Centrality dependence of strange baryon yields in Pb–Pb collisions

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Abstract: New data on strange baryon yields in Pb–Pb interactions at 158 GeV/c per nucleon are presented as a function of the collision centrality. The possible onset of a deconfined phase when the collision involves from 50 to 100 wounded nucleons is discussed.

The study of strange particle production in ultra-relativistic nuclear collisions plays an important role in the search for deconfined quark-gluon matter. The strangeness enhancement, i.e. the enhanced abundance of strange particles in central nucleus-nucleus with respect to proton–proton and proton–nucleus interactions, was recognized as one of the sensitive signatures of the transient existence of a quark-gluon plasma (QGP) phase [1, 2, 3]. In the QGP scenario, such an enhancement could be created as a result of rapidly developing flavour equilibration. Strange quark pairs are easily produced in a gluon rich QGP environment, predominantly in a gluon-gluon fusion process. The equilibration time

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is estimated to be comparable with the interaction time of the high energy heavy-ion collision (a few fm/c). The establishment of a similar enhancement is also possible in a pure hadronic scenario (hot and dense hadronic gas), where the relative abundance of strange particles could grow gradually in a chain of rescattering processes. However, in that case the characteristic time scale is much longer, of the order of 100 fm/c. It is expected that the enhancement should be more pronounced for multi-strange than for singly-strange particles [4].

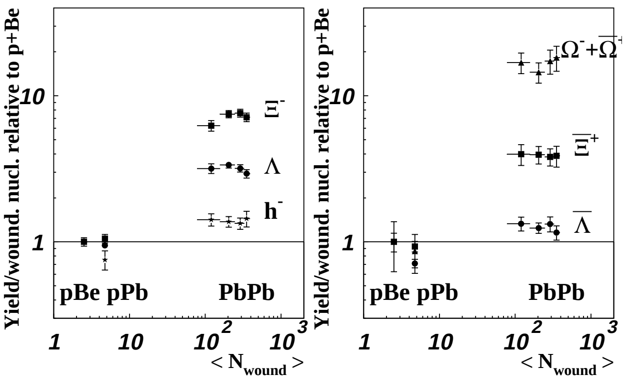

Figure 1: Yields per wounded nucleon relative to the p–Be yields as a function of the number of wounded nucleons for negative particles, Λ and Ξ^- (left) and for $\overline{\Lambda}$, $\overline{\Xi}^+$, $\Omega^- + \overline{\Omega}^+$ (right). The two groups are kept separate (particles with at least one valence quark in common with the nucleon on the left, particles with no valence quarks in common with the nucleon on the right) since it is empirically known that the yields per participant have similar values in per participant in Pb–Pb are clearly above the p–A values.

The NA57 experiment has been designed to study the onset of strange baryon and anti-baryon enhancements in Pb–Pb with respect to p–Be collisions, first observed by the WA97 experiment at Fig. 1). The enhancement is larger for particles of larger strangeness content, up to a factor $\sim$15 for $\Omega^- + \overline{\Omega}^+$. Such a behaviour fits naturally into a QGP scenario, while no conventional hadronic microscopic model has succeeded in reproducing it.

The aim of NA57 is to study the dependence of the strangeness enhancement on the interaction volume (measured by the number of wounded nucleons, i.e. nucleons which undergo at least one primary inelastic collision with another nucleon) and on the collision energy per incoming nucleon. For that reason the experiment has extended its centrality range down to a limit of about 50 wounded nucleons (the corresponding limit in WA97 was about 100) and has collected data using 158 and 40 A GeV/c beams at the CERN SPS.

1. The NA57 experiment

The layout of the NA57 experiment is similar to that of WA97. However, to achieve the goals of the experiment, a significant upgrade was necessary. A detailed description of the NA57 set-up can be found in [6, 7].

Strange and multi-strange particles are identified by reconstructing their weak decays into final states containing only charged particles (e.g. $\Xi^- \rightarrow \Lambda + \pi^-, \Lambda \rightarrow \mathrm{p} + \pi^-$) in the silicon tracking detector (telescope). The acceptance windows are similar to those of WA97, covering about one unit of rapidity centred at mid-rapidity, and transverse momenta down to a few hundred MeV/c [6]. The centrality trigger for Pb-Pb, based on a system of scintillator detectors, selects the most central 60% of the inelastic cross section. The centrality of the collision is determined from the charged particle multiplicity, sampled at central rapidity by silicon strip detectors. A special effort has been made to extend the centrality coverage towards more peripheral events with respect to WA97, by reducing various background sources. NA57 has taken Pb–Pb data both at 158 and at 40 A GeV/c beam momentum. Reference p–Be data at 40 GeV/c were also collected, the last sample in the summer 2001. As a reference data at 158 A GeV/c we intend to use the WA97 p–Be and p–Pb data samples.

In the following we are describing the results on the cascade hyperon Ξ production, based on the part of 158 A GeV/c Pb–Pb data (the 1998 run) available for analysis. In the case of Ξ the statistics of the available data sample allows us to study the centrality dependence of yields down to ~ 50 wounded nucleons. A similar analysis of triply strange Ω hyperon will require the full collected statistics. The reconstruction of the data sample from the 2000 run is well under way and will double the statistics of Pb–Pb events at 158 A GeV/c.

2. Results

As a measure of collision centrality we use the number of wounded nucleons N_{wound}, extracted from the charged particle multiplicity measurement in the pseudorapidity range $2 < \eta < 4$. Fig. 2 shows the charged particle multiplicity distribution for Pb-Pb collisions. The data have been binned into five classes. The most central classes (I to IV) correspond to the four centrality classes used in the analysis of WA97, while the more peripheral class 0, corresponding to an average of $N_{\mathrm{wound}} = 62$, is accessible to NA57 only. The drop at very low multiplicities is due to the threshold of our centrality trigger. The distribution of N_{wound} for the five multiplicity classes, computed from the trigger cross sections using a Glauber model [8], is shown in Fig. 3.

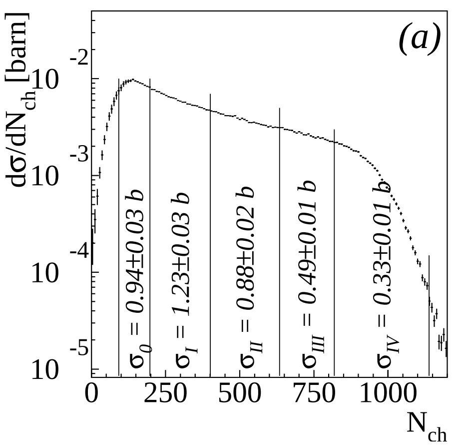

Figure 2: Charged particle multiplicity distribution. The 5 classes used in the analysis are shown together with their cross sections.

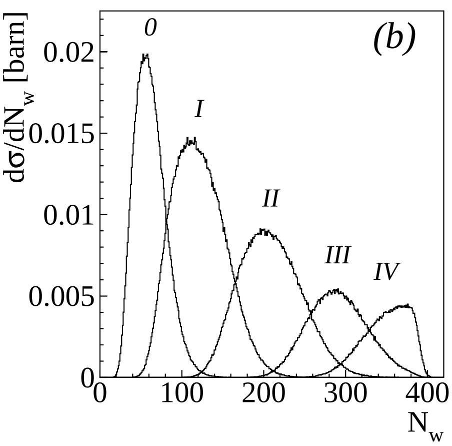

Figure 3: Distribution of N_{wound} for the five centrality classes used in NA57.

Data were corrected for acceptance and efficiency losses by calculating a weight for each particle. Description of the weighting procedure can be found in [9]. The Ξ^- and $\overline{\Xi}^+$

signals, together with their acceptance window, are shown in Fig. 4 and 5.

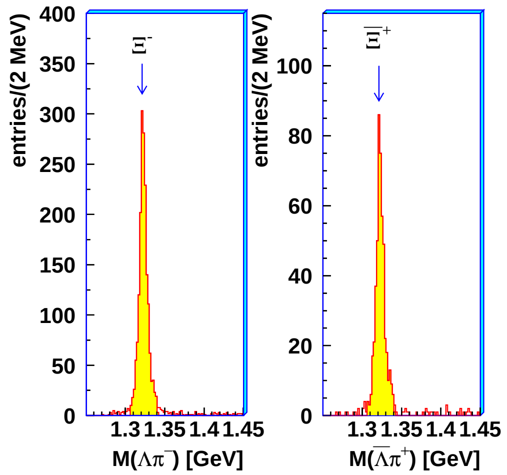

Figure 4: Ξ^- and $\overline{\Xi}^+$ signals for Pb–Pb collisions.

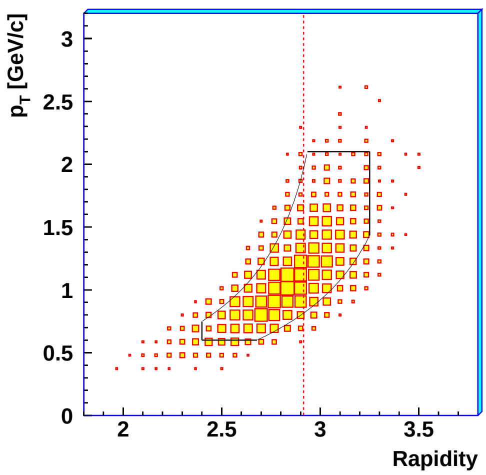

Figure 5: Acceptance window for Ξ^- and $\overline{\Xi}^+$ in transverse momentum p_T and rapidity.

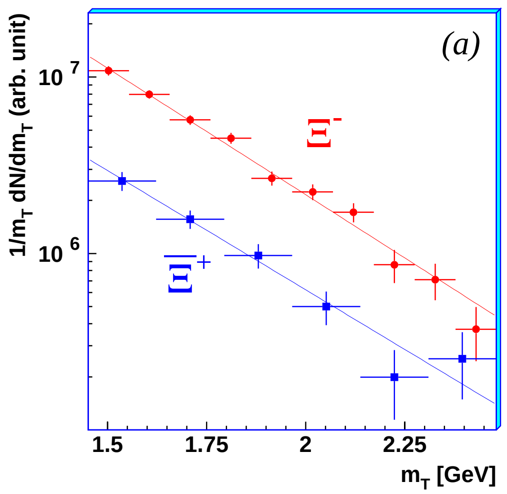

Figure 6: Transverse mass spectra for Ξ^-, $\overline{\Xi}^+$.

Fig. 6 shows the corresponding transverse mass (m_T) spectra, corrected both for acceptance and efficiency losses. The superimposed straight lines are the results of the fit with the function

$$\frac{1}{m_T}\frac{\mathrm{d}N}{\mathrm{d}m_T} = A\ \exp\left(-\frac{m_T}{T}\right).$$

The resulting inverse slopes T were compared with the values obtained by the WA97 experiment [9, 10]. The agreement is good. The statistics, however, is not yet sufficient to study a possible variation of T over the full centrality range covered by the experiment.

Fig. 7 shows the fully corrected yields per participant for the five centrality classes defined in Fig. 2. The corresponding WA97 points, available only for the four more central classes, are also shown. We note that in the common centrality range, the yields from NA57 are 20%-30% larger. The reasons for this systematic effect are presently being investigated. In the new low-centrality bin the $\overline{\Xi}^+$ (Ξ^-) yields, as measured by NA57, drop by a factor 2.6 (1.3), corresponding to a 3.5 (1.8) standard deviation effect. Such a sudden reduction of yields as a function of centrality can not be an artefact of our acceptance corrections procedure since a similar drop is already present in the uncorrected data [10]. It is noteworthy that such a drop is not foreseen by any of the known models. As an example, a recent prediction from a canonical statistical

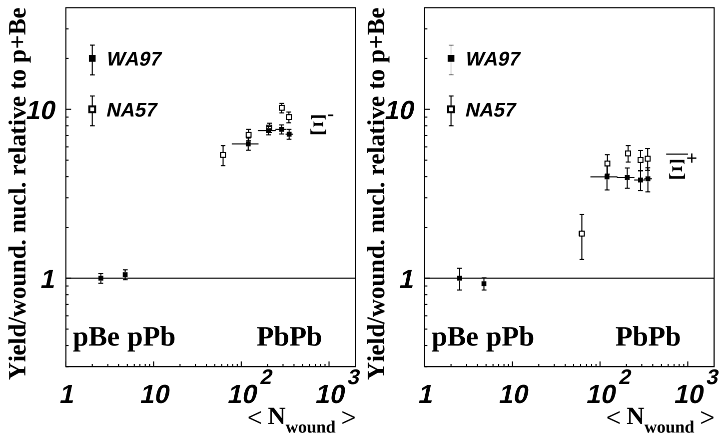

Figure 7: $\overline{\Xi}^+$ and Ξ^- yields per wounded nucleon relative to the p–Be yields. The NA57 data (open symbols) are shown together with the WA97 results (closed symbols).

model [11] succeeds in reproducing the enhancements measured by WA97, but predicts that the yields of multi-strange baryons are already close to saturation for $N_{\text{wound}} \sim 20$.

3. Conclusions and outlook

The indication of an onset for the Ξ^- and $\overline{\Xi}^+$ enhancements when the collision involves between 50 and 100 nucleons, urges us to look at the full set of strange particle enhancements, since it could indicate the point of the QGP phase transition. Such a study is under way.

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