Observation of narrow baryon resonance in $pK_s^0$ mode in $pA$-interactions at 70 GeV/c with SVD-2 setup.

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We report on the SVD-2 experiment data analysis aimed to search for an exotic baryon state, the $\Theta^+$-baryon, in a $pK_s^0$ decay mode with IHEP U-70 accelerator proton beam at 70 GeV/c. A resonant structure with $M = 1526 \pm 3(\text{stat.}) \pm 3(\text{syst.})$ MeV/$c^2$ and $\Gamma < 24$ MeV/$c^2$ was found in the $pK_s^0$ invariant mass spectrum, with the statistical significance of this peak estimated as $5.6 \sigma$.

Keywords: pentaquark, exotic baryons

SVD-2 EXPERIMENT

The present analysis was made in a framework of SVD-2 experiment, the main goal of which is a study of the charm hadroproduction at the near-threshold energy\[1, 2, 3\]. SVD-2 setup consists of high-precision microstrip vertex detector (beam telescope, active target and tracking detector), large aperture magnetic spectrometer, multicell threshold Cherenkov counter and Cherenkov full absorption lead glass gamma detector.

The primary vertex position determination procedure was based on well-known "tear-down" approach\[4, 5\]. Only events with a well reconstructed primary vertex were selected. After excluding the tracks that belongs to primary vertex, the secondary vertex position was determined by finding $V_0$-decay downstream the primary vertex. The primary vertex resolution was estimated as $70 - 120 \mu m$ for Z-coordinate and $8 - 12 \mu m$ for X(Y)-coordinates. For the two-tracks secondary vertices ($K^0_s$, $\Lambda$) those values were $250 \mu m$ and $15 \mu m$ respectively. The impact parameter resolution for $3 - 5$ GeV momentum tracks is about $12 \mu m$. The angular acceptance of the vertex detector averages to $\pm 250$ mrad.

The SVD-2 setup permits obtaining the high effective mass resolution of $\sigma = 4.4$ MeV/$c^2$ for $K_s^0$ and $1.6$ MeV/$c^2$ for $\Lambda^0$ masses (see fig.1). The momentum resolution for the track with 15 measured hits is $(0.5 \div 1.0)\%$ in the $(4 \div 20)$ GeV/c momentum range. The angular measurement error was estimated to be $0.2 \div 0.3$ mrad. The angular acceptance of spectrometer averages to $\pm 200$ mrad for horizontal and $\pm 150$ mrad for vertical coordinates.

![Graph 1](https://example.com/graph1.png)

**FIG. 1:** Left: the $(\pi^+\pi^-)$ invariant mass spectrum. A window corresponding to $\pm 2\sigma$ is shown by the vertical lines. Right: the $(p\pi^-)$ invariant mass spectrum.
The combined \((\pi^+K_s^0)\) and \((\pi^-K_s^0)\) invariant mass spectrum is shown on fig.2a. The \(K^+(892)\) peak is clearly seen on the distribution. Fig.2b shows \((\Lambda^0\pi^+)\) invariant mass spectrum. \(\Sigma^+(1385)\) peak is clearly seen. The masses of observed \(K_s^0, \Lambda^0\) and also masses and widths of \(K^+(892)\) and \(\Sigma^+(1385)\) are consistent with their PDG values.

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\begin{align*}
M_{eff}(K_s^0p) & \\
M_{eff}(\Lambda^0p) & \\
\end{align*}
\]

\[
\begin{align*}
\theta^+ & \\
\end{align*}
\]

\[
\begin{align*}
\Theta^+ - \text{BARYON SEARCHES} \text{ } & \text{ } \\
\Theta^+ - \text{BARYON SEARCHES} \text{ } & \text{ } \\
\end{align*}
\]

Exotic baryons with 5-quarks content (pentaquarks) and their properties have been predicted by Diakonov, Petrov, and Polyakov in the framework of the chiral soliton model, although such 5-quarks structures were proposed years ago. The lightest member of the pentaquarks antidecuplet, \(\Theta^+\)-baryon, has positive strangeness, mass \(M \sim 1530\text{ MeV}/c^2\), \(\Gamma \leq 15\text{ MeV}/c^2\), spin \(1/2\) and even parity.

Experimental evidence for \(\Theta^+\)-baryon with positive strangeness came recently from several experimental groups (LEPS, DIANA-ITEP, CLAS, SAPHIR). In those experiments \(\Theta^+\)-baryon was observed in the \(nK^+\) or \(pK_s^0\) invariant mass spectra with the mass near 1540 \(\text{MeV}/c^2\). More recently HERMES collaboration observed narrow baryon state at the mass of 1528 \(\text{MeV}/c^2\) in quasi-real photoproduction. Also ZEUS collaboration reported an evidence of the exotic baryon in \(pK_s^0\)-channel with the mass of 1527 \(\text{MeV}/c^2\).

\[
\begin{align*}
\text{EVENTS SELECTION AND } & pK_s^0\text{-SPECTRUM ANALYSIS.} \\
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\end{align*}
\]

We were searching for the \(\Theta^+\)-baryon in the reaction \(pN \rightarrow \Theta^+ + X, \Theta^+ \rightarrow pK_s^0, K_s^0 \rightarrow \pi^+\pi^-\). The data pre-selected at the search for the charm production were used. It consisted of events with V0-candidates decayed within the vertex detector: decay length \(\leq 35\text{ mm}\) with a mean of 20 mm. The following criteria were then applied:

- Primary charged particles multiplicity \(\leq 5\). Minimizes the combinatorial background, reduces the probability of appearance of the events with rescattering on nuclei and background of \(K_s^0\)-mesons produced in the central rapidity region.

- A presence of proton as well-measured primary positive track with a momentum of \(4\text{ GeV}/c \leq P_p \leq 21\text{ GeV}/c\) leaving no hit in Cherenkov counter.

- \(490\text{ MeV}/c^2 \leq M_{\pi^+\pi^-} \leq 505\text{ MeV}/c^2\) to select well-identified \(K_s^0\).

- \(\cos(\alpha) \geq 0\), where \(\alpha\) is angle of flight of \(pK_s^0\)-system in the center mass system of the beam proton and the target nucleon(beam proton fragmentation region).
• $P_{K^0} \leq P_p$ kinematical cut: effectively destroys most of the decays of $\Sigma^{*+}$-resonances with high masses while cutting only 10% of $\Theta^+$-peak events.

Resulting distribution is shown on fig. 3. The distribution was fitted by Gaussian function and fourth-order polynomial background. There are 50 events in the peak over 78 background events. The statistical significance for the fit inside a $45 \text{ MeV}/c^2$ mass window was calculated as $N_p/\sqrt{N_B}$, where $N_B$ is the number of counts in the background fit under the peak and $N_p$ is the number of counts in the peak. We estimate the significance to be of $5.6 \sigma$. It is impossible to determine the strangeness of this state in such an inclusive reaction, however there are no reported $\Sigma^{*+}$-resonances in $1500 \div 1550 \text{ MeV}/c^2$ mass area, so we interpret observed state as recently reported $\Theta^+$-baryon with a positive strangeness.

![FIG. 3: The ($pK_0^0$) invariant mass spectrum in the reaction $pA \rightarrow pK_0^0 + X$. Dashed line: background obtained from FRITIOF simulations.](image)

The $A$-dependence analysis in the observed peak area showed no difference (within measuring errors) from the $A^{0.7}$ dependence for background inelastic events (fig. 4).

In a summary, the inclusive reaction $pA \rightarrow pK_0^0 + X$ was studied at IHEP accelerator with proton energies at 70 GeV using SVD-2 detector. With several cuts applied a narrow baryon resonance was observed with mass $M = 1526 \pm 3 \text{(stat.)} \pm 3 \text{(syst.)} \text{ MeV}/c^2$ and $\Gamma < 24 \text{ MeV}/c^2$. The width of this state is close to SVD-2 experimental resolution for $pK_0^0$-system and its mass and width are consistent with recently reported $\Theta^+$-resonance $\Theta^{++}$ (uudd $\bar{s}$), which was predicted as an exotic pentaquark (uudd$\bar{s}$) baryon state.

![FIG. 4: The ratio of $\Theta^+$ events to the total of $K_0^0$ events for the different target materials](image)
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