Study of light nuclei by polarization observables in electron scattering

S. Širca, U of Ljubljana, Slovenia

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Unpolarized electron scattering

\[ Q^2 = \vec{q}^2 - \omega^2 \]

\[ \omega = \vec{E}_e - \vec{E}_e' \]

\[ \vec{q} = \vec{p}_e - \vec{p}_e' \]

\[ \vec{p}_m = \vec{q} - \vec{p}_x \]

\[
\frac{d\sigma}{dE_e'd\Omega_e'dE_x'd\Omega_x} = \sigma_0 \left[ \nu_{LL}R_L + \nu_{TT}R_T + \nu_{LT}R_LT + \nu_{TT}R_{TT} \right]
\]
Electron scattering with beam and target polarization

\[ A = \frac{\sigma(h_+, \vec{S}) - \sigma(h_-, \vec{S})}{\sigma(h_+, \vec{S}) + \sigma(h_-, \vec{S})} \propto \nu_{T'} R_{T'} + \nu_{LT'} R_{LT'} \]
Electron scattering with beam and recoil polarization

\[ P'_{z} = P'_{\ell} \propto \nu_{LT} R_{LT}' + \nu_{TT} R_{TT}' \]
\[ P_{n} \propto \nu_{L} R_{L}^{n} + \nu_{T} R_{T}^{n} + \nu_{LT} R_{LT}^{n} + \nu_{TT} R_{TT}^{n} \]
\[ P'_{x} = P'_{t} \propto \nu_{LT} R_{LT}' + \nu_{TT} R_{TT}' \]
Experiments covered in this talk

$^3\text{He}$

- JLab E05–102
  Double-spin asymmetries in quasi-elastic $^3\text{He} (\vec{e}, e'd)p$
  $^3\text{He} (\vec{e}, e'p)d$
  $^3\text{He} (\vec{e}, e'p)pn$

- JLab E05–015
  Target single-spin asymmetry in quasi-elastic $^3\text{He}^\uparrow (e, e')$

- JLab E08–005
  Target single-spin asymmetry in quasi-elastic $^3\text{He}(\vec{e}, e'n)$
  Double-spin asymmetries in quasi-elastic $^3\text{He}(\vec{e}, e'n)$

- MAMI (Mainz) Project ‘N’
  *Triple*-polarized $^3\text{He} (\vec{e}, e'\vec{p})$

$^2\text{H}$ and $^{12}\text{C}$

- MAMI (Mainz)
  Single-spin asymmetries in $^{12}\text{C}(e^\uparrow, e')$

- MAMI (Mainz + TAU) joint recoil-polarimetry effort
  Double-spin asymmetries in $^2\text{H}(\vec{e}, e'\vec{p})$ and $^{12}\text{C}(\vec{e}, e'\vec{p})$
Physics motivation for studying processes on $^3$He

- Knowledge of ground-state structure of $^3$He needed to extract information on the neutron from $^3\text{He}(e, e'X)$ or $^3\overline{\text{He}}(\bar{e}, e')$.
  Examples: $G^n_E$, $G^n_M$, $A^n_1$, $\mathcal{G}^n_1$, $\mathcal{G}^n_2$, GDH.

- Complications: protons in $^3$He partly polarized due to presence of $S'$- and $D$-state components.

- Addressing differences in $\sqrt{\langle r^2 \rangle}$ ($^3$H, $^3$He).

- Understanding (iso)spin dependence of reaction mechanisms (MEC, IC).

- Understanding role of $D$ and $S'$ states is one of key issues in “Standard Model” of few-body theory.

- Persistent discrepancies among theories regarding double-polarization observables most sensitive to $^3$He ground-state structure.
Polarized $^3$He: it is easy to draw the cartoon ...

- $S$: spatially symmetric
  \[ \approx 90\% \text{ of spin-averaged WF; “polarized neutron”} \]
- $D$: generated by tensor part of NN force, \[ \approx 8.5\% \]
- $S'$: mixed symmetry component; (spin-isospin)-space correlations,
  \[ \approx 1.5\% \quad P'_S \approx E_b^{-2.1} \]
- $P_{\text{eff}}^n \approx +0.86$, $P_{\text{eff}}^p \approx -0.03$

| Hamiltonian    | $S$   | $S'$  | $P$   | $D$   |
|----------------|-------|-------|-------|-------|
| AV18           | 90.10 | 1.33  | 0.066 | 8.51  |
| AV18/TM        | 89.96 | 1.09  | 0.155 | 8.80  |
| AV18/UIX       | 89.51 | 1.05  | 0.130 | 9.31  |
| CD-Bonn        | 91.62 | 1.34  | 0.046 | 6.99  |
| CD-Bonn/TM     | 91.74 | 1.21  | 0.102 | 6.95  |
| Nijm I         | 90.29 | 1.27  | 0.066 | 8.37  |
| Nijm I/TM      | 90.25 | 1.08  | 0.148 | 8.53  |
| Nijm II        | 90.31 | 1.27  | 0.065 | 8.35  |
| Nijm II/TM     | 90.22 | 1.07  | 0.161 | 8.54  |
| Reid93         | 90.21 | 1.28  | 0.067 | 8.44  |
| Reid93/TM      | 90.09 | 1.07  | 0.162 | 8.68  |

Schiavilla++ PRC 58 (1998) 1263
TM = Tucson-Melbourne $\pi$-$\pi$ exchange 3NF
UIX = Urbana 3NF
... supported e. g. by data on $^3\text{He}(\bar{e}, e'p)d/pn$ ...

- quasi-elastic ($Q^2 = 0.31$, $\omega = 135$, $q = 570$)
- 3NF, MEC negligible, FSI small in 2bbu, large in 3bbu

\[ A_{pd} \]

\[ A_1 + A_2 \]

\[ \gamma \]

\[ \Delta \]

\[ 2bbu \]

$A_{\text{PWIA}} \approx A_{\text{PWIA+FSI}}$

|| kinematics + small $p_d$

$\Rightarrow$ polarized p target, $P_p \approx -\frac{1}{3}P_{\text{He}}$

\[ \triangleright \]

\[ 3bbu \]

$A_{\text{PWIA}} \approx 0 \text{ (p } \uparrow \text{ p } \downarrow)$

$A_{\text{PWIA+FSI}}$ large & negative

not a polarized p target

PRC 72 (2005) 054005, EPJA 25 (2005) 177
... and which has a nice analogue in the deuteron ...

\[ \vec{d}(\vec{e}, e'p) \]

\[ A_{ed}^V \]

\[ p_m \text{ [MeV/c]} \]

\[ \sigma = \sigma_0 \left( 1 + h P_1^d A_{ed}^V \right) \]

\[ P_2^p = \sqrt{\frac{2}{3}} \left( P_S - \frac{1}{2} P_D \right) P_1^d \]

Passchier++ PRL 82 (1999) 4988
Passchier++ PRL 88 (2002) 102302
... but the true ground state of $^3$He is like lace

| Channel number | $L$ | $S$ | $l_\alpha$ | $L_\alpha$ | $P$ | $K$ | Probability (%) |
|----------------|-----|-----|------------|------------|-----|-----|-----------------|
| 1              | 0   | 0.5 | 0          | 0          | $A$ | 1   | 87.44           |
| 2              | 0   | 0.5 | 0          | 0          | $M$ | 2   | 0.74            |
| 3              | 0   | 0.5 | 1          | 1          | $M$ | 1   | 0.74            |
| 4              | 0   | 0.5 | 2          | 2          | $A$ | 1   | 1.20            |
| 5              | 0   | 0.5 | 2          | 2          | $M$ | 2   | 0.06            |
| 6              | 1   | 0.5 | 1          | 1          | $M$ | 1   | 0.01            |
| 7              | 1   | 0.5 | 2          | 2          | $A$ | 1   | 0.01            |
| 8              | 1   | 0.5 | 2          | 2          | $M$ | 2   | 0.01            |
| 9              | 1   | 1.5 | 1          | 1          | $M$ | 1   | 0.01            |
| 10             | 1   | 1.5 | 2          | 2          | $M$ | 2   | 0.01            |
| 11             | 2   | 1.5 | 0          | 2          | $M$ | 2   | 1.08            |
| 12             | 2   | 1.5 | 1          | 1          | $M$ | 1   | 2.63            |
| 13             | 2   | 1.5 | 1          | 3          | $M$ | 1   | 1.05            |
| 14             | 2   | 1.5 | 2          | 0          | $M$ | 2   | 3.06            |
| 15             | 2   | 1.5 | 2          | 2          | $M$ | 2   | 0.18            |
| 16             | 2   | 1.5 | 3          | 1          | $M$ | 1   | 0.37            |

Blankleider, Woloshyn PRC 29 (1984) 538
The E05–102 and E08–005 experiments at JLab

- **Benchmark measurement** of $A'_x$ and $A'_z$ asymmetries in $^3\text{He}(\vec{e}, e'd)$, $^3\text{He}(\vec{e}, e'p)$, and $^3\text{He}(\vec{e}, e'n)$.

- **Better understanding of ground-state spin structure of polarized $^3\text{He}$** — $S$, $S'$, $D$ wave-function components. Improve knowledge of $^3\text{He}$ rather than using it as an effective neutron target.
  
  Direct consequences for all polarized $^3\text{He}$ experiments.

- Distinct manifestations of $S$, $D$, $S'$ with changing $p_{\text{miss}}$ in $(e, e'\{p/d/n\})$.

- Data at (almost) identical $Q^2$ for $(\vec{e}, e'd)$, $(\vec{e}, e'p)$, and $(\vec{e}, e'n)$ simultaneously over a broad range of $p_{\text{miss}}$ poses **strong constraints on state-of-the-art calculations**.
What is so special about $^3\text{He}(e, e'd)$ and $^3\bar{\text{He}}(\bar{e}, e'd)$?

**unique isoscalar-isovector interference in** $(e, e'd)$

Tripp++ PRL 76 (1996) 885

in $(e, e'p)$ the $D/S'$ effects seen only at high $p_{\text{miss}}$

Laget PLB 276 (1992) 398
Exploiting state-of-the-art calculations

**Bochum/Krakow** (full Faddeev)
- AV18 NN-potential (+ Urbana IX 3NF, work in progress)
- Complete treatment of FSI, MEC

**Hannover/Lisbon** (full Faddeev)
- CC extension and refit of CD-Bonn NN-potential
- Includes FSI, MEC
- $\Delta$ as active degree-of-freedom providing effective 3NF and 2-body currents
- Coulomb interaction for outgoing charged baryons

**Pisa**
- AV18 + Urbana IX (or IL7)
- Inclusion of FSI by means of the variational PHH expansion and MEC
- Not Faddeev, but accuracy completely equivalent to it

**Trento**
- Coming up
Basic machinery: Faddeev calculations

Nuclear transition current for breakup of $^{3}$He: \[ J^\mu = \left\langle \Psi_f \mid \hat{O}^\mu \mid \Psi_{3\text{He}}(\theta^*, \phi^*) \right\rangle \]

Photon absorption operator: \[ \hat{O}^\mu = \sum_{i=1}^{3} \left[ \hat{J}_{SN}(i) + \hat{J}_{MEC}(i) \right] \]

Final-state interactions (auxiliary states): \[ \left\langle \Psi_f \mid \hat{O}^\mu \mid \Psi_{3\text{He}}(\theta^*, \phi^*) \right\rangle \rightarrow \left\langle \Psi_f \mid U_f^\mu \right\rangle \]

\[ U_0^{\text{ppa}} \]

\[ U_0^{\text{pd}} \]

\[ + \]

\[ \cdots \]

\[ G_0 \]

\[ + 6 \text{ more terms} \]

\[ + 24 \text{ more terms} \]

\[ + 4 \text{ more terms} \]

\[ + 16 \text{ more terms} \]

\[ + \cdots \]

Golak++ Phys Rep 415 (2005) 89
**Indication of $D$ and $S'$ components in $^3\text{He}(\bar{e}, e')$**

**Inclusive $A'_T (= A_Z)$ and $A'_{LT} (= A_x)$**

- $A'_T$ receives contributions from ingredients which go beyond most simplistic picture [$F_1^{(n)} = 0$]
- sensitive to replacement PWIA(PS) $\rightarrow$ PWIA.
- $S'$- and $D$-state pieces contribute very strongly to $A'_{LT}$

Ishikawa++ PRC 57 (1998) 39
$^3\text{He}(\tilde{e}, e'd) \text{ vs. } ^3\text{He}(\tilde{e}, e'p)$

- $S'$ state relevant at small $p_r (= p_{\text{miss}})$
- $D$ state governs variation of $A_z$ at large $p_r$
Beam-target asymmetry in QE p/d knockout from $^3\text{He}^-$

- Cannot disentangle effects of WF components ($S, D, S'$) by measurement of cross-sections alone: need polarization observables

$$\frac{d\sigma(h, \mathbf{S})}{d\Omega_e dE_e d\Omega_d dp_d} = \frac{d\sigma_0}{\ldots} \left[ 1 + \mathbf{S} \cdot \mathbf{A}^0 + h(A_e + \mathbf{S} \cdot \mathbf{A}) \right]$$

$$A(\theta^*, \phi^*) = \mathbf{S}(\theta^*, \phi^*) \cdot \mathbf{A} = \frac{[d\sigma_{++} + d\sigma_{--}]}{[d\sigma_{++} + d\sigma_{--}]} - \frac{[d\sigma_{+-} + d\sigma_{-+}]}{[d\sigma_{++} + d\sigma_{--}]}$$

- Access to [effects of] small WF components ($D, S'$)

- E05–102: simultaneous measurement of all break-up channels: $^3\text{He}(\mathbf{e}, \mathbf{e}'d)p, ^3\text{He}(\mathbf{e}, \mathbf{e}'p)d, ^3\text{He}(\mathbf{e}, \mathbf{e}'p)pn$ ... and also $^3\text{He}(\mathbf{e}, \mathbf{e}'n)pp$
Experimental Setup

All Channels

Hall A

BigBite

Right HRS

Left HRS

Beam Dump

Compton Polarimeter

Elastic Polarimeter

Raster

Moller Polarimeter

Neutron Arm

Polarized He Target

Wire Chambers

Trigger Plane (Scintillators)

QDCs

Scintillators

Pion Rejectors (Pb Glass)

Gas Cerenkov

ARC

BCM

eP

BPM

D

Particle Detectors

$E_e = 2.425 \text{ GeV}$

$\theta_e = 12.5^\circ$

$\theta_{d,p} = 75^\circ$

$Q^2 = 0.25 \text{ GeV}^2$

$\ldots$

$\theta_e = 14.5^\circ$

$\theta_{d,p} = 82^\circ$

$Q^2 = 0.35 \text{ GeV}^2$

$\ldots$

$\theta_e = 17^\circ$

$\theta_n = 62.5^\circ$

$Q^2 = 0.46 \text{ GeV}^2$

$E_e = 3.605 \text{ GeV}$

$\theta_e = 17^\circ$

$\theta_n = 54^\circ$

$Q^2 = 0.96 \text{ GeV}^2$
Results on $^3\text{He}(\bar{e}, e'd)p$

- **Asymmetries are small** (typically a few %), thus hard to reproduce theoretically (cancellations)
- **Good agreement on the transverse asymmetry** ($71^\circ$)
- **Worse for the longitudinal asymmetry** ($160^\circ$) ... but it improves when $\omega$ is restricted to QE peak
- **Discrepancy due to**
  - incomplete treatment of FSI (?)
  - unaccounted for 3NF (?)
  - underestimated $S'$ component of g.s. WF (?)

Mihovilović++ PRL 113 (2014) 232505
Results on $^3\text{He}(\bar{e}, e'd)p$ \(\omega\)-dependence

Mihovilović++ PRL 113 (2014) 232505
Attempt to evaluate \( P_Z \) and \( P_{ZZ} \)

\[ \begin{align*}
3\text{He}(\bar{e}, e'd)p & \\
\text{Assume } & 3\text{He}(\bar{e}, e'd)p \text{ at low } p_{\text{miss}} \text{ is like elastic scattering off polarized } d \\
\text{Use } & A_x^{(3\text{He})}, A_z^{(3\text{He})} \text{ as if they were } A_x^{(ed)}, A_z^{(ed)} \text{ with appropriate deuteron FFs, and extract } P_Z \text{ and } P_{ZZ} \\
\text{Toy model } |3\text{He}\rangle & = |d\rangle + |p\rangle \\
\text{Spin decomposition } |3\text{He}\rangle & = \left| \frac{1}{2}, \frac{1}{2} \right\rangle = \sqrt{2/3} |1, 1\rangle - \sqrt{1/3} |1, 0\rangle |\frac{1}{2}, \frac{1}{2}\rangle \\
gives \quad & P_Z = \langle I_z \rangle_{3\text{He}} = \frac{2}{3}, \quad P_{ZZ} = \langle 3I_z^2 - 2 \rangle_{3\text{He}} = 0
\end{align*} \]
Results on $^3\text{He}(\bar{e}, e'p)$

\[ \rho_m \text{-dependence} \]

No 2bbu/3bbu separation possible; rely on MC to disentangle $A_{2\text{bbu}}/A_{3\text{bbu}}$
- Unpolarized 2bbu and 3bbu XS as well as $A_{2\text{bbu}}$ well established

Only qualitative agreement of data with theory. Issues:
- Cancellation of 2bbu and 3bbu contributions
- 3bbu asymmetry dominant — possibly too much so
- Pertinent ingredients: Coulomb, RC, FSI, 3NF (?)
Simple interpretation of $^3\text{He}(\bar{e}, e'p)$

- Valid for $p_m \approx 0$
- Assume PWIA
- $S$-state dominates
- Missing energy: $E_m = \omega - T_p - T_d$
- Low-$E_m$ region dominated by 2bbu: $A \approx A(\bar{e} - \bar{p} \text{ elastic})$
- High-$E_m$ region dominated by 3bbu: $A \approx 0$
- Non-zero asymmetry in 3bbu probably caused by FSI
Extraction of 2bbu and 3bbu asymmetries in $^3\text{He}(\bar{e}, e^{'p})$
Message on 2bbu and 3bbu asymmetries in $^3\text{He}(\bar{e}, e'p)$

- A3BBU consequence of the FSI (established with Mainz experiment);
- Effect of the FSI overestimated!

$$A_{3\text{BBU}} = -\frac{1}{3} A_{ep}$$

$$A_{3\text{BBU}} = 0$$

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Mihovilović++ PLB **788** (2019) 117
More $^3$He($\bar{e}, e^'d$) and $^3$He($\bar{e}, e^'p$) ...

- High-statistics data also available at $Q^2 \approx 0.35$ GeV$^2$ in all channels

- Opportunity to study $Q^2$-dependence of asymmetries
- Theoretical calculations pending
Single-spin asymmetry in QE $^3$He$^\uparrow$(e, e$'$)

**Motivation**

\[ A_y = \frac{\sigma^\uparrow - \sigma^\downarrow}{\sigma^\uparrow + \sigma^\downarrow} \]

\[ \propto \mathbf{s} \cdot (\mathbf{k} \times \mathbf{k}') \]

- $A_y = 0$ in Born approximation ($T$-invariance)
- $A_y \neq 0$ indicative of $2\gamma$ effects, $\propto \text{Im}\{T_1\gamma T_2^{*}\gamma\}$ interference; relevant for $G_E^p/G_M^p$, GPDs
- no measurement of comparable precision on neutron
Single-spin asymmetry in QE $^3$He$^\uparrow$ (e, e')

$$A_y(-\theta) = -A_y(\theta)$$

| $E_0$ [GeV] | $E'$ [GeV] | $\theta_{lab}$ [Deg] | $Q^2$ [GeV]$^2$ | $|q|$ [GeV] | $\theta_q$ [Deg] |
|--------------|-------------|---------------------|----------------|-------------|----------------|
| 1.25         | 1.22        | 17                  | 0.13           | 0.359       | 71             |
| 2.43         | 2.18        | 17                  | 0.46           | 0.681       | 62             |
| 3.61         | 3.09        | 17                  | 0.98           | 0.988       | 54             |

Figure & table courtesy of Yawei Zhang, Rutgers
Single-spin asymmetry in QE $^3\text{He}^{\uparrow}(e, e')$

- First measurement of $A_y^n$ (extracted from transversely polarized $A_y^{^3\text{He}}$)
- Uncertainty several times better than previous proton data
- Asymmetry clearly non-zero and negative

Zhang++ PRL 115 (2015) 172502
Single-spin asymmetries in $^{12}\text{C}(e^\uparrow, e')$

MAMI/A1

- Several calculations for $A_\gamma$ in p(e$^\uparrow$, e), very few on nuclei
- Generalization of forward inclusive model to nuclear targets:

$$A_\gamma \sim C_0 \log \left( \frac{Q^2}{m_e^2 c^2} \right) \frac{F_{\text{Compton}}(Q^2)}{F_{\text{charge}}(Q^2)}$$
Single-spin asymmetries in QE $^3$He($\bar{e}, e'\eta$)

- Ideal probe of FSI and MEC
- Should be zero in PWIA and should die out at high $Q^2$
- Difficult calculations at high $Q^2$
Table 5: Experimental results for $A_0$ scaled by $10^{-2}$. 

$\langle Q^2 \rangle (\text{GeV}/c)^2$ $A_0^y \pm \delta A_{\text{stat}}$ $A_0^y \pm \delta A_{\text{sys}}$

$0.46^{+2.3}_{-1.5} \pm 0.58 \pm 0.43$ Krafft, et al., J. Phys. Conf. Ser. 299 (2011) 012015.

[14] R. Subedi, Studying Short-Range Correlations with the

$\Rightarrow$ PWIA good enough for high-$Q^2$ experiments at JLab 12 GeV!
Double-spin asymmetries in QE $^3\text{He}(\bar{e}, e'\text{n})$

$Q^2 \approx 0.5$

$Q^2 \approx 0.95$

- Calculations?

*** PRELIMINARY *** Figures courtesy of Elena Long, UNH
Triple-polarized $^3\text{He}(\vec{e}, e'\vec{p})$

- PWIA: $\sigma_L$, $\sigma_T$, $\sigma_T'$ yield spin-dependent momentum distribution
- FSI, MEC preclude direct access except at $p_d \lesssim 2 \text{ fm}^{-1}$
- Rich interplay $\triangleright$ **final-state symmetrization:** large effect in $C_3$
  $\triangleright$ **FSI:** largest in $C_2$
  $\triangleright$ **MEC:** most prominent in $C_1$

Fig. courtesy of M. Distler, JGU Mainz
Triple-polarized $^3\text{He}(\vec{e}, \vec{e}'\vec{p})$

- Spin-dependent momentum distributions of $\vec{p}\vec{d}$ clusters in polarized $^3\text{He}$

Golak++ PRC 65 (2002) 064004

\[ N_\mu = \left\langle \Psi_{pd}^{(-)} M_d m | \hat{j}_\mu(q) | \Psi M \right\rangle \]

\[ y \left( M = \frac{1}{2}, M_d = 0, m = +\frac{1}{2} \right) \propto \left| N_{-1}^{\text{spin PWIA}} \left( \frac{1}{2}, 0, -\frac{1}{2} \right) \right|^2 \]

\[ y \left( M = \frac{1}{2}, M_d = 1, m = -\frac{1}{2} \right) \propto \left| N_{+1}^{\text{spin PWIA}} \left( \frac{1}{2}, 1, +\frac{1}{2} \right) \right|^2 \]

\[ A = \frac{y(1/2, 0, 1/2) - y(1/2, 1, -1/2)}{y(1/2, 0, 1/2) + y(1/2, 1, -1/2)} \]

\[ \sigma_L \propto |N_0|^2 \]

\[ \sigma_T \propto |N_{+1}|^2 + |N_{-1}|^2 \]

\[ \sigma_{T'} \propto |N_{+1}|^2 - |N_{-1}|^2 \]
Form-factor modification in medium

- Observable $Q^2$- and $\rho$-dependent effects predicted by various models
- Exploit polarization-transfer technique in $\approx$ QE proton knock-out:

$$\frac{G_E^p}{G_M^p} = -\frac{P'_x}{P'_z} \frac{E_e + E'_e}{2M_p} \tan \frac{\theta_e}{2} \quad \Rightarrow \quad \left( \frac{P'_x}{P'_z} \right)_A / \left( \frac{P'_x}{P'_z} \right)_p$$

\[ A \, X(\vec{e}, e' \vec{p}) \, A^{-1} \, X \]
Form-factor modification: calculations for $^{12}\text{C}$

- Different shells $\Leftrightarrow$ different local densities // Ron++ PRC 87 (2013) 028202
- Disentangle via $E_m$ cuts
- Need to explore $\pm p_m$ and $\pm \nu$ regions (no a priori symmetry)
Form-factor modification in medium: “universality”

- Virtuality: \( \nu = p^2 - m_p^2 \) or, better, \( \nu = \left( m_A - \sqrt{m_{A-1}^2 + p_m^2} \right)^2 - p_m^2 - m_p^2 \)
- Relevant variable: \( \nu \). No \( A \)-dependence ("universality")
- Largest effects due to FSI and WF of proton in nucleus, not due to FF modification — hard to disentangle \( \Rightarrow \) new JLab proposal at higher \( Q^2 \)
Preliminary results on $^{12}$C $P'_x$ and $P'_z$ (not ratios)

Figs courtesy of T. Kolar
Any Questions?
Acceptance-averaging of $^3\text{He}(\tilde{e}, e'p)$ and $^3\text{He}(\tilde{e}, e'd)p$

- Calculations available only on a discrete kinematic mesh acceptance averaging needed
- Decision: Manipulate calculations — not data
- Asymmetry for each $(E', \theta_e)$ at each $(p_m, \theta_{xq})$ determined by calculating the weighted mean of the nearest points
- Weak dependence on cell size
- Data at $Q^2 = 0.25$ and 0.35 GeV$^2$, only first set published: PRL 113 (2014) 232505
“Fine-tuning” the calculations for $^3\text{He}(\bar{e}, e'p)$

- **Rescale 3bbu calculations** to roughly match magnitude and zero-crossing of $A$
  
  - $A = \frac{\sigma_2 A_2 + \sigma_3 A_3}{\sigma_2 + \sigma_3} = \frac{A_2 + A_3 R_{32}}{1 + R_{32}}$
  
  - $\approx 30\text{-}40\%$ reduction needed
Extraction of $A^n_\gamma$ from $A^{3\text{He}}_\gamma$ — effective polarization approximation:

$$A^{3\text{He}}_\gamma = P_n f_n A^n_\gamma + P_p (1 - f_n) A^p_\gamma$$

$$f_n = \frac{\sigma^n}{\sigma^{3\text{He}}} = \frac{\sigma^n}{2\sigma^p + \sigma^n}$$

$$P_n = 0.86 \pm \cdots \quad P_p = -0.028 \pm \cdots$$

high $Q^2$: $f_n$ computed with Kelly’s parameterization of nucleon FFs

low $Q^2$: theoretical estimate (due to FSI): $f_n = 0.042$ (A. Deltuva)

$A^p_\gamma$ computed by Afanasev et al.