Baryon anomaly in heavy-ion collisions & colour correlations in QGP

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Constituent (additive) quark model:

Experimental observation \[ \frac{\sigma_{\pi p}}{\sigma_{pp}} \approx \frac{2}{3} \] value equal to the ratio of number of quarks in meson and baryon in naïve quark model!

Emerging picture: hardrons are made of loosely bounded (constituent) quarks

Baryon-to-meson ratio

If so, what would be the ratio of baryon to meson produced from a (symmetric) soup of quarks and antiquarks (e.g. at mid-rapidity of a hadron–hadron collision at infinite energy)? Starting from a quark:

$$q \begin{cases} q_{\frac{1}{2}}^{\frac{1}{2}} & \text{q}_4^{\frac{1}{4}} \rightarrow B \\ \bar{q}_{\frac{1}{2}}^{\frac{1}{2}} & \text{q}_4^{\frac{1}{4}} \rightarrow M \end{cases}$$

and starting from antiquark we obtain another $\frac{3}{4}$ of $M$ and $\frac{1}{4}$ of $\bar{B}$ thus:

$$B: \bar{B}: M = 1: 1: 6$$

It was assumed that the first (closest) combination of quarks is prepared in colour-singlet state

V.V. Anisovitch, V.M. Schekhter Nucl. Phys. B55 455 (1973)
Let’s assume that colour states of quarks are completely random, then:

only 1/9 of \( q\bar{q} \) pairs will bind into a meson  
\[ 3 \otimes \bar{3} = 1 \oplus 8 \]

1/3 of qq pairs will became a di-quark  
\[ 3 \otimes 3 = \bar{3} \oplus 6 \]

1/9 of diquark–q will bound into a baryon  
\[ 3 \otimes 3 \otimes 3 = 1 \oplus 8 \oplus 8 \oplus 10 \]

Summing all that up…
Colour de-correlation favours baryon production up to a factor 9/5 (=1.8)

This would be hardly applicable for hadron–hadron collisions because:
average number of steps needed to find correct colour partner(s) is
for a meson 9.99 (exactly 899/90)
for a baryon 13.5
consequently we would get very high inv. masses, e.g. ≈ 30 GeV
mesons for quarks with the mean distance in rapidity of Δy ≈ 0.5

 Proposed solution was:
soft gluon exchange to adjust colours with probability ∼ α_s^2 ≈ O(0.1)
to penalize each step by factor ∼ exp(-Δy) due to a quark (spin-½)
t-channel exchange

This brings baryon-to-meson ratio practically back to 1 : 6 value…

E.M. Levin, M.G. Ryskin, K. Safarik 1979, unpublished
B/M ratio at $p_T \approx 2–3$ GeV/c in central heavy-ion collisions is $\sim 2–3$ times higher than that in pp; at $p_T$ above $\sim 7–10$ GeV/c back to the “normal” pp value.
Recombination – coalescence

Up to some (intermediate) $p_T [< O(10 \text{ GeV})]$ recombination will be favourable compared to fragmentation.

This is even more true for baryons.

Recombination explains the enhancement of baryons, i.e. baryon anomaly.

However, colour de-correlation can enhance baryons even further, in the region where it is dominant production process.

This is plausible for heavy-ion collisions, contrary to $h-h$, where in string fragmentation colours are naturally adjusted (i.e. correlated).


15 August 2012 Baryon anomaly & colour... K.Safarik
In previous study, when di-quark was created, we do not consider the possibility that the original quark can meet later another quark suited to be in di-quark combination and at the same time not to form a baryon di-quark was assumed to be a well-bounded state thus only the first di-quark combination was kept and should eventually end up in a baryon

For the recombination from QGP we search for the “closest” colour singlet combination to coalesce, thus we keep track of more than one di-quarks

This assumption favour baryons even more baryon-to-meson ratio become

\[ B: \bar{B}: M = 29: 29: 82 \]

compared to

\[ B: \bar{B}: M = 3: 3: 10 \]

or

\[ B: \bar{B}: M = 1: 1: 6 \]

The relative increase of probability for baryons between the two extreme scenaria (“always adapted colours” and “completely random colours”) is

\[ \frac{87}{41} \approx 2.122 \]

G.Matulewicz, K.Safarik 2012, unpublished
In our simple model at each step, when comes a quark with an unsuitable colour, we consider with some probability $p_g$ (so called “gluon probability”) that the colour is adjusted to the suitable one, by some sort of soft gluon emission.

Thus for $p_g = 0$ and $p_g = 1$ the two extreme cases are recovered.

In order to calculate the final baryon-to-meson ratio we assign to quarks flavour (s quark being suppressed by factor 0.3)

Hadrons from lowest ($l = 0$) multiplets are constructed with weights according the number of spin states, and decayed

2-d model assuming thermal distribution for quark $p_T$ is under construction, utilizing for quark ordering inv. mass


![Graph showing the baryon/meson ratio as a function of gluon probability](image-url)
Colour correlations among nearby quarks and antiquarks in QGP can alter the baryon-to-meson ratio, resulting from their recombination, by a factor:

~ 2 (for directly produced particles)
~ 3 (taking into account decays)

Random distribution of colours in QGP favour baryon production
Contrary, when colours are adjusted to form white state with a neighbour, the baryon-to-meson ratio is lowered

Simple model is being prepared to calculate the $p_T$-dependence of baryon-to-meson ratio (and of different particle species) taking into account assumptions about degree of colour correlations in QGP