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BARYON, HEAVY STABLE PARTICLE AND STRANGE MESON PRODUCTION

Karin Daum
Bergische Universität Wuppertal, Gaußstrasse 20,D-42097 Wuppertal, Germany *

Abstract

Results on particle production in *ep* scattering at HERA are presented. The fragmentation into charged particles in deep-inelastic *ep* scattering is investigated. Proton and deuteron production is studied and the data on differential cross sections, the baryon-to-meson ratios and Bose-Einstein correlations of neutral and charged strange hadrons are summarized.

1 Introduction

The study of particle production provides valuable insights into parton fragmentation and hadronisation processes and thereby sheds light on the non-perturbative regime of Quantum Chromodynamics (QCD). The comparison of

* Permanent address: DESY, Notkestrasse 85, D-22607 Hamburg, Germany; e-mail:daum@mail.desy.de

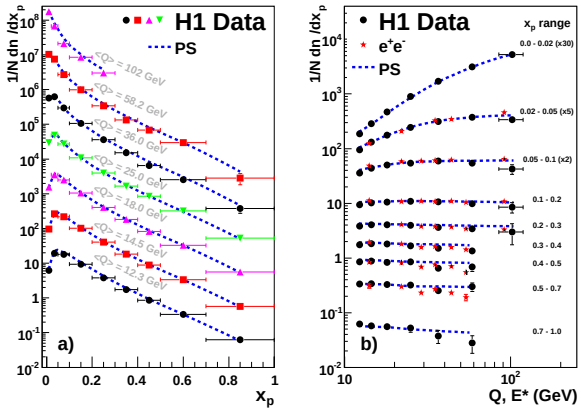

Figure 1: *Charged particle fragmentation function (a) as a function of x_p in bins of Q and b) as a function of Q in bins of x_p together with e^+e^- results.*

the results obtained in *ep* scattering at HERA to e^+e^- annihilation data makes it possible to test the universality of QCD in the particle formation process.

2 Inclusive Particle Production

In deep-inelastic *ep* scattering (DIS) the charged particle momentum spectrum is measured in the current hemisphere of the Breit-frame [1)], where the photon virtuality, Q, can be related to the momentum of the scattered parton. The influence from QCD processes absent in e^+e^- annihilation is reduced by requiring 100 GeV^2 $< Q^2 <$10000 GeV^2. Fig.1 shows the charged hadron momentum distribution scaled by $Q/2$ [2)] in comparison to the charged particles fragmentation function from e^+e^--annihilation [3)] for which half the centre-of-mass energy $E^*/2$ is the relevant scale. The agreement observed between *ep*- and e^+e^--data supports the concept of quark fragmentation universality.

3 (Anti)Deuteron Production in DIS

The fragmentation to light stable nuclei, such as deuterons (d), is poorly understood. In the coalescence model [4)] the d production rate is given by the

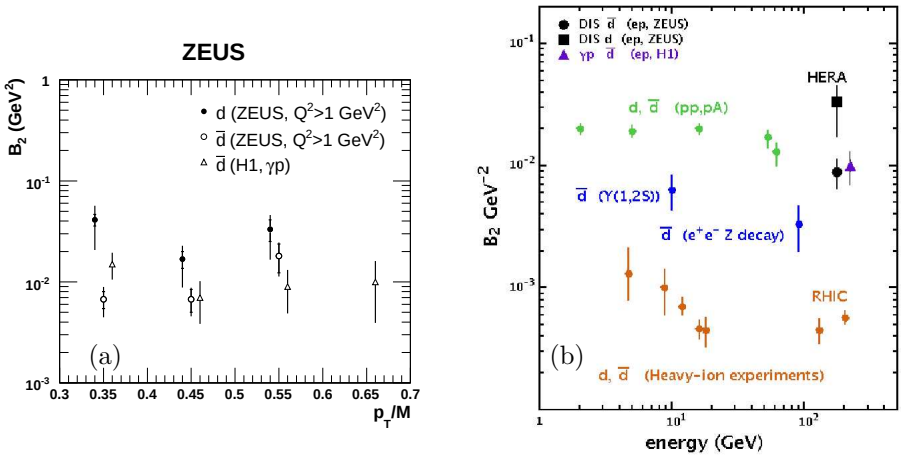

Figure 2: *Coalescence parameter B_2 for $d(\overline{d})$: (a) as a function of p_T/M from ep collisions at HERA and (b) for different scattering processes.*

overlap of its wave function with those of its constituents, the proton (p) and neutron (n). By assuming isospin invariance the invariant d cross section is proportional to the square of the invariant p cross section, where the proportionality, the coalescence parameter B_2, corresponds to the inverse volume of the fragmentation region for d formation.

Fig. 2a shows the measurements on B_2 for d and $\overline{d}$ as a function of p_T/M from ep collisions at HERA. The results obtained for $\overline{d}$ in DIS [5] and in photoproduction (γp) [6] agree within the errors. However, the results for d production are systematically above the $\overline{d}$ data. Fig. 2b summarizes the B_2 results from various high energy scattering processes [7]. Large variations in B_2 are observed which clearly indicates that $d(\overline{d})$ production cannot be understood as universal within this model.

4 Strange Hadron Production

The study of strange hadron production at particle colliders yields information on the strangeness content of the QCD vacuum and on the effect of the relatively large bare strange quark mass on particle formation. In the current fragmentation models this is accounted for by introducing a single parameter - the

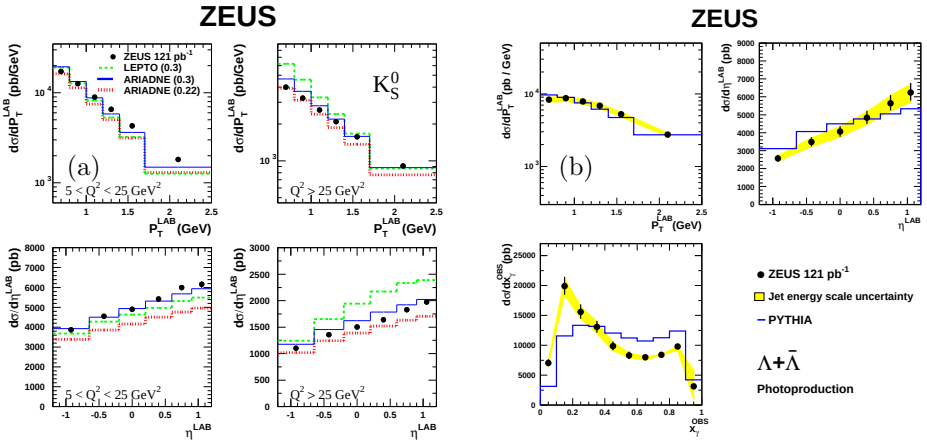

Figure 3: *Differential production cross sections of (a) K^0_S in DIS as a function of p_T^{lab} and η^{lab} and (b) of $\Lambda(\overline{\Lambda})$ in γp as a function of p_T^{lab}, η^{lab} and x_γ^{obs}.*

strangeness suppression factor λ_s. This parameter may be accessed quite easily in e^+e^- annihilation analyses because the contribution from $e^+e^- \to s\overline{s}$ is well known. In ep scattering the situation is more complex since the strangeness contribution to the proton structure F_2 has considerable uncertainties.

Fig. 3 shows the differential cross sections for the production of K^0_s mesons in DIS and of Λ baryons in γp in ep collisions at HERA [8]. The DIS cross sections are compared to absolute predictions of ARIADNE [9] and LEPTO [10] MC calculations. The γp cross sections are compared to the PYTHIA [11] predictions normalized to the cross section observed in data. In DIS reasonable agreement with data is observed for ARIADNE when setting $\lambda_s = 0.3$ as preferred by e^+e^- data [12]. Previous ep data [13] were favouring $\lambda_s = 0.22$ which leads to a less satisfactory description of the data presented here. The LEPTO MC with $\lambda_s = 0.3$ disagrees with data. In γp, PYTHIA with multiple interactions yields an adequate description of the shapes of the measured cross sections in p_T^{lab} and in η^{lab}. However, it fails to reproduce the x_γ^{obs} distribution which measures the momentum fraction carried by the photon entering the hard subprocess. Especially at small x_γ^{obs} the description is poor.

The formation of baryons in the fragmentation process is yet not well understood. In ep collisions the possible rôle of the incident proton's baryon

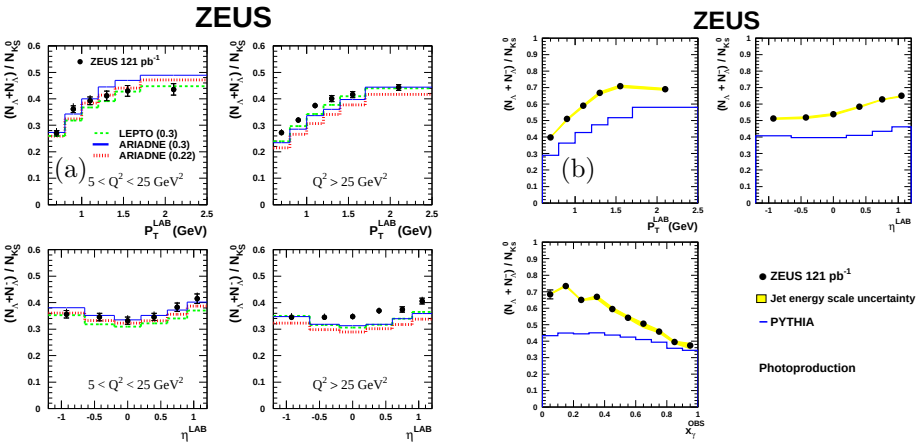

Figure 4: *Strange baryon-to-meson ratio (a) in DIS as a function of* p_T^{lab} *and* η^{lab} *and (b) in* γp *as a function of* p_T^{lab}, η^{lab} *and* x_γ^{obs}.

number on final state baryon formation is of specific interest. The study of the strange baryon-to-meson ratio, defined as $\mathcal{R} = (N(\Lambda) + N(\overline{\Lambda}))/N(K_s^0)$, may provide deeper insight into this process.

Fig. 4 shows the strange baryon-to-meson ratio in DIS and γp in comparison to the model expectations. In DIS the overall agreement of ARIADNE using $\lambda_s = 0.3$ with the data is better than about 10%. At low Q^2 the agreement is even better. The $\mathcal{R}$ value varies between about 0.2 and 0.5. This compares well to the e^+e^- annihilation results, where $\mathcal{R}$ lies in the range of 0.2 to 0.4 [14] for 10 GeV< $\sqrt{s}$ <200 GeV. In γp significantly larger values for $\mathcal{R}$ are observed. At small x_γ^{obs} values of $\mathcal{R} \approx 0.7$ are reached, while in the region of direct photoproduction, i.e. $x_\gamma^{obs} \approx 1$, it approaches 0.4 consistent with the observations in DIS and in e^+e^- annihilation. The rise at low x_γ^{obs} is not reproduced by the PYTHIA model suggesting a lack of understanding of strange baryon formation in the multi-parton environment at small x_γ^{obs}.

5 Bose-Einstein Correlations of Strange Mesons

Due to the symmetrization of the two-particle wave function the production of identical bosons is expected to be enhanced at small distances in phase space.

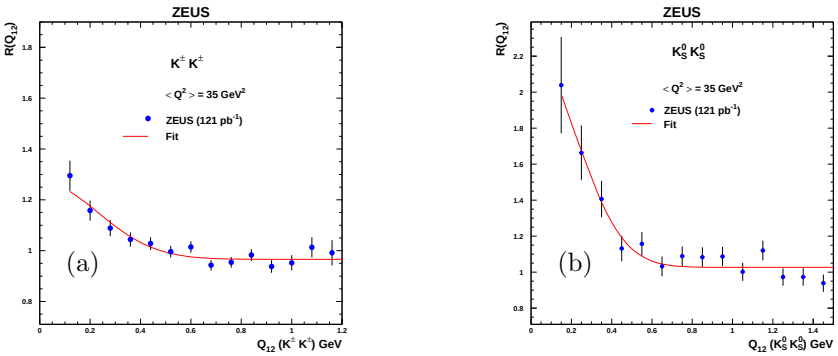

Figure 5: *The correlation function of (a) $K^{\pm}K^{\pm}$ and (b) of $K^0_sK^0_s$ pairs.*

This effect is called Bose-Einstein correlations (BEC). It allows determining the size of the particle formation region. Using the four-momentum difference $Q_{12} = \sqrt{-(p_1 - p_2)^2}$ and assuming a static source with a Gaussian density distribution, the correlation function can be written as [15]

$$R(Q_{12}) = 1 + \lambda \exp(-r^2 Q_{12}^2). \tag{1}$$

Here λ denotes the strength of the BEC and r is the radius of the formation region.

Fig. 5 shows the two-particle correlation $R(Q_{12})$ for $K^{\pm}K^{\pm}$ and for $K^0_sK^0_s$ pairs in DIS at HERA [16] together with the result from a fit according to eqn. 1. In both samples a strong rise in the correlation function towards small values of Q_{12} is observed. This is a clear sign of BEC in case of the $K^{\pm}K^{\pm}$ sample. For the $K^0_sK^0_s$ pairs a complication arises from the fact that the strange quantum number of K^0_s mesons is undetermined. Therefore, contaminations from $f_0(980)$ decaying to $K^0\overline{K}^0$ are possible. After this effect is taken into account the $K^0_sK^0_s$ data still show evidence for the presence of BEC, however with reduced significance.

A compilation of the correlation radius r from DIS and e^+e^- annihilation measurements at LEP [17] is given in fig. 6 for different boson pairs. Within the uncertainties r agrees very well for the different processes, meson pairs and particle charges. This suggests that the particle formation region for pseudoscalar mesons is universal.

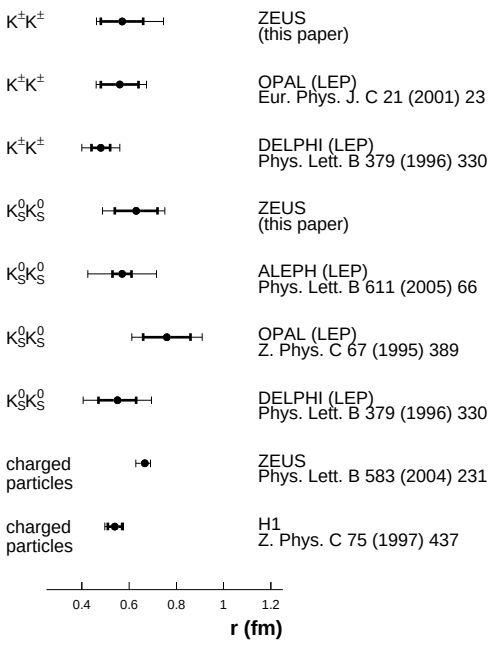

Figure 6: *Comparison of DIS and LEP results on r from BEC studies.*

6 Conclusions

Results on particle production in *ep* collisions at HERA have been presented and compared to data from other scattering processes. Universality has been observed for the inclusive charged particle production within current uncertainties. Strange meson production could be understood within the models in most of the phase space suggesting the strangeness suppression factor λ_s being process independent. The analysis of BEC shows universality of the formation region for pseudo-scalar mesons.

The results on strange baryon-to-meson ratio uncovers a lack of understanding of the fragmentation to strange baryons in the multi-parton environment at small x_γ^{obs}. The results from different processes on the deuteron formation region are found to be inconsistent within the coalescence model.

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