New results on the parton mass and color-charge dependence of jet quenching with ATLAS

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Flavor dependence in medium induced Energy loss

Jets are known to lose energy when going through the Quark-Gluon-Plasma.

- Color-charge dependence

\[ \sim \frac{4}{3} \]

\[ \sim 3 \]

QCD suggest, gluons are more likely to radiate than quarks.

- Mass dependence expected due to “dead-cone effect”

Large parton mass

Small parton mass

Radiation is suppressed in \( \theta < \frac{m}{E} \)
In this talk, two new ATLAS measurements

**b-jets vs inclusive jets**

$$\sqrt{s} = 5.02 \, \text{TeV}$$

**anti-$$k_T$$ R = 0.2**

$$|y| < 2.1$$

**Pythia8**

- **b-jets**
- inclusive jets

Sensitive to color-charge and parton mass

**\(\gamma\)-tagged jets vs inclusive jets**

**ATLAS Simulation Preliminary**

$$\sqrt{s} = 5.02 \, \text{TeV}$$

**anti-$$k_T$$ R = 0.4 jets**

$$|\eta^{\gamma\text{-jets}}| < 2.8$$

For **\(\gamma\)**-tagged jets

- \(p_T^{\gamma} > 50 \, \text{GeV, } |\eta^{\gamma}| < 2.37\)
- \(\Delta\phi(\gamma, \text{jet}) > \pi/2\)

- **Inc. jets**
- **\(\gamma\text{-jets}**
  - Pythia
  - Sherpa
  - Herwig

Sensitive to color-charge
**b-jets** from semi-leptonic decays

\[ p_T^{rel} = \frac{|| \vec{p}_\mu \times \vec{u} ||}{|| \vec{p}_{jet+\mu} ||} \] is the jet + \( \mu \) axis

Muons selection:
- Muon \( p_T > 4 \) GeV
- \( \Delta R(\text{jet}, \mu) < R \)

Raw \( b \)-jet spectra obtained from fit is **unfolded** to correct detector effects and missing neutrino energy
**b-jets vs inclusive jets in pp collisions**

- **ATLAS**
  - *pp 2017, 260 pb⁻¹*
  - anti-κ, $R = 0.2$ jets
  - $\sqrt{s} = 5.02$ TeV, $|y| < 2.1$

### b-jet to inclusive $R=0.2$ cross-section ratio:

- Good agreement found between data and simulation in the ratio
- Comparison to CMS results consistent within errors
- Ratio consistent with flat withing uncertainties, relevant $R_{AA}$ modification interpretation

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**ATLAS**

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**Legend**

- ATLAS
- CMS 7 TeV, $R = 0.5$ jets, $|y| < 0.5$
- PYTHIA8 5.02 TeV, $R = 0.2$ jets, $|y|<2.1$
- NNPDFLO23 A14
**b-jets vs inclusive jets** in Pb+Pb collisions

Nuclear modification factor, $R_{AA}$, measured for $b$-jets and inclusive jets:

- **Similar suppression in peripheral collisions**
- $b$-jet found to be less suppressed than inclusive jets in central collisions
- Both calculations capture the $R_{AA}$ difference
- LIDO calculations reproduce well the measured $R_{AA}$

![Graph showing $R_{AA}$ versus $p_T$ for $b$-jets and inclusive jets](https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HION-2018-24/)
**$b$-jets vs inclusive jets** in Pb+Pb collisions

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Ratio of nuclear modification factor, $R_{AA}$, between $b$-jets and inclusive jets:

- Smaller systematic uncertainties than $R_{AA}$, systematic uncertainties which are shared cancels in ratio
- Ratio consistent with unity in peripheral and ~20% above unity in central collisions
- Dai et al, calculations reproduce well $R_{AA}$ ratio
Ratio of nuclear modification factor, $R_{AA}$, between $b$-jets and inclusive jets:

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Isolating color-charge effects

We have studied how mass can modify quenching

$b$-jets vs inclusive jets
Sensitive to color-charge and parton mass

Now, can we ask the same question about color-charge?

$\gamma$-tagged jets vs inclusive jets
Sensitive to color-charge
**y-tagged jets** analysis

\[ \Delta \phi(y, \text{jet}) > \pi/2 \]

- Combinatorial background removed
- Correction for background photons using photon purity
- 2D unfolding in y and jet momentum
- Corrects for resolutions, efficiency
\( \gamma \)-tagged jets \( pp \) cross-section

- \( \gamma \)-tagged jets cross-section measured for Jet \( R = 0.4 \) in \( pp \) collisions
- **Fully unfolded** results, \( \gamma \)-tagged jets \( p_T > 50 \) GeV
- Results are compared against generators
  - Good agreement up to 100 GeV
  - Data spectra steeper than MC for \( p_T > 100 \) GeV
    - Sensitive to multijet topology, fragmentation photon contribution
    - Opportunity to improve modeling
**γ-tagged jets vs inclusive jets** in *pp* and *Pb+Pb* collisions

**γ-tagged jets** measured for three centralities classes in *Pb+Pb* data

**γ-tagged jets** to inclusive $R=0.4$ cross-section ratio:

- Relevant for $R_{AA}$ modification interpretation
  - Inclusive jet spectra steeper than γ-tagged jets
    → less suppression for γ-tagged jets
  - Isospin/nPDF effect also plays an important role
    → larger suppression for γ-tagged jets
- The two effects are expected to have similar magnitude but opposite sign

Inclusive jets from *PLB 790 (2019) 108*
γ-tagged jets vs inclusive jets in Pb+Pb collisions

Nuclear modification factor, $R_{AA}$, measured for γ-tagged jets and inclusive jets from PLB 790 (2019) 108:

- γ-tagged jets $R_{AA}$ measured for three centrality classes, central $R_{AA}$ more suppressed than peripheral
- γ-tagged jets (quark-jet dominant) found to be less suppressed than inclusive (gluon-jet dominant) jets in central collisions

[Graph showing $R_{AA}$ vs γ-tagged jet $p_T$, with data points and error bars for different centrality classes]
**Central collisions** nuclear modification factor, $R_{AA}$, of inclusive jets, $\gamma$-tagged jets, and ratio:

- **Inclusive jets** $R_{AA}$, is well modeled by theoretical calculations.
\(\gamma\)-tagged jets vs inclusive jets in Pb+Pb collisions

Central collisions nuclear modification factor, \(R_{AA}\), of inclusive jets, \(\gamma\)-tagged jets, and ratio:

- Inclusive jets \(R_{AA}\), is well modeled by theoretical calculations
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- SCET\(_G\) reproduces both, this results could help constrain the parameter space
γ-tagged jets vs inclusive jets in Pb+Pb collisions

Central collisions

- nuclear modification factor, $R_{AA}$, of inclusive jets, γ-tagged jets, and ratio:
  - Inclusive jets $R_{AA}$, is well modeled by theoretical calculations
  - γ-tagged jets $R_{AA}$, in general, under-estimated by theoretical calculations
  - SCET$_G$ reproduces both, this results could help constrain the parameter space
  - $R_{AA}$ ratio ~30% above unity in central collisions
Evidence of mass and color-charge energy loss dependence find by ATLAS

- **b-jet** $R_{AA}$ central collisions were found to be **less suppressed than inclusive jets for the first time**
- **γ-tagged jets** $R_{AA}$, dominated by quark-jets, presented for the first time, **found to be less suppressed than inclusive jets**
Thank you!

more results at: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

New and more precise results coming for **RUN3 data**!
Additional slides
**b-jets** muon fragmentation

$p_T$-rel is sensitive to muon momentum modeling

Independent test on muon fragmentation function, “$z$”, using measured flavor-fractions

$$z = \frac{p_T^\mu \cos(\theta)}{p_T^{jet+\mu}}$$

The muon momentum distribution is well reproduced by PYTHIA8

PYTHIA8 setting:
- **A14** (ATLAS-PHYS-PUB-2014-021)
- **NNPDF23LO** (arXiv:1207.1303)
**b-jets** *pp* cross-section

- *b*-jet cross-section measured for Jet $R = 0.2$, and 0.4 in *pp* collisions
- **Fully unfolded** results include neutrino energy, *b*-jet $p_T$ range: 80-250 GeV
- Results are compared against generators and theoretical calculations

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**ATLAS**

*pp* 2017, 260 pb$^{-1}$
anti-$k_t$, $R = 0.4, 0.2$ *b*-jets
$\sqrt{s} = 5.02$ TeV, $|y| < 2.1$

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**Theory/Data**

- Li and Vitev
- Li and Vitev; uncertainty
- PYTHIA8 NNPDF23lo A14
- HERWIG7 NNPDF30nlo

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**R = 0.4 total uncertainty**

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**R = 0.2 total uncertainty**

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**b-jets** $R_{AA}$ CMS comparison

**ATLAS**

Pb+Pb 2018, 1.4 nb$^{-1}$

$pp$ 2017, 260 pb$^{-1}$

anti-$k_T$, $R = 0.2$ b-jets, $|y| < 2.1$

$\sqrt{s_{NN}} = 5.02$ TeV

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**b-jets systematics**

**ATLAS**

- Pb+Pb 2018, 1.4 nb⁻¹, √s_{NN} = 5.02 TeV
- pp 2017, 260 pb⁻¹, √s = 5.02 TeV
- anti-κ, R = 0.2, b-jet, |y| < 2.1

**Centrality 0-20%**

- pp lumi. uncer. 1.6%
- Pb+Pb 1.4(1.7) nb⁻¹, √s_{NN} = 5.02 TeV

**ATLAS**

- Pb+Pb 2018, 1.7 nb⁻¹, √s_{NN} = 5.02 TeV
- pp 2017, 260 pb⁻¹, √s = 5.02 TeV
- anti-κ, R = 0.2, inclusive jet, |y| < 2.1

**Centrality 0-20%**

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