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V.F.Kurshetsov, L.G.Landsberg

SEARCH FOR EXOTIC BARYONS WITH THE SPHINX FACILITY[1]

SPHINX Collaboration (IHEP-ITEP)

[1]The extended version of the talks of authors on the conferences "Hadron-93" (Italy, Como, June, 1993) and "NAN-93" (Moscow, ITEP, September, 1993)

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Abstract

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In the experiments at the SPHINX facility in the proton beam of the IHEP accelerator (E_p=70 GeV) a number of diffractive production reactions were studied. Among them are $p + N \rightarrow (K^+K^-p) + N$, $p + N \rightarrow (\phi p) + N$, $p + N \rightarrow [\Lambda(1520)K^+] + N$, $p + N \rightarrow [\Sigma(1385)^o K^+] + N$, $p + N \rightarrow [\Sigma(1385)^o K^+] + N$+(neutral particles), $p + N \rightarrow [\Sigma^o K^+] + N$ as well as some other processes. The results of the search for narrow heavy baryon states, candidates for the cryptoexotic hadrons with hidden strangeness, are presented. The first results for the meson production in the deep fragmentation region are also obtained.

Аннотация

Куршецов В.Ф., Ландсберг Л.Г. Поиски экзотических барионов на установке СФИНКС: Препринт ИФВЭ 94-7. – Протвино, 1994. – 29 с., 14 рис., 2 табл., библиогр.: 21.

В экспериментах на установке СФИНКС, работавшей на пучке протонов ускорителя ИФВЭ (E_p=70 ГэВ), исследован ряд реакций дифракционного образования барионных состояний. Среди этих реакций $p + N \rightarrow (K^+K^-p) + N$, $p + N \rightarrow (\phi p) + N$, $p + N \rightarrow [\Lambda(1520)K^+] + N$ и $p + N \rightarrow [\Sigma(1385)^o K^+] + N$, $p + N \rightarrow [\Sigma(1385)^o K^+] + N$+(neutral particles), $p + N \rightarrow [\Sigma^o K^+] + N$ и ряд других процессов. Приводятся результаты поисков образования узких тяжелых барионов, являющихся кандидатами в криптоэкзотические адроны со скрытой странностью. Получены первые данные об образовании мезонов в процессах с глубокой фрагментацией.

1. INTRODUCTION

In the experiments of the SPHINX Collaboration a wide program of studying the hadron diffractive production by protons with E_p=70 GeV and search for exotic baryons in these processes are carried out. This program has been detailed in Refs.[1,2]. Here are presented the first results of measuring the reactions

$$p + N \rightarrow (K^+K^-p) + N, \tag{1}$$

$$p + N \rightarrow (\phi p) + N, \quad \phi \rightarrow K^+K^- \tag{2}$$

$$p + N \rightarrow [\Lambda(1520)K^+] + N, \quad \Lambda(1520) \rightarrow pK^- \tag{3}$$

$$p + N \rightarrow [\Sigma(1385)^o K^+] + N, \quad \Sigma(1385)^o \rightarrow \Lambda\pi^o \tag{4}$$

$$p + N \rightarrow [\Sigma(1385)^o K^+] + N + (\text{neutral particles}), \quad \Sigma(1385)^o \rightarrow \Lambda\pi^o \tag{5}$$

$$p + N \rightarrow [\Sigma^o K^+] + N, \quad \Sigma^o \rightarrow \Lambda\gamma \tag{6}$$

and some other processes. Here N is nucleon or light nucleus (C, Be).

As it is stated in a number of papers, the diffractive production processes with Pomeron exchange offer some new possibilities to search for exotic hadrons [1-5].. This is because of multigluon character of Pomeron exchange and is especially true for the searches of heavy hadrons with anomalously narrow decay width, that can be serious candidates for cryptoexotic states. There were obtained some evidences of possible existence of such states — mesons $X(1740)$ [6], $U(3100)$ and $M_\phi(3250)$ [7,8], baryons $N_\phi(1960)$ [9], $\Sigma(3170)$ [10], $R(3520)$ [11] and several other hadrons. Thus systematical searches for such baryons with hidden strangeness in reactions (1)-(5) in the not very well known mass region of $\sim 2 \div 4$ GeV seems quite desirable.

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 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 ($dN/dP_T^2 \simeq const \cdot exp(-bP_T^2)$ where $b \simeq (8 \div 10)A^{2/3}$ GeV^{-2}. It has been suggested that coherent production on nuclei is a good tool for the separation of resonances against multiparticl background because of the difference in the absorption of single-particle and multiparticle objects in the target nuclei (see, for example, Ref.[12]).

The SPHINX facility [2], used for the measurements in the proton beam, includes a wide-aperture magnet spectrometer with scintillation counter hodoscopes, proportional chambers, drift chambers and multichannel γ-spectrometer with total absorption Cherenkov lead glass counters. The charged particles in the final state were identified by two multichannel threshold gas Cherenkov counters and differential RICH detector registering images of several Cherenkov radiation rings. The experimental details connected with the setup, with the measurements at the accelerator, with the data handling and the methods of selecting reactions (1)-(5) can be found in Refs. [2,13-15].

Below we have summarized the main physical results obtained from the SPHINX measurements.

2. SEARCH FOR HEAVY EXOTIC BARYONS WITH HIDDEN STRANGENESS IN REACTIONS (1)-(3)

During the measurements with the SPHINX setup a proton flux of $N_p = 1.12 \cdot 10^{11}$ p passed through the target ($4.85 \cdot 10^{23}$ CH_2/cm^2). The apparatus was triggered by the signals, corresponding to the events with 3 charged particles in the final state which had passed through the magnetic spectrometer. At least two (one) of these particles gave no signal in the Cerenkov threshold counters $\check{C}_1(\check{C}_2)$, e.g., they are candidates for the protons with momentum $P_p < 40$ GeV or kaons with $P_K < 21$ GeV. The main identification procedure for charged particles was performed in the off line analysis of the RICH detector data (see Ref.[2]).

In the invariant mass spectra of K^+K^- and pK^- systems in (1) clear peaks for ϕ-meson and $\Lambda(1520)$ baryon have been obtained (Fig.1) and reactions (2) and (3) have been singled out [2,14].

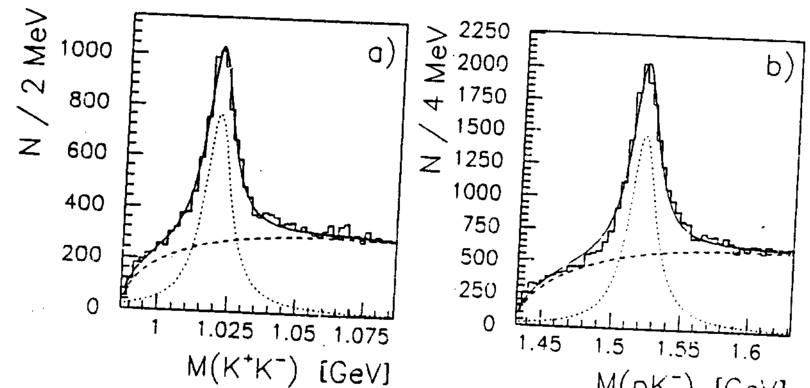

Figure 1. The effective mass spectra of secondaries in the reaction $p + N \to [pK^+K^-] + N$ at E_p=70 GeV. a) K^+K^--system: the ϕ peak with $M = 1020.0 \pm 0.2$ MeV and $\Gamma = 12.0 \pm 0.6$ MeV is clearly seen. b) pK^- system: the $\Lambda(1520)$ peak with $M = 1520 \pm 0.3$ MeV and $\Gamma = 22.0 \pm 0.8$ MeV is observed in this spectrum (the errors are statistical). The experimental data on ϕ and $\Lambda(1520)$ are in agreement with their tabulated parameters (with the account of the instrumental resolution).

As is seen from the event distributions dN/dP_T^2 for reactions (1)-(5) as functions of the transverse momentum squared, there are considerable contributions of coherent diffractive production of pK^+K^-, $p\phi$, $\Lambda(1520)K^+$, $\Sigma(1385)^oK^+$ systems on the carbon nuclei. These coherent processes are characterized by slopes $b \gtrsim$30-40 GeV^{-2} (see Fig.2).

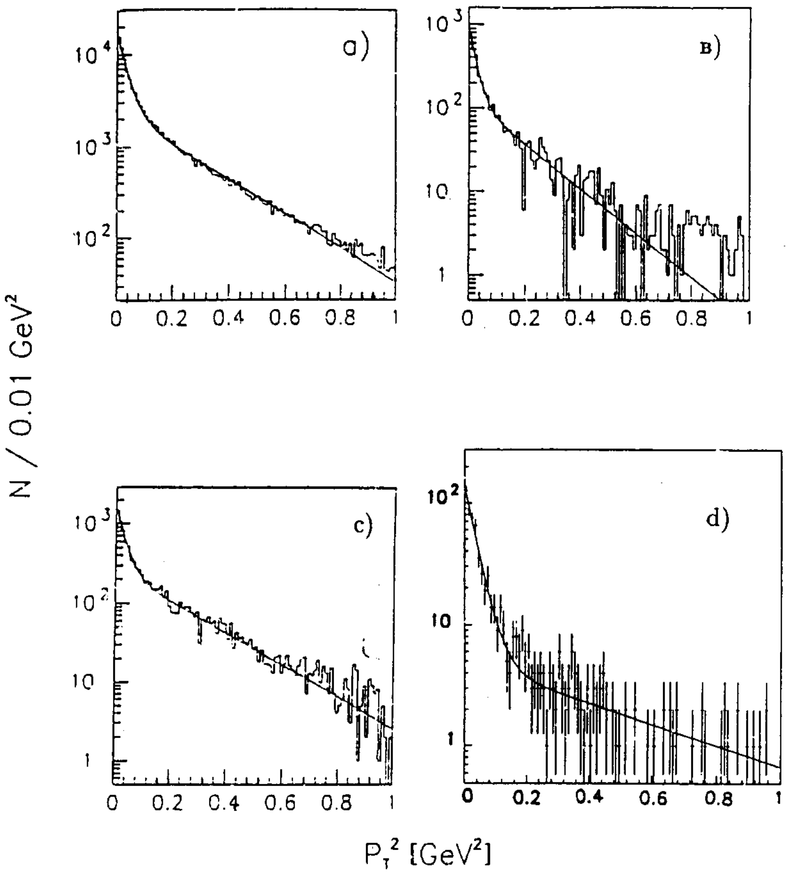

Figure 2. The events distribution over the square of transverse momentum for the diffractive production processes. These distibutions are fitted in the form of $dN/dP_T^2 = c_1 exp(-b_1 P_T^2) + c_2 exp(-b_2 P_T^2)$: a) dN/dP_T^2 for the reaction $p + N \to [K^+K^-p] + N$ with the slope $b_1 = (32.0 \pm 0.6)$ GeV^{-2}; b) dN/dP_T^2 for the reaction $p + N \to [p\phi] + N$ with the slope $b_1 = (48.0 \pm 0.6)$ GeV^{-2}; c) dN/dP_T^2 for the reaction $p + N \to [\Lambda(1520)K^+] + N$ with the slope $b_1 = (37.0 \pm 1.7)$ GeV^{-2}; d) dN/P_T^2 for the reaction $p + N \to [\Sigma(1385)^o K^+] + N$ with the slope $b_1 = (30 \pm 8)$ GeV^{-2}.

In the mass spectra for $p\phi$ system in (2) and $\Lambda(1520)K^+$ system in (3) there is a structure with mass $M \simeq$2170 MeV and width $\Gamma \simeq$110 MeV (Fig. 3a,b). Both spectra have the same characteristics and can be summed for a more detailed study of this structure. The resulting mass spectrum for $X = [\phi p + \Lambda(1520)K^+]$ is presented in Fig.3c. It must be emphasized that the nature of the "X(2170)" structure is still unclear now and needs further study. The inverted commas in the notation of the state are used to stress this point.

The sizable acceptance of the SPHINX facility in the region of high masses has made it possible to search for heavy baryon resonances in reactions (1)-(3) in the effective mass region up to M=4.5 GeV and first of all for baryons with anomalously small decay widths, that can be candidates for exotic pentaquark states with hidden strangeness. The results of these searches for pK^+K^-, $p\phi$ and $\Lambda(1520)K^+$ systems in reactions (1)-(3) in the region of $M >$2.75 GeV are presented in Fig.4.

There are no statistically significant heavy baryon structures in all three mass spectra under study. Very sensitive upper limits for the cross sections of the narrow resonance production reactions have been obtained. They are given in Fig.5. As is seen from this Figure, the experiments on the SPHINX setup failed to confirm the existence of narrow heavy baryons $R(3520)$, observed in the reaction

$$\pi^- + p \to [pK^+K^*(892)^-\pi^-] + X^o \tag{7}$$

at P_{π^-}=16 GeV with cross section $\sigma \cdot BR = 14$ μb [11]. The SPHINX upper limits for the cross sections of $R(3520)$ production in reactions (1)-(3) are

$$\sigma_p[R(3520)]|_{nucleon} \cdot BR[R(3520) \to \phi p] \leq 0.27 \text{ nb/nucleon}, \tag{8}$$

$$\sigma_p[R(3520)]|_{nucleon} \cdot BR[R(3520) \to \Lambda(1520)K^+] \leq 3.4 \text{ nb/nucleon}, \tag{9}$$

$$\sigma_p[R(3520)]|_{nucleon} \cdot BR[R(3520) \to K^+K^-p] \leq 2.6 \text{ nb/nucleon} \tag{10}$$

(95% C.L.). These values are by 4-5 orders of magnitude lower than the cross section of $R(3520)$ production in reaction (7), claimed in Ref. [11].

In the currently available data there is no statistically significant evidence for possible existence of nonstrange analog of $\Sigma(3170)$ baryon with the mass around 3 GeV (Figs.4 and 5).

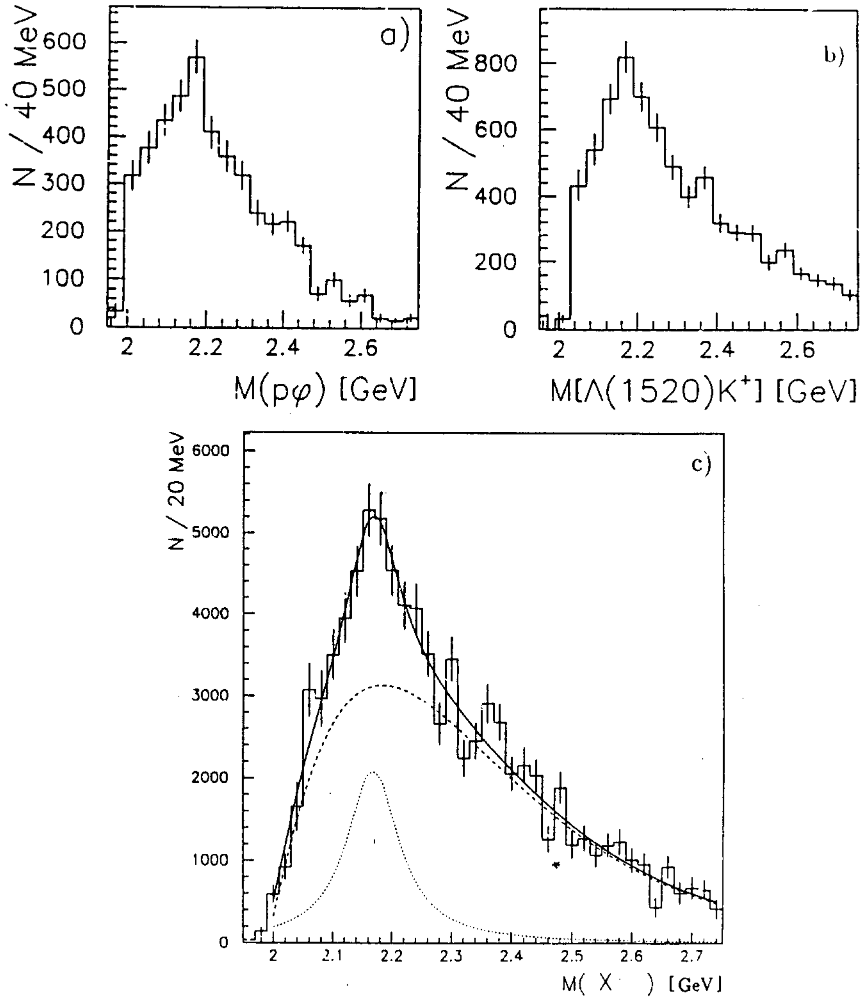

Figure 3. The effective mass spectra of ϕp and $\Lambda(1520)K^+$ systems for coherent diffractive processes (2) and (3) ($P_T^2 < 0.075$ GeV^2). a) The mass spectrum $M(\phi p)$ in reaction (2). b) The mass spectrum $M[\Lambda(1520)K^+]$ in reaction (3). c) The summed invariant mass spectrum for $X = \phi p + \Lambda(1520)K^+$ (for $P_T^2 < 0.075$ GeV^2) in reactions (2) and (3). The events of ϕp and $\Lambda(1520)K^+$ type are weighted with the acceptance of the setup with account of the branching $BR(\phi \to K^+K^-) = 0.49$ and $BR[\Lambda(1520) \to pK^-] = 0.225$. The summed spectrum is fitted with Breit-Wigner peak with parameters $M \simeq 2170$ MeV and $\Gamma \simeq 110$ MeV and smooth polynomial background.

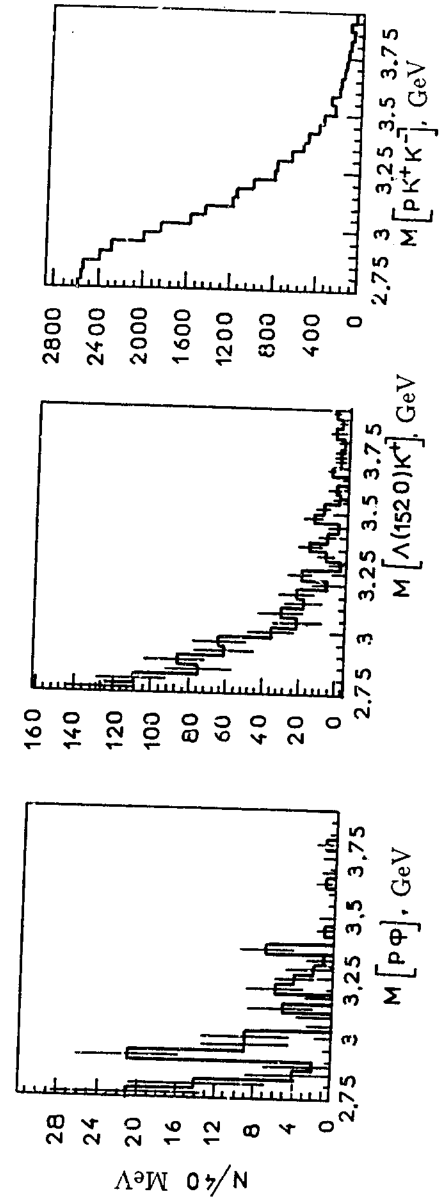

Figure 4. Search for the narrow heavy exotic baryon resonances with $M > 2.75$ GeV with hidden strangeness $B_\phi = |qqqs\bar{s}>$ in the diffractive production process $p + N \to B_\phi + N$ in the decay channels: a) $B_\phi \to \phi p$; b) $B_\phi \to \Lambda(1520)K^+$; c) $B_\phi \to pK^+K^-$ (for all P_T^2).

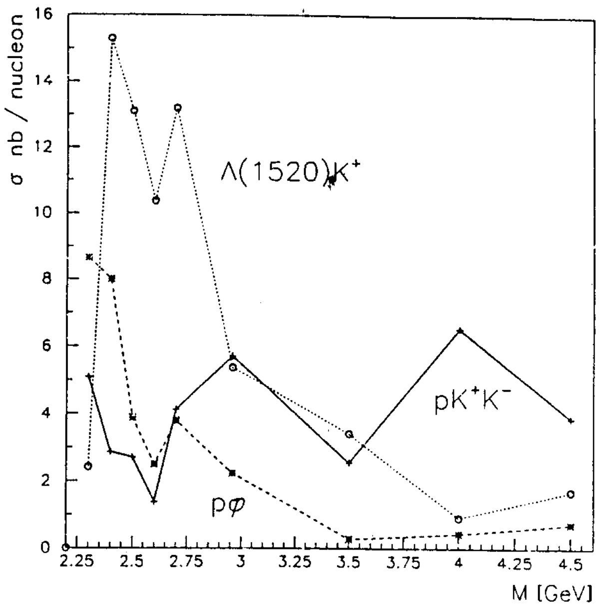

Figure 5. Upper limits (with 95% C.L.) for the cross sections of the diffractive production of heavy B_ϕ baryons with $\Gamma \leqslant 50$ MeV in the decay channels $B_\phi \to K^+K^-p$, $B_\phi \to \phi p$, $B_\phi \to \Lambda(1520)K^+$ (here $BR(\phi \to K^+K^-)$ and $[BR(\Lambda(1520) \to K^-p]$ are taken into account).

3. SEARCH FOR $N_\phi(1960)$ BARYON

In the experiments with the BIS-2 setup in a neutron beam of the IHEP 70 GeV proton synchrotron with the mean energy $< E_n > \simeq 40$ GeV the reaction

$$n + N \to [\Sigma(1385)^- K^+] + N + , \quad \Sigma(1385)^- \to \Lambda\pi^- \tag{11}$$

was studied [9][2] In the effective mass spectrum of the $[\Sigma(1385)^- K^+]$ system in this experiment a narrow peak with mass $M = 1956^{+8}_{-9}$ MeV and width $\Gamma = 27 \pm 15$ MeV was observed. This structure was interpreted as a candidate for cryptoexotic baryon with hidden strangeness $|qqqs\bar{s}>$ ($q = u$ or d) and was designated as $N_\phi(1960)$ baryon [9]. The data on the cross section of $N_\phi(1960)$ production in [9] are presented in Table 1.

Bearing in mind the importance of the possible existence of cryptoexotic $|qqqs\bar{s}>$ baryons SPHINX Collaboration have performed a new search for this state in reactions (4) and (5) [13,15].

These reactions were singled out in the analysis of the same trigger events with 3 charged particles in the final state discussed in Section 2. The analyzed statistics correspond to the total flux of $N_p = 0.9 \cdot 10^{11}$ protons passing through the setup target.

For the selection of reaction (4) 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 [2]) and for the detection of the π^o meson in the γ spectrometer ($0.10 < M(\gamma_1\gamma_2) < 0.17$ GeV, see Refs. [2,13] for more details).

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

As a result of this analysis the process

$$p + N \to (p\pi^-\pi^oK^+) + N \tag{12}$$

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

$$65\text{GeV} < E_p + E_{\pi^-} + E_{\pi^o} + E_{K^+} < 75 \text{ GeV} \tag{13}$$

($\sim$ 6000 "elastic" events of (12)). As is clear from the two-dimensional distribution of the effective masses $M(\pi^-p)$ versus $M(\pi^op)$ in this process [13], the main contribution to the events (12) results from the hyperon decays $\Lambda \to p\pi^-$ and $\Sigma^+ \to p\pi^o$. The decay path for Λ hyperons in the run with the SPHINX setup is limited to ~ 30 cm by trigger requirements. The detection of the decay $\Sigma^+ \to p\pi^o$ is possible practically over the whole decay base for Σ^+ hyperons.

[2] Reaction (11) with limited charged multiplicity for the particles passed through the magnetic spectrometer of the BIS-2 setup is not a full-scale inclusive reaction. Let one designate it as "the reaction with a limited inclusivness".

Table 1. Cross section estimations

BIS-2 data. The reaction with limited inclusivness $n + N \to N_\phi(1960) + ...$	SPHINX data (upper limits for the cross section with 95% c.l.) "Elastic" reaction $p + N \to N_\phi(1960) + N$	Partially-inclusive inelastic reaction $p + N \to N_\phi(1960) + N +$ (neutr. particl.)
$\sigma[N_\phi(1960)]\|_C \cdot BR =$ $= \begin{cases} (1725 \pm 28[illegible]) \text{ nb/C} \\ \text{or with account of factor 1.7} \\ \sim 3 \cdot 10^3 \text{ nb/C} \end{cases}$	Coherent process ($P_T^2 \leqslant 0.075$ GeV^2) $\sigma[N_\phi(1960)\|_C \cdot BR < 660$ nb/C	Coherent process ($P_T^2 \leqslant 0.075$ GeV^2) $\sigma[N_\phi(1960)]\|_C \cdot BR < 820$ nb/C
The same cross section per 1 nucleon $\sigma[N_\phi(1960)]\|_{nucleon} \cdot BR =$ $< \begin{cases} 330 \pm 60 \text{ nb/nucleon} \\ \text{or with account of factor 1.7} \\ \simeq 560 \text{ nb} \end{cases}$ (for $\sigma \sim A^{2/3}$)	The same cross section per 1 nucleon $\sigma[N_\phi(1960)]\|_{nucleon} \cdot BR <$ $< \begin{cases} 55 \text{ nb/nucleon } (\sigma \sim A) \\ 125 \text{ nb/nucleon } (\sigma \sim A^{2/3}) \end{cases}$	The same cross section per 1 nucleon $\sigma[N_\phi(1960)]\|_{nucleon} \cdot BR <$ $= \begin{cases} 70 \text{ nb/nucleon } (\sigma \sim A) \\ 150 \text{ nb/nucleon } (\sigma \sim A^{2/3}) \end{cases}$
	For all P_T^2 $\sigma[N_\phi(1960)]\|_{nucleon} \cdot BR < 120$ nb/nucleon ($\sigma \sim A^{2/3}$)	For all P_T^2 $\sigma[N_\phi(1960)]\|_{nucleon} \cdot BR < 230$ nb/nucleon ($\sigma \sim A^{2/3}$)

Notes:

1) $\sigma[N_\phi(1960)]|_C$ – the cross section for the corresponding reactions per C nucleus;

2) $\sigma[N_\phi(1960)|_{nucleon}$ – the same but per 1 nucleon;

3) $\sigma \sim A$ is possible for coherent reactions;

4) $BR = BR[N_\phi(1960) \to \Sigma(1385)K]$ – for all isotopic states (for $I(N_\phi) = 1/2$);

5) It must be bear in mind that the values for the cross sections in the experiment BIS-2 [9] were obtained not very correctly. It was shown by fitting the $[\Sigma(1385)^- K^+]$ effective mass spectrum from the BIS-2 data in the same way, as for the SPHINX data in Fig.7, that the number of the events in the N_ϕ–peak, as well as the BIS-2 cross sections must be increased by a factor of 1.7÷2.0, as compared with the published values in Ref. [9].

Thus, in the analysis of reaction (6) the processes with Λ and Σ hyperons were singled out

$$p + N \to [\Lambda\pi^o K^+] + N, \quad \Lambda \to p\pi^- \tag{14}$$

$$p + N \to [\Sigma\pi^- K^+] + N, \quad \Sigma \to p\pi^o \tag{15}$$

The inelastic partially inclusive reaction with additional neutral particles

$$p + N \to (\Lambda\pi^o K^+) + N + \text{ (neutral particles)} \tag{16}$$

was also separated in the analysis of the SPHINX data. For this the events with $\Lambda \to p\pi^-$ decay and with two or more than two γ-clusters in the photon spectrometer of the SPHINX setup where analyzed. The events with at least one photon pair with the effective mass in π^o region ($0.10 < M(\gamma_1\gamma_2) < 0.17$ GeV) were selected. When there are more than one $\gamma_i\gamma_j$ combinations for which $M(\gamma_i\gamma_j)$ in agreement with the π^o requirement, we use all of them ($\Lambda\pi^o_{(1)}K^+$, $\Lambda\pi^o_{(2)}K^+$ and so on) with appropriate weights.

Of course the "elastic requirement" (12) is not used any more in this selection. The number of detected events for reaction (16) is 2855, which exceeds more than four times the number of "elastic" events of type (14), which was descussed above.

For reactions (14) and (16) the invariant mass spectra $M(\Lambda\pi^o)$ were studied (see Fig.6a and b). In "elastic" reaction (14) the peak of $\Sigma(1385)^o \to \Lambda\pi^o$ is dominating and the background level under the peak is very small. For partially–inclusive inelastic reaction (16) the $\Sigma(1385)^o$ peak is also clearly seen. The background under the peak in this case, although significantly exceeding the one in the "elastic" reaction, is much lower than in the BIS-2 measurements for (9), where the background exceeds more than 2 times the number of the events in $\Sigma(1385)$ peak (see Ref. [9]). Thus reactions (4) and (5) were well identified in the SPHINX measurement. In the mass spectra of $M[\Sigma(1385)^o K^+]$ in these reactions for different regions of P_T^2 we do not observe $N_\phi(1960)$ peak either for the full spectra (for all values of P_T^2) or for coherent processes, i.e. for $P_T^2 < 0.075$ GeV^2 — see, for example, Fig.7.

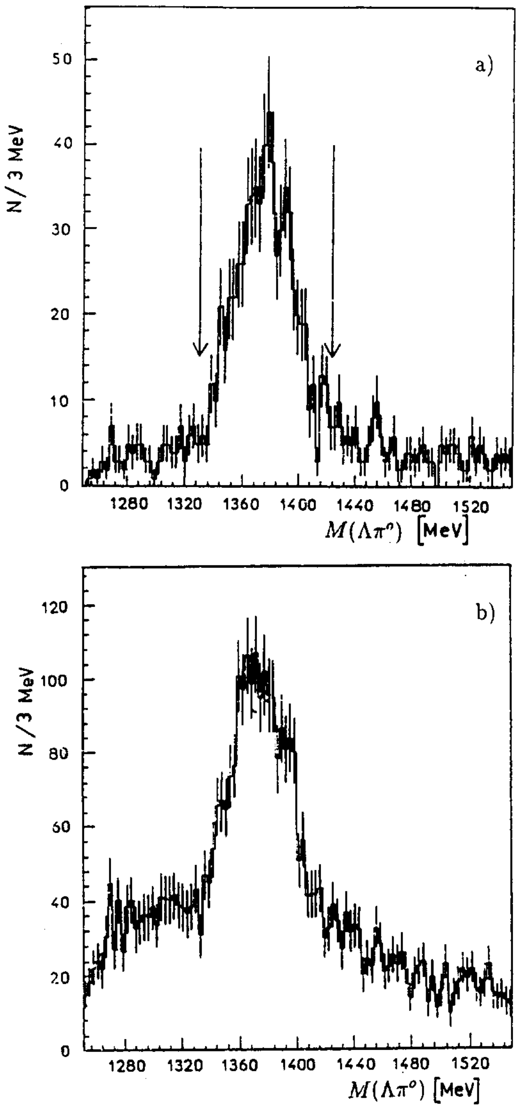

Figure 6. The invariant mass spectra for $\Lambda\pi^o$ system: a) in "elastic" diffractive production reaction (14); b) in inelastic partially-inclusive reaction (16). The parameters of $\Sigma(1385)^o$ peak are in agreement with tabulated values (with the account of the apparatus mass resolution $\sigma = \pm 9$ MeV and systematic errors). The arrows indicate the region of $\Sigma(1385)$ band.

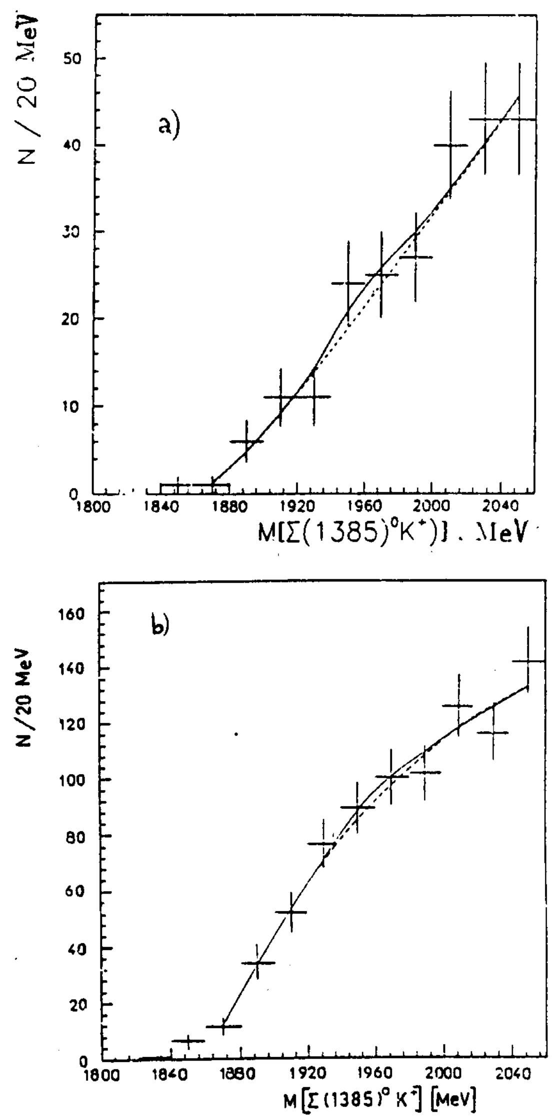

Figure 7. **Search for $N_\phi(1960)$ baryon in the mass spectra of $\Sigma(1385)^o K^+$ system in the SPHINX setup: a) for "elastic" reaction (4) (all P_T^2); b) for inelastic partially-inclusive reaction (5) (all P_T^2). The spectra are fitted by the sum of polynomial background and the Breit-Wigner $N_\phi(1960)$ peak with parameters of Ref. [9]. There are neither N_ϕ signals in the same spectra for coherent processes (4) and (5) on carbon nuclei (i.e. for P_T^2 <0.075 GeV^2).**

The SPHINX upper limits for the cross sections of the reactions

$$p + N \to \quad N_\phi(1960)^+ + N, \quad \hookrightarrow \Sigma(1385)K \tag{17}$$

and

$$p + N \to \quad N_\phi(1960)^+ + N + (\text{neutral particles}), \quad \hookrightarrow \Sigma(1385)K \tag{18}$$

are presented in Table 1. They are significantly smaller than the BIS-2 cross sections for the $N_\phi(1960)^o$ production in (9). Strictly speaking, there are no direct contradictions between the SPHINX and BIS-2 data because they have been obtained for somewhat different processes.[3] But it seems to us, that the big difference between the values of these cross sections (see Table 1), as well as very hard background conditions for the separation of reaction (11) and $N_\phi(1960)$ state in the BIS-2 measurements give some doubts in the real existence of $N_\phi(1960)$ baryon (see Refs.[13,15]) for more detailed discussions.

4. FURTHER ANALYSIS OF THE EFFECTIVE MASS SPECTRUM OF $\Sigma(1385)^o K^+$ SYSTEM

Let us further analyze the effective mass spectrum of $\Sigma(1385)^o K^+$ in reaction (4). In Fig.8 this spectrum is presented for the coherent events with $P_T^2 < 0.075$ (GeV)^2. But the form of the observed spectra in the region of $M \sim$ 2 GeV does not change too much in going from the region $P_T^2 < 0.075$ (GeV)^2 to the region of $P_T^2 > 0.075$ (GeV)^2. There is a structure with mass $M \simeq$2060 MeV and width $\Gamma \simeq$120 MeV in all these spectra. The nature of this "$X(2060)$" structure is quite unclear now. Its resonance interpretation is possible, but it may also be that the form of the observed spectra is due to the diffractive nonresonance production mechanism with account of the Deck–effect.

[3]It is possible only to conclude that the statement in Ref.[9] about the diffractional character of $N_\phi(1960)$ production in the BIS-2 measurement is incorrect.

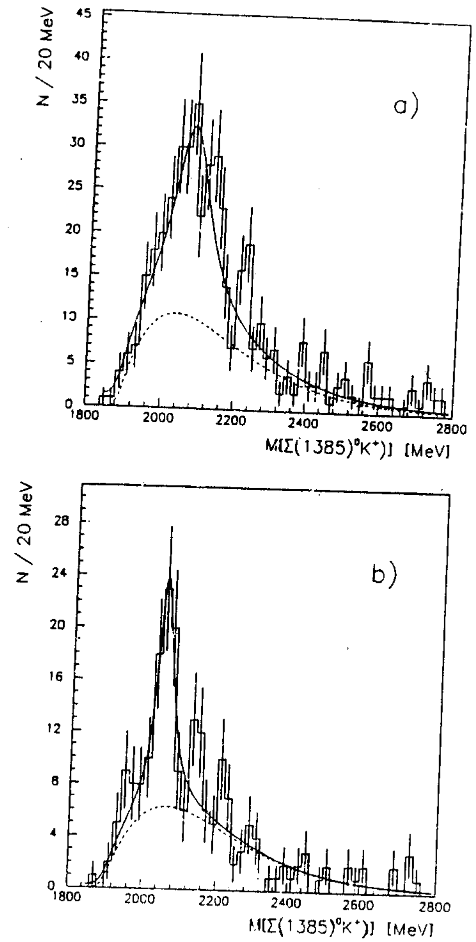

Figure 8. a) The invariant mass spectrum of the $\Sigma(1385)^o K^+$ system in the SPHINX experiment for coherent production process (4) on carbon nuclei (i.e. at $P_T^2 <$0.075 (GeV)^2). The spectrum is fitted by the sum of polynomial background and the Breit-Wigner peak with M=2065±11 MeV and Γ = 118±19 MeV. The soft P_T^2 cut, which is used in this spectrum leads to significant noncoherent background ($\gtrsim$30%). b) The same spectrum, but with more stringent cut ($P_T^2 < 0.02$ (GeV)^2) to stress the selection of coherent events. The spectrum is fitted by the sum of smooth polynomial background and the Breit-Winger peak with M = 2050 ± 6 MeV and Γ = 50 ± 20 MeV.

This drastically calls for the determination of quantum numbers of "$X(2060)$" as well as the thorough study of the dynamics of reaction (4). As the first step in this direction let one analyze 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 $(\mathrm{GeV})^2$ for the selection of coherent production reaction and rejection of noncoherent events.

It is a soft cut which allows for more than 30% of the noncoherent background in the mass spectrum in Fig.8. Besides, the measured value of the slope of the diffractive cone for carbon nuclei $b_1 \simeq 30$ $(\mathrm{GeV})^2$ seems to be somewhat reduced due to the instrumental uncertainties. If the real value of b_1 is in agreement with the expected value for carbon nuclei (50 GeV^{-2}) then one would anticipate an additional increase of noncoherent background in the mass spectrum of Fig.8a, which was obtained under the soft cut on P_T^2.

In order to reduce this noncoherent background and to obtain the $\Sigma(1385)^o K^+$ mass spectrum for "pure" coherent production reaction a stringent requirement P_T^2 <0.02 $(\mathrm{GeV})^2$ has been used (see Fig.8b). As is seen from the comparison of the mass spectra in Figs.8a and b, under the stringent P_T^2 cut the narrow peak with mass $M = 2050 \pm 6$ MeV and $\Gamma = 50 \pm 19$ MeV is clearly observed. This anomalously narrow structure can not be explained by diffractive nonresonant process of the Deck type and seems to be caused by the production of new exotic baryon with hidden strangeness. This conclusion must be considered as preliminary and should be confirmed in further measurements with increased statistics.

The effective mass spectra $M[\Sigma(1385)^o K^+]$ in reaction (4) in the region of M >2.5 GeV was also studied in the SPHINX measurement. In this spectrum there is no statistically significant evidences for any resonance structure. The upper limits for the corresponding cross sections are presented in Fig.9. In particular, the upper limit for $R(3520)$ baryon is found to be

$$\sigma[R(3520)^+]|_{nucleon} \cdot BR[R^+(3520) \to \Sigma(1385)^o K^+] \leqslant 16 \text{ nb/nucleon} \quad (19)$$

(95% C.L.).

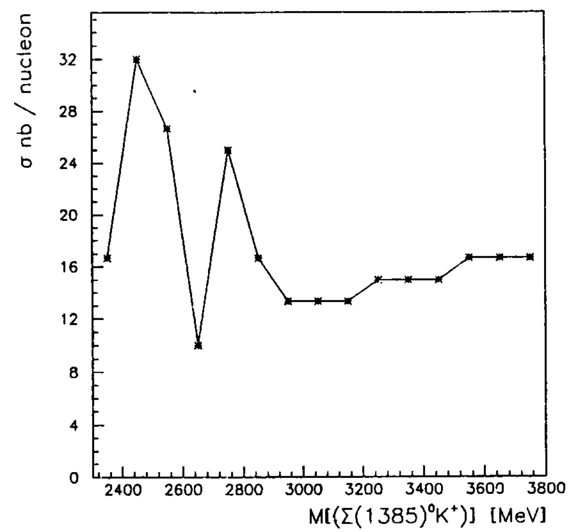

Figure 9. Upper limits (with 95% C.L.) for the cross sections of the diffractive production reaction for heavy B_ϕ baryons with the width $\Gamma \leqslant 50$ MeV for the decay channel $B_\phi \to \Sigma(1385)^o K^+$.

5. STUDY OF THE REACTION $p + N \to [\Sigma^o K^+] + N$

During the study of the reactions with Λ hyperons and K mesons we singled out the events which satisfy the standard selection criteria for the identification of the process

$$p + N \to [\Lambda \gamma K^+] + N. \quad (20)$$

In Fig.10a the mass spectrum of $\Lambda\gamma$ system in (20) is presented. In this spectrum the peak of $\Sigma^o \to \Lambda\gamma$ decay is clearly seen. The background under the peak is mainly due to the imitation of single photons in the γ spectrometer of the SPHINX setup by the remaining hadron showers. To reduce this hadron backgroubd more stringent criteria for the selection of the single photons were used (the increase of the threshold energy for the detection of photons – from E_γ >0.65 GeV up to E_γ > 1.2 GeV; the increase of the minimal distance between the nearest hadron treak and the photon shower; the cuts on the transverse dimensions of the showers). As the result of this more reliable single photon identification, the hadron background was strongly reduced as is seen from Figs.10a and 10b. Reaction (6) $p + N \to [\Sigma^o K^+] + N$ is now clearly singled out. The good background conditions for this reaction make it possible to study the effective mass spectra $M[\Sigma^o K^+]$ in it. The mass spectrum for the coherent diffractive production of $[\Sigma K^+]$ system on carbon nucleus (i.e. for P_T^2 <0.1 GeV^2) is presented in Fig.11. In this spectrum $M[\Sigma^o K^+]$ besides of some small structure with M ~1800 GeV in the threshold region, a strong $X(2000)$ peak with $M = 1999 \pm 7$ MeV and $\Gamma = 91 \pm 7$ MeV is observed.

First results for some decay channels of $X(2000)$ and $X(2050)$ states were obtained from the simultaneous analysis of the SPHINX data on the coherent reactions $p + C \rightarrow \Sigma(1385)^o K^+ + C$ or $p + C \rightarrow \Sigma^o K^+ + C$ together with $p + C \rightarrow p\pi^+\pi^- + C$ and $p + C \rightarrow \Delta^{++}\pi^- + C$ in the same kinematical conditions. The lower limits for the ratios of several decay branchings were estimated

$$\left.\begin{aligned}
R_1 &= \frac{BR\{X(2050)^+ \rightarrow [\Sigma(1385)K]^+\}}{BR\{X(2050)^+ \rightarrow [\Delta\pi]^+\}} > 1.2 \pm 0.6 \\
R_2 &= \frac{BR\{X(2050)^+ \rightarrow [\Sigma(1385)K]^+\}}{BR\{X(2050)^+ \rightarrow p\pi^+\pi^-\}} > 1.4 \pm 0.6 \\
R_3 &= \frac{BR\{X(2000)^+ \rightarrow [\Sigma K]^+\}}{BR\{X(2000)^+ \rightarrow [\Delta\pi]^+\}} > 0.3 \pm 0.12 \\
R_3 &= \frac{BR\{X(2000)^+ \rightarrow [\Sigma K]^+\}}{BR\{X(2000)^+ \rightarrow p\pi^+\pi^-\}} > 1.2 \pm 0.5
\end{aligned}\right\} \quad (21)$$

(preliminary results).

The small enough widths of $X(2000)$ (Fig.11) and $X(2050)$ (Fig.8b) as well as the anomalously large branchings for their decay channels with strange particles (large values for $R_1 - R_4$) are the reason to consider these states as serious candidates for the cryptoexotic baryons with hidden strangeness $|qqqs\bar{s}>$. Possible connection between $X(2000)$ and $X(2050)$ will be studied and the nature of these structures will be further clarified in future experiments with enlarged statistics.

The study of nonperipheral processes in reactions (4)-(6) in the region of $P_T^2 \gtrsim 0.3$ GeV^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. OTHER DIFFRACTIVE PROCESSES

In the experiments with the SPHINX facility besides reactions (1)-(6) many other diffractive proceesses were studied, for example, the reactions

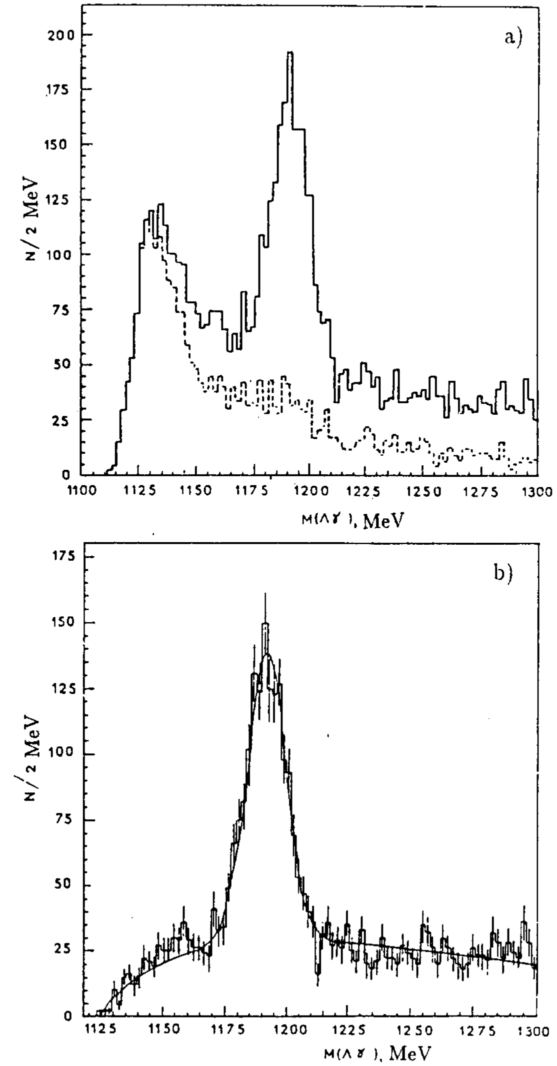

Figure 10. The effective mass spectrum for $\Lambda\gamma$ system in the reaction $p + N \rightarrow [\Lambda\gamma K^+] + N$. a) For the standard criteria for photon identification. Dotted histogram is for the background from the hadronic showers which imitates single photons in γ spectrometer. This background is reduced by special criteria for single photon identification (see the text). b) The same spectrum after special cuts for single photon identification.

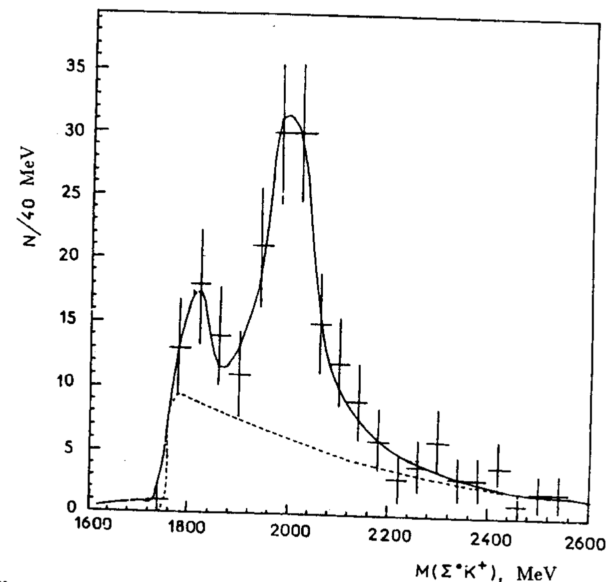

Figure 11. The effective mass spectrum $M[\Sigma^o K^+]$ for the coherent diffractive production reaction $p+C \to [\Sigma^o K^+]+C$ ($P_T^2 < 0.1$ GeV²). In this spectrum some structure in the threshold region with $M = 1802 \pm 3$ MeV and a clear peak with $M = 1999 \pm 7$ MeV and $\Gamma = 91 \pm 17$ MeV are observed. The dotted curve is for the polynomial background.

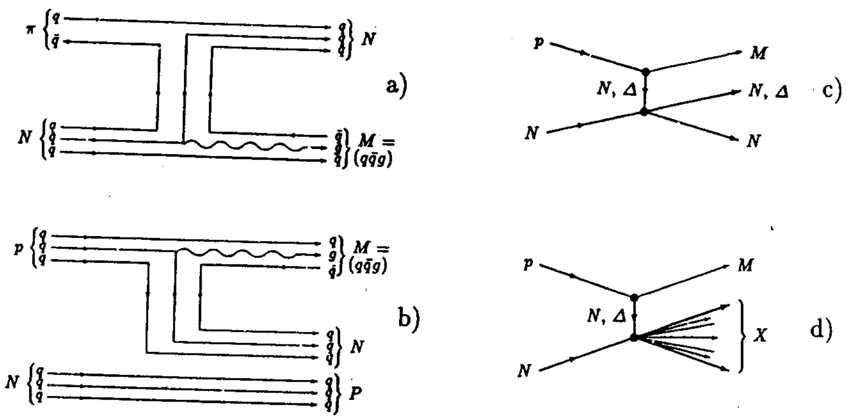

Figure 12. Diagrams for the exotic meson production in the processes with baryon exchange: a) hybrid meson production in πN interactions with baryon exchange; b) hybrid meson production in pN interactions with baryon exchange; c) baryon exchange reactions (28)-(33); d) baryon exchange reaction of quasi-exclusive type in pN interactions in a deep fragmentstion region (inclusive over the bottom vertex).

$$p + N \to [\Lambda K^+] + N, \tag{22}$$

$$p + N \to [\Lambda(1405)^o K^+] + N, \quad \Lambda(1405)^o \to \Sigma^+\pi^- \tag{23}$$

$$p + N \to [pp\bar{p}] + N, \tag{24}$$

$$p + N \to [p\omega] + N, \quad \omega \to \pi^+\pi^-\pi^o \tag{25}$$

$$p + N \to [p\eta] + N, \quad \eta \to \pi^+\pi^-\pi^o \tag{26}$$

$$p + N \to [p\eta'] + N. \quad \eta' \to \pi^+\pi^-\eta \tag{27}$$

All these reactions are clearly observed in the preliminary studies, and full-scale data handling for them is now in progress (see the results for (24) in Ref.[16]).

7. DEEP FRAGMENTATION PROCESSES AND THE SEARCH FOR EXOTIC MESON STATES

In connection with the studies of resonance states there were already many discussions about the possibilities of more effective excitation of inner colour degrees of freedom, at which the exotic multiquark or hybrid systems can be formed in the processes with large momentum transfers and, in particular, in the reactions of the backward scattering, caused by baryon exchange (see, for example, Refs. [17-20] and reviews [1,5,21]).

The production of exotic states in such processes is expected to be characterized by the cross sections comparable with those of ordinary particles. As an example of such backward scattering reaction the diagram for the hybrid meson production in the process $\pi N \to NM$ is shown on Fig.12a.

Some experimental difficalties hinder a wide development of searches for backward exotic meson production in pion interactions. The thing is that in these processes mesons go backward in the c.m. (Fig.12a), and hence in the lab frame their decay products have a soft momentum spectrum and wide angular distribution. In the experiments with magnetic spectrometers the efficiency for these mesons detection and identification is, as a rule, not very high.

However, one can overcome all these difficulties by studying meson resonance production in the baryon exchange processes in a proton beam in the reactions [17]

$$p + N \to M^{++} + [N\pi^- n] \qquad (\Delta^- \text{ exchange }), \qquad (28)$$
$$p + N \to M^{+} + [N\pi^- p] \qquad (\Delta^o \text{ exchange }), \qquad (29)$$
$$p + N \to M^{o} + [N\pi^o p] \qquad (\Delta^+ \text{ exchange }), \qquad (30)$$
$$p + N \to M^{-} + [N\pi^+ p] \qquad (\Delta^{++} \text{ exchange }), \qquad (31)$$
$$p + N \to M^{+} + [Nn] \qquad (n \text{ exchange }), \qquad (32)$$
$$p + N \to M^{o} + [Np] \qquad (p \text{ exchange }) \qquad (33)$$

(see Fig.12b and 12c).

In this case the mesons produced will go forward in the lab frame and may quite easily be detected in wide aperture magnetic spectrometers. The charged particles that emerge from meson decays can be identified by Cherenkov detectors. Reactions (28)-(33) must be studied at not very high energies because the exclusive cross sections with baryon exchange decrease rather rapidly with the growth of the primary energy: must be $\sigma \sim E_{lab}^{-(2\div3)}$ (for $E_{lab} > 10$ GeV and much more rapidly at smaller energies). The proton energy in the region of $E_{lab} \sim 10 \div 15$ GeV seems quite optimal for this type of experiment. Nevertheless the search for exotic mesonic states in the baryon exchange processes may be realized at even higher proton energies, which in a number of case is of a considerable interest, since it allows one to increase the setup acceptance and to identify more precisely secondary particles and mesonic resonances under investigation.

As the expected cross sections of exclusive reactions (28)-(33) are small enough at high energies, one can use the baryon exchange processes of an inclusive type in the bottom vertex (see Fig.12d)

$$p + N \to M + X_{\text{bottom. vertex}} \qquad (34)$$

when all admissible states for the dibaryon system in the bottom vertex are summed up, and the cross sections may very weakly depend on the initial energy E_p. At sufficiently high E_p secondary particles from the bottom and

top vertices for the diagram of Fig.12d will be quite efficiently separated in their rapidities. Therefore, in the study of mesonic resonances, produced in the top vertex the inclusive character of the reaction in the bottom vertex does not create undesirable combinatorial background (we shall call such processes quasi-exclusive ones). For these reactions one may expect the cross sections of hundreds of nb [17]. In this case the search for exotic mesons in quasi-exclusive processes will be rather promising.

All these qualitative considerations show that processes (28)-(32) may be of significant importance for the exotic hadron physics. In particular, the experiments with the SPHINX facility in a 70 GeV proton beam of IHEP accelerator provide a good opportunity for the study of quasi-exclusive reactions (34) with baryon exchange. But before proceeding to a wide program of the search for exotic resonances in these reactions it would be quite desirable to check the validity of the above assumptions on the significant values of the high energy cross sections for processes (34). This may be realized in the study of the simplest quasi-exclusive charge exchange reactions

$$p + N \to \pi^o_{\text{forward}} + X_{\text{bottom vertex}}, \quad \pi^o \to 2\gamma \qquad (35)$$

$$p + N \to \eta_{\text{forward}} + X_{\text{bottom vertex}}, \quad \eta \to 2\gamma \qquad (36)$$

$$p + N \to \omega_{\text{forward}} + X_{\text{bottom vertex}}, \quad \omega \to \pi^o\gamma \to 3\gamma \qquad (37)$$

in a deep fragmentation region (i.e. for $x_F > 0.85 \div 0.90$). Here we present preliminary results for these processes based on the analysis of the small part of the SPHINX statistics. The study of reactions (35)-(37) was performed in a special measurement simultaneosly with main processes (1)-(6) described above. For this purpose the 70 GeV proton interactions satisfying the following selection criteria were singled out on the trigger level:

a) there are no fast charged secondaries, i.e. charged particles that passed through the magnetic spectrometer of the setup;

b) there is a large released energy of neutral particles in the γ spectrometer (displaced at the end part of the setup): $\Sigma E_i > 45$ GeV.

In the analysis of these trigger events one used two additional cuts:

c) there are two or three γ-clusters in the γ spectrometer with the energy of each cluster above 1 GeV; for three cluster events two of them must satisfy the π^o requirement $(0.1 < M(\gamma_i\gamma_j) < 0.17)$ GeV;

d) $\Sigma_{i=1}^{n} E_{i\gamma} > E_{\text{thresh.}}$ ($n = 2$ or 3; $E_{\text{thresh.}}$ =50; 60; 65 GeV).

For a more detailed description of this experiment see Ref. [21].

Fig.13 and Fig.14 show effective mass spectra for 2γ and $\pi^o\gamma$ events satisfy the above requirements a)-d). In these spectra clear peaks were seen for π^o, η and ω production in reactions (35)-(37) in a deep fragmentation region. The corresponding cross section estimations are presented in Table 2. In spite of the preliminary character of these data it is possible to conclude that quasiexclusive meson production processes in pN-interactions at $E_p = 70$ GeV in a deep fragmentation region (for baryon exchange mechanism) are characterized by large enough cross sections and may be of great importance in the search and study of exotic mesons.

8. CONCLUSION

Thus the first results of the SPHINX experiment failed to confirm the existence of narrow heavy baryons $N_\phi(1960)$, $R(3520)$ and nonstrange analog of $\Sigma(3170)$ that were the candidates for cryptoexotic baryons. Strictly speaking there are no direct experimental contradictions between the SPHINX data and the results of previous experiments with these baryons because they have been obtained for different processes. But it must be stressed that the results of the SPHINX experiments are of better sensitivity and are obtained under better background conditions as compared with the results of other works.

Thus, for example, for the $R(3520)$ baryons the upper limits for cross-sections (8)–(10),(19) in different decay channels are by 4–5 orders of magnitude lower, than the data of Ref.[11]. At the same time the background conditions for the search of $N_\phi(1960)$ baryon in coherent diffractive reaction (4) as well as in partially-inclusive nonelastic process (5) in the SPHINX facility are much better than for the corresponding measurements with the BIS-2 [9]. Based on these data there are serious doubts about the real existence of the $R(3520)$ and $N_\phi(1960)$ baryons.

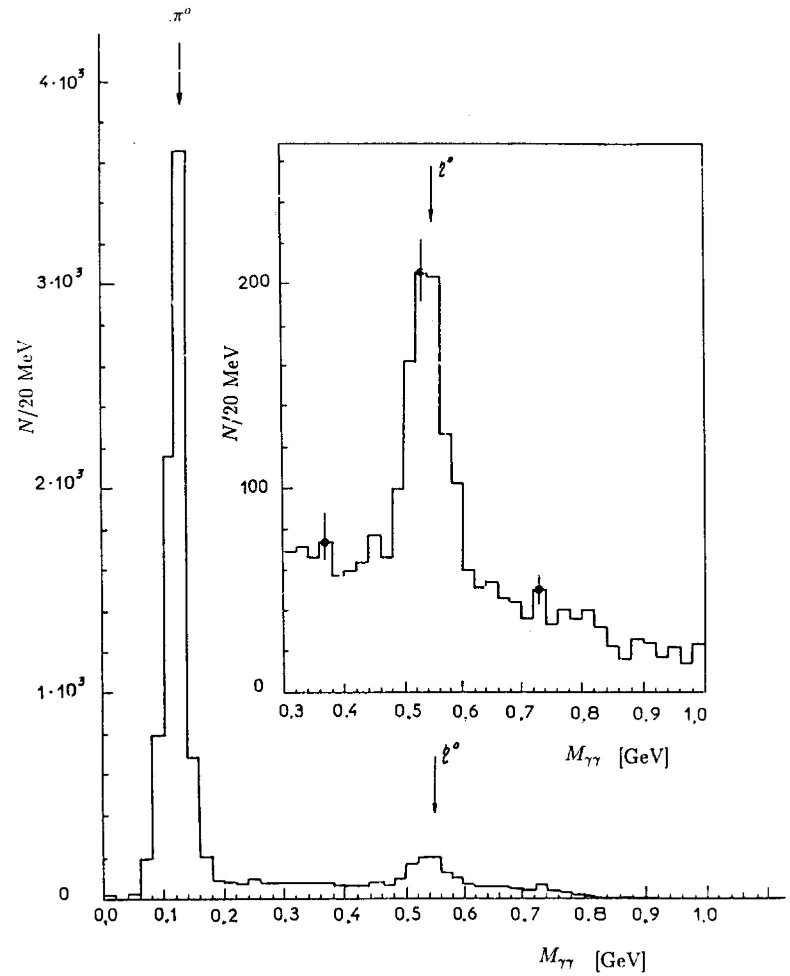

Figure 13. The effective mass spectrum for $\gamma\gamma$ clusters in the charge-exchange reactions in a deep fragmentation region $p + N \to (\gamma\gamma)|_{E>E_{threshold}} + X_{bottom\ vertex}$ on the SPHINX facility: $E_{threshold}$=60 GeV. In this spectrum π^o and η meson production in a deep fragmentation region for reactions (35) and (36) is singled out.

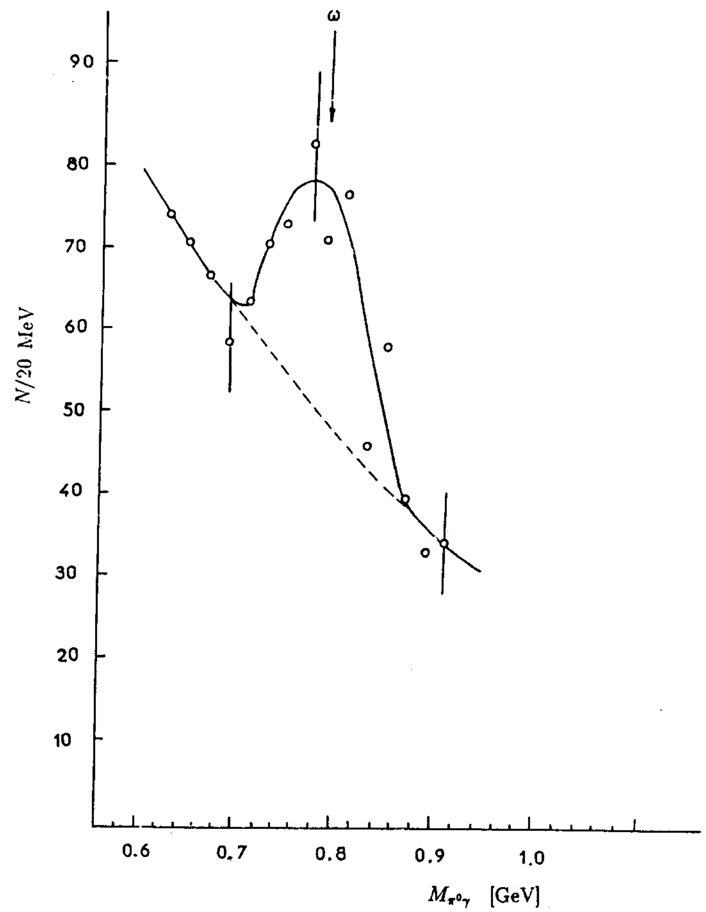

Figure 14. The effective mass spectrum for $\pi^o\gamma$ system for the events of the reaction $p+N \to (\gamma\gamma\gamma)|_{E>E_{threshold}} + X_{\substack{bottom\\vertex}}$ on the SPHINX facility ($E_{threshold}$=60 GeV). In this spectrum ω meson production in a deep fragmentation region for reactions (37) is singled out.

Table 2. Cross sections for quasi-exclusive charge-exchange reactions (35)-(37) in a deep fragmentation region

Reaction	$0.86 < x_F \leqslant 1$ N_{events}	$(E_M > 60$ GeV) σ (μb/nucleon)
$p+N \to \pi^o_{forward} + X_{\substack{bottom\\vertex}}$	7197 ± 90	~ 0.35
$p+N \to \eta_{forward} + X_{\substack{bottom\\vertex}}$	576 ± 36	~ 0.05
$p+N \to \omega_{forward} + X_{\substack{bottom\\vertex}}$	155 ± 24	~ 0.25

But it is true enough, that the SPHINX results are mainly obtained for the coherent and diffractive processes. Up to now there are no statistically significant SPHINX data for the corresponding reactions in the intermediate and large transverse momenta region as well as for other processes in which there are no limitations for the flavors of the produced baryons constrained by the initial particles (as it takes place in the diffractive baryon production due to Pomeron exchange). And here it is possible to find some unexpected phenomena.

At the same time in the SPHINX experiments the new interesting structures in the effective mass spectra of $\Sigma(1385)^o K^+$ and $\Sigma^o K^+$ systems were obtained in the coherent diffractive production reactions on the carbon nuclei ($X(2050)$ and $X(2000)$ – see Figs.8b and 11). The nature of these states and their possible connection need further investigation. It is possible that these relatively narrow heavy states with considerable decay modes with strange particles are candidates for exotic baryons with hidden strangeness. But it must be remainded that the experimental data on these states need further confirmations in new measurements with increased statistics.

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