SEARCHES FOR MULTIBARYON STATES WITH Λ HYPERON SYSTEMS IN pA COLLISION AT 10 GeV/c

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Abstract

Experimental data as a stereo photographs from the 2 m propane bubble chamber LHE, JINR have been analyzed for exotic multibaryon metastable and stable states searches. A number of peculiarities were found in the effective mass spectra of: 1) $\Lambda\pi^\pm, \Lambda\pi^+\pi^-$, $\Lambda p$, $\Lambda p\pi, \Lambda\Lambda$ and $\Lambda K^0_S$ subsystems. The observed well known $\Sigma^+(1385), \Lambda^+(1600)$ and $K^+(892)$ resonances are good tests for this method. The width of $\Sigma^-(1385)$ for p+A reaction is two time larger than that presented in PDG. The $\Lambda\pi^-$ spectrum observed enhancement in mass range of 1345 MeV/c² which interpreted as a stopped in nucleus $\Xi^-$. The cross section of stopped $\Xi^-$ production is $\approx 8$ times larger than obtained by fritiof model with same experimental conditions.
1 Preview

There are a few actual problems of nuclear and particle physics which are concerning subject of this report \cite{8, 14}. These are following: in-medium modification of hadrons, the origin of hadron masses, the restoration of chiral symmetry, the confinement of quarks in hadrons, the structure of neutron stars. Strange multi-baryonic clusters are an exiting possibility to explore the properties of cold dense baryonic matter and non-perturbative QCD. Multi-quark states, glueballs and hybrids have been searched for experimentally for a very long time, but none is established.

2 Experiment

The full experimental information of more than 700000 stereo photographs are used to select of events by $V^0$ channel \cite{8}. The momentum resolution charged particles are found to be $< \Delta P/P > = 2.1\%$ for stopped particles and $< \Delta P/P > = 9.8\%$, for nonstopped particles. The mean values of measurement errors for the depth and azimuthal angles are equal to $\leq 0.5$ degrees. The masses of the identified 8657-events with $\Lambda$ hyperon 4122-events with $K^0_s$ meson are consistent with their PDG values \cite{8}. The experimental total cross sections are equal to 13.3 and 4.6 mb for $\Lambda$ and $K^0_s$ production in the p+C collisions at 10 GeV/c. Protons can be identified by relative ionazation over the following momentum range: $0.150 < P < 0.900$ GeV/c.

The background has been obtained by methods: polynomial function, mixing angle and by FRITIOF model \cite{11}. The statistical significance of resonance peaks were calculated as $NP / \sqrt{NB}$, where $NB$ is the number of counts in the background under the peak and $NP$ is the number of counts in the peak above background.

3 $(\Lambda, \pi^+)$ and $(\Lambda, \pi^-)$ spectra

The $\Lambda\pi^+$- effective mass distribution for all 15444 combinations with bin size of 13 MeV/$c^2$ in Fig\ref{fig1}, has shown \cite{12, 13}. The resonance with similar decay properties for $\Sigma^{*(1382)} \rightarrow \Lambda\pi^+$ identified which was a good test for this method. The decay width is equal to $\Gamma \approx 45$ MeV/$c^2$. $\Delta M/M = 0.7$ in range of $\Sigma^{*(1382)}$ invariant mass. The cross section of $\Sigma^{*(1382)}$ production (540
exp. events) is approximately equal to 0.9 mb for p+C interaction.

The Λπ− effective mass distribution for all 6730 combinations with bin sizes of 18 and 12 MeV/c² in Fig. 1b has shown. The solid curve (Fig. 1b) is the sum of the background (by the polynomial method) and 1 Breit-Wigner resonance ($\chi^2/N.D.F. = 39/54$). There is significant enhancement in the mass range of 1372 MeV/c² with 11.3 S.D., $\Gamma = 93$ MeV/c². The cross section of Σ∗− production (≈ 680 events) is equal to ≈ 1.3 mb at 10 GeV/c for p+C interaction. The width for Σ∗− observed ≈ 2 times larger than PDG value. One of possible explanation is nuclear medium effects on invariant mass spectra of hadrons decaying in nuclei.

The Λπ− effective mass distribution with bin size of 12 MeV/c², where there are significant enhancements in mass regions of 1345(S.D.) and 1480(3.2) too. The solid curve (Fig. 2a) is the sum of the background and 1 Breit-Wigner resonance ($\chi^2/N.D.F. = 109/88$). The background curve is the sum of the six-order polynomial and 1 Breit-Wigner function with parameters for identified resonance Σ∗−(1385)(Fig. 1b). There are negligible enhancements in mass regions of 1410, 1520 and 1600 MeV/c². The cross section of Ξ− production (≈ 60 events) stopped in nuclear medium is equal to 315 µb at 10 GeV/c for p+propane interaction. The observed number events with Ξ− by weak decay channel is equal to 8 (w=1/εΛ =5.3, where is a full geometrical weight of registered for Λs) Then experimental cross section for identified Ξ− by weak decay channel is equal to 44µb and 11.7µb in p+propane and p+C collisions, respectively, which are conformed with FRITIOF calculation. The observed experimental cross section for stopped Ξ−(60 events) is 8 times larger than the cross section which is obtained by fritiof model with same experimental conditions. The width of Σ∗−(1385) for p+A reaction is two times larger than that presented in PDG. Figures shows that there is observed Σ∗−(1480) correlation which is agreed with report from SVD2 collaboration too.

4 (Λp) and (Λ, p, p) spectra

Figure 2 shows the invariant mass for all Λp 13103 combinations with bin size of 15 MeV/c². There are enhancements in mass regions of 2100, 2150, 2225 and 2353 MeV/c²(Fig. 2b). There are many published articles for the (Λp) invariant mass with identified protons in momentum range of 0.350 < $P_p$ < 0.900 GeV/c. There are significant enhancements in mass regions...
of 2100, 2175, 2285 and 2353 MeV/$c^2$. Their excess above background by the second method is 6.9, 4.9, 3.8 and 2.9 S.D., respectively. There is also a small peak in 2225(2.2 S.D.) MeV/$c^2$ mass region.

Figure 2 shows the invariant mass of 4011($\Lambda p$) combinations with bin size 15 MeV/$c^2$ for stopped protons in momentum range of $0.14 < P_p < 0.30$ GeV/c. The dashed curve is the sum of the 8-order polynomial and 4 Breit-Wigner curves with $\chi^2 = 30/25$ from fits (Table 1). A significant peak at invariant mass 2220 MeV/$c^2$ (6.1 S.D.), $B_K$ 120 MeV was specially stressed by Professor T. Yamazaki on $\mu$CF2007, Dubna, June-19-2007 that is conform with KNC model [1] prediction by channel of $K^- pp \rightarrow \Lambda p$.

The $\Lambda p$ effective mass distribution for 2025 combinations with relativistic protons over a momentum of $P > 1.65$ GeV/c is shown in Figure 2. The solid curve is the 6-order polynomial function ($\chi^2 / n.d.f = 205/73$). There are significant enhancements in mass regions of 2155 (2.6 S.D.), 2225 (4.7 S.D.), 2280 (4.2 S.D.), 2363 (3.6 S.D.) and 2650 MeV/$c^2$ (3.7 S.D.). These observed peaks for combinations with relativistic protons $P > 1.65$ GeV/c agreed with peaks for combination with identified protons and with stopped protons (Table 1).

The $\Lambda pp$ effective mass distribution for 3401 combinations for identified protons with a momentum of $P_p < 0.9$ GeV/c is shown in Figure 2. The solid curve is the 6-order polynomial function ($\chi^2 / n.d.f = 245/58$, Fig 3). The backgrounds for analysis of the experimental data are based on FRITIOF and the polynomial method. There is significant enhancements in mass regions of 3145 MeV/$c^2$ (6.1 S.D.) and with width 40 MeV/$c^2$. There are small enhancements in mass regions of 3225 (3.3 S.D.), 3325 (5.1 S.D.), 3440 (3.9 S.D.) and 3652 MeV/$c^2$ (2.6 S.D.)/(Table 1). These peaks from $\Lambda p$ and $\Lambda pp$ spectra were partly conformed with experimental results from FOPI (GSI), FINUDA (INFN), OBELIX (CERN) and E471 (KEK).

5  ($\Lambda, \Lambda$) spectrum

There is observed significant enhancement in mass region of 2360 (4.5 S.D.) Mev/$c^2$ for ($\Lambda, \Lambda$) spectrum in Figure 3(b)/(137 combination). This peak is conformed with theoretical predictions and with earlier published result from neutron exposure by PBC method with very poor statistics too. There is small
enhancement in mass range of 2525 Mev/c^2 (3.0 S.D.) too (Table I).

6 (Λ, p, π−) spectrum

The (Λ, p, π−) effective mass distribution (Fig. ??c) for 2975 combinations for identified protons in momentum range of P < 0.9 GeV/c can taken by the 6-order polynomial function which is satisfactory described the experimental data with χ²/(N.D.F.)=1. But the background by FRITIOF model do not describe the experimental distribution. The sum of BW (with mass 2520 MeV/c^2 and experimental width 280 MeV/c^2) and FRITIOF model for Λpπ− effective mass distribution is satisfactory described the experimental data too. Therefore one of probably interpretation of this peak that it can be reflection from phase space distribution too. Earlier published result about observation of resonance with mass 2495 MeV/c^2 and width 200 MeV/c^2 for Λpπ− spectrum by PBC method for neutron exposure (7 GeV/c) is not uniquely conformed.

7 (Λ, π+, π−) spectrum

The Λπ+π− effective mass distribution for all 3476 combinations with bin size 36 MeV/c^2 has shown in Figure 3d. The dashed curve is the the background by the polynomial method. There are significant enhancement in mass region of Λ*(1600)(5.5 S.D., Γe=80 MeV/c^2, ∆M=25 MeV/c^2) with width 55 (from PDG). There are small enhancements in mass regions of Λ*(1520)(3.5 S.D.), Λ*(1690)(3.8 S.D.) and Λ*(1800)(2.8 S.D.) MeV/c^2 which are interpreted as a reflection from resonances of Λ*(1520), Λ*(1690) and Λ*(1800) from PDG. There are not observed exotic states which were earlier observed and published for Λπ+π− spectrum (in mass ranges of 1704, 2071, 2604 MeV/c^2) with small statistic in neutron exposure by PBC method ?(shakh).

8 Conclusion

● The invariant mass of Λπ+, Λπ+π− and K_S^0π± spectra has observed well known resonances from PDG as Σ^*(1385), Λ*(1520), Λ*(1600), Λ*(1690) and K^*(892) which are a good test for this method.
● A number of important peculiarities were observed in pA → Λ(K_S^0) X reactions in the effective mass spectrum for exotic states with decay modes (TABLE II, III : 1) (Λ, π), (Λ, π+, π−), (Λ, p), (Λ, p, p, p), (Λ, Λ), Λ, p, π−), (Λ, K_S^0)
and $K^0\pi^\pm$.

- Particularly, peaks for $(\Lambda, p)$ and $(\Lambda, p, p)$ spectra are agreed with experimental data from the reports of FOPI, E471(KEK), OBELIX, FINUDA collaborations, but there are some inconstancy by widths.

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Figure 1: (a) The $\Lambda\pi^+$ spectrum; (b) All $\Lambda\pi^-$ comb with bin size of 18 MeV/c². The simulated events by FRITIOF is the dashed histogram. The background is the dashed curve.
Figure 2: a) $\Lambda\pi^-$ spectrum with bin size of 12 MeV/c$^2$, b) All comb for the $\Lambda p$ spectrum; c) $\Lambda p$ spectrum with stopped protons in momentum range of $0.14 < P_p < 0.30$ GeV/c; d) $\Lambda p$ spectrum for relativistic positive tracks in range of $P_p > 1.65$ GeV/c. The dashed histogram is simulated events by FRITIOF.
Figure 3: a) $\Lambda p p$ spectrum with identified protons $P_p < 0.9$ GeV/c; b) $\Lambda \Lambda$ spectrum; c) $\Lambda p^\pi^-$ spectrum with identified protons $P_p < 0.9$ GeV/c; d) $\Lambda \pi^+ \pi^-$ spectrum for positive tracks in momentum range of $P_{\pi^+} < 0.9$ GeV/c. The dashed histogram is simulated events by FRITIOF. The experimental background is the dashed curve.
Table 1: The effective mass, width(Γ) and S.D. for observed exotic strange resonances in p+ propane collisions.

| Λp   | 2100 | 24  | 5.7 |
|------|------|-----|-----|
|      | 2150 | 19  | 5.7 |
|      | 2220 | 23  | 6.1 |
|      | 2310 | 30  | 3.7 |
|      | 2380 | 32  | 3.5 |
| Λpp  | 3145 | 40  | 6.1 |
|      | 3225 | 50  | 3.3 |
|      | 3325 | 53  | 4.8 |
| ΛΛ   | 2365 | 55  | 4.5 |
|      | 2525 | 63  | 3.0 |
| ΛK₀  | 1750 | 14±6| 5.6 |
|      | 1795 | 26±15| 3.3|
| K₀π± | 890  | 50  | 6.0-8.2 |
|      | 780-800| 10  | 2.5-4.2 |
|      | 720-730| 30-125| 4.1-15.2 |
|      | 1060 | -   | 7.2 |

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