E1-2005-150

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Λ AND K_s^0 PRODUCTION IN p+C COLLISIONS AT 10 GeV/c

Presented at the International Conference LEAP-05, Bonn–Jülich, Germany, May 16–22, 2005, and Workshop QGP-05, Vienna, August 9–12, 2005. Submitted to «Particles and Nuclei, Letters»

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Асланян П. Ж., Емельяненко В. Н., Рихвицкая Г. Г. E1-2005-150
Инклюзивные сечения для выходов Λ и K_s^0 в реакции p+C
при импульсе пучка 10 ГэВ/c

Экспериментальные данные, полученные с помощью 2-м пропановой пузырьковой камеры, проанализированы для канала реакции $p\mathrm{C}\to \Lambda(K_s^0)X$ при импульсе пучка протонов 10 ГэВ/c. Экспериментальные измерения инклюзивных сечений для выходов Λ и K_s^0 в столкновениях p^{12}C равны σ_Λ = (13,3±1,7) мб и $\sigma_{K_s^0}$ = (3,8±0,6) мб соответственно.

Также измерены отношения для средних множественностей Λ/π^+ и K_s^0/π^+ для реакции pC. Экспериментально получаем, что величина для отношений Λ/π^+((5,3±0,8)$\cdot 10^{-2}$) в реакции pC приблизительно в два раза больше, чем это же отношение, рассчитанное моделью FRITIOF при одинаковых экспериментальных условиях. Это отклонение для отношений средних множественностей увеличивается и достигает максимальных значений ($\approx$ в 4 раза больше) при импульсах пучка 10–15 A ГэВ/c не только в столкновениях тяжелых ионов, но и в реакции C+C, как и предсказывает термальная статистическая адронная модель.

Работа выполнена в Лаборатории высоких энергий им. В. И. Векслера и А. М. Балдина ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 2005

Aslanyan P. Zh., Emelyanenko V. N., Rikhvitzkaya G. G. E1-2005-150
Λ and K_s^0 Production in p+C Collisions at 10 GeV/c

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

The measured Λ/π^+ ratio from pC reaction is equal to (5.3±0.8)$\cdot 10^{-2}$. The experimental Λ/π^+ ratio in the pC reaction is approximately two times larger than the Λ/π^+ ratio received with FRITIOF model for the same reaction and energy. The Λ/π^+ ratio has significant enhancement for heavy-ion and also for C+C collisions at 10–15 A GeV/c as a thermal statistical hadron model predicted.

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

Preprint of the Joint Institute for Nuclear Research. Dubna, 2005

1. INTRODUCTION

Strangeness enhancement has been extensively discussed as a possible signature for the quark–gluon plasma (QGP) [1, 2]. Strange-particle production has also been analyzed regarding such reaction mechanisms as the multinucleon effect [3], the fireball effect [4], and the deconfiment signal within the context of thermal equilibration models [5–8] (Fig. 3).

In particular, strange particles have been observed extensively in hadron–nucleus and nucleus–nucleus collisions in 4–15-Gev regions [9–14]. The strange-hyperon yields [9–11] are therefore of great interest as an indicator of strange-quark production. The number of Λ's produced in $\overline{p}$+Ta reaction at 4 GeV/c was 11.3 times larger than that expected from the geometrical cross section [9]. In experiments with Si+Au and Au+Au collisions at 11.6 [13] and 14.6 A GeV/c [14] a K^+/π^+ ratio in heavy-ion reactions was measured to be 4–5 times larger than the K^+/π^+ ratio in $p + p$ reactions at the same energy. The thermal model [6] gives a good description of K^+/π^+, Λ/π^+ ratios for data Au+Au, Si+Au interactions at momentum 10–15 A Gev/c, 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 this paper, new results are presented — the measured inclusive cross sections for ΛK^0_s production and Λ/π^+ ratio in the reaction p+^{12}C.

2. EXPERIMENTAL PROCEDURE

2.1. Method. Experimantal data on $\approx$ 700 000 stereo photographs by the JINR 2-m propane bubble chamber exposed to a 10-GeV/c proton beam [15–21] were analyzed. The primary proton beams must satisfy conditions: $\mid tg\alpha \mid < 0.02$, $1.62 < \beta < 1.69$ rad. The magnetic field (B=15.2 kG) measurement error is $\Delta B/B = 1\%$. The fit GRIND-based program GEOFIT [18, 15] is used to measure the kinematics track parameters p, α, β. Measurements were repeated three times for events which failed in reconstruction by GEOFIT [15].

The estimation of ionization for charged tracks and length for stopped 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 Λ and K_s^0. The events with V^0 (Λ and K_s^0) were identified using the following criteria [19, 20, 21]: 1) V^0 stars from the photographs were selected according to $\Lambda \to \pi^- + p$, neutral $K_s \to \pi^- + \pi^+$ or $\gamma \to e^+ + e^-$ hypothesis. A momentum limit of K_s^0 and Λ is greater than 0.1 and 0.2 GeV/c, respectively ; 2) V^0 stars should have the effective mass of K_s^0 and Λ; 3) these V^0 stars are directed to some vertices (coplanarity); 4) they should have one vertex, a three-constraint fit for the M_K or M_Λ hypothesis and after the fit $\chi^2_{V^0}$ should be selected over the range less than 12; 5) the analysis has shown [20] that the events with undivided ΛK_s^0 were assumed to be Λ.

Table 1 presents the number of experimental V^0 events (70% of all events have been identified) produced from interactions of: a) primary beam protons, b) secondary charged particles, and c) secondary neutral particles.

Table 1. The number of V^0 events from interactions of different types which were registered in stereo photographs without restrictions over effective ranges of propane bubble chamber

Channel	The number of events from interactions			Total events
	Primary beam protons	Sec. charged particles	Sec. neutral particles	
$\to \Lambda(\text{only})x$	5276	2814	1063	9387
$\to K_s^0(\text{only})x$	4122	1795	481	6543
$\to (\Lambda$ and $K_s^0)$ x	3381	1095	376	4608

The V^0's can be classified into three grades. The first grade comprised V^0's which could be identified with the above criteria (1–4) and bubble densities of the positive track emitted from V^0's. The second grade comprised V^0's which could be undivided ΛK_s^0. For correct identification of the undivided V^0's, the α Armenteros parameter and the $\cos\theta^*_{\pi^-}$ distributions in the rest frame V^0 (Fig. 1) are used:

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

where $P^+_\parallel$ and $P^-_\parallel$ are the momentum components of positive and negative charged tracks from the V^0 relative direction of the V^0 momentum. The $\theta^*_{\pi^-}$ is the angle between π^- (from K_s^0 decay) and V^0 in V^0 rest frame. The α (Fig. 1, a) and $\cos\theta^*_{\pi^-}$ distributions from K_s^0 decay were isotropic in the K_s^0 rest frame after removing undivided ΛK_s^0. Then these ΛK_s^0 events are assumed to be Λ events. In Fig. 1, c we show that the $\cos\theta^*_{\pi^-}$ distributions for the Λ+ΛK_s^0 have been also isotropic in V^0 rest frame. As a result of the above procedure, 8.5% of K_s^0 are lost and 4.6% of K_s^0 are interpreted as Λ. The third grade comprised V^0's which could be the invisible V^0's at a large azimuth angle ϕ [20]. The average ϕ weights were $< w_\phi >$ = 1.06±0.02 for K_s^0 and $< w_\phi >$ = 1.14±0.02 for Λ.

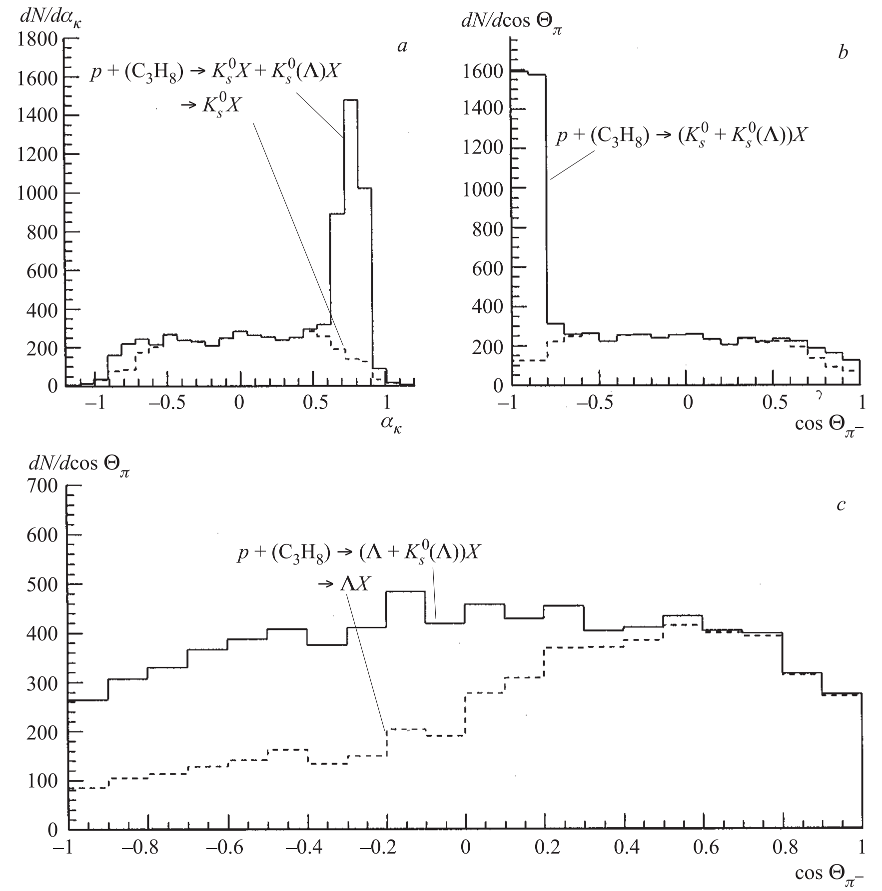

Fig. 1. Distributions of α (Armenteros parameter) and cos Θ^* are used for correct identification of the undivided V^0's. $\alpha = (P_{\|}^{+} - P_{\|}^{-})/((P_{\|}^{+} + P_{\|}^{-})$, where $P_{\|}^{+}$ and $P_{\|}^{-}$ are the parallel components of momenta of positive and negative charged tracks with respect to the direction of momentum $K_s^0(\Lambda)$, cos Θ^* is the angular distribution of π^- from K_s^0 decay. Distributions of α and cos Θ were isotropic in the rest frame of K_s^0 when undivided $K_s^0(\Lambda)$ were assumed to be Λ

Figures 2, a, c and 2, b, d show the effective mass distribution of Λ (8657 events), K^0 (4122 events) particles and their χ^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 $< M(K_s) >$ = 497.7±3.6, SD = 23.9 MeV/c^2 and $< M(\Lambda) >$ = 1117.0±0.6, SD = 10.0 MeV/c^2. The masses of the observed Λ, K_s^0 are consistent with their PDG values. The expected functional form for χ^2 is depicted with the dotted histogram (Fig. 2).

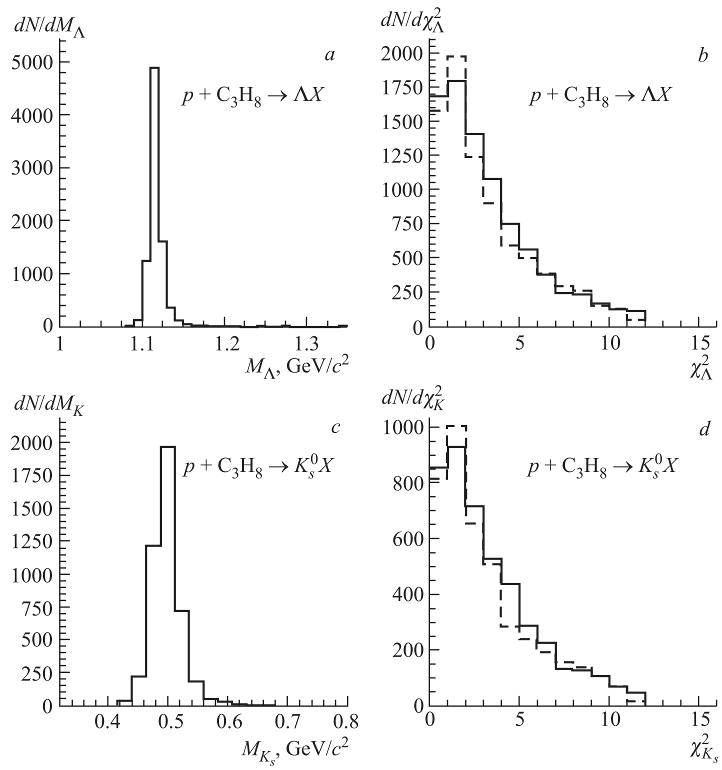

Fig. 2. The distribution of experimental V^0 events produced from interactions of beam protons with propane: *a*) for the effective mass of M_Λ; *b*) for χ^2_Λ of the fits via the decay mode $\Lambda \to \pi^- + p$; *c*) for the effective mass of $M_{K^0_s}$; *d*) for $\chi^2_{K^0_s}$ of the fits via decay mode $K^0_s \to \pi^- + \pi^+$. The expected functional form for χ^2 is depicted with the dotted histogram

Each V^0 event weighted by a factor $w_{\rm geom}$ = 1/e_τ, where e_τ is the probability for potentially observed V^0, can be expressed as

$$e_\tau = \exp\left(-L_{\rm min}/L\right) - \exp\left(-L_{\rm max}/L\right), \tag{1}$$

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

Now, let us examine a possibility from neutron stars of imitating Λ and K^0_s by using FRITIOF model [22] for the hypothesis reaction p+C→ $n + X$,

$n+n \rightarrow \pi^- p(\pi^-\pi^+)+X^0$ including Fermi motion in carbon. Then, these background events were analyzed by using the same experimental conditions for the V^0 selection. The 2-vertex analysis has shown that the background from neutron stars is equal to 0.1 % for Λ and 0.001 for K_s^0 events.

2.3. The Selection of Interactions on Carbon Nucleus. The criteria for selection of interaction with carbon has been shown [19,25]. The p+C$\rightarrow \Lambda(K_s^0)X$ reaction was 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. $n_{\rm ch}$ = odd number ;
6. $\dfrac{E_p(\Lambda) - P_{p(\Lambda)}\cos\Theta_{p(\Lambda)}}{m_t}$ >1;

n_+ and n_- > are the numbers of positive and negative particles on the star; n_p and n_Λ are the numbers of protons and Λ hyperons with momentum $P < 0.75$ GeV/c on the star; n_p^b and n_Λ^b are the numbers of protons and Λ hyperons emitted in backward direction; $E_{p(\Lambda)}$, $P_{p(\Lambda)}$ and $\Theta_{p(\Lambda)}$ are an energy, a momentum and an emitted angle of protons (or Λ's) in the lab system; m_t is a mass of the target. These criteria were separated $\approx$ 83% from all inelastic p+C interactions [25]. The p+C events were selected by the above criteria from simulated p+propane interactions by using FRITIOF model [22] under experimental conditions and by the above criteria. Results of the simulation show loss of 18% and 20% from interactions pC$\rightarrow \Lambda X$ and pC$\rightarrow K_s^0 X$, respectively. The simulation by FRITIOF model also shows that the contribution from $pp \rightarrow \Lambda X$ and $pp \rightarrow K_s^0 X$ in pC interactions is equal to 1.0% and 0.3%, respectively.

3. THE MEASURED CROSS SECTIONS Λ AND K^0

The cross section is defined by the formula:

$$\sigma = \frac{\sigma_0 N_r^{V^0}}{e}\prod_i w_i = \frac{\sigma_r N_r^{V^0} w_{\rm hyp} w_{\rm geom} w\phi w_{\rm kin} w_{\rm int}}{N_{\rm int}^r e_1 e_2 e_3}, \qquad (2)$$

where e_1 is the efficiency of search for V^0 on the photographs, e_2 is the efficiency of measurements, e_3 is the probability of decay via the channel of charged particles ($\Lambda \rightarrow p\pi^-, K^0 \rightarrow \pi^+\pi^-$), $\sigma_0 = \sigma_r/N_r$ is the total cross section, where σ_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. $\sigma_t(p + {\rm C_3H_8}) =$ $3\sigma_{p\rm C} + 8\sigma_{pp}$ = (1456$\pm$88) mb [27], where $\sigma_t, \sigma_{p\rm C}$ and σ_{pp} are the total cross sections in interactions $p+{\rm C_3H_8}$, p+C and $p+p$, respectively. The propane bubble chamber method has allowed the registration of the part of all elastic interactions with the propane [23, 24], therefore the total cross section of registered events is equal to $\sigma_r(p + \mathrm{C_3H_8}) = 3\sigma_{p\mathrm{C}}(\mathrm{inelastic}) + 8\sigma_{pp}(\mathrm{inelastic}) + 8\sigma_{pp}(\mathrm{elastic})0.70$ = (1049±60) mb [23]. w_i are weights for the lost events with V^0 for (Table 2): w_{geom} — the V^0 decay outside the chamber; w_ϕ — the required isotropy for V^0 in the azimuthal (XZ) plane; w_{hyp} — the undivided ΛK_s^0 events; w_{int} — the selected as $p\ +\ ^{12}\mathrm{C}$ from the interaction of $p\ +\ \mathrm{C_3H_8}$; w_{kin} — the kinematic conditions (by FRITIOF); w_{int} — the V^0+ propane interactions.

Table 2. Weight of the lost experimental events with Λ and K_s^0 for pC and pp interactions

Type of reaction	$1/e_1$	$1/e_2$	w_{geom}	w_ϕ	w_{int}	w_{kin}	$1/e_3$	$\mathrm{W_{sum}}$
$p\mathrm{C}\to \Lambda X$	1.14	1.25	1.34	1.14	1.11	1.18	1.56	4.37±0.37
$pp \to \Lambda X$	1.14	1.25	1.36	1.14	1.11	1.37	1.56	5.15±0.44
$p\mathrm{C}\to K_s^0 X$	1.14	1.25	1.22	1.06	1.04	1.04	1.47	2.93±0.25
$pp \to K_s^0 X$	1.14	1.25	1.36	1.06	1.05	1.06	1.47	3.31±0.28

Table 3 shows that the experimental cross sections are calculated by (2) for inclusive Λ hyperon and K_s^0 meson productions in the interactions of pp and pC at beam momentum of 10 GeV/c.

Table 3. Cross sections of Λ hyperons and K_s^0 mesons for pp and pC interactions at beam momentum of 10 GeV/c

Type of reaction	$N_{V^0}^{\mathrm{exp}}$	W_{sum}	$N_{V^0}^t$ (total)	$n_{V^0} = N_{V^0}^t / N_{\mathrm{in}}$	σ, mb
$p\mathrm{C}\to \Lambda X$	6126	4.37±0.37	26770	0.053±0.005	13.3±1.6
$pp \to \Lambda X$	836	5.15±0.44	4303	0.026±0.003	0.80±0.08
$p\mathrm{C}\to K_s^0 X$	3188	2.93±0.25	9341	0.018±0.002	3.8±0.6
$pp \to K_s^0 X$	699	3.31±0.28	2313	0.015±0.001	0.43±0.04

Ratios of average multiplicities of Λ hyperons and K_s^0 mesons to multiplicities of π^+ mesons in p+C interaction at beam momenta 4.2 and 10 GeV/c are shown in Table 4. Experimental data on multiplicity of π^+ mesons in the interaction of pC at momenta 4.2 GeV/c ($< n_{\pi+} >= 0.71$±0.01) and 10 Gev/c ($< n_{\pi+} >= 1.0$±0.05) are taken from publications [26] and [25], respectively.

The Λ/π^+ ratio for C+C reaction is shown in Table 5 and in Fig. 3. This Λ/π^+ ratio at momentum 10 GeV/c has been obtained by using the Glauber approach on the experimental cross section for p+C $\to \Lambda X$ reaction. As can be seen from experimental data in Table 5 and thermal statistical model (Fig. 3)

Table 4. Ratios of average multiplicities of Λ hyperons and K_s^0 mesons to multiplicities of π^+ mesons for p+C interaction at beam momenta of 4.2 and 10 GeV/c

	pC experiment (10 GeV/c)	pC FRITIOF (10 GeV/c)	Cp experiment (4.2 GeV/c)	Cp FRITIOF (4.2 GeV/c)
$< n_\Lambda > / < n_{\pi+} > \cdot 10^2$	5.3±0.8	2.6	0.7±0.3	0.9
$< n_{K_s^0} > / < n_{\pi+} > \cdot 10^2$	1.8±0.3	1.8	0.3±0.2	0.3

there is a very clearly pronounced enhancement specially in the Λ/π^+ ratio for hadron–nucleus and nuclear collisions at 10–15 A GeV/c.

Table 5. Ratios of average multiplicity of Λ hyperons to multiplicity of π^+ mesons for C+C interactions at beam momenta of 4.2 and 10 GeV/c

	Experiment (4.2 GeV/c)	Experiment (10 GeV/c)
$< n_\Lambda > / < n_{\pi+} > \cdot 10^2$	2.0±0.6	10.9±1.7

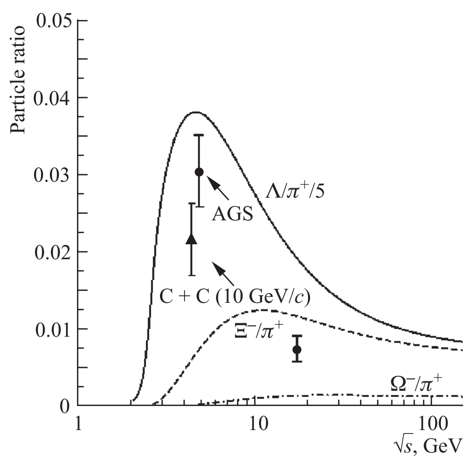

Fig. 3. Prediction of the statistical thermal model [6] for Λ/π^+(note the factor 5), Ξ^-/π^+ and Ω^-/π^+ ratios versus $\sqrt{s}$. For compilation of AGS data see [7]. The Λ/π^+ ratio in interaction C+C in figure is obtained by using data from this experiment

4. CONCLUSION

The experimental data from the 2-m propane bubble chamber have been analyzed for pC→ $\Lambda(K_s^0)X$ reaction at 10 GeV/c. The estimation of experimental inclusive cross sections for Λ and K_s^0 production in pC collisions is equal to σ_Λ = (13.3±1.7) mb and $\sigma_{K_s^0}$ = (3.8±0.6) mb, respectively. The measured Λ/π^+ ratio in pC and pp reactions is equal to (5.3±0.8)$\cdot10^{-2}$ and (2.6±0.4)$\cdot10^{-2}$, respectively. The experimental Λ/π^+ ratio in the pC reaction is approximately two times larger than the Λ/π^+ ratio received from pp or pC reaction by FRITIOF model for the same energy. There is a very clearly pronounced enhancement in the Λ/π^+ ratio for Au+Au and C+C collisions at 10–15 A GeV/c as predicted by the thermal statistical hadron model.

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Received on October 5, 2005.

Редактор *Н. С. Скокова*

Подписано в печать 21.11.2005.
Формат 60 × 90/16. Бумага офсетная. Печать офсетная.
Усл. печ. л. 0,69. Уч.-изд. л. 0,99. Тираж 365 экз. Заказ № 55105.

Издательский отдел Объединенного института ядерных исследований
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