NEAR THRESHOLD STRANGENESS PRODUCTION IN THE SYSTEM ^{58}Ni (1.93 A·GeV) ON ^{58}Ni

J. L. RITMAN[a] for the **FOPI** collaboration

[a] Gesellschaft für Schwerionenforschung (GSI) Postfach 110552, D-64220 Darmstadt, Germany

The production of particles with strange quark content in relativistic heavy-ion collisions near and below the free threshold is expected to provide detailed information on in-medium modification to hadronic properties. The detection of such effects has been the motivation behind a recent series of experiments with the system ^{58}Ni + ^{58}Ni at beam energies from 1.0 to 1.93 A·GeV at SIS/GSI Darmstadt. A significant first result of this experiment is the generation of the first clear kaon and $\Lambda \rightarrow \pi p$ signals in the FOPI detector. Preliminary results at 1.93 A·GeV on the K^+ and Λ production as a function of collisional centrality as well as the kaon azimuthal distribution relative to the reaction plane are presented.

1. Introduction

An intriguing method to study modifications to hadronic properties in nuclear matter is the measurement of near- and sub-threshold particle production in relativistic heavy ion collisions. Sub-threshold production (at beam energies per nucleon below the free nucleon-nucleon threshold) probes collective processes during the stage of high density and temperature. Furthermore, the measurement of strange hadrons is expected to provide relatively undistorted information due to the low reabsorption probability and/or long mean free path in nuclear matter. At SIS beam energies kaon and Λ hadrons are expected to be predominantly produced during the initial high density stage of the reaction when both a large fraction of the nuclear matter is excited to be the largest [1].

2. Identification of K^+ and Λ Signals with FOPI

Charged reaction products emitted at $\Theta_{LAB} > 30°$ are measured within the existing FOPI detector by the **C**entral **D**rift **C**hamber (CDC) which is described in detail elsewhere [2,3]. In the final construction phase of the FOPI system, the scintillator/Cherenkov Barrel will provide a velocity measurement for reaction products emitted at large laboratory angles, thereby improving the quality of the particle identification. During a recent test of the partially completed Barrel (28% of azimuthal angle coverage), the system ^{58}Ni on ^{58}Ni was studied at beam energies of 1.0, 1.45, 1.7, and 1.93 A·GeV; about $1-2\times10^6$ central events were recorded per energy. One of the immediate objectives of this test was to determine if kaons could be detected by combining the Barrel velocity information with the momentum from the CDC. In this report preliminary results of the search for kaon and Λ signals in the data at 1.93 A·GeV are presented.

After matching the CDC tracks with Barrel hits, particle identification was performed by combining the specific energy loss and momentum measured by the CDC with the Time of Flight (ToF) recorded in the Barrel. The sign of the reaction product's charge is given by the direction that the particle's flight path is bent in the magnetic field, and the velocity is derived by combining the ToF with the flight path which can be determined by the radius of curvature of the fitted CDC track. The magnitude of the charge is then determined by linearizing the specific energy loss as a function of velocity via the Bethe-Bloch function. After selecting particles of a given charge, the mass can be determined by two independent methods. The first method relies only on CDC information by interpolating between Bethe-Bloch curves on the energy loss versus momentum plane. However, this method gives ambiguous results for large momentum since the specific energy loss rises again after a broad minimum. On the other hand, by combining the momentum with the velocity, the mass determination is restricted only by the finite detector resolution.

After a linearization of the momentum versus velocity data was performed for $Z = \pm 1$ particles with $P_{LAB} \leq 0.6$ GeV/c, the mass spectra shown in Fig. 1 were produced. For the positively charged particles a large peak is located near 0.5 GeV/c^2 which is associated to the K^+ meson. At high momenta this peak vanishes below the background which is due to the finite detector resolution, whereas at lower momenta the background is dominated by mismatched Barrel and CDC data. The mass spectrum of negatively charged particles ($P_{lab} < 0.6$ GeV/c) reveals, in addition to the π^- contribution, an intriguing structure near 0.5 GeV/c^2 albeit with low statistics. Not only are the location and width of this structure in agreement with the expected values for anti-kaon production, the yield relative to the K^+ is comparable to previous measurements near this energy [4].

The acceptance for kaons in the transverse momentum versus laboratory rapidity plane is shown in Fig. 2. The data analyzed here are within the horizontally hashed region displayed for the Barrel, but with a further restriction imposed that the maximum laboratory momentum be 0.5 GeV/c. For reference, the arrow marks mid-rapidity for a colliding system at 1.93 A·GeV. The kaon yield is concentrated mostly in the range of rapidity between the target and mid-rapidity. At 1.93 A·GeV K^+ mesons can be produced in first chance nucleon-nucleon collisions with a maximum momentum up to the kinematic limit ($P^{k.l.}_{1.93GeV} = 0.32$ GeV/c) which is denoted by the dot-dashed curve. Since almost the full detector acceptance is beyond this limit, even at beam energies slightly above the free nucleon-nucleon threshold FOPI is primarily sensitive to kaons produced by collective production processes.

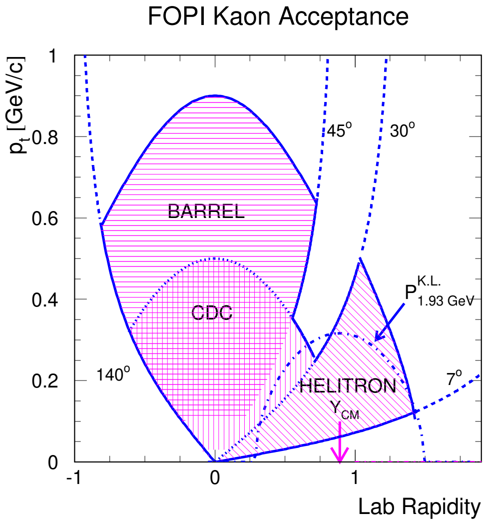

Figure 2. Kaon acceptance of the FOPI detector system. The data evaluated here are from within the horizontally hashed area marked for the Barrel. For reference, mid-rapidity of systems at 1.93 A·GeV is denoted by the arrow.

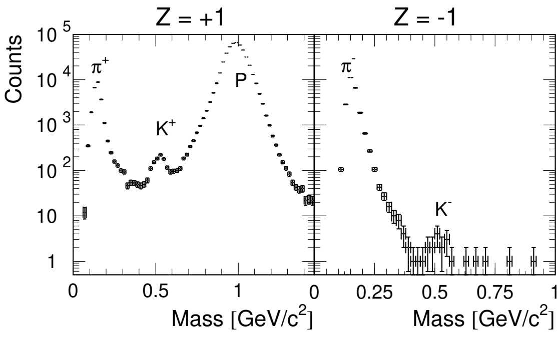

Figure 1. Reconstructed mass using the matched CDC-Barrel data for $P_{lab} < 0.6$ GeV/c for (left) positively charged particles and (right) negatively charged particles.

The reaction channel to produce a K^+ with the lowest threshold (1.6 GeV) includes a hyperon in order to conserve strangeness:

$$N + P \rightarrow N + \Lambda + K^+.$$

Since the Λ is neutral and decays with a lifetime $c \cdot \tau_0 = 7.9$ cm it can not be directly measured by FOPI. However, the products of its main decay channel ($\Lambda \rightarrow p\pi^-$, branching ratio 64%) can be readily detected by the CDC. The Λ is identified by calculating the invariant mass (M_{inv}) of all $p\pi^-$ pairs that intersect to form a secondary vertex away from the main event vertex as shown by the open points in Fig. 3. In this figure a very pronounced peak from the Λ is visible above the mixed event background which is marked by the dashed histogram.

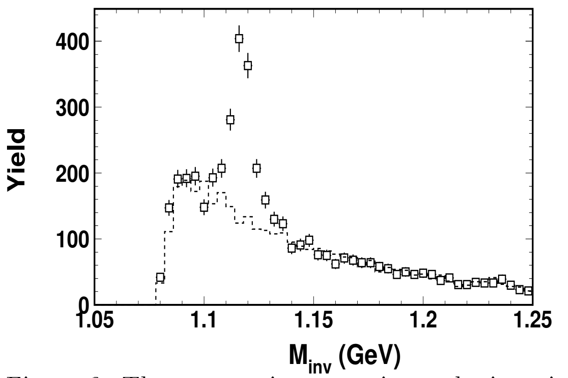

Figure 3. The open points constitute the invariant mass spectra for π^--p pairs forming a secondary vertex away from the target. The large peak above the mixed event background (dashed line) is due to the decay of the Λ meson.

3. Yield as a Function of Centrality

Subthreshold kaon production primarily occurs via multi-step processes of the type

$$N_1 + N_2 \rightarrow N_1 + B, \quad N_3 + B \rightarrow N_3 + Y + K^+.$$

Here N represents a nucleon, B a baryonic resonance (e.g. Δ), and Y a hyperon (e.g. Λ). The probability for collisions of the second type to occur increases strongly with density. Since both the size of the collisional zone and the maximum density are expected to increase with increasing centrality of a heavy ion collision (decreasing impact parameter), the yield of subthreshold particles is expected to vary sharply as a function of the event centrality [5]. Indeed, previous measurements far below threshold show this effect [6].

The event centrality has been determined in the present experiment by summing the number of charged particles detected in both the Forward Wall and the CDC which together provide almost the full 4π coverage. The distribution of the number of events as a function of the total detected multiplicity extends up to 120 particles which corresponds to the complete disassembly of the projectile and target nuclei. Although a connection can be made between the total particle multiplicity and either the impact parameter [7] or the number of participating nucleons [8], the measured quantity will be used in this talk to avoid unnecessary model assumptions.

The π^+ and K^+ multiplicities within a restricted portion of phase space are plotted in Fig. 4 as a function of the total particle multiplicity of the event. At this stage the kaon and pion detection efficiencies have not been studied in detail; therefore, these preliminary results presented here have not yet been corrected and will undergo potentially large modifications. Nevertheless, several features are of note: Events with particle multiplicity less than about 45 show a dramatic rise in the π^+ and K^+ yields, which levels off for events with higher total multiplicity. This results from the large fluctuations in this small system which wash out the correlation between total multiplicity and impact parameter ifor more central events.

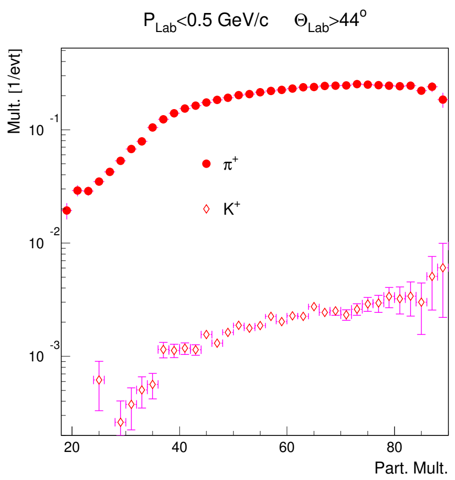

Figure 4. Uncorrected pion and kaon multiplicities for $P_{LAB} < 0.5$ GeV/c and $\Theta_{LAB} > 44°$ as a function of the total number of charged particles measured in FOPI.

At this beam energy (1.93 A·GeV) which is far above the pion threshold, the pion yield is very roughly proportional to the number of participants in the reaction zone [9]. Thus, the K^+/π^+ ratio is a quantity that scales with the kaon production probability per nucleon-nucleon collision. The data presented in Fig. 5 clearly show that the K^+/π^+ ratio increases by a factor of 2-3 from peripheral to central events, which is an indication that multistep processes play an important role in the kaon production mechanism.

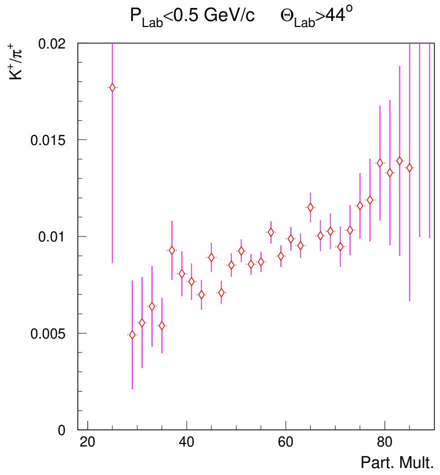

Figure 5. Uncorrected ratio of kaon to pion multiplicities which were given in the previous figure.

The same effect can be seen in the Λ yield and Λ/π ratios which are displayed in Fig. 6. Here these data are plotted as a function of the particle multiplicity measured in only the CDC which covers about half of the full CM solid angle. Within the acceptance range available, there are approximately 2 Λ per 1000 central events recorded, while for peripheral events this ratio drops to 1:10^4. These counts rates are primarily determined by acceptance effects and will require detailed analysis to yield production probabilities. Since the K^+ and Λ are produced together, and reabsorption is low, differences in these ratios give an indication of the magnitude of the systematic efficiency effects that have not yet been corrected.

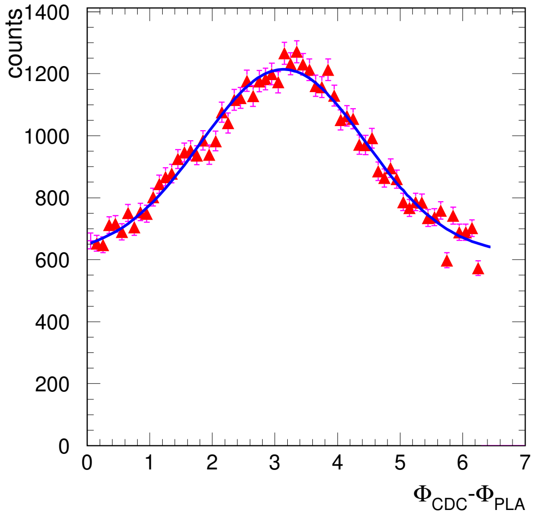

Figure 7. Difference in the reaction plane angle determined by the Forward Wall and that determined by the CDC. The solid line is a gaussian plus constant fit to the data with a width of $\approx$70°.

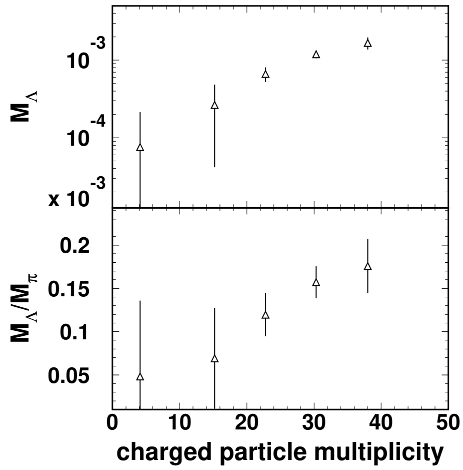

Figure 6. (a) Λ multiplicity plotted versus the number of charged particles measured in the CDC. (b) Λ/π ratio.

4. Azimuthal Dependence of the Kaon Yield

The correlation between the particle emission pattern and the event geometry contains detailed information on both the nuclear flow and in-medium scattering properties. In order to experimentally access this information, the reaction plane must be determined. In the current setup, this is achieved by summing the transverse momentum vectors for all particles (excluding pions in the CDC) taking care to apply a negative sign to all particles with less than half the beam rapidity. The accuracy of the reaction plane is estimated by plotting the difference of the value determined by the Forward Wall (projectile rapidity range) minus that of the CDC (target rapidity). A gaussian plus constant fit to these data in Fig. 7 has a width of $\approx 70°$ which corresponds to a $\sigma_{RP} \approx 30°$ resolution in the reaction

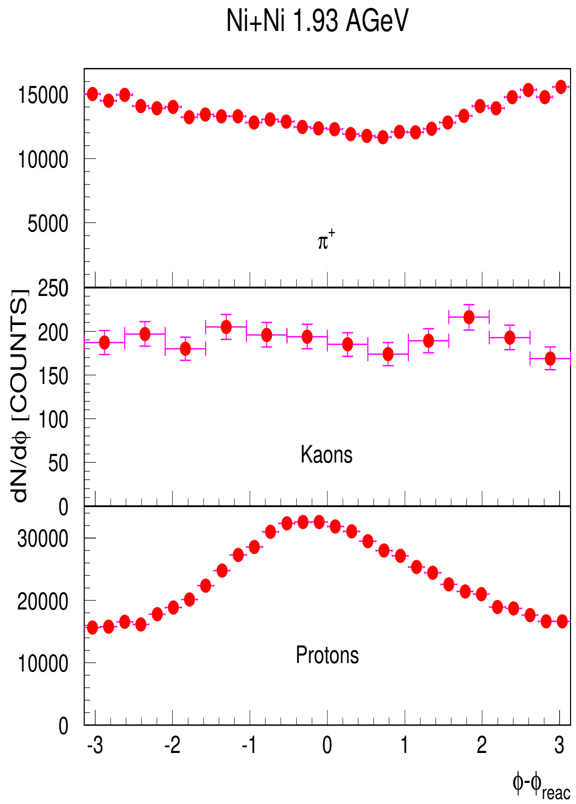

Figure 8. Preliminary spectra of the π^+,K^+, and p yields as a function of the angle relative to the reaction plane. These data are primarily in the target rapidity range because of the requirements that $P_{LAB} < 0.5$ GeV/c and $\Theta_{LAB} > 44°$.

plane when both hemispheres are combined.

Preliminary data for the π^+, K^+, and proton yield with $P_{LAB} < 0.5$ GeV/c and $\Theta_{LAB} > 44°$ are plotted as a function of the azimuthal angle relative to the reaction plane in Fig. 8. As expected the protons are located in the reaction plane. These low momentum, target rapidity pions are preferentially emitted opposite to the reaction plane which is a phenomena that has already been seen [3] and this "antiflow" has been interpreted as the rescattering of the pions in the cold spectator material [10]. Within the limited statistics available, the preliminary kaon yield appears to be consistent with an isotropic angular distribution which is in agreement with earlier measurements [11] and expectations based on the long mean free path of kaons in nuclear matter.

5. Summary and Outlook

In conclusion, the first major test of the final construction phase of the FOPI system with 30% of the Barrel installed has been successfully completed. During this test the Barrel performed quite well, and the data in this report show that the following goals have been successfully achieved: By combining the velocity measurement of the Barrel with the momentum determination of the CDC, K^+ mesons have been measured. Furthermore, proton-π^- pairs have been combined showing a strong resonance due to the Λ baryon decay outside of the target. Preliminary production probabilities have been determined which show a strong rise with increasing centrality for both the K^+ and Λ. This rise is an indication of the importance of multi-step processes in their production mechanism. While the low momentum target rapidity pions are seen to be emitted opposite to the reaction plane, the present statistics do not support any deviations from isotropic emission for the kaon yield.

In the next stage of the analysis the detector acceptance needs to be understood in detail in order to determine quantitative results from these preliminary data. Further results to be expected in the near future include obtaining a measure of the in-medium rescattering length which might be determined from both K-Λ correlations and from the Λ polarization arising from its parity violating decay. Moreover, signals from the decay of the K^0 and K^* mesons may soon become visible with refinements to the analysis routines.

REFERENCES

1. X. S. Fang et al.: *Nucl Phys* **A575** (1994), 766.
2. A. Gobbi et al.: *NIM* **A324** (1993), 156.
3. C. Pinkenburg: *PhD Diss., Heidelberg* (1995).
4. A. Shor et al.: *Phys Rev Lett* **63** (1989), 2192.
5. C. Hartnack et al.: *Nucl Phys* **A580** (1994), 643.
6. D. Miśkowiec et al.: *PRL* **72** (1994), 3650.
7. H. Nifenecker and J. P. Bondorf: *Nucl Phys* **A 442** (1985), 478.
8. J. Gosset: *Phys Rev C* **16** (1977), 629.
9. J. W. Harris et al.: *PRL* **58** (1987), 463. A. Rosenhauer *GSI Report* **88-09**.
10. S. A. Bass et al.: *Preprint* **GSI-95-07**.
11. S. Schnetzer et al.: *Phys Rev C* **40** (1989), 640.