Universal Mass Dependence
for Meson and Baryon Inclusive Cross-Sections

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Abstract. We show that the data on inclusive cross-sections for light mesons and baryons in high energy hadron-hadron interactions are consistent with a simple empirical formula $\sigma_{incl} = a \frac{2J+1}{2I_m+1} \exp(-bM^2)$ observed recently in e^+e^- annihilations, where J is the spin, I_m is a modified isospin and M is the mass of the produced particle. The same value of the slope parameter b is observed for e^+e^- annihilations at PEP/PETRA and LEP energies and for proton-proton interactions at ISR energies. This universal dependence points to a simple mass law for hadron states produced locally in string fragmentation irrespective of the configuration of the strings in various processes.

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1 Introduction

Hadron production in multiparticle hadron-hadron interactions with low momentum transfer is still one of the least understood processes in high energy physics. Perturbative QCD is not applicable to soft processes and one has to rely on phenomenological descriptions. Although the main properties of these reactions are satisfactorily described by models [1], many details are not well reproduced [2]. The production of hadrons is much better understood in e^+e^- annihilations, where the most successful are the string [3] and the cluster [4] fragmentation models. These require, however, a large number of parameters. In such a situation it is particularly important to look for universal regularities in hadronic production in various reactions. These can guide attempts to fully understand the complicated mechanisms of multiparticle production in hadron-hadron interactions.

Recently one such empirical regularity was found for hadron production in e^+e^- annihilations [5]. It was shown from e^+e^- data that the production rates of particles belonging to the SU(3) nonets of the pseudoscalar and vector mesons and to the octet and decuplet of the baryons are determined only by particle spins, isospins and their masses. The meson and baryon

production rates as a function of particle mass squared lie on one universal curve described by the simple formula

$$\langle N(\text{particle}) \rangle = a \frac{2J+1}{2I_m+1} \exp(-bM^2),$$

where J is a spin, I_m is a modified isospin as described later in this paper and M is the mass of the produced particle. The same value of the slope parameter b is observed at PEP/PETRA and at LEP energies, so only the normalization parameter a is energy dependent. Apart from pions, almost all data points for $\langle N(\text{particle}) \rangle$ lie on the same curve. A slight upward deviation from the curve is observed for the hadrons with very high masses.

In this paper we look for the same regularity in meson and baryon production in high energy hadron-hadron collisions. The data are scarce due to well known experimental difficulties in the identification of particles and in the measurement of inclusive cross-sections for hadron resonances in a many particle environment. An additional complication in hadronic reactions comes from the fact that the quantum numbers of the initial state are different from those of the vacuum state. For instance, in pp interactions baryon resonances production is enhanced in comparison to antibaryons because two baryons are present in the initial state. To avoid these initial state

effects in this analysis we use only the measurements of cross-sections for antibaryons and neutral or negative mesons. These particles are produced mainly from quark-antiquark or diquark-antidiquark pairs created during string fragmentation. Although the configurations of the strings are more complicated in hadron-hadron scattering than in e^+e^- annihilations, we can expect that some features of the local hadron production will be similar in the two processes.

2 Analysis

Four sets of data were used for the analysis of proton-proton scattering: LEBC-EHS Collaboration results at $p_{LAB} = 400$ GeV/c (center of mass energy $\sqrt{s} = 27.4$ GeV) [2,6], Fermilab 30-inch bubble chamber data at $p_{LAB} = 405$ GeV/c ($\sqrt{s} = 27.6$ GeV) [7,8,9] and results from two ISR experiments: the SFM and ACCHMN Collaborations at $\sqrt{s} = 53$ GeV [10,11]. The inclusive cross-section for antiprotons at $\sqrt{s} = 53$ GeV was calculated from the compilation [12]. The results from the two ISR experiments for high mass resonances are not consistent; for $K^*(1430)$ they differ by an order of magnitude. The data are plotted in Figs 1a and 2a as a function of particle mass

squared . The $A \exp(-bM^2)$ curve with the parameter $b = 3.9 \text{ (GeV/c}^2\text{)}^{-2}$ taken from the e^+e^- data fit [5] and normalized to the negative pions inclusive cross-section is shown in Figs 1 and 2 for comparison. The pp data are scattered around this curve.

As a next step we introduce spin and isospin weighting factors. If each spin projection of a hadron state is produced with the same probability, hadrons with spin J are enhanced by a factor $(2J + 1)$. In order to check this conjecture the meson and baryon inclusive cross-sections can be compared using the $1/(2J + 1)$ weight factor.

In comparing inclusive cross-sections for production of different particles, the measured values corresponding to certain isospin projections of a hadron are often used. Such data should be corrected to obtain the sum of the cross-sections for all the projections of the hadron state. In e^+e^- annihilations the states with different isospin projections are produced with practically the same probabilities. To correct for unmeasured projections the inclusive cross-sections can be simply multiplied by the $(2I + 1)$ isospin counting factor. In hadron-hadron interactions this is generally no longer true due to the above-mentioned initial particles effect. Positive pions are more abundant in pp collisions than negative ones. For particles produced

from quark-antiquark pairs created inside a string, however, all isospin projections should occur with the same probability. Starting with antibaryons and negative or neutral mesons in pp collisions and correcting for unmeasured isospin projection states with the $(2I+1)$ factor we can obtain approximately the total inclusive cross-sections for hadrons produced inside the strings.

An additional complication comes from the fact that K^+ and K^0 and their antiparticles K^- and $\bar{K}^0$ belong to two different isodoublets, while for π and ρ particles and antiparticles belong to the same isotriplet. To correct for all unmeasured kaon states the measured cross-section for one kaon isospin projection should be multiplied by four. We can include this factor into the general formula if following ref. [5] we modify ad hoc the isospin for kaons and their resonances $K^*(890)$ and $K^*(1430)$ by taking $I_m = \frac{3}{2}$.

As in ref. [5], for the mixed physical states ω and ϕ we take two states ω_a and ω_b with modified isospin $I_m = \frac{1}{2}$. The inclusive cross-section and the mass are calculated from

$$(2I_m + 1)\sigma_{incl}(\omega_a) = \sigma_{incl}(\omega) + \sigma_{incl}(\phi)$$

and

$$M^2(\omega_a) = M^2(\omega_b) = \frac{1}{2}(M^2(\omega) + M^2(\phi)).$$

The data with spin and isospin weighting factors are plotted in Figs 1b

and 2b. The corrected inclusive cross-sections as a function of particle mass squared approximately follow the exponential curve with the slope taken from e^+e^- data fit. We observe, however, two significant deviations. The weighted value for the pion inclusive cross-section lies much higher than predicted. The same effect is observed in e^+e^- annihilations [5]. A compelling explanation for this effect is the contribution of pions from the decays of high mass resonances in addition to the direct pion production. A consistent upward deviation from the exponential curve is also observed for very high mass resonances. The effect is more pronounced at the lower energy, where the deviation starts also at lower masses. A similar effect, although on a much smaller scale, is visible also in e^+e^- annihilations with qualitatively the same energy dependence [5]. The production of high mass resonances is suppressed in low energy strings. If cross-sections for the resonances are dominated by contributions from other mechanisms such as leading quarks in e^+e^- annihilations or diffraction dissociation in hadronic reactions the upward deviation from the exponential curve can be expected for these particles. Data at higher energies where more energetic strings are produced could clarify this point.

3 Conclusions

In conclusion, it has been shown that the inclusive cross-sections for light mesons and baryons in high energy proton-proton collisions are consistent with a simple empirical formula observed recently for hadron production in e^+e^- annihilations. This universal dependence points to a simple mass law for hadron states produced locally in string fragmentation irrespective of the configuration of the strings in various processes. To further check this conjecture, precise data on meson and baryon inclusive cross-sections in pp interactions at CERN $p\bar{p}$ Collider or Fermilab Tevatron energies are needed.

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FIGURE CAPTIONS

Fig.1 (a) Inclusive cross-sections of negative or neutral mesons and antibaryons in pp collisions at $\sqrt{s} = 27.4$ GeV, as a function of particle mass squared. (b) Inclusive cross-sections of mesons and baryons from Fig. 1a weighted with the $(2I_m + 1)/(2J + 1)$ factor, as a function of particle mass squared. The lines in both figures show the $A \exp(-bM^2)$ dependence with the parameter $b = 3.9 \text{ (GeV/c}^2\text{)}^{-2}$ taken from the fit to e^+e^- annihilation data [5] and normalized to the negative pion inclusive cross-section in Fig. 1a.

Fig.2 (a) Inclusive cross-sections of negative or neutral mesons and antibaryons in pp collisions at $\sqrt{s} = 53$ GeV, as a function of particle mass squared. (b) Inclusive cross-sections of mesons and baryons from Fig. 2a weighted with the $(2I_m + 1)/(2J + 1)$ factor, as a function of particle mass squared. The lines in both figures show the $A \exp(-bM^2)$ dependence with the parameter $b = 3.9 \text{ (GeV/c}^2\text{)}^{-2}$ taken from the fit to e^+e^- annihilation data [5] and normalized to the negative pion inclusive cross-section in Fig. 2a.

CROSS SECTION VS MASS SQUARED, $\sqrt{s}=27.4$ GeV

Fig. 1a

CROSS SECTION VS MASS SQUARED, $\sqrt{s}=27.4$ GeV

Fig. 1b

CROSS SECTION VS MASS SQUARED, $\sqrt{s}=53$ GeV

Fig. 2a

CROSS SECTION VS MASS SQUARED, $\sqrt{s}=53$ GeV

Fig. 2b