# Production and Flow of $K_s^0$-Mesons and $\Lambda$-Hyperons in $^{58}$Ni + $^{58}$Ni Collisions at 1.93 $A$GeV

Ralf Kutsche, FOPI Collaboration
GSI, Darmstadt, Germany

**Abstract**

We present preliminary results of an analysis of the neutral strange particles $K_s^0$ and $\Lambda$ produced in $^{58}$Ni+$^{58}$Ni collisions at 1.93 $A$GeV. The experiment was performed at GSI in Darmstadt with the detector system FOPI. The incident energy is close to the threshold of strange particle production in free nucleon-nucleon collisions. Therefore the production of kaons and $\Lambda$-particles is sensitive to multi particle effects and multi step processes. The particle yields and their phase-space distributions can be used as probes of the hot and high-density phase of nuclear matter. Neutral strange particles are of special interest since they are not influenced by the Coulomb interaction and are less affected by detection thresholds. The reconstruction of $K_s^0$ meson and $\Lambda$ hyperon events and the determination of preliminary physical results is presented.

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## 1 Introduction

In the central overlap zone of relativistic heavy-ion collisions $E_{\text{kin.}} \leq 2$ $A$GeV nuclear matter can be compressed to densities of $2-3$ times the normal nuclear density ($\rho_0 = 0,17$ fm$^{-3}$) and temperatures up to 100 MeV may be reached. One of the main topics addressed in the study of such collisions is the question whether hadronic properties undergo modifications in this nuclear environment as compared to their properties in vacuum. Indeed, theories predict, in the framework of a partial restoration of chiral symmetry in QCD, changes of hadron masses [1, 2].

In this context the behavior of particles with strange quark content has attracted much theoretical and experimental attention. Particularly the production of kaons and $\Lambda$-particles in near and sub threshold heavy ion reactions has raised much interest. Their yield and phase-space distribution can be used as a probe of the hot and high density phase of collisions.

At collision energies near the particle production threshold, the impact of in-medium effects on the production cross section could be sizeable. The sign and size of the nuclear potential, which accounts for the propagation of particles in nuclear matter, is expected to produce observable effects on the flow pattern. Neutral strange particles like $K_s^0$ and $\Lambda$-particles are especially interesting, because in experiment one can obtain a full coverage of the momentum range. Also they are not influenced by Coulomb interaction.

## 2 Experimental Techniques

The $^{58}$Ni+$^{58}$Ni reactions were produced by bombarding a fixed target with a beam energy of 1.93 $A$GeV supplied by the UNILAC/SIS accelerator combination at GSI Darmstadt. The reactions were measured with the detector system FOPI [4, 5] which is capable of detecting charged reaction products over a large fraction of the total solid angle.

A sample of $6.6 \times 10^6$ central events was recorded. These correspond to those 10% of events which show the highest measured charged-particle multiplicity in the Forward-Wall (Scintillators) of FOPI. Within a sharp-cutoff model this corresponds to roughly the innermost 4 fm of the impact parameter distribution.

All information used in this analysis is derived from the Central Drift Chamber (CDC) which is installed in a superconducting solenoid with a homogeneous magnetic field of 0.6 T. The CDC covers the polar angular range of $33^o \leq \Theta_{\mathrm{Lab.}} \leq 150^o$. The momentum and the sign of the charge of a particle can be measured by its track curvature in the magnetic field. For each hit in the CDC the corresponding energy loss is measured simultaneously. The specific energy loss and the momentum Fig. 1 determine the mass via the Bethe-Bloch relation thus allowing to identify charged particles. Clearly visible are pions, protons, deuterons and tritons or $^3$Helium. By the introduction of specific cuts it is possible to select the $K^+$ but this will not be discussed here. Neutral strange particles are identified by reconstructing the

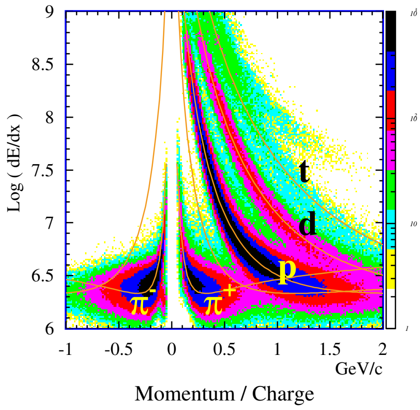


Figure 1: *Specific energy loss as function of particle momentum. Negatively charged particles are assigned a negative momentum.*

invariant mass from their charged decay products, i. e. from a ($\pi^+$, $\pi^-$)-pair for $K^0_s$ and a ($p$, $\pi^-$)-pair for $\Lambda$. Due to their weak decay these particles have a quite long lifetime corresponding to $c\tau_{K^0_s} = 2.7$ cm and $c\tau_\Lambda = 7.9$ cm, respectively. Hence they decay at a secondary vertex outside the target. Particle pairs were accepted as possible decay candidates only if they originate from such a vertex with a certain minimum distance from the target. Track quality and kinematic conditions were imposed in order to suppress the combinatorial background contributions. Good tracks are required to have at least 20 CDC hits (signals recorded on different wires), a momentum $p \geq 100$ MeV/$c$ to exclude all tracks which spiral inside the CDC, and the masses calculated for both tracks have to be compatible with the pion or proton mass, respectively. Finally we demand that the calculated momentum of $K^0_s$ or $\Lambda$ points in the direction of the vector connecting the primary and secondary vertex. About 67% for $K^0_s$ and 80% for $\Lambda$ hyperons, whose decay product fall into the geometrical acceptance of the CDC, are lost by this procedure, whose the main contribution is due to the secondary-vertex cut. Fig. 2 shows the invariant mass spectra for ($\pi^+$, $\pi^-$)-pairs and ($p$, $\pi^-$)-pairs which fulfill all $K^0_s$ and $\Lambda$ conditions. The combinatorial background is derived by the technique of mixed-event analysis and is denoted by the dashed line. After subtraction of this background the peaks are fitted with Gaussians, yielding widths of 14 MeV/c$^2$ and 4.5 MeV/c$^2$ for the $K^0_s$ and $\Lambda$ peaks, respectively.

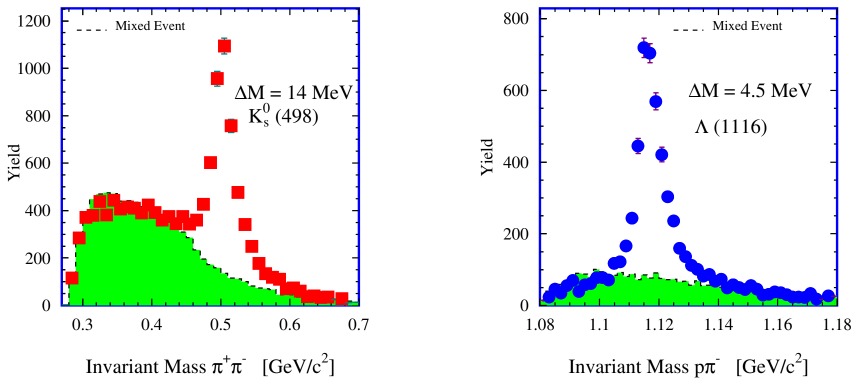


Figure 2: *Invariant mass spectrum for ($\pi^+$, $\pi^-$)-pairs and ($p$, $\pi^-$)-pairs. The dashed line is the mixed event background.*

## 3 Preliminary Results

FOPI is an axially symmetric detector; this simplifies acceptance corrections. The phase-space distribution of kaons and $\Lambda$-particles in the transverse momentum versus rapidity plane is presented in Fig. 3. One of the main advantages of reconstructing particles from their decay products is that the covered phase-space can be extended beyond the geometrical acceptance. The reconstruction efficiency and the geometrical acceptance are determined in a Monte Carlo simulation with the GEANT package; small improvements are still in progress. In non-central collisions the presence of spectators produces various flow phenomena manifesting themselves

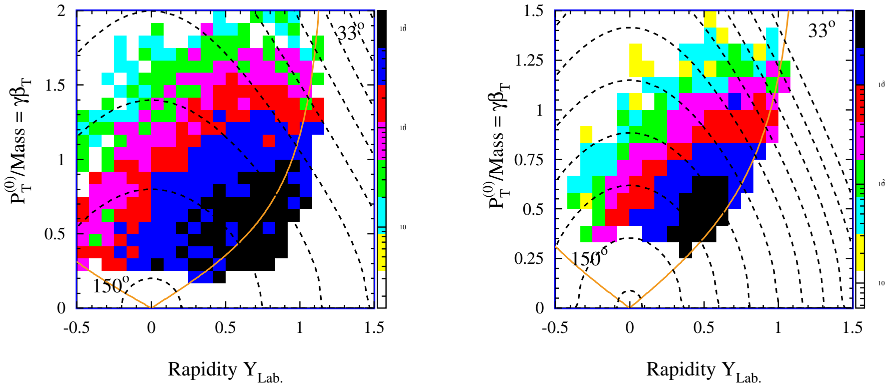


Figure 3: *Phase-space distribution of reconstructed $K_s^0$ and $\Lambda$ after efficiency correction measured in Ni+Ni collisions at 1.93 AGeV. The solid lines denote the detector boundaries at $33^o$ and $150^o$, and the dashed curves correspond to the laboratory momentum $p_{\rm Lab}$ between* 0.1 *GeV and* 3.0 *GeV in steps of 0.3 GeV.*

in in-plane and out-of-plane asymmetries. In our analysis the reaction plane was determined by using the method proposed in [6]. To estimate the accuracy of the procedure we divided randomly each event into two sub-events. The azimuthal correlation between the reconstructed event-plane vectors $Q_1$ and $Q_2$ gives us an accuracy of $43^o$ varying by roughly $\pm 5\%$ as a function of centrality.

Recent theoretical work has suggested that especially the sideward flow of strange particles may provide useful information on in-medium properties of these particles in dense nuclear matter [3].

Results on $K^+$ flow have been published only recently [7]. Existing data on neutral strange particle flow [8] suffer from the lack of statistics. Compared to these measurements the analysis presented in this contribution is based on a three times larger data set. Systematics studies in greater details allows for a better signal to background ratio.

Fig. 4 shows the $\Lambda$ and $K^+$ sidewards flow in terms of the quantity $< p_X >$ as the function of rapidity $Y^0$ together with the proton flow. There is a remarkable difference in the flow of these two particles despite their associated production. While the $\Lambda$-particles follow the flow of protons no kaon flow is visible. This observation is consistent with the ones, which wound expect a non-vanishing primordial kaon flow, only if some repulsive potential pushes the kaon flow to zero. A trivial potential of such a kind is the Coulomb potential, which also could push the $K^+$ out of the main flow direction of the protons. That is why the simultaneous investigation of the $K^+$ and $K_s^0$ flow is import. For $K_s^0$ a possible Coulomb push

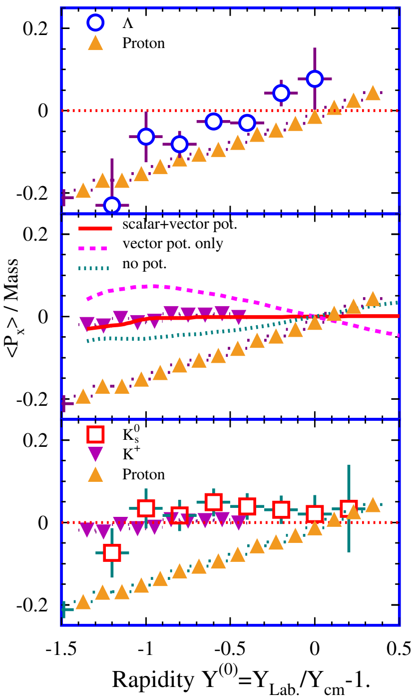


Figure 4: *Mean transverse momentum $< p_x >$ divided by the particle's mass $m$ as a function of scaled rapidity. Upper panel: Comparison of sideward flow for proton and $\Lambda$; Center panel: Theoretical calculation (RBUU) with various $KN$ potentials in comparison with $K^+$ [10]. Lower panel: Comparison of sideward flow for $K^0_s$ and $K^+$.*

can be ruled out as an explanation for disappearance of the kaon flow. Within the experimental uncertainties our results show no difference between the Coulomb affected $K^+$ and the $K^0_s$ flow. This indicates that Coulomb forces are too weak to explain the observations [9].

One of the interesting explanations for this flow pattern is the interplay of scalar and vector parts in the potential describing the interaction of kaons in nuclear matter. Within such a scenario the present results might indeed point to density dependent in-medium mass modification of kaons. Up to now the observed flow pattern can be reproduced by introducing scalar and vector potentials describing the kaon potential [9, 10, 3, 11].

# 4 Summary and Outlook

We have shown that the invariant mass distribution of $(\pi^+, \pi^-)$-pairs and $(p, \pi^-)$-pairs exhibit a strong signal attributed to $K^0_s$-mesons and $\Lambda$-hyperons decaying outside of the target. With optimized cuts preliminary $p_T$-distributions have been determined and sideward flow patterns extracted.

The preliminary $K_s^0$ flow analysis show within the experimental uncertainties that the Coulomb effect can not describe the flow behavior by themselves. It seems that not until an additional scalar and vector potential is added the flow profile can explained.

In the next step of the analysis the detector acceptance needs to be understood in full detail in order to determine final quantitative results. Then we will apply the established method of this analysis to the heavier systems like $Ru/Zr$ which have already been measured by the FOPI collaboration.

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