DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 74/13
April 1974

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Abstract

There are certain quantities involving charged particles produced in $e^+ e^-$ collisions which average to zero, but whose average square can serve as a probe for the dynamics. One of these is the mean square charge in one hemisphere of $e^+ e^-$ annihilation. We suggest studying additionally the mean square asymmetry in the distribution of charged particles between two appropriately chosen hemispheres.

The vast increase in $e^+ e^-$ annihilation data anticipated in the next few years makes it useful to devise empirical probes of the annihilation dynamics. The most popular procedure is to invent tests of those models which have arisen in connection with deep-inelastic or hadron processes, and are usually taken over in the most direct way to $e^+ e^-$ annihilation (parton models, the Hagedorn thermodynamic picture,. . .). Thus one can look at the multiplicities of particles in the final state to check the most common parton /1/ or thermodynamic /2/,/3/ models. One can also look at other quantities, and it has been suggested recently that one try the mean square charge found in one hemisphere of $e^+ e^-$ annihilation /4/. One can define right (R) and left (L) hemispheres in many ways--relative to the fastest hadron as axis; perpendicular to the $e^+ e^-$ beam axis (or parallel to it), and probably in other ways. For example, it might be useful in suppressing $\gamma\gamma$ background /5/ to demand that at least one charged hadron have some minimum transverse momentum ($p_T > 1$ GeV, say) relative to the $e^+ e^-$ axis. In this case one would analyze only a subset of events. This might also be useful if the dynamics in $e^+ e^-$ annihilation is different for particles of predominantly low momentum (e.g. thermodynamics) and high momentum (parton ideas). One might keep the number of charged particles fixed, too.

In any event, consider $N_R^{\pm}$, $N_L^{\pm}$ (positives and negatives right and left) and $N^{ch} = N_R^{ch} + N_L^{ch}$, where $N_{R,L}^{ch} = N_{R,L}^{+} + N_{R,L}^{-}$. Then define the mean square charge in the right hemisphere /4/

$$U = \langle (N_R^+ - N_R^-)^2 \rangle \tag{1}$$

averaged over some set of events with one of the definitions of R and L mentioned. We wish to suggest studying also

$$V = \frac{1}{4} \langle (N_R^{ch} - N_L^{ch})^2 \rangle \tag{2}$$

which, as we shall see, tests for an asymmetry in the energy distribution among charged and neutral particles in some models. These quantities satisfy the inequalities

$$\frac{1}{4} (N^{ch})^2 \geq U, V \geq 0$$
$$\frac{1}{4} (N^{ch})^2 + U \geq V \tag{3}$$

The main interest in U and V is experimental; we will only illustrate their use (particularly V) with some very simple examples (overlapping partly those of Ref. /4/), and by some comments.

Consider first the quark parton model. We use Feynmans' idea /6/ that the charge of a parton emerges on the average in its fragmentation region in order to estimate U /*/; for adjustments to this idea, see the literature /7/. We expect $U \lesssim 1$ in any model where two jets (coming from resonance decay, for example)

/*/ Actually, we put $U = \sum e_i^4 / \sum e_i^2$ (where e_i are the parton charges) which is stronger than Feynmans proposal; but we only need an estimate.

are formed with non-exotic quantum numbers. For V we ignore the constraints of conservation laws and take a Poisson distribution for the particles in the jet. Then if R and L are chosen with respect to the jet axis (we assume that it can be identified!) ,

$$U = \frac{1}{3} \qquad V = \frac{1}{4} N^{ch} \tag{4}$$

Thermodynamic models are even simpler: all particles are independent, the definition of R and L is irrelevent and we can use the binomial distribution to get trivially /4/,

$$U = \frac{1}{4} N^{ch} \qquad V = \frac{1}{4} N^{ch} \tag{5}$$

Next we wish to consider an interesting cascade model /8/. The basic idea of the model is that the virtual photon couples to an off-shell vector meson (ρ, ω) which decays to a pion and a further off-shell meson (ω, ρ this time, by G-parity) and so on. The decay chain is determined by the behavior of the off-shell $\rho\omega\pi$ vertex, and we consider the version which gives a jet structure in the final state /8/. This model is solvable and is evidently the prototype of similar models with different (or more) decay chains, more vector mesons, etc. . The mean squared charge in one hemisphere is small in this model because the mostly isovector photon decays predominantly into π^0 plus an off-shell ω meson. The π^0 goes one way and the decay products of the off-shell ω the other. Including the isoscalar photon piece but without kaon production, we get (with R and L chosen as for the parton model)

$$U = \frac{1}{6} \qquad V = \frac{1}{4}(N^{ch})^2 - \frac{1}{6}(N^{ch} - 1) \qquad (6)$$

If one were to examine U alone, this might look like a parton model. V is big because of the large energy carried off by a single π^0 in most of the events. It is possible to calculate the ratio of neutral to charged pions in this model if one makes the simplifying assumption that one can take the weighted average of the ratios for G-parity positive and negative states. On the same basis as (6),

$$\frac{\langle N^{neut} \rangle}{\langle N^{ch} \rangle} = \frac{4n + 5}{8(n-1)} \qquad (7)$$

where n is the mean total pion multiplicity. This expression applies only when the distribution is sufficiently broad, and at low energies one might have an energy-dependent oscillation about the value (7). It might be interesting to look for such oscillations of this ratio; they arise from the fact that for odd numbers of pions in the final state, the ratio must be $\frac{1}{2}$ while it is larger if the number of pions is even (see, for example, /9/). It is important to keep in mind the possibility that the mean energy carried away by neutrals can be large even when the neutral/charged ratio lies well inside the isospin bounds/9/. The model of Ref. /8/ illustrates this. If one imagines more complex models of the same type -- including SU_3, resonance rather than pion production and so forth -- they should all have $U \leq 1$ and V significantly larger than in the other models we have mentioned, provided only that one resonance or stable particle appears in one hemisphere and the decay products of the off-shell link of the decay chain appear in the other hemisphere.

We conclude with some comments. First, parton models could in principle have U of order unity; at low energies the measured value of $N^{ch}/4 \sim 1$ ($E_{cm} \lesssim 5$ GeV, /10/) so it will not be easy to tell parton and thermodynamic models apart on this basis. Here V is no help -- only high energies (or cleverer tests) can be useful. The situation may be more favorable for testing cascade models. Added to this, a mis-identification of the jet axis surely smears the predictions of different parton or cascade models into those of thermodynamic models. One may have to check independently for the presence of jets and the best way to identify their axis (e.g. /2/, /11/). Second, it may be interesting to consider other fluctuations like $\langle (E_R^{ch} - E_L^{ch})^2 \rangle$, where E is the hadron energy; this emphasizes high energy particles and may allow one to evade non-asymptotic effects arising from low energy particles which contribute heavily to N^{ch}. Finally, we note that measurments of V do not require a magnetic detector if one is satisfied with choosing R as, say, along the $e^+ e^-$ axis or perpendicular to it. This could have its uses , since a large $\gamma\gamma$ background would give a larger value for V in the former case than in the latter. This is because the particles from $\gamma\gamma$ background events are skewed along the beam direction by the missing momentum carried off by the unobserved $e^+ e^-$ system in the final state.

In this connection, it might be useful to carry out this test for fixed $N^{ch} = 2, 4, \ldots$, as $\gamma\gamma$ processes probably yield mostly low-multiplicity final states.

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