Collinear Drop

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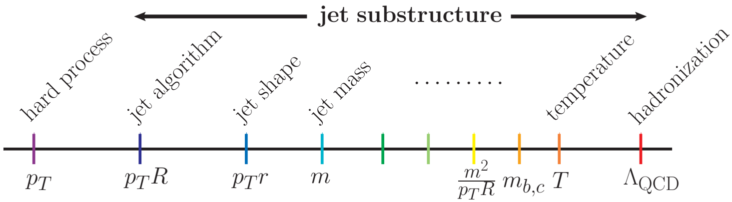
In collaboration with Iain Stewart, in preparation

Precision jet substructure studies



Relate precise jet modifications to medium properties

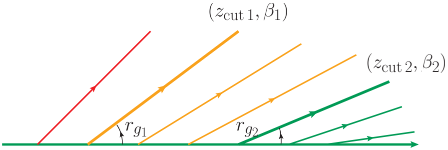
Guiding principles in the "......":

- 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

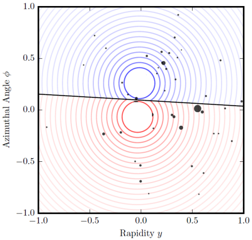
- Understanding soft QCD is the goal
- Monte Carlo accuracy limited by soft radiation and hadronization modeling
- Heavy ion medium scale is low
- Want to directly probe soft physics by disentangling hard components of jets
- Specific examples:
  (i) multiple soft drop
  (ii) telescoping deconstruction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

(i) Two soft-drop settings $z_{\text{cut1}} < z_{\text{cut2}}, \beta_1 \geq \beta_2$



(ii) Telescoping deconstruction

(with Raghav, 1803.03589)



(iii) Flattened angularity

$$\tau_\omega = \sum_{i \in \text{jet}} z_i \, \omega(\theta_i)$$

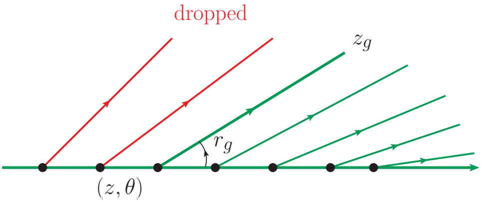
Suppress collinear and wide-angle radiation

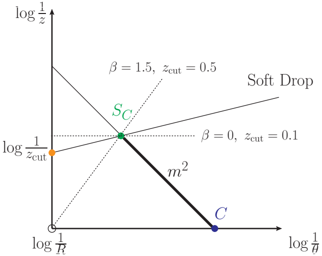
$$\omega(\theta) \to 0 \,, \quad \theta \to 0, R$$

Outline

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

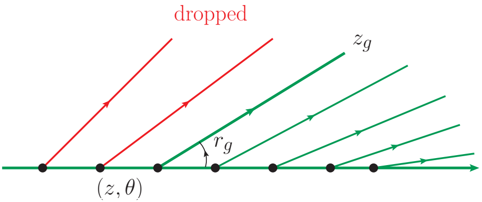
Soft Drop

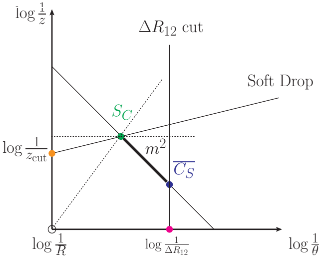




- Tree-based procedure to drop soft radiation (Larkoski, Marzoni, Soyez, Thaler, 1402.2657)
  - Recluster a jet using C/A algorithm: angular ordered tree
  - For each branching, consider the p_T of each branch and the angle θ between branches
  - Soft drop condition: drop the soft branch if $z < z_{\rm cut}\ \theta^{\beta}$, where $z = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}}$
  - $(z_{\rm cut}, \beta)$ parameterize the operation on jet

Soft Drop





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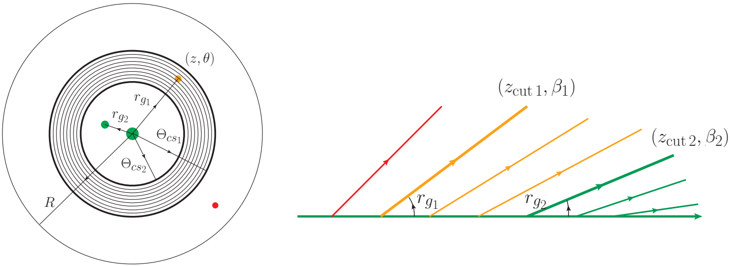
  - Extra cut selection can be imposed (e.g. CMS ΔR_{12} cut, 1805.05145)

Collinear Drop using soft drop + anti soft drop



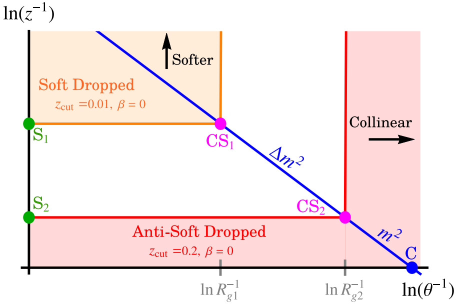
- $\Delta m^2 = m^2_{\mathrm{SD}_1} - m^2_{\mathrm{SD}_2}$ probes the mass of the soft radiation within the “ring"
- Phase space constraints on the kinematics of soft emissions,

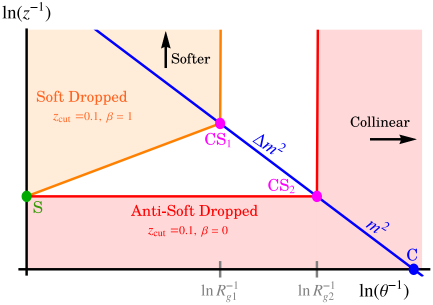
$$z\theta^2 \approx \frac{\Delta m^2}{E_J^2}\,, \qquad z_{\mathrm{cut}\,1}\left(\frac{\theta}{R}\right)^{\beta_1} \lesssim z \lesssim z_{\mathrm{cut}\,2}\left(\frac{\theta}{R}\right)^{\beta_2}$$

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

$$p_{cs_i} \sim E_{cs_i}\Big(1,\ \Theta^2_{cs_i},\ \Theta_{cs_i}\Big),\ \ E_{cs_i} \ll E_J \text{ and } \Theta_{cs_2} \ll 1$$

Factorization of Δm^2





- Two examples:
  - fixed β and varying $z_{\rm cut}$
  - fixed $z_{\rm cut}$ and varying β (ATLAS 13 TeV data: $z_{\rm cut} = 0.1,\ \beta = 0, 1, 2.\ 1711.08341$)
- Identify relevant soft-collinear effective theory modes by corners of phase space boundaries

Factorization and resummation of Δm^2

- Factorization of Δm^2

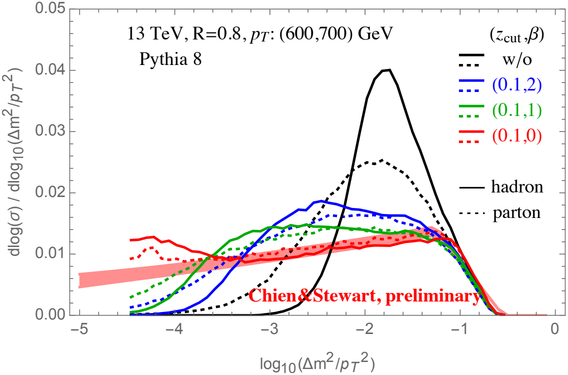
$$\frac{d\sigma}{d\Delta m^2} = \sum_{i=q,g} N_i(\mu) J^{\rm SD}_{{\rm un},i}(z_{{\rm cut}\,2}, \beta_2, \mu) S^{\rm CD}_i(\Delta m^2, z_{{\rm cut}\,i}, \beta_i, \mu)$$

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

$$S^{\rm CD}_i(\Delta m^2, \mu) = \int dk_i \overline{S_{C_2,i}}(k_2, \mu) S_{C_1,i}(k_1, \mu) \delta(\Delta m^2 - 2E_J(k_1 + k_2))$$

- Factorization expression allows us to resum Δm^2 using renormalization group techniques

Validation with soft drop: turning off collinear drop



- Grooming-ungrooming transition happens at $\log_{10}(R^2 z_{\rm cut})$, 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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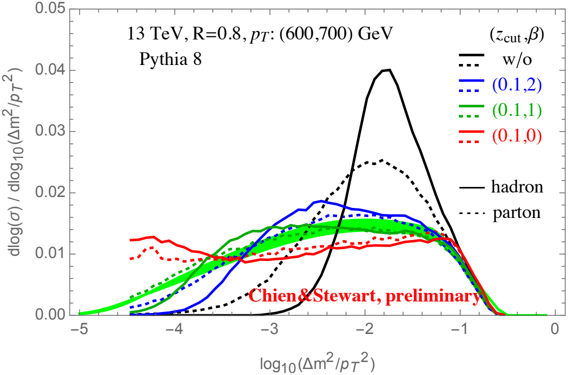

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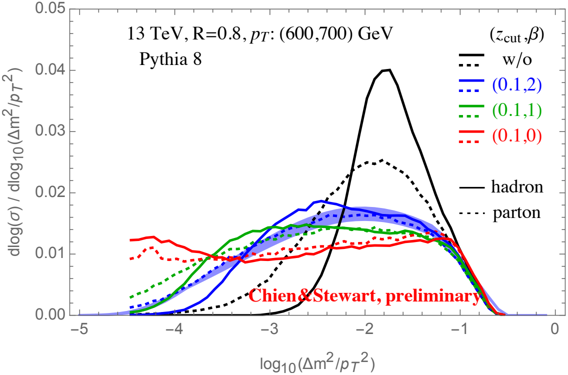

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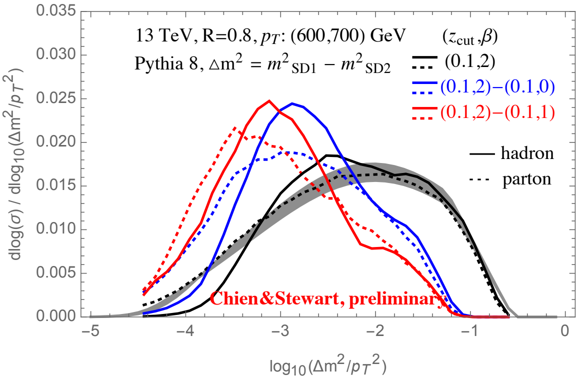
Collinear Drop results



- New and different observables
- $\Delta m^2 = m^2_{\mathrm{SD}_1} - m^2_{\mathrm{SD}_2}$ labeled by $(z_{\mathrm{cut}_1}, \beta_1) - (z_{\mathrm{cut}_2}, \beta_2)$
- Increase sensitivity to soft radiation and nonperturbative hadronization
- New hadronization features in Pythia simulation appear
- Band corresponds to NLL SCET calculation with uncertainty estimation

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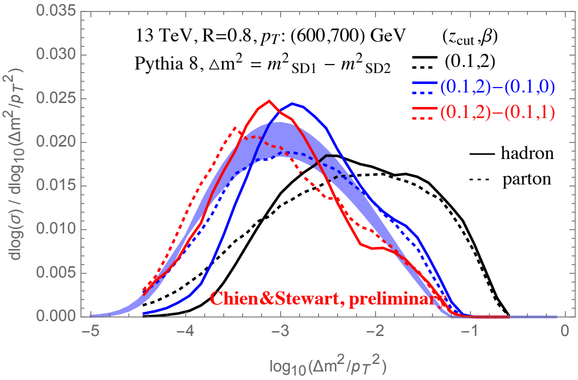

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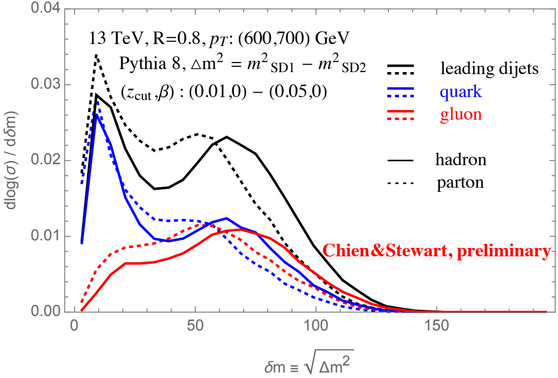
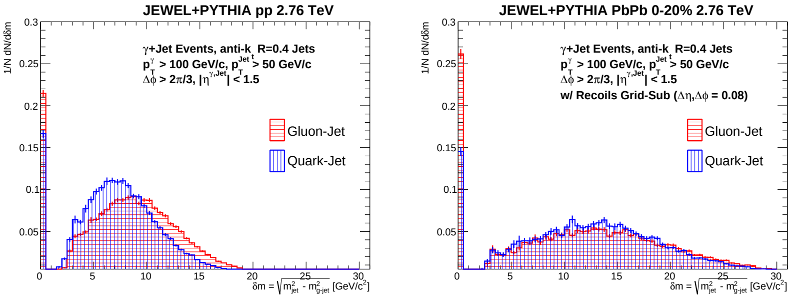
Quark gluon discrimination



- 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