PARITY-VIOLATING MOMENTUM CORRELATIONS AS A MEANS OF OBSERVING WEAK INTERACTIONS IN $e^+e^- \to$ HADRONS

J. H. Klems

Abstract

Parity violations in $e^+e^- \to$ hadrons may be detectable in correlations of the form $(\vec{p}_1 \times \vec{p}_2)\cdot\vec{k}_e$ between two hadrons and the electron beam. In the absence of specific guidance as to where to look for an effect, it is noted that if the low yield of energetic hadrons observed in parity conserving processes at lower energies persists at PEP, then the weak interactions, for which the rate is enhanced by a factor of p_1p_2, may be most easily observed by examining correlations between energetic hadrons in the plane perpendicular to the electron beam.

Parity-violating momentum correlations in a hadronic final state can arise only from the interference between a weak axial-vector current and the electromagnetic current. The simplest such interference term is of the form

$$\vec{p}_1 \times \vec{p}_2 \cdot \vec{k}_e$$

where 1 and 2 denote particles labeled in some arbitrary but unambiguous manner and $\vec{k}_e$ is the momentum of one of the incident particles. The differential cross section to be expected may be written as follows:

$$\frac{d\sigma}{d^3p_1\, d^3p_2} = \sigma_0 \left[E(\vec{p}_1,\vec{p}_2) + \frac{Gs}{4\pi\alpha} W(\vec{p}_1,\vec{p}_2)\ \vec{p}_1 \times \vec{p}_2 \cdot \vec{k}_e \right] \qquad (1)$$

where σ_0 is the electromagnetic cross section for $e^+e^- \to \mu^+\mu^-$. The coordinate system is shown in Fig. 1. If particle 1 is detected uniformly over the azimuthal angle relative to the beam, then the parity-conserving terms in the cross section can contribute no dependence on ψ and the cross section becomes

$$\frac{d\sigma}{p_1^2p_2^2\, d\Omega_1\, dp_1\, d\Omega_2\, dp_2} = \sigma_0 \left[E'(p_1,\theta_1,p_2,\theta_2) + \frac{Gs}{4\pi\alpha} W'(p_1,p_2)\sin\theta_1 \sin\theta_2 \sin\varphi \times (p_1p_2k_e) \right] \qquad (2)$$

where θ_1, θ_2 are the polar angles of particles 1 and 2 relative to the beam.

Equation (2) contains as much, or as little, as can definitely be said about 2-particle correlations. Several points should be emphasized:

1) E' and W' are unknown.
2) E' cannot depend on φ.
3) The weak interaction term is kinematically enhanced by the product p_1p_2.
4) Both E' and W' have their origins in the strong interactions.
5) The weak term is maximized for secondaries in the plane perpendicular to the beam.

Given these uncertainties, one is reduced to searching for a correlation of the form

$$\frac{d\sigma}{d\varphi} = N(1 + B\sin\varphi)$$

where N is the total number of events for which two particles (identified in some manner as 1 and 2) are accepted into an angular bite $\pm\,\theta_0$ centered about the plane perpendicular to the beam and B is an unknown parameter. One may ask how many events are necessary to determine B to a given accuracy. We estimate this by considering the number of times, N_+, in which the particles 1, 2, and beam form a right-handed system and the number of times, N_-, in which they form a left-handed system (see Fig. 2). To maximize signal to background we restrict particle 2 to a narrow internal $\Delta\varphi$ near $\varphi = \mp\,\pi/2$. We then form the left-right asymmetry

$$A = \frac{N_+ - N_-}{N_+ + N_-} = B\,\frac{\sin(\Delta\varphi)}{\Delta\varphi} \approx B$$

for $\Delta\varphi$ small. This statistical error in this quantity is

$$\sigma_A = \frac{\sin(\Delta\varphi)}{\Delta\varphi}\,B\,\frac{1}{\sqrt{N}}\sqrt{1 + \frac{1}{\left(\frac{\sin(\Delta\varphi)}{\Delta\varphi}\,B\right)^2}}$$

For a four-standard-deviation effect we then need $4\sigma_A \leq A$, or

$$1 + \left(\frac{1}{\frac{\sin(\Delta\varphi)}{\Delta\varphi}\,B}\right)^2 \approx 1 + \frac{1}{B^2} \leq \frac{N}{16}\,,$$

which gives the following results:

to see B of	need N of
1	32
.1	1600
.01	1.6×10^5

Because of the complications of strong interactions this experiment has several disadvantages:

1) Only a positive result is unambiguous.
2) A positive result might occur only if the neutral-current interaction (a) couples to e^+e^- and (b) has an axial-vector part. Neither of these conditions is currently known to hold.
3) One does not know where the effect is most likely to show up.
4) One does not currently know enough about $e^+e^- \rightarrow$ hadrons even to make reliable guesses about the background. Still less is known about the size of the weak interaction term.

In view of these disadvantages, especially (3), it is not feasible (or desirable) to design an apparatus tailored to this experiment. Instead we recommend that a search for this effect be carried out in one or more detectors designed primarily to do other experiments, and that at least one of the detectors to be built at PEP be designed so as not to exclude such a search.

The minimal requirements for such a detector are:

1) 2π (or nearly 2π) acceptance in φ in a plane perpendicular to the beam.
2) At least 4-fold symmetry in φ (preferably 8-fold or more).
3) Good angular resolution in φ.
4) Modest momentum resolution and 2-particle acceptance over a wide range of momenta.
5) Ability to identify charged particles.
6) Minimum triggering biases.

The detector proposed by the high momentum hadron group, in either the axial-field or toroidal-field geometry, satisfies all of these requirements. In addition, the low inclusive rate of high-momentum hadrons from parity-conserving processes obtained by an extrapolation of the SPEAR data, together with the kinematic enhancement to be expected for the weak interaction, leads one to expect that correlations between high-momentum hadrons may be a particularly fruitful place to search for weak interaction effects.

Fig. 1 Coordinate System

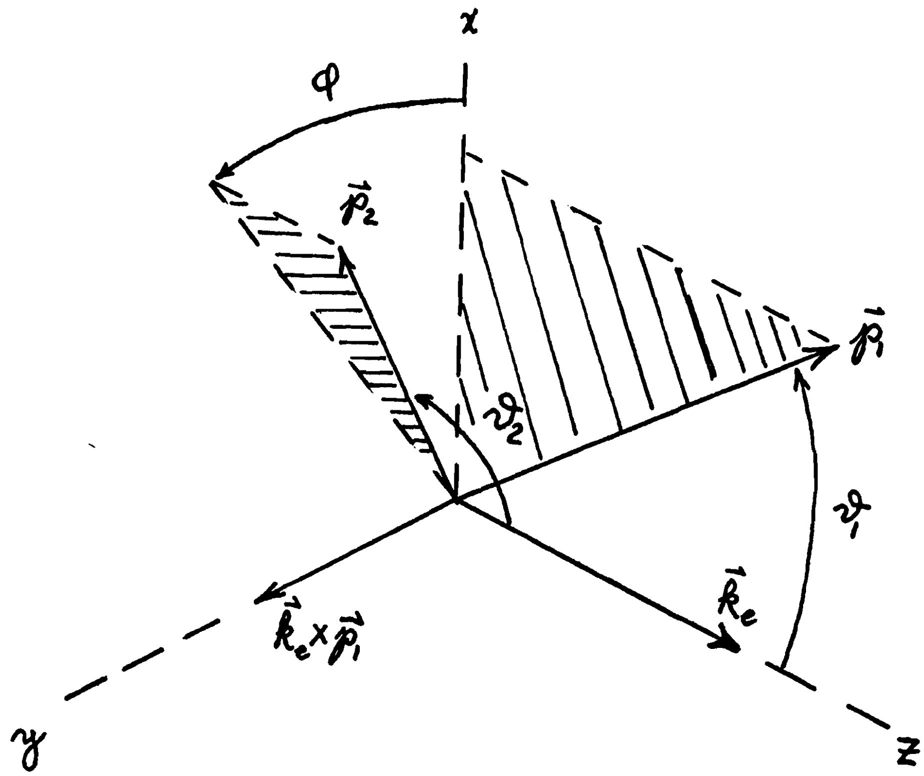
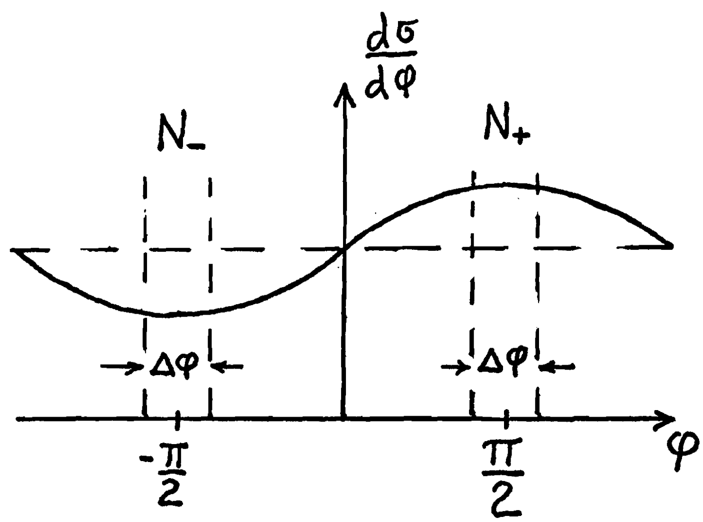


Fig. 2

(a) φ distribution



(b) Kinematic Configurations