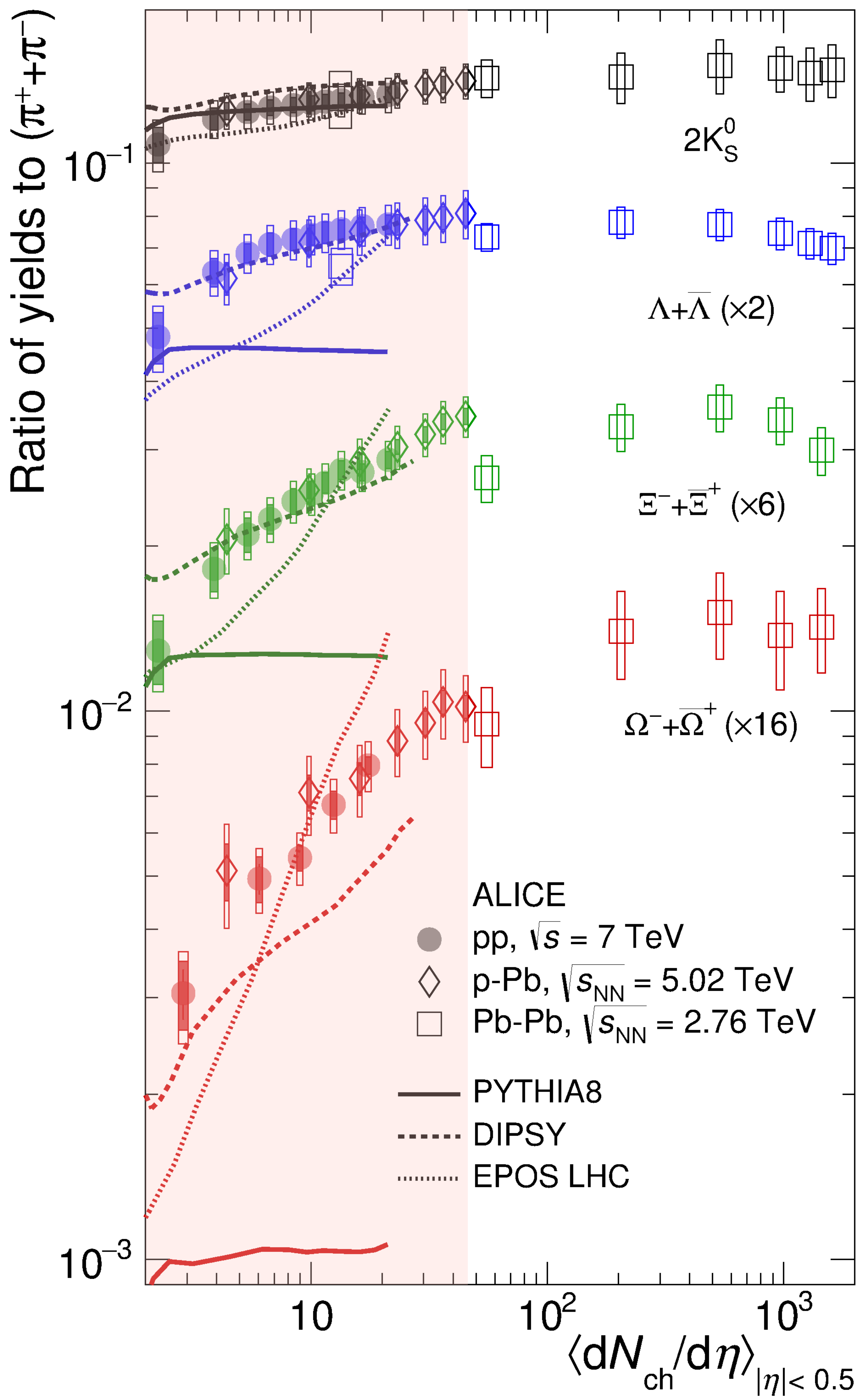
Exploring light flavor hadronization in hard and soft events with event shape classifiers in small collision systems at the LHC with ALICE

Feng Fan, for the ALICE Collaboration

Central China Normal University

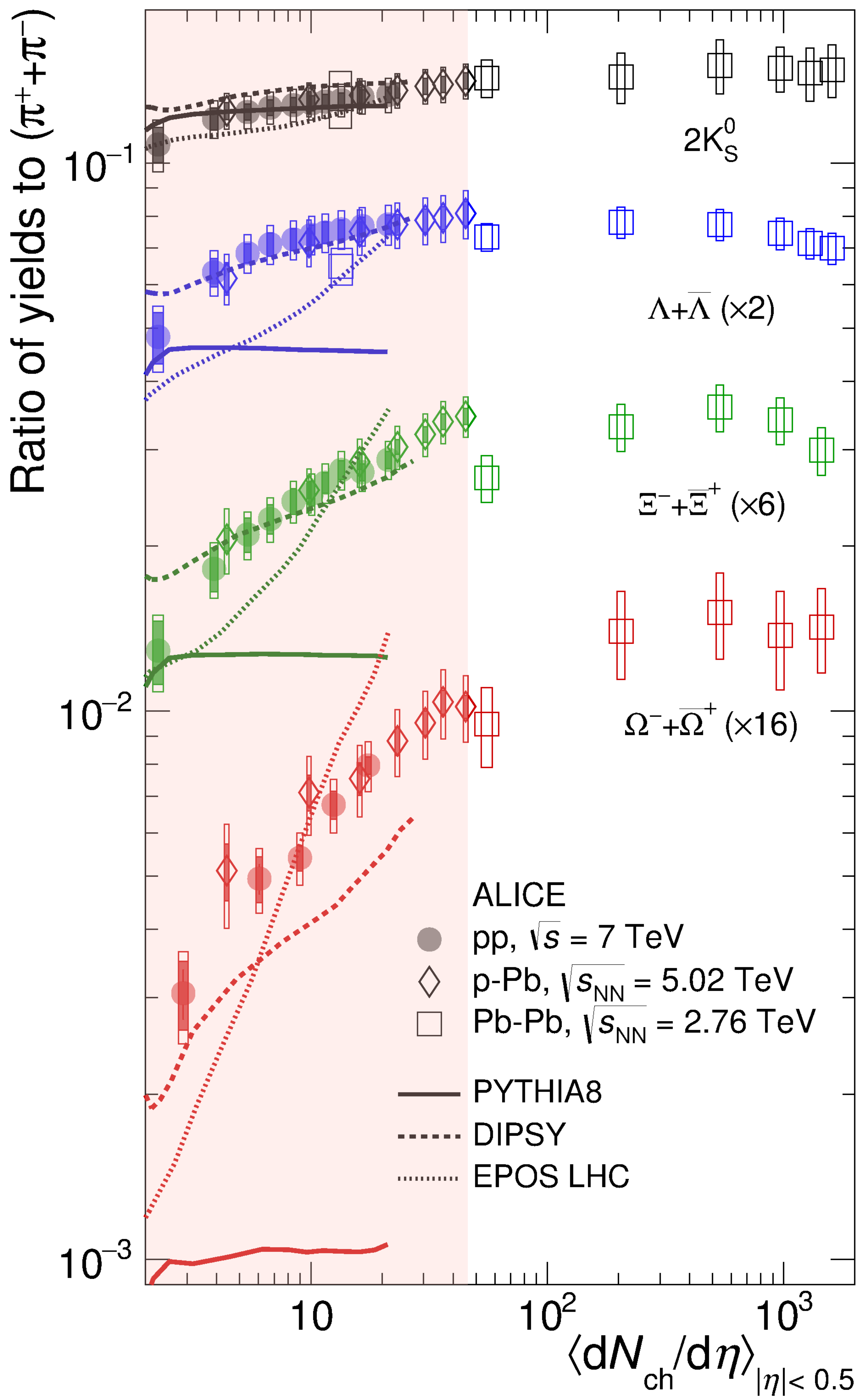
ALICE, Nature Physics 13 (2017) 535-539



✓ Strangeness enhancement in high-multiplicity (HM) small collisions systems

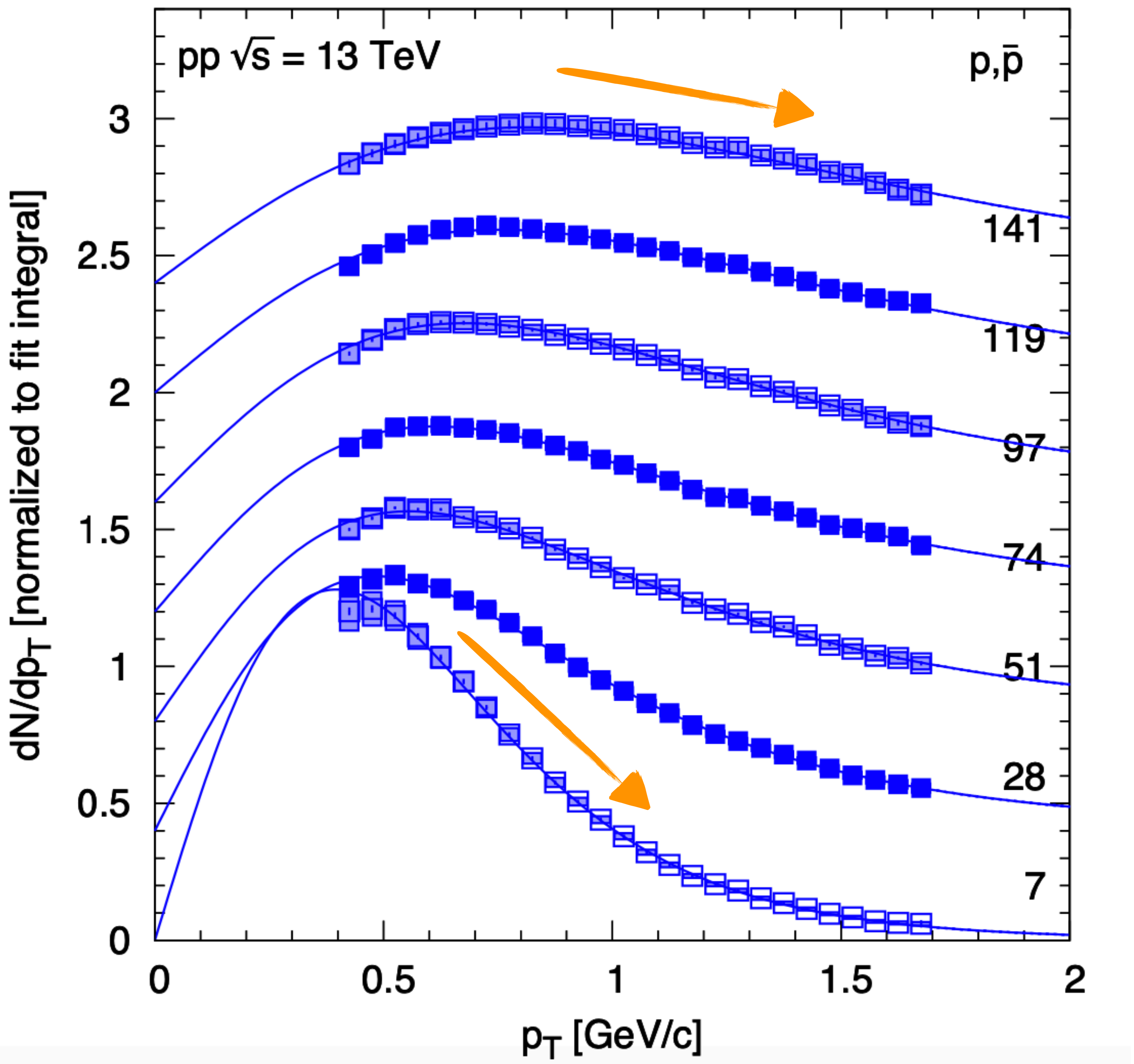
sQGP in small collision systems?

ALICE, Nature Physics 13 (2017) 535-539



- ✓ Strangeness enhancement in high-multiplicity (HM) small collisions systems
- ✓ Radial flow signatures emerge with increasing event multiplicity

CMS, Phys. Rev. D 96, 112003 (2017)



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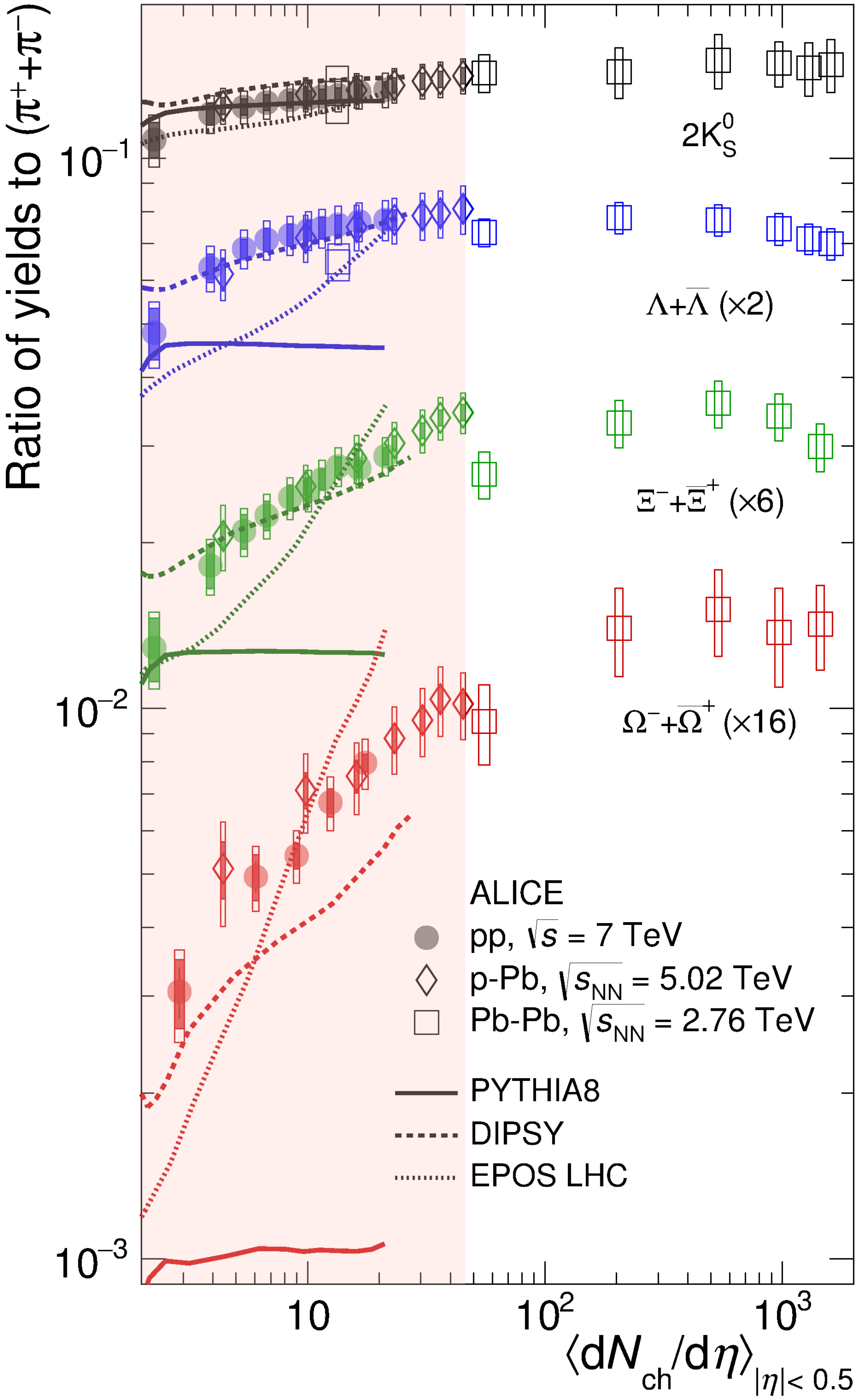

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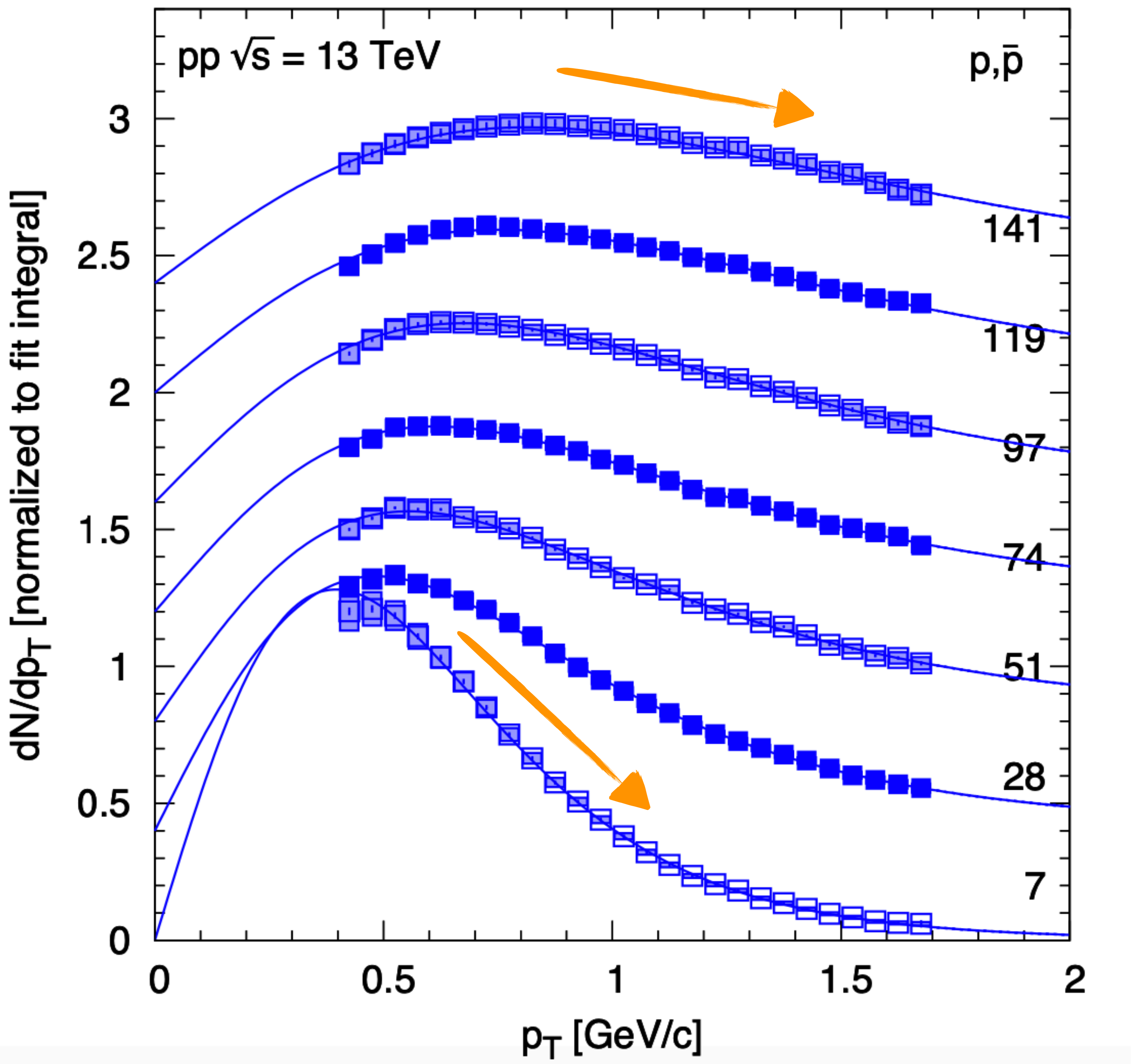
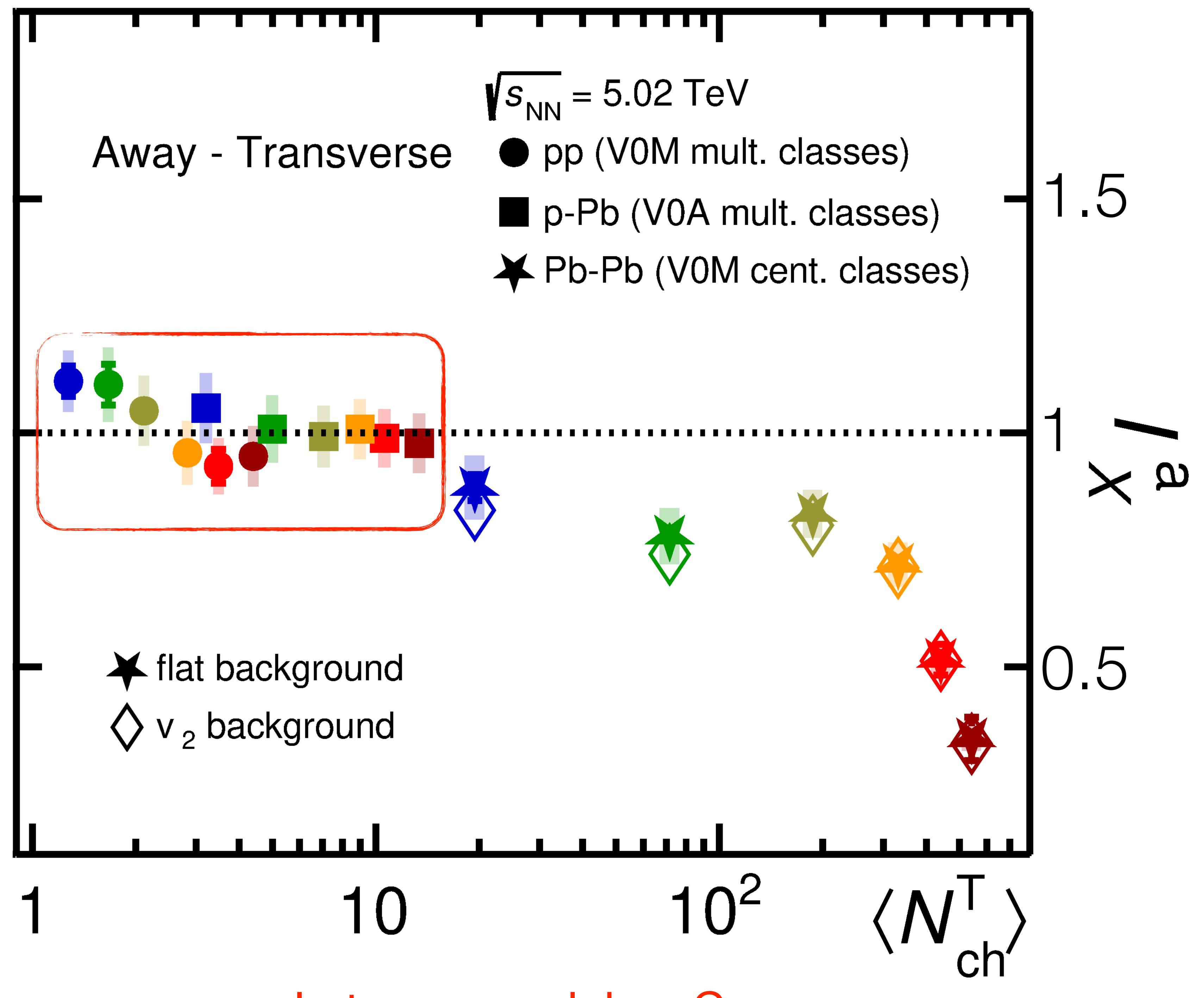


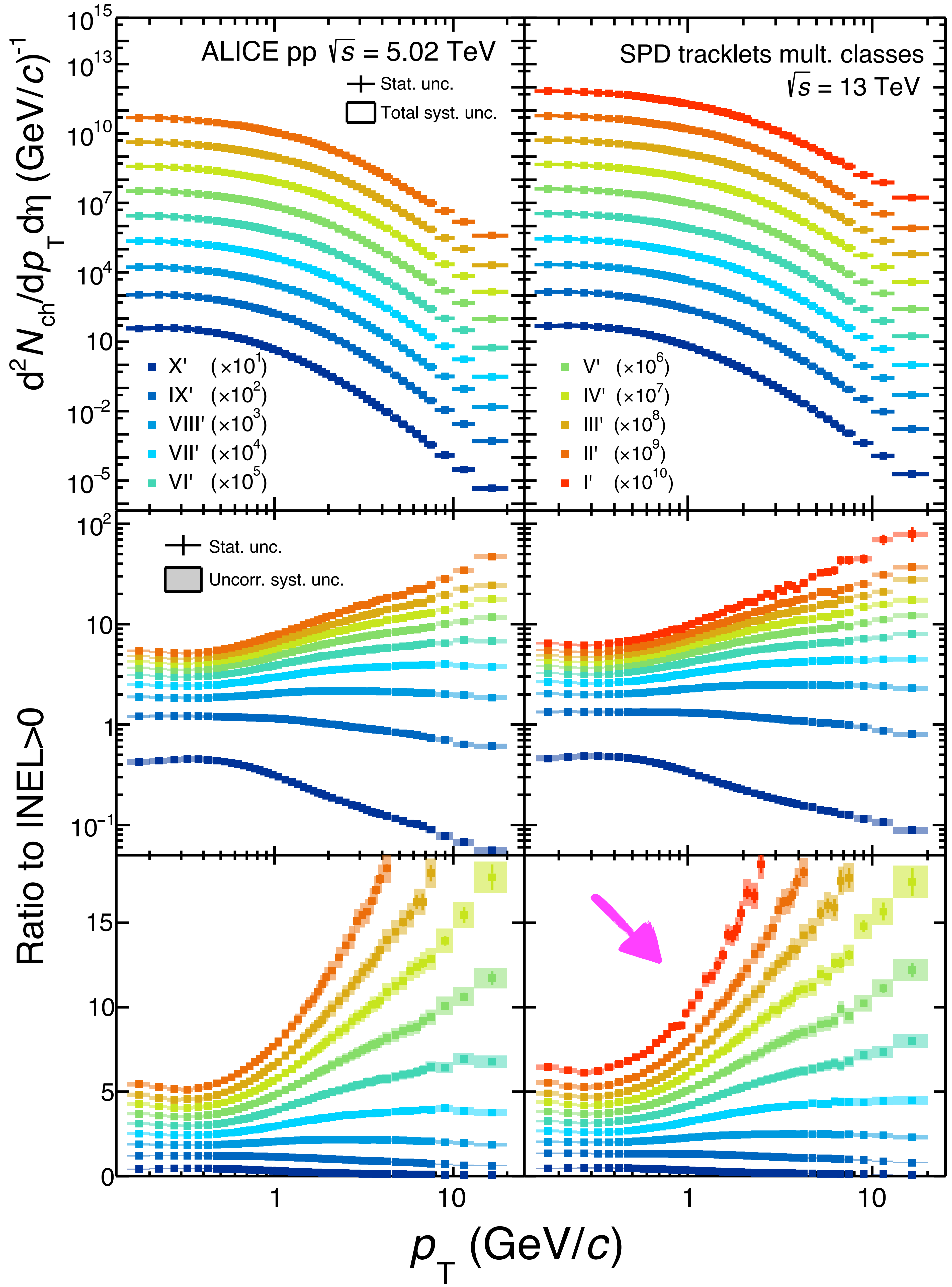
$$I_X^a = \frac{\left(dN_{ch}^{AS-TS}/dp_T\right)_{V0M}}{\left(dN_{ch}^{AS-TS}/dp_T\right)_{MB}}$$

ALICE, Phys. Lett. B 843 (2022) 137649



Jet quenching?

Selection bias



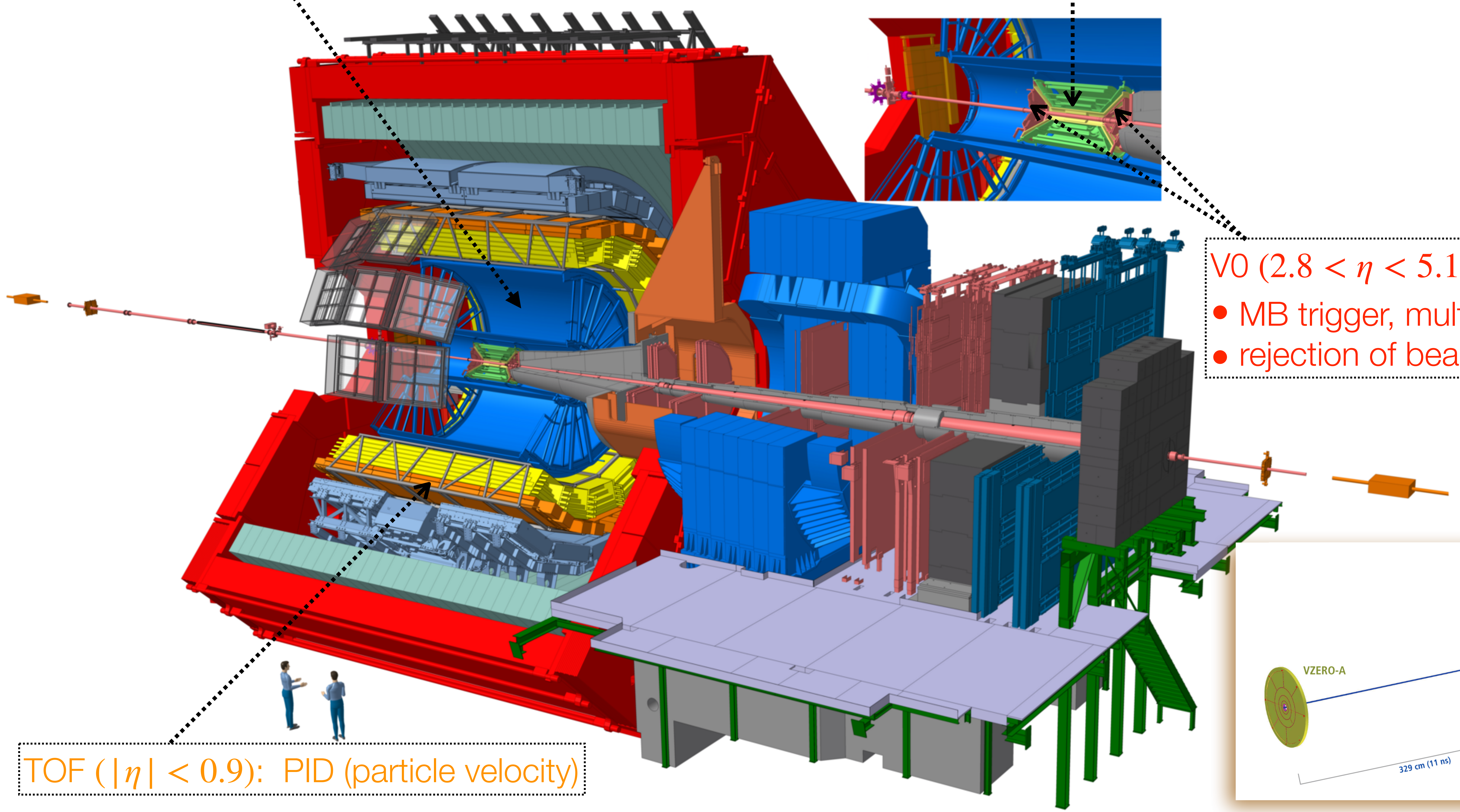
ALICE, Eur.Phys.J. C79 (2019) no.10, 857

- ✓ Selection bias towards hard pp collisions → selecting multiplicity classes and measuring particle spectra in the same pseudorapidity interval
- ✓ We need new observables to isolate events with specific topologic characteristics
  - Transverse spherocity $S_O^{p_T=1}$
  - Relative transverse activity R_T
  - Charged-particle flattenicity $1-\rho$

The ALICE detector in Run 1 and Run 2

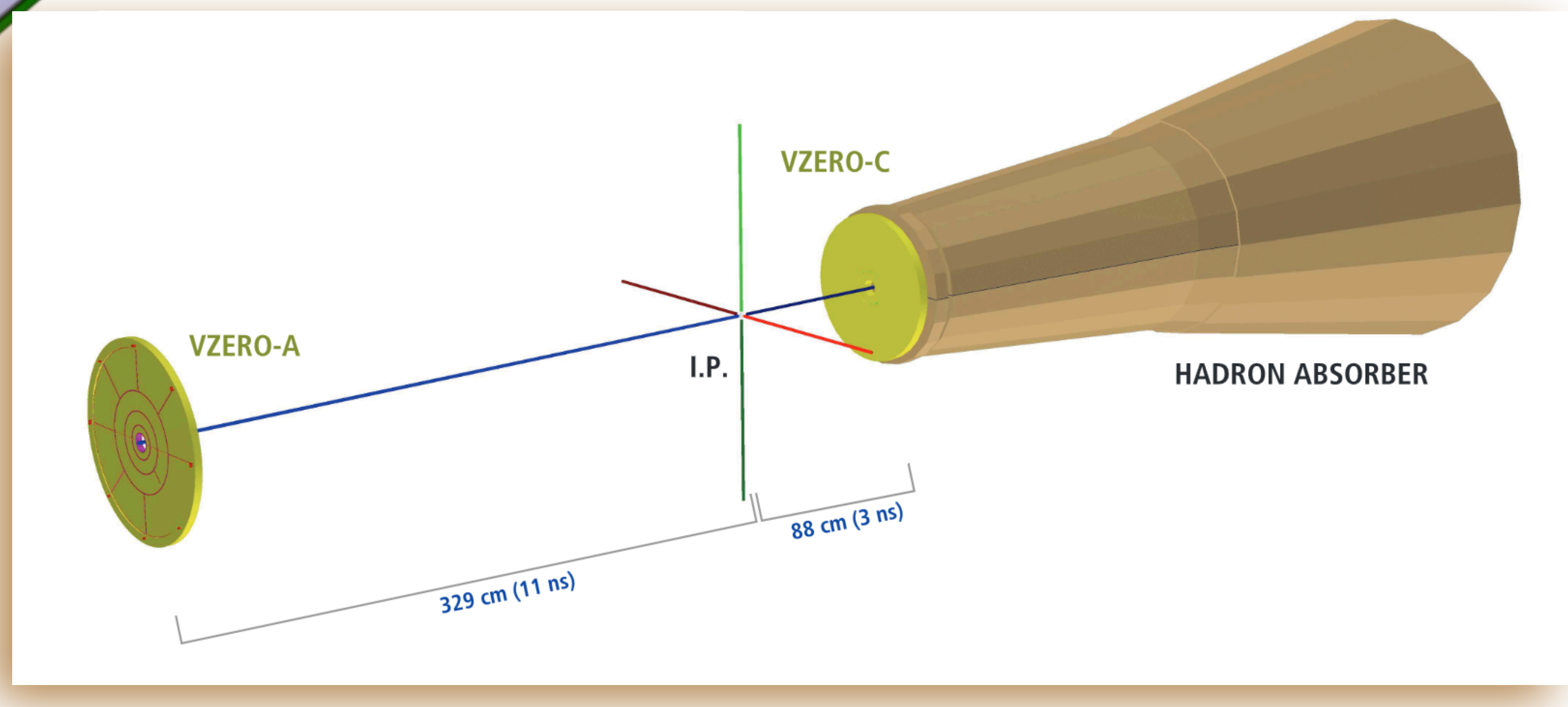
TPC ($|\eta| < 0.9$): tracking, PID (dE/dx)

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



V0 ($2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$)

- MB trigger, multiplicity (V0M), flattenicity
- rejection of beam induced background



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

Transverse spherocity $S_{O}^{p_{T}=1}$ measurement

Transverse spherocity $S_{\mathrm{O}}^{p_{\mathrm{T}}=1}$

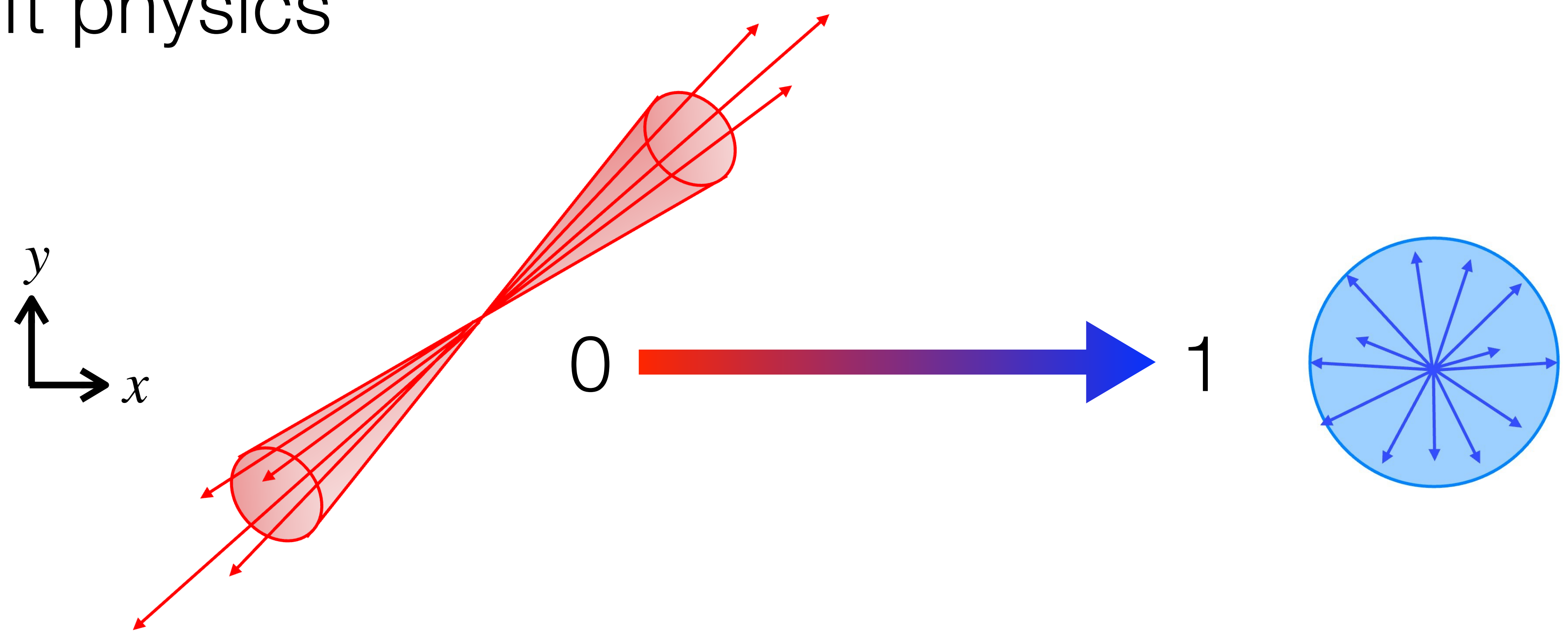
Event-by-event selection quantified the topology in the azimuthal plane

$$S_{\mathrm{O}}^{p_{\mathrm{T}}=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\sum_i |\hat{p}_{\mathrm{T},i} \times \hat{n}|}{N_{\mathrm{trks}}} \right)^2$$

- $\hat{p}_{\mathrm{T},i}$ is the transverse momentum unit vector for a charged particle
- N_{trks} is the number of charged particles in a given event
- $\hat{n}$ is the unit vector that minimizes $S_{\mathrm{O}}^{p_{\mathrm{T}}=1}$

✓ $S_{\mathrm{O}}^{p_{\mathrm{T}}=1} \rightarrow 0$: jet-like event, particle production driven by hard physics

✓ $S_{\mathrm{O}}^{p_{\mathrm{T}}=1} \rightarrow 1$: isotropic event, particle production driven by soft physics



Transverse spherocity $S_{\mathrm{O}}^{p_{\mathrm{T}}=1}$

ALICE, JHEP 05 (2024) 184

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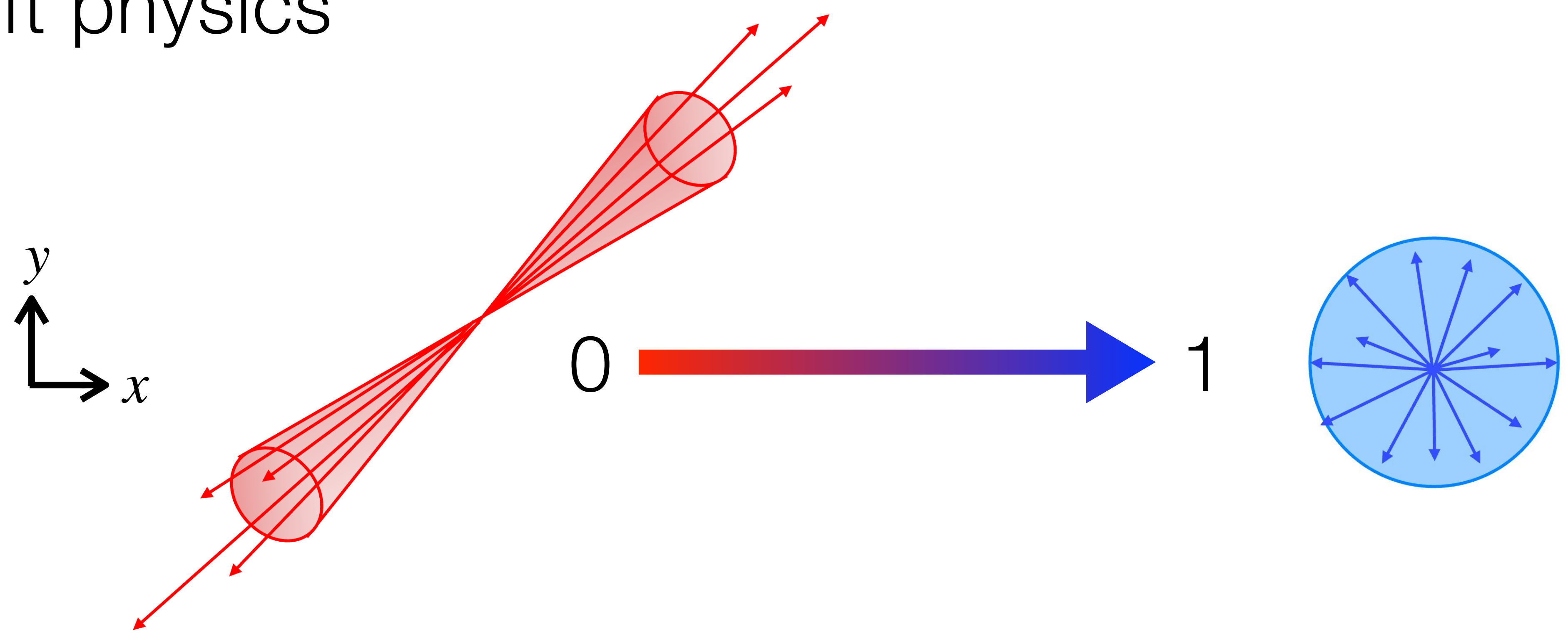

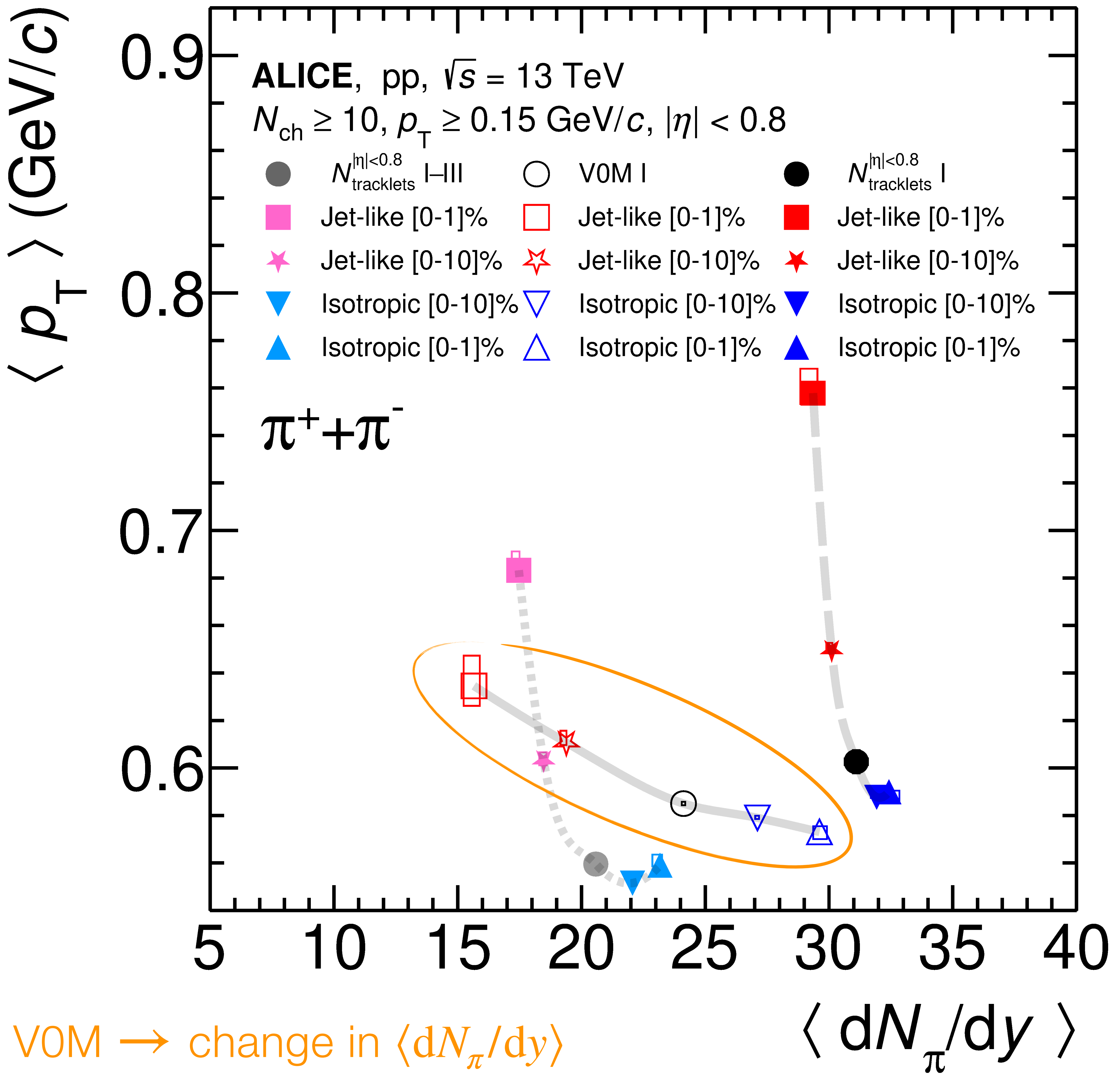

Transverse spherocity $S_{\mathrm{O}}^{p_{\mathrm{T}}=1}$

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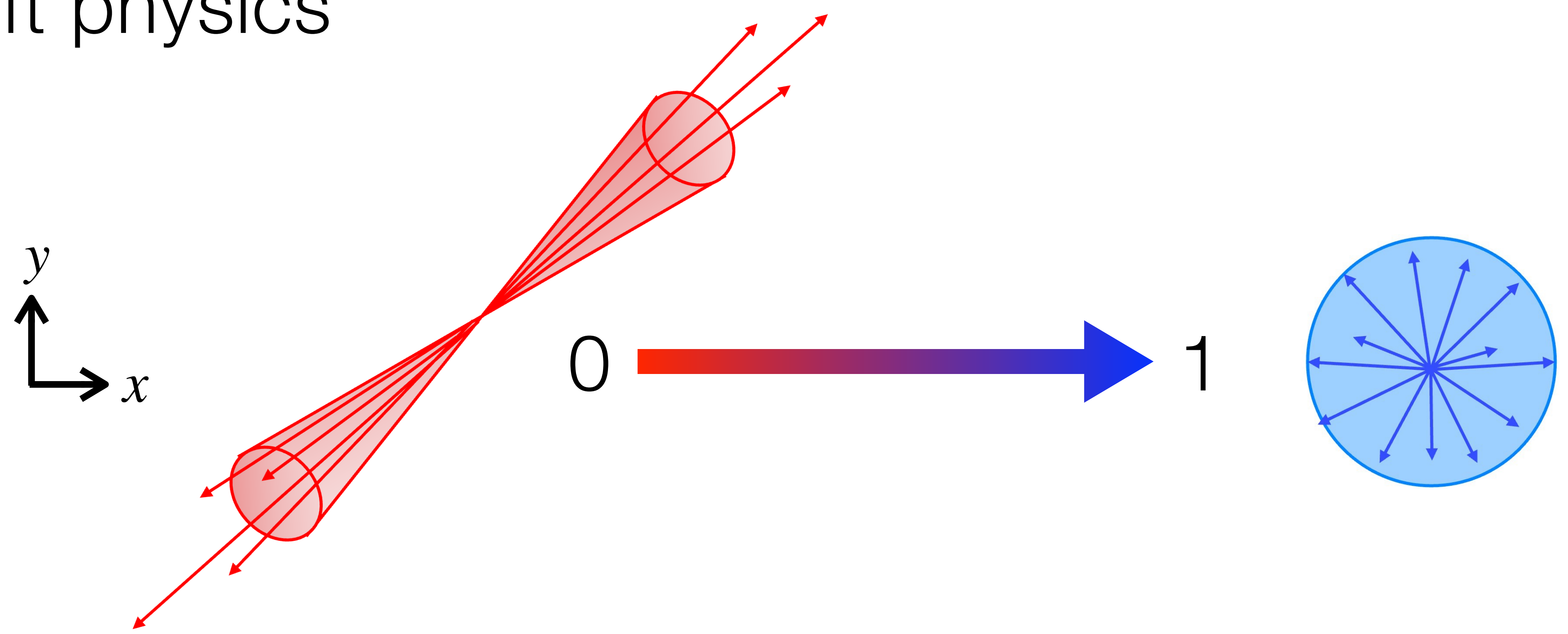
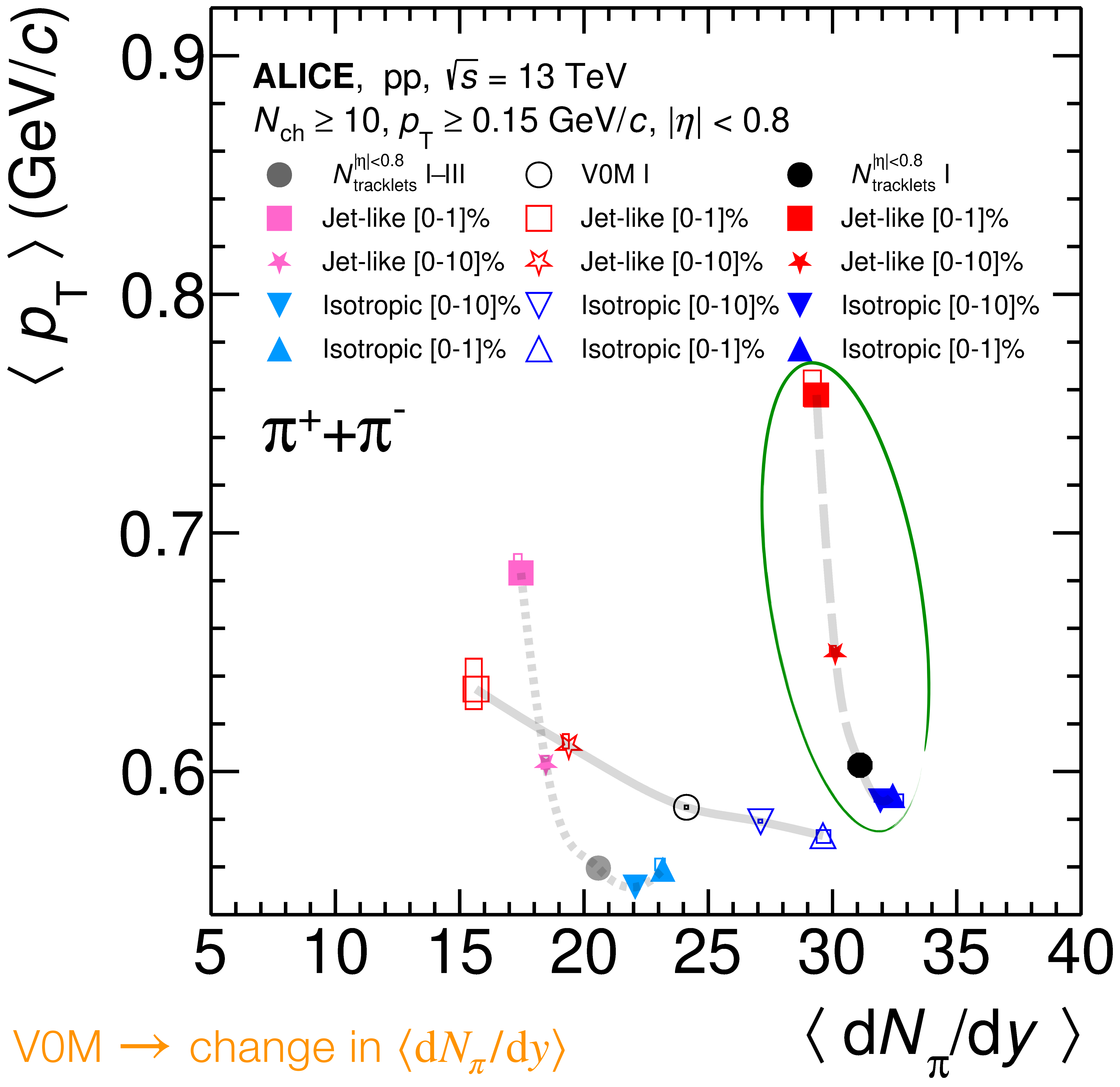


NEW

ALICE, JHEP 05 (2024) 184



V0M → change in $\langle \mathrm{d}N_{\pi}/\mathrm{d}y \rangle$

$N_{\mathrm{tracklets}}^{|\eta|<0.8}$ → change in $\langle p_{\mathrm{T}} \rangle$, capture the jet bias

ALICE, JHEP 05 (2024) 184

- p_{T}-hardening in jet-like events
- Little difference between isotropic and $S_{\mathrm{O}}^{p_{\mathrm{T}}=1}$-integrated events

$S_{\mathrm{O}}^{p_{\mathrm{T}}=1}$-differential average transverse momentum $\langle p_{\mathrm{T}} \rangle$

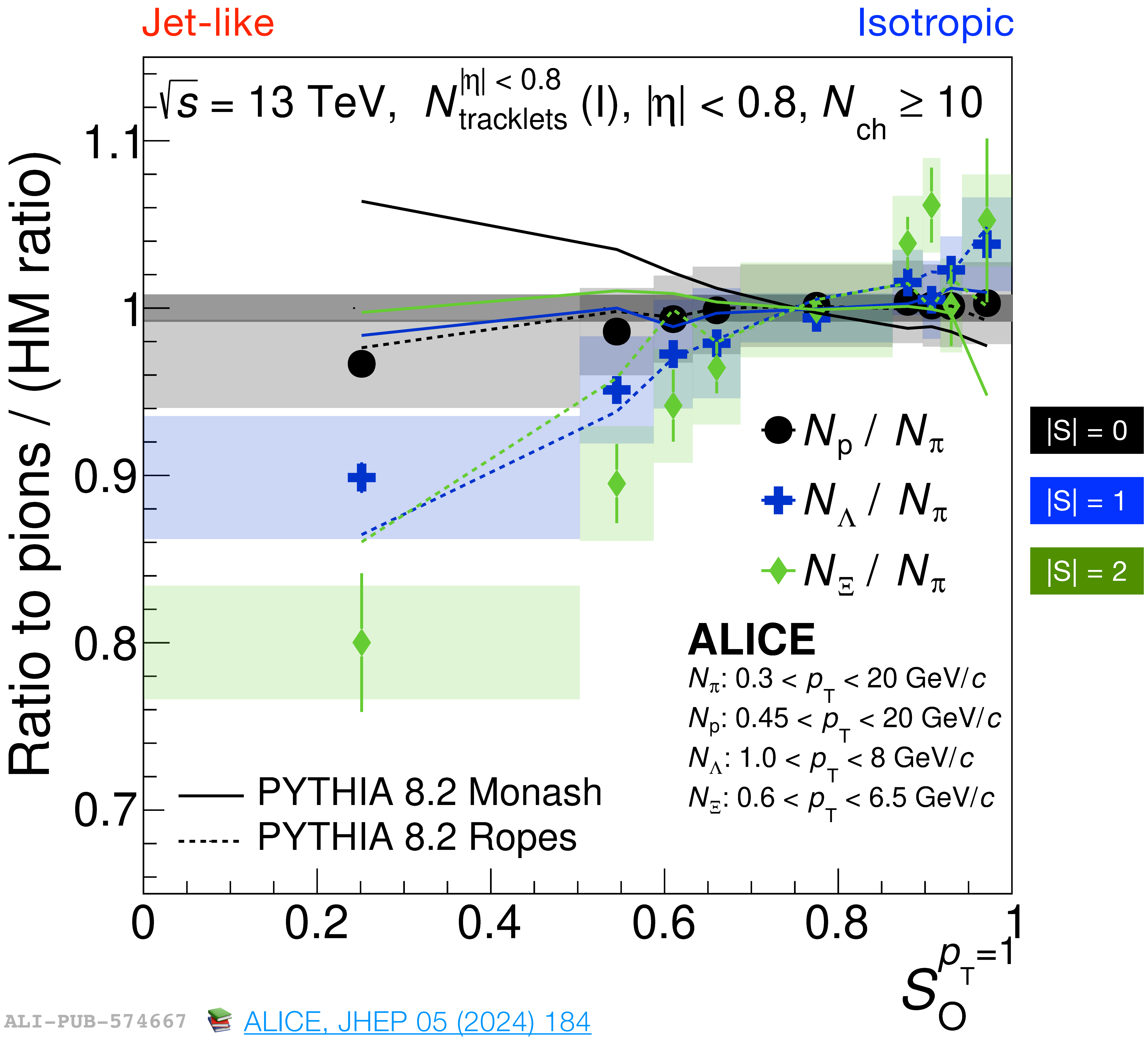
ALICE, JHEP 05 (2024) 184

- p_{T}-hardening in jet-like events
- Little difference between isotropic and $S_{\mathrm{O}}^{p_{\mathrm{T}}=1}$-integrated events
- A mass ordering for the identified particles, except for resonance particles
- Most of the presented models overestimate $\langle p_{\mathrm{T}} \rangle$ for species shown, except K^{*0}

Comput.Phys.Commun. 191 (2015) 159-177
Eur. Phys. J. C 80 (2020) 5, 452
Phys. Rev. C 92, 034906 (2015)

Integrated yield as a function of $S_{O}^{p_{T}=1}$

- Strangeness enhancement in isotropic events
- Strangeness-based ordering
- Proton remains mostly unaffected (S=0)



ALI-PUB-574667 ALICE, JHEP 05 (2024) 184

- Strangeness enhancement in isotropic events
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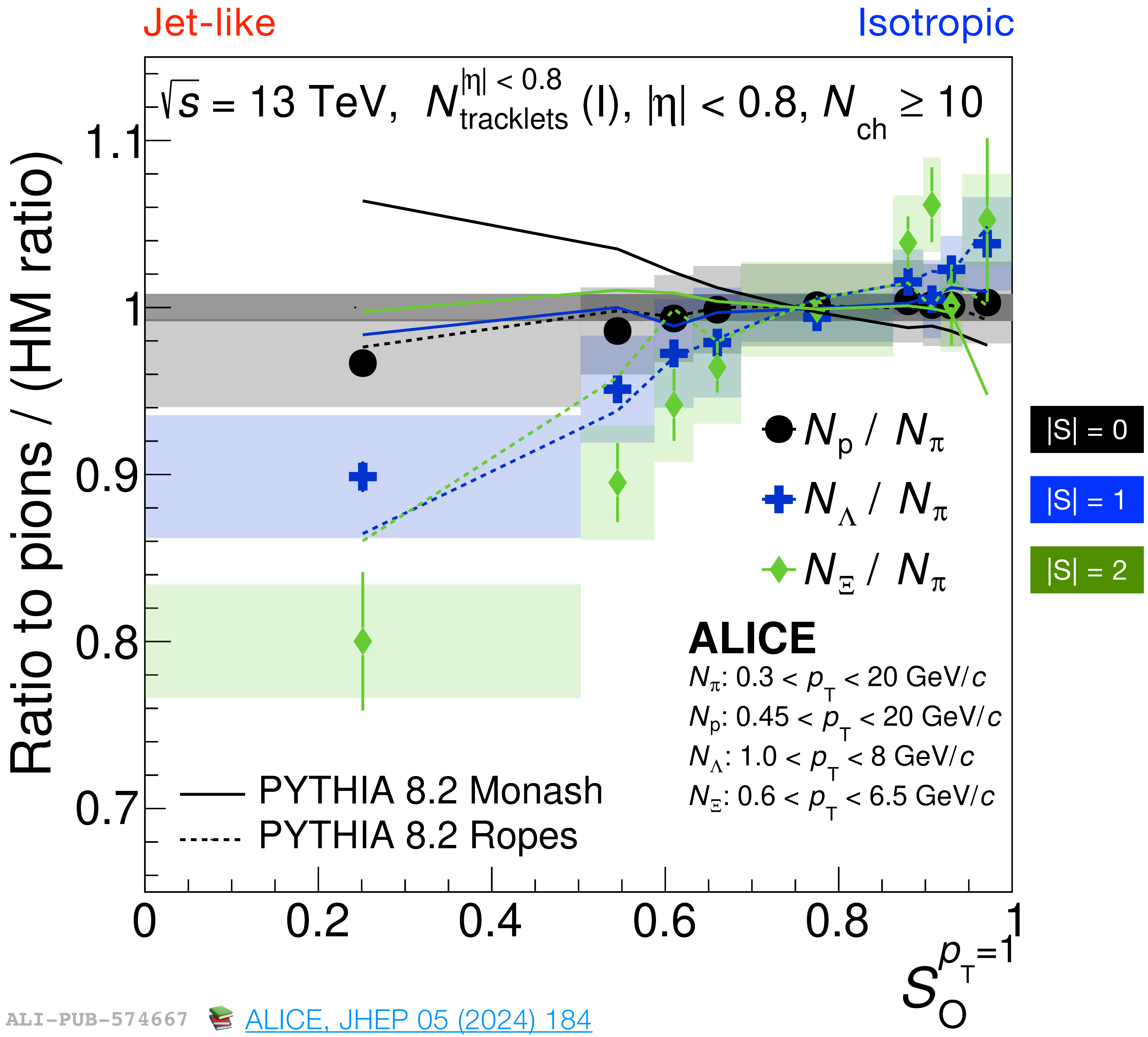
PYTHIA 8.2 predictions

- Ropes tune qualitatively reproduce the trends, but not the strangeness ordering
- Monash tune cannot capture the trends



ALI-PUB-574667 📚 ALICE, JHEP 05 (2024) 184

Integrated yield as a function of $S_{O}^{p_{T}=1}$

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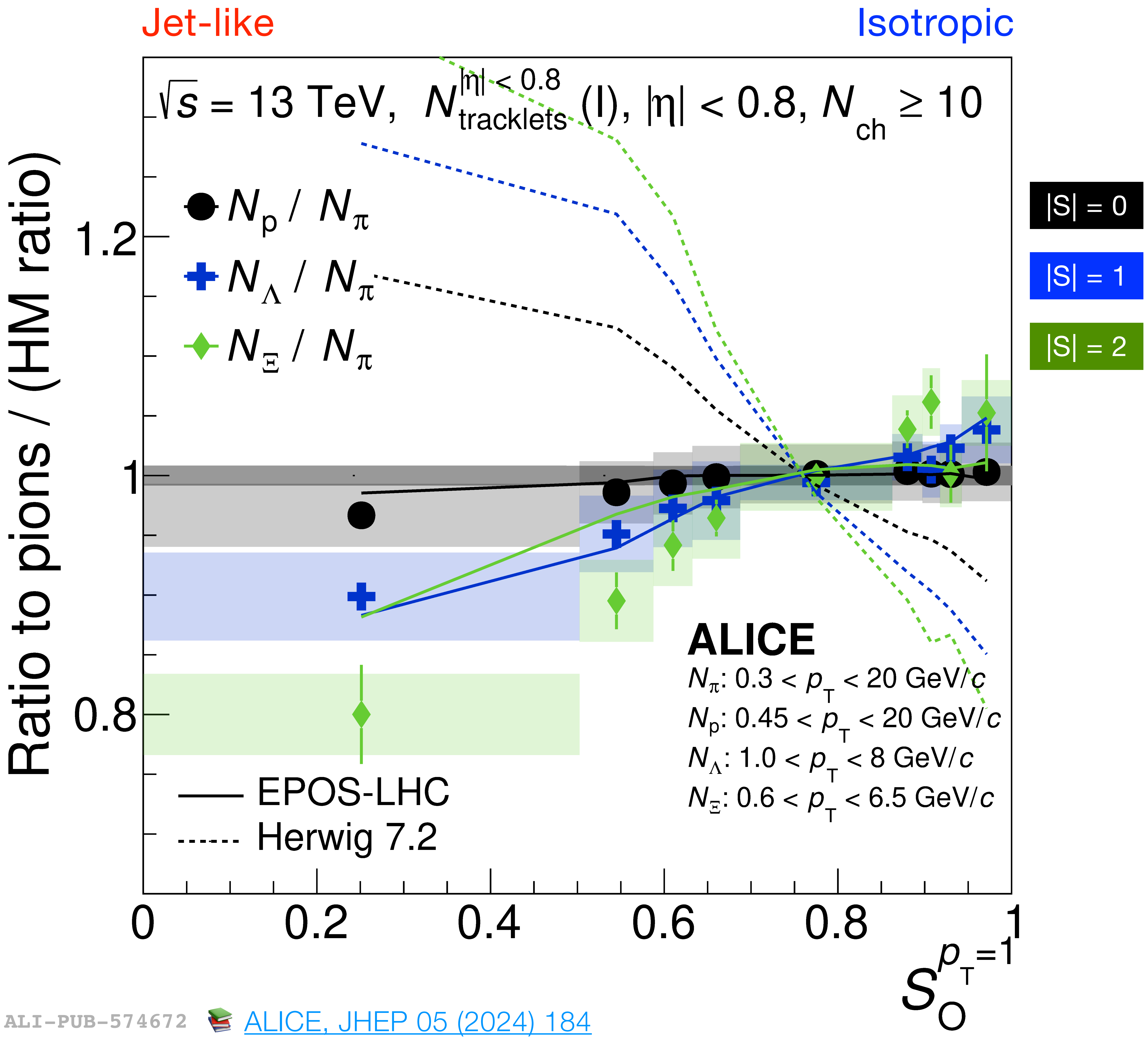
- Ropes tune qualitatively reproduce the trends, but not the strangeness ordering
- Monash tune cannot capture the trends

- EPOS-LHC qualitatively reproduced the trends, but not the strangeness ordering
- Herwig 7.2 cannot capture the trends



ALI-PUB-574672 ALICE, JHEP 05 (2024) 184

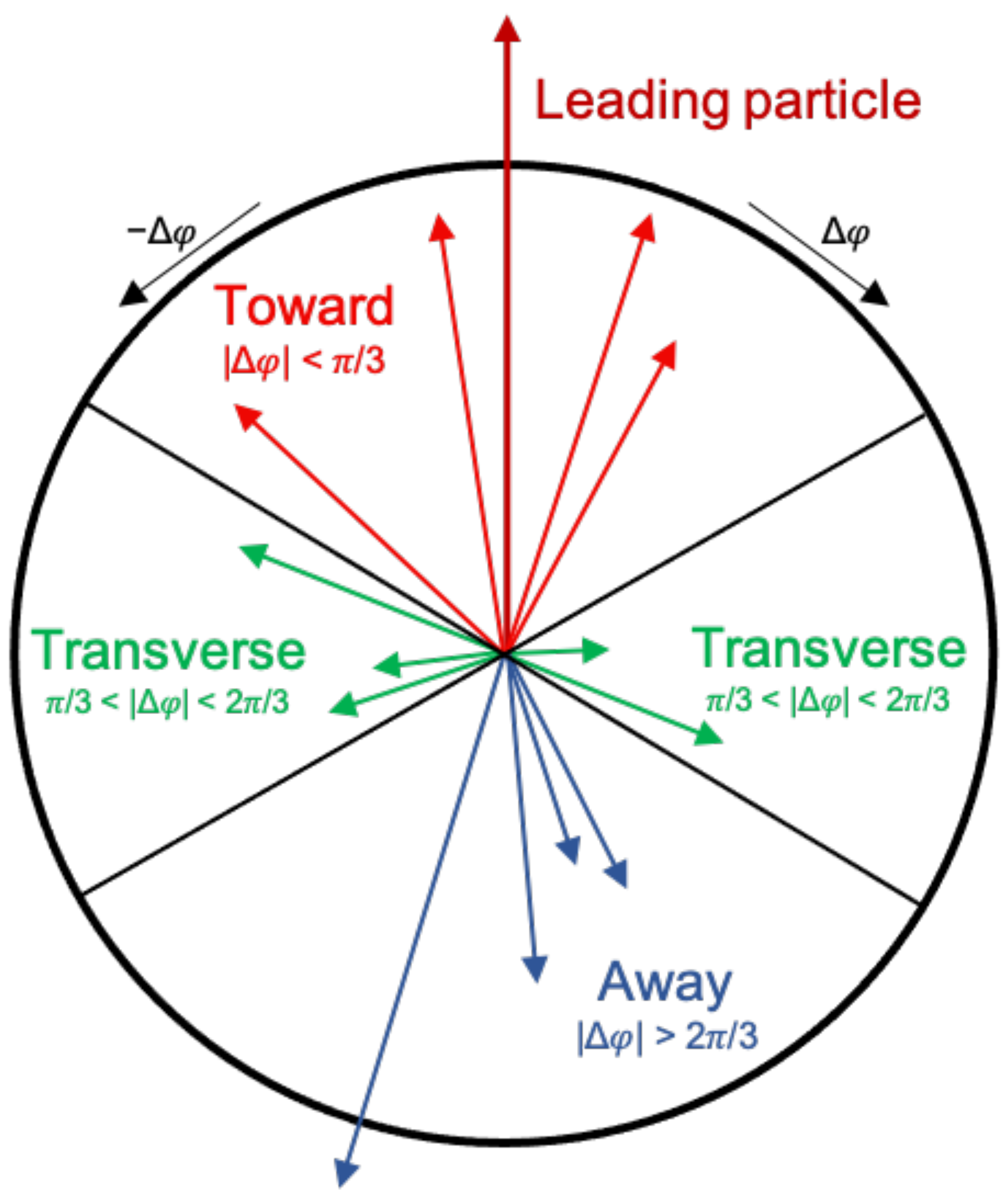
Relative transverse activity R_{T} measurement

Relative transverse activity R_T

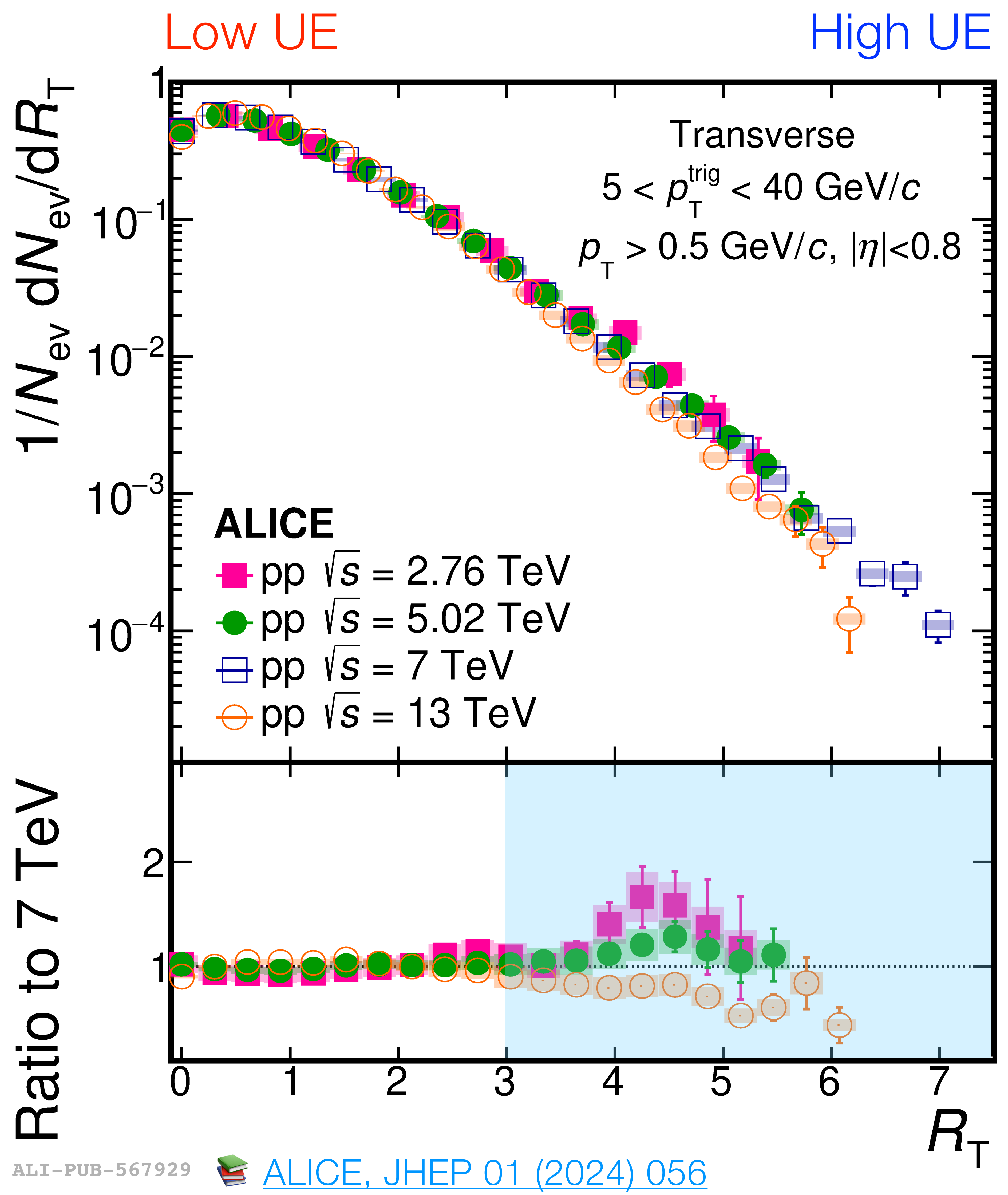
Event-by-event selection based on the underlying-event (UE) activity in the midrapidity interval (UE refers to everything that does not come from the main hard partonic scattering)

$$R_T = N_{ch}^{TS} / \langle N_{ch}^{TS} \rangle$$

- N_{ch}^{TS} is the charged-particle multiplicity in the transverse region (TS)
- $\langle N_{ch}^{TS} \rangle$ is the average multiplicity over all events in TS



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

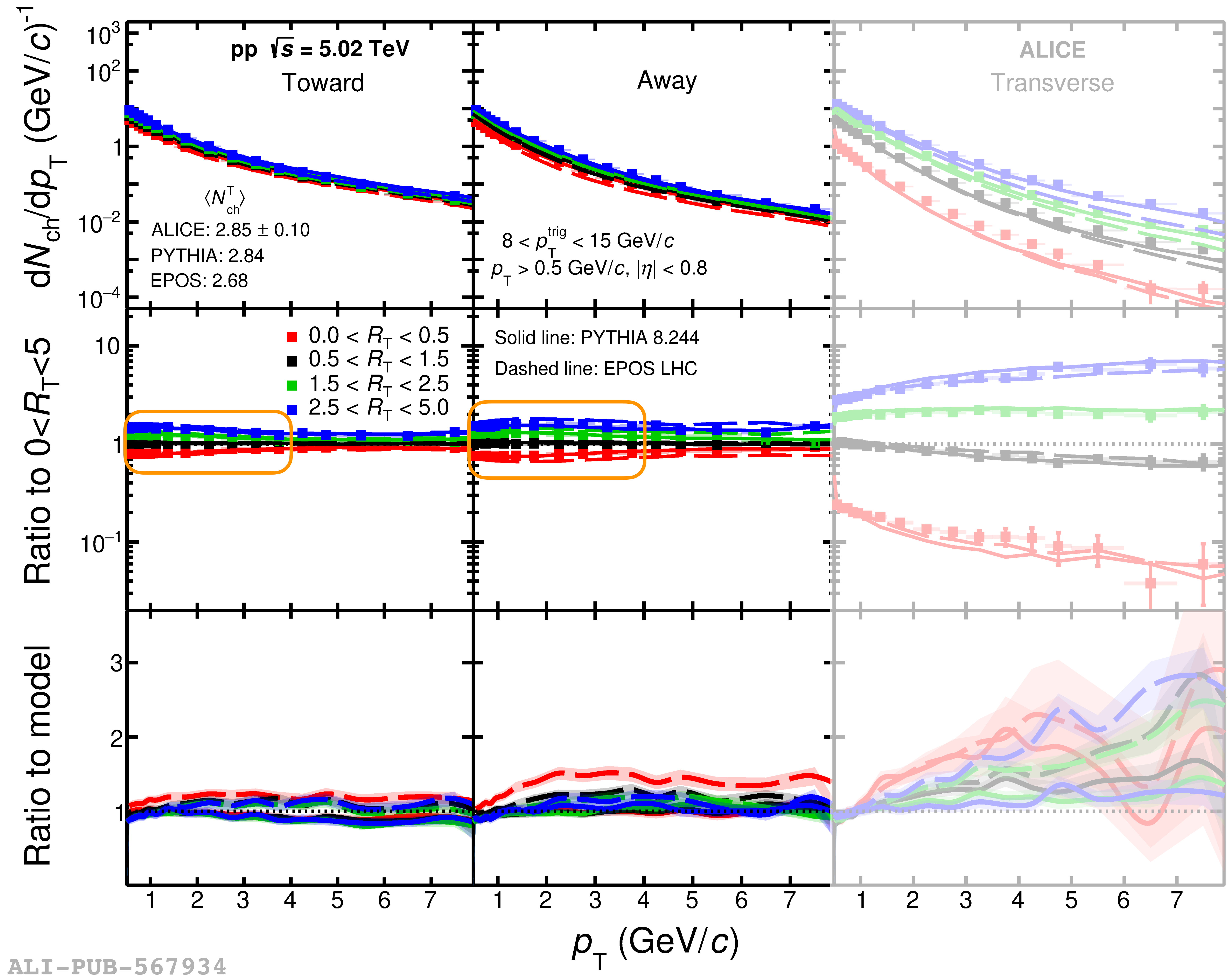


ALICE, JHEP 01 (2024) 056

Koba-Nielsen-Olesen-like scaling is broken for $R_T > 3$, which might be attributed to the initial- and final-state radiations

p_T-spectra as a function of R_T

ALICE, JHEP 01 (2024) 056

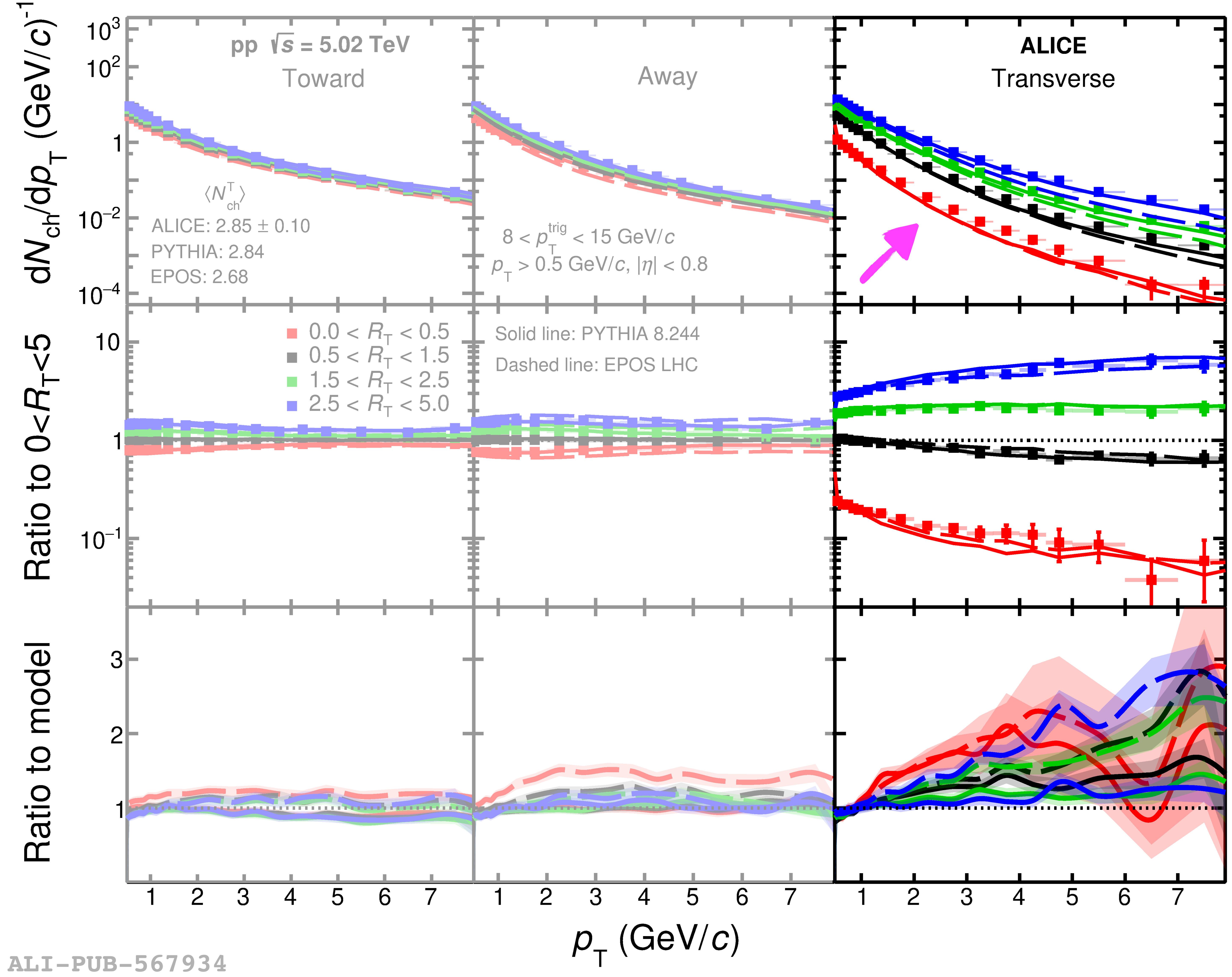


Toward and Away regions:

- For $p_T < 4$ GeV/c, the p_T spectra is R_T dependent
- For $p_T > 4$ GeV/c, the spectral shape is almost R_T independent

p_T-spectra as a function of R_T

ALICE, JHEP 01 (2024) 056



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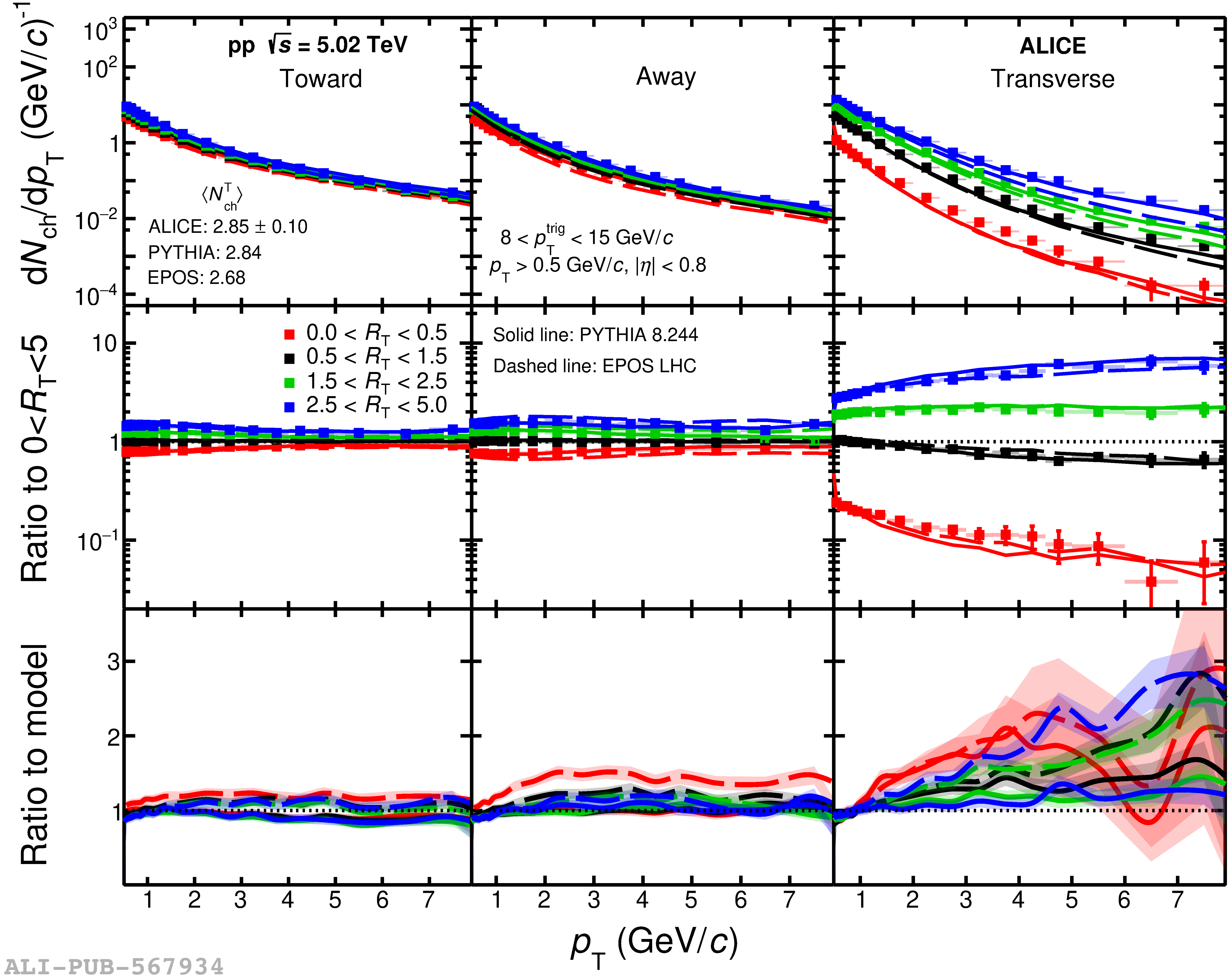
Transverse region:

- A p_T-hardening with increasing R_T, due to autocorrelation effects

Phys. Rev. D 104 (2021) 016017

p_T-spectra as a function of R_T

ALICE, JHEP 01 (2024) 056



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Transverse region:

- A p_T-hardening with increasing R_T, due to autocorrelation effects

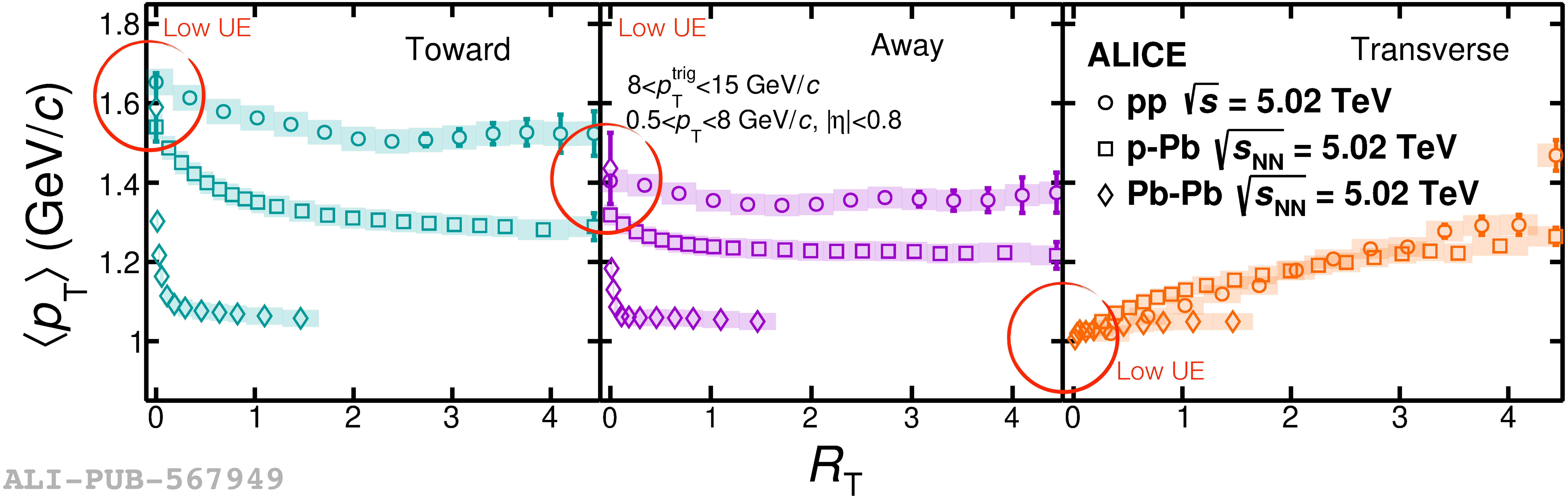
  Phys. Rev. D 104 (2021) 016017

MC predictions:

- PYTHIA 8.2 describes data better than EPOS LHC

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

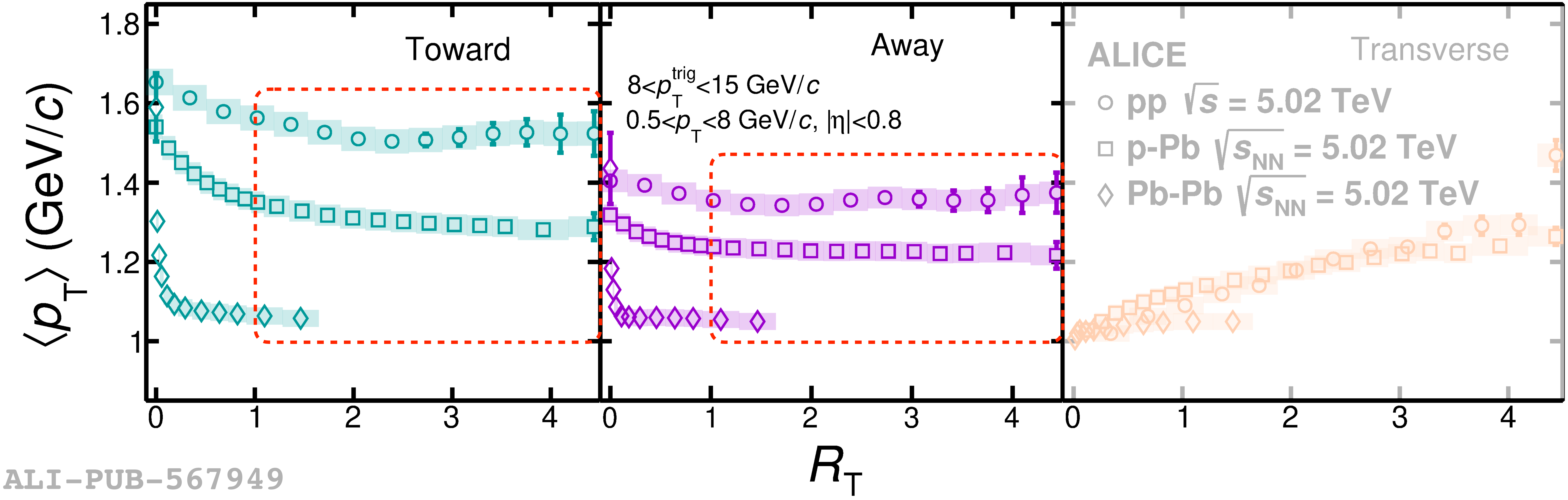
ALICE, JHEP 01 (2024) 056



Low $R_{\rm T}$: the $\langle p_{\rm T} \rangle$ is independent of collision system for $R_{\rm T} \approx 0$ as jet dominates at low $R_{\rm T}$

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

ALICE, JHEP 01 (2024) 056



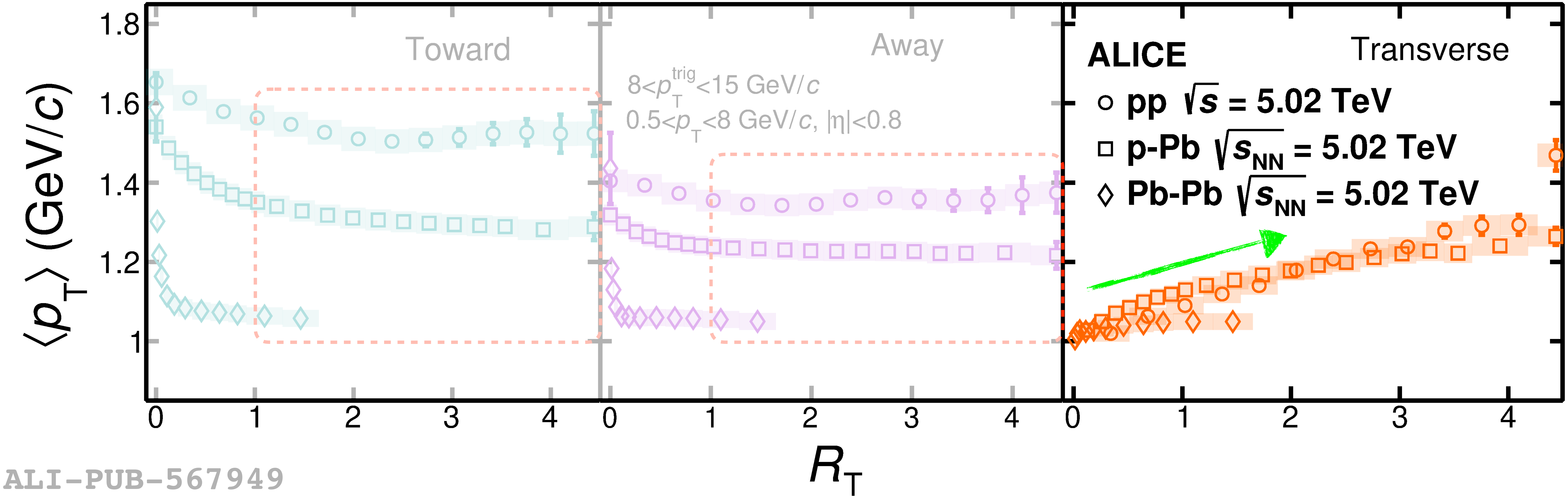
Low R_T: the $\langle p_T \rangle$ is independent of collision system for $R_T \approx 0$ as jet dominates at low R_T

High R_T:

- Toward and Away: the $\langle p_T \rangle$ is nearly flat for $R_T > 1$, and exhibits a system size ordering

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

ALICE, JHEP 01 (2024) 056



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High R_T:

- Toward and Away: the $\langle p_T \rangle$ is nearly flat for $R_T > 1$, and exhibits a system size ordering
- Transverse: the $\langle p_T \rangle$ is increasing with increasing R_T

Charged-particle flattenicity 1-ρ measurement

Charged-particle flattenicity 1-ρ

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

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

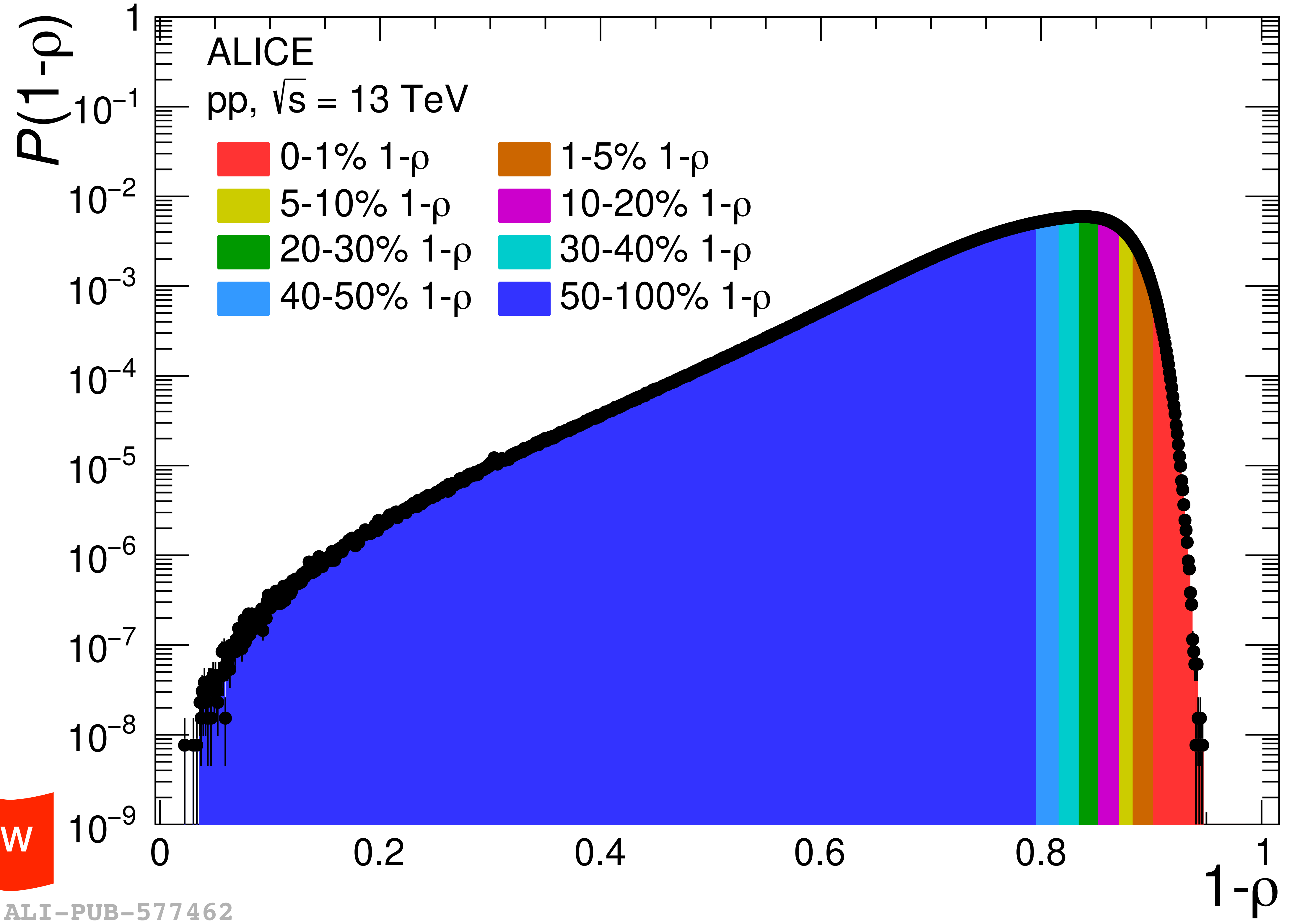
- $N_{ch}^{cell,i}$ is the particle multiplicity in the i-th cell
- $\langle N_{ch}^{cell} \rangle$ is the average multiplicity over the all 64 cells per event

✓ large flattenicity $1 - \rho \rightarrow 0$: jet-like events, with low N_{mpi}

✓ small flattenicity $1 - \rho \rightarrow 1$: isotropic events, with high N_{mpi}

Jet-like Isotropic

Low N_{mpi} High N_{mpi}



NEW

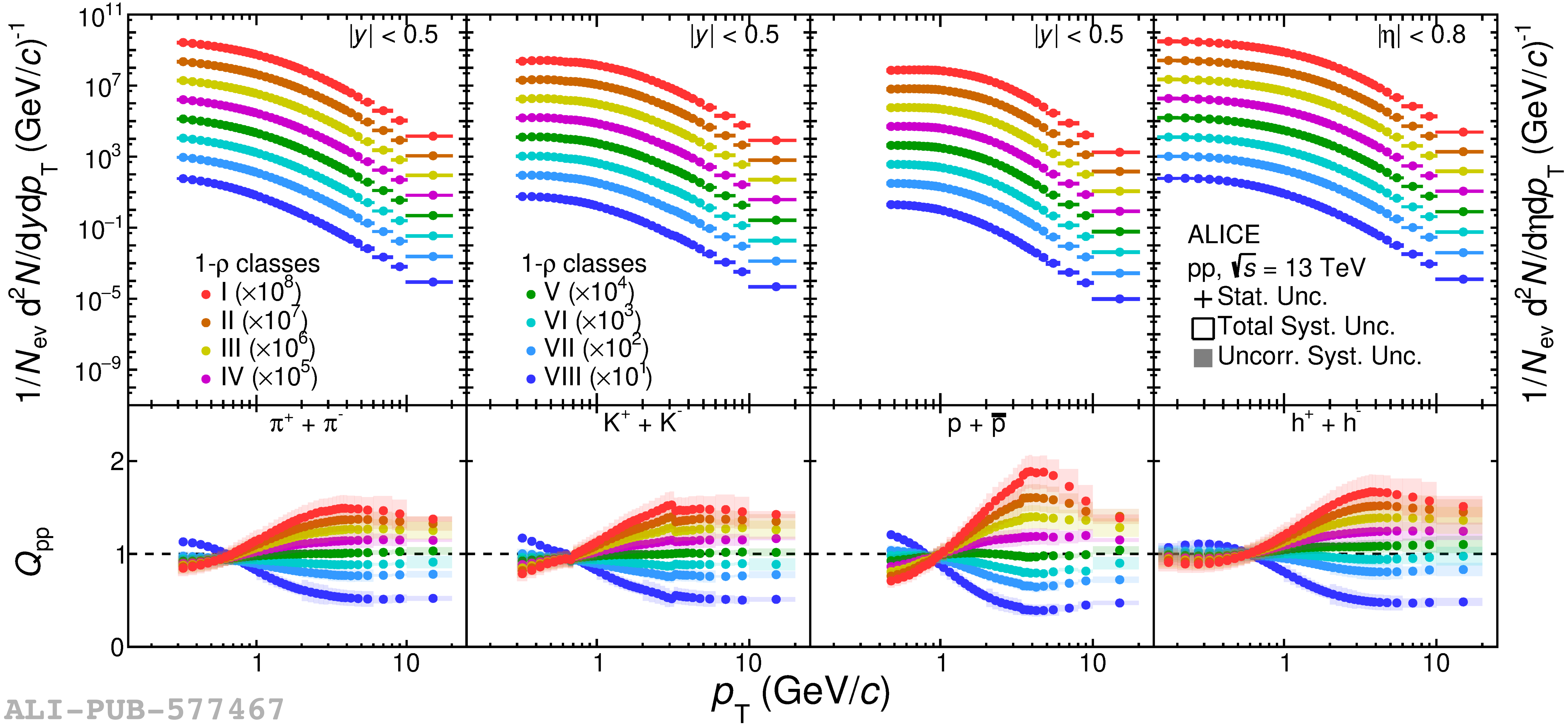
arXiv:2407.20037

Q_{pp} as a function of p_T

NEW

arXiv:2407.20037

$$Q_{pp}(p_T) = \left(\frac{1}{N_{ev}} \frac{d^2N_{ch}}{dy dp_T} \frac{1}{\langle dN_{ch}/d\eta \rangle} \bigg|_{1-\rho} \right) \bigg/ \left(\frac{1}{N_{ev}} \frac{d^2N_{ch}}{dy dp_T} \frac{1}{\langle dN_{ch}/d\eta \rangle} \bigg|_{MB} \right)$$



- Intermediate p_T: a bump structure develops with increasing multiplicity

Q_{pp} as a function of p_T

NEW

arXiv:2407.20037

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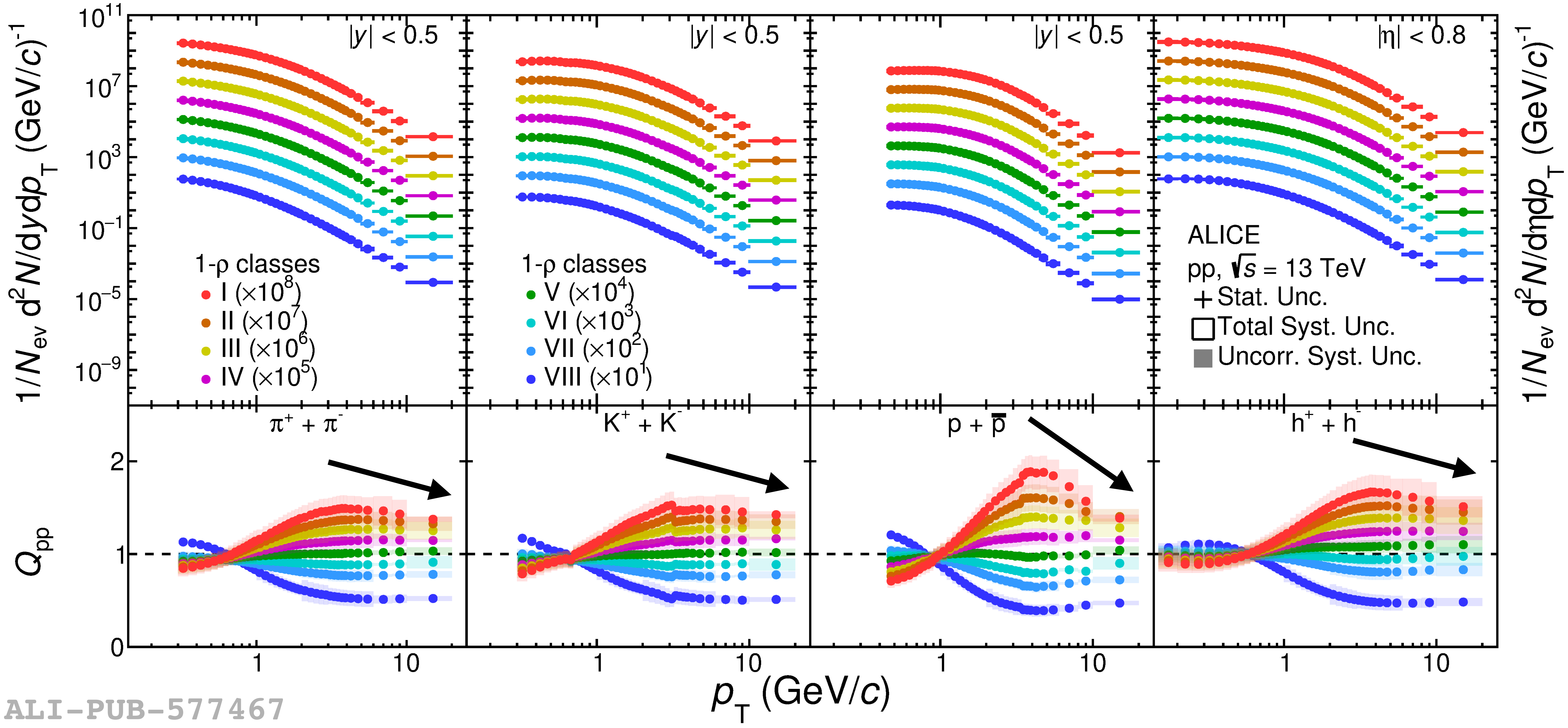
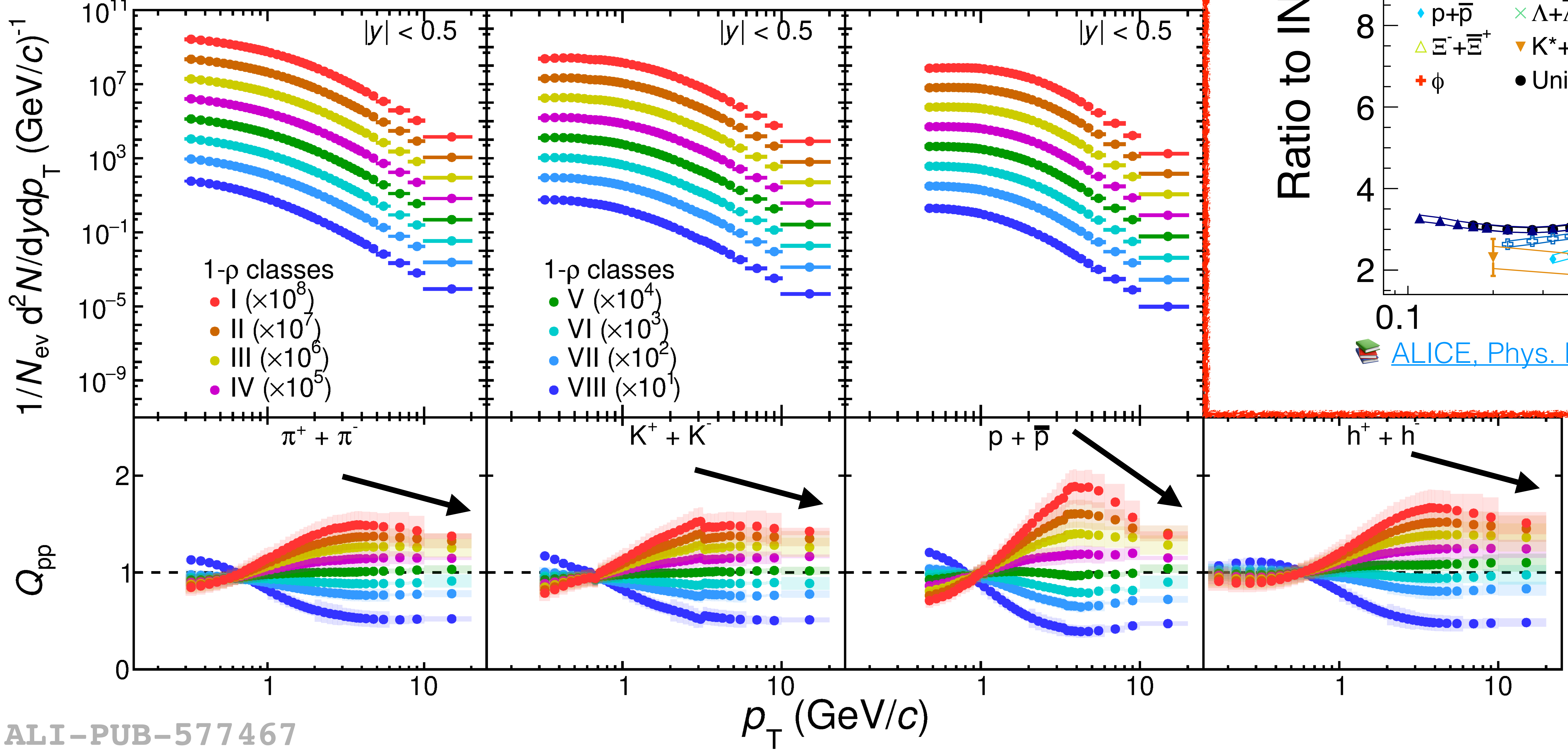
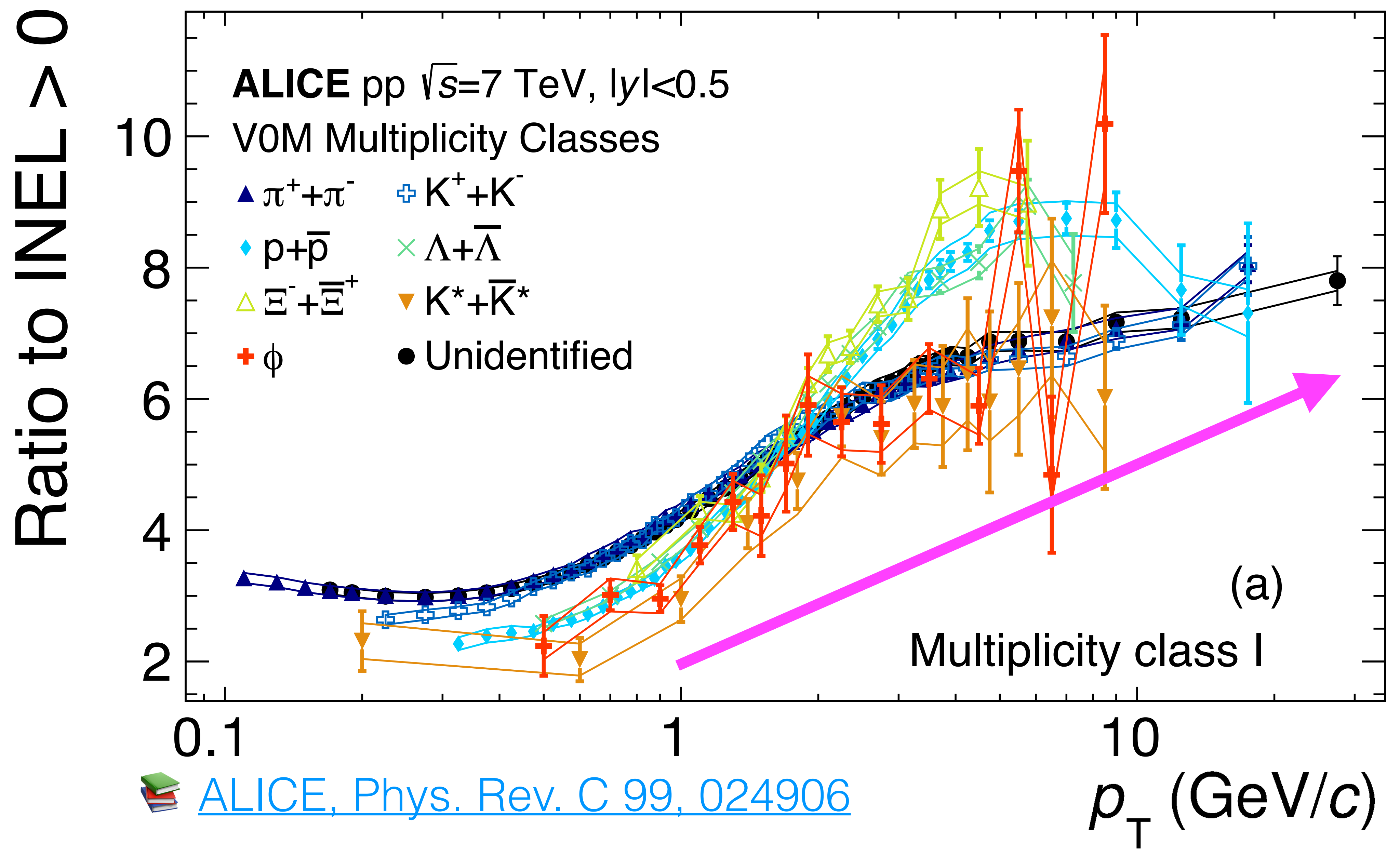


- Intermediate p_T: a bump structure develops with increasing multiplicity
- High p_T: Q_{pp} approaches unity

NEW

arXiv:2407.20037

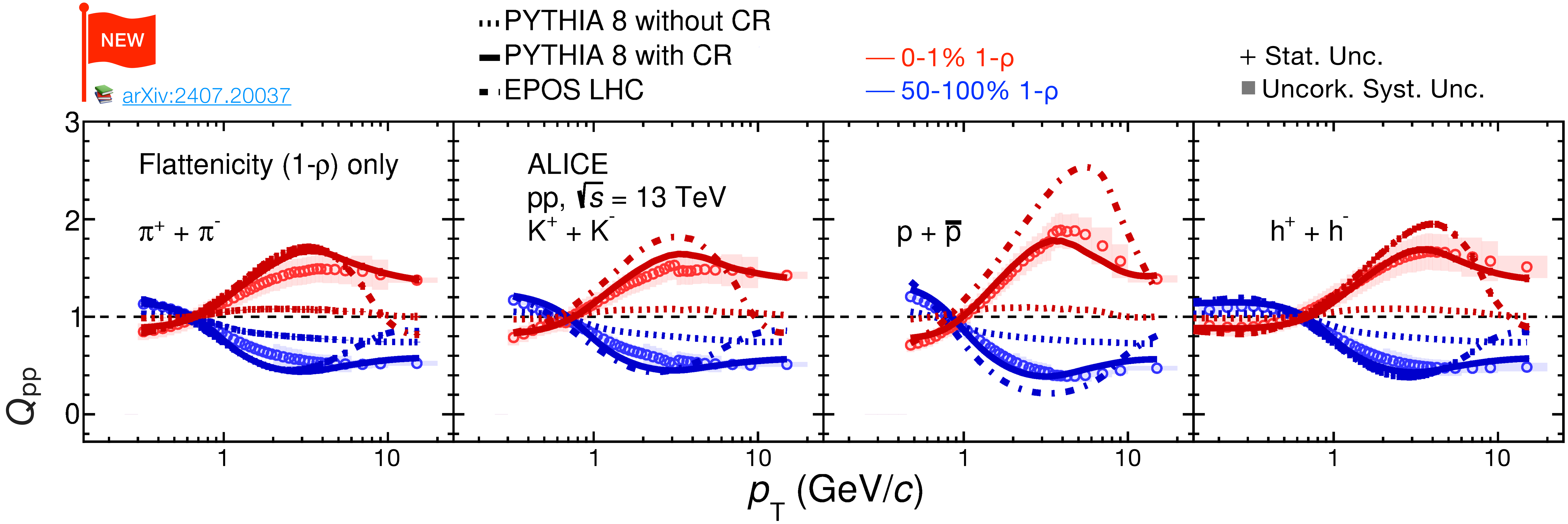




ALICE, Phys. Rev. C 99, 024906

The effect was not seen in the standalone multiplicity (V0M) analysis!

- Intermediate p_T: a bump structure develops with increasing multiplicity
- High p_T: Q_{pp} approaches unity

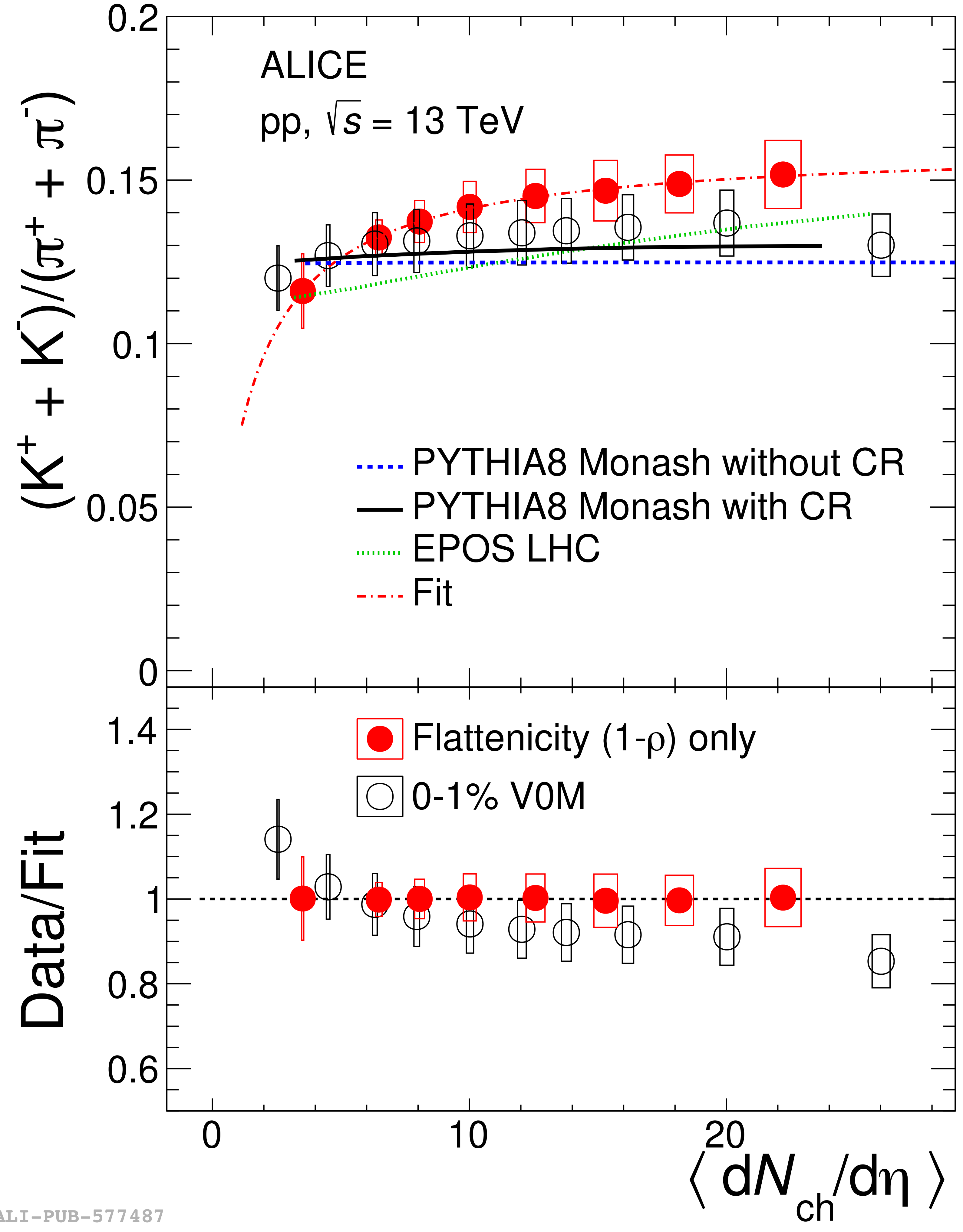


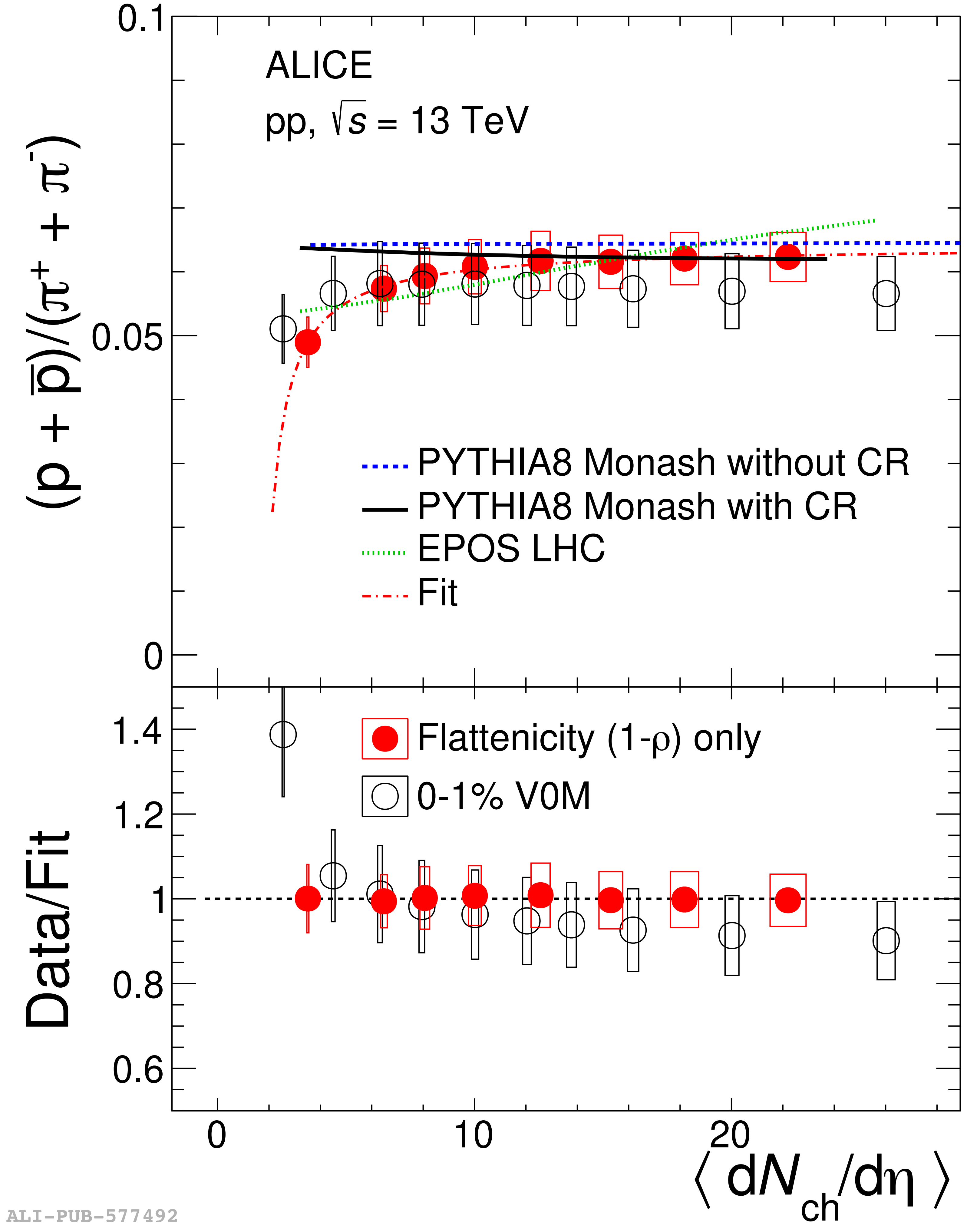
- PYTHIA 8 w/o CR: a nearly flat Q_{pp} as a function of p_T
- PYTHIA 8 w CR: overall the best description of data
- EPOS LHC: overestimates and underestimates Q_{pp} at intermediate and high p_T values, respectively

Particle ratios: flattenicity vs multiplicity

NEW

arXiv:2407.20037





Flattenicity (1-ρ) only:
flattenicity selection based on unbiased events (0-100% V0M)

0-1% V0M:
flattenicity selection based on high-multiplicity events (0-1% V0M)

The particle ratios as a function of flattenicity exhibit a steeper increase with multiplicity than those as a function of V0M

Summary

1. Transverse spherocity $S_{\mathrm{O}}^{\mathrm{p_T}=1}$
   - $S_{\mathrm{O}}^{\mathrm{p_T}=1}$ can be used to select strangeness enhanced/suppressed events
   - Strangeness enhancement in high-multiplicity pp collisions is a feature of the isotropic events

2. Relative transverse activity R_{T}
   - $R_{\mathrm{T}} > 3$ emerges bias towards multi-jet topologies
   - p_{T}-spectra are hardening with increasing R_{T} due to autocorrelation effects

3. Charged particle flattenicity $1 - \rho$ can be used to select pp collisions with large number of MPI and small bias than the V0M multiplicity estimator

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3. Charged particle flattenicity $1 - \rho$ can be used to select pp collisions with large number of MPI and small bias than the V0M multiplicity estimator

Outlook: measurement of ϕ meson production in and out of jets for pp collisions at $\sqrt{s} = 13.6$ TeV is ongoing

Thank you for your attention!