Jet substructure measurements in Pb-Pb collisions with ALICE

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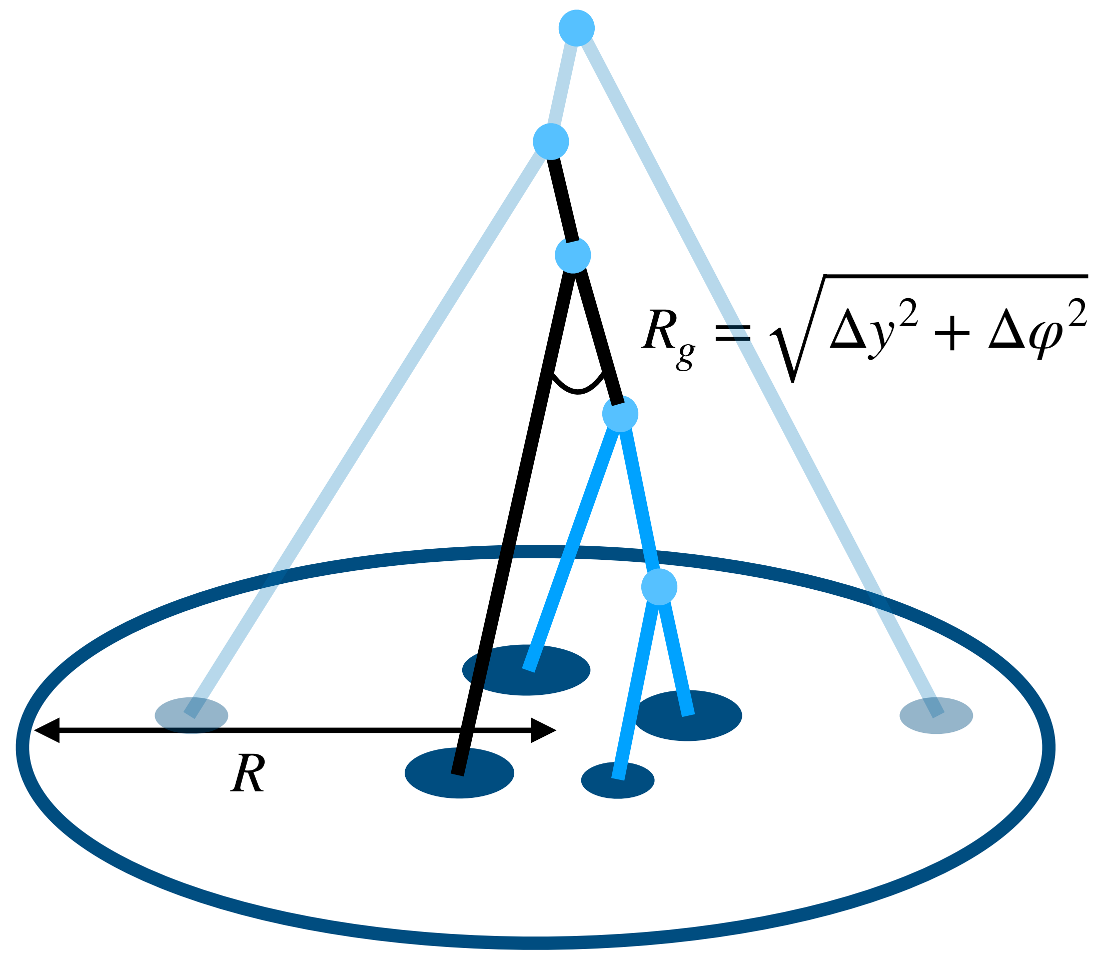
Jet Substructure

A powerful class of observables

Sensitive to a wide span of scales

Provide complementary information to disentangle multiple QCD effects

Many are analytically calculable from pQCD



Groomed jet substructure

Recluster and groom jet to expose hard splitting

Soft Drop: $z < z_{\mathrm{cut}}\theta^{\beta}$

Dasgupta, Fregoso, Marzani, Salam 1307.0007
Larkoski, Marzani, Soyez, Thaler 1402.2657
Larkoski, Marzani, Thaler 1502.01719

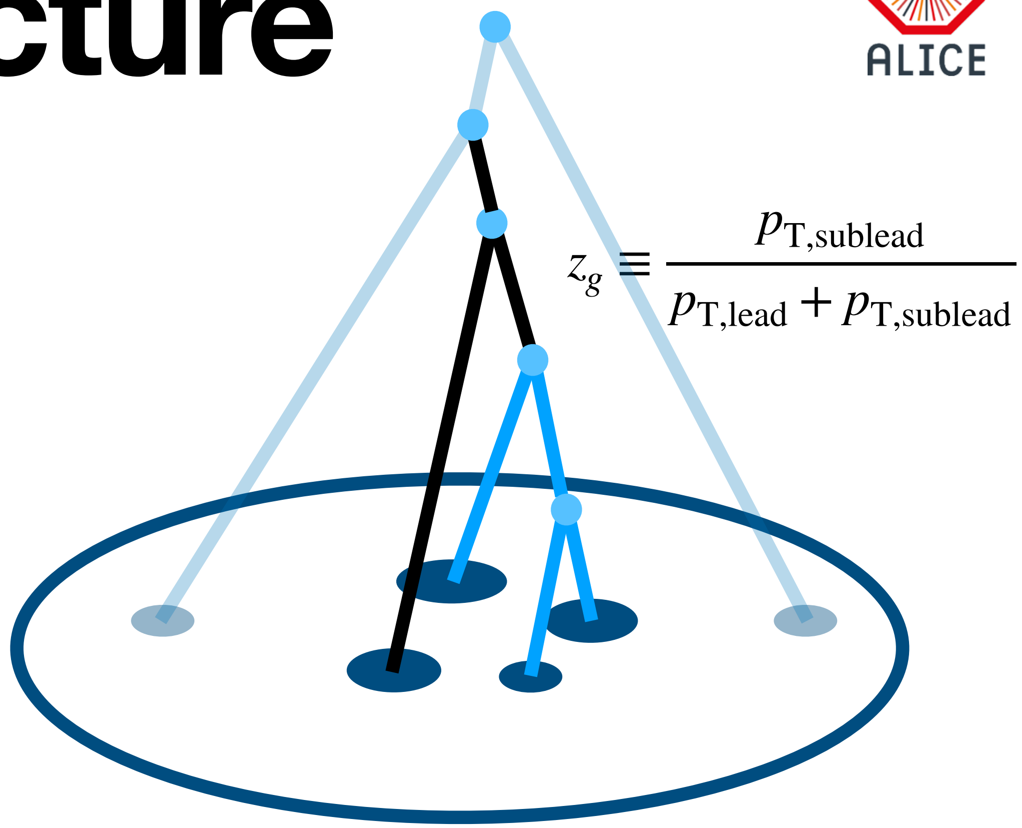
$$\theta_g \equiv \frac{R_g}{R}$$

Theoretical control: Isolate a pQCD-dominated, calculable observable in the complicated heavy-ion environment

Identifies quantities related to the **ordering of hard splittings in parton showers**, which may give us a handle on pathlength/coherence effects in AA

Groomed jet substructure

Groomed jet momentum fraction, z_g

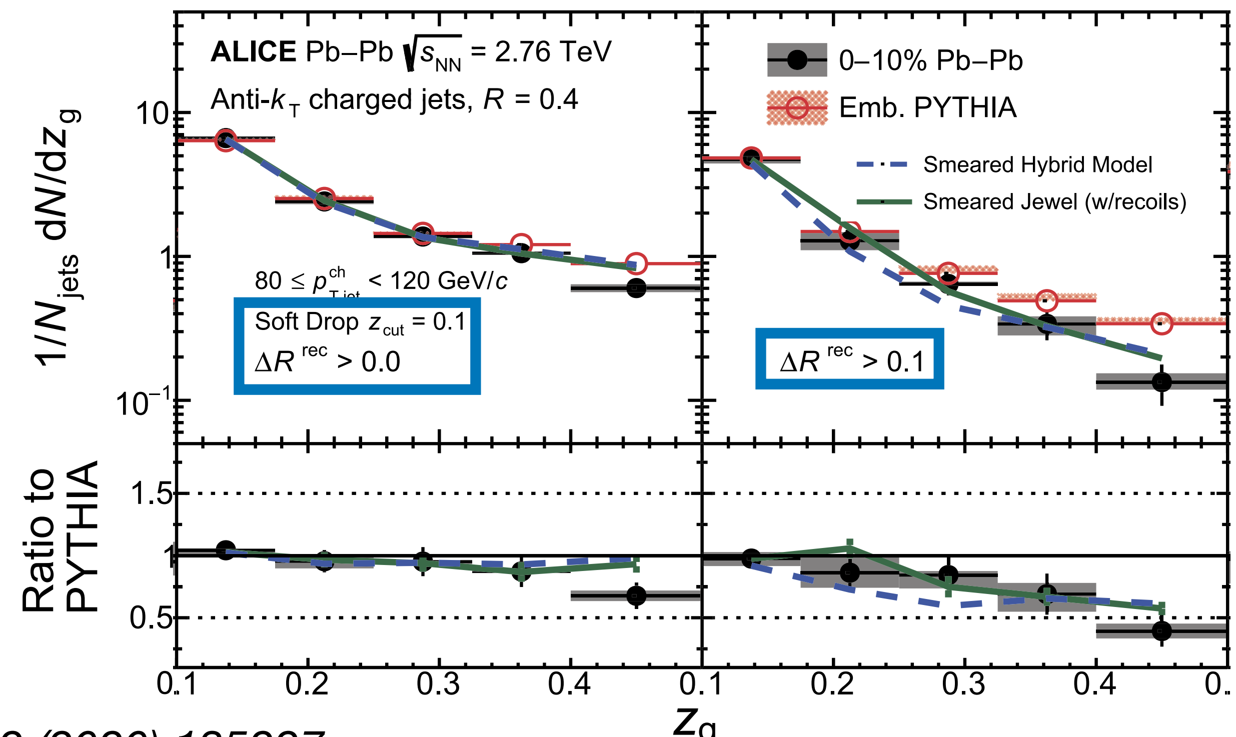


Modification of splitting function?
Coherent vs. incoherent energy loss?

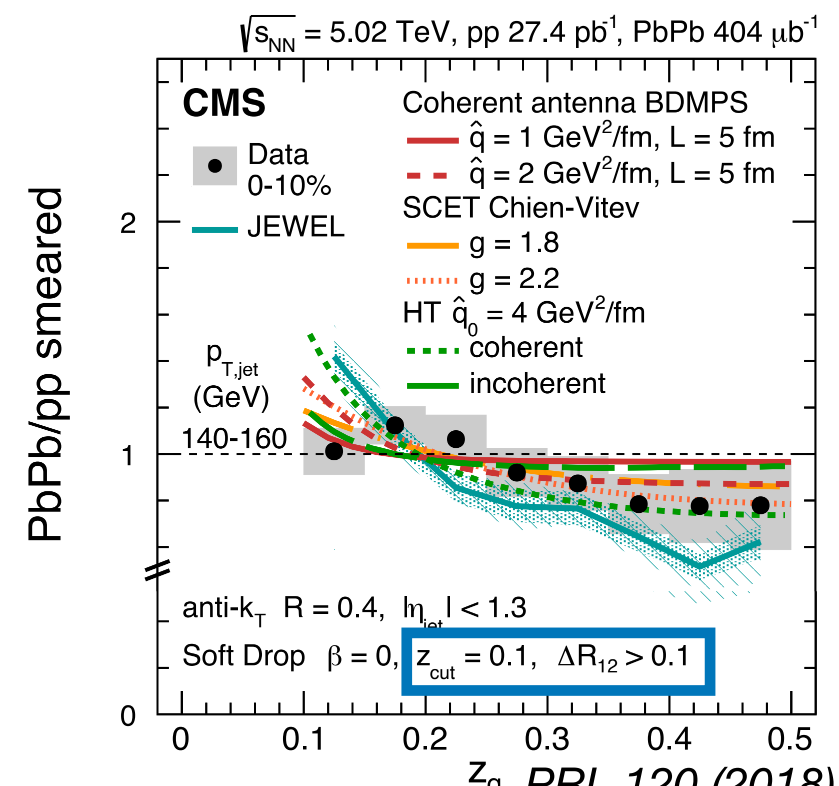
Previous measurements:

Slight suppression when integrated over ΔR

Larger suppression when integrated over $\Delta R > R_{min}$



PLB 802 (2020) 135227



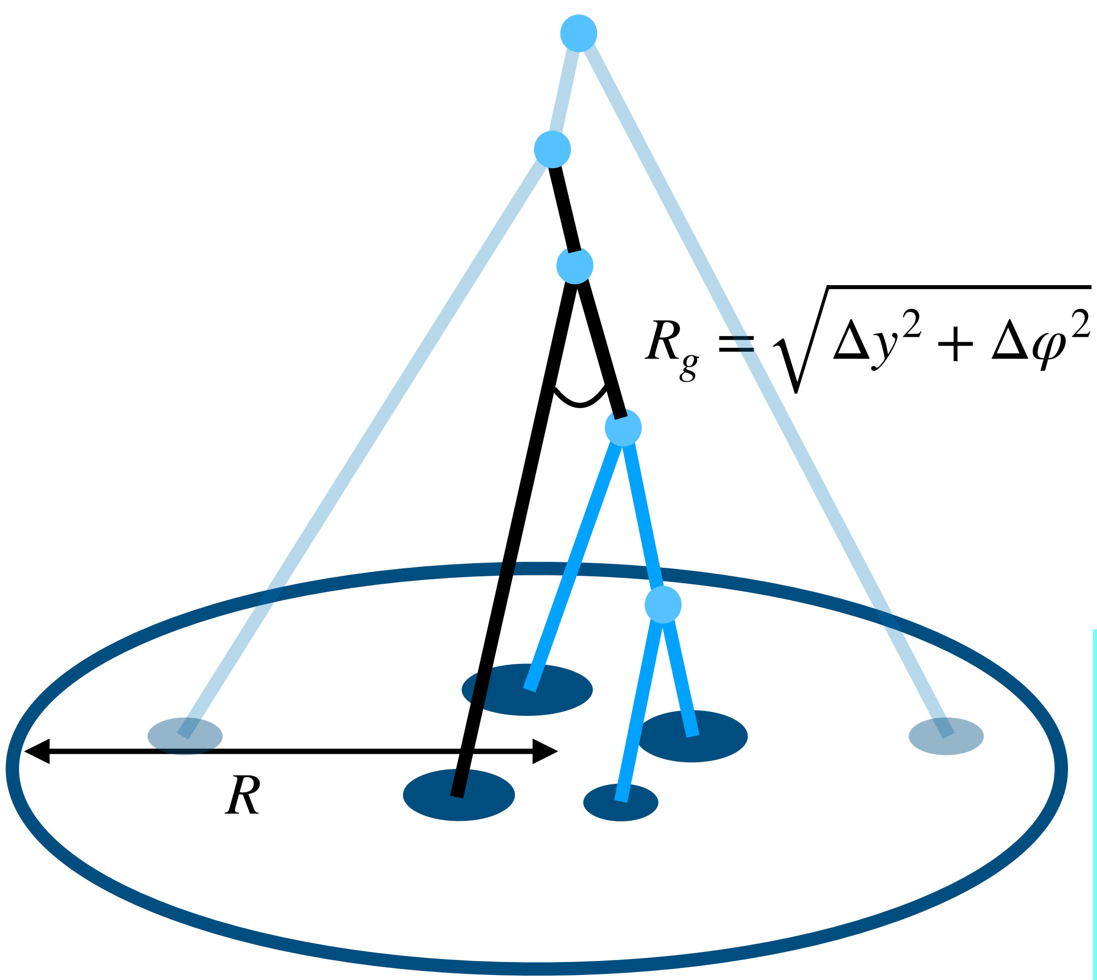
PRL 120 (2018) 142302

Never unfolded in heavy-ion collisions

Also: STAR NPA 967 (2017)

Groomed jet substructure

Groomed jet radius, θ_g



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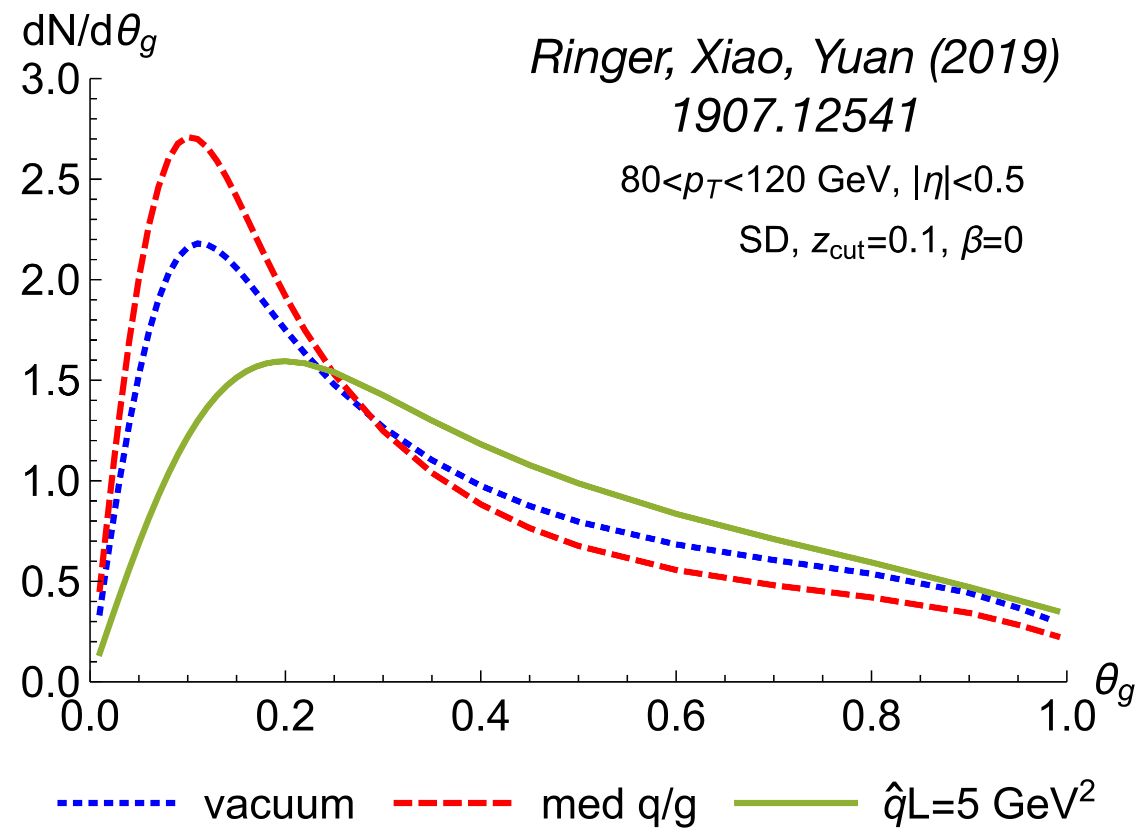


Medium-induced gluon radiation ($\hat{q}$) broadens jets

Energy loss narrows jets

q-g fractions, coherent vs. incoherent energy loss

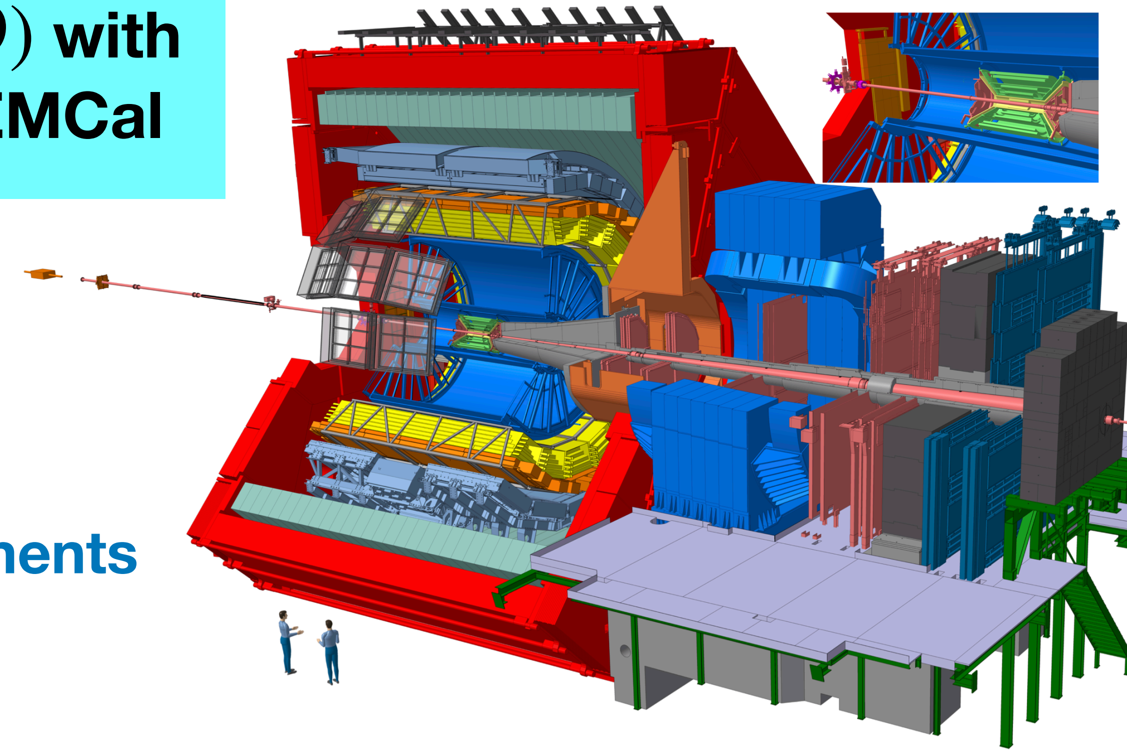
And more, e.g. $t_f \sim 1/\theta_g^2$ affects path-length

→ **Disentangle and constrain these effects**

Never measured in heavy-ion collisions

Jets in ALICE

ALICE reconstructs jets at mid-rapidity $(|\eta| < 0.9)$ with a high-precision tracking system (ITS+TPC) and EMCal



Charged particle jets

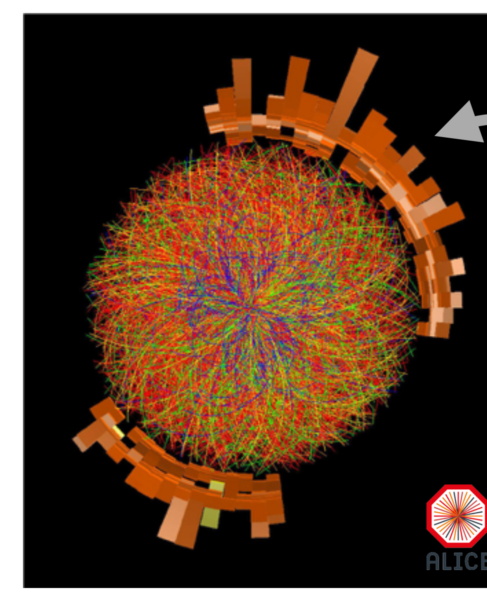
- Pro: High-precision spatial resolution to resolve particles; Experimentally simpler

→ **Ideal for precise jet substructure measurements**

- Con: Additional modeling to compare to theory

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

- Pro: Direct comparison to theory
- Con: Significant experimental complication; Limited EMCal coverage



EMCal φ acceptance: 107°

ALICE is very good for:

- Jet substructure
- Low-p_T tracks: 150 MeV/c
- Particle Identification

ALICE is not so good for:

- High statistics
- High p_T > ~100 GeV/c
- Jets at forward/backward rapidity

ALICE

pp collisions

Dynamical grooming: z_g, θ_g

Jet angularities: λ_β

Dataset:

$\sqrt{s} = 5.02$ TeV

$\mathscr{L}_{\text{int}} = 18.0 \text{ nb}^{-1}$

Unfolded distributions

Dynamical grooming

Y. Mehtar-Tani, A. Soto-Ontoso, and K. Tywoniuk
PRD 101 (2020) 034004
2005.07584 (2020)

Alba Soto Ontoso
Wed 11:10

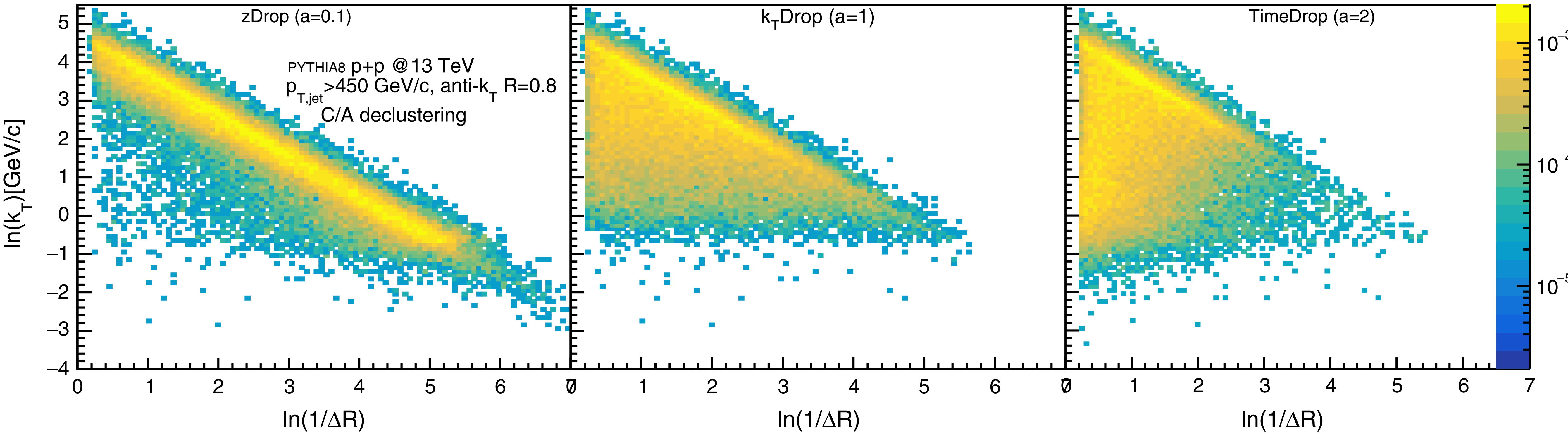
ALICE

Identify splitting in C/A tree as the **maximum** of a particular grooming condition:

$$z_i(1 - z_i)p_{T,i}\theta_i^a$$

$a \to 0$	hardest z	$z_{cut} \approx e^{-a\pi/\alpha_s C_F}$
$a = 1$	hardest k_T	$\ln k_t \approx -\sqrt{a}$
$a = 2$	smallest t_f	$\ln k_t(R_{\rm jet}) \approx -\sqrt{a}$

Similar to Soft Drop — except grooming condition varies jet-by-jet

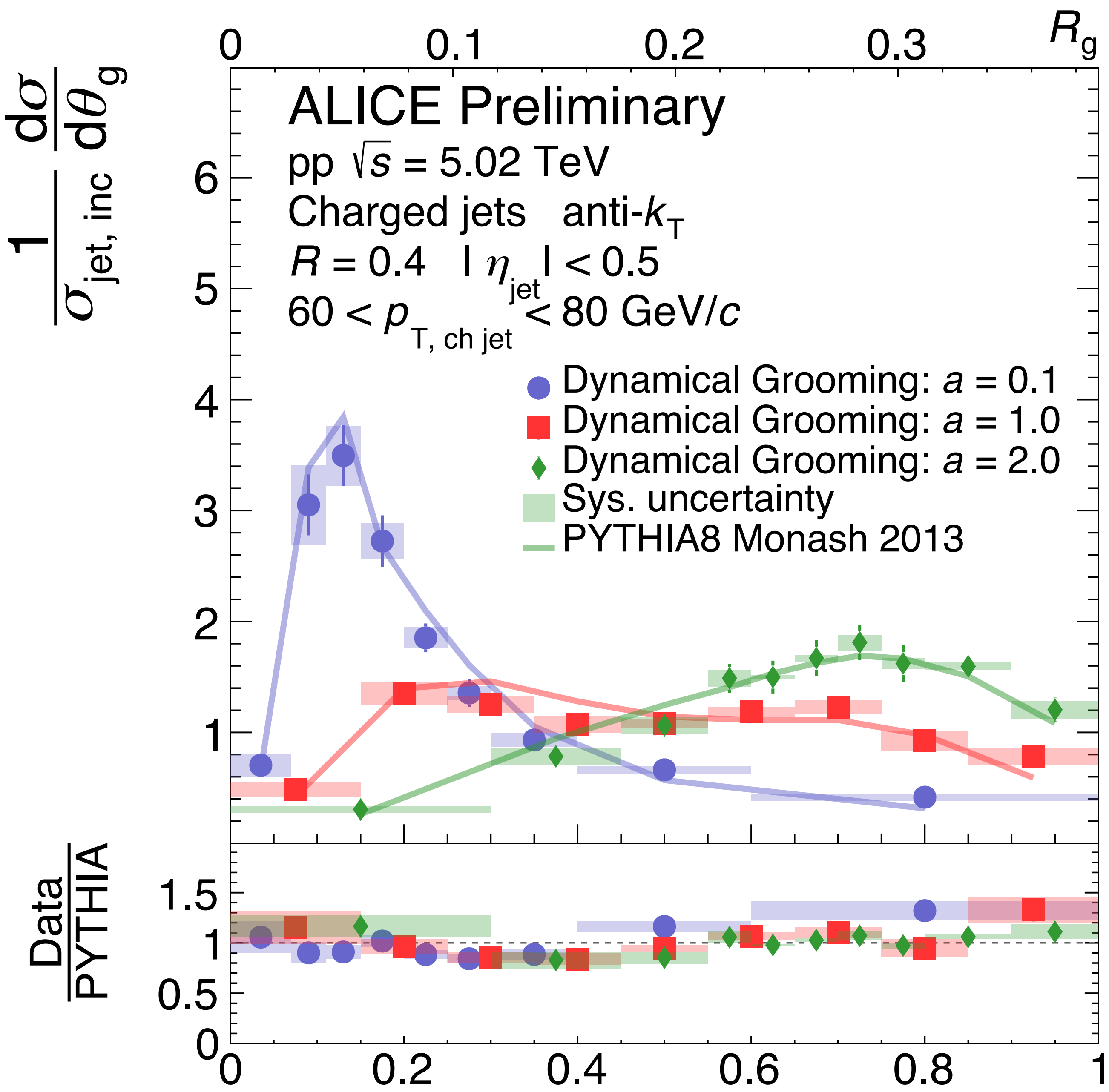


Results — Dynamical Grooming

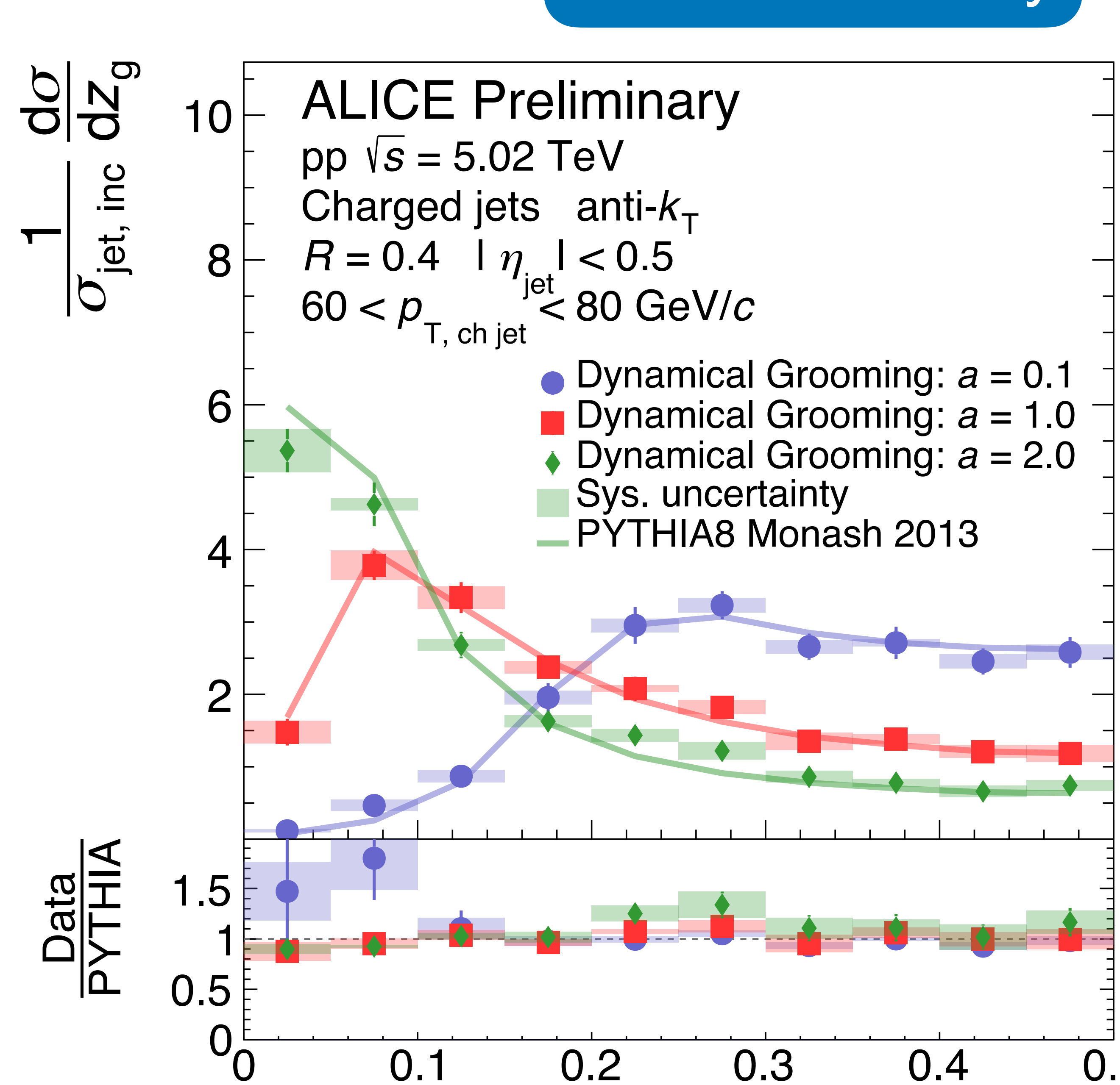
proton-proton

Y. Mehtar-Tani, A. Soto-Ontoso, and K. Tywoniuk
PRD 101 (2020) 034004

New Preliminary



Larger a → Larger θ



Smaller a → Larger z

First measurement of Dynamical Grooming → Well described by PYTHIA

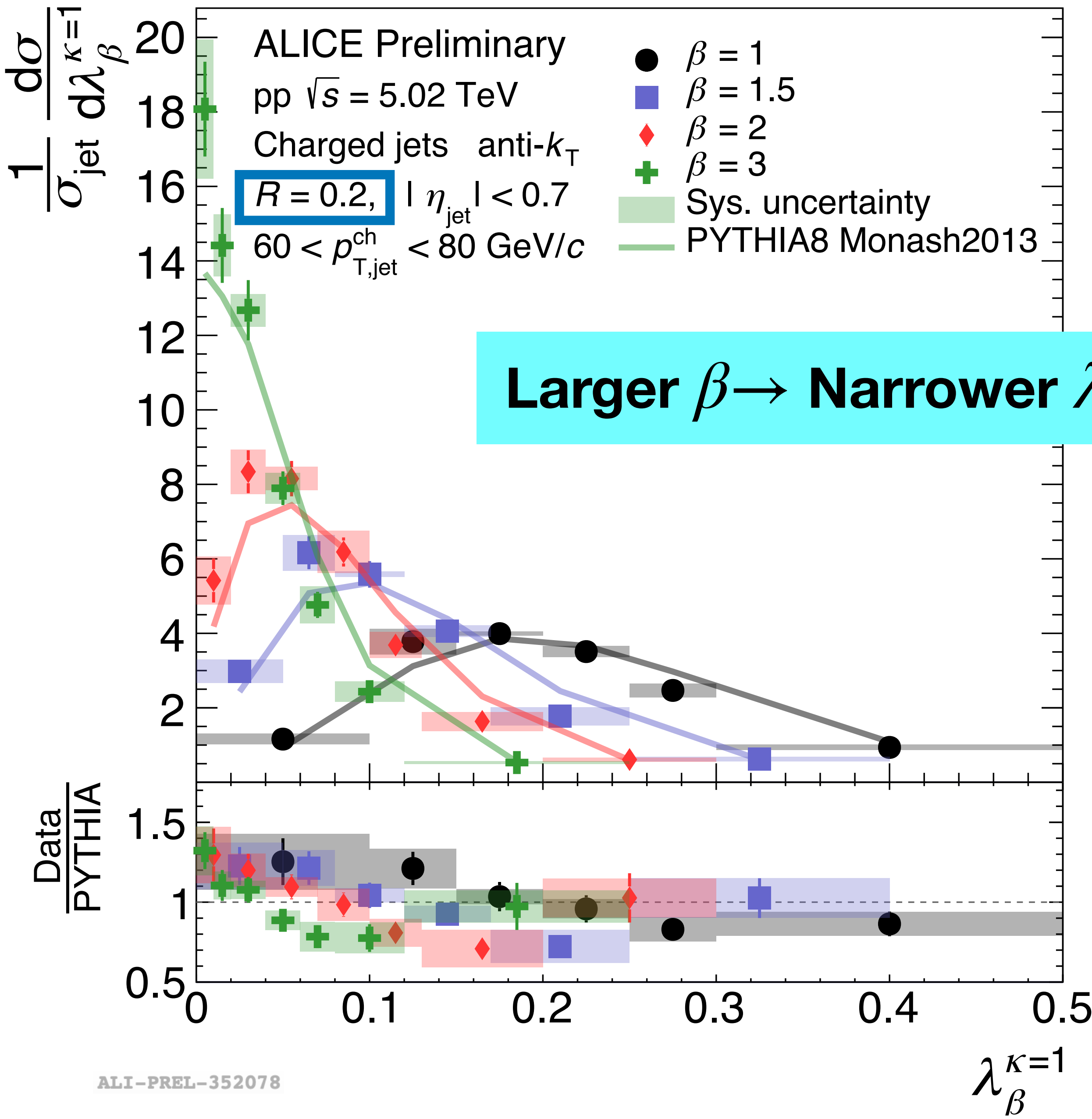
Results — Jet angularities

proton-proton

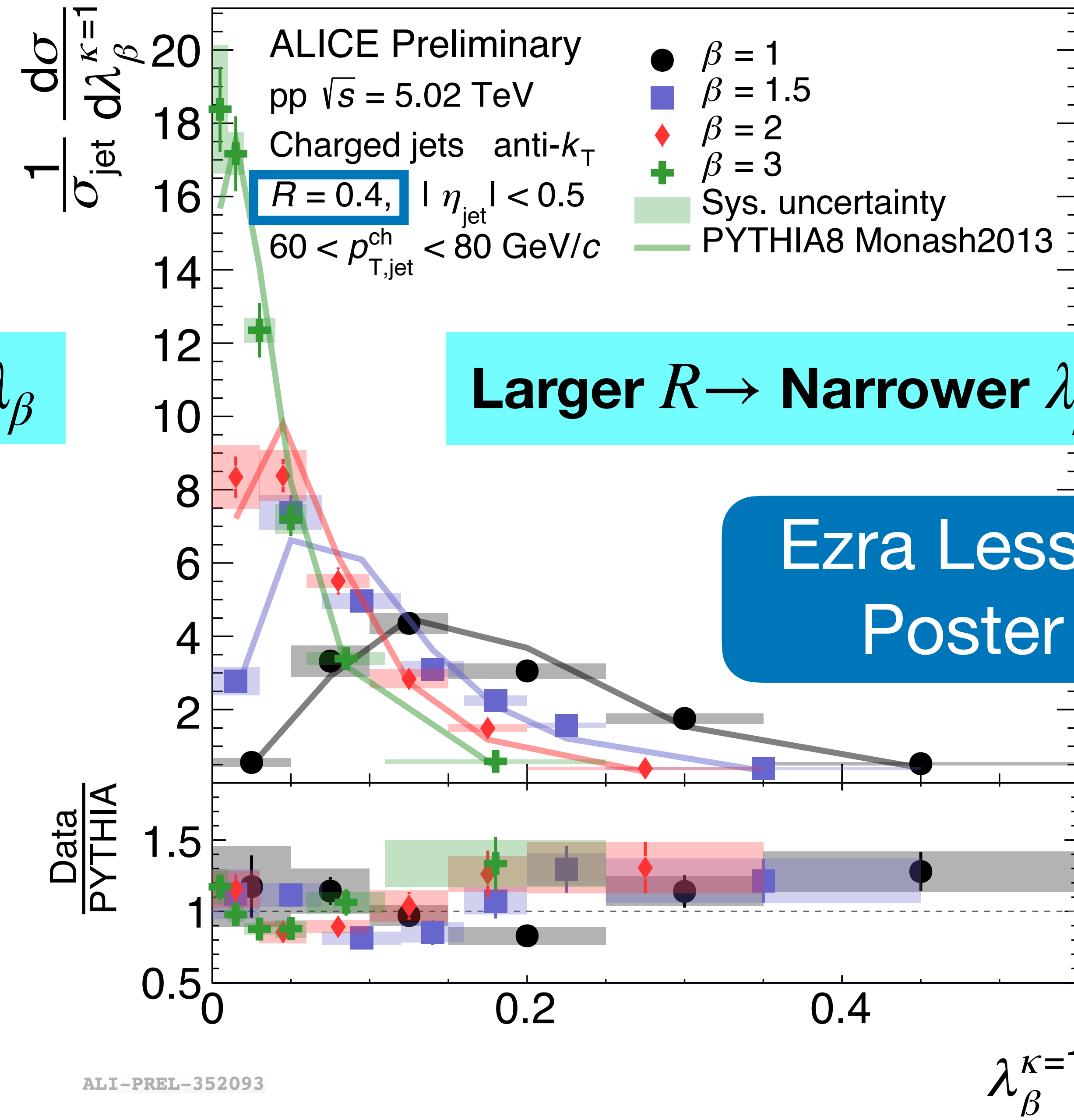
$$\lambda_\beta^\kappa \equiv \sum_{i \in \text{jet}} \left(\frac{p_{T,i}}{p_{T,\text{jet}}}\right)^\kappa \left(\frac{\Delta R_{jet,i}}{R}\right)^\beta$$

New Preliminary

Measurements for multiple R, β systematically ⟶ test pQCD predictions



Larger $\beta \rightarrow$ Narrower λ_β



Larger $R \rightarrow$ Narrower λ_β

Ezra Lesser Poster

Reasonably well-described by PYTHIA

Pb-Pb collisions

Soft Drop: z_g, θ_g

Dataset:

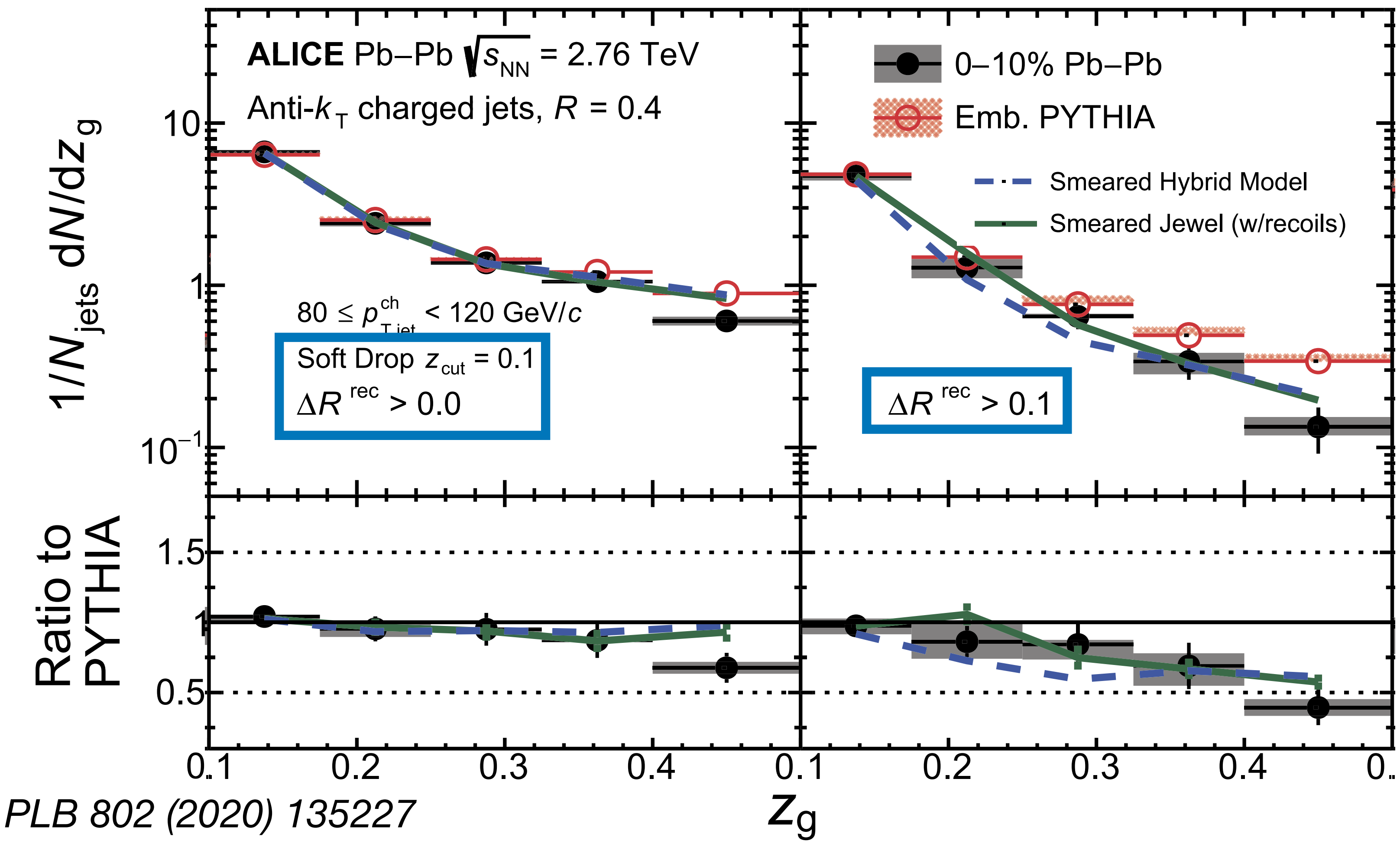
$\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

$\mathscr{L}_{\mathrm{int}} = 0.12\ \mathrm{nb}^{-1}$

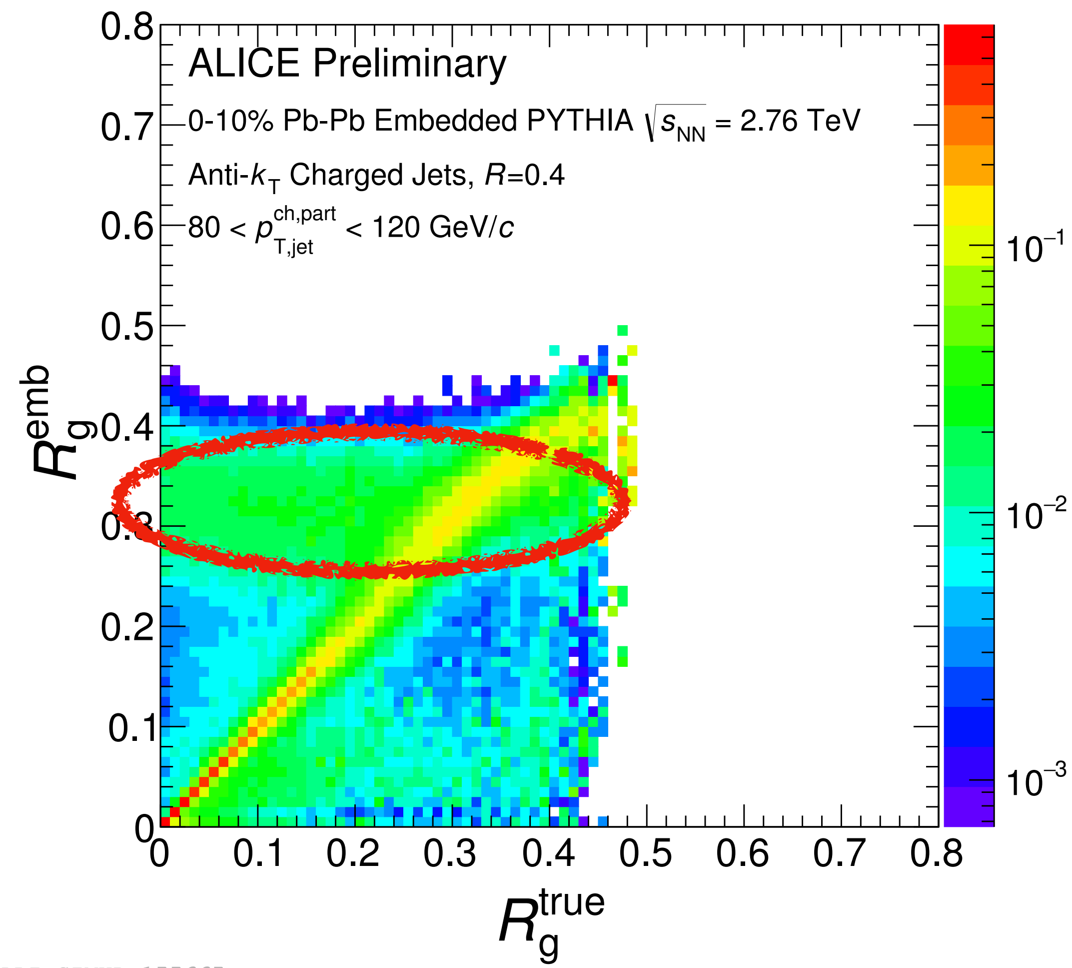
Unfolded distributions

Groomed jet splittings in Pb-Pb

Measurements of z_g have not been unfolded in AA, due to a large number of misidentified Soft Drop splittings predominantly at large angle



PLB 802 (2020) 135227



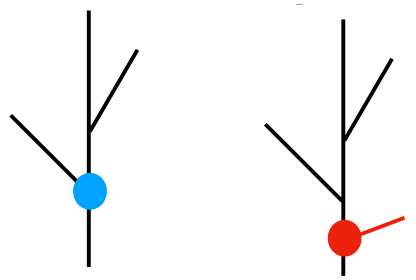
Previous measurements with $z_{cut} = 0.1$ are significantly contaminated with background

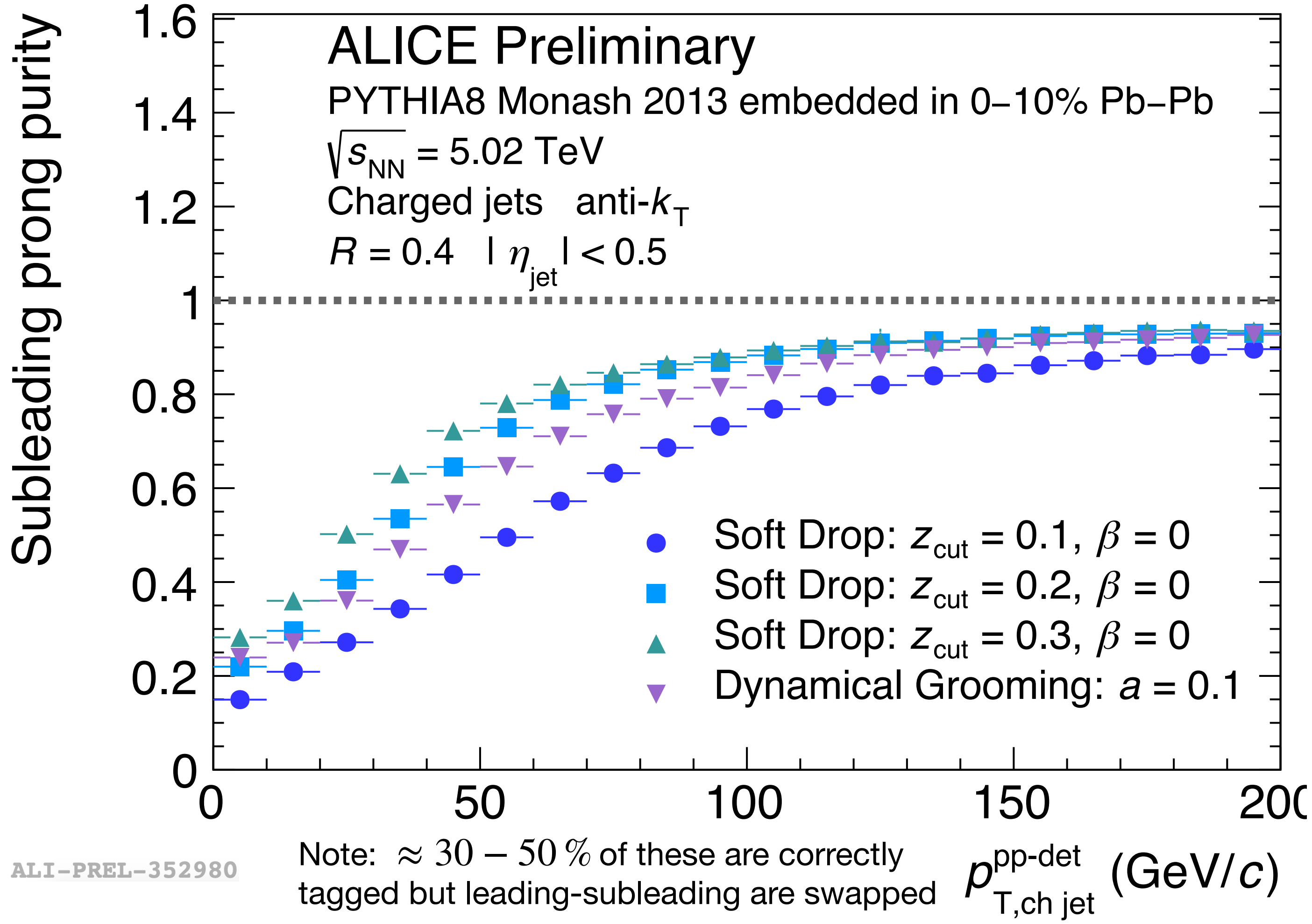
Prong matching studies

Pb-Pb 0-10%

JM, M. Ploskon
2006.01812

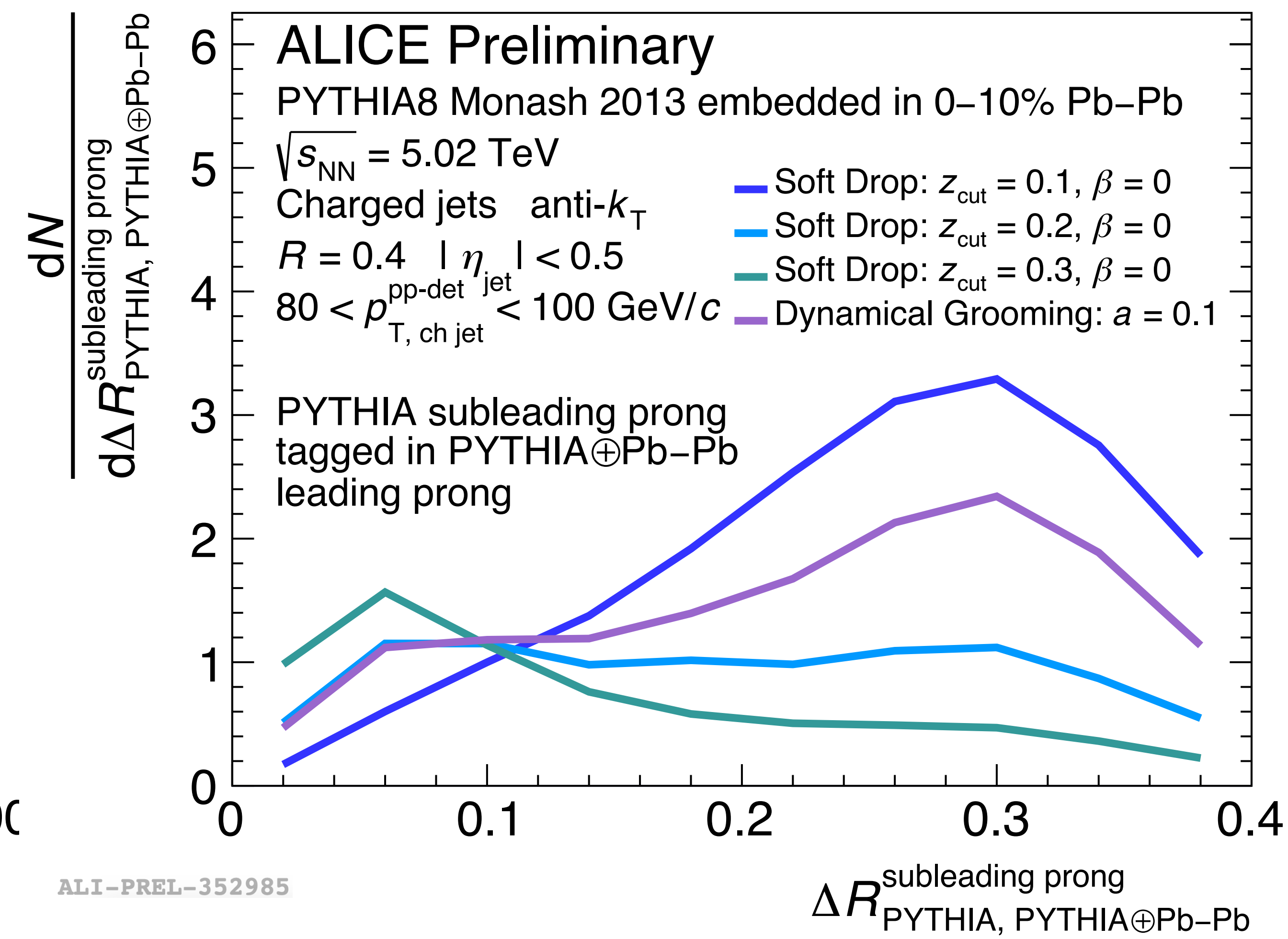
Embed PYTHIA into Pb-Pb background to estimate the fraction of subleading prongs in PYTHIA that are reconstructed in the subleading prong of the combined event





ALI-PREL-352980

Note: $\approx 30-50\,\%$ of these are correctly tagged but leading-subleading are swapped



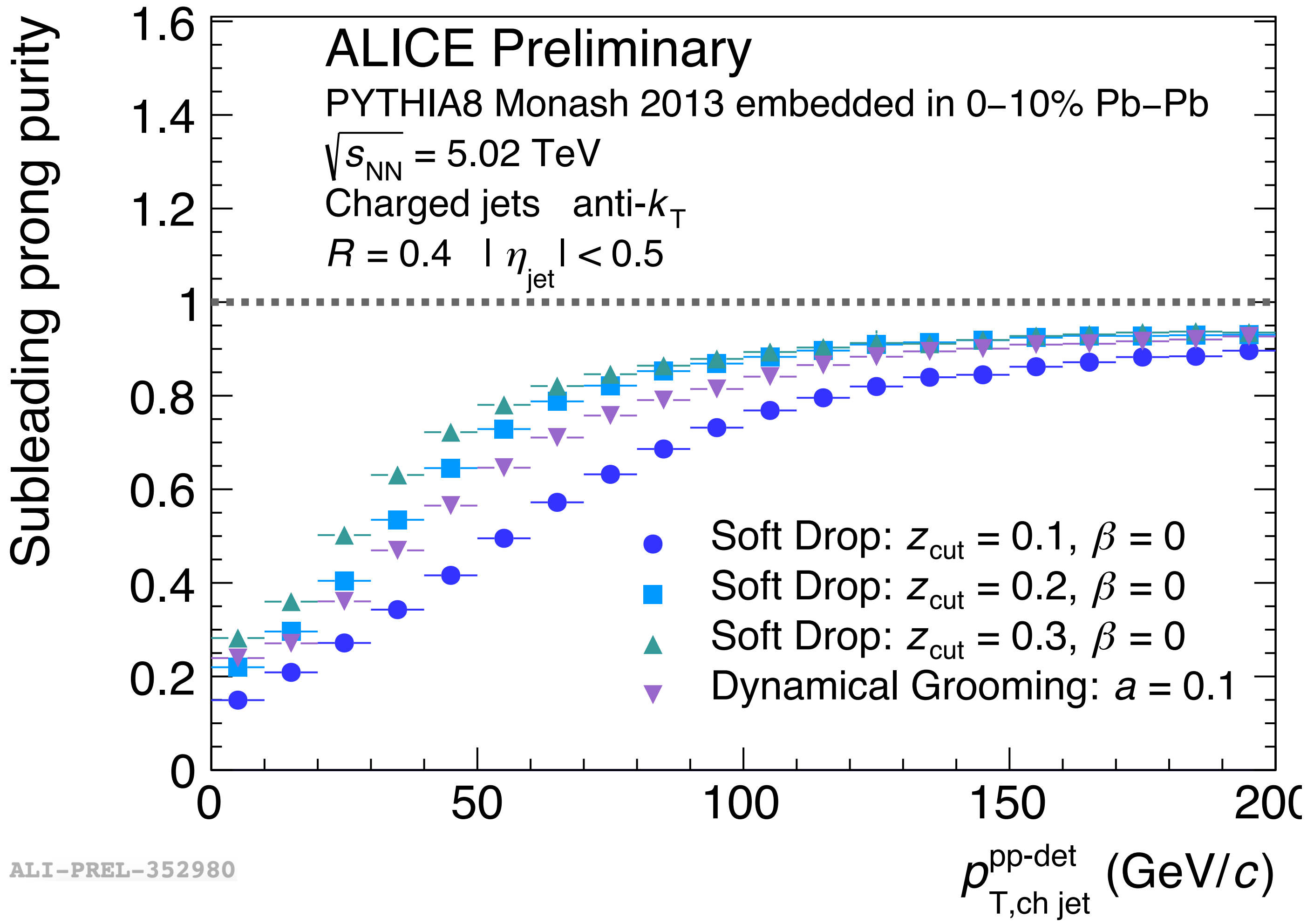
ALI-PREL-352985

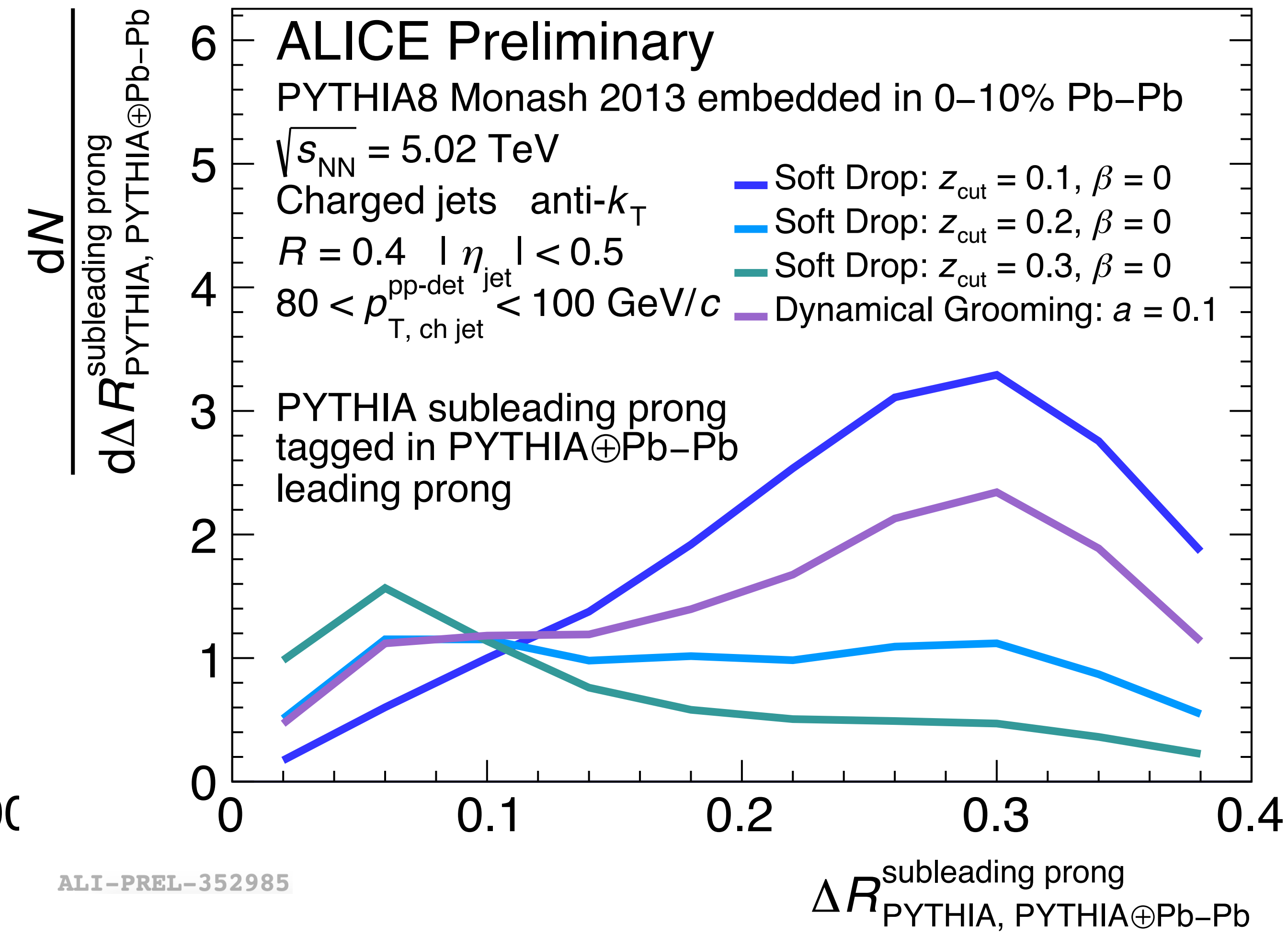
Experimental challenge: Heavy-ion background causes the reclustering/grooming process to reconstruct the wrong splitting

Prong matching studies

Pb-Pb 0-10%

JM, M. Ploskon
2006.01812





Our solution: Measure in the background-reduced part of phase space

Raising z_{cut} removes mis-identified splittings and reduces their impact

Also:

- Reducing R reduces mis-tagged splittings
- Event-wide constituent subtraction *Berta et al. JHEP (2019) 175*
- Explore semi-central collisions

This leaves ~5-10% mis-tagged splittings → Unfolded measurement feasible

Results — Soft Drop z_g

Pb-Pb 0-10%

JETSCAPE *1903.07706*
Multi-stage energy loss
MATTER+LBT

Caucal et al. *JHEP 10 (2019) 273*
pQCD parton shower, vacuum-like
+ medium-induced emissions

Chien, Vitev *PRL 119 (2017) 112301*
Soft Collinear Effective Theory

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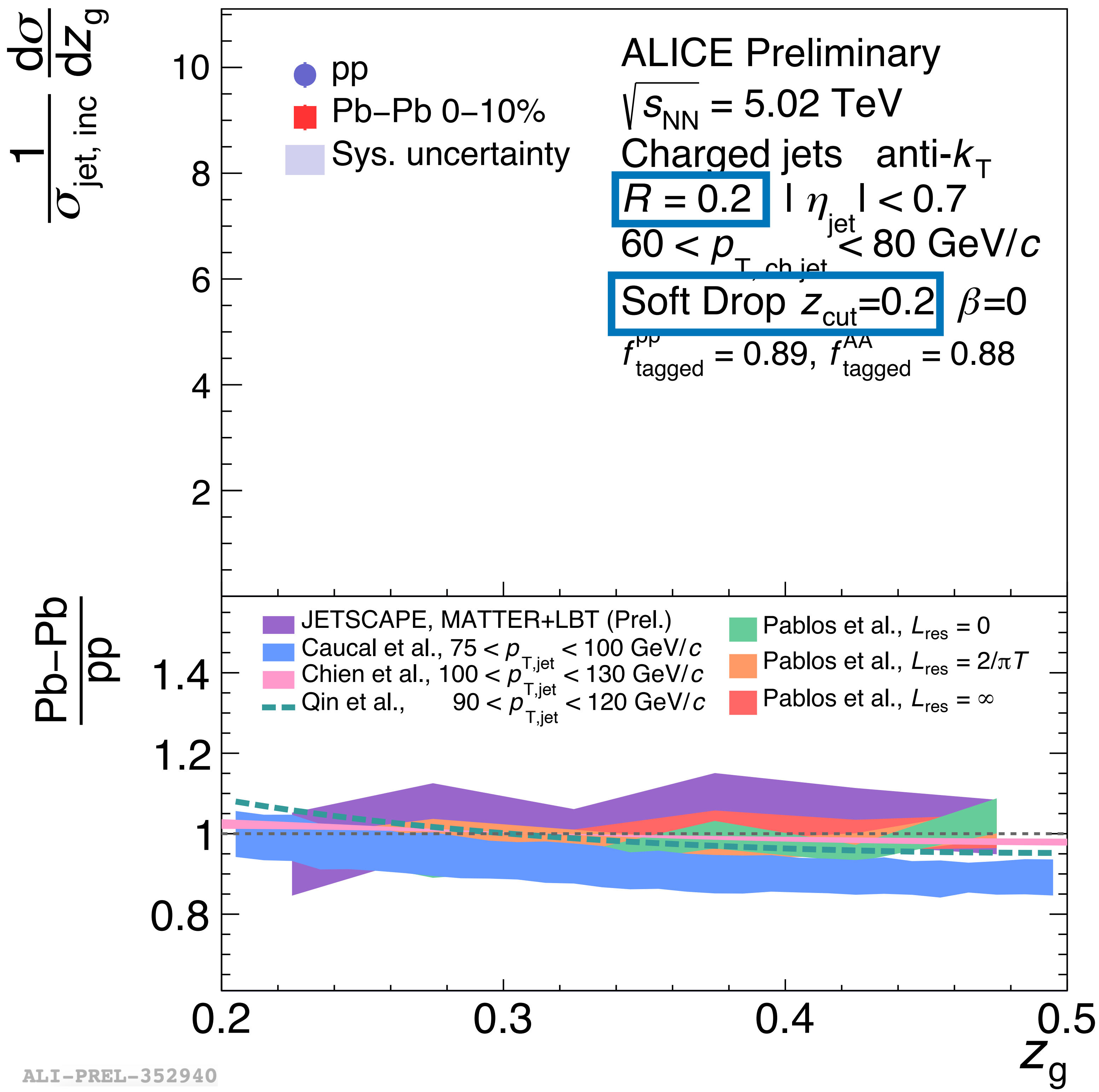
Higher-Twist, coherent energy loss

Pablos et al. *JHEP (2020) 044*
Hybrid model based on AdS/CFT

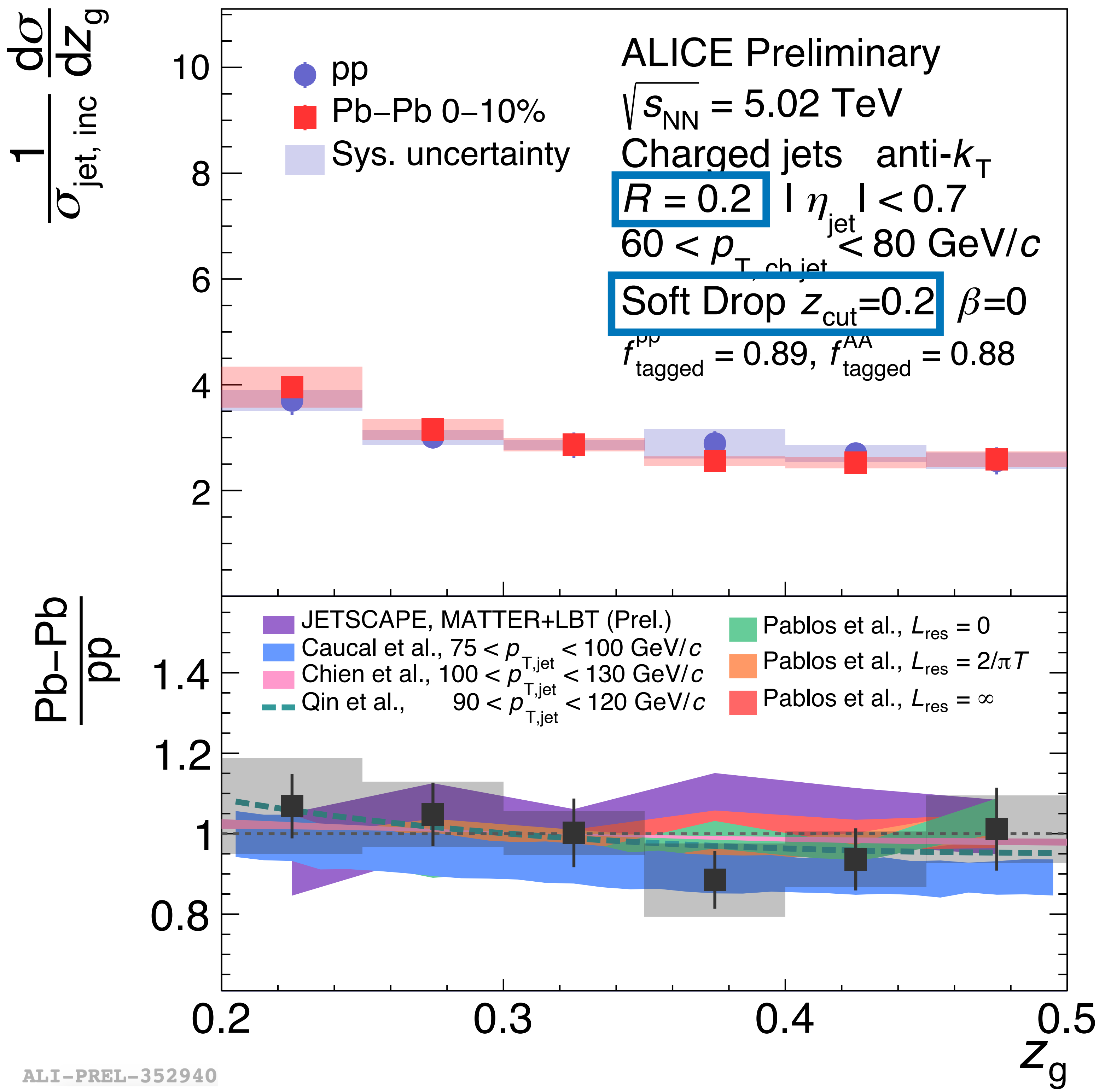


Results — Soft Drop z_g

New Preliminary

Pb-Pb 0-10%

Fully corrected for background and detector effects



No significant modification in z_g distribution

Results — Soft Drop z_g

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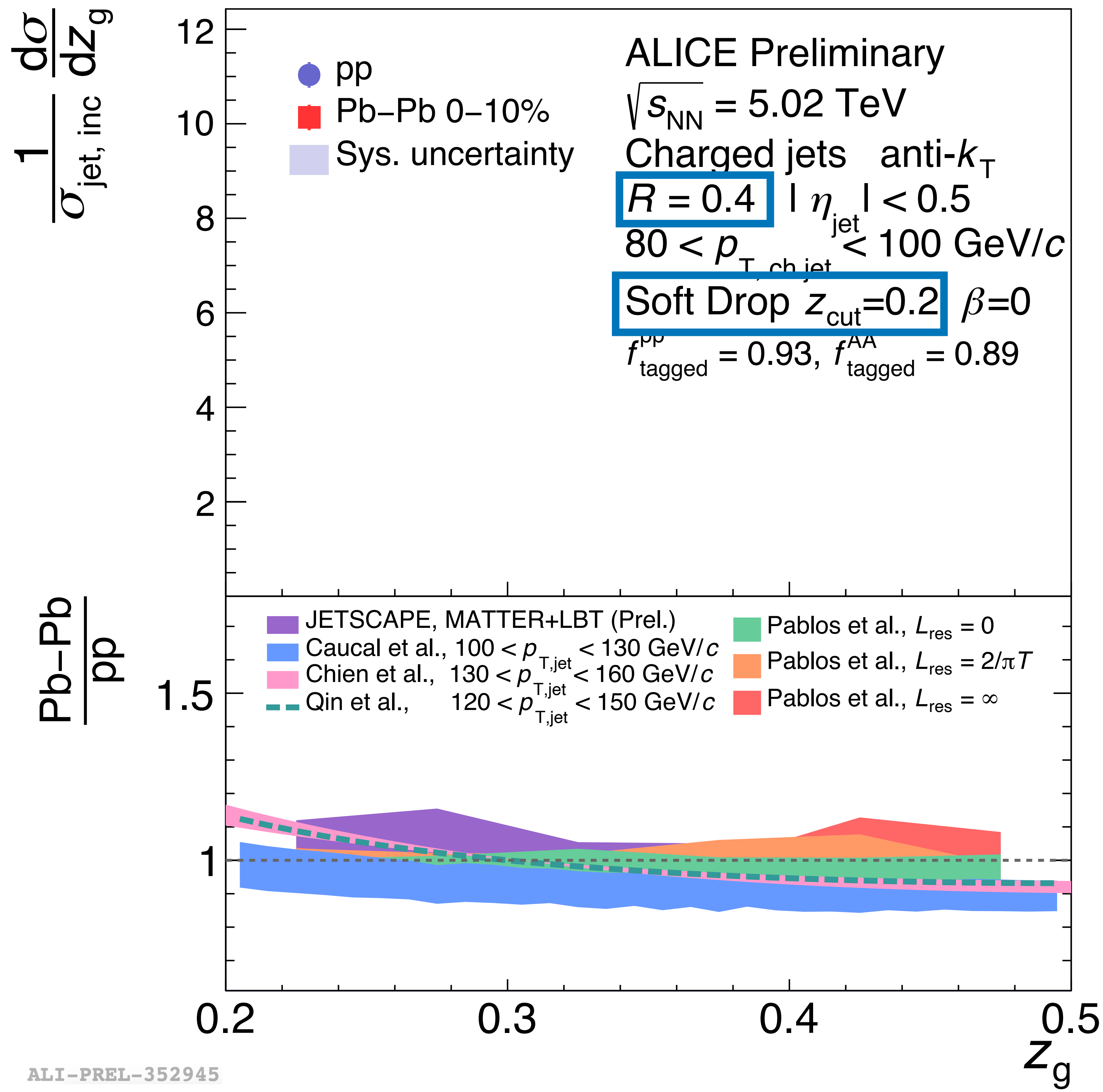


Results — Soft Drop z_g

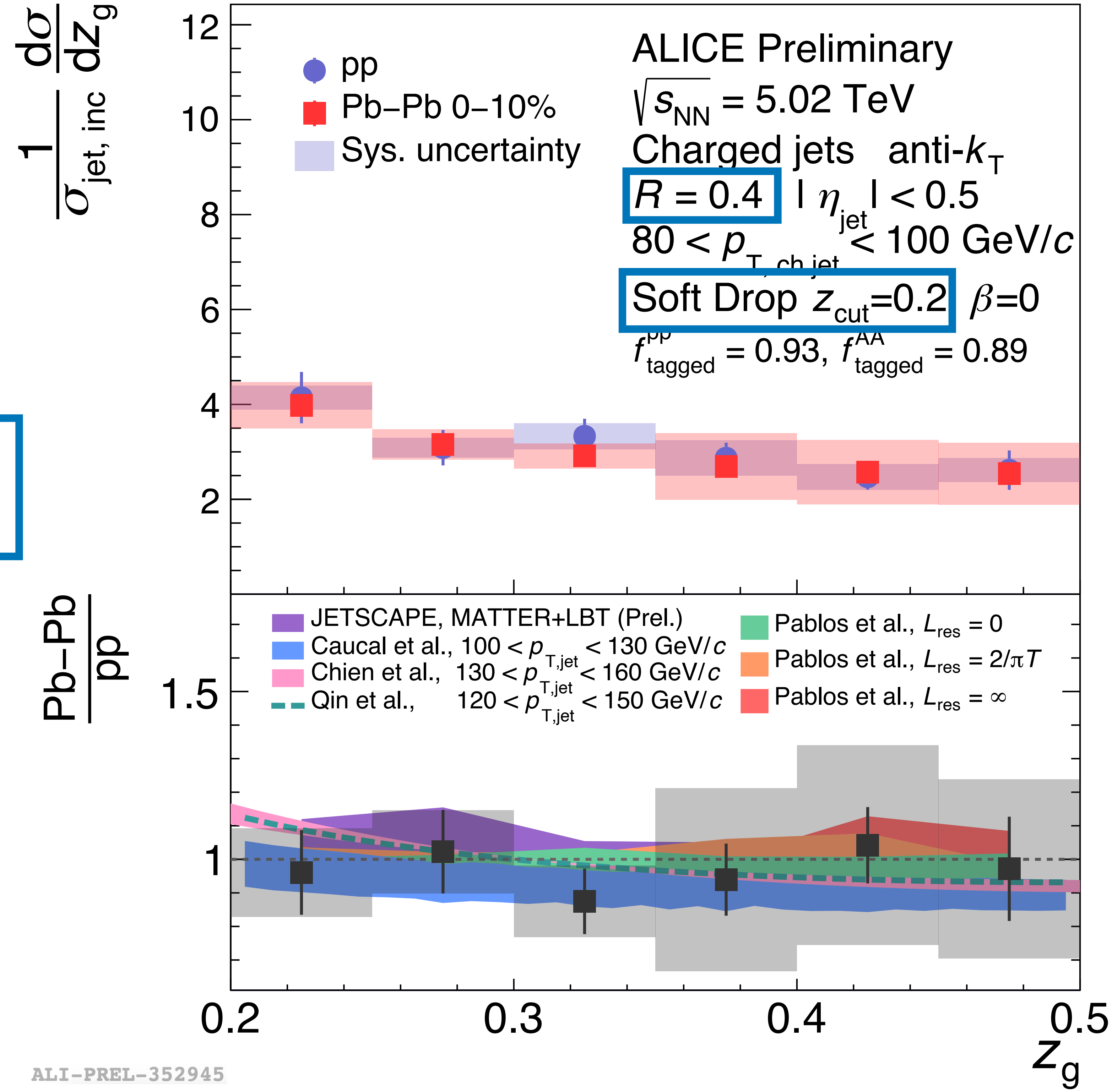
New Preliminary

Pb-Pb 0-10%

Fully corrected for background and detector effects

Precision limited due to background contamination

No significant modification in z_g distribution



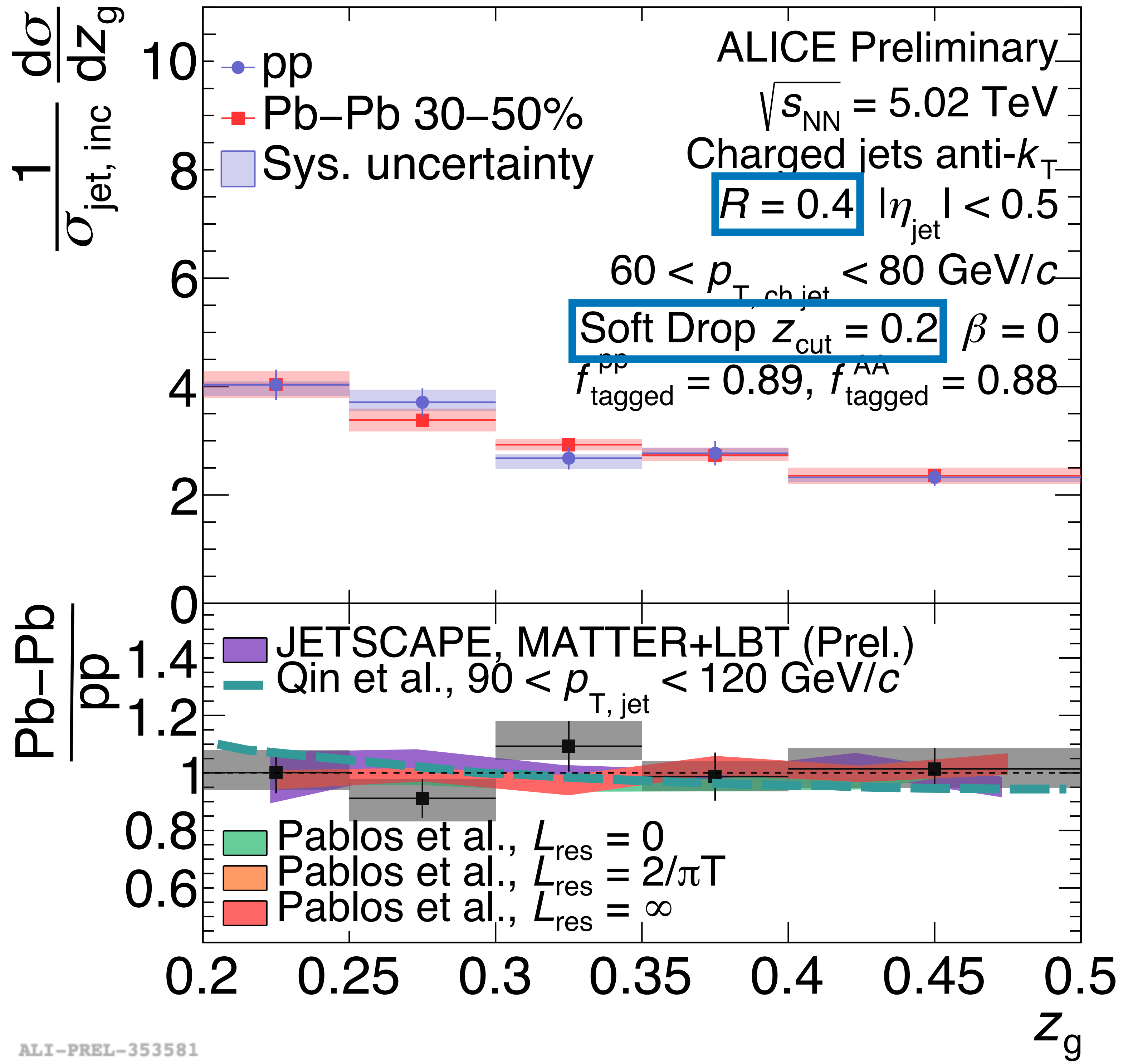
Results — Soft Drop z_g

New Preliminary

Pb-Pb 30-50%

Fully corrected for background and detector effects

No significant modification in z_g distribution



Results — Soft Drop θ_g

Pb-Pb 0-10%

New Preliminary

JETSCAPE *1903.07706*

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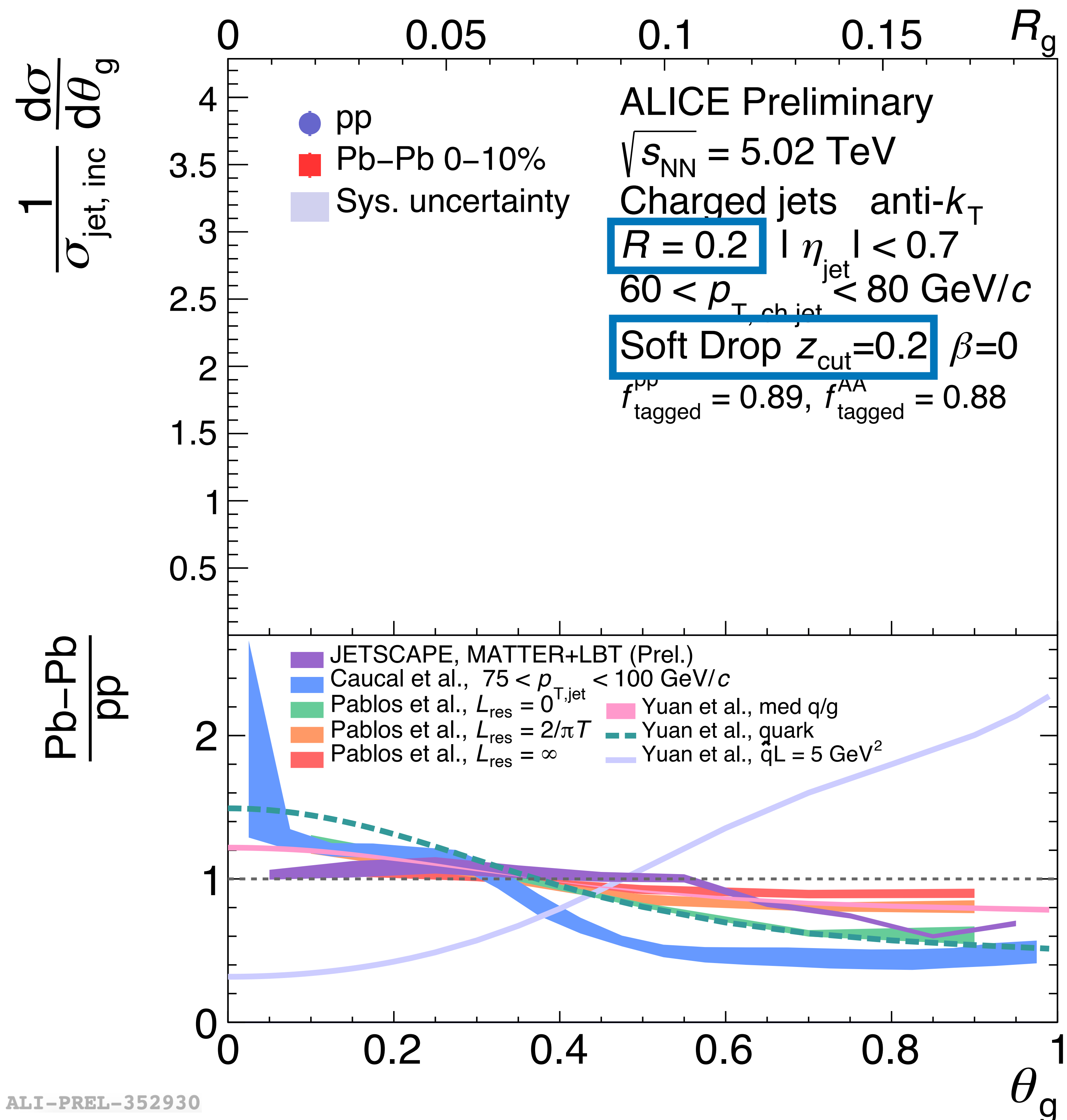
Hybrid model based on AdS/CFT

Yuan et al. *1907.12541*

Two approaches:
(1) Modification of q/g fractions
med q/g fractions from:
Ringer et al. PRL 122 (2019)
(2) $\hat{q}$ broadening



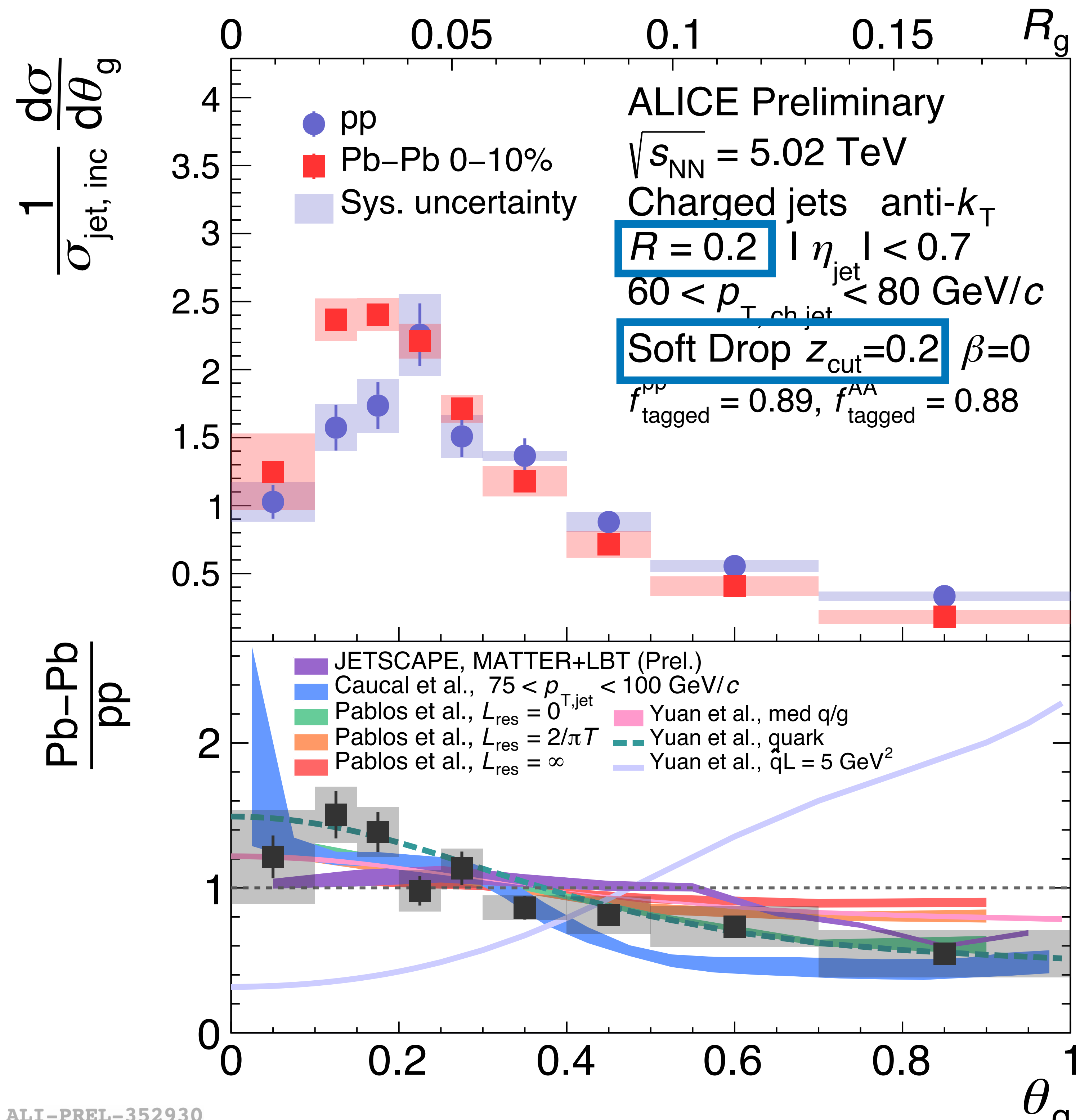
Results — Soft Drop θ_g

New Preliminary

Pb-Pb 0-10%

Fully corrected for background and detector effects

Modification of θ_g: Collimation / Narrowing



Results — Soft Drop θ_g

Pb-Pb 0-10%

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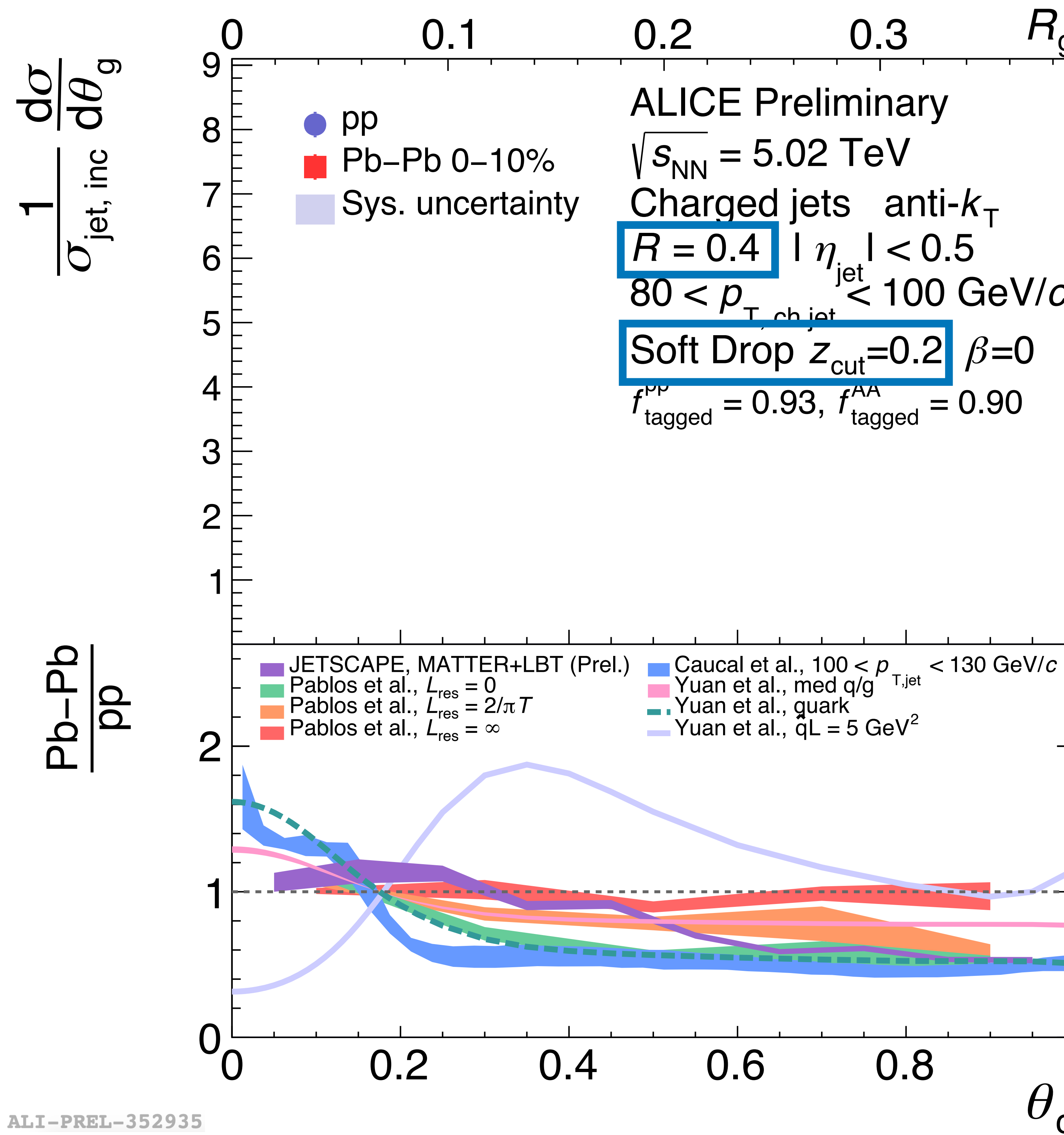


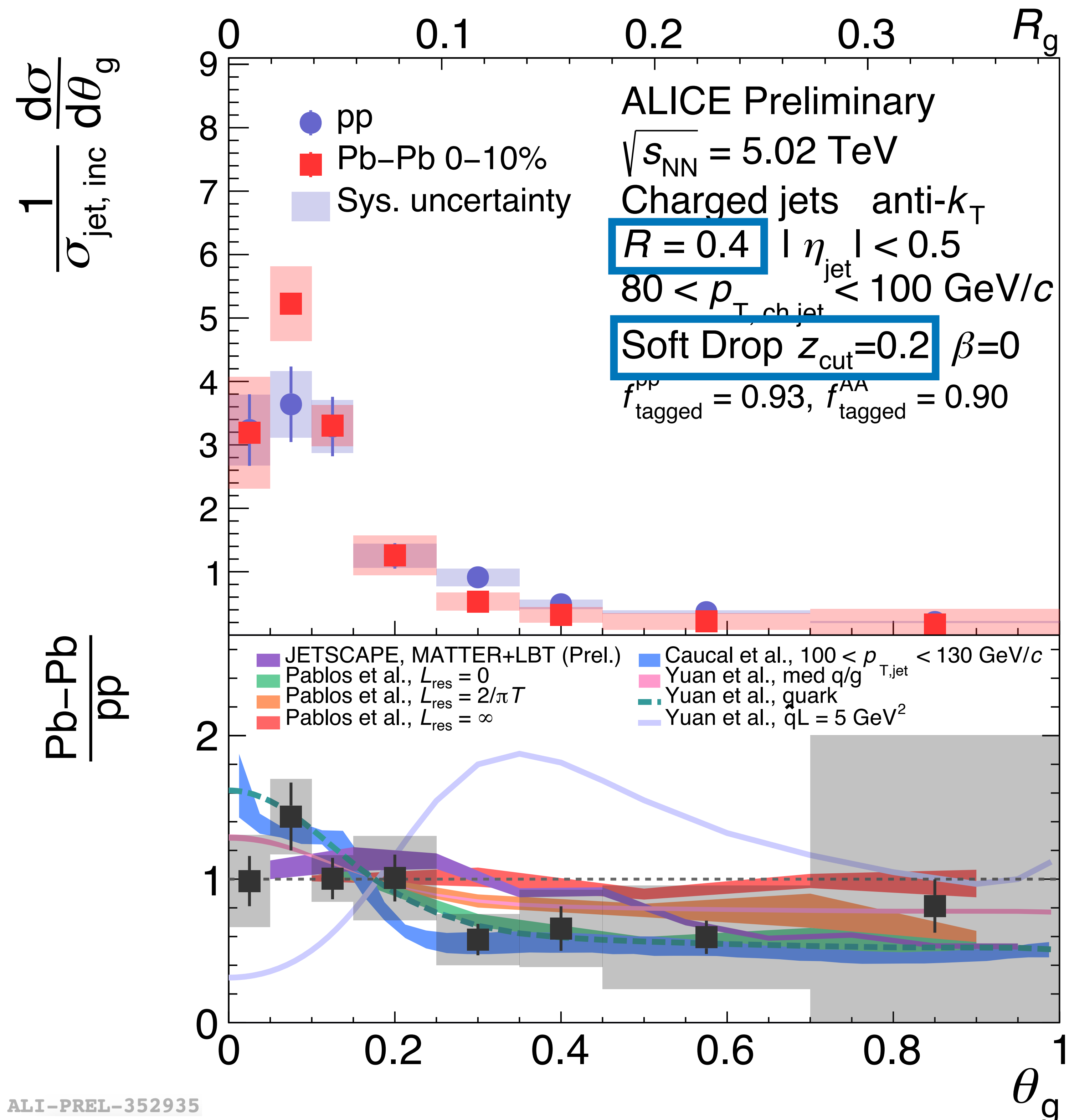
Results — Soft Drop θ_g

New Preliminary

Pb-Pb 0-10%

Fully corrected for background and detector effects

Precision limited due to background contamination



Modification of θ_g: Hint of collimation

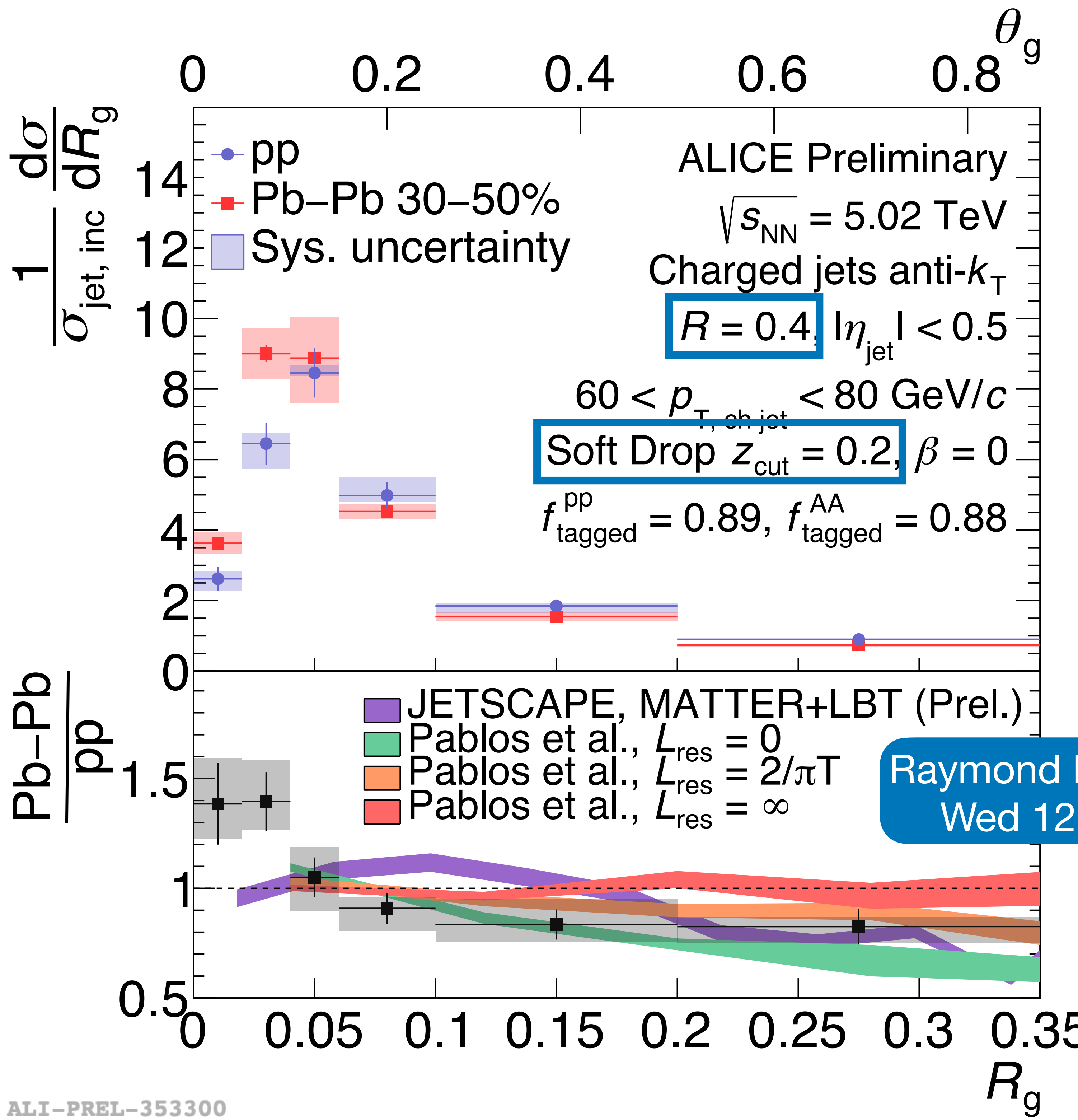
Results — Soft Drop θ_g

Pb-Pb 30-50%

New Preliminary

Fully corrected for background and detector effects

Modification of θ_g: Hint of collimation



Raymond Ehlers
Wed 12:25

Results — Soft Drop θ_g

Pb-Pb 30-50%

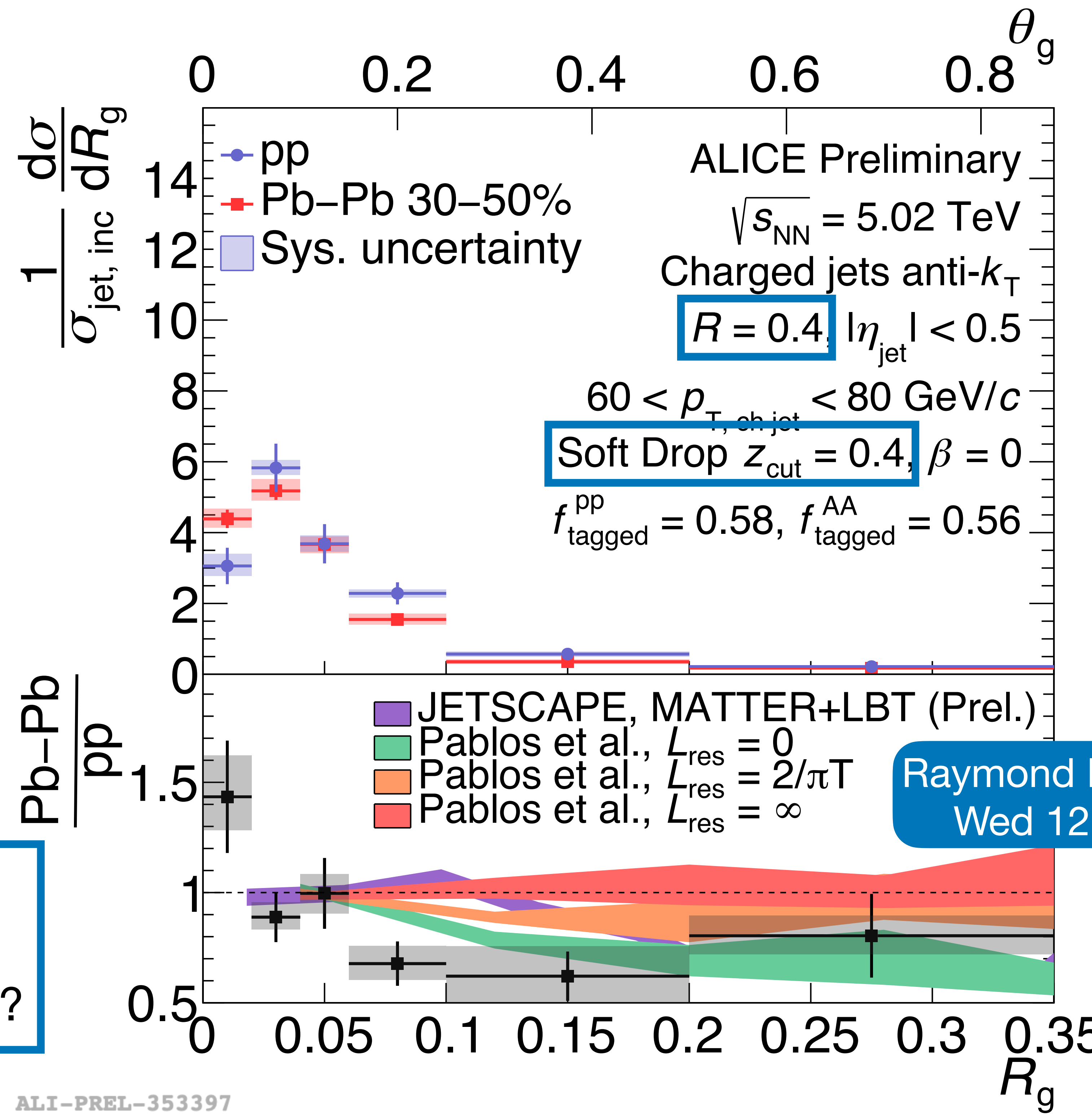
New Preliminary

Fully corrected for background and detector effects

Modification of θ_g: Collimation

$z_{cut} = 0.4$ selects symmetric splittings

→ Increased suppression?



Raymond Ehlers Wed 12:25

Summary

New substructure measurements in proton-proton collisions

Dynamical grooming $z_{\rm g}, \theta_{\rm g}$

Jet angularities λ_β

First fully corrected measurements of z_g, θ_g in heavy-ion collisions

→ Advance in heavy-ion jet substructure measurements

Modification of $z_{\rm g}$: Constrained to be small

Modification of $\theta_{\rm g}$: Significant collimation

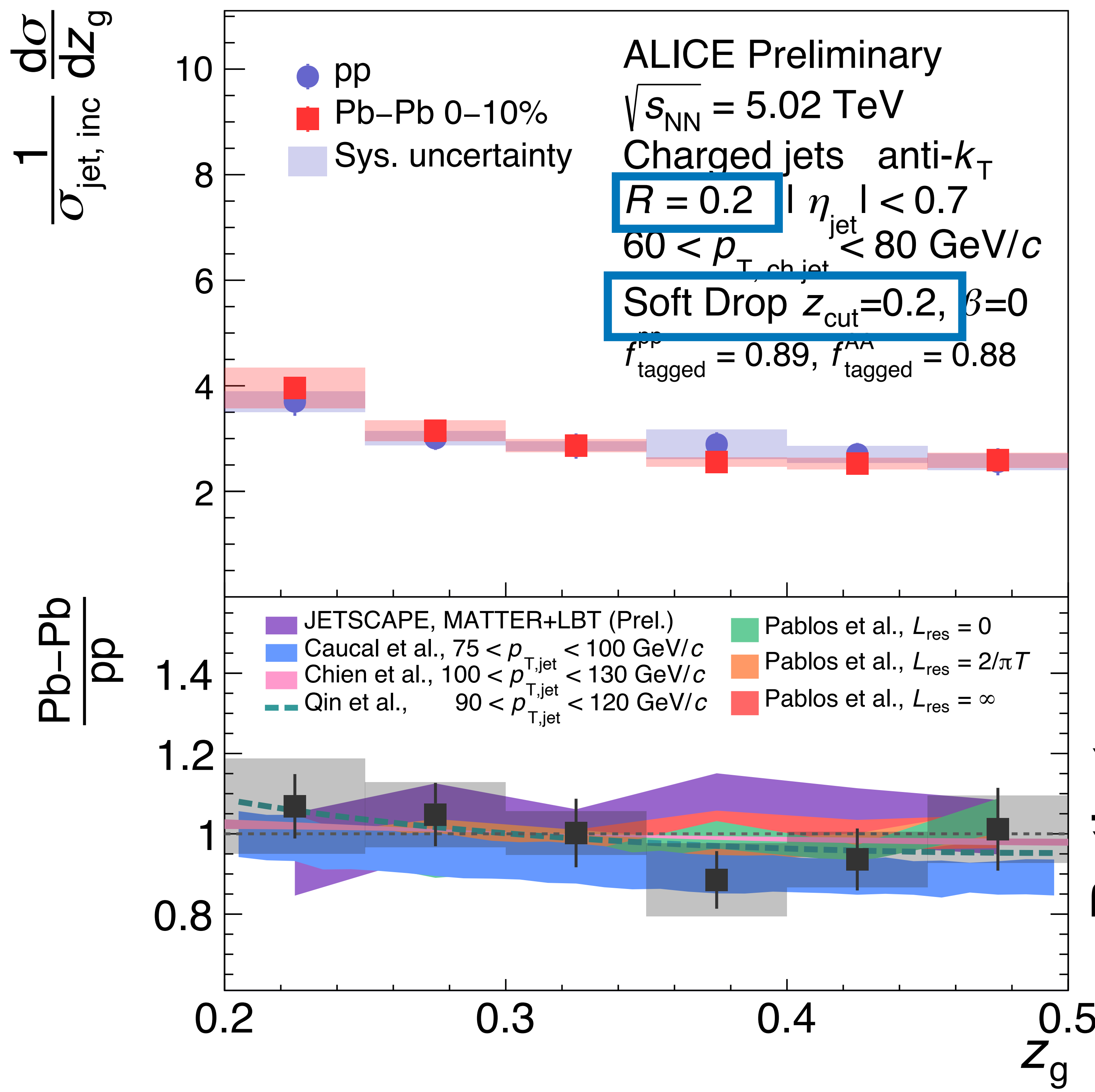
Outlook

Expect new groomed jet measurements

Explore alternate groomers to address experimental challenges of groomed observables, and establish their limitations

Backup

Unfolded, $z_{cut} = 0.2$



Not unfolded, $z_{cut} = 0.1$

PLB 802 (2020) 135227