SciPost Phys. Proc. 8, 081 (2022)

Measurement of charged-particle production in single diffractive proton-proton collisions with the STAR detector

Leszek Adamczyk[1⋆] for the STAR Collaboration

1 Faculty of Physics and Applied Computer Science,
AGH University of Science and Technology, 30 Mickiewicza Ave., b30-059 Kraków, Poland

⋆ leszek.adamczyk@agh.edu.pl

Proceedings for the XXVIII International Workshop on Deep-Inelastic Scattering and Related Subjects, Stony Brook University, New York, USA, 12-16 April 2021
doi:10.21468/SciPostPhysProc.8

Abstract

We present results on the inclusive and identified (pion, kaon, proton and their antiparticles) charged-particle production in single diffractive (SD) dissociation process in proton-proton collisions at $\sqrt{s} = 200$ GeV with the STAR detector at RHIC. The forward-scattered proton is measured in the Roman Pot (RP) system, while the charged particle tracks are reconstructed in the STAR Time Projection Chamber. The proton-antiproton production asymmetry is measured to study the baryon number transfer over a large rapidity interval in SD process. In addition, K/π ratio is measured, showing a larger strangeness production at $p_T > 0.5$ GeV/c compared to measurements in inclusive proton-proton collisions.

Received 15-08-2021
Accepted 06-05-2022
Published 12-07-2022
Check for updates
doi:10.21468/SciPostPhysProc.8.081

1 Introduction

The yields of charged-hadrons emitted in high-energy particle collisions are among basic observables used to study Quantum Chromodynamics in both perturbative and non-perturbative regimes. The most significant contribution to the number of produced particles comes from soft interactions, which are usually modeled phenomenologically. In this paper we present studies for a class of pp collisions, $p + p \rightarrow p + X$, where X denotes the hadronic final state produced in the interaction due to dissociation of the beam proton, in which other of the colliding protons escapes the collision intact at a very small angle and is measured in the Roman Pot (RP) system. Experimentally diffractive events are often defined as the events with large rapidity gaps, which are not exponentially suppressed. However experiments equipped with tracking detectors in RP for detecting forward scattered protons use a more strict definition in terms of a leading proton taking a large fraction of the beam proton momentum. We also study anti-proton to proton multiplicity ratio as a function of the particle transverse momentum, p_T

and the relative energy loss of the forward-scattered proton, ξ. This study aims toward a better understanding of the baryon number transfer in single diffractive (SD) process. Since most of the baryons are created as baryon-anti-baryon pairs in the hadronization process, it is expected that the same amounts of baryons and anti-baryons should be observed in the central rapidity region, and the initial baryon number should appear in the very forward direction. In addition we measure kaon to pion multiplicity ratio. Such ratio is sensitive to the strangeness production in the fragmentation process. Strangeness production in inclusive *pp* collisions was observed to be significantly suppressed compared to *up* and *down* quarks production [1].

2 Results

The STAR experiment [2] at RHIC has performed a high-statistics measurement of the SD process in *pp* collisions based on a sample collected in 2015 at the center-of-mass energy $\sqrt{s} = 200$ GeV corresponding to an integrated luminosity of 15 nb^{-1}. The comparison to the corrected data distribution is done for several Monte Carlo (MC) generators: the 4C tune of PYTHIA 8 [3] with SaS (Schuler and Sjöstrand) [4] model, version 7.1 of the HERWIG generator [5] which includes a new model for soft interactions and diffraction [6], the EPOS [7] tuned to LHC data (EPOS-LHC) [8]. In addition all results are compared to the alternative A2 tune [9] of PYTHIA 8, with the MBR (Minimum Bias Rockefeller) model [10] and to MBR expectation without arbitrary suppression of the cross section at relatively large values of ξ (MBR-tuned). EPOS predicts a very large contribution of the forward protons well separated in rapidity from other final state particles from non-diffractive events. Therefore, for the comparison with data EPOS-LHC predictions are separated into two classes: EPOS-LHC SD, with diffractive flag, and EPOS-LHC SD$'$, with non-diffractive flag. For the purpose of this measurement, EPOS SD$'$ sample is selected by requirement that the mass of the excited beam remnant is low (< 1 GeV), and only proton is produced from it while EPOS ND consists of other non-diffractive events.

In Fig. 1 we show multiplicity distributions of charged particles in different intervals of ξ as well as the average values of n_{ch} in those ξ ranges. Data exhibit an expected increase of the $\langle n_{\text{ch}} \rangle$ with ξ due to the larger diffractive masses probed at increasing ξ in SD process. The shapes of the measured distributions are reproduced reasonably well by all models except the EPOS-LHC (SD+SD$'$), which predicts much smaller $\langle n_{\text{ch}} \rangle$ at $\xi < 0.1$ and the HERWIG SD, which for $0.1 < \xi < 0.2$ predicts too large $\langle n_{\text{ch}} \rangle$. It should be noted, that EPOS-LHC SD$'$ describes data much better compared to EPOS-LHC (SD+SD$'$).

We compare present measurement of charged particle density with non single diffractive enhanced (NSD) measurements. For this comparison present results were extrapolated from the fiducial $|\eta| < 0.7$ region to midrapidty region $\eta_m = -\ln(\sqrt{s}/M_X)$. Extrapolation was performed based on model implemented in PYTHIA 8 and includes also correction for $n_{\text{ch}} = 1$ events not included in present measurement. Figure 2 shows densities of charged-particles at midrapidity as a function of $\sqrt{s}$ and M_X for NSD enhanced measurements and present results, respectively. SD points lay very well on the power-like fit to the NSD enhanced measurements [11] showing similarity of charged particle densities at midrapidity between SD and NSD enhanced measurements.

The left panel in Fig. 3 shows the ratios of production yields of $\bar{p}/p$ in three intervals of ξ as a function of p_T. In the last two ξ ranges, data are consistent with equal amounts of p and $\bar{p}$ with no p_T dependence. However, in the first ξ range at $p_T < 0.7$ GeV/c, data show a significant deviation from unity indicating a large transfer of the baryon number from the forward to the central region. PYTHIA 8, EPOS-LHC SD$'$ and EPOS-LHC (SD+SD$'$) agree with data in the last two ξ ranges. In the first ξ range, PYTHIA 8 and EPOS-LHC SD$'$ predict small deviation from unity by $\sim 5\%$, which is smaller than $\sim 15\%$ observed in data, while EPOS-

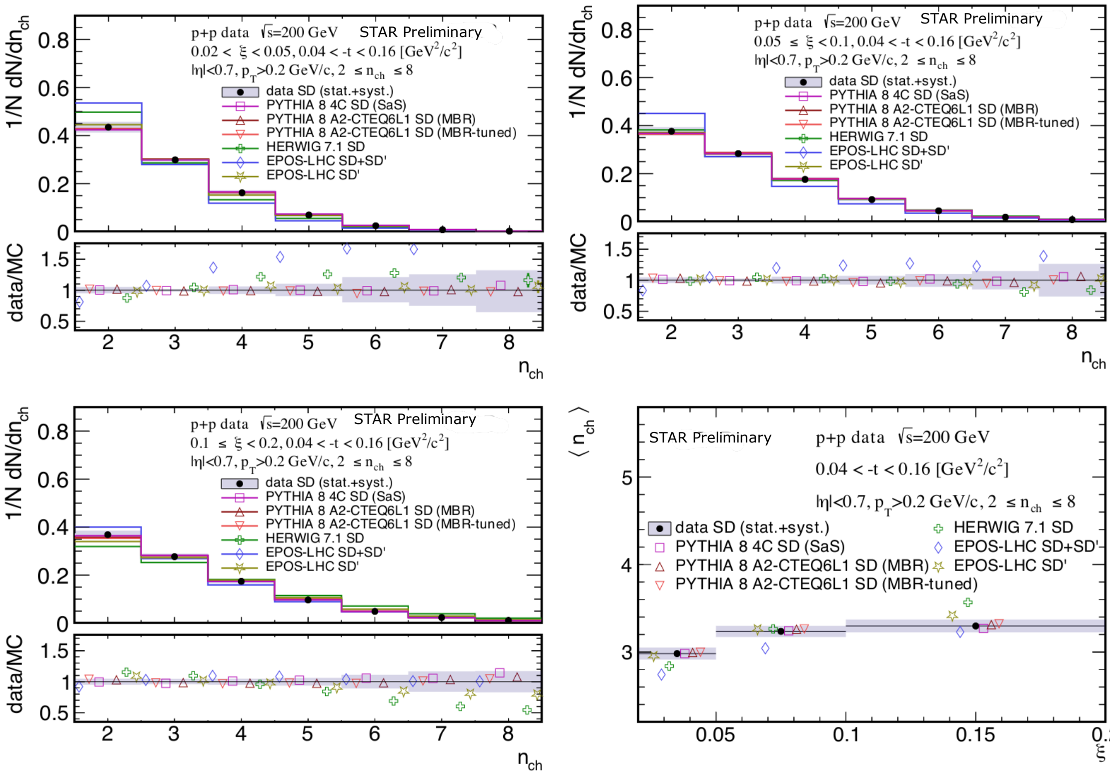

Figure 1: Primary charged-particle multiplicities shown in three ranges of the ξ: (top left) $0.02 < \xi < 0.05$, (top right) $0.05 < \xi < 0.1$, (bottom left) $0.1 < \xi < 0.2$. (bottom right) The mean multiplicity $\langle n_{\text{ch}} \rangle$ as a function of ξ. Data are shown as full dots with error bars representing the statistical uncertainties. Gray boxes represent statistical and systematic uncertainties added in quadrature. Predictions from MC models are shown as histograms or the open symbols. The bottom panels show ratios of data to the MC models predictions. In the ratio plots and in the $\langle n_{\text{ch}} \rangle$ distribution, points representing different MC models are spread within bins for better visibility.

LHC (SD+SD′) predicts larger deviation by $\sim 25\%$. HERWIG SD predicts much larger baryon number transfer compared to data in all three ξ ranges. This observation is caused by the fact, that HERWIG SD is effectively an extreme realization of the model in which there is almost always a baryon present at gap edge. Significant increase of $\bar{p}/p$ ratio with increasing ξ is related to the fact that the gap edge is further away from the fiducial η region at larger ξ.

The right panel in Fig. 3 shows the ratios of production yields of $(K^+ + K^-)/(\pi^+ + \pi^-)$ in three intervals of ξ as a function of p_T. The ratio increases from 0.05 at $p_T = 0.3$ GeV/c to $0.22 - 0.28$ at $p_T = 0.65$ GeV/c. The slope of the p_T dependence significantly increases at $p_T = 0.5$ GeV/c in all three ξ intervals. The change of the p_T slope increases with ξ. All models predict very similar $(K^+ + K^-)/(\pi^+ + \pi^-)$ ratio except HERWIG, which predicts almost twice larger value independently from p_T. PYTHIA 8 and EPOS-LHC agree very well with data at $0.3 < p_T < 0.5$ GeV/c but do not expect a change of the slope of p_T dependence at $p_T > 0.5$ GeV/c predicting rather almost twice smaller ratio at the highest p_T value.

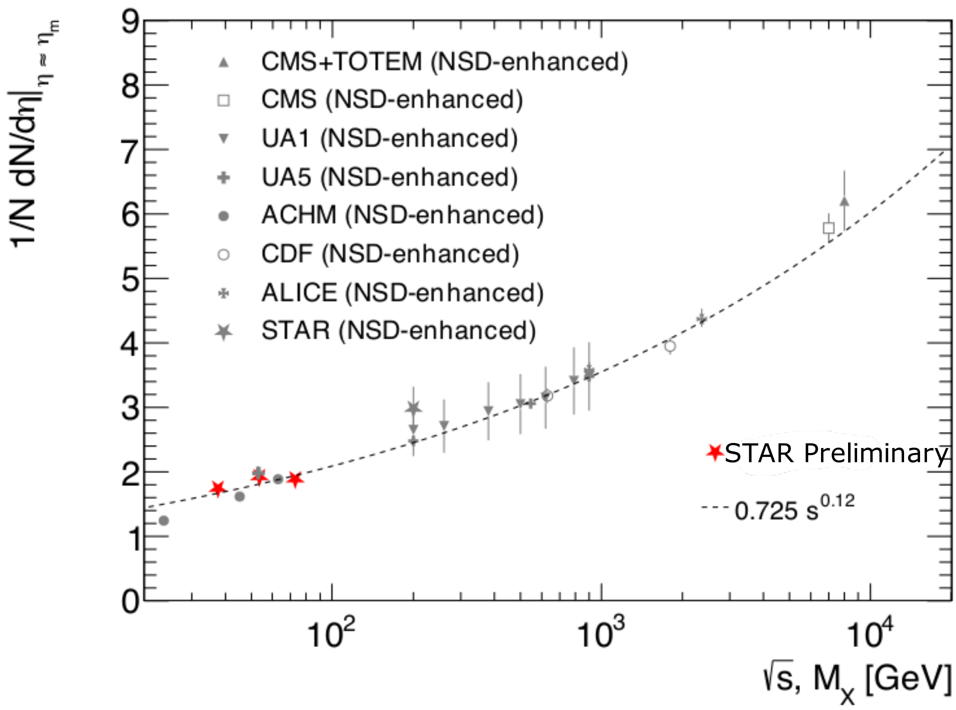

Figure 2: Primary charged particle densities at mid-rapidity as a function of $\sqrt{s}$ and M_X for inelastic (non single diffractive (NSD) enhanced) and single diffractive measurements respectively. The dashed line represents power-law fit to the NSD-enhanced measurements [11].

3 Conclusion

Primary-charged-particle multiplicities are well described by PYTHIA 8 and EPOS-LHC SD′ models. EPOS-LHC SD and HERWIG 7.1 do not describe the data. Similarity between the dissociation of a diffractively produced system of mass M_X and the hadronization of the system resulting from non-diffractive pp collisions at $\sqrt{s} \approx M_X$ was shown. $\bar{p}/p$ production ratio shows a significant deviation from unity in the $0.02 < \xi < 0.05$ range indicating a non-negligible transfer of the baryon number from the forward to the central region. Equal amounts of protons and antiprotons are observed in the $\xi > 0.05$ range. PYTHIA 8 and EPOS-LHC SD′ agree with data for $\xi > 0.05$. For $0.02 < \xi < 0.05$ they predict small deviations from unity (0.93), however even larger effect is observed in the data (0.86 ± 0.02). This observation is consistent with increase of the baryon number transfer to the central rapidity region with decreasing ξ expected from Ref. [12] where an extra baryon can appear close to the rapidity gap edge (so called backward peak). At $p_T > 0.5$ GeV/c, the measured $(K^+ + K^-)/(\pi^+ + \pi^-)$ ratio is significantly larger compared to inclusive inelastic measurements in pp or $\bar{p}p$ collisions. This excess is not predicted by any model. It can be due to the smaller $s\bar{s}$ suppression in fragmentation process (factor 0.2 in PYTHIA 8) in diffractive system and p_T kicks during string(cluster) breaking producing $s\bar{s}$ is larger compared to $u\bar{u}$ or $d\bar{d}$ production.

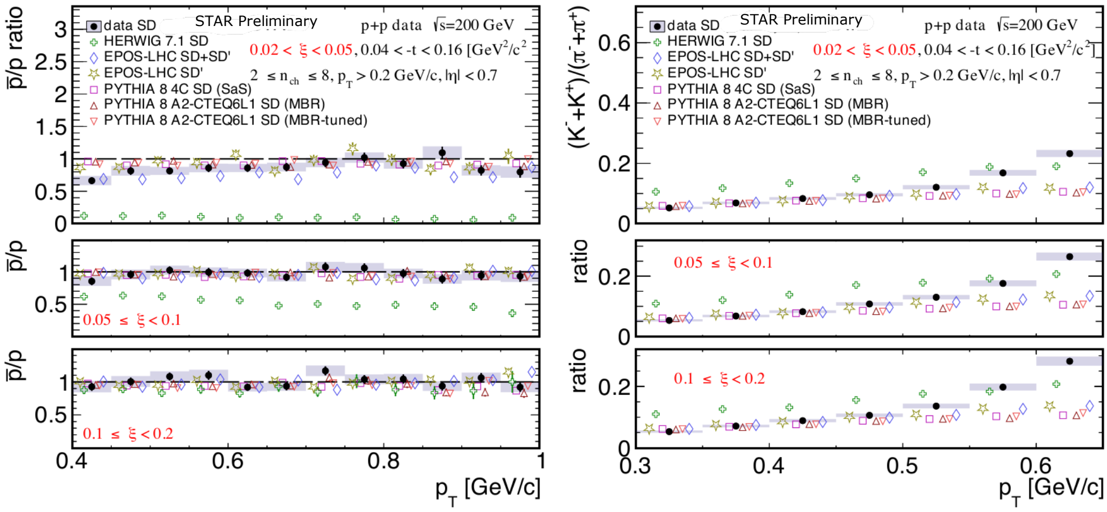

Figure 3: Ratio of production yields of $\bar{p}/p$ as a function of p_T shown in three ranges of ξ: (top left) $0.02 < \xi < 0.05$, (middle left) $0.05 < \xi < 0.1$, (bottom left) $0.1 < \xi < 0.2$. Ratio of production yields of $\left(K^- + K^+\right) / \left(\pi^- + \pi^+\right)$ as a function of p_T shown in three ranges of ξ: (top right) $0.02 < \xi < 0.05$, (middle right) $0.05 < \xi < 0.1$, (bottom right) $0.1 < \xi < 0.2$. Data are shown as full dots with error bars representing the statistical uncertainties. Gray boxes represent statistical and systematic uncertainties added in quadrature. Predictions from MC models are shown as open symbols.

Acknowledgements

This work was partly supported by the National Science Centre of Poland under grant number UMO-2018/30/M/ST2/00395.

References

[1] H.-Y. Long, S.-Q. Feng, D.-M. Zhou, Y.-L. Yan, H.-L. Ma and B.-H. Sa, *trange quark suppression and strange hadron production in pp collisions at RHIC and LHC*, Phys. Rev. C **84**, 034905 (2011), doi:10.1103/PhysRevC.84.034905.

[2] K. H. Ackermann et al., *STAR detector overview*, Nucl. Instrum. Meth. A **499**, 624 (2003), doi:10.1016/S0168-9002(02)01960-5.

[3] T. Sjöstrand, S. Mrenna and P. Skands, *A brief introduction to PYTHIA 8.1*, Comp. Phys. Commun. **178**, 852 (2008), doi:10.1016/j.cpc.2008.01.036.

[4] G. A. Schuler and T. Sjöstrand, *Hadronic diffractive cross sections and the rise of the total cross section*, Phys. Rev. D **49**, 2257 (1994), doi:10.1103/PhysRevD.49.2257.

[5] J. Bellm et al., *Herwig 7.1 Release Note*, arXiv:1705.06919.

[6] S. Gieseke, F. Loshaj and P. Kirchgaeßer, *Soft and diffractive scattering with the cluster model in Herwig*, Eur. Phys. J. C **77**, 156 (2017), doi:10.1140/epjc/s10052-017-4727-7.

[7] K. Werner, L. Karpenko, M. Bleicher, T. Pierog, *The physics of EPOS*, EPJ Web Conf. **52**, 05001 (2013), doi:10.1051/epjconf/20125205001.

[8] T. Pierog, Iu. Karpenko, J. M. Katzy, E. Yatsenko and K. Werner, *EPOS LHC: Test of collective hadronization with data measured at the CERN Large Hadron Collider*, Phys. Rev. C **92**, 034906 (2015), doi:10.1103/PhysRevC.92.034906.

[9] ATLAS Collaboration, *Further ATLAS tunes of PYTHIA 6 and Pythia 8*, ATL-PHYS-PUB-2011-014.

[10] R. Ciesielski, K. Goulianos, *MBR Monte Carlo simulation in PYTHIA 8* , arXiv:1205.1446.

[11] CMS and TOTEM Collaborations, *Measurement of pseudorapidity distributions of charged particles in proton-proton collisions at $\sqrt{s} = 8$ TeV by the CMS and TOTEM experiments*, Eur. Phys. J. C **74**, 3053 (2014), doi:10.1140/epjc/s10052-014-3053-6.

[12] F.W. Bopp, *Central baryons in dual models and the possibility of a backward peak in diffraction*, arXiv:hep-ph/0002190.