PROCEEDINGS OF SCIENCE

Inclusive Photoproduction of $\rho(770)^0$, $K^*(892)^0$ and $\phi(1020)$ Mesons at HERA

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Inclusive non-diffractive photoproduction of $\rho(770)^0$, $K^*(892)^0$ and $\phi(1020)$ mesons is investigated with the H1 detector in ep collisions at HERA. The corresponding average γp centre-of-mass energy is 210 GeV. The mesons are measured in the transverse momentum range $0.5 < p_T < 7$ GeV and the rapidity range $|y_{lab}| < 1$. Differential cross sections are presented as a function of transverse momentum and rapidity, and are compared to the predictions of hadroproduction models.

35th International Conference of High Energy Physics - ICHEP2010,
July 22-28, 2010
Paris France

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PoS(ICHEP 2010)353

1. Introduction

High energy particle collisions which give rise to large multiplicities of produced hadrons provide an opportunity to study the hadronisation process, in which quarks and gluons convert to colourless hadrons. Measurements in high energy hadronic interactions have so far been restricted to long-lived hadrons and hadrons containing heavy quarks. Recently, the production of the hadronic resonances $\rho(770)^0$, $K^*(892)^0$ and $\phi(1020)$ was measured in heavy-ion and proton-proton (pp) collisions at RHIC [1]. The electron-proton (ep) collider HERA allows the study of particle production in quasi-real photon-proton (γp) collisions, where the nuclear density is much lower than at RHIC. This is particularly interesting, because the γp centre-of-mass energy at HERA is about the same as for colliding nucleons at RHIC.

2. Phenomenology

The invariant differential cross section for meson production can be expressed as a function of the meson's transverse momentum p_T and its rapidity y_{lab}, assuming azimuthal symmetry. Hadrons produced in hadronic collisions are approximately uniformly distributed in the central rapidity range, while their transverse momentum spectra fall steeply with increasing p_T. It is convenient to parametrise the invariant differential cross section of the produced hadrons with a power law distribution,

$$\frac{1}{\pi}\frac{d^2\sigma^{\gamma p}}{dp_T^2\,dy_{lab}} = \frac{A}{(E_{T_0}+E_T^{kin})^n}\,, \tag{2.1}$$

where $E_T^{kin} = \sqrt{m_0^2+p_T^2} - m_0$ is the transverse kinetic energy, m_0 is the nominal resonance mass, A is a normalisation factor independent of p_T and E_{T_0} a free parameter. When $E_T^{kin} \lesssim E_{T_0}$, the power law function (2.1) behaves like a Boltzmann distribution $\exp(-E_T^{kin}/T)$, with $T = E_{T_0}/n$. This exponential behaviour of hadronic spectra follows from a thermodynamic model of hadroproduction [2]. In this framework, the parameter T plays the role of the temperature at which hadronisation takes place. At high E_T^{kin}, the power law originates from a convolution of the parton densities of the colliding particles with the cross sections of parton-parton interactions.

3. Inclusive Photoproduction of $\rho^0(770)$, $K^*(892)^0$ and $\phi(1020)$ Mesons

First measurements of inclusive non-diffractive photoproduction of ρ^0, K^{*0} and ϕ mesons at HERA are presented by the H1 collaboration [3]. To extract these signals, the distributions of the respective invariant masses of their decay products, $m_{\pi^+\pi^-}$, $m_{K^\pm\pi^\mp}$ and $m_{K^+K^-}$, are fitted using a function composed of three parts:

$$F(m) = B(m) + \sum R(m) + \sum S(m).$$

The terms correspond to contributions from the combinatorial background, $B(m)$, from hidden resonance effects, termed reflections, $R(m)$, and from the relevant signals, $S(m)$, respectively. The function $S(m)$ is a convolution of a relativistic Breit-Wigner function and a detector resolution function.

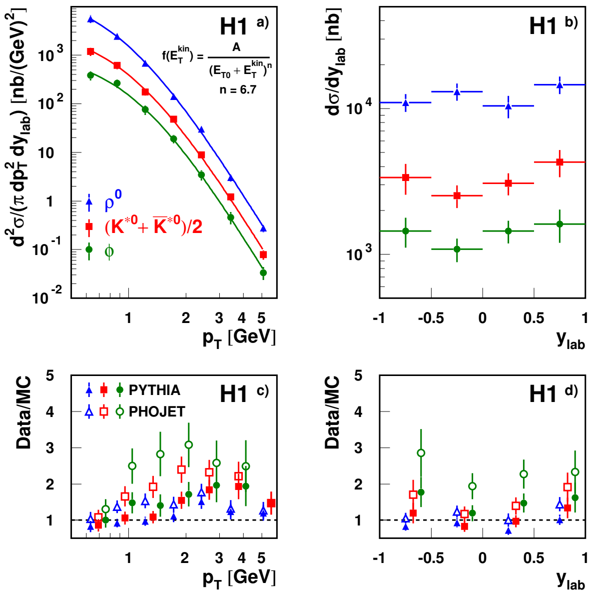

Figure 1: The measured differential non-diffractive photoproduction cross-sections for ρ^0, K^{*0} and ϕ mesons. (For more details see the text.)

For the ρ^0 meson, the detector resolution is significantly smaller than its width. However, Bose-Einstein correlations (BEC) between the ρ^0 decay pions and other pions in the event strongly distort the ρ^0 line shape. The BEC play an important role in broadening the ρ^0 mass peak and in shifting it towards lower masses. Similar effects are observed in pp and heavy-ion collisions at RHIC [1] and in e^+e^- collisions at LEP using Z^0 decays. The Monte Carlo model with BEC is in good agreement with the data in the region of the ρ^0 resonance, whereas the model without BEC fails to describe the di-pion mass spectrum.

The differential cross sections for the photoproduction of ρ^0, K^{*0}, and ϕ mesons are presented in Figure 1. In the fit, the value of the power n is fixed to be 6.7, as derived previously from measurements of charged particle spectra by the H1 collaboration [4] which gave $n = 6.7 \pm 0.3$. The power law distribution, with this value of n, also describes K_S^0 meson, Λ^0 baryon and $D^{*\pm}$ meson production at HERA. The results of fits of function (2.1) to the data are shown in Figure 1a).

We observe that the resonances with different masses, lifetimes and strangeness content are produced with about the same value of the average transverse kinetic energy $\langle E_T^{kin} \rangle$. This observation supports the thermodynamic picture of hadronic interactions [2], in which the primary hadrons are thermalised during the interaction.

The PYTHIA and PHOJET models do not describe the shape of the measured p_T spectra.These observations are illustrated in Figures 1c) and 1d). Moreover, contrary to the data, the Monte Carlo p_T spectra are not described by the power law function (2.1).

The measurements in the visible kinematic range of the ρ^0, K^{*0} and ϕ mesons, $p_T > 0.5$ GeV and $|y_{lab}| < 1$, are extrapolated to the full p_T range using the parametrisation (2.1) to determine the total inclusive non-diffractive photoproduction cross sections. The extrapolation factors are of order two. To calculate the ratios of the ϕ and K^{*0} cross sections, their average values of the differential cross sections $\langle d\sigma/dy_{lab}\rangle_{|y_{lab}|<1}$ are used. These calculations are compared to the corresponding ratios measured by STAR in pp and Au-Au collisions [1] at $\sqrt{s_{NN}} = 200$ GeV. The resulting ratios for pp and γp interactions are very close. For ϕ meson production a tendency to be more abundant in Au-Au collisions is observed.

4. Conclusions

First measurements of the inclusive non-diffractive photoproduction of $\rho(770)^0$, $K^*(892)^0$ and $\phi(1020)$ mesons at HERA are presented. The differential cross sections for the production of these resonances as a function of transverse momentum are described by a power law distribution. These resonances, despite their different masses, lifetimes and strangeness content are produced with about the same value of the average transverse kinetic energy. This observation supports a thermodynamic picture of hadronic interactions. The description of the shape of the ρ^0 resonance produced in γp collisions at HERA is improved by taking Bose-Einstein correlations into account. A tendency for ϕ meson production to be more abundant in Au-Au collisions is observed.

5. Acknowledgments

The support of the Rosnauka, DESY and Helmholtz Association in the framework of the Helmholtz-Russian-Joint-Research Group (HRJRG-002) are gratefully acknowledged. I would like to thank Anna Kropivnitskaya for helpful discussions.

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