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

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Hard Probes 2018

Workshop at 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

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Questions and support

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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

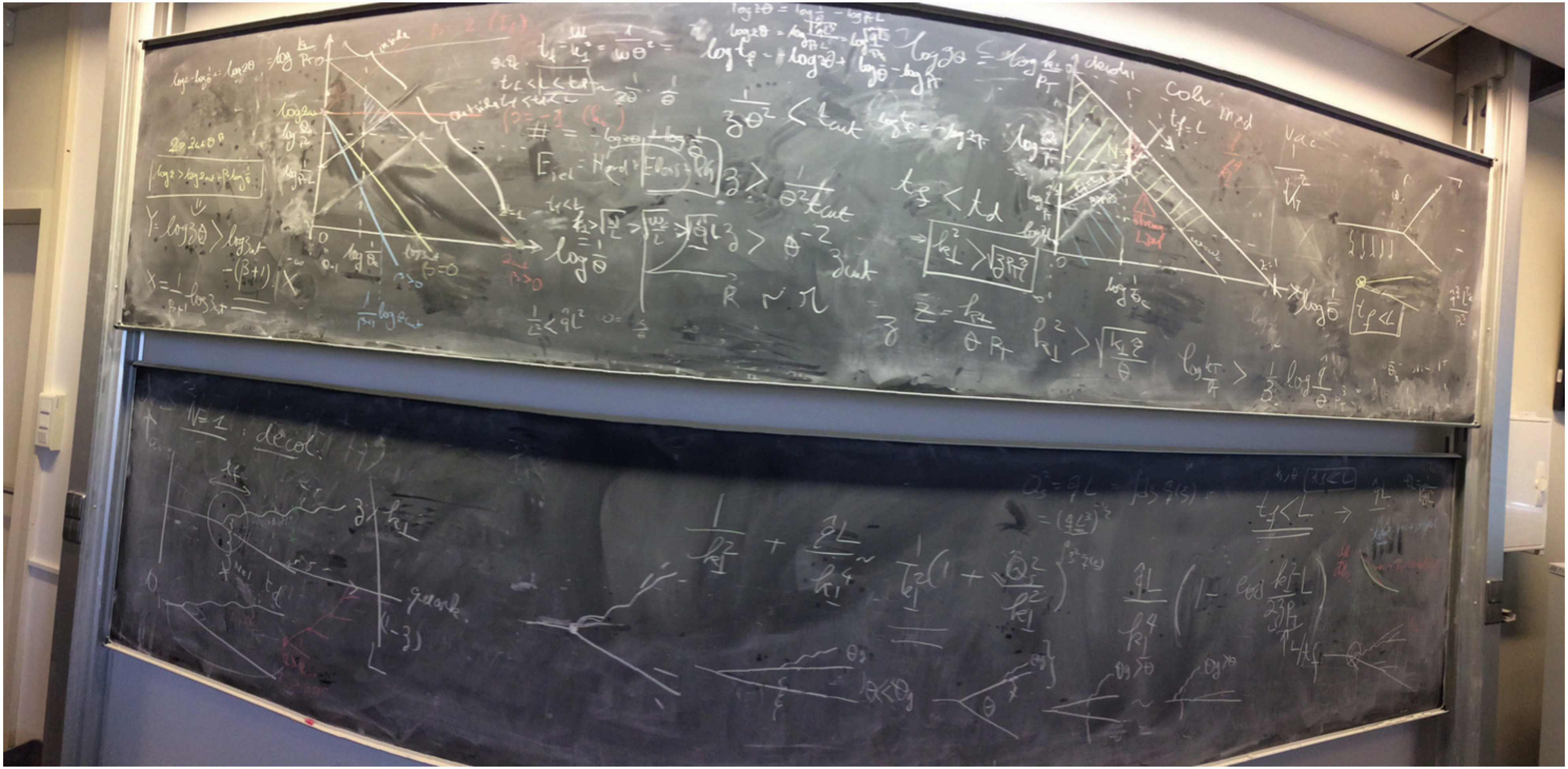
OC: Matteo Cacciari, Leticia Cunqueiro, Yen-Jie Lee, Yacine Mehtar-Tani, Guilherme Milhano, Matthew Nguyen, Dennis Perepelitsa, Konrad Tywoniuk, Marta Verweij, Urs Wiedemann, Korinna Zapp

Questions we asked ourselves

- Can we devise a strategy that reduces sensitivity to background while preserving theoretical control of perturbative jet structure?

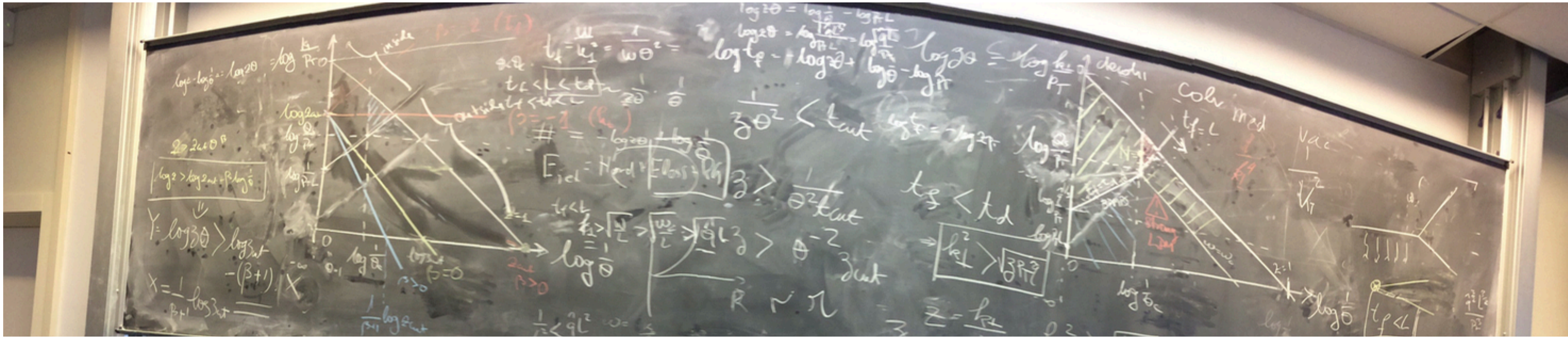
- Can we isolate specific physics effects using jet substructure? (regimes of dominant contribution)

Conclusion from discussions



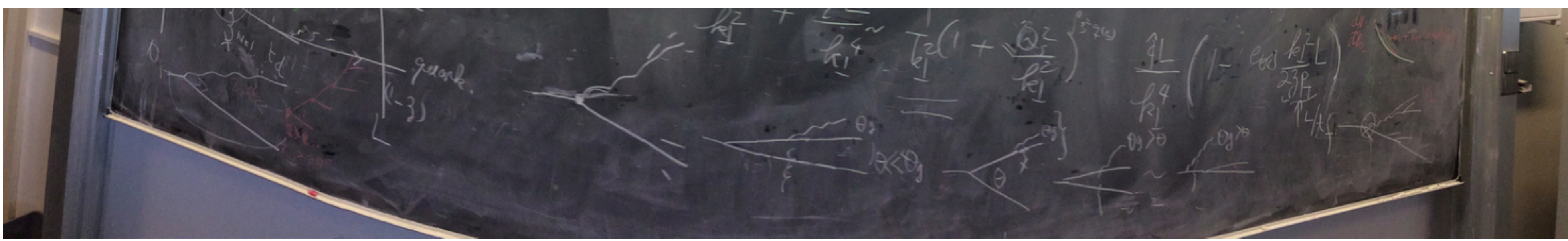
+ many figures from simulations on the group chat

Conclusion from discussions



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

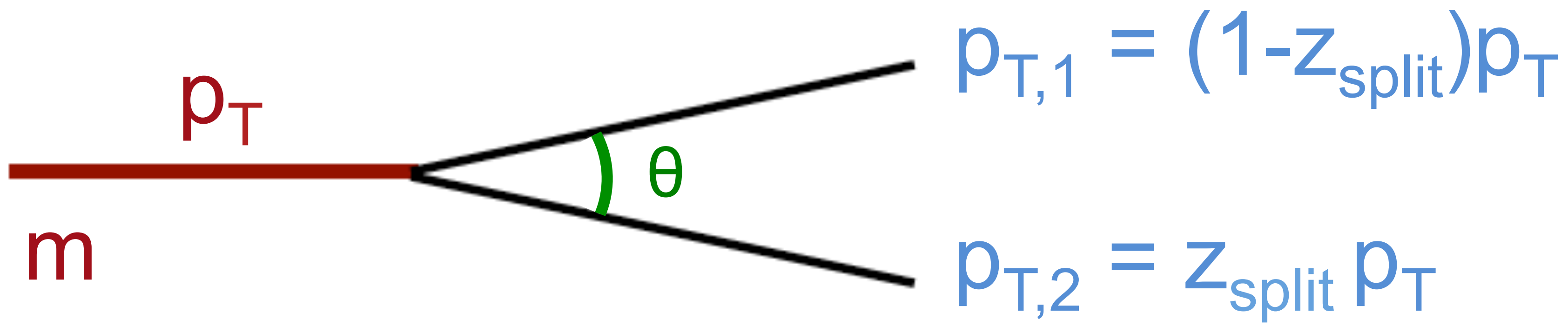
Harry Arthur Andrews, Liliana Apolinario, Redmer Alexander Bertens, Christian Bierlich, Matteo Cacciari, Yi Chen, Yang-Ting Chien, Leticia Cunqueiro Mendez, Michal Deak, David d'Enterria, Fabio Dominguez, Philip Coleman Harris, Krzysztof Kutak, Yen-Jie Lee, Yacine Mehtar-Tani, James Mulligan, Matthew Nguyen, Chang Ning-Bo, Dennis Perepelitsa, Gavin Salam, Martin Spousta, Jose Guilherme Milhano, Konrad Tywoniuk, Marco Van Leeuwen, Marta Verweij, Victor Vila, Urs A. Wiedemann, Korinna C. Zapp



Documented in a report after the workshop: arXiv:1808.03689

Parton splittings

Generic 1 → 2 splitting in QCD



Two relevant scales:

- Opening angle between the two branches: θ
- Momentum balance between the two branches: z_{split}

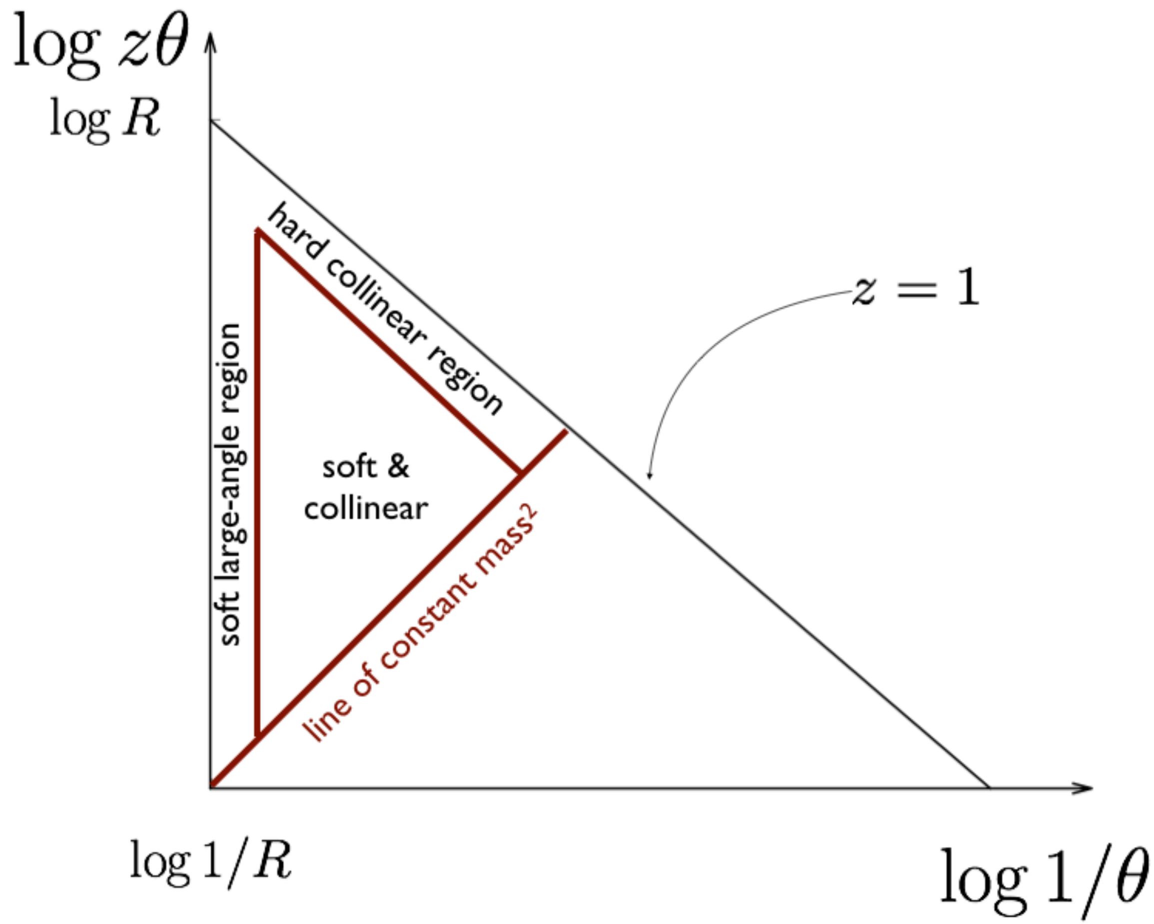
Splitting probability in vacuum:

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

The Lund diagram

Just a plane to depict parton splittings

$k_\perp / E \sim z\theta$



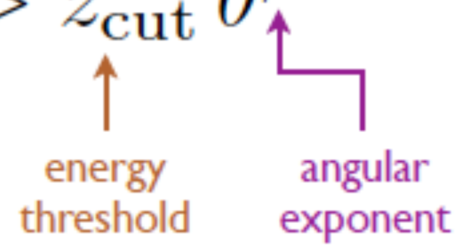
Triangle uniformly filled for unquenched parton shower

B. Andersson, G. Gustafson, L. Lönnblad and U. Pettersson, Z. Phys. C 43 (1989) 625
F. Dreyer, G. Salam, G. Soyez arXiv:1807.04758

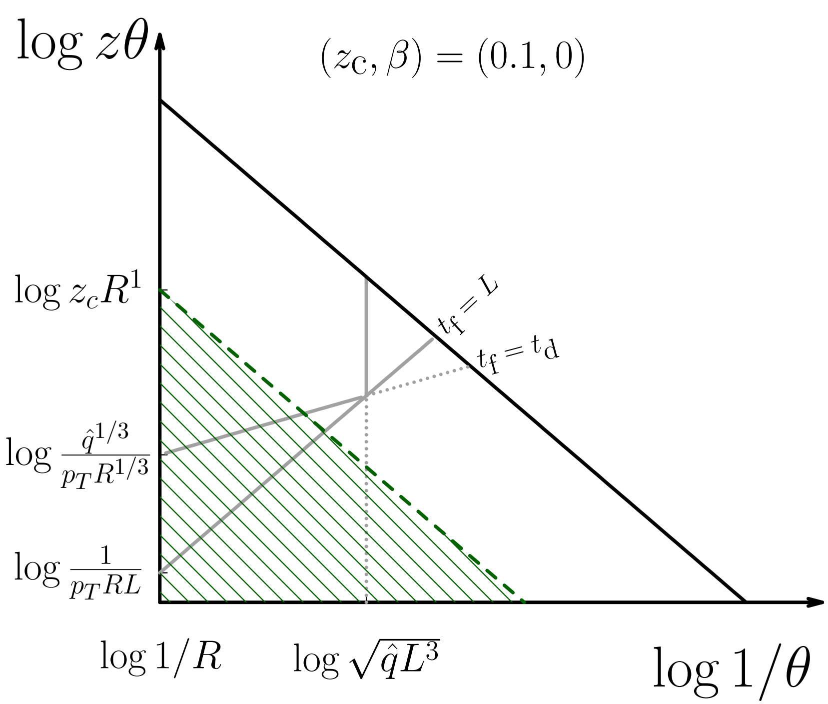
Lund and grooming

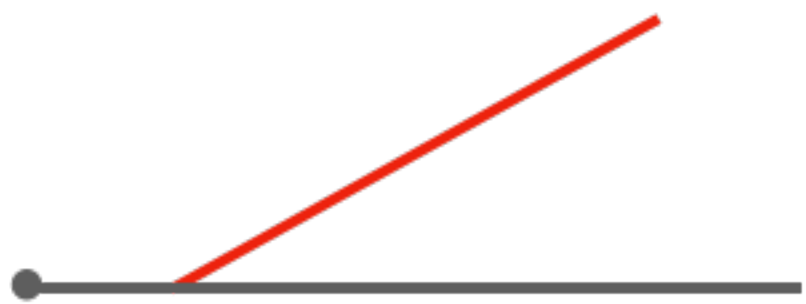
Grooming selects on momentum fraction and angle of branches in angular ordered tree

$$z > z_{\text{cut}}\, \theta^{\beta}$$



Z_{cut} = 0.1 and β = 0





First branching in angular ordered tree

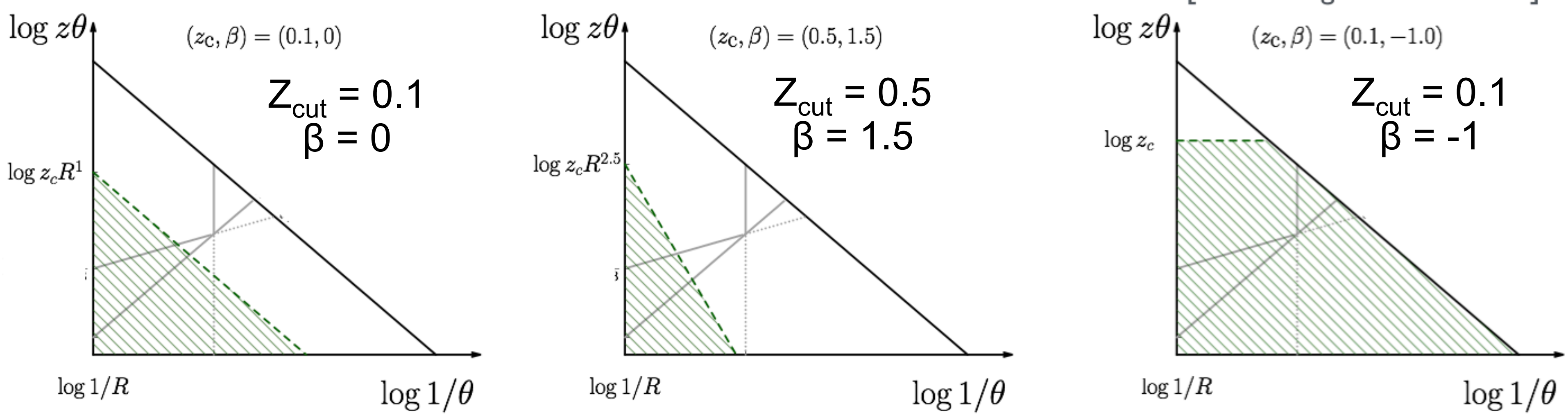
Lund and grooming

Grooming selects on momentum fraction and angle of branches in angular ordered tree

$$z > z_{\text{cut}}\, \theta^{\beta}$$

energy threshold (z_{cut}) — angular exponent (β)

[Shaded region is excluded.]

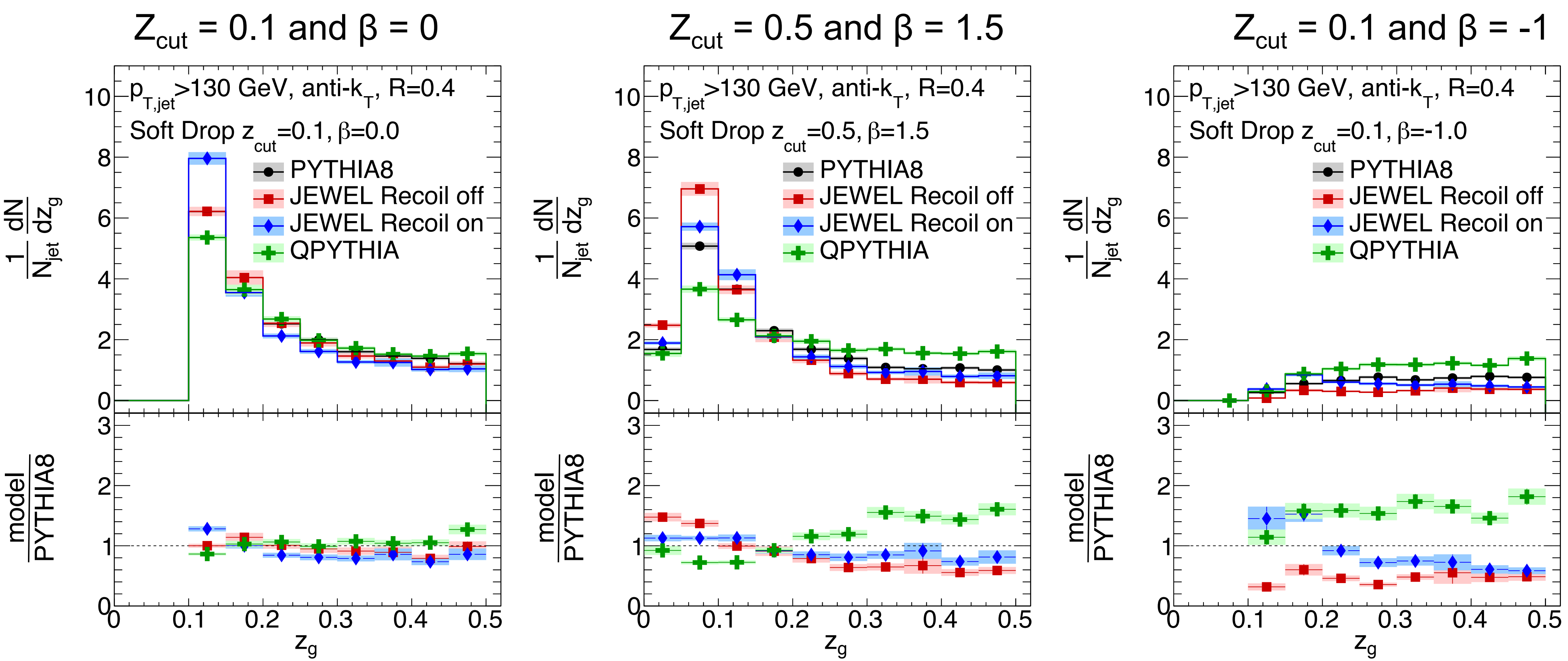


cuts only on the energy sharing fraction | stronger grooming at large angle | only hard radiation remains

Varying the grooming condition allows to select different regions of radiation phase space

Grooming settings and z_g

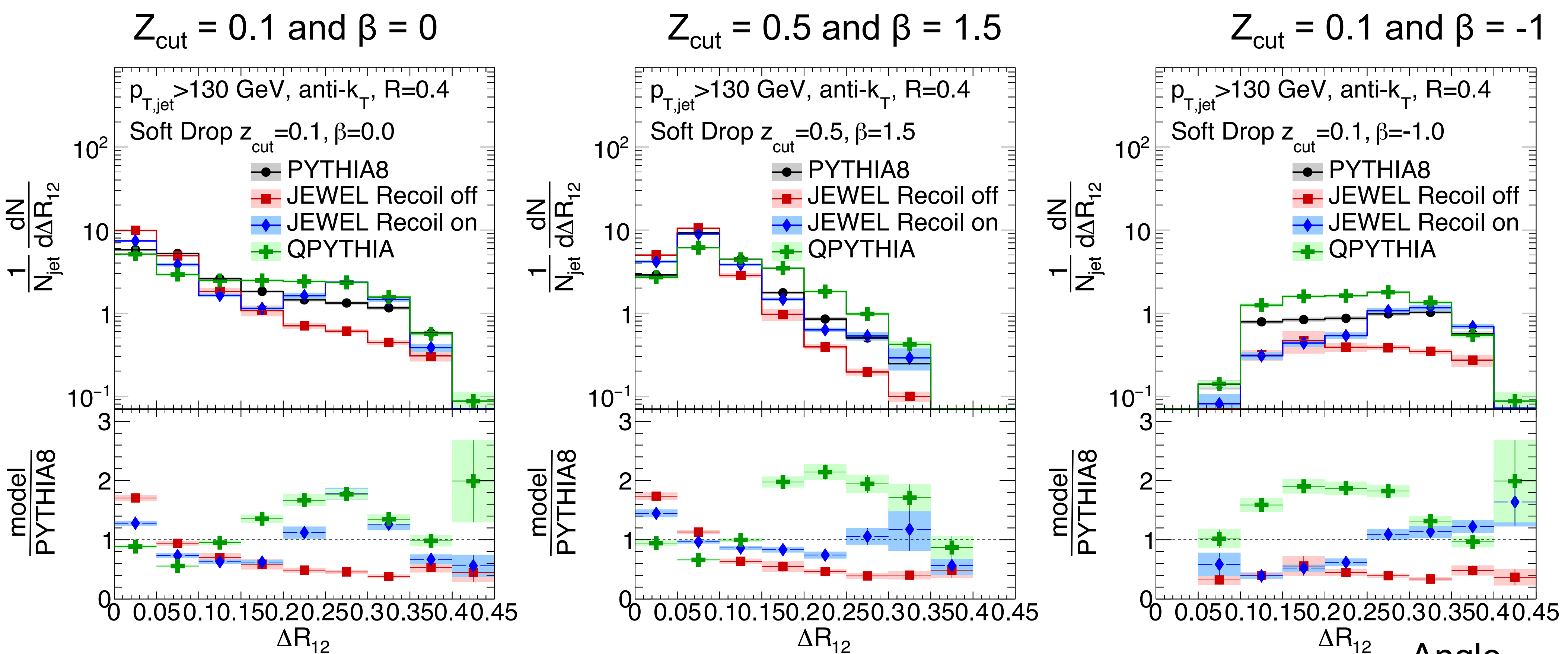
Comparison of jet quenching MCs (JEWEL,QPYTHIA) with vacuum model (PYTHIA)



Not all grooming settings equally sensitive to different physics assumptions

Grooming settings and ΔR_{12}

Comparison of jet quenching MCs (JEWEL,QPYTHIA) with vacuum model (PYTHIA)

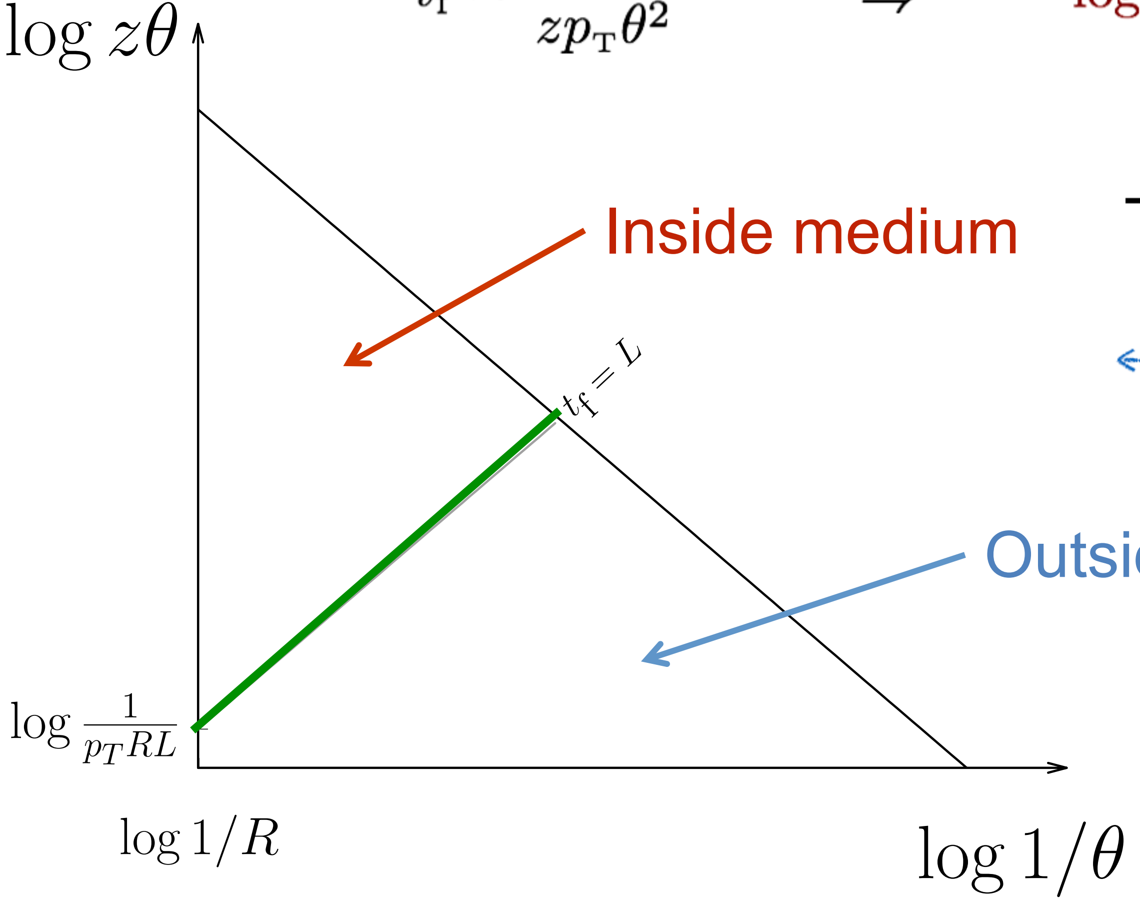


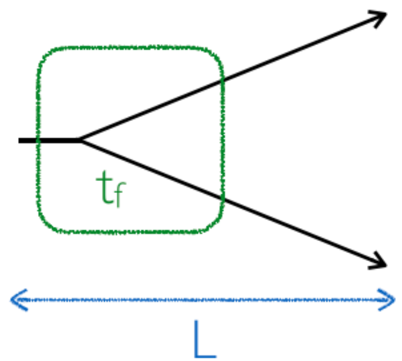
Not all grooming settings equally sensitive to different physics assumptions

In or outside the medium

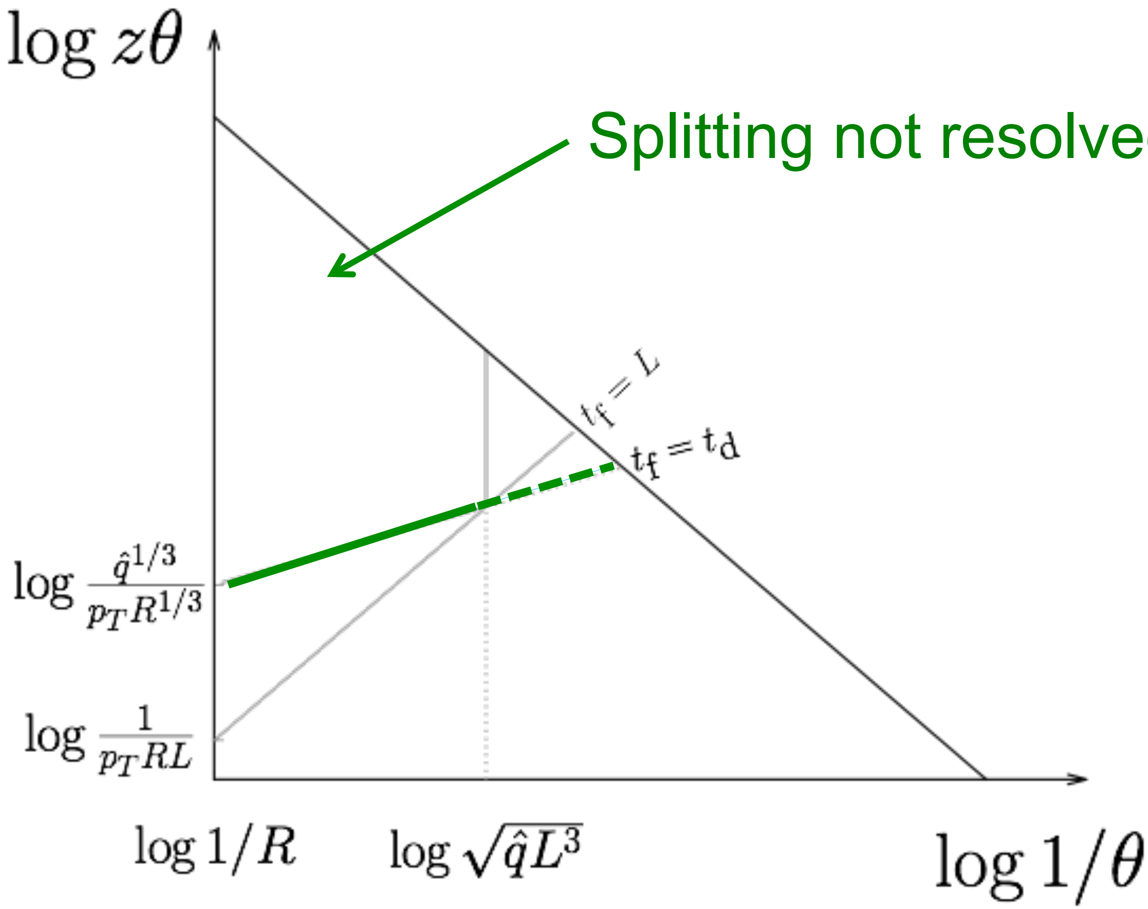
A splitting can either occur inside or outside the medium
→ depends on the formation time of the splitting

$$t_{\mathrm{f}} \sim \frac{1}{z p_{\mathrm{T}} \theta^2} \quad \Rightarrow \quad \log z\theta = \log \frac{1}{\theta} + \log \frac{1}{p_{\mathrm{T}} L}$$





Coherent or incoherent splitting



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

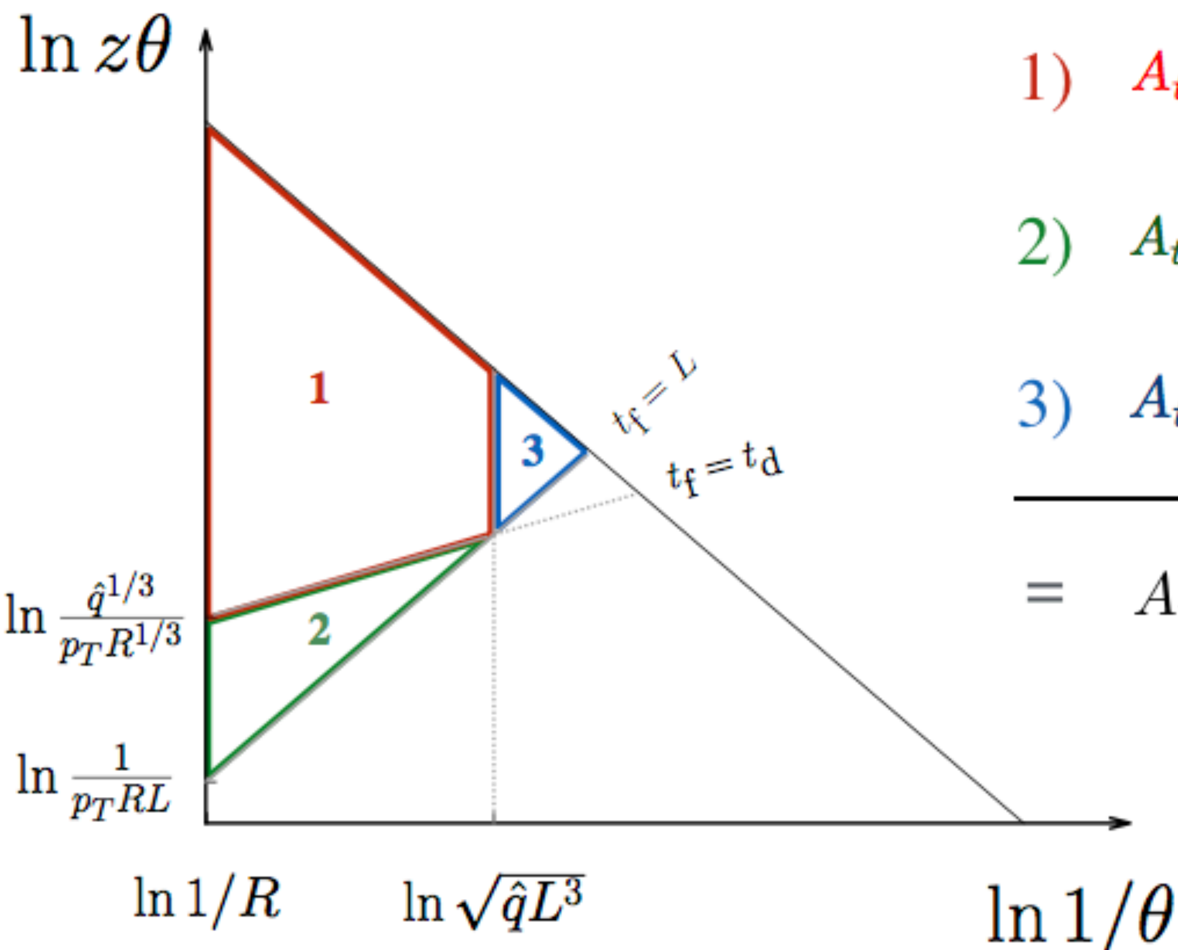
Decoherence time: $t_\mathrm{d} \sim \frac{1}{(\hat{q}\theta^2)^{1/3}}$

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

Phase space in medium

3 regions for a splitting happening in medium

1) vacuum splitting inside medium
2) medium-induced splitting → not uniform in Lund plane
3) unresolved splitting



1) $A_{t_f < t_d < L} = \frac{1}{2} \ln \frac{R^2}{\theta_c^2} \left(\ln \frac{p_T}{\omega_c} + \frac{1}{3} \ln \frac{R^2}{\theta_c^2} \right)$

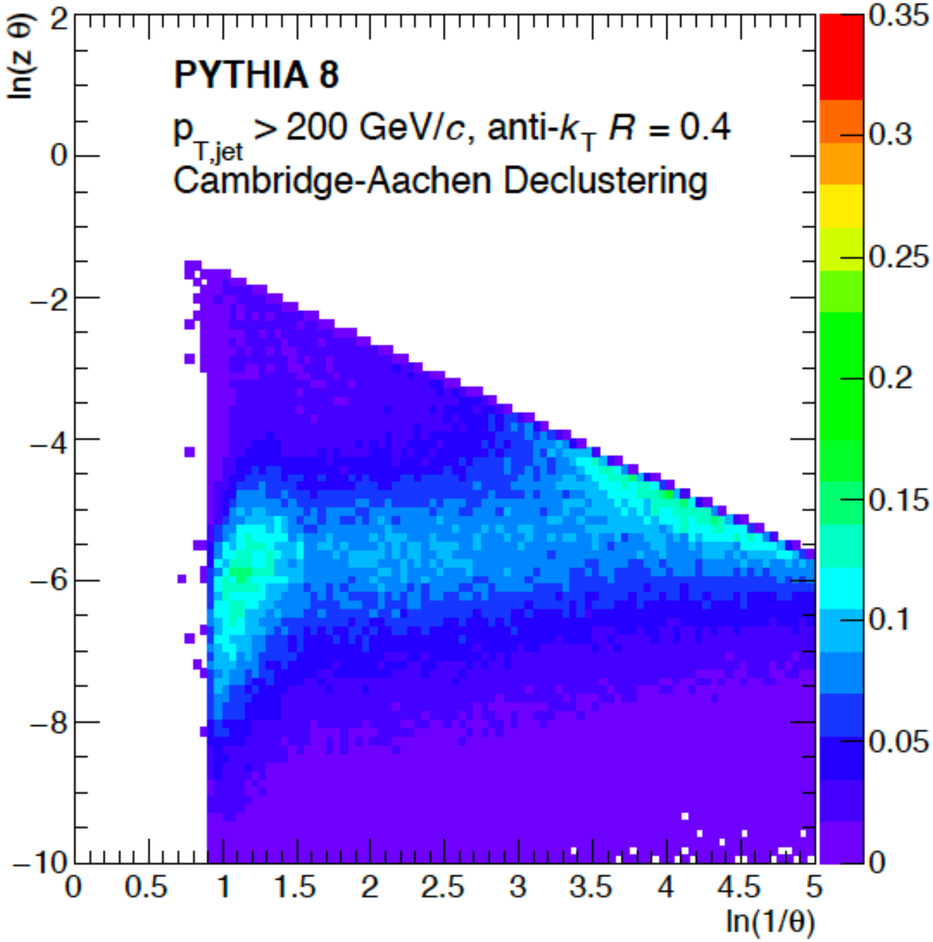
2) $A_{t_d < t_f < L} = \frac{1}{12} \ln^2 \frac{R^2}{\theta_c^2}$

3) $A_{t_f < L < t_d} = \frac{1}{4} \ln^2 \frac{p_T}{\omega_c}$

$= \quad A_{t_f < L} = \frac{1}{4} \ln^2 p_T R^2 L$

Lund plane in MC

Measure Lund diagram in data or Monte Carlo event generator:
Use **iterative declustering technique** to unwind the angular ordered tree retrieving information about all parton splittings
→ probe of QCD branching history



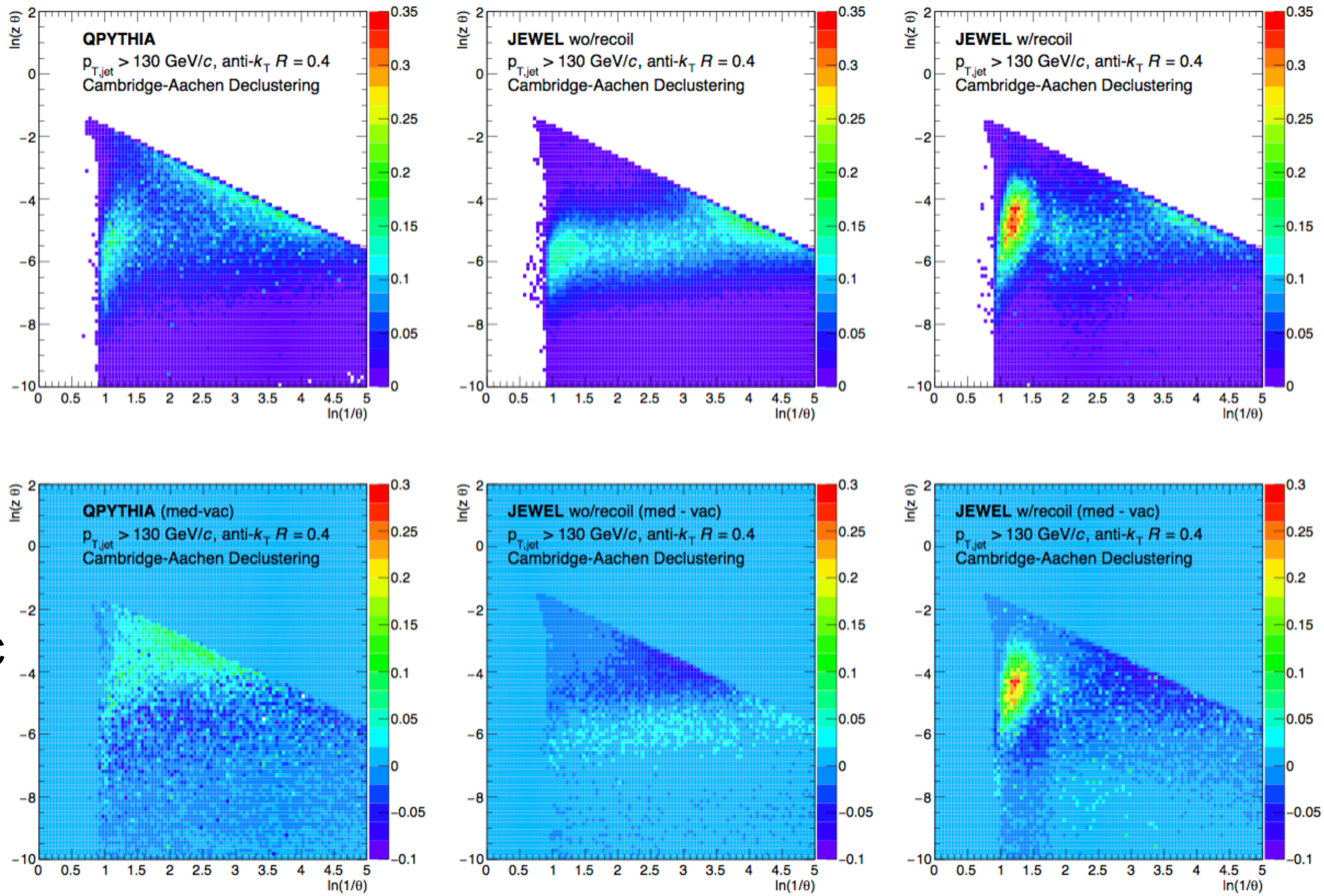
More radiation for larger k_T due to running coupling

+ some distortion from underlying event uncorrelated to jet

Lund plane in jet quenching MC

QPYTHIA | JEWEL (wo/ recoil) | JEWEL (w/ recoil)

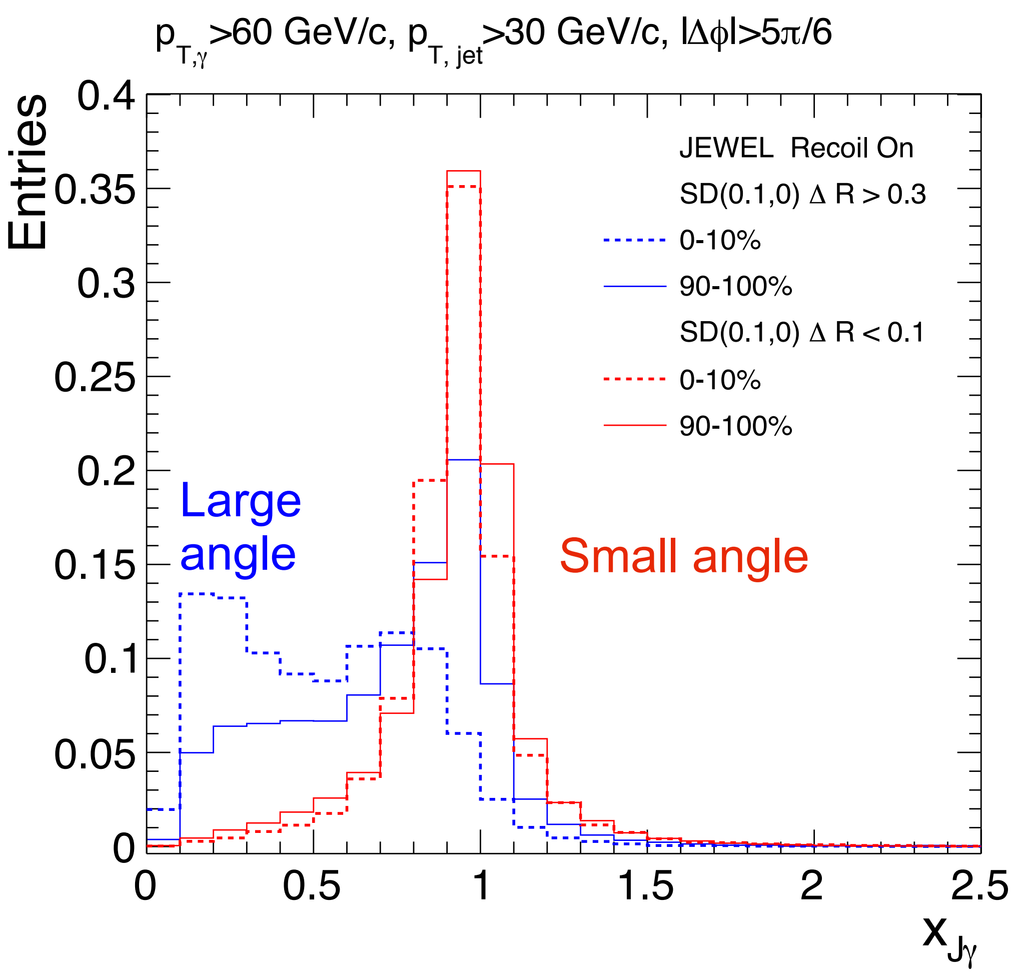
MED-VAC



Medium effects visible in difference distribution (quenched − vacuum)

Correcting for detector inefficiencies not trivial

Well-defined selections



Example: photon-jet

Select population of jets using groomed angle
- Narrow jets (small angle)
- Wide jets (large angle)

Could help pinning down details of jet quenching mechanism
- Role of coherence
- Energy loss dependence on number of partons in shower

+ eventually medium properties

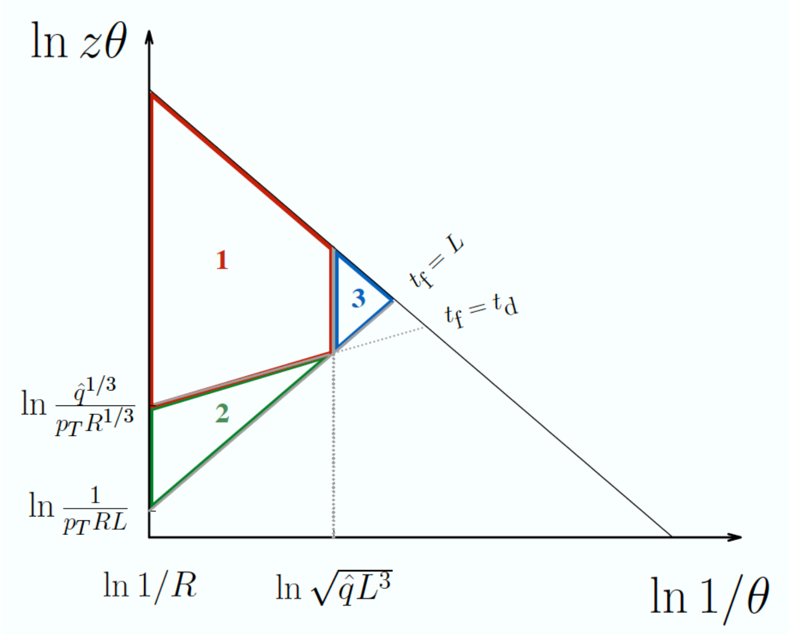
Summary

Effort to establish strategy to get the most out of jet substructure observalbes

- requires theory & experiment collaboration

At this conference already results based (partially) on these findings from both theory and experiment communities

Full report here: arXiv:1808.03689



Thanks to all workshop participants

Special thanks to Konrad Tywoniuk