Parity-Violating Effects in Few-Nucleon Systems

Joe Carlson (LANL)
Rocco Schiavilla (JLAB/ODU)
Alejandro Kievsky (INFN-Pisa)
Laura Marcucci (U-Pisa)
Michele Viviani (INFN-Pisa)

Mark Paris (JLAB)
Ben Gibson (LANL)
Virginia Brown (MIT-UMD)
Outline

- A realistic model of strong and electromagnetic interactions in nuclei: an update
- From PV observables to PV interactions in few-nucleon (mostly $NN$) systems: model dependence
- Effects of hadronic weak interactions in $d(e, e')np$ at quasielastic kinematics
- Summary (I)
- Isospin mixing in the nucleon and $^4$He and the PV asymmetry in $^4$He$(e, e')^4$He
- Summary (II)
Nuclear Interactions

- $NN$ interactions alone fail to predict:
  1. spectra of light nuclei
  2. $Nd$ scattering
  3. nuclear matter $E_0(\rho)$

- $2\pi$-$NNN$ interactions:

  \[
  A_{pw}^{2\pi} + A_{sw}^{2\pi} \quad \text{very weak}
  \]

  EFT w/o explicit $\Delta$’s overestimates strength of $V_{pw}^{2\pi}$

  Pandharipande et al., PRC71, 064002 (2005)

- $V^{2\pi}$ alone does not fix problems above
Proton-Deuteron Elastic Scattering

Ermisch et al. (KVI collaboration), PRC 71, 064004 (2005); Kalantar-Nayestanaki, private communication.
Beyond $2\pi$-exchange (IL2 model)

\[ V^{2\pi} + A^{3\pi} + A \sum_{\text{cyc}} T^2(r_{ij})T^2(r_{jk}) \]

parameters ($\sim 3$) fixed by a best fit to the energies of low-lying states of nuclei with $A \leq 8$

- AV18/IL2 Hamiltonian reproduces well spectra of $A=9$–$12$ nuclei
- but needs to be tested in three- and four-nucleon scattering (work by the Pisa group is in progress)
- $A_y$ puzzle in 4-body scattering: strong isospin dependence, discrepancy in $^3\text{H}-p$ or $^3\text{He}-n$ much reduced relative to $^3\text{He}-p$

(Deltuva and Fonseca, PRL98, 162502 (2007) and nucl-th/0703066)
Nuclear Electromagnetic Currents

Marcucci et al., PRC\textbf{72}, 014001 (2005)

\[ j = j^{(1)} + j^{(2)}(v) + j^{(3)}(V^{2\pi}) \]

- Gauge invariant:

\[ q \cdot \left[ j^{(1)} + j^{(2)}(v) + j^{(3)}(V^{2\pi}) \right] = \left[ T + v + V^{2\pi}, \rho \right] \]

\( \rho \) is the nuclear charge operator
Terms from static part $v_0$ of $v$:

$$j_{ij}(v_0; \text{leading}) = \left( \tau_i \times \tau_j \right)_z \left[ v_{PS}(k_j) \sigma_i (\sigma_j \cdot k_j) \right. + \left. \frac{k_i - k_j}{k_i^2 - k_j^2} v_{PS}(k_i) (\sigma_i \cdot k_i) (\sigma_j \cdot k_j) \right] + i \Rightarrow j$$

with $v_{PS} = v^{\sigma \tau} - 2 v^{t \tau}$

- $j^{(2)}(v_0)$ satisfies:

$$j^{(2)}(v_0) \xrightarrow{\text{long range}} \pi + \pi + \pi$$
$^1H(n,\gamma)^2H$ capture

Deuteron threshold photodisintegration

- AV18
- BONN
- AV18 (M1 only)
- EFT (M1 to N^2LO, E1 to N^4LO)

$\sigma(\omega)(fm^2)$ vs $\omega$(MeV)

$\sigma(\omega)(mb) \times v(m/nsec) \times 10^4$ vs $E_n$(keV)
$^2\text{H}(p, \gamma)^3\text{He}$ Radiative Capture at $E \leq 50$ keV

Marcucci et al., PRC 72, 014001 (2005)

- Suppressed process, $S$- and $P$-wave capture both important

\[
\begin{array}{c|c}
S(E = 0) \text{ (eV b)} \\
\hline
\text{Theory} & 0.219 \\
\text{LUNA} & 0.216 \pm 0.010 \\
\end{array}
\]

however, $^2\text{H}(n, \gamma)^3\text{H}$ experimental cross section at thermal energies is overestimated by theory by $\approx 9\%$
Constraining PV interactions

- $A_z$ in $\bar{p}p$ scattering
- $A^\gamma$ in $\bar{n}p$ capture and $P^\gamma$ in $d(\gamma, n)p$
- Neutron spin rotation in $\bar{n}p$ (and $\bar{n}\alpha$) scattering
Longitudinal Asymmetry in $\bar{p}p$ Scattering

Liu et al., PRC\textbf{73}, 065501 (2006); Carlson et al., PRC\textbf{65}, 035502 (2002); Driscoll and Miller, PRC\textbf{39}, 1951 (1989)

$$A_z = \frac{[\sigma(+) - \sigma(-)]}{[\sigma(+) + \sigma(-)]}$$

$$= \text{Im} \left[ M(S = 0 \text{ or } 1 \rightarrow S' = 1 \text{ or } 0) \right]$$

$M$=scattering amplitude

- PC potentials forbid $|S - S'| = 1$ transitions
- $A_z$ is the “nuclear” asymmetry, Coulomb effects need to be included
- DDH model for PV potential:

\[ v^{PV} = -g_{\rho} \frac{\hbar^{pp}_\rho}{m} \left[ (\sigma_1 - \sigma_2) \cdot \left\{ \mathbf{p}, Y_\rho(r) \right\} + (1 + \kappa_\rho)Y'_\rho(r)\sigma_1 \times \sigma_2 \cdot \hat{r} \right] \]

\[ -g_{\omega} \frac{\hbar^{pp}_\omega}{m} \left[ \rho \rightarrow \omega \right] \]

with

\[ Y_\alpha(r) = \frac{1}{4\pi r} \left[ e^{-m_\alpha r} - e^{-\Lambda_\alpha r} \left[ 1 + \frac{1}{2} \left( 1 - \frac{m^2_\alpha}{\Lambda^2_\alpha} \right) \Lambda_\alpha r \right] \right] \]

- \( v^{PV} \) acts only in even \( J \) channels: at low and moderate \( T_{lab} \) the \( ^1S_0-^3P_0 \) and \( ^1D_2-^3P_2 \) are the relevant PV mixings

- EFT version of \( v^{PV} \) has same structure, but with \( Y(r) \) replaced by \( \sim \delta \)-function [Zhu et al., NPA748, 435 (2005)]
$A_z$ in $\bar{p}p$ Elastic Scattering

\[ A^{(J=0)} \sim h_{\rho}^{pp} g_{\rho}(2 + \kappa_{\rho}) + h_{\omega}^{pp} g_{\omega}(2 + \kappa_{\omega}) \]
\[ A^{(J=2)} \sim h_{\rho}^{pp} g_{\rho} \kappa_{\rho} + h_{\omega}^{pp} g_{\omega} \kappa_{\omega} \]

Strong correlation between $h_{\rho}^{pp}$ and $h_{\omega}^{pp}$
Sensitivity to modeling of short-range $v^{PV}$
Photon Asymmetry in $^{1}H(\vec{n},\gamma)^{2}H$ Radiative Capture

- Measure correlation $a^\gamma \cos \theta$ between $n$ spin and $\gamma$ momentum:

$$a^\gamma = -\frac{\sqrt{2} \text{Re} (M_1^* E_1)}{|M_1|^2}$$

with

$M_1$: $|^{1}S_0; \text{PC}\rangle \rightarrow | d; \text{PC}\rangle$ well known transition

$E_1$: $|^{3}S_1; \text{PC}\rangle \rightarrow | d; \text{PV}\rangle$

$|^{3}P_1; \text{PV}\rangle \rightarrow | d; \text{PC}\rangle$

- $^{3}P_1$ PV wave functions in $d$ and continuum dominated by $v_\pi^{PV}$:

$$v_\pi^{PV}(T = 0 \rightarrow T = 1) = -i \frac{g_\pi h_\pi}{\sqrt{2}m} Y'_\pi(r) (\sigma_1 + \sigma_2) \cdot \hat{r}$$

+ vector meson terms
PC and PV Deuteron Wave Functions

\[ u_{\text{LST}}(r) \sim (\frac{1}{2}) \text{PC}^3S_1 \text{D}_1 \]

\[ u_{\text{LST}}(r) \sim (\frac{1}{2}) \text{PV}^3P_1 \text{x10}^7 \]

\[ u_{\text{LST}}(r) \sim (\frac{1}{2}) \text{PV}^3P_1 \text{no} \pi \text{in DDH} \]

\[ u_{\text{LST}}(r) \sim (\frac{1}{2}) \text{AV18} \text{BONN2000} \]

\[ u_{\text{LST}}(r) \sim (\frac{1}{2}) \text{AV18} \text{BONN2000} \]

\[ u_{\text{LST}}(r) \sim (\frac{1}{2}) \text{AV18} \text{BONN2000} \]
• Contributions to $a^\gamma$ (schematically):

\[
E_1 \sim i \int dx \, \hat{e} \cdot j(x)
\]

• Large cancellations between asymmetries induced by PV interactions and those due to the associated PV MEC

• Potentially large model dependence is minimized via Siegert evaluation of $E_1$:

\[
E_1 \sim \omega_{\gamma} \int dx \, \hat{e} \cdot x \, \rho(x)
\]
<table>
<thead>
<tr>
<th>Interaction</th>
<th>Impulse Current</th>
<th>Full Current</th>
<th>$\sigma_\gamma \text{ (mb)}$</th>
<th>$a_\gamma \times 10^8$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV18</td>
<td>304.6</td>
<td>332.7</td>
<td>DDH$\pi$</td>
<td>DDH</td>
</tr>
<tr>
<td>BONN</td>
<td>306.5</td>
<td>331.6</td>
<td>$-4.97$</td>
<td>$-4.89$</td>
</tr>
<tr>
<td>EXP</td>
<td></td>
<td>332.6±0.7</td>
<td>???</td>
<td></td>
</tr>
</tbody>
</table>

- In units of $h_\pi$, $a_\gamma \simeq -0.11 h_\pi$ in agreement with a number of recent calculations [Desplanques, PLB512, 305 (2001); Hyun et al., PLB516, 321 (2001)]
Helicity-Dependent Asymmetry in $^2\text{H}(\gamma, n)p$ Photodisintegration

In the threshold region ($\simeq 1$ keV above breakup):

$$P^\gamma = -\frac{2 \text{Re} \left( M_1^* E_1 \right)}{|M_1|^2}$$

$E_1$: $|d(1P_1); PV\rangle \rightarrow |1S_0; PC\rangle$

$|d; PC\rangle \rightarrow |3P_0; PV\rangle$

- $\nu^\text{PV}_\pi$ does not contribute

- $P^\gamma$ exhibits large sensitivity to modeling of short range strong and weak $NN$ interactions

$P^\gamma$ in units of $10^{-8}$

<table>
<thead>
<tr>
<th></th>
<th>AV18+DDH</th>
<th>BONN+DDH</th>
<th>AV18+DDH$\pi$</th>
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</thead>
<tbody>
<tr>
<td>Impulse</td>
<td>5.44</td>
<td>9.41</td>
<td>-0.035</td>
</tr>
<tr>
<td>Full</td>
<td>5.19</td>
<td>9.05</td>
<td>-0.037</td>
</tr>
</tbody>
</table>
At higher energies, remarks in previous slide remain valid:
Neutron Spin Rotation

- Transmission of a low energy neutron through matter:

\[ e^{ipz}|\sigma> \quad e^{i(p(z-d)+pdn)\sigma}|\sigma> \]

\[ d \]

\[ n_\sigma = 1 + \frac{2\pi \rho}{p^2} M_\sigma(\theta = 0) \]

- PV observable:

\[ \frac{d\phi}{dd} = -\frac{2\pi \rho}{p} Re [M_+(\theta = 0) - M_-(\theta = 0)] \]
\[ \frac{d\phi}{dd} \text{ in units of } 10^{-9} \text{ rad/cm} \]

<table>
<thead>
<tr>
<th></th>
<th>DDH</th>
<th>DDH(\pi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV18</td>
<td>5.09</td>
<td>5.21</td>
</tr>
<tr>
<td>BONN</td>
<td>4.63</td>
<td>5.18</td>
</tr>
<tr>
<td>Plane waves</td>
<td>-5.67</td>
<td>-6.87</td>
</tr>
</tbody>
</table>

- Earlier study \([\text{Avishai and Grange, JPG10, L263 (1984)}]\) finds, incorrectly, the same sign w/ and w/o strong interaction leading term \(\sim \langle {}^3S_1 \mid v_{\pi}^{\text{PV}} \mid {}^3P_1 \rangle \)
Neutron Spin Rotation in $^4$He

Pion PV Matrix Element

GFMC $\langle 1/2^- | V^\pi | 1/2^+ \rangle$
\[ A^{\text{th}}(Q^2 = 0.038 \text{GeV/c}) = -2.14 + 0.27 G^{s}_M + 0.76 G^{(e)}_{A,T=1} \]

\[ A^{\text{th}}(Q^2 = 0.091 \text{GeV/c}) = -7.06 + 0.77 G^{s}_M + 1.66 G^{(e)}_{A,T=1} \]
\[ A = \left( A_{\gamma} + A_{\gamma\gamma} \right) \]

\[ A_{\gamma\gamma} \text{ well known, } A_{\gamma\gamma} \sim \sum_{i,f} \text{Im} \left[ j_{fi}(\gamma) \times j_{fi}^*(\gamma) \right]_z \delta(\omega + E_i - E_f) \]

\[ A_{\gamma\gamma} \text{ (related to } P^\gamma \text{ at the photon point) originates from:} \]

1. Small \( |\text{PV}\rangle \) components induced by \( v^{\text{PV}} \) into \( |\text{PC}\rangle \) states
2. \( j_2^{\text{PV}} \) associated with \( v^{\text{PV}} \)
3. anapole contributions: \( a(q^2)\overline{u}'(qq^\sigma - q^2\gamma^\sigma)\gamma_5 u/m^2 \)

\[ a(q^2) = \frac{g_\pi h_\pi}{8 \sqrt{2} \pi^2} (\alpha_S + \alpha_V \tau_z) \]

with estimates for \( \alpha_S \) and \( \alpha_V \) from either pion loops (Musolf et al.), or the quark model (Riska), or EFT (Maekawa and van Kolck)
Sample-III Kinematics

\[ \left| A_{\gamma\gamma} \right| \text{ two orders of magnitude smaller than } \left| A_{\gamma Z} \right| \]
Summary (I)

- $A_z(\bar{p}p)$ is weakly dependent on input $v^{PC}$, but sensitive to short-range modeling of $v^{PV}$

- $A^\gamma(\bar{n}p)$ and, to a less extent, the neutron spin rotation provide the “cleanest” determination of $h_\pi$

- $P^\gamma(d\gamma)$ is strongly affected by short-range modeling of both $v^{PC}$ and $v^{PV}$

- PV electrodisintegration of the deuteron at quasielastic kinematics probes, almost exclusively, $\gamma Z$ interference on individual nucleons

- Outlook:
  1. GFMC studies of $\bar{n}$- and $\bar{p}$-α scattering
  2. Possibly, HH studies of $\bar{n}^2$H and $\bar{n}^3$He radiative captures
\[ A_{PV} = -\frac{G_{\mu} Q^2}{4\pi \alpha \sqrt{2}} \frac{\langle ^4\text{He} | j_{\mu=0}^{\text{NC}} | ^4\text{He} \rangle}{\langle ^4\text{He} | j_{\mu=0}^{\text{EM}} | ^4\text{He} \rangle} \to \frac{G_{\mu} Q^2}{4\pi \alpha \sqrt{2}} 4 s_W^2 \]

where

\[
\begin{align*}
    j_{\text{EM}}^{\mu=0} &= j^{(0)} + j^{(1)} \\
    j_{\text{NC}}^{\mu=0} &= -4 s_W^2 j^{(0)} + (2 - 4 s_W^2) j^{(1)} - j^{(s)}
\end{align*}
\]

- \( A_{PV} \) sensitive to \( G_E^s(Q^2) \), provided negligible:
  1. relativistic corrections (RC) and MEC contributions
  2. isospin symmetry breaking (ISB) in the nucleon and \(^4\text{He}\)
- At low \( Q^2 \), RC+MEC contributions calculated to be tiny\(^a\)

\(^a\)Musolf, Schiavilla, and Donnelly, PRC\textbf{50}, 2173 (1994)
Parameterizing ISB in the nucleon

Dmitrasinović and Pollock, PRC 52, 1061 (1995); Kubis and Lewis, PRC 74, 015204 (2006)

In terms of the measured $G_{E}^{p/n} = \langle p/n | j_{\mu =0}^{\mu} | p/n \rangle$:

\[
\frac{(G_{E}^{p} + G_{E}^{n})}{2} = G_{E}^{0} + G_{E}^{I} \quad (G_{E}^{p} - G_{E}^{n})/2 = G_{E}^{1} + G_{E}^{\phi}
\]

from which

\[
G_{E}^{p,Z} = (1 - 4s_{W}^{2})G_{E}^{p} - G_{E}^{n} + 2(G_{E}^{I} - G_{E}^{\phi}) - G_{E}^{s}
\]
\[
G_{E}^{n,Z} = (1 - 4s_{W}^{2})G_{E}^{n} - G_{E}^{p} + 2(G_{E}^{I} + G_{E}^{\phi}) - G_{E}^{s}
\]

where ISB in $G_{E}^{s}$ are ignored: $\langle p | j^{(s)} | p \rangle = \langle n | j^{(s)} | n \rangle \rightarrow G_{E}^{s}(Q^{2})$
Nuclear EM and NC (Vector) Charge Operators

\[ \rho^{(\text{EM})}(q) = G^p_E \sum_{k=1}^{Z} e^{i\mathbf{q} \cdot \mathbf{r}_k} + G^n_E \sum_{k=Z+1}^{A} e^{i\mathbf{q} \cdot \mathbf{r}_k} \equiv \rho^{(0)}(q) + \rho^{(1)}(q) \]

\[ \rho^{(0)}(q) = \frac{G^p_E + G^n_E}{2} \sum_{k=1}^{A} e^{i\mathbf{q} \cdot \mathbf{r}_k} \]

\[ \rho^{(1)}(q) = \frac{G^p_E - G^n_E}{2} \left( \sum_{k=1}^{Z} e^{i\mathbf{q} \cdot \mathbf{r}_k} - \sum_{k=Z+1}^{A} e^{i\mathbf{q} \cdot \mathbf{r}_k} \right) \]

With \( G^p/n \rightarrow G^p/n,Z \), \( \rho^{(\text{NC})}(q) \) can be written as

\[ \rho^{(\text{NC})}(q) = -4s_W^2 \rho^{(\text{EM})}(q) + \frac{2 G^I_E - G^s_E}{(G^p_E + G^n_E)/2} \rho^{(0)}(q) \]

\[ + 2 \rho^{(1)}(q) - \frac{2 G^\phi_E}{(G^p_E - G^n_E)/2} \rho^{(1)}(q) \]
Up to linear terms in ISB corrections:

\[ A_{PV} = \frac{G_{\mu} Q^2}{4\pi \alpha \sqrt{2}} \left[ 4 s_W^2 - 2 \frac{F^{(1)}(q)}{F^{(0)}(q)} - \frac{2 G_E^I - G_E^s}{(G_E^p + G_E^n)/2} + \text{RC/MEC} \right] \]

where

\[ \langle ^4\text{He}|\rho^{(a)}(q)|^4\text{He}\rangle/Z \equiv F^{(a)}(q) , \quad a = \text{EM, 0, 1} \]

The HAPPEX collaboration [PRL98, 032301 (2007)] reports:

\[ A_{PV}[Q^2 = 0.077 \text{ (GeV/c)}^2] = [+6.40 \pm 0.23 \text{ (stat)} \pm 0.12 \text{ (syst)}] \text{ppm} \]

from which, using \( G_\mu = 1.16637 \times 10^{-5} \text{ GeV}^{-2} \), \( \alpha = 1/137.036 \), and \( s_W^2 = 0.2286 \) (with radiative corrections),

\[ \Gamma \equiv -2 \frac{F^{(1)}(q)}{F^{(0)}(q)} - \frac{2 G_E^I - G_E^s}{(G_E^p + G_E^n)/2} = 0.010 \pm 0.038 \]
Up to NLO in ChPT:

1. Loop effects due $\Delta m = m_n - m_p$

2. A single counterterm, fixed by resonance saturation
\begin{align*}
G^I_E(Q^2) &= -\frac{g_A^2 m_N \Delta m}{F_\pi^2} \left\{ \frac{M_\pi}{m_N} \left[ \overline{\gamma}_0(-Q^2) - 4\overline{\gamma}_3(-Q^2) \right] \\
&\quad - \frac{Q^2}{2m_N^2} \left[ \xi(-Q^2) - \frac{M_\pi}{m_N} \left[ \overline{\gamma}_0(-Q^2) - 5\overline{\gamma}_3(-Q^2) \right] \\
&\quad - \frac{1}{16\pi^2} \left( 1 + 2\log \frac{M_\pi}{M_V} - \frac{\pi(\kappa^v + 6)M_\pi}{2m_N} \right) \right\} \\
&\quad + \frac{g_\omega F_\rho \Theta_{\rho\omega} Q^2}{2M_V(M_V^2 + Q^2)^2} \left( 1 + \frac{\kappa_\omega M_V^2}{4m_N^2} \right)
\end{align*}

- $\overline{\gamma}_0$, $\overline{\gamma}_3$, and $\xi$ are loop functions: $\propto Q^2$ as $Q^2 \to 0$
- Largest uncertainty in $\omega$ tensor coupling $\kappa_\omega$
• Band provides an estimate of higher order ChPT corrections as well as of uncertainties in vector-meson couplings

• At \( Q^2 = 0.077 \) (GeV/c)^2:

\[
- \frac{2 \frac{d}{Q^2}}{\left( \frac{d}{Q^2} + \frac{d}{Q^2} \right)/2} = 0.008 \pm 0.003
\]
ISB Corrections (II): $^4$He Nucleus

Nuclear ISB Hamiltonian: $H_{\text{ISB}} = H_C + H_{\text{CD/CA}} + H_{\text{EM}} + K_{\Delta}$

- $H_C$ from (point) Coulomb interaction
- $H_{\text{CD/CA}}$ from CD and CA strong-interactions
- $H_{\text{EM}}$ from remaining EM interactions (magnetic moments, ...)
- $K_{\Delta}$ from $n$-$p$ mass difference in kinetic energy

Viviani, Kievsky, and Rosati, PRC 71, 024006 (2005)

<table>
<thead>
<tr>
<th>ISB term (AV18)</th>
<th>$P^{(1)}$ %</th>
<th>$P^{(2)}$ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_C$</td>
<td>$1.5 \times 10^{-3}$</td>
<td>$0.1 \times 10^{-3}$</td>
</tr>
<tr>
<td>$H_C + H_{\text{CD/CA}}$</td>
<td>$3.0 \times 10^{-3}$</td>
<td>$4.9 \times 10^{-3}$</td>
</tr>
<tr>
<td>$H_C + H_{\text{CD/CA}} + H_{\text{EM}}$</td>
<td>$2.8 \times 10^{-3}$</td>
<td>$5.2 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
Contributions of ISB terms to isomultiplet energies (keV)

Pieper, Pandharipande, Wiringa, and Carlson, PRC 64, 014001 (2001)

<table>
<thead>
<tr>
<th>A</th>
<th>T</th>
<th>n</th>
<th>$K_\Delta$</th>
<th>$H_C$</th>
<th>$H_{EM}$</th>
<th>$H_{CD/CA}$</th>
<th>TOT</th>
<th>EXP</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1/2</td>
<td>1</td>
<td>14(0)</td>
<td>649(1)</td>
<td>29(0)</td>
<td>64(0)</td>
<td>757(1)</td>
<td>764</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1</td>
<td>16(0)</td>
<td>1091(5)</td>
<td>18(0)</td>
<td>47(1)</td>
<td>1172(6)</td>
<td>1173</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1</td>
<td>23(0)</td>
<td>1686(5)</td>
<td>24(0)</td>
<td>76(1)</td>
<td>1810(6)</td>
<td>1770</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>2</td>
<td></td>
<td>166(1)</td>
<td>19(0)</td>
<td>107(13)</td>
<td>293(13)</td>
<td>223</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>2</td>
<td></td>
<td>141(1)</td>
<td>4(0)</td>
<td>−3(8)</td>
<td>143(8)</td>
<td>145</td>
</tr>
</tbody>
</table>

- Good overall agreement between theory and experiment
Weak model dependence

- $F^{(1)}$ scales as $\approx \sqrt{P^{(1)}}$; RC/MEC small at low $q$ ($\leq 1.5$ fm$^{-1}$)
- $F^{(1)}/F^{(0)} \approx -0.00157$ from AV18/UIX and CDB/UIXb
Summary

Using: i) \(-2 \frac{G_E^I}{[(G_E^p + G_E^n)/2]} \approx 0.008\) for hadronic ISB

\[\text{ii) } -2 \frac{F^{(1)}(q)}{F^{(0)}(q)} \approx 0.00314\] for nuclear ISB

in

\[\Gamma \equiv -2 \frac{F^{(1)}(q)}{F^{(0)}(q)} - \frac{2 G_E^I - G_E^s}{(G_E^p + G_E^n)/2} = 0.010 \pm 0.038\]

gives \(G_E^s [Q^2 = 0.077 \text{ (GeV/c)}^2] = -0.001 \pm 0.016\)

- Measuring ISB admixtures? (arguably ... error on \(\Gamma\) too large!)
- \(G_E^s [Q^2 = 0.1 \text{ (GeV/c)}^2] = +0.001 \pm 0.004 \pm 0.003\) estimated by using LQCD input [Leinweber et al., PRL\textbf{97}, 022001 (2006)]

- At this level, contributions to \(A_{PV}\) induced by PV components in the nuclear potentials need to be studied (competitive with ISB?)