Isolating perturbative QCD splittings in heavy-ion collisions

[Phys. Rev. D 110, 014015 (2024)]

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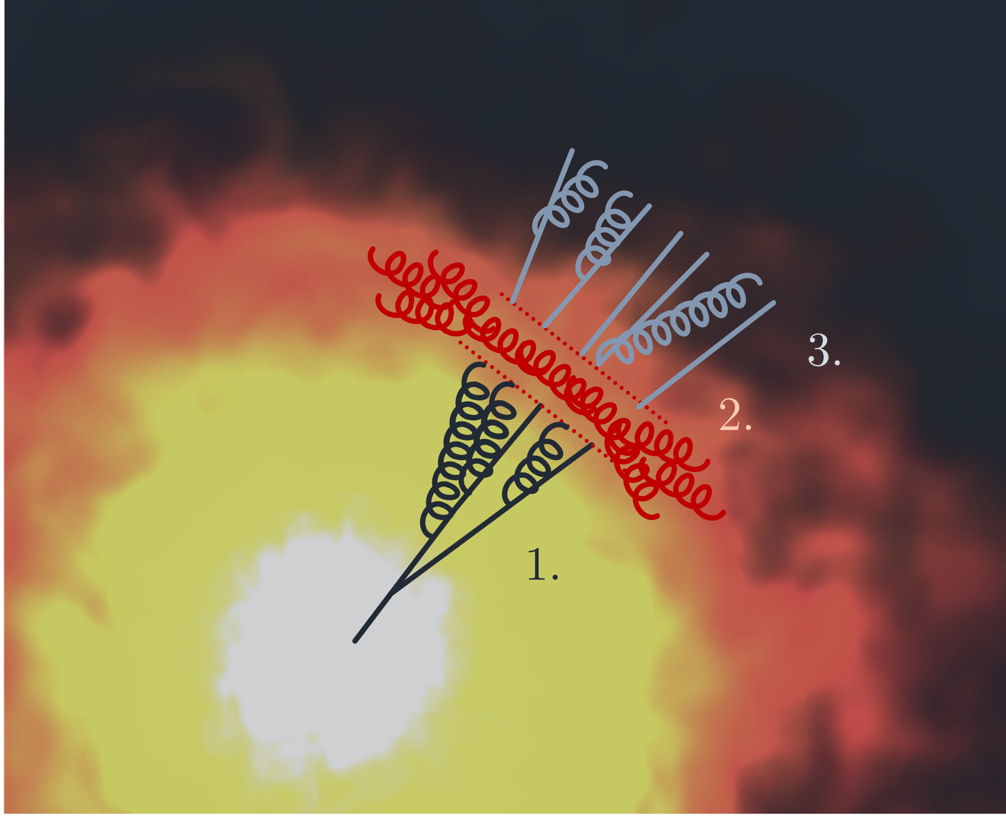
SoftJet 2024, Tokyo, Japan

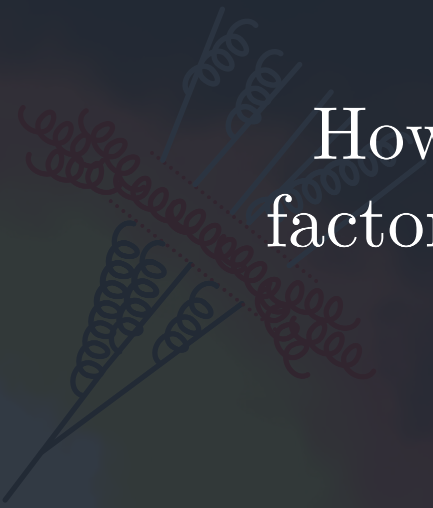
Introduction



Factorized picture of jet evolution:

1. Early vacuum evol.
2. Energy-loss
3. Out-of-medium vacuum evol.

Introduction



Factorized picture:

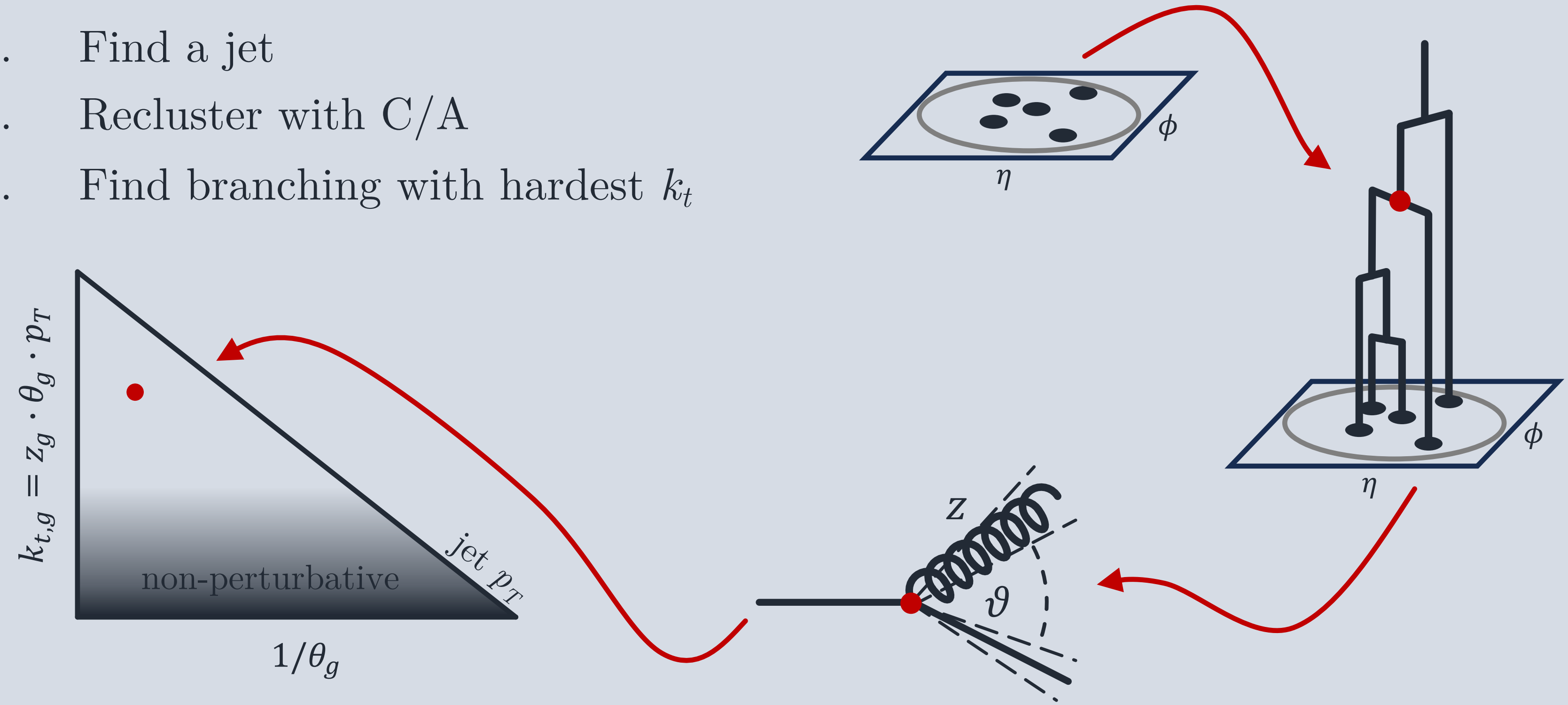
1. Early vacuum evol.
2. Energy-loss
3. Out-of-medium vacuum evol

How to test the factorized picture?

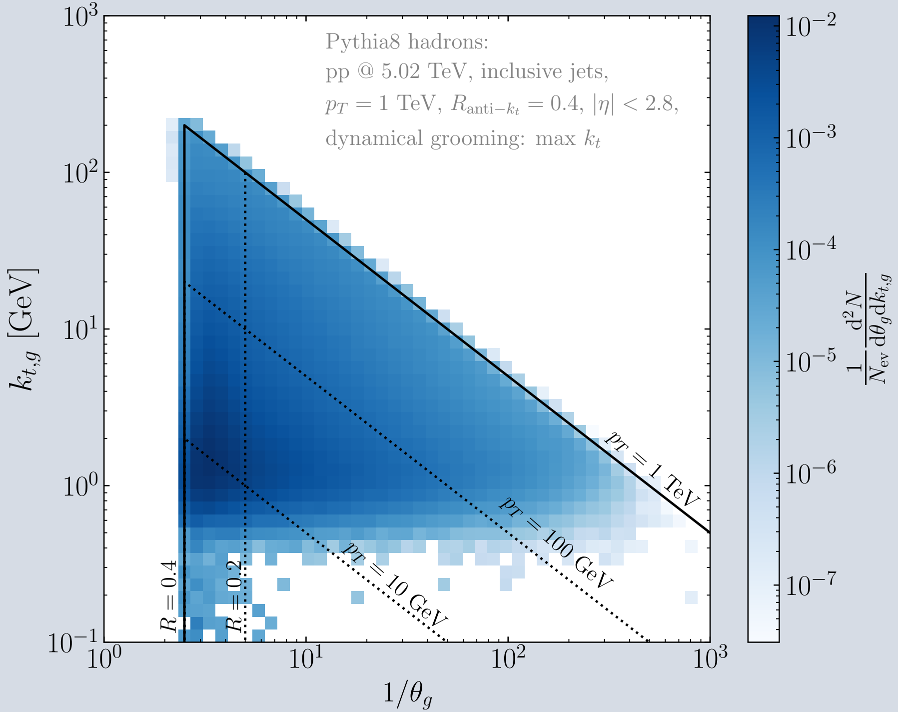
Hardest splitting in jets

Dynamical grooming:
[Mehtar-Tani, Soto-Ontoso, Tywoniuk]
[Caucal, Soto-Ontoso, Takacs]
[ALICE, JHEP 05 (2023) 244]
[ATLAS, PRC 107 (2023) 054909]

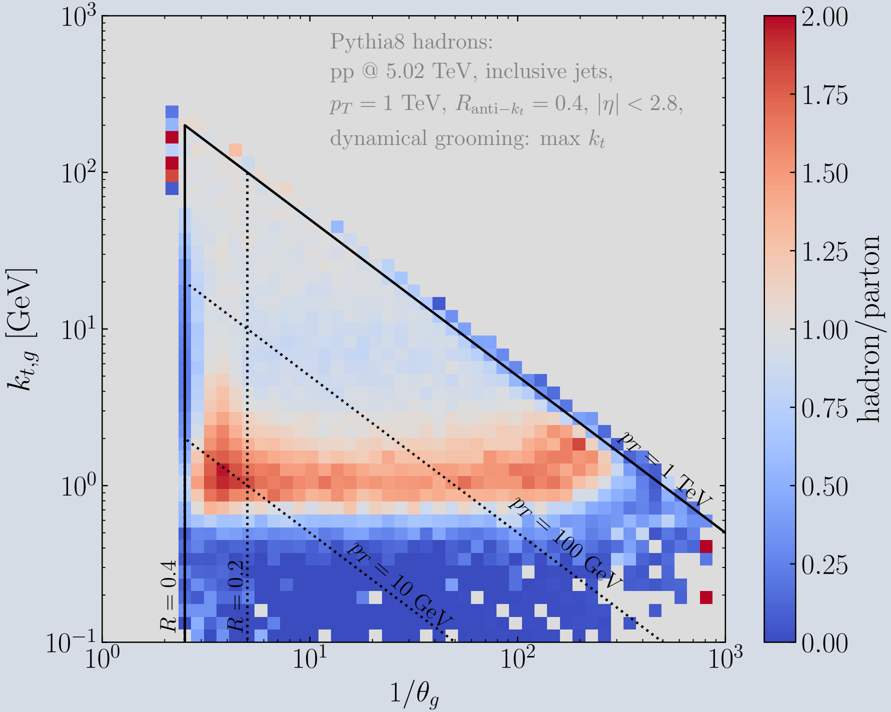
1. Find a jet
2. Recluster with C/A
3. Find branching with hardest k_t



Hardest splitting in jets

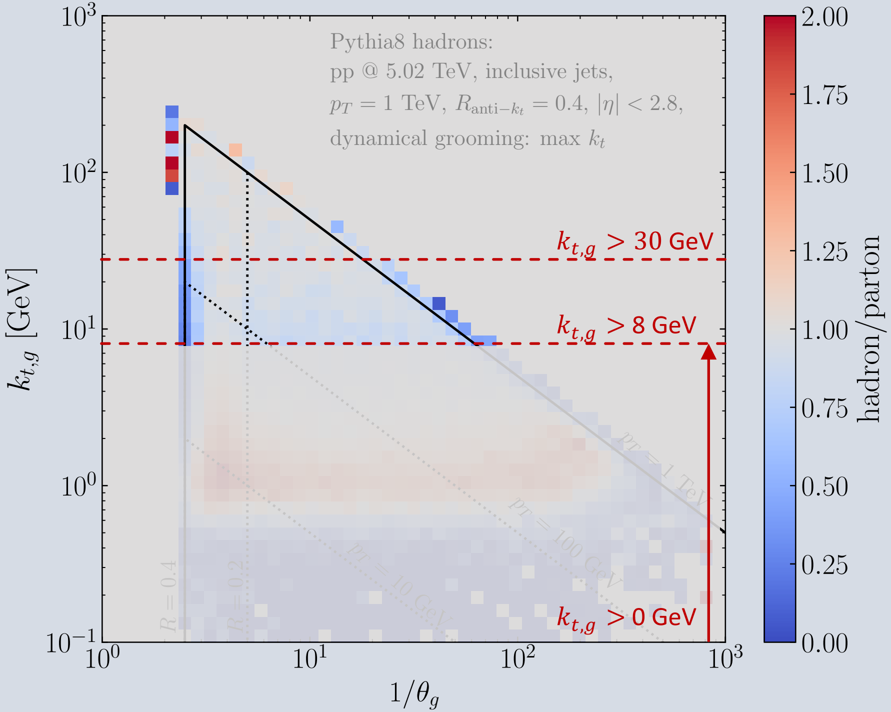


Hardest splitting in jets



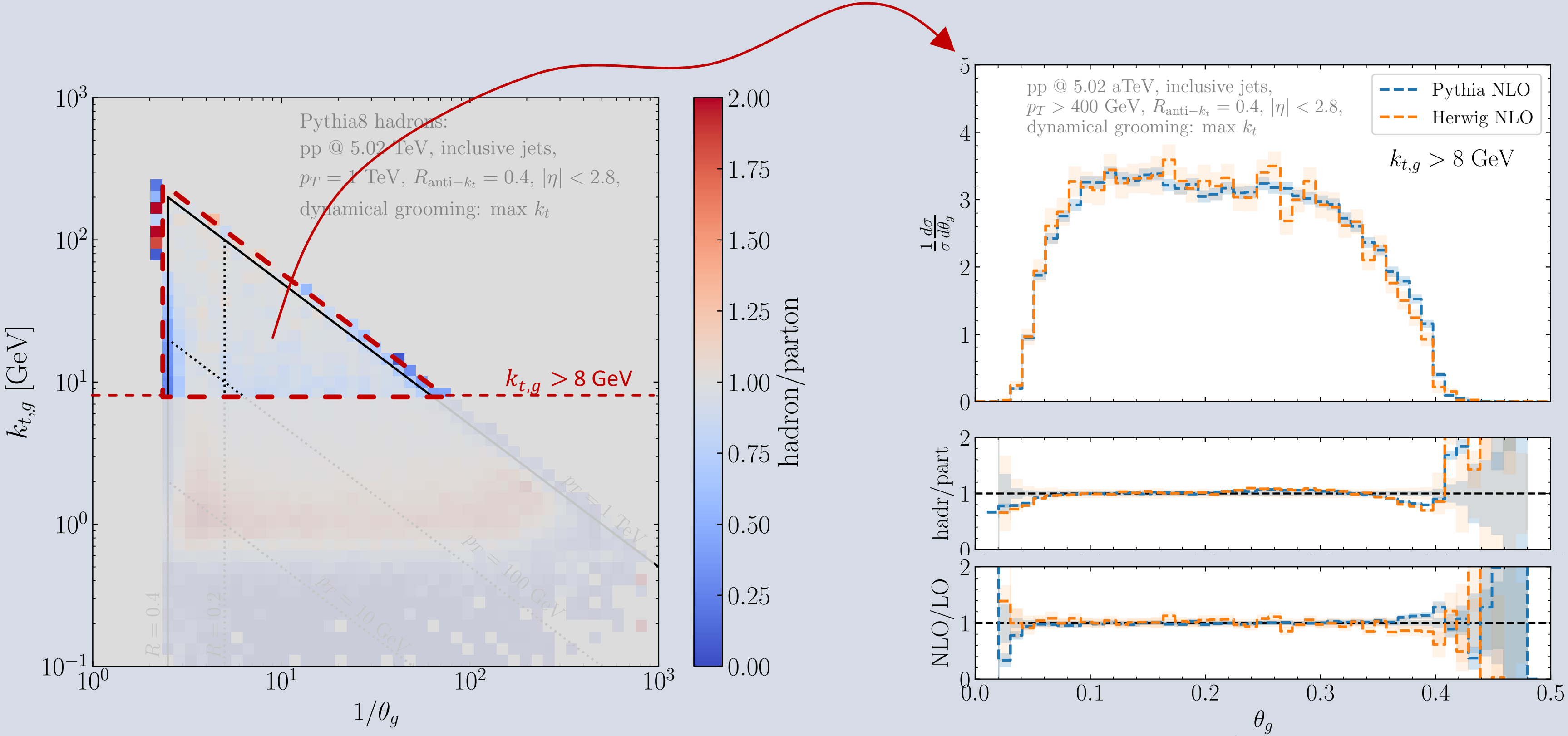
- Higher energy = more perturbative
- Low k_t = non-pert. corrections

Hardest splitting in jets



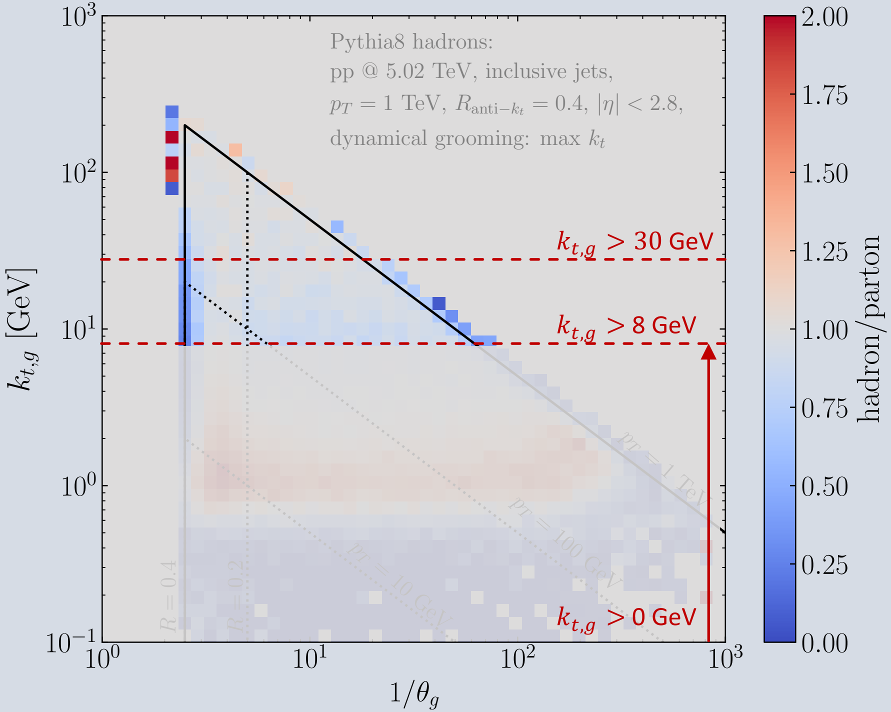
- Higher energy = more perturbative
- Low k_t = non-pert. corrections
- Cuts on k_t

Hardest splitting in jets



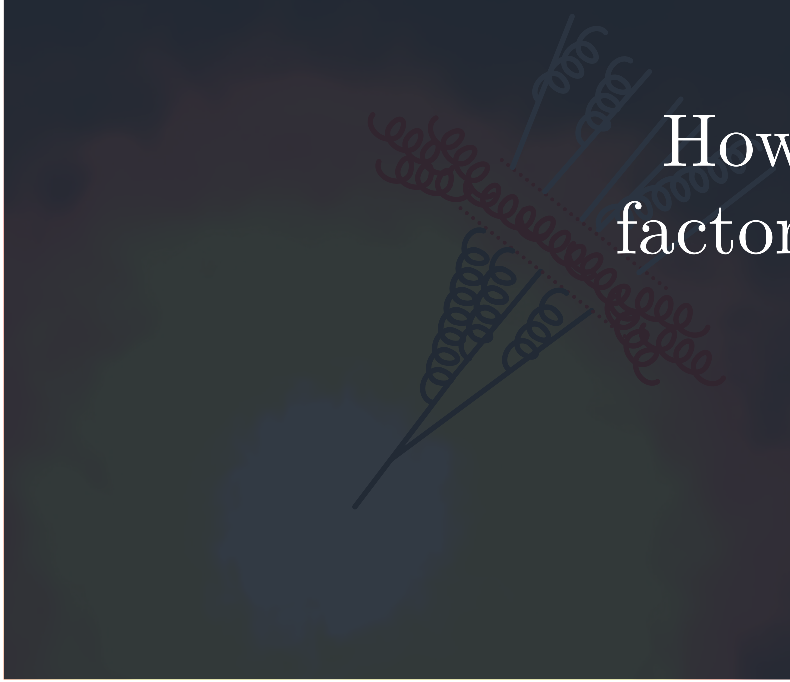
*Reduce p_{T} to 400 GeV to enhance statistics.

Hardest splitting in jets



- Higher energy = more perturbative
- Low k_t = non-pert. corrections
- Cuts on k_t
- Solid pp baseline!

Introduction



Factorized picture:

1. Early vacuum evol.
2. Energy-loss
3. Out-of-medium vacuum evol

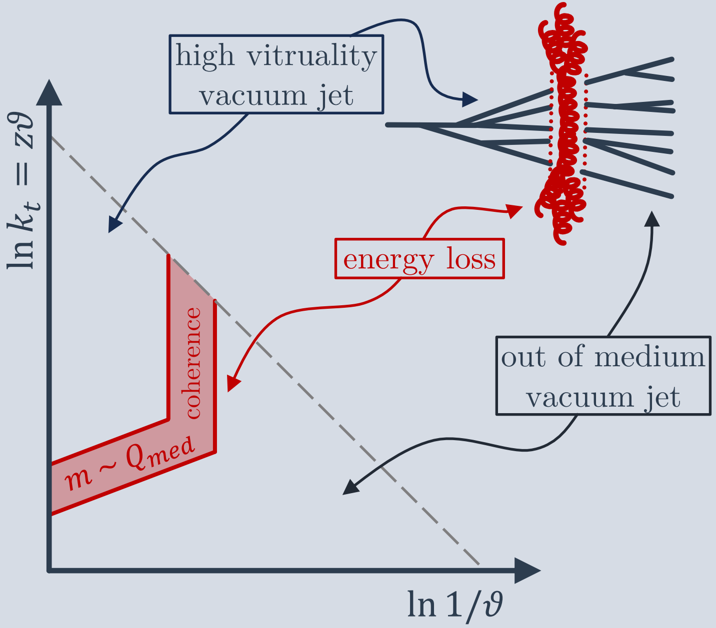
How to test the factorized picture?

Jet evolution in QGP

[Mehtar-Tani, Tywoniuk, Salgado]
[Caucal, Iancu, Mueller, Soyez]

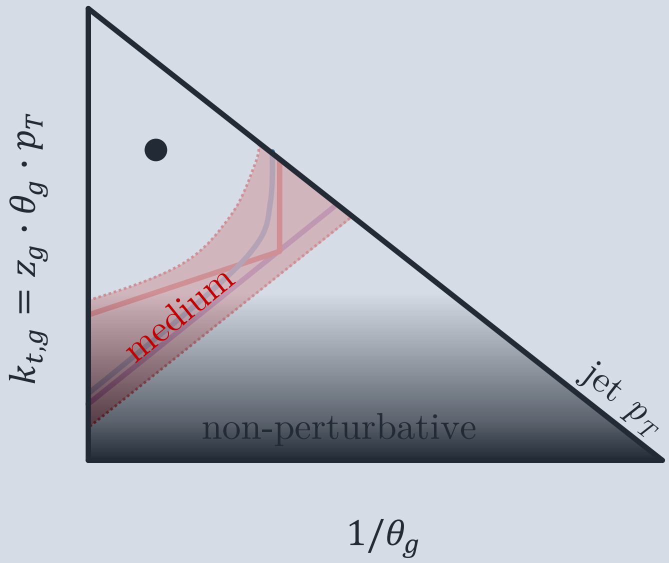
Factorized picture:

1. High virtuality: vacuum evolution*
   (not all model has this)
2. Low virtuality $\sim Q_{med}$: energy loss
   (very different eloss models)
3. Out of medium: vacuum evolution*
   (not all model has this)



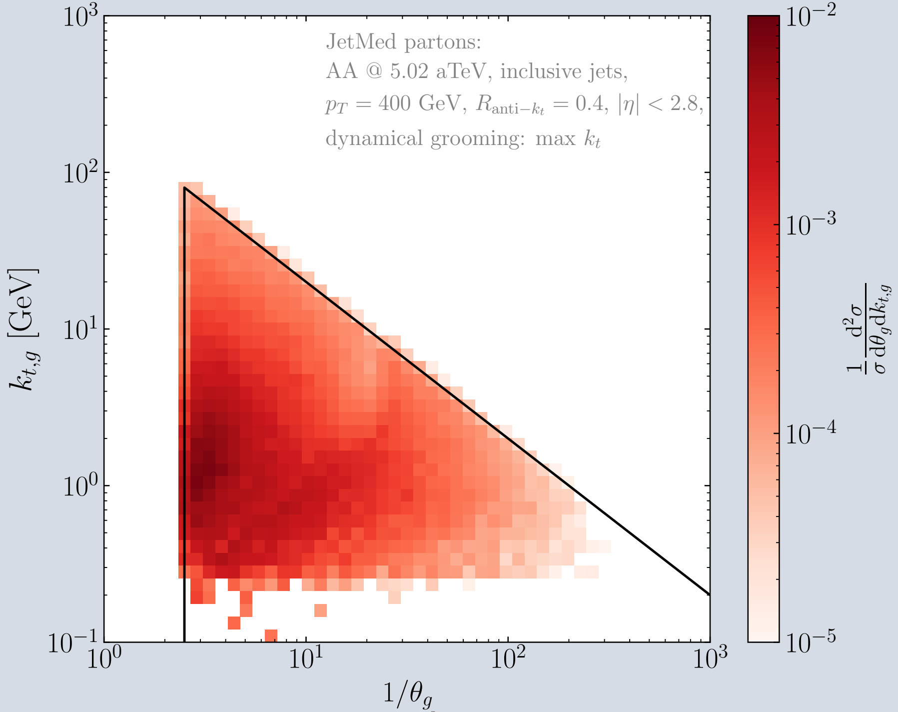
*Modifications appear beyond the leading accuracy.

Hardest splitting in quenched jets



- Different boundaries

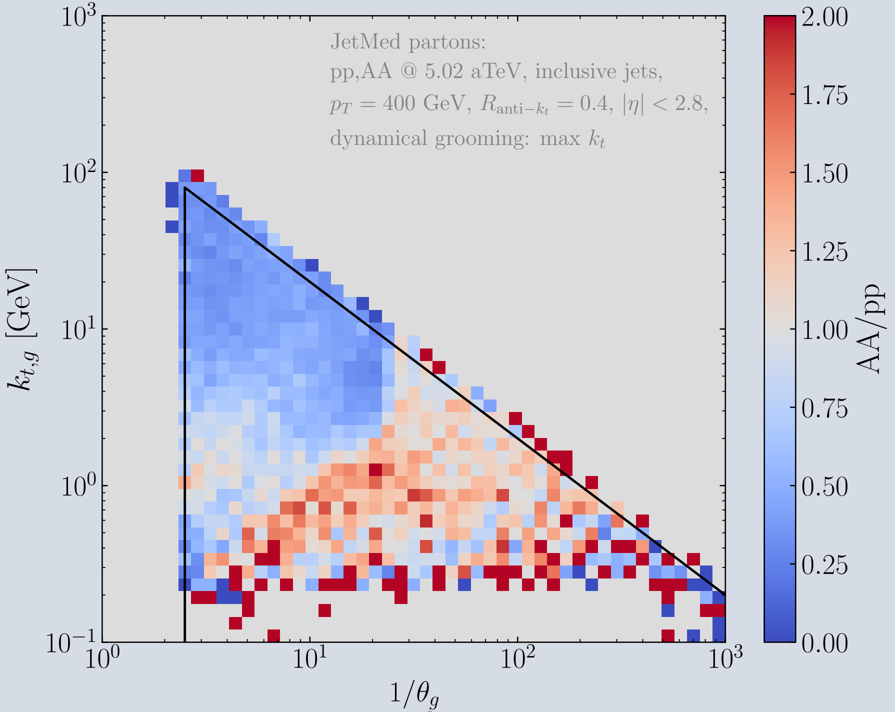
Hardest splitting in quenched jets



[JetMed: Caucal, Iancu, Mueller, Soyez]

- Different boundaries

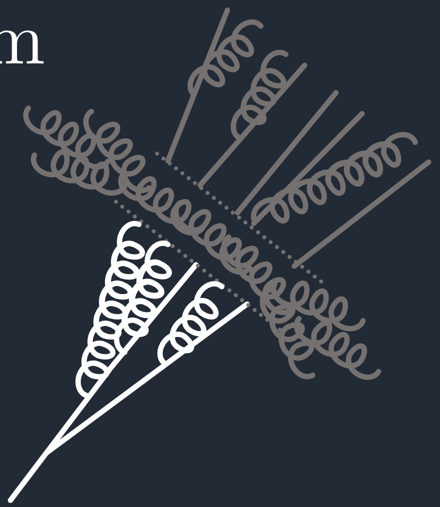
Hardest splitting in quenched jets



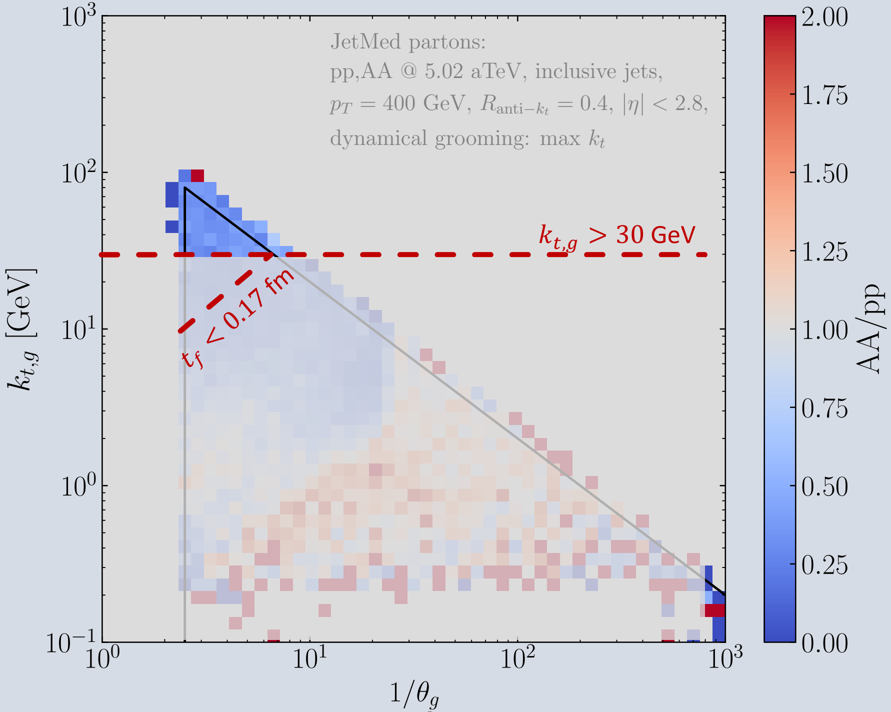
[JetMed: Caucal, Iancu, Mueller, Soyez]

- Different boundaries

I. Test of early vacuum evolution



Hardest splitting in quenched jets (high-k_t)

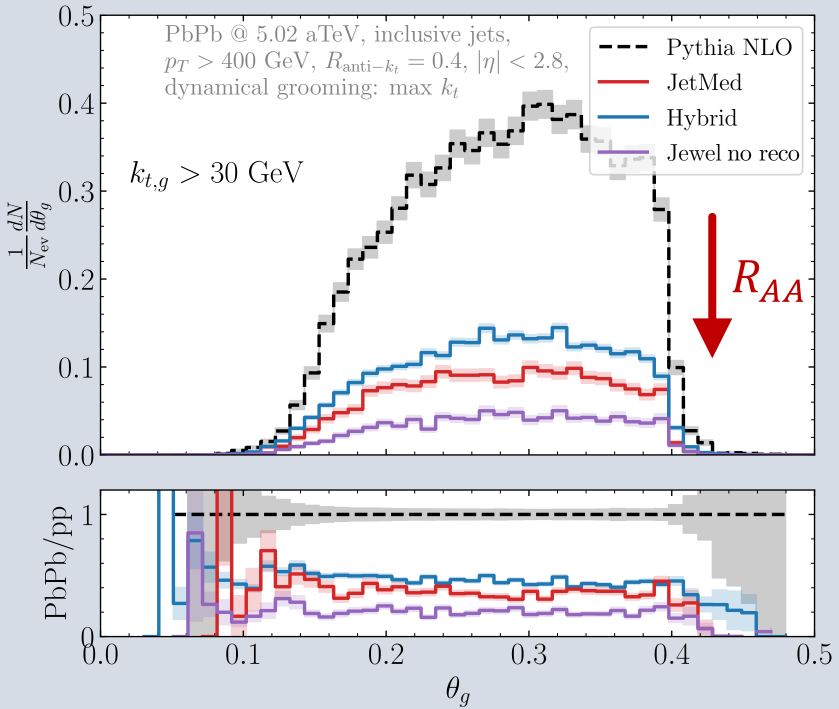


[JetMed: Caucal, Iancu, Mueller, Soyez]

- Different boundaries
- $k_{t,\text{cut}}$ for very hard emissions
- very early emissions!

Hardest splitting in quenched jets (high-k_t)

- less jets = R_{AA}, self-normalize!

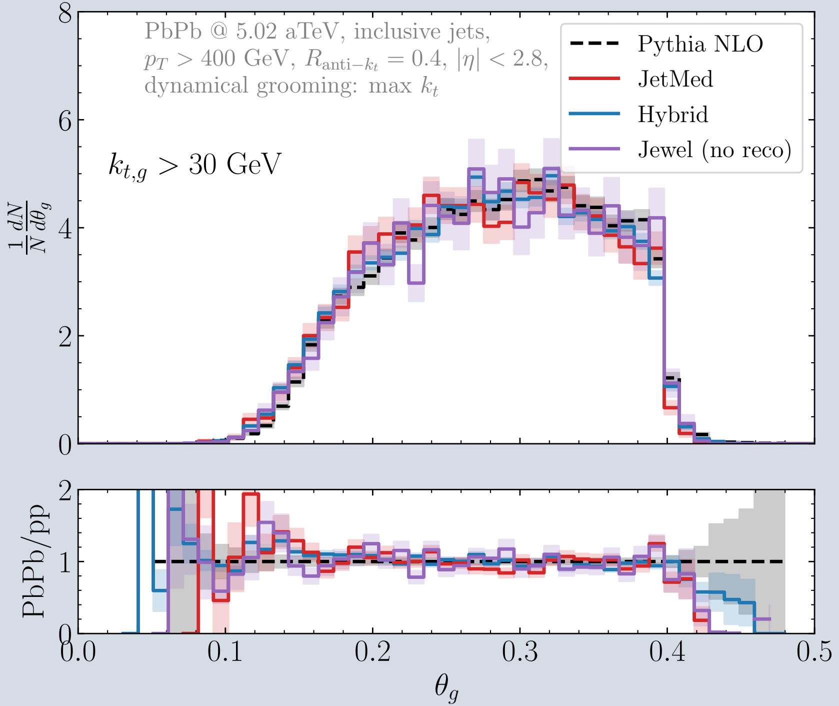


[JetMed: Caucal, Iancu, Mueller, Soyez]
[Hybrid: Casalderrey-Solana,Gulhan,Milhano,Pablos, Rajagopal]
[Jewel: Zapp, Krauss, Stachel, Wiedemann]

Hardest splitting in quenched jets (high-k_t)

- less jets = R_{AA}, self-normalize!
- no modification:

  pp = AA = most models
- vacuum-like baseline in AA!



[JetMed: Caucal, Iancu, Mueller, Soyez]
[Hybrid: Casalderrey-Solana,Gulhan,Milhano,Pablos, Rajagopal]
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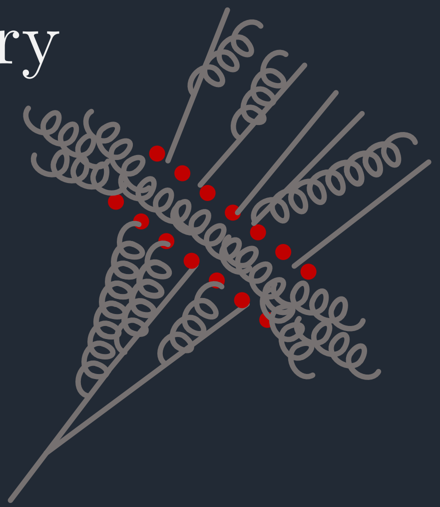
II. Test of the boundary and color coherence

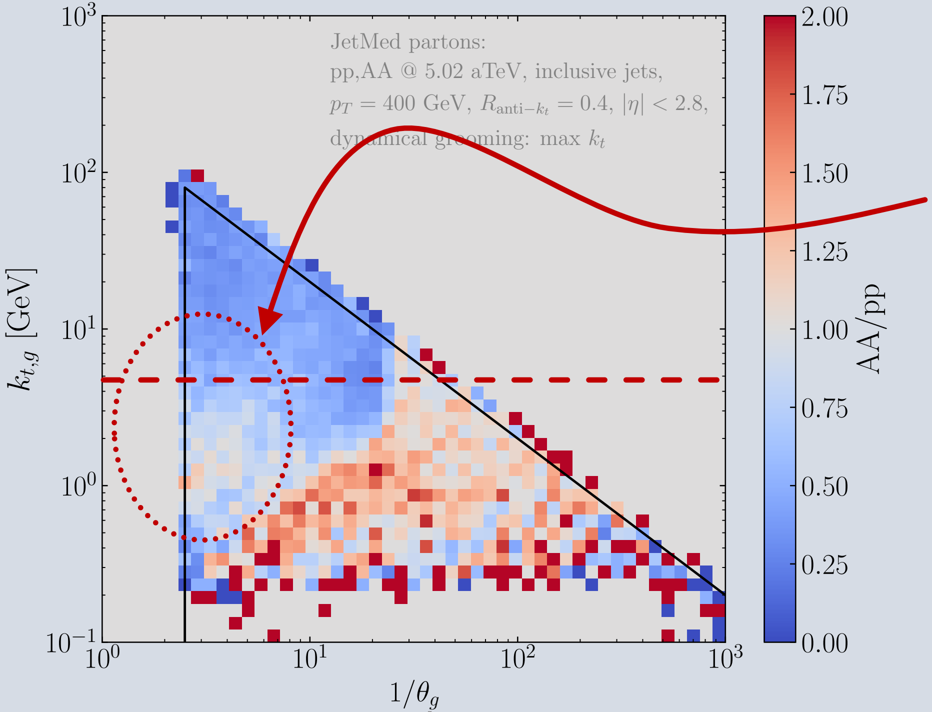
(more on this in Hard Probes)



III. Test of medium response

(and medium induced radiation)

Hardest splitting in quenched jets



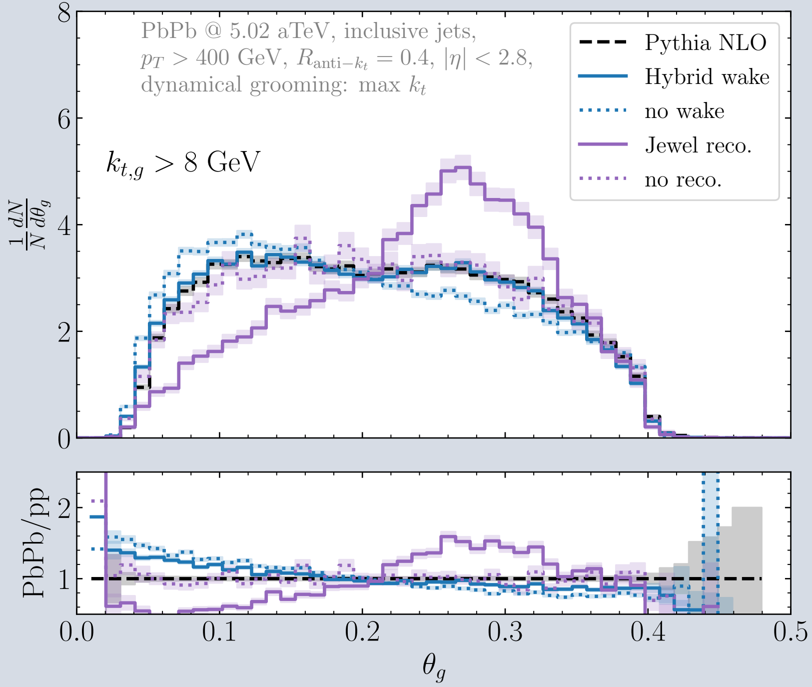
[JetMed: Caucal, Iancu, Mueller, Soyez]

- Medium response (and medium induced radiation): not collinear, not hard

Hardest splitting in quenched jets (mid-k_t)

- less jets = R_{AA}, self-normalize!
- modification in shape!
- test of jet thermalization!

+1 study soft?



[Hybrid: Casalderrey-Solana,Gulhan,Milhano,Pablos, Rajagopal]
[Jewel: Zapp, Krauss, Stachel, Wiedemann]

IV. Experimental aspects

Reconstructing the hardest splitting

- Expected luminosity ~ 13 nb^{-1}

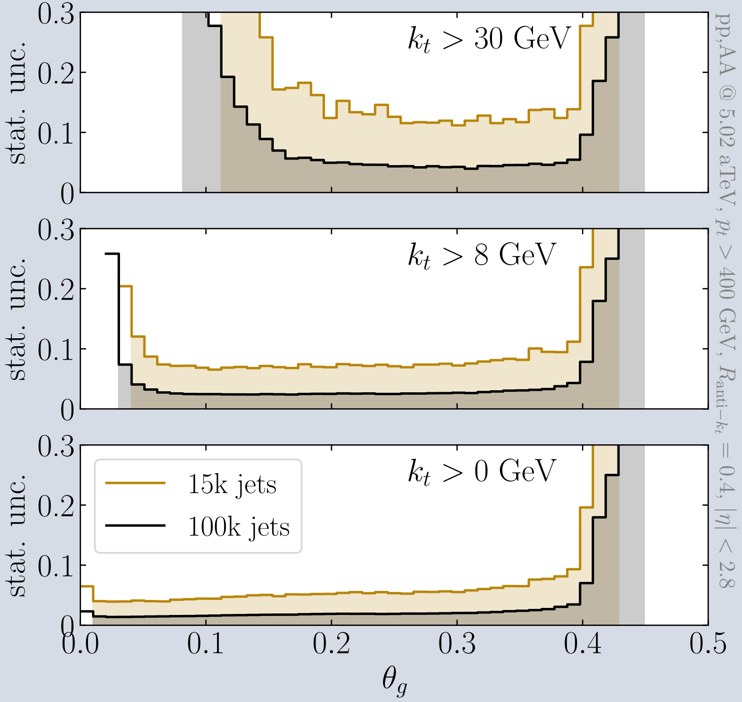
  (15k jets above 400 GeV)

- Measuring small angles: $\theta_g \sim 0.01$

  (for color coherence)

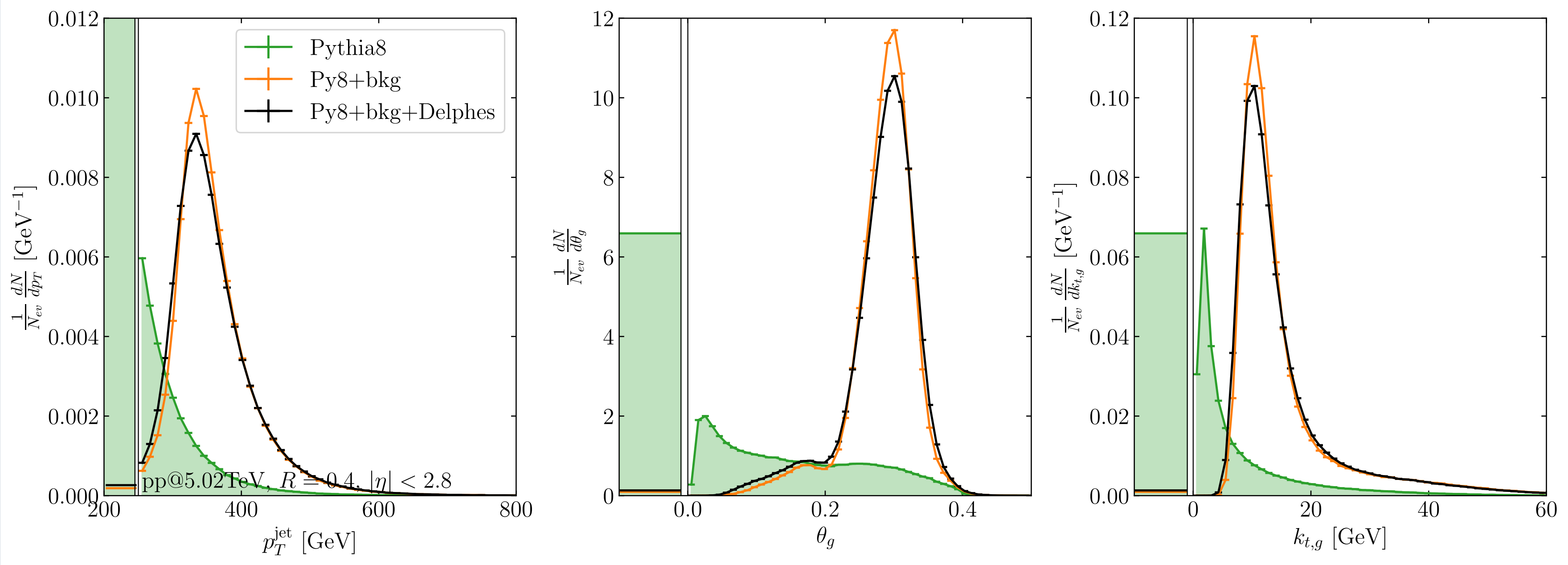
- Unfolding at small k_t cut

  (for soft wake and medium induced radiation)



Unfolding example

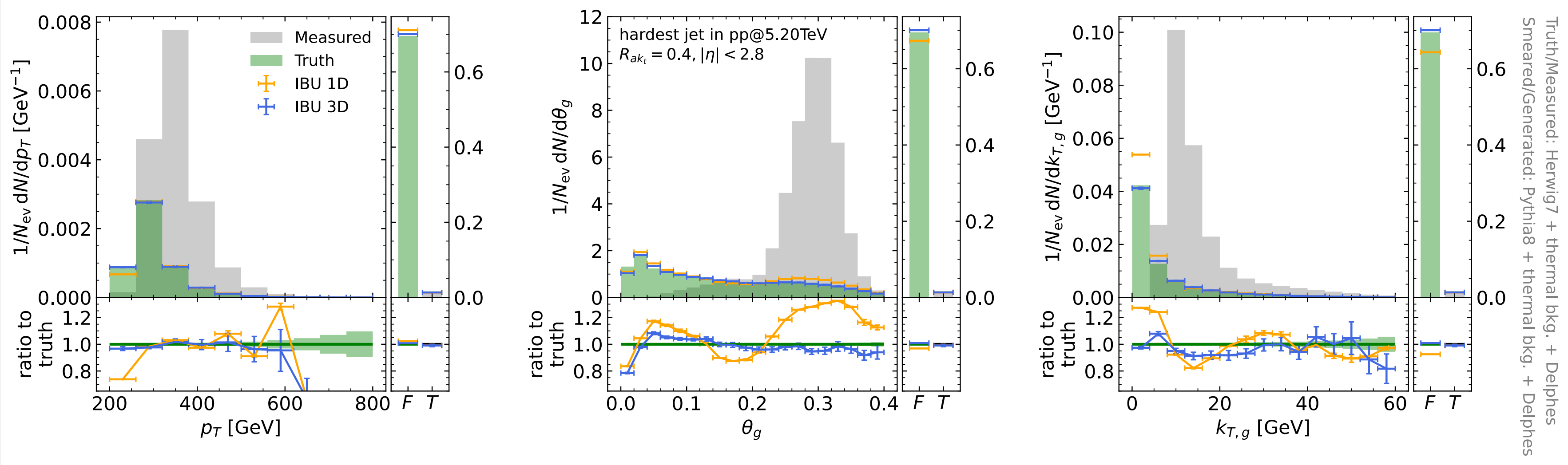
- 3 observables: $p_T^{jet}, \theta_g, k_{t,g}$



Unfolding example

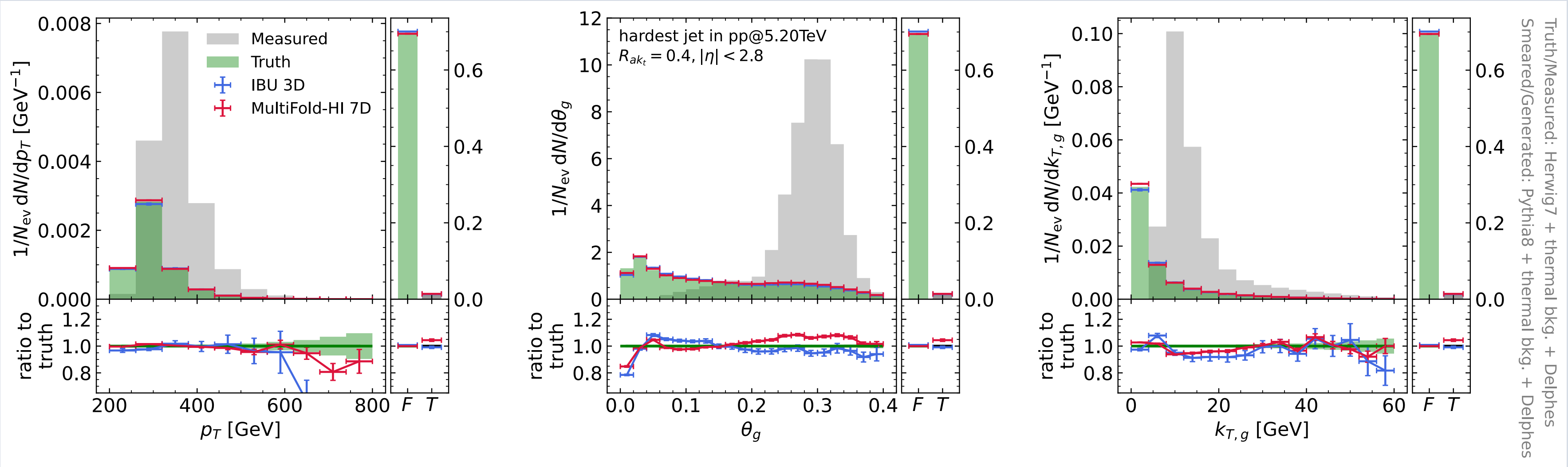
- Iterative Bayesian Unfolding: $p(tru) = \int dmeas\ \underbrace{p(tru|meas)}_{\text{response matrix}}\ p(meas)$

(includes bkg+Delphes)



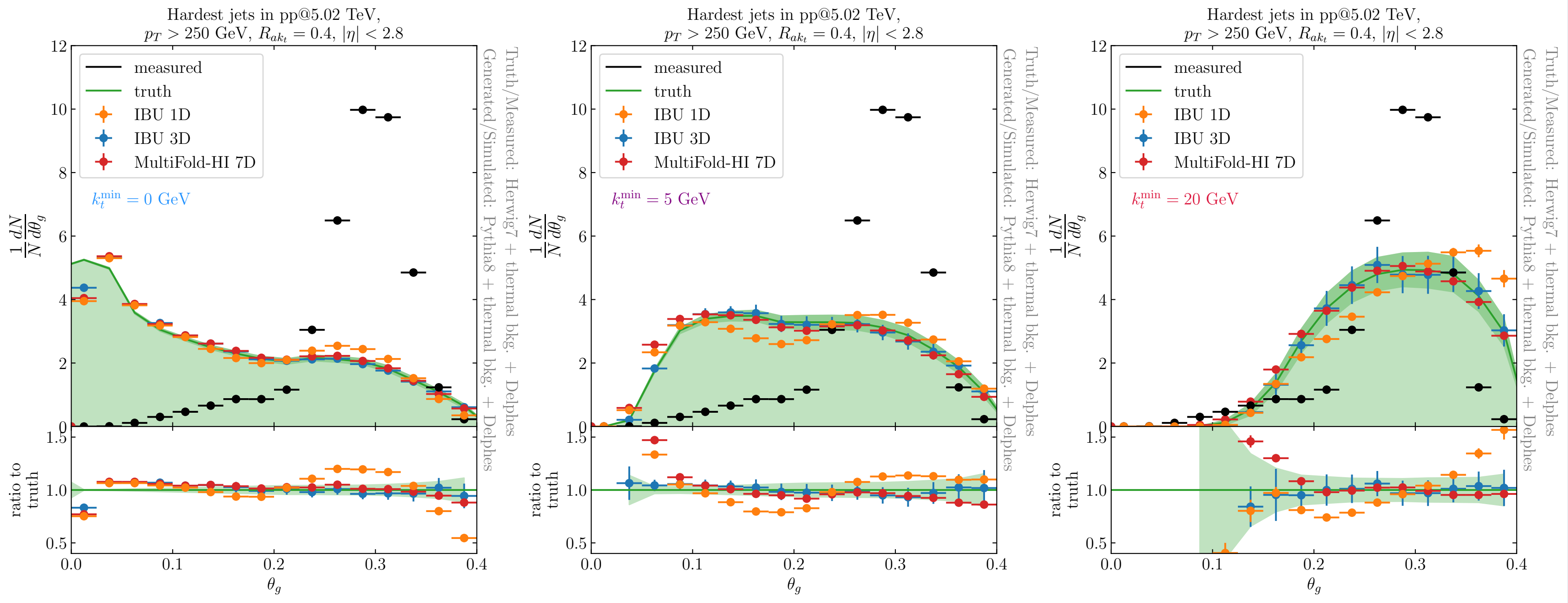
Unfolding example

- Iterative Bayesian Unfolding extending to higher dimensions (OmniFold-HI)



Unfolding example

- Applying the ktg cuts!

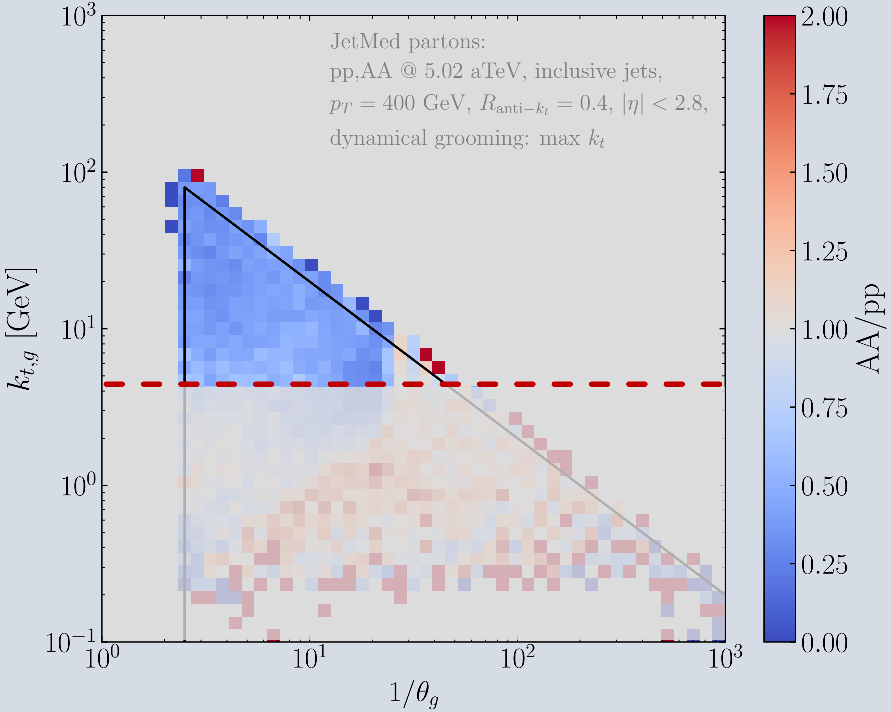


Summary: perturbative splittings in AA

1. high kt:
   - test of mode separation
   - vacuum-like baseline in AA collision
2. moderate kt:
   - test of color resolution
   - test of jet thermalization
   - new baseline for AA collision
3. Outlook:
   - low kt: test of induced emissions [Alexander Falcao talk on Tue]
   - measurement [Vangelis Vladimirov (CMS) talk on Mon]

Thank you for your attention!

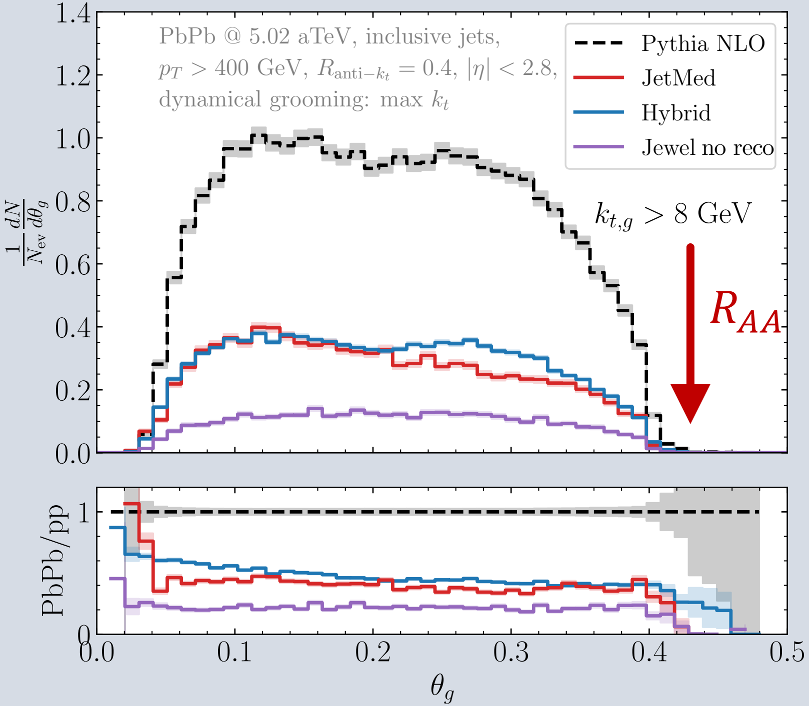
Hardest splitting in quenched jets (mid-k_t)



- Different boundaries
- $k_{t,\mathrm{cut}}$ for perturbative emissions
- not so early emissions!

Hardest splitting in quenched jets (mid-k_t)

- less jets = R_{AA}, self-normalize!



[JetMed: Caucal, Iancu, Mueller, Soyez]
[Hybrid: Casalderrey-Solana,Gulhan,Milhano,Pablos, Rajagopal]
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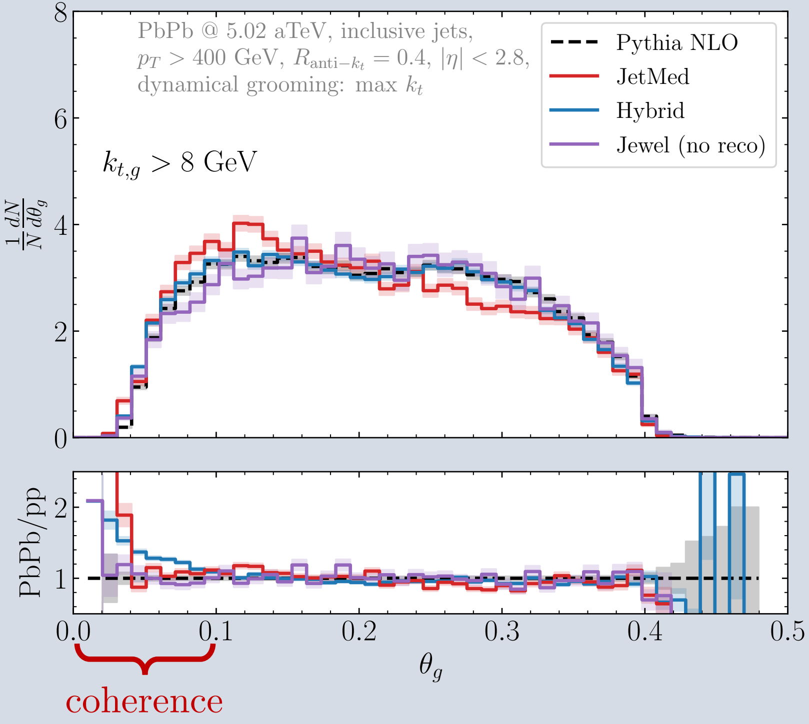
Hardest splitting in quenched jets (mid-k_t)

- less jets = R_{AA}, self-normalize!
- modification in shape!
- test of color resolution!



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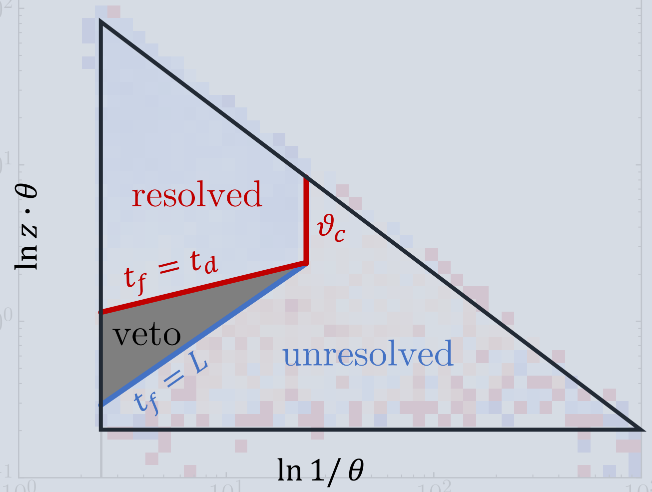
Hardest splitting in quenched jets

Quick reminder of JetMed



- Multiple soft scattering approximation in infinite plasma
- vacuum-like emissions undisturbed:

$$t_f < t_d < L$$

- wide angle energy loss of resolved emissions

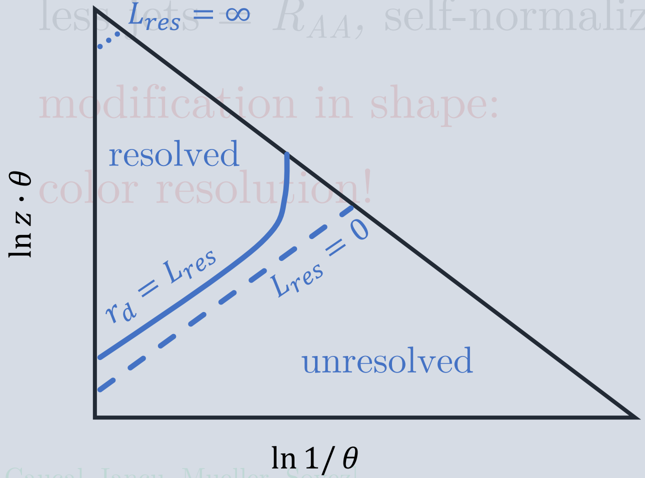
Medium scales

[JetMed: Caucal, Iancu, Mueller, Soyez]

Hardest splitting in quenched jets

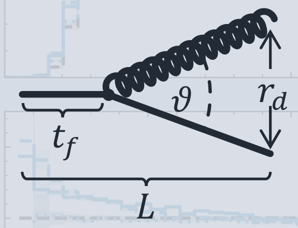
Quick reminder of Hybrid

- less jets = R_{AA}, self-normalize!
- modification in shape:
- color resolution!



- vacuum emissions are undisturbed:
- energy loss of resolved emissions:

$$r_d = (L - t_f)\theta > L_{res}$$



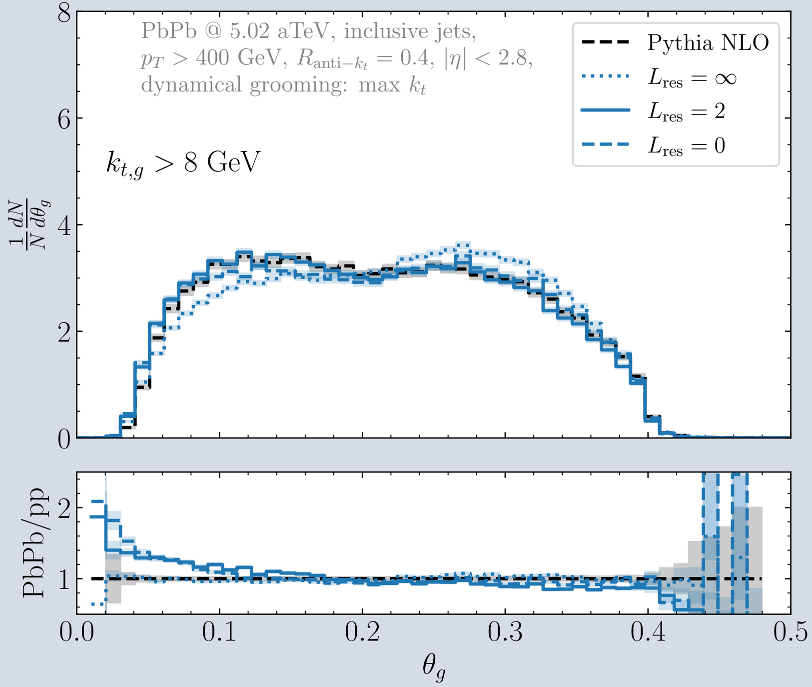
- 2+1D hydro

[JetMed: Caucal, Iancu, Mueller, Soyez]
[Hybrid: Casalderrey-Solana,Gulhan,Milhano,Pablos, Rajagopal]
[Jewel: Zapp, Krauss, Stachel, Wiedemann]

coherence

Hardest splitting in quenched jets (coherence)

- less jets = R_{AA}, self-normalize!
- modification in shape!
- test of color resolution!



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The Jewel model

1. Generate Pythia6 event with nPDFs without FSR

2. Time and formation time are the same

3. Vacuum radiation or elastic scattering every timestep

$$-\ln S_{rad}(t,t_0) = \int_{t_0}^{t} \frac{dt}{t} \int dz \frac{\alpha_s}{\pi} P(z)$$

$$-\ln S_{el}(t,t_0) = \frac{t-t_0}{\lambda_{mfp}}$$

4. Elastic scatterings reset the shower scale, multiple scatterings are suppressed ("LPM")

5. The recoiler from 2-2 scatterings freestream