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ЦЕНТРАЛЬНЫЙ НАУЧНО-ИССЛЕДОВАТЕЛЬСКИЙ ИНСТИТУТ  
ИНФОРМАЦИИ И ТЕХНИКО-ЭКОНОМИЧЕСКИХ ИССЛЕДОВАНИЙ  
ПО АТОМНОЙ НАУКЕ И ТЕХНИКЕ

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EXOTIC HYPERONS IN SUM RULES  
FOR REGGEONS SCATTERING ON PARTICLES

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ЭКЗОТИЧЕСКИЕ ГИПЕРОНЫ В ПРАВИЛАХ  
СУММ ДЛЯ РАССЕЯНИЯ РЕДЖЕОНОВ НА ЧАСТИЦАХ

Сверхсходящиеся правила сумм (СПС) для амплитуд рассеяния реджеонов на частицах применяются к исследованию взаимодействия гиперонов с  $\rho$ ,  $A_2$ ,  $\pi$  - реджеонами. Продемонстрированы предсказательные возможности метода СПС. Показано, что рассматривая рассеяние на  $\Lambda$  - гиперонах, можно прийти к выводу о существовании  $\Sigma$  и  $\Sigma^*(1385)$  - гиперонов. Предсказания СПС для отношения ширины распадов  $\Sigma^*(1385) \rightarrow \Sigma\pi$  и  $\Sigma^*(1385) \rightarrow \Lambda\pi$  хорошо согласуются с экспериментом. Последовательное применение метода СПС к процессам рассеяния реджеонов с  $I = I$  на гиперонах со странностью  $S = -I$  приводит к предсказанию экзотических состояний с  $I > 2$ . В частности, при  $I = 2$  предсказывается существование двух резонансов со спинами  $S = 5/2$ ,  $3/2$  и положительной странностью. Анализируются свойства этих резонансов и возможности их экспериментального поиска в реакциях рассеяния назад, а также в процессах на  $\Sigma$  - пучках. Даются теоретические оценки сечений этих процессов. Обсуждаются результаты применения СПС к процессам рассеяния реджеонов с  $I = I$  на гиперонах со странностью  $S = -2$  и  $-3$ .

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The superconvergent sum rules (SSR) for the reggeon-particle scattering amplitudes are applied to the investigation of interaction of hyperons with  $\rho, A_2, \pi$ -reggeons. The predictive possibilities of the SSR method are demonstrated. It is shown that from the sum rules for the  $I=1$  reggeons scattering on  $\Lambda$ -hyperons follows the existence of  $\Sigma$  and  $\Sigma^*(1385)$  hyperons. The SSR prediction for the  $\Sigma^*(1385) \rightarrow \Lambda \pi$  and  $\Sigma^*(1385) \rightarrow \Sigma \pi$  decays ratio agrees well with experiment. The successive application of the SSR method to  $I=1$  reggeons scattering on hyperons with strangeness  $S=-1$  leads to the prediction of the exotic states with  $I \geq 2$ . In particular, for  $I=2$ , two resonances with spins  $S=5/2, 3/2$  and positive parity are predicted. The properties of these resonances are analyzed. The experiments to search for them in backward scattering and in  $\Sigma$ -beam processes are proposed. The theoretical estimations of these processes cross sections are given. The application of the SSR to the processes of  $I=1$  reggeons scattering on hyperons with strangeness  $S=-2$  and  $-3$  is discussed.

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It is shown that from the sum rules for the reggeon-particle scattering amplitudes follows the existence of the multi-quark hyperon resonance series with strangeness  $S = 1, -2, -3$  and increasing spins and isospins. The properties of these resonances are investigated and the possibilities of their experimental search are discussed.

### Introduction

The problem of exotic (multi-quark) states has recently acquired a peculiar significance. The existence of exotic resonances is predicted in a variety of theoretical models: in the Chew-Low bootstrap model [1], in the model of bags [2], strings [3], in the dual [4] and quasi-nuclear [5] approaches, in the soliton model of baryons [6]. The problem of exotic states may turn out crucial for the verification of adequacy of one or another approach.

The superconvergent sum rules (SSR) approach for the amplitudes of reggeons scattering on particles with arbitrary spin and isospin has been developed in Refs. [7, 8]. The application of this approach to the scattering of  $I = 1(\rho, \rho_2, \pi)$  reggeons on nuclei and  $\Delta_{33}$ -isobar has led to the prediction of the existence of a series of exotic baryons with isospin  $I > 5/2$ , spins  $S=I$  and positive  $P$ -parity [9-11]. Active experimental investigation of these states are now carrying out at present at JINR and IHEP. The results of these experiments point out the existence of a group of resonances with

$I = 5/2$  [62-15]. The width of the lowest resonance ( $E_{SS}$ -resonance) agrees with the value predicted from SSR, and the angular distributions do not contradict both  $S = 5/2$  and positive parity.

Of great interest is the application of the SSR method to study the question on the existence of exotic baryons with non-zero strangeness. The present report is devoted to this question. Section 1 deals with the sum rules for the scattering of reggeons with  $I=1$  ( $\rho$ ,  $A_2$ ,  $\pi$ ) on hyperons with strangeness  $S=-1$ . It is shown that considering the reggeon  $\Lambda$  hyperon scattering, one can conclude that there should exist two strange hyperons with  $I=1$ . The properties of these hyperons predicted from SSR allow one to identify them with the well-known  $\Sigma(1385)$  and  $\Sigma$ -hyperons. A successive application of the SSR method to the scattering of  $I=1$  reggeons on hyperons with strangeness  $S=-1$  leads to the prediction of exotic hyperons with  $I \geq 2$ . Two resonances with spins  $S = I + 1/2$  and  $S = I - 1/2$  and with positive parity are predicted at each isospin state. In Section 2, the properties of states with  $I=2$  are discussed and the experiments are proposed where an effective search for these states is possible. Section 3 deals with the results of SSR as applied to the investigation of scattering processes on hyperons with strangeness  $S = -2, -3$ .

### 1. SSR and Hyperons with $S = -1$ Strangeness

In the investigations of the strong interactions the crossing-antisymmetric superconvergent dispersion relations for the

reggeon-particle scattering helicity amplitudes can be successfully used. The saturation of these relations by the contributions of  $S$  - and  $u$  - channels resonances,  $d_s$  and  $d_u$ , results in numerous equations (sum rules) for helicity residues of reggeons (Fig.1).

$$\sum_{d_s} G_{\lambda_a \lambda_{d_s}}^{\alpha_i d_s} G_{\lambda_{d_s} \lambda_b}^{d_s \alpha_k} - \sum_{d_u} G_{\lambda_a \lambda_{d_u}}^{\alpha_k d_u} G_{\lambda_{d_u} \lambda_b}^{d_u \alpha_i} = 0$$

Fig. 1

The main problem in the sum rules physics is the choice of the saturation scheme. In Ref.[9] the SSR for the processes  $\alpha_i a \rightarrow \alpha_k b$  ( $a, b = N, \Delta_{33}$ ;  $i, k = \rho, \rho_2, \pi$ ) were considered. It was shown that the saturation scheme, where each  $S(u)$  channel isospin state  $I_{S(u)}$  is saturated by the contribution of single state (nucleon in  $I_{S(u)}=1/2$  and  $\Delta_{33}$  in  $I_{S(u)}=3/2$ ), is self-consistent and leads to predictions which agree well with experimental data.

Let us now discuss the saturation scheme in the case of scattering on hyperons with  $S = -1$ . Consider the reactions

$$\alpha_i \Lambda \rightarrow \alpha_k \Lambda \quad (1.1)$$

of  $I = 1$  reggeons scattering on  $\Lambda$ -hyperon which is the lowest state among baryons with  $S = -1$ . Saturate the sum rules for these reactions by contributions of resonances  $\sum_m$ . Next consider SSR for reactions (1.1) and

$$\alpha_i \Lambda \rightarrow \alpha_n \Sigma_m \quad (1.2)$$

$$\alpha_i \Sigma_m \rightarrow \alpha_k \Sigma_n \quad (1.3)$$

saturating  $I_{S(u)} = 0$  by contribution of  $\Lambda$ , and  $I_{S(u)} = 1$  by those of  $\Sigma_m$ .

The analysis shows that SSR for reactions (1-1)-(1.3) can be saturated by the contribution of two states in  $I_{S(u)} = 1$ :

$\Sigma^*$  with spin  $S = 3/2$ ,  $\Sigma$  with  $S = 1/2$  and positive parity. As in the case of  $N$  and  $\Delta_{33}$  [9] the SSR solution is self-consistent in the limit  $M_{\Sigma^*} = M_{\Sigma} = M_{\Lambda}$ . Identifying  $\Sigma^*$  and  $\Sigma$  with the well-known  $\Sigma^*(1385)$  and  $\Sigma$ -hyperons, we get the SSR prediction for the decay widths ratio

$$\frac{\Gamma_{\Sigma^*(1385) \rightarrow \Lambda \pi}}{\Gamma_{\Sigma^*(1385) \rightarrow \Sigma \pi}} = 8,4 \quad (1.4)$$

which agrees with the experimental data. Such agreement testifies to the correctness of the chosen saturation scheme\*).

The consideration of SSR scattering of  $I = 1$  reggeons on and  $\Sigma^*(1385)$  hyperons leads to the conclusion that two exotic states with  $S = -1$  and  $I = 2$ :  $S_E (S = 3/2)$ ,  $S_E^* (S = 5/2)$  must exist. Analyzing the scattering on  $S_E$  and  $S_E^*$  one can show that the states with  $I = 3$  should be taken into account to

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\*) The consideration of the sum rules for the amplitude  $B$  of  $\pi \Sigma \rightarrow \pi \Sigma$  scattering shows [16] that the contribution of high-lying states to this amplitude is indeed small.

satisfy SSR. A successive use of this procedure leads to the conclusion of the existence of two series of resonances ( $\begin{smallmatrix} I \\ S=I-1/2 \end{smallmatrix}$ ) and ( $\begin{smallmatrix} I \\ S=I+1/2 \end{smallmatrix}$ ). SSR allow one to determine the interaction properties of these resonances and, in particular, their decay widths.

$$\left[ \begin{smallmatrix} I \\ S=I-1/2 \end{smallmatrix} \right] \rightarrow \left( \begin{smallmatrix} I-1 \\ S=I-1-1/2 \end{smallmatrix} \right) + \pi = (G^{\Sigma^* \pi \Lambda})^2 |\vec{p}|^3 \frac{I-1}{2\pi I} \quad (1.5)$$

$$\left[ \begin{smallmatrix} I \\ S=I+1/2 \end{smallmatrix} \right] \rightarrow \left( \begin{smallmatrix} I-1 \\ S=I-1+1/2 \end{smallmatrix} \right) + \pi = (G^{\Sigma^* \pi \Lambda})^2 |\vec{p}|^3 \frac{2I-1}{2\pi(2I-1)} \quad (1.6)$$

$$\left[ \begin{smallmatrix} I \\ S=I+1/2 \end{smallmatrix} \right] \rightarrow \left( \begin{smallmatrix} I \\ S=I-1/2 \end{smallmatrix} \right) + \pi = (G^{\Sigma^* \pi \Lambda})^2 |\vec{p}|^3 \frac{1}{2\pi(I+1)(2I+1)} \quad (1.7)$$

## 2. Properties of $S_E$ and $S_E^*$ Resonances

Let us dwell at greater length on the properties of the exotic hyperons  $S_E$  and  $S_E^*$  with  $I=2$ . The decay modes of these hyperons are

$$\begin{array}{l} S_E \begin{cases} \rightarrow \Sigma + \pi \\ \rightarrow \Sigma^*(1385) + \pi \end{cases} \\ S_E^* \rightarrow \Sigma^*(1385) + \pi \end{array}$$

Table 2.1 lists the values of these decays widths at different values of  $M_{S_E}$  and  $M_{S_E^*}$ .

$M_{S_E}$ (MeV)	$\Gamma_{S_E \rightarrow \Sigma \pi}$ (MeV)	$\Gamma_{S_E \rightarrow \Sigma^* \pi}$ (MeV)	$M_{S_E^*}$ (MeV)	$\Gamma_{S_E^* \rightarrow \Sigma^* \pi}$ (MeV)
1600	240	2	1600	28
1700	470	9	1700	130
1800	780	20	1800	320

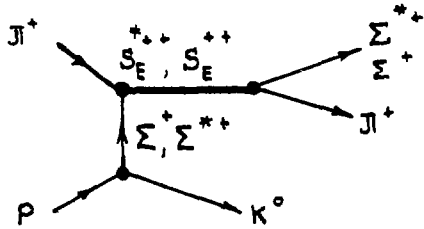


Fig. 2.1

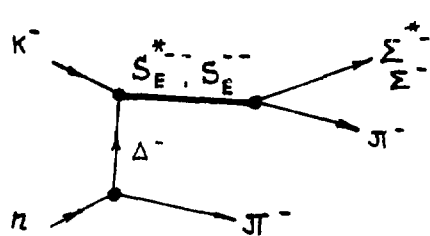


Fig. 2.2

For the experimental study of  $S_E$  and  $S_E^*$ , the backward scattering processes on  $\pi$  and  $K$  beams should be efficient [10]. The diagram corresponding to these processes are shown in Figs. 2.1 and 2.2.

The use of the  $\Sigma$ -beams will enable one to proceed active search for the  $S_E$  and  $S_E^*$  states in the forward scattering processes. For example, to observe  $S_E^{--}$  and  $S_E^{*-}$  one should study the reactions shown in Figs. 2.3 and 2.4.

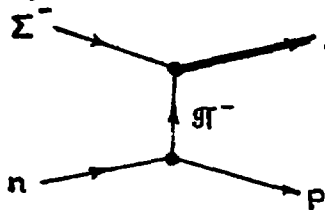


Fig. 2.3

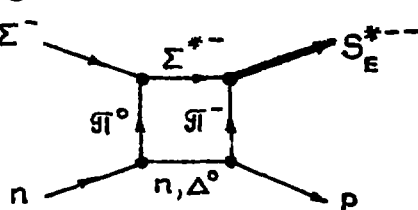
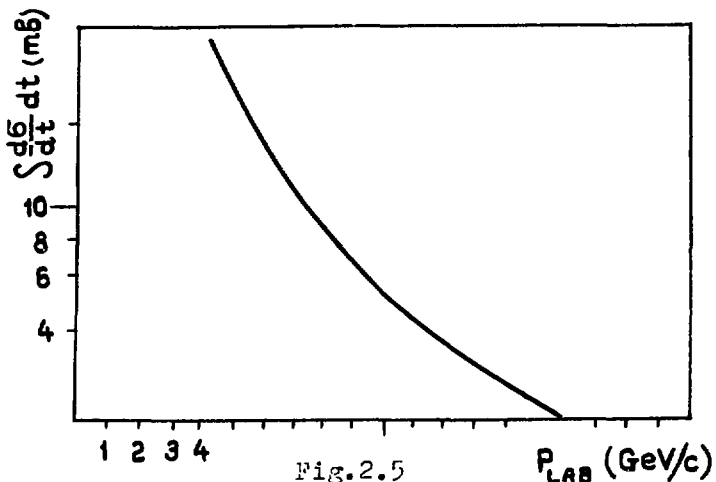


Fig. 2.4

Using the SSR predictions one can estimate theoretically the cross section corresponding to the mechanism shown in Fig.2.3. Fig.2.5 presents the results of our calculations.



As is seen from Fig.2.5, the efficient search for the strange exotic resonances is possible in the reactions on  $\Sigma$ -beams in the wide range of energies. The production mechanism of  $S_E^*$  in the reactions on  $\Sigma$  beams is analogous to that of  $E_{55}$  in the NN-collisions [17]. The calculations of the cross section corresponding to the diagram of Fig. 3.4 have been carrying out at present.

### 3. SSR and Hyperons with $S=-2,-3$

The problem of saturation of the sum rules for scattering of  $I=1$  reggeons on  $\Xi$  and  $\Omega$  hyperons seem to be more complicated. Consider, first, the scattering on  $\Xi$  hyperons. Since isospin  $I_{\Xi} = I_N$ , then the minimum saturation scheme in this case can be analogous to the case of the scattering on nucleon and  $\Delta_{33}$  [9,10], where isospin  $I_{S(u)}=1/2$  was saturated by the contribution of  $N$ , and  $I_{S(u)}=3/2$  by that of  $\Delta_{33}$ -isobar. In

the case of  $S = -2$  the state with  $I = 3/2$  is exotic. Thus, there exists a general solution of SSR completely coincides with [11]. there arises however the question of  $\Sigma^*$  isobar, which drops out of the consideration. The lack of the experimental information doesn't allow one to carry out the analysis of the resonances contribution to the amplitude  $B$  of  $\pi\Sigma \rightarrow \pi\Sigma$  scattering, which can verify the correctness of the chosen saturation scheme, as in the case of  $\pi N \rightarrow \pi N$  [18] and  $\pi\Sigma \rightarrow \pi\Sigma$  [16] scatterings. In this connection, we have considered the version where both  $\Sigma$  and  $\Sigma^*$  hyperons contribute to  $I_{S(U)} = 1/2$ . The SSR general solution has in this case a rather complicated form. Note only, that at such "input", there arise three resonances in the exotic state with  $I = 3/2$ . The further iteration brings us to two solutions. One of them corresponds to the case when at each  $I$  three resonances with spins  $I-1, I, I+1$  are needed, and in the second one the number of resonances increases with  $I$ . Note that the choice of one or another saturation scheme depends on the relation between  $G^{\Sigma\pi\Sigma}$  and  $G^{\Sigma\pi\Sigma^*}$ . For example, in the version of fixed number of resonances in each the value

$$x = G^{\Sigma\pi\Sigma} / G^{\Sigma\pi\Sigma^*} = \sqrt{3} \quad (3.1)$$

is predicted, while in the second version

$$x = \sqrt{3}/2 \quad (3.2)$$

As to the scattering of  $I = 1$  reggeons on  $\Omega$ -resonance, both  $S$  and  $U$ -channel states have only exotic quantum numbers ( $S = -3, I = 1$ ). In this case, there is a self-consistent saturation scheme, where the contribution of three states with  $S = 1/2, 3/2$  and  $5/2$  and positive parity should be taken into account.

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ЭКЗОТИЧЕСКИЕ ГИПЕРОНЫ В ПРАВИЛАХ СУММ ДЛЯ РАССЕЯНИЯ  
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