Exploring proton in-medium modifications through polarization-transfer measurements

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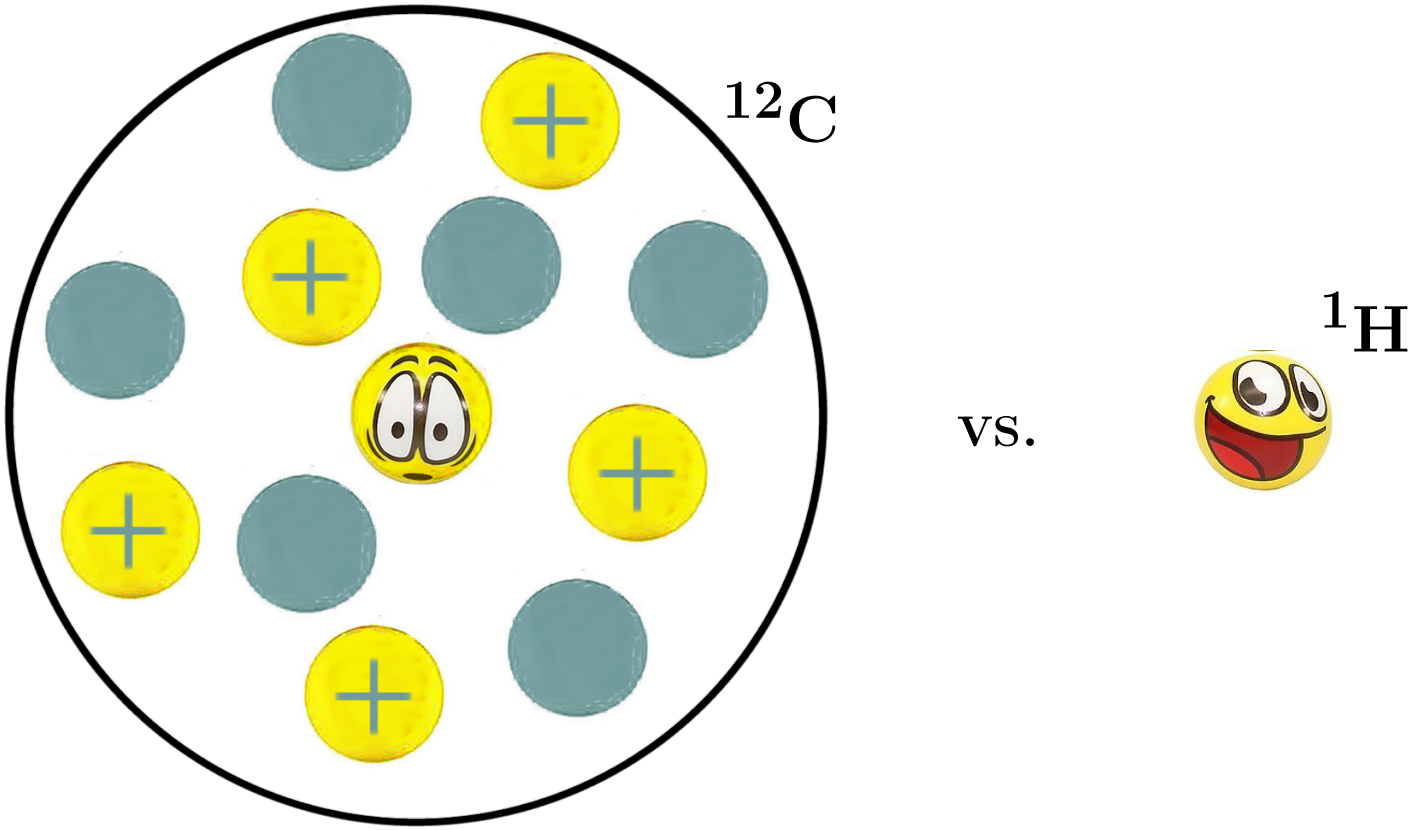
Tim Kolar

Frontiers and Careers in Nuclear
and Hadronic Physics

MIT, 8/6/22

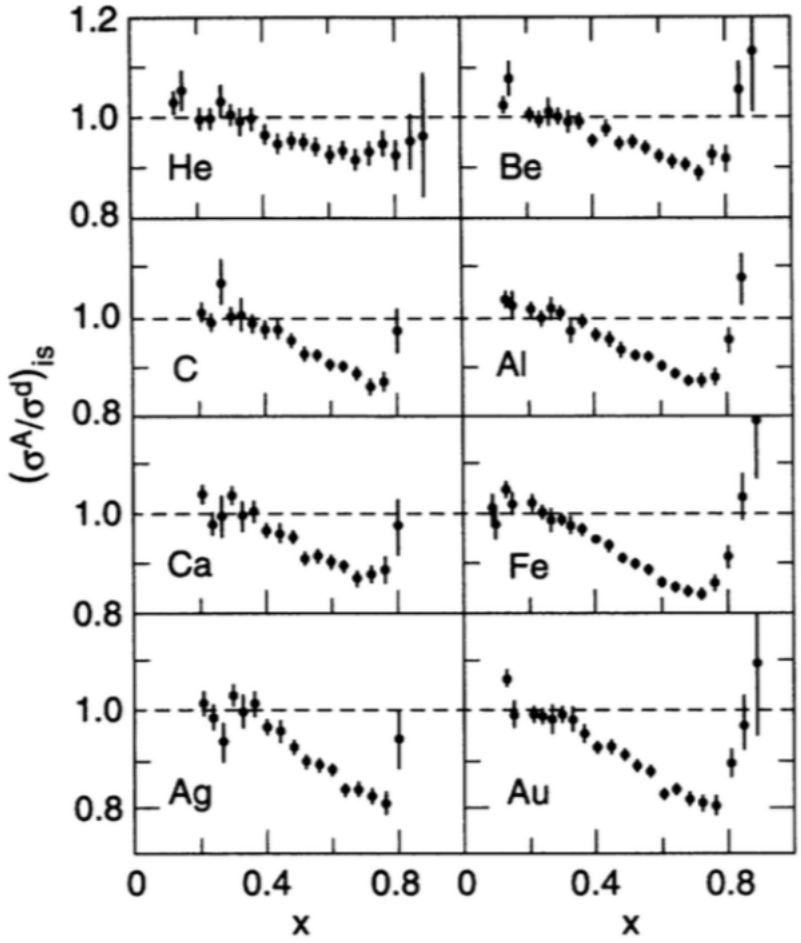
Motivation

- Does the proton change when embedded in nucleus?



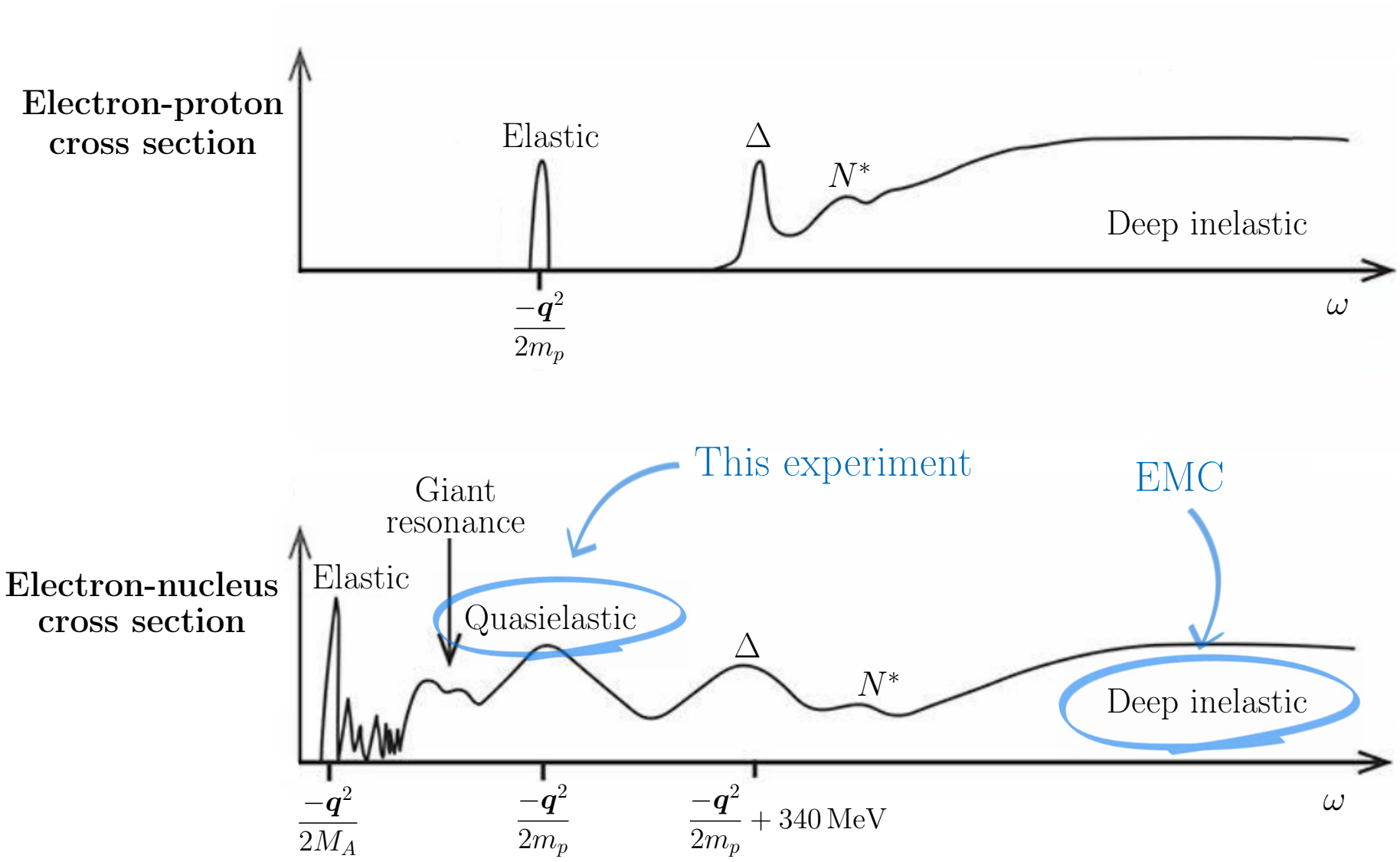
Motivation

- EMC effect: nucleus does have an affect on proton partonic structure



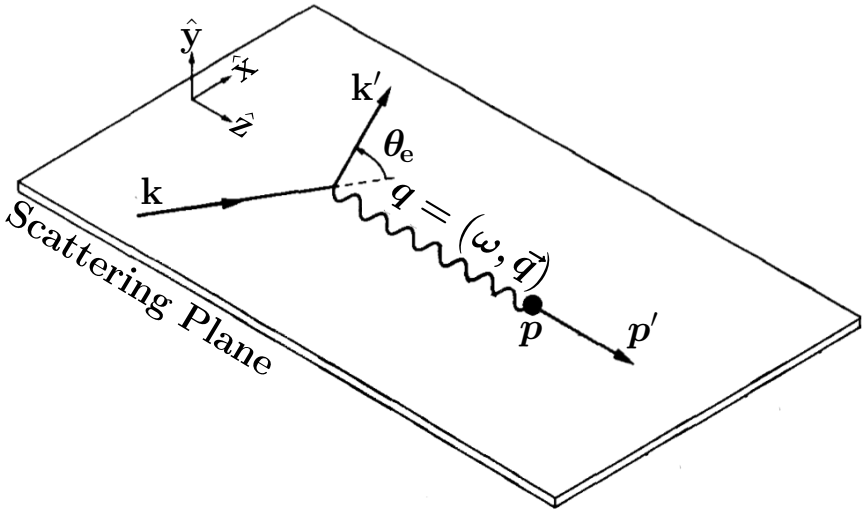
The per-nucleon cross-section ratio of various nuclei to deuterium as measured at SLAC (Gomez et al., 1994)

Quasi-elastic scattering



Polarization transfer in $A(\vec{e}, e'\vec{p})$ reaction

$A = 1 \rightarrow$  ... elastic



$$\left(\frac{P'_x}{P'_z}\right)_{\mathrm{H}} = \frac{2\varepsilon}{\tau(1+\varepsilon)}\frac{G_E}{G_M}$$

proton EM form factors

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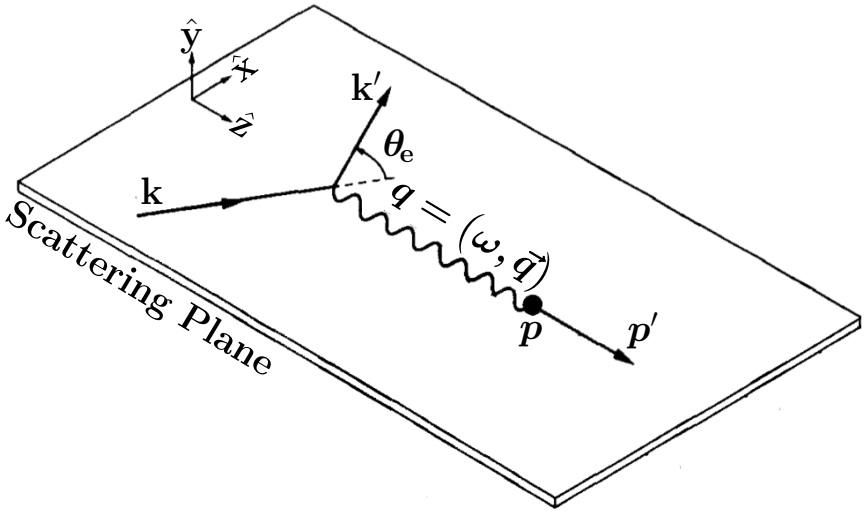
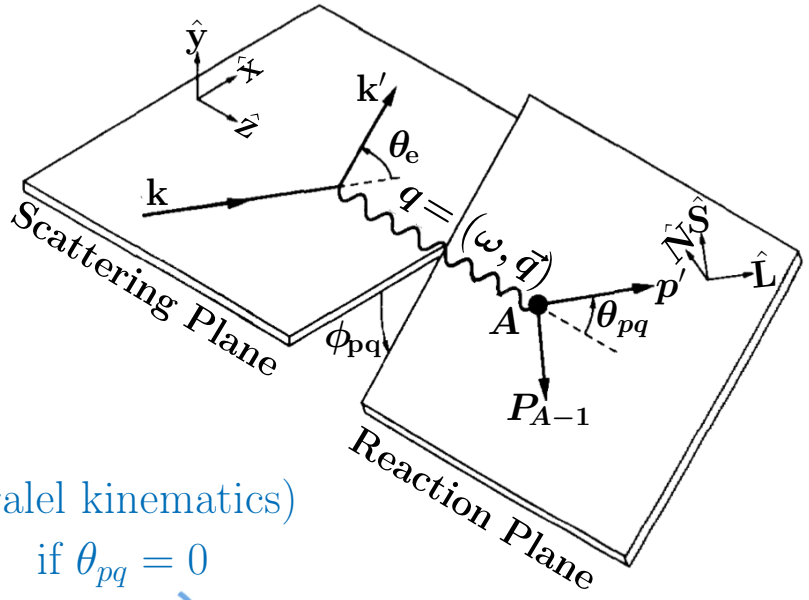
quasi-elastic ... $A > 1 \rightarrow$ e.g.  ^{3}He





$$\left(\frac{P'_x}{P'_z}\right)_{\mathrm{H}} = \frac{2\varepsilon}{\tau(1+\varepsilon)}\frac{G_E}{G_M}$$

proton EM form factors

(paralel kinematics) if $\theta_{pq} = 0$

$$\left(\frac{P'_S}{P'_L}\right)_{A} = \frac{P'_x}{P'_z} = \frac{V'_{LT}R'^{S}_{LT}}{V'_{TT}R'^{L}_{TT}} \propto \frac{G_E}{G_M}$$

PWIA, DWIA

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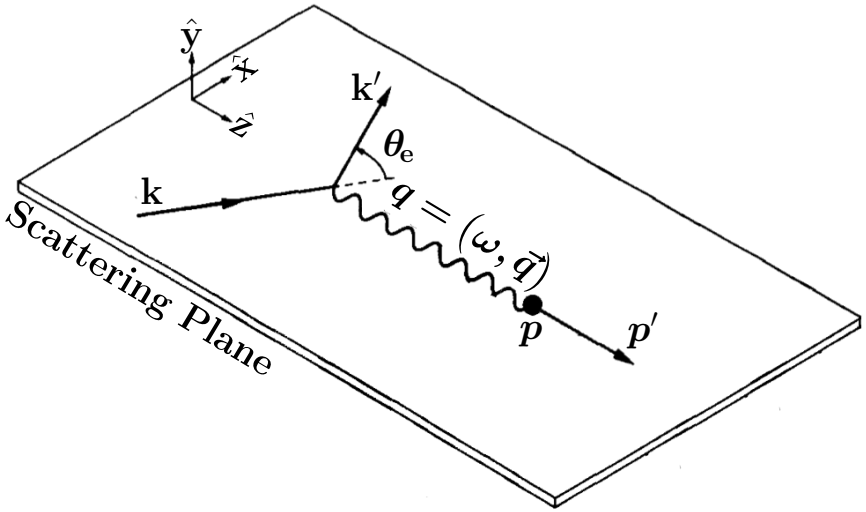

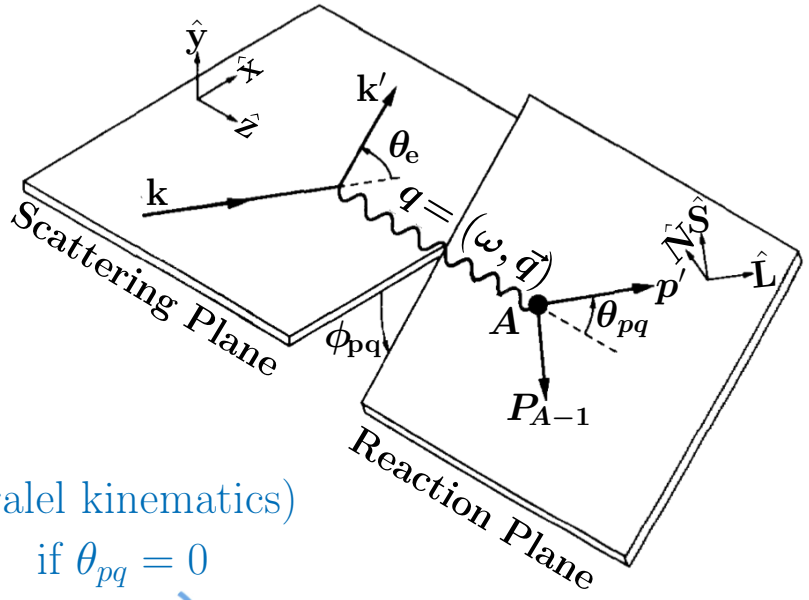

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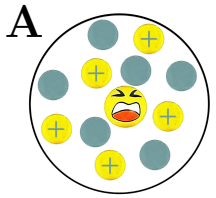
PWIA, DWIA

$$\rightarrow \quad \frac{(P'_x/P'_z)_{\mathrm{A}}}{(P'_x/P'_z)_{\mathrm{H}}} \propto \frac{(G_E/G_M)_{\mathrm{A}}}{(G_E/G_M)_{\mathrm{H}}}$$

Polarization transfer experiments

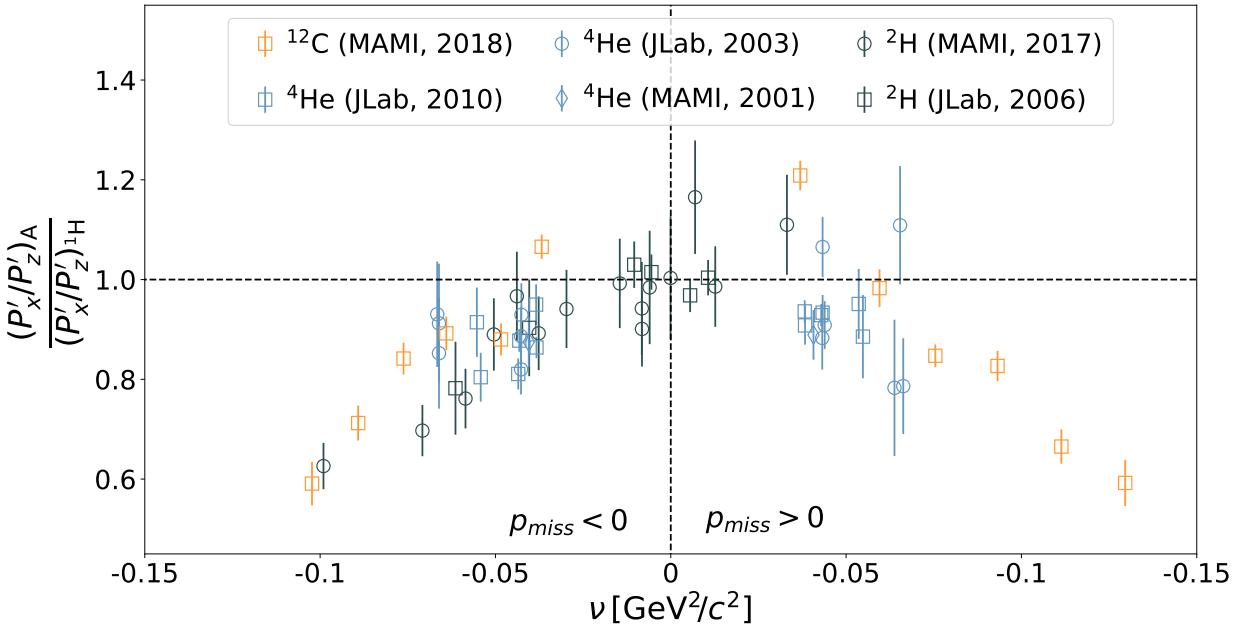


VS. 

$$\frac{(P'_x/P'_z)_{\mathrm{A}}}{(P'_x/P'_z)_{\mathrm{H}}} \propto \frac{(G_E/G_M)_{\mathrm{A}}}{(G_E/G_M)_{\mathrm{H}}}$$

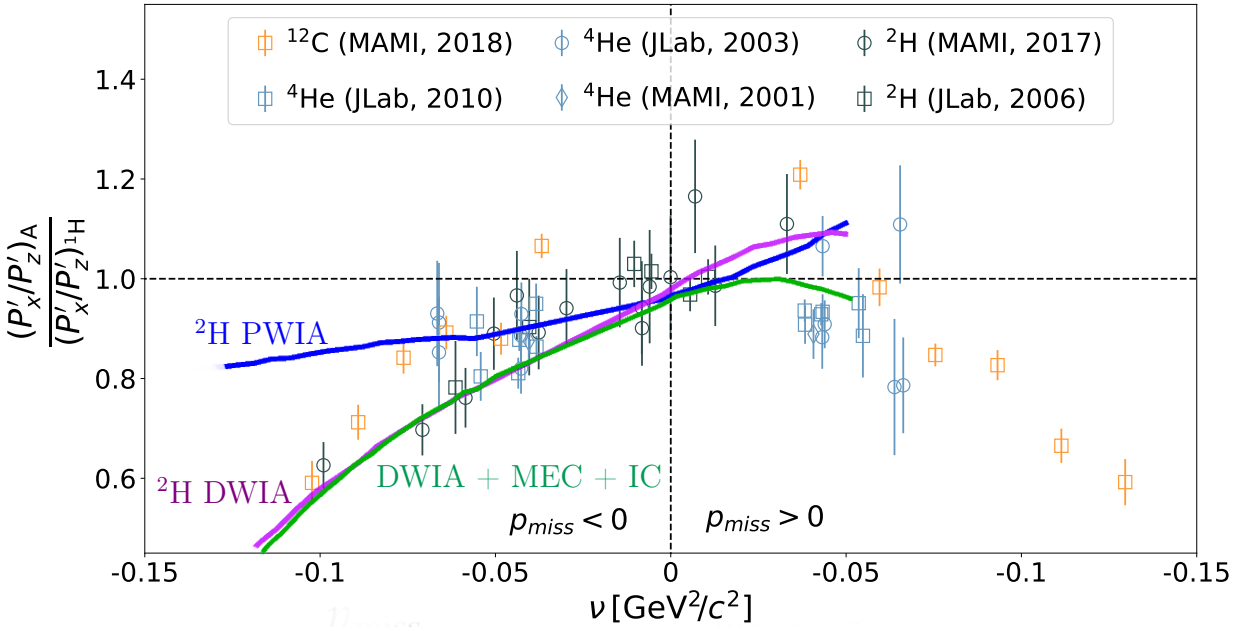
- Virtuality: $\nu = \left(m_p^2\right)_{emb} - m_p^2 = \left(M_A - \sqrt{M_{A-1}^{*2} + \vec{p}_{miss}^{\,2}}\right)^2 - \vec{p}_{miss}^{\,2} - m_p^2$

$$M_{A-1}^{*} = \sqrt{(\omega - T_{p'} + M_{A-1})^2 - \vec{p}_{miss}^{\,2}}$$



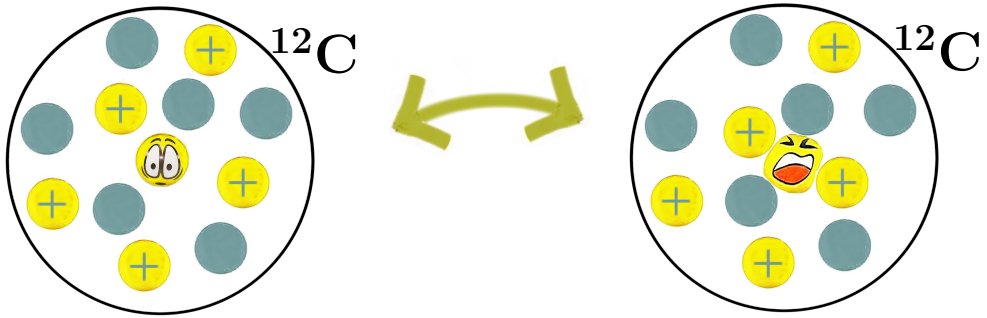
- Universal behaviour for different nuclei

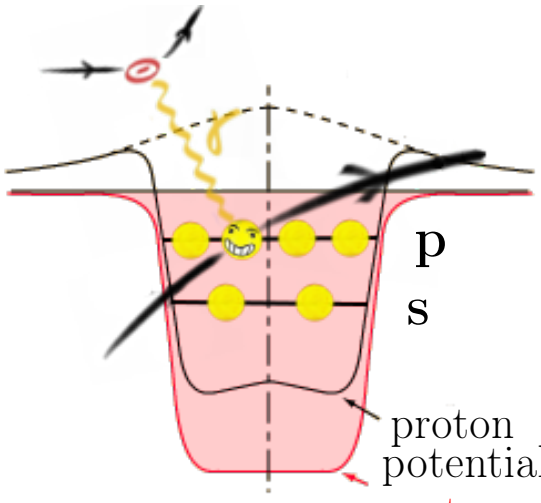
Polarization transfer experiments



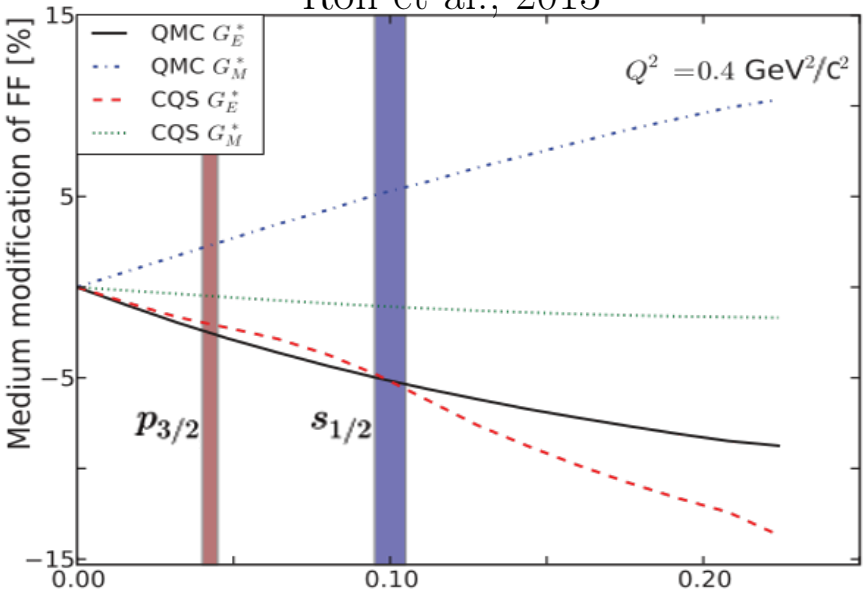
- Universal behaviour for different nuclei
- Dominated by other nuclear medium effects, such as *final-state interactions* (FSI), *meson-exchange currents* (MEC) and *isobar currents* (IC)
  $\rightarrow$ need to be accounted for with theoretical calculations

Different Approach





Ron et al., 2013



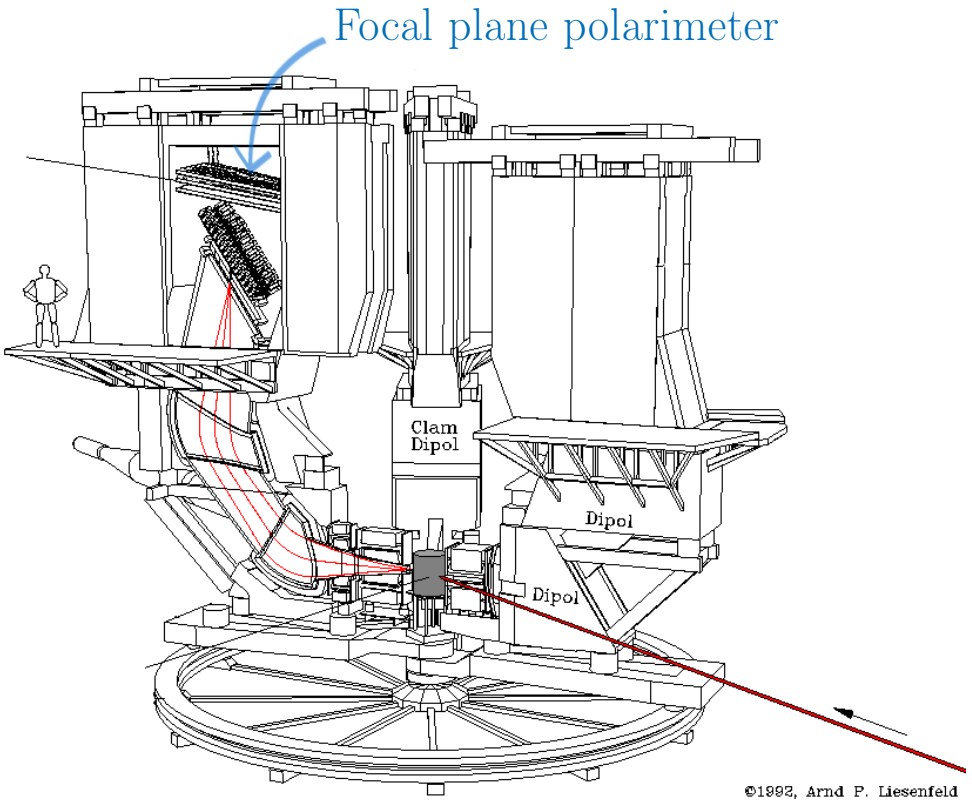
local nuclear density

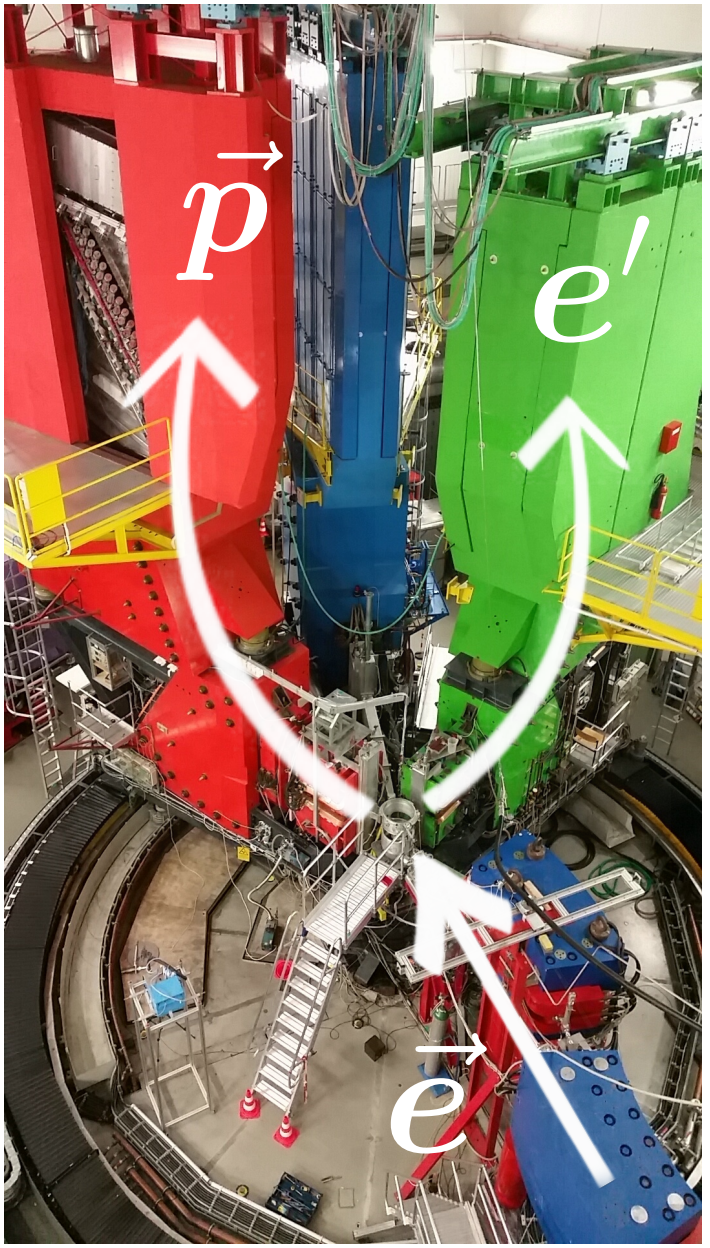
$$\frac{(P'_x/P'_z)^s_{^{12}\mathrm{C}}}{(P'_x/P'_z)^p_{^{12}\mathrm{C}}} \propto \frac{(G_E/G_M)^s_{^{12}\mathrm{C}}}{(G_E/G_M)^p_{^{12}\mathrm{C}}}$$

Experimental setup in A-Hall at Mainz

- **A1-Hall**

  3 magnetic spectrometers



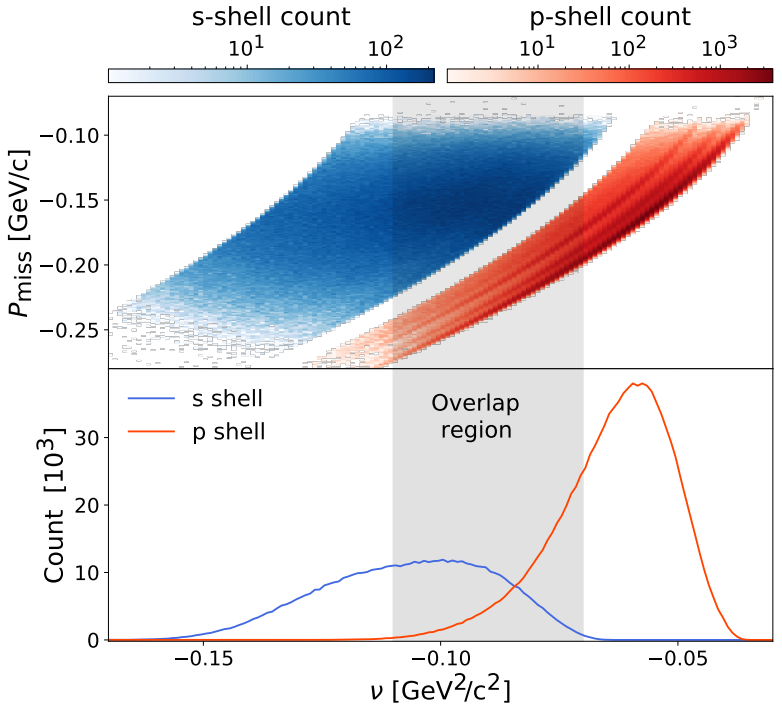


The Experiment - kinematics

- Central kinematics:

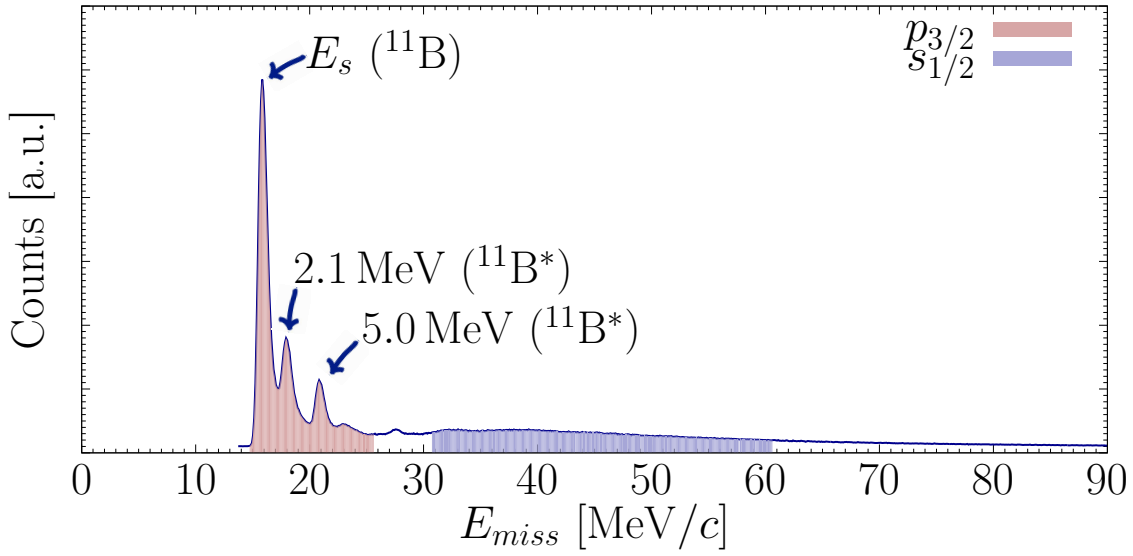
E_{beam}	[MeV]	600
Q^2	[GeV$^2/c^2$]	0.175
p_e	[MeV/c]	368
θ_e	[°]	−52.9
p_p	[MeV/c]	665
θ_p	[°]	37.8
p_{miss}	[MeV/c]	−270 to −100
ν	[MeV$^2/c^2$]	−160 to −40

- Covered p_{miss}-ν phase space:



The Experiment

- Separation of protons ejected from s and p shell



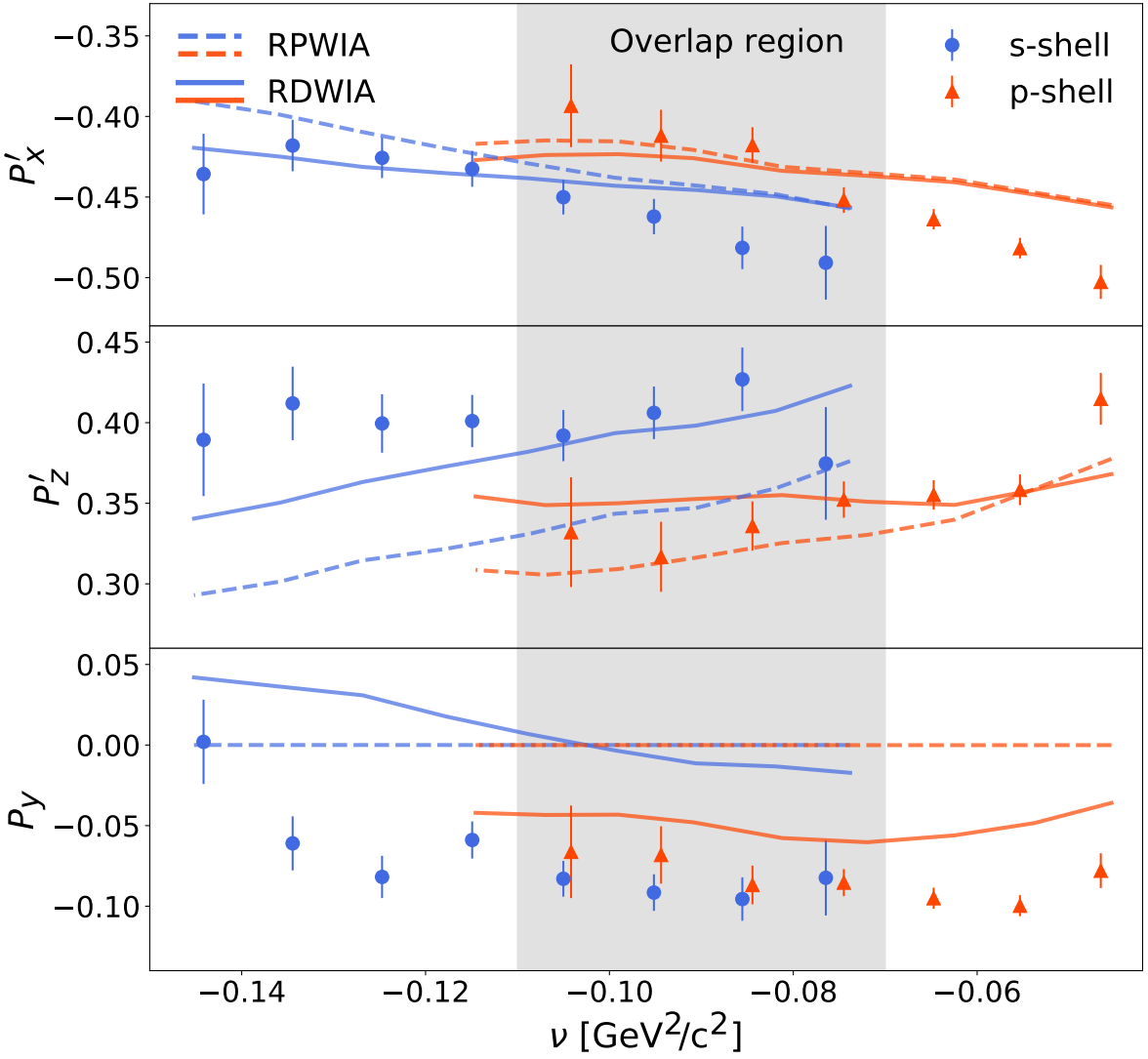
Limits were based on previously measured spectral functions for ^{12}C (Dutta, 2003)

$$p_{3/2} \text{ shell:} \qquad 14 \leq E_{miss} \leq 25\,\text{MeV}$$

$$s_{1/2} \text{ shell:} \qquad 30 \leq E_{miss} \leq 60\,\text{MeV}$$

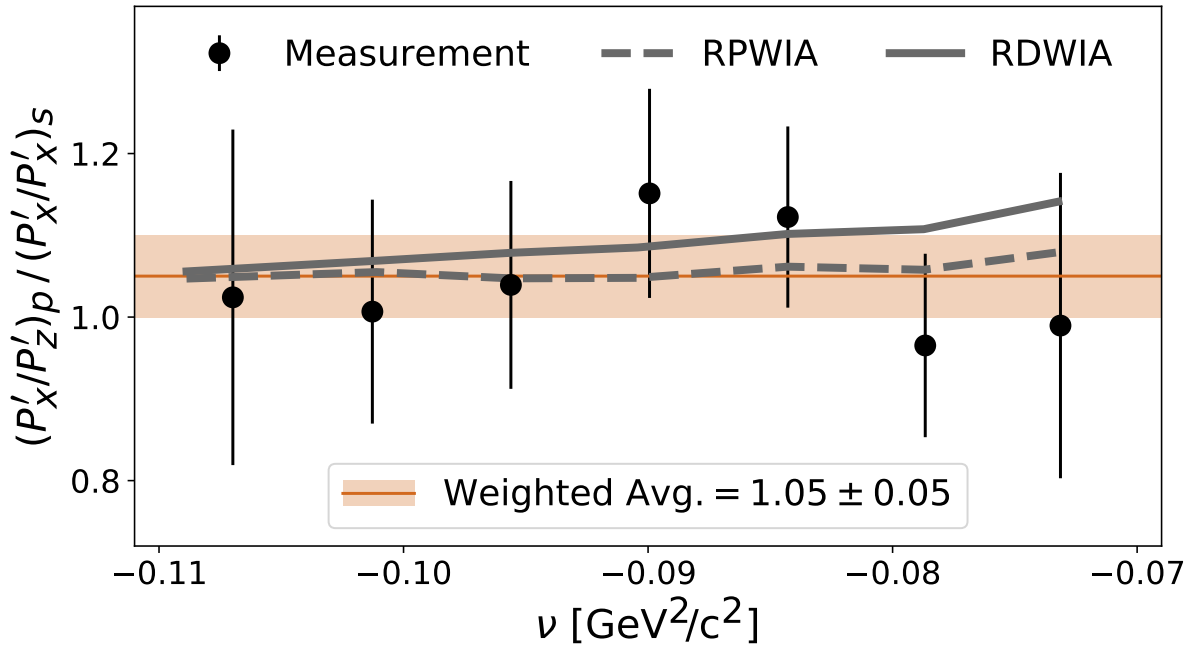
The Experiment - Results

- Individual polarization components



The Experiment - Results

- Polarization double ratio - comparison between the two ^{12}C shells in the virtuality overlap region

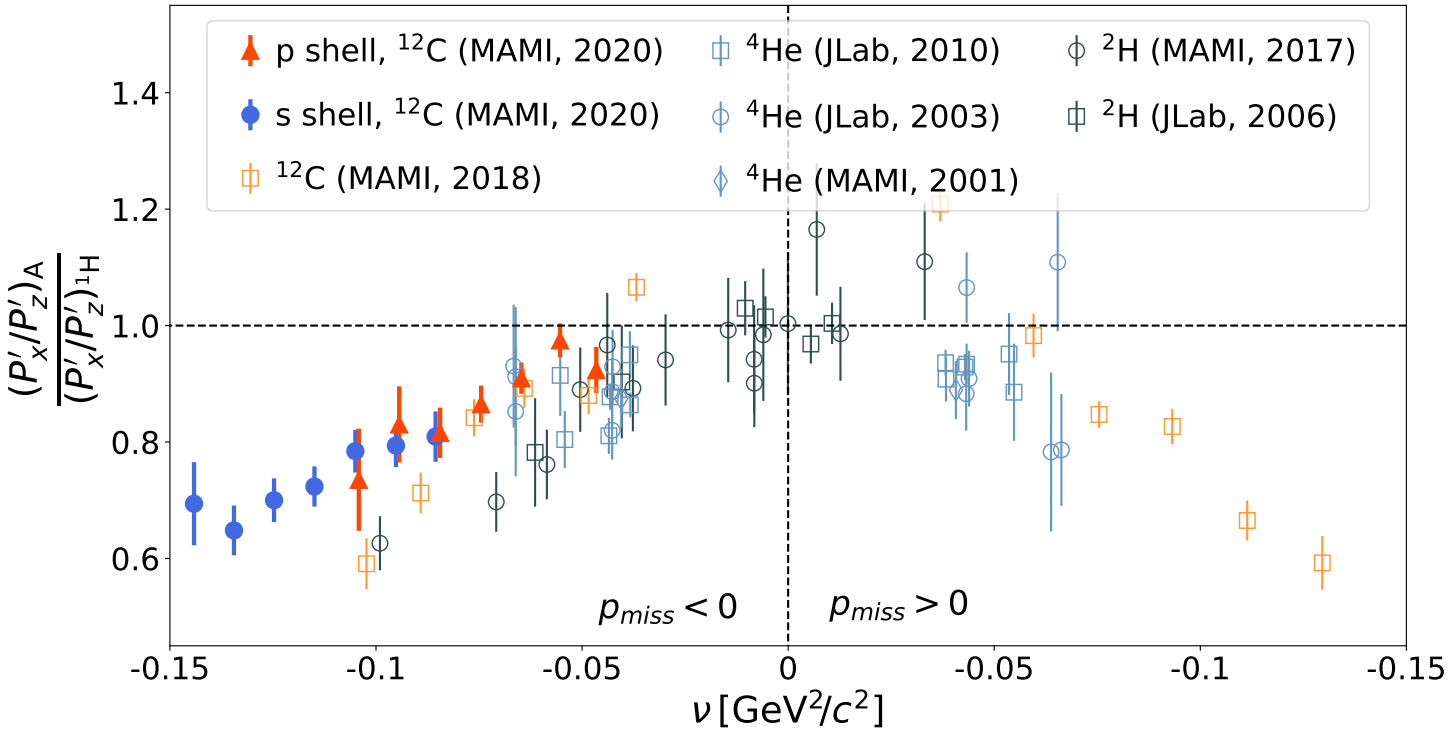


→ Forming polarization double ratio $\frac{(P'_x/P'_z)^s_{^{12}\mathrm{C}}}{(P'_x/P'_z)^p_{^{12}\mathrm{C}}}$ reduces FSI contribution

→ Based on the s- and p- shell comparison there is no density-dependent modification of protons with the same virtuality

The Experiment - Results

- Polarization double ratio - comparison with a free proton



→ Observed universality of $\frac{(P_x/P_z)_A}{(P_x/P_z)_H}$ when examined as function of virtuality is perserved

Conclusions

- We presented a novel method for exploration of in-medium effects with polarization transfer method
- Theoretical input remains mandatory
- For protons of the same virtuality we did not observe any density-dependent modifications
- Preserved universality of $\frac{(P_x/P_z)_A}{(P_x/P_z)_H}$ when examined as function of virtuality
- Similar experiment with ^{40}Ca target ran earlier this year at MAMI (currently ongoing analysis)

Thank you!