E03-104
Probing the Limits of the Standard Model of Nuclear Physics with the $^4He(\vec{e},e'\vec{p})^3H$ Reaction

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Hall A Collaboration Meeting, 22-23 June 2006

Nucleon in the Nuclear Medium

QCD *vs.* conventional Nuclear Physics

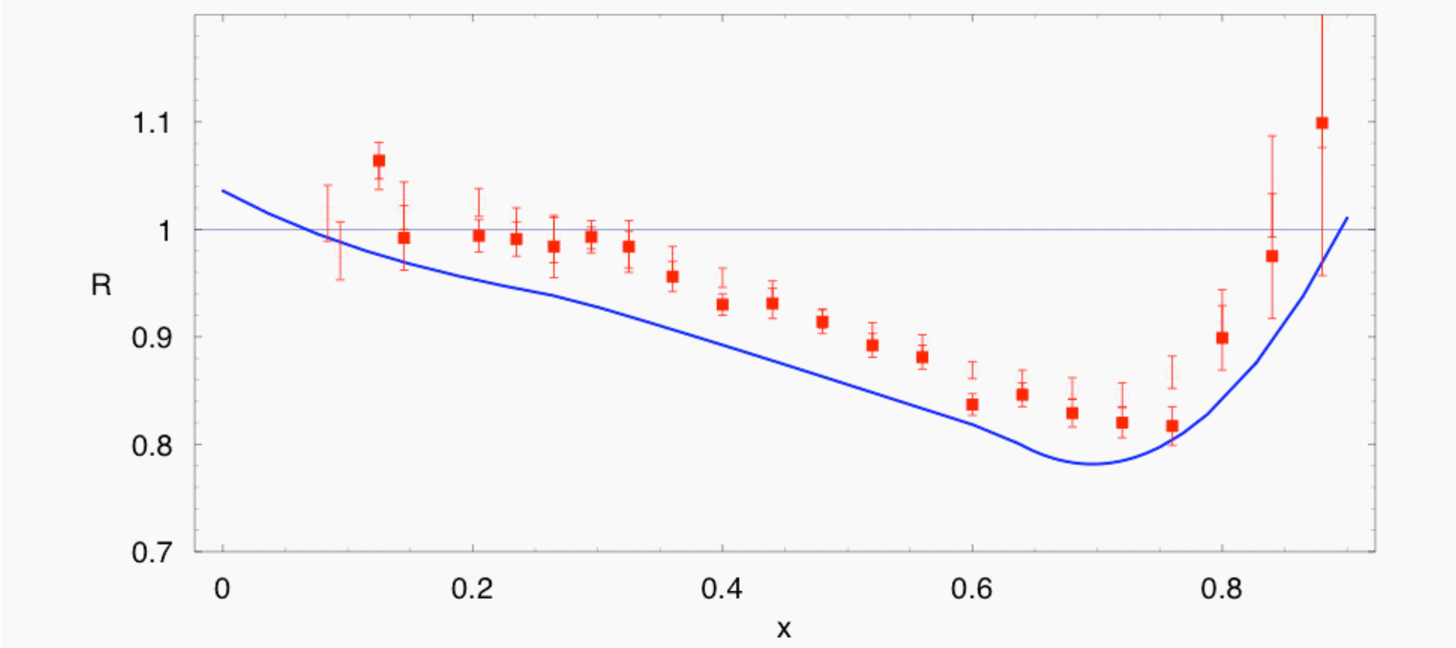
- Underlying theory: QCD
  - Nucleons and mesons are not the fundamental entities
  - In the chiral limit, phase transition to quark-gluon plasma
- Conventional Nuclear Physics:
  Nuclei are effectively and well described as
  - point-like protons and neutrons
  - interaction through effective forces (meson exchange)
- Nuclear Mass

$$M_A \approx [NM_N + ZM_P](1 - 0.01)$$

P.A.M. Guichon and A.W. Thomas, Phys. Rev. Lett. **93**, 132502 (2004)

Interpretation of the EMC Effect

- $R(x,Q^2) = F_2^A / AF_2^N$: Depletion of the nuclear structure function $F_2^A(x)$ in the valence-quark regime $0.3 \leq x \leq 0.8$ (1983)



- Conventional nuclear physics does not explain EMC effect
  → Nucleon structure is modified in the nuclear medium [G. Miller]
- E.g., chiral quark-soliton model of the nucleon

SLAC-E139 data for Iron and Gold;
Figure from Jason R. Smith and Gerald A. Miller, Phys. Rev. Lett. **91**, 212301 (2003)

Polarization-Transfer Technique

- Free electron-nucleon scattering

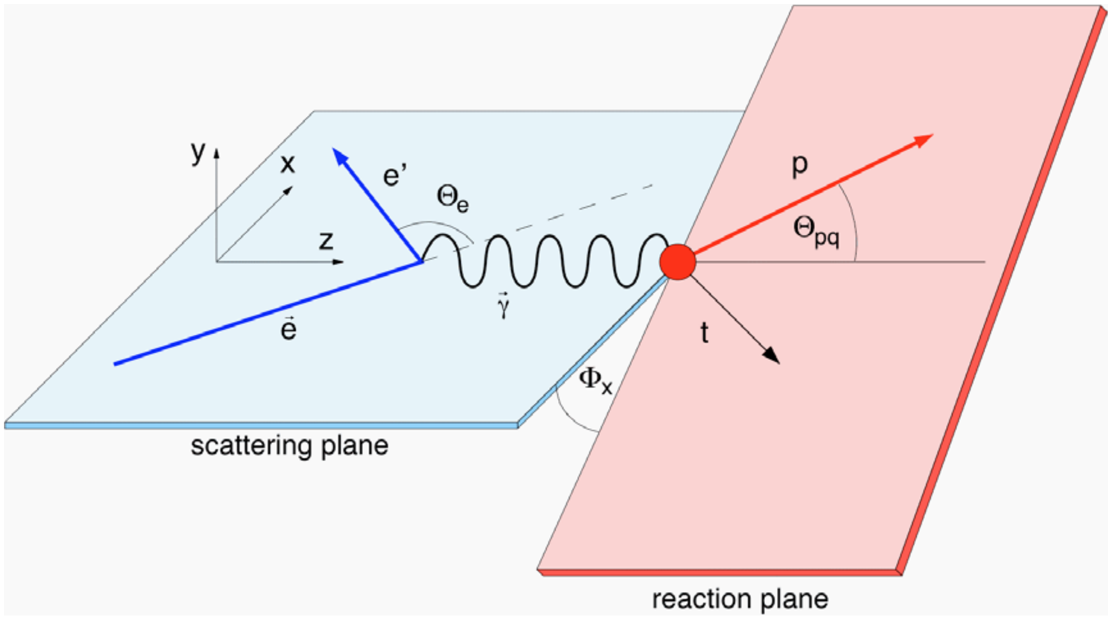
$$\frac{G_E}{G_M} = -\frac{P'_x}{P'_z} \cdot \frac{(E_i + E_f)}{2m} \tan\left(\frac{\theta_e}{2}\right)$$

- Bound nucleons → evaluation within model
- Reaction mechanism effects in A(e,e'p)B predicted to be small and minimal for
  - Quasielastic scattering
  - Low missing momentum
  - Symmetry about $p_m = 0$

[1] R. Arnold, C. Carlson, and F. Gross, Phys. Rev. C **23**, 363 (1981).
[2] E.g. 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).

Proton Polarization in $^4\mathrm{He}(\vec{e},e'\vec{p})^3\mathrm{H}$

- MAMI and JLab: Q^2 = 0.4, 0.5, 1.0, and 2.6 $(\mathrm{GeV}/c)^2$
- Low missing momentum, quasielastic scattering

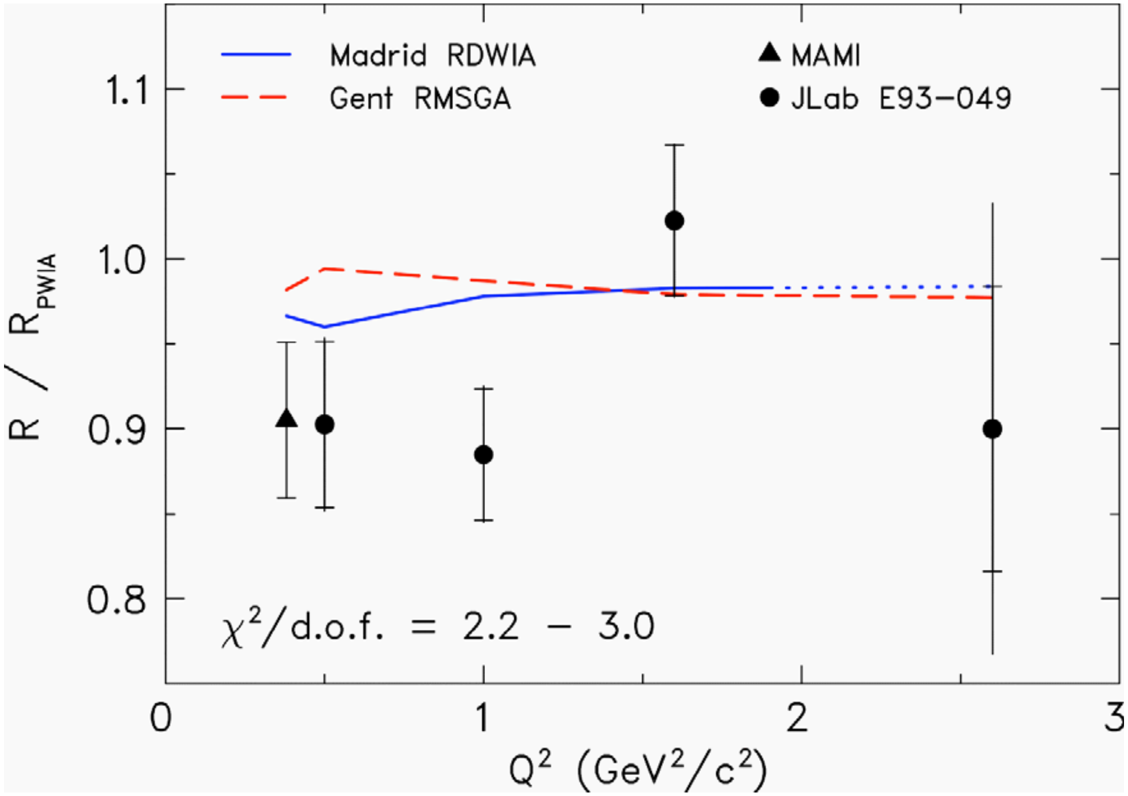


- Polarization-transfer ratio P'_x/P'_z: sensitive to G_E/G_M
- Induced polarization P_y: sensitive to Final-State Interactions (FSI)

S. Dieterich, *et al.*, Phys. Lett. **B500**, 47 (2001);
S. Strauch *et al.*, Phys. Rev. Lett. **91**, 052301 (2003)

$^4He(\vec{e},e'\vec{p})^3H$ - Polarization-Transfer Ratio

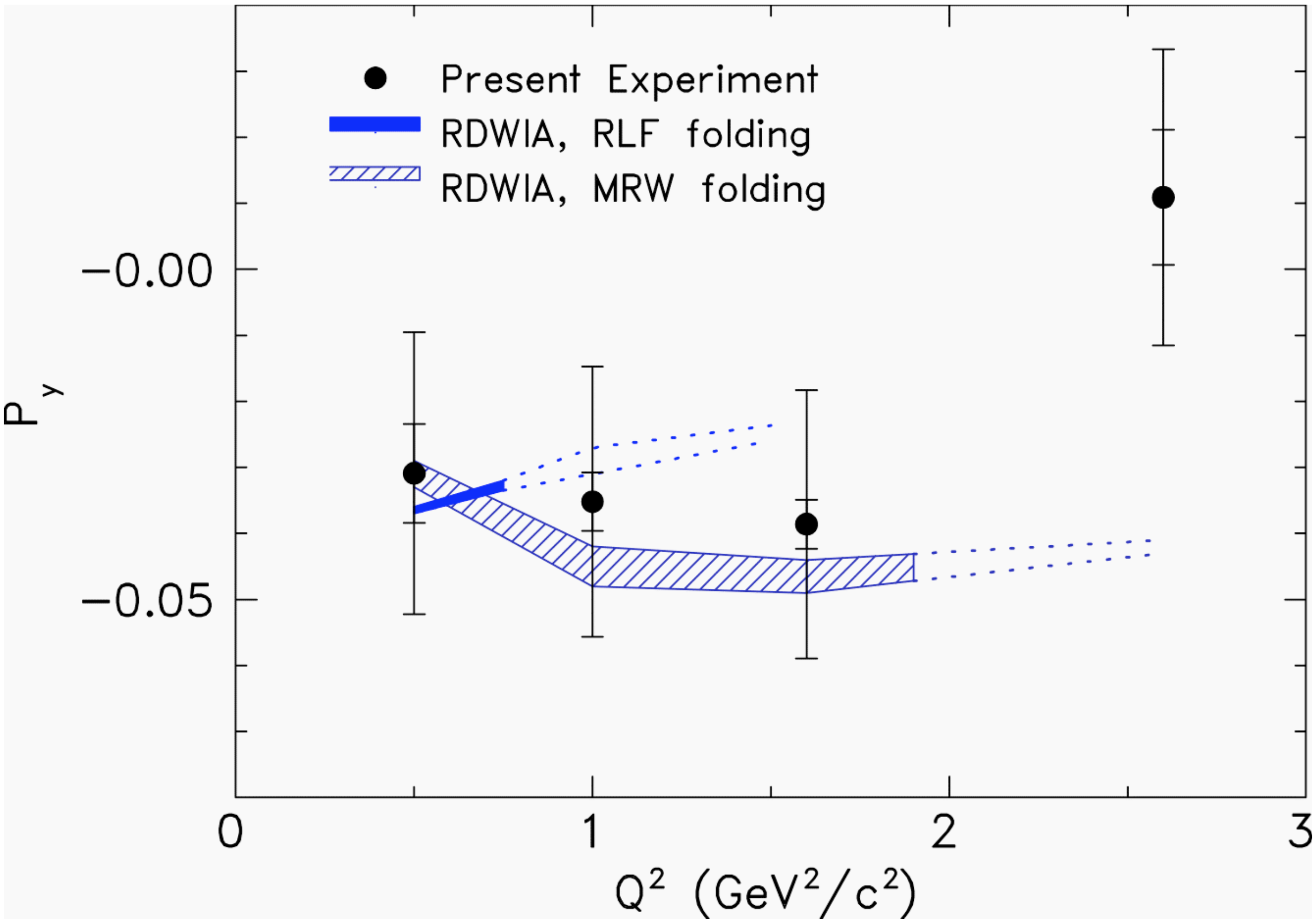
$$R = \left(P'_x / P'_z\right)_{He} / \left(P'_x / P'_z\right)_H$$



Optical potential *vs.* Glauber approximation to describe FSI

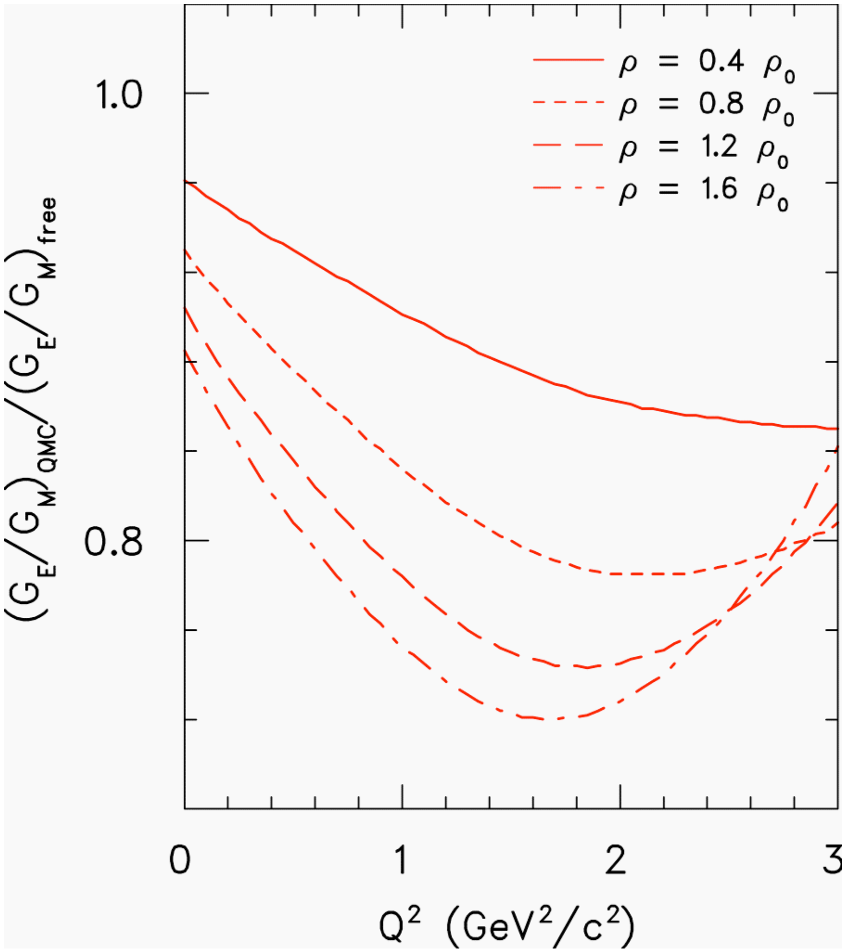
RDWIA: J.M. Udias *et al.*, Phys. Rev. Lett. **83**, 5451 (1999);
RMSGA: P. Lava, J. Ryckebusch, B. Van Overmeire, and S. Strauch, Phys. Rev. C **71**, 014605 (2005)

Induced Polarization



- Final-state interactions are small
- RDWIA results consistent with data

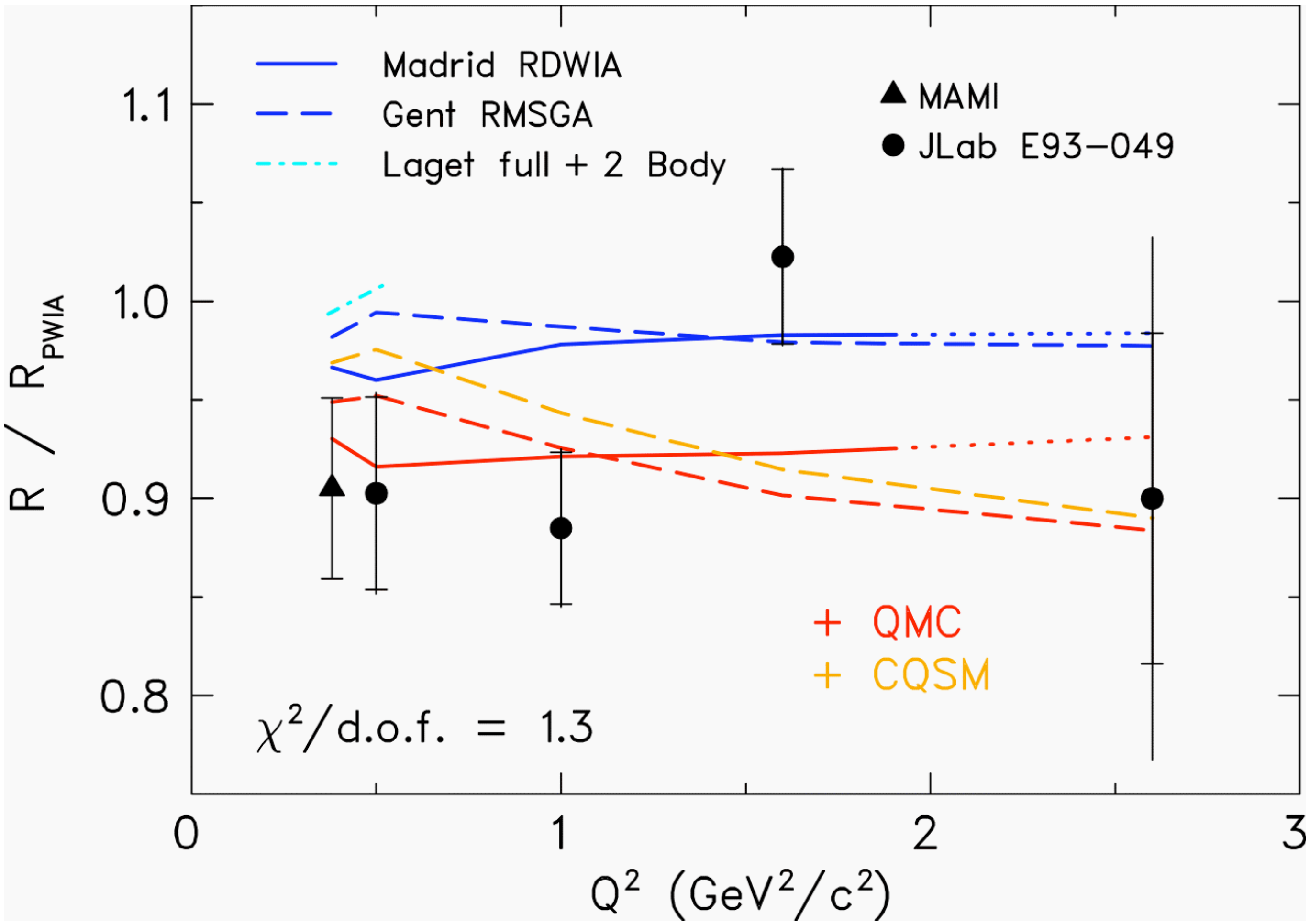
In-Medium Nucleon Form Factor



- Quark meson coupling model
- Chiral quark-soliton model
- Modified Skyrme model
- Form-factor ratio suppressed as density increases
- Calculations in agreement with existing experimental limits on medium modifications

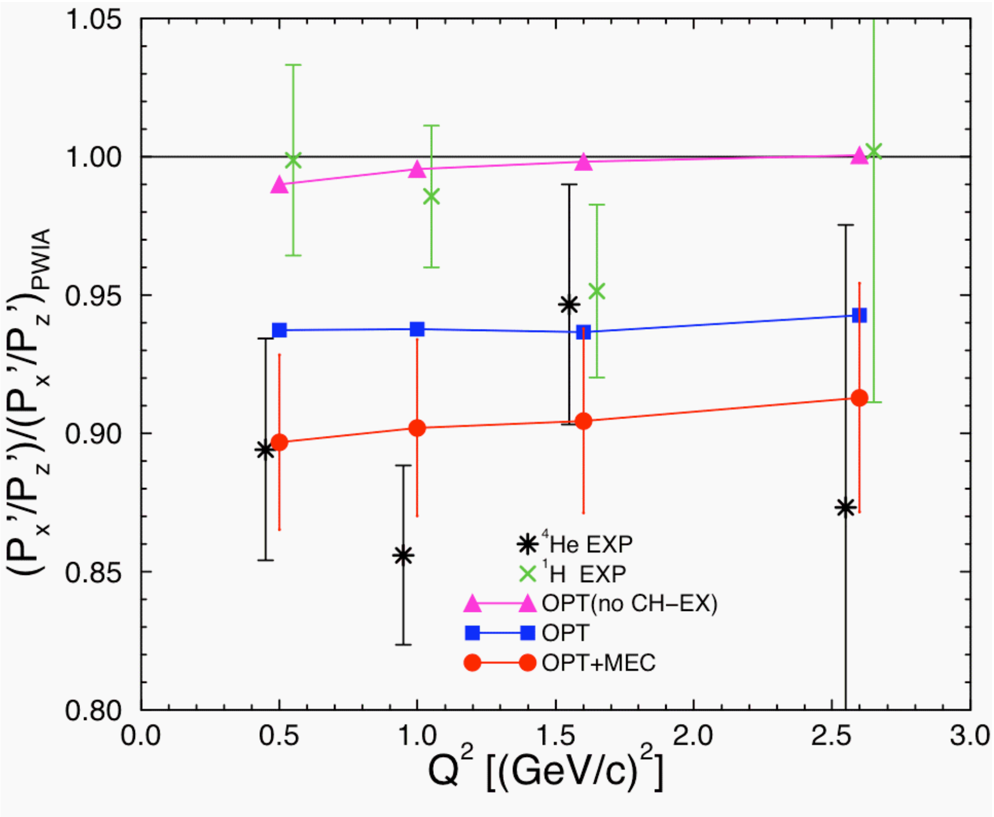
QMC: D. H. Lu *et al.*, Phys. Rev. C. **60**, 068201 (1999)
CQSM: J. R. Smith and G. A. Miller, Phys. Rev. Lett. **91**, 212301 (2003)
Skyrme: U. Yakhshiev, U. Meißner, A. Wirzba, Eur. Phys. J. A **16**, 569 (2003)

Polarization-Transfer Double Ratio



- Data effectively described by proton medium modifications
- In-medium form factors reduce double ratio by ≈ 6% at 1 GeV^2/c^2

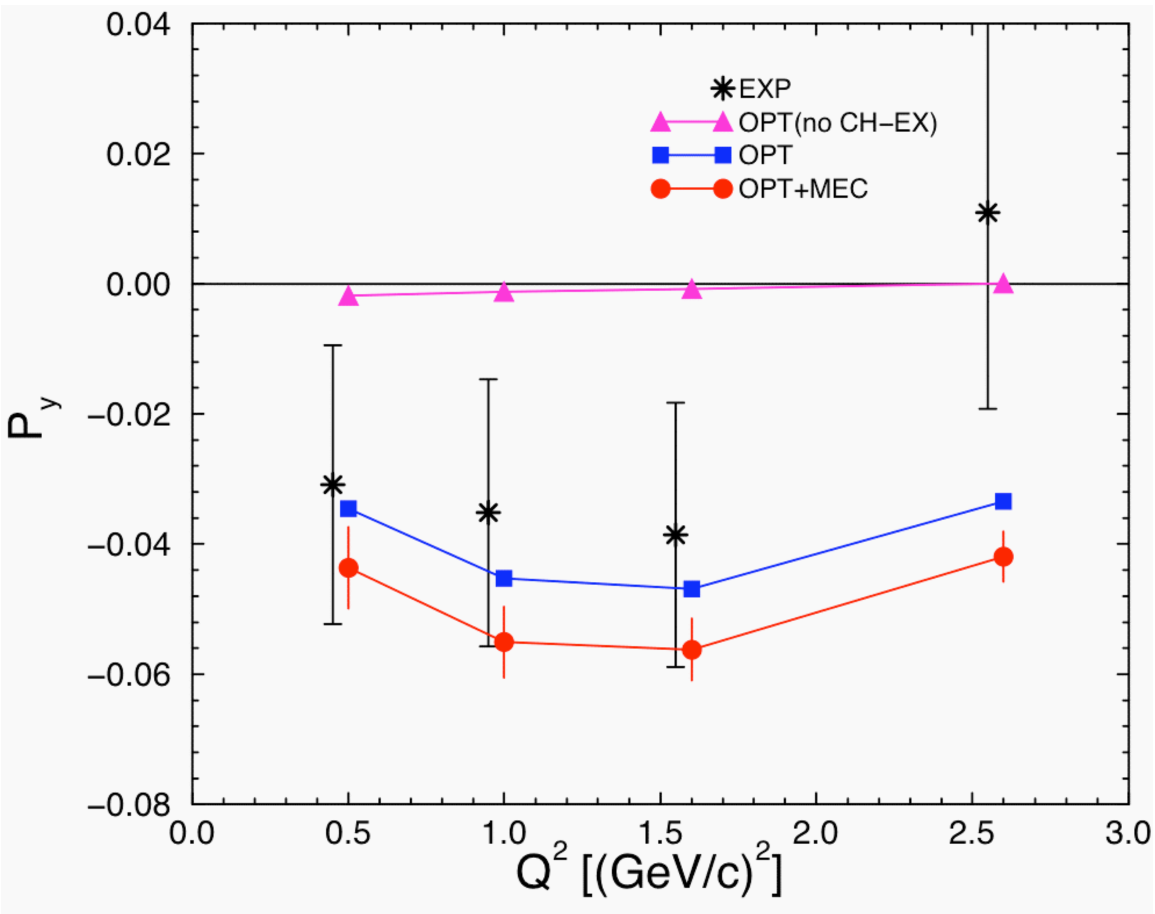
Is the Ratio G_{Ep}/G_{Mp} Modified in the Nuclear Medium?



- Accurate bound-state wave function
- Realistic model for the nuclear electromagnetic current operator
- Treatment of final-state interactions with an optical potential
- Charge-exchange components in the optical potential crucial.

R. Schiavilla, *et al.*, Phys. Rev. Lett. **94**, 072303 (2005); Results given for a single kinematical point.

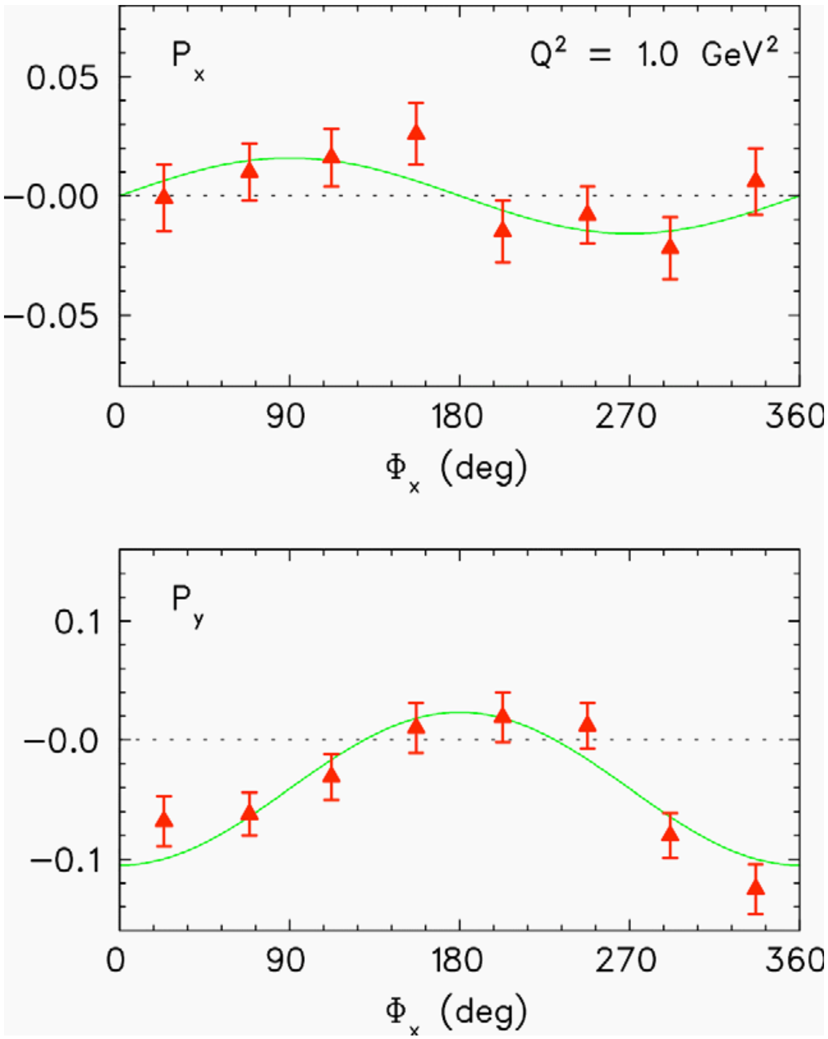
Induced Polarization



- Effect of acceptance average:
  +0.5% for R,
  -40% for P_y
- Are the (unconstrained) charge-exchange FSI overestimated?
  ($P_y \approx -0.08$)
- A reduction of CH-EX effects would no longer give a good description of the polarization-transfer ratio.

R. Schiavilla, *et al.*, Phys. Rev. Lett. **94**, 072303 (2005)

Induced Polarization



- Far more detailed investigation possible with upcoming experiment:
  - angular distribution
  - missing momentum distribution
  - response functions
- Tightly constrain FSI

Understanding False Asymmetries

- E93-049: $\sigma_{Syst}(P_y) = 0.02$

- Sources of false asymmetries
  - misalignment
  - detector inefficiencies
  - detector acceptance (cone-test)

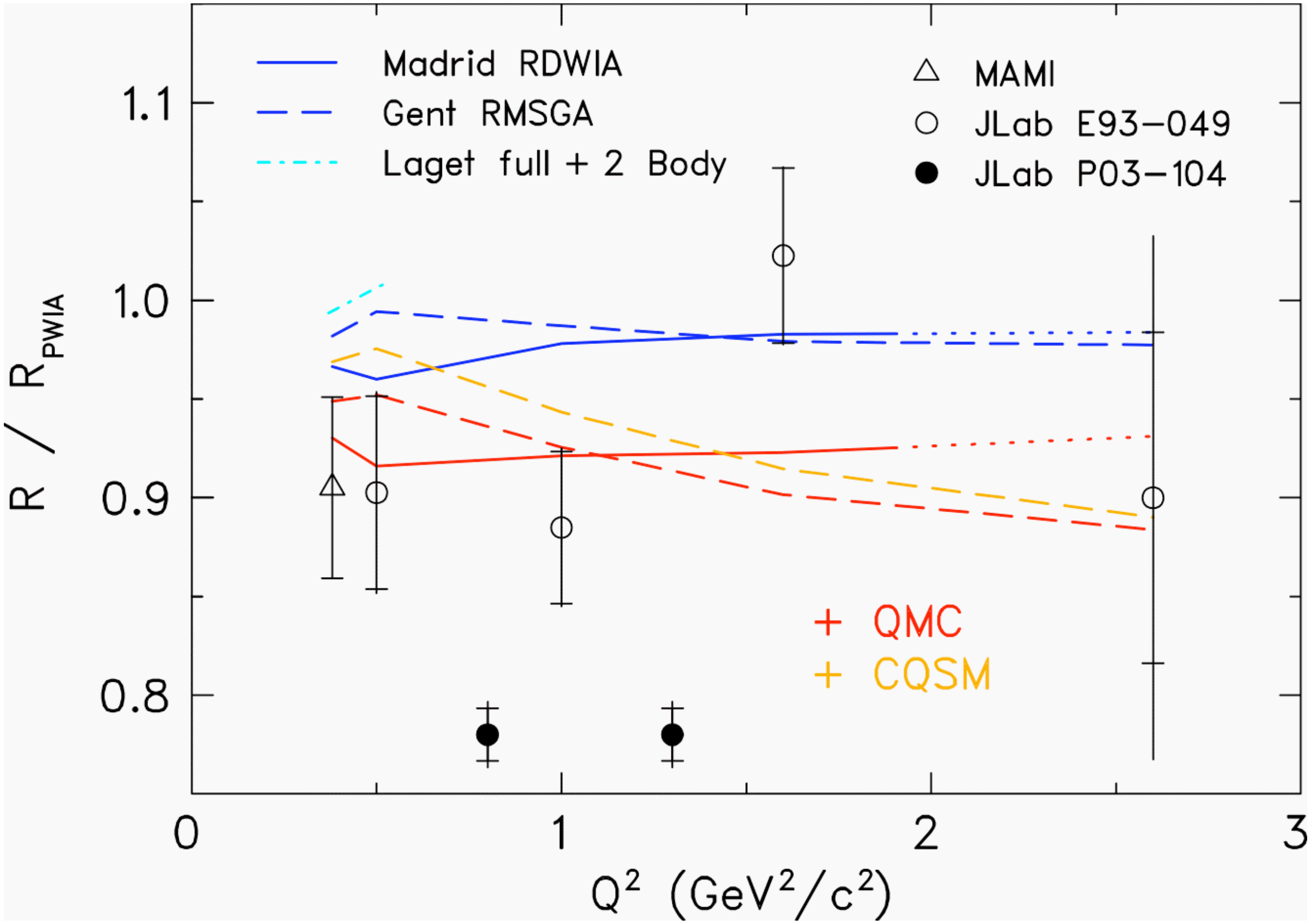
- Data needed to understand and correct for false asymmetries:
  - $^1H(e,e'p)$
  - $^4He(e,e'p)$
  - $^1H(e,\pi)$: possible option

E03-104: Run Plan

Q^2 (GeV^2/c^2)	**Run Plan**	**Time (d)**
0.8	He, H Production	5
1.3	He, H Production	10
	False Asymmetry studies and Overhead	3
	Total	**18**

- Schedule: October 3 - November 12, 2006
- New 10-cm ^1H and ^4He target cells

E03-104: Projected Results



- New data on polarization-transfer ratio and induced polarization could put conventional model of nuclear physics to rigorous test.

Summary

- Present $^4He(e,e'p)$ recoil-polarization data
  - **Polarization transfer**
    Significant deviation from RDWIA and most microscopic results; effectively described by proton medium modifications; also described by large charge exchange FSI
  - **Induced polarization**
    Crucial to constrain FSI

- Goals of upcoming experiment
  - Obtain high-precision data of polarization-transfer ratio, individual polarization-transfer observables, and induced polarization
  - Put conventional model of nuclear physics to its most rigorous test by providing significantly improved data for this reaction