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SCALING EFFECTS AND PROPERTIES OF DELTA-ISOBAR RESONANCES

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Масштабные эффекты и свойства дельта-изобар

Предложена простая модель для описания свойств дельта-изобар как двойных резонансов формы.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Ratis Yu.L., Gareev F.A. E2-92-3

Scaling Effects and Properties of Delta-Isobar Resonances

A simple model is suggested for the description of the gross properties delta-isobars based on the twofold shape resonances.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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1 Introduction

Despite of the abundant theoretical and experimental publications (see for example [1, 2] and references therein) devoted to study the excitations of nucleon and subnucleon degrees of freedom, the Δ-isobar excitations are of great interest. Such interest is mainly due to an enigmatic selectivity of the Δ-isobar excitations. Indeed from the fact of presence of the P_{33}-resonance in the πN-scattering it is follow logically that this resonance will be excited in the nucleon-nucleon collisions while in the nucleon-nucleus collisions the same phenomenon should be much less pronounced. It is naturally to wait that first of all a lot of the soft low-lying states in nuclei will be excited by the nucleon-nucleus collision. However one observed in the experiment the pronounced Δ-isobar peak (see, for example, the (p,n) [3] and $(^3He, t)$ [4, 5] reaction data on nuclei) on the nonresonance background due to the "soft" processes. Therefore the display of the pronounced Δ-isobar peak in the reactions of type $(N, N')_\Delta$ can be considered as an analog of the giant resonances. If we remember the existence of the shape resonance than it is natural to search the characteristic quantities having dimensions of length which can help us to understand the problem of the selectivity of the Δ-isobar excitations and the systematics of the Δ-resonance.

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2 Resonances and stationary waves

As a rule, the resonances in the wave systems arise if the ratio of the effective radius l_{eff} of resonating system ("well") to the length λ of the corresponding wave is equal to:

$$l_{eff} = n\lambda, \tag{1}$$

where n=1,2,3,...

We should like to analyze the spectrum of the Δ-isobar (see Baryon Summary Table in [6]). From this table we can conclude, neglecting the effects of the L-dependence and spin-orbital interaction, that the spectrum contains four multiplets being away from each other on ~ 400 MeV. Such oscillator-like character of the gross-structure of the Δ-spectrum admits us to assume that the Δ- resonant states of the πN system can be approximately described by the oscillator potential with the parameter $< r_0 >= \sqrt{\hbar/m\omega} \sim 0.86$ fm, which is close to the electromagnetic radius of the nucleon.

Table 1

Scaling properties of the Δ-isobars. Here $P_\pi(lab)$ is the projectile-pion momentum in the laboratory system corresponding to the maximum of Δ-resonance cross section in the πN-scattering, $P_\pi(cm)$ the same momentum in the center of mass, $\tilde{P}_\pi(cm)$ is the pion momentum from the Δ-decay in the Δ-isobar rest frame, $< r_0 >= \sqrt{\hbar/m\omega} = 0.86$ fm.

Resonances	$P_\pi(lab)$ (scatt.) (GeV/c)	$P_\pi(cm)$ (scatt.) (GeV/c)	$\tilde{P}_\pi(cm)$ (decay) (GeV/c)	$1/\tilde{P}_\pi(cm)$ (fm)	$< r_0 > /n$ (fm)
Δ(1232)	0.30	0.210	0.227	0.867	0.86/1=0.86
Δ(1620)	0.91	0.523	0.526	0.38	0.86/2=0.43
Δ(1900)	1.44	0.709	0.710	0.28	0.86/3=0.29
Δ(2420)	2.64	1.022	1.023	0.19	0.86/4=0.21

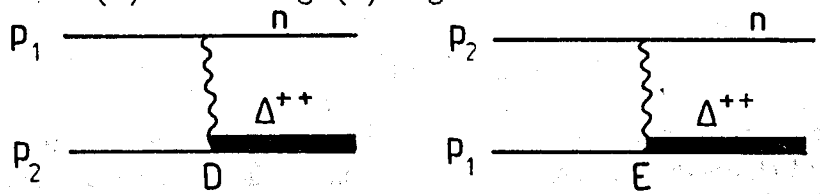
For the pions emitted from the Δ-isobar decay the values of the momenta in the Δ-isobar rest frame do not contradict to the such estimation and coincide practically with the analogous values of momenta for the pion beam (see Table 1) exciting the Δ-resonances. Besides this the momenta of the emitted pions are with good accuracy equal to the

momentum $\tilde{P}^0_\pi(cm) \sim 0.23$ GeV/c ($\tilde{P}^0_\pi(cm)$ means the pion momentum from Δ(1232) decay) multiplied to the integer. The momentum $\tilde{P}^0_\pi(cm)$ defines the nucleon size, $1/\tilde{P}^0_\pi(cm) \sim 0.86$ fm.

Therefore the above-mentioned arguments tell us in favour that the Δ- isobars are the shape resonances in πN-scattering.

3 Δ-resonances in nucleon-nucleon scattering

The characteristic features of the nucleon-nucleon scattering with the Δ -isobar excitation are the following: 1) the Δ-isobars are excited by the virtual pions and not by the real pions and 2) the colliding nucleons are the identical particles and therefore in the reaction $NN \to N\Delta$ two coherent processes give the contribution. For example the charge-exchange reaction $p + p \to n + \Delta^{++}$ is described by the superposition of the direct (D) and exchange (E) diagrams



Therefore, unlike from the free πN-scattering, in the reaction $(p,n)_\Delta$ and analogous processes the two characteristic scales have to correspond to two invariant transfer momenta

$$t_d = (P_1 - P_n)^2 = (P_2 - P_\Delta)^2 \equiv t, \tag{2}$$

$$t_{ex} = (P_2 - P_n)^2 = (P_1 - P_\Delta)^2 \equiv u, \tag{3}$$

where t and u are the standard Mandelstam variables. We can introduce the some distances corresponding to these variables

$$r_d = 1/\sqrt{-t_d}, \tag{4}$$

$$r_{ex} = 1/\sqrt{-t_{ex}}. \tag{5}$$

As one can see from Fig.1, for the all main Δ-isobars (Δ(1232), Δ(1620), Δ(1900) and Δ(2450) the values r_d and r_{ex} for the charge-exchange reaction $p + p \to n + \Delta^{++}$ at $\theta = 0°$ are close only in the vicinity of the Δ-isobar creation threshold (at the threshold u=t, $s = s_{min}$, where $s = (P_1 + P_2)^2$ is the third Mandelstam-squared invariant mass of the system). With increasing the projectile-proton energy the value of r_d increases rather quickly while the value of r_{ex} decreases slowly. The starting points of r_d for the different isobars change unevenly (roughly speaking according to ∼1/n, where n=1, 2, 3, 4 for the Δ(1232), Δ(1620), Δ(1900) and Δ(2420) respectively). The same is valid for the values of r_{ex} with the exception that the amplitudes of these jumps are essentially less and r_{ex} lies in the region $0.2 \leq r_{ex} \leq 0.3$ fm that is sufficiently close to the value of the characteristic "hard" size of the nucleon: $r_q \sim 0.2$ fm. The quantity r_q can be interpreted as the radius of the hard core or of the Jastrov correlations as the radius of the constituent quark or somewhat like this. We will call r_q further as the size of nucleonic constituents without a concrete interpretation.

It is useful to introduce the characteristic functions:

$$\delta x_d \equiv 1 - (\frac{r_d - < r_0 >}{< r_0 >})^2, \quad (6)$$

$$\delta x_{ex} \equiv 1 - (\frac{r_{ex} - r_q}{r_q})^2. \quad (7)$$

The energy dependence of δx_d and δx_{ex} exhibits rather prominent resonant character; the positions of maxima of the δx_d and δx_{ex} coincide for the Δ(1232)-isobar case (we used $< r_d >= 0.86$ fm and r_q=0.18 fm). The curves $\delta x_d(T)$ and $\delta x_{ex}(T)$ are correlated with each other and also with the function

$$\tilde{\sigma_\Delta}(T) \equiv \sigma_{p+p\to n+\Delta^{++}}(T)/\sigma^{max}_{p+p\to n+\Delta^{++}}(T), \quad (8)$$

describing the energy dependence of the total P_{33}-resonant creation cross section [6].

The positions of maxima of the δx_d and δx_{ex} becomes different with increasing of the Δ-isobar mass; the maximum of δx_{ex} approaches rapidly to the Δ-isobar creation threshold and comes to the kinematically forbidden region of the Δ(2450).

The above-mentioned behaviour of quantities δx_d and δx_{ex} can be interpreted in the following way. At the energy region $T \approx 1$ GeV the "direct" virtual pion comes in the resonance with the nucleon as whole

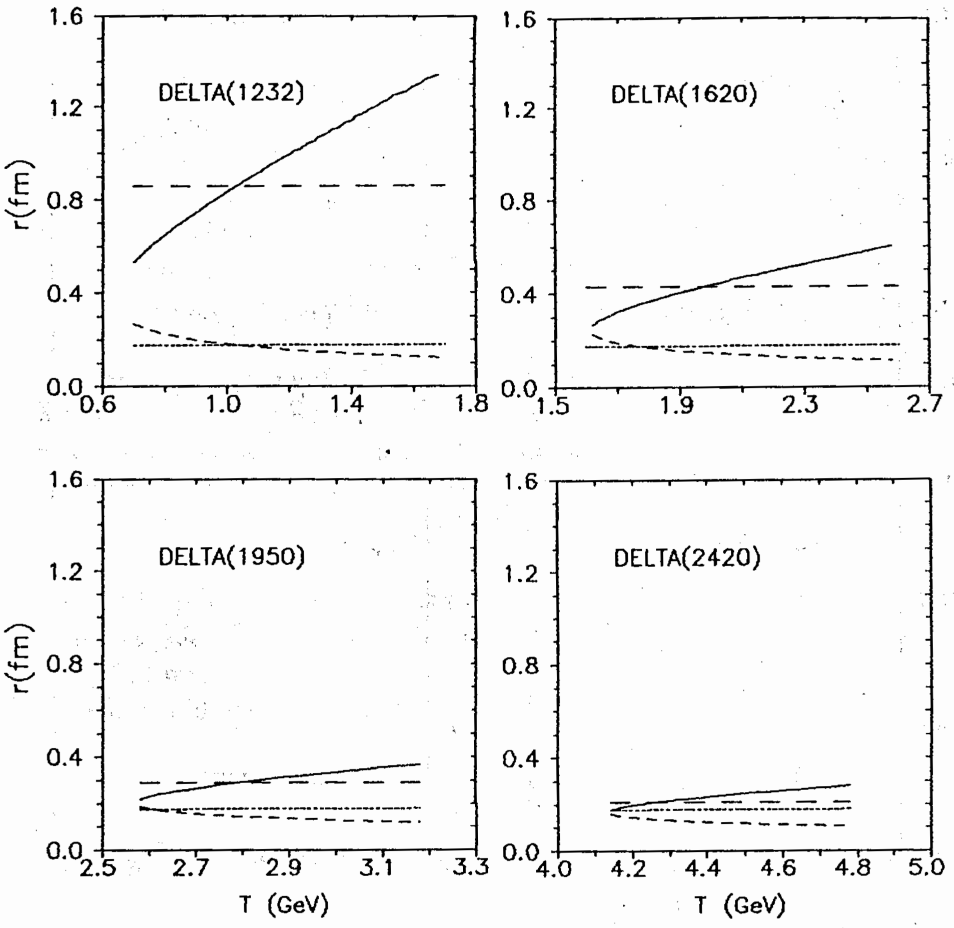


Fig.1 The energy dependence of the direct radius r_d (solid curves) and exchange one r_{ex} (dotted curves). The long-dashed lines correspond to the "nucleon" size $< r_0 >$=0.86 fm while the short-dashed-r_q=0.18 fm.

while the "exchange" virtual pion comes simultaneously in the resonance with the constituent of nucleon. The constructive interference between the "direct" and "exchange" amplitude lead to the resonance amplification of the Δ-isobar creation cross section and also to the remarkable increasing of the total and inelastic cross section for the p+p collision

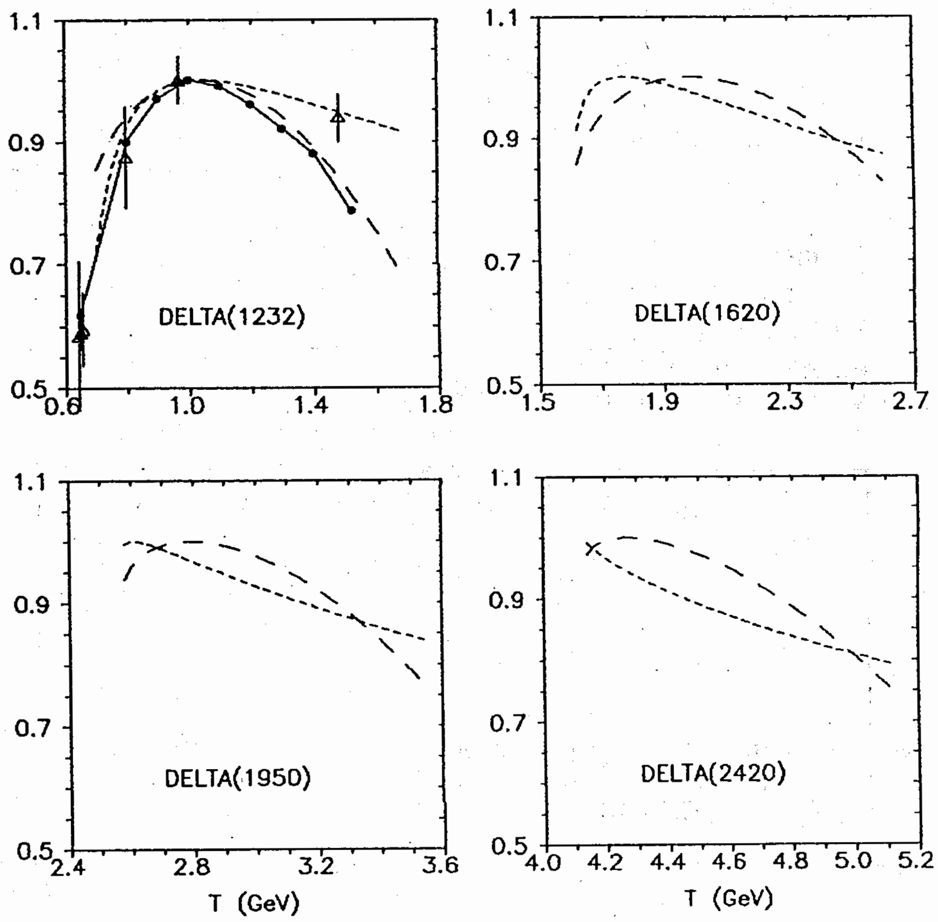


Fig.2 The energy dependence of the functions δ_d (long-dashed curves), δ_{ex} (short-dashed curves). The triangles (bullets) correspond to the total cross sections of the reaction $p+p \rightarrow n+p+\pi^+$ $(p+p \rightarrow n+\Delta^{++})$ normalized to the unity in the maximum [6].

[3]. With the increasing beam energy the "direct" and "exchange" resonances move apart from each other; therefore the $\Delta(1232)$-isobar is excited weakly at $T_p > 3$ GeV. The formation of heavier Δ-resonances in proton-proton collisions is always suppressed due to the destroying of the resonance conditions for the "direct" and "exchange" amplitude.

4 Conclusion

We conclude, that the selective excitation of the $\Delta(1232)$-isobar in the energy region $T_p \sim 1$ GeV can be considered as a display of the twofold shape resonance. From the point of view of the scattering theory such resonance can be interpreted as an anomalous amplification of the process due to the fulfillment of condition for the simultaneous resonance interaction in the final (initial) states of the two pairs of particles [7] (in our case the interaction of the virtual pions with the nucleon and constituent).

The suggested twofold scaling model of the Δ-isobar creation allows us also to explain qualitatively the disappearance of the heavier Δ-resonances. Indeed, in accordance with the Table 1 the condition

$$\frac{< r_0 >}{n} \geq r_q, \qquad (9)$$

does not fulfil at n=5 this means that the wave length of the pion becomes smaller than the size of constituent and the wall of the "nucleonic potential well" is screened by r_q.

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