Measurement of polarisation transfer to a bound proton at large virtuality

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55. International Winter Meeting on Nuclear Physics
Bormio, 23.–27. January 2017

Motivation

Do bound nucleons have the same properties as free ones?
Are there any "medium modifications"?

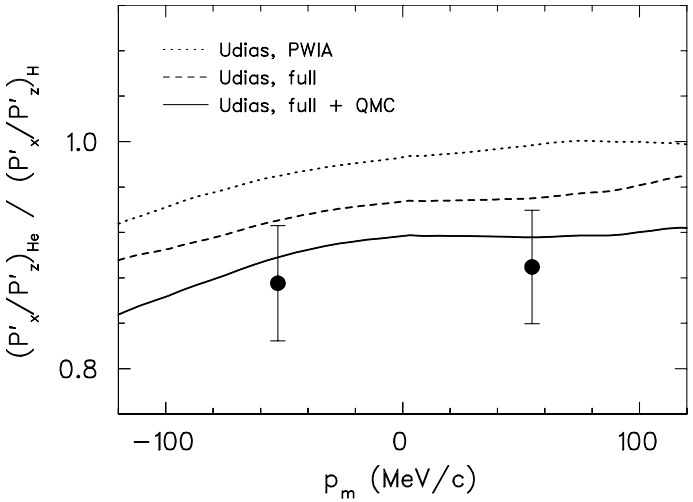
- Influence on electromagnetic form factors G_E and G_M?
- Accessible via polarisation observables
- Measure ratio P_x/P_z of polarisation transfer components for free and bound protons
- (Double) ratio eliminates many systematic uncertainties

Motivation

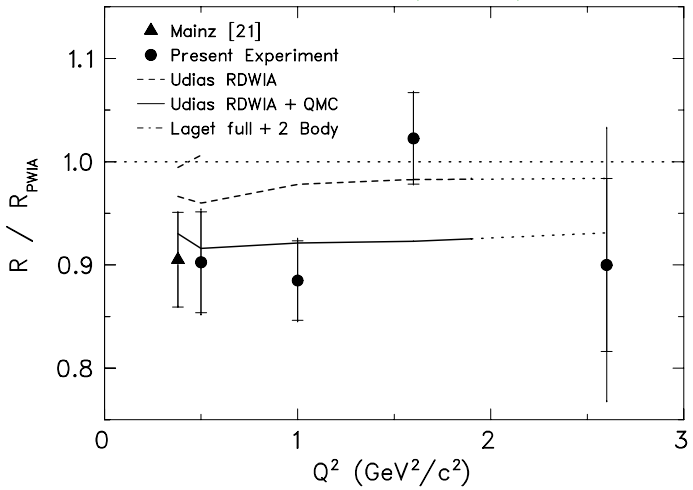
Previous experiments

- $^4\mathrm{He}(\vec{e}, e'\vec{p})^3\mathrm{H}$ reaction previously measured at Mainz and JLab
- Ratio P_x/P_z for protons bound in helium smaller than for free protons
- Attributed to "... medium modification of the proton form factors predicted by a quark-meson coupling model"

Dieterich et al., PLB 500 (2001) 47

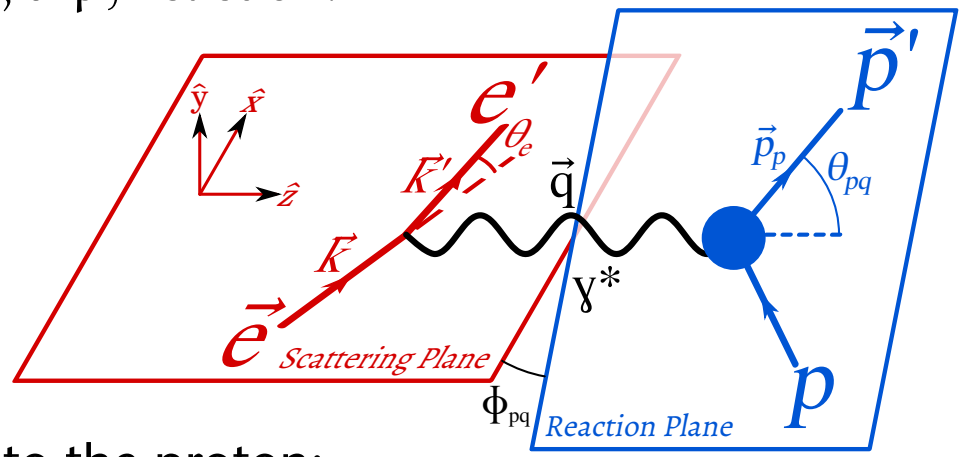


Strauch et al., PRL 91 (2003) 052301



Principle of measurement

Kinematics of the $(\vec{e}, e'\vec{p})$ reaction:



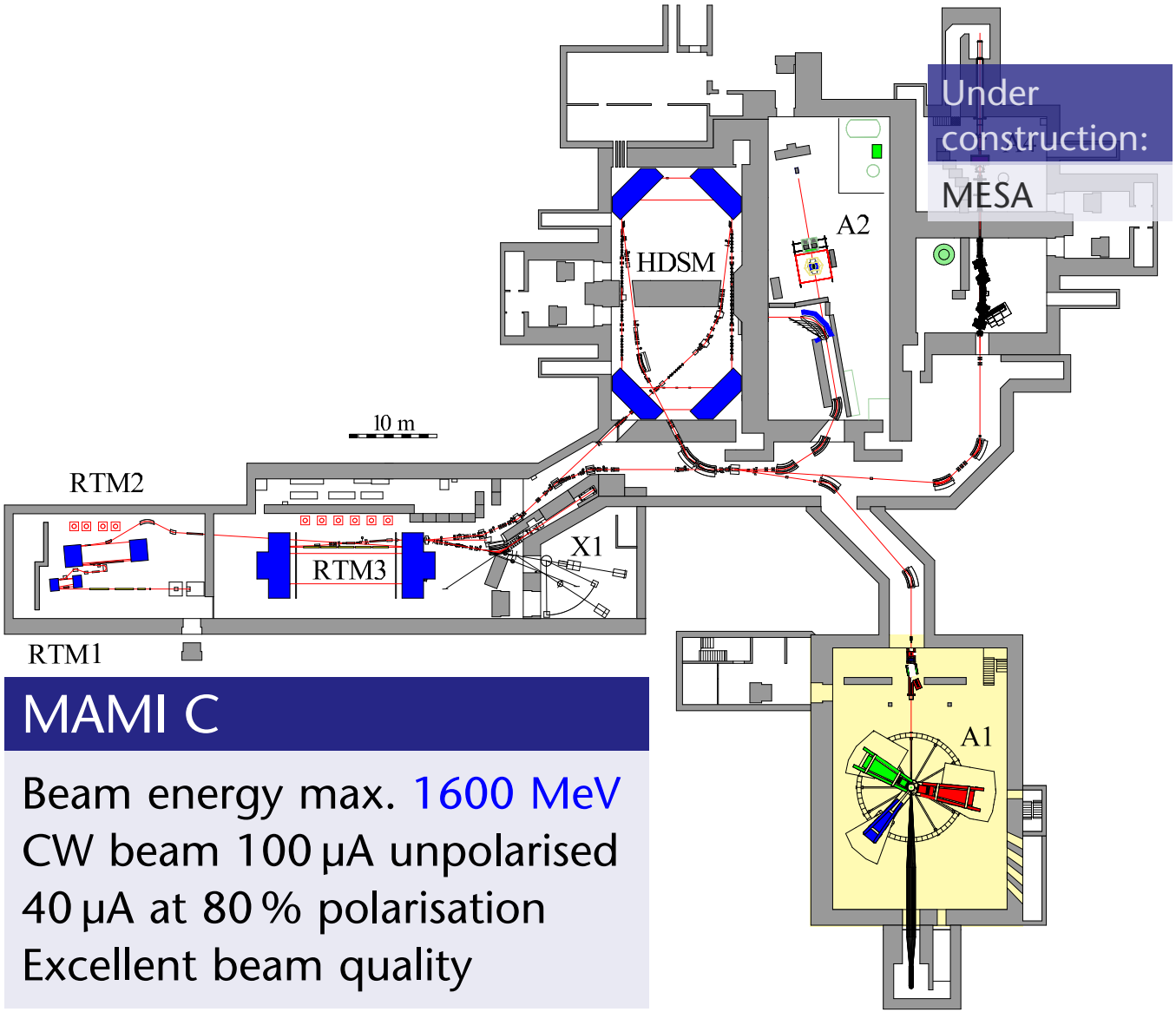
Polarisation transfer to the proton:

Arnold, Carlson, Gross, PRC 23 (1981) 363

$$
\begin{aligned}
P_x &= -P_e \frac{2\sqrt{\tau(1+\tau)}\tan(\theta/2) G_E G_M}{G_E^2 + \tau G_M^2 (1 + 2(1+\tau)\tan^2(\theta/2))} \\
P_y &= 0 \\
P_z &= P_e \frac{2\tau\sqrt{1+\tau+(1+\tau)^2\tan^2(\theta/2)}\tan(\theta/2) G_M^2}{G_E^2 + \tau G_M^2 (1 + 2(1+\tau)\tan^2(\theta/2))}
\end{aligned}
$$

Ratio P_x/P_z proportional to G_E/G_M.

The Mainz Microtron MAMI



MAMI C

Beam energy max. 1600 MeV
CW beam 100 µA unpolarised
40 µA at 80 % polarisation
Excellent beam quality

Three-spectrometer setup of the A1 collaboration

Spectrometer A:

$\alpha > 20°$
$p < 735\,\mathrm{MeV}/c$
$\Delta\Omega = 21\,\mathrm{msr}$
$\Delta p/p = 20\%$
Focal plane polarimeter

Spectrometer B:

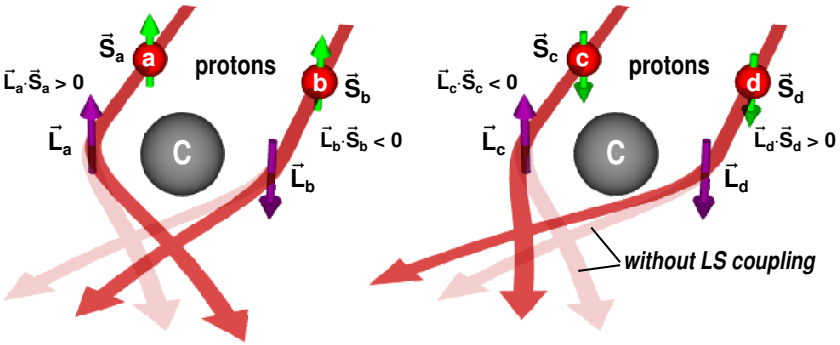
$\alpha > 8°$
$p < 870\,\mathrm{MeV}/c$
$\Delta\Omega = 5.6\,\mathrm{msr}$
$\Delta p/p = 15\%$

Spectrometer C:

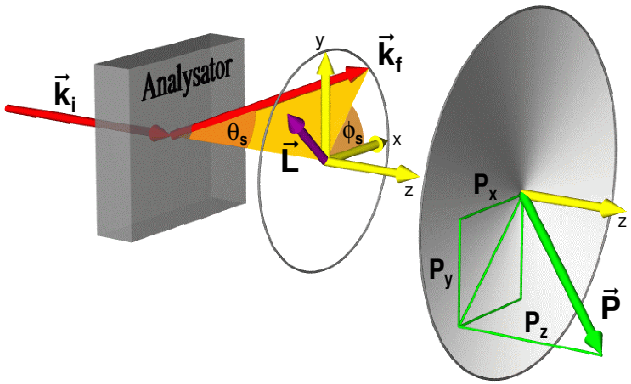
$\alpha > 55°$
$p < 655\,\mathrm{MeV}/c$
$\Delta\Omega = 21\,\mathrm{msr}$
$\Delta p/p = 25\%$

Focal Plane Polarimeter

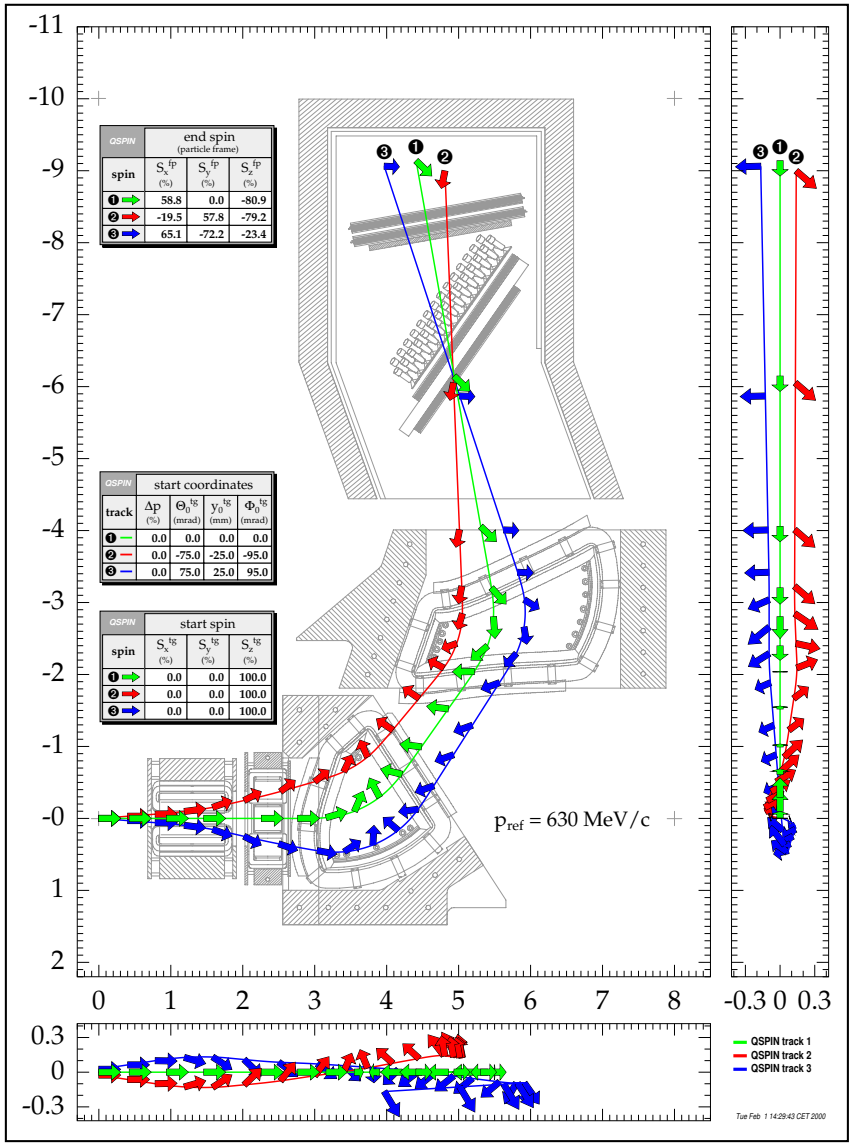
- Scatter polarised proton at ^{12}C nucleus
- Spin-orbit term V_{LS}



- Azimuthal asymmetry:
  $f(\phi) \propto 1 + A(\theta)\cos(\phi - \phi_0)$



- Analysing power for carbon well known
- Spin tracing $\rightarrow$ all 3 pol. components



Deuterium: Experiment

Kinematics:

Setup	E [MeV]	Q^2 [GeV$^2/c^2$]	p_{miss} [MeV/c]	e'	$p_{e'}$ [MeV/c]	$\theta_{e'}$	p_p MeV/c	θ_p	Events after cuts
A	600	0.4	0	C	384	82.4°	668	−34.7°	210 000
B	600	0.4	+150	C	463	73.8°	495	−43.3°	170 000
C	630	0.18	−50	B	509	43.4°	484	−39.1°	2 400 000
D	630	0.18	−186	C	398	49.4°	665	−53.3°	790 000

Missing momentum:

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

Virtuality:

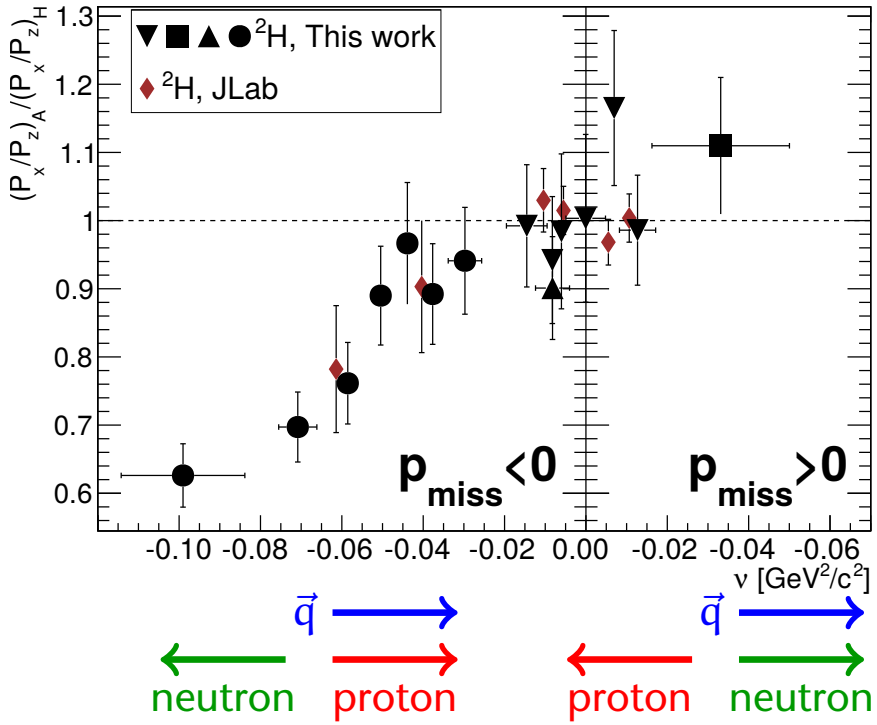
$$\nu = \left(M_A - \sqrt{M_{A-1}^2 + p_{miss}^2}\right)^2 - p_{miss}^2 - M_p^2$$

Virtuality range in this experiment: $\nu = -0.10$ to $0\ (\mathrm{GeV}/c)^2$

Deuterium: Results

Double-ratio $(P_x/P_z)_A \,/\, (P_x/P_z)_p$

- Quasi-free differs from free
- Strong dependence on virtuality
  Depends on sign of p_{miss}
- Good agreement with JLab ^{2}H data
- No Q^2 dependence
  - Mainz: $Q^2 = 0.18,\ 0.4\ (GeV/c)^2$
  - JLab: $Q^2 = 0.43,\ 1.0\ (GeV/c)^2$



^{2}H, JLab: Hu et al., PRC 73 (2006) 064004

A1 collaboration: I. Yaron, D. Izraeli et al., accepted for publication in PLB (2017)

Deuterium: Results

Comparison to ^{4}He

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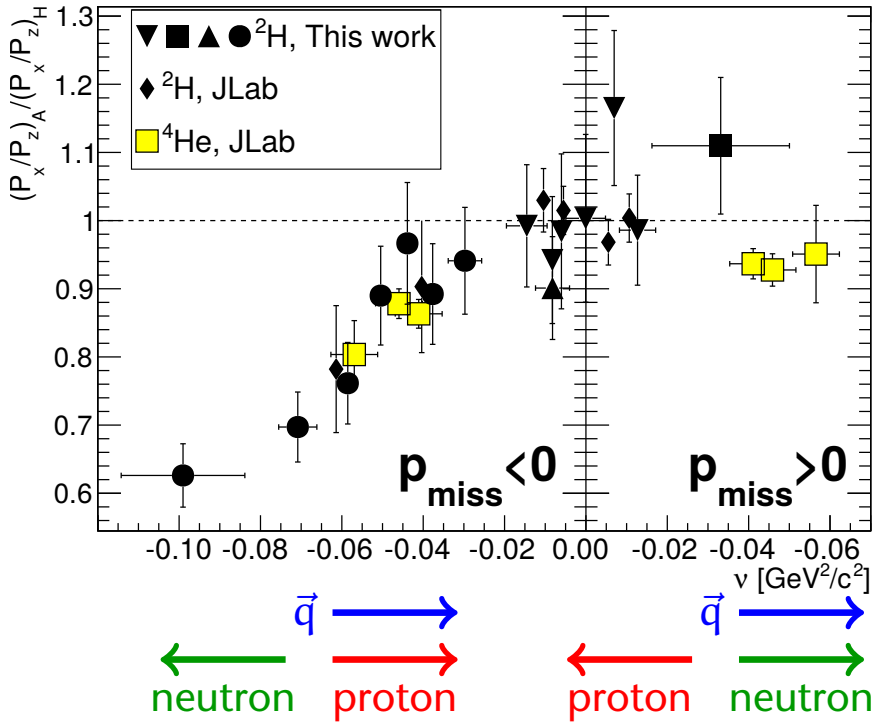
Comparison to ^{4}He:

- No dependence on nuclear density!



^{2}H, JLab: Hu et al., PRC 73 (2006) 064004

^{4}He, JLab: Strauch et al., PRL 91 (2003) 052301

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Comparison to calculation

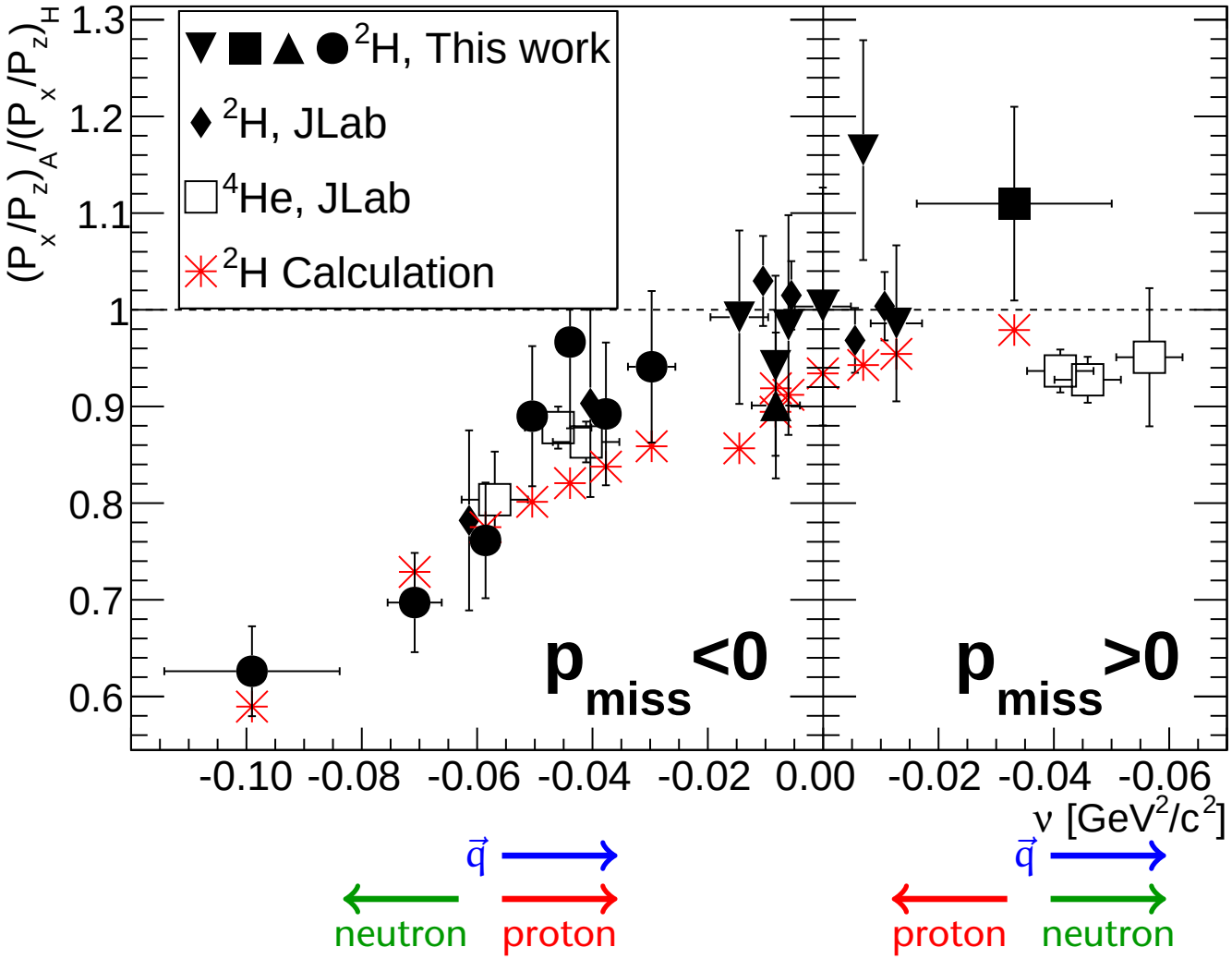
- Calculation of $(P_x/P_z)_{^2H}$ by H. Arenhövel
- Assumes *free* form factors for the proton

  Bernauer et al., PRC 90 (2014) 015206
- 7 models:
  - DWIA, non-relativistic (NR)
  - + relativistic corrections (RC)
  - + meson exchange currents (MEC)
  - + isobar configuration (IC)
  - + final state interaction (FSI)
  - PWBA (NR)
  - PWBA + RC
- Calculated for each kinematical bin in E', θ_e, θ_{qp}, ϕ_{qp}
- Only full calculation shown in diagrams

Leidemann, Tomusiak, Arenhövel, PRC 43 (1991) 1022

Arenhövel, Leidemann, Tomusiak, EPJA 23 (2005) 147

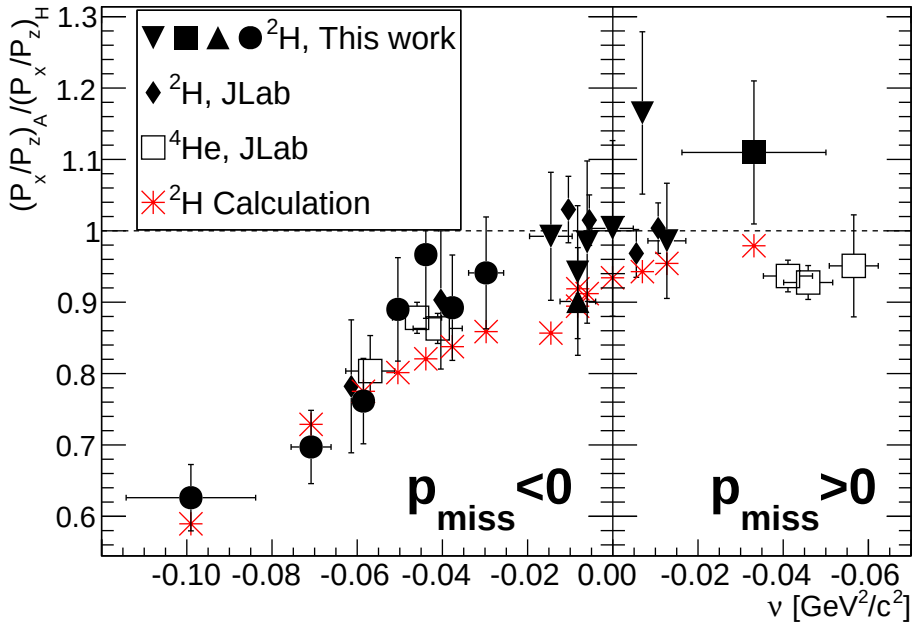
Comparison to calculation

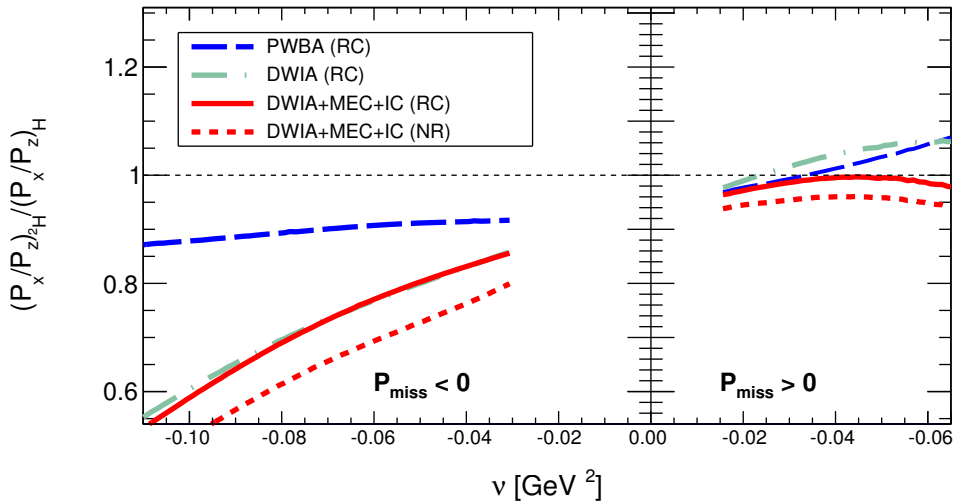


Virtuality dependence reproduced by calculation

Reason for virtuality dependence?

- Mostly due to final state interaction
- Little contribution from MEC and IC
- Relativistic corrections improve agreement with data but do not change the slope

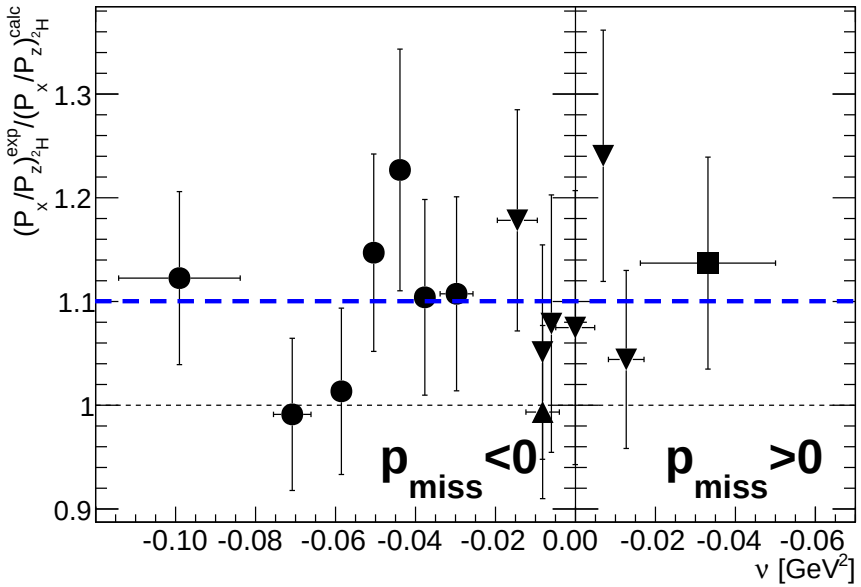




Comparison to calculation

- ^{2}H data 10 % above calculation
- No systematic virtuality dependence
- Larger than theoretical uncertainty:
  - NN potential AV18 $\longrightarrow$ Bonn: $\approx 2\,\%$
  - Form factor shape: almost no effect

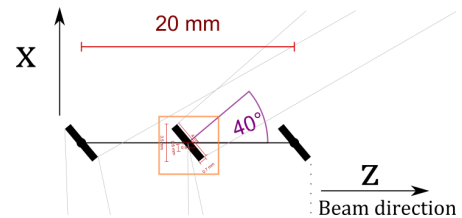
$1.100 \pm 0.025 \quad \chi^2/\text{n.d.f.} = 0.63$

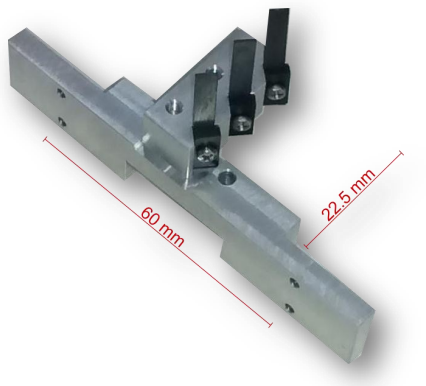


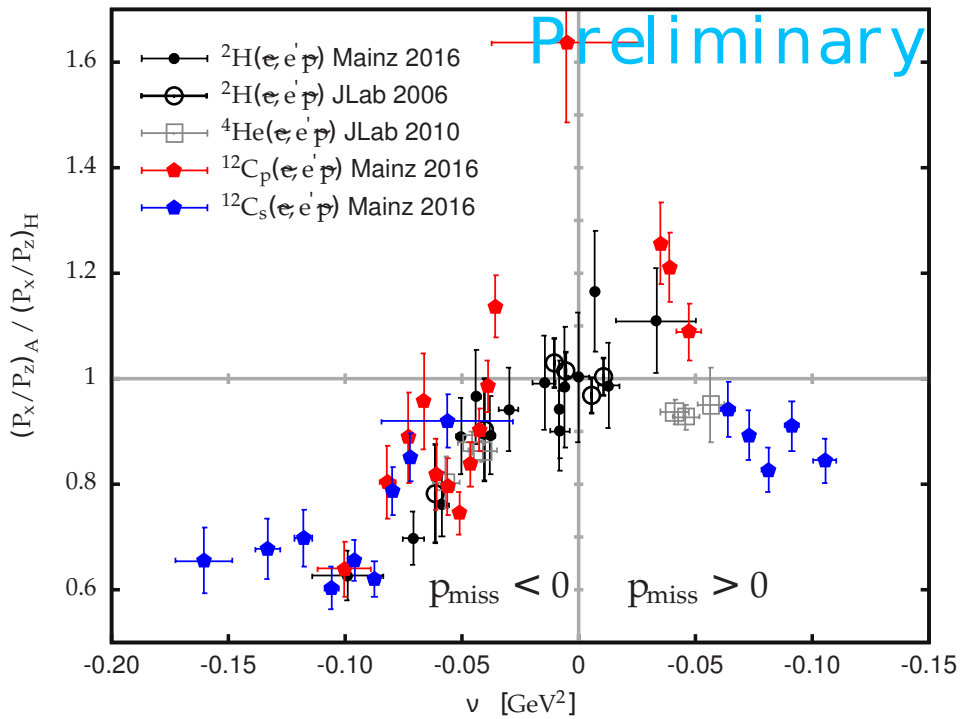
Carbon: Experiment and results

Very preliminary – Not for quotation!

- $^{12}C(\vec{e}, e'\vec{p})^{11}B$ data taken in 2015
- 600 MeV beam energy
- $Q^2 = 0.175, 0.4\ (GeV/c)^2$
- Segmented graphite target
  $\longrightarrow$ reduce proton energy loss



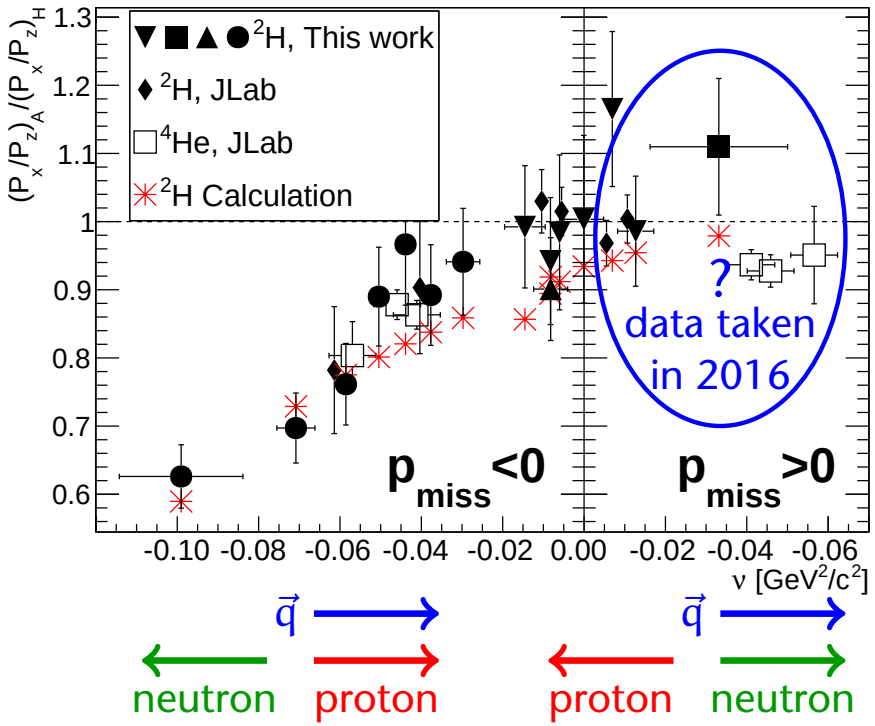




- Same shape of data for $p_{miss} < 0$
- s-shell versus p-shell protons?
- Analysis ongoing

Deuterium: New data for positive p_{miss}

- Sparse data for large $p_{miss} > 0$
- Low-energy proton $\rightarrow$ more difficult
- Data taking in July 2016
- Analysis in progress
- Scheduled run in 2017



Summary

P_x/P_z in $^2H(\vec{e}, e'\vec{p})n$ reaction

- Strong dependence on virtuality of knock-out proton
- Difference for positive and negative momentum
- No Q^2 dependence
- No evidence for nuclear density effect
- Virtuality dependence predicted by calculations (FSI)
- Calculations are off by an overall 10 %

Upcoming results

- Analysis of $^{12}C(\vec{e}, e'\vec{p})^{11}B$
- New $^2H(\vec{e}, e'\vec{p})n$ data for $p_{miss} > 0$
- Ongoing program, additional beam time scheduled for 2017

The A1 Collaboration

P. Achenbach, H. Arenhövel, J. Beričič, R. Böhm, D. Bosnar, T. Brecelj, E. O. Cohen, L. Debenjak, M. O. Distler, A. Esser, I. Friščić, R. Gilman, D. Izraeli, I. Korover, J. Lichtenstadt, H. Merkel, D. G. Middleton, M. Mihovilovič, U. Müller, E. Piasetzky, J. Pochodzalla, G. Ron, B. S. Schlimme, M. Schoth, F. Schulz, C. Sfienti, S. Širca, S. Štajner, S. Strauch, M. Thiel, A. Tyukin, A. Weber, I. Yaron