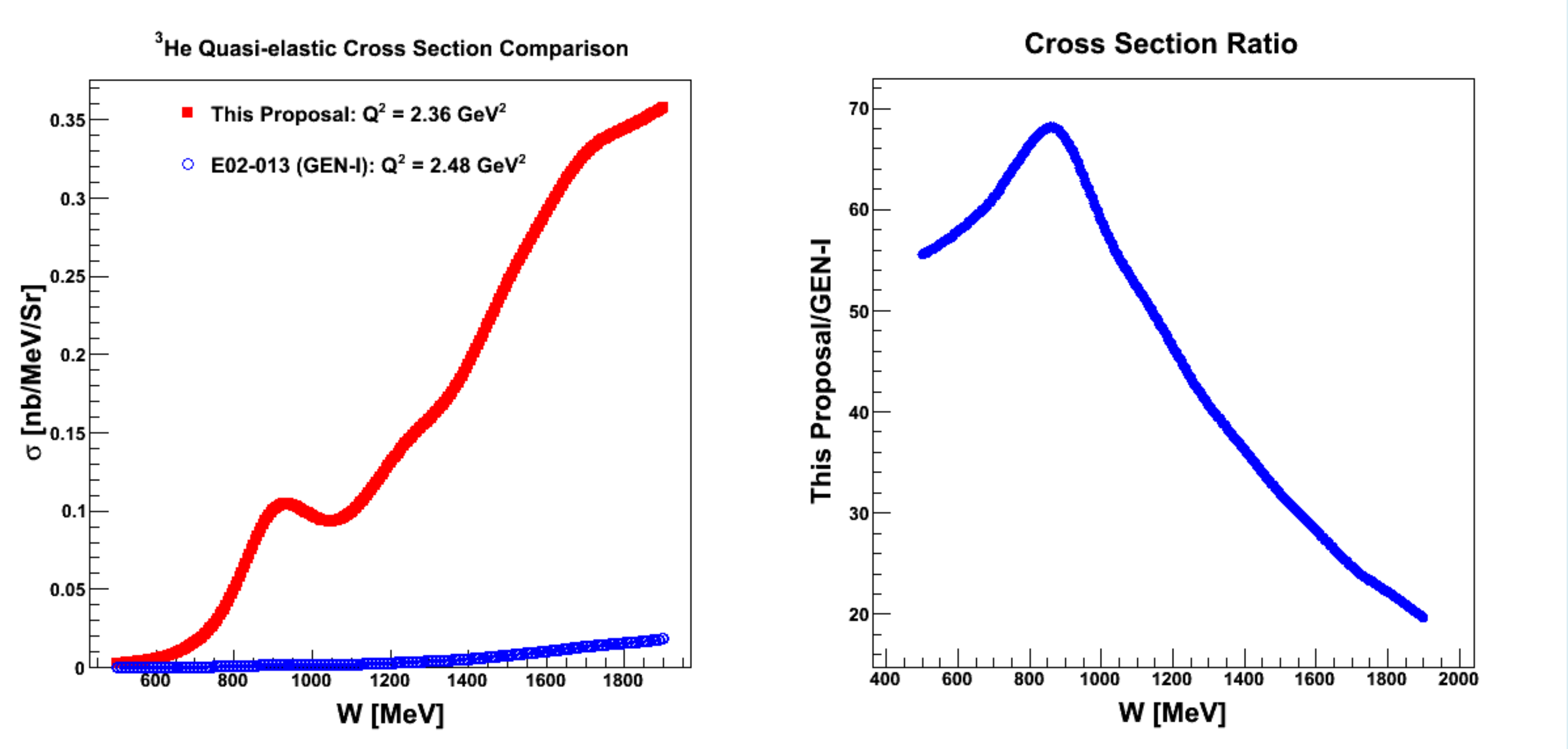
$$A_{QE} = \frac{(A_{raw} - f_c \cdot A_{in})}{1 - f_c}$$

- f_c is the amount of contamination under the quasi-elastic peak
- A_{QE}, A_{raw}, and A_{in} are the quasi-elastic, measured and inelastic asymmetries
- Using the determined contamination numbers from the models and the measured asymmetries from experiments E01-012 and E05-102 with the assumption that $A_{in} = A_{\Delta}$, the effect on the asymmetry was calculated

Q^2 $(GeV/c)^2$	A_{raw}	A_{QE}	Difference [%]
1.0	-0.1656	-0.1699	2.5
2.6	-0.2325	-0.2258	3.0

Comparison of Cross Sections at $Q^2 \sim 2.5$ GeV^2

The quasi-elastic cross section is about a factor of 70x larger at forward angle compared to the GEN-1 data point.

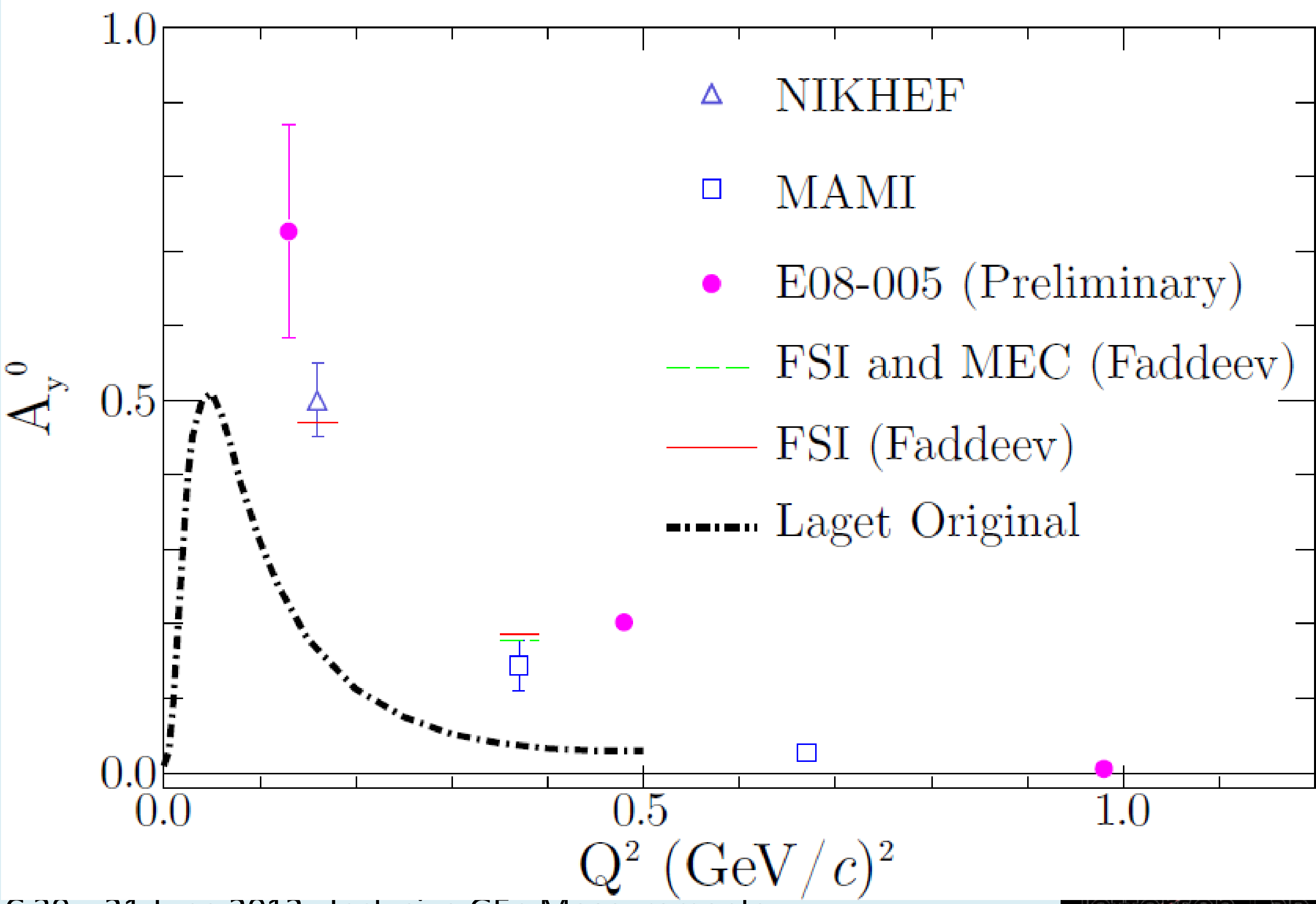


Cross section model from P. Bosted

- The proposed measurement benefits from the SHMS resolutions compared to BigBite
- We will also measure the inelastic contribution within the SHMS momentum acceptance, allowing us to **carefully choose our cuts for each Q^2 point**

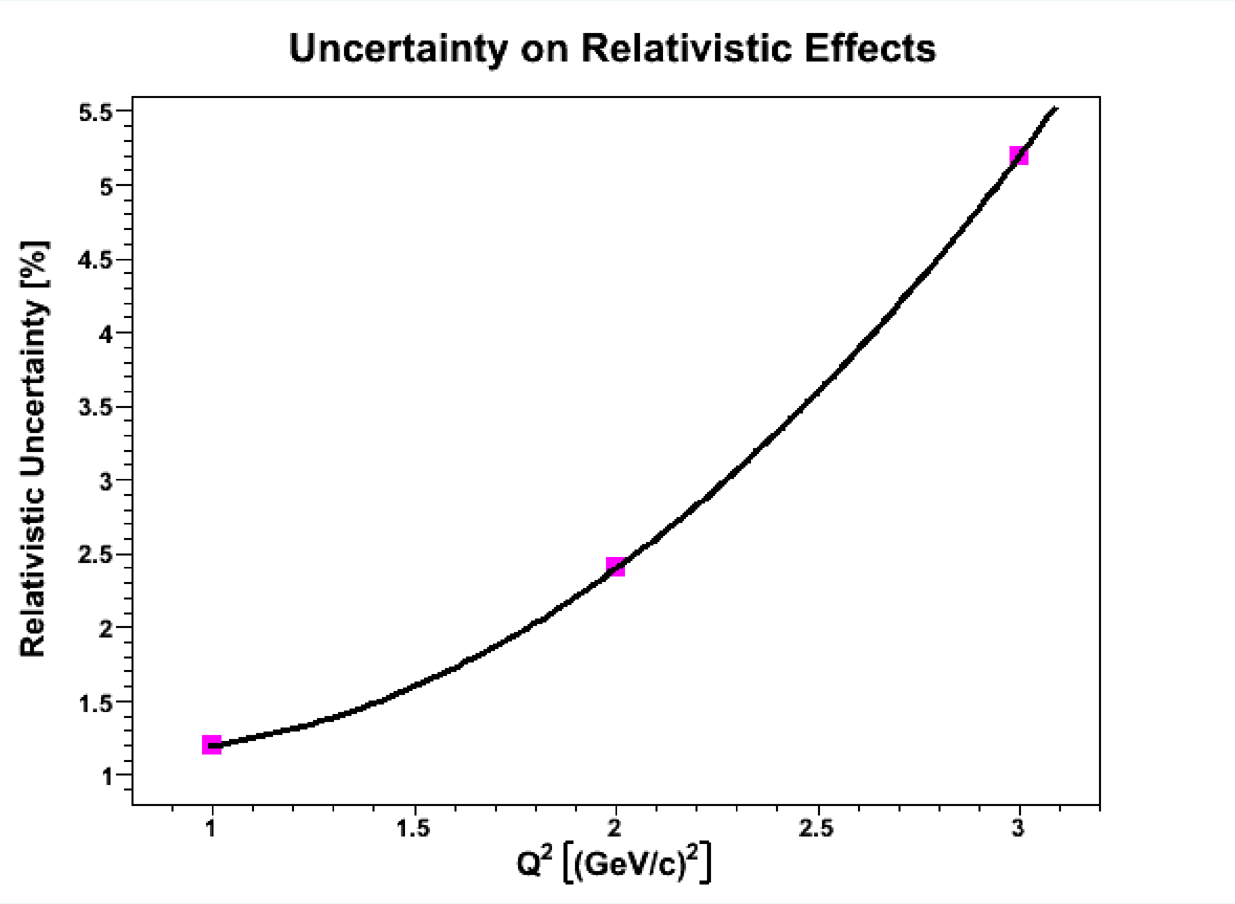
FSI and MEC vs. Q^2

- Experiment E08-005: recent **$^3He^{\uparrow}(e,e'n)$ single spin asymmetry (A_y)** measurements, **target polarized normal to scattering plane**
- **A_y** vanishes in PWIA, and measurements of this asymmetry are a good check of **FSI and MEC contributions**
- Small asymmetry near 1 $(GeV/c)^2$ is indicative that these mechanisms have become negligible
- Analysis by E. Long



Relativistic Effects

- Misak Sargsian compared his model calculation using the Virtual Nucleon and Light Cone approximations
- He provided the difference in these two methods as the uncertainty due to relativistic effects
- Giovanni Salme` is constructing a Poincare` invariant approach for the relativistic treatment in his calculation



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Q^2 $(\mathrm{GeV/c})^2$	Total Model Uncertainty (2012) [%]
1.06	2.2
1.45	2.4
2.11	3.2
2.60	4.3

Estimated Systematic Uncertainties

Q^2 $(\mathrm{GeV/c})^2$	G_E^p [%]	G_M^p [%]	G_M^n [%]	Model [%]	Experimental [%]	Inelastics [%]	(σ_{syst}) [%]	(σ_{stat}) [%]	$(\sigma_{\mathrm{total}})$ [%]
1.057	1.4	1	0.1	2.2	2.3	2.0	4.1	3.5	5.4
1.446	1.4	0.8	0.5	2.4	2.3	2.0	4.2	4.5	6.4
2.114	1.4	0.6	0.9	3.2	2.3	3.0	5.2	5.0	7.2
2.604	1.4	0.5	1.3	4.3	2.3	3.0	6.0	8.0	10.0

- Relative systematic uncertainties from nucleon form factors, model (updated numbers from M. Sargsian), experimental (beam pol. 1.5%, target pol. 1%, radiative corrections 1%), and the inelastic contamination
- GEp: 1% at Q^2 = 1 $(\mathrm{GeV/c})^2$ with a linear increase up to 3% at 3 $(\mathrm{GeV/c})^2$
- GMp: 1% over the planned Q^2 range
- GMn: 2% to 2.4% from the high precision Hall B data (J. Lachniet *et al.*)

Beam Time Request

	Time (Hours)	Time (Days)
Long. Pol. ^{3}He at 11 GeV, 6 degs	48	2
Trans. Pol. ^{3}He at 11 GeV, 6 degs	6	0.25
Long. Pol. ^{3}He at 11 GeV, 8.5 degs	240	10
Trans. Pol. ^{3}He at 11 GeV, 8.5 degs	36	1.5
Dilution, calibrations	24	1
Total Time Requested	336 + 24	14 + 1

We request a total of 15 days of beam time

Summary

- Experiment is a straight forward $^{3}\overrightarrow{\mathrm{He}}(\vec{e}, e')$ measurement at Q^2 from 1 to 2.6 $(\mathrm{GeV/c})^2$
- Already have theoretical support from G. Salme` and M. Sargsian to make G_E^n extractions from the data
- Makes use of the Hall C investments for the A_1^n and d_2^n experiments **without requiring additional equipment**
- We request 15 days of beam


Thank You!
04.22.2009 16:20

PR12-12-011 Collaboration

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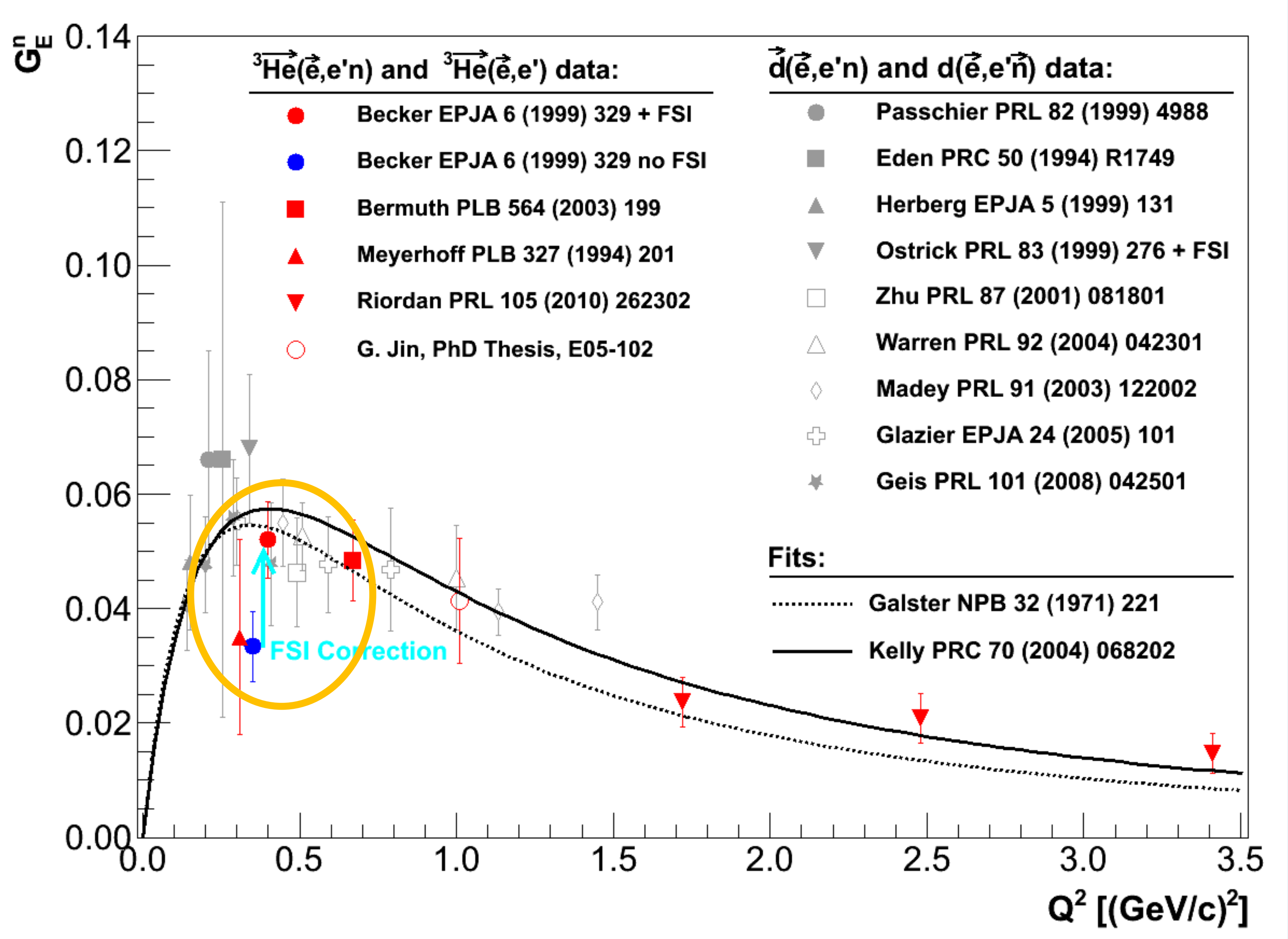
Motivation

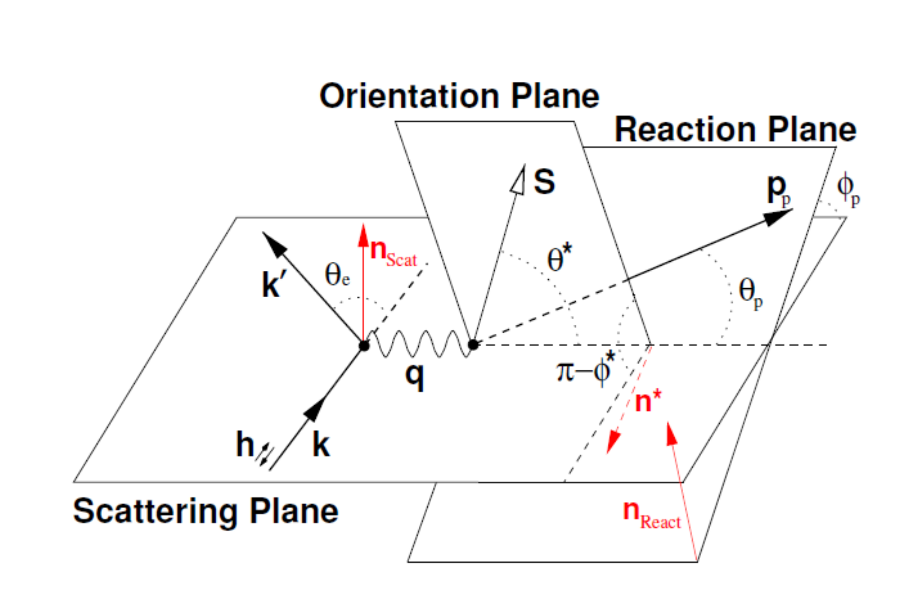


G_E^n
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
$^3\vec{He}(\vec{e},e'n)$ and $^3\vec{He}(\vec{e},e')$ data:
Becker EPJA 6 (1999) 329 + FSI
Becker EPJA 6 (1999) 329 no FSI
Bermuth PLB 564 (2003) 199
Meyerhoff PLB 327 (1994) 201
Riordan PRL 105 (2010) 262302
G. Jin, PhD Thesis, E05-102
$\vec{d}(\vec{e},e'n)$ and $d(\vec{e},e'\vec{n})$ data:
Passchier PRL 82 (1999) 4988
Eden PRC 50 (1994) R1749
Herberg EPJA 5 (1999) 131
Ostrick PRL 83 (1999) 276 + FSI
Zhu PRL 87 (2001) 081801
Warren PRL 92 (2004) 042301
Madey PRL 91 (2003) 122002
Glazier EPJA 24 (2005) 101
Geis PRL 101 (2008) 042501
Fits:
Galster NPB 32 (1971) 221
Kelly PRC 70 (2004) 068202
FSI Correction
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Q^2 [(GeV/c)^2]

Helicity Asymmetry in Electron Scattering

$$A = -\frac{\sin\theta^* \cos\phi^* v_{TL'} R^{^3He}_{TL'} + \cos\theta^* v_{T'} R^{^3He}_{T'}}{v_L R^{^3He}_L + v_T R^{^3He}_T}$$

where *R*'s are response functions and v's are kinematics factors



T. D. Donnelly and A. S. Raskin, Ann. Phys 169, 247 (1986)

Ratio of Asymmetries

$$\text{when } \theta^* = 0, \text{ transverse asymmetry } A_{T'} = -\frac{v_{T'} R^{^3He}{}_{T'}}{v_L R^{^3He}{}_L + v_T R^{^3He}{}_T}$$

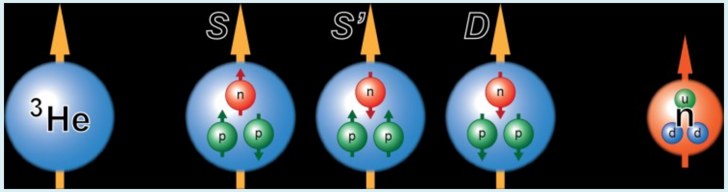
$$\text{when } \theta^* = \pi/2 \text{ and } \phi^* = 0, \text{ transverse - longitudinal asymmetry}$$

$$A_{TL'} = -\frac{v_{TL'} R^{^3He}{}_{TL'}}{v_L R^{^3He}{}_L + v_T R^{^3He}{}_T}$$

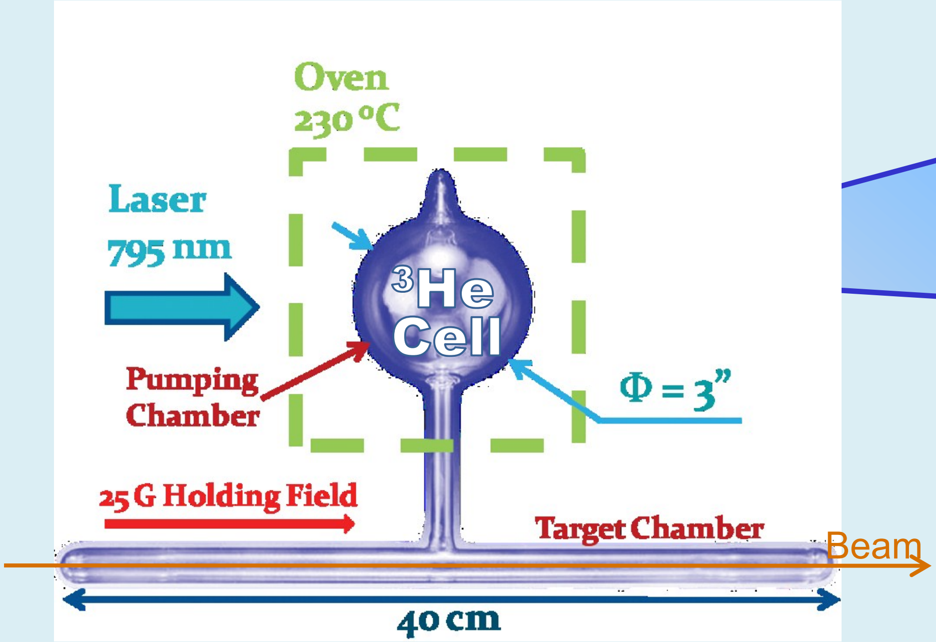
$$\Rightarrow \frac{A_{TL'}}{A_{T'}} = \frac{v_{TL'} R^{^3He}{}_{TL'}}{v_{T'} R^{^3He}{}_{T'}}$$

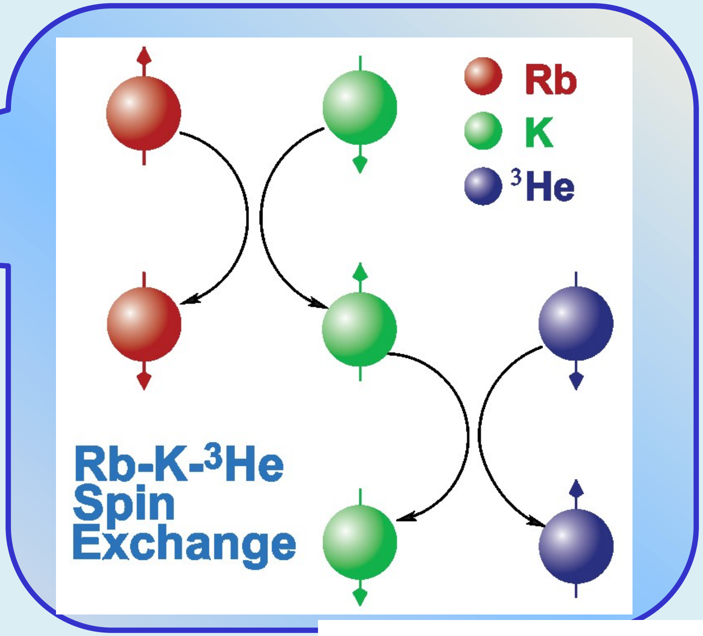
Polarized ^{3}He Target

- Improved figure of merit
  - Rb+K hybrid mixture cell
  - Narrow bandwidth lasers
- Compact size: No cryogenic support needed



~90% ~1.5% ~8%

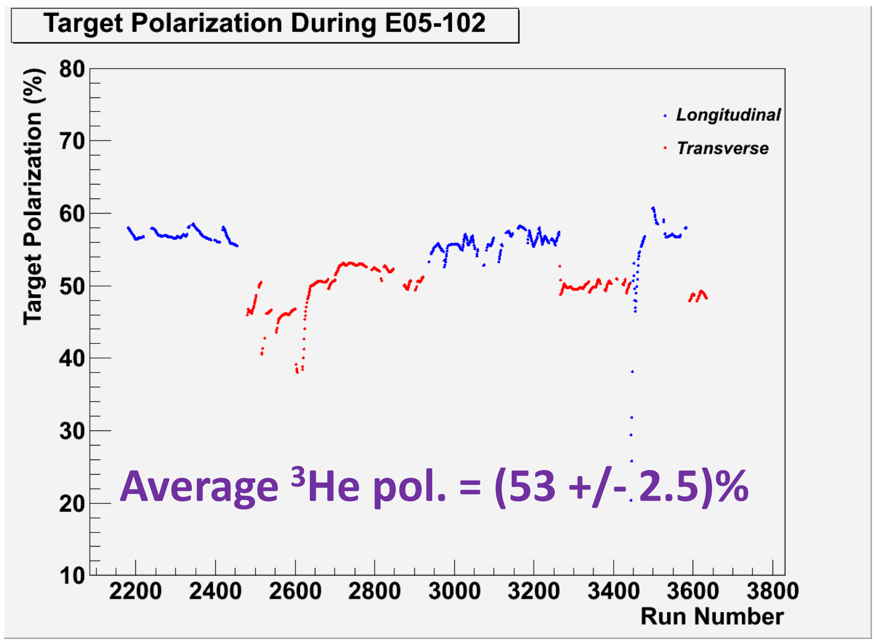




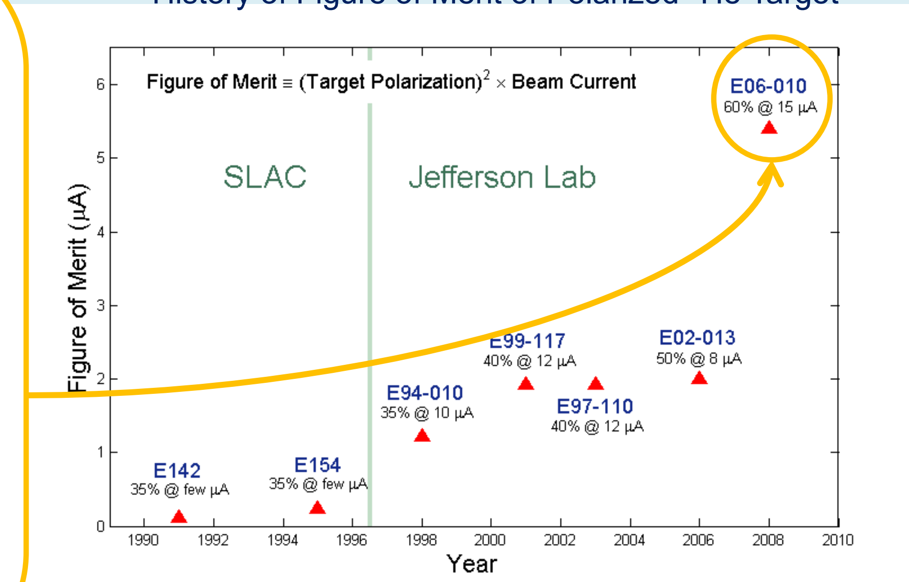
Jefferson Lab

6-GeV Performance of ^{3}He Target

- Luminosity: $L(n) = 10^{36}$ cm^{-2} s^{-1}
- **Achieved record high steady ~ 60% polarization** with a beam current up to 15 μA



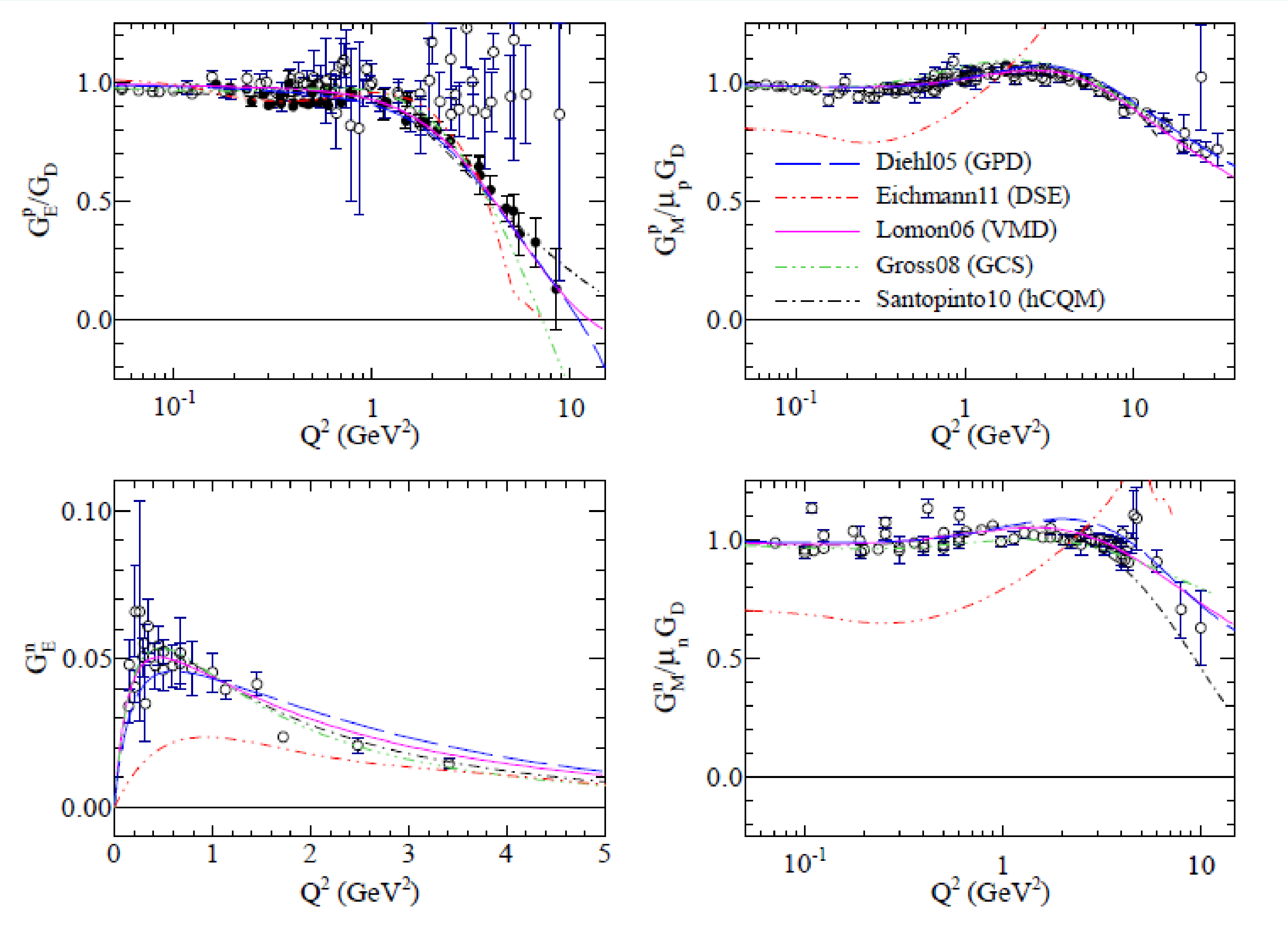
History of Figure of Merit of Polarized ^{3}He Target



Planned ^{3}He Target for 12-GeV Experiments

- Upgrade takes advantage improvements of hybrid spin exchange optical pumping and spectrally narrowed lasers
- This proposal takes advantage of the already planned factor of 8 improvement in polarized luminosity discussed in the and the Hall C approved A_1^n experiment
  - "Dual transfer tube" design for convection mixing of polarized gas
  - Additional diagnostics for direct measurement of ^{3}He and alkali-vapor polarizations
- **Goal: 60% target polarization with a beam current of 60 μA on a 60-cm long target**

Current Status of EM Form Factors

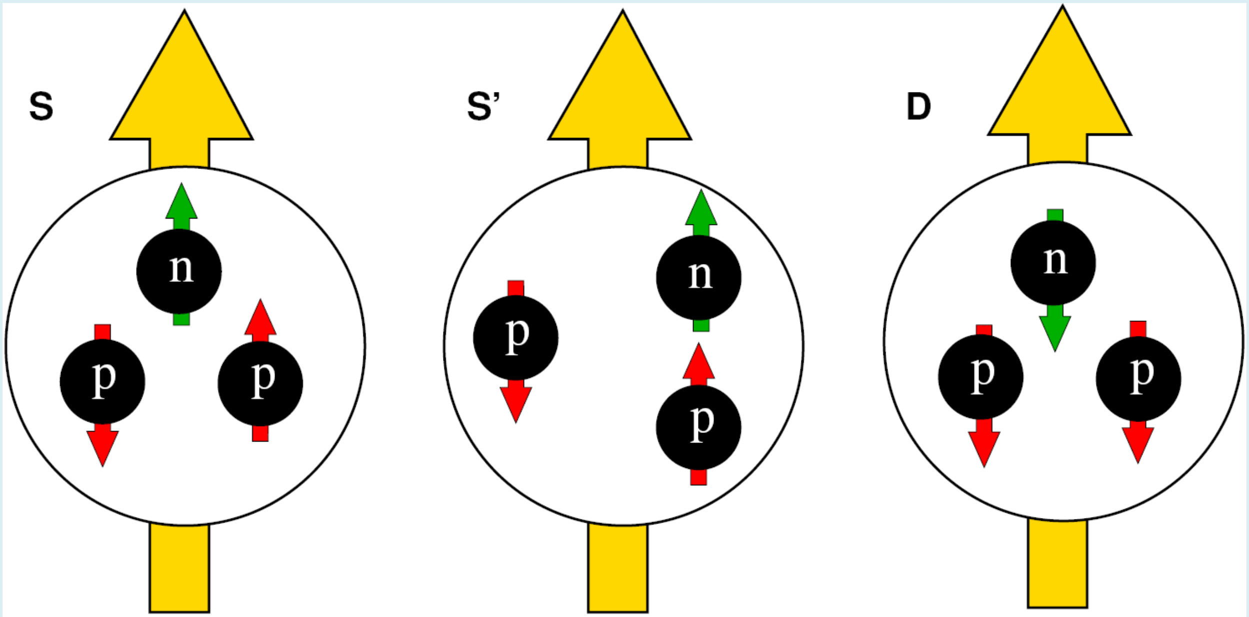


^{3}He spin structure

- Spin-1/2 Particle, 3 spin-1/2 Nucleons (Proton and Neutron)
- Protons are in spin-singlet state. ^{3}He spin is dominated by spin of **n**. Therefore ^{3}He can be used as an effective **n** target
- S' mixed symmetry, (spin-isospin)-space correlations

Effective Polarized Neutron Target

$$\frac{\mu_{^3He}}{\mu_n} = \frac{-2.131}{-1.913} \approx 1$$



Angular Momentum: L=0 ~90% | L=0 ~1-2% | L=2 ~8%