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# STUDY OF ISOBAR FORMATION IN CENTRAL INTERACTIONS AT 20.8 GeV/C

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## ABOUT ARTICLE

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**Abstract:** This work is devoted to the study of the formation of isobars in the interactions of protons with the nuclei of a photoemulsion irradiated with protons with a pulse of 20.8 GeV/s. Events with at least two relativistic particles ejecting at an angle of less than 170 were selected for research. At the same time, the presence of highly ionizing particles with a number of at least 8 was required. Pulse and ionization measurements were carried out on the traces of highly ionizing particles. The method of selecting pπ± stars is described. For stars in which the proton was accurately identified, 472 pπ+ and 340 pπ--pairs were collected. It was assumed that the leading Δ++(1232)-isobar could form in the identified pπ+-pairs, and the leading Δ°(1232)-isobar could form in the pπ--pairs. In the mass distribution of the pπ+ events, a significant excess over the background was observed in the range of 1.12 < M < 1.4 GeV. The cross-section for the formation of Δ++(1232)-isobars is σΔ++ = 79 ± 26 mbn. In the distribution of events by Mpπ-, the excess of events over the background was less significant, and the cross-section for the formation of the leading Δ°(1232) isobar was found to be σΔ° = 65 ± 51 mbn. Based on the data on the formation of Δ++- and Δ°-isobars in

central pAgBr-collisions at 20.8 GeV/c, it was concluded that most of the leading protons in such collisions are formed through the decay of isobars.

**Introduction.** Research into the interactions of high-energy particles with nucleons and nuclei is conducted using a wide variety of methods. A significant number of studies on particle interactions with nucleons and nuclei, for example, have been conducted in photographic emulsions. This is facilitated by the relative ease and low cost of conducting experiments with emulsions. When a new energy region emerges, such experiments are traditionally the first to be conducted on fixed nuclear targets. Undoubtedly, the development of experimental techniques in high-energy physics has led to methods for detecting particles and measuring their characteristics, which allow us to study the extremely subtle features of elementary particle interactions, even with very small cross sections. However, the creation of specialized equipment and setups for these purposes is extremely expensive.

Photographic emulsions are detectors with continuous sensitivity, capable of storing information over long periods of time. The main advantage of photographic emulsion is its high spatial and ionization resolution. This allows for precise geometric measurements, registration of recoil nuclei, short evaporation traces, slow electrons, etc.; ionization can be measured with sufficient accuracy. Pulsed measurements in emulsion at high energies are very difficult; the method of nuclear emulsions in a strong magnetic field is free from this drawback and allows for additional determination of the particle charge, although measurements of this type in photographic emulsion are difficult to automate. Pulsed and ionization measurements in photographic emulsion allow for identification of secondary shower particles [1]. Analysis of the elemental composition of nuclear emulsions shows that the emulsion mainly contains two widely separated groups of atoms: light ones - H, C, N, O and heavy ones - Ag, Br with a very small number of S, J, Au atoms. The complexity of the composition of the photographic emulsion substance does not allow for a clear answer to the question of which nucleus the interaction of the incident particle occurred with. It is eliminated by introducing additional elements and introducing criteria for selecting the events to be processed. A significant drawback is the low processing speed of the datasets. And, as a consequence, the need for a long time to collect statistics. However, as a rule, this is compensated by the obtained result [2-5], thereby allowing for the planning of electron experiments.

Of interest is the study of the characteristics of a special class of proton-nucleus (pA) interactions – central collisions, which result in more or less complete splitting of the target nucleus and, in the final state of the reaction, the formation of a sufficiently large number of fragments in the photographic emulsion.

The FRITIOF-1 model allows for a satisfactory description of a significant volume of experimental data on the general characteristics of pA interactions [6,7].The observed deviations of the model predictions from the experiment for the angular distributions of the produced particles can be attributed to the failure to take intranuclear cascades into account in the model.

For the experimental studies, a stack of Ilford K5 emulsions irradiated at CERN with protons with a momentum of 20.8 GeV/c was used. A total of 722 stars with the number of strongly ionizing particles nh ≥ 8 and having at least two shower particles with an emission angle Θ < 170 were selected. (It can be shown that particles emitted into the forward hemisphere in the c.m. of NN collisions in the laboratory system have an angle Θ less than 170). The number nh ≥ 8 was chosen as an experimental criterion for the centrality of a pA collision at 20.8 GeV/c, where nh is the total number of black nb and gray ng tracks in the star. Gray and black particles are collectively called strongly ionizing or h-particles and their multiplicity is nh = ng + nb;

To select pπ± stars in which the proton and π± meson have the highest momenta among shower particles with emission angles Θ < 170 , the least squares method [8] applied in [9] was used. In the present work, 331 stars with χ2min < 4 are analyzed. With this selection, 13.5% of pπ± stars are lost, and the contribution of other stars to the selected ones is 13.3%. The upper limit of pπ+ stars in which the proton and π+ meson are entangled is 45±7. In the pπ± star, all shower particles with Θ < 170 , except for one proton, were conditionally considered to be π± -mesons. Random stars prepared according to the model [10] were analyzed similarly. According to our experimental data, the numbers of collisions with heavy emulsion nuclei with nh ≥ 8 and nh < 8 are approximately the same. Since the FRITIOF-1 model does not take into account the processes of the low-energy intranuclear cascade, it is impossible to directly take into account the experimental limitations on the number of highly ionizing particles within the framework of this model and it is necessary to invoke additional considerations. For this purpose, we will use the phenomenological model [7], which makes it possible to establish a relationship between the number of intranuclear collisions of an incident particle ν or the impact parameter of a collision and the multiplicity of highly ionizing particles produced as a result of hadron-nucleus interactions. Using the model [10], 2425 collisions of protons with Ag and Br nuclei were simulated. From these, 1213 random stars with impact parameters less than

4 fm were selected for comparison with the experimental data for nh ≥ 8. However, instead of selecting random stars by the impact parameter, we use selection by nh.

**Search for δ(1232)-isobars in pπ±-stars.** One of the important questions in the physics of hadron-nucleus interactions is the formation of resonances, especially in the projectile fragmentation region (see, for example, [6]). Before investigating this question in the central interactions of protons with heavy emulsion nuclei at 20.8 GeV/c, which we consider, we examined the effect of secondary particle momentum measurement errors on the effective mass spectra. Using the Monte Carlo method, we drew random stars taking into account momentum measurement errors and under the assumption of N(1470)-isobar formation in (+-) events. For the distribution density, we used the Breit-Wigner formula. It turned out [9] that the histograms for M(pπ-), constructed taking into account momentum measurement errors, differ little from the true distribution. This allows us to conclude that momentum measurement errors do not change the shape of the Breit-Wigner curve.

For 331 stars in which the proton was accurately identified, we have 472 pπ+ and 340 pπ- pairs. It was assumed that a Δ++(1232) isobar could form in the identified pπ+ pairs, and a Δ°(1232) isobar in pπ- pairs. Our selection criteria make it possible to investigate the formation of leading Δ(1232) isobars (the proton momentum is the largest or second largest among σ-particles with ϴ < 17°). Figure 1 shows the distribution of (pπ+) pairs by invariant mass M.

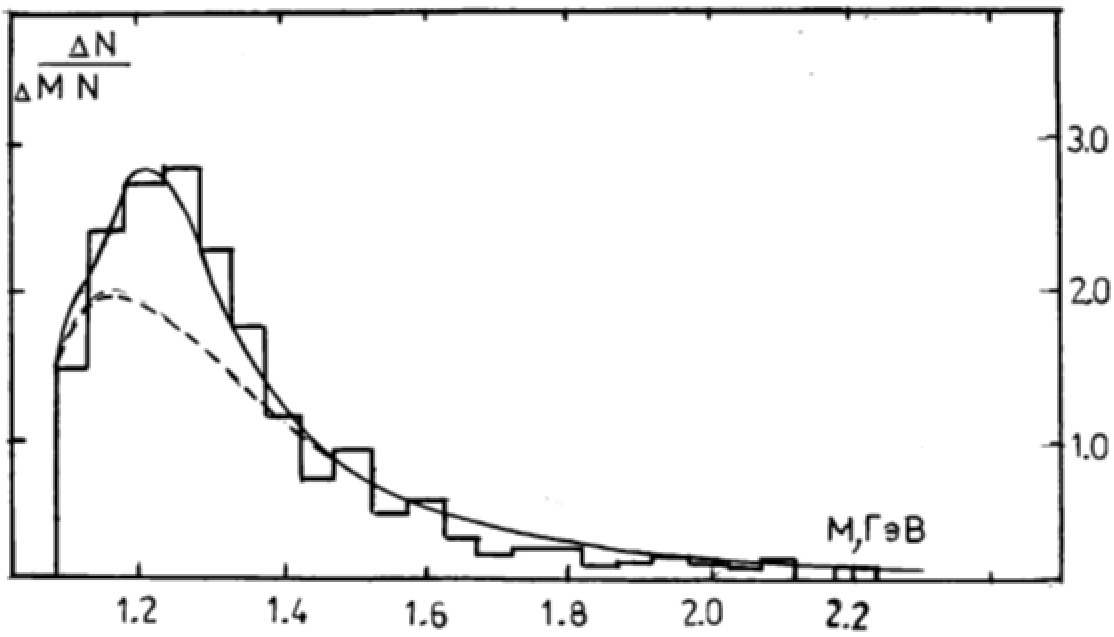


**Fig. 1. Distribution of the invariant mass M of pπ+ pairs (histogram – experiment, dotted line – background, curve – sum of background and Breit-Wigner curves).**

The background curve is constructed from combinations of proton and $\pi^+$ meson from different stars. Comparison of the experimental histogram with the background curve (see Fig. 1), normalized in the region M < 2.3 GeV, by $\chi^2$ gave $\chi^2$ = 13.4 with the number of degrees of freedom l = 7. When normalizing the histogram to the background outside the region 1.12 < M < 1.4 GeV, good agreement is observed: $\chi^2$ = 4.5 with 1 = 7. An excess of the experiment over the background is observed in the specified region. Assuming that this excess is associated with the formation of the Δ-isobar, we compared the experimental histogram in the region M < 2.3 GeV with the sum of the background curve and the Breit-Wigner distribution. The best agreement is achieved with the value of the share of the Breit-Wigner distribution α = 0.2, considered as a free parameter. The number of formed “leading” $\Delta^{++}$-isobars in the specified region turned out to be equal to

$$N = (N_1 – N_2S_1/S_2)/0.86 = 93 \pm 31, \qquad (1)$$

where $N_1$ is the number of $p\pi^+$-pairs in the region 1.12 < M < 1.4 GeV;

$N_2$ is the number of pairs outside this interval; $S_1$ and $S_2$ are the corresponding areas under the background curve; the factor 1/0.86 takes into account the loss of $p\pi^\pm$-stars during selection by $\chi^2_{min}$. Note that here we call “leading” isobars the decay of which leads to the formation of leading protons and $\pi^+$-mesons emitted at an angle θ < 17°. Hence, for the probability of formation of the "leading" $\Delta^{++}$-isobar in the central collision of a proton with a heavy nucleus of the emulsion we have

$$P_{\Delta^{++}} = 0.129 \pm 0.043. \qquad (2)$$

For the events obtained using the FRITIOF-1 model, a search for the $\Delta^{++}$-(1232)-isobar was performed, exactly the same as for the experimental ensemble of interactions. As a result of the analysis, it was found that in the selected stars the probability of formation of the "leading" $\Delta^{++}$-isobars is equal to

$$P_{\Delta^{++}} = 0.125 \pm 0.010. \qquad (3)$$

The obtained values of the number and probability of formation of the "leading" $\Delta^{++}$-isobars reflect the experimental limitations and therefore represent the lower limits of the corresponding quantities. Within the framework of the FRITIOF-1 model, the issue of the influence of experimental limitations on the efficiency of registration of the $\Delta^{++}$ isobar was investigated. It was found that the leading isobar detection efficiency under our experimental conditions was 0.61. Isobar losses are due to the fact that a significant portion of $\pi^{+}$-mesons from isobar decays may have $\Theta > 17°$ in l.s. It should be emphasized that in the central interactions of protons with emulsion nuclei under consideration at 20.8 GeV/c, projectile rescattering processes occur with a significant probability, leading to significant energy losses, so that the formed $\Delta^{++}$-isobars will not necessarily produce protons with very large (close to the primary) momentum values. Previously, in [12], the spectra of leading protons in pA and pN interactions were studied and it was concluded that in pA collisions these spectra are significantly “softer” and the number of fast protons in pA collisions at $x > 0.3$ (x is the Feynman variable $x = p/p_0$) decreases compared to pN collisions the more strongly the larger x. In this case, the decrease in the number of "leading" protons and the "softening" of their energy spectrum during the transition from pN to pA interactions is accompanied by an increase in their transverse momentum. All these features of the leading protons are quantitatively explained by multiple scattering models [13-14]. Therefore, the efficiency of recording $\Delta^{++}$-isobars W, under the adopted assumptions, was too low to detect their formation in the experiment ($W \approx 0.06$). Taking into account the efficiency of recording the leading $\Delta^{++}$-isobars, for their total number in 331 experimental p $p\pi^{\pm}$ stars we have

$$N_{\Delta^{++}} = 153 \pm 51. \qquad (4)$$

From here, for the cross section of formation of “leading” $\Delta^{++}$-isobars, we obtain

$$\sigma_{\Delta^{++}} = N_{\Delta^{++}} / L \Sigma ⍰_I = 79 \pm 26 \text{ mbn}. \qquad (5)$$

where L = 961 m is the length of the scanned track, ⍰I is the number of Ag and Br nuclei in 1 cm3 of emulsion, and for their average multiplicity

$$\bar{n}_{\Delta^{++}} = 0.21 \pm 0.07. \qquad (6)$$

**Conclusion.** Thus, a significant part of the leading protons in the collisions under consideration is formed from the decay of $\Delta^{++}$-isobars. If we take into account the formation of $p\pi^{\pm}$-isobars in experimental events in which their decay does not lead to the production of leading protons, then the total number of $\Delta^{++}$-isobars in 722 events is equal to

$$N_{\Delta^{++}} = 346 \pm 115, \qquad (7)$$

(where we assumed that the relative error in their number for 722 stars is the same as for 331 ($p\pi^{\pm}$) events), and for the cross section of their formation we have

$$\sigma = 178 \pm 59 \text{ mbn.} \quad (8)$$

For the average multiplicity of isobars in the considered central pAgBr collisions at 20.8 GeV/c we have

$$\bar{n}_{\Delta^{++}} = 0.48 \pm 0.16. \quad (9)$$

From the above analysis it is evident that in the central interactions of protons with heavy nuclei of the emulsion considered by us at 20.8 GeV/c, processes of projectile rescattering occur with a significant probability, leading to significant energy losses, so that the formed Δ++-isobars will not necessarily produce protons with very high momentum values. We also studied the question of the formation of Δ°-isobars in central pAgBr-collisions. For the number of Δ°-isobars, according to the experimental data, we obtained

$$N_{e\Delta^{\pm}} = 24 \pm 19. \quad (10)$$

Processing of theoretical events obtained using the Lund model gives for their number and detection efficiency (taking into account two Δ° decay channels) under the conditions of our experiment

$$N_{\Delta 0} = 47, W = 0.19. \quad (11)$$

Hence, for the true number of Δ°-isobars formed in 331(pπ++)-stars, we have

$$N_{e\Delta^{\pm}} = 126 \pm 100. \quad (12)$$

which corresponds to the cross-section for the formation of “leading” Δ0-isobars

$$\sigma = 65 \pm 51 \text{ mb.} \quad (13)$$

Based on the data on the formation of Δ++- and Δ°-isobars in central pAgBr-collisions at 20.8 GeV/c, we can conclude that the majority of the leading protons in such collisions are formed due to the decay of isobars [15].

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