Parity-Violating Effects in Few-Nucleon Systems

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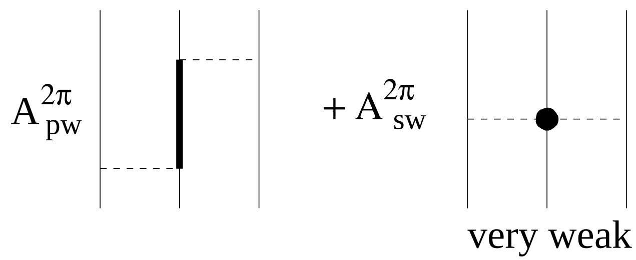
Outline

- 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}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:



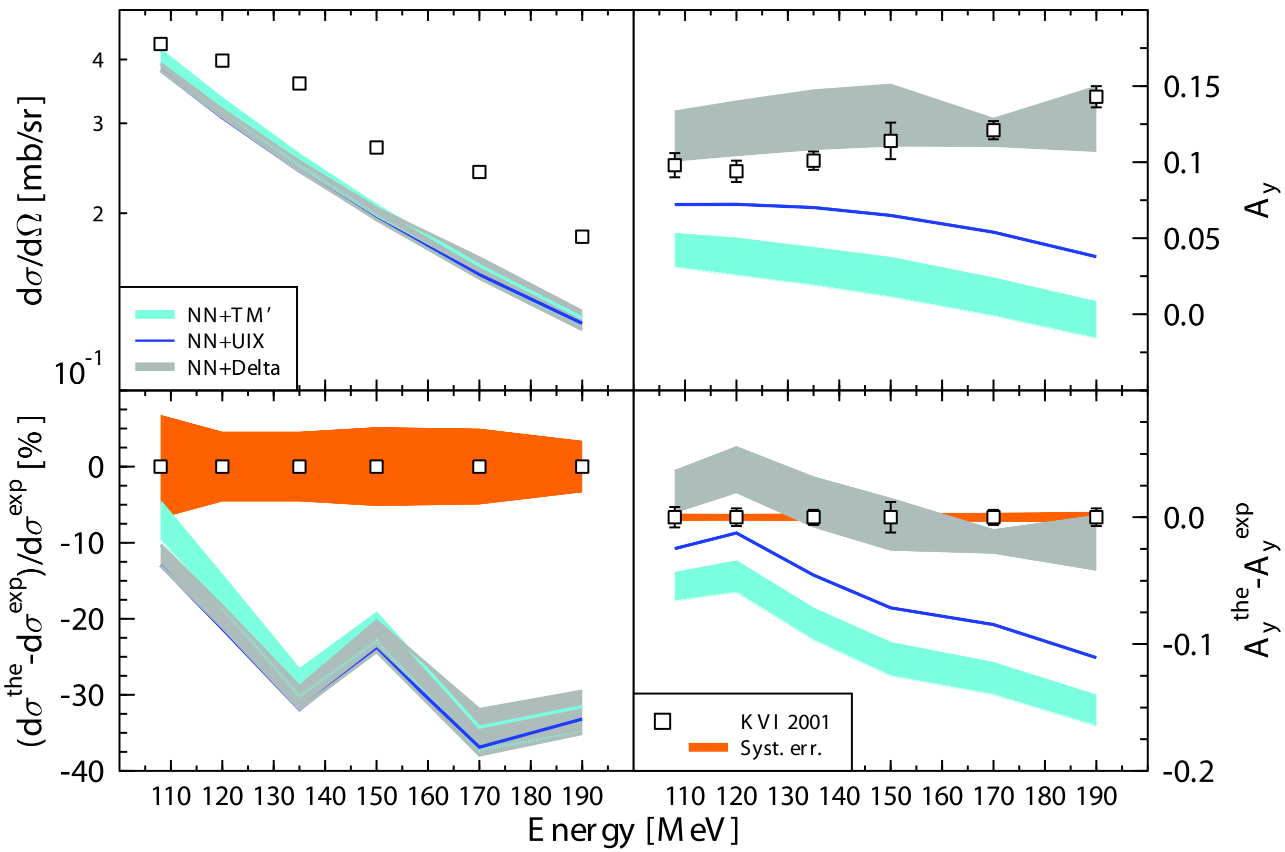
EFT w/o explicit Δ's overestimates strength of $V^{2\pi}_{pw}$

Pandharipande *et al.*, PRC**71**, 064002 (2005)

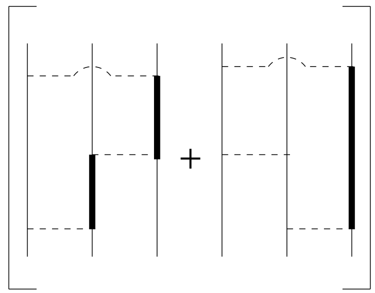
- $V^{2\pi}$ alone does not fix problems above

Proton-Deuteron Elastic Scattering

Ermisch *et al.* (KVI collaboration), PRC**71**, 064004 (2005); Kalantar-Nayestanaki, private communication



Beyond 2π-exchange (IL2 model)

$V^{2\pi} + A^{3\pi}$  $+ A^{R} \sum_{cyc} T^2(r_{ij})\, T^2(r_{jk})$

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}H-p or ^{3}He-n much reduced relative to ^{3}He-p

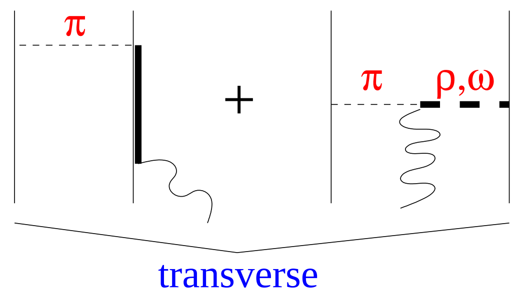
  (Deltuva and Fonseca, PRL**98**, 162502 (2007) and nucl-th/0703066)

Nuclear Electromagnetic Currents

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

$$\mathbf{j} = \mathbf{j}^{(1)}$$

$$+\, \mathbf{j}^{(2)}(\mathrm{v}) \, +$$



$$+\, \mathbf{j}^{(3)}(\mathrm{V}^{2\pi})$$

- 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

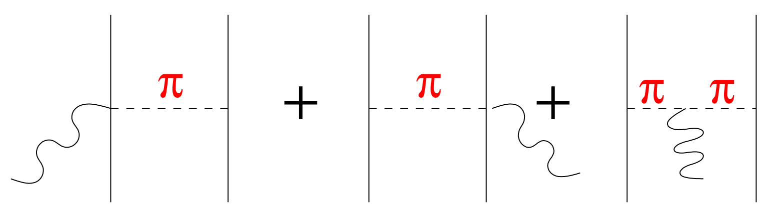
- Terms from static part v_0 of v:

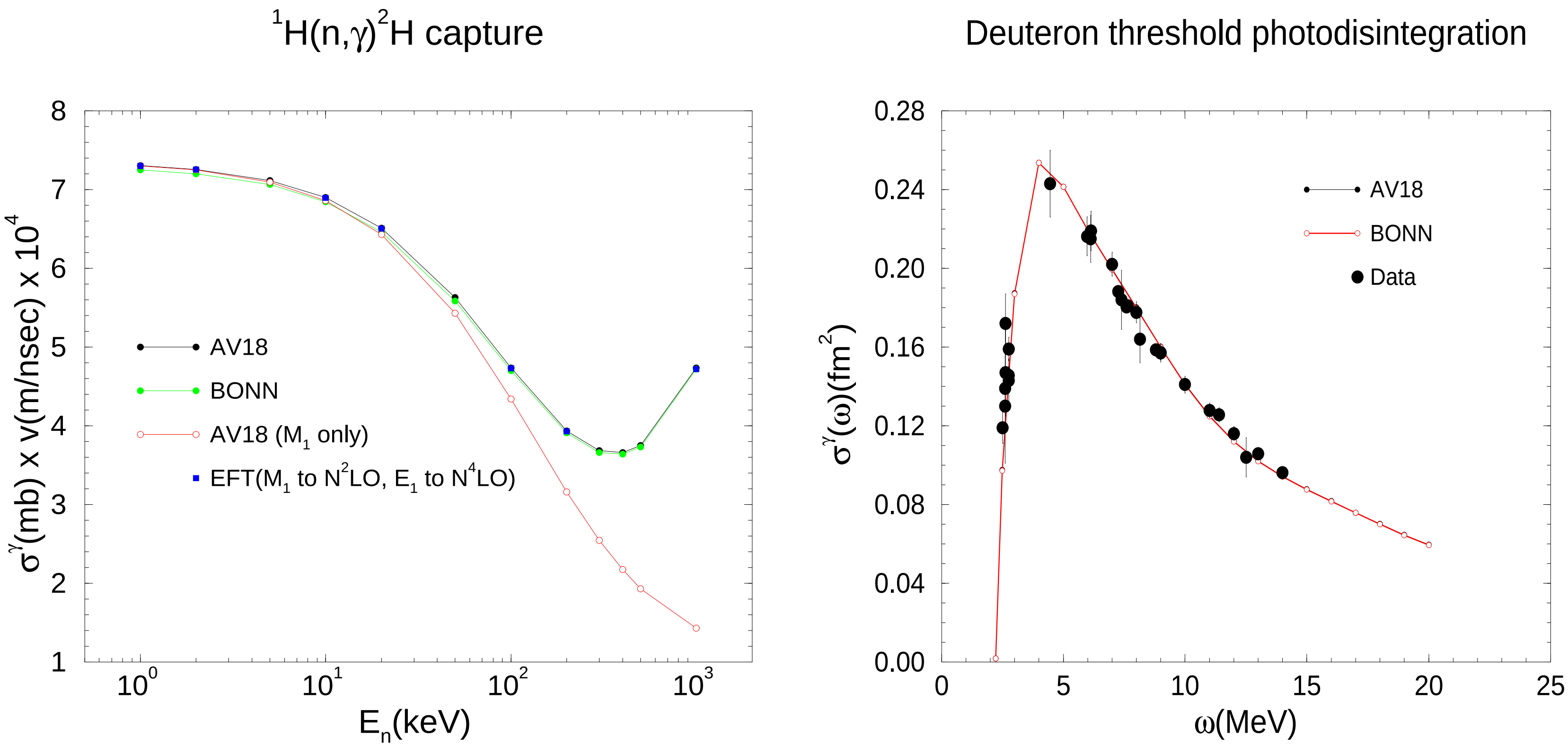
$$\mathbf{j}_{ij}(v_0;\text{leading}) = \mathrm{i}\,(\boldsymbol{\tau}_i \times \boldsymbol{\tau}_j)_z \Big[v_{PS}(k_j)\boldsymbol{\sigma}_i\,(\boldsymbol{\sigma}_j \cdot \mathbf{k}_j) + \frac{\mathbf{k}_i - \mathbf{k}_j}{k_i^2 - k_j^2} v_{PS}(k_i)\,(\boldsymbol{\sigma}_i \cdot \mathbf{k}_i)\,(\boldsymbol{\sigma}_j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

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

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

$$\mathbf{j}^{(2)}(\mathrm{v}_0) \xrightarrow[\text{long range}]{}$$



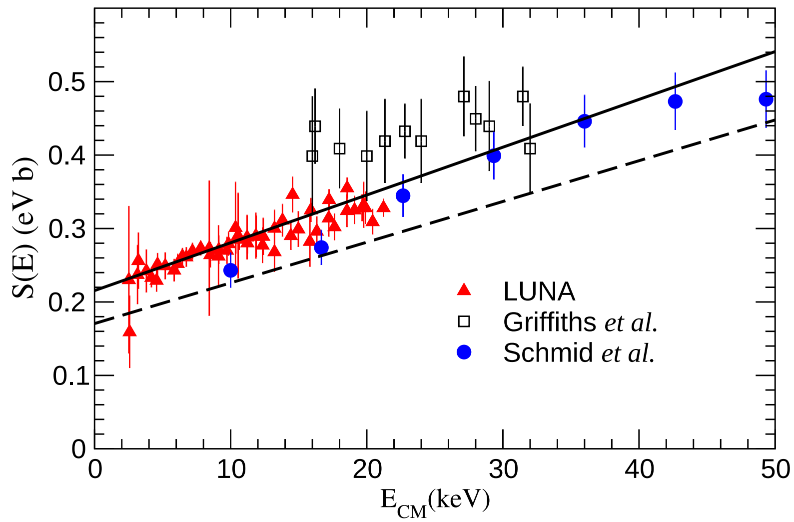


1H(n,γ)2H capture
σγ(mb) x v(m/nsec) x 10^4
En(keV)
AV18
BONN
AV18 (M1 only)
EFT(M1 to N2LO, E1 to N4LO)
Deuteron threshold photodisintegration
σγ(ω)(fm2)
ω(MeV)
AV18
BONN
Data

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

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

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

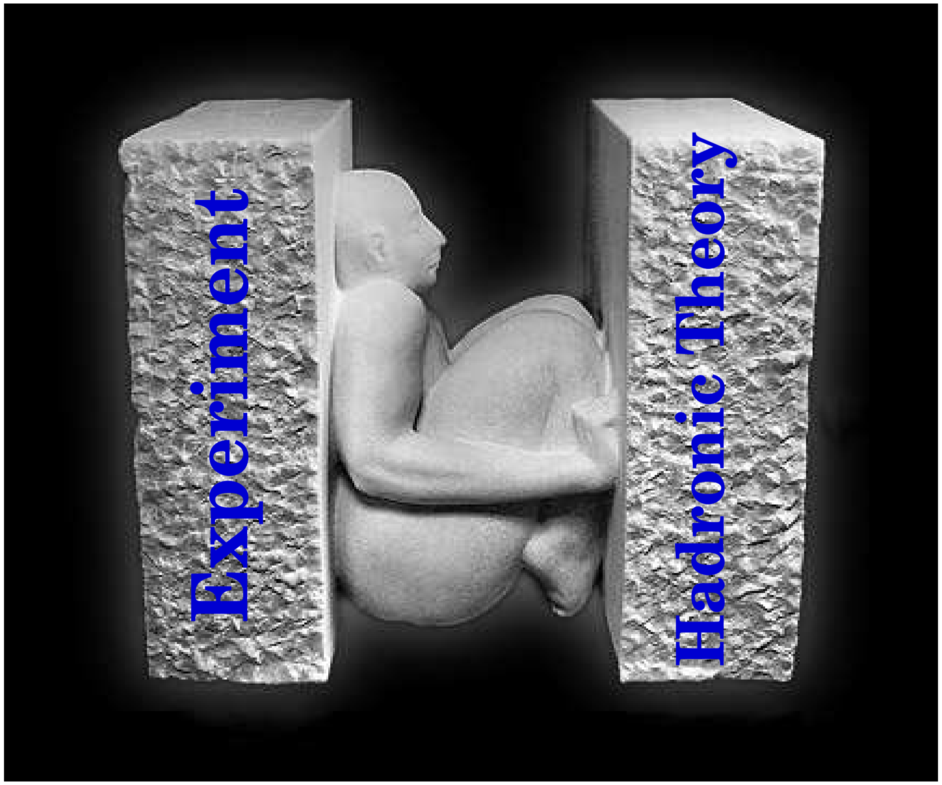


	S$(E=0)$ (eV b)
Theory	0.219
LUNA	0.216±0.010

however, ^{2}H$(n,\gamma)^3$H experimental cross section at thermal energies is overestimated by theory by ≈ 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)

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

M=scattering amplitude

- PC potentials forbid $\mid S - S' \mid = 1$ transitions
- A_z is the "nuclear" asymmetry, Coulomb effects need to be included

- DDH model for PV potential:

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

$$-\frac{g_\omega\, h_\omega^{pp}}{m}\Big[\rho\rightarrow\omega\Big]$$

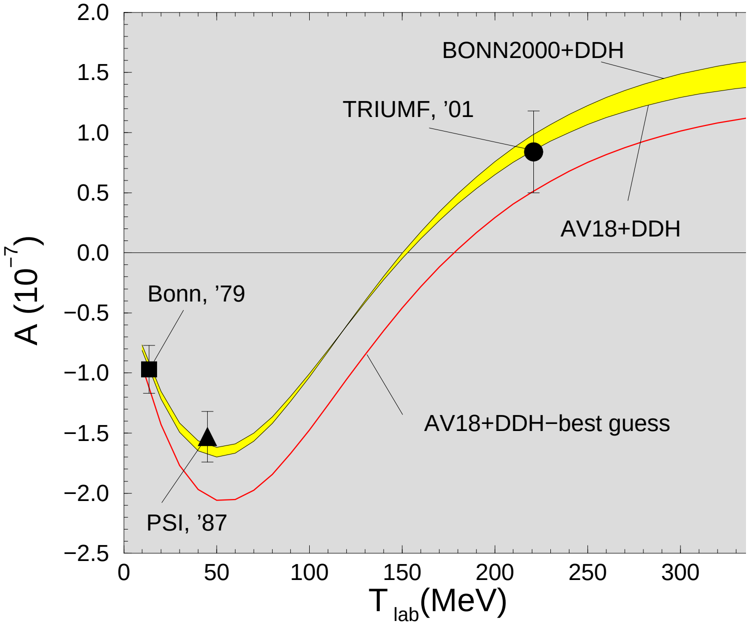
with

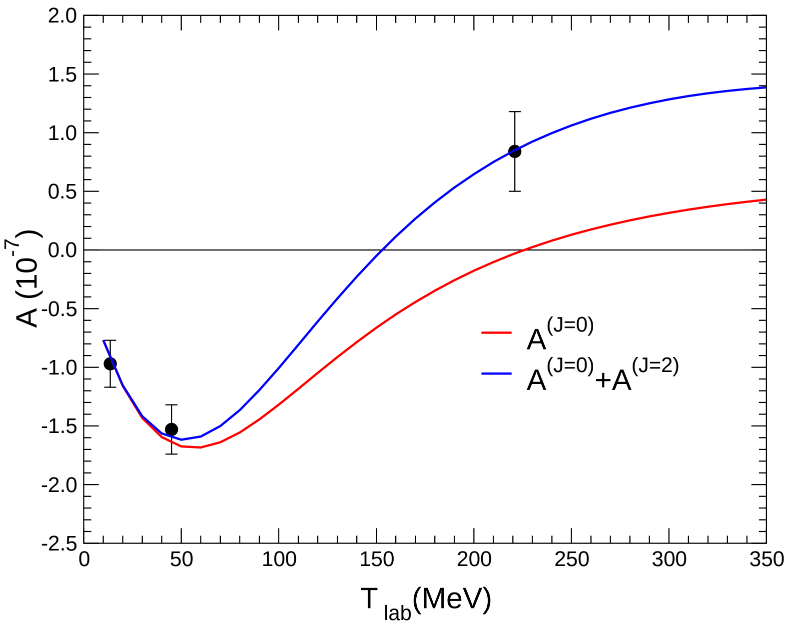
$$Y_\alpha(r) = \frac{1}{4\pi\, r}\left[{\rm e}^{-m_\alpha r} - {\rm e}^{-\Lambda_\alpha r}\left[1+\frac{1}{2}\left(1-\frac{m_\alpha^2}{\Lambda_\alpha^2}\right)\Lambda_\alpha r\right]\right]$$

- $v^{\rm PV}$ acts only in even J channels: at low and moderate $T_{\rm lab}$ the $^1{\rm S}_0$-$^3{\rm P}_0$ and $^1{\rm D}_2$-$^3{\rm P}_2$ are the relevant PV mixings

- EFT version of $v^{\rm PV}$ 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

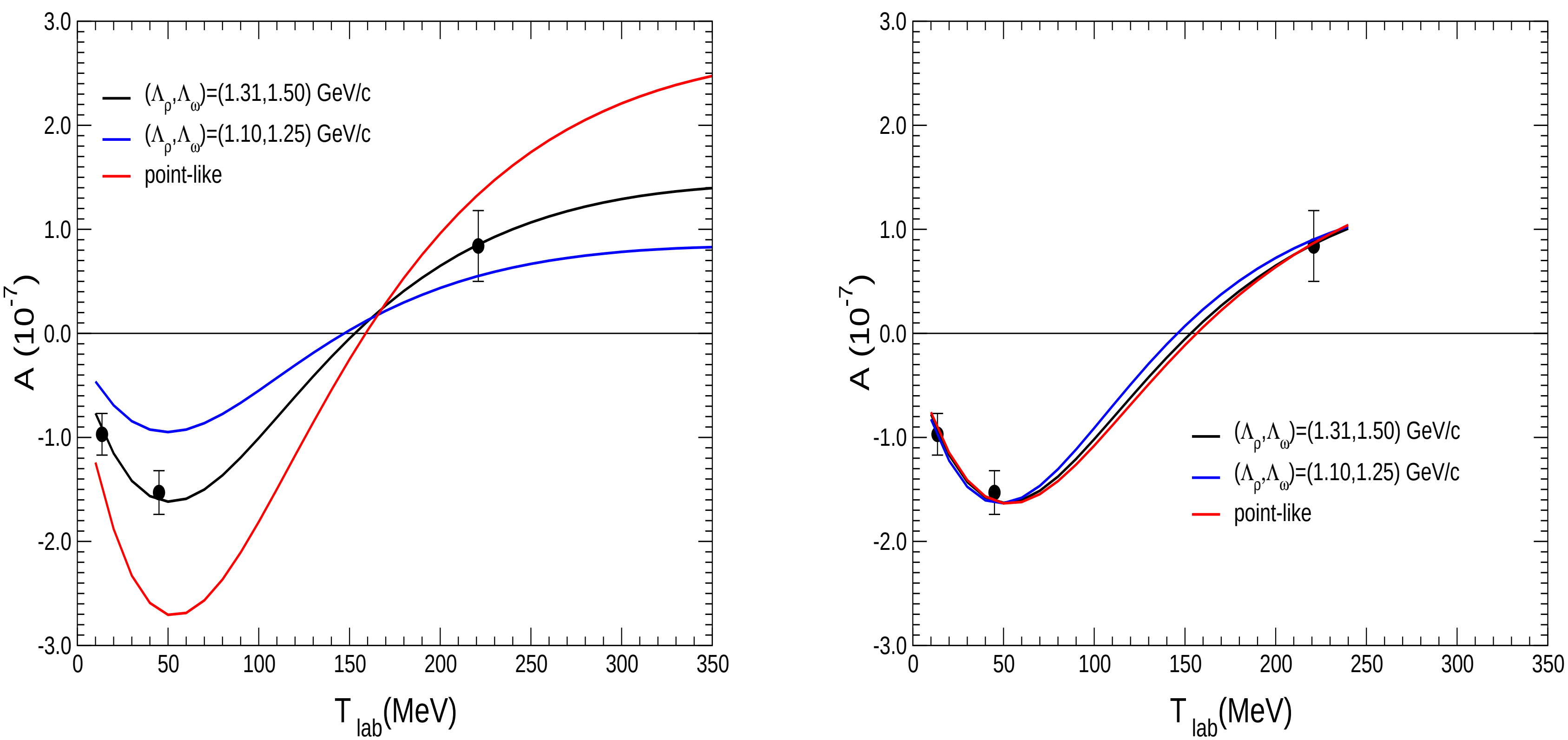




$$A^{(J=0)} \sim h_\rho^{pp} g_\rho (2+\kappa_\rho) + h_\omega^{pp} g_\omega (2+\kappa_\omega) \quad A^{(J=2)} \sim h_\rho^{pp} g_\rho \kappa_\rho + h_\omega^{pp} g_\omega \kappa_\omega$$

Strong correlation between h_ρ^{pp} and h_ω^{pp}

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



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

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

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

with

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

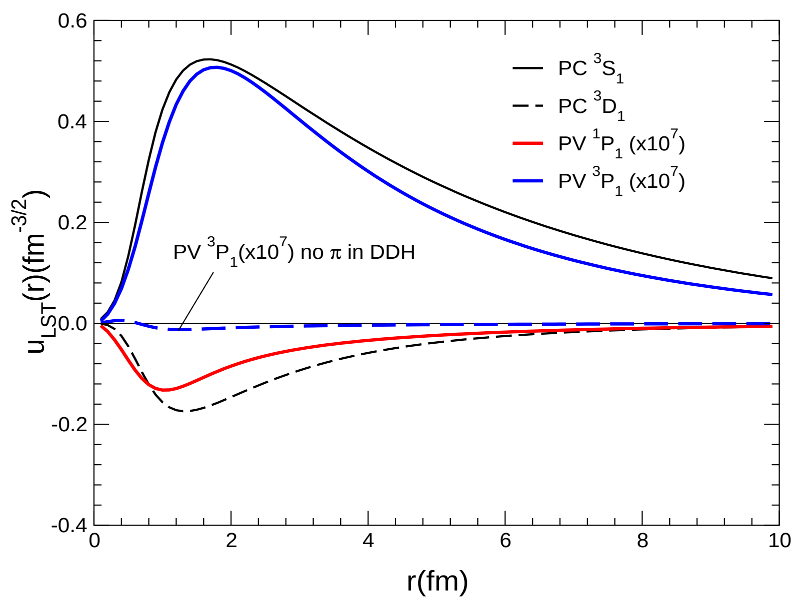
E_1: $\quad |^3\mathrm{S}_1;\mathrm{PC}\rangle \rightarrow |\, d;\mathrm{PV}\rangle$

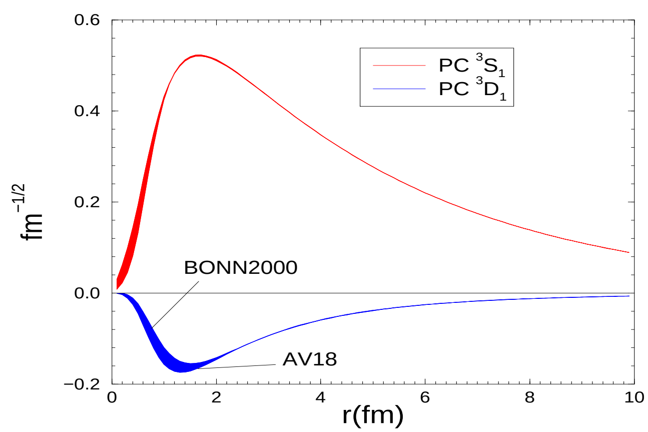
$\quad |^3\mathrm{P}_1;\mathrm{PV}\rangle \rightarrow |\, d;\mathrm{PC}\rangle$

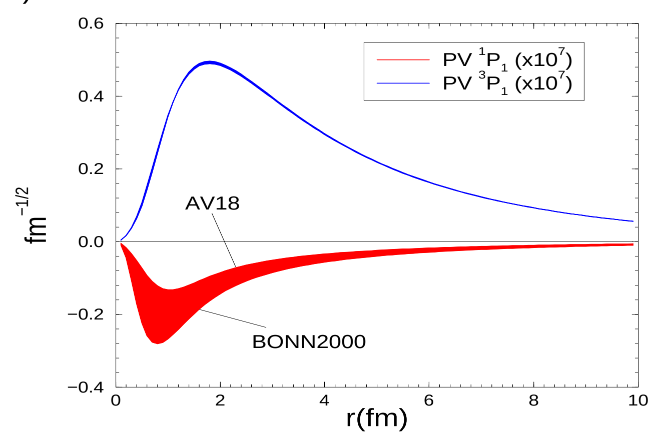
- $^3\mathrm{P}_1$ PV wave functions in d and continuum dominated by v_π^{PV}:

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

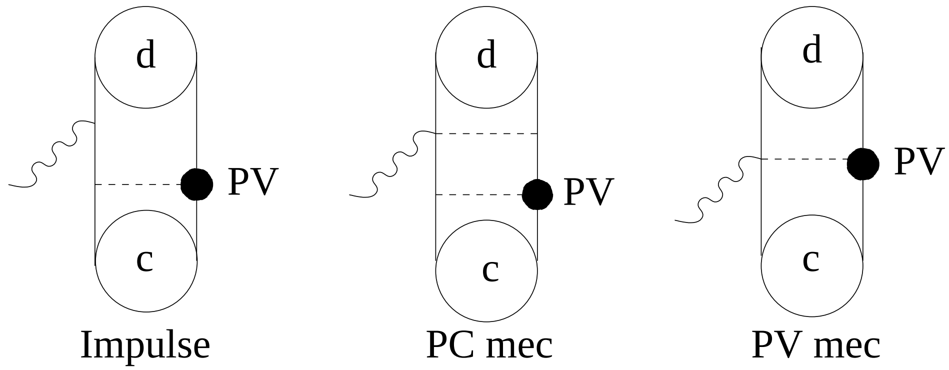
PC and PV Deuteron Wave Functions







- Contributions to a^γ (schematically):



$$E_1 \sim \mathrm{i} \int \mathrm{d}\mathbf{x}\, \hat{\boldsymbol{\epsilon}} \cdot \mathbf{j}(\mathbf{x})$$

- 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:

$$E_1 \sim \omega_\gamma \int \mathrm{d}\mathbf{x}\, \hat{\boldsymbol{\epsilon}} \cdot \mathbf{x}\, \rho(\mathbf{x})$$

	σ^γ(mb)		$a^\gamma \times 10^8$	
Interaction	Impulse Current	Full Current	DDHπ	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 $^2\mathrm{H}(\vec{\gamma},n)p$ Photodisintegration

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

$$P^\gamma = -\frac{2\,Re\left(M_1^*\,\overline{E}_1\right)}{\mid M_1 \mid^2}$$

$\overline{E}_1$: $\quad \mid d(^1\mathrm{P}_1);\mathrm{PV}\rangle \rightarrow \mid ^1\mathrm{S}_0;\mathrm{PC}\rangle$

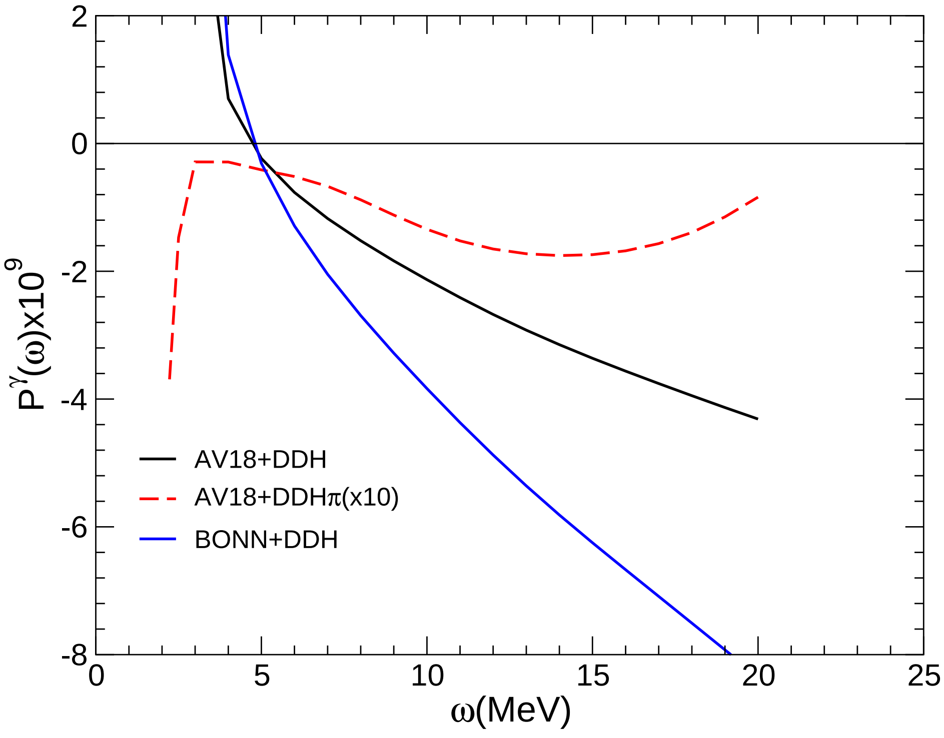
$\quad \mid d;\mathrm{PC}\rangle \rightarrow \mid ^3\mathrm{P}_0;\mathrm{PV}\rangle$

- 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}

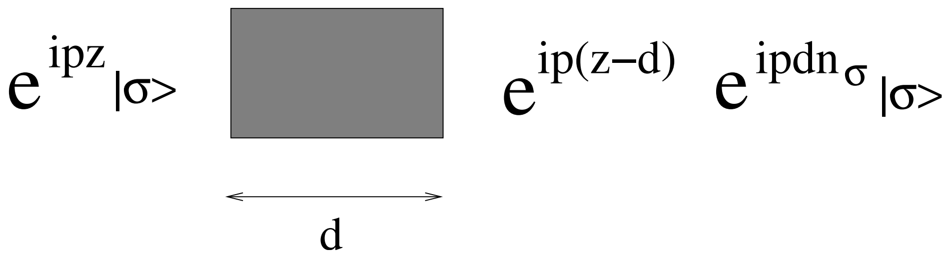
	AV18+DDH	BONN+DDH	AV18+DDHπ
Impulse	5.44	9.41	−0.035
Full	5.19	9.05	−0.037

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



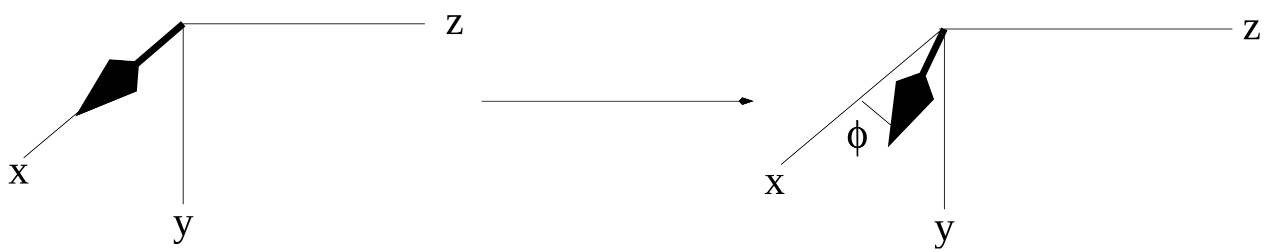
Neutron Spin Rotation

- Transmission of a low energy neutron through matter:



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

- PV observable:



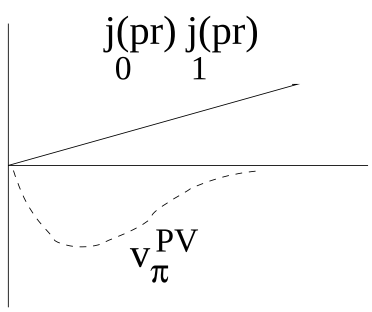
$$\frac{\mathrm{d}\phi}{\mathrm{d}d} = -\frac{2\pi\,\rho}{p} Re\left[M_+(\theta = 0) - M_-(\theta = 0)\right]$$

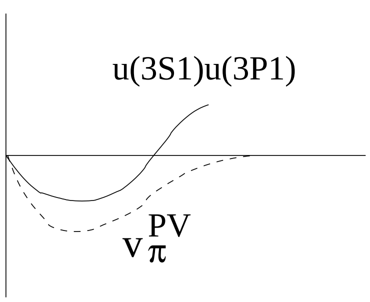
$d\phi/dd$ in units of 10^{-9} rad/cm

	DDH	DDHπ
AV18	5.09	5.21
BONN	4.63	5.18
Plane waves	–5.67	–6.87

- Earlier study [Avishai and Grange, JPG**10**, L263 (1984)] finds, incorrectly, the same sign w/ and w/o strong interaction

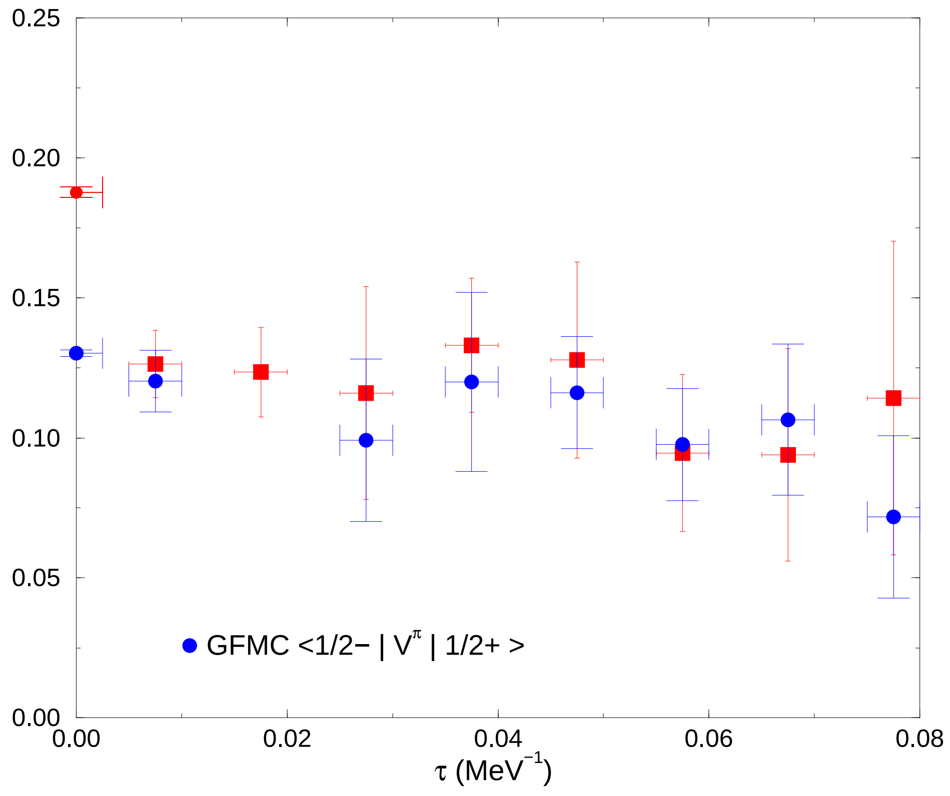
$$\text{leading term} \sim \langle\, ^3\mathrm{S}_1 \mid v_\pi^{\mathrm{PV}} \mid ^3\mathrm{P}_1 \rangle$$





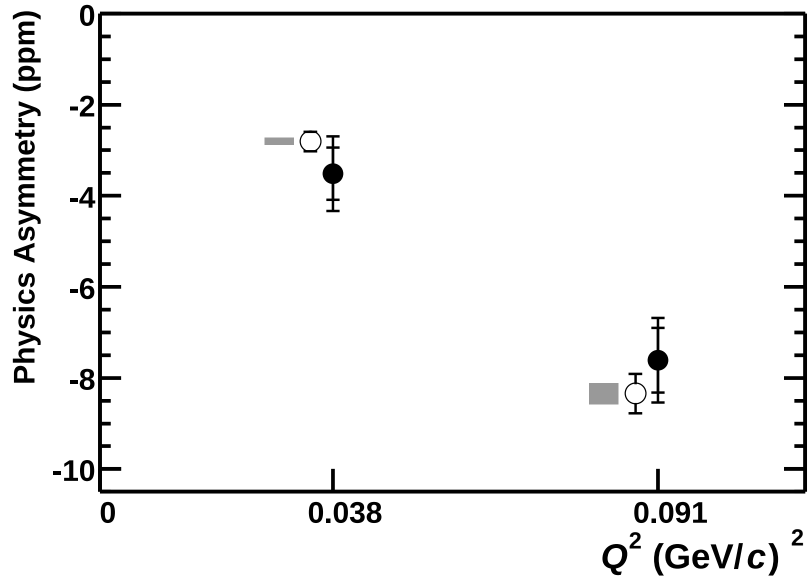
Neutron Spin Rotation in ^{4}He

Pion PV Matrix Element



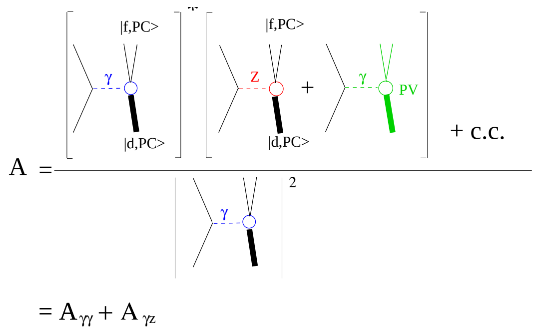
$d(\vec{e}, e')np$ at quasielastic kinematics: SAMPLE

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



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

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



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

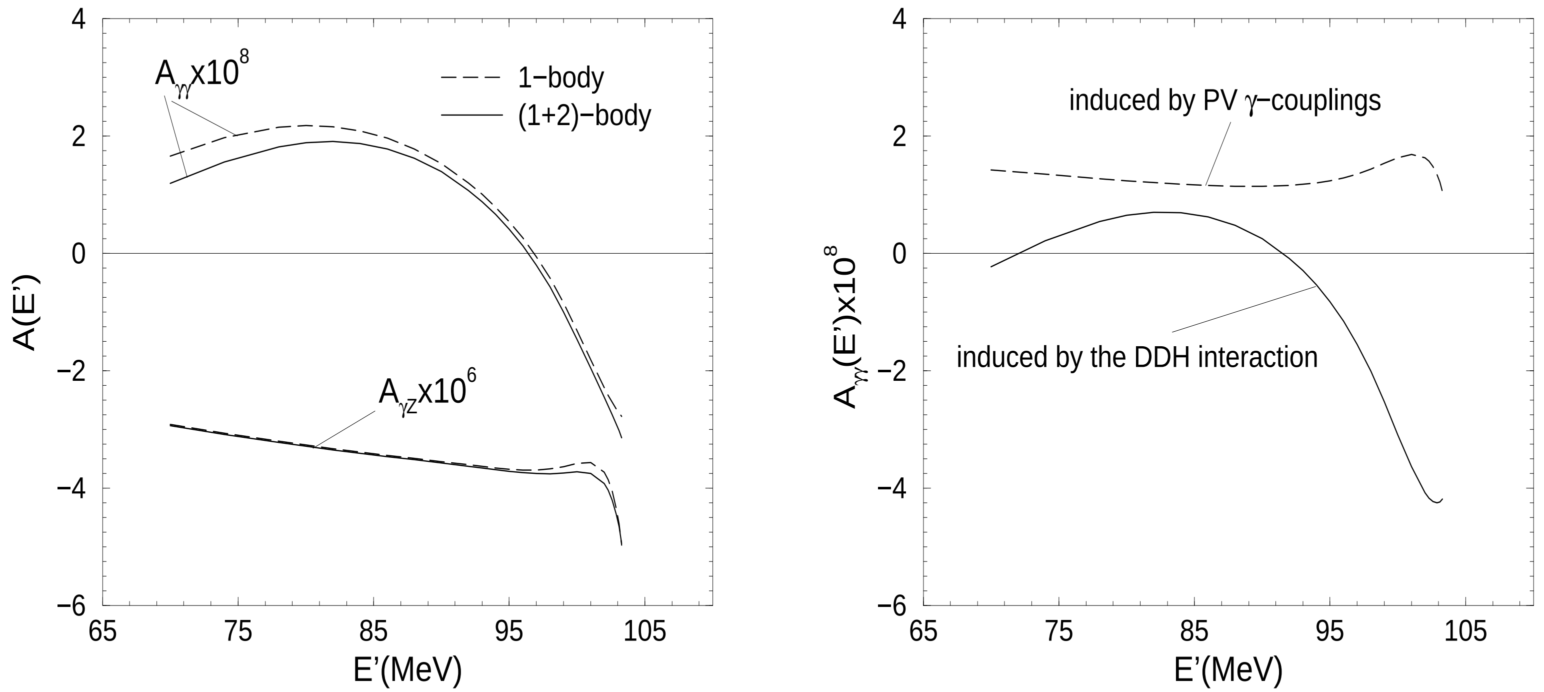
$A_{\gamma\gamma}$ (related to P^γ at the photon point) originates from:

1. Small $|\,\mathrm{PV}\rangle$ components induced by v^{PV} into $|\,\mathrm{PC}\rangle$ states
2. $\mathbf{j}_2^{\mathrm{PV}}$ 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



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

Summary(I)

- $A_z(\vec{p}p)$ is weakly dependent on input $v^{\rm PC}$, but sensitive to short-range modeling of $v^{\rm PV}$
- $A^\gamma(\vec{n}p)$ 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 $v^{\rm PC}$ and $v^{\rm PV}$
- 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 $\vec{n}\,{}^2$H and $\vec{n}\,{}^3$He radiative captures

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

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

where

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

- 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}He
- At low Q^2, RC+MEC contributions calculated to be tiny[a]

[a] Musolf, Schiavilla, and Donnelly, PRC**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 $G_E^{p/n} = \langle p/n | j_{\rm EM}^{\mu=0} | p/n \rangle$:

$$(G_E^p + G_E^n)/2 = G_E^0 + G_E^{\not{1}} \qquad (G_E^p - G_E^n)/2 = G_E^1 + G_E^{\not{0}}$$

from which

$$\begin{aligned} G_E^{p,Z} &= (1 - 4s_W^2) G_E^p - G_E^n + 2(G_E^{\not{1}} - G_E^{\not{0}}) - G_E^s \\ G_E^{n,Z} &= (1 - 4s_W^2) G_E^n - G_E^p + 2(G_E^{\not{1}} + G_E^{\not{0}}) - G_E^s \end{aligned}$$

where ISB in G_E^s are ignored: $\langle p | j^{(s)} | p \rangle = \langle n | j^{(s)} | n \rangle \to G_E^s(Q^2)$

Nuclear EM and NC (Vector) Charge Operators

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

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

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

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

$$\rho^{(\mathrm{NC})}(\mathbf{q}) = -4 s_W^2 \rho^{(\mathrm{EM})}(\mathbf{q}) + \frac{2\, G_E^{\not 1} - G_E^s}{(G_E^p + G_E^n)/2} \rho^{(0)}(\mathbf{q})$$

$$+2\rho^{(1)}(\mathbf{q}) - \frac{2\, G_E^{\not 0}}{(G_E^p - G_E^n)/2} \rho^{(1)}(\mathbf{q})$$

Up to linear terms in ISB corrections:

$$A_{\rm PV} = \frac{G_\mu Q^2}{4\pi\alpha\sqrt{2}} \left[4\, s_W^2 - 2\, \frac{F^{(1)}(q)}{F^{(0)}(q)} - \frac{2\, G_E^{\not{1}} - G_E^s}{(G_E^p + G_E^n)/2} + {\rm RC/MEC} \right]$$

where

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

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

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

from which, using G_μ=1.16637×10^{-5} GeV^{-2}, α=1/137.036, and s_W^2=0.2286 (with radiative corrections),

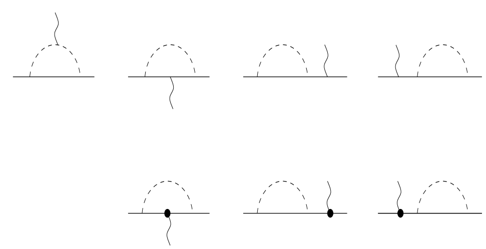
$$\Gamma \equiv -2 \frac{F^{(1)}(q)}{F^{(0)}(q)} - \frac{2\, G_E^{\not{1}} - G_E^s}{(G_E^p + G_E^n)/2} = 0.010 \pm 0.038$$

ISB Corrections (I): Nucleon

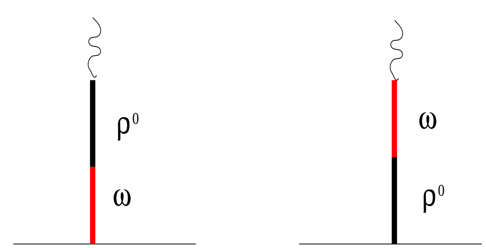
Kubis and Lewis, PRC**74**, 015204 (2006)

Up to NLO in ChPT:

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



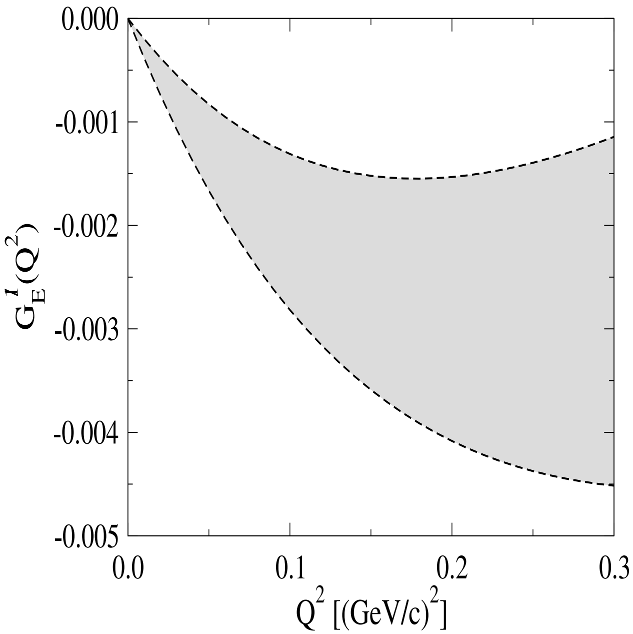
2. A single counterterm, fixed by resonance saturation

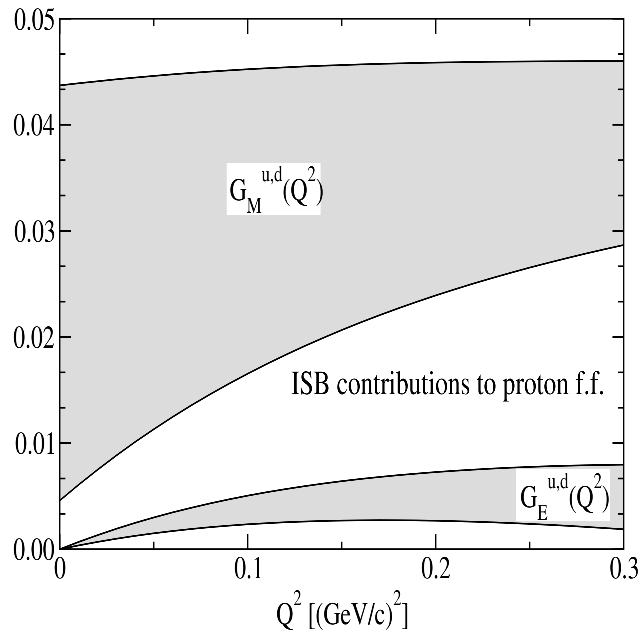


Kubis and Lewis, PRC**74**, 015204 (2006)

$$
\begin{aligned}
G_E^{\not 1}(Q^2) \;=\; & -\frac{g_A^2 m_N \Delta m}{F_\pi^2}\Bigg\{ \frac{M_\pi}{m_N}\left[\overline{\gamma}_0(-Q^2) - 4\overline{\gamma}_3(-Q^2)\right] \\
- \; & \frac{Q^2}{2m_N^2}\Bigg[\xi(-Q^2) - \frac{M_\pi}{m_N}\left[\overline{\gamma}_0(-Q^2) - 5\overline{\gamma}_3(-Q^2)\right] \\
& -\frac{1}{16\pi^2}\left(1 + 2\log\frac{M_\pi}{M_V} - \frac{\pi(\kappa^v + 6)M_\pi}{2m_N}\right)\Bigg]\Bigg\} \\
+ \; & \frac{g_\omega F_\rho \Theta_{\rho\omega} Q^2}{2M_V(M_V^2 + Q^2)^2}\left(1 + \frac{\kappa_\omega M_V^2}{4m_N^2}\right)
\end{aligned}
$$

- $\overline{\gamma}_0$, $\overline{\gamma}_3$, and ξ are loop functions: $\propto Q^2$ as $Q^2 \to 0$
- 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 $Q^2 = 0.077$ (GeV/c)^2:

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

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

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

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

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

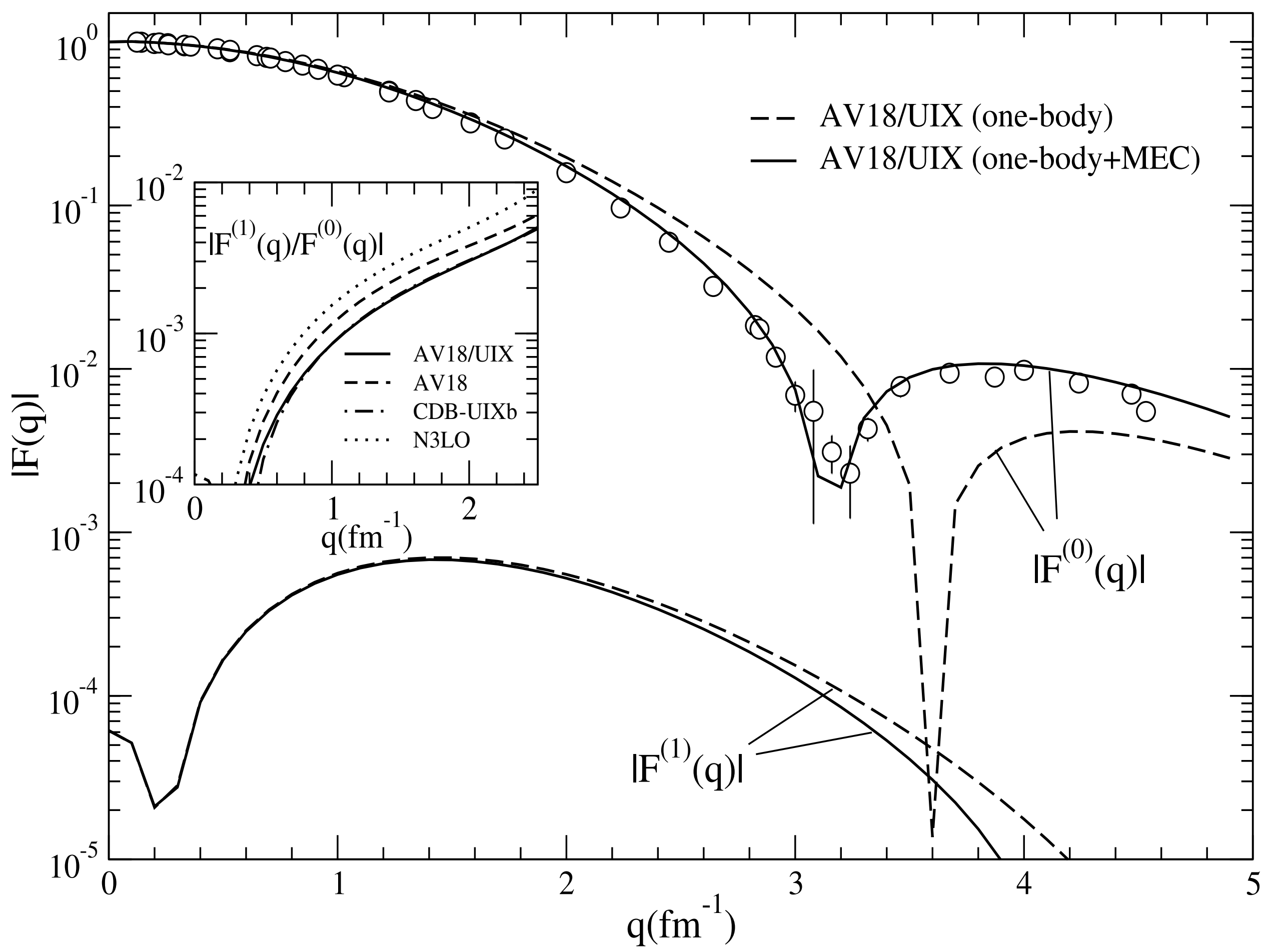
ISB term (AV18)	$P^{(1)}$ %	$P^{(2)}$ %
$H_{\rm C}$	1.5×10^{-3}	0.1×10^{-3}
$H_C + H_{\rm CD/CA}$	3.0×10^{-3}	4.9×10^{-3}
$H_C + H_{\rm CD/CA} + H_{\rm EM}$	2.8×10^{-3}	5.2×10^{-3}

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 (≤ 1.5 fm^{-1})
- $F^{(1)}/F^{(0)} \approx -0.00157$ from AV18/UIX and CDB/UIXb

Summary(II)

Using: i) $-2\, G_E^{\not{1}} / [(G_E^p + G_E^n)/2] \approx 0.008$ for hadronic ISB

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

in

$$\Gamma \equiv -2 \frac{F^{(1)}(q)}{F^{(0)}(q)} - \frac{2\, G_E^{\not{1}} - G_E^s}{(G_E^p + G_E^n)/2} = 0.010 \pm 0.038$$

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

- Measuring ISB admixtures? (arguably … error on Γ too large!)
- $G_E^s \left[Q^2 = 0.1\, (\mathrm{GeV/c})^2 \right] = +0.001 \pm 0.004 \pm 0.003$ 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?)