On the nature of new baryon state X(2000) observed in the experiments with the SPHINX spectrometer.

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Abstract. In the experiment with the SPHINX spectrometer in 1995-99 a new baryon state $X(2000) \rightarrow \Sigma^0 K^+$ was observed in the proton diffractive reactions $p + N(C) \rightarrow \Sigma^0 K^+ + N(C)$. The main parameters of $X(2000)$ baryon are $M = 1986 \pm 6$ MeV, $I = 98 \pm 21$ MeV. Unusual features of massive $X(2000)$ state (narrow decay width $\Gamma \simeq 0.05$, anomalously large branching ratio with strange particle emission) make it serious candidate for cryptoexotic pentaquark baryon with hidden strangeness. New data on the SPHINX with by an order of magnitude enlarge statistics are in agreement with previous data and are supported our conclusions. We propose further studies $X(2000)$ baryon production in the meson reactions with baryon exchange: $\pi^\pm + p \rightarrow X(2000)^\pm + \pi^\pm$ (OZI - forbidden suppressed reaction for the state $|qqqs\rangle$) and $K^\pm + p \rightarrow X(2000)^\pm + K^\pm$ (OZI - allowed reaction). If the value of $R = \frac{BR[\pi^\pm + p \rightarrow X(2000)^\pm + \pi^\pm]}{BR[K^\pm + p \rightarrow X(2000)^\pm + K^\pm]} \ll 1$ it will be the crucial argument in favor of $X(2000) = |qqqs\rangle$ structure. These experiments may be done on IHEP separated kaon beam with OKA spectrometer.

PACS. 12.39.Mk Glueball and nonstandard multi-quark/glueon states – 13.85.Rm Limits on production of particles – 14.20.-c Baryons – 25.40.-h Nucleon-induced reactions

1 Introduction

In the experiments with SPHINX spectrometer an extensive program of studying diffractive production proton reactions on nucleons and nuclei (coherent processes) was carried out on the secondary proton beam of IHEP accelerator with energy $E_p = 70$ GeV and intensity $I_p = (2 \div 4) \cdot 10^8 p/spill$. The main aim of this program is the search for cryptoexotic baryons with hidden strangeness $|qqqs\rangle$ (here $q = u$ or $d$-quarks). This program was discussed in detail in the review papers[1][2][3]. These searches were performed primarily in the gluon-enriched Pomeron exchange diffractive production reactions. According to modern ideas, the main component of a Pomeron is sort of gluon "ladder", which can provide for Pomeron processes a special role in production of exotic hadrons (Fig. 1). Of significant interest are coherent diffractive processes taking place on the nucleus as a whole. We shall deal with these processes with more detail and discuss method for identification of them. Consider a diffractive production of a certain set of secondary particles, for example $p + A \rightarrow [abc] + A$, which can proceed coherently on the nucleus $A$. For identification of a coherent processes we consider the distribution of events for the reaction of interest over the square of transverse momentum $P_T^2$. In accordance with the uncertainty principle a coherent process proceeding on a nucleus as a whole is characterized by relatively small transverse momenta $P_T$ inversely proportional to the radius of the target nucleus $R = cons \cdot A^\frac{1}{3}$. A coherent process manifests itself as a narrow diffractive peak in the distribution of events over $P_T^2$ (see below).

Coherent processes serve as a certain filter that permits more clear identification of the produced resonances $R \rightarrow a + b + c$ with respect of non-resonance multiparticle background. In the case of multiparticle events the probability of secondary interactions in the nucleus exceeds the respective probability for resonances. Secondary interactions violate the condition of coherence. Therefore, in the case of coherent events the non-resonance background can be significantly reduced with respect to the resonance effects. These arguments are qualitatively illustrated by the diagrams depicted in Fig. 2.

The experiment for studying diffractive production reaction were carried out on the SPHINX spectrometer. This multipurpose facility includes wide aperture magnetic spectrometer with proportional chambers, drift tubes and hodoscopes, hodoscopic electromagnetic spectrometer with lead-glass counters, Cherenkov detectors for identification of secondary particles, the guard system for separation of exclusive diffractive-like reactions. In the pro-
The experiments of the second generation with completely upgraded SPHINX detector (in runs of 1996 - 1999).

"Old" and completely upgraded SPHINX spectrometer had the same general structure. But after upgrade the facility was equipped with a new tracking system, new hodoscopes, hadron calorimeter, new electronics, DAQ and on-line computers (which increase the maximal available flux of data per spill more than by order of magnitude). As a result of the upgrade, we have obtained a practically new setup, which is described in [19, 20].

With the upgraded setup during the runs 1996 - 1999 more than $10^9$ events were recorded on magnetic tapes. This statistics now used to study different physical processes. First result of these studies are published in [21, 22].

**2 The main result for X(2000) baryon obtained in the first generation of experiments with the SPHINX detector.**

The most important result obtained in the first generation of experiments with the SPHINX spectrometer is observation of new X(2000) baryon in the reaction

$$ p + N(C) \rightarrow X(2000) + N(C) $$

This result was obtained in studying the reaction

$$ p + N(C) \rightarrow \Sigma^0 K^+ + N(C) $$

(see ref. [1, 2, 3, 4, 5, 6, 7, 8, 9, 13, 14, 17]). Fig. 3 presents the effective mass spectrum in [2] for the entire range of transverse momentum $P_T$.

A clear peak with parameters

$$ M = 1986 \pm 6MeV; \Gamma = 98 \pm 21MeV $$

is seen in this spectrum and thus reaction (1) on quasi-free nucleons N was identified. Reaction (4) was very clear observed in different kinematical regions for all $P_T^2$ - Fig. 4 in the coherent region $P_T^2 < 0.1GeV^2$ - Fig. 5 in the region of very small $P_T^2$ - Fig. 6. In Fig. 7 presented the $P_T^2$ distribution $dN/dP_T^2$ for the reaction (1). From this distribution the coherent diffractive production reaction on carbon nuclei is identified as the narrow peak with the slope $b_1 \simeq 63 \pm 10GeV$.

The values of cross sections for the reactions under study were obtained [14]:

a) X(2000) production in the entire region of $P_T^2$

$$ \sigma_{p+N \rightarrow X(2000)+N} \cdot BR[X(2000) \rightarrow \Sigma^0 K^+] = [95 \pm 20(stat.) \pm 20(syst.)] nbm/nucleon $$

b) Diffractive coherent production of X(2000) on carbon nuclei

$$ \sigma_{p+C \rightarrow X(2000)+C} \cdot BR[X(2000) \rightarrow \Sigma^0 K^+] = [285 \pm 60(stat.) \pm 60(syst.)] nbm/nucleus $$

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1 N(C) means that reaction is on quasi-free nucleons N or in coherent process on carbon nuclei as a whole.
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Fig. 3. Effective mass spectrum $M(\Sigma^0 K^+)$ in the diffractive reaction $p + N \rightarrow [\Sigma^0 K^+] + N$ for the entire range of transverse momentum $P_T^2$: (a) raw data; (b) spectrum weighted with the efficiency of the setup. A clear peak with parameters $M = 1986 \pm 6 \text{MeV}, \Gamma = 98 \pm 21 \text{MeV}$ is seen in the spectrum owing to production of X(2000) baryon.

Fig. 4. Effective mass spectrum $M(\Sigma^0 K^+)$ in the coherent diffractive reaction $p + C \rightarrow [\Sigma^0 K^+] + C$ with small transverse momenta $P_T^2 < 0.01(\text{GeV}/c)^2$ (coherence condition). Besides the near-the-threshold structure of X(1810) with mass $M \approx 1807 \text{ MeV}$, the spectrum has a dominant clearly defined peak of the X(2000) state.

Fig. 5. Effective mass spectrum $M(\Sigma^0 K^+)$ in the coherent reaction $p + C \rightarrow [\Sigma^0 K^+] + C$ small transverse momenta $P_T^2 < 0.01(\text{GeV}/c)^2$. The state X(1810) is produced only in the region of very small $P_T^2$, where it is displayed very clearly and has the parameters $M = 1807 \pm 7 \text{MeV}, \Gamma = 62 \pm 19 \text{MeV}$. The spectrum presented is weighted taking into account the efficiency of the setup; the run is the one with the modified setup.

Fig. 6. $dN/dP_T^2$ distribution for the diffractive production reaction $p + N \rightarrow X(2000) + N$. The distribution is fitted in the form $dN/dP_T^2 = a_1 \cdot \exp(-b_1 \cdot P_T^2) + a_2 \cdot \exp(-b_2 \cdot P_T^2)$ with the slopes $b_1 = 63 \pm 10 \text{GeV}^2$ (coherent production on carbon nuclei) and $b_2 = 5.8 \pm 0.6 \text{GeV}^2$ (production on quasifree nucleons).
In the diffractive coherent reaction \(2\) was also observed the peak \(X(1810) \rightarrow \Sigma^0 K^+\) with \(M = 1807 \pm 7 MeV\) and \(\Gamma = 62 \pm 19 MeV\). This state is produced only in the region of very small \(P^2_{2^+}\) (\(< 0.01 \pm 0.02 GeV^2\) - see Fig.5). We will not consider possible interpretation of this near threshold peak here. This structure needs special investigation.

Very important property of \(X(2000)\) baryon is its large probability of the decays with strange particles in the final state. In the study of the effective mass spectra \(M(p\pi^+\pi^-)\) and \(M(\Delta(1232)^{++}\pi^-)\) in the reactions

\[
p + N(C) \rightarrow p\pi^+\pi^- + N(C) \quad \text{(6)}
\]

\[
\rightarrow \Delta(1232)^{++}\pi^- + N(C)
\]

In the same kinematical conditions as in (1) the state \(X(2000)\) was not observed and lower limits of the corresponding branchings were obtained

\[
R1 = \frac{BR[X(2000)^+ \rightarrow (\Sigma K)^+]}{BR[X(2000)^+ \rightarrow (\Delta\pi)^+]} > 0.83,
\]

\[
R2 = \frac{BR[X(2000)^+ \rightarrow (\Sigma K)^+]}{BR[X(2000)^+ \rightarrow p\pi^+\pi^-]} > 7.8 \quad \text{(7)}
\]

(with 95% C.L.).

We also observed the decay \(X(2000)^+ \rightarrow \Sigma^+ K^0\). These data are in agreement with main result \(X(2000)^+ \rightarrow \Sigma^0 K^+\) in spite of limited statistics for \(X(2000)^+ \rightarrow \Sigma^+ K^0\). It is reasonable also to mention that in the reaction \(\Sigma^- + N \rightarrow [\Sigma^- K^+]K^- + N\) with \(P_{2^-} \approx 600 GeV\) in the SELEX experiment the state with \(M = 1962 \pm 12 MeV\) and \(\Gamma = 96 \pm 32 MeV\) (near the value of the corresponding parameter of \(X(2000)\)) was observed in the mass spectrum \(M(\Sigma^- K^+)\) - see [2,4].

3 The experiment with the upgraded SPHINX spectrometer.

New study of reactions

\[
p + N(C) \rightarrow [\Sigma K] + N(C)
\]

were carried out with the upgraded SPHINX spectrometer. \(X(2000)\) baryon was observed in this study on the statistics which more than by one order of magnitude exceeded the statistics on our previous work [17]. Now we are in the final stage of the data analysis and preparation of new results for publication. Our preliminary conclusion is that new results are in good agreement with previous data.

4 The nature of \(X(2000)\) baryon and its interpretation as cryptoexotic state with hidden strangeness \(|X(2000)\rangle = |qqq\bar{s}\rangle\).

The main characteristics of \(X(2000)\) baryon:

4.1 The new baryon state \(X(2000)\) is produced in the SPHINX experiment in gluon-enriched diffractive production reactions with Pomeron exchange

\[
p + N(C) \rightarrow X(2000) + +N(C) \quad \text{(8)}
\]

\[
|\Sigma^0 K^+; \Sigma^0 \rightarrow \Lambda \gamma
\]

\[
|\Sigma^+ K^0; \Sigma^+ \rightarrow p\pi^0; n\pi^+
\]

in the region of all \(P^2_{2^+}\), as well as in the coherent diffractive reaction on carbon nucleus in the region \(P^2_{2^+} < 0.1 GeV^2\)

4.2 Due to proton diffractive production of \(X(2000)\) baryon its isotopic spin must be \(I = \frac{1}{2}\) and the most probable set of quantum numbers is \(J^P = \frac{1}{2}^+; \frac{3}{2}^-; \frac{5}{2}^+; \frac{7}{2}^-; ...\) (Gribov-Morisson selection rule). For \(I = \frac{1}{2}\) the ratio of the branchings are

\[
\frac{BR[X(2000)^+ \rightarrow \Sigma^0 K^+]}{BR[X(2000)^+ \rightarrow (\Sigma K)^+]} = \frac{1}{3};
\]

\[
\frac{BR[X(2000)^+ \rightarrow (\Sigma K)^+]}{BR[X(2000)^+ \rightarrow \Delta(1232)^{++}\pi^-]} = \frac{1}{2};
\]

4.3 The state \(X(2000)\) has the mass \(M = 1986 \pm 6 MeV\) and the width \(\Gamma = 98 \pm 21 MeV\). It must be stressed that \(X(2000)\) has a large one mass with a small enough width \((\Gamma/M \approx 0.05)\). In the same time all well known ordinary isobars \(|qqq\rangle\) with close masses have large widths \(\Gamma > 300 \div 500 MeV\) (see [28] and Table 1).

4.4 The \(X(2000)\) state has been experimentally shown to decay mainly via channels involving the emission of strange particles

\[
R = \frac{BR[X(2000) \rightarrow \Sigma K]}{BR[X(2000) \rightarrow p\pi^+\pi^-, \Delta(1232)\pi]} \gtrsim 1 \quad \text{(9)}
\]

while the decays \(X(2000) \rightarrow p\pi^+\pi^-, \Delta(1232)\pi\) are strongly suppressed (by two order of magnitude) - see [28] and Table 1. Thus the \(X(2000)\) baryon exhibit anomalous dynamical properties that can not be explained if it is interpreted as ordinary \(|qqq\rangle\) baryon. But all these anomalies can be readily explained if this state is assumed to be a cryptoexotic pentaquark baryon with hidden strangeness \(|qqq\bar{s}\rangle\). It must be specified more exactly that when we mention ordinary baryon having the structure \(|qqq\rangle\), or exotic baryon \(|qqq\bar{s}\rangle\), or hybrid \(|qqq\bar{g}\rangle\), we actually mean only those hadronic components that determine their principal characteristics (quantum numbers, main dynamical properties). They are called valence quarks and gluons.

Any hadron also contains a quark-gluon "sea" of virtual gluons and quark-antiquark pairs emitted and absorbed by the valence structure elements. The quark-gluon "sea" determines many hadron properties (such as, for example, the spacial distribution of electric charges and magnetic moments inside the particles). In the region of large distances compared with the dimensions of hadron (i.e. in the region of small enough \(P^2_{2^+}\) ) they may behave like system composed of valence quarks. When studies of phenomena of relatively large transverse momentum (small distances) are performed (i.e. when the structure of hadron is investigated) manifestations of quark-gluon
Probability ratio for different decay channels

| \( N^* \) | \( J^P \) (status) | \( \Gamma/(\text{MeV}) \) | \( N^* \to N\pi \) \( N^* \to \Delta \pi \) | \( N^* \to N\Sigma \) \( N^* \to \Sigma K \) | \( N^* \to \Sigma K \) \( N^* \to \Delta \pi \) |
|---|---|---|---|---|---|
| \( N(1900) \) | \( 3/2^+ \) (†) | 498 ± 78 | 0.26 | 0.4 | |
| \( N(1900) \) | \( 7/2^+ \) (‡) | 200 ± 500 | 0.6 | 0.3 ± 0.9 | (2 ± 60) \( \cdot 10^{-3} \) | < 0.1 |
| \( N(2000) \) | \( 3/2^- \) (‡‡) | 490 ± 310 | 0.6 | 0.15 ± 0.20 | 0.6 ± 0.7 | (1 ± 4) \( \cdot 10^{-2} \) | (6 ± 25) \( \cdot 10^{-2} \) | (1 ± 3) \( \cdot 10^{-2} \) |
| \( N(2000) \) | \( 1/2^- \) (‡) | 200 ± 600 | 0.13 ± 0.16 | 0.25 ± 0.30 | 0.5 ± 0.6 | (1.5 ± 40) \( \cdot 10^{-3} \) | (6 ± 40) \( \cdot 10^{-3} \) | (3 ± 20) \( \cdot 10^{-3} \) |
| \( N(2100) \) | \( 1/2^+ \) (‡) | 414 ± 185 | 0.10 ± 0.15 | 0.4 | |
| \( N(2100) \) | \( 1/2^+ \) (‡) | 260 ± 10 | 0.10 ± 0.15 | 0.4 | |
| \( N(2190) \) | \( 7/2^- \) († † † †) | 450 ± 100 | 0.1 ± 0.2 | \( \geq 0.4 \) | (1.5 ± 3) \( \cdot 10^{-3} \) | (3 ± 6) \( \cdot 10^{-3} \) |

\( \ast \) **** - well established isobar state; * or ** - only some weak evidence of their existence are obtained

Table 1. Properties of massive isobars \( N^* = \{qqq\} (q = u, d - \text{quarks}) \).
I am clearly understand that observation of even strong candidate for for cryptoexotics by some indirect dynamical properties do not allow one to claim unambiguously that this state is really a new cryptoexotic form of hadronic matter. May be it still possible to find another interpretation of these anomalous properties. This is general problem not only for the X(2000) baryon, but for all known meson and baryon candidates for cryptoexotics (for example, for the candidate to hybrid meson $\pi(1800)$ [26]). In all these cases we need additional studies and new arguments.

Thus, let us to try to direct the way for future study of X(2000) baryon to produce new information for the nature of this hadron. Certainly, we must determine its quantum numbers and to investigate another decay channels. But it seems that the decisive arguments will be obtained in the studies of different mechanisms for X(2000) production. Let us remain first of all some data for the production of well known $\phi$ - meson with hidden strangeness ($|\phi\rangle \approx |s\bar{s}\rangle$) in the pion and kaon beams in reactions

$$\pi^- + p \rightarrow \phi + n$$  \hspace{1cm} (10)$$

and

$$K^- + p \rightarrow \phi + Y$$  \hspace{1cm} (11)$$

As seen from the diagrams in Fig. 8 the $\phi$ production in (10) is OZI forbidden and strongly suppressed and in (11) is OZI allowed. From the experimental data of the $M(K^+K^-)$ mass spectra in reaction (10) and (11) at $P_{\pi,K} = 32.5 GeV$ (Fig. 9 and Fig. 10), it is seen that ratio of cross sections is

$$\frac{\sigma(\pi^- + p \rightarrow \phi + n)}{\sigma(K^- + p \rightarrow \phi + Y)} \sim 10^{-2}$$  \hspace{1cm} (12)$$

(the cross section $\sigma(\pi^- + p \rightarrow \phi + n)|_{P_{\pi,K} = 32.5 GeV} = 11.5 \pm 3.3 nbm$)

We propose to use the same technic of studying the hidden strangeness in the valent quark system of hadrons

$$\pi^+ + p \rightarrow X(2000)^+ + \pi^+$$ (13)$$

$$K^+ + p \rightarrow X(2000)^+ + K^+$$ (14)$$

If X(2000) baryon is really pentaquark state with hidden strangeness ($|X(2000)\rangle = |qqqs\rangle$), the reaction (13) are OZI forbidden and strongly suppressed and the reaction (14) is OZI allowed (see diagrams in Fig. 11 and Fig. 10). Thus, in this case it is possible to expect that the ratio of cross sections is

$$\frac{\sigma(\pi^+ + p \rightarrow X(2000)^+ + \pi^+)}{\sigma(K^+ + p \rightarrow X(2000)^+ + K^+)} \ll 1$$  \hspace{1cm} (15)$$
Fig. 11. Reaction $\pi^\pm + p \to X(2000) + \pi^\pm$ for $|X\rangle = |uuds\rangle$

May be the ratio is not too small as for $\phi$ - meson, but significantly enough to obtain the definite conclusion about the hidden strangeness of $X(2000)$ baryon. Such experiment is of crucial importance for pentaquark interpretation of $X(2000)$ baryon.

The experimental studies of reaction and with baryon exchange can be performed with the new OKA experiment on the IHEP kaon separated beam with momenta 12.5 and 17 GeV. This momentum region seems to be optimal for studying baryon exchange processes as a compromise between the drop of cross section of these reactions with energy and the increasing of the efficiency for their registration.

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