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STUDY OF QUASIEXCLUSIVE NEUTRAL MESON PRODUCTION IN pN INTERACTIONS AT E_p=70 GeV IN THE DEEP FRAGMENTATION REGION

The SPHINX Collaboration (IHEP-ITEP)

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Abstract

Golovkin S.V. et al. Study of Quasiexclusive Neutral Meson Production in pN Interactions at E_p=70 GeV in the Deep Fragmentation Region. The SPHINX Collaboration (IHEP-ITEP): IHEP Preprint 97-21. – Protvino, 1997. – p. 17, figs. 10, tables 6, refs.: 26.

Quasiexclusive neutral meson production in pN-interactions is studied in experiments with the SPHINX facility operating in a proton beam from the IHEP accelerator (E_p=70 GeV). The cross sections and the parameters of the differential distributions for π^o, ω, η and K^o production in the deep fragmentation region ($x_F > 0.79 \div 0.86$) are presented. The results show that such proton quasiexclusive reactions with baryon exchange may be promising in searches for exotic mesons.

Аннотация

Головкин С.В. и др. Исследование квазиэксклюзивных процессов образования нейтральных мезонов в pN-соударениях при энергии 70 ГэВ в области глубокой фрагментации. Сотрудничество СФИНКС (ИФВЭ-ИТЭФ): Препринт ИФВЭ 97-21. – Протвино, 1997. – 17 с., 10 рис., 6 табл., библиогр.: 26.

В опытах на установке СФИНКС исследовались квазиэксклюзивные процессы образования нейтральных мезонов в pN-соударениях при энергии E_p=70 ГэВ в области глубокой фрагментации ($x_F > 0.79 \div 0.86$). Приводятся значения сечений для соответствующих процессов с π^o-, $\omega-$, $\eta-$ и K^o-мезонами, а также данные об их дифференциальных распределениях. Полученные результаты показывают, что протонные квазиэксклюзивные реакции с барионным обменом могут представлять значительный интерес для исследований с экзотическими мезонами.

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1. DEEP FRAGMENTATION PROCESSES AND SEARCHES FOR EXOTIC MESON STATES

In connection with the study of mechanisms underlying exotic hadron production there were many discussions about the possibilities of more effective excitation of inner color 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 Refs. [1-6] and reviews [7-9]).

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 a backward scattering reaction we present the diagram for the hybrid meson production in the process $\pi + N \to N + M$ (see Fig.1a).

Some experimental difficulties 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., and hence in the lab frame their decay products have a soft momentum spectrum and wide angular distribution. This kinematics is a good one for the bubble chamber and missing mass experiments, but not for those with wide aperture magnetic spectrometers with good identification of charged and neutral decay products of mesons under study, which is very important for nanobarn mesonic spectroscopy.

However, one can overcome all these difficulties by studying meson resonance production in the baryon exchange processes in the proton-induced reactions [6]:

$$p + N \to M^{++} + [N\pi^- n] \quad (\Delta^- \ \text{exchange}), \tag{1}$$
$$p + N \to M^{+} + [N\pi^- p] \quad (\Delta^o \ \text{exchange}), \tag{2}$$
$$p + N \to M^{o} + [N\pi^+ n] \quad (\Delta^+ \ \text{exchange}), \tag{3}$$
$$p + N \to M^{-} + [N\pi^+ p] \quad (\Delta^{++} \ \text{exchange}), \tag{4}$$
$$p + N \to M^{+} + [Nn] \quad (n \ \text{exchange}), \tag{5}$$
$$p + N \to M^{o} + [Np] \quad (p \ \text{exchange}) \tag{6}$$

(see Figs.1b,c). In these reactions product mesons M move in the forward direction, so that they can easily be detected in a wide-aperture magnetic spectrometer. Decay charged particles can be identified with Cherenkov detectors. In studying reactions (1)-(6), moderate proton energies are necessary, because the cross sections for exclusive processes with baryon exchange decrease rather fast with increasing incident energy: $\sigma \sim E^{-n}$, where $n = 2 - 3$ (for energies below 10 GeV, n is 5-7). Proton energies of E_p=10-15 GeV seem optimal for such experiments (as a compromise between a decrease in the cross sections and an increase in the acceptance with increasing incident energy).

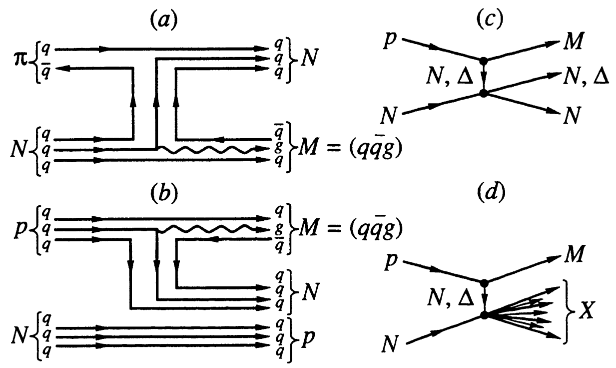


Fig. 1. Diagrams describing exotic-meson production in baryon exchange processes: (a) production of a hybrid meson in πN interactions; (b) production of a hybrid meson in pN interactions; (c) production of exotic mesons in reactions (1)-(6), and (d) production of exotic mesons in reaction (7) in the deep fragmentation region (inclusive bottom vertex).

Baryon exchange processes can be accompanied by substantial quark rearrangement in hadrons. This can lead to gluon bremsstrahlung and to the bremsstrahlung-gluon pick up by a quark-antiquark pair that moves in the forward direction. This mechanism must cause the production of hybrids and other exotic mesons (see the diagram in Fig.1b).

Exotic meson states in baryon-exchange processes can also be sought at higher proton energies. This may be of considerable interest because an increase in the efficiency and a clearer identification of secondary particles and mesons under investigation are achieved in some cases.

At high energies, the cross sections anticipated for the exclusive processes (1)-(6) are rather small. Therefore, in the search for exotic mesons, we will consider baryon-exchange reactions in which summation over all possible final states is performed in the bottom vertex (b.v.). Processes of this type — we refer to them as processes with the inclusive bottom vertex – are described by the diagram in Fig.1 and can be specified as

$$p + N \to M_f + X_{b.v.}. \qquad (7)$$

Here, the M_f meson is formed in the deep fragmentation region; that is, it is characterized by x_F values in excess of 0.8-0.9 ($x_F = p_M/p_p$, where p_M and p_p are the momenta of the M meson and incident proton, respectively). The cross sections for reactions of type (7) are much larger than those for reactions (1)-(6) and are dependent on the primary energy

E_p only slightly (in the region of several tens of GeV and above). For these reactions one may expect the cross sections of hundreds of nb and the search for exotic mesons in such baryon-exchanged processes looks rather promising.

In studying mesonic resonances M_f produced in the top vertex of the diagram in Fig.1d, experimental conditions for the corresponding deep fragmentation inclusive reactions of type (7) must be implemented in such a way that a combinatorial background due to inclusive production in the bottom vertex does not contribute to the effective-mass spectra used to single out M_f. At comparatively high incident energy E_p, secondaries from the top and bottom vertexes are well separated in rapidities, and the combinatorial background can be removed by introducing additional selection criteria in energies and emission angles of particles that enter into the system under study at large x_F. Of course, the additional selections distort the true inclusive process (7), which becomes, as a result, a partially inclusive process possibly with smaller (but still comparatively large) cross section. To stress this circumstance, we denote such processes as

$$p + N \to M_f + (\tilde{X})_{b.v.} \tag{8}$$

and refer to them as quasiexclusive reactions in the deep fragmentation region.

Experiments with the SPHINX setup operating in the E_p=70 GeV proton beam from the IHEP accelerator ensure favourable conditions for the investigation of the quasiexclusive processes (8) in the deep fragmentation region and for searches of exotic meson production in these reactions. As the first stage aimed at testing the conjecture that the cross sections for reactions of type (8) are fairly large and at estimating these cross sections for ordinary neutral mesons, we studied some of the quasiexclusive processes in the deep fragmentation region. These are

$$p + N \to \quad \pi^o_f + (\tilde{X})_{b.v.}; \quad \pi^o_f \hookrightarrow 2\gamma \tag{9}$$

$$\to \quad \eta_f + (\tilde{X})_{b.v.}; \quad \eta_f \hookrightarrow 2\gamma; 3\pi^o \tag{10}$$

$$\to \quad \omega_f + (\tilde{X})_{b.v.}; \quad \omega_f \hookrightarrow \pi^o\gamma \to 3\gamma \tag{11}$$

$$\to \quad K^o_f + (\tilde{X})_{b.v.}. \quad K^o_f \hookrightarrow 2\pi^o \tag{12}$$

In general, the production of fast π^o, η and ω mesons in proton collisions can occur not only in deep fragmentation processes contributed significantly by baryon exchange, but also via the more trivial processes of heavy isobar decays. However, simple kinematical calculations revealed that, at primary energy E_p=70 GeV, decay mesons from all presently known isobars with masses M <2,6 GeV [10] have energies that do not reach the deep fragmentation region. For this reason, we do not consider this isobar mechanism below.

2. DETECTION OF NEUTRAL MESONS WITH THE SPHINX SETUP

2.1. SPHINX Setup

The SPHINX setup [11] used to study reactions (9)-(12) is a wide-aperture magnetic spectrometer equipped with proportional and drift chambers operating together with the system of Cherenkov detectors for identification of secondary charged particles and with a multichannel γ spectrometer. Figure 2 shows the layout of the SPHINX setup.

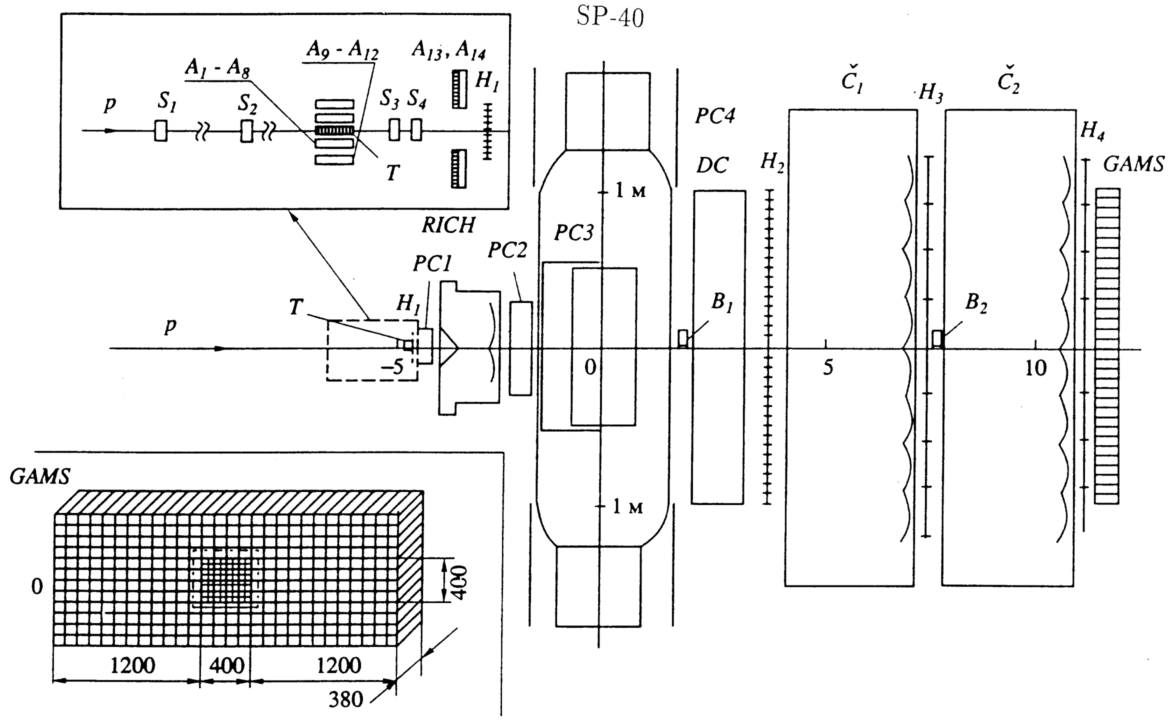


Fig. 2. The layout of the SPHINX spectrometer: $S1 - S4$, $B1$, $B2$ are scintillation counters; $A1 - A14$ — scintillation guard counters; $H1 - H4$ — scintillation hodoscopes; $PC1 - PC4$ — block of proportional chambers; DC — block of drift chambers; SP-40, a spectrometer magnet; $\check{C}_1$ $\check{C}_2$ — hodoscope threshold Cherenkov counters; RICH — Cherenkov ring image spectrometer; GAMS – hodoscop γ -spectrometer, which is presented on the left lower part of the figure; dash-dotted line points the active region of γ detector which in used for trigger requirement.

In this study, we use primarily the results obtained by analyzing data from the γ spectrometer. Let us dwell at some length on the details of its construction (Fig.2) and on our procedure for data processing.

The γ spectrometer consists of 272 total absorption Cherenkov counters with F8 lead-glass radiators (of radiation length (r.l.) 3.17 cm and cross-sectional area 10×10 cm^2) scanned by FEU-110 photomultipliers. In the central part of the γ spectrometer, there are 63 similar counters with radiators from the TF101 radiation-resistant glass (r.l. is 2.70 cm, and the cross-sectional area is 5×5 cm^2) that are scanned by a FEU-84 photomultiplier (one counter at the center of the detector was removed to let the beam of noninteracted protons out). The radiator length along the beam was 38 and 40 cm (12 and 14 r.l.) for the blocks of dimensions 10×10 and 5×5 cm^2, respectively. The outside cross-sectional area of the detector was 280×120 cm^2, and its central part had dimensions of 40×40 cm^2.

The exstended central part of γ-spectrometer (with area of 80×80 cm^2, see the region of the γ-detector on Fig.2 encircled by dash-dotted lines) is used as active device for trigger requirements. The signals from dynode outputs of the phototubes of the counters in this area were linearly summed up and used to generate of the trigger signal. It was required that the summary-signal amplitude corresponding to the energy released in the active central part of the detector exceeds the threshold: $\sum E_{\gamma i} > E_{thr}$.

2.2. Experimental Procedure

Investigation of π^o, η, ω and K^o production in the quasiexclusive proceesses (9)-(12) with the SPHINX setup at large x_F was performed in parallel with other experiments aimed at studying the diffractive production of baryon systems [12-16]. In this measurement incident-proton interactions in the target that result in the production of high-energy neutral particles were singled out by means of the trigger logic of the setup with "neutral trigger" requirements. It was demanded that separated interactions satisfy the following conditions:

(1) There are no fast charged particles (i.e. particles with momenta P_h >1.5-2 GeV) that have traversed the magnetic spectrometer of the setup.

(2) The large net energy $\sum E_{\gamma i} > E_{thr}$=45 GeV is released in the central active part of the γ spectrometer.

These conditions are met for the trigger signal

$$T_{neutr.} = (S_o S' S_1 S_2)(\overline{B_1 B_2})\bar{H}_2 \bar{H}_3 \bar{H}_4 [\sum E_{\gamma_i} > E_{thr.}], \tag{13}$$

where $(S_o S' S_1 S_2)$ denote the requirements of coincidences; $(\overline{B_1 B_2})$, $\bar{H}_2$, $\bar{H}_3$, $\bar{H}_4$ denote the requirements of anticoincidences (the beam scintillation counters S_o and S' are not shown in Fig.2); $\sum E_{\gamma_i} > E_{thr.}$ is the requirement of energy release in the central part of the γ detector.

The data on reactions (9)-(12) presented below were obtained in the optimal trigger conditions for separation of quasiexclusive reactions of (8) type and with more precise calibration of γ-spectrometer to compare with our preliminary measurements, where such experimental conditions could not be realized (see [17]).

The data presented in this paper correspond to a proton flux of $I_p = 4.12 \times 10^{10}$ hitting the polyethylene target 16 cm thick (6.43×10^{23} CH_2/cm^2). The total of $2.8 \cdot 10^6$ events was recorded with a neutral trigger requirement (13) throughout the experiment. For the cross section estimations in pN-interactions we used the assumption that for nuclei $\sigma \sim A^{2/3}$ (i.e. the effective number of nucleons per CH_2 molecula is 7.2). Then the luminosity of these measurements was estimated to be L=175 events/nb per nucleon (with systematic uncertainty of 10%).

2.3. Determination of Energy and Coordinates of Photons in the γ Detector

Methods for reconstructing photon energy and coordinates in the hodoscopic γ detector are widely covered in the literature. For this reason, we only mention some features of our experimental procedure.

The energy calibration of the detector was preliminarily performed in an electron beam and finally fixed by using the data of the physical exposure and the tabular values of the masses of neutral π^o and η-mesons.

Counters with nonzero signals were combined into connected groups (clusters). The cross-sectional areas of the clusters associated with incident hadrons are larger than those of the photon clusters. Owing to this difference in dimensions, clusters of these two types are well separated. The cross-sectional profile of energy release in the cluster generated by a photon was described by an exponential form whose slope parameter was determined experimentally. If the profile of this cluster could not be described by an exponential, we attempted to represent the cluster as two overlapping electromagnetic showers and to separate them. If such a description still proved unsatisfactory, the cluster was rejected as the one caused by hadron interaction in the detector.

The distribution of energy release in the counters forming a cluster was used to determine the coordinates of the point at which a photon enters the detector. A simulation of electromagnetic showers in the detector which was followed by processing them according to the above procedure revealed that, on average, errors in determining the coordinates were 10-20 mm for the 10$\times$10 cm^2 counters and 1-3 mm for the 5$\times$5 cm^2 counters.

The energy resolution of γ-spectrometer was rather conservatively approximated as $\sigma_E/E \simeq (0.1/\sqrt{E}) + 0.03$ (E in GeV).

3. SELECTION OF QUASIEXCLUSIVE NONSTRANGE NEUTRAL MESON PRODUCTION

After the processing of electromagnetic showers for the neutral trigger events the additional selection criteria were used for their further analysis. These criteria are as follows:

a) in γ-spectrometer two (or three) γ clusters with energy over 2 (or 1) GeV were selected; in three-cluster events at least one pair of clasters was required to satisfy the criterion of π^o identification (0.11< $M(\gamma_i\gamma_j)$ <0.16 GeV);

b) the events with 4γ and 6γ-clusters with energies over 1 GeV which satisfy $2\pi^o$ and $3\pi^o$ conditions were also selected in data analysis;

c) the total energy in γ-spectrometer $\sum E_{\gamma i}$ >55 or 60 GeV;

d) for some type of events additional restrictions on the energy of π^o-mesons were used (see below).

A signal from π^o and η production was separated in their decay mode involving two photons in the final state. For this purpose, we selected events with two clusters in the γ spectrometer, each having an energy in excess of 2 GeV. The η meson was also separated in the decay $\eta \to 3\pi^o$. In this case, it was required that the γ spectrometer recorded six clusters such that each had an energy higher than 1 GeV and these clusters form three π^o mesons each having an energy higher than 7.5 GeV. In calculating the invariant mass of three π^o-mesons, we applied the 3C fit procedure to the π^o-meson mass.

To separate a signal from the decay $\omega \to \pi^o\gamma$, we selected events with three clusters in the γ-spectrometer each having an energy exceeding 1 GeV, and required that the effective mass of only one photon pair be in the range 111 MeV< $M_{\gamma\gamma}$ <159 MeV with the two other photon combinations being in the mass region $M_{\gamma\gamma}$ >200 MeV. The main source of background in this mode is due to the production of a pion pair $\pi^o\pi^o \to 4\gamma$ with one of the photons being undetected in the γ detector and to the production of isobars decaying into the $\pi^o\pi^+n$ system with a soft π^+-meson or a neutron mimicking a cluster in the γ calorimeter. To reduce this background we imposed an additional cut on the cosine of the photon-emission angle in the rest frame of three photons with respect to the direction of motion of this frame: $0 < cos\theta^* < 0.5$. It will be shown below that the product ω mesons are aligned, so that this cut reduces the detection efficiency only slightly, but it strongly suppresses the background processes.

The experimental statistics is as follows:

Total number of trigger events	2787800
Two photons with energies higher than 2 GeV	568264
Three photons with energies higher than 1 GeV, only one pair having a mass less than 200 MeV	179973
Four photons with energies higher than 1 GeV	210470
Six photons having energies higher than 1 GeV and forming three π^o-mesons with energies no less than 7.5 GeV	2121

Figure 3 shows the invariant-mass distributions of two photons, the $\pi^o\gamma$ system, and three π^o-mesons satisfying the requirement that the total energy of photons is $\sum E_i >$ 60 GeV ($x_F > 0.86$). Signals corresponsing to meson production and the decay processes $\pi^o \to \gamma\gamma$ (Fig.3a) and $\eta \to \gamma\gamma$ (Fig. 3b) are reliably isolated in these spectra. The η meson was also separated in the mode $\eta \to 3\pi^o$ (Fig. 3d). Figure 3c shows the effective-mass distribution of the $\pi^o\gamma$ system for events with $x_F > 0.86$. An ω-meson signal is clearly seen in this distribution.

Thus, under the conditions of this experiment the events of quasiexclusive production of π^o, η and ω-mesons in the deep fragmentation region of reactions (9)-(11) were reliably separated.

Figure 4 displays the p_T^2 distribution for π^o-meson production in the region $x_F > 0.79$ and $x_F > 0.86$. This distribution was approximated by the expression

$$d\sigma/dp_T^2 = \sigma_1 b_1 exp(-b_1 p_T^2) + \sigma_2 b_2 exp(-b_2 p_T^2), \qquad (14)$$

where σ_1 and σ_2 are the total cross sections for meson production with the slopes b_1 and b_2, respectively. The parameters of the distributions are presented in Table 1.

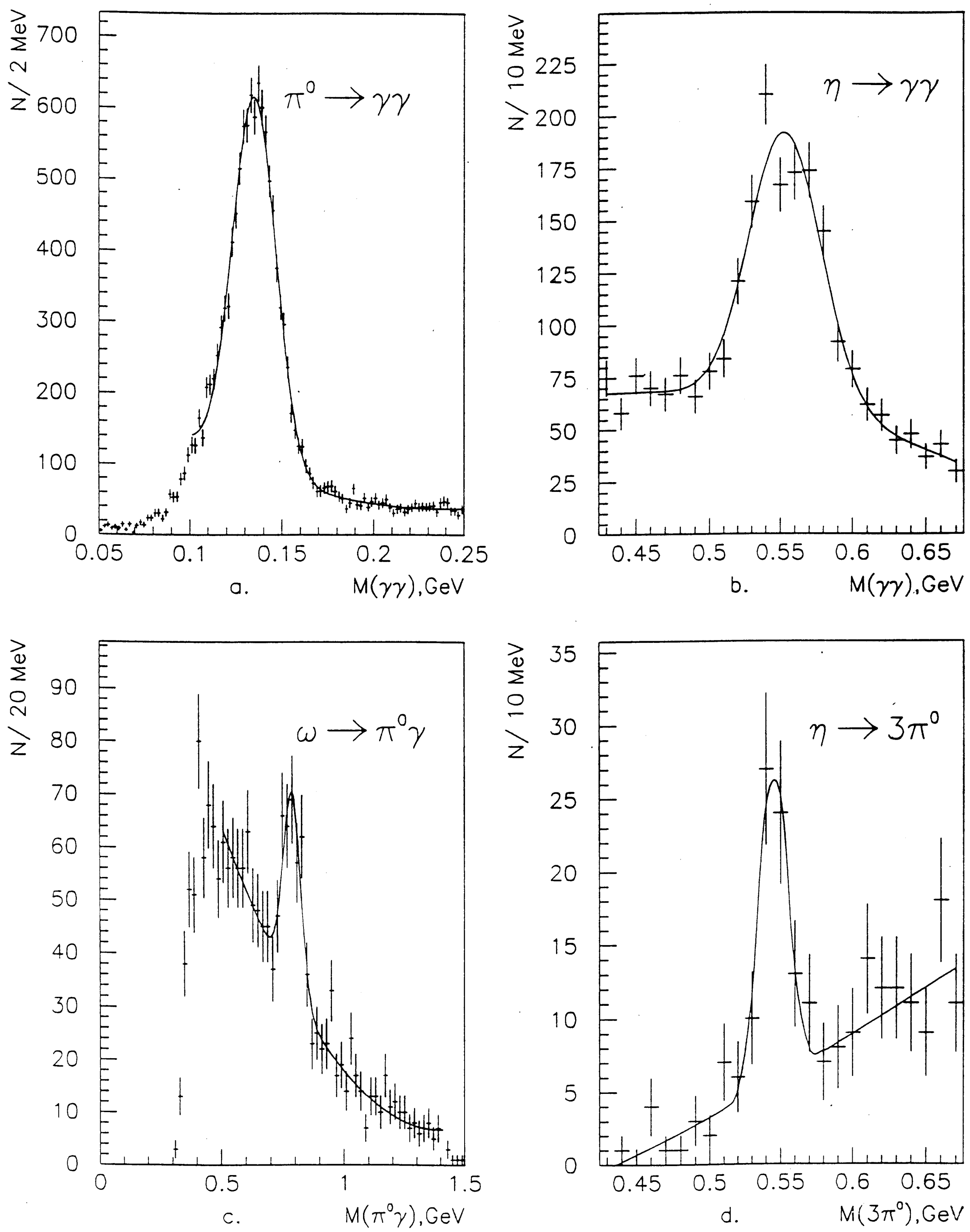


Fig. 3. Invariant mass spectra for $\gamma\gamma, \pi^0\gamma$- and three π^0-systems in the reactions $p + N \to (n\gamma)_f + \widetilde{X}_{b.v.}$ with $x_F > 0.86$. Signals from $\pi^0 \to \gamma\gamma$ (a), $\eta \to \gamma\gamma$ (b), $\omega \to \pi^0\gamma$ (c), $\eta \to 3\pi^0$ (d) in reactions (9)-(11) are clearly seen.

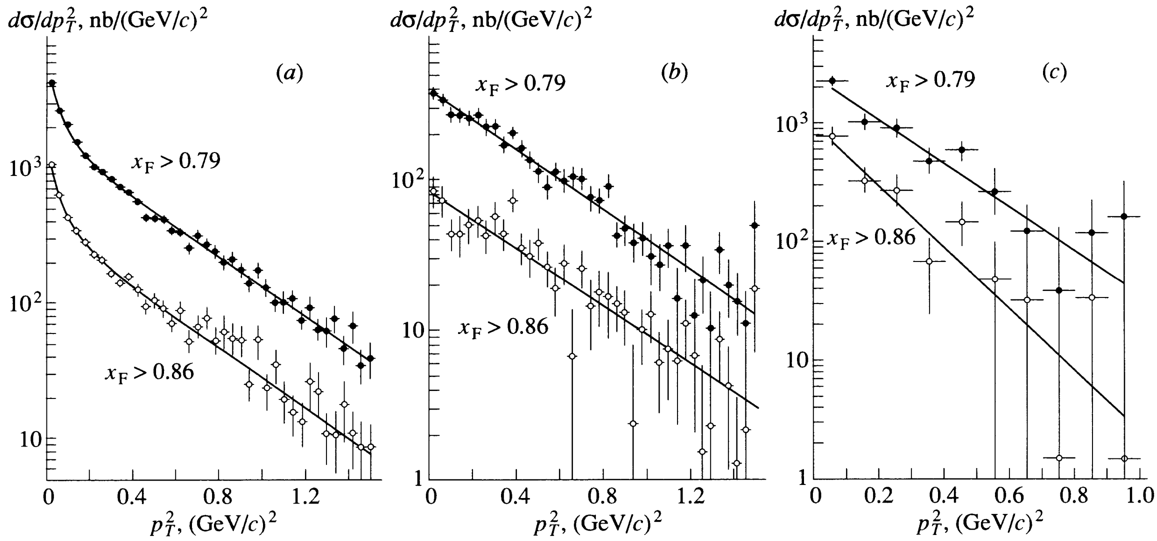


Fig. 4. Differential cross sections $d\sigma/dp_T^2$ as a function of the squared transverse momentum of (a) π^o-mesons in reaction (9), (b) η mesons reaction (10), and (c) ω mesons in reaction(11) for $x_F > 0.79$ and $x_F > 0.86$.

Table 1. Parameters of the $d\sigma/dp_T^2$ distributions for π^o-meson production in the regions $x_F > 0.79$ and $x_F > 0.86$

x_F	σ_1, nb	b_1, (GeV/c)$^{-2}$	σ_2, nb	b_2, (GeV/c)$^{-2}$
>0.79	637±13	2.52×0.07	234± 13	15.6±0.9
>0.86	143±5	2.58±0.12	54±5	17.9±2.0

Note: only statistical errors are presented; systematic errors amount to 15%.

The distribution involves two exponentials with $b_1 = 2.5$ (GeV/c)$^{-2}$ and b_2=15-17 (GeV/c)$^{-2}$. The steeper exponent may correspond to the diffractive production of heavy isobars decaying subsequently into a π^o-meson and a neutron. To obtain a more conservative estimate of the cross sections for π^o-meson production with baryon exchange, we will henceforth use only the values corresponding to the exponential with a slope of 2.5 (GeV/c)$^{-2}$ — that is, the σ_1 and b_1 values from Table 1. When the second exponent is taken into account, the cross section becomes larger by 35%.

The squared-transverse-momentum distributions of ω and η-meson are fairly well approximated by the formula

$$d\sigma/dp_T^2 = \sigma \cdot b \cdot exp(-bp_T^2), \quad (15)$$

which involves only one exponential.

In the region $x_F > 0.79$, the differential cross sections for π^o, ω and η production were fitted to the expression

$$d\sigma/dx_F = \sigma(1 - x_F)^\alpha(\alpha + 1)/(1 - x_{F_{min}})^{\alpha+1}, \quad (16)$$

where σ is the total cross section for the production of a particle with $x_F > x_{F_{min}}$. To estimate the parameter σ for π^o-mesons, we selected events with $p_T^2 > 0.2$ (GeV/c)^2.

This made it possible to avoid distortions of this distribution due to the possible contribution of processes involving the diffractive production isobars.

Tables 2-4 present the cross sections for π^o, ω and η production, their ratios and the parameters of the differential distributions. Figures 4 and 5 show the differential cross sections for the production of these particles. The differential cross sections for η mesons were obtained from data for two decay modes ($\gamma\gamma$ and $3\pi^o$); the results prove to be consistent within errors. However the tables present only the results based on the decay $\eta \rightarrow \gamma\gamma$, which are much more accurate from the statistical point of view. For comparison, the production cross section for η mesons estimated from data on $\eta \rightarrow 3\pi^o$ are 186±28 nb (for x_F >0.79) and 47±15 nb (for x_F >0.86).

The quoted errors are purely statistical. Systematic uncertainties in the total cross sections and in the slopes of the distributions may amount to 15% (they were estimated by the spread in the corresponding quantities which is associated with various assumptions made in data processing; they include also the systematic error in normalization). Our results agree with our previous data presented in [17], despite a substantial difference in the kinematical conditions under which these two measurements were performed.

Table 2. Total cross sections for π^o, ω and η production for $x_F > 0.79$ and $x_F > 0.86$

Reaction	$x_{F_{min}}$	Number of events	Efficiency	$\sigma_{tot}(x_F > x_{F_{min}})$, nb
$p + N \rightarrow \pi^o_f + X$	0.79	28617±580	0.26	637±13
	0.86	6424±225	0.26	143±5
$p + N \rightarrow n_f + X$	0.79	3424±98	0.29	174±5
	0.86	820±63	0.31	39±3
$p + N \rightarrow \omega_f + X$	0.79	520±36	0.060	584±40
	0.86	173±21	0.071	164±20

Note: only statistical errors are presented; systematic errors amount to 15%.

Table 3. Parameters of differential distribution

Reaction	$x_{F_{min}}$	$d\sigma/dp_T^2 \sim exp(-bp_T^2)$	$d\sigma/dx_F \sim (1-x_F)^\alpha$
		b, (GeV/c)$^{-2}$	α
$p + N \rightarrow \pi^o_f + X$	0.79	2.52±0.07	2.70±0.04
	0.86	2.58±0.12	2.88±0.08
$p + N \rightarrow n_f + X$	0.79	2.31±0.08	2.64±0.08
	0.86	2.20±0.15	2.95±0.21
$p + N \rightarrow \omega_f + X$	0.79	4.22±0.45	1.98±0.18
	0.86	5.9±1.1	2.38±0.5

Note: only statistical errors are presented; systematic errors amount to 15%.

Table 4. Ratios of the cross sections for π^o, ω and η production

	$x_F > 0.79$	$x_F > 0.86$
$\sigma(\eta)/\sigma(\pi^o)$	0.273±0.010	0.273±0.023
$\sigma(\omega)/\sigma(\pi^o)$	0.916±0.065	1.15±0.15

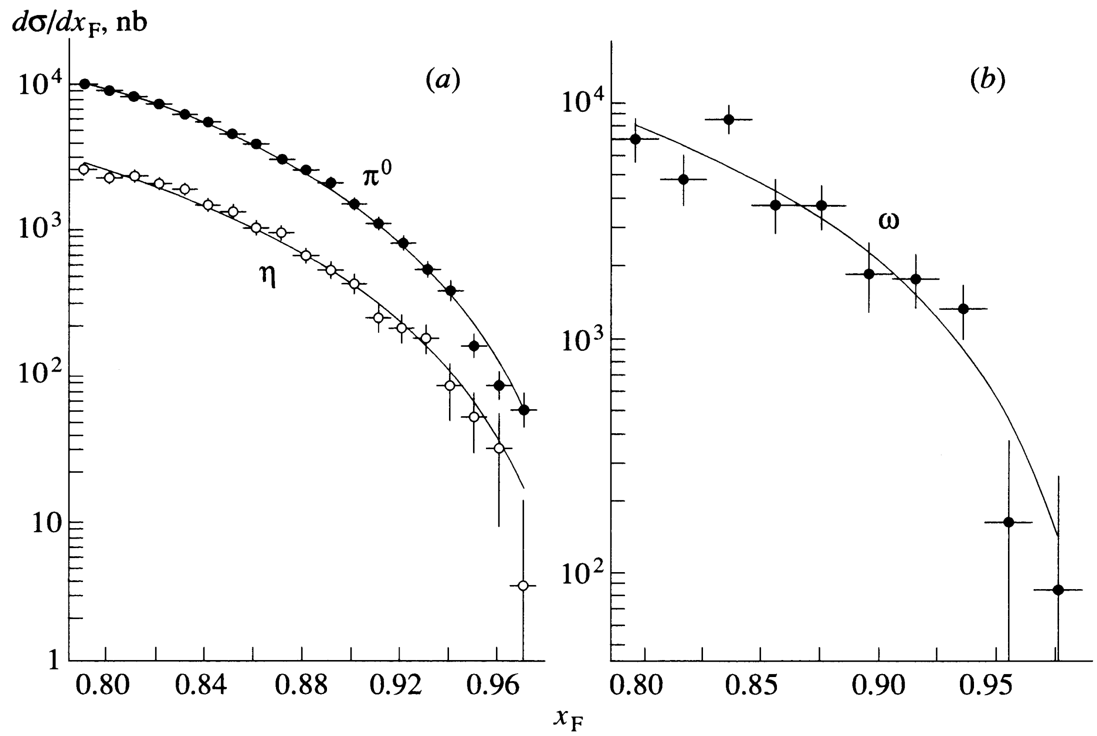


Fig. 5. Differential cross sections $d\sigma/dx_F$ for the production of (a) π^o and η mesons in reactions (9) and (10), respectively, and of (b) ω mesons in reaction (11).

Figure 6 shows the distribution in the cosine of the polar angle of photon emission for the decay $\omega \to \pi^o\gamma$ in reaction (11) (in the ω-meson rest frame with respect to the momentum of this particle). These data are presented for $x_F > 0.79$. The distribution was approximated by the expression

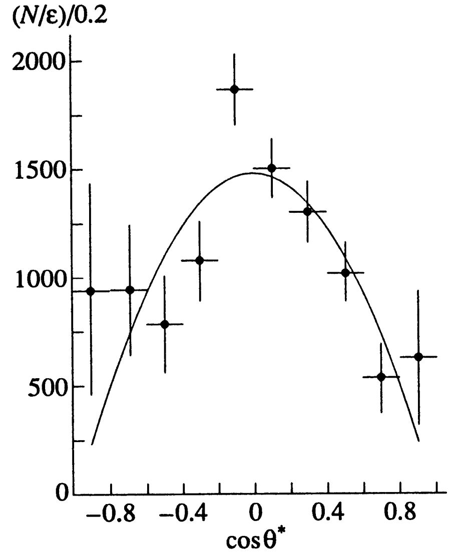
$$dN/dcos\theta^* \sim 1 + (3cos^2\theta^* - 1)(1 - 3\rho_{oo})/4, \tag{17}$$

where ρ_{oo} is the density-matrix element corresponding to ω production in reaction (11). It proved to be $\rho_{oo} = 1.0 \pm 0.16$ for events with $x_F > 0.79$ and $\rho_{oo} = 1.0 \pm 0.22$ for events with $x_F > 0.86$. This means that ω mesons produced in (11) are aligned.

Comparison of our results with other data [18,19] characterized by very limited statistics in the deep fragmentation region is difficult because of our didicated trigger requirements which were used to separate the quasiexclusive process $p + N \to M_f + (\tilde{X})_{b.v.}$ (partially inclusive process for bottom vetrex of diagram on Fig.1d — see the discussion in Section 1).

According to our results, the cross sections for π^o, ω and η production in quasiexclusive deep fragmentation processes in pN interactions at E_p=70 GeV are between 50 and 600 nb. This gives reason to hope that proton reactions with the deep fragmentation would be usefull in searches for new particles.

Fig. 6. Distribution in cosine of the polar angle of photon emission in the ω meson rest frame with respect to the momentum of this particle for the decay $\omega \to \pi^0\gamma$ in reaction (11) ($x_F > 0,79$). This distribution is weighted with the setup efficiency.



4. K^o-MESON PRODUCTION IN THE DEEP FRAGMENTATION REGION

Study of reaction (12) with neutral kaon production in the deep fragmentation region was performed in the same measurements with the SPHINX setup. Neutral kaons were detected by their decays into two π^o-mesons. Toward this, we selected events with four clusters in the γ-spectrometer with the energy of each cluster being required to exceed 1 GeV. Among 210470 four-photon events there were 32654 ones with two reconstructed π^o-mesons with $E_\pi \geqslant 10$ GeV. The invariant mass of the π^o-pair was estimated by subjecting the masses of the two π^o candidates to the 2C fit.

The data on the invariant masses of the π^o-pairs statisfying the requirement that the total energy of the four photons be higher than 55 and 60 GeV ($x_F > 0.79$ and 0.86, respectively) are presented in Fig.7. These distributions show distinct signals from the decays $K^o_s \to 2\pi^o$ of the produced neutral kaons. In various regions of the variable x_F, the quasiexclusive cross sections in the deep fragmentation region were estimated as

$$\sigma(p + N \to K^o_f + \tilde{X}_{b.v.}|_{x_F > x_{F_{min}}} = \frac{N}{BR(K^o_s \to 2\pi^o) \times 0.5\epsilon L}, \qquad (18)$$

where N is the total number of detected events, ϵ is the detection efficiency obtained through a Monte Carlo simulation, and L=175 event/nb is the integrated luminosity of the exposure. The factor of 0.5 in the denominator takes into account the fact that only the K^o_s componenet of all emitted neutral kaons is detected experimentally. In deep fragmentation processes mediated by hyperon exchange, K^o_s-mesons are expected to originate from K^o-production, while $\bar{K}^o$-production is strongly suppressed.

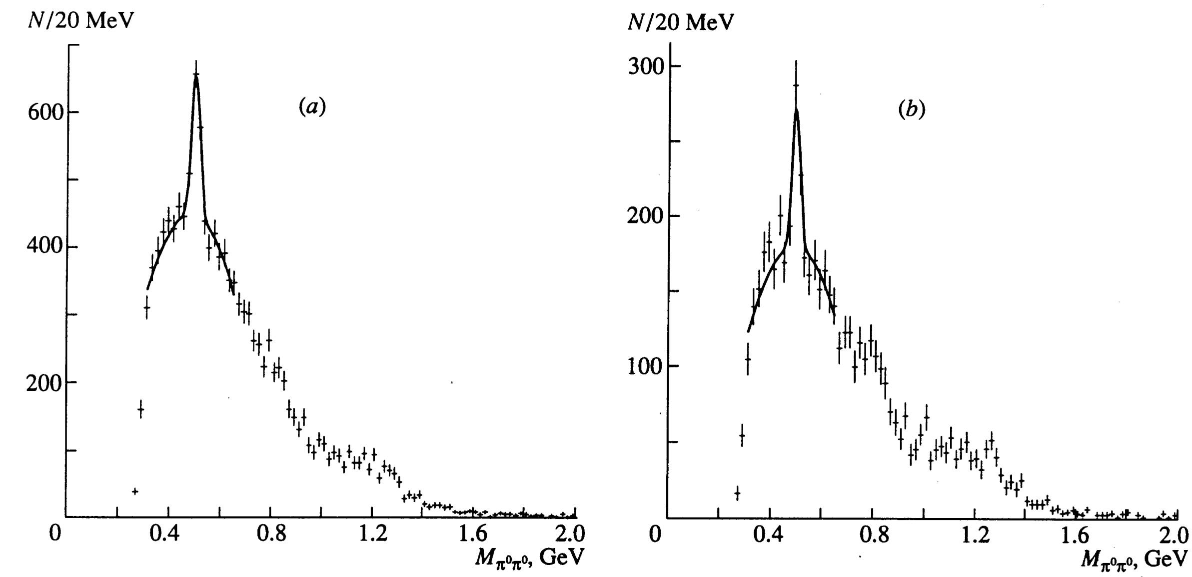


Fig. 7. Invariant-mass distribution of the $\pi^o\pi^o$-system for two cuts on the total energy of emitted photons: (a) $\sum E_i > 55$ GeV ($x_F > 0,79$) and (b) $\Sigma E_i > 60$ GeV ($x_F > 0,86$). The distributions show clear signals from the decays $K_S^o \to \pi^o\pi^o$ of produced neutral kaons.

The p_T^2 distribution of emitted K^o-mesons is shown in Fig.8 for $x_F > 0.79$. This distribution was fitted to the form (15). The differential cross sections for K^o-production $d\sigma/dx_F$ are presented in Fig.9. They were approximated by the expression (16). The measured cross sections for K^o-production and the parameters of differential distributions are listed in Tables 5 and 6, respectively. The uncertainties quoted in these tables are purely statistical. Systematic errors in the total cross sections and in the slope parameters may reach ±15%.

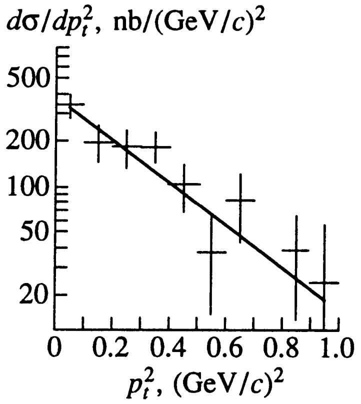


Fig. 8. Differential cross section $d\sigma/dp_T^2$ as a function of the squared transverse momentum of K^o mesons produced in reaction (12) for $x_F > 0,79$.

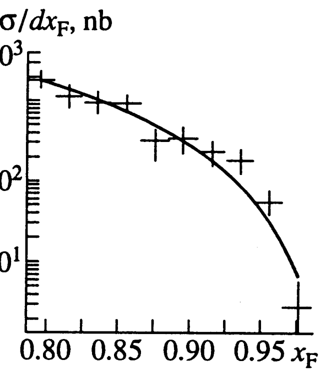


Fig. 9. Differential cross section $d\sigma/dx_F$ for K^o production in reaction(12).

Table 5. Total cross section for K^o production in reaction (1) for $x_F > 0.79$ and $x_F > 0.86$

Reaction	$x_{F_{min}}$	Number of events	Efficiency	$\sigma_{tot}(x_F > x_{f_{min}}$, nb
$p + n \to$	0.79	421± 44	0.12	123±13
$\to K_f^o + \tilde{X}_{b.v.}$	0.86	185±22	0.22	30±4

Table 6. Fitted parameters of differential distributions

Reaction	$x_{F_{min}}$	$d\sigma/dp_T^2 \sim exp(-bp_T^2)$	$d\sigma/dx_F \sim (1-x)^\alpha$
		b, (GeV/c)$^{-2}$	α
$p + N \to K_f^o + \tilde{X}_{b.v.}$	0.79	3.2±0.6	2.65±0.20

Comparing data on quasiexclusive π^o- and K^o-production in the deep-framgentation region that were obtained under the same kinematical conditions, we may conclude that transitions involving strange quarks are suppressed (the suppression factor is $\lambda \sim 5$).

5. THE OUTLOOK FOR THE EXPERIMENTS IN THE DEEP FRAGMENTATION REGION

Hence the study of ordinary meson production in quasiexclusive pN-reactions in the deep fragmentation region has shown that the values of cross sections for these processes are comparatively large. These baryon exchange reactions may be a good tool for exotic meson production due to a pick up mechanism for gluon bremsstrahlung as it is illustrated by diagram in Fig.1b.

In further experiments on the SPHINX setup we intend to study the deep fragmentation processes with forward production of $\eta\eta$; $\eta\eta'$ and $\eta\omega$ meson systems in pN collisons. These systems are strongly coupled with gluons (see for example the reviews [7,8]) and are rather promising for the search for hybrid mesons. In particular it seems interesting to use the deep fragmentation reactions for more precise study of anomalous narrow meson states $X(1650)^o \to \omega\eta$, $X(1740)^o \to \eta\eta$ and $X(1910)^o \to \eta\eta'$, which were observed previously in the experiments of the GAMS Collaboration in nonperipheral charge exchange pion induced reaction $\pi^- + p \to X^o + n$ (see [20-22]). It is interesting also to search for $C(1480)^-$ meson production in the pN-reaction with Δ^{++} exchange. Here $C(1480)^- \to \phi\pi^-$, a candidate for cryptoexptoc meson with hidden strangeness (or may be hybrid) was observed earlier in the measurements with the LEPTON-F facility also in charge exchange pion reaction $\pi^- + p \to C(1480)^o + n$; $C(1480)^o \to \phi\pi^o$ (see [23,24]). It must be stressed that in the quasiexclusive reaction $p + N \to M^- + \tilde{X}_{b.v.}$ with Δ^{++} exchange, in which the electric charge of produced meson system is opposite to the charge of initial proton, we can expect the most favorable background conditions for $C(1480)^-$ meson separation.

Next possibility is associated with the search for open exotic mesons in quasiexclusive baryon exchange reactions of (8) type. Let us consider, for example, a possible search for heavy narrow meson states $\bar{U}$ with mass $M \simeq 3.1$ GeV, width $\Gamma \lesssim 20 \div 30$ MeV, isospin $I = 3/2$ and strangeness $S = +1$ (for U-mesons $S = -1$). Some evidences of possible existence of these open exotic mesons ($I = 3/2$) with quark structure $U = (qs\bar{q}\bar{q})$ and $\bar{U} = (qq\bar{q}\bar{s})$ were obtained in [25,26] (see also reviews [7,8] for the discussion of the status of these states). $U(\bar{U})$-mesons, if they are really existed, formed meson quartets – for example, $\bar{U}^- \to \bar{\Lambda}p\pi^-\pi^-$; $\bar{U}^o \to \bar{\Lambda}p\pi^-$; $\bar{\Lambda}p\pi^+\pi^-\pi^-$; $\bar{U}^+ \to \bar{\Lambda}p$; $\bar{\Lambda}p\pi^o$; $\bar{\Lambda}p\pi^+\pi^-$; $\bar{U}^{++} \to \bar{\Lambda}p\pi^+$, etc. The diagrams for possible $\bar{U}^o$; $\bar{U}^+$; $\bar{U}^{++}$ production in quasiexclusive reactions $p + N \to \bar{U} + \tilde{X}_{b.xv.}$ with Y hyperon exchange are presented on Fig.10. These reactions are analogs of the process $p + N \to K^o + (\tilde{X}_{b.v.})$, which was investigated in our experiment (see Sec. 4). Reactions of $\bar{U}$-production can be studied in future measurements with the SPHINX facility.

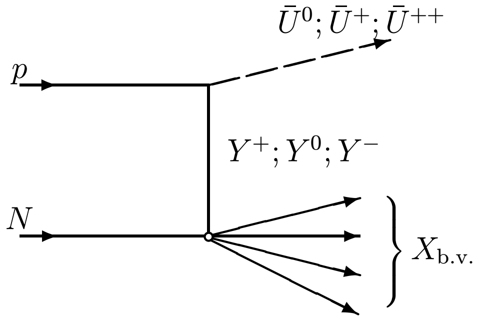


Fig. 10. Diagrams for $\bar{U}^o$; $\bar{U}^+$; $\bar{U}^{++}$ exotic meson production in quasiexlusive reactions with Y^+; Y^o; Y^- hyperon exchange.

The search for exotic mesons in quasiexclusive processes with baryon exchange is a new trend in the physics of exotic hadrons. As we know from the previous exotic searches, the possibility for the separation of exotic states is tightly connected with a proper choice of production reactions, to reduce the background and to provide the best conditions for isolation of the object under study. Thus, the use of a new type of production process with baryon exchange can open some new possibility and, in any case, it deserves to be experimentally tested.

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