

# Measurements of subjet fragmentation with ALICE

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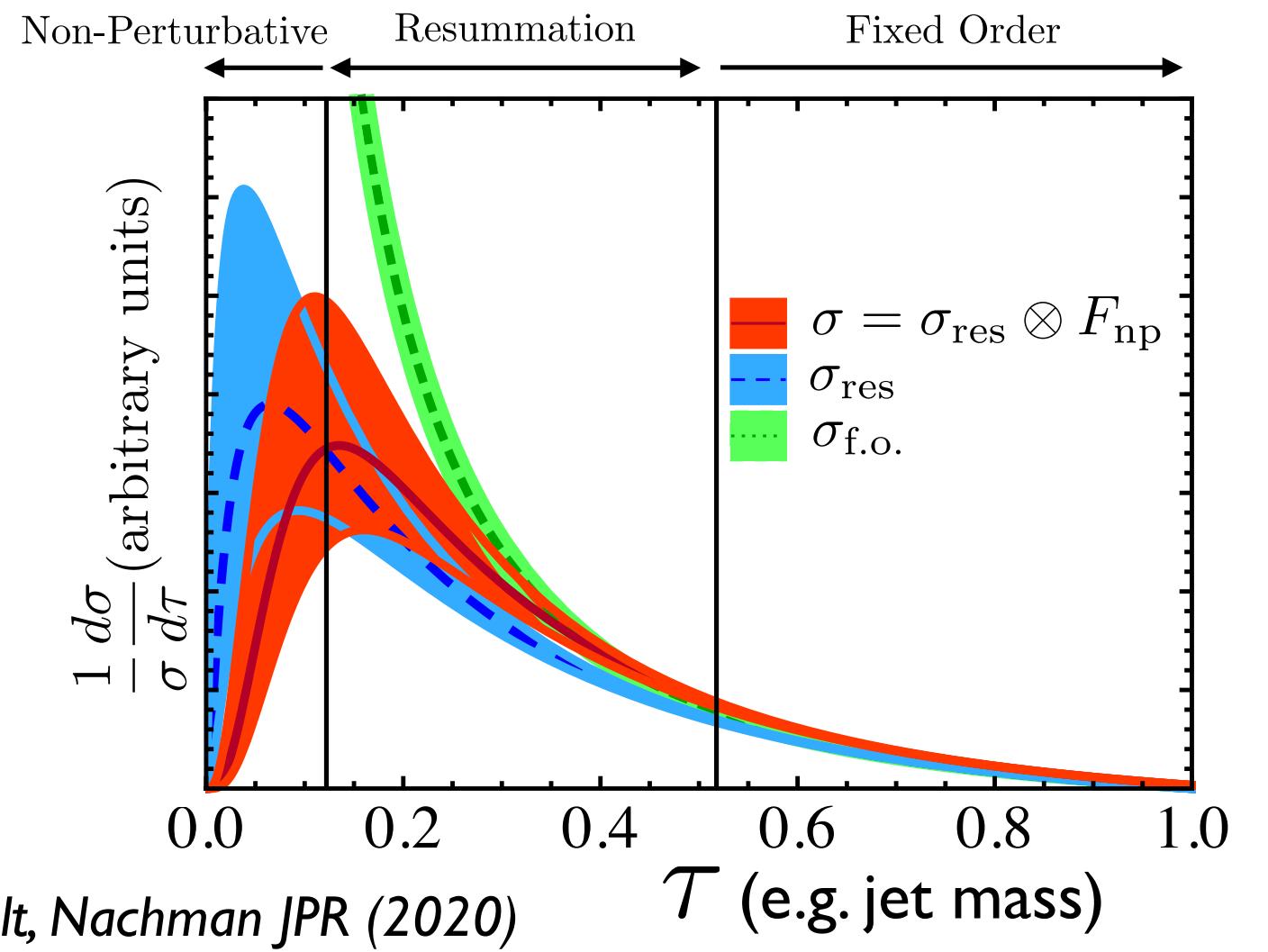


50th International Symposium on Multiparticle Dynamics  
July 12, 2021



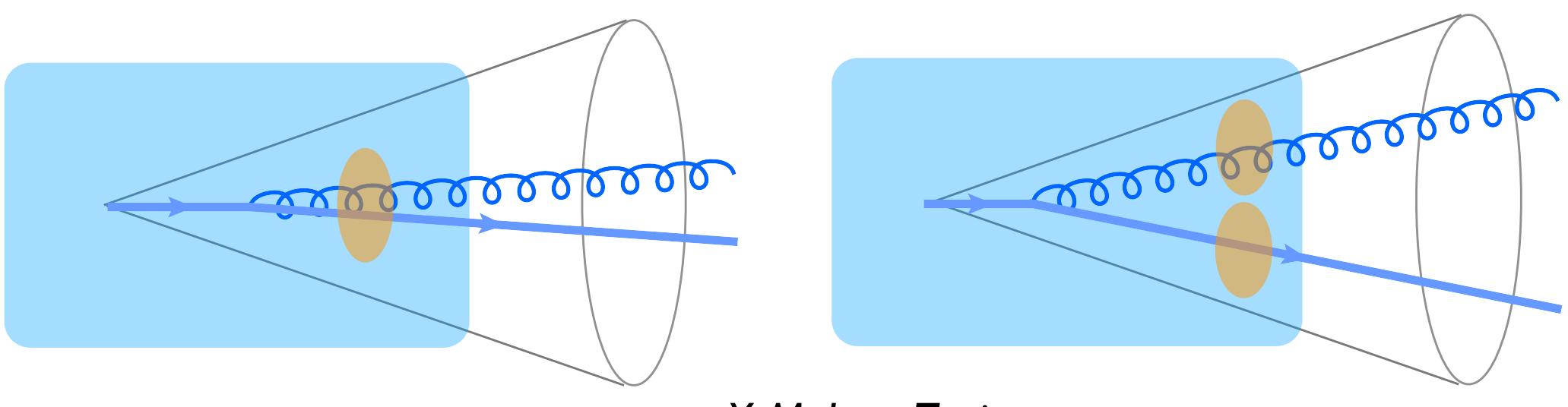
# Jets to study QCD

- Understanding validity of perturbative vs. nonperturbative physics



Larkoski, Moult, Nachman JPR (2020)

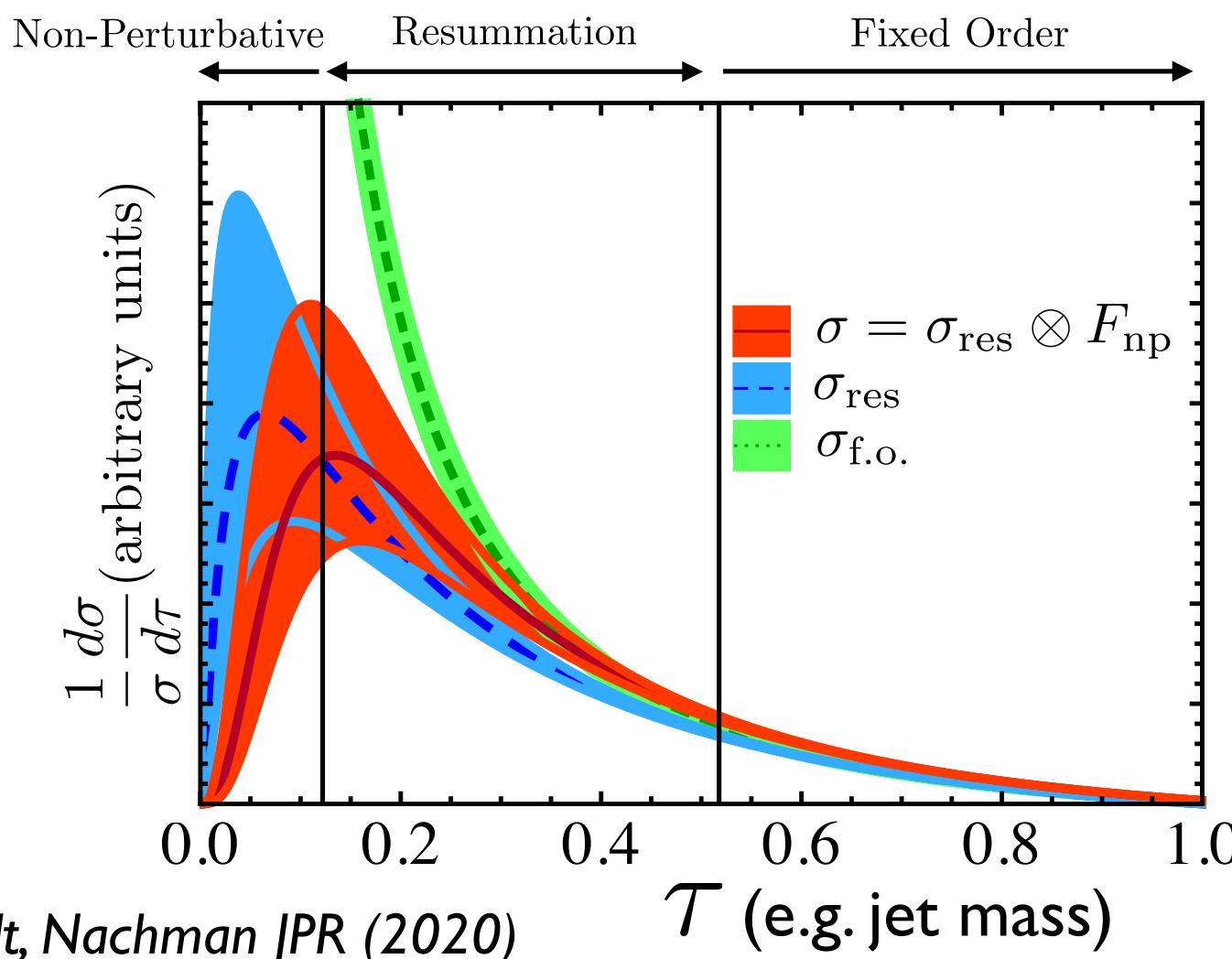
- Probes of quark-gluon plasma



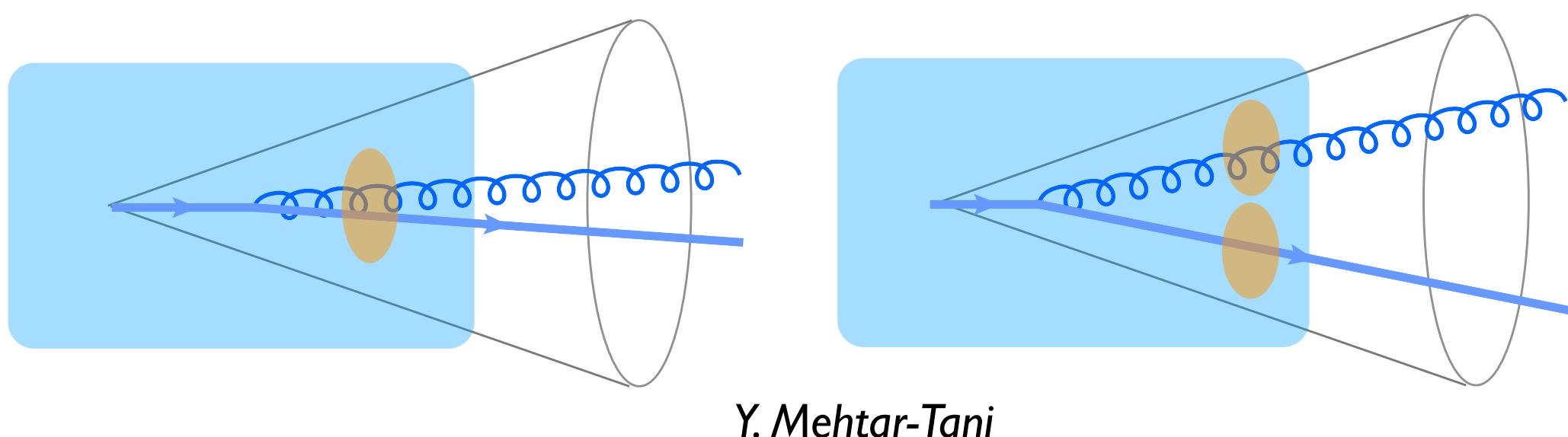
Y. Mehtar-Tani

# Jets to study QCD

- Understanding validity of perturbative vs. nonperturbative physics

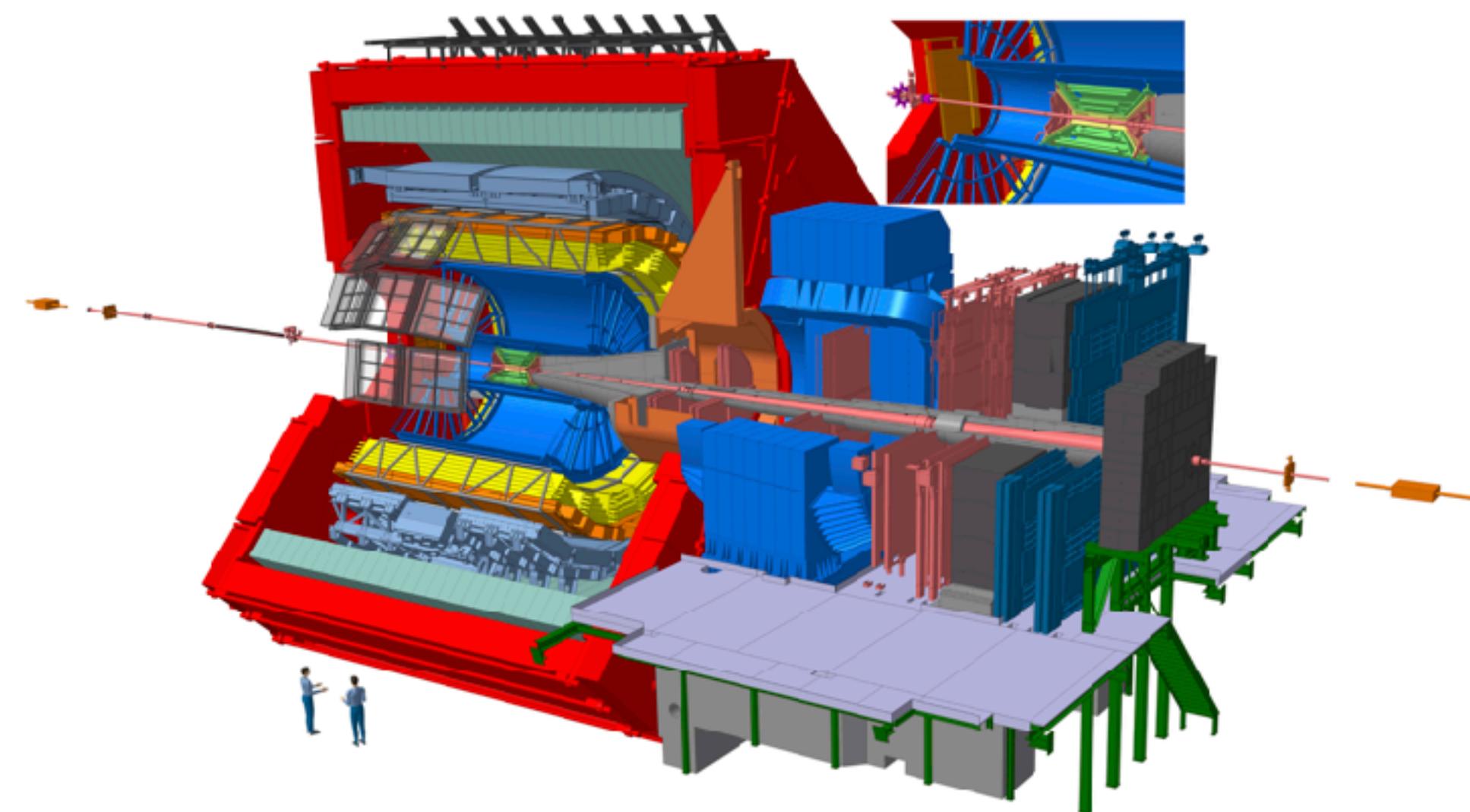


- Probes of quark-gluon plasma



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

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



## Charged particle jets

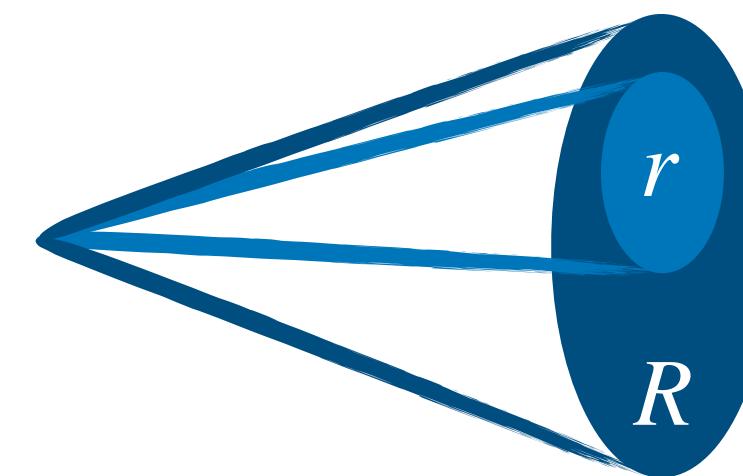
- High-precision spatial resolution to resolve particles
- **Ideal for jet substructure measurements**

## Full jets (charged tracks + EMCal $\pi^0, \gamma$ )

- More direct comparison to theory

# Subjet fragmentation

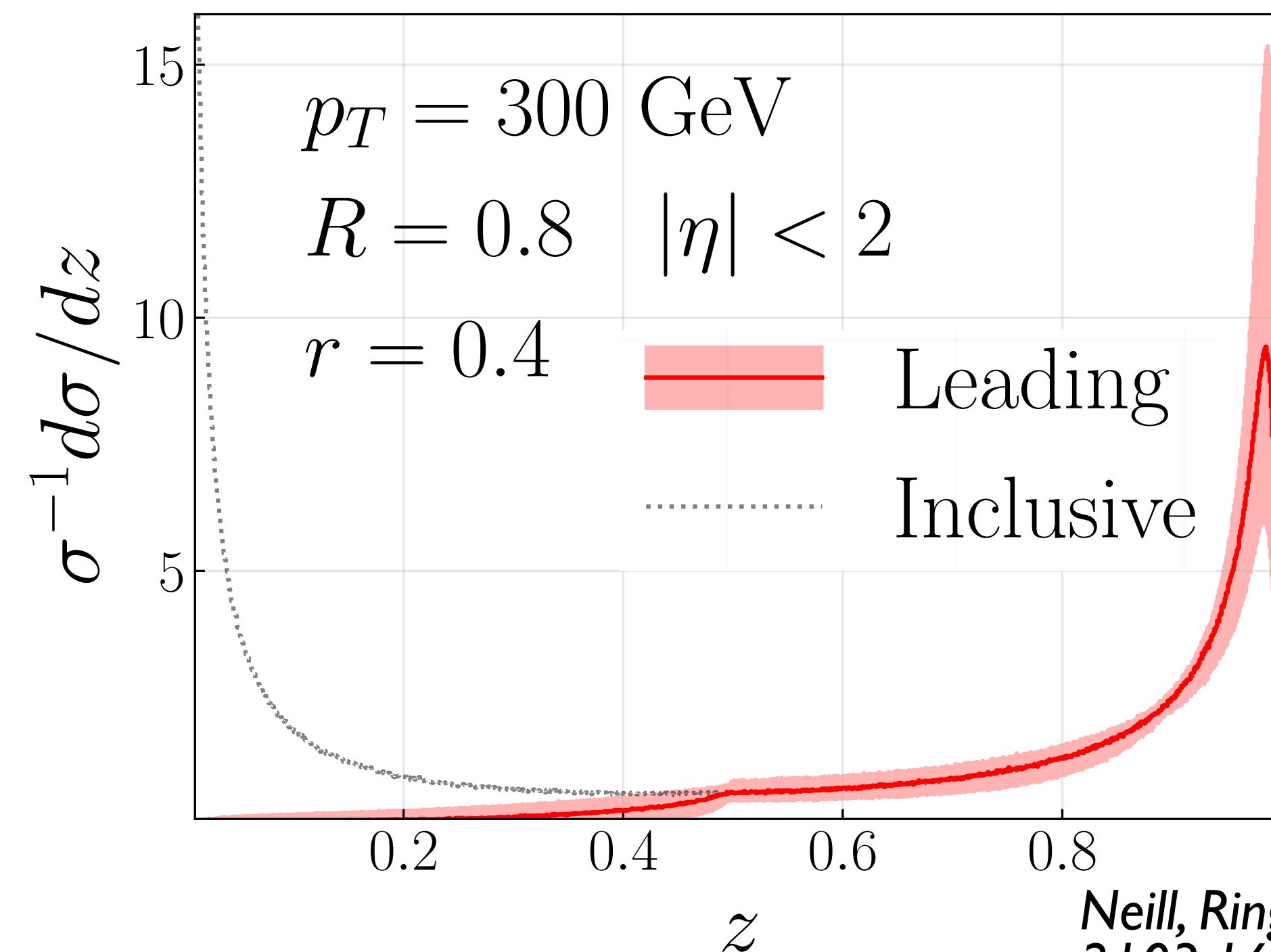
Cluster inclusive jets with radius  $R$ , then recluster with anti- $k_t$  with radius  $r$



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

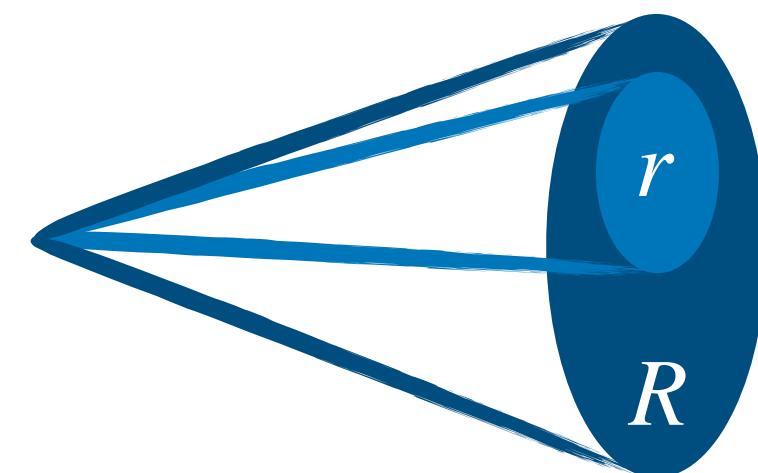
We can then measure either the *inclusive subjets* or the *leading subjets*

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



# Subjet fragmentation — pp

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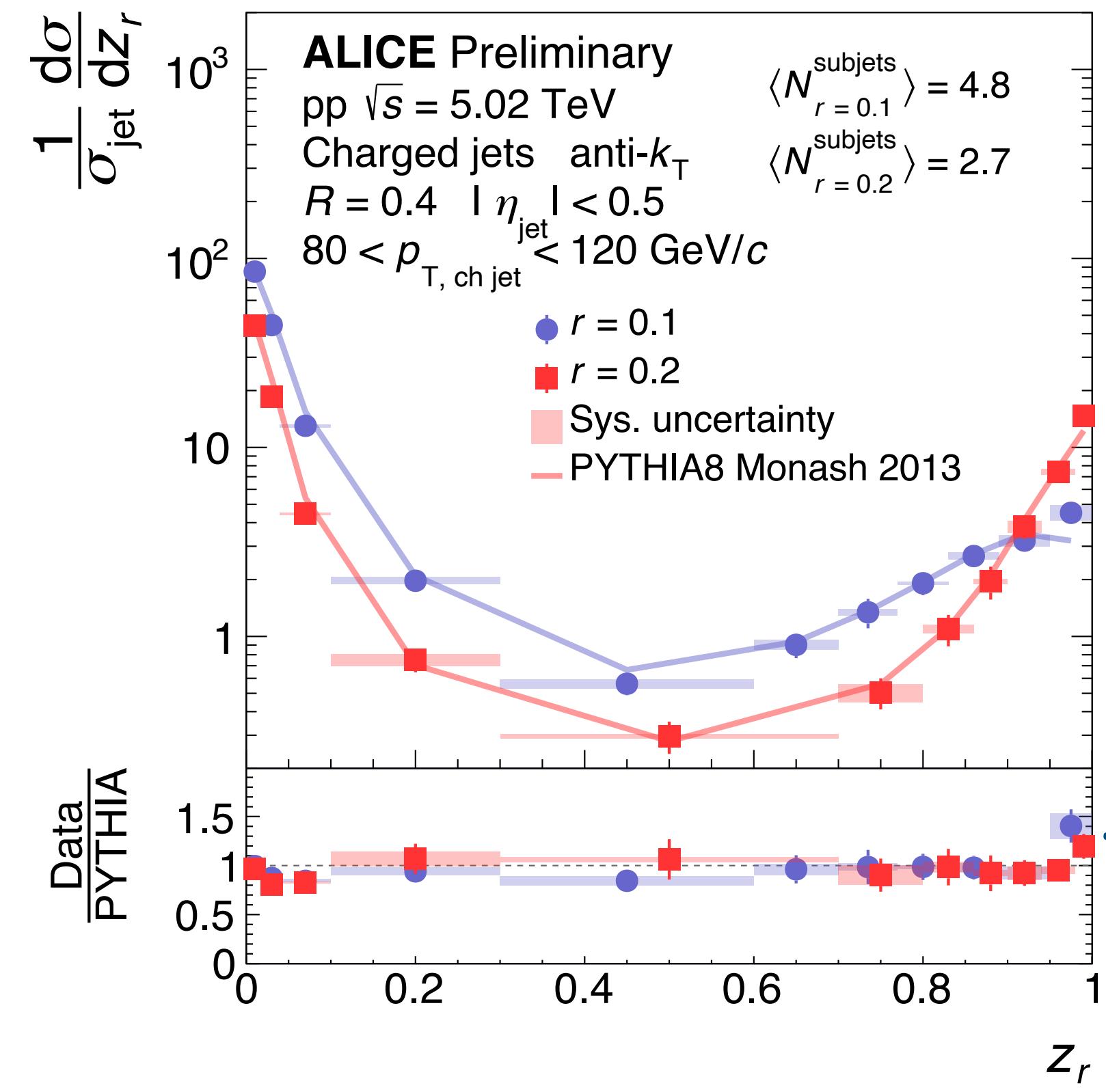
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Generally good agreement with PYTHIA

- Disagreement at large- $z_r$ 
  - threshold resummation?
  - hadronization?

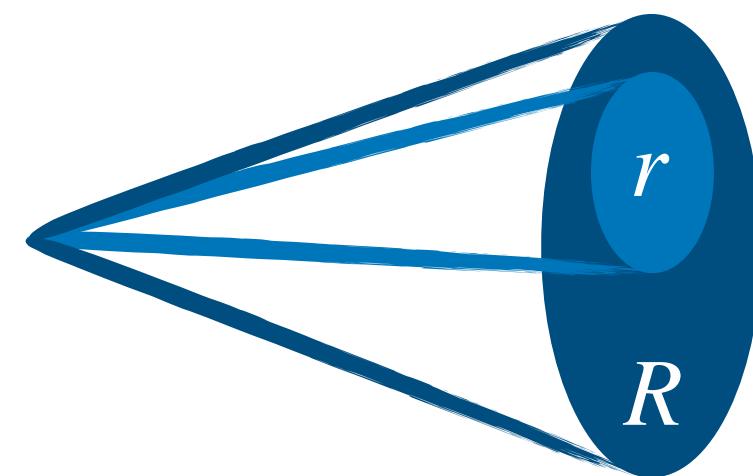
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## Inclusive subjets



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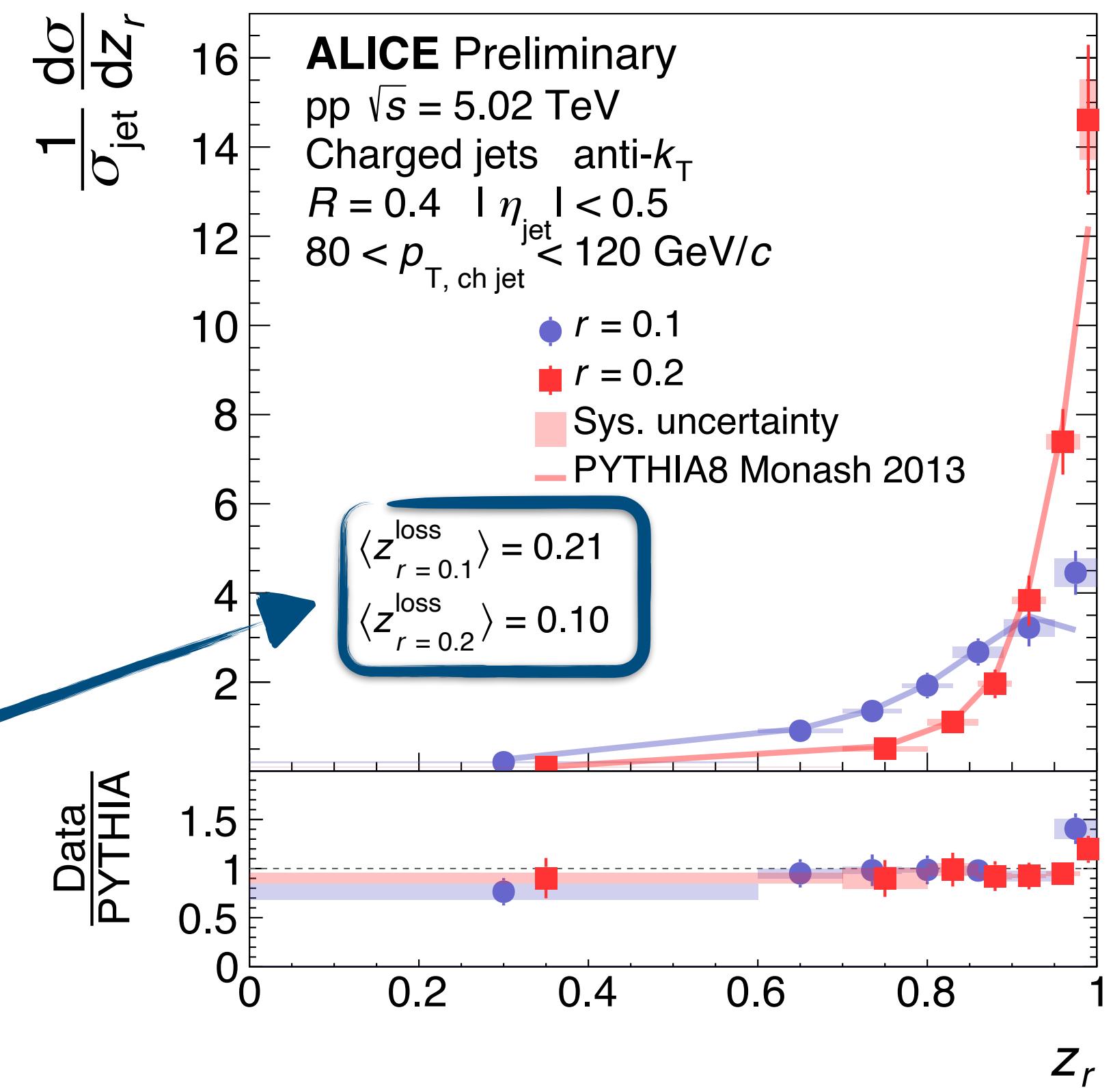
We can then measure either the *inclusive subjets* or the *leading subjets*

We can compute the “energy loss” outside of the leading subjet:

$$\langle z^{\text{loss}} \rangle = 1 - \int_0^1 dz_r z_r \frac{1}{\sigma} \frac{d\sigma}{dz_r}$$

Neill, Ringer, Sato 2103.16573  
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## Leading subjets

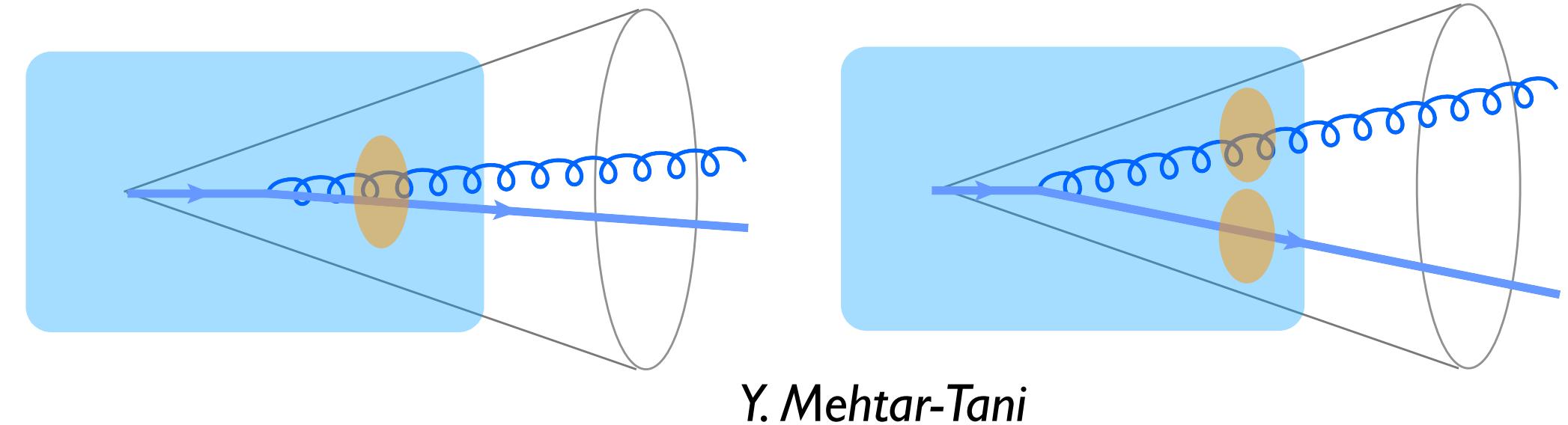


# Jet substructure in heavy-ion collisions



There are many simultaneous unknowns in jet quenching theory:

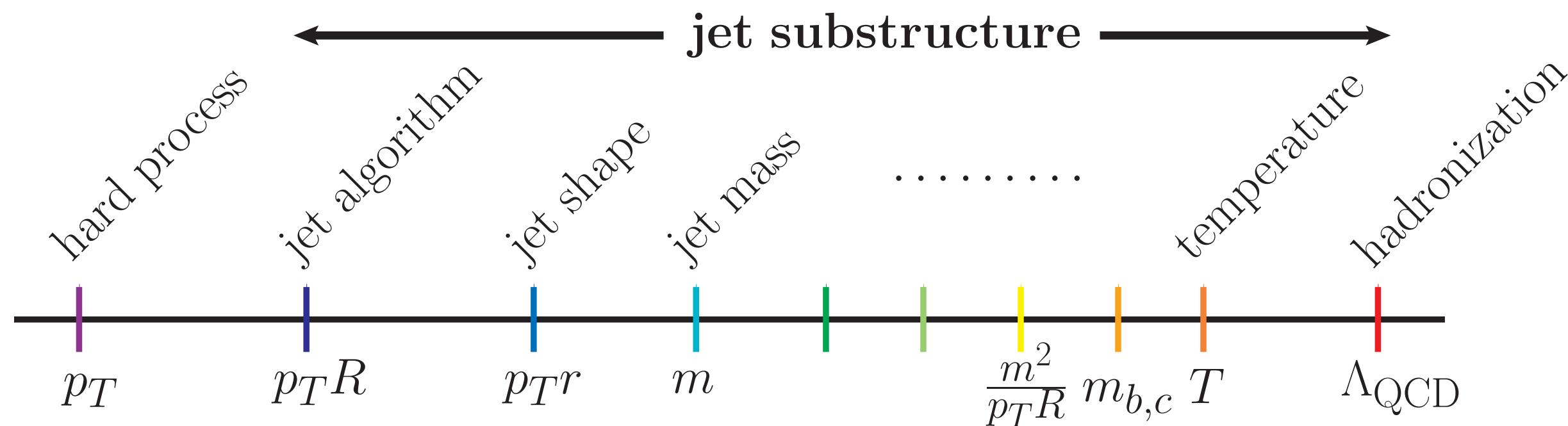
- Strongly-coupled vs. weakly-coupled interaction
- Color coherence
- Spacetime picture of parton shower
- Nature of quasiparticles
- ...



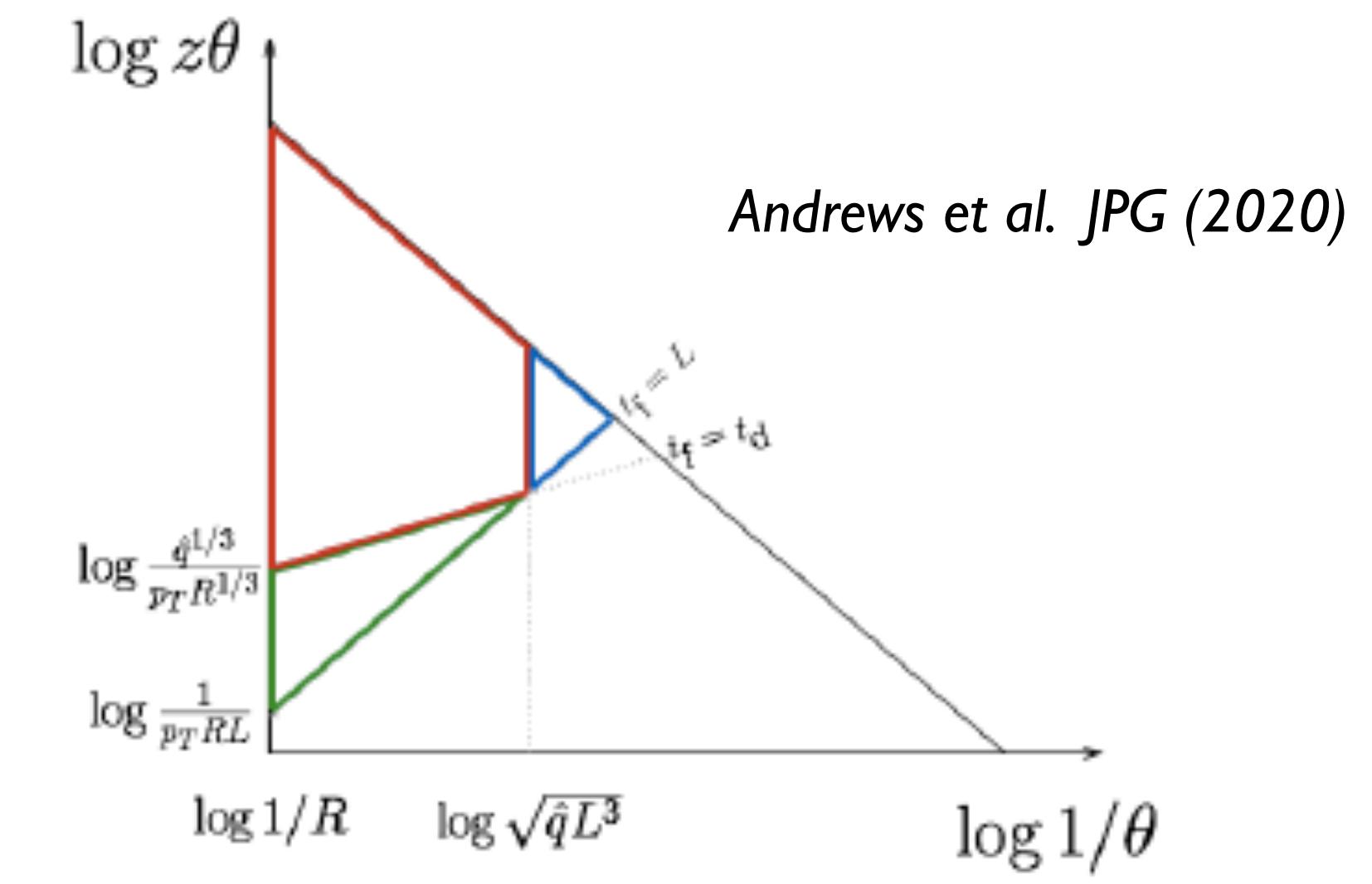
Y. Mehtar-Tani

Jet substructure is an appealing tool to disentangle these

- Target specific regions of phase space



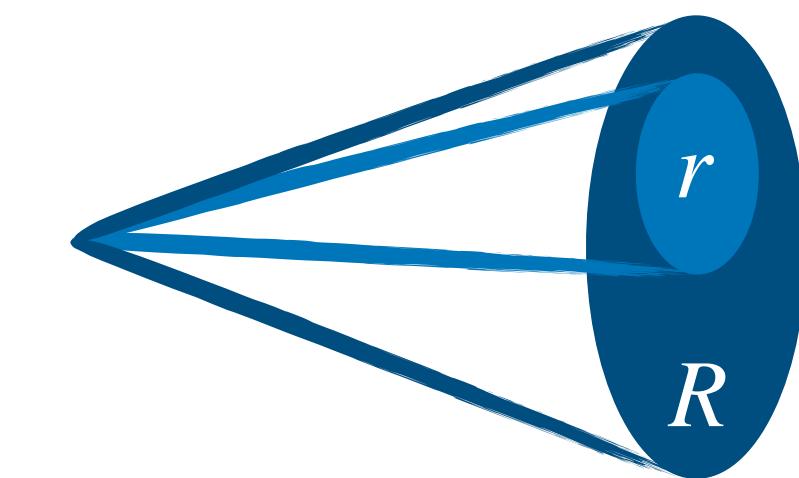
Yang-Ting Chien, QM2018



# Subjet fragmentation — Pb-Pb

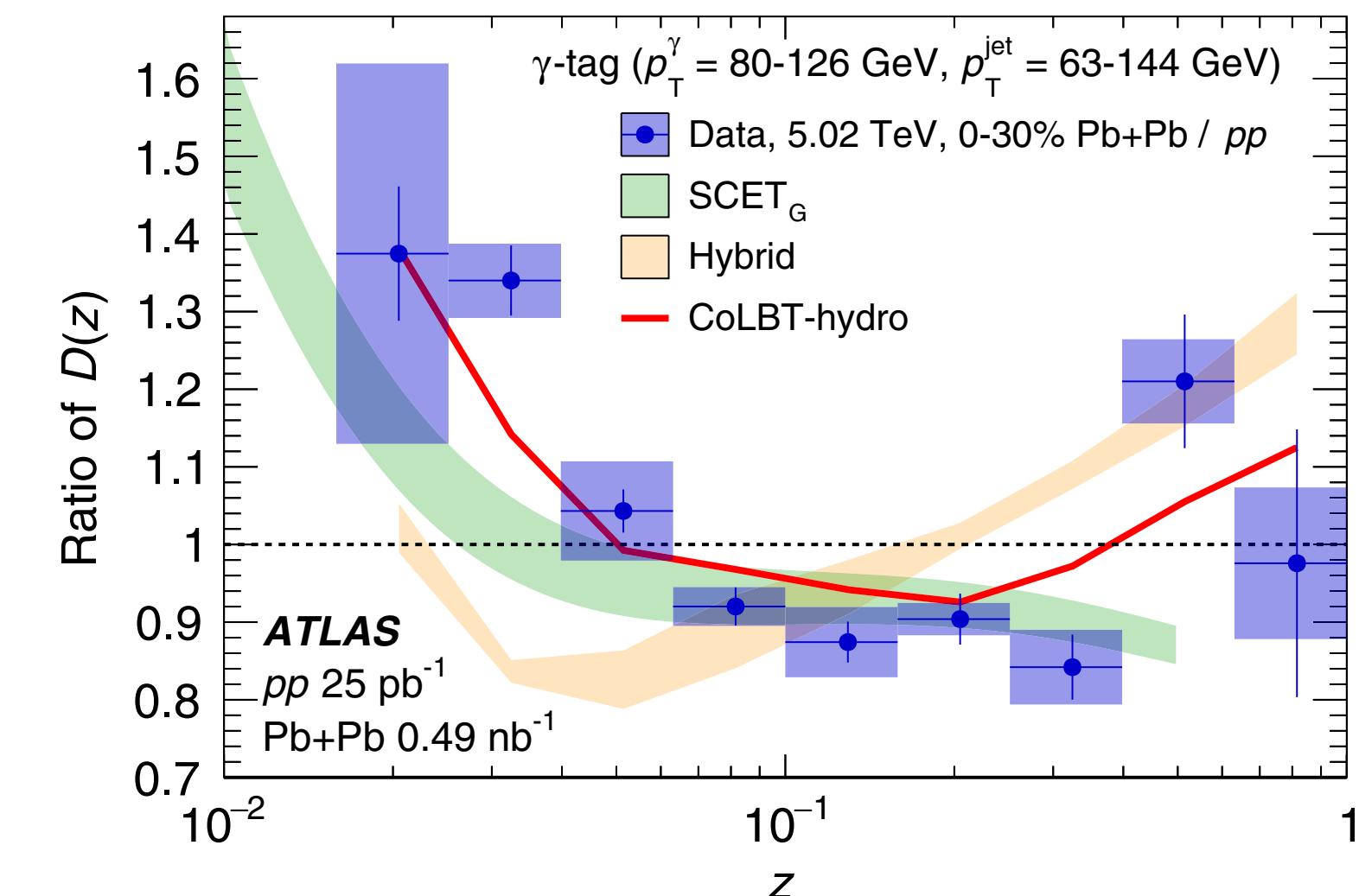
**Measure subjets in heavy-ion collisions to probe jet quenching**

See also: Caucal, Iancu, Mueller, Soyez JHEP 10 (2020) 204  
 Apolinario, Milhano, Ploskon, Zhang EPJC 78 (2018) 6, 529



**Can probe higher  $z$  than hadron fragmentation measurements**

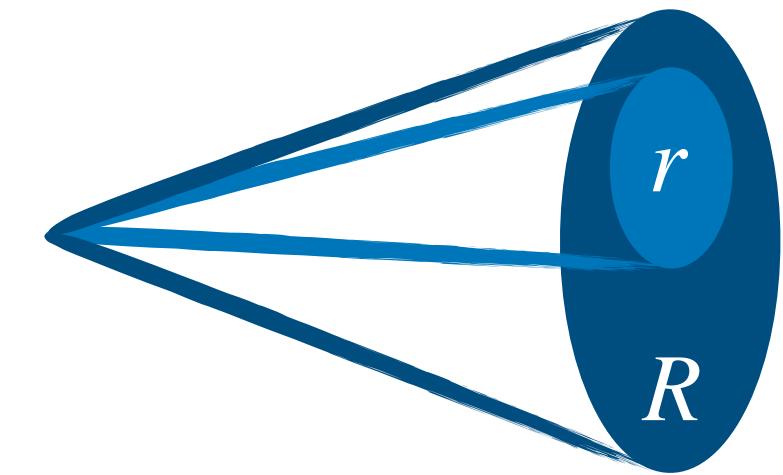
CMS PRC 90 (2014) 2 024908  
 ATLAS PRL 123 (2019) 4 042001



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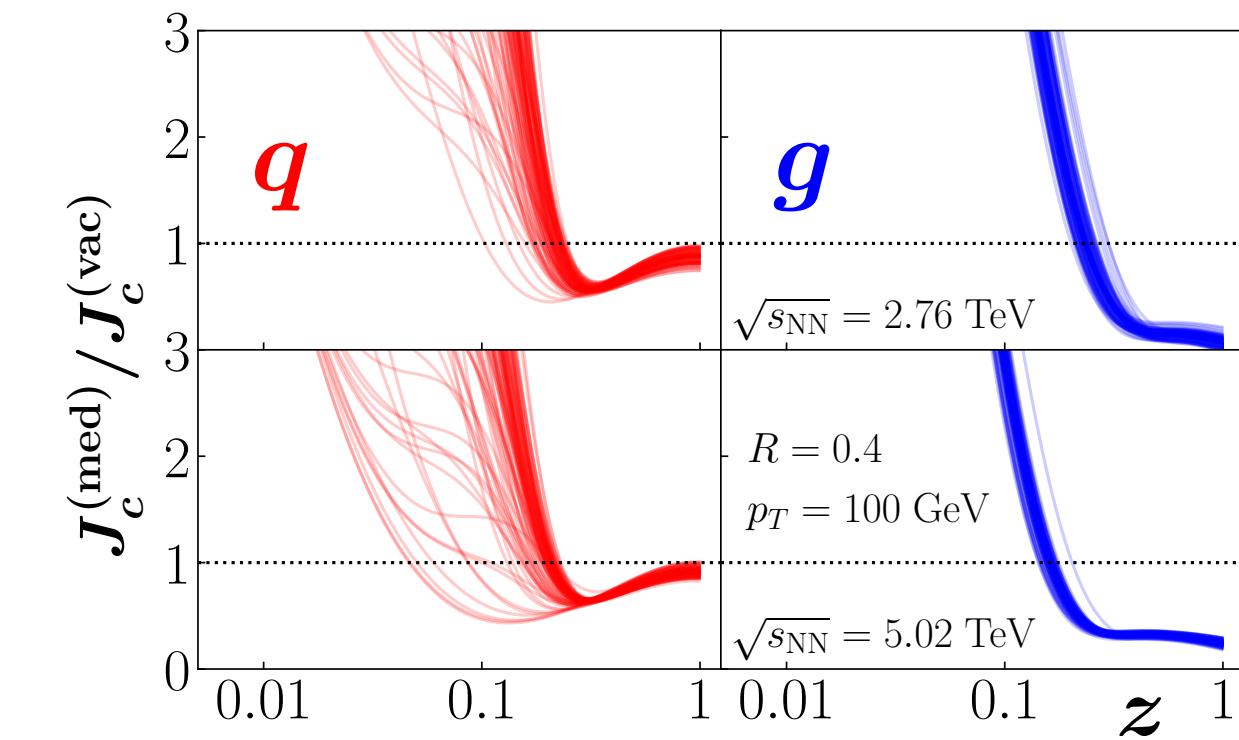
CMS *PRC* 90 (2014) 2 024908  
 ATLAS *PRL* 123 (2019) 4 042001

**Opportunity to test universality of jet fragmentation functions**

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

parton → subjet      parton → jet

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

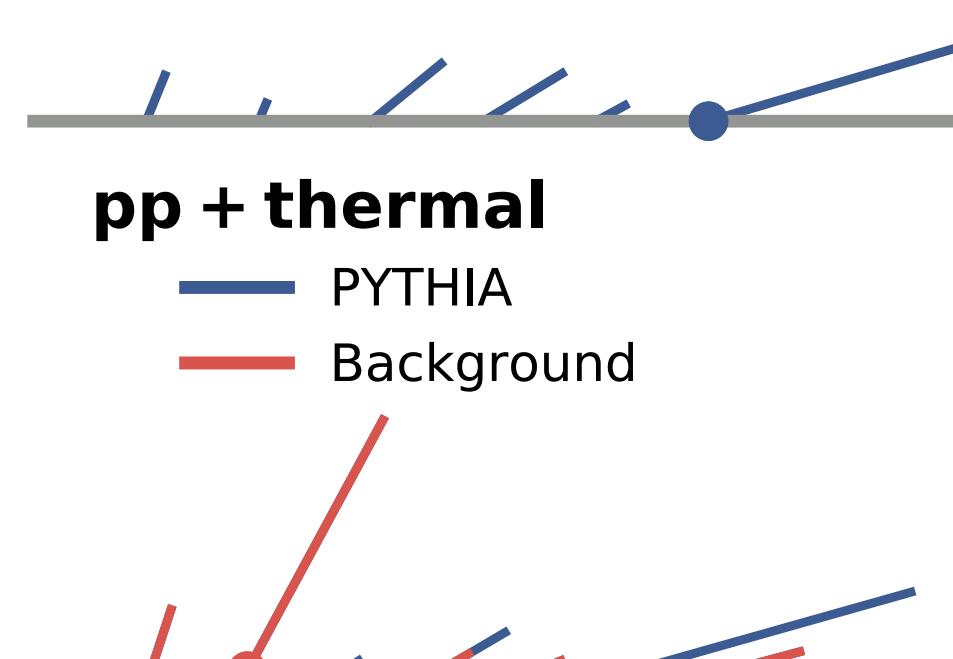


# Experimental challenge: Background

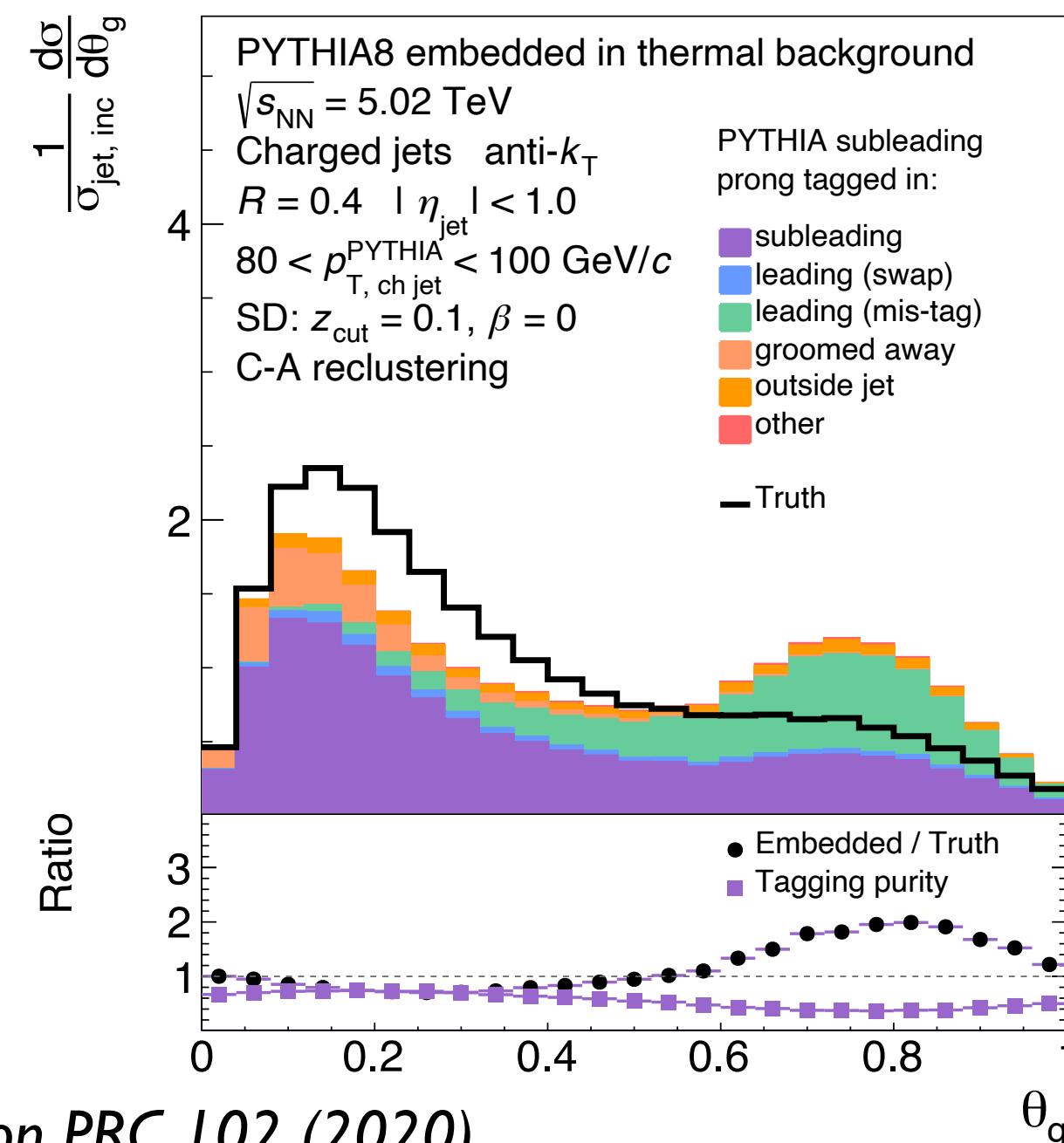
For observables that involve event-by-event tagging, the background can induce mis-tagging

## Example: Soft Drop groomed radius

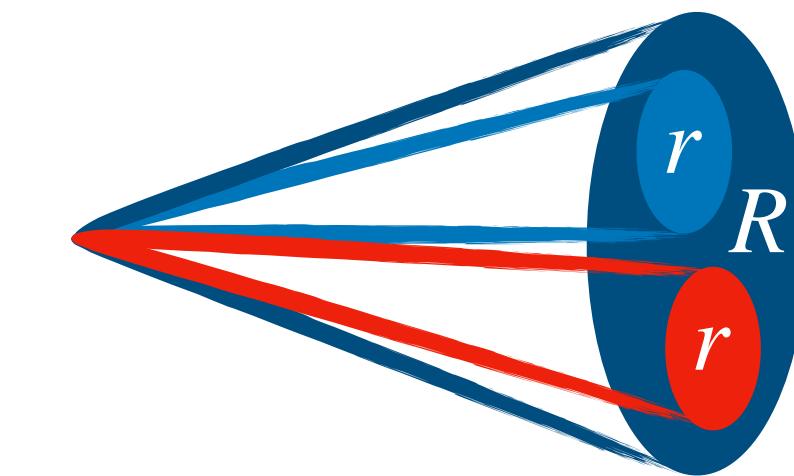
**pp**  
 Soft Drop  $z_{\text{cut}} = 0.1$   
 CA reclustering  
 $p_{\text{T, jet}} = 49 \text{ GeV}/c$



JM, Ploskon PRC 102 (2020)



→ Recommendation: Measure in phase space where tagging purity is high



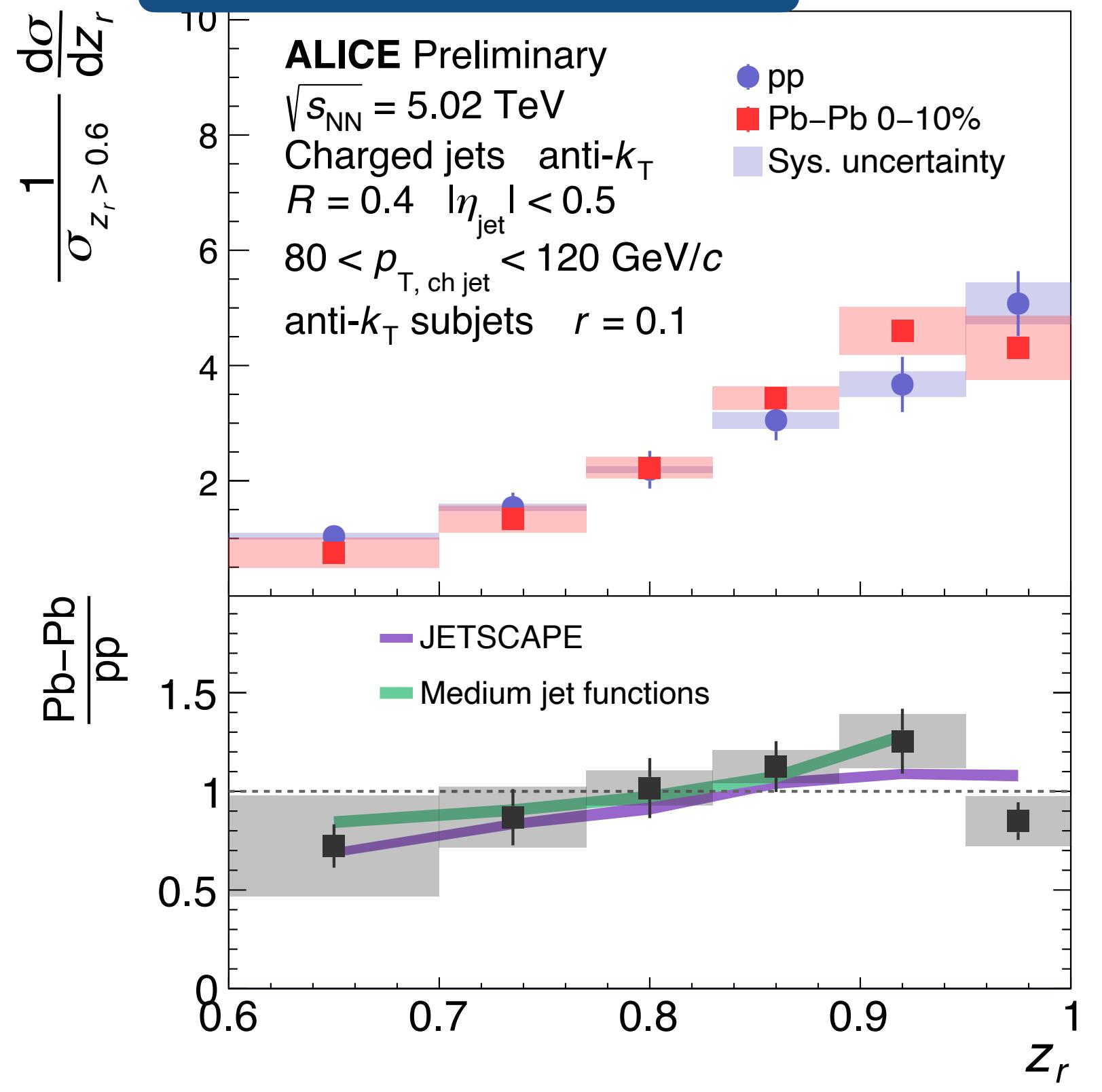
In heavy-ion collisions,  
 we restrict ourselves to  
 measure leading subjets

For  $z_r \gtrsim 0.5$ , the subjet  
 tagging purity remains high

# Subjet fragmentation — Pb-Pb



$R = 0.4, r = 0.1$

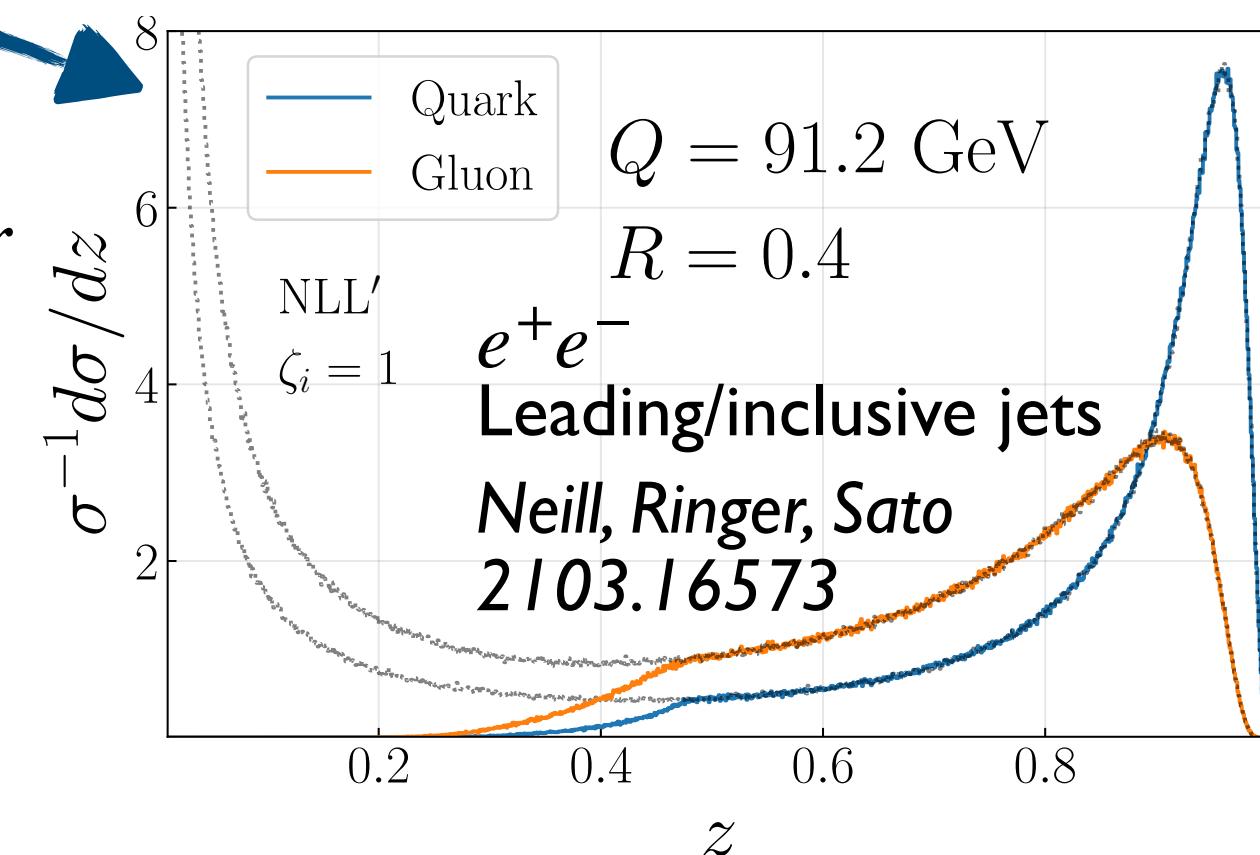


ALI-PREL-490655

# Subjet fragmentation — Pb-Pb

Hardening distribution at intermediate  $z_r$

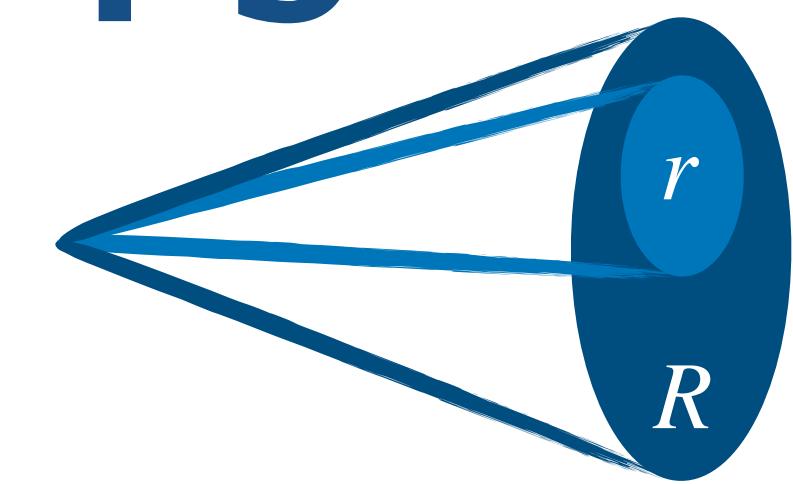
- Large quark-gluon differences in vacuum
- Competing effects?
  - Gluon suppression → larger  $z_r$
  - Soft radiation → smaller  $z_r$



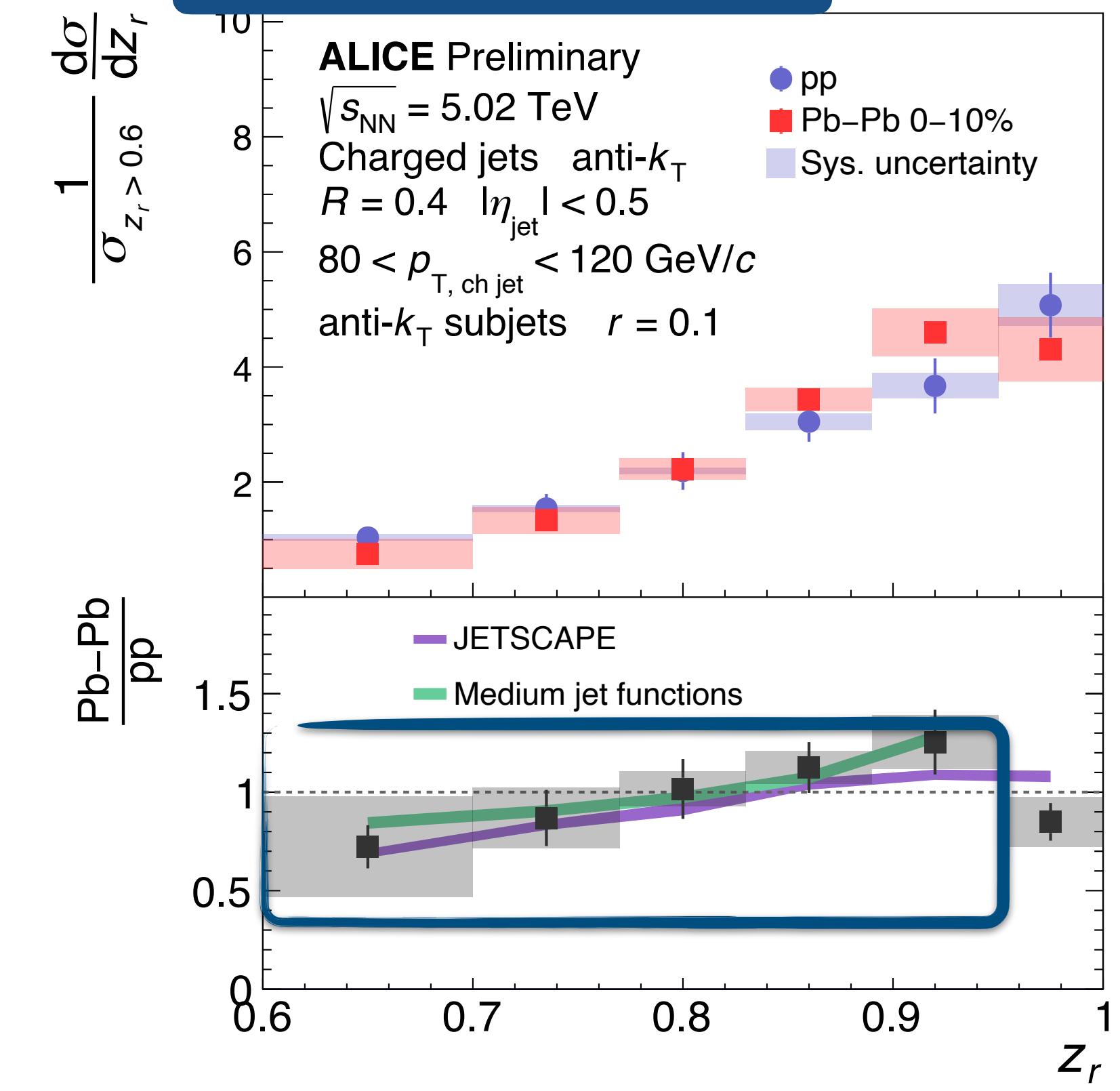
Well-described by theoretical predictions

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

*Qiu, Ringer, Sato, Zurita PRL 122 (2019) 25*  
*Neill, Ringer, Sato 2103.16573*  
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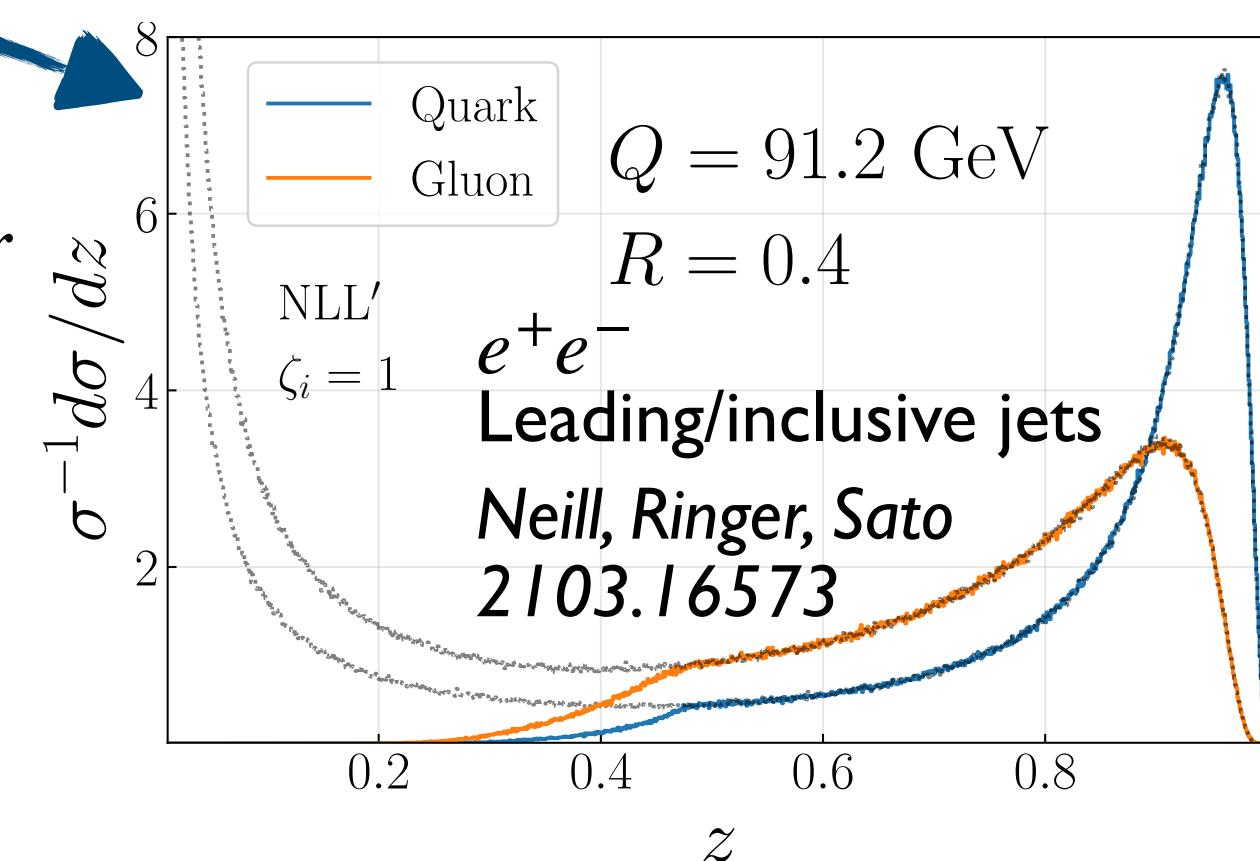
$$R = 0.4, r = 0.1$$



# Subjet fragmentation — Pb-Pb

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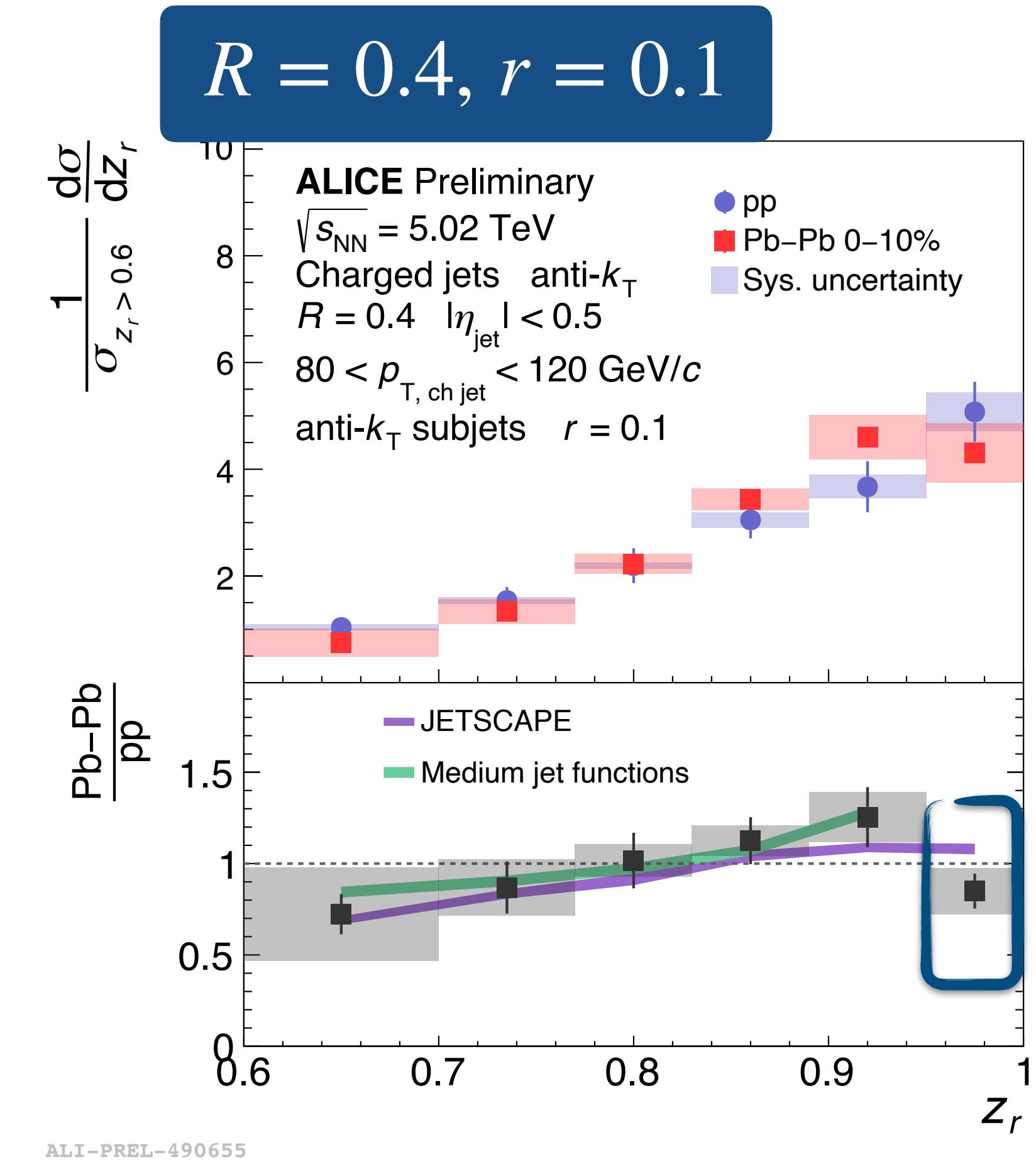
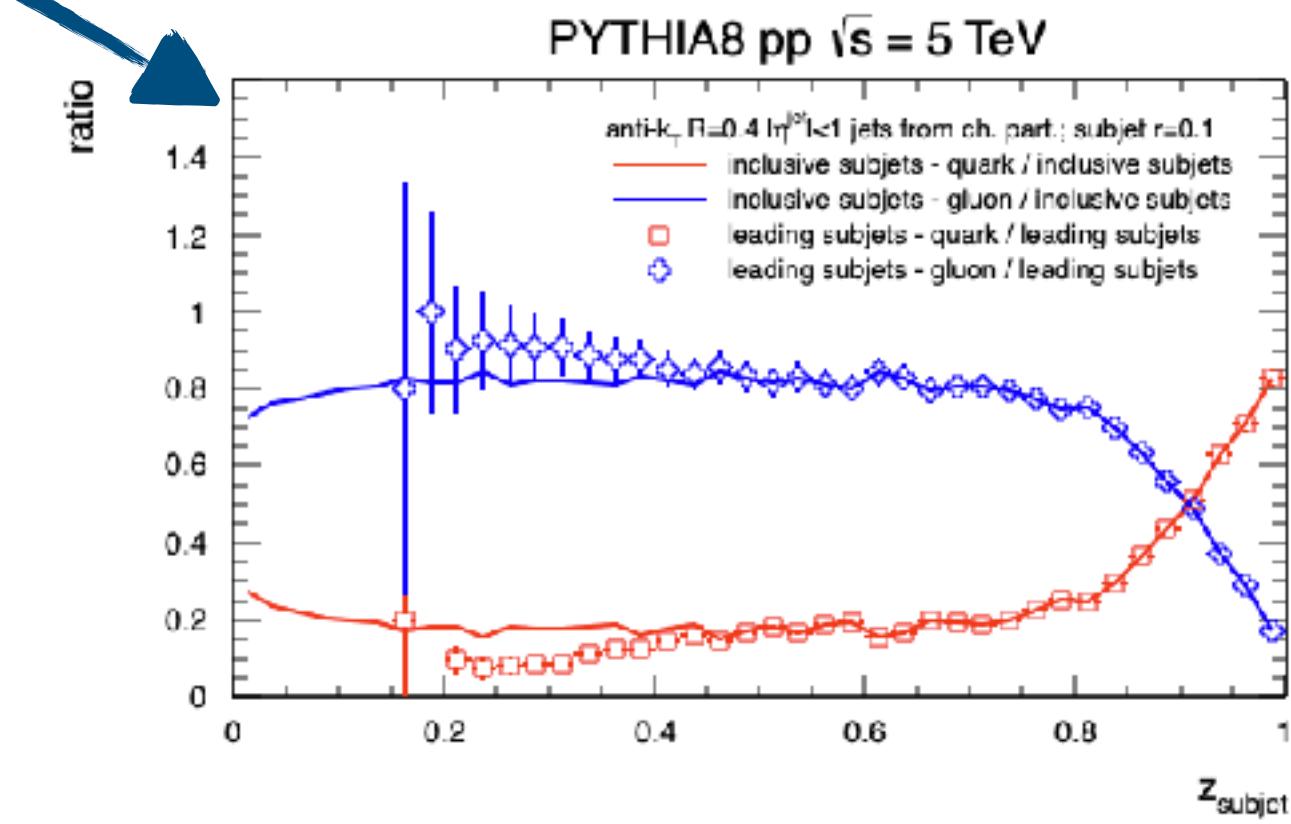
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- Competing effects?
  - Gluon suppression  $\rightarrow$  larger  $z_r$
  - Soft radiation  $\rightarrow$  smaller  $z_r$



Hint of suppression as  $z_r \rightarrow 1$

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

New path to disentangle quenching effects



# Summary

## New ALICE measurements of subjet fragmentation in proton-proton and heavy-ion collisions

- pp: Test pQCD — threshold resummation, hadronization
- AA: Probe jet quenching — high- $z$ , universality

By measuring to large  $z_r$ , we isolate a region dominated by quark jets, and begin to expose the region depleted by medium-induced soft splitting

- Complementary to recent measurements of hard splitting ( $z_g, \tau_N$ ) and collimation ( $\theta_g$ )
- Provides opportunity to disentangle competing jet quenching mechanisms