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Identified hadron spectra in p+p interactions at 20, 31, 40, 80 and 158 GeV/c from NA61/SHINE at the CERN SPS

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The NA61/SHINE experiment aims to discover the critical point of strongly interacting matter and study the properties of the onset of deconfinement. These goals are achieved by measurements of hadron production properties in nucleus-nucleus, proton-proton and proton-nucleus interactions as a function of collision energy and size of the colliding nuclei. In this contribution, inclusive spectra of identified hadrons in p+p interactions at the SPS energies are shown as a function of transverse momentum/mass and rapidity. The new data is compared with corresponding results from the experiment NA49 for central Pb+Pb collisions. A significant difference is observed between spectra shapes in p+p and central Pb+Pb collisions.

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1. Data and analysis methods

The presented data results concern inclusive spectra of identified hadrons produced in inelastic p+p interactions at 20, 31, 40, 80, 158 GeV/c. Two analysis methods were used:

- for π^- spectra the h^- method [1], which is based on the fact that the majority of negatively charged particles are π^- mesons. The contribution of other particles is subtracted using calculations based on the VENUS and EPOS models
- for all hadrons the dE/dx method, which uses information on particle energy loss in the TPC gas to identify particles. In each bin of p, p_T and charge a sum of Gauss functions G is fitted to the dE/dx spectrum. For each track its Likelihood value for being a given hadron is calculated based on the fitted dE/dx distribution:

$$L_{\pi,K,p,e}(p_{tot}, p_T, dE/dx) = \frac{G_{\pi,K,p,e}(p_{tot}, p_T, dE/dx)}{\sum_{i=\pi,K,p,e} G_i(p_{tot}, p_T, dE/dx)}.$$

The sum of Likelihoods for a given hadron type gives the multiplicity of this hadron.

The results are corrected for particles from weak decays (feed-down) and detector effects using Monte-Carlo models. Out of target interactions are subtracted using events recorded with empty liquid hydrogen target.

2. Results on single-particle spectra

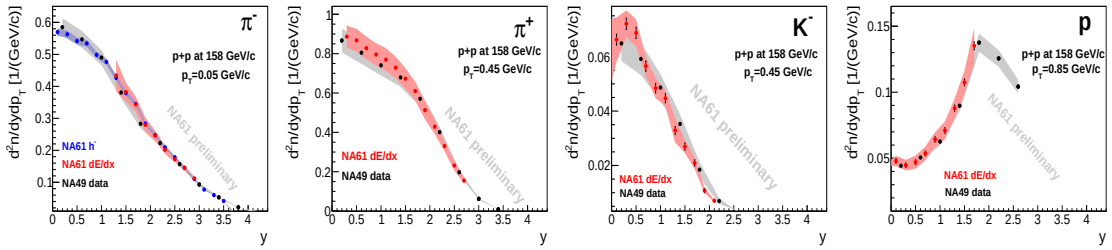

Figure 1: Examples of rapidity spectra from inelastic p+p interactions at 158 GeV/c. Comparison of two identification methods and corresponding results from experiment NA49 are shown. Statistical errors are indicated by vertical bars and systematic uncertainties by colored bands.

Examples of rapidity spectra of π^-, π^+, K^- mesons and protons produced in inelastic p+p interactions at 158 GeV/c are presented in Fig. 1. The results are compared with the corresponding NA49 data [2, 3, 4]. π^- spectra obtained using the h^- and dE/dx methods agree. Moreover, NA61/SHINE and NA49 results are consistent for all particle types.

Transverse mass spectra of pions, negative kaons and protons for 158 GeV/c collision energy at mid-rapidity are presented in Fig. 2 (left). The corresponding data for Pb+Pb interactions measured by the NA49 collaboration [5, 6, 7] are shown in the right panel of Fig. 2 (right). Both data sets were fitted using the simplified blast wave model parameterization [8]:

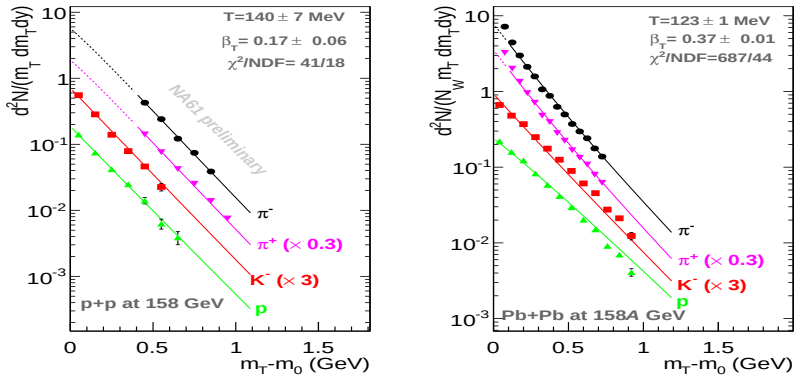

Figure 2: Transverse mass spectra of pions, negative kaons and protons at mid-rapidity for collision energy 158 GeV/c are approximately exponential in p+p interactions (left). In central Pb+Pb collisions the exponential dependence is modified by the transverse flow (right). Only statistical error are shown.

$\frac{dN_i}{m_T dm_T dy} = A_i m_T K_1(\frac{m_T cosh\rho}{T}) I_0(\frac{p_T sinh\rho}{T})$. The transverse flow velocity β_T was calculated from the equation $\rho = tanh^{-1}\beta_T$. The value of β_T is much higher in central Pb+Pb than in p+p reactions.

Transverse mass spectra are approximately exponential in p+p interactions. The exponential dependence is modified by the transverse flow in central (7%) Pb+Pb collisions. Transverse collective flow in Pb+Pb can explain the significant spectra shape difference between p+p and central Pb+Pb reactions.

3. Study of the onset of deconfinement

The Statistical Model of the Early Stage (SMES) [9] predicts a 1^{st} order phase transition to QGP between top AGS and top SPS energies. When this happens one expects constant temperature and pressure in the mixed phase and an increase of the number of internal degrees of freedom.

These predictions were confirmed for central Pb+Pb interactions by the NA49 experiment. NA61/SHINE data from p+p reactions together with NA49 results from central Pb+Pb collisions and other published data are shown on Fig. 3. The inverse slope parameter T of K^- transverse mass spectra at the SPS energies shows a different behavior in central Pb+Pb ("step") than in p+p (smooth increase) reactions as is visible in Fig. 3 (left). The π multiplicity at SPS energies increases faster in central Pb+Pb ("kink") than in p+p collisions. These two dependencies, presented in Fig. 3 (middle), cross each other at about 40*A* GeV/c. Both examples show that the precision of NA61/SHINE is sufficient to study properties of the onset of deconfinement as well as energy dependence of the inverse slope parameter T and of mean pion multiplicity for different systems.

Based on Landau hydrodynamics, it is possible to calculate the sound velocity [10, 11] from the width of the rapidity distributions of pions, using the formula

$$c_S^2 = -\frac{4}{3}\frac{ln(\sqrt{s}_{NN}/2m_p)}{\sigma_y^2} + \sqrt{[\frac{4}{3}\frac{ln(\sqrt{s}_{NN}/2m_N)}{\sigma_y^2}]^2 + 1}.$$

The energy dependence of c_s^2 is similar in p+p and central Pb+Pb reactions, see 3 (right).

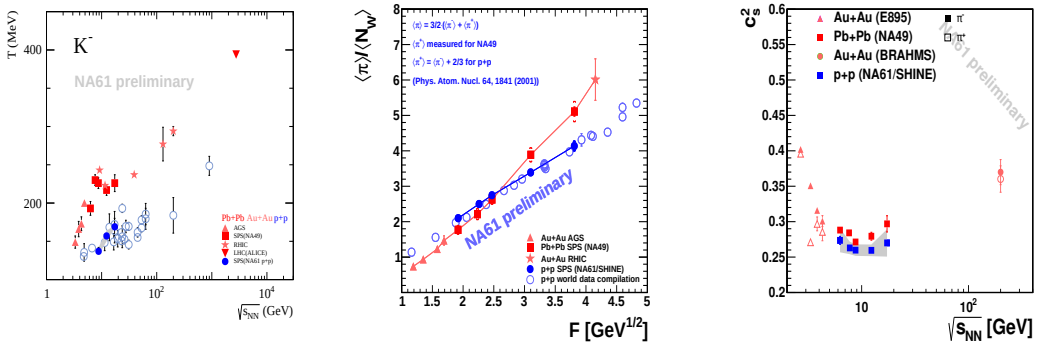

Figure 3: Signatures related to onset of deconfinement. Inverse slope parameter T of K^- transverse mass spectra at SPS energies shows different behavior in central Pb+Pb ("step") than in p+p (smooth increase) (left). Multiplicity of pions per wounded nucleon at the SPS energies increases faster in central Pb+Pb than in p+p ("kink") (middle). The energy dependence of c_s^2 is similar in p+p and central Pb+Pb ("dale") (right).

4. Conclusions

Preliminary NA61/SHINE results on p+p interactions and their comparison with central Pb+Pb collisions were presented. Transverse momentum spectra are significantly steeper in p+p than in central Pb+Pb collisions. The difference is likely due to transverse collective flow. Inverse slope parameter T of K^- transverse mass spectra at SPS energies shows different behavior in central Pb+Pb ("step") than in p+p (smooth increase). $< \pi > / < N_W >$ increases with energy slower in p+p than in central Pb+Pb collisions ("kink"). The two dependencies cross at about 40A GeV/c. The minimum in c_s^2 ("dale") seems to be also be present in p+p interactions.

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