TEST OF CP VIOLATION IN NON-LEPTONIC HYPERON DECAYS

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ABSTRACT

In this talk I discuss CP violation in hyperon decays in Left-Right symmetric models. I show that the asymmetry in polarization in $\Lambda \rightarrow p\pi^-$ can be as large as $6 \times 10^{-4}$ in these models, which is an order of magnitude larger than the Standard Model prediction.

1. Introduction

Non-leptonic hyperon decay, $\Lambda \rightarrow p\pi^-$, is an interesting process to test CP conservation outside the neutral Kaon system. The decay amplitude can be written as

$$M(\Lambda \rightarrow p\pi^-) = S + P\sigma \cdot \bar{q},$$

where $\bar{q}$ is the momentum direction vector of the pion. One particularly interesting CP violating observable is the asymmetry in polarization,

$$A(\Lambda) = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}},$$

where $\alpha = 2Re(S^*P)/(|S|^2 + |P|^2)$, and $\bar{\alpha}$ is the corresponding quantity for $\bar{\Lambda}$ decays. A non-zero $A(\Lambda)$ signals CP violation. To a very good approximation,

$$A(\Lambda) = -\tan(\delta_{11} - \delta_1)\sin(\phi_1^s - \phi_1^p),$$

where $\delta_1 = 6^0$, $\delta_{11} = -11^0$ are the strong rescattering phases, $\phi_1^s$ and $\phi_1^p$ are the weak CP violating phases for the S-wave and P-wave amplitudes with $I = 1/2$, respectively. To calculate the weak phases $\phi^{s,p}$, I will take the approach to use experimentally determined decay amplitudes as CP conserving ones and calculate theoretically the CP violating ones.

A new experiment E871 at Fermilab will measure $\alpha_{\Lambda\alpha_{\Xi}}$ in the decay $\Xi^- \rightarrow \Lambda\pi^- \rightarrow p\pi^-\pi^-$, and also similar measurement for anti-$\Xi$ decay. CP asymmetry in these decays will be measured. The CP asymmetry in polarization in this case is dominated by $A(\Lambda)$. The expected sensitivity for $A(\Lambda)$ is $10^{-4}$ and eventually will reach $10^{-5}$. In the SM $A(\Lambda)$ is predicted to be in the range $-(0.5 \sim 0.1) \times 10^{-4}$. This prediction will not be tested at the initial stage of the E871 experiment. It is extremely interesting to see if $A(\Lambda)$ can be larger in extensions of the SM and can be tested by the E871 experiment. In this talk I will show that in Left-Right symmetric models $A(\Lambda)$ can be as large as $6 \times 10^{-4}$ and will be tested soon.

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2. \( A(\Lambda) \) in Left-Right Symmetric Models

Left-Right symmetric extensions of the SM is based on the gauge group \( SU(3)C \times SU(2)L \times SU(2)R \times U(1)_{B-L} \). In general there will be mixing between \( W_L \) of the \( SU(2)_L \) charged gauge boson and \( W_R \) of the \( SU(2)_R \). The effective Hamiltonian \( H_{eff} \) for non-leptonic hyperon decays by exchanging gauge bosons up to one loop level contains different contributions

\[
H_{eff} = H_{SM} + H_R + H_{LR} .
\]

In the zero mixing limit, \( H_{SM} \) reduces to the SM contribution. \( H_R \) is due to \( W_R \) exchange. \( H_{LR} \) is due to \( W_L \) and \( W_R \) mixing and therefore should be proportional to the mixing angle \( \xi \). It is given by

\[
H_{LR} = \frac{G_F}{\sqrt{2}} \xi \{ V_{Lud}^* V_{Rus} (O_{LR}^+ \eta_+ - O_{LR}^- \eta_-) + V_{Rud}^* V_{Lus} (O_{RL}^+ \eta_+ - O_{RL}^- \eta_-) 
+ \sum_i \tilde{G}(x_i) \frac{g_8}{16\pi^2} m_i \eta_g G^{\mu\nu} \sigma_{\mu\nu} \lambda^i [V_{Rid}^* V_{Lis} (1 - \gamma_5) + V_{Lid}^* V_{Ris} (1 + \gamma_5)] s \} ,
\]

where \( \eta_+ = (\alpha_s(1\text{GeV})/\alpha_s(m_c))^{-3/27} (\alpha_s(m_c)/\alpha_s(m_b))^{-3/25} (\alpha_s(m_b)/\alpha_s(m_W))^{-3/23} , \eta_- = \eta_8^- , \eta_9 = 14^3/5 , \xi = \xi g_R/g_L , g_{L,R} \) are the \( SU(2)_{L,R} \) gauge couplings, \( V_{L,R} \) are the KM mixing matrices, and

\[
\tilde{G}(x) = - \frac{3x}{2(1-x)^3} \ln x - \frac{4 + x + x^2}{4(1-x)^2} ,
\]

\[
O_{LR}^+ = \bar{d}\gamma_\mu Lu \bar{u} \gamma^\mu Rs + \frac{2}{3} \bar{d}Rs \bar{u} Lu , \quad O_{LR}^- = \frac{2}{3} \bar{d}Rs \bar{u} Lu .
\]

Here \( R(L) = 1 \pm \gamma_5 \), \( O_{LR}^{\pm} \) are obtained by exchanging \( R \) and \( L \).

\( H_{SM} \) contribution to \( A(\Lambda) \) is in the range of \(-0.5 - 0.1 \times 10^{-4}\), and \( H_R \) contribution is smaller. Possible large contribution can come from \( H_{LR} \). Using factorization approximation, the \( O_{LR}^\pm \) operator contribution \( A_W(\Lambda) \) is estimated to be

\[
A_W(\Lambda) = 1.73 \{ \xi^u - 0.06 \xi^u \} ,
\]

where \( \xi^i = \xi Im(V_{Lid}^* V_{Ris} \pm V_{Rid}^* V_{Lis}) \). Using the matrix element evaluated in Ref.[3], the gluon dipole contribution \( A_G(\Lambda) \) (terms proportional to \( \tilde{G}(x) \)) is found to be

\[
A_G(\Lambda) = 0.21 \sum_i \frac{m_i}{\text{GeV}} \frac{\xi^i}{\text{GeV}} \{ \xi^i + 1.17 \xi^i \} .
\]

The S-wave and P-wave contributions are proportional to \( \xi^i_+ \) and \( \xi^i_- \), respectively.

3. Discussions

There are constraints on the allowed value for \( A(\Lambda) \) because \( \xi \) and \( \xi^u \) are both constrained. From CP conserving hyperon decays, \( \xi \) is found to be less than \( 4 \times 10^{-3} \).
Experimental limit of $|\epsilon'/\epsilon| < 3 \times 10^{-3}$ implies $|\xi^u| < 2 \times 10^{-6}$. The S-wave contribution to $A_W(\Lambda)$ is constrained to be less than $4 \times 10^{-6}$. If $|\xi^u|$ is small by cancellation, the P-wave contribution is approximately given by

$$A_W(\Lambda) = -0.2\xi \text{Im}(V^*_{Rud}V_{Lus}).$$

(9)

$A_W(\Lambda)$ can be as large as $10^{-4}$ if $\text{Im}(V^*_{Rud}V_{Lus}) > 0.1$.

The magnitude for $A_G(\Lambda)$ is also constrained for the same reasons discussed above. The S-wave contribution to $A_G(\Lambda)$ is found to be less than $1.3 \times 10^{-4}$ from experimental limit on $\epsilon'/\epsilon$. However the P-wave contribution is not directly constrained and may be larger. Assuming $\text{Im}(V^*_{Lid}V_{Ris}) = \text{Im}(V^*_{Rid}V_{Lis})$ and using $m_t = 176$ GeV, one finds that $A_G(\Lambda)$ can be as large as $6 \times 10^{-4}$. Such a large $A(\Lambda)$ will be probed by the E871 experiment.

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