

## HADRON SPECTROSCOPY AT HERA

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Inclusive photoproduction cross-sections of the neutral mesons  $\eta$ ,  $\rho^0$ ,  $f_0(980)$  and  $f_2(1270)$  have been measured by H1 and compared to the photoproduction of  $\pi^+$  in  $ep$  collisions at HERA. Also, inclusive  $K_s^0 K_s^0$  production and evidence for a narrow baryonic state decaying to  $K_s^0 p$  have been observed by ZEUS at HERA.

### 1. Inclusive photoproduction of $\eta$ , $\rho^0$ , $f_0(980)$ and $f_2(1270)$ resonances

Production of long-lived hadrons at central values of rapidity in hadron collisions is expected to be independent of the type of colliding hadrons, being dominated by the properties of the QCD vacuum. At HERA, photoproduction events provide an opportunity to study particle production in light hadron collisions at about the same energy as in the heavy ion collisions at RHIC. In this contribution, the results from the first measurements of inclusive photoproduction of the resonances  $\eta$ ,  $\rho^0$ ,  $f_0(980)$  and  $f_2(1270)$  and a comparison with production of particle of other species at  $\gamma p$  centre-of-mass energy of  $\sim 210$  GeV using the H1 experiment are shown <sup>1</sup>.

A detailed description of the H1 detector can be found elsewhere <sup>2</sup>. The data used for this analysis correspond to an integrated luminosity of  $38 \text{ pb}^{-1}$ .

A small angle positron tagger was used to select photoproduction events with photon virtuality  $Q^2 < 10^{-2} \text{ GeV}^2$ . Monte Carlo simulations were used to estimate the selection efficiency and detector acceptance for cross-section measurement. Details on the event selection and the method used

for cross-section calculations can be found in <sup>1</sup>.

The  $\eta$  meson candidates were reconstructed through their  $\eta \rightarrow \gamma\gamma$  decay mode using the liquid argon calorimeter. The  $\rho^0$ ,  $f_0(980)$  and  $f_2(1270)$  were reconstructed through their  $\pi^\pm\pi^\mp$  decay mode using the central jet chamber. The measured photons and charged tracks were required to be in the polar angle range  $0.5 < \theta < 2.6$ , limiting the study to a region of rapidity  $|y| < 1$  in the laboratory frame.

Figure 1 shows the invariant-mass  $M(\pi^+\pi^-)$  distributions for the  $\rho^0$ ,  $f_0(980)$  and  $f_2(1270)$  candidates. The double differential cross sections for  $\eta$ ,  $\rho^0$ ,  $f_0(980)$  and  $f_2(1270)$  are shown as a function of  $m + p_T$ , where  $m$  is the meson nominal mass. Also shown is the cross-section for pions <sup>1</sup> at the same  $\gamma p$  centre-of-mass energy. The cross sections follow a similar power-law function and appear to depend on the masses of the hadrons and transverse momentum but not on their internal structure. This universal feature for long-lived hadrons is supported by <sup>3</sup>. These measurements are also important to understand hadron production at RHIC, where similar processes can be wrongly interpreted as associated to formation of a quark-gluon plasma.

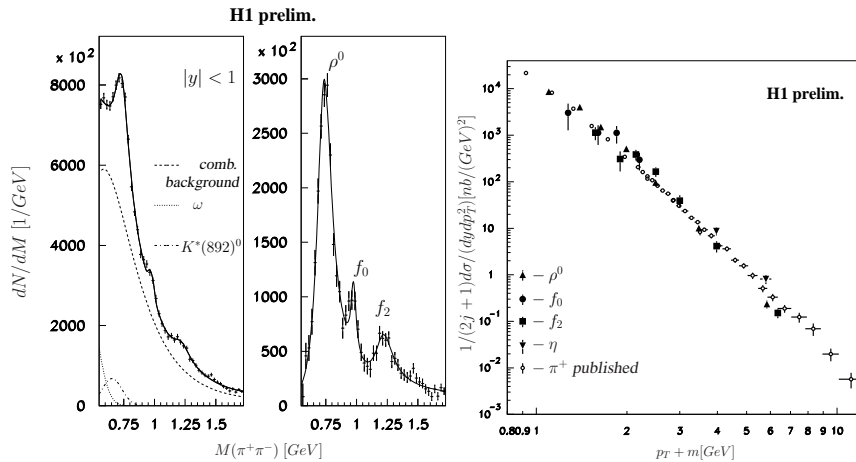


Figure 1. The invariant-masses for the  $\rho^0$ ,  $f_0(980)$  and  $f_2(1270)$  meson candidates are shown before background subtraction (left) and after background subtraction (center). The differential cross-sections (right) are shown as a function of  $p_T + m$ .

## 2. Evidence for a narrow baryonic state decaying to $K_s^0 p(\bar{p})$ in deep inelastic scattering at HERA

The existence of a narrow baryon resonance with a mass close to 1530 MeV and positive strangeness has been reported by several experiments <sup>4</sup>. This state has been interpreted as a bound state of 5 quarks and identified as a candidate for the  $\Theta^+$  state ( $uudd\bar{s}$ ) predicted in the chiral soliton model <sup>5</sup>. In this contribution, results of a resonance search in the  $K_s^0 p(\bar{p})$  invariant-mass spectrum measured using the ZEUS detector at HERA are presented. Details on this analysis can be found in <sup>6</sup>.

A detailed description of the ZEUS detector can be found elsewhere <sup>7</sup>. An integrated luminosity of  $121 \text{ pb}^{-1}$  was used to select deep inelastic scattering events with photon virtuality  $Q^2 > 1 \text{ GeV}^2$  at an  $ep$  energy of 300-318 GeV.

The inclusive DIS selection was defined by requiring an electron found in the Uranium Calorimeter, and further requirements were applied to ensure a well defined data sample <sup>6</sup>.

The Central Tracking Detector (CTD) was used to select charged tracks. The  $K_s^0$  candidates were reconstructed through their  $K_s^0 \rightarrow \pi^+\pi^-$  decay mode. The (anti-)proton candidate was selected using the energy-loss  $dE/dx$  measured in the CTD. A detailed description of the  $K_s^0$  and (anti-)proton candidate selection can be found in <sup>6</sup>.

The  $K_s^0 p(\bar{p})$  invariant-mass spectrum,  $M$ , for<sup>a</sup>  $Q^2 > 20 \text{ GeV}^2$  is shown in Fig. 2. The distribution was fitted using two Gaussians and a three-parameter background function. A peak is seen at  $1521.5 \pm 2.9(\text{stat.}) \text{ MeV}$  with a measured width of  $6.1 \pm 1.6(\text{stat.}) \text{ MeV}$  and significance corresponding to  $4.6\sigma$  ( $3.9\sigma$  if only one Gaussian is used), consistent with the predicted  $\Theta^+$  pentaquark with a mass close to 1530 MeV and a width of less than 15 MeV. Also shown are the independent measurements for  $K_s^0 p$  and  $K_s^0 \bar{p}$  candidates. The latter presents the first evidence for the production of a  $\bar{\Theta}^+$  ( $\bar{u}\bar{u}\bar{d}\bar{d}\bar{s}$ ) state in a kinematical region dominated by fragmentation processes.

## 3. $K_s^0 K_s^0$ final state in deep inelastic scattering at HERA

The  $K_s^0 K_s^0$  system is expected to couple to scalar and tensor glueballs <sup>8</sup>. Lattice QCD calculations <sup>9</sup> predict the existence of a scalar glueball with a mass of  $1730 \pm 100 \text{ MeV}$  which can mix with  $q\bar{q}$  states with  $I = 0$  from

<sup>a</sup>Distributions in different regions of  $Q^2$  can be found in <sup>6</sup>

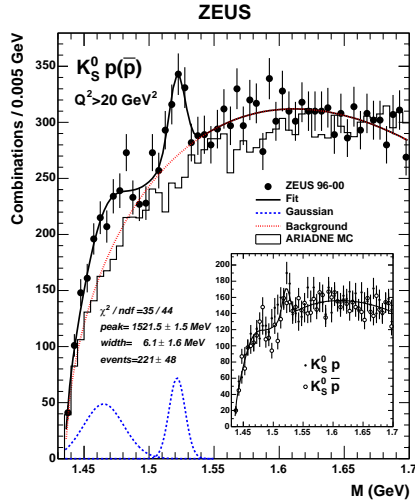


Figure 2. Invariant mass for the  $K_s^0 p(\bar{p})$  resonance. The solid line is the result of a fit using two Gaussians (dashed lines) plus a three-parameter background function (dotted line). The histogram depicts the predictions from the ARIADNE Monte Carlo simulation which contains only well established resonances. The inset shows the independent measurements for  $K_s^0 p$  (black dots) and  $K_s^0 \bar{p}$  (open circles) candidates.

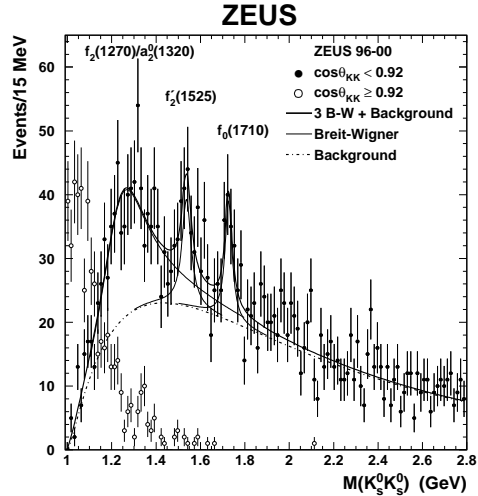


Figure 3. The  $K_s^0 K_s^0$  invariant-mass spectrum for  $K_s^0$  pair candidates with  $\cos\theta_{K_s^0 K_s^0} < 0.92$  (filled circles). The thick solid line is the result of a fit using three Breit-Wigners (thin solid lines) and a background function (dotted-dashed line). The  $K_s^0$  pair candidates that fail the  $\cos\theta_{K_s^0 K_s^0} < 0.92$  cut are also shown (open circles).

the scalar meson nonet, leading to three  $J^{PC} = 0^{++}$  states whereas only two can fit into the nonet. In this contribution, the first observation of resonances in the  $K_s^0 K_s^0$  final state in inclusive deep inelastic  $ep$  scattering is reported <sup>10</sup>.

Deep inelastic scattering events with  $Q^2 > 4 \text{ GeV}^2$  and with at least one pair of  $K_s^0$  candidates were selected from the same ZEUS data sample as described in the previous section. The  $K_s^0$  candidates were identified through their  $K_s^0 \rightarrow \pi^+ \pi^-$  decay mode using the central tracking detector. A detailed description of the event selection and  $K_s^0$  pair candidate reconstruction can be found in <sup>10</sup>.

Figure 3 shows the measured  $K_s^0 K_s^0$  invariant-mass spectrum. A strong enhancement near the  $K_s^0 K_s^0$  threshold due to the  $f_0(980)/a_0(980)$  state <sup>11</sup>

was removed by imposing the cut  $\cos\theta_{K_s^0 K_s^0} < 0.92$ , where  $\theta_{K_s^0 K_s^0}$  is the opening angle between the two  $K_s^0$  candidates in the laboratory frame. Below 1500 MeV, a region strongly affected by the  $\cos\theta_{K_s^0 K_s^0}$  cut, a peak is seen around 1300 MeV where a contribution from  $f_2(1270)/a_2^0(1320)$  is expected. This mass region was fitted with a single Breit-Wigner.

Above 1500 MeV, the lower-mass state has a fitted mass of  $1537_{-8}^{+9}$  MeV and a width of  $50_{-22}^{+34}$  MeV, in good agreement with the well established  $f_2'(1525)$  state. The higher-mass state has a fitted mass of  $1726 \pm 7$  MeV and a width of  $38_{-14}^{+20}$  MeV, consistent with the glueball candidate  $f_0(1710)$ .

It was found that 93% of the  $K_s^0$ -pair candidates selected within the detector and trigger acceptance are in a region where sizeable initial state gluon radiation may be expected.

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