PR-08-001
Investigation of the Role of Nuclear Medium Modifications in the $^{4}He(e,e'p)^{3}H$ Reaction in Hall C

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Purpose of this proposal

Investigation of the role of nuclear medium modifications.

→ $^{4}He(e,e'p)^{3}H$ proton recoil polarization is the observable of choice.

To improve the interpretability of the existing data, we propose to acquire:

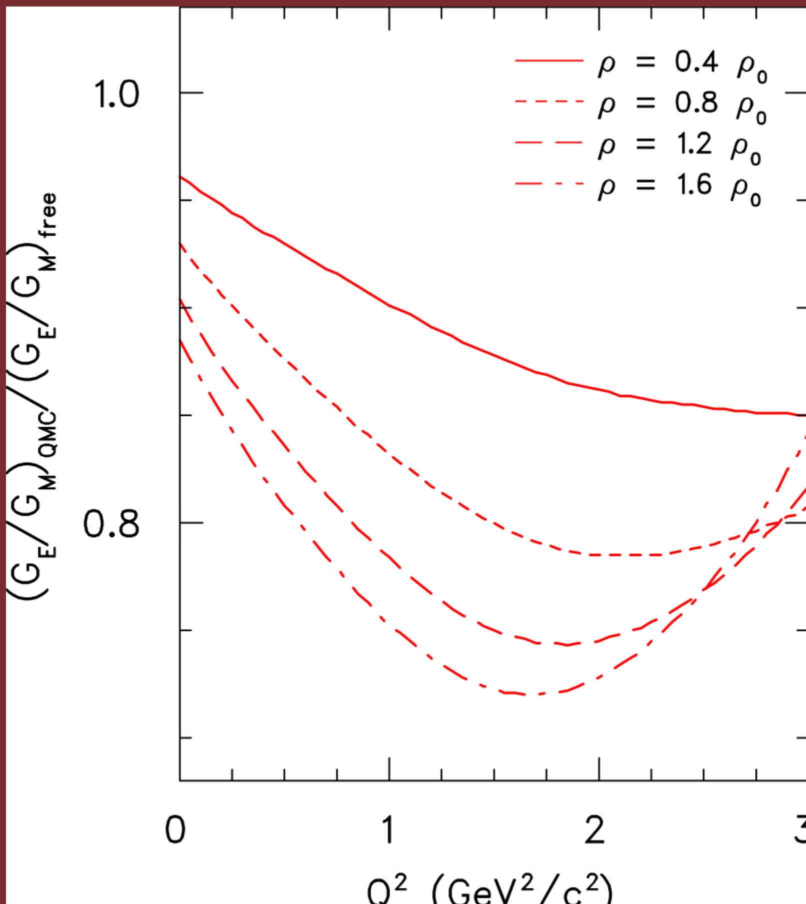
1. More detailed Q^2 coverage with high-precision points.
2. Wide-range missing-momentum coverage at low Q^{2}.
3. Induced polarization data to constrain models of FSI.
4. Additional ^{2}H data to allow comparison of ^{4}He with both free and low density targets.

Nucleons in the Nuclear Medium

- Conventional Nuclear Physics:
  - Nuclei are effectively and well described as point-like protons and neutrons (+ form factor) and interaction through effective forces (meson exchange).
  - Medium effects arise through non-nucleonic degrees of freedom.
  - Are *free* nucleons and mesons, under every circumstance, the best quasi-particle to chose?

- Nucleon Medium Modifications:
  - Nucleons and mesons are not the fundamental entities in QCD.
  - Medium effects arise through changes of fundamental properties of the nucleon.
  - Do nucleons change their quark-gluon structure in the nuclear medium?

In-Medium Form Factors



QMC: D.H. Lu *et al.*, Phys. Lett. B **417**, 217 (1998)

- **QCD**: nuclear constituents change in medium.
  $\Rightarrow$ bound nucleon form factors.
- **Observable effects predicted**:
  Quark Meson Coupling (QMC), Chiral Quark Soliton (CQSM), Skyrme, NJL, GPD Models.
- **Model Predictions:**
  - differ in size and Q^2 dependence.
  - consistent with experimental data (within large uncertainties).

Medium-modified form factors are not an experimental observable. How can we test these predictions?

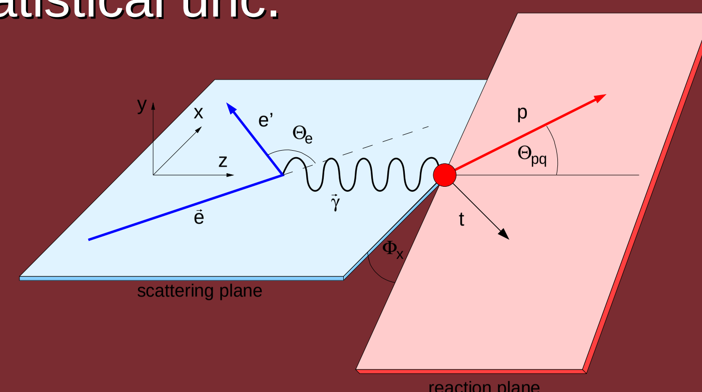
Strategy:

- choose an observable with high sensitivity to nucleon structure while being at the same time least sensitive to conventional medium effects.
- chose a dense yet simple nuclear target, which allows for microscopic calculations.
- provide high-precision data to put Nuclear Physics models to rigorous test.

Polarization-Transfer Technique

- Simultaneous measurement of transverse and longitudinal polarization-transfer components.
- The best technique to probe the structure of the free proton.
- Systematic uncertainties mostly cancel in the ratio, and are therefore small compared to statistical unc.

$$\frac{G_E}{G_M} = -\frac{P'_x}{P'_z} \cdot \frac{(E_i + E_f)}{2m} \tan\left(\frac{\theta_e}{2}\right)$$



- Also the best technique to probe bound proton structure.
- Bound nucleons → measure P'_x, P'_z.

  → a model is used to make linkage between polarization observables and bound proton structure.

Polarization-Transfer Observables

- **One of best experimental methods to challenge conventional meson-nucleon calculations where conventional effects are suppressed.**

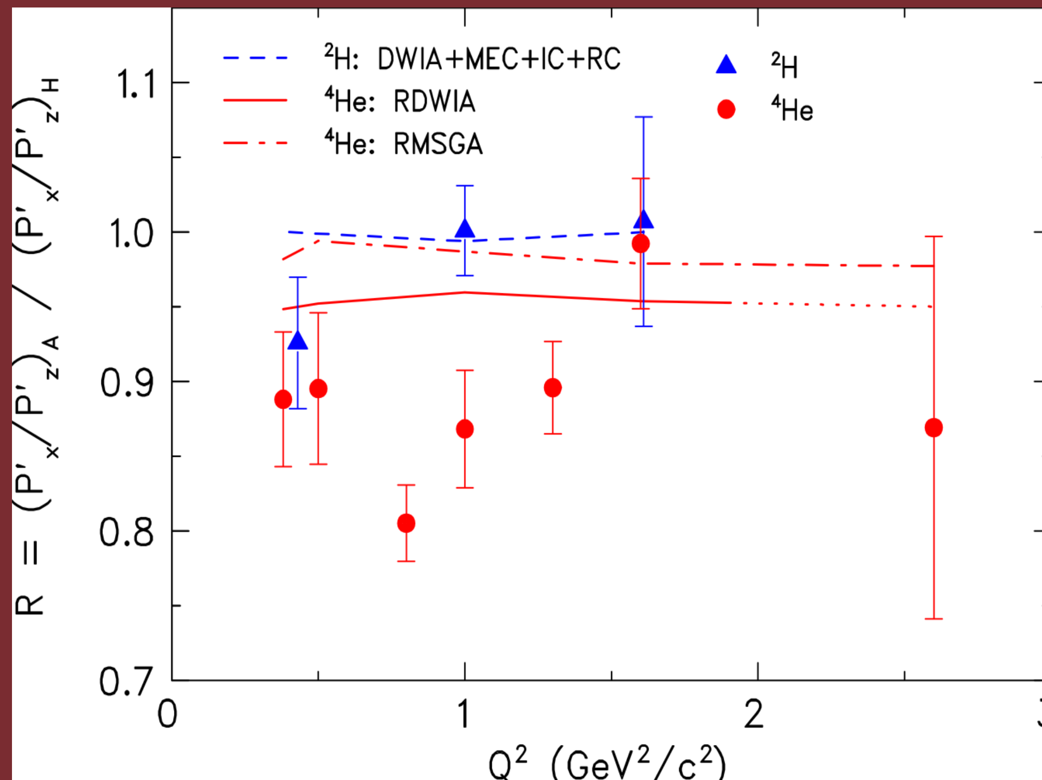
- Reaction-mechanism effects in $A(\vec{e},e'\vec{p})B$ predicted to be small and minimal for:
  - Quasielastic scattering.
  - Low missing momentum.
  - Effects symmetric about $P_{MISS} = 0$.

Reaction mechanism effects small for polarization transfer observables:
J.M. Laget, Nucl. Phys. A **579**, 333 (1994)
J.J. Kelly, Phys. Rev. C **59**, 3256 (1999),
A. Meucci, C. Guisti, and F.D. Pacati, Phys. Rev. C **66**, 034610 (2002).

- **Measurement of Induced polarization P_y gives constraint on FSI.**
  - Observable is identically zero in the absence of FSI effects (1-photon exchange approximation).

^{2}H,^{4}He(e,e'p) Polarization Ratios

- **^{4}He data are significantly different than ^{2}H data.**
- **Small effect for less dense nucleus, larger for denser.**
- RDWIA and RMSGA models cannot describe ^{4}He data.
- Interesting Q^2 dependence.



10-20% Effect

^{2}H Model: H. Arenövel; see: B. Hu *et al.*, Phys. Rev. C **73**, 064004 (2006).
RDWIA: J.M. Udias *et al.*, Phys. Rev. Lett. **83**, 5451 (1999);.
Relativistic Multiple-Scattering Glauber Approximation (RMSGA):
P. Lava *et al.*, Phys. Rev. C **71**, 014605 (2005), D. Debruyne *et al.*, Phys. Rev. C **62**, 024611 (2000).

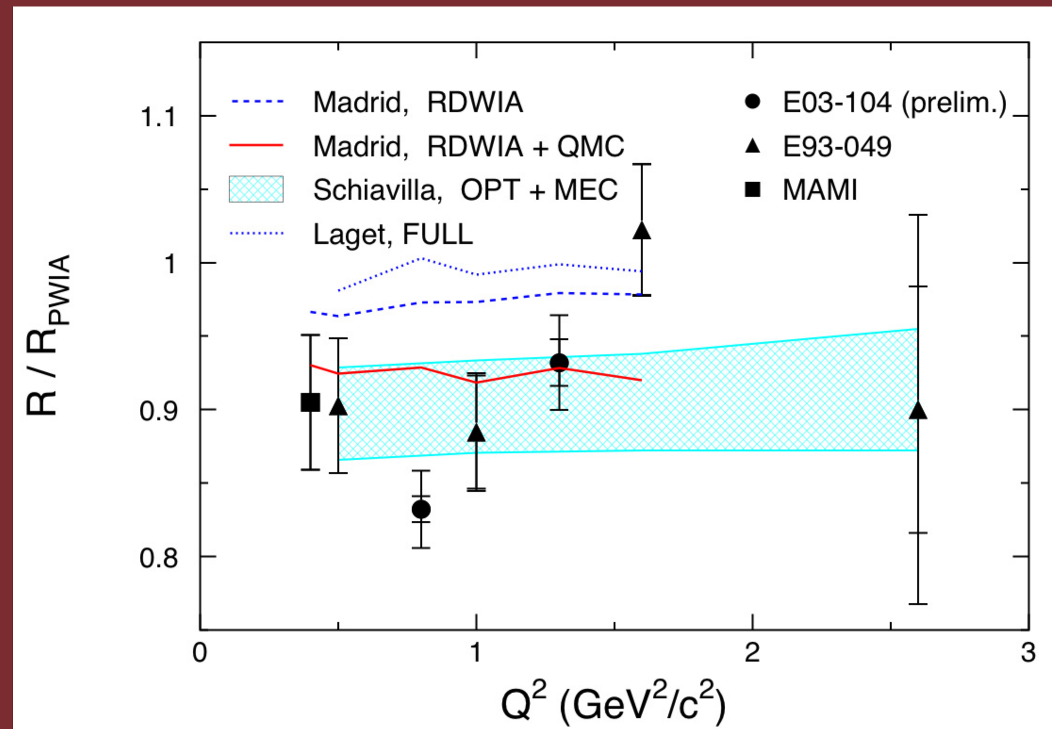
Interpretation of Polarization-Transfer Data

DATA ROUGHLY CONSISTENT WITH:

- RDWIA+QMC density-dependent medium modified form factors.

OR:

- Free form factors+ Spin-dependent charge-exchange FSI.



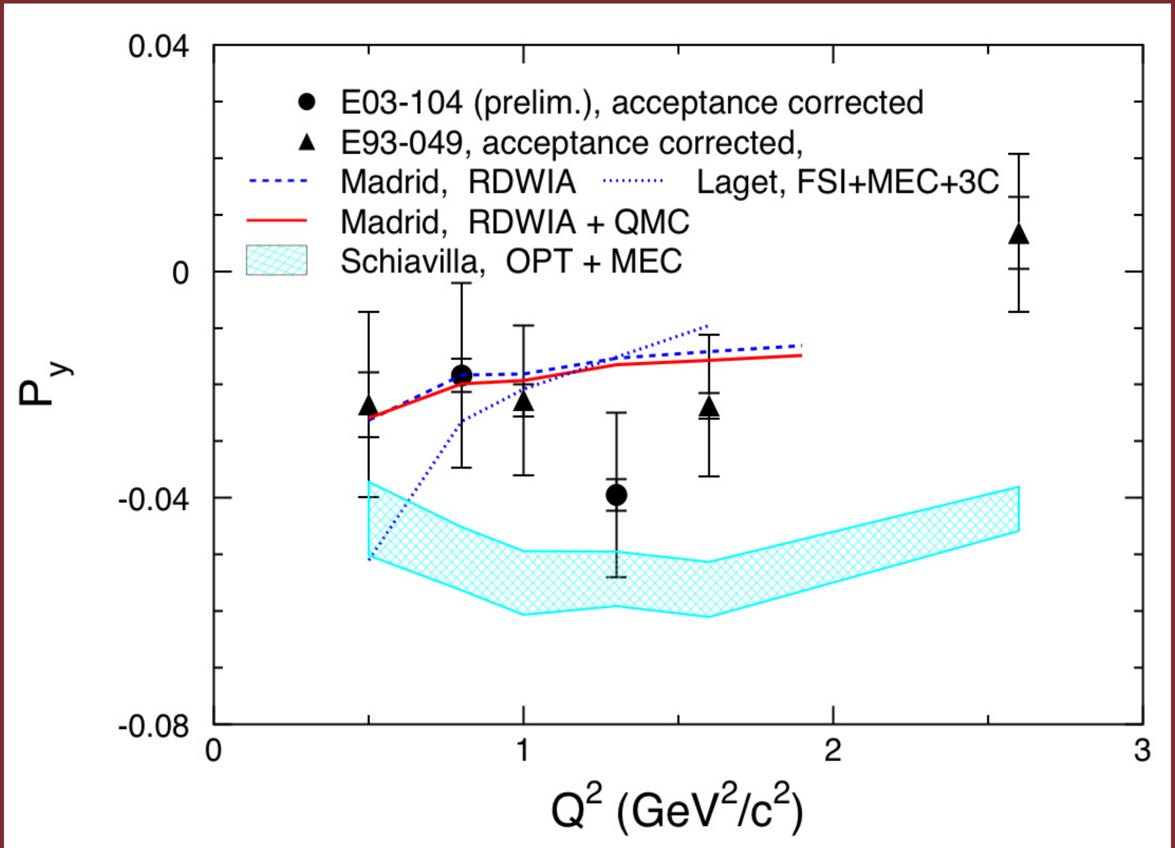
$R = (P'_x/P'_z)_{4He} / (P'_x/P'_z)_{1H}$

Models are acceptance averaged to match that of the data.

- **The modeling of final-state interactions can be tested by measuring the induced polarization, P_y.**

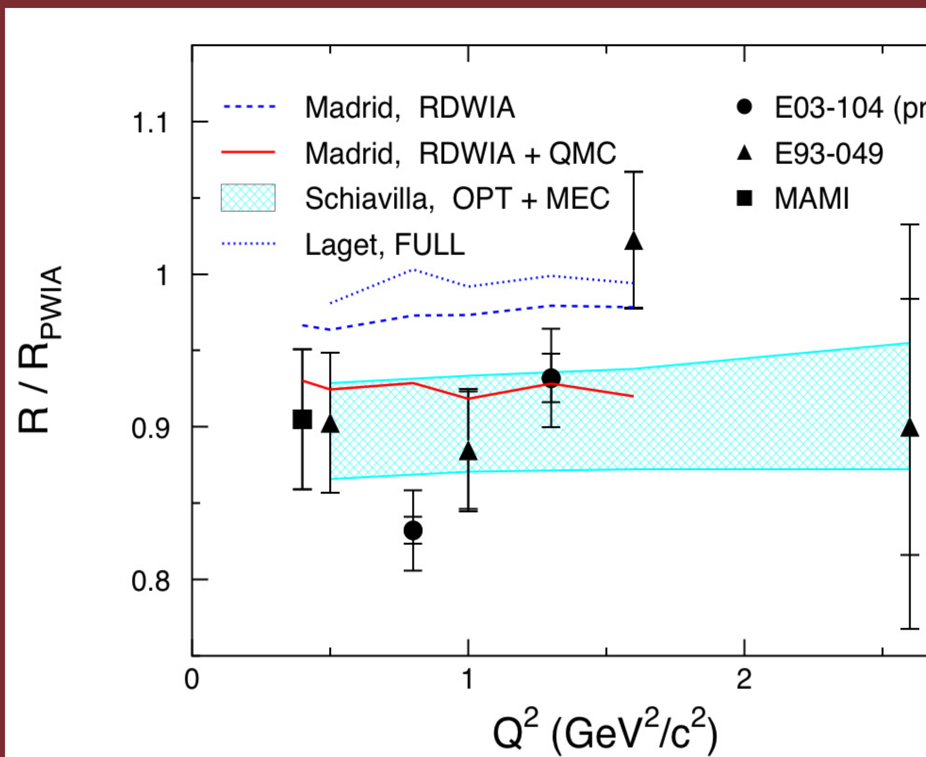
Induced Polarization P_y is a Measure of FSI

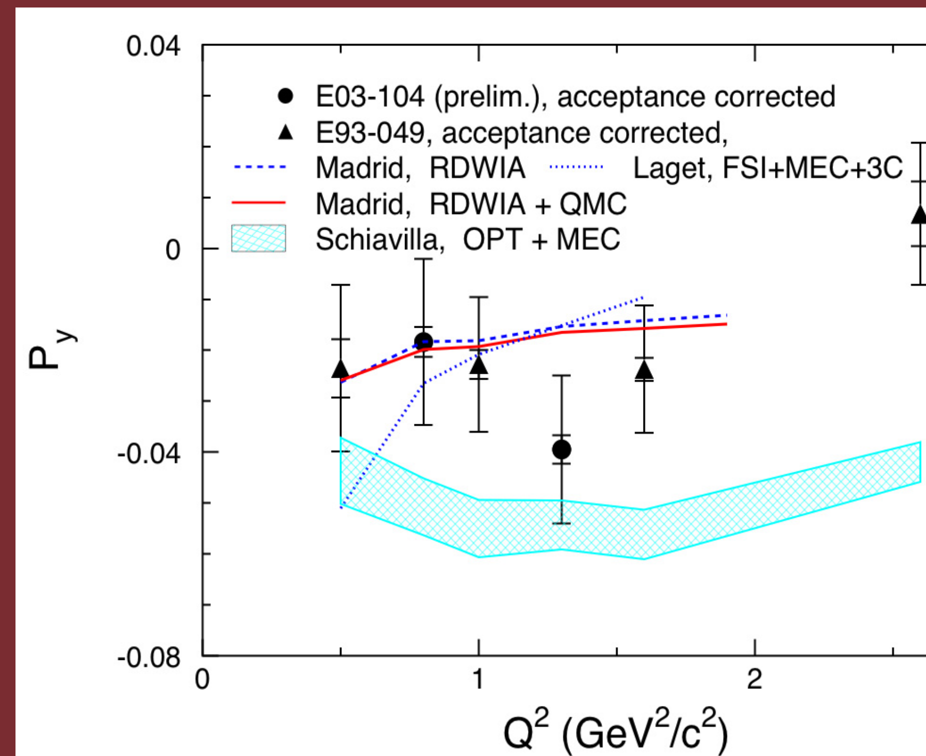
- **Observed final-state interaction small and with only very weak Q^2 dependence.**
- RDWIA,Laget results consistent with data.
- Spin-dependent charge-exchange terms not constrained by *N-N* scattering data and possibly overestimated.



Inner uncertainties are statistical only.
Full analysis of E03-104 will have reduced systematic uncertainties.

Both observables act together to constrain interpretations of the data





$R = (P'_x/P'_z)_{4He} / (P'_x/P'_z)_{1H}$

Models are acceptance averaged to match that of the data.

Additional Data Are Needed Because:

- Q^2 dependence of $^4He(e,e'p)^3H$ polarization transfer ratio data hints at unexpected structure, needs to be better mapped out.
  - More detailed Q^2 coverage with higher precision points.

- Effect is density dependent (none on ^2H).
  - Additional ^2H data to allow comparison of ^4He with both ^2H and ^1H would aid interpretability.
  - ^2H data include MEC+FSI but at lower density.

- Medium modification may depend upon the virtuality of the interacting nucleon.
  - Propose wide range missing momentum coverage at low Q^2.
  - Additional data helps single out successful models.

Choice of Targets

^{4}He is chosen because its relative simplicity allows for realistic microscopic calculations.

- High density enhances any possible medium effects.

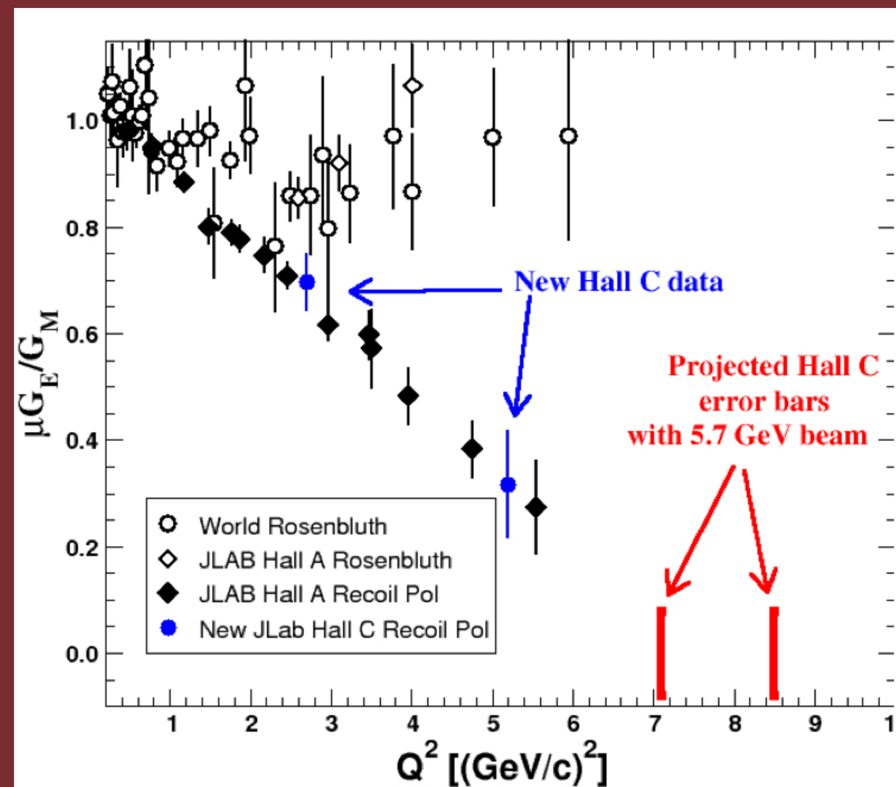
Comparison with ^{1}H, ^{2}H.

- Data on both ^{1}H and ^{2}H allow comparison of ^{4}He knockout data to both free and weakly bound protons and help in the interpretation of the ^{4}He data.
- The data come in quickly and so the additional time investment is small.

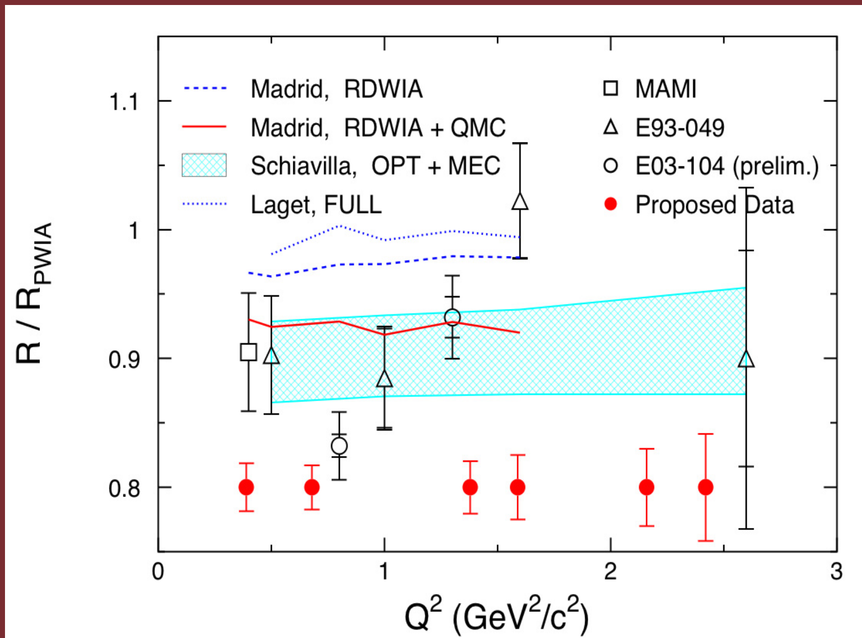
With the new HMS FPP, the SOS+HMS is the preferred apparatus for this study

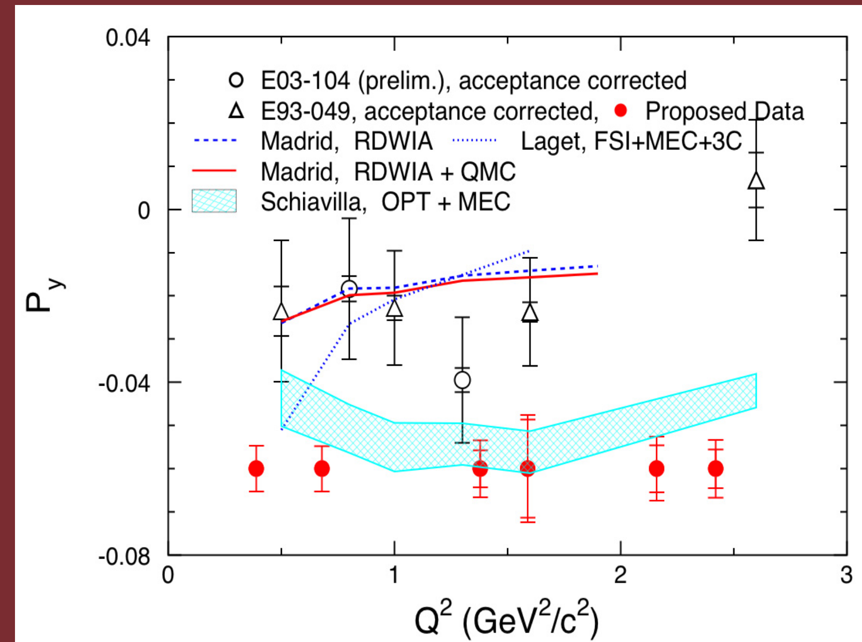
This is a standard equipment experiment in either Hall A or C.

- **HMS+SOS:**
  - Larger momentum and angular acceptances.
  - Optimal spin precession for higher Q^2 points.
  - HMS FPP with new thinner analyzer.
  - 6 cm cryotargets.
- **Beam:**
  - 1.4, 1.85, 2.5, 3.0 GeV.
  - We are flexible on the beam energies to optimize scheduling.



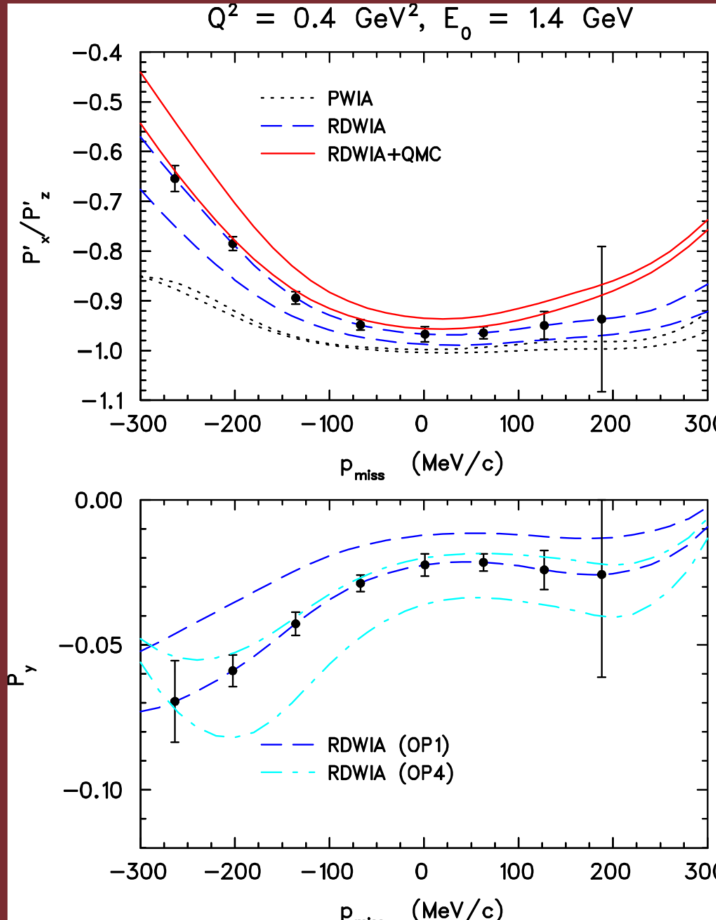
Proposed ^{4}He Q^2 Distributions

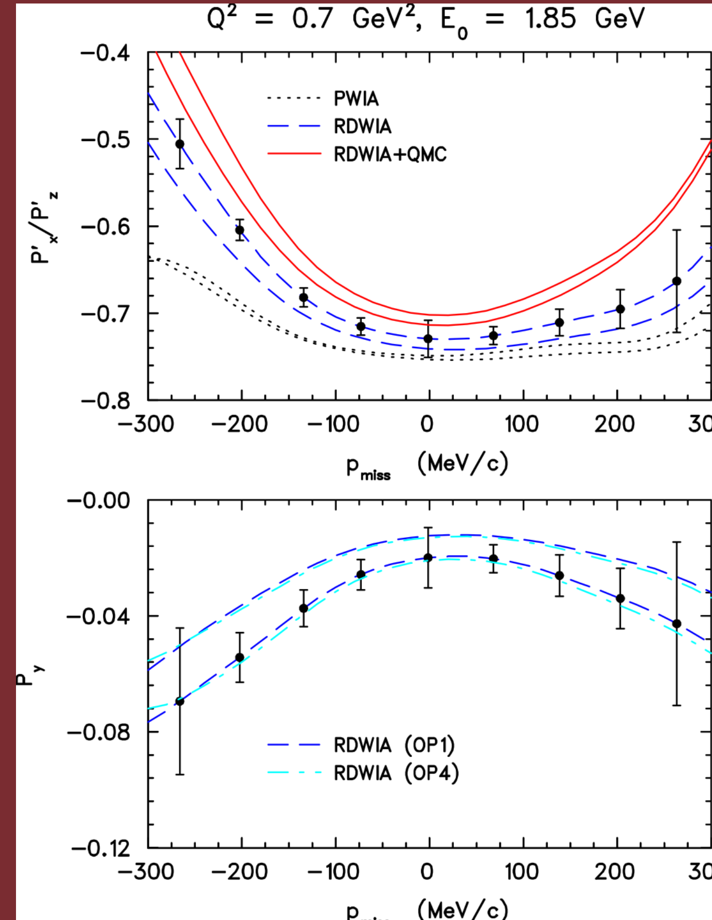




- Preliminary ^{4}He(e,e'p)^{3}H E03-104 results hint at an unexpected Q^2 dependence of the polarization-transfer ratio.
  - Particularly interesting because various calculations of in-medium form factors suggest different Q^2 dependences.
- Precise new data for these two observables, over a wide range of Q^2, will provide a significant challenge to any model interpretations based on nuclear medium modifications.
  - Projected uncertainties dominated by statistical uncertainties.

Proposed ⁴He P_{MISS} Studies





- Ciofi degli Atti, Frankfurt, Kaptari & Strikman, argue that the modification of the bound nucleon wave function should strongly depend on the momentum of the nucleon.

  ⇒ Suppression of PLCs in bound nucleons.

- **Acquire P'_x/P'_z and P_y at larger values of P_{MISS} to constrain A(e,e'p)B models.**

Hall A Option

- If Hall C is not available for scheduling or any other reason, then many of the goals of this experiment can be met by the Hall A apparatus.
- A detailed MC comparison of Hall A vs. C was made:
  - HRS solid angles and momentum acceptances smaller than Hall C.
  - Resulting Q^2 vs. P_{MISS} coverage is also smaller.
  - 10 cm target lengths can be accommodated, instead of 6 cm.
  - HRS bend angle is larger (45^o vs. 25^o), adversely affecting the spin precession at $Q^2=2.30\ (GeV/c)^2$.
- 45 days of beam would be required to generate the same statistical sample in Hall A as 28 days would in Hall C.

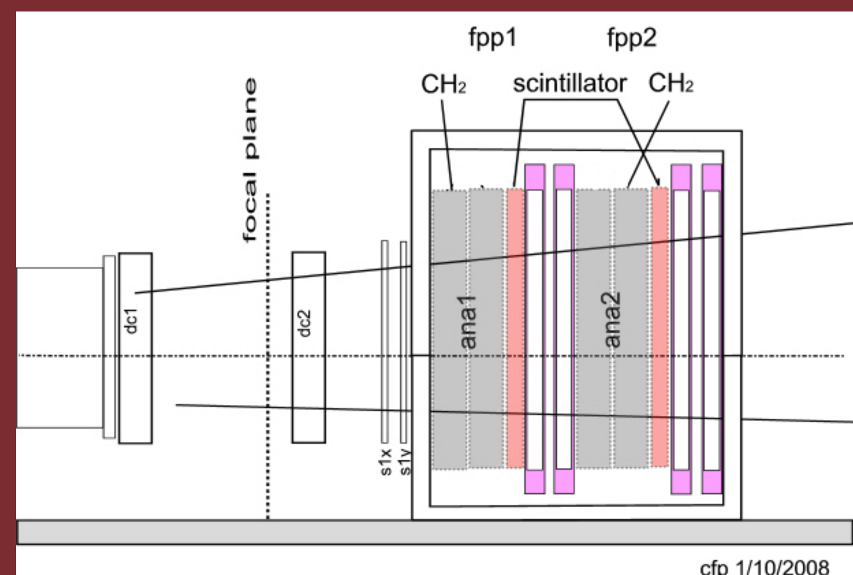
Reply to TAC comments

SOS:

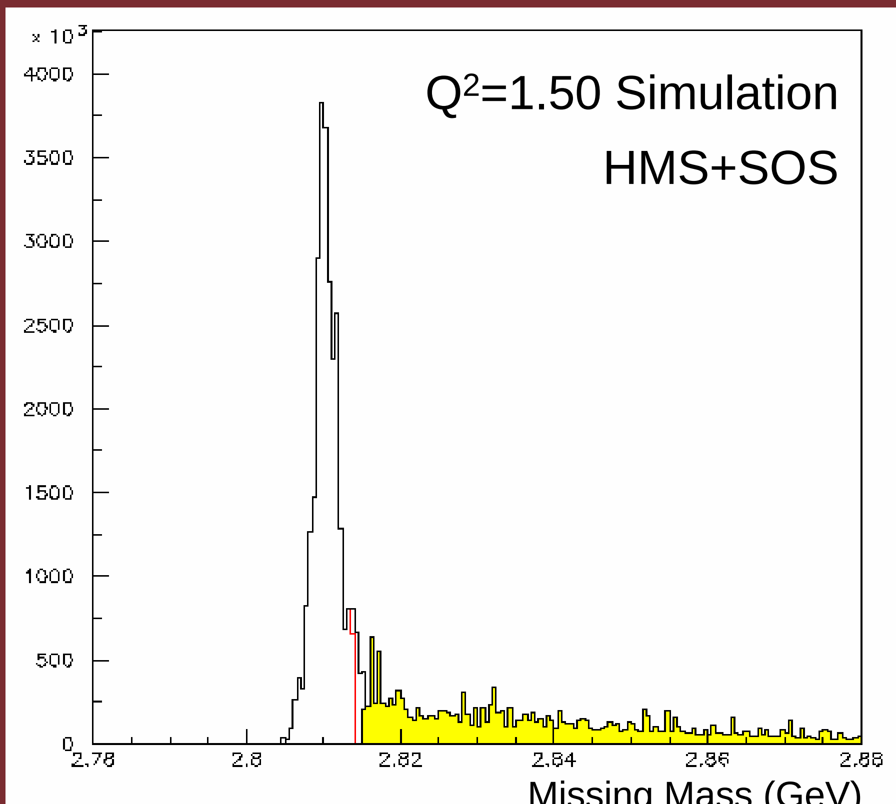
- SOS used last spring for parasitic detector tests.
- The Collaboration will assist with detector and electronics commissioning using cosmics and beam before the start of the expt.
- **TAC recommendation to add extra time for SOS optics calibrations between 1.0 and 1.7 GeV/c is a good one.**
- We can do these calibrations prior to the $^1H(e,e'p)$ elastics scans at Q^2=0.40, 0.70 $(GeV/c)^2$.

HMS:

- We propose to install new FPP analyzers incorporating two active scintillator planes.
- Will provide efficient triggering across focal plane while preserving good missing mass resolution.
- A straightforward project expected to take ~6 months.



Anticipated $^4He(e,e'p)$ Missing Mass Resolution



- **HMS+SOS missing resolution is sufficient to identify ^3H final state.**
  - ±5 MeV cut is generous compared to projected 3 MeV FWHM of the ^3H peak.
- **We are not sensitive to a 40% worse missing mass resolution:**
  - Previous ^4He measurements indicate polarization transfer observables in 'near breakup' region are same (within uncertainties) as ^3H peak.

Beam Request – Hall C

Q^2 $(GeV/c)^2$	^1H Hours	^2H Hours	^4He Hours	Dummy Hours	Over-head	Total Hours
0.4	6	2	46	5	20	79
0.7	7	2	117	12	20	158
1.5	16	12	83	8	20	139
2.3	--	38	225	22	8	293
Subtotals	**29**	**54**	**471**	**47**	**68**	
Grand Total: 669 hrs (28 days)						

- Overhead assumes 8 hours per beam energy change and an additional 12 hour overhead at Q^2=0.4,0.7,1.5 $(GeV/c)^2$ for a target configuration change.
- **The proposed experiment is standard and it is flexible as to different beam energies (and even halls) in order to optimize scheduling.**

Beam Request – Hall A

Q^2 $(GeV/c)^2$	^1H Hours	^2H Hours	^4He Hours	Dummy Hours	Over-head	Total Hours
0.4	8	2	62	6	20	98
0.7	9	2	334	34	20	399
1.5	15	13	120	12	20	180
2.3	--	38	330	33	8	409
Subtotals	32	55	846	85	68	
Grand Total: 1086 hrs (45 days)						

- **Beam times necessary to obtain the same statistical sample as in Hall C.**

Medium-modified form factors are not an experimental observable. How can we test these predictions?

Strategy:

- choose an observable with high sensitivity to nucleon structure while being at the same time least sensitive to conventional medium effects
- chose a dense yet simple nuclear target, which allows for microscopic calculations
- provide high-precision data to put Nuclear Physics models to rigorous test