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Observation and Mass Measurement of $\Omega_c^0 \rightarrow \Sigma^+ K^- K^- \pi^+$

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Abstract

We present evidence for the Ω_c^0 in a new decay mode $\Omega_c^0 \to \Sigma^+ K^- K^- \pi^+$, for which we find 42.5±8.8 events with a mass of 2699.9±1.5±2.5 MeV/c^2. The data are from Fermilab high energy photoproduction experiment E687.

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At present the published evidence for the doubly strange charmed baryon Ω_c^0 is not strong. Evidence for the Ω_c^0 baryon was first reported in the CERN experiment WA62 [1] in the decay channel $\Omega_c^0 \rightarrow \Xi^- K^- \pi^+ \pi^+$ where 3 events clustered around a mass of 2740 ± 20 MeV/c^2 were observed. Evidence for $\Omega_c^0 \rightarrow \Omega^- \pi^+ \pi^+ \pi^-$ has also been presented by the ARGUS collaboration [2], where in a preliminary analysis they find 6.5 ± 3.2 events at a mass of 2713.0 ± 5.1 MeV/c^2. The best published evidence so far are results from ARGUS on $\Omega_c^0 \rightarrow \Xi^- K^- \pi^+ \pi^+$ [3] and the results we published in an earlier paper on $\Omega_c^0 \rightarrow \Omega^- \pi^+$ [4]. The ARGUS collaboration reported a mass of $2719 \pm 7.0 \pm 2.5$ MeV/c^2 with 12.2 ± 4.5 events while we measured the mass to be $2705.9 \pm 3.3 \pm 2.0$ MeV/c^2 with 10.3 ± 3.9 events. Both these two signals are about 2.7 standard deviations in statistical significance. In a preliminary analysis [5], the CLEO collaboration finds no evidence for $\Omega_c^0 \rightarrow \Xi^- K^- \pi^+ \pi^+$, and reports a 90% confidence level upper limit on the cross-section × branching ratio of 0.40 pb, which is much lower than the value of $2.41 \pm 0.90 \pm 0.30$ pb measured by ARGUS. Preliminary results from CERN experiment WA89 have recently been presented [6], where they find some evidence for the Ω_c^0 in three decay modes: $\Omega_c^0 \rightarrow \Omega^- \pi^+$; $\Omega_c^0 \rightarrow \Omega^- \pi^+ \pi^+ \pi^-$; and $\Omega_c^0 \rightarrow \Xi^- K^- \pi^+ \pi^+$. However, the WA89 collaboration have not yet presented a mass measurement of the Ω_c^0. There is clearly a need for further confirmation of the Ω_c^0 and an improvement in the determination of its mass. In this paper we present further evidence for the Ω_c^0 in a new decay mode $\Omega_c^0 \rightarrow \Sigma^+ K^- K^- \pi^+$ and give a new measurement of its mass.

We have studied the Ω_c^0 exclusive decay channel $\Sigma^+ K^- K^- \pi^+$ in data collected by Fermilab high energy photoproduction experiment E687. Throughout this paper, the charge conjugate state is implied when a decay mode of a specific charge is stated. The E687 detector is described in detail elsewhere [7].

The Σ^+ hyperons which decay downstream of the silicon strip detector (SSD) are reconstructed through both the decays modes $\Sigma^+ \rightarrow p\pi^0$, and $\Sigma^+ \rightarrow n\pi^+$. The π^0 and neutron are not directly observed so such candidates appear in the spectrometer as the intersection between the Σ track which is reconstructed in the SSD, but missing in the multiwire proportional chambers (MWPC), and a proton or pion track found in the MWPC system but missing in the SSD. The Σ decay region is limited to the 3.6 meters between the end of the microstrip detector and the first MWPC chamber.

Two cases of Σ^+ decays were considered: ones that decay within the magnetic field of the upstream spectrometer magnet and ones that decay upstream of the magnet and downstream of the SSD. If the Σ^+ decayed within the magnetic field then its momentum can be fully determined by tracing it through the magnetic field to the Σ^+ decay vertex. This momentum is then improved by constraining the reconstructed Σ^+ mass. When the Σ^+ decay occurs upstream of the magnetic field, the direction of Σ^+ is given by its SSD track and, since the proton/pion momentum can be determined, the magnitude of the momentum of the Σ^+ can be calculated using energy and momentum conservation. In this case there is a two-fold ambiguity in this calculation of the Σ^+ momentum.

Particle identification cuts are used to reject false Σ^+ candidates. For $\Sigma^+ \to p\pi^0$ decays, the proton track is required to be identified by the Čerenkov counters as proton definite or K/p ambiguous. For $\Sigma^+ \to n\pi^+$ decays the pion track is required to not be identified as proton, kaon or electron definite, or K/p ambiguous. For the daughter neutron, we required an energy deposition in the electromagnetic and hadronic calorimeters consistent with a neutron hypothesis. The locations at which the neutron strikes the inner electromagnetic (IE) and the hadronic calorimeter (HC) are determined from the reconstructed Σ^+ and daughter π momenta. The nearest electromagnetic shower is associated with the candidate neutron if the transverse centroid of the shower is within 10 cm of the projected impact point. In the hadron calorimeter, energy associated with charged particles is first removed. Next, the energy deposited within a 16.8 cm radius around the calculated impact point (which is the typical transverse size for hadronic showers [8]) is associated with the neutron. Using the sum of electromagnetic and hadronic energies E and the neutron momentum p (determined indirectly by kinematics), we required the ratio E/p to lie in the range 0.3 to 1.7. This kept 85% of the reconstructable $\Sigma^+ \to n\pi^+$ decays while rejecting 75% of the background.

The Ω_c^0 decays were reconstructed using the standard E687 candidate driven vertex algorithm [7]. A number of cuts are used to select $\Sigma^+K^-K^-\pi^+$ combinations. The Σ^+ hyperons were reconstructed as described above. The other decay secondaries must be reconstructed in both the SSD and MWPC, and the two sets of track parameters have to agree within measurement errors. The kaons must be identified by the Čerenkov counters as kaon definite or K/p ambiguous, and the pion must not be identified as electron, kaon or proton definite or K/p ambiguous. The four microstrip tracks of the $\Sigma^+K^-K^-\pi^+$ combination are required to form a (secondary) vertex with a confidence level (CLS) greater than 3%. The candidate Ω_c^0 "track" must form a primary vertex with at least one other microstrip track with a confidence level (CLP) greater than 3%. The confidence level for any of the four $\Sigma^+K^-K^-\pi^+$ tracks to individually extrapolate back to the primary vertex (ISO1) is required to be less than 85%. The confidence level that other SSD tracks not already assigned to the primary or secondary vertices point back to the secondary vertex (ISO2) is required to be less than 0.1%. The cut on ISO1 is designed to cut out decay secondaries that were actually produced in the primary interaction vertex and the cut on ISO2 is designed to cut out higher multiplicity decays and fake decay vertices caused by secondary interactions. While we usually use the significance of separation of the primary and secondary vertices to isolate longer lived charm signals from non-charm background, in this analysis we just require that the secondary decay vertex be reconstructed downstream of the primary vertex. It is possible for the secondary vertex to be reconstructed upstream of the primary vertex because of finite resolution and due to fake vertices. Monte Carlo studies show that $\Sigma^+K^-K^-\pi^+$ combinations from Ω_c^0 decays have a harder momentum spectrum than background $\Sigma^+K^-K^-\pi^+$ combinations. The momentum of the $\Sigma^+K^-K^-\pi^+$ combination is required to be greater than 50 GeV/c.

Figures 1(a) and 1(b) show separately the $\Sigma^+K^-K^-\pi^+$ invariant mass plots for the two decay modes of the Σ^+, $\Sigma^+ \to p\pi^0$ and $\Sigma^+ \to n\pi^+$ respectively. The cuts used were as described above. A peak in both plots at a mass of about 2.7 GeV/c^2 is clearly evident and remains even with a large variety of different event selection criteria. The fits shown are to a Gaussian peak over a quadratic background. The fitted mass and width of the peak for the $p\pi^0$ mode are 2698.8±2.5 MeV/c^2 and 6.4±1.9 MeV/c^2 respectively, and for the $n\pi^+$

mode they are 2700.0±2.0 MeV/c^2 and 5.6±1.3 MeV/c^2. The two masses agree well with each other. The widths are consistent with the value of 8.0±2.0 MeV/c^2 due to resolution alone. The uncertainty on this resolution width was determined by a Monte Carlo study where the background and small statistics that are characteristic of the data are taken into account. As a further validity check of the signal we have verified the agreement of the Ω_c^0 corrected yields for the two channels $\Sigma^+ \to p\pi^0$ and $\Sigma^+ \to n\pi^+$, using Monte Carlo calculated efficiencies and taking into account the relative branching ratios of the two Σ^+ decay modes. We have also investigated the possibility of contamination in our signal from $\Xi_c^0 \to \Sigma^+ K^- \pi^- \pi^+$, where the π^- is misidentified as a K^-. By studying the $\Sigma^+ K^- \pi^- \pi^+$ invariant mass we find no evidence for this contamination in our signal. Figure 1(c) shows the total $\Sigma^+ K^- K^- \pi^+$ invariant mass plot using both Σ^+ decay modes. The fit to this mass distribution gives a yield of 42.5±8.8 events at a mass of 2699.9±1.5 MeV/c^2. The fitted width is 5.9±1.1 MeV/c^2, which is consistent with the experimental mass resolution.

For the mass measurement we have investigated the effect of events that contain a two-fold ambiguity in the Σ^+ momentum; these events make up less than about 30% of the total. This two-fold ambiguity leads to two candidate combinations with different $\Sigma^+ K^- K^- \pi^+$ invariant masses. This can distort the peak and background in the invariant mass plot and thus create a possible systematic shift in the mass measurement. This was studied in a Monte Carlo analysis and also in data by using different methods of resolving the two-fold ambiguity, and by fitting with a line-shape determined by Monte Carlo instead of with a simple Gaussian. No significant shift in the measured mass was seen due to the two-fold ambiguity in the Σ^+ momentum, and we assign an uncertainty of 0.1 MeV/c^2 associated with this.

It should be noted that since the two-fold ambiguity in the Σ^+ momentum leads to two candidate combinations with different $\Sigma^+ K^- K^- \pi^+$ invariant masses, if both these masses are within the peak then we could overestimate the number of signal events. This effect was also studied in detail and we found that the fitted yield overestimates the true number of signal events by about 8%. This correction was not made for the signal yields quoted. This correction would only slightly decrease the statistical significance of this signal from 4.8 σ to 4.6 σ, and does not affect the mass measurement error.

We assign a systematic uncertainty of 2.0 MeV/c^2 on our absolute mass scale for this mass measurement. This was studied in Monte Carlo analyses of this and other charm particle decay modes, and by comparing the agreement of our (high statistics) data on other charm particle masses with the current world average values [9]. In particular, modes including reconstructed Σ^+ hyperons, like $\Lambda_c^+ \rightarrow \Sigma^+\pi^+\pi^-$ were studied [10].

The systematic uncertainties due to our choice of binning, fitting function, fitting method and choice of selection criteria were studied. Though we find no systematic shifts associated with our choice, the study was limited by statistics, and we conservatively assign an upper limit of 1.5 MeV/c^2 in the systematic uncertainty in the mass from these sources.

Adding the different systematic uncertainties incoherently we obtain a final mass measurement for the Ω_c^0 of 2699.9±1.5(stat)±2.5(syst) MeV/c^2. This mass is within 1.7 σ (using statistical errors only) of the Ω_c^0 mass we measured for the $\Omega^-\pi^+$ mode; this corresponds to a confidence level of 9% for the agreement between our two measured masses for the Ω_c^0.

In summary, we report an observation of 42.5±8.8 events in a new decay mode of the $\Omega_c^0 \rightarrow \Sigma^+K^-K^-\pi^+$ at a mass of 2699.9±1.5(stat.)±2.5(syst.) MeV/c^2. This strengthens the evidence for the existence of the Ω_c^0 at a mass lower than that given by the ARGUS measurements but consistent with our previous measurement using the decay mode $\Omega_c^0 \rightarrow \Omega^-\pi^+$.

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FIGURES

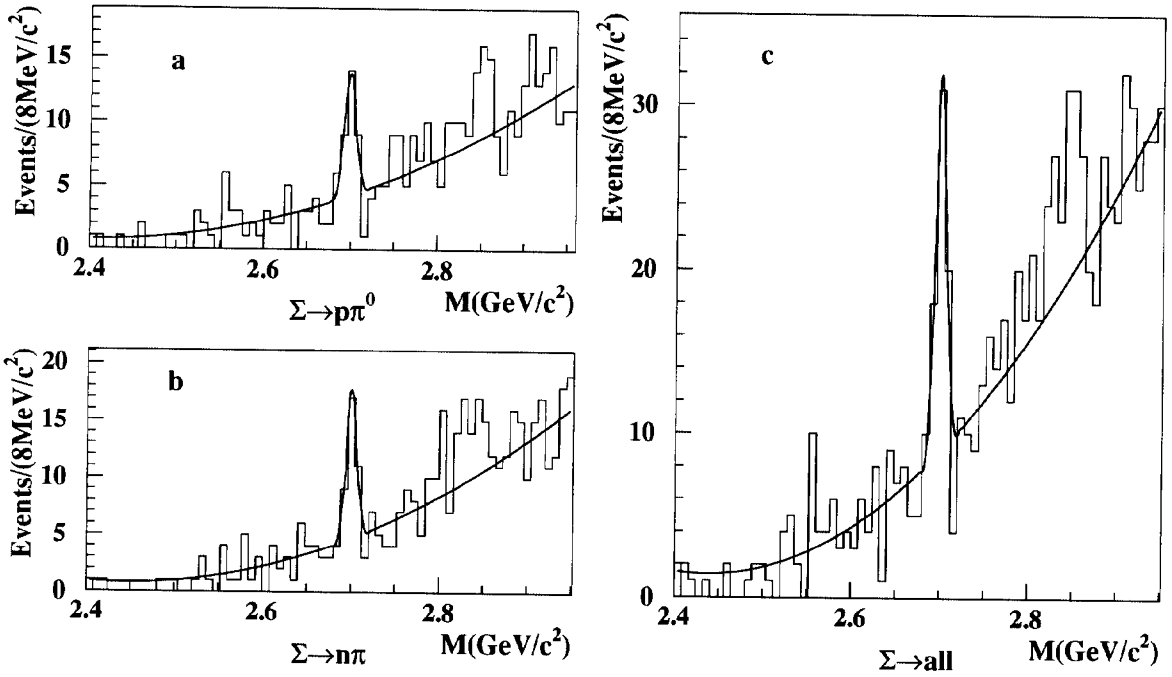

FIG. 1. (a) $\Sigma^+K^-K^-\pi^+$ invariant mass distribution for the $\Sigma^+ \to p\pi^0$ decay mode; (b) $\Sigma^+K^-K^-\pi^+$ invariant mass distribution for the $\Sigma^+ \to n\pi^+$ decay mode; and (c) $\Sigma^+K^-K^-\pi^+$ invariant mass distribution for both decay modes of the Σ^+.