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Publication Date

1976-07-01

Submitted to Physics Letters B

LBL-5346
Preprint c.1

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July 1976

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Right-Left Asymmetry of Inclusive Hadron Production

in

Electron-Positron Annihilation

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We calculate a possible right-left asymmetry of inclusive hadron production in highly transversely polarized e^+e^- annihilation, which is, if successfully measured, an unambiguous clean evidence for parity violation.

* Supported by U.S. Energy Research and Development Administration.

** Supported by National Science Foundation under Grant Number PHY

Various tests of weak interactions in e^+e^- annihilation have been proposed [1,2], and one of the few promising tests is to measure a forward-backward asymmetry in $\cos\theta$ distribution of final hadrons. Unlike the $e^+e^- \rightarrow \mu^+\mu^-$ process, strong interaction dynamics prevents us from estimating accurately hadrons due to two-photon-annihilation (without e^+e^- in final states) interfering with one-photon-annihilation. We propose here an alternative method to detect an interference of weak and electromagnetic interactions by making use of high transverse polarization of e^+e^- beams.

Let us write a weak neutral current interaction as

$$L_{int} = -g_\ell \bar{e} \gamma_\mu (1 + g_a \gamma_5) e Z^\mu - g_h J_\mu^{(w)} Z^\mu, \quad (1)$$

where $J_\mu^{(w)}$ is a hadronic weak neutral current, and g_ℓ and g_h are model-dependent weak couplings. It interferes in cross sections with the electromagnetic interaction $L_{int} = e \bar{e} \gamma_\mu e A^\mu - e J_\mu^{(em)} A^\mu$. The inclusive cross section of one-photon-annihilation is given through a straightforward calculation by

$$E_p \frac{d^3\sigma}{dp^3} \simeq \frac{1}{s^2} \left(\frac{e^2}{4\pi} \right)^2 \left\{ F_1^{(e)} + \frac{1}{4} \beta^2 x F_2^{(e)} \sin^2\theta (1 - P^2 \cos 2\phi') \right\} + \frac{1}{s(s-M_Z^2)} \left(\frac{e^2 g_a g_\ell g_h}{16\pi^2} \right) \left\{ \frac{1}{2} \beta^2 x P^2 \text{Im} F_2^{(ew)} \sin^2\theta \sin 2\phi' - \beta \text{Re} F_3^{(ew)} \cos\theta \right\}, \quad (2)$$

where $\underline{p}$ is the detected hadron momentum, $\beta = |\underline{p}|/E_p$, s is the center-of-mass energy squared, $x = 2E_p/s^{\frac{1}{2}}$, M_Z is the neutral W boson mass, P is the magnitude of transverse polarization of e^+e^- , ϕ' is the azimuthal angle of $\underline{p}$ measured from the direction of the polarization vector of e^- ^{†1} and F 's are structure functions. ^{†2}

The interference term of structure function $F_2^{(ew)}$ is defined by $F_2^{(ew)} = \nu W_2^{(ew)} / m$, where m is the hadron mass, and $W_2^{(ew)}$ is the coefficient of the covariant absorptive part $\sum_X \langle 0 | J_\nu^{(w)} | X, \underline{p}^{(+)} \rangle \langle X, \underline{p}^{(+)} | J_\mu^{(em)} | 0 \rangle \times (2\pi)^3 \delta^{(4)}(q-p-p_X)$. It is particularly emphasized here that unlike the diagonal structure functions, $F_2^{(ew)}$ is generally complex even if time reversal invariance holds. Interference of final interactions in different eigenchannels ($I=0$ and 1) gives rise to a nonzero imaginary part since $\sum_X |X, \underline{p}^{(+)} \rangle \langle X, \underline{p}^{(+)}| \neq \sum_X |X, \underline{p}^{(-)} \rangle \langle X, \underline{p}^{(-)}|$ when $\underline{p}$ is not summed over. ‡

Equation 2 shows a right-left asymmetry in the ϕ' angular distribution. With $\alpha(x) = -\frac{1}{2} x F_2^{(e)} / F_1^{(e)}$ for the purely electromagnetic structure functions, the inclusive cross sections for relativistic hadrons ($\beta \simeq 1$) can be written as

$$E_p \frac{d^3\sigma}{dp^3} \simeq \frac{1}{2s^2} \left(\frac{e^2}{4\pi} \right)^2 \left\{ 2 - \alpha(x) \sin^2\theta - \alpha(x) P^2 \sin^2\theta \cos 2\phi' \right\} F_1^{(e)} + \frac{1}{s(s-M_Z^2)} \left(\frac{e^2 g_a g_l g_h}{16\pi^2} \right) \left\{ \frac{1}{2} P^2 x \operatorname{Im} F_2^{(ew)} \sin^2\theta \sin 2\phi' - \operatorname{Re} F_3^{(ew)} \cos\theta \right\}. \quad (3)$$

Let us define a right-left asymmetry parameter at $\theta = 90^\circ$ as

$$\Delta(\phi') = \{N(\phi') - N(-\phi')\} / \{N(\phi') + N(-\phi')\}, \quad (4)$$

where $N(\phi')$ is the number of hadrons coming out in the direction of $(\theta=90^\circ, \phi')$. Then

$$\Delta(\phi') - \Delta(\pi-\phi') = \left(\frac{g_a g_l g_h}{e^2} \right) \left(\frac{s}{s-M_Z^2} \right) \frac{P^2 \sin 2\phi'}{2 - \alpha(x)(1 + P^2 \cos 2\phi')} \frac{x \operatorname{Im} F_2^{(ew)}}{F_1^{(e)}}. \quad (5)$$

At $\sqrt{s} = 7.4$ GeV, $\alpha(x)$ is close to unity for $x \gtrsim 0.5$, and P is about 70 % [3]. It is expected that at higher energies $\alpha(x)$ will be close to unity above even smaller values of x and P will reach as high as 92.4 % [4].

Hadrons produced by the electromagnetic current are depleted at $\theta = 90^\circ$ with $\phi' = 0^\circ$ and 180° , while the right-left asymmetry shows up maximally at $\phi' = \frac{1}{2} \cos^{-1} \{ \alpha P^2 / (2 - \alpha) \}$.

In the standard Salam-Weinberg model [5],^{†4} the weak couplings are given by $g_a g_l g_h = \frac{1}{2} e^2 / \sin^2 \theta_W$, where $\sin^2 \theta_W \simeq 0.30$ to fit experimental data. Equation 5 is written in this model as

$$\Delta(\phi') - \Delta(\pi - \phi') \simeq - 0.29 (\sqrt{s}/37 \text{ GeV})^2 \xi(\phi') \frac{x \text{Im } F_2^{(ew)}}{F_1^{(e)}} \quad (6)$$

$$\xi(\phi') = P^2 \sin 2\phi' / \{ 2 - \alpha(x) - \alpha(x) P^2 \cos 2\phi' \} \quad (7)$$

The function $\xi(\phi')$ is of the order of unity or less. It is plotted in Figure 1 for a few different values of P^2 and $\alpha(x)$. A crucial question is how large $x \text{Im } F_2^{(ew)} / F_1^{(e)}$ would be. If all parton distribution functions are chosen equal, the parton model predicts that in the four-quark model

$$|x F_2^{(ew)}| / F_1^{(e)} \simeq \frac{9}{5} - 4 \sin^2 \theta_W \simeq 0.60 \quad (8)$$

Only a product of currents antisymmetric in isovector and isoscalar currents can contribute to $\text{Im } F_2^{(ew)}$. Estimate of its imaginary part involves details of strong interaction dynamics at low energies, which forbids anything beyond a mere guess.^{†5} We find from the isospin structure of currents that the ratio $\text{Im } F_2^{(ew)} / F_2^{(ew)}$ is about 0.50 at maximum interference in the Salam-Weinberg model. It should be pointed out that if final states consists only of pions, G parity forbids the interference. Only the events that contain $K\bar{K}$, $\bar{N}\bar{N}$, and so forth contribute to the asymmetry. At higher energies such events occupy a large portion of total events enough to produce a substantial right-left asymmetry. Although this test seems to be rather difficult at

SPEAR/DORRIS energies,^{†6} it will be quite realistic at PEP/PETRA energies ($\sqrt{s} = 20 \sim 36$ GeV).

To conclude, we emphasize that unlike the forward-backward asymmetry the right-left asymmetry is a clean direct test of parity nonconservation free from backgrounds due to higher order electromagnetic interactions or to weak decays of heavy leptons or charmed hadrons produced electromagnetically. If a hadronic weak neutral current is parity-conserving but a leptonic current contains both vector and axial vector currents, there would be no $\cos\theta$ asymmetry besides a possible secondary effect due to weak decays in final states and therefore the present method would be useful to supplement informations obtainable in the $e^+e^- \rightarrow \mu^+\mu^-$ process.

FIGURE CAPTION

Figure 1. $\xi(\phi')$ for three sets of values of P^2 and $\alpha(x)$. I for $P^2 = 0.85$ and $\alpha(x) = 1.0$, II for $P^2 = 0.70$ and $\alpha(x) = 0.80$, and III for $P^2 = 0.50$ and $\alpha(x) = 0.60$.

FOOTNOTES

- 1 The spherical angles (θ, ϕ') are so defined that the polarization vector of e^- is along the positive x axis and the e^- beam is along the positive z axis.
- 2 We have suppressed in (2) contributions of $\text{Re } F_1^{(ew)}$ and $\text{Re } F_2^{(ew)}$ as well as all of the diagonal weak structure functions, since they are insignificant to the asymmetry parameter $\Delta(\phi')$ that we calculate as long as $s \ll M_Z^2$.
- 3 The superscripts (+) and (-) in the state vectors refer to "outgoing" and "incoming" boundary conditions, respectively.

4 The asymmetry is zero in models where a leptonic weak neutral current is a pure vector as well as in the model proposed in Reference 6.

5 We can not exclude a pessimistic guess that the phase difference of $I = 0$ and $I = 1$ final state interactions may come out to be negligibly small.

6 It should be noted here that statistical accuracy of 0.67 % has been reached for parity tests using angular correlations of two and three final hadrons at SPEAR energies. G. Goldhaber, private communication.

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Figure 1

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