Production of neutral pions and antideuterons, and observation of proton - antiproton asymmetry in the photon hemisphere at HERA

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Electron or positron beams at HERA provide a source of quasi - real photons which, after collision with a proton, convert into hadron - rich photon "remnants". Here, preliminary results are presented on production of neutral pions and antideuterons in the photon hemisphere, and on the asymmetry observed in the production of protons and antiprotons.

1. Introduction

The backward region of the laboratory system as seen by the H1 detector is mainly populated by particles from the "photon remnant", that is by hadrons produced in so called resolved photon interactions. The stage for the hadronization is the "photon hemisphere" which is defined in and by the photon - proton CM frame. In the following, three snapshots - preliminary results from the H1 Collaboration [1–3] - at this scene are presented.

2. Photoproduction of neutral pions in the backward region

The detection of π^0s is performed through their decay into two photons which are recorded in the backward calorimeter "SpaCal" [4]. The SpaCal is a fine - segmented electromagnetic calorimeter covering the polar angular range from 153° to 178°, corresponding to a laboratory frame rapidity range for pions of $-3.5 < y_{LS} < -1.4$. Its energy resolution is described by

$$\frac{\sigma(E)}{E} = \frac{0.075}{\sqrt{E/\mathrm{GeV}}} \oplus 0.010, \tag{1}$$

The absolute energy scale, in the lower energy range from 0.2 GeV to 10 GeV, is known with an uncertainty of 3%. The angular resolution is better than 2 mrad. The electromagnetic section of the SpaCal is followed by a hadronic section of equal size.

Events are triggered by an energy deposition in the electromagnetic part of the SpaCal of more than 2 GeV, and an electron recorded in the "electron tagger", a calorimetric device which is part of the luminosity system and ensures that $Q^2 < 0.01$ GeV^2, i.e. that the exchanged photon is quasi - real. In the offline analysis, the existence of an event vertex reconstructed from the tracker information is required. The number of π^0s produced is derived from the two - photon invariant mass spectra reconstructed from the calorimeter information.

The cross section for inclusive photoproduction of π^0s was determined in dependence of pion rapidity and transverse momentum. Fig. 1 shows the transverse momentum distribution, integrated over the SpaCal rapidity range. The inclusive charged particle cross section for photoproduction in the central region ($|\eta| < 1.5$) [2], presented in the same figure, has been taken from Ref. [6].

Obviously, at lower $p_\perp$ the π^0 cross section is well described by an exponential, as expected in thermodynamical models [5]. Above $p_\perp$ = 1.6 GeV/c, however, an enhancement of the data relative to the exponential form is seen, indicating the presence of hard parton–parton scattering processes.

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[2]η is the pseudorapidity defined as $\eta = -ln\ tan\ \theta/2$

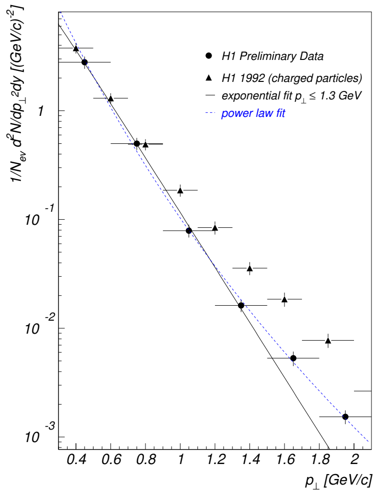

Figure 1. Inclusive π^0 transverse momentum distribution, integrated over the SpaCal rapidity range. For comparison, the distribution for charged particles in the central region is shown.

This observation can be quantified by fitting a power law function of the form

$$\frac{d^2\sigma}{dp_\perp^2\,dy} = A \cdot (1 + p_\perp/p_\perp^0)^{-n}\ . \qquad (2)$$

The value of $p_\perp^0$ has been fixed to the fit value determined in [6], i.e. $p_\perp^0 = 0.63$ GeV/c. The fit yields $n = 8.3 \pm 0.2$.

The exponent found for this differential cross section is consistent with the "classical" value of 8 , as predicted by theory (for a pioneering paper, see [7]), and found in many hadron - hadron interactions. The exponent found for the charged particle cross section measured in the central region, which is bigger and due to the larger phase space available extends to higher $p_\perp$ values, is $n = 7.1 \pm 2.0$.

The findings of this analysis are satisfactorily described by current models as e.g. the Monte Carlo generators Pythia [8] and Phojet [9]. These models do, in principle, also allow to look for the effect of parton - k_T inside the photon, which is however yet obscured by the limited accuracy.

3. Production of antideuterons

Matter, in the form of charged and neutral elementary particles, is created in most high energy interactions. It is less obvious that also "complex" nuclei, i.e. nuclei heavier than light hydrogen, are produced.

The lightest complex nucleus is the deuteron. In order to identify particles, i.e. to determine their mass, one needs two kinematical quantities as e.g. momentum and velocity from which the particle's four - momentum can be calculated.

The central jet chambers CJC1 and CJC2 of the H1 detector [10], exposed to a homogeneous magnetic field of 1.15 T, allow not only the determination of charged particles' momenta, but also the measurement of their specific ionization loss in the chamber gas. The dE/dx measurement, by virtue of the Bethe - Bloch formula, corresponds to a velocity determination.

An unambiguous separation of deuterons from lighter particles, especially from protons, can be performed only at low momenta. However, light nuclei such as protons, deuterons, and tritons are copiously produced in interactions of the proton beam particles with the matter surrounding the beam line. One therefore looks for antideuterons which can only be created in genuine $\gamma - p$ interactions. A set of cuts is applied to suppress the background, based mainly on quality requirements for track reconstruction and momentum and dE/dx determination.

Counting the number of antideuterons in the momentum interval under consideration
($0.55 < p_{\bar{d}} < 1.0$ GeV/c), one finds

$$N(\bar{d})/\text{event} = (13 \pm 4) \cdot 10^{-6}. \qquad (3)$$

This value is not far away from that measured by the ARGUS Collaboration [11] in e^+e^- collisions at the energy of the $\Upsilon(1S)$ resonance which is believed to decay mainly via three gluons. ARGUS find

$$N(\bar{d}) = (6.0 \pm 2.0 \pm 0.6) \cdot 10^{-5} \qquad (4)$$

per direct $\Upsilon(1S)$ decay.

No antideuteron production has been observed so far at LEP. Lund theorists G. Gustafson and J. Häkkinen [12] predict a rate of $5 \cdot 10^{-5}$ per event at the Z resonance, i.e. the same rate as at the $\Upsilon(1S)$.

4. Proton - antiproton asymmetry in the central region

In very high energy collisions with nucleons one expects to find baryons in the final state as "leading" ones, i.e. close to the incoming nucleon in phase space, e.g. in rapidity. Several (in the H1 case: 8) units in rapidity away from the incoming baryon one expects to find baryons and antibaryons in equal portions as they must be produced in pairs.

Of course one can test this hypothesis. If there exists a mechanism that transports net baryon number to phase space regions far away from the incoming baryon, then it should manifest itself in an asymmetry of baryons over antibaryons.

H1 looked for a proton - antiproton asymmetry in the central region, i.e. roughly 8 units of rapidity away from the incoming proton. As in the antideuteron case, the analysis relies on the momentum and dE/dx measuring capabilities of the central trackers, and an efficient background suppression. They find an asymmetry, defined as $A = 2 \cdot (N(p) - N(\bar{p})/(N(p) + N(\bar{p}))$, of

$$A = (8.0 \pm 1.0 \pm 2.5)\%. \tag{5}$$

Apparently, net baryon number does "travel" through phase space. The theoretical interpretation is still under discussion. One possible explanation in terms of a gluonic transport mechanism is given by B. Kopeliovich and B. Povh [13]: The incoming proton is completely dissolved by antiquarks out of the fragmentation chain, while a new baryon emerges from (sea + fragmentation) - quarks. This model has the interesting feature that the probability for re - creating a baryon is independent of its position in phase space.

5. Summary

Our understanding of the nature of the photon has deepened in recent years. It is a rich laboratory for hadron production and interaction, as demonstrated by the studies discussed above, and will hopefully yield more insight in strong interaction mechanisms.

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