XV Latin American Symposium on High Energy Physics

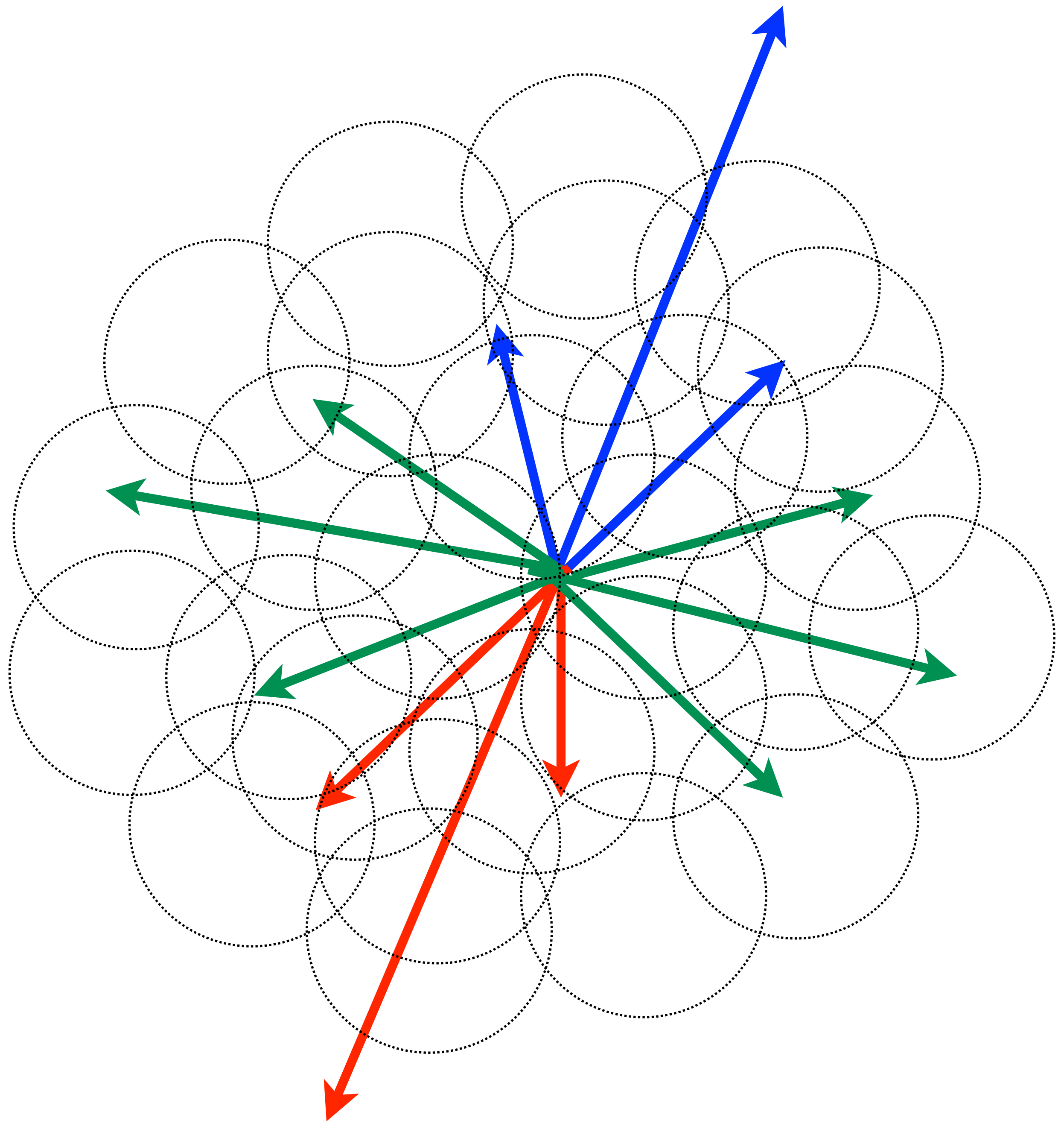
November 4-8, 2024, Cinvestav, Mexico City

Novel approaches to unveil the origin of collective-like behavior in pp and p-Pb collisions using the ALICE detector at the LHC

Paola Vargas, for the ALICE collaboration

Outline

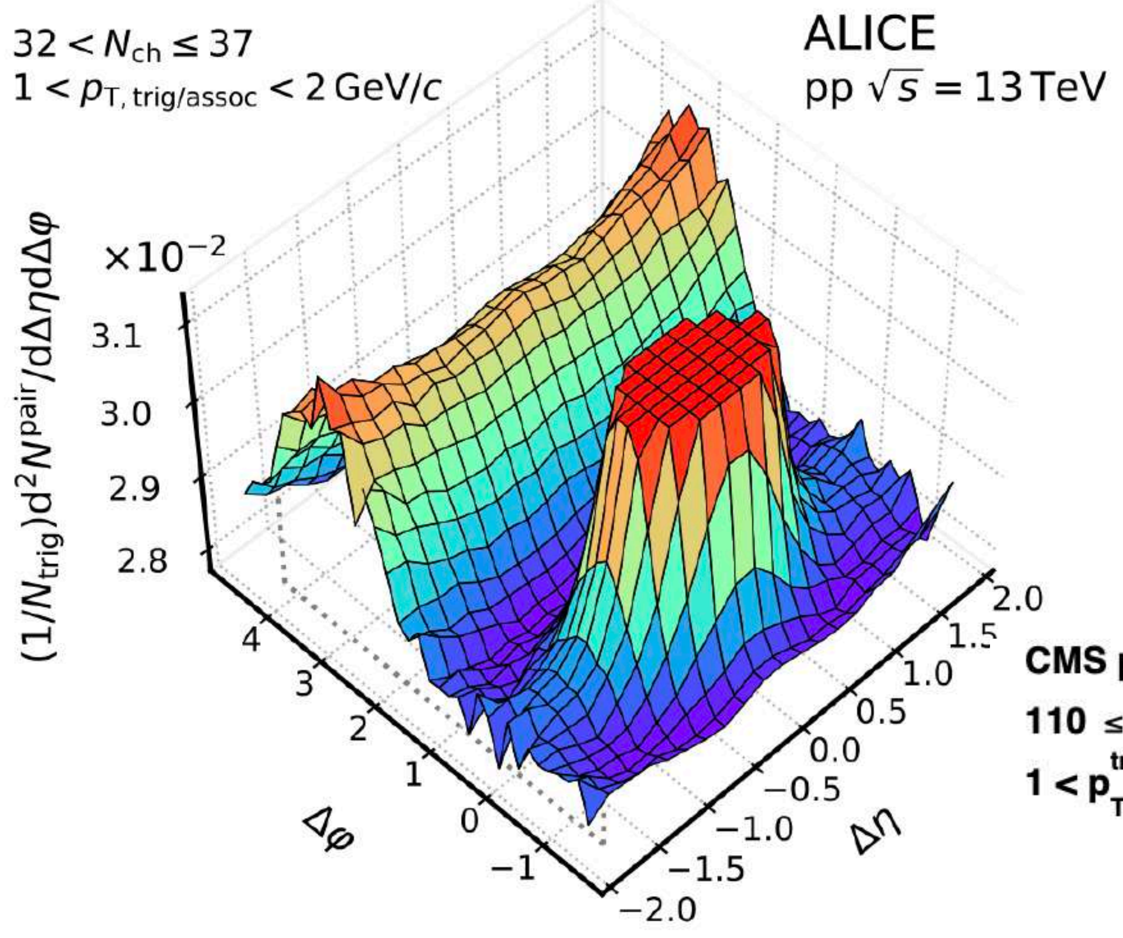
- **Introduction**
  - QGP-like effects in small systems
  - Underlying event and multiparton interactions
  - Selection biases in pp collisions
  - The ALICE detector in Run 2
- **Relative transverse activity classifier R_T**
  - R_T definition
  - p_T-spectra as a function of R_T
  - $\langle p_T \rangle$ as a function of R_T
  - Normalized Integrated yields as a function of R_T
- **Charged-particle flattenicity ρ**
  - Flattenicity definition
  - Q_{pp} as a function of p_T
  - Q_{pp} data vs MC predictions
- **Summary**



QGP-like effects in small systems

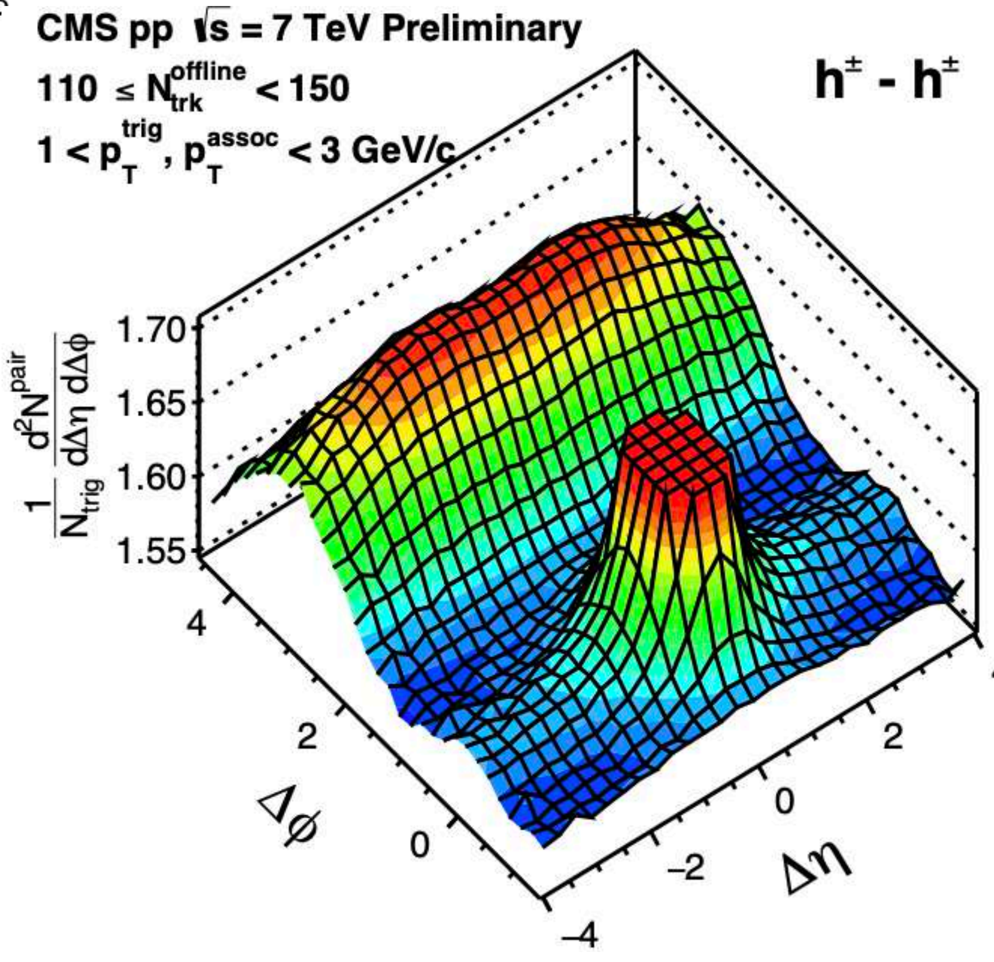
Long-range angular correlations

$$\Delta\varphi = \varphi^{a} - \varphi^{b}$$
$$\Delta\eta = \eta^{a} - \eta^{b}$$



Phys. Rev. Lett. 132, 172302

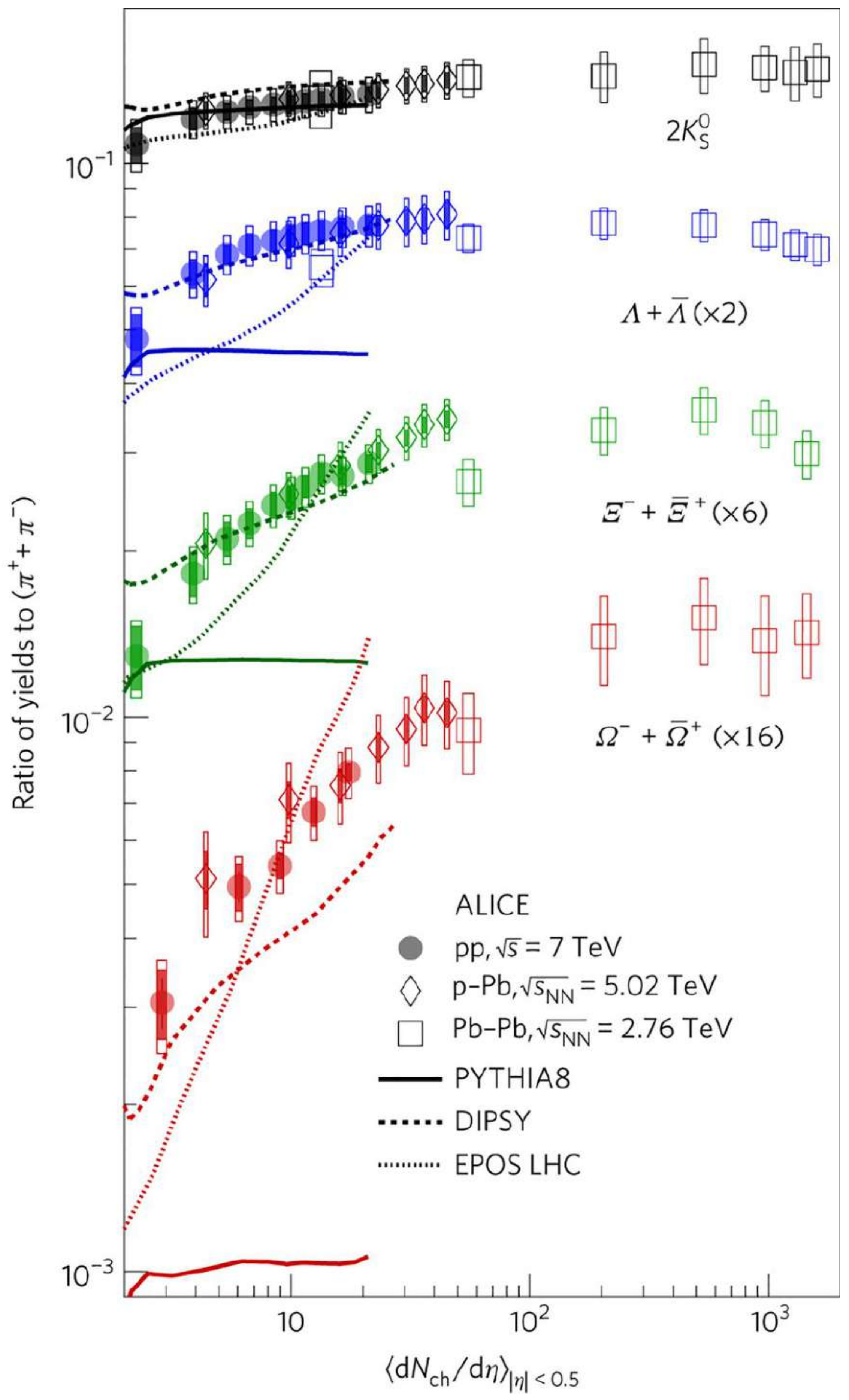
Low-multiplicity



High-multiplicity

Nucl. Phys. A 956 (2016) 773-776

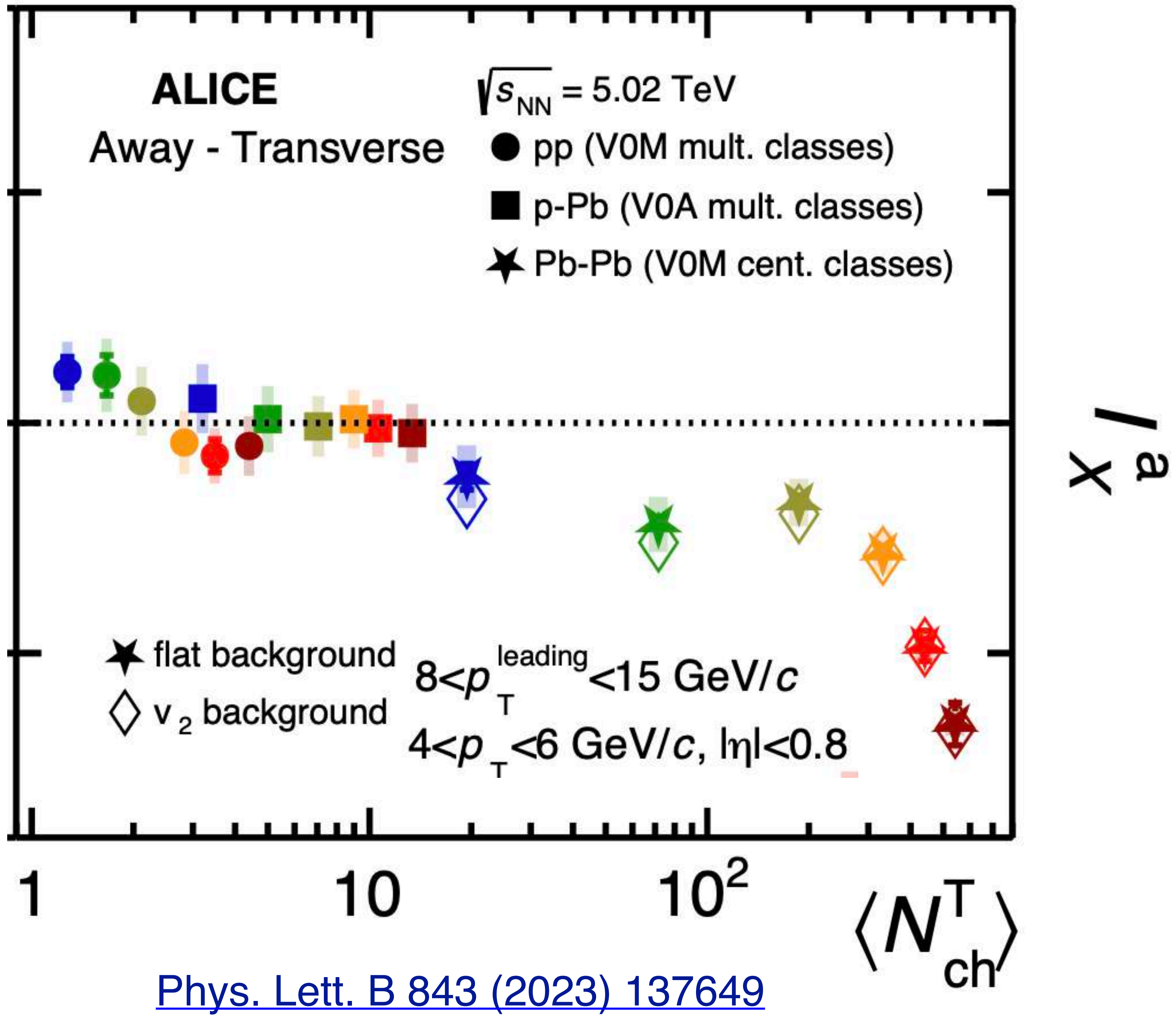
Strangeness Enhancement



Nat. Phys. 13 (2017) 535-539

Jet quenching?

$$I_X^{away} = \frac{Y_X^{away} - Y_X^{T}}{Y_{pp}^{away} - Y_{pp}^{T}}$$



Phys. Lett. B 843 (2023) 137649

Underlying event and Multiparton interactions

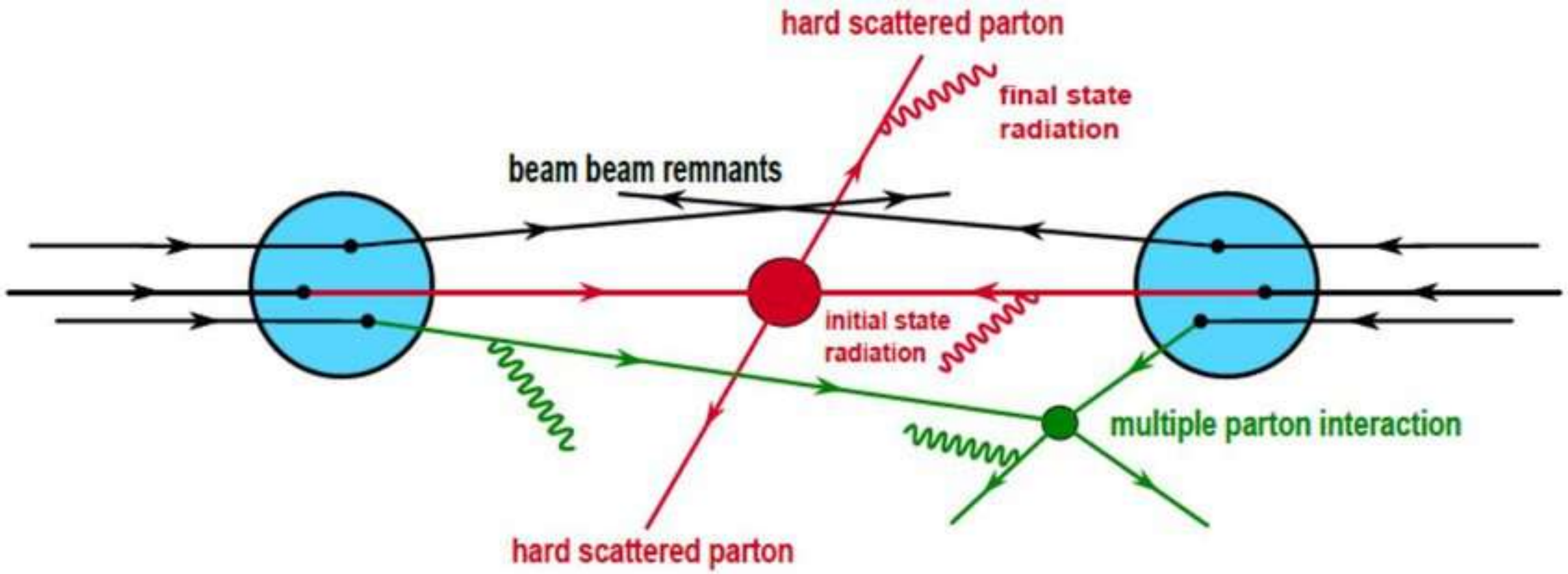
Instituto de Ciencias Nucleares UNAM

The effects can be explained qualitatively by two schemes:

- **QGP formation** Ann.Rev.Nucl.Part.Sci. 68 (2018) 211-235
- **Multiparton interactions (MPI) and color string interaction** Phys. Rev. Lett. 111, 042001 (2013)

In pp collisions:

- Underlying event (UE): refers to everything that does not come from the hard partonic scattering
- Multiparton interactions (MPI): Several parton scattering occurring in the same pp collision

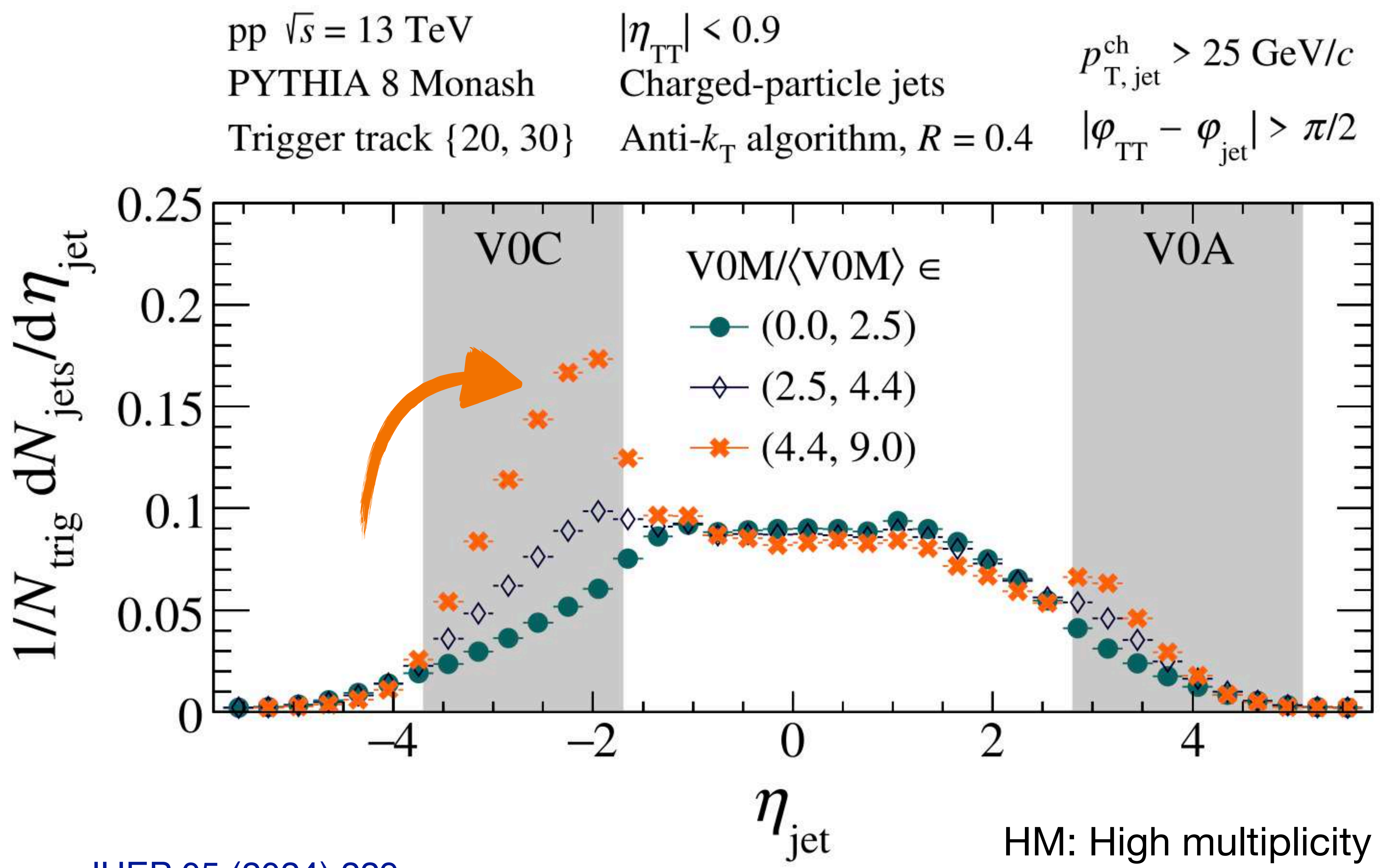


collisions with high charged-particle multiplicities are dominantly those with larger-than-average MPIs

Selection bias in pp collisions

Hard process

The selection of high-multiplicity events affects the distribution for recoil jets showing a higher rate of hard-recoil jets in HM events compared to MB events

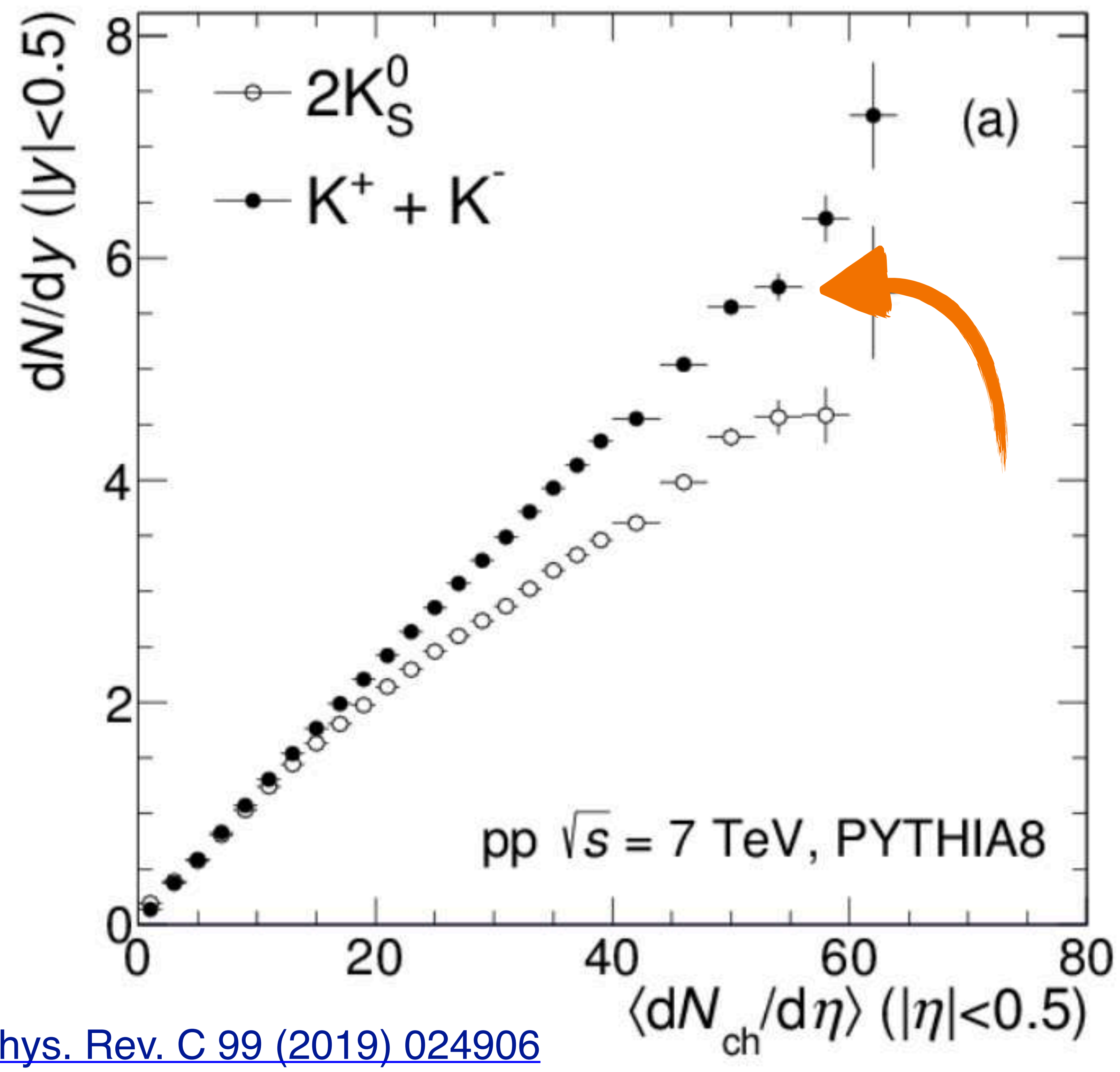


JHEP 05 (2024) 229

HM: High multiplicity
MB: Minimum bias

Charged particles

The neutral-to-charged particle yield is biased by requiring high charge-particle multiplicity



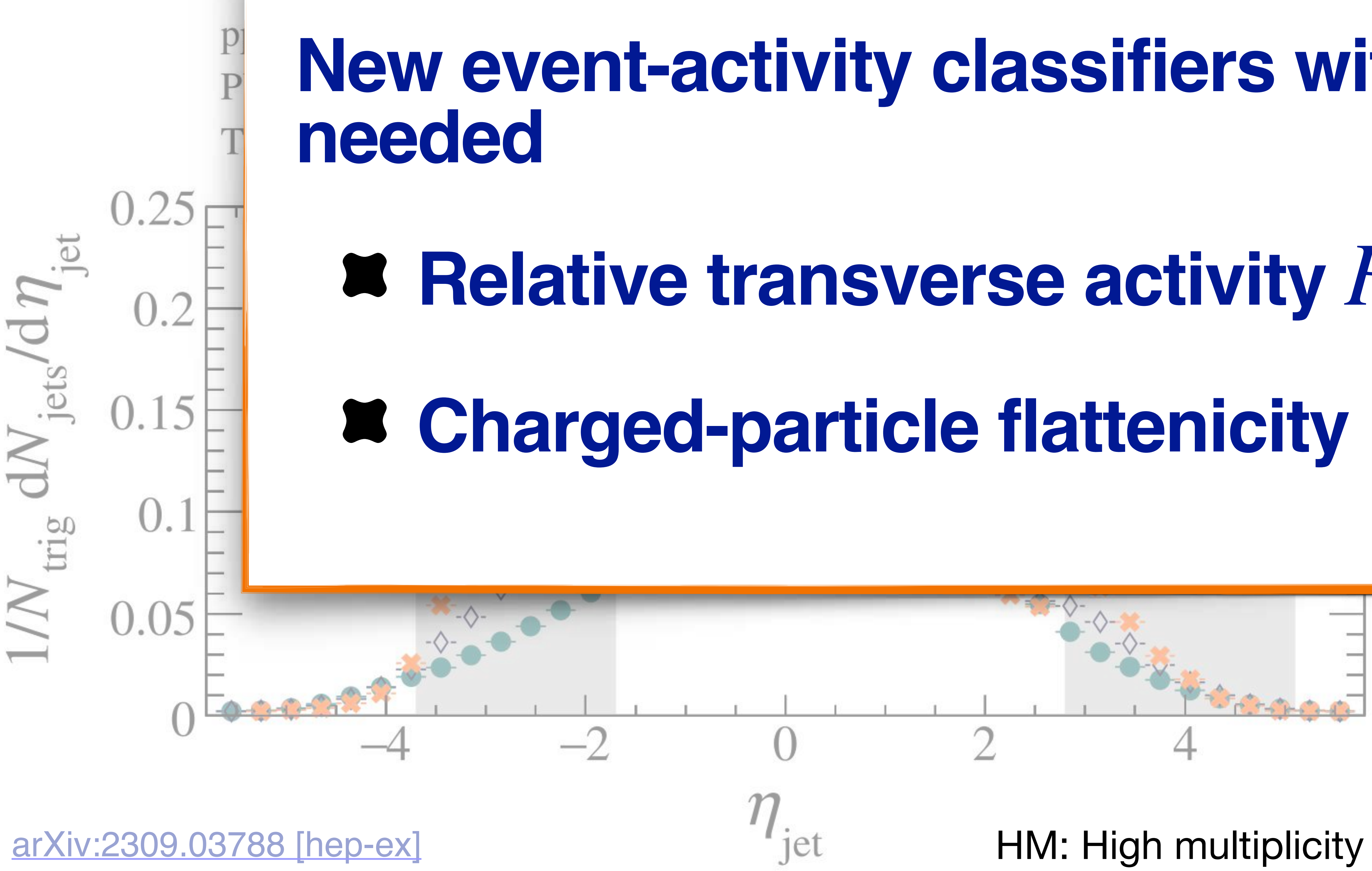
Phys. Rev. C 99 (2019) 024906

Selection bias in pp collisions

Instituto de Ciencias Nucleares UNAM

Hard process

The selection of high-multiplicity events affects the distribution for recoil jets showing a higher rate of hard-recoil jets in HM events compared to MB events

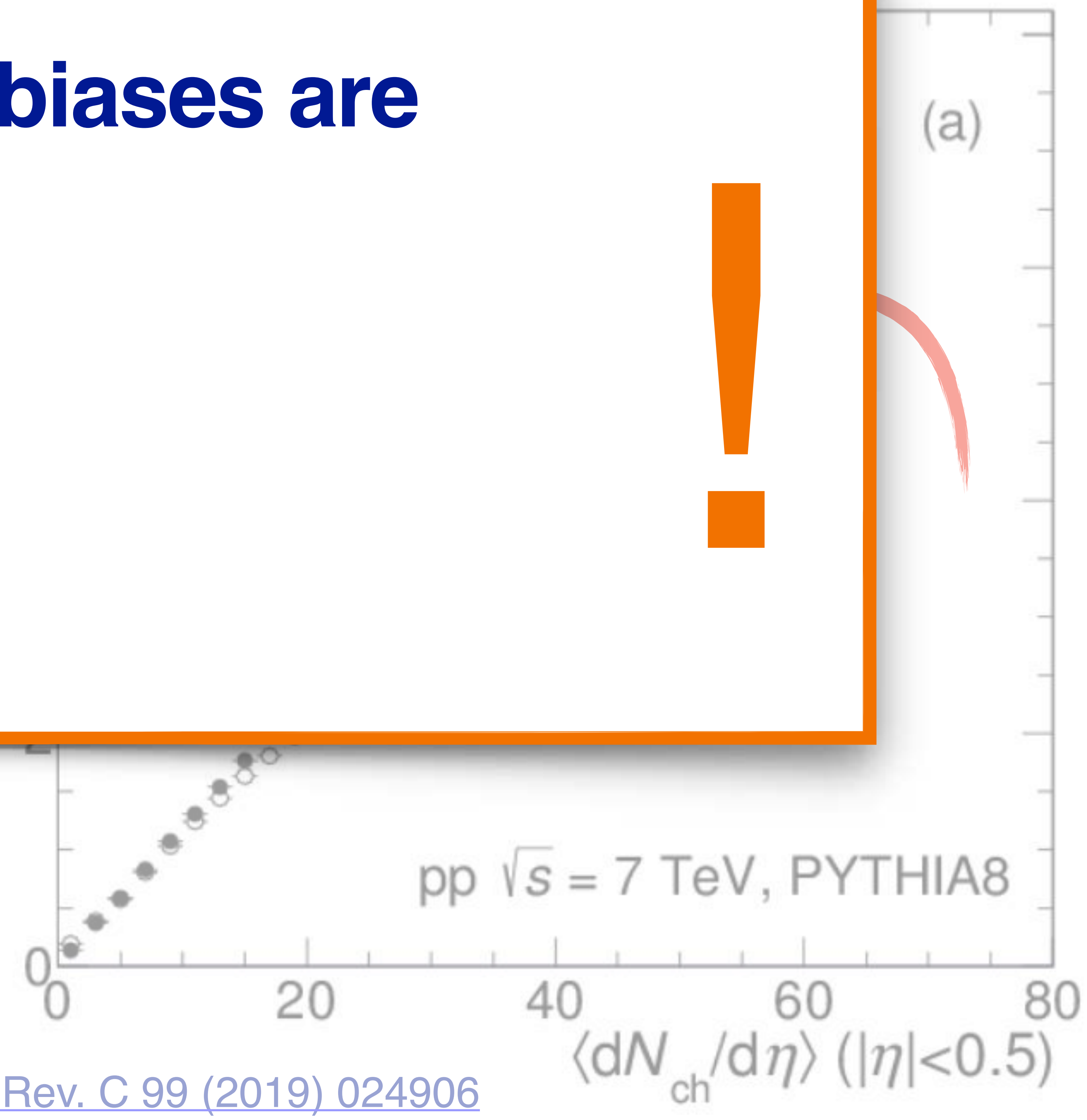


arXiv:2309.03788 [hep-ex]

HM: High multiplicity
MB: Minimum bias

Charged particles

The neutral-to-charged particle yield is biased by requiring high charge-particle multiplicity



Phys. Rev. C 99 (2019) 024906

New event-activity classifiers with smaller biases are needed

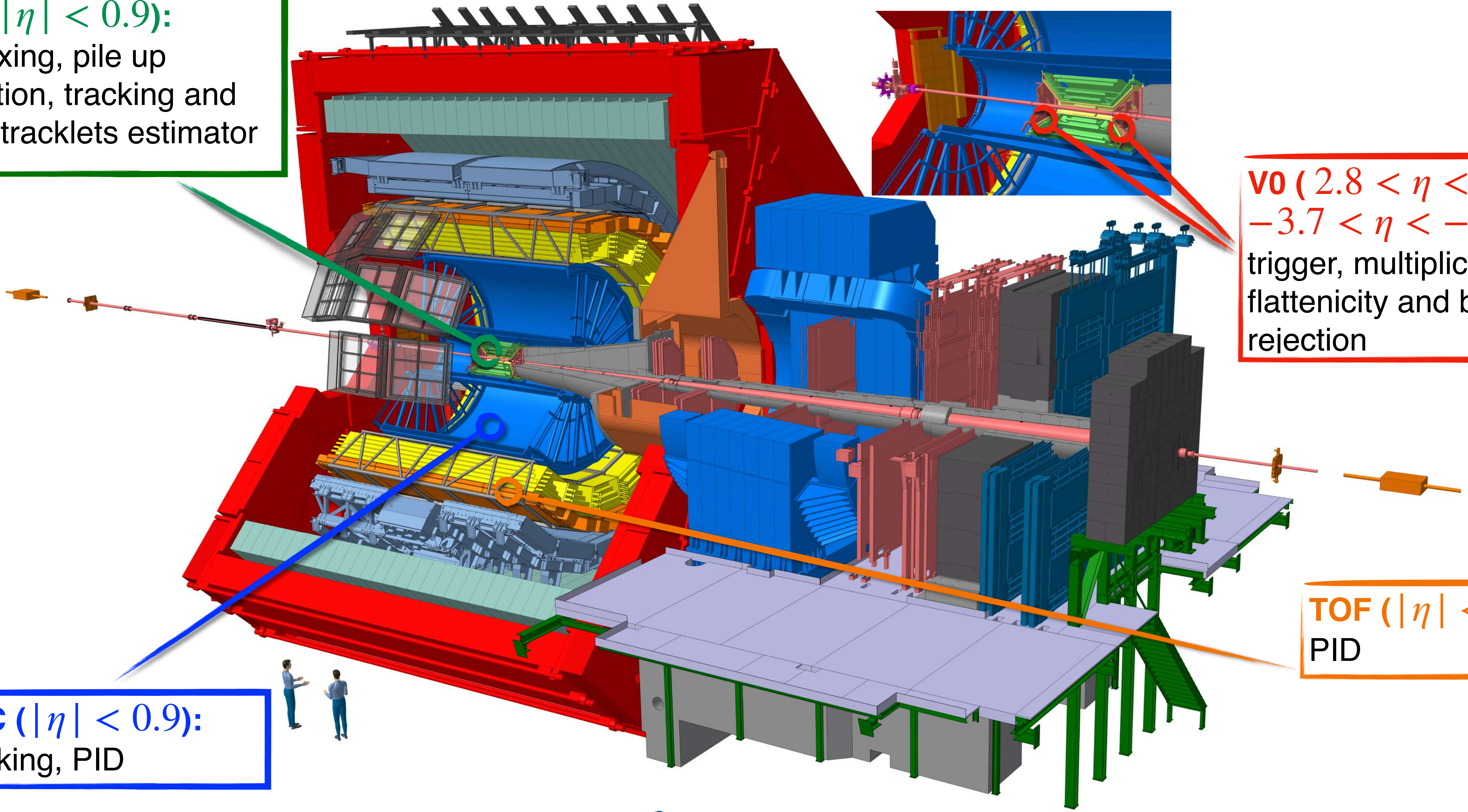
- **Relative transverse activity R_{T}**
- **Charged-particle flattenicity $1-\rho$**

!

The ALICE detector in Run 2

ITS ($|\eta| < 0.9$): vertexing, pile up rejection, tracking and SPD tracklets estimator

V0 ($2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$): MB trigger, multiplicity (V0M), flattenicity and background rejection



TOF ($|\eta| < 0.9$): PID

TPC ($|\eta| < 0.9$): tracking, PID

Relative transverse activity classifier R_{T}

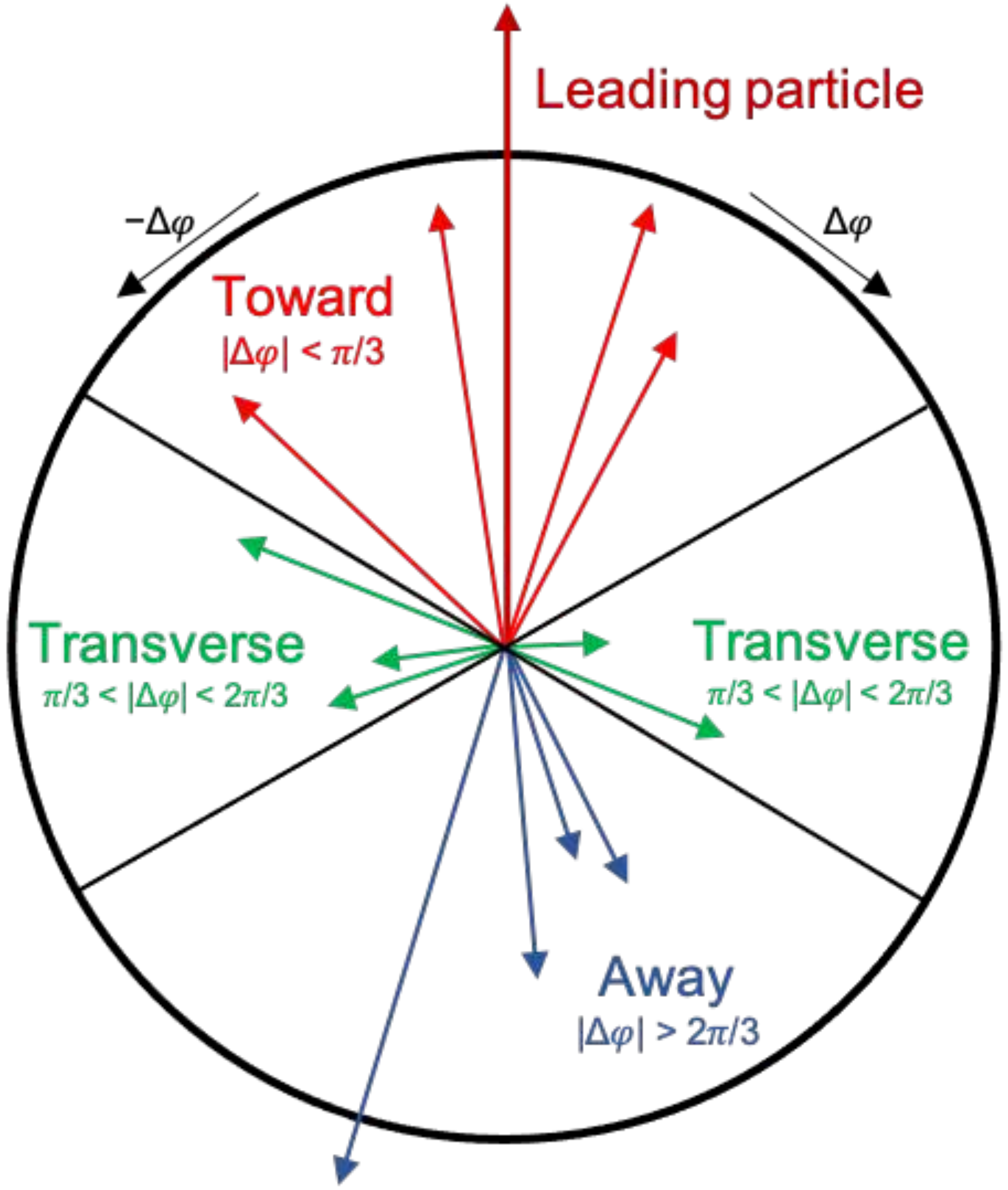
The topological regions are defined relative to the direction of the charged particle with the highest transverse momentum ($p_{\mathrm{T}}^{\mathrm{trig}}$) in the event

Relative transverse activity classifier

$$R_{\mathrm{T}} = \frac{N_{\mathrm{ch}}^{\mathrm{T}}}{\langle N_{\mathrm{ch}}^{\mathrm{T}} \rangle}$$

with $N_{\mathrm{ch}}^{\mathrm{T}}$: multiplicity in the transverse region

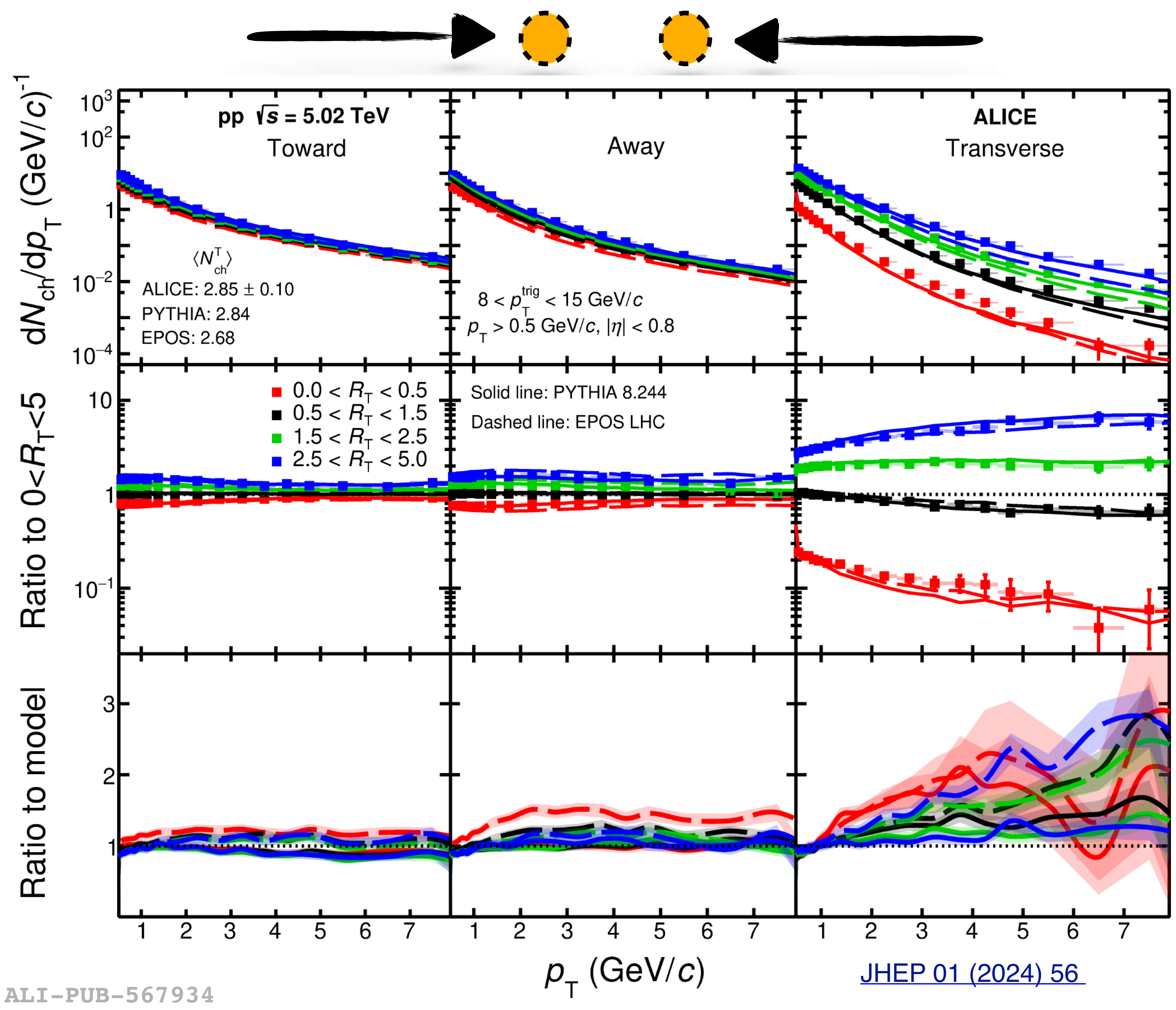
Phys. Lett. B 843 (2023) 137649



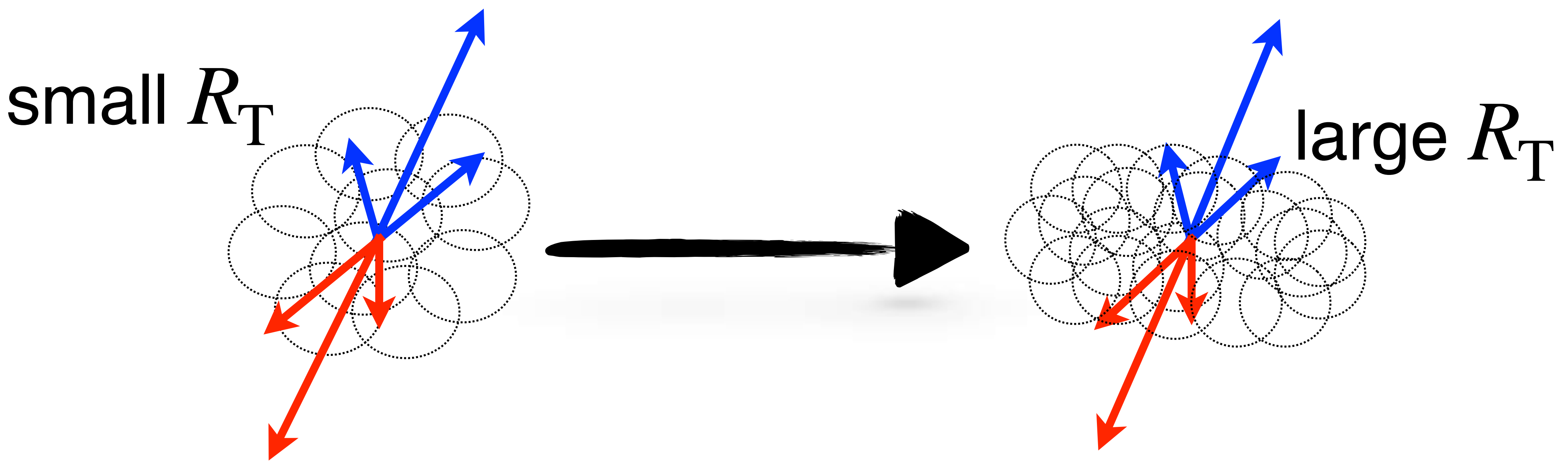
$$|\Delta\varphi| = |\varphi^{\mathrm{assoc}} - \varphi^{\mathrm{trig}}|$$

- By definition the multiplicity estimator R_{T} excludes the jet fragments
- The neutral-to-charged particle yield in the toward and away region is not biased at high-R_{T} values

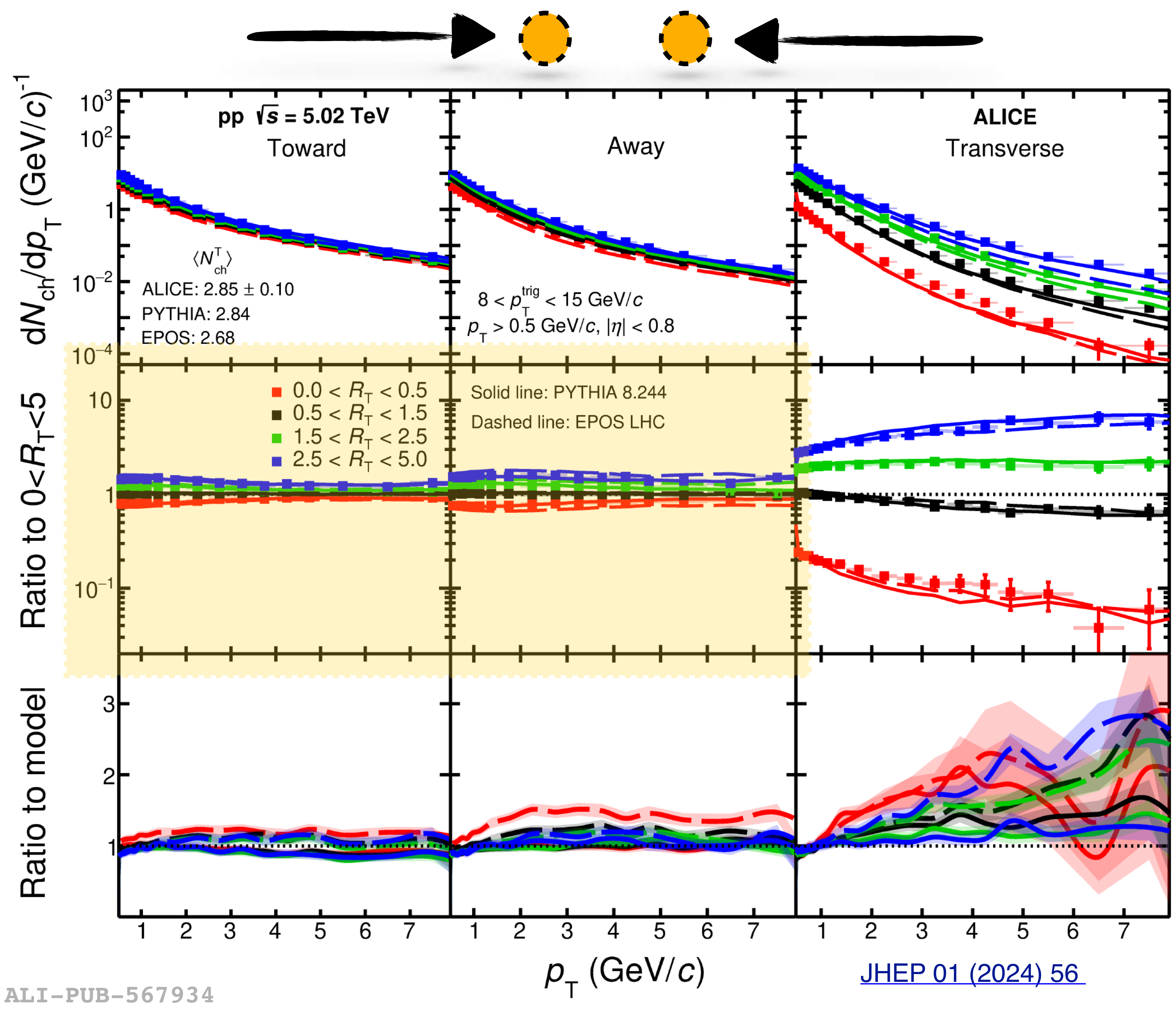
p_T-spectra as a function of R_T



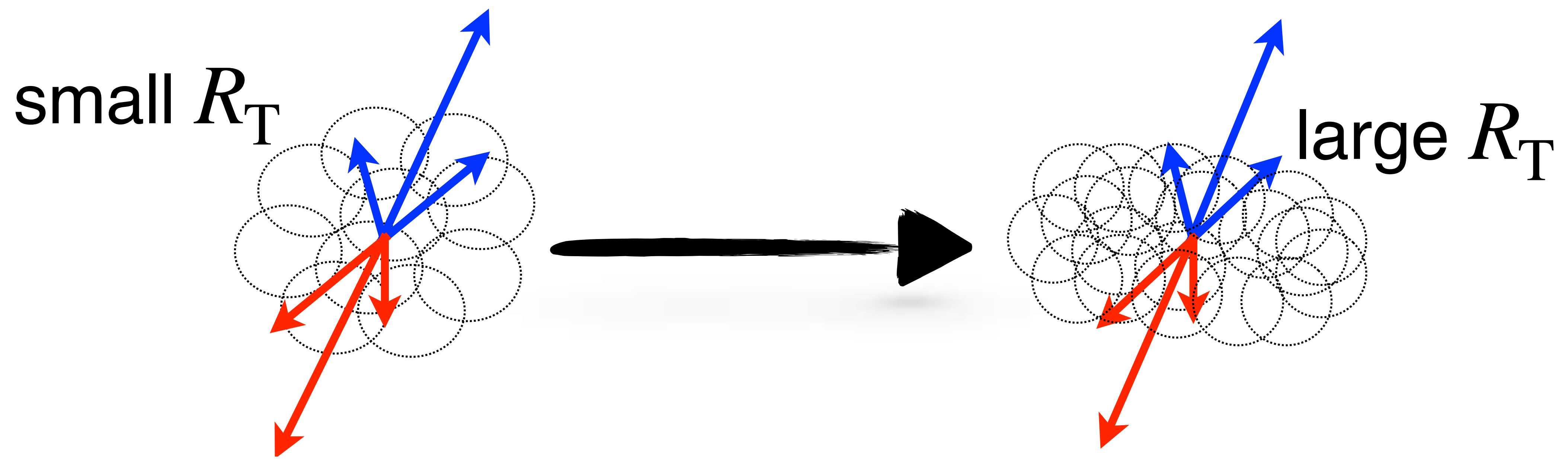
JHEP 01 (2024) 56



p_T-spectra as a function of R_T



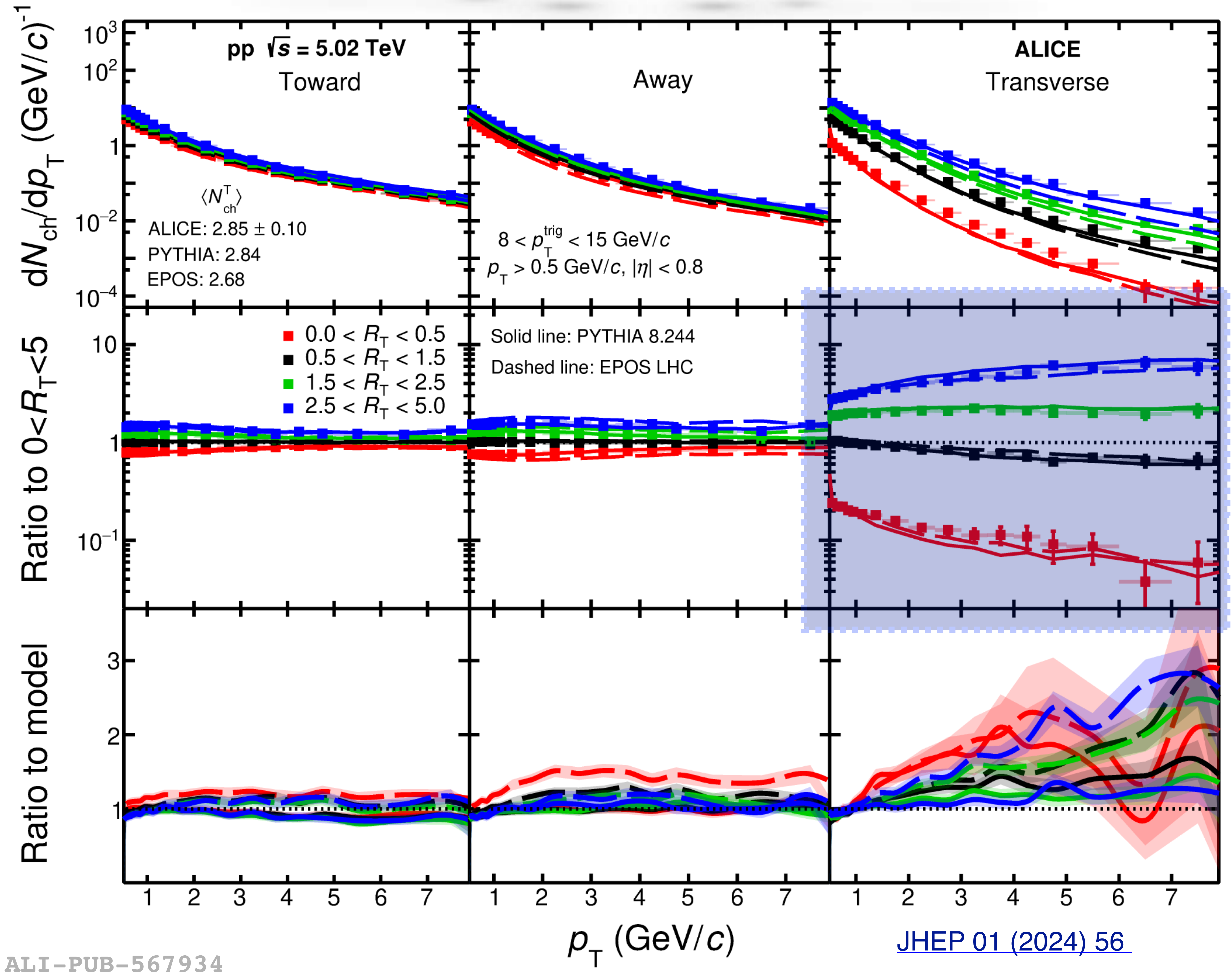
JHEP 01 (2024) 56



Toward and away regions:

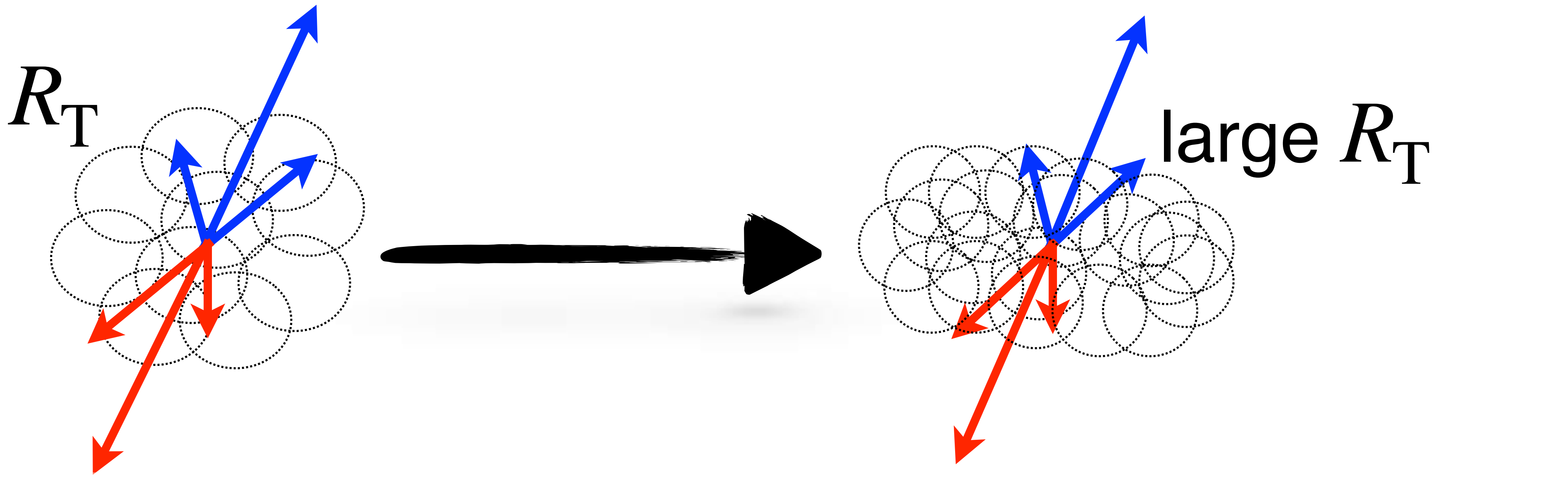
- For $p_T < 4$ GeV/c, the p_T spectra exhibit a R_T -dependence. **Color reconnection produces this effect in PYTHIA 8**
- For $p_T > 4$ GeV/c, spectral shapes is almost independent of R_T

p_T-spectra as a function of R_T



ALI-PUB-567934

JHEP 01 (2024) 56



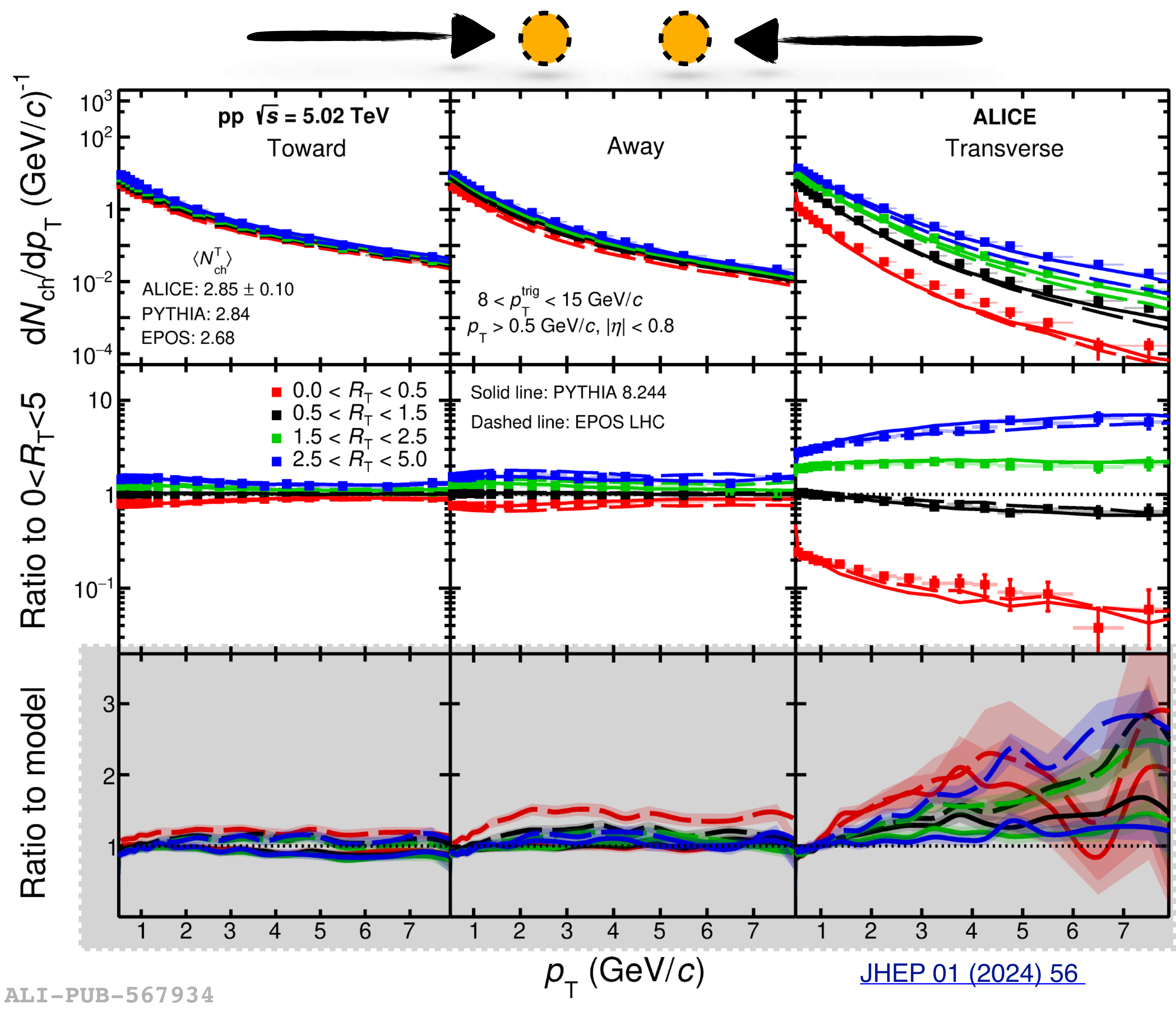
Toward and away regions:

- For $p_T < 4$ GeV/c, the p_T spectra exhibit a R_T -dependence. **Color reconnection produces this effect in PYTHIA 8**
- For $p_T > 4$ GeV/c, spectral shapes is almost independent of R_T

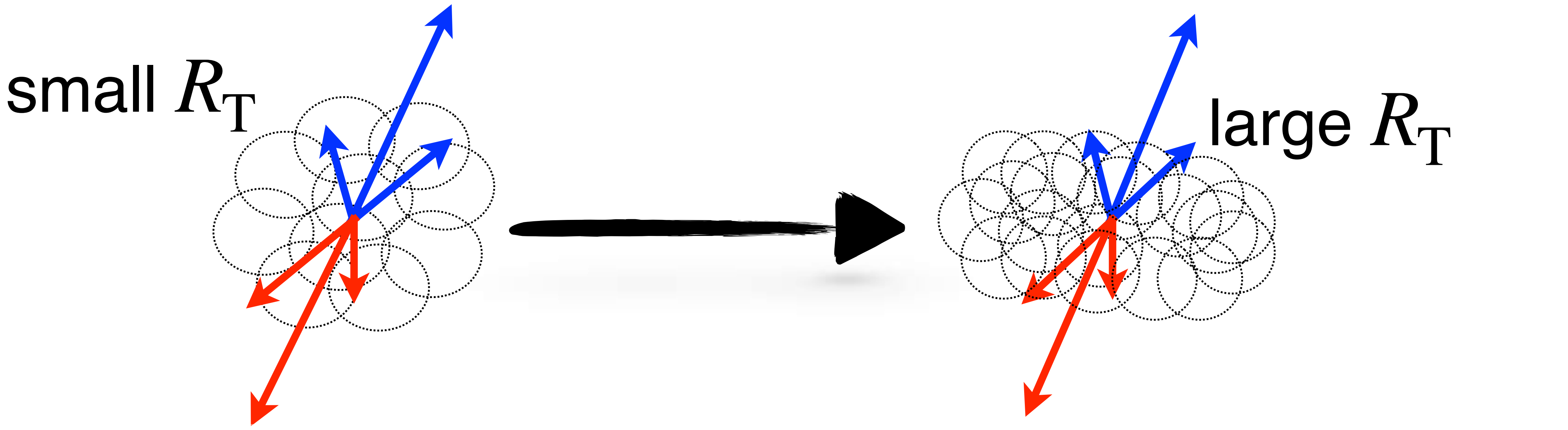
Transverse region:

- The p_T spectra harden with increasing R_T, due to **autocorrelation effects** Phys. Rev. D 104 (2021) 016017

p_T-spectra as a function of R_T



JHEP 01 (2024) 56



Toward and away regions:

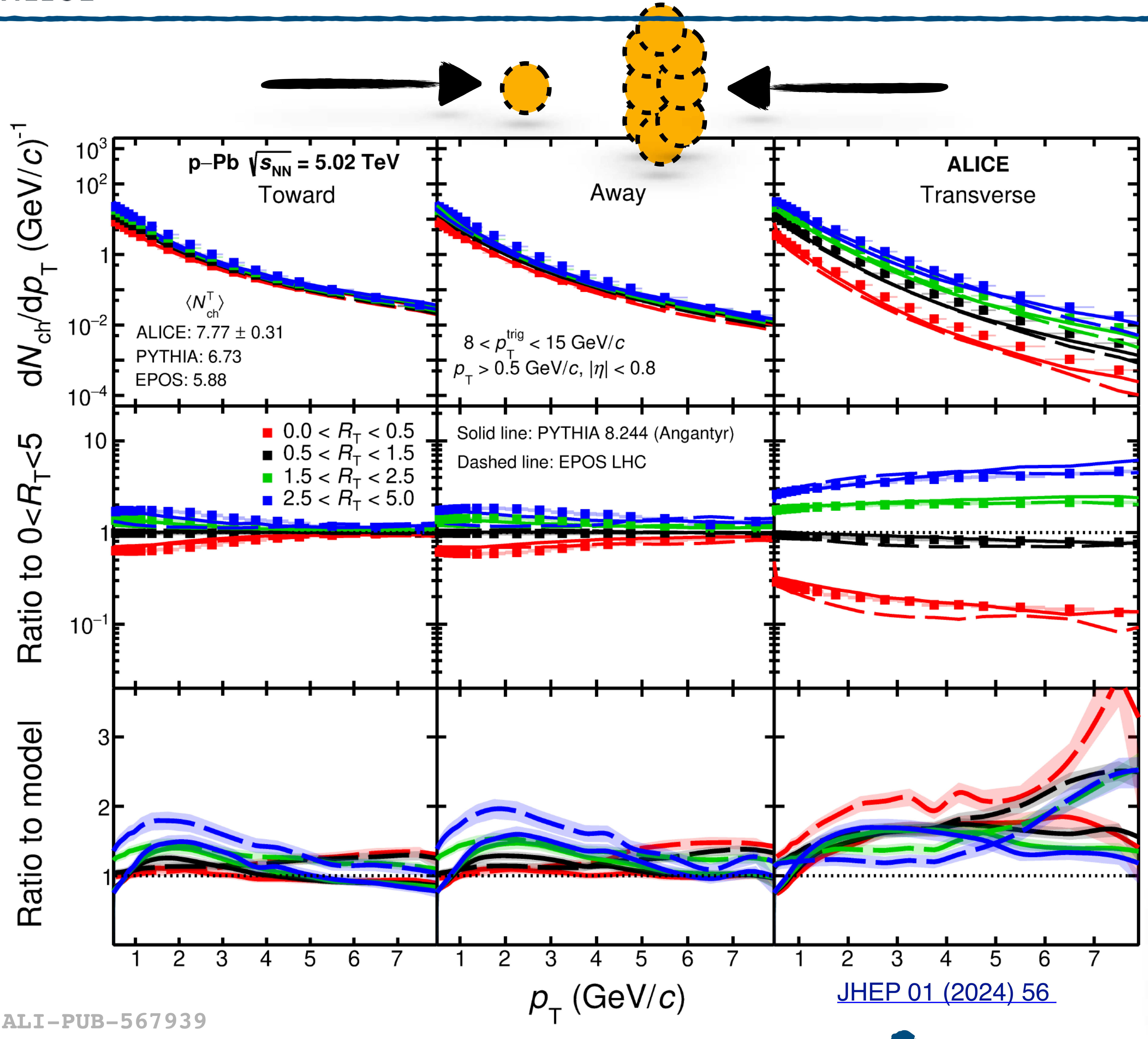
- For $p_T < 4$ GeV/c, the p_T spectra exhibit a R_T-dependence. **Color reconnection produces this effect in PYTHIA 8**
- For $p_T > 4$ GeV/c, spectral shapes is almost independent of R_T

Transverse region:

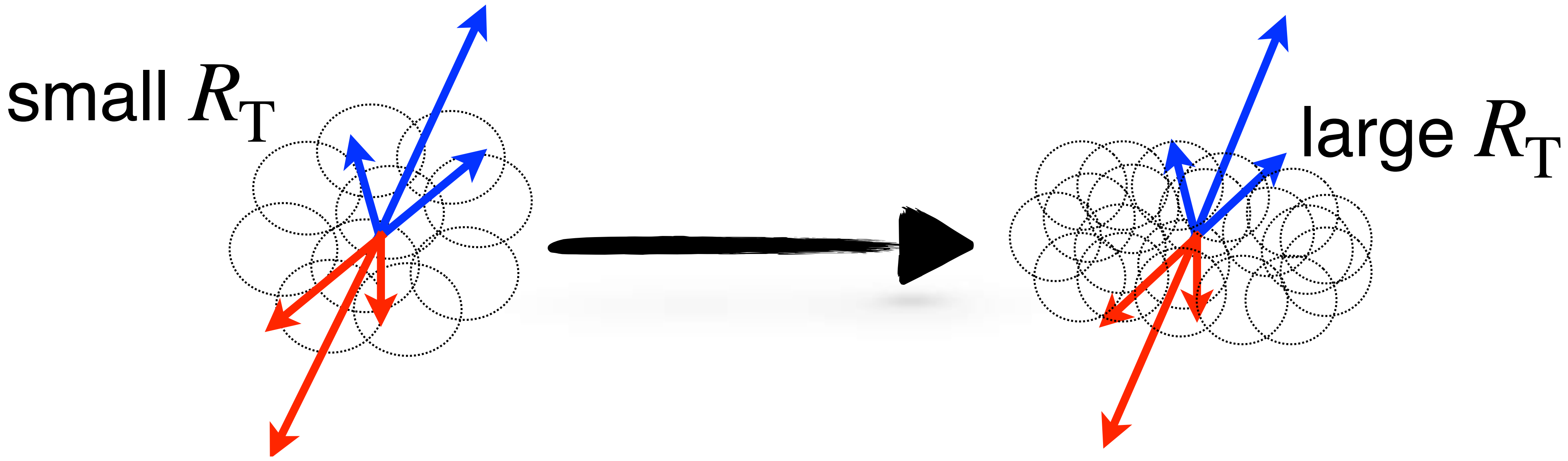
- The p_T spectra harden with increasing R_T, due to **autocorrelations effects** Phys. Rev. D 104 (2021) 016017

- In general, PYTHIA 8 describes data better than EPOS LHC

p_T-spectra as a function of R_T



JHEP 01 (2024) 56



Toward and away regions:

- For $p_T < 4$ GeV/c, the p_T spectra exhibit a R_T -dependence. **Color reconnection produces this effect in PYTHIA 8**
- For $p_T > 4$ GeV/c, spectral shapes is almost independent of R_T

Transverse region:

- The p_T spectra harden with increasing R_T, due to **autocorrelation effects** Phys. Rev. D 104 (2021) 016017

- In general, Argantyr describes data better than EPOS LHC except for the transverse region

Similar features as seen in pp collisions for all the three topological regions

$\langle p_T \rangle$ as a function of R_T

JHEP 01 (2024) 56

Low R_T:

- The jet contribution dominates at low R_T, as expected for $R_T \to 0$

$\langle p_{\mathrm{T}} \rangle$ as a function of R_{T}

JHEP 01 (2024) 56

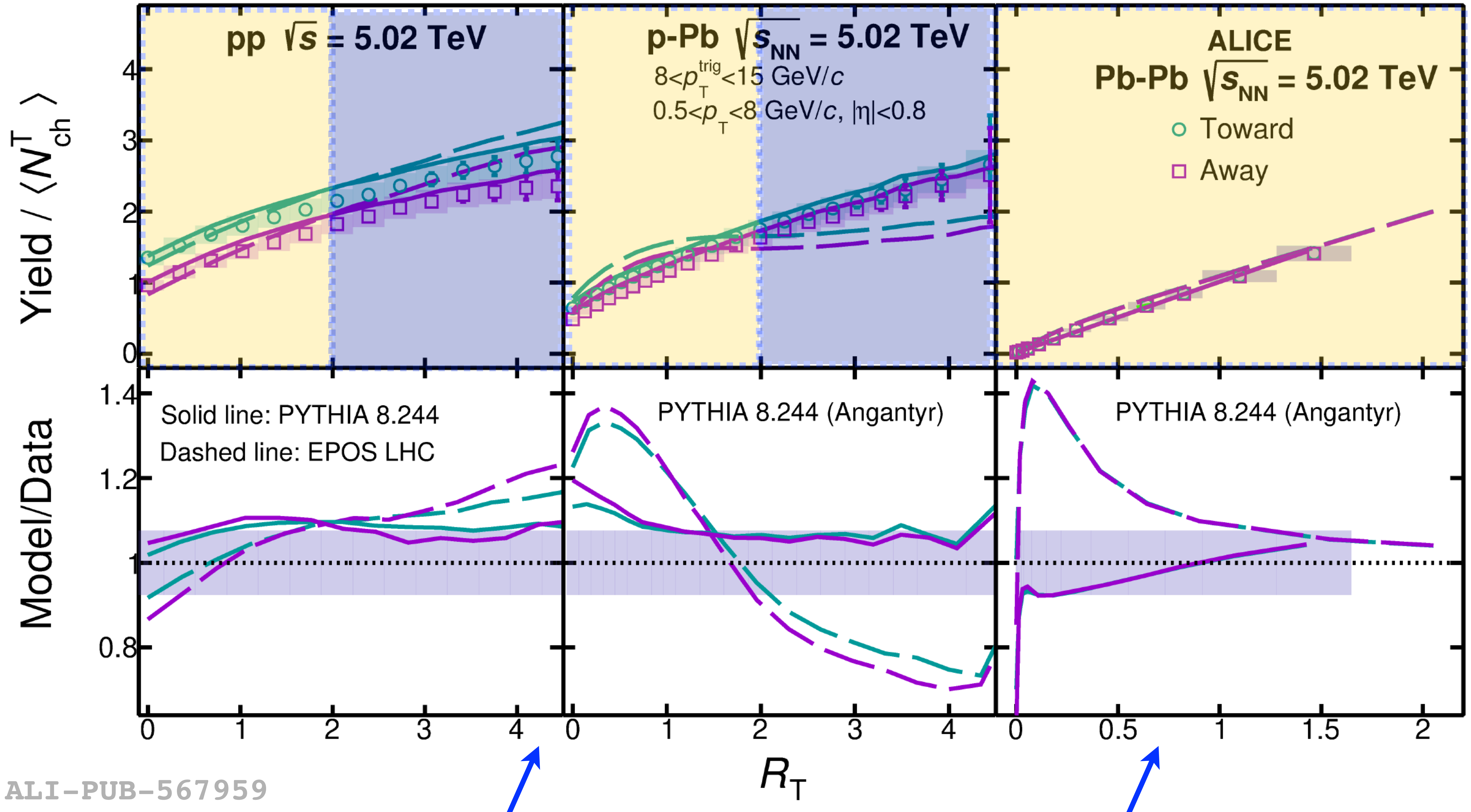
Low R_{T}:

- The jet contribution dominates at low R_{T}, as expected for $R_{\mathrm{T}} \to 0$

High R_{T}:

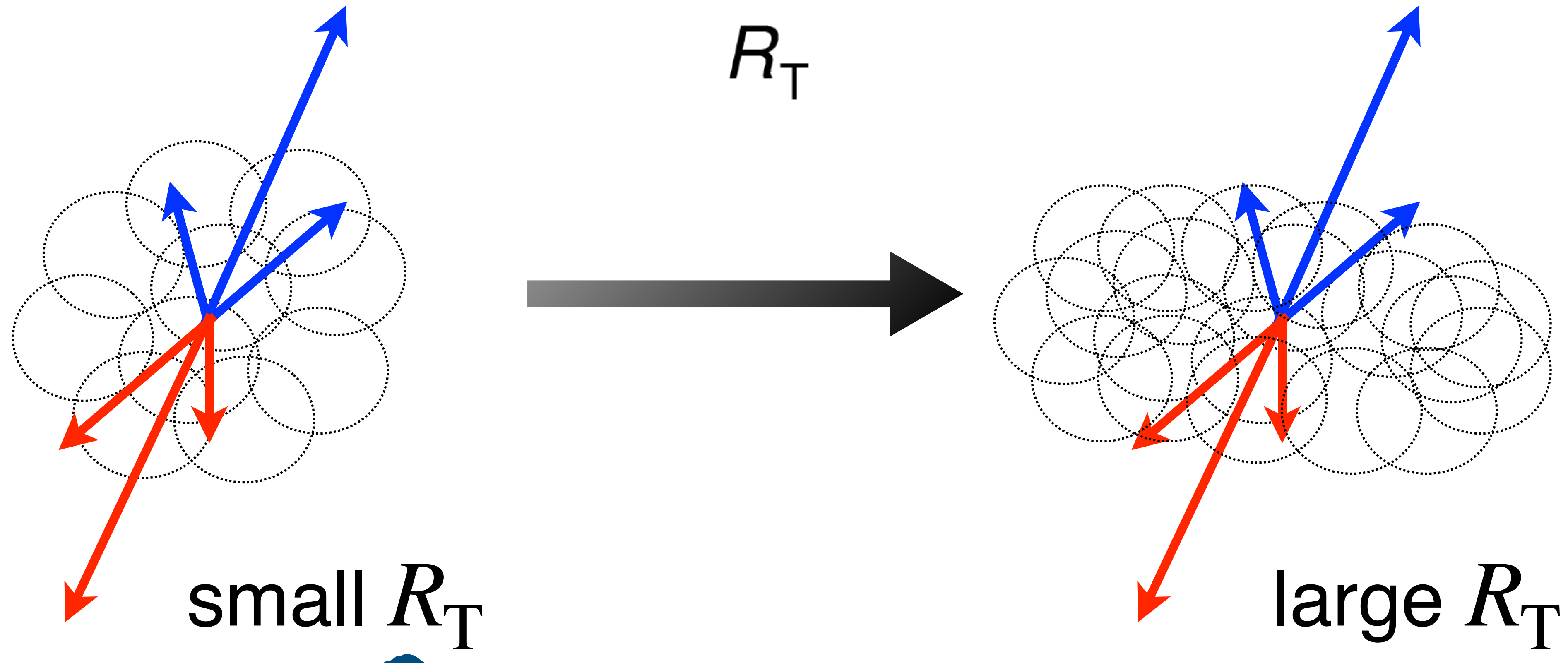
- The $\langle p_{\mathrm{T}} \rangle$ is dominated by bulk contribution and exhibits a system size ordering

Normalized integrated yield as a function of R_T



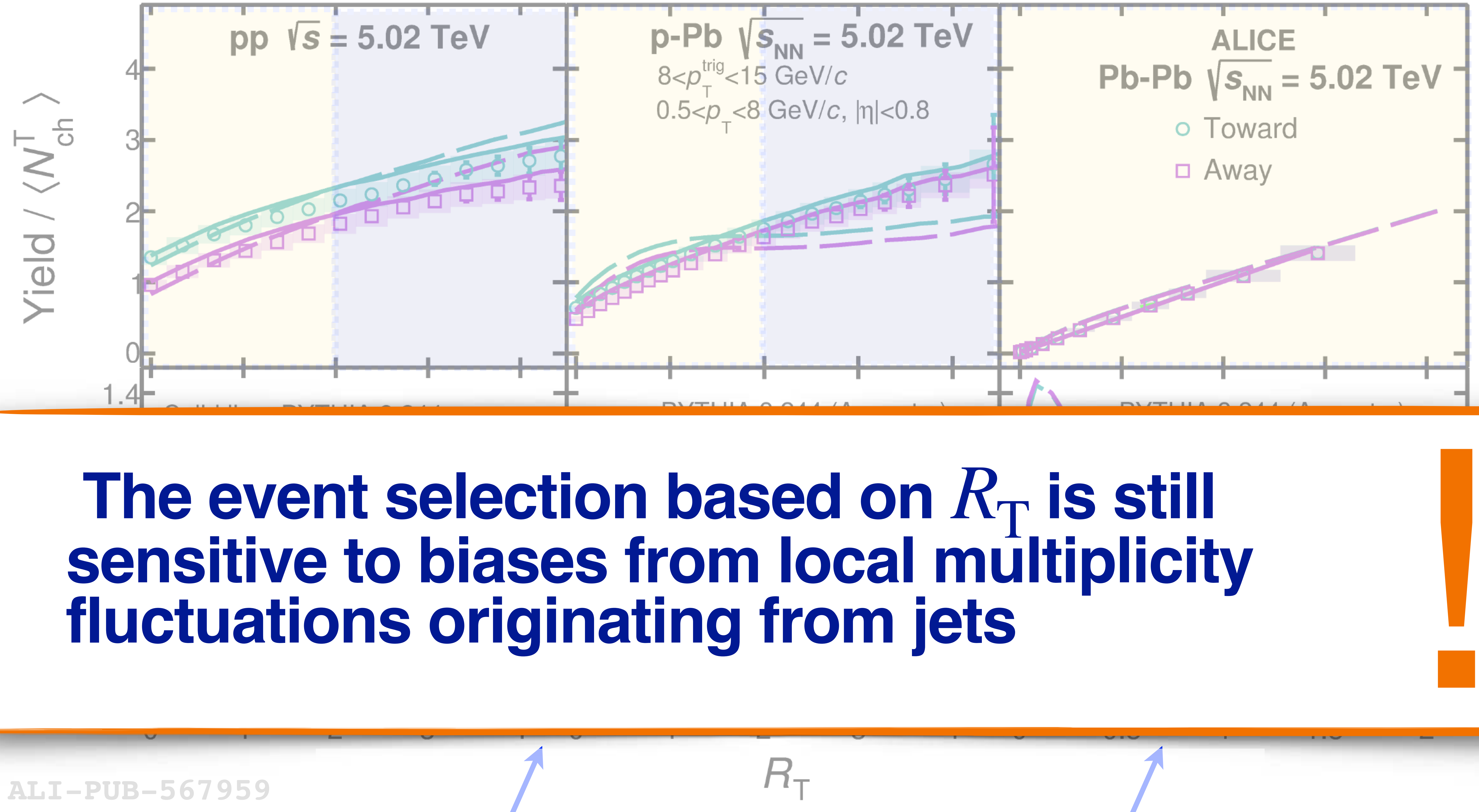
JHEP 01 (2024) 56

UE is isotropically distributed



More activity in the transverse region

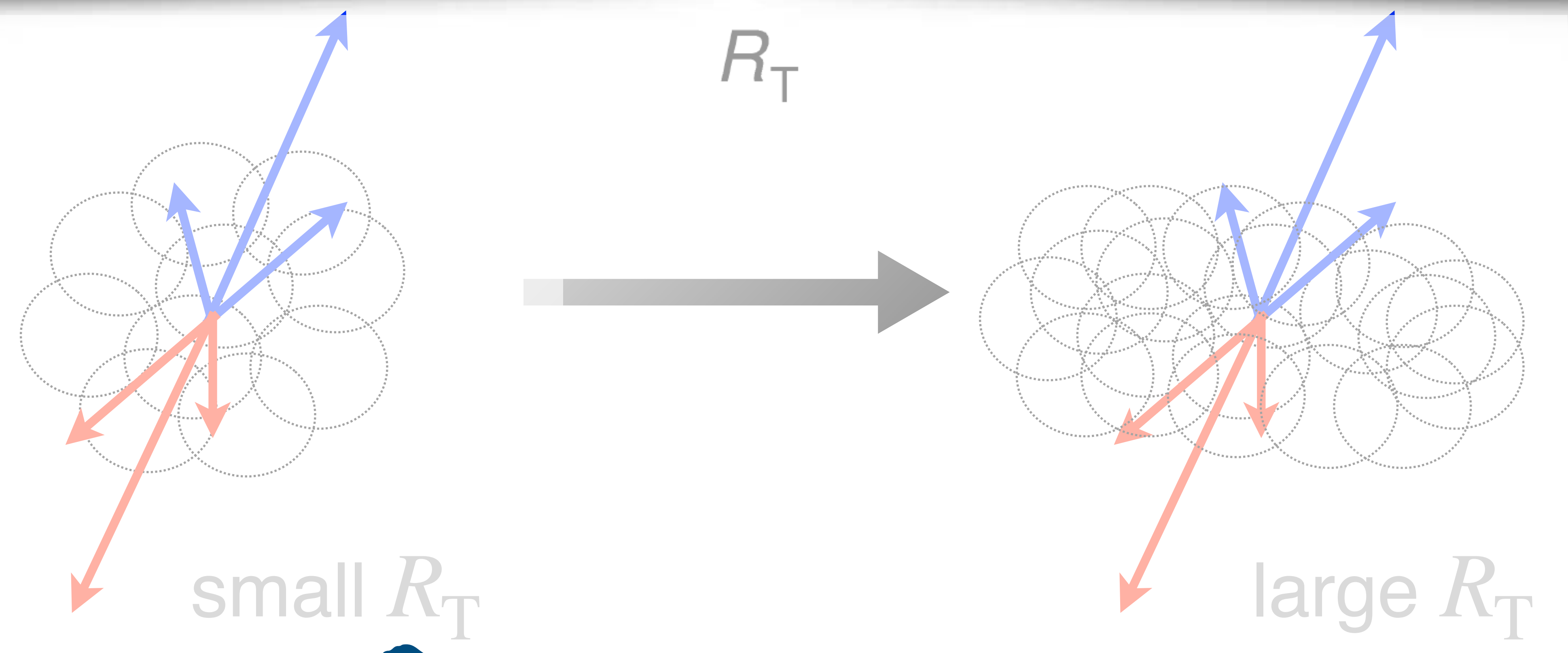
Normalized integrated yield as a function of R_T



The event selection based on R_T is still sensitive to biases from local multiplicity fluctuations originating from jets

!

UE is isotropically distributed



More activity in the transverse region

Charged-particle flattenicity ρ

Flattenicity is a measurement of the local multiplicity fluctuations

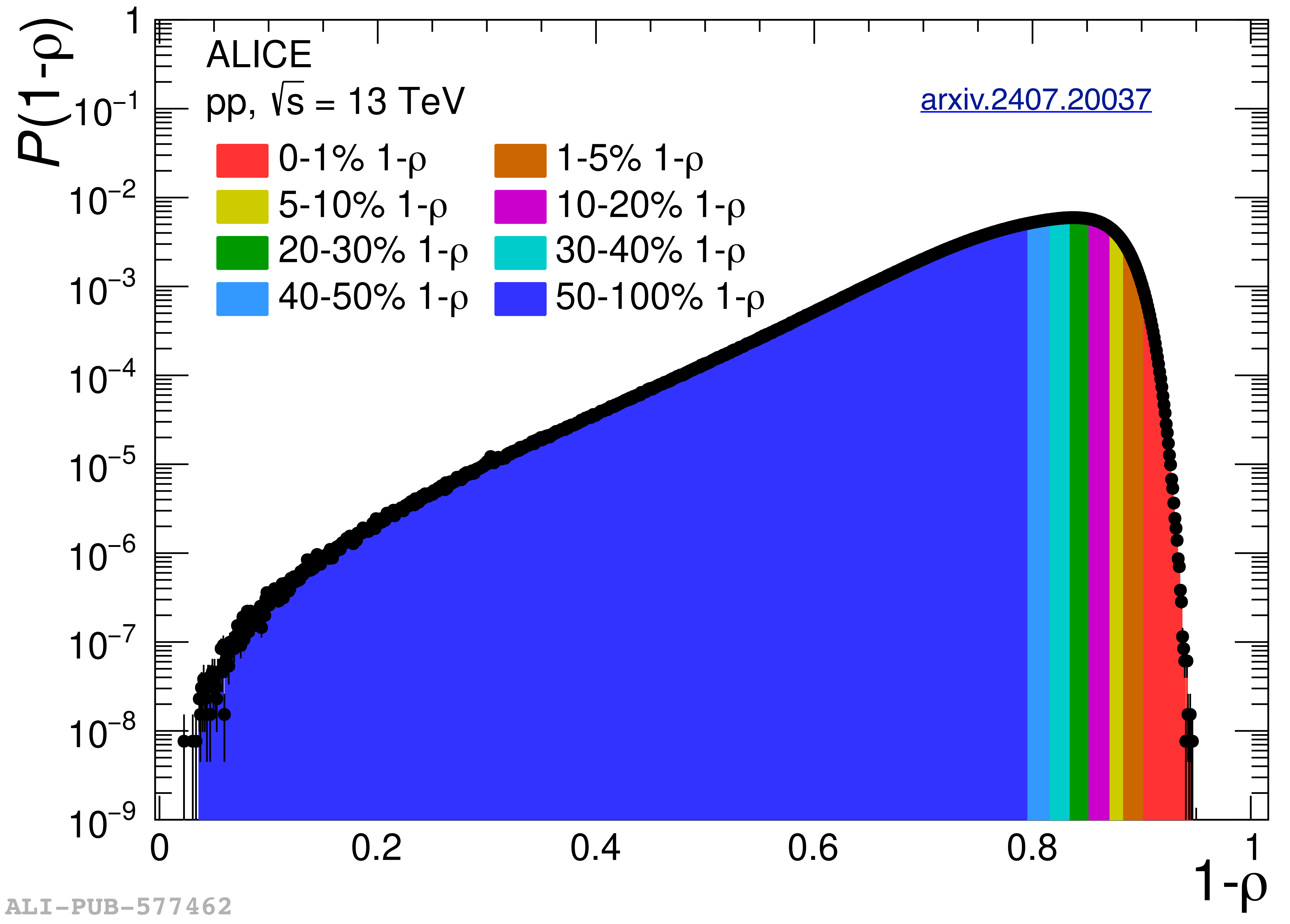
Event-by-event selection based on the relative standard deviation of the multiplicity measured in the 64 V0-channels

Phys. Rev. D 107 (2023) 076012

$$\rho = \frac{\sqrt{\sum_{i=1}^{64} \left(N_{\rm ch}^{\rm cell,i} - \langle N_{\rm ch}^{\rm cell}\rangle\right)^2 / N_{\rm cell}^2}}{\langle N_{\rm ch}^{\rm cell}\rangle}$$

with $N_{\rm ch}^{\rm cell,i}$: particle multiplicity in the i-th cell

$\langle N_{ch}^{\rm cell}\rangle$: average multiplicity per event over the all 64 cells



High flattenicity ($1-\rho \rightarrow 0$):

- Large local multiplicity fluctuations
- ↓Low multiplicity → ↓MPIs

Low flattenicity ($1-\rho \rightarrow 1$):

- Small local multiplicity fluctuations
- ↑High multiplicity → ↑MPIs

Q_{pp} as a function of p_{T}

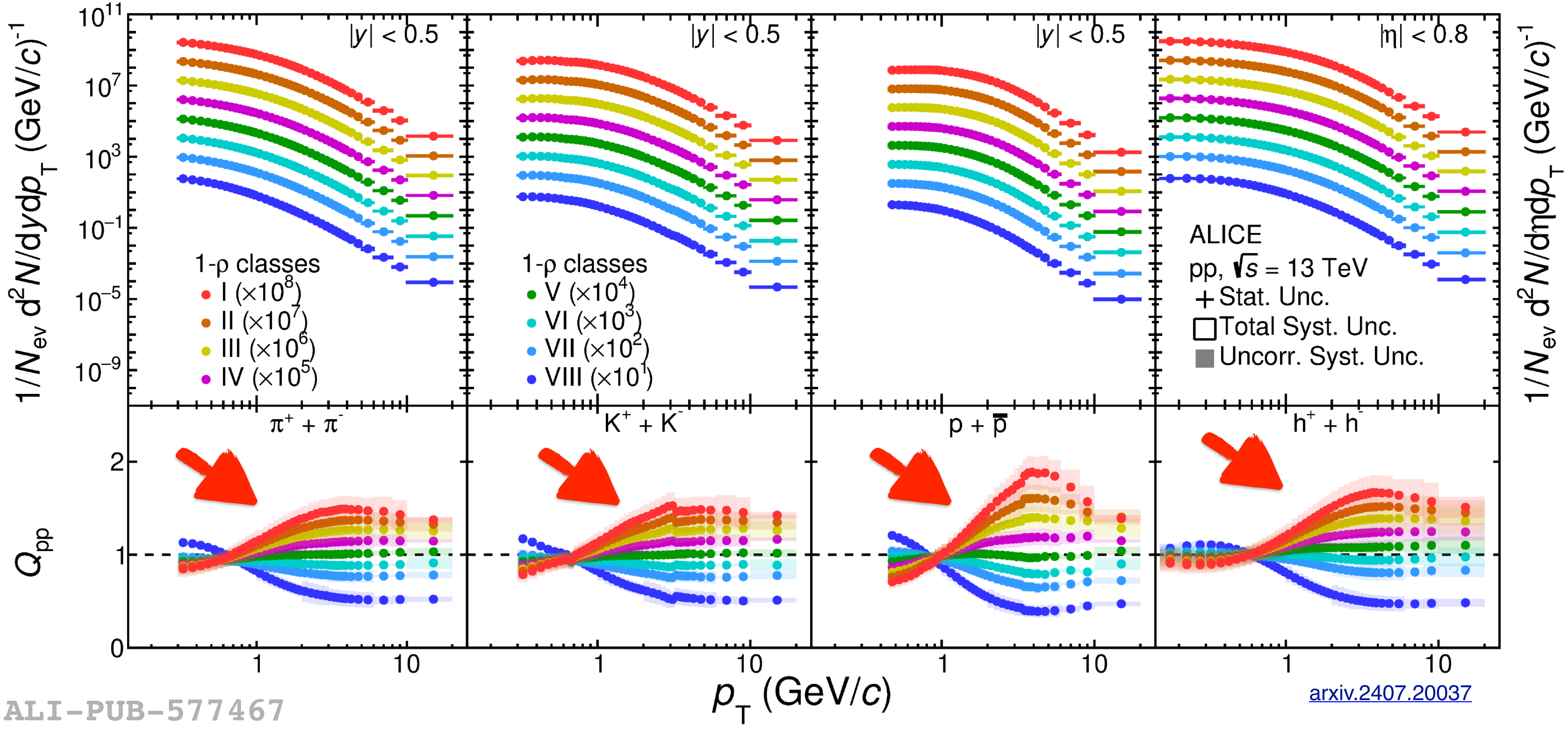
Q_{pp} **demonstrates the evolution of the** p_{T}**-spectral shapes with flattenicity and illustrate the sensitivity to MPI and CR effects**

arxiv.2407.20037

$$Q_{\mathrm{pp}} = \frac{\frac{1}{N_{\mathrm{ev}}} \frac{\mathrm{dN_{ch}}}{\mathrm{dp_T}} \frac{1}{\langle N_{\mathrm{ch}} \rangle} \Big|_{1-\rho}}{\frac{1}{N_{\mathrm{ev}}} \frac{\mathrm{dN_{ch}}}{\mathrm{dp_T}} \frac{1}{\langle N_{\mathrm{ch}} \rangle} \Big|_{\mathrm{MB}}}$$

arxiv.2407.20037

Q_{pp} as a function of p_T

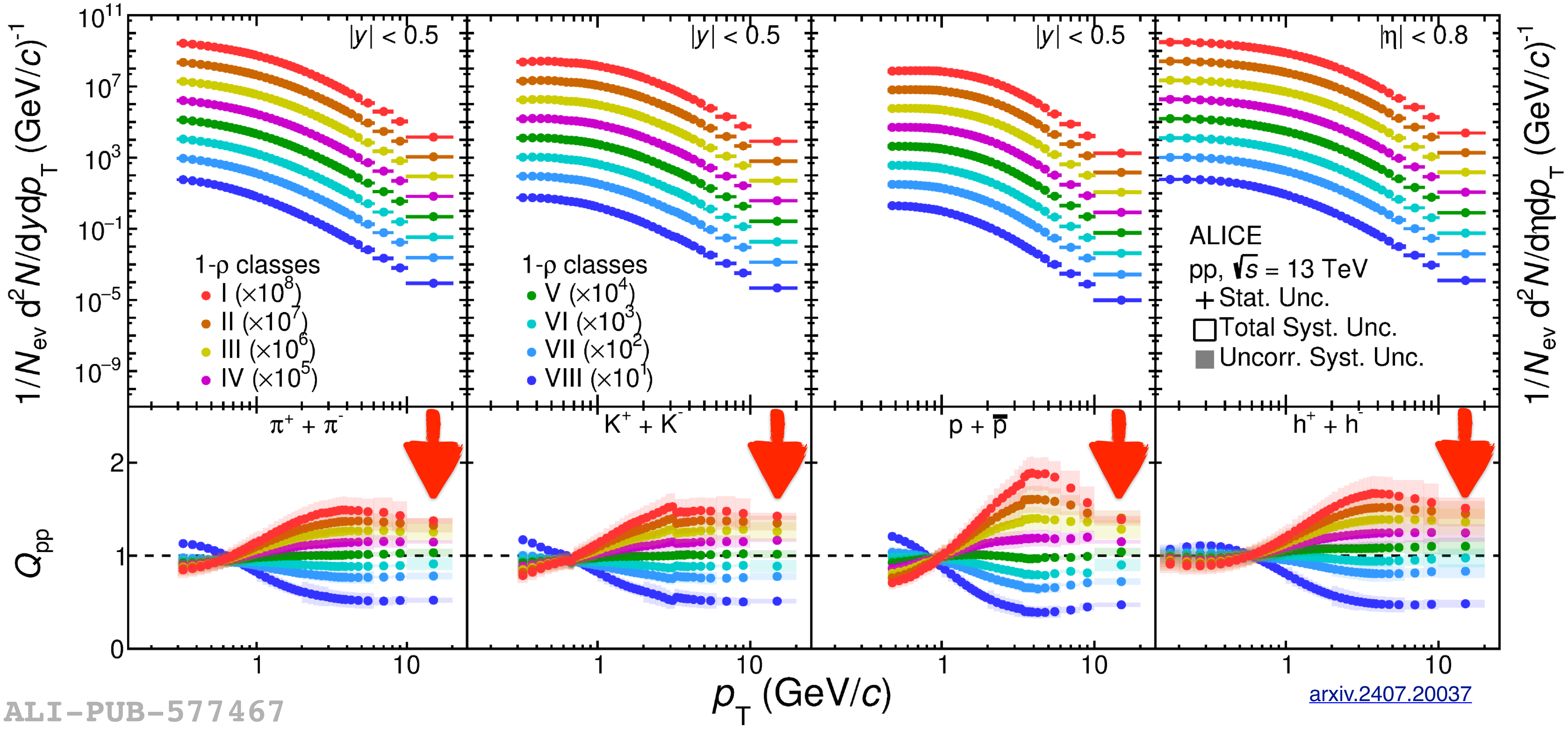


Intermediate p_T:

- a bump structure is developed with increasing multiplicity

arxiv.2407.20037

Q_{pp} as a function of p_{T}



Intermediate p_{T}:

- a bump structure is developed with increasing multiplicity

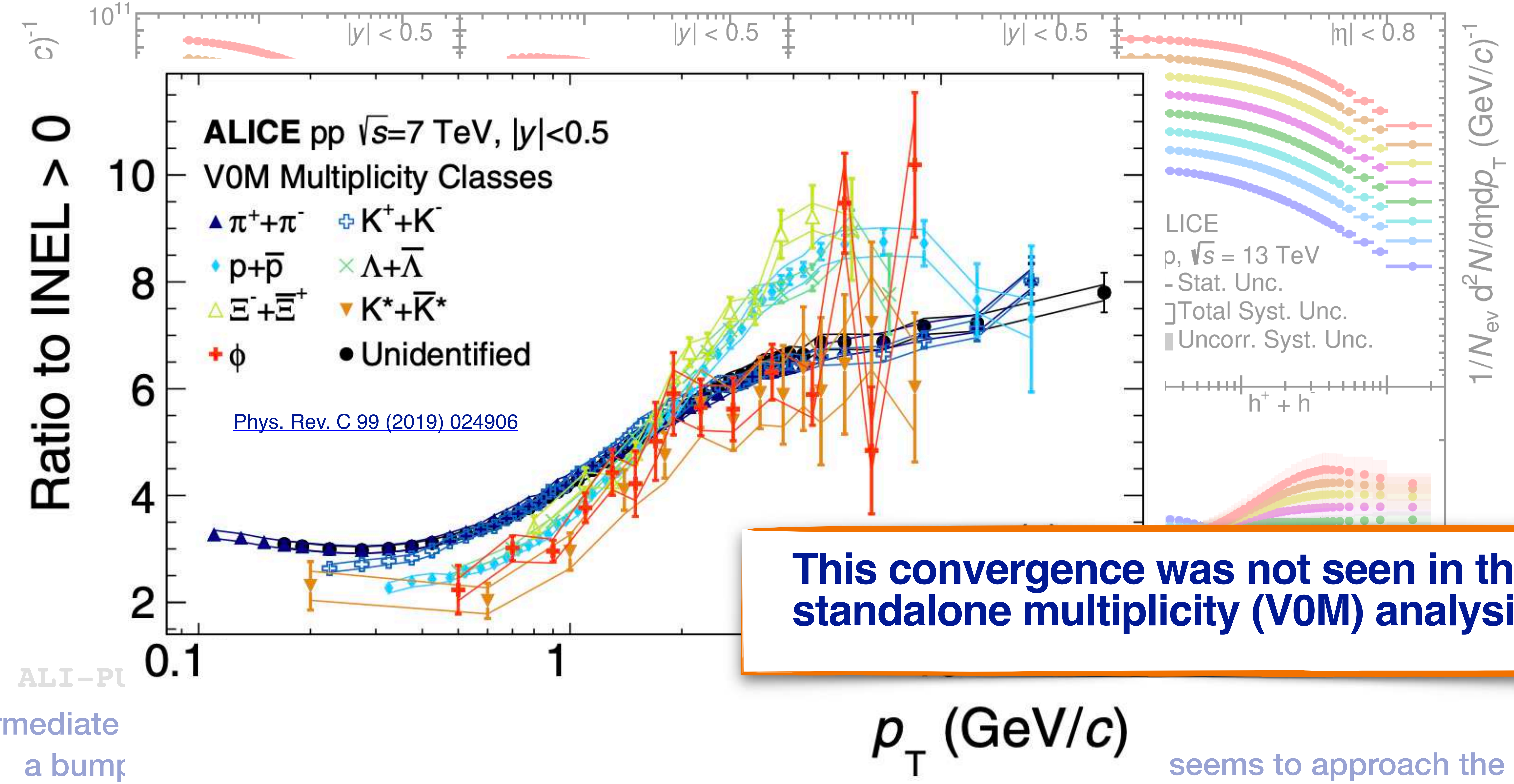
High p_{T}:

- Q_{pp} seems to approach the unity

arxiv.2407.20037

Q_{pp} as a function of p_{T}

Instituto de Ciencias Nucleares UNAM



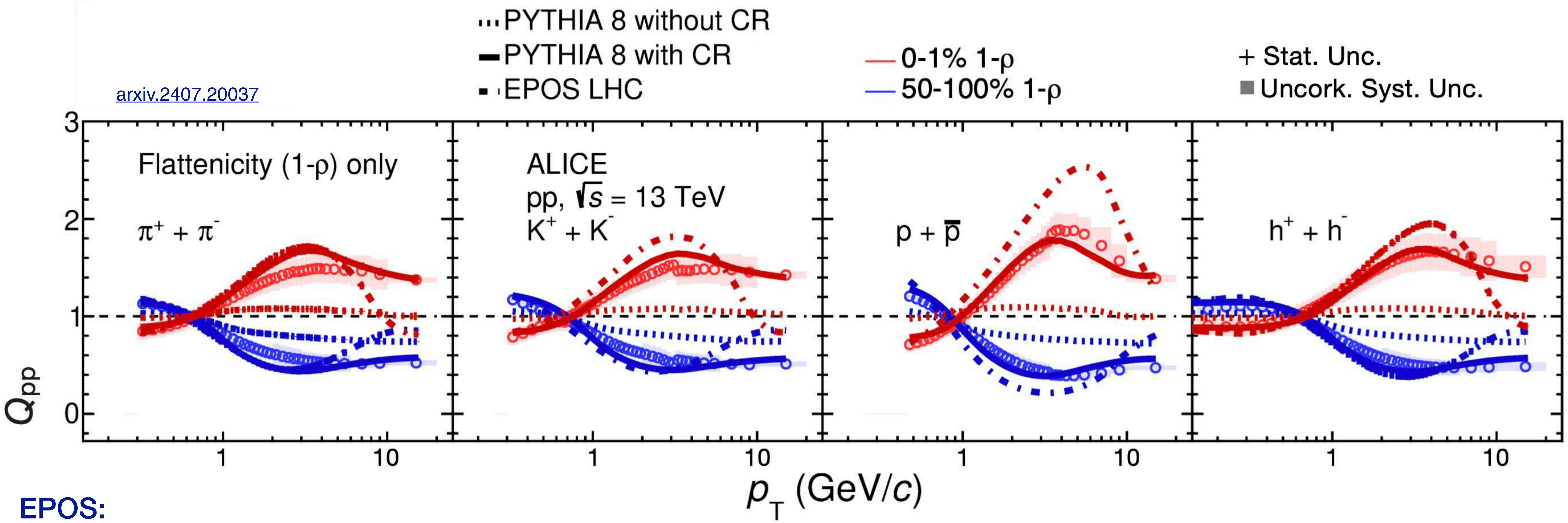
This convergence was not seen in the standalone multiplicity (V0M) analysis !

Intermediate

- a bump ... seems to approach the unity

Q_{pp} data vs MC predictions

arxiv.2407.20037



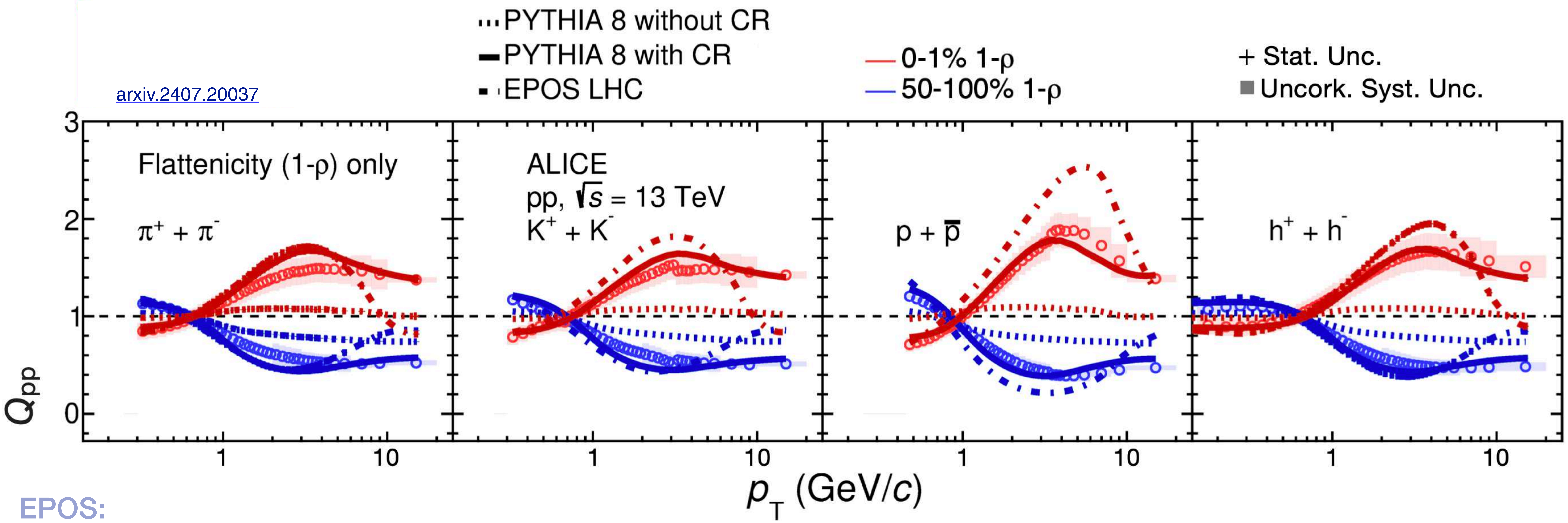
EPOS:

- Overestimates Q_{pp} ratios at intermediate p_{T}
- Underestimates Q_{pp} ratios at high p_{T}

arxiv.2407.20037

Q_{pp} data vs MC predictions

[arxiv.2407.20037](https://arxiv.org/abs/2407.20037)



EPOS:

- Overestimates Q_{pp} ratios at intermediate p_{T}
- Underestimates Q_{pp} ratios at high p_{T}

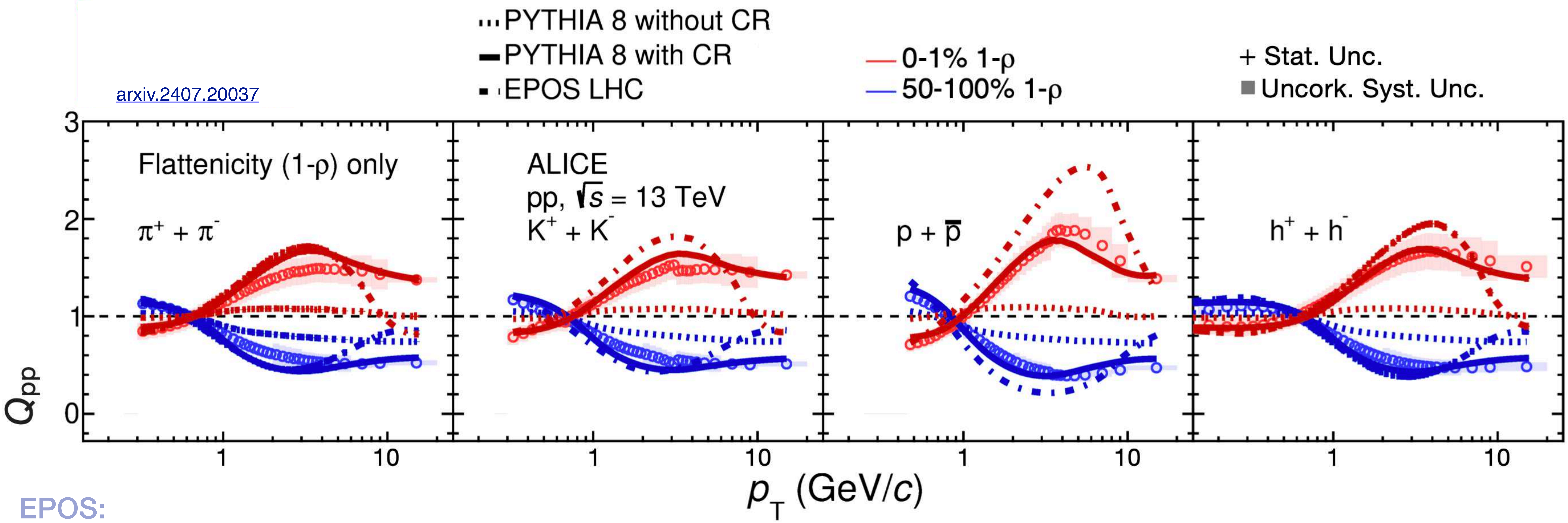
PYTHIA 8 w/o CR:

- Q_{pp} ratios consistent with unity
- It does not describe the data

[arxiv.2407.20037](https://arxiv.org/abs/2407.20037)

Q_{pp} data vs MC predictions

arxiv.2407.20037



EPOS:

- Overestimates $Q_{\rm pp}$ ratios at intermediate $p_{\rm T}$
- Underestimates $Q_{\rm pp}$ ratios at high $p_{\rm T}$

PYTHIA 8 w/o CR:

- $Q_{\rm pp}$ ratios consistent with unity
- It does not describe the data

PYTHIA 8 w CR:

- **Describes the measurements quite well**

arxiv.2407.20037

Summary

Relative transverse activity classifier R_{T}:

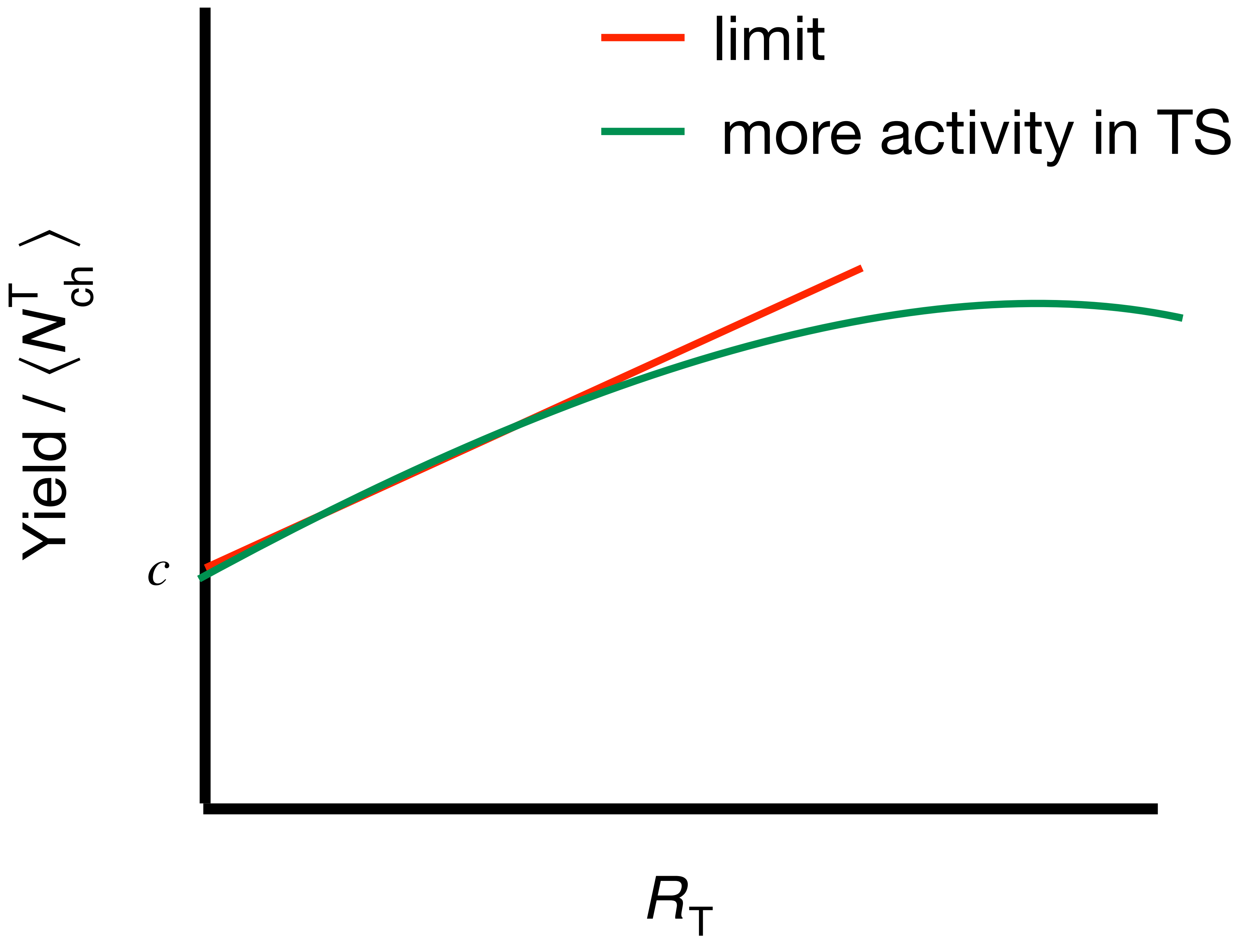
- For $R_{\mathrm{T}} < 2$, the activity in the transverse region is a good proxy for UE
- For $R_{\mathrm{T}} > 2$, the activity in the transverse region gets biased towards multi-jet final states (probably from hard Bremsstrahlung radiation)
- The transverse region is affected by autocorrelations: the p_{T} spectra get harder with increasing R_{T}. Similar behavior is seen using the track multiplicity instead of R_{T}

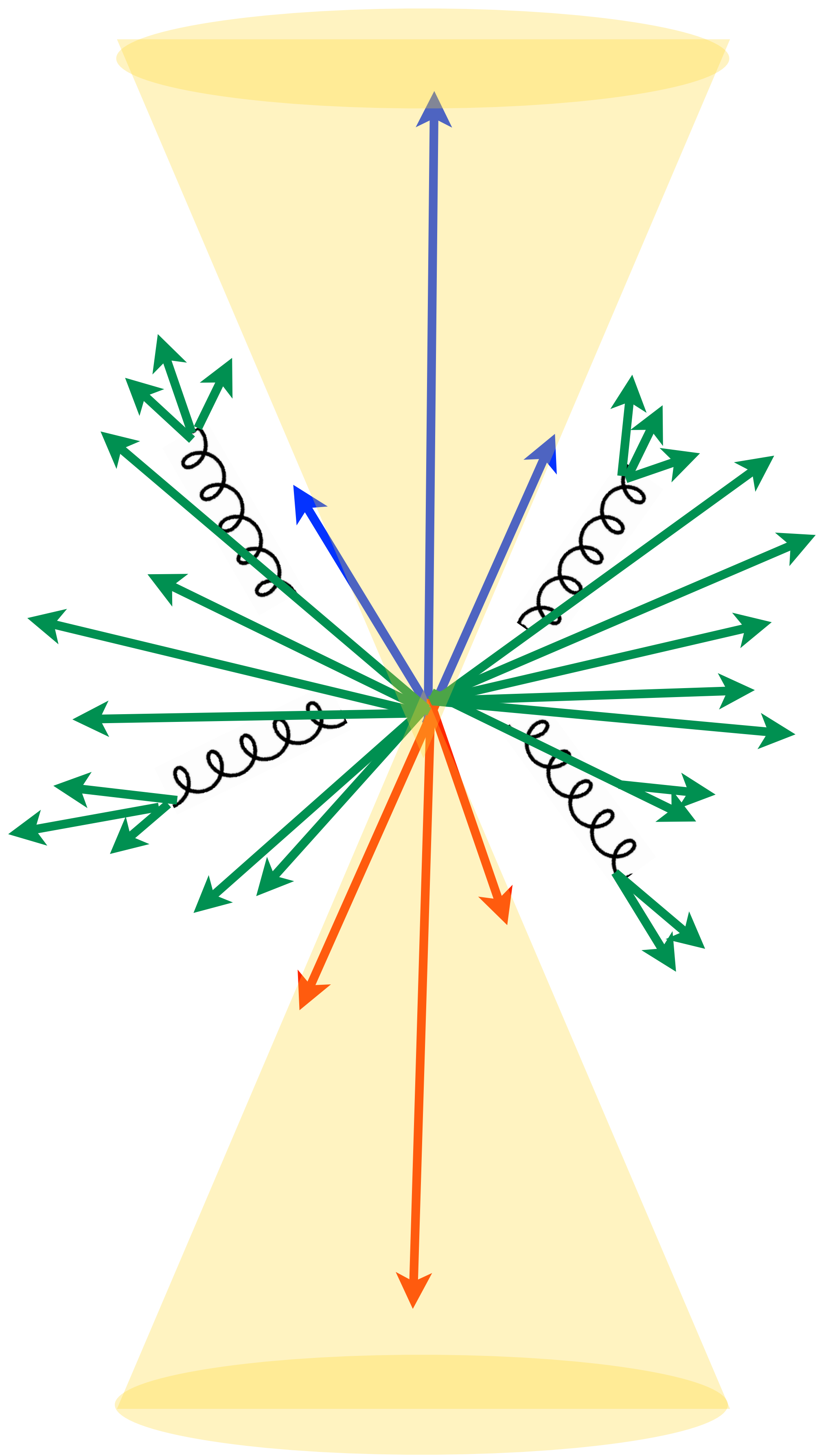
Charged particle flattenicity $1-\rho$:

- Flattenicity is sensitive to MPIs and is less affected by biases towards larger p_{T} due to local multiplicity fluctuations in the V0 acceptance
- The good description of PYTHIA 8 with CR suggests that a simple superposition of independent parton-parton scatterings cannot describe pp data. Final-state interactions are needed.

Backup

Normalized integrated yield explanation





The gluon radiation produce more activity in TS

higher $\langle N_{ch}^{TS} \rangle$ value

$$\frac{\mathrm{Yield}^{\mathrm{toward}}}{\langle \mathrm{N_{ch}^{TS}} \rangle} = \frac{\mathrm{N_{ch}^{jet}} + \mathrm{N_{ch}^{TS}}}{\langle \mathrm{N_{ch}^{TS}} \rangle} = \frac{\mathrm{N_{ch}^{jet}}}{\langle \mathrm{N_{ch}^{TS}} \rangle} + \mathrm{R_T} = \mathrm{c} + \mathrm{R_T}$$