Dynamical grooming beyond the leading-log approximation

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with A. Soto-Ontoso and A. Takacs

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BOOST conference - online

Talk based on JHEP07 (2021) 020

Jet substructure observables

- Large variety of techniques and observables: mMDT, SoftDrop, ...
  Dasgupta, Fregoso, Marzani, Salam, 1307.0007, Larkoski, Marzani, Soyez, Thaler, 1402.2657

- Many applications: boosted objects tagging, precision determination of α_s, heavy-ion collisions...

Goal of this presentation

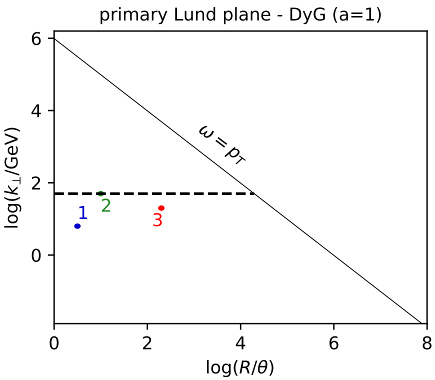
In this talk, calculation of a promising such substructure technique: **dynamical grooming** Mehtar-Tani, Soto-Ontoso, Tywoniuk, 1911.00375 & 2005.07584 and comparison to preliminary ALICE data.

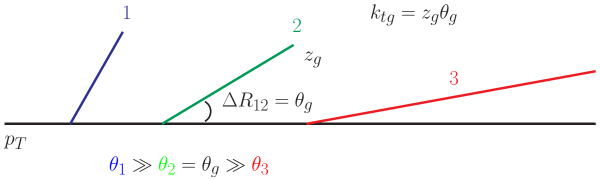
Dynamically groomed distributions

Mehtar-Tani, Soto-Ontoso, Tywoniuk, 1911.00375

Definition

- Tag the hardest declustering in all the C/A sequence, with hardness mesure $\kappa^{(a)} = z(1-z)p_t(\Delta R/R)^a$.
- Then measure the $k_t = z\Delta R/R$, or z or ΔR of this branching.





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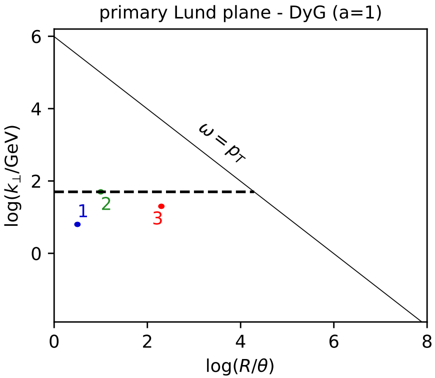


- Contrary to Soft Drop, only one free parameter a, and grooming condition is set on a "jet-by-jet" basis.

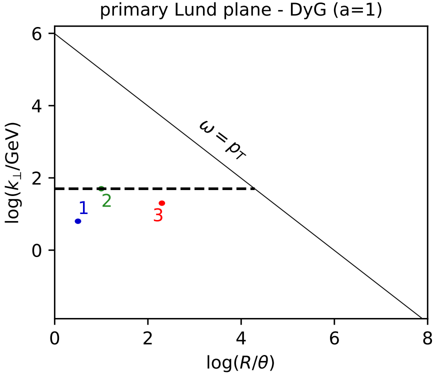
All order k_{tg} calculation in pp

At DLA, Mehtar-Tani, Soto-Ontoso, Tywoniuk, 2020

$$\frac{1}{\sigma_0}\frac{d\sigma^{(a)}}{dk_{tg}} = \frac{2\alpha_s C_R}{\pi}\int_0^1 \frac{dz}{z}\int_0^1 \frac{d\theta}{\theta}\Delta(\kappa = z\theta^a|a)\delta(k_{tg} - z\theta)$$

with

$$-\ln(\Delta(\kappa|a)) = \frac{2\alpha_s C_R}{\pi}\int_0^1 \frac{dz}{z}\int_0^1 \frac{d\theta}{\theta}\Theta(z\theta^a - \kappa)$$



All order k_{tg} calculation in pp

- Cumulative distribution:

$$\Sigma(k_{tg}) = \frac{1}{\sigma_0}\int_0^{k_{tg}} \mathrm{d}k'_{tg}\,\frac{\mathrm{d}\sigma^{(a)}}{\mathrm{d}k'_{tg}}$$

- Contrary to many jet observables (event shapes, Soft Drop energy correlations,...), the log resummation **does not exponentiate**:

Catani, Trentadue, Turnock, B. Webber, 1993

$$\Sigma(k_{t,g}) = 1 - \bar{\alpha}\ln^2\left(\frac{1}{k_{t,g}}\right) + \frac{1+a+a^2}{6a}\bar{\alpha}^2\ln^4\left(\frac{1}{k_{tg}}\right) + \mathcal{O}(\bar{\alpha}^3)$$

- The log accuracy is then defined at the level of Σ:

$$\Sigma(k_{tg}) = \sum_{n=0}^{\infty}\alpha_s^n\sum_{m=0}^{2n} c_{nm}\,\ln^m(k_{tg})\,,$$

Def.: **N^{p}DL accuracy** $\Leftrightarrow c_{nm}$ known $\forall n$ and $2n - p \leq m \leq 2n$.

Banfi, Salam, Zanderighi, 2005

All order k_{tg} calculation in pp PC, Soto-Ontoso, Takacs, 2103.06566

$$\Sigma(k_{t,g}) = \int_0^1 \mathrm{d}z \int_0^1 \mathrm{d}\theta \widetilde{P}(z,\theta)\Delta(\kappa|a)\Theta(k_{t,g} - z\theta)$$

with

$$\widetilde{P}(z,\theta) = \left[\frac{2\alpha_s^{2\ell}(z\theta Q)C_i}{\pi z\theta} - 2C_iC_A\frac{\pi^2}{3}\left(\frac{\alpha_s}{2\pi}\right)^2\frac{\ln(z)}{z}\right]\Theta\left(e^{-B_i} - z\right)$$

The physical effects that come into play at N^{2}DL:

- ✓ Hard collinear splittings
- ✓ Running coupling corrections at two loops

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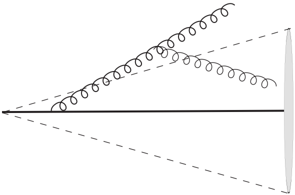
- ✓ Non global configurations Dasgupta, Salam, 2001



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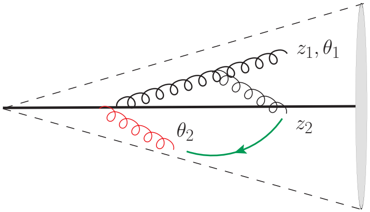
- × No "clustering" logarithms! Kang, Lee, Liu, Ringe Lifson, Salam, Soyez, 2020

$$z_1 \gg z_2 \Longrightarrow z_1\theta_1^a \gg z_2\theta_2^a \text{ if } \theta_1 \sim \theta_2.$$



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- ✓ Hard collinear splittings
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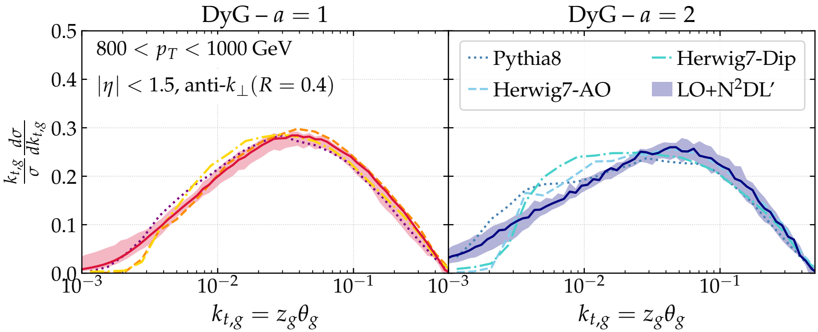
- ✓ Non global configurations Dasgupta, Salam, 2001
- × No "clustering" logarithms! Kang, Lee, Liu, Ringer, 2019, Lifson, Salam, Soyez, 2020
- ✓ C_1 term ⇒ requires a $\mathcal{O}(\alpha_s)$ matching.

N^2DL resummation matched to LO

PC, Soto-Ontoso, Takacs, 2103.06566

Comparison to parton-level MCs

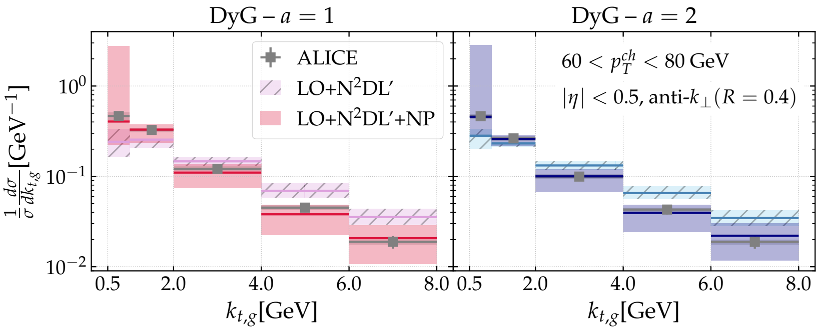


Comments

- Good agreement with parton-level MCs.
- Small differences due to sub-leading effects at N^2DL, such as energy recoil of the hard branch.
- Importance at low k_{tg} of the infrared cut in the MC parton shower.

Comparison to preliminary ALICE data

J. Mulligan, R.Ehlers, 2009.07172, 2009.12247



Comments

- At such low p_t, hadronization corrections are large.
- Good agreement once a NP factor determined from MCs is included.

The Dynamically groomed z_g distribution

- The splitting fraction z_g of the tag declustering is measured.

$$\frac{1}{\sigma_0}\frac{d\sigma^{(a)}}{dz_g} = \frac{2\alpha_s C_R}{\pi}\int_0^1 \frac{dz}{z}\int_0^1 \frac{d\theta}{\theta}\Delta(z\theta^a|a)\delta(z_g - z)$$

- Not an IRC safe quantity, but rather "Sudakov safe".

  Larkoski, Marzani, Thaler, 1502.01719

- As such, the α_s expansion has non-integer powers:

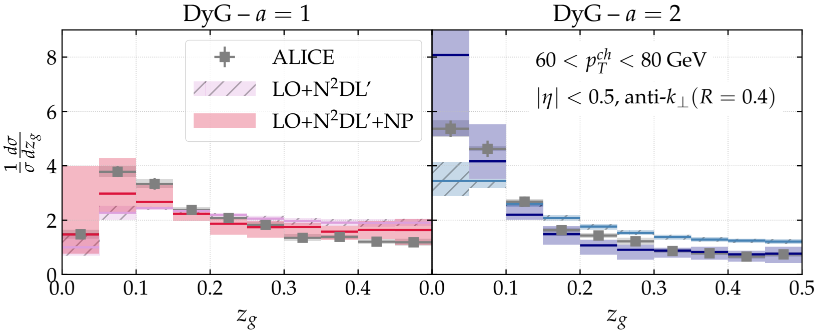
$$\Sigma(z_g) = 1 \underbrace{-\sqrt{\frac{\bar{\alpha}\pi}{a}}\ln\left(\frac{1}{z_g}\right)}_{\text{non analytic term}} + \frac{\bar{\alpha}}{a}\ln^2\left(\frac{1}{z_g}\right) + \mathcal{O}(\bar{\alpha}^2)$$

DyG z_g distribution in pp collisions

- N^2DL resummation achieved by taking the limit of IRC safe distributions:

$$\Sigma(z_g) = \lim_{c\to 0} \int_0^1 \mathrm{d}z \int_0^1 \mathrm{d}\theta\, \widetilde{P}(z,\theta)\Delta(\kappa|a)\Theta(z_g - z\theta^c)$$

- Comparison to ALICE data:



Summary

- Analytical calculation of dynamically groomed jet substructure observables, up to N^2DL accuracy, supplemented by a LO matching and a Monte-Carlo estimation of NP corrections.
- Good agreement with ALICE data, within the uncertainty.
- Nice features of DyG: relatively simple resummation structure.
  $\Rightarrow$ in particular, no clustering logs.
- Ultimate groomer: DyG+mMDT?
- Applications to heavy-ion collisions: probing color coherence of in-medium jet evolution.
  PC, Soto-Ontoso, Takacs, in preparation.

THANK YOU !