SOFT PARTICLE PRODUCTION AT HERA

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HERA data on soft hadron production are discussed. The measured inclusive and exclusive hadron cross sections show a simple scaling behaviour.

The final state hadrons produced in collision of high energy particles carry information about the underlying dynamics of the interaction. Different theoretical approaches have been adopted to describe such hadroproduction. Generally, the applicability of these theoretical calculations depends on the type of produced hadrons and the value of hadron transverse momentum (p_t). In practice, to describe the production of hadrons within whole kinematic range, phenomenological models such as the Lund string model[1] are used. These models, however, contain a large number of parameters, values of which are not known *a priori* and have to be determined from experiment. Experimentally, measurements of hadroproduction are available up to ISR energies and in e^+e^- collisions at LEP. At higher collision energy only the HERA experiments provide the detailed information about hadrons of different flavours produced within a broad range of p_t. In this paper, the HERA data on inclusive and exclusive production of hadrons in γp interactions at average $W \equiv \sqrt{s_{\gamma p}} \approx 200\ GeV$ and $Q^2 \approx 0$ (so-called, photoproduction) are discussed.

Recently, H1 has measured the inclusive $p(\bar{p})$ photoproduction cross section. In H1 the protons are identified using dE/dx measurement in the central drift chamber. Thus, the proton data are limited in momentum ($0.3 < p_t < 0.55\ GeV$) and rapidity ($-0.3 < y < 0.3$) range. The measurements are made in the laboratory frame of reference and are presented as the average cross-sections $Ed^3\sigma/d^3p$ for the photoproduction of protons and antiprotons, that is, half the sum of the proton and anti-proton cross sections. Here E and p are the proton energy and momentum, respectively. This cross-section in Fig.1 is shown as a function of the particle transverse momentum p_t. The errors shown are the quadratic sum of the statistical and systematic uncertainties. The systematic component is dominant.

The production of baryons within the Lund model is regulated by several parameters, the most important of which in the context of this measurement

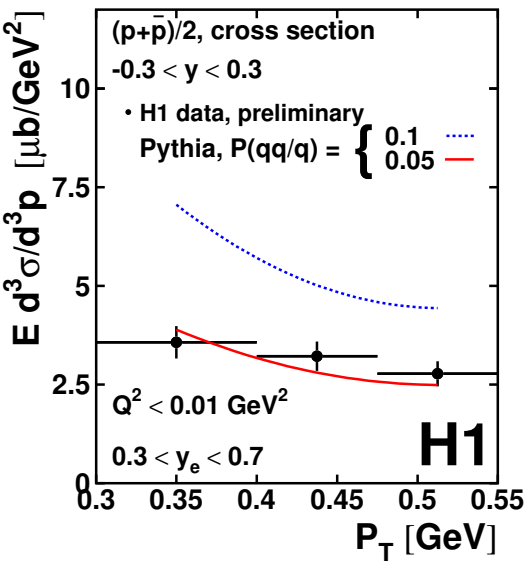

Figure 1. The measured cross-section $E\frac{d^3\sigma}{d^3p}$ as a function of transverse momentum, p_t, for rapidity values in the range $-0.3 < y < 0.3$. The cross-section represents half of the sum of protons and anti-protons inclusively produced in photoproduction interactions. Calculations of the PYTHIA model are shown with different values of the diquark suppression factor of 0.1 (upper curve) and 0.05 (lower curve).

being the diquark suppression factor $P(qq/q)$ which determines the probability of producing a $(qq, \bar{q}\bar{q})$ pair relative to a $(q, \bar{q})$ pair in the colour field. Results from e^+e^- collisions at LEP favour a value of $P(qq/q)$ approximately 0.1[2].

The predictions of the Lund model are presented using diquark suppression factors of 0.1 and 0.05. The model over-estimates the data with the e^+e^--derived value of 0.1 although it provides a fair description the shape of the spectra. However, a description of both shape and yield is provided if a diquark suppression value of 0.05 is used. This could signal an absence of the universality of baryon production within this approach. However, more studies are required of different baryons over a wider range of phase space range than covered in this work in order to further investigate this.

The measurement of the proton inclusive cross section completes the series of measurements on the long-lived low mass hadrons π[3], K, and Λ[4]. The pion

data are recalculated from the measured charged particle spectra by reducing these spectra by 17% to take in to account an admixture of kaons and protons. In Fig.2 the low mass hadron production cross sections are plotted as function of p_t. To make the comparison of different spices of hadrons the cross sections are given for the particle's one isospin and one spin projection. This approach follows the one used to compare the hadron yields in e^+e^- collisions[5].

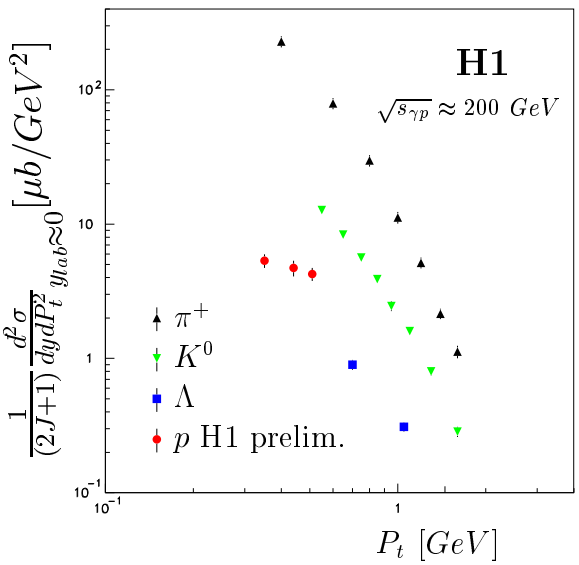

Figure 2. The measured inclusive double differential hadron cross-section $d^2\sigma/dydP_t^2$ function of transverse momentum, p_t, for rapidity values $y = 0$ as measured in lab. system. The cross-sections are given for the particle's one spin and isospin projection.

As seen from the figure 2, the behaviour of the individual particle cross sections at low values of p_t seems to depend strongly on the specific hadron mass. It was shown (*e.g.* V.Khoze *et al*[6]), that in QCD in the limit of $p \to 0$ the inclusive hadron yield is defined by the hadron mass (m), which plays a role of an infrared cutoff in the QCD calculations. Moreover, it was found at LEP, that the production rates of hadrons are determined only by particle spins, isospins and their masses. On the other hand, in high energy hadronic collisions the inclusive particle spectra are described[3,7] by a simple function $A(p_0 + p_t)^{-n}$. It is tempting to assume an intrinsic relation between

p_0 and m. We test this conjecture with the HERA data and replot the cross section data as function of $m + p_t$ (see Fig.3). Surprisingly, the data shown in

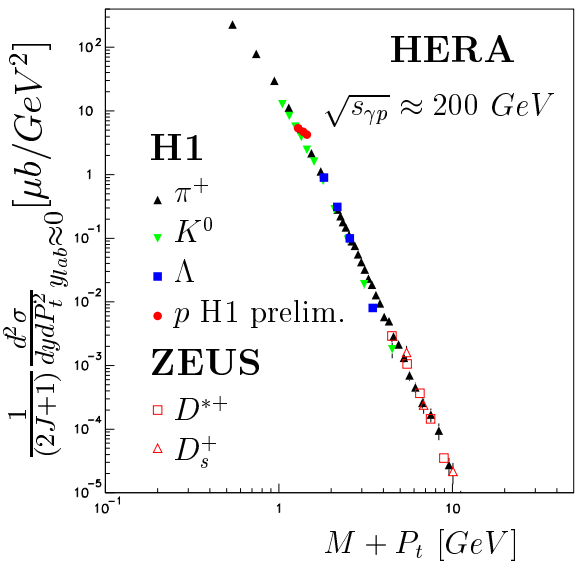

Figure 3. The measured inclusive double differential hadron cross-section $d^2\sigma/dydP_t^2$ function of transverse energy squared, $m + p_t$, for rapidity values $y = 0$ as measured in lab. system. The cross-sections are given for the particle's one spin and isospin projection.

Fig.3 for different hadrons lay along one universal curve. Adding the charm data[8] doesn't spoil this picture. The inclusive D^* and D_s cross section data impressively follow the observed universal behaviour. The Tevatron data[9] (not shown here) demonstrate an approximate scaling for pions K^0 and $D^{*\pm}$ mesons when plotted against the $m + p_t$.

The H1 and ZEUS collaborations have also performed precision studies of the exclusive production of vector mesons in the diffractive reaction

$$\gamma + p \longrightarrow V + p \quad (V = \rho^0, \omega, ...\Upsilon) \tag{1}$$

Different assumptions and models prescriptions are used to describe the meson yield from π to Υ. The low mass vector meson production is traditionally described by Vector Dominance model, while J/Ψ production is calculated in LO QCD with two gluon exchange. It was found, that for heavier Υ one needs

sizable corrections in addition to LO QCD calculations. In addition, different mesons show different dependences on t and W. Given such a complicated theoretical cookery the HERA data show an amazing scaling behaviour[10] similar to that found for inclusive particle production. This universality is demonstrated in Fig.4 where cross section for various vector mesons produced in the reaction 1 at $W \approx 130\ GeV$ and $Q^2 \approx 0$ and normalized by electronic meson width Γ_{ee} are plotted as function of m^2. The data demonstrate an approximately universal $1/m^4$ behaviour. It is interesting to note the striking similarity with a scaling law found by F.Halzen *et al.* 1977 for narrow vector mesons $(\phi, J/\Psi, \Upsilon)$ inclusively produced in hh interactions[11].

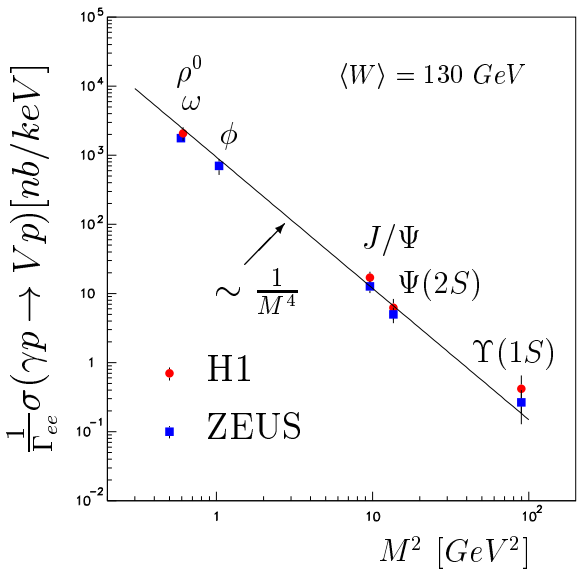

Figure 4. The measured cross-section of exclusive vector meson photoproduction as function of meson mass, m. The cross-sections are normalized by meson electronic width Γ_{ee}.

The data used in the Fig.4 include the recent measurements on high W $\Psi(2S)$ (ZEUS) and ω (H1) production. The omega cascade decay in the reaction 1 is reconstructed by detecting three photons at very low angle w.r.t. to the electron beam axis. This experimentally challenging task was accomplished by using the new low angle calorimeter installed in H1. This devise was also used to search the exclusive production of C=+1 mesons (π^0, f_2 and

a_2) decaying into even number of photons. No signals for C=+1 states have been observed and upper limits reported by H1 collaboration can be used to constrain the cross-section of Odderon-induced processes.

In summary, the HERA collider experiments are rich and unique source of the data on soft particle production. While different assumptions and models prescriptions are used to describe the meson yield from π to Υ the data show an approximate scaling behaviour Similar scaling was found in lower energy data[12] and decay products of Z^0 at LEP [5]. Although the reason for this scaling is unknown this phenomenon is very interesting and needs further studies. To this end, it is important that HERA experiments provide further detailed information on the hadronic resonance production.

Acknowledgments

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