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ADDENDUM–7 to PROPOSAL SPSLC/P264

Study of the Onset of Deconfiment in Nucleus–Nucleus Collisions at Low SPS Energies

The NA49 Collaboration

Abstract

In view of first preliminary results from an analysis of a sample of events from the 1999 40 A·GeV Pb–beam data the case for more heavy–ion runs at low SPS energy is discussed.

NA49 requests 5 days of Pb beam at 80 A·GeV this year and 15 days split between 20 and 30 A·GeV in 2002.

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1 Central Pb+Pb Collisions at 40 A·GeV

Rich experimental data on hadron production in nucleus–nucleus (A+A) collisions in a wide range of collision energies have been obtained at LBL (Berkeley, USA), GSI (Darmstadt, Germany), JINR (Dubna, Russia), BNL (Brookhaven, USA) and CERN (Geneva, Switzerland) [1]. The analysis of the results on pion and strangeness production performed in the mid 90s indicated that a substantial change of the collision energy dependence occurs between top AGS ($p \approx 15$ A·GeV) and top SPS ($p \approx 200$ A·GeV) energies [2]. Within a statistical approach to the reaction process the observed change was interpreted as due to the appearance of an intermediate Quark Gluon Plasma (QGP) phase in the early stage of A+A collisions [3]. Within this model the specific energy dependence in the transition region was predicted. In order to test this interpretation NA49 requested for the first time in 1997 heavy ion runs at low SPS energies [4]. During the 1999 running period the Pb ions were accelerated to 40 A·GeV and about 800k central Pb+Pb collisions at this energy were registered by NA49. In addition data for the study of system size dependence at 40 A·GeV were taken: minimum bias C+C, Si+Al and Pb+Pb collisions as well as d+p and p+p interactions.

The 40 A·GeV data are now fully calibrated, the reconstruction software is established and the processing of the events has been started. The reconstruction of the full statistics is expected to be finished by the end of this year.

In the following the results of a preliminary analysis of 10^5 reconstructed central Pb+Pb collisions will be presented. The data on pion and strangeness yields support the prediction [3] that the threshold for QGP production is crossed near 40 A·GeV. This indicates the necessity of further heavy ion runs at low SPS energies close the 40 A·GeV point.

The particle identification capabilities at 40 A·GeV are illustrated in Fig. 1, where the track distribution in the $m^2 - dE/dx$ plane is plotted together with 1–dimensional projections. The particle mass m is measured by the Time of Flight Walls, the specific ionization dE/dx by the Time Projection Chambers. These data provide the measurement of K^+ and K^- production at midrapidity ($y_{CM} = 2.22$). In the rapidity range $2.5 < y < 4.0$ identification of charged kaons is performed using dE/dx measurements only. The study of the production of negatively charged hadrons (more than 90% π^- mesons) in a wide rapidity range is possible due to the large acceptance of the NA49 TPCs. The resulting rapidity distributions of K^+, K^- and h^- are shown in Fig. 2. From these spectra average multiplicities of kaons and pions were determined.

The energy dependence of the ratio of mean pion multiplicity ($\langle\pi\rangle$) to the mean multiplicity of the nucleons participating in the collision ($\langle N_P\rangle$) is shown in Fig. 3. The comparison of the results for A+A collisions and nucleon–nucleon (N+N) interactions is done by plotting the difference of the ratio in A+A collisions and the ratio in N+N interactions as a function of the collision energy It is observed that the pion yield per participant nucleon in central Pb+Pb collisions at 40 A·GeV follows the trend established by low energy data (AGS and below). Pion production in these collisions is suppressed in comparison to their production in N+N interactions. In contrast, an enhancement of pion yield per participant for central Pb+Pb and S+S collisions compared to N+N reactions is observed at the top SPS energy. This effect may be attributed to the increase of the entropy caused by the increase of the effective number of degrees of freedom when a transition to a QGP phase takes place.

The dependence of strangeness production on collision energy is shown in Fig. 4. The ratio $E_S \equiv (\langle\Lambda\rangle + \langle K + \overline{K}\rangle)/\langle\pi\rangle$ is plotted as a function of collision energy for A+A and N+N interactions separately. In order to calculate the E_S ratio for Pb+Pb collisions at 40 A·GeV using measured K^+ and K^- multiplicities overall strangeness conservation and approximate isospin symmetry of the Pb+Pb system were assumed. The strangeness to pion ratio in Pb+Pb collisions at 40 A·GeV is higher by about 30% than the corresponding ratios at top AGS and top SPS energies. This result may be the first indication of a non–monotonic energy dependence of the strangeness to pion ratio. Within the statistical model this behaviour is due to a different ratio of strange to non–strange degrees of freedom in confined and deconfined matter.

Preliminary results from the analysis of pion–pion Bose–Einstein correlations at 40 A·GeV are plotted in Fig. 5 together with data from the AGS and the top SPS energy. The radius parameters R_{side} and R_{out} are nearly constant. Consequently, $R_{diff} = \sqrt{R_{out}^2 - R_{side}^2}$, a measure of the duration of pion emission, does not show an anomaly. A long duration might have been a sign of a long–lived mixed phase due to a first order phase transition [6] which leads to a significant softening of the equation of state and consequently modification of the expansion process [7, 8].

The preliminary data on pion and strangeness production at 40 A·GeV are consistent with the predictions of the statistical model of the early stage of the collision [3], as indicated by the dashed (confined matter and QGP) and dotted (mixed phase) lines in Figs. 3 and 4. This model comparison suggests that the transition region is close to 40 A·GeV. It is obvious that the results at several energies around 40 A·GeV are necessary in order to further explore the energy dependence of all relevant observables.

The experimental and theoretical communities widely recognize the necessity of the study of energy dependence at the SPS. As example we recall the letters addressed to the SPSC which support the NA49 programme and give additional physics arguments (attachment to Addendum 4 [9]). A similar study was already completed at the AGS and lead to the important results presented in Figs. 3 and 4. A new high energy domain is opened this year by the start of the Relativistic Heavy Ion Collider (RHIC) at BNL. Data on identified particle yields at several RHIC energies ($\sqrt{s} = 65, 130$ and 200 GeV) should be available soon. In order to illustrate their role in understanding physics of A+A collisions we replot in Fig. 6 the results presented in Fig. 4 but extending the energy scale up to the RHIC range. Within the statistical model the strangeness to pion ratio is expected to be constant over the range from top SPS energy to the RHIC energies and beyond provided that a threshold for QGP creation is located below the top SPS energy. The interesting transition energy domain probably lies at low SPS energies.

The study of energy dependence can not be substituted by the study of the system size (A– or centrality) dependence. In current models the early stage energy density is a monotonically increasing function of the collision energy. However it is not excluded by the experimental data that at fixed collision energy the energy density is approximately independent of the size of colliding nuclei or the impact parameter of the collision [3]. In the study of system size dependence the results are potentially sensitive to two effects: a possible deconfiment for large systems and a reduction of the role of kinematical and quantum number conservation laws. In the case of strangeness production the latter effect alone may cause a substantial decrease ('canonical suppression') of the strangeness to pion ratio for small systems [10] and it can be partially responsible for the measured enhancement of (multi)strange hadron production in A+A collisions [11]. Preliminary results from two–pion Bose–Einstein correlations can serve as an example of a possibly non–trivial dependence on system size which should be unaffected by conservation laws. Fig. 7 shows the effective pion emitting volume $R_{side}^2 R_{long}$ plotted versus the midrapidity negative pion density dN_{π^-}/dy. A sudden increase of the volume for the most central Pb+Pb collisions is observed. It may indicate increased transverse expansion and a change of the equation of state. A similar observation is reported by NA44 [12].

The ambiguity in the data interpretation is reduced when the energy dependence is studied for central collisions of large nuclei. The increase of the early stage energy density is assured and the grand canonical approximation is applicable as a tool of accounting for the influence of conservation laws.

2 Beam Request

Based on the results and arguments presented in the previous section we would like to request heavy ion beams at several low SPS energies in two running periods:

- year 2000:
  5 days of 80 A·GeV Pb beam in addition to the full energy heavy ion run,
- year 2002:
  15 days of Pb beam split between 20 A·GeV and 30 A·GeV.

During one day of heavy ion run NA49 records about 100k central A+A collisions , the same number of events was used in the preliminary analysis of 40 A·GeV data presented in this document.

3 Infrastructure and Manpower

The requested additional running time of NA49 at low collision energies does not require any modifications of the NA49 set–up, hardware and software of the reconstruction processor farm. The data calibration and final physics analysis can be done with the established procedures.

The NA49 experimental groups from the European countries will participate in this project and will carry the data analysis effort. Strong contribution are expected in particular from Amsterdam, Dubna, Darmstadt, Frankfurt and Marburg.

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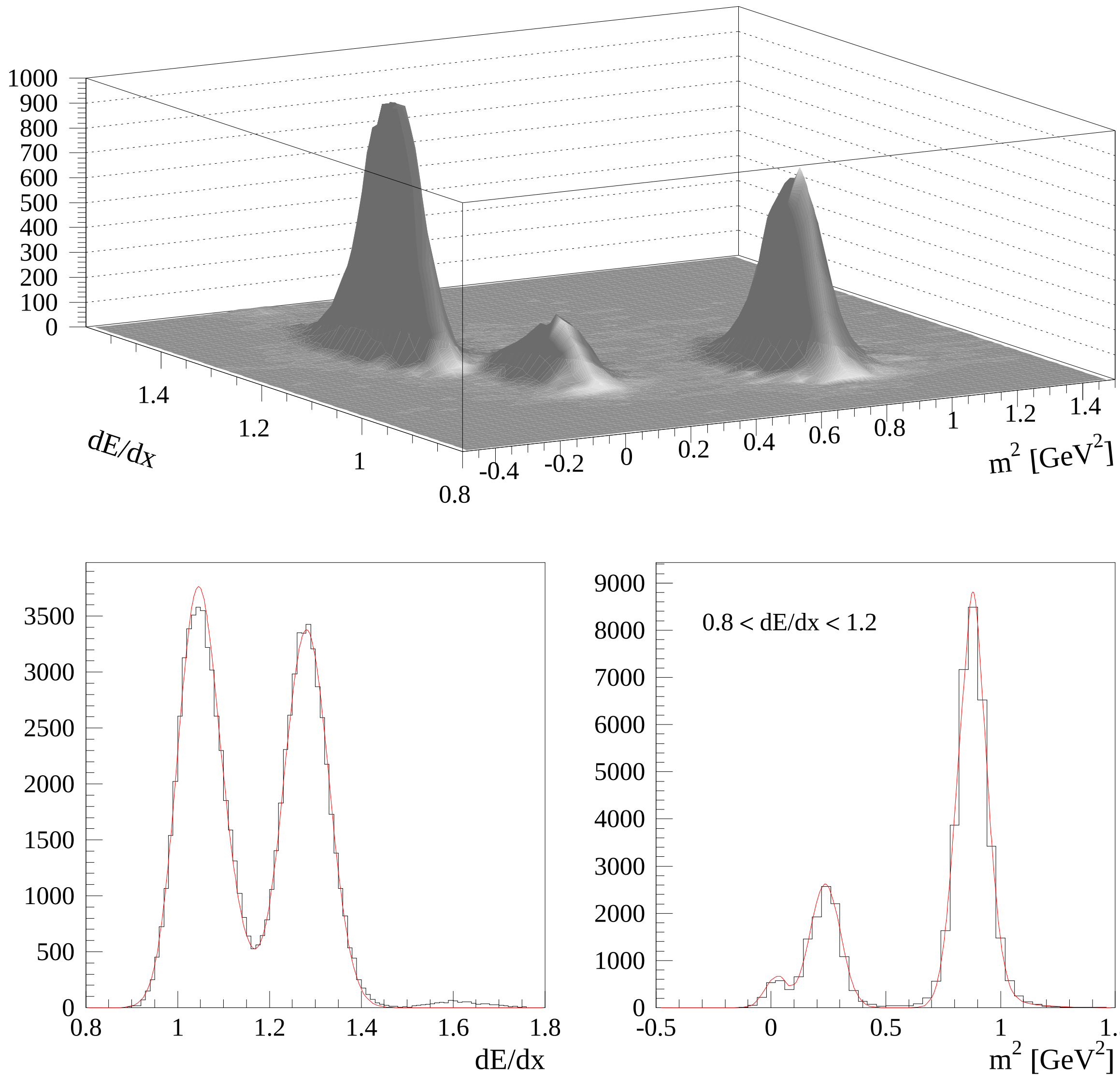

Figure 1: The distribution of positively charged hadrons in the m^2–dE/dx plane and its 1–dimensional projections for central Pb+Pb collisions at 40 A·GeV. The particle mass m is measured by Time of Flight detectors, whereas the specific energy loss dE/dx by Time Projection Chambers. Particles with momenta $4 < p < 5$ GeV/c are selected. Good separation between π^+, K^+ and protons (peaks from left to right) is seen.

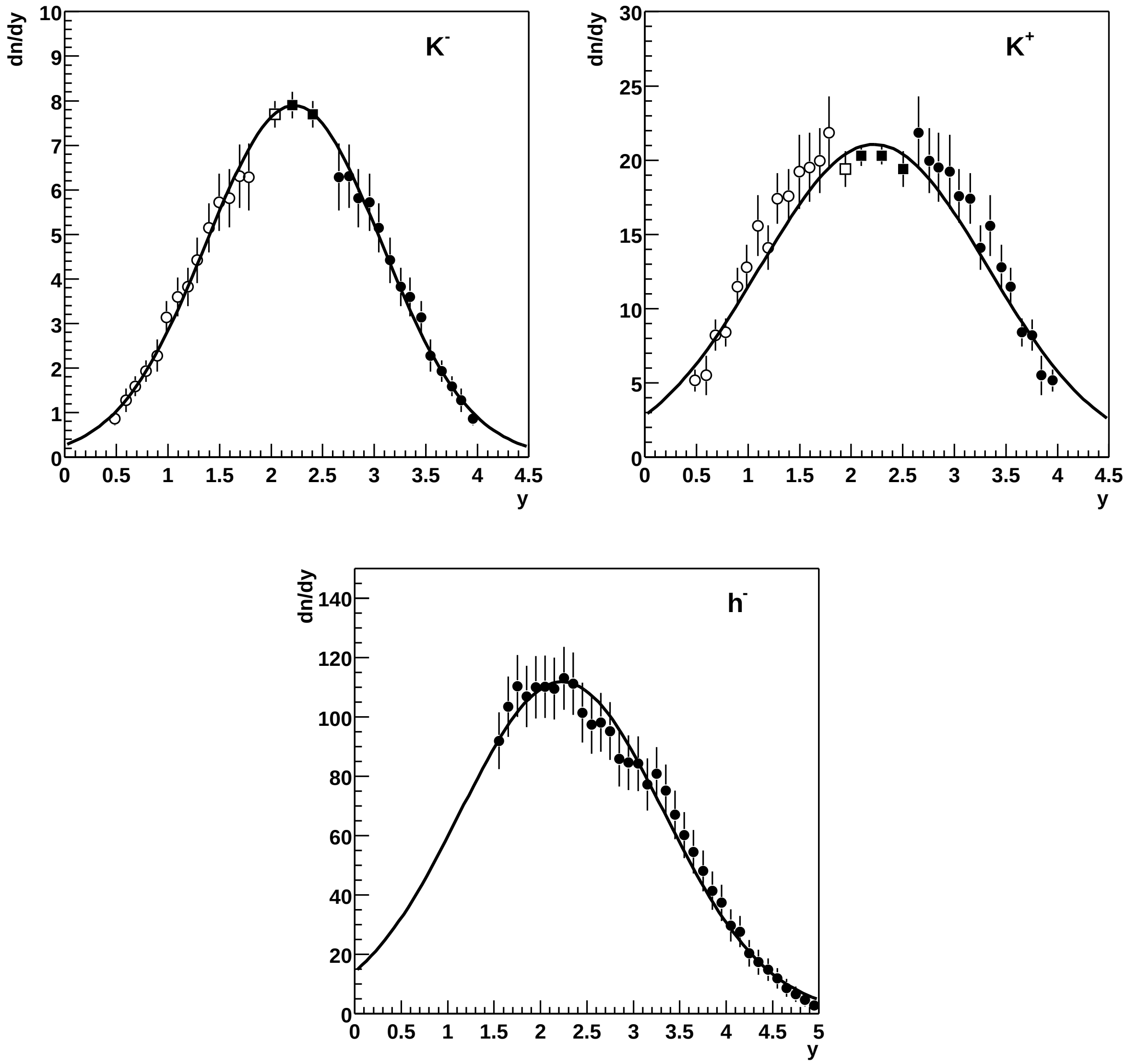

Figure 2: The rapidity distributions of K^-, K^+ and π^+ mesons measured in central Pb+Pb collisions at 40 A·GeV. The results obtained by TOF–dE/dx analysis are indicated by full squares whereas those obatined by dE/dx analysis only by the full circles. The open symbols indicate points reflected with respect to midrapidity. The solid lines represent Gaussian fits to the data.

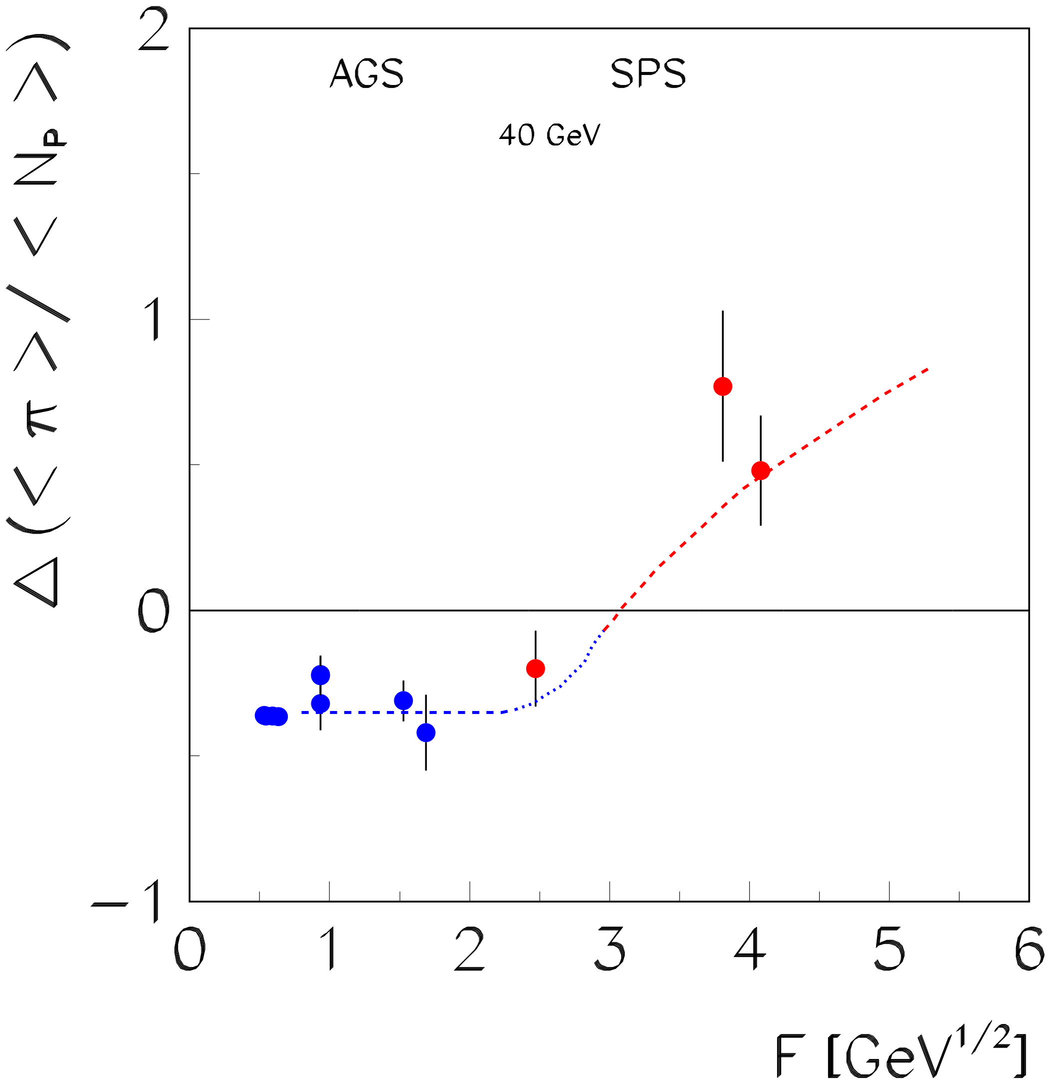

Figure 3: The dependence of the difference between pion to participant ratios for central A+A collisions and N+N interactions on the collision energy expressed by the Fermi's measure: $F \equiv (\sqrt{s} - 2m)^{3/4}/\sqrt{s}^{1/4}$ [5]. The line indicates the prediction of the statistical model. The transition region between confined and deconfined matter is indicated by the dotted section of the line. The values of F for the requested 20, 30 and 80 A·GeV runs are 1.92, 2.23 and 3.10 GeV$^{1/2}$, respectively.

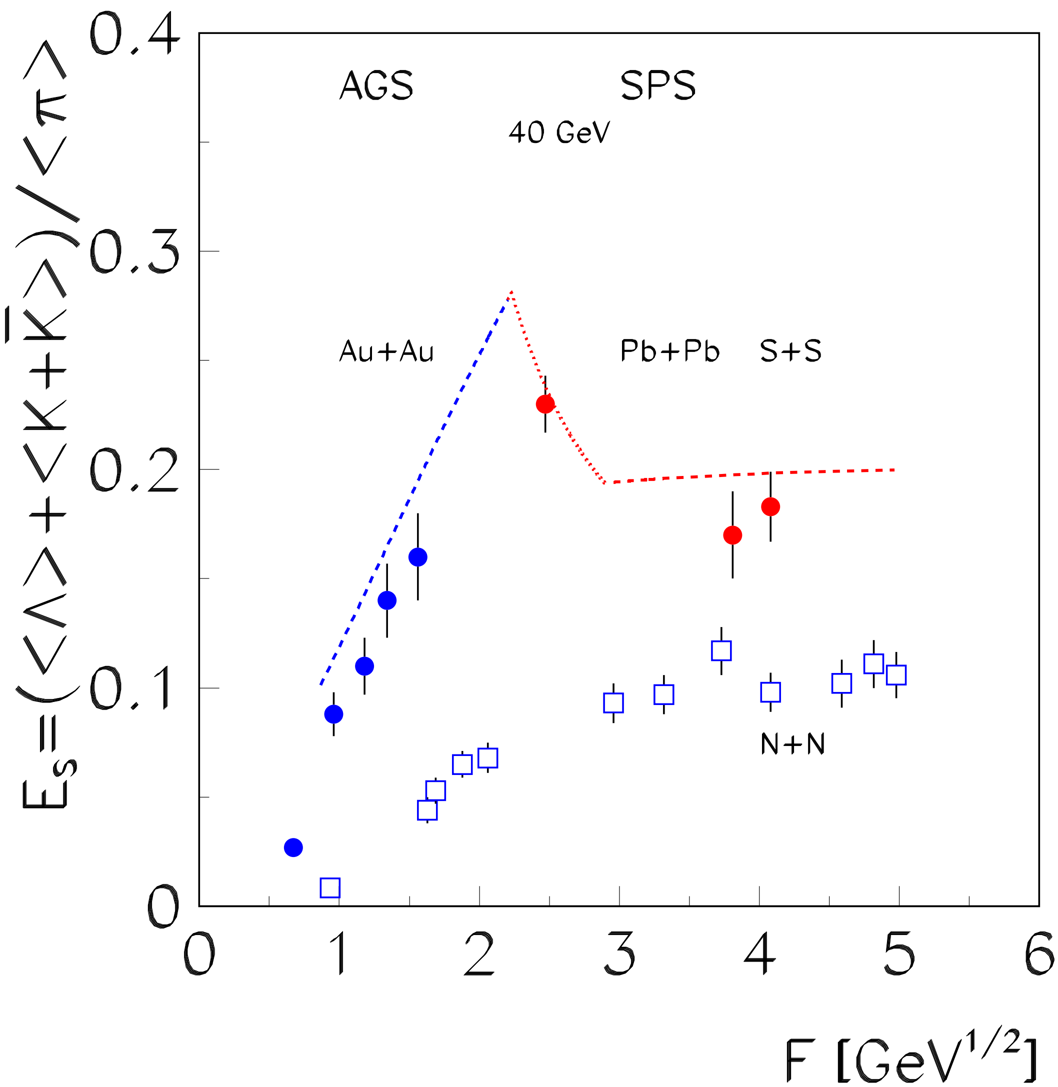

Figure 4: The dependence of the strangeness to pion ratio for central A+A collisions and N+N interactions on the collision energy expressed by the Fermi's measure: $F \equiv (\sqrt{s} - 2m)^{3/4}/\sqrt{s}^{1/4}$ [5]. The line indicates the prediction of the statistical model. The transition region between confined and deconfined matter is indicated by the dotted section of the line. The values of F for the requested 20, 30 and 80 A·GeV runs are 1.92, 2.23 and 3.10 GeV$^{1/2}$, respectively.

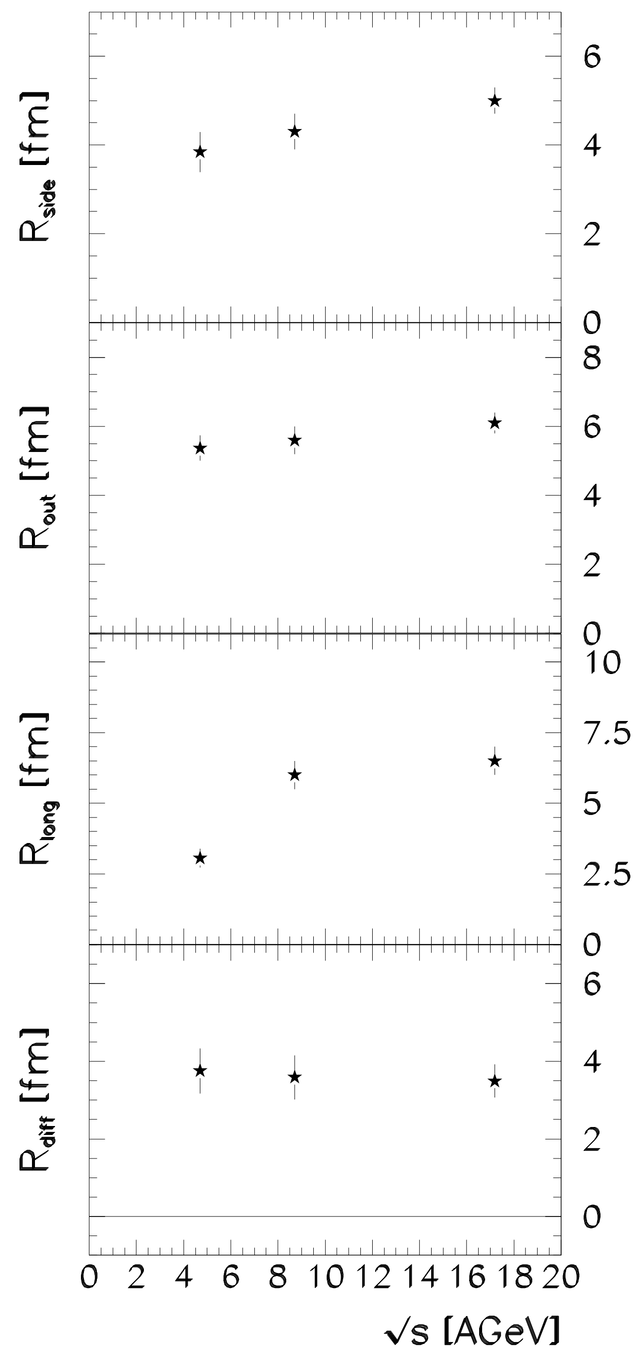

Figure 5: The collision energy dependence of the radius parameters extracted from the measurements of the two pion correlation function in central Pb+Pb collisions at 40 A·GeV together with the results from top AGS and SPS energies.

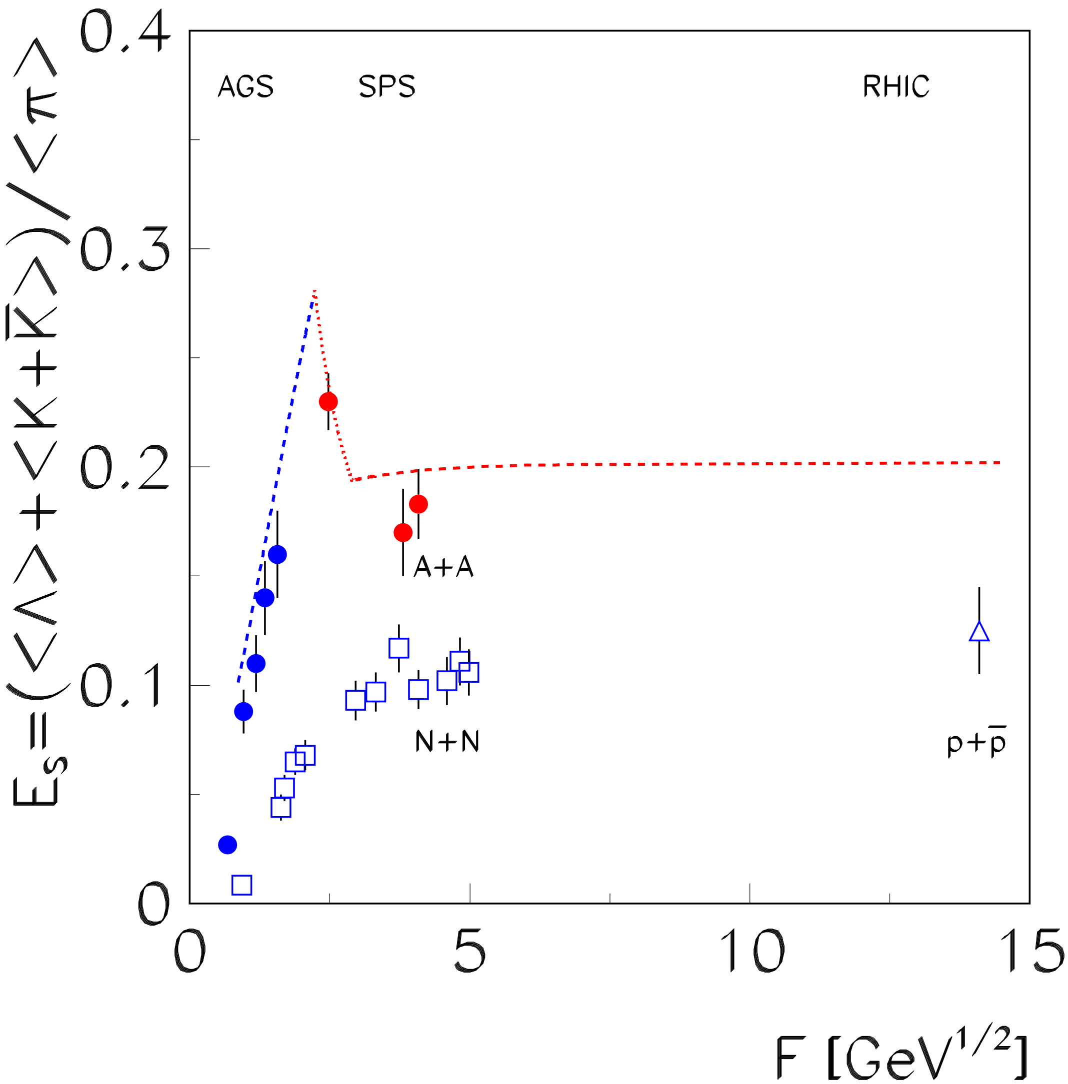

Figure 6: Same as Fig. 4 but with the energy scale extended up to the domain covered by the Relativistic Heavy Ion Collider at BNL. The p+p̄ point measuerd by the UA5 Collaboration is also included for the comparison.

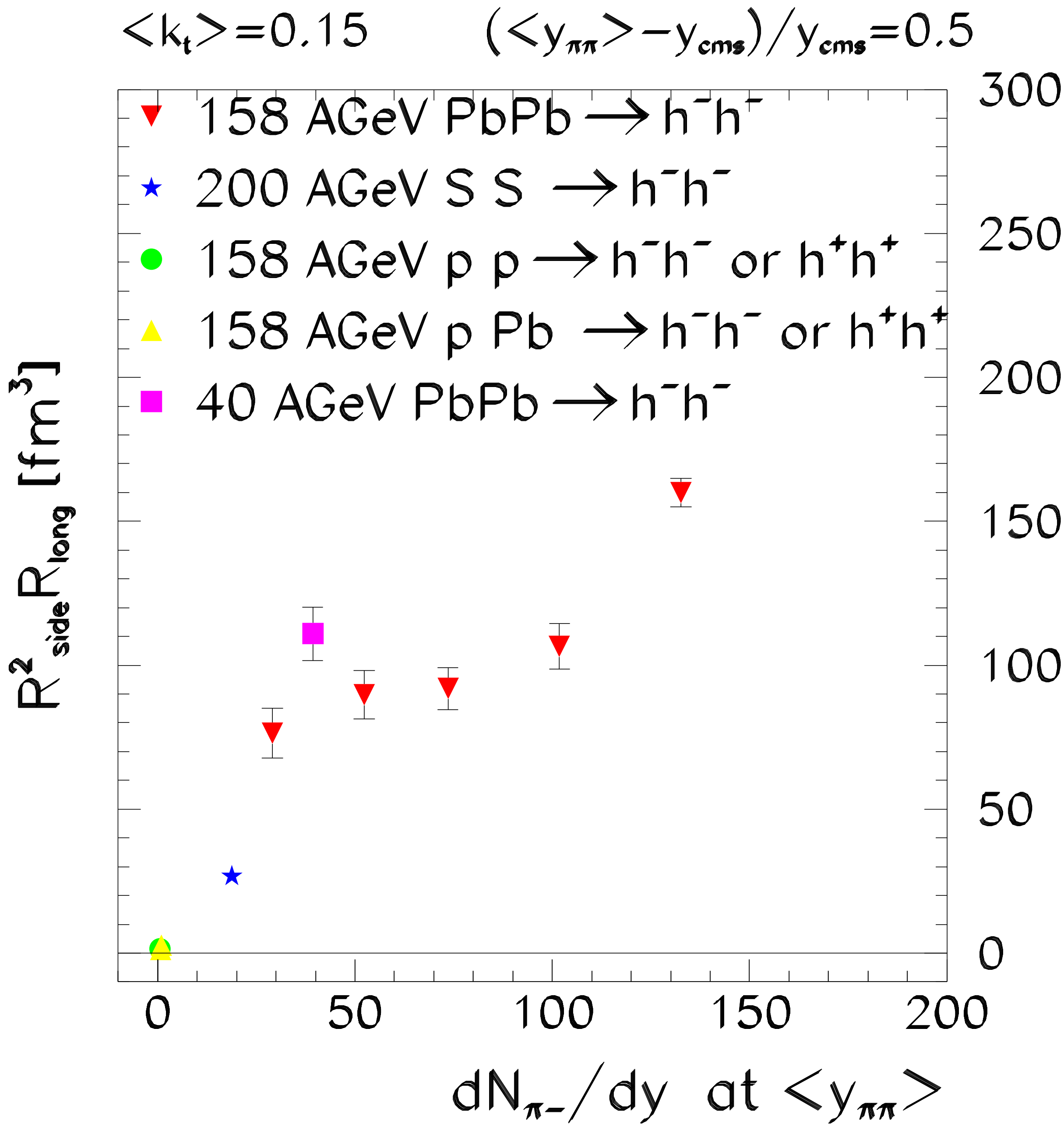

Figure 7: The effective pion emitting volume $R_{side}^2 R_{long}$ plotted versus the midrapidity negative pion density dN_{π^-}/dy.