Z^0 asymmetries in jets in e^+e^- annihilation as a test of quark-fragmentation models

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We derive a relation between the theoretical quark-production asymmetries and measured jet asymmetries in e^+e^- annihilation using simple parameters obtained from quark-fragmentation models. We show that with a suitable choice of jet criteria one should be able to observe sizable effects in spite of problems caused by quark misidentification. Mass effects near new-quark thresholds and the shapes of quark asymmetries for different flavors are discussed.

I. INTRODUCTION

As the energy of available e^+e^- accelerators approaches the mass of the neutral intermediate vector boson Z^0, all neutral-current effects should become large and easily observable. Although the largest existing e^+e^- storage rings, PETRA and PEP, are plagued with low event rates in looking for the muon asymmetries of the order of a few percent, the next generation of accelerators (e.g., LEP,[1] single-pass collider,[2] or "semicollider"[3]) should be free of these problems. The muonic final state provides the cleanest tests of the Weinberg-Salam model, whereas the analysis of possible quark-jet asymmetries leads to somewhat ambiguous results due to the strong dependence on the particular quark-fragmentation model used and the problems associated with defining the jet axis. However, since the comparatively low PETRA luminosity has made the direct measurements of muon asymmetries virtually impossible so far, one naturally turns to the hadronic channels for additional tests.

The subject of our paper is the comparison of the jet and muon asymmetries. In particular, we discuss two complementary aspects of jet analysis.

(1) If the statistics are low and muon asymmetries small, one would like to use quarks to test the weak-electromagnetic model used. Assuming that we have a reliable fragmentation model at our disposal we compare the size of measured quantity and the statistics for different jets. In spite of the enhancement factor $R=\sigma_{e^+e^-\to \text{hadrons}}/\sigma_{e^+e^-\to\mu^+\mu^-}$, the large probability of misidentification of the parent quark from jet analysis decreases both the statistics and the observed asymmetry effect. As discussed in Sec. III, only a few clever choices of jets may allow them to compete with muons in the feasibility of the low-statistics experiments.

(2) Assuming the weak-electromagnetic model to be correct one can use jet asymmetries to test quark-fragmentation models. This is especially interesting in the region of center-of-mass energies $\sqrt{s}=40-80$ GeV, where the asymmetries should be sizable.

In principle, the effects we discuss in this paper are well known[4] and there is not much we can add to the subject. What is new is an attempt to separate the weak-electromagnetic (or production) part from fragmentation (see Fig. 1) and express the fragmentation part in terms of a few easily testable parameters, following the general suggestions of Ref. 5, generalized to the case of many flavors. This leads to some interesting predictions, in particular, direct measurability of the reliability parameters introduced in Ref. 5 in the case of one-flavor dominance. Unfortunately, the price one has to pay for this rather simple and attractive (for experimentalists) formulation of the problem is that such a separation ignores complications such as hard-gluon emission, quantum-chromodynamics (QCD) evolution of the jets, etc. Hence, the present formulation has to be treated as the zeroth-order QCD approximation with the nonperturbative hadronization part replaced by some phenomenological model.

In Sec. II we derive the relation between experimental and theoretical jet asymmetry in the general case of partial misidentification of quarks from jet analysis. One-flavor and multiflavor

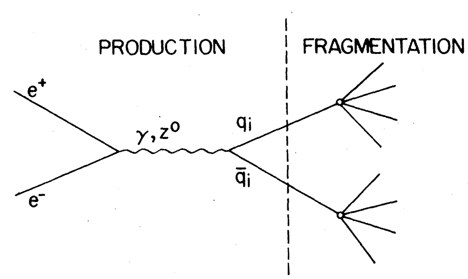

FIG. 1. Schematic representation of the separation of production and fragmentation processes.

cases are discussed. In Sec. III we give all parameters calculable from weak-electromagnetic interaction including possible quark-mass effects close to threshold. In the case of the Weinberg-Salam model we compare the quark and muon asymmetries. Finally, in Sec. IV we discuss the necessary future improvements of this model and give some conclusions.

II. RELATION BETWEEN THE EXPERIMENTAL ASYMMETRY OF JETS AND THE QUARK ASYMMETRIES

In order to distinguish between quark and antiquark jets, let us introduce the concept of a jet criterion k. For example, given a set of hadronic events, we could define a suitable jet axis for each event according to some standard procedure.[6] We could then let the criterion k correspond to selecting only those jets with a π^+ as the fastest particle, and a K^- as the next fastest. In the cascade model of Feynman and Field, our criterion would then tend to select $\bar{d}$-quark jets. Clearly, other choices of k are possible.

Let us now attempt to relate the asymmetries of the quark-antiquark distributions to the asymmetry of the distribution of jets satisfying our criterion k. Let us suppose that we have a total of T hadronic events, and thus $2T$ jets. We define

$T_i(\Theta)$ = total number of quark jets of flavor i in an element of solid angle $d\Omega = 2\pi d(\cos\Theta)$ making an angle Θ with respect to the electron beam axis, and

$\overline{T}_i(\Theta)$ = total number of antiquark jets of flavor i in $d\Omega$.

In the zeroth order of QCD, we have the relations

$$T_i(\Theta) = \overline{T}_i(\pi - \Theta)\,, \tag{2.1}$$

$$2\pi \int_{-1}^{1} d(\cos\Theta) \sum_i T_i(\Theta) = T\,. \tag{2.2}$$

Now, if we let

$N_i^k(\Theta)$ = number of quark jets of flavor i satisfying the criterion k in solid angle $d\Omega$, and

$\overline{N}_i^k(\Theta)$ = number of antiquark jets of flavor i satisfying the criterion k in $d\Omega$,

we can define the following probabilities:

$$\omega_i^k \equiv \frac{N_i^k(\Theta)}{T_i(\Theta)}\,, \tag{2.3}$$

$$\overline{\omega}_i^k \equiv \frac{\overline{N}_i^k(\Theta)}{\overline{T}_i(\Theta)}\,, \tag{2.4}$$

$$\gamma_i(\Theta) \equiv \frac{T_i(\Theta) + \overline{T}_i(\Theta)}{\sum_i [T_i(\Theta) + \overline{T}_i(\Theta)]}\,. \tag{2.5}$$

The quantity $\gamma_i(\Theta)$ is the probability that a jet found in solid angle $d\Omega$ is either a quark or antiquark jet of flavor i and can be calculated in perturbation theory. The quantity ω_i^k is the probability that the i quark fragments in such a way that it satisfies the criterion k, and $\overline{\omega}_i^k$ is the corresponding probability for the i antiquark. The fact that ω_i^k and $\overline{\omega}_i^k$ are independent of Θ depends on our ability to separate the "production" and "fragmentation" pieces of Fig. 1. If we use specific fragmentation models such as that of Feynman and Field, ω_i^k and $\overline{\omega}_i^k$ may be calculated using Monte Carlo methods.

We can define the theoretical asymmetry for the ith flavor of quark as follows:

$$A_i(\Theta) \equiv \frac{T_i(\Theta) - \overline{T}_i(\Theta)}{T_i(\Theta) + \overline{T}_i(\Theta)}\,. \tag{2.6}$$

The number of jets satisfying the criterion k in solid angle $d\Omega$ is given by

$$N^k(\Theta) \equiv \sum_i [N_i^k(\Theta) + \overline{N}_i^k(\Theta)]\,. \tag{2.7}$$

It is easy to show that

$$N^k(\Theta) - N^k(\pi - \Theta) = \sum_i (\omega_i^k - \overline{\omega}_i^k)\gamma_i(\Theta) A_i(\Theta) T(\Theta)\,, \tag{2.8}$$

where $T(\Theta) = \sum_i [T_i(\Theta) + \overline{T}_i(\Theta)]$. It is convenient to define an experimental asymmetry associated with the criterion k as follows:

$$A_{\text{expt}}^k(\Theta) \equiv \frac{N^k(\Theta) - N^k(\pi - \Theta)}{\mathfrak{N}^k(\Theta)}\,, \tag{2.9}$$

where $\mathfrak{N}^k(\Theta)$ is the total number of jets which satisfy k at Θ or $\pi - \Theta$, but excluding k-type jets produced simultaneously with a jet satisfying k in the opposite hemisphere. If we assume that the quark and antiquark jets fragment independently, we have

$$A_{\text{expt}}^k(\Theta) = \frac{\sum_i (\omega_i^k - \overline{\omega}_i^k)\gamma_i(\Theta) A_i(\Theta)}{\sum_j (\omega_j^k + \overline{\omega}_j^k - 2\omega_j^k \overline{\omega}_j^k)\gamma_j(\Theta)}\,. \tag{2.10}$$

Our definition, along with certain others, has the property that for an "infallible" criterion such that $\overline{\omega}_j^{k'} = 0$ for all flavors, $\omega_j^{k'} = 0$ for $j \neq i$, and $\omega_i^{k'} \neq 0$, we have

$$A_{\text{expt}}^{k'}(\Theta) = A_i(\Theta)\,.$$

If we let

$$(N^k)_F \equiv 2\pi \int_0^1 d(\cos\Theta) N^k(\Theta)\,,$$
$$(N^k)_B \equiv 2\pi \int_0^1 d(\cos\Theta) N^k(\pi-\Theta)\,,$$
$$(T_i)_F \equiv 2\pi \int_0^1 d(\cos\Theta) T_i(\Theta)\,, \tag{2.11}$$
$$(T_i)_B \equiv 2\pi \int_0^1 d(\cos\Theta) T_i(\pi-\Theta)\,,$$
$$\tilde{\mathfrak{N}}^k \equiv 2\pi \int_0^1 d(\cos\Theta) \mathfrak{N}^k(\Theta)\,,$$

and

$$\tilde{\gamma}_i \equiv [(T_i)_F + (T_i)_B] \Big/ \sum_j [(T_j)_F + (T_j)_B]\,,$$

we can define the integrated asymmetries as

$$\tilde{A}_i \equiv \frac{(T_i)_F - (T_i)_B}{(T_i)_F + (T_i)_B}\,, \tag{2.12}$$

$$\tilde{A}^k_{\text{expt}} \equiv \frac{(N^k)_F - (N^k)_B}{\tilde{\mathfrak{N}}^k}\,. \tag{2.13}$$

It is easy to show that

$$\tilde{A}^k_{\text{expt}} = \frac{\sum_i (\omega_i^k - \overline{\omega}_i^k)\tilde{\gamma}_i \tilde{A}_i}{\sum_j (\omega_j^k + \overline{\omega}_j^k - 2\omega_j^k \overline{\omega}_j^k)\tilde{\gamma}_j}\,. \tag{2.14}$$

We point out to the reader that, in the case of one flavor, the quantity

$$\frac{\omega^k - \overline{\omega}^k}{\omega^k + \overline{\omega}^k - 2\omega^k\overline{\omega}^k}$$

is precisely the quantity termed "reliability" by Feynman and Field. We should also caution the reader that, with our set of definitions,

$$2\pi \int_0^1 d(\cos\Theta) A^k_{\text{expt}}(\Theta) \neq \tilde{A}^k_{\text{expt}}\,,$$
$$2\pi \int_0^1 d(\cos\Theta) A_i(\Theta) \neq \tilde{A}_i\,.$$

On the other hand, if we redefine the angle-dependent asymmetries, normalizing to the global (angle-integrated) rate,

$$\mathfrak{A}_i(\Theta) \equiv \frac{T_i(\Theta) - \overline{T}_i(\Theta)}{(T_i)_F + (T_i)_B}\,, \tag{2.15}$$

$$\mathfrak{A}^k_{\text{expt}}(\Theta) \equiv \frac{\mathfrak{N}^k(\Theta) - \mathfrak{N}^k(\pi-\Theta)}{\tilde{\mathfrak{N}}^k}\,, \tag{2.16}$$

the above definitions imply the following relations:

$$2\pi \int_0^1 d(\cos)\mathfrak{A}_i(\Theta) = \tilde{A}_i\,, \tag{2.17}$$

$$2\pi \int_0^1 d(\cos\Theta)\mathfrak{A}^k_{\text{expt}}(\Theta) = \tilde{A}^k_{\text{expt}}\,. \tag{2.18}$$

Our newly defined asymmetries are related by

$$\mathfrak{A}^k_{\text{expt}}(\Theta) = \frac{\sum_i (\omega_i^k - \overline{\omega}_i^k)\tilde{\gamma}_i \mathfrak{A}_i(\Theta)}{\sum_j (\omega_j^k + \overline{\omega}_j^k - 2\omega_j^k\overline{\omega}_j^k)\tilde{\gamma}_j}\,. \tag{2.19}$$

We wish to point out that although the definitions (2.15) and (2.16) yield simple relations between the angular and integrated asymmetries, the definitions (2.6) and (2.9) depend on localized regions of phase space. The latter definitions, then, may be useful for isolating dynamical processes competing with single-photon–Z^0 interferences effects. In practice, all theoretical quantities related to the production part of Fig. 1 are known once we compute the cross section $d\sigma_i/d(\cos\theta)$, the cross section for producing a quark of flavor i at an angle θ with respect to the incident electron beam. Then

$$A_i(\Theta) = \frac{\left.\frac{d\sigma_i}{d(\cos\theta)}\right|_{\theta=\Theta} - \left.\frac{d\sigma_i}{d(\cos\theta)}\right|_{\theta=\pi-\Theta}}{\left.\frac{d\sigma_i}{d(\cos\theta)}\right|_{\theta=\Theta} + \left.\frac{d\sigma_i}{d(\cos\theta)}\right|_{\theta=\pi-\Theta}}\,, \tag{2.20}$$

$$\tilde{A}_i = \frac{\int_0^1 d(\cos\theta)\frac{d\sigma_i}{d(\cos\theta)} - \int_{-1}^0 d(\cos\theta)\frac{d\sigma_i}{d(\cos\theta)}}{\int_{-1}^1 d(\cos\theta)\frac{d\sigma_i}{d(\cos\theta)}}\,, \tag{2.21}$$

$$\mathfrak{A}_i(\Theta) = \frac{\left.\frac{d\sigma_i}{d(\cos\theta)}\right|_{\theta=\Theta} - \left.\frac{d\sigma_i}{d(\cos\theta)}\right|_{\theta=\pi-\Theta}}{\int_{-1}^1 d(\cos\theta)\frac{d\sigma_i}{d(\cos\theta)}}\,. \tag{2.22}$$

In practice, one must choose the criterion k so as to minimize cancellations in the sums found in the numerators of Eqs. (2.10), (2.14), and (2.19). We will discuss possible choices shortly, but let us first turn our attention to calculating $d\sigma_i/d(\cos\theta)$ and thus determine all quantities related to the production part of the amplitude.

III. THEORETICAL QUARK ASYMMETRY PARAMETERS

In this section, we shall present and discuss the formulas for quantities related to the production part of the diagram shown in Fig. 1, leaving the discussion of higher-order QCD effects to Sec. IV. Since our formalism may have important applications in the energy region near the bottom-quark threshold (and, perhaps that of the top quark) we include quark-mass effects by treating them as pointlike particles, in analogy to leptons. Although the correctness of such an approach, especially near quark-antiquark thresholds where nonperturbative effects may be large, may be suspect, we adopt it for simplicity's sake.

For the case of massive quarks, using the expressions in Eqs. (2.20) and (2.22), we get for the angle-dependent asymmetries

$$A_i(\Theta)=\frac{4\chi a a_i\beta_i\cos\Theta(2\chi v v_i-Q_i)}{(Q_i{}^2-2\chi Q_i v v_i)(2-\beta_i{}^2+\beta_i{}^2\cos^2\Theta)+\chi^2(v^2+a^2)[(v_i{}^2+a_i{}^2)(1+\beta_i{}^2\cos^2\Theta)+(v_i{}^2-a_i{}^2)(1-\beta_i{}^2)]}\,, \quad (3.1)$$

$$\mathfrak{a}_i(\Theta)=\frac{\pi\alpha^2}{s}\,\frac{4\beta_i{}^2\chi a a_i(2\chi v v_i-Q_i)\cos\Theta}{\sigma_i}\,, \quad (3.2)$$

and the production rate for flavor i,

$$\tilde{\gamma}_i=\frac{\sigma_i}{\sum_j\sigma_j}\,, \quad (3.3)$$

with

$$\sigma_i=\frac{\pi\alpha^2\beta_i}{s}\left\{(2Q_i{}^2-4\chi Q_i v v_i)\left(1-\frac{\beta_i{}^2}{3}\right)+\chi^2(v^2+a^2)\left[(v_i{}^2+a_i{}^2)\left(1+\frac{\beta_i{}^2}{3}\right)+(v_i{}^2-a_i{}^2)(1-\beta_i{}^2)\right]\right\}. \quad (3.4)$$

Here we use the notation from Ref. 4: v_i (v) and a_i (a) are the vector and axial-vector couplings of quark i (electron), respectively; Q_i is the corresponding electric charge in units of e; $\chi=gsM_Z{}^2/(s-M_Z{}^2)$;

TABLE I. Comparison of couplings, external asymmetries with their positions in energy, and actual asymmetries and production rates at $\sqrt{s}=30$, 50, and 70 GeV for leptons and quarks with $I_3=+\frac{1}{2}$ and $-\frac{1}{2}$, respectively. All numbers are calculated assuming the Glashow-Weinberg-Salam model with $\sin^2\theta_W=0.23$ which corresponds to $M_Z=88.9$ GeV and $\chi_\infty\equiv 0.353$. The effects of finite Z^0 width are unimportant.

	μ	$u, c, \ldots$	d, s, b
v	−0.08	0.3867	−0.6933
a	−1	1	−1
$\left.\frac{\tilde{A}_i}{\tilde{A}_\mu}\right\vert_{\chi\ll 1}$	1	1.5	3
$\tilde{A}_{\min}$	−0.7405	−0.6778	−0.5877
$\tilde{A}_{\max}$	0.7500	0.7179	not reached
$\tilde{A}\vert_{s\to\infty}$	0.4703	0.6043	0.6366
$\chi_{\min}$	−0.9811	−0.5861	−0.2503
$\chi_{\max}$	1.0064	0.6576	0.3017
$\sqrt{s}_{\min}$	76.0	70.0	57.0
$\sqrt{s}_{\max}$	110.3	130.6	does not exist
$\sqrt{s}\vert_{A=0}$	88.4	87.2	83.9
$\tilde{A}(\sqrt{s}=30$ GeV)	−0.068	−0.102	−0.200
$\tilde{\gamma}(\sqrt{s}=30$ GeV)		0.363	0.092
$\tilde{A}(\sqrt{s}=50$ GeV)	−0.241	−0.346	−0.535
$\tilde{\gamma}(\sqrt{s}=50$ GeV)		0.342	0.106
$\tilde{A}(\sqrt{s}=70$ GeV)	−0.651	−0.678	−0.392
$\tilde{\gamma}(\sqrt{s}=70$ GeV)		0.239	0.175

and $\beta_i=(1-4m_i{}^2/s)^{1/2}$ is the velocity of the quark in the center of mass. To take into account the Z^0-width effects, one has to substitute in all formulas[4]

$$\chi\to\chi_1=\frac{gsM_Z{}^2(s-M_Z{}^2)}{(s-M_Z{}^2)+\Gamma_Z{}^2M_Z{}^2}\,,$$

$$\chi^2\to\chi_2=\frac{g^2s^2M_Z{}^4}{(s-M_Z{}^2)^2+\Gamma_Z{}^2M_Z{}^2}\,.$$

The integrated asymmetry can be calculated from Eq. (2.21),

$$\tilde{A}_i=\frac{\pi\alpha^2}{s}\,\frac{2\beta_i{}^2\chi a a_i(2\chi v v_i-Q_i)}{\sigma_i}\,. \quad (3.5)$$

In the massless-quark limit, we get

$$\tilde{A}_i=\frac{3}{2}\,\frac{\chi a a_i(2\chi v v_i-Q_i)}{Q_i{}^2-2\chi Q_i v v_i+\chi^2(v^2+a^2)(v_i{}^2+a_i{}^2)}\,. \quad (3.6)$$

This formula does not depend on the particular model for the weak interaction used. To estimate

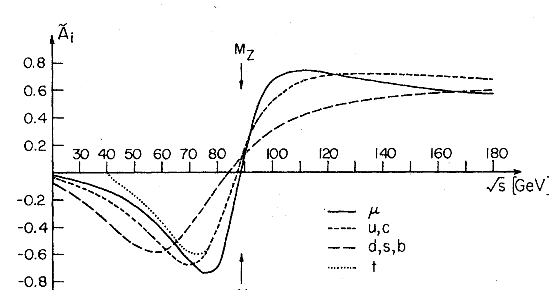

FIG. 2. Energy dependence of integrated asymmetries defined in Eqs. (2.12) and (3.5) for various flavors. The dotted curve illustrates the threshold effects for a hypothetical top quark with arbitrarily assumed mass $m_t=20$ GeV.

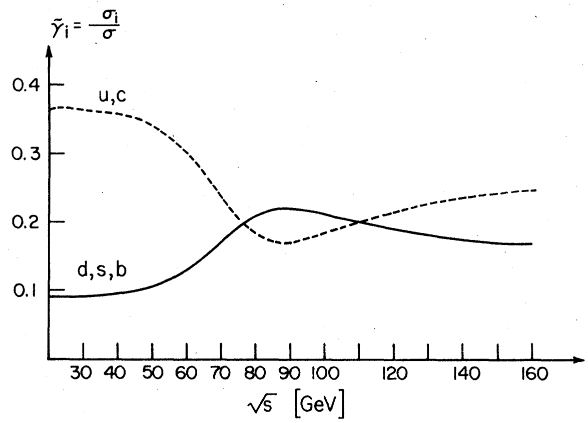

FIG. 3. Energy dependence of total production rates $\tilde\gamma_i$ for various flavors.

the size of the experimentally observable effects, we use the Weinberg-Salam model with couplings given in Table I[4] and $\sin^2\theta_W = 0.23$.

In Fig. 2, we give the shapes of $\tilde A_i$ as a function of s for muons and various quarks. The s dependence of the production rate $\tilde\gamma_i$ for the weak-isospin $I_3 = \frac{1}{2}$ quark is presented in Fig. 3. From Figs. 2 and 3 and Eqs. (3.4) and (3.5) some simple conclusions may be drawn.

(1) As in the case of muons, all quarks have a negative asymmetry far below the Z^0 threshold, and all antiquarks have a positive asymmetry independent of charge.

(2) For small energies, where χ, $\chi^2 \ll 1$, the ratio of quark to muon asymmetry is given by the formula

$$\frac{\tilde A_i}{\tilde A_\mu} = \frac{a_i(2\chi v v_i - Q_i)}{a_i(2\chi v^2 + 1)} \times \frac{1 + 2\chi v^2 + \chi^2(v^2+a^2)^2}{Q_i^2 - 2\chi Q_i v v_i + \chi^2(v^2+a^2)(v_i^2+a_i^2)}$$

$$\xrightarrow[\chi,\,\chi^2\ll 1]{} -\frac{a_i}{aQ_i} = \begin{cases} 1.5 \text{ for } u,c \\ 3 \text{ for } d,s,b \end{cases} \quad (3.7)$$

The fact that in the PEP/PETRA energy region the quark asymmetry is substantially bigger than that of the muons may arouse some hope of measuring this effect, provided we have a resonable experimental criterion to identify quarks of a given flavor. However, when going to higher energies one has to remember that χ and χ^2 terms quickly damp this ratio.

(3) By analyzing Eq. (3.6), one can find the positions and values of minima and maxima of $\tilde A_i$ for muons and quarks:

$$X_{\min,\max} = -Q_i \frac{2vv_i \mp \operatorname{sgn}(aa_i)[(v^2+a^2)(v_i^2+a_i^2)]^{1/2}}{(v^2+a^2)(v_i^2+a_i^2) - 4v^2 v_i^2} . \quad (3.8)$$

In the zero-width approximation for the Z^0, the asymmetry vanishes at

$$\chi = \frac{Q_i}{2vv_i} . \quad (3.9)$$

All energies corresponding to those points and the values of the asymmetries are quoted in Table I. It is interesting to note that in certain cases, $\chi_{\max}$ may be outside the allowed χ region, that is

$$\chi_{\max} > \chi_\infty \equiv g M_Z^2 = 0.353 \quad (3.10)$$

for our choice of θ_W. Then the asymmetry goes to its asymptotic limit from below. This is the case for d, s, and b quarks, as shown in Fig. 2.

(4) It follows from Eq. (3.5) that $\tilde A_i$ is proportional to β_i and vanishes at the threshold. To illustrate this effect we have included in Fig. 2 a curve corresponding to a hypothetical top quark assuming $m_t = 20$ GeV. For higher masses the threshold effect may be observable even far beyond the Z^0 resonance.

(5) Asymmetries and production rates for various quark flavors depend differently on energy. They are listed in Table I for three energies: $\sqrt{s} = 30$, 50, and 70 GeV. Whereas at 30 and 50 GeV the $I_3 = -\frac{1}{2}$ quarks dominate, their contribution becomes quite small at 70 GeV. These relations should lead to well-defined qualitative experimental effects, for example, a decrease in the asymmetry of leading charged kaon production, in association with the enhancement of leading kaon production.

Having discussed the theoretical expectations regarding the production-process asymmetries, we come to the problem of the size of the experimentally observable effects. As follows from Sec. II, in general $\tilde A_{\text{expt}}$ will be much smaller than $\tilde A_i$, partially due to small ω_i^k coefficients and partially due to cancellations connected with different signs of $\tilde A_i$ for quarks and antiquarks. Hence it is crucial that some jet criterion be found which selects quite exclusively some specific flavor, even at the cost of very low efficiency (high event-rejection rate). The ideal case would correspond to

$$\frac{\omega^k_{i\neq i_0}}{\omega^k_{i_0}}, \quad \frac{\bar\omega^k_i}{\omega^k_{i_0}} \ll 1 , \quad (3.11)$$

so that

$$\tilde A^k_{\text{expt}} \simeq \tilde A_i > A_\mu , \quad (3.12)$$

at least up to $\sqrt{s} \sim 70$ GeV. On the other hand, accepting all jets, we would get $\tilde A^k_{\text{expt}} = 0$ even if the $\tilde A_i$ are very large. In this respect, the jet criteria such as choosing "jets with a leading D^+," which may be characteristic of charmed-quark jets, seem to be desirable. However, at large energies, the $\bar{d}$ jets may also develop a non-negligible leading D^+ rate, and unfortunately c and $\bar{d}$ quarks have opposite asymmetry. Clearly, the experimental asymmetries provide a useful, independent test to study the rate at which exact flavor symmetry is approached.

IV. SUMMARY

We have given in this paper the relations between theoretical quark asymmetries, governed by production process, and experimentally observable jet asymmetries. This relation relies on a few parameters which summarize all the information from the fragmentation model used. The more or less direct measurability of these parameters may provide a good test of this model. Moreover, owing to the fact that raw quark asymmetries are higher than muon asymmetries in the PETRA/PEP energy region, and that there are about $R=\sigma_{\text{hadronic}}/\sigma_{\mu^+\mu^-}=3.67$ as many hadronic as muonic events (for five flavors), one may hope that in spite of small efficiencies of good criteria and some smearing effect connected with summation over all flavors, the remaining experimental asymmetry of jets will be comparable to that of muons.

Our present approach suffers from several oversimplifications. In particular, one should check the effect of higher-order QED effects which in the case of $\mu^+\mu^-$ are producing sizable corrections[7] and at least lowest-order QCD corrections.[8] These problems are now under investigation. One should also take correctly into account quark-mass effects. Also the correct inclusion of quark masses is crucial since the top quark, if it exists, will show presumably some mass-threshold deviations throughout a very large energy region.

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[1]L. Camillieri *et al.*, CERN Yellow Report No. 76-18, 1976 (unpublished).

[2]B. Richter, single-pass-collider proposal (unpublished).

[3]R. Stroynowski, Report No. SLAC-PUB 2451, 1980 (unpublished).

[4]J. Ellis and M. K. Gaillard, in Ref. 1, p. 21; J. Ellis, in *Weak Interactions—Present and Future,* proceedings of the Sixth SLAC Summer Institute, 1978, edited by Martha C. Zipf (SLAC, Stanford, California, 1978).

[5]R. D. Field and R. P. Feynman, Nucl. Phys. B136, 1 (1978).

[6]J. Ellis, M. K. Gaillard, and G. G. Ross, Nucl. Phys. B111, 253 (1976); B130, 516(E) (1977).

[7]G. J. Komen, Phys. Lett. 68B, 275 (1977); G. Pessarino and M. Veltman, Nucl. Phys. B160, 151 (1979).

[8]H. A. Olsen, P. Osland, and I. Øverbø, Phys. Lett. 89B, 221 (1980); Nucl. Phys. B171, 209 (1980).