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SEARCH FOR $N_\phi(1960)$ BARYON

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Abstract

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In the experiments at the SPHINX facility in the 70 GeV proton beam of the IHEP accelerator the diffractive production reactions $p + N \to [\Sigma(1385)^0 K^+] + N$ and $p + N \to [\Sigma(1385)^0 K^+] + N +$ (neutral particles) were studied. In the effective mass spectra of the $[\Sigma(1385)^0 K^+]$ system in these processes there were no signals from the anomalously narrow baryon state $N_\phi(1960)$, which had been observed earlier in the measurement at the BIS-2 setup.

Аннотация

Балац М.Я. и др. Поиски $N_\phi(1960)$ бариона: Препринт ИФВЭ 93-97. – Протвино, 1993. – 15 с., 7 рис., библиогр.: 6.

В опытах на установке СФИНКС исследовались процессы дифракционного образования $p + N \to [\Sigma(1385)^0 K^+] + N$ и $p + N \to [\Sigma(1385)^0 K^+] + N +$ (нейтральные частицы) с протонами с энергией $E_p = 70$ ГэВ. При анализе спектров масс $[\Sigma(1385)^0 K^+]$ системы в этих процессах не найдено аномально узкое барионное состояние $N_\phi(1960)$, наблюдавшееся ранее в опытах на БИС-2.

1. INTRODUCTION

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

$$n + C \to \Sigma(1385)^- K^+ + \cdots, \quad \Sigma(1385)^- \to \Lambda\pi^- \tag{1}$$

was studied [1].

In the effective mass spectrum of the $\Sigma(1385)^- K^+$ system a narrow peak was observed with mass $M = 1956^{+8}_{-9}$ MeV and width $\Gamma = 27 \pm 15$ MeV. This structure was interpreted in Ref [1] as a candidate for the cryptoexotic baryon with hidden strangeness $|uddss\bar{s}>$ and was designated as $N_\phi(1960)$ baryon.

The cross section for the $N_\phi(1960)^o$ production in (1) was obtained to be in Ref. [1]

$$\sigma[n + (C) \to N_\phi(1960) + \cdots] \cdot BR[N_\phi(1960)^o \to \Sigma(1385)^- K^+] =$$
$$= (1150 \pm 190) \text{ nb/C nucleus.} \tag{2}$$

From (2) with account of isotopic conditions for the decays $N_\phi^o \to \Sigma(1385)K$ it is possible to obtain

$$\sigma[n + (C) \to N_\phi(1960)^o + \cdots] \cdot BR[N_\phi(1960)^o \to \Sigma(1385)K] =$$
$$= (1725 \pm 285) \text{ nb/C nucleus} \tag{3}$$

(if the isospin of $N_\phi(1960)$ is $I = 1/2$). The value of the cross section for N_ϕ production per nucleon (for $\sigma \sim A^{2/3}$) can be also evaluated as

$$\sigma[n + N \to N_\phi(1960)^0 + \cdots] \cdot BR[N_\phi^0 \to \Sigma(1385)K] =$$

$$= (330 \pm 60)\ \text{nb/nucleon}^1 \qquad (4)$$

Because of the importance of the problem of the possible existence of the cryptoexotic $N_\phi(1960)$ baryon we have performed a new search for this state in recent experiments using the SPHINX facility.

2. STUDY OF THE REACTION $p + N \to [\Sigma(1385)^0 K^+] + N$ IN THE EXPERIMENTS ON THE SPHINX FACILITY

In the experiments with the SPHINX facility a wide program of study of hadron diffractive production by protons with $E_p = 70$ GeV and of search for exotic baryons in these processes is carried out. This program has been detailed in Refs. [2,3]. First results of the measurements for the reaction $p + N \to (K^+K^-p) + N$ were described in Ref. [2] (see also [4]).

In this paper the data on the reaction

$$p + N \to [\Sigma(1385)^0 K^+] + N \qquad (5)$$

are presented which have been obtained simultaneously with the study of $p + N \to (K^+K^-p) + N$

The SPHINX facility [2], which is used for this measurement, includes a wide-aperture magnetic spectrometer with scintillation counters, hodoscopes, proportional chambers, drift chambers and a multichannel γ-spectrometer with lead glass detectors. The charged particles in the final state were identified by means of a RICH differential Cherenkov spectrometer and two threshold gas Cherenkov hodoscope counters.

Reaction (5) was singled out in the analysis of the same trigger events with 3 charged particles in the final state which were discussed in Ref. [2].

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[1] As it was shown by fitting the $[\Sigma(1385)^- K^+]$ effective mass spectrum from the BIS data by the sum of a Breit-Wigner peak N_ϕ and a polynomial background the number of events in the N_ϕ-peak as well as cross section in (2) (and hence also in (3) and (4)) were obtained in Ref. [1] not very correctly and must be increased by a factor of $1.7 \div 2.0$ as compared with the published values in Ref. [1]

The analyzed statistics correspond to the total flux of $N_p = 0.9 \cdot 10^{11}$ protons passing through the setup target. The effective thickness of this polyethylene target was $0.48 \cdot 10^{24}\ CH_2/cm^2$.

For the selection of reaction (5) at the first stage of the data processing the events with 3 charged particles and 2 γ 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 [5]).

The corresponding events were classified as events of the $p\pi^-\pi^o K^+$ type. For these events the 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

$$p + N \to (p\pi^-\pi^o K^+) + N \qquad (6)$$

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

$$65\ \text{GeV} < E_p + E_{\pi^-} + E_{\pi^o} + E_{K^+} < 75\ \text{GeV} \qquad (7)$$

(~6000 "elastic" events of (6)). As was shown from the study of the two-dimensional distribution of the events in effective masses $M(\pi^- p)$ and $M(\pi^o p)$ in this process, the main contribution to the events of type (6) resulted from the hyperon decays $\Lambda \to p\pi^-$ and $\Sigma^+ \to p\pi^o$. The decay path for Λ hyperons in the run on the SPHINX setup is limited to ~ 30 cm by trigger requirements. The registration of the decay $\Sigma^+ \to p\pi^o$ is possible over the whole decay base for Σ^+ hyperons.

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

$$p + N \to [\Lambda\pi^o K^+] + N, \quad \Lambda \hookrightarrow p\pi^- \qquad (8)$$

$$p + N \to [\Sigma^+\pi^- K^+] + N, \quad \Sigma^+ \hookrightarrow p\pi^o \qquad (9)$$

In Fig.1 the effective mass spectrum of the $\Lambda\pi^0$ system in reaction (8) is presented. In this spectrum the peak of $\Sigma(1385)^o \rightarrow \Lambda\pi^o$ is dominating. The background level under the $\Sigma(1385)^o$ peak is quite small. This fact simplifies the identification of reaction (5) because there is no need to subtract background in this case.

As it follows from dN/dP_T^2 distribution for the events of reaction (5) the dominant role of the coherent production of the $\Sigma(1385)^o K^+$ system (with slope $b \gtrsim 30$ $(\mathrm{GeV})^{-2}$) is evident for this process. All the details connected with the selection and study of reactions (5), (6) and (8) can be found in Ref. [5].

The results of the thorough study of the $\Sigma(1385)^o K^+$ effective mass spectra in reaction (5) are given in Fig.2. Fig.3 shows the same spectra using an enlarged scale around the expected position of the $N_\varphi(1960)$ peak. These data include coherent diffractive production of $[\Sigma(1385)^o K^+]$ on carbon nuclei (in the region of $P_T^2 < 0.075$ GeV^2), as well as the events with larger transverse momenta.

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

As it is clear from the data of Fig.3, the anomalously-narrow $N_\phi(1960)$ baryon, which had been observed earlier by the BIS-2 group, was not seen in the SPHINX experiment. The upper limit on the cross section for coherent diffractive production of the N_ϕ baryon on carbon nuclei was obtained from the SPHINX data (Fig.3b)

$$\sigma[p + C \rightarrow N_\phi(1960)^+ + C] \cdot BR[N_\phi(1960)^+ \rightarrow \Sigma(1385)^o K^+] \leq$$

$$\leq 220 \ \ \mathrm{nb/C\ nucleus} \quad (95\%\ \mathrm{C.L.}). \qquad (10)$$

By using the isotopic relations for the decays $N_\phi^+ \rightarrow \Sigma(1385)K$ more general limitation is found (if the isospin of $N_\phi(1960)$ is $I = 1/2$)

$$\sigma[p + C \rightarrow N_\phi(1960)^+ + C] \cdot BR[N_\phi(1960)^+ \rightarrow \Sigma(1385)K] \leq$$

$$\leq 660 \ \ \mathrm{nb/C\ nucleus} \quad (95\%\ \mathrm{C.L.}). \qquad (11)$$

From here it is possible to estimate the cross section limits for $N_\phi(1960)$ production per nucleon

$$\sigma[p + N \to N_\phi(1960)^+ + N] \cdot BR[N_\phi(1960)^+ \to \Sigma(1385)K] \leq$$

$$\leq \begin{cases} 55 \text{ nb/nucleon} & (\text{ for } \sigma \sim A) \quad (12) \\ 125 \text{ nb/nucleon} & (\text{ for } \sigma \sim A^{2/3}) \quad (13) \end{cases}$$

(the linear cross section dependence on atomic number $\sigma \sim A$ can take place due to the coherent character of the production process on nuclei).

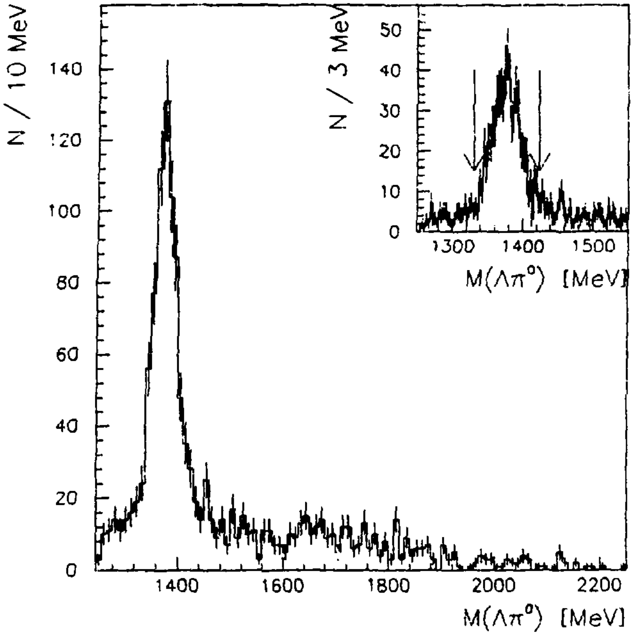

Figure 1. The invariant mass spectrum of $\Lambda\pi^0$ system in the reaction (8). The parameters of the $\Sigma(1385)^0$ peak are $M = 1377 \pm 3$ MeV and $\Gamma = 39 \pm 3$ MeV. They are in agreement with tabulated values of these parameters (with the account of the apparatus mass resolution $\sigma = \pm 9$ MeV and systematic errors). The arrows indicate the region of $\Sigma(1385)$ band.

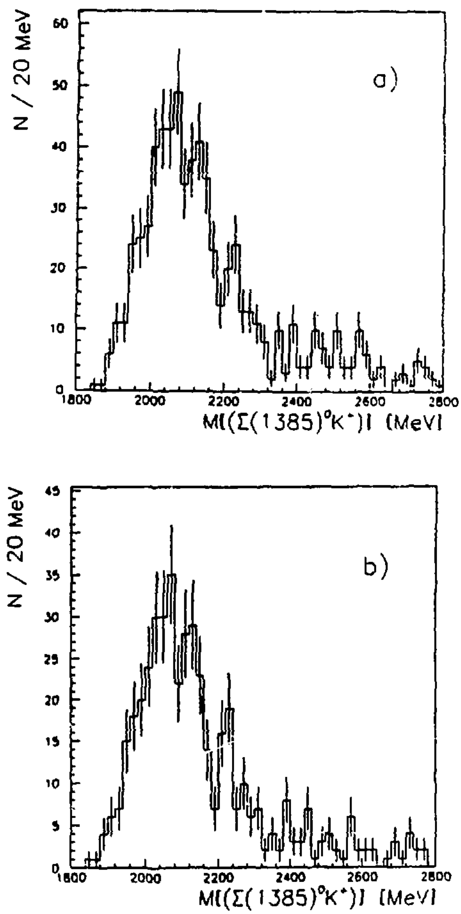

Figure 2. The invariant mass spectra of $\Sigma(1385)^{\circ}K^{+}$ system in the reaction (5) in the SPHINX experiment: a) for all P_T^2; b) for P_T^2 <0.075 (GeV)^2 (coherent production process on carbon nuclei).

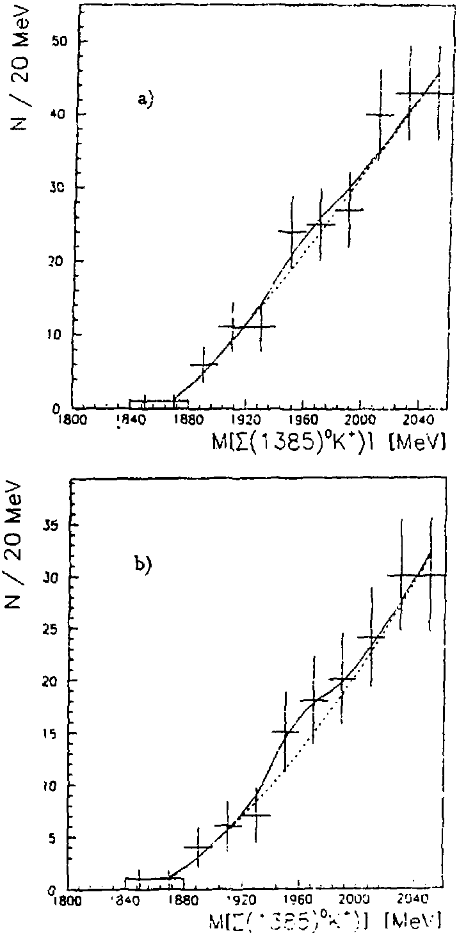

Figure 3. The same $M[\Sigma(1385)^0 K^+]$ spectra in a large scale in the expected region for the $N_\phi(1960)$-peak: a) for all P_T^2; b) for coherent production on carbon ($P_T^2 <$ 0.075 GeV^2). The solid curves show the results of the fits with $N_\phi(1960)$ Breit Wigner resonance with parameters of Ref.[1] and polynomial background (dotted curves).

From the data in Fig.3a (without the P_T^2 selection cut) it is possible to obtain the cross section limits for N_ϕ production for all the processes (and not only for coherent one). We obtain this estimation only for the cross section limits per nucleon (because the target has the composition CH_2). We use a $\sigma \sim A^{2/3}$ atomic number dependence for the comparison with the BIS-2 data. As a result we have a conservative upper limit estimation for this case

$$\sigma[p + N \rightarrow N_\phi(1960)^+ + N] \cdot BR[N_\phi(1960)^+ \rightarrow$$

$$\rightarrow \Sigma(1385)K] \leq 120 \text{ nb/nucleon} \qquad (14)$$

(which is very close to (13)).

Upper limits (11)-(14) are significantly lower than the corresponding values of cross sections for $N_\phi(1960)$ production from the BIS-2 experiment (see (3), (4) and footnote on page 3). What is still more important, there is a sharp difference in the forms of effective mass spectra for these two measurements (see Fig.4).

In the comparison of the results of these studies one must bear in mind some significant differences between the SPHINX and BIS-2 experiments.

a) The BIS-2 setup has a very limited acceptance which quickly decreases with increasing effective mass $M[\Sigma(1385)^- K^+]$.

For the SPHINX setup the efficiency is much more uniform and still significant up to $M \simeq 4.0$ GeV.

b) There was no direct identification of charged secondaries in the BIS-2 experiment. Such identification was only possible by kinematical fitting. For the SPHINX setup there was a very good identification of charged particles with RICH spectrometer and two threshold Cherenkov counters (see Ref. [2]).

c) In the SPHINX measurement the additional elastic condition (7) for the total energy was used in the analysis. For the BIS-2 data such a requirement can not be imposed because of the nonmonochromatic and unknown energy of the initial neutrons. Furthermore, on the SPHINX setup the charged secondaries as well as neutral ones were detected whereas on the BIS-2 only charged particles were registered.

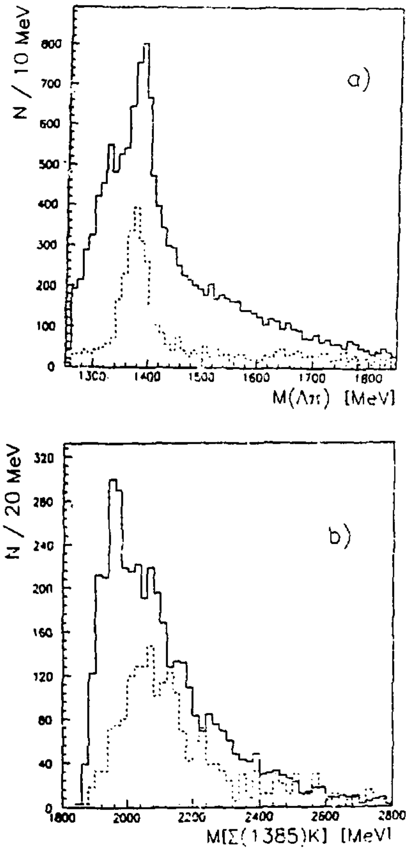

Figure 4. The comparison of the SPHINX (dotted line) and the BIS-2 (solid line) data, which were normalized on the same number of the Σ(1385) hyperons: a) the invariant mass spectra of $\Lambda\pi^{\circ}$ (SPHINX) and $\Lambda\pi^{-}$ (BIS-2); b) the invariant mass spectra of $\Sigma(1385)K^{+}$ systems: $\Sigma(1385)^{\circ}K^{+}$ (SPHINX) and $\Sigma(1385)^{-}K^{+}$ (BIS-2). In last spectra the full "Σ(1385)-band" is used ($1330 < M(\Lambda\pi) < 1424$ MeV). Thus in the BIS-2 spectrum 2/3 of events are from the background under the Σ(1385) peak. On the SPHINX data this background is negligible.

d) In the invariant mass spectra of $\Lambda\pi^o$ in the SPHINX measurement the peak for the decay $\Sigma(1385) \to \Lambda\pi^o$ is clearly singled out with a very small background under the peak. Meanwhile, for the BIS-2 experiment the background under the $\Sigma(1385)^-$ peak is twice as large as resonance effect (see Fig.4).

e) In the experiments on the BIS-2 facility only decays with charged secondaries were detected ($\Sigma(1385)^- K^+ \to \Lambda\pi^- K^+ \to p\pi^-\pi^- K^+$). The mass resolution in these measurements was equal to $\sigma = \pm 4$ MeV in the $N_\phi(1960)$ mass region. In the SPHINX measurements with π^o production the mass resolution for $\Sigma(1385)^o K^+ \to \Lambda\pi^o K^+ \to p\pi^-\pi^o K^+$ is $\sigma = \pm 11$ MeV. In spite of the worse mass resolution in the SPHINX data it is quite sufficient for the selection of $N_\phi(1960)$ peak with $\Gamma = 27 \pm 15$ MeV if this state really exists. Of course, this mass resolution was taken into account in the procedure of the evaluation of cross-section limits (10)-(14).

Thus from the experimental point of view the study of the $[\Sigma(1385)K]$ system in our measurement on the SPHINX facility is carried out under much better background conditions as compared with the BIS-2 experiment.

One can suggest different reasons for the considerable disagreement between these two experiments. Strictly speaking, there are no direct contradictions between their results because they have been obtained for different processes. But in Ref.[1] it is stated that the $N_\phi(1960)$ baryon is produced in (1) by diffractive dissociation of primary neutrons on the nucleons of the target nucleus (C). This conclusion is in evident contradiction with the SPHINX data, where we do not observe the $N_\phi(1960)$ in the diffractive production processes. It can neither be supported by energy consideration because of the unknown neutron energy in the BIS measurement. If a diffractive production process for $N_\phi(1960)$ does really take place in (1), it must manifest itself in the coherent reaction on C nuclei with a P_T^2 slope $b \gtrsim 30$-40 GeV^{-2} which is much larger than the observed value $b = 9.9 \pm 3.0$ (GeV)$^{-2}$ [1]. Thus the statement about the dominance of diffractive production in (1) seems incorrect. Then there are two possibilities for the explanation of the difference between the SPHINX and BIS-2 $N_\phi(1960)$ data:

a) The N_ϕ baryon exists but is not produced in the diffractive production reactions. Such situation would take place, for example, if the isospin of $N_\phi(1960)$ is $I = 3/2$. Then the $N_\phi(1960)$ baryon would not be seen in the SPHINX experiment where from the very beginning the conditions for the selection of diffractive production are fulfilled (the trigger, the elastic energy requirement 65 GeV $< \Sigma E_i <$ 75 GeV);

b) Because of the poor background conditions for the isolation of reaction (1) the procedure of the background subtraction in the BIS-2 experiment is not correct and the narrow $N_\phi(1960)^o$ from [1] is, in fact, fake. This last explanation seems to be the most natural one.

In the SPHINX experiment the study of $(\Lambda\pi^o K^+)$ production is performed also in inelastic partially - inclusive reaction with additional neutral particles

$$p + N \to [\Lambda\pi^o K^+] + N + \text{ (neutral particles)} \qquad (15)$$

For this purpose we analyze the trigger events with two and more than two γ-clusters in the photon spectrometer of the SPHINX setup and then separate the events for which at least one photon pair has effective mass in π^o region $(0.10 \leqslant M(\gamma_1\gamma_2) \leqslant 0.17\,\text{GeV})$. When there are more than one $\gamma_i\gamma_j$ combinations for which $M(\gamma_i\gamma_j)$ is 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.

The numbers of events for reaction (15) is 2855, which exceeds more than four times the number of "elastic" events of type (8). The effective mass spectrum of the $\Lambda\pi^o$ system in (15) is presented in Fig.5. The $\Sigma(1385)^o$ peak is clearly seen and the background under the peak, although significantly exceeding the one in the "elastic" case (see Fig.1), is much lower than in the BIS-2 measurement (Fig.4a).

The mass spectra of $M[\Sigma(1385)^o K^+]$ in (15) for the "$\Sigma(1385)$-band" on Fig.5 (1330 MeV $\leqslant M(\Lambda\pi^o) \leqslant$1424 MeV) are presented in Figs.6 and 7 for different cuts on P_T^2. In these spectra also we do not observe the $N_\phi(1960)$ peak. The upper limits on the cross sections for $N_\phi(1960)$ production in partially-inclusive reaction (15) are obtained (with 95% c.l.):

a) For the coherent production on C nuclei (Fig.7b; $P_T^2 < 0.075\ (GeV)^2$)

$$\sigma[N_\phi(1960)]_C \cdot BR = \sigma[p + C \to N_\phi(1960) + C + \text{ neutrals }]\cdot$$

$$\cdot BR[N_\phi(1960)^+ \to \Sigma(1385)K] < 820 \text{ nb/C nucleus} \qquad (16)$$

or, per nucleon,

$$\sigma[N_\phi(1960)]_{nucleon} \cdot BR < \begin{cases} 70 \text{ nb/nucleon} & (\sigma \sim A) \\ 150 \text{ nb/nucleon} & (\sigma \sim A^{2/3}) \end{cases} \qquad (17)$$

b) For all the events of reaction (15) (Fig.7a, all P_T^2)

$$\sigma[N_\phi(1960)]_{nucleon} \cdot BR < 230 \text{ nb/nucleon} . \qquad (18)$$

These upper limits are also significantly smaller than the BIS-2 cross section for $N_\phi(1960)$ production. Thus the SPHINX data on partially-inclusive inelastic reaction (15) support the hypothesis of a fake $N_\phi(1960)$ signal in the BIS-2 experiment.

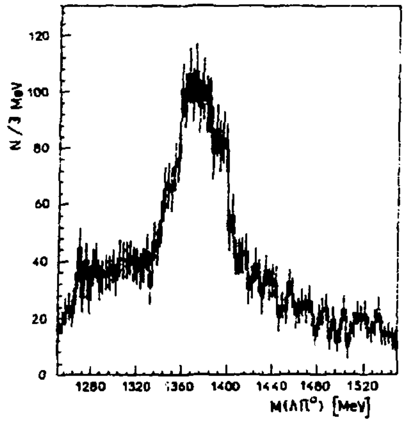

Figure 5. The invariant mass spectrum of $\Lambda\pi$ system in the inelastic reaction (15). The background conditions under $\Sigma(1385)$ peak are significantly worse then in elastic process (8) (see Fig.1), but much better then in the BIS-2 measurement (Fig.4a).

4. $\Sigma(1385)^o K^+$ EFFECTIVE MASS SPECTRA

Let us return to the analysis of the effective mass spectra of $\Sigma(1385)^o K^+$ in reaction (1). These spectra obtained in different regions of transverse momenta are presented in Fig.2. There is a structure with mass $M \simeq 2060$ MeV and width $\Gamma \simeq 120$ MeV in all of these spectra. The nature of this "X(2060)" structure is quite unclear now. A resonance interpretation is possible, but it may also be that the form of the observed spectra due to the diffractive nonresonance production with account of the Deck-effect. The inverted commas in the notation "X(2060)" are used to stress this uncertainty.

It must be stated that the data on effective mass spectra in Fig.2 are in agreement with the results of experiments [6], in which the neutron diffractive production of $\Sigma(1385)K$ system on a proton target in the energy range of 6-24 GeV seems to take place. However,the statistics achieved in Ref. [6] is quite small.

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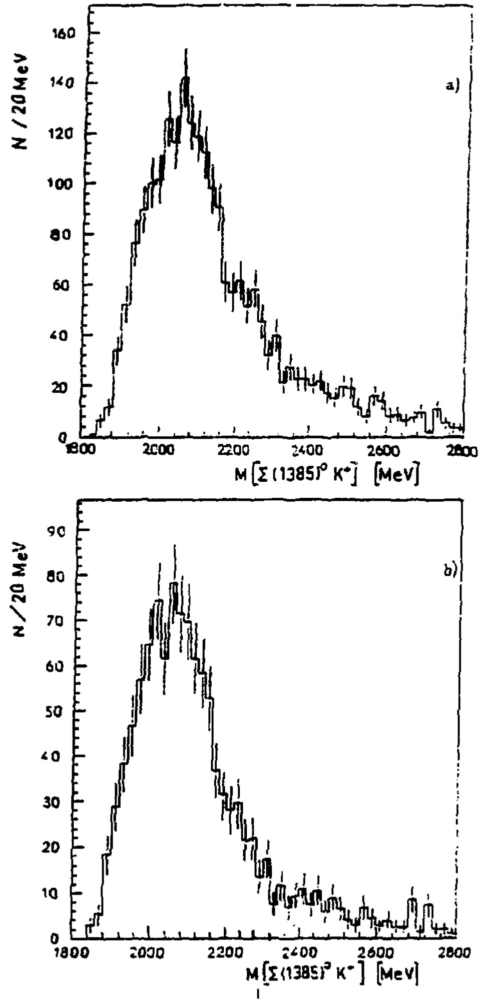
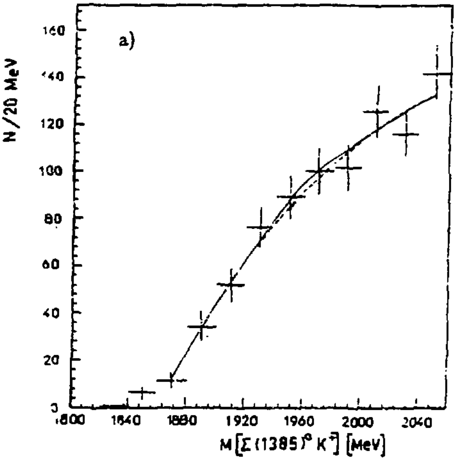


Figure 6. The invariant mass spectra of $[\Sigma(1385)^o K^+]$ system in partially-inclusive reaction (15): a) for all P_T^2; b) for coherent events ($P_T^2 < 0.075$ GeV^2).



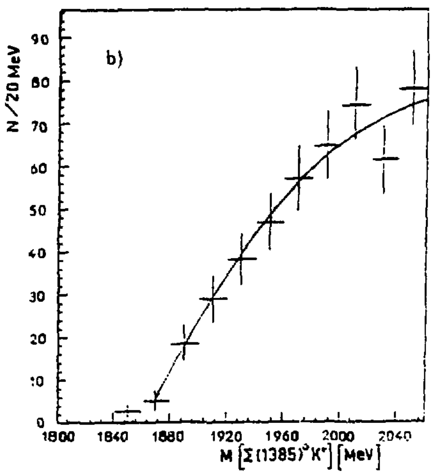


Figure 7. The same as on Fig.6, but only for the mass region of $N_\phi(1960)$.

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