

Dynamical grooming (and possible application at the EIC)

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Workshop “Jets on 3D imaging at the EIC” - September 27th
Stony Brook University

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

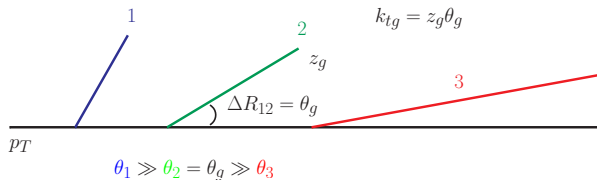
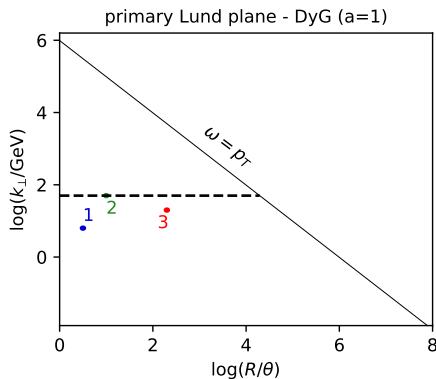
In this talk, calculation of a promising such substructure technique: **dynamical grooming** Mehtar-Tani, Soto-Ontoso, Tywoniuk, 1911.00375 & 2005.07584 , and brief discussion of possible applications at the EIC.

Dynamically groomed distributions

Mehtar-Tani, Soto-Ontoso, Tywoniuk, 1911.00375

Definition

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

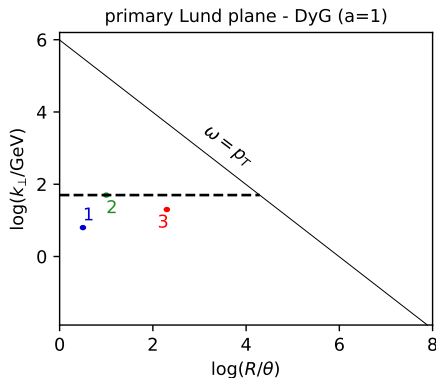


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- Contrary to Soft Drop, only one free parameter a , and grooming condition is set on a “jet-by-jet” basis.

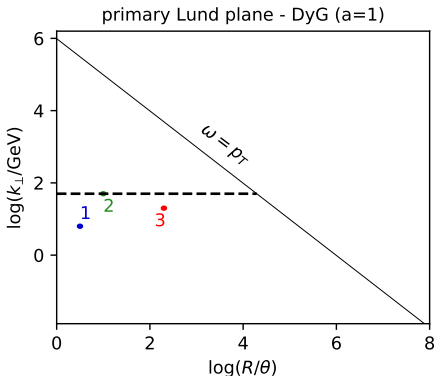
k_{tg} calculation in pp : double-log estimation

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

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



k_{tg} calculation in pp : double-log estimation

- Cumulative distribution:

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

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

Catani, Trentadue, Turnock, B. Webber, 1993

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

- 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^pDL accuracy $\Leftrightarrow c_{nm}$ known $\forall n$ and $2n - p \leq m \leq 2n$.

Banfi, Salam, Zanderighi, 2005

N²DL calculation in pp

PC, Soto-Ontoso, Takacs, 2103.06566

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

with (in the small R limit)

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

The physical effects that come into play at N²DL:

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

N²DL calculation in pp

PC, Soto-Ontoso, Takacs, 2103.06566

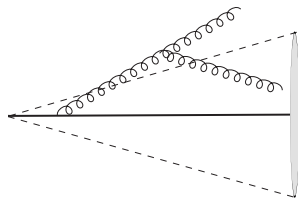
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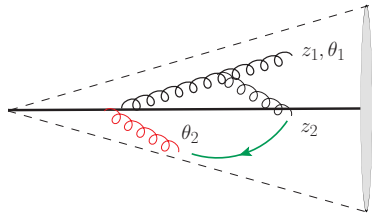
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- ✗ No “clustering” logarithms! Kang, Lee, Liu, Ringer
Lifson, Salam, Soyez, 2020

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



N²DL calculation in pp PC, Soto-Ontoso, Takacs, 2103.06566

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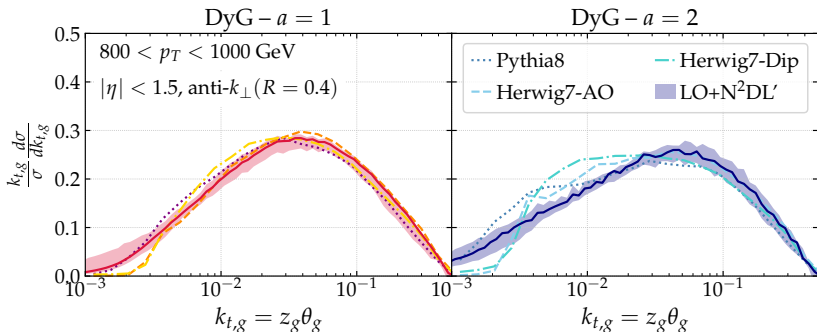
The physical effects that come into play at N²DL:

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

N²DL resummation matched to LO

PC, Soto-Ontoso, Takacs, 2103.06566

Comparison to parton-level MCs

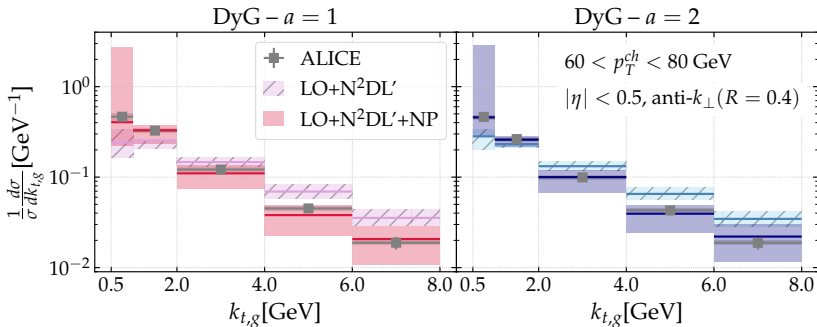


Comments

- Good agreement with parton-level MCs.
- Small differences due to sub-leading effects at N²DL, such as energy recoil of the hard branch.
- Importance at low $k_{t,g}$ 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 and θ_g distributions

- The splitting fraction z_g (θ_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:

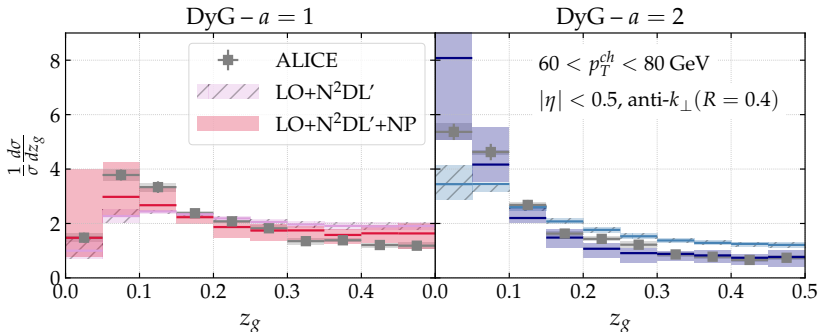
$$\Sigma(z_g) = 1 - \underbrace{\sqrt{\frac{\bar{\alpha}\pi}{a}} \ln\left(\frac{1}{z_g}\right)}_{\text{non analytic term}} + \frac{\bar{\alpha}}{a} \ln^2\left(\frac{1}{z_g}\right) + \mathcal{O}(\bar{\alpha}^2)$$

DyG z_g distribution in pp collisions

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

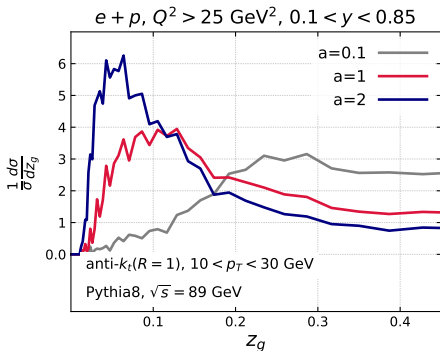
$$\Sigma(z_g) = \lim_{c \rightarrow 0} \int_0^1 dz \int_0^1 d\theta \tilde{P}(z, \theta) \Delta(\kappa|a) \Theta(z_g - z\theta^c)$$

- Comparison to ALICE data:



Possible applications at the EIC

- So far, no analytic predictions \Rightarrow Pythia8 simulations in $e + p$.
- Event selection based on [Arratia, Song, Ringer, Jacak 1912.05931](#).



- Measurement at the EIC looks promising. Sensitivity to q/g fraction in the hard process.

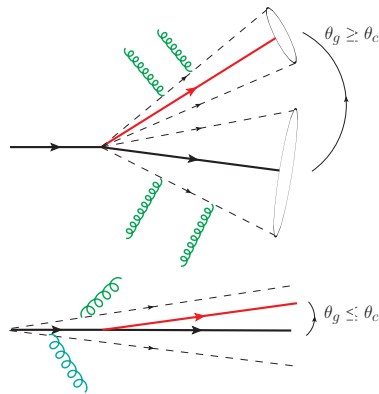
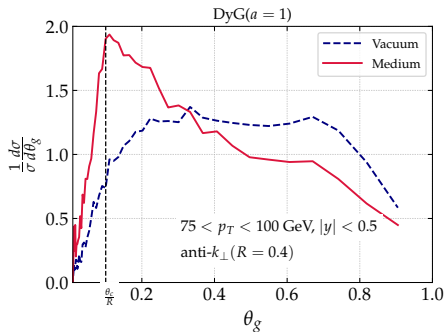
[Cal, Lee, Ringer, Waalewijn, 2106.04589](#)

- Help constraining NP corrections in the cleaner $e + p$ background.

Lessons from $A + A$ collisions

- Modifications of substructure observables are driven by the medium capability to resolve the intrajet structure.
- Example: the θ_g distribution after dynamical grooming.

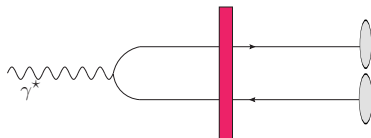
PC, Soto-Ontoso, Takacs, in preparation



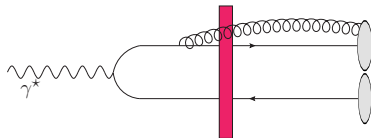
- Large θ_g are more quenched than small θ_g jets.

Analogy with the saturated regime at small- x ?

- The medium \simeq the small- x gluons (CGC).
- However, contrary to what happens in the jet quenching problem, jets fragment out of the “medium”.
- The final state evolution is not resolved by the shock-wave.



- But DyG observables could be sensitive to gluon emissions induced by the shock-wave (NLO contributions).



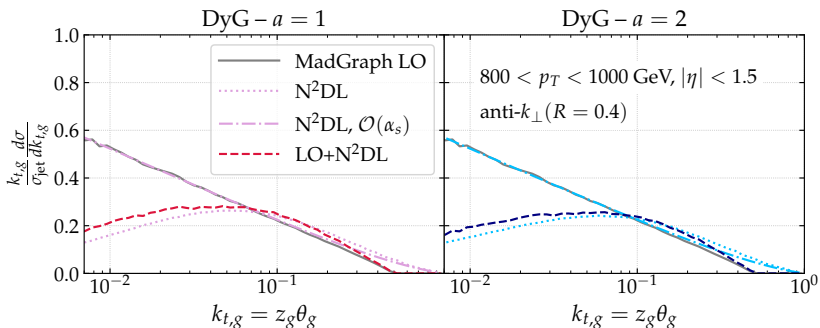
Summary

- 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.
⇒ in particular, no clustering logs.
- Application for the EIC: constrain NP corrections, and quark-gluon fraction via the matching.
- **More work required** to understand if substructure observables are sensitive to saturation at small x .

THANK YOU !

BACK-UP

LO matching



Minimal N²DL calculation

