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Strange Particle Measurements from the EOS TPC

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Abstract

A high statistics sample of Λ's produced in 2 GeV/nucleon ^{58}Ni + $^{\mathrm{nat}}$Cu collisions has been obtained with the EOS Time Projection Chamber at the Bevalac. The coverage of the EOS TPC is essentially 100% for $y > y_{cm}$ and extends down to $p_T = 0$ where interesting effects such as collective radial expansion may be important. In addition, the detection of a majority of the charged particles in the TPC, along with the presence of directed flow for protons and heavier fragments at this beam energy, allows for the correlation of Λ production with respect to the event reaction plane. Our preliminary analysis indicates the first observation of a sidewards flow signature for Λ's. Comparisons with the cascade code ARC are made.

1. Introduction

The existence of collective flow for nucleons and light fragments has been firmly established in relativistic nucleus-nucleus collisions at Bevalac/SIS energies [1]. The preferential sidewards emission of participant matter into the reaction plane, or 'sidesplash', is considered an important signature of nuclear compression and an indirect measure of

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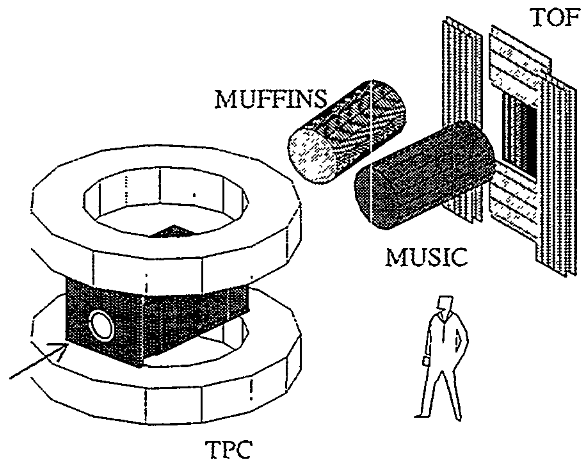

Figure 1: The EOS setup.

the nuclear matter equation of state. Recently, theoretical attention has been focussed on the flow of produced particles such as pions [2], antiprotons [3], and subthreshold kaons [4]. To date reaction plane correlations have been experimentally verified for pions only [5-8]. New data from the EOS experiment, which combines a large acceptance for protons and other light fragments and a high efficiency for the detection of Λ's, provides the first observation of directed flow behavior for strange baryons.

2. The EOS Experiment

The EOS experimental setup, depicted in Fig. 1, consists of four main detector subsystems which, together, provide substantial phase space coverage with simultaneous particle identification. The heart of the setup is a state-of-the-art Time Projection Chamber (TPC) which provides continuous 3D tracking and pid for particles with $Z \leq 8$ [9]. Fragments with $8 \leq Z \leq Z_{beam}$ are tracked and identified with a multiple sampling ionization chamber (MUSIC). Neutron multiplicities and energy spectra are obtained from a high efficiency neutron detector (MUFFINS) centered at zero degrees with respect to the beam. Downstream is a TOF wall, composed of ~100 individual scintillator slats, which is intended to provide particle id in the charge region not well covered by either the TPC or MUSIC.

The EOS TPC has a rectangular geometry and operates in anti-parallel 1.3 T $\vec{B}$ and 120 V/cm $\vec{E}$ fields. Unlike previous TPC's, EOS relies solely on pads for readout. The pad plane covers an area of 1.54×0.96 m^2 and is divided into 128 pad rows along the longer, $\hat{z}$, dimension. Each pad row is, in turn, segmented into 120 pads in the $\hat{x}$ direction. At each pad row crossing, the x coordinate of a track is determined to ~750 μm accuracy through charge division between the pads, while the y coordinate is

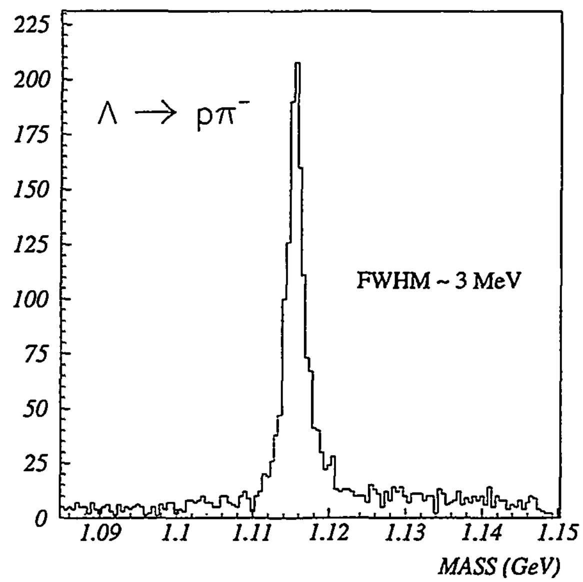

Figure 2: Λ invariant mass spectrum.

determined with ~1 mm resolution by measuring the time it takes for the ionization electron cloud to drift to the pad plane. The integrated charge deposited on each row provides up to 128 separate energy loss measurements from which dE/dx versus rigidity plots are constructed.

Λ's are reconstructed in the TPC through the charged particle decay: $\Lambda \longrightarrow p+\pi^-$, which has a branching ratio of ~64%. After all TPC tracks in an event are found and the overall event vertex has been determined, each pair of $p\pi^-$ tracks is looped over and their point of closest approach is calculated. Pairs whose trajectories intersect at a point other than the main vertex are fit with a V0 hypothesis from which an invariant mass and momentum are extracted. Cuts are made on quantities such as distance of decay from the main vertex, impact parameter, χ^2/ν etc. in order to eliminate the combinatoric background. The invariant mass distribution resulting from one particular set of cuts is shown in Fig. 2. The combined acceptance plus efficiency is ~20%.

3. Directed Flow

A sample of ~1500 events containing good Λ candidates was selected by cutting on the peak of the invariant mass distribution. The standard transverse momentum analysis of Danielewicz and Odyniec [10] was performed on these events. A separate reaction plane vector for each particle with $Z \leq 8$ was determined by summing over

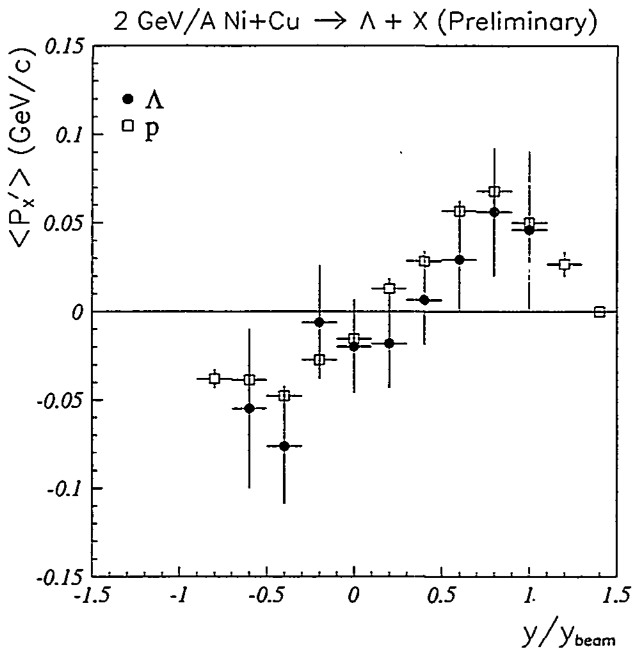

Figure 3: Average in-plane momentum versus normalized rapidity.

all the other particles in an event:

$$\mathbf{Q}_\nu = \sum_{\mu \neq \nu} w_\mu(y) \mathbf{p}_\mu^\perp \,, \qquad (1)$$

where the weighting function, $w_\mu(y)$, is defined as in Ref. [11]. Λ's, π's, K's, and protons from Λ decays were excluded from the sum in Eq. 1. For protons, the in-plane transverse momentum was obtained from:

$$p_\nu^{x'} = \mathbf{p}_\nu \cdot \hat{\mathbf{Q}}_\nu \,. \qquad (2)$$

Averaging $p^{x'}$ as a function of rapidity results in the typical S-shaped curve shown in Fig. 3. In principle, the data points should be nearly antisymmetric about $y/y_{beam} = 0$, reflecting the near symmetry between projectile and target masses. The smaller $|\langle p^{x'} \rangle|$ for backward rapidity protons in Fig. 3 is a consequence of reduced acceptance for $y_{cm} < 0$. The sub-event method of Ref. [10] was used to obtain an estimated error of $\sigma_R = 34°$ in the determination of the average reaction plane. The data in Fig. 3 have not been corrected for this dispersion.

An average reaction plane for each event was calculated from the individual $\mathbf{Q}_\nu$ vectors. The Λ momentum vector was projected onto this plane on an event-by-event basis and the resulting $\langle p^{x'} \rangle$ versus rapidity is shown as the filled circles in Fig. 3. The statistical errors are large but the overall trend is clear — the Λ's "flow" in the same direction as the protons. The magnitude of the Λ flow appears to be somewhat smaller than the proton flow; however, preliminary simulations indicate that inclusion of even

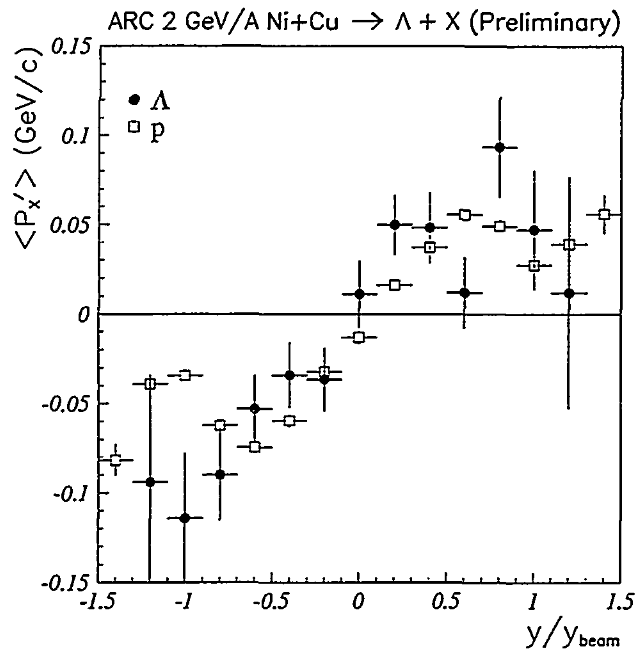

Figure 4: $\langle p^{x'} \rangle$ versus rapidity for unfiltered ARC events.

a small amount of background tends to reduce the sidesplash effect for Λ's. Therefore, we prefer to wait until more detailed simulation studies have been performed before making any quantitative statements about the magnitude of Λ directed flow.

Preliminary comparisons to the data of Fig. 3 have been made with the cascade code ARC [12]. The ARC model has been successful at reproducing a wide range of inclusive observables at AGS energies and, more recently, it has been used to study directed flow in Au + Au collisions at Bevalac energies [13]. A large sample of minimum bias 2 GeV/nucleon Ni + Cu ARC events has been obtained and is currently being passed through the EOS detector filter. The number of filtered events containing Λ's is not yet sufficient for a flow analysis; however, the transverse momentum analysis has been applied to unfiltered events. Reaction plane vectors were constructed from the ARC data using Eq. 1 and mean in-plane transverse momenta were calculated for protons and Λ's. The results are shown in shown in Fig. 4. Qualitatively, we see that the cascade is in good agreement with the data. More quantitative comparisons await higher statistics for filtered ARC.

4. Radial Flow

At $y = y_{cm}$ the $\langle p^{x'} \rangle$ for protons and Λ's goes through zero in Fig. 3, as it should for this approximately symmetric system. The question arises whether the kinetic energy spectra at central rapidity are characteristic of a simple thermal distribution. For a pure Maxwell-Boltzmann, the mid-rapidity spectra take on an especially simple

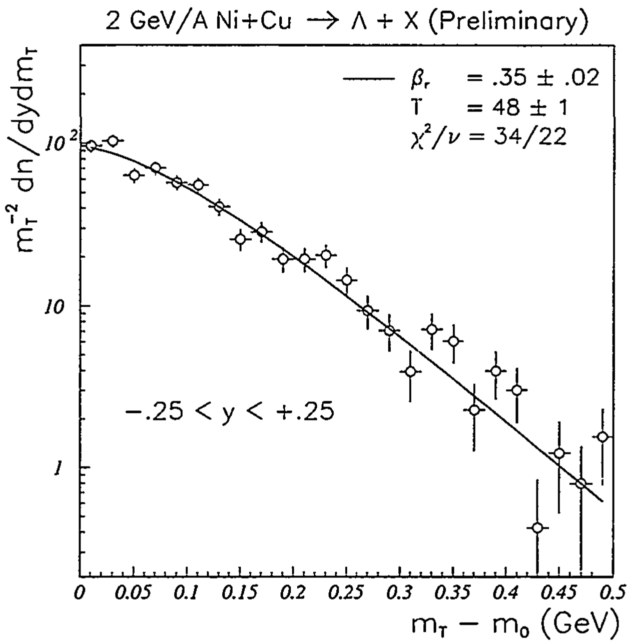

Figure 5: Mid-rapidity Λ transverse mass spectrum.

form when expressed as a function of transverse mass, $m_T = \sqrt{p_T^2 + m^2}$:

$$\frac{1}{m_T^2} \frac{dn}{dm_T} \propto e^{-m_T/T} \ . \tag{3}$$

More than 15 years ago, it was noted that the spectra of protons and pions measured at 90° in the center of mass at the Bevalac deviated from this simple form [14]. Instead, the distributions showed a pronounced shoulder at low p_T, which the authors of Ref. [14] attributed to collective radial expansion. By assuming a spherically symmetric expansion with a constant velocity, β_r, they were able to derive an analytical expression which, in terms of transverse mass, is:

$$\frac{1}{m_T^2} \frac{dn}{dm_T} \propto e^{-\gamma m_T/T} \left[\frac{\sinh \alpha}{\alpha} \left(\gamma + \frac{T}{m_T} \right) - \frac{T}{m_T} \cosh \alpha \right] \ , \tag{4}$$

where $\alpha = \beta_r \gamma p/T$ and $\gamma = (1 - \beta_r^2)^{1/2}$. Equation 3 can be recovered from Eq. 4 by setting $\beta_r = 0$.

Recently, this collective expansion picture has been applied to central Au + Au EOS data spanning an energy range from 250 MeV/nucleon to 1.2 GeV/nucleon [15]. Equation 4 was used in a simultaneous fit of p, d, t, ^{3}He, and ^{4}He at each beam energy. The relative normalizations of each particle species were allowed to be free parameters but the radial flow velocity and temperature were common to all species. Good fits to the mid-rapidity spectra were obtained, with β_r increasing from approximately 0.2c at 250 MeV/nucleon to around 0.3c at 1.2 GeV/nucleon.

The mid-rapidity m_T distribution for the EOS Λ's is shown in Fig. 5. In this representation, a purely thermal distribution would result in a straight line. The data of Fig. 5, however, have the characteristic shoulder indicative of a collective outward expansion depleting the low m_T region. Equation 4 has been used to fit the data and the results are shown on the figure. The m_T spectrum of mid-rapidity protons from the same event sample also shows a shoulder. An independent fit of the protons results in a β_r of $0.42 \pm .01$, in close agreement with the β_r for the Λ's. The proton temperature, however, is much higher — 80 MeV as opposed to 48 MeV. Therefore, it is not possible to simultaneously fit the protons and Λ's with Eq. 4. For protons, the mid-rapidity p_T spectrum is known from simulations to be relatively undistorted by the EOS acceptance out to relatively large transvere momenta. The acceptance for high p_T Λ's at mid-rapidity is still being studied, however. It is possible that their low relative temperature is due to acceptance.

5. Summary

The EOS experiment has obtained new, high quality, exclusive data on Λ production at 2 GeV/nucleon. Correlation of the Λ momentum with the reaction plane on an event-by-event basis reveals an unambiguous directed flow signature. A pronounced shoulder in the Λ m_T spectrum at mid-rapidity may be evidence for collective radial expansion. The beam energy and A dependence of Λ collective flow will be addressed in 1995 when the EOS TPC is moved to the AGS.

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