Study of coherent diffractive production reactions of $p + C \rightarrow [Y^0 K^+] + C$ type and observation of narrow structures in $\Sigma(1385)^0 K^+$ and $\Sigma^0 K^+$ effective mass spectra

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Abstract. In the experiments at the SPhINX facility in 70 GeV proton beam of the IHEP accelerator the coherent diffractive production reactions on carbon nuclei $p + C \rightarrow [\Sigma(1385)^0 K^+] + C$ and $p + C \rightarrow [\Sigma^0 K^+] + C$ were investigated. The evidences for new baryon states were obtained in the study of hyperon-kaon effective mass spectra in these two reactions: $X(2050)$ with mass $M = (2052 \pm 6)$ MeV and width $\Gamma = (35^{+25}_{-35})$ MeV in $M[\Sigma(1385)^0 K^+]$ and $X(2000)$ with $M = 1999 \pm 6$ MeV and $\Gamma = 91 \pm 17$ MeV in $M[\Sigma^0 K^+]$. 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.

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 is carried out. This program has been detailed in reviews [1].

As was 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 which offers 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 $\Delta P = (-1)^J J$. Here $\Delta P$ and $\Delta J$ 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 $J^P = \frac{1}{2}^+, \frac{1}{2}^+, \frac{3}{2}^+, \frac{5}{2}^-, \frac{7}{2}^-$ 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 can induce the coherent processes on the target nucleus. In such processes the nucleus acts as a discrete unit. Coherent processes can be easily identified from the events distribution in the transverse momentum of the final state particle system. They manifest themselves as diffractive peaks with large values of the slope parameters determined by the size of the nucleus: $dN/dP_T^2 \sim \exp(-bP_T^2)$, where $b \approx (8 \pm 10)A^{2/3} (\text{GeV}/c)^{-2}$. Owing to the difference in the absorption of single-particle and multiparticle objects in nuclei, coherent processes could serve as an effective tool for the separation of resonance against multiparticle nonresonant background (see, for example, Ref. [7]). This suggestion can be illustrated schematically by Fig. 2.

The studies of several proton induced diffractive production processes of $p+N \rightarrow Y^0 K^+ N$ type as well as $p+N \rightarrow pK^+ K^- N$, $p+N \rightarrow pp\bar{p} N$, $p+N \rightarrow p\pi^+\pi^-\pi^0 N$ and some other reactions were performed in the experiments of the SPhINX collaboration with 70 GeV proton beam and polyethylene target. 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 $\gamma$-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 [8–16] (see also reviews [1]).

As it is seen from $dN/dP^2$ plots for all above mentioned processes there are strong narrow forward cones in these distributions with the slope $b \geq 30 \pm 40 \text{(GeV/c)}^{-2}$, which correspond to coherent diffractive production reactions on carbon nuclei. For the isolation of the coherent production events the "soft" or "stringent" cuts in $P_T^2$ can be used:

1. the soft transverse momentum cut
   
   
   $P_T^2 < 0.075 \pm 0.1 \text{(GeV/c)}^{-2}$; with soft cut the noncoherent background among the selected events may be as large as $30 \pm 40\%$;

2. the stringent transverse momentum cut
   
   
   $P_T^2 < 0.02 \text{(GeV/c)}^{-2}$; with this cut the noncoherent background constitutes no more than $8 \pm 10 \%$ of the selected events. The price for this low noncoherent background is partial reducing of the coherent reaction statistics.

In this paper the new data on the diffractive coherent reactions on carbon nuclei

\begin{align}
 p + C & \rightarrow [\Lambda \pi^0 K^+] + C, \\
 & \quad \text{(1)}
\end{align}

and

\begin{align}
 p + C & \rightarrow [\Sigma^0 K^+] + C, \\
 & \quad \text{(2)}
\end{align}

are presented. These reactions are used for the search for cryptoexotic baryons with hidden strangeness $B^+_8 = (uuds\bar{s})$.

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 search for heavy baryons with anomalously narrow decay widths, would it be successful, will provide the most compelling evidence for the existence of cryptoexotic baryon states. In this connection let us consider the properties of multiquark baryons with hidden strangeness $B^+_8 = (qqq\bar{s})$, where $q = u$ or $d$ quarks. The theoretical possibilities for the existence of such states are rather uncertain. If, for example, the mass of the baryon with hidden strangeness is less than $M(\Lambda) + M(K) (< 1.6 \text{GeV})$, this state can decay only through $OZI$ suppressed processes, and it must therefore be very narrow. Its possible decay modes are $B^+_8 \rightarrow N\pi^0$; $N\pi^+\pi^0$. Observation of such state is complicated by the background from the decay of numerous baryonic iso-

\footnote{If $M(B^+_8) > 1.5 \text{GeV}$ the decay mode $B^+_8 \rightarrow p\eta$ is also possible because of a large $s\bar{s}$ component in the valence structure of $\eta$-meson (the ideal mixing in the pseudoscalar meson nonet is badly broken)}