

# Centrality and Energy Dependence of Proton, Light Fragment and Hyperon Production

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**Abstract.** Recent results of the NA49 collaboration are discussed. These include the energy dependence of stopping and the production of the light fragments  $t$  and  ${}^3\text{He}$ . New data on the system size dependence of hyperon production at 40A and 158A GeV are also presented.

## 1. Introduction

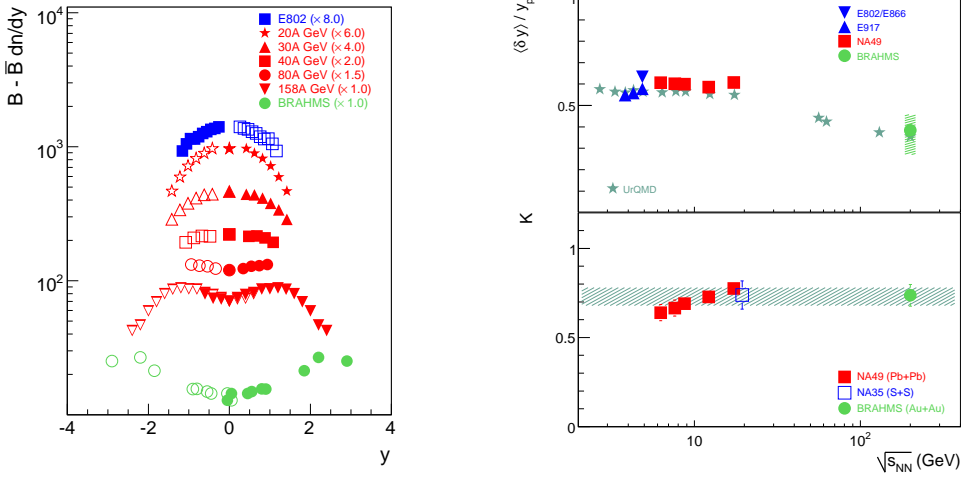
In the recent years the NA49 experiment has collected data on Pb+Pb collisions at beam energies between 20A and 158A GeV with the objective to cover the critical region of energy densities where the expected phase transition from a deconfined phase might occur in the early stage of the reactions. NA49 is a fixed target experiment at the CERN SPS. Details on the experimental setup can be found in [1].

## 2. Energy Dependence of Stopping

New results on rapidity spectra of (anti-)protons in central Pb+Pb reactions at 20A - 80A GeV in combination with previously published results [2, 3] allow to study the energy evolution of stopping. Based on the measured rapidity spectra for  $p$ ,  $\bar{p}$ ,  $\Lambda$ ,  $\bar{\Lambda}$ ,  $\Xi^-$ , and  $\bar{\Xi}^+$ , all corrected for feed down from weak decays, the net-baryon distributions  $dN_{(B-\bar{B})}/dy$  are constructed. The contribution of unmeasured baryons ( $n$ ,  $\Sigma^\pm$ ,  $\Xi^0$ ) is estimated using the results of a statistical hadron gas model [4]. In the SPS energy region a clear evolution of the shape can be observed (see Fig. 1 left). From these distributions an averaged rapidity shift  $\langle\delta y\rangle$  can be derived:

$$\langle\delta y\rangle = y_p - \frac{2}{N_{\text{part}}} \int_0^{y_p} y \frac{dN_{(B-\bar{B})}}{dy} dy, \quad (1)$$

where  $y_p$  is the projectile rapidity and  $N_{\text{part}}$  the number of participating nucleons. At AGS and SPS energies a value of  $\langle\delta y\rangle/y_p \approx 0.6$  is observed, which drops to  $\langle\delta y\rangle/y_p \approx 0.4$  at  $\sqrt{s_{\text{NN}}} = 200$  GeV (see Fig. 1 right). The measurements agree quite well with the



**Figure 1.** Left panel: The rapidity distributions of net-baryons at SPS energies [3] together with results from the AGS [5] and from RHIC [6] for central Pb+Pb(Au+Au) collisions. Right panel: The relative rapidity shift  $\langle \delta y \rangle / y_p$  as a function of the projectile rapidity  $y_p$  [3, 6, 7, 8] (upper part). Also shown are results for the UrQMD model [9]. The lower part summarizes the  $\sqrt{s_{NN}}$ -dependence of the inelasticity  $K$ , including NA35 data for central S+S reactions [10].

UrQMD model [9]. Using  $dN_{(B-\bar{B})}/dy$  and the measured  $\langle m_t \rangle$  the inelastic energy per net-baryon:

$$E_{\text{inel}} = \frac{\sqrt{s_{NN}}}{2} - \frac{1}{N_{(B-\bar{B})}} \int_{-y_p}^{y_p} \langle m_t \rangle \frac{dN_{(B-\bar{B})}}{dy} \cosh y dy \quad (2)$$

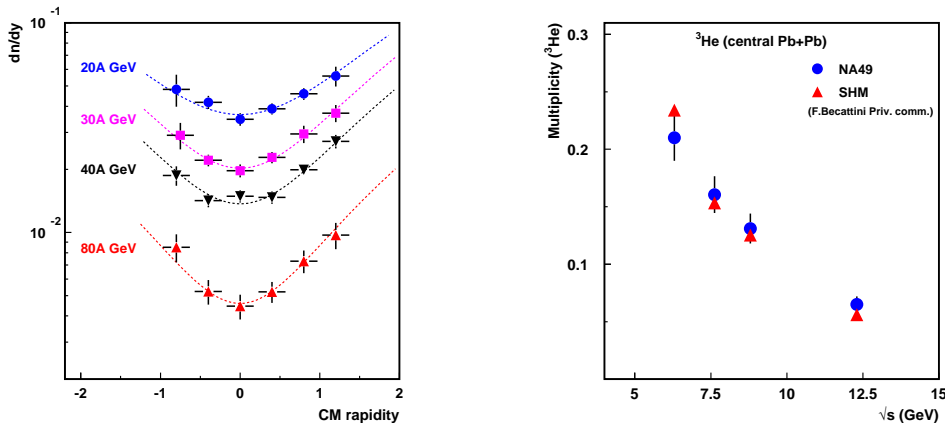
and the inelasticity  $K = 2 E_{\text{inel}} / (\sqrt{s_{NN}} - 2m_p)$  can be calculated.  $K$  is approximately energy independent with a value of  $K \approx 0.7 - 0.8$  (see right panel of Fig. 1).

### 3. Light Fragments

NA49 has measured the energy dependence of tritons at midrapidity (not discussed here) and  ${}^3\text{He}$  in a wide rapidity range. The left panel of Fig. 2 shows the rapidity distributions for  ${}^3\text{He}$  at four different beam energies. The spectra have a similar concave shape at all investigated energies. This is in remarkable contrast to the case of protons, where the shape of the rapidity distributions is strongly energy dependent. By extrapolating the measured distributions total multiplicities can be determined (see right panel of Fig. 2). The values agree very well with a prediction of a statistical hadron gas model [4], similar to what was suggested for AGS energies in [11].

### 4. System Size Dependence of Hyperons

Figure 3 shows new NA49 results on  $\Lambda$  and  $\bar{\Lambda}$  production in minimum bias Pb+Pb reactions at 40A and 158A GeV, together with preliminary data on  $\Xi^-$  [12]. The  $\Lambda$



**Figure 2.** Left panel: Rapidity distributions of  ${}^3\text{He}$  in central Pb+Pb collisions at 20A, 30A, 40A, and 80A GeV. The dashed lines are fits with a parabola which is used to extract the total multiplicities. Right panel: The total multiplicity of  ${}^3\text{He}$  in central Pb+Pb collisions as a function of  $\sqrt{s_{NN}}$  (solid points). The triangles represent predictions of a statistical hadron gas model [4].

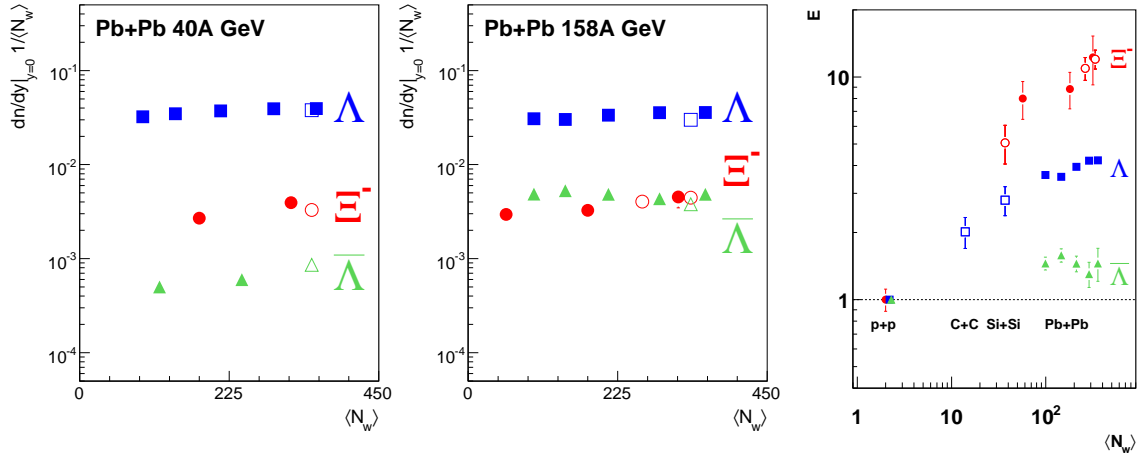
data are corrected for feed down from weak decays. While there is no system size dependence of the rapidity densities per wounded nucleon for  $\Lambda$  and  $\bar{\Lambda}$ , a weak rise can be observed in the case of the  $\Xi^-$ . In combination with measurements of yields in p+p, central C+C and Si+Si [13] the system size dependence of the enhancement factor  $E$ , defined as:

$$E = \left( \frac{1}{\langle N_w \rangle} \frac{dN(\text{Pb+Pb})}{dy} \Big|_{y=0} \right) / \left( \frac{1}{2} \frac{dN(\text{p+p})}{dy} \Big|_{y=0} \right) \quad (3)$$

can be studied (rightmost panel of Fig. 3).  $\langle N_w \rangle$  has been determined using the Glauber model [14]. The enhancement exhibits a clear hierarchy ( $E(\Xi^-) > E(\Lambda) > E(\bar{\Lambda})$ ) and is almost independent on system size for  $\langle N_w \rangle > 40$  for  $\Lambda$  and  $\bar{\Lambda}$ . For  $\Xi^-$  a moderate  $\langle N_w \rangle$  dependence is seen. Similar trends have been observed by the NA57 collaboration, however relative to a p+Be baseline [15]. Since already in p+A reactions a slight enhancement of strange particle production is observed [16], the enhancement relative to p+Be is less.

## 5. Conclusions

New data on (anti-)proton production at 20A – 80A GeV provide insight into the energy dependence of stopping in the region where the onset of deconfinement possibly occurs. No significant energy dependence of  $\langle \delta y \rangle / y_p$  is observed. For the first time total multiplicities of  ${}^3\text{He}$  have been measured, being in remarkable agreement with statistical model predictions. New results on the system size dependence of hyperon production allows to determine the evolution of strangeness enhancement relative to elementary p+p collisions.



**Figure 3.** The rapidity densities per wounded nucleon of  $\Lambda$ ,  $\bar{\Lambda}$ , and  $\Xi^-$  at midrapidity ( $|y| < 0.4$  for  $\Lambda$  ( $\bar{\Lambda}$ ),  $|y| < 0.5$  for  $\Xi^-$ ) for minimum bias Pb+Pb collisions (filled symbols) as a function of  $\langle N_w \rangle$ . Open symbols represent the results for online selected central reactions. Right panel: The midrapidity yields per wounded nucleon relative to p+p yields for central C+C, Si+Si and minimum bias Pb+Pb reactions at 158A GeV.

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