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PRODUCTION OF γ-QUANTA AND NEUTRAL STRANGE PARTICLES IN dTa AND CTa INTERACTIONS AT 4.2 GeV/c PER NUCLEON

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A systematic study of inelastic nucleus-nucleus interactions at Dubna and Berkeley has yielded a large amount of data on charged particle production. Information on neutral particles in nucleus-nucleus interactions is still very scarce. First results have been published on Λ production in Ar+KCl central collisions at 2.6 GeV/c/N/1/ and in the ^{4}He+^{6}Li-collisions at 4.5 GeV/c/N/2/.

In this paper we present some experimental data on γ, Λ and K°_s production in dTa and CTa interactions at 4.2 GeV/c/N. The pictures obtained in the 2 m propane bubble chamber of JINR were used. Three tantalum plates ($140\times70\times1$ mm^3) used as a target were mounted inside the fiducial volume of the chamber. They were placed 93 mm apart /3/.

SELECTION OF γ-QUANTA AND V°-EVENTS

About 26000 and 50000 pictures from deuteron and carbon irradiation, respectively, were scanned for γ-quanta. To search for V°'s, 26000 and 90000 pictures from d and ^{12}C irradiation, respectively, were scanned. After measurements and geometrical reconstruction by the GEOFIT program 278γ, 10Λ and 5K°_s were obtained for dTa and 687γ, 33Λ and 20K°_s for CTa interactions.

The following conditions were used as selection criteria:

1. χ^2-probability should be larger than 1% for the hypotheses of γ, Λ and K°_s.

2. Coordinates of the points of γ conversion or Λ and K°_s decay should be within the fiducial volume of the chamber/4/. Among the γ-quanta selected according to the above criteria there was some number of γ's converting in the tantalum plates (23 for dTa and 73 for CTa interactions). They all were excluded from further consideration because the number of e^+e^--pairs, having undergone scattering in the plates, could not be established. Bremsstrahlung γ's (2%) were also excluded from the γ-quanta selected, using standard criteria on $m_{\gamma\gamma}$ and $\theta_{\gamma\gamma}$/4/.

The particles, which either satisfied one hypothesis or even two hypotheses with χ^2-probability > 1% and could be separated by the ionization or energy of δ-electrons on the tracks of positively charged decay products, were assumed to be unambiguously identified (Λ, K^0_s). The ambiguous particles ($\Lambda \sim K^0_s$) (they were seven) were attributed to Λ or K^0_s by maximum χ^2 -probability. The average masses of Λ-hyperons and K^0_s -mesons were the following

$$\langle m_\Lambda \rangle = 1116 \pm 2\ \mathrm{MeV}/c^2,$$

$$\langle m_{K^0_s} \rangle = 498 \pm 5\ \mathrm{MeV}/c^2.$$

To find the total number of γ's, Λ's and K^0_s-particles produced in dTa and CTa interactions, some corrections were introduced. To all γ-quanta, converting in propane, were attributed the weight W^{geom} inversely proportional to their probability of conversion inside the fiducial volume of the chamber excluding the Ta plates. In addition, corrections were introduced for: a) the losses of e^+e^- pairs in the vicinity of the interaction point (at a distance smaller than 3 cm for CTa and 1 cm for dTa), b) scanning and measurement efficiency and c) Compton effect and change of the e^+e^- direction from that of γ-quantum by an angle of $> 3°$ in the conversion act[5]. The average values of W^{geom} and W^{tot} of γ-quanta are presented in Table 1.

Table 1

Average multiplicities of π^0, Λ and K^0_s

Reaction	N	$\langle W^{geom} \rangle$	$\langle W^{tot} \rangle$	$\langle n \rangle$
$dTa \to \gamma + \ldots$	249	8.78 ± 0.40	12.0 ± 1.7	1.1 ± 0.2
$CTa \to \gamma + \ldots$	606	8.45 ± 0.26	11.6 ± 0.9	3.8 ± 0.4
$dTa \to \Lambda + \ldots$	10	1.05 ± 0.02	1.8 ± 0.2	0.013 ± 0.006
$CTa \to \Lambda + \ldots$	31	1.08 ± 0.03	2.0 ± 0.2	0.046 ± 0.010
$dTa \to K^0_s + \ldots$	5	1.00 ± 0.01	1.6 ± 0.2	0.006 ± 0.003
$CTa \to K^0_s + \ldots$	18	1.02 ± 0.01	1.7 ± 0.2	0.023 ± 0.007

For each Λ and K^0_s the "weight", inversely proportional to their probability of decay in the fiducial volume of the chamber, was also determined[4]. Additional corrections were introduced for the losses of Λ and K^0_s in the vicinity of the interaction point (up to 2 cm), for scanning efficiency and for neutral decay modes. The average weights are given in Table 1.

AVERAGE MULTIPLICITIES, MOMENTUM AND ANGULAR DISTRIBUTIONS OF γ-QUANTA IN dTa AND CTa INTERACTIONS

The average multiplicities of γ-quanta determined from the relation

$$\langle n_\gamma \rangle = \frac{N_\gamma \cdot \langle W^{tot}_\gamma \rangle}{N_{ev}}$$

are equal, respectively, $\langle n_\gamma \rangle^{dTa} = 2.20 \pm 0.36$ and $\langle n_\gamma \rangle^{CTa} = 7.52 \pm 0.74$. Assuming that π^0-mesons are the only source of γ-quanta, we obtain the average multiplicities of π^0's presented in Table 1. The values of $\langle n_{\pi^0} \rangle$, within the errors, coincide with the average multiplicities of π^-'s obtained previously for dTa and CTa interactions: $\langle n_{\pi^-} \rangle^{dTa} = 0.91 \pm 0.05$ and $\langle n_{\pi^-} \rangle^{CTa} = 3.4 \pm 0.2$[6]. It should be noted that there is a tendency toward some excess of $\langle n_{\pi^0} \rangle$ over $\langle n_{\pi^-} \rangle$ for both dTa and CTa interactions. This can be a consequence of some excess of $\langle n_{\pi^0} \rangle$ over $\langle n_{\pi^-} \rangle$ for NN interactions[7].

The ratio of average π^0 multiplicities in CTa and dTa interactions equals

$$\langle n_{\pi^0} \rangle^{CTa} / \langle n_{\pi^0} \rangle^{dTa} = 3.4 \pm 0.7,$$

and within the errors, it is equal to the ratio

$$\langle \nu \rangle^{CTa} / \langle \nu \rangle^{dTa} = 4.1 \pm 0.3.$$

where $\langle \nu \rangle$ is the average number of interacting projectile nucleons experimentally determined in our previous paper[8]. Thus, not only the multiplicity of π^--mesons (as found in ref.[8]), but also the π^0 multiplicity in the interactions of light nuclei with Ta grows proportionally to the average number of projectile nucleons participating in the interaction.

The momentum and angular distributions of γ-quanta for dTa and CTa interactions are shown in figs.1 and 2; the rapidity distributions, in fig.3. Table 2 presents the average characteristics of γ-quanta.

The increase of the atomic number of the projectile (from d to C) leads to a small (10%) decrease of the average emission angle of γ-quanta in the laboratory system and to an increase of the average longitudinal momentum and average rapidity of γ's. The average transverse momentum of γ-quanta is independent of the atomic weight of the projectile.

Table 3 presents the average values of $\langle P_{\parallel lab} \rangle$ and $\langle P^2_\perp \rangle$ for π^0-mesons determined by the respective average values for γ-quanta[9] and the average values of $\langle y^{\pi^0}_{lab} \rangle$ equal to $\langle y^{\gamma}_{lab} \rangle$. For the proof of the equality $\langle y^{\pi^0}_{lab} \rangle = \langle y^{\gamma}_{lab} \rangle$ see Appendix.

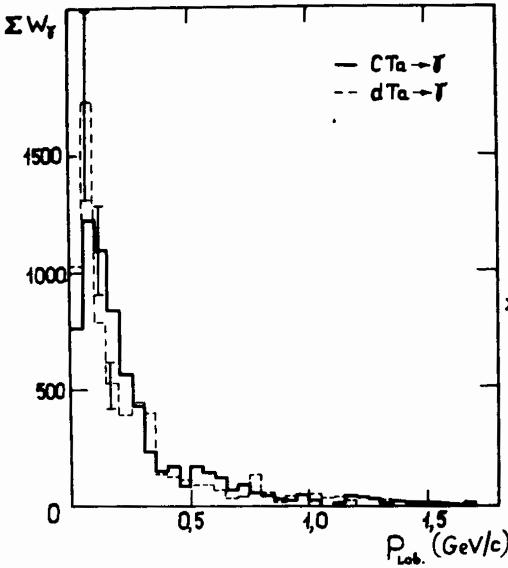
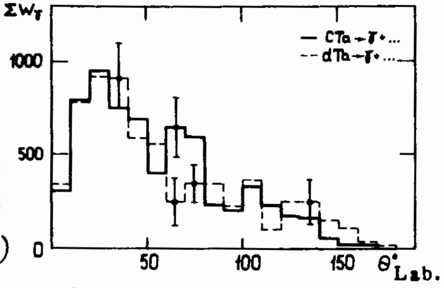


Fig.1. Momentum spectra of γ-quanta in the lab. system for dTa and CTa interactions.

Fig.2. Angular distributions of γ-quanta in the lab.system for dTa and CTa interactions.



In figs.1 and 2 distributions of γ's from dTa interactions are normalized to the respective distributions of γ's from CTa .

Table 2

Average characteristics of γ-quanta

Reaction	dTa → γ+ ...	CTa → γ+ ...
$\langle P_{lab} \rangle$ (GeV/c)	0.242±0.006	0.254±0.004
$\langle P_{\perp} \rangle$ (GeV/c)	0.132±0.003	0.139±0.002
$\langle P_{\parallel\, lab} \rangle$ (GeV/c)	0.153±0.007	0.172±0.004
$\langle P_{\perp}^2 \rangle$ $(GeV/c)^2$	0.036±0.001	0.039±0.001
$\langle \theta^{\circ}_{lab} \rangle$	60.2 ±0.8	55.0 ±0.5
$\langle y_{lab} \rangle$	0.74±0.02	0.85±0.01

The average characteristics for π^--mesons from dTa and CTa interactions/10/ are presented in this Table for comparison. One can see that the average values for π° and π^- shown in Table 3 coincide, within the errors, for the respective types of interaction.

The model of multiple scattering/11/ predicts the ratios of inclusive production cross sections of secondaries in the central region and in the fragmentation regions of colliding particles:

	x < −0,1	|x| < 0,1	x > 0,1
$\frac{\sigma(A_1B \to h\,...)}{\sigma(A_2B \to h\,...)}$	$\left(\frac{A_1}{A_2}\right)^{-\gamma} \frac{\sigma_{in}^{NA_1}}{\sigma_{in}^{NA_2}}$	$\frac{A_1}{A_2}$	$\frac{A_1}{A_2}$

$\gamma = 0.2$ at $x \approx -0.5$.

The experimental rapidity distributions of γ-quanta in the laboratory system are used for comparison with the model. As

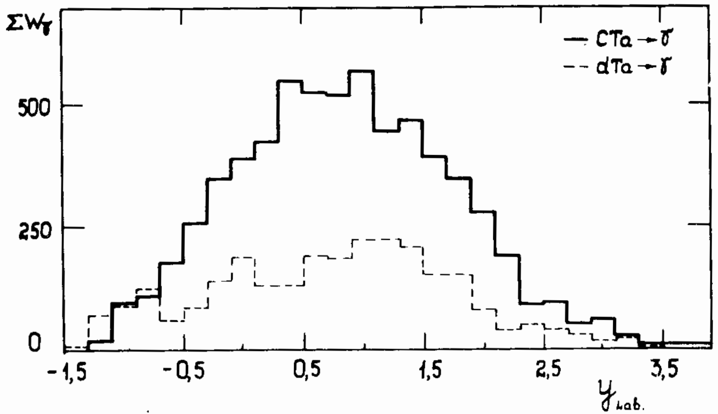


Fig.3. Rapidity distributions of γ's in the lab. system for dTa and CTa interactions.

Table 3

Average Characteristics of π° and π^-.

Reaction	$\langle P_{\parallel\, lab} \rangle$ (GeV/c)	$\langle P_{\perp}^2 \rangle$ $(GeV/c)^2$	$\langle y_{lab} \rangle$ (GeV/c)
dTa → π°+ ...	0.306±0.014	0.098±0.005	0.74±0.02
dTa → π^-+ ...	0.311±0.013	0.101±0.005	0.70±0.01
CTa → π°+ ...	0.344±0.008	0.107±0.003	0.85±0.01
CTa → π^-+ ...	0.343±0.007	0.097±0.003	0.79±0.01

is shown in Table 4, an agreement with the model is good enough. An agreement of similar ratios with this model for π^- from (d , ^{4}He , ^{12}C) Ta interactions has been shown previously /6/.

Table 4

		$y^{\gamma}_{lab.}<0$	$y^{\gamma}_{lab.}>0$
$R = \frac{\sigma(CTa\to\gamma+...)}{\sigma(dTa\to\gamma+...)}$	Model	2.7	6
	Experim.	4.4 ± 1.1	6.4 ± 1.5

AVERAGE MULTIPLICITIES OF Λ AND K^o_s AND SOME CHARACTERISTICS OF THEIR PRODUCTION IN dTa AND CTa INTERACTIONS

The average multiplicities of Λ and K^o_s for dTa and CTa interactions are presented in Table 1. As in the case of π^o-mesons, the increase of the projectile atomic number (from d to C) leads to an increase of $<n_\Lambda>$ and $<n_{K^o_s}>$ in the ratio $<\nu>^{CTa}/<\nu>^{dTa}$. For CTa interactions the average multiplicities $<n_\Lambda>$ and $<n_{K^o_s}>$ correspond to the inclusive production cross sections $\sigma_\Lambda = (158\pm34)$ and $\sigma_{K^o_s} = (79\pm21)$ mb at $\sigma_{in}^{CTa} = (3445\pm140)$ mb /8/. For comparison we present the inclusive production cross sections of Λ and K^o_s in pp interactions at p = 3.7 GeV/c /12/: $\sigma_\Lambda = (0.091\pm0.016)$ mb, $\sigma_{K^o_s} = (0.048\pm0.012)$ at $\sigma_{in}^{pp} = 26.8\pm1.4$ mb /7/. Thus, the average multiplicity of Λ's increases by a factor of 15 in CTa interactions at 4.2 GeV/c/N as compared to pp interactions at 3.7 GeV/c.

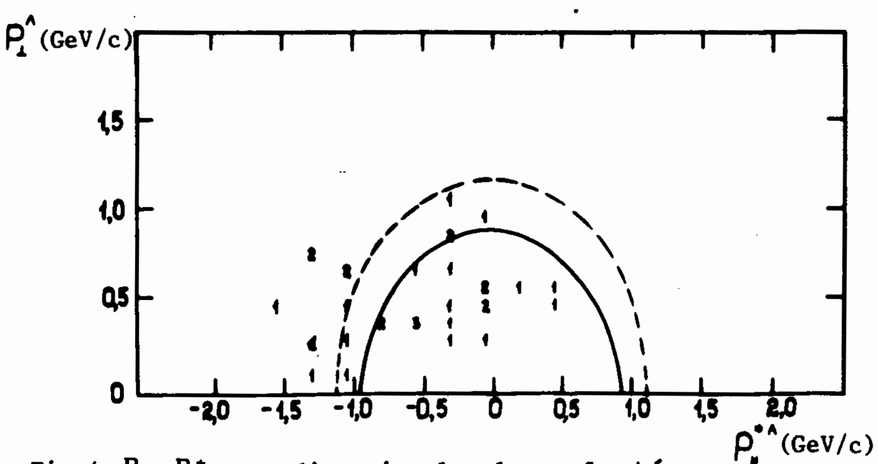


Fig.4. $P_\perp - P_\parallel^*$ two-dimensional plot of Λ's. Solid line - is the limit of the kinematically allowed region for reaction NN→NΛK. Dotted line - is the limit of the region for reaction NN→NΛK taking into account the Fermi motion of nucleons in both nuclei.

The analysis of CTa events involving Λ's has shown that (35 ± 3) charged particles are produced in them on average including (4.8 ± 0.6) negative particles. These values significantly exceed the average multiplicities of charged and negative particles in all inelastic CTa interactions which are equal to $<n_\pm> = 21.2\pm0.6$ and $<n_-> = 3.4\pm0.2$, respectively.

Figure 4 shows the $P_\perp - P_\parallel^*$ distributions of Λ's from CTa interactions, where $P_\parallel^*$ is determined in the nucleon-nucleon c.m. frame. About 40% of Λ's lie outside the kinematically allowed region for reaction NN→ΛNK (solid line). The dashed line limits the region where 99% of Λ's should lie, according to the Monte-Carlo calculation with the phase space Λ momentum distribution and Fermi motion in both colliding nuclei taken into account. The distribution of Fermi momentum was of the form $f(p) \sim \exp(-P^2/2\sigma^2)$ with σ = 90 MeV/c /1/. A few Λ's lie outside this boundary.

A visible shift of Λ momenta toward negative $P_\parallel^*$ values can result from Λ rescattering inside the Ta nucleus or from some Λ production in secondary π^- interactions in tantalum.

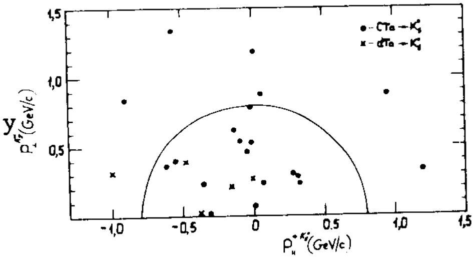
The average transverse momentum of Λ's from CTa is 0.49 ± 0.03 GeV/c, close to the value of $<P_\perp>$ for Λ's from pp interactions at high energies /13/.

The above described specific features of Λ hyperon production are indicative of a more central character of Λ-producing CTa interactions compared to the "average" CTa collision.

To complement the information, the $P_\perp$ versus $P_\parallel^*$ distributions of K^o_s mesons are given in Fig.5.

The authors express their gratitude to the staff of the 2 m propane bubble chamber and to the technicians for the help in obtaining the data. Thanks are due to Yu.M.Shabelsky for helpful suggestions and remarks and to M.Gazdzicki for performing the Monte-Carlo calculations.

Fig.5. $P_\perp - P_\parallel^*$ two-dimensional plot of K_s°'s. Solid line is the limit of the kinematically allowed region for reaction NN→NΛK.



APPENDIX

Let us shown that, if an unstable particle decays isotropically in its rest frame, then in any other reference frame the average longitudinal rapidity of any "daughter" particle is equal to the average longitudinal rapidity of the unstable "maternal" particle independent of the choice of Z axis onto which particle momenta are projected.

By definition longitudinal rapidities of a "maternal" particle A and a "daughter" particle a in the laboratory reference frame are given by

$$y^A = \frac{1}{2}\ln\frac{1+v_z^A}{1-v_z^A} = \frac{1}{2}\ln\frac{E^A + P_z^A}{E^A - P_z^A} \qquad (1)$$

$$y^a = \frac{1}{2}\ln\frac{1+v_z^a}{1-v_z^a} = \frac{1}{2}\ln\frac{E^a + P_z^a}{E^a - P_z^a}.$$

Here E is the energy, v_z and P_z are Z projections of particle velocity and momentum respectively.

As is known rapidities add up under the Lorentz transformation along Z axis. Namely, if the reference frame $\tilde{K}$ moves with the velocity V along Z axis relative to the reference frame K, then the longitudinal rapidities of particle a in these two systems are related by

$$y^a = \frac{1}{2}\ln\frac{1+V}{1-V} + \tilde{y}^a \quad . \qquad (2)$$

Let the system $\tilde{K}$ coincide with the reference frame, where the longitudinal momentum of the "maternal" particle A equals to zero, while K is laboratory frame. Then

$$V = v_z^A = \frac{P_z^A}{E^A},$$

and according to Eq.(2) the longitudinal rapidity of "daughter" particle in the laboratory system is given by

$$y^a = y^A + \tilde{y}^a , \qquad (3)$$

where y^A is the longitudinal rapidity of the "maternal" particle in the laboratory system, while

$$\tilde{y}^a = \frac{1}{2}\ln\frac{\tilde{E}^a + \tilde{P}_z^a}{\tilde{E}^a - \tilde{P}_z^a} \qquad (4)$$

is the longitudinal rapidity of the "daughter" particle in the $\tilde{K}$ reference frame. Note, that in this frame the longitudinal momentum of A particle equals to zero, while its transverse momentum is the same as in the laboratory frame.

One can see that if the decay of A particle is isotropic in its rest frame then in the reference frame $\tilde{K}$ the momentum distribution of the "daughter" particle is symmetric relative to the reflection in the plane perpendicular to Z axis, though this distribution depends on the angle between $\vec{P}_A$ and $\vec{P}_\perp^A$. This means, that particle "a" at a fixed energy can have the momentum projections onto Z axis with equal absolute values and opposite signs with equal probability. The same is true for the longitudinal rapidity values, too. Therefore, the average value of the "daughter" particle longitudinal rapidity is equal to zero in the reference frame $\tilde{K}$, where $P_z^A = 0$.

Thus at a fixed momentum of the "maternal" particle A we have

$$\langle y^a \rangle = y^A . \qquad (5)$$

Averaging over the momentum distribution of particle A, we obtain

$$\langle y^a \rangle = \langle y^A \rangle . \qquad (6)$$

It follows now that the average longitudinal rapidity of γ-quanta from the decay of the π°-mesons is equal to that of the π°-mesons.

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Ахабабян Н. и др. Д1-82-445

Образование γ-квантов и нейтральных странных частиц в dTa и CTa-взаимодействиях при импульсе 4,2 ГэВ/с на нуклон

Представлены первые результаты по образованию γ-квантов, Λ-гиперонов и K_s°-мезонов в dTa и CTa-взаимодействиях при импульсе 4,2 ГэВ/с на нуклон. Определены средние множественности

	dTa	CTa
$<n_\gamma>$	2,20±0,36	7,52±0,74
$<n_{\pi^\circ}>$	1,1±0,2	3,8±0,4
$<n_\Lambda>$	0,013±0,006	0,046±0,010
$<n_{K_s^\circ}>$	0,006±0,003	0,023±0,007

Показано, что средние множественности γ-квантов, Λ- и K_s°-частиц при переходе от dTa к CTa-взаимодействиям возрастают пропорционально среднему числу провзаимодействовавших нуклонов ядра-снаряда. В CTa-взаимодействиях с образованием Λ-гиперонов средняя множественность всех заряженных частиц в 1,5 раза выше, чем во всех CTa-взаимодействиях.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

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Akhababian N. et al. E1-82-445

Production of γ-Quanta and Neutral Strange Particles in dTa and CTa Interactions at 4.2 GeV/c per Nucleon

First results on γ-quantum, Λ-hyperon and K°-meson production in dTa and CTa interactions at 4.2 GeV/c per nucleon are presented. The following average multiplicities were obtained:

	dTa	CTa
$<n_\gamma>$	2.20±0.36	7.52±0.74
$<n_{\pi^\circ}>$	1.1±0.2	3.8±0.4
$<n_\Lambda>$	0.013±0.006	0.046±0.010
$<n_{K_s^\circ}>$	0.006±0.003	0.023±0.007.

Comparing γ-quantum, Λ- and K_s°-production in dTa and CTa interactions, an increase of the average multiplicity of these particles proportionally to the average number of interacting nucleons of the projectile-nucleus is observed. In CTa interactions with Λ-hyperon production the charged particle average multiplicity is 1.5 times higher than in all inelastic CTa interactions.

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

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