

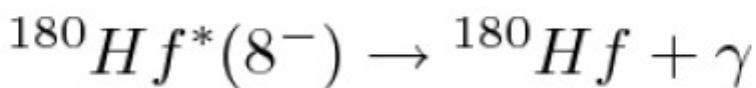
Hadronic Parity Violation

Barry R. Holstein
UMass Amherst

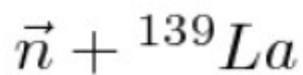
Parity violating effects in strong
and electromagnetic hadronic interactions.

Examples:

First experiment—PV in $^{19}F(p,\alpha)^{16}O$ by Tanner (1957)—no effect seen



$$A_\gamma = -(1.66 \pm 0.18) \times 10^{-2} \quad \text{PRC4, 1906 (1971)}$$



$$A_z = (9.55 \pm 0.35) \times 10^{-2} \quad \text{PRC44, 2187 (1991)}$$

Parity IQ Question

When was weak interaction PV first seen?

Choices:

- i) C.S. Wu et al., Phys. Rev. **105**, 1413 (1957).
- ii) J.L. Friedman and V.L. Telegdi, Phys. Rev. **105**, 1681 (1957).
- iii) R.T. Cox, C.G. McIlwraith, and B. Korrelmeyer, Proc. Natl. Acad. Sci. **14**, 544 (1928).

Three HPV Periods:

- i) 1957-1980 Ancient Times
- ii) 1980-2004 Middle Ages
- iii) 2004-present Modern Era

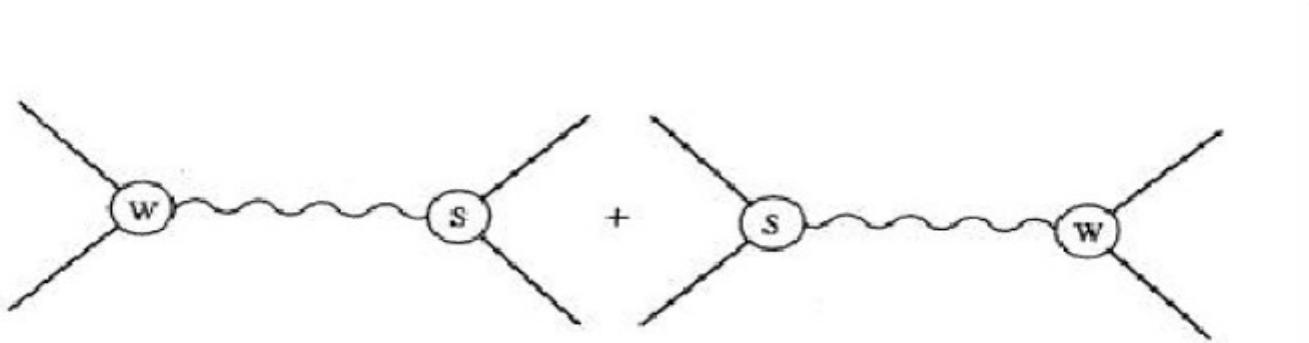
Origin of Transition from Ancient Times to Middle Ages was DDH—

Basic idea:

Meson exchange gives good picture of PC NN interaction, with

$$\begin{aligned}\mathcal{H}_{\text{st}} = & ig_{\pi NN} \bar{N} \gamma_5 \tau \cdot \pi N + g_\rho \bar{N} \left(\gamma_\mu + i \frac{\mu_V}{2M} \sigma_{\mu\nu} k^\nu \right) \tau \cdot \rho^\mu N \\ & + g_\omega \bar{N} \left(\gamma_\mu + i \frac{\mu_S}{2M} \sigma_{\mu\nu} k^\nu \right) \omega^\mu N\end{aligned}$$

so use for PV NN



Then define general PV weak couplings:

$$\mathcal{H}_{\text{wk}} = \frac{f_\pi^1}{\sqrt{2}} \bar{N} (\tau \times \pi)_3 N$$

$$+ \bar{N} \left(h_\rho^0 \tau \cdot \rho^\mu + h_\rho^1 \rho_3^\mu + \frac{h_\rho^2}{2\sqrt{6}} (3\tau_3 \rho_3^\mu - \tau \cdot \rho^\mu) \right) \gamma_\mu \gamma_5 N$$
$$+ \bar{N} (h_\omega^0 \omega^\mu + h_\omega^1 \tau_3 \omega^\mu) \gamma_\mu \gamma_5 N - h_\rho'^1 \bar{N} (\tau \times \rho^\mu)_3 \frac{\sigma_{\mu\nu} k^\nu}{2M} \gamma_5 N$$

Yields two-body PV NN potential

$$V^{\text{PNC}} = i \frac{f_\pi^1 g_{\pi NN}}{\sqrt{2}} \left(\frac{\tau_1 \times \tau_2}{2} \right)_3 (\sigma_1 + \sigma_2) \cdot \left[\frac{\mathbf{p}_1 - \mathbf{p}_2}{2M}, f_\pi(r) \right]$$

$$\begin{aligned} & -g_\rho \left(h_\rho^0 \tau_1 \cdot \tau_2 + h_\rho^1 \left(\frac{\tau_1 + \tau_2}{2} \right)_3 + h_\rho^2 \frac{(3\tau_1^3\tau_2^3 - \tau_1 \cdot \tau_2)}{2\sqrt{6}} \right) \\ & \quad \times ((\sigma_1 - \sigma_2) \cdot \left\{ \frac{\mathbf{p}_1 - \mathbf{p}_2}{2M}, f_\rho(r) \right\} \\ & \quad + i(1 + \chi_V) \sigma_1 \times \sigma_2 \cdot \left[\frac{\mathbf{p}_1 - \mathbf{p}_2}{2M}, f_\rho(r) \right]) \\ & \quad - g_\omega \left(h_\omega^0 + h_\omega^1 \left(\frac{\tau_1 + \tau_2}{2} \right)_3 \right) \\ & \quad \times ((\sigma_1 - \sigma_2) \cdot \left\{ \frac{\mathbf{p}_1 - \mathbf{p}_2}{2M}, f_\omega(r) \right\} \\ & \quad + i(1 + \chi_S) \sigma_1 \times \sigma_2 \cdot \left[\frac{\mathbf{p}_1 - \mathbf{p}_2}{2M}, f_\omega(r) \right]) \\ & \quad - (g_\omega h_\omega^1 - g_\rho h_\rho^1) \left(\frac{\tau_1 - \tau_2}{2} \right)_3 (\sigma_1 + \sigma_2) \cdot \left\{ \frac{\mathbf{p}_1 - \mathbf{p}_2}{2M}, f_\rho(r) \right\} \\ & \quad - g_\rho h_\rho^{1'} i \left(\frac{\tau_1 \times \tau_2}{2} \right)_3 (\sigma_1 + \sigma_2) \cdot \left[\frac{\mathbf{p}_1 - \mathbf{p}_2}{2M}, f_\rho(r) \right] \end{aligned}$$

$$f_V(r) = \exp(-m_V r)/4\pi r$$

w

Key problem is to evaluate seven weak couplings

Represent in terms of "Reasonable Range" and "Best Value"

Coupling	DDH Reasonable Range	DDH "Best" Value
f_π^1	$0 \rightarrow 30$	12
h_ρ^0	$30 \rightarrow -81$	-30
h_ρ^1	$-1 \rightarrow 0$	-0.5
h_ρ^2	$-20 \rightarrow -29$	-25
h_ω^0	$15 \rightarrow -27$	-5
h_ω^1	$-5 \rightarrow -2$	-3

all times "sum rule value" 3.8×10^{-8}

Middle Age Experiment

Can use nucleus as amplifier—first order perturbation theory

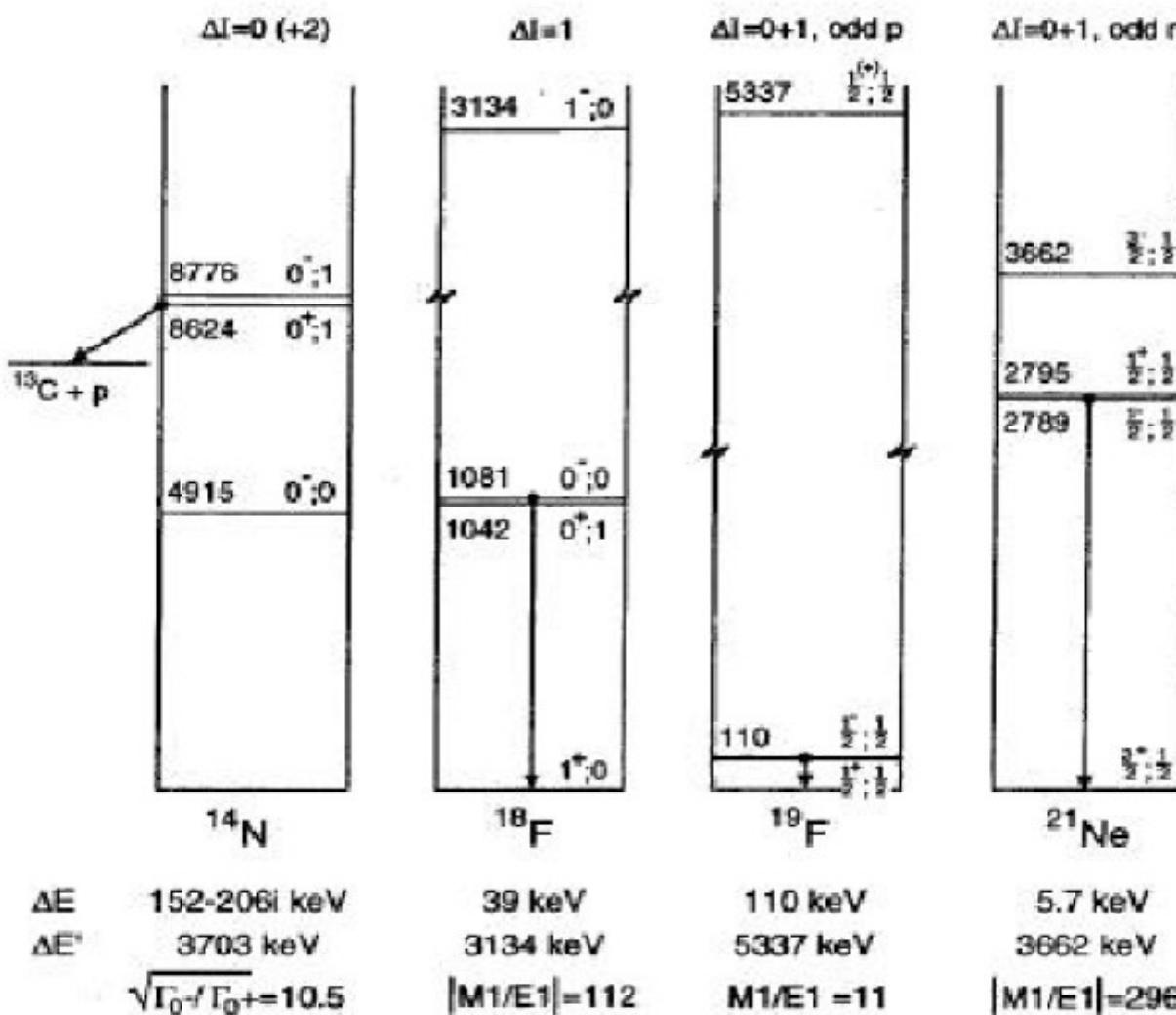
$$|\psi_{J^+}\rangle \simeq |\phi_{J^+}\rangle + \frac{|\phi_{J^-}\rangle \langle \phi_{J^-}| \mathcal{H}_{\text{wk}} | \phi_{J^+}\rangle}{E_+ - E_-}$$

$$= |\phi_{J^+}\rangle + \epsilon |\phi_{J^-}\rangle$$

$$|\psi_{J^-}\rangle \simeq |\phi_{J^-}\rangle + \frac{|\phi_{J^+}\rangle \langle \phi_{J^+}| \mathcal{H}_{\text{wk}} | \phi_{J^-}\rangle}{E_- - E_+}$$

$$= |\phi_{J^-}\rangle - \epsilon |\phi_{J^+}\rangle$$

Then enhancement if $\Delta E \ll$ typical spacing.
 Examples are



Typical results: Circular polarization in ^{18}F E1 decay
of 0^- 1.081 MeV excited state

$$|P_\gamma(1081)| = \begin{cases} (-7 \pm 20) \times 10^{-4} & \text{Caltech/Seattle} \\ (3 \pm 6) \times 10^{-4} & \text{Florence} \\ (-10 \pm 18) \times 10^{-4} & \text{Mainz} \\ (2 \pm 6) \times 10^{-4} & \text{Queens} \\ (-4 \pm 30) \times 10^{-4} & \text{Florence} \end{cases}$$

Asymmetry in decay of polarized $\frac{1}{2}^-$ 110 KeV excited
state of ^{19}F

$$A_\gamma = \begin{cases} (-8.5 \pm 2.6) \times 10^{-5} & \text{Seattle} \\ (-6.8 \pm 1.8) \times 10^{-5} & \text{Mainz} \end{cases}$$

Circular Polarization in ^{21}Ne E1 decay of $\frac{1}{2}^-$ 2.789 Mev excited state

$$P_\gamma = \begin{cases} (24 \pm 24) \times 10^{-4} & \text{Seattle/Chalk River} \\ (3 \pm 16) \times 10^{-4} & \text{Chalk River/Seattle} \end{cases}$$

Also results on NN systems which are not enhanced:

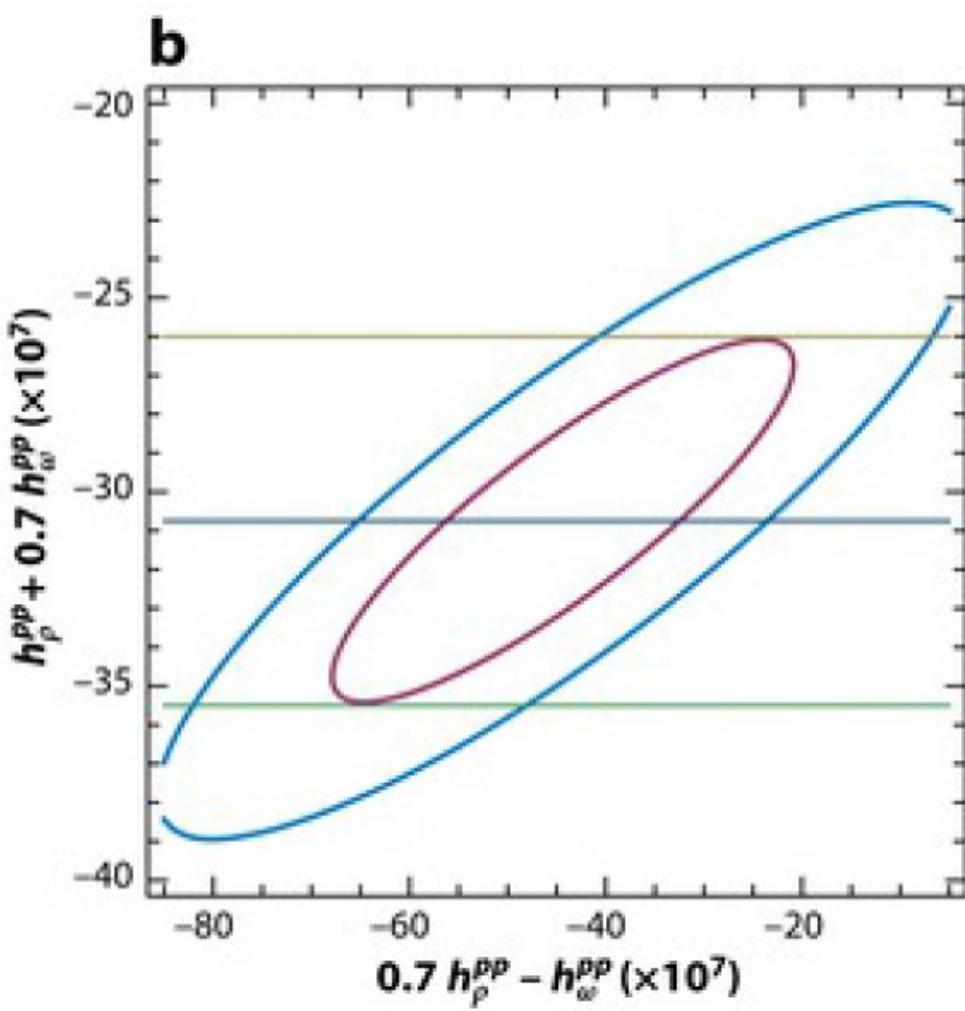
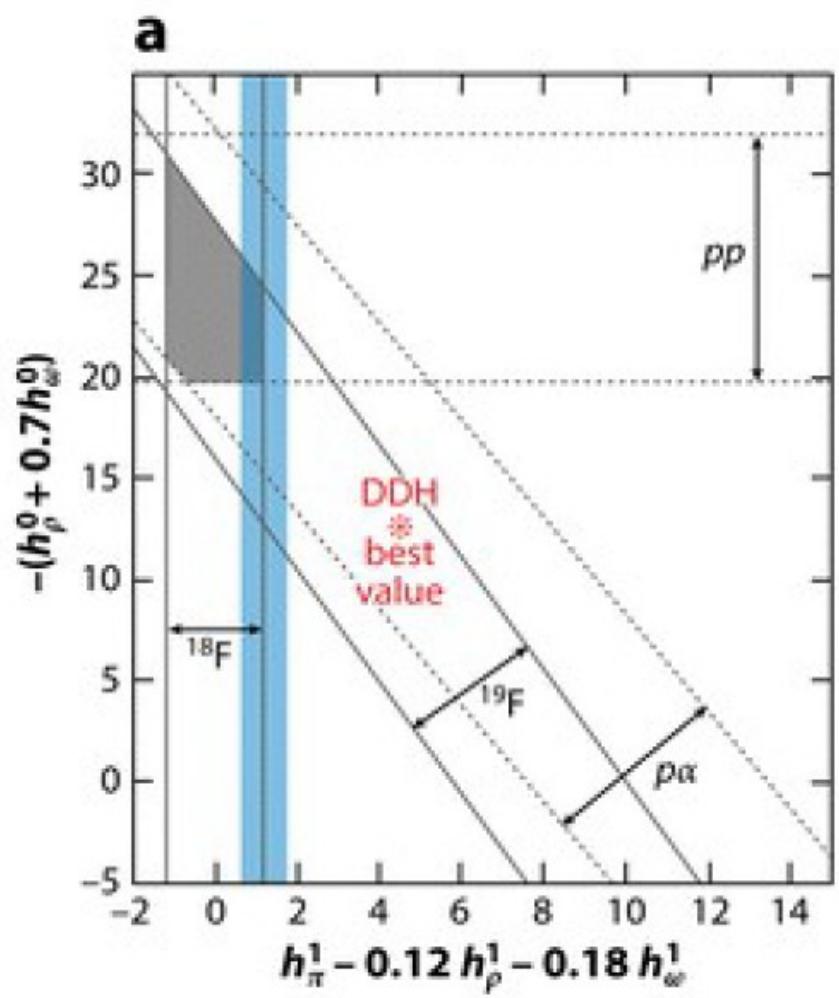
pp: PSI $A_z^{tot}(45.0 \text{ MeV}) = -(1.57 \pm 0.23) \times 10^{-7}$

pp: Bonn $A_z(13.6 \text{ MeV}) = -(0.93 \pm 0.20 \pm 0.05) \times 10^{-7}$

p α : PSI $A_z(46.0 \text{ MeV}) = -(3.3 \pm 0.9) \times 10^{-7}$

Important Middle Ages contributions by Wick:

- i) 1981 PRL related pion-exchange contribution to ^{19}Ne and pion-exchange contribution to ^{18}F experiment, allowing important calibration of the latter.
- ii) 1985 ARNPS review with Adelberger provided valuable overview of the field as well as an important graphical way to understand results.



Origin of Transition from Middle Ages to Modern Era
 (Renaissance) is Application of Effective Field Theory
 Since low-energy use pionless NN EFT, wherein only
five independent couplings:

$$\begin{aligned}
 V_{LO}^{PNC}(r) = & \Lambda_0^{1S_0-3P_0} \left(\frac{1}{i} \frac{\overleftrightarrow{\nabla}_A}{2m_N} \frac{\delta^3(r)}{m_\rho^2} \cdot (\boldsymbol{\sigma}_1 - \boldsymbol{\sigma}_2) - \frac{1}{i} \frac{\overleftrightarrow{\nabla}_S}{2m_N} \frac{\delta^3(r)}{m_\rho^2} \cdot i(\boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2) \right) \\
 & + \Lambda_0^{3S_1-1P_1} \left(\frac{1}{i} \frac{\overleftrightarrow{\nabla}_A}{2m_N} \frac{\delta^3(r)}{m_\rho^2} \cdot (\boldsymbol{\sigma}_1 - \boldsymbol{\sigma}_2) + \frac{1}{i} \frac{\overleftrightarrow{\nabla}_S}{2m_N} \frac{\delta^3(r)}{m_\rho^2} \cdot i(\boldsymbol{\sigma}_1 \times \boldsymbol{\sigma}_2) \right) \\
 & + \Lambda_1^{1S_0-3P_0} \left(\frac{1}{i} \frac{\overleftrightarrow{\nabla}_A}{2m_N} \frac{\delta^3(r)}{m_\rho^2} \cdot (\boldsymbol{\sigma}_1 - \boldsymbol{\sigma}_2)(\tau_{1z} + \tau_{2z}) \right) \\
 & + \Lambda_1^{3S_1-3P_1} \left(\frac{1}{i} \frac{\overleftrightarrow{\nabla}_A}{2m_N} \frac{\delta^3(r)}{m_\rho^2} \cdot (\boldsymbol{\sigma}_1 + \boldsymbol{\sigma}_2)(\tau_{1z} - \tau_{2z}) \right) \\
 & + \Lambda_2^{1S_0-3P_0} \left(\frac{1}{i} \frac{\overleftrightarrow{\nabla}_A}{2m_N} \frac{\delta^3(r)}{m_\rho^2} \cdot (\boldsymbol{\sigma}_1 - \boldsymbol{\sigma}_2)(\boldsymbol{\tau}_1 \otimes \boldsymbol{\tau}_2)_{20} \right),
 \end{aligned}$$

New Experimental Results

[i)] Photon asymmetry in $\vec{n}p \rightarrow d\gamma$ (SNS):

$$A_\gamma = -(3.0 \pm 1.4 \pm 0.2) \times 10^{-8}$$

[ii)] Neutron spin rotation in ${}^4\text{He}$ (NIST):

$$\frac{d\phi_n}{dz} = (2.1 \pm 8.3 \pm 1.4) \times 10^{-7} \text{ rad/m}$$

[iii)] Proton asymmetry in $\vec{n}{}^3\text{He} \rightarrow p{}^3\text{H}$ (SNS):

$$A_p = ? \text{ (soon to be announced)}$$

New Theoretical Developments

[i)] Application of $1/N_c$ expansion

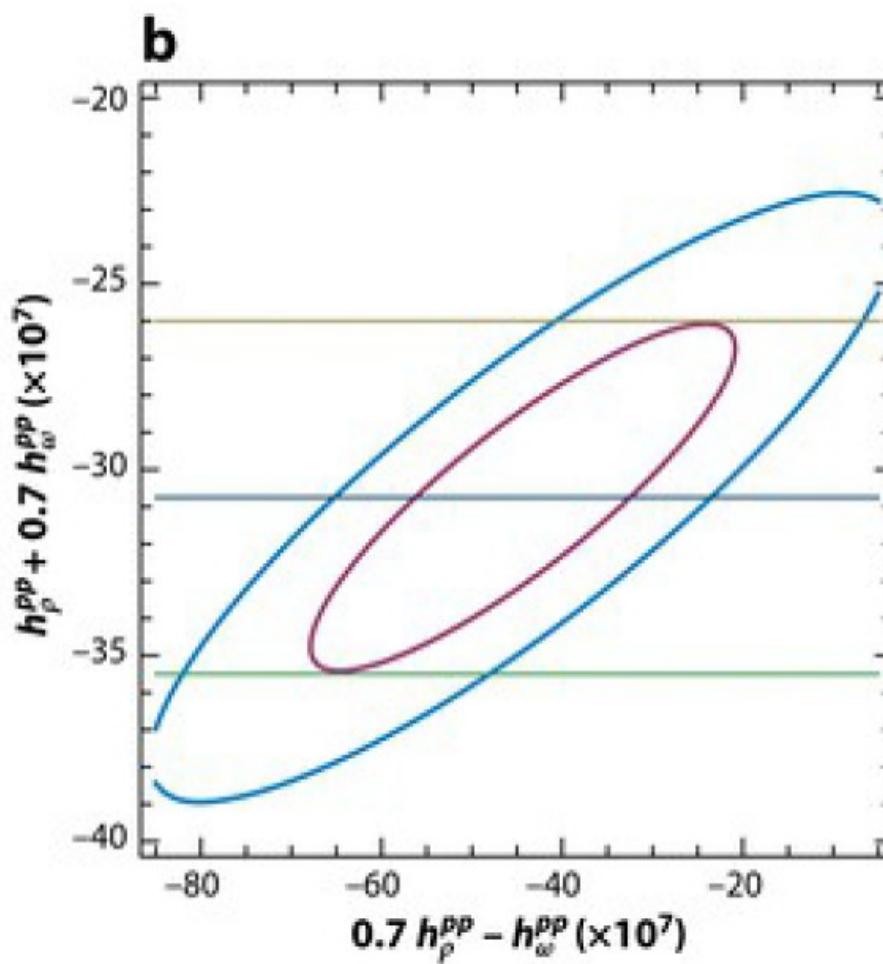
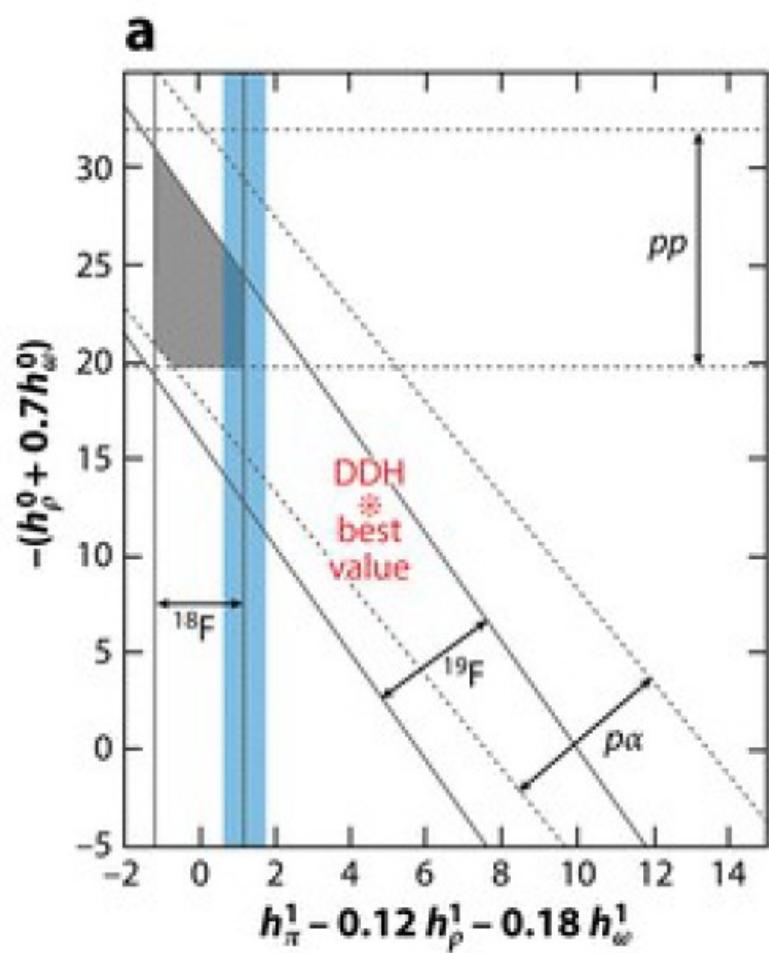
[ii)] Lattice calculations

[iii)] Three-body and Four-body EFT techniques

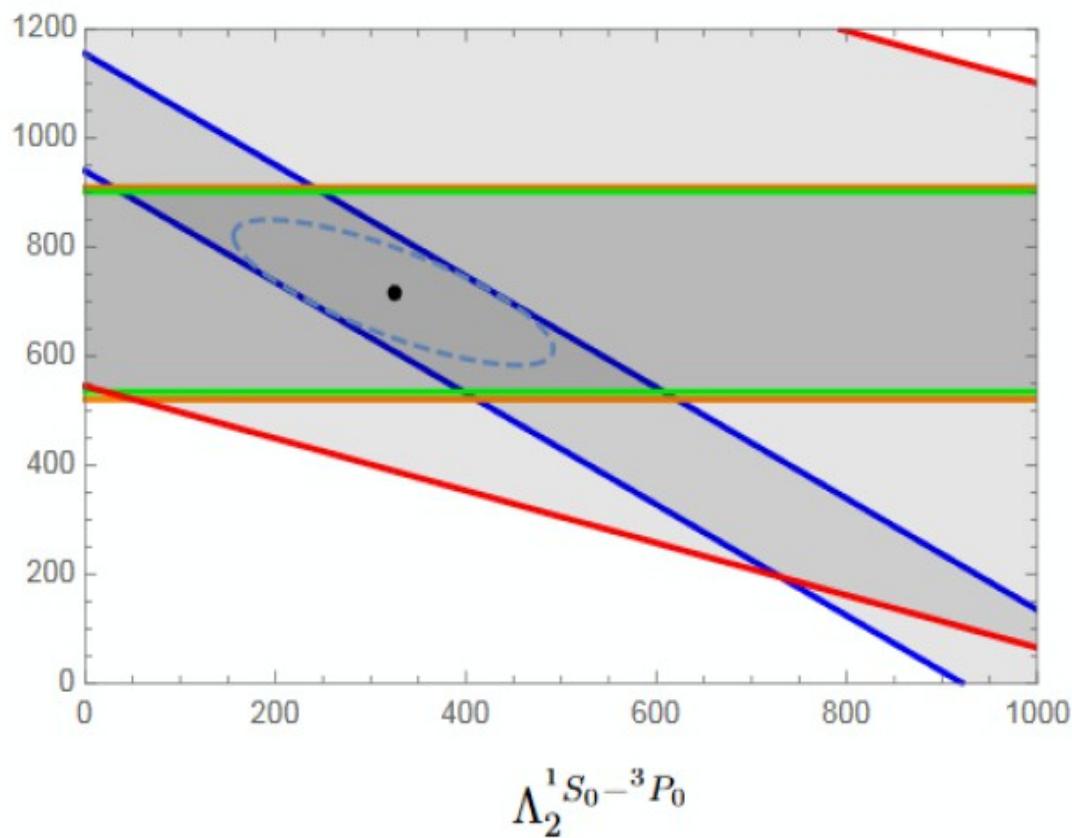
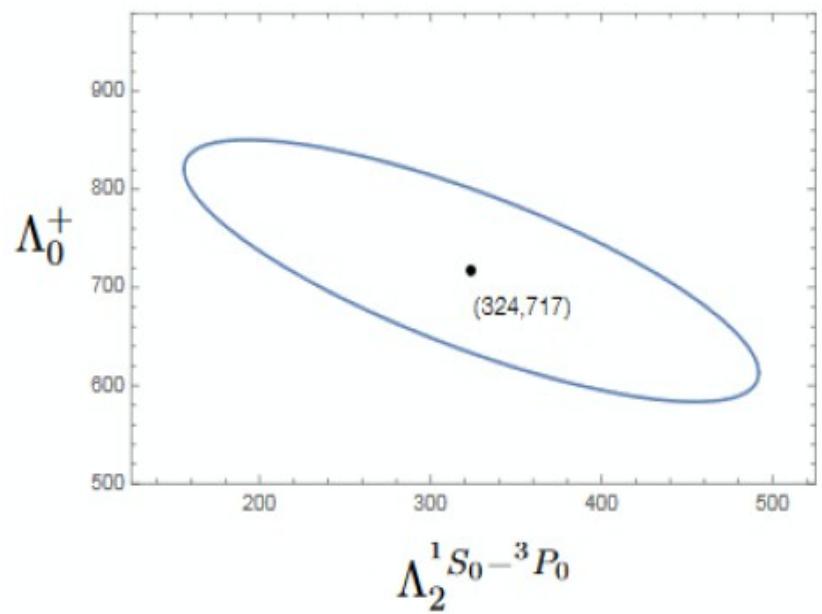
"Rosetta Stone" Table

Coeff	DDH	Girlanda	Large N_c
$\Lambda_0^+ \equiv \frac{3}{4}\Lambda_0^{3S_1-1P_1} + \frac{1}{4}\Lambda_0^{1S_0-3P_0}$	$-g_\rho h_\rho^0(\frac{1}{2} + \frac{5}{2}\chi_\rho) - g_\omega h_\omega^0(\frac{1}{2} - \frac{1}{2}\chi_\omega)$	$2\mathcal{G}_1 + \tilde{\mathcal{G}}_1$	$\sim N_c$
$\Lambda_0^- \equiv \frac{1}{4}\Lambda_0^{3S_1-1P_1} - \frac{3}{4}\Lambda_0^{1S_0-3P_0}$	$g_\omega h_\omega^0(\frac{3}{2} + \chi_\omega) + \frac{3}{2}g_\rho h_\rho^0$	$-\mathcal{G}_1 - 2\tilde{\mathcal{G}}_1$	$\sim 1/N_c$
$\Lambda_1^{1S_0-3P_0}$	$-g_\rho h_\rho^1(2 + \chi_\rho) - g_\omega h_\omega^1(2 + \chi_\omega)$	\mathcal{G}_2	$\sim \sin^2 \theta_w$
$\Lambda_1^{3S_1-3P_1}$	$\frac{1}{\sqrt{2}}g_{\pi NN}h_\pi^1 \left(\frac{m_\rho}{m_\pi}\right)^2 + g_\rho(h_\rho^1 - h_\rho^{1'}) - g_\omega h_\omega^1$	$2\mathcal{G}_6$	$\sim \sin^2 \theta_w$
$\Lambda_2^{1S_0-3P_0}$	$-g_\rho h_\rho^2(2 + \chi_\rho)$	$-2\sqrt{6}\mathcal{G}_5$	$\sim N_c$

What is the pattern here? Traditionally, use Adelberger-Haxton plot, emphasizing $h_\pi^{(1)}$ and $h_\rho^{(0)} + 0.7h_\omega^{(0)}$



New and "improved" plot:



Finally

- i) Happy Birthday Wick
- ii) Keep working on HPV—we need your help!