Recent Results on Hard Probes of the Quark-Gluon Plasma with the ATLAS Experiment at the LHC

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Motivation

- The main goal of the presented measurements is to study properties of the strongly coupled medium created in Heavy-ion (HI) collisions
- Hard probes are ideal tools for these studies
  - created in the early stages of the collision
  - relatively low background from the underlying event
ATLAS is multi-purpose detector well capable of measuring heavy-ion collisions

- Excellent tracking performance within $|\eta| < 2.5$. Combination of silicon pixel and strip detectors and transition radiation tracker.
- Powerful calorimeter system with fine segmentation with $\eta$ coverage up to $|\eta| < 4.9$
Calorimetry system is composed of electromagnetic, hadronic and liquid-argon (LAr) forward calorimeters

- High granularity LAr electromagnetic calorimeter covers range of $|\eta| < 3.2$ and is composed of barrel and end-cap modules
- EM calorimeter is backed by hadronic calorimeter
- Allows for precise measurement of photons, electrons and jets
- Forward calorimeters are located in the range $3.1 < |\eta| < 4.9$, used for centrality bin selection
Centrality expresses measure of overlap of two colliding nuclei. It is closely related to the average number of participant nucleons and number of binary inelastic collisions. Centrality is determined by the sum of $E_T$ deposited in the FCAL calorimeter ($3.1 < |\eta| < 4.9$). Events are divided into successive percentiles of the $\sum E_T^{FCAL}$. 

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- Events divided into successive percentiles of the $\sum E_T^{FCAL}$.
Since EW bosons don’t interact strongly, they aren’t influenced by the medium
We can look at the EW boson+jet events - is $p_T$ balanced?
Or we can test modification of the PDF’s caused by the nuclear effects
Differential production yield per binary collision for $W^+$ and $W^-$ integrated over centralities and compared to theoretical predictions.
W bosons (2)

- W production yield per binary collision doesn’t show any dependence on \( \langle N_{\text{part}} \rangle \) and is consistent with POWHEG prediction.
- Lepton charge asymmetry agrees with theoretical predictions.
• Fully corrected yields of prompt photons in four centrality intervals as a function of $p_T$
• Compared to JETPHOX calculations
The ratio of the data to the JETPHOX $pp$ prediction

Data agree well with JETPHOX predictions in all centrality and $\eta$ regions
Partons from the hard scattering have to traverse through the deconfined medium.

Do we observe suppression of jet yields or modification of fragmentation functions?

Is production of the associated jets influenced by the medium?

We can compare to \( pp \) data at the same energy or look at differences between central and peripheral collisions.
Differential cross sections for the different rapidity ranges

Differential per-event jet yield in Pb+Pb collisions divided by $1/\langle T_{AA} \rangle$ with pp jet cross sections

Normalized Pb+Pb yields in central collisions are below the pp yields
Variable that expresses the size of the suppression/enhancement is the so called $R_{AA}$ defined as

$$R_{AA} = \left. \frac{1}{N_{\text{evt}}} \frac{d^2 N_{\text{jet}}}{dp_T dy} \right|_{\text{central}} \frac{\langle T_{AA} \rangle \frac{d^2 \sigma_{pp}^{\text{jet}}}{dp_T dy}}{d^2 N_{\text{jet}}}/dy \right|_{\text{central}}$$
Jet $R_{AA}$

$R_{AA}$ plots clearly show suppression down to $\approx 0.5$ for most central collisions.

- Weak dependence of $R_{AA}$ on the $p_T$ (slope parameter significantly above zero)
- No significant dependence on the $y$ observed
Fragmentation functions $D(p_T)$ and $D(z)$ are defined as

$$D(z) = \frac{1}{N_{jet}} \frac{dN_{ch}}{dz}$$

$$D(p_T) = \frac{1}{N_{jet}} \frac{dN_{ch}}{d\rho_{T}^{ch}}$$
Centrality dependence evaluated as the ratio of the all centrality bins to the 60-80% bins

Enhanced yield of small and large $z$ fragments for all centralities, suppression of fragments at intermediate $z$

Size of modification gradually decreases from central to peripheral collisions
Centrality dependence evaluated as the ratio of the all centrality bins to the 60-80% bins

Similar modifications of $D(p_T)$ as for $D(z)$
The rate of the neighbouring jets that accompany a test jet, $R_{\Delta R}$, is defined as

$$R_{\Delta R} = \frac{1}{dN_{\text{jet}}^{\text{test}}/dE_T^{\text{test}}} \sum_{i=1}^{N_{\text{jet}}^{\text{test}}} \frac{dN_{\text{jet},i}^{\text{nbr}}}{dE_T^{\text{test}}} (E_T^{\text{test}}, E_{T,\text{min}}^{\text{nbr}}, \Delta R)$$
Nearby jets (2)

- $R_{\Delta R}$ for $R = 0.4$ jets evaluated as a function of $E_T^{\text{test}}$
- Production of nearby jets is suppressed in central collisions compared to peripheral collisions
The ratio of $R_{\Delta R}$ for three centrality bins to 40-80% centrality bin

Suppression by a factor $\approx 2$ in central collisions, no strong $E_T$ dependence observed
Conclusions

- Measurements of EW probes don’t imply any modification of production yields
  - $W$ production yield doesn’t show any dependence on $\langle N_{\text{part}} \rangle$
  - Photon yields agree well with JETPHOX prediction
- Jet measurements clearly shows the modification of jet properties due to the interaction with the medium created in the collision
  - Jet $R_{AA}$ falls down to 0.5
  - $R_{AA}$ dependence on the $\langle N_{\text{part}} \rangle$
  - Modification of the fragmentation functions