Hyperon-99

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Search for pentaquark baryons with hidden strangeness

Plan of my talk

1. Exotic baryons (general introduction)
2. The SPHINX setup
3. Study of diffractive production reaction $p + N \to [\Sigma^0 K^+] + N$ and observation of the state $X(2000) \to \Sigma^0 K^+$ (new data)
4. Coherent reaction $p + C \to [\Sigma^0 K^+] + C$ at $P_{\mathrm{T}}^2 < 0.01\,\mathrm{GeV}^2$ and the state $X(1810)$ (new data)
   Coulomb production ?
5. Reality of $X(2000)$
   (a) Supporting data in reaction $p + N \to [\Sigma^+ K^0] + N$ (SPHINX)
   (b) Supporting data in reaction $\Sigma^- + N \to [\Sigma^- K^+] K^- + N$ (SELEX)
6. Future plans
7. Conclusion

1 Introduction: exotic baryons and their production processes

The main aim of the experiments: the search for exotic pentaquark baryons with hidden strangeness ($B_\phi = |qqqs\bar{s}\rangle$- valence quark structure, $q = u; d$).
Three main questions:

1. How to identify these cryptoexotic baryons without open exotic properties (exotic charge and so on) and how to distinguish them from $\sim 40\,N, \Delta$ isobars ?

2. How to produce such exotic baryons in the most effective way ?

3. How to suppress background ?

To answer these questions we use only qualitative arguments (there is no good theory)

The main expected properties of $|qqqs\bar{s}\rangle$:

1. $R(B_\phi) = BR(B_\phi \to YK)/BR(B_\phi \to p\pi\pi; \Delta\pi) \gtrsim 1$
   The decays $B_\phi \to p\pi\pi, p\pi, \Delta\pi$ are OZI suppressed (Fig. 1). For ordinary isobars $R(N; \Delta) \lesssim$ several %.

2. Cryptoexotic B_ϕ baryons can posses both large masses ($M > 1.8 \div 2.0$ GeV) and narrow decay widths ($\Gamma \lesssim 50 \div 100$ MeV). This is due to a complicated internal color structure of these baryons, with significant quark rearrangement of color clusters in the decay processes, and to a limited phase space for OZI allowed decays $B_\phi \to YK$. At the same time typical decay widths for all well established N, Δ isobars with similar masses are $\Gamma_{N;\Delta} > 300$ MeV.

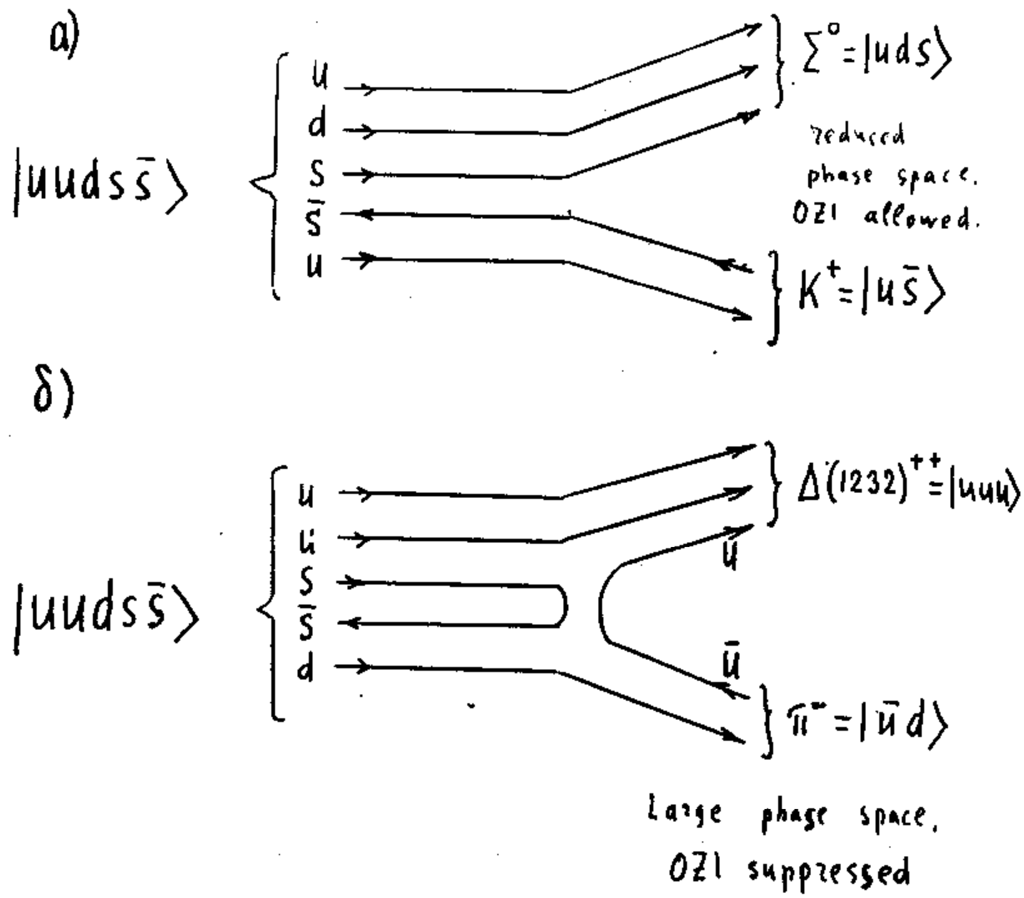


Fig. 1 OZI allowed and OZI suppressed decays of exotic baryons with hidden strangeness $|uuds\bar{s}\rangle$.

The search for exotic B_ϕ baryons on the SPHINX setup were performed in gluon-rich diffractive production processes in the proton beam of IHEP accelerator with $E_p = 70\,\mathrm{GeV}$ (Fig. 2). We use two complementary approaches.

1. Study of the coherent diffractive production on carbon nuclei:

   - $P_T^2 \leqslant 0.075 \div 0.1\,\mathrm{GeV}^2$ – soft coherent cut with $\sim 30\%$ noncoherent background;
   - $P_T^2 \leqslant 0.02\,\mathrm{GeV}^2$ stringent coherent cut with $< 10\%$ noncoherent background, but with reduced number of events.

   Owing to the difference in the absorption of a single particle and multiparticle system in nucleus, coherent processes could serve as an effective tool for separation a resonance against nonresonance multiparticle background

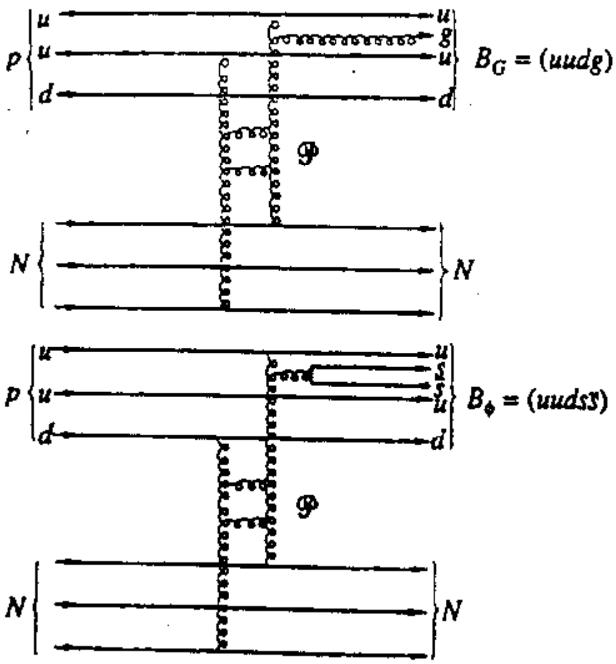
$$\left.\begin{array}{l}\text{Coherent}\\ \text{filter}\end{array}\right\} \left[\frac{\sigma_{\text{reson}}}{\sigma_{\text{nonres.backgr.}}}\right]_{\text{coherent}} > \left[\frac{\sigma_{\text{reson.}}}{\sigma_{\text{nonres.backgr.}}}\right]_{\text{noncoherent}}$$

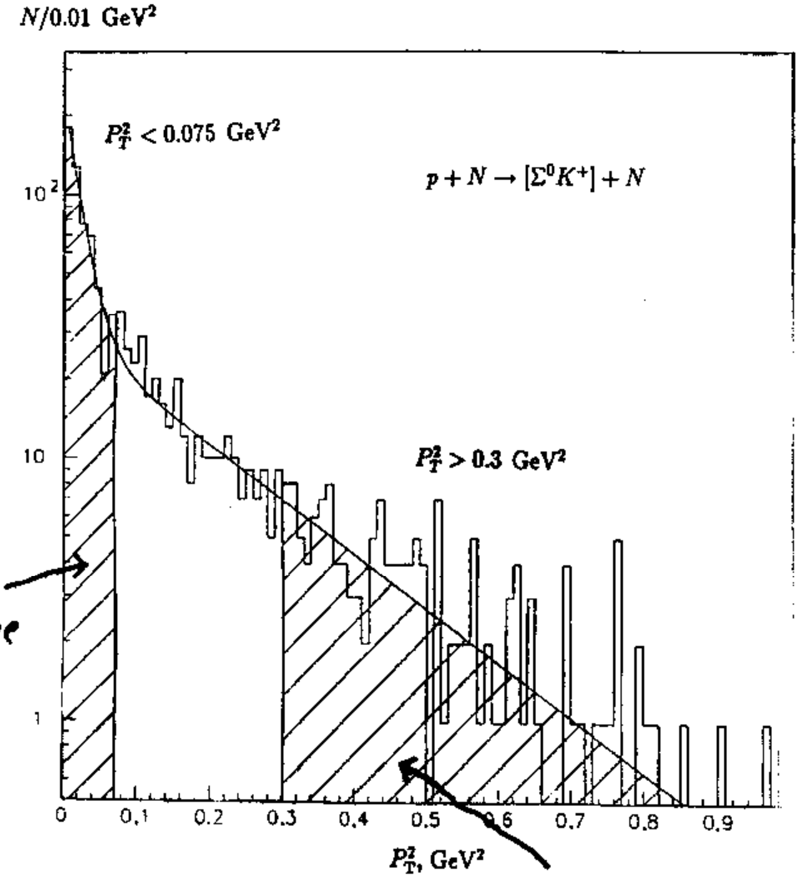
2. Study of nonperipheral production in the region $P_T^2 > 0.3 \div 0.5\,\mathrm{GeV}^2$ where peripheral background is suppressed. It is possible that diffractive-like production in this P_T^2 region is due to mechanism of multiple pomeron rescattering (gluon-rich processes).

3. Electromagnetic mechanism for production of baryons with hidden strangeness (due to the strong enough γ-ϕ coupling (VDM)

Coulomb production reactions - interesting new possibility for the beams of unstable particles (Σ^- for the search for $|qqs\bar{s}\rangle$, π^-, K^- beams for the search for exotic mesons - $|q\bar{q}s\bar{s}\rangle$, etc)

Diffractive production

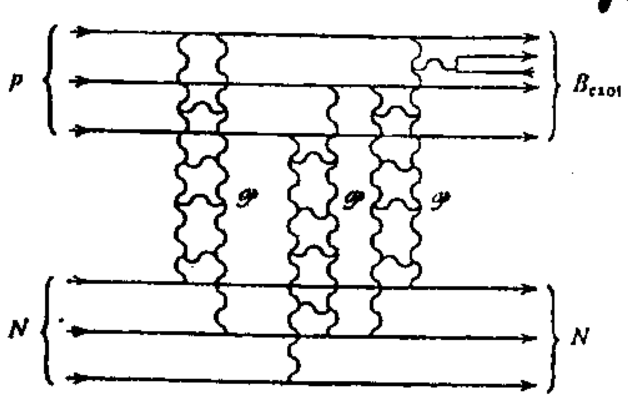


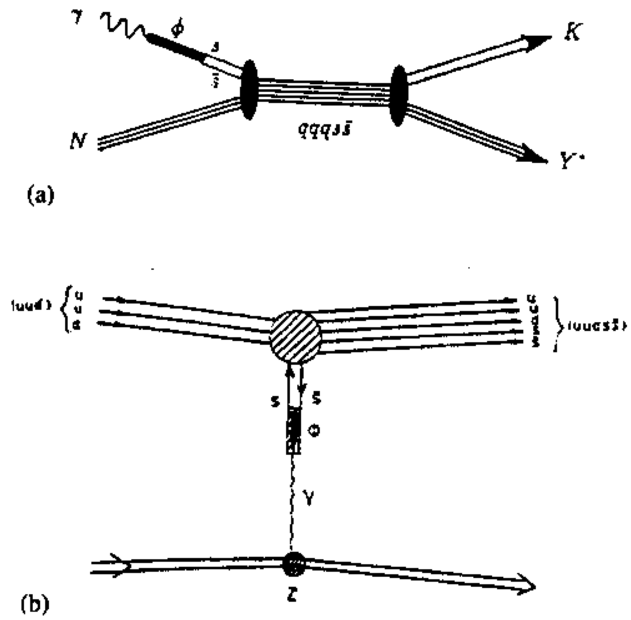


Diffractive coherent region

nonperipheral region

Nonperipheral production
(mechanism of pomeron rescattering)





2 The SPHINX facility

The search for exotic baryons was performed on the SPHINX detector (Fig. 3) which includes:

1. A wide aperture magnetic spectrometer with proportional wire chambers, drift chambers, drift tubes, scintillator hodoscopes.
2. Multichannel γ-spectrometer with lead glass shower counters.
3. System of Cherenkov counters for identification of secondary charge particles (including RICH detector with photomatrix equiped with 736 small phototubes – first counter of this type).

The SPHINX spectrometer is working in the proton beam with energy $E_p = 70\,\mathrm{GeV}$ and intensity $I \simeq (2 \div 3) \cdot 10^6 p/\mathrm{spill}$.

Now the SPHINX is completely upgraded (new tracking system, new γ-spectrometer, better conditions for the registration of Λ and Σ^0 decays, new electronics, trigger system, DAQ system, on-line computers).

As a result of this upgrade we increased significantly the possibility of working with higher luminosity. The number of recorded events is increased by an order of magnitude

$$(3 \cdot 10^2\,\mathrm{events/spill})_{\mathrm{old\ setup}} \Rightarrow (3 \cdot 10^3\,\mathrm{events/spill})_{\mathrm{upraged\ setup}}$$

Now we finished the first part of our experimental program – on the old setup and on the setup after a partial modification (new γ-spectrometer, better conditions for Λ and Σ^0 detection – see Fig. 4).

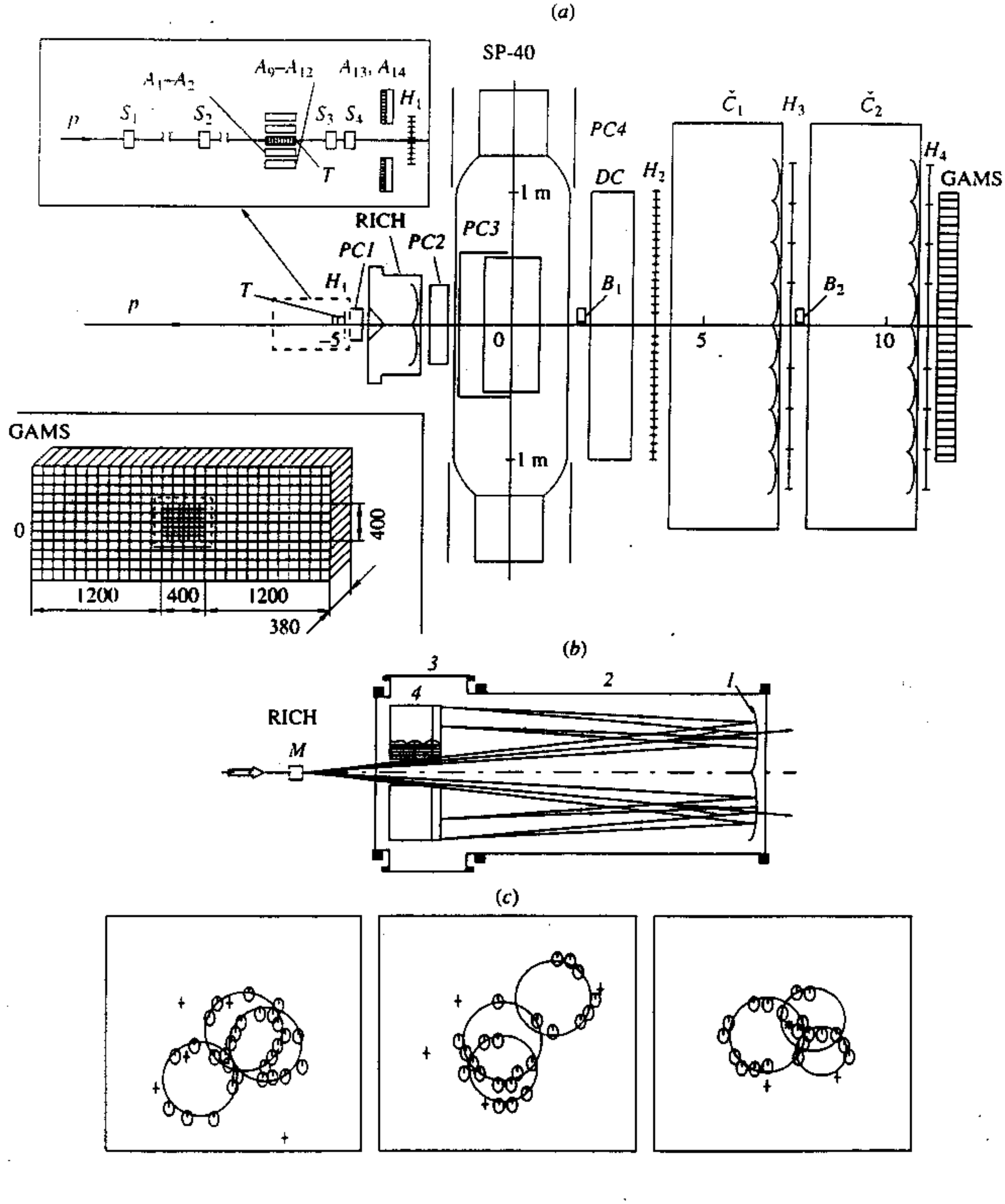


Fig. 4. (*a*) Layout of the SPHINX spectrometer: (S_1–S_4, B_1, and B_2) scintillation counters, (A_1–A_{14}) scintillation veto counters, (H_1–H_4) scintillation hodoscopes, (*PC*1–*PC*4) blocks of proportional chambers, (DC) block of drift chambers, (SP-40) spectrometer magnet, ($\check{C}_1$ and $\check{C}_2$) hodoscope threshold Cherenkov counters, (RICH) ring-image Cherenkov spectrometer, and (GAMS) hodoscope γ spectrometer (which is presented on the left lower part of the figure; the dash-dotted contour indicates the active region of the γ detector used for trigger requirements). (*b*) Layout of the RICH spectrometer ensuring detection of radiation rings: (*1*) spherical mirror from thin glass ($\Delta = 5$ mm and $f = 1250$ mm), (*2*) body of the counter, (*3*) flanges, and (*4*) photomatrix involving 736 phototubes FEU-60 with a photocathode 10 mm in diameter. (*c*) Examples of detection of Cherenkov radiation rings in the photomatrix of the RICH spectrometer for trigger events with three charged particles in the final state.

A study of several proton-induced diffractive production processes

$$
\begin{aligned}
p + N &\rightarrow [pK^+K^-] + N\\
&\rightarrow [p\phi] + N\\
&\qquad \hookrightarrow K^+K^-\\
&\rightarrow [\Lambda(1520)K^+] + N\\
&\qquad \hookrightarrow K^-p\\
&\rightarrow [\Sigma(1385)^0 K^+] + N\\
&\qquad \hookrightarrow \Lambda\pi^0\\
&\rightarrow [\Sigma(1385)^0 K^+] + N + (neutrals)\\
&\qquad \hookrightarrow \Lambda\pi^0\\
\circledast \qquad &\rightarrow [\Sigma^0 K^+] + N \qquad ; \rightarrow [\Sigma^+ \;\; K^0 \;] + N\\
&\qquad \hookrightarrow \Lambda\gamma \qquad\qquad\quad \hookrightarrow p\pi^0 \;\; \hookrightarrow \pi^+\pi^-\\
&\rightarrow [pp\bar{p}] + N\\
&\rightarrow [p\omega] + N\\
&\qquad \hookrightarrow \pi^+\pi^-\pi^0\\
&\rightarrow [p\pi^+\pi^-] + N\\
&\rightarrow [\Delta^{++}\pi^-] + N\\
&\qquad \hookrightarrow p\pi^+
\end{aligned}
$$

and several other reactions was carried out in the experiments with the SPHINX spectrometer (here N is nuclon or carbon nucleus for the coherent process). The main results of these experiments are presented below (see also [1-7]).

Table 1
The main results of the previous SPHINX data for coherent diffractive reactions $p + C \to [\Sigma^0 K^+] + C$ and $p + C \to [\Sigma^*(1385)^0 K^+] + C$

1. Coherent diffractive production reaction $p + C \to [\Sigma^0 K^+] + C$ with coherent cut $P_T^2 < 0.1\,\mathrm{GeV}^2$ was studied in the old and new runs. The combined mass spectrum $M(\Sigma^0 K^+)$ is presented in Fig. 5. This spectrum is dominated by $X(2000)$ state with parameters

$$\begin{cases} M = 1997 \pm 7\,\mathrm{MeV} \\ \Gamma = 91 \pm 17\,\mathrm{MeV} \end{cases}$$

statistical significance of the peak is 7 SD

2. There are also some near threshold structure $X(1810)$, which is produced only in the region of very small $P_T^2(\lesssim 0.01\text{–}0.02\,\mathrm{GeV}^2)$. The parameters of this peak are

$$\begin{cases} M = 1812 \pm 7\,\mathrm{MeV} \\ \Gamma = 56 \pm 16\,\mathrm{MeV} \end{cases}$$

3. Coherent diffractive production reaction $p + C \to [\Sigma^*(1385)K^+] + C$ with tight coherent cut $P_T^2 < 0.02\,\mathrm{GeV}^2$ was studied in the old run ([12,17–20]). The mass spectra of $M[\Sigma^*(1385)^0 K^+]$ are in Fig. 6. The peak was observed in these spectra with average value of parameters

$$\begin{cases} M = 2052 \pm 6\,\mathrm{MeV} \\ \Gamma = 35^{+22}_{-35}\,\mathrm{MeV} \end{cases}$$

(with the account of the apparatus mass resolution); statistical CL of the peak ≥ 5 SD

4. From analysis

$$p + N \to [\Sigma^0 K^+] + N \; (P_T^2 < 0.1\,\mathrm{GeV}^2)$$
$$\to [\Sigma^*(1385)K^+] + N$$
$$(P_T^2 < 0.02\,\mathrm{GeV}^2)$$

and

$$p + N \to p\pi^+\pi^- + N$$
$$\to \Delta^{++}\pi^- + N$$

in the same kinematical conditions

$$R_1 = \frac{BR\{X(2050)^+ \to [\Sigma^*(1385)K]^+\}}{BR\{X(2050)^+ \to [\Delta(1232)\pi]^+\}} > 1.7$$

$$R_2 = \frac{BR\{X(2050)^+ \to [\Sigma^*(1385)K]^+\}}{BR\{X(2050)^+ \to p\pi^+\pi^-\}} > 2.6$$

$$R_2' = \frac{BR\{X(2050)^+ \to \Sigma^*(1385)^o K^+\}}{BR\{X(2050)^+ \to p\pi^+\pi^-\}} > 0.86$$

$$R_3 = \frac{BR\{X(2000)^+ \to [\Sigma K]^+\}}{BR\{X(2000)^+ \to [\Delta(1232)\pi]^+\}} > 0.83$$

$$R_4 = \frac{BR\{X(2000)^+ \to [\Sigma K]^+\}}{BR\{X(2000)^+ \to p\pi^+\pi^-\}} > 7.8$$

$$R_4' = \frac{BR\{X(2000)^+ \to \Sigma^o K^+\}}{BR\{X(2000)^+ \to p\pi^+\pi^-\}} > 2.6.$$

$$\boxed{R[X(2000);\; X(2050)] \gtrsim 1 \div 10 \qquad (95\%\ \text{C.L.})}$$

These states are $|qqqs\bar{s}\rangle$ candidates

New analysis of the data for reaction $p + N \to [\Sigma^0 K^+] + N$

In what follows we present the results of a new analysis of the data obtained in the run with partially upgraded SPHINX spectrometer where conditions for Λ and Σ^0 separation were greatly improved as compared with an old version of this setup. The key element of the new analysis lays in a detailed study of the $\Sigma^0 \to \Lambda + \gamma$ decay separation, which makes it possible to reach the reliable identification of this decay and reaction with the increased efficiency in comparison with the previous analysis of Bezzubor et al. [21]. Good M.-C. description of the setup (ε).

The effective mass spectra $M(\Sigma^0 K^+)$ in $p + N \to [\Sigma^0 K^+] + N$ for all P_T^2 are presented in Fig. The peak of $X(2000)$ baryon state with $M = 1986$ MeV and $\Gamma = 98 \pm 20$ MeV is seen very clear in these spectra with a very good statistical significance. Thus, the reaction

$$p + N \to X(2000) + N, \quad X(2000) \to \Sigma^0 K^+$$

is well separated in the SPHINX data. The cross section for $X(2000)$ production in (26) is

$$\sigma[p + N \to X(2000) + N] \cdot BR[X(20000) \to \Sigma^0 K^+] = 95 \pm 20 \text{ nb/nucleon}$$

(with respect to one nucleon under the assumption of $\sigma \propto A^{2/3}$, e.g. for the effective number nucleons in carbon nucleus equal to 5.24). The parameters of $X(2000)$ are not sensitive to t different photon cuts, as is seen from Table 2. The dN/dP_T^2 distribution for reaction is shown Fig. From this distribution the coherent diffractive production reaction on carbon nuclei identified as a diffraction peak with the slope $b \simeq 63 \pm 10$ GeV^{-2}. The cross section for cohere reaction is determined as

$$\sigma[p + C \to X(2000)^+ + C]_{\text{Coherent}} \cdot BR[X(2000)^+ \to \Sigma^0 K^+]$$
$$= 260 \pm 60 \text{ nb/C nucleus}.$$

We must bear in mind that it is more convenient to use other relations for cross sections:

$$\sigma[p + N \to X(2000)^+ + N] BR[X(2000)^+ \to (\Sigma K)^+] = 285 \pm 60 \text{ nb/nucleon},$$

$$\sigma[p + C \to X(2000)^+ + C] BR[X(2000)^+ \to (\Sigma K)^+] = 780 \pm 180 \text{ nb/nucleus},$$

with $$BR[X^+_{I=1/2} \to \Sigma^0 K^+] = \frac{1}{3} BR[X^+_{I=1/2} \to (\Sigma K)^+]$$

$I_x = \frac{1}{2} \}$ $p \to X^+$ diffraction dissociation

$p + N \to \Sigma^0 K^+ + N$

X(2000)

m = 1989 ± 6 MeV

Γ = 91 ± 20 MeV

all p_T^2

Weighted with efficiency

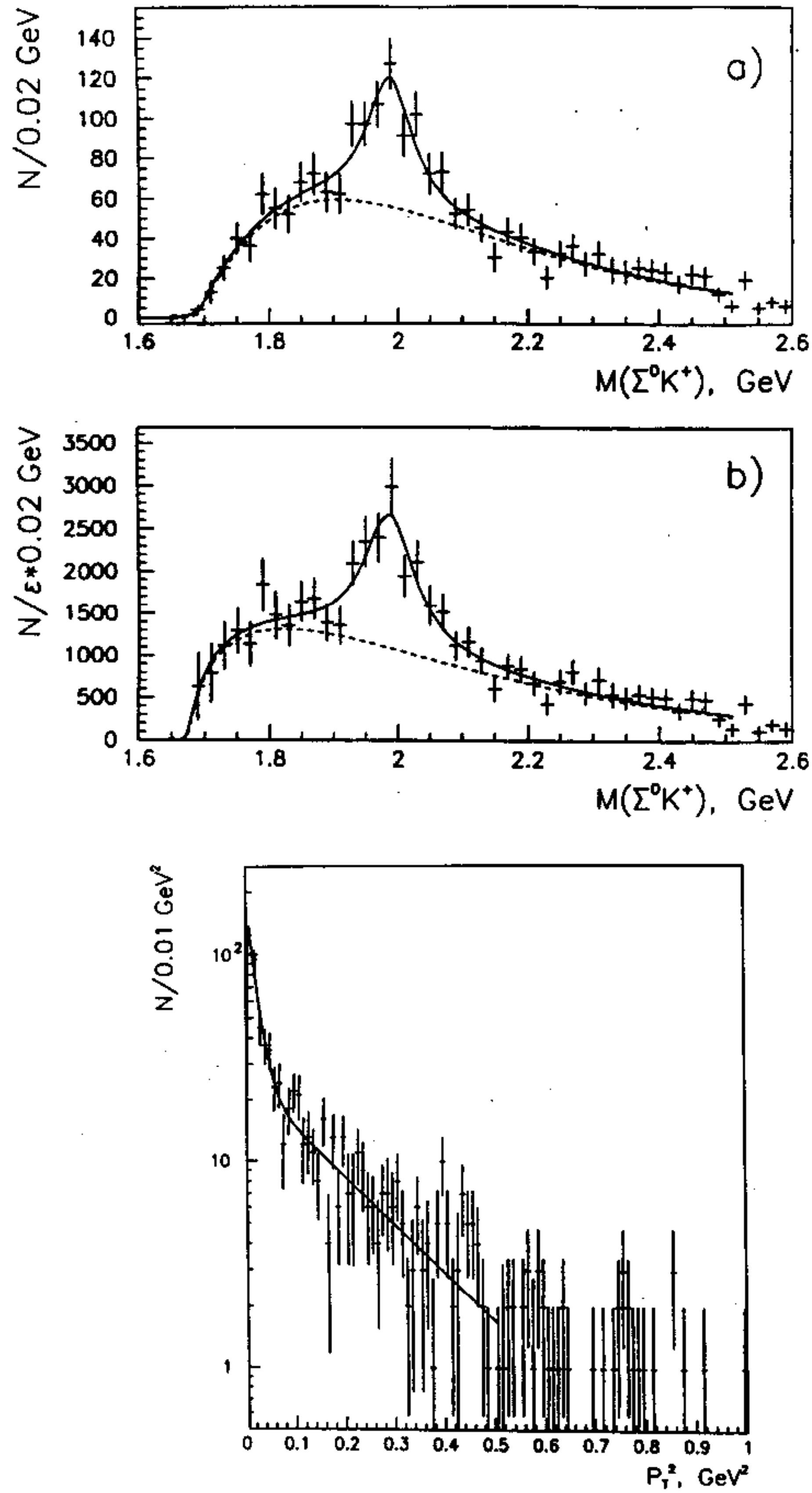


Fig. 8. dN/dP_T^2 distribution for the diffractive production reaction $p + N \to X(2000) + N$. The distribution is fitted in the form $dN/dP_T^2 = a_1 \exp(-b_1 P_T^2) + a_2 \exp(-b_2 P_T^2)$ with the slope parameters $b_1 = 63 \pm 10\,\mathrm{GeV}^{-2}$; $b_2 = 5.8 \pm 0.6\,\mathrm{GeV}^{-2}$.

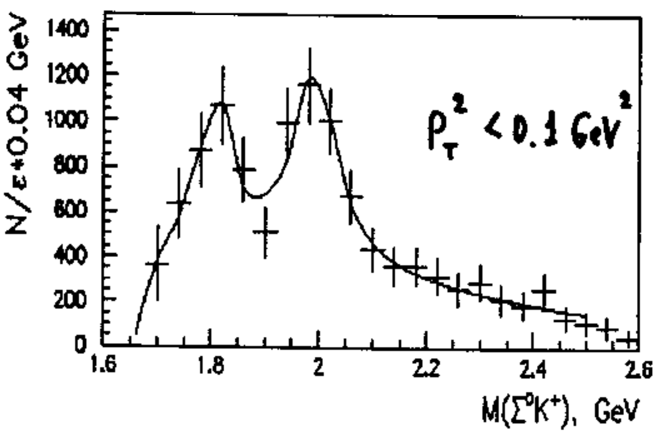
Study of coherent reaction $p + C \to [\Sigma^0 K^+] + C$ $(P_T^2 < 0.1\,\mathrm{GeV}^2)$

In the $M(\Sigma^0 K^+)$ for this P_T^2 region the $X(2000)$ state and some threshold structure with $M \sim 1810\,\mathrm{MeV}$ are clearly seen (this structure is practically not seen in mass spectrum for all P_T^2 due to difficult background conditions). Study of the yield of $X(1810)$ as function of P_T^2 demonstrate that this state is produced only in the region of very small P_T^2 ($\lesssim 0.01\,\mathrm{GeV}^2$) where it is well defined:

$$X(1810) \to \Sigma^0 K^+ \left\{ \begin{array}{lcl} M & = & 1807 \pm 7\,\mathrm{MeV} \\ \Gamma & = & 62 \pm 19\,\mathrm{MeV} \end{array} \right.$$

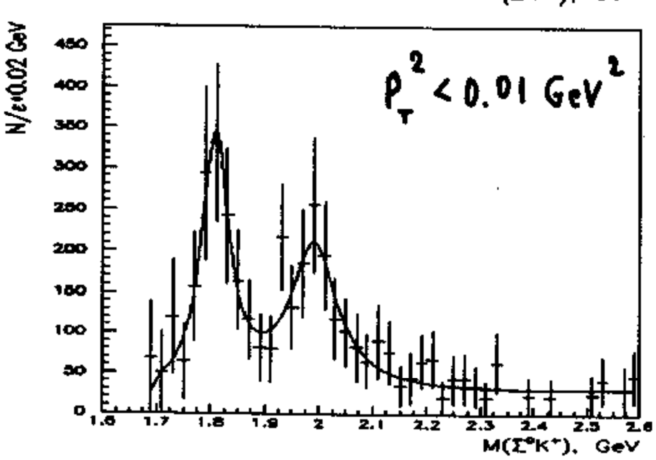
$$\sigma[p+C \to X(1810)+C]_{P_T^2<0.01\,\mathrm{GeV}^2} \cdot BR[X(1810) \to \Sigma^0 K^+] = 215 \pm 44\,\mathrm{nb}(\pm 30\%\,\mathrm{syst.})$$

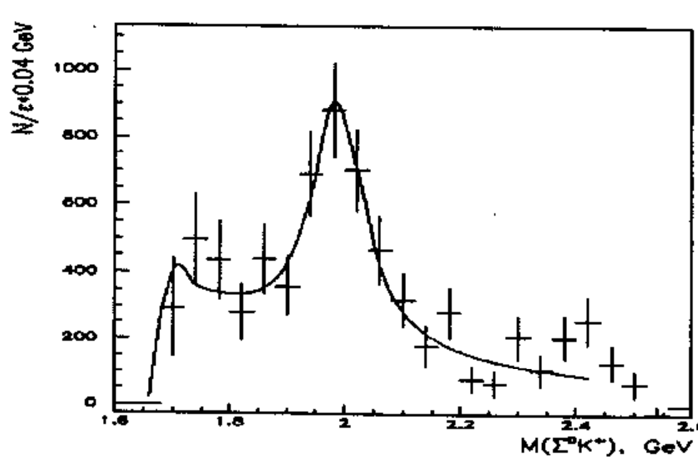
Possible explanation of unusual production properties of $X(1810)$: may be this is a Coulomb production process ? The value of the coherent cross section is not in contradiction with this hypothesis which is also supported by observation of $\Delta(1232)^+$ Coulomb production in the SPHINX experiment.



In the "restricted coherent region" $0.02 < P_T^2 < 0.1\,\mathrm{GeV}^2$ (without the influence of $X(1810)$ in $M(\Sigma^0 K^+)$ $X(2000)$ baryon is observed in the clearest way.

$\Downarrow$





Reality of X(2000) state, candidate for exotic baryon $|uuds\bar{s}\rangle$

The data on $X(2000)$ baryon state with unusual dynamical properties (large decay BR with strange particle emission, limited decay width Γ) were obtained with a good statistical significance in the different SPHINX runs with widely different experimental conditions and in several kinematical regions for reaction $p + N \to [\Sigma^0 K^+] + N$. Due to its anomalous dynamical properties the $X(2000)$ state can be considered as a serious candidate for pentaquark exotic baryon with hidden strangeness: $|X(2000)\rangle = |uuds\bar{s}\rangle$.

New preliminary data in support of the reality of $X(2000)$ state:

a) The SPHINX experiment (IHEP): in the study of the reaction

$$p + N \to [\underset{\hookrightarrow p\pi^0}{\Sigma^+} \quad \underset{\hookrightarrow \pi^+\pi^-}{K^0}] + N$$

The decay $X(2000) \to \Sigma^+ K^0$ was also observed. These data are in a good agreement with a previous SPHINX result ($X(2000) \to \Sigma^0 K^+$).

b) The SELEX experiment in Fermilab: in the study of $M(\Sigma^- K^+)$ in the diffractive production reaction $\Sigma^- + N \to [\Sigma^- K^+ K^-] + N$ at $E_{\Sigma^-} \simeq 600\,\text{GeV}$ The peak has parameters which are very close to $X(2000)$ ($M = 1962 \pm 12\,\text{MeV}$; $\Gamma = 96 \pm 32\,\text{MeV}$).

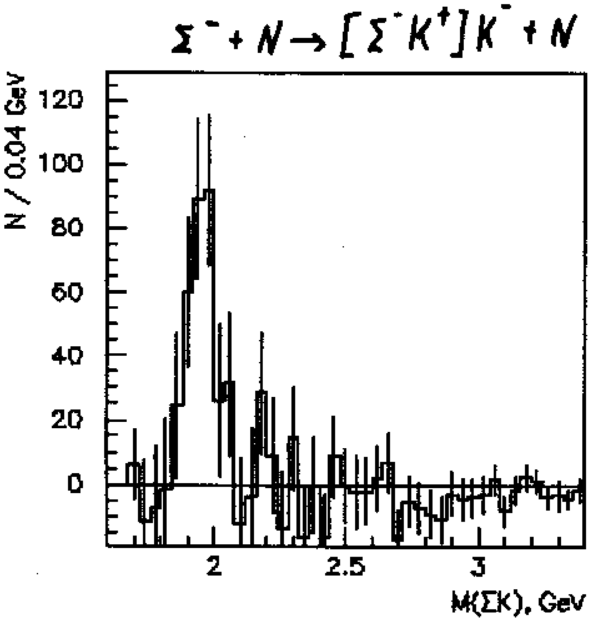
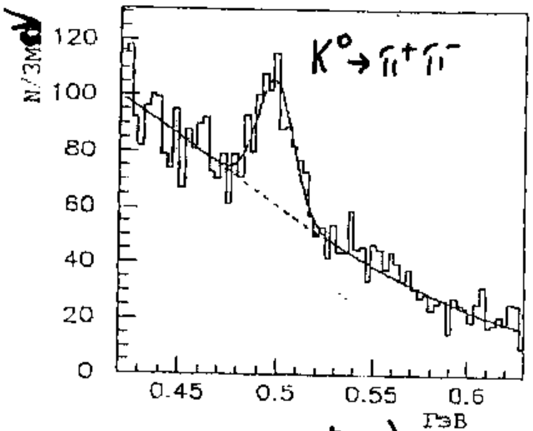


Figure: Mass spectrum $M(\Sigma^- K^+)$ after background subtraction

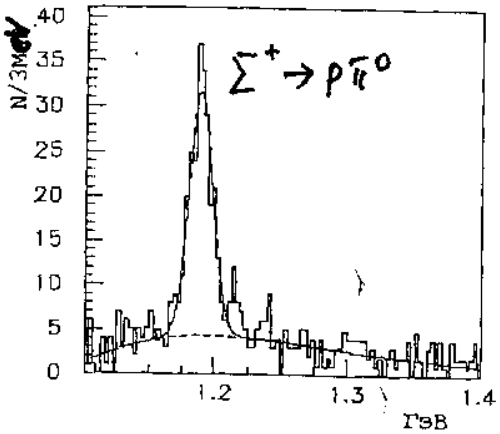
Now more than an order of magnitude increase of statistics for diffractive proton reactions was obtained with the totally upgraded SPHINX setup.
The analysis of this statistics is in progress.

Study $p + N \to \Sigma^+ K^0 + N$ (SPHINX)

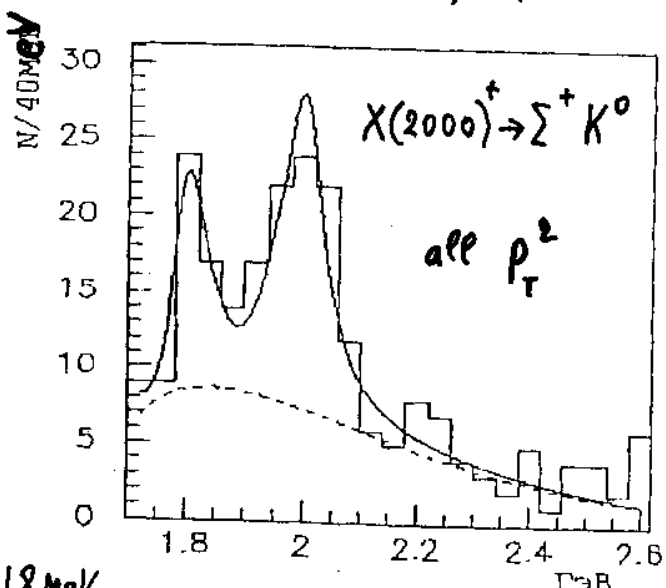
$\quad\quad\quad\Sigma^+ \to p\pi^0, \quad K^0 \to \pi^+\pi^-$



$M(\pi^+\pi^-)$, GeV



$M(p\pi^0)$, GeV



$M(\Sigma^+ K^0)$, GeV

(2000)

M = 1995 ± 18 MeV

Γ = 90 ± 32 MeV

a) $p + N \to p\, \pi^+ \pi^- \gamma\gamma + N$

в) $\to p\, \pi^+ \pi^- \pi^0 + N$

c) $\to p\, \pi^0 + K^0 + N$, $\quad \pi^0 \to 2\gamma$, $\quad K^0 \to \pi^+\pi^-$

d) $\to \Sigma^+ \quad K^0 + N$, $\quad \Sigma^+ \to p\pi^0$, $\quad K^0 \to \pi^+\pi^-$

e) $M(\Sigma^+ K^0) \left\{ \begin{array}{l} X(2000) \\ X(1810) \end{array} \right.$

$$\sigma[p + N \to X(2000) + N] \cdot BR[X(2000) \to \Sigma^+ K^0] = 182 \pm 32 \text{ nb}$$

$\pm 20\%$ syst

$$F = BR[X(2000) \to \Sigma^+ K^0] / BR[X(2000) \to \Sigma^0 K^+] = 1.91 \pm 0.38$$

$\pm 15\%$ syst.

$$F(X_{I=1/2}) = 2$$

4 First results of the study of the Σ^- hyperon diffractive production reactions (E781 Collaboration)

Σ^- beam of the Fermilab Tevatron: $P_{\Sigma^-} \simeq 600\,\text{GeV}$, Σ^- content of the beam is $\simeq 50\%$. Diffractive-like reactions under study:

$$\begin{aligned}\Sigma^- + N &\to [\Sigma^- K^+ K^-] + N\\ &\to [\Sigma^-\phi] + N\\ &\to [\Sigma^\pm \pi^\mp \pi^-] + N\\ &\to [pK^-\pi^-] + N\\ &\to [\Xi^- K^+ \pi^-] + N\end{aligned}$$

This work is in the very begin. But we obtained 2 new results which I want to mention here.

4.1 In the reaction

$$\Sigma^- + N \to [\Sigma^- K^+ K^-] + N$$

we studied mass spectra $M[\Sigma^- K^+]$ and $M[\Sigma^- K^-]$.

Assumption: $M[\Sigma^- K^-]$ can be used for nonresonance background subtraction.

$$M = M[\Sigma^- K^+] - \underbrace{0.95}_{\text{normalization}} M[\Sigma^- K^-] \text{ (see Fig. 12)}$$

We observed in M a sharp peak with parameters $\left\{\begin{array}{lcr} M & = & (1962 \pm 12)\,\text{MeV} \\ \Gamma & = & (99 \pm 32)\,\text{MeV}\end{array}\right.$

These parameters are rather close to the state $X(2000)$ which we observed before in absolutely different process and in different experiment.

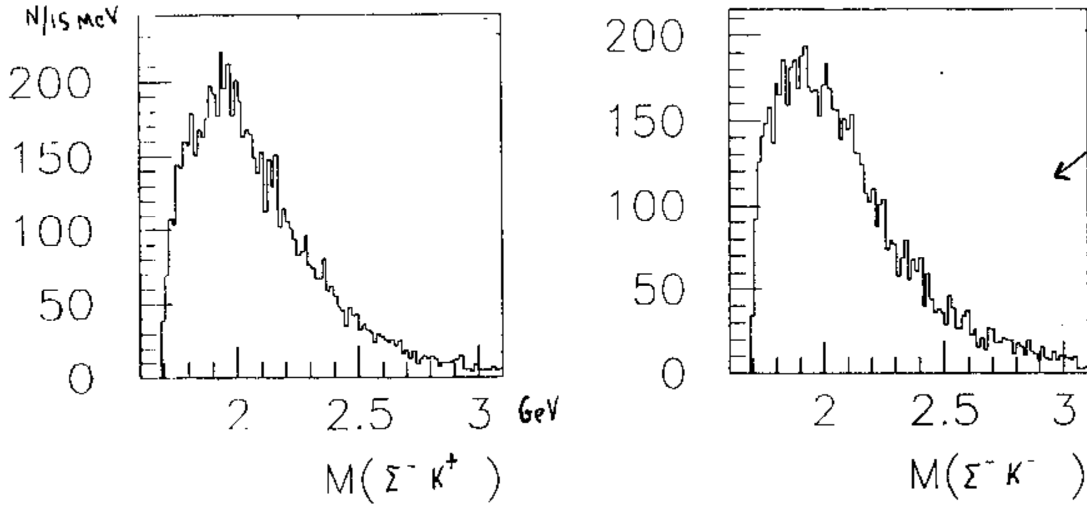
4.2 In the reaction

$$\Sigma^- + N \to [\Sigma^\pm \pi^\mp \pi^-] + N$$

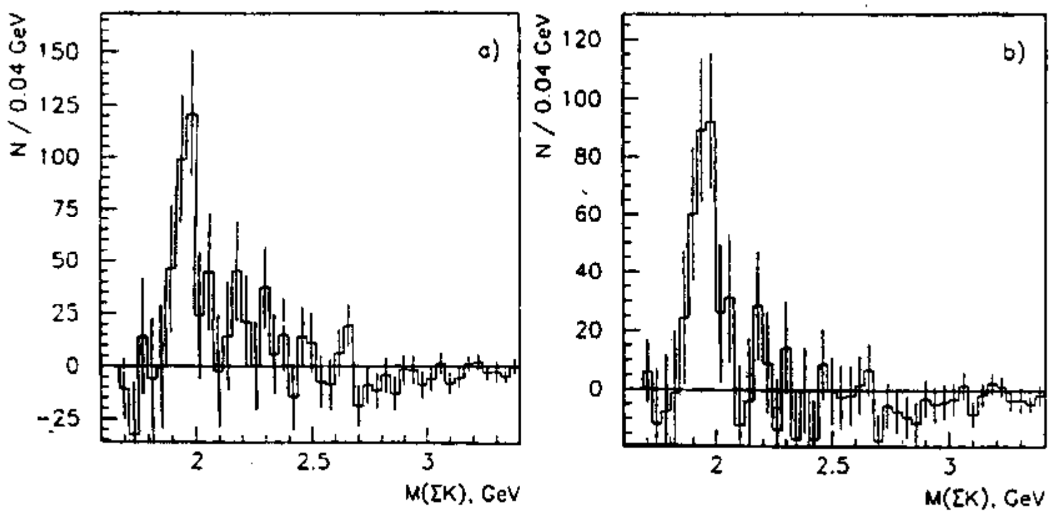
in the region of high $P_T^2 (> 0.3\,\text{GeV}^2$, or even $> 0.6\,\text{GeV}^2)$ we observed very clear and narrow peak with $\left\{\begin{array}{lcr} M & = & (1666 \pm 13)\,\text{MeV} \\ \Gamma & = & (29 \pm 3)\,\text{MeV}\end{array}\right.$ (see Fig. 13 and 14).

Old $K^- p \to \Sigma + (n\pi)$ experiments in bubble chambers: in the mass region $1660 - 1670\,\text{MeV}$ several Σ^* hyperon resonances were observed. The data for their properties are rather controversial (for example, the values for Γ were from $40\,\text{MeV}$ up to $200\,\text{MeV}$ [8]). Nobody observed such clear and narrow structure before and its further study is quite desirable.

$\Sigma^- + N \to \Sigma^- K^+ K^- + N$



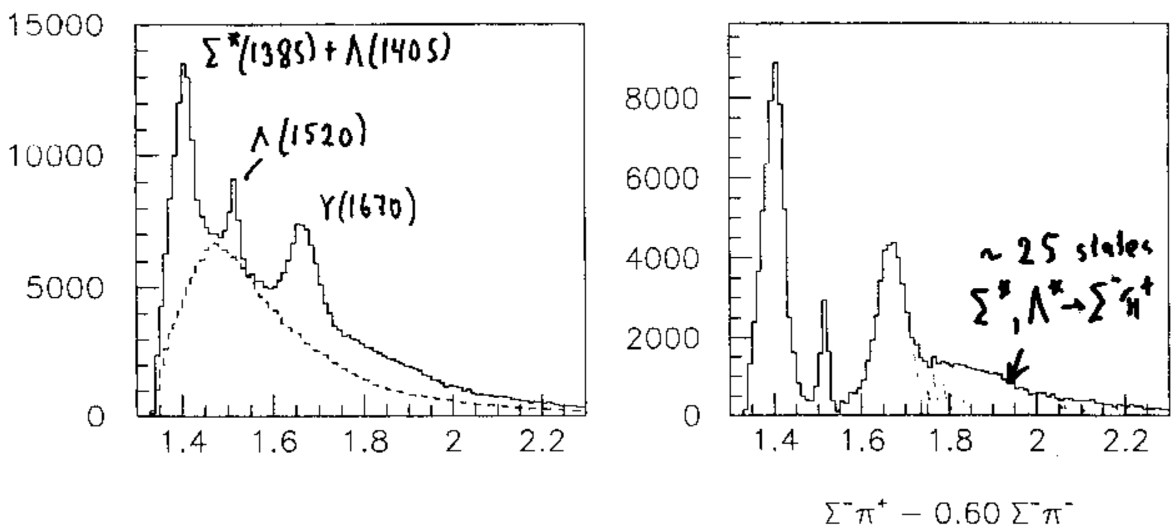
For nonresonance background evaluation



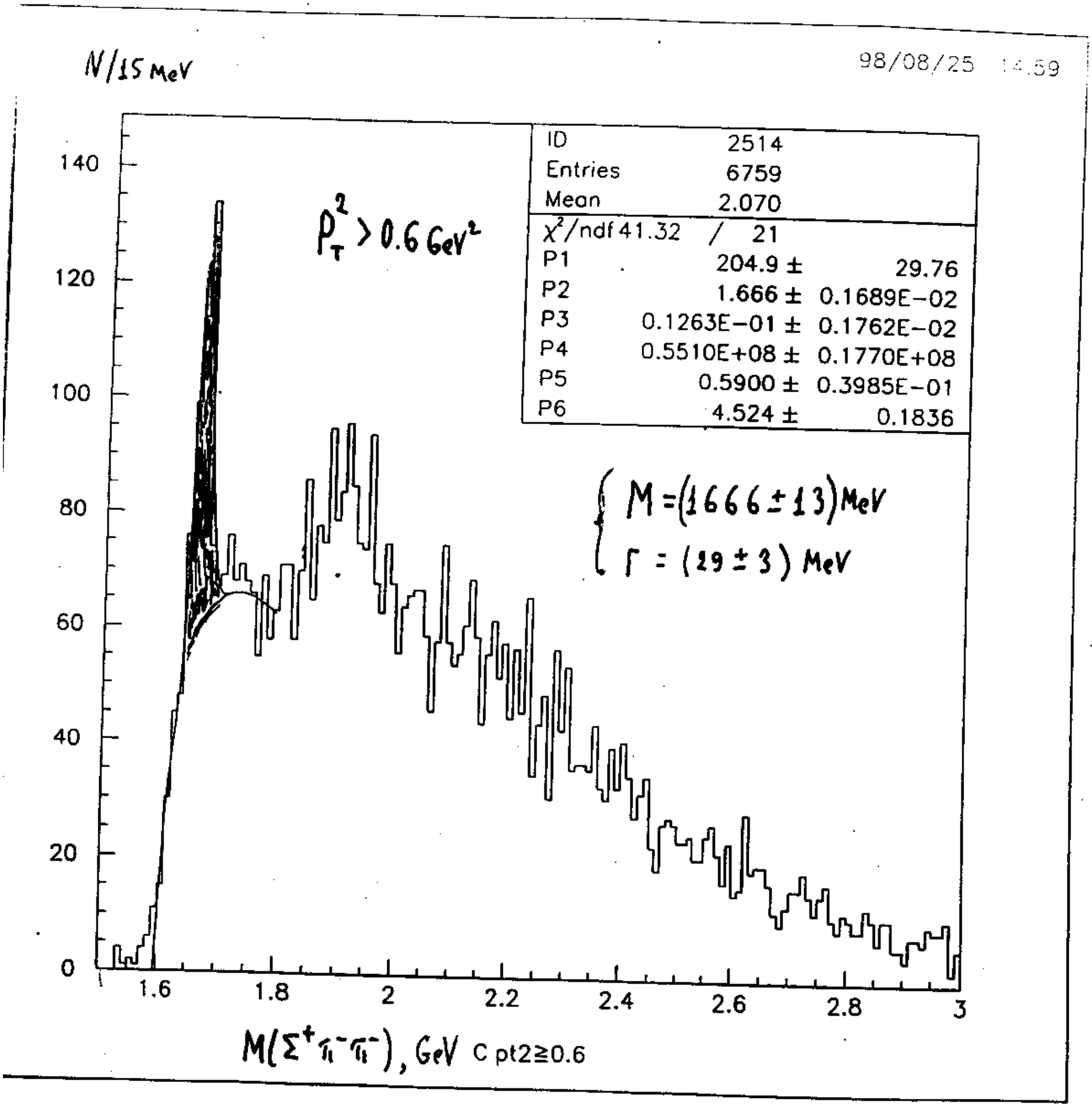
without $\phi \to K^+K^-$ band

Study of $M(\Sigma^- K^+)$ in the reaction $\Sigma^- + N \to [\Sigma^- K^+ K^-] + N$ in the SELEX experiment. Here the spectr[um] $M(\Sigma^- K^-)$ with open exotic quantum number used for subtraction of nonresonance background in $M(\Sigma^- K^+)$ after so[me] normalization. One presents in this figure $M(\Sigma^- K^+) - 0.95M(\Sigma^- K^-)$ (here 0.95 – normalization factor): (a) all [...] events; (b) after subtraction of the events in ϕ band to suppress the influence of the reaction $\Sigma^- + N \to [\Sigma^- \phi] + N$

$\Sigma^- + N \to \Sigma^- \pi^+ \pi^- + N$



$$\Sigma^- + N \rightarrow [\Sigma^+ \pi^- \pi^-] + N$$



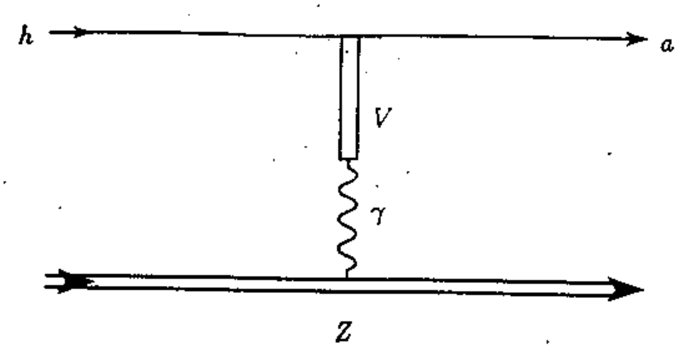


Fig. 1. Diagram for the Coulomb process $h + (Z, A) \to a + (Z, A)$. The cross section for this reaction is proportional to the radiative width $\Gamma(a \to h\gamma)$. Symbol V denotes the vector mesons in the $ha\gamma$ vertex in the vector-dominance model.

$$\sigma[h + Z \to a + Z]|_{Coulomb} \simeq \sigma_o \, \frac{2J_a + 1}{2J_h + 1} \, \Gamma(a \to h + \gamma).$$

$$\sigma_o = 8\pi\alpha Z^2 \Big[\frac{M_a}{M_a^2 - m_h^2}\Big]^3 \int_{q^2_{min}}^{q^2} \frac{[q^2 - q^2_{min}]}{q^4} |F_z(q^2)|^2 dq^2$$

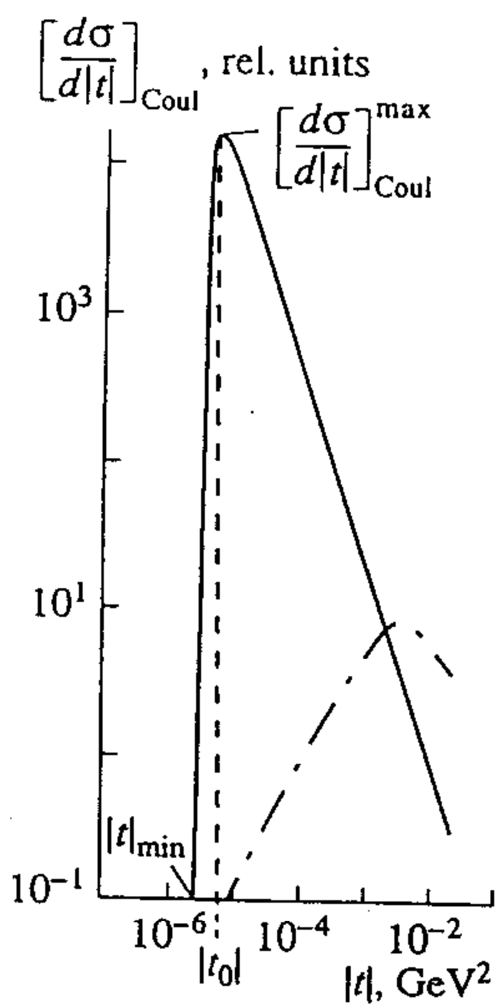


Fig. 2. Schematic behavior of the differential cross sections $[d\sigma/dt]_{Coul}$ for the Coulomb-production process $h + (Z, A) \to a + (Z, A)$ (see the diagram in Fig.1). In this figure, $|t| = q^2$ is the squared momentum transfer, and $q_0^2 = |t_0| = 2|t_{min}|$ the squared momentum transfer that corresponds to the maximum differential cross section $[d\sigma/dt]^{max}_{Coul.}$ (the maximum cross section grows with energy in proportion to E_h^2, while the position of the peak shifts toward lower $|t_0|$ values according to the E_h^{-2} law). The dash-dotted curve represents the background from the coherent process due to strong interaction (with ω exchange).

To explain the unusual properties of X(1810) state in a very small P_T^2 region the hypothesis of the electromagnetic production of this state in the Coulomb field of carbon nucleus was proposed earlier   It is possible to estimate the cross section for the Coulomb X(1810) production

$$\sigma[p + C \to X(1810)^+ + C]|_{P_T^2 < 0.01 \text{ GeV}^2;\ \text{Coulomb}} =$$
$$= (2J_x + 1)\{\Gamma[X(1810)^+ \to p + \gamma][\text{MeV}]\} \cdot 2.8 \cdot 10^{-30}\ \text{cm}^2/\text{C nucleus} \geq$$
$$\geq 5.6 \cdot 10^{-30}\ \text{cm}^2\{\Gamma[X(1810)^+ \to p + \gamma][\text{MeV}]\}$$

($J_x \geq 1/2$ is the spin of X(1810)).

Let us compare this Coulomb hypothesis prediction with the experimental value

$$\sigma[p + C \to X(1810)^+ + C]|_{P_T^2 < 0.01 \text{ GeV}^2} \gtrsim 645 \text{ nb/C nucleus}.$$

$BR(X^+ \to \Sigma^o K^+) \leqslant 1/3$ (here $\simeq$ means that $BR[X^+ \to (\Sigma K)^+] \simeq 1$)

For $\Gamma[X(1810) \to p + \gamma] \gtrsim 0.1 - 0.3$ MeV the data for X(1810) production do not contradict to Coulomb production hypothesis

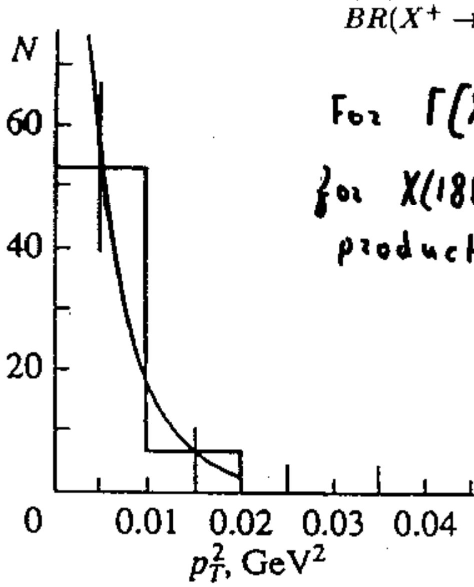


Figure. The P_T^2 dependence for the $X(1810)$ structure production in the coherent reaction $p + C \to X(1810) + C$.

$$X(1810) \to \Sigma^0 K^+ \left\{ \begin{array}{lcl} M & = & 1807 \pm 7\,\text{MeV} \\ \Gamma & = & 62 \pm 19\,\text{MeV} \end{array} \right.$$

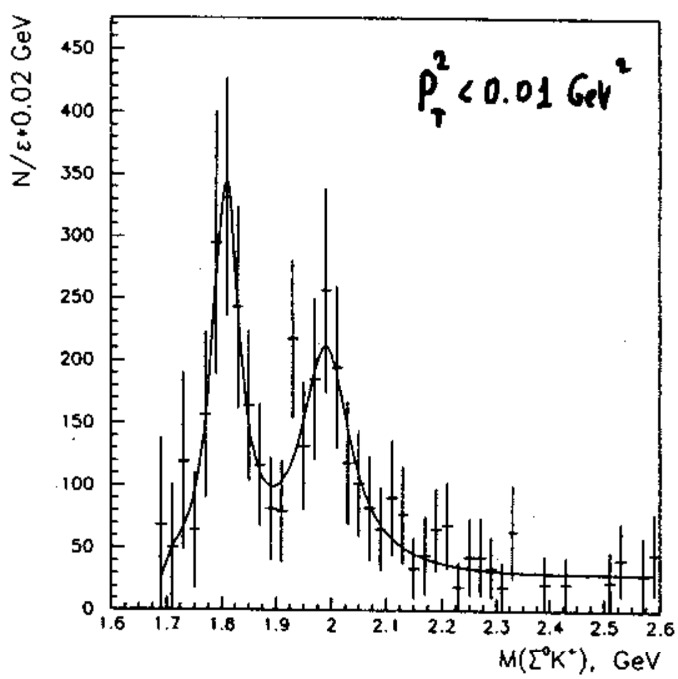


Figure   Invariant mass spectra $M(\Sigma^o K^+)$ in the coherent diffractive production reaction $p + C \to [\Sigma^o K^+] + C$ in the region of very small $P_T^2 < 0.01$ GeV^2 (with strong photon cut) weighted with the efficiency of the setup.

If the value of radiative width $\Gamma[X(1810) \to p + \gamma]$ is around 0.1-0.3 MeV and the branching $BR[X(1810)^+ \to (\Sigma K)^+]$ is significant, then the experimental data for cross section of the coherent X(1810) production (34) can be in agreement with the Coulomb mechanism prediction (33). It seems that such value of radiative width is quite reasonable. For example, the radiative width for $\Delta(1232)$ isobar is $\Gamma[\Delta(1232)^+ \to p + \gamma] \simeq 0.7$ MeV. The value of radiative width depends on the amplitude of this process A and on kinematical factor: $\Gamma = |A|^2 \cdot (P_\gamma)^{2l+1}$ (P_γ is the momentum of photon in the rest frame of the decay baryon and l is orbital momentum). For $X(1810) \to p + \gamma$ decay the kinematical factor may be by an order of magnitude larger than for $\Delta(1232)^+ \to p + \gamma$ because of the large mass of X(1810) baryon. Certainly, the predictions for amplitude A are quite speculative. But if, for example, X(1810) is the state with hidden strangeness $|qqqs\bar{s}>$, then the amplitude A might be not very small due to a possible VDM decay mechanism $(qqqs\bar{s}) \to (qqq) + \phi_{\text{virt}} \to (qqq) + \gamma$. Thus it seems that the experimental data for the coherent production of X(1810) (34) is not in contradiction with the Coulomb production hypothesis.

It is possible that the candidate state $X(2050) \to \Sigma^*(1385)^\circ K^+$ which was observed in coherent reaction (14) in the region of very small transverse momenta ($P_T^2 < 0.02$ GeV^2) is also produced not by diffractive, but by the electromagnetic Coulomb production mechanism [46].

The feasibility to separate the Coulomb production processes in the coherent proton reactions at $E_p = 70$ GeV on the carbon target in the measurements with the SPHINX setup was demonstrated recently by observation of the Coulomb production of $\Delta(1232)^+$ isobar with $I = 3/2$ in the reaction

$$p + C \to \Delta(1232)^+ + C$$

$\Delta(1232)^+ \to p\pi^0$ $\qquad$ $p_T^2 < 0.01\ GeV^2$

$I_\Delta = 3/2$ $\qquad$ all p_T^2 $\qquad$ diffraction is subtructed

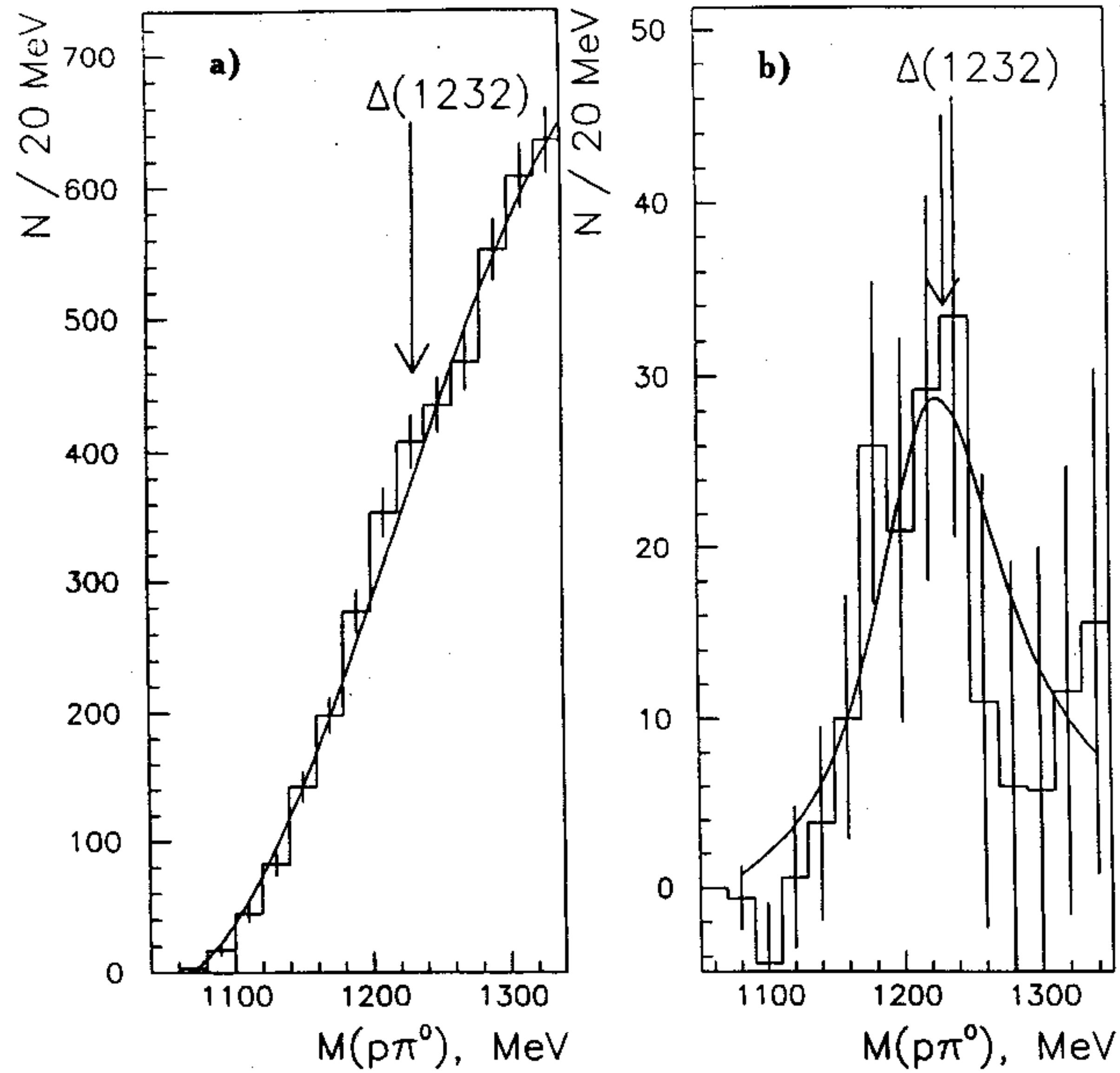
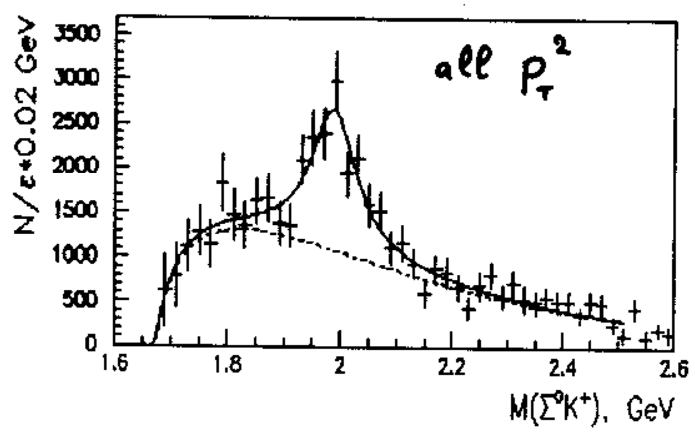


Fig. 6. The Coulomb production of isobar $\Delta(1232)^+$ in the coherent reaction $p + C \to \Delta(1232)^+ + C$; $\Delta(1232)^+ \to p\pi^0 \to p\gamma[\gamma \to e^+e^-]$ in the SPHINX experiment. Because of the trigger requirment we used the decay $\pi^0 \to \gamma[\gamma \to e^+e^-]$ with e^+e^--conversion of one of the photons in the setup target for π^0-detection. a) The effective mass spectrum $M(p\pi^0)$ for the diffractive reaction $p + N \to [p\pi^0] + N$ (all P_T^2). There is no evidence for $\Delta(1232)^+$ in this mass spectrum because Δ isobar (with isospin $I = 3/2$) cannot be produced in the diffractive dissociation of the proton. b) $M(p\pi^0)$ mass spectrum for the coherent reaction $p + C \to [p\pi^0] + C$ in the Coulomb region ($P_T^2 < 0.01$ GeV^2) after the subtruction of diffractive $p\pi^0$ background. A clear peak with parameters $M = (1232 \pm 10)$ MeV and $\Gamma = (119 \pm 20)$ MeV which corresponds to the Coulomb production of $\Delta(1232)^+$ isobar is seen in this mass spectrum.

Search for exotic pentaquark baryons with hidden strangeness $|qqqs\bar{s}\rangle$ in diffractive production reactions $p + N \to Y^*K + N$

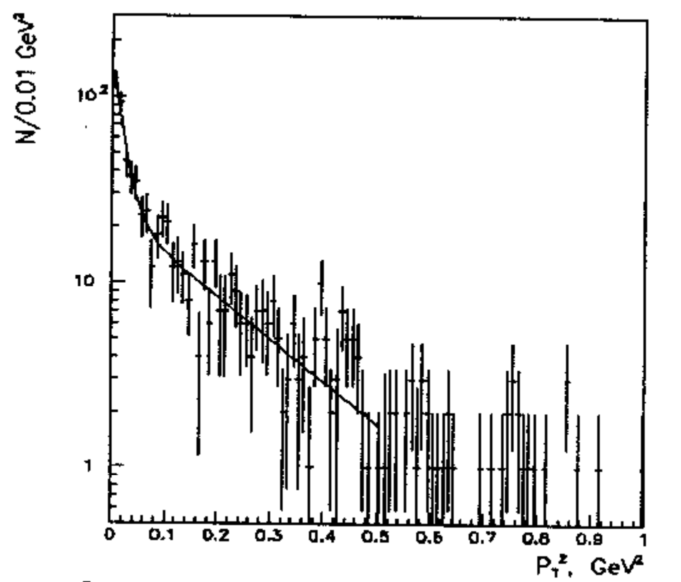
Experiment SPHINX at proton beam of IHEP accelerator with $E_p = 70\,\text{GeV}$. Reaction $p + N \to [\Sigma^0 K^+] + N; \Sigma^0 \to \Lambda\gamma$ was separated (N-nucleon or C nucleus for coherent reaction).



$M(\Sigma^0 K^+)$ for all P_T^2 weighted with efficiency of the setup.

$X(2000) \to \Sigma^0 K^+ \Big\} \begin{array}{lcl} M & = & 1989 \pm 6\,\text{MeV} \\ \Gamma & = & 91 \pm 20\,\text{MeV} \end{array}$

This state is seen with high statistical level (> 10 s.d.).



dN/dP_T^2 – strong coherent production on C nuclei is observed ($b = 63 \pm 10\,\text{GeV}^{-2}$)

Cross sections

$$\sigma[p + N \to X(2000) + N] \cdot BR[X(2000) \to \Sigma^0 K^+] = 95 \pm 20\,\text{nb/nucleon}$$
$$\sigma[p + C \to X(2000) + C]_{\text{coh.}} \cdot BR[X(2000) \to \Sigma^0 K^+] = 260 \pm 60\,\text{nb}/C\ \text{nucleus}$$

(±20% (system.) – Monte Carlo + absolute normalization)

Unusual dynamic properties of X(2000) state

a) $R = \frac{BR[X(2000) \to \Sigma K]}{BR[X(2000) \to \Delta(1232)\pi; p\pi^+\pi^-]} \gtrsim 1$

b) $\Gamma[X(2000)] \lesssim 100\,\text{MeV}$

For usual $|qqq\rangle$ isobars:

a) $R \lesssim (\text{few}) \cdot 10^{-2}$

b) $\Gamma(M \gtrsim 2000\,\text{MeV}) \sim 300 \div 400\,\text{MeV}$

X(2000) is serious candidate for pentaquark exotic baryon with hidden strangeness $|X(2000)\rangle = |uuds\bar{s}\rangle$

Reality of X(2000) is supported by other data

(SPHINX, SELEX)

Further plans

We already had 3 runs with completely upgraded SPHINX setup in which 10^9 trigger signals were recorded. Now this statistics is in process of data handling and we expect to increase our statistics for the reactions above more than by order of magnitude and to carry out the detailed study of the properties of observed new baryon states. Several other processes would be also investigated. For example, very clean data for Λ^* hyperon isosinglet states can be obtained in the diffractive reaction $p + N \rightarrow [(\Sigma^0\pi^0)K^+] + N$ for $(\Sigma^0\pi^0)_{I=0}$ system.

We will continue the analysis of E781 data for diffractive and Primakoff reactions(SELEX)..

Conclusion

In the study of diffractive production proton reactions with the SPHINX setup we observed several interesting objects with anomalous properties. The most important data was obtained for a new baryon state $X(2000) \rightarrow \Sigma^0K^+$. Unusual features of this massive state (relatively narrow decay width, large branching ratio for decay channels with strange particle emission) make it a serious candidate for cryptoexotic pentaquark baryon with hidden strangeness. We hope to increase significantly our statistics in the near future and to obtain a new information about the supposed exotic baryons.