Elliptic flow of Λ hyperons in Pb+Pb collisions at 158 A GeV

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The elliptic flow of Λ hyperons has been measured by the NA49 experiment in semi-central Pb+Pb collisions at 158 A GeV. The standard method of correlating particles with an event plane has been used. Measurements of v_2 near mid-rapidity are reported as a function of rapidity, centrality and transverse momentum. Elliptic flow of Λ particles increases both with the impact parameter and with the transverse momentum. It is compared with v_2 for pions and protons as well as with models predictions.

1. Introduction

Elliptic flow at ultrarelativistic energies is interpreted as an effect of the pressure in the interaction region. It is thus sensitive both to the equation of state of nuclear matter and to the degree of thermalization reached in the system. The flow of heavier particles is particularly interesting as it is less sensitive to the freeze-out temperature and thus more directly reflects conditions at the early stage of the collision than the flow of light particles. In this context the measurement of the elliptic flow can serve to test various models and gain insight into the mechanism of the collision at the early stage.

The measurements of the elliptic flow of Λ hyperons supplement earlier results on directed and elliptic flow for protons and π mesons [1] and represents the first results on elliptic flow of Λ particles at SPS energies.

2. Analysis

The main components of the NA49 detector [2] are four large-volume Time Projection Chambers for tracking and particle identification by dE/dx measurement with resolution 3−6%. The TPC system deploys two vertex chambers inside the magnets and two main chambers on both sides of the beam behind the magnets. Downstream of the TPCs a veto calorimeter detects projectile spectators and serves as a trigger device and a centrality selector. The analysed sample consists of 3M semi-central Pb+Pb events with online trigger selection of the 23.5% most central collisions. Events were divided into three from among six previously used centrality bins (table 1 in [1]). The measurement in the centrality range $\sigma/\sigma_{TOT} = 5 - 23.5\%$ is the integral over bins 2 plus 3.

The candidates for Λs are selected on a statistical basis utilizing the kinematic properties of the reconstructed decay $\Lambda \rightarrow p + \pi^-$ (BR=63.9%). The identification method [3] relies on the invariant mass cut and daughter track identification by a cut in dE/dx around the expectation value derived from a Bethe-Bloch parametrization. The extracted Λ candidates have some background contamination which is below 8% in our case. The raw yields of Λ hyperons are obtained by counting the number of entries in the invariant mass peak above estimated background in every bin of the azimuthal angle with respect to the event plane. The acceptance of Λ hyperons covers the range $p_t \approx 0.4 - 4$ GeV/c and y $\approx$ -1.5 $-$ +1.0. The elliptic flow analysis used the standard procedure outlined in [1,4] to reconstruct the reaction plane for each event with the necessary corrections for the reaction plane dispersion. Acceptance corrections are introduced by the recentering method [1] and the event mixing technique with 10 artificial events per one real event.

Presented NA49 results on Λ elliptic flow are still preliminary. Error bars contain statistical errors and uncertainty of the background subtraction and mixed-events correction.

3. Results

The final statistics in Pb+Pb collisions consists of about 1M Λs. It makes possible flow analysis for several rapidity and p_t bins. Example azimuthal distributions of Λ particles with respect to the estimated event plane are shown in Fig.1 for real and mixed events. Curves represent fits of the function in the form of a Fourier series with two parameters v_2 and v_4, see eq.(1) in [4]. The distributions exhibit a strong correlation for real events (solid symbols, solid lines) and no correlation for mixed-events (open symbols, dashed lines). The correlation significantly increases with transverse momentum and also with impact parameter.

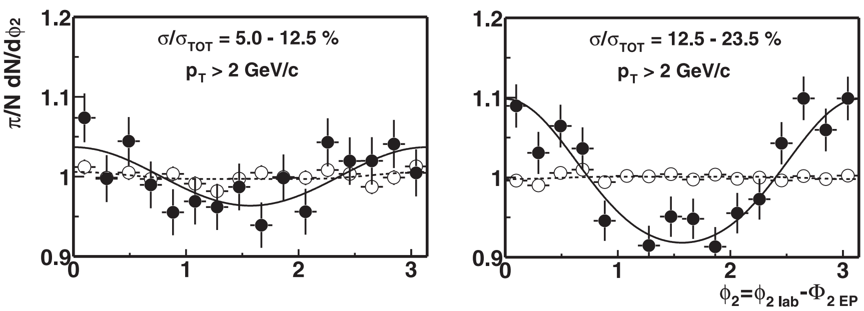

Figure 1. Azimuthal distributions of Λ hyperons with respect to the event plane for real events (solid symbols) and mixed-events (open symbols) in two centrality bins. The curves are Fourier expansion fits.

The p_t integrated Λ elliptic flow exhibits no significant dependence on rapidity as shown in Fig.2. Similar weak dependence v_2(y) for protons in mid-central events is observed in [1](Fig.6).

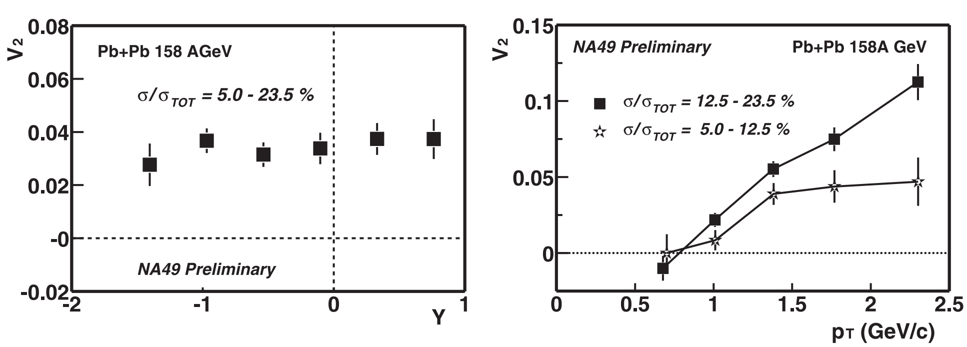

Figure 2. Elliptic flow of Λ hyperons as a function of rapidity (left) and p_t (right).

The pronounced flatness of $v_2(y)$ suggests that event samples can be directly compared even in different rapidity ranges as long as Λs are measured near midrapidity. The p_t dependence of rapidity integrated Λ elliptic flow is shown in Fig.2(left) for two centrality ranges. The v_2 parameter significantly increases with transverse momentum; the rise is stronger for more peripheral events. The p_t dependence of Λ elliptic flow measured by the NA49 experiment is in agreement with CERES/NA45 data [5]. Fig.3 shows a comparison of $v_2(p_t)$ of Λ hyperons in mid-central and central events measured by the NA49 and STAR experiments [6].

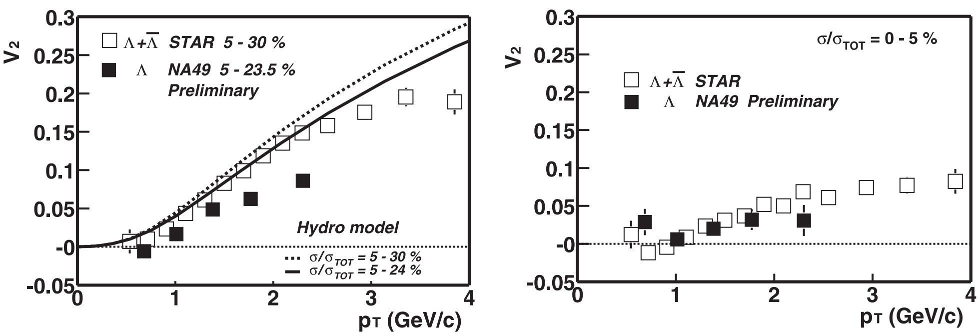

Figure 3. Elliptic flow of Λ hyperons as a function of p_t from mid-central (left) and central (right) events measured by the STAR (open symbols) and NA49 (solid symbols) experiments. Curves are hydrodynamical model predictions at RHIC energy.

For mid-central collisions NA49 elliptic flow grows linearly with p_t up to ~2 GeV/c but significantly slower then at RHIC energy. It has to be emphasized that RHIC mid-central data have been measured in the centrality range $\sigma/\sigma_{TOT} = 5{-}30\%$ while SPS events are more central. The effect of different centrality ranges has been estimated by hydrodynamic calculations [7] at RHIC energy in two centrality bins shown in Fig.3 as two curves. It only partly explains the difference between both measurements. For central events both measurements agree within errors. The elliptic flow $v_2(p_t)$ for pions, protons and Λ hyperons measured by the NA49 experiment in mid-central events is displayed in Fig.4. The values for pions and protons are calculated on the basis of previous results

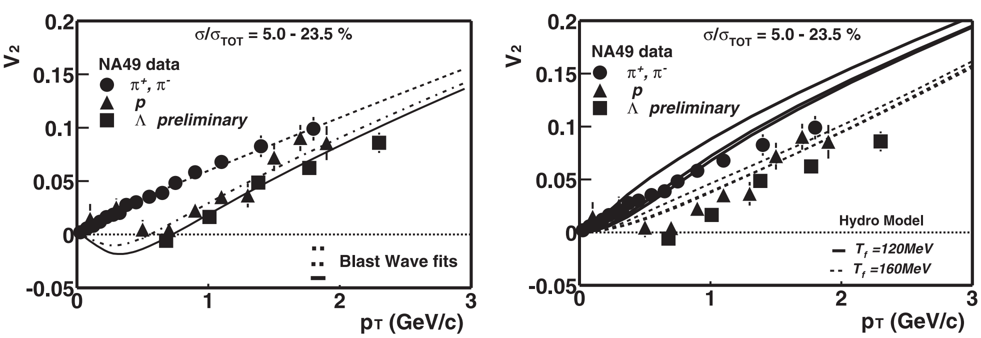

Figure 4. Elliptic flow for charged pions (circles), protons (triangles) and Λ hyperons (squares) as a function of p_t from 158 A GeV Pb+Pb mid-central events measured by NA49 experiment. Curves are blast wave fits (left) and hydrodynamic model predictions for two freeze-out temperatures at SPS energy (right).

published in [1]. Curves in Fig.4(left) indicate fits of the blast wave parametrization [8,9] and in Fig.4(right) predictions of a hydrodynamical model [10]. The elliptic flow grows linearly with p_t for all species but the rise for pions starts from p_t equal zero while for protons and Λs it starts from p_t=0.5 GeV/c. The elliptic flow for pions is significantly larger than for heavier particles although at $p_t \approx 2$ GeV/c the magnitude of the flow for all particle species becomes similar. Data are reproduced by the blast wave fits with parameters similar to those obtained by fitting pt spectra and HBT radii [11]. Hydrodynamical model calculations assume a first order phase transition to QGP at critical temperature T_c=165 MeV. The freeze-out temperature T_f=120 MeV is tuned to reproduce particle spectra. Model calculations significantly overestimate the SPS data for semi-central collisions in contradiction to predictions at RHIC energy which agree with data quite well for $p_t \lesssim 2$GeV [6]. The discrepancy at SPS may indicate a lack of complete termalisation or a viscosity effect. On the other hand the model reproduces the characteristic hadron mass ordering of elliptic flow and thus supports the hypothesis of early development of collectivity. The calculation from the same model with higher temperature T_f=160 MeV exhibits better agreement with Λ flow data. This might be considered as an interesting check of the early decoupling scenario for hyperons, but the model with such a high freeze-out temperature has a problem to simultaneously reproduce m_T spectra and v_2 values.

4. Summary

The NA49 collaboration has measured Λ hyperon elliptic flow at the highest SPS energy. Elliptic flow of Λ hyperons exhibits no significant dependence on rapidity for $y = y_{mid} \pm 1.5$. It rises linearly with p_t and is smaller than v_2 for pions and protons. Both features are well reproduced by the blast wave parametrization and the hydrodynamic model. The increase of v_2 with p_t is weaker at SPS than at RHIC energy and is significantly overpredicted by hydrodynamical calculations.

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