Collinear Drop

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Precision jet substructure studies

Relate precise jet modifications to medium properties

Guiding principles in the "......":
- Design observables sensitive to physics at certain energy scale
- Exploit all types (different quantum numbers) of probes: quark jet, gluon jet, heavy flavor, etc
- Use "features" in jet substructure distribution
- Need to mitigate background contaminations
Collinear Drop: veto energetic, collinear particles

- Understanding soft QCD is the goal
- Monte Carlo accuracy limited by soft radiation and hadronization modeling
- Heavy ion medium scale is low
- Want to directly probe soft physics by disentangling hard components of jets
- Specific examples:
  1. multiple soft drop
  2. telescoping deconstruction
  3. flattened angularity

(i) Two soft-drop settings \( z_{\text{cut}1} < z_{\text{cut}2} \), \( \beta_1 \geq \beta_2 \)

(ii) Telescoping deconstruction
(with Raghav, 1803.03589)

(iii) Flattened angularity

\[
\tau_\omega = \sum_{i \in \text{jet}} z_i \omega(\theta_i)
\]

Suppress collinear and wide-angle radiation

\[
\omega(\theta) \to 0, \quad \theta \to 0, R
\]
Outline

- Soft drop and collinear drop
- Analytic and Monte Carlo studies
- Conclusions
Soft Drop

▶ Tree-based procedure to drop soft radiation (Larkoski, Marzoni, Soyez, Thaler, 1402.2657)

▶ Recluster a jet using $C/A$ algorithm: angular ordered tree

▶ For each branching, consider the $p_T$ of each branch and the angle $\theta$ between branches

▶ Soft drop condition: drop the soft branch if $z < z_{cut} \theta^\beta$, where $z = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$

▶ $(z_{cut}, \beta)$ parameterize the operation on jet
Soft Drop

Tree-based procedure to drop soft radiation (Larkoski, Marzoni, Soyez, Thaler, 1402.2657)

- Recluster a jet using \( C/A \) algorithm: angular ordered tree
- For each branching, consider the \( p_T \) of each branch and the angle \( \theta \) between branches
- Soft drop condition: drop the soft branch if \( z < z_{cut} \theta^\beta \), where \( z = \frac{\min(p_{T,1},p_{T,2})}{p_{T,1}+p_{T,2}} \)
- Extra cut selection can be imposed (e.g. CMS \( \Delta R_{12} \) cut, 1805.05145)
Collinear Drop using soft drop + anti soft drop

- $\Delta m^2 = m_{SD1}^2 - m_{SD2}^2$ probes the mass of the soft radiation within the "ring".
- Phase space constraints on the kinematics of soft emissions,

$$z \theta^2 \approx \frac{\Delta m^2}{E_J^2} , \quad z_{cut 1} \left( \frac{\theta}{R} \right)^{\beta_1} \lesssim z \lesssim z_{cut 2} \left( \frac{\theta}{R} \right)^{\beta_2}$$

- Two collinear-soft modes emerge from the phase space boundaries

$$p_{cs_i} \sim E_{cs_i} \left( 1, \Theta_{cs_i}^2, \Theta_{cs_i} \right), \quad E_{cs_i} \ll E_J \text{ and } \Theta_{cs_2} \ll 1$$
Two examples:

- fixed $\beta$ and varying $z_{\text{cut}}$
- fixed $z_{\text{cut}}$ and varying $\beta$ (ATLAS 13 TeV data: $z_{\text{cut}} = 0.1$, $\beta = 0, 1, 2$. 1711.08341)

Identify relevant soft-collinear effective theory modes by corners of phase space boundaries
Factorization and resummation of $\Delta m^2$

- Factorization of $\Delta m^2$

\[ \frac{d\sigma}{d\Delta m^2} = \sum_{i=q,g} N_i(\mu) J_{\text{un},i}^{\text{SD}}(z_{\text{cut}2}, \beta_2, \mu) S_i^{\text{CD}}(\Delta m^2, z_{\text{cut}i}, \beta_i, \mu) \]

- If two soft-drop conditions are hierarchically separated, collinear-soft sector can be further factorized

\[ S_i^{\text{CD}}(\Delta m^2, \mu) = \int dk_i S_{C_2,i}(k_2, \mu) S_{C_1,i}(k_1, \mu) \delta(\Delta m^2 - 2E_J(k_1 + k_2)) \]

- Factorization expression allows us to resum $\Delta m^2$ using renormalization group techniques
Validation with soft drop: turning off collinear drop

- Grooming-ungrooming transition happens at $\log_{10}(R^2 z_{\text{cut}})$, treated by EFT merging
- Soft drop reduces nonperturbative effects
- Band corresponds to next-to-leading log (NLL) SCET calculation with uncertainty estimated by scale variation. Previous work: Larkoski et al ’16, Marzani et al ’17, Kang et al ’18
- Analytic calculation agrees with Pythia partonic simulation: collinear physics dominates
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Collinear Drop results

- New and different observables
- \( \Delta m^2 = m_{SD1}^2 - m_{SD2}^2 \) labeled by \((z_{cut_1}, \beta_1) - (z_{cut_2}, \beta_2)\)
- Increase sensitivity to soft radiation and nonperturbative hadronization
- New hadronization features in Pythia simulation appear
- Band corresponds to NLL SCET calculation with uncertainty estimation

13 TeV, \( R=0.8, p_T: (600,700) \text{ GeV} \)

Pythia 8, \( \Delta m^2 = m_{SD1}^2 - m_{SD2}^2 \)

Band corresponds to NLL SCET calculation with uncertainty estimation
New and different observables

\[ \Delta m^2 = m^2_{SD1} - m^2_{SD2} \]

labeled by \((z_{cut1}, \beta_1) - (z_{cut2}, \beta_2)\)

Increase sensitivity to soft radiation and nonperturbative hadronization

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Band corresponds to NLL SCET calculation with uncertainty estimation
Quark gluon discrimination

- Decompose total leading dijet into quark jet and gluon jet components
- Enhance the difference between quark jets and gluon jets: promising observable for improving quark-gluon discrimination
- Nonperturbative effects enhance the features of quark and gluon peaks in mixed jet samples
Collinear-drop in heavy ion (with Raghav, 1803.03589)

Significant modification of collinear drop observable from pp to AA: potential for extracting medium properties

In JEWEL-simulated AA collisions, quark/gluon jet difference is washed out: enhancing the universal components within jets
Conclusions

- Collinear-drop observables allows one to directly probe soft physics and color flows in jets
  - for probing soft radiation contributions
  - for testing Monte Carlo simulations
  - for tagging hard probes (color-singlet jet isolation, Chien et al 1711.11041)
  - for determining hadronization corrections
  - for studying perturbative-nonperturbative transition

- Factorization expression of a specific collinear drop observable is derived in SCET which allows us to resum logarithmically-enhanced contributions

- Stay tuned (a separate paper) for detailed studies of hadronization and applications to heavy ion using collinear drop observables
  - Include Deductor, Sherpa, ...
  - Understanding different nonperturbative effects in different hard probes