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Direct photon production at LHCb

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Abstract

At small Bjorken-x, the large gluon number density in the nucleon leads to gluon recombination competing with gluon splitting, which could result in saturation of the gluon PDF. This gluon saturation has yet to be conclusively observed. Direct photon production provides sensitivity to gluon densities in protons and nuclei, and the forward acceptance of LHCb detector allows for measurements of this process at low Bjorken-x, providing an ideal probe of saturation effects. Progress towards the measurement of forward direct photon production using the LHCb detector is presented.

Keywords:
Heavy ion physics, photons, direct photons, gluon saturation, LHCb

1. Introduction

Photons in hadron collisions are predominantly produced in hadron decays. Photons that are not produced in hadron decays are known as direct photons. Direct photons are produced at tree-level via quark-gluon compton scattering, providing sensitivity to the gluon parton distribution function (PDF) [1]. As Bjorken-x (x) decreases, the gluon PDF increases as high-momentum gluons split into low-momentum gluons. As the number density of gluons increases, recombination competes with gluon splitting, which could lead to gluon saturation. Because the number density of gluons in a Lorentz-contracted nucleus increases with the atomic mass A, saturation effects should be most significant in collisions involving heavy ions [2].

The LHCb detector is a single-arm forward spectrometer instrumented for tracking, calorimetry, and particle identification in the region $2 < \eta < 5$ [3]. LHCb collected proton-lead collision data at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV in 2016, including an integrated luminosity of 13 nb^{-1} with the proton beam travelling towards the spectrometer at the interaction point (the pPb configuration) and 17 nb^{-1} with the lead ion beam travelling towards the spectrometer at the interaction point (the Pbp configuration). The forward acceptance of the LHCb detector provides sensitivity to the nuclear gluon PDF at $x < 10^{-5}$ through measurements of low-p_{T} forward direct photon production in pPb collisions. Sensitivity to the gluon PDF in the nucleus at low x makes direct photons at LHCb an ideal probe of gluon saturation. Progress on studies of direct photons in the $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV pPb and Pbp data sets collected by the LHCb detector in 2016 is presented. Results using 13 TeV and 5.02 TeV pp control samples are also shown.

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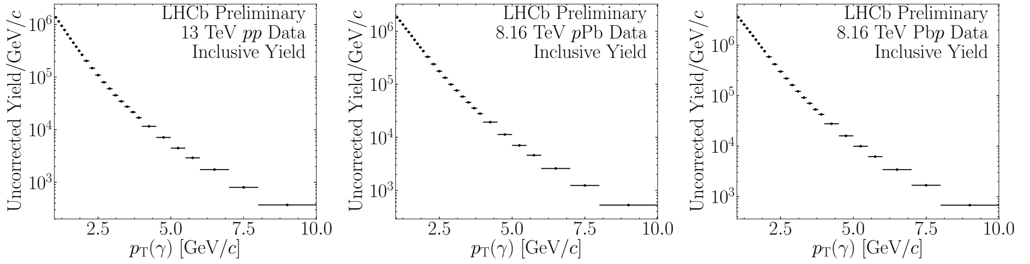

Fig. 1. Uncorrected inclusive converted photon yields for (left) 13 TeV pp, (center) 8.16 TeV pPb, and (right) 8.16 TeV Pbp data.

2. Analysis

Most reconstructed photons are hadron decay products. The direct photon contribution to the total photon yield is quantified by the double ratio $R_\gamma = (\gamma_{\rm inc}/\gamma_{\pi^0})_{\rm data}\big/(\gamma_{\rm dec}/\gamma_{\pi^0})_{\rm MC}$ where $\gamma_{\rm inc}$ is the inclusive photon yield in data, $\gamma_{\rm dec}$ is the yield of photons from hadron decays in simulation, and γ_{π^0} is the yield of photons from π^0 decays in data in the top ratio and in simulation in the bottom ratio. After correcting for differences between simulation and data in electromagnetic calorimeter (ECAL) photon reconstruction efficiency and the fraction of decay photons from π^0 decays, this double ratio reduces to $\gamma_{\rm inc}/\gamma_{\rm dec}$. Any excess of this double ratio over unity indicates the presence of direct photons. The ALICE collaboration recently measured the direct photon contribution in 8 and 2.76 TeV pp collisions finding no significant direct photon signal in agreement with theoretical predictions of a percent level contribution [4].

In this analysis photons converting to e^+e^- in the detector material are reconstructed using their conversion products. This offers better momentum resolution than photons reconstructed in the ECAL and eliminates backgrounds from photon pairs originating from π^0 decays reconstructed as a single ECAL cluster. To further improve momentum resolution, only tracks without associated segments in the vertex locator (VELO) are used. These photons must convert in an average of about 0.37 X_0 of material between the interaction point and the first tracking station [5, 6]. The material budget in this region has an estimated uncertainty of 6% [5]. In order to avoid detector edge effects, the reconstructed photon fiducial region is restricted to $2.5 < \eta < 4.0$. The uncorrected converted photon yields are shown in Fig. 1. These converted photons are combined with photons reconstructed as ECAL clusters in order to construct π^0 candidates. The π^0 yield is extracted from a fit to the diphoton mass spectrum. Sample mass distributions are shown in Fig. 2. Direct photons are surrounded by less hadronic activity than photons from hadron decays. Isolation requirements will be imposed in the final analysis in order to increase the relative direct photon fraction. Because the direct photon contribution reported by the ALICE collaboration is small relative to expected systematic uncertainties, pp data without any isolation requirement is used as a control sample in this analysis.

The resulting double ratio must be corrected for differences in ECAL photon reconstruction efficiency between simulation and data. Studies are underway to measure this correction using the ratio of B decays $(B^+ \to \chi_{c1}(\to \gamma J/\psi)K^+)/(B^+ \to J/\psi K^+)$. Preliminary results show percent level differences in efficiency between data and simulation with an uncertainty of 6% dominated by the B^+ branching ratio uncertainties [7]. An additional correction is needed to account for differences between simulation and data in the relative production rates of π^0 and η mesons. This correction can be determined by measuring the η/π^0 production ratio in data and simulation. Because about 95% of decay photons come from π^0 and η meson decays, differences in contributions from other mesons will lead to sub-percent level systematic uncertainties in R_γ. Both π^0 and η meson yields are extracted from fits to the mass spectrum of diphotons consisting of one converted photon and one ECAL photon. Results are shown for 13 TeV pp in Fig. 3 along with comparisons to EPOS-LHC [8] and PYTHIA 8 [9]. Because only about 15% of decay photons are from η decays, the statistical uncertainty in this correction leads to a percent level systematic uncertainty in R_γ.

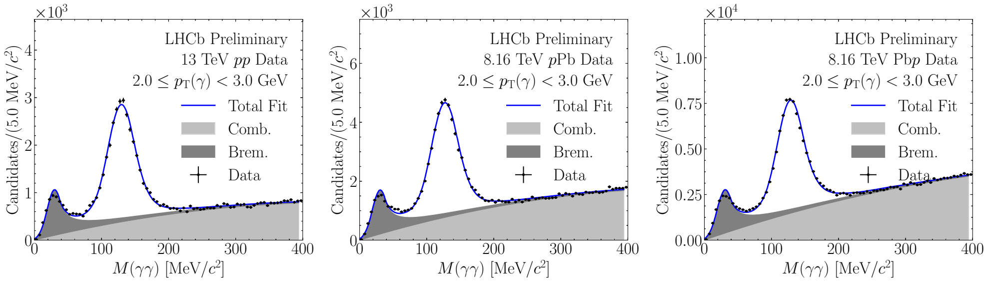

Fig. 2. Sample mass distributions of diphoton candidates consisting of one converted photon and one ECAL photon for (left) 13 TeV pp, (center) 8.16 TeV pPb, (right) and 8.16 TeV Pbp data in the π^0 mass region. Fit results are also shown. The total fit is shown as a solid line, while the combinatoric background is shown as a lightly shaded region. An additional background component resulting from the combination of a converted photon with a bremsstrahlung photon emitted by one of its conversion products is shown as a darkly shaded region.

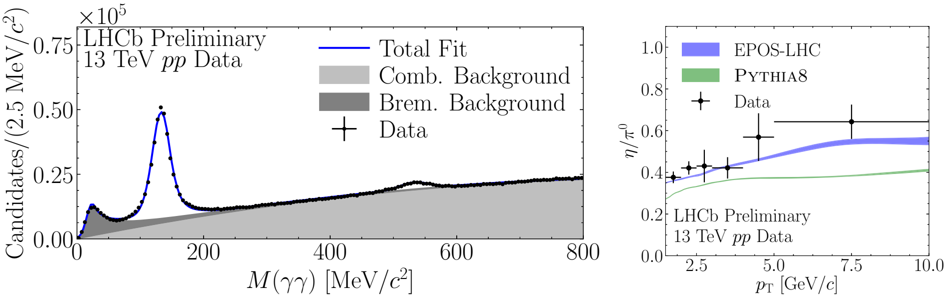

Fig. 3. (Left) Mass distribution of diphotons consisting of one converted photon and one ECAL photon. The fit components are the same as those in Fig. 2. (Right) The η/π^0 production ratio as a function of meson p_{T} for 13 TeV pp data.

3. Control results

To demonstrate that systematic effects are understood, R_γ is measured in pp control samples with no isolation criterion applied. Because the largest available simulation sample is 13 TeV pp, this is used as the denominator in both the 5.02 and 13 TeV double ratios. Simulated candidates are weighted to account for differences in multiplicity and the underlying meson momentum spectrum. Results are shown for 13 and 5.02 TeV in Fig. 4. Because the 13 TeV simulation sample is used in both results, the effects of reweighting are smaller in the 13 TeV case than in the 5.02 TeV case. The results are consistent with each other, and both are consistent with unity to well within the ECAL efficiency uncertainty. This consistency indicates that these control measurements can be used to further reduce the systematic uncertainty from the ECAL photon reconstruction efficiency.

4. Summary

The LHCb detector has the ability to measure forward direct photon production, an ideal process for studying the effects of gluon saturation. Progress towards a measurement of direct photon production in pPb collisions using the LHCb detector is shown. Control measurements are presented which demonstrate that systematic effects are well understood.

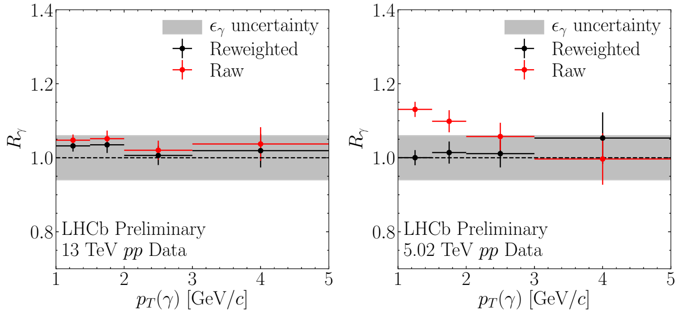

Fig. 4. Measured values of R_γ for (left) 13 TeV pp and (right) 5.02 TeV pp data. The red points show the raw value of R_γ, while the black points show the value after weighting the simulated converted photons to account for differences in event multiplicity and the underlying meson p_{T} spectra. The shaded region illustrates the 6% ECAL photon reconstruction efficiency uncertainty.

Acknowledgements

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References

[1] I. Helenius, K. J. Eskola, H. Paukkunen, Probing the small-x nuclear gluon distributions with isolated photons at forward rapidities in p+Pb collisions at the LHC, JHEP 09 (2014) 138. arXiv:1406.1689, doi:10.1007/JHEP09(2014)138.

[2] J. L. Albacete, C. Marquet, Gluon saturation and initial conditions for relativistic heavy ion collisions, Prog. Part. Nucl. Phys. 76 (2014) 1–42. arXiv:1401.4866, doi:10.1016/j.ppnp.2014.01.004.

[3] R. Aaij, et al., LHCb Detector Performance, Int. J. Mod. Phys. A30 (07) (2015) 1530022. arXiv:1412.6352, doi:10.1142/S0217751X15300227.

[4] S. Acharya, et al., Direct photon production at low transverse momentum in proton-proton collisions at $\sqrt{s}$ = 2.76 and 8 TeVarXiv:1803.09857.

[5] R. Aaij, et al., Measurement of the track reconstruction efficiency at LHCb, JINST 10 (02) (2015) P02007. arXiv:1408.1251, doi:10.1088/1748-0221/10/02/P02007.

[6] R. Aaij, et al., Performance of the LHCb Vertex Locator, JINST 9 (2014) P09007. arXiv:1405.7808, doi:10.1088/1748-0221/9/09/P09007.

[7] C. Patrignani, et al., Review of Particle Physics, Chin. Phys. C40 (10) (2016) 100001. doi:10.1088/1674-1137/40/10/100001.

[8] T. Pierog, I. Karpenko, J. M. Katzy, E. Yatsenko, K. Werner, EPOS LHC: Test of collective hadronization with data measured at the CERN Large Hadron Collider, Phys. Rev. C92 (3) (2015) 034906. arXiv:1306.0121, doi:10.1103/PhysRevC.92.034906.

[9] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, P. Z. Skands, An Introduction to PYTHIA 8.2, Comput. Phys. Commun. 191 (2015) 159–177. arXiv:1410.3012, doi:10.1016/j.cpc.2015.01.024.