Baryon number transport at LHC energies with the ALICE experiment

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Abstract. This article presents the ratio of the yields of antiprotons to protons in pp collisions as measured by the ALICE experiment at \( \sqrt{s} = 0.9 \) and 7 TeV. The ratio is measured to be \( R|_{y<0.5} = 0.957 \pm 0.006(\text{stat.}) \pm 0.014(\text{syst.}) \) at 0.9 TeV and \( R|_{y<0.5} = 0.991 \pm 0.005(\text{stat.}) \pm 0.014(\text{syst.}) \) at 7 TeV independent of both rapidity and transverse momentum. The results are compared with theoretical predictions.

1. Introduction

The ratios of particle yields in hadronic interactions are important indicators of the collision dynamics. The ratio of the yields of antiprotons to protons, is of particular interest since it provides information about the transport of the baryon number (BN). The latter has been debated theoretically for some time \([1, 2, 3, 4, 5, 6]\). Experimental data on soft hadronic processes are well understood with the Quark-Gluon String Model (QGSM) \([2]\), within which the baryon is considered to be a bound diquark–quark state. Within this framework the mechanism responsible for baryon-number transport is the break-up of this configuration \([2]\). The diquark in general retains a large fraction of the proton momentum and therefore stays close to beam rapidity, typically within one or two units. Additional processes have been proposed to transport the baryon number over larger distances in rapidity, in particular via purely gluonic exchanges, where the proton breaks up into three quarks. In this case, the baryon number resides in a non-perturbative configuration of gluon fields, the so-called “baryon string junction”, which connects the valence quarks \([1]\). In this picture, the baryon-number transport is suppressed exponentially with the rapidity interval \( \Delta y \), proportional to \( \exp[(\alpha_J - 1) \Delta y] \), where \( \alpha_J \) is the intercept of the junction. In one other approach \([3]\), based on a modified version of the string junction exchange model described above, the junction trajectory is assumed to have unit intercept and thus lead to an energy independent uniform rapidity component.

The \( p/p \) ratio has been reported by several experiments \([7, 8, 9]\) at lower energies. The LHC opens the possibility to investigate the baryon transport over very large rapidity intervals by measuring the antiproton-to-proton production ratio at midrapidity, \( R = N_{\overline{p}}/N_p \). In this article, we describe the measurement of the \( \overline{p}/p \) ratio at midrapidity in non-diffractive pp collisions at center-of-mass energies \( \sqrt{s} = 0.9 \text{ TeV and 7 TeV (}\Delta y \approx 6.9-8.9, \text{ with the ALICE experiment at the LHC [10].} \)

2. Data Analysis

Data from 2.8 (\( \sqrt{s} = 0.9 \text{ TeV} \)) and 4.2 (\( \sqrt{s} = 7 \text{ TeV} \)) million pp collisions, recorded during the first LHC runs (December 2009 and March–April 2010) were used for this analysis. The events
were recorded with both magnetic field polarities for each energy. The trigger required a hit in one of the VZERO counters or in the SPD detector [11], in coincidence with the signals from two beam pick-up counters, one on each side of the interaction region, indicating the presence of passing bunches. Measurements of momentum and particle identification are performed using information from the TPC detector, which measures the ionization in the TPC gas and the particle trajectory. The phase space of the analysis was restricted to the rapidity and momentum range of $|y| < 0.5$ and $0.45 < p < 1.05$ GeV/c, respectively.

Corrections that do not cancel out in the ratio were applied. Corrections for absorption in detector material were extracted using a complete Monte Carlo model, simulating the detector response with GEANT3. In addition, a detailed study using GEANT3 and FLUKA was performed to extract the scaling factors for the $p(\overline{p})$–A inelastic cross-sections. Corrections for background (i.e. protons originating from the interaction of particles with the material) and feed–down (i.e. weak decay of hyperons) were estimated by parameterizing the distribution of the distance of closest approach ($dca$) of the tracks to the primary vertex from data. Finally, the effect of the differences in the efficiencies of the analysis cuts for the different charges, resulting from the corresponding differences between p–A and $\overline{p}$–A elastic cross-sections, was taken also into account. For more details about the corrections and the estimation of the systematic uncertainty, see [11, 12].

3. Results
The final, feed-down corrected $\overline{p}/p$ ratio $R$ integrated within our rapidity and $p_t$ acceptance rises from $R_{|y|<0.5} = 0.957 \pm 0.006$ (stat.) $\pm 0.014$ (syst.) at $\sqrt{s} = 0.9$ TeV to $R_{|y|<0.5} = 0.991 \pm 0.005$ (stat.) $\pm 0.014$ (syst.) at $\sqrt{s} = 7$ TeV. Within statistical errors, the measured ratio $R$ shows no dependence on transverse momentum (Fig. 1), rapidity or multiplicity [12]. The ratio is also independent of momentum and rapidity in our acceptance for all theoretical models considered, with the exception of HIJING/B, which predicts a decrease with increasing transverse momentum for the lower energy.

The data are compared with various model predictions for pp collisions [5, 6, 13] in Tab. 1 (integrated values) and Fig. 1. The QGSM model does not predict the $p_t$ dependence and is therefore not included in Fig. 1. For both energies, two of the PYTHIA tunes [13] (ATLAS-CSC and Perugia-0) as well as the version of QGSM with the value of the string junction intercept $\alpha_t = 0.5$ [5] describe the experimental values well. On the other hand QGSM without string junctions ($\epsilon = 0$, $\epsilon$ is a parameter proportional to the probability of the string-junction exchange) is slightly above the data. HIJING/B [6] underestimates the experimental results, in particular at the lower LHC energy. Also, QGSM with a value of the junction intercept $\alpha_t = 0.9$ [5] predicts a smaller ratio, as does the Perugia-SOFT tune of PYTHIA, which also includes enhanced baryon transfer.

Figure 3 shows a compilation of central rapidity measurements of the ratio $R$ in pp collisions as a function of center-of-mass energy (upper axis) and the rapidity interval $\Delta y$ (lower axis). The ALICE measurements correspond to $\Delta y = 6.87$ and $\Delta y = 8.92$ for the two energies, with the lower energy data points taken from [7, 8, 9]. The lower ALICE point indicates that there is still a small but significant excess of protons over antiprotons. On the other hand, the ratio at $\sqrt{s} = 7$ TeV is consistent with unity, which sets a stringent limit on the amount of baryon transport over 9 units in rapidity.

The $\Delta y$ dependence of the ratio $R$ can be parameterized with the help of different diagrams describing the particle production of both $p$ and $\overline{p}$ based on the Regge model. The baryon pair production at very high energy is governed by Pomeron exchange and baryon transport by string-junction exchange [4]. Following this formulation the $p/\overline{p}$ ratio can be described by the simple form $1/R = 1 + C \exp[(\alpha_t - \alpha_P)\Delta y]$ [11, 12]. The value for the Pomeron intercept is chosen to be $\alpha_P = 1.2$ in accordance with the energy dependence of the rapidity density [14].
Figure 1. The $p_t$ dependence of the $\bar{p}/p$ ratio integrated over $|y| < 0.5$ for pp collisions at $\sqrt{s} = 0.9$ TeV (left) and $\sqrt{s} = 7$ TeV (right).

Figure 2. Central rapidity $\bar{p}/p$ ratio as a function of the rapidity interval $\Delta y$ (lower axis) and center-of-mass energy (upper axis). Error bars correspond to the quadratic sum of statistical and systematic uncertainties for the RHIC and LHC measurements and to statistical errors otherwise.
Table 1. The measured central rapidity $\bar{p}/p$ ratio compared to the predictions of different models (the statistical uncertainties in the models are less than 0.005). The quoted errors for the ALICE points are the quadratic sum of statistical and systematic uncertainties.

| Energy [TeV] | 0.9      | 7      |
|--------------|----------|--------|
| ALICE        | 0.957 ± 0.015 | 0.991 ± 0.015 |
| PYTHIA Perugia-0 Tune (320) | 0.96 | 1.0 |
| PYTHIA Perugia-SOFT Tune (322) | 0.88 | 0.94 |
| QGSM $\epsilon = 0$ | 0.98 | 1.0 |
| QGSM $\epsilon = 0.076$, $\alpha_J = 0.5$ | 0.96 | 0.99 |
| QGSM $\epsilon = 0.024$, $\alpha_J = 0.9$ | 0.89 | 0.95 |
| HIJING/B 0.83 | 0.97 |

and $\alpha_J = 0.5$ (intercept of the Reggeon). The parameter $C$, which determines the relative contributions of the two diagrams, is adjusted to the measurements from ISR, RHIC, and LHC. The fit, shown in Fig. 3, gives a reasonable description of the data with only one free parameter ($C$), except at lower energies, where contributions of other diagrams (exchange of two junctions at both vertices) cannot be neglected [4]. The contribution of a second string junction diagram with a larger intercept [3], i.e., $1/R = 1 + C \exp[(\alpha_J - \alpha_P)\Delta y] + C' \exp[(\alpha_J' - \alpha_P)\Delta y]$ with $\alpha_P = 1$, is compatible with zero ($C \approx 10$, $C' \approx -0.1 \pm 0.1$).

4. Summary

In summary, we have measured the ratio of antiproton to proton production at $\sqrt{s} = 0.9$ and $\sqrt{s} = 7$ TeV. The obtained values are $R_{|y|<0.5} = 0.957 \pm 0.006$(stat.) $\pm 0.014$(syst.) at 0.9 and $R_{|y|<0.5} = 0.991 \pm 0.005$(stat.) $\pm 0.014$(syst.) at 7 TeV. The $\bar{p}/p$ ratio is independent of both rapidity and transverse momentum and the results are consistent with standard models of baryon-number transport over very large rapidity intervals in pp collisions.

References

[1] G.C. Rossi and G. Veneziano, Nucl. Phys. B123, (1977) 507.
[2] A. Capella et al. Phys. Rep. 236, 225 (1994); A.B. Kaidalov and K.A. Ter-Martirosyan, Sov. J. Nucl. Phys. 39, 1545 (1984).
[3] B.Z. Kopeliovich, Sov. J. Nucl. Phys. 45, 1078 (1987).
[4] D. Kharzeev, Phys. Lett. B378, 238 (1996).
[5] C. Merino et al. Eur. Phys. J. C54 577 (2008); C. Merino, M.M. Ryzhinskiy, Yu.M. Shabelski, arXiv:0906.2659.
[6] S. E. Vance and M. Gyulassy, Phys. Rev. Lett. 83, 1735 (1999).
[7] T. Anticic et al. (NA49 Collaboration), Eur. Phys. J. C65, 9 (2010).
[8] A.M. Rossi et al. Nucl. Phys. B84, 269 (1975); M. Aguilar-Benitez et al. Z. Phys. C50, 405 (1991).
[9] B.I. Abelev et al. (STAR Collaboration), Phys. Rev. C79, 034909 (2009); I.G. Bearden et al. (BRAHMS Collaboration), Phys. Lett. B607, 42 (2005); B.B. Back et al. (PHOBOS Collaboration), Phys. Rev. C71, 021901 (2005); S.S. Adler et al. (PHENIX Collaboration), Phys. Rev. C69, 034909 (2004).
[10] K. Aamodt et al. (ALICE Collaboration), JINST 3, S08002 (2008).
[11] K. Aamodt et al. (ALICE Collaboration), Phys. Rev. Lett. 105, 072002 (2010), arXiv:1006.5432.
[12] P Christakoglou, ALICE Internal Note ALICE-INT-2010-006, 2010.
[13] T. Sjostrand, P. Skands, Eur. Phys. J. C59, 129 (2005); P. Skands, arXiv:1005.3457 [hep-ph] (2010). Perugia-0 (320) and Perugia-SOFT (322) tunes; A. Moraes (ATLAS Collaboration), ATLAS Note ATLAS-CONF-2009-119, 2009.
[14] A.B. Kaidalov, L.A. Ponomarev and K.A. Ter-Martirosyan, Sov. J. Nucl. Phys., 44, 468 (1986).