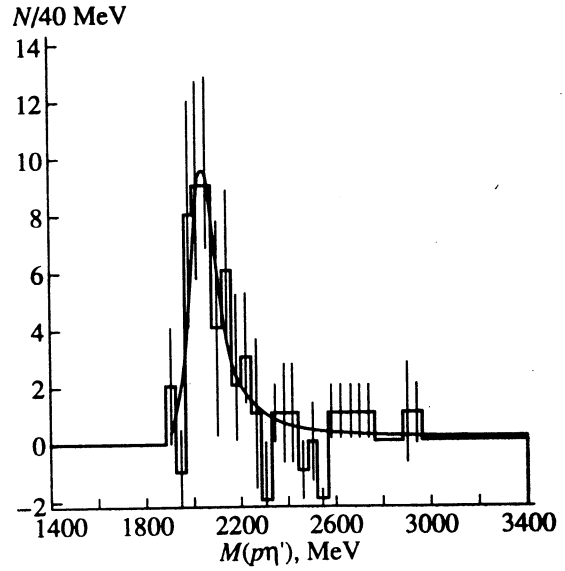

Fig. 19. The invariant mass spectrum $M(p\eta')$ in the reaction $p+N \to [p\eta']+N$ (32) in the region of $P_T^2 > 0.3$ GeV^2. This spectrum is dominated by a threshold structure with $M \sim 2000$ MeV and $\Gamma \sim 100$ MeV.

9. Reaction $p + N \to (\Sigma^0\pi^0)K^+ + N$ and prospects for a study of Λ^* hyperon resonances

Diffractive reactions of $p + N \to [Y^*K^+] + N$ type with hyperon and kaon production can be also used to probe the excited hyperon states Y^*. For example, we present here some results of the SPHINX Collaboration on the study of $\Sigma^0\pi^0$ system in the diffractive reaction

$$p + N \;\to\; \underbrace{(\Sigma^0\pi^0)}_{\Sigma^0 \to \Lambda\gamma,\ \pi^0 \to \gamma\gamma}K^+ + N. \tag{33}$$

The $(\Sigma^0\pi^0)$ - system can be characterized by the isotopic spin values $I = 0$ or $I = 2$. But in the proton diffractive process (33) with the Pomeron exchange only isoscalar $(\Sigma^0\pi^0)$ - system can be produced (because the primary proton and secondary kaon are isospinors). Thus, reaction (33) offers a possibility to study isoscalar Λ^* hyperon resonances in the $\Sigma^0\pi^0$ system in pure conditions, without the influence of isovector Σ^* background. As is clear from PDG [38], the properties of the most of Λ^* states are poorly understood now and new data for these states are quite desirable. On Fig.20 the first results of the SPHINX experiment for the invariant mass spectra $M(\Sigma^0\pi^0)$ are presented (they are obtained in the old run with a small decay path for $\Lambda \to p\pi^-$ and with limited statistics). One might expect from this figure that in new measurement with enlarged statistics it would be possible to obtain a rich data for several Λ^* states. In particular, it seems quite interesting to perform a detailed study of the shape for $\Lambda(1405)$ peak in this process. There were some previous evidences of an anomalous (non-Breit-Wigner) behavior of mass spectra for $\Lambda(1405)$ hyperon [38-40]. Such non-Breit-Wigner form of $\Lambda(1405)$ peak can be caused by possible exotic nature of this hyperon (bound K^-p state?).

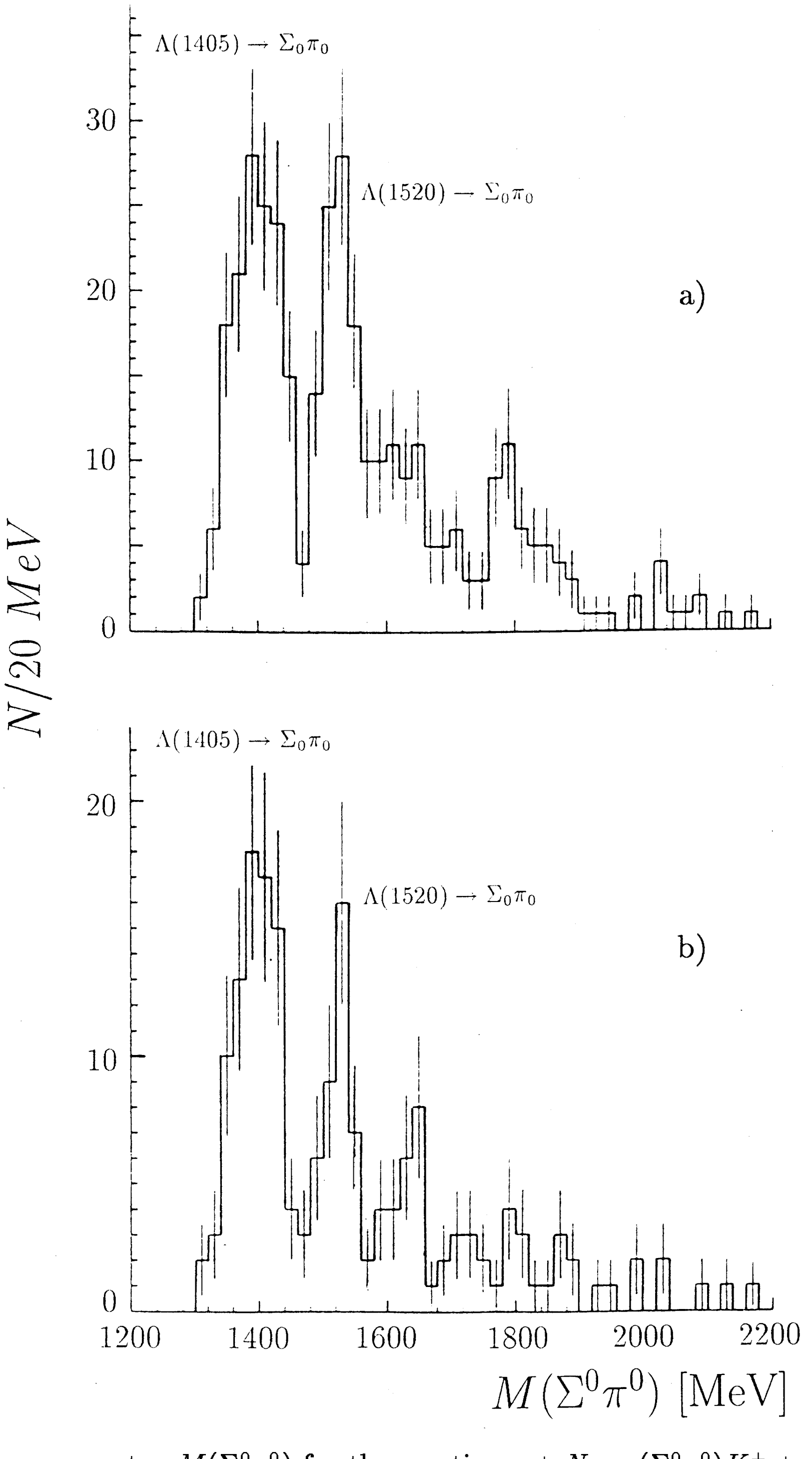

Fig. 20. The mass spectra $M(\Sigma^0\pi^0)$ for the reaction $p + N \rightarrow (\Sigma^0\pi^0)K^+ + N$: a) for all P_T^2; b) for $P_T^2 < 0.075$ GeV^2.

10. Study of the OZI selection rule in hadronic processes [22-24]

10.1. The OZI rule

The selection rule for connected and disconnected quark diagrams that is referred to as the OZI rule has been known for a long time [41-43]. According to this rule, processes involving the annihilation or creation of a quark-antiquark pair entering into the composition of the same hadron are forbidden or, strictly speaking, strongly suppressed. The OZI rule may be illustrated by the diagrams for the production and decay of the vector mesons ω and ϕ (Fig.21). It is the OZI rule that makes it possible to explain the anomalously small decay width of the J/ψ particle representing a bound $c\bar{c}$ state.

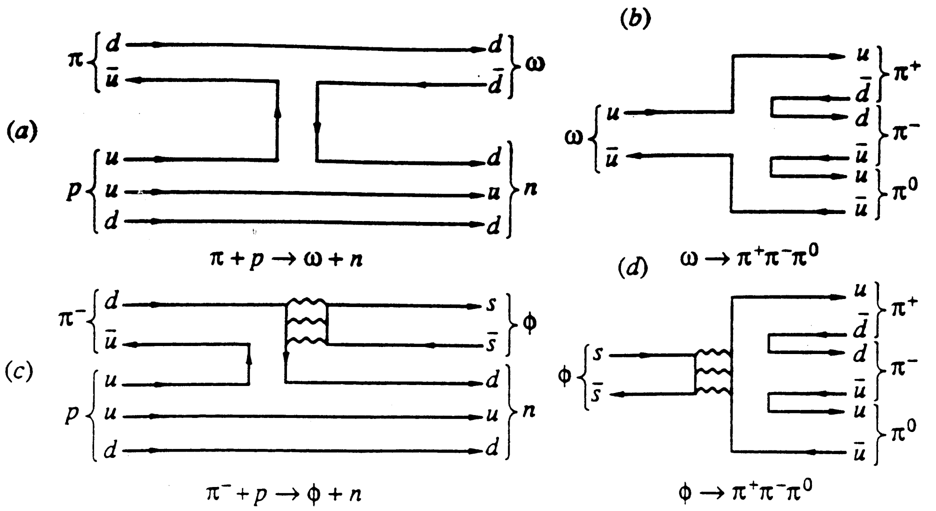

Fig. 21. Diagrams for: (a,b) OZI-allowed and (c,d) OZI-suppressed production and decay processes: (a) reaction $\pi^- + p \to \omega + n$, (b) decay $\omega \to \pi^+\pi^-\pi^0$ (connected quark diagrams); (c) reaction $\pi^- + p \to \phi + n$, and (d) decay $\phi \to \pi^+\pi^-\pi^0$ (disconnected quark diagrams).

Recent years have seen a revived interest in the OZI rule. First, intensive searches for exotic hadrons (see the surveys in [1-7] and references therein) are greatly facilitated by choosing production processes in which the formation of conventional particles is suppressed by the OZI rule [44-46, 33]. Since this rule may be significantly violated for exotic hadrons because of their complex color structure, signals from exotic and cryptoexotic particles are expected to benefit from more favorable background conditions in OZI-suppressed production processes. While the $\phi\pi$ and $\phi\rho$ decays of isovector mesons with conventional quark structure $\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$ are suppressed by the OZI rule (the corresponding probabilities are reduced more than by two orders of magnitude), the same decay channels may prove much more probable for exotic multiquark mesons with hidden strangeness $[(u\bar{u} - d\bar{d})s\bar{s}/\sqrt{2}]$ and hybrid states like $(u\bar{u} - d\bar{d})g/\sqrt{2}$. Furthermore, the unexpected results obtained in deep-inelastic lepton scattering on polarized nucleons led to the well-known nucleon-spin crisis [47,48]. To explain this phenomenon, it was hypothesized that nucleons involve an enhanced quark component with hidden strangeness, which may induce substantial violations of the OZI rule in nucleon processes [49,50]. Strong violations of the OZI rule were indeed observed in the relative ϕ and ω yields from some channels of $\bar{p}p$ annihilation (the reactions $\bar{p}p \to \phi\pi^0, \bar{p}p \to \omega\pi^0, \bar{p}p \to \phi\gamma$, and $\bar{p}p \to \omega\gamma$ [50,51]).

The above arguments suggest that the OZI rule must be further tested in various production and decay processes involving conventional particles. Toward this, we analyzed a number of processes studied in experiments with LEPTON-F and SPHINX detectors. In particular, in earlier measurements on the LEPTON-F setup the investigation of this selection rule was performed in the OZI-suppressed charge-exchange reaction

$$\pi^- + p \quad \to \quad \phi + n \tag{34}$$

at a relatively high primary momentum of $P_{\pi^-} = 32.5$ GeV [22], as well as in the decay of the isovector meson $B/b_1(1235)$ with conventional quark structure $\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$:

$$B/b_1(1235) \quad \to \quad \phi\pi^0. \tag{35}$$

(see [23]). Preliminary results of these studies were reported in [52]. In the experiments with the SPHINX spectrometer (which evolved from the LEPTON apparatus) a comparative analysis of $p\phi$ and $p\omega$ systems produced in pN diffractive-like reactions was carried out [24] and the OZI rule in nucleon processes was tested by these data.

10.2. Charge exchange reaction $\pi^- + p \to \phi + n$ at $P_\pi = 32.5$ GeV [22]

Reaction (34) was studied with the LEPTON-F spectrometer simultaneously with the main research program for this setup aimed at the investigation of $\phi\pi^0$ system in meson reactions [45,52,53], as well as at the search for rare meson radiative decays on $\phi\gamma$ and $\pi^+\pi^-\gamma$ channels [52,54-56].

The LEPTON-F setup included a magnetic spectrometer with proportional chambers and scintillator hodoscopes and multichannel γ-spectrometer with total absorption lead glass detectors. Three gas Cherenkov counters $\check{C}_1 - \check{C}_3$ were used to identify beam particles, while a wide-aperture threshold gas counter $\check{C}_4$ placed downstream the target in front of magnetic spectrometer identified charge secondaries. A detailed description of the LEPTON-F setup was published in [53,57].

The material and geometry of the target of the LEPTON-F setup were chosen so as to maximize the overall yields of $\phi\pi^0$, $\phi\gamma$ and $\pi^+\pi^-\gamma$ production in the corresponding charge exchange reactions ($\pi^- + p \to M + n$; $M \to \phi\pi^0$ or $M \to \phi\gamma$; $\pi^+\pi^-\gamma$). A 40 cm thick LiH target (28 g/cm^2) was found to be optimal for these purposes. The target was enclosed by a special guard veto system (scintillator counters, lead-scintillator sandwiches) aimed at selecting exclusive processes under study. In these measurements $4 \times 10^{11}\pi^-$ and $8 \times 10^9 K^-$ mesons passed through the target [52-56].[1]

[1]The fraction of K^- mesons in the negative beam with $P_\pi = 32.5$ GeV was $\simeq 2\%$.

In the analysis of two-track events detected in the LEPTON-F magnetic spectrometer and identifed by Cherenkov detectors the reactions

$$\pi^- + p \;\rightarrow\; [K^+K^-] + (n; \Delta, N^*) \tag{36}$$

and

$$K^- + p \;\rightarrow\; [K^+K^-] + Y \tag{37}$$

were selected after the "elastic" restriction $29 < E_{K^+} + E_{K^-} < 34$ GeV was imposed. In the invariant mass spectra on reactions (36) and (37) clear peaks corresponding to the ϕ meson production in

$$\pi^- + p \;\rightarrow\; \phi + (n, \Delta, N^*) \tag{38}$$

and

$$K^- + p \;\rightarrow\; \phi + Y \tag{39}$$

were observed (Fig. 22 and 23). In selection of the OZI forbidden processes (38) a special attention was paid to suppress the background from the OZI allowed reaction (39) which has two orders of magnitude higher cross section to compare with (38). Special choice of the working regime for $\check{C}_1 - \check{C}_3$ counters allowed one to suppress this background to a negligibly small level.

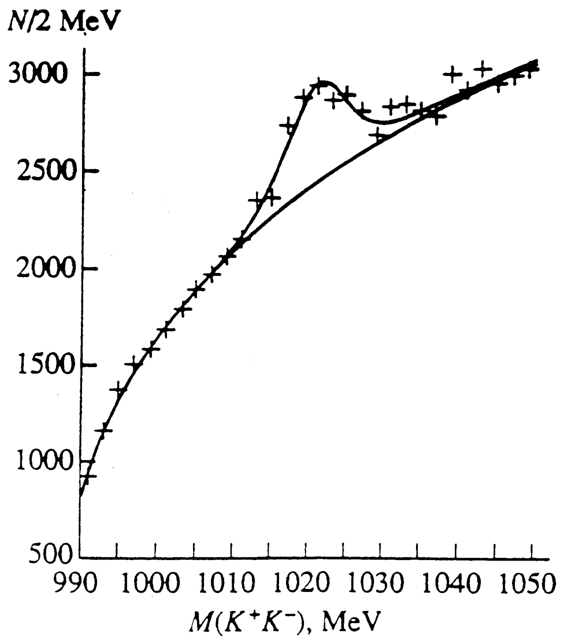

Fig. 22. a) Effective mass spectrum of K^+K^- system in OZI - suppressed reaction $\pi^- + p \rightarrow K^+K^- + (n; \Delta; N^*)$.

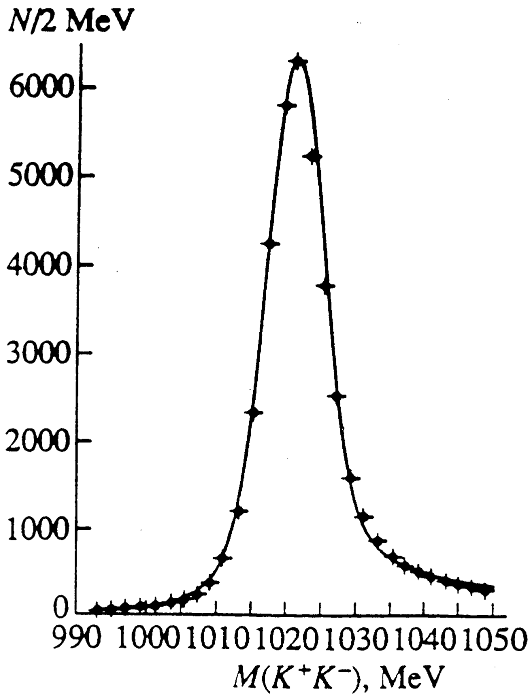

Fig. 23. Effective mass spectrum of K^+K^- system in OZI-allowed reaction $K^- + p \rightarrow K^+K^- + Y$.

In order to determine the number of ϕ mesons, produced in "elastic" processes (38) (i.e. the number of events in the ϕ-peak in Fig.22), the corresponding distribution was fitted by the sum of polynomial background and the convolution of a P-wave Breit-Wigner resonance with a Gaussian function of the spectrometer resolution. Reaction (39), in which the background under the ϕ-peak is very small (see Fig.23), was used to determine the shape of the peak. Fixing the standard value of the ϕ meson width ($\Gamma = 4.22$ MeV), the spectrometer resolution was found to be $\sigma_\phi = (3.0 \pm 0.3)$ MeV. Finally, the total number of events of reactions (38) was determined to be:

$$N_{n;\Delta;N^*}(\phi) \quad = \quad 2890 \pm 160. \tag{40}$$

In the next step of the data processing it was necessary to single out reaction (34) with neutron in the final state. In order to separate contributions from reactions the $\pi^- + p \to \phi + n$ and $\pi^- + p \to \phi + (\Delta; N^*)$ the information from the veto counters around the target was used. The special procedure for such analysis and for absolute normalization of cross sections (34) with the help of the known value of the cross section for ρ^0 meson production in the charge exchange reaction $\pi^- + p \to \rho^0 + n$ are detailed in [22]. As a result, the number of the events for $\pi^- + p \to \phi + n$

$$N_n(\phi) = 1670 \pm 410 \tag{41}$$

and the value of the total cross section for OZI suppressed reaction (34) at $P_{\pi^-} = 32.5$ GeV

$$\sigma(\pi^- + p \quad \to \quad \phi + n)|_{P_\pi = 32.5\,\mathrm{GeV}} = (11.5 \pm 3.3) \cdot 10^{-33}\,\mathrm{cm}^2 \tag{42}$$

were obtained. The quoted error is largely due to systematic uncertainties associated with the normalization of the cross sections and with the separation of the contributions from different reaction channels of (38).

The cross-section for the reaction $\pi^- + p \to \omega + n$ was most accurately measured in two experiments [58,59]. Taking the average value from these measurements, we can determine the cross-section ratio

$$\begin{aligned} R(\phi/\omega) \quad &= \quad \frac{\sigma(\pi^- + p \to \phi + n)}{\sigma(\pi^- + p \to \omega + n)} = \frac{(11.5 \pm 3.3) \cdot 10^{-33}}{(4.0 \pm 0.5) \cdot 10^{-30}} = \\ &= \quad (0.29 \pm 0.09) \cdot 10^{-3}. \end{aligned} \tag{43}$$

This ratio characterizes the OZI suppression of the ϕ meson production in the pion charge exchange reaction (34) - see diagrams on Fig.21. The available data on the cross-sections of the reactions $\pi^- + p \to \phi + n$ and $\pi^- + p \to \omega + n$ at different energies [58-60] are presented in Fig. 24.

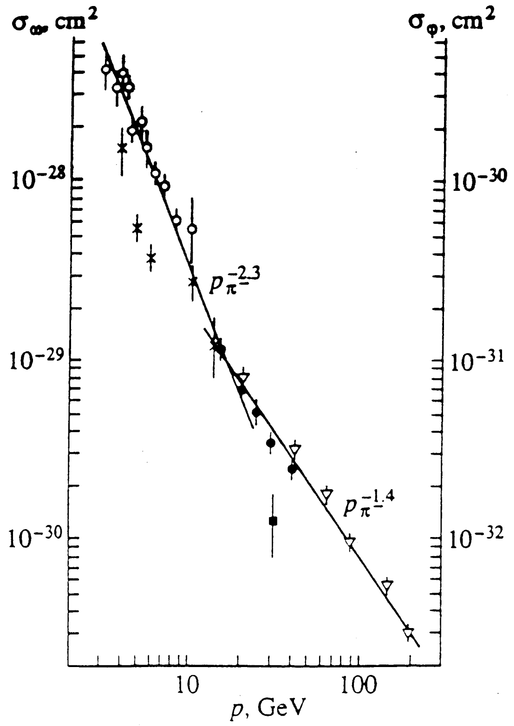

Fig. 24. Total cross sections for the reactions $\pi^- + p \to \phi + n$ and $\pi^- + p \to \omega + n$ as functions of the beam momentum P_{π^-}. Results for the reaction $\pi^- + p \to \omega + n$ correspond to the left-hand scale: ($\circ$) low-energy data [25], ($\bullet$) data from [23], ∇ data from [24]; and straight lines correspond to power-law parametrizations $\sigma \sim P_{\pi^-}^{-2.3}$ and $\sigma \sim P_{\pi^-}^{-1.4}$. Results for the reaction $\pi^- + p \to \phi + n$ correspond to the right-hand scale: $\times$ - data from [25] for relatively low energies; $\blacksquare$ - result of this investigation with the LEPTON-F detector.

Ratio (43) can be used in the naive quark model for the determination of the mixing angle θ_V for the vector meson nonet from the relation $\mathrm{tg}^2\Delta\theta_V = R(\phi/\omega)$ [61]. Here $\Delta\theta_V = \theta_V - \theta_V^0$ and $\theta_V^0 = \mathrm{arctg}\frac{1}{\sqrt{2}} = 35.3^0$ is the angle of ideal mixing. It follows from (43) that $|\Delta\theta_V| = (3.1 \pm 0.5)^0$, in excellent agreement with the data on the radiative widths $\Gamma(\phi \to \pi^0\gamma)$ and $\Gamma(\omega \to \pi^0\gamma)$ ($|\Delta\theta_V| = (3.0 \pm 0.2)^0$ [62]) and on the quadratic mass formula for the vector nonet ($|\Delta\theta_V| = 3.7 \pm 0.4^0$[38]).

We conclude that the data on the charge exchange reactions $\pi^- + p \to \phi + n$ and $\pi^- + p \to \omega + n$ at relatively high beam momentum ($P_{\pi^-} = 32.5$ GeV) are in a good agreement with the OZI rule and with a value of the mixing angle for the vector meson nonet, determined from other data.

10.3. Search for the OZI suppressed decay $B/b_1(1235) \to \phi\pi^0$ [23]

For isovector neutral mesons with quark structure $|M_{I=1}> = |(u\bar{u} - d\bar{d})/\sqrt{2}>$ the decay to $\phi\pi^0$ is OZI-forbidden and should be strongly suppressed with respect to $\omega\pi^0$ decay channel. Here are presented the LEPTON-F data on the search for the decay $B/b_1(1235) \to \phi\pi^0$(35). It is known that the main decay channel of the $B/b_1(1235)$ meson ($M = 1231 \pm 3$ MeV, $\Gamma = 142 \pm 8$ MeV, $J^{PC} = 1^{+-}$, $I^G = 1^+$) is $B/b_1(1235) \to \omega\pi^0$ [38]. The search for decay (35) was performed in the study of the charge exchange reaction

$$\pi^- + p \;\to\; [\phi\pi^0] + n. \qquad (44)$$
$$\hookrightarrow K^+K^-$$

In these measurements (see [45, 52, 53] for more details) the new vector meson $C(1480)$ was observed in the reaction

$$\pi^- + p \;\rightarrow\; C(1480) + n, \qquad (45)$$
$$\hookrightarrow \phi\pi^0$$

which made a dominant contribution to (44) and which was a major source of background for the decay signal (35). Reaction (45) is largely due to one-pion exchange mechanism (OPE) and is therefore characterized by a narrow $|t'|$ distribution. At the same time OPE is forbidden for the reaction

$$\pi^- p \;\rightarrow\; B/b_1(1235)^0 + n, \qquad (46)$$

because of the $B/b_1(1235)$-meson quantum numbers (opposite parity and charge parity). Reaction (46) is expected to be dominated by the A_2 exchange leading to a broader $|t'|$ distribution.

Therefore the "anti OPE-cut" $|t'| > 0.1$ GeV^2 decreases the efficiency of $B/b_1(1235)$ detection in reaction (46) by no more than 25%, while $C(1480)$ production and other OPE background processes are suppressed by a factor of about 5.

The effective mass spectrum of the $\phi\pi^0$-system in reaction (44) at $|t'| > 0.1$ GeV^2 weighted with the efficiency of the setup is shown on Fig.25. For the evaluation of the upper limit of the cross section $\sigma[\pi^- + p \rightarrow B/b_1(1235)^0 + n] \cdot \mathrm{BR}[B/b_1(1235)^0 \rightarrow \phi\pi^0]$ the number of events in the interval $1150 < M(\phi\pi) < 1330$ MeV was determined to be 78 ± 167. Therefore the upper limit for the cross section of (46) is

$$\begin{aligned} \sigma[\pi^- + p \;&\rightarrow\; B/b_1(1235)^0 + n]|_{P_{\pi^-}=32.5\,\mathrm{GeV}} \cdot \\ \cdot BR[B/b_1(1235)^0 \;&\rightarrow\; \phi\pi^0] < 5\,\mathrm{nb}(95\%\mathrm{C.L.}). \end{aligned} \qquad (47)$$

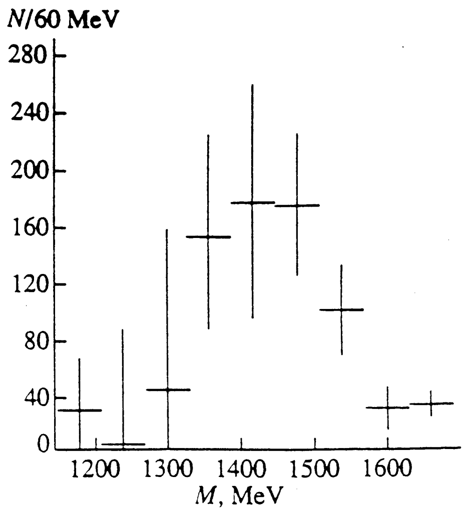

Fig. 25. Effective mass spectrum of the $\phi\pi^0$ system in the reaction $\pi^- + p \rightarrow (\phi\pi^0) + n$ (the results are weighted with detector efficiency). An "anti-OPE" selection $|t'| > 0.1$ (GeV)^2 is applied, which affects only slightly the efficiency for the reaction $\pi^- + p \rightarrow B/b_1(1235) + n$ (not proceeding via OPE exchange), but which reduces the background from the OPE-mediated reaction $\pi^- + p \rightarrow C(1480)^0 + n$ by a factor close to 5.

In the experiment with the GAMS-2000 facility [63] the cross section of $B/b_1(1235)$ production was determined to be

$$\begin{aligned}\sigma[\pi^- + p &\rightarrow B/b_1(1235)^0 + n]|_{P_{\pi^-}=38\,\mathrm{GeV}} \cdot \\ \cdot BR[B/b_1(1235)^0 &\rightarrow \omega\pi^0] = 0.8 \pm 0.2\mu\mathrm{b}.\end{aligned} \quad (48)$$

Taking into consideration the energy dependence of the cross section for this process $\sigma \sim P_\pi^{-1.5\pm0.2}$ [63], the upper limit for the ratio of decay branchings for $B/b_1(1235)$-meson can be obtained from (47) and (48) to be

$$\begin{aligned}R_B = BR[B/b_1(1235)^0 &\rightarrow \phi\pi^0]/BR[B/b_1(1235)^0 \rightarrow \\ &\rightarrow \omega\pi^0] < 4 \cdot 10^{-3}(95\%\ \mathrm{C.L.}).\end{aligned} \quad (49)$$

Since the decay $B/b_1(1235)^0 \rightarrow \omega\pi^0$ proceeds mostly with zero orbital angular momentum [38], we can represent (49) in the form

$$R_B \;=\; [p_\phi^{(B)}/p_\omega^{(B)}]|g^2_{B\phi\pi}/g^2_{B\omega\pi}| < 4 \cdot 10^{-3} \quad (50)$$

or

$$|g^2_{B\phi\pi} \;\;/\;\; g^2_{B\omega\pi}| \leq 1 \cdot 10^{-2} \quad (51)$$

(after some small correction for possible contributions from D-wave decays of $B/b_1(1235)$ meson). Here, $p_\phi^{(B)}$ and $p_\omega^{(B)}$ are the decay momenta of ϕ and ω mesons in the rest frame of the $B/b_1(1235)$ meson, and $g_{B\phi\pi}$ and $g_{B\omega\pi}$ are the corresponding coupling constants. Thus, in a framework of naive quark model it is possible to obtain from (51) the limitation $|g_{B\phi\pi}/g_{B\omega\pi}|^2 \simeq tg^2\Delta\theta_V < 1 \cdot 10^{-2}$ for the mixing angle $\Delta\theta_V = \theta_V - \theta_V^0$ and to conclude that the decays of the ordinary isovector meson $B/b_1(1235)$ do not contradict the OZI selection rule for connected and disconnected quark diagrams.

10.4. Study the OZI rule in the nucleon diffractive-like reactions $p + N \rightarrow [p\phi] + N$ and $p + N \rightarrow [p\omega] + N$ [24]

The test of the OZI selection rule for ϕ and ω meson production in proton-nucleon processes was performed in the experiments with the SPHINX spectrometer in the study of diffractive reactions $p + N \rightarrow [p\phi] + N$ (6) and $p + N \rightarrow [p\omega] + N$ (12).

Process (6) should be suppressed by the OZI rule because of disconnected character of quark diagram for ϕ production. In the naive quark model (assuming the strict OZI rule) the ratio of cross sections for ϕ and ω production is related to $\phi - \omega$ mixing and should be

$$R(\phi/\omega) \;=\; \mathrm{tg}^2\Delta\theta_V \simeq 0.4 \cdot 10^{-2}. \quad (52)$$

Here $\Delta\theta_V = \theta_V - \theta_V^0$ and $\theta_V^0 = 35.3^0$ is the angle of ideal mixing in vector nonet (see Section 10.2).

The reactions (6) and (12) were separated in the investigation of the reactions $p+N \to [pK^+K^-] + N$ (5) and $p + N \to [p\pi^+\pi^-\pi^0] + N$ (29). In plotting different distributions for (6) and (12) the standard sideband background subtraction technique (with respect to ϕ or ω peaks) was used as it is demonstrated on Fig.26.

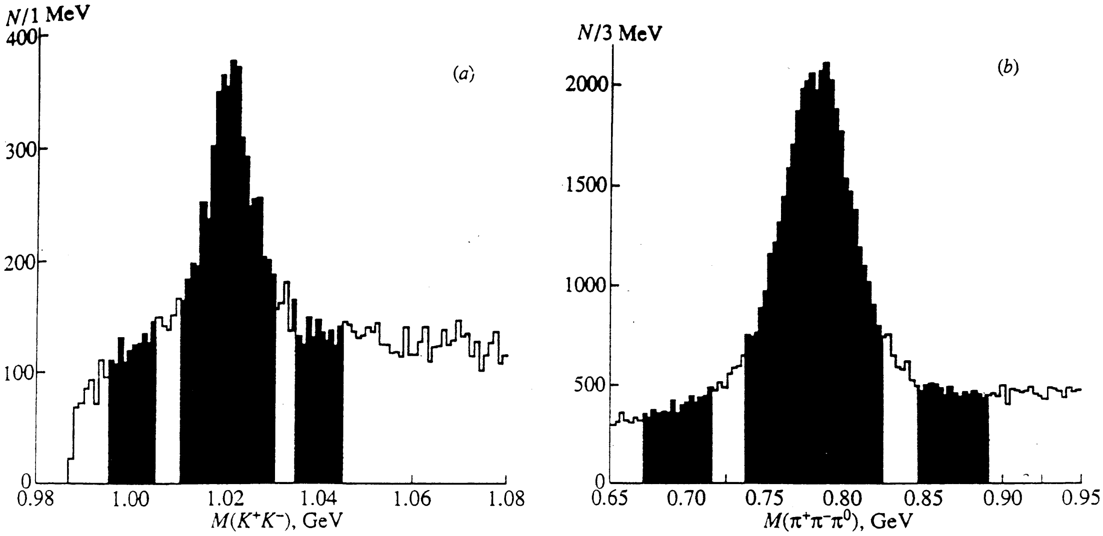

Fig. 26. Selection of the reactions $p + N \to [p\phi] + N$ (6) and $p + N \to [p\omega] + N$ (12) and illustration of sideband method for background subtraction for the separation of these processes: a) effective mass spectrum $M(K^+K^-)$ in $p + N \to [pK^+K^-] + N$ (5); b) effective mass spectrum $M(\pi^+\pi^-\pi^0)$ in $p+N \to [p\pi^+\pi^-\pi^0] + N$ (29). The regions of the ϕ and ω peaks and sideband regions for background subtractions to obtain all distributions in (6) and (12) are shown on these spectra.

The distributions in the squared transverse momentum P_T^2 for reactions (6) and (12) were presented earlier, on Fig.4. The narrow forward peaks with the slopes $b \geq 50$ GeV^{-2} are dominated in these distributions. They correspond to coherent diffractive production on carbon nuclei. Since the character of these distributions is identical for both reactions under study the main results for these processes are presented for the entire P_T^2 region (except the data on Fig.31, see below).

The invariant mass spectra $M(p\phi)$ and $M(p\omega)$ were corrected for detection efficiencies and for the $\phi \to K^+K^-$ and $\omega \to \pi^+\pi^-\pi^0$ branching ratios. The weighted mass spectra $M(p\phi)$ and $M(p\omega)$ are presented on Fig.27. For convenience, the distribution in $M(p\phi)$ is scaled up by a factor of 100. The quoted errors are purely statistical. Some details of detection efficiencies estimations for (6) and (12) are discussed in Ref.[24]. Many systematic errors are expected to cancel out in the ratio $R(\phi/\omega)$ since events for reactions (6) and (10) were detected simultaneously and under similar experimental conditions. The estimated systematic uncertainty in $R(\phi/\omega)$ is 20% (due to the different final states in these reactions).

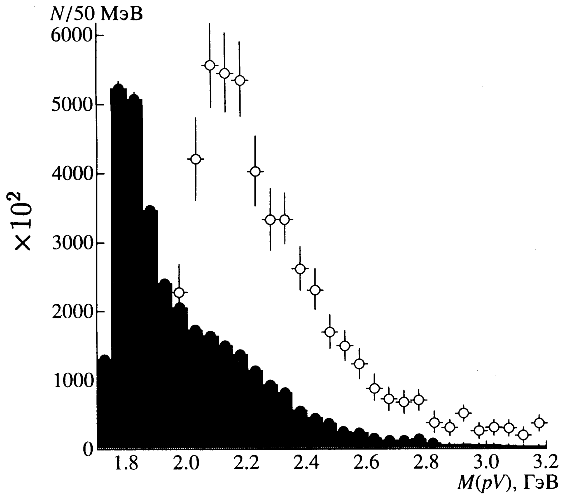

Fig. 27. Weighted distributions of events in the mass $M(pV)$ (here and in other figures of this subsection all distributions are weighted with efficiency of the setup). Closed and open circles represent, respectively, the distribution on $p\omega$ and the scale distribution of $p\phi$ (scale factor is 100).

Derivation of the ratio $R(\phi/\omega)$ for pN collisions and the OZI rule testing in these processes are not as straightforward as in charge exchange pion reactions (Section 10.2), meson decays (Section 10.3) or in nucleon-antinucleon annihilation [50,51]. The problem is that a significant contribution to the cross section for reaction (12) comes from the kinematical region below the threshold of $p\phi$ production.

Bearing in mind this difficulty we used two approaches to the OZI rule test in proton reactions.

A. On Fig.28 we present the data for the distributions dN/dP_v for reactions (6) and (12) as a function of vector meson momentum P_v in the rest frame for pV system with the invariant mass $M(pV)$

$$P_v = \frac{\{[M(pV)^2 - (m_v + m_p)^2][M(pV)^2 - (m_v - m_p)^2]\}^{1/2}}{2M(pV)} \tag{53}$$

(here and elsewhere V denotes vector ϕ or ω mesons).

For testing the OZI rule we obtain the ratio of the cross sections for reactions (6) and (12) as a function of some minimal value of momentum $P_{\mathrm{vmin}} = P_0$

$$R_1(\phi/\omega)|_{P_v>P_0} = \frac{\int_{P_0}^{P_{max}} (d\sigma/dP)_\phi \cdot dP_\phi}{\int_{P_0}^{P_{max}} (d\sigma/dP)_\omega \cdot dP_\omega} \simeq \frac{\Sigma_{P_\phi>P_0} N_\phi(P_\phi)}{\Sigma_{P_\omega>P_0} N_\omega(P_\omega)} \tag{54}$$

(see Fig.29). To avoid the influence of possible resonances or resonance-like threshold structure effects which can be different for reactions (6) and (12), we use the value $P_0 > 1$ GeV ("asymptotic region" for $R_1(\phi/\omega)$, see Fig.29). For this value of P_0

$$R_1(\phi/\omega)|_{P_v>1GeV} = (4.0 \pm 0.04 \pm 0.08) \cdot 10^{-2} \tag{55}$$

This approach is justified if the cross sections of (6) and (12) are functions of P_V only.

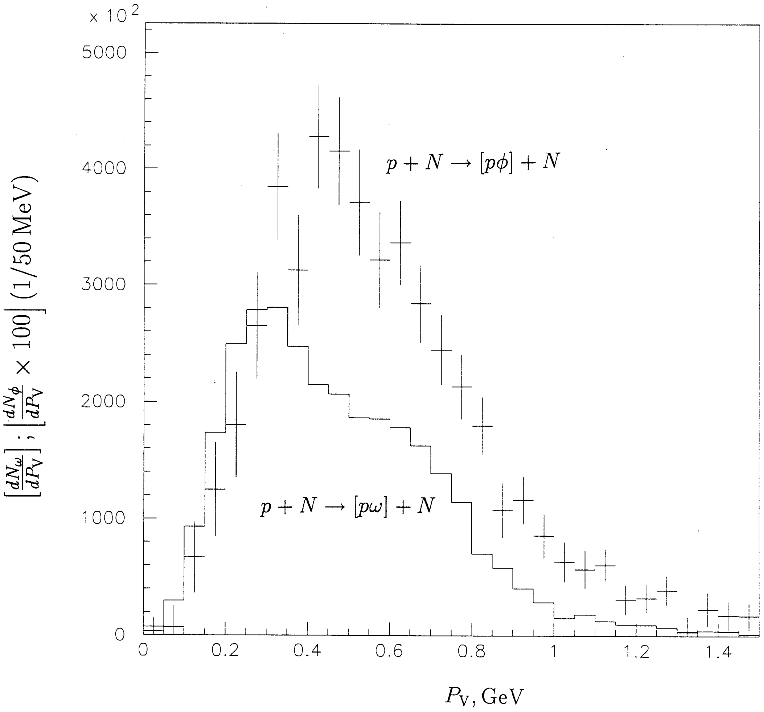

Fig. 28. The weigted distributions dN/dP_v for reactions (6) and (12) as functions of momentum P_v in the rest frame of pV system. The distribution for $p\phi$ is scale by a factor of 100.

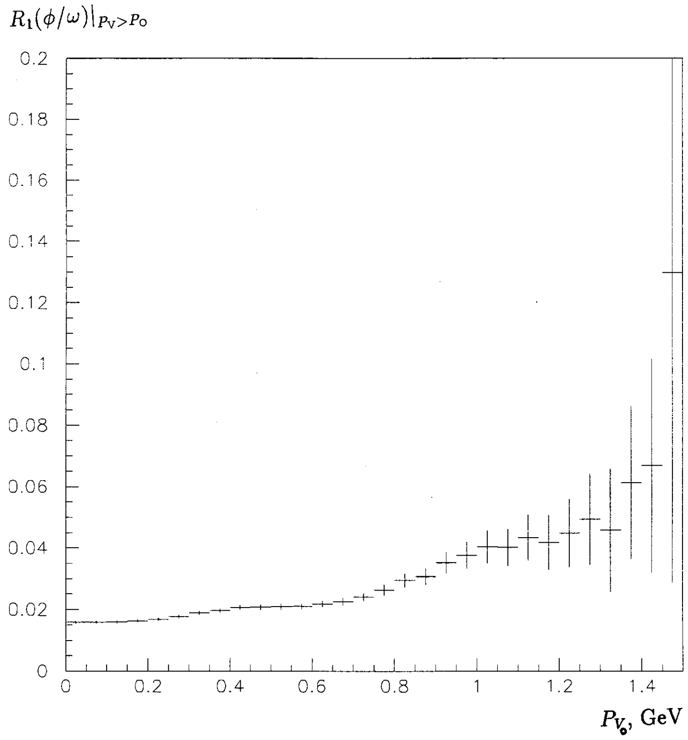

Fig. 29. Integrated ratio $R_1(\phi/\omega)$ (see(54)) as a function of minimal momentum $P_{\text{vmin}} = P_0$.

B. Another approach can be used if these cross sections are functions of invariant mass $M(pV)$ and phase space. For this case we can obtain the values of $\rho_2(\phi/\omega)$ as a function of mass $M(pV)$ at $M > M_p + M_\phi$ with correction for phase space [2]

$$\rho_2(\phi/\omega) \quad = \quad \frac{(d\sigma/dM)_\phi}{(d\sigma/dM)_\omega} \cdot \frac{P_\omega}{P_\phi} = \rho_2(\phi/\omega; M). \tag{56}$$

The data on $\rho_2(\phi/\omega)$ are presented on Fig.30.

For a more precise testing of the OZI rule in proton reactions (6) and (12) in this approach we use weighted average values of the ratio $\rho_2(\phi/\omega)$ in different regions of masses $M(pV) > M_0$. The mass threshold M_0 is introduced to avoid the influence of some nearthreshold peculiarities or resonance effects in the invariant mass spectra $M(p\phi)$ and $M(p\omega)$ (see Fig.27). Thus we define

$$< \rho_2(\phi/\omega) > |_{M(pV)>M_0} \quad = \quad \frac{1}{\xi} \sum_{M_i > M_o}^{M_{max}} \rho_2(\phi/\omega; M_i)\xi_i \tag{57}$$

Here $\xi_i = 1/\sigma_i^2$ are statistical weights; σ_i^2 - variances of $\rho_2(\phi/\omega; M_i)$; $\xi = \sum \xi_i$. Variance of $< \rho_2(\phi/\omega) >$ is $1/\xi$. Weighted average values $< \rho_2(\phi/\omega) > |_{M(pV)>M_0}$ where obtained from the data of Fig.30 for different values of M_0. We give here several numbers for this ratio:

$$< \rho_2(\phi/\omega) > |_{M(pV)>M_o} = \begin{cases} (7.3 \pm 0.5 \pm 1.5) \cdot 10^{-2} & (M_o = 2.5\text{GeV}); \\ (6.5 \pm 0.3 \pm 1.3) \cdot 10^{-2} & (M_0 = 2.3\text{GeV}); \\ (5.8 \pm 0.2 \pm 1.2) \cdot 10^{-2} & (M_0 = M_p + M_\phi = 1.96\text{GeV}). \end{cases} \tag{58}$$

We see that $< \rho_2(\phi/\omega) > |_{M>M_0}$ is not critically dependent on the value of minimal mass M_0.

The values of $R_1(\phi/\omega)$ (55) and $< \rho_2(\phi/\omega) >$ (58) must be compared with the OZI rule prediction $R_{OZI} = 0.4 \cdot 10^{-2}$ (52). Thus, we see that in proton-nucleon reactions the OZI rule is significantly violated – by more than an order of magnitude for $< \rho_2(\phi/\omega) >$, in strong contradiction with data on pion reactions. This violation is practically independent of transverse momenta, as is demonstrated for $< \rho_2(\phi/\omega) > |_{M>m_p+m_\phi}$ on Fig.31.

The ϕ/ω ratio had also been measured in pp collisions at low energies of 10 and 11.75 GeV. The reported values exceed the OZI prediction by a factor varying between 2 and 5 [64,65].

Thus, intriguing violations of the OZI rule in proton-induced reactions and, in particular, in high energy diffractive processes, have been revealed. These may suggest an enhanced component with hidden strangeness in the proton quark structure [49,50].

Very large violations of the OZI rule have also been observed in some antiproton-induced reactions (see [50,51] for details).

[2]We use designation $\rho(\phi/\omega)$ for the ratio of differential cross sections and $R(\phi/\omega)$ - for the ratio of integrated cross sections.

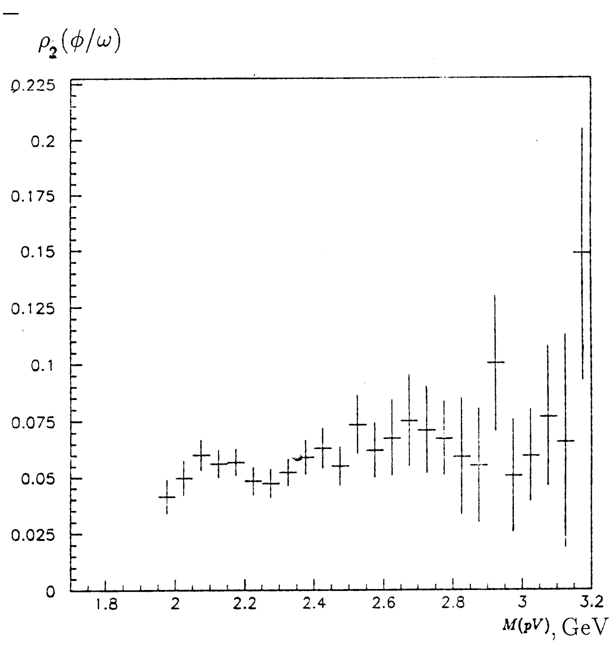

Fig. 30. Differential ratio $\rho_2(\phi/\omega; M)$ (see (56)) as a function of effective mass $M(pV)$.

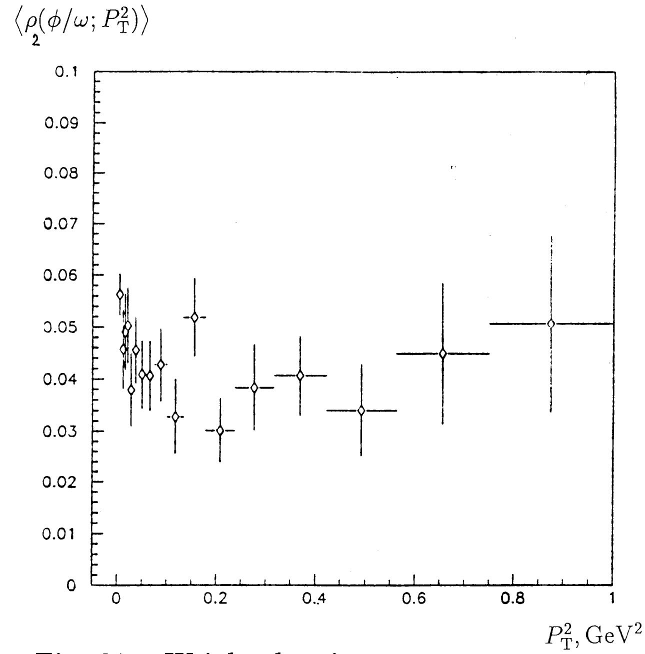

Fig. 31. Weighted ratio $< \rho_2(\phi/\omega) > |_{M>M_p+M_\phi}$ as a function of squared transverse momentum P_T^2 of the pV system.

11. Search for heavy narrow baryons in proton-induced diffractive-like reactions [12,25]

Some curious indications on possible existence of heavy narrow meson and baryon states with anomalous properties in the mass region of $M \geq 3$ GeV were obtained previously in the works of several groups [9,11,66,67]. The search for anomalously narrow heavy hadrons in the decay channels with strange particles or with $p\bar{p}$ pairs seems to be a promising way in search for cryptoexotic hadrons with hidden strangeness or with strong coupling with baryon-antibaryon fields (see, for example, reviews [2]). Owing to a substantial acceptance of the SPHINX detector in the high mass area the search for such heavy baryons was performed in the experiments of this Collaboration in the studying of reactions $p + N \to [pK^+K^-] + N$ (5), $p + N \to [p\phi] + N$ (6), $p + N \to [\Lambda(1520)K^+] + N$ (7), $p + N \to [\Sigma^*(1385)^0 K^+] + N$ (8), $p + N \to [pp\bar{p}] + N$ (11) (see [12,16,25]).

For example, Fig.32 shows the results of searches in the $M > 2.75$ GeV region involving the pK^+K^-, $p\phi$, and $\Lambda(1520)K^+$ systems produced in reactions (5)-(7), respectively. No statistically significant resonance structures are observed in the mass spectra investigated. Very sensitive upper limits on the cross sections for the production of narrow heavy baryons were obtained in these and other SPHINX measurements and are shown in Fig.33. It follows from this figure that the SPHINX analysis does not confirm the earlier observation of the narrow $R(3520)$ resonance (with $M = 3520 \pm 3$ MeV and $\Gamma = 7^{+2}_{-7}$ MeV) in the reaction

$$\pi^- + p \;\to\; [pN^+K^*(892)^-\pi^-] + X^0 \qquad (59)$$

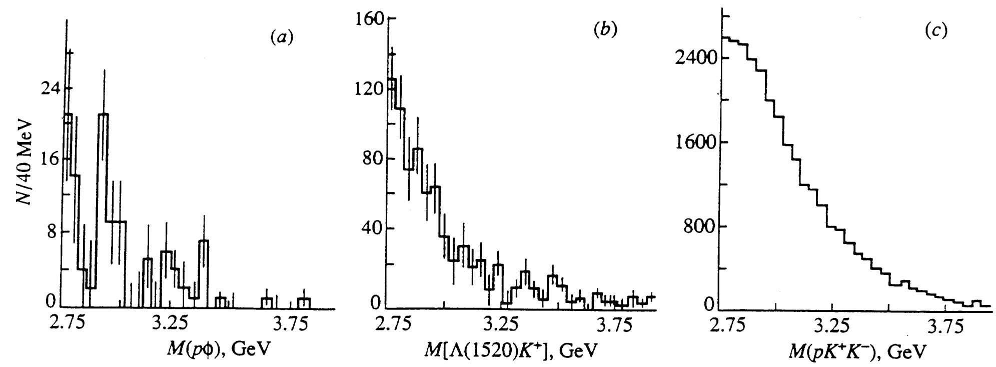

Fig. 32. Results of the search for narrow heavy exotic baryon resonances $B_\phi = |qqqs\bar{s}>$ (with $M >$ 2.75 CeV) with hidden strangeness that can be produced in the diffractive process $p + N \to B_\phi + N$ and can decay through the following channels: (a) $B_\phi \to p\phi$; (b) $B_\phi \to \Lambda(1520)K^+$; and (c) $B_\phi \to pK^+K^-$ (for all P_T^2 values).

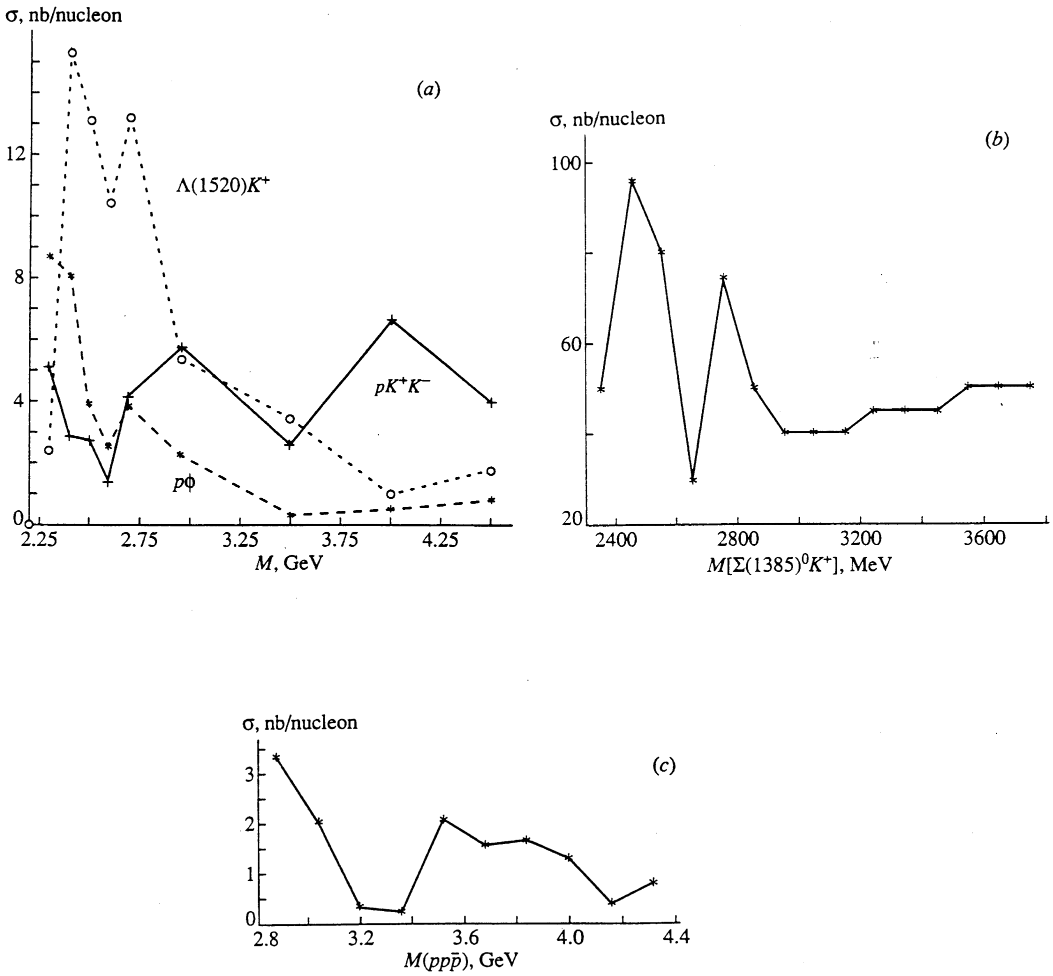

Fig. 33. Upper limits (at the 95% confidence level) on the cross sections for the diffractive production of heavy baryon resonances with $\Gamma \leq 50$ MeV that decay through the channels: a) $B_\phi \to p\phi$, $B_\phi \to \Lambda(1520)K^+$, and $B_\phi \to pK^+K^-$; b) $B_\phi \to \Sigma(1385)^0K^+$; c) $B \to pp\bar{p}$. All these data are for reactions $p + N \to B_\phi(\text{or } B) + N$.

with the production cross section $\sigma \cdot \mathrm{BR} = 14\mu\mathrm{b}$ [11]. The following upper limits on $R(3520)$ production cross sections were obtained in the SPHINX experiment in the study of reactions (5)-(8):

$$\begin{aligned}
\sigma[R(3520)^+] &\cdot BR[R^+ \to p\phi] < 0.27\text{nb/nucleon}, & (60)\\
\sigma[R(3520)^+] &\cdot BR[R^+ \to \Lambda(1520)K^+] < 3.4\text{nb/nucleon}, & (61)\\
\sigma[R(3520)^+] &\cdot BR[R^+ \to pK^+K^-] < 2.6\text{nb/nucleon}, & (62)\\
\sigma[R(3520)^+] &\cdot BR[\Sigma^*(1385^0 K^+] < 16\text{nb/nucleon} & (63)
\end{aligned}$$

(95% C.L.) These values are by 3-5 orders of magnitude lower than the cross section of $R(3520)$ production in reaction (59) claimed in [11].

In the currently available data there is no statistically significant evidence for possible existence of nonstrange analog of $\Sigma(3170)$ baryon [9] with the mass around 3 GeV. However, it is clear from the data on Fig.32a, that these searches must be continued with new statistics.

12. Investigation of quasiexclusive neutral-meson production in pN collisions at $E_p = 70$ GeV in the deep-fragmentation region [26-28]

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. [9,68-72] and reviews [1,2,33]).

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. 34a).

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, 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 [72]:

$$\begin{aligned}
p + N &\to M^{++} + [N\pi^- n](\Delta^- \text{ exchange}), & (64)\\
p + N &\to M^{+} + [N\pi^- p](\Delta^0 \text{ exchange}), & (65)\\
p + N &\to M^{0} + [N\pi^+ n](\Delta^+ \text{ exchange}), & (66)
\end{aligned}$$

$$p + N \rightarrow M^- + [N\pi^+ p](\Delta^{++} \text{ exchange}), \quad (67)$$
$$p + N \rightarrow M^+ + [Nn](n \text{ exchange}), \quad (68)$$
$$p + N \rightarrow M^0 + [Np](p \text{ exchange}) \quad (69)$$

(see Figs.34 b,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 charge particles can be identified with Cherenkov detectors. In studying reactions (64)-(69), 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).

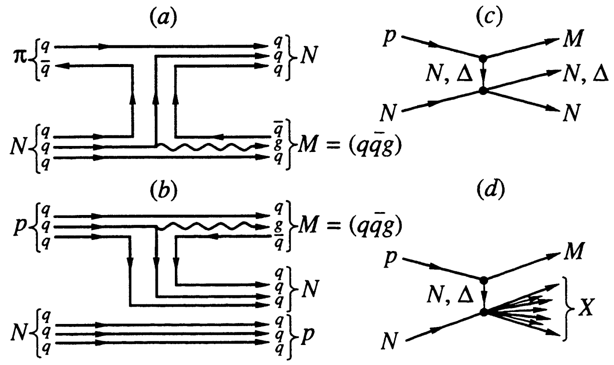

Fig. 34. Diagrams describing exotic-meson production in baryon exchange processes: (a) production of a hybrid meson in πN interactions; (b) production of a hybrid meson in pN interactions; (c) production of exotic mesons in reactions (64)-(69), and (d) production of exotic mesons in reaction (70) in 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 capture 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. 34 b).

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 (64)-(69) 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. 34 d and can be specified as

$$p + N \rightarrow M_f + X_{b.v.} \quad (70)$$

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 (70) are much larger than those for reactions (64)-(69) and are dependent on the primary energy E_p only slightly (in the energy 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-exchange processes looks rather promising.

In studying mesonic resonances M_f produced in the top vertex of the diagram in Fig.34 d, experimental conditions for the corresponding deep fragmentation inclusive reactions of type (70) must be implemented in such a way that a combinatorial background due to inclusive particle 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 vertices 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 (70), 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

$$p + N \quad \rightarrow \quad M_f + \widetilde{X}_{b.v.} \tag{71}$$

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 favorable conditions for the investigation of quasiexlusive processes (71) in the deep fragmentation region and for searches of exotic mesons produced in (71). As the first stage aimed at testing the conjecture that the cross sections for reactions of type (71) 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

$$\begin{aligned} p + N \quad &\rightarrow \quad \pi^0_f + (\widetilde{X})_{b.v.}, && (72)\\ &\qquad \hookrightarrow 2\gamma \\ &\rightarrow \quad \eta_f + (\widetilde{X})_{b.v.}, && (73)\\ &\qquad \hookrightarrow 2\gamma; 3\pi^0 \\ &\rightarrow \quad \omega_f + (\widetilde{X})_{b.v.} && (74)\\ &\qquad \hookrightarrow \pi^0\gamma \rightarrow 3\gamma \end{aligned}$$

In general, the production of fast π^0, 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 [38] have energies that do not reach the deep fragmentation region. For this reason, we do not consider this isobar mechanism below.

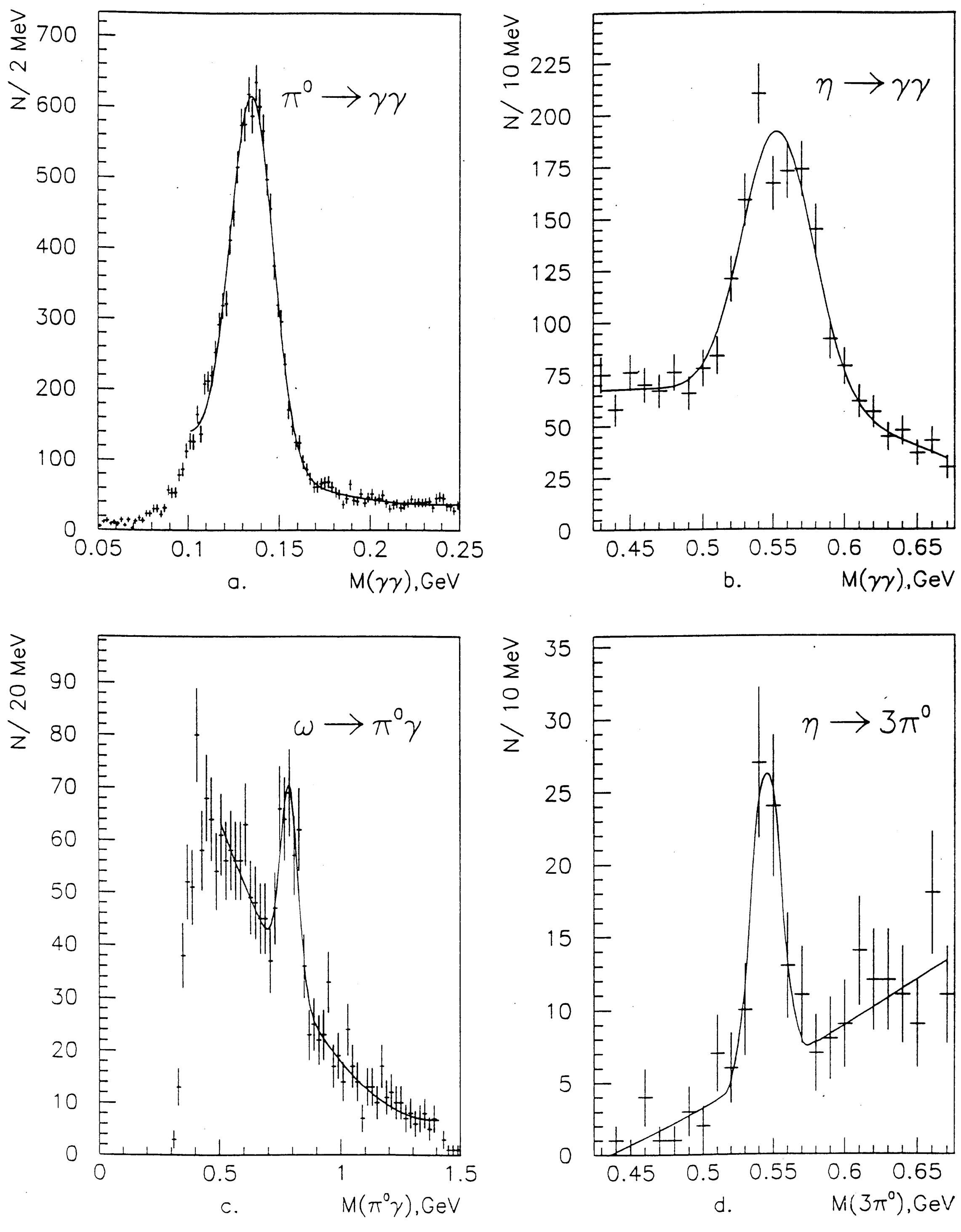

Fig. 35. Invariant mass spectra for $\gamma\gamma, \pi^0\gamma$- and three π^0-systems in the reactions $p + N \rightarrow (n\gamma)_f + \widetilde{X}_{b.v.}$ with $x_F > 0.86$. Signals from $\pi^0 \rightarrow \gamma\gamma$ (a), $\eta \rightarrow \gamma\gamma$ (b), $\omega \rightarrow \pi^0\gamma$ (c), $\eta \rightarrow 3\pi^0$ (d) in reactions (72)-(74) are clearly seen.

Reactions (72)-(74) were investigated in special measurements simultaneously with the main directions of the experimental studies – reactions (5)-(14), described above. Events satisfying the following criteria were selected at the trigger level:

a) absence of fast charge secondaries, i.e. charged particles with momenta $P > 1.5 - 2$ GeV that can traverse the magnetic spectrometer of the setup;
в) the large net energy of neutral particles, as measured in the γ-spectrometer in the downstream part of the detector (Fig.3), satisfying the condition $\sum E_i > 45$ GeV.

In analysis of these trigger events additional selection criteria were used. They are as follows:

c) in the 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 clusters was required to satisfy the criterion of π^0 identification ($0.11 < M(\gamma_i\gamma_j) < 0.16$ GeV);
d) the events with 4γ and 6γ-clusters with energies over 1 GeV which satisfy $2\pi^0$ and $3\pi^0$ conditions were also selected in data analysis;
e) the total energy in γ-spectrometer $\sum E_{\gamma i} > 55$ or 60 GeV.

On Fig.35 the invariant mass spectra for $\gamma\gamma$, $\pi^0\gamma$ and $3\pi^0$ events are presented (for $\sum E_{i\gamma} > 60$ GeV). In these spectra clear peaks of π^0, η and ω mesons produced in reactions (72)-(74) in the deep fragmentation region ($x_F > 0.86$) are observed. The same data are also obtained for $\sum E_{\gamma i} > 55$ GeV ($x_F > 0.79$). The corresponding cross sections for quasiexclusive meson production processes in pN interactions at $E_p = 70$ GeV in a deep fragmentation region (baryon exchange mechanism) are presented in Tables 2 and 3. The data on dN/dP_T^2 and dN/dx_F distributions were also obtained in these measurements (see Ref.[27]). It is seen from Table 2 that cross sections of the quasiexclusive reactions (72)-(74) are large enough. Thus, the results of this experiment show that the quasiexlusive meson production processes with baryon exchange may be a useful tool in searching for new exotic mesons.

Table 2. Total cross sections for the reactions (72)-(74).

Reaction	Decay mode	$x_{F\min}$	N events	$\sigma_{\text{total}}(x_F > x_{F\min})$ α=174 ev/nb *)
$p + N \to \pi^0_{\text{forward}} + \tilde{X}_{b.v.}$	$\pi^0 \to \gamma\gamma$	0.79	39904	(637 ± 13) nb
		0.86	9777	(143 ± 5) nb
$p + N \to \eta^0_{\text{forward}} + \tilde{X}_{b.v.}$	$\eta^0 \to \gamma\gamma$	0.79	3416	(174 ± 5) nb
		0.86	865	(39 ± 3) nb
$p + N \to \omega^0_{\text{forward}} + \tilde{X}_{b.v.}$	$\omega^0 \to \pi^0\gamma$	0.79	559	(584 ± 40) nb
		0.86	200	(164 ± 20) nb

Note: The luminosity of the experiment is α=174 events/nb. The errors are statistical only. The systematic uncertainties are about 15%.

Table 3. The ratio for the total cross sections of the reactions (72)-(74).

Ratio	$x_F > x_{F\min}$=0.79	$x_F > x_{F\min}$=0.86
$\frac{\sigma(p+N\to\eta^0_{\rm forward}+\widetilde{X_{b.v.}})}{\sigma(p+N\to\pi^0_{\rm forward}+\widetilde{X_{b.v.}})}$	0.198 ± 0.005	0.273 ± 0.023
$\frac{\sigma(p+N\to\omega^0_{\rm forward}+\widetilde{X_{b.v.}})}{\sigma(p+N\to\pi^0_{\rm forward}+\widetilde{X_{b.v.}})}$	0.71 ± 0.06	1.15 ± 0.15

On Fig. 36 in the invariant mass spectra $M(\pi^0\pi^0)$ a clear signal of $K^0_s \to \pi^0\pi^0$ is seen, which corresponds to quasi-exclusive K^0 production

$$p + N \to K^0 + \widetilde{X}_{b.v.} \tag{75}$$

in the reaction with hyperon exchange [28]. The cross sections (75) for $x_F > 0.79$ and $x_F > 0.86$ are, respectively, 121 ± 13 nb and 30 ± 4 nb. The comparison of the data for π^0 and K^0 production in the same kinematical conditions in the deep fragmentation region shows that the processes by the strange quarks are suppressed by the factor $\lambda \sim 5$.

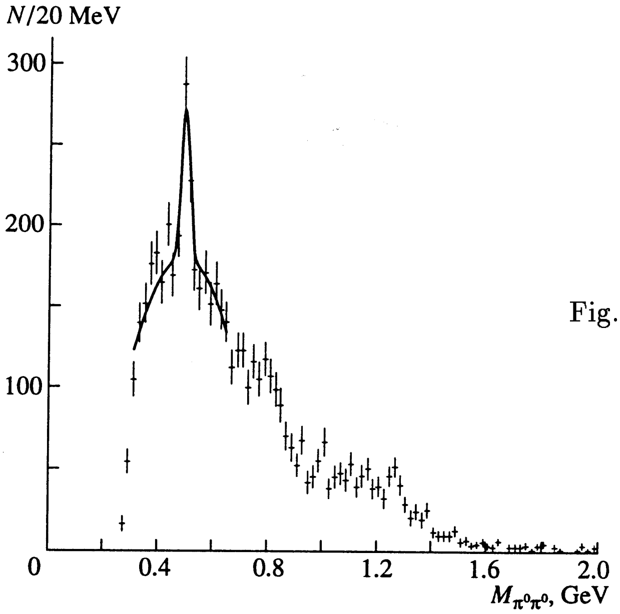

Fig. 36. Invariant mass spectra for $\pi^0\pi^0$ system in the reaction $p + N \to (2\pi^0)_f + \widetilde{X}_{b.v.}$ ($x_F > 0.86$). In this spectrum signals for $K^0_s \to \pi^0\pi^0$ production in reaction (75) are clearly seen.

13. Conclusion

Let us summarize the main results of the SPHINX Collaboration presented above.

1. The extensive research program of studying the diffractive production reactions on the proton beam with $E_p = 70$ GeV is carried out in the experiments at the SPHINX setup [2, 12-26]. The main aims of this program are the searches for cryptoexotic baryons with hidden strangeness $B_\phi = |uuds\bar{s}>$. Only part of these experiments is discussed here.

2. In our earlier measurements [18-20] the coherent diffractive production reactions $p + C \to [\Sigma(1385)^0 K^+] + C$ and $p + C \to [\Sigma^0 K^+] + C$ were investigated. The evidences for new baryon states were obtained in the study of hyperon-kaon effective mass spectra in these two reactions: $X(2050) \to \Sigma(1385)^0 K^+$ with mass $M = (2052 \pm 6)$ MeV and width $\Gamma = (35^{+22}_{-35})$ MeV and $X(2000) \to \Sigma^0 K^+$ with $M = (1997 \pm 6)$ MeV and $\Gamma = (91 \pm 17)$ MeV. The unusual dynamical feature of these massive states (relatively narrow decay widths, anomalously large branching ratios for decays with strange particles emission) make them serious candidates for cryptoexotic pentaquark baryons with hidden strangeness. In spite of significant statistical confidence of the observation of new states we considered these results as preliminary, which must be confirmed in further measurements with increased statistics.
3. The first results for the coherent reaction $p + C \to [\Sigma^0 K^+] + C$ in a new test run with partly modified SPHINX setup (with a new γ-spectrometer and under better conditions for $\Lambda \to p\pi^-$ identification) were presented recently in [21]. These results are in a very good agreement with our previous data for this reaction. In the combined effective mass spectrum $M(\Sigma^0 K^+)$, besides some threshold structure with $M \sim 1800$ MeV, a strong peak $X(2000) \to \Sigma^0 K^+$ is dominated. The average mass and width of this peak are $M = 1996 \pm 7$ MeV and $\Gamma = 99 \pm 21$ MeV. Because of the significant modification of the equipment, the good agreement between previous and new data gives us an additional confidence in the real existence of $X(2000)$ anomalous baryon state – the candidate for the baryon exotics with hidden strangeness $|uuds\bar{s}>$.
4. A narrow threshold structure with $M \sim 1810$ MeV and $\Gamma \sim 60$ MeV was observed in the $M(\Sigma^0 K^+)$ mass spectrum, as it was stated before. It was found that this structure is produced practically only in the region of very small $P_T^2 (\leq 0.01 \div 0.02 \text{ GeV}^2)$, where it is seen quite clearly.
5. The first data in nonperipheral domain (at $P_T^2 > 0.3$ GeV^2) were obtained in the reactions $p + N \to [\Sigma^0 K^+] + N$ and $p + N \to [p\eta] + N$. In both reactions there is evidence for a narrow enhancement with $M \sim 2350$ MeV and $\Gamma \leq 60$ MeV [20,21].
6. A further study of Λ^* hyperon isoscalar resonances might be performed in the $[\Sigma^0\pi^0]$ system (to be produced in the diffractive reaction $p + N \to [\Sigma^0\pi^0]K^+ + N$).
7. A very sensitive search for narrow heavy baryons in the study of invariant mass spectra $M[pK^+K^-]$, $M[p\phi]$, $M[\Lambda(1520)K^+]$, $M[\Sigma^*(1385)^0 K^+]$ and $M(pp\bar{p})$ in diffractive-like proton-induced reactions was performed for the mass range $2.7 < M < 4.5$ GeV. No statistically significant structures in this mass region were seen up to now. Corresponding upper limits for cross sections of their production processes have been obtained and are presented here.
8. The results of the SPHINX experiments failed to confirm the existence of either the narrow baryon states $N_\phi(1960)$ and $R(3520)$ or of the nonstrange analog of $\Sigma(3170)$, all of which are candidates for exotic baryons with hidden strangeness. Some evidences for possible observation of these states were obtained earlier in the experiments of other groups [9-11]. Strictly speaking, there is no direct contradiction

between the SPHINX data and the results obtained by other experimental groups because different processes were investigated. However, we must emphasize that the sensitivity was higher and the background conditions were better in the SPHINX experiment than in previous studies. Thus, in the case of the $R(3520)$ baryon, our upper limits for various decay channels are 3-5 orders of magnitude lower than those obtained in experiments reported in [11]. At the same time, the background conditions for the search for the $N_\phi(1960)$ baryon in the "elastic" diffractive reaction (8) and in partially inclusive reaction (9) are much better in the SPHINX experiment, than in the BIS measurements [10]. All this casts some doubt on the existence of the $R(3520)$ and $N_\phi(1920)$ baryons.

9. Study of the OZI selection rule was performed by comparison of the cross sections for pion-induced charge exchanged reactions $\pi^- + p \to \phi + n$ and $\pi^- + p \to \omega + n$ at $P_{\pi^-} = 32.5$ GeV, as well as for proton-induced diffractive reactions $p + N \to [p\phi] + N$ and $p + N \to [p\omega] + N$ at $E_p = 70$ GeV in the experiments with LEPTON-F and SPHINX spectrometers. It has been demonstrated that in pion reactions the ratio $R(\phi/\omega) \simeq (3 \pm 1) \cdot 10^{-3}$ is in a good agreement with naive quark model and the OZI rule predictions ($R(\phi/\omega)_{\rm OZI} = {\rm tg}^2\Delta\theta_V \simeq 4 \cdot 10^{-3}$). At the same time in proton reactions $R(\phi/\omega) \sim (4 \div 7) \cdot 10^{-2}$, i.e. a strong violation of the OZI rule is observed for proton-nucleon interactions.
10. The quasiexclusive production of neutral mesons $M^0 = \pi^0;\ \eta;\ \omega$ in pN collisions was studied in the deep fragmentation region ($x_F > 0.8$). Owing to the appreciable values of the cross sections for reactions $p + N \to M^0_{\rm forward} + \widetilde{X}_{\rm bottom\ vertex}$ these quasiexclusive processes with baryon exchange can be very usefule in searches for exotic mesons.

In this review the data of the first stage of the experiments with the SPHINX facility are summarized. Further development of experimental program of the search for exotic baryons is expected in future measurements of the SPHINX Collaboration. We hope to obtain a significantly larger statistics for the processes discussed above and for other proton reactions in the next runs with a totally upgraded SPHINX detector. This upgrade has been successfully completed now and new measurements on the beam are underway.

Acknowledgements. It is a pleasure for me to express my deep gratitude to my colleagues from the SPHINX Collaboration and especially to V.P. Kubarovsky, V.F. Kurshetsov and V.V. Molchanov for tight cooperation in obtaining the main results presented in this review. I am very grateful to N. Isgur, A.B. Kaidalov, L. Montanet, L.B. Okun and Yu.D. Prokoshkin for many illuminating discussions. I am very obliged to the Organizing Committee of XIX Workshop on High Energy Physics and the Field Theory (A.A. Logunov, V.A. Petrov) for their kind invitation to present my review talk at the Workshop. This work was partly supported by INS (grant JA 2100) and by RFBR (grant 96-02-16759a).

References

[1] Landsberg L.G. // Surveys in High Energy Phys., 1992, v.6, p.257;

[2] Landsberg L.G. // Yad Fiz., 1994, v.57, p.47; Landsberg L.G. // UFN, 1994, v.164, p.1129.

[3] Peters K. // Proc. of the Second Biennial Conf. on Low Energy Antiproton Phys. (LEAP-92), Courmayeur, Aosta Valley, Italy, September 14-19, 1992 (Ed C.Guaraldo et al.), Nucl. Phys., 1993, v.A558, p.92.

[4] Dover C.B. // LEAP-92 Summary talk, Ibid. Nucl. Phys., 1993, v. A558, p.721.

[5] Amsler C. // Rapporter talk, Proc. of 27 Intern. Confer. on High Ehergy Phys. (ICHER), Glasgow, Scotland, July 1994.

[6] Close F.E. // Preprint RAL-87-072, Chilton, 1987.

[7] Blum P. // Int. Journ. of Mod. Phys., 1996, v. 11A, p. 3003.

[8] Hirose T. et al. // Nuov. Cim., 1979, v.50A, p.120; Fucunage C. at al. Nuov. Cim., 1980, v.58, p.199.

[9] Amirzadeh J. et al. // Phys. Lett., 1979, v. 89B, p.125.

[10] Aleev A.N. et al. // Z.Phys., 1984, v. 25C, p.205.

[11] Karnakov V.M. et al. // Phys. Lett., 1991, v. 281B, p. 148.

[12] Vavilov D.V. et al. // Yad. Fiz., 1994, v.57, p.241; Balatz M.Ya. et al. // Z.Phys., 1994, v. 61C, p.220.

[13] Balatz M.Ya et al. // Z.Phys., 1994, v. 61C, p.399.

[14] Vavilov D.V. et al. // Yad. Fiz., 1994, v.57, p.253.

[15] Landsberg L.G. et al. // Proc. of "Hadron-93", Villa Olmo, Como, June 21-25, 1993 (ed. Bressani T. et al.), Nuov. Cim., 1994, v. 107A, p. 2441.

[16] Kurshetsov V.F., Landsberg L.G. // Yad. Fiz., 1994, v. 57, p. 2030.

[17] Vavilov D.V. et al. // Yad. Fiz., 1994, v. 57, p. 1449.

[18] Vavilov D.V. et al. // Yad. Fiz., 1995, v. 58, p. 1426.

[19] Golovkin S.V. et al. // Z. Phys., 1995, v. 68C, p. 585.

[20] Golovkin S.V. et al. // Yad.Fiz., 1996, v. 59, p. 1395.

[21] Bezzubov V.A. et al. // Yad. Fiz., 1996, v. 59, p. 2199.

[22] Victorov V.A. et al. // Yad. Fiz., 1996, v. 59, p. 1229.

[23] Victorov V.A. et al. // Yad. Fiz., 1996, v. 59, p. 1239.

[24] Balatz M.Ya. et al. // Yad. Fiz., 1996, v. 59, p. 1242.

[25] Vavilov D.V. et al. // Yad. Fiz., 1994, v. 57, p.2046.

[26] Balatz M. Ya. et al. // Yad. Fiz., 1996, v. 59, p.1247.

[27] Balatz M. Ya. et al. // Yad. Fiz., 1996, v. 59, p.1770.

[28] Vavilov D.V. et al. // Yad. Fiz., 1996, v. 59, p.1994.

[29] Chan Hong-Mo, Hogaasen H. // Phys. Lett., 1977, v. 72B, p. 121; Chan Hong-Mo, et al., // Phys. Lett., 1978, v. 76B, p. 634.

[30] Hogaasen H., Sorba P. // Nucl. Phys., 1978, v. 145B, p. 119; Hogaasen H., Sorba P. Invited Talk at Conf. on Hadron Interastions at High Energy, Marseiler, June, 1978.

[31] De Crombrugghe M. et al. // Nucl. Phys., 1979, v. 156B, p.347.

[32] Chan Hong-Mo, Tsou. S.T. // Nucl. Phys., 1977, v. 118B, p. 413.

[33] Landsberg L.G. // UFN, 1990, v. 160, p. 1.

[34] Bellini G. et al. // Nuov. Cim., 1984, v.79A, p. 282.

[35] Alde D. et al. // Phys. Lett., 1986, v. 182B, p.105; Alde D. et al. // Yad. Fiz., 1991, v. 54, p. 745; Phys. Lett., 1992, v. 276B, p. 457.

[36] Alde D. et al. // Phys. Lett., 1989, v. 216B, p.447; Alde D. et al. // Yad. Fiz., 1991, v. 54, p. 751; Phys. Lett., 1992, v. 276B, p. 375.

[37] Gershtein S.S. // Proc. of the Third Intern. Conf. on Hadron Spectroscopy ("Hadron-89"), Ajaccio, Corsica, September 23-27, 1989 (ed. F.Binon et al.), Paris, 1989, p.175.

[38] Barnett R.M. et al. // (PDG), Phys. Rev., 1996, v. 54D, p. 1; Montanet L. et al. // (PDG) Phys. Rev., 1994, v. 80D, p.1173; Betsch G.I. et al. // (PDG) Phys. Lett., 1990, v. 239B, p.1.

[39] Hemingway R.J. // Nucl. Phys., 1985, v. 253B, p. 742.

[40] Barrett R.C. // Nuov. Cim., 1989, v. 102A, p. 179.

[41] Okubo S. // Phys. Lett., 1963, v. 5, p. 165.

[42] Zweig G. // CERN report TH-401, TH-402, Geneva, 1964.

[43] Iizuka J. // Progr. Theor. Phys. Suppl., 1966, v. 37-38, p.21; Iizuka J. et al. // Progr., Theor. Phys., 1966, v. 35, p. 1061.

[44] Close F.E., Lipkin H.J. // Phys. Lett., 1987, v. 196B, p. 245; Phys. Rev. Lett., 1978, v.41, p.1263.

[45] Bityukov S.I. at al. // Phys. Lett., 1987, v. 188B, p. 383.

[46] Etkin A. et al. // Phys. Lett., 1985, v. 165B, p. 217, 1988, v. 201B, p. 568.

[47] Ashman J. et al. // Phys. Lett., 1988, v. 206B, p. 364; Nucl. Phys., 1989, v. 328B, p.1.

[48] Ratcliffe P.G. // "Hadron-93", Como. June 21-25, 1993; Nuovo Cim., 1994, v. 107A, p. 2211.

[49] Ellis J. et al. // Phys. Lett., 1989, v. 217B, p. 173; Karliner M. In: Proc. LEAP-90, Stockholm, July 2-6, 1980, p. 331; Ellis E., Karliner M. // Phys. Lett., 1993, v. 313B, p.407.

[50] Faessler M.A. //"NAN-93", ITEP, Moscow, September 13-18, 1993; Yad.Fiz., 1994, v. 57, p. 1764; "Hadron-93", Como, June 21-25, 1993; Nuovo Cim., 1994, v. 107A, p. 2237.

[51] Abelev V.G. // "NAN-93", ITEP, Moscow, September 13-18, 1993; Yad.Fiz., 1994, v. 57, p. 1787;
Sapoznikov M.G. // "Hadron-93", Como, June 21-25, 1993; Nuovo Cim., 1994, v. 107A, p. 2315.

[52] Landsberg L.G. // Talk at the Workshop on Glueballs, Hybrids, and Exotic States, BNL, August 1988; Preprint IHEP 88-143, Serpukhov, 1988;
Kurshetsov V.F. // Talk at the Session of Nuclear Physics Division, USSR Academy of Sciences, ITEP, November 1988;
Landsberg L.G. // Fiz. Elem. Chastits At. Yadra, 1990, v. 21, p. 1054.

[53] Bityukov S.I. et al. // Yad. Fiz., 1987, v. 46, p. 506.

[54] Bityukov S.I. et al. // Phys. Lett., 1988, v. 203B, p. 327.

[55] Bityukov S.I. et al. // Yad. Fiz., 1988, v. 47, p. 1285.

[56] Bityukov S.I. et al. // Yad. Fiz., 1991, v.54, p. 529. Bityukov S.I. et al. // Z.Phys., 1991, v. 50C, p. 451.

[57] Bityukov S.I. et al. // Preprint IHEP 84-216, Serpukhov, 1984.

[58] Apel W.D. et al. // Lett. at Nuovo Cim., 1979, v. 25, p. 493.

[59] Dahl O.I. et al. // Phys. Rev. Lett., 1977, v. 38, p. 54.

[60] Flaminio et al. // CERN-HERA 83-01, Geneva, 1983.

[61] Anisovich V.V., Shekhter V.M. // Yad. Fiz., 1973, v. 18, p. 701; Lipkin H. // Phys. Lett., 1976, v. 60B, p. 371.

[62] Druzhinin V.P. et al. // Phys. Lett. 1984, v. 144B, p. 131.

[63] Alde D. et al. // Z. Phys. C: Part. Fields, 1992, v. 54, p. 553;
Landsberg G.L. // Proc. 4th Int. Conf. on Hadron Spectroscopy HADRON-91, p. 12 (Eds. Oneda S. and Peaslee D.C.), // New York, World Sci., 1992.

[64] Baldi R. et al., // Phys. Lett. B. 1977, vol. 68, p. 381.

[65] Arenton M.W. et al. // Phys. Rev. D: Part. Fields, 1982, v. 25, p. 2241.

[66] Bourguin M. et al. // Phys. Lett., 1986, v. 172B, p. 113.

[67] Aleev A.N. et al. // Z. Phys., 1990, v. 47C, p. 533
Tatishvili G.T. // Hadron-91, Proc. of the Fourth Intern. Conf. on Hadron Spectroscopy, College Park, August 12-16, 1991 (Ed. D. Peaslee), p. 733.

[68] Rosner J. // Phys. Rev. Lett., 1968, v. 21, p. 950.

[69] Jacob M. and Weyers J., // Nuovo Cimento B, 1970, v. 69, p. 521.

[70] Balitzky Ya. Ya. et al. // Yad. Fiz., 1982, v. 35, p. 1300.

[71] Grigoryan A. A. and Kaidaiov A.B., // Pis'ma Zh. Eksp. Teor. Fiz., 1978, v. 28, p. 318; Yad., Fiz., 1980, v. 32, p. 540.

[72] Landsberg L.G. // Yad., Fiz., 1990, v. 52, p. 192; Nucl. Phys. (Proc. Suppl.), 1991, v. 21, p. 179c.

Received December 11, 1996

Л.Г.Ландсберг
Поиски экзотических барионов в экспериментах на протонном пучке с энергией 70 ГэВ и другие измерения на установке СФИНКС.

Оригинал-макет подготовлен с помощью системы LATEX.
Редактор Е.Н.Горина. Технический редактор Н.В.Орлова.

Подписано к печати 16.12.96г. Формат $60 \times 84/8$. Офсетная печать.
Печ.л. 6. Уч.-изд.л. 4.6. Тираж 240. Заказ 957. Индекс 3649.
ЛР №020498 06.04.92.

ГНЦ РФ Институт физики высоких энергий
142284, Протвино Московской обл.

Индекс 3649

П Р Е П Р И Н Т 96-104, И Ф В Э, 1997