

Tracing Remnants of the Baryon Vector Current Anomaly in Neutron Radiative β -Decay

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Based on work done in collaboration with Daheng He (U. Kentucky).



- Harvey, Hill, and Hill (2007, 2008): “New” interactions which involve N , γ , and W^\pm or Z^0 emerge from gauging the axial anomaly of QCD under the electroweak symmetry of the Standard Model
 - ⇒ What is their import? What is their expected size?
- But how can we discover them? Enter radiative neutron β -decay.
A triple product correlation in momenta can isolate the new interaction.
- What sort of limit on its strength can follow?
- How large can the “induced” correlation be from known FSI?
- What empirical bounds already exist? What other studies are possible?

Anomalous interactions at low energies

The low energy spectrum of QCD contains pseudoscalar mesons which we interpret as the Nambu-Goldstone bosons of a spontaneously broken chiral symmetry, e.g., $SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$.

Upon inclusion of the **Wess-Zumino-Witten (WZW) term** the chiral Lagrangian can describe known processes such as $K\bar{K} \rightarrow 3\pi$ and $\pi^0 \rightarrow \gamma\gamma$. The latter reflects nonconservation of the axial current: the axial current is **anomalous**.

[Bell and Jackiw (1969); Adler (1969)]

If we study the gauge invariance of the WZW term with vector-like gauge theories (photons) only, then the vector current is conserved.

[Adler (1969); Bardeen (1969)]

Harvey, Hill, and Hill: This changes once we consider the gauge invariance of the WZW action under the full electroweak gauge group of the SM ($SU(2)_L \times U(1)_Y$); the vector current is no longer conserved.

In the presence of spin one fields which couple to baryon number, the baryon vector current is anomalous and new contact interactions of pseudo-Chern-Simons form result.

[Harvey, Hill, and Hill (2007, 2008)]

Anomalous interactions at low energies

Promoting these “spin one fields” to a description of the vector mesons of QCD, we have the new interactions, e.g.,

$$\sim \varepsilon^{\mu\nu\rho\sigma} \omega_\mu Z_\nu F_{\rho\sigma} \text{ and } \sim \varepsilon^{\mu\nu\rho\sigma} \rho_\mu^\pm W_\nu^\mp F_{\rho\sigma}$$

[Harvey, Hill, and Hill (2007, 2008)]

Such structures can also be recovered in a chiral Lagrangian framework. In a theory of nucleons and pions with a complete set of electroweak gauge fields, they appear at N²LO in the chiral expansion. The earlier analysis suggests that ω and ρ degrees of freedom should “saturate” these coefficients.

[Hill (2010)]

At low energy we will adopt an effective action of form

$$S_{\text{HHH}} = \sum_f \xi \int d^4x \varepsilon^{\mu\nu\rho\sigma} \bar{N} \gamma_\mu N \bar{V}_L^f \gamma_\nu V_L^f F_{\rho\sigma}$$

as well as its charged-current analogue.

[Harvey, Hill, and Hill (2007)]

Under vector-meson dominance in the SM, we'd expect $\xi = \frac{N_c}{12\pi^2} \frac{g_\omega^2}{m_\omega^2} \frac{eG_F}{\sqrt{2}}$.

Anomalous interactions at low energies

The baryon vector current should be anomalous in theories in which the gauge fields couple differently to L- and R-handed quarks.

Thus we suppose that “HHH” (pCS) interactions have broader support. They should exist in theories beyond the SM which possess $SU(2)_L \times U(1)_Y$ symmetry at low energy. One popular example is the MSSM.

Thus searching for such interactions may give insight into remnants of the baryon vector current anomaly at low energy.

How, then, can we identify the size of the coefficient?

The interactions could play a role in a broad swath of processes. These include the interpretation of MiniBooNE data as well as the interpretation of parity violation in hadronic observables such as $np \rightarrow d\gamma$. [Hill (2008)]

We will consider the simplest possible system which can reveal the effect: neutron radiative β -decay.

We will find constraints on $\text{Im} \xi$; thus we are searching for traces of new sources of CP violation in the baryon vector current anomaly at low energy.

Isolating the “HHH” interaction in neutron radiative β -decay

Its $\varepsilon^{\mu\nu\rho\sigma}$ structure suggests its symmetry properties can be used to isolate it. In $n(p) \rightarrow p(p') + e^-(l_e) + \bar{\nu}_e(l_\nu) + \gamma(k)$ decay interference with the $V - A$ terms yields to LO

$$|\mathcal{M}|^2 = -64MM' \frac{e^2 G_F^2}{2} \text{Im} \bar{\xi} \frac{E_e}{l_e \cdot k} (\mathbf{l}_e \times \mathbf{l}_\nu) \cdot \mathbf{k} + \dots$$

The pseudo-T-odd interference term is finite as $\omega \rightarrow 0$.

Defining $\eta \equiv (\mathbf{l}_e \times \mathbf{l}_\nu) \cdot \mathbf{k}$ we partition phase space into regions of definite sign:

$$\mathcal{A} \equiv \frac{(\Gamma_{\eta>0} - \Gamma_{\eta<0})}{(\Gamma_{\eta>0} + \Gamma_{\eta<0})}$$

To leading recoil order, where ω^{\min} is lowest detectable photon energy,

$$\mathcal{A}(\omega^{\min} = 0.035 \text{ MeV}) = -2.14 \cdot 10^{-3} \text{Im} \bar{\xi} (\text{MeV}^{-2}), \text{Br}_{\omega^{\min}} = 1.83 \cdot 10^{-3}$$

and

$$\mathcal{A}(\omega^{\min} = 0.3 \text{ MeV}) = -1.34 \cdot 10^{-2} \text{Im} \bar{\xi} (\text{MeV}^{-2}), \text{Br}_{\omega^{\min}} = 8.62 \cdot 10^{-5}$$

In neutron radiative β -decay the study of “hard” photons is phase-space limited.

How large is $\bar{\xi}$ in the SM?

Adopting g_ω and g_ρ from a phenomenological analysis of nucleon-nucleon phase shifts yields

[Machleidt, Holinde, Elster (1987)]

$$\bar{\xi}_\omega \approx 4.1 \times 10^{-6} \text{ MeV}^{-2} \text{ (NC)}$$

$$\bar{\xi}_\rho \approx 4.6 \times 10^{-7} \text{ MeV}^{-2} \text{ (CC)}$$

Of course $\text{Im } \bar{\xi}$ in the SM is zero.

The HHH interaction engenders parity violation but it does not involve the nucleon spin; it is thus **coherent** at amplitude level.

In contradistinction EDM limits lever constraints on chirality-changing operators.

To estimate the ability to detect an asymmetry we consider the counting rates from the neutron radiative β -decay experiment at NIST. The ep double coincidence counting rate was 20 s^{-1} for a quoted neutron flux of $1.1 \times 10^8 \text{ cm}^{-2} \text{ s}^{-1}$. [Nico et al. (2006); Nico, private communication]

Noting that flux at the NG-6 end station is some ~ 20 larger, then in one week of running one could have a stat. error on the asymmetry of $\mathcal{O}(10^{-3})$. Both the incident flux and usable beam size will be larger in the New Guide Hall....

Isolating the HHH interaction in nuclear radiative β -decay

The asymmetry will be larger in nuclear radiative β decays with larger energy release.

There are different possibilities for its study....

Perhaps one could study $^{19}\text{Ne} \rightarrow ^{19}\text{F}$ radiative β -decay, e.g., in an atom trap experiment. The asymmetry would be enhanced by $\sim Z$, and the ^{19}Ne lifetime is 17.2 s.

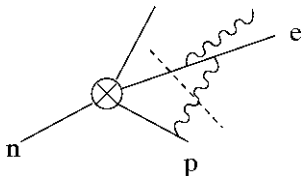
Since the asymmetry grows linearly with the number of nucleons, a large nucleus with a β decay mediated by a pure Fermi transition with a large energy release would be the best candidate system. Perhaps this could be studied at a rare isotope accelerator such as RIA.

Induced Correlations from Known FSI

$\mathcal{O}(\alpha)$ radiative corrections can mimic T-odd effects.

[Callan and Treiman (1967); Okun and Khriplovich (1967)]

In a diagram such as



there are three physical cuts, though only one is shown. Using the Cutkosky rules, we can compute the discontinuity across each physical cut. Namely,

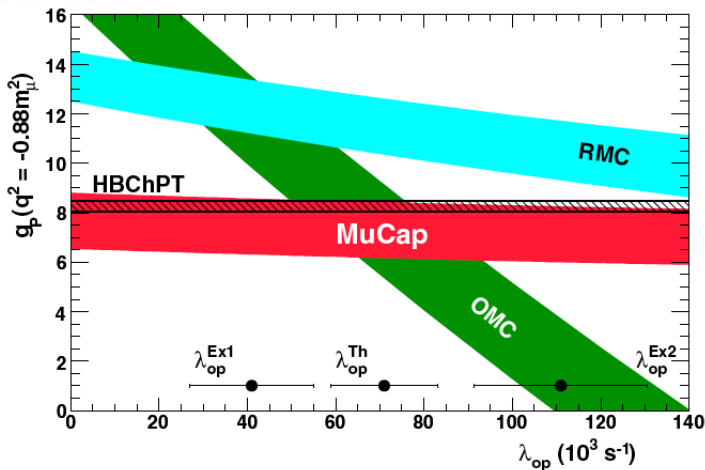
$$\begin{aligned} -i\text{Disc}\mathcal{M}^{\gamma e}(n \rightarrow pe\bar{\nu}) &= \sum_f \int \frac{d^4 l_1 d^4 l_2}{(2\pi)^2} \delta^{(4)}(l_1 + l_2 - l_e - k) \\ &\times \delta^{(+)}(l_1^2 - m^2) \delta^{(+)}(l_2^2) \mathcal{M}^*(\gamma e \rightarrow \gamma e) \mathcal{M}(n \rightarrow p\bar{\nu}e\gamma) \end{aligned}$$

The first nontrivial term is in radiative recoil order, which is encouraging.

Other Processes: PCAC Tests in Muon Capture

g_p is also predicted by PCAC (HBChPT) and can be studied in μ capture. After much controversy, there has been significant progress:

[Andreev et al., MuCap, PRL 99, 032002 (2007).]



Summary and Outlook

Harvey, Hill, and Hill suggest it is possible to study remnants of the baryon vector current anomaly in the Standard Model in low energy interactions.

We have argued that the new contact (“HHH”, “pCs”) interactions can also appear in theories BSM with $SU(2)_L \times U(1)_Y$ electroweak symmetry at low energies.

We have studied how new sources of CP violation connected to such interactions can be probed through a triple-product momentum correlation in neutron radiative β -decay.

The HHH interaction does not involve the nucleon spin; the constraints offered through the study of the pseudo-T-odd, P-odd asymmetry in neutron (or nuclear) radiative β -decay are complementary but distinct from those from EDMs.