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Abstract

We have analysed experimental data on (i) e^+e^- annihilation to hadrons, (ii) leptoproduction, (iii) hadron-hadron interactions, and (iv) heavy particle decays to determine SU(3) symmetry violation, i.e. the suppression factor (λ) for strange quark-antiquark pairs relative to $u\bar{u}$ and $d\bar{d}$ pairs in the hadronic vacuum. Inclusive particle ratios, i.e. K/π ratios at large x and ratios between the inclusive production rates of relevant resonances, yield similar values for λ, the weighted mean being $\langle\lambda\rangle=0.29\pm0.02$. No significant energy dependence of λ is observed.

We also find that the average net electric charge measurements for lepton produced quark jets are consistent with the above value of λ.

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1. Introduction

A general characteristic of hadron production or decay is a suppression of strange particles among the final state hadrons. In QCD it is not unreasonable that strange-antistrange quark pairs ($s\bar{s}$) are formed less often than up-antiup ($u\bar{u}$) or down-antidown ($d\bar{d}$) quark pairs, for s-quarks may have larger mass than u or d quarks (1-13).

In this paper we shall analyze different possibilities of determining the relative suppression of $s\bar{s}$ pairs as compared to $u\bar{u}$ - or $d\bar{d}$ - pairs formed in hadronic vacuum.

2. Inclusive Particle Ratios

2.1 Definitions

The simple quark-parton picture predicts universal absolute multiplicities of hadrons in the final states of all the hard scattering processes producing quark jets (14), i.e.

$$\frac{dN^h}{dz} = \frac{1}{\sigma_{TOT}} \frac{d\sigma^h}{dz} = \sum_i P_i D_i^h(z) \qquad (1)$$

where z is the fraction of quark momentum carried by the final state hadron (h) $z=E_h/E_{beam}$ for e^+e^--annihilation, $z=E_h/\nu$ with $\nu=E_\ell-E_{\ell'}$, for leptroproduction and $z=2p_t/\sqrt{s}$ for large p_t hadron jets. In eq. (1) P_i represents the probability that the fragmenting quark is of flavor i $(\sum_i P_i=1)$ and $D_i^h(z)$ the probability of finding hadron h with energy fraction z among the fragmentation products of quark i.

In e^+e^- annihilation to hadrons the probabilities P_i are given as

$$P_i^{e^+e^-} = Q_i^2/\sum_i Q_i^2 \tag{2}$$

where Q_i is the electric charge of quark of flavor i. Similarly, for electron - or muon-nucleon scattering-probabilities $P_i^{e(\mu)N}$ are given as

$$P_i^{e(\mu)N} = Q_i^2 f_i^{e(\mu)N}(x)/\sum_i Q_i^2 f_i^{e(\mu)N}(x), \tag{3}$$

where $f_i^{e(\mu)N}(x)$ is the density distribution of parton i inside the target nucleon. In $\nu(\bar{\nu})N$ charged current interactions the probabilities $P_i^{\nu(\bar{\nu})N}$ can be expressed as

$$P_u^{\nu N} = f_d(x)/(f_d(x)+f_{\bar{u}}(x)(1-y)^2) \tag{4a}$$

$$P_{\bar{d}}^{\nu N} = f_{\bar{u}}(x)(1-y)^2/(f_d(x)+f_{\bar{u}}(x)(1-y)^2) \tag{4b}$$

$$P_d^{\bar{\nu}N} = f_u(x)(1-y)^2/(f_{\bar{d}}(x)+f_u(x)(1-y)^2) \tag{4c}$$

$$P_{\bar{u}}^{\bar{\nu}N} = f_{\bar{d}}(x)/(f_{\bar{d}}(x)+f_u(x)(1-y)^2) \tag{4d}$$

where $y = \nu/E_\nu$.

In recent years a fair amount of data has accumulated on the inclusive yields of the vector mesons ρ^o, K* and ϕ in hadron-hadron interactions. We have used this data to deduce the value of the strangeness suppression factor λ. In order to do this we have applied a small correction due to the feed down contributions from the decay of heavier resonances. For this purpose we have adopted the quark model of V. Anisovitch and V. Shekhter (15) in which one of the incident quarks interacts with a quark in the target hadron leading to production of a number of quark-antiquark pairs. The incident quarks both in the projectile hadron and in the target hadron remain "spectators", which eventually combine with newly created quarks and antiquarks to form hadrons into the fragmentation region. The remaining quarks generally have smaller momenta in the c.m.s. and combine to form hadrons in the central region. We note here that for the purpose of measuring the relative suppression of $s\bar{s}$-pairs as compared to $u\bar{u}$ or $d\bar{d}$ -pairs it is sufficient to consider only the incident quarks since the gluons would contribute equally to both strange and non-strange particle production above kinematical thresholds.

2.2 e^+e^- annihilation to hadrons

Theoretically, e^+e^- annihilation to hadrons provides a clean way to measure SU(3) symmetry breaking in the hadronic vacuum. Using weights of eq.(2) we should be able to measure the suppression factor $\lambda = s\bar{s}/u\bar{u}(d\bar{d})$ directly as a ratio between the inclusive cross sections for the processes $e^+e^- \to K^\pm X$ and $e^+e^- \to \pi^\pm X$ with small corrections from the $s\bar{s}$ production in e^+e^- annihilation and from $d\bar{d}$ production (in which no primary charged K can be produced). At moderate values of the hadron fractional energy, z, resonance production effects λ by favoring π-meson production. However, at high values of z contribution from resonance decays diminishes and at the limit $z \to 1$ only directly produced, primary hadrons remain [16]. Denoting the ratio of primary mesons by r, $r = K^\pm/\pi^\pm$, we can deduce for $z \to 1$ the suppression factor λ from

$$\lambda = (5r-1)/4 \qquad (5)$$

To measure λ in e^+e^- annihilation one therefore has two possibilities: (1) Measure λ at the limit $z \to 1$ as the ratio $\sigma(e^+e^- \to KX)/\sigma(e^+e^- \to \pi X)$, or (2) measure $d\sigma/dz$ for K and π and use a model that incorporates resonance production with λ as a free parameter. Then fitting the model prediction to the experimental data would result in an estimate for λ [17].

To extract λ we have used the e^+e^- annihilation data on inclusive K/π ratio as a function of z at various c.m.s. energies [18]. Combining the data at c.m.s. energies of 4.7-5.2 GeV and choosing mesons with $z>0.4$ only, we get for r, $r=0.51 \pm 0.06$. Using eq. (5) we obtain

$$\lambda = 0.38 \pm 0.08 \qquad (6)$$

The result (6) is in good agreement with the estimate $\lambda=0.30 \pm 0.10$ reported by the PETRA experiments using method (2) [17].

2.3 e(μ)N interactions

Measurements of the K/π-ratio in $e(\mu)N$ interactions at low center-of-mass energies (~ few GeV) are plagued by two major problems: (1) incomplete separation of the current fragmentation region [19] and (2) the fact that the flavor of the final state quark is not uniquely defined (eq. 3). In addition, one faces the effects of resonance production which tend to decrease the K/π-ratio at small values of z ($z<.4$) [20]. At relatively large values of z ($z>.4$) bias from the overlapping fragmentation regions (19) and resonance production (20) will be minimized. At relatively large $x_B = Q^2/2m\nu$ it is the u-quark that should appear most often in the final state; only about 1/8 of the time the struck quark in $e(\mu)p$ interaction should be of d-flavor.

A measurement of the K^+/π^+ ratio in ep interactions by Martin et. al (21) gives $K^+/\pi^+=0.255\pm0.020$ for $z>0.4$, $x_B>0.2$ and $\sqrt{s}_{eff}=4.6$ GeV. Corrections for resonance production and for contributions from the interactions off sea quarks (antiquarks) slightly effect the value of λ derived from this result. Using the measured proton structure functions (22) and an estimate for the effects of resonance production (20) we obtain, $\lambda=0.29\pm0.04$.

There are only some preliminary data for the K^+/π^+ ratio in μp interactions (23) suggesting a value of ~0.3 for λ, as well.

2.4 $\nu(\bar{\nu})N$ interactions

Antineutrino interactions provide us with a unique possibility of measuring SU(3) symmetry breaking in hadronic vacuum (Eq. 4c) as the ratio K^o/π^-. With a suitable selection in $x_B=Q^2/2M\nu$ one effectively probes the u-valence quarks in the target nucleon by the $\bar{\nu}$ charged current interactions. A measurement performed at Fermilab (20) gives for λ:

$$\lambda=0.27\pm0.04, \qquad (7)$$

Here resonance effects have been accounted for by using a Monte

Carlo program. At large $z=E_h/\nu$ the resonance production was found to contribute less than 10% in the value of λ.

In principle λ could be determined in νp interactions as the ratio K^+/π^+ at the limit $z\to 1$ but no ν experiment identifies K^+'s from π^+'s at high momenta ($p_{lab}>1$ GeV/c).

3. Particle production in hadron-hadron interactions

In recent years a considerable amount of evidence has been accumulated to suggest that the production of resonances is an important feature of multiparticle processes (24-31). As a consequence the ground state mesons, pions and kaons, arise dominantly through the decay of heavier resonances [24,28,30,31]. This is in fair agreement with the prediction of the naive quark model [15].

Inclusive cross sections for a number of meson resonances such as ρ^o, f, $K^{*\pm}$, K^{*o}, $\bar{K}^{*o}$, $\bar{K}^*$ (1430), and ϕ have been measured in hadron-hadron interactions at energies ranging from about 10 GeV/c to the ISR.

In this section we shall use the hadron-hadron data on resonance production to deduce the magnitude of the SU(3) symmetry breaking parameter λ. In our estimate we shall also take account of the feed down contribution from the decay of heavier mesons. The heavy meson correction is found to be small and can be estimated using the naive quark model [15].

3.1 pp interactions

Inclusive cross sections for a number of meson resonances have been measured in pp interactions in a wide energy range: from 12 GeV/c to the ISR energies (27-29, 32-36). In general, these data are fully inclusive. However, at 24 GeV/c an attempt (25) has been made to estimate the production of ρ^0 and $K^{*\pm}$ in the fragmentation and central regions separately. At high energies there exists one important experiment at $\sqrt{s}$=63 GeV in which the production cross sections have been measured in the central region (29).

Let us consider the production of the vector mesons ρ^0, K^* (892) and ϕ in pp interactions. Since the valence quark content of the proton is not symmetric with respect to u, $\bar{u}$, d, $\bar{d}$, s and $\bar{s}$, the relative yields of the vector mesons are expected to be different in the fragmentation region as compared to the central region. We therefore need a model for particle production. For our purposes it is adequate to use the simple approach of the naive quark model (15), which has been fairly successful not only in explaining the relative yields of mesons but also their longitudinal spectra, particularly in the fragmentation regions. In this specific version of the constituent quark model, the fragmentation region (FR) mesons are produced in recombination of leading quarks (antiquarks) with an antiquark (quark) from the central "sea" which is formed in the inelastic quark-quark collisions. Likewise, the mesons in the central region are produced in the recombination of a sea quark with a sea antiquark. In addition, there is also a feed down contribution from the decay of the heavier hadrons. In this model, possible phase space effects arising from mass differences between ρ^o, K^* and ϕ are ignored.

Let λ' denote an estimate of the strangeness suppression factor λ when the feed down contributions are neglected. The relative yields of the vector mesons ρ^o, K^*, and ϕ as expected in the model are summarized in table 1 ignoring the feed down contributions. Quantities A and B denote the probabilities of formation a vector meson from the recombination of a valence quark with a sea antiquark (fragmentation component) and from the recombination of a sea quark with a sea antiquark (central component), respectively.

We have assumed that ϕ is only centrally produced through the $s\bar{s}$ recombination. This is in accord with the results of Daum et. al (38) who conclude that the gluon-gluon fusion contribution in ϕ production is negligible. Table 1 yields the following useful measures of λ'.

$$\lambda' = (3\sigma_{K^{*+}} + \sigma_{K^{*-}})/4\sigma_{\rho^o} \tag{8}$$

$$\begin{aligned} \lambda' &= \sigma^C_{\bar{K}^{*o}} / \sigma^C_{\rho^o} \\ &= (\sigma^C_{\bar{K}^{*o}} + \sigma^C_{K^{*o}})/2\sigma^C_{\rho^o} \end{aligned} \tag{9}$$

$$\lambda' = \sigma_\phi/\sigma_{K^{*-}} = \sigma_\phi/\sigma_{\bar{K}^{*o}} \tag{10}$$

$$\lambda'^2 = \sigma_\phi/\sigma^C_{\rho^o} \tag{11}$$

Here, σ_M is the inclusive cross section for the production of the meson M and C refers to the central component only. It can be seen from eq. 8 that $\lambda' \simeq \sigma_{K^{*+}}/\sigma_{\rho^o}$ is valid only at high energies where the fragmentation contribution is relatively small and, therefore $\sigma_{K^{*-}} \sim \sigma_{K^{*+}}$. At low energies, where fragmentation contribution dominates, $\lambda' \sim 3\sigma_{K^*}/4\sigma_{\rho^o}$. it may be pointed out that it is not correct to use the relation $\lambda' = \sigma_{K^{*+}}/\sigma_{\rho^o}$ at low energies as has been done in the literature (33).

The inclusive cross sections for ρ^o, K^{*+} and K^{*-} have been measured (11-15) in pp experiments using the bubble chamber at 12, 24, 69 and 405 GeV/c. The values of λ' deduced by us using eq. 8 are given in column 6 of table 2.

At the ISR, the cross sections for the vector meson production have been measured at $\sqrt{s}$=52.5 GeV (28) and at 63 GeV (29) and for the tensor meson production at 52.5 GeV (28). The data at $\sqrt{s}$=63 GeV refer to central production only and are therefore simpler to use. The ratio $\sigma_{\bar{K}^{*o}}(1430)/\sigma_f$ used in (28) to deduce λ (Table 2) has the merit that the contribution of the heavier resonances is expected to be small and can therefore be neglected. Since the ratio is expected to be different in central and fragmentation regions, the naive quark model and $K^{\pm}/\pi^{\pm}$ has been used to estimate the relative contributions from the two regions. We have followed a similar procedure to establish λ, from the data (28) on $\sigma_{\bar{K}^{*o}}$, σ_{ρ^o} and σ_ϕ, (Table 2).

3.2 π^+p interactions

High statistic data (25, 33, 39) on meson production in π^+p interactions at 16 GeV/c are available. Unfortunately, the analysis of the meson production in the π^+p interactions is considerably more involved than in pp interactions. The reason for the complexity is that for ρ^o production in π^+p interactions, not only the beam and target fragmentation plus the central component contribute but also diffraction dissociation (including the two-body quasi-elastic reactions) and the fusion of valence $\bar{d}$ antiquark from the initial π^+ with the valence d-quark from the initial proton to form a ρ^o.

Ignoring the feed down contribution, the mechanisms for K* production in π^+p interactions are relatively simpler as compared to the ρ^o production. The K^{*-} is only produced centrally while the $\bar{K}^{*o}$ can also be produced in beam fragmentation. The K^{*o} has both the central and the target fragmentation components, while the K^{*+} has three components, the central and the two fragmentation components.

Following the simple model outlined previously in 3.1, we can express λ' in terms of K* and ρ^o production cross sections. We assume that the valence u quarks in π^+ and p are equally effective in forming a fragmentation ρ^o although u-quark average momentum fractions in π^+ and p are somewhat different. In this way we obtain the following relations:

$$\lambda_1 = 2.5(\sigma_{K^{*+}} - \sigma_{K^{*-}})/3(\sigma_{\rho^o}{}^B+\sigma_{\rho^o}{}^T), \qquad (12)$$

and also

$$\lambda'_2 = \sigma_{K^{*-}}/\sigma^C_{\rho^o}, \qquad (13)$$

where labels B, T and C stand for beam fragmentation, target fragmentation and central component (sea-sea component), respectively.

Bockmann (25) has estimated the magnitudes of the different components for ρ^o production in π^+p interactions at 16 GeV/c. Using this information, we obtain

$$\lambda'_1 = \frac{2.5[(1.71\pm0.20)-(0.18\pm0.05)]}{3(1.7\pm0.4)} = 0.26\pm0.08$$

$$\lambda'_2 = \frac{0.18\pm0.05}{0.7\pm0.2} = 0.26\pm0.10$$

These two estimates are in good agreement with each other. They are included in table 2 together with the values (λ) corrected for the feed down contribution. We believe that these estimates of λ' are more reliable than the ones obtained in (33).

3.3 $K^{\pm}p$ interactions

Production cross sections of the vector mesons ρ^o, $K^{*\pm}$, K^{*o} and ϕ have been measured in K^-p interactions (25,40,41) at 10, 16 and 32 GeV/c and in K^+p interactions (42) at 32 GeV/c. The ρ^o

data is difficult to use because of the unknown contributions from the valence-valence component. Both ϕ and $\bar{K}^{*0}$ have beam fragmentation and central components while $\bar{K}^{*0}$, in addition, has a diffractive (and quasi two-body) component. We can use the following relations to estimate λ'.

$$\lambda' = \sigma_\phi/\sigma^{ND}_{\bar{K}^{*0}} \quad , \qquad (14)$$

for K^-p interactions and

$$\lambda' = \sigma_\phi/\sigma^{ND}_{K^{*0}} \quad , \qquad (15)$$

for K^+p interactions. In eqs. 14 and 15 ND stands for the non-diffractive component. Of the $\sigma_{\bar{K}^*}$ =3.3±0.4 mb (40) obtained in K^-p interactions at 16 GeV/c, Bockmann (25) has estimated that the "diffractive" component is 1.0 mb. We now assume that the diffractive component is energy independent in the above narrow energy range. The values of λ', obtained using eqs. 14 and 15, and the values of λ are given in table 2.

4. Heavy particle decays

4.1 Introduction

A heavy particle decaying into a pair of particles provides us with an independent method of determining the $s\bar{s}$ suppression parameter λ. The decaying particle state has to be massive enough to minimize the possible kinematical effects due to different masses of the produced particles. Here again, we rely on a simple zeroth order picture of meson decays.

4.2 J/ψ decays

The ratio between the decay modes $J/\psi \rightarrow KK^*$ and $J/\psi \rightarrow \rho\pi$ [43] should provide a measure of the SU(3) symmetry violation in hadronic vacuum (Fig. 1).

A measurement [44] of the ratio R,

$$R = \frac{Br(J/\psi \rightarrow K^*K)}{Br(J/\psi \rightarrow \rho\pi)} = 0.49 \pm 0.11$$

corrected for phase space effects gives for λ (eq. 5)

$$\lambda = \frac{5R-1}{4} = 0.36 \pm 0.14 \quad .$$

This result is consistent with values obtained by previous methods.

5. Net charge measurements

5.1 Definitions

Violation of SU(3) symmetry has measurable consequences for the retention of quark quantum numbers in the quark jets. It was first suggested by Feynman that quark quantum numbers are absolutely retained in the quark jets, averaged over many events [45]. Farrar and Rosner subsequently showed that there is a net quantum number leakage through the central rapidity plateau due to the relative suppression of strange-antistrange quark-antiquark pairs [46].

For any additive quark quantum number in a quark jet, one finds, averaged over many events,

$$\langle N\rangle = N_q - \sum_i \gamma_i N_i \quad , \tag{16}$$

where γ_i is the relative probability of creating a $q_i\bar{q}_i$ pair of flavor i in the quark fragmentation process. For SU(3) symmetric case $\gamma_u=\gamma_d=\gamma_s=1/3$. In general, for suppression parameter $\lambda=\gamma_s/\gamma_u=\gamma_s/\gamma_d=\gamma_s/\gamma$ (Isospin Symmetry) we get from unitarity ($\gamma_u+\gamma_d+\gamma_s=1$)

$$\lambda = \frac{1-2\gamma}{\gamma} \tag{17}$$

An easily measured quantity is the average net charge in the quark jet. From eq. 16 we obtain

$$\langle Q\rangle = e_q - \sum_i \gamma_i e_i \tag{18}$$

where e_i is the electric charge of quark of flavor i. With the isospin symmetry assumption and probability conservation (we neglect charm production) we find, using the charge constraints $e(u\bar{d})=+1$, $e(u\bar{s})=+1$ from π^+ and K^+ quark contents, respectively:

$$\begin{aligned} \langle Q\rangle &= 1-\gamma \quad &&\text{for a u-quark jet} \\ &= -\gamma \quad &&\text{for a d- or s-quark jet.} \end{aligned}$$

Utilizing eq. 17 we finally get

$$\lambda_u = \frac{2\langle Q\rangle-1}{1-\langle Q\rangle} \tag{19a}$$

for a u-quark jet, and

$$\lambda_{d,s} = -\frac{1+2\langle Q\rangle}{\langle Q\rangle} \tag{19b}$$

for a d- or s-quark jet.

5.2 e(μ)N interactions

In e(μ)N interactions all quark flavors should be found among the final state quark jets according to the eq. (3). Therefore, the prediction (19) will be modified to be

$$\lambda = \frac{1-2(8/9-\langle Q\rangle)}{8/9 - \langle Q\rangle} \quad . \tag{20}$$

Using the ep measurement [47]

$$\langle Q\rangle = 0.44\pm0.01$$

($x_F>0.2$, $x_B>0.2$) we obtain for λ (from eq. (20))

$$\lambda = 0.23\pm0.05 \tag{21}$$

5.3 $\nu(\bar{\nu})$N interactions

In $\nu N(\bar{\nu}N)$ charged current interactions dominantly u(d) quark jets are produced and thus the measurement of $\langle Q\rangle$ should directly give λ. There are several measurements of average net electric charge in $\nu(\bar{\nu})$ induced jets [19, 48]. The weighted average for $\langle Q\rangle_\nu$ ($\langle Q\rangle_{\bar{\nu}}$) is 0.58±.07 (−0.46±.05). Using eqs. (19) we obtain for $\lambda_\nu(\nu N)$

$$\lambda_\nu = 0.4 \pm 0.4 \tag{22}$$

From the $\bar{\nu}$ result we do not obtain any constraints for λ.

6. Baryon Production in Quark Jets

Adopting a simple model for baryon production in quark jets (49) leads to another posibility of deducing amount of SU(3) symmetry breaking in hadronic vacuum as a function of the ratio ($\rho=\Lambda\bar{\Lambda}/p\bar{p}$) between the inclusive production rates of $\Lambda\bar{\Lambda}$ and $p\bar{p}$ pairs, namely

$$\lambda = \frac{13.5\ \rho - 2}{14 - 4\ \rho} \qquad (23)$$

Here we have neglected the contribution of charmed baryons in the proton and lambda production rates. Relative branching ratios of charmed baryons into the channels ($\Lambda+\pi$'s) and ($p+K+\pi$'s) are not well known, but the data are consistent with lambdas and protons being produced equally in Λ^+_c decays (44). The data tend to suggest, therefore, that charmed baryon production should not strongly effect the ratio $\rho=\Lambda/p$.

Several e^+e^- experiments have recently measured the ratio ρ: JADE and TASSO experiments at PETRA obtain $\rho_J=0.32\pm0.12$ (50) and $\rho_T=0.4\pm0.1$ (51), respectively, while Mark II at PEP gets $\rho_M=0.32\pm0.13$ at $\sqrt{s}\simeq29$ GeV and 0.33 ± 0.12 at $\sqrt{s}\simeq7$ GeV (52). If we interpret the ratios ρ to solely reflect the relative suppression of $s\bar{s}$ quark pairs in the quark jets, we obtain a new measure of parameter λ (eq. 23) as the weighted average of the three measurements at $\sqrt{s}\simeq29$ GeV (table 3):

$$\langle\lambda\rangle = 0.21 \pm 0.07 \ .$$

We note, that in ref. (53) the model in which Λ/p ratio in a d-quark jet is given by λ (49) is utilized to correct for unidentified proton contributions in the measured inclusive spectra. Measurements of inclusive proton and lambda spectra in deeply inelastic lepton-nucleon collisions support this picture of baryon production in quark jets (53).

7. Energy dependence of λ

In order to compare λ in different interactions and to look for a possible energy dependence of λ it is necessary to use a suitable kinematic variable to represent the effective energy of the subprocess, $\sqrt{\hat{s}_{eff}}$. While the evaluation of $\hat{s}_{eff}$ is unambiguous for e^+e^- annihilation and lepton-hadron interactions, the inherent complexity of hadron-hadron interactions and their poor theoretical description makes the task of evaluating $\hat{s}_{eff}$ in the soft hadronic processes difficult. In view of this we will assume that $\hat{s}_{eff}$ is given by the average energy of the valence quark in the beam particle interacting with the valence quark in the target. We therefore have

$$\hat{s}_{eff} = s\langle x_1\rangle \langle x_2\rangle$$

where $\langle x_1\rangle$ and $\langle x_2\rangle$ are the average momentum fractions of the beam valence quark and target valence quark respectively. If $xq(x) = A\, x^{\alpha}\,(1-x)^{\beta}$ is the valence quark distribution function, we have

$$\langle x\rangle = \int_0^1 xq(x)\,dx \Big/ \int_0^1 q(x)\,dx = \frac{\alpha}{\alpha+\beta+1} \quad .$$

If we now use the values $\alpha=0.48$, $\beta=2.7$ for the proton and $\alpha\simeq0.5$, $\beta\simeq1$ for the pion, we obtain for the average effective energies

$$\sqrt{s}_{eff}(pp) = 0.11\,\sqrt{s} \quad , \tag{24}$$

$$\sqrt{s}_{eff}(\pi p) = 0.15\,\sqrt{s} \quad . \tag{25}$$

The values of $\sqrt{s}_{eff}$ so obtained are included in table 2. Fig. 2 shows the strangeness suppression factor (λ) as a function of $\sqrt{s}_{eff}$ for hh interactions, e^+e^- annihilations, lepton and photon interactions and for J/ψ decays. As might be expected, λ shows a tendency to increase with $\sqrt{s}_{eff}$ for $\sqrt{s}_{eff} \lesssim 1$ GeV. Fig. 2 also shows that for $\sqrt{s}_{eff} > 1$ GeV, λ is essentially constant and the weighted mean deduced from the hh interactions (0.30 ± 0.02) agrees with the weighted mean value (0.29 ± 0.02) from other processes. We therefore conclude that the overall weighted mean value of the strangeness suppression factor for hadronic vacuum is

$$\langle\lambda\rangle = 0.29 \pm 0.02$$

8. Discussion and conclusions

We have analyzed measurements of the inclusive particle ratios in e^+e^- annihilation to hadrons, in deeply inelastic lepton-nucleon interactions, in hadron-hadron interactions and in J/ψ decays into hadrons to evaluate the relative suppression factor of $s\bar{s}$ pairs in hadronic vacuum (tables 2 and 3). Above 1 GeV effective energies a fair consistency of the λ-values deduced from different processes emerges. No apparent energy dependence of λ is observed (fig. 2). The internal consistency of λ values obtained by using several independent methods of evaluation support the simple quark-parton picture of the processes considered.

The apparent universality of the measured suppression parameter also tends to support our phenomenological picture of soft hadron-hadron process. It is not unreasonable in QCD to expect that heavier $q\bar{q}$ pairs would be suppressed relative to the lighter pairs produced from the hadronic vacuum. The lattice treatment of QCD leads to a picture in which a narrow color flux tube develops between a separated $q\bar{q}$ pair (2,3). When the color tube is sufficiently long to contain internal energy greater than the rest mass of a $q\bar{q}$ pair (2M), i.e. when TL>2M, where T is the tube energy per unit length, one obtains for the probability of creating a new $q\bar{q}$ pair from the tube

$$\Gamma = LT \exp\{ - \frac{\pi}{\alpha_s} \frac{A}{T} M^2 \} \quad ,$$

where A is the area of the tube, i.e. energy density $\varepsilon = T/A$, and α_s the strong coupling constant (3). For λ one then obtains

$$\lambda = \Gamma_{s\bar{s}}/\Gamma_{u\bar{u}} = \exp\{- \frac{\pi}{\alpha_s} \frac{\Delta M^2}{\varepsilon^2} \} \quad , \tag{26}$$

where $\Delta M^2 = M_s^2 - M_u^2$. Using the values $\alpha_s = .16 \pm .06$ (54), $M_s = 0.5$ GeV, $M_u = 0.1$ GeV and $\varepsilon = 1$ GeV, we obtain for λ:

$$\lambda = 0.35 \pm {}^{.05}_{.09}$$

For the suppression of $c\bar{c}$ pairs we get from eq. (26), using $M_c = 1.8$ GeV, $\lambda = 6 \times 10^{-7}$, i.e. it should be very hard to create a new $c\bar{c}$ pair from hadronic vacuum in this model.

In conclusion, we note that there is a remarkable internal consistency in the various values of the $s\bar{s}$ suppression parameter deduced from hadron-hadron, lepton-lepton and lepton-nucleon interactions. Our work suggests that there is a universal SU(3) violating suppression factor λ in all these processes with a value of $\lambda = 0.29 \pm 0.02$.

Finally, we note that the recent analysis of the opposite sign dimuons in ν and $\bar{\nu}$ interactions by the CDHS Collaboration (55) indicates that there is a significant suppression of the momentum fraction carried by the strange sea quarks within the nucleon as compared to the non-strange quarks. Their value of 0.52 ± 0.09 for the suppression of the momentum fraction carried by the strange quarks may be compared with our value of 0.29 ± 0.02 for the suppression of the number of strange quarks.

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16. Consider the cross section $d\sigma/dx$ for a resonance R. A usual parameterization for $d\sigma/dx$ is $d\sigma/dx \sim (1-x)^{\rho}$. The x-spectrum of the daughter (D) is then obtained by convoluting $d\sigma_R/dx$ over x, i.e.

$$d\sigma_D/dx \sim (1-x)^{\rho+1}$$

and thus the spectrum will be softer for the daughter. Note that by helicity arguments a further softening of the daughter spectrum often results.

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Table 1: Relative yields of ρ^0, $K^{*\pm}$, K^{*0}, $\bar{K}^{*0}$ and ϕ in naive quark model in pp → MX, ignoring the contribution from the decay of heavier mesons.

Meson	Fragmentation Region		Central Region
	Beam	Target	
ρ^0	3/2 A	3/2 A	2B
K^{*+}	$2A\lambda'$	$2A\lambda'$	$2B\lambda'$
K^{*-}	--	--	$2B\lambda'$
K^{*0}	$A\lambda'$	$A\lambda'$	$2B\lambda'$
$\bar{K}^{*0}$	--	--	$2B\lambda'$
ϕ	--	--	$2B\lambda'^2$

Table II. Suppression factors λ' and λ deduced from measurements of production cross sections in hadronic interactions.

Inter-action	P_{Lab} (GeV/c)	$\sqrt{\hat{s}_{eff}}$ (GeV)	Inclusive hadrons	Prod. Region	λ'	λ	Reference for cross-section
pp	12	0.54	$K^{*\pm},\rho^0$	-	0.12 ± 0.02	0.13 ± 0.02	(32,33)
pp	24	0.75	$K^{*\pm},\rho^0$	-	0.15 ± 0.02	0.16 ± 0.02	(32,33)
pp	69	1.26	$K^{*\pm},\rho^0$	-	0.28 ± 0.12	0.31 ± 0.12	(34)
pp	205	2.16	$K^{*\pm},\rho^0$	-	0.18 ± 0.11	0.20 ± 0.11	(35)
pN	240	2.34	$\Lambda\bar{\Lambda}$,$p\bar{p}$	-	0.25 ± 0.04	0.25 ± 0.04	(37)
pp	405	3.04	$K^{*\pm},\rho^0$	-	0.31 ± 0.08	0.34 ± 0.08	(36)
pp	1468	5.77	$\bar{K}^{*0}(1430),f$	-	0.30 ± 0.10	0.30 ± 0.10	(28)
			$\bar{K}^{*0},\rho^0$	-	---	0.35 ± 0.12	
			$\phi,\bar{K}^{*0}$	-	0.30 ± 0.11	0.36 ± 0.13	
pp	2115	6.93	$K^{*0},\bar{K}^{*0},\rho^0$	C	0.29 ± 0.05	0.32 ± 0.06	(29)
			$\phi,K^{*0},\bar{K}^{*0}$	C	0.30 ± 0.07	0.36 ± 0.08	
			ϕ,ρ^0	C	0.30 ± 0.03	0.32 ± 0.03	
π^+p	16	0.85	K^{*+},ρ^0	F_B+F_T	0.26 ± 0.08	0.29 ± 0.09	(39,33,25)
			K^{*-},ρ^0	C	0.26 ± 0.10	0.29 ± 0.11	
K^-p	10	0.68	$\phi,\bar{K}^{*0}$	F_B+C	0.17 ± 0.03	0.20 ± 0.04	(40)
K^-p	16	0.85	$\phi,\bar{K}^{*0}$	F_B+C	0.17 ± 0.04	0.20 ± 0.05	(40)
K^-p	32	1.18	$\phi,\bar{K}^{*0}$	F_B+C	0.29 ± 0.09	0.35 ± 0.06	(41)
K^+p	32	1.18	ϕ,K^{*0}	F_B+C	0.20 ± 0.05	0.24 ± 0.06	(42)

Table III. Strangeness suppression factor λ deduced from data from e^+e^- annihilation, lepton-nucleon interactions and J/ψ decay.

Method	$\sqrt{\hat{s}}_{eff}$ (GeV)	λ	Reference
e^+e^-, K/π at large x	5	0.38 ± 0.08	(18)
e^+e^-, K/π Monte Carlo	33	0.30 ± 0.10	TASSO (17)
e^+e^-, K/π Monte Carlo	34	0.33 ± 0.12	JADE (17)
e^+e^-, $\Lambda\bar{\Lambda}/p\bar{p}$	6.6	0.18 ± 0.13	MARK II (52)
e^+e^-, $\Lambda\bar{\Lambda}/p\bar{p}$	29	0.19 ± 0.10	MARK II (52)
e^+e^-, $\Lambda\bar{\Lambda}/p\bar{p}$	33	0.27 ± 0.14	TASSO (51)
e^+e^-, $\Lambda\bar{\Lambda}/p\bar{p}$	34	0.18 ± 0.12	JADE (50)
eN, K/π at large x	4.6	0.26 ± 0.04	(21)
$\bar{\nu}N$, K/π at large x	5	0.27 ± 0.04	(20)
$J/\psi \to KK^*, \rho\pi$	3.1	0.36 ± 0.14	(44)
Net charge in $(e,\mu,\gamma)N$	3.2	0.23 ± 0.05	(47)
Weighted mean	3-34	0.27 ± 0.02	
$hh \to \rho^0, K^*, \phi$	> 1	0.30 ± 0.02	

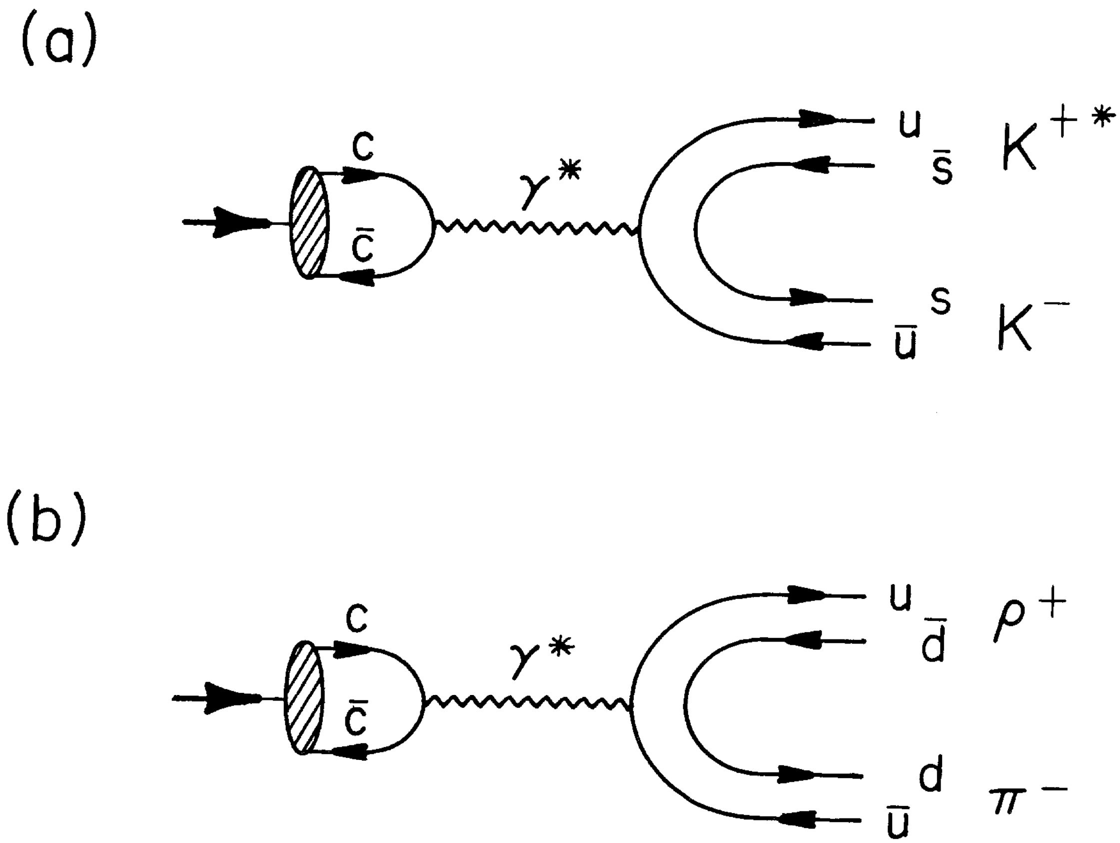

Fig. 1. Electromagnetic decays of J/ψ: (a) $J/\psi \rightarrow K^{*+}K^-$ and (b) $J/\psi \rightarrow p^+\pi^-$ used for a determination of the strangeness suppression factor (λ).

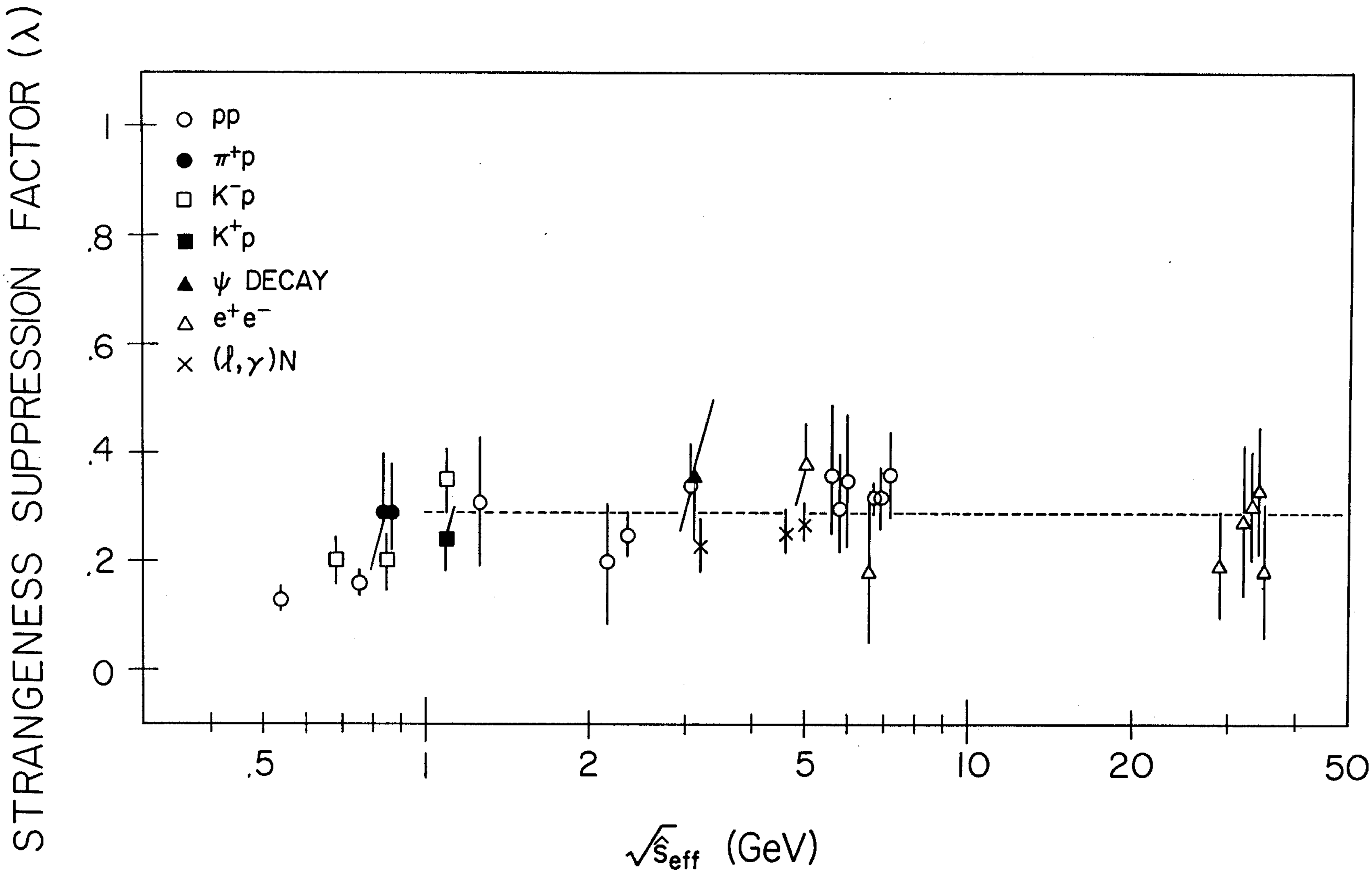

Fig. 2. Strangeness suppression factor (λ) as a function of the effective energy $\sqrt{\hat{s}}_{eff}$.