HADRONIC PAIR PRODUCTION OF NEW QUANTUM NUMBERS

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Associated production of strangeness and baryon number is discussed in typical hadronic multiparticle production models. Estimates of charm production are presented.

1. Introduction

The production of heavy particles in high energy multiparticle reactions is well described empirically [1–4] by using the transverse mass variable $m_T = (p_T^2+m^2)^{1/2}$. Thus the central region production of π, K, η, ϱ, ϕ and ψ all follow an approximately universal curve in m_T. Using this observation to predict the level of charmed meson production then gives an estimate of $d\sigma/dy \sim 5$ μb [1–4] at FNAL energies and thus $\sigma \sim 5$ μb. A search for long-lived tracks in emulsion [5] has given an upper limit, at these energies, of $\sigma < 1.5$ μb for charmed meson production. Other experiments have also failed to see any charm production in hadronic collisions.

It is thus of considerable importance to quantify the m_T-dependence method of comparing heavy particle production yields. One feature of particular relevance is that charmed mesons must be produced in pairs to conserve charm, unlike the ψ meson. In a thermodynamic or statistical approach this may lead to a large suppression of charmed meson production at available energies [6]. In models with a finite rapidity correlation length, however, it will be shown that this suppression is rather small at existing energies. The latter class of model thus tends to reinforce the expectation of a signal for charmed meson production with $d\sigma/dy \sim 2$—5 μb. We shall investigate these ideas by applying them first to the associated production of strangeness or of baryons and comparing with data on the energy dependences, etc.

The observed near-universality of single particle spectra in the variable m_T is expected in thermodynamic models since m_T is the energy of the produced particle in the frame in

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which its longitudinal momentum is zero. In the Mueller–Regge approach to multiperipheral models, a universal dependence on m_T also arises naturally at high energies but additional "quark size" factors are also expected to be present [1, 2]. In the latter approach, an exponential dependence on m_T is not particularly favoured, whereas in the thermodynamic approach a non exponential distribution could only be obtained by considering a temperature distribution [7].

2. *A statistical model*

Thermodynamic equilibrium will only be expected when the multiplicity of particles of a given species is large so that quantum number conservation constraints can be neglected. To illustrate this we consider a statistical (or independent emission) model of the production of a conserved quantum number A and show how the threshold rise to the thermodynamic or asymptotic value is achieved.

Consider three states a^+, a^- and a^0 with quantum numbers $A = +1, -1, 0$ which are produced with relative coupling ε, ε and $1-2\varepsilon$ respectively. This formalism [8] can be applied to the production of Q, S, B or C although the values of ε will be different in each case of course[1]. Then in a statistical approach with only global conservation of the quantum number, the cross section to produce n particles (from initial state of $A = A_0$) is given by the trinomial expansion as

$$\sigma_n(A_0) = \sum_p \frac{n!\varepsilon^p\varepsilon^{p-A_0}(1-2\varepsilon)^{n+A_0-2p}}{p!(p-A_0)!(n+A_0-2p)!}$$

$$= \sum_p \sigma_n(p, p-A_0, n+A_0-2p), \tag{1}$$

where p is the number of a^+ produced such that p, $p-A_0$ and $n+A_0-2p$ are all non negative. The fraction of a^+ particles produced is thus

$$\frac{\langle n_+\rangle}{n} = \frac{\sum_p \sigma_n(p, p-A_0, n+A_0-2p)}{n\sigma_n(A_0)} \tag{2}$$

$$\sim \frac{(n-1)\varepsilon^2}{1-2\varepsilon} \tag{3}$$

if $\varepsilon n < 1$ and $A_0 = 0$. While if $\varepsilon n > 1$, one can use the central limit theorem approach to obtain (for $A_0 = 0$)

$$\frac{\langle n_+\rangle}{n} \sim \varepsilon \frac{\sqrt{n}}{\sqrt{n-1}} e^{-\frac{1}{4\varepsilon(n-1)}}. \tag{4}$$

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[1] Where the lightest states produced with non-zero quantum number are of mass M, the asymptotic particle ratio $\varepsilon/(1-2\varepsilon)$ can be estimated using m_T-universality from $\int_M^\infty d^2 m_T f(m_T) / \int_{m_\pi}^\infty d^2 m_T f(m_T)$ together with possible "quark size" factors which provide some additional suppression of strangeness and charm production [2, 8].

These equations exhibit the transition from the constant ratio ε at very large n to the ratio proportional to ε^2 at small n where single pair production is the dominant process. An approximate scaling is present in both limits since we have

$$\langle n_+ \rangle \sim g(\varepsilon(n-1)), \tag{5}$$

where $g(x) \sim x^2$ for small x and $\sim xe^{-1/4x}$ for large x.

To compare with data [9] we plot $\langle n_+ \rangle$ against $\varepsilon(n-1)$ and look for a universal curve g of the form expected. For strange meson production we take n as the average meson multiplicity and $\langle n_+ \rangle = \langle n_- \rangle = 2\langle n_{K^-} \rangle$ (the observed excess of K^+ plus K^0 over K^- plus $\bar{K}^0$ is considered to be related to hyperon production). For baryon number

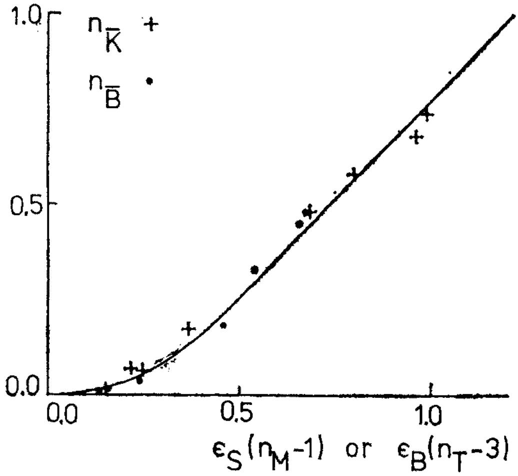

Fig. 1. An illustration of the onset of strangeness production and of antibaryon production with increasing total multiplicity for a series of energies in pp collisions. At each energy, the strange meson multiplicity $n_{\bar{K}}$ (taken as $2n_{K^-}$) is plotted (+) against $\varepsilon_S(n_M-1)$ where n_M is the average meson multiplicity at that energy. Similarly, the antibaryon multiplicity $n_{\bar{B}}$ (taken as $3n_{\bar{p}}$) is plotted (●) against $\varepsilon_B(n_T-3)$ where n_T is the total multiplicity at that energy. Data are from Ref. [9]. The values of $\varepsilon_S = 0.07$ and $\varepsilon_B = 0.045$ have been used. The curve shown is the universal form of Eq. (5) of the text which results from a statistical approach to the constraint of quantum number conservation. Strangeness and antibaryon productions are seen to be consistent with this approach

production, we assume that two leading baryons are produced in pp collisions and take n as $\langle n_{tot} \rangle - 2$, while $\langle n_+ \rangle = \langle n_- \rangle$ is taken as the average antibaryon multiplicity (we guess that $\langle n_- \rangle \sim 3\langle n_{\bar{p}} \rangle$ to account for $\bar{n}$, $\bar{\Lambda}$ and $\bar{\Sigma}$ production). Then ε_S and ε_B respectively are adjusted to give the required high energy behaviour and the results are shown in Fig. 1. With $\varepsilon_S = 0.07$ and $\varepsilon_B = 0.045$ the two independent sets of data lie on top of each other and, furthermore, the simple independent emission calculation given above reproduces extremely well this common energy dependence.

In the above statistical model approach the asymptotic ratio ε is reached when the total multiplicity $n \gtrsim 1/\varepsilon$. This is because the multiplicity of particles a_+ or a_- is then approximately 1 and the constraint of conservation of quantum number A is achieved relatively easy. Thus for S or B production one has a rise to the asymptotic value controlled by $n \sim 1/\varepsilon \sim 15$ to 20. For charm production, on the other hand, a thermodynamic approach leads to $\varepsilon \sim 5\ 10^{-5}$ and the asymptotic yield will only be reached when the total multiplicity $n \sim 2\ 10^4$ or $s \sim 10^{2900}$. At existing energies, one is in the regime of Eq. (3) and there will be an extra suppression factor [6] of $\varepsilon(n-1) \sim 10^{-3}$. This estimate makes charm production in hadronic production very small indeed and extremely hard to detect. In a statistical/thermodynamic approach one can easily reproduce the level of ψ and ψ' production at FNAL energies of $d\sigma/dy \sim 100$ nb and 10 nb respectively. The 10^{-3} suppressed D$\bar{\text{D}}$ production would be at about 5 nb—50 nb which is a comparable level. If D$\bar{\text{D}}$ production came predominantly from several heavy ψ-like states which decay to D$\bar{\text{D}}$ then such an estimate would be consistent. This is of course not the case for K production at FNAL energies where the level of ϕ production is $d\sigma/dy \sim 100$ μb while $\bar{\text{K}}$ production has $d\sigma/dy \sim 5000$ μb so that $\bar{\text{K}}$ production is much more copious than ϕ production.

3. *A model with correlations*

The model estimates of the suppression of associated pair production have been based on the global conservation constraint. It is known, however, that short range correlations are present experimentally. In particular, the measured charge transfer distribution is known to be narrower and more energy dependent than the distribution resulting from global conservation of charge [10]. Such correlations may be introduced through a cluster approach, a multitemperature approach [7] or through a generalized multiperipheral approach. The link correlated model [11] (LCM) provides a general framework which enables a finite correlation length to be introduced. This model has been applied successfully to charge and to strangeness production in high energy multiparticle reactions [12]. We may apply the proposed strangeness production formalism [12] equally well to baryon and to charm production. We retain a nearest neighbour stepping matrix limited to quantum number values of ± 1 and 0 in the links, and with general end couplings the results can be evaluated exactly.

We define a multiplicity correlation length $n_{\text{CL}} = 2/(1-\lambda_2)$ where λ_2 is an eigenvalue of the stepping matrix and, for strangeness production, unitarity considerations [12] lead to $(1-\lambda_1) \sim (1-\lambda_2) \sim (\alpha_{\text{p}}-\alpha_{\omega})/(dn/dy) \sim 1/6$. A similar argument applied to baryon number or charm production results in the expectation that λ_1 and λ_2 should be the same for those cases also, thus $n_{\text{CL}} \sim 12$ is anticipated. In the model, a particle of quantum number $+1$ is accompanied by a balancing particle of quantum number -1 within the finite correlation length, which corresponds to a balance among $\sim n_{\text{CL}}$ particles of neighbouring rapidity. Asymptotically many such pairs are produced and the particle production ratio is defined as ε. At low energies, when only one pair will be produced, a suppression of $\sim n/n_{\text{CL}}$ arises when less accompanying particles are produced than the number n_{CL} needed asymptotically to balance the produced quantum number. The explicit result in the LCM may be expressed simply in the two limits

$$n \ll n_{CL}: \frac{\langle n_+ \rangle}{n} \sim \frac{\varepsilon(n-1)}{n_{CL}}, \tag{6}$$

$$n \gg n_{CL}: \frac{\langle n_+ \rangle}{n} \sim \varepsilon\left(1 - \frac{\gamma n_{CL}}{2n}\right), \tag{7}$$

where γ is determined by λ_1, λ_2 and the end couplings and is $\lesssim 1$ in practice.

These equations may be contrasted with equations (3) and (4) where one sees a somewhat similar dependence with n_{CL} here replaced by $1/\varepsilon$. Thus for strangeness and baryon production, $n_{CL} = 12$ is comparable to the expected value of $1/\varepsilon$ and the two approaches give a very similar description. This is encouraging in that Fig. 1 then also shows reasonable agreement with Eqs (6) and (7) if $n_{CL} \simeq 12$. For charm production, however, things are very different and the suppression of associated charm production at existing energies given by Eq. (6) is relatively small. Thus, in this latter approach, an approximately asymptotic particle production ratio is obtained when the total multiplicity n is comparable to the correlation length n_{CL} which is expected to be roughly independent of the nature of the quantum number produced. Indeed a factor of 3 or so suppression is the most that the LCM will yield at FNAL energies.

4. *Conclusions*

Thermodynamic, statistical and Mueller–Regge approaches lead to the observed approximate m_T-universality of particle production. This universality will only be valid above the effective threshold and we have used two different models to estimate the energy at which this effective threshold lies. Thus there will be an extra suppression of particle production at presently available energies ($\sqrt{s} \sim 20$ GeV) if this effective threshold is at even higher energies. For strange particle or antibaryon production, these threshold suppressions have been found to operate below $n \sim 10$—20. This value of n may be interpreted either as related to a correlation length or to the statistical model criterion that the associated multiplicity should be of the order of one. For charmed meson production, the extra suppression is related to the "cost" of producing a second charmed particle to conserve charm. In a statistical/thermodynamic approach this extra suppression will be $\sim 10^{-3}$ while in a model with a finite rapidity correlation length for charm production, the extra suppression should only be $\sim 1/3$. This latter approach thus leads to a charmed meson production yield in the central region of $d\sigma/dy \sim 1$—2 μb at energies of $\sqrt{s} \sim 20$ GeV.

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