Neutron β-decay in Effective Field Theory

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Outline

1. Values of g_A and CKM unitarity (Introduction)
2. Neutron β-decay in Effective Field Theory (EFT)
3. Discussion and Conclusions

1. Introduction

Neutron β-decay

$$n \to p + e + \bar{\nu}_e \, .$$

The hadronic current

$$J^\mu = \bar{u}_p \left[G'_V \gamma^\mu - G'_A \gamma^\mu \gamma_5 \right] u_n \, ,$$

and radiative corrections and weak magnetism.

“Standard calculations”:
Sirlin *et al.*’s works, and Bunatian, and Fukugita and Kubota’s recent works.

Observables of NBD

1. Decay rate (or lifetime)

$$\Gamma \quad = \quad \frac{G_V'^2}{4\pi^3}(1+3g_A^2)\int_{m_e}^{E_E^{max}} dE_e p_e E_e (E_e^{max}-E_e)^2 F(Z,E_e)\left[1+\frac{\alpha}{2\pi}g(E_e,E_e^{max})\right],$$

with

$$G_V'^2 = (G_F V_{ud})^2(1+\Delta_R^V)\,.$$

2. Correlation coefficients

$$\frac{d\Gamma}{dE_e d\Omega_{\hat{p}_e} d\Omega_{\hat{p}_\nu}} \propto 1 + a\frac{\vec{p}_e\cdot\vec{p}_\nu}{E_e E_\nu} + \hat{n}\cdot\left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e\times\vec{p}_\nu}{E_e E_\nu}\right),$$

where

$$a = \frac{1-g_A^2}{1+3g_A^3}\,,\quad A = 2\frac{g_A-g_A^2}{1+3g_A^2}\,,\quad B = 2\frac{g_A+g_A^2}{1+3g_A^2}\,,\quad D = 0\,,$$

with $g_A = G_A'/G_V'$.

Values of g_A

The neutron-spin and electron correlation coefficient A

$$A = \frac{2g_A(1 - g_A)}{1 + 3g_A^2}\,, \qquad g_A = G'_A/G'_V\,,$$

and a recommended value by PDG2004

$$g_A = 1.2695 \pm 0.0029\,.$$

CKM Unitarity

(1) $$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 - \Delta$$

Using V_{ud} from $0^+ \to 0^+$ nuclear β-decay and V_{us} from PDG2002, $\underline{\Delta = 2.2\sigma}$ (0.0032$\pm$ 0.0014).

Suggested solution:
New V_{us} values from E865, KTeV K_{e3}, *etc.*

From the most recent data of neutron β-decay (A), however, $\underline{\Delta = 2.7\sigma}$ (0.0076$\pm$ 0.0028).

New features in NBD

Experiment:

1) New neutron facilities under construction, *e.g.*, at Oak Ridge and J-PARC,

2) New UCN source under investigation in RCNP,

3) New experiment proposals and new detectors under investigation, *e.g.*, in RIKEN.

Theory:

1) Model independent calculations,

2) Error estimations for theoretical uncertainties using EFT approach

2. NBD in EFT

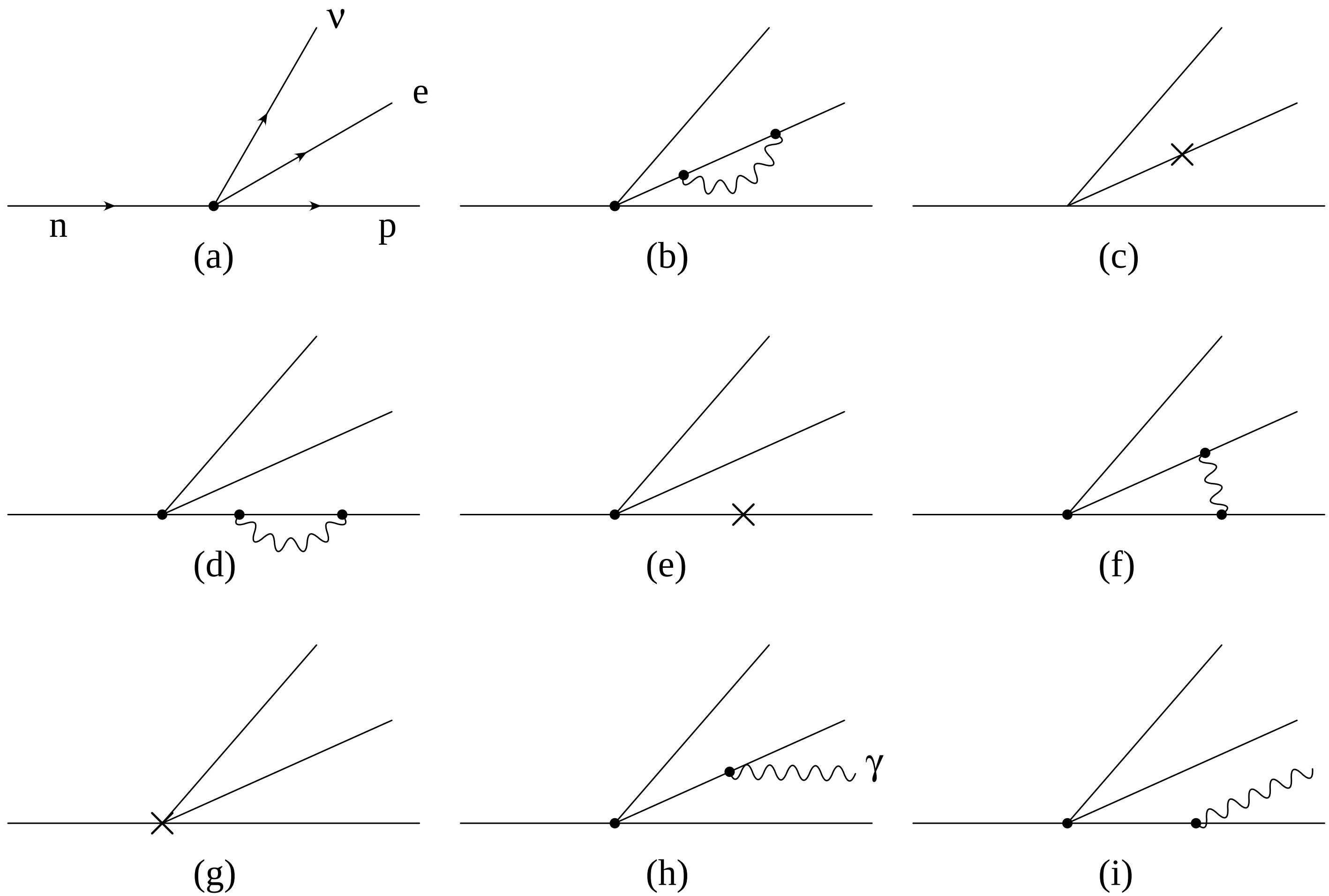
The standard model lagrangian
$\rightarrow$ SSB of chiral sym. of QCD (pions as Goldstone bosons) at low energies. Low energy EFT, “Chiral Perturbation Theory”

$$\mathcal{L}_{SM} \rightarrow \mathcal{L}_{\chi} = \mathcal{L}^{(0)} + \mathcal{L}^{(1)} + \mathcal{L}^{(2)} + \ldots \qquad (2)$$

$$M \sim \sum \left(\frac{Q}{\Lambda_\chi} \right)^{\nu} , \qquad (3)$$

where $Q \simeq m_\pi$ or $|\vec{p}|$, $\Lambda_\chi \simeq 4\pi f_\pi \sim m_N \sim 1$ GeV.

2. NBD in EFT(Cont.)



2. NBD in EFT(Cont.)

(4) $$\bar{Q} \simeq m_n - m_p - m_e << m_\pi$$

Now features for NBD:

1) One-pion exchange diagram $(\bar{Q}/m_\pi)^2 \sim 10^{-5}$

2) Weak-magnetism term $\bar{Q}\kappa_V/(2m_N) \sim 10^{-3}$

Thus:

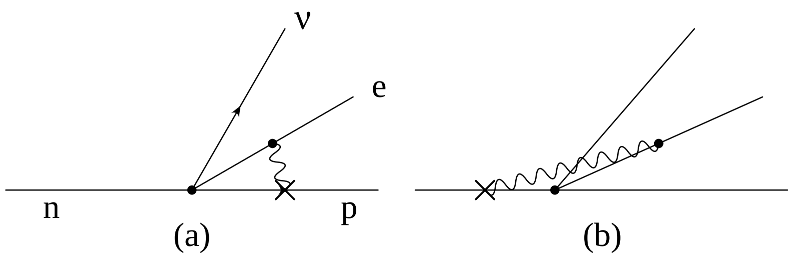
1) Sub-leading terms, $\alpha/(2\pi)$, $\bar{Q}/(2m_N) \sim 10^{-3}$

2) $(m_\pi/\Lambda_\chi)^2$ corrections in the renormalized coupling constants, g_A and κ_V, and

3) Two low energy constants (LEC's), e_V^R and e_A^R.

A difference in estimations of the C term

Low-energy model-dependent radiative correction C in Δ_R^V



In the standard (graphical) calculations, one (Towner) has

(5) $$C(Born) = 0.881 \pm 0.030\,.$$

In HBχPT calculation, they are higher order terms and

(6) $$C(HB) \sim 10^{-6}\,,$$

with the undetermined LEC, e_V^R.

3. Discussion and conclusions

1) The results of EFT reproduce well those of low-energy model-independent terms in the standard calculations. While the high-energy and low-energy model-dependent terms are replaced by the LEC's.

2) After one fixes the LECs, the theoretical uncertainty of our results would be less than $\sim 10^{-3}$.

3) The estimation of the C term in EFT is much smaller than that in the standard calculation. While we have the LEC e_V^R to determine.

4) Next precise measurement of A will be very important.

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