Collinear Drop

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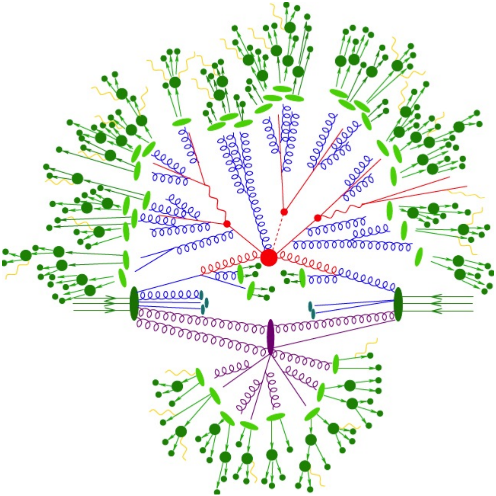
Outline

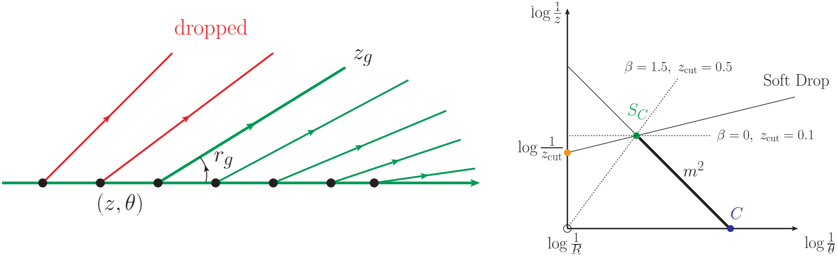
- Motivation
- Collinear drop
- Analytic SCET and Monte Carlo studies
- Conclusions

Soft radiation is complicated

- Great achievement from decades of efforts to simulate collider events
- But, how reliable are these simulations?
    - parton shower accuracy beyond collinear expansion
    - underlying events e.g. multiparton interaction
    - hadronization and nonperturbative modeling
    - heavy ion collisions !!??
- How to systematically improve the description?
- Is there novel phenomenon from strong interaction?

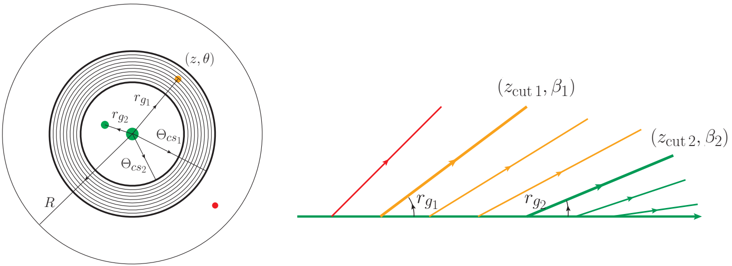


Soft Drop



- Tree-based procedure to drop soft radiation (Larkoski et al, 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 $z = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1}+p_{T,2}}$

Collinear Drop using soft drop + anti soft drop

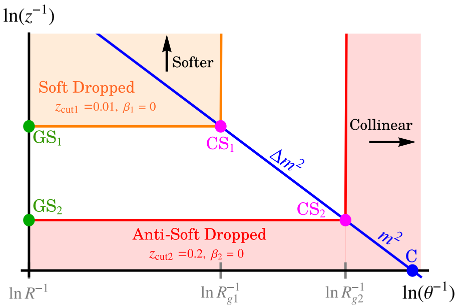


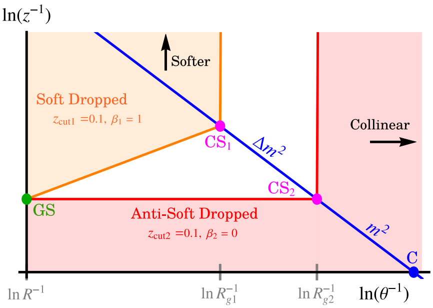
- $\Delta m^2 = m^2_{\text{SD}_1} - m^2_{\text{SD}_2}$ probes the soft radiation within the ring
- Phase space constraints on soft emissions with $(z, \theta) = (\text{momentum fraction, angle})$,

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

- Relevant degrees of freedom emerge from phase space boundaries, with characteristic energies E_{cs_i} and angles Θ_{cs_i}.

Factorization of Δm^2





- Two ways to create hierarchical soft-drop conditions $\mathrm{SD}_1 < \mathrm{SD}_2$
  - fixing β and varying $z_{\rm cut}$
  - fixing $z_{\rm cut}$ and varying β (ATLAS 13 TeV data: $z_{\rm cut} = 0.1,\ \beta = 0, 1, 2.$ 1711.08341)
- Identify relevant SCET degrees of freedoms by corners of phase space boundaries

Factorization and resummation of Δm^2

- Factorization of Δm^2

$$\frac{d\sigma}{d\Delta m^2} = \sum_{i=q,g} N_i(z_{\text{cut}\,i}, \beta_i, \mu) P_i^{\text{CD}}(\Delta m^2, z_{\text{cut}\,i}, \beta_i, \mu)$$

- If two soft-drop conditions are hierarchically separated, cross sections can be further factorized

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

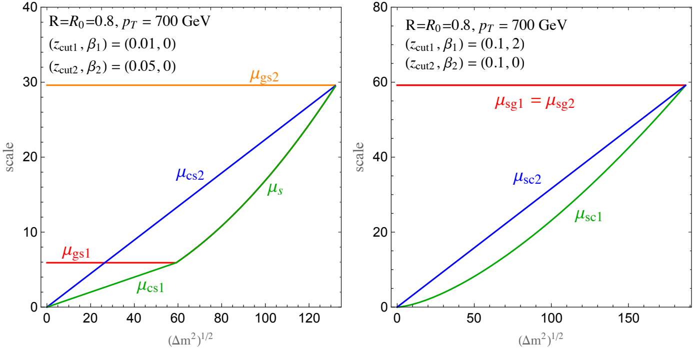
- Factorization allows us to resum Δm^2 using renormalization group (RG) techniques

RG evolution and anomalous dimensions

- Characteristic scales: $\mu_{sc_i} = \sqrt{\Delta m^2 z_{\text{cut}\,i}} \left(\frac{\Delta m^2}{(E_J R)^2 z_{\text{cut}\,i}} \right)^{\frac{\beta_i}{2(2+\beta_i)}}$, $\mu_{sg_i} = E_J R z_{\text{cut}\,i}$

$$d\tilde{S_C}(\nu,\mu)/d\ln\mu = \Gamma_{S_C}(\mu)\tilde{S_C}(\nu,\mu)\ , \quad \text{where } \tilde{S_C}(\nu,\mu) = \int dk \exp\Big(-\frac{2E_J\nu k}{e^{\gamma_E}}\Big) S_C(k,\mu)$$

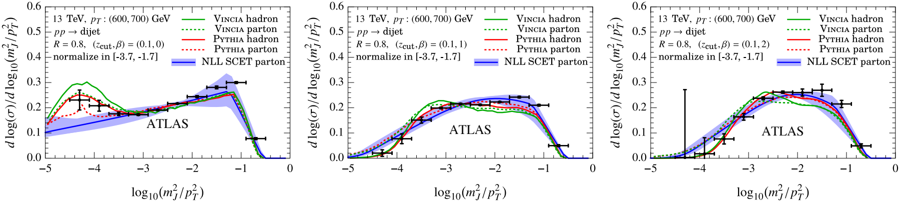
- An infinite class of single-logarithmic observables for $\beta_1 = \beta_2$



Soft drop is a special case of collinear drop

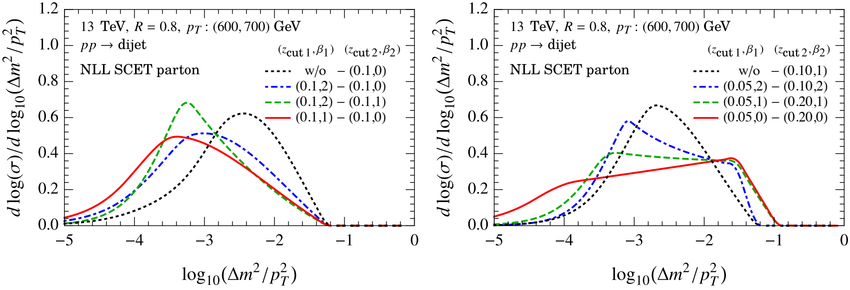
Previous soft drop work: Larkoski et al ’16, Marzani et al ’17, Kang et al ’18

ATLAS: 1711.08341, CMS:1807.05974



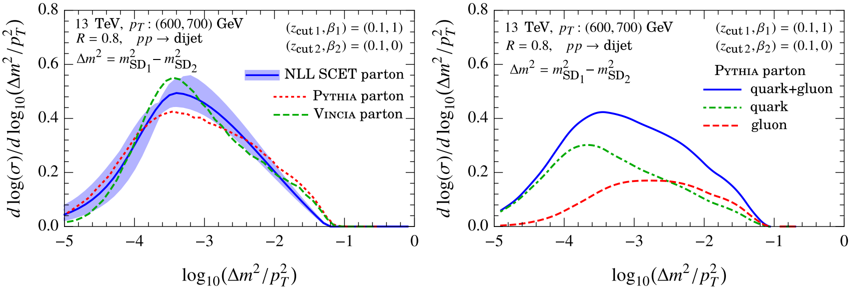
- Groomed-ungroomed transition happens at $\log_{10}(R^2 z_{\rm cut})$, treated by EFT merging
- Soft drop reduces sensitivity to soft physics
- Bands correspond to next-to-leading log (NLL) calculation with uncertainty estimated by scale variation, respecting groomed-ungroomed transition

First glance of Collinear Drop examples



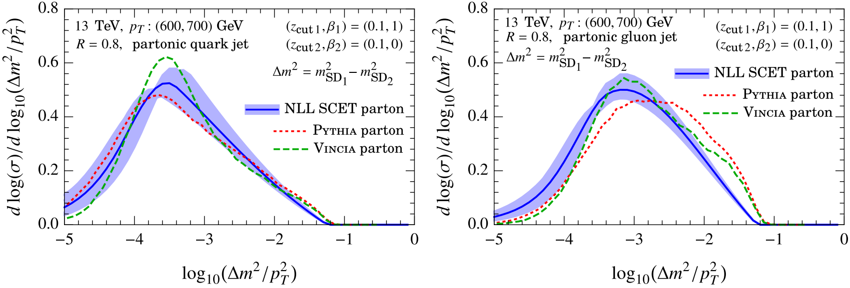
- $\Delta m^2 = m^2_{\text{SD}_1} - m^2_{\text{SD}_2}$ with two soft drop conditions $\text{SD}_1 : (z_{\text{cut}_1}, \beta_1)$ and $\text{SD}_2 : (z_{\text{cut}_2}, \beta_2)$
- Upper limit of the spectrum controlled by $z_{\text{cut}\,2}$
- Left panel has no groomed-ungroomed transition controlled by $z_{\text{cut}\,1}$, while right panel has groomed-ungroomed transition

SCET and MC studies



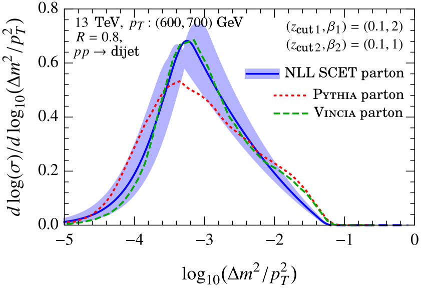
- Band corresponds NLL calculation with uncertainty estimated by scale variation, respecting groomed-ungroomed transition and observable bound
- Dijet has contributions from both quark and gluon jets

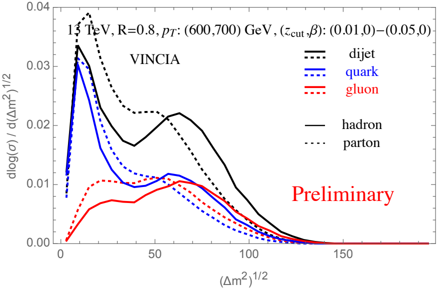
Collinear Drop quark and gluon jets



- Significant difference between Pythia and Vincia is observed
- Pythia gluon jet simulation seems to be disfavored

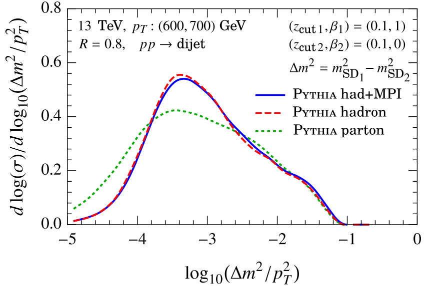
Collinear Drop quark and gluon jets

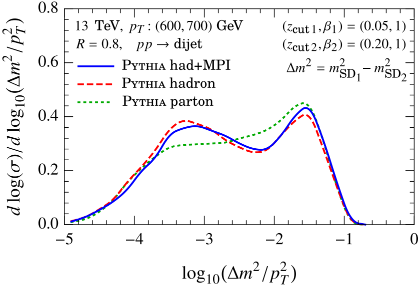




- Impressive agreement between Vincia and analytic calculation
- Enhance the difference between quark jets and gluon jets: promising observable for improving quark-gluon discrimination
- Nonperturbative effects enhance the features of quark and gluon peaks in mixed jet samples

Sensitivity to hadronization and underlying events

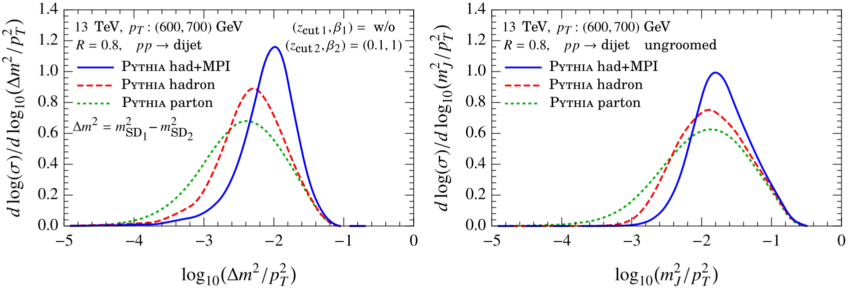




- Underlying event effects can be suppressed while keeping sensitivity to hadronization

Or enhanced sensitivity to underlying events

- A different Collinear Drop observable without soft grooming



- Sensitivity to underlying events for this collinear drop observable is larger than ungroomed jet mass

Conclusions

- Collinear-drop is a new class of observables. I discussed one example here.
- Collinear-drop can be used to directly probe soft physics and color flows in jets for
  - probing soft radiation contributions
  - testing Monte Carlo simulations
  - determining hadronization corrections
  - studying perturbative-nonperturbative transition
  - probing QCD medium in heavy ion collisions (1803.03589)
- Factorization of Δm^2 is derived in SCET which allows us to resum logarithmically-enhanced contributions