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STUDY OF COHERENT DIFFRACTIVE PRODUCTION REACTIONS OF $p + C \to [Y^0 K^+] + C$ TYPE AND OBSERVATION OF THE NEW BARYONIC STATES $X(2050) \to \Sigma(1385)^0 K^+$ and $X(2000) \to \Sigma^0 K^+$

SPHINX Collaboration (IHEP–ITEP)

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Abstract

Golovkin S.V. et al. Study of Coherent Diffractive Production Reactions of $p+C \to [Y^0K^+]+C$ Type and Observation of the New Baryonic States $X(2050) \to \Sigma(1385)^0K^+$ and $X(2000) \to \Sigma^0K^+$: IHEP Preprint 94-78. – Protvino, 1994. – p. 21, figs. 10, tables 1, refs.: 18.

In the experiments at the SPHINX facility in 70 GeV proton beam of the IHEP accelerator the coherent diffractive production reactions on carbon nuclei $p + C \to [\Sigma(1385)^0K^+] + C$ and $p + C \to [\Sigma^0K^+] + C$ were studied. In the effective mass spectrum $M(YK)$ of the first reaction $X(2050)$ peak with mass $M = (2052 \pm 6)$ MeV and width $\Gamma = (35^{+22}_{-35})$ was observed (with $C.L. > 6{\div}8$ standard deviations) and in the second reaction $X(2000)$ state with $M = 1999 \pm 7$ MeV and $\Gamma = 91 \pm 17$ MeV ($C.L. > 10\,s.d.$) was clearly seen. The unusual features of these massive states (small enough decay widths, anomalously large branching ratios for decays with strange particles emission) make them very serious candidates for cryptoexotic pentaquark baryons with hidden strangeness.

Аннотация

Головкин С.В. и др. Исследование когерентных дифракционных реакций типа $p + C \to [Y^oK^+]+C$ и наблюдение новых барионных состояний $X(2050) \to \Sigma(1385)^oK^+$ и $X(2000) \to \Sigma^oK^+$: Препринт ИФВЭ 94-78. – Протвино, 1994. – 21 с., 10 рис., 1 табл., библиогр.: 18.

В опытах на установке СФИНКС исследовались когерентные дифракционные реакции $p + C \to [\Sigma(1385)^oK^+] + C$ и $p + C \to [\Sigma^oK^+] + C$ при энергии E_p=70 ГэВ. В спектре масс $\Sigma(1385)^oK^+$ в первом из этих процессов наблюдена структура $X(2050)$ с $M = (2052 \pm 6)$ МэВ и $\Gamma = 35^{+22}_{-35}$ МэВ (степень достоверности $> 6 \div 8\ \sigma$), а в спектре масс Σ^oK^+ во второй реакции – структура $X(2000)$ с $M = 1999 \pm 7$ МэВ и $\Gamma = 91 \pm 17$ МэВ (степень достоверности $> 10\ \sigma$). Сравнительно узкая полная распадная ширина этих состояний и преобладающий вклад их распадов с испусканием странных частиц делает их серьезными кандидатами в криптоэкзотические барионы со скрытой странностью $|qqqs\bar{s}>$.

1. Introduction

In the experiments of the SPHINX Collaboration a wide program of studying the hadron diffractive production by protons with $E_p = 70\,\mathrm{GeV}$ and search for exotic baryons in these processes is carried out. This program has been detailed in review [1].

As it is stated in a number of papers, the diffractive production processes with the Pomeron exchange offer new perspectives in searching for exotic hadrons (see [1–6]). Originally these possibilities were considered in connection with a model of Pomeron with small cryptoexotic ($qq\bar{q}\bar{q}$) component [2, 3]. In modern notions Pomeron is a multigluon system offering the possibility of exotic hadron production in diffractive processes according to diagrams in Fig. 1. Certainly, as it is apparent from the Pomeron exchange mechanism, only the states with the same charges and flavors as those of the primary hadrons can be produced in these processes. Moreover, the quantum numbers of the states to be produced must satisfy the Gribov-Morrison spin-parity selection rule $\Delta P = (-1)^{\Delta J}$. Here ΔP and ΔJ represent the change in parity and spin in the transition from the primary hadron to the diffractively produced hadronic system. According to this rule, in the proton diffractive dissociation only baryonic states with natural set of quantum numbers $J^P = \frac{1}{2}^+; \frac{3}{2}^-; \frac{5}{2}^+; \frac{7}{2}^-$; etc. can be excited. True enough, the Gribov-Morrison rule is not a rigorous law and has an approximate character.

The Pomeron exchange mechanism in diffractive production reactions opens the possibility to study the coherent processes on the target nucleus where it acts as a unit. These coherent processes are easily identified in the study of the events distribution in the transverse momentum of the secondary particle system. They are seen as diffractive peaks with large slope values related with the radius of atomic nucleus: $\mathrm{d}N/\mathrm{d}P_\mathrm{T}^2 \simeq \exp(-bP_\mathrm{T}^2)$, where

$b \simeq (8 \div 10) A^{2/3}\,(\mathrm{GeV}/c)^{-2}$. It has been suggested that the coherent production on nuclei is a good tool for the separation of resonances against multiparticle background because of the difference in the absorption of single-particle and multiparticle objects in the target nuclei (see, for example, Ref. [7]).

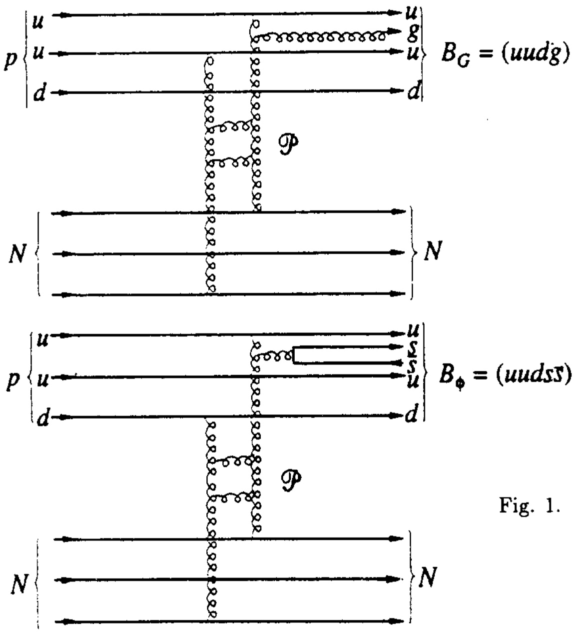

Fig. 1. The diagrams for the exotic baryon production in the diffraction processes with Pomeron exchange (Pomeron is a multigluon system).

In this paper the new data are presented on the search for cryptoexotic baryons with hidden strangeness in the diffractive coherent reactions on carbon nuclei

$$p + C \to \quad [\Sigma(1385)^0 K^+] + C, \qquad (1)$$
$$\hookrightarrow \Lambda\pi^0$$

and

$$p + C \to \quad [\Sigma^0 K^+] + C. \qquad (2)$$
$$\hookrightarrow \Lambda\gamma$$

The SPHINX facility [8], which is used in these measurements, includes a wide-aperture magnetic spectrometer with scintillation counter hodoscopes, proportional chambers, drift chambers and multichannel γ-spectrometer with lead glass total absorption detectors. The charged particles in the final state were identified by means of a RICH differential Cherenkov spectrometer and two threshold gas multicell Cherenkov counters. The detailed description of the apparatus, as well as the measurement procedure, the data processing and the first experimental results are presented in the previous papers of the SPHINX Collaboration, see Refs. [8–14].

2. Cryptoexotic baryons

Cryptoexotic baryons do not have external exotic features and their complex internal valence structure can only be established indirectly by examining their anomalous dynamic properties (such as small decay widths, unusual decay branching ratios and so on).

The searches for heavy baryons with anomalously narrow decay widths, would they be successful, make it possible to obtain the best evidence of cryptoexotic baryon states. In this connection let us consider the properties of multiquark baryons with hidden strangeness $B_\phi = |qqqs\bar{s}\rangle$, where $q = u$ or d quarks. Theoretical possibilities for the existence of such states are rather uncertain. If, for example, the mass of the baryon with hidden strangeness is smaller than $M(\Lambda) + M(K)$ ($< 1.6\,\mathrm{GeV}$), this state can decay only through OZI suppressed processes and it must be very narrow. Its possible decay modes are $B_\phi \to N\pi; N\pi\pi$.[1] The observation of such state is very difficult due to background from the numerous baryonic isobar decays. Moreover, because of rather large constituent mass of strange quark it seems unlikely that the mass value of B_ϕ is smaller than $1.6\div1.7\,\mathrm{GeV}$. For more heavier B_ϕ baryons with hidden strangeness the main decay modes are with two strange particles in the final states (such as $B_\phi \to YK$) or with particles with large hidden strangeness valence component ($B_\phi \to p\phi; p\eta; p\eta'$). Certainly in all these decay modes the emission of additional pions is possible.

If such cryptoexotic baryon with a complicated internal structure consists of two colored parts separated in space because of a centrifugal barrier, then its decay into the color singlet final states may be suppressed. The properties of multiquark exotic baryons with internal color structure

$$|qqqq\bar{q}\rangle_{1c} = |(qqq)_{8c} \odot (q\bar{q})_{8c}\rangle \tag{3}$$

(color octet bonds)

[1]If $M(B_\phi) > 1.5\,\mathrm{GeV}$ the decay mode $B_\phi \to p\eta$ is also possible because of a large $s\bar{s}$ component in the valence structure of η-mason (the ideal mixing in the pseudoscalar meson nonet is badly broken).

or

$$|qqqq\bar{q}\rangle_{1c} = |(qq\bar{q})_{\bar{6}c} \odot (qq)_{6c}\rangle \, , \tag{4}$$
(color sextet – antisextet bonds)

are discussed in Refs. [3, 15, 16]. Here subscripts 1_c, 8_c and so on specify the representations of the color $SU(3)_c$ group.

Depending on the mechanism of quark rearrangement of the decay states the decay probability may be greatly reduced. Thus, such heavy states, in principle, can have anomalously narrow decay widths (of the order of several tens of MeV). The theoretical predictions here are quite arbitrary (see, for example, Refs. [15–17]). So the question of the existence of such narrow baryon resonances with hidden strangeness can be resolved only by experiments. The existing data in this field are quite limited and can not answer this question (see, for example, review [1]). Thus it seems quite desirable to perform the further search for cryptoexotic $|qqqs\bar{s}\rangle$ baryons with hidden strangeness and with anomalous dynamic features which are quite different from the properties of usual (qqq)-isobars in [18]. These anomalous features are:

1. heavy enough baryonic mass ($M \geq 1.8 \div 2$ GeV) with narrow enough decay width ($\Gamma \leq 50 \div 100$ MeV);
2. the main decay modes of these baryons are with strange particles in the final states (for usual isobars branching ratios for the decays with strange particles are at several percent level).

The SPHINX data on reactions (1) and (2) are used in the search for exotic baryons.

3. Study of the reaction $p + N \to \Sigma(1385)^0 K^+ + N$ and the observation of the state $X(2050) \to \Sigma(1385)^0 K^+$

The study of the reaction $p + N \to \Sigma(1385)^0 K^+ + N$ was described in detail in our previous publications [9, 10]. Here we briefly recall that for the selection of this reaction at the first stage of the data processing the events with 3 charged particles and 2γ clusters in the photon detector were chosen, which must satisfy the requirements for the identification of the $p\pi^- K^+$ system in the RICH counter (see Ref. [8]) and for the detection of the π^0-meson in the γ-spectrometer ($0.10 < M(\gamma_1\gamma_2) < 0.17$ GeV).

For the events with $(p\pi^- K^+\pi^0)$ production a constrained procedure for the definition of the energy and coordinates of the photons was used with the tabulated value of the π^0 mass, the resolution of the γ-detector being taken into account (the π^0 mass constraint).

As a result of this analysis the process

$$p + N \to (p\pi^-\pi^0K^+) + N \tag{5}$$

was finally singled out with total energy which satisfied the "elastic" requirement for energy

$$65 < E_p + E_{\pi^-} + E_{\pi^0} + E_{K^+} < 75\,\mathrm{GeV} \tag{6}$$

($\sim$ 6000 "elastic" events of (5)). As was shown from the study of two-dimensional distribution in effective masses $M(\pi^-p)$ and $M(\pi^0p)$ in this process (see Fig. 2), the main contribution to the events of type (5) resulted from the hyperon decays $\Lambda \to p\pi^-$ and $\Sigma^+ \to p\pi^0$. The decay path for Λ hyperons was limited to $\sim$ 30 cm by trigger requirements. The detection of the decay $\Sigma^+ \to p\pi^0$ was possible practically over the whole decay base for Σ^+ hyperons.

Thus, in the analysis of reaction (5) the processes with Λ- and Σ^+-hyperons were identified

$$p + N \to [\Lambda\pi^0K^+] + N, \quad \Lambda \to p\pi^- \tag{7}$$

$$p + N \to [\Sigma^+\pi^-K^+] + N. \quad \Sigma^+ \to p\pi^0 \tag{8}$$

In Fig. 3 the effective mass spectrum of the $\Lambda\pi^0$ system in reaction (7) is presented. In this spectrum the peak of $\Sigma(1385)^0 \to \Lambda\pi^0$ is dominating. The background level under the $\Sigma(1385)^0$ peak is quite small. This fact simplifies the identification of the reaction

$$p + N \to [\Sigma(1385)^0K^+] + N \tag{9}$$

because there is no need to subtract background in this case.

In our previous works [9, 10] the search for the baryon $N_\phi(1960) \to \Sigma(1385)^0K^+$ in reaction (9) was performed, as well as in the partially inclusive inelastic process

$$p + N \to [\Sigma(1385)^0K^+] + N + (\text{neutral particles}). \tag{10}$$

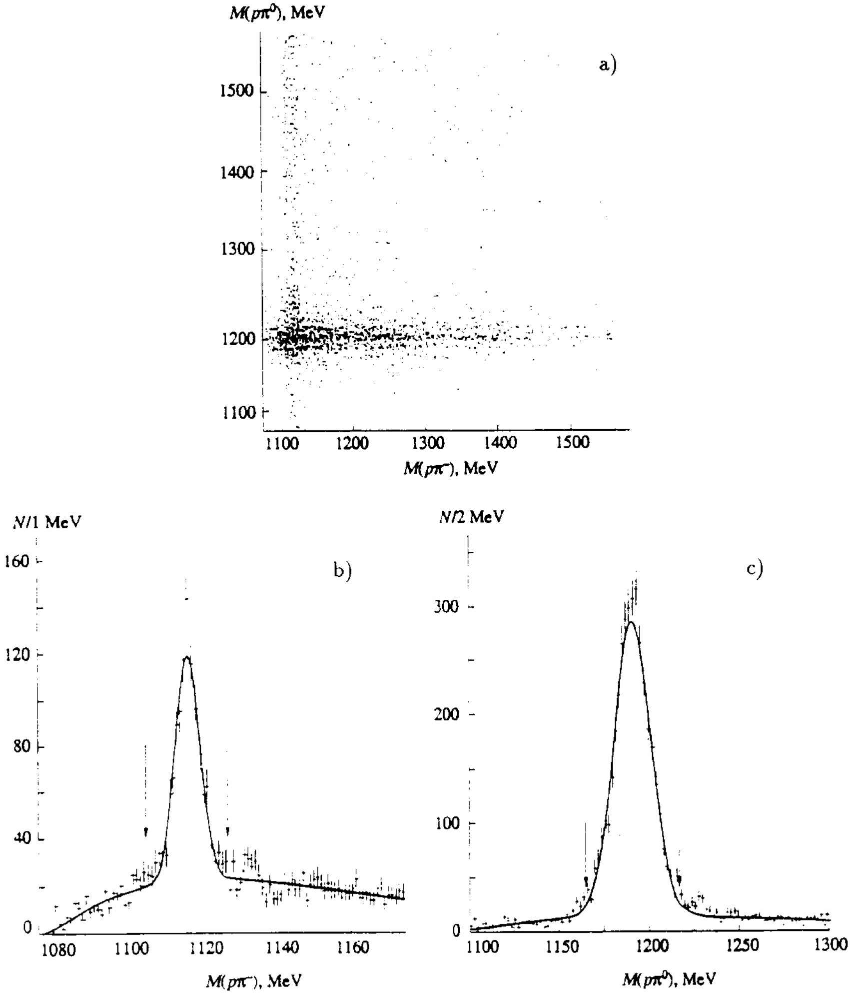

Fig. 2. The analysis of the events of the reaction $p + N \to (p\pi^-\pi^0K^+) + N$: a) the biplot distribution of events over $M(p\pi^-)$ and $M(p\pi^0)$; b) the invariant mass spectrum of $p\pi^-$ system (the signal from the decay $\Lambda \to p\pi^-$); c) the invariant mass spectrum of $p\pi^0$ system (the signal from the decay $\Sigma^+ \to p\pi^0$). As it is clear from this figure, the main contribution to the reaction under study is connected with the production and decay of Λ and Σ^+ hyperons.

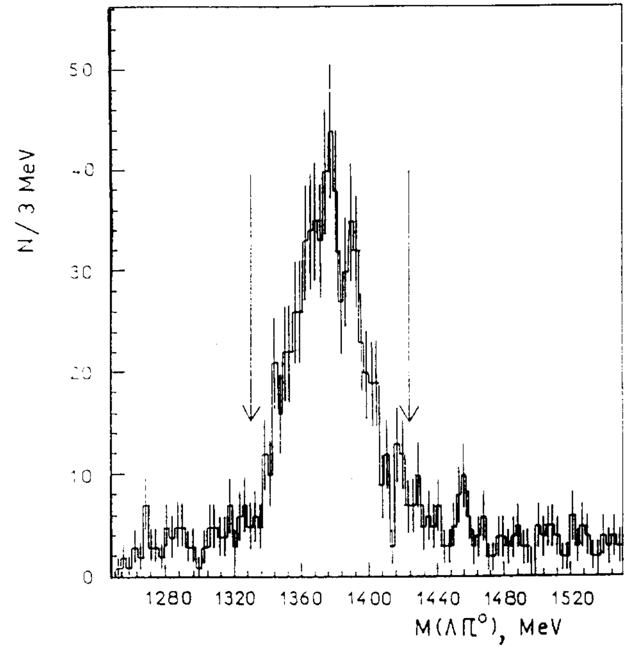

Fig. 3. The invariant mass spectrum of the $\Lambda\pi^0$ system in the reaction $p+N \to (\Lambda\pi^0 K^+)+N$. The parameters of the $\Sigma(1385)^0$ peak are $M = 1377 \pm 3\,\mathrm{MeV}$ and $\Gamma = 39 \pm 3\,\mathrm{MeV}$. They are in agreement with tabulated values of these parameters (with the account of the apparatus mass resolution $\sigma = \pm 9\,\mathrm{MeV}$ and systematic errors). The arrows indicate the region of the $\Sigma(1385)$ band.

The $N_\phi(1960)$ baryon with mass $M = 1956^{+8}_{-6}\,\mathrm{MeV}$ and width $\Gamma = 27 \pm 15\,\mathrm{MeV}$, a candidate for cryptoexotic state with hidden strangeness, was observed earlier by the BIS-2 group in the reaction of $[\Sigma(1385)^- K^+]$ production in the diffractive dissociation of neutrons with an average energy of $\langle E_n \rangle = 40\,\mathrm{GeV}$ [6]. In the SPHINX experiment we have not seen the $N_\phi(1960)$ state either in "elastic" reaction (9) or in inelastic process (10). The upper limits for the cross sections of $N_\phi(1960)$ production in (9) and (10) were established which are significantly lower than the corresponding cross section from BIS-2 data. Strictly speaking, there is no direct contradiction between these two results, because they have been obtained for somewhat different processes.[2] But it seems that the large difference between the cross section values, as well as very

[2]But we must conclude that the statement in Ref. [6] about the diffactional character of $N_\phi(1960)$ production in the BIS-2 measurement is incorrect.

poor background conditions for the separation of $\Sigma(1385)$ and $N_\phi(1960)$ in the BIS-2 measurements rise some doubts in the real existence of this anomalously-narrow baryon (see [9, 10, 12] for more detailed discussions).

We studied the event distribution dN/dP_T^2 for reaction (9) as a function of the transverse momentum squared P_T^2. As it is seen from Fig. 4 the dominant role of the coherent production of $[\Sigma(1385)^0K^+]$ system (with slope $b \geq 30\,(\mathrm{GeV}/c)^{-2}$) is evident for this reaction. Thus by the cut of $P_T^2 < 0.075\,(\mathrm{GeV}/c)^2$ it is possible to obtain the final separation of coherent reaction (1) and to produce the effective mass spectrum of $M[\Sigma(1385)^0K^+]$ for this process. This mass spectrum is presented in Fig. 5a. There is a structure "X(2060)" with mass $M \simeq 2060\,\mathrm{MeV}$ and width $\Gamma \simeq 120\,\mathrm{MeV}$ in this spectrum.

The nature of "X(2060)" structure needs further study. It is feasible to interpret it as a result of some resonance production, but it is also possible to explain the observed shape of the mass spectrum by nonresonance diffractive mechanism of the Deck-type.

Thus it is essential that a thorough study of the dynamics of reactions (1) and (9) should be made. As the first step in this direction we analyzed the role of the P_T^2 cut in singling out the coherent diffractive production process on carbon nuclei.

Basing on the study of dN/dP_T^2 distributions we have used up to now the cut $P_T^2 < 0.075\,(\mathrm{GeV}/c)^2$ for the selection of coherent production reaction and rejection of noncoherent events. It is a very mild criterion that leaves more than 30% of the noncoherent background in the mass spectrum in Fig. 5a. Besides, the measured value $b_1 \simeq 30\,(\mathrm{GeV}/c)^{-2}$ of the slope of the diffractive cone for carbon nuclei seems to be somewhat reduced due to instrumental uncertainties. If the real value of b_1 was in agreement with the expected value for carbon nuclei ($50\,(\mathrm{GeV}/c)^{-2}$) then one would anticipate an additional increase of noncoherent background in the mass spectrum of Fig. 5a, which was obtained under the soft cut on P_T^2.

In order to reduce this noncoherent background and to obtain the $\Sigma(1385)^0K^+$ mass spectrum for "pure" coherent production reaction on carbon nuclei a stringent requirement $P_T^2 < 0.02\,(\mathrm{GeV}/c)^2$ has been used (see Fig. 5b). As is seen from the comparison of the mass spectra in Fig. 5a and Fig. 5b, under the stringent P_T^2 cut the narrow peak with mass $M \simeq 2050\,\mathrm{MeV}$ and $\Gamma \simeq 50\,\mathrm{MeV}$ is clearly observed.

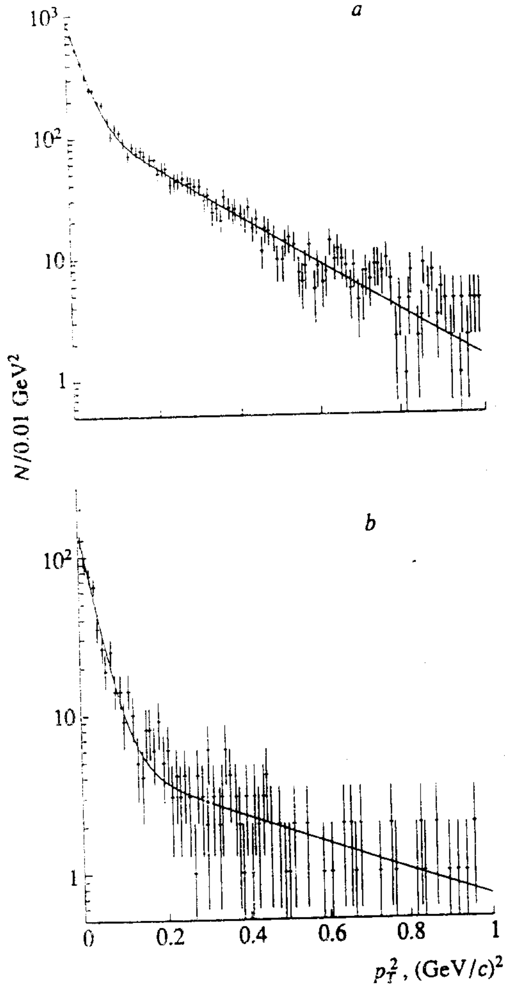

Fig. 4. The dN/dP_T^2 distribution for the events with hyperon production: a) for all events $p + N \to (p\pi^-\pi^0 K^+) + N$; b) for $p + N \to [\Sigma(1385)^0 K^+] + N$. These distributions were fitted in the form $dN/dP_T^2 = c_1 exp(-b_1 P_T^2) + c_2 exp(-b_2 P_T^2)$. The large values of the slope ($b_1 = (31 \pm 2)\,(\mathrm{GeV}/c)^{-2}$ for (a)-type events, and $b_1 = (30 \pm 8)\,(\mathrm{GeV}/c)^{-2}$ for (b)-type events) show that there is a strong contribution of coherent production reactions on carbon nuclei.

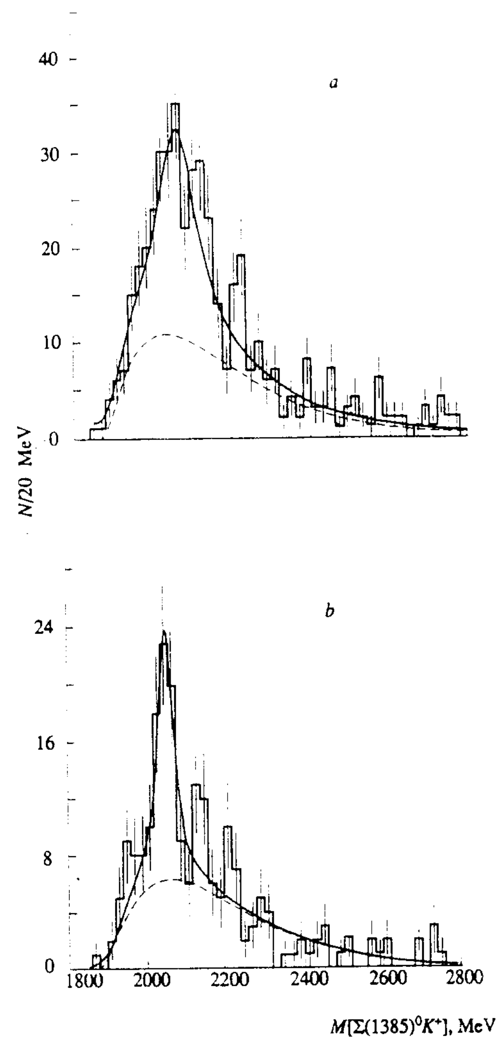

Fig. 5. a) The invariant mass spectrum of the $\Sigma(1385)^0 K^+$ system in the SPHINX experiment for the coherent production process on carbon nuclei (i.e. at $P_T^2 < 0.075\,(\mathrm{GeV}/c)^2$). The spectrum is fitted to the sum of the polynomial background and the Breit-Wigner peak with $M = 2065 \pm 11\,\mathrm{MeV}$ and $\Gamma = 118 \pm 19\,\mathrm{MeV}$. The soft P_T^2 cut, which is used in this spectrum, leads to significant noncoherent background (> 30% - see text). b) The same spectrum, but with more stringent cut ($P_T^2 < 0.02\,(\mathrm{GeV}/c)^2$) to stress the selection of coherent events. The spectrum is fitted by the sum of a smooth polynomial background and the Breit-Wigner peak with $M = 2050 \pm 6\,\mathrm{MeV}$ and $\Gamma = 50 \pm 20\,\mathrm{MeV}$.

Further study of this narrow structure was performed with a slightly increased statistics, as is shown on Fig. 6. More detailed study of the shape of observed mass spectra $M[\Sigma(1385)^0 K^+]$ for the coherent events of (1) (with $P_T^2 < 0.02\,(\mathrm{GeV}/c)^2$) is presented on this figure. The spectra were studied with different values of ΔM bin widths in histograms and with bin shifting. The thorough background evaluation under the peaks was obtained using the information on the side bands near the peak. The statistical confidence levels of the peaks were determined from these data.

The fits of the spectra with Breit-Wigner peaks and polynomial smooth background were carried out. The results of this analysis are summarized in Table 1.

Table 1. The data on the structure X(2050) in the effective mass spectra $M[\Sigma(1385)^0 K^+]$ for coherent diffractive reaction (1).

The width of the mass bin in histograms (MeV)	M (MeV)	Γ (MeV)	The number of the events in the peak $X(2050)$	Confidence level of the peak (standard deviations)
10	2053 ± 4	40 ± 15	74 ± 23	> 8
20	2049 ± 6	48 ± 20	75 ± 29	> 6
30	2053 ± 5	35 ± 16	59 ± 19	> 7
40	2052 ± 7	50 ± 24	75 ± 42	> 6.5

Note: the instrumental width of the peak is $\Gamma_{\mathrm{instr}} = 25\,\mathrm{MeV}$.

In these measurements the average values for the main parameters of $X(2050)$ structure were determined:

$$\left.\begin{array}{l} M = 2052 \pm 6\,\mathrm{MeV}; \\ \Gamma = \left(35\begin{array}{l}+22\\-35\end{array}\right)\,\mathrm{MeV} \\ \text{(with account of the apparatus mass resolution);} \\ \text{statistical C.L. of the peak } > 6\div 8\,\text{s.d.} \end{array}\right\} \quad (11)$$

This narrow structure can not be explained by diffractive nonresonant process of the Deck-type and seems to be caused by the production of a new cryptoexotic baryon with hidden strangeness.

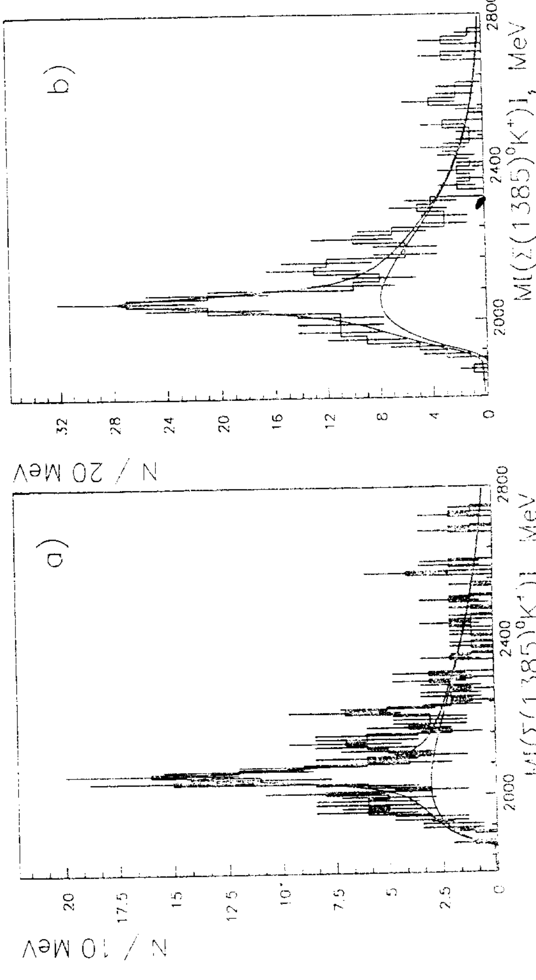

Fig. 6.

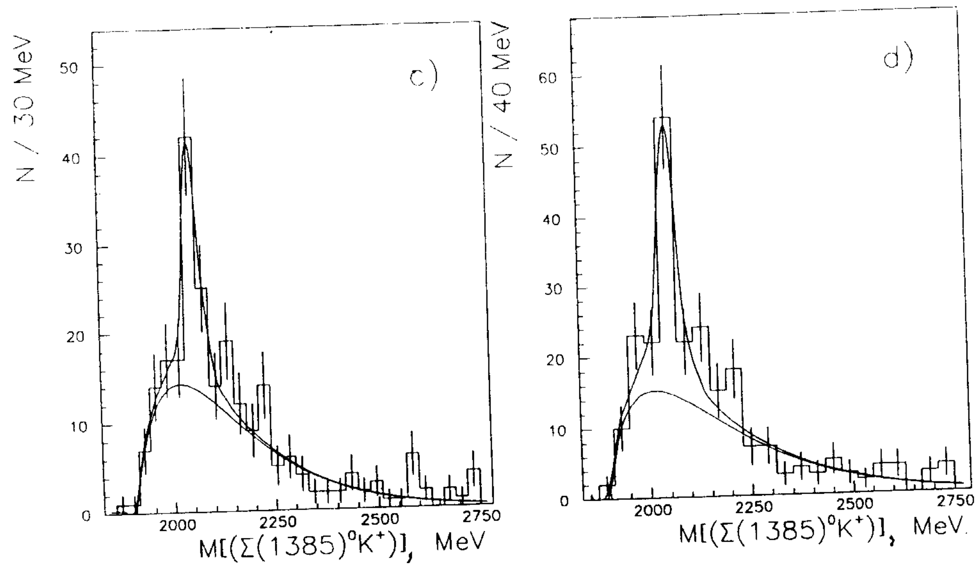

Fig. 6. The study of effective mass spectrum $M[\Sigma(1385)^0K^+]$ in coherent reaction (1) (at $P_T^2 < 0.02\,(\mathrm{GeV}/c)^2$) with different width of the bins ΔM in histograms: a) $\Delta M = 10\,\mathrm{MeV}$; b) $\Delta M = 20\,\mathrm{MeV}$; c) $\Delta M = 30\,\mathrm{MeV}$; d) $\Delta M = 40\,\mathrm{MeV}$. The spectra are fitted by the sum of the smooth polynomial background and the Breit-Wigner peaks with parameters from Table 1. Statistical confidence level of the peaks are estimated on the assumption of maximal possible background (i.e. with the number of events in the side bands near the main peak and not for the results of the background fit).

4. Study of the reaction $p + N \to [\Sigma^0 K^+] + N$ and the observation of $X(2000)$ state

During the study of the reactions with Λ-hyperons and K-mesons we singled out the events with one and only one additional γ-cluster detected in γ-spectrometer of the SPHINX apparatus. These events satisfied the standard selection criteria for identification of $\Lambda \to p\pi^-$ decays and photons which were discussed in [9, 10]. The effective mass spectrum of $\Lambda\gamma$ system for these events is shown in Fig. 7. The peak of $\Sigma^0 \to \Lambda\gamma$ decay in this spectrum is clearly seen, but the background under the peak and in the neibouring bands is rather significant. This background is mainly due to the imitation of single photons in the γ-spectrometer of the SPHINX setup by the remaining hadron showers. The high level of this background means that standard criteria for photon identification which were used before for π^0 registration ([9, 10]) are inadequate for the selection of single photons. To reduce this hadron background more stringent criteria for photon identification are used:

1. a minimal energy of photon cluster has been increased from $E_\gamma > 0.65\,\mathrm{GeV}$ to $E_\gamma > 1.2\,\mathrm{GeV}$;
2. a minimal distance between photon shower and the nearest hadron track has been increased from 7.5 cm to 15 cm;
3. single photon clusters in the high rate lead glass counters around the beam hole in the γ-spectrometer have been rejected;
4. the showers with large transverse dimensions (more than four $10 \times 10\,\mathrm{cm}^2$ lead glass counters in the periphery of γ-spectrometer have been rejected.

The events which don't satisfy these special conditions comprise the main part of the background in Fig. 7. As the result of this more reliable procedure for single photon identification the hadron background is strongly reduced as is seen from Fig. 7 and Fig. 8. The reaction

$$p + N \to [\Sigma^0 K^+] + N \tag{12}$$

which satisfies the additional "elastic requirement"

$$65 < E_\Lambda + E_K + E_\gamma < 75\,\mathrm{GeV} \tag{13}$$

is now clearly singled out. Good background conditions for (12) make it possible to study the effective mass spectra $M(\Sigma^0 K^+)$.

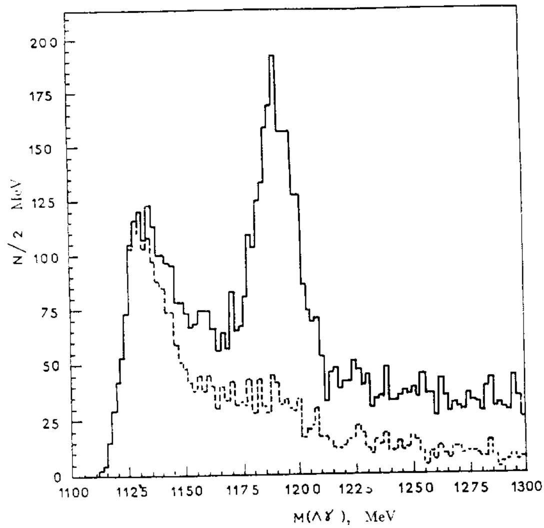

Fig. 7. The effective mass spectrum of $[\Lambda\gamma]$ system in the reaction of production Λ, K^+ and "γ-clusters" (with standard procedure of the identification of single photons in γ-spectrometer). Dotted histogram is for the background from hadron showers which imitate single photons. This background was eliminated by special selection criteria for single photons (see text).

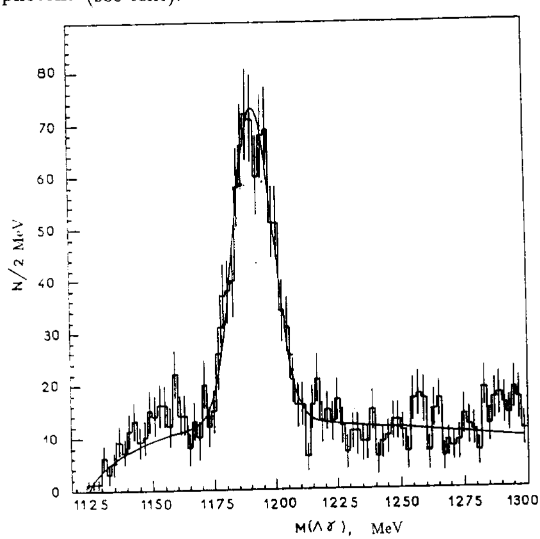

Fig. 8. The effective mass spectrum $\Lambda\gamma$ after all the cuts for the selection of the single photon and the "elastic" reaction $p + N \to [\Lambda\gamma K^+] + N$ (see text).

As it follows from the dN/dP_T^2 distribution for the events of reaction (12) the dominant role of the coherent production of the $\Sigma^0 K^+$ system (with slope $b > 30\,(\mathrm{GeV}/c)^{-2}$) is evident for this process. The coherent diffractive reaction on carbon nuclei (2) can be singled out at $P_T^2 < 0.1\,(\mathrm{GeV}/c)^2$.

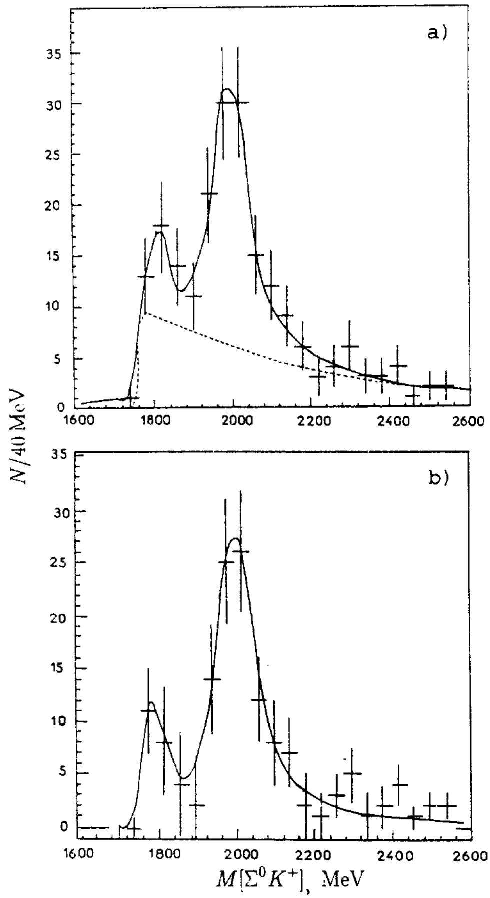

Fig. 9. The effective mass spectrum $M(\Sigma^0 K^+)$ for the coherent diffractive reaction $p + C \to (\Sigma^0 K^+) + C(P_T^2 < 0.1\,(\mathrm{GeV}/c)^2)$: a) for all the events in "Σ^0"-band on Fig. 8; b) after subtraction of the background under the Σ^0 peak (by using sidebands in $\Lambda\gamma$ spectrum on Fig. 8). In these spectra some structure in the threshold region with $M = 1802 \pm 3\,\mathrm{MeV}$ and a clear peak with $M = 1999 \pm 7\,\mathrm{MeV}$ and $\Gamma = 91 \pm 17\,\mathrm{MeV}$ are observed (the values of these parameters are obtained for the spectrum in Fig. 9b). The dotted curve in Fig. 9a is for the polynomial background.

The effective mass spectrum $M(\Sigma^0 K^+)$ for coherent reaction (2) is presented in Fig. 9. In this spectrum besides some small structure with $M \sim 1800\,\text{GeV}$ in the threshold region, a strong peak $X(2000)$ is clearly observed. The main parameters of $X(2000)$ structure are:

$$\left.\begin{array}{l} M = 1997 \pm 7\,\text{MeV}; \\ \Gamma = 91 \pm 17\,\text{MeV}; \\ \text{statistical C.L. of the peak } > 10\,\text{s.d.}; \end{array}\right\} \qquad (14)$$

Such shape of mass spectrum $\Sigma^0 K^+$ (with additional structure in the threshold region) shows that $X(2000)$ peak can not be explained by nonresonant Deck-type diffractive singularity. It seems that this peak has a resonant nature.

We studied the influence of more stringent P_T^2 cuts on the mass spectrum of $\Sigma^0 K^+$ system in reaction (12). These cuts may reduce noncoherent background and more clearly single out the coherent process (2). But, as it is seen from Fig. 10, such stringent cuts ($P_T^2 < 0.075; 0.05; 0.04; 0.02\,(\text{GeV}/c)^2$) do not change the shape of mass spectrum $M(\Sigma^0 K^+)$ and only reduce the number of events.

5. Study of the decay channels for $X(2050)$ and $X(2000)$ states

For the searches of other decay channels for $X(2050)$ and $X(2000)$ baryon states we performed the simultaneous analysis of the SPHINX data on the coherent reactions

$$p + C \;\rightarrow\; p\pi^+\pi^- \;+\; C \qquad (15)$$

$$\rightarrow\; \Delta(1232)^{++}\pi^- \;+\; C \qquad (16)$$

$$\rightarrow\; \Lambda K^+ \;+\; C \qquad (17)$$

together with (1) and (2) and under the same kinematical conditions. Preliminary data on the reaction of $[\Delta(1232)^{++}\pi^-]$ production were obtained in our previous work [9]. The diffractive production of some isobar-like structures with mass $\approx 1460\,\text{MeV}$ and $\approx 1715\,\text{MeV}$ were clearly seen in these data.

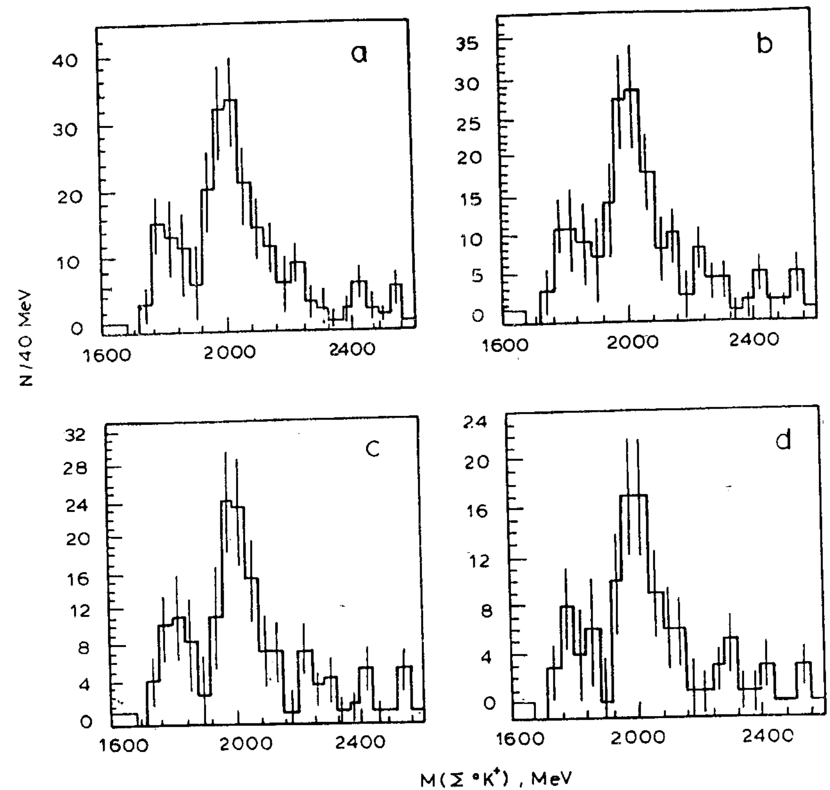

Fig. 10. The study of the influence of P_T^2 cuts on the shape of $\Sigma^0 K^+$ spectrum in reaction (2): a) $P_T^2 < 0.075\,(\mathrm{GeV}/c)^2$; b) $P_T^2 < 0.05\,(\mathrm{GeV}/c)^2$; c) $P_T^2 < 0.04\,(\mathrm{GeV}/c)^2$; d) $P_T^2 < 0.02\,(\mathrm{GeV}/c)^2$.

But in the mass region of $X(2050)$ and $X(2000)$ states there are no such structures in all mass spectra of $M(p\pi^+\pi^-)$, $M[\Delta(1232)^{++}\pi^-]$, or $M(\Lambda K^+)$ in reactions (15)–(17). The lower limits for the ratios of the corresponding decay branchings were estimated to be (with 95% C.L.):

$$R_1 = \frac{\mathrm{BR}\{X(2050)^+\to[\Sigma(1385)K]^+\}}{\mathrm{BR}\{X(2050)^+\to[\Delta(1232)\pi]^+\}} > 1.7 \quad (18)$$

$$R_2 = \frac{\mathrm{BR}\{X(2050)^+\to[\Sigma(1385)K]^+\}}{\mathrm{BR}\{X(2050)^+\to p\pi^+\pi^-\}} > 2.6 \quad (19)$$

$$R_2' = \frac{\mathrm{BR}\{X(2050)^+\to\Sigma(1385)^0K^+\}}{\mathrm{BR}\{X(2050)^+\to p\pi^+\pi^-\}} > 0.86 \quad (20)$$

$$R_3 = \frac{\mathrm{BR}\{X(2000)^+\to[\Sigma K]^+\}}{\mathrm{BR}\{X(2000)^+\to[\Delta(1232)\pi]^+\}} > 0.83 \quad (21)$$

$$R_4 = \frac{\mathrm{BR}\{X(2000)^+\to[\Sigma K]^+\}}{\mathrm{BR}\{X(2000)^+\to p\pi^+\pi^-\}} > 7.8 \quad (22)$$

$$R_4' = \frac{\mathrm{BR}\{X(2000)^+\to\Sigma^0K^+\}}{\mathrm{BR}\{X(2000)^+\to p\pi^+\pi^-\}} > 2.6 \quad (23)$$

$$R_5' = \frac{\mathrm{BR}\{X(2050)^+\to\Sigma(1385)^0K^+\}}{\mathrm{BR}\{X(2050)^+\to\Lambda K^+\}} > 1.4 \quad (24)$$

$$R_6' = \frac{\mathrm{BR}\{X(2000)^+\to\Sigma^0K^+\}}{\mathrm{BR}\{X(2000)^+\to\Lambda K^+\}} > 1.1 \quad (25)$$

Here we use the isotopic conditions for the decays of $X(2050)$ and $X(2000)$ baryons with isotopic spin $I=\frac{1}{2}$ (they are produced in the diffractive dissociation of protons):

$$\frac{BR[X^+(I=\frac{1}{2})\to(\Sigma^0K^+)]}{BR[X^+(I=\frac{1}{2})\to(\Sigma K)^+]} = \frac{1}{3};$$

$$\frac{BR[X^+(I=\frac{1}{2})\to(\Delta^{++}\pi^-)]}{BR[X^+(I=\frac{1}{2})\to(\Delta\pi)^+]} = \frac{1}{2}.$$

The ratios $R_1 - R_4$ for $X(2050)$ and $X(2000)$ decays on strange and non-strange particles are much larger than the same ratios for the decays of usual (qqq)-isobars (where they are of the order of several percent — see [18]).

The small enough widths of $X(2000)$ and $X(2050)$ baryon states (see (11) and (14)) as well as the anomalously large branching ratios for their decay channels with strange particles (large values of $R_1 - R_4$) are the reasons to consider these states as serious candidates for the cryptoexotic baryons with hidden strangeness $|qqqs\bar{s}>$. The problem of possible connection between $X(2050)$ baryon state observed in reaction (1) and $X(2000)$ state observed in reaction (2) seems to be quite interesting. At first sight the difference in their parameters (11) and (14) is significant one. But to obtain the ultimate answer about the existence of two different baryonic states or only one state with two different decay channels we need to perform the further study of reactions (1) and (2) with increased statistics. It would give a possibility to obtain more precise information about the shape of these peaks, their decay widths and quantum numbers.

Curiously, that the possible existence of exotic baryon pairs with a small enough mass difference ($\Delta m \sim 40 - 50\,\mathrm{MeV}$) was predicted before in the color octet bond model [16].

The study of nonperipheral processes in reactions (9) and (12) in the region of intermediate transverse momenta $P_{\mathrm{T}}^2 \geq 0.3\,(\mathrm{GeV}/c)^2$ was also performed in the SPHINX measurements. Some interesting effects in this region might be observed, but the existing statistics is not enough to obtain any definite conclusion on this subject.

6. Conclusion

In the study of coherent diffractive production reactions (1) and (2) for the energy of proton beam $E_p = 70\,\mathrm{GeV}$ two new baryon states $X(2050)^+ \to \Sigma(1385)^0 K^+$ and $X(2000)^+ \to \Sigma^0 K^+$ were observed with statistically significant confidence level. These baryons were characterized by unusual dynamical features: small enough decay widths and anomalously high decay rates with strange particles in final states. Thus $X(2050)$ and $X(2000)$ are serious candidates for cryptoexotic baryons with hidden strangeness.

In spite of large enough statistical significance of the data above we consider all these results and conclusions as preliminary. They should be confirmed in further measurements with greatly increased statistics.

References

[1] Landsberg L.G. Yad.Fiz., 1994, v.57, p.47.

[2] Chan Hong-Mo, Tsou S.T. Nucl.Phys., 1977, v.118B, p.413.

[3] Högaasen H., Sorba P. Nucl.Phys., 1978, v.145B, p.119.

[4] Landsberg L.G. UFN, 1990, v.160, p.1;
Landsberg L.G. Surveys in High Energy Phys., 1992, v.6, p.257.

[5] Hirose T. et al. Nuov.Cim., 1979, v.50A, p.120;
Fucunage C. et al. Nuov.Cim., 1980, v.58A, p.199.

[6] Aleev A.N. et al. Z.Phys., 1984, v.26C, p.205.

[7] Bellini G. et al. Nuov.Cim., 1984, v.79A, p.282.

[8] Vavilov D.V. et al. Yad.Fiz., 1994, v.57, p.241;
Balatz M.Ya. et al. Z.Phys., 1994, v.61C, p.220.

[9] Vavilov D.V. et al. Yad.Fiz., 1994, v.57, p.253.

[10] Balatz M.Ya. et al. Z.Phys., 1994, v.61C, p.399.

[11] Vavilov D.V. et al. Preprint IHEP 93-138, Protvino, 1993;
Yad.Fiz., 1994 (in press).

[12] Landsberg L.G. Preprint IHEP 93-100, Protvino, 1993;
Nuov.Cim. (in press).

[13] Balatz M.Ya. et al. Preprint IHEP 94-06, Protvino, 1994;
Vavilov D.V. et al. Yad.Fiz, 1994 (in press).

[14] Kurshetsov V.F., Landsberg L.G. Preprint IHEP 94-07, Protvino, 1994; Yad.Fiz., 1994 (in press).

[15] Chan Hong-Mo, H.Högaasen Phys.Lett., 1977, v.72B, p.121, p.400.

[16] De Crombrugghe M. et al. Nucl.Phys., 1979, v.156B, p.347.

[17] Pietrzyk B. Preprint CERN-EP/80-116, Geneva, 1980. (Talk, given at the Fifth European Symposium on Nucleon Interactions, Bressanone, June 23-28, 1980).

[18] Hikasa K. et al. (PDG) Phys.Rev., 1992, v.45D, p.1.

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