PENTAQUARK SEARCH WITH THE H1 EXPERIMENT

J. GAYLER, DESY
on behalf of the H1 collaboration

We report on the observation of a narrow resonance in $D^{*-}p$ and $D^{*+}\bar{p}$ invariant mass combinations in inelastic ep collisions at centre-of-mass energies of 300 and 320 GeV at HERA. The mass of the resonance is measured to be 3099 ± 3 (stat.) ± 5 (syst.) MeV, the Gaussian width of 12 ± 3 (stat.) MeV is compatible with the experimental resolution. The state can be interpreted as an anti-charmed baryon with minimal constituent quark composition $uudd\bar{c}$, together with the charge conjugate.

1 Introduction

Since the year 2003 several experiments reported on the observation of a narrow resonance in the K^+n channel at mass values around 1540 MeV[1]. The minimal constituent quark content of such a state is $uudd\bar{s}$. These measurements, supported by similar observations in the K^0_Sp channel[2], were therefore interpreted as evidence for a pentaquark state. This evidence motivated the H1 collaboration to search for a charmed pentaquark state, the possible existence of which had been discussed before[3].

The most clear signature of charm production at the HERA ep collider is the observation of D^* mesons. A $uudd\bar{c}$ resonance might therefore lead to an observable signal in D^*p invariant mass combinations. In the following I will shortly report on the relevant steps of this published analysis[4].

2 Event Selection

The analysis is based on a data sample with an integrated luminosity of 75 pb^{-1}, taken in 1996-2000 when HERA collided electrons[a] with $E_e = 27.6$ GeV with protons at $E_p = 820$ GeV and $E_p = 920$ GeV. Deep inelastic scattering (DIS) events[b] were selected by the detection of scattered electrons requiring an exchanged photon virtuality $Q^2 > 1$ GeV^2. The condition $0.05 < y < 0.7$ ensures substantial hadronic final state energy in the central detector region.

D^* mesons give a particularly clean charm signal due to the golden decay channel $D^{*+} \to D^0\pi^+_S \to (K^-\pi^+)\pi^+_S$ (and c.c.), exploiting the standard mass difference technique $\Delta M = m(K\pi\pi_S) - m(K\pi)$, where in this analysis $|m(K\pi) - M(D^0| < 60$ MeV and $|\Delta M - (M(D^*) - M(D^0))| < 2.5$ MeV with $M(D^*)$ and $M(D^0)$ the nominal D^* and D^0 mass values[5]. Using the cuts $p_T(D^*) > 1.5$ GeV, $p_T(K) + p_T(\pi) > 2$ GeV, pseudorapidity[c] $-1.5 < \eta(D^*) < 1$ and production elasticity $z(D^*) = (E - p_z)_{D^*}/2yE_e > 0.2$, a good signal to background ratio is achieved, as shown in Fig.1, with about 3500 D^* candidates above background.

The background is well described by "wrong charge D" combinations where the K and π candidates, yielding the "D^0", have same charge.

The proton selection uses dE/dx measurements in the central drift chamber which yield a mip resolution of about 8%. Normalised likelihoods for pions, kaons and protons are used with $L(\pi) + L(K) + L(p) = 1$. Non-proton background is reduced by the cuts $L(p) > 0.3(0.1)$ for $p(p) < (>)2$ GeV, respectively.

For comparison with the DIS analysis, also a photoproduction sample is selected.

[a] the beam leptons were positrons in 88% of the integrated luminosity and electrons in 12%.
[b] the DIS variables are defined as $Q^2 = -q^2, y = q \cdot p/k \cdot p$, where k, p and q are the 4-vectors of the incident electron, proton and the exchanged photon.

[c] pseudorapidity $\eta = -\ln\theta/2$, where the polar angle θ is measured with respect to the proton beam.

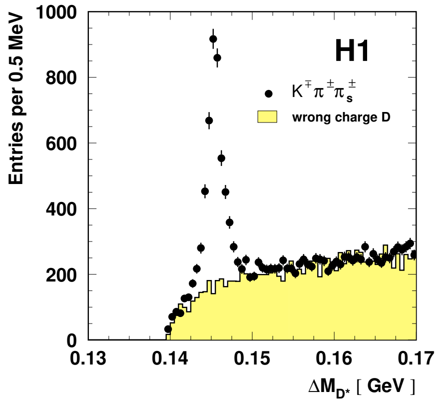

Figure 1. Distribution of $\Delta M = m(K^{\mp}\pi^{\pm}\pi^{\pm}_S) - m(K^{\mp}\pi^{\pm})$. For comparison, "wrong charge D" combinations are also shown (see text).

Here the combinatorial background is larger and somewhat more stringent cuts are used (see ref.[4] for further details).

3 D*p signal

From the selected D^* and p candidates the invariant mass of D^*p combinations is formed according to $M(D^*p) = m(K\pi\pi_S p) - m(K\pi\pi_S) + m(D^*)$ and shown in Fig.2 for

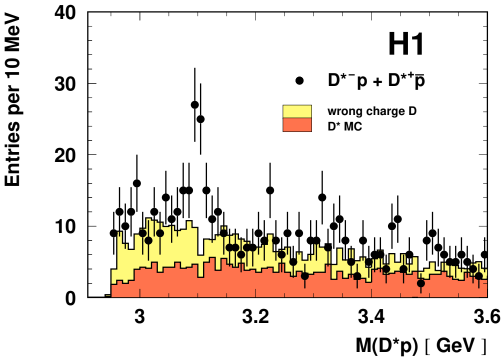

Figure 2. Distribution in $M(D^*p)$ for opposite-charge D^*p combinations. The data are compared with the sum of a non-charm contribution based on "wrong charge D" and a simulated charm contribution (see text).

opposite-charge combinations $D^{*+}\bar{p} + D^{*-}p$. A strong peak is observed at $M(D^*p) \approx 3100$ MeV. The signal is observed with similar strength in the $D^{*+}\bar{p}$ and the $D^{*-}p$ combinations (Fig.3). The same-charge combination $D^{*+}p + D^{*-}\bar{p}$ shows a small enhancement at this mass value[4].

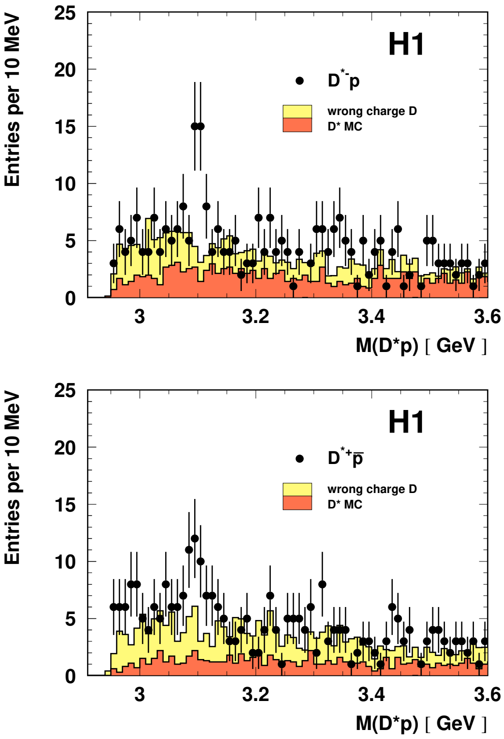

Figure 3. Distribution in $M(D^*p)$ for opposite-charge D^*p combinations, separately for $D^{*-}p$ combinations (upper) and $D^{*+}\bar{p}$ (lower). Background model as in Fig.2.

The spectra in Figs.2,3 are reasonably described by the sum of a non-charm contribution, taken from "wrong charge D" mesons combined with proton candidates and a charm contribution where D^* mesons are randomly combined with proton candidates. The latter contribution is obtained from simulated DIS charm production using the RAPGAP generator[6].

The signal in Fig.2 is quantified by fitting the mass distribution by a Gaussian together with a power law background $\alpha[M(D^*p) - M(D^*)]^{\beta}$. The fit is shown in Fig.4. The resulting peak position is $3099 \pm 3(\text{stat})$ MeV, the width of the Gaussian (RMS) is $12 \pm$

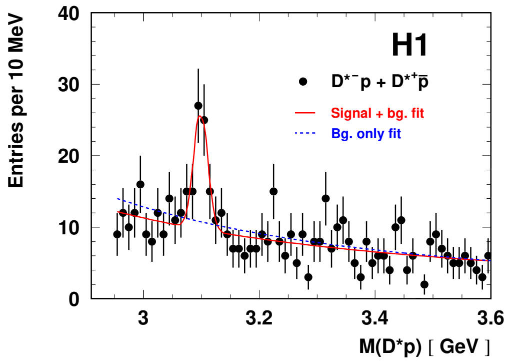

Figure 4. Distribution in $M(D^*p)$ for opposite-charge D^*p combinations. The data are compared with a fit in which both signal and background are included (solid line) and with a fit where only the background component is included.

3(stat) MeV, compatible with the experimental resolution of 7 ± 2 MeV. The systematic uncertainty of the peak position is 5 MeV. The fit yields $N_S = 50.6 \pm 11.2$ signal events and within 2σ of the peak $N_B = 45.0 \pm 2.8$ background events. This signal corresponds to a raw measured ratio $N_S/N(D^*)$ of $1.46 \pm 0.32\%$ without detector corrections.

In a more conservative approach the full distribution is fitted by the background shape without a Gaussian (broken line in Fig.4) This yields within the above 2σ range $N_B = 51.7 \pm 2.7$ background events. The Poisson probability for an expectation of $N_B = 51.7$ events to fluctuate to the observed 95 or more events is 4×10^{-8} which corresponds to $5.4\ \sigma$ when expressed in equivalent Gaussian standard deviations.

4 Signal Tests

Extensive tests have been performed to examine the observed signal. All events in the peak were visually scanned. No anomalies were found.

Sideband studies confirmed that the peak has large D^* content and is not produced in the D^* side bands. A peak at $M(D^*p) \simeq 3100$ GeV is also visible for a proton enriched sample with $p(p) < 1.2$ GeV with more stringent dE/dx requirement $L(p) > 0.5$.

The momentum spectrum of the proton candidates is however harder in the D^*p peak region than in the sidebands[4], which might be expected for a two-body resonance decay. At high proton momenta ($p > 2$ GeV), the signal in the D^*p invariant mass is visible without any dE/dx requirement (see Fig.5) with

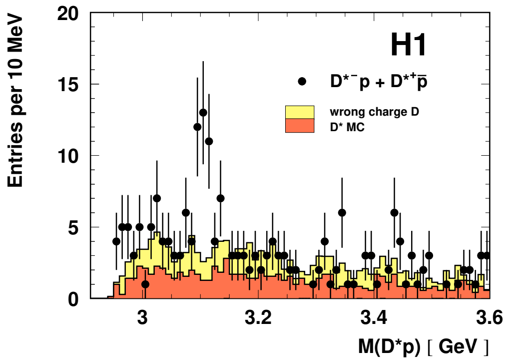

Figure 5. Distribution in $M(D^*p)$ for opposite-charge D^*p combinations with $p(p) > 2$ GeV and no proton dE/dx requirement. Background model as in Fig.2.

a mass value and width compatible with the standard selection.

Possible reflections of other resonances have been studied. Mass distributions and correlations with different mass hypothesis for the K, π and proton candidates gave no explanations for the observed structure. In particular the orbitally excited D_1 and D_2 states decaying to $D^*\pi$ do not give a significant contribution to the peak.

An independent photoproduction sample shows a D^*p resonance structure compatible with the discussed DIS selection.

In addition to the Monte Carlo comparisons, shown in Figs.2,3 and 5, the data were compared with a DJANGO[7] simulation of inclusive DIS and with generators with different parton dynamics or fragmentation (CASCADE[8] and HERWIG[9] respectively). None of the simulations shows a resonance structure in the D^*p mass spectrum.

5 Discussion

A clear structure is observed in the invariant mass of D^*p combination with a width compatible with the experimental resolution. An explanation in terms of reflections or reconstruction failure could not be found. No such structure is visible in charm or more general DIS Monte Carlo generators including a full simulation of the H1 detector. The final state particles are measured in the central detector far away from the proton remnant, implying that the pentaquark candidate is produced in fragmentation.

However several experiments searched for this structure and did not observe it. The negative statements[10] of FOCUS, ALEPH, CDF, BELLE refer to different reactions in different phase space regions which make a direct comparison difficult. The ZEUS collaboration[11] found no signal in the same reaction with similar kinematic cuts. This experimental discrepancy needs further investigation.

6 Conclusion

A narrow resonance is observed in $D^{*-}p$ and $D^{*+}\bar{p}$ combinations at $M(D^*p) = 3099 \pm 3$ (stat.) ± 5 (syst.) MeV with a Gaussian width (RMS) of 12 ± 3 (stat.) MeV, compatible with the experimental resolution. The statistical significance is estimated to be 5.4σ. The state can be interpreted as anti-charmed baryon with minimal constituent quark content $uudd\bar{c}$.

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