CHARGE ASYMMETRY IN THE LEPTON PAIR DECAY OF POLARIZED RESONANCES ☆

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The charge asymmetry in the lepton pair of a polarized Υ (or any other heavy resonances) decay is computed. It provides a good test of the Weinberg-Salam model.

The study [e.g. 1] of the weak neutral current interaction seems to indicate that the standard Weinberg-Salam (W-S) model [2] is consistent with various neutrino-induced reactions and the Novosivirisk experiment on the Bi atom [3], although the Oxford and Seattle experiment [4] on the Bi atom may contradict the W-S model. Recent asymmetry measurements of polarized electron deuteron scattering [5] seems to be best described by the WS model. However, lack of precision in the y-value measurement does not allow a decisive conclusion. In this article, it is shown that charge asymmetry in the decay, (polarized $\Upsilon \to {}^{e^+e^-}_{\mu^+\mu^-}$), is a sensitive test of the WS model. Of course, the asymmetry test in $e^+e^- \to \mu^+\mu^-$ had been proposed since the early days of the PEP design [6]. Nevertheless, it is important to look at lepton pair data in the resonance regions, since (a) it has a smaller background and (b) it probes the property of the heavy quarks directly.

We assume that Υ or any other higher resonance expected to be observed in the PETRA and PEP experiments are polarized in the beam direction. This is what happened with the ψ/J resonance produced by SPEAR.

The relevant neutral current interaction in the W-S model is given by

$$\mathcal{L} = ieA_\mu(-\bar{e}\gamma_\mu e + \tfrac{2}{3}\bar{t}\gamma_\mu t - \tfrac{1}{3}\bar{b}\gamma_\mu b) + \frac{igZ^0_\mu}{4\cos\theta_W}(-\bar{e}\gamma_\mu e(1-4\sin^2\theta_W) - \bar{e}\gamma_\mu\gamma_5 e + \bar{t}\gamma_\mu t(1-\tfrac{8}{3}\sin^2\theta_W) + \bar{t}\gamma_\mu\gamma_5 t - \bar{b}\gamma_\mu b(1-\tfrac{4}{3}\sin^2\theta_W) - \bar{b}\gamma_\mu\gamma_5 b)\,, \quad (1)$$

where t, (b) stands for the top (bottom) quark with charge 2/3 (−1/3). We notice that

$$\langle 0|\bar{q}\gamma_\mu\gamma_5 q|\,{}^3S_1\ q\bar{q}\ \text{bound state}\rangle = 0 \quad (2)$$

since the axial current is even under charge conjugation while the ${}^3S_1$ state is odd. Thus only the vector part of the quark current contributes to the weak neutral current decay of the resonances.

The leptonic decay of a polarized Υ, is computed by

$$|M|^2 \propto \sum_{\text{spin}} |\epsilon_\mu(\bar{u}(\gamma_\mu + A\gamma_\mu\gamma_5)v)|^2$$
$$= \epsilon_\mu\epsilon^*_\nu \mathrm{Tr}\left[\frac{-i\gamma p_-}{2m}\gamma_\mu\frac{i\gamma p_+}{2m}\gamma_\nu + 2A\frac{-i\gamma p_-}{2m}\gamma_\mu\gamma_5\frac{i\gamma p_+}{2m}\gamma_\nu\right]$$
$$= \frac{1}{m^2}\epsilon_\mu\epsilon^*_\nu[(p_-)_\mu(p_+)_\nu + (p_+)_\mu(p_-)_\nu + \tfrac{1}{2}m_V^2\delta_{\mu\nu} - 2A\,\epsilon_{\mu\nu\alpha\beta}(p_-)_\alpha(p_+)_\beta]\,, \quad (3)$$

where $p_-(p_+)$ is the momentum of the massless lepton (antilepton) and ϵ_μ and m_V are the polarization vector

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Table 1
The integrated asymmetry of the lepton pair in a polarized resonance decay

	$\sin^2\theta_W = 0.25$		$\sin^2\theta = 0.2$	
	b-quark	t-quark	b-quark	t-quark
Υ	−0.012	−0.0030	−0.013	−0.0042
"30 GeV"	−0.12	−0.030	−0.13	−0.041

and the mass of the resonance respectively. For polarization $\epsilon_\mu = (1/\sqrt{2}, i/\sqrt{2}, 0, 0)$, we obtain

$$|M|^2 \propto \frac{m_V^2}{4m^2}(1 + \cos^2\theta + 4A\cos\theta) \equiv f(\theta)\,, \qquad (4)$$

where the z axis is chosen to be the direction of the spin polarization and the polar angle of p_+ is θ. The integrated asymmetry is then given by

$$B = \frac{\int_0^{\pi/2} f(\theta)\sin\theta\, d\theta - \int_{\pi/2}^{\pi} f(\theta)\sin\theta\, d\theta}{\int_0^{\pi} f(\theta)\sin\theta\, d\theta} = \tfrac{3}{2}A\,. \qquad (5)$$

The ratio of the axial vector and vector coupling, A, of the lepton pair is estimated from eq. (1),

$$A = \frac{(G_\pi/2\sqrt{2})(1 - \frac{4}{3}\sin^2\theta_W)}{-(4\pi/3)\alpha/m_V^2} \quad \text{for the b quark} \qquad (6)$$

and

$$A = \frac{(G_\pi/2\sqrt{2})(1 - \frac{8}{3}\sin^2\theta_W)}{-(8\pi/3)\alpha/m_V^2} \quad \text{for the t quark}\,. \qquad (7)$$

Table 1 gives the numerical result for the integrated asymmetry, B, for various masses. For Υ or higher resonances, the observation of asymmetry is much easier if it is due to the bottom quark than if it is due to the top quark.

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