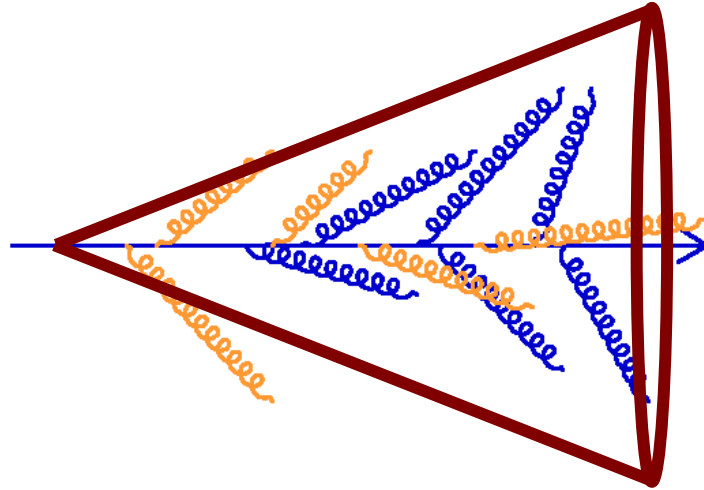# Experimental signatures of coherence and medium response

Marta Verweij
Utrecht University / Nikhef

QCD challenges from pp to AA collisions
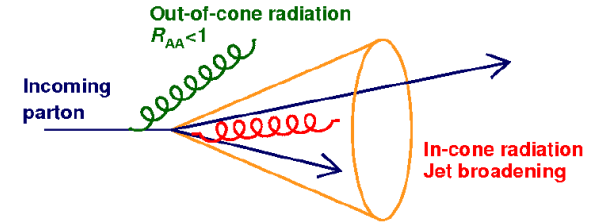February 13, 2023

Jet Quenching

- How is the parton shower modified?

- What is the exact mechanism modifying the shower?

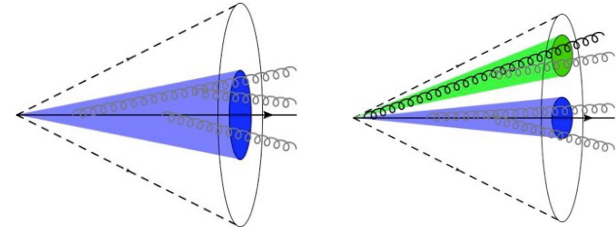- Can we relate shower modifications to medium properties?

Main experimental tool: jet substructure
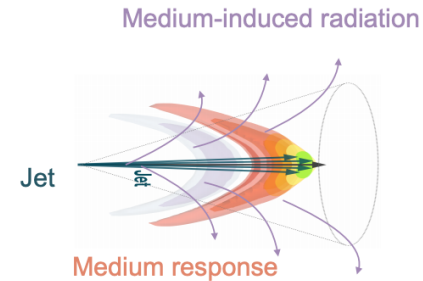
Jet modification in hot QCD medium
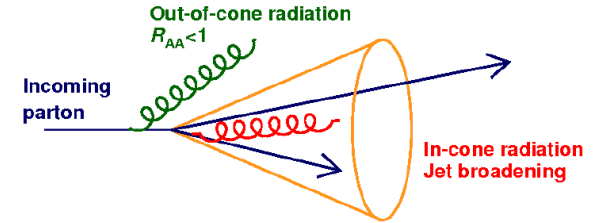
Medium-induced energy loss
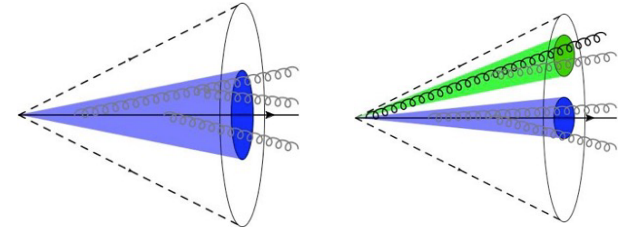

Coherence effects

Medium recoil

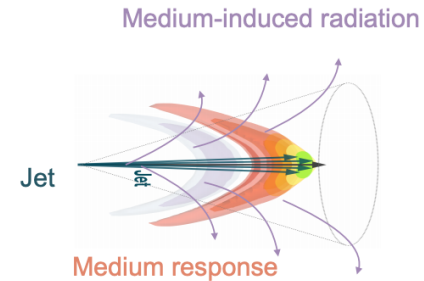# Jet modification in hot QCD medium

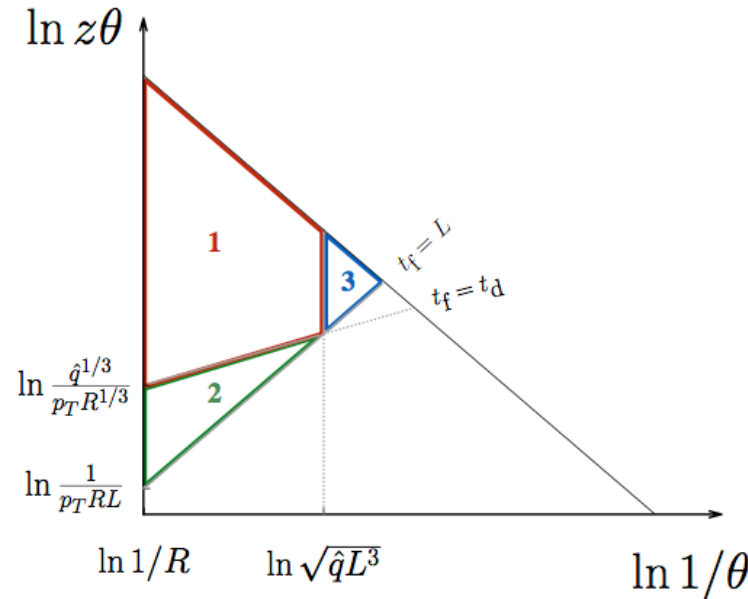Medium-induced energy loss

Coherence effects

Medium recoil

Phase space in medium

3 regions for a splitting happening in medium

    1) vacuum-like splitting inside medium that will be quenched

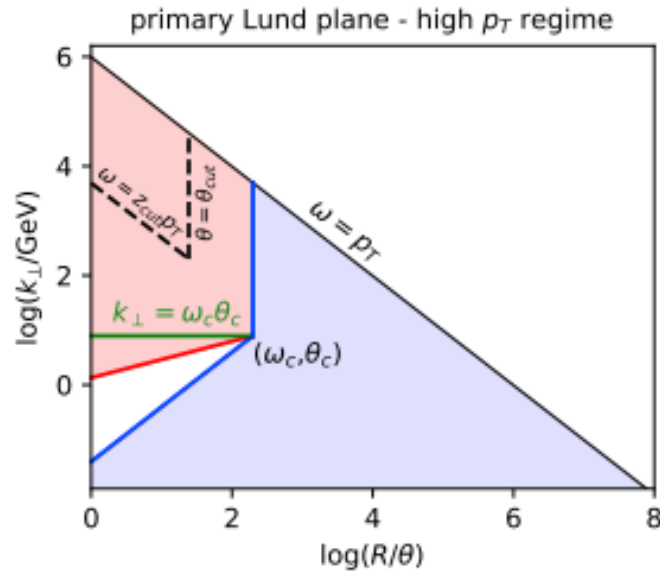   2) medium-induced splitting → not uniform in Lund plane

    3) unresolved splitting

arXiv:1808.03689

Regimes in radiation phase space

Medium-induced emission are possible if:
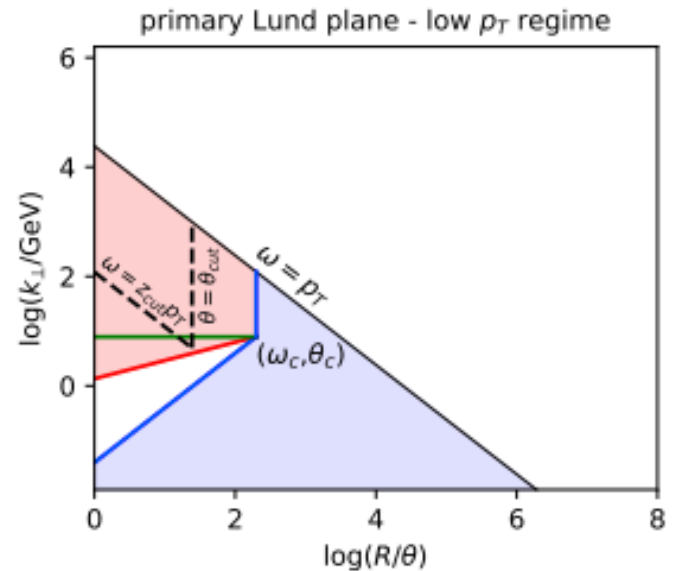
$$\omega < \omega_C = \frac{1}{2}\hat{q}L^2 \qquad \text{and} \qquad k_T < Q_s = \omega_C \theta_C = \sqrt{\hat{q}L} \qquad \text{Finite size effect}$$

primary Lund plane - high p_T regime

primary Lund plane - low p_T regime
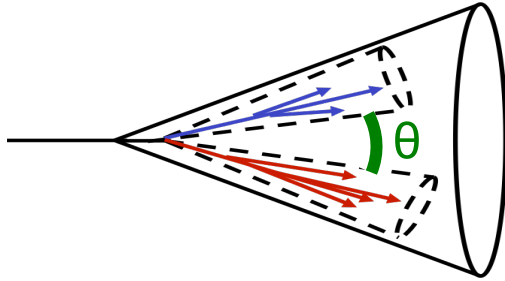
High p_T: $p_T z_{cut} \gg \omega_C$

→ Can only detect vacuum-like emissions

Low p_T: $p_T z_{cut} \leq \omega_C$

→ Can also detect medium-induced
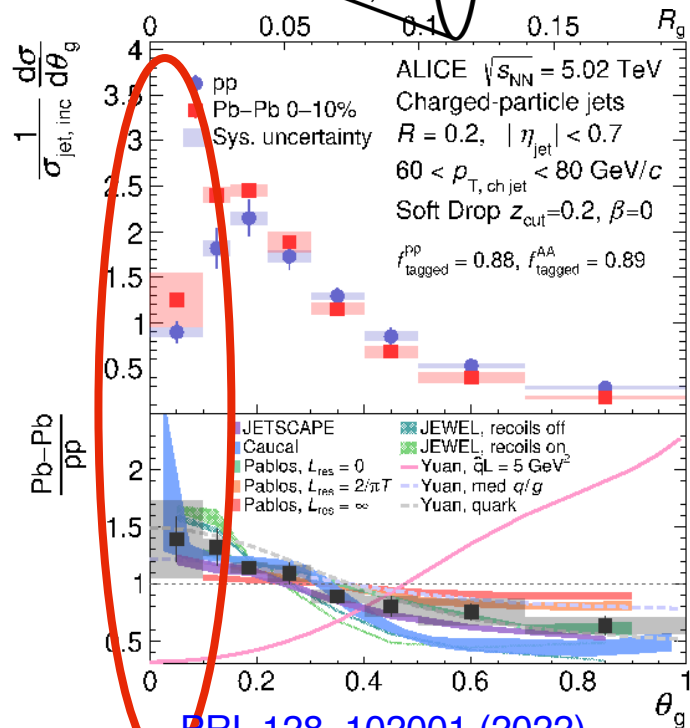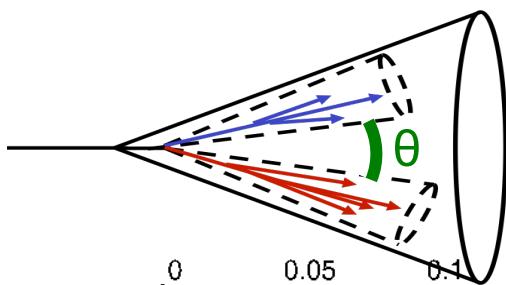
Splitting angle

Caucal, Iancu, Soyez, 1907.04866 & 2012.01457
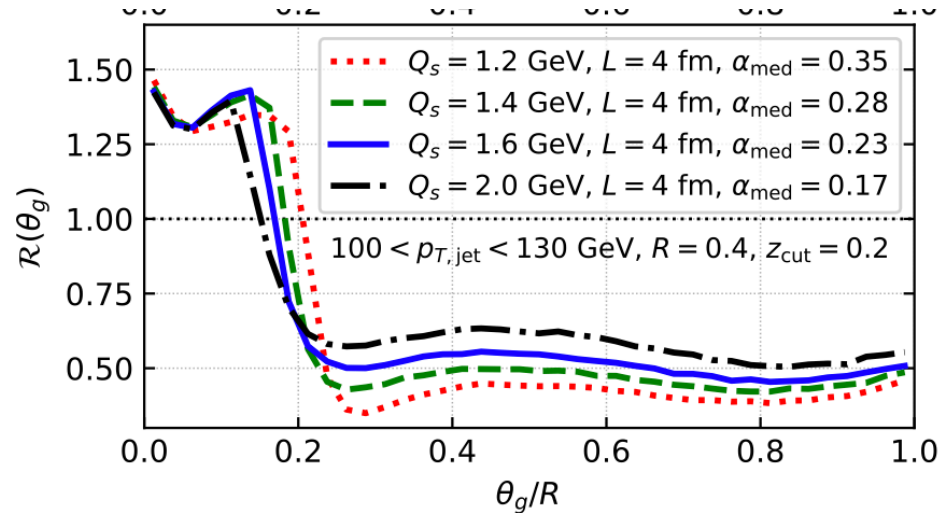
Jets with $\theta_g \geq \theta_c$ are suppressed while jets with $\theta_g \leq \theta_c$ are relatively enhanced.

Clear signature to look for
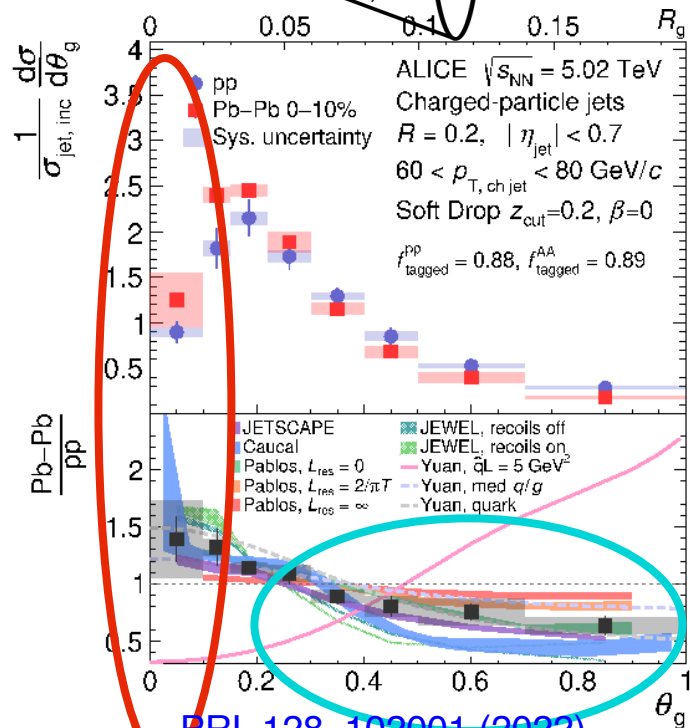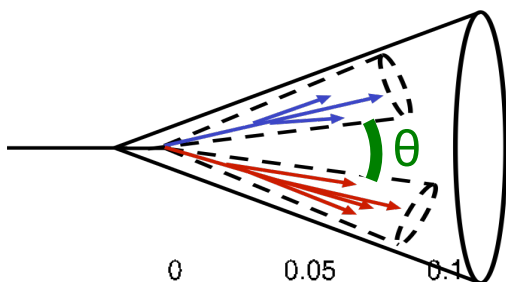Expecting decoherence angle to be smaller than 0.1

Splitting angle

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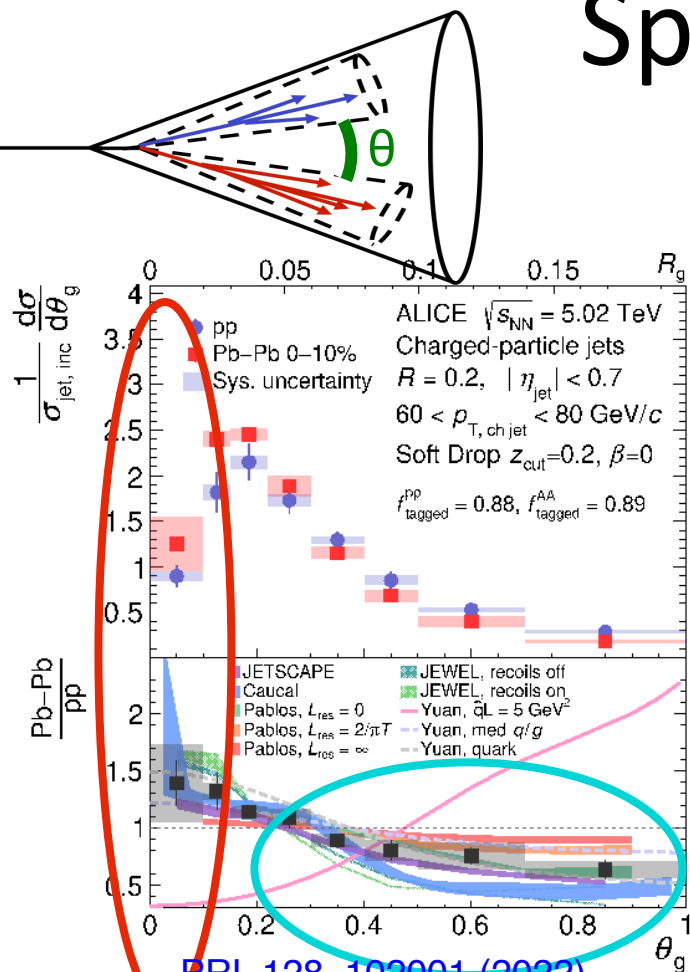→ less suppression observed in data

PRL 128, 102001 (2022)

Splitting angle

θ

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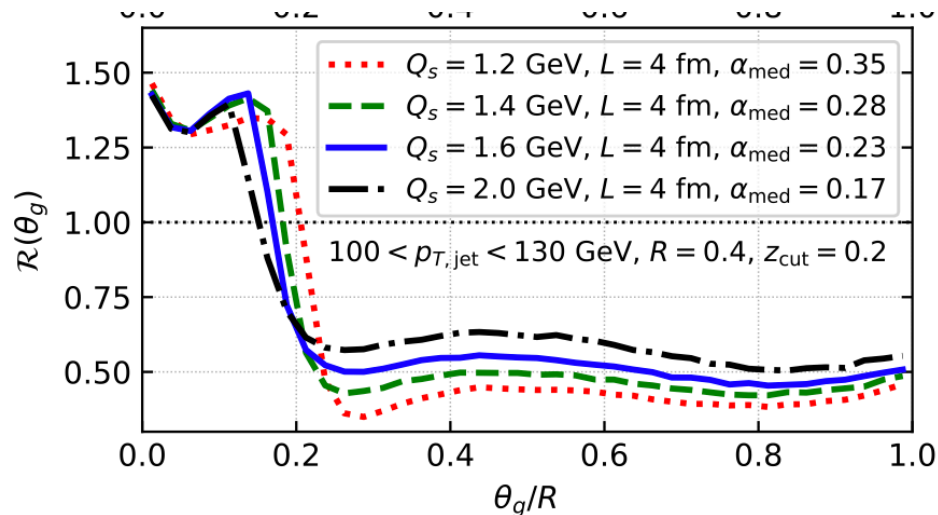→ less suppression observed in data

Large θ_g : more suppressed

PRL 128, 102001 (2022)

Splitting angle

Caucal, Iancu, Soyez, 1907.04866 & 2012.01457

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

Is ALICE seeing the critical angle?
Or is this due to the number of emitters?
Or a selection bias?

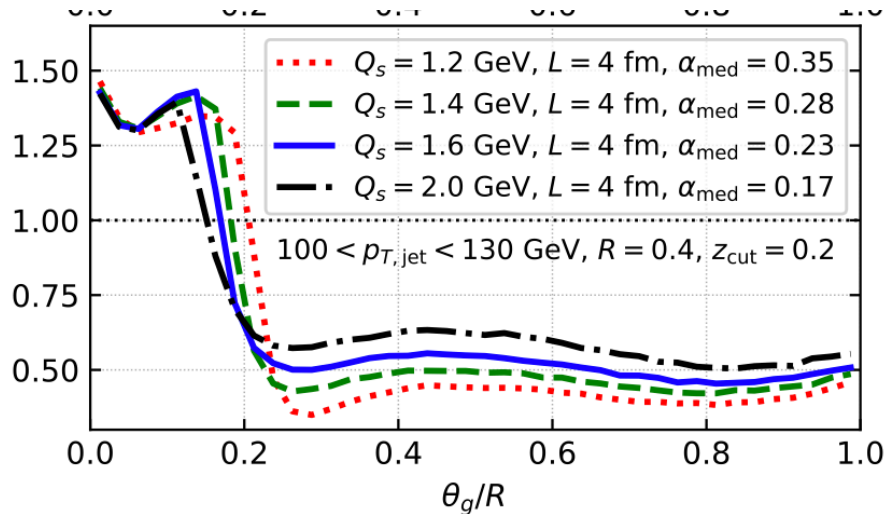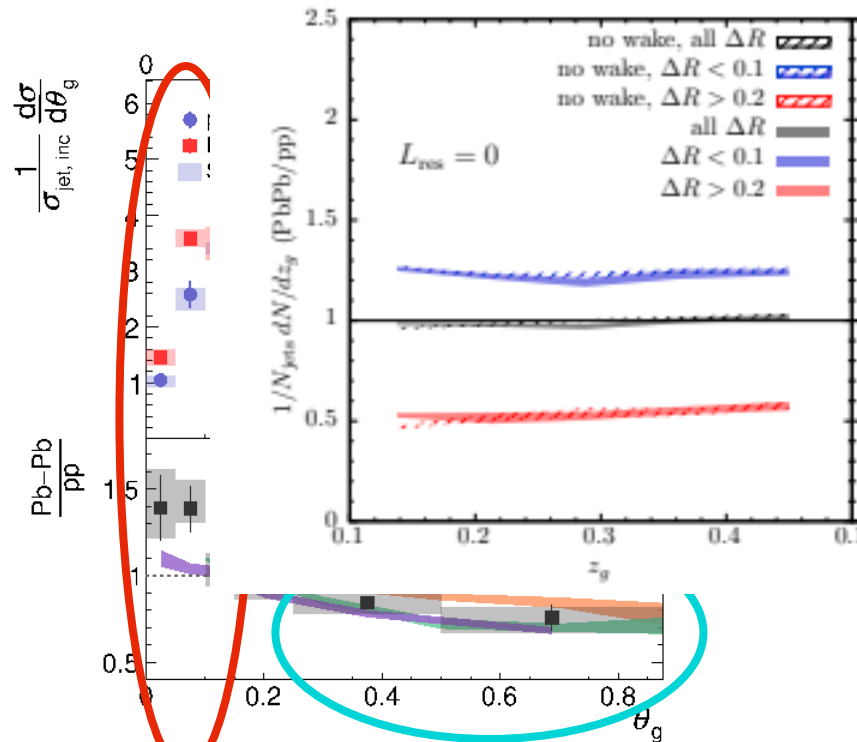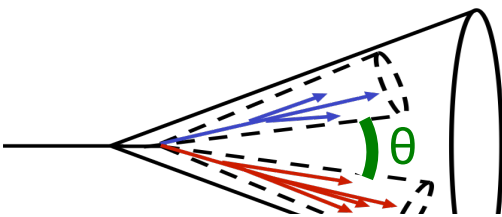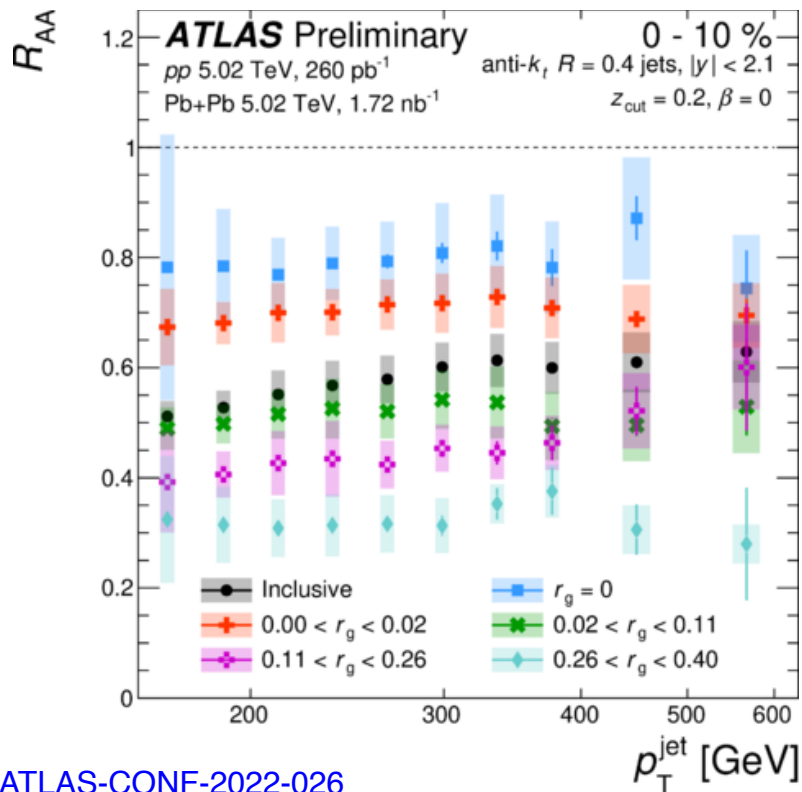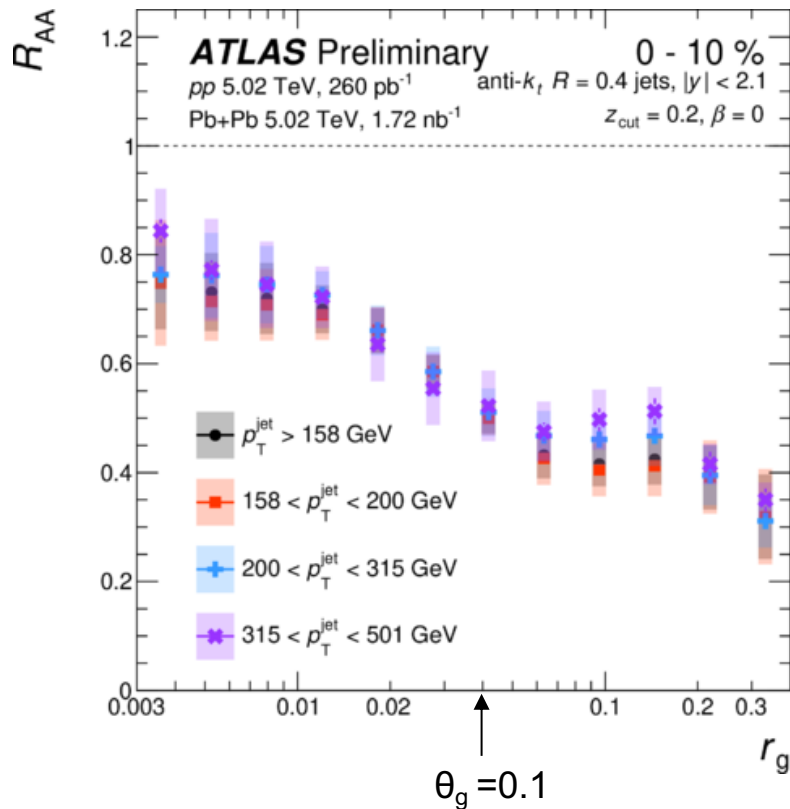PRL 128, 102001 (2022)

Splitting angle

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

Is ALICE seeing the critical angle?
Or is this due to the number of emitters?
Or a selection bias? Or....?
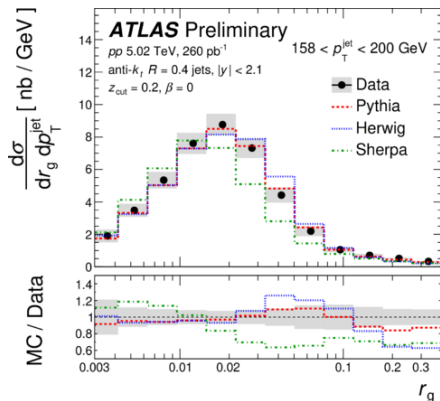
Suppression vs splitting angle
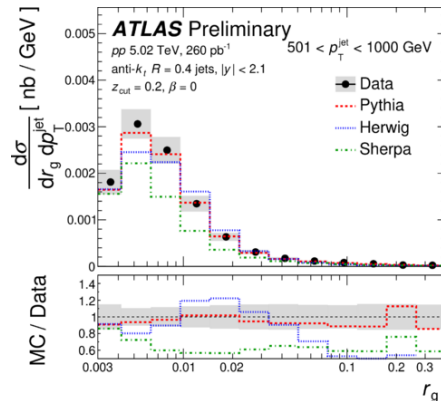

ATLAS-CONF-2022-026

Suppression vs splitting angle

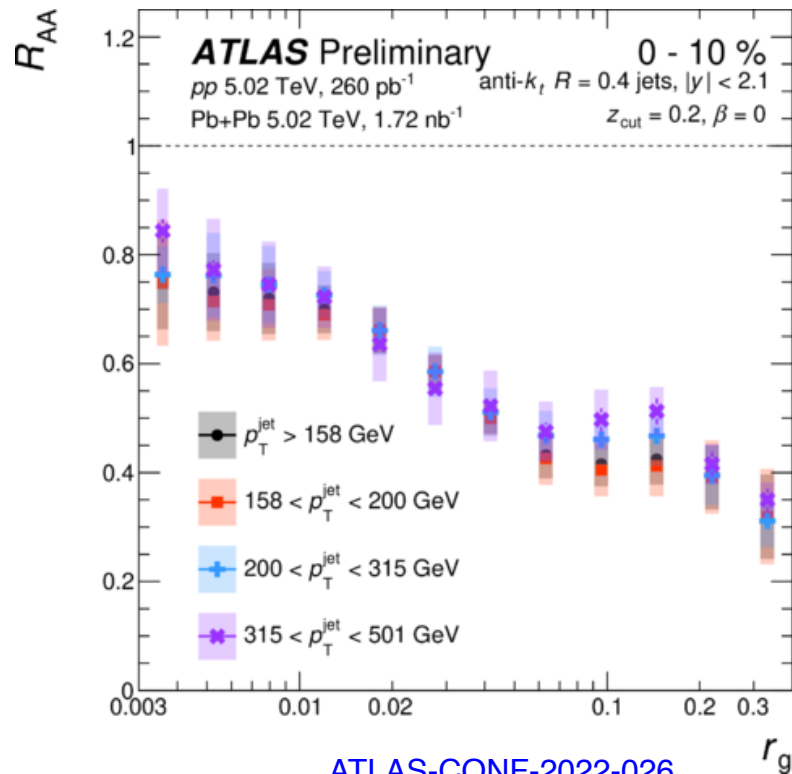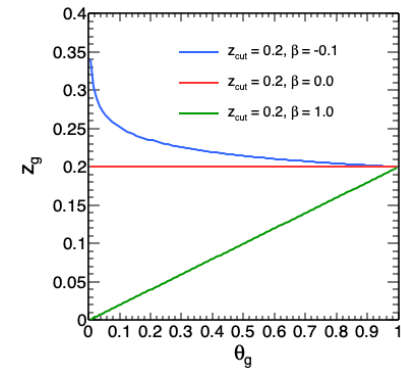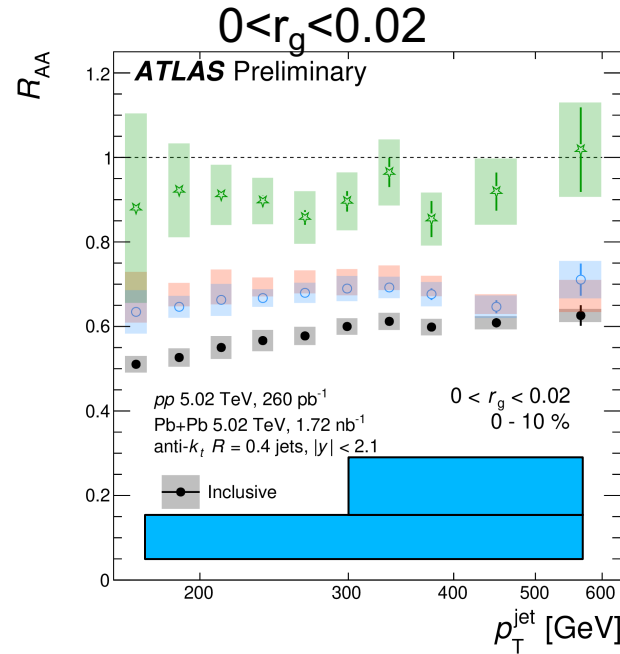r_g decreases with p_T in vacuum

Low p_T

High p_T

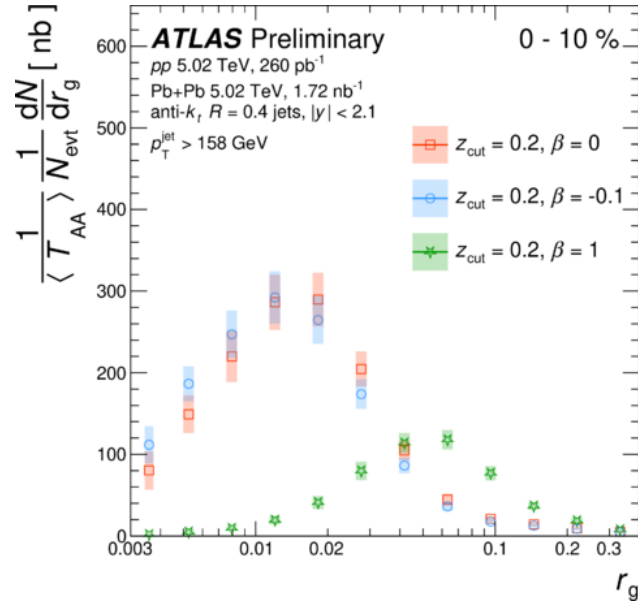Jet p_T selection + energy loss results in observed r_g dependence

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

ATLAS-CONF-2022-026
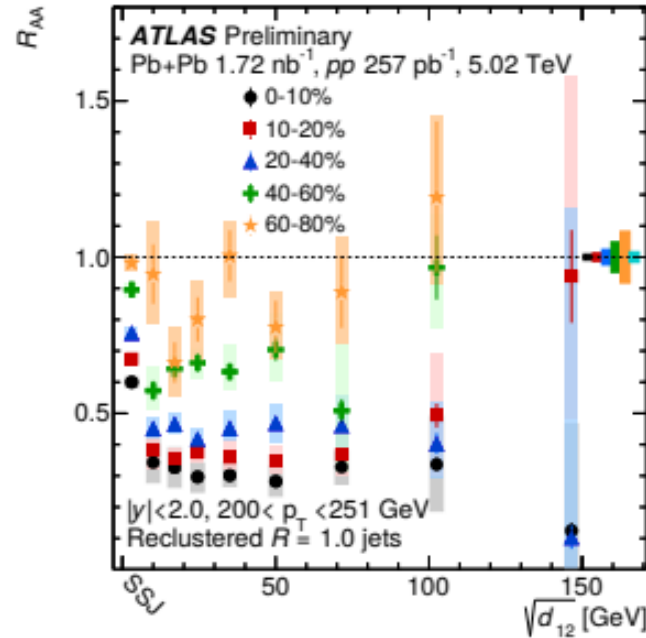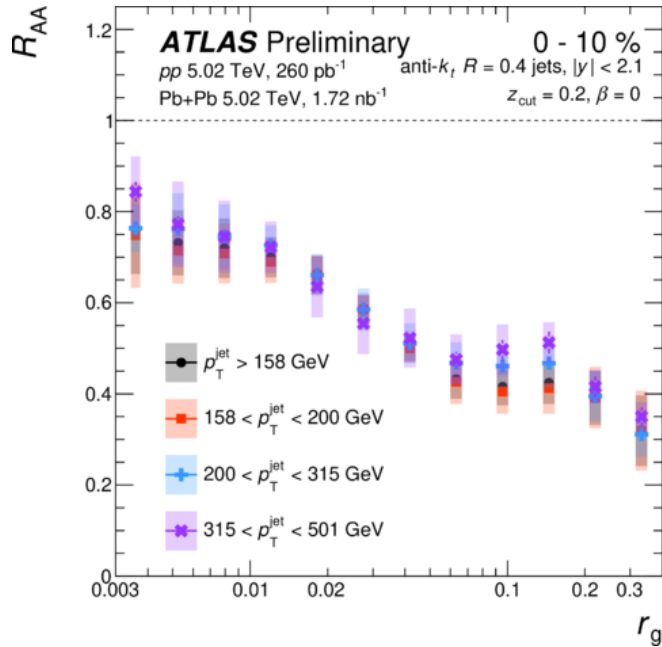
Grooming strength

0 < r_g < 0.02

Jets with small r_g are less suppressed when more softer branches survive grooming

Suppression vs opening angle
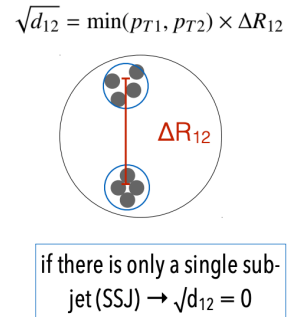
Similar suppression observed for both measurements for large splitting angle

Jet axes as substructure
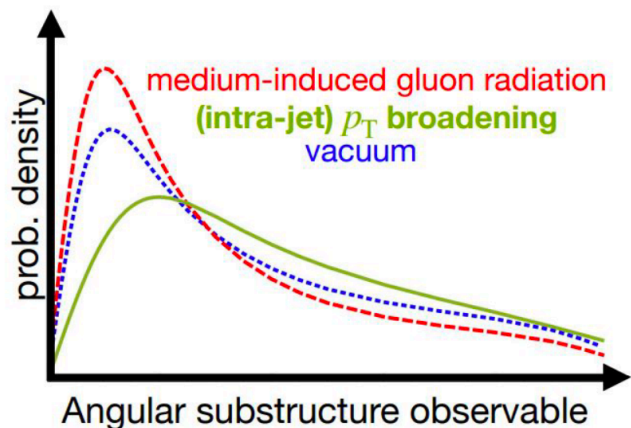
Ringer et al., PLB 808 (2020) 135634

Use pointing direction of jets to study
- Medium-induced radiation
- p_T broadening
→ Study their interplay

Observable: angle between jet axes
- Standard ungroomed axis
- Groomed axis
- Winner-takes-all axis

Jet axes as substructure
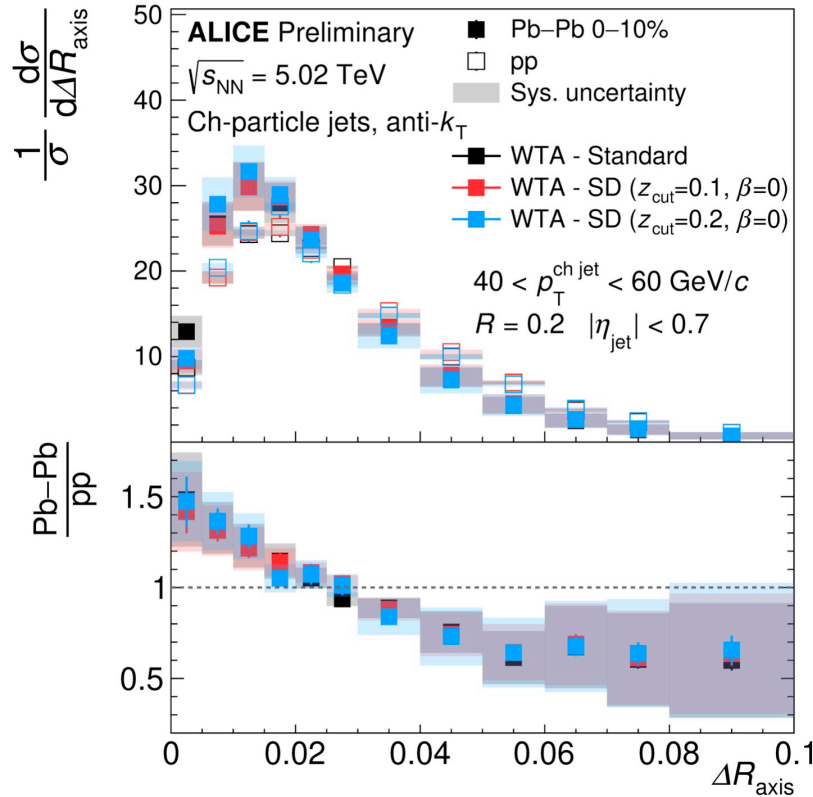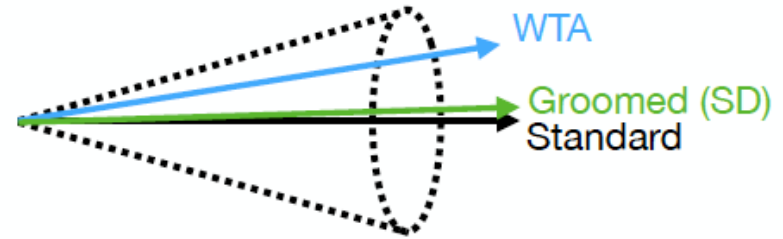
Grooming hardly moves the jet axis

Narrowing effect also visible for ungroomed jets

Jet axes as substructure
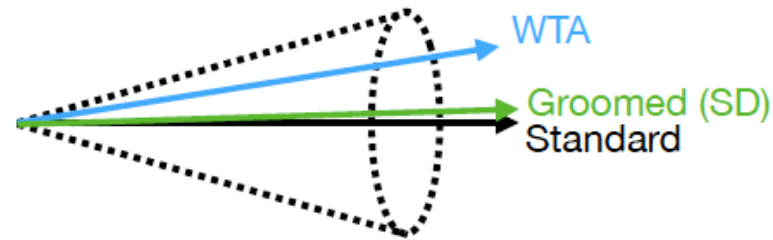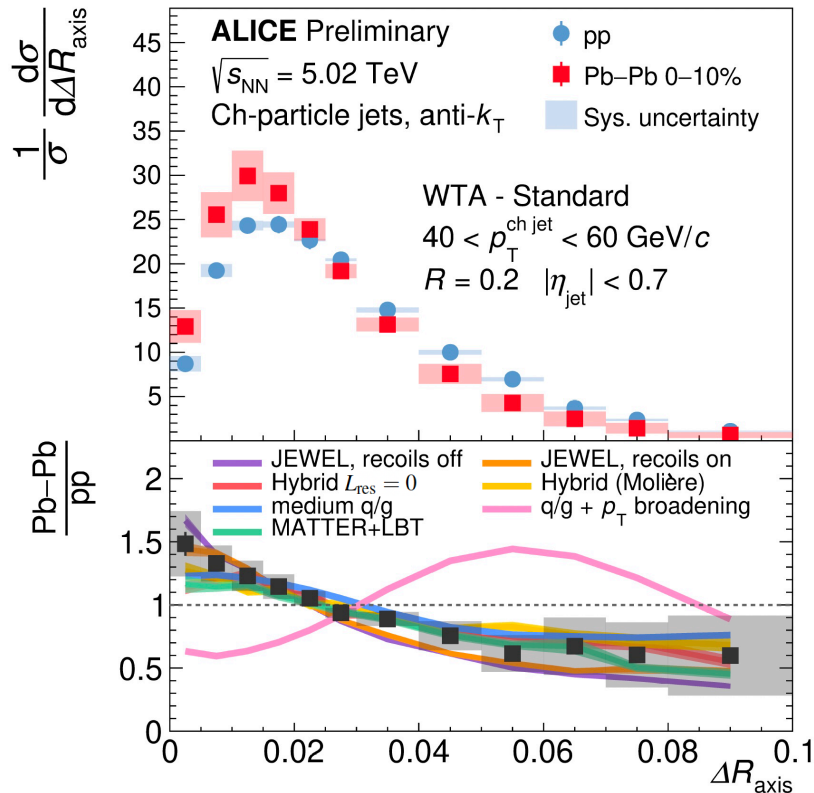
Disagreement with p_T broadening model remains when no grooming is used
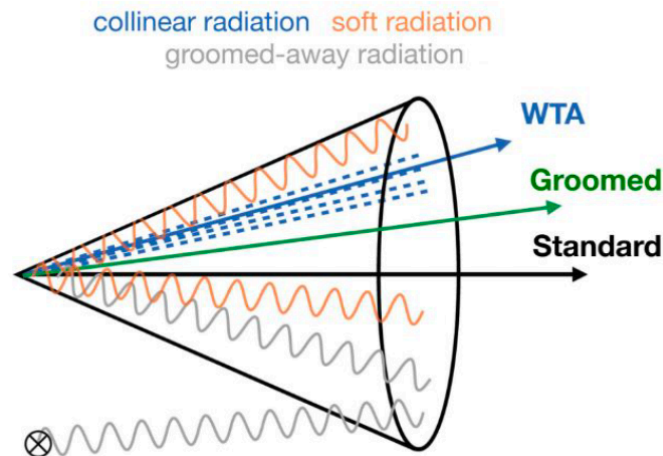
Data consistent with incoherent energy loss

Limited sensitivity to distinguish between models → upgraded detectors should help

Medium response and mass

PLB 776 (2018) 249

Improved procedure to subtract recoils in JEWEL improves agreement with data
Sensitivity to recoil subtraction procedure make it hard to interpret the data

Angularities: models vs data

pp
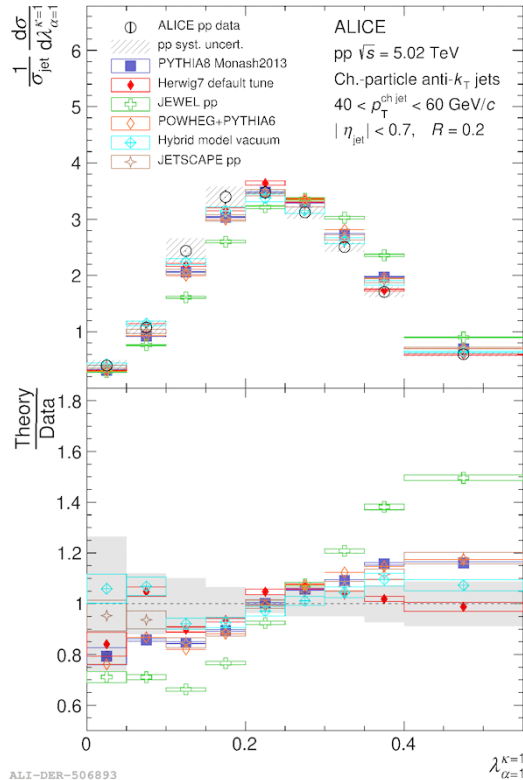
Pb-Pb
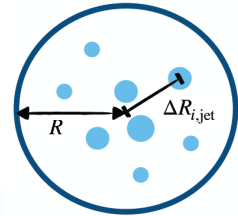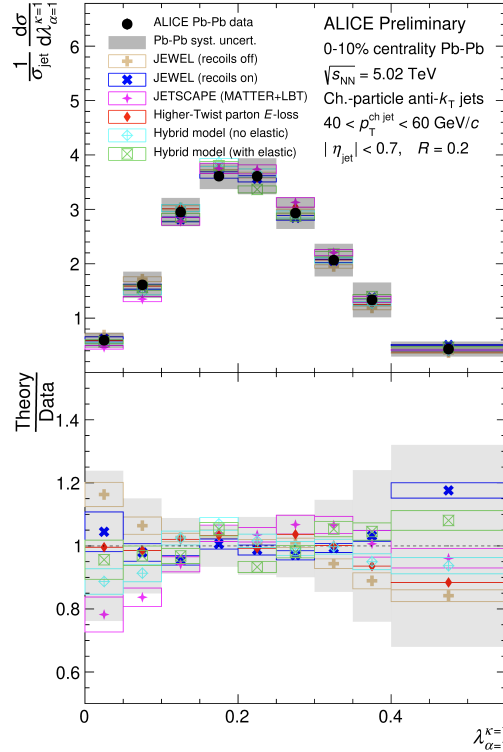
$$\lambda_\alpha \equiv \sum_{i\in\text{jet}} z_i \theta_i^\alpha$$

$$z_i \equiv \frac{p_{T,i}}{p_{T,\text{jet}}}$$

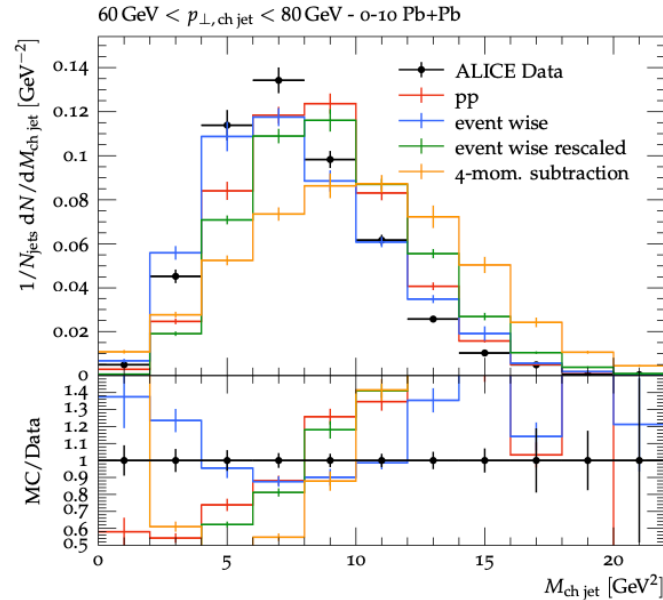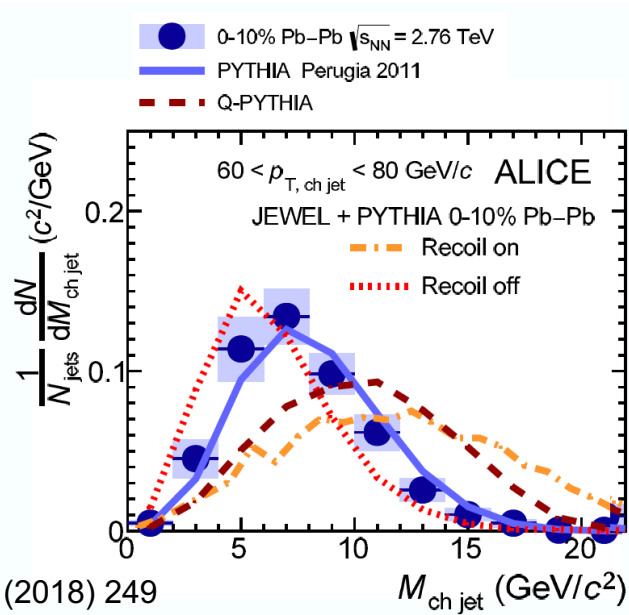$$\theta_i \equiv \frac{\Delta R_{i,\text{jet}}}{R}$$

Large variation in models when comparing the distribution directly

- JEWEL pp baseline is off and causes the disagreement with data in PbPb-to-pp ratio

ALI-DER-506893

Medium response

Medium excitation | wake | jet-correlated medium

→ Causing excess of soft particles at large angle

Tachibana et. al arXiv:1701.07951.
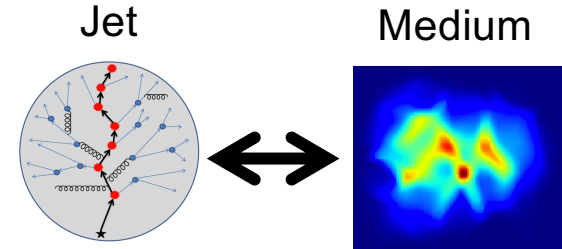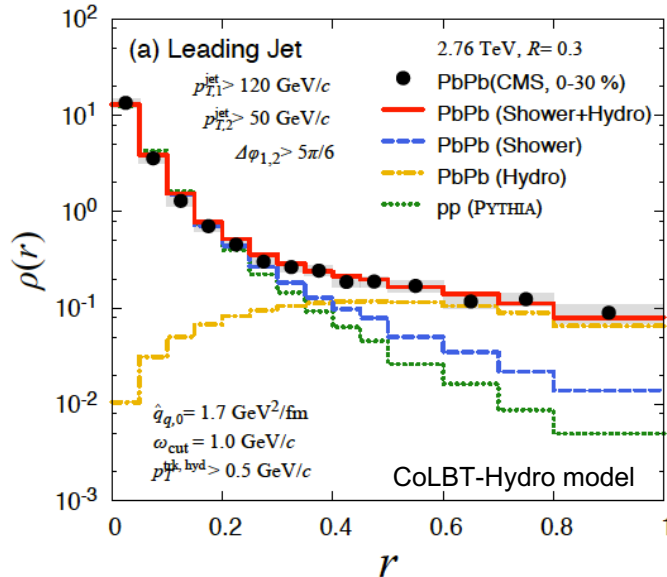
Quenched parton shower
+ medium excitation

Quenched parton shower

Vacuum parton shower

In this model, medium response needed to describe large angle.

Ideally, constrain medium response contribution with data → hadrochemistry

Dilution of signal in heavy-ion jet data due to

→ Multiple physics mechanisms happening at the same time

→ Selection / survivor biases

→ QGP is not a brick: signal strength not equal for every jet

Dilution of signal in heavy-ion jet data due to

→ Multiple physics mechanisms happening at the same time
possible solutions: less inclusive measurements, correlations

→ Selection / survivor biases
possible solutions: Z-hadron

→ QGP is not a brick: signal strength not equal for every jet
possible solutions: introduce surface bias, select on energy loss

Z-hadron

ATLAS
$p_T^Z > 60$ GeV
pp, $\sqrt{s} = 5.02$ TeV, 260 pb^{-1}
Pb+Pb, $\sqrt{s_{NN}} = 5.02$ TeV, 1.4-1.7 nb^{-1}

PRL 126 (2021) 072301

$30 < p_T^Z < 60$ GeV

$15 < p_T^Z < 30$ GeV

30-80%/pp
10-30%/pp
0-10%/pp
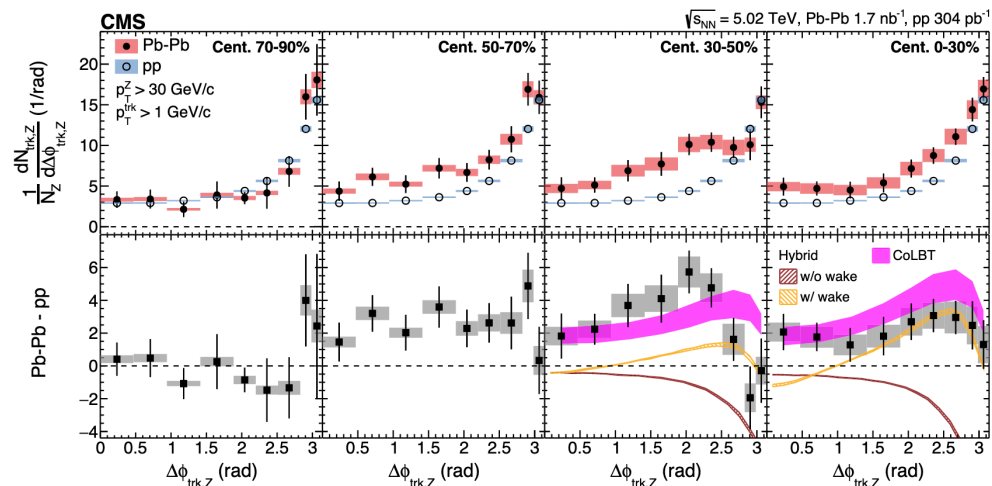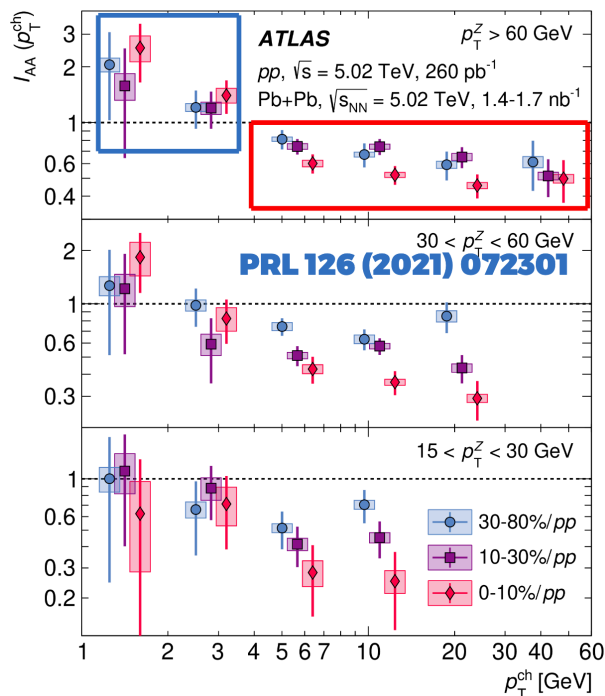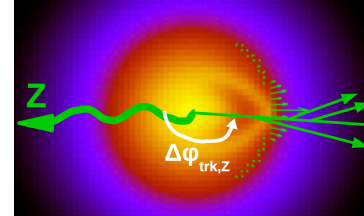
CMS PRL 128 (2022)122301

Summary

Jets are never simple.

And even more complicated when traversing a quark-gluon plasma.

Making progress on understanding in-medium parton shower

→ This leads to more accurate extraction of QGP properties (transport coefficient $\hat{q}$, (de)coherence angle θ_c, …)

But there are open questions