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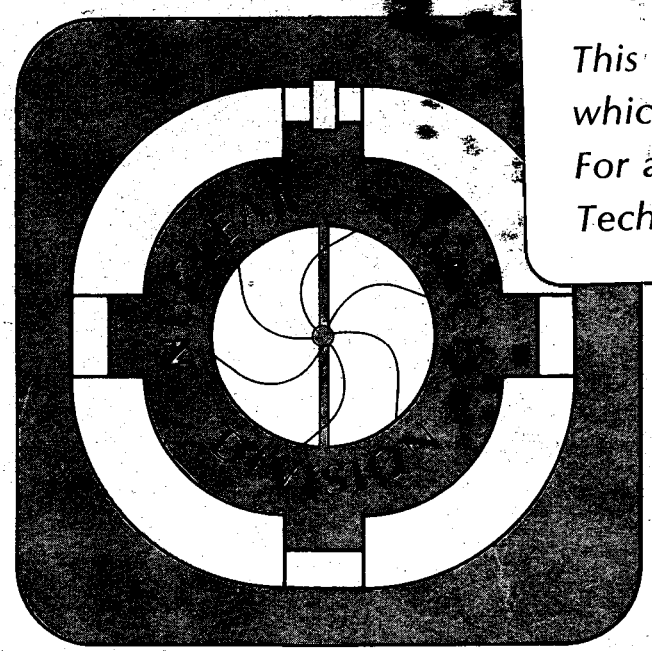
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A. Shor, J. Carroll, E. Barasch, S. Abachi, V. Perez-Mendez, T. Mulera, P. Fisher, G. Igo, S. Trentalange, K. Ganezer, and F. Kazeminzhad

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Abstract

We have measured the production cross section and momentum distribution of K^- produced at 0° in ^{28}Si + ^{28}Si collisions at an energy of 2.1 GeV/nucleon. The K^- spectrum is approximately exponential. The large yield in the "subthreshold" production of K^- that we observe corresponds to a production rate of 1K^- per 50 collisions at impact parameters less than 1f. Productions mechanisms involving collective effects and thermal equilibration are discussed.

Relativistic nuclear collisions (RNC) may demonstrate interesting and possibly exotic nuclear phenomena involving abnormally dense nuclear matter,[1] meson condensation,[2] or a phase transition to quark-gluon plasma.[3] For these nuclear effects to occur, some degree of equilibration or collective interactions among the colliding nucleons must take place. A straightforward indication of thermal or collective behavior is the creation of particles whose production threshold is significantly above the available nucleon-nucleon collision energy. At the maximum Bevalac energy of 2.1 GeV/nucleon, the lightest particle for which production is "subthreshold" is the K^-, which requires an N-N bombarding energy >2.5 GeV.

We have recently measured the momentum distribution of K^- produced at 0° in the reaction ^{28}Si + ^{28}Si at 2.1 GeV/nucleon. Negative secondaries produced in the heavy ion collision were momentum selected and transported along a magnetic beam line. Three bends, each followed by a detector station, allowed for multiply redundant measurements and particle identification. The detector stations were instrumented with an array of scintillation counters, focusing liquid Cerenkov counters, and high-pressure gas Cerenkov counters at the first two locations. Time of flight, along with multiple dE/dX measurements, determined particle mass and charge. Identification of the dominant background was made with the liquid Cerenkov counters for $P < 1$ GeV/c and with the gas counters for $P > 1$ GeV/c.

As an example of the good particle separation in our data, we show in figure 1 the results for laboratory momentum of 2.4 GeV/c. The TOF distribution for events that registered at the first two detector stations but that did not trigger the Cerenkov counters is plotted. This data set represents about 60,000 events prior to the Cerenkov cuts. The events in the peak at 0.85 ns are identified as kaons by their mean TOF. Four of these events actually survived to the third detector station to register correlated TOF information, thus confirming that these events were kaons. Cross

sections were determined by taking into account kaon and pion decay, channel acceptance, target thickness, and integrated projectile intensity.

We measured yields of K^- at laboratory momenta of 0.63, 0.73, 0.90, 1.4, 1.9, and 2.4 GeV/c. The invariant K^- cross sections, plotted as a function of the kaon kinetic energy in the nucleus-nucleus center-of-mass frame, are shown in figure 2, which includes the cross section for K^- at P_{lab} = 0.98 GeV/c that we measured in a previous experiment.[4] In these preliminary results from our recent experiment, we have assigned tentative error bars only.

The data, plotted in the c.m. frame, appear to fall off approximately in an exponential manner, with a slope parameter E_0 of about 80 MeV. This may indicate a thermal source at the mid-rapidity region. However, it is difficult to imagine equilibration for a system as small as ^{28}Si. Nevertheless, barring a thermal source, it may be difficult to account for the K^- at the higher momenta. Since the K^- requires a relatively large energy for its creation, it should be produced primarily at or near the mid-rapidity. For the K^- to acquire a momentum significantly larger than $p = m_k \beta$ c.m. γ c.m. (which in our case corresponds to 0.5 GeV/c), it would have to be produced coherently or to undergo several hard collisions subsequent to its production. (Note that a kaon at the projectile velocity has a momentum of only 1.5 GeV/c.)

An exponential fit to the seven data points gives a χ^2 value of 1.43. A fit excluding the measured point at 525 MeV gives χ^2 = 0.43 and a temperature of ~80 MeV. This last point is then 2.5 S.D. above the 80 MeV line and could indicate a change in slope.

Several models have been studied in an effort to account for the observed high K^- yields. At 2.1 GeV, the de-Broglie wavelengths of the incoming projectile nucleons are about 0.3 Fermi, certainly much smaller than the internucleon separation. It is therefore reasonable to assume that the nuclear collisions consist of independent N-N interactions. Although N-N collisions at 2.1 GeV are below the K^- production threshold, the nuclear Fermi momentum of the projectile and target nucleons allows for more of the N-N bombarding energy to be used for excitation rather than translational energy. A calculation has been performed[4] that assumed a double gaussian parameterization for the Fermi momentum. Although very good agreement was obtained for subthreshold anti-proton production in proton nucleus collision, calculations for K^- production in nucleus-nucleus collisions were more than twenty times below what we observed. Recent high energy muon and electron scattering experiments[5] report systematic differences between the structure functions in iron and deuterium. These results indicate a distortion in the structure function of nucleons embedded in a nucleus that cannot be attributed to Fermi momenta. Theoretical speculations suggest that these distortions may be due to 6-quark states in nuclei. This effect would change our picture of independent N-N collisions and would have a marked effect on subthreshold production.

We have made an estimate of the effects of intermediate π-N and Δ-Δ interactions on K^- production. A perturbation approach using hadron-hadron center-of-mass energies obtained from a cascade calculation show these effects to be small. Recently C.M. Ko has shown that hyperon-pion interactions

contribute significantly to the K^- production rates.[7] However, his calculations assumed thermal pions and did not take into account finite Δ lifetimes and noncentral collisions, and when these effects are included we estimate that this production mechanism accounts for only about 20% of the yield at 1 GeV/c.

With the present K^- data, we are able to rule out the ϕ-Bremsstrahlung model proposed by K.H. Muller.[8] In his model, ϕ-mesons are radiated by decelerated nuclear matter and decay to K^- that are sharply peaked at the mid-rapidity. It also seems unlikely that the suggestion of $K\bar{K}$-condensation is reasonable since it implies a structure in the K^- spectrum that we do not observe.

Subthreshold K^- production will no doubt shed light on the collision dynamics in nucleus-nucleus collisions, if not on new production mechanisms, and therefore warrants further investigation.

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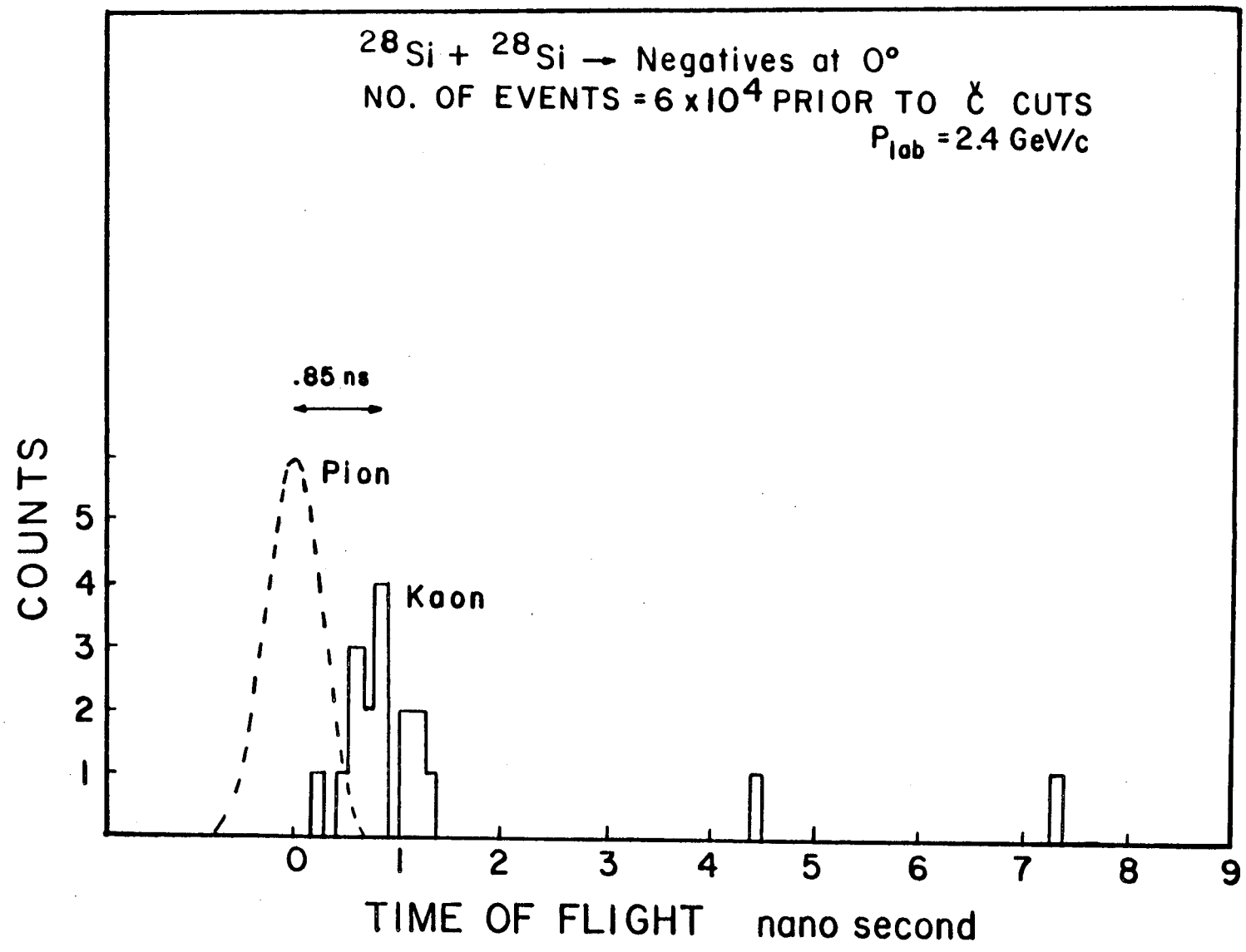


Fig. 1. Time of flight cuts showing the separation between π^- and K^-.

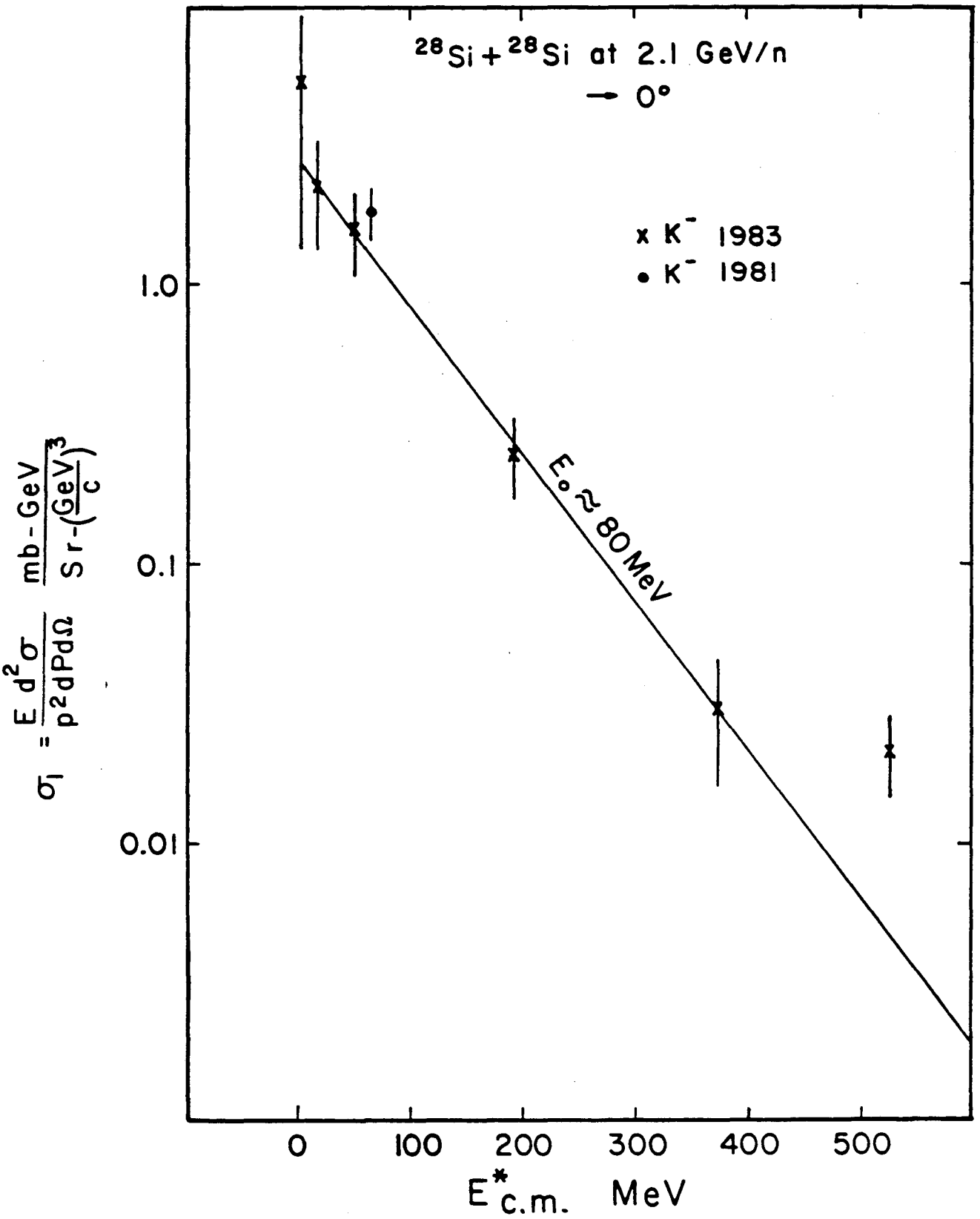


Fig. 2. Energy distribution in the c.m. system of the K^- produced in Si-Si collisions. The line drawn is fitted to the first six points (χ^2 = 0.43/degree of freedom).

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