14th International Workshop on Multiple Parton Interactions at the LHC
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ALICE measurements of particle production as a function of event topology in small collision systems

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Introduction and motivation

- Measurements at the LHC have revealed that small collision systems exhibit behaviors formerly thought to be achievable only in heavy-ion collisions, where the data support the formation of QGP.

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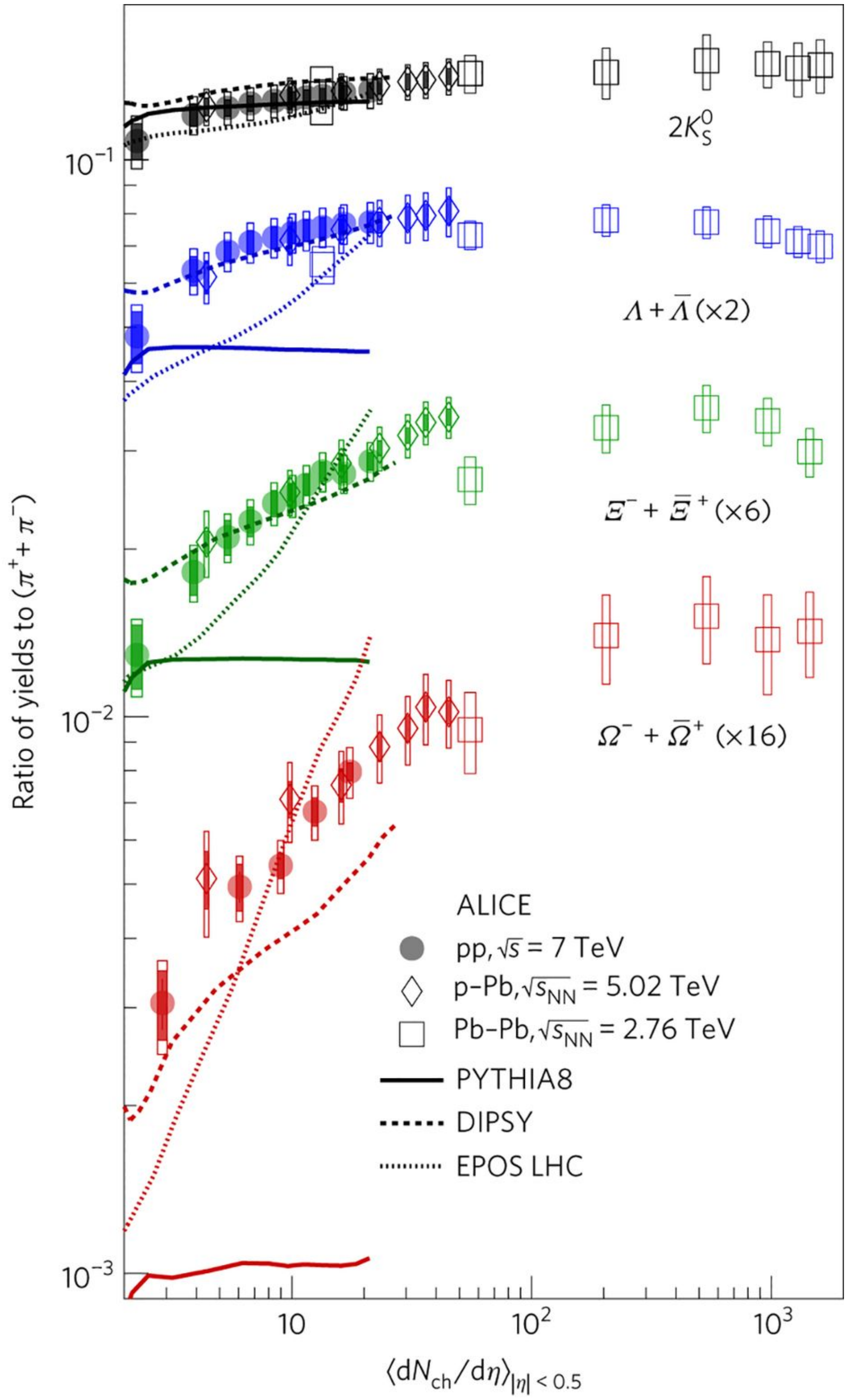

ALICE, Nature Physics 13, 535 (2017)

- **Strangeness enhancement** in high multiplicity pp and p-Pb are similar to Pb-Pb collisions
- Can this behavior be characterized by other event properties other than a difference in multiplicity?
- Is it possible to find high-multiplicity events with suppressed strangeness production?

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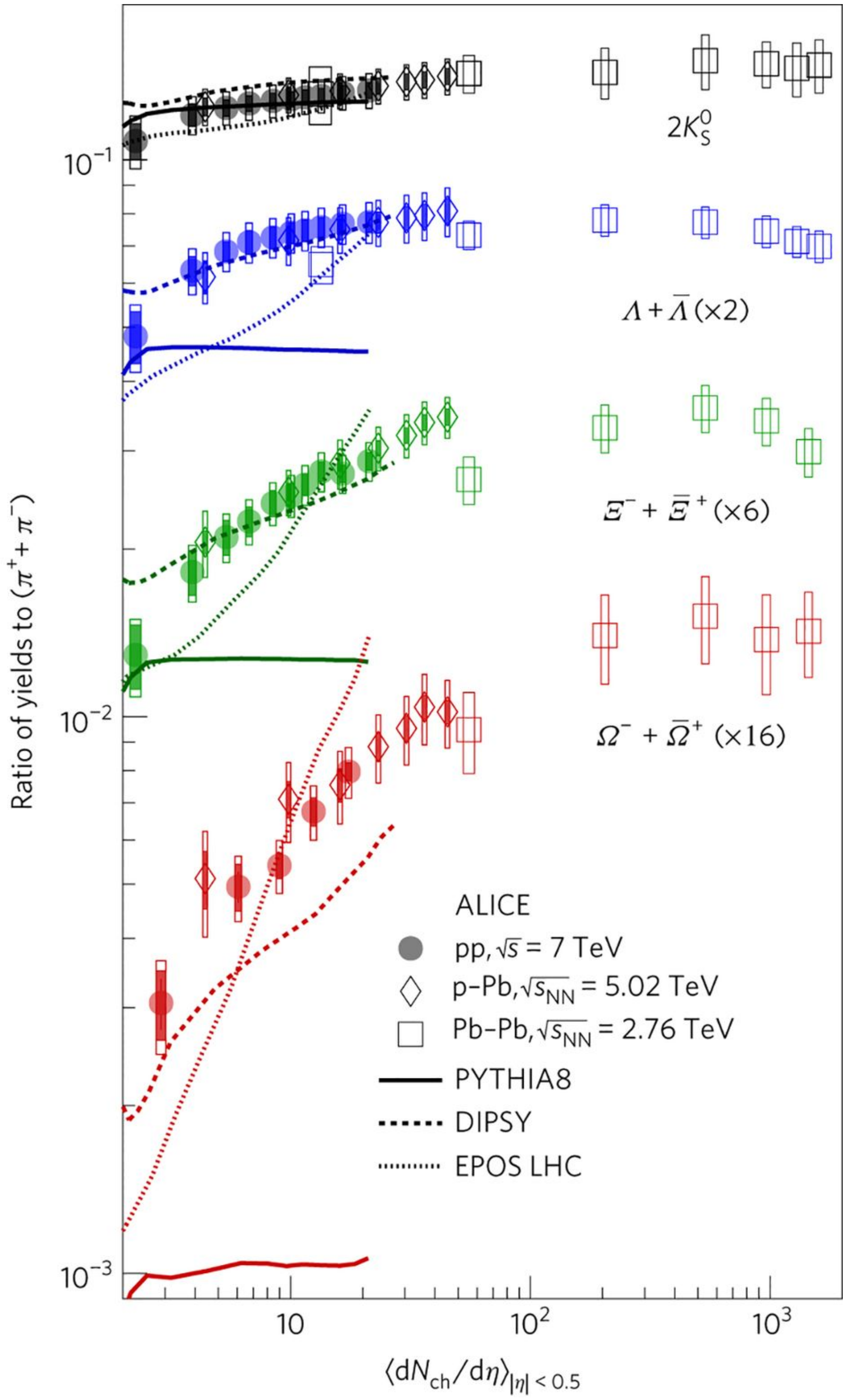
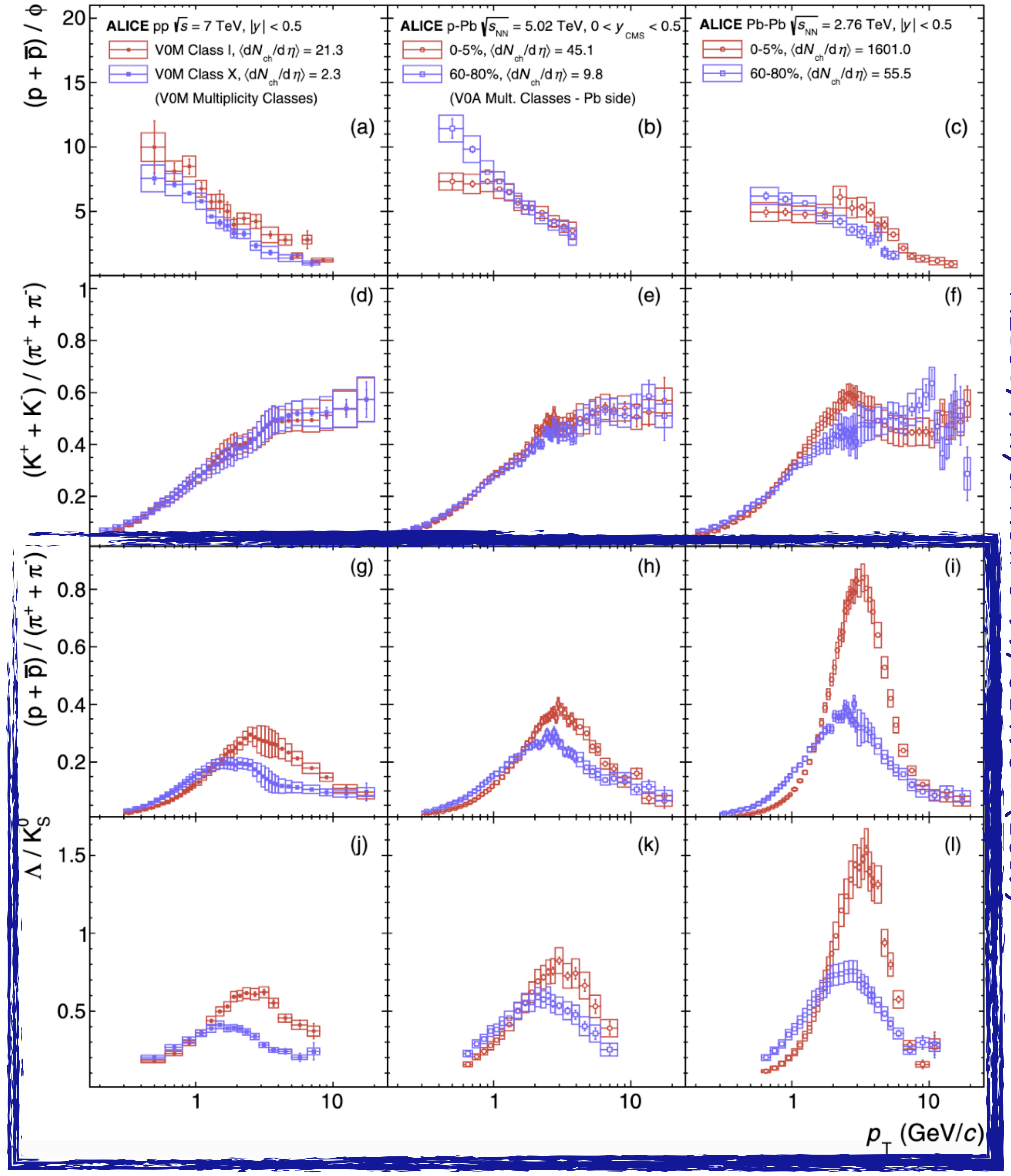


- **Strangeness enhancement** in high multiplicity pp and p-Pb are similar to Pb-Pb collisions
- Can this behavior be characterized by other event properties other than a difference in multiplicity?
- Is it possible to find high-multiplicity events with suppressed strangeness production?
- Similar features of **baryon-to-meson ratios** in pp, p-Pb and Pb-Pb collisions
- Is the origin the same in small and large collision systems?



ALICE, Phys. Rev. C 99, 024906 (2019)

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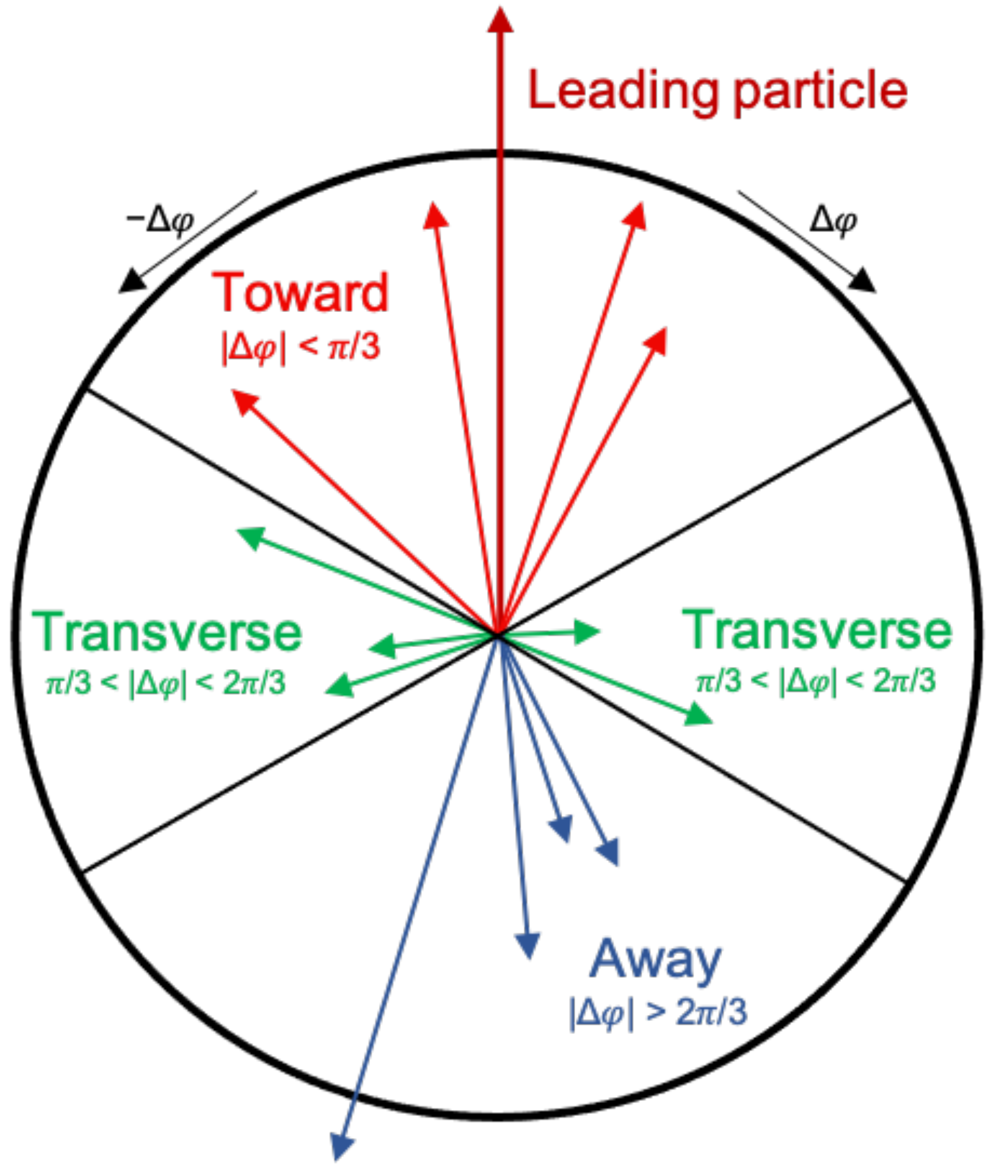
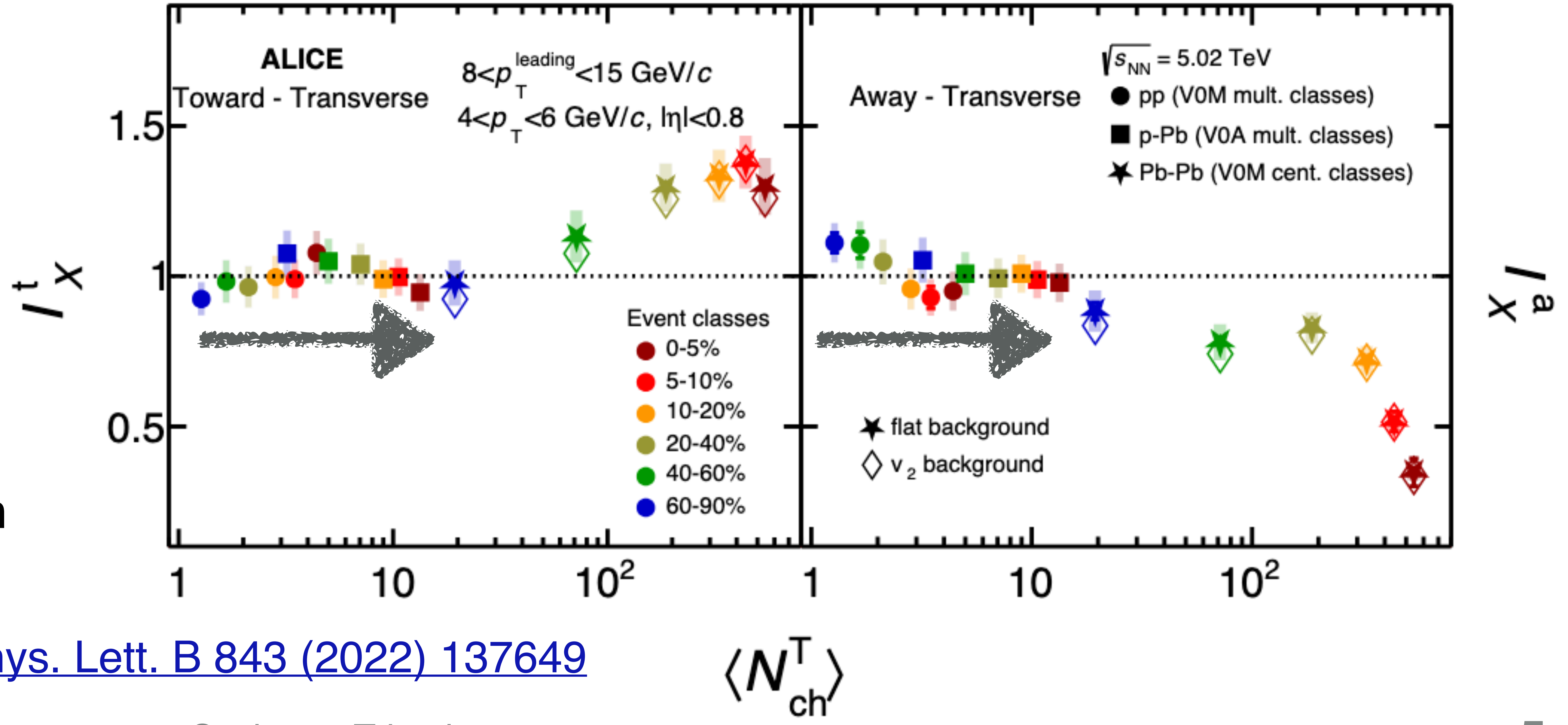
$$I_X = \frac{\left.\frac{dN_{ch}}{dp_T}\right|_{\text{jet-like signal in X collision}}}{\left.\frac{dN_{ch}}{dp_T}\right|_{\text{jet-like signal for MB pp collision}}}$$

Jet-like signal: yield difference between toward/away region and transverse region

X = pp, p-Pb and Pb-Pb collisions





No jet-like region modification is seen in experiments

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

Introduction and motivation

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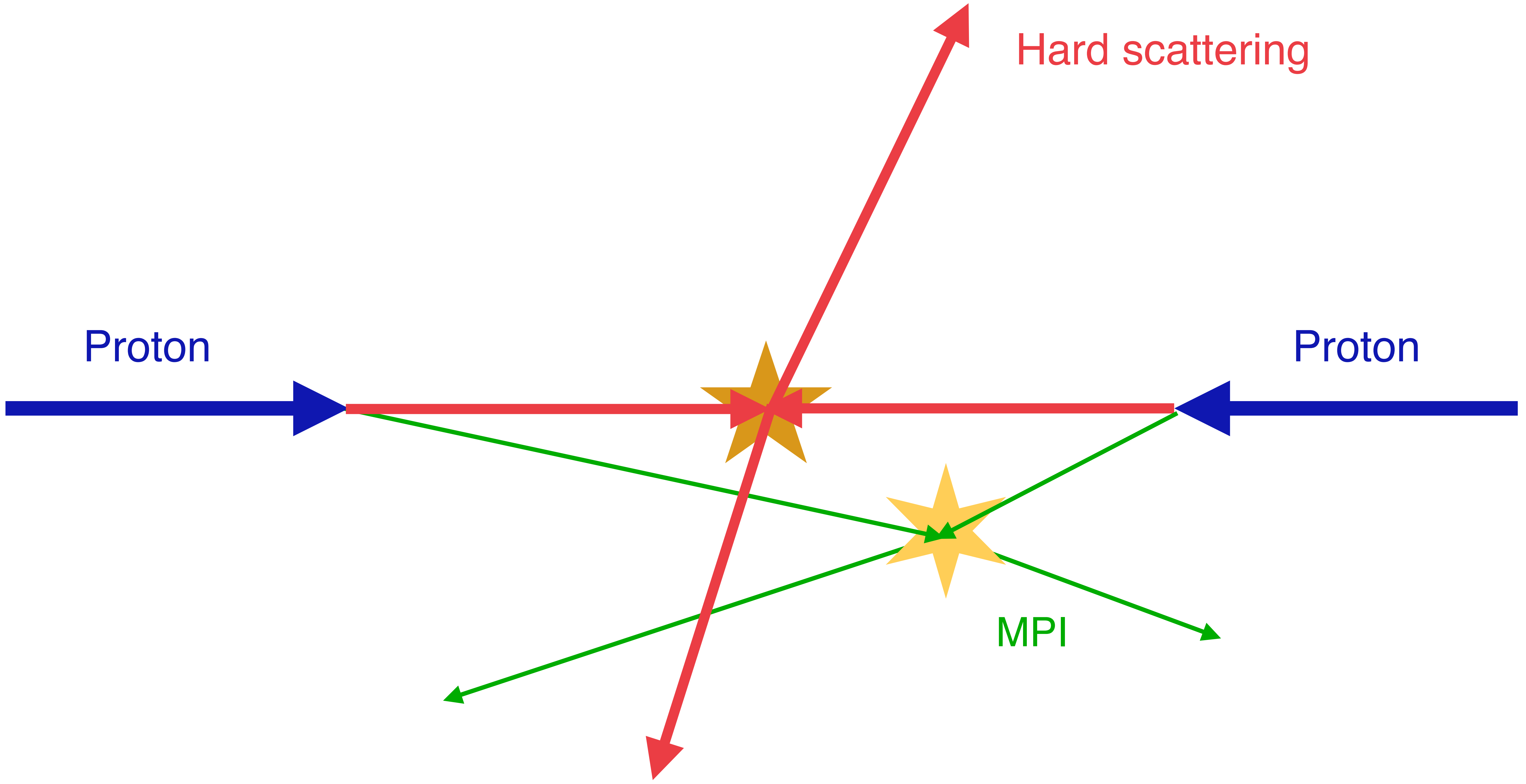
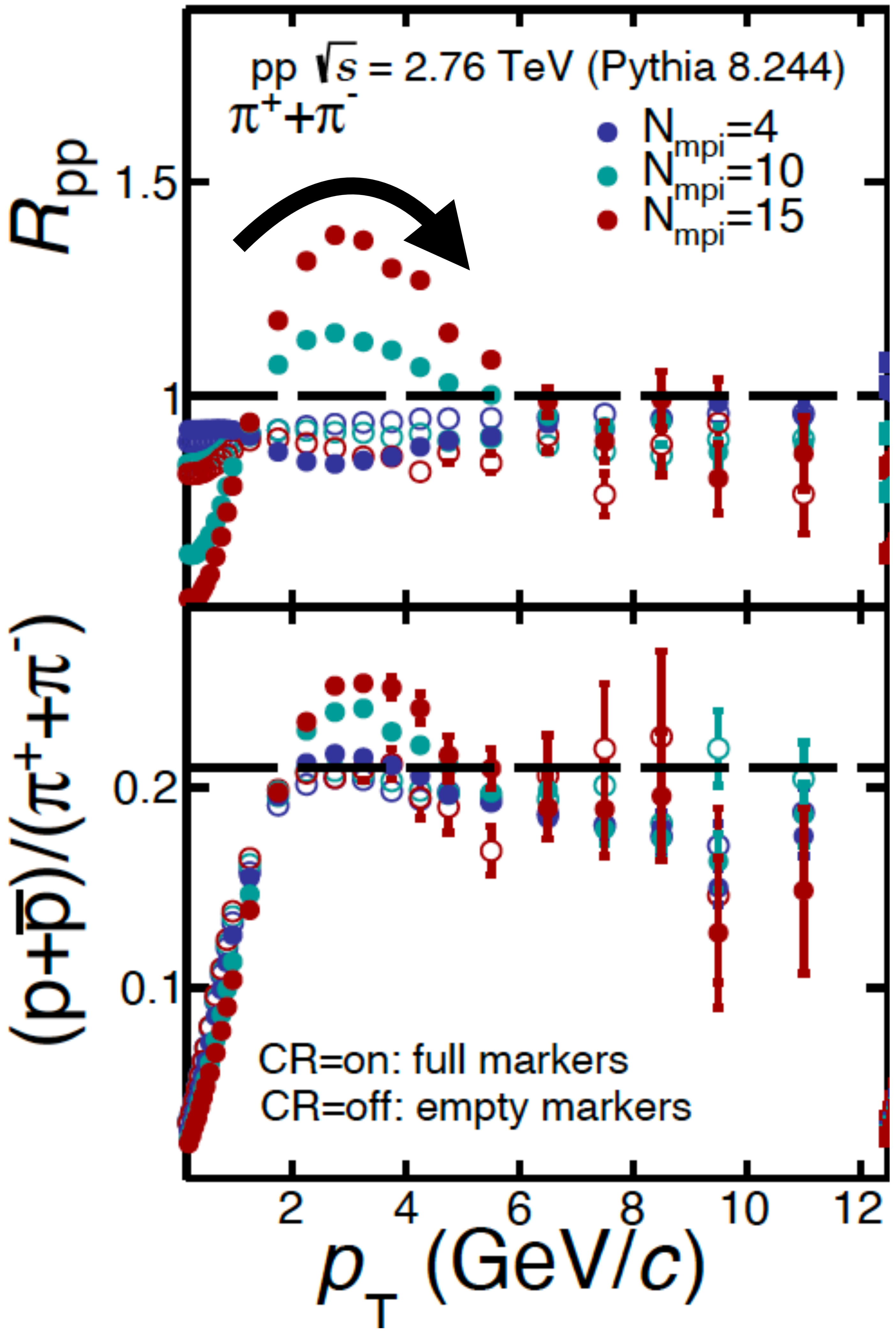
- The origin of the QGP-like behavior in small systems is still unclear. One of the explanations is a multiple parton interactions (MPI) based picture with colour reconnection and ropes, however, MPI can not be accessible directly in experiments.

MPI: strong interaction between strings overlapping on distance scales of O(1 fm)



Introduction and motivation

PYTHIA 8



A. Ortiz, A. Paz, J. D. Romo, S.Tripathy, E. A. Zepeda, I. Bautista,
Phys. Rev. D 102, 076014 (2020)

Ratio of yield in MPI-enhanced pp collisions to yield for minimum bias (MB) pp collisions:

$$R_{\mathrm{pp}} = \frac{\mathrm{d}^2 N_{\pi}^{\mathrm{mpi}} / (\langle \mathrm{N_{mpi}} \rangle \mathrm{d}y \mathrm{d}p_{\mathrm{T}})}{\mathrm{d}^2 N_{\pi}^{\mathrm{MB}} / (\langle \mathrm{N_{mpi,\,MB}} \rangle \mathrm{d}y \mathrm{d}p_{\mathrm{T}})}$$

Introduction and motivation

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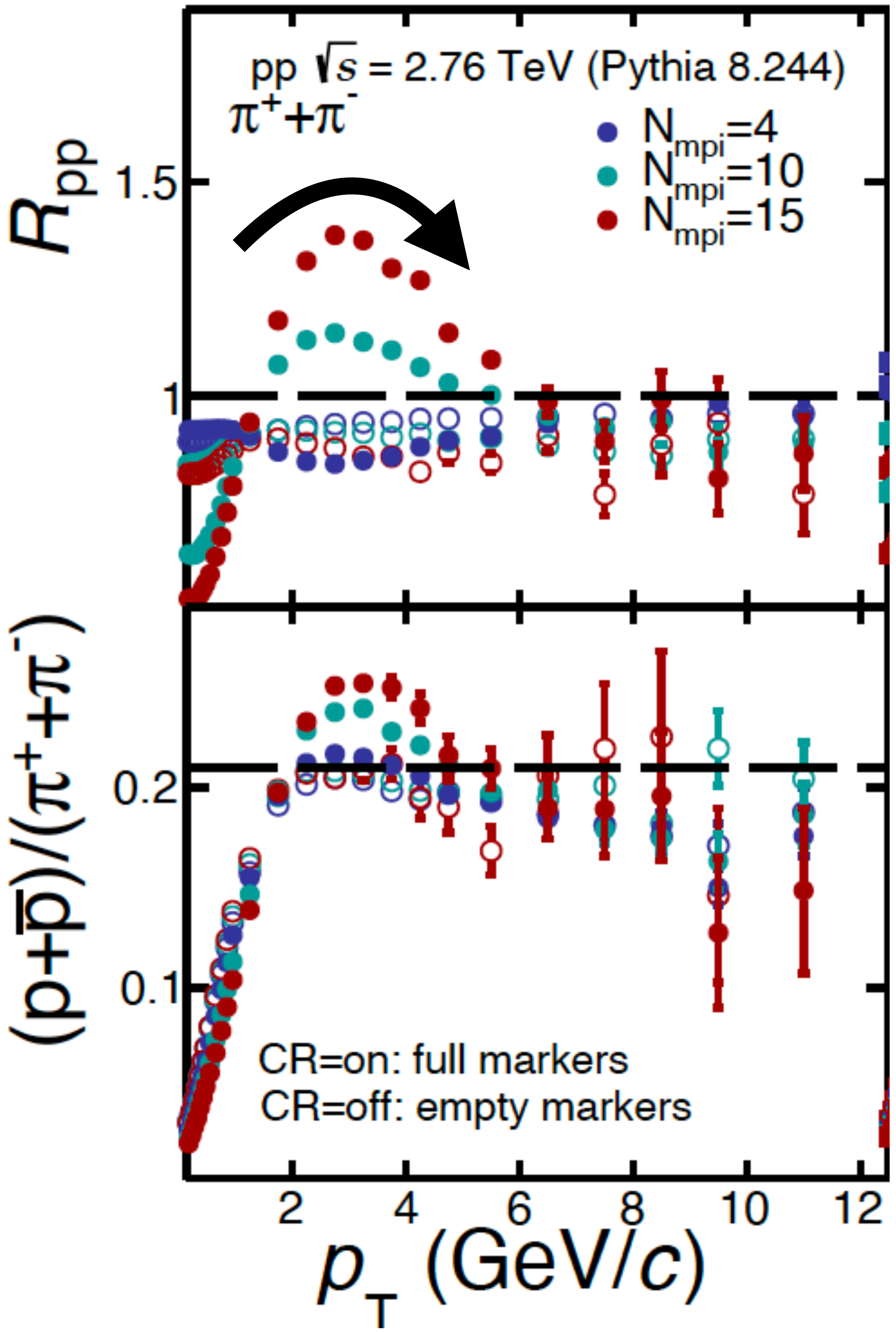

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- Up to 40% increase w.r.t. the binary parton-parton scaling: "bump" structure in p_T = 1-6 GeV/c: The effect is driven by CR
- MPI selection does not bias the high-p_T yield

Introduction and motivation

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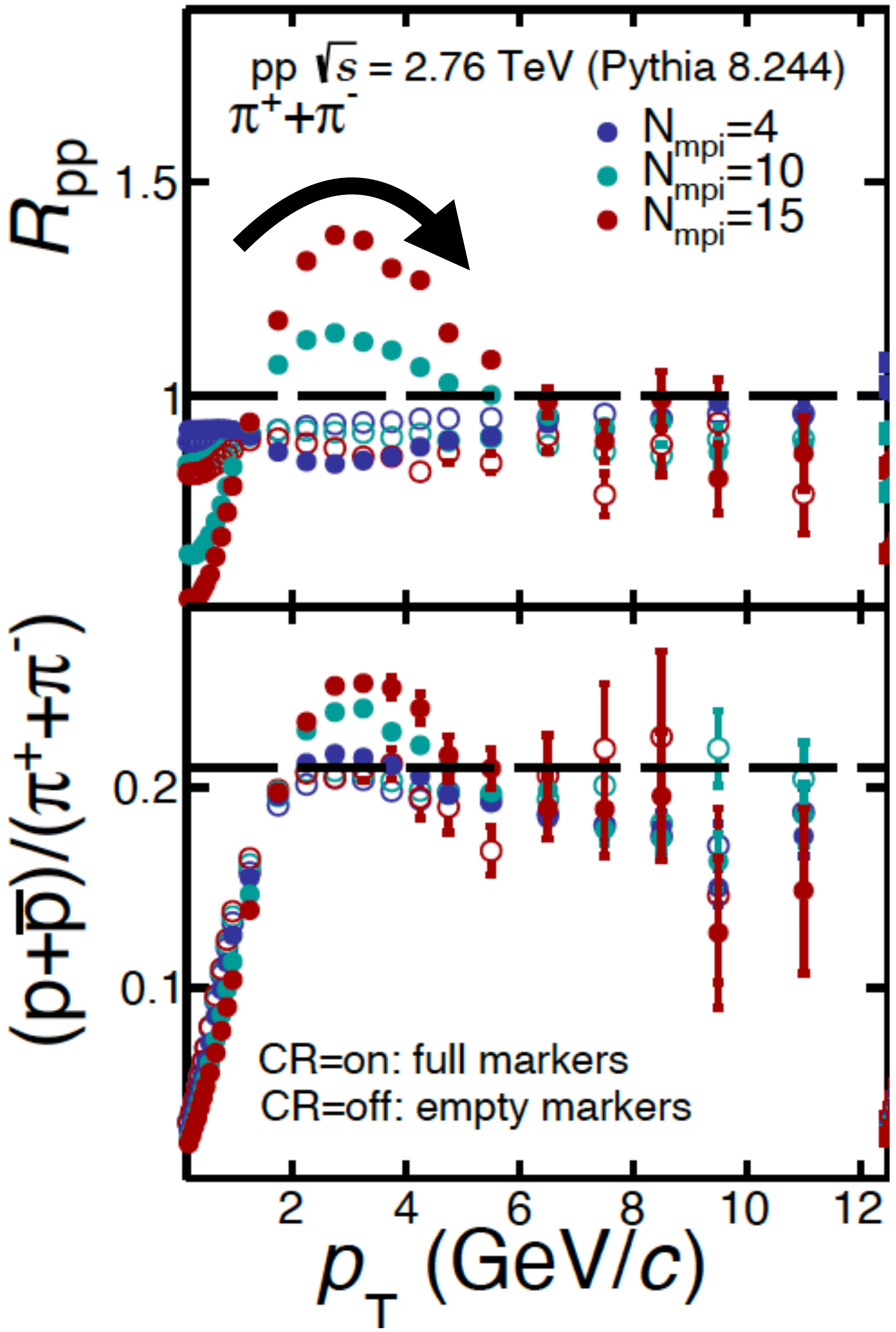

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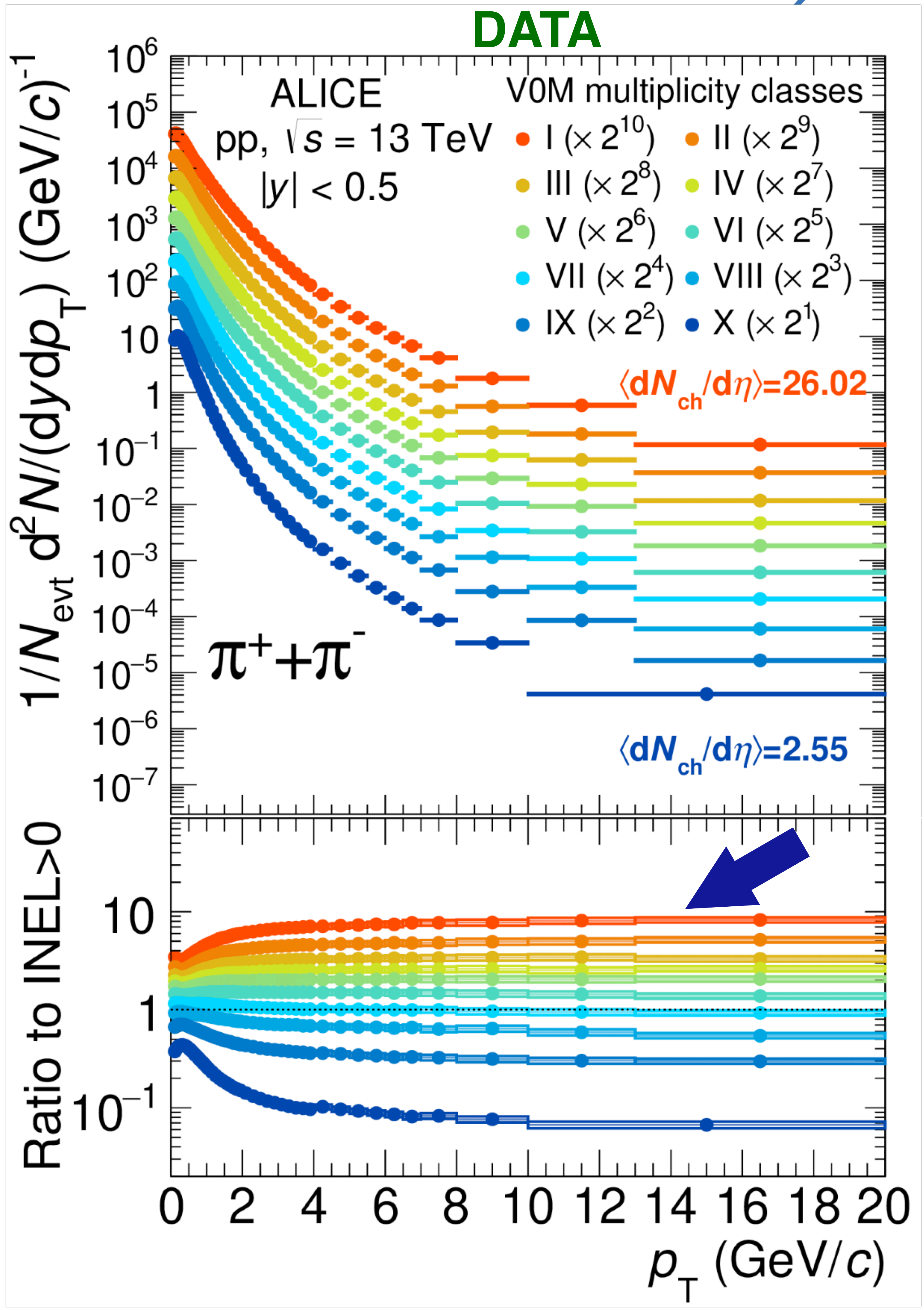
- Up to 40% increase w.r.t. the binary parton-parton scaling: "bump" structure in p_T = 1-6 GeV/c: The effect is driven by CR
- MPI selection does not bias the high-p_T yield
- The "bump" structure is not seen in measurements as a function of multiplicity and a selection bias is seen in high-p_T yield
- Explore event classifier: sensitivity to MPI with reduced selection bias

DATA



ALICE, EPJ C 80 (2020) 693

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- The origin of the QGP-like behavior in small systems is still unclear. One of the explanations is an MPI-based picture with colour reconnection and ropes, however, MPI can not be accessible directly in experiments.

- Event selections based only on multiplicity have shown significant bias towards hard pp collisions (selection biases)

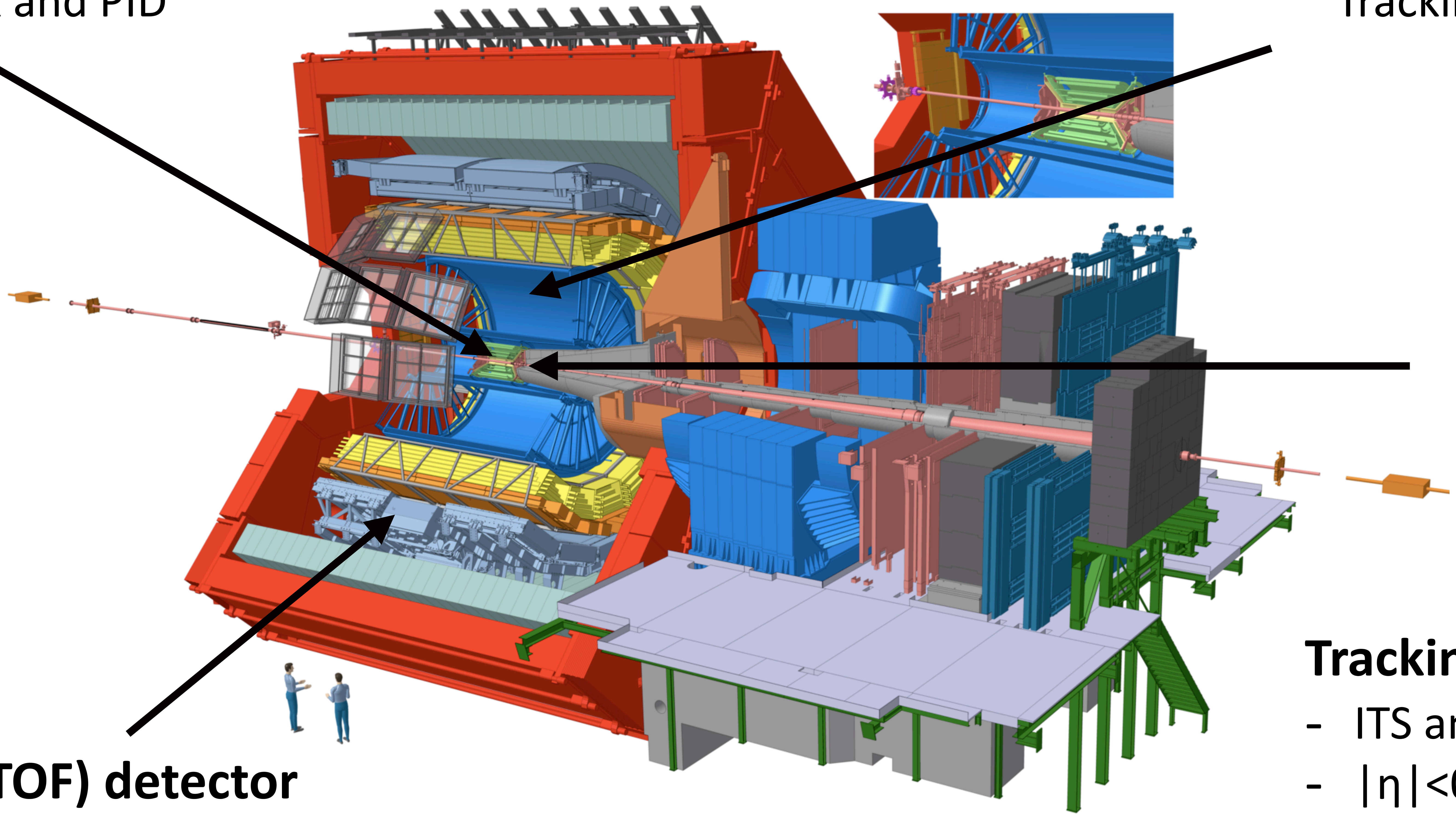
- Based on MC studies, event topology classifiers have shown a significant reduction of the selection biases and one can also isolate different physics regimes (soft and hard physics).
  - Transverse Spherocity ($S_0^{p_{\rm T}=1}$)
  - Relative Transverse Activity Classifier ($R_{\rm T}$)
  - Charged particle flattenicity ($\rho_{\rm ch}$) (A new classifier -> discussed later in slides)

A Large Ion Collider Experiment

Run 2

Inner Tracking System (ITS)
Tracking, vertex and PID

Time Projection Chamber (TPC)
Tracking and PID (d*E*/dx)



V0
Trigger, multiplicity/ centrality estimator, event classification based on amplitude

Tracking and kinematics

- ITS and TPC tracks
- $|\eta|<0.8$

Time of Flight (TOF) detector
PID via time-of-flight method

Transverse Spherocity

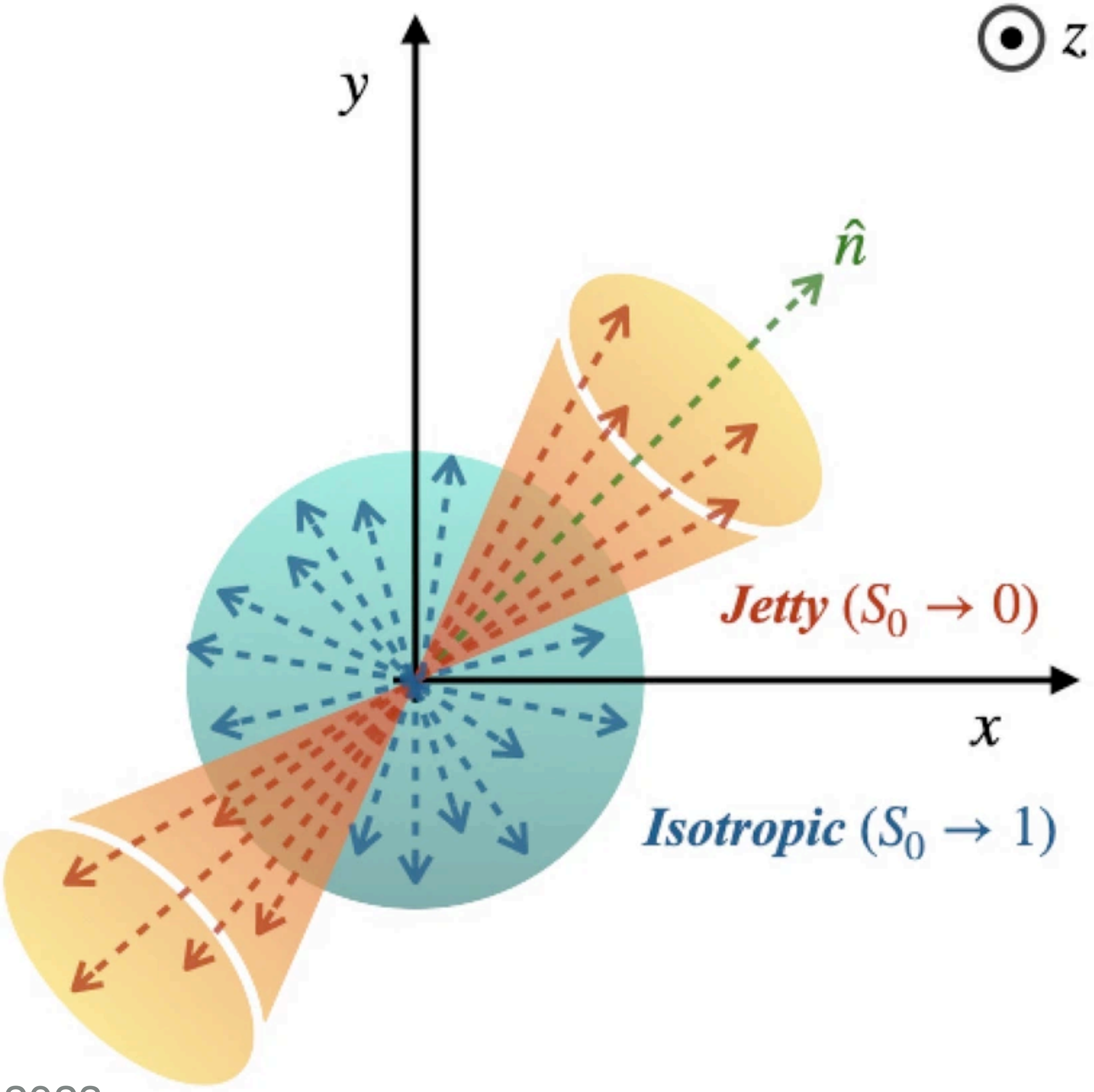
- Transverse spherocity distinguishes hard and soft processes

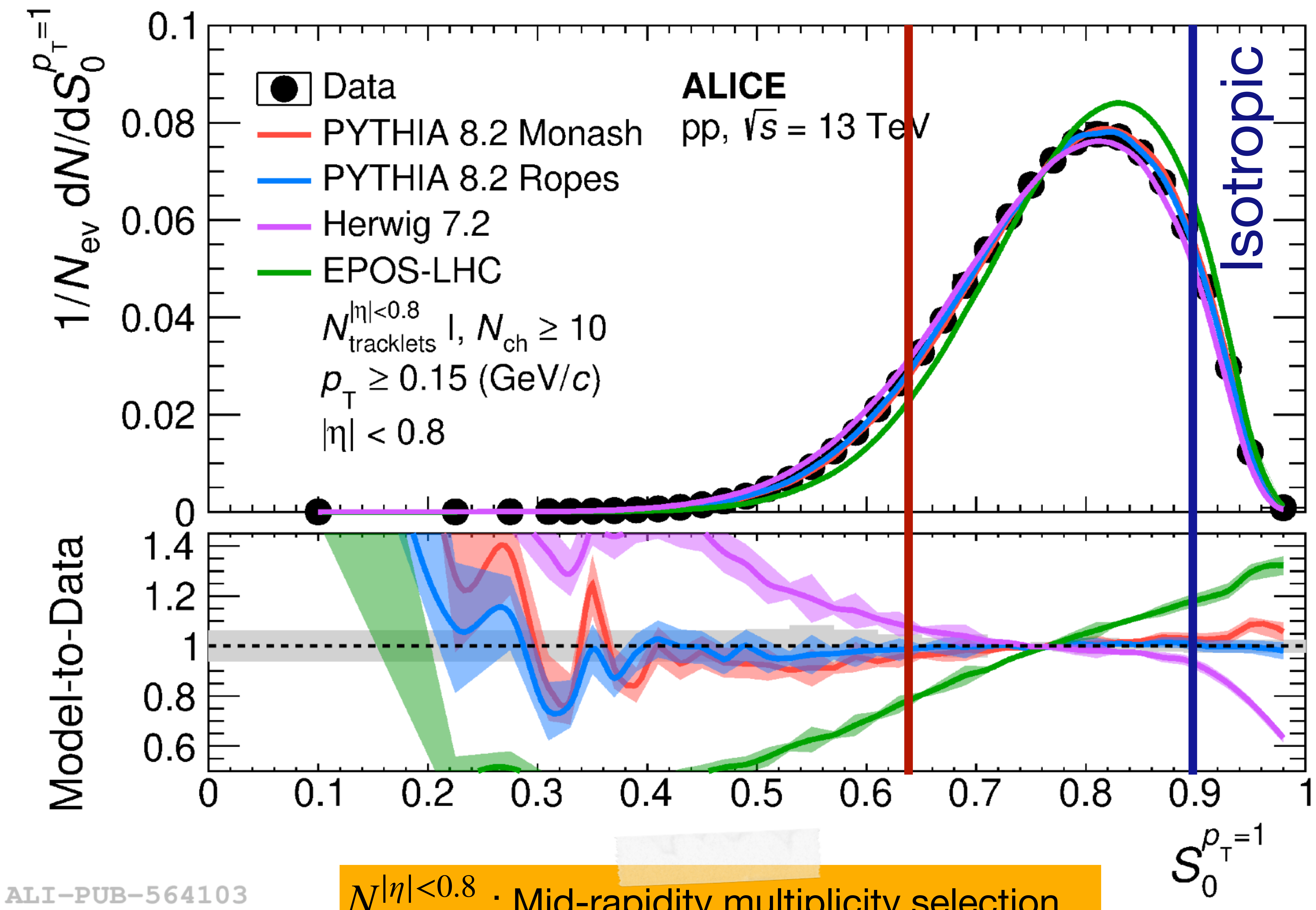
  Jet-like: Back-to-back structure, an indication of hard-QCD

  Isotropic: soft-QCD process

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

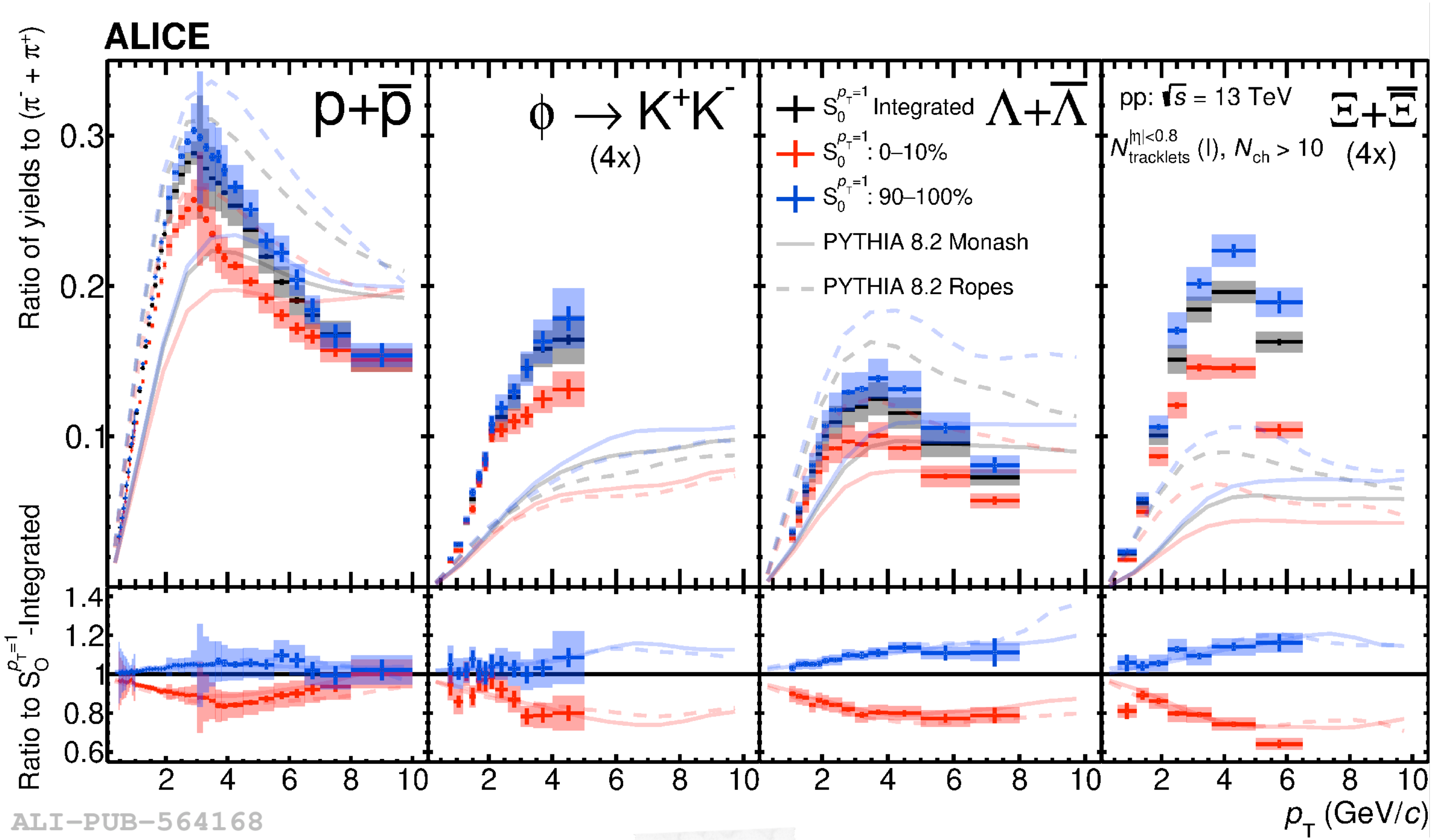
$p_{\mathrm{T}} = 1$: p_{T}-unweighted transverse spherocity





$N_{\mathrm{tracklets}}^{|\eta|<0.8}$: Mid-rapidity multiplicity selection

Identified particle ratios vs $S_0^{p_T=1}$

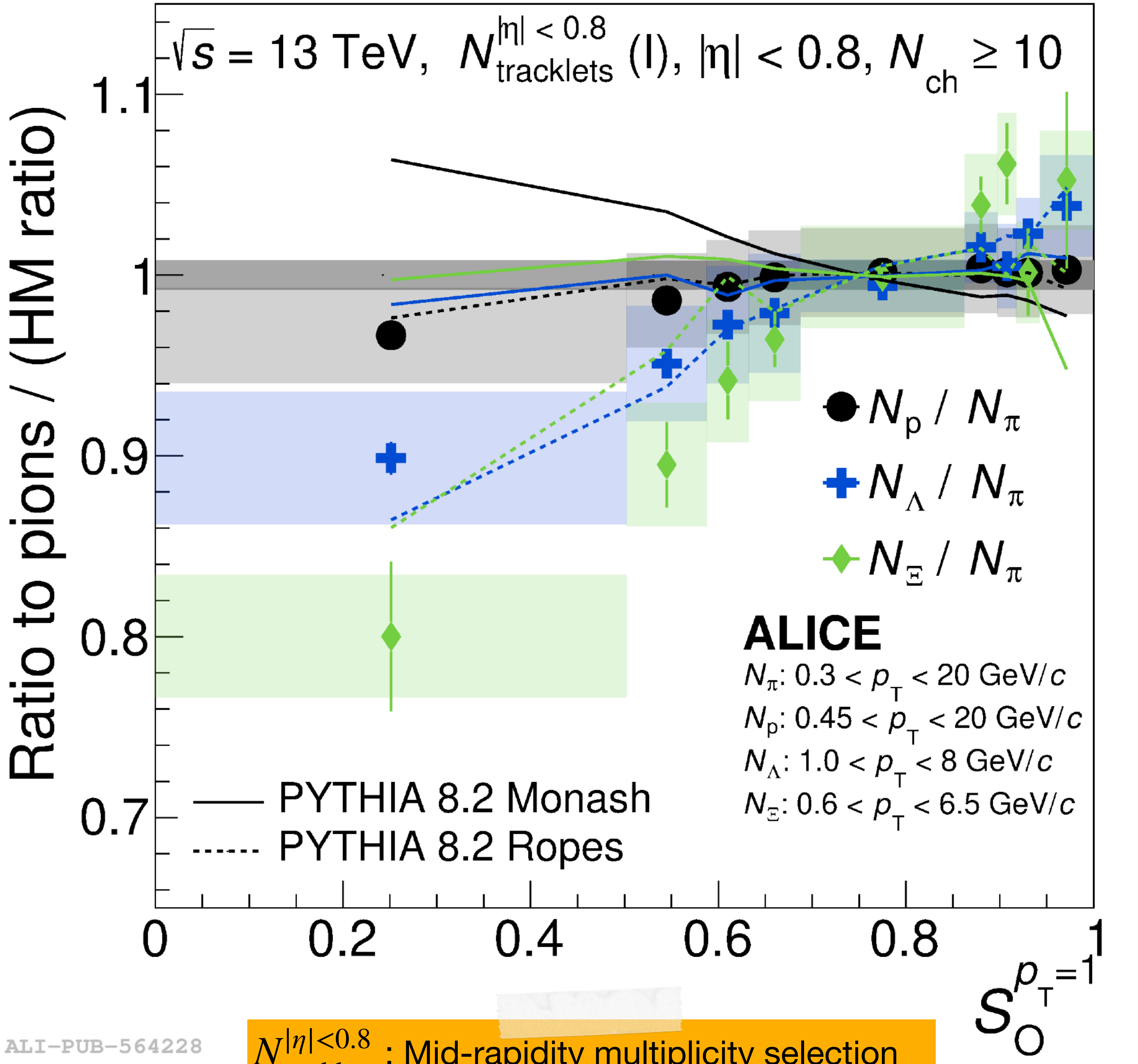


$N_{\mathrm{tracklets}}^{|\eta|<0.8}$: Mid-rapidity multiplicity selection

- Reduction of ratios relative to pion yields in jet-like events for all particle species -> significant strangeness suppression
- Both PYTHIA Monash and Ropes fail to capture the absolute trends but the ratios to $S_0^{p_T=1}$-integrated events are well explained by the models

ALICE, arXiv:2310.10236

Integrated double ratio vs $S_0^{p_T=1}$



$N_{\text{tracklets}}^{|\eta|<0.8}$: Mid-rapidity multiplicity selection

- Proton yield is not modified with spherocity
- Approximately 20% effect for Ξ
- Strength is ordered in strangeness

ALICE, arXiv:2310.10236

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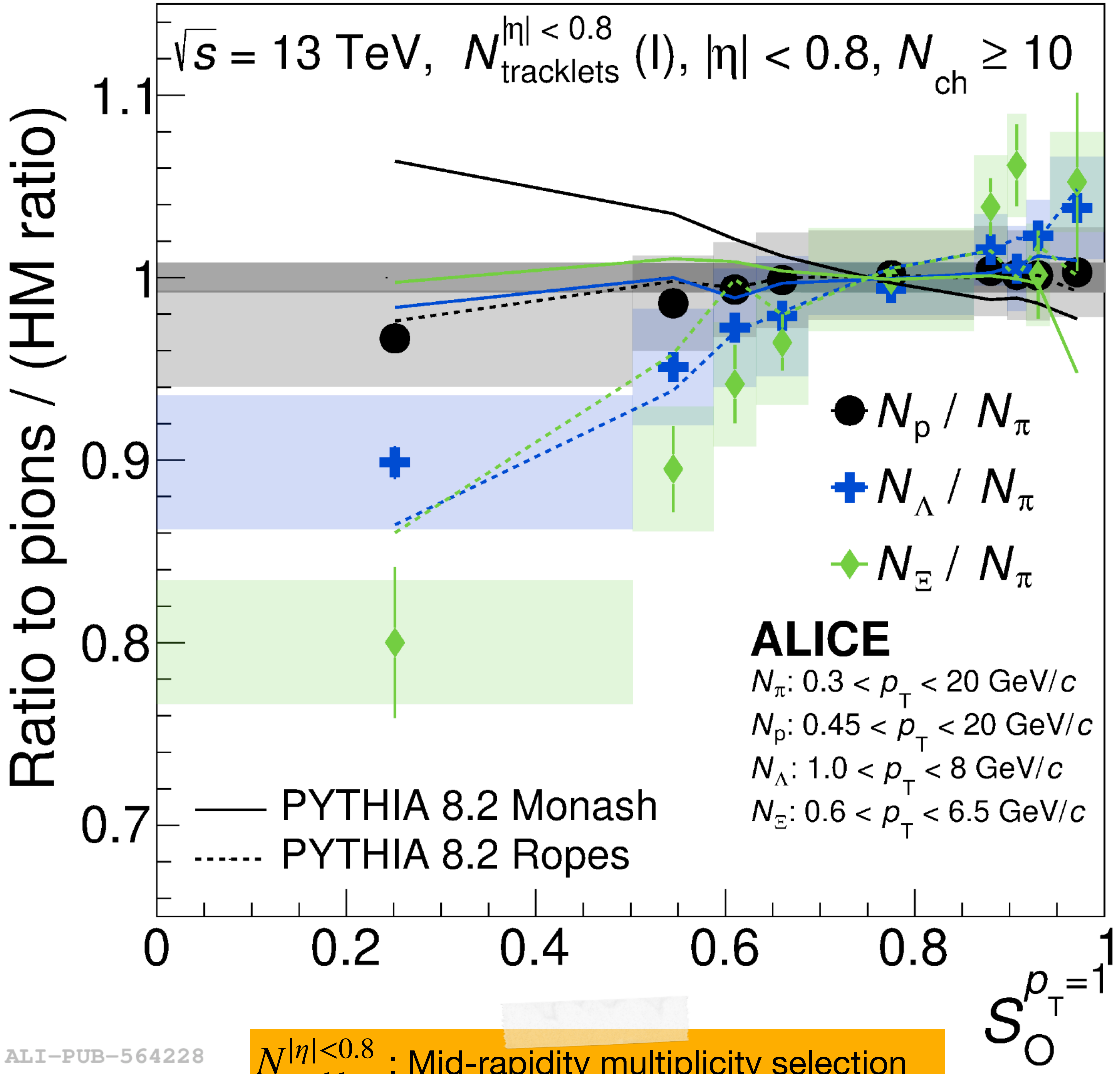

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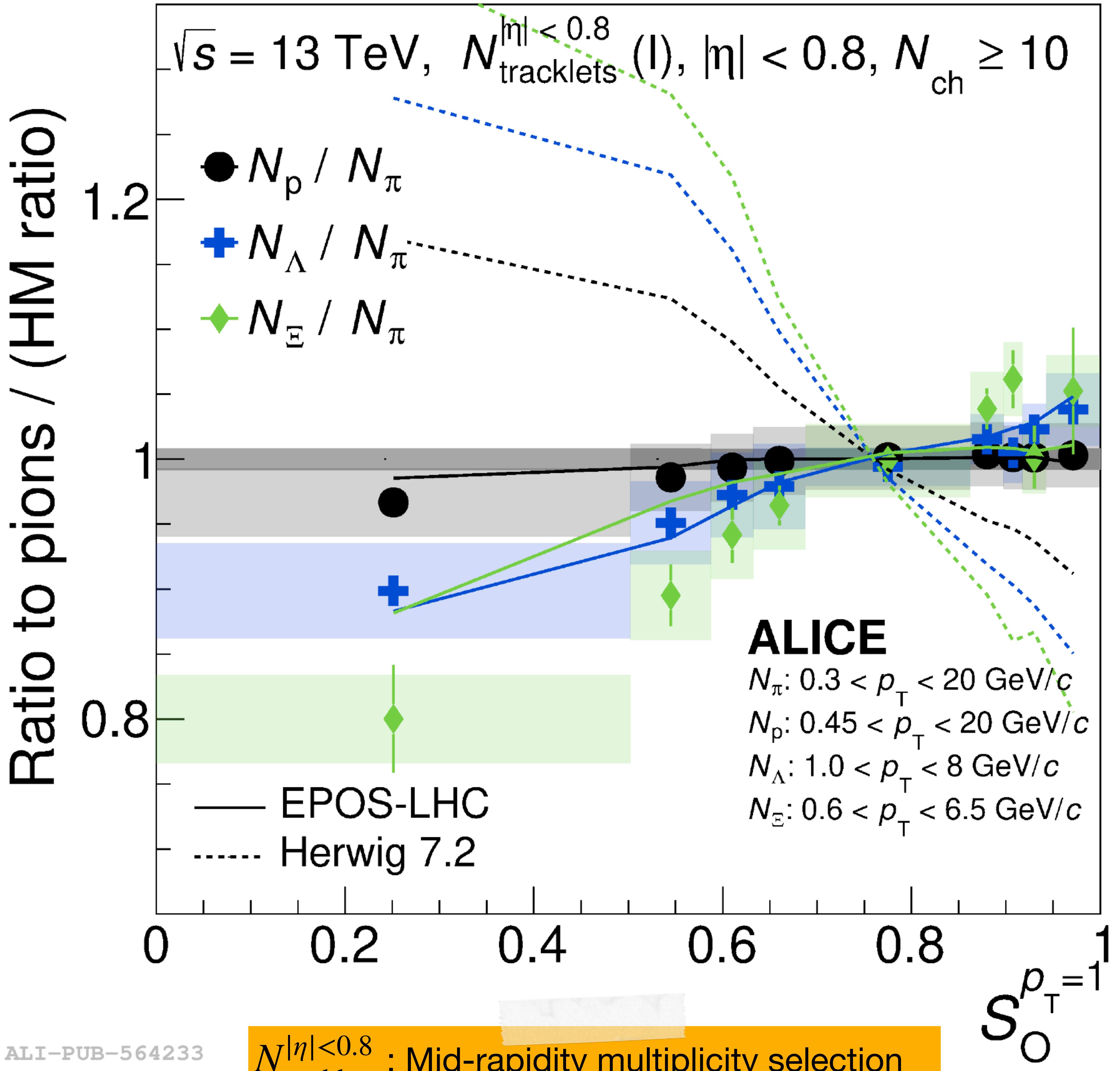

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ALICE, arXiv:2310.10236

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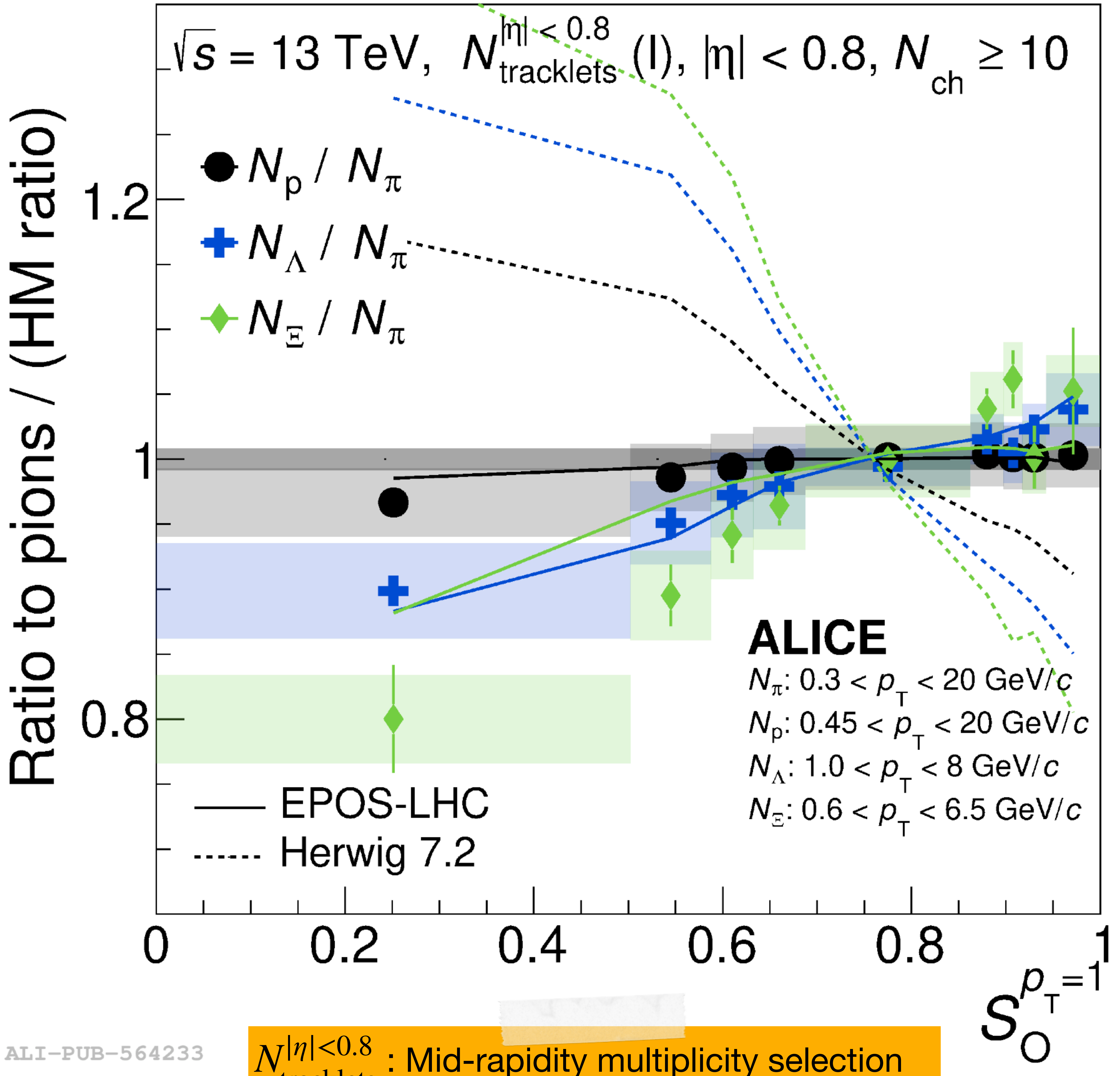

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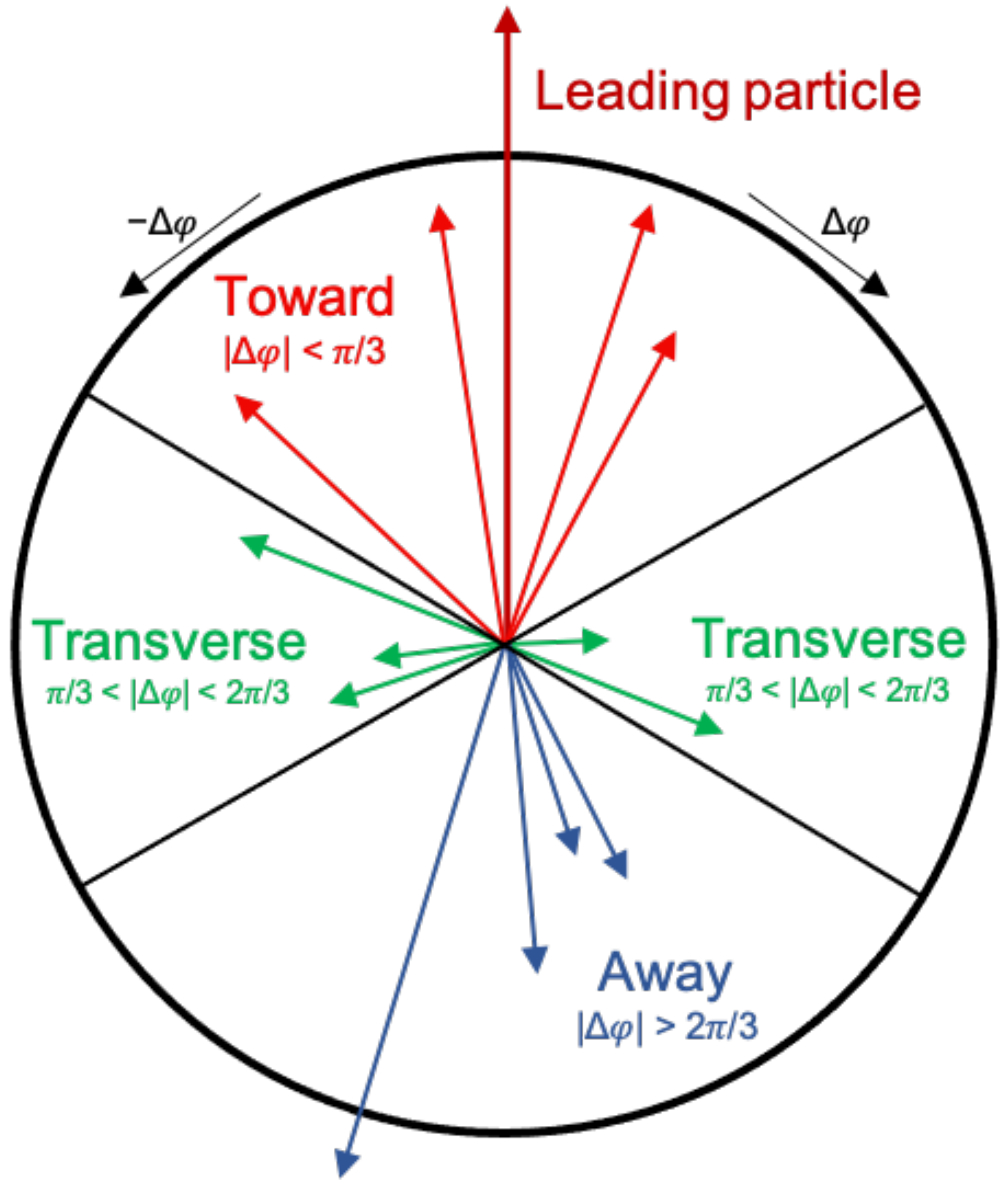
Enhanced strangeness production in high-multiplicity collisions seems to be the feature of isotropic events

ALICE, arXiv:2310.10236

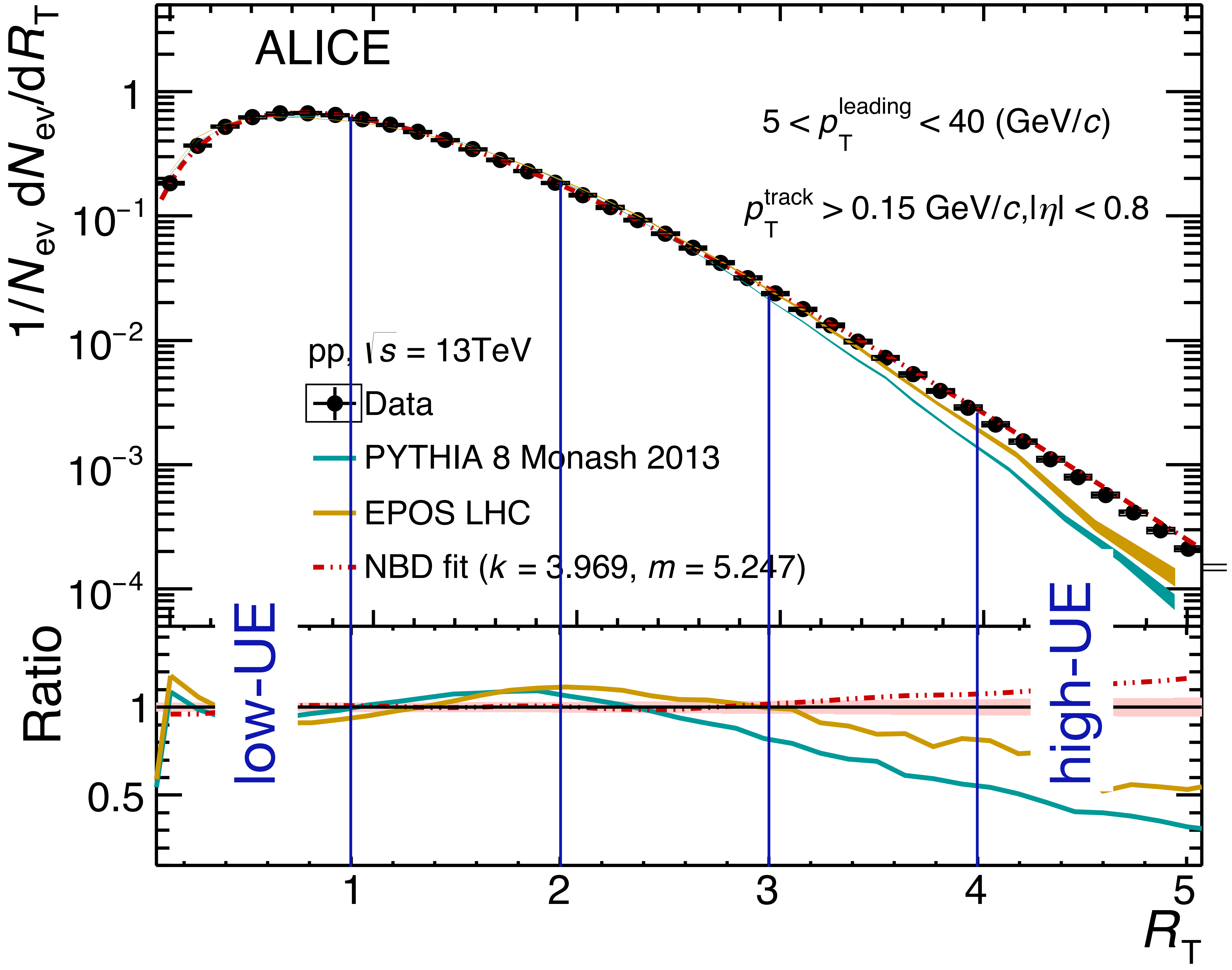
Relative transverse activity classifier



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

T. Martin, P. Skands, and S. Farrington, Eur. Phys. J. C 76 no. 5, (2016) 299

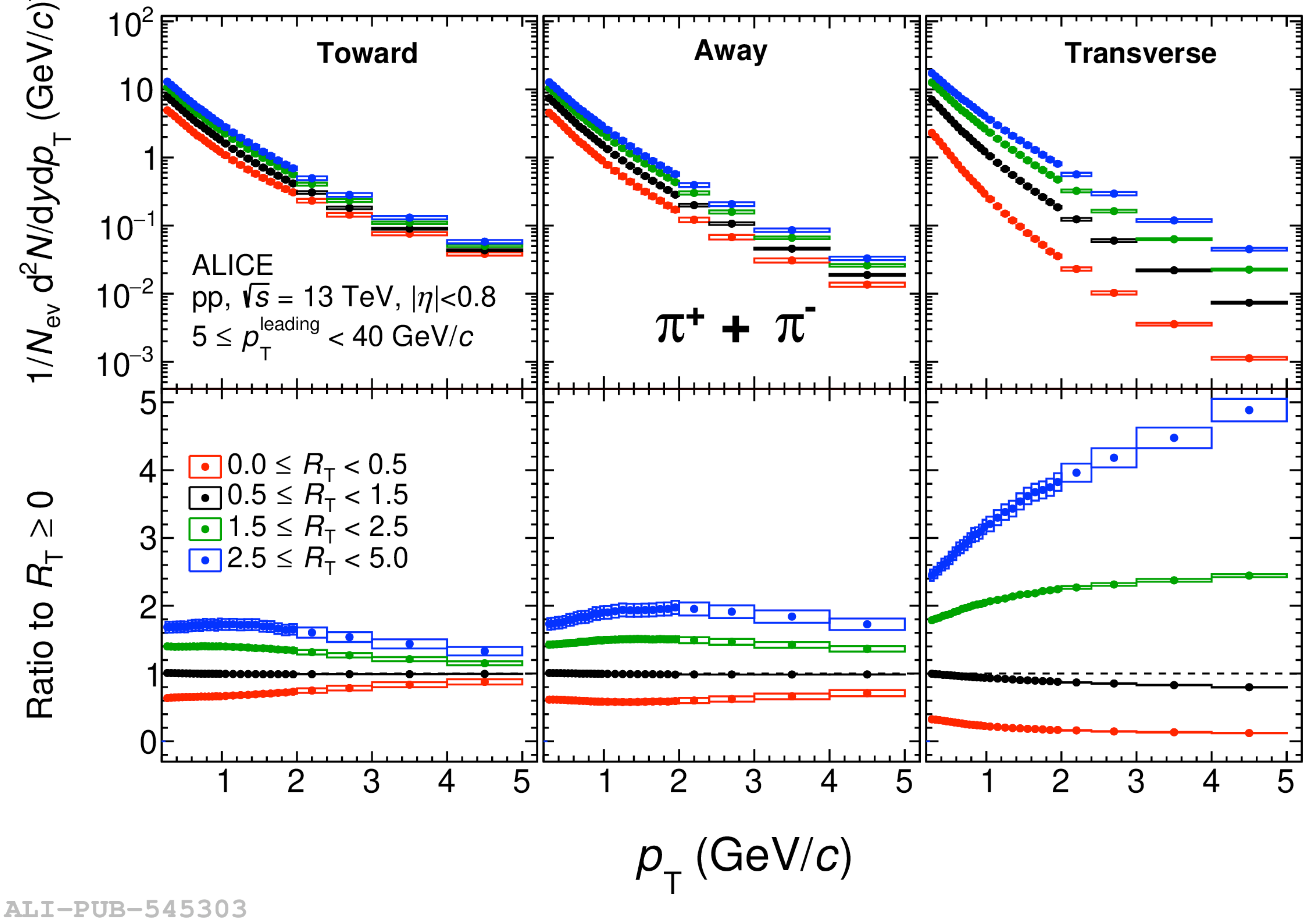
P. Vargas, Tuesday at 16:00
"Charged-particle production as a function of the relative transverse activity classifier in pp, p-Pb, and Pb-Pb collisions"



ALICE, JHEP04 (2020) 192

- Using R_T, one can vary the magnitude of the underlying event (UE)
- $R_T \to 0$: Events with less UE (dominated by jets)
- Higher R_T → Higher UE contribution
- A minimum threshold on leading particle p_T is applied to ensure no bias on spectra vs R_T measurements up to the minimum p_T of the leading particle

Identified particle production vs. R_T



ALICE, JHEP 06 (2023) 027

- For the transverse region, the ratio of p_T spectra to the R_T-integrated spectra rises with increasing R_T.
- Toward and away regions' high-p_T yields are independent of R_T (an artefact of the leading p_T requirement). However, at low-p_T, the R_T dependence is more evident.
- No "bump" structure seen in these measurements → selection bias
- Explore event classifier to have sensitivity to MPI with reduced selection bias

Event classification with charged particle flattenicity

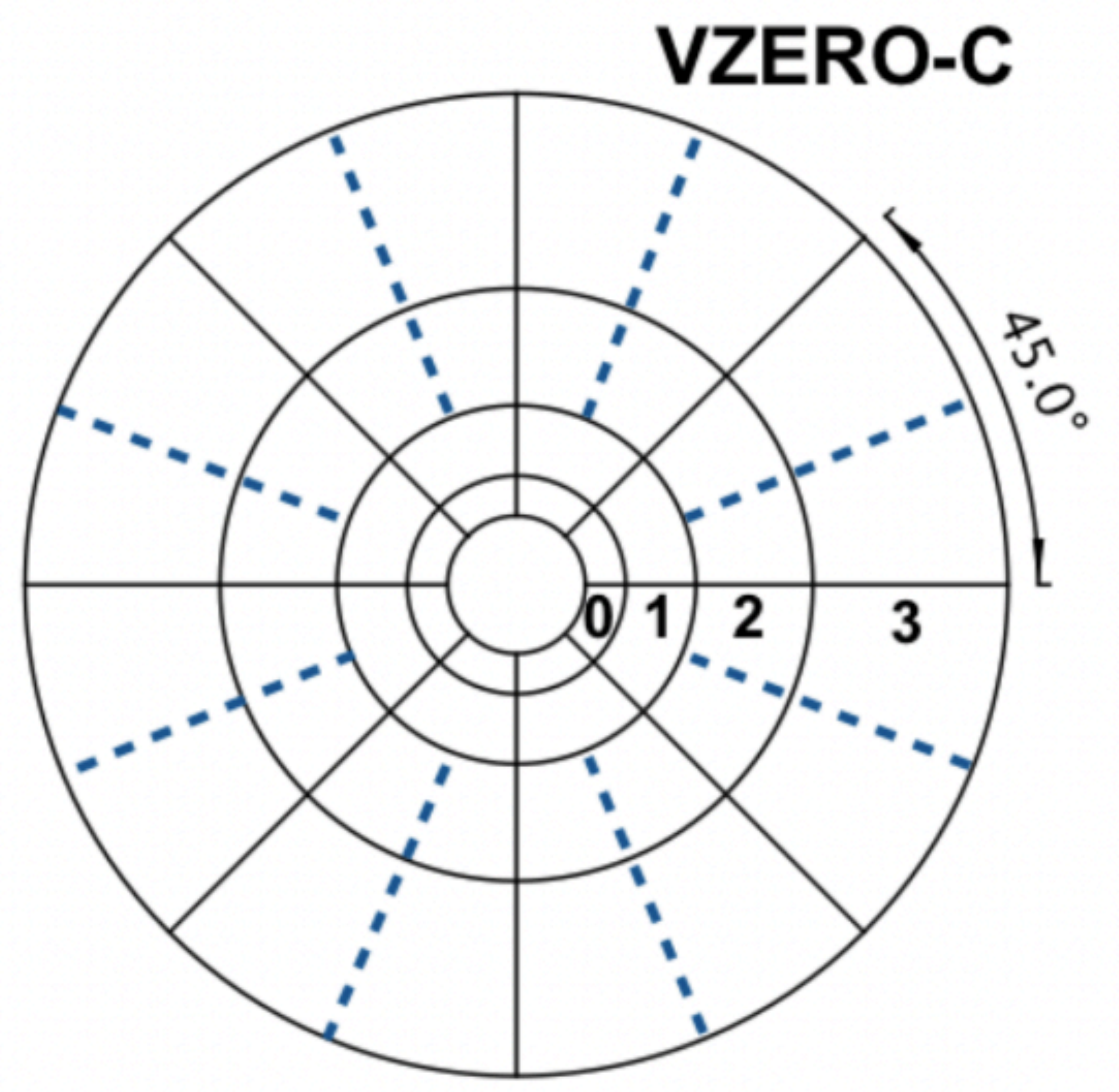
Motivation: Search for observable highly sensitive to SOFT particle production (MPI) and CR effects without introducing a bias toward HARD production (multi-jets, high p_T yield)

Charged-particle Flattenicity

- Define a grid in the η-ϕ space covered by the V0 detector (10×8 cells)
- The particle multiplicity per cell is measured and flattenicity is calculated

$$\rho_{\mathrm{nch}} = \frac{\sqrt{\sum_i (N_{\mathrm{ch}}^{\mathrm{cell},i} - \langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle)^2 / \mathrm{N}_{\mathrm{cell}}^2}}{\langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle}$$

~0 isotropic topology ➧ soft pp collisions
~1 jet-like topology ➧ hard pp collisions



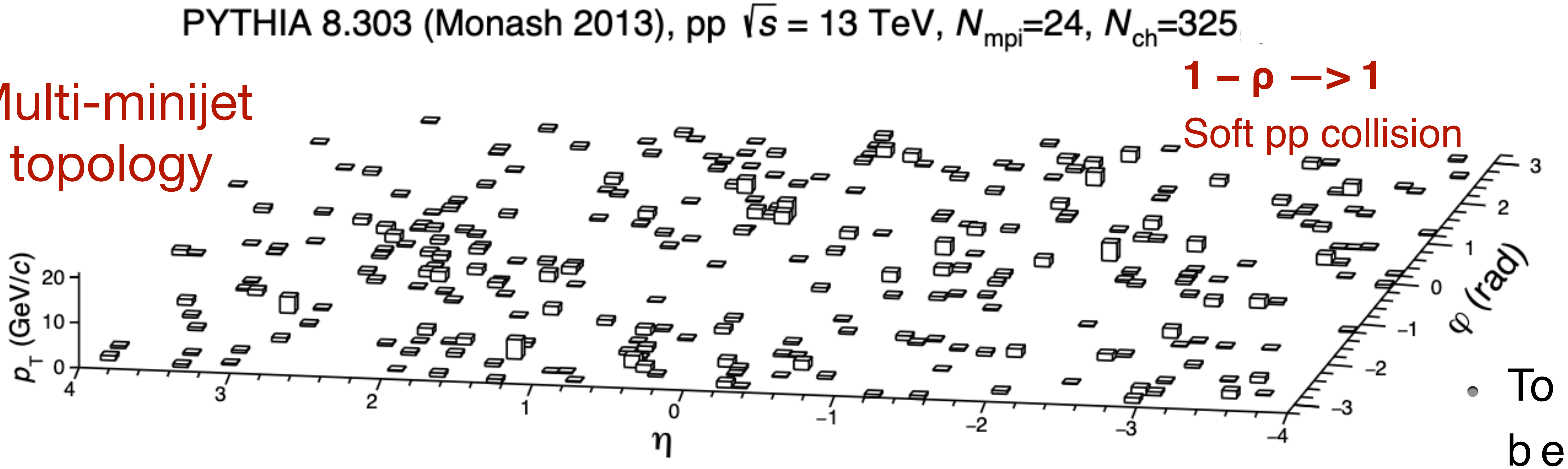
Event classification with charged particle flattenicity

A. Ortiz et. al,
Rev.Mex.Fis.Suppl. 3 (2022) 4, 040911

Multi-minijet topology

$1 - \rho \rightarrow 1$

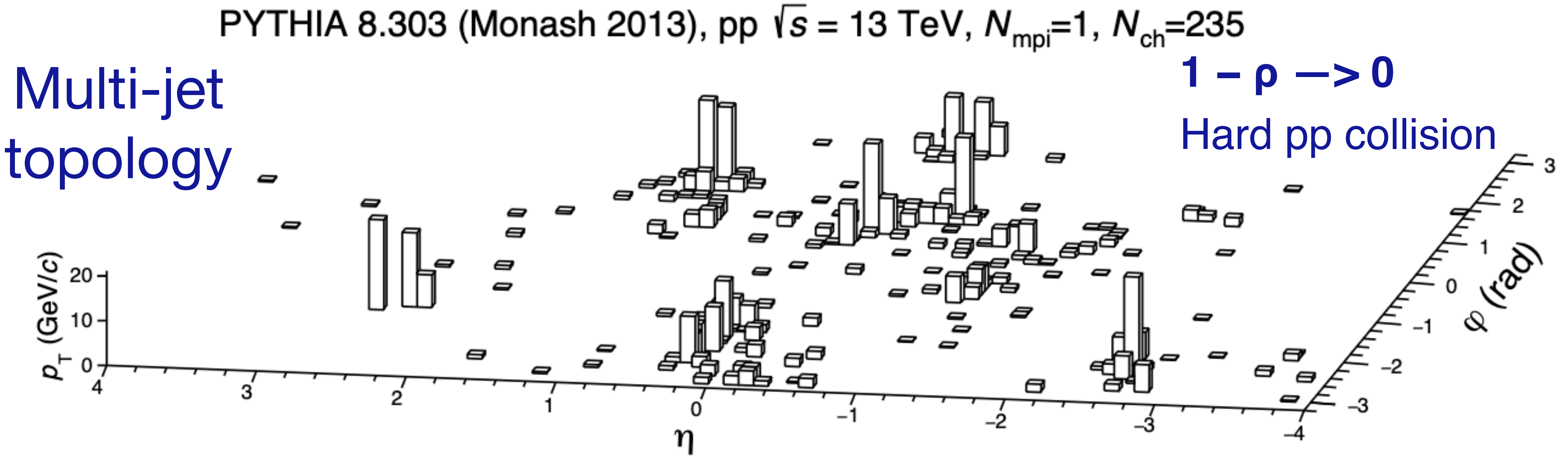
Soft pp collision



Multi-jet topology

$1 - \rho \rightarrow 0$

Hard pp collision

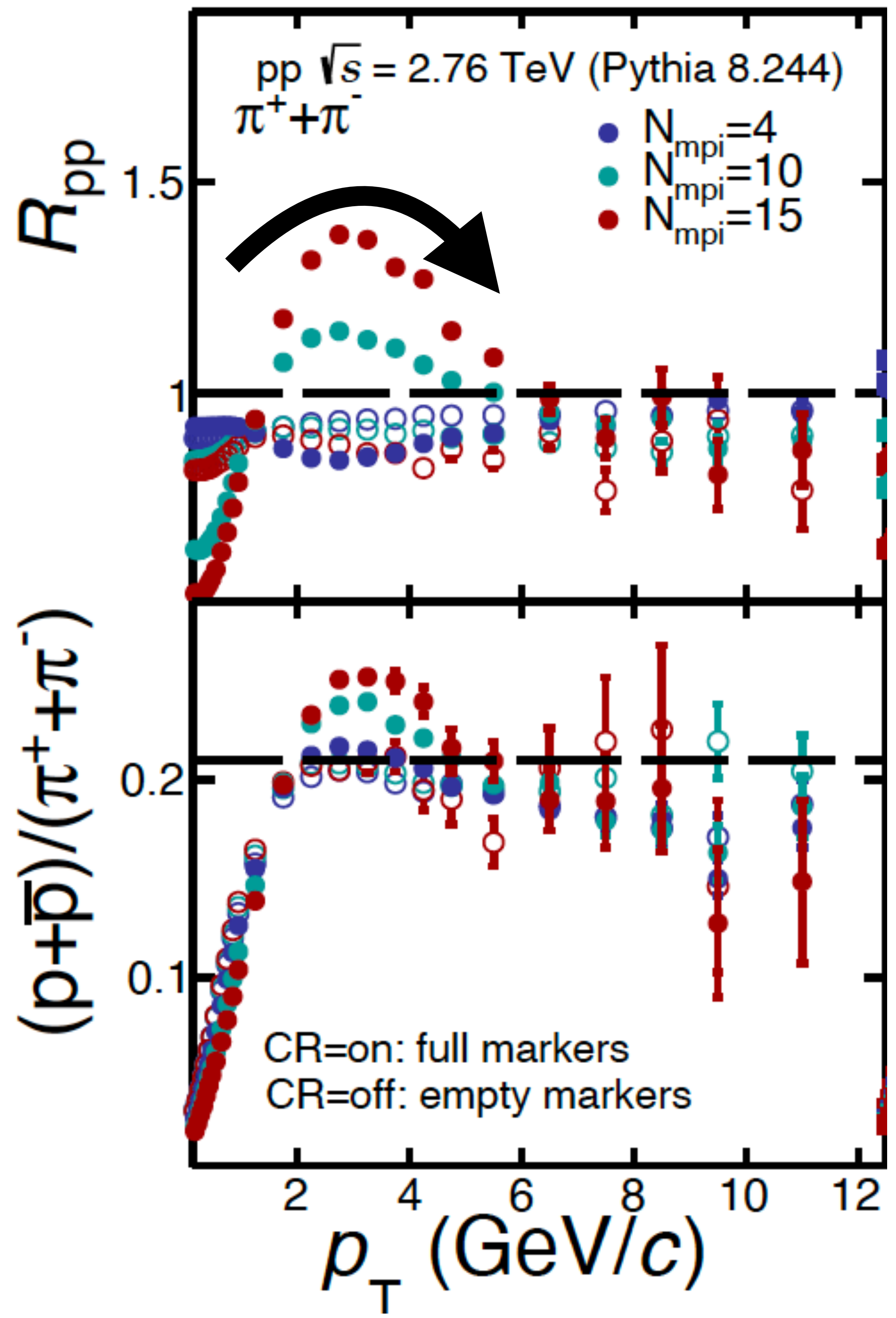


- To relate the types of events between Spherocity and Flattenicity, a change of variable is performed: $\rho \rightarrow 1 - \rho$
- Thus, events with large number of MPI are selected when $1 - \rho \rightarrow 1$

Event classification with charged particle flatteniity

A. Ortiz, A. Paz, J. D. Romo, S.Tripathy, E. A. Zepeda, I. Bautista,
Phys. Rev. D 102, 076014 (2020)

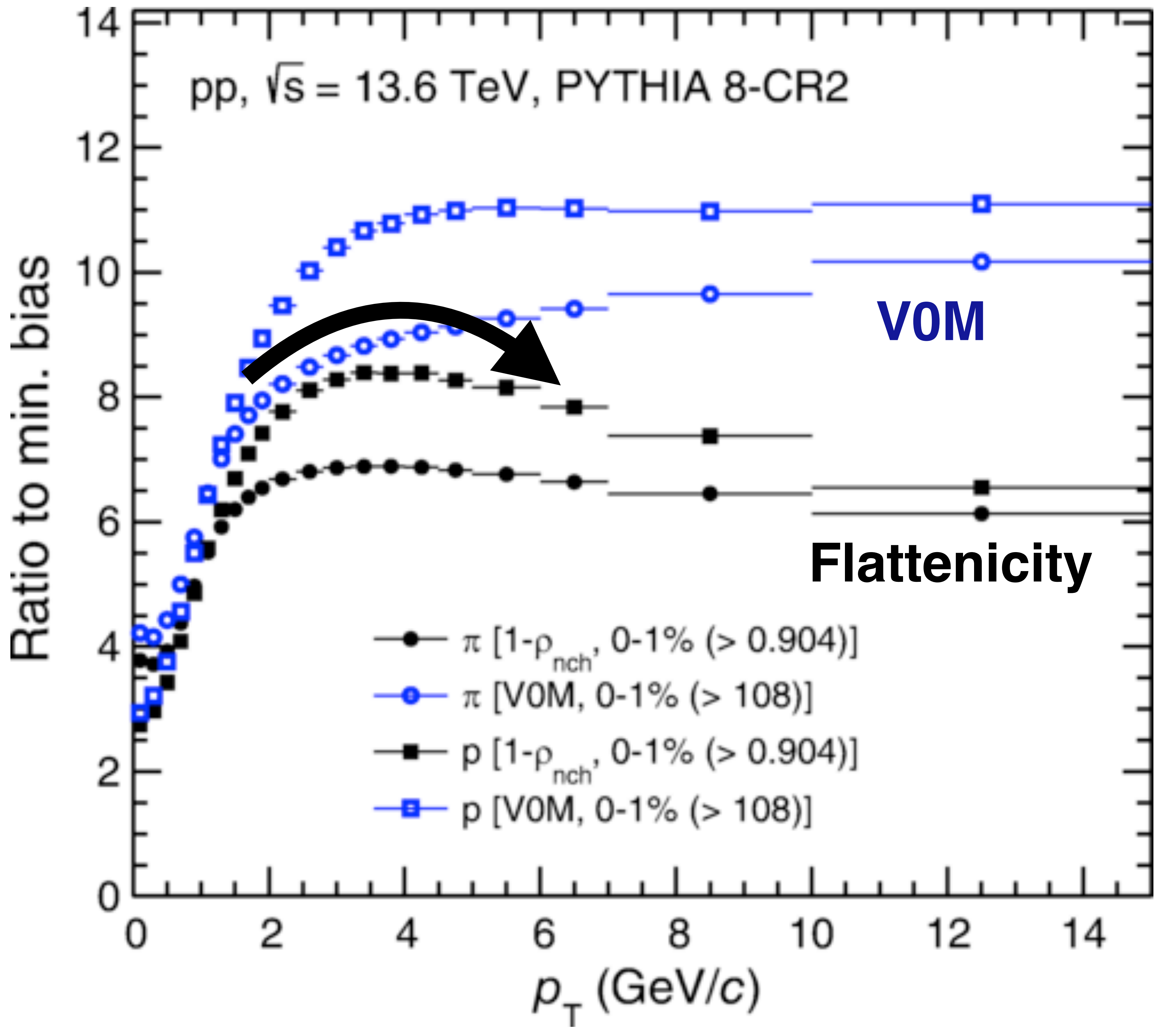
PYTHIA 8



- Selection based on MPI
- high-p_T yield is not biased

A. Ortiz, A. Khuntia, O. Vazquez, S.Tripathy, G. Bencedi,
Phys. Rev. D107 (2023) 7, 076012

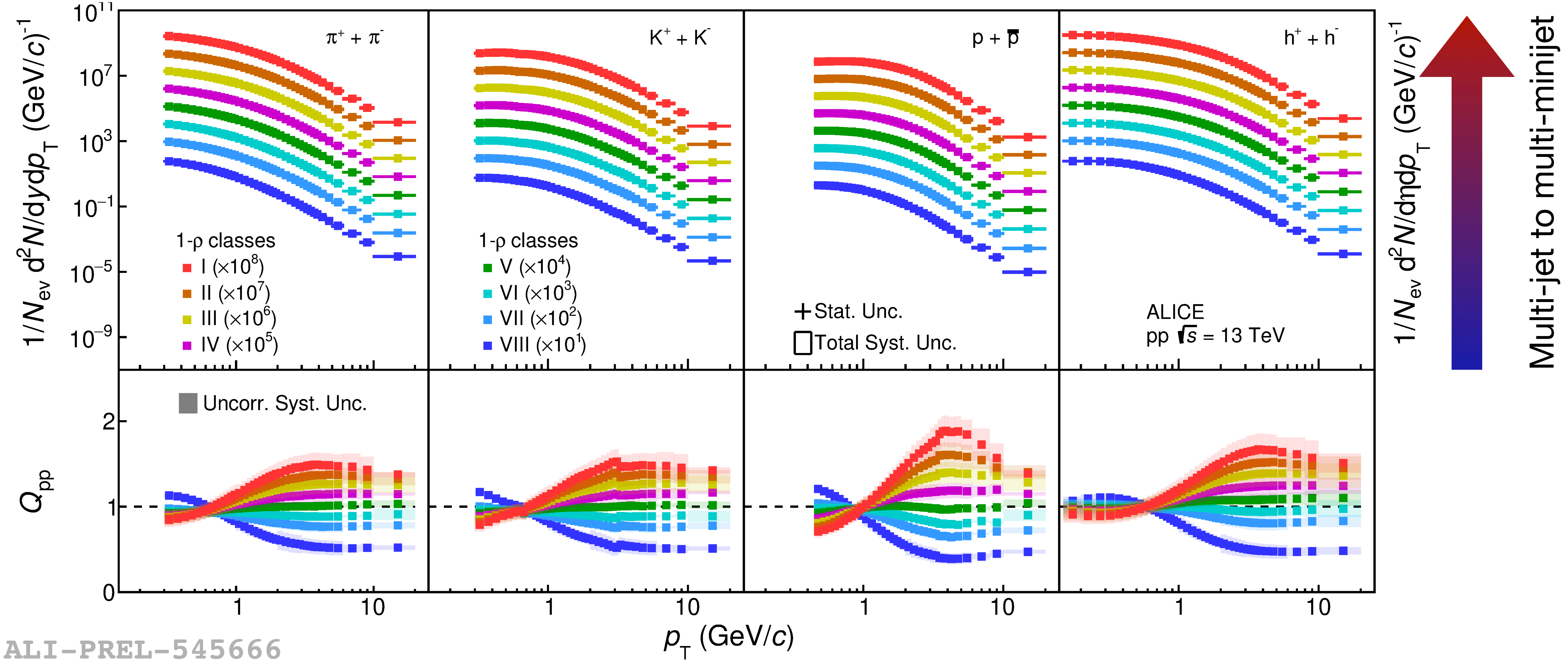
PYTHIA 8



- Selection using flattenicity shows a **"bump" structure**
- Reduced bias towards hard physics

Particle production vs charged particle flattenicity

Flattenicity class only



Ratio of yields to MB:

$$Q_{pp} = \frac{d^2N^{1-\rho\ \text{class}}/(\langle dN_{ch}/d\eta\rangle dy dp_T)}{d^2N^{MB}/(\langle dN_{ch}/d\eta\rangle dy dp_T)}$$

- “Bump” structure: development of a peak for isotropic events and more evident for protons (flattenicity class (I))
- Mass dependency: the maximum of the peak shows a mass-dependent ordering

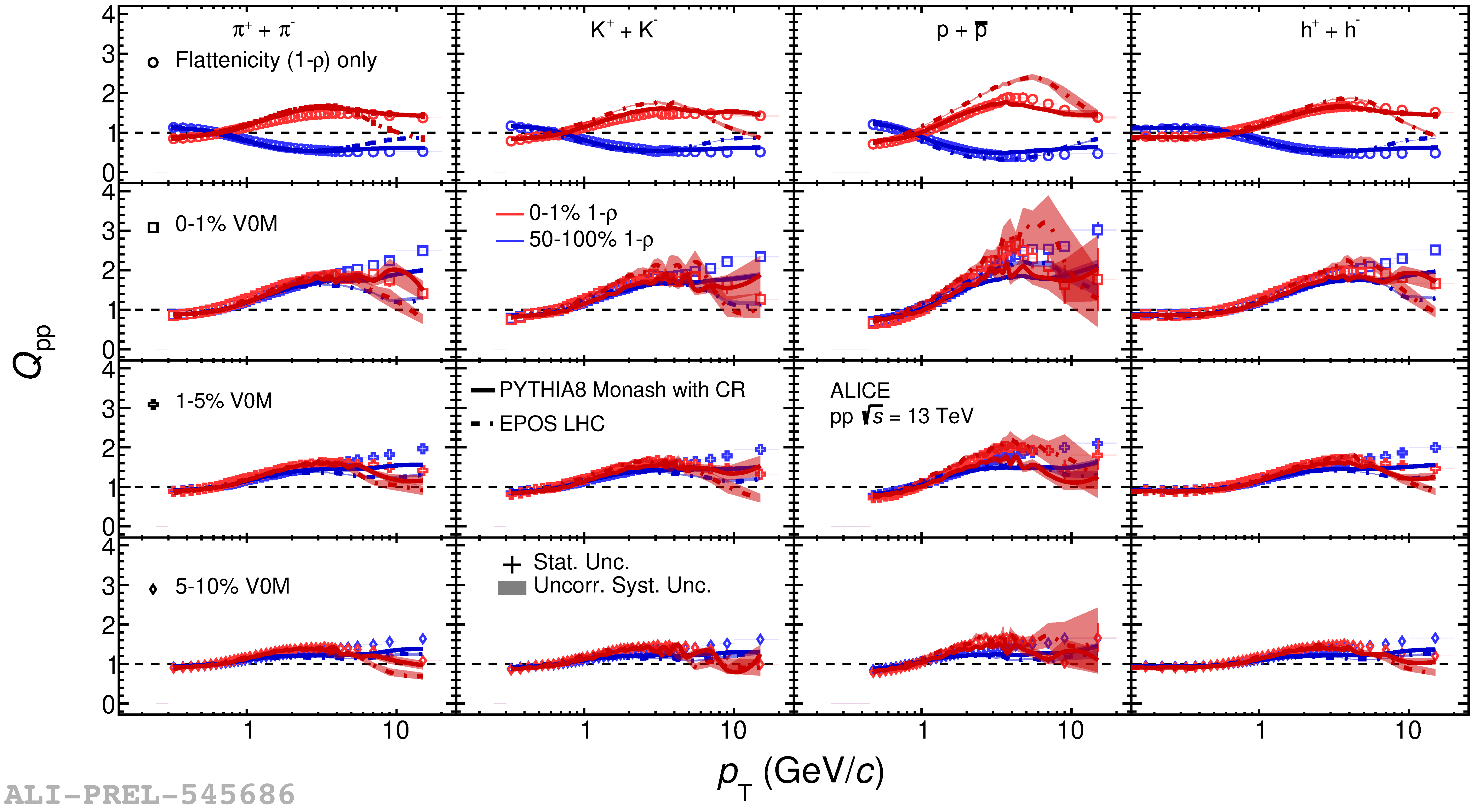
Particle production vs charged particle flattenicity

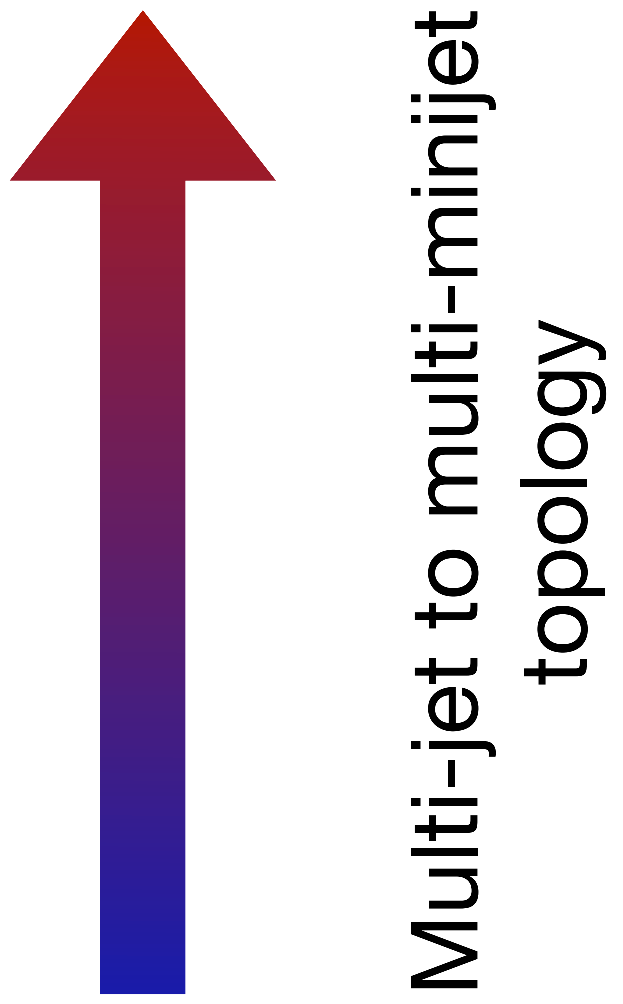
Flattenicity class only

Flattenicity + 0-1% V0M

Flattenicity + 1-5% V0M

Flattenicity + 5-10% V0M





$$Q_{\rm pp} = \frac{{\rm d}^2 N^{1-\rho\ \rm class}/(\langle {\rm d}N_{\rm ch}/{\rm d}\eta\rangle {\rm d}y{\rm d}p_{\rm T})}{{\rm d}^2 N^{\rm MB}/(\langle {\rm d}N_{\rm ch}/{\rm d}\eta\rangle {\rm d}y{\rm d}p_{\rm T})}$$

- PYTHIA 8 Monash 2013 with MPI and CR effects describes the data; sensitive to event selection due to CR
- EPOS LHC describes the data partially (low-to-mid $p_{\rm T}$); opposite trend seen w.r.t. PYTHIA8 at high $p_{\rm T}$

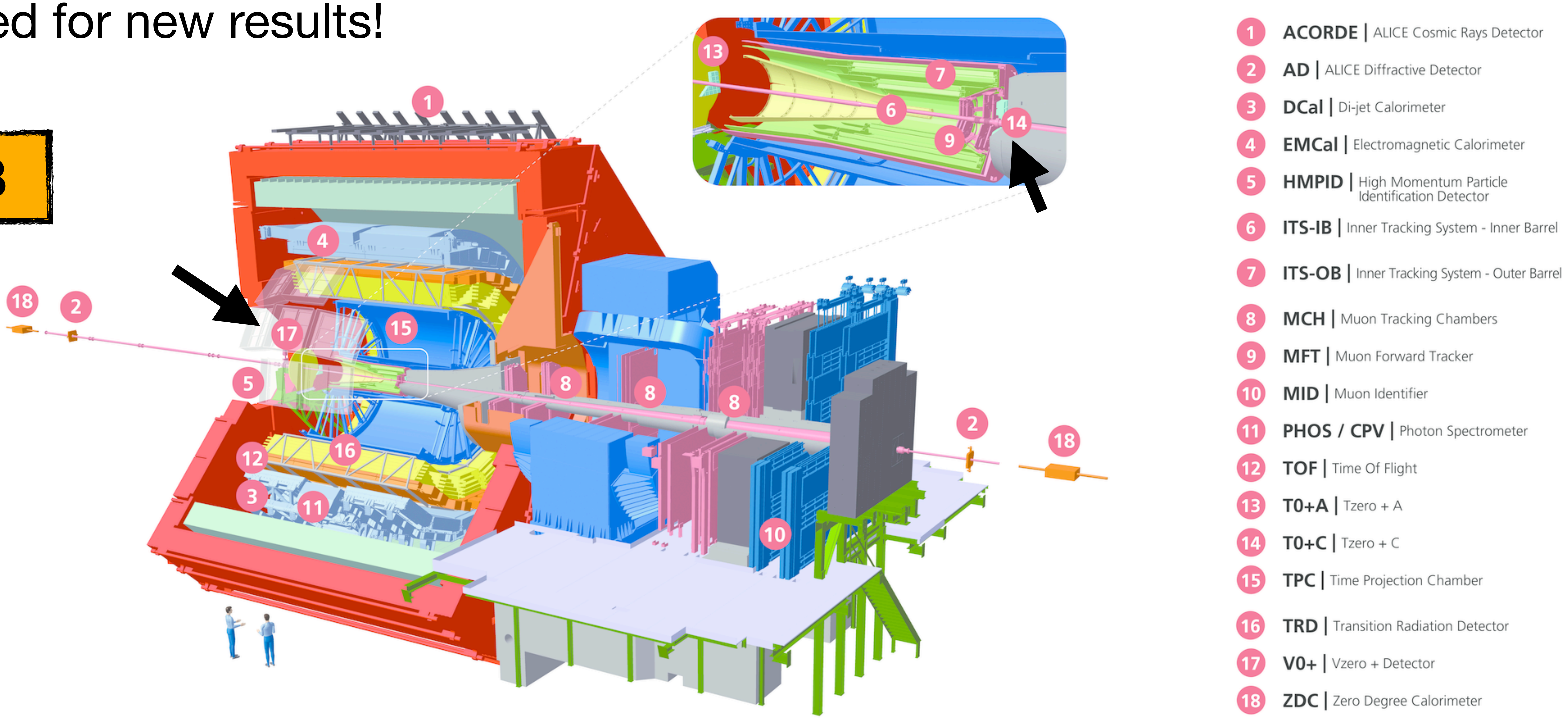
What do we learn?

- Along with multiplicity, the event topology classifiers add a new dimension of separating jet-like and isotropic events for pp collisions. They significantly reduce the selection biases.
- Jet-like events produce less strange hadrons than the average high-multiplicity event and the observed strangeness enhancement in high-multiplicity pp collisions is a feature of isotropic events.
- As suggested by MC studies, selections based on Flattenicity are sensitive to soft particle production and less sensitive to a (jet-) bias.
- Isotropic events develop a bump-like structure with increasing multiplicity similar to the behavior seen as a function of MPI where it is attributed to CR.

Outlook

- Flattenicity is defined in the pseudorapidity regions covered by the new V0 and T0C detectors in Run 3 of LHC.
- Stay tuned for new results!

Run 3



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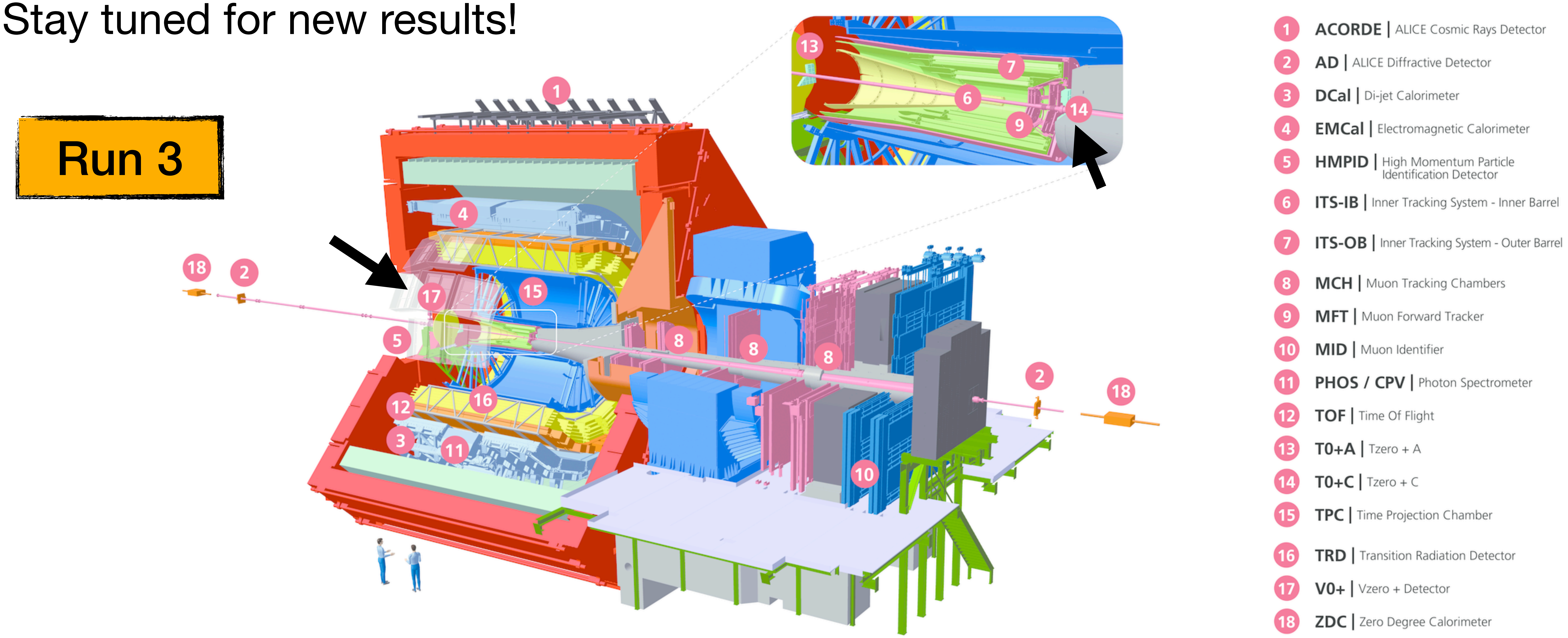
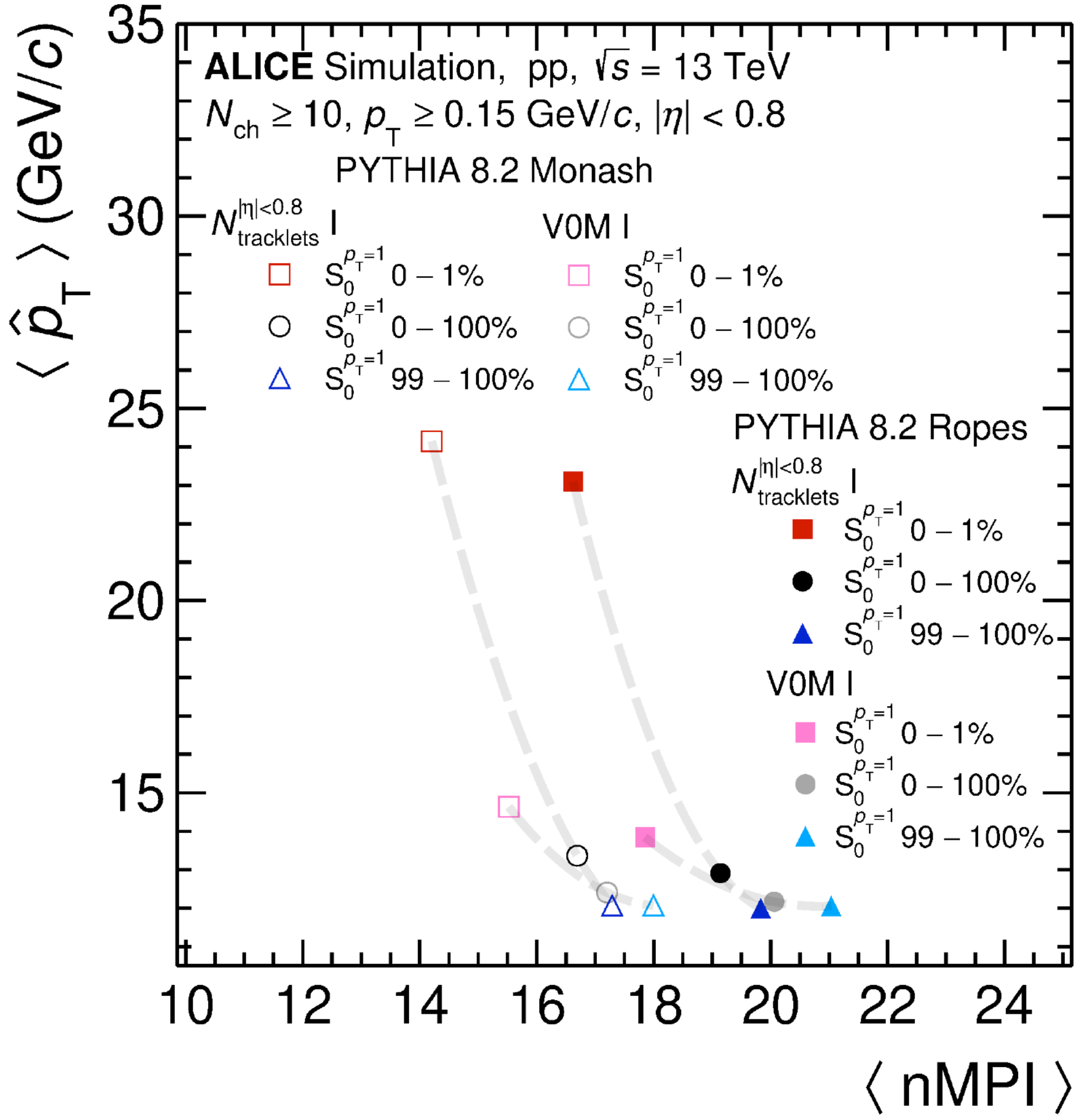


Thank you for your attention!

Backup

Integrated yield and mean transverse momentum vs $S_0^{p_T=1}$

PYTHIA 8



ALI-PUB-564123

$N_{tracklets}^{|\eta|<0.8}$: Mid-rapidity multiplicity selection

V0M: Forward-rapidity multiplicity selection

- Using mid-rapidity tracklets as an event classifier in conjunction with spherocity in MC shows a large shift in $\langle p_T \rangle$ and a small change in <nMPI>.
- High-multiplicity midrapidity measurements are biased towards jets -> Captured by jet-like events
- Reduced bias in isotropic events

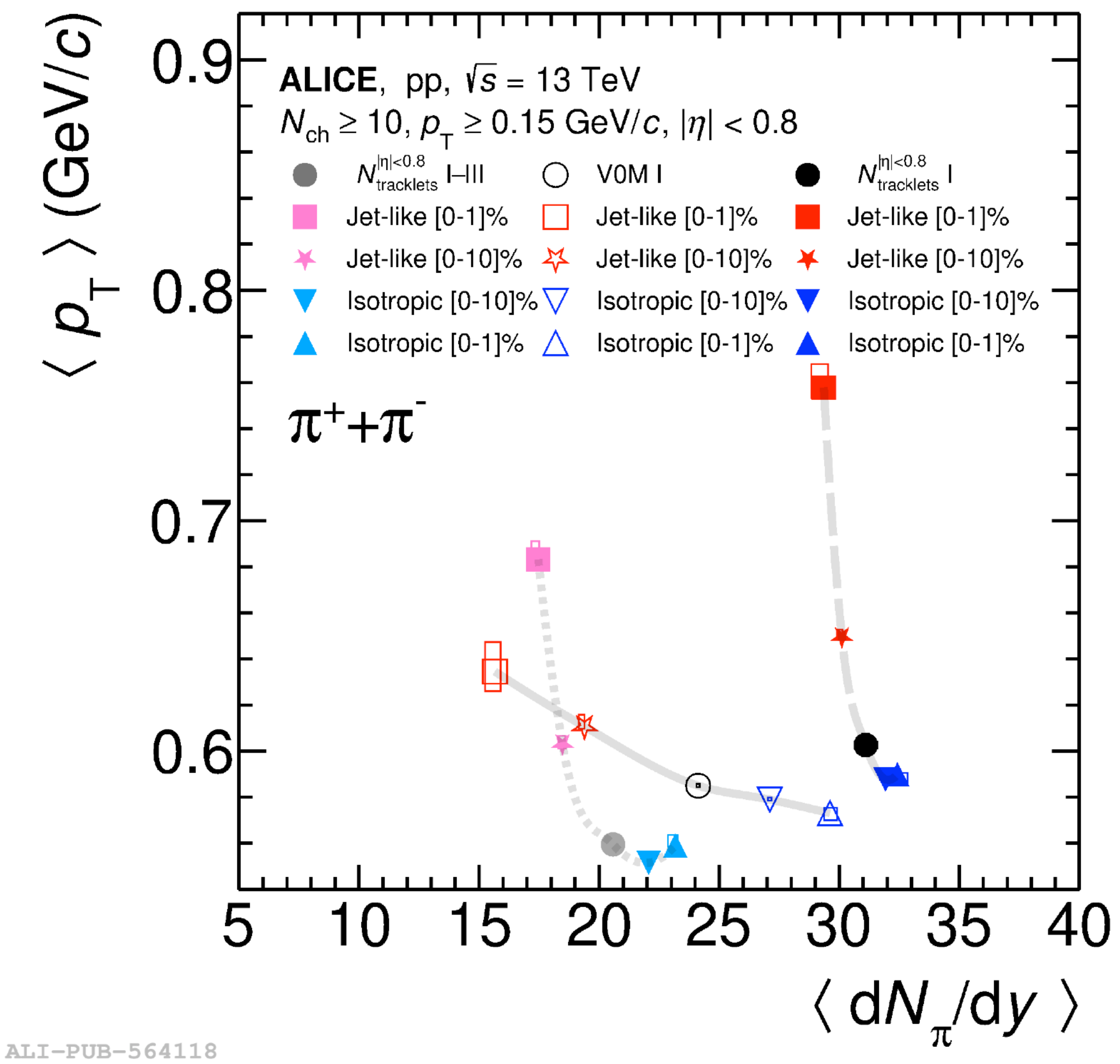
ALICE, arXiv:2310.10236

Integrated yield and mean transverse momentum vs $S_0^{p_T=1}$

$N_{\text{tracklets}}^{|\eta|<0.8}$: Mid-rapidity multiplicity selection
V0M: Forward-rapidity multiplicity selection

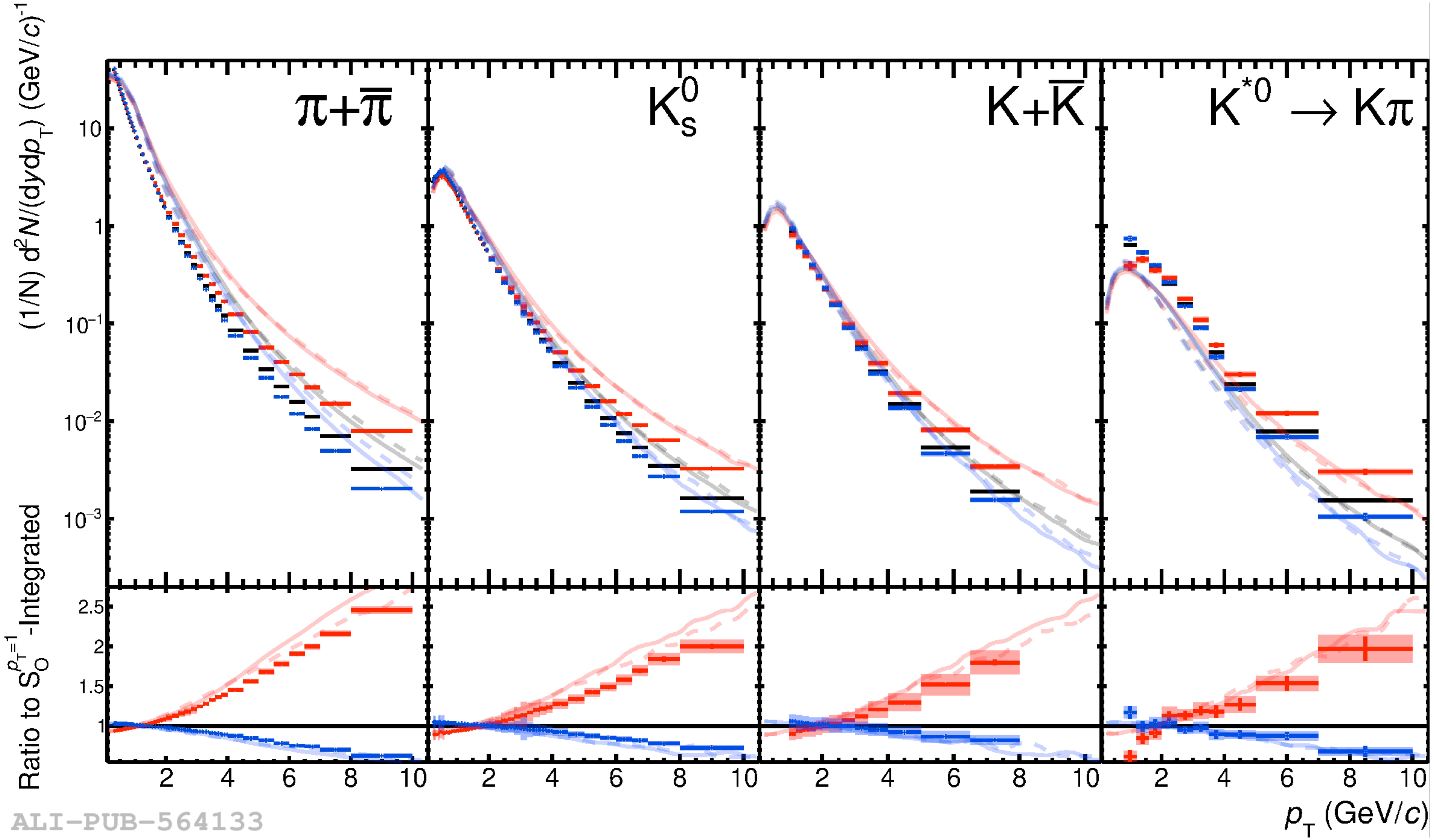
- Using mid-rapidity tracklets as an event classifier in conjunction with spherocity in data shows similar behavior as expected from studies as a function of <nMPI> in MC.
- High-multiplicity midrapidity measurements are biased towards jets -> Captured by jet-like events
- Reduced bias in isotropic events

DATA



ALICE, arXiv:2310.10236

Identified particle production vs $S_0^{p_T=1}$

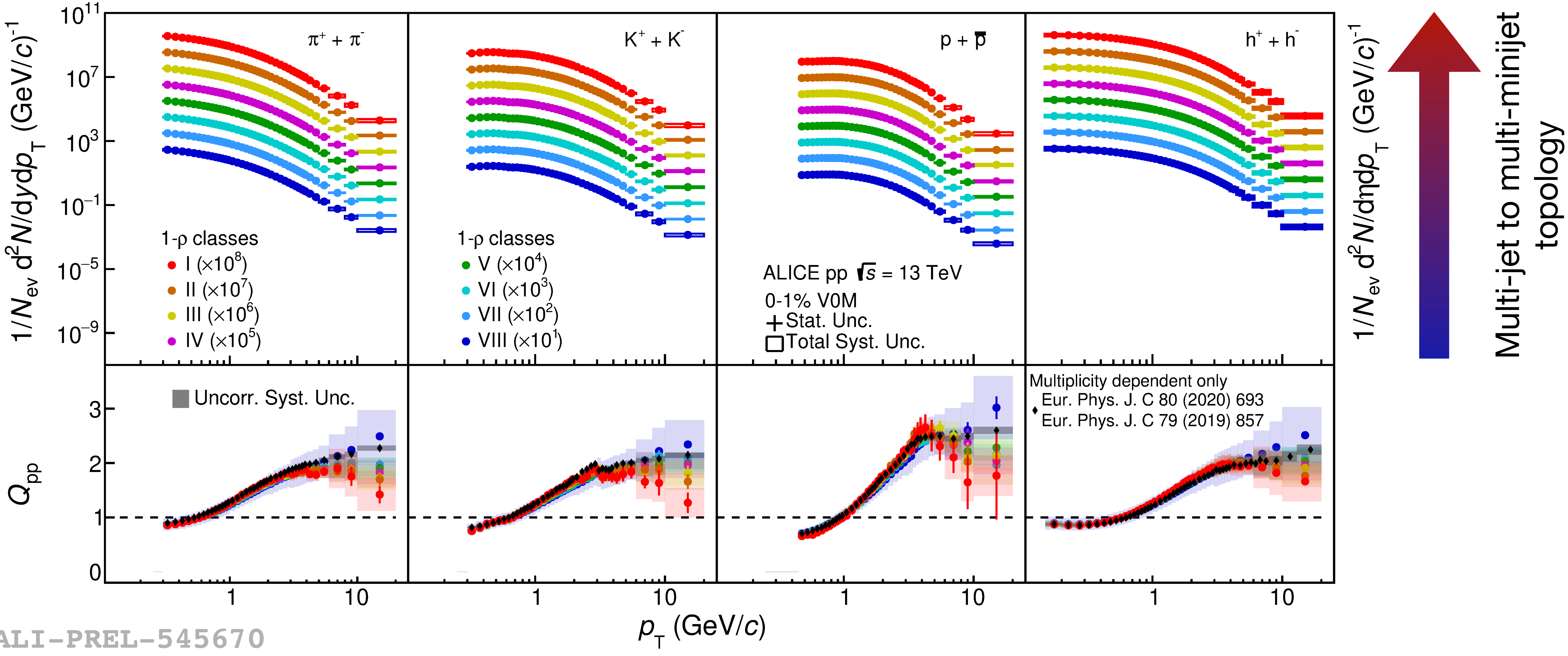


ALICE, arXiv:2310.10236

- Particle production for jet-like events is suppressed at low-p_T but enhanced at high-p_T; vice versa for isotropic events
- Indicates hardening of the spectra in Jet-like events
- Both PYTHIA Monash and Ropes describe the qualitative trends

Particle production vs charged particle flattenicity

Flattenicity + 0-1% V0M class



ALI-PREL-545670

Ratio of yields to MB:

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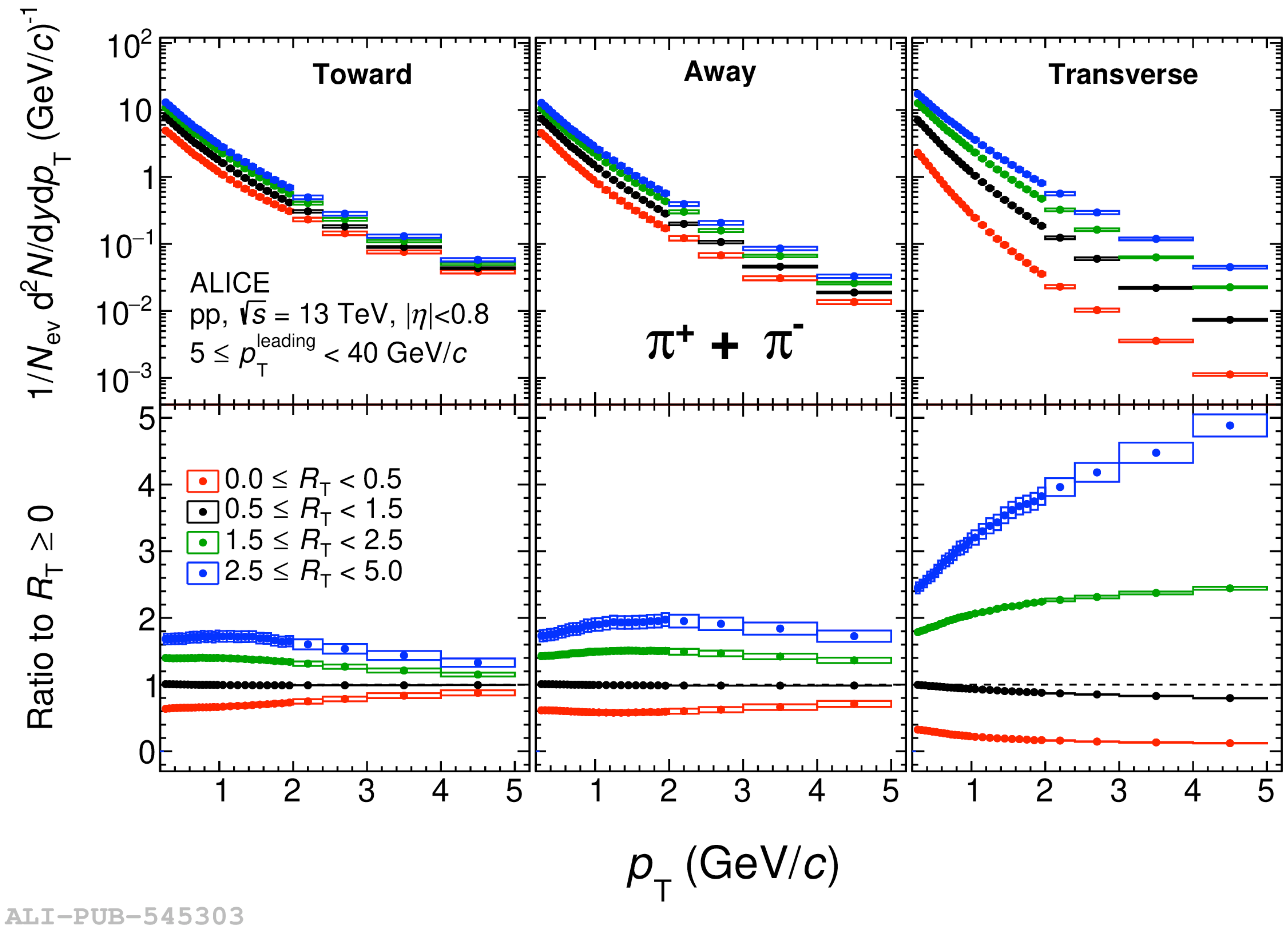
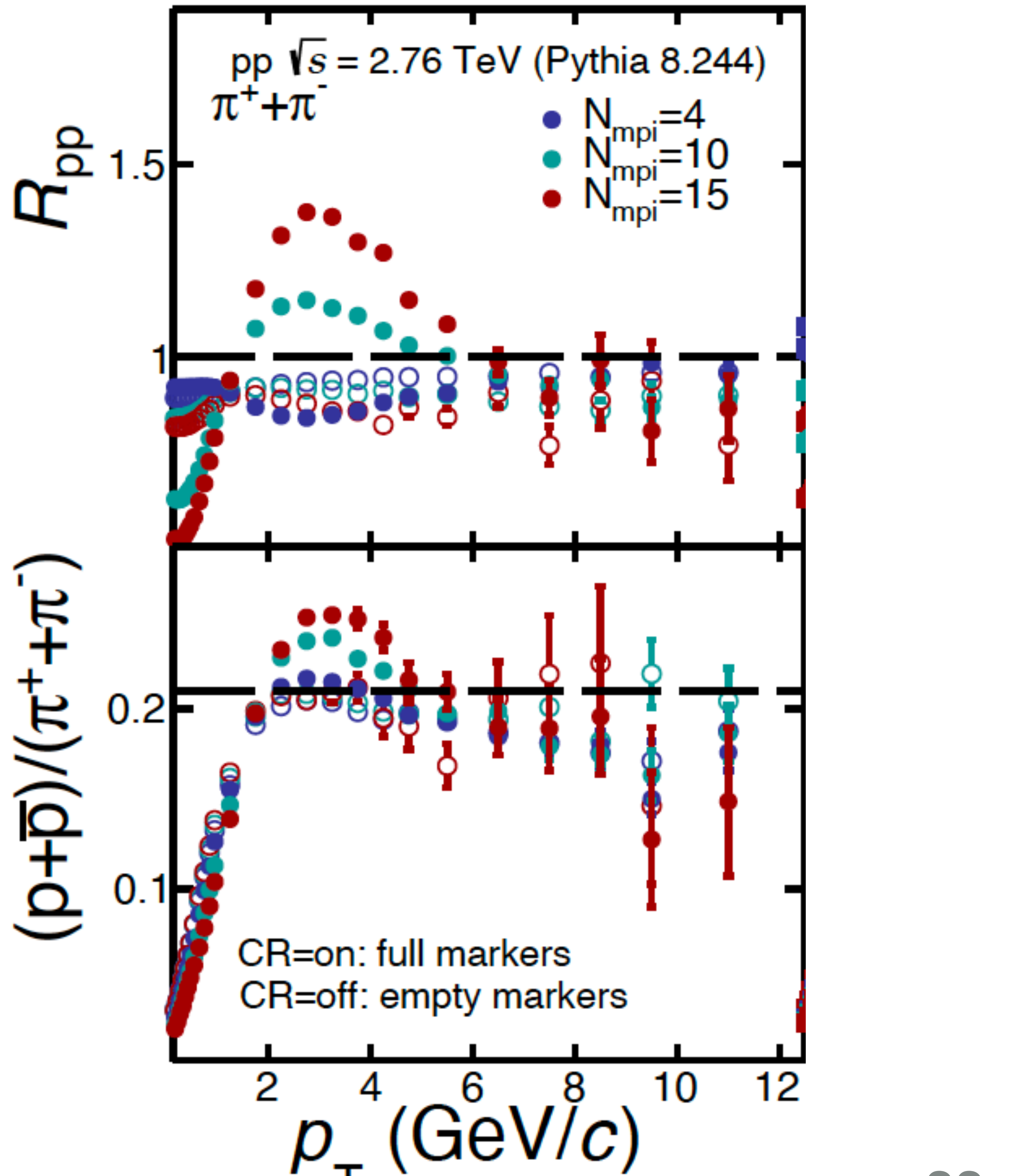
- "Bump" structure: clear development of a peak for isotropic events (flattenicity class (I), 0–1% 1-ρ)
- Mass dependency: the maximum of the peak shows a mass-dependent ordering
- Reduced selection bias: due to flattenicity selection with increasing multiplicity (not seen for V0M-only)

Identified particle production vs. R_T

ALICE, JHEP 06 (2023) 027



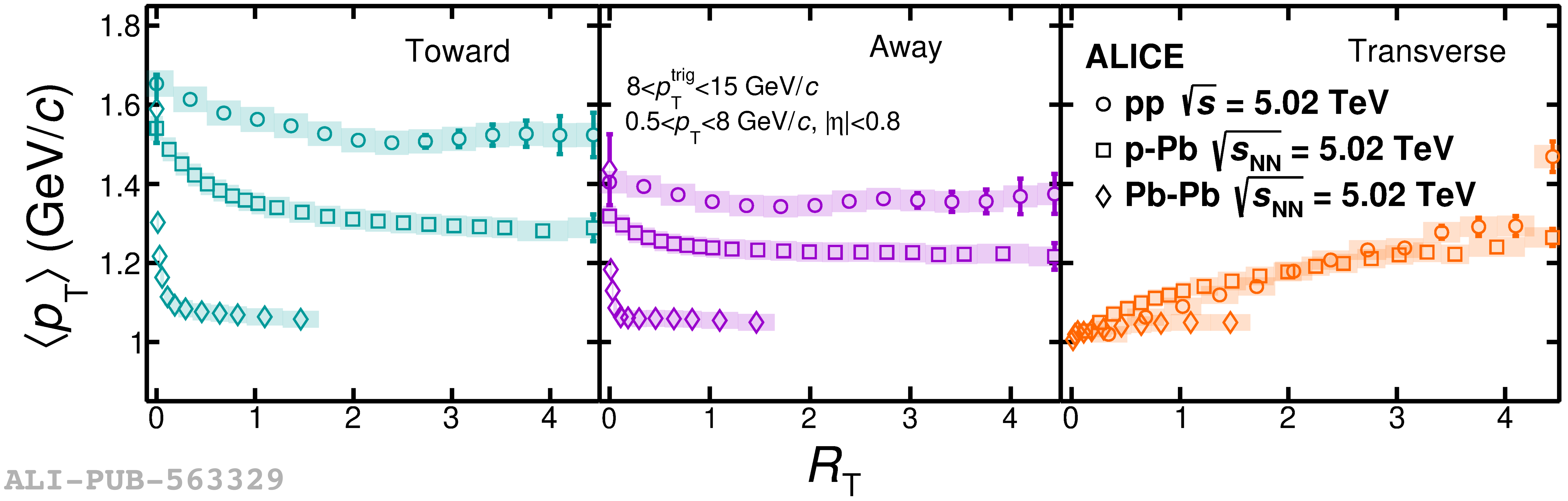
A. Ortiz, A. Paz, J. D. Romo, S.Tripathy, E. A. Zepeda, I. Bautista, Phys. Rev. D 102, 076014 (2020)



- No "bump" structure seen in these measurements → selection bias
- Explore event classifier: sensitivity to MPI with reduced selection bias

Charged particle production vs. R_T

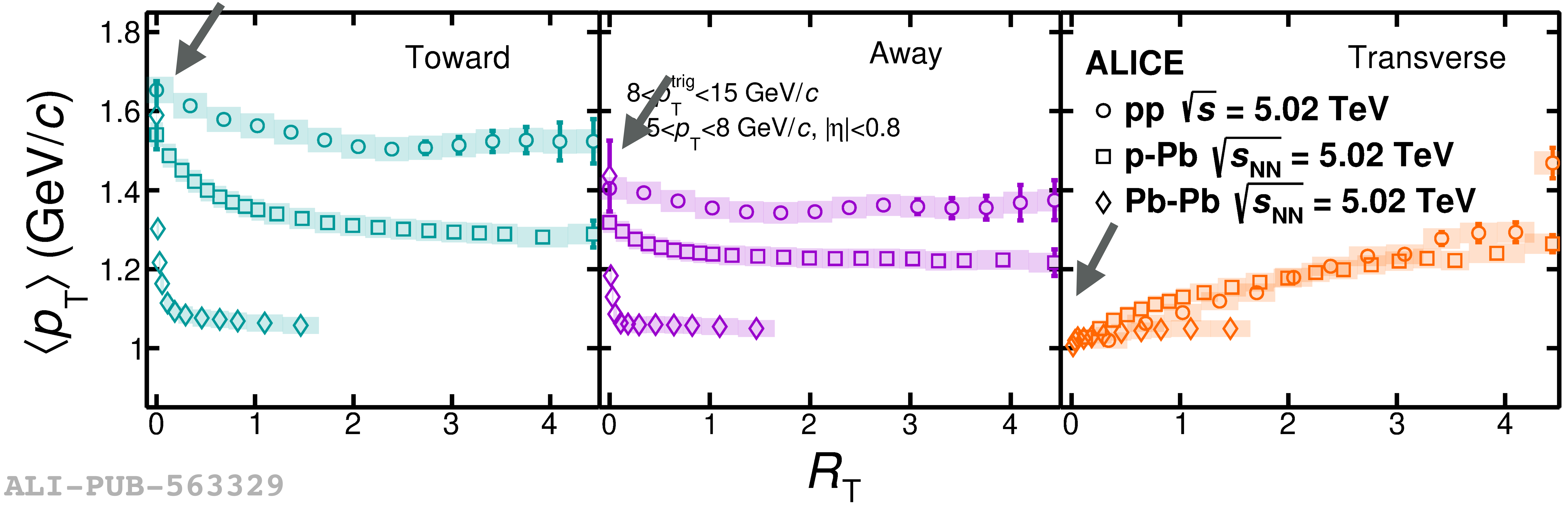
Relative Transverse activity classifier, $R_T = N_{ch}^{Transverse} / \langle N_{ch}^{Transverse} \rangle$



ALICE, arXiv:2310.07490

Charged particle production vs. R_T

Relative Transverse activity classifier, $R_T = N_{ch}^{Transverse} / \langle N_{ch}^{Transverse} \rangle$

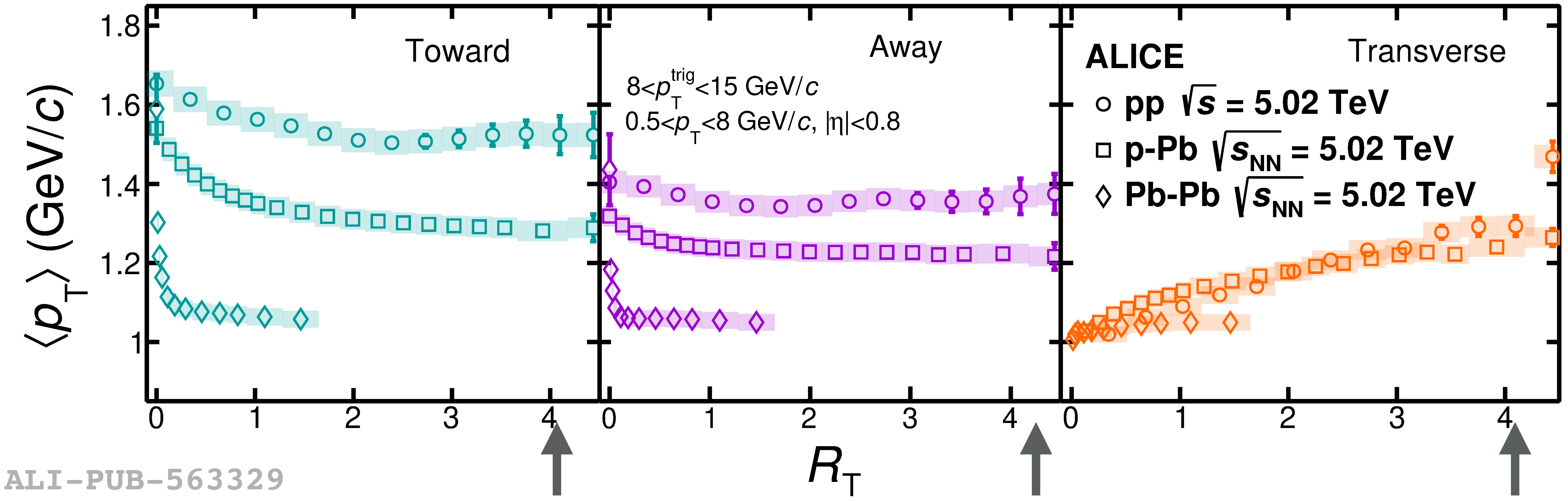


- The contribution from the jets dominate at low R_T and the values are similar for all systems, as one would naively expect for $R_T \to 0$

ALICE, arXiv:2310.07490

Charged particle production vs. R_T

Relative Transverse activity classifier, $R_T = N_{ch}^{Transverse} / \langle N_{ch}^{Transverse} \rangle$

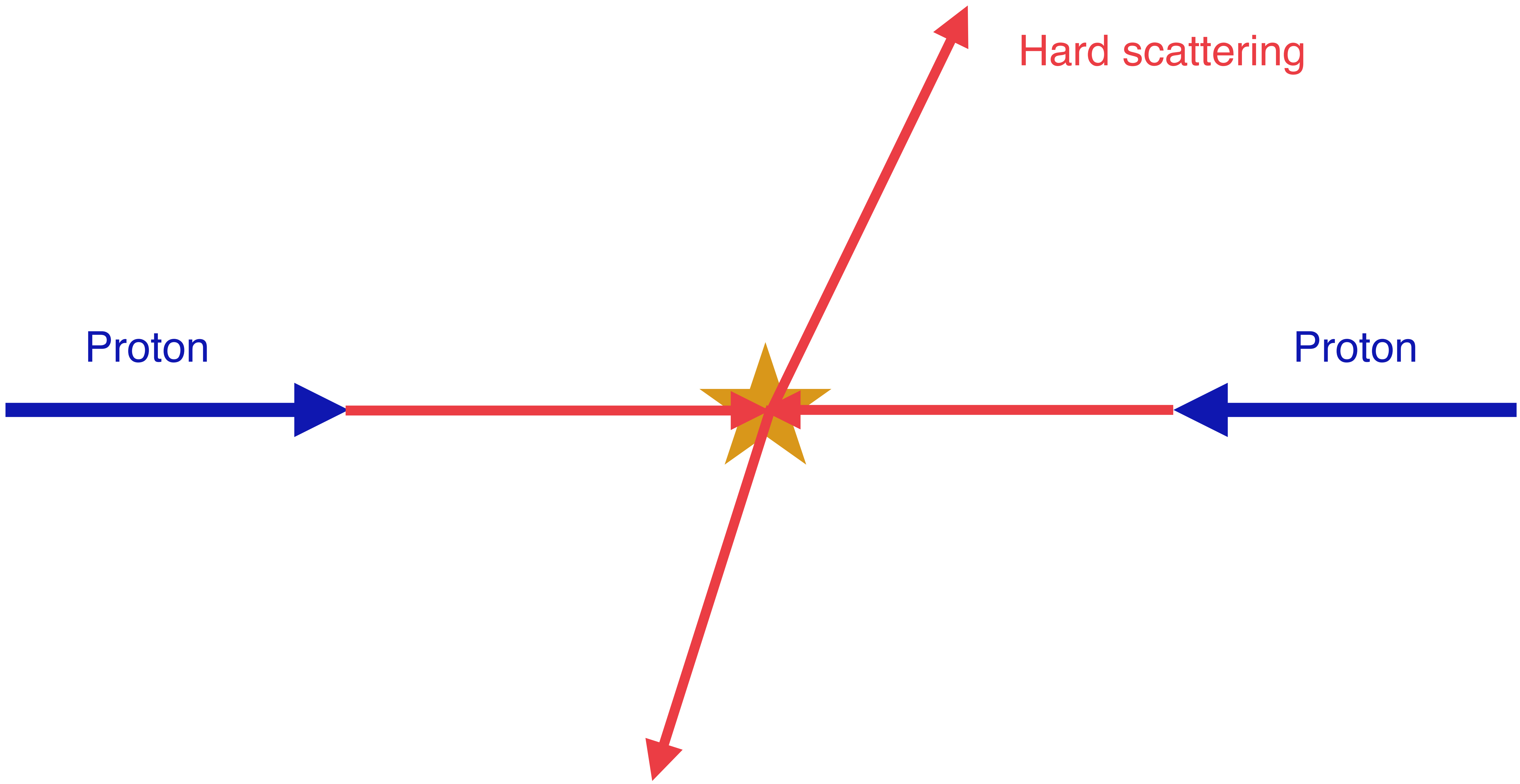


- For large R_T, the $\langle p_T \rangle$ approaches similar values in all three topological regions for a given system: dominant UE contribution

ALICE, arXiv:2310.07490

Hypothetical picture of a pp collision

Hard scattering: perturbative QCD



A basic PYTHIA8 picture

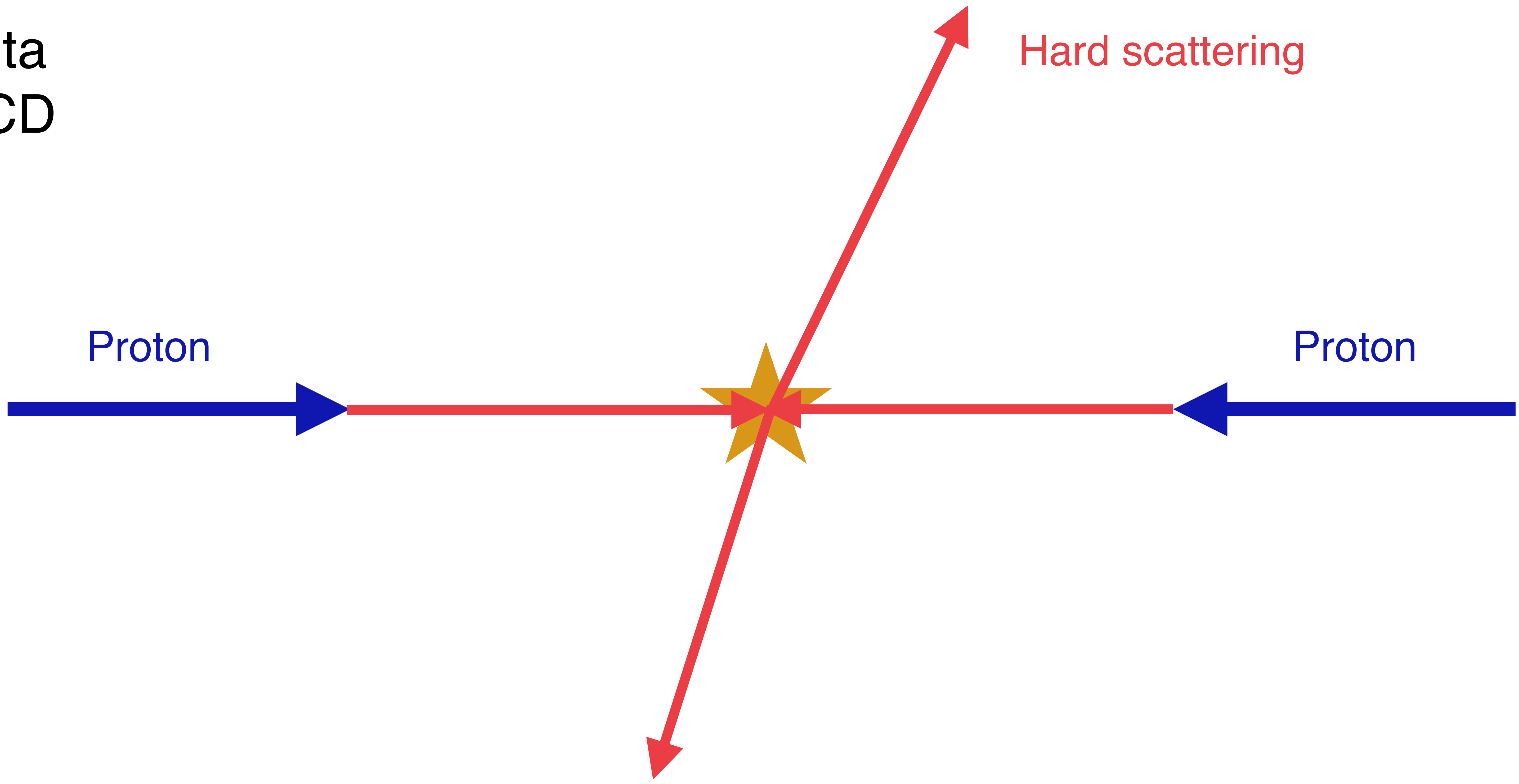
Hypothetical picture of a pp collision

Hard scattering: perturbative QCD

Soft QCD processes: low transverse momenta
→ non-perturbative QCD

Includes:

- Underlying Event (UE)



A basic PYTHIA8 picture

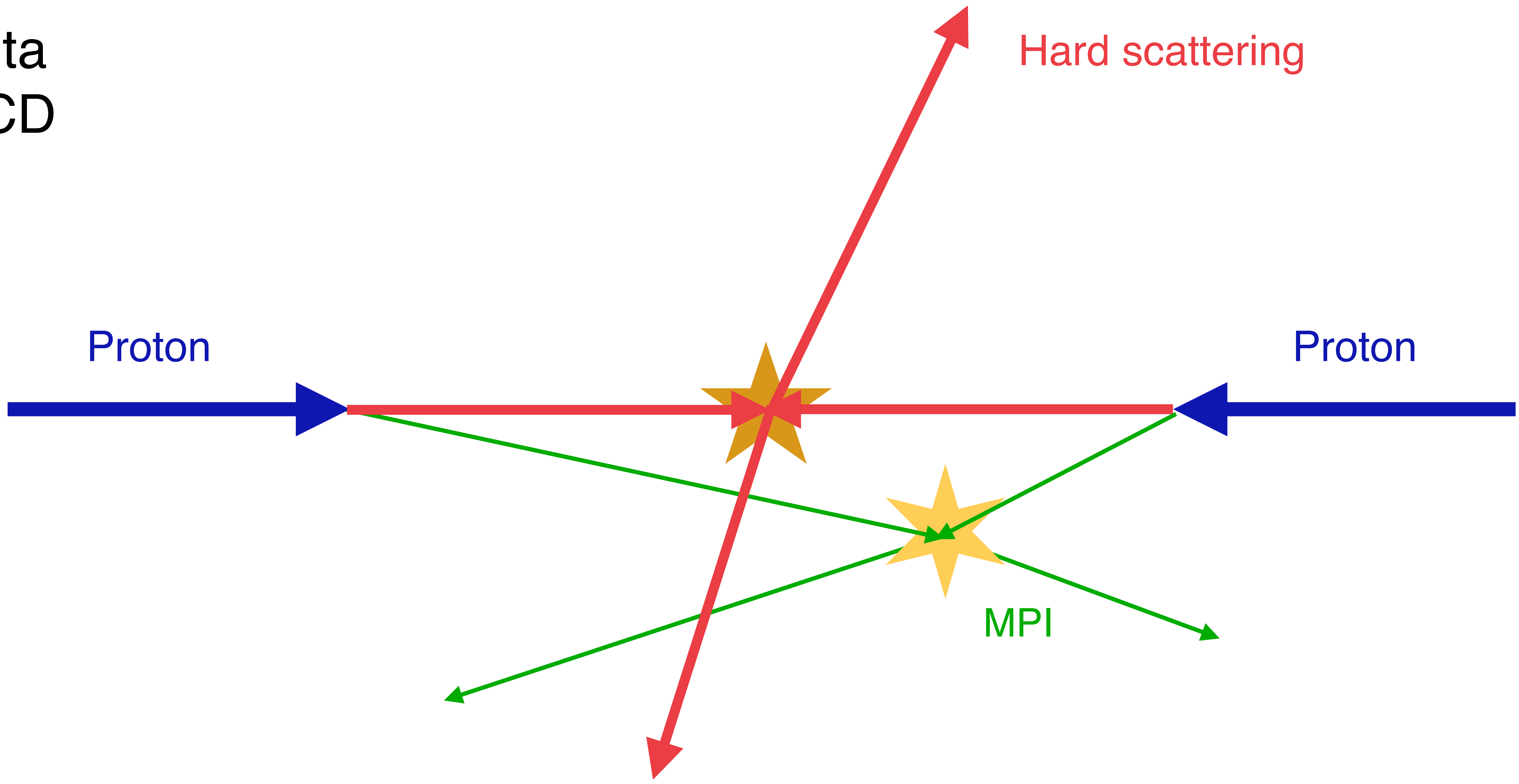
Hypothetical picture of a pp collision

Hard scattering: perturbative QCD

Soft QCD processes: low transverse momenta
→ non-perturbative QCD

Includes:

- Underlying Event (UE)
  - Multiparton interactions (MPI)



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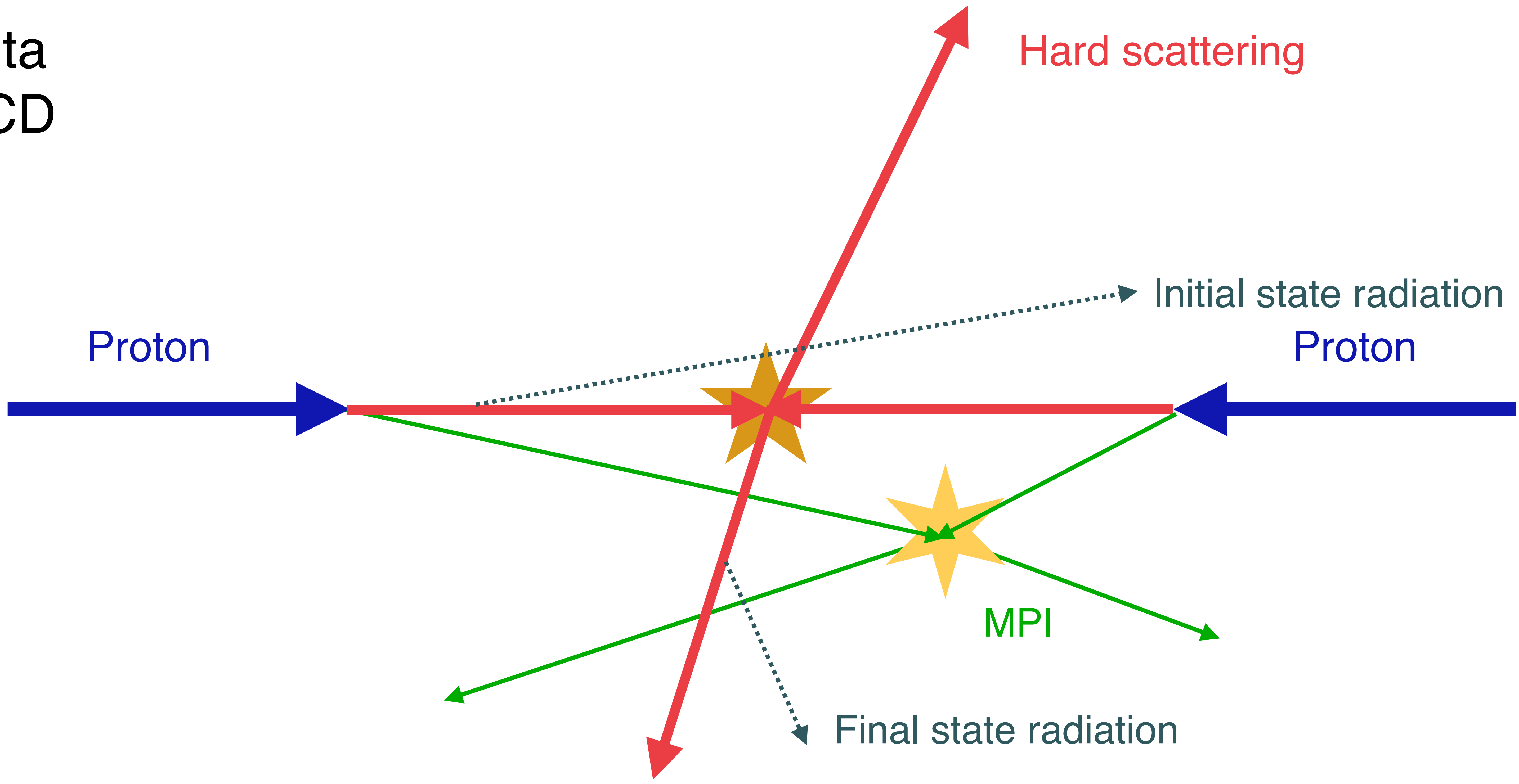

A basic PYTHIA8 picture

Hypothetical picture of a pp collision

Hard scattering: perturbative QCD

Soft QCD processes: low transverse momenta → non-perturbative QCD

Includes:

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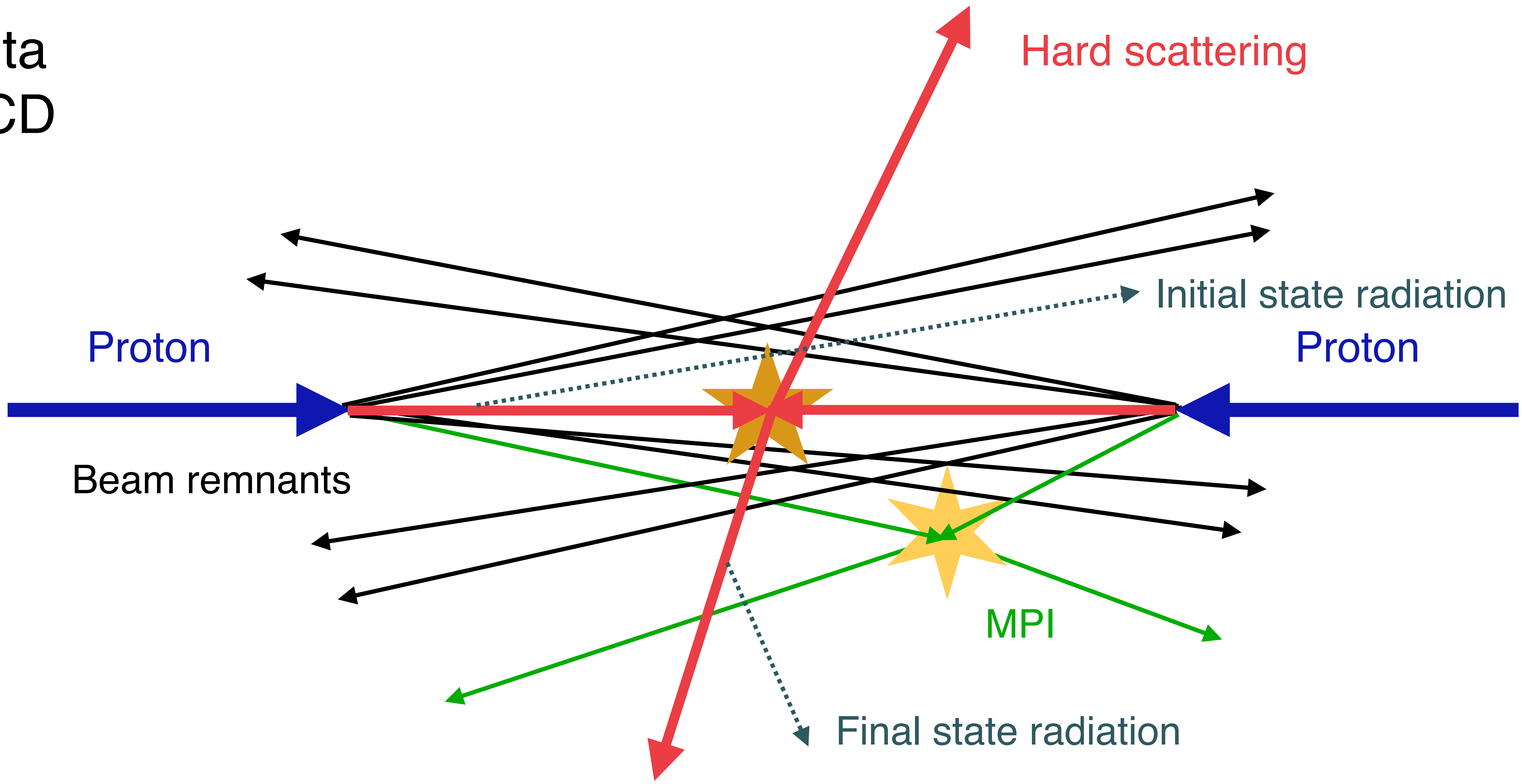
  - Multiparton interactions (MPI)
  - Initial- and final-state radiation
  - Beam remnants



A basic PYTHIA8 picture

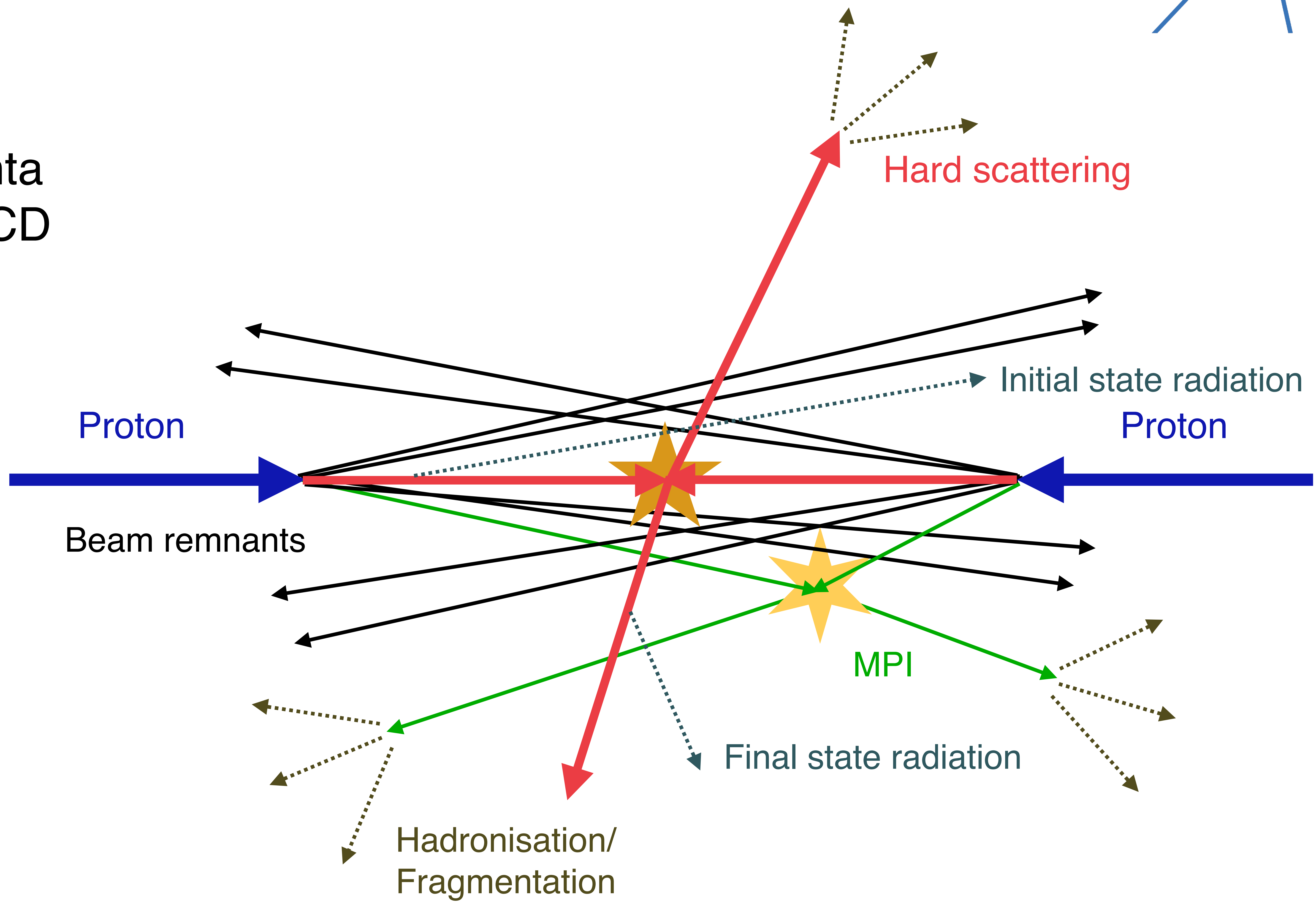
Hypothetical picture of a pp collision

Hard scattering: perturbative QCD

Soft QCD processes: low transverse momenta → non-perturbative QCD

Includes:

- Underlying Event (UE)
  - Multiparton interactions (MPI)
  - Initial- and final-state radiation
  - Beam remnants
- Hadronisation products
- Collective effects



A basic PYTHIA8 picture

Relative transverse activity classifier

To reduce the contribution from ISR and FSR, Transverse region is further sub-divided into two regions: Trans-min and Trans-max based on minimum and maximum number of charged particles

$$R_{T,min} = N_{ch}^{T,min} / \langle N_{ch}^{T,min} \rangle$$

$$R_{T,max} = N_{ch}^{T,max} / \langle N_{ch}^{T,max} \rangle$$

G. Bencedi, A. Ortiz, and A. Paz,
Phys. Rev. D 104, (2021) 016017