PHYSICAL REVIEW C VOLUME 46, NUMBER 6 DECEMBER 1992

Production of $\Delta^{++}(1232)$ in carbon-carbon collisions at 4.2 GeV/c per nucleon

D. Krpić, J. Puzović, S. Drndarević, and R. Maneska
Faculty of Physics, University of Belgrade, 11000 Belgrade, Yugoslavia

S. Backović
Faculty of Physics and Mathematics, University of Podgorica, 81000 Podgorica, Yugoslavia

J. Bogdanowicz, A. P. Cheplakov, S. Y. Sivoklokov, and V. G. Grishin
Laboratory of High Energies, Joint Institute for Nuclear Research, Dubna, Russia
(Received 14 January 1992)

The production of the Δ^{++} resonance in high energy collisions of ^{12}C with the carbon nucleus, using a 2 m propane bubble chamber, was investigated. The technique for background estimation is proposed. The mass and the width of the resonance were obtained. The ratio between pion production from Δ^{++} and direct pion creation was estimated assuming that the $NN \to N\Delta$ process is dominant.

PACS number(s): 25.70.Ef, 14.20.Gk

I. INTRODUCTION

In high energy collisions of light nuclei at energies higher than a few GeV per nucleon, a considerable number of pions is produced. Carrying information concerning conditions under which they have been created, these pions are significant for understanding the mechanism of nucleus-nucleus collisions. However, directly produced pions have to be distinguished from those created later, mainly in baryon resonances decays.

The decay of the delta resonance is one of the most important mechanisms of pion production. In the model of independent nucleon-nucleon interactions, the delta resonance is predominantly created in the reaction $NN \to \Delta N$ which is concurrent with the processes of direct pion production: $NN \to NN\pi$, $NN \to NN\pi\pi$, $NN \to \Delta N\pi$, etc.

We analyzed the production process of Δ^{++}

$$pp \to \Delta^{++} n + k\pi \quad (k=0,1,\dots) \qquad \Delta^{++} \to p\pi^+ \tag{1}$$

Several earlier papers [1–4] suggest that the width and the mass of the delta resonance, produced in free high-energy nucleon collisions and in nucleus-nucleus collisions, could be different.

The intention of this paper is the test of this statement and the estimation of the $\Delta^{++}(1232)$ resonance production rate. A correct prediction of mass, width, and production rate of delta resonance could be helpful for the deeper understanding of delta's role in nucleus-nucleus collisions, and especially of its contribution to the pion spectrum.

II. EXPERIMENT

We have studied a Δ^{++} resonance production using data obtained at the 2 m propane bubble chamber exposed to the light ion beams at Dubna Synchrophasotron. 3421 inelastic interactions of ^{12}C with carbon nuclei at an incident momentum of 4.2 GeV/c per nucleon were selected. Pions and protons were satisfactorily separated using the momentum-range relation and the detection of $\pi^+\mu^+e^+$ decay. The measured momenta of protons and π^+ mesons were used to calculate the invariant mass of the $(p\pi^+)$ system, M, from the relation

$$M^2=(E_p+E_\pi)^2-(\mathbf{p}_p+\mathbf{p}_\pi)^2 \tag{2}$$

where E_p, E_π, $\mathbf{p}_p$, $\mathbf{p}_\pi$ are the total energy and momentum of proton and positive pion, respectively.

The experimental invariant mass distribution, dN/dM, for $(p\pi^+)$ pairs was produced using the following criteria: (a) The stripping protons—protons with momentum $p>3$ GeV/c and an angle between the beam and the emitted particle $\theta<4°$—were treated as spectators of the projectile and excluded. (b) The protons emitted from the target carbon nucleus during the process of evaporation (the protons with momentum $p<p_{\text{Fermi}}$) were eliminated. (c) According to the relation (1) the missing mass for all $(p\pi^+)$ pairs should be equal or greater than neutron mass. (d) All events should lie in the kinematically allowed region for pp interactions defined by the Byckling and Kajantie inequality [5]. These criteria should eliminate production of false, physically uncorrelated $(p\pi^+)$ pairs.

Applying criteria from (a) to (d), the initial invariant mass spectrum of 18 010 $(p\pi^+)$ pairs was reduced to 12 760. The corresponding invariant mass distribution (Fig. 1, solid line) has an obvious maximum. To check if this peak belongs to delta resonance, we made a Monte Carlo simulation of the background spectrum and compared it with the experimental one.

The procedure was the following: We calculated the invariant mass for $(p\pi^+)$ pairs randomly selected using a proton from one and a pion from another event (event mixing method). We respected the event topology in this way that we combined only events with equal positive particles multiplicities. All kinematic criteria from (a) to (d) were included. This procedure was repeated until the

 ©1992 The American Physical Society

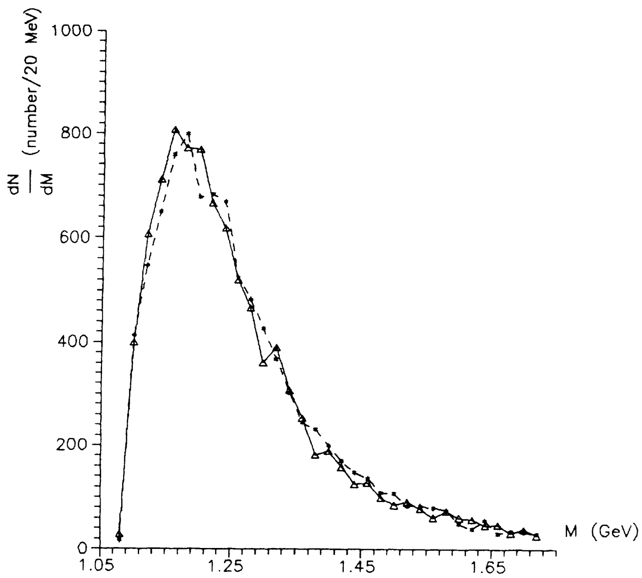

FIG. 1. The invariant mass distribution for $(p\pi^+)$ measured pairs in CC collisions at 4.2 GeV/c per nucleon (solid line), and the background distribution (dashed line).

total number of events became equal to the spectrum value; i.e., the background distribution was normalized to the number of pairs in the spectrum.

In this manner we obtained the uncorrelated background (Fig. 1, dashed line). The uncorrelated background evaluated by Monte Carlo simulation has very similar shape to the invariant mass distribution. This fact means that it is very difficult to extract a signal of delta and suggests that it is necessary to find some additional kinematic criteria.

We used as the additional criterion the angle α between the proton and pion from delta resonance decay in flight, defined by

$$\cos\alpha=\frac{1}{p_p p_\pi}\left\{\sqrt{(M_p^2+p_p^2)(M_\pi^2+p_\pi^2)}+\frac{M_\Delta^2-M_p^2-M_\pi^2}{2}\right\}, \tag{3}$$

where p_p and p_π are proton and pion momenta and $M_\Delta=1.232$ GeV. We compared this value with the cosine of the experimentally measured angle β

$$\cos\beta=\frac{\mathbf{p}_p\cdot\mathbf{p}_\pi}{p_p p_\pi}, \tag{4}$$

and kept only combinations satisfying the inequality

$$|\cos\beta-\cos\alpha|<\varepsilon \quad [\text{criterion}(e)]$$

where ε is an arbitrary cutoff parameter lying in the interval [0,2].

A set of experimental spectra was produced using various cutoff parameters (Fig. 2, solid line). If ε is low the statistics of invariant mass spectrum in the vicinity of the signal is poor and the effect of chosen mass of delta in (3) is too strong. For higher values of ε ($\varepsilon>1$), the shape of the distribution becomes similar to the distribution obtained without the criterion e. We estimated that the reasonable values of ε lie in the interval [0.1,0.6].

We also repeated the Monte Carlo simulation of the

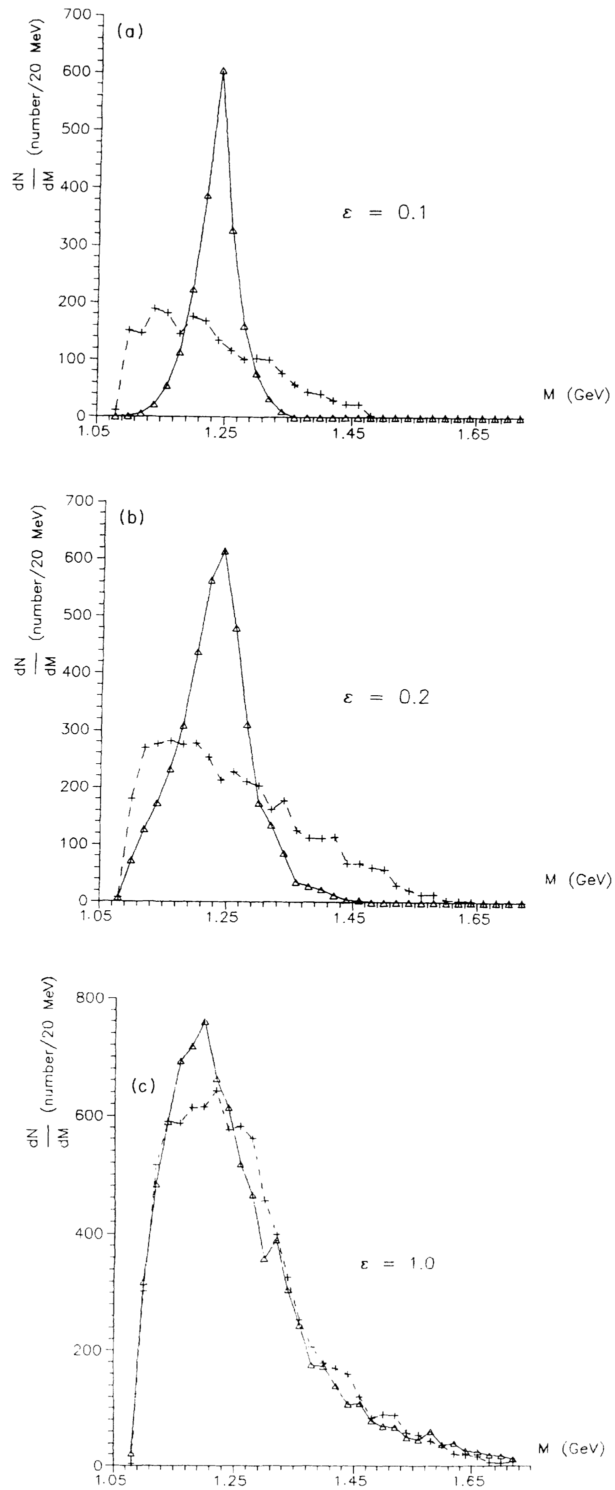

FIG. 2. The invariant mass distribution for $(p\pi^+)$ for correlated (solid line) and uncorrelated (dashed line) pairs for various values of the cutoff parameter. The ordinate axis shows a true number of pairs per 20 MeV.

background spectrum including the cutoff criterion (*e*). The uncorrelated background (Fig. 2, dashed line) is now quite different from the distribution obtained using correlated events, i.e., experimental spectrum.

To subtract the background contribution, we analyzed the distribution of the difference between invariant mass spectra for correlated and uncorrelated pairs, defined by

$$D(M)=\frac{dN}{dM}-a\frac{dN}{dM}^{\text{uncor}}, \tag{5}$$

where a is a normalization factor.

The normalization factor a is connected with delta production rate R, defined as the ratio of the number of π^+ which do originate from Δ^{++} and from other mechanisms, by the simple relation

$$R=1-a . \tag{6}$$

We determined the normalization factor a so that $\int D(M)dM=0$ for an invariant mass greater than 1400 MeV. In this region the contribution of delta is expected to be negligible (normalization to the tail of the spectrum). Figure 3 presents the $D(M)$ distribution for $\varepsilon=0.23$.

Interpreting the difference distribution $D(M)$ as a pure Δ^{++} signal, we approximated it by a modified classical Breit-Wigner shape [6]

$$b(M)=\frac{\Gamma M M_\Delta}{(M^2-M_\Delta^2)^2+\Gamma^2 M_\Delta^2}, \tag{7}$$

where M_Δ and Γ are the mass and the width of the resonance.

The data set $D(M)$ for each ε was fitted by the function $b(M)$ and the values of χ^2 was found for each fit. The parameters M_Δ and Γ were determined minimizing the difference $D(M)-b(M)$. In this way we got the set of two parameters for each experimental spectrum produced for the chosen value of the cutoff parameter ε.

The results are thus valid only on the assumption that the delta resonance has a Breit-Wigner shape.

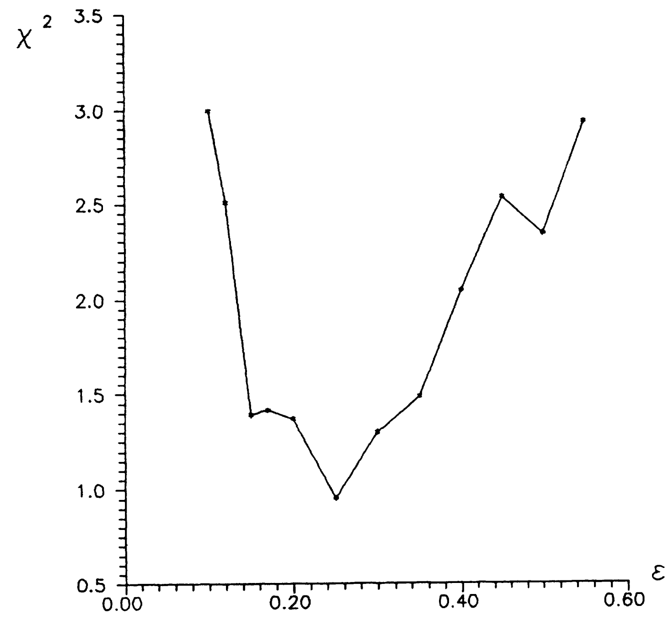

FIG. 4. The function $\chi^2(\varepsilon)$.

III. RESULTS

The best value of ε was determined from the behavior of the function $\chi^2(\varepsilon)$. The minimum of the χ^2, obviously seen in Fig. 4, suggests that $\varepsilon=0.23$. We estimated that, from the experimental error of momentum, $\Delta p/p \leq 3\%$, the uncertainty of ε is $\Delta\varepsilon \leq 0.03$.

Figures 5–7 show the main results for Δ^{++} production

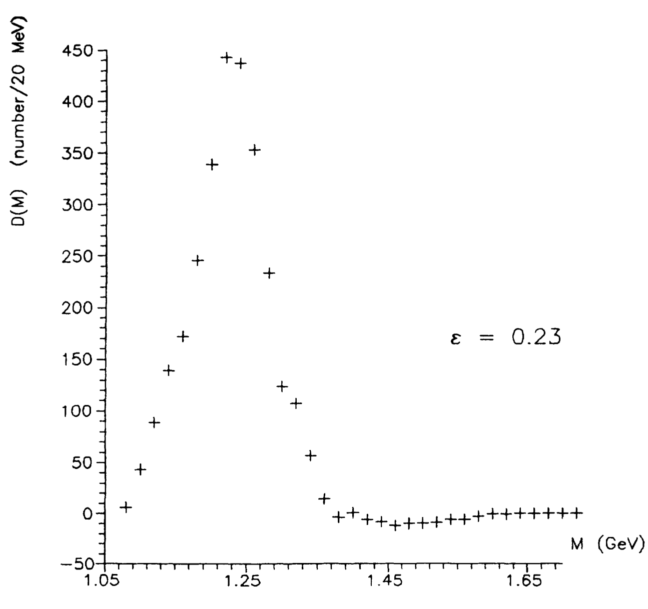

FIG. 3. The difference between invariant mass distribution and uncorrelated background for $(p\pi^+)$ pairs produced for the best value cutoff parameter ε (crosses).

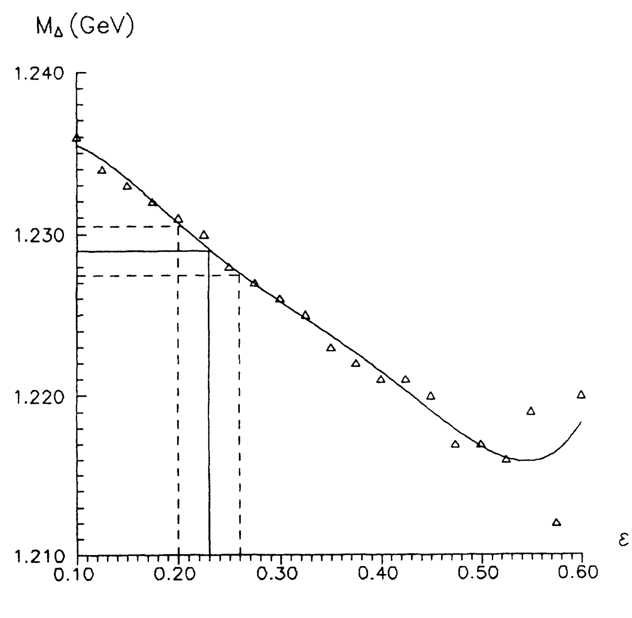

FIG. 5. The dependence of delta mass on the cutoff parameter. The solid line is a polynomial fit.

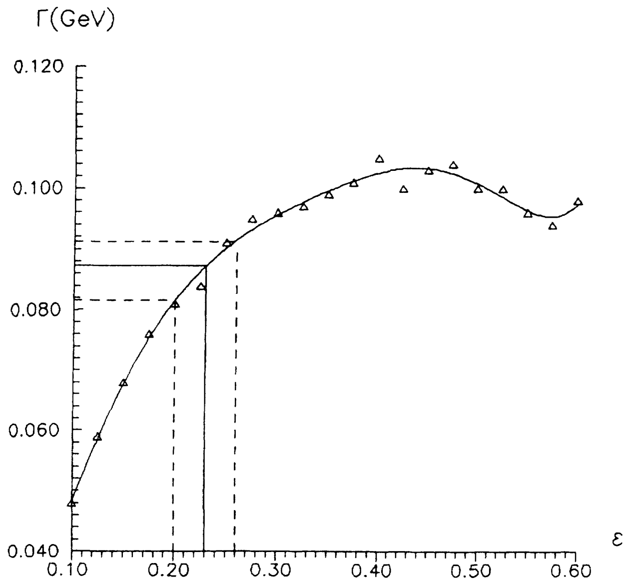

FIG. 6. The dependence of delta width on the cutoff parameter. The solid line is a polynomial fit.

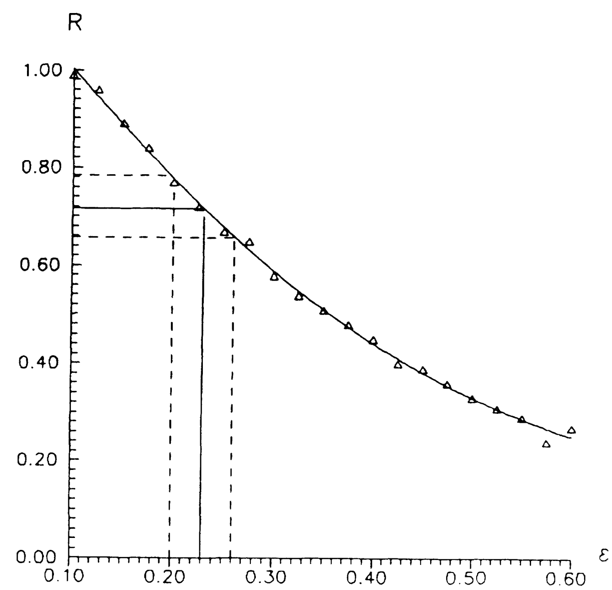

FIG. 7. The dependence of delta production rate on the cutoff parameter. The solid line is a polynomial fit.

in C-C collisions at 4.2 GeV/c per nucleon. The solid line is obtained by polynomial fitting the data. Figure 5 presents the dependence of M_Δ on the cutoff parameter. The mass smoothly decreases in the whole interval of ε. The width Γ (Fig. 6) increases, and for $\varepsilon=0.35$ becomes slightly sensitive to ε. The production rate R (Fig. 7) sharply decreases with increasing ε.

The experimental values for mass, width, and production rate of Δ^{++}, obtained by choosing the cutoff parameter ε according to the minimum of χ^2 value and results of the polynomial fit, are

$$M_\Delta = 1.229 \pm 0.006 \text{ GeV} ,$$

$$\Gamma = 0.087 \pm^{0.004}_{0.007} \text{ GeV} ,$$

$$R = 0.72 \pm 0.06 .$$

Errors were estimated from the uncertainty of ε, as also shown in Figs. 5, 6, and 7.

The resonant peak is, within the error limits, at the expected position (1.232 GeV). Within the error limits, the delta width Γ is slightly lower than that for free nucleons collision (0.115 GeV). Thus, our experiment cannot confirm some significant mass shift to lower values, neither a broadening of delta width. The rate R for Δ^{++} production has a relatively high value which means that a delta decay is a dominant mechanism of pion production.

[1] D. Contardo *et al.*, Phys. Lett. **168B**, 331 (1986).
[2] V. G. Abeleev *et al.*, Yad. Fiz. **48**, 27 (1988) [Sov. J. Nucl. Phys. **48**, 17 (1988)].
[3] M Trzaska *et al.*, GSI Report Darmstat 61 (1988).
[4] D. L. Hôte *et al.*, Contributed paper to Corine 90, Nantes, 1990 (unpublished).
[5] B. Byckling and K. Kajantie, *Particle Kinematics* (Wiley, London, 1973), p. 119.
[6] D. Higgins *et al.*, Phys. Rev. **D 19**, 731 (1979).