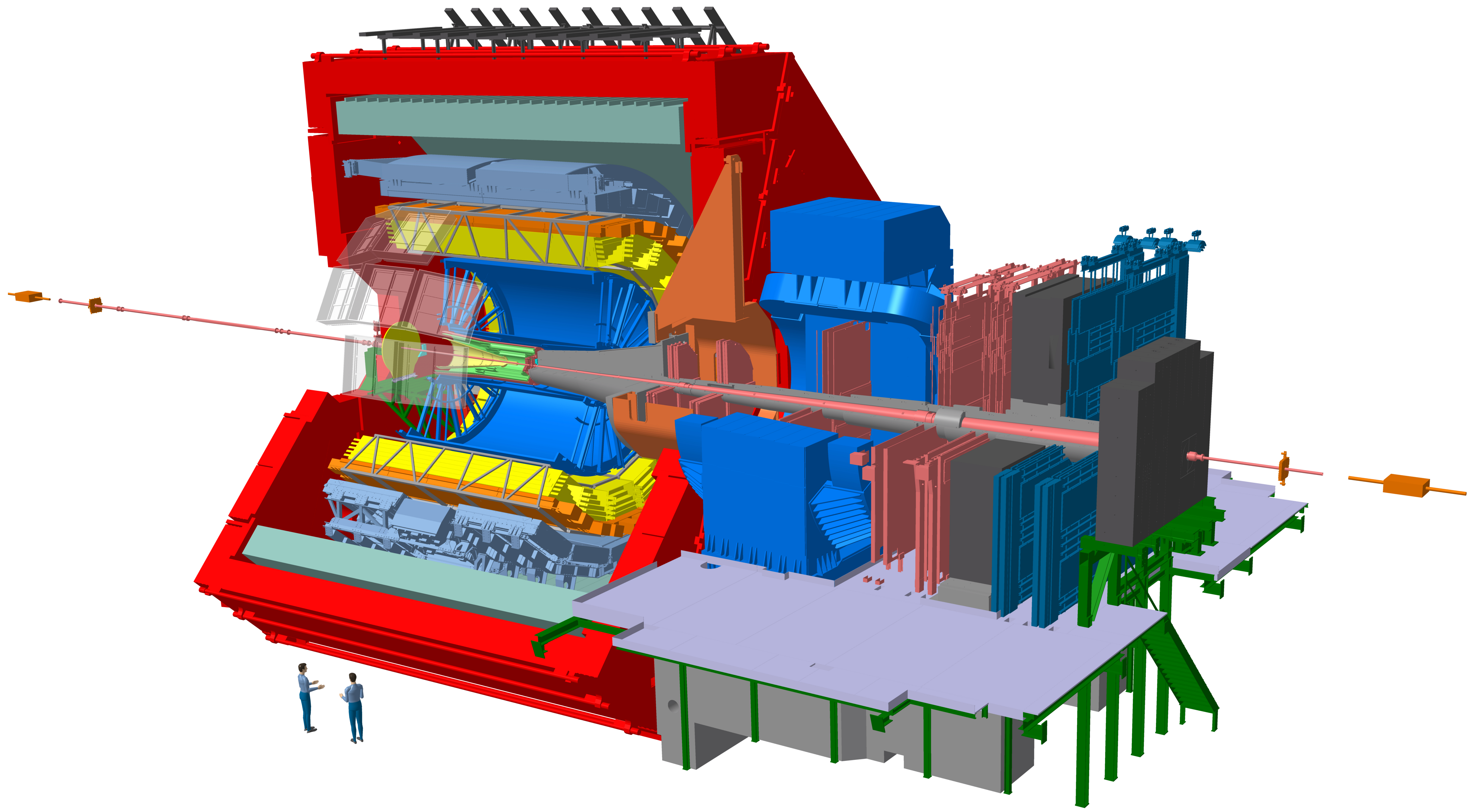
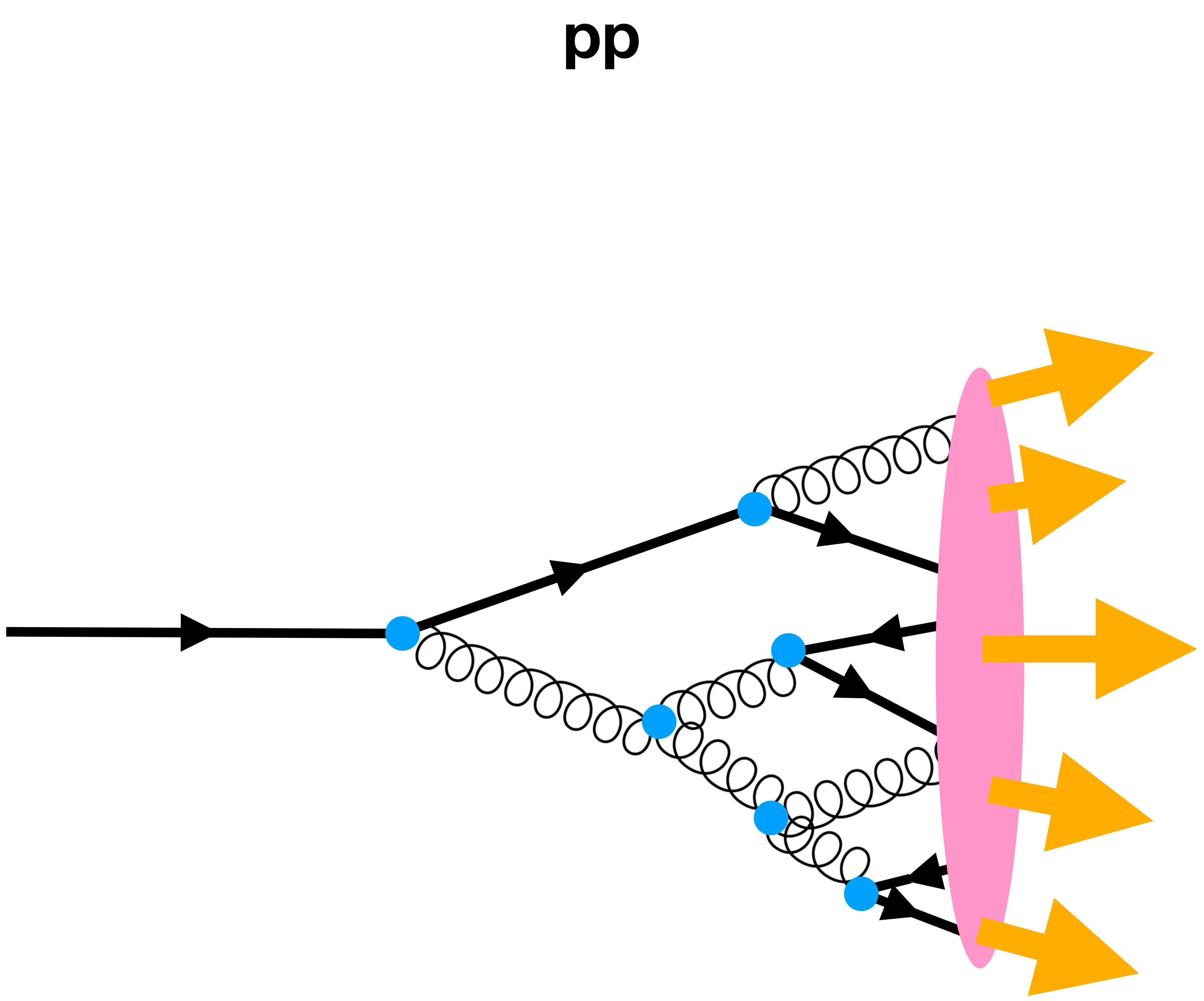
Measurement of the angle between jet axes and energy-energy correlators with ALICE

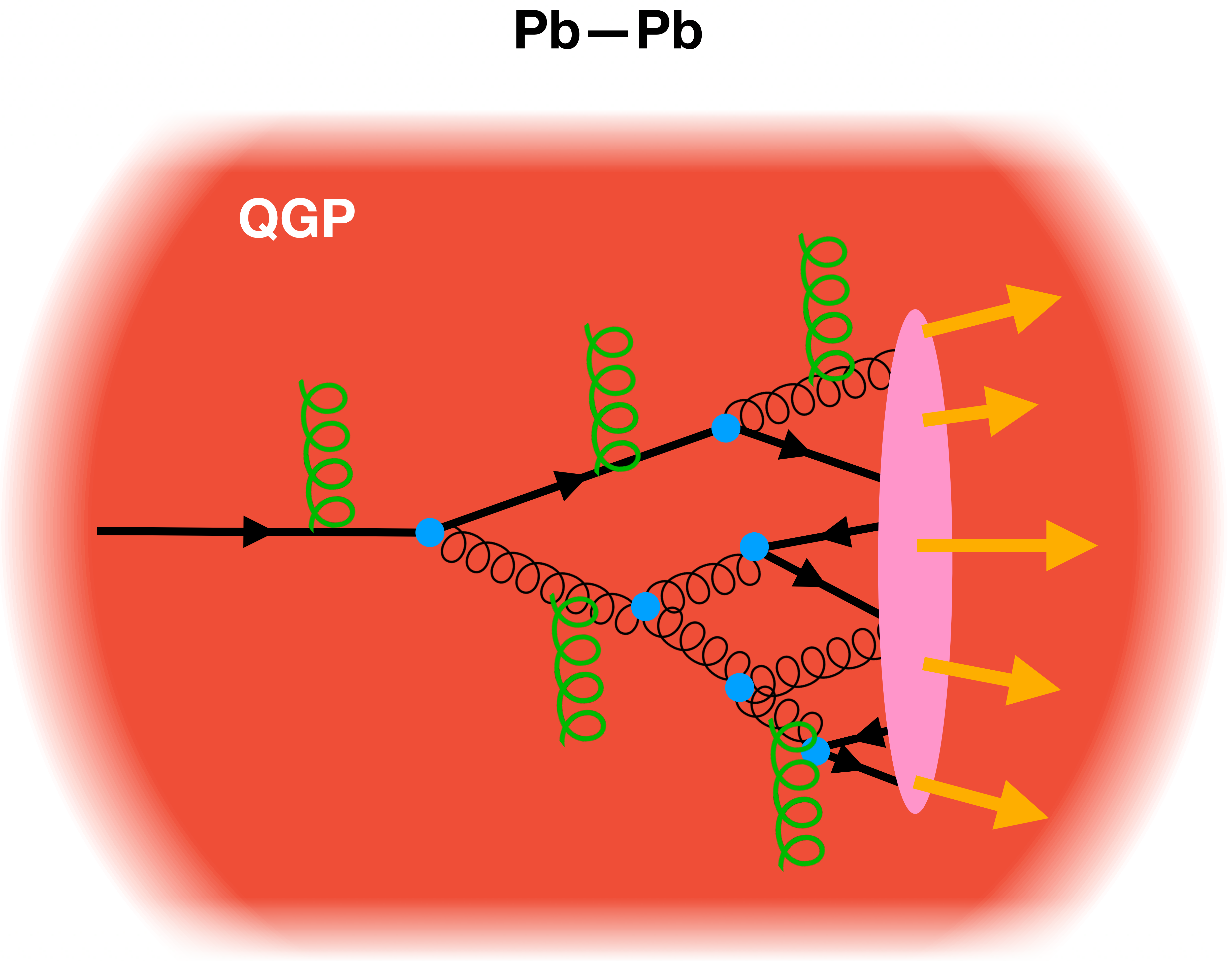


Rey Cruz-Torres
reynier@lbl.gov
On behalf of the ALICE Collaboration

03/28/2023

Jet substructure as QCD tools





Vacuum fragmentation vs in-medium fragmentation

Outline

NEW

First measurement of jet-axis differences in Pb—Pb and pp collisions

ALICE, arXiv:2211.08928, accepted by JHEP
ALICE, arXiv:2303.13347

NEW

Energy-energy correlators in pp collisions

PRELIMINARY

Outline

First measurement of jet-axis differences in Pb—Pb and pp collisions

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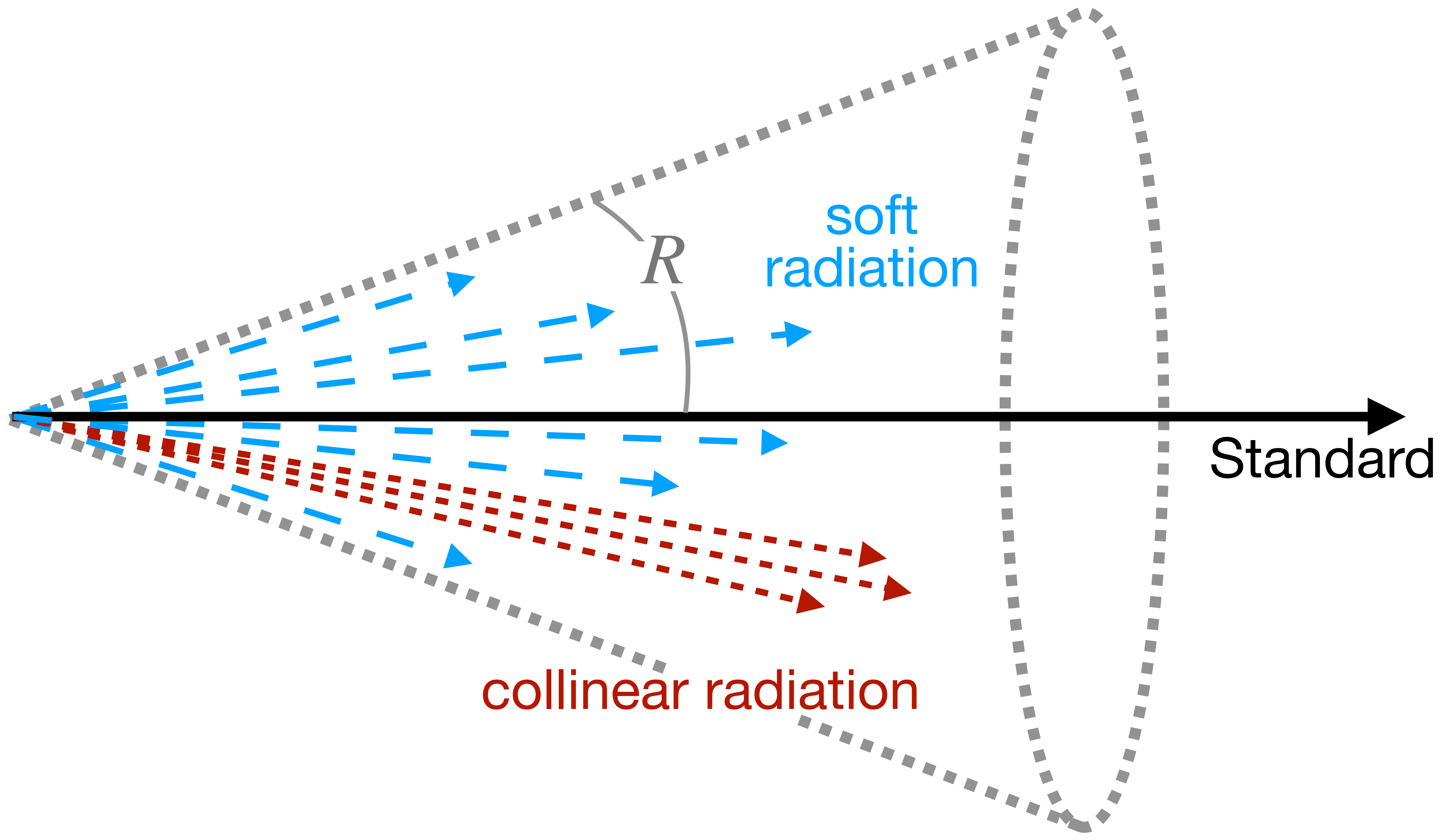
Energy-energy correlators in pp collisions

PRELIMINARY

Jet have different axes

P. Cal et al., JHEP 04 (2020) 211
ALICE, arXiv:2211.08928, JHEP In press
ALICE, arXiv:2303.13347

- **Standard axis:**
  coordinates in (y, φ) of jet clustered with anti-k_T algorithm and combined with E-Scheme



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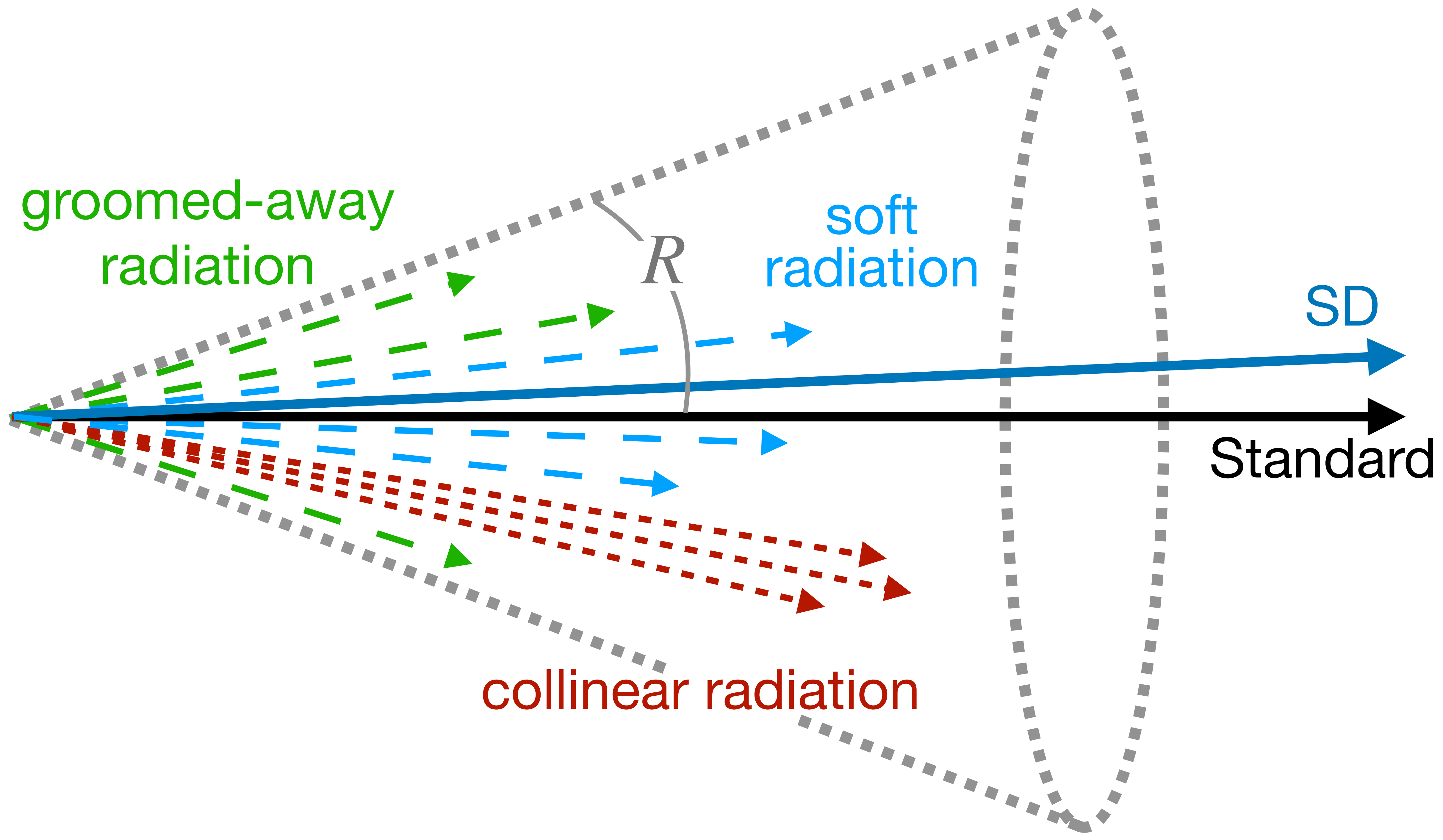
- **Groomed axis:**
  standard axis of groomed (with Soft Drop) jet



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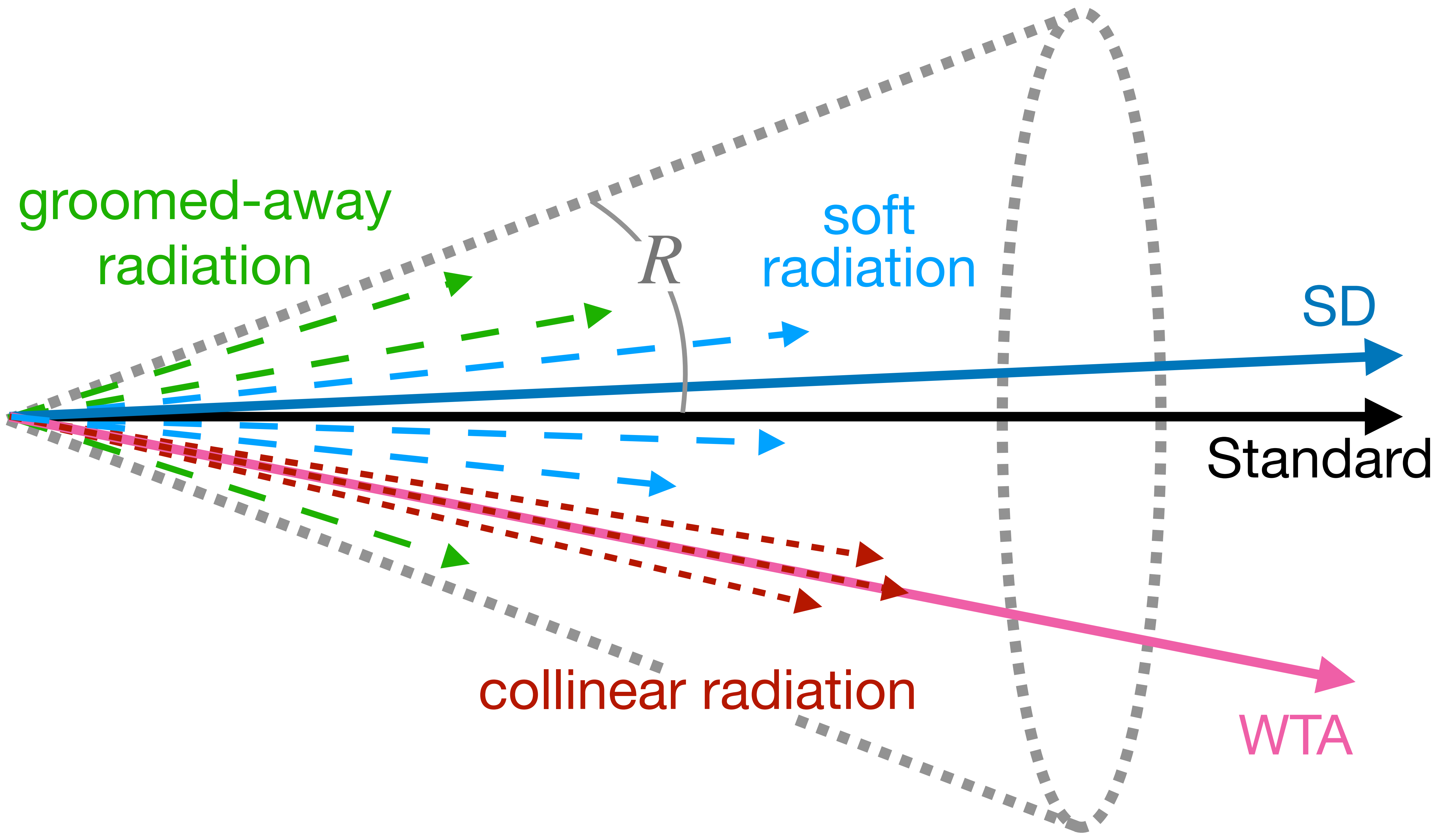
- **Winner-Takes-All (WTA) axis:**
  - recluster jet with CA algorithm
  - $2 \rightarrow 1$ prong combination by taking direction of harder prong and $p_{\mathrm{T,tot}} = p_{\mathrm{T},1} + p_{\mathrm{T},2}$
  - Resulting axis insensitive to soft radiation at leading power



Angle between pairs of jet axes

P. Cal et al., JHEP 04 (2020) 211
ALICE, arXiv:2211.08928, JHEP In press
ALICE, arXiv:2303.13347

- **Standard axis:**
  coordinates in (y, φ) of jet clustered with anti-k_T algorithm and combined with E-Scheme

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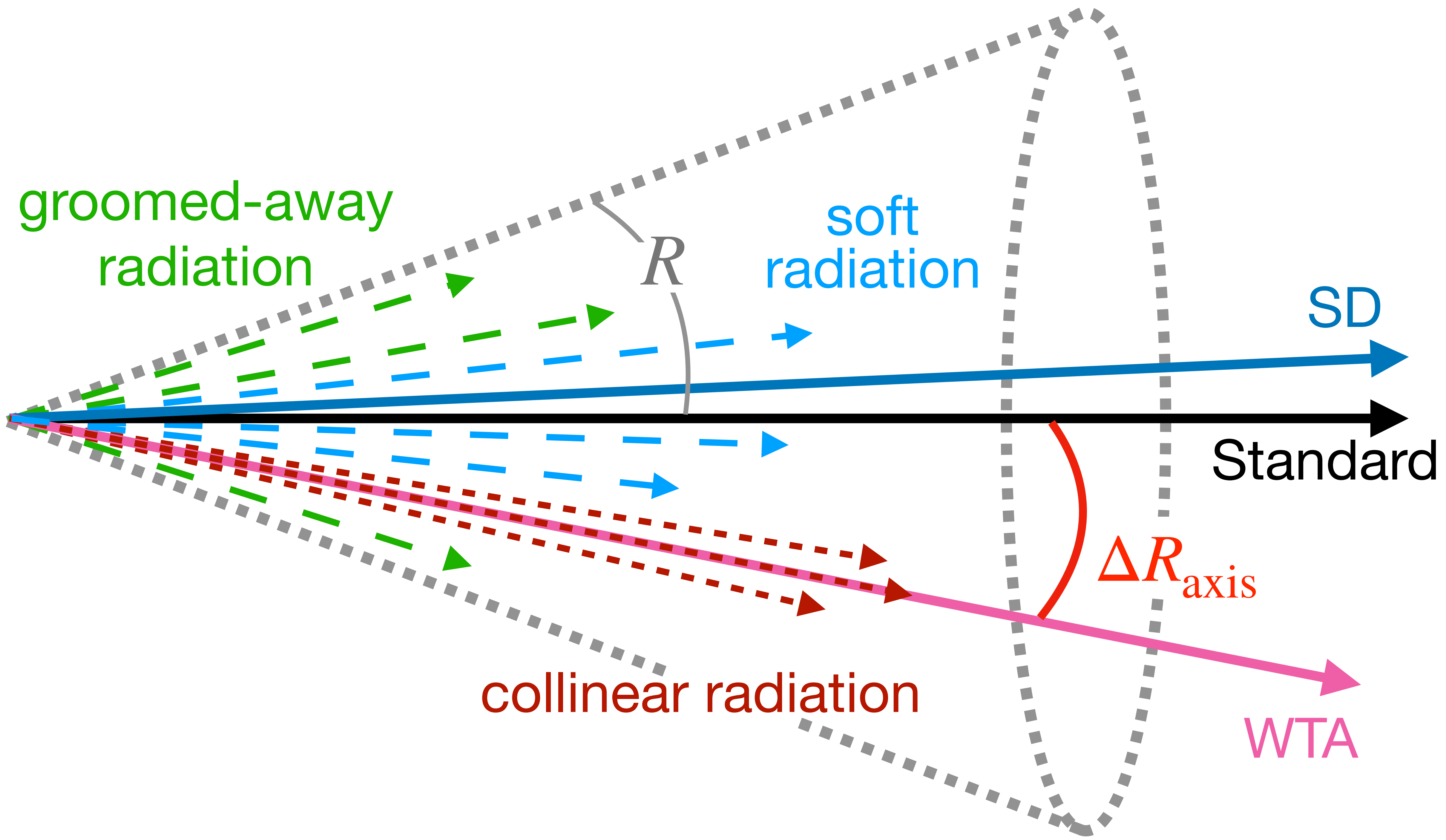
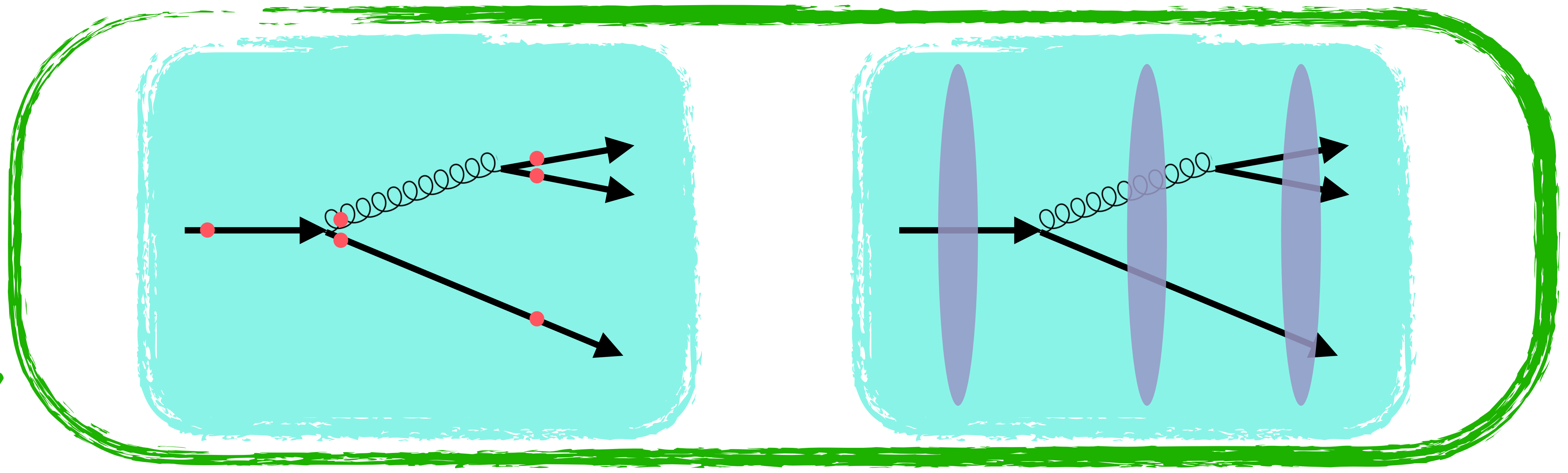


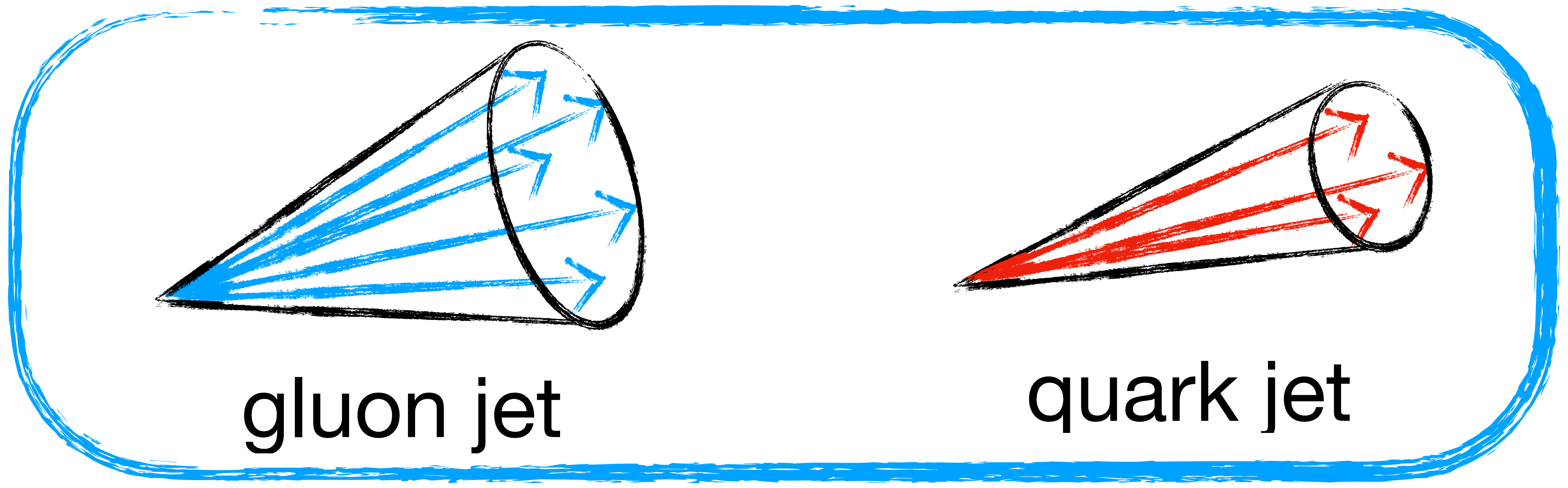
Substructure observable: $\Delta R_{\mathrm{axis}} = \sqrt{(y_2 - y_1)^2 + (\varphi_2 - \varphi_1)^2}$ between two axes

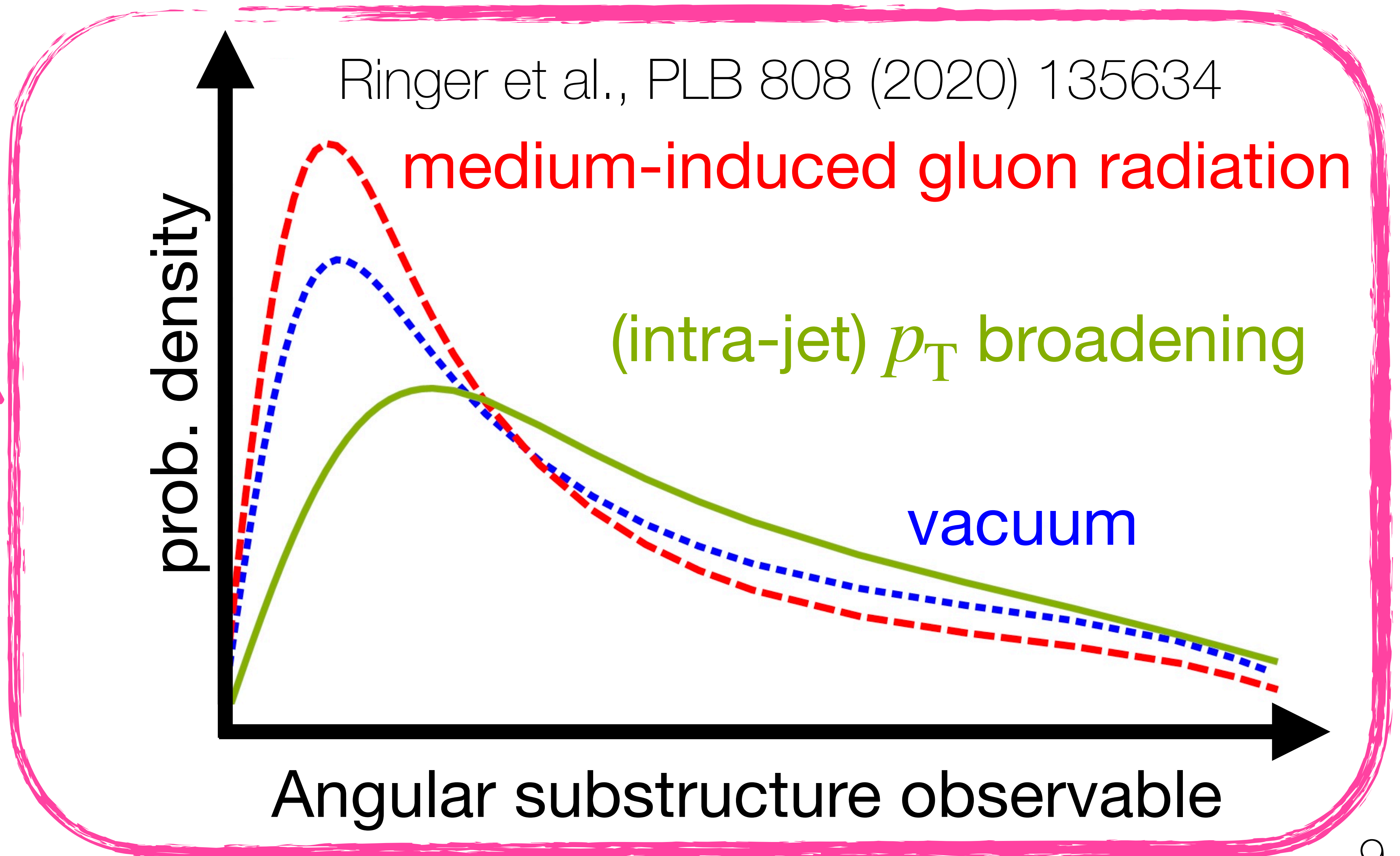
Why study this observable?

ALICE, arXiv:2303.13347

- Infrared and collinear safe observable (calculable)
- Sensitive to how coherent energy loss in QGP is
- Sensitive to modified fraction of q/g jets in medium
- Sensitive to interplay between QGP competing effects
  - e.g. **medium-induced gluon radiation** vs. **multiple-scattering-like (intra-jet) p_T broadening**

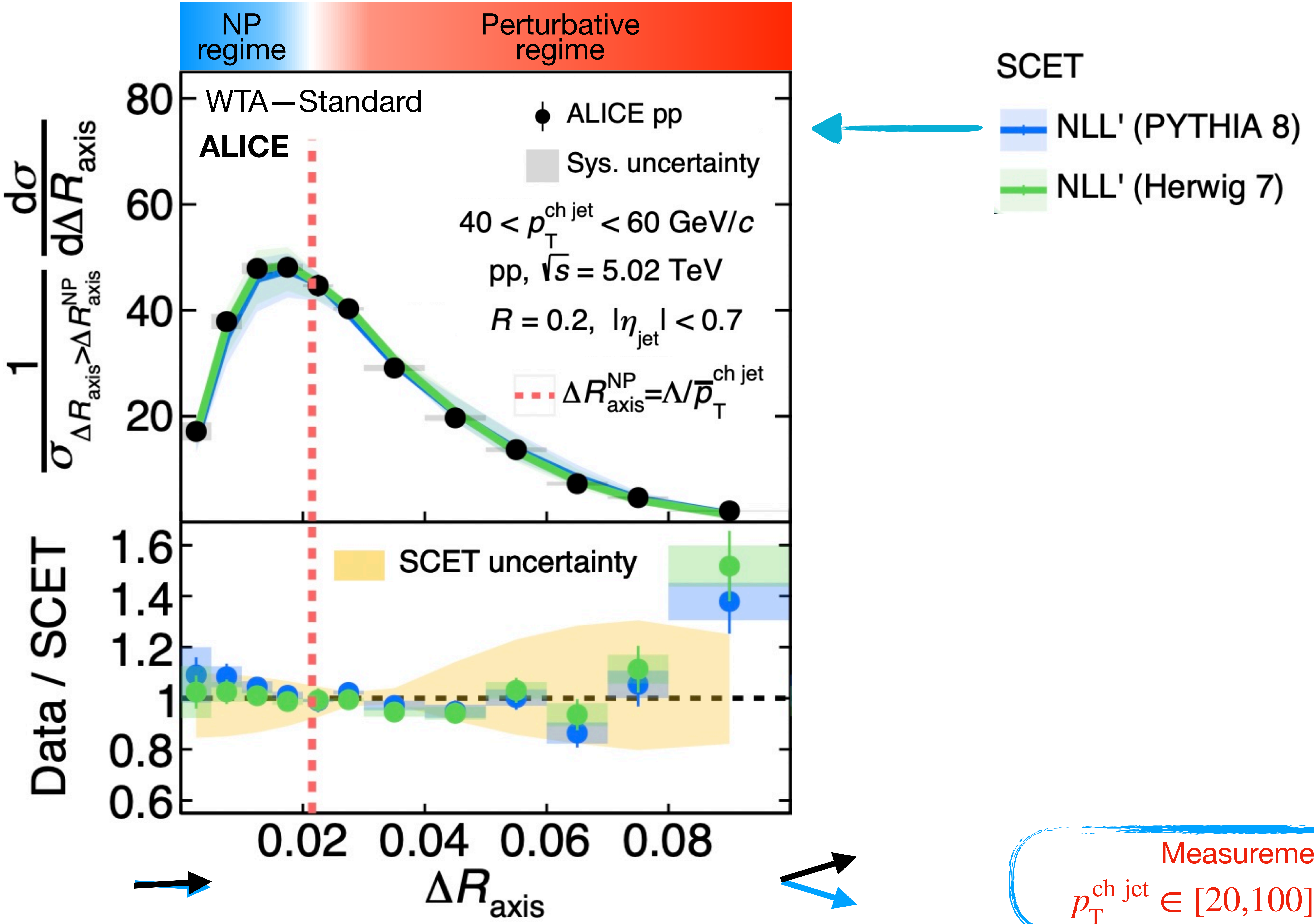






Results in pp

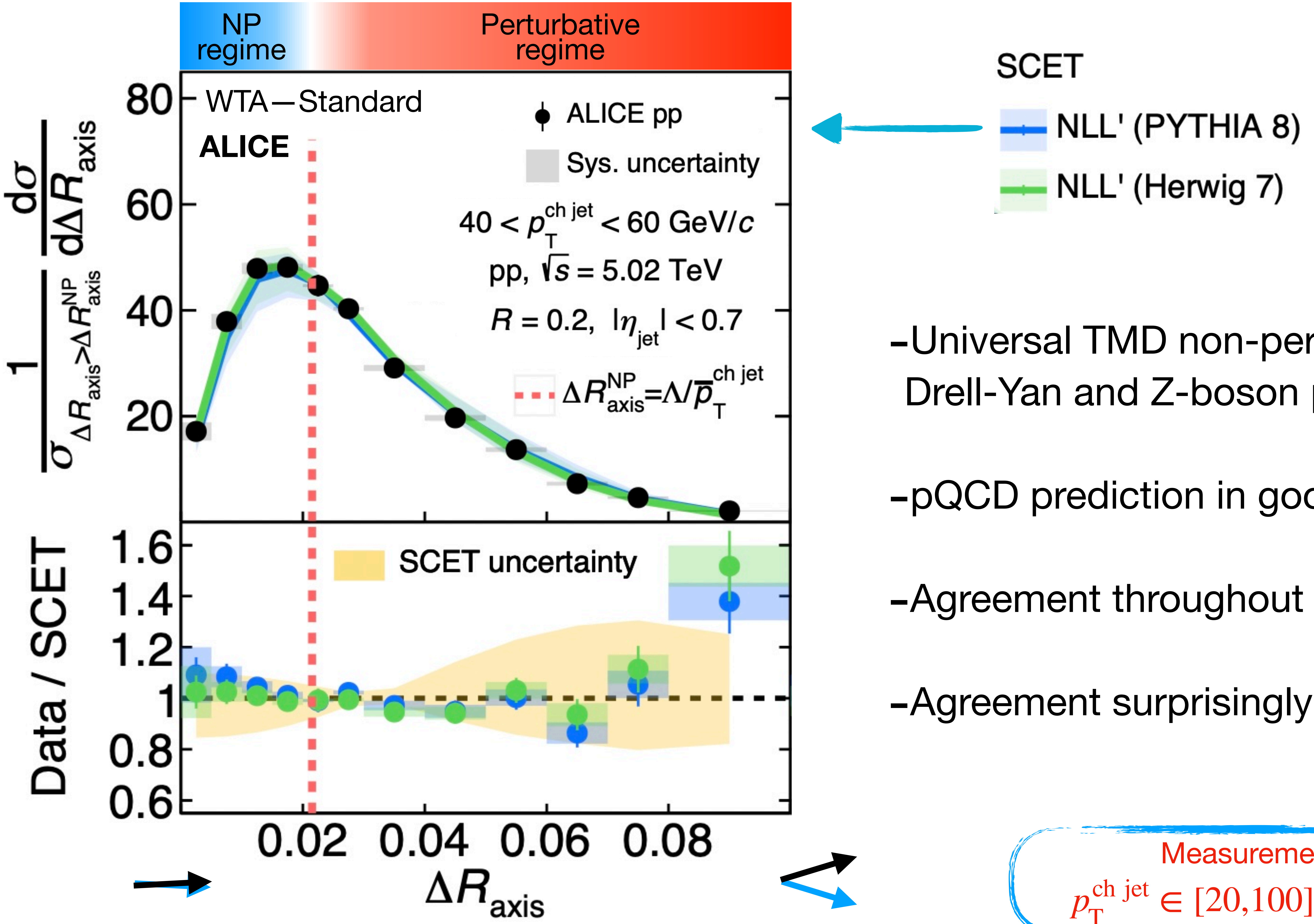
ALICE, arXiv:2211.08928



Measurement carried out for
$p_T^{ch\ jet} \in [20,100]$ GeV/c ($R = 0.2,\ 0.4$)

Results in pp

ALICE, arXiv:2211.08928



- Universal TMD non-perturbative correction from Drell-Yan and Z-boson production

- pQCD prediction in good agreement with data

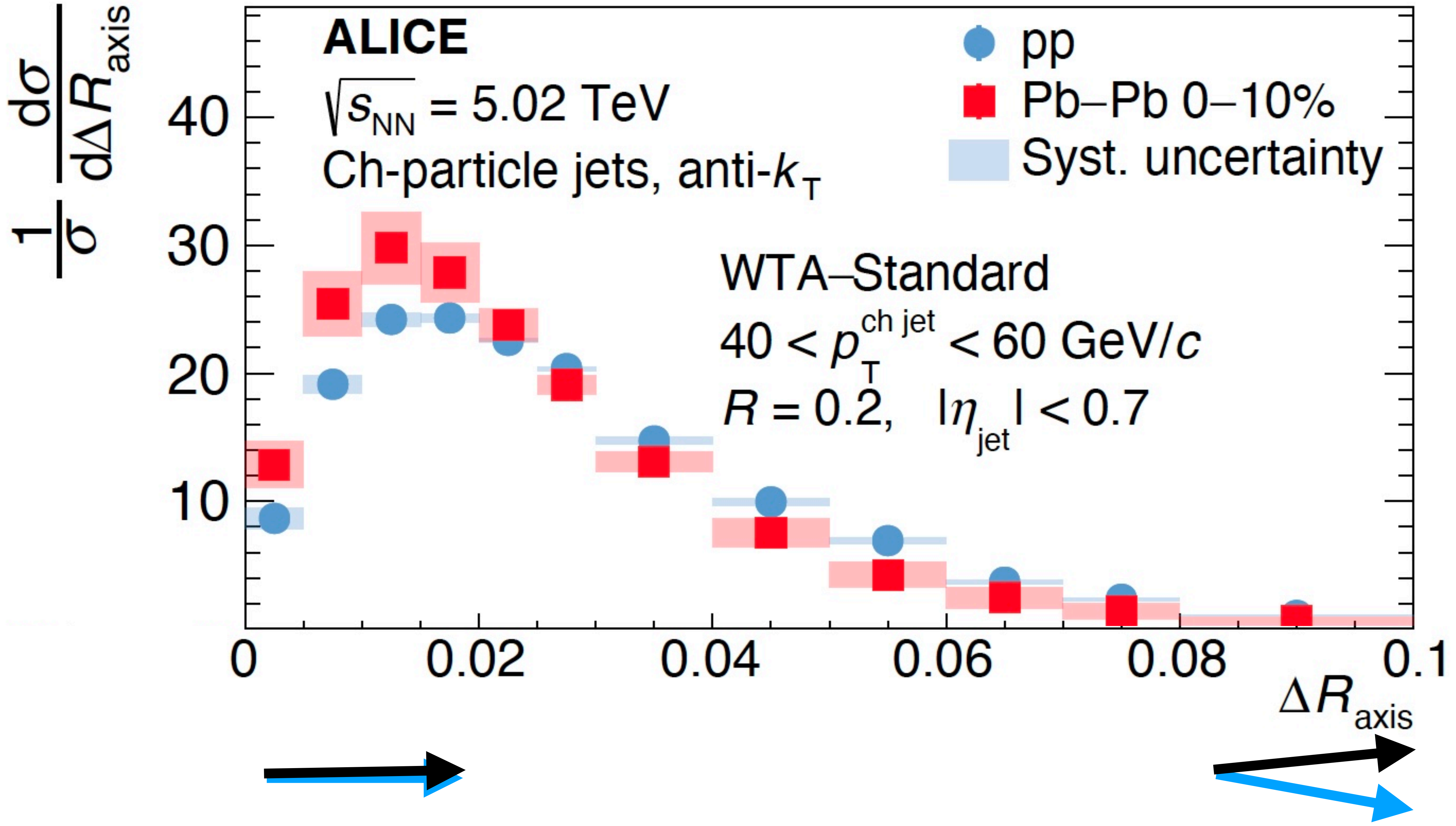
- Agreement throughout entire kinematics probed

- Agreement surprisingly good in the NP region

Measurement carried out for
$p_T^{ch\ jet} \in [20,100]$ GeV$/c$ $(R = 0.2,\ 0.4)$

Experimental results

ALICE, arXiv:2303.13347



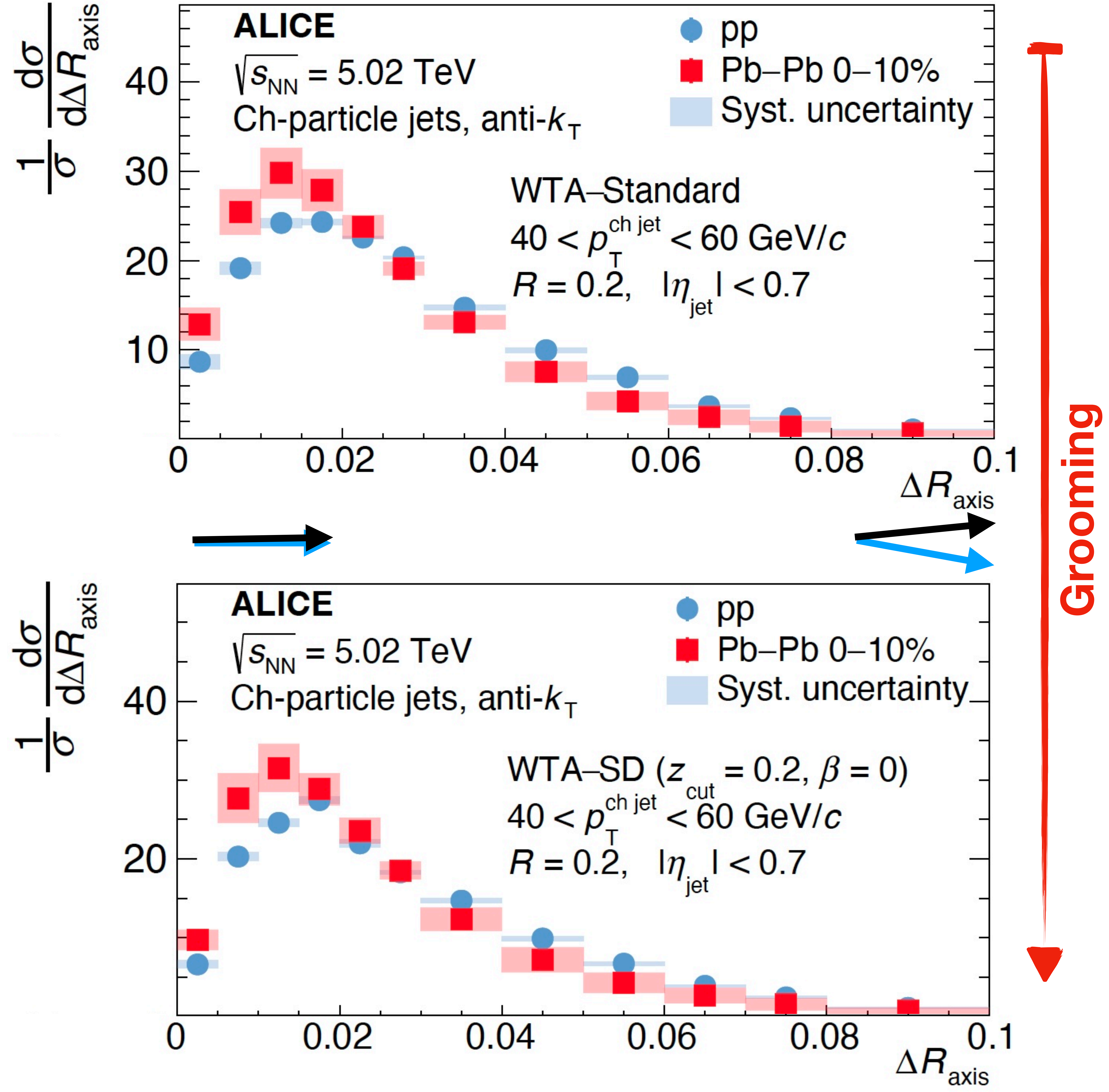
Narrower distribution in Pb—Pb

- Measurement carried out for $R = 0.2$ ($p_T^{ch\ jet} \in [40,140]$ GeV/c) and $R = 0.4$ ($p_T^{ch\ jet} \in [80,140]$ GeV/c)

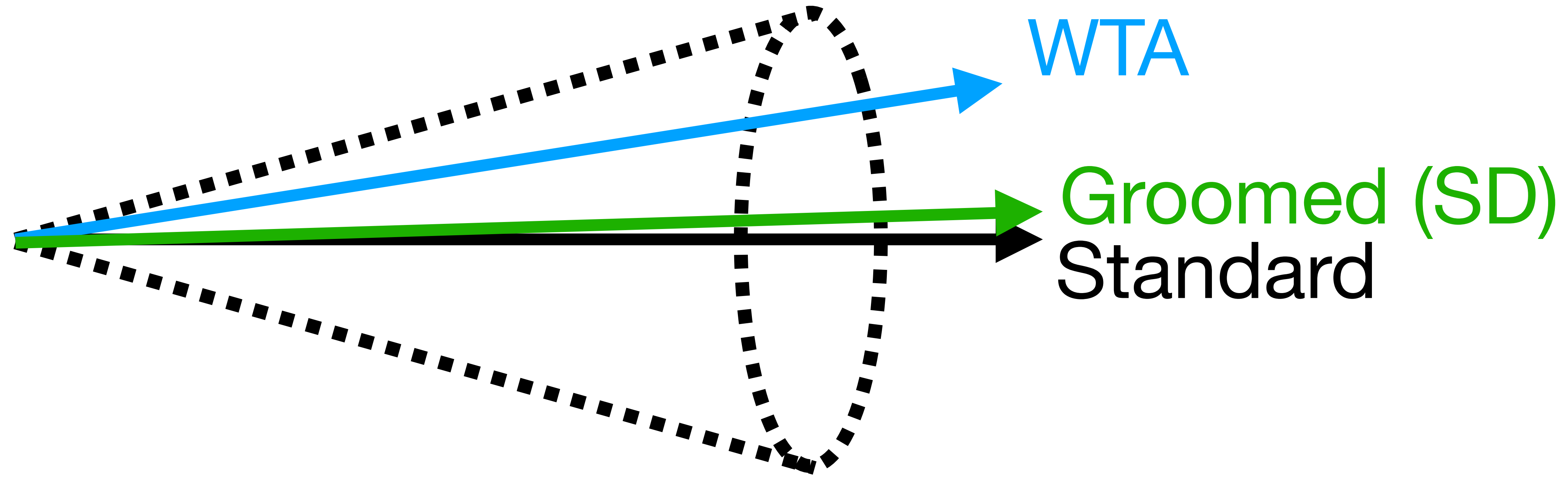
Fully corrected: Event-wide UE constituent subtraction + 2D Bayesian unfolding procedure (in ΔR_{axis} and $p_T^{ch\ jet}$)

Grooming impact

ALICE, arXiv:2303.13347

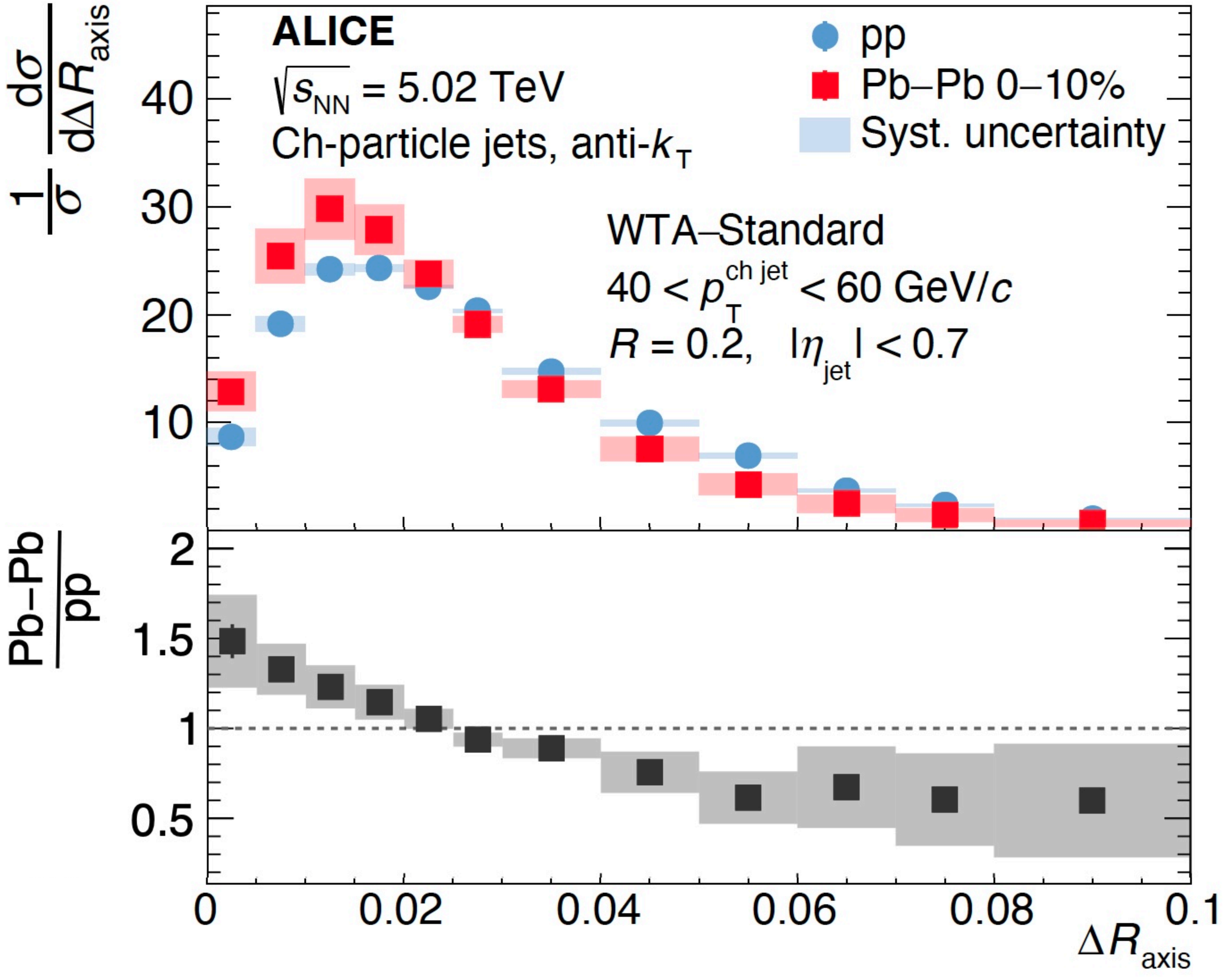


Overall insensitivity to grooming



Modification in Pb—Pb

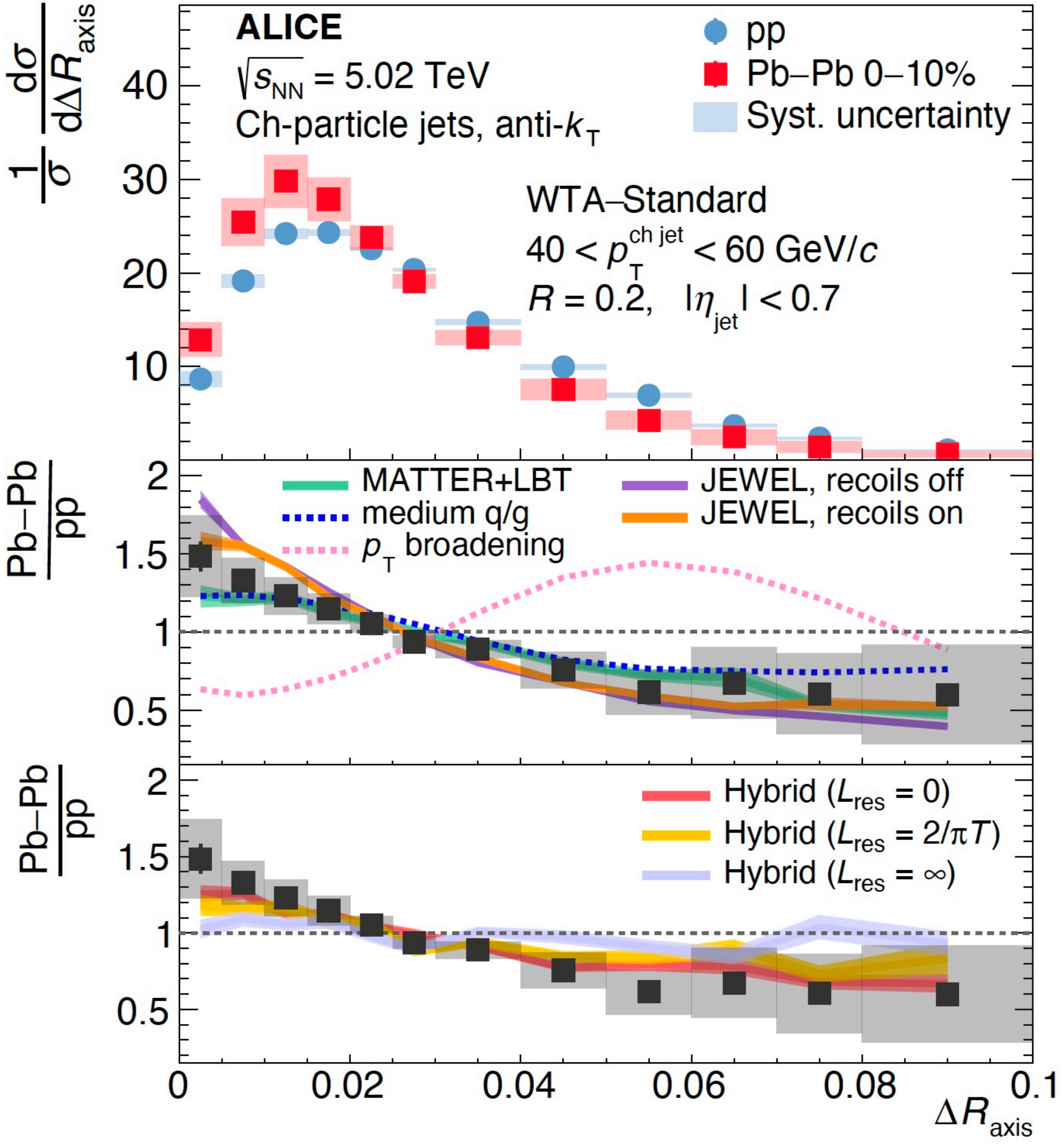
ALICE, arXiv:2303.13347



Model comparison

NEW

ALICE, arXiv:2303.13347



Hybrid .... Casalderrey-Solana et al., JHEP 10 (2014) 019
Hulcher et al., JHEP 03 (2018) 010
Casalderrey-Solana, et al JHEP 03 (2017) 135

JEWEL .... Zapp, Eur.Phys.J.C 74 (2014) 2

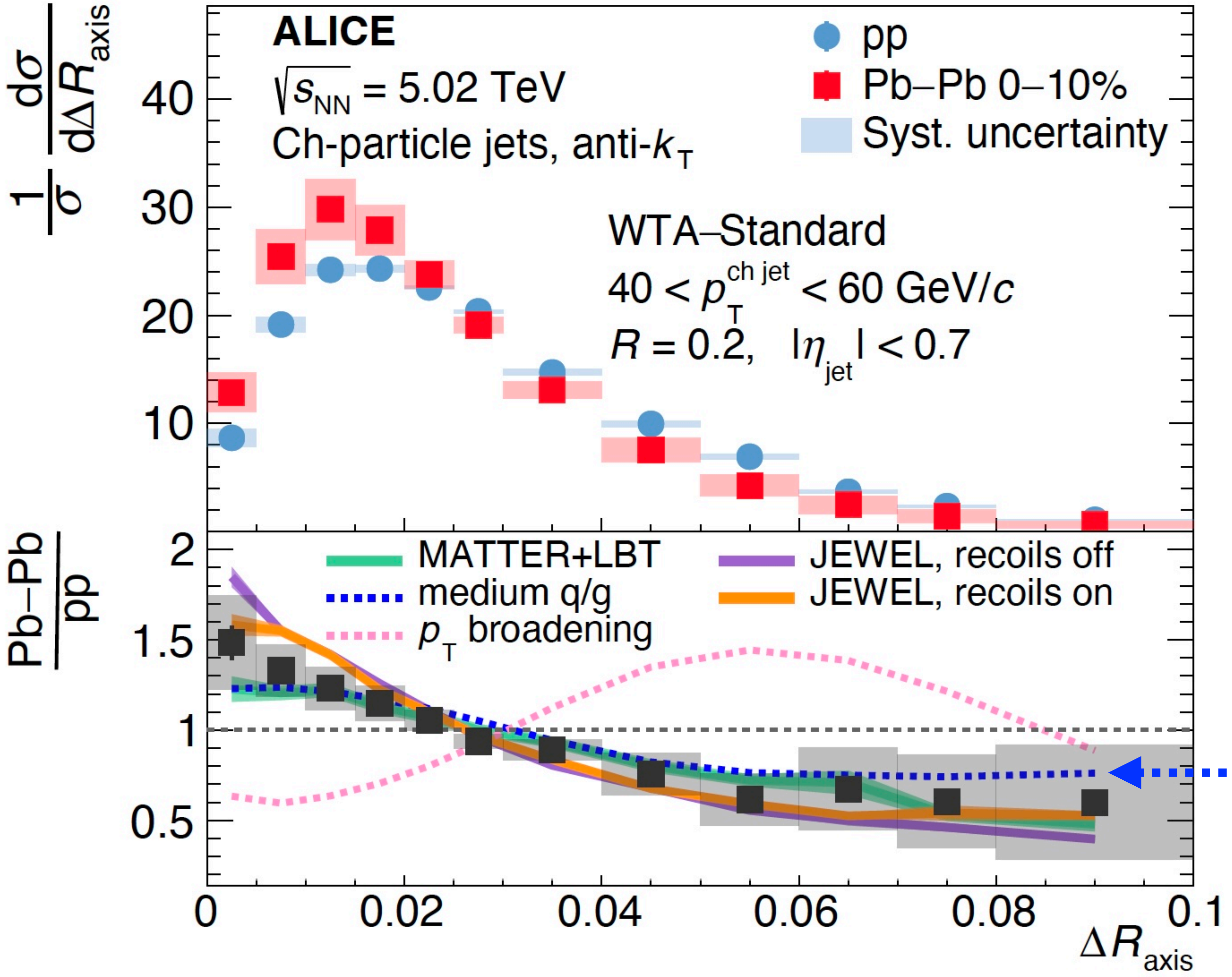
MATTER+LBT .... JETSCAPE, arXiv:2204.01163

medium q/g
p_T broadening .... Ringer et al., PLB 808 (2020) 135634

All models (but one) qualitatively agree with measurement

Modified q/g fraction

ALICE, arXiv:2303.13347



medium q/g

Qiu et al., PRL 122 (2019) 252301
Ringer et al., PLB 808 (2020) 135634

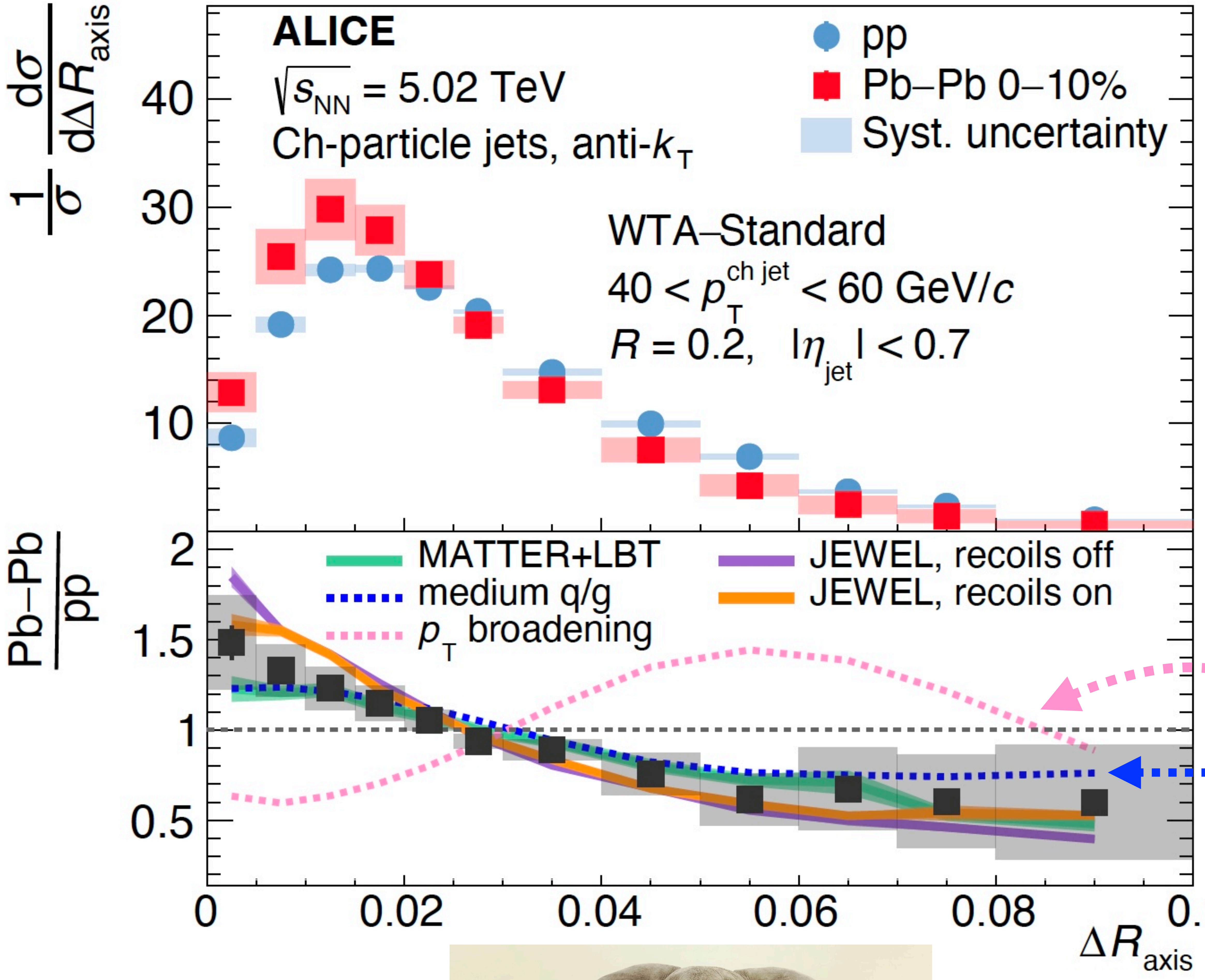
$$\Sigma(x) = f_q\Sigma_q(x) + f_g\Sigma_g(x)$$

- Phenomenological model
- Modification of q / g fraction

Narrowing of the angular substructure.
Selection bias?

Intra jet p_T broadening

ALICE, arXiv:2303.13347



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Qiu et al., PRL 122 (2019) 252301
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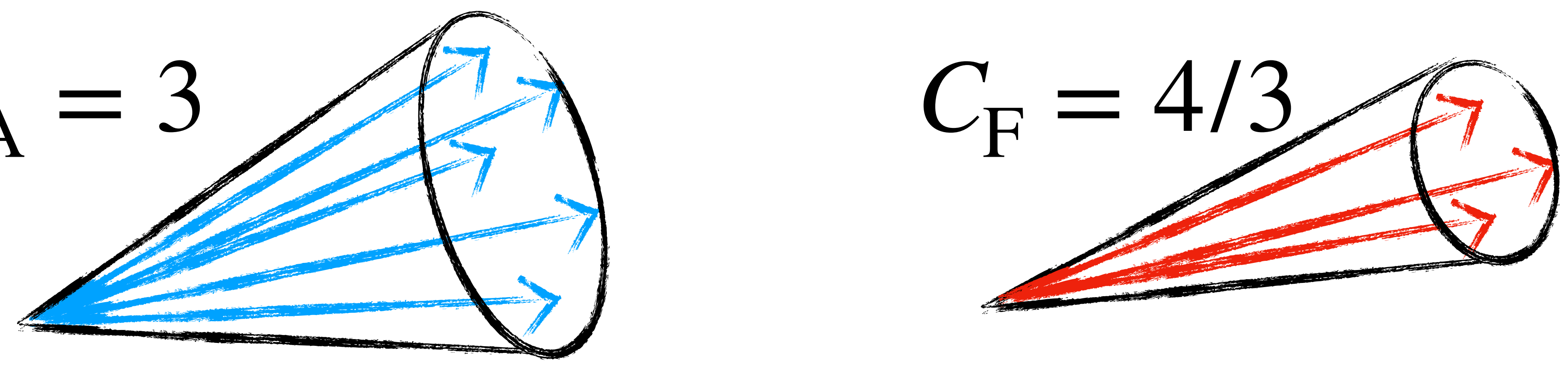


$C_A = 3$ $C_F = 4/3$

gluon jet quark jet

q/g + p_T broadening

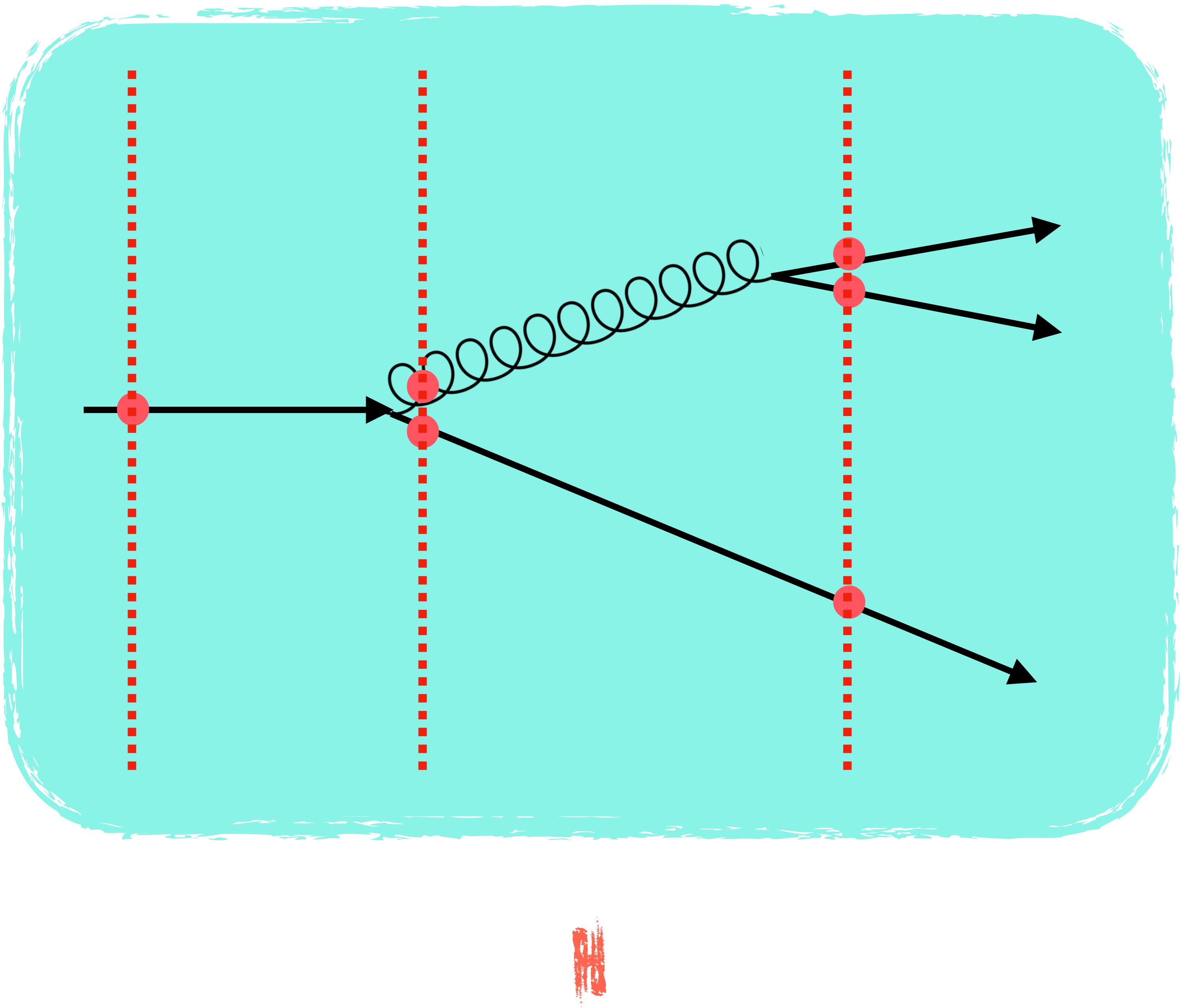
- p_T-broadening
- BDMPS approach

$$\langle\theta_\perp^2\rangle \propto \langle\hat{q}L\rangle = 5\ \mathrm{GeV}^2$$

Opposite trend with respect to data

Medium resolution length

L_{res}: characteristic scale of the medium at which a splitting can be resolved



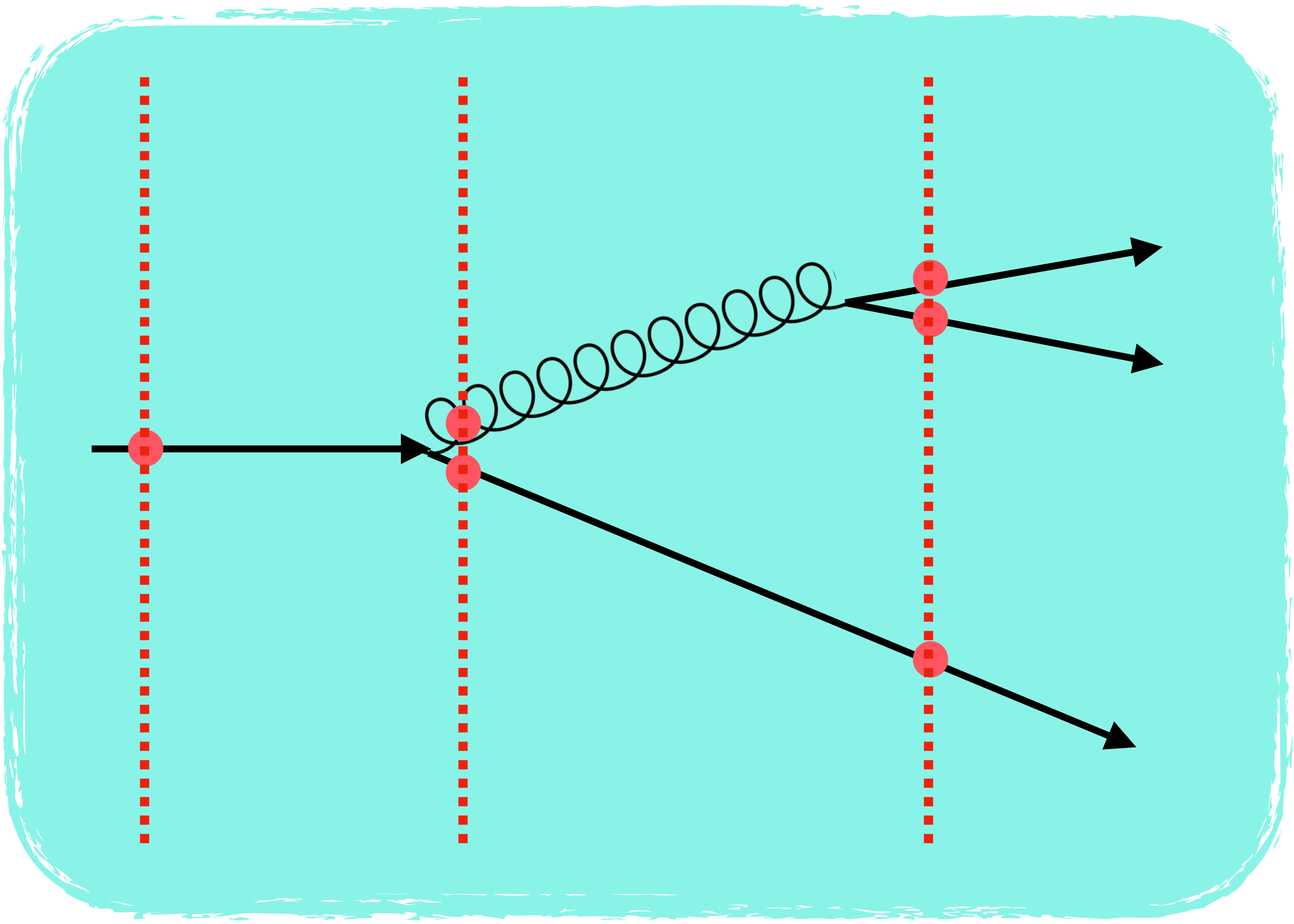
L_{res} = 0

medium resolves splitting
immediately after parton fragments.

Fully-incoherent energy loss

Medium resolution length

L_{res}: characteristic scale of the medium at which a splitting can be resolved



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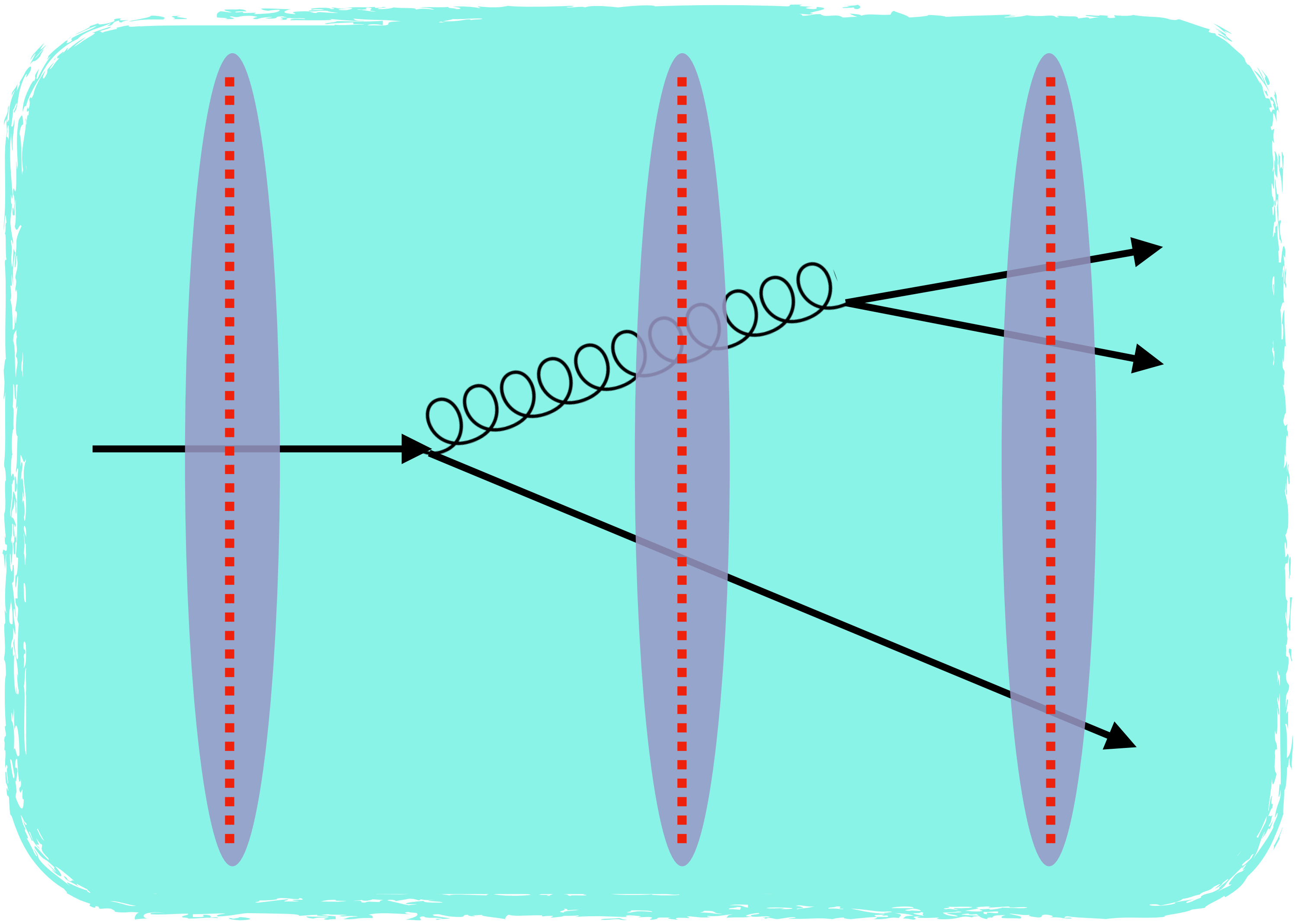


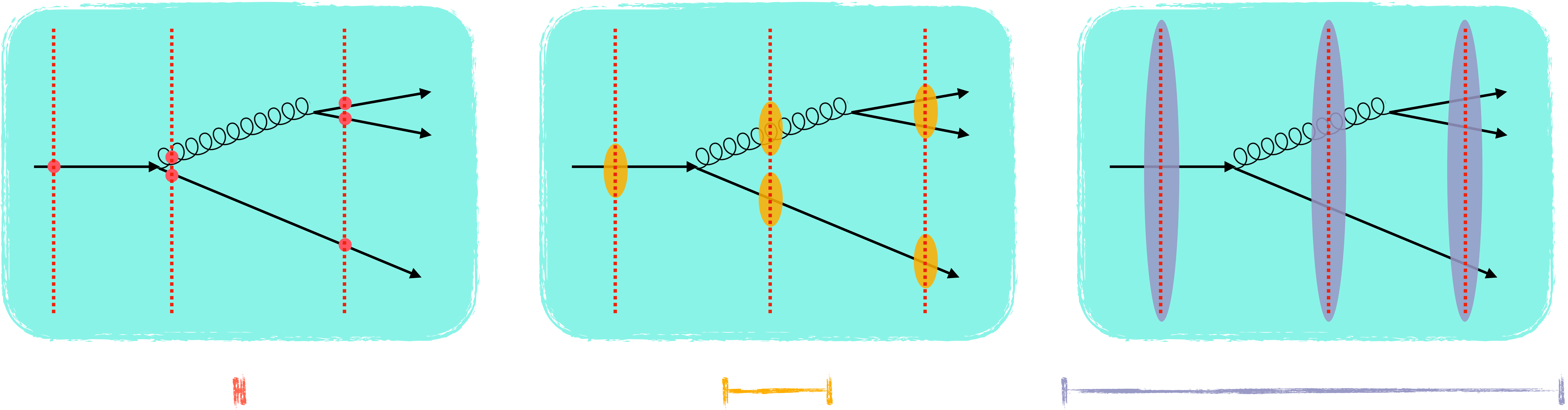
$L_{res} = \infty$

medium does not resolve splitting.

Fully-coherent energy loss

Medium resolution length

L_{res}: characteristic scale of the medium at which a splitting can be resolved



$L_{res} = 0$	**$L_{res} = 2/\pi T$**	**$L_{res} = \infty$**
medium resolves splitting immediately after parton fragments. Fully-incoherent energy loss	Intermediate case	medium does not resolve splitting. Fully-coherent energy loss

ΔR_{axis} to probe microscopic structure of QGP

ALICE, arXiv:2303.13347
Casalderrey-Solana et al., JHEP 10 (2014) 019
Hulcher et al., JHEP 03 (2018) 010
Casalderrey-Solana, et al JHEP 03 (2017) 135

Data favors mechanisms of incoherent energy loss in the QGP*
*based on the Hybrid model

Outline

ALICE

First measurement of jet-axis differences in Pb—Pb and pp collisions

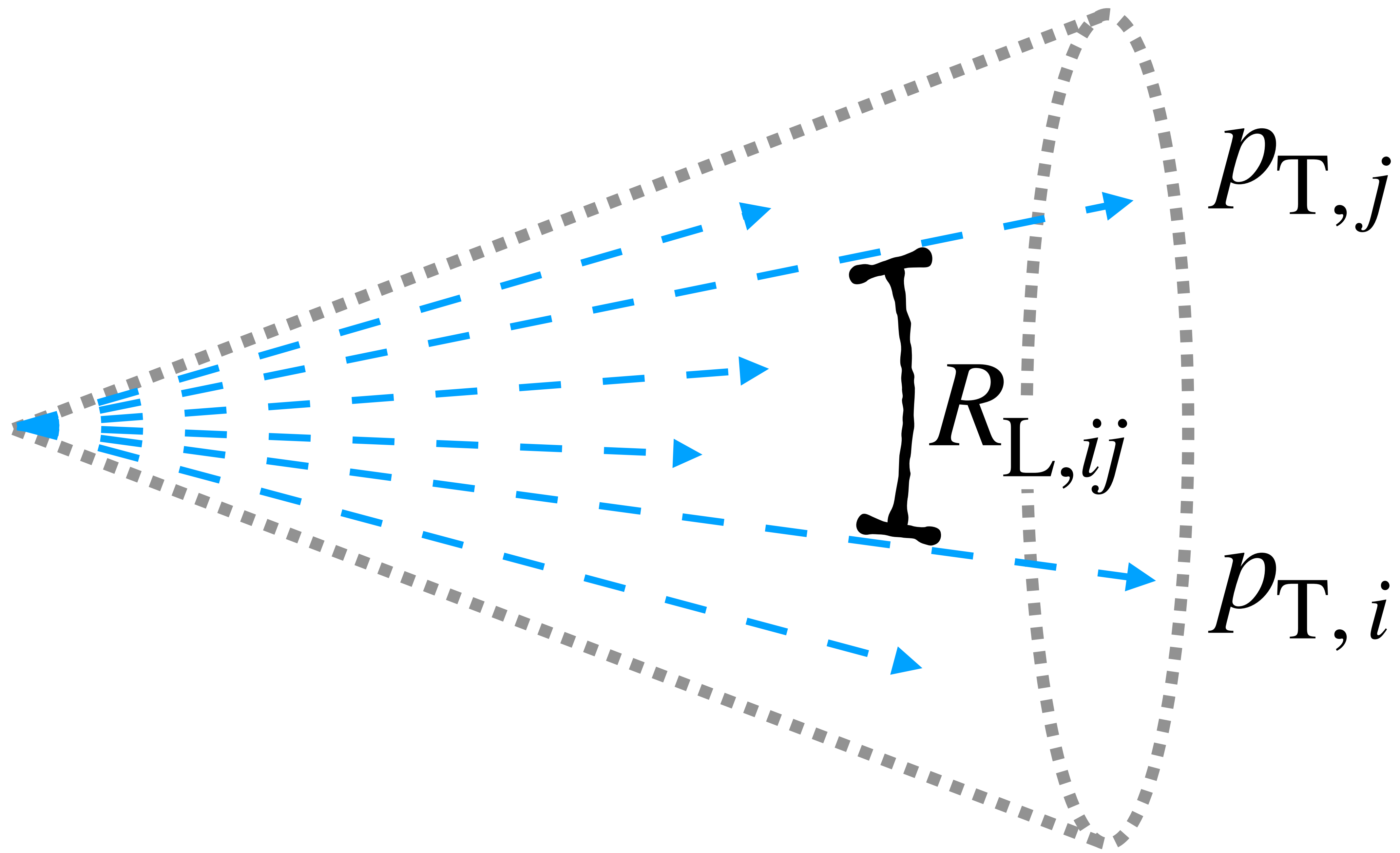
ALICE, arXiv:2211.08928, JHEP In press
ALICE, arXiv:2303.13347

Energy-energy correlators in pp collisions

PRELIMINARY

Energy-energy correlators

$$R_L = \sqrt{\Delta\varphi_{ij}^2 + \Delta\eta_{ij}^2}$$



$$\frac{p_{T,i}\, p_{T,j}}{p_{T,jet}^2}$$

$$\frac{d\sigma_{EEC}}{dR_L} = \sum_{i,j} \int d\sigma(R'_L)\, \frac{p_{T,i}\, p_{T,j}}{p_{T,jet}^2}\, \delta(R'_L - R_{L,ij})$$

Komiske et al., PRL 130 (2023) 051901
Lee et al., arXiv:2205.03414

- Reduced sensitivity to soft radiation
  - related to p_T weighting
  - No need for grooming

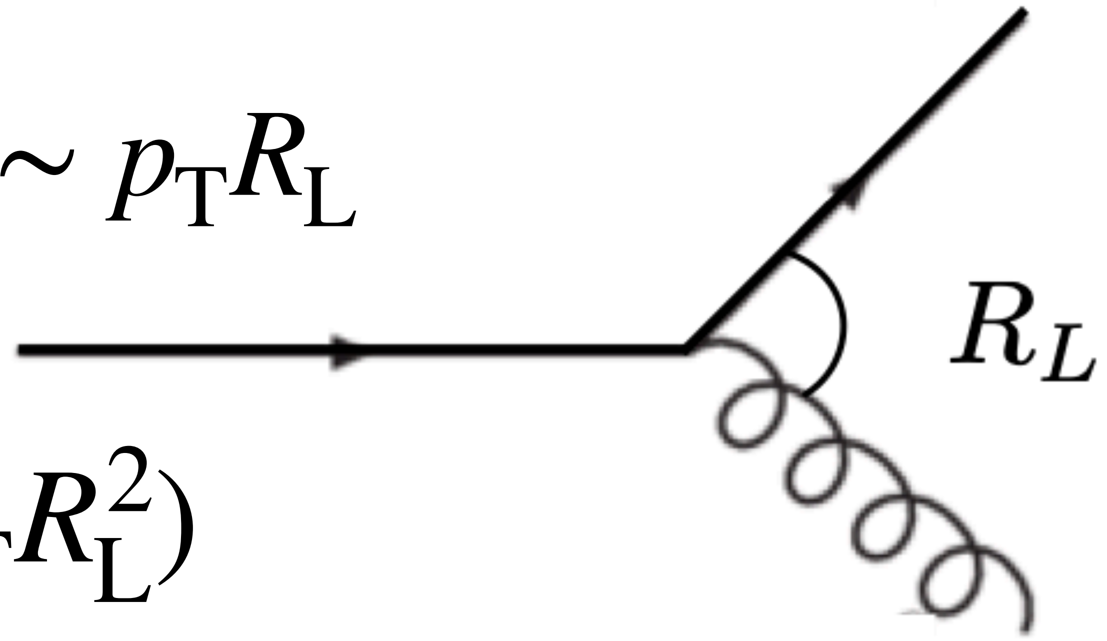
Why study this observable?

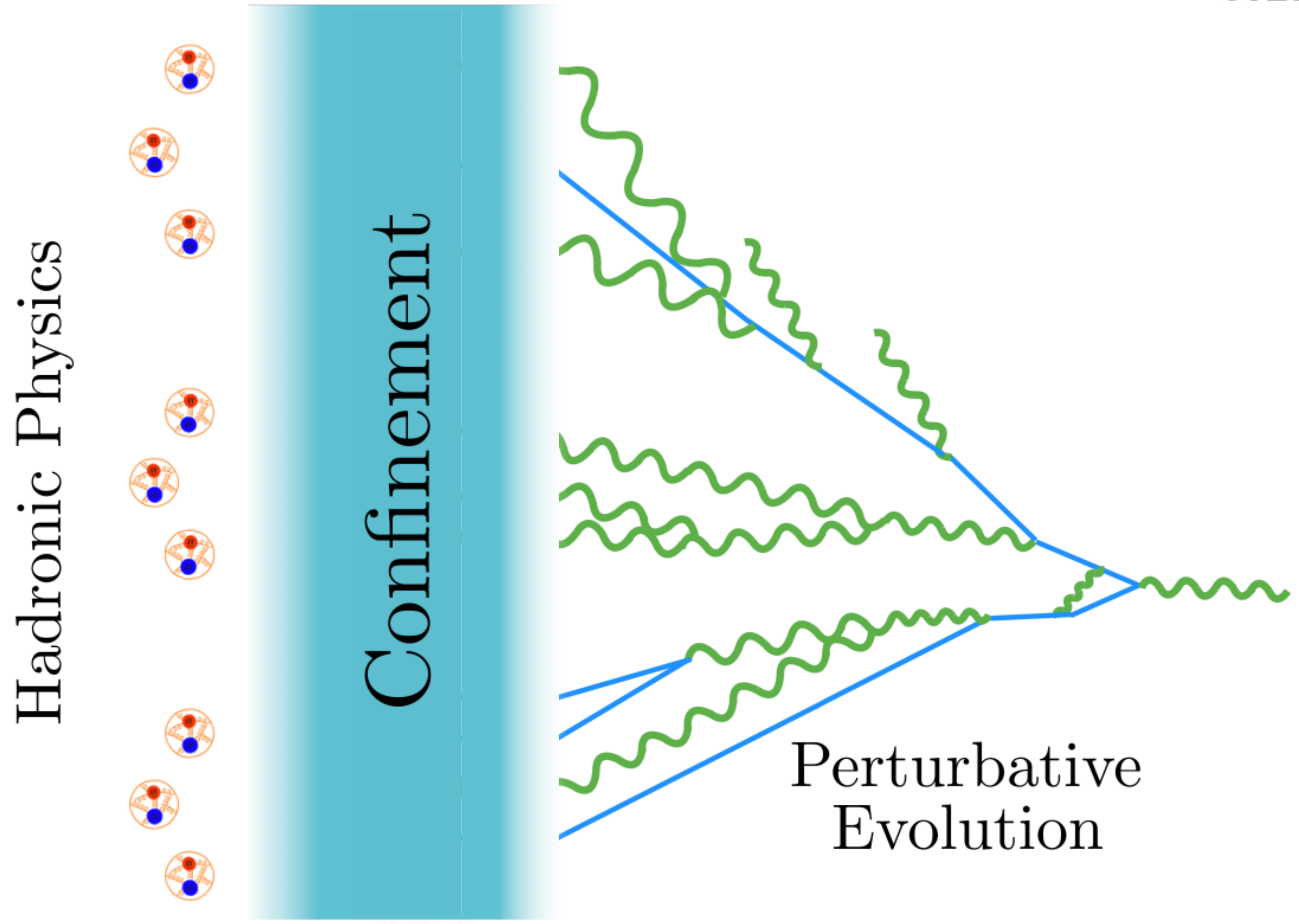
- **Separation of perturbative and non-perturbative regimes**
  - When virtuality approaches $\Lambda_{\mathrm{QCD}} \sim p_{\mathrm{T}}^{\mathrm{jet}} R_{\mathrm{L}} \rightarrow$ EEC undergoes phase transition

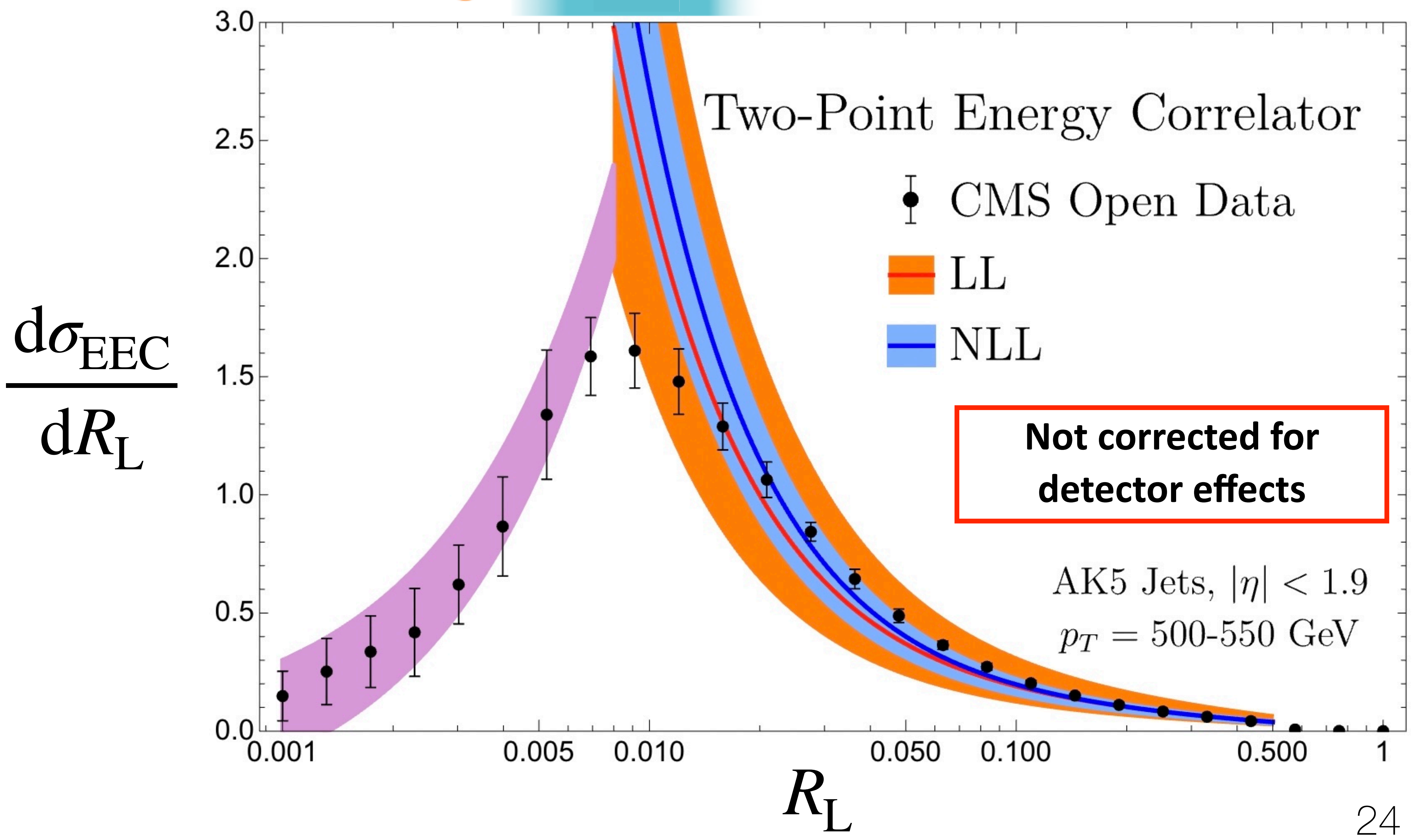
- **Calculable in pQCD (stringent theory tests)**
  - path towards calculations in strongly-coupled limit

$$\text{virtuality} \sim p_{\mathrm{T}} R_{\mathrm{L}}$$

$$\tau \simeq 1/(p_{\mathrm{T}} R_{\mathrm{L}}^2)$$







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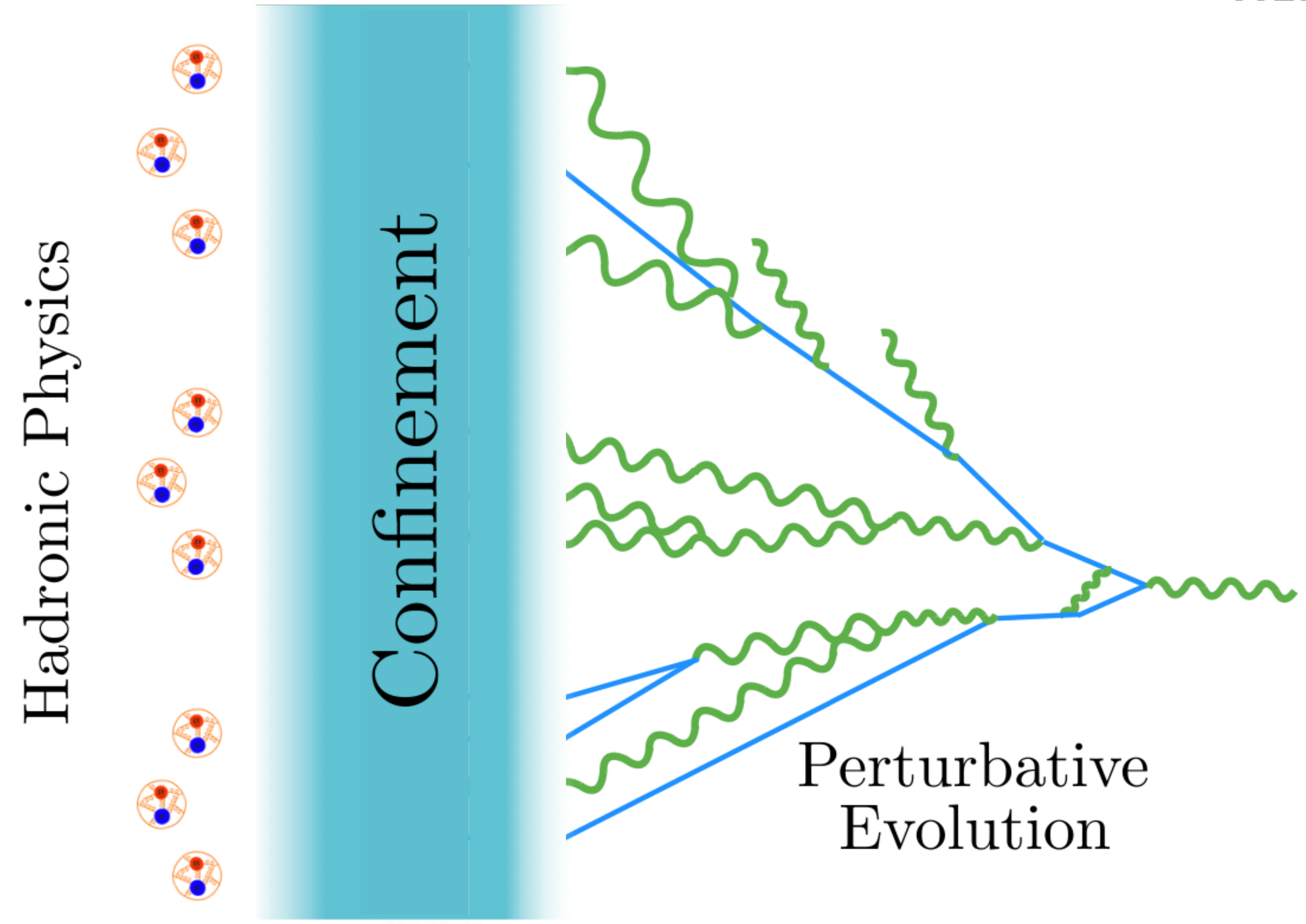
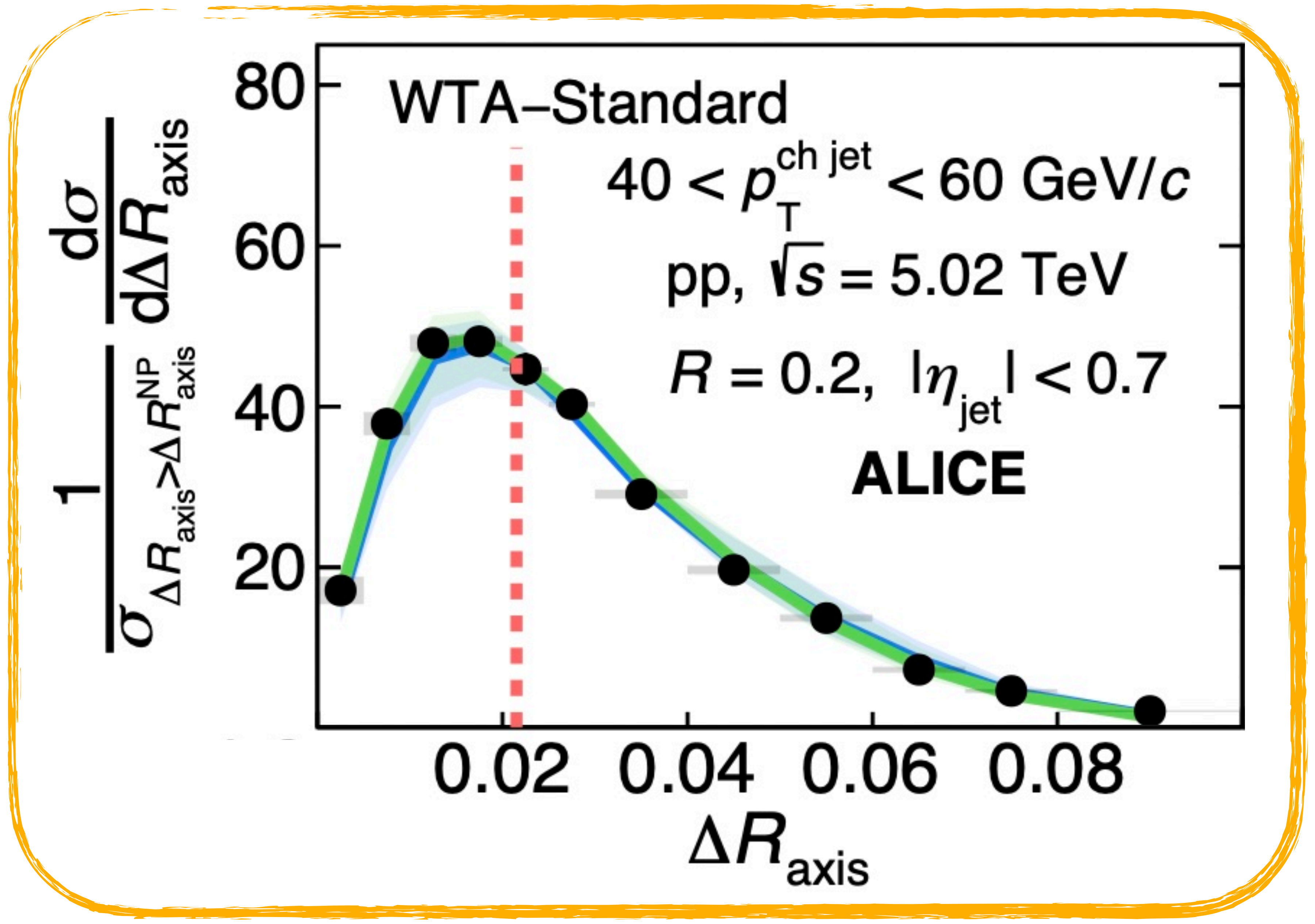
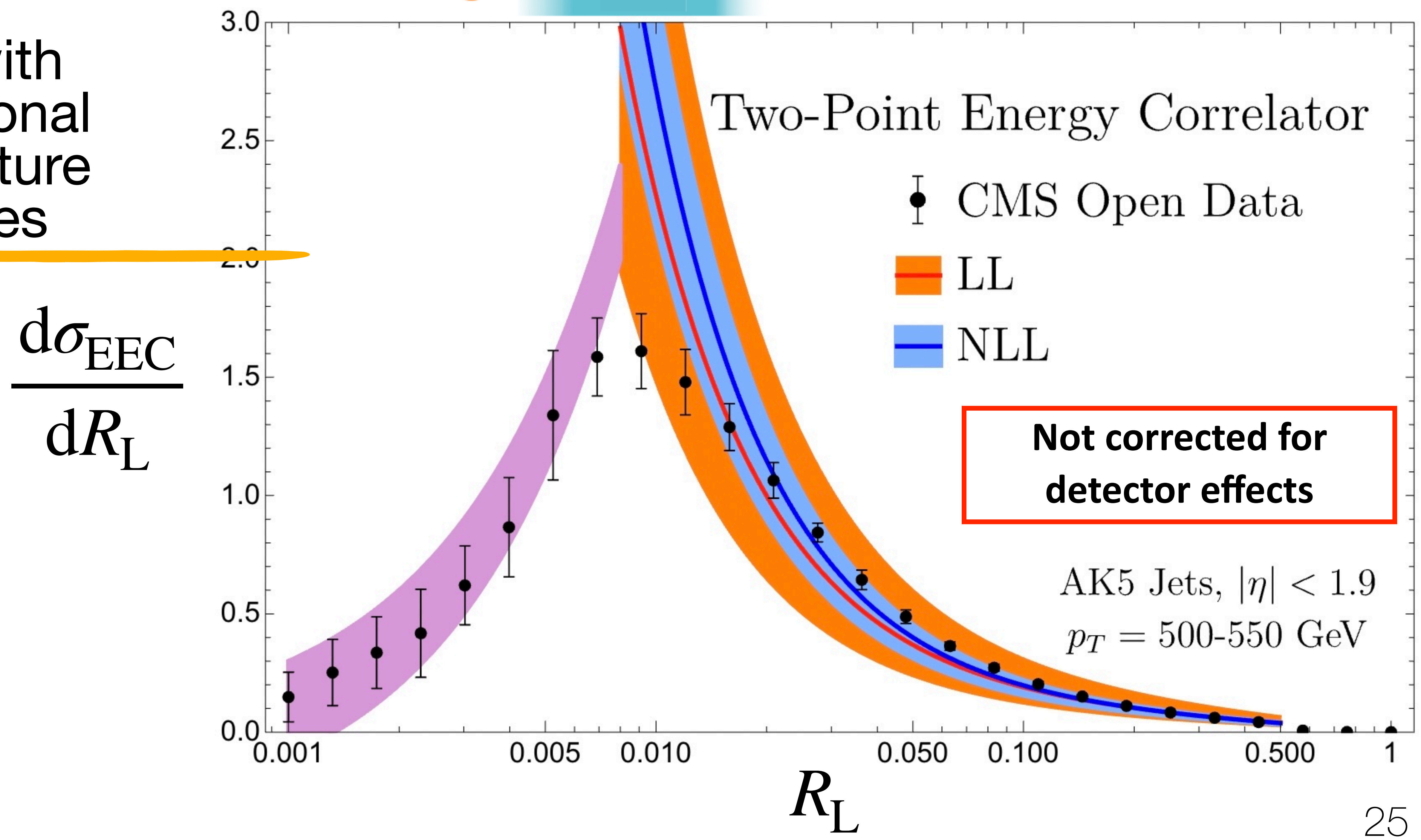
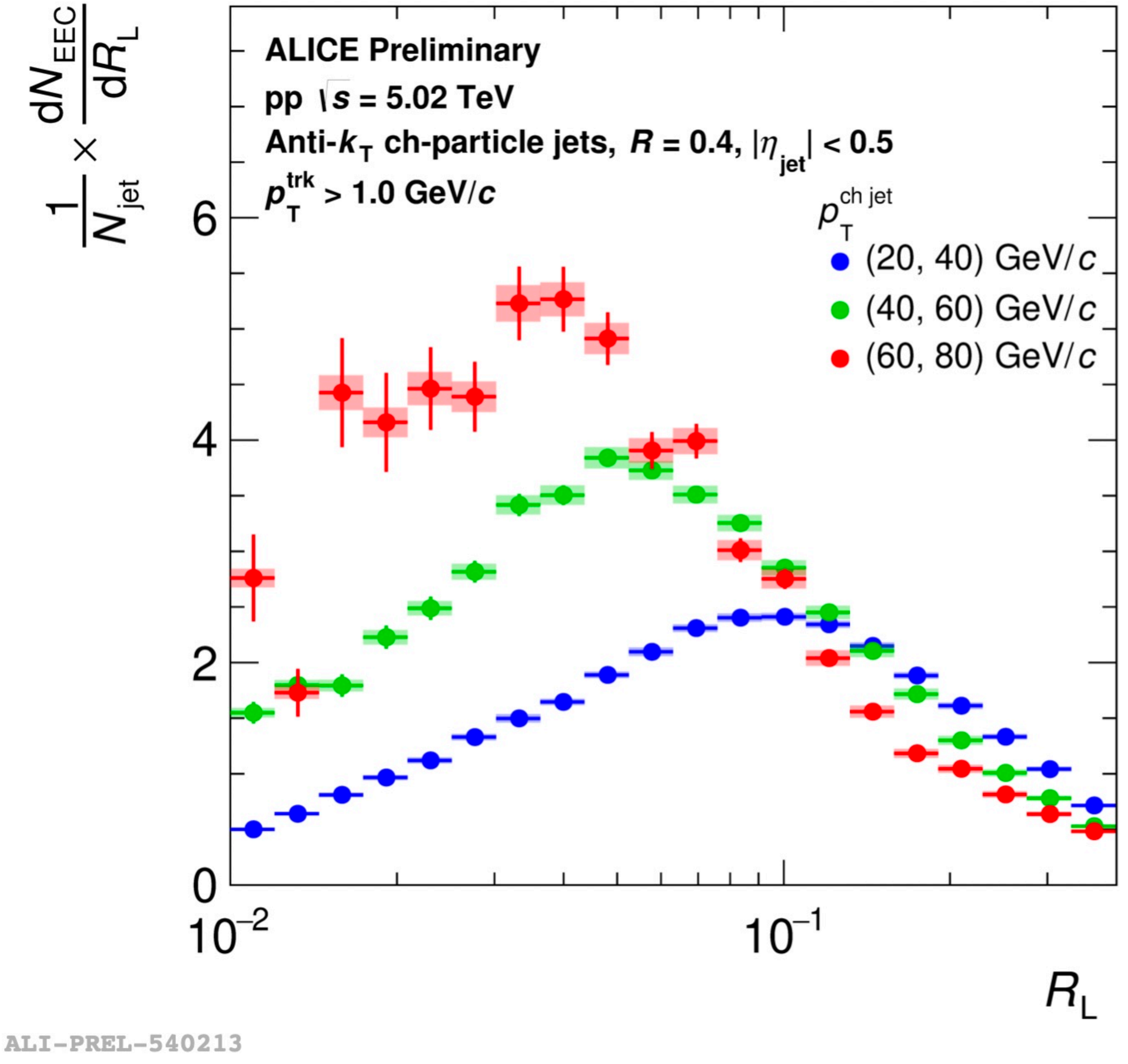




Contrast with more traditional jet substructure observables



Experimental results

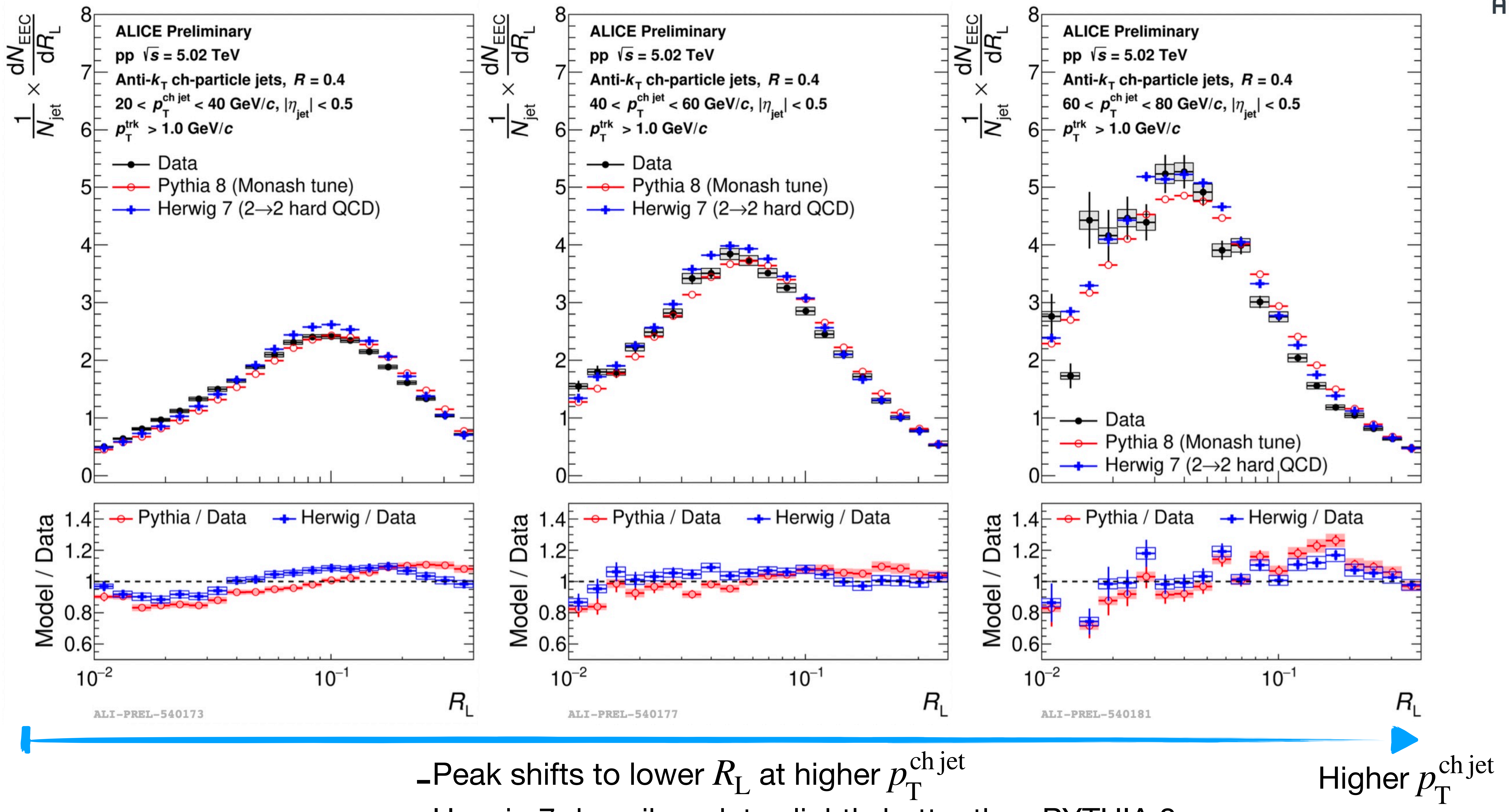


Measurement carried out in
$p_T^{ch\ jet} \in [20,80]$ GeV/c ($R = 0.4$)

Detector effects corrected bin-by-bin

- Data and MC (PYTHIA 8 & Herwig 7) agree at detector level
- Correction factor is small
- Small systematics (< 4%)

Model comparison

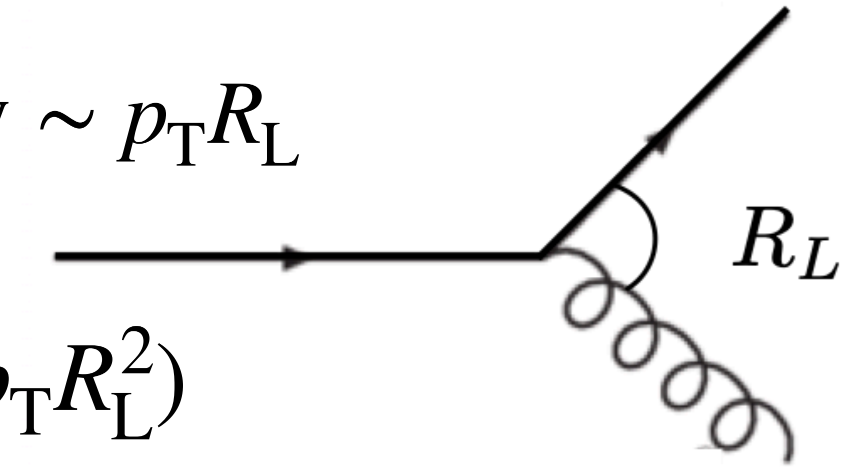


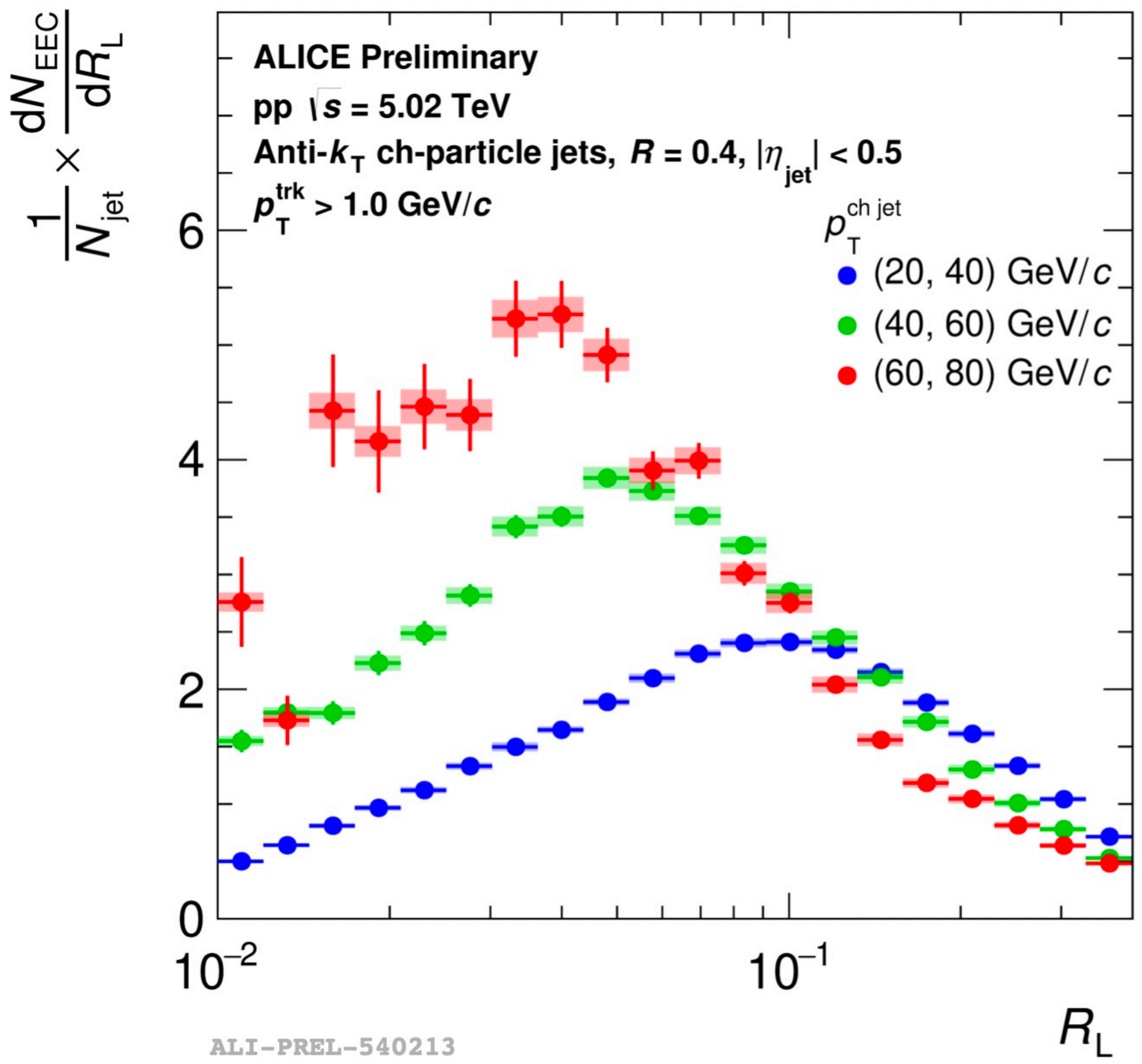
- Peak shifts to lower R_L at higher $p_T^{ch\,jet}$
- Herwig 7 describes data slightly better than PYTHIA 8
- Data has broader width than Herwig 7

Universal behavior of the transition region

virtuality $\sim p_\mathrm{T} R_\mathrm{L}$

$\tau \simeq 1/(p_\mathrm{T} R_\mathrm{L}^2)$





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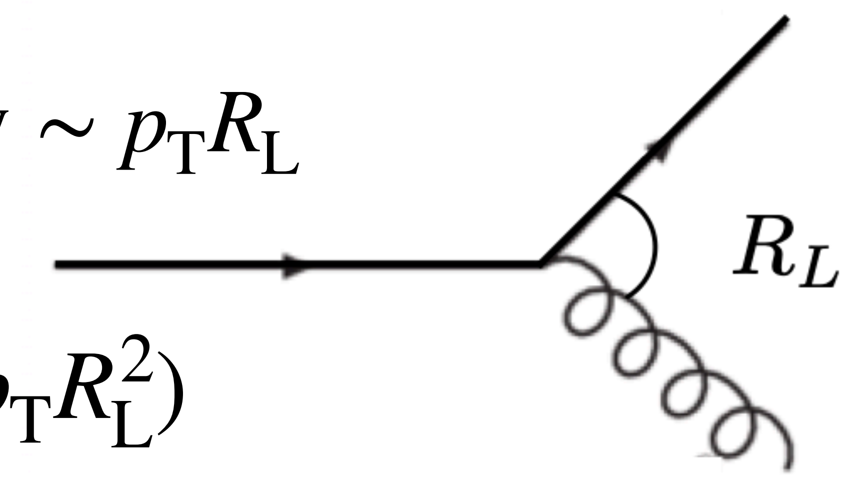
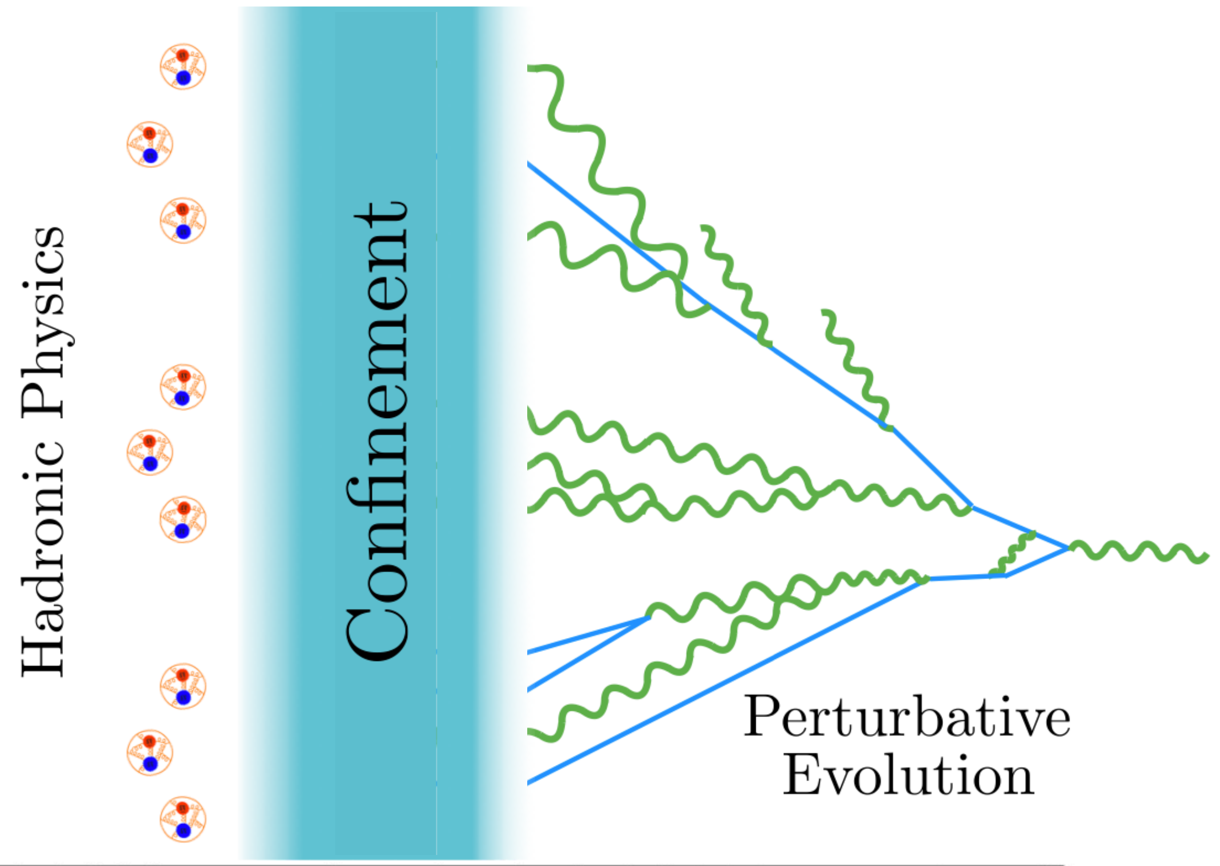
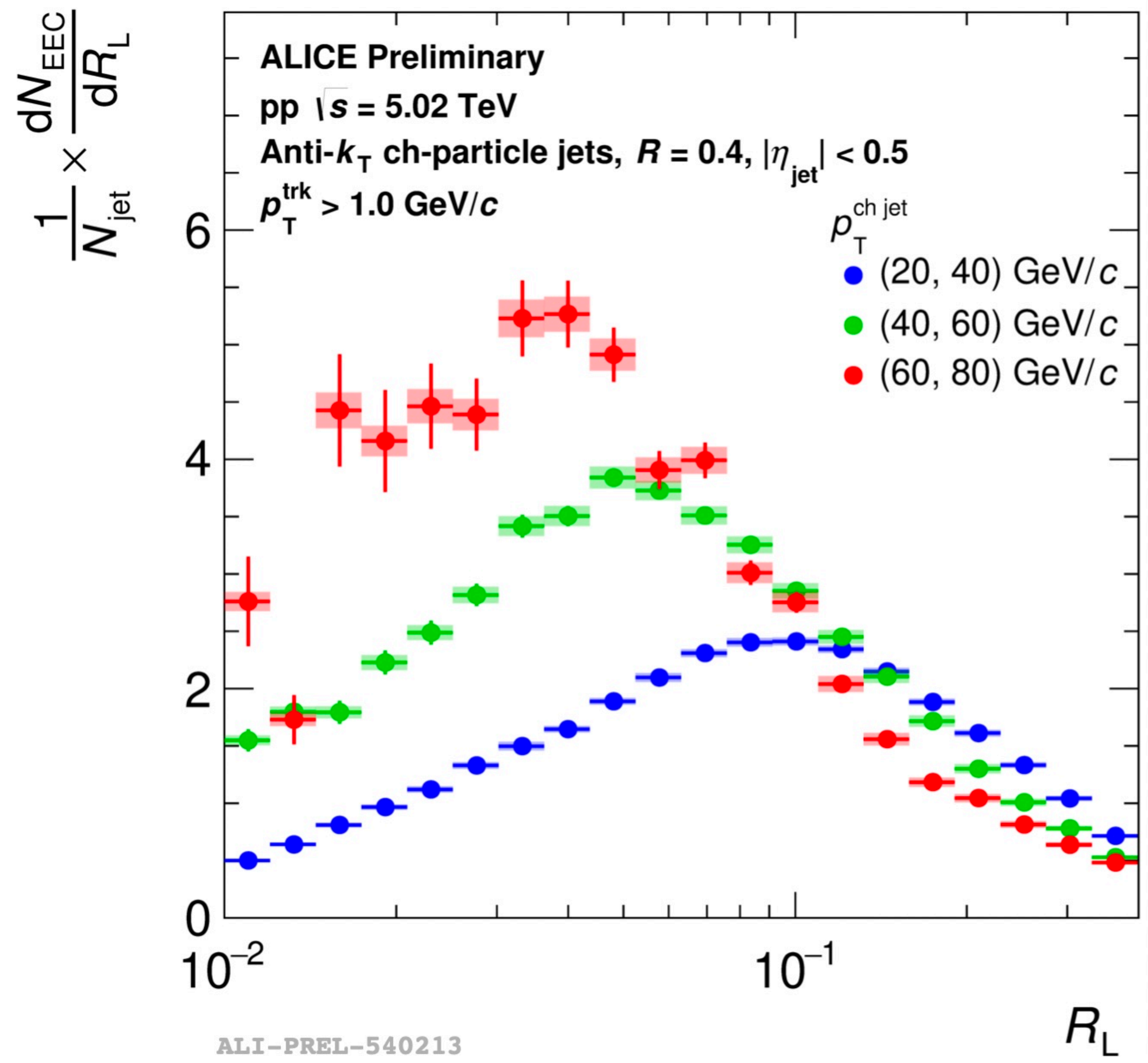
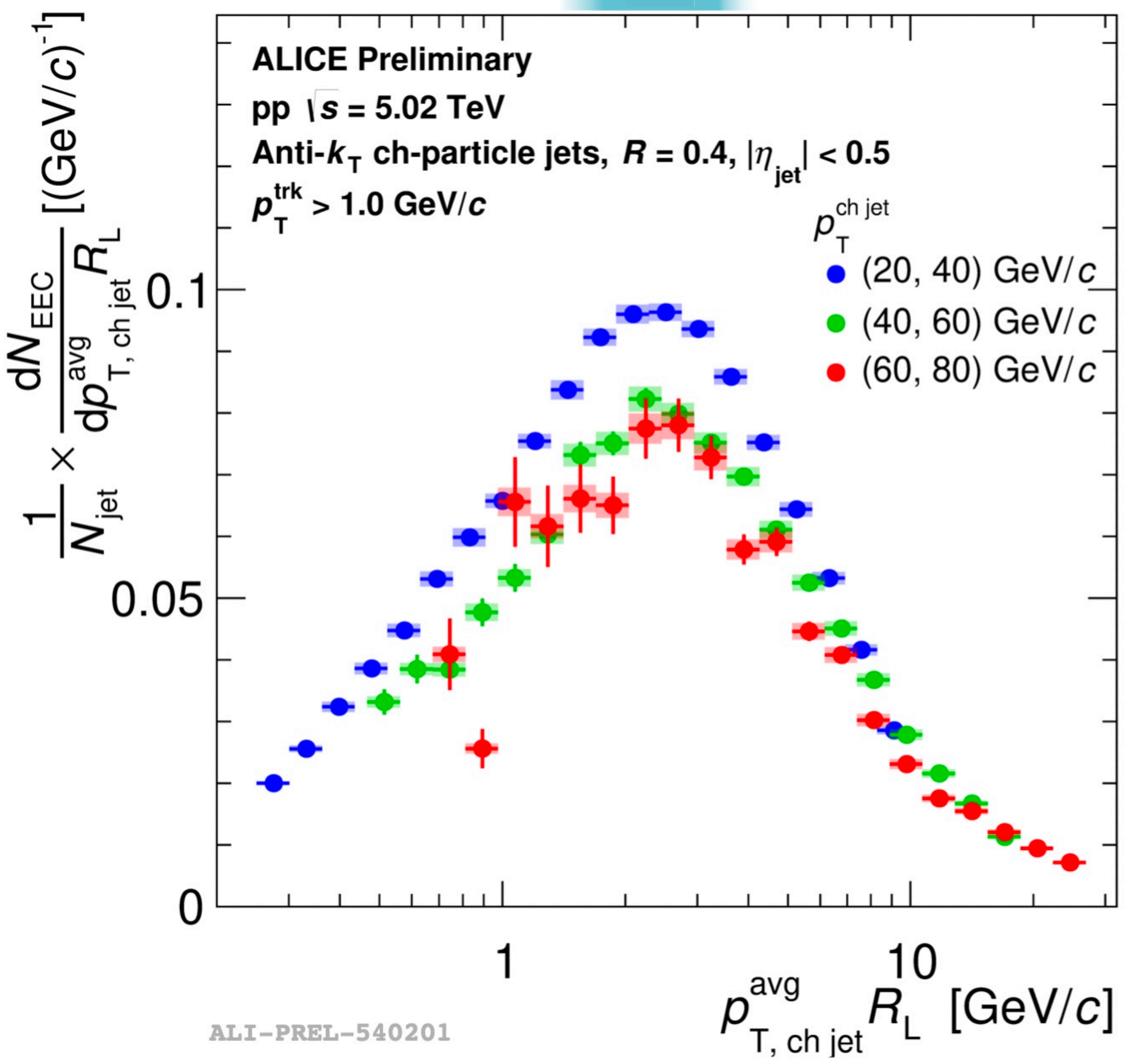


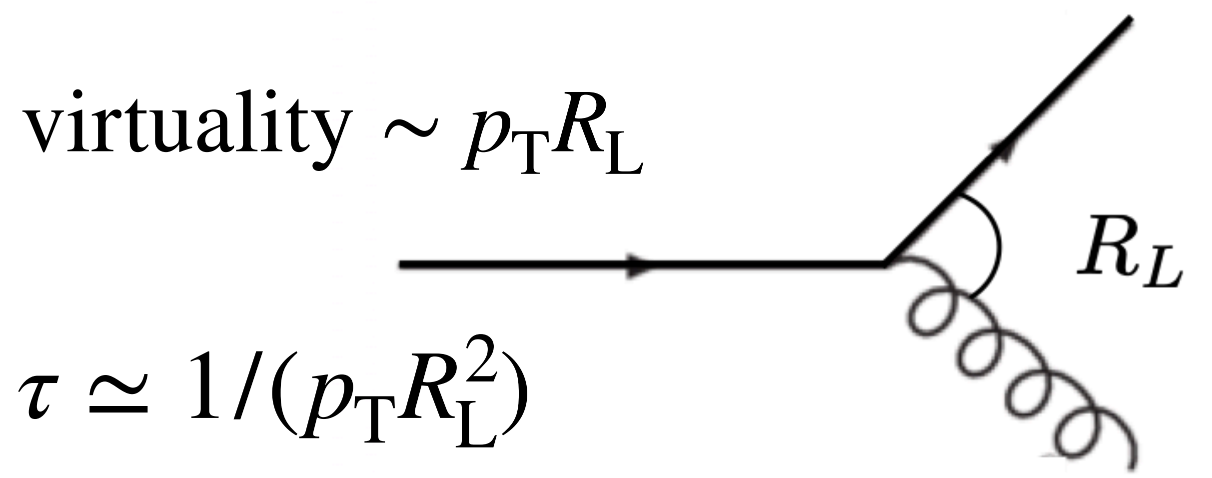


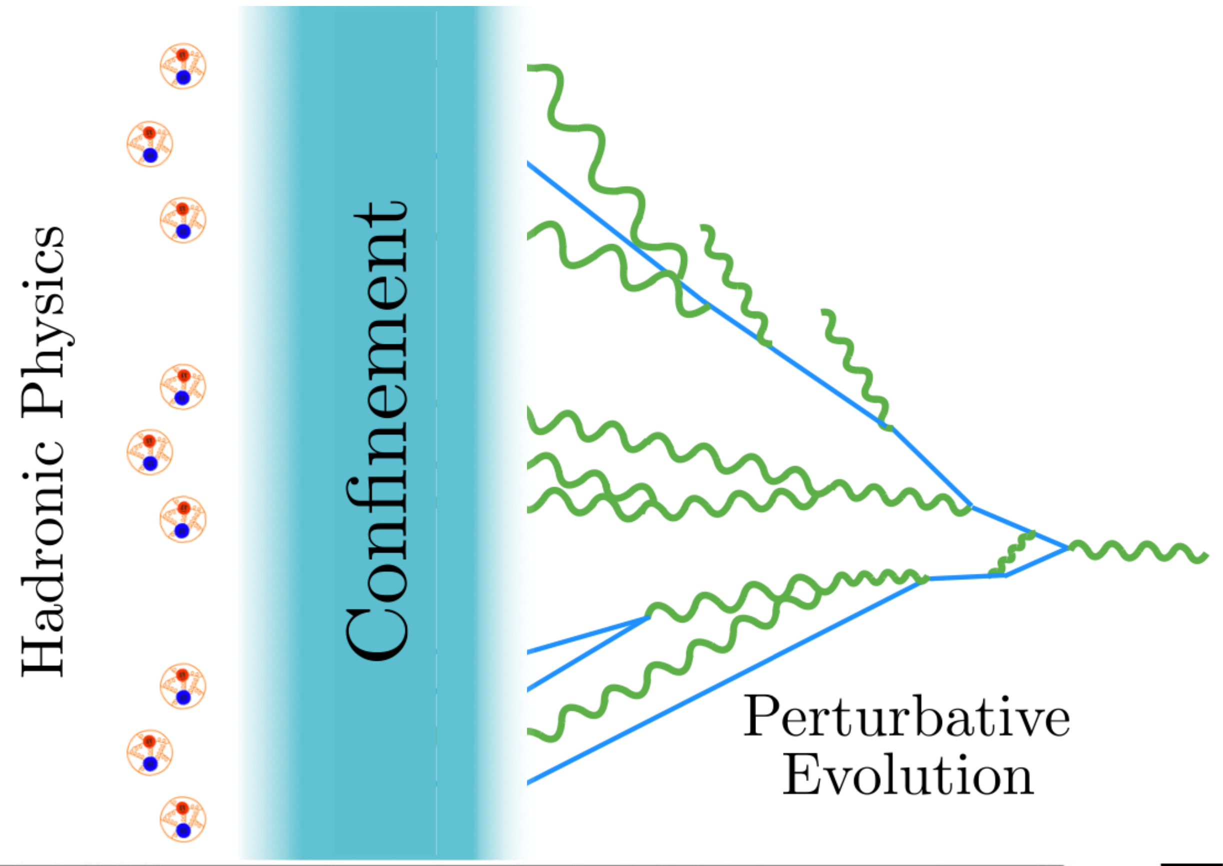




Scaling R_{L} by $p_{\mathrm{T}}^{\mathrm{ch\ jet}}$

Universal behavior of the transition region

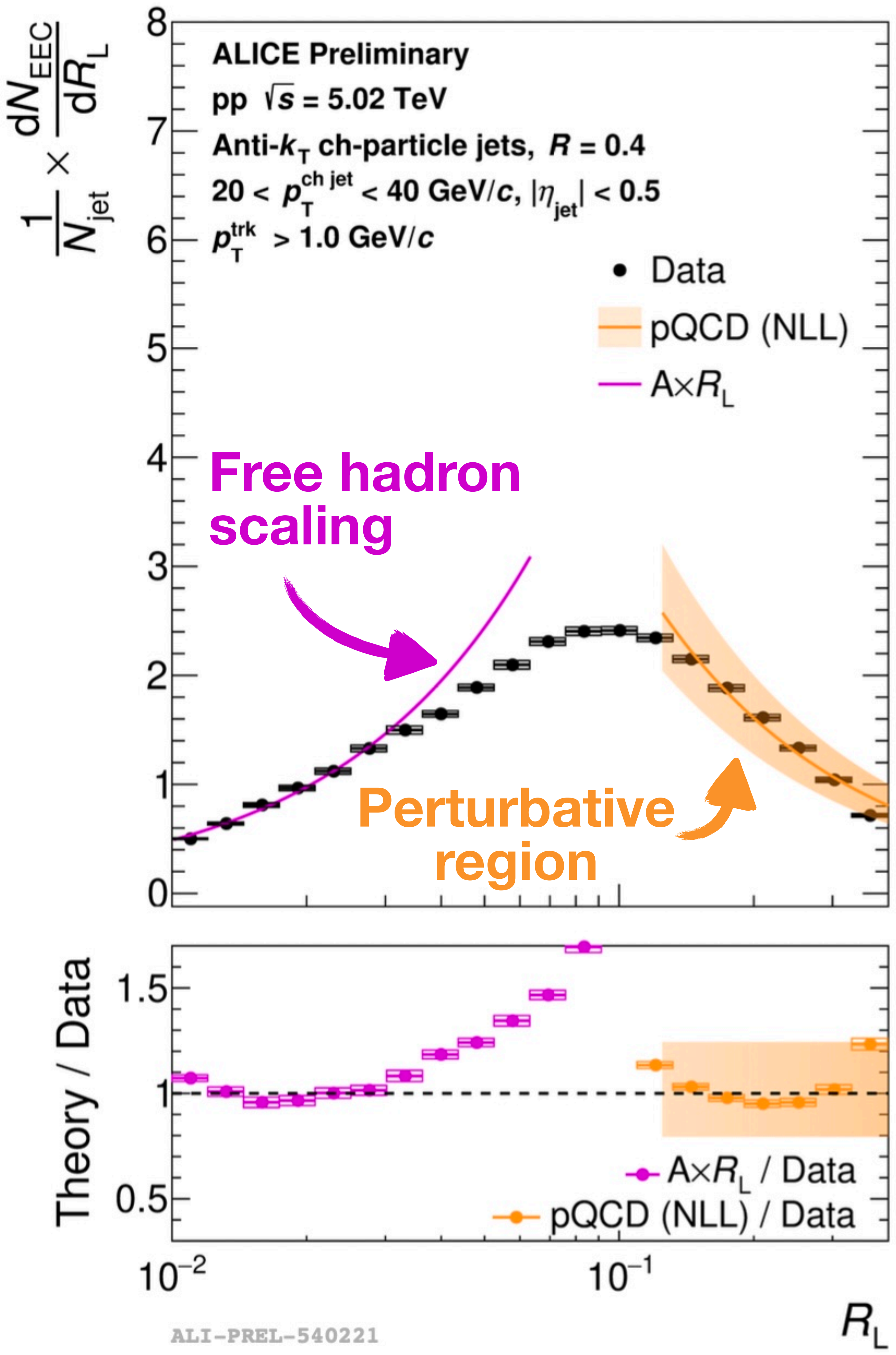




Scaling R_L by $p_T^{ch\,jet}$

Normalizing curves

Comparison to pQCD



Lee et al., arXiv:2205.03414

From right to left:

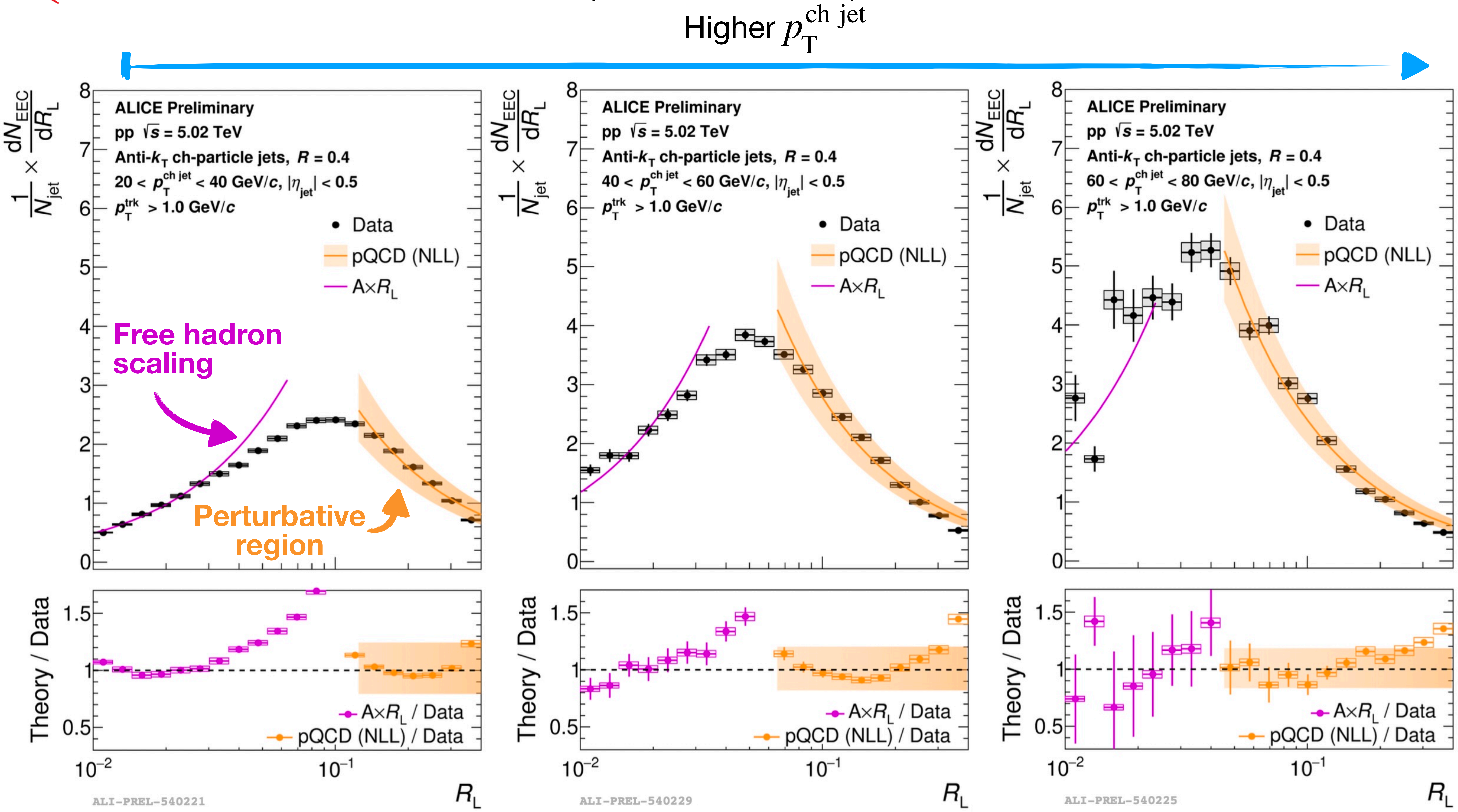
Deviation between **data** and **NLL calculations**: onset of non-perturbative effects

Agreement between **data** and **free hadron scaling**: onset of uniformly distributed hadron scaling behavior

NLL calculations correspond to full (charged+neutral) jets and are normalized to data in perturbative region

Comparison to pQCD

Lee et al., arXiv:2205.03414

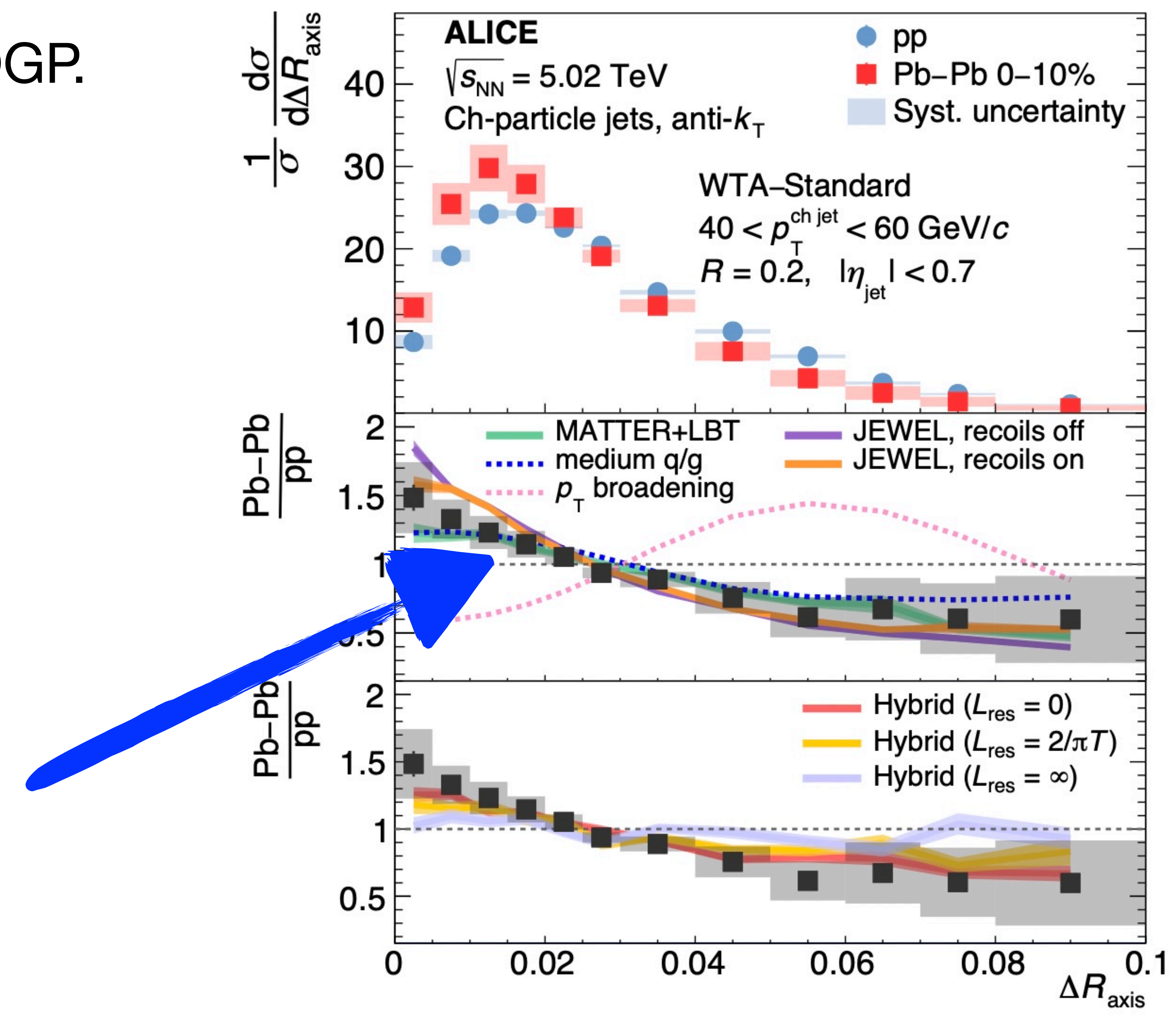


NLL calculations correspond to full (charged+neutral) jets and are normalized to data in perturbative region

Summary

First measurement of angle between jet angles

- Pb—Pb distributions narrower than pp -> consistent with g jets more active than q jets in the QGP.



ALICE, arXiv:2211.08928
ALICE, arXiv:2303.13347

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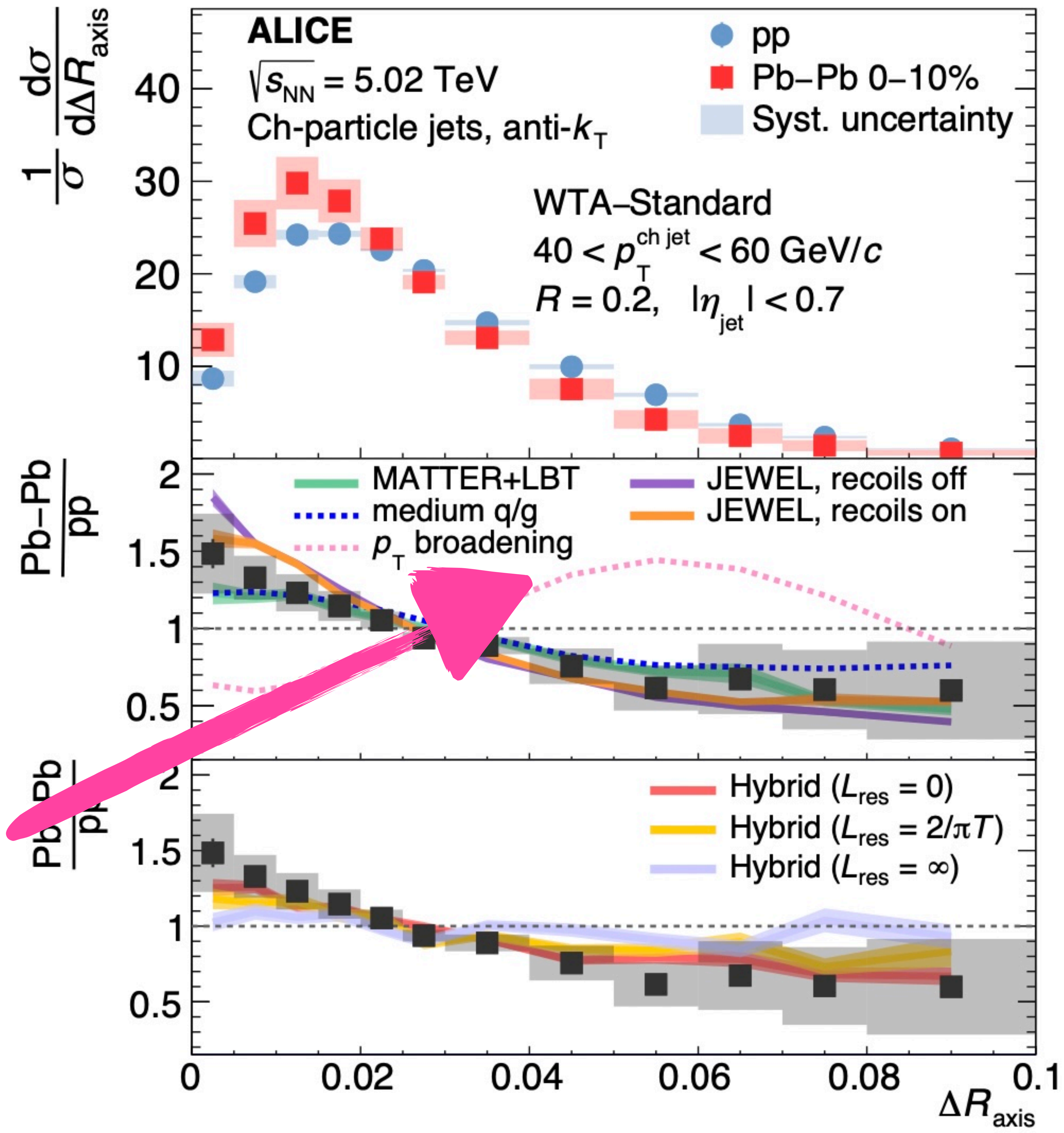
- Data rejects BDMPS-based intra-jet p_T broadening model as main energy-loss mechanism in the QGP.



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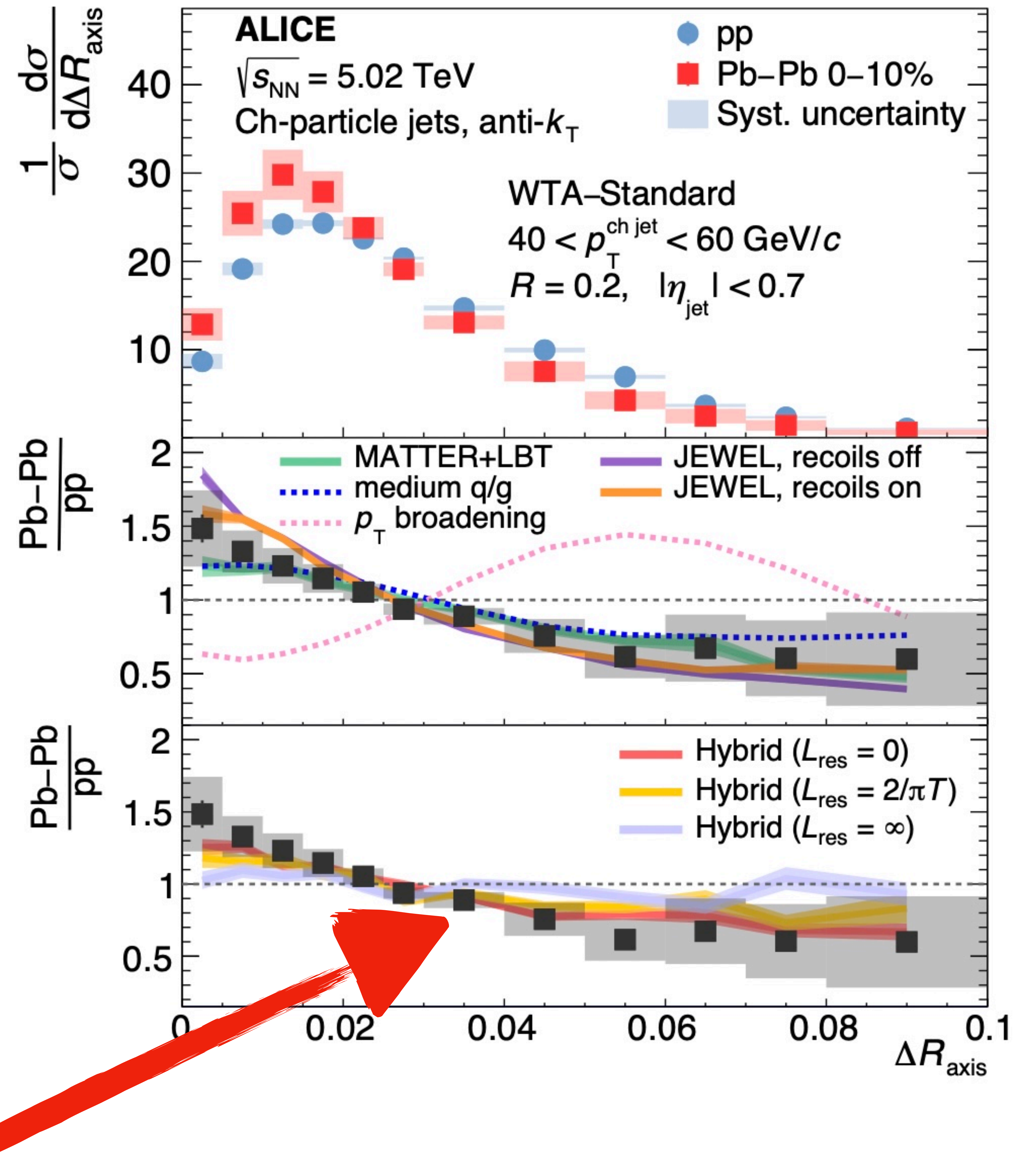
- Pb—Pb distributions narrower than pp -> consistent with g jets more active than q jets in the QGP.
- Data rejects BDMPS-based intra-jet p_T broadening model as main energy-loss mechanism in the QGP.
- Data sensitive to L_{res} and favors models with mechanisms of incoherent energy loss.

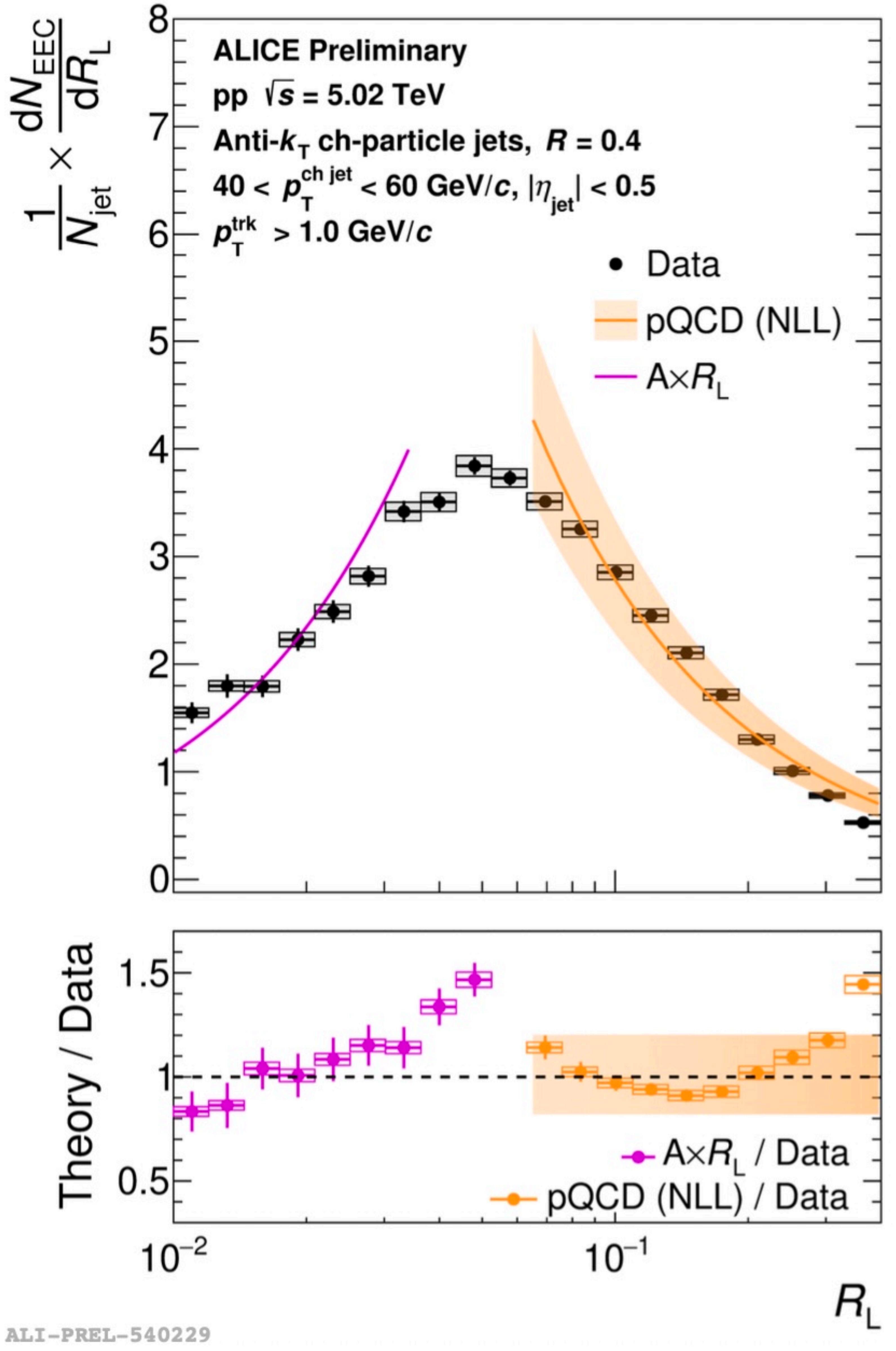


ALICE, arXiv:2211.08928
ALICE, arXiv:2303.13347

Summary

Energy-Energy Correlators

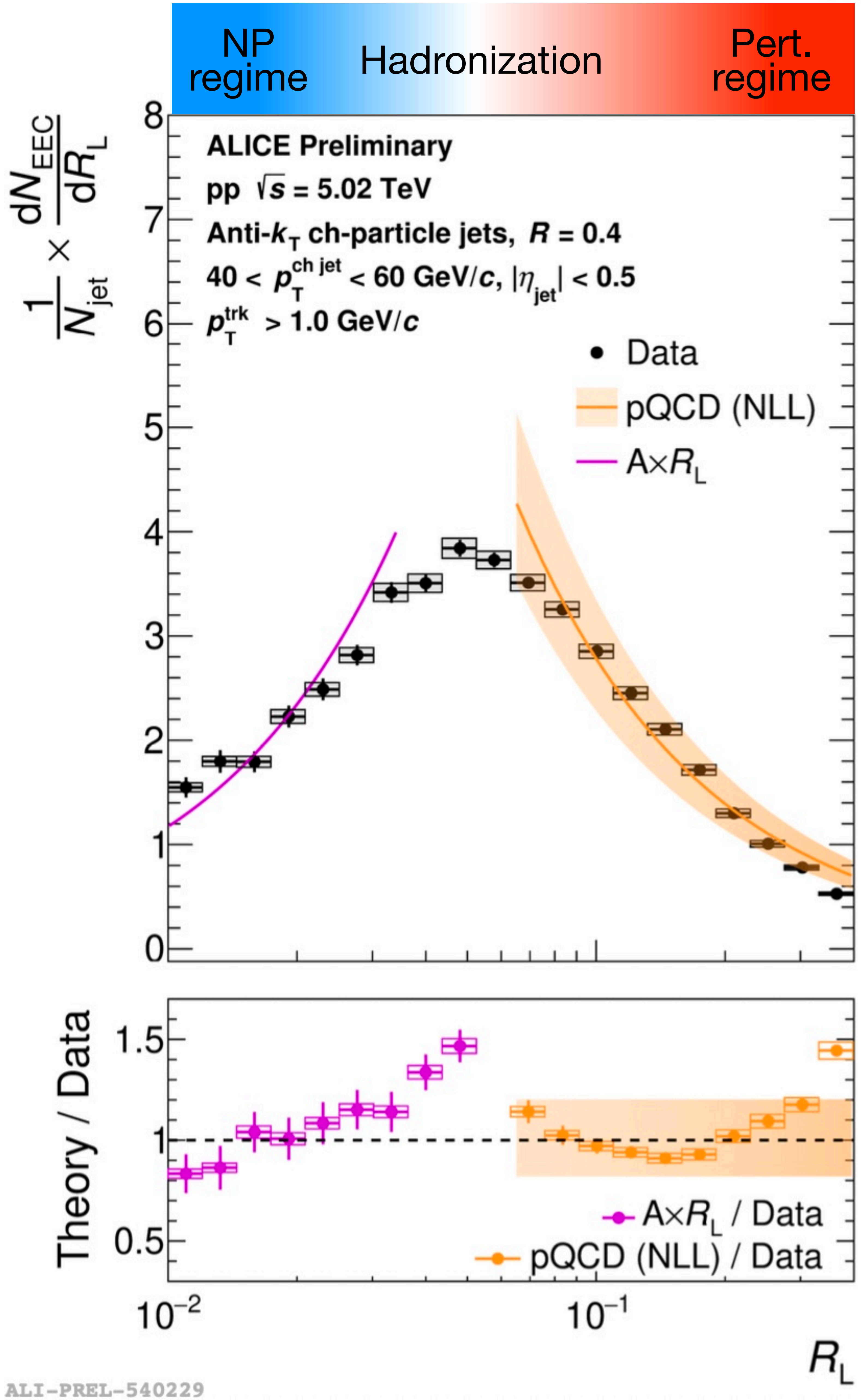
- First fully-corrected EEC measurement at LHC.



Summary

Energy-Energy Correlators

- First fully-corrected EEC measurement at LHC.
- Clear separation between hadronic, partonic, and transition (hadronization) regions.



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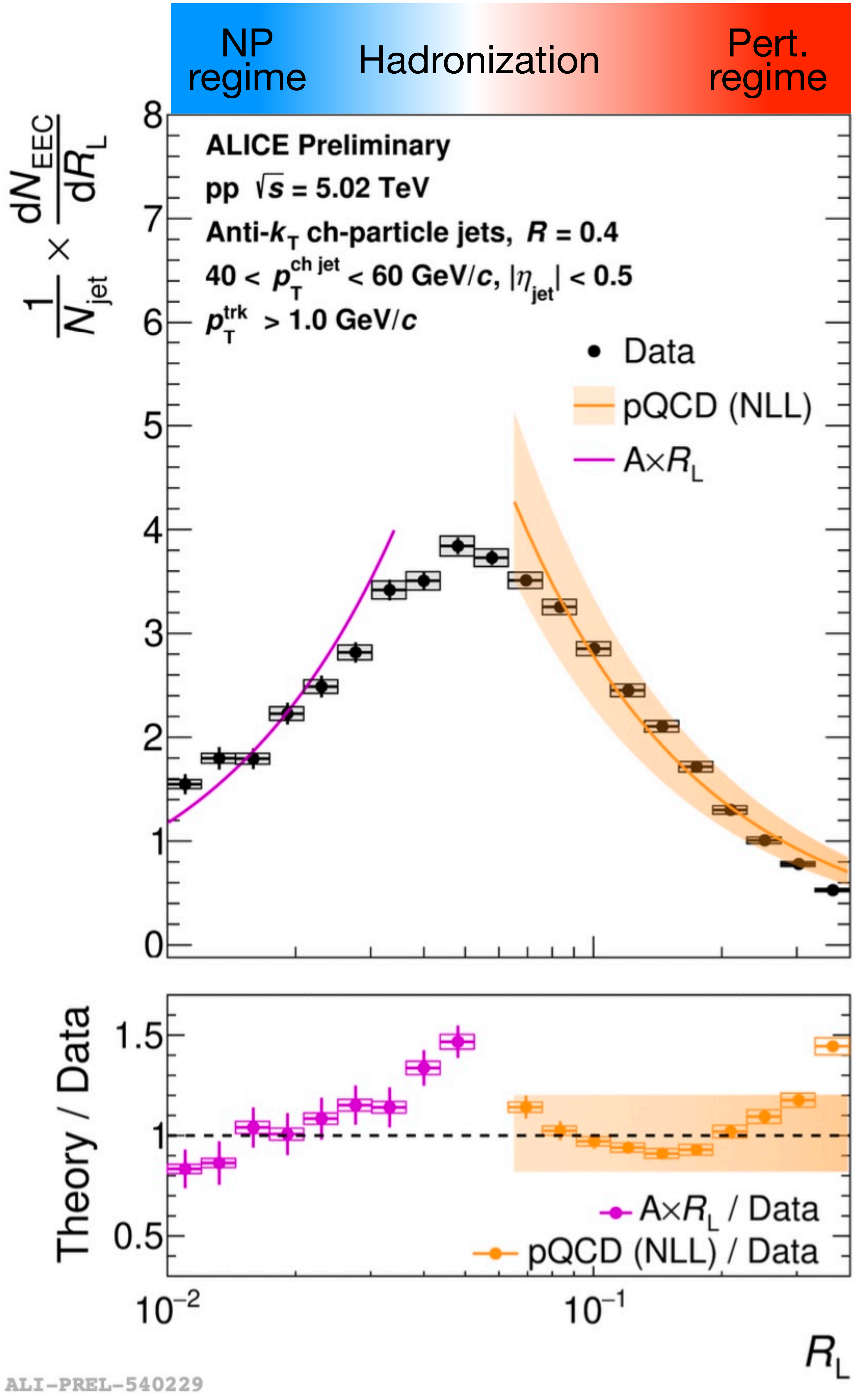
- First fully-corrected EEC measurement at LHC.
- Clear separation between hadronic, partonic, and transition (hadronization) regions.
- p—Pb and Pb—Pb coming in the future. Stay tuned!



Thanks for your attention

Check out other related ALICE talks!

- **Exploring medium properties with hard transverse momentum splittings using groomed jet substructure measurements in Pb-Pb collisions with ALICE** (link)
Raymond Ehlers

- **Measurement of the jet mass and angularities in Pb-Pb collisions at 5.02 TeV with ALICE** (link)
Ezra Lesser

- **First measurement of jet angularities with D^0-meson tagged jets with ALICE** (link)
Preeti Dhankher

And posters:

- **Multiplicity dependence of charged-particle jet properties in pp and p-Pb collisions with ALICE** (link)
Debjani Banerjee

- **Measurement of the transverse momentum (j_T) distributions of charged-particle jet fragments in pp collisions at $\sqrt{s}$ = 5.02 TeV with ALICE** (link)
Jaehyeok Ryu

Backup

Results: WTA - Standard

Results: WTA - SD (0.1,0)

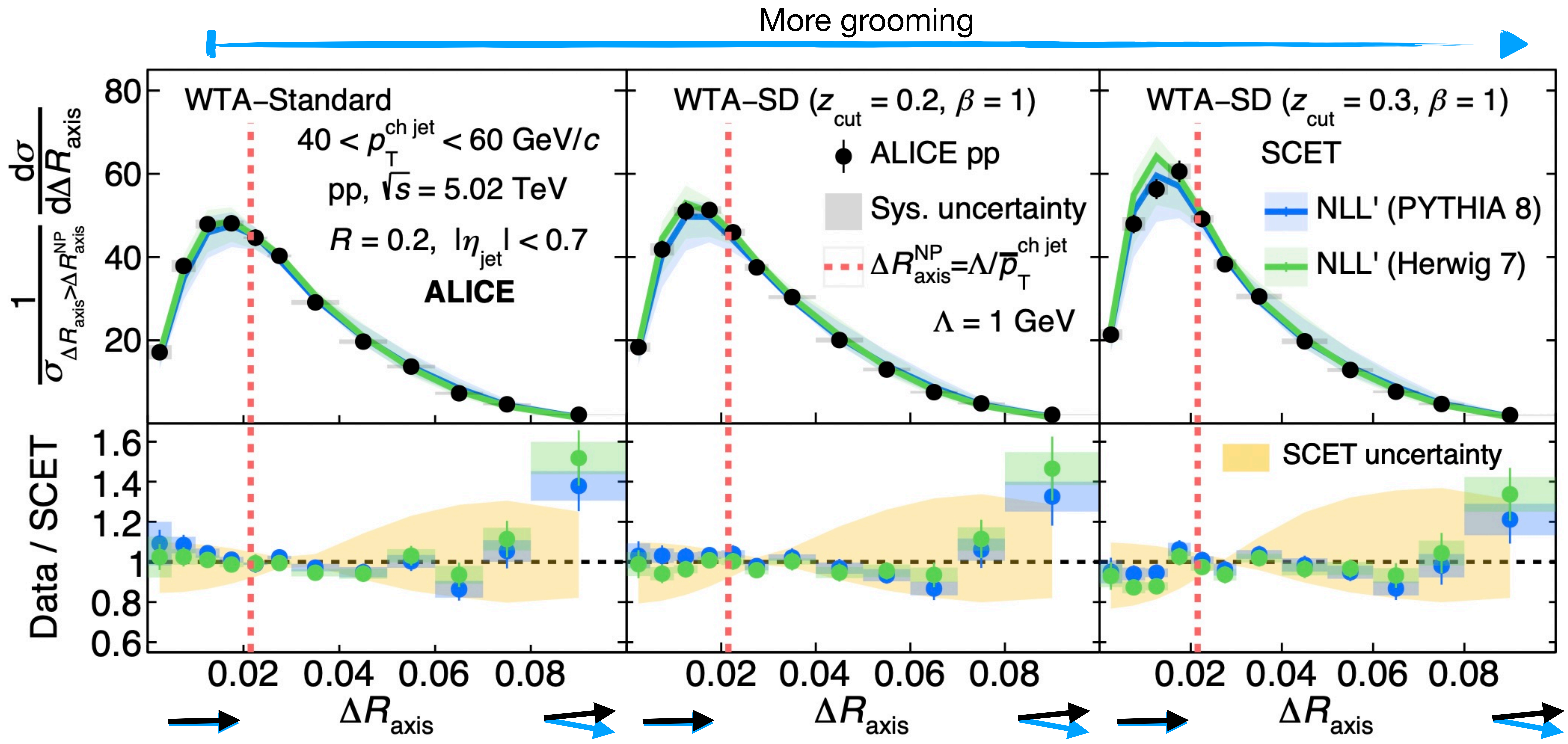
NEW

Results: WTA - SD (0.2,0)

Results: 100 < p_T < 140 GeV/c

Results in pp

ALICE, arXiv:2211.08928, accepted by JHEP



- pQCD prediction in good agreement with data
- Agreement surprisingly good in the NP region
- Agreement persists throughout the entire grooming, R, and p_T parameter space probed

Grooming and Soft Drop

Grooming: systematically removing soft, wide-angle radiation from a jet to mitigate effects such as ISR, MPI, and pileup.

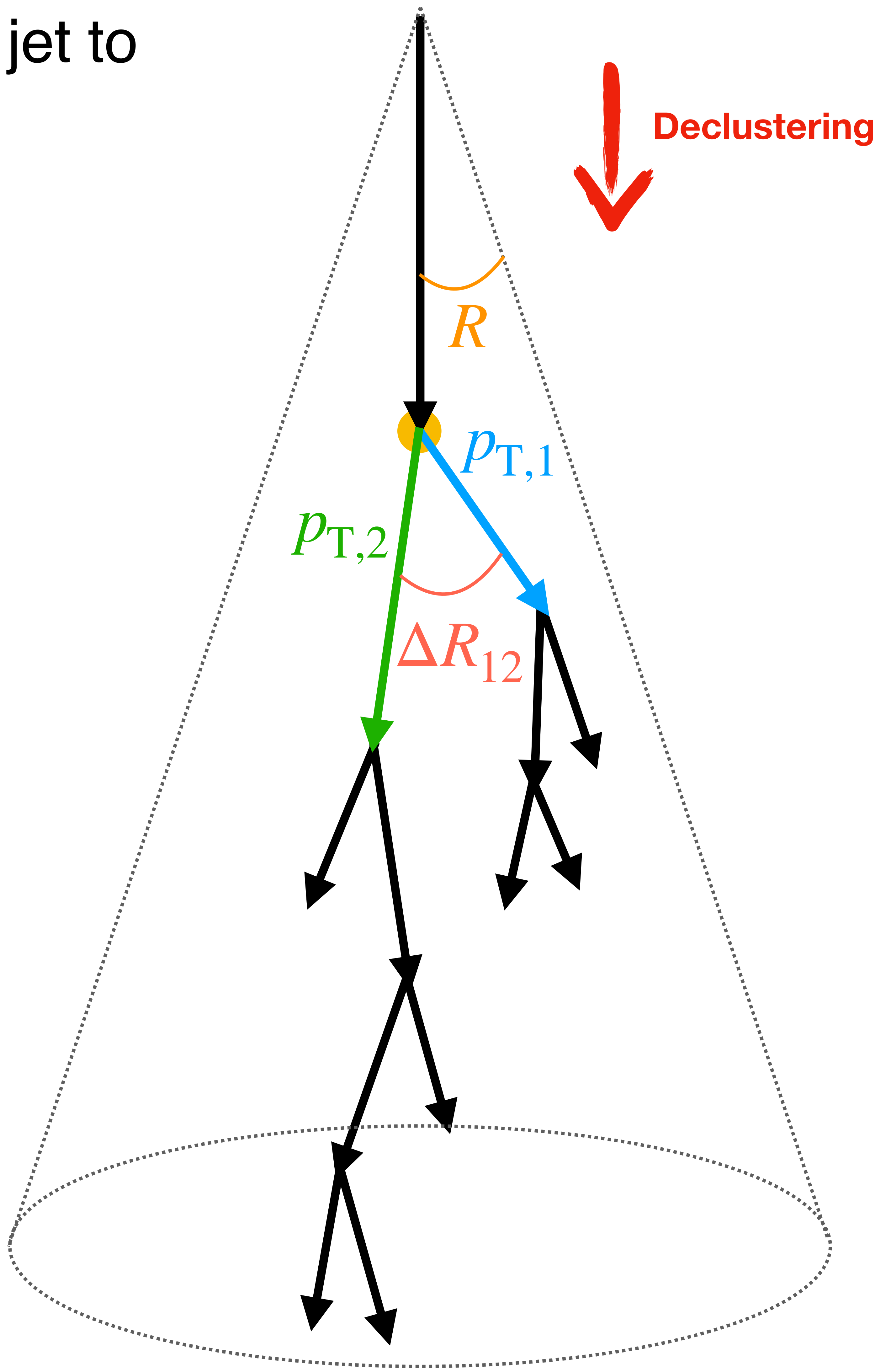
Soft Drop: JHEP 1405 (2014) 146 (1402.2657)

After reclustering with C-A, decluster and check:

$$\frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} \overset{?}{>} z_{cut} \left(\frac{\Delta R_{12}}{R}\right)^{\beta}$$

$$\Delta R_{12} = \sqrt{(y_1 - y_2)^2 + (\varphi_1 - \varphi_2)^2}$$

z_{cut} and β free parameters



Check is the first split satisfies the SD condition

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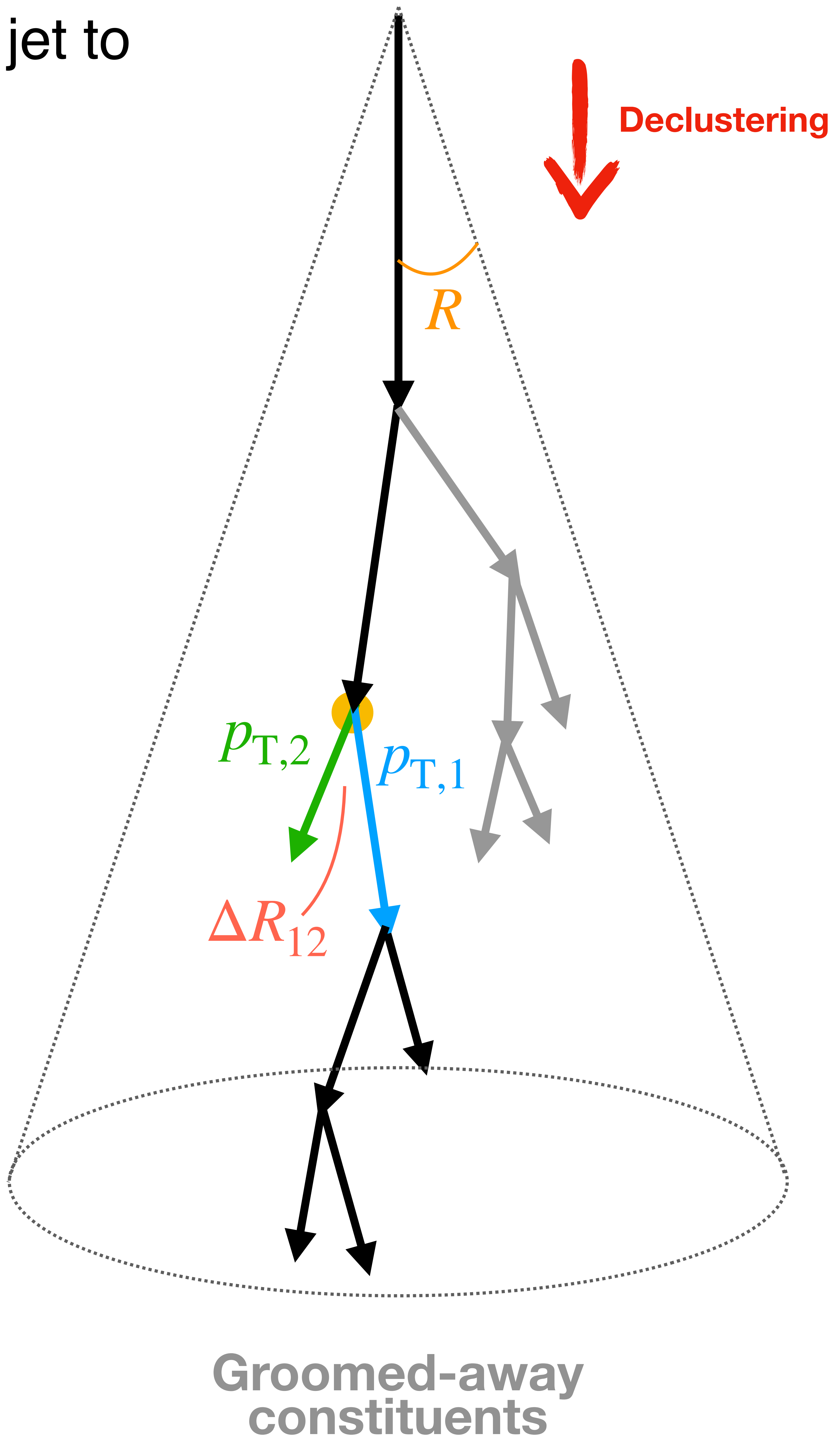
It does not:

- Drop softer branch
- check if next split in harder branch satisfies SD condition



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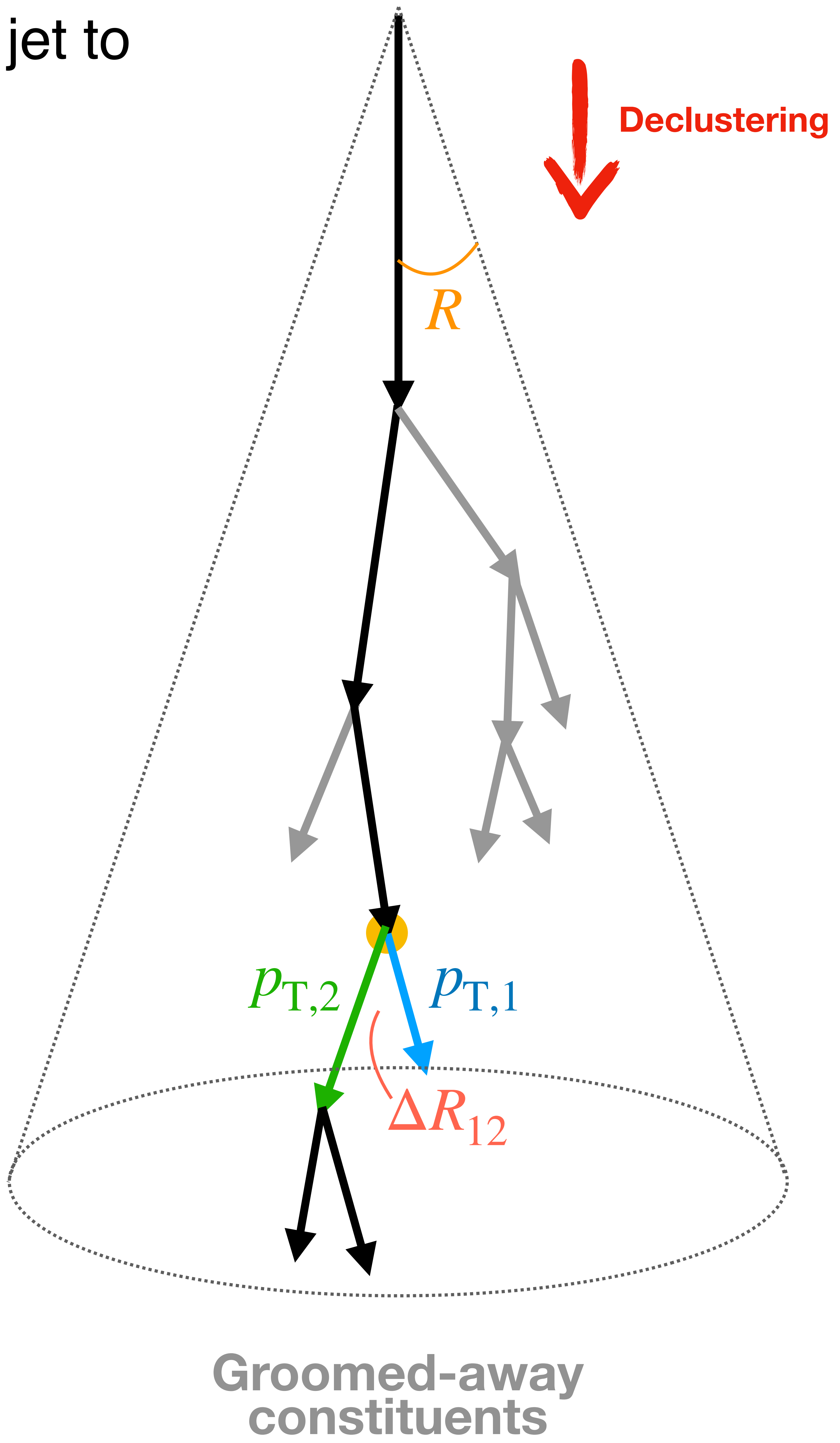

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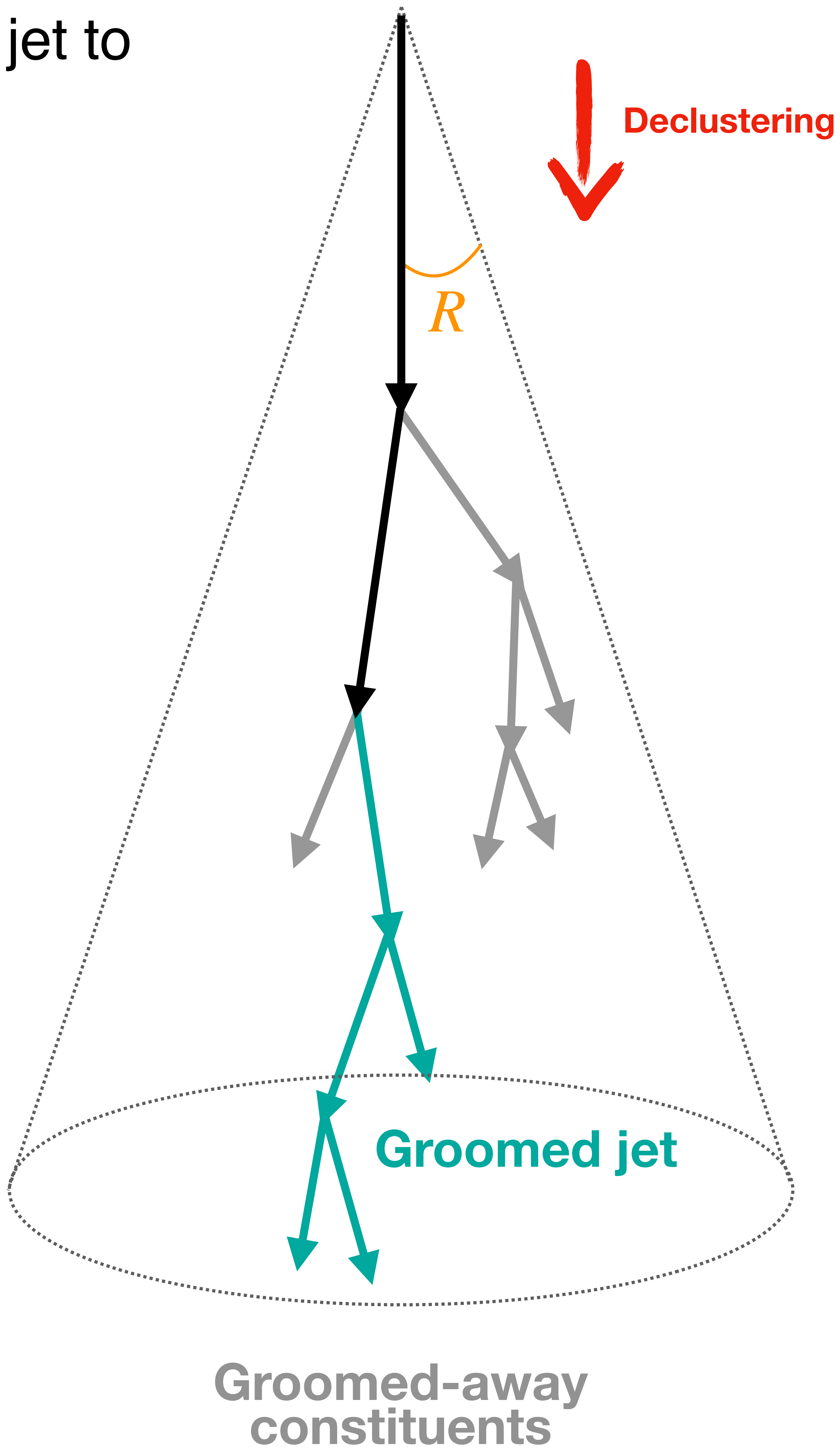
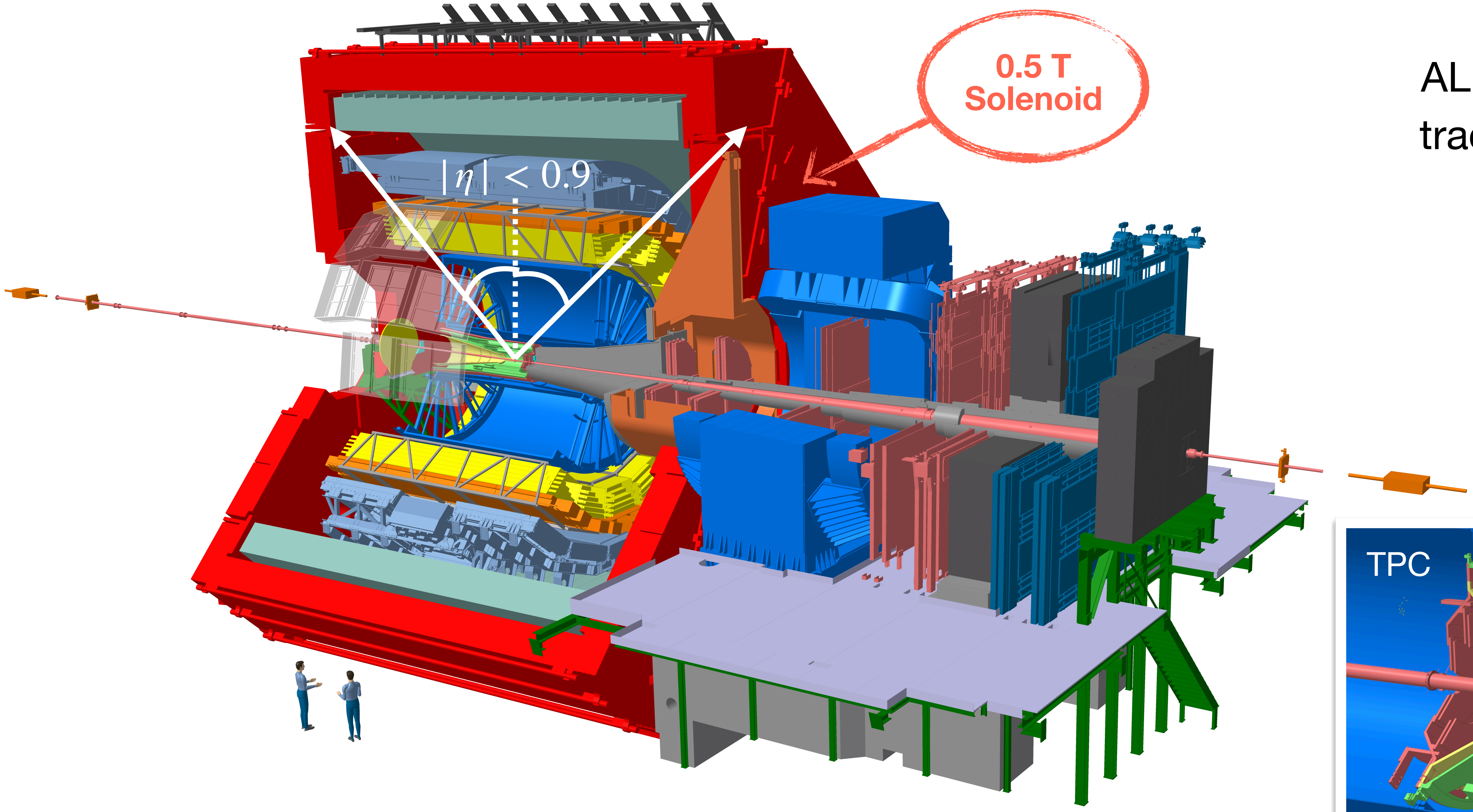
It does:

- What remains defines the groomed jet



ALICE Detector



ALICE high-resolution tracking (ITS+TPC) → high-precision measurement