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MASTER

4π PHYSICS

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Abstract

Exclusive π^- and charged-particle production in collisions of ^{40}Ar on KCl are studied at incident energies from 0.4 to 1.8 GeV/A. The correlation between the π^- and the total charged particle multiplicity confines the reaction along a narrow ridge with no exotic islands of pion production. For high multiplicities the system reaches the total disentegration of target and projectile into singly charged fragments and pions. Every 200 MeV/A data was taken with a central and inelastic trigger. For central collisions the mean π^- multiplicity increases linearly with the bombarding energy with no marked discontinuities due to the $\Delta(3.3)$ resonance. At 1.8 GeV/A evidence for nonthermal π^- production in central collisions is found. The total c.m. energy in π^- shows linear dependence on the π^- multiplicity with a slope of ϵ = 300 MeV/π^-. Strange particle production in the central collision of 1.8 GeV/A Ar on KCl is seen.

The natural framework for the description of high energy nucleus-nucleus interactions, above the pion production threshold is given by the quark model. For example the production and decay of the $\Delta(3,3)$ isobar, the most important inelastic channel up to bombarding energies of several GeV/A, is described by the quark exchange between two nucleons with the coupling of the quarks in one of them to $I = 3/2$: the decay occurs by the emission of one quark from the Δ and the quark antiquark production from the vacuum to form a nucleon and a pion (Fig. 1). The families of excited states of the nucleon N^*, Δ and strange bayons are higher angular momentum states in the coupling of three quarks: u's and d's coupled to $I = 1/2$ for the N^*, u's and d's coupled to $I = 3/2$ for the Δ and u's and d's with one strange quark s for the strange bayons Λ's and Σ's. Correspondingly the mesons are quark antiquark pairs. The energies at which these states can be formed in an NN collision are given in Fig. 2. At these energies the πN cross sections[1] vary by a factor of 10 resulting in a very energy dependent pion mean free path in nuclear matter.

The aim of this work[2] is to study the energy dependence of the isobar and meson production in central collisions of an equal mass system (Ar + KCl) from below the $\Delta(3,3)$ resonance up to the highest Bevalac energies. Exclusive measurements of all the reaction products are necessary in order to measure the energy flux in pions, the energy flux in certain parts of phase space, to obtain invariant masses to extract isobar decays and search for exotic states with baryon number greater than 1, and to do two and many particle correlations.

At the Bevalac the steamer chamber with it's 4π geometry and 100 percent efficiency for charged particles, is the most suitable detector for such experiments. Nevertheless, all the neutral particles remain undetected. We have measured the central and inelastic interactions of Ar on KCl at 360, 566, 772, 977, 1180, 1385, 1609 and 1808 MeV/nucleon. For each event three pictures are taken, in order to reconstruct the momenta of the charged particles. The events have been scanned, classified according to the number of negative pions, total charged particles, and leading tracks. Scanning results and preliminary results from the negative pion momentum reconstruction will be presented.

In Figure 3 the total charged particle multiplicity distributions and π^- multiplicity distribution for the central and inelastic triggers are shown, together with the correlation of π^- and total multiplicity for the 1.8 GeV/A bombarding energy. For the inelastic trigger the total multiplicity distribution falls off exponentially for small multiplicities, reaches a plateau for multiplicities between 23 and 40 followed by a sharp cut off at higher multiplicities. This plateau is also apparent in the distribution of the number of participant protons, which can be extracted using the multiplicity of leading particles. The fireball and cascade models[3] do not reproduce this extra yield which comes from a larger transverse momentum spread in near central collisions than assumed by these models.

The total cross sections for the inelastic and central trigger are 1.8 barns and 180 mbarns respectively. The π^- multiplicity distribution has a mean of 2.5 for the inelastic trigger and 5.9 for the central trigger. The fireball and firestreak models overpredict the number of π^- by a factor of 2. This places in doubt the assumption of chemical equilibrium of pions and Δ's as the production mechanism.

The correlation between negative pion and total charged-particle multiplicity is shown in Figure 3 as contour lines of constant cross section. The reaction is confined to a narrow ridge with no discernable exotic islands of pion production. For the higher multiplicities the system reaches the total disintegration into singly charged fragments and pions.

Surprisingly, the energy dependence of the π^- multiplicity distributions is very smooth as one traverses the different N^* and Δ resonances. For the central trigger the mean π^- multiplicity shows a linear dependence on the bombarding energy (Fig. 4). At each bombarding energy and as a function of the number of participant protons in the interaction (Q) and mean π^- multiplicity shows a linear dependence on Q. It is interesting to see if this is compatible with a short pion and Δ mean free path.

A small sample of π^- from the 1.8 GeV/A central interactions have been reconstructed. A scatter plot $p_\parallel$ vs $p_\perp$ plane in the center of mass is shown in Figure 5. The signature of a nonthermal pion source is clearly visible in which the Δ decay's forwards-backward is still present.

It is of great interest to extract the total c.m. energy in negative pions (E_{π^-}) as function of the π^- multiplicity. Figure 6 shows the correlation between M_{π^-} and E_{π^-} for the reconstructed sample. A distribution peaking at 1.2 GeV for 4 π^- is observed with a linear dependence of E_{π^-} on M_{π^-} with a slope of ϵ = 300 MeV/π^-. Further theoretical analysis needs to be done to see if this linear relationship and the dispersions are in agreement with independent nucleon-nucleon isobar production or if some signature of other coherent processes in highly compressed nuclear matter is present.

A clearer signature from the primary most compressed stage of the interaction is expected from the strange particle production.[4] In the streamer chamber the charged decay of neutral strange hadrons can be detected with good efficiency by identifying secondary vertices (Vees). In this way the $K^0 \rightarrow \pi^+\pi^-$ and $\Lambda \rightarrow p\pi^-$ decays can be measured, identified by their invariant mass and their momenta can be extracted from the decay kinematics. The identified vees in the 1.8 GeV/A central trigger run have been measured and reconstructed. Since we do not have particle discrimination between π^+ and p each event is plotted in the plane of invariant masses assuming it is a $\pi^+\pi^-$ pair or a $p\pi^-$ pair (Figure 7). We see that most of them correspond to decaying Λ's. A c.m. $p_\parallel$ vs $p_\perp$ scatter plot is shown for the identified Λ's in in Figure 8. The distribution in the c.m. is expected to show a forward backward peaking due to phase space, while the K^+ distribution is expected to be isotropic. More data is needed to improve the statistics for the strange particle production.

In summary we have presented our first results of charged particle-4π-experiments in high energy nucleus-nucleus collisions. Existing models describing relativistic heavy ion interactions must be able to provide predictions for more exclusive measurements like the ones reported here. So far, none of the models can coherently explain our data.

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3. Y. Yariv and Z. Frankel, Phys. Rev. C 20, 2270 (1979).
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Figure Captions

Fig. 1. Quark diagram for the reaction $p + p \rightarrow \Delta^{++} + n$, $\Delta^{++} \rightarrow \pi^{+} + p$

Fig. 2. Known baryon and meson states plotted as function of the laboratory bombarding energy at which they can be excited in nucleon-nucleon reactions. At left the arrows give the energy per nucleon at which we took data.

Fig. 3. Top: Total multiplicity and π^- multiplicity distributions for the inelastic and central trigger in the interaction of Ar on KCl at 1.8 GeV/A. Bottom: Correlation between total multiplicity and π^- multiplicity for the inelastic trigger as contours of constant cross section (mbarns).

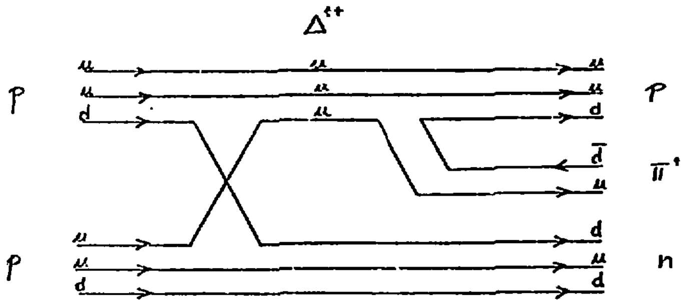
Fig. 4. Energy dependence of the mean π^- multiplicity in the central interaction of Ar on KCl.

Fig. 5. Scatter plot of the π^- produced in 373 central interactions of Ar + KCl at 1.8 GeV/A, plotted in the center of mass $p_\parallel$ vs $p_\perp$ plane.

Fig. 6. Total center of mass energy in negative pions of each reconstructed event vrs the π^- multiplicity at 1.8 GeV/A. The straight line corresponds to a slope of 300 MeV/π^-.

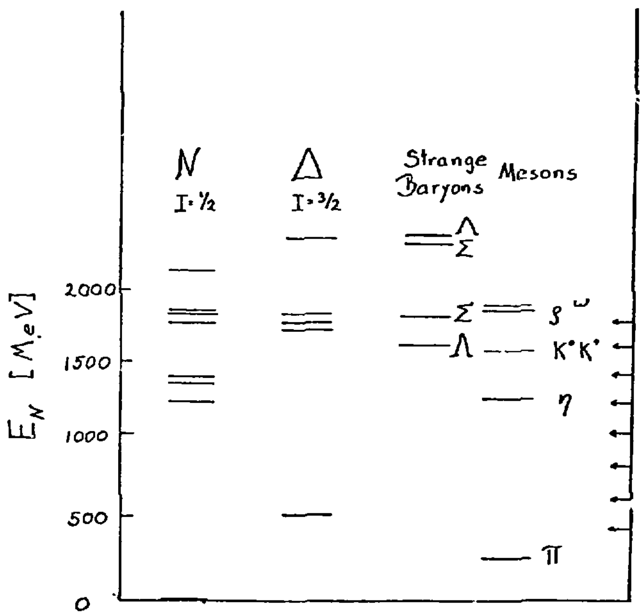
Fig. 7. Scatter plot of the reconstructed vees due to neutral strange particle decay in the streamer chamber for the 1.8 GeV/A energy, plotted in the plane of invariant masses assuming a $\pi^+\pi^-$ or a $p\pi^-$ pair. Most events correspond to Λ decays.

Fig. 8. Scatter plot of the reconstructed Λs center of mass perpendicular and transverse momentum.



Δ++
u
u
d
u
u
d
p
p
u
u
d
d̄
u
d
u
d
p
π+
n

Fig. 1



N
I=½
Δ
I=3/2
Strange
Baryons
Mesons
Λ
Σ
Σ
Λ
ρ ω
K°K+
η
π
2000
1500
1000
500
0
E_N [MeV]

Fig. 2

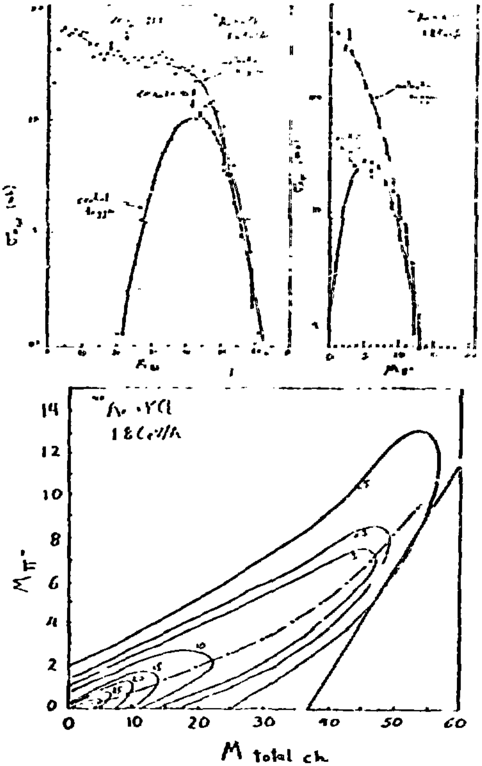


Fig. 3

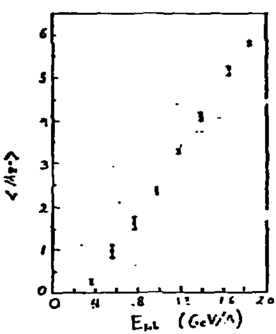


Fig. 4

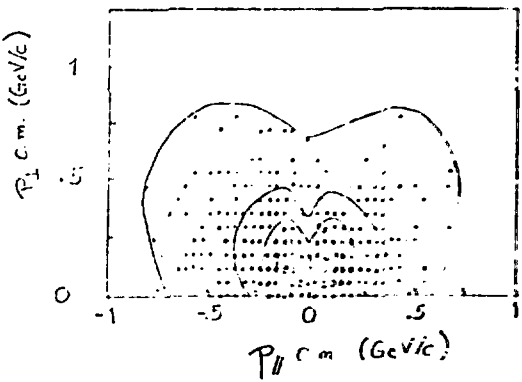


Fig. 5

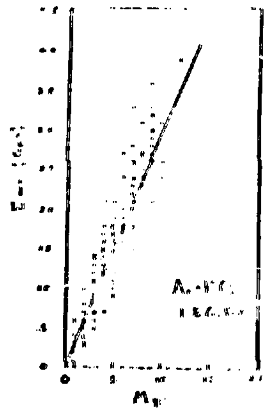


Fig 6

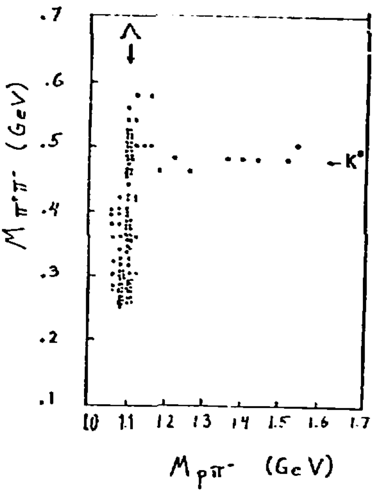


Fig. 7

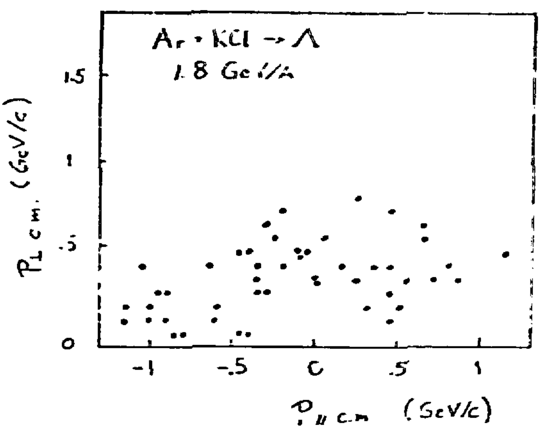


Fig. 8