PROCEEDINGS OF SCIENCE

Photon and jet probes of small collision systems with ATLAS

Martin Spousta on behalf of the ATLAS Collaboration[*]
Institute of Particle and Nuclear Physics,
Faculty of Mathematics and Physics,
Charles University,
V Holešovičkách 2,
Czech Republic
E-mail: martin.spousta(at)cern.ch

Recent results from p+Pb collisions at the LHC provide important information for constraining initial state effects of nuclear collisions and possible modifications of parton distribution functions in the nuclear environment. In these proceedings we summarize new ATLAS results on dijet azimuthal correlations and conditional yields in pp and p+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and prompt photon production in $\sqrt{s_{NN}} = 8.16$ TeV p+Pb collisions.

International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions
30 September - 5 October 2018
Aix-Les-Bains, Savoie, France

[*]Speaker.

1. Introduction

Recent results from p+Pb collisions at the LHC provide important information for constraining initial state effects of nuclear collisions and, in particular, possible modifications of parton distribution functions in the nuclear environment. In these proceedings we summarize new ATLAS results on dijet azimuthal correlations and conditional yields in pp and p+Pb collisions [1] and prompt photon production in p+Pb collisions [2]. The measurements of dijet azimuthal correlations and conditional yields utilise 25 pb^{-1} of pp data and 360 μb^{-1} of p+Pb data, both at $\sqrt{s_{NN}} = 5.02$ TeV, collected in 2015 and 2016, respectively. They are performed in the center-of-mass frame of the nucleon-nucleon system in the center-of-mass rapidity range between -4.0 and 4.0 using the two highest transverse momentum jets in each event. The measurement of the prompt photon production utilises 162 nb^{-1} of p+Pb data at $\sqrt{s_{NN}} = 8.16$ TeV collected in 2016. Measured prompt photons cover the transverse energy range of $\approx 25 - 500$ GeV.

2. Dijet azimuthal correlations and conditional yields in pp and p+Pb collisions

Studies of particle collisions at accelerators have contributed significantly to an improved understanding of the strong interaction in quantum chromodynamics, and the knowledge of parton distribution functions (PDFs) of the proton. Global analyses of structure functions in deep-inelastic lepton-nucleon scattering at HERA, as well as jet and hadron cross sections at the LHC, Tevatron, and RHIC were performed in a wide kinematic range, providing several sets of PDFs with high degree of precision. These analyses constrain quark and gluon contributions over a wide range of the Bjorken variable x: the longitudinal momentum fraction of a nucleon carried by its constituent partons. From these measurements, the gluon distribution in the proton is found to rise rapidly for decreasing x. At the same time, unitarity requires that the first moment of the gluon momentum distribution remains finite. Therefore, the steep rise at low x must change at some x value; this phenomenon is known as saturation [3]. The search for the onset of saturation is a major scientific goal of proton-nucleus collisions. The new measurement of dijet azimuthal correlations and conditional yields in pp and p+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV by ATLAS [1] can provide an important input to constrain saturation models.

The measurement is performed in intervals of the center-of-mass rapidity, y^* ($y^* \equiv y - \Delta y$), where y is the rapidity in the laboratory frame and Δy is the rapidity shift in the center-of-mass frame. The leading jet has the highest transverse momentum ($p_{\mathrm{T},1}$) in the event and is required to be in the forward proton-going direction. The sub-leading jet has the second-highest transverse momentum ($p_{\mathrm{T},2}$) in the event and is not restricted to a single rapidity range. The center-of-mass rapidities of the leading and sub-leading jets are y_1^* and y_2^*, respectively.

Figure 1 shows the ratios of yields, ρ_I^{pPb}, and widths of dijet azimuthal correlations, ρ_W^{pPb}, between p+Pb and pp collisions defined as

$$\rho_I^{\mathrm{pPb}} = I_{12}^{\mathrm{pPb}} / I_{12}^{\mathrm{pp}}, \quad (2.1)$$

$$\rho_W^{\mathrm{pPb}} = W_{12}^{\mathrm{pPb}} / W_{12}^{\mathrm{pp}}, \quad (2.2)$$

where

$$I_{12}(p_{\mathrm{T},1}, p_{\mathrm{T},2}, y_1^*, y_2^*) = \frac{1}{N_1} \frac{\mathrm{d}^4 N_{12}}{\mathrm{d}p_{\mathrm{T},1} \mathrm{d}p_{\mathrm{T},2} \mathrm{d}y_1^* \mathrm{d}y_2^*} \tag{2.3}$$

and $W_{12}(p_{\mathrm{T},1}, p_{\mathrm{T},2}, y_1^*, y_2^*) = RMS(C_{12})$ with C_{12} being the dijet azimuthal correlation,

$$C_{12}(p_{\mathrm{T},1}, p_{\mathrm{T},2}, y_1^*, y_2^*) = \frac{1}{N_1} \frac{\mathrm{d}N_{12}}{\mathrm{d}\Delta\phi}. \tag{2.4}$$

The uncertainties on the ρ_I^{pPb} and ρ_W^{pPb} ratios are dominated by systematic uncertainties, which are correlated in jet p_{T} and y^*. The ratios ρ_W^{pPb} between p+Pb collisions and pp collisions for different ranges of $p_{\mathrm{T},1}$ and $p_{\mathrm{T},2}$ as a function of y_2^* are consistent with unity. The ratios ρ_I^{pPb} are consistent with unity for sub-leading jets in the lead-going direction and for central-forward dijets. The ratio of conditional yields of jet pairs when both leading and sub-leading jets are in the proton-going direction is suppressed by approximately 20% in p+Pb collisions compared to pp collisions, with no significant dependence on jet p_{T}. In the most forward-forward configuration, with both jets in the lowest jet p_{T} interval $28 < p_{\mathrm{T},1}, p_{\mathrm{T},2} < 35$ GeV, the approximate x range probed is between 10^{-4} and 10^{-3} of the lead nucleus. This suppression is an indication of possible nuclear effects including saturation and shadowing and can be used to constrain models aiming to describe nuclear effects including saturation.

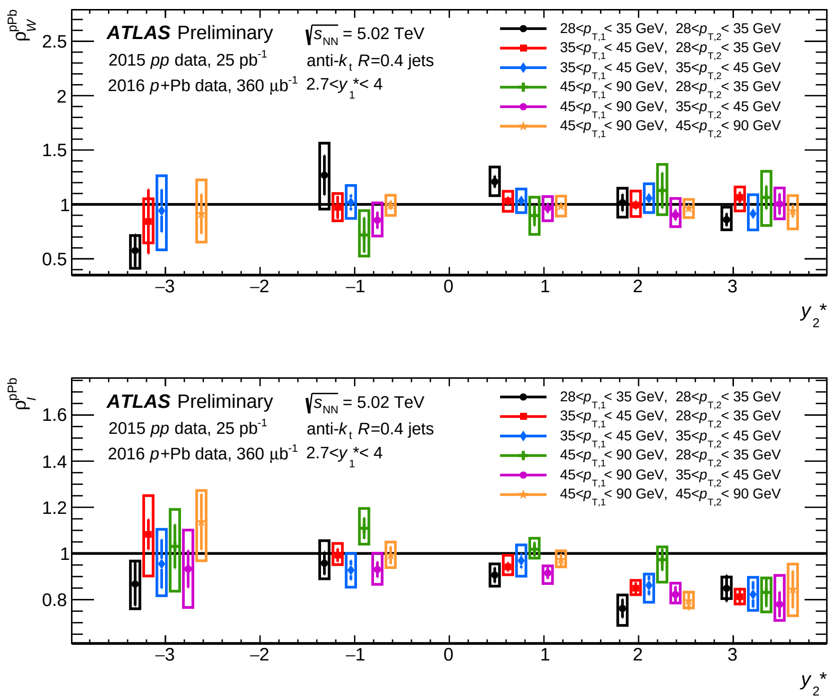

Figure 1: Ratios ρ_W^{pPb} (top) and ρ_I^{pPb} (bottom) for different selections of $p_{\mathrm{T},1}$ and $p_{\mathrm{T},2}$ as a function of y_2^*. The central values are shifted horizontally for visibility. The open boxes indicate systematic uncertainties and vertical error bars represent statistical uncertainties. For details see Ref. [1].

3. Prompt photon production in p+Pb collisions

Measurements of photon production rates are a sensitive probe of nuclear modification of parton densities [4]. Additionally, photon rates may be modified due to energy loss arising from interactions in the initial stages of the collision [5]. The new measurement of prompt photon production in p+Pb collisions by ATLAS [2] can provide an important input to quantify these intial state effects. Understanding these effects is particularly important for putting into context the observed modifications of strongly interacting processes, such as jet and hadron production, in nucleus-nucleus collisions.

In a leading order picture, $p+\mathrm{Pb}\rightarrow\gamma+X$ has contributions from direct processes, in which the photon is produced in the hard interaction, and fragmentation processes, in which it is produced in the parton shower. Beyond leading order the direct and fragmentation components have no physical meaning and cannot be factorized; the sum of their cross sections is the physical observable. However, the impact of the fragmentation contribution can be reduced through the use of an isolation criterium, which also suppresses the background associated to photons produced in the decays of neutral hadrons in jets. The isolation prescription requires the transverse energy sum within a $\Delta R=(\Delta\eta)^2+(\Delta\phi)^2<0.4$ cone around the photon to be smaller than 4.8 GeV+$4.210^{-3}E_{\mathrm{T}}^{\gamma}$ [GeV]. The same isolation requirement is implemented at the simulation level and data level. Modification of isolated photon production is quantified using the nuclear modification factor defined as

$$R_{\mathrm{p}Pb}=\frac{\mathrm{d}\sigma^{p+\mathrm{Pb}\rightarrow\gamma+X}/\mathrm{d}E_{\mathrm{T}}^{\gamma}}{A\cdot\mathrm{d}\sigma^{p+p\rightarrow\gamma+X}/\mathrm{d}E_{\mathrm{T}}^{\gamma}} \tag{3.1}$$

with $A=82$. To obtain the pp reference, a previous measurement of cross-section for prompt photon production in pp at 8 TeV was used and results were extrapolated to 8.16 TeV using PYTHIA8 [6] and JETPHOX [7] Monte Carlo generators. The measurement is performed for photons with $E_{\mathrm{T}}>25$ GeV in the following pseudorapidity intervals in the nucleon-nucleon frame: $-2.83<\eta^*<-2.02$, $-1.83<\eta^*<0.91$ and $1.10<\eta^*<1.91$. These intervals correspond to the acceptance of the ATLAS detector in the laboratory frame.

Figure 2 shows the nuclear modification factor $R_{\mathrm{p}Pb}$ as functions of E_{T}^{γ} and η^*. At forward rapidities and low to moderate E_{T}^{γ} at mid-rapidity, the $R_{\mathrm{p}Pb}$ is consistent with unity, indicating that isospin or other nuclear effects are small. At high E_{T}^{γ} and backward pseudorapidity, the $R_{\mathrm{p}Pb}$ is significantly lower than unity. This feature primarily reflects the difference in the up and down quark composition of the nucleus relative to the proton, for which the larger relative down quark density decreases the matrix element for diagrams with an outgoing photon. This effect is evident in the JETPHOX theory curve in blue which includes the proton-neutron asymmetry and the free proton PDF set CT14. Within the present uncertainties, the central values of the data are consistent with both the free proton PDFs and with the small effects expected from a nuclear modification of the parton densities. However, the data do disfavor a large suppression in the cross-section due to energy loss effects.

Acknowledgment: This work was supported by Grant Agency of the Czech Republic (18-12859Y) and by Charles University grant UNCE/SCI/013.

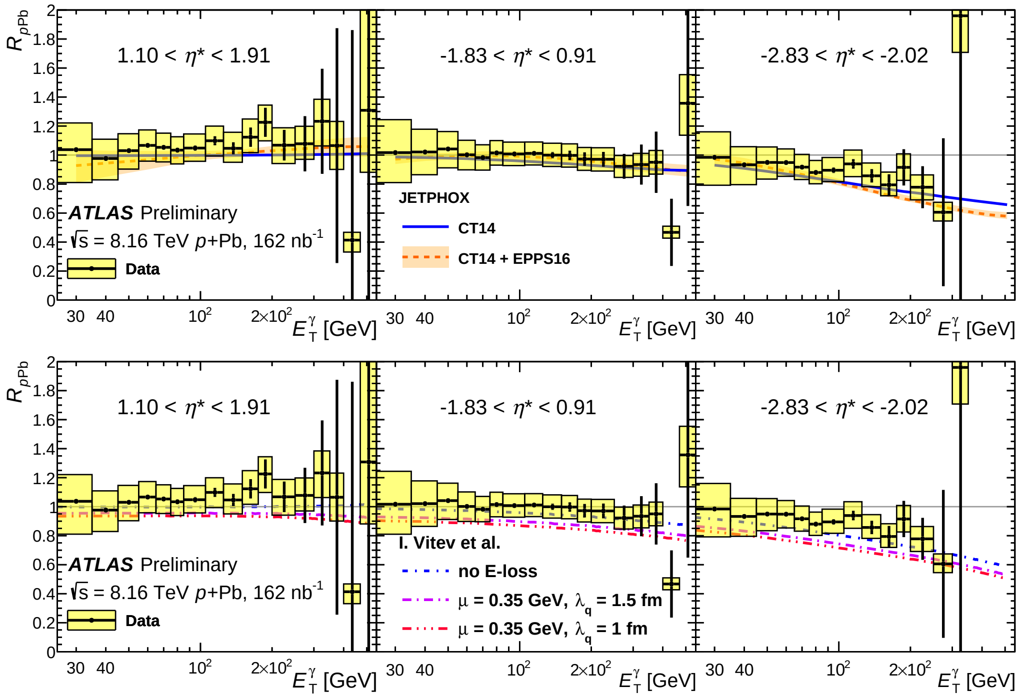

Figure 2: Nuclear modification factor R_{pPb} for isolated, prompt photons as a function of E_T^γ, shown for different η^* selections in each panel. The data are identical in each row, but show comparisons to the expectations based on JETPHOX with the EPPS16 nuclear PDF set (top) and with an initial state energy loss calculation (bottom). In all plots, the yellow bands and vertical bars correspond to total systematic and statistical uncertainties on the data, respectively. The orange and purple band corresponds to the systematic uncertainties on the calculations. For details see Ref. [2].

References

[1] ATLAS Collaboration. ATLAS-CONF-2018-050, http://cds.cern.ch/record/2641591.

[2] ATLAS Collaboration. ATLAS-CONF-2017-072, http://cds.cern.ch/record/2285810.

[3] Javier L. Albacete and Cyrille Marquet. Gluon saturation and initial conditions for relativistic heavy ion collisions. *Prog. Part. Nucl. Phys.*, 76:1–42, 2014.

[4] C. A. Salgado et al. *J. Phys.*, G39:015010, 2012.

[5] Zhong-Bo Kang, Ivan Vitev, and Hongxi Xing. *Phys. Rev.*, C92(5):054911, 2015.

[6] Torbjorn Sjostrand, Stephen Mrenna, and Peter Z. Skands. *Comput. Phys. Commun.*, 178:852–867, 2008.

[7] Patrick Aurenche, Michel Fontannaz, Jean-Philippe Guillet, Eric Pilon, and Monique Werlen. *Phys. Rev.*, D73:094007, 2006.