EFB23
23RD EUROPEAN CONFERENCE ON
FEW-BODY PROBLEMS IN PHYSICS
DEPARTMENT OF MATHEMATICS, AARHUS UNIVERSITY, DENMARK
8TH-12TH AUGUST 2016

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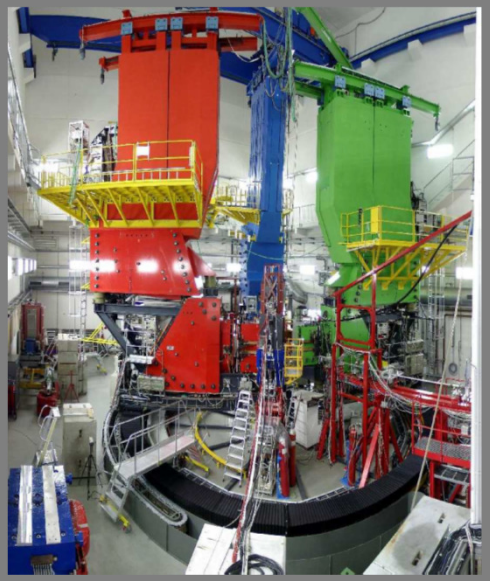
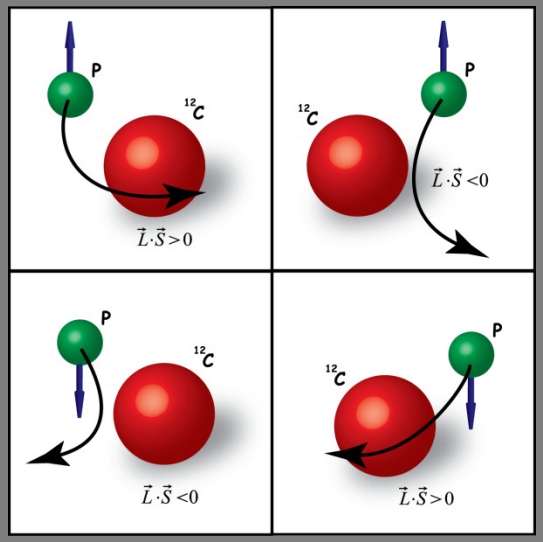
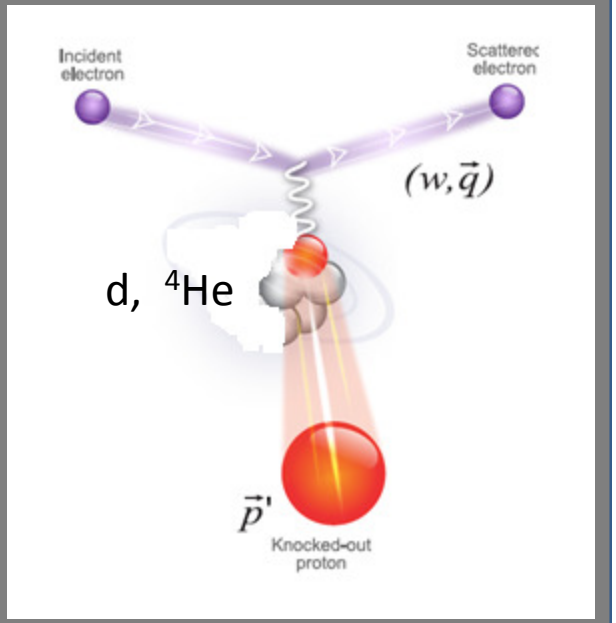
Measurement of polarization transferred to a proton bound in nuclei







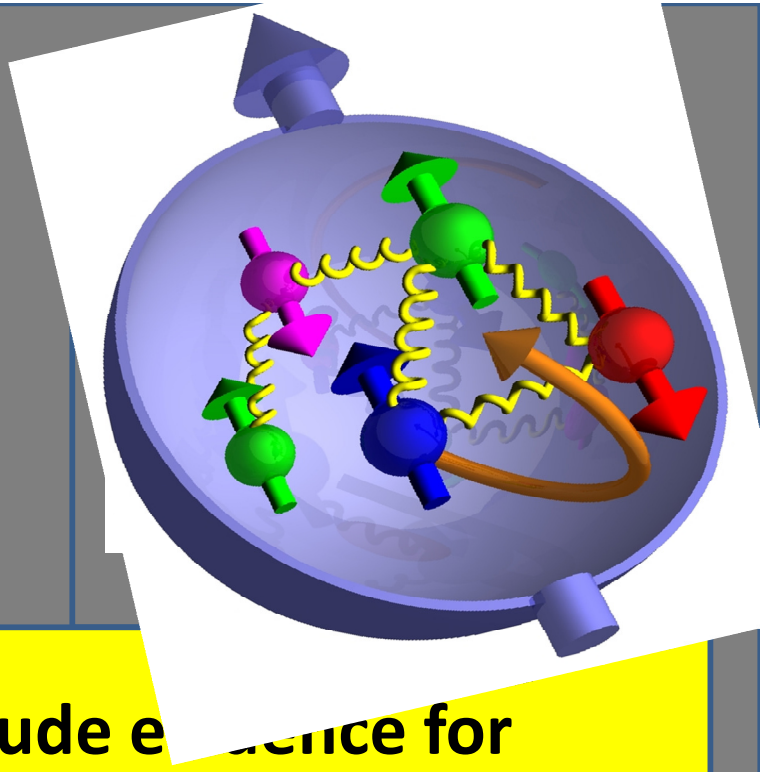
New data from MAMI / A1 (d)
+data from JLab. (^{4}He and d)

Eli Piasetzky
Tel Aviv University, ISRAEL

Nucleons are complex objects .
Are nucleons being modified in the nuclear medium ?

Free neutron

Bound neutron



The challenge is to observe or exclude evidence for changes in the bound nucleon compare to a free one.

Do nucleons change their quark-gluon structure in the nuclear medium ?

DIS

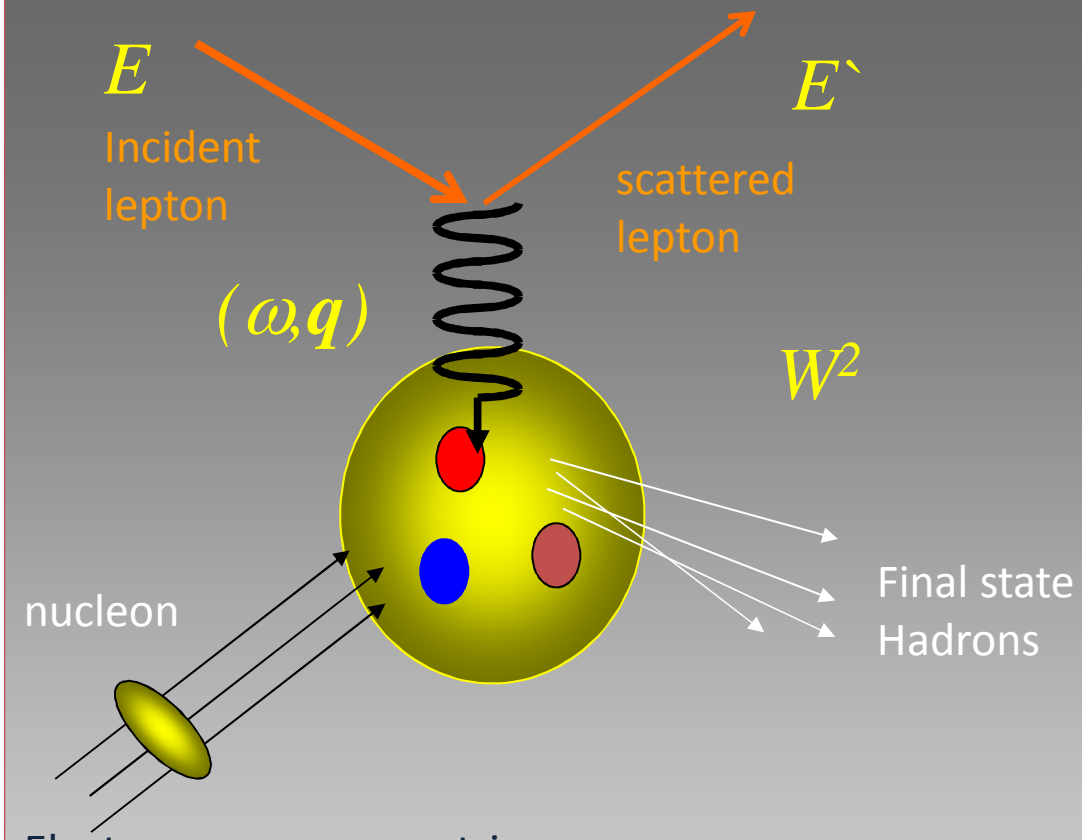
Structure Function
In-Medium vs. Free

Do nucleons change global properties (radius, mass ...) ?

QE

Form Factors
In-Medium vs. Free

Deep Inelastic Scattering (DIS)



$$Q^2 = -q_\mu q^\mu = q^2 - \omega^2$$

$$\omega = E' - E$$

$$x_B = \frac{Q^2}{2m\omega} \qquad (= \frac{Q^2}{2(q \cdot p_T)})$$

$$0 \le x_B \le 1$$

SLAC, CERN, HERA, FNAL, JLAB

E, E' 5-500 GeV

Q^2 5-50 GeV^2

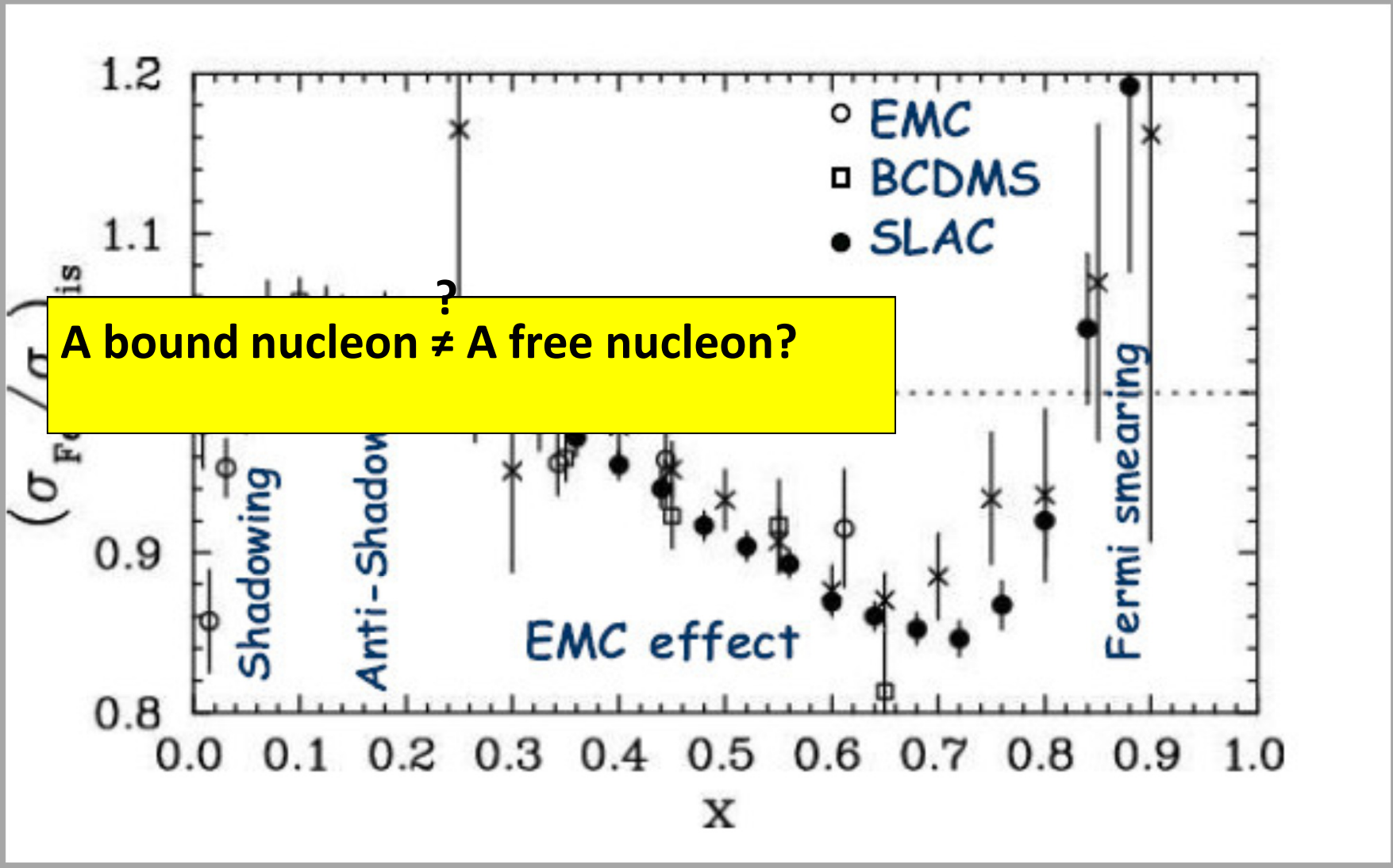
w^2 >4 GeV^2

$0 \le X_B \le 1$

X_B gives the fraction of nucleon momentum carried by the struck parton

Information about nucleon vertex is contained in $F_1(x,Q^2)$ and $F_2(x,Q^2)$, the unpolarized structure functions

The European Muon Collaboration (EMC) effect



σ^{DIS} per nucleon in nuclei ≠ σ^{DIS} per nucleon in deuteron

PRL 106, 052301 (2011), also PRC 85 047301 (2012)

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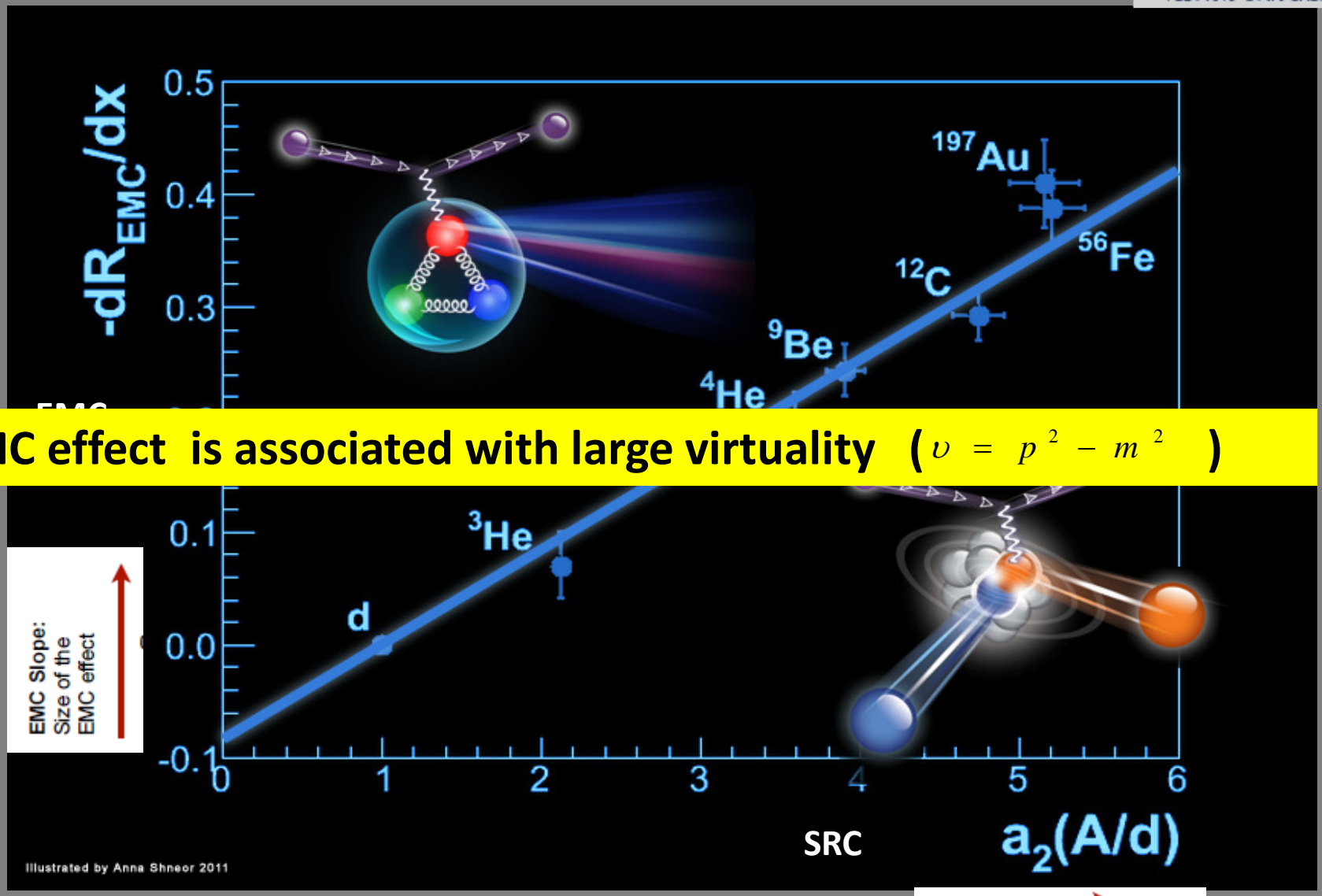

the EMC effect is associated with large virtuality ($\upsilon = p^2 - m^2$)

SRC Scaling Factor: Probability to find SRC pairs (low c.m., high relative momentum) in the nucleus

Is the EMC effect associated with large virtuality ?

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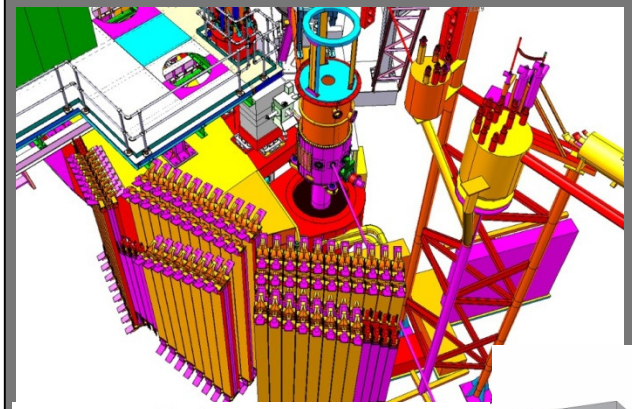
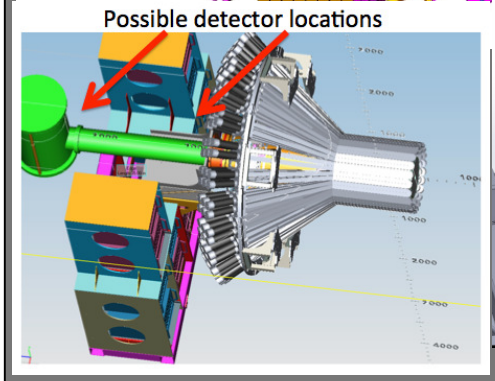
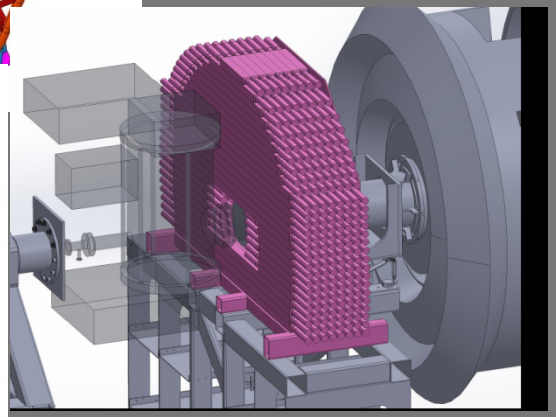
Hypothesis can be verified by measuring DIS off Deuteron tagged with high momentum recoil nucleon

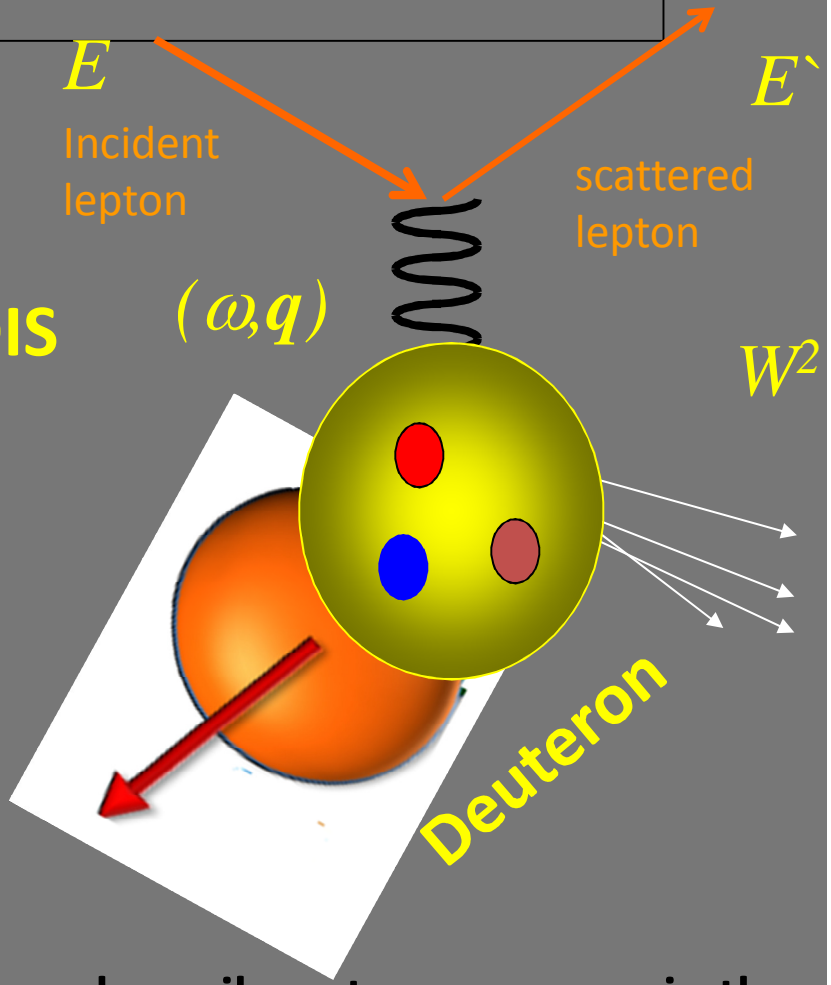
12 GeV JLab/ Hall C approved experiment E 12-11-107

Tagged recoil proton measure neutron structure function









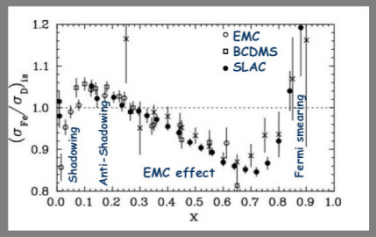
Tagged recoil neutron measure in the proton structure function

12 GeV JLab/ Hall B approved experiment

Change nucleons quark-gluon structure in the nuclear medium ?

DIS → **Structure Function** In-Medium vs. Free

EMC effect



Do nucleons change global properties (radius, mass ...) ?

QE → **Form Factors** In-Medium vs. Free

Fock space decomposition of:

- *FREE* proton

$$|proton\rangle = \alpha_{PLC}|PLC\rangle + \alpha_{3qg}|3q+g\rangle \ldots + \alpha_{3q\pi}|3q+\pi\rangle + \alpha|\ \rangle$$

- *BOUND* proton

$$|proton^*\rangle = \alpha^*_{PLC}|PLC\rangle + \alpha^*_{3qg}|3q+g\rangle \ldots + \alpha^*_{3q\pi}|3q+\pi\rangle + \alpha^*|\ \rangle$$

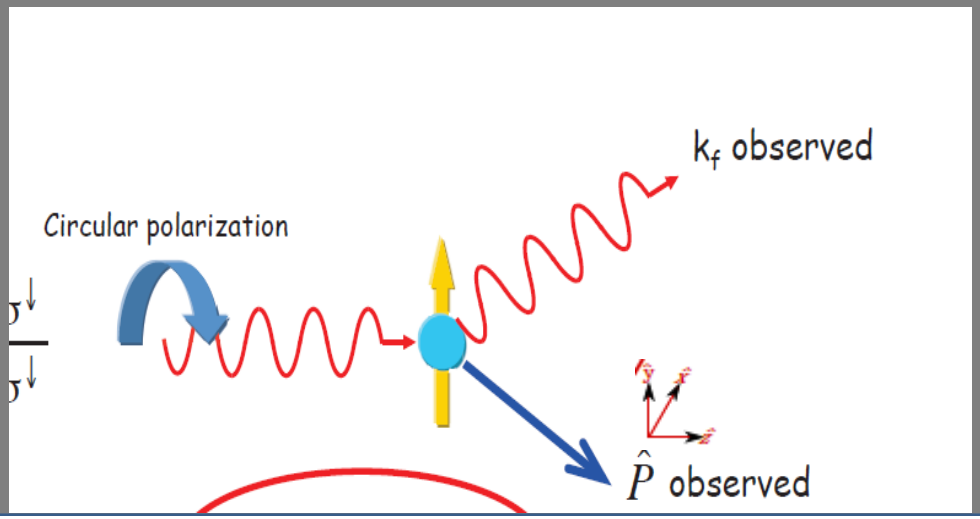
Suppression of PLC → less high momentum (large xB) valance quark
→ larger radius

Deep Inelastic Scattering (DS)

Qasi Free Scattering (QF)

The observable of choice:

The recoil polarization of a knockout proton in quasi-elastic scattering



The observable of choice:

The polarization of the knockout proton in quasi-elastic scattering

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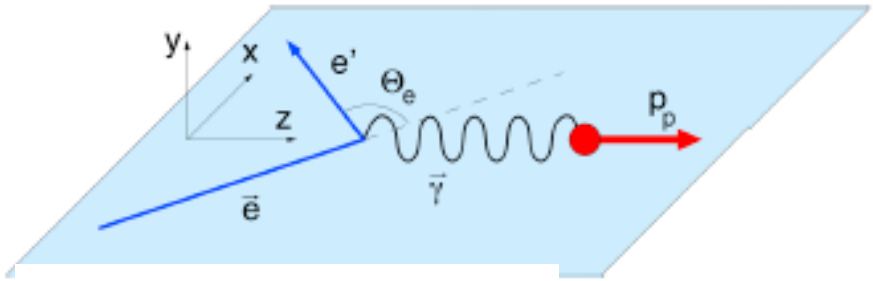
Free proton

$$\frac{G_{Ep}}{G_{Mp}} = -\frac{P'_x}{P'_z}\frac{(E_i + E_f)}{2m}\tan\frac{\theta_e}{2}$$



Bound proton

$$A(\vec{e}, e'\,\vec{p})$$

$$R = \left(\frac{P'_x}{P'_z}\right)_A \Big/ \left(\frac{P'_x}{P'_z}\right)_H$$

*G_{Ep}/G_{Mp}

* obtained from a single measurement with syst. and stat. uncertainties ~1%.

*sensitive to the properties of the nucleon (size, charge dist…

*only moderately sensitive to MEC, IC, FSI.

*Minimal affected by radiative corrections.

The polarization of the knockout proton in quasi-elastic scattering

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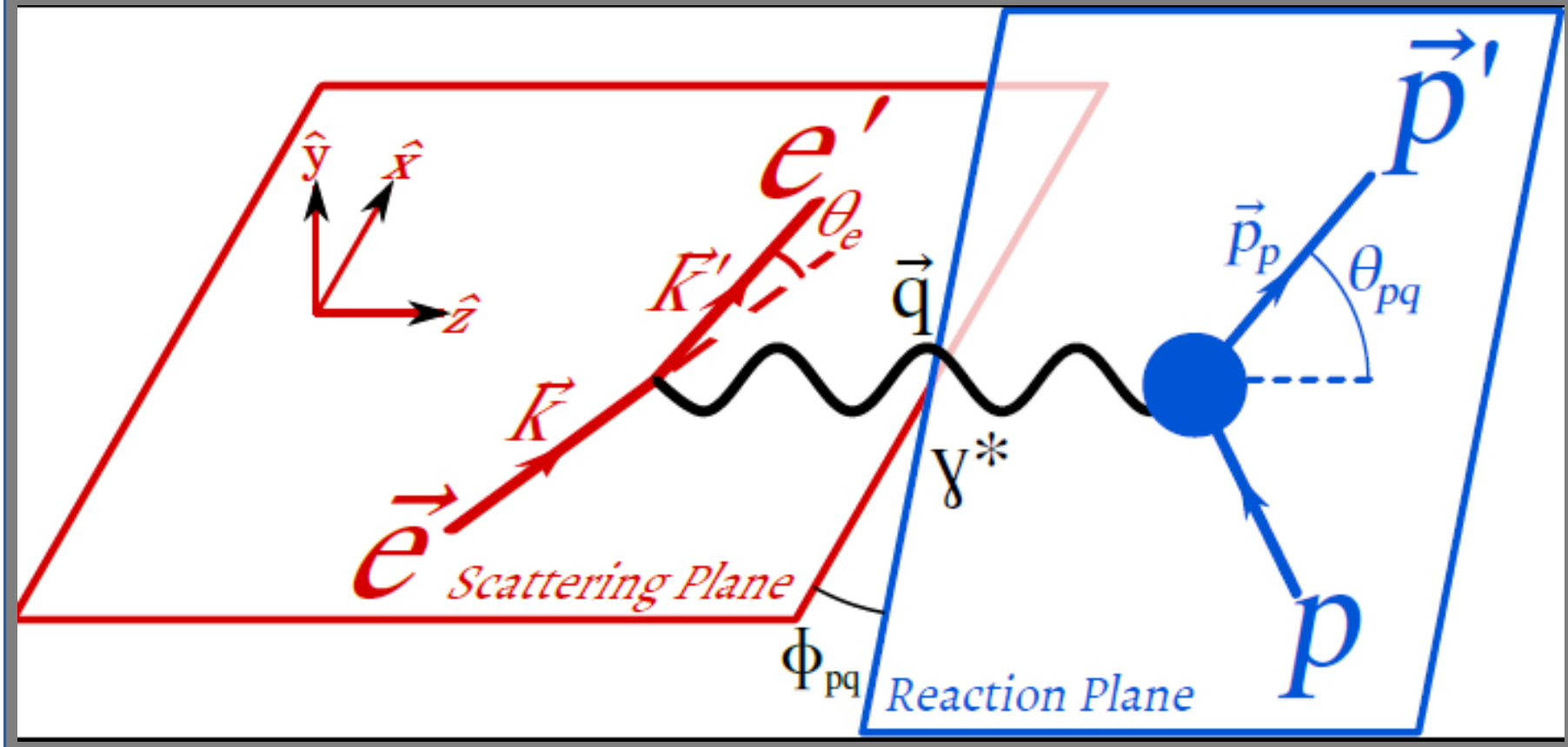
$$A(\vec{e}, e' \vec{p})$$



$^4He(\vec{e},e'\vec{p})$ Px/Pz polarization transferred ratio

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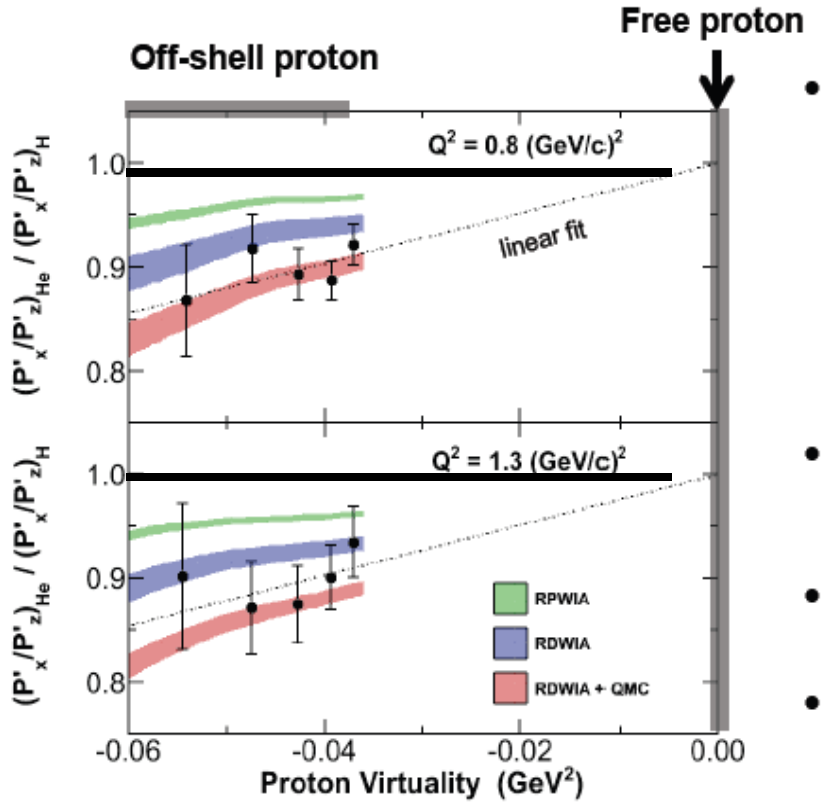
QF ^{4}He ≠ free proton
≠ calc. with free FF

Jlab E03-104 Data



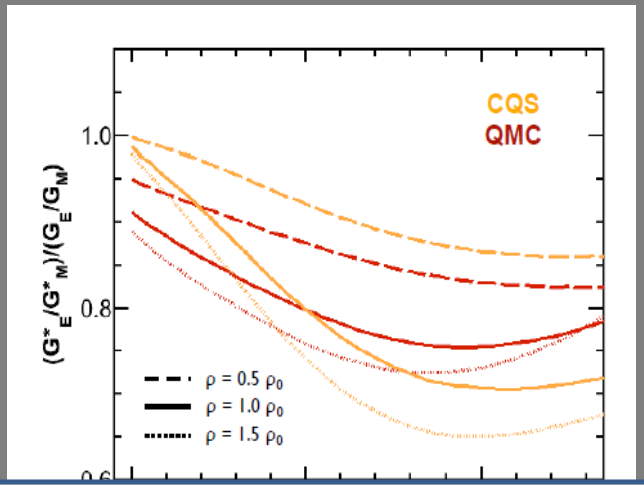
Calculations by the Madrid group
see: C. Ciofi degli Atti, L.L. Frankfurt, L.P. Kaptari, M.I. Strikman, Phys. Rev. C **76**, 055206 (2007

S. Dieterich et al. PL B500, 47 (2001).

S. Strauch et al. PRL. 91 052301 (2003).

M. Paolone et al. PRL. 91 052301 (2003).

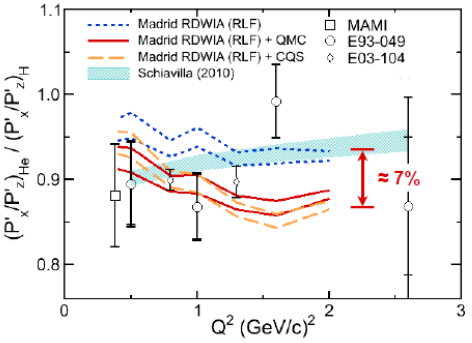
Can be explained by:
Medium FF≠ Free



CQS: Chiral Quark Soliton

QMC: Quark Meson Coupling

CQS: J.R. Smith and G.A. Miller, Phys. Rev. C **70**, 065205 (2004)
QMC: D.H. Lu et al., Phys. Lett. B 417, 217 (1998)



Also proposed
SCX FSI
R. Schiavilla (2010)

$^4He(\vec{e},e'\vec{p})$ **Px/Pz polarization transferred ratio**

bound nucleon ≠ free nucleon

$$R = \left(\frac{P'_x}{P'_z}\right)_A \Big/ \left(\frac{P'_x}{P'_z}\right)_H$$

BUT

If it due to in-medium FF modification

Does it depend on ?

The virtuality (momentum off -shellness) of the nucleon

The local nuclear density

$d(\vec{e},e'\vec{p})$

$^{12}C(\vec{e},e'\vec{p})$

s- and p- shell removal

Use a large-virtuality bound proton in the deuteron

MAMI / A1

$$d(\vec{e},e'\vec{p})$$

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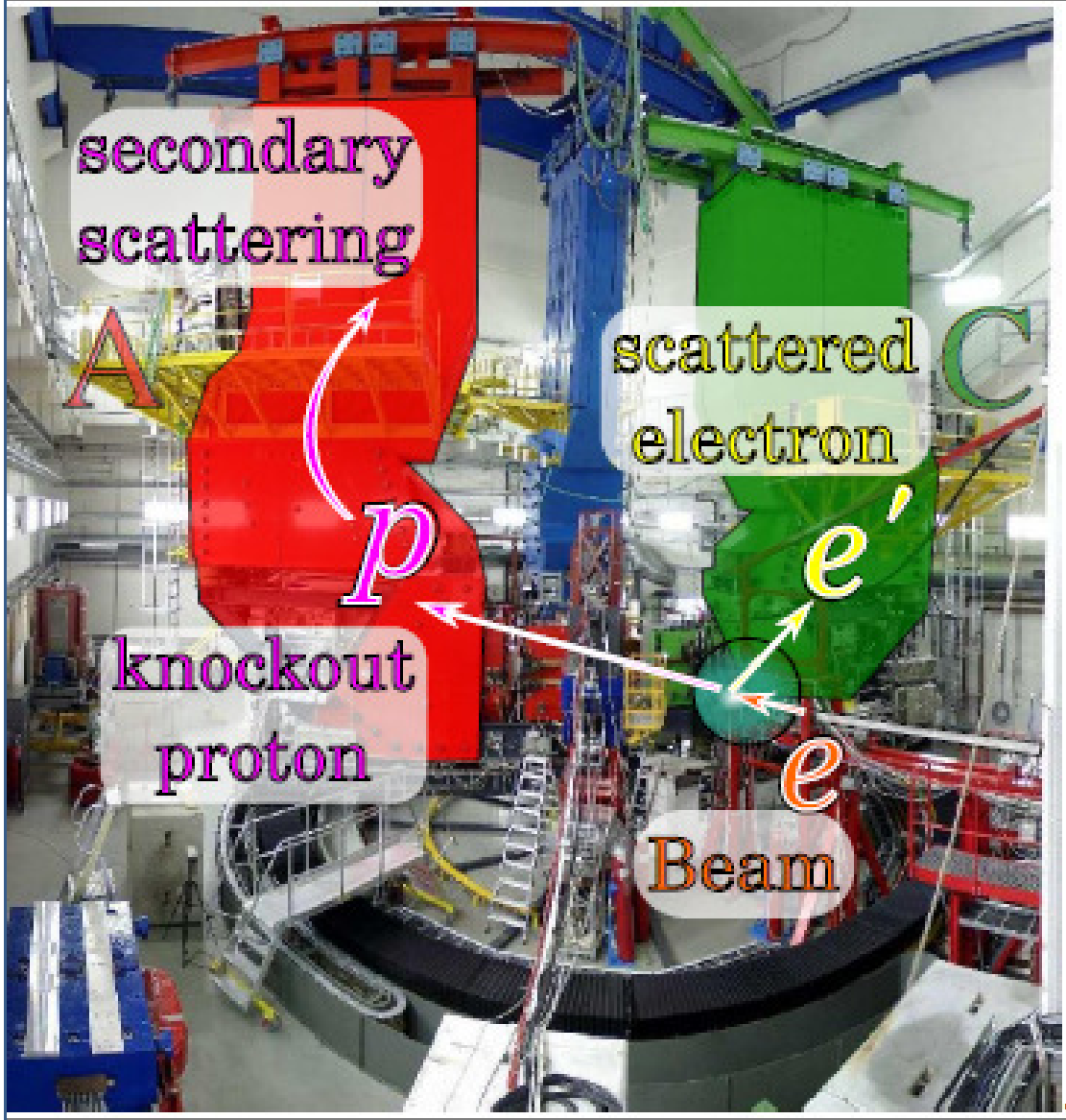
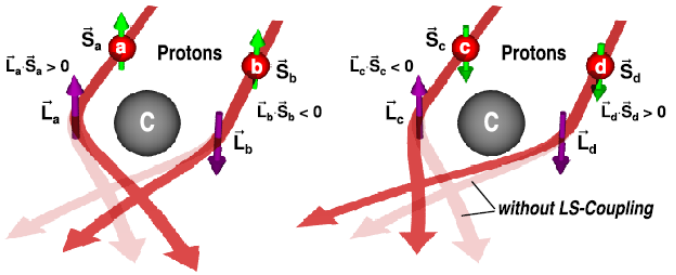
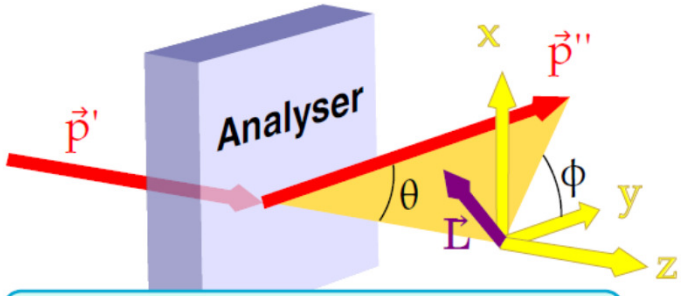
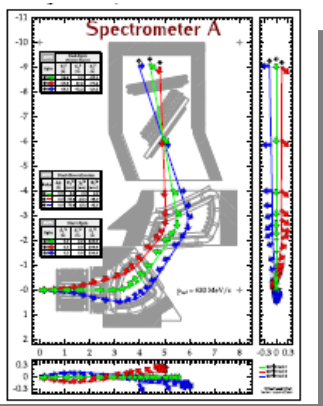


Polarization-transfer Measurement





$$f(\phi) \propto 1 \pm A_C P_\rho \cos(\phi - \phi_0)$$



MAMI / A1 June –July 2012

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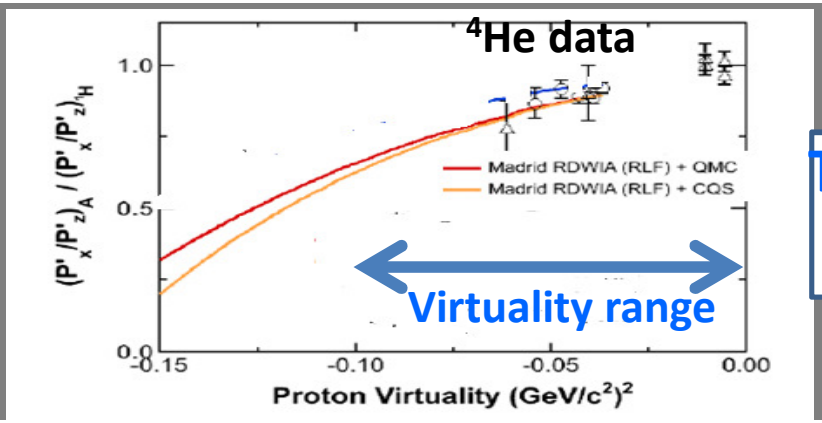
$d(\vec{e},e'\vec{p})$ data

Setup Name	Q^2 $[(\mathrm{GeV}/c)^2]$	B/C (e')	Pmiss [MeV/c]	P_e [MeV/c]	θ_e [deg]	P_p [MeV/c]	θ_p [deg]	Nx $[10^6]$	Events $[10^6]$
K30_H	0.4	C	0	384	82.4	668	-34.7	9	32
K30	0.4	C	0	384	82.4	668	-34.7	9	21
K18	0.4	C	150	462.8	73.8	495	-43.3	18	74
G90	0.175	C	186	397.6	49.4	665	-39.1	60	191
G91	0.175	B	50	508.6	43.4	484	-53.3	159	245

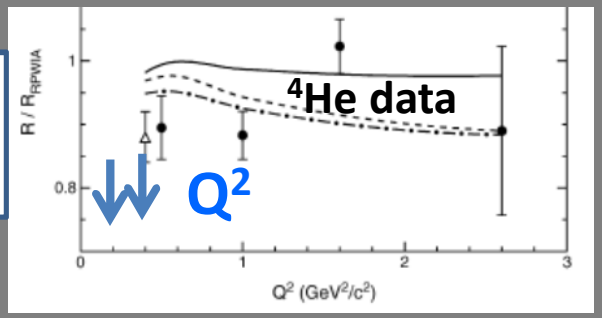
virtuality defined as:

$$\nu \equiv \left(M_A - \sqrt{M_{A-1}^2 + p_{\mathrm{miss}}^2}\right)^2 - p_{\mathrm{miss}}^2 - M_p^2$$

$$\vec{p}_{\mathrm{miss}} = \vec{q} - \vec{p}_p,$$



This experiment



Px/Pz polarization transferred ratios

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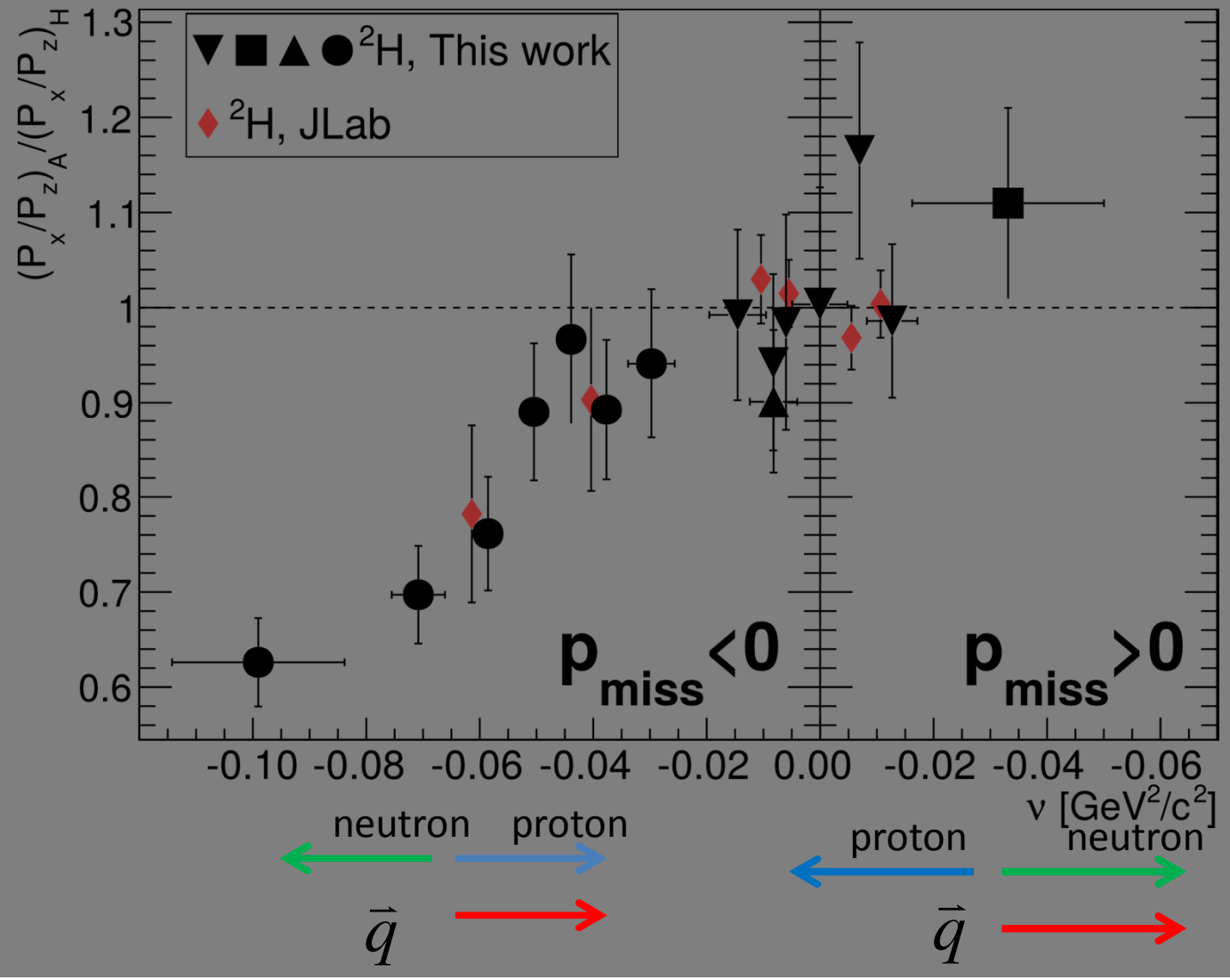
* **Deuteron QF ≠ free**
* **Strong virtuality dependence**
* **No Q^2 dependence**

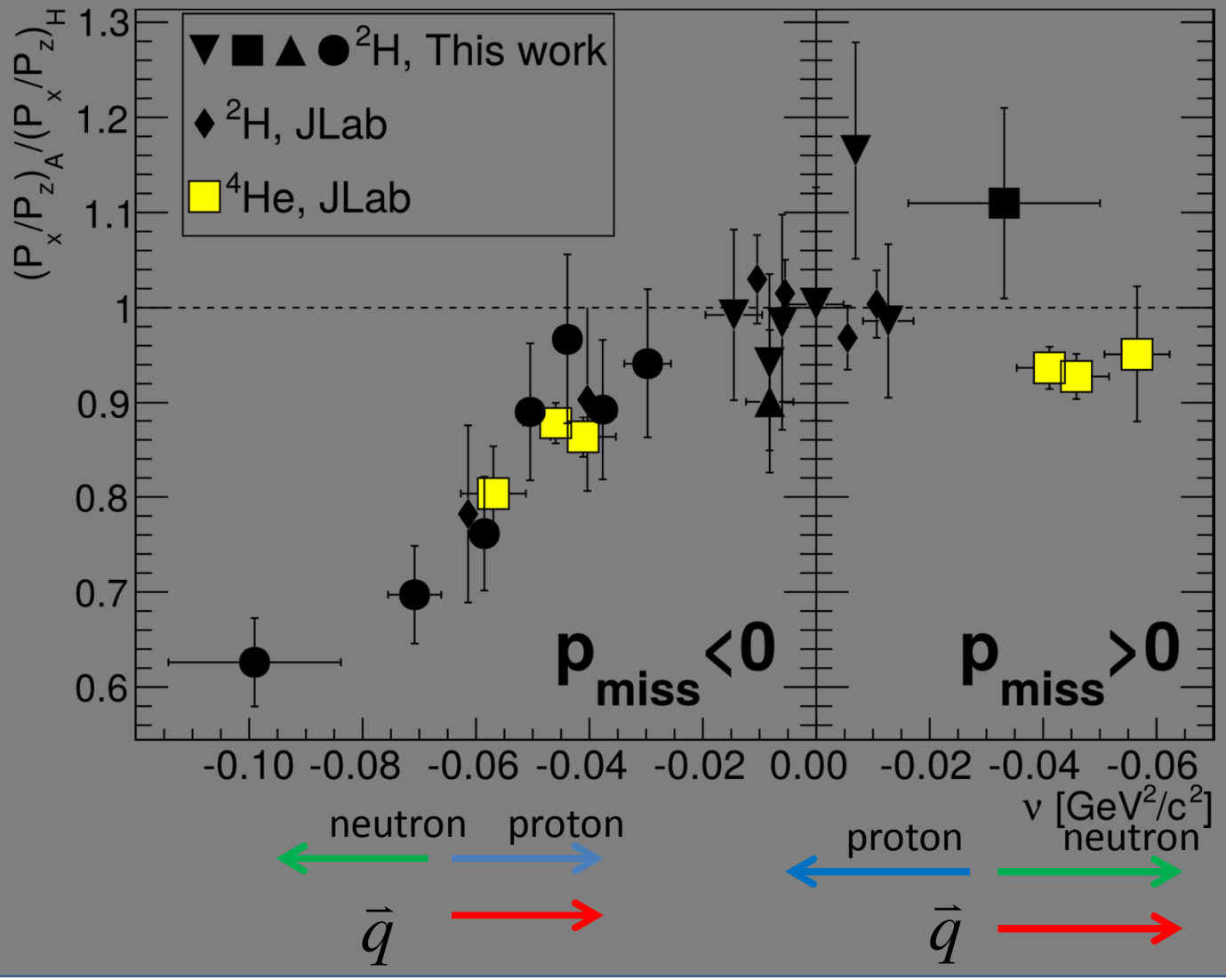
JLab (Hu et al.) Q^2=, 0.43 1.00

MAINZ Q^2= 0.175, 0.4

[(GeV/c)^2]



No Nuclear density (B.E.) dependence !

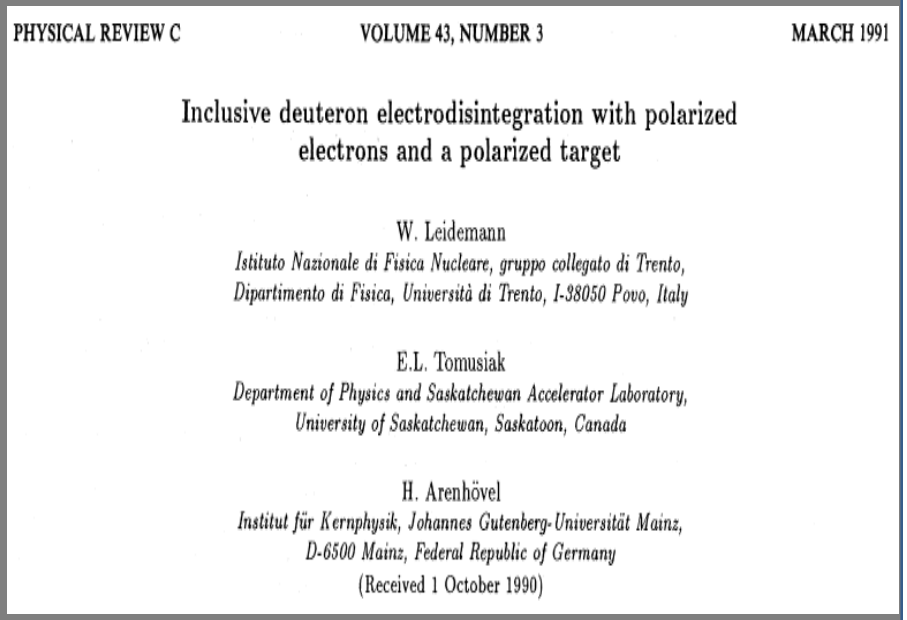


Compare to calculations with free FFs

H. Arenhovel (7 models)

1. NORMAL (DWIA)
2. PWBA
3. NORMAL+MEC
4. NORMAL+MEC+IC
5. NORMAL+REL
6. PWBA (RC)
7. NORMAL+MEC+IC+REL

For each bin the calculation were done for The same kinematical condition as the real data in that bin $f(E', \theta_e, \theta_{pq}, \varphi_{pq})$.



PHYSICAL REVIEW C VOLUME 43, NUMBER 3 MARCH 1991

Inclusive deuteron electrodisintegration with polarized electrons and a polarized target

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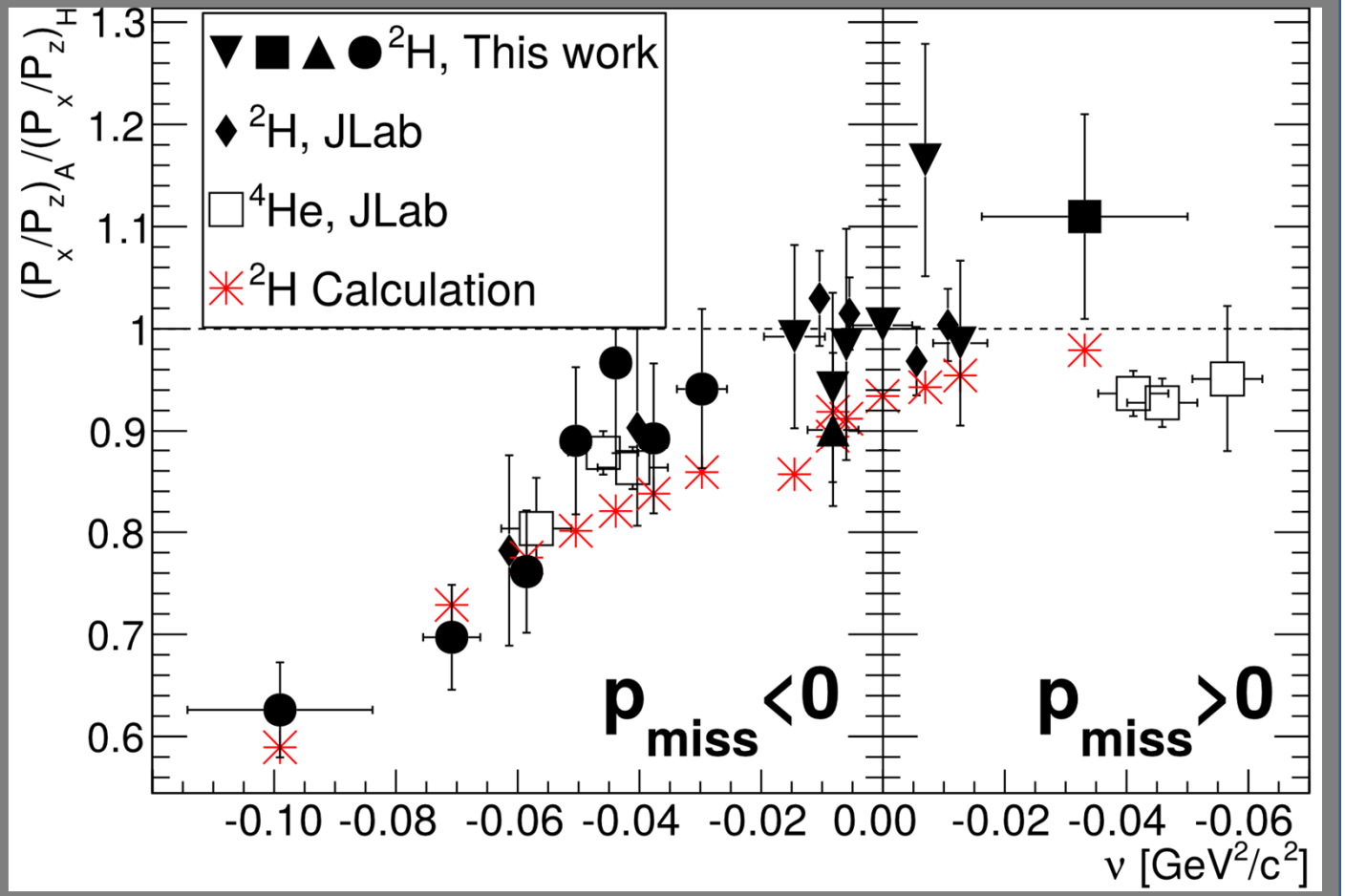
(Received 1 October 1990)

Compare to calculations (free FFs)

- * The virtuality dependence is reproduced by the calculations



neutron proton

$\vec{q}$

proton neutron

$\vec{q}$

What produce the virtuality dependence ?

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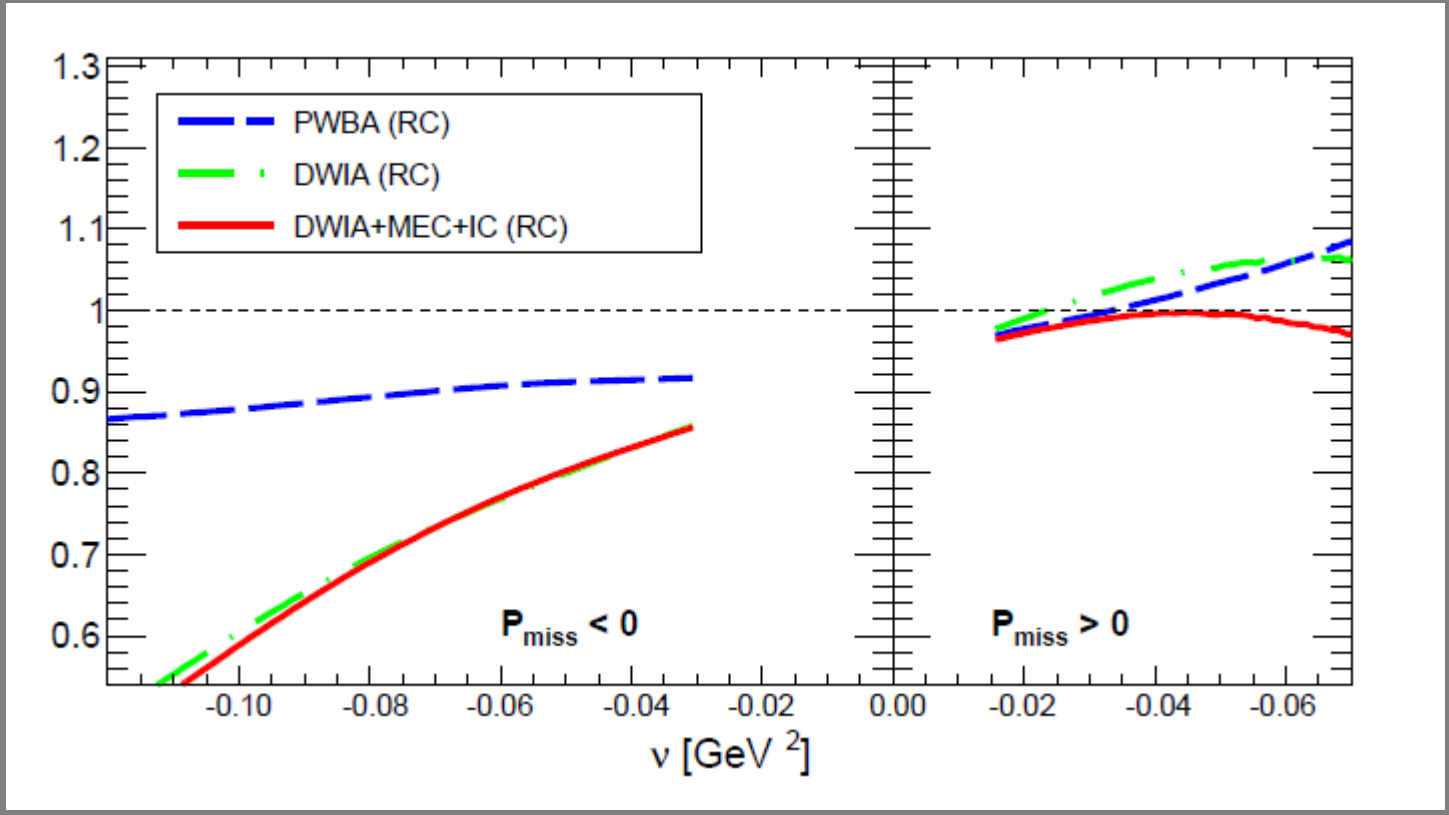
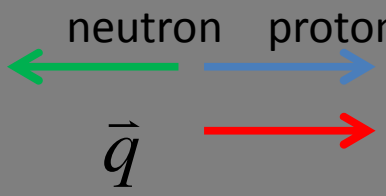
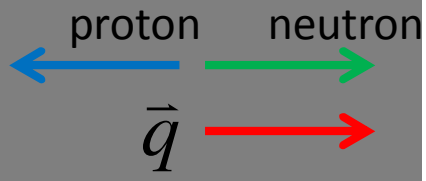
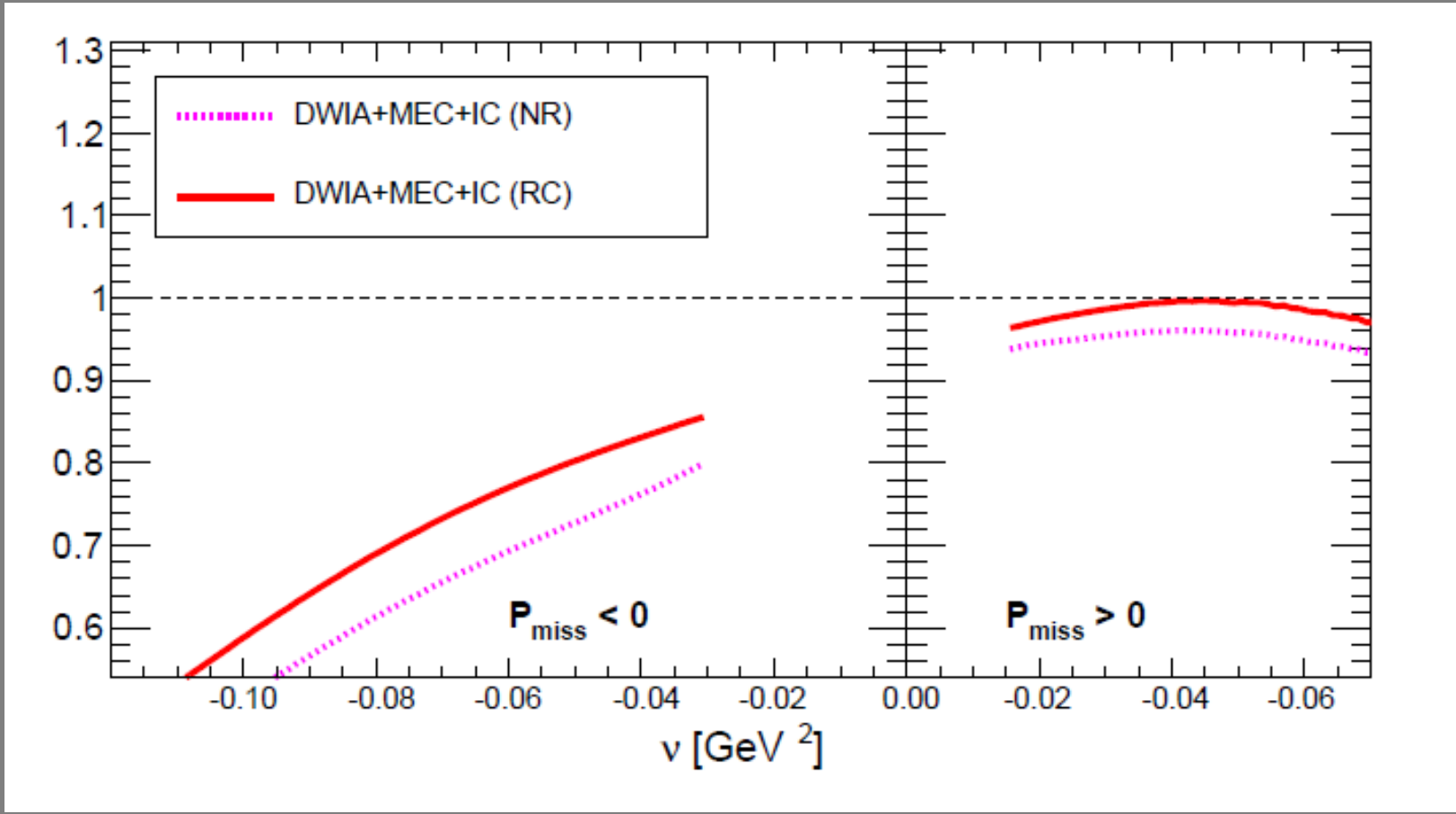
FSI

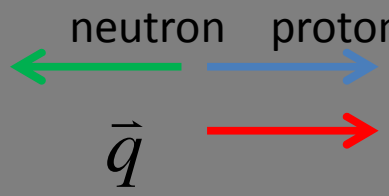


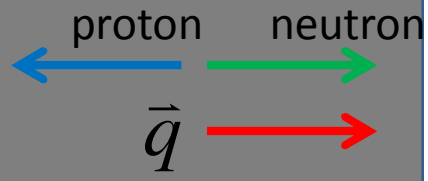




Effect of first order relativistic correction:





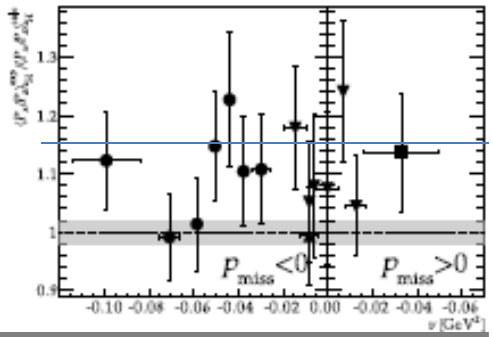


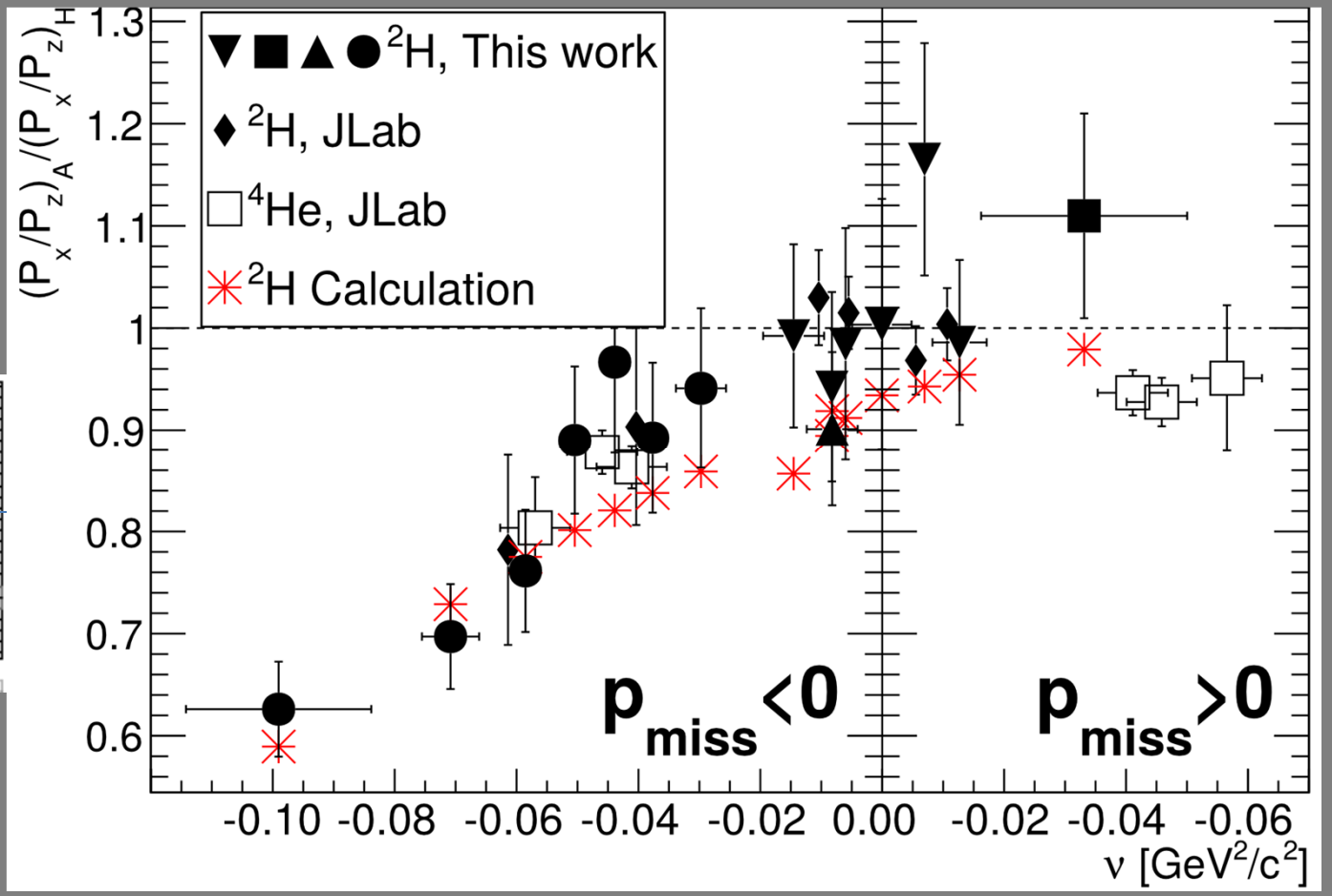
Compare to calculations (Free FFs)

* **Calculation with FF are below the data**

- **Why ?**

$1.100 \pm 0.025 \quad \chi^2 = 0.63$





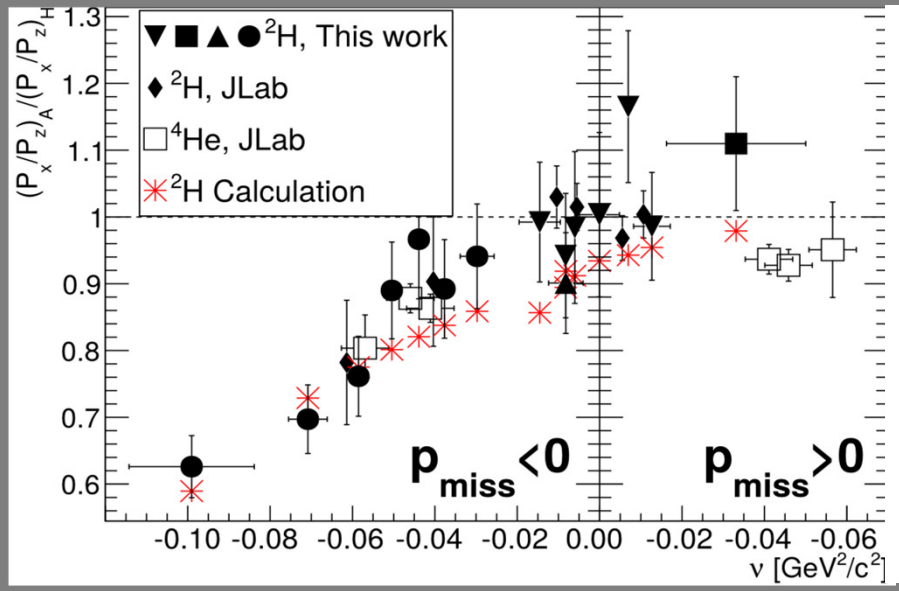
neutron proton

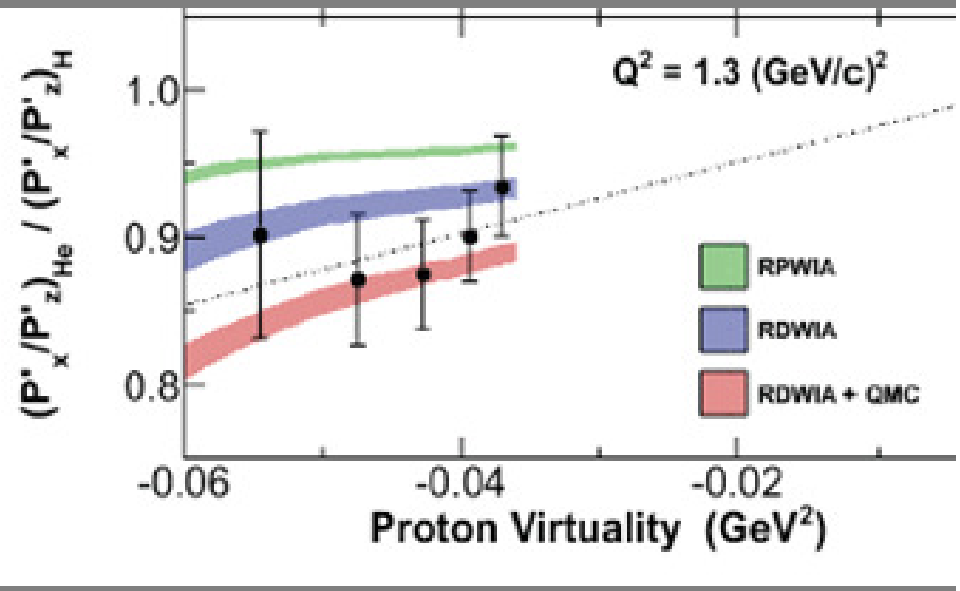
$\vec{q}$

proton neutron

$\vec{q}$

Compare to Free FFs calculations





- **Calculation < data**
- **Calculations > data**

- **10 % is a large deviation !**
- **Changing NN potential AV18→Bonn**
- **Changing FFs shape to dipole**
- **Changing FFs for free proton and neutron**
- **(within measured)unceratinties**

1-2 %

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Dependent on nuclear local density:

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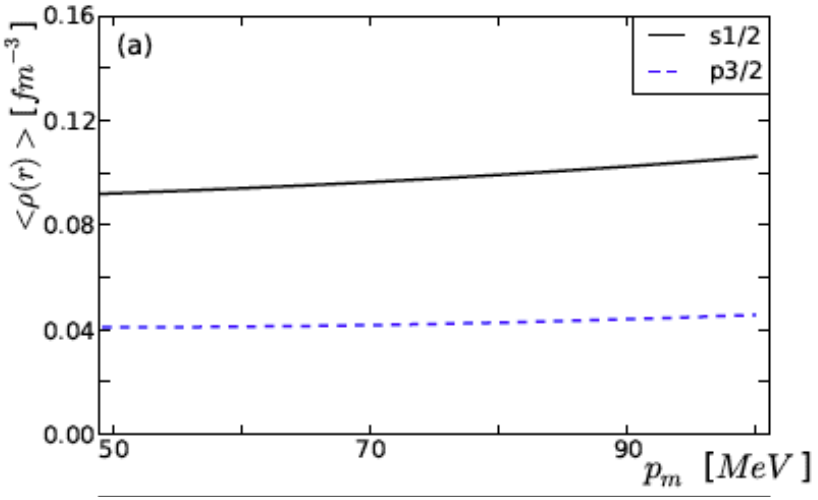
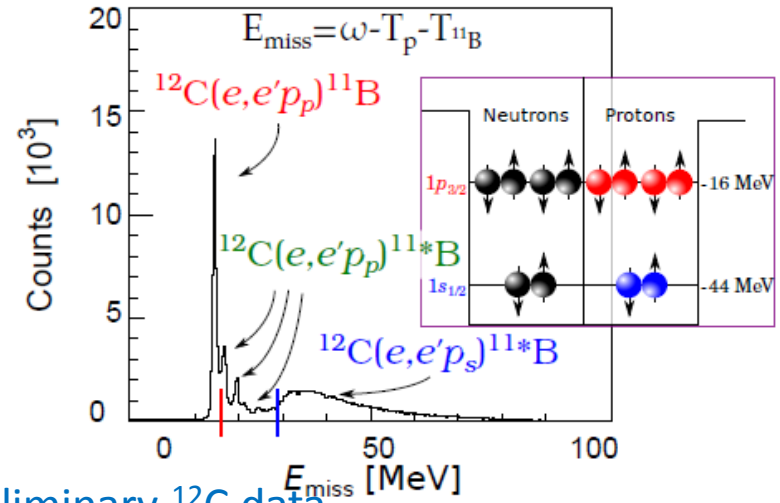
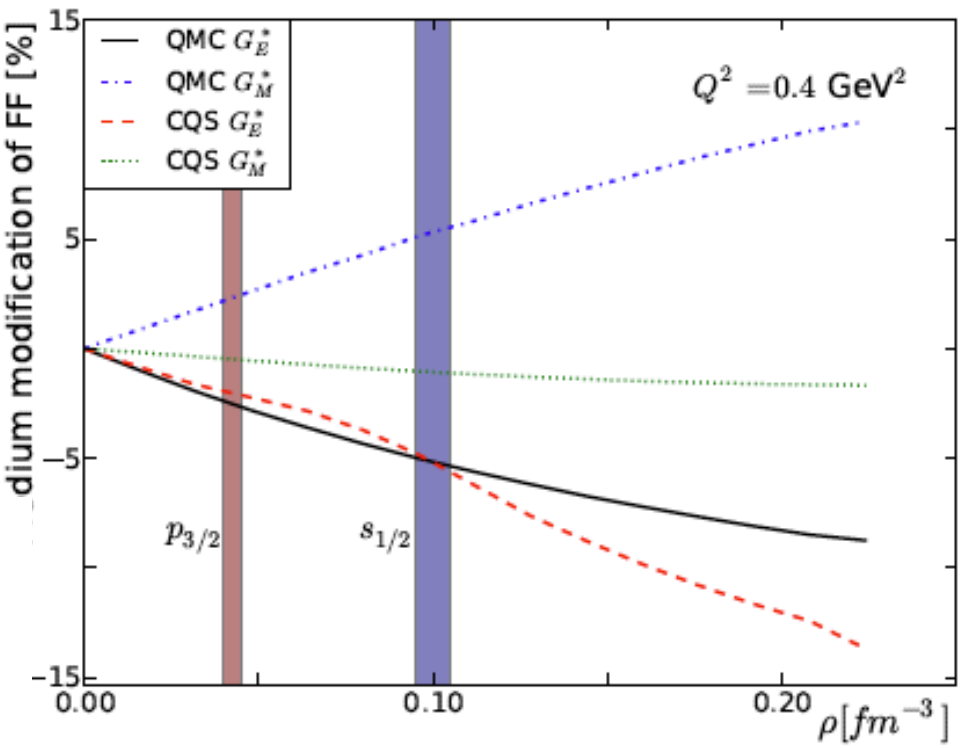
Ron, Cosyn, Piasetzky, Ryckebusch, Lichtenstat, PRC87,028208 (2013).

$^{12}C(\vec{e},e'\vec{p})$ s- and p- shell removal

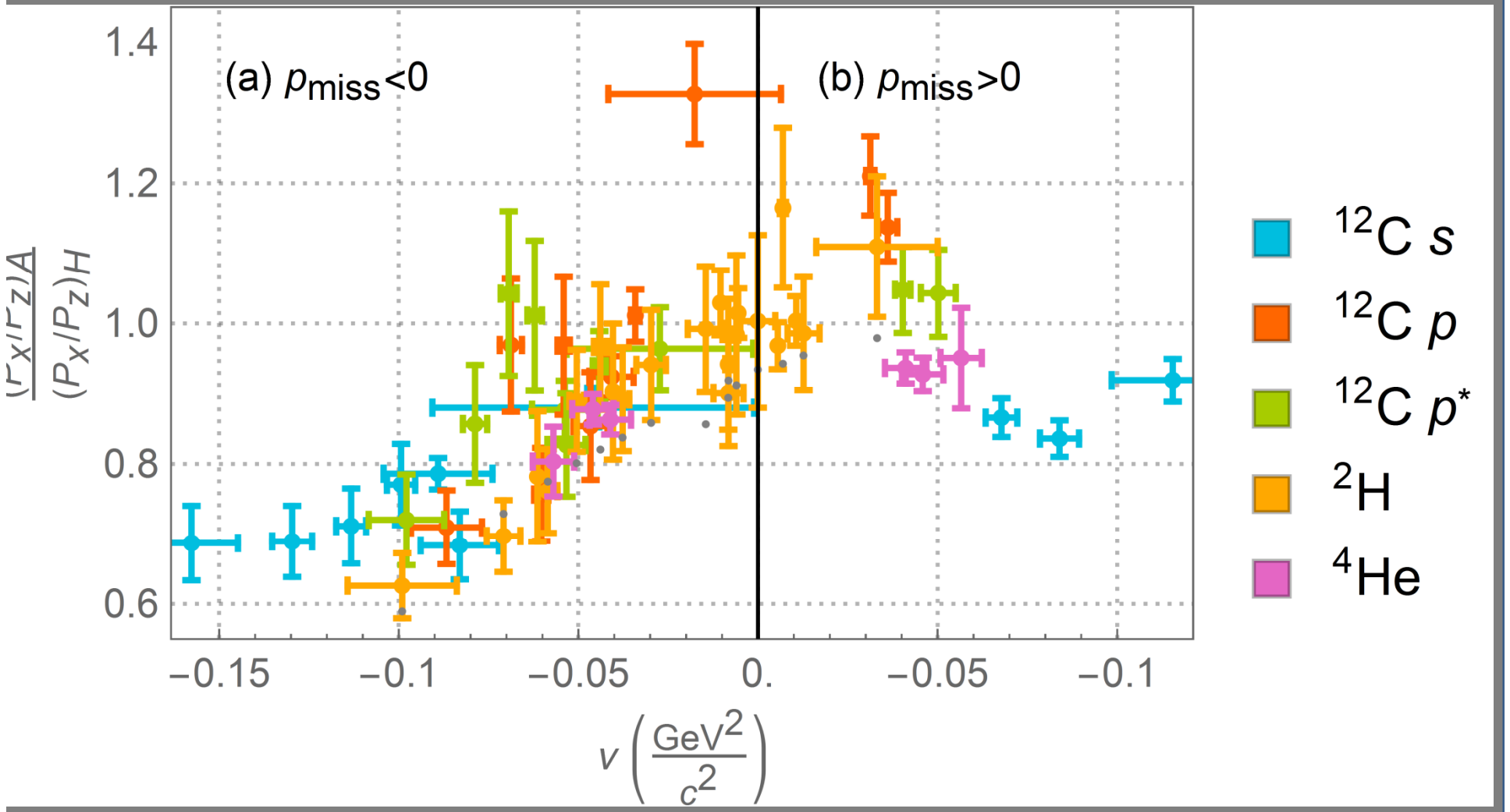






preliminary ^{12}C data

Very preliminary ^{12}C data



neutron proton

$\vec{q}$

proton neutron

$\vec{q}$

More deuteron data for $P_{miss}>0$

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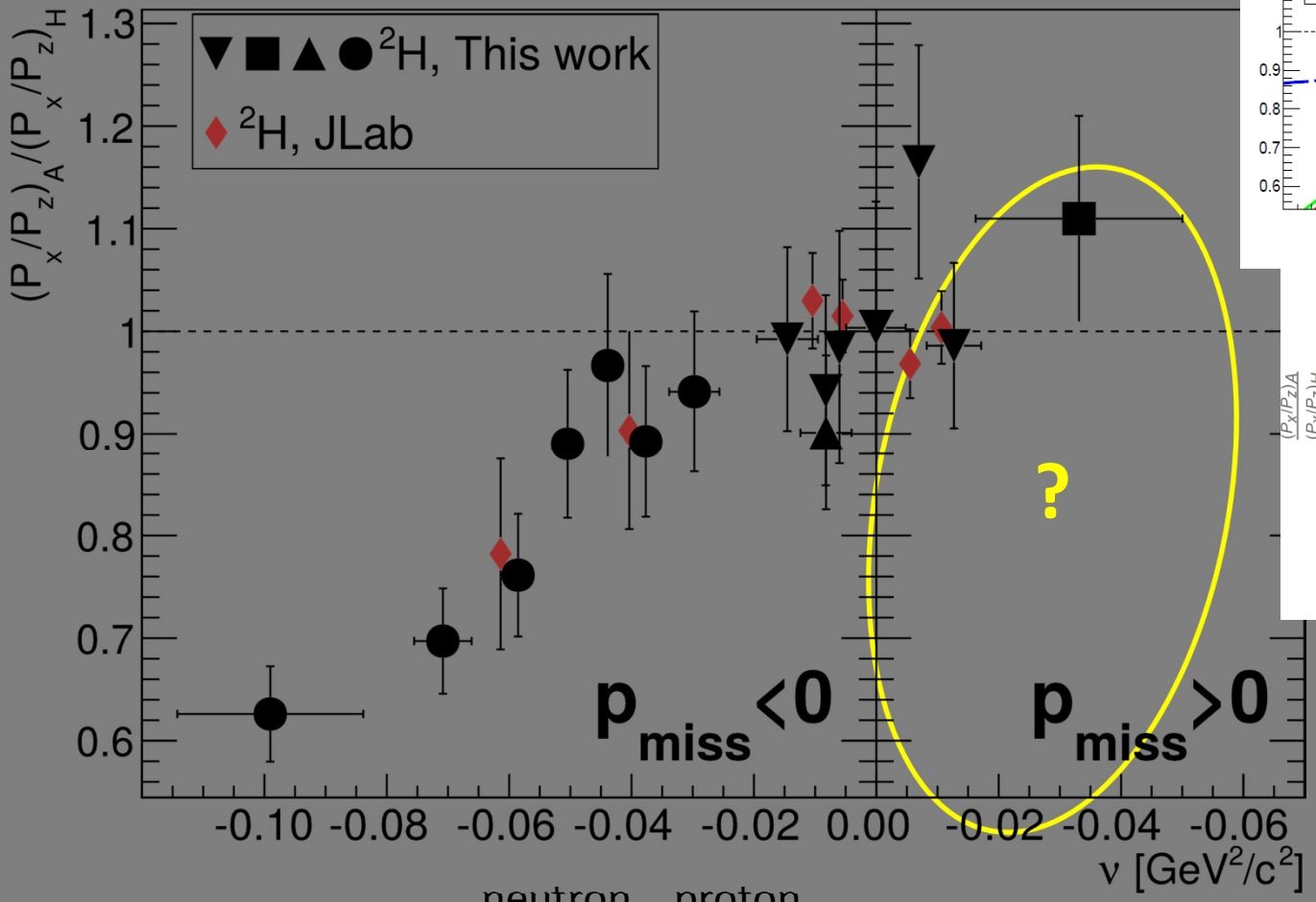
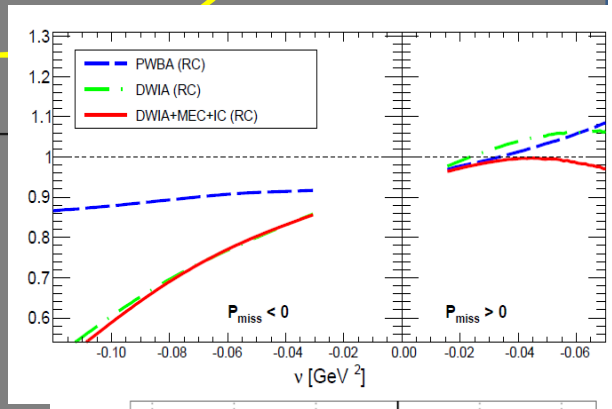
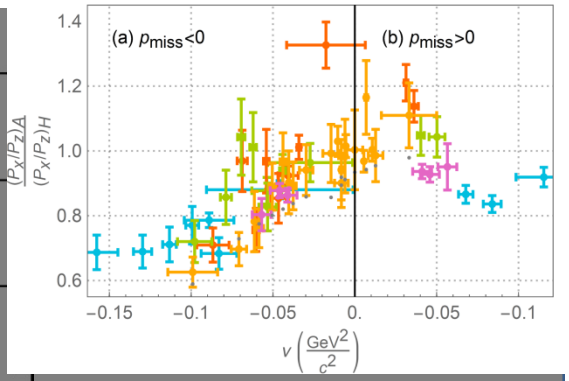
- **July 2016**







neutron proton

$\vec{q}$

proton neutron

$\vec{q}$

Summary

Deuteron QF ≠ free

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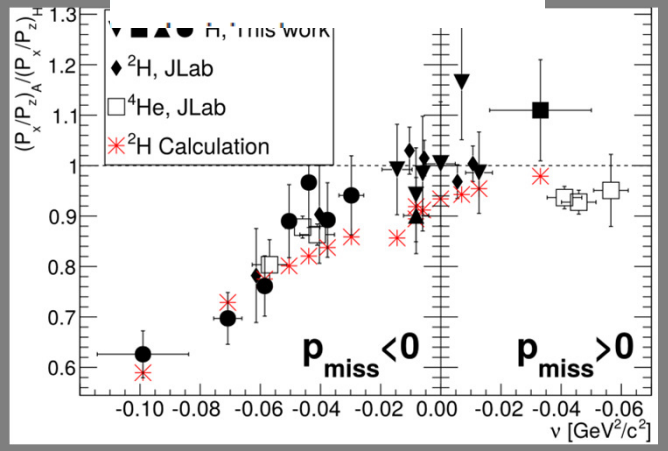
- smooth virtuality dependence.
- no Q^2 – dependence.
- No nuclear density (binding energy) dependence.

$$R = \left(\frac{P'_x}{P'_z}\right)_A \Big/ \left(\frac{P'_x}{P'_z}\right)_H$$



- calculations predicts the smooth virtuality dependence (FSI).
- The calculations are off by an overall 10%.

Why ? Is it a "baryon" or "nuclear" issue ?

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Acknowledgment

Polarization-transfer measurement to a large-virtuality bound proton in the deuteron **Nucl-ex arXiv:1602.06104**

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and the organizers for the invitation.

Dmitri Fedorov