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INVESTIGATION OF THE DYNAMICS OF HADRON-NUCLEUS INTERACTIONS AT 40 GeV UTILIZING THE CHARACTERISTICS OF NEUTRAL STRANGE PARTICLES

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1. Introduction

An investigation of the high energy particle collisions with nuclei expected to yield information on the nuclei interaction mechanism [1]. Here it is important to obtain experimental data based on a large number of nuclei targets for the different types of incident particles. On the other hand, it is important to note that up to now a scarce information about the behavior of the nuclei matter in the time of hadrons creation has existed. To study the strange particles production in $\pi^- A$ interactions is actual from the following points of view:

1. The initial particles do not contain constituent strange quark, that as a consequence decreases the probability of its production.
2. The strange particles keep some important information concerning the early stage dynamics of the particle interactions.
3. K_s^0 mesons and Λ hyperons are convenient particles from the methodical point of view, since they can be easily identified; their decays into charged pairs provide an excellent experimental signature for the production of strangeness over a large range of phase-space.

Models concerning hadron-nucleus interactions [2]÷[4] can roughly be divided into two categories, namely models where the incoming projectile rescatters and the secondaries are not allowed to produce cascades and models where no rescattering occurs, but the secondaries produce cascade. There could be phase-space regions where the certain aspects of models are distinguished better than for integrated over full phase-space, for instance, regions with one of the secondary particles having a high transverse momentum.

QCD predicts that the formation of particles with high $P_\perp$ could be due to either the deformation of structure function of partons in nucleus or the rescattering effect of partons in nuclei matter [5].

The comparison of the neutral strange particle characteristics in minimum-bias and high $P_\perp$ processes gives important information about the differences between the dynamics of these processes.

2. Experimental Setup

Experimental data of the multiple production in $\pi^- A$ interactions at 40 GeV with trigger particle $P_\perp \geq 1.1$ GeV/c for H, D, C, Cu, Pb targets were obtained using the magnetic spectrometer RISC [6]. The main detector of this spectrometer is a bipolar streamer chamber. Magnetic field of 1.5 T was directed along the electric field of the streamer chamber. The $P_\perp$ trigger was formed by the telescope of three multiwire proportional chambers placed above the streamer chamber. They covered the polar angle $12° < \Theta_(lab) < 22°$ for particles originated from target, which corresponds to $85° < \Theta^* < 120°$ in $\pi^- N$ c.m.s.

V^0-particles are identified by means of kinematical fitting for four alternative hypothesis: K^0_s, Λ, γ, $\bar\Lambda$ using the least square fit method with three degrees of freedom (3C-FIT). Ambiguous Λ/K^0_s particles has been taken as K^0_s, if the transverse momentum of negative decay products exceeds 105 MeV/c.

The invariant mass distribution for identified K^0_s, Λ and $\bar\Lambda$ particles is shown in Fig.1(a,b,c). The identification correctness of neutral strange particles can be checked by using the Podolanski-Armenteros technique. Fig.1d shows the Podolanski-Armenteros plot for identified particles.

3. Experimental method

We investigated A-dependence of the neutral strange particles in the following reactions:

$$\pi^- \mathrm{A} \to X \tag{1}$$

$$\pi^- \mathrm{A} \to K^o(K^oY) + X \tag{2}$$

$$\pi^- A \to \Lambda + X \tag{3}$$

$$\pi^- A \to \bar\Lambda + X \tag{4}$$

$$\pi^- \mathrm{A} \to K^o(K\bar K) + X \tag{5}$$

for the events with a trigger particle $P_\perp \geq 1.1$ GeV/c and $X_F=0$. The similar investigation has been carried out by the authors of this work for minimum-bias events several years ago[7]. The main problem is to establish the mechanism of transverse momentum increasing in triggered events. There could be mainly two reasons:

1. The hard interaction between projectile particle and the nucleon of nuclei.
2. A higher number of rescatterings inside the nuclei.

These reasons may act together, but it is important to find out which one is the main reason at intermediate energies. The production ratios of $K\bar K$ pairs and Λ hyperons are convenient parameters for studying this problem.

In the case of minimum-bias processes the following results have been obtained:

1. The production ratio of $K\bar K$ pairs does not depend on atomic mass number A.
2. The yield of Λ hyperons increases with increasing A.
3. The average momentum of K^0_s mesons from $K\bar K$ pairs does not depend on A, while for Λ hyperons decreases with increasing A.
4. The average multiplicity of associated particles increases with A for Λ hyperons and does not depend on A for $K\bar K$ pairs.

These results show that Λ hyperons can be generated in any act of interaction inside a nucleus. $K\bar K$ pairs distinguishes the cases with single particle interaction between primary particle and nucleus. These results indicate that $K\bar K$ pairs production is a convenient signature for selecting and studying the hadron-nucleus interaction, having a specific mechanism; namely the change of $K\bar K$ pairs production ratio in high $P_\perp$ processes indicates on the different mechanism of first interaction,while the Λ hyperons production is sensitive to the change of secondary interactions mechanism. There is not enough statistics of the reaction with $K\bar K$ pairs, but some information about this process has been obtained from the study of the reactions with K^0_s mesons and with $\Lambda,\bar\Lambda$ hyperons. **For ligh nuclei:**

$$\langle N^{K^o}_{K\bar K}\rangle = \langle N_{K^o}\rangle - 0.44\langle N_Y\rangle \tag{6}$$

and for heavy nuclei:

$$\langle N^{K^o}_{K\bar K}\rangle = \langle N_{K^o}\rangle - 0.62\langle N_Y\rangle \tag{7}$$

where $\langle N_Y\rangle = \langle N_\Lambda\rangle + \langle N_{\bar\Lambda}\rangle$

These relations are based on the experimentally well supported hypothesis.

4. Experimental results

Fig.2 shows the production ratios of K^0,$K\bar K$ mesons and Λ, $\bar\Lambda$ hyperons as a function of atomic mass number in minimum-bias and high $P_\perp$ processes. These dependencies are parametrised as a function $a \cdot A^\alpha$. As seen from Fig.2 in minimum bias processes the production ratio of $K\bar K$ pairs practically does not depend on A, while in high $P_\perp$ processes this ratio increases with A. The behavior of A dependence of Λ hyperons production ratio in minimum bias and $P_\perp$ processes is the same. The values of production ratios of all discussed particles for hydrogen target in both processes are the same within statistical errors. For heavy nuclei the yield of K^0 mesons and $K\bar K$ pairs are more in high $P_\perp$ processes. The values of production ratio of Λ hyperons are equal in both processes for all discussed targets. Fig.3 shows A-dependence of the momentum of neutral strange particles. As is seen from this figure the momentum values of neutral strange particles for light nuclei are more in high $P_\perp$ processes,while for heavy targets they are more in minimum bias processes. Fig.4 shows A-dependence of associated negative particle multiplicity. The associated particles are divided into two categories: the particles with momentum less than 0.5 GeV/c - slow particles and with momentum greater than 0.5 GeV/c - fast particles . The division of particles into slow and fast ones is interesting because the fast particles are generated advantageously in first collisions, while the slow particles production is mainly from secondary interactions inside nuclei.

This figure shows that the slow particles average multiplicities in minimum bias and high $P_\perp$ processes are the same for all discussed reactions (1)–(5) within statistical errors.

The fast particles average multiplicity $< N_f >$ is the same in both processes for light nucleus. Started from carbon target the value of fast particle multiplicity is more in high $P_\perp$

processes than in minimum bias interactions. Correspondingly the behavior of A-dependence is different: in high $P_\perp$ processes $< N_f >$ increases rapidly with A than in minimum bias processes. The dependencies are parametrised with function of $a \cdot A^\alpha$.

Fig.5 shows A dependence of ratios $< N_\Lambda >/< N_{slow} >$, $< N_\Lambda >/< N_{fast} >$, $< N_{K\bar{K}} >/< N_{slow} >$, $< N_{K\bar{K}} >/< N_{fast} >$.

As is seen from this figure the ratios $< N_\Lambda >/< N_{slow} >$ and $< N_{K\bar{K}} >/< N_{fast} >$ are almost constant and do not depend on A. The ratio $< N_\Lambda >/< N_{fast} >$ decreases sharply with A, on the contrary, the ratio $< N_{K\bar{K}} >/< N_{slow} >$ increases with A.

As already noted the fast particles and $K\bar{K}$ pairs are generated advantageously in first collisions, while the slow particles and Λ hyperons production are mainly from secondary interactions inside the nucleus.

Comparison of the results from minimum bias and high $P_\perp$ processes shows that the characteristics of $K\bar{K}$ pairs,as well as of fast particles in these processes are different. It means that the mechanism of first collision in minimum bias and high $P_\perp$ processes are not the same. These differences indicate that in high $P_\perp$ processes there exist some part of hard interactions. The same behavior of slow particles and Λ hyperons in minimum bias and high $P_\perp$ processes means that the mechanism of secondary interactions in both processes is the same.

5. Results of the Monte-Carlo Simulations

At the experiment it is practically impossible to determine the part of hard interactions. We discuss the results obtained from high $P_\perp$ processes within quark-gluon string model on which the program FRITIOF-7.02 [8] is based. In quark-gluon string model hadron is treated as a vertex line in a superconducting vacuum. The vertex line consists of a hard core which is surrounded by an exponentially dumped field. In a soft interaction a momentum transfer between two colliding hadrons is assumed to be due to the overlap of those fields. Having transferred momenta we end up with two longitudinally excited string states which finally fragment into hadrons. When the model is extended into hadron- nucleus interactions, the incoming hadrons may collide more than once and the excited states continue to collide during their passage through the nucleus. Most of the energy is contained in the hard core; It means that an overlap of the extended fields involves only a small part of the available energy and an interactions of this kind is treated as soft. Hard scattering may occur if the cores are involved. In this model the secondaries are not allowed to produce cascade. When the projectile hits the target it collides with say n nucleons, as it past through the nucleus. Since the time for fragmentation is considered to be long compare to the internucleon distance, the projectile will not have time to fragment in between the subcollisions. In each subcollision momentum is transferred and the mass of the projectile string is gradually increasing. If after k-th subcollision the mass of the projectile is M, the $(k+1)$-th subcollision is treated as a collision between two hadrons one with the nucleon mass and one with the mass M. After the interaction we are left with n string from the target and one from the projectile. These (n+1) strings fragment independently. The fragmentation is done according to the LUND fragmentation scheme using the LUND Monte-Carlo program Jetset 6.2.

Fig.2 shows A-dependence of the production ratio of K^o and $K\bar{K}$ mesons and Λ,$\bar{\Lambda}$ hyperons in the experimental high $P_\perp$ processes and in similar processes in FRITIOF-7.02. As is seen from this figure there is a good agreement between these results.

In the model it is possible to separate the hard and soft interactions. In high $P_\perp$ processes within FRITIOF-7.02 at 40 GeV the portion of hard interactions is 50÷30% for H÷Pb targets respectively.

Fig.6 shows A-dependence of the production ratio of strange particles in soft and hard interactions separately within FRITIOF-7.02. As is seen from this figure the yield of K^o,$K\bar{K}$ mesons and $\bar{\Lambda}$ hyperons are more in hard interactions practically for all discussed nuclei, while the yield of Λ hyperons is more in soft processes for heavy nuclei. This means that $K\bar{K}$ pairs and $\bar{\Lambda}$ hyperons are advantageously produced in hard interactions.

In Fig.4 the A-dependence of associated particles multiplicities in different reactions is shown. As seen from this figure there is a good agreement between high $P_\perp$ experiment and FRITIOF-7.02.

6. Conclusion

Comparison of the results from FRITIOF-7.02 and high $P_\perp$ experiment shows that the characteristics of neutral strange particles in this experiment are the same as quark-gluon string model prediction within statistical errors.

This agreement gives the basis to suggest that the portion of hard interaction in high $P_\perp$ experiment is nearly the same as in FRITIOF-7.02. It means that the rescattering inside the nucleus is not the main reason of increasing $P_\perp$ at 40 GeV and both reasons (hard interaction and rescattering) act together.

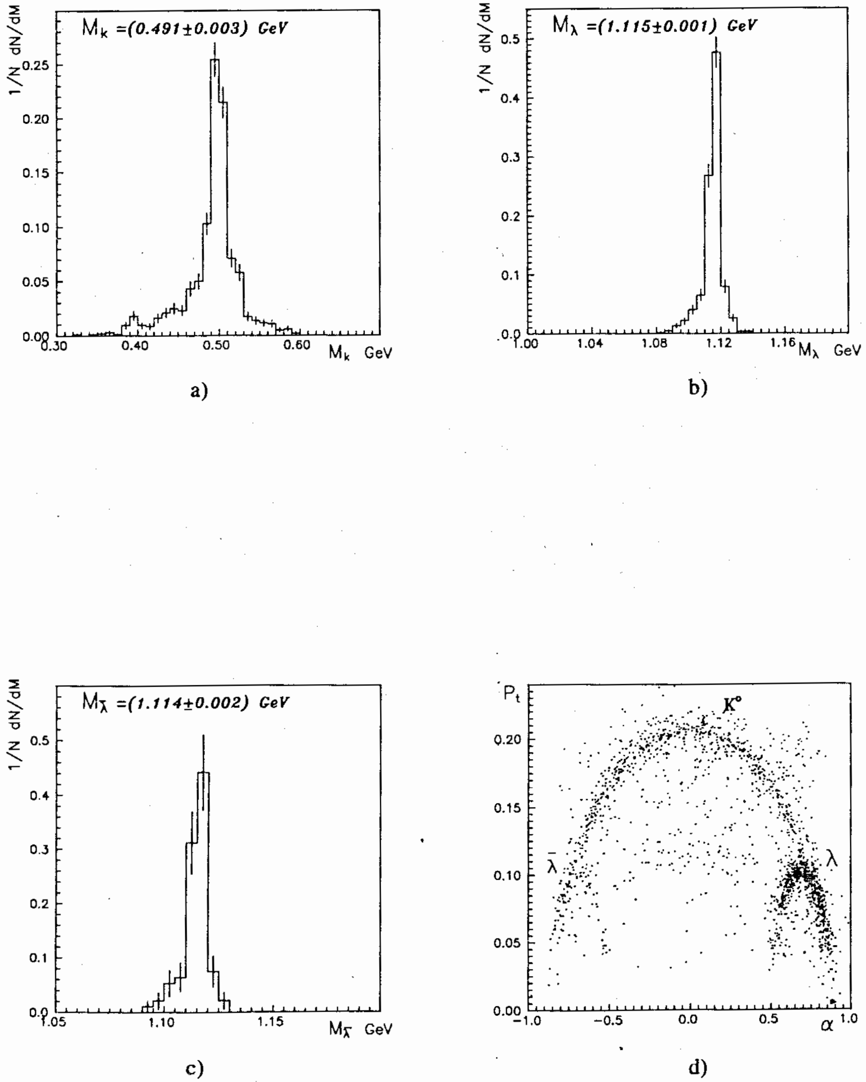

Fig.1a),b),c) The invariant mass distribution for identified K^0_s, Λ and $\bar\Lambda$ particles.
d): The Podolanski-Armenteros plot for identified particles.

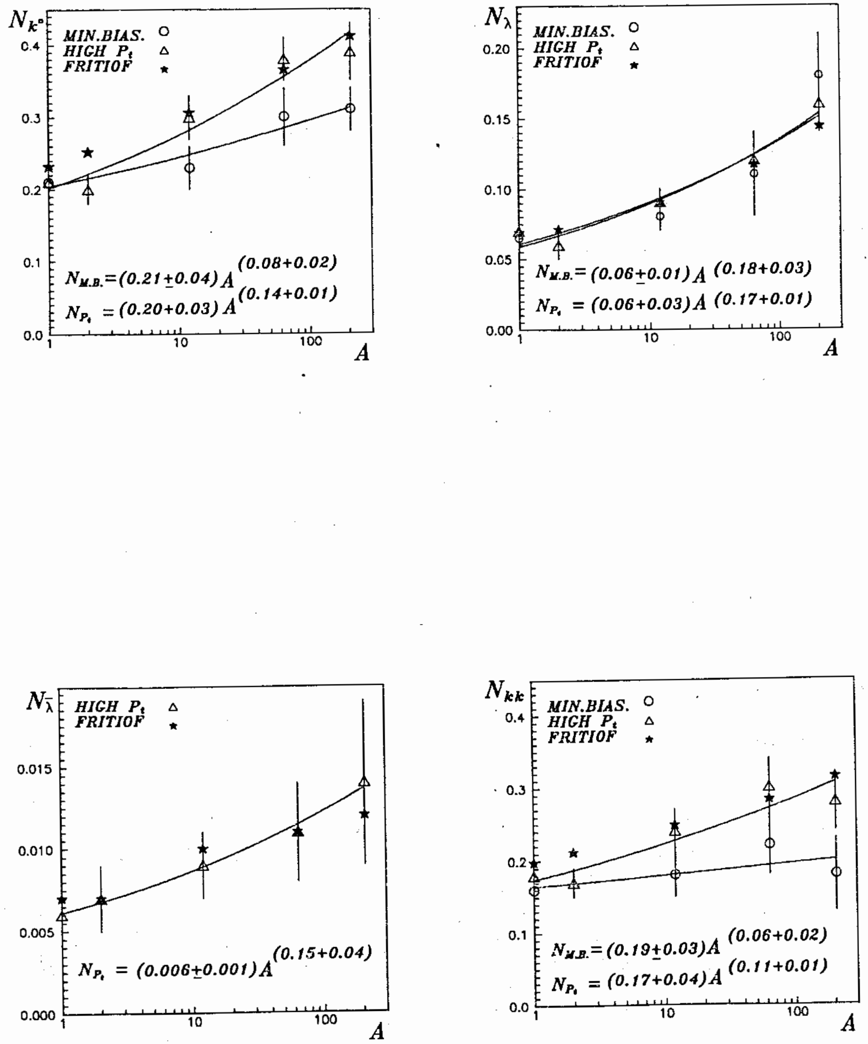

Fig.2: The production ratios of K^0,$K\bar{K}$ mesons and Λ, $\bar\Lambda$ hyperons as a function of atomic mass number.

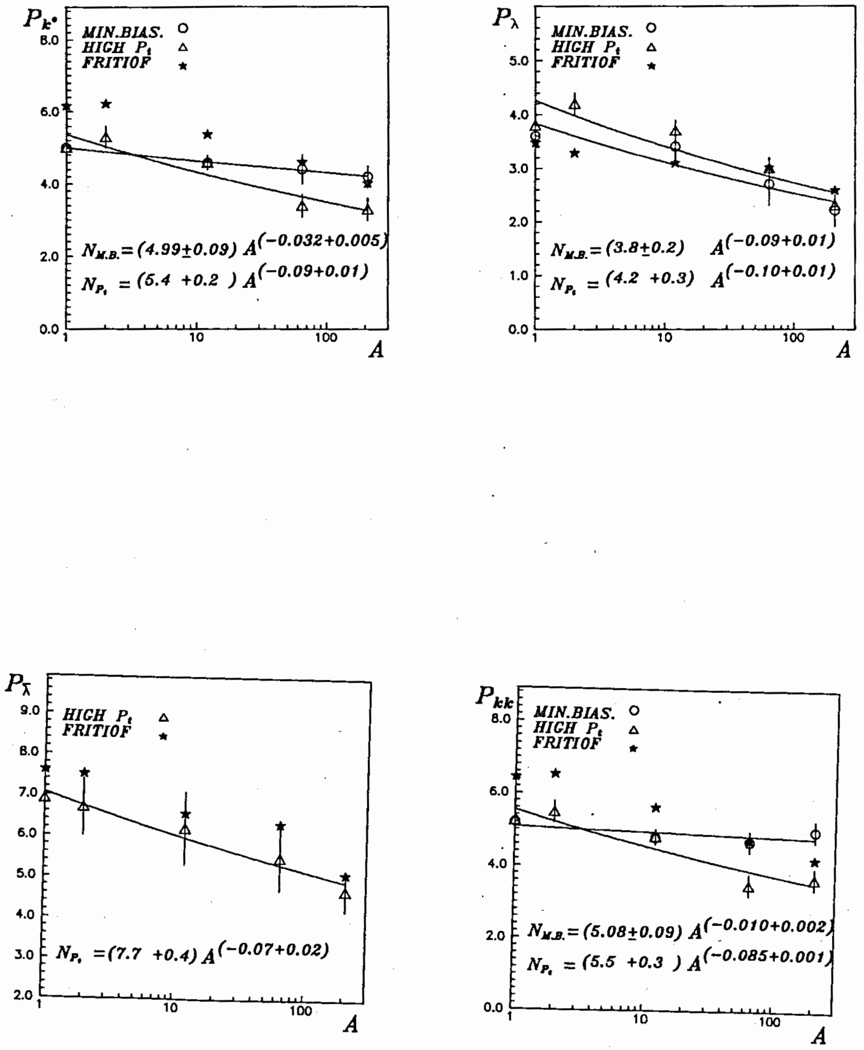

Fig.3: A-dependence of the neutral strange particles momentum.

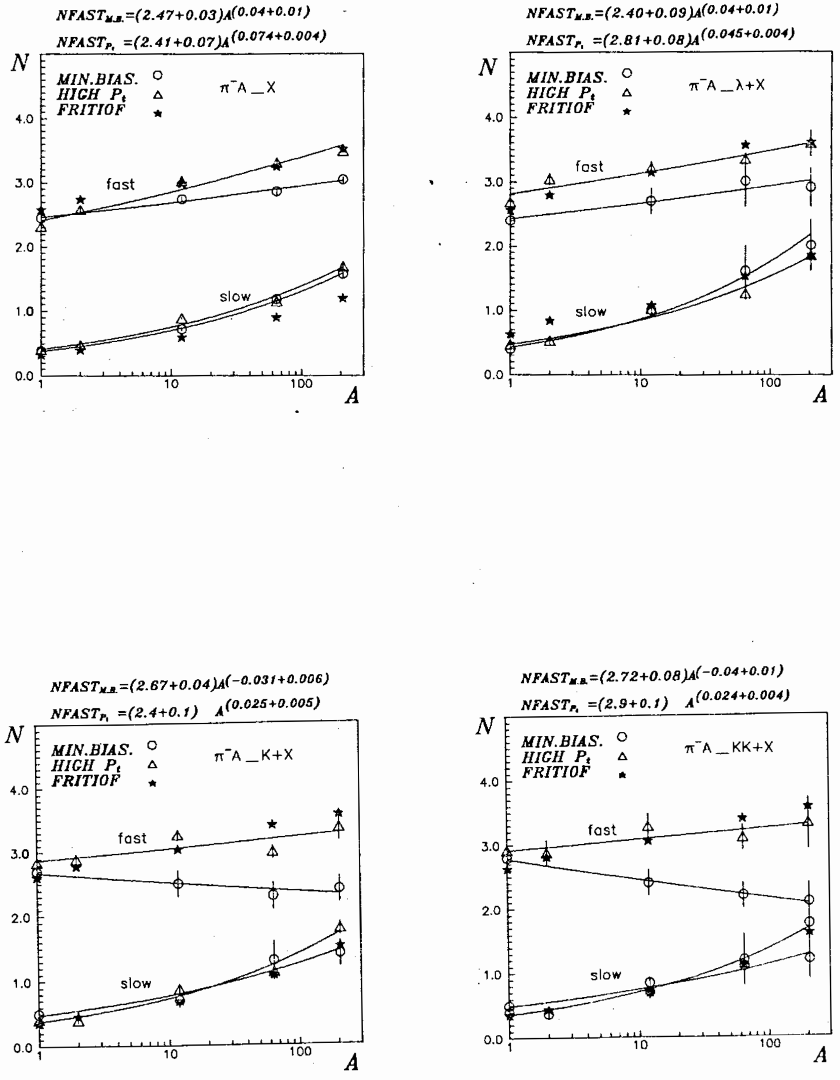

Fig.4: A-dependence of associated negative particle multiplicity.

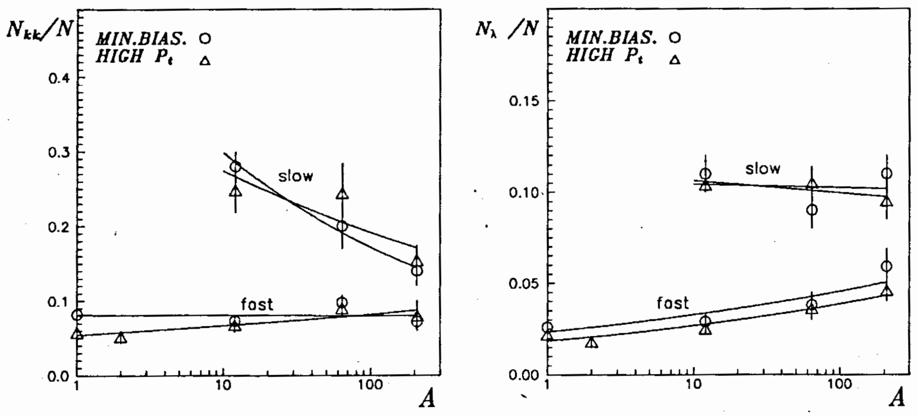

Fig.5: A dependence of ratios $< N_\Lambda >/< N_{slow} >$, $< N_\Lambda >/< N_{fast} >$, $< N_{K\bar{K}} >/< N_{slow} >$, $< N_{K\bar{K}} >/< N_{fast} >$.

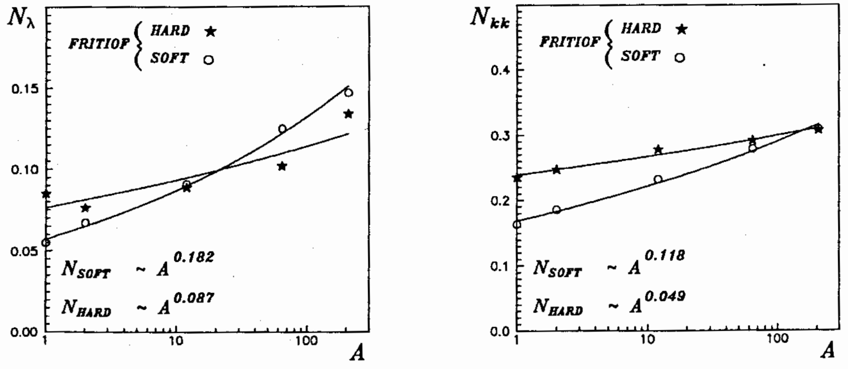

Fig.6: A-dependence of the neutral strange particle production ratio in soft and hard interactions within FRITIOF-7.02.

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