Measurement of the Sensitivity of Two-Particle Correlations in $pp$ Collisions to the Presence of Hard Scatterings

Pengqi Yin, Columbia University, For the ATLAS Collaboration

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Ridge in small system

Collective flow

Arise from collective behavior?
Artifact of semi-hard processes?
Method

• Jets are reconstructed using particle-flow algorithm (Eur. Phys. J. C 77 (2017) 466)
  • $p_T > 15$ GeV, $|\eta| < 4.5$
  • Excluding particles within $|\Delta \eta| < 1$ of jets

• Measure 2PC
  • between two tracks not associated with jets
    • $h^{UE}_1 - h^{UE}_2$
Method

• Jets are reconstructed using particle-flow algorithm ([Eur. Phys. J. C 77 (2017) 466](https://doi.org/10.1140/epjc/s10052-017-4951-4))
  - $p_T > 15$ GeV, $|\eta| < 4.5$
  - Excluding particles within $|\Delta\eta| < 1$ of jets

• Measure 2PC
  • between two tracks not associated with jets
    - $h^{UE-h^{UE}}$: (requiring the presence or absence of jets)
  • between tracks that are constituents of jets and tracks from the UE
    - $h^{UE-h^J}$
Problem

- From previous studies, we know there is a global **modulation** due to elliptic flow. **Not fluctuation!**
  - Particles from this flow mainly have low $p_T$.
  - Around 0 and $\pi$, more particles due to the modulation.
  - When a jet appear around 0 or $\pi$, reconstruction will catch more of these UE particles.
- The modulation provides a bias on jet $p_T$

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<th>Hard S</th>
<th>Collectivity</th>
<th>&lt; 4 GeV</th>
<th>&gt; 4 GeV</th>
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Problem

- The UE bias was studied by overlying PYTHIA8 event onto pp minimum-bias data
  - PYTHIA8 with MPI off and ISR on
- A strong modulation of jet yield vs $\phi^{\text{jet}} - \Psi_{2}^{\text{Data}}$ is observed
  - Event plane angle $\Psi_{2}^{\text{Data}}$ is measured in the pp data before overlay
  - $\phi^{\text{jet}}$ is reconstructed taking particles from data and PYTHIA together, after overlay
Problem

- After trying a number of grooming and correction methods, the best suppression of UE bias was obtained by introducing a minimum $p_T$ on jet constituents.

- The jet $p_T$ is redefined by summing constituents above 4 GeV: $p_T^{G} = \sum_{constituents} p_T > 4 \text{ GeV}$.
Selections

• $h-h$
• $h^{UE}-h^{UE}$ AllEvents
• $h^{UE}-h^{UE}$ NoJets
• $h^{UE}-h^J$
Selections

- $h-h$
- $h^{\text{UE}}-h^{\text{UE}}$ AllEvents
- $h^{\text{UE}}-h^{\text{UE}}$ NoJets
- $h^{\text{UE}}-h^{J}$

- Tracks within $\Delta\eta = \pm 1$ from the jet axis of any jets with $p_T^G > 15$ GeV are dropped.
- NoJets: Events do not have a single jet with $p_T^G > 15$ GeV
- WithJets: Events with at least one jet with $p_T^G > 15$ GeV
Selections

- $h-h$
- $h^{UE}-h^{UE} \text{ AllEvents}$
- $h^{UE}-h^{UE} \text{ NoJets}$
- $h^{UE}-h^{UE} \text{ WithJets}$
- $h^{UE}-h^J$

- Jet particles:
  - Jet $p_T^G > 40$ GeV, $|\eta| < 2.1$
  - Require balance jet with $p_T^G > 15$ GeV and $|\Delta \phi| > 5\pi/6$ to reduce non-flow effects in 2PC
  - Apply isolation to remove potential distortion of 2PC
Two-particle Correlations

- 2PC for $h-h$ (left), $h^{UE}-h^{UE}$ NoJets (middle), $h^{UE}-h^{UE}$ WithJets (right)
- Charged particle multiplicity is measured excluding jet constituents
  - Ensure the event activity is not biased by the presence of jets
  - Only reflects the soft multiplicity in the event
- Template-fit is used to extract $v_2$
- Near-side ridges are observed in $h^{UE}-h^{UE}$
Two-particle Correlations

- $h^{\text{UE}} - h^J$ 2PC for different multiplicity bins
- No ridge is observed in the 2PC for any multiplicity interval
**Template-fit \( v_2 \)**

- The \( v_2 \) values are observed to vary weakly with multiplicity
  - Rejecting particles associated with jet in the \( pp \) collisions has negligible impact
- \( h^{\text{UE}}-h^{J} \) \( v_2 \) consistent with zero within uncertainties
  - Both multiplicity dependent and \( p_T \) dependent
  - Ridge is not related to jets
Conclusions

• In pp collision, jet $p_T$ are biased by event modulation in the UE
  • The bias is suppressed by applying a $p_T$ threshold to jet constituents
• Absence or presence of jets in $pp$ collision does not impact $v_2$
  • $h^{UE} - h^J$ 2PC $v_2$ consistent with zero
  • Hard scattering and soft collectivity are unrelated
Conclusions

- In pp collision, jet $p_T$ are biased by event modulation in the UE
  - The bias is suppressed by applying a $p_T$ threshold to jet constituents
- Absence or presence of jets in $pp$ collision does not impact $v_2$
  - $h^{UE}-h^J$ 2PC $v_2$ consistent with zero
  - Hard scattering and soft collectivity are unrelated
- Previous analysis in p+Pb show correlations between jet particles and the UE
  - $\sim 0.02 \ v_2$ at $p_T > 8$ GeV region in p+Pb
  - Maybe due to physics-related factor
  - Different techniques used with different $p_T$ range
- Further studies are needed to understand the difference
Backup
Multiplicity distribution

ATLAS

$pp \sqrt{s}=13$ TeV, $15.8$ pb$^{-1}$
Event plane resolution

- Calculated using sub-event method with particle-flow objects 1 unit in eta away from $p_T^{G} > 15$ GeV jets
Two-particle Correlations with different $p_T$ bins

$\phi, \Delta$:

- $1<\phi<1.5$ GeV
- $1<\phi<3$ GeV
- $1<\phi<6$ GeV

ATLAS

$pp \sqrt{s}=13$ TeV, $15.8$ pb$^{-1}$

$2<|\Delta\eta|<5$, $0.5<\phi<4$ GeV

$40\leq N_{\text{ch}}^{\text{rec,corr}}<150$

$|\Delta\phi|<5$

$C(\Delta\phi)$

$G+FC_{\text{periph}}(\Delta\phi)$

Fit

$C_{\text{ridge}}^{\text{periph}}(\Delta\phi)+FC_{\text{periph}}(0)$

$C_{\text{ridge}}^{\text{periph}}(\Delta\phi)+FC(0)$

$2<p_T^\text{h}<40$ GeV

$4<p_T^\text{h}<6$ GeV

$|\Delta\phi|<4$ GeV

$0.5<p_T^\text{h}<150$

$|\eta^\text{h}|<4$ GeV

$|\Delta\phi|<5$

$C_{\text{periph}}^{\text{FC}}(0)$

$C_{\text{periph}}^{\text{FC}}(0)+G(0)$

$C_{\text{periph}}^{\text{FC}}(0)+G(0)$

$N_{\text{ch}}^{\text{rec,corr}}\leq 40$

$C_{\text{periph}}^{\text{FC}}(0)+G(0)$

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Crosscheck of $p_T^G$ threshold

- $h^{UE}-h^J \nu_2$ obtained using three different $p_T^G$ threshold
  - $p_T^G > 35$ GeV, $p_T^G > 40$ GeV, $p_T^G > 50$ GeV
- No $p_T^G$ dependence observed
- Results are consistent with each other and consistent with zero
$p_T^G$ vs original jet $p_T$

- Comparison of $p_T^G$ to original jet $p_T$ in data (left) and PYTHIA 8 (right)
- Low multiplicity events are used as UE bias is negligible
- Fits are consistent between data and MC