Looking for Compositeness at the SSC by Probing for Large P or T Violations

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(Notes based on discussions with G. Kane, D. Kosower, and other members of the compositeness group.)

1. Introduction

If quarks and leptons are composite, it is possible that the interaction binding their constituents will have unusual symmetries. For example, Adler[1] has suggested that composite models of the Harari-Shupe[2] type should be based on an underlying quaternionic quantum mechanics, and has shown that such theories lead to an effective superweak CP violation at low energies, with an energy scale $\Lambda^* \sim 20\ TeV$ characterizing strong CP-violating effects. Independent of the details of particular models, we can ask the general question of whether the presence of abnormal symmetries can be used as a signature for detecting compositeness at TeV excitation energies.

In addressing this question, we will adhere to the following ground rules:

(i.) We are interested in very high excitation energies and thus will be analyzing *production processes* rather than *decays*. (In a decay the excitation energy is limited to the mass of the decaying particle.)

(ii.) We will assume that the underlying interaction binding quark-lepton constituents is effectively CPT-conserving, although possibly P, T or PT violating. This allows its leading effects below the preonic energy scale Λ^* to be represented by a non-renormalizable effective four-fermion interaction, as in the compositeness studies of Eichten, Lane and Peskin[3] and Eichten *et. al.*[4] (EHLQ). (A CPT-violating interaction cannot be represented by an effective local Lorentz-invariant Lagrangian density.)

(iii.) We will look for abnormal-symmetry effective interactions through their interference with "old physics" QCD or electroweak processes, since such interference effects should be detectable at energies well below Λ^*. (At energies of order Λ^* and above, many dramatic "new physics" effects are expected, irrespective of the symmetries of the underlying interaction.)

2. The case of P-Violating, T-(and CP-) Conserving Underlying Interactions

We begin with the case in which the underlying composite physics is P-violating but T-conserving. An effective four-fermion interaction of this type is given in Eq. (8.8) of EHLQ,

$$\mathcal{L}_P = \frac{g^2}{2\Lambda^{*2}} \Big\{ \eta_0 \bar{q}_L \gamma^\mu q_L \bar{q}_L \gamma_\mu q_L + \eta_{uu} \bar{u}_R \gamma^\mu u_R \bar{u}_R \gamma_\mu u_R + \eta_{dd} \bar{d}_R \gamma^\mu d_R \bar{d}_R \gamma_\mu d_R + \eta_{ud} \bar{u}_R \gamma^\mu u_R \bar{d}_R \gamma_\mu d_R + \ldots \Big\} , \quad q_L \equiv \begin{pmatrix} u_L \\ d_L \end{pmatrix} ; \tag{1}$$

the indicated terms are parity-conserving only for the special choice of coefficients $\eta_0 = \eta_{uu} = \eta_{dd} = \frac{1}{2}\eta_{ud}$. Since Eq. (1) is flavor diagonal and helicity conserving, it will interfere with the one-gluon-exchange QCD interactions which lead to 2-jet production, and which are expected to be the dominant reaction at SSC energies. (It will also interfere with the QCD interactions producing 3 or more jets in the final state.) Assuming initially unpolarized beams, this interference will lead to parity-violating $\vec{\sigma} \cdot \vec{p}$ terms in the differential cross section, where $\vec{\sigma}$ is a jet polarization and $\vec{p}$ is any momentum. Standard model electroweak neutral current processes will also lead to such parity violating terms, but in general will be a small and theoretically calculable correction. Detailed calculations have yet to be done.

3. The Case of T- (and CP-) Violating Underlying Interactions

We consider next the case in which the underlying interaction is T- (and CP-) violating. An example of such an interaction (drawn from a recent paper of Barbieri *et. al.*[5]) is

$$\mathcal{L}_{CP} = \frac{g^2}{2\Lambda^{*2}} \left[i\ \bar{u}_L \gamma_\mu d_L\ \bar{\ell}_L \gamma^\mu \nu_\ell + \text{h.c.} \right] , \tag{2}$$

$$\ell = e,\ \mu,\ \text{etc.}$$

There are two ways of looking for CP-violating interactions: (i) By looking for charge asymmetries in reactions with a CP-symmetric initial state or density matrix, and (ii) By looking for P- and T-violating $\vec{p}_1 \cdot \vec{p}_2 \times \vec{p}_3$ terms in differential cross sections, where $\vec{p}_1$, $\vec{p}_2$, and $\vec{p}_3$ are three linearly independent momenta. We consider these methods in turn.

(i.) As examples of the charge asymmetry method, consider the reactions

$$\bar{p} + p \to \ell^\pm + X, \quad \ell = e,\ \mu,\ \text{etc.}, \tag{3a}$$

$$\bar{p} + p \to f^+ + f^- + X , \tag{3b}$$

with $f^\pm$ any charge-identifiable particle-antiparticle pair. The initial $\bar{p} + p$ state is not a CP eigenstate, but since the CP quantum number for $\bar{p} + p$ is $(-1)^{S+1}$ with S the spin, the density matrix for *unpolarized* p and $\bar{p}$ beams will be diagonal in a CP-eigenstate basis,

$$\rho = \sum_\ell C_\ell \frac{1}{4} \Big[|\ell,\ S=0 >< \ell,\ S=0| + \sum_{S_z=0,\ \pm 1} |\ell,\ S=1,\ S_z >< \ell,\ S=1,\ S_z| \Big] . \tag{4}$$

If all interactions are CP-conserving, final state distributions produced from this initial density matrix cannot exhibit CP-violating asymmetries. Thus, a nonvanishing cross section difference

$$\sigma(\bar{p} + p \to \ell^+ + X) - \sigma(\bar{p} + p \to \ell^- + X) \tag{5}$$

would indicate a CP violation; this is the test proposed by Barbieri *et. al.*[5]. Similarly, an asymmetry between the f^+ and f^- energy distributions in the Dalitz plot for the $f^+ + f^- + X$ final state of Eq. (3b) would indicate a CP violation.

There is a difficulty, noted by Barbieri *et. al.*, with tests of this type. Both the cross section difference of Eq. (5), and the $f^\pm$ energy asymmetry, are forbidden by CPT invariance in the absence of initial- and final-state interactions. In other words, the relevant CP-violating interference term has the form

$$Re\left[\, \mathcal{L}_{CP}\, \mathcal{L}_{\text{"old physics"}} \,\right] , \tag{6}$$

and vanishes when $\mathcal{L}_{\text{"old physics"}}$ is treated in Born approximation. A non-zero contribution to Eq. (6) is obtained only when 1-loop radiative corrections are included, giving the effective action $\mathcal{L}_{\text{"old physics"}}$ an imaginary part.

Further problems with this type of test are that it uses $\bar{p}$ beams, and requires careful control over the rate systematics for detecting the oppositely charged particles $\ell^\pm$ or $f^\pm$.

(ii.) As an example of the triple product method, we consider the Drell-Yan reaction seen at $p + p$ machines,

$$u + \bar{d} \to \mu^+ + \nu_\mu + \text{jet} . \tag{7}$$

A CP-violating interaction, such as the Lagrangian of Eq. (2), can contribute through the diagram of Fig. 1a, and interference effects with standard model amplitudes will then lead to a P- and T-violating triple product term $\vec{p}_1 \cdot \vec{p}_2 \times \vec{p}_3$ in differential cross sections. Unfortunately, when the standard model contribution is treated in Born approximation (see Fig. 1b), the triple product term vanishes as a result of helicity conservation; hence this test, like (i) above, is only sensitive to interference between a possible CP-violating amplitude and 1-loop (or higher order) radiative corrections to the standard model. A concrete calculation of the effect remains to be done. The three momenta in the triple product can be taken as the beam direction, the μ^+ direction and the jet axis. The experimental signature for the reaction of Eq. (7) should be a good one; however an important issue, which must be analyzed by detailed calculation, is what selection cuts should be used to assign a sign to the beam direction vector, since the initial configurations u(left moving) + $\bar{d}$(right moving) and u(right moving) + $\bar{d}$(left moving) are *a priori* equally probable. One must check that selection cuts which guarantee a non-vanishing triple product leave a large enough event rate for an experiment to be feasible.

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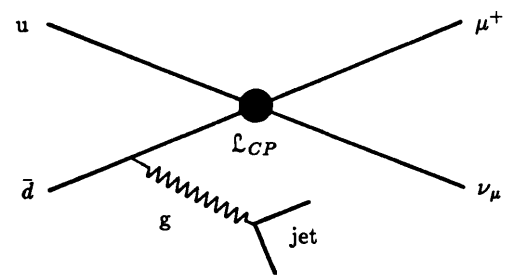
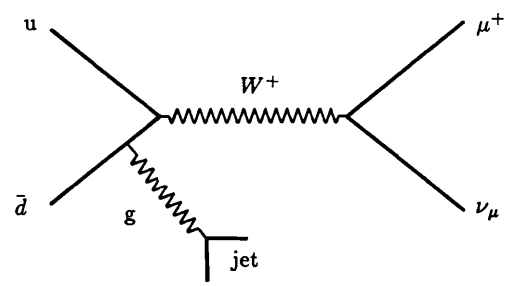


+ g emitted from u

Fig. 1a
Possible CP Violating Contributions to Eq. (7)



+ g emitted from u

Fig. 1b
Standard Model Born Approximation
Contributions to Eq. (7)