Novel tools and observables for jet physics in heavy-ion collisions

A summary

Konrad Tywoniuk

JETSCAPE 2018 Winter School & Workshop, Berkeley, 3-7 January 2018

Workshop/TH institute @ CERN

Novel tools and observables for jet physics in heavy-ion collisions / 5th Heavy Ion Jet Workshop

21 August 2017 to 1 September 2017
CERN
Europe/Zurich timezone

Search...

- Overview
- Timetable
- Registration
- Participant List
- Videoconference Rooms
- Practical information
- Workshop objectives

Questions and support
- konrad.tywoniuk@cern.ch
- angela.ricci@cern.ch

The deadline for application is currently extended to Aug 11. There is still the possibility for financial support for a limited of participants.

Welcome to the CERN TH institute "Novel tools and observables for jet physics in heavy-ion collisions", which will be organised together with the 5th Heavy Ion Jet Workshop. The workshop and ensuing institute aims at bringing together theorists and experimentalists interested in jet observables in heavy-ion collisions.

The study of QCD jets and their modifications in the dense environment provided in heavy-ion collisions is motivated by two main aspects. Most prominently, jets serve as perturbative and well-controlled probes of the characteristics of the underlying medium. In this, they complement the physics information obtained by analysing the features of bulk particle production, such as flow observables and heavy-quark measurements. However, the processes underlying jet quenching share many similar features with generic equilibration mechanisms. In this respect, characterizing the medium-modification of the jet substructure may open a window of testing the dynamics responsible for medium collective behaviour, for which there is ample experimental evidence.

The scope of the workshop will span a wide range of topics, striving to connect theoretical ideas with clearly defined observables and exploring the related technical challenges. A focal point of the discussions will also be novel grooming techniques for jet substructure observables. We invite interested participants to reflect on the following points:

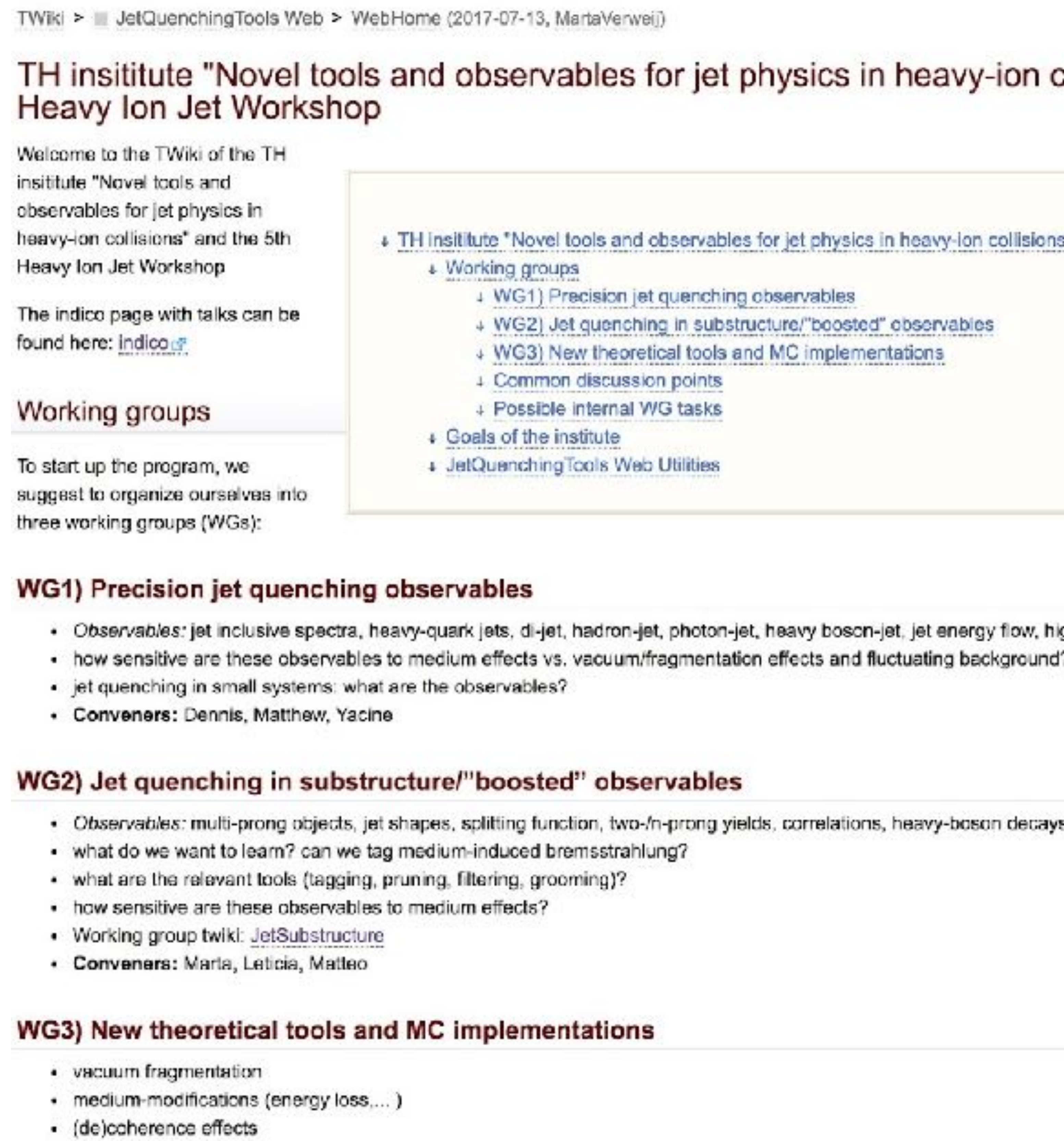
- How to extract meaningful information about medium properties from jet measurements, in particular jet substructure?
- What are the physical mechanisms and what are the relevant observables?
- What do we learn from jet grooming and declustering techniques, and what are the right tools?
- What are the prospects for jet measurements in heavy-ion collisions for the future (for example, sPHENIX, HL-LHC)?

- bring together theorists and experimentalists
- connect theoretical ideas with clearly defined observables & exploring technical challenges
- focal point of discussions: grooming techniques for jet substructure observables

OC: Matteo Cacciari, Leticia Cunqueiro, Yen-Jie Lee, Yacine Mehtar-Tani, Guilherme Milhano, Matthew Nguyen, Dennis Perepelitsa, Konrad Tywoniuk, Marta Verweij, Urs Wiedemann, Korinna Zapp

COLLABORATIVE EFFORT

- Twiki
  - working groups/topics for future discussions
- GitHub
  - available tools and samples
  - (currently need CERN account…)
- Slack
  - discussion forum
- mailing list



TWiki > JetQuenchingTools Web > WebHome (2017-07-13, MartaVerweij)

TH insititute "Novel tools and observables for jet physics in heavy-ion c Heavy Ion Jet Workshop

Welcome to the TWiki of the TH insititute "Novel tools and observables for jet physics in heavy-ion collisions" and the 5th Heavy Ion Jet Workshop

The indico page with talks can be found here: indico

- TH insititute "Novel tools and observables for jet physics in heavy-ion collisions
  - Working groups
    - WG1) Precision jet quenching observables
    - WG2) Jet quenching in substructure/"boosted" observables
    - WG3) New theoretical tools and MC implementations
    - Common discussion points
    - Possible internal WG tasks
  - Goals of the institute
  - JetQuenchingTools Web Utilities

Working groups

To start up the program, we suggest to organize ourselves into three working groups (WGs):

WG1) Precision jet quenching observables

- *Observables:* jet inclusive spectra, heavy-quark jets, di-jet, hadron-jet, photon-jet, heavy boson-jet, jet energy flow, hig
- how sensitive are these observables to medium effects vs. vacuum/fragmentation effects and fluctuating background
- jet quenching in small systems: what are the observables?
- **Conveners:** Dennis, Matthew, Yacine

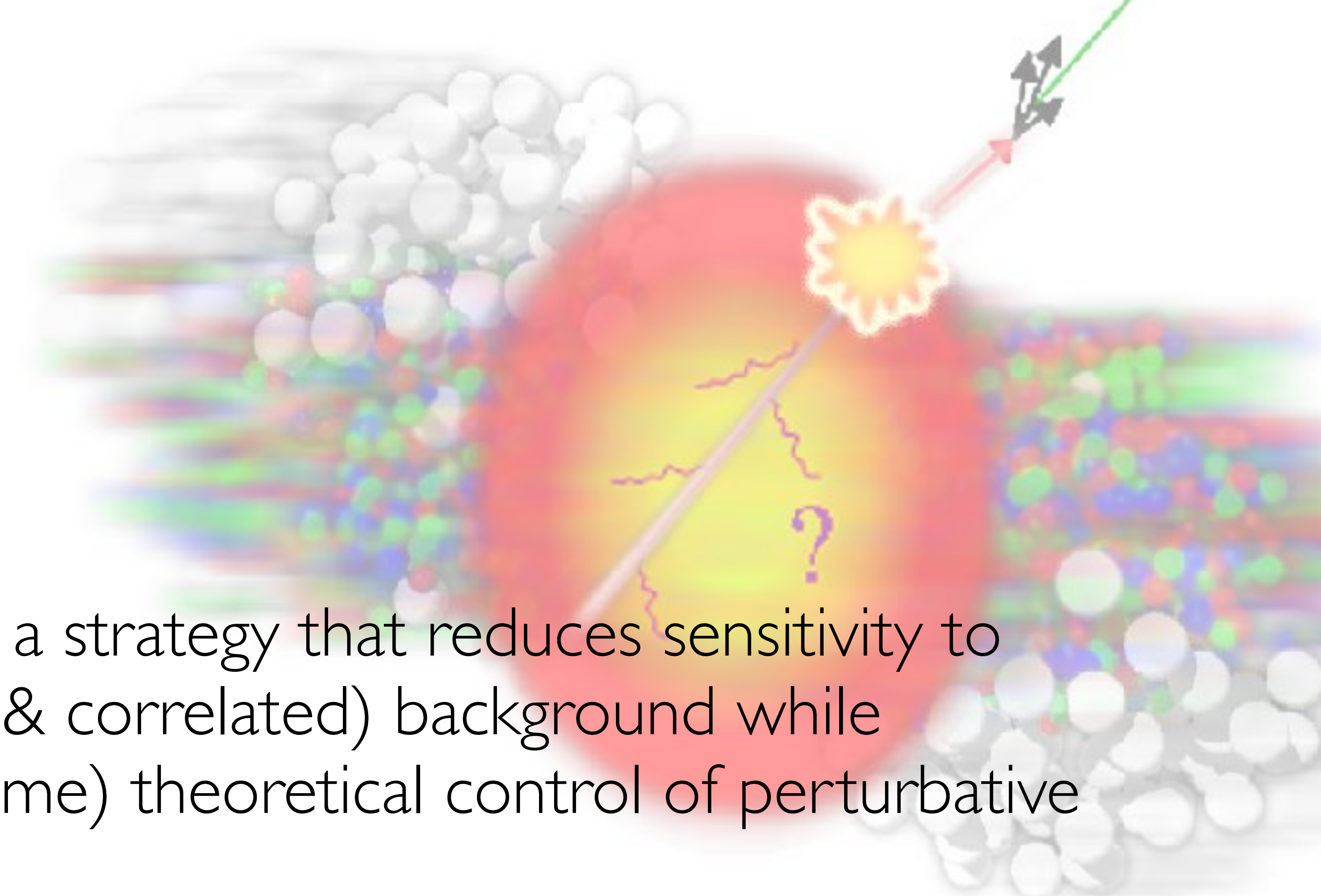
WG2) Jet quenching in substructure/"boosted" observables

- *Observables:* multi-prong objects, jet shapes, splitting function, two-/n-prong yields, correlations, heavy-boson decays
- what do we want to learn? can we tag medium-induced bremsstrahlung?
- what are the relevant tools (tagging, pruning, filtering, grooming)?
- how sensitive are these observables to medium effects?
- Working group twiki: JetSubstructure
- **Conveners:** Marta, Leticia, Matteo

WG3) New theoretical tools and MC implementations

- vacuum fragmentation
- medium-modifications (energy loss,...)
- (de)coherence effects

MOTIVATION



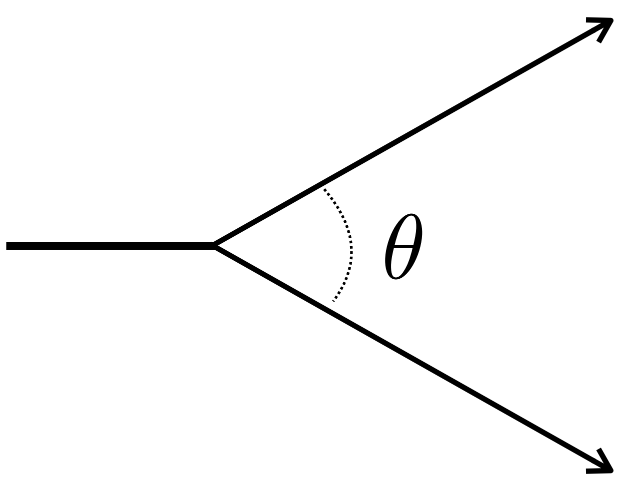
- can we devise a strategy that reduces sensitivity to (uncorrelated & correlated) background while preserving (some) theoretical control of perturbative jet structure?
- can we isolate effects (regimes of dominant contribution)?
  - useful for crosschecking MC's and theory
- summary of main discussion topics & results to appear as a "round-table" doc soon…

THIS TALK:

I will try to outline some of the main lines of discussion, using simple theoretical arguments to discuss phase space generation, motivating further MC studies of specific (groomed) observables.

SPLITTING KINEMATICS

Consider a generic 1→2 splitting in QCD.



$$\mathrm{d}\mathcal{P}_{\rm vac} = 2\frac{\alpha_s C_R}{\pi}\, \mathrm{d}\log z\theta\, \mathrm{d}\log\frac{1}{\theta}$$

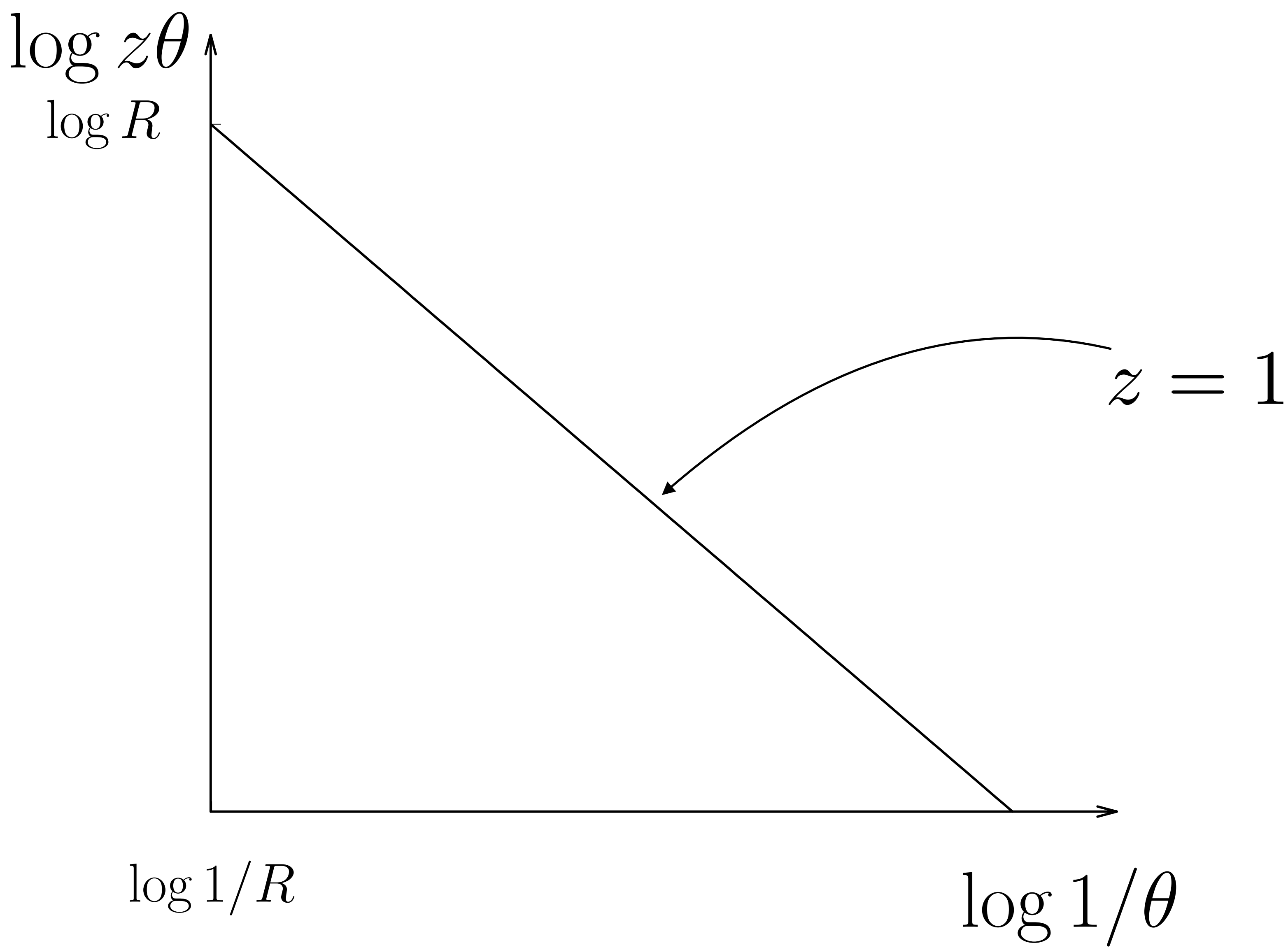
For soft & collinear radiation, we can write a splitting probability!

The pair invariant mass $\quad m^2 = z(1-z)E^2\theta^2$

Formation time of splitting: $\quad t_{\rm f} \sim \Delta E^{-1} = \frac{2z(1-z)E}{p_\perp^2}$

LUND DIAGRAM

B. Andersson, G. Gustafson, L. Lönnblad and U. Pettersson, Z. Phys. C 43 (1989) 625.



Triangle is uniformly filled, with probability: $2\frac{\alpha_s C_R}{\pi}$

[This holds iteratively for a vacuum jet, given C/A recombination algo.]

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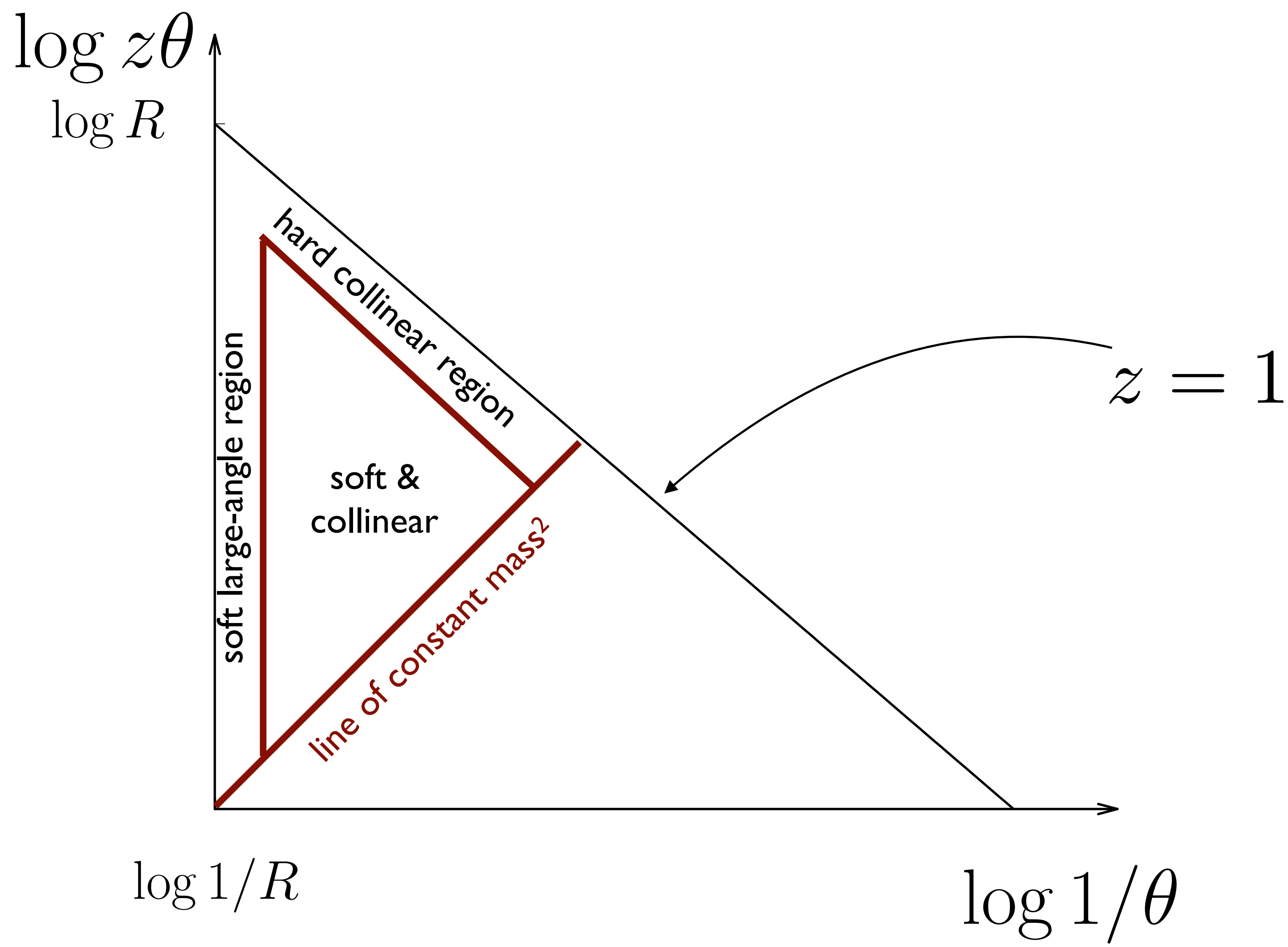

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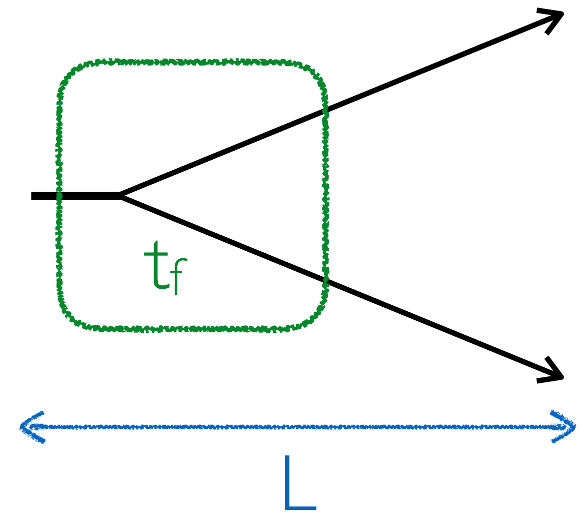
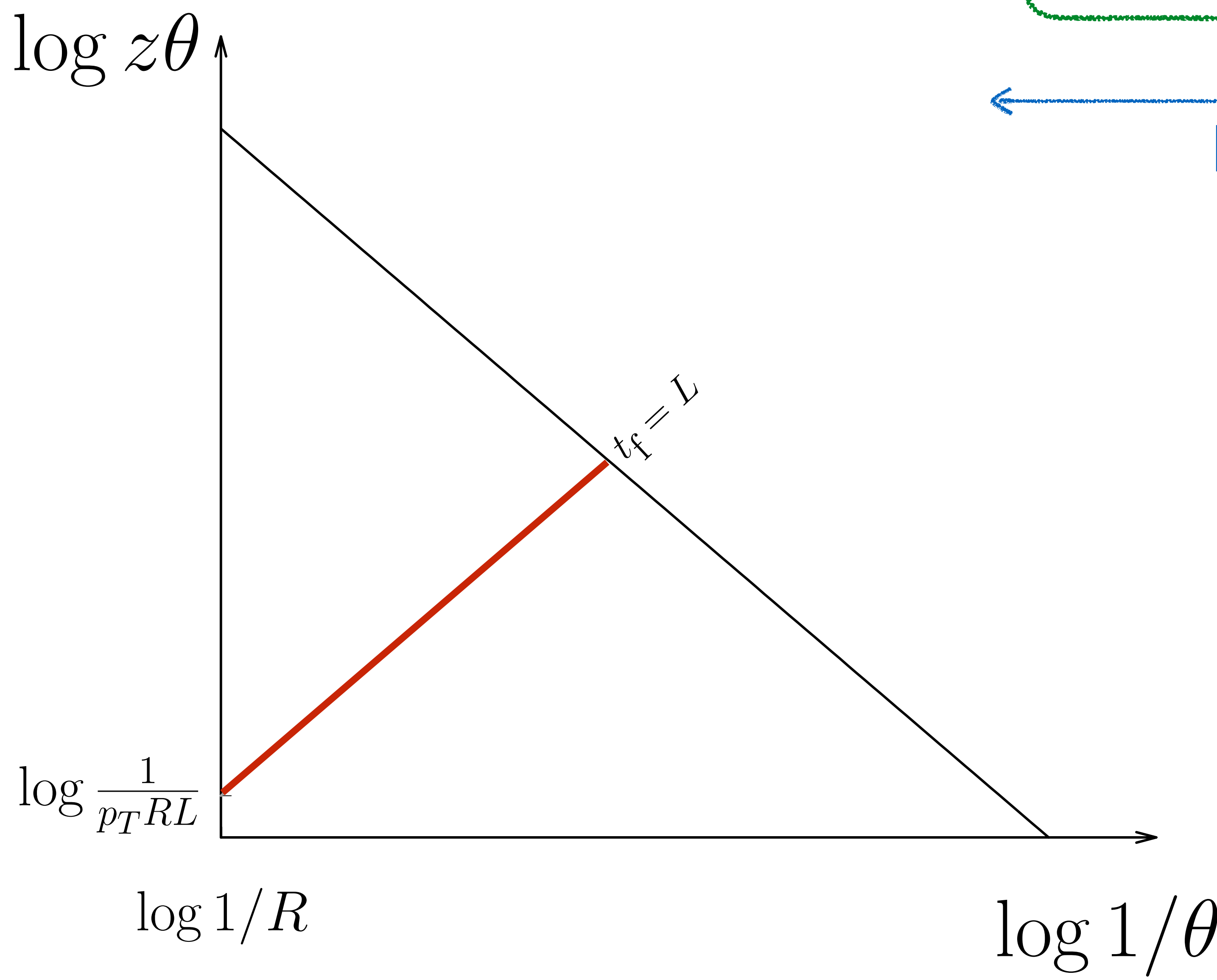
When does the splitting take place?





Formation time: $t_{\rm f} \sim \dfrac{1}{z p_{\rm T} \theta^2}$ $\Rightarrow$ $$\log z\theta = \log \frac{1}{\theta} + \log \frac{1}{p_{\rm T} L}\,,$$

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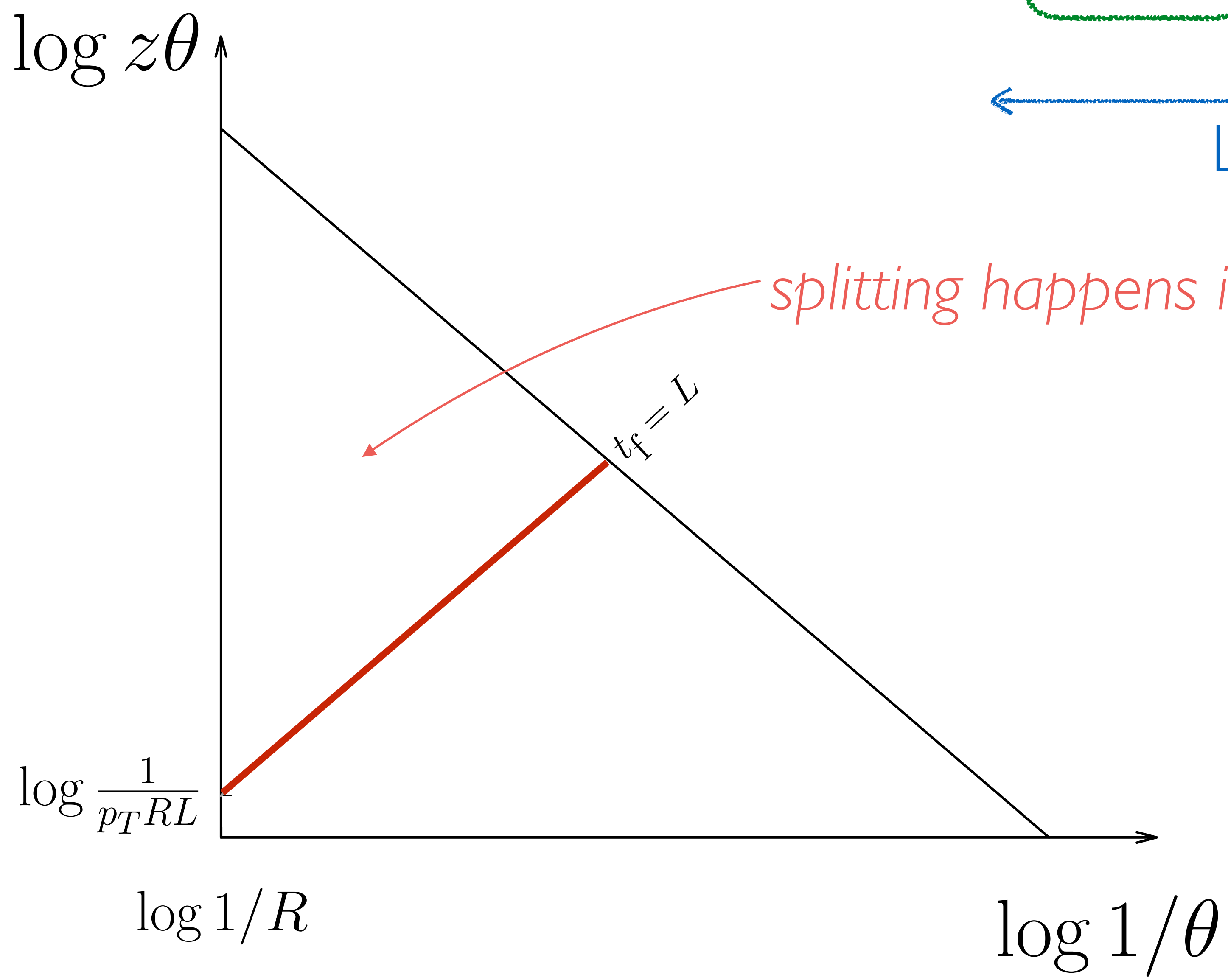

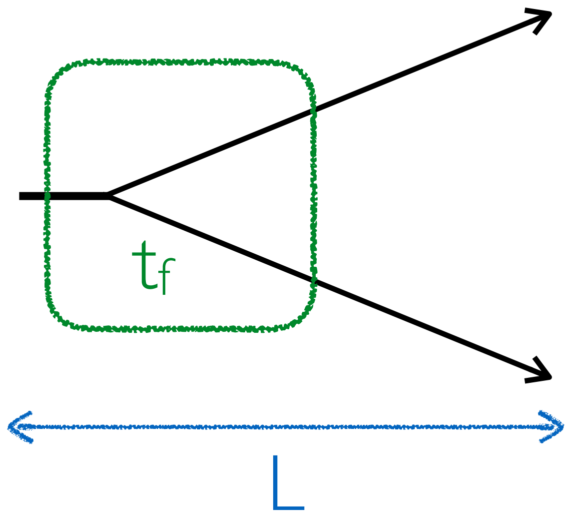

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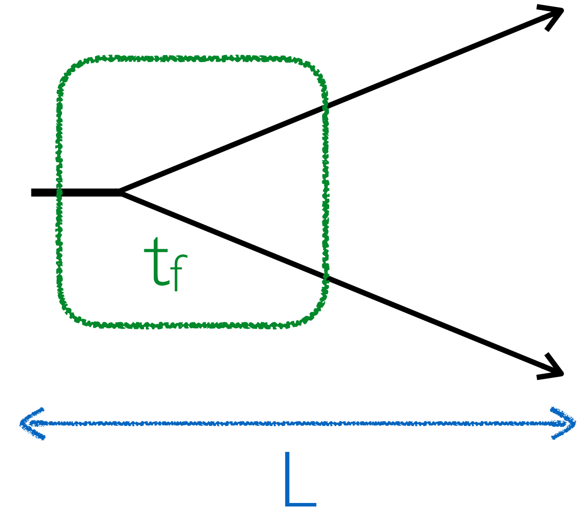

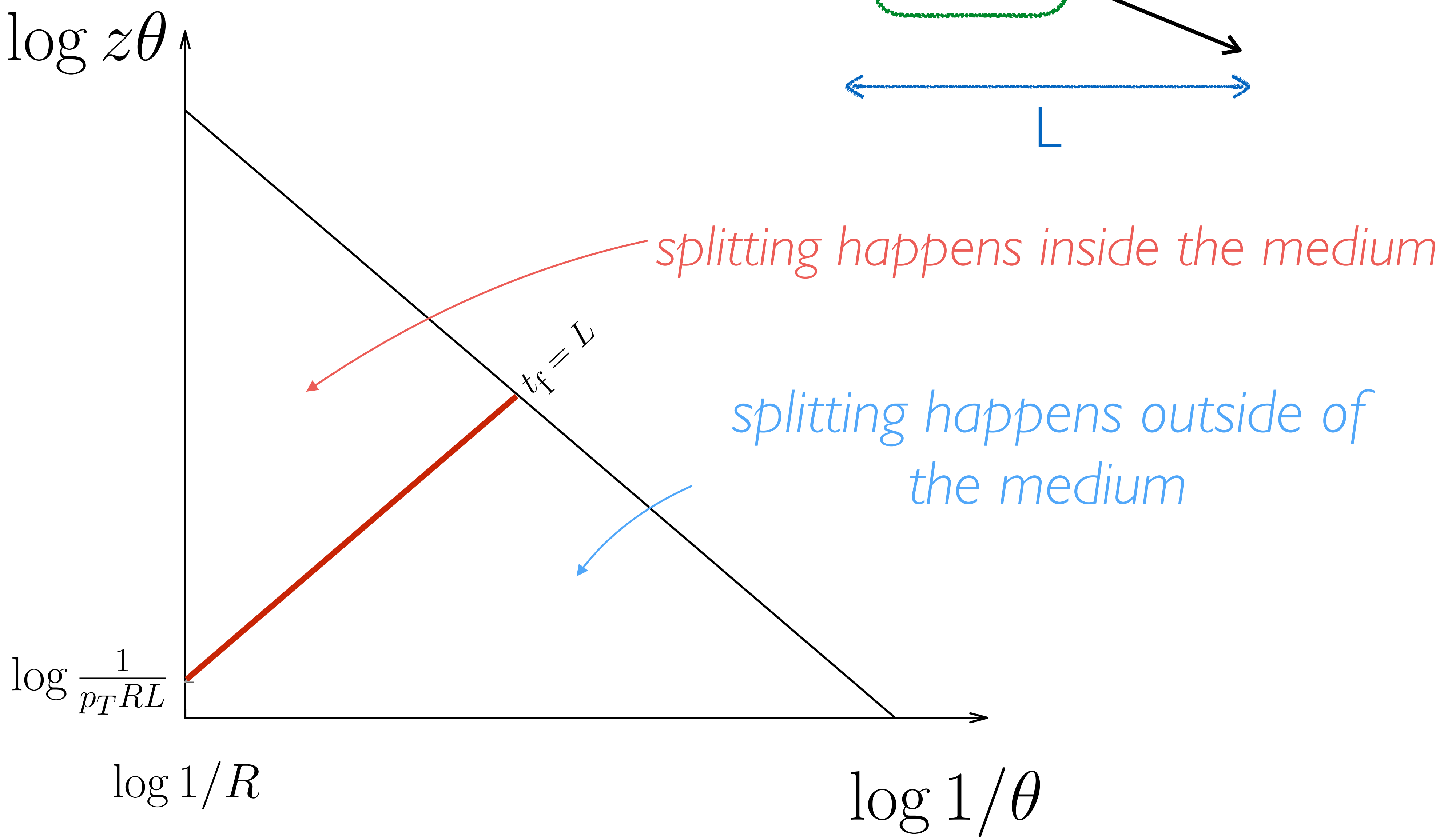

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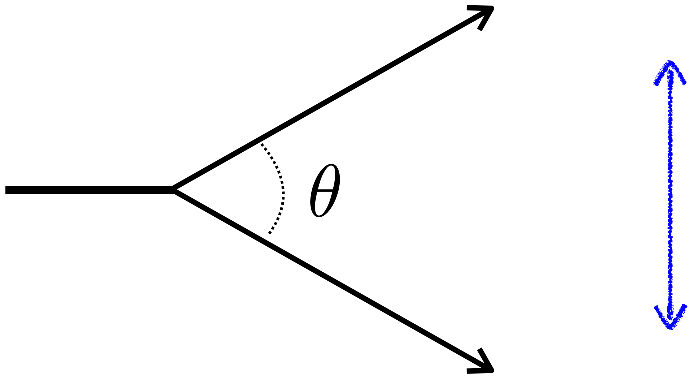
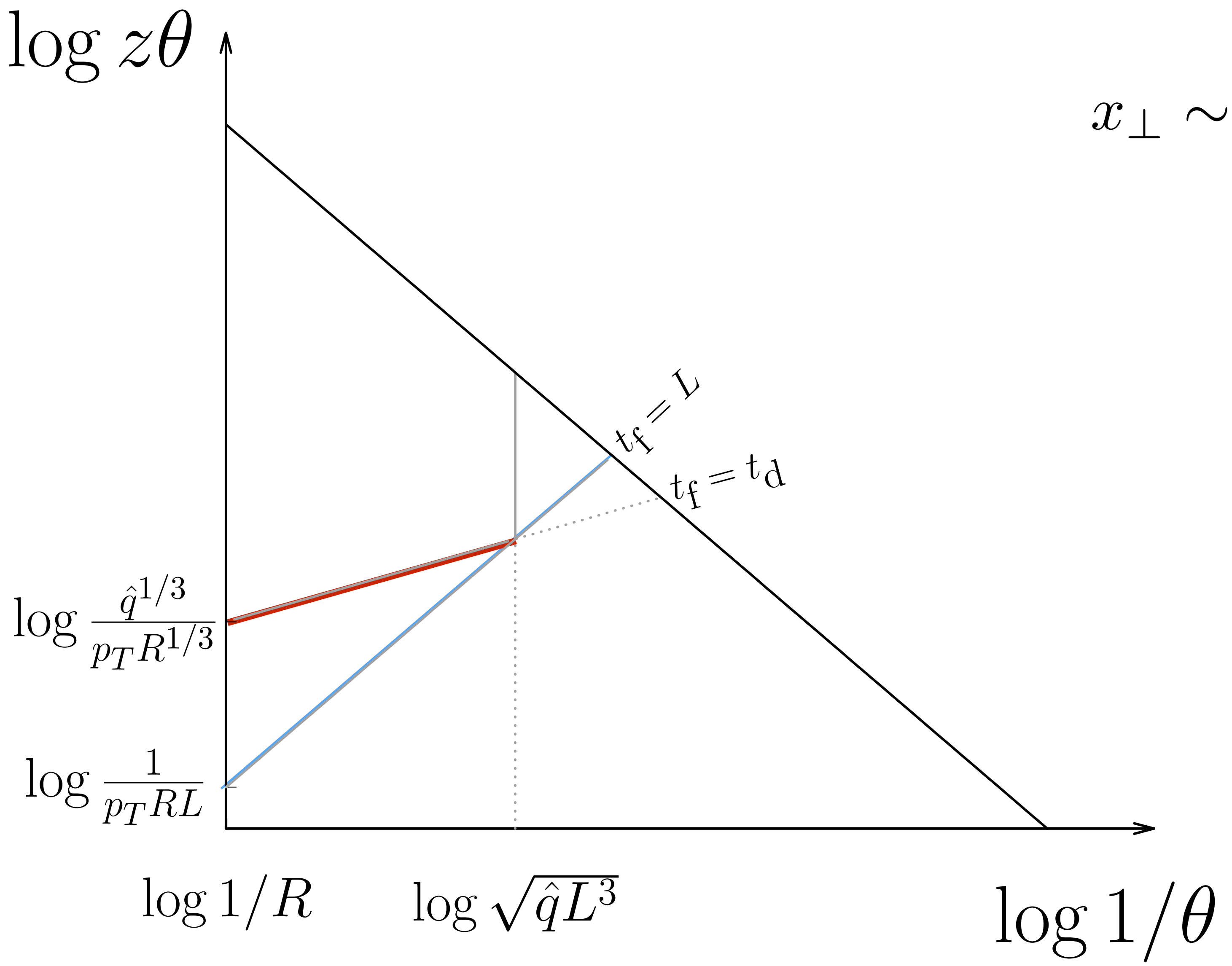
When does the medium resolve the splitting?



$x_\perp \sim \theta t$ $\qquad$ $\lambda_\perp \sim \frac{1}{\sqrt{\hat{q} t}}$



Formation time: $t_{\rm f} \sim \frac{1}{z p_{\rm T} \theta^2}$

Decoherence time: $t_{\rm d} \sim \frac{1}{(\hat{q}\theta^2)^{1/3}}$

$$\Rightarrow \quad \log z\theta = \frac{1}{3} \log \frac{1}{\theta} + \log \frac{\hat{q}^{1/3}}{p_{\rm T}} \,,$$

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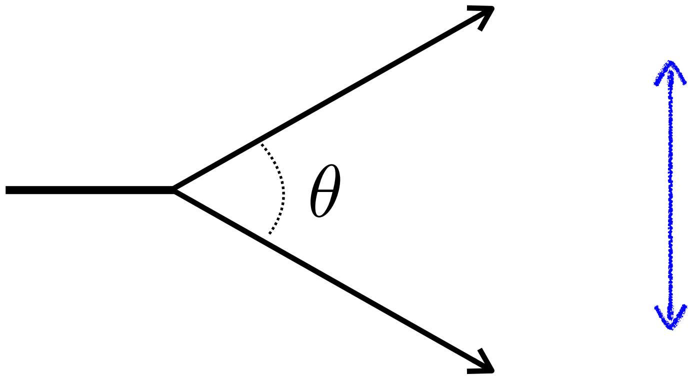

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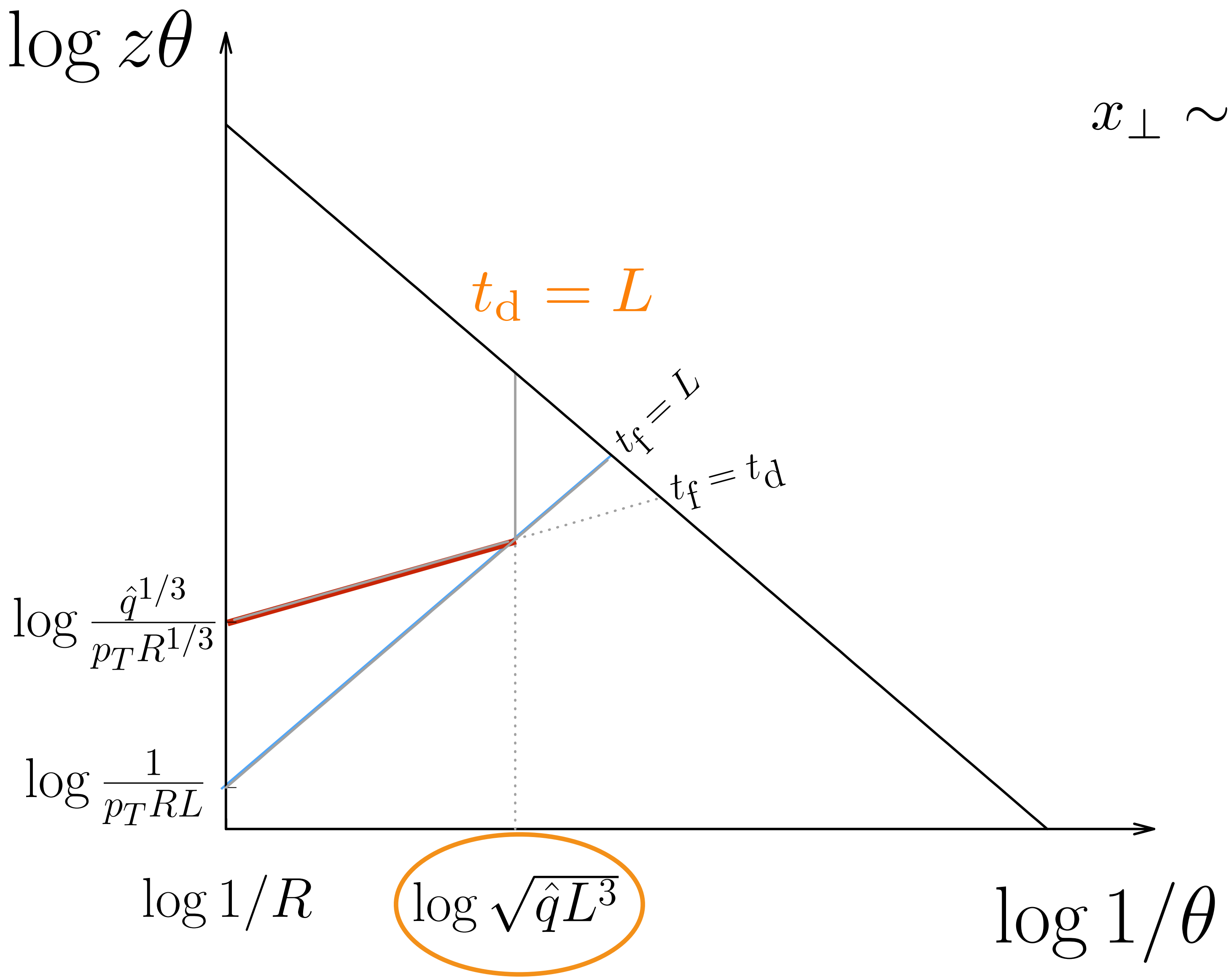

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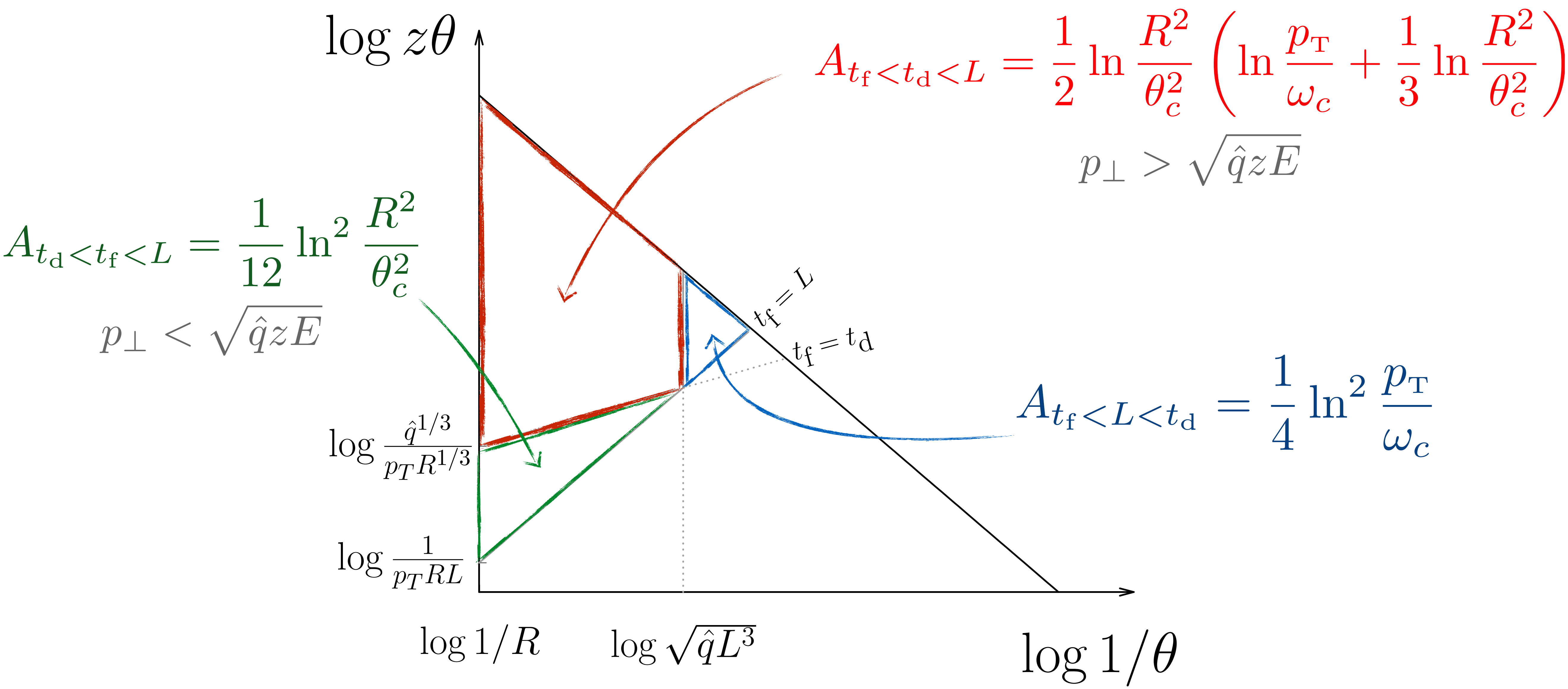
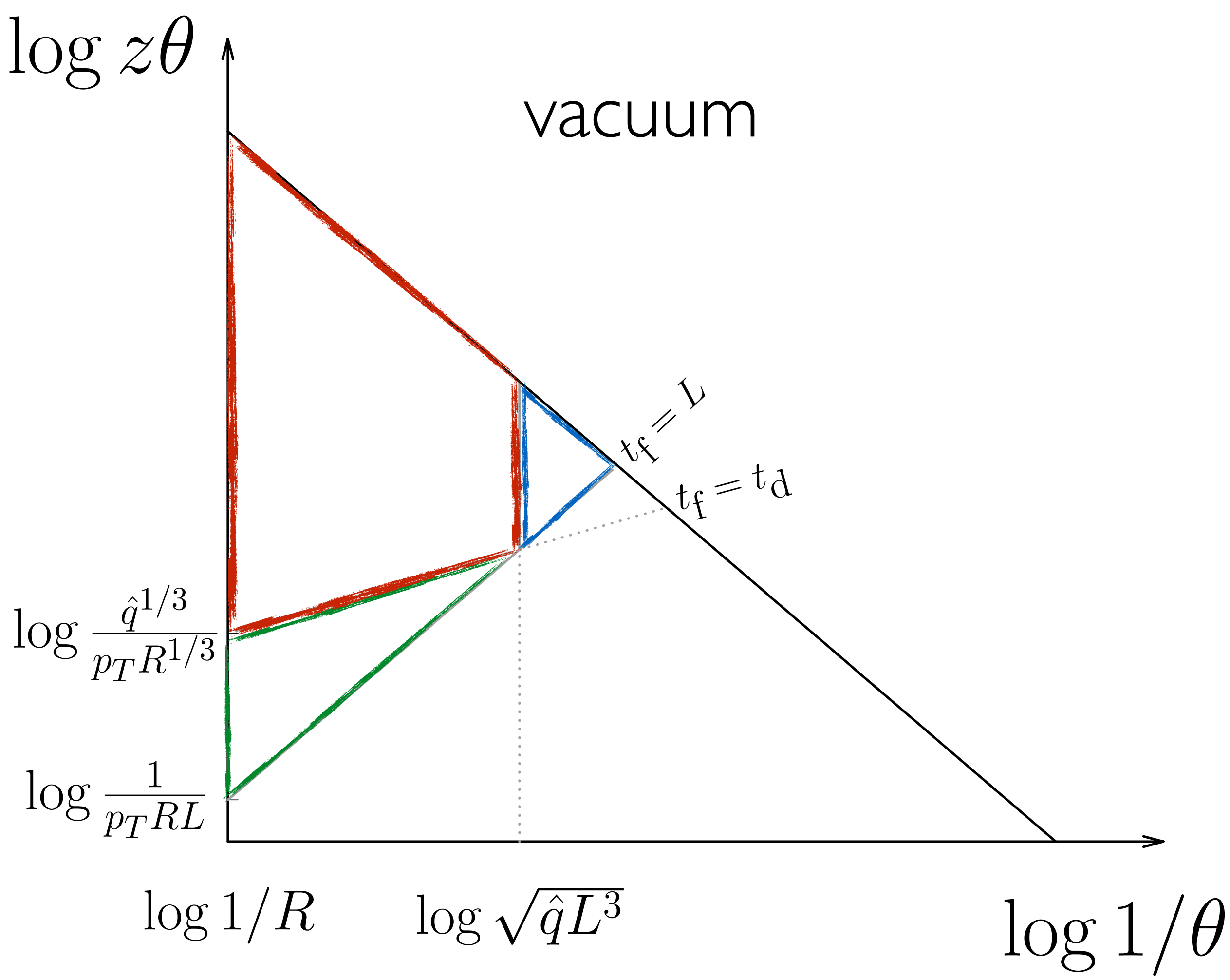
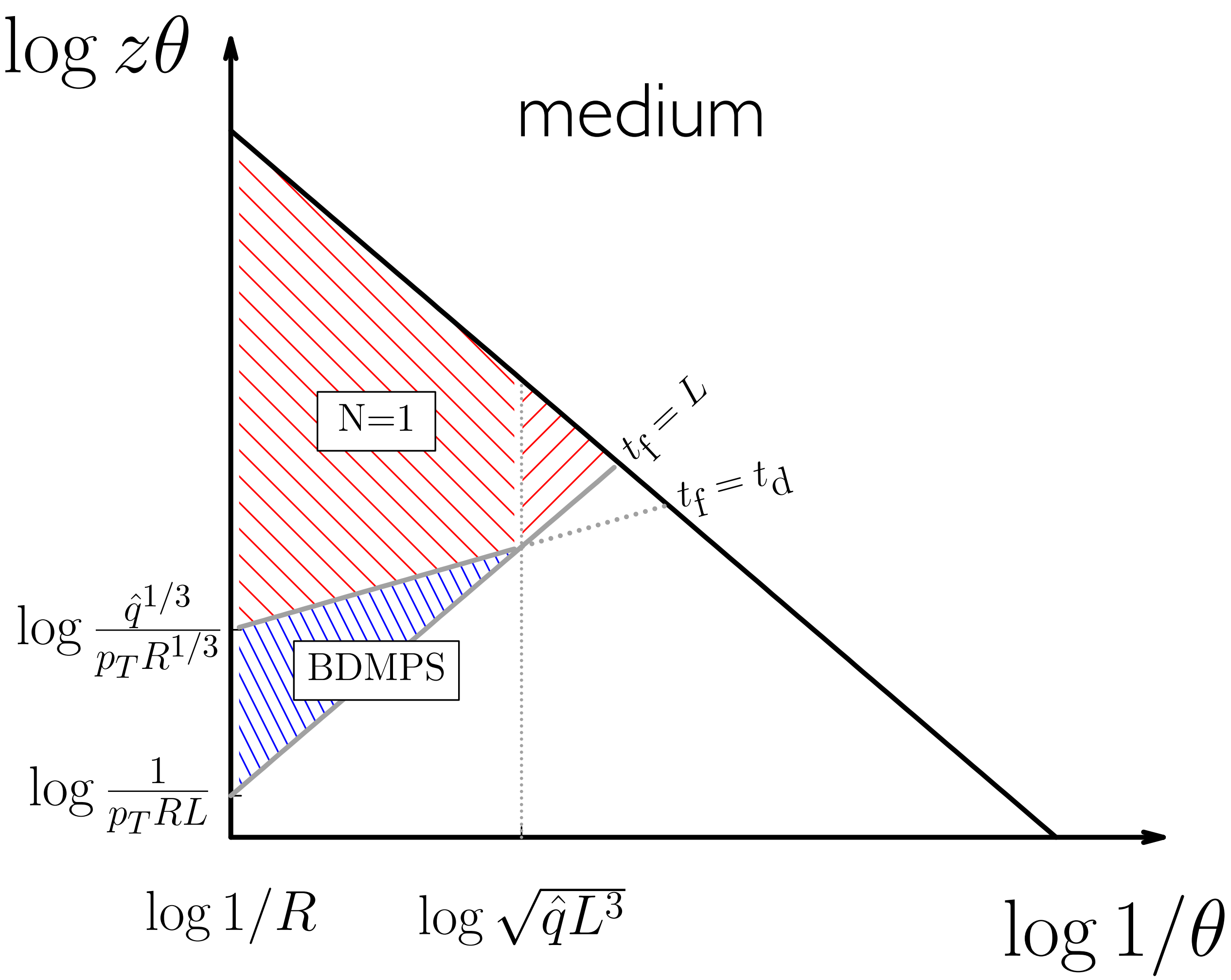


$$A_{t_\mathrm{f}<L} = \frac{1}{4}\ln^2 p_\mathrm{T} R^2 L$$

THE MAP…

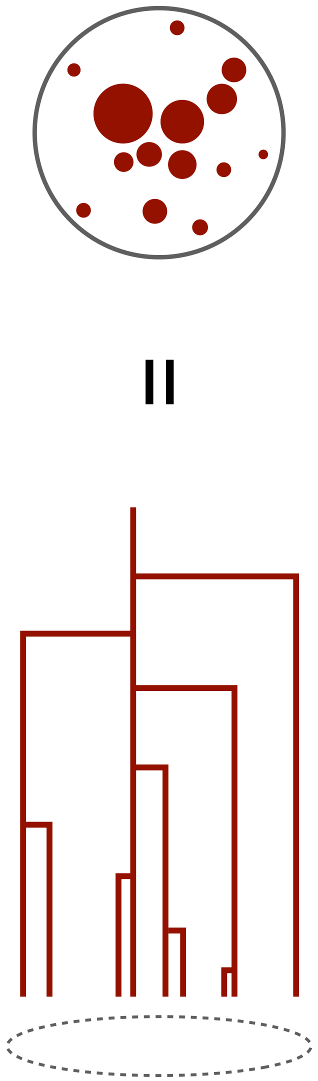


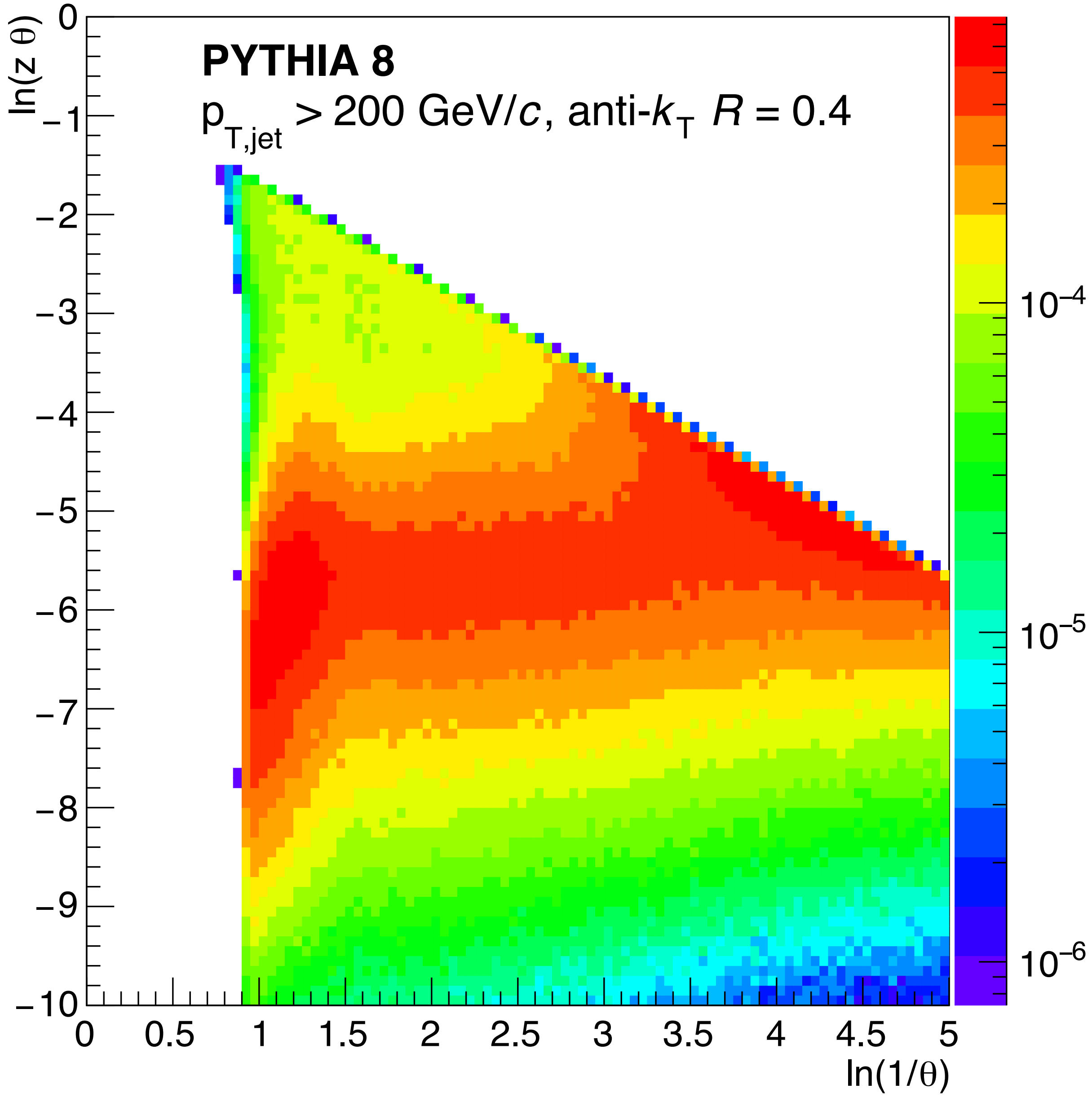


- mapping out possible parton splittings
- in vacuum process self-similar (running of α_s)
- for medium-induced radiation, splitting is not uniform in the plane ⇒ not directly comparable!

…AND THE TERRITORY

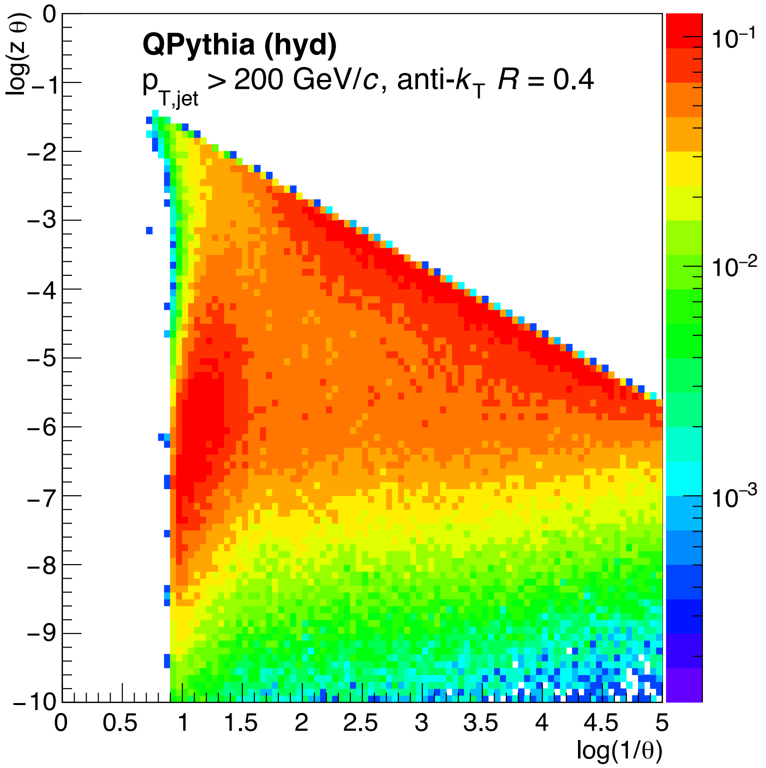
Perform a mapping iteratively from a C/A tree:



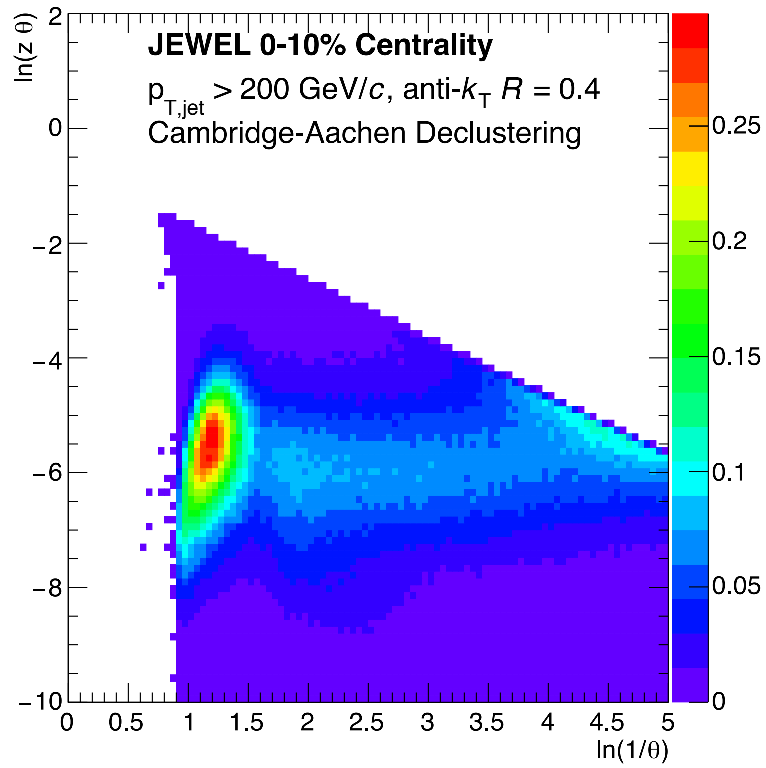


Radiation pattern

QPYTHIA



JEWEL (wo/ recoil)



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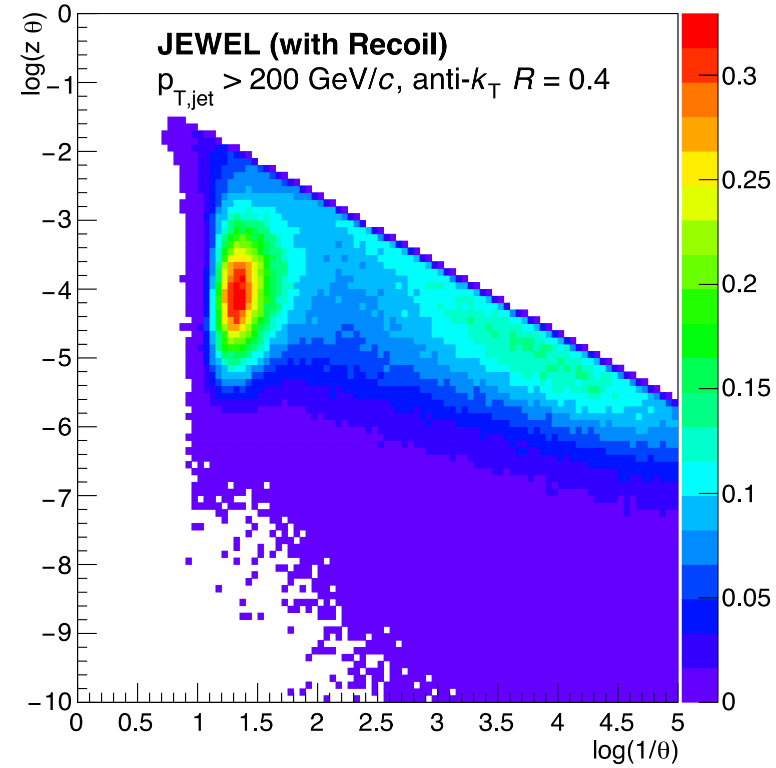
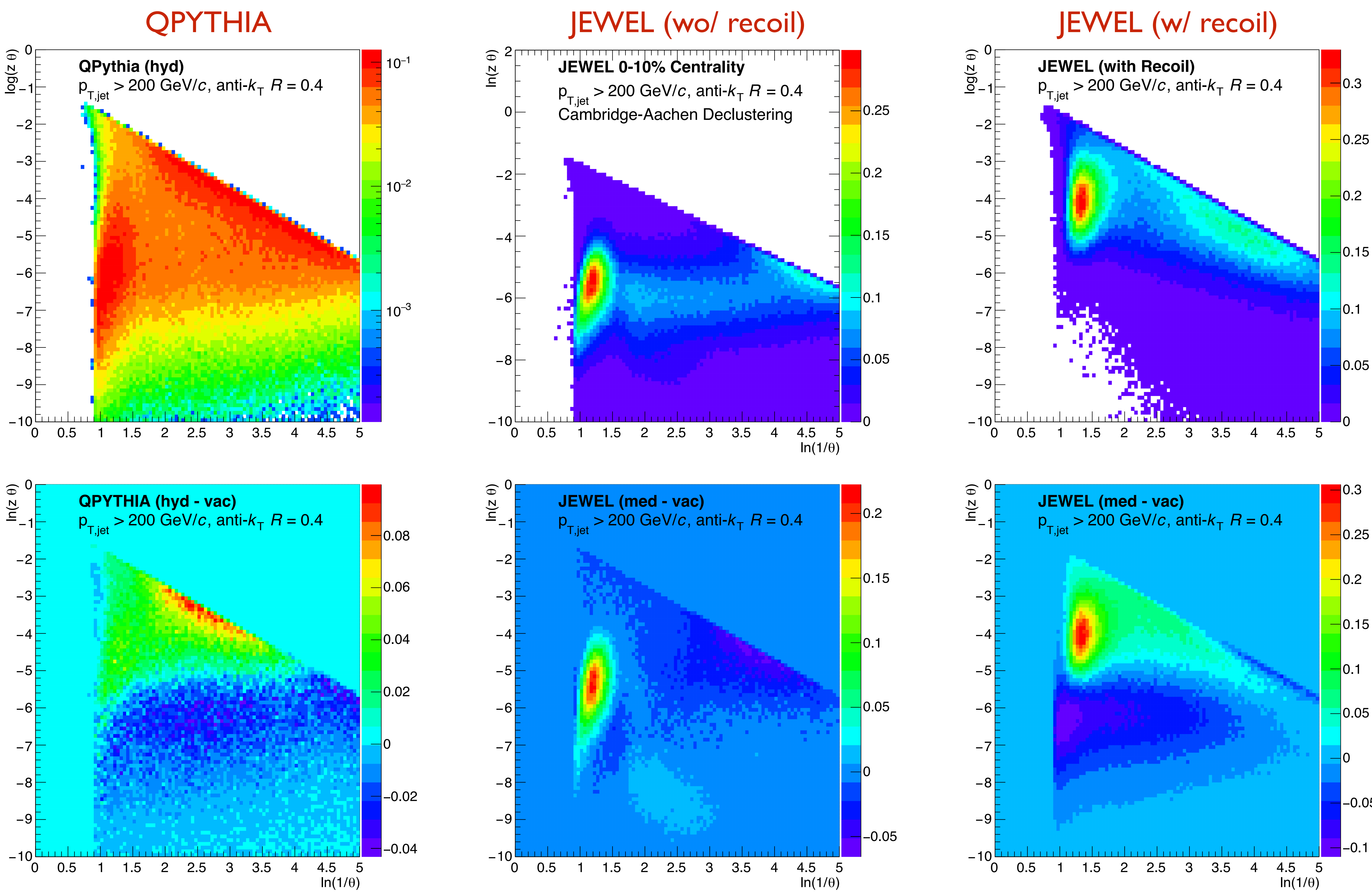


RADIATION PATTERN



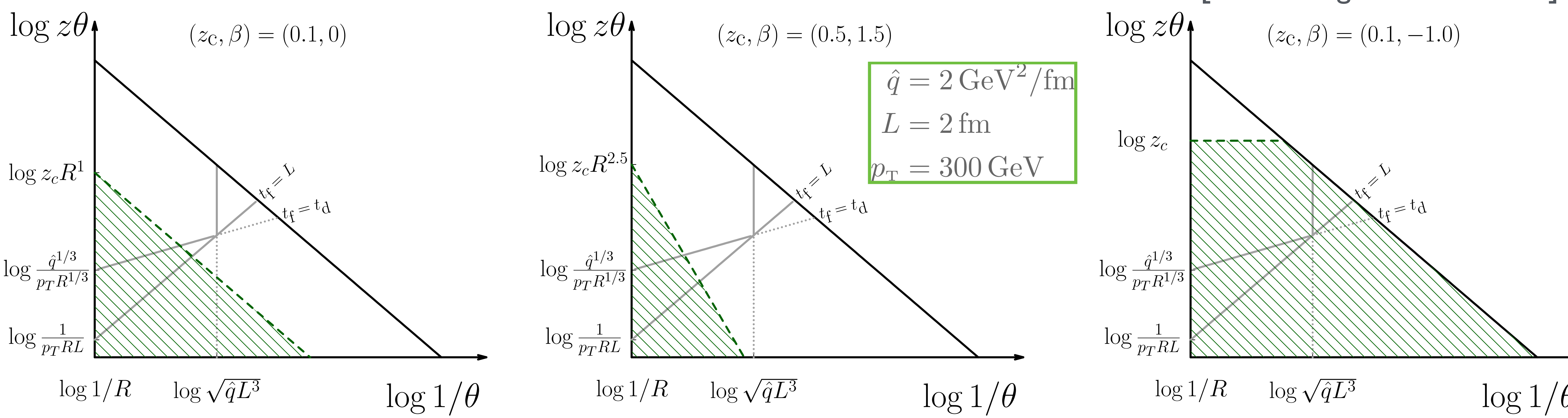
GROOMING EXERCISES

SoftDrop condition (mMDT)

$$\frac{\min(p_{\mathrm{T},i}, p_{\mathrm{T},j})}{p_{\mathrm{T},i} + p_{\mathrm{T},j}} > z_{\mathrm{cut}} \left(\frac{\Delta R_{ij}}{R_0} \right)^{\beta}$$

A. Larkoski, S. Marzani, G. Soyez, and J. Thaler, JHEP 05, 146 (2014)

[Shaded region is excluded.]



cuts only on the energy sharing fraction

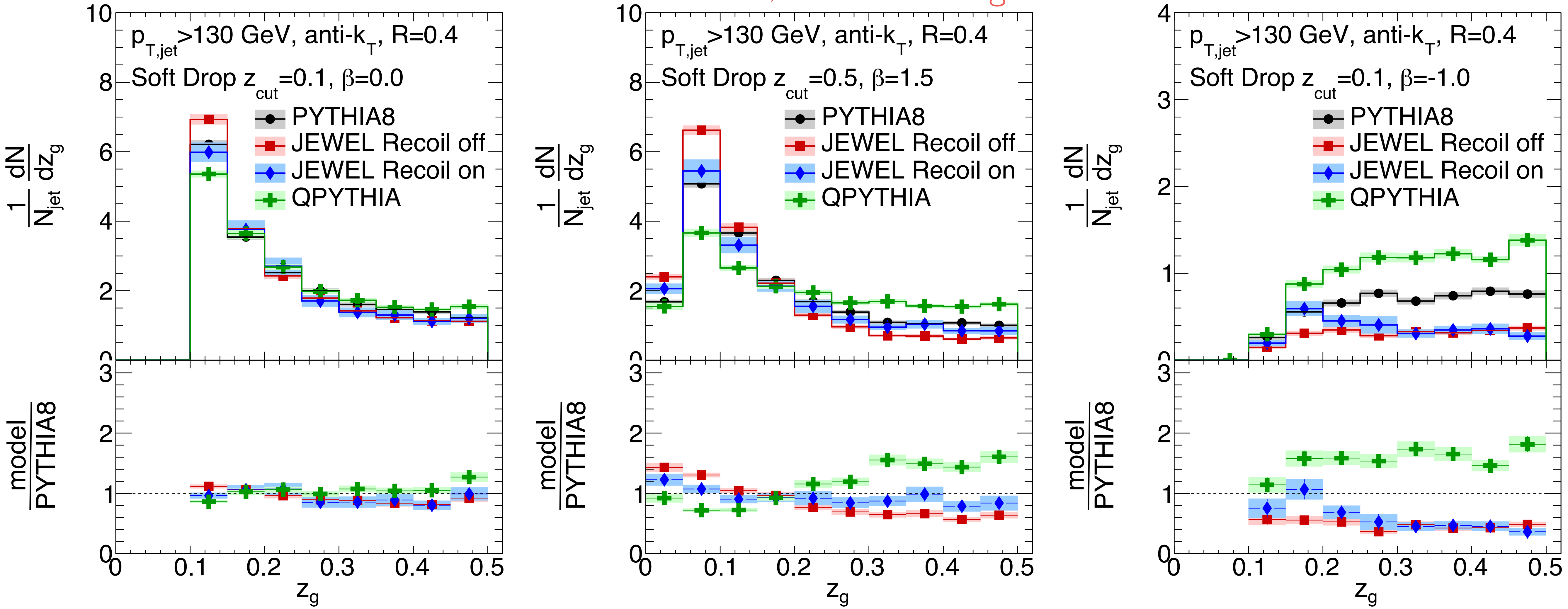
stronger grooming at large angle

only hard radiation remains

Carving out regions of phase space
[sometimes an angular cut-off is applied to account for detector resolution]

1) Groomed momentum fraction

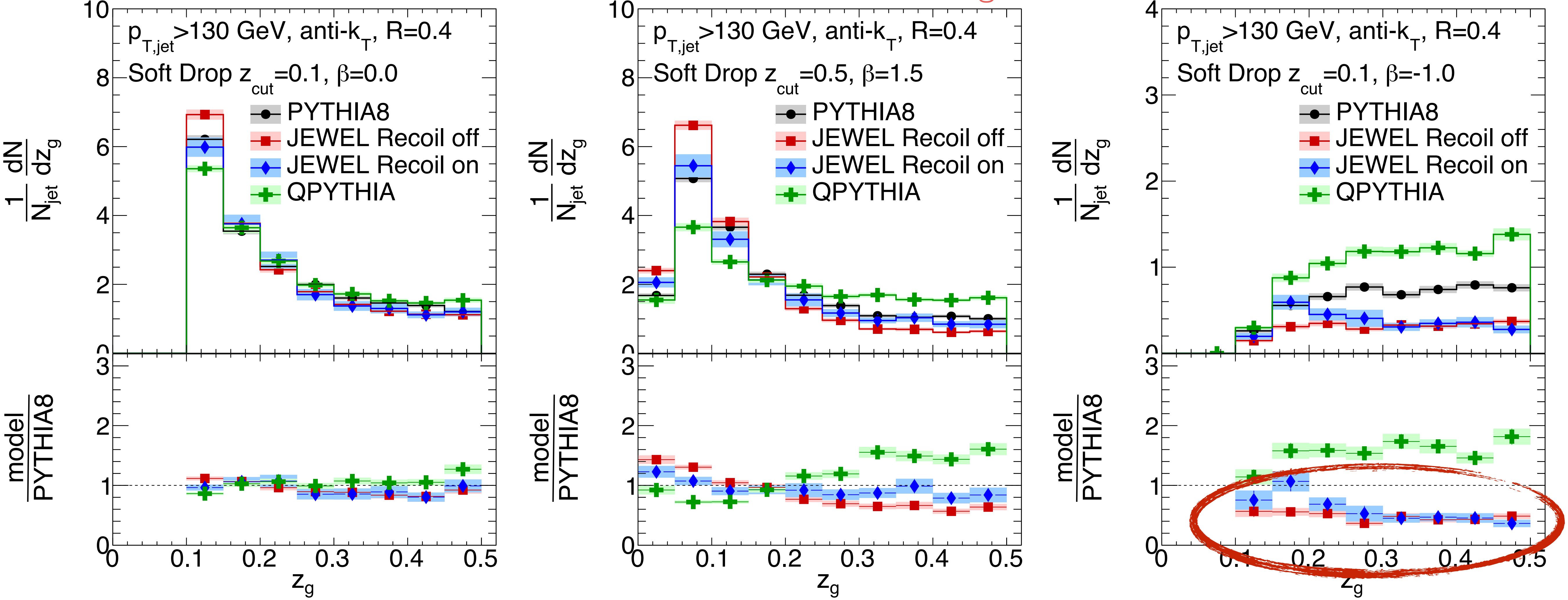
no ΔR cut, no embedding…



- normalized to # of ungroomed jets
  - # of surviving jets depend on angular structure!
  - for vacuum: resilient to splitting kinematics!
- sensitivity to recoils most visible for small zg

1) GROOMED MOMENTUM FRACTION

no ΔR cut, no embedding…



- normalized to # of ungroomed jets
  - # of surviving jets depend on angular structure!
  - for vacuum: resilient to splitting kinematics!
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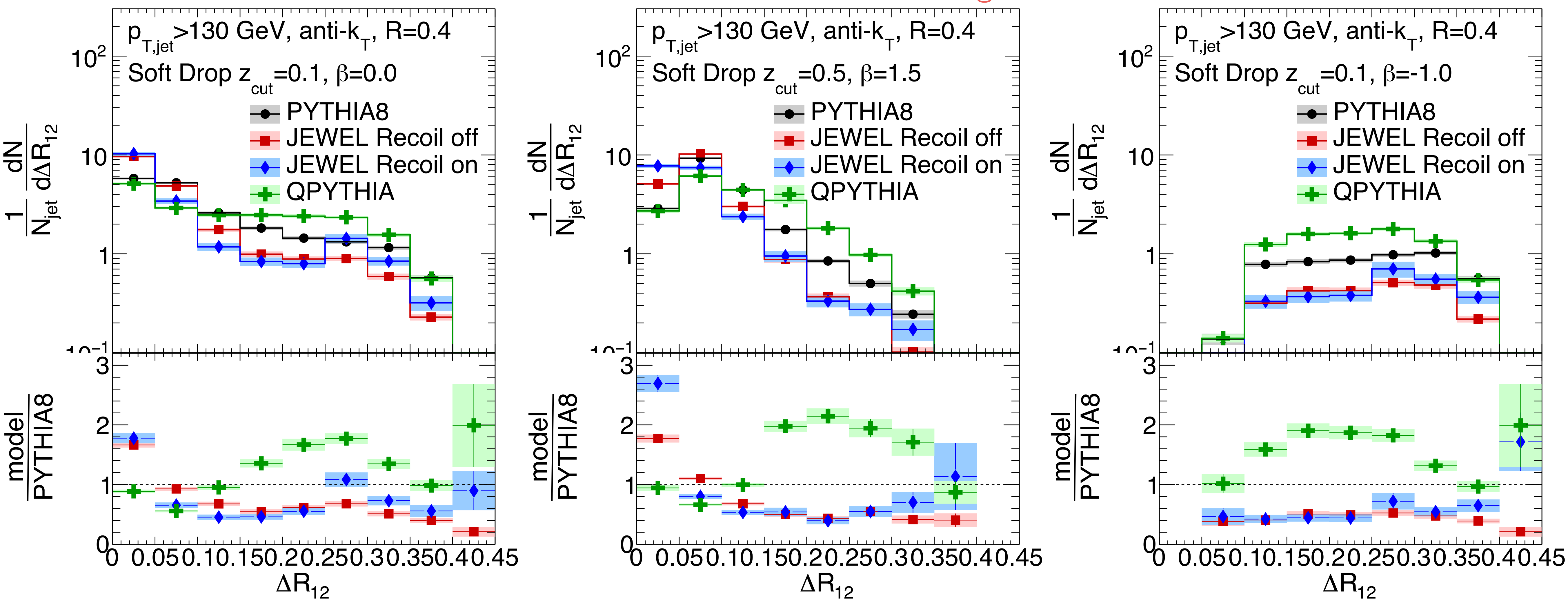
2) Groomed angular distance

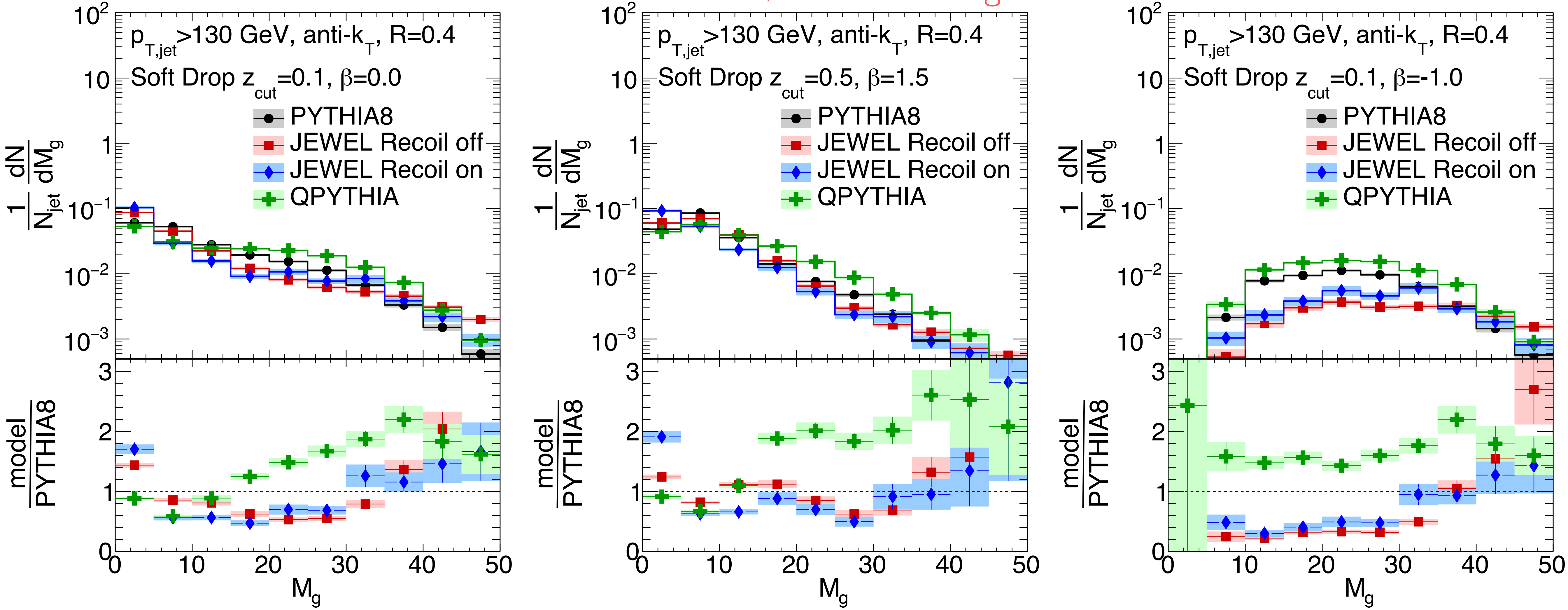
no ΔR cut, no embedding…



- QPYTHIA broadens jets wrt vacuum
  - consequence of increased splitting prob early in the shower
- JEWEL jets more collimated

3) Groomed jet mass

no ΔR cut, no embedding…

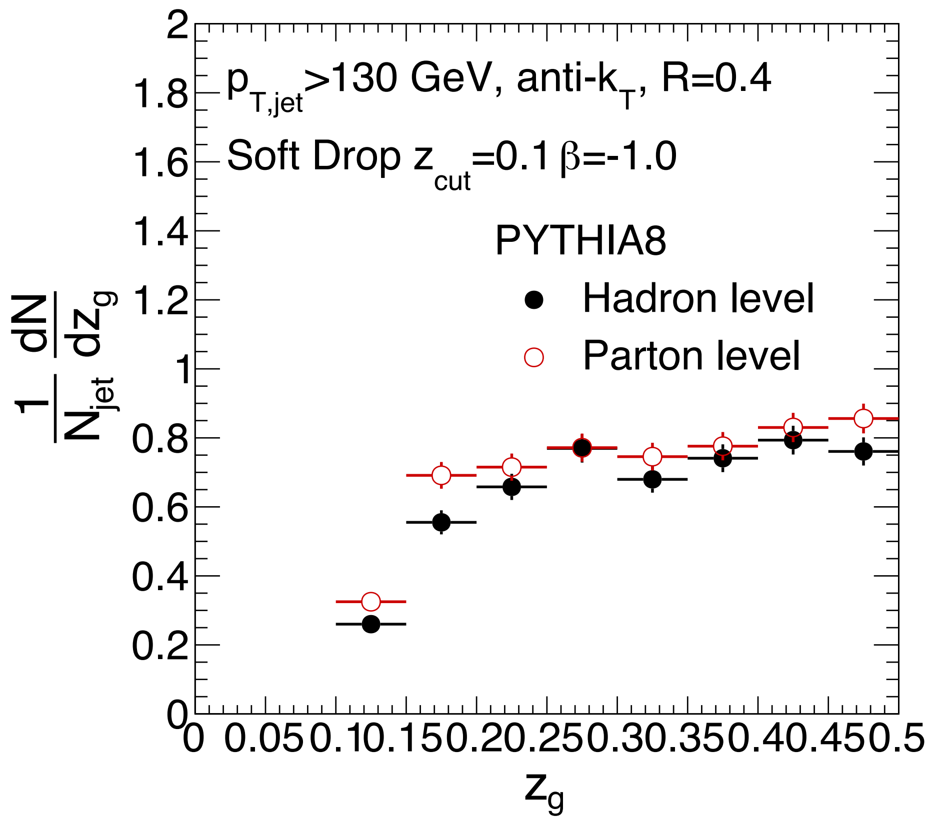


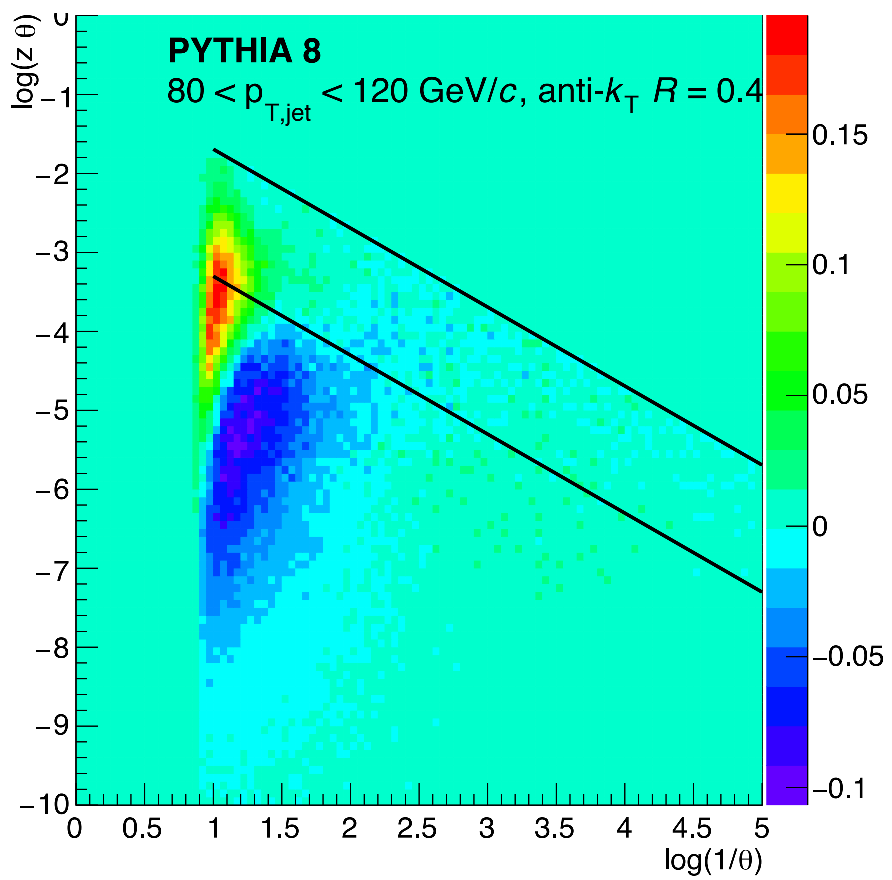
- more resilient to recoil effects - just a coincidence?
- further studies possible
  - serve as MC-exp, theory-MC comparisons

OTHER STUDIES

- hadronization effects, sensitivity to shower ordering variable
- embedding into heavy-ion background
  - tuning sophisticated background subtraction techniques (CS, SoftKiller,…)
  - realistic observables w/ grooming
- leverage from reclustering algo?
- plenty of ideas for the future!

Stay tuned!





INSTEAD OF CONCLUSIONS…

- it was a lot of fun!
  - opportunity to learn, discuss & check expectations!
- open (source)
  - discussion forum agnostic to modeling of underlying physics processes
  - using publicly available tools
- effort to establish jet quenching observables
  - demands theory & experiment collaboration

THANKS FOR YOUR ATTENTION!

Special thanks to Leticia Cunqueiro, Harry Andrews and Marta Verweij
for providing most of the MC plots!