Jet substructure measurements in heavy-ion collisions with ALICE

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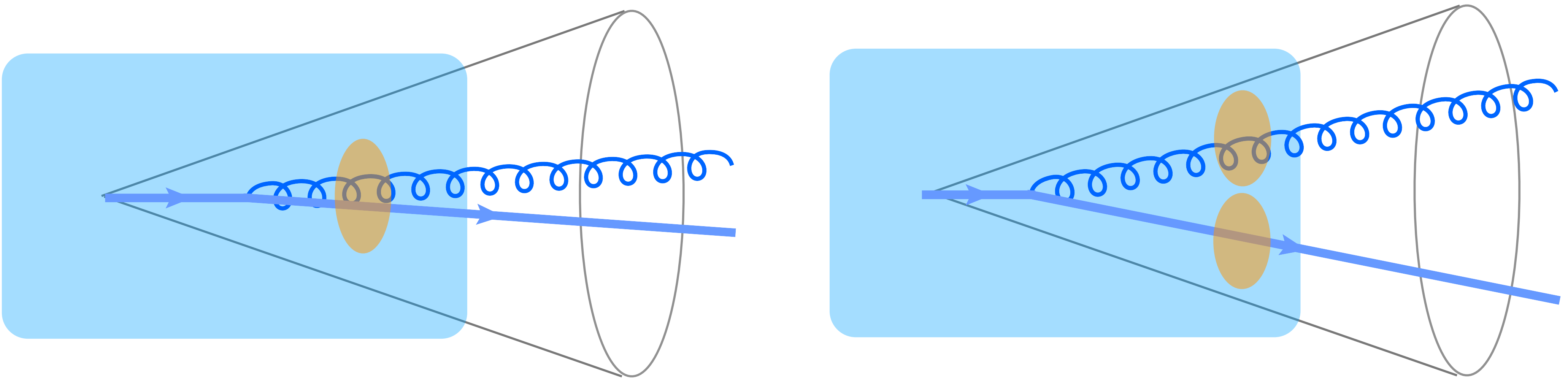
Jet substructure in heavy-ion collisions

There are many simultaneous unknowns in jet quenching theory:

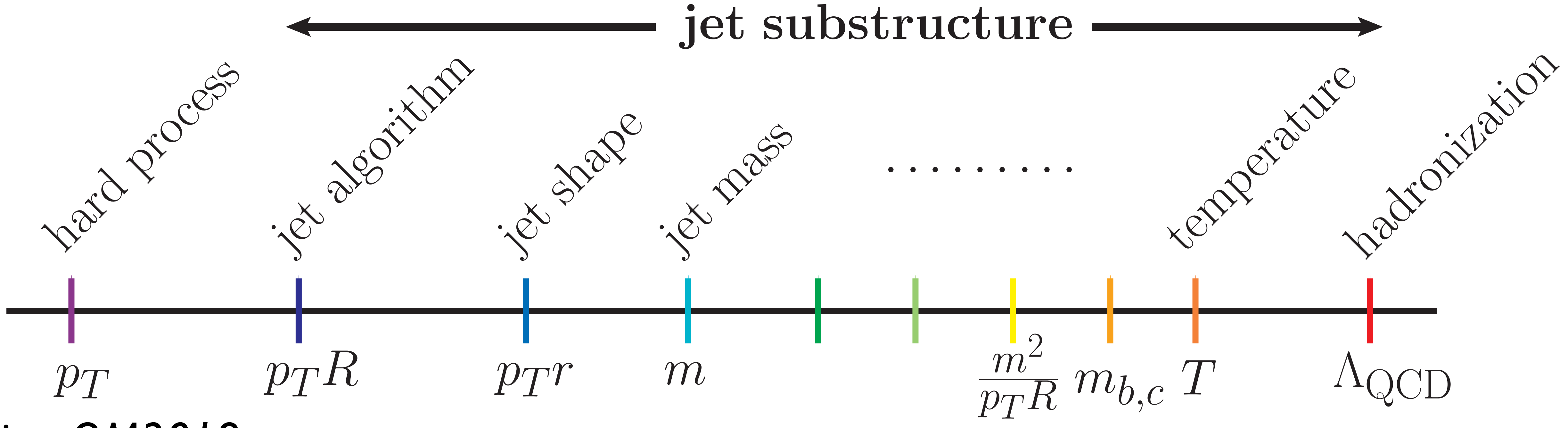
- Strongly-coupled vs. weakly-coupled interaction
- Color coherence
- Spacetime picture of parton shower
- Nature of quasiparticles
- …



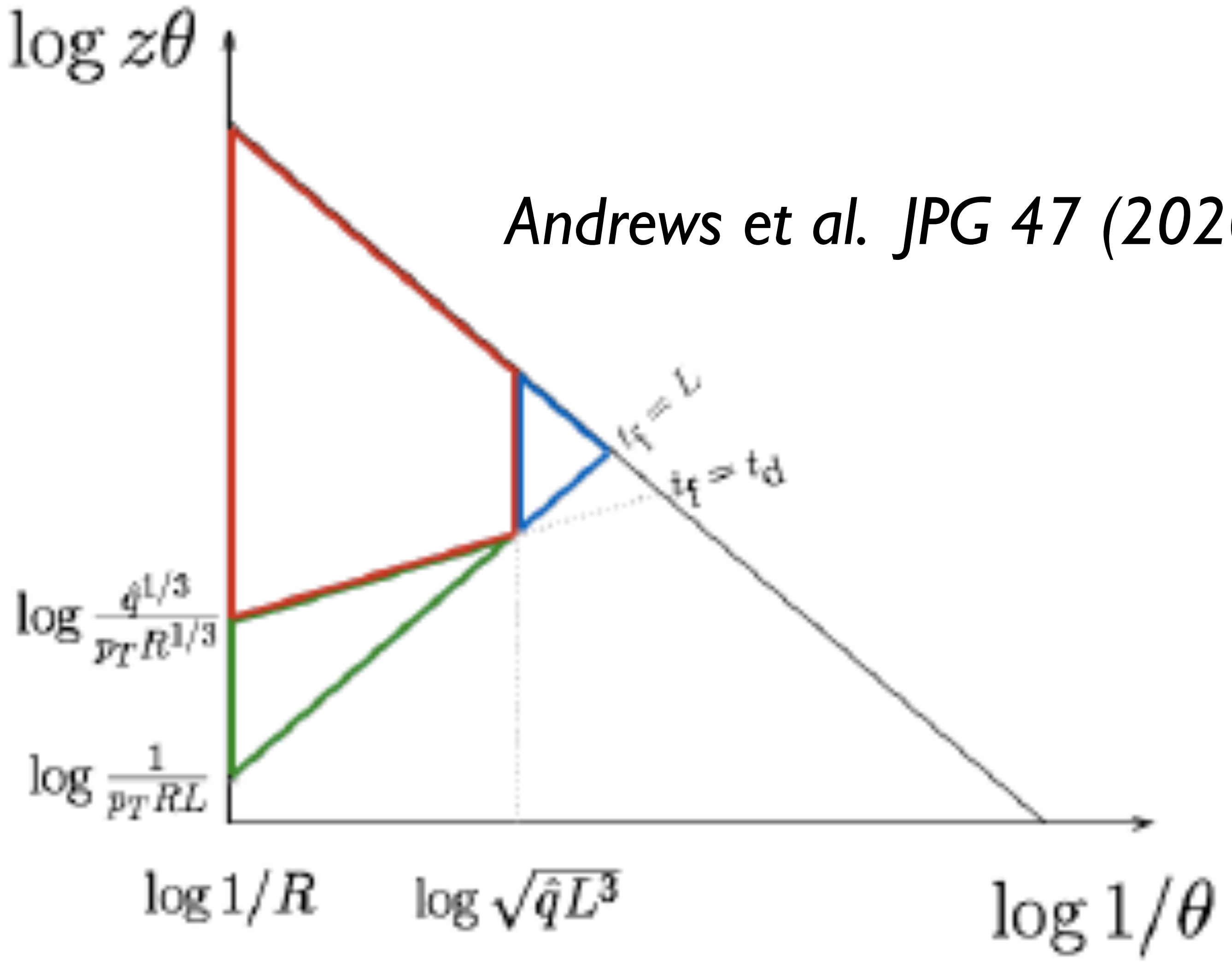
Y. Mehtar-Tani

Jet substructure is an appealing tool to disentangle these

- Target specific regions of phase space



Yang-Ting Chien, QM2018

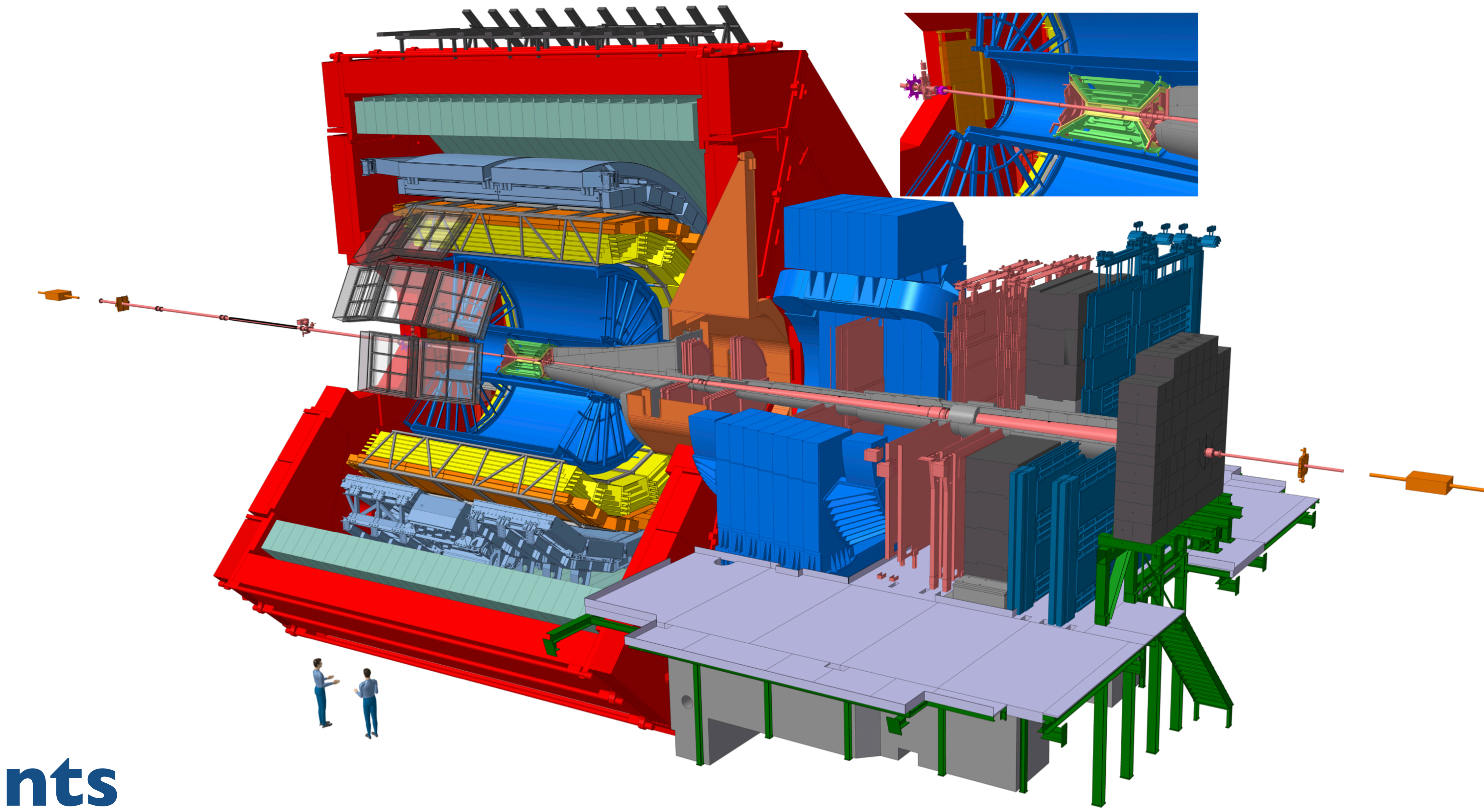


Andrews et al. JPG 47 (2020) 065102

Jets with ALICE

ALICE reconstructs jets at midrapidity with a high-precision tracking system (ITS+TPC) and EMCal

- $p_{\mathrm{T,jet}} \approx 20 - 200$ GeV/c
- $|\eta| < 0.9$



Charged particle jets

- High-precision spatial resolution to resolve particles

  → **Ideal for jet substructure measurements**

Full jets (charged tracks + EMCal π^0,γ)

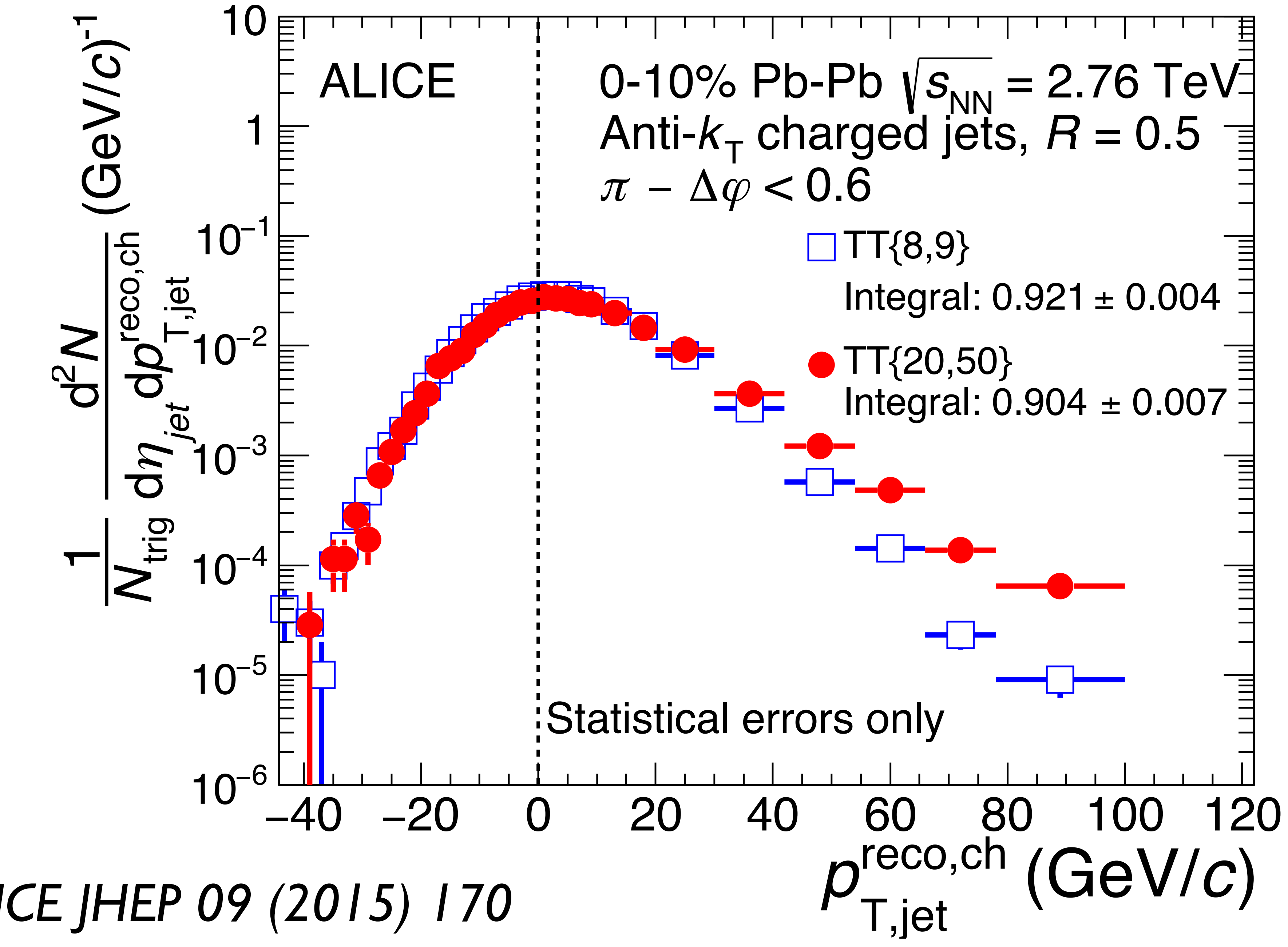
- More direct comparison to theory

Experimental challenge: Background

Ensemble observables

For observables that don't involve event-by-event identification of objects: ensemble-based methods

Ungroomed angularity, mass, N-subjettiness, …

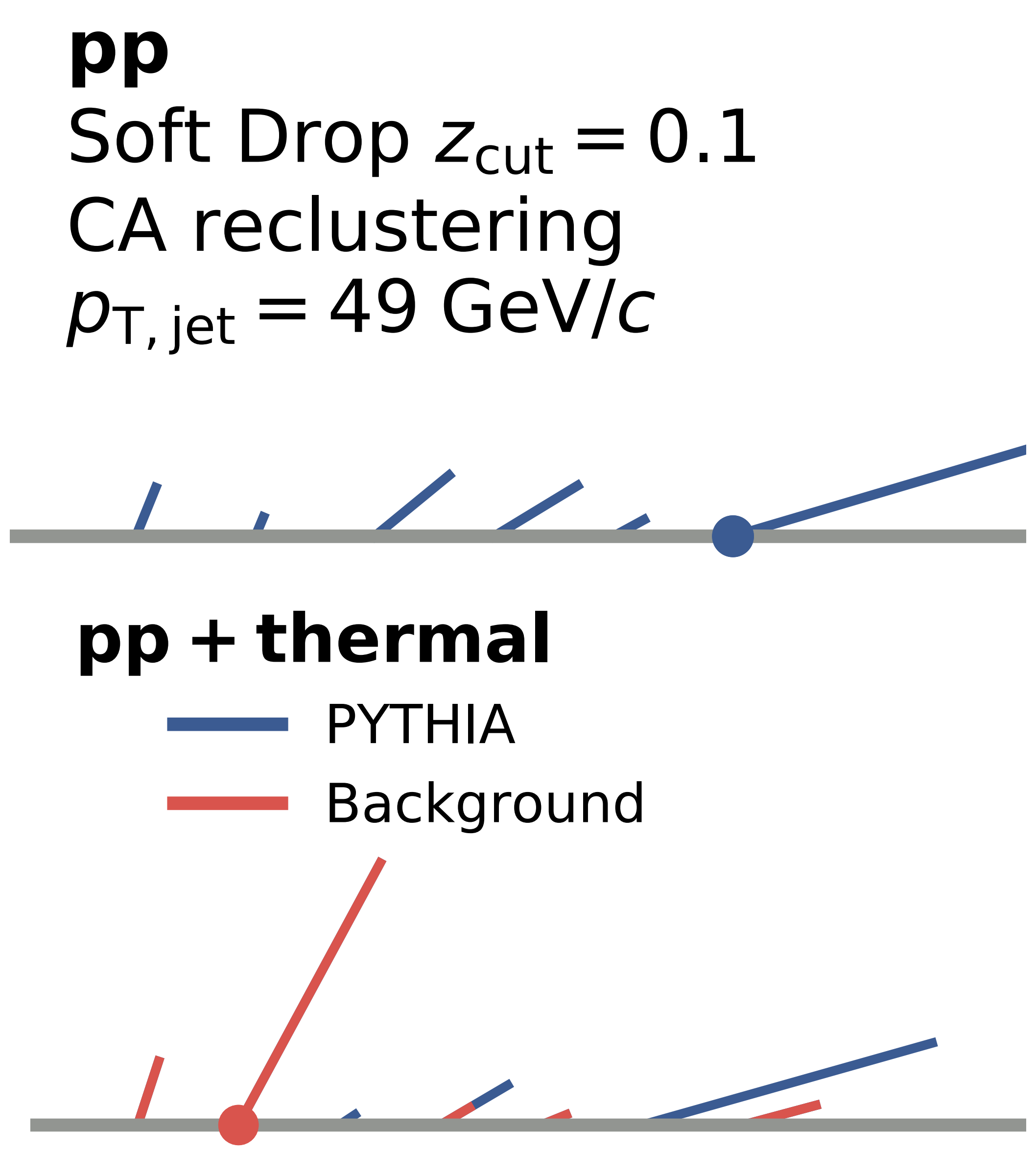


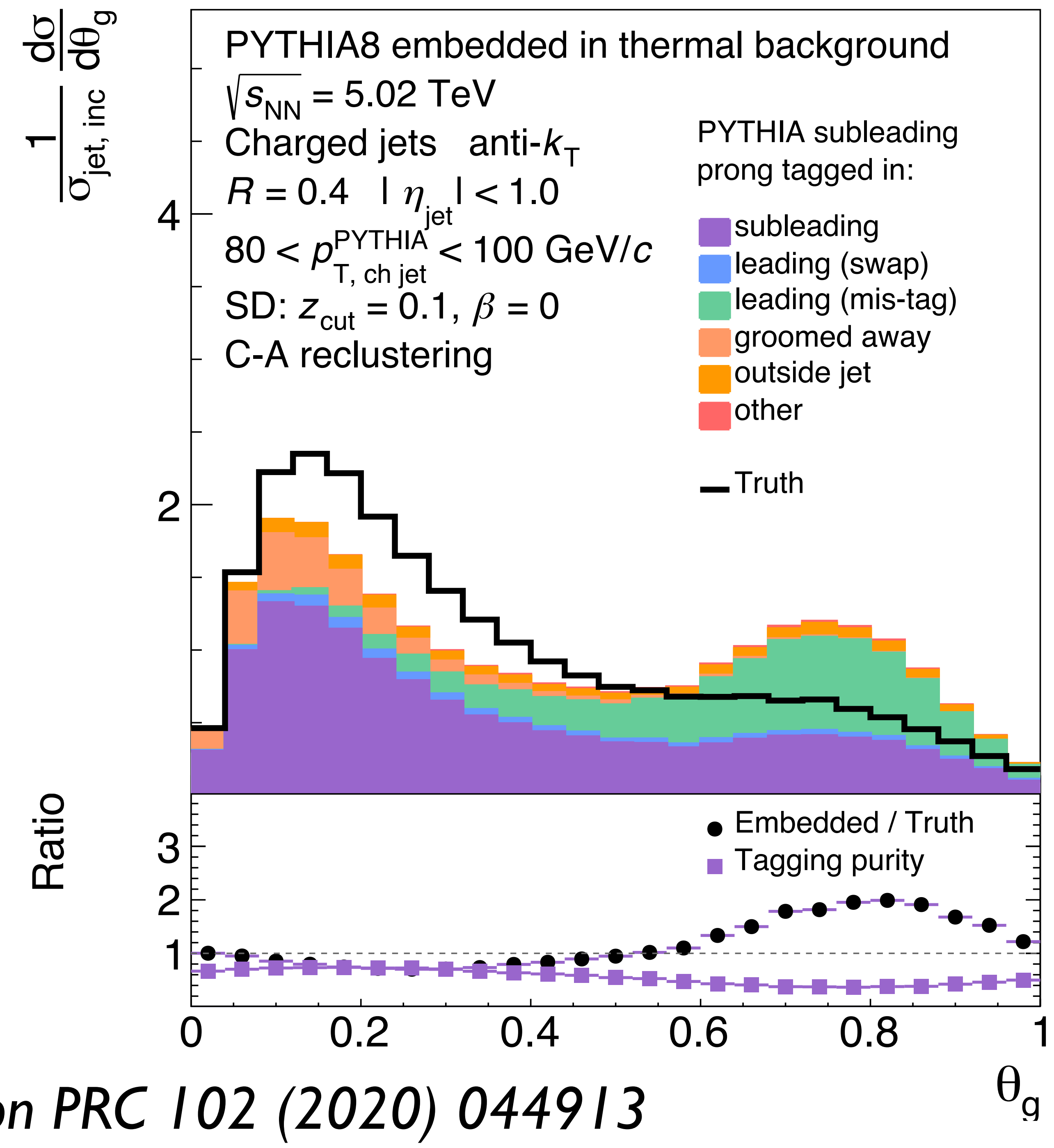
ALICE JHEP 09 (2015) 170

Object identification

For observables that involve jet-by-jet object identification: background can induce mis-tagging

Groomed observables, leading subjets, …





JM, Ploskon PRC 102 (2020) 044913

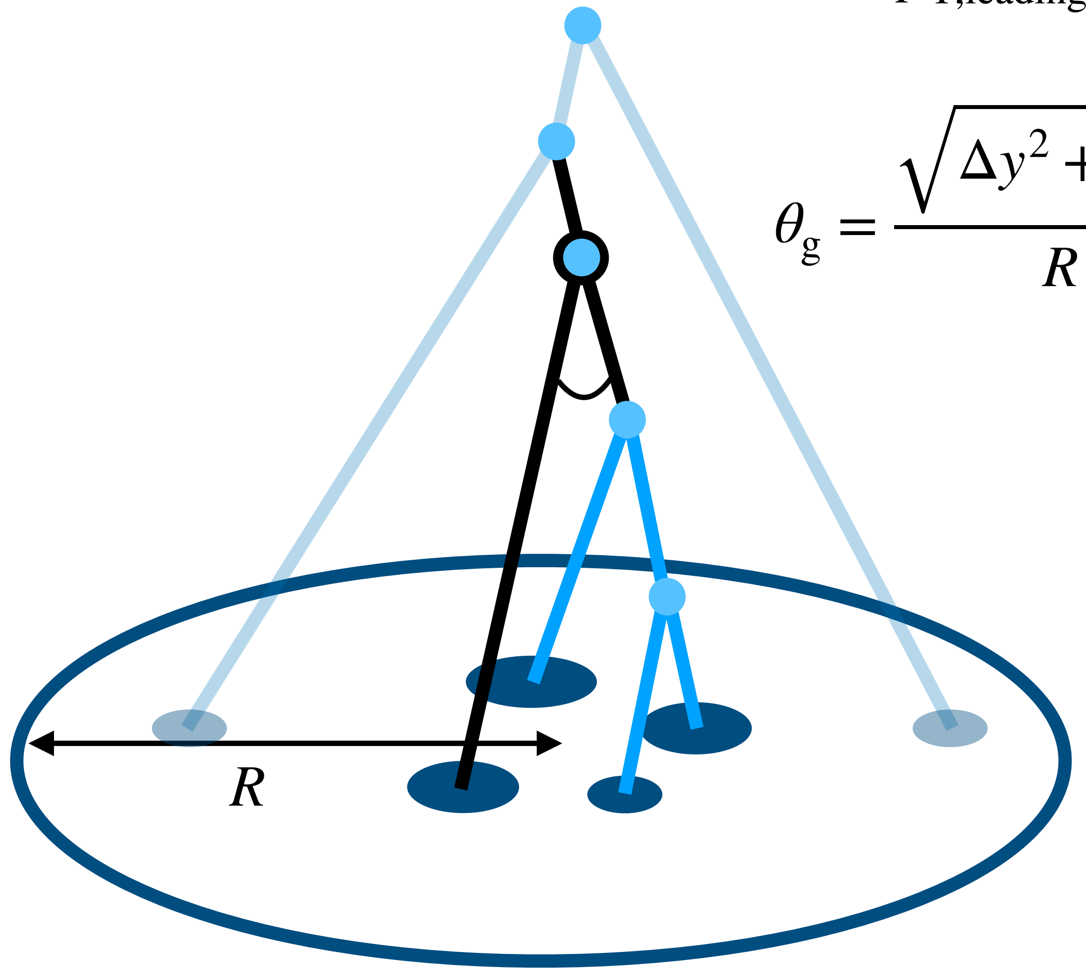
Groomed jet substructure

arXiv 2107.12984

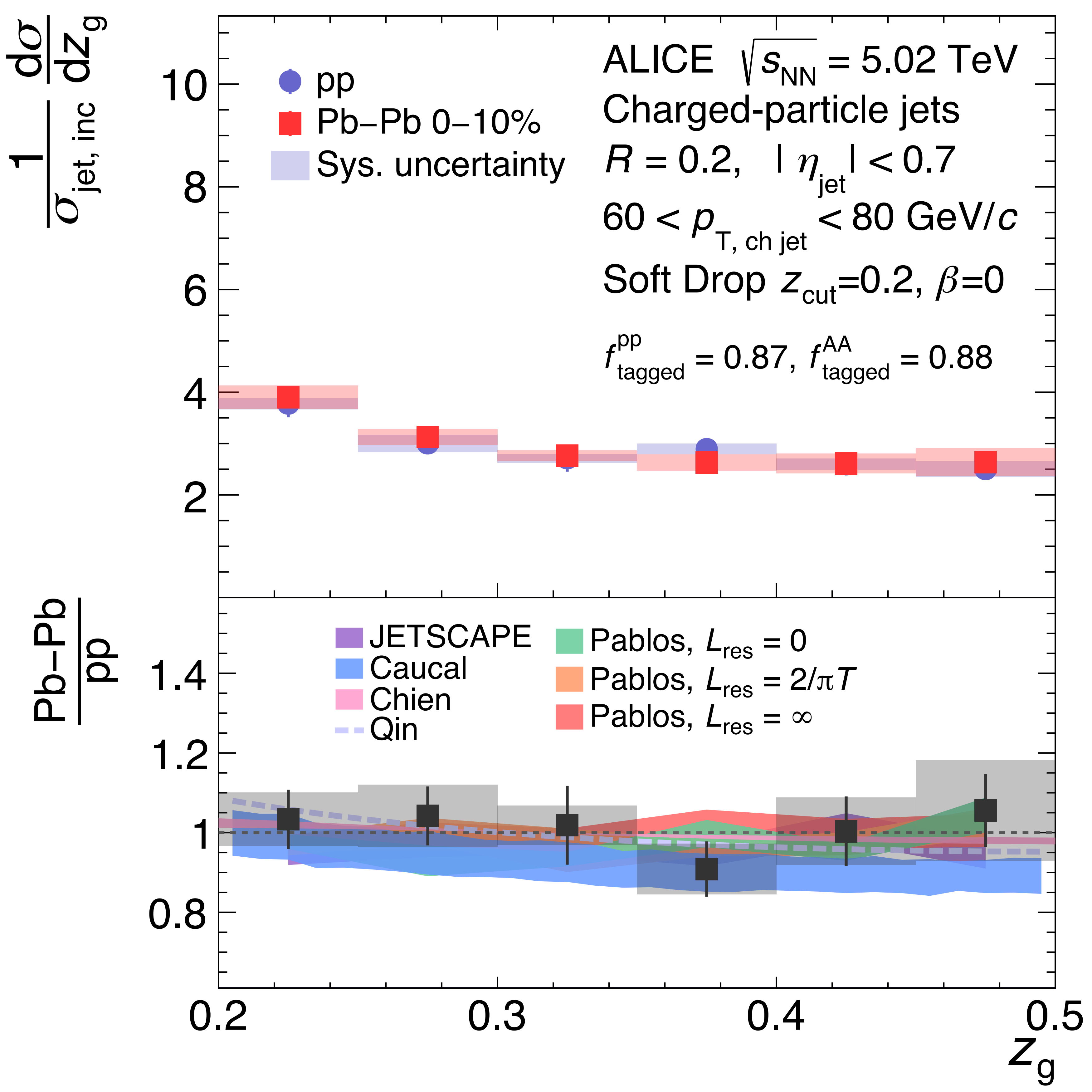
How is the hard jet substructure modified in heavy-ion collisions?

$$z_g \equiv \frac{p_{T,\mathrm{subleading}}}{p_{T,\mathrm{leading}} + p_{T,\mathrm{subleading}}}$$

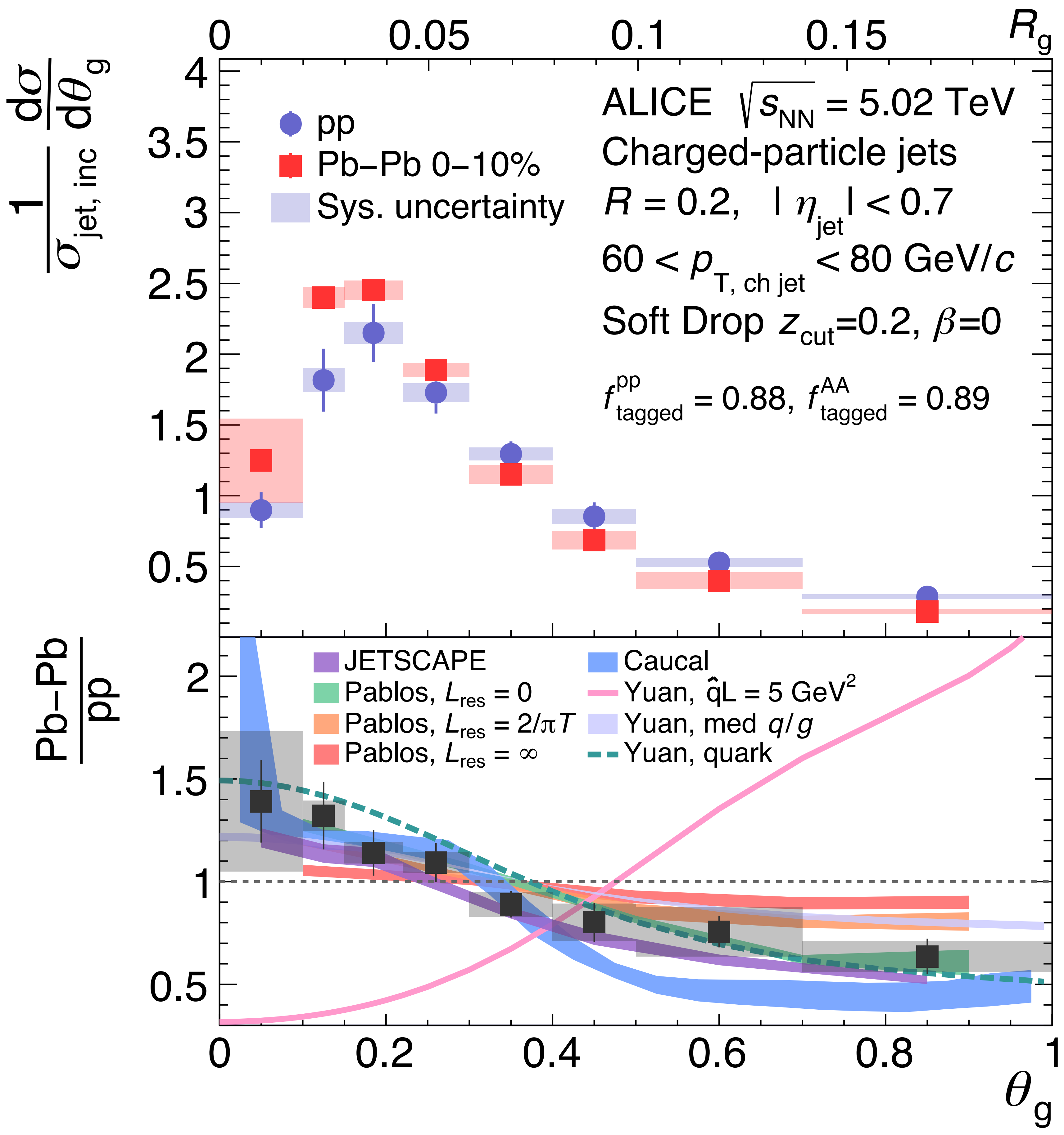
$$\theta_g = \frac{\sqrt{\Delta y^2 + \Delta\varphi^2}}{R}$$



Grooming condition: $z > z_{cut}$



No significant modification in z_g distribution



The cores of jets are narrower in Pb-Pb compared to pp collisions

Sensitive to QGP resolution length

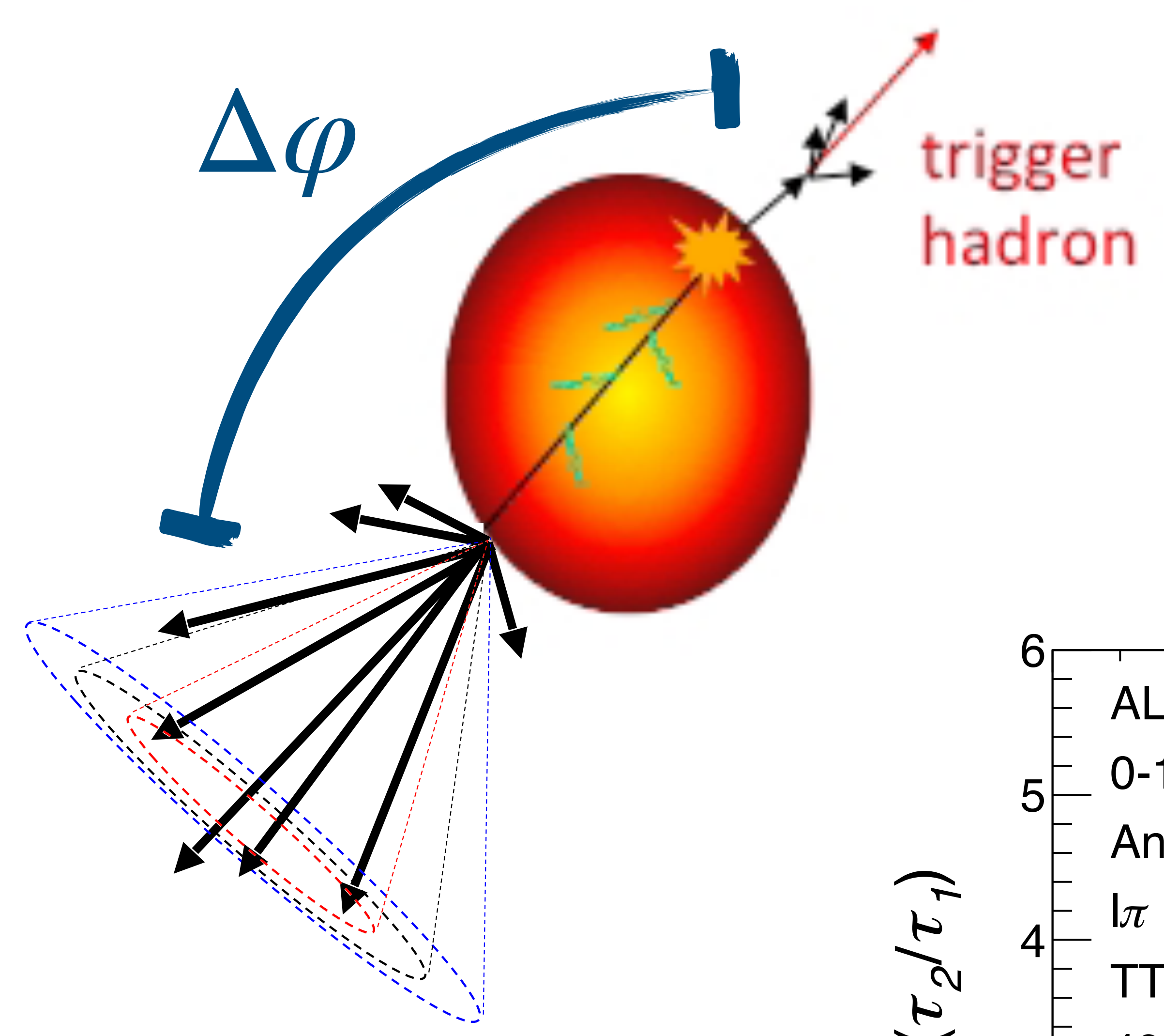
N-subjettiness

arXiv 2105.04936

Substructure of recoiling jet in semi-inclusive hadron-jet coincidence

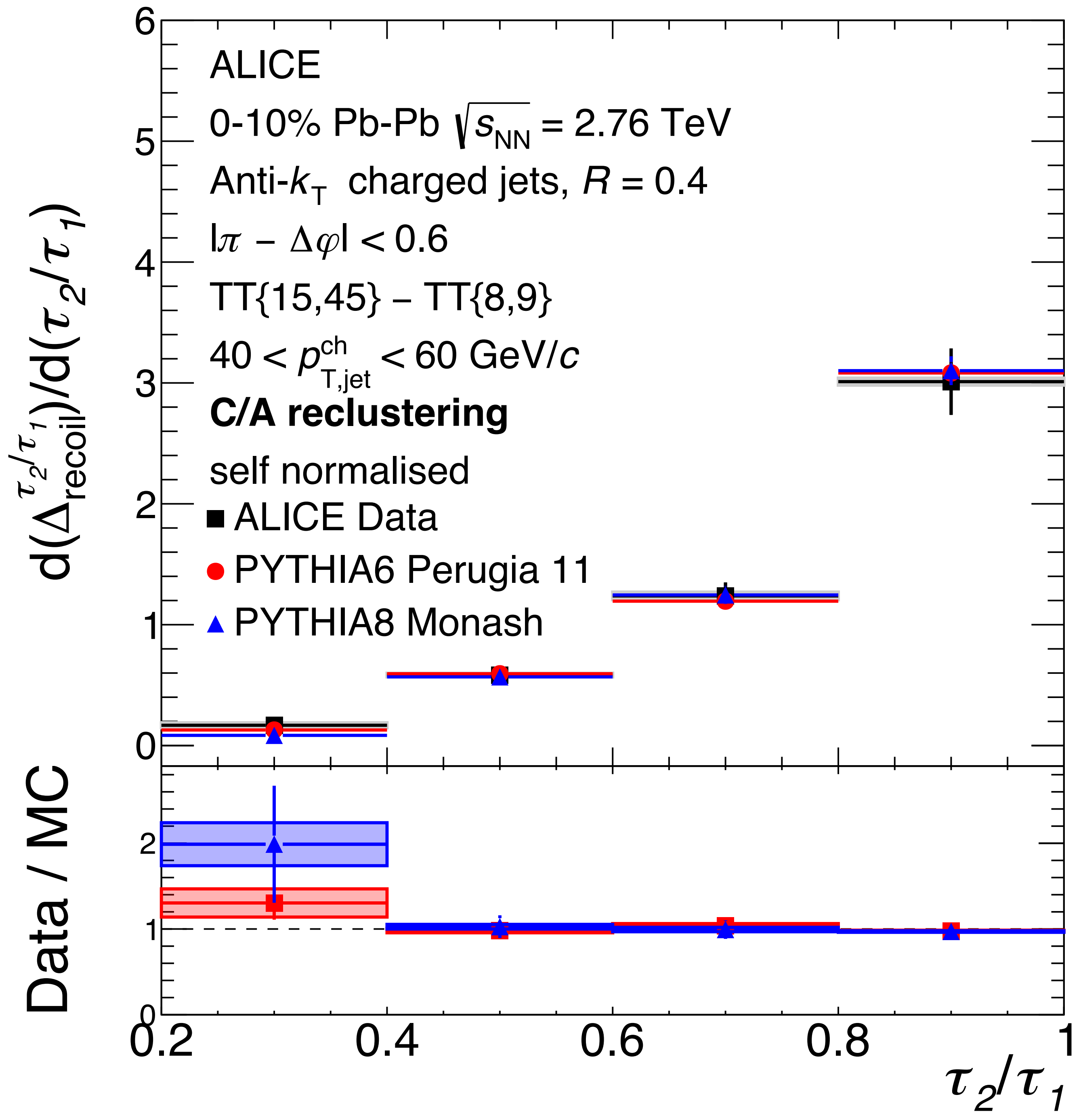
$$\tau_N = \frac{1}{p_{\mathrm{T,jet}} \times R} \sum_k p_{\mathrm{T},k} \, \mathrm{minimum}(\Delta R_{1,k}, \Delta R_{2,k}, ..., \Delta R_{\mathrm{N},k})$$

$$\Delta_{\mathrm{recoil}}^{\tau_2/\tau_1} = \frac{1}{N_{\mathrm{trig,Sig}}} \frac{\mathrm{d}^2 N}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\tau_2/\tau_1}\Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT_{Sig}}} - \frac{1}{N_{\mathrm{trig,Ref}}} \frac{\mathrm{d}^2 N}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}} \mathrm{d}\tau_2/\tau_1}\Bigg|_{p_{\mathrm{T,trig}} \in \mathrm{TT_{Ref}}}$$



Small τ_2/τ_1:
"2-prongy"

Large τ_2/τ_1:
"1-prongy"



No strong modification of "pronginess" of jets in heavy-ion collisions

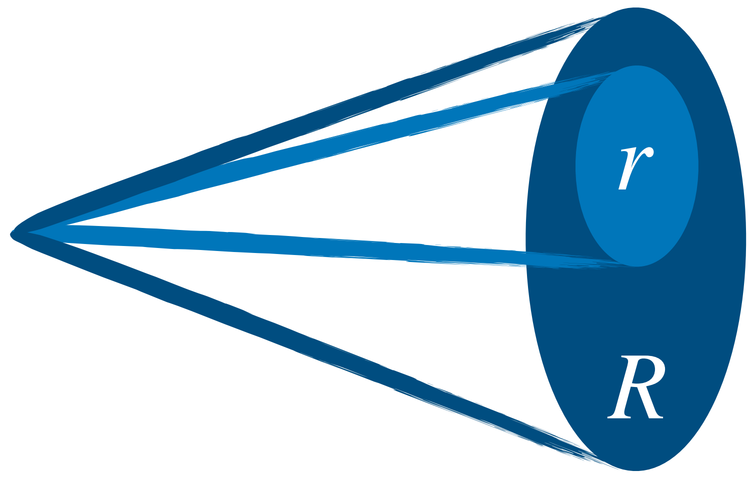
Medium-induced emissions are not hard enough to produce a new prong

Similar to z_g being unmodified?

Subjet fragmentation

Cluster inclusive jets with radius R, then recluster with anti-k_t with radius r

Neill, Ringer, Sato 2103.16573
Kang, Ringer, Waalewijn JHEP 07 (2017) 064



$$z_r = \frac{p_T^{\text{ch subjet}}}{p_T^{\text{ch jet}}}$$

Measure subjets to probe jet quenching

- Can probe higher z than hadron fragmentation measurements

CMS PRC 90 (2014) 2 024908
ATLAS PRL 123 (2019) 4 042001

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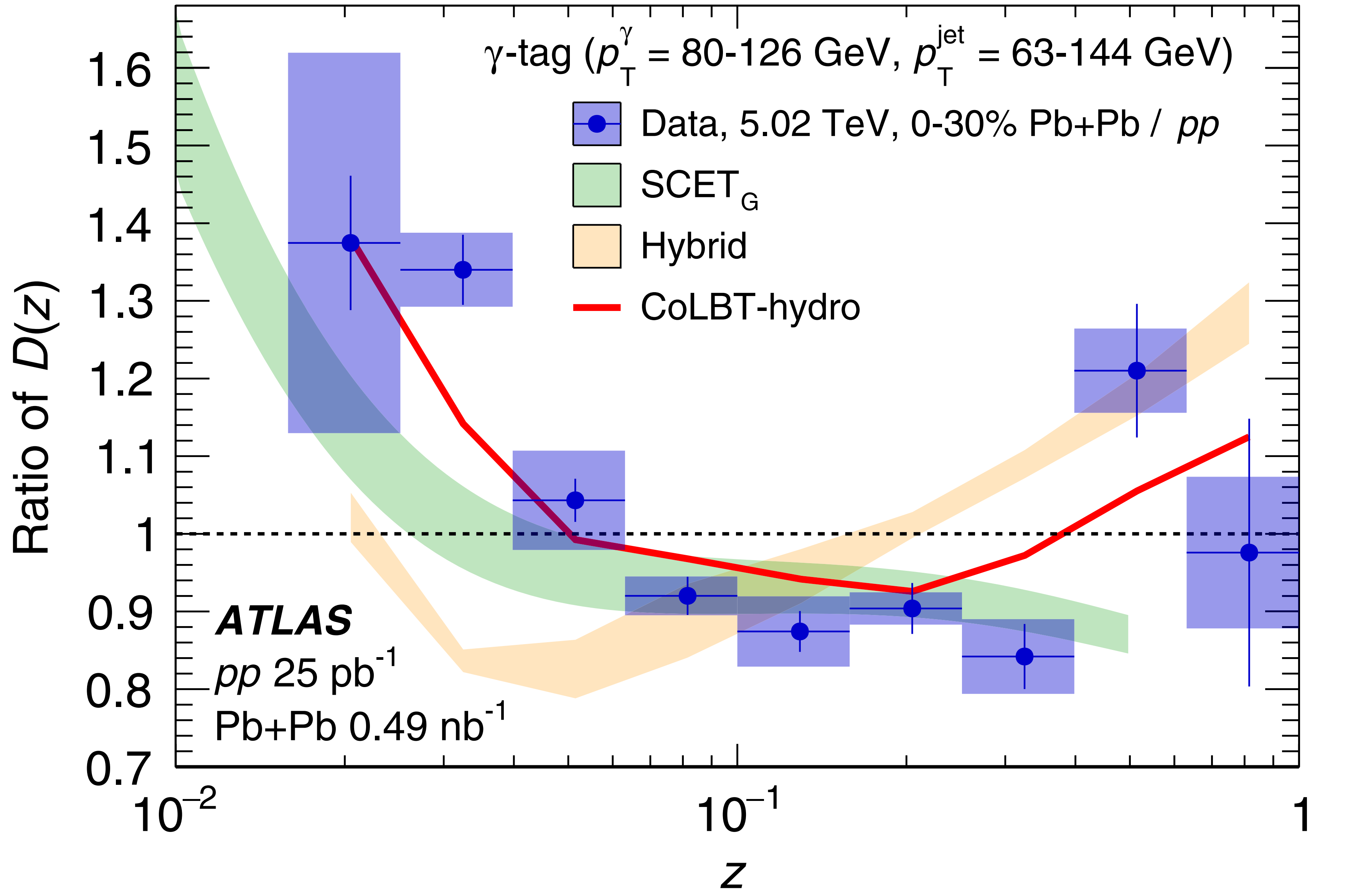

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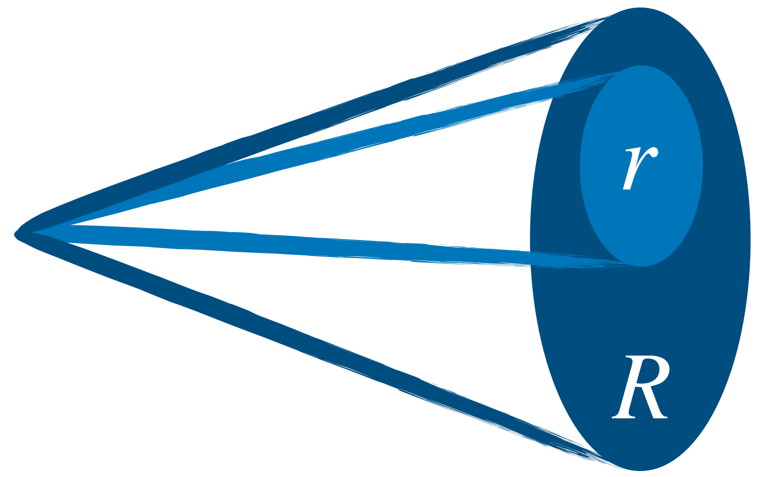

$$z_{\rm r} = \frac{p_{\rm T}^{\rm ch\ subjet}}{p_{\rm T}^{\rm ch\ jet}}$$

Measure subjets to probe jet quenching

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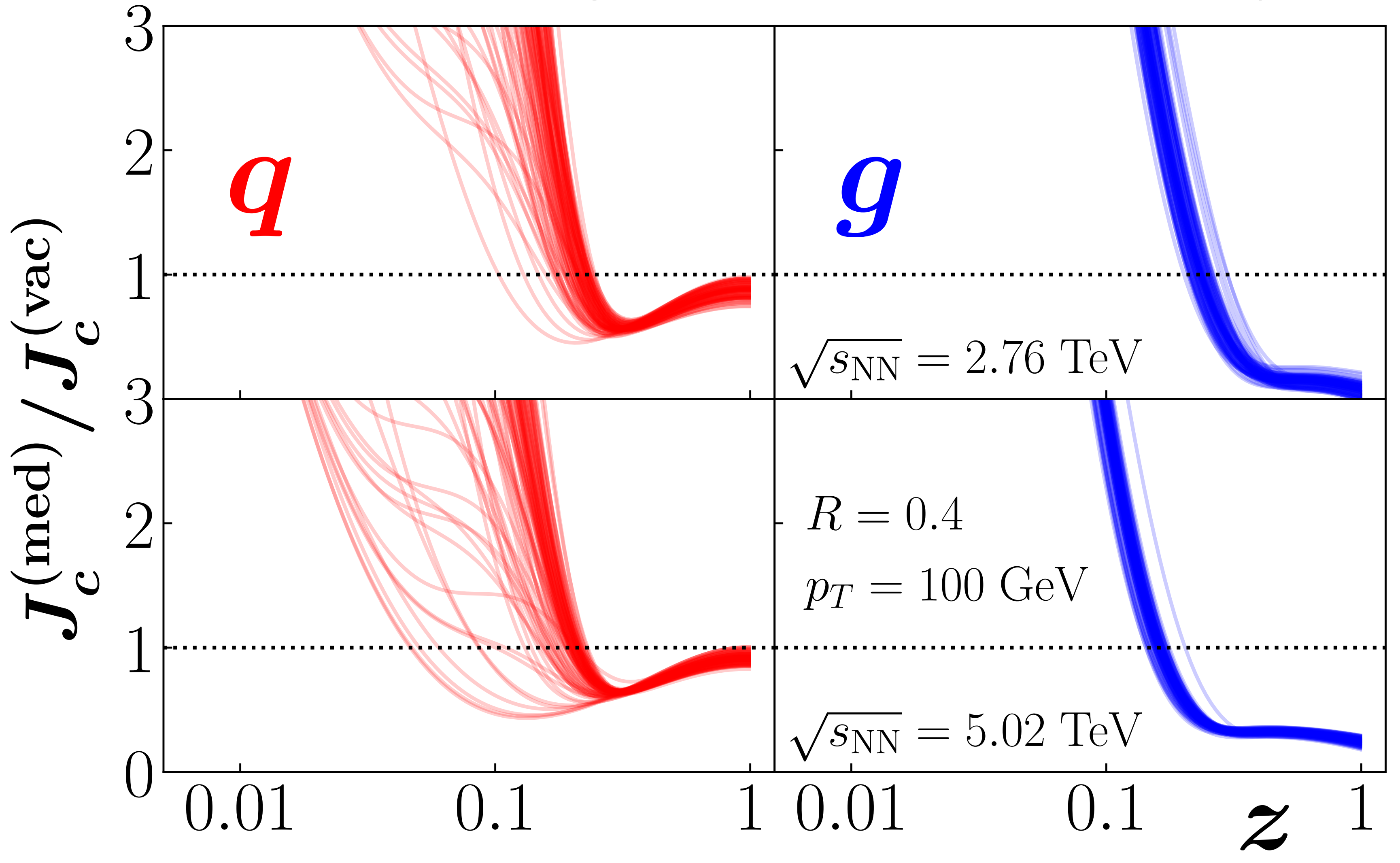
  CMS PRC 90 (2014) 2 024908
  ATLAS PRL 123 (2019) 4 042001

- Opportunity to test universality of jet fragmentation functions

$$J_{r,\rm med}(z) = J_{\rm med}(z)$$

parton → subjet   parton → jet

Qiu, Ringer, Sato, Zurita PRL 122 (2019) 25



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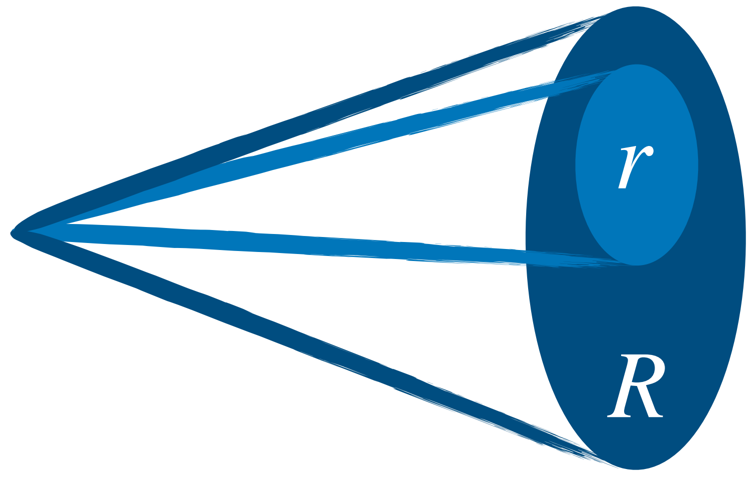
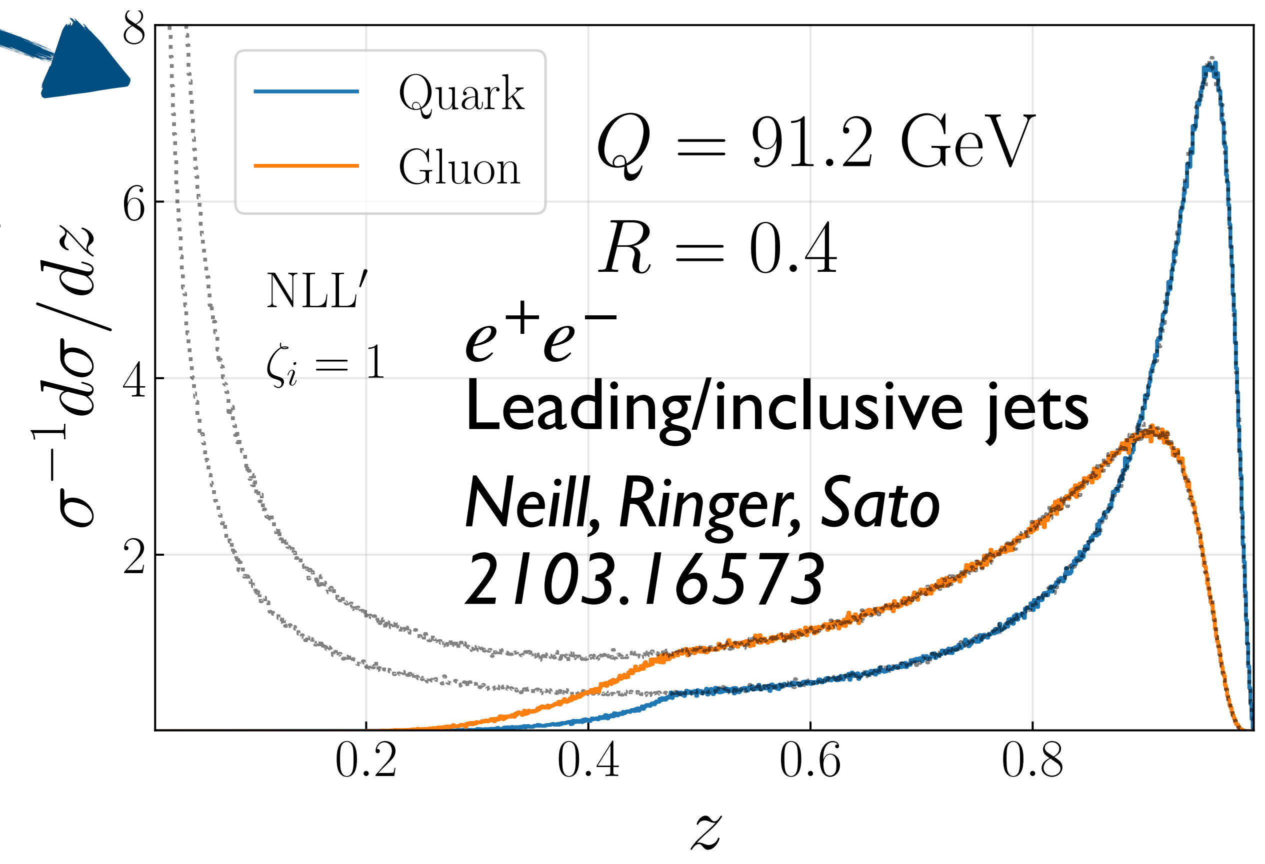


Hardening distribution at intermediate z_r

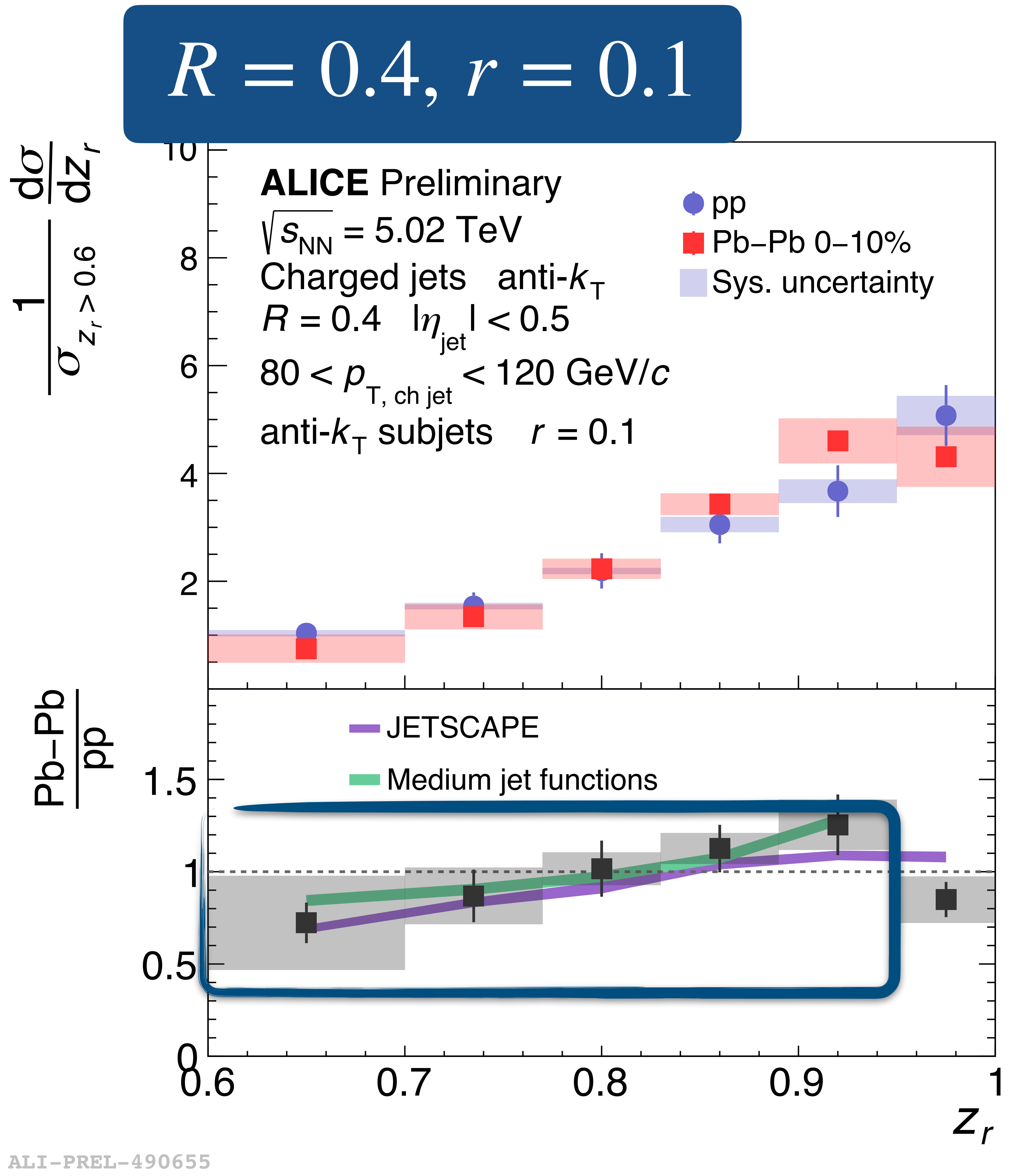
- Large quark-gluon differences in vacuum
- Competing effects?
  - Gluon suppression → larger z_r
  - Soft radiation → smaller z_r



Well-described by theoretical predictions

- JETSCAPE *JETSCAPE Collaboration 1903.07706*
- In-medium jet functions

Qiu, Ringer, Sato, Zurita PRL 122 (2019) 25
Neill, Ringer, Sato 2103.16573
Kang, Ringer, Waalewijn JHEP 07 (2017) 064



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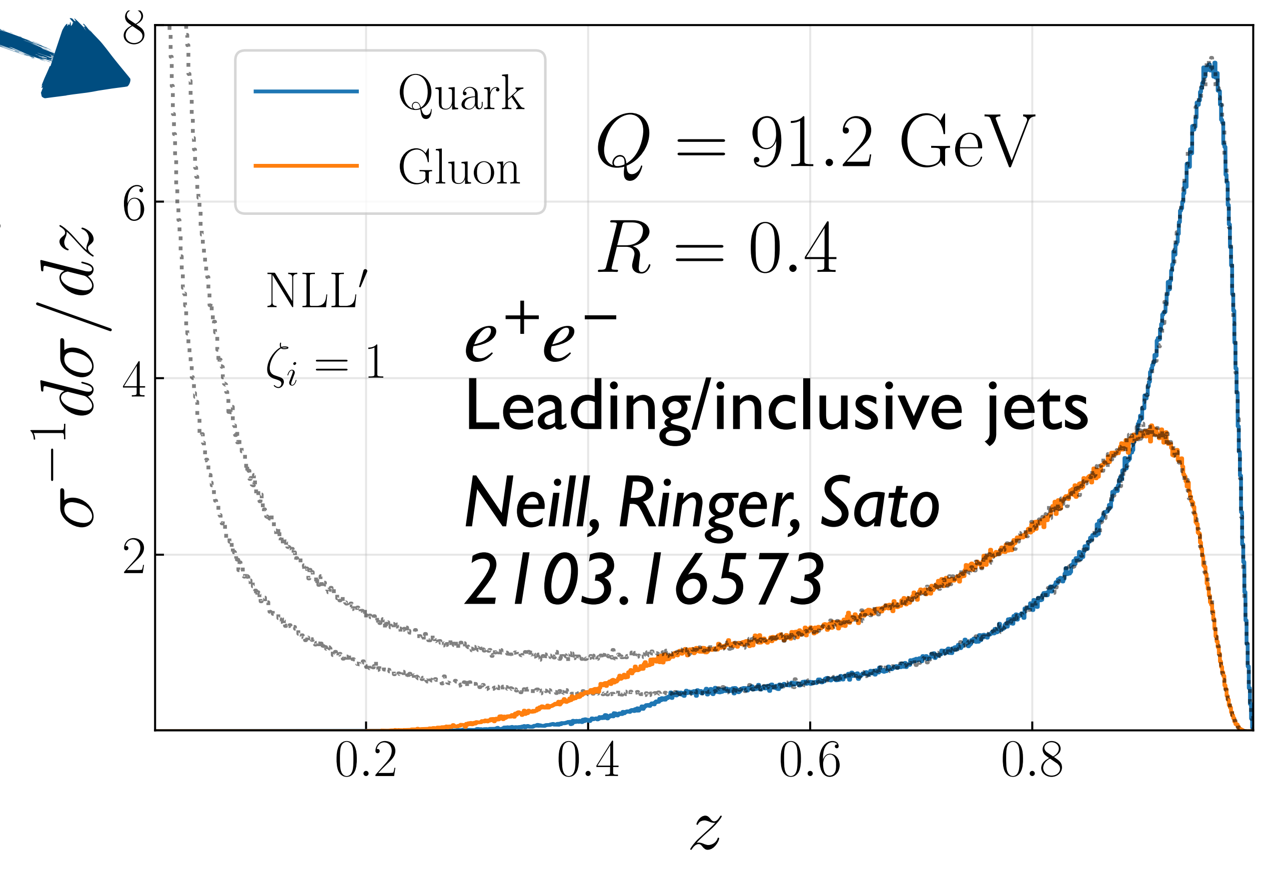
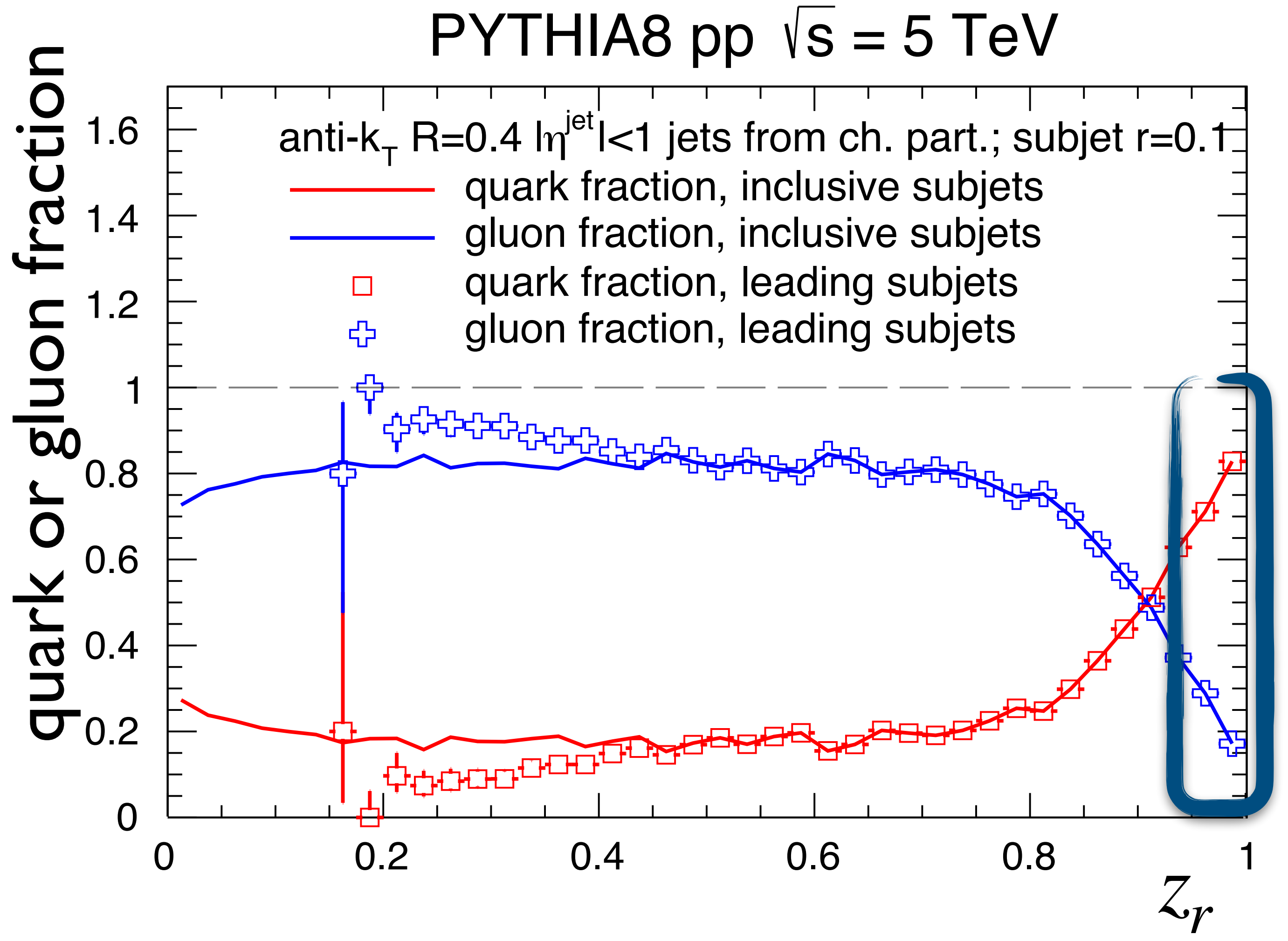


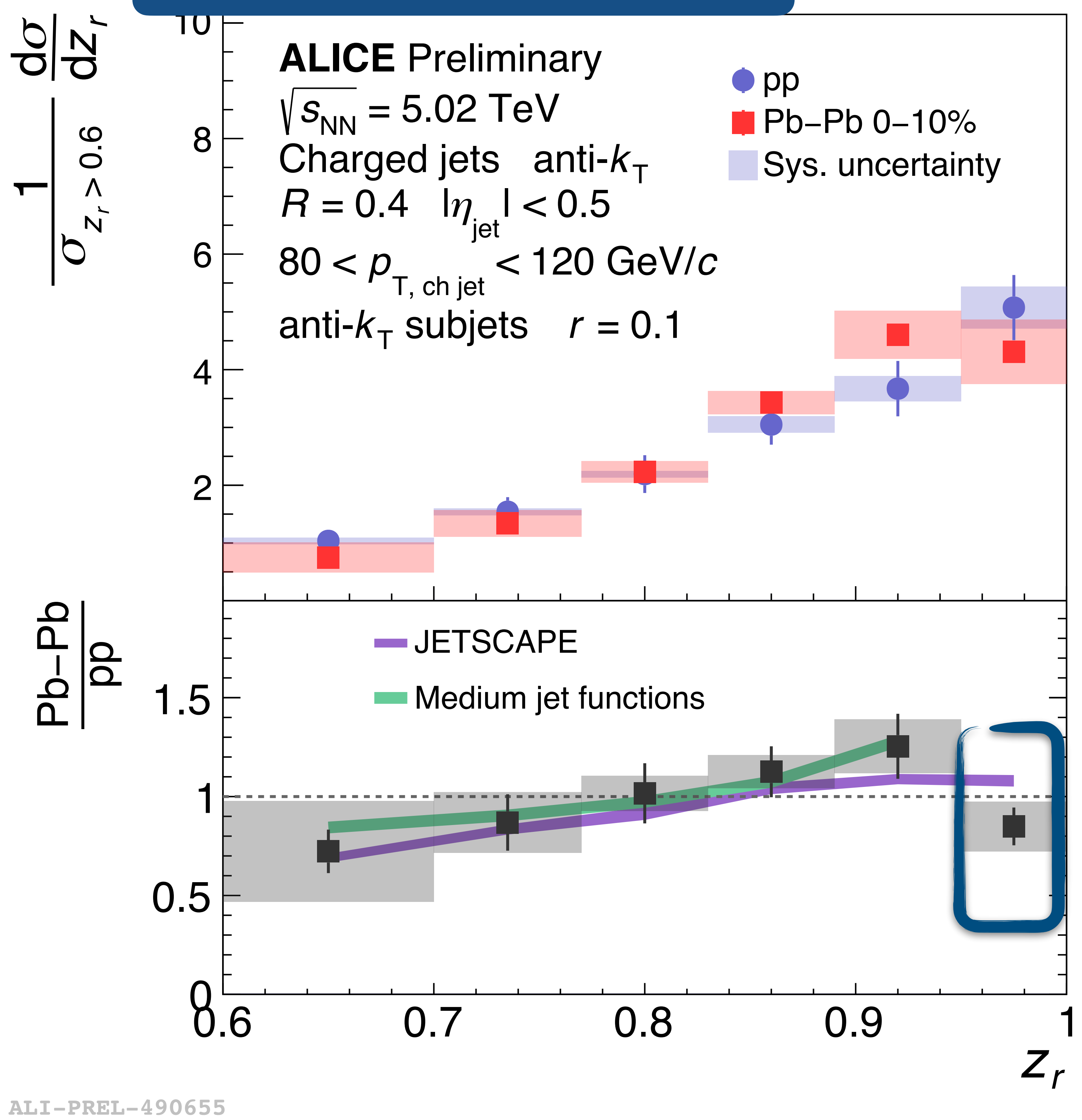
Hint of suppression as $z_r \to 1$

- At $z_r \to 1$, the sample becomes closer to purely quark jets!
- **Expose region depleted by soft medium induced emissions**



New path to disentangle quenching effects

$R = 0.4,\ r = 0.1$



Summary

New ALICE measurements of jet substructure in heavy-ion collisions — emphasis on observables that can be directly compared to theoretical calculations

- Unfolded for background and detector effects
- Analytically calculable in proton-proton collisions

Emerging picture of jet quenching phenomenology

- Hard splitting not strongly modified — z_{g}, τ_N
- Collimation/filtering of wide jets — θ_{g}
- Medium-induced soft splitting can be exposed in region dominated by quark jets — z_r