The $\bar{\Lambda}/\Lambda$ production ratio measured in a wide range of proton scattering experiments $pZ \to \Lambda(\bar{\Lambda})X$ has been found to be a universal function $f(y_p - y)$ of “rapidity loss” $y_p - y$, where $y_p$ and $y$ are, respectively, the rapidities of the beam proton and the produced $\Lambda$ or $\bar{\Lambda}$. The function $f(y_p - y)$ is observed to be independent, or depends only weakly, on the total center of mass energy $\sqrt{s}$ of the two colliding hadrons in the range 0.24 to 7 TeV, on the target $Z = p, \bar{p},$ Be or Pb, on the transverse momentum $p_T$ of the $\Lambda$ or $\bar{\Lambda}$, or on sample composition. We consider the picture in which an $u$ quark produced in the scattering may coalesce with a $ud$ diquark remnant of the beam proton and produce a $\Lambda$.

Let $n_{\Lambda}(y)$ and $n_{\bar{\Lambda}}(y)$ be the distributions of $\Lambda$’s and $\bar{\Lambda}$’s as a function of rapidity $y$ in the center of mass frame of the two colliding hadrons. Rapidity is defined so that the $p$ beam has positive rapidity $y$. We write these distributions as follows:

$$n_{\Lambda}(y) = n_{\Lambda,1}(y) + n_{\Lambda,2}(y) + n_{\Lambda,3}(y),$$

$$n_{\bar{\Lambda}}(y) = n_{\bar{\Lambda},1}(y) + n_{\bar{\Lambda},2}(y) + n_{\bar{\Lambda},3}(y),$$

(1)

where $n_{\Lambda,1}(y)$ is the distribution of $\Lambda$’s containing a diquark remnant of beam 1, $n_{\Lambda,2}(y)$ is the distribution of $\Lambda$’s containing a diquark remnant of beam 2, and $n_{\Lambda,3}(y)$ is the distribution of $\Lambda$’s containing no beam remnant, and similarly for $\bar{\Lambda}$. Production mechanism $\beta$ has no memory of the beams and hence $n_{\Lambda,\beta}(y) = n_{\bar{\Lambda},\beta}(y) = n_{\beta}(y) = n_{\beta}(-y)$. The distribution $n_{\beta}(y)$ is approximately independent of $y$ within the “rapidity plateau” $-y_{\text{max}} < y < y_{\text{max}}$ as shown schematically in Fig. 1.

FIG. 1: Distributions of $\Lambda$ and $\bar{\Lambda}$ production as a function of rapidity $y$ in the center of mass frame of $pp$ scattering. The beam rapidities are respectively $y_1$ and $y_2$. The sub-index $\alpha$ ($\beta$) denotes $\Lambda$’s or $\bar{\Lambda}$’s containing (not containing) a beam diquark remnant. Lowering the total center of mass energy $\sqrt{s}$ translates $y_p$ and $n_{\Lambda,1}(y)$ left, and translates $y_\bar{p}$ and $n_{\bar{\Lambda},2}(y)$ right.

The purpose of this note is to point out that the ratio $r$ can be fit over four orders of magnitude, from $r \approx 0.01$ to $r \approx 100$, with a simple universal function with only two parameters $\kappa$ and $i$:

$$r = \left[\frac{\kappa}{y_p - y}\right]^i.$$  

(4)

Figure 2 presents the ratios $r = 1/f - 1$ measured in a wide range of proton scattering experiments. The data points with $y < 0.75$ of the DØ $p\bar{p}$ experiment were omitted because for them we can not neglect $n_{\bar{\Lambda},2}(y)$. The data point of the STAR $pp$ experiment has $y = 0$, so $n_{\Lambda,1} = n_{\bar{\Lambda},2}$. Therefore we have divided $1/f - 1$ by 2.

The parameters $\kappa$ and $i$ have a simple interpretation and can be read off the log $(y_p - y)$ vs log $r$ graph in Fig. 2. $\kappa \approx 2.8$ is the rapidity loss at which $r = 1$, and $i \approx -4.4$ is the slope of the straight line in Fig. 2.
For $y_p - y < \kappa$ production mechanism $\alpha$ dominates. For $y_p - y > \kappa$ production mechanism $\beta$ dominates. The fit to all of the data in Fig. 2 obtains $\kappa = 2.79 \pm 0.03$ and $i = 4.54 \pm 0.08$ with $\chi^2 = 637$ for 121 degrees of freedom. The large $\chi^2$ is due to tension between the data points of different experiments as can be seen in Fig. 2. Omitting the R-603 and R-607 measurements, which have some data points off the rapidity plateau, obtains $\kappa = 2.86 \pm 0.03$ and $i = 4.39 \pm 0.06$ with $\chi^2 = 342$ for 102 degrees of freedom. This is the fit shown in Fig. 2. Fitting only the E8 Pb data points where production mechanism $\alpha$ dominates obtains $\kappa = 2.93 \pm 0.15$ and $i = 4.06 \pm 0.30$ with $\chi^2 = 10.6$ for 13 degrees of freedom. Fitting all data with $y_p - y > 2.8$, where production mechanism $\beta$ dominates, obtains $\kappa = 2.94 \pm 0.10$ and $i = 4.23 \pm 0.25$ with $\chi^2 = 37$ for 32 degrees of freedom. In conclusion, we see no significant departure from Eq. (4) at either end of the data range. Our final estimate from several fits is

$$\kappa = 2.86 \pm 0.03 \pm 0.07, i = 4.39 \pm 0.06 \pm 0.15,$$

where the first uncertainty is statistical from the fit, and the second uncertainty is systematic and accounts for different data selections for the fits.

From $\sqrt{s} = 0.024$ to 7 TeV the cross-sections $\sigma(pp)$ and $\sigma(\bar{p}\bar{p})$, and the width of the rapidity plateau $2\gamma_{\text{max}}$, increase by approximately a factor 2 [2], so $n_s(y)$ is approximately independent of $\sqrt{s}$ and $y$ on the rapidity plateau. We conclude that the probability density that a $p$ scatters and becomes a $\Lambda$ with rapidity $y$ is proportional to $[\kappa/(y_p - y)]^i$. This result should also be valid for $\Lambda_c$, $\Lambda_b$, $\Sigma^+$, etc.

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