Utrecht University

Nikhef

Exploring perturbative QCD splittings in heavy-ion collisions

https://arxiv.org/abs/2311.07643

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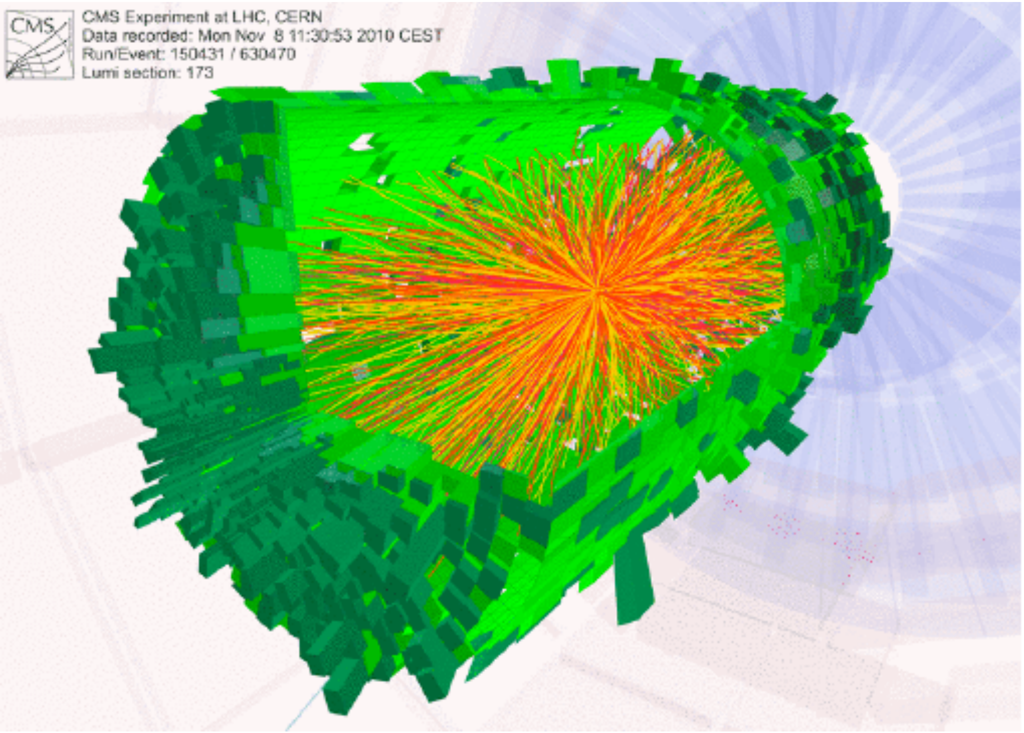
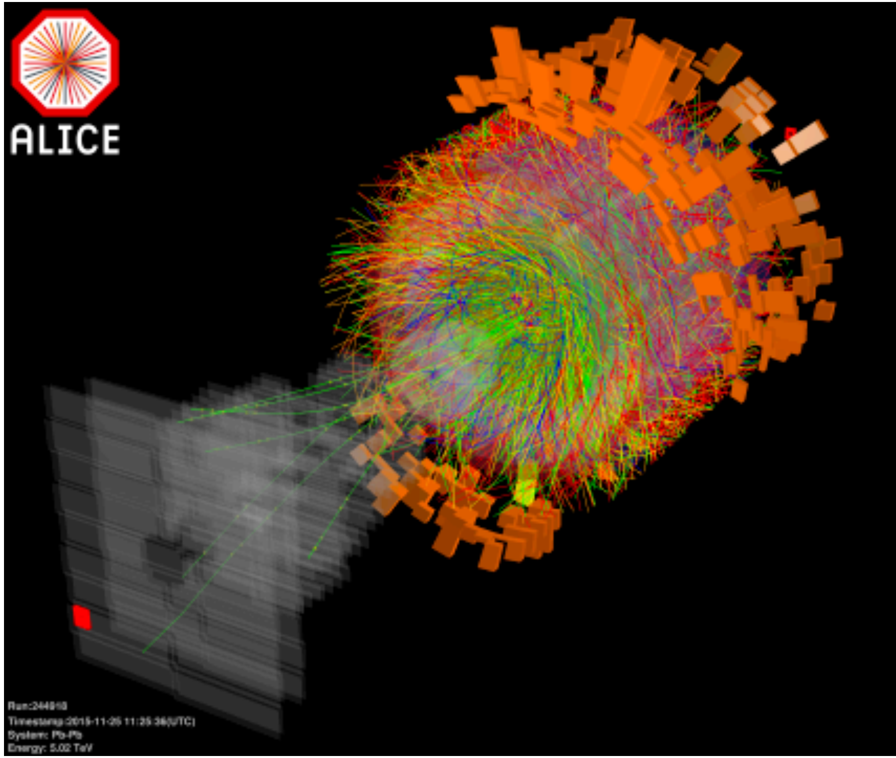
Marta Verweij

Utrecht University

Nikhef Theory Seminar

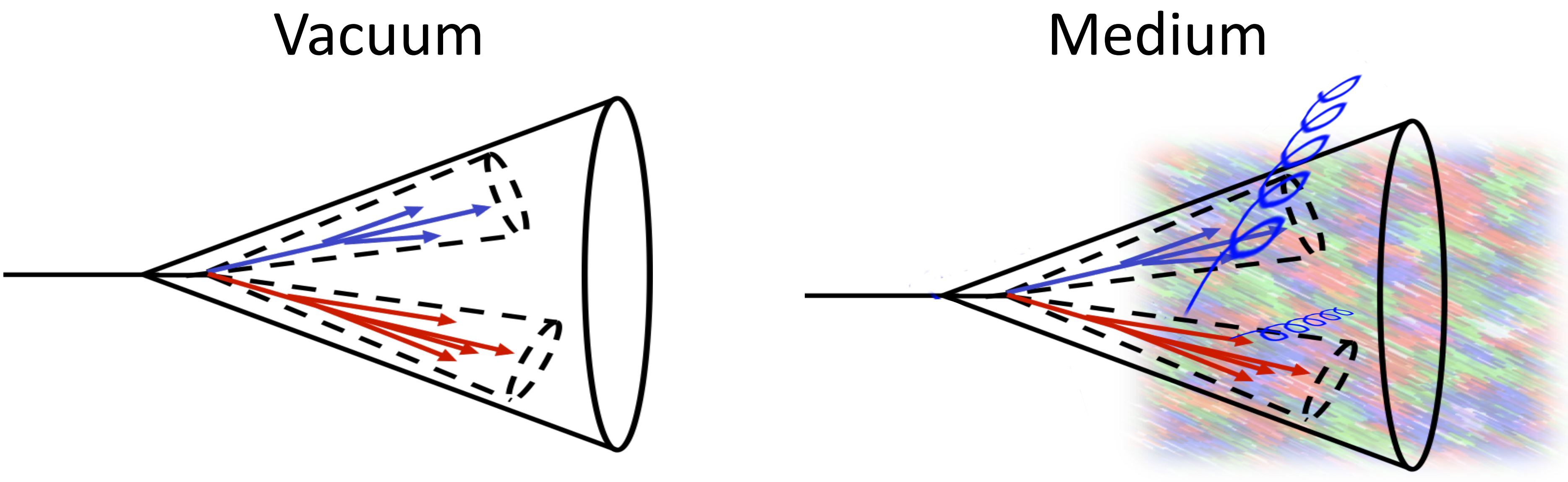
February 1, 2024





Thousands of particles are produced in one heavy ion collision

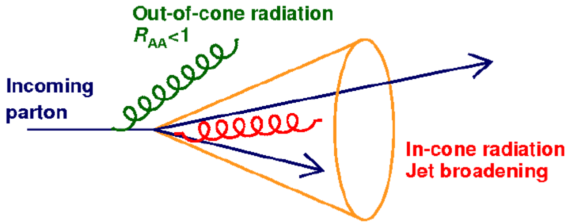
Parton showers



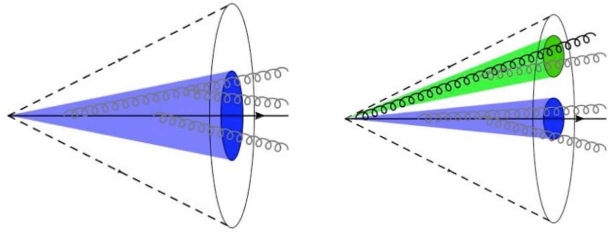
What happens to the parton shower in a hot QCD medium?
And what does that tell us about this medium?

Jet modification in hot QCD medium

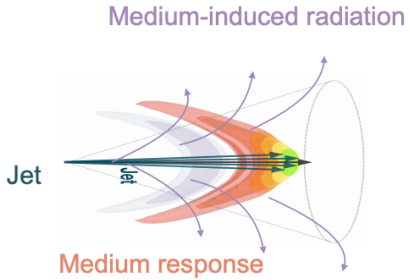
Medium-induced energy loss



Coherence effects

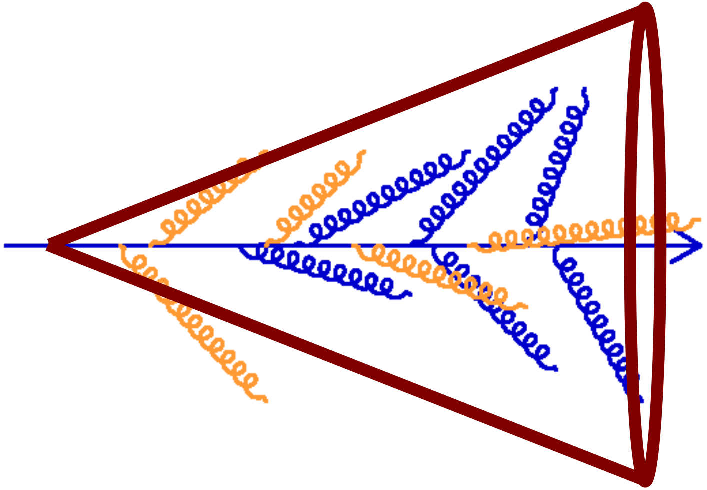


Medium recoil



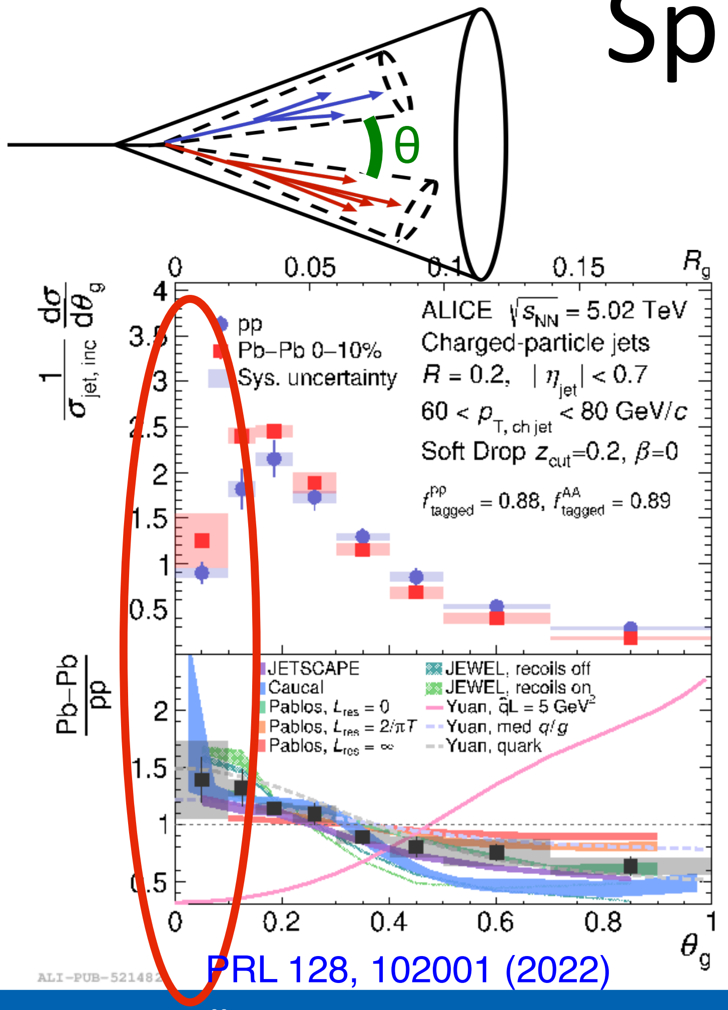
Jet Quenching

- How is the parton shower modified?
- What is(are) the mechanism(s) modifying the shower?
- Can we relate shower modifications to medium properties?



Main experimental tool: jet substructure

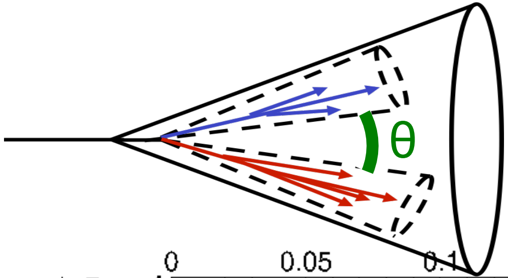
Splitting angle

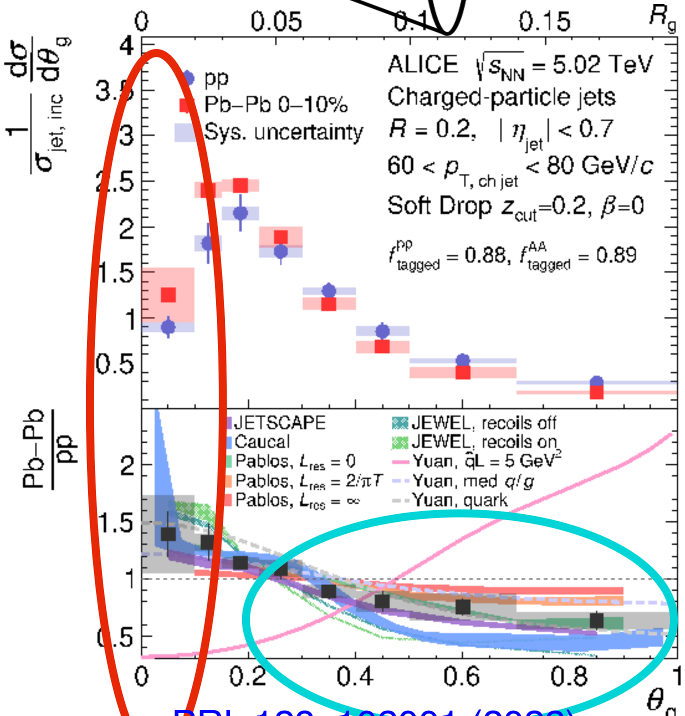


PRL 128, 102001 (2022)

Small θ_g: less vacuum-like emitters from which energy can be radiated
→less suppression observed in data

Splitting angle

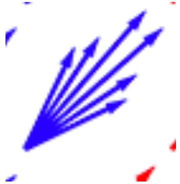




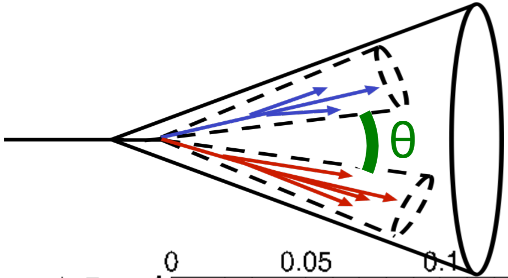
PRL 128, 102001 (2022)

Small θ_g: less vacuum-like emitters from which energy can be radiated
→less suppression observed in data

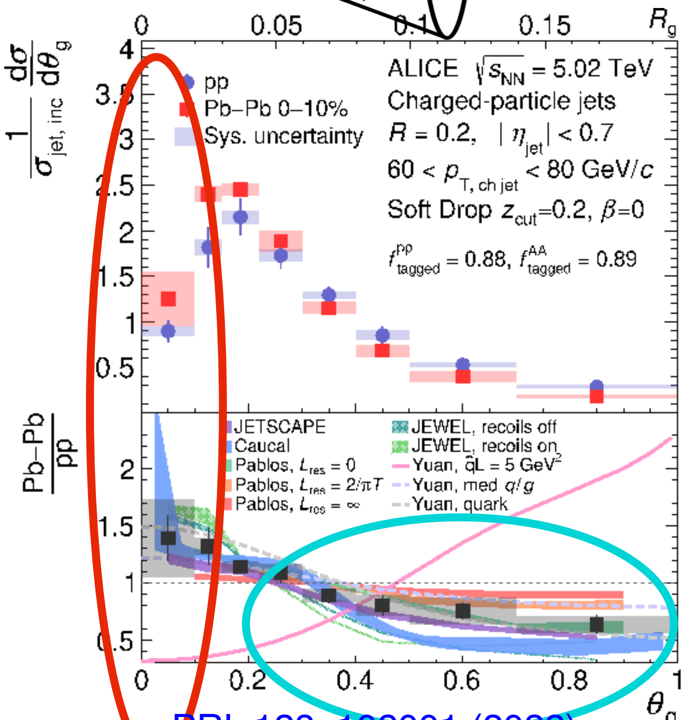
Large θ_g : more suppressed



Splitting angle



Caucal, Iancu, Soyez, 1907.04866 & 2012.01457



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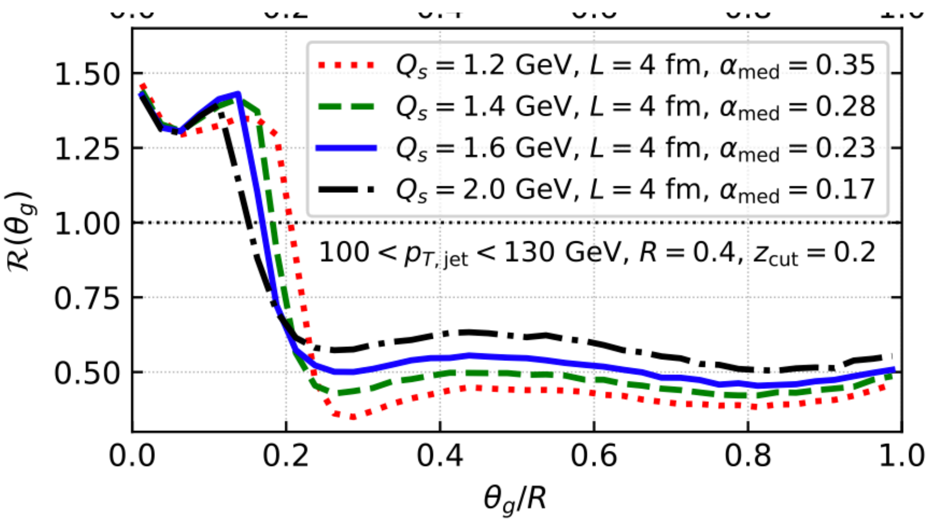


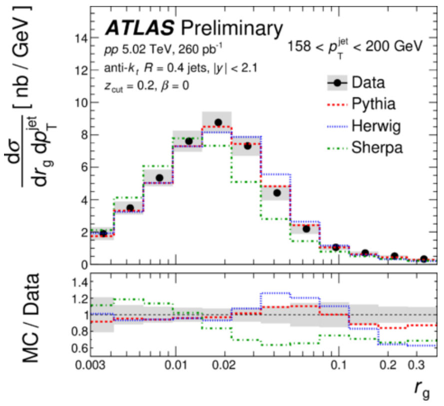
Jets with $\theta_g \geq \theta_c$ are suppressed while jets with $\theta_g \leq \theta_c$ are relatively enhanced.

Is ALICE seeing color coherence effect?
Or is this due to the number of emitters?
Or a selection bias?

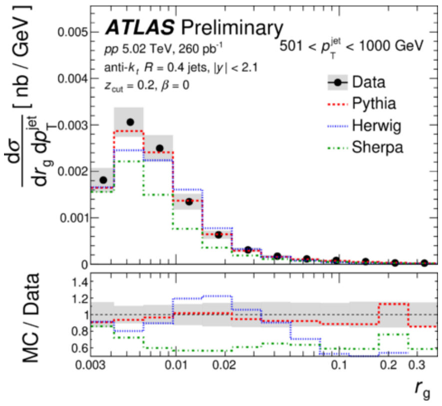
Suppression vs splitting angle

r_g decreases with p_T in vacuum

Low p_T

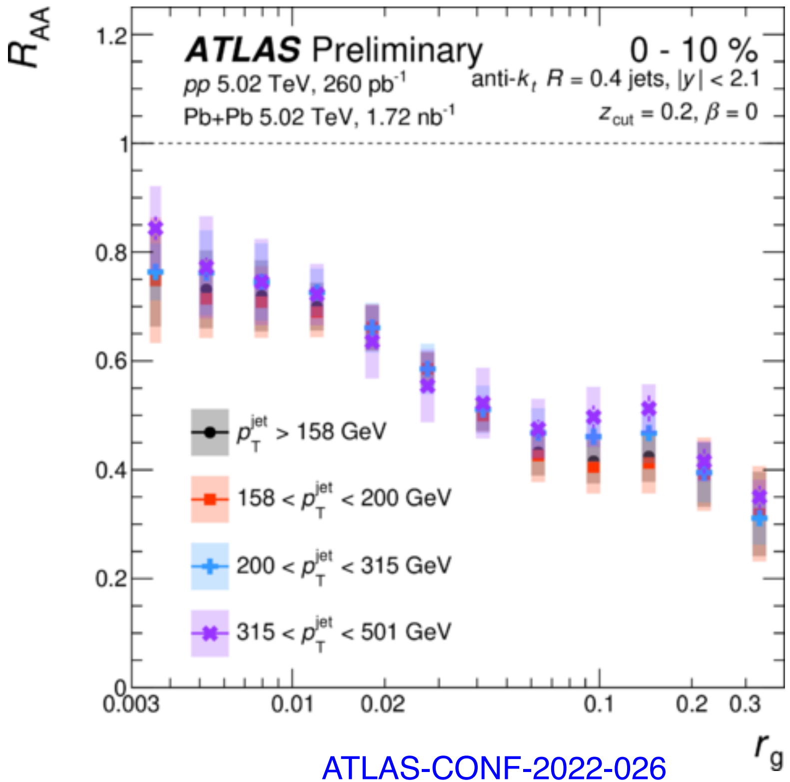


High p_T



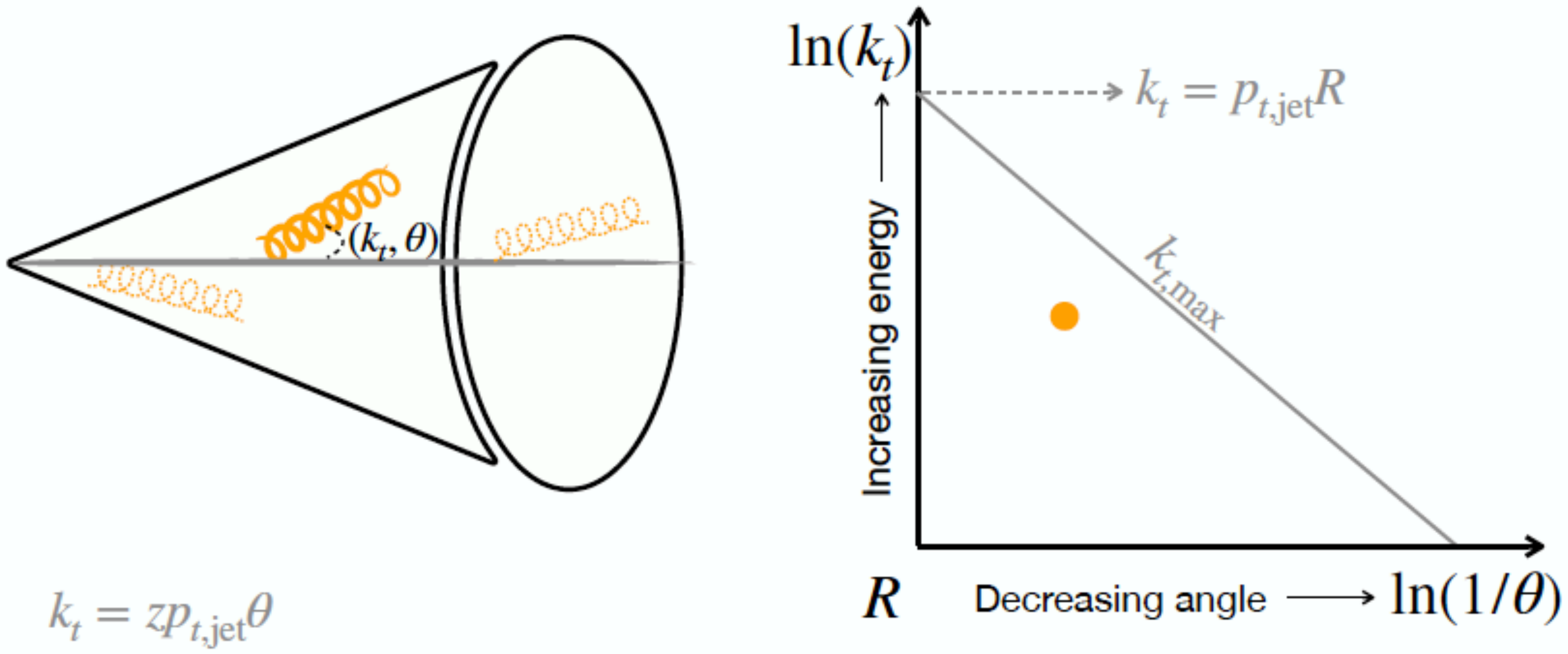
Jet p_T selection + energy loss results in observed r_g dependence

How much room remains for decoherent energy loss within the cone picture?



ATLAS-CONF-2022-026

Tagged splitting Lund plane



Tagged splitting Lund plane

Dynamical grooming

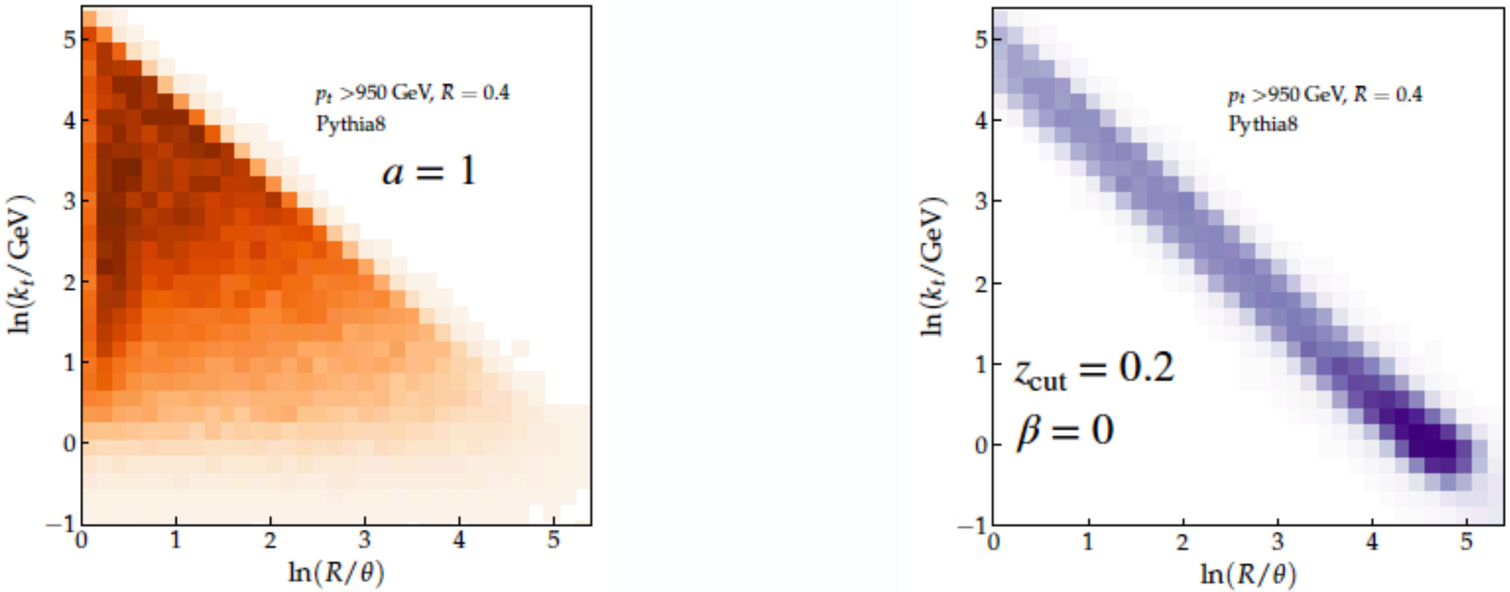
[PRD 101 (2020) 3, 034004]

$$\max(z\theta^a)$$

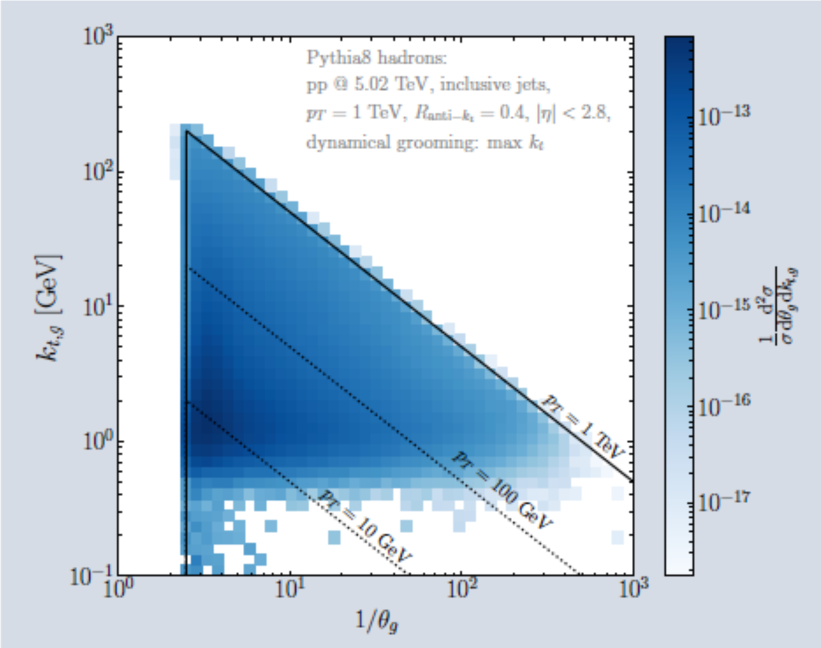
SoftDrop

[JHEP 09 (2013) 029, JHEP 05 (2014) 146]

$$\Theta(z > z_{\rm cut}\theta^\beta)$$

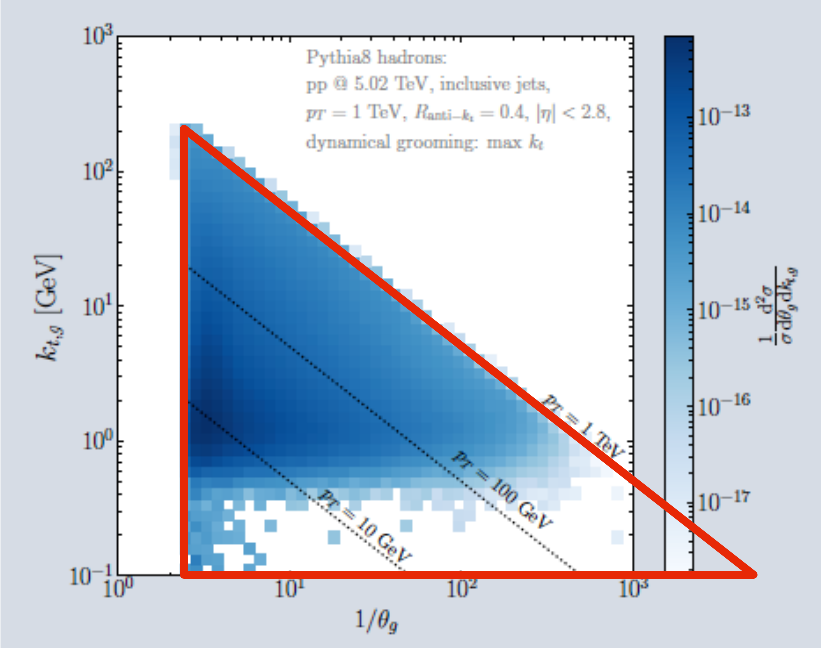


Hardest splitting in jets



Higher energy = more perturbative

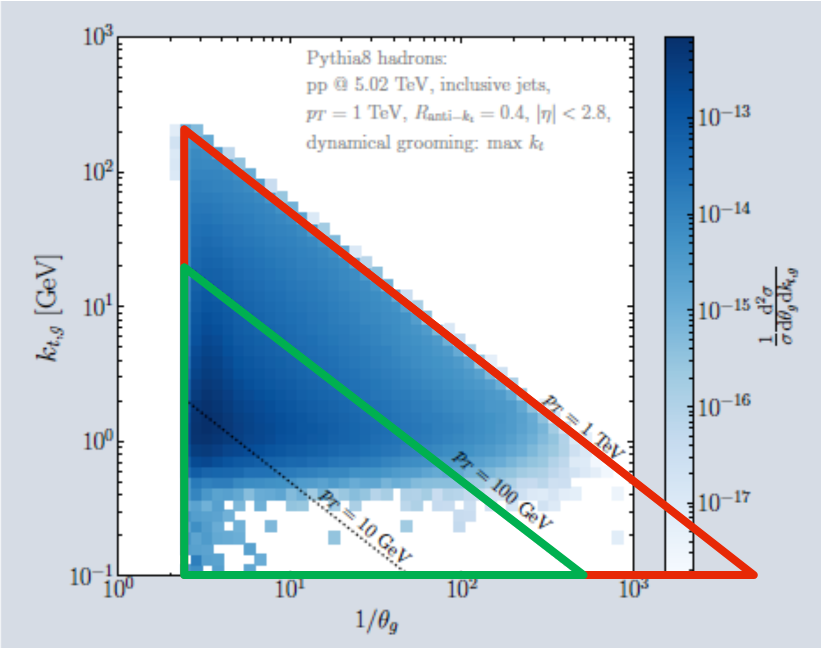
Hardest splitting in jets



Higher energy = more perturbative

1 TeV jets

Hardest splitting in jets

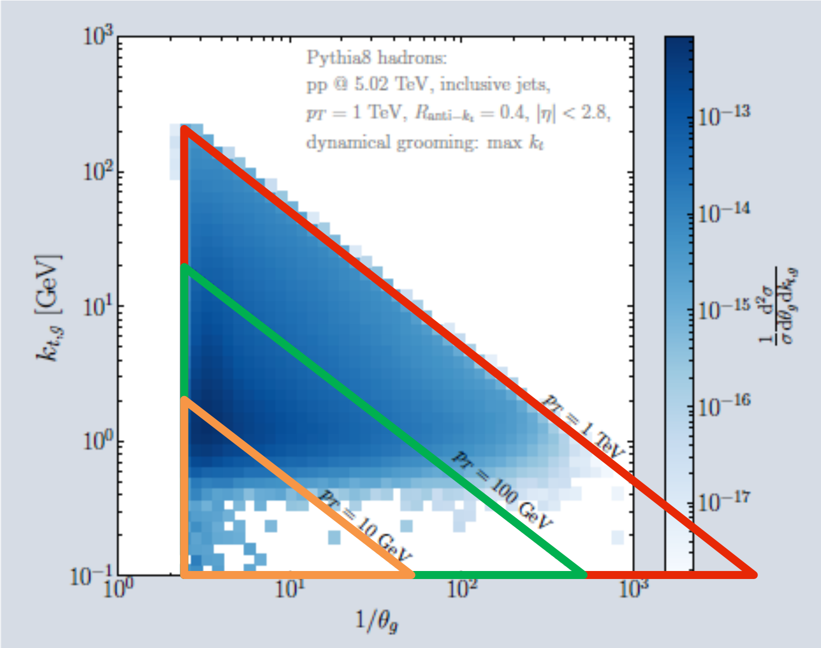


Higher energy = more perturbative

1 TeV jets

100 GeV jets

Hardest splitting in jets



Higher energy = more perturbative

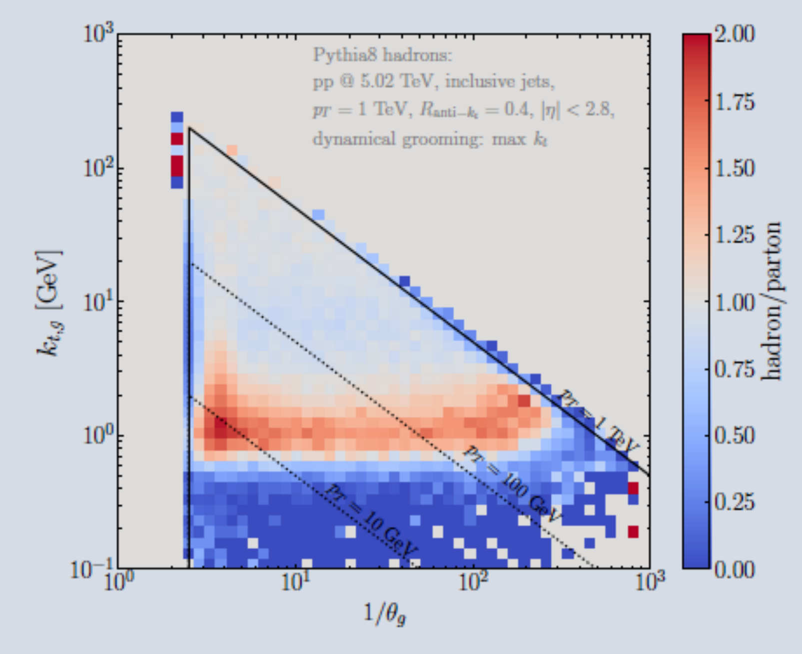
1 TeV jets

100 GeV jets

10 GeV jets

Hardest splitting in jets

Hadron/parton level

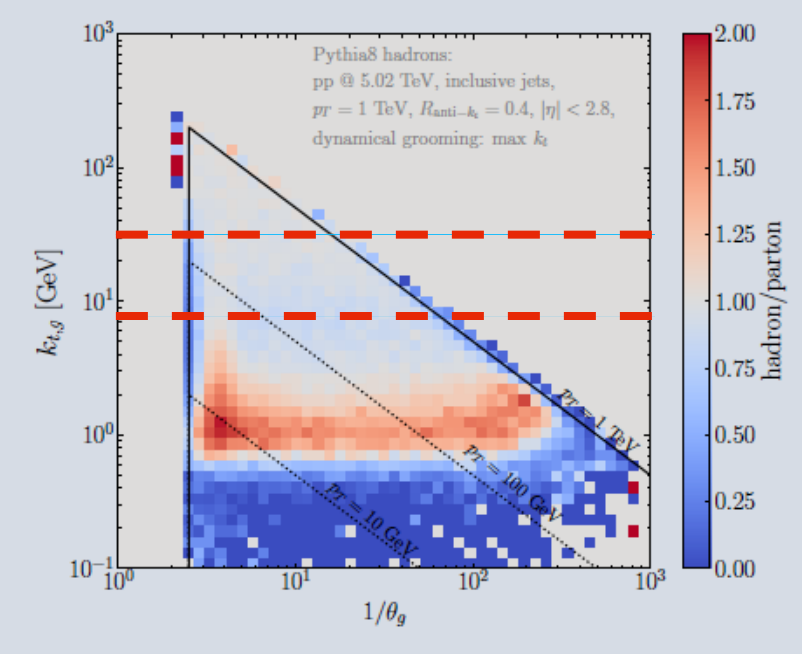


Higher energy = more perturbative

Low k_T = non-perturbative corrections

Hardest splitting in jets

Hadron/parton level

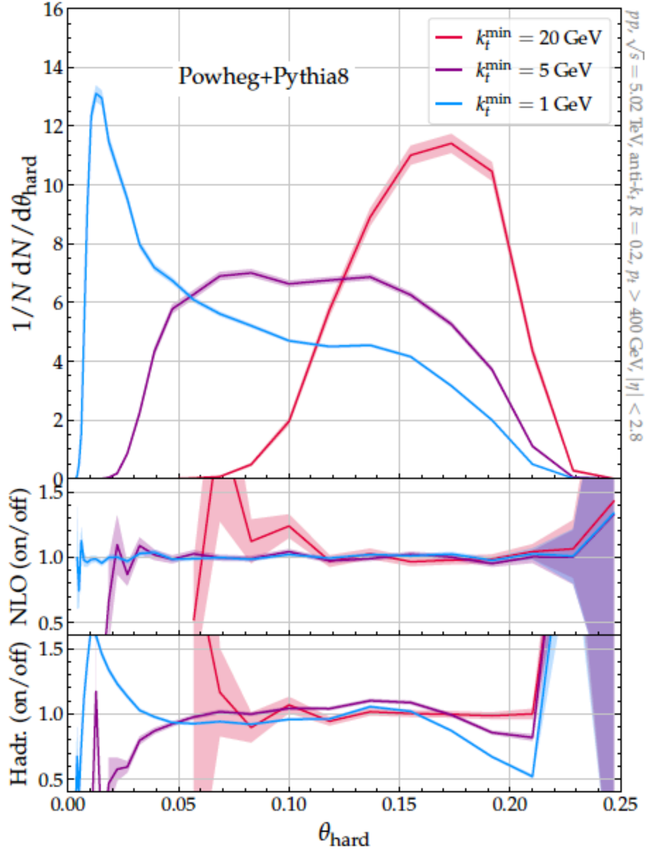


Higher energy = more perturbative

Low k_T = non-perturbative corrections

Cut on k_T to reduce corrections

Hardest splitting in jets



Higher energy = more perturbative

Low k_T = non-perturbative corrections

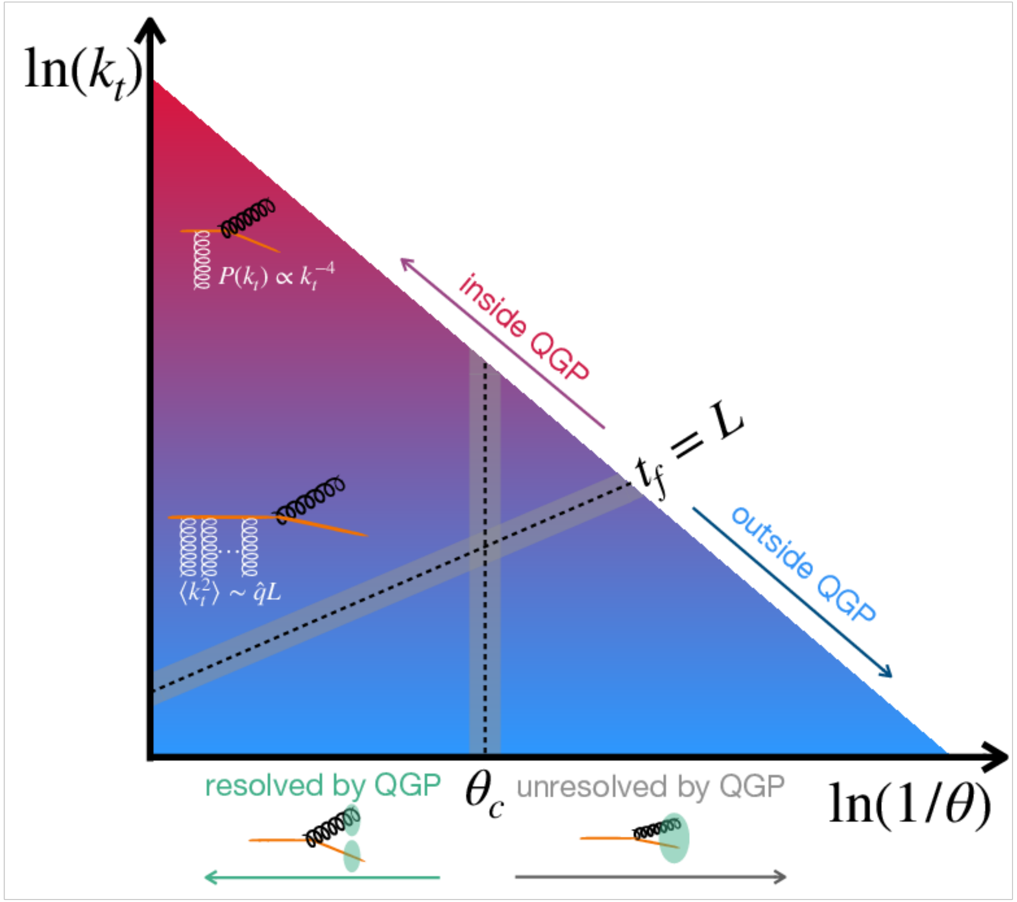
Cut on k_T to reduce corrections

Project to the splitting angle

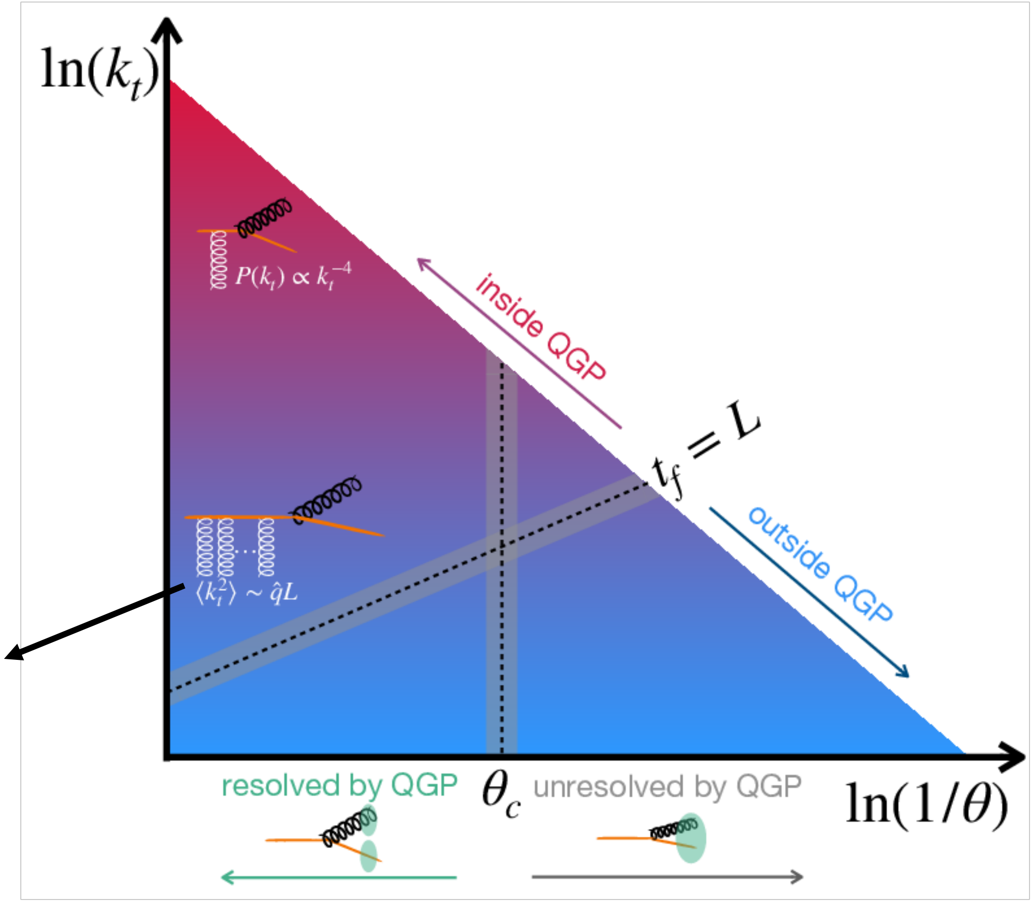
For high enough k_T
→ controlled baseline

How to use this for quenched jets?

Radiation phase space



Radiation phase space

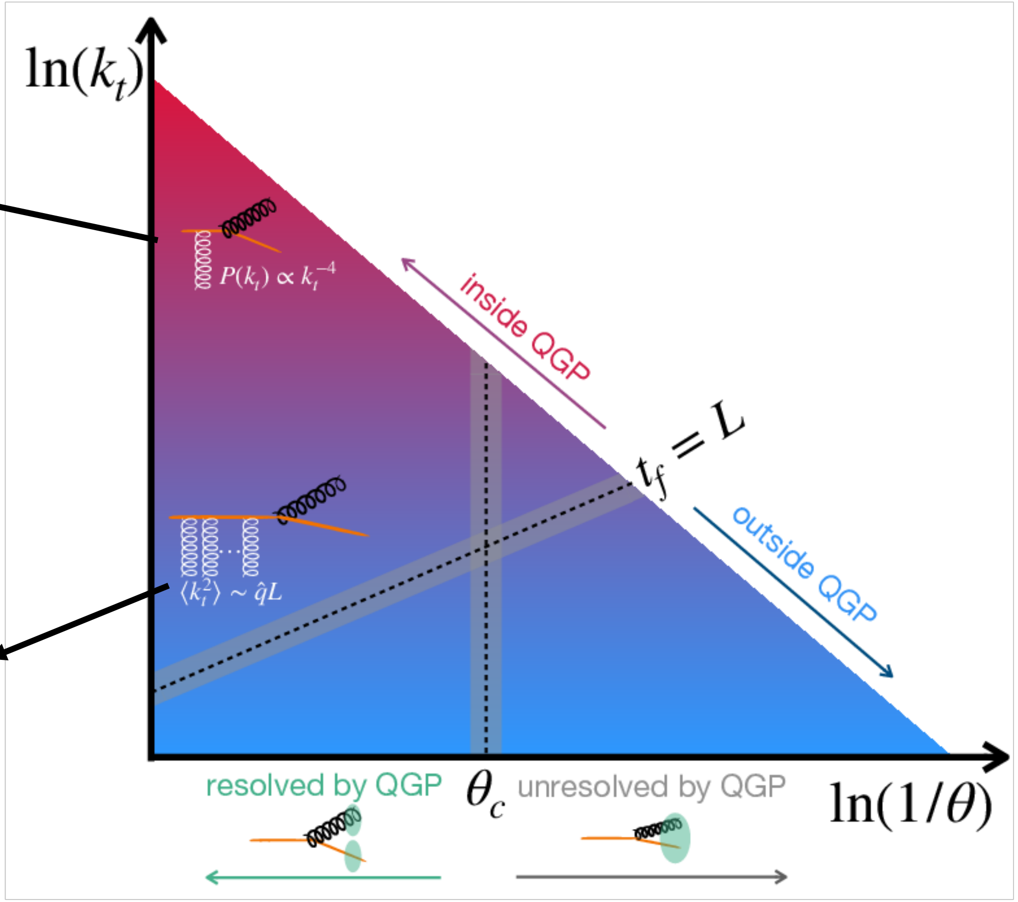


$\langle k_T^2 \rangle \sim \hat{q}L$
Multiple-soft scatterings

Radiation phase space

$\langle k_T^2 \rangle > \hat{q}L$
Single-hit (higher-twist) scatterings

$\langle k_T^2 \rangle \sim \hat{q}L$
Multiple-soft scatterings

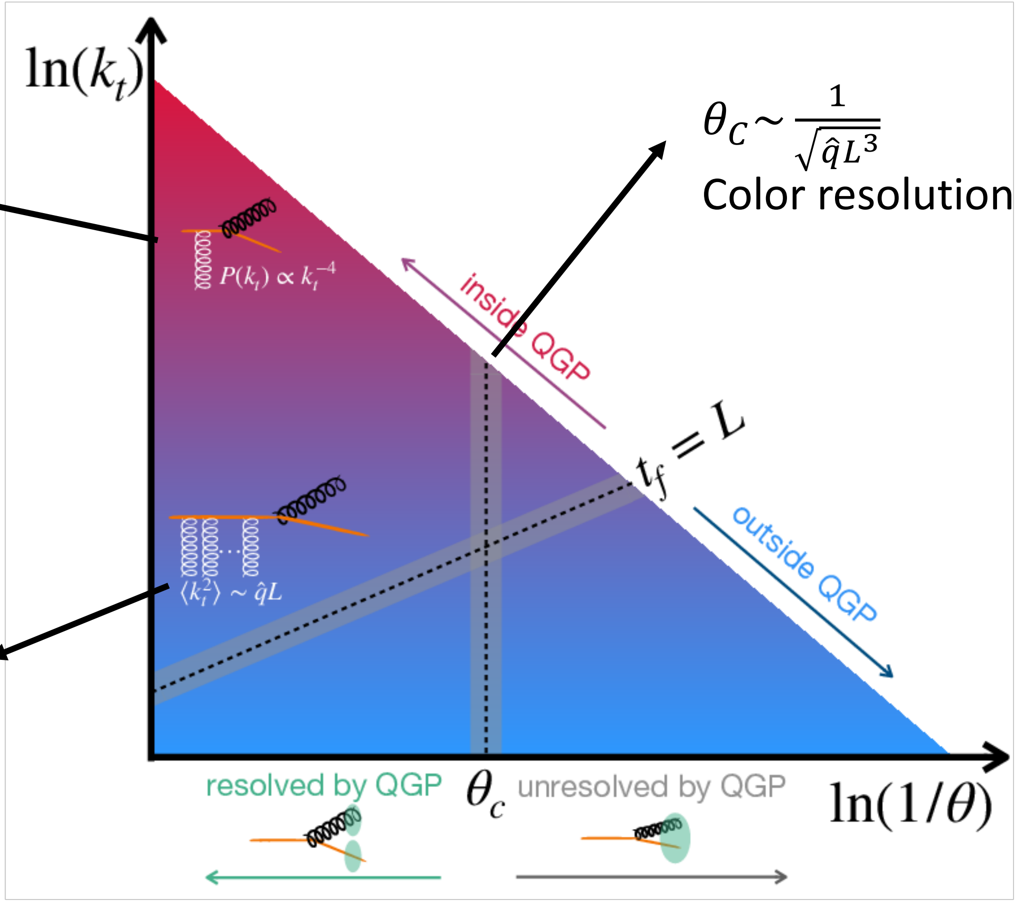


Radiation phase space

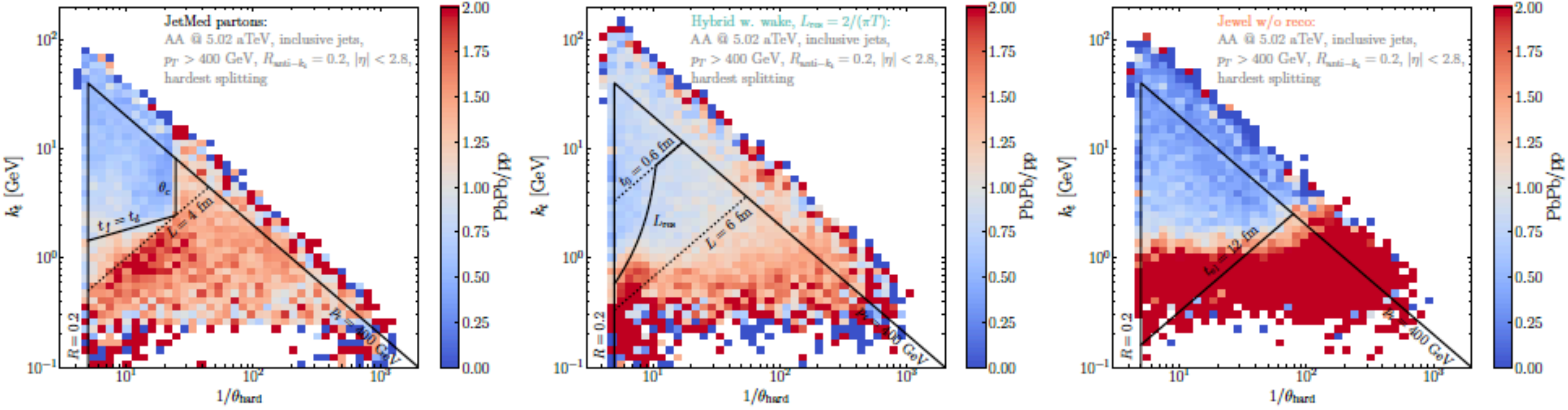
$\langle k_T^2 \rangle > \hat{q}L$
Single-hit (higher-twist) scatterings

$\langle k_T^2 \rangle \sim \hat{q}L$
Multiple-soft scatterings

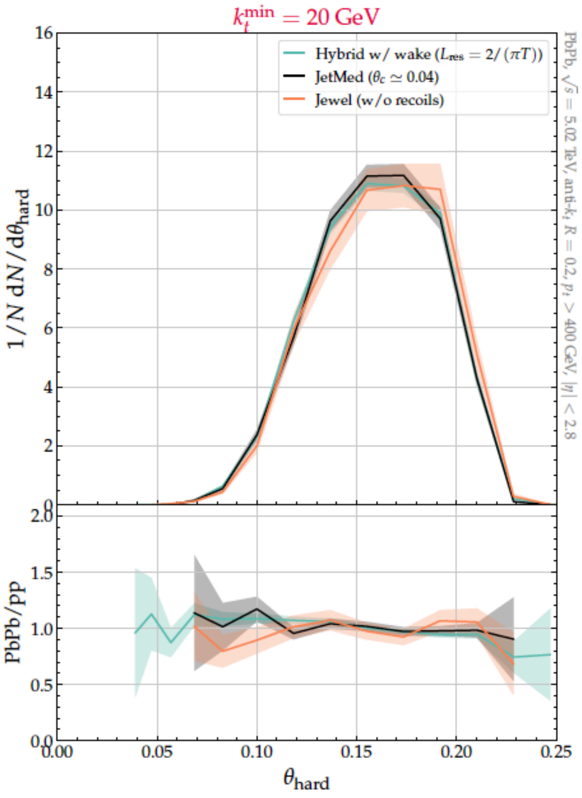
$\theta_C \sim \frac{1}{\sqrt{\hat{q}L^3}}$
Color resolution angle



Radiation phase space

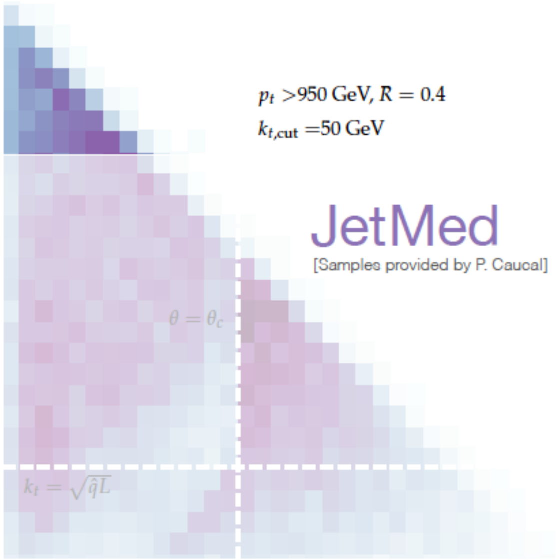


Very hard splittings

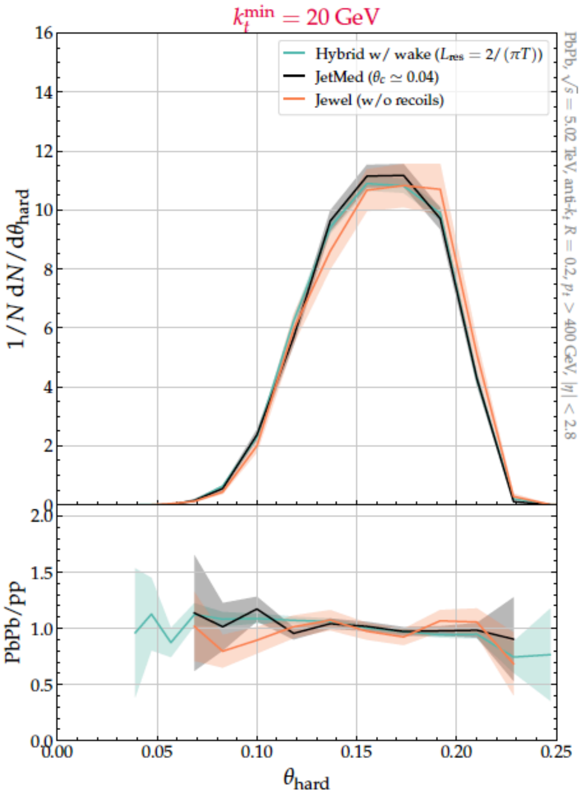


These are all vacuum-like emissions

Only energy loss playing a role



Very hard splittings



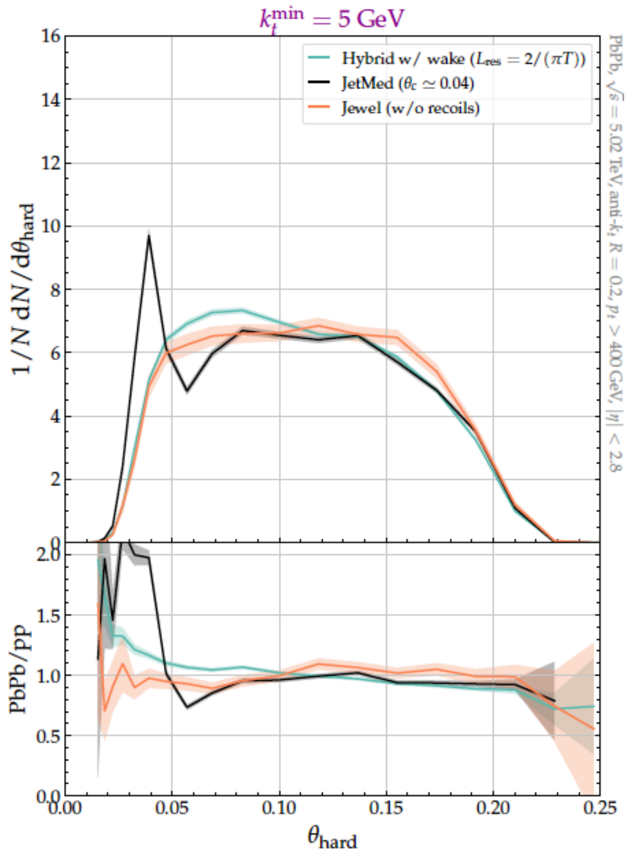
These are all vacuum-like emissions

Only energy loss playing a role

Any jet quenching model should agree with the pp baseline

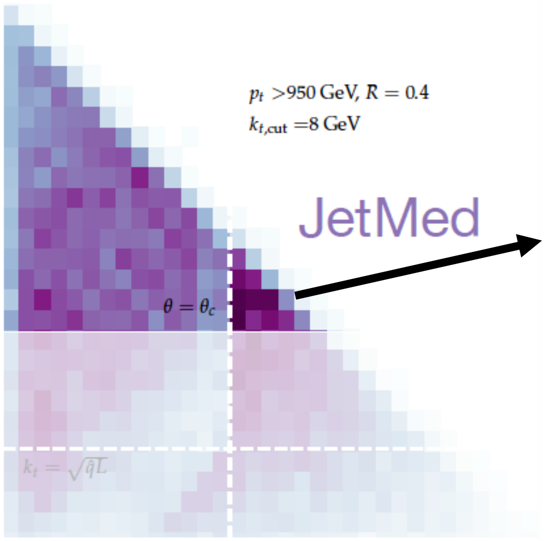
To do: verify experimentally that vacuum physics dominates the early stages of jet evolution in medium

Lowering to intermediate scale



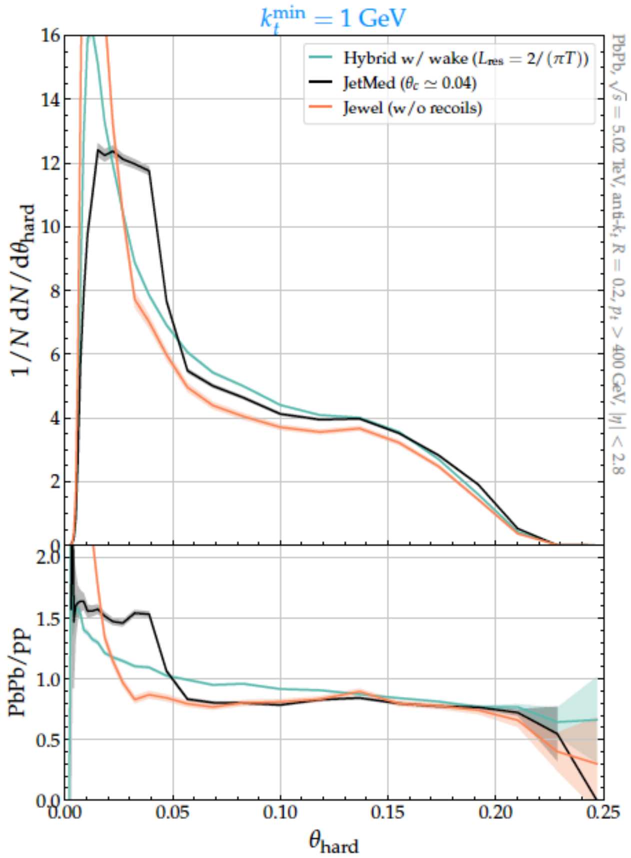
At a intermediate scale you see:

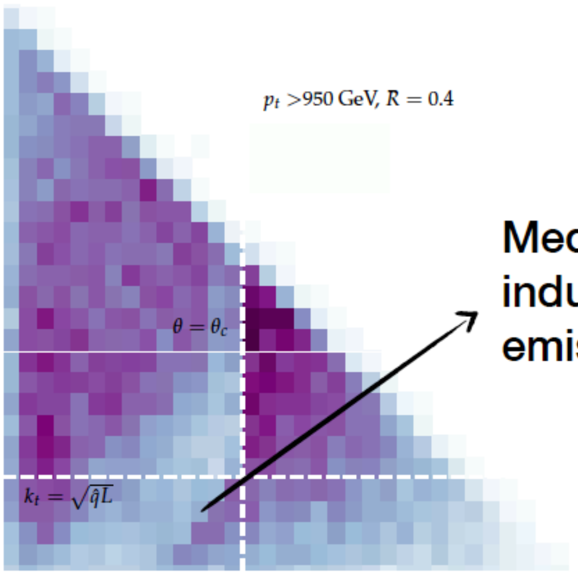
- Color coherence effects
- Selection bias due to energy loss
- No medium-induced emissions yet



Color coherence
$\theta < \theta_C$: unresolved
$\theta > \theta_C$: energy loss

Non-perturbative regime





Medium induced emissions + { Hadronisation, Medium response [Yeonju Go talk Mon (17:30h)], Underlying event [PRC 102 (2020) 4, 044913] }

Summary: perturbative splittings in AA

Very high k_T:

- Test of mode separation
- Vacuum-like baseline in AA collisions

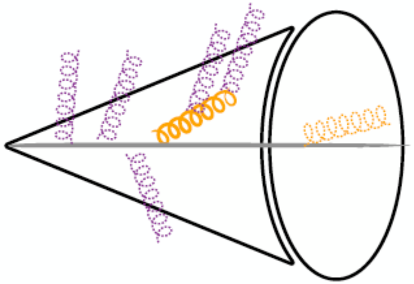
Moderate k_T:

- Test of color resolution
- Test of jet thermalization
- New baseline for AA collisions

Conclusions

Hardest splittings in jet allow to separate different effects in the jet evolution and identify medium scales.

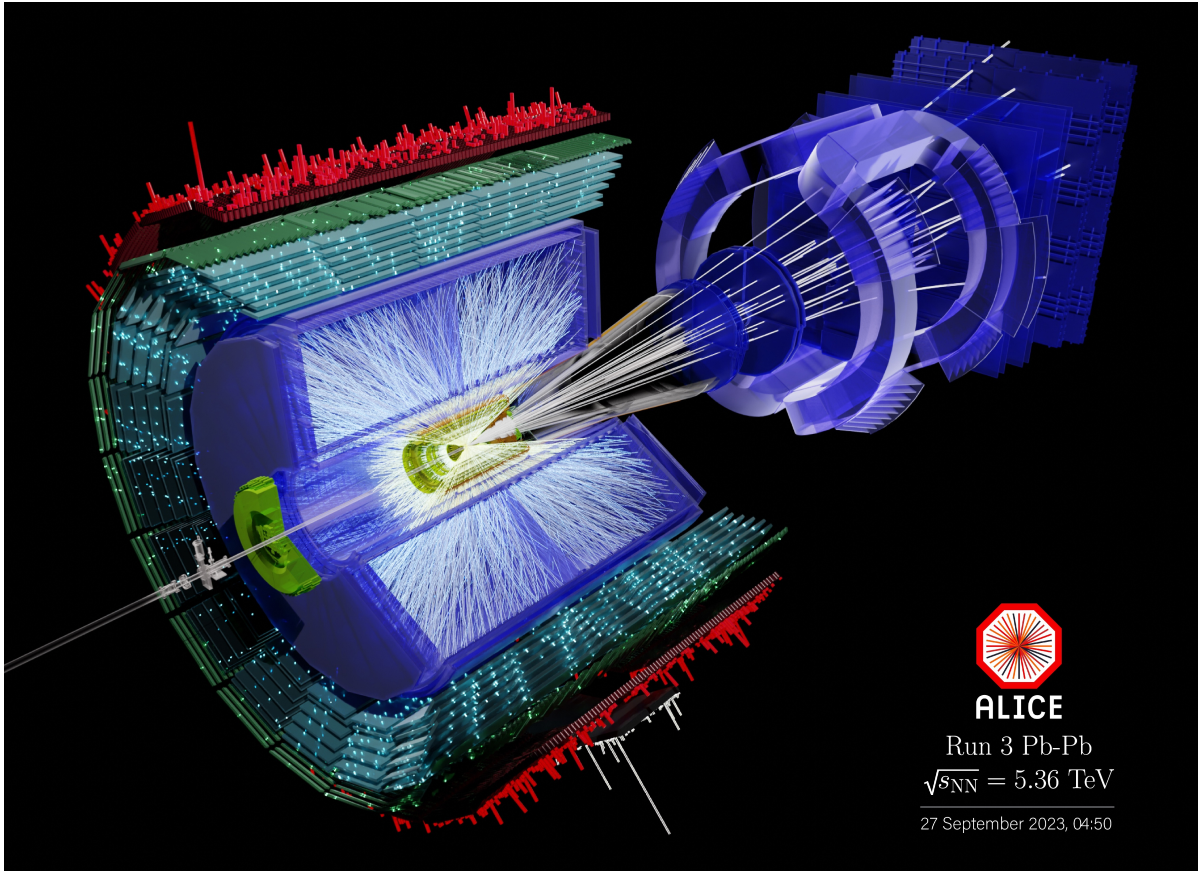
Description of baseline is crucial for meaningful interpretation of data



Evidence of jet substructure modifications (i.e. not energy loss) remains elusive

HL-LHC allows to maximize sensitivity to pQCD-like in-medium physics

Pb-Pb collisions 2023!



- Is there a regime of pure vacuum evolution in the in-medium development of a parton shower?
- Does energy loss depend on the opening angle of the splitting? If so, at which energy scale does this effect become relevant?
- Are elastic scatterings with the medium visible in jet substructure observables?

Bonus