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OBSERVATION OF Σ_c^{*++} PRODUCTION IN NEUTRINO INTERACTIONS ON BUBBLE CHAMBER SKAT

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Abstract

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The reactions of quasielastic production of charmed baryons on protons in SKAT neutrino experiment are investigated. The first observation of Σ_c^{*++} production with mass $M(\Sigma_c^{*++}) = (2.530 \pm 0.005 \pm 0.005)$ GeV is presented. The cross sections for the reactions $\nu p \to \mu^- \Sigma_c^{++}$ and $\nu p \to \mu^- \Sigma_c^{*++}$ are estimated.

Аннотация

Аммосов В.В., Васильев И.Л., Иванилов А.А. и др. Наблюдение образования очарованных барионов Σ_c^{*++} в нейтринных взаимодействиях на пузырьковой камере СКАТ: Препринт ИФВЭ 93-91. – Протвино, 1993. – 6 с., 2 рис., 1 табл., библиогр.: 15.

Представлены результаты изучения реакций квазиупругого образования очарованных барионов на протоне с помощью пузырьковой камеры СКАТ, экспонированной в нейтринном пучке Серпуховского ускорителя У-70. Приведены результаты первого наблюдения Σ_c^{*++}-бариона с массой $M(\Sigma_c^{*++}) = (2.530 \pm 0.005 \pm 0.005)$ ГэВ. Получены оценки сечений реакций $\nu p \to \mu^- \Sigma_c^{++}$ и $\nu p \to \mu^- \Sigma_c^{*++}$.

1. INTRODUCTION

The very first experimental data on the production of charmed baryons were obtained more than 15 years ago in the neutrino experiments with bubble chamber Gargamelle[1]. However, even nowadays the experimental data on charmed baryons is considerably scarce as compared with the information about charmed mesons.

This paper is devoted to the study of the quasi-elastic production of charmed baryons on protons in the reactions

$$\nu p \to \mu^- \Sigma_c^{++}, \qquad \Sigma_c^{++} \to \Lambda_c^+ \pi^+, \tag{1}$$

$$\nu p \to \mu^- \Sigma_c^{*++}, \qquad \Sigma_c^{*++} \to \Lambda_c^+ \pi^+. \tag{2}$$

It is also possible to use quasi-elastic production of charmed baryons on neutrons , using such reactions as

$$\nu n \to \mu^- \Lambda_c^+, \tag{3}$$

$$\nu n \to \mu^- \Sigma_c^+, \qquad \Sigma_c^+ \to \Lambda_c^+ \pi^0, \tag{4}$$

$$\nu n \to \mu^- \Sigma_c^{*+}, \qquad \Sigma_c^{*+} \to \Lambda_c^+ \pi^0. \tag{5}$$

Reactions (1) and (2) are more advantageous as compared with reaction (3) because the $\Sigma_c^{(*)++}$ and Λ_c^+ mass difference is determined more precisely in experiment than the masses of the particles themselves. The analysis of reactions (4) and (5) is aggravated by the presence of π^o meson, since the detection efficiency for it is not very high.

The search for charmed baryons in quasi-elastic reactions allows us to reduce combinatorial background and to efficiently use the kinematic analysis of the event.

The IHEP neutrino beam is the most suitable for the search of the charmed baryon quasi-elastic production, because the maximum of the ratio of the cross sections for these reactions to the total cross section of the neutrino interaction is in the maximum of the neutrino beam intensity.

2. MODEL PREDICTIONS

The experimental situation for Σ_c^{*++} baryon is quite different from that for Σ_c^{++}. The Σ_c^{++} baryon has been observed in several experiments in νN scattering [1][2][3][4][5], e^+e^-[6][7], nA[8] collisions, as for Σ_c^{*++} no experimental data are available today. There are several model predictions for the Σ_c^{*++} mass (see Table). As is seen from the Table all these predictions for the Σ_c^{*++} mass lie within the interval 2.5-2.6 GeV, note that recent works predict the value occurring in the interval 2.530 -2.550 GeV. The problem of the Σ_c^{*++} width is of great importance for its experimental search. Fig.1 presents the dependence of the Σ_c^{*++} width on its mass, which has been calculated with the formula from ref.[15]. As it is clear from the plot, the width is approximately equal to 10 MeV in the Σ_c^{*++} mass interval we are interested in, which is quite comparable with our experimental resolution.

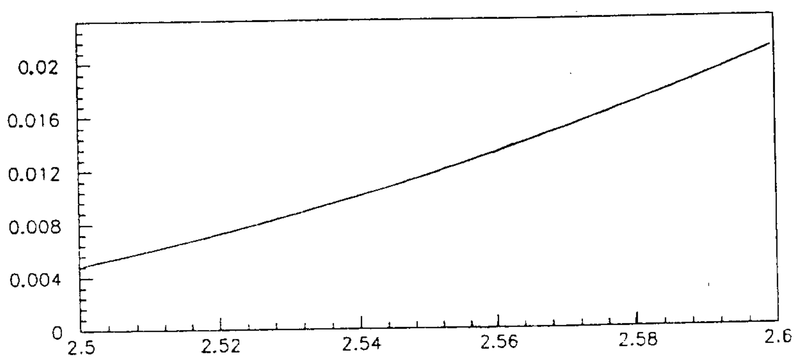

Figure 1. The dependence of the width Σ_c^{*++} on its mass (GeV).

3. EXPERIMENTAL PROCEDURE

The experiment was carried out with the bubble chamber SCAT in a wide-band neutrino beam at the proton energy 70 GeV. The most part of the statistics was obtained when propan-freon mixture (13% of freon) was used as working mixture, one third of the statistics was obtained with ethan-propan-freon

Table 1. The theoretical prediction for mass of Σ_c^{*++}

Model	Λ_c^+	Σ_c^{++}	Σ_c^{*++}
J.Basdevant et al. [9]	2.251	2.372	2.496
S.Samuel et al. [10]	2.282	2.431	2.594
C.Kalman et al. [11]	inp	2.424	2.499
Chiaki Iton et al. [12]	2.282	2.455	2.532
Kalinovsky et al. [13]	2.282	2.499	2.555
S.Fleck et al. [14]	inp	2.443	2.542

mixture. The properties of these mixtures are very close ($\lambda_{rad} = 52$ cm, interaction length for hadron $\simeq 120$ cm) and they provide quite good momentum reconstruction ($\Delta p/p = 0.02$, 0.08 and 0.20 for muons, hadrons and γ quanta, respectively), and quite nice detection efficiency for γ quanta ($\epsilon = 0.5$). The analysis is based on the statistics taken during several runs in 1987-1992, the total spill being $4 \cdot 10^{18}$ protons onto the target.

To suppress the background processes we selected the events that satisfied the following criteria:

-neutrino visible energy is higher than 3 GeV;

-muon momentum is larger than 0.5 GeV/c;

-the invariant mass of hadronic system is larger than 1 GeV/c^2.

12800 events of $\nu_\mu N$-interactions in charged current were detected, they satisfied the criteria mentioned above. 8% of the events were caused by neutrino interaction with hydrogen, 30% -due to neutrino interaction with proton inside the nucleus. To single out the quasi-elastic production of the $\Sigma_c^{(*)++}$ baryons we selected the events with the total charge +1. The charge particle multiplicity should not be less than 3, if V^0 is present in the detected event, as for the remaining cases, it should not be less than 5. The event should not contain more than one identified baryon: proton or Λ hyperon. The number of the γ quanta in the event should be even. At the stage of physical scanning protons and π^+ mesons were identified by ionization and their secondary interactions. The results of the kinematic analysis were used to identify Λ hyperons and K_s^0 mesons.

To select the events without undetected neutrons and γ quanta , as well as to suppress the combinatorial background we used the kinematic fitting procedure. The direction of neutrino motion was considered to be known. We also took into account the angular spread of neutrino which has earlier been determined in neutrino beam simulation for the conditions of our experiment. The 3C-fit was used to select the events on hydrogen. Since the main fraction of the events was caused by the neutrino interaction with proton inside the nuclei we worked out a special procedure. In this we assumed the proton momentum to be distributed according to the normal law with its mean value 180 MeV/c and dispersion σ = 46 MeV/c. Such parameters were chosen in accordance with the Fermi distribution for nucleon inside nucleus. The hypothesis was recognized if its probability was more than 0.5% and the fitted value for the proton momentum of the target was less than 230 MeV. Having both 3C-fit and 1C-fit, we preferred 3C-fit hypothesis.

When fitting events the π^+/p ambiguous tracks were treated with two mass hypothesis π^+ and p. In the events that did not contain V^0 particle, the negatively charged particles, which were not muons, were also treated with two mass hypothesis π and K. In each event we chose the hypothesis that had the highest probability out of all the hypothesis having one strange particle and one baryon in the final state. The fitted events allowed us to reduce 4 times the background from the events, which contained undetected neutral particles.

For the selected hypothesis we calculated the total hadronic mass M^{++} and the mass of hadronic system with exception of one π^+ M^+ and their difference $\Delta M = M^{++}$ - M^+. The mean errors for these quantities were equal to $< \sigma(M^{++}) >=< \sigma(M^+) > = 60$ MeV, $< \sigma(\Delta M) >$=15 MeV. Further on we selected the events, where M^+ differed from the tabulated value for the $\Lambda_c^+(2285)$ not more than by 2 error in M^+. After all limitations there left only 14 events.

To check the fitting procedure and selection criteria we simulated the events of the quasielastic production of charmed $\Sigma^{(*)++}$ baryons as well as of usual neutrino interactions. The chamber sizes and experimental resolution were taken into consideration in our simulation. The simulated events were kinematically fitted. The results of this fit made it clear, that in 90% of the cases the topology of the events, chosen in accordance with the criteria mentioned above, is true topology of the event.

4. EXPERIMENTAL RESULTS

Fig.2 presents the distribution over the mass difference for these events. We interpreted two events with Δ=(174 $\pm$ 2) MeV and (160 $\pm$ 5) MeV as the events of the Σ_c^{++} quasielastic production for which the tabulated value for the mass difference is equal to 168 MeV. In this case the background was $\sim 0.1 \div 0.2$ events. The probability for the imitation by the background was 0.1% for them. Then, we had a cluster of 6 events in the region of $\Delta = 220 \div 260$ MeV, which corresponded to the mass values M^{++}=2.520 -2.560 GeV. To estimate the background in this mass region such analysis was repeated with two shifted mass values Λ_c^+: M("Λ_c^+") - 2.085 GeV and 2.485 GeV. Our estimate was that the background in the M^{++}=(2.520-2.560) GeV was equal to 1 event.

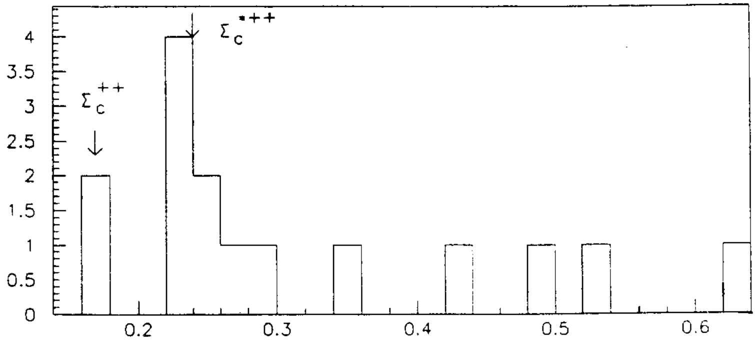

Figure 2. The distribution over mass difference (GeV).

Hence an excess of events in the mass region 2.520-2.560 GeV is observed, that we interpret as the very first observation of Σ_c^{*++} baryon production. The probability of the background simulation makes up 0.01%. Two of them contain a neutral strange particle in the final state (1 event with Λ hyperon and 1 - with K_s^0 meson). The background for the events with one neutral particle in the final state is equal to $\simeq$ 0.1 event. The probability of the background simulation for these events is also equal to 0.01%. The Σ_c^{*++} baryon mass estimated with these events is equal to $M(\Sigma_c^{*++}) = (2.530 \pm 0.005)$ GeV. The distribution of the $\Sigma_c^{++}, \Sigma_c^{*++}$ events over the kinematic variables Q^2, X and Y are in a satisfactory agreement with the expected ones.

We have also estimated the production cross section for Σ_c^{++}, Σ_c^{*++} baryon production. Photon conversion outside the fiducial volume of the chamber and the presence of poorly measured tracks ($\Delta p/p \geq 0.6$) is the main reason for loosing the events for the analysis. In the case with neutral particle additional losses are caused by their decay outside the effective volume of the chamber and decay in neutral modes. The efficiency of the event passing through the handling procedure was determined from the analysis of the simulated events of reactions (1) and (2). JETSET 6.3 program was used to simulate Λ_c^+ baryon decays. The total efficiency for the events containing K^- meson was estimated to be equal to 0.5, and for the events containing neutral strange particle, it was 0.2. With account for these efficiencies we obtain the estimates the cross sections for reactions (1) and (2) to be

$$\sigma(\nu p \to \mu^- \Sigma_c^{++}) = (2.3 \pm 2.0)10^{-40} \text{ cm}^2 \ ,$$

$$\sigma(\nu p \to \mu^- \Sigma_c^{*++}) = (4.5 \pm 4.0)10^{-40} \text{ cm}^2.$$

These results agree with the cross section estimates for the Σ_c^{++} production obtained with the bubble chamber BEBC[2]

$$10^{-40} \text{ cm}^2 < \sigma(\nu p \to \mu^- \Sigma_c^{++}) < 1.310^{-39} \text{ cm}^2 .$$

In conclusion we express our deep gratitude to the team of the IHEP machine, neutrino beam line, SCAT bubble chamber as well as to the staff of the film information handling department for their great help and participation in experiment.

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