Hyperon enhancement in the dual parton model

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Abstract. We review the two sources of hyperon enhancement in the dual parton model: strings originating from diquark–antidiquark pairs in the nucleon sea and net baryons containing two or three sea quarks with a yield controlled by the observed stopping. We show that by adding final state interactions (including strangeness exchange reactions as well as the inverse reactions required by detailed balance) with a single averaged cross section, $\sigma = 0.2$ mb, we can explain the observed hyperon enhancement in PbPb collisions at CERN SPS.

The dual parton model is an independent string model. The total number of strings is $2n$ where $n$ is the number of inelastic collisions. When a nucleon undergoes a single inelastic scattering, the two strings produced have only valence constituents (quark and diquark) at their ends. In the case of multiple collisions the extra strings involve sea quarks or diquarks at their ends. We have shown [1, 2] that this produces a substantial increase of the ratio of strange over non-strange baryons in $AA$ collisions with increasing centrality. However, this mechanism produces an equal enhancement of baryons and antibaryons—in disagreement with experiment. Fortunately, there is another source of hyperon enhancement, which is intimately related to baryon stopping and enhances only the net hyperon yield $Y - \bar{Y}$. Indeed, a large number of net baryons are produced at mid-rapidities in central $AA$ collisions. It has been argued [1]–[5] that they are dominantly made out of the string junction (SJ) (see [6]), which carries the baryon quantum number, plus three sea quarks (see figure 1). It is then obvious that a large number of net \( \Lambda \), \( \Xi \) and \( \Omega \) (i.e. an increase of their yields per participant) will also take place. As a matter of fact, this is the only opportunity to produce net $\Omega$’s. The experimental value $\Omega / \bar{\Omega} \sim 0.4$ [7] in central PbPb collisions at mid-rapidities is very much in favour of the above picture. Moreover, there will also be a substantial increase in the yield of $K^+$ associated with the production of $\Lambda$’s.

The two sources of strangeness enhancement described above were studied in detail in [1, 2]. The numerical results are shown by the broken lines in figure 2. We see that the $p$ and $\Lambda$
yields are well reproduced. The $\Xi$’s are slightly underestimated. However, the $\Omega$’s are too low by a factor of five.

In an attempt to describe the $\Omega$ yield, in [1, 2] we introduced the final state interactions:

$$\pi N \rightarrow K \Lambda \quad \pi N \rightarrow K \Sigma \quad \pi \Lambda \rightarrow K \Xi \quad \pi \Sigma \rightarrow K \Xi \quad \text{and} \quad \pi \Xi \rightarrow K \Omega \quad (1)$$

plus the corresponding reactions for the antiparticles. They are governed by the gain and loss differential equations [9]

$$\frac{dN_i}{d^4x} = \sum_{K,\ell} \sigma_{k\ell} \rho_k(x) \rho_\ell(x) - \sum_k \sigma_{ik} \rho_i(x) \rho_k(x). \quad (2)$$

The first term on the right-hand side of (2) describes the production of particle $i$ resulting from the interaction of particles $k$ and $\ell$ with space–time densities $\rho(x)$ and cross sections $\sigma_{k\ell}$ (averaged over the momentum distributions of the interacting particles). The second term describes the loss of particle $i$ due to its interaction with particle $k$. The initial densities are those obtained without final state interaction and the averaged cross sections are taken to be the same for all processes. For details see [1].

Proceeding in this way, we were able to reproduce the observed enhancement of all hyperon species [1, 2]. However, in our approach we neglected the inverse reactions, which are required by detailed balance, as well as the charge exchange reactions:

$$\pi \Lambda \rightarrow K \Lambda \quad \pi \Sigma \rightarrow K \Lambda \quad \pi \Xi \rightarrow K \Xi \quad \pi \Xi \rightarrow K \Sigma \quad \text{and} \quad \pi \Omega \rightarrow K \Xi \quad (3)$$

together with the corresponding ones for antiparticles.

Although the possibility to neglect such reactions was qualitatively justified using the relative size of the initial densities involved [1, 2, 10], this was considered to be a crucial drawback of our model [11]. In view of this, we have now introduced all these reactions. For simplicity we use a single value for all averaged cross sections $\sigma_{k\ell} = \sigma$. The results with $\sigma = 0.2$ mb are shown by the full lines of figure 2. We see that the agreement with experiment is satisfactory.

The reason why the introduction of the new reactions has produced no substantial change in our former results is the following: concerning the non-strangeness enhancement reactions (inverse of those in (1)) such as $K \Lambda \rightarrow \pi N$, it is obvious that since $\rho_K < \rho_\pi$ and $\rho_\Lambda < \rho_N$ one has $\rho_{K \Lambda} \ll \rho_{\pi N}$, and the effect of these reactions is very small (of course, if the interaction time...
Yields of \( p, \Lambda, \Xi^-, \Omega + \bar{\Omega}, \bar{p}, \bar{\Lambda} \) and \( \bar{\Xi}^+ \) for minimum bias \( pPb \) (158 Gev \( c^{-1} \)) and central \( PbPb \) collisions (158 A GeV \( c^{-1} \)) in four centrality bins. Experimental data are from WA97 [7] (full points) and NA49 [8] (open square). The broken lines are our results before final state interaction and the full lines are the results including this final state interaction.

would be much larger than the 6 fm measured from Bose–Einstein interferometry, the inverse reactions would be crucial). For the strangeness exchange reactions, in (3), such as \( \pi \Omega \rightarrow \bar{K} \Xi \), the situation is different. If we compare this reaction with \( \pi \Xi \rightarrow K \Omega \), the former is unfavourable since \( \rho_{\Xi} > \rho_{\Omega} \). However, since the \( \Omega \)'s are strongly enhanced, the effect of the former might be important—and would destroy the \( \Omega \)'s. Actually, it turns out that the effect of this reaction is only moderate. Moreover, the inverse reaction \( \bar{K} \Xi \rightarrow \pi \Omega \) turns out to be of comparable importance and restores the yield of \( \Omega \)'s obtained without the strangeness–exchange reactions (3).

In conclusion, we have shown that the dual parton model, supplemented with final state interactions (both with and without strangeness exchange), describes the observed enhancement of hyperon and antihyperon yields with a single value of the averaged cross sections—which turns out to be rather small: \( \sigma = 0.2 \) mb.

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