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Search for jet-induced diffusion wake in heavy-ion collisions using photon-jet events with the ATLAS Detector

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Abstract. A search for the quark-gluon plasma medium response to jet energy loss, via modifications of hadron distributions opposite to jets in photon-jet events measured with the ATLAS detector in Pb+Pb collisions, is presented. Photon-jet events provide a particularly clean probe of the quark-gluon plasma medium response, since the photon does not interact with the quark-gluon plasma and therefore defines the initial parton kinematics. Results are shown differentially in the momentum balance variable, $x_{J\gamma} = p_T^{Jet}/p_T^{\gamma}$, and compared to theoretical expectations from the CoLBT model.

1 Introduction

One of the most striking signatures of quark-gluon plasma (QGP) formation in heavy-ion collisions is the suppression of the jet production rate relative to expectations from pp collisions, commonly called "Jet quenching" [1, 2]. The energy lost by such quenched jets are theorized to elicit several types of collective response from the bulk QGP medium, such as generation of a mach cone, a "wake" – an enhancement in the medium particles in the direction of the quenched jet – and a "diffusion wake"– a depletion in the number of medium particles opposite to the direction of the quenched jet [3]. Such phenomena are sensitive to QGP properties such as the speed of sound and the specific shear viscosity η/s, and thus are of interest. However, it is difficult to experimentally observe these effects due to contamination from the jet's own fragmentation products. It was recently proposed [4] that the diffusion wake can be cleanly observed in photon-jet ($\gamma -$ jet) events, as the photon escapes the QGP medium without interaction and does not contaminate the region where the diffusion wake is expected to be present. An additional advantage of using the $\gamma -$ jet events is that the ratio of the p_T of the jet (p_T^{Jet}) and the p_T of the photon (p_T^{γ}): $x_{J\gamma} = \frac{p_T^{Jet}}{p_T^{\gamma}}$, can be used to get a handle on the degree of quenching of the jet. Events with smaller $x_{J\gamma}$, on average, correspond to more quenched jets and are expected to have a smaller wake.

2 Dataset, analysis and results

The analysis is performed using 5.02 TeV Pb+Pb data recorded by ATLAS in 2018, corresponding to an integrated luminosity of 1.72 nb^{-1}. The measurement is restricted to the

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0–10% most central Pb+Pb collisions, where the diffusion wake signal is expected to be strongest. Photon candidates are required to have $90 < p_T^{\gamma} < 180$ GeV and $|\eta| < 2.37$. To reduce contamination from fake and fragmentation photons, the photon candidates are required to be isolated, as described in Ref. [5]. Jets are reconstructed with the anti-k_t algorithm with radius $R = 0.4$, and required to have $p_T^{\mathrm{Jet}} > 40$ GeV, $|\eta| < 2.5$, and be back-to-back with the photon ($|\Delta\phi_{\gamma,\mathrm{jet}}| > 3\pi/4$). Only the highest-$p_T$ jet passing these requirements is paired with the photon. The events are categorized into three $x_{J\gamma}$ intervals: (0.3, 0.6), (0.6, 0.8), and (0.8, 1.0). Charged-particle tracks with $0.5 < p_T^{\mathrm{trk}} < 2$ GeV and located in the hemisphere opposite to the jet ($|\Delta\phi_{\mathrm{jet,trk}}| > \pi/2$) are used to construct jet-track correlations.

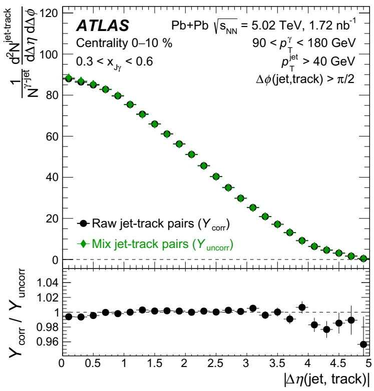

Figure 1. Top panel: the $|\Delta\eta(\mathrm{jet,track})|$ distributions for signal (Y_{corr}) and mixed (Y_{uncorr}) events for the Pb+Pb 0–10% centrality interval for the $0.3 < x_{J\gamma} < 0.6$ interval. Bottom panel: the ratio $Y_{\mathrm{corr}}/Y_{\mathrm{uncorr}}$ as a function of $|\Delta\eta(\mathrm{jet,track})|$. The vertical bars associated indicate the statistical uncertainties. Figure taken from Ref. [5].

Figure 1 shows the distribution of tracks as a function of $|\Delta\eta(\mathrm{jet,trk})| = |\eta_{\mathrm{jet}} - \eta_{\mathrm{trk}}|$ in signal events (black points), normalized by the number of γ – jet pairs: $Y_{\mathrm{corr}} = \frac{1}{N^{\gamma-\mathrm{jet}}}\frac{d^2N^{\mathrm{jet-trk}}}{d\Delta\eta d\Delta\phi}$. The estimate shape of this distribution in the absence of the diffusion wake is obtained using a mixed-event technique, where tracks from events matched in centrality, vertex-z, and event-plane angle are combined with jets from the signal events, (green points). Upon taking the ratio of the signal (Y_{corr}) and the mixed distributions (labelled as Y_{uncorr}) detector acceptance effects cancel and the ratio quantifies the strength of the diffusion wake. This is shown in the bottom panel of Figure 1.

Figure 2 shows the measured correlations in Pb+Pb collisions for the three $x_{J\gamma}$ intervals. The distributions show a small depletion near $|\Delta\eta| = 0$, with the effect most pronounced in the lowest-$x_{J\gamma}$ bin. To quantify the strength of the diffusion wake and the correlations are fit with a pedestal plus Gaussian function:

$$a_0 + a_{\mathrm{dw}} \exp\left(-\frac{|\Delta\eta|^2}{2\sigma_{\mathrm{dw}}^2}\right), \tag{1}$$

where a_{dw} characterizes the strength of the diffusion wake and σ_{dw} its width. The fits are performed by scanning σ_{dw} and treating a_0 and a_{dw} as fit parameters. The fits yield small negative a_{dw} values, but the measurements are consistent with zero within 2σ uncertainty in the lowest $x_{J\gamma}$ interval and within 1σ uncertainty in the other two intervals.

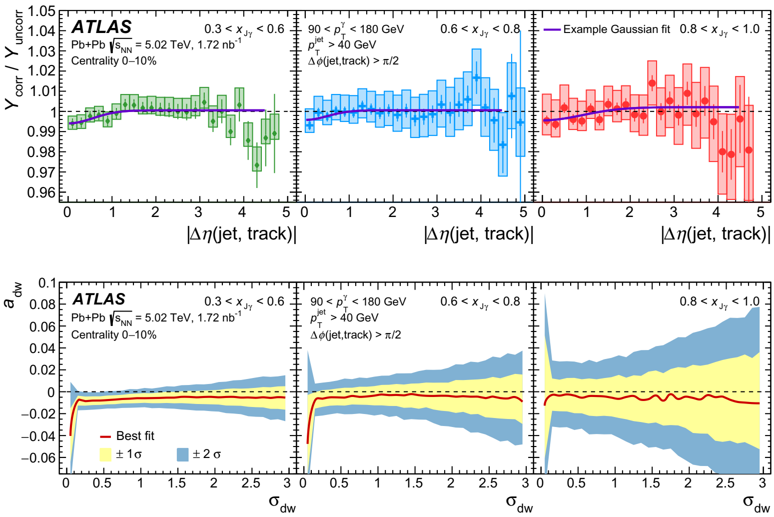

Figure 2. Top row: The $Y_{\mathrm{corr}}/Y_{\mathrm{uncorr}}$ as a function of $|\Delta\eta(\mathrm{jet, track})|$ in 0–10% central Pb+Pb collisions for the (left) 0.3–0.6, (center) 0.6–0.8, and (right) 0.8–1.0 $x_{\mathrm{J}\gamma}$ intervals. The vertical lines and bands indicate statistical and systematic uncertainties, respectively. The purple lines show example Gaussian fits to Eq. 1. Bottom row: The diffusion wake amplitude a_{dw} as a function of the diffusion wake width σ_{dw} obtained from fits to Eq. 1 for the (left) 0.3–0.6, (center) 0.6–0.8, and (right) 0.8–1.0 $x_{\mathrm{J}\gamma}$ intervals. The red solid line indicates the most probable amplitude. The inner and outer shaded areas represent one- and two-σ uncertainty bands, respectively. Figure taken from Ref. [5].

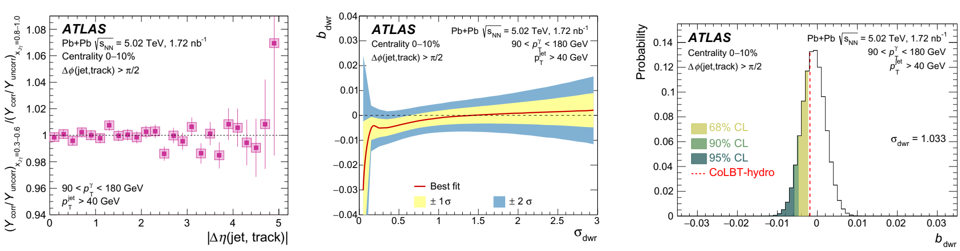

Figure 3. Left: The double ratio $(Y_{\mathrm{corr}}/Y_{\mathrm{uncorr}})_{x_{\mathrm{J}\gamma}=0.3-0.6}/(Y_{\mathrm{corr}}/Y_{\mathrm{uncorr}})_{x_{\mathrm{J}\gamma}=0.8-1}$ as a function of $|\Delta\eta(\mathrm{jet, track})|$ in 0–10% central Pb+Pb collisions. The vertical lines and bands indicate statistical and systematic uncertainties, respectively. Center : The amplitude b_{dwr} a function of σ_{dwr} (Eq. 2). Right : The probability distribution of b_{dwr} for $\sigma_{\mathrm{dwr}} = 1.033$. Figure taken from Ref. [5].

To enhance sensitivity, a double ratio is also measured between the correlations measured in the lowest-$x_{\mathrm{J}\gamma}$ (0.3–0.6) and highest-$x_{\mathrm{J}\gamma}$ (0.8–1) intervals. This cancels common systematic effects and isolates the quenching dependence. This is shown in the left-panel of Figure 3. The double ratio is fit with a similar functional form as Eq. 1:

$$b_0 + b_{\mathrm{dwr}} \exp\left(-\frac{|\Delta\eta|^2}{2\sigma_{\mathrm{dwd}}^2}\right), \qquad (2)$$

As before, the fits are performed by scanning $\sigma_{\rm dwr}$ and treating b_0 and $b_{\rm dwr}$ as fit parameters. The results of the fit are shown in the middle panel of Figure 3. The $b_{\rm dwr}$ values are consistent with zero within two-σ uncertainties. This implies that the measurements are consistent with no significant dependence of the diffusion wake strength on the degree of the jet's quenching. The CoLBT-hydro model [4] calculations with the same kinematic selections as the data predict a diffusion wake strength $b_{\rm dwr}$ of -0.00185 and a $\sigma_{\rm dwr}$ of 1.033. The right panel of Figure 3, shows the probability distribution of $b_{\rm dwr}$ in the data analysis, when fixing the $\sigma_{\rm dwr}$ to the CoLBT-hydro prediction of 1.033. While the measured $b_{\rm dwr}$ is statistically compatible with zero within 2σ uncertainties, it is also consistent with the predictions from the CoLBT-hydro model. However, for the CoLBT-hydro predicted value of $\sigma_{\rm dwr}$, a 95% confidence-level upper limit excludes $|b_{\rm dwr}| > 0.058$.

3 Conclusions

This proceeding summarizes the first ATLAS measurement of a diffusion wake, quantified by measuring hadron yields opposite to jets in γ−jet events in 5.02 TeV Pb+Pb collisions. These measurements are described in further detail in Ref. [5]. The measurements are consistent with CoLBT theory predictions, but also compatible with a no diffusion-wake scenerio within uncertainties. However, the measurements impose stringent upper limits on the strength of the diffusion wake in central Pb+Pb collisions. The constraining power of the measurements is limited by the statistical uncertainties, and with improved statistics, achievable with the data recorded in the ongoing Run 3 of the LHC, these measurements can provide significantly stronger constraints on the strength of the diffusion wake.

Acknowledgments

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