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Measurements of photo-nuclear jet production in Pb+Pb collisions with ATLAS

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Abstract

Ultra-peripheral heavy ion collisions provide a unique opportunity to study the parton distributions in the colliding nuclei via the measurement of photo-nuclear jet production. An analysis of jet production in ultra-peripheral Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV performed using data collected with the ATLAS detector in 2015 is described. The data set corresponds to a total Pb+Pb integrated luminosity of 0.38 nb^{-1}. The ultra-peripheral collisions are selected using a combination of forward neutron and rapidity gap requirements. The cross-sections, not unfolded for detector response, are compared to results from Pythia Monte Carlo simulations re-weighted to match a photon spectrum obtained from the STARlight model. Qualitative agreement between data and these simulations is observed over a broad kinematic range suggesting that using these collisions to measure nuclear parton distributions is experimentally realisable.

Keywords: UPC, photoproduction, jets, nuclear parton distributions

1. Introduction

In the past few decades significant interest has developed on the subject of nuclear parton distribution functions (PDFs) and their modifications relative to the proton PDFs. In particular the possible connection between the suppression of nuclear PDFs at small values of x (shadowing) and non-linear evolution of the PDFs at large parton density [1, 2, 3] has received significant theoretical attention. A method for studying nuclear parton distributions using photo-nuclear production of dijets was proposed a decade ago [4, 5]. The intense electromagnetic fields accompanying the ions can be viewed as beams of quasi-real photons with energies distributed according to the Weizsäcker-Williams spectrum. Photons with wavelengths of order the size of the nucleus, R_N, are emitted coherently by the entire nucleus, and the flux is enhanced by a factor of Z^2 compared to the flux in pp collisions. For ultra-relativistic ion beams, the large longitudinal boost means the photons can have energies up to $E_\gamma \lesssim \sqrt{s_{NN}}/2m_N R_N \sim 40$ GeV at the LHC. Such photons have sufficient energy to stimulate hard-scattering processes and can thus resolve the partonic structure of the nucleus.

Processes may occur in which virtual excitations of the photon are probed by the hard interaction. In these "resolved" events the photon serves as a source of partons and only a fraction of the photon's four-momentum contributes to the hard scattering. Hard photo-production was studied extensively at HERA,

[1] A list of members of the ATLAS Collaboration and acknowledgements can be found at the end of this issue.

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where the interplay between the direct and resolved contributions was exploited to study the partonic structure of both the proton and the photon [6, 7].

This process is one of many types of photon-induced reactions that are referred to as "ultra-peripheral collisions" (UPCs) because they can occur when the impact parameters between the incoming nuclei are large such that there is no hadronic interaction between the nuclei. In hadronic nuclear collisions the net color exchange gives rise to particle production that usually populates the entire rapidity region. As the photon carries no color, it is expected that photon-induced reactions will be accompanied by a *rapidity gap* in the the direction of the photon-emitting nucleus, although the gap may be reduced in size in the case of resolved events. Furthermore, the photon-emitting nucleus is expected to remain intact resulting in no neutrons along the beam direction, while multiple neutrons are expected in hadronic collisions due to the nuclear breakup.

These proceedings present a measurement of photo-nuclear jet production cross-sections in Pb+Pb collisions at a per nucleon center-of-mass energy of $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, recorded in 2015 [8]. Photo-nuclear events are identified by requirements on the number of neutrons and the presence of rapidity gaps. Specifically, events are required to have zero neutrons in one direction and one or more neutrons in the opposite direction, referred to as the "0nXn" event topology. The photon going direction is defined to be the direction in which zero neutrons are observed. Jets are reconstructed using the anti-k_t algorithm [9] with $R = 0.4$. The jets are used to construct per-event observables H_T, $x_{\mathrm{A}}$and z_γ, which are defined in Section 3, and the cross-sections are measured differentially as a function of each of these variables. The cross-sections are not unfolded for detector response. In the limit of $2 \to 2$ scattering kinematics, x_{A} corresponds to the ratio of the energy of the struck parton in the nucleus to the (per nucleon) beam energy and $H_T \to 2\sqrt{Q^2}$, where Q^2 is the invariant momentum transfer in the hard scattering. The variable $z_\gamma = x_\gamma y$, where y is the energy fraction carried by the photon. For direct processes x_γ is unity, while for resolved events it is the fraction of the photon's energy carried by the resolved parton entering the hard scattering.

2. Data and Monte Carlo samples

The measurements described in these proceedings are performed using the ATLAS detector [10] in the Run 2 configuration. They rely on the calorimeter system, the inner detector, the zero degree calorimeters, and the trigger system. The zero degree calorimeters (ZDCs), which measure neutrons emitted at small rapidity separation from the incident nuclei, were used for triggering and for offline event selection. The ZDCs are located a distance of 140 m on either side of the nominal interaction point and cover $|\eta| > 8.3$. Events are selected by a ZDC XOR trigger in which one of the ZDCs is required to have an energy deposit consistent with one or more neutrons while the opposite side ZDC was required to be consistent with zero neutrons.

To evaluate the impact of the detector response on the measured cross-sections, a Monte Carlo (MC) sample of events is used. The sample uses the Pythia event generator version 6.41 [11] with the Perugia2012 tune [12] configured for $\gamma^* + p$ collisions with the photons produced via bremsstrahlung from a muon beam. It uses the CTEQ6L1 proton PDF set and the SaS 1D photon PDFs [13, 14] and is configured to contain a mixture of direct and resolved processes. The generated events are passed through a GEANT4 [15] simulation of the ATLAS detector response [16] and analyzed in the same manner as ATLAS data. Events produced in this fashion do not have the appropriate photon flux for Pb beams. To account for this a weighting is applied as a function of photon energy on an event-by-event basis. The weighting is obtained by comparing the photon distribution in Pythia with that using the STARlight [17] generator, which contains a description of the equivalent photon flux for ions. The per-jet and rapidity gap distributions in the reweighted sample, referred to as Pythia+STARlight for the duration of these proceedings, agree well with data.

3. Data analysis

The rapidity gap analysis proceeds by applying the same selections on calorimeter clusters that are applied in other ATLAS measurements [18]. The resulting clusters and the charged particle tracks are