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First Evidence of $\Omega_c^0 \to \Omega^- \pi^+$

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Abstract

We report evidence of a narrow resonance at a mass of $2705.9 \pm 3.3 \pm 2.0$ MeV/c^2 in the final state $\Omega^- \pi^+$ and the charge conjugate. The mass and width support the interpretation of a weakly decaying doubly strange charmed baryon, the Ω_c^0. Limits on the relative branching ratios for $\Omega_c^0 \to \Xi^- K^- \pi^+ \pi^+$ and $\Omega_c^0 \to \Omega^- \pi^- \pi^+ \pi^+$ are also presented.

The Ω_c^0 state is defined as the baryon state containing one charm quark and two strange quarks. This baryon is expected to decay weakly [1] since its mass is expected to be below the threshold for decay into a baryon and a charmed meson.

The first evidence [2] for the Ω_c^0 came from the CERN experiment WA-62 in which three events in the invariant mass plot $\Xi^- K^- \pi^+ \pi^+$ were found to be clustered around 2740 $\pm$ 20 MeV/c^2. Recently, the ARGUS collaboration has found further evidence [3] for this same mode with 12.2 $\pm$ 4.5 events with a mass of 2719.0 $\pm$ 7.0 $\pm$ 2.5 MeV/c^2. ARGUS has also shown evidence for $\Omega_c^0 \to \Omega^- \pi^- \pi^+ \pi^+$ at the same mass [4].

We have studied the $\Omega^- \pi^+$ decay channel in a sample of approximately 500 million triggers produced by the interactions of high energy photons striking a Be target. We have chosen to study this channel because there is little background expected. The previously identified $\Xi^- K^- \pi^+ \pi^+$ and $\Omega^- \pi^- \pi^+ \pi^+$ channels have many more combinations falling into the expected signal region.

The E687 detector, described in detail elsewhere [5], is a large aperture spectrometer with good detection capabilities for charged hadrons and photons. A microvertex detector consisting of 12 planes of silicon microstrips arranged in three views provides high resolution tracking allowing the separation of primary and secondary vertices. Deflection of charged particles by two analyzing magnets of opposite polarity is measured by five stations of multiwire proportional chambers (PWCs). Three multicell Čerenkov counters operating in threshold mode are used for particle identification. The decay volume for reconstructing Λ^0's and K_s^0's is nine meters long. The photon beam is derived from a 320 GeV/c electron beam with $\sigma = 13\%$ momentum spread. The electron beam impinges on a 27% radiation length lead foil, producing bremsstrahlung photons. The photons are directed to a 4 cm long Be target. The experimental trigger required that at least 40–50 GeV of energy be detected in the hadron calorimeter and that at least two tracks be present outside the region where Bethe-Heitler pairs are produced. The average photon energy for the data sample was 221 GeV.

The Ω^-'s are fully reconstructed through the decay channel $\Omega^- \to \Lambda^0 K^-$. Two different types of Ω decays are reconstructed. Decays which occur upstream of the silicon microstrip detectors are reconstructed by intersecting the Λ^0 vector and the K^- track and demanding that the confidence level of this vertex be greater than 1% and that the $\Lambda^0 K^-$ candidate is consistent with coming from a vertex further upstream. Decays which occur downstream of the microstrip detectors are reconstructed by intersecting the daughter K^- track and the Λ^0 vector and by requiring that the direction of the resultant momentum vector agree (to within two milliradians) with an unmatched microstrip track (the Ω^- candidate track). Figure 1a shows the $\Lambda^0 K^-$ and $\overline{\Lambda^0} K^+$ (references to a specific charge state should be taken to include the charge conjugate state) invariant mass plot for the decays which occur upstream of the silicon microstrip detectors and Figure 1b presents the same plot for downstream decays. For the remainder of this paper, only the downstream decays will be used because of the important advantage achieved by having a measured hyperon track in the microstrip detector (the well measured hyperon track, when combined with other charm daughter tracks, yields a high quality vertex which is an important tool in eliminating background). Figures 1c and 1d show the $\Lambda^0 \pi^-$ invariant mass plots for upstream and downstream decays, respectively. These Ξ^-'s are reconstructed in a manner identical to the Ω^- reconstruction with the Čerenkov detectors being used to identify the daughter track as either a kaon or a pion. As with Ω^-'s, only the downstream Ξ^-'s are used in forming charmed baryon states.

The $\Omega^- \pi^+$ combinations are obtained using a candidate-driven vertex finder using the silicon vertex information. The vertex finder works as follows. A secondary vertex is first formed from the Ω^- silicon track and the π^+ track which is found in both the proportional wire chamber system and the silicon microstrip system. Next, a seed track is constructed from the momentum vectors of the Ω^- and π^+ tracks. Other tracks consistent with intersecting the seed track are used to form a primary vertex candidate.

Four additional cuts were studied with Monte Carlo simulations and applied to the data: the Ω_c^0 candidate must have a momentum greater than 55 GeV/c; the π^+ from the decay must have a momentum greater than 0.4 GeV/c transverse to the Ω_c^0 direction; the π^+ must be identified by the Čerenkov system to be either π definite or e/π ambiguous; and the confidence level of the fit to the $\Omega^- \pi^+$ vertex must be greater than 20%.

Figure 2 shows the final fitted $\Omega^- \pi^+$ invariant mass distribution. A total of 10.3 ± 3.9 events above a background of 5.8 events are found in the peak. The efficiency for reconstructing this state, given that we triggered on the event, is calculated to be 3.3%. The yield of events was determined by a maximum likelihood fit to a linear background plus a Gaussian. The width of the Gaussian was fixed at 9 MeV/c^2, as determined from Monte Carlo studies. The mass is measured to be 2705.9 ± 3.3 ± 2.0 MeV/c^2, one standard deviation lower than the ARGUS mass. The systematic error was obtained by comparing the masses of our $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ and $\Xi_c^0 \to \Xi^-\pi^+$ signals [6] with the current world averages [7]. We believe that our mass scale is quite accurate since the masses of our previously published charm signals [8] agree well with world averages [7]. Of the 14 events in the region between 2.69 Gev/c^2 and 2.72 GeV/c^2 six are $\Omega^-\pi^+$ combinations and the remaining eight are $\Omega^+\pi^-$ combinations.

We have also looked for Ω_c^0 decaying into the two modes previously reported: $\Xi^-K^-\pi^+\pi^+$ and $\Omega^-\pi^-\pi^+\pi^+$. The same cuts used on the $\Omega^-\pi^+$ sample were applied, with the exception of the transverse momentum cut on the pion track (this cut is only efficient in the two body decay where a large amount of phase space is available to the daughters). Figures 3a and 3b show the $\Xi^-K^-\pi^+\pi^+$ and $\Omega^-\pi^-\pi^+\pi^+$ invariant mass distributions. The efficiencies, relative to the $\Omega^-\pi^+$ efficiency, for these two modes are 0.97 and 0.84, respectively. As no signals have been detected, limits on the relative branching ratios have been calculated. The plots are fitted with a third order polynomial for the background and a Gaussian for the signal. The signal Gaussian is fixed at the Ω_c^0 mass measured in our $\Omega^-\pi^+$ mode and its width is fixed at its Monte Carlo width. The fit yields 0.0 ± 17.6 events for $\Xi^-K^-\pi^+\pi^+$ and 4.84 ± 5.85 events for $\Omega^-\pi^-\pi^+\pi^+$. Taking into account the efficiencies and the hyperon branching fractions, the relative branching ratios were calculated, along with their errors. At the 90% confidence level $\Gamma(\Xi^-K^-\pi^+\pi^+)/\Gamma(\Omega^-\pi^+) < 2.8$ and $\Gamma(\Omega^-\pi^-\pi^+\pi^+)/\Gamma(\Omega^-\pi^+) < 1.6$.

In conclusion, we have found evidence for a narrow peak in the final state $\Omega^-\pi^+$ which is consistent with the weak decay of the Ω_c^0. The mass is measured to be $2705.9 \pm 3.3 \pm 2.0$ MeV/c^2. We find the relative branching ratios of $\Gamma(\Xi^-K^-\pi^+\pi^+)/\Gamma(\Omega^-\pi^+) < 2.8$ and $\Gamma(\Omega^-\pi^-\pi^+\pi^+)/\Gamma(\Omega^-\pi^+) < 1.6$ at the 90% confidence level.

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Footnotes

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Figure Captions

Fig. 1a: $\Omega^- \to \Lambda K^-$ + c.c. candidates with decay vertex between the experimental target and the microstrip detectors. The confidence level of the vertex is required to be greater than 1%. The yield is 388 ± 32 events.

Fig. 1b: $\Omega^- \to \Lambda K^-$ + c.c. candidates with decay vertex between the microstrip detectors and the first PWC plane. The microstrip track of the Ω^-/Ω^+ candidate is required to agree within two milliradians with the momentum vector. The yield is 1258 ± 54 events.

Fig. 1c: $\Xi^- \to \Lambda^0 \pi^-$ + c.c. candidates with decay vertex between the experimental target and the microstrip detectors. The confidence level of the vertex is required to be greater than 1%. The yield is 7687 ± 108 events.

Fig. 1d: $\Xi^- \to \Lambda^0 \pi^-$ + c.c. candidates with decay vertex between the microstrip detectors and the first PWC plane. The microstrip track of the Ξ^-/Ξ^+ candidate is required to agree within two milliradians with the momentum vector. The yield is 43110 ± 255 events.

Fig. 2: $\Omega^- \pi^+$ invariant mass distribution with cuts described in the text.

Fig. 3a: $\Xi^- K^- \pi^+ \pi^+$ invariant mass distribution.

Fig. 3b: $\Omega^- \pi^- \pi^+ \pi^+$ invariant mass distribution.

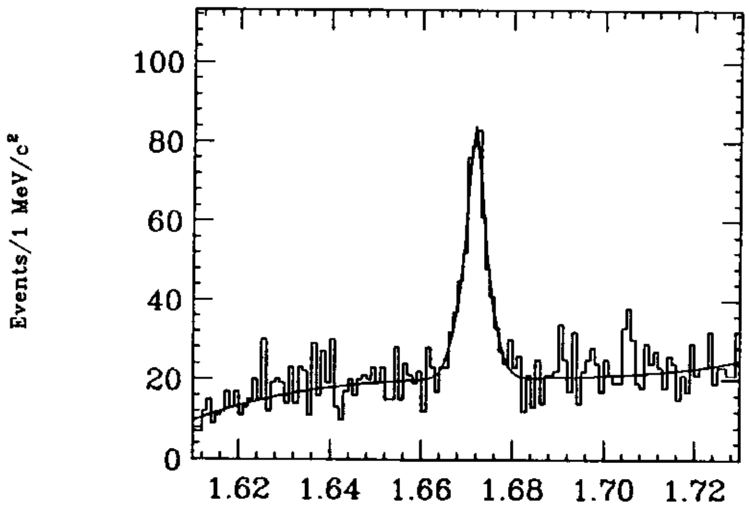

Fig. 1a: $M(\Lambda^0 K^-)$ GeV/c^2

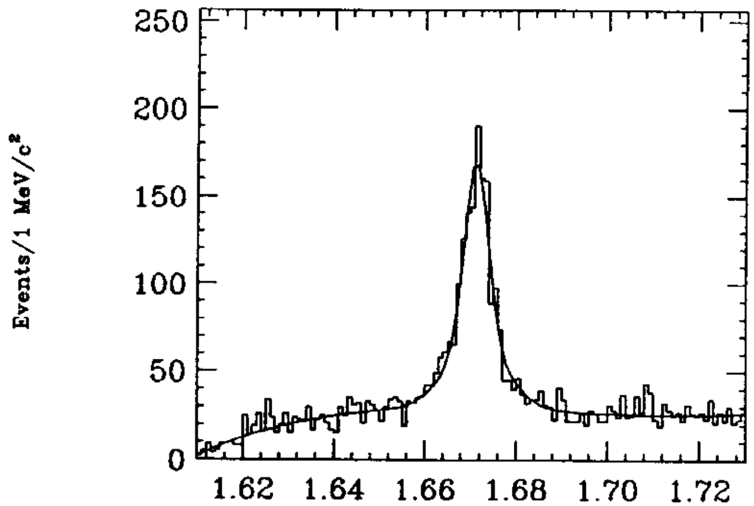

Fig. 1b: $M(\Lambda^0 K^-)$ GeV/c^2

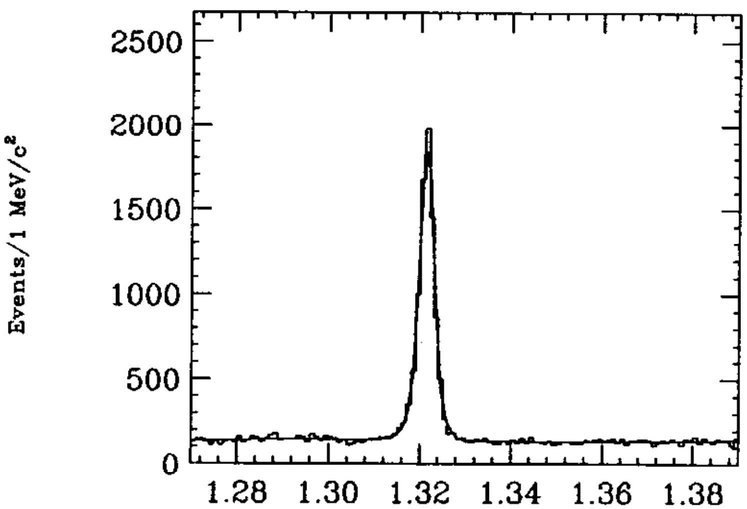

Fig. 1c: $M(\Lambda^0 \pi^-)$ GeV/c^2

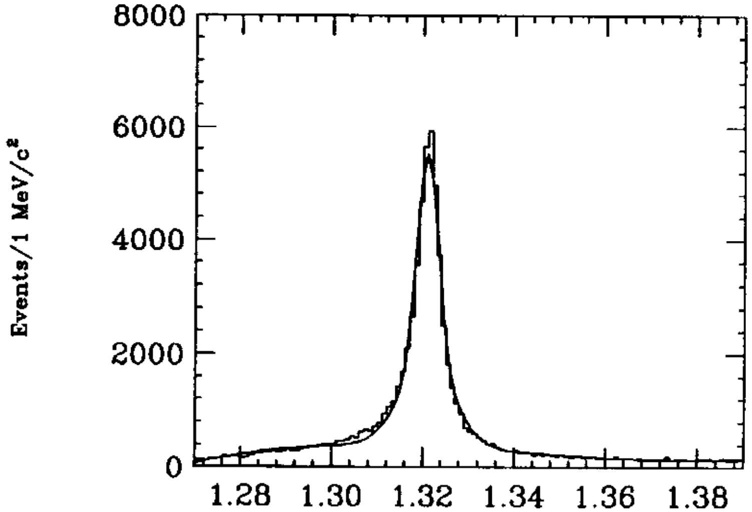

Fig. 1d: $M(\Lambda^0 \pi^-)$ GeV/c^2

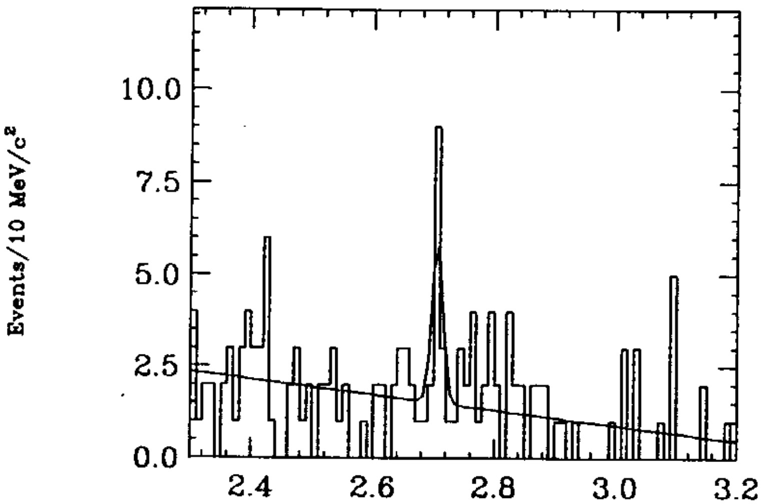

Fig. 2: $M(\Omega^-\pi^+)$ GeV/c^2

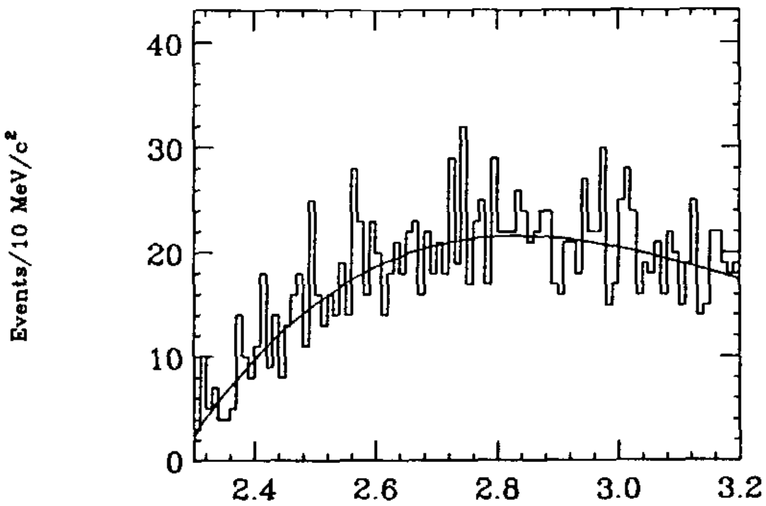

Fig. 3a: $M(\Xi^- K^- \pi^+ \pi^+)$ GeV/c^2

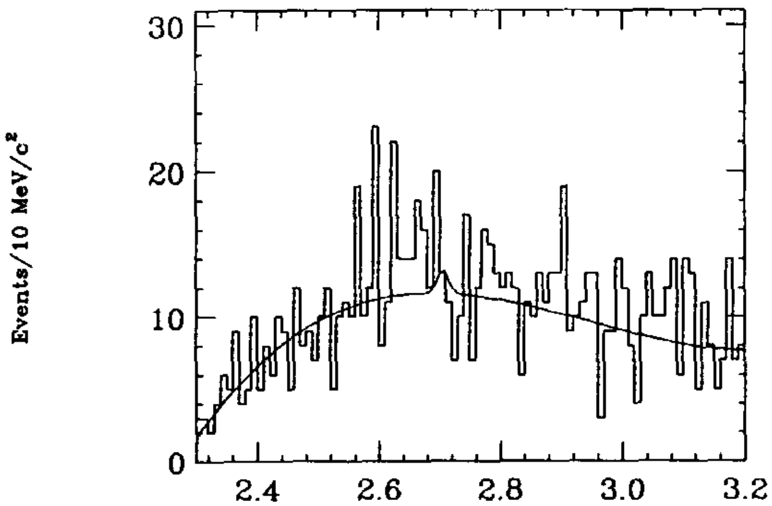

Fig. 3b: $M(\Omega^- \pi^- \pi^+ \pi^+)$ GeV/c^2