Exploring perturbative QCD splittings in heavy-ion collisions

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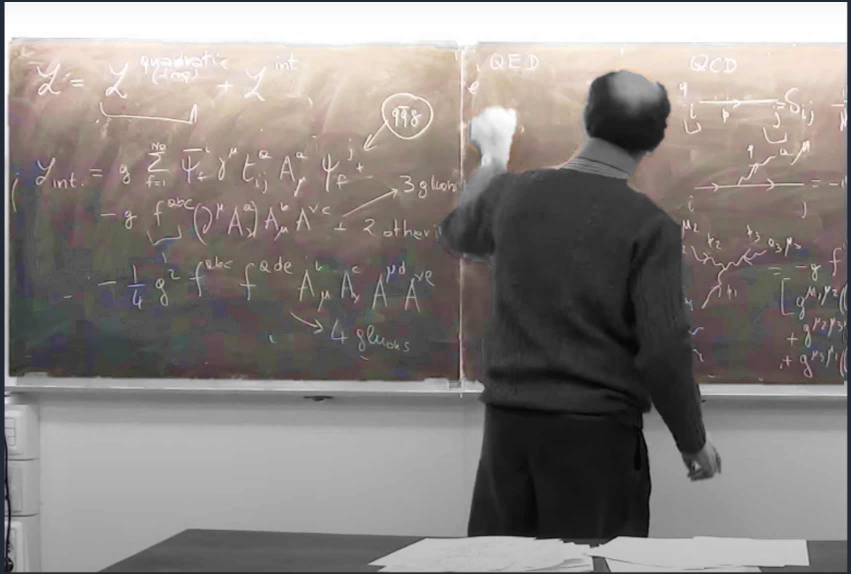
Probing QCD at High Energy and Density with Jets 2023, Seattle

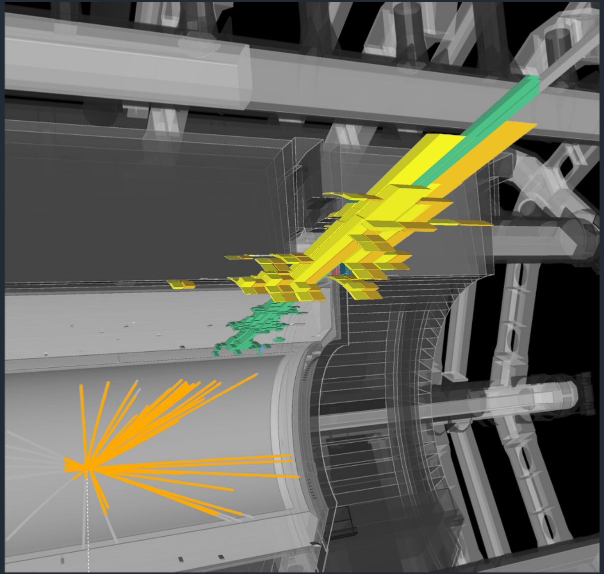
Introduction

theory



[S, Catani's lectures on yt]

observation



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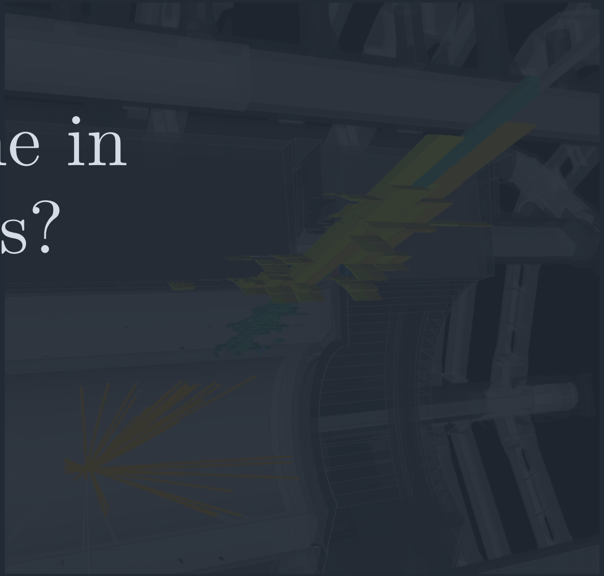
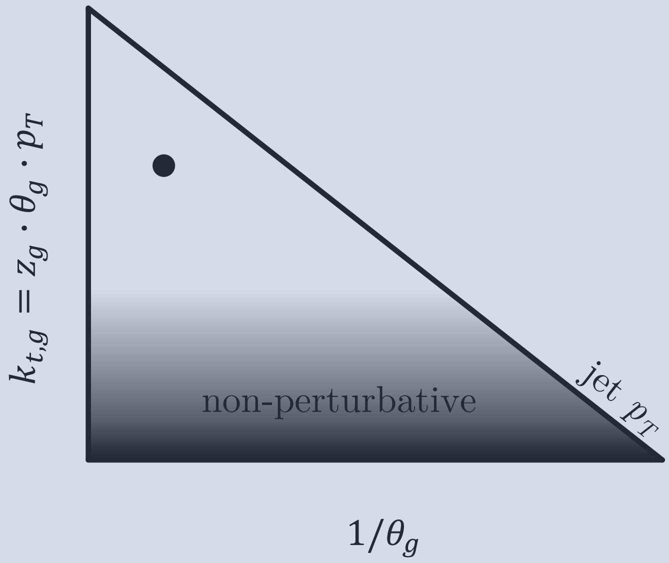


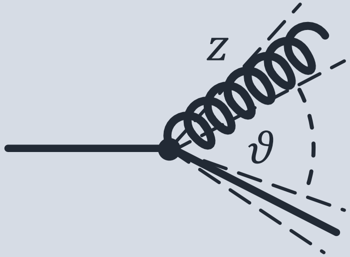
How is it done in pp collisions?

Hardest splitting in jets

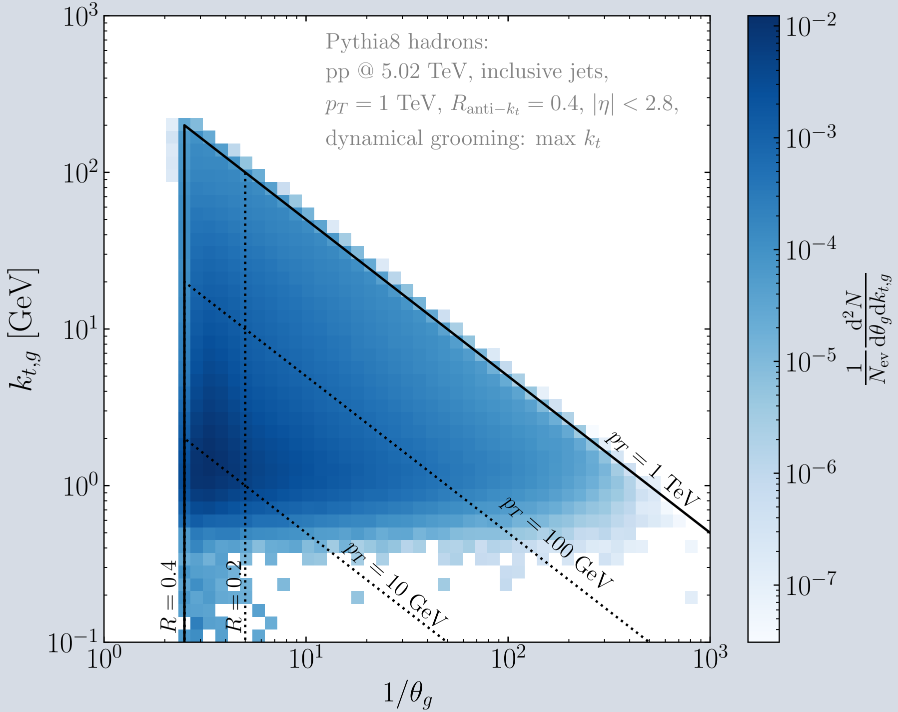
[Mehtar-Tani, Soto-Ontoso, Tywoniuk]
[Caucal, Soto-Ontoso, Takacs]
[ALICE, JHEP 05 (2023) 244]
[ATLAS, PRC 107 (2023) 054909]



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

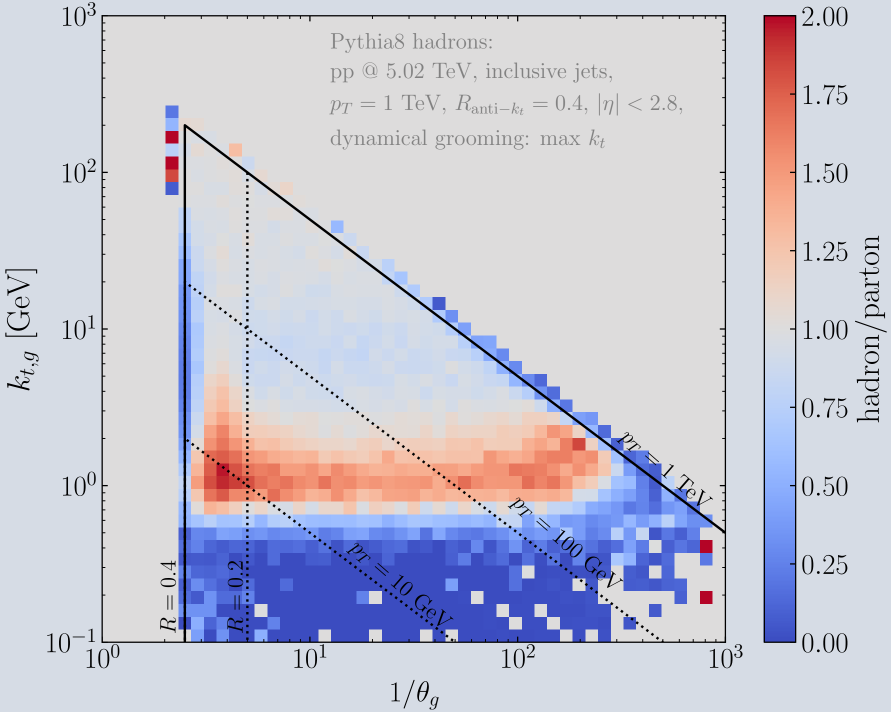


Hardest splitting in jets



- Higher energy = more perturbative

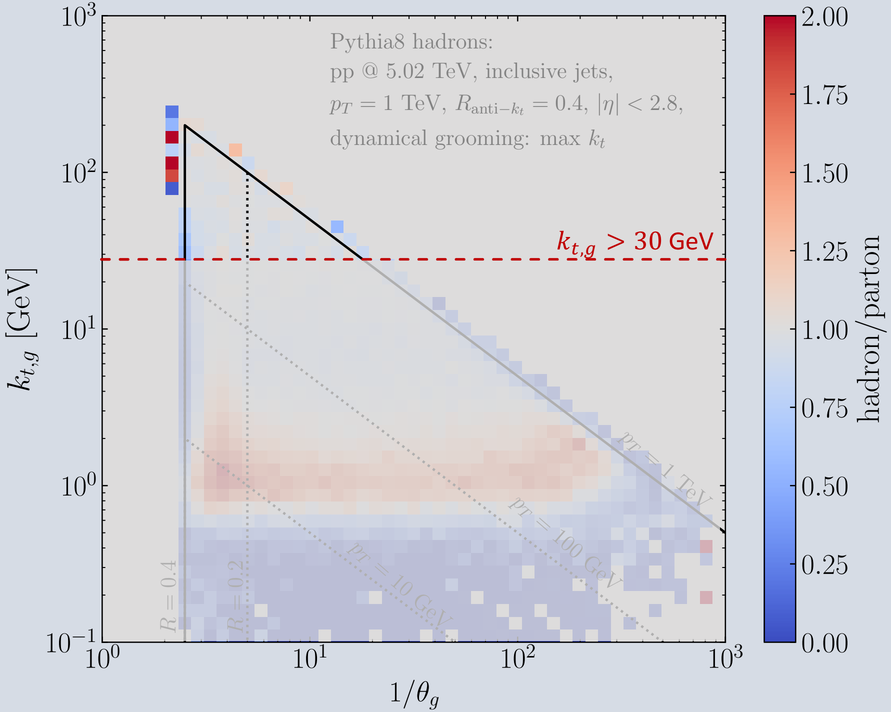
Hardest splitting in jets

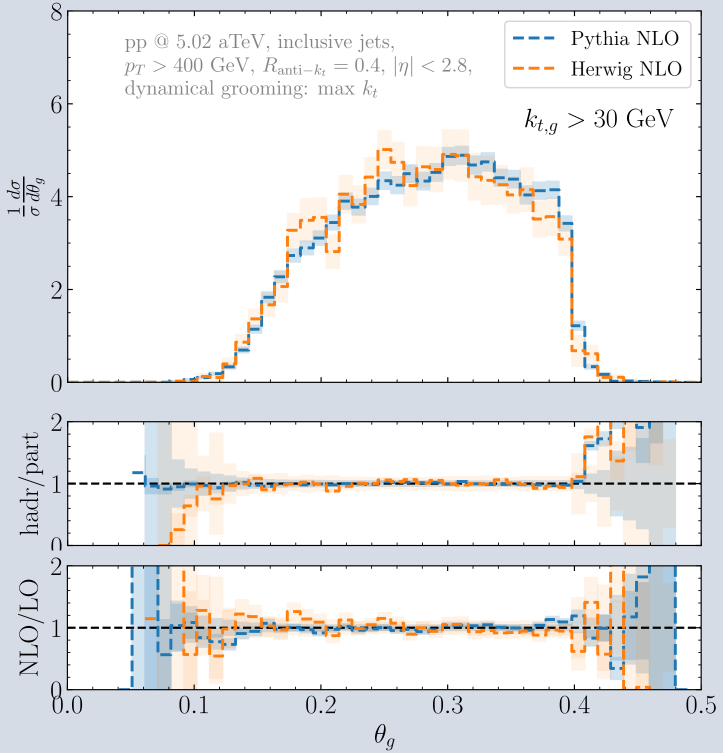


- Higher energy = more perturbative
- Low k_t = non-pert. corrections
- Cut on k_t to reduce corrections
- ($p_T > 400$ GeV to enhance stat.)

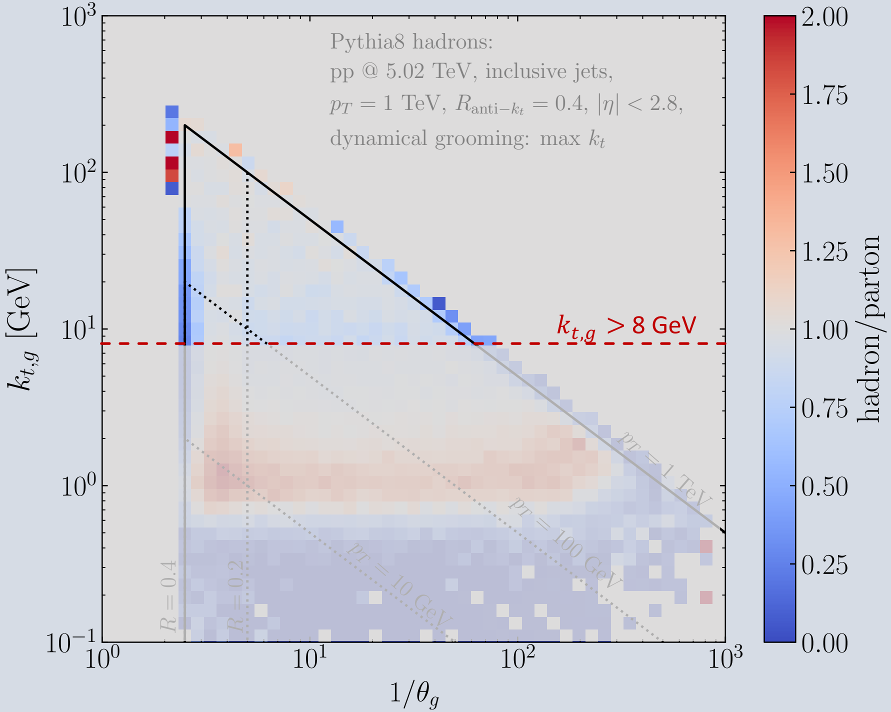
Ask for more explanation!

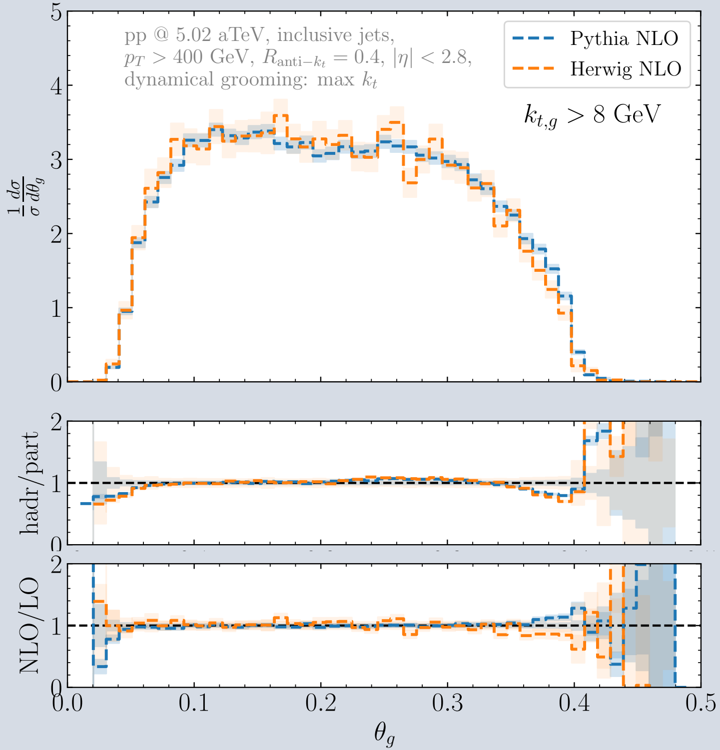
Hardest splitting in jets



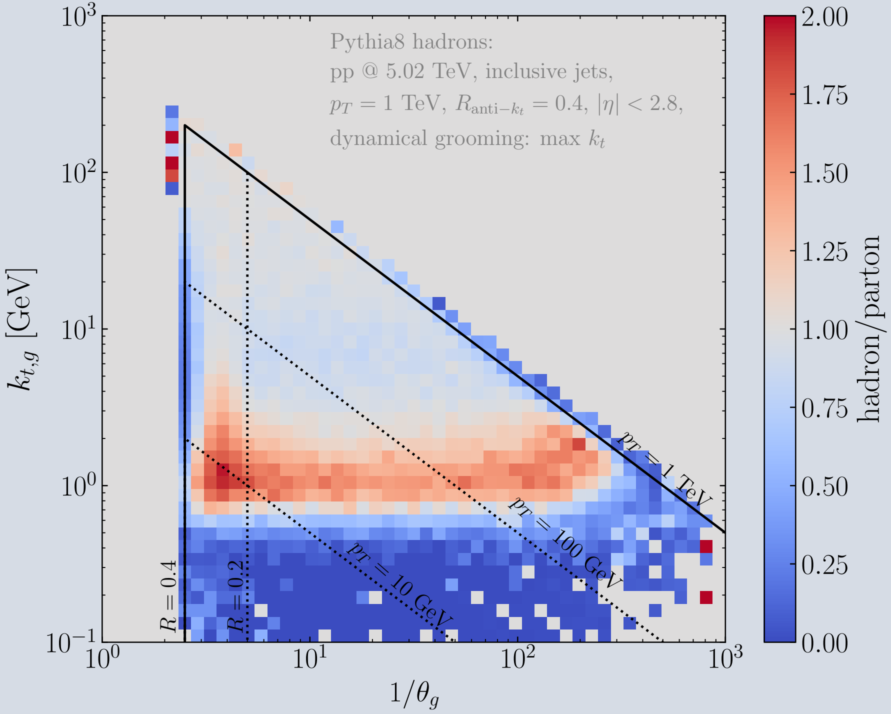


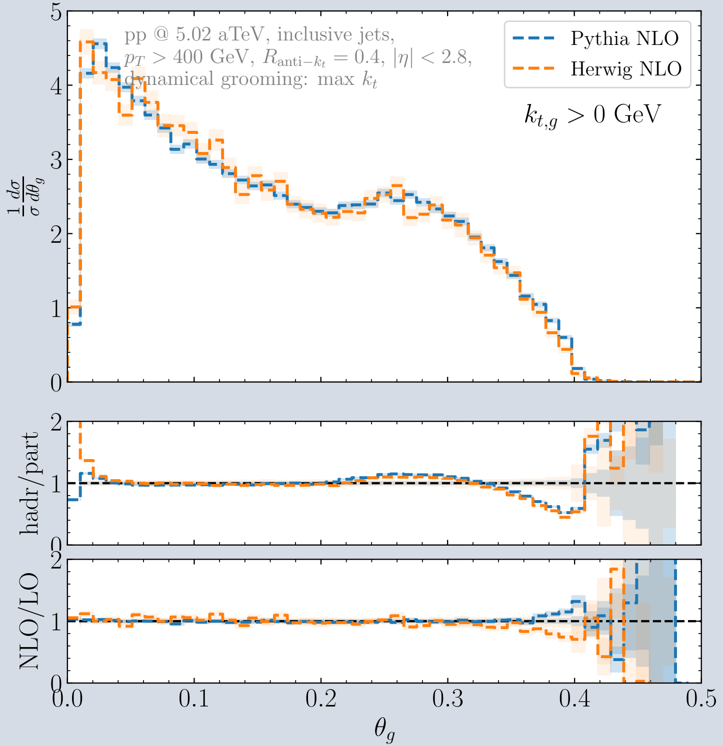
Hardest splitting in jets



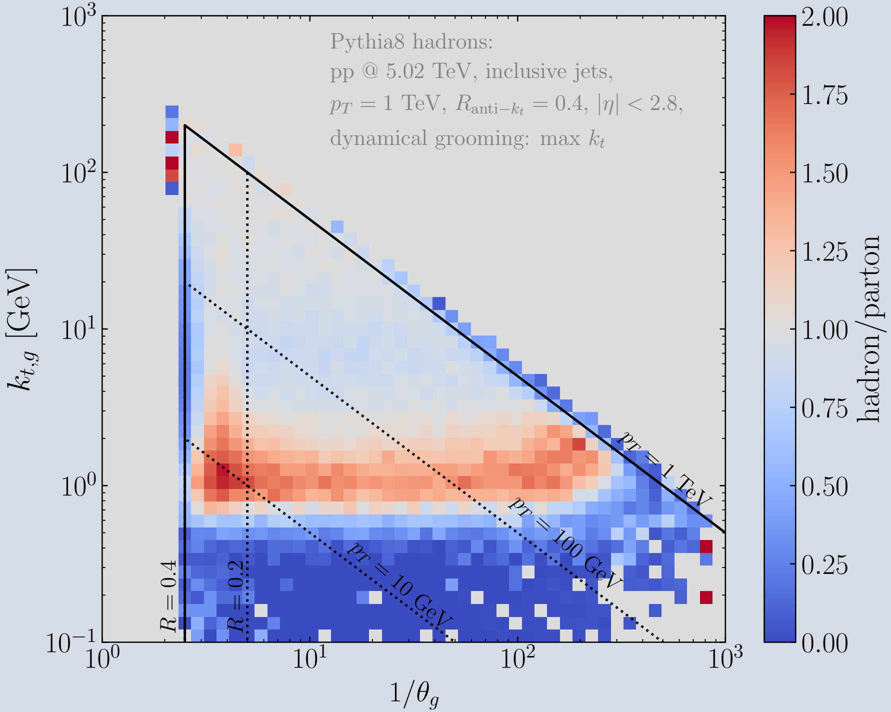


Hardest splitting in jets





Hardest splitting in jets

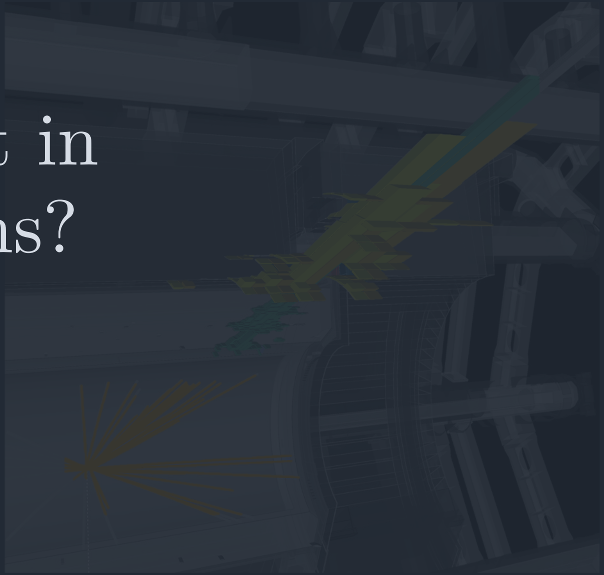


- Higher energy = more perturbative
- Low k_t = non-pert. corrections
- Cut on k_t to reduce corrections
- ($p_T > 400$ GeV to enhance stat.)
- Controlled pp baseline!

Introduction

theory

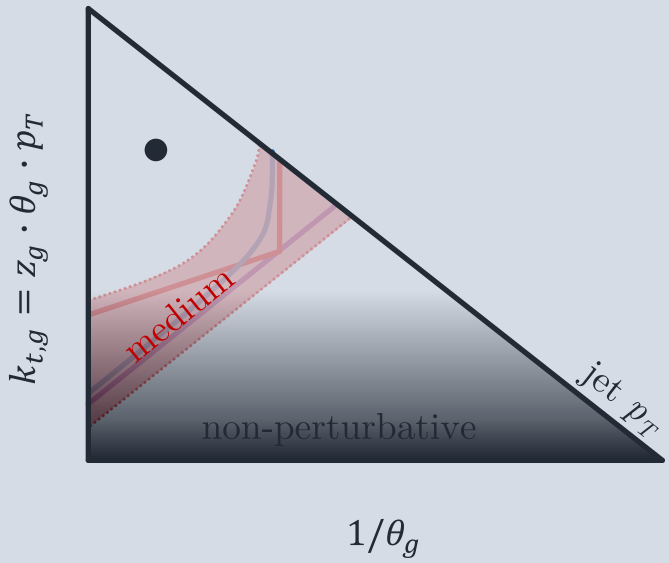
observation



How to do it in AA collisions?

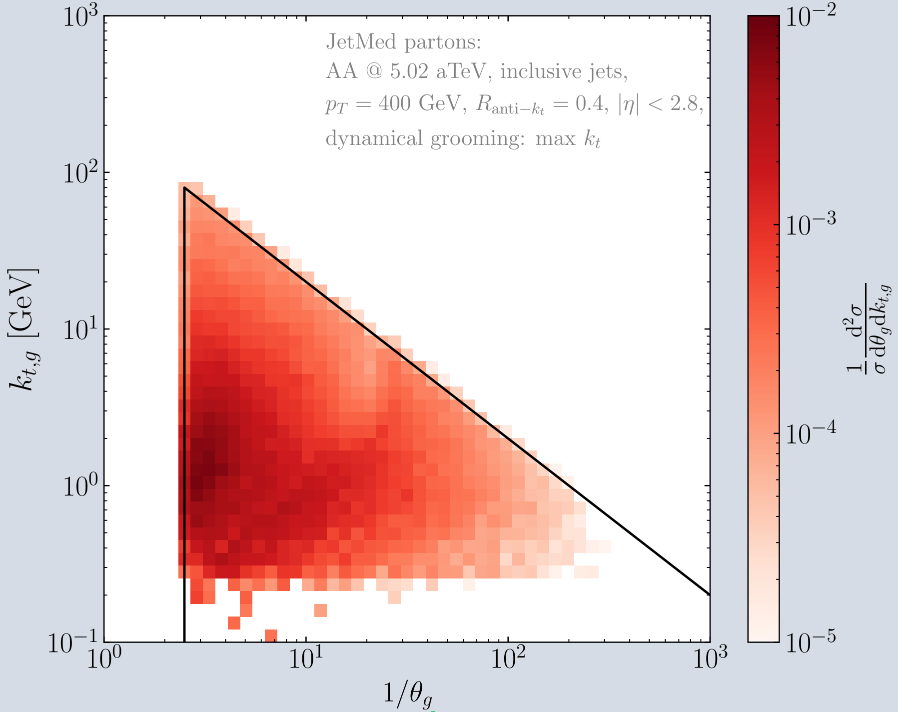
Hardest splitting in quenched jets

[HI Jet Workshop 2017]
[Caucal, Soto-Ontoso, Takacs]
[ATLAS, PRC107(2023)054909]



- Medium scales

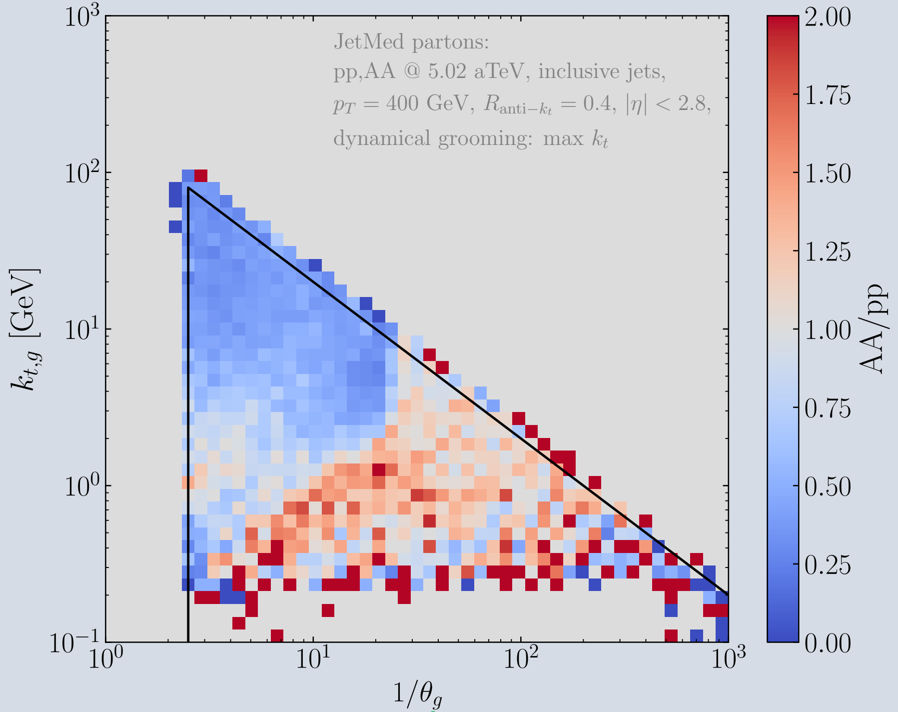
Hardest splitting in quenched jets



- Medium scales

[JetMed: Caucal, Iancu, Mueller, Soyez]

Hardest splitting in quenched jets

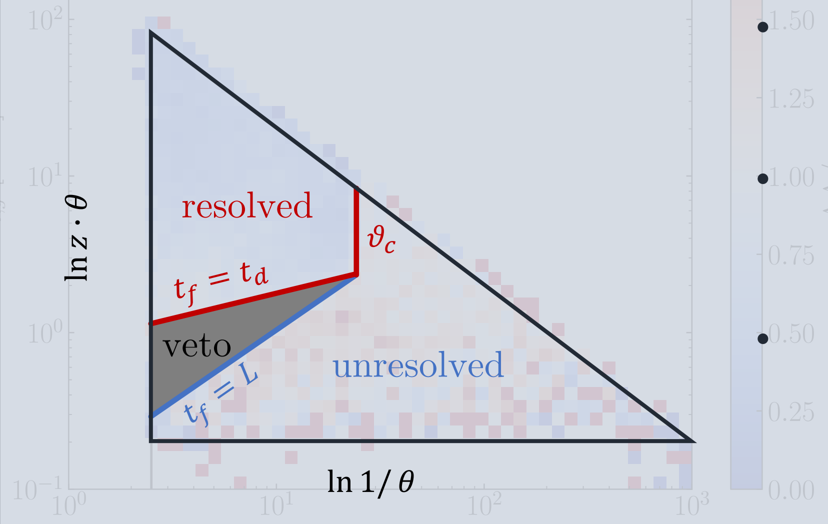


[JetMed: Caucal, Iancu, Mueller, Soyez]

- Medium scales

Hardest splitting in quenched jets

Quick reminder of JetMed



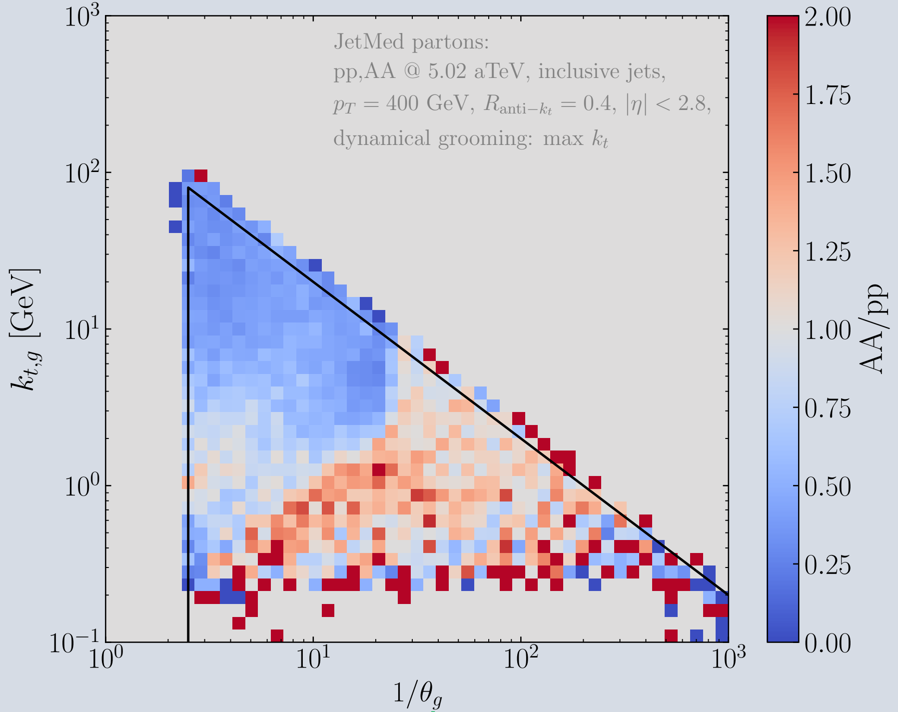
- Multiple soft scattering approximation in infinite plasma
- vacuum-like emissions undisturbed:

$$t_f < t_d < L$$

- wide angle energy loss of resolved emissions

[JetMed: Caucal, Iancu, Mueller, Soyez]

Hardest splitting in quenched jets

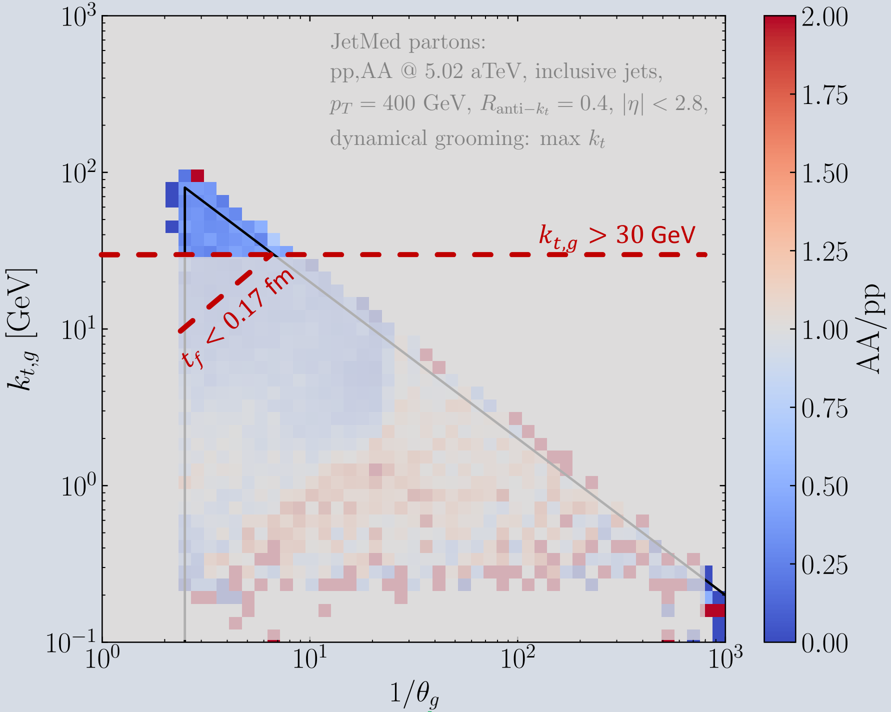


[JetMed: Caucal, Iancu, Mueller, Soyez]

- Medium scales

I. Test of vacuum-like factorization

Hardest splitting in quenched jets (high-k_t)

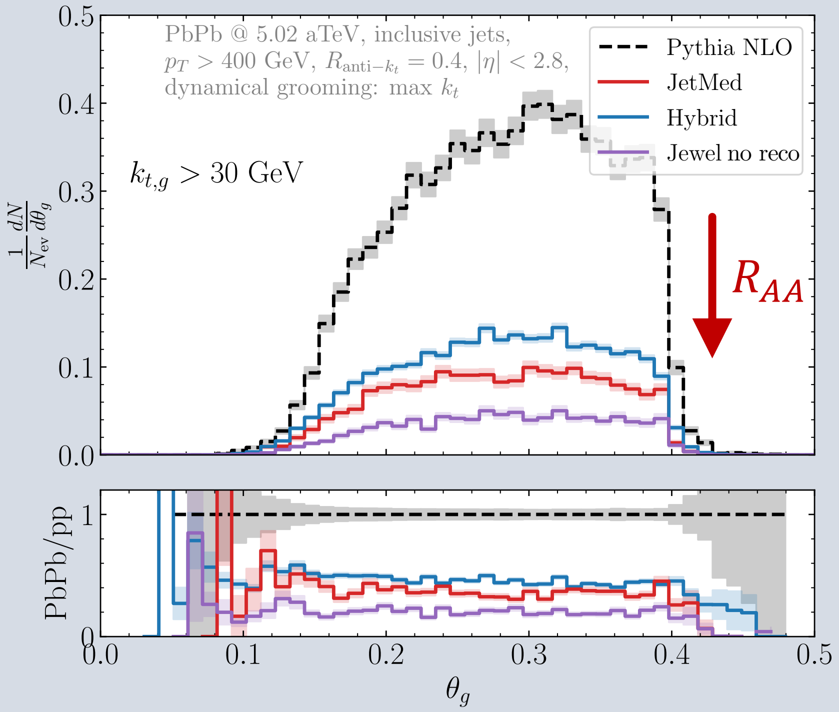


[JetMed: Caucal, Iancu, Mueller, Soyez]

- Medium scales
- $k_{t,\mathrm{cut}}$ for very hard emissions
- very early emissions!

Hardest splitting in quenched jets

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

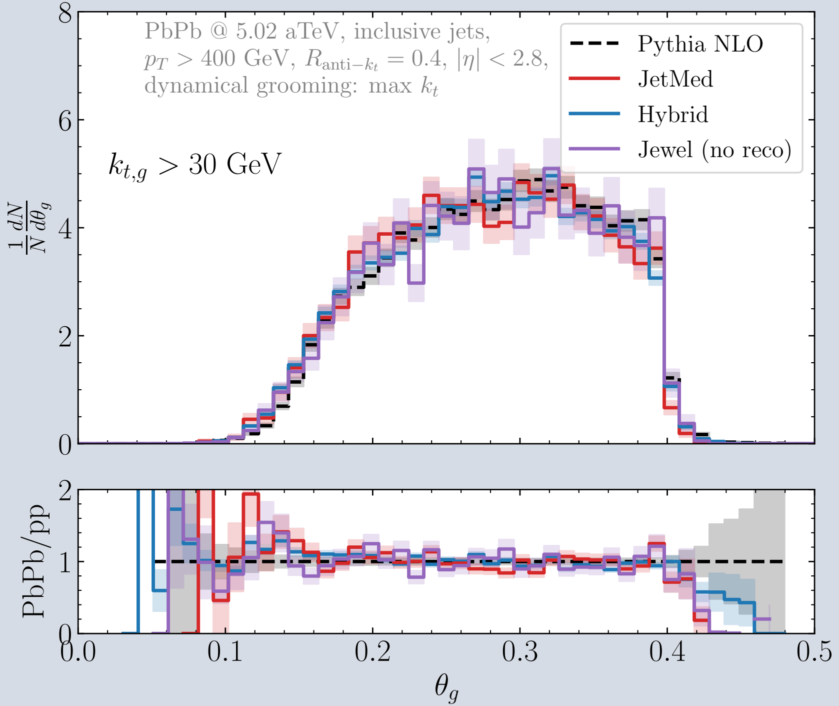


[JetMed: Caucal, Iancu, Mueller, Soyez]
[Hybrid: Casalderrey-Solana,Gulhan,Milhano,Pablos, Rajagopal]
[Jewel: Zapp, Krauss, Stachel, Wiedemann]

Hardest splitting in quenched jets

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

  pp = AA = most models



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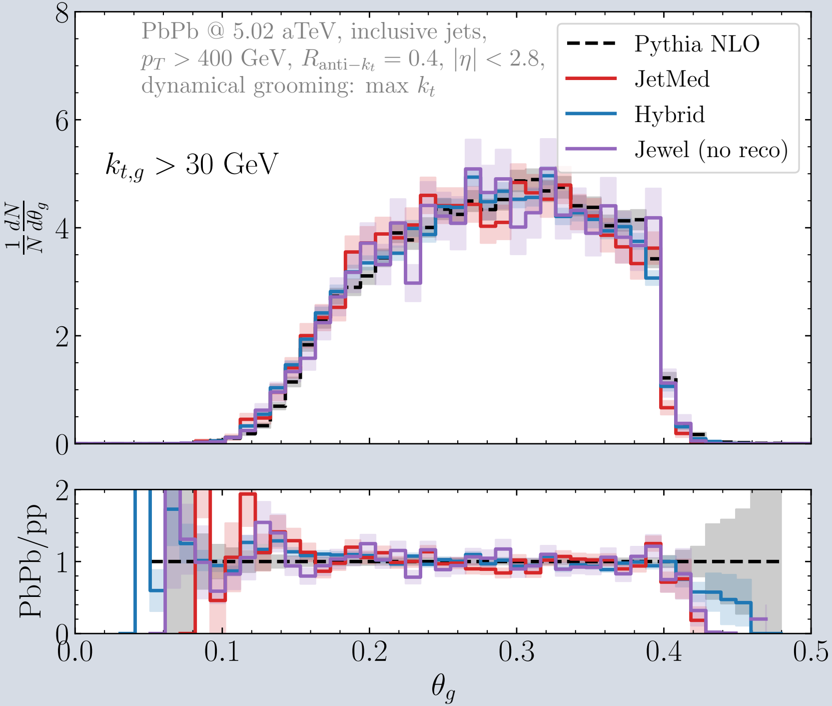
Hardest splitting in quenched jets

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

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



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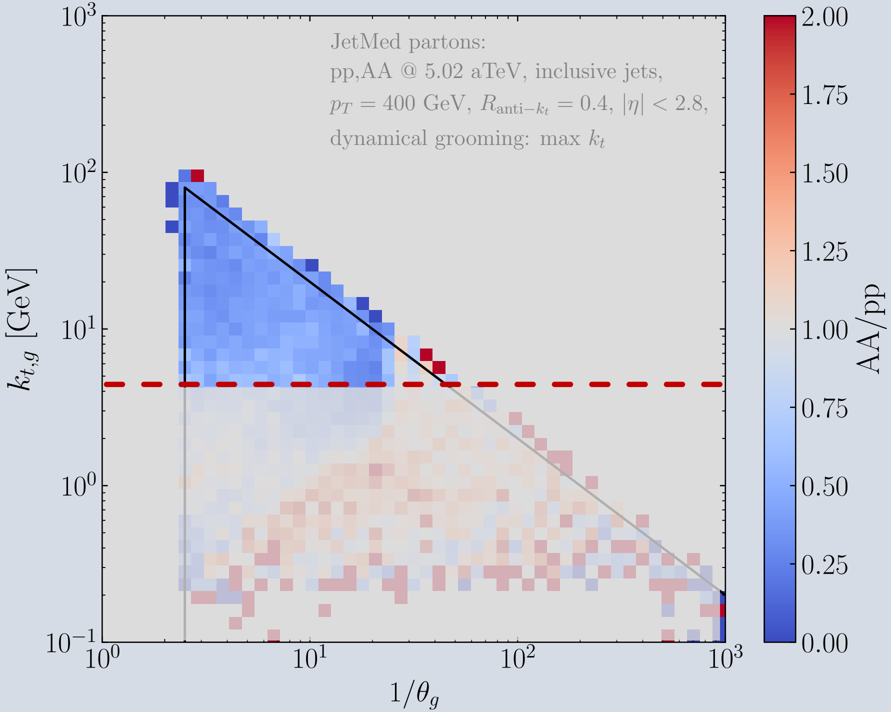
II. Test of color resolution

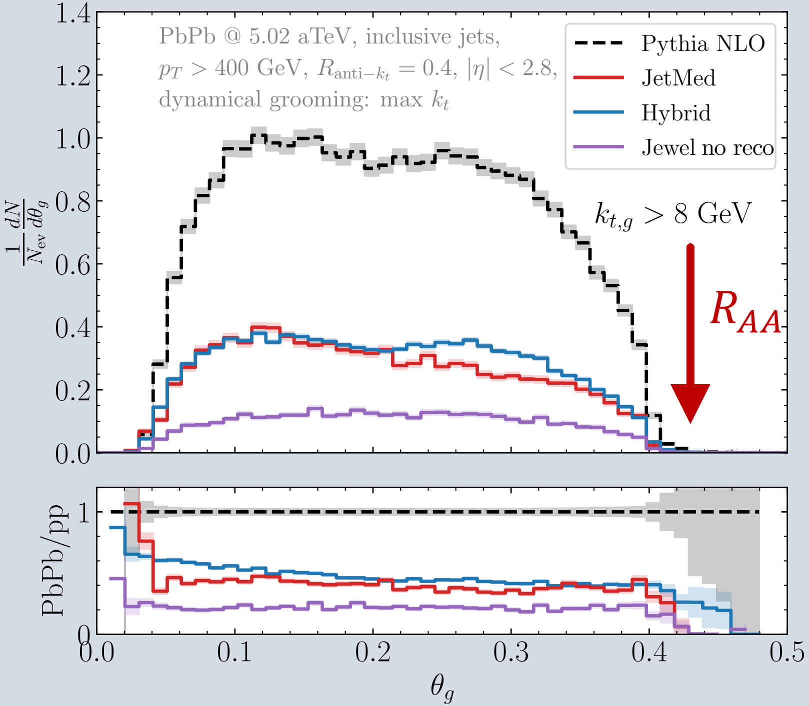
Hardest splitting in quenched jets



- Medium scales
- $k_{t,\text{cut}}$ for perturbative emissions
- not so early emissions!

Hardest splitting in quenched jets (coherence)

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



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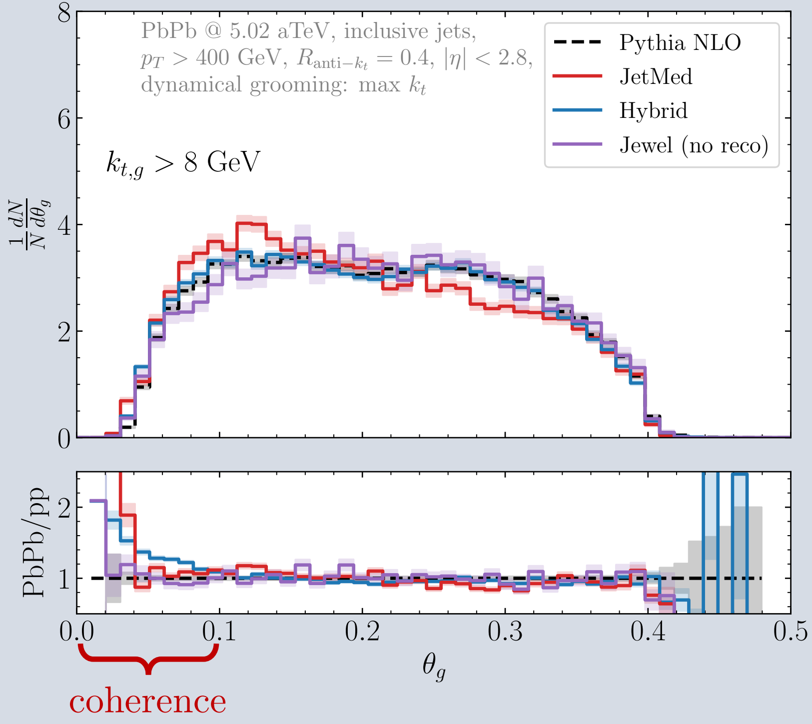
Hardest splitting in quenched jets (coherence)

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



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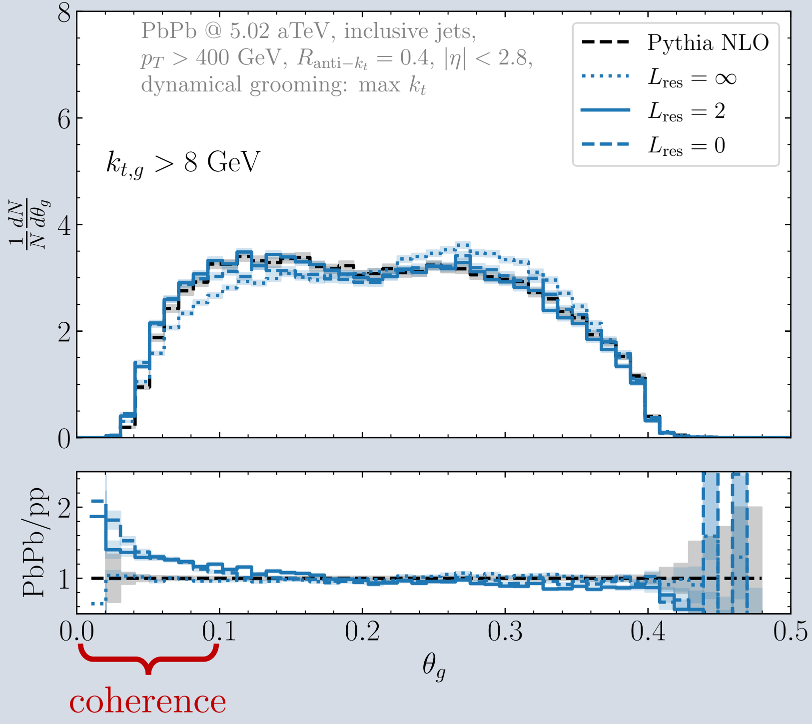

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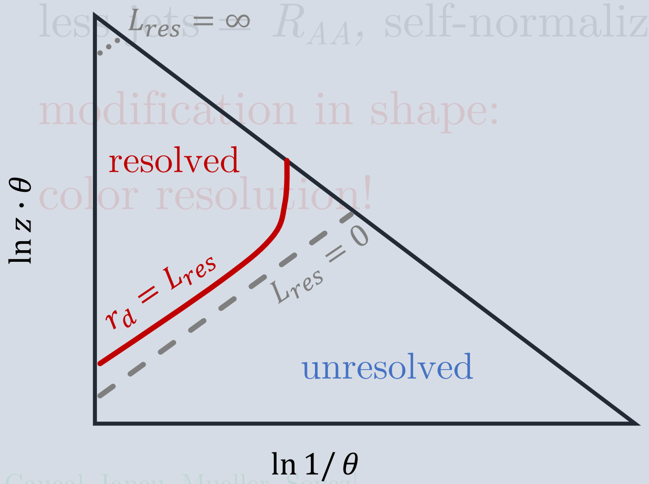
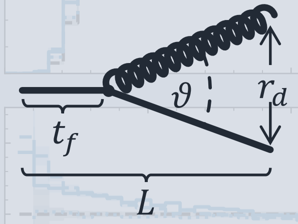
Hardest splitting in quenched jets

Quick reminder of Hybrid



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

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

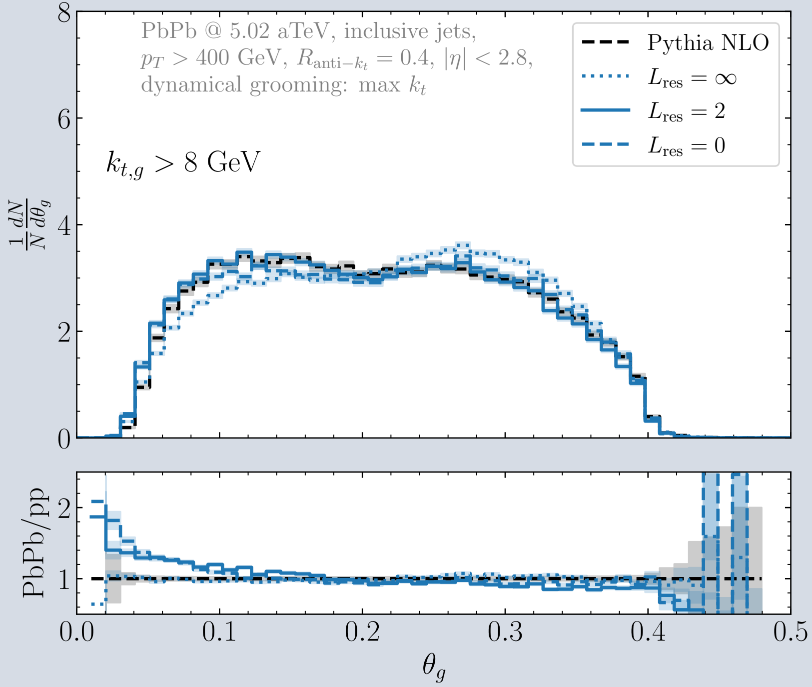


- 2+1D hydro

Much more in the backup!

Hardest splitting in quenched jets (coherence)

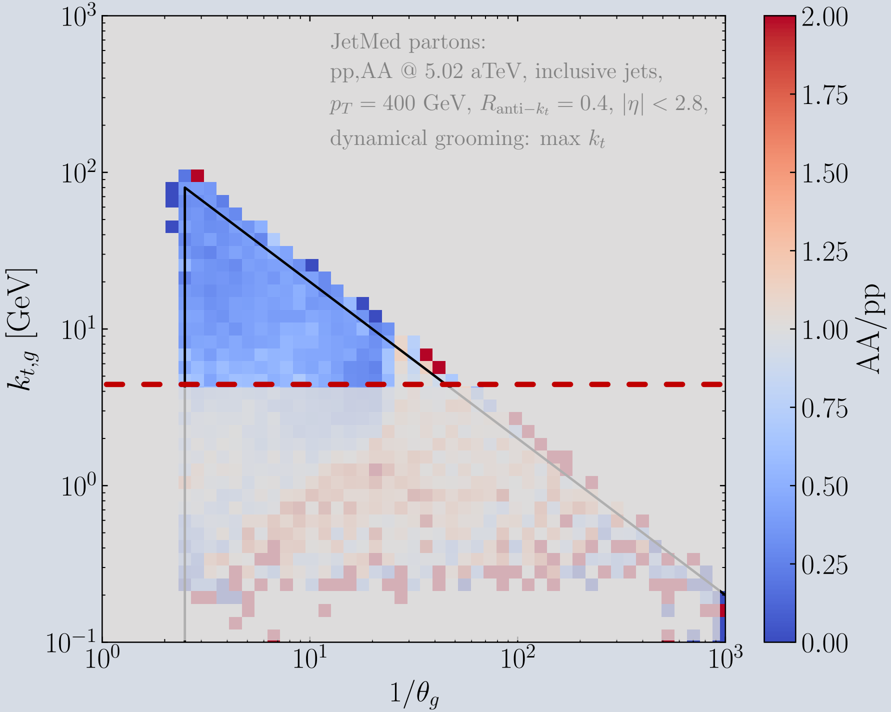
- less jets = R_{AA}, self-normalize!
- modification in shape!
- test of color resolution!



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

III. Test of medium response

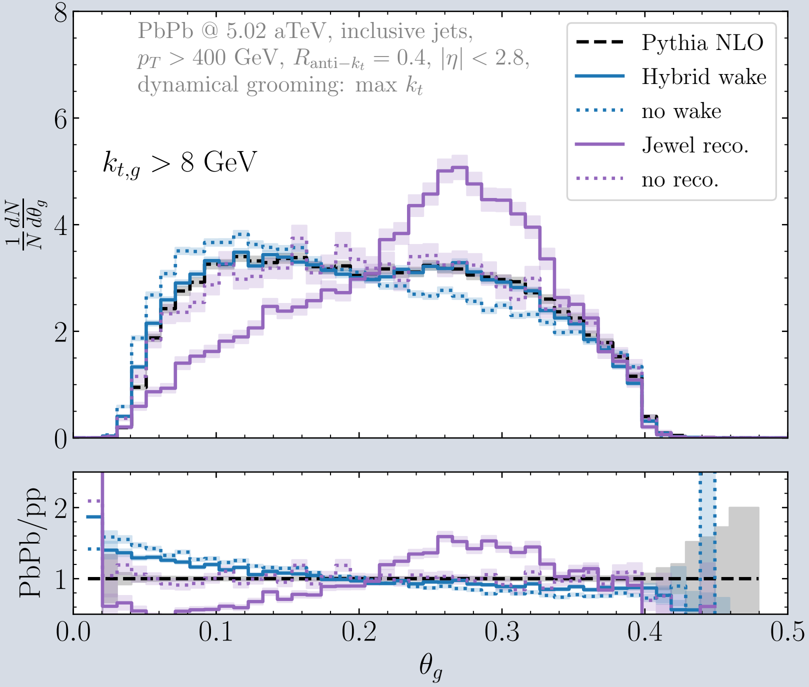
Hardest splitting in quenched jets



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

Hardest splitting in quenched jets (medium resp)

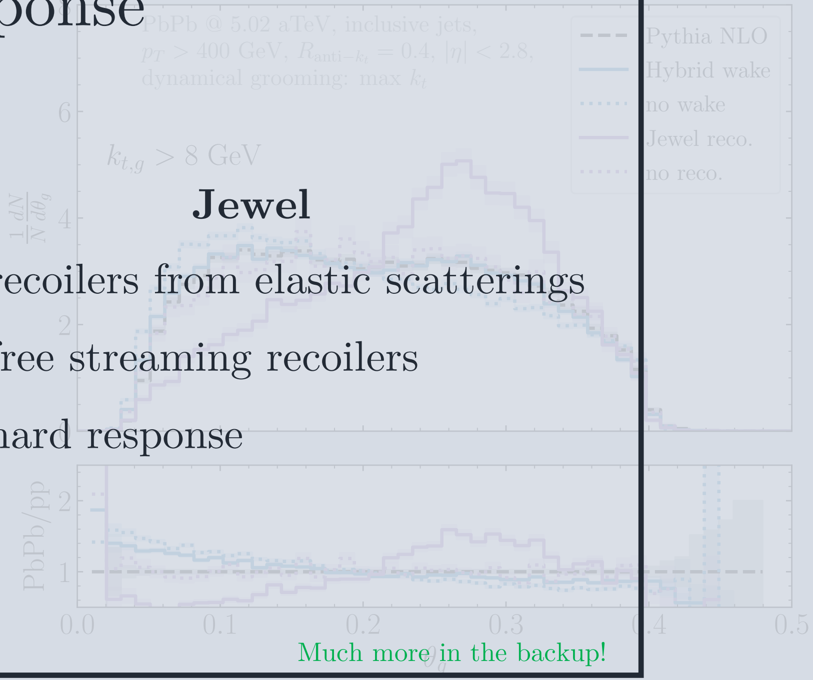
- less jets = R_{AA}, self-normalize!
- modification in shape!
- test of color resolution!
- test of thermalization!



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

Hardest splitting in quenched jets (medium resp)

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



Quick reminder of medium response

Hybrid

- lost jet energy sources hydro
- instant thermalization
- soft response

Jewel

- recoilers from elastic scatterings
- free streaming recoilers
- hard response

Much more in the backup!

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

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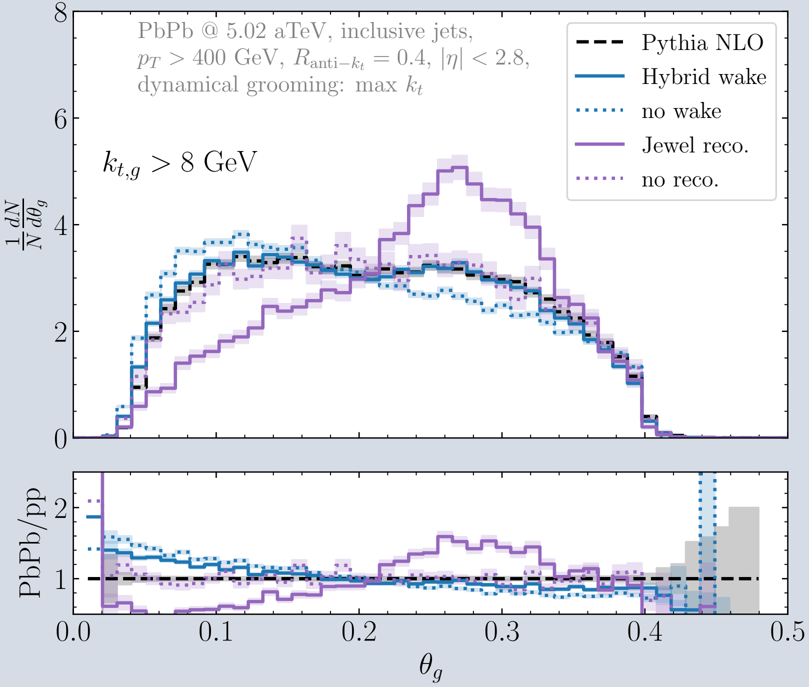

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[Jewel: Zapp, Krauss, Stachel, Wiedemann]

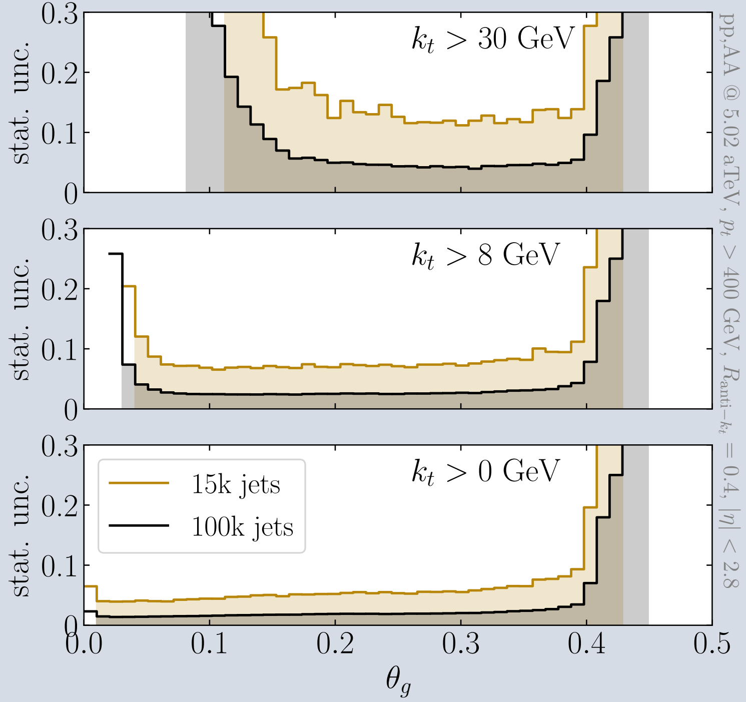
IV. Experimental aspects

Reconstructing the hardest splitting

- Expected luminosity ~ 13 nb^{-1}

  (15k jets above 400 GeV)

- Small angles: $\theta_g \sim 0.01$



Reconstructing the hardest splitting

- Expected luminosity ~ 13 nb^{-1}

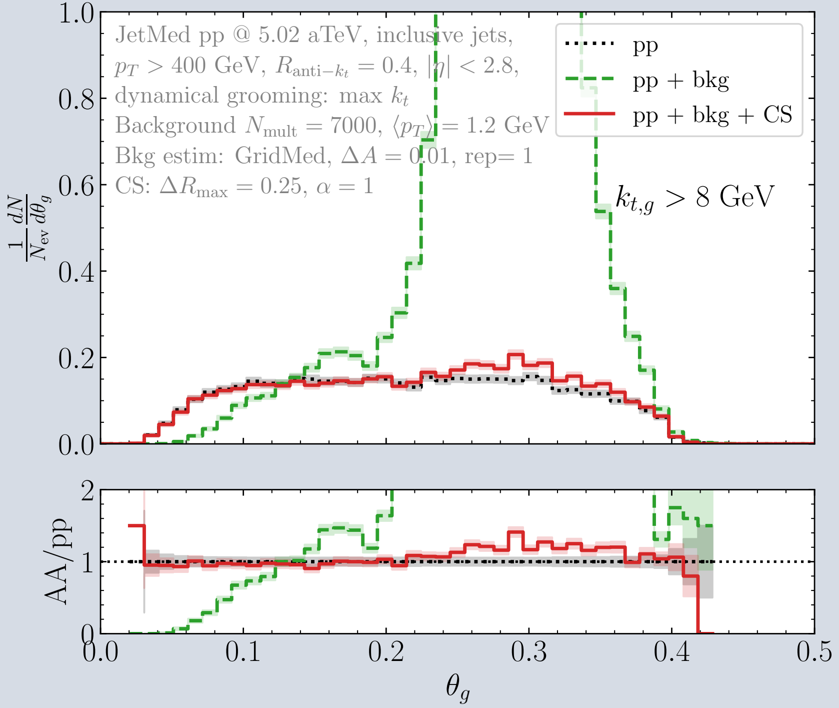
  (15k jets above 400 GeV)

- Small angles: $\theta_g \sim 0.01$

- Unfolding is stable (fakes < 5%):

  $R = 0.4, k_t > 7$ GeV

  $R = 0.2, k_t > 2.8$ GeV

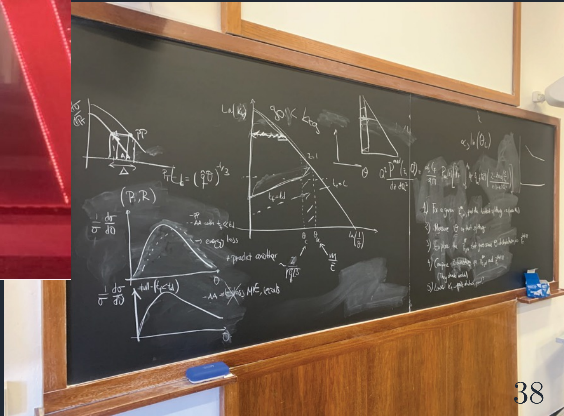


[Berta,Spousta,Miller,Leitner]

Summary: perturbative splittings in AA

1. high kt:
   - test of mode separation
   - vacuum-like baseline in AA collisions
2. moderate kt:
   - test of color resolution
   - test of jet thermalization
   - new baseline for AA collisions

Thank you for your attention!

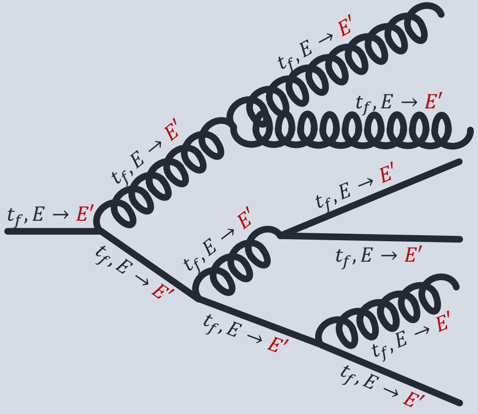


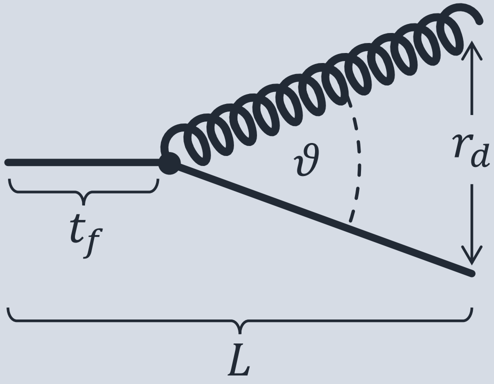
The Hybrid model

1. Generate Pythia8 event with nPDFs
2. Space-time structure using formation time
3. Remove energy according to holography: $\frac{dE}{dx}(E,T)$
4. Energy only lost for resolved partons

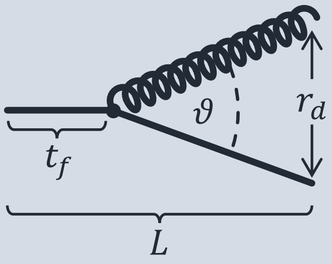
$$r_d = \vartheta(L - t_f) > L_{res}$$

5. The lost energy sources additional freeze out.

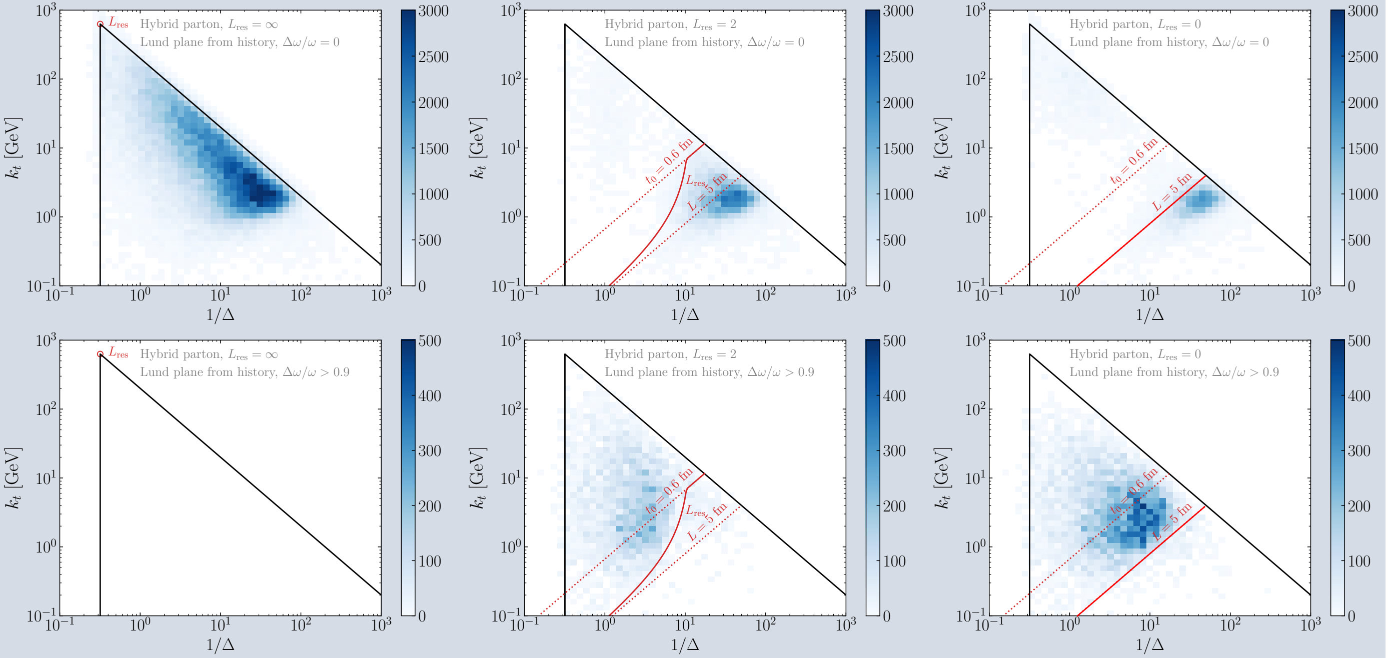




Hybrid model: primary Lund plane (from shower history)



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



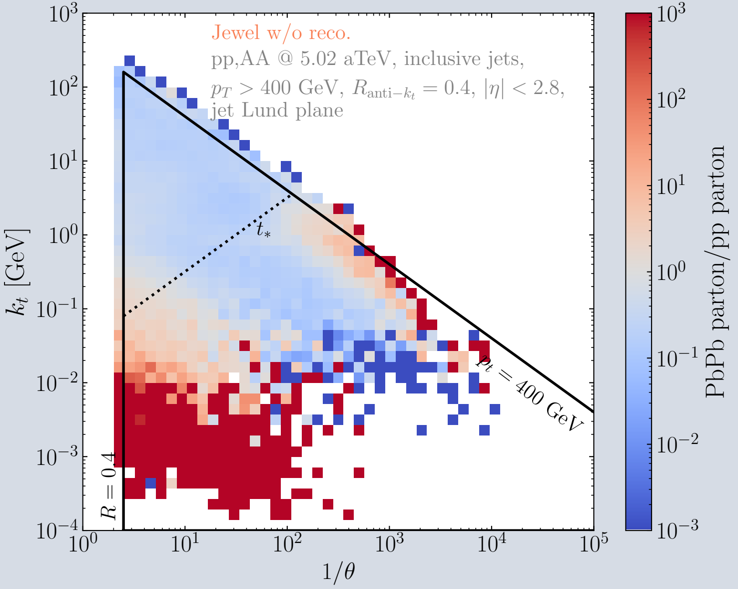
The Jewel model

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



Jewel model: Lund plane