Dynamically groomed jet radius in heavy-ion collisions

(towards sPHENIX predictions)

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Based on JHEP07 (2021) 020 and PRD 105-11 (2022)

Jet substructure observables

- Jet substructure in small collision systems (pp, e^+e^-):
  - Large variety of techniques: mMDT, SoftDrop, ...

    Dasgupta, Fregoso, Marzani, Salam, 1307.0007, Larkoski, Marzani, Soyez, Thaler, 1402.2657
  - Many applications: boosted objects tagging, precision determination of α_s,...
- Jet substructure in AA collisions:
  - Vacuum baseline under pQCD control.
  - Tuned to be sensitive to specific medium effects.

Dynamically groomed jet angle

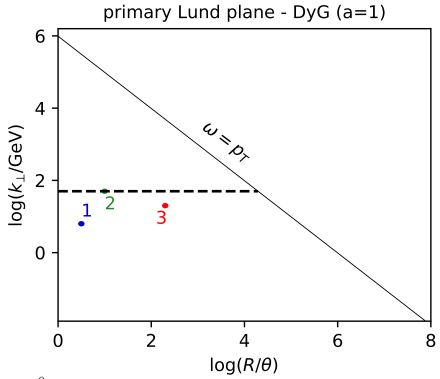
- Good pQCD control, but plagued by large NP corrections at low p_t.
- Sensitivity to the coherence angle of the medium θ_c.
- Can help to constrain jet quenching models.

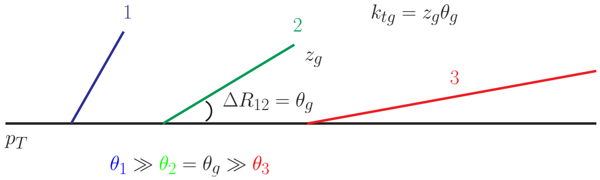
Dynamically groomed distributions

Dynamical grooming techniques proposed by
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 $k_{tg} = z\Delta R/R$ or $\theta_g = \Delta R$ of this branching.





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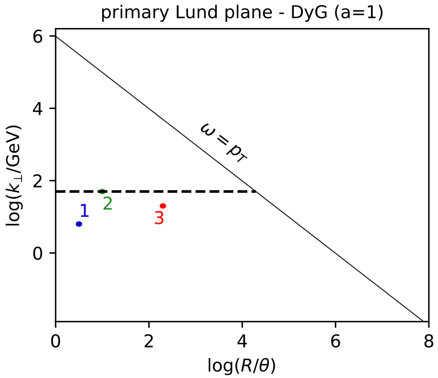


- Contrary to Soft Drop, only one free parameter $a \Rightarrow$ easier to systematically study the grooming parameter dependence.
- Grooming condition is set on a "jet-by-jet" basis.

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, 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

$$\widetilde{P}(z,\theta) = \left[\frac{2\alpha_s^{2\ell}(z\theta Q)C_i}{\pi z\theta} - 2C_iC_A\frac{\pi^2}{3}\left(\frac{\alpha_s}{2\pi}\right)^2\frac{\ln(z)}{z}\right]\Theta\left(e^{-B_i} - z\right), \text{ and } \ln\Delta(\kappa|a) = -\int_{z\theta^a\geq\kappa}\widetilde{P}(z,\theta)$$

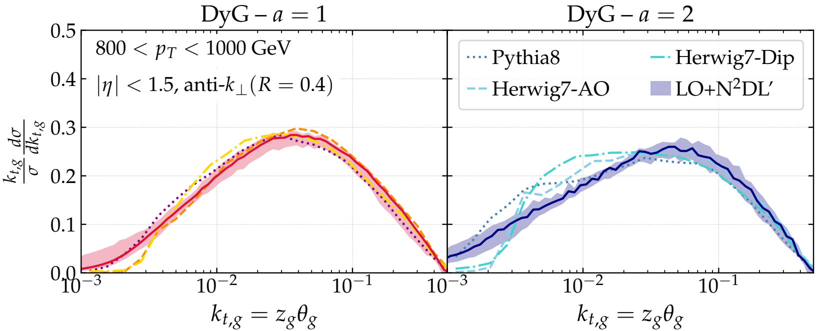
The physical effects that come into play at N^{2}DL:

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

N^2DL resummation matched to LO

PC, Soto-Ontoso, Takacs, 2103.06566

Comparison to parton-level MCs

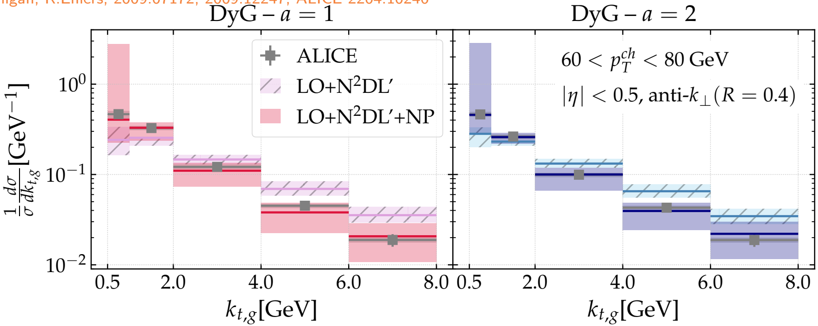


Comments

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

Comparison to ALICE data

J. Mulligan, R.Ehlers, 2009.07172, 2009.12247, ALICE 2204.10246



Comments

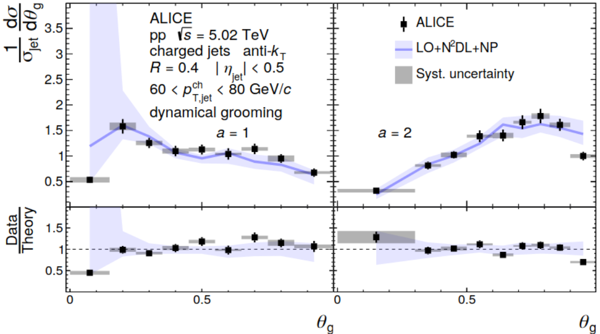
- At such low p_t, hadronization corrections are large.
- Good agreement once a NP factor determined from MCs is included.

The Dynamically groomed θ_g distribution

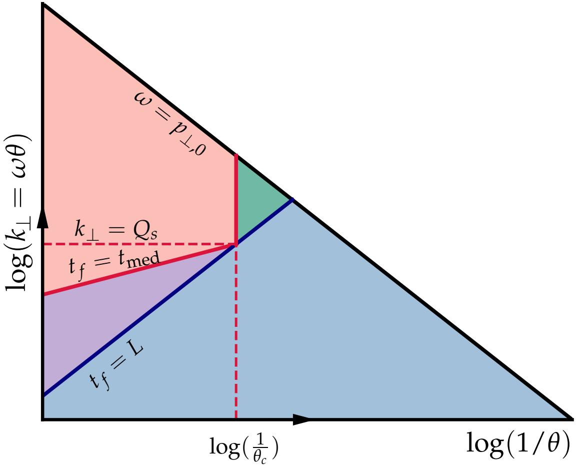
- The opening angle θ_g of the splitting is measured: only Sudakov safe.
- N^2DL resummation achieved by taking the limit of IRC safe distributions:

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

- Comparison to ALICE data: ALICE 2204.10246



Modification of the phase space in heavy-ion collisions



- In-medium constraint: $k_\perp^2 \geq \hat{q} t_f$.
- Out-medium condition: $t_f \geq L$.
- **NB: because of color coherence, emissions "inside" with $t_f \leq L$ is not modified if**

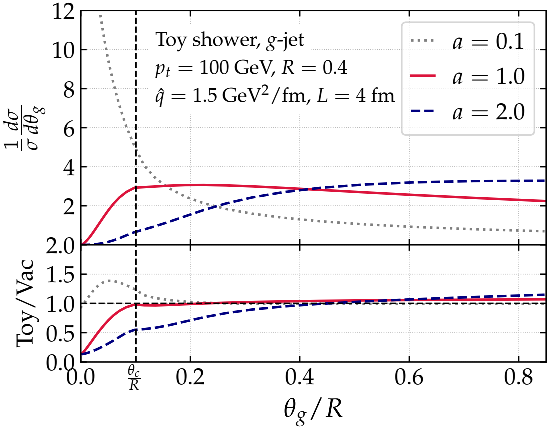
$$\theta \leq \theta_c = 2/\sqrt{\hat{q} L^3}$$

.

- Phase-space at RHIC: lower p_{t0}, lower $\hat{q} \Rightarrow$ the green region shrinks.

Analytic toy calculation

Relatively hard intrajet medium-induced emissions



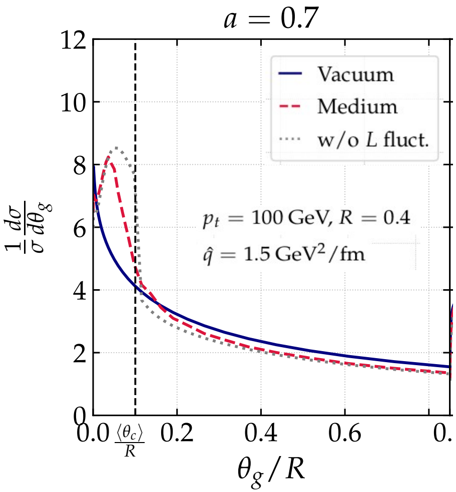
- DyG can select a semi-hard MIEs inside the jet.
- From the factorization:

$$\widetilde{P}_{\rm vac}(z,\theta) \to \widetilde{P}_{\rm vac}(z,\theta) + \underbrace{\bar{\alpha}_s \sqrt{\frac{\hat{q}L^2}{z^3 p_t}} \mathcal{B}(z,\theta)}_{\sim \text{BDMPS-Z}}$$

- Minimal angle of semi-hard MIEs, $\theta \sim Q_s/\omega_c \sim \theta_c \Rightarrow$ transition around θ_c.

Analytic toy calculation

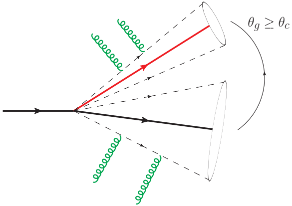
θ_c dependent large angle energy loss:

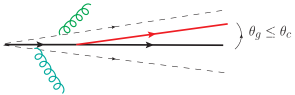


- Coherence angle $\theta_c \sim 2/\sqrt{\hat{q}L^3}$ measures resolution power of the medium.

  Mehtar-Tani, Salgado, Tywoniuk, 2011 - Casalderrey-Solana, Iancu, 2011

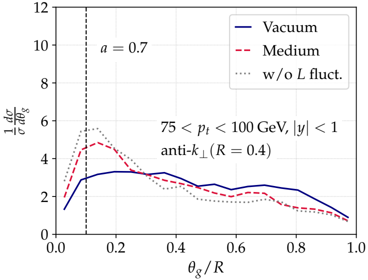
- Jets with $\theta_g \geq \theta_c$ lose more energy.
- θ_g dependent energy loss implemented using quenching weights.





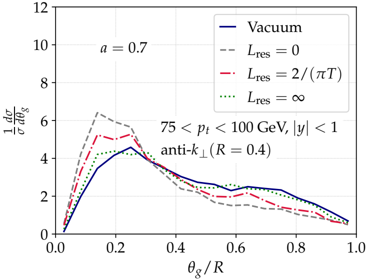
Dependence upon jet quenching model

- Many jet quenching models have a notion of "resolution scale" incorporated.
- Example: L_{res} parameter in the Hybrid strong-weak coupling model.
  Casalderrey-Solana, Gulhan, Hulcher, Milhano, Pablos, Rajagopal, 2015-17
- Need for an "orthogonal" observable to discriminate between models.



MC JetMed (weak coupling picture)

PC, Iancu, Mueller, Soyez, 2018

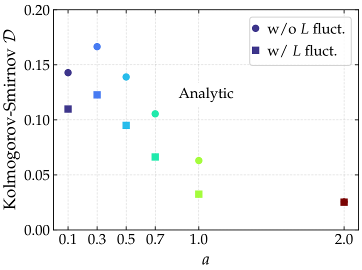


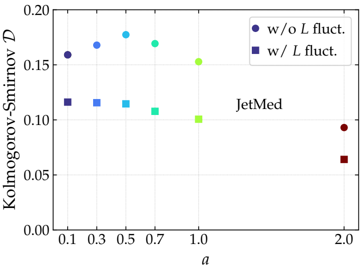
MC Hybrid model (hybrid strong/weak coupling picture)

Best experimental set-up

- Kolmogorov-Smirnov distance measures the difference between the medium and vacuum baseline. $KS = \max|\Sigma_{\mathrm{PbPb}}(\theta_g) - \Sigma_{\mathrm{pp}}(\theta_g)|$
- Analytic results confirm our numerical findings.
- "Ideal" set-up:

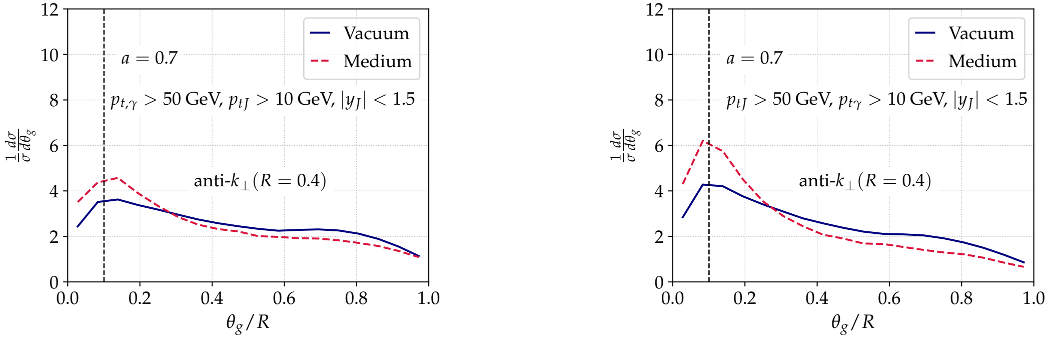
$$0.5 \lesssim a \lesssim 1 \quad \text{and} \quad \underbrace{R = 0.2}_{\text{reduce medium response and background effects}}$$





sPHENIX opportunities: θ_g distribution in γ-jet events

- Theoretical analysis that should be taken with a grain of salt.
- γ-jet events reduce the effect from quark-gluon mixture,
- and help to quantify the selection bias effect. See Brewer, Brodsky, Rajagopal, 2110.13159



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.
- In heavy-ion collisions, observable strongly sensitive to the coherence angle θ_c of the plasma, even when selection bias are reduced as in γ-jet events.
- Further studies are necessary to see if a measurement in γ-jet is realistic at RHIC with STAR or sPHENIX.

THANK YOU !