Measurements of photon- and *Z*-tagged jet quenching by ATLAS

Jeff Ouellette, on behalf of the ATLAS Collaboration[a,*]

[a]*University of Colorado Boulder,*
Boulder, CO, 80302

E-mail: jeff.ouellette@cern.ch

The latest measurements of jet quenching by ATLAS with photon- and *Z*-tagged events are presented, as described during a parallel talk in the Hard Probes 2020 conference. Emphasis is on the newest measurement using *Z*-tagged events.

HardProbes2020
1-6 June 2020
Austin, Texas

---

[*]Speaker

1. Introduction

Studies of jets produced in events tagged by an electroweak boson have proven a useful way to study bulk properties of the Quark-Gluon Plasma created in heavy ion collisions. Due to the colorless nature of the electroweak bosons, such events provide an experimental handle on the initial p_T of the hard-scattered parton before parton-medium interactions begin (i.e. at the very beginning of the post-collision evolution). This provides both an initial-state snapshot of the parton as well as a final-state measurement of the modified shower, which helps understand the nature of parton-medium interactions. Previous measurements at the LHC by ATLAS have used photon-tagged events to study partonic energy loss in this manner, including studies of the photon-jet momentum balance $x_{j\gamma}$ [1] and the fragmentation pattern of jets in photon-tagged events [2] with the 2015 collision data.

New, high luminosity Pb+Pb data recorded in 2018, at 5.02 TeV per nucleon pair, enable new measurements of jet quenching in previously inaccessible channels – namely in events tagged by a Z boson. These proceedings summarize a preliminary measurement of hadron yields in Z boson-tagged events in pp and Pb+Pb collisions [3], which is now finalized in Ref. [4]. This measurement uses the yield of charged particles opposite the Z boson in the transverse plane as a proxy for the parton emerging from the hard scattering. No reconstructed jet is required in this measurement to investigate partonic energy loss without bias on the final state. Charged particles are selected with transverse momenta $p_T^{ch} > 1$ GeV and required to be opposite the Z boson in the transverse plane with $\Delta\phi > 3\pi/4$. The yields of these charged particles are normalized per Z boson and compared between Pb+Pb and pp by taking the ratio I_{AA}. Both the yields and ratios are reported as a function of p_T^{ch} and the hadron-to-boson p_T ratio $x_{hZ} \equiv p_T^{ch}/p_T^Z$. The measurement is performed for two different p_T^Z selections to control for the initial hard-scattered parton p_T and for different Pb+Pb centralities to control for the size of the nuclear overlap region.

2. Analysis

The ATLAS detector [5] is a large, general purpose particle detector with tracking, calorimeter, and muon spectrometer systems. 260 pb^{-1} of pp and 1.7 nb^{-1} of Pb+Pb collision data were used in this measurement, taken in 2017 and 2018 respectively. Z boson events were recorded during data taking with single lepton triggers using the ATLAS high level trigger system.

Similar to previous measurements of Z boson production [6, 7], events with a Z boson are tagged via their decays to opposite-sign electron or muon pairs. Candidate leptons are required to match to a trigger, have a $p_T > 20$ GeV and meet a set of identification criteria. Z bosons are then reconstructed from lepton pairs with an invariant mass in the range $76 < m_Z < 106$ GeV. Events are grouped based on the Z boson p_T, with two selections: $30 < p_T^Z < 60$ GeV and $p_T^Z > 60$ GeV. 1,300 (9,000) $Z \to ee$ and 1,500 (11,000) $Z \to \mu\mu$ events were selected with this method in Pb+Pb (pp) collisions. The total transverse energy produced at forward rapidity, $3.2 < |\eta| < 4.9$, is used to determine centrality percentiles. For this study, events were divided into three categories: 0–10% ("central events"), 10–30%, and 30–80% ("peripheral events"). Typically, central events correspond to collisions with larger nuclear overlap size and produce a larger QGP medium per collision.
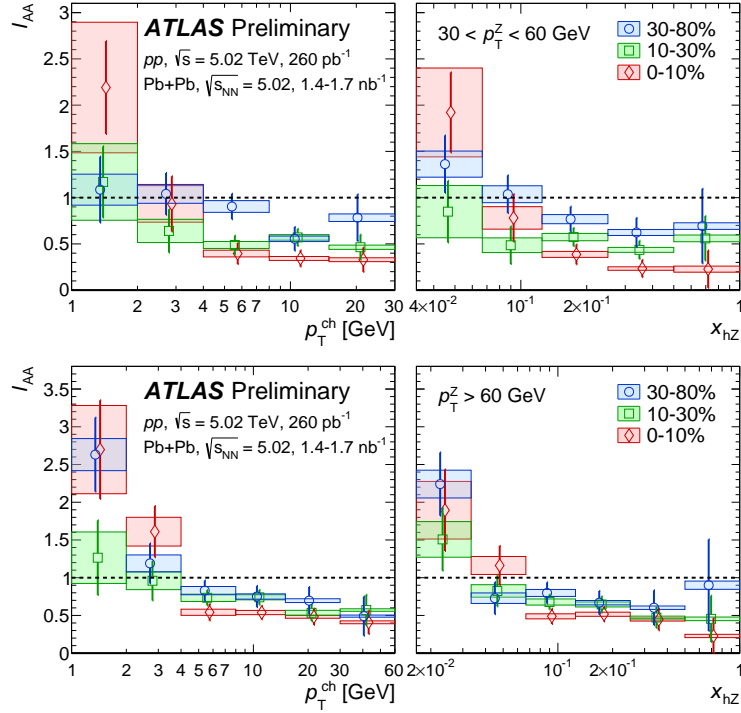
Figure 1: Ratio I_{AA} of the hadron yield opposite to a Z boson, normalized per-Z, between Pb+Pb and pp collisions. Events are separated by Pb+Pb centrality (30–80% in blue circles, 10–30% in green squares, and 0–10% in red diamonds) and by two different Z boson p_T (p_T^Z) selections: $30 < p_T^Z < 60$ GeV (top) and $p_T^Z > 60$ GeV (bottom). Points are shown as a function of p_T^{ch} (left) and as a function of the momentum balance $x_{hZ} \equiv p_T^{ch}/p_T^Z$ (right).

Charged particle tracks are reconstructed using the inner detector subsystems, with the same procedure for track reconstruction as used in previous studies [2, 8]. Charged particles are required to have transverse momentum $p_T^{ch} > 1$ GeV and pseudorapidity $|\eta| < 2.5$. A set of quality requirements such as a minimum number of silicon hits and vertex matching criteria were applied to reject potential fake tracks. The underlying event (UE), which is generally large at low $p_T^{ch} \lesssim 2$–3 GeV and in more central Pb+Pb collisions, is subtracted off statistically with a mixed event procedure. Z bosons in both pp and Pb+Pb were mixed with minimum bias events recorded during the same data taking periods, with Pb+Pb mixed events also required to closely match Z events in centrality. The number of UE particles per signal particle was roughly 100-to-1 at low p_T in central events.

Both tracks and Z events were weighted to account for finite triggering and reconstruction effects. Trigger efficiencies were measured per-lepton in data [9], whereas reconstruction and selection efficiencies were determined in Monte Carlo simulations by matching leptons at the truth and reconstructed levels. Possible effects from p_T migration of Z bosons were accounted for by small bin-by-bin correction factors (derived in simulation) which were applied to the UE subtracted charged particle yields. Per-track corrections were also applied to account for both finite charged particle reconstruction efficiency and imperfect track purity. Several sources of systematic uncertainty were considered, including those associated with charged particle reconstruction, lepton
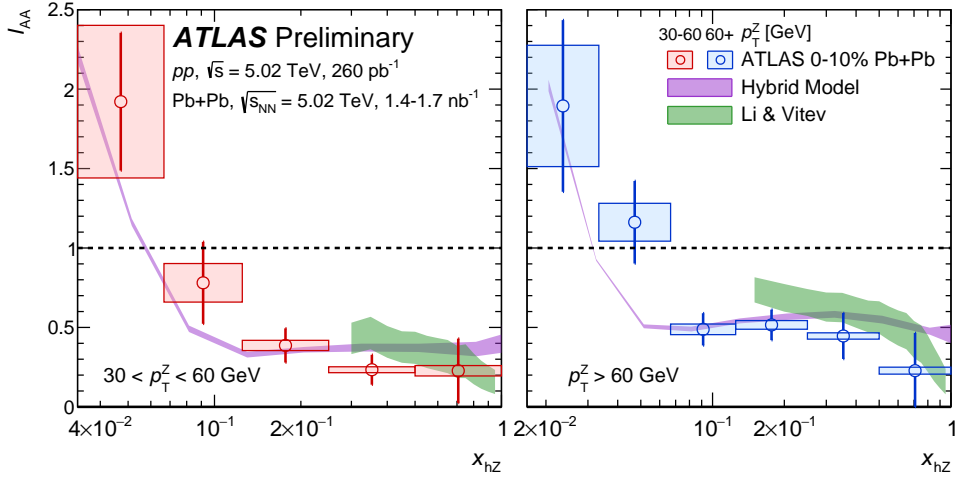
3

Figure 2: I_{AA} in 0–10% central Pb+Pb events is compared between two different jet quenching models (see text) as a function of the momentum balance $x_{hZ} \equiv p_T^{ch}/p_T^Z$. Events with $30 < p_T^Z < 60\,\text{GeV}$ and $p_T^Z > 60\,\text{GeV}$ are shown on the left and right, respectively.
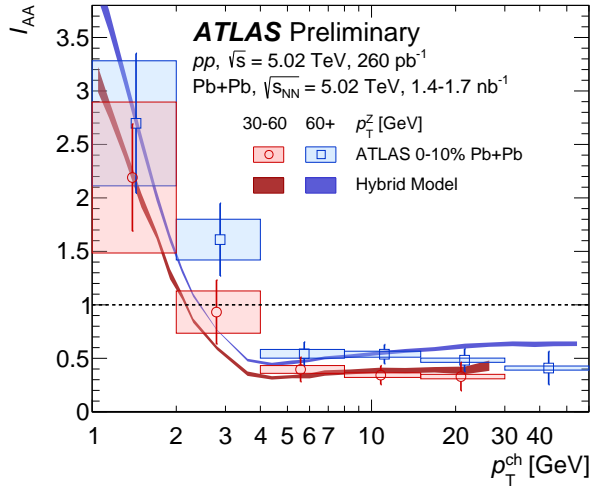

Figure 3: I_{AA} in 0–10% central Pb+Pb events is compared with predictions in the hybrid strong/weak coupling model (see text) as a function of p_T^{ch} for events with $30 < p_T^Z < 60\,\text{GeV}$ (red) and $p_T^Z > 60\,\text{GeV}$ (blue).

energy scale uncertainties, and uncertainties on the UE, the latter of which were dominant.

3. Results

Figure 1 presents the ratio I_{AA} between per-Z charged particle yields in Pb+Pb and pp events. At low values of $p_T^{ch} \lesssim 3 - 4\,\text{GeV}$ there is evidence for an enhancement of charged particles in Pb+Pb collisions, whereas above this range there is a strong suppression. The degree of suppression is found to be systematically greater in central compared to peripheral Pb+Pb collisions, reflecting expectation that hard-scattered partons will redistribute their energy to the QGP.

Different jet quenching models reflect this trend but the exact details differ model-to-model. In Fig. 2 I_{AA} is compared to two different jet quenching theory models. The first is a hybrid strong/weak coupling model, which uses the gauge/gravity duality to model the dynamics of partonic energy loss [10], and is shown in purple. This calculation includes particles originating in the wake of the parton as it traverses the medium. In green, a calcuation within the framework of soft collinear effective theory (SCET$_G$, labelled "Li & Vitev") models parton-medium interaction with Glauber gluon interactions [11, 12], with systematic uncertainty on the parton-medium coupling $g = 2.0 \pm 0.2$ shown by shaded bands. Both models reproduce the suppression of high-x_{hZ} charged particles observed in data, and the hybrid model produces a similar level of particle enhancement that is observed in data, rising to $I_{AA} \sim 2$ around $x_{hZ} \sim 0.02 - 0.04$. In the case of the SCET$_G$, the x_{hZ} dependence of the suppression matches the data well, although the overall magnitude is shifted to larger values, suggesting that a slight increase in the coupling might match the data better. For the hybrid model, the value of x_{hZ} at which I_{AA} is unity seems slightly too low compared to data. This is reflected in Fig. 3, where the two p_T^Z selections are compared with the hybrid model as a function of p_T^{ch}.

4. Conclusions

These proceedings present the first measurement of the modification to per-Z charged particle yields in Pb+Pb collisions. The enhancement-suppression pattern exhibits a centrality and p_T^{ch} (x_{hZ}) dependence consistent with the parton shower being modified through its interactions with the QGP. This pattern is reproduced by theoretical predictions of Z-tagged charged hadron yields.

References

[1] ATLAS Collaboration, *Measurement of photon–jet transverse momentum correlations in 5.02 TeV Pb+Pb and pp collisions with ATLAS*. Phys. Lett. B **789**, 167 (2019).

[2] ATLAS Collaboration, *Comparison of Fragmentation Functions for Jets Dominated by Light Quarks and Gluons from pp and Pb+Pb Collisions in ATLAS*. Phys. Rev. Lett. **123**, 042001 (2019).

[3] ATLAS Collaboration, *Measurement of Z-tagged charged-particle yields in 5.02 TeV Pb+Pb and pp collisions with the ATLAS detector*. ATLAS-CONF-2019-052 (2019), Available at https://cds.cern.ch/record/2698294.

[4] ATLAS Collaboration, *Medium-induced modification of Z-tagged charged particle yields in Pb+Pb collisions at 5.02 TeV with the ATLAS detector*. (2020), arXiv:2008.09811 [nucl-ex].

[5] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*. JINST **3** (2008) S08003.

[6] ATLAS Collaboration, *Measurements of W and Z boson production in pp collisions at $\sqrt{s} =$ 5.02 TeV with the ATLAS detector*. Eur. Phys. J. C **79**, 128 (2019).

[7] ATLAS Collaboration, *Z boson production in Pb+Pb collisions at* $\sqrt{s_{\mathrm{NN}}}$ = 5.02 *TeV measured by the ATLAS experiment*. Phys. Lett. B **802**, 135262 (2020).

[8] ATLAS Collaboration, *Measurement of angular and momentum distributions of charged particles within and around jets in Pb+Pb and pp collisions at* $\sqrt{s_{\mathrm{NN}}}$ = 5.02 *TeV with the ATLAS detector*. Phys. Rev. C **100**, 064901 (2019).

[9] ATLAS Collaboration, *Performance of electron and photon triggers in ATLAS during LHC Run 2*. Eur. Phys. J. C **80**, 47 (2020).

[10] J. Casalderrey-Solana et al., *A hybrid strong/weak coupling approach to jet quenching*. JHEP **10**, 019 (2014).

[11] Y.-T. Chien and I. Vitev, *Towards the understanding of jet shapes and cross sections in heavy ion collisions using soft-collinear effective theory* . JHEP **05**, 023 (2016).

[12] H. T. Li and I. Vitev, *Jet charge modification in finite QCD matter*. Phys. Rev. D **101**, 076020 (2020).