Gamma-jet correlations in 5.02 TeV Pb+Pb collisions by ATLAS

Prof. Brian A. Cole
for the ATLAS collaboration

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ATLAS probes of jet quenching

ATLAS
2011 Pb+Pb data, 0.14 nb⁻¹
\( \sqrt{s_{NN}} = 2.76 \text{ TeV} \)
\( L_{int} = 0.14 \text{ nb}^{-1} \)

ATLAS
anti-\( k_T \), \( R = 0.4 \) jets

ATLAS
0-10% 10-20% 20-40% 40-50% 50-60%

ATLAS
E_{T,nbr} > 30 GeV 0.8 < \Delta R < 1.6

ATLAS
E_{T,nbr} > 45 GeV 0.8 < \Delta R < 1.6

ATLAS
E_{T,nbr} > 60 GeV 0.8 < \Delta R < 1.6
ATLAS probes of jet quenching

**Jet $R_{AA}$**

- Anti-$k_t$ $R = 0.4$ jets
- 2011 Pb+Pb data, 0.14 nb$^{-1}$
- 2013 $pp$ data, 4.0 pb$^{-1}$

$p_T$ [GeV]

| $|y| < 2.1$ |
| $0 - 10\%$ | $30 - 40\%$ | $60 - 80\%$ |

| $0.3 < |y| < 0.8$ |
| $|y| < 2.1$ |

| $1.2 < |y| < 2.1$ |
ATLAS probes of jet quenching

- Modified jet fragmentation
ATLAS probes of jet quenching

- Dijet asymmetry (unfolded)
ATLAS probes of jet quenching

- Small-angle jet pairs

\[ \rho_{R,\Delta R} \]

**ATLAS**
Pb+Pb 2011
\[ \sqrt{s_{NN}} = 2.76 \text{ TeV} \]
\[ L_{\text{int}} = 0.14 \text{ nb}^{-1} \]

- \( E_T^{\text{nbr}} > 30 \text{ GeV} \)
  - anti-\( k_t \), \( d = 0.4 \)
  - \( 0.8 < \Delta R < 1.6 \)

- \( E_T^{\text{test}} > 45 \text{ GeV} \)
  - anti-\( k_t \), \( d = 0.4 \)
  - \( 0.8 < \Delta R < 1.6 \)

- \( E_T^{\text{test}} > 60 \text{ GeV} \)
  - anti-\( k_t \), \( d = 0.4 \)
  - \( 0.8 < \Delta R < 1.6 \)

Saturday, September 24, 16
ATLAS probes of jet quenching

- ATLAS
- Pb+Pb data, 0.14 nb⁻¹
- \( \sqrt{s_{NN}} = 2.76 \) TeV

- ATLAS Preliminary
- Pb+Pb data, 0.14 nb⁻¹
- \( |y| < 2.1 \)

- ATLAS
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1st Run 2 Pb+Pb jet result: Gamma-Jet

**Data collected in Nov. - Dec. 2015:**

- $\sqrt{s_{\text{NN}}} = 5.02$ TeV Pb+Pb, $\int \mathcal{L} dt = 0.52$ nb$^{-1}$
- $\sqrt{s} = 5.02$ TeV pp, $\int \mathcal{L} dt = 26$ pb$^{-1}$

**Using photon triggers that sampled full luminosity**

$\Rightarrow$ 38 k photons with $60 < p_T < 150$ in pp data
$\Rightarrow$ 29 k " " " in Pb+Pb, 0-50%
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  - $\Rightarrow 38$ k photons with $60 < p_T < 150$ in pp data
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• Usual centrality analysis using two-component model, but applied over 0-85% centrality range
  ⇒ Avoids complications with photo-nuclear, electromagnetic backgrounds in peripheral Pb+Pb

• For this analysis:
  ⇒ 0-10%, 10-20%, 20-30%, 30-50% intervals
• ATLAS measurement of prompt, isolated photon production in 2.76 TeV Pb+Pb collisions
  – compared to JETPHOX with & without isospin, EPS09
  ⇒ Good agreement when isospin included in Jetphox
  ⇒ Similar methods, systematics for Run 2 photon analysis
Photon identification

- Candidate photons obtained from clusters in EM calorimeter with shower shape cuts applied
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  ⇒ Compare isolation distributions for clusters that pass “tight” and “non-tight” selections
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  • Photon purity (data driven) $\geq 70\%$ in Pb+Pb data
    ⇒ subtracted using sideband method (below)
Gamma-Jet jet energy scale

- Heavy ion jet reconstruction energy scale:
  - Calibrated using 5.02 TeV pp MC
  => POWHEG
- Apply 13 TeV pp "in-situ" correction
  - Corrects for data-MC differences
- Apply 5.02 - 13 TeV "cross-calibration"
  - Transfer jet energy scale systematic uncertainties
- Test in 5.02 TeV pp data using gamma-jet events
Gamma-jet Jet performance

- MC: PYTHIA8 + data overlay evaluation of jet performance in γ-jet events
  - Jet energy resolution ↑ due to underlying event fluctuations
  - Jet efficiency ↓ due to increased JER
    ⇒ ~ entirely due to jets falling below minimum $p_T$ cut

- Jets in gamma-jet events have $p_T$ corrected for flavor-dependent JES offset (previous slide)
The measurement

• Measure $\gamma$-jet $p_T$ balance: $x_j \equiv p_T^{\text{jet}} / p_T^\gamma$

– And $\gamma$-jet acoplanarity ($\Delta \varphi$) distribution
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  – And $\gamma$-jet acoplanarity ($\Delta\varphi$) distribution

• For three bins in photon $p_T$:
  $\Rightarrow$ 60–80 GeV, 80–100 GeV, 100–150 GeV
  $\Rightarrow |\eta_\gamma| < 2.37$ but also excluding $1.37 < |\eta_\gamma| < 1.52$. 
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• Using $R = 0.4$ anti-$k_T$ jets
  – iterative background subtraction a la Run 1
  – accounting for $v_2$ in underlying event
  ⇒ $p_T^{\text{jet}} > 30$ GeV, $|\eta_{\text{jet}}| < 2.1$
The measurement

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  $\Rightarrow p_{T,jet} > 30$ GeV, $|\eta_{jet}| < 2.1$

• Inclusive measurement with $\Delta \varphi$ selection
  – include all jets in $\gamma$-jet events
  $\Rightarrow$ straightforward combinatoric subtraction
  – For $x_j$ measurement, require $\Delta \varphi > 7\pi/8$
Multiple hard scattering + UE fluctuations produce jets uncorrelated with γ-jet hard scattering

- Measure combinatoric rate using MC data overlay
  ⇒ The underlying events are minimum-bias Pb+Pb
- Subtract differentially in Δφ, \( p_T^{\text{jet}} \)

Also subtract background pairs via photon sideband

⇒ Shown above: yield for Δφ > 7\( \pi/8 \)
Gamma-Jet in 5.02 TeV pp collisions

- Comparing data (measured) to PYTHIA8 + GEANT (reconstructed)

  ⇒ Top: $1/N_\gamma$ dN/dx_j

  ⇒ Bottom: $1/N_{\text{pair}}$ dN/d $\Delta\phi$

- Important: PYTHIA8 sample does not include frag. photon contribution
• Start with 0-10% centrality bin:
  – solid points in the figure
  – systematic uncertainties from:
    ⇒ Jet energy scale uncertainties (pp & Pb+Pb)
    ⇒ Jet energy resolution uncertainties
    ⇒ photon purity, combinatoric subtraction
• Start with 0-10% centrality bin:
  – Compare measured, background-subtracted $1/N_\gamma dN/dx_j$ for inclusive pairs with $\Delta \varphi > 7\pi/8$.
  – to PYTHIA8+GEANT + Pb+Pb data overlay
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  – to PYTHIA8+GEANT + Pb+Pb data overlay
  – and to 5.02 TeV pp data (previous slide)
Gamma-Jet in 5.02 TeV Pb+Pb collisions

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  - and to 5.02 TeV pp data (previous slide)

⇒ See clear modification (downward shift) in central Pb+Pb due to energy loss of balance jets
Gamma-Jet in 5.02 TeV Pb+Pb collisions

• Centrality dependence for two photon $p_T$ ranges
  – Left: 60–80 GeV, right: 80–100 GeV
  ⇒ Observe a smaller shift in less central collisions
  ⇒ At higher $p_T$, can see evolving peak + lower $x_j$ contribution
Gamma-Jet in 5.02 TeV Pb+Pb collisions

- Centrality dependence for two photon $p_T$ ranges
  - Left: 80–100 GeV, right: 100–150 GeV
  - Observe a smaller shift in less central collisions
  - At higher $p_T$, can see evolving peak + lower $x_j$ contribution
• Look at $\Delta \phi$ distribution for 0-10% centrality
  – $p_T^{jet} > 50$ GeV to limit combinatoric contribution
  – compare to PYTHIA8 + GEANT + data overlay, pp data

$\Rightarrow$ same disagreement with PYTHIA8 as seen for pp

$\Rightarrow$ agreement between 0-10% Pb+Pb and pp
Summary and Conclusions

• ATLAS has measured gamma-jet correlations in 5.02 TeV pp and Pb+Pb collisions
  ⇒ $\int \mathcal{L} dt = 26 \text{ pb}^{-1}, 0.52 \text{ nb}^{-1}$, respectively

• Jets reconstructed using anti-$k_t$ with $R = 0.4$
  ⇒ heavy ion jet algorithm with underlying event subtraction and $v_2$ flow correction
  ⇒ full set of jet energy scale corrections and uncertainties propagated from 13 TeV pp data

• Measured distributions (no unfolding):
  – $1/N_\gamma dN/dx_j$ for $\Delta\varphi > 7\pi/8$ and $1/N_{\text{pair}} dN/d \Delta\varphi$
  – compared to PYTHIA8 + GEANT + PbPb overlay

• See data-PYTHIA8 agreement for pp $x_j$ distribution
  ⇒ In Pb+Pb collisions see clear quenching effects

• See data-PYTHIA8 disagreement for pp $\Delta\varphi$ distribution
  ⇒ Pb+Pb and pp $\Delta\varphi$ dist’s agree within uncertainties