

Parity-Violating Effects in Few-Nucleon Systems

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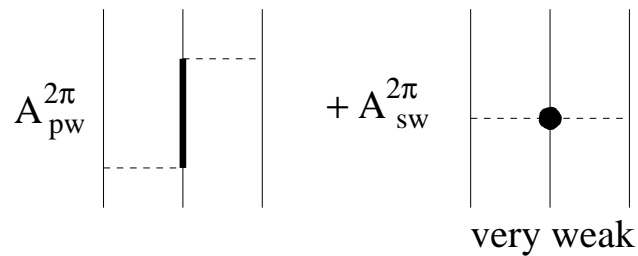
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Outline

- 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 $d(\vec{e}, e')np$ at quasielastic kinematics
- Summary(I)
- Isospin mixing in the nucleon and ${}^4\text{He}$ and the PV asymmetry in ${}^4\text{He}(\vec{e}, e'){}^4\text{He}$
- Summary (II)

Nuclear Interactions

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



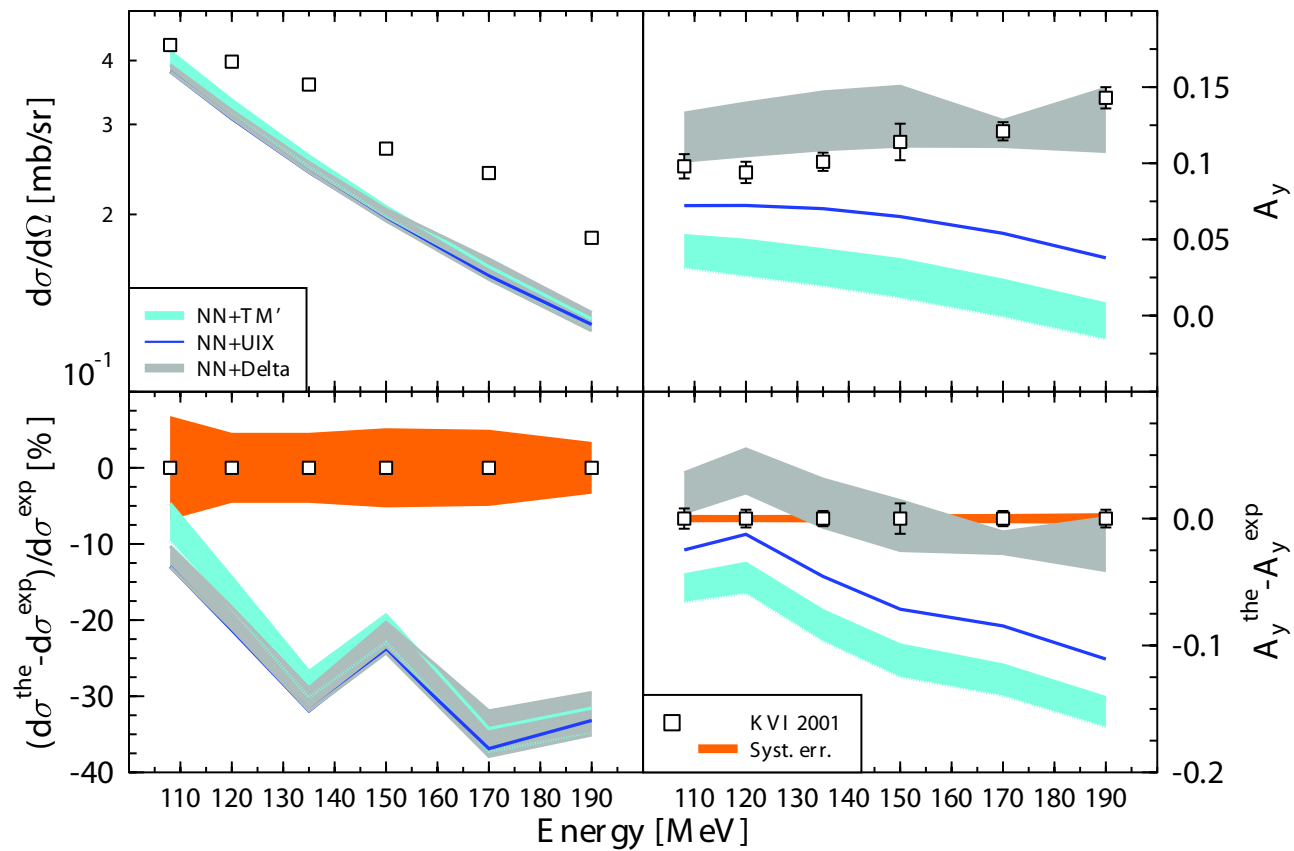
EFT w/o explicit Δ 's overestimates strength of $V_{pw}^{2\pi}$

Pandharipande *et al.*, PRC71, 064002 (2005)

- $V^{2\pi}$ alone does not fix problems above

Proton-Deuteron Elastic Scattering

Ermisch *et al.* (KVI collaboration), PRC71, 064004 (2005); Kalantar-Nayestanaki, private communication



Beyond 2π -exchange (IL2 model)

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

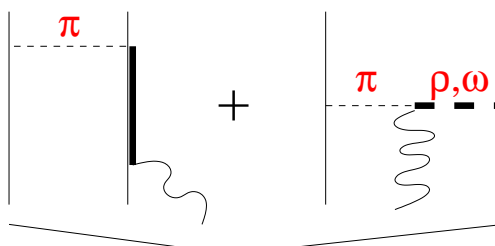
parameters (~ 3) fixed by a best fit to the energies of low-lying states of nuclei with $A \leq 8$

- 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, PRL**98**, 162502 (2007) and nucl-th/0703066)

Nuclear Electromagnetic Currents

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

$$\begin{aligned}
 \mathbf{j} &= \mathbf{j}^{(1)} \\
 &+ \mathbf{j}^{(2)}(v) + \mathbf{j}^{(3)}(V^{2\pi})
 \end{aligned}$$


transverse

- Gauge invariant:

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

ρ is the nuclear charge operator

- Terms from static part v_0 of v :

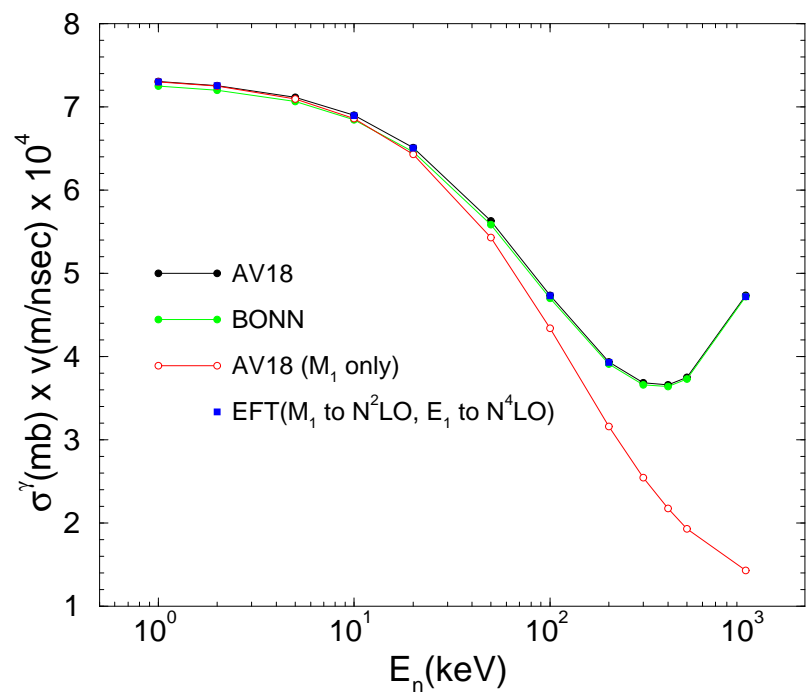
$$\mathbf{j}_{ij}(v_0; \text{leading}) = i (\boldsymbol{\tau}_i \times \boldsymbol{\tau}_j)_z \left[v_{PS}(k_j) \boldsymbol{\sigma}_i (\boldsymbol{\sigma}_j \cdot \mathbf{k}_j) + \frac{\mathbf{k}_i - \mathbf{k}_j}{k_i^2 - k_j^2} v_{PS}(k_i) (\boldsymbol{\sigma}_i \cdot \mathbf{k}_i) (\boldsymbol{\sigma}_j \cdot \mathbf{k}_j) \right] + i \Leftrightarrow j$$

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

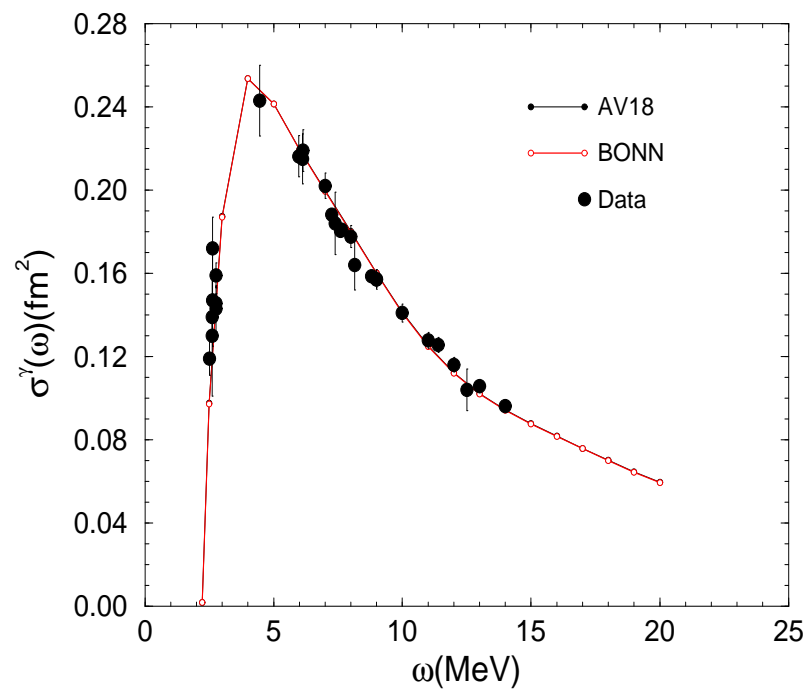
- $\mathbf{j}^{(2)}(v_0)$ satisfies:

$$\mathbf{j}^{(2)}(v_0) \xrightarrow{\text{long range}} \begin{array}{c} | \quad \pi \quad | \\ \text{---} \end{array} + \begin{array}{c} | \quad \pi \quad | \\ \text{---} \end{array} + \begin{array}{c} | \quad \pi \quad \pi \quad | \\ \text{---} \end{array}$$

$^1\text{H}(n,\gamma)^2\text{H}$ capture



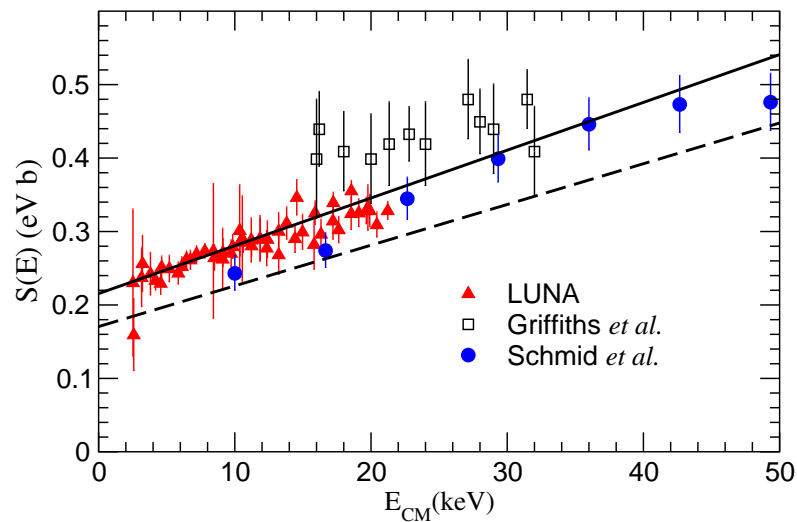
Deuteron threshold photodisintegration



${}^2\text{H}(p, \gamma){}^3\text{He}$ Radiative Capture at $E \leq 50$ keV

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

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



	$S(E = 0)$ (eV b)
Theory	0.219
LUNA	0.216 ± 0.010

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 $\vec{p}p$ scattering
- A^γ in $\vec{n}p$ capture and P^γ in $d(\vec{\gamma}, n)p$
- Neutron spin rotation in $\vec{n}p$ (and $\vec{n}\alpha$) scattering



Longitudinal Asymmetry in $\vec{p}p$ Scattering

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

$$\begin{aligned} A_z &= [\sigma(+)-\sigma(-)]/[\sigma(+)+\sigma(-)] \\ &= \text{Im} [M(S=0 \text{ or } 1 \rightarrow S'=1 \text{ or } 0)] \end{aligned}$$

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:

$$v^{\text{PV}} = -\frac{g_\rho h_\rho^{\text{pp}}}{m} \left[(\boldsymbol{\sigma}_1 - \boldsymbol{\sigma}_2) \cdot \left\{ \mathbf{p}, Y_\rho(r) \right\} + (1 + \kappa_\rho) Y'_\rho(r) \boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2 \cdot \hat{\mathbf{r}} \right]$$

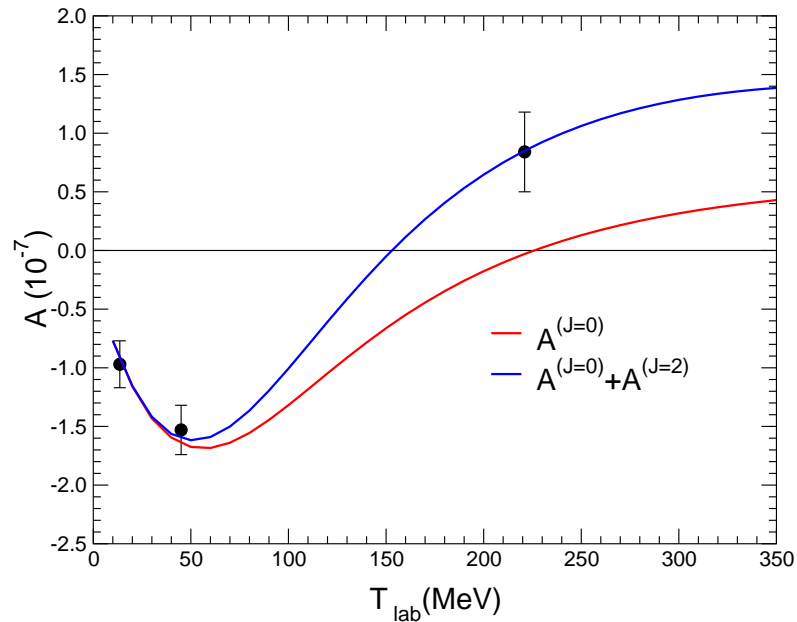
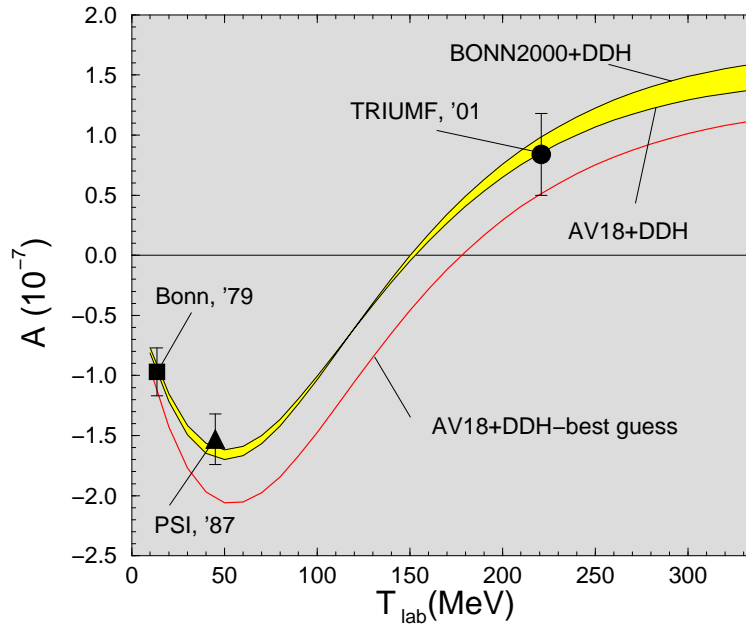
$$-\frac{g_\omega h_\omega^{\text{pp}}}{m} \left[\rho \rightarrow \omega \right]$$

with

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

- v^{PV} acts only in even J channels: at low and moderate T_{lab} the $^1\text{S}_0$ - $^3\text{P}_0$ and $^1\text{D}_2$ - $^3\text{P}_2$ 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.*, NPA**748**, 435 (2005)]

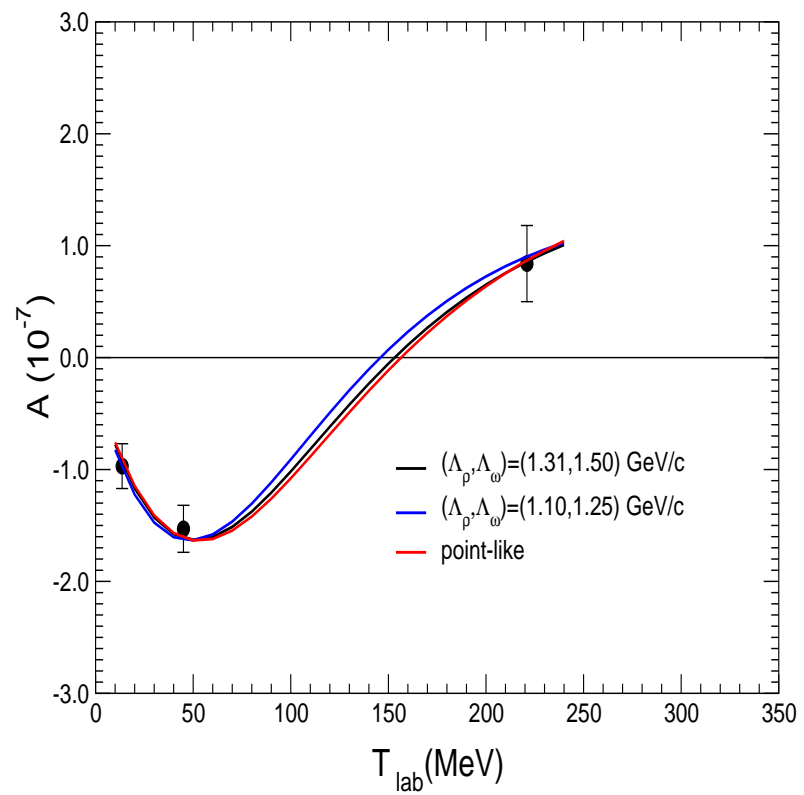
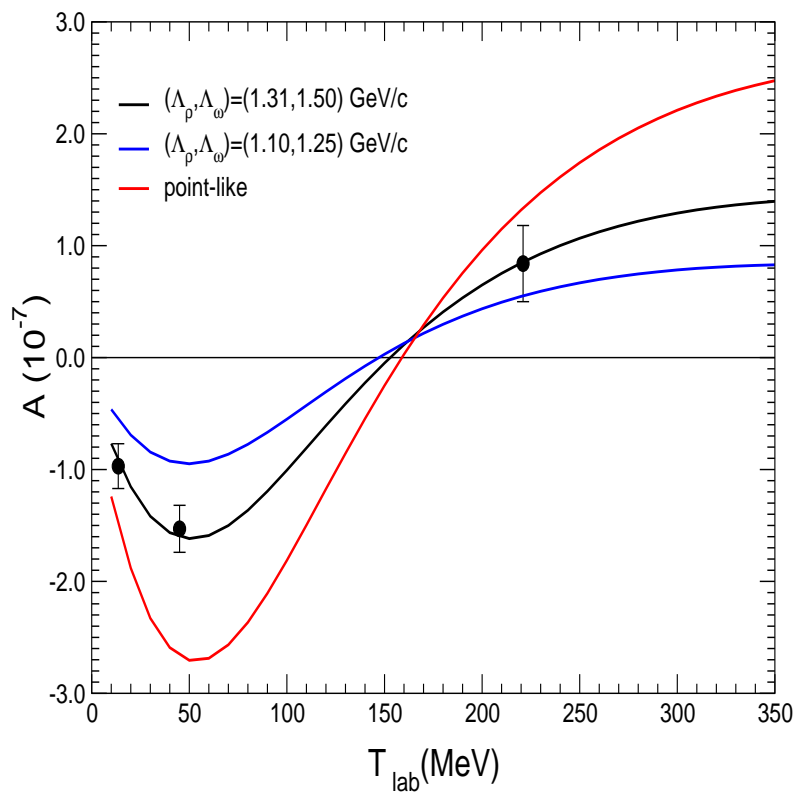
A_z in $\vec{p}p$ Elastic Scattering



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

Strong correlation between h_{ρ}^{pp} and h_{ω}^{pp}

Sensitivity to modeling of short-range v^{PV}



Photon Asymmetry in $^1\text{H}(\vec{n}, \gamma)^2\text{H}$ Radiative Capture

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

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

with

$$M_1: \quad |^1\text{S}_0; \text{PC}\rangle \rightarrow |d; \text{PC}\rangle \quad \text{well known transition}$$

$$E_1: \quad |^3\text{S}_1; \text{PC}\rangle \rightarrow |d; \text{PV}\rangle$$

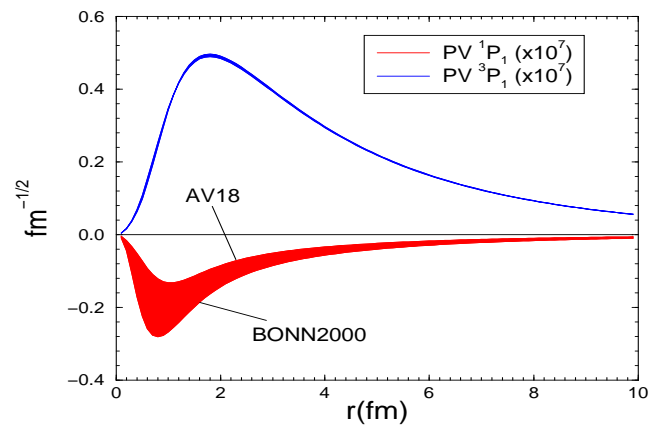
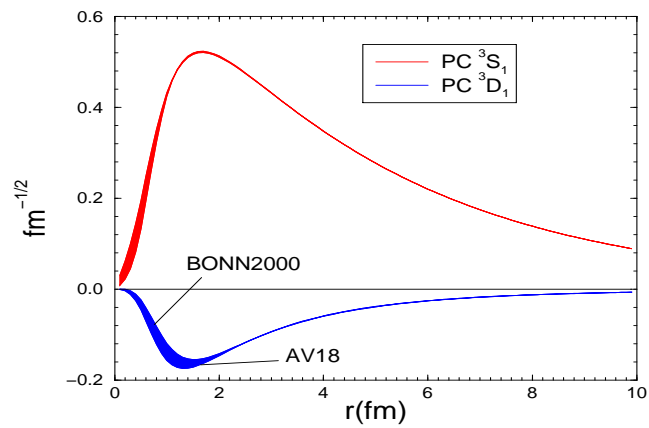
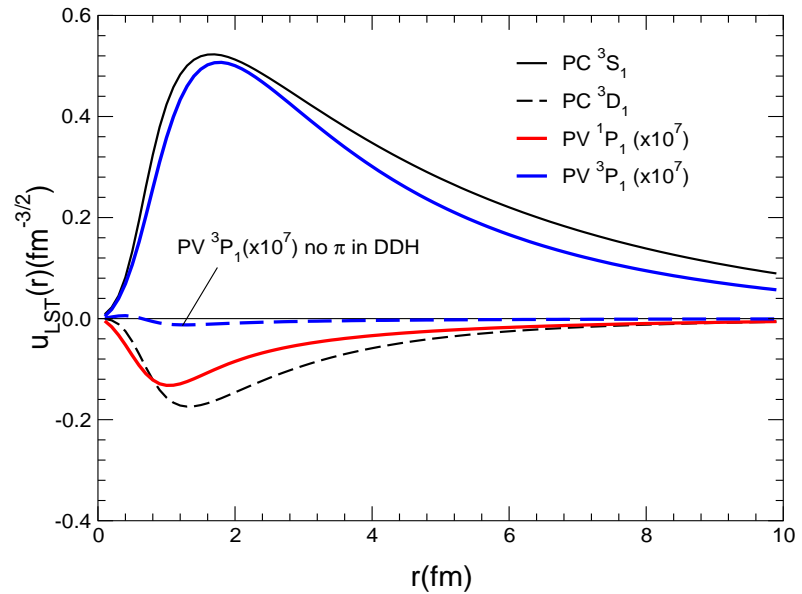
$$|^3\text{P}_1; \text{PV}\rangle \rightarrow |d; \text{PC}\rangle$$

- $^3\text{P}_1$ PV wave functions in d and continuum dominated by v_π^{PV} :

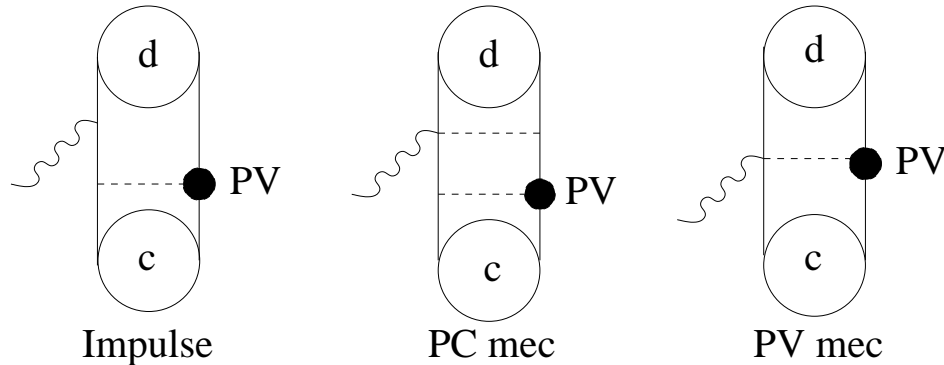
$$v_\pi^{\text{PV}}(T=0 \rightarrow T=1) = -i \frac{g_\pi h_\pi}{\sqrt{2} m} Y'_\pi(r) (\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2) \cdot \hat{\mathbf{r}}$$

+ vector meson terms

PC and PV Deuteron Wave Functions



- Contributions to a^γ (schematically):



$$E_1 \sim i \int d\mathbf{x} \hat{\mathbf{e}} \cdot \mathbf{j}(\mathbf{x})$$

- 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 :

$$E_1 \sim \omega_\gamma \int d\mathbf{x} \hat{\mathbf{e}} \cdot \mathbf{x} \rho(\mathbf{x})$$

Interaction	σ^γ (mb)		$a^\gamma \times 10^8$	
	Impulse Current	Full Current	DDH π	DDH
AV18	304.6	332.7	- 4.98	- 4.92
BONN	306.5	331.6	- 4.97	- 4.89
EXP		332.6 ± 0.7		???

- In units of h_π , $a^\gamma \simeq -0.11 h_\pi$ in agreement with a number of recent calculations [Desplanques, PLB**512**, 305 (2001); Hyun *et al.*, PLB**516**, 321 (2001)]

Helicity-Dependent Asymmetry in ${}^2\text{H}(\vec{\gamma}, n)p$ Photodisintegration

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

$$P^\gamma = -\frac{2 \operatorname{Re}(M_1^* \bar{E}_1)}{|M_1|^2}$$

$$\bar{E}_1: \quad |d({}^1\mathbf{P}_1); \text{PV}\rangle \rightarrow |{}^1\mathbf{S}_0; \text{PC}\rangle$$

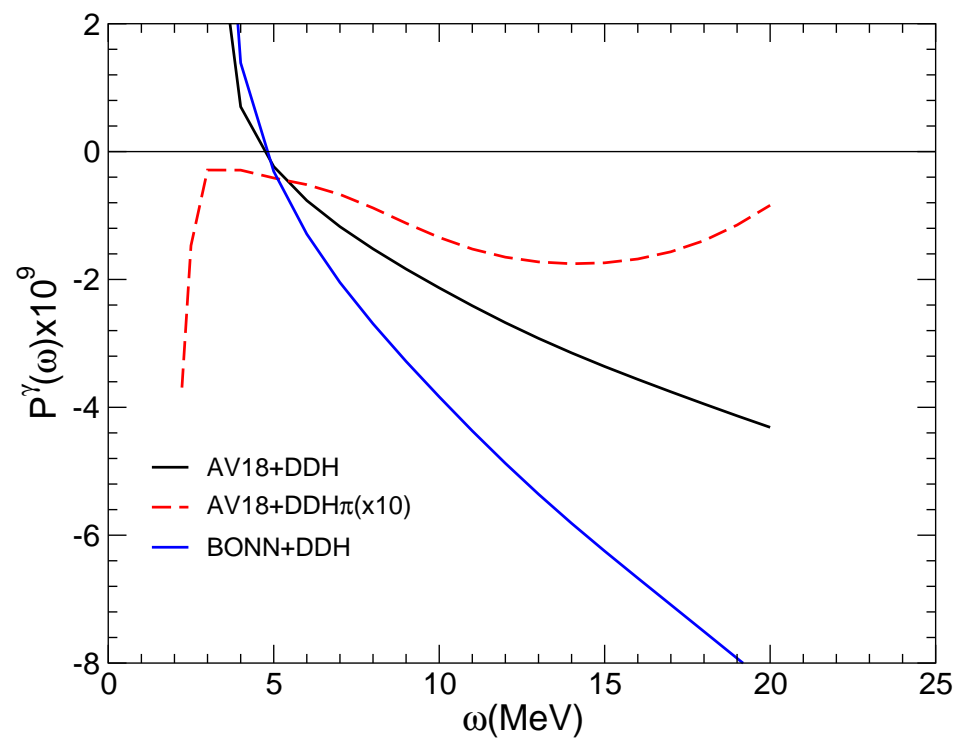
$$\quad \quad \quad |d; \text{PC}\rangle \rightarrow |{}^3\mathbf{P}_0; \text{PV}\rangle$$

- v_π^{PV} does not contribute
- P^γ exhibits large sensitivity to modeling of short range strong and weak NN interactions

P^γ in units of 10^{-8}

	AV18+DDH	BONN+DDH	AV18+DDH π
Impulse	5.44	9.41	-0.035
Full	5.19	9.05	-0.037

- At higher energies, remarks in previous slide remain valid:



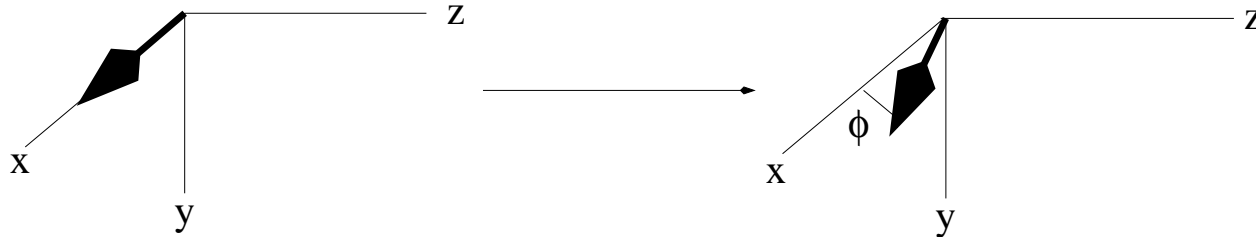
Neutron Spin Rotation

- Transmission of a low energy neutron through matter:

$$e^{ipz} |\sigma\rangle \quad \left[\text{Grey Box} \right] \quad e^{ip(z-d)} \quad e^{ipdn_\sigma} |\sigma\rangle$$

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

- PV observable:



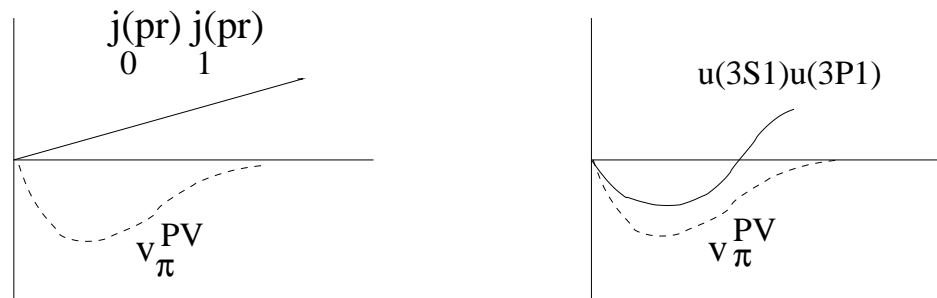
$$\frac{d\phi}{dd} = -\frac{2\pi\rho}{p} \text{Re} [M_+(\theta = 0) - M_-(\theta = 0)]$$

$d\phi/dd$ in units of 10^{-9} rad/cm

	DDH	DDH π
AV18	5.09	5.21
BONN	4.63	5.18
Plane waves	-5.67	-6.87

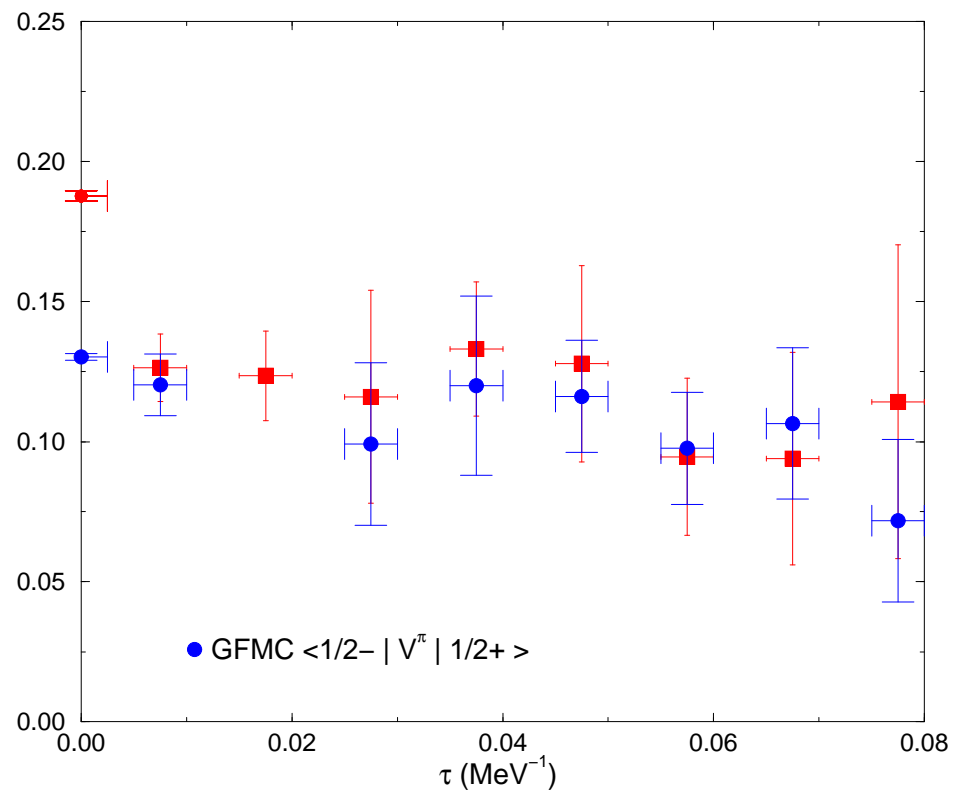
- Earlier study [Avishai and Grange, JPG10, L263 (1984)] finds, incorrectly, the same sign w/ and w/o strong interaction

$$\text{leading term} \sim \langle {}^3S_1 | v_{\pi}^{\text{PV}} | {}^3P_1 \rangle$$



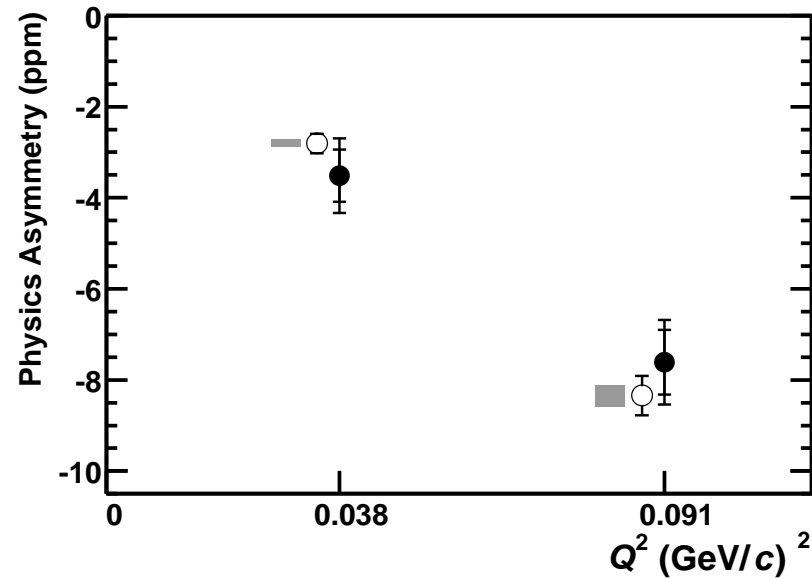
Neutron Spin Rotation in ^4He

Pion PV Matrix Element



$d(\vec{e}, e')np$ at quasielastic kinematics: SAMPLE

Ito *et al.*, PRL**92**, 102003 (2004)



$$A^{\text{th}}(Q^2 = 0.038 \text{ GeV}/c) = -2.14 + 0.27 G_M^s + 0.76 G_{A,T=1}^{(e)}$$

$$A^{\text{th}}(Q^2 = 0.091 \text{ GeV}/c) = -7.06 + 0.77 G_M^s + 1.66 G_{A,T=1}^{(e)}$$

$$A = \frac{\left[\begin{array}{c} |f, PC\rangle \\ \text{---} \gamma \\ \text{---} \gamma \\ |d, PC\rangle \end{array} \right] \left[\begin{array}{c} |f, PC\rangle \\ \text{---} z \\ \text{---} \gamma \\ |d, PC\rangle \end{array} \right] + \left[\begin{array}{c} |f, PC\rangle \\ \text{---} \gamma \\ \text{---} \gamma \\ |d, PC\rangle \end{array} \right] \left[\begin{array}{c} |f, PC\rangle \\ \text{---} \gamma \\ \text{---} \gamma \\ |d, PC\rangle \end{array} \right] + \text{c.c.}}{\left| \begin{array}{c} |f, PC\rangle \\ \text{---} \gamma \\ \text{---} \gamma \\ |d, PC\rangle \end{array} \right|^2}$$

$$= A_{\gamma Z} + A_{\gamma\gamma}$$

$A_{\gamma Z}$ well known, $A_{\gamma\gamma} \sim \overline{\sum}_{i,f} \text{Im} \left[\mathbf{j}_{fi}(\gamma) \times \mathbf{j}_{fi}^*(\gamma) \right]_z \delta(\omega + E_i - E_f)$

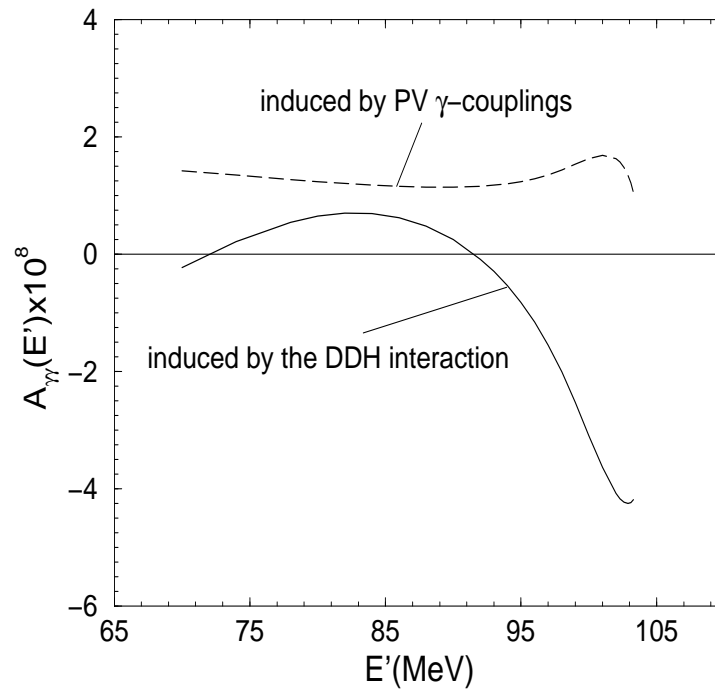
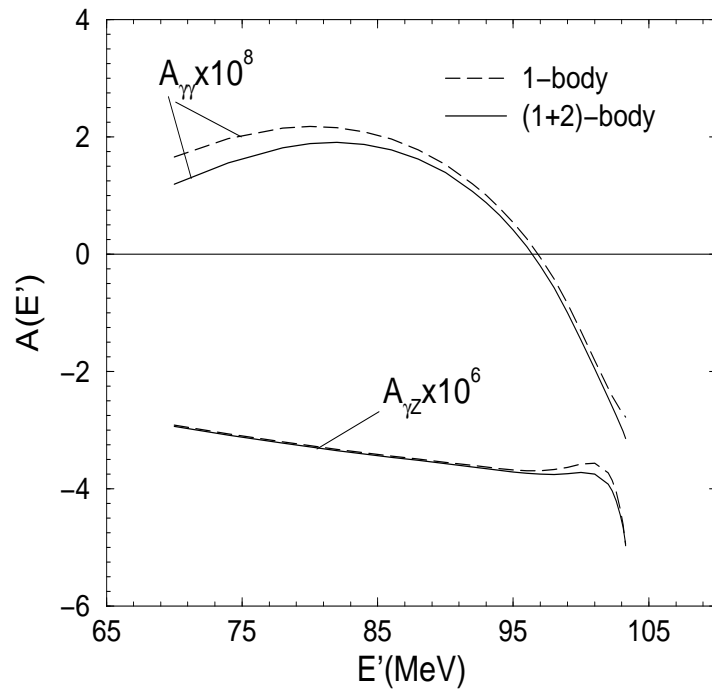
$A_{\gamma\gamma}$ (related to P^γ at the photon point) originates from:

1. Small $|PV\rangle$ components induced by v^{PV} into $|PC\rangle$ states
2. \mathbf{j}_2^{PV} associated with v^{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 α_S and α_V from either pion loops (Musolf *et al.*), OR the quark model (Riska), or EFT (Maekawa and van Kolck)

Sample-III Kinematics



$|A_{\gamma\gamma}|$ two orders of magnitude smaller than $|A_{\gamma Z}|$

Summary(I)

- $A_z(\vec{p}p)$ is weakly dependent on input v^{PC} , but sensitive to short-range modeling of v^{PV}
- $A^\gamma(\vec{n}p)$ and, to a less extent, the neutron spin rotation provide the “cleanest” determination of h_π
- $P^\gamma(d\vec{\gamma})$ 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, γZ interference on individual nucleons
- Outlook:
 1. GFMC studies of \vec{n} - and \vec{p} - α scattering
 2. Possibly, HH studies of \vec{n} ^2H and \vec{n} ^3He radiative captures

${}^4\text{He}(\vec{e}, e'){}^4\text{He}$ Scattering

$$A_{\text{PV}} = -\frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}} \frac{\langle {}^4\text{He} | j_{\text{NC}}^{\mu=0} | {}^4\text{He} \rangle}{\langle {}^4\text{He} | j_{\text{EM}}^{\mu=0} | {}^4\text{He} \rangle} \rightarrow \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}} 4 s_W^2$$

where

$$j_{\text{EM}}^{\mu=0} = j^{(0)} + j^{(1)}$$

$$j_{\text{NC}}^{\mu=0} = -4 s_W^2 j^{(0)} + (2 - 4 s_W^2) j^{(1)} - j^{(s)}$$

- 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

^aMusolf, Schiavilla, and Donnelly, PRC $\mathbf{50}$, 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 $G_E^{p/n} = \langle p/n | j_{EM}^{\mu=0} | p/n \rangle$:

$$(G_E^p + G_E^n)/2 = G_E^0 + G_E^{\lambda} \quad (G_E^p - G_E^n)/2 = G_E^1 + G_E^{\phi}$$

from which

$$G_E^{p,Z} = (1 - 4s_W^2)G_E^p - G_E^n + 2(G_E^{\lambda} - G_E^{\phi}) - G_E^s$$

$$G_E^{n,Z} = (1 - 4s_W^2)G_E^n - G_E^p + 2(G_E^{\lambda} + G_E^{\phi}) - G_E^s$$

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

$$\rho^{(\text{EM})}(\mathbf{q}) = G_E^p \sum_{k=1}^Z e^{i\mathbf{q}\cdot\mathbf{r}_k} + G_E^n \sum_{k=Z+1}^A e^{i\mathbf{q}\cdot\mathbf{r}_k} \equiv \rho^{(0)}(\mathbf{q}) + \rho^{(1)}(\mathbf{q})$$

$$\rho^{(0)}(\mathbf{q}) = \frac{G_E^p + G_E^n}{2} \sum_{k=1}^A e^{i\mathbf{q}\cdot\mathbf{r}_k}$$

$$\rho^{(1)}(\mathbf{q}) = \frac{G_E^p - G_E^n}{2} \left(\sum_{k=1}^Z e^{i\mathbf{q}\cdot\mathbf{r}_k} - \sum_{k=Z+1}^A e^{i\mathbf{q}\cdot\mathbf{r}_k} \right)$$

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

$$\begin{aligned} \rho^{(\text{NC})}(\mathbf{q}) = & -4s_W^2 \rho^{(\text{EM})}(\mathbf{q}) + \frac{2G_E^1 - G_E^s}{(G_E^p + G_E^n)/2} \rho^{(0)}(\mathbf{q}) \\ & + 2\rho^{(1)}(\mathbf{q}) - \frac{2G_E^\emptyset}{(G_E^p - G_E^n)/2} \rho^{(1)}(\mathbf{q}) \end{aligned}$$

Up to linear terms in ISB corrections:

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

where

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

The HAPPEX collaboration [PRL**98**, 032301 (2007)] reports:

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

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),

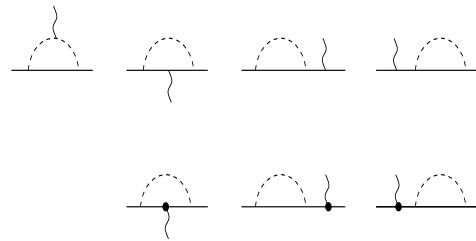
$$\Gamma \equiv -2 \frac{F^{(1)}(q)}{F^{(0)}(q)} - \frac{2 G_E^{\lambda} - G_E^s}{(G_E^p + G_E^n)/2} = 0.010 \pm 0.038$$

ISB Corrections (I): Nucleon

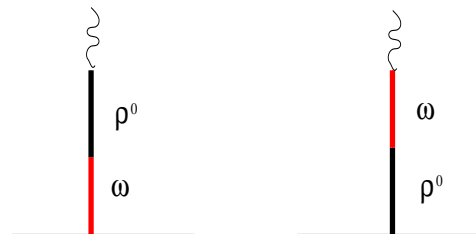
Kubis and Lewis, PRC74, 015204 (2006)

Up to NLO in ChPT:

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

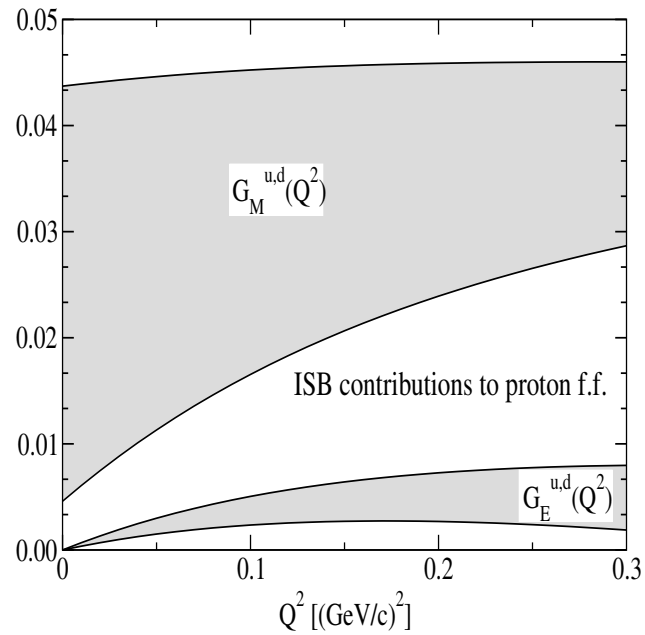
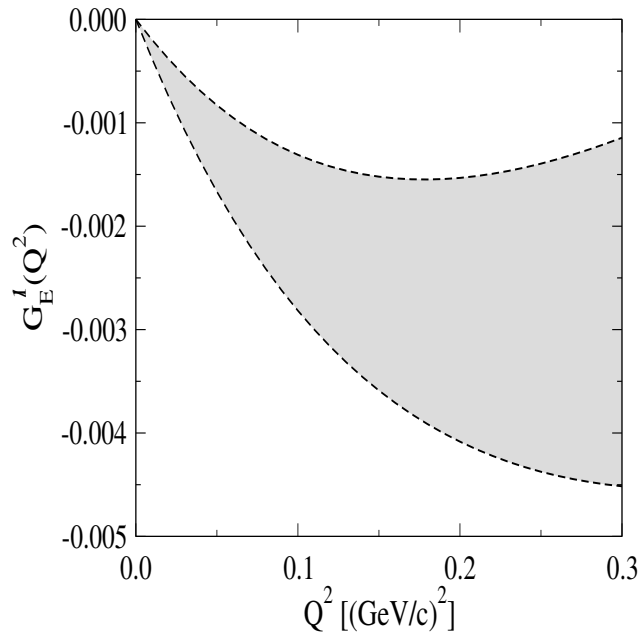


2. A single counterterm, fixed by resonance saturation



$$\begin{aligned}
 G_E^1(Q^2) = & -\frac{g_A^2 m_N \Delta m}{F_\pi^2} \left\{ \frac{M_\pi}{m_N} \left[\bar{\gamma}_0(-Q^2) - 4\bar{\gamma}_3(-Q^2) \right] \right. \\
 & - \frac{Q^2}{2m_N^2} \left[\xi(-Q^2) - \frac{M_\pi}{m_N} \left[\bar{\gamma}_0(-Q^2) - 5\bar{\gamma}_3(-Q^2) \right] \right. \\
 & \left. \left. - \frac{1}{16\pi^2} \left(1 + 2 \log \frac{M_\pi}{M_V} - \frac{\pi(\kappa^\nu + 6)M_\pi}{2m_N} \right) \right] \right\} \\
 & + \frac{g_\omega F_\rho \Theta_{\rho\omega} Q^2}{2M_V (M_V^2 + Q^2)^2} \left(1 + \frac{\kappa_\omega M_V^2}{4m_N^2} \right)
 \end{aligned}$$

- $\bar{\gamma}_0$, $\bar{\gamma}_3$, and ξ are loop functions: $\propto Q^2$ as $Q^2 \rightarrow 0$
- Largest uncertainty in ω tensor coupling κ_ω



- Band provides an estimate of higher order ChPT corrections as well as of uncertainties in vector-meson couplings
- At $Q^2 = 0.077 \text{ (GeV/c)}^2$:

$$-\frac{2 G_E^1}{(G_E^p + G_E^n)/2} = 0.008 \pm 0.003$$

ISB Corrections (II): ${}^4\text{He}$ Nucleus

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

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

Viviani, Kievsky, and Rosati, PRC71, 024006 (2005)

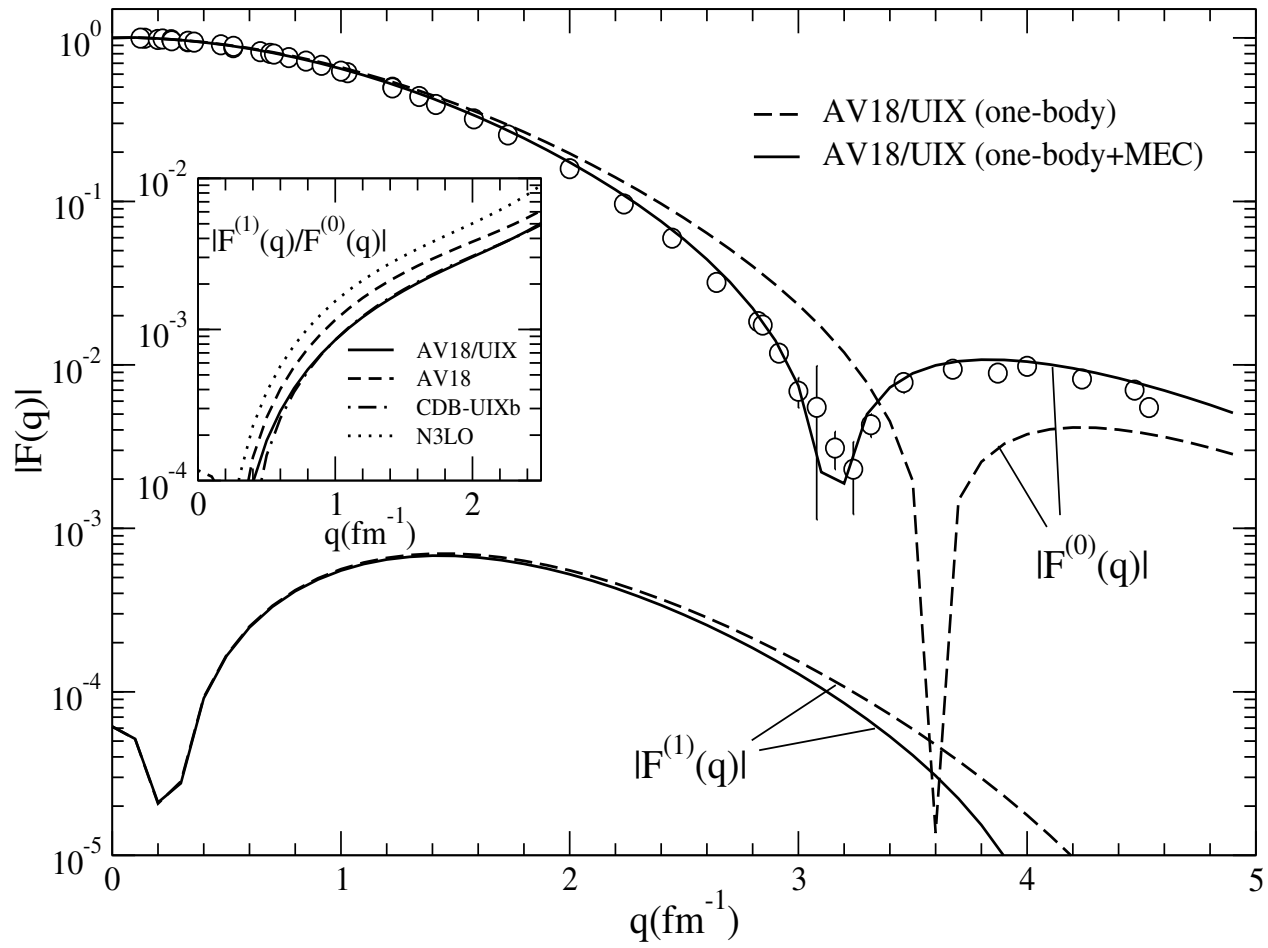
ISB term (AV18)	$P^{(1)}$ %	$P^{(2)}$ %
H_{C}	1.5×10^{-3}	0.1×10^{-3}
$H_{\text{C}} + H_{\text{CD/CA}}$	3.0×10^{-3}	4.9×10^{-3}
$H_{\text{C}} + H_{\text{CD/CA}} + H_{\text{EM}}$	2.8×10^{-3}	5.2×10^{-3}

Contributions of ISB terms to isomultiplet energies (keV)

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

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

- Good overall agreement between theory and experiment



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

Summary(II)

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

ii) $-2 F^{(1)}(q) / F^{(0)}(q) \approx 0.00314$ for nuclear ISB

in

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

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

- Measuring ISB admixtures? (arguably ... error on Γ 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**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?)