Λ AND $K^0_s$ PRODUCTION IN pC COLLISIONS AT 10 GeV/c

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Abstract

The experimental data from the 2m propane bubble chamber have been analyzed for pC→Λ($K^0_s$)X reactions at 10 GeV/c. The estimation of experimental inclusive cross sections for Λ and $K^0_s$ production in the p$^{12}$C collision is equal to σ$_\Lambda$= 13.3±1.7 mb and σ$_{K^0_s}$= 3.8±0.6 mb, respectively.

The measured Λ/$\pi^+$ ratio from pC reaction is equal to (5.3±0.8)×10$^{-2}$. The experimental Λ/$\pi^+$ ratio in the pC reaction is approximately two times larger than the Λ/$\pi^+$ ratio from pp reactions or from simulated pC reactions by FRITIOF model for the same energy. The Λ/$\pi^+$ ratio in interaction C+C at momentum 10 GeV/c is four times larger than the Λ/$\pi^+$ ratio from p+p reactions at the same energy.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energies, JINR.

1 Introduction

Strangeness enhancement has been extensively discussed as a possible signature for the quark-gluon plasma (QGP)\cite{1, 2}. Strange particle production has also been analyzed regarding such reaction mechanisms as the multinucleon effect\cite{3}, or the fireball effect\cite{4}, or as the deconfinement signal, within the context of thermal equilibration models\cite{5}-\cite{8}.

In particular, strange particles have been observed extensively on hadron - nucleus and nucleus-nucleus collisions 4-15 Gev regions\cite{9}-\cite{11}. The strange hyperon yields\cite{9}-\cite{11} are therefore of great interest as an indicator of strange quark production. The number of Λs produced in $\bar{p}$+Ta reaction at 4 GeV/c was 11.3 times larger than that expected from the geometrical cross section\cite{9}. Experiments with Si+Au and Au+AU collisions at 11.6\cite{13} and 14.6 A GeV/c\cite{14} measured a $K^+/\pi^+$ ratio in heavy-ion reactions that is four to five times larger than the $K^+/\pi^+$ ratio from p+p reactions at the same energy. The thermal model\cite{11} gives an good description of $K^+/\pi^+$, Λ/$\pi^+$ ratio for data Au+Au, Si+Au interaction at momenta 10-15 A GeV/c and, showing a broad maximum at the same energies.

However, there have not been sufficient experimental data concerning strange-hyperon production over 10-40 GeV/c momentum range in proton - nucleus and nucleus-nucleus reactions. In this paper the new results are presented the measured inclusive cross sections for Λ($K^0_s$) production and Λ/$\pi^+$ ratio in the reaction p+$^{12}$C.

2 Experimental procedure

2.1 METHOD

Searching for the $V^0$ on $\approx$ 700000(or 345*2 tapes) photographs of the JINR 2m propane bubble chamber exposed to a 10GeV/c proton beam\cite{16}-\cite{21}. The primary proton beams must be to satisfy of conditions: $|tg\alpha |< 0.02$, 1.62 < β <1.69 rad. The magnetic
GEOFIT is used to measure the kinematics track parameter $p$, $\alpha$, $\beta$. Measurements were repeated three times for events which failed in reconstruction by GEOFIT.

The estimate of ionization, the peculiarities of the end track points of stopping particles permitted one to identify them over the following momentum ranges: protons of 0.150 $\leq p \leq 0.900$ GeV/c and $K^\pm of p \leq 0.6$ GeV/c.

2.2 Identification of $\Lambda$ and $K^0_s$

The events with $V^0$ ($\Lambda$ and $K^0_s$) were identified using the following criteria [19, 20]:

1) $V^0$ stars from the photographs were selected according to $\Lambda \rightarrow \pi^- + p$, neutral $K_s \rightarrow \pi^- + \pi^+$ or $\gamma \rightarrow e^+ + e^-$ hypothesis. A momentum limit of $K^0_s$ and $\Lambda$ is greater than 0.1 and 0.2 GeV/c, respectively; 2) $V^0$ stars should have the effective mass of $K^0_s$ and of $\Lambda$; 3) these $V^0$ stars are directed to some vertices (complanarity); 4) they should have one vertex, three constraint fit for the $M_K$ or $M_\Lambda$ hypothesis and after the fit, $\chi^2_{V^0}$ should be selected over range less than 12; 5) The analysis has shown [20] that the events with undivided $\Lambda K^0_s$ were assumed to be events as $\Lambda$.

Table I presents (70%) the number of experimental $V^0$ events produced from interactions of: a) primary proton beams, b) secondary charged particles and c) secondary neutral particles.

The $V^0$s classified into three grades. The first grade comprised $V^0$s which could be identified with above cuts and bubble densities of the positive track emitted from the $V^0$s. The second grade comprised $V^0$s which could be undivided $\Lambda K^0_s$. For correctly identification the undivided $V^0$s are used the $\alpha$ (Fig.1a) and the $cos\theta^*_{\pi^-}$ (Fig.1b) distributions.

$$\alpha = (P^+_\parallel - P^-\parallel)/(P^+_\parallel - P^-\parallel)$$

Where $P^+_\parallel$ and $P^-\parallel$ are the momentum components of positive and negative charged tracks from the $V^0$s relative direction of the $V^0$s momentum. The

$cos\theta^*_{\pi^-}$ is the angular distribution of $\pi^-$ from $K^0_s$ decay. The $\alpha$ (Fig.1a) and the $cos\theta^*_{\pi^-}$ distributions from $K^0_s$ decay were isotropic in the $K^0_s$ rest frame after removing undivided $\Lambda K^0_s$. Then these $\Lambda K^0_s$ events appropriated events as $\Lambda$. After we show in Fig.1c that the $cos\theta^*_{\pi^-}$ distributions for the $\Lambda + \Lambda K^0_s$s have been also isotropic in $V^0$ rest frame. As a result of above procedure have lost of $K^0_s$ 8.5% and admixture of $K^0_s$ in $\Lambda$s events 4.6%. The third grade comprised $V^0$s which could be the invisible $V^0$s at a large azimuth angle $\phi$. The average $\phi$ weights were $< w_\phi > = 1.06 \pm 0.02$ for $K^0_s$ and $< w_\phi > = 1.14 \pm 0.02$ for $\Lambda$.

Figures 2a,c and 2b,d show the effective mass distribution of $\Lambda$ (8657-events), $K^0_s$ (4122-events) particles and their $\chi^2$ from kinematics fits, respectively, produced from the beam protons interacting with propane targets. The measured masses of these events have the following Gaussian distribution parameters: $< M(K^0_s) >= 497.7 \pm 3.6$, s.d. = 23.9 MeV/c$^2$ and $< M(\Lambda) > = 1117.0 \pm 0.6$, s.d. = 10.0 MeV/c$^2$. The masses of the observed $\Lambda$, $K^0_s$ are consistent with their PDG values. The expected functional form for $\chi^2$ is depicted with the dotted histogram (Fig.2).

Each $V^0$ event weighted by a factor $w_{geom}$ (=1/$e_r$), where $e_r$ is the probability for potentially observing the $V^0$, it can be expressed as

$$e_r = exp(-L_{min}/L) - exp(-L_{max}/L),$$
where \( L(=c\tau/M) \) is the flight length of the \( V^0 \), \( L_{\text{max}} \) the path length from the reaction point to the boundary of fiducial volume, and \( L_{\text{min}}(0.5 \text{ cm}) \) an observable minimum distance between the reaction point and the \( V^0 \) vertex. \( M, \tau, \) and \( p \) are the mass, lifetime, and momentum of the \( V^0 \). The average geometrical weights were 1.34\( \pm \)0.02 for \( \Lambda \) and 1.22\( \pm \)0.04 for \( K^0 \).

Now, let us examine a possibility from neutron stars of imitating \( \Lambda \) and \( K^0 \) using the model FRITIOF [22] for the hypotheses reaction \( p+C \rightarrow n+X, n+n \rightarrow \pi^- p (or \pi^- \pi^+) + X^0 \) with including fermi motion in carbon. Then, these background events were analyzed by using the same experimental condition for the selection \( V^0 \)s. The 2 vertex analysis have shown the background from neutron stars are equal to 0.1\% for \( \Lambda \) and 0.001 for \( K^0 \) events.

### 2.3 The selection of interactions on carbon nucleus

The criteria for selection of interaction with carbon has shown[19, 25]. The \( p+C \rightarrow \Lambda(K^0 \text{s})X \) reaction were selected by the following criteria:

1. \( Q = n_+ - n_- > 2; \)
2. \( n_p + n_\Lambda > 1; \)
3. \( n_p^b + n_\Lambda^b > 0; \)
4. \( n_- > 2; \)
5. \( n_{ch} \text{ odd number ;} \)
6. \( \frac{E_p(\Lambda) - P_p(\Lambda) \cos \theta_p(\Lambda)}{m_t} > 1. \)

\( n_+ \) and \( n_- \) are the number of positive and negative particles on the star; \( n_p \) and \( n_\Lambda \) are the number protons and \( \Lambda \) hyperons with momentum \( p<0.75 \text{ GeV/c} \) on the star. \( n_p^b \) \( n_\Lambda^b \) are the number protons and \( \Lambda \) hyperons to emitted in backward direction. \( E_p(\Lambda), P_p(\Lambda) \) and \( \theta_p(\Lambda) \) are a energy, a momentum and a emitted angle of protons(or \( \Lambda \)s) in the Lab. system. \( m_t \) is the mass of target. These criteria were separated \( \approx 83 \% \) from all inelastic \( p+C \) interactions[25]. The \( p+C \) events were selected by the above criteria the using FRITIOF model [22]. Results of the simulation have lost 18\% and 20\% from interactions \( p+C \rightarrow \Lambda X \) and \( p+C \rightarrow K^0 X \), respectively. The contribution from \( pp \rightarrow \Lambda X \) and \( pp \rightarrow K^0 X \) in \( p+C \) interactions are equal to 1.0\% and 0.3\%, respectively.

### 3 The measured cross sections \( \Lambda \) and \( K^0 \)

The cross section is defined by the formula:

\[
\sigma = \frac{\sigma_0}{e} \prod_i w_i = \frac{\sigma_r * N_r^{V^0} * w_{\text{hyp}} * w_{\text{geom}} * w_{\phi} * w_{\text{kin}} * w_{\text{int}}}{N_{r\text{int}}^F * e_1 * e_2 * e_3},
\]

where \( e_1 \) is the efficiency of search for \( V^0 \) on the photographs, \( e_2 \) the efficiency of measurements. The \( V^0 \)s of 75\% (preliminary) could be successfully reconstructed and accepted in the analysis. \( e_3 \) the probability of decay via the channel of charged particles \((\Lambda \rightarrow p\pi^-, K^0 \rightarrow \pi^+\pi^-)\), \( \sigma_0 = \sigma_r/N_r \) the total cross section, where \( \sigma_r \) is the total cross section for registered events, \( N_r \) is the total number of registered interactions of beam protons over the range of the chamber. \( \sigma_r(p + C_3 H_8) = 3\sigma_{pC} + 8\sigma_{pp}=(1456\pm88)\text{mb} \) [27], where \( \sigma_r, \sigma_{pC} \) and \( \sigma_{pp} \) are the total cross sections in interactions \( p + C_3 H_8, p+C \) and \( p+p \), respectively. The propane bubble chamber method have been permitted the registration.
Table 1: The amount (70 %) of $V^0$ events from interactions of different types which were registrated on photographs with propane bubble chambers method.

| Channel | The amount events from interactions: | Total events |
|---------|-------------------------------------|--------------|
|         | primary beam protons | sec. charged particles | sec. neutral particles |         |
| $\rightarrow \Lambda(only)x$ | 5276 | 2814 | 1063 | 9387 |
| $\rightarrow K^0_s(only)x$ | 4122 | 1795 | 481 | 6543 |
| $\rightarrow (\Lambda$ and $K^0_s)x$ | 3381 | 1095 | 376 | 4608 |

The part of all elastic interactions with the propane $^{23}$ $^{24}$ therefore the total cross section of registered events is equal to: $\sigma_r(p + C_3H_8) = 3\sigma_{pC}(inelastic) + 8\sigma_{pp}(inelastic) + 8\sigma_{pp}(elastic)0.70 = (1049 \pm 60)mb.$

$w_i$ are weights for the lost events with $V^0$ for (Table 2): $w_{geom}$ - the $V^0$ decay outside the chamber; $w_{\phi}$ - the required isotropy for $V^0$ in the azimuthal (XZ) plane; $w_{hyp}$ - the undivided $\Lambda K^0_s$ events; $w_{int}$ - the selected as $p + ^{12}C$ from the interaction of $p + C_3H_8$; $w_{kin}$ - the kinematic conditions (with FRITIOF); $w_{int}$ - the $V^0$ + propane interactions.

Table 3 show that the experimental cross sections are calculated by formula 3.1 for inclusive $\Lambda$ hyperons and $K^0_s$ mesons productions in the interactions of $pp$ and $pC$ at beam momentum 10 GeV/c.

Ratios of average multiplicities $\Lambda$ hyperons and $K^0_s$ mesons to multiplicities $\pi^+$ mesons in $p+C$ interaction at beam momenta 4.2 GeV/c and 10 GeV/c show in Table 4. Experimental data on multiplicities $\pi^+$ mesons in the interactions of $pC$ at momenta 4.2 GeV/c ($<n_{\pi^+}> = 0.71 \pm 0.01$) and 10 GeV/c ($<n_{\pi^+}> = 1.0 \pm 0.05$) taken from publications $^{25}$ and $^{26}$, respectively.

The $\Lambda/\pi^+$ ratio for $C+C$ reaction is shown in Table 5 and on Fig.3. This ratio have been obtained by using the Glauber approach on the experimental cross section for $p+C \rightarrow \Lambda X$ reaction.

4 Conclusion

The experimental data from the 2 m propane bubble chamber have been analyzed for $pC \rightarrow \Lambda(K^0_s)X$ reactions at 10 GeV/c. The estimation of experimental inclusive cross sections for $\Lambda$ and $K^0_s$ production in $pC$ collisions is equal to $\sigma_\Lambda = 13.3 \pm 1.7$ mb and $\sigma_{K^0_s} = 3.8 \pm 0.6$ mb, respectively. The measured $\Lambda/\pi^+$ ratio in $pC$ and $pp$ reactions is equal to $(5.3 \ 0.8)*10^{-2}$ and $(2.7 \ 0.4)*10^{-2}$, respectively. The experimental $\Lambda/\pi^+$ ratio in the $pC$ reaction is approximately two times larger than the $\Lambda/\pi^+$ ratio from $pp$ reactions or from simulated $pC$ reactions by FRITIOF model for the same energy. The $\Lambda/\pi^+$ ratio in $C+C$ collisions at 10.0 A GeV/c obtained that is four times larger than the $\Lambda/\pi^+$ ratio from $p+p$ reactions at the same energy.

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Table 2: Weight of the lost experimental events with Λ and $K^0_s$ for pC and pp interactions.

| Type of reaction | $1/e_1$ | $1/e_2$ | $w_{geom}$ | $w_\phi$ | $w_{int}$ | $w_{kin}$ | $1/e_3$ | $W_{sum}$ |
|------------------|---------|---------|------------|----------|----------|----------|---------|----------|
| pC→ ΛX           | 1.14    | 1.25    | 1.34       | 1.14     | 1.11     | 1.18     | 1.56    | 4.37±0.37|
| pp→ ΛX           | 1.14    | 1.25    | 1.36       | 1.14     | 1.11     | 1.37     | 1.56    | 5.15±0.44|
| pC→ $K^0_s$X     | 1.14    | 1.25    | 1.22       | 1.06     | 1.04     | 1.04     | 1.47    | 2.93±0.25|
| pp→ $K^0_s$X     | 1.14    | 1.25    | 1.36       | 1.06     | 1.05     | 1.06     | 1.47    | 3.31±0.28|

Table 3: Cross sections Λ hyperons and $K^0_s$ mesons for pp and pC interactions at beam momentum 10 GeV/c.

| Type of reaction | $N_{\Lambda}^{exp.}$ | $W_{sum}$ | $N_{V^0}^{Total}$ | $n_{V^0} = N_{V^0}^{Total}/N_{in}$ | $\sigma$ |
|------------------|----------------------|-----------|-------------------|----------------------------------|----------|
| pC→ ΛX           | 6126                 | 4.37±0.37 | 26770             | 0.053±0.005                      | 13.3±1.6 |
| pp→ ΛX           | 836                  | 5.15±0.44 | 4303              | 0.026±0.003                      | 0.80±0.08|
| pC→ $K^0_s$X     | 3188                 | 2.93±0.25 | 9341              | 0.018±0.002                      | 3.8±0.5  |
| pp→ $K^0_s$X     | 699                  | 3.31±0.28 | 2313              | 0.015±0.001                      | 0.43±0.04|

Table 4: Ratios of average multiplicities Λ hyperons and $K^0_s$ mesons to multiplicities $\pi^+$ mesons for p+C interaction at beam momenta 4.2 GeV/c and 10 GeV/c.

|                  | pC This experiment (10 GeV/c) | pC FRITIOF (10 GeV/c) | Cp Experiment (4.2 GeV/c) | Cp FRITIOF (4.2 GeV/c) |
|------------------|------------------------------|-----------------------|---------------------------|------------------------|
| $< n_\Lambda > / < n_{\pi^+} > \times 10^2$ | 5.3±0.8                     | 2.6                   | 0.7±0.3                   | 0.9                    |
| $< n_{K^0_s} > / < n_{\pi^+} > \times 10^2$  | 1.8±0.3                     | 1.8                   | 0.3±0.2                   | 0.3                    |

Table 5: Ratios of average multiplicities Λ hyperons to multiplicities $\pi^+$ mesons for C+C interactions at beam momentum 4.2 and 10 GeV/c.

|                  | 4.2 Experiment | 10 Experiment |
|------------------|----------------|---------------|
| $< n_\Lambda > / < n_{\pi^+} > \times 10^2$ | 2.0±0.6 | 10.9±1.7 |
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Figure 1: Distributions of $\alpha$ (Armenteros parameter) and $\cos\Theta^*$- are used for correctly identification of the undivided V0s. $\alpha = (P^+ - P^-)/((P^+ - P^-)$. Where $P^+$ and $P^-$ are the parallel components of momenta positive and negative charged tracks. $\cos\Theta^*$ - is the angular distribution of $\pi^-$ from $K_s^0$ decay. Distributions of $\alpha$ and $\cos\theta^*$ were isotropic in the rest frame of $K_s^0$ when undivided $\Lambda K_s^0$ were assumed to be events as $\Lambda$. 
Figure 2: The distribution of experimental $V^0$ events produced from interactions of beam protons with propane: a) for the effective mass of $M_\Lambda$; b) for $\chi^2_\Lambda(1V - 3C)$ of the fits via the decay mode $\Lambda \to \pi^- + p$; c) for the effective mass of $M_{K^0_S}$; d) for $\chi^2_{K^0_S}(1V - 3C)$ of the fits via decay mode $K^0_S \to \pi^- + \pi^+$. The expected functional form for $\chi^2$ is depicted with the dotted histogram.
Figure 3: Prediction of the statistical-thermal model\cite{6} for $\Lambda/\pi^+$ (note the factor 5), and $\Xi^-/\pi^+$ and $\Omega^-/\pi^+$ ratios a function of $\sqrt{s}$. For compilation of AGS data see \cite{7}. The $\Lambda/\pi^+$ ratio in interaction C+C on figure is obtained by using data from this experiment.