Small systems: an open issue in heavy-ion collisions

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Outline

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- The ALICE detector
- Heavy-ion-like effects in pp and p-Pb collisions
- Selection biases in small systems
- Flattenicity
- ALICE results
- Conclusions

ALICE in Run 2

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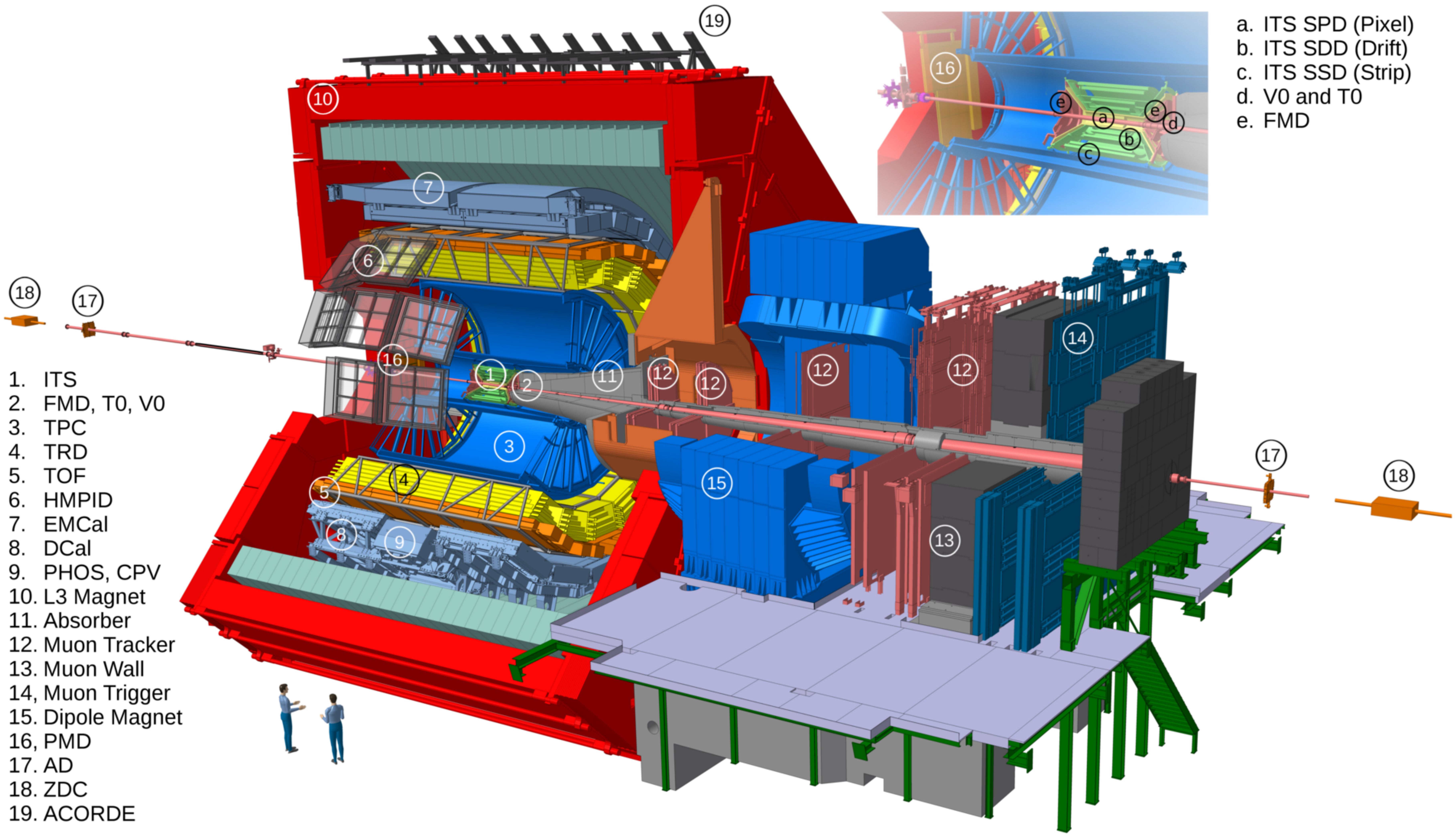

a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD

1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14, Muon Trigger
15. Dipole Magnet
16, PMD
17. AD
18. ZDC
19. ACORDE

ALICE in Run 2

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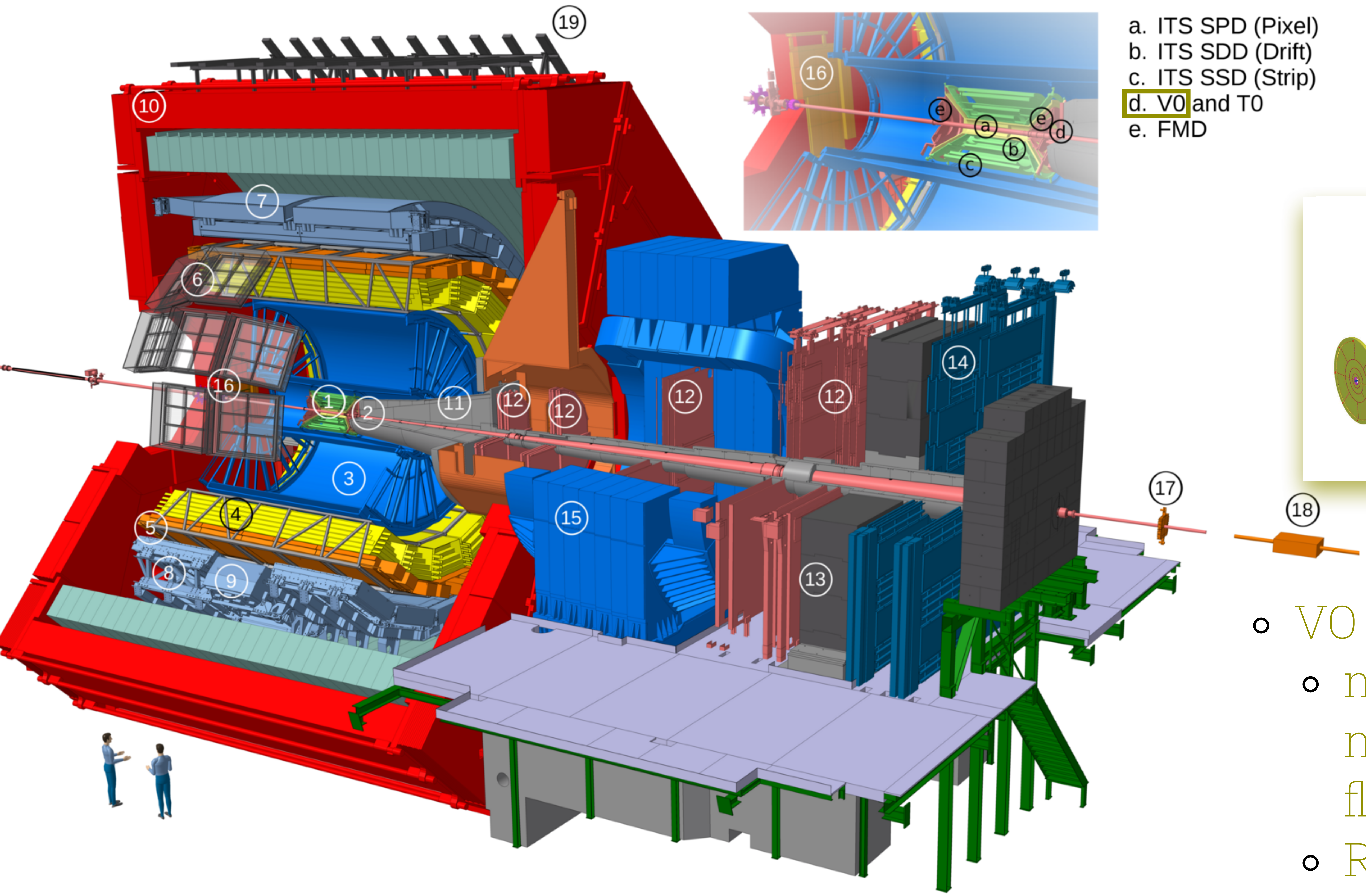

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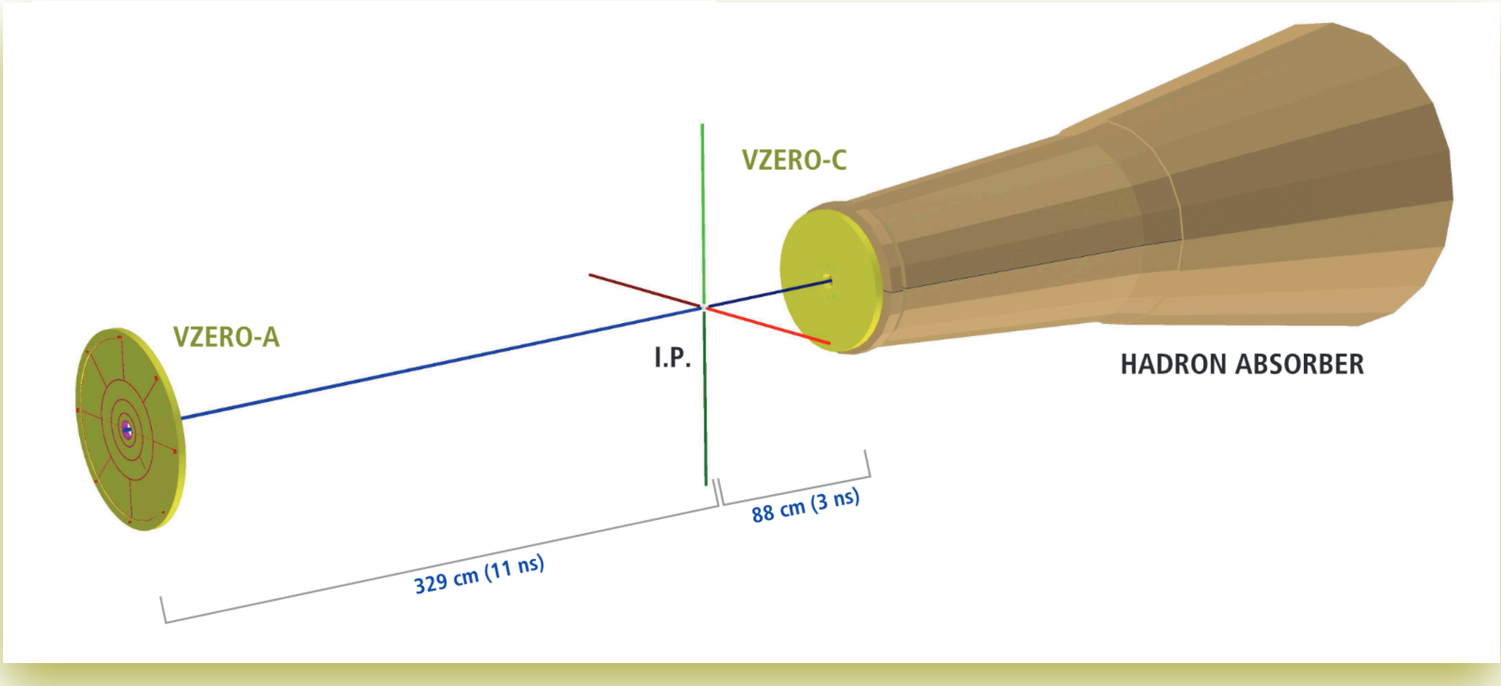
VOA: $2.8 < \eta < 5.1$

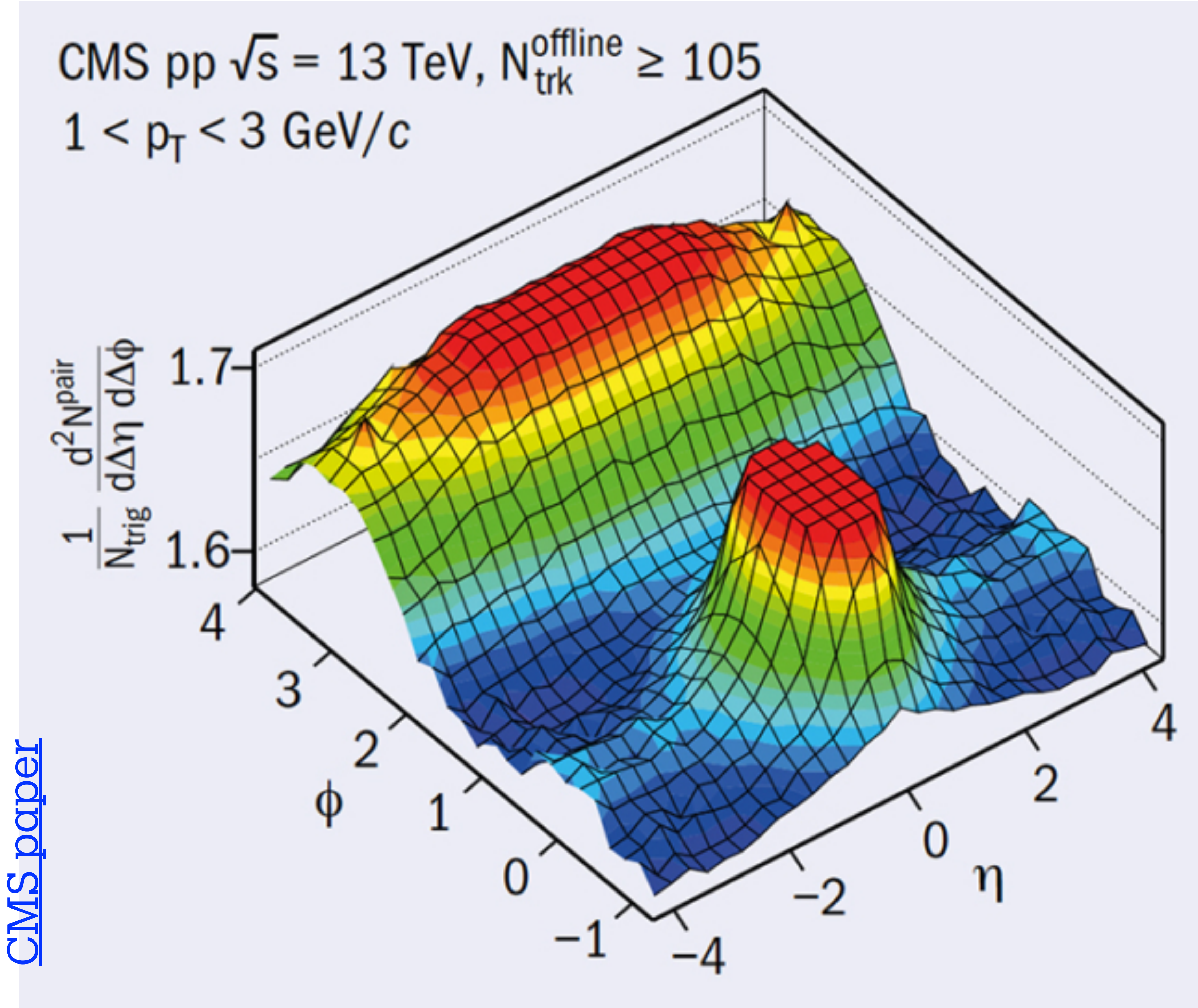
VOC: $-3.6 < \eta < -1.7$



- V0 detector:
  - minimum-bias (MB) trigger, multiplicity (V0M), and flattenicity
  - Rejection of beam induced background

- TPC: tracking and particle identification (PID) using dE/dx in gas
- TOF: Particle velocity (PID)

sQGP in pp collisions?



CMS paper

Long range angular correlations in low- and high-multiplicity (HM) pp collisions ALICE. Phys. Rev. Lett. 132 (2024) 17, 172302

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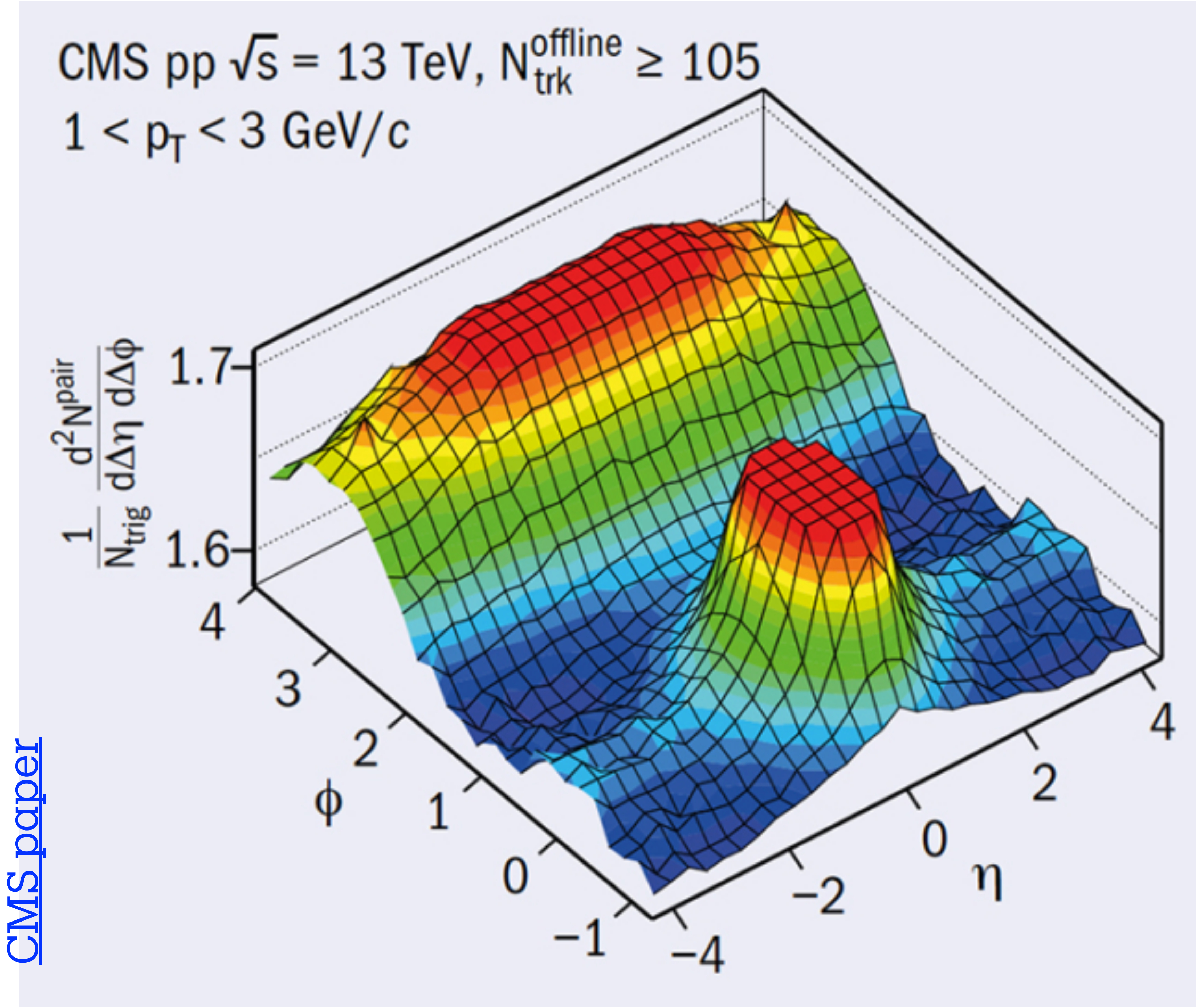

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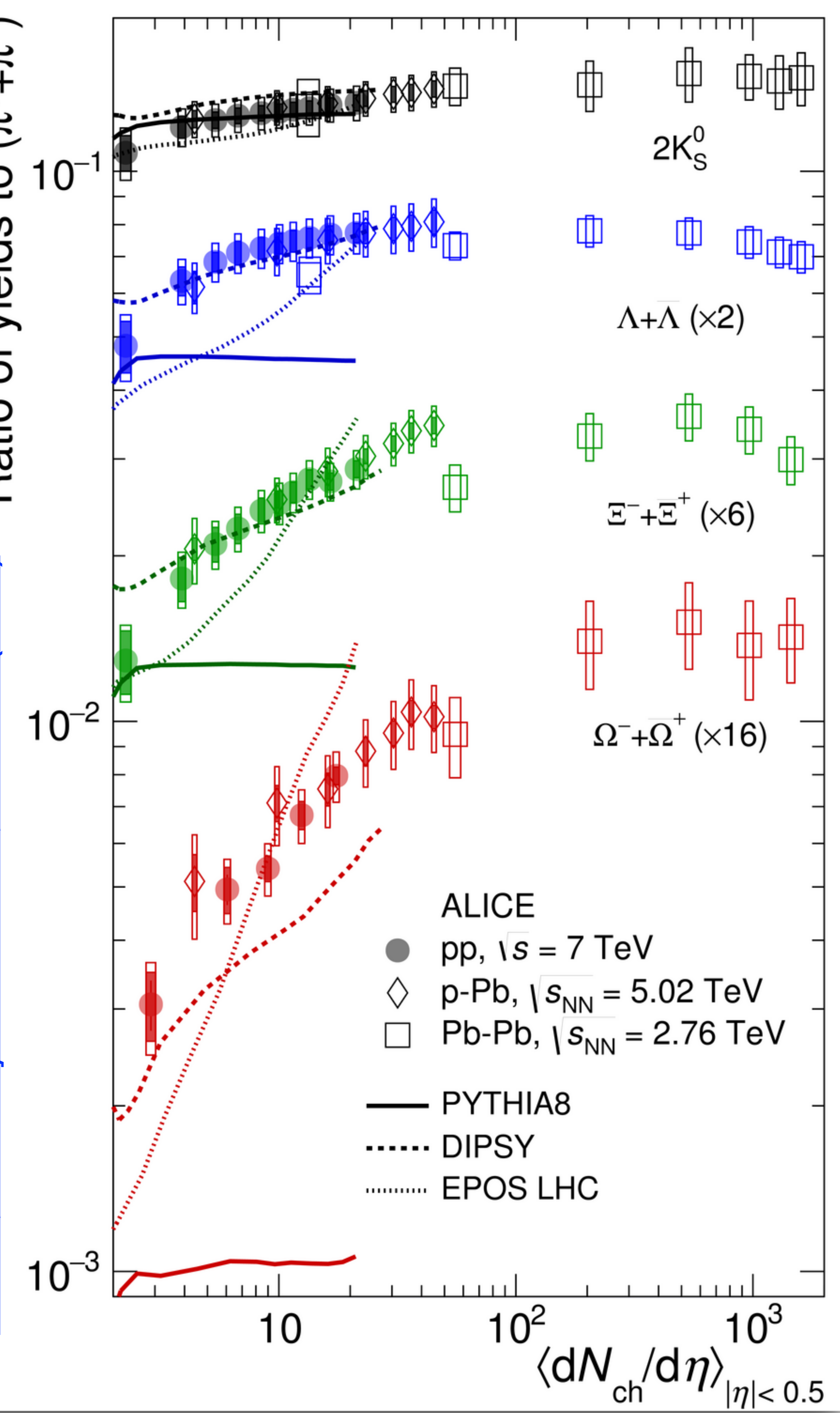
Strangeness enhancement



ALICE, Nat. Phys. volume 13, 535-539 (2017)

sQGP in pp collisions?

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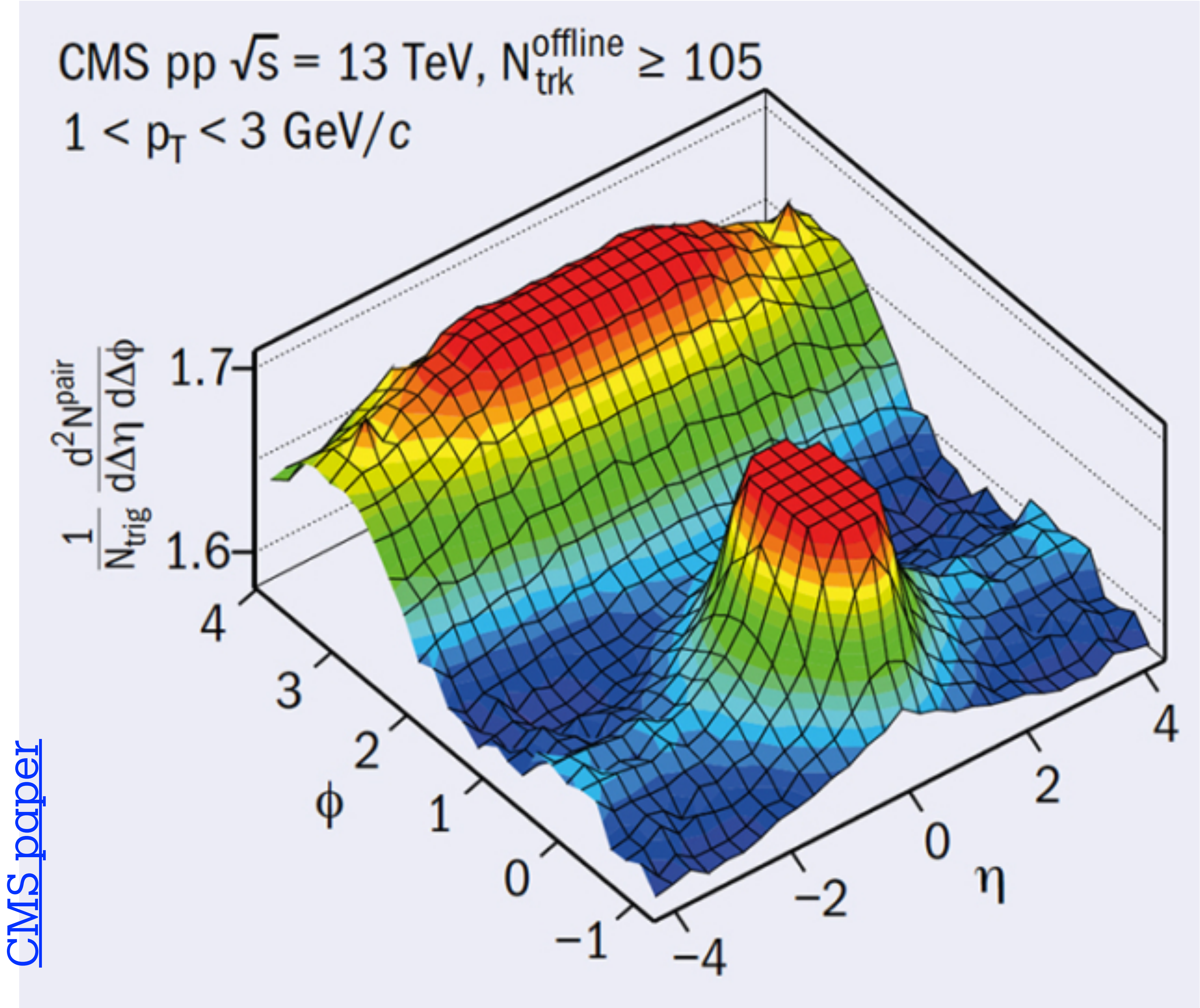

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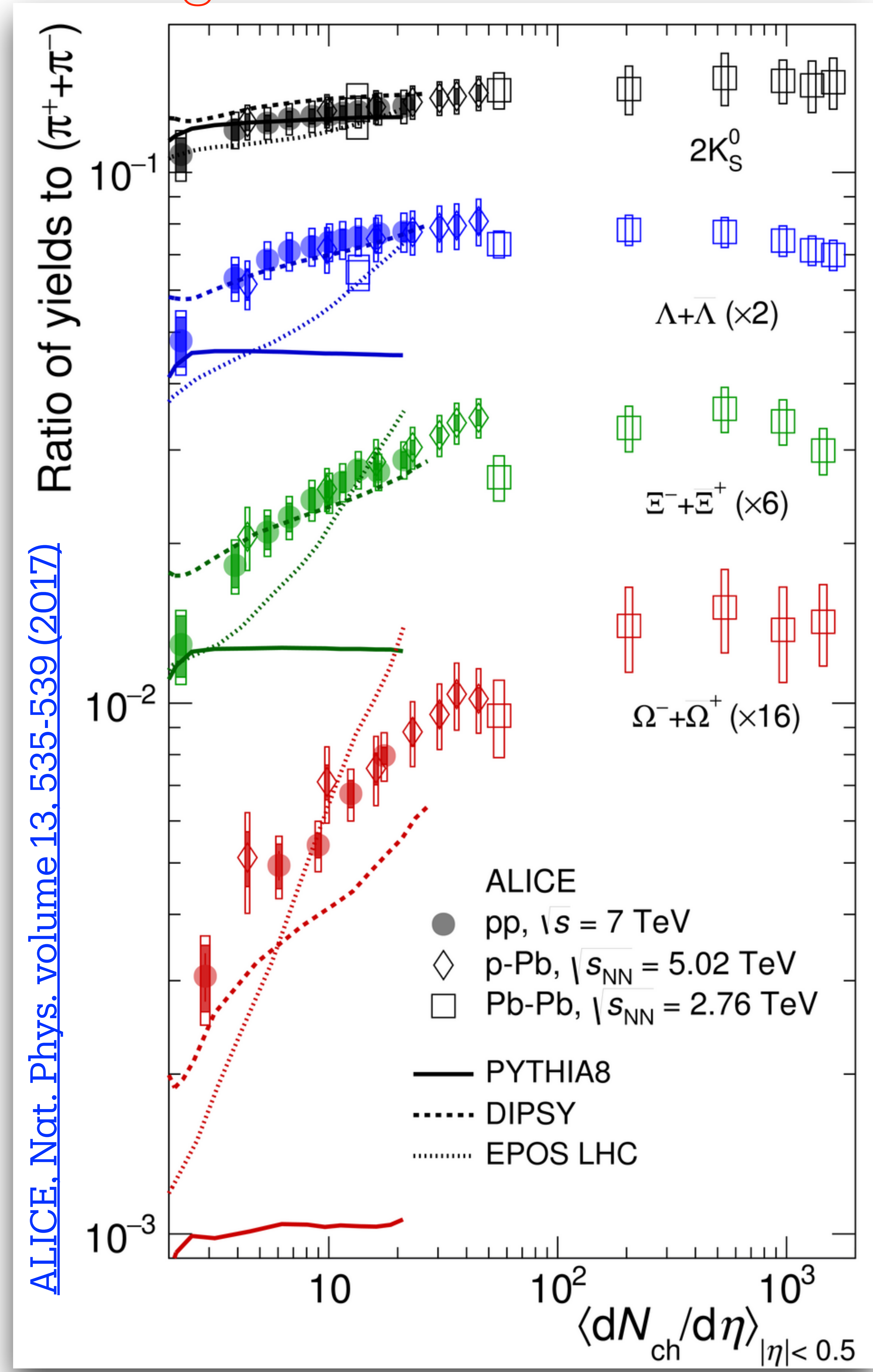
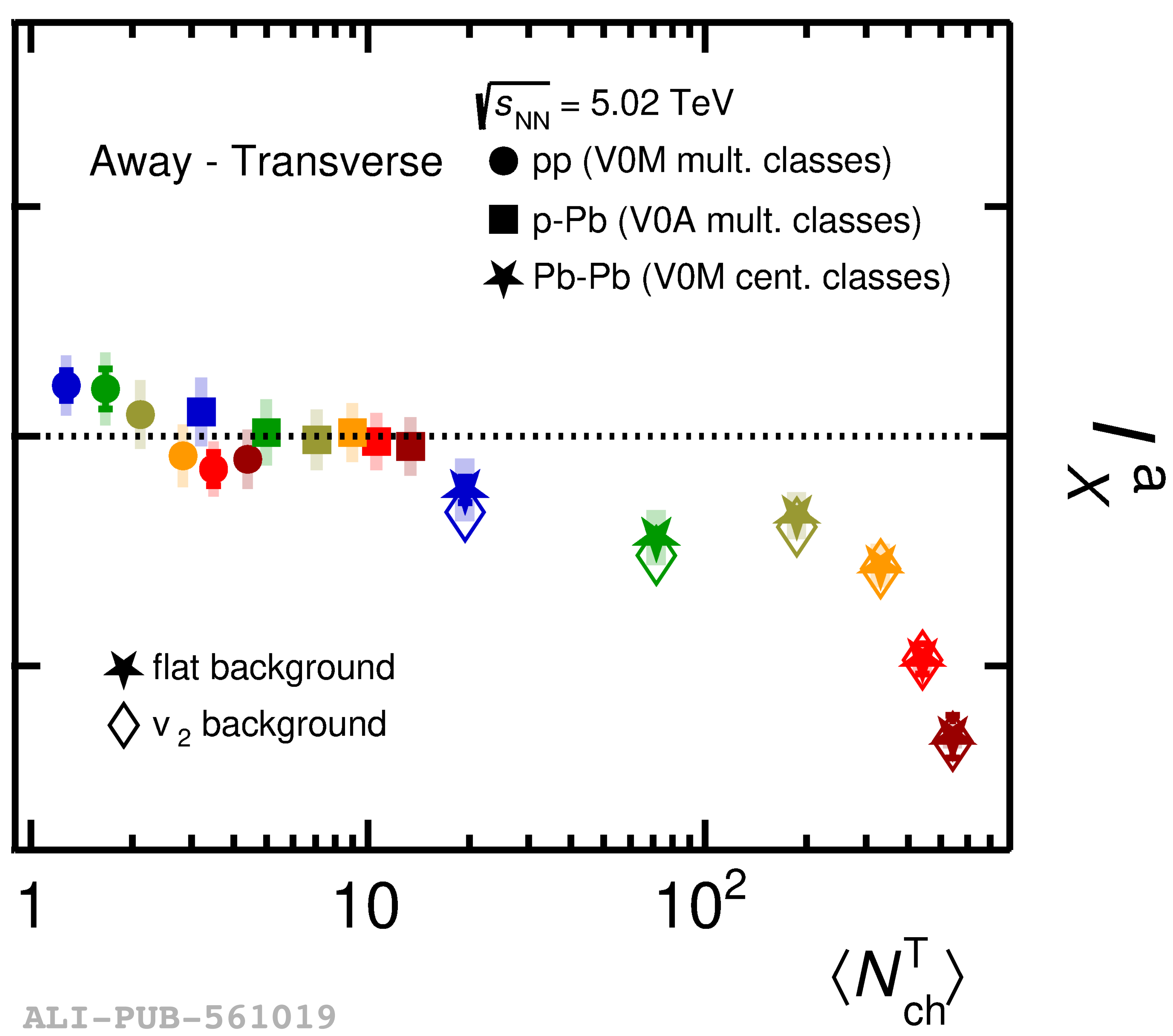


ALICE, Nat. Phys. volume 13, 535-539 (2017)

Jet quenching?



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

pp and p-Pb collisions: no hint of jet quenching

Bias due to local mult. fluctuations

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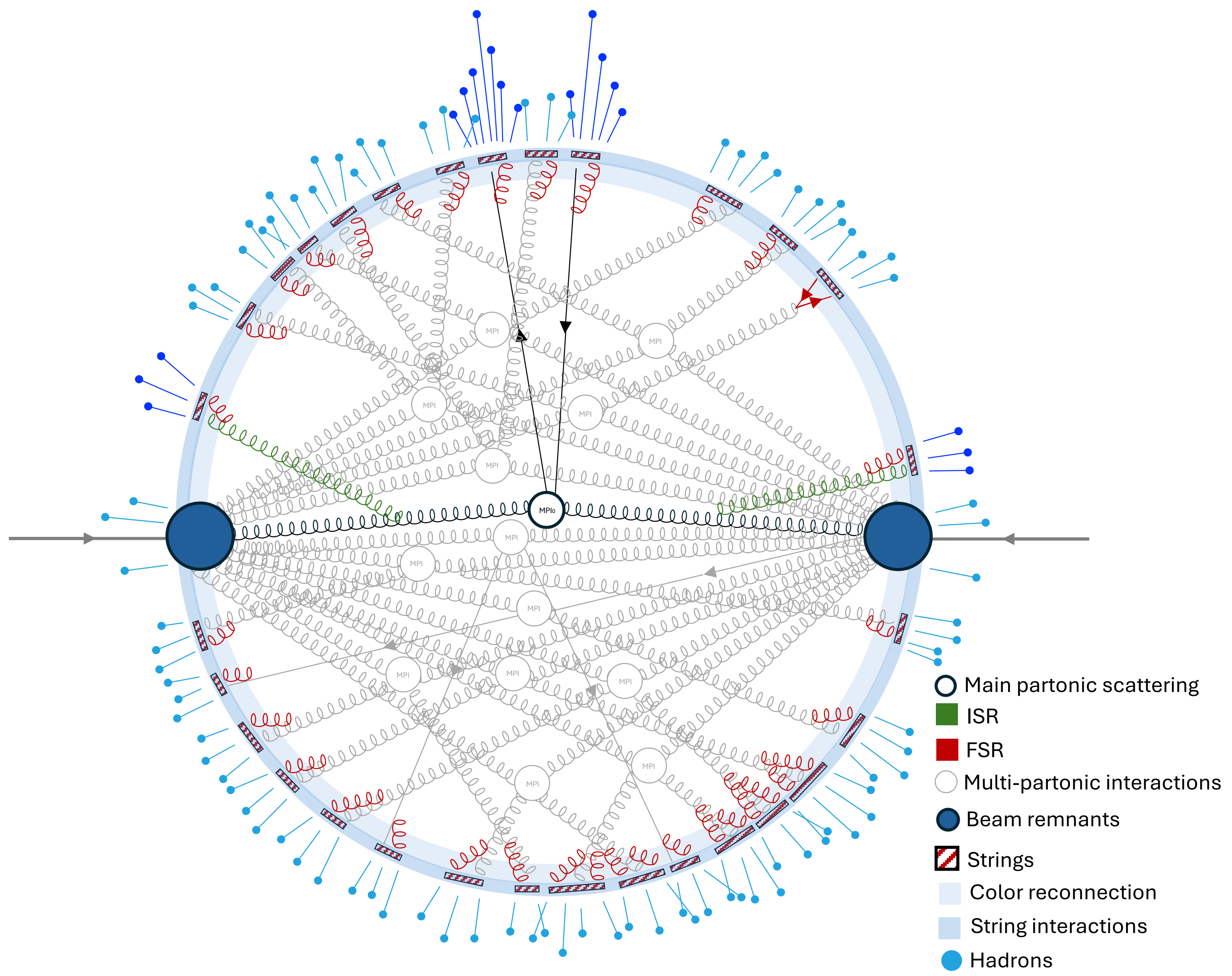

Multiparton interactions (MPI): more than one parton-parton scattering occurring in the same pp collision. Color reconnection (CR) produce collective-like effects

Bias due to local mult. fluctuations

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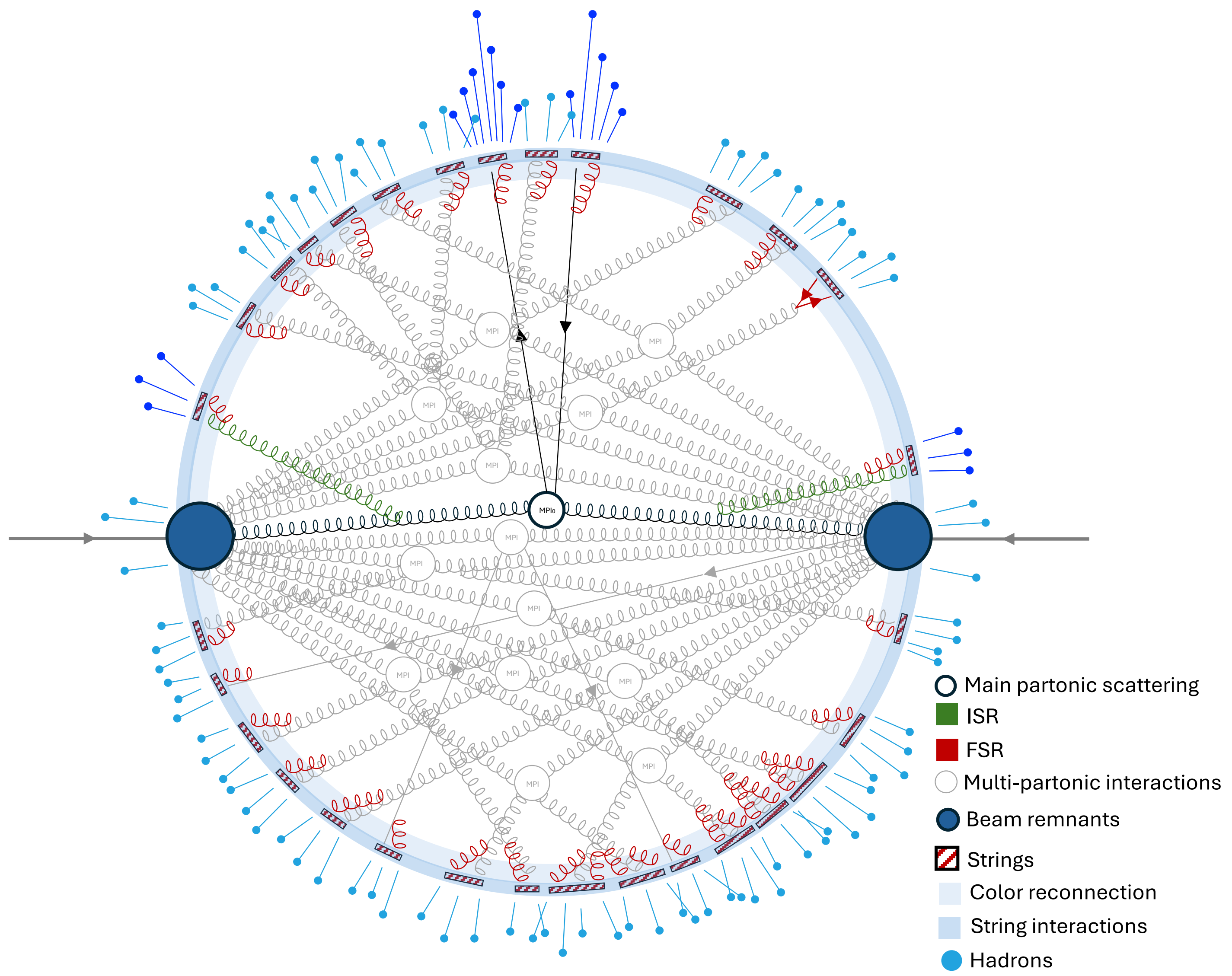
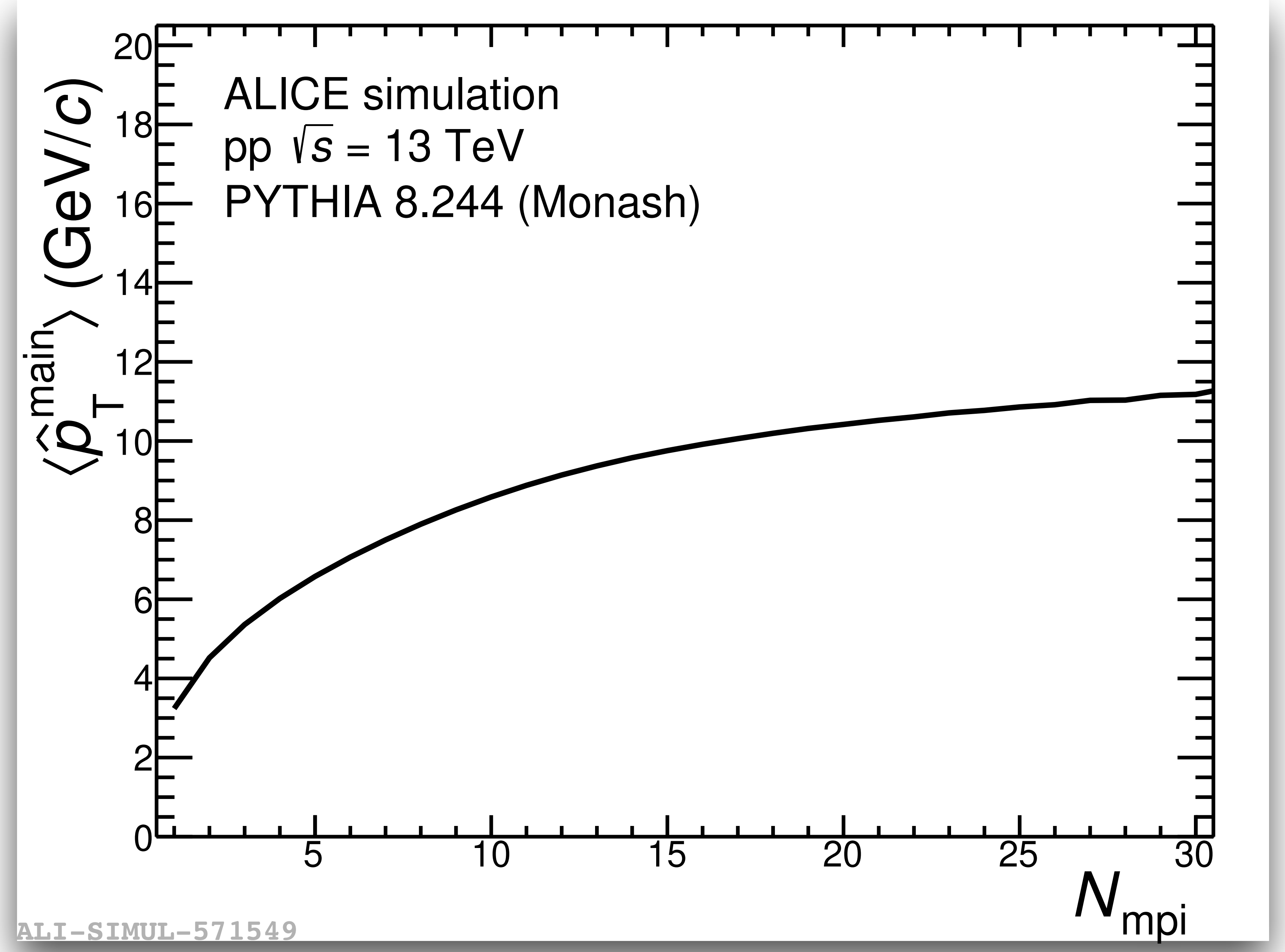


The more central the pp collision, the higher the probability to find a high-p_{T} parton ($\hat{p}_{T}^{main}$)



Bias due to local mult. fluctuations

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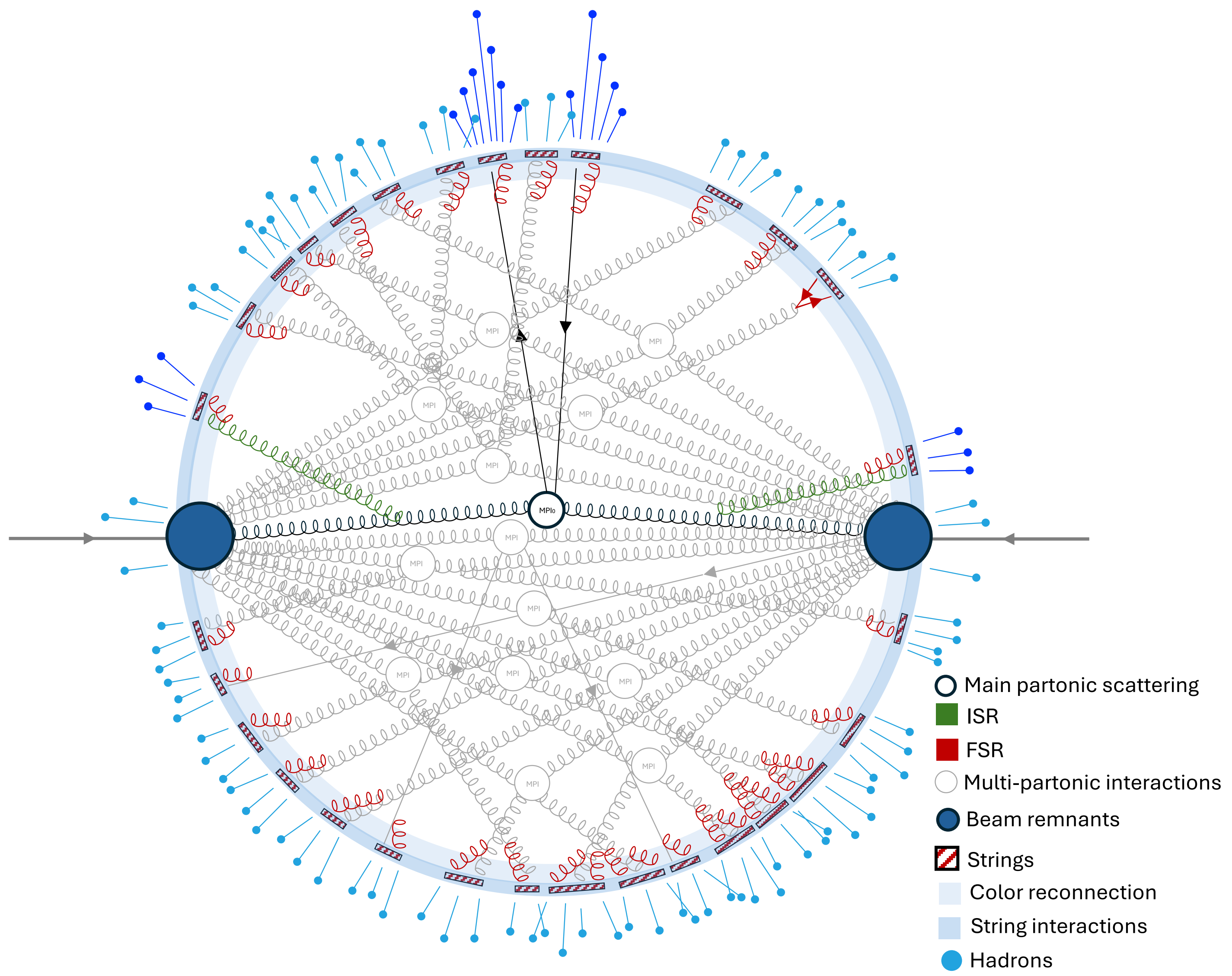

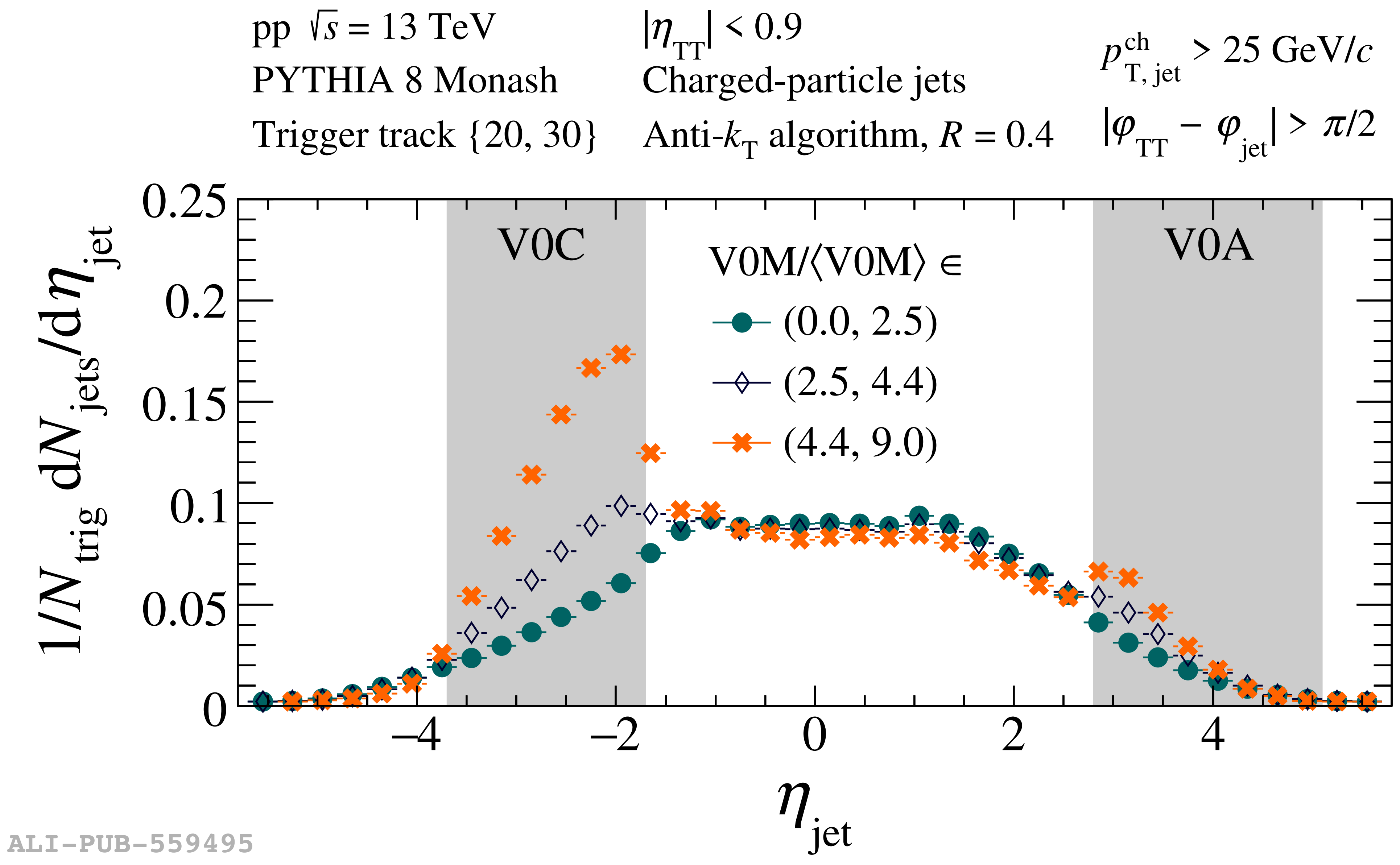

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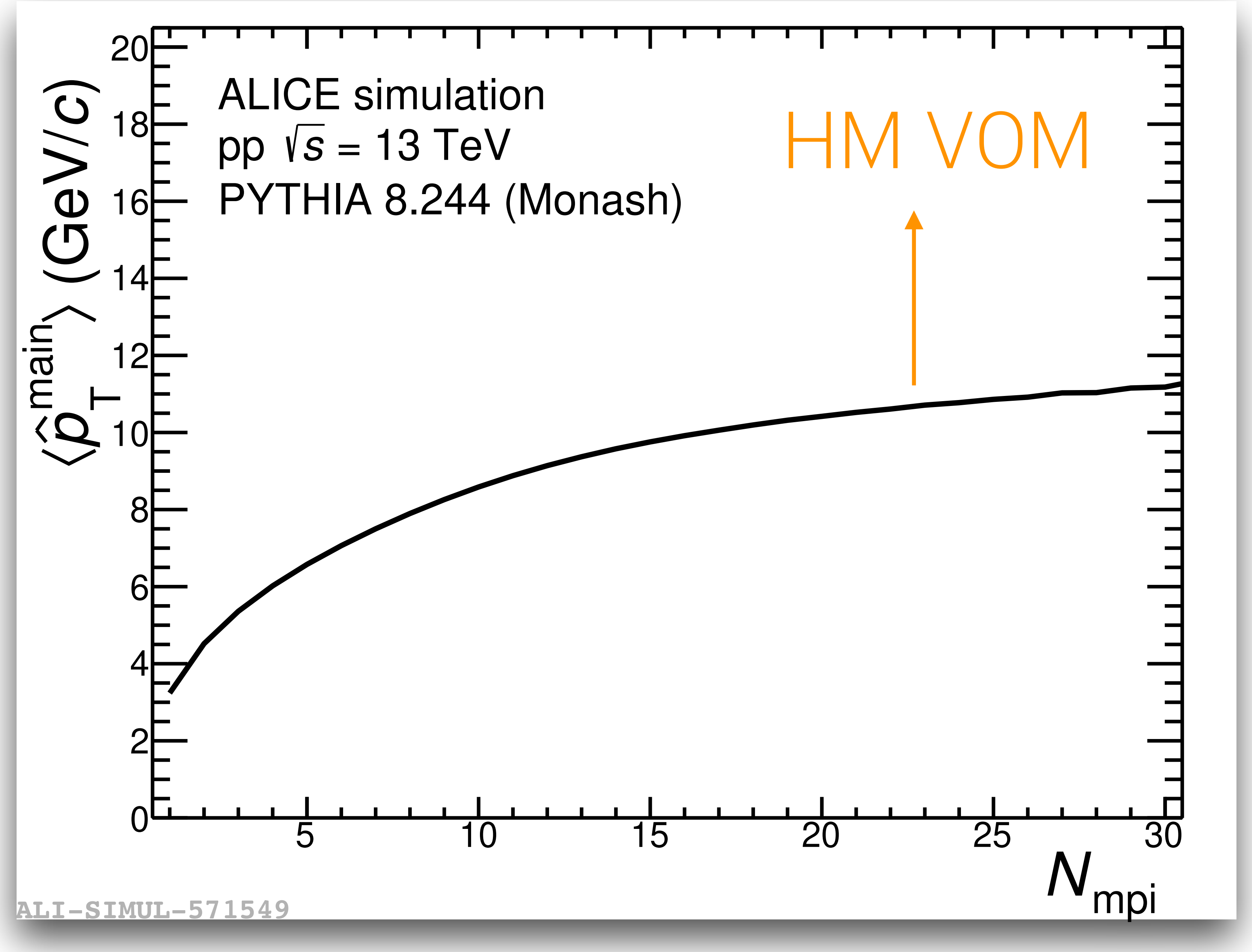

The high-V0M multiplicity class selects pp collisions with jets in the forward detector

ALICE, arXiv:2309.03788 ALICE, Phys. Lett. B 843 (2022) 137649

Flattenicity

Event-by-event selection based on the relative standard deviation of the multiplicity measured in the 64 V0 channels, $N^{(\mathrm{ch.}\,i)}$

A. Ortiz et al., Phys. Rev. D107 (2023) 7, 076012

$$\rho = \sqrt{\sum_{i}^{64} \left(N^{(\mathrm{ch}.i)} - \langle N^{(\mathrm{ch})} \rangle \right)^2 / 64^2} \bigg/ \langle N^{(\mathrm{ch})} \rangle$$

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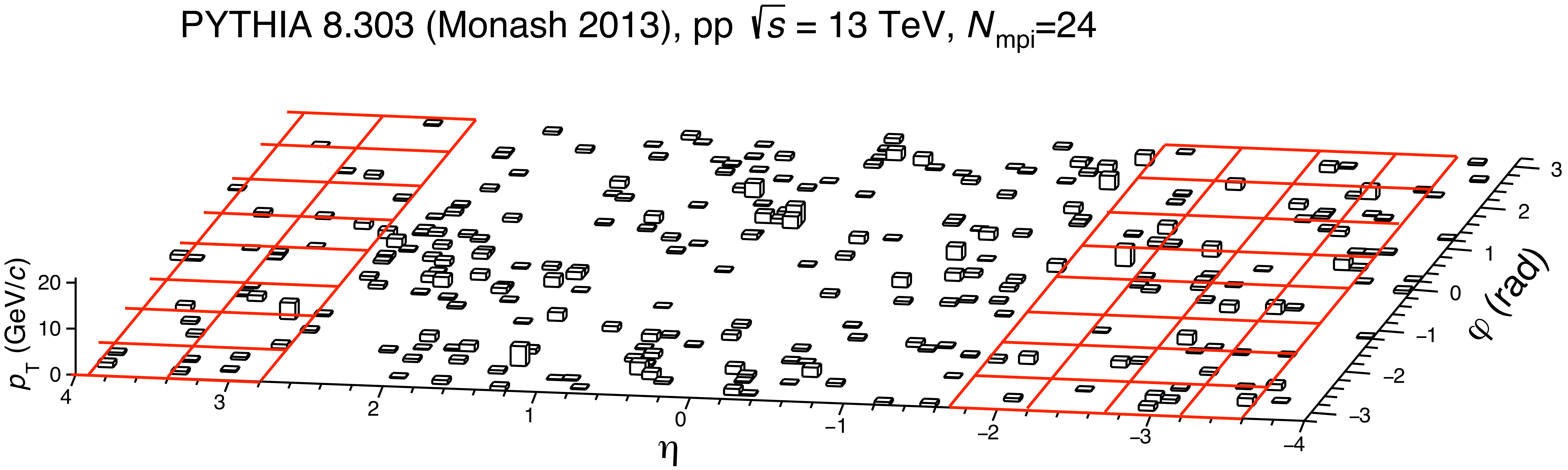

Small local $N^{(\mathrm{ch}.\,i)}$ fluctuations in the V0 acceptance: small flattenicity values

- "isotropic" distribution of particles in the V0 acceptance (large multiplicities)

Flattenicity

Event-by-event selection based on the relative standard deviation of the multiplicity measured in the 64 V0 channels, $N^{(\mathrm{ch}.\,i)}$

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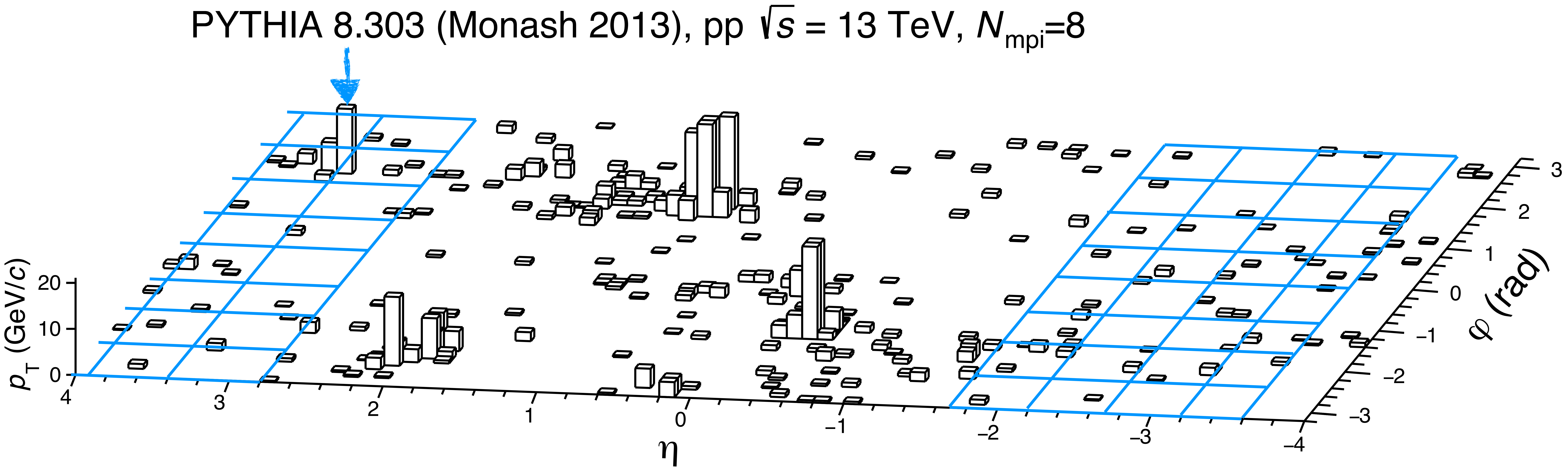

Large local $N^{(\mathrm{ch}.\,i)}$ fluctuations in the V0 acceptance: large flattenicity values

- jet structures, small multiplicity

High-p_T physics: V0M vs flattenicity

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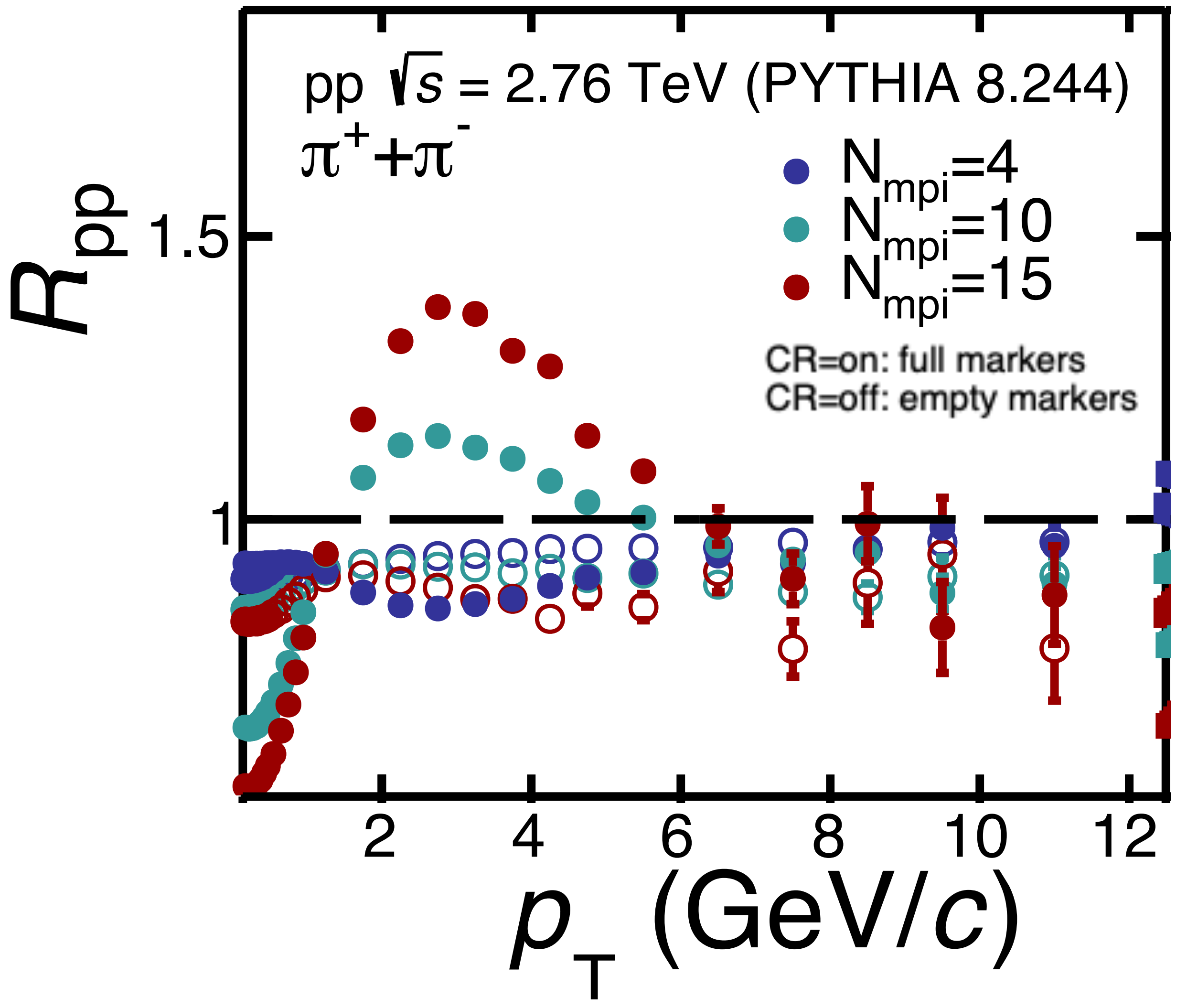
A. Ortiz et al., Phys. Rev. D102 (2020) 7, 076014

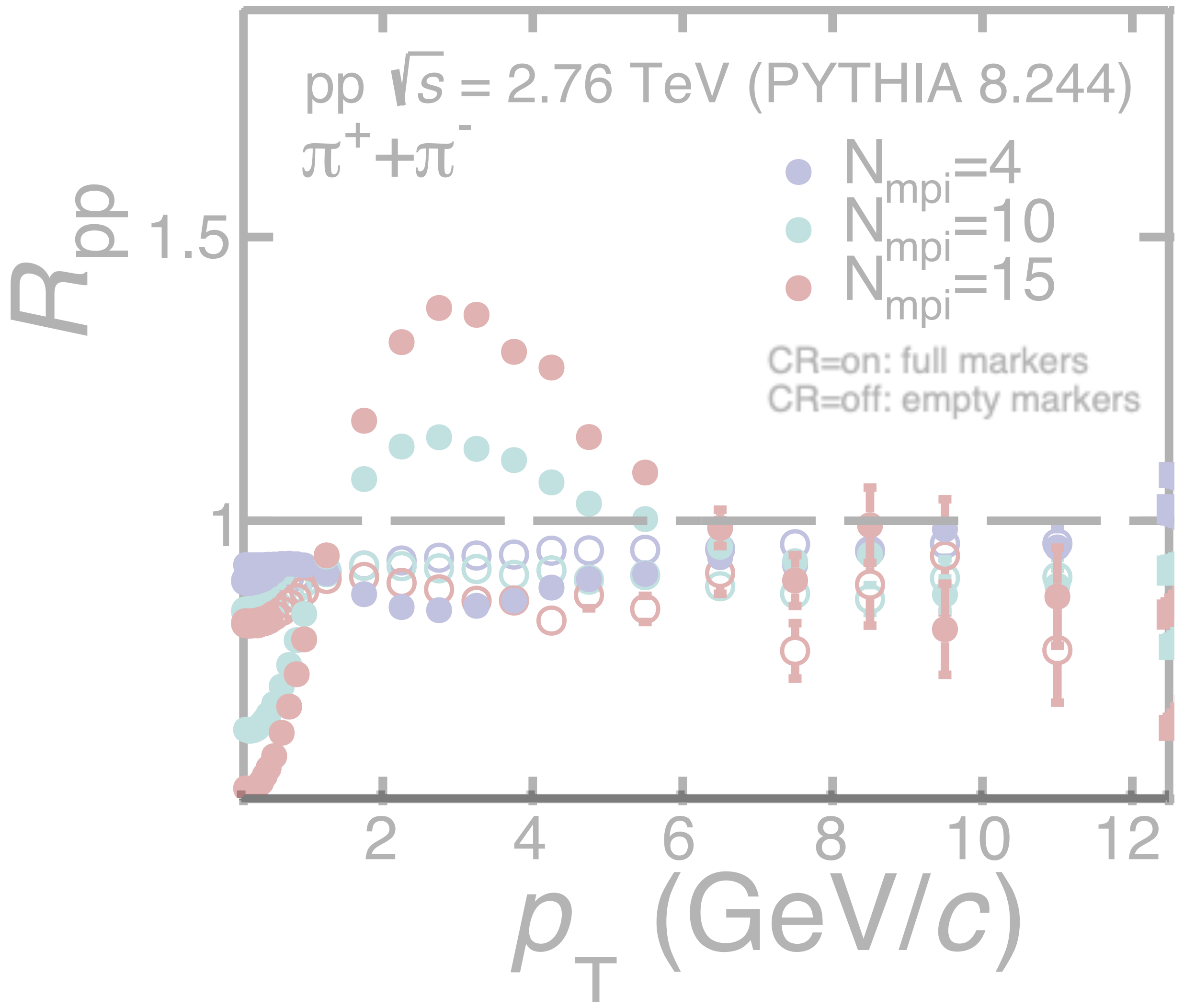


$$R_{\rm pp}(p_{\rm T}) = \frac{\left.\frac{1}{N_{\rm ev}}\frac{{\rm d}N_{\rm ch}}{{\rm d}p_{\rm T}}\frac{1}{\langle N_{\rm mpi}\rangle}\right|_{\rm high\,MPI}}{\left.\frac{1}{N_{\rm ev}}\frac{{\rm d}N_{\rm ch}}{{\rm d}p_{\rm T}}\frac{1}{\langle N_{\rm mpi}\rangle}\right|_{\rm MB}}$$

- Intermediate p_T: CR peak
- High p_T: the ratio is flat and in the vicinity of unity

High-p_T physics: V0M vs flatenicity

A. Ortiz et al., Phys. Rev. D102 (2020) 7, 076014



$$R_{pp}(p_T) = \frac{\frac{1}{N_{ev}}\frac{dN_{ch}}{dp_T}\frac{1}{\langle N_{mpi}\rangle}\Big|_{\text{high MPI}}}{\frac{1}{N_{ev}}\frac{dN_{ch}}{dp_T}\frac{1}{\langle N_{mpi}\rangle}\Big|_{\text{MB}}}$$

- Intermediate p_T: CR peak
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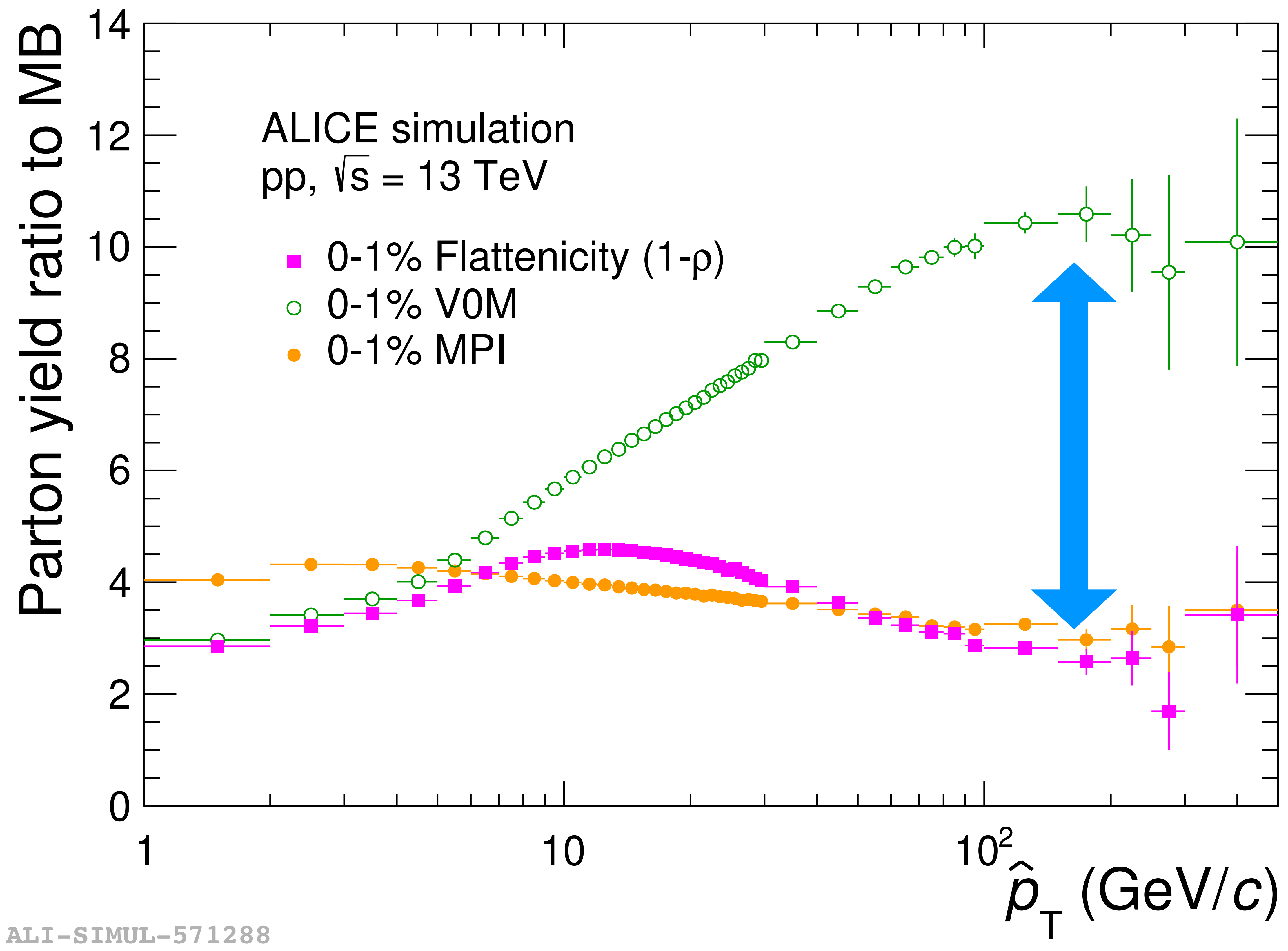
$$\text{ratio}(\hat{p}_T) = \frac{\frac{1}{N_{ev}}\frac{dN_{parton}}{d\hat{p}_T}\Big|_{1\%\text{ xsec}}}{\frac{1}{N_{ev}}\frac{dN_{parton}}{d\hat{p}_T}\Big|_{\text{MB}}}$$



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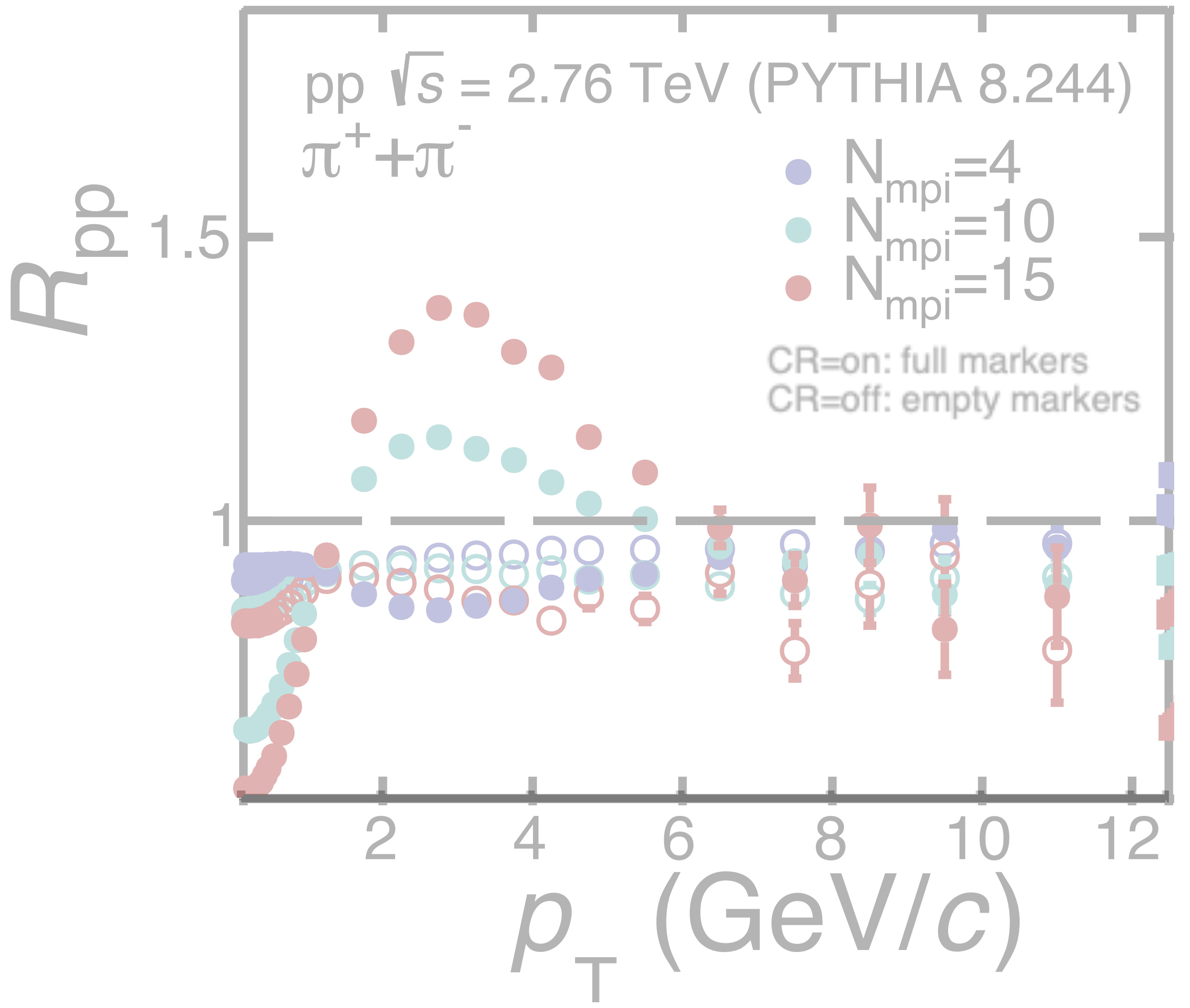

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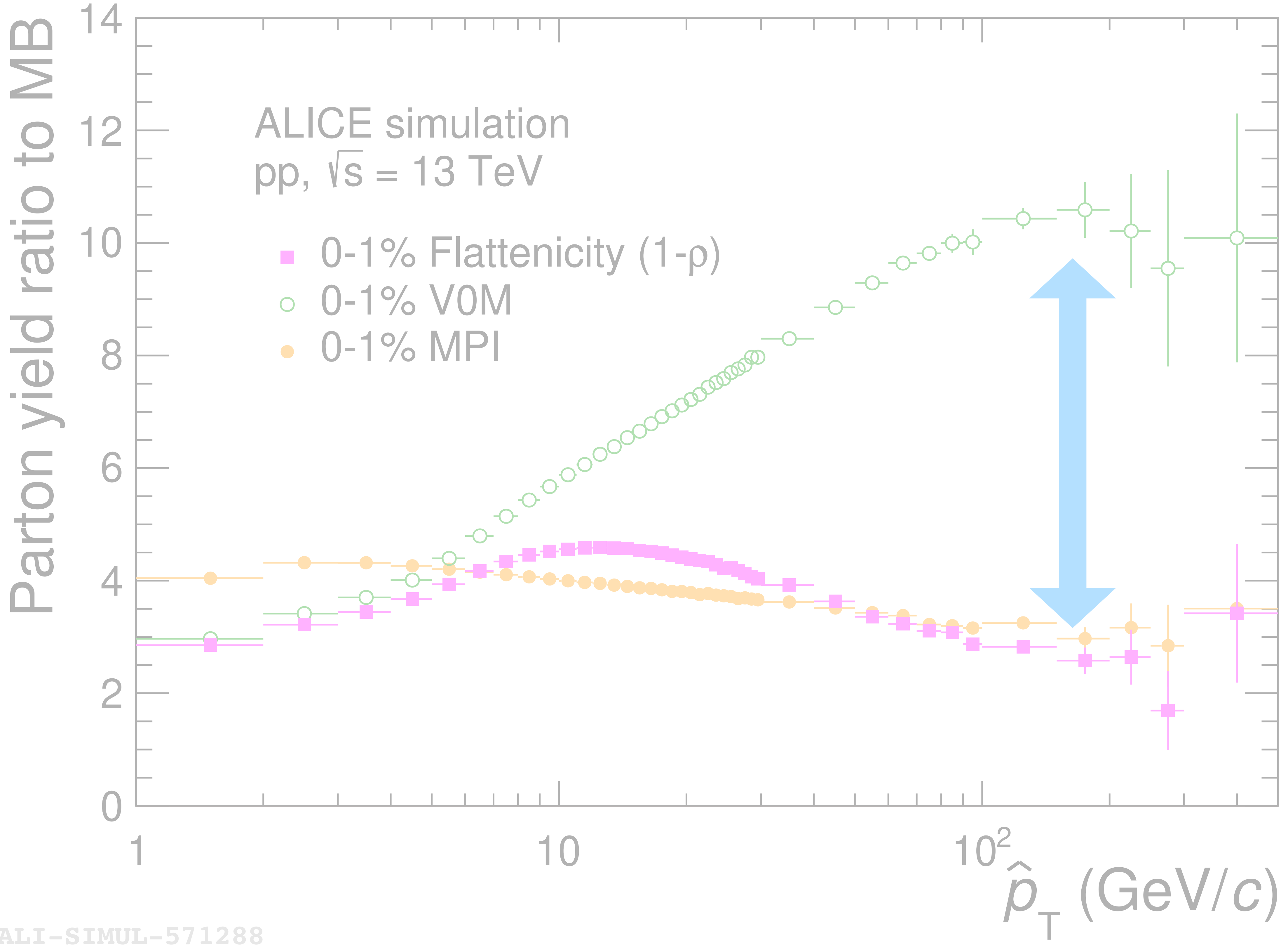

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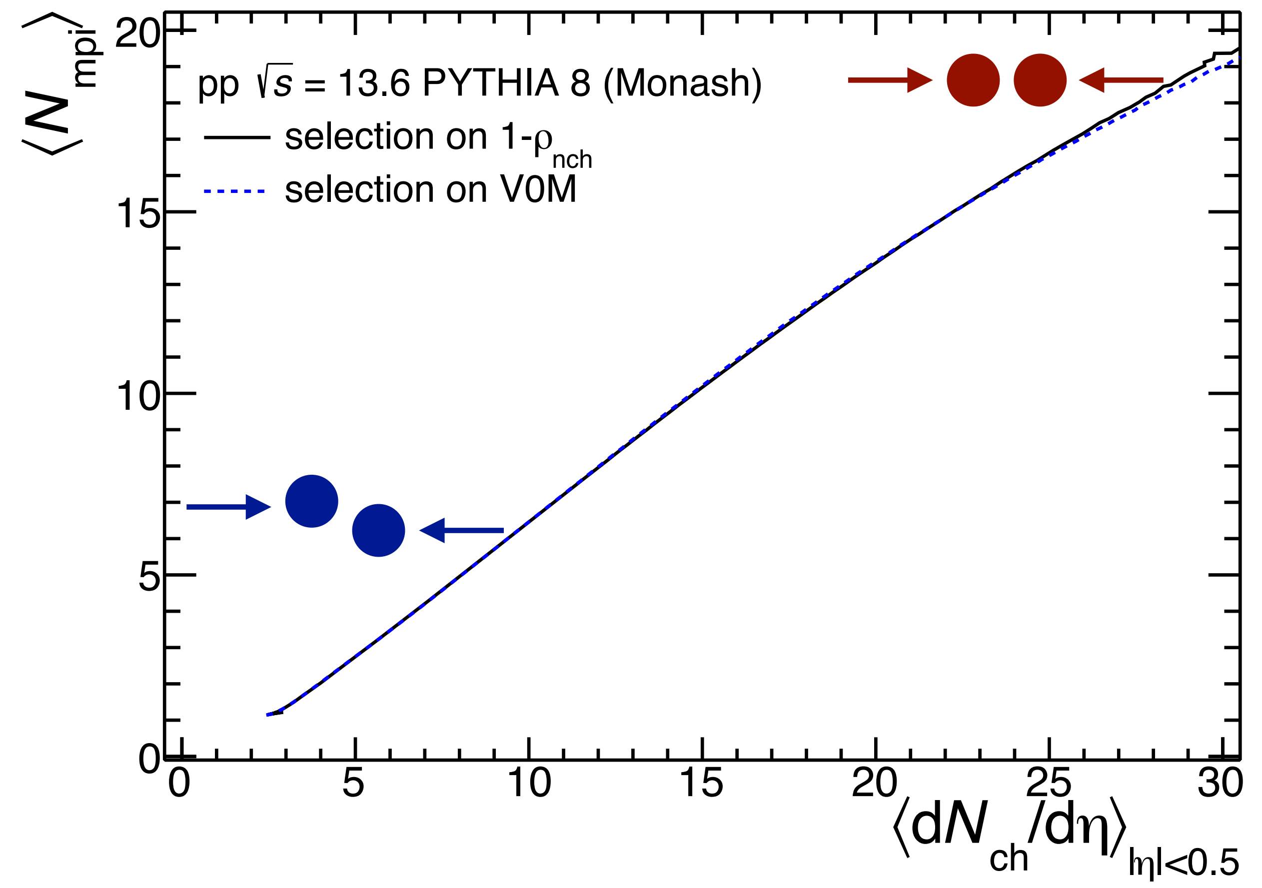
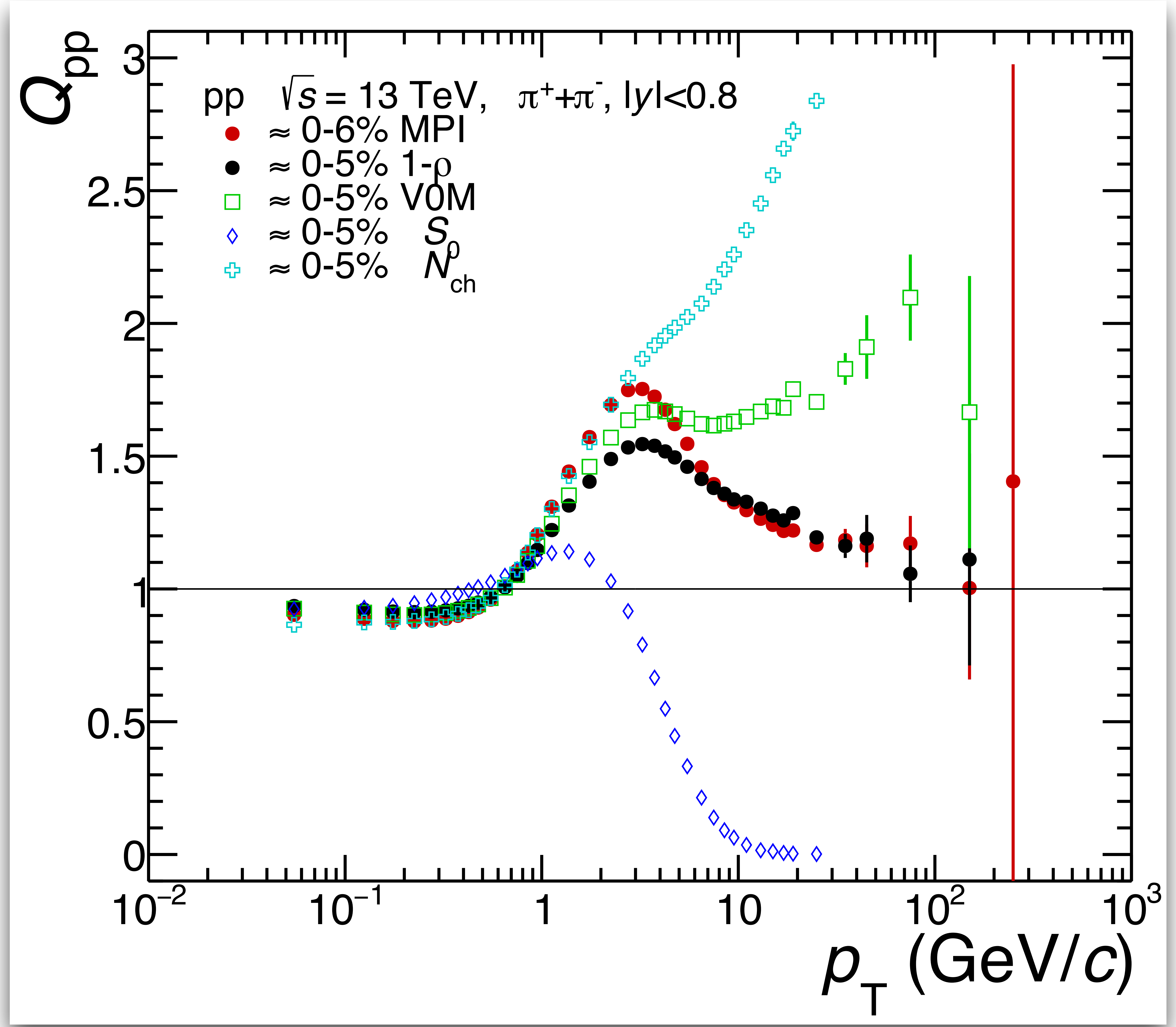


$$\left\langle \frac{dN_{ch}}{d\eta} \right\rangle \propto \langle N_{mpi} \rangle$$

Experimentally:

$$Q_{pp}(p_T) = \frac{\frac{1}{N_{ev}}\frac{dN_{ch}}{dp_T}\frac{1}{\langle N_{ch}\rangle}\Big|_{HM}}{\frac{1}{N_{ev}}\frac{dN_{ch}}{dp_T}\frac{1}{\langle N_{ch}\rangle}\Big|_{MB}}$$

Flattenicity vs other estimators



Data analysis

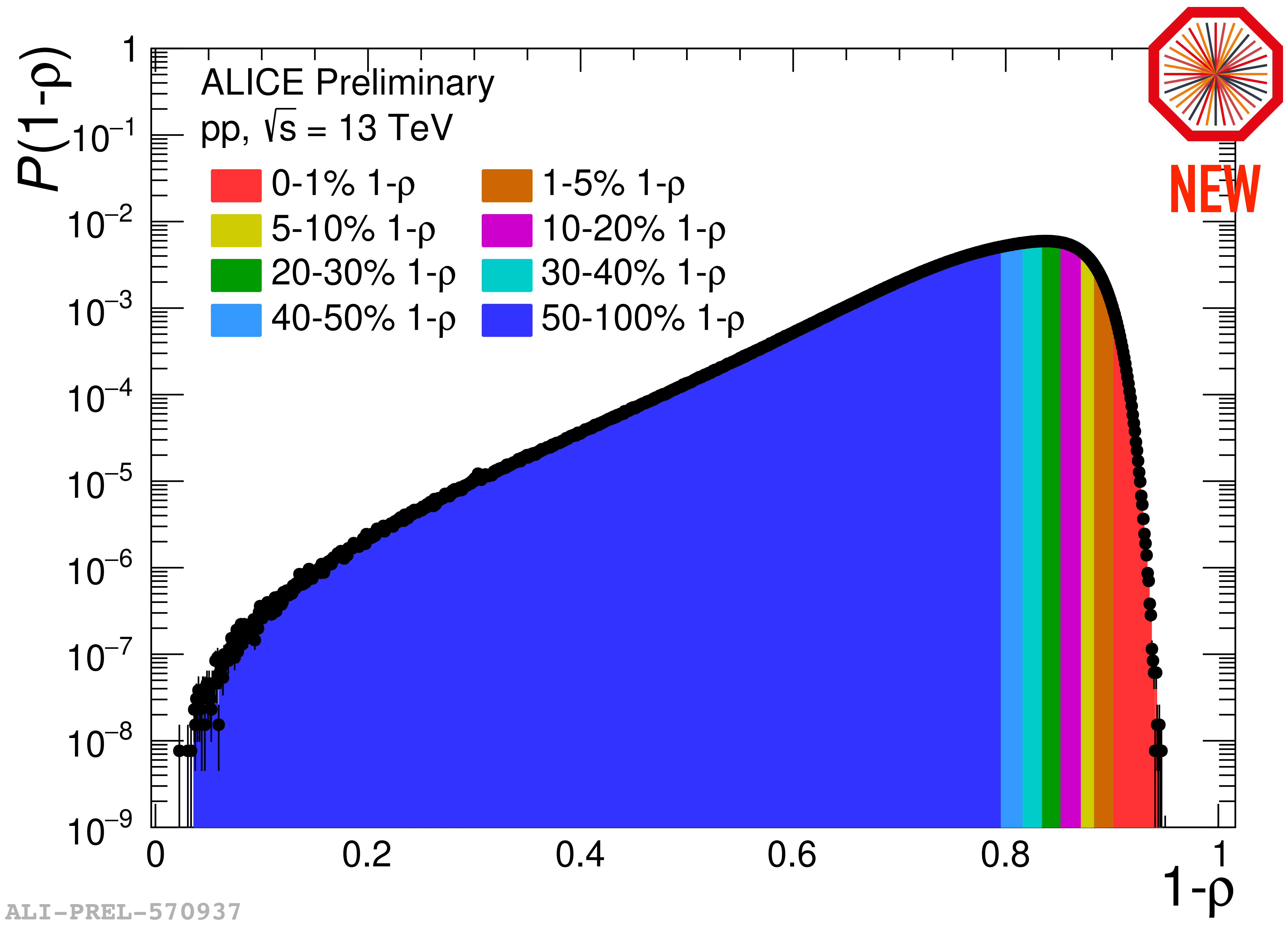
Integrated luminosity ~21 nb^{-1}

MB trigger: signals in both V0 detectors
Vertex position within $|v_z|$<10 cm (SPD)
Events with multiple primary vertexes are rejected

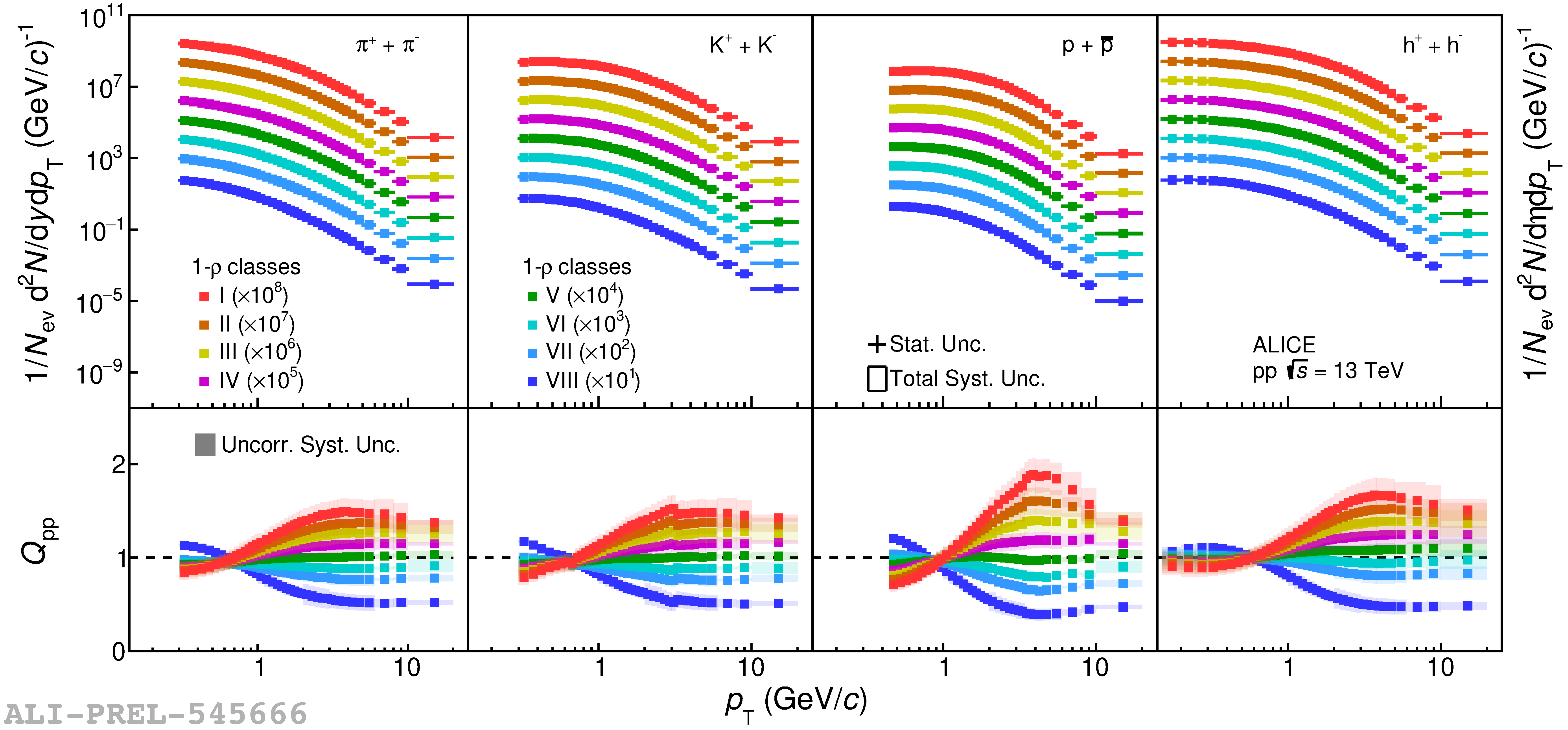
Particle identification with TPC and TOF detectors
Flattenicity is measured with the V0 detector

Systematic uncertainties: vertex, track selection, MC non-closure, signal extraction (PID): up to 10%

Low N_{mpi} High N_{mpi}



Q_{pp} as a function of p_T



- Intermediate p_T: a bump structure is developed with increasing multiplicity

Q_{pp} as a function of p_T

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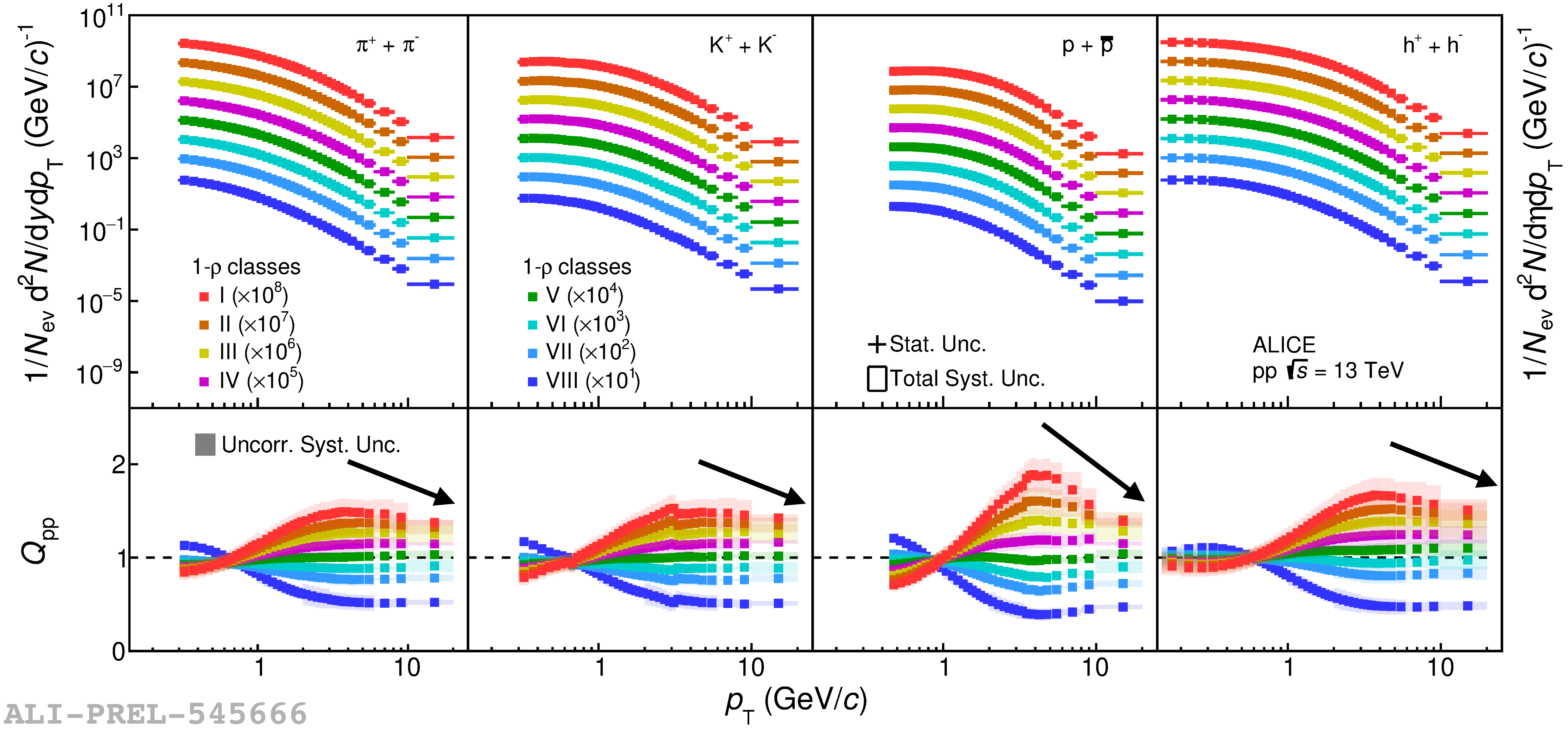

ALI-PREL-545666

- Intermediate p_T: a bump structure is developed with increasing multiplicity
- High p_T: Q_{pp} seems to approach to the vicinity of one

Q_{pp} as a function of p_T

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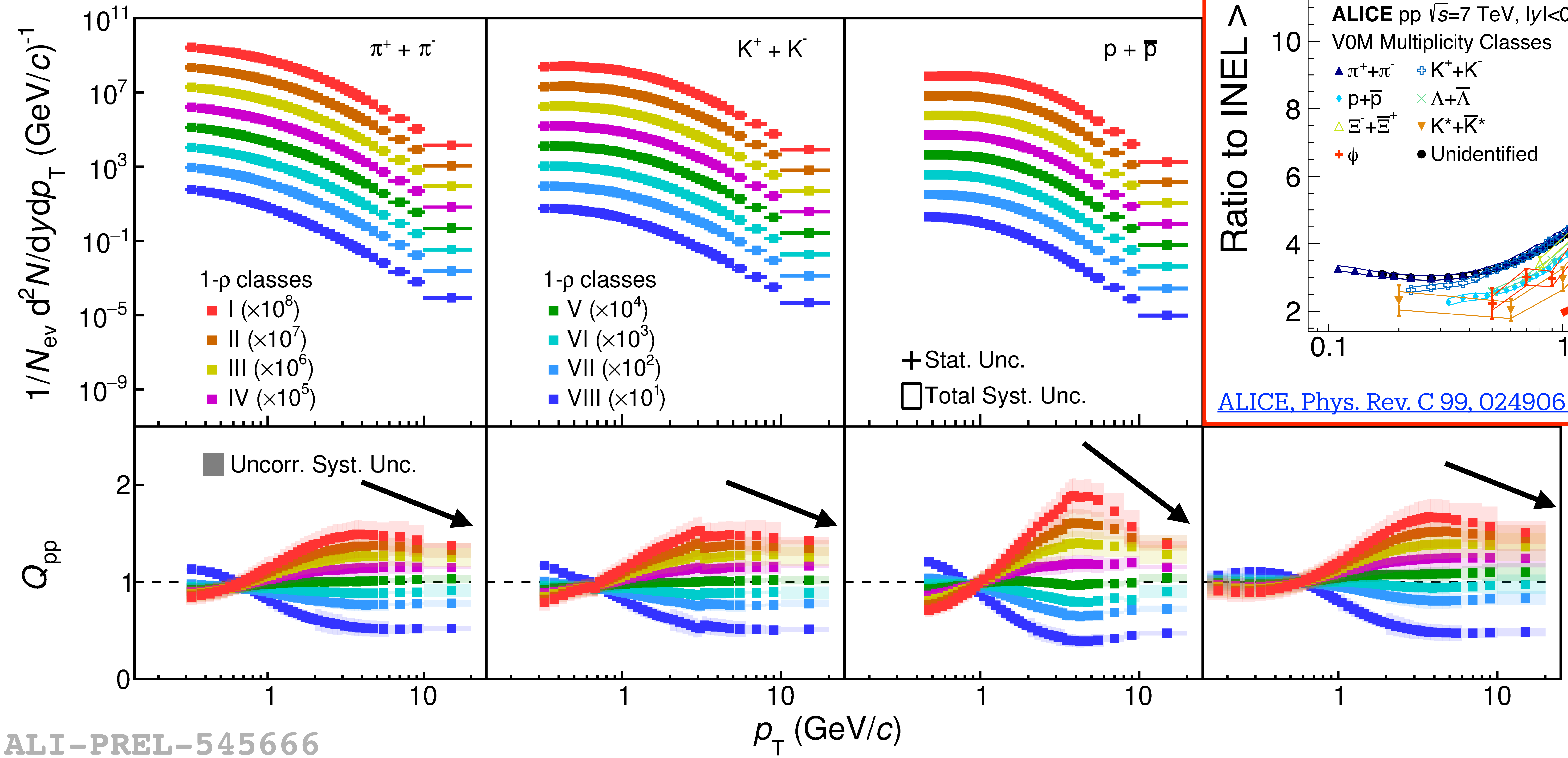
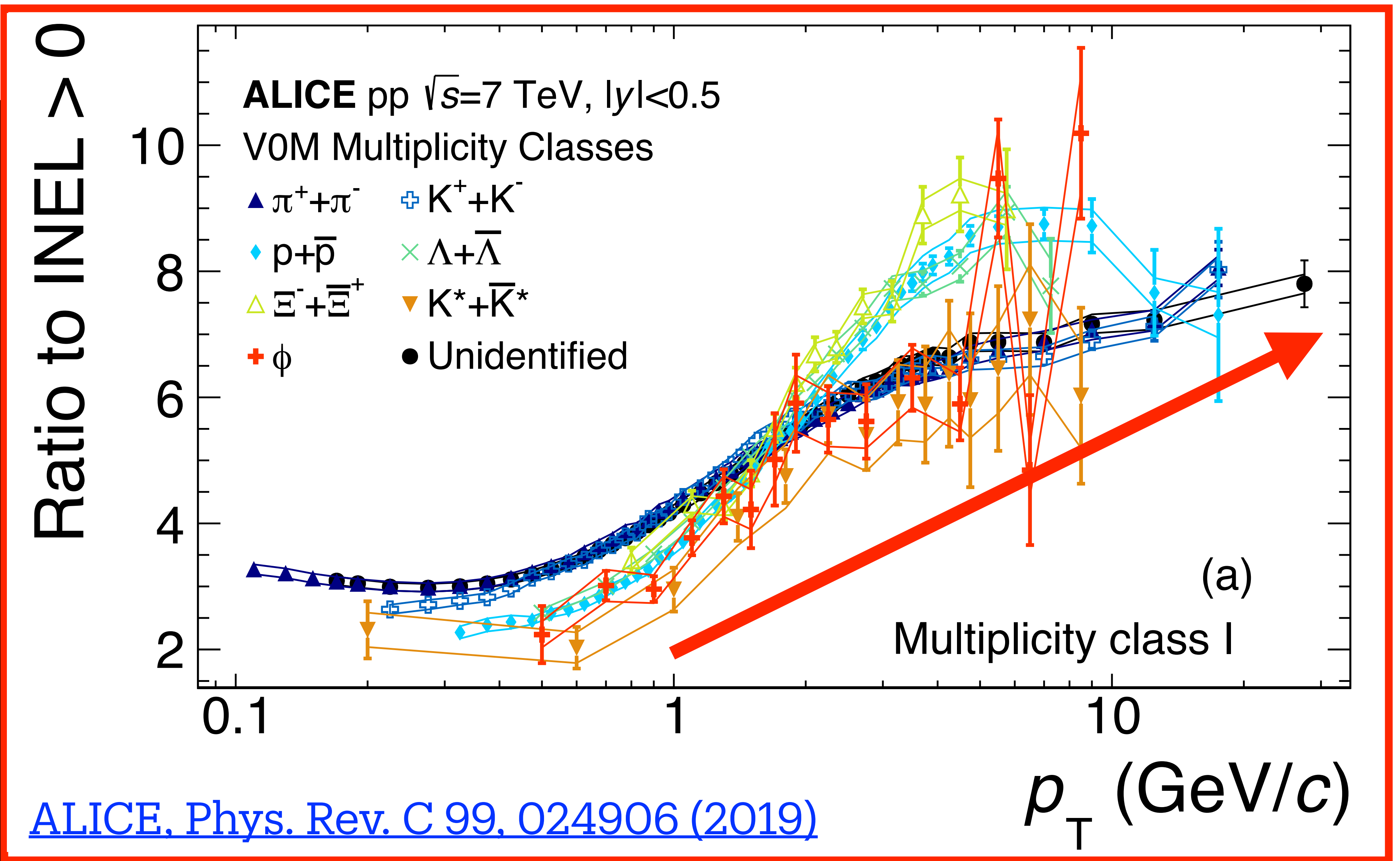


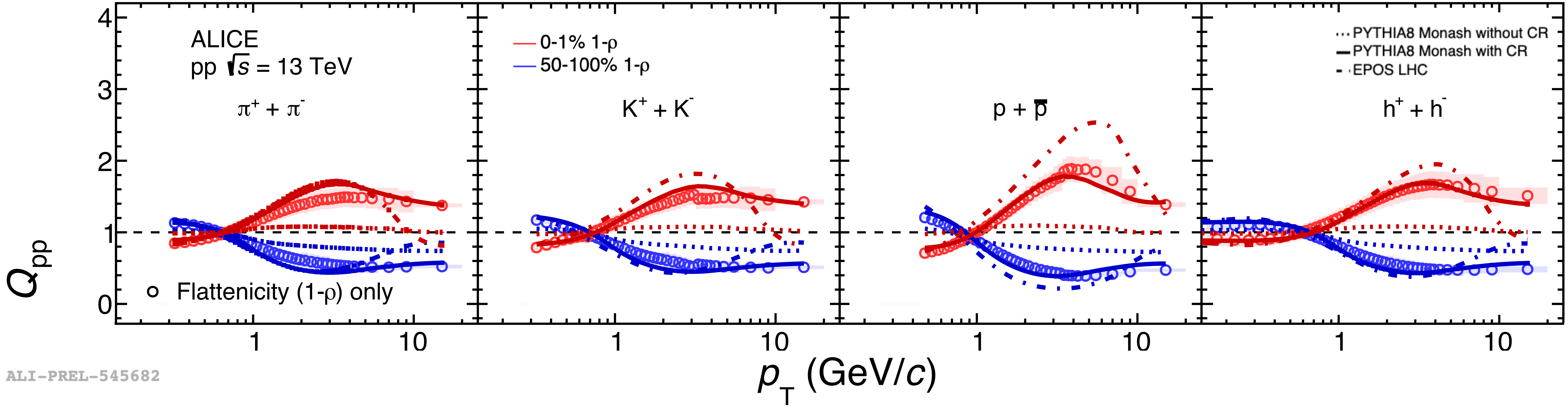
ALI-PREL-545666



The effect is not seen in the V0M analysis!

- Intermediate p_T: a bump structure is developed with increasing multiplicity
- High p_T: Q_{pp} seems to approach to the vicinity of one

Q_{pp}: data vs MC models



PYTHIA 8 without CR: a nearly flat Q_{pp} as a function of p_{T}

Pythia Monash (with 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 V0M

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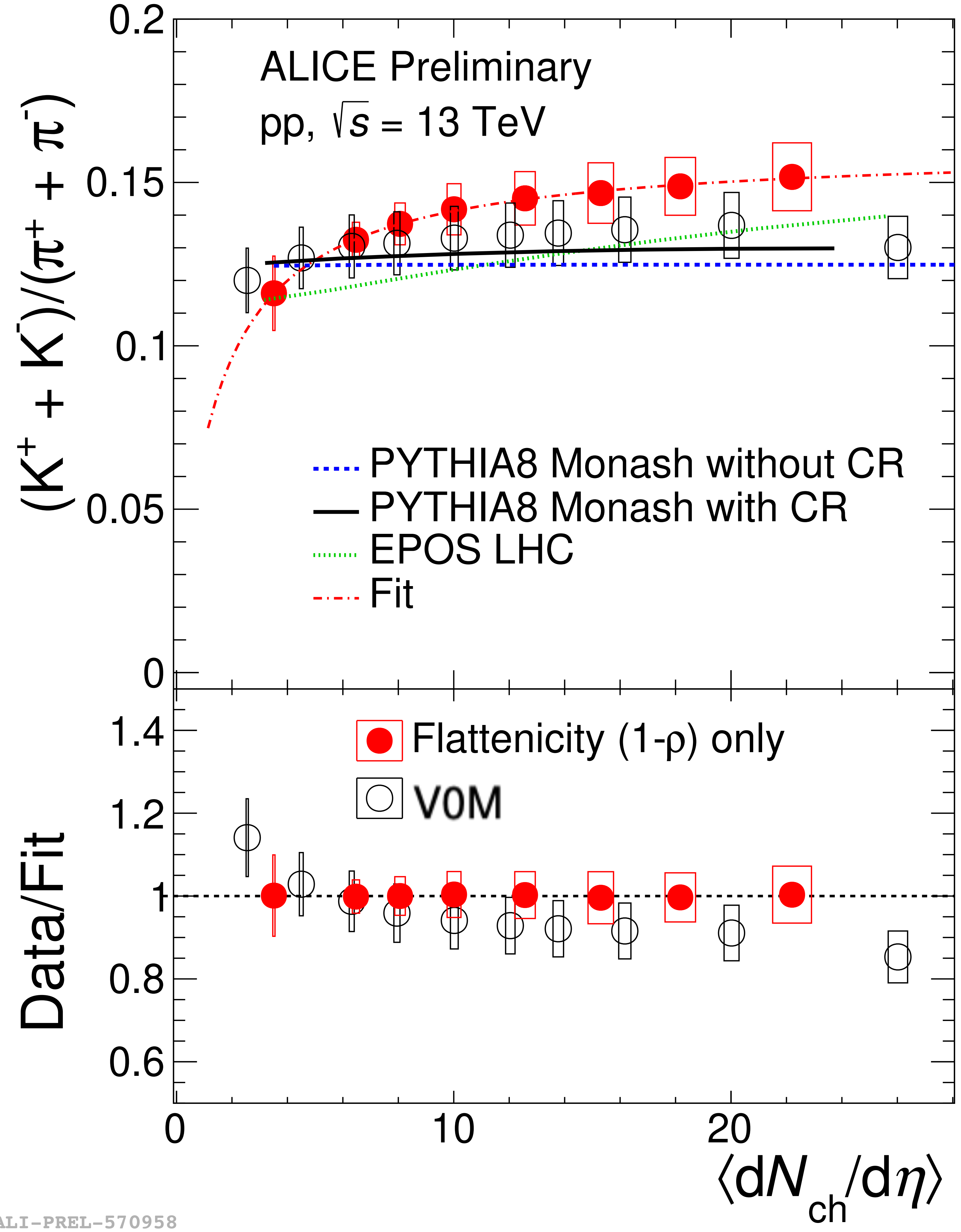

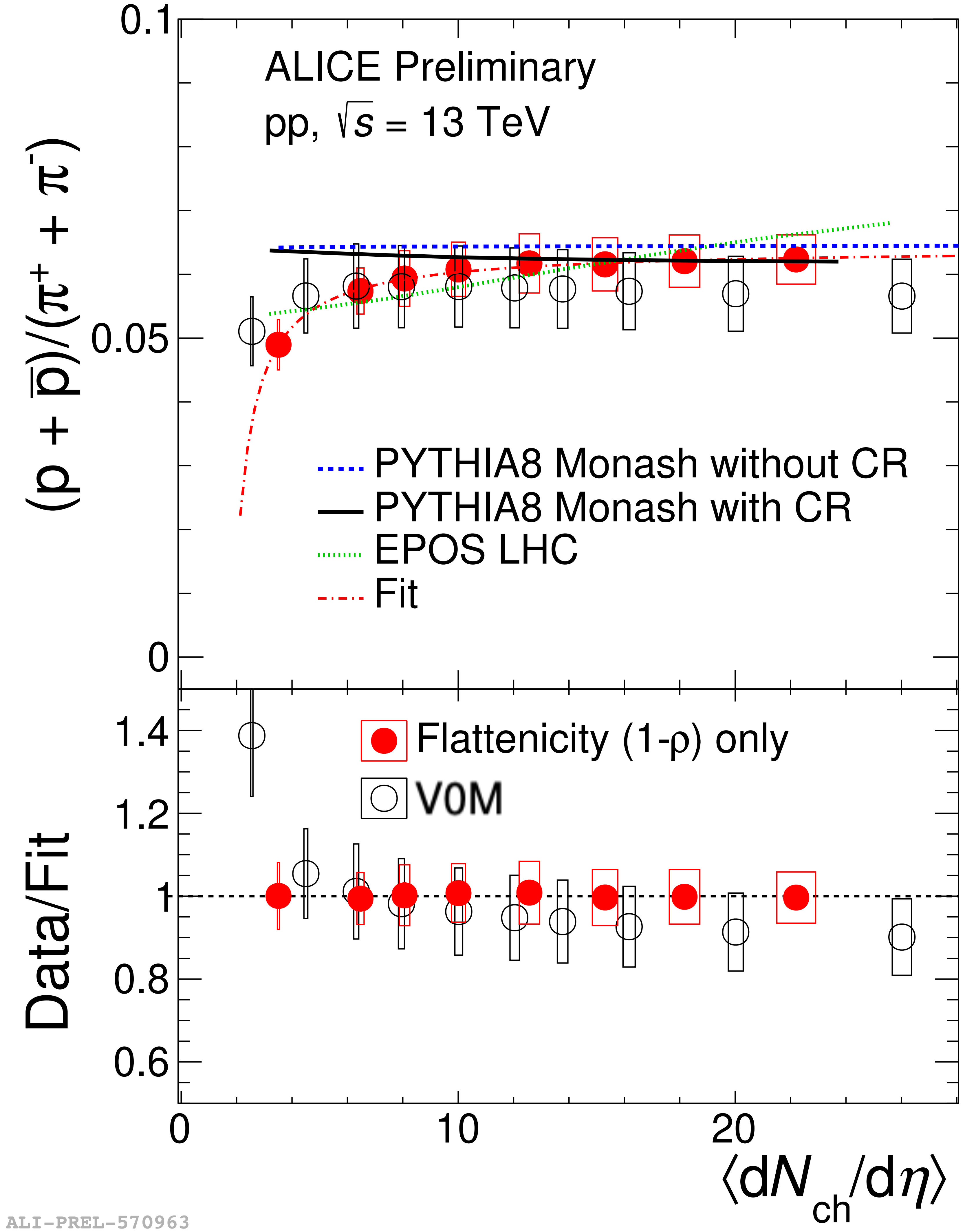

NEW

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

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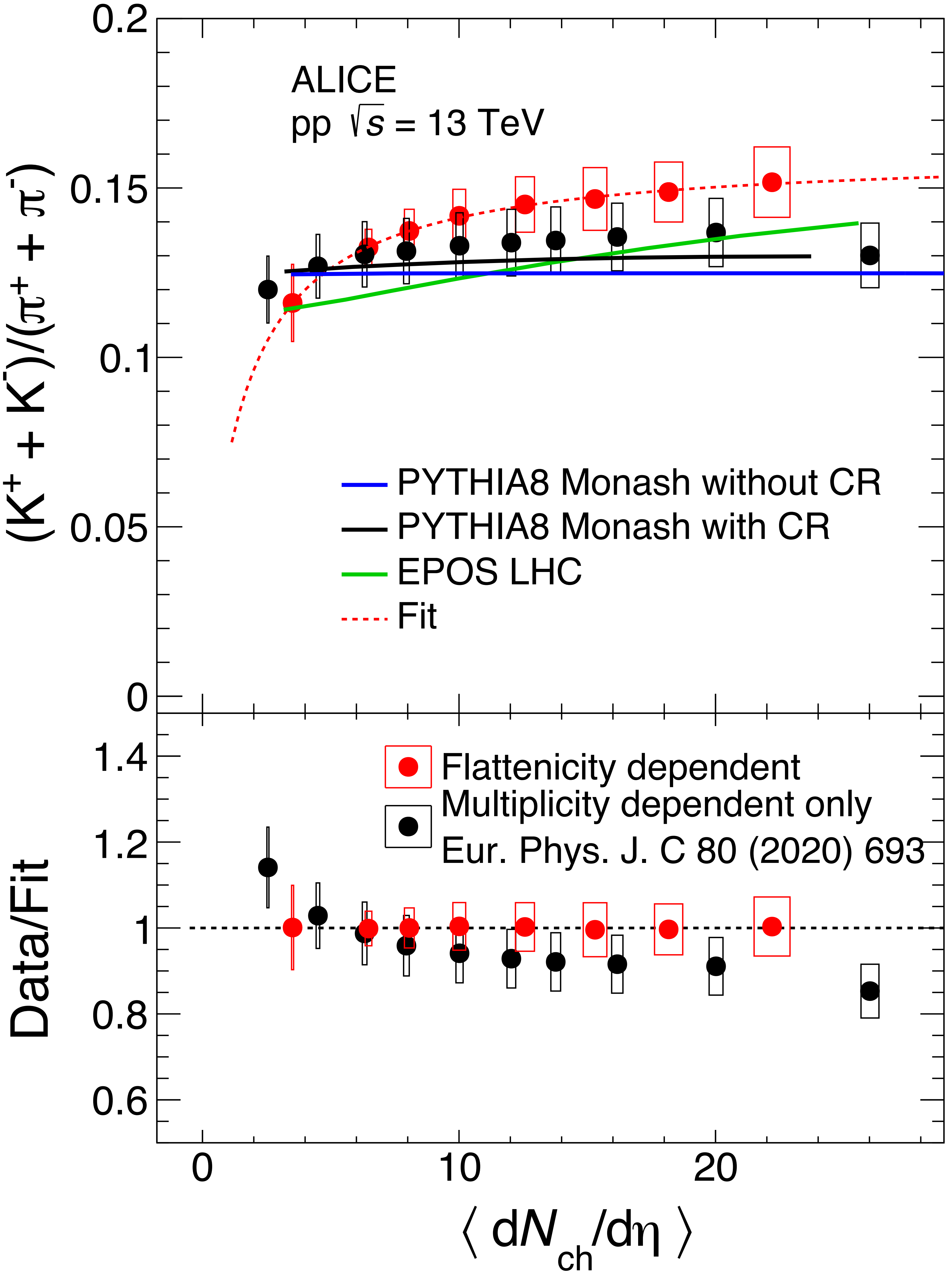
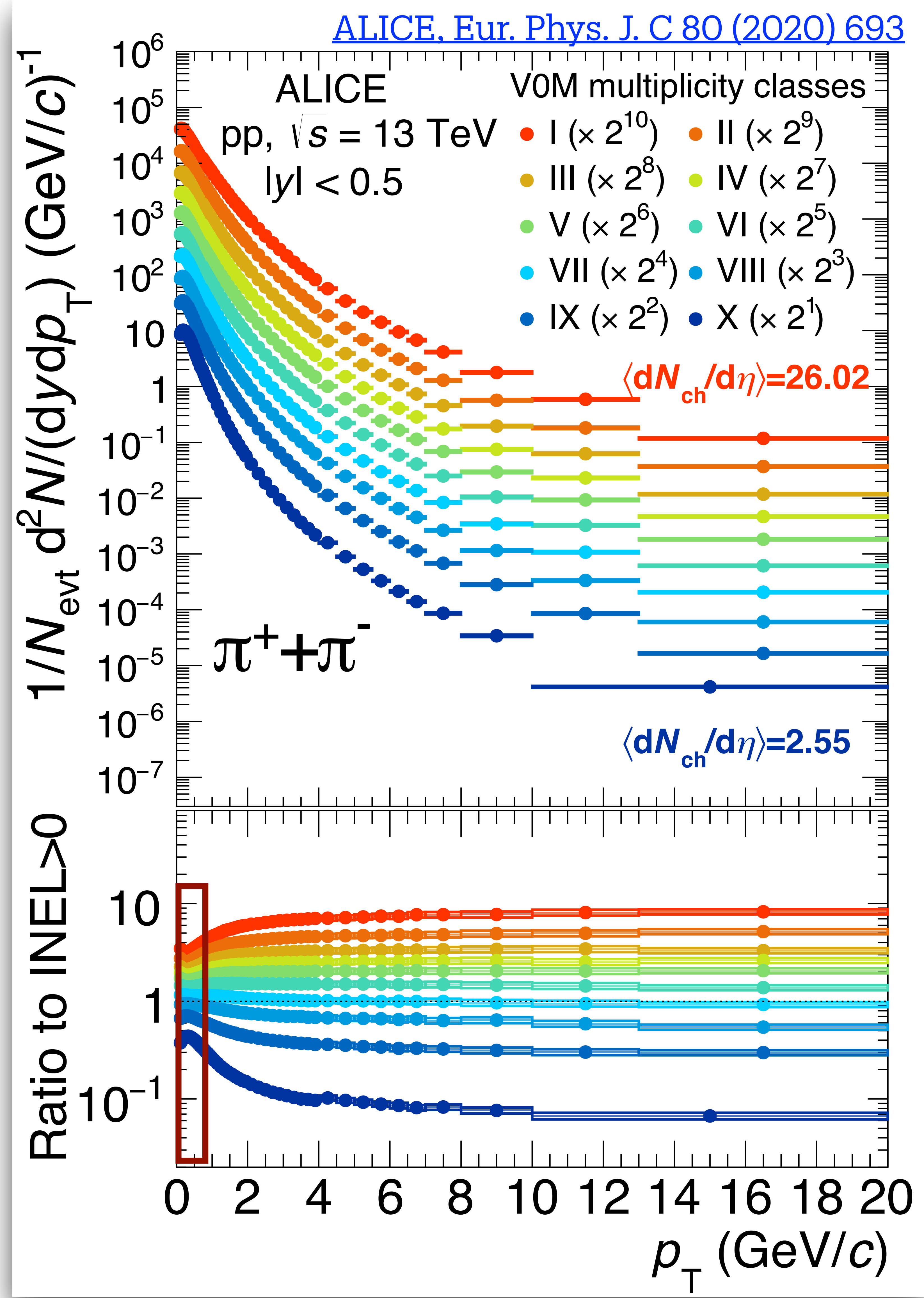
Particle ratios: flattenicity vs V0M





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

The reason is that V0M multiplicity biases the low p_T pion yield

Average p_T

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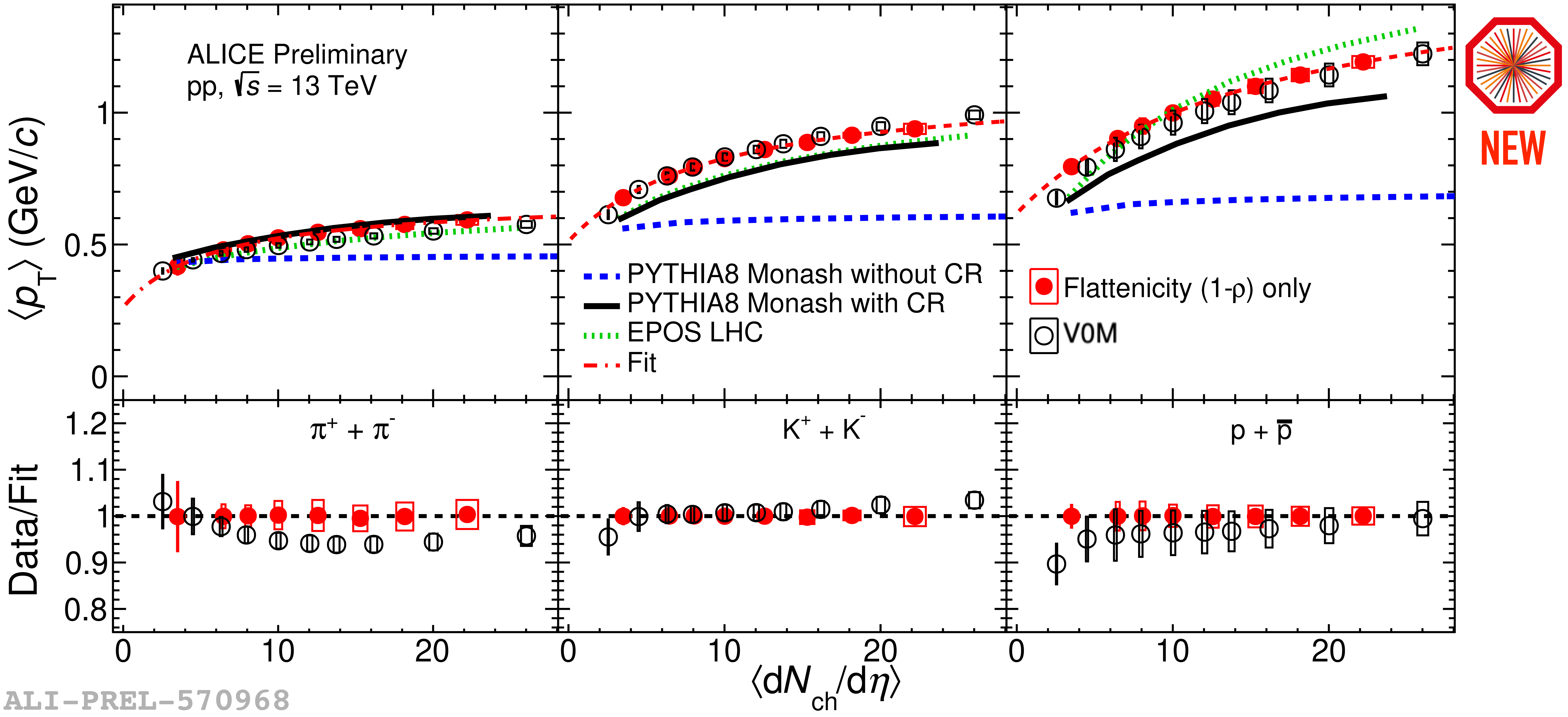


Little or no difference is observed between flattenicity and V0M selections for kaons and protons

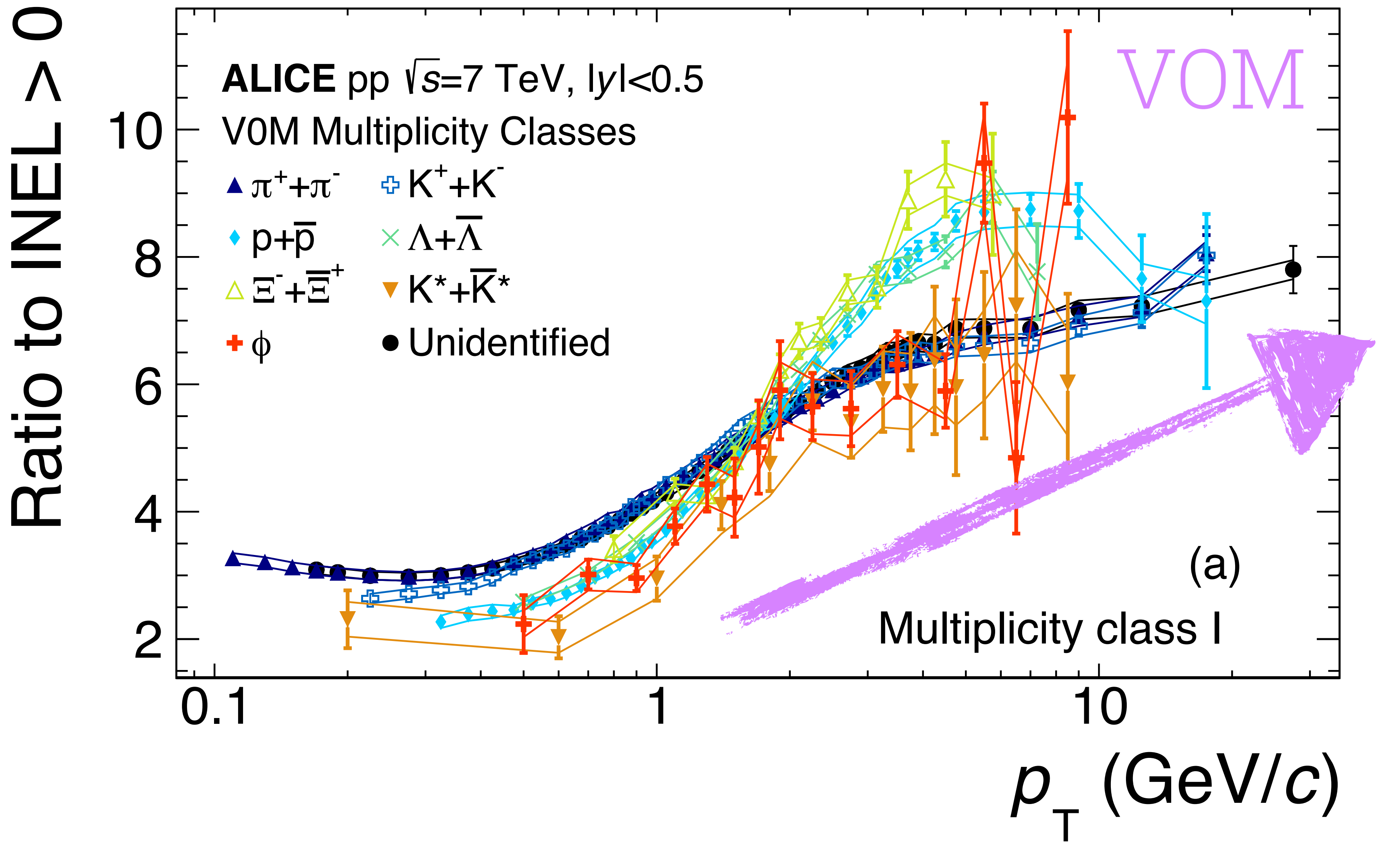
A slightly larger mean p_T as a function of multiplicity for flattenicity selection

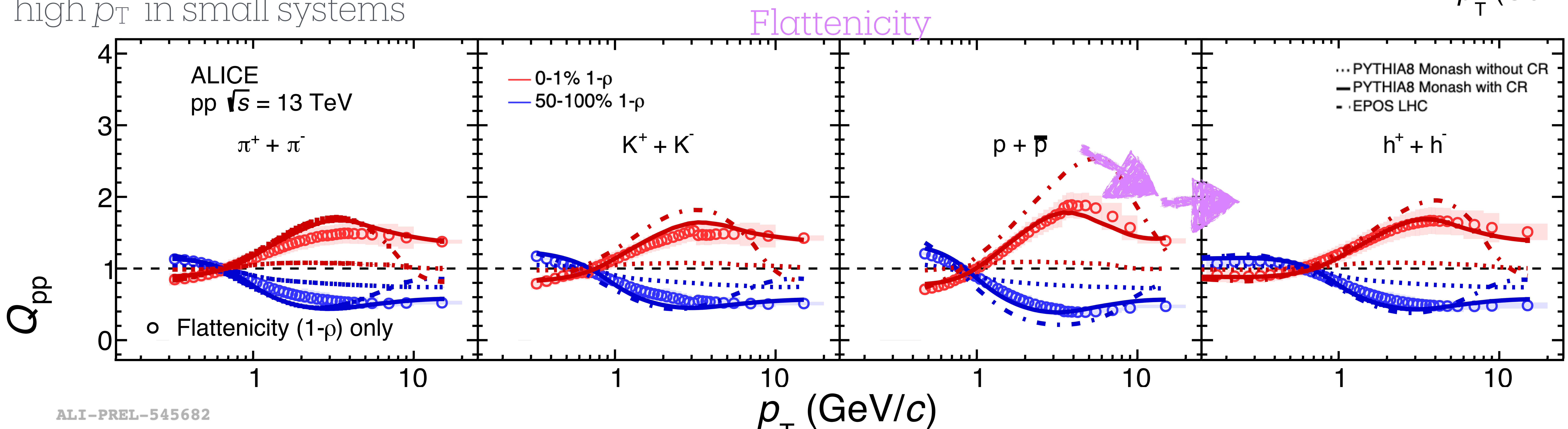
Summary

Flattenicity is more sensitive to MPI (and therefore to the impact parameter of the collision) than the V0M multiplicity estimator

An approximately scaling with MPI is seen at large p_{T}

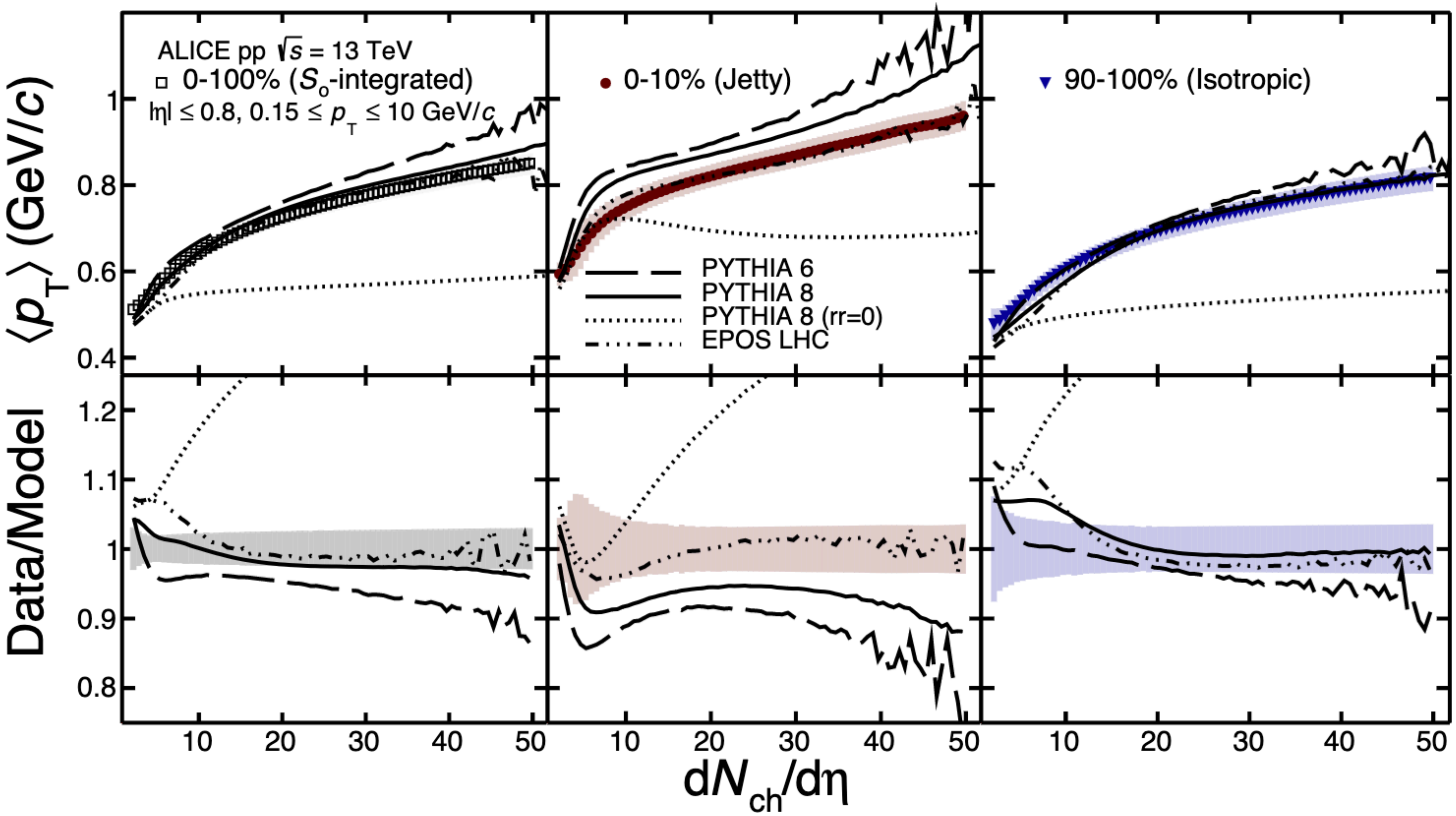
Promising tool to study QGP observables at both low and high p_{T} in small systems





Thank you!

backup



$$S_0 \equiv \frac{\pi^2}{4} \min_{\hat{\mathbf{n}}_\mathbf{s}} \left(\frac{\sum_i |\vec{p}_{\mathrm{T},i} \times \hat{\mathbf{n}}_\mathbf{s}|}{\sum_i p_{\mathrm{T},i}} \right)^2,$$

MPI

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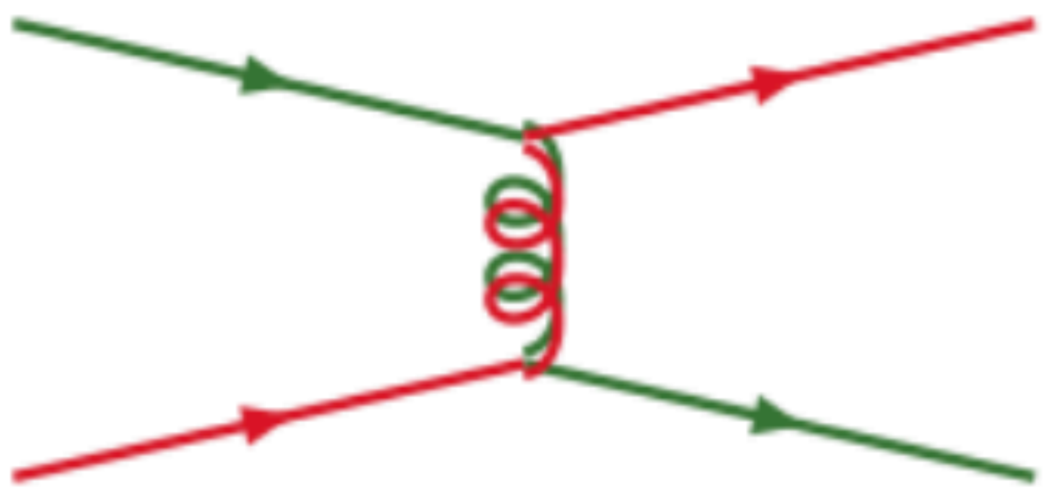
At high energies, the leading order cross-section for $2 \rightarrow 2$ parton scatterings with momentum transfer $Q > Q_{\text{min}} \gg \Lambda_{\text{QCD}}$ exceeds the total pp cross-section at a range of Q_{min}-values where perturbative QCD is applicable (at LHC, $Q_{\text{min}} \approx 4$ GeV/c) [T. Sjöstrand and M. Zijil Phys. Rev. D36 (1987)]

T. Sjöstrand, 6th MPI @ LHC Workshop



Integrate QCD $2 \rightarrow 2$

$qq' \rightarrow qq'$

$q\bar{q} \rightarrow q'\bar{q}'$

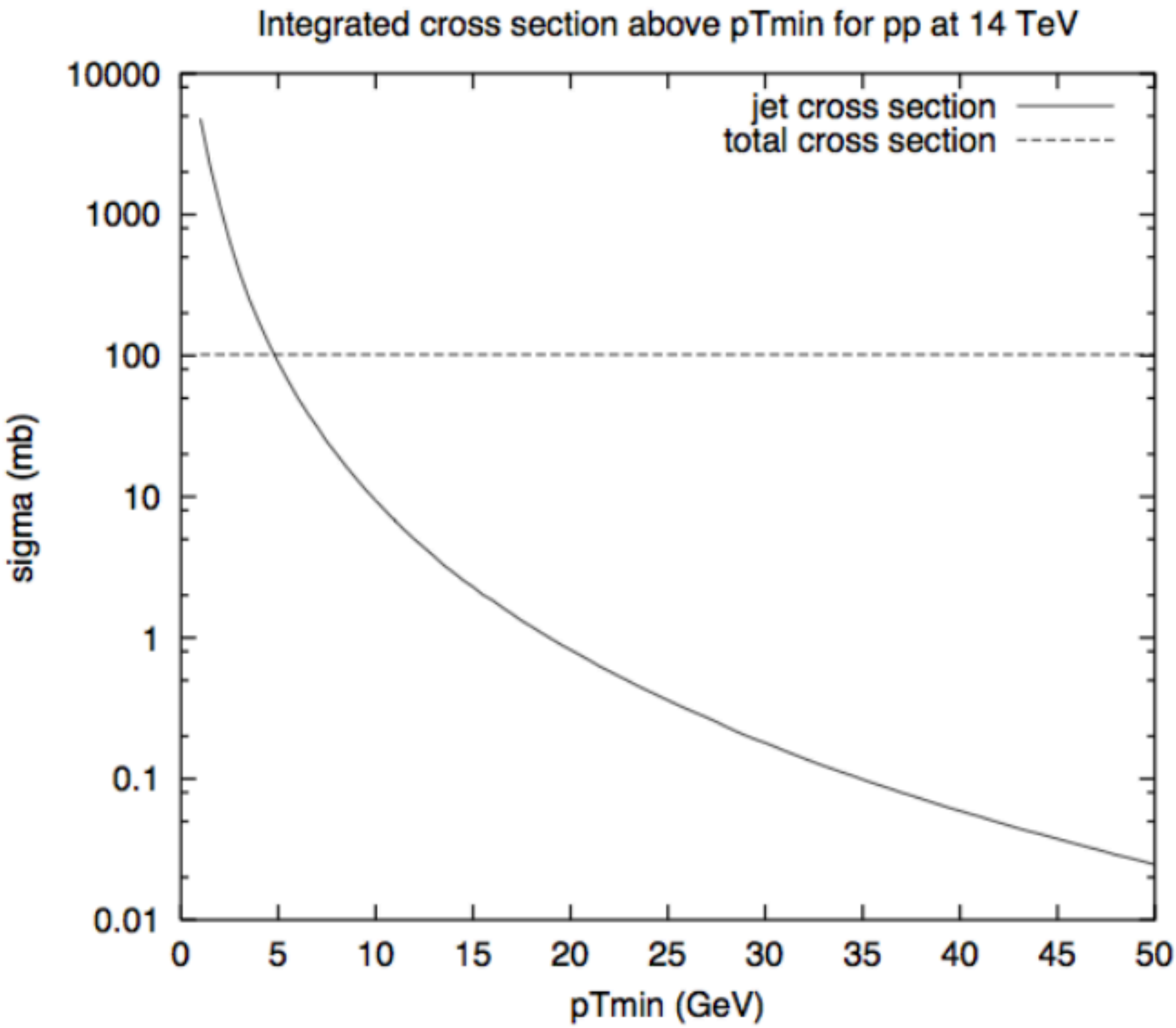
$q\bar{q} \rightarrow gg$

$qg \rightarrow qg$

$gg \rightarrow gg$

$gg \rightarrow q\bar{q}$

(with CTEQ 5L PDF's)



MPI

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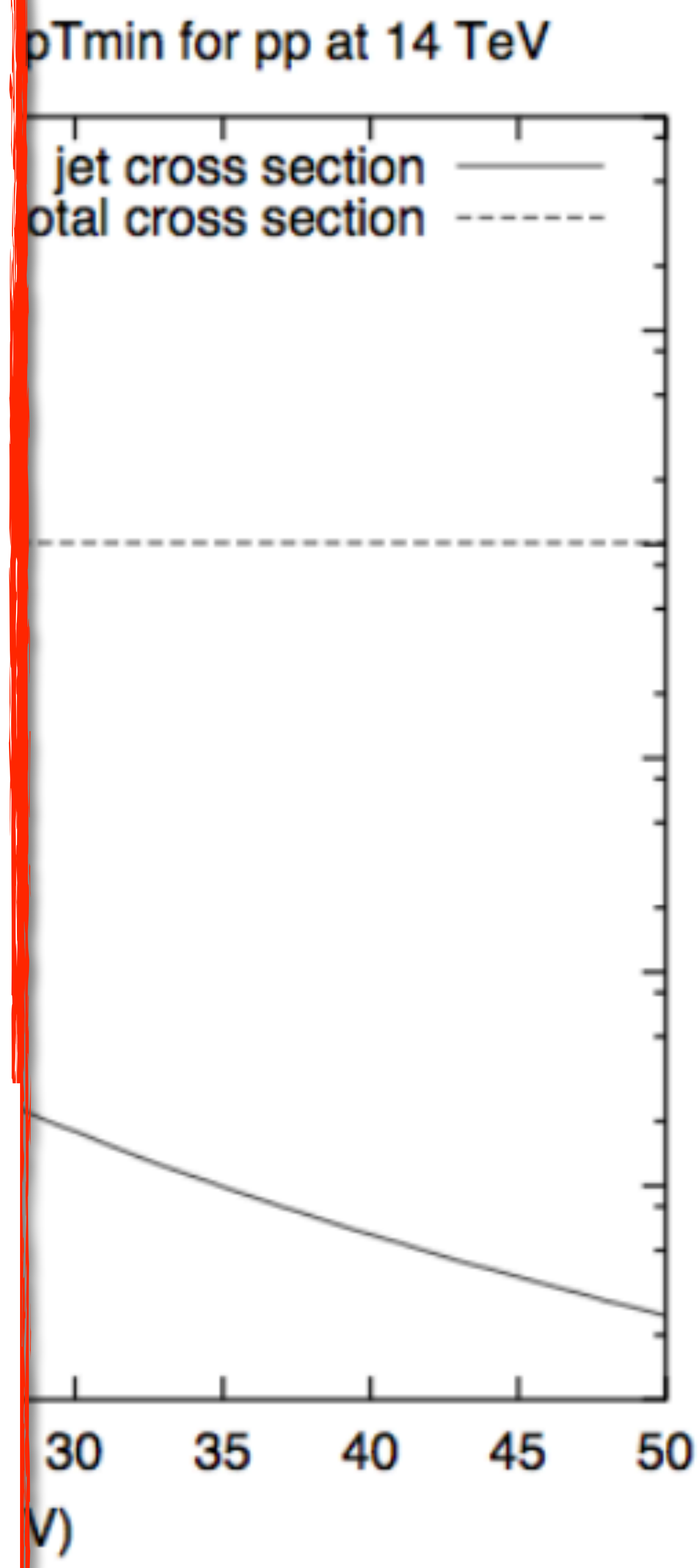
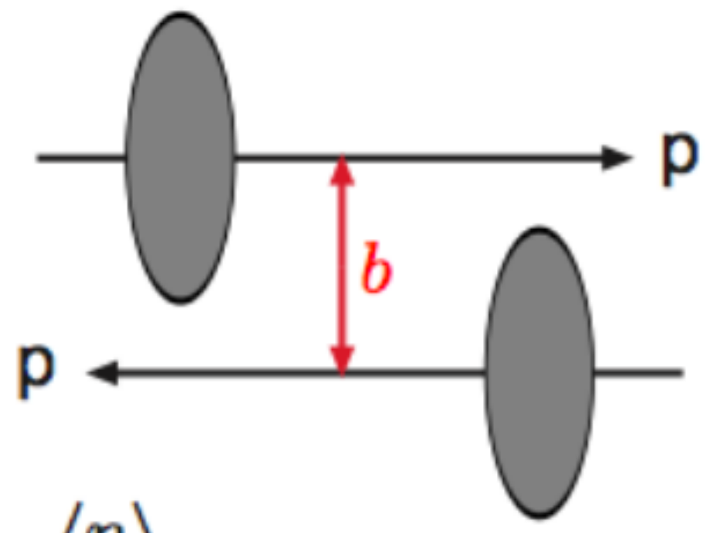
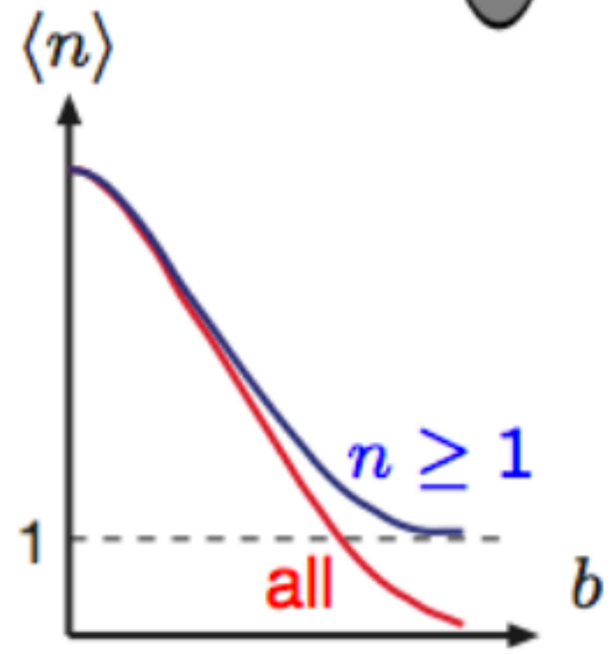
At high ene
order cross-
parton scatt
momentum
$Q > Q_{\min} >$
the total pp
range of Q_{m}
perturbative
applicable (
GeV/c) [T. Sj
Zijil Phys. Re



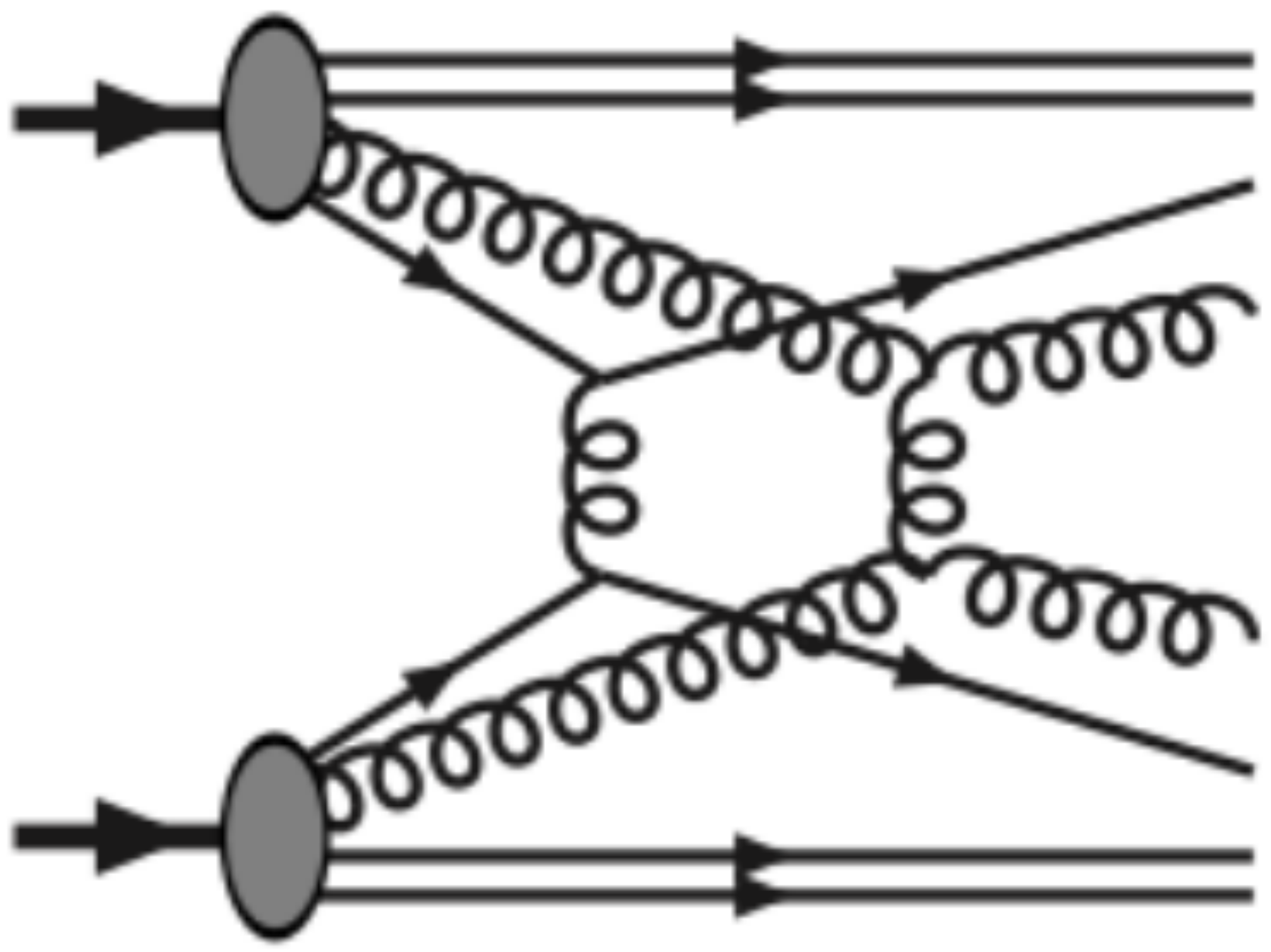
Interpretation: Many partonic scatterings per event: (MPI)

- MPI is a logical consequence of the composite nature of protons





- In event generators like Pythia, an impact parameter dependence is considered



Overlap of protons during encounter is

$$\mathcal{O}(b) = \int \mathrm{d}^3\mathbf{x}\,\mathrm{d}t\; \rho_1(\mathbf{x},t)\,\rho_2(\mathbf{x},t)$$

where ρ is (boosted) matter distribution in p, e.g. Gaussian or more narrow peak.

T. Sjöstrand, ISAPP 2018

MPI

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Interpretation: Many partonic scatterings per event: (MPI)

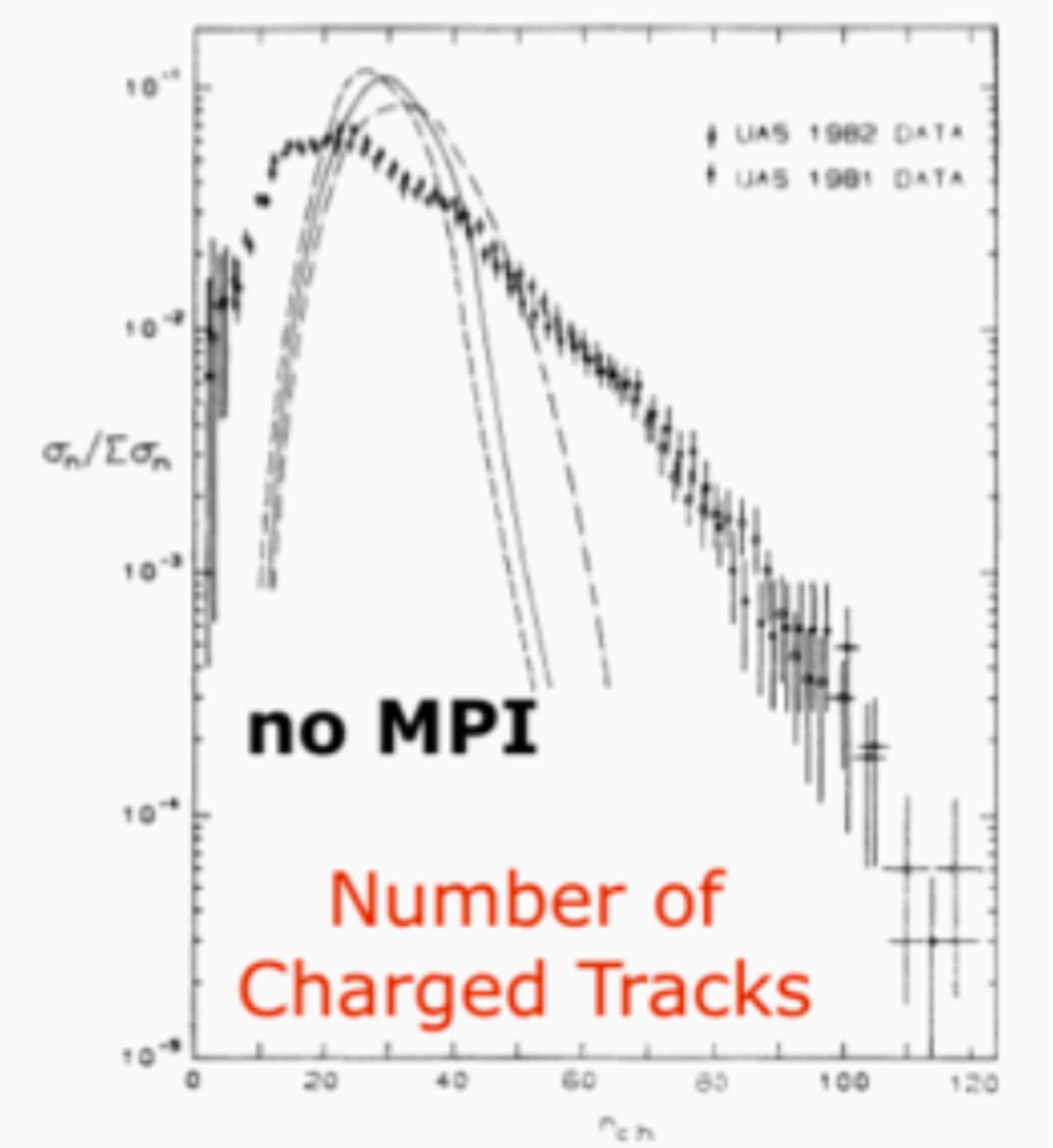


FIG. 3. Charged-multiplicity distribution at 540 GeV, UA5 results (Ref. 32) vs simple models: dashed low p_T only, full including hard scatterings, dash-dotted also including initial- and final-state radiation.

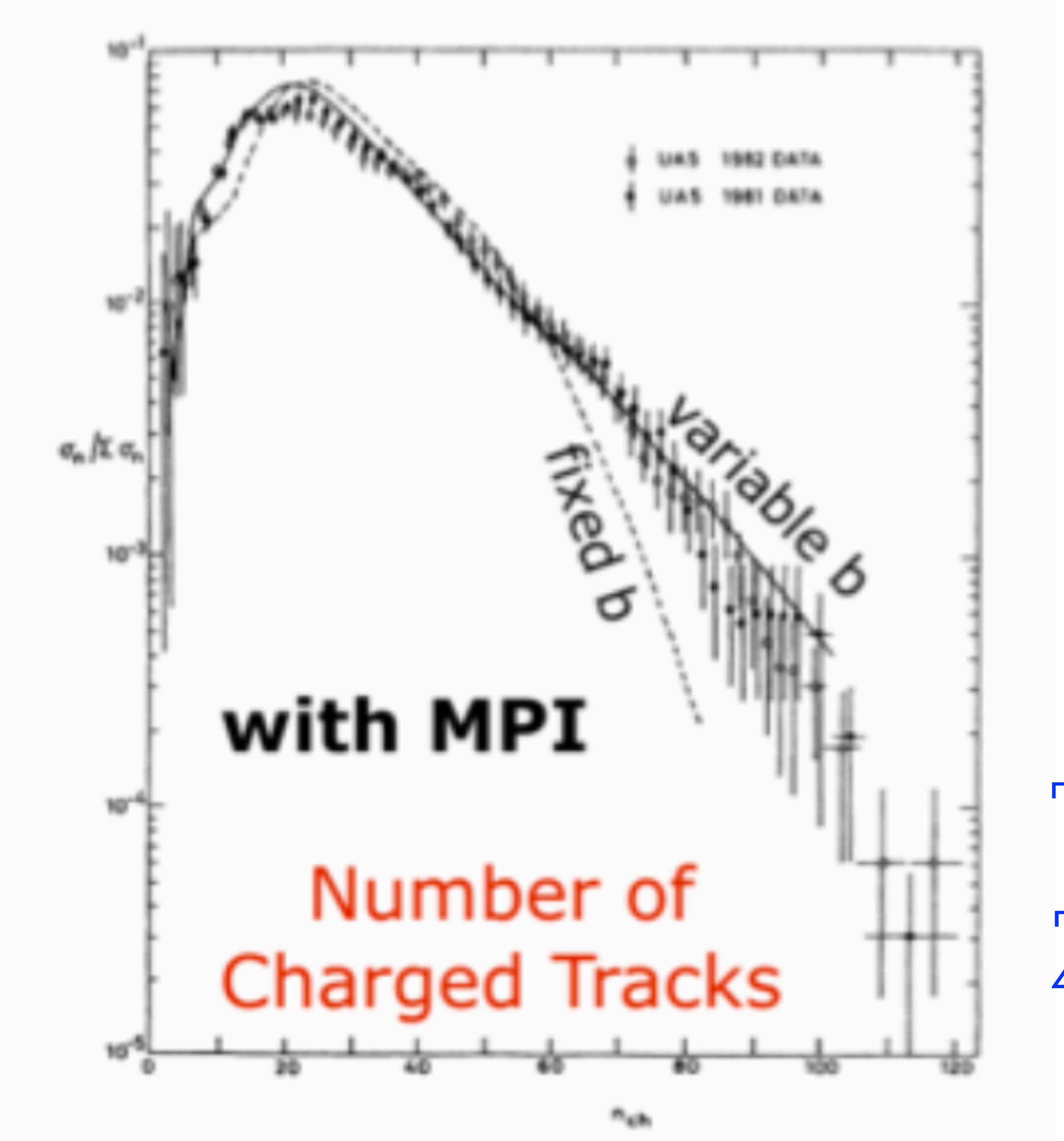


FIG. 12. Charged-multiplicity distribution at 540 GeV, UA5 results (Ref. 32) vs multiple-interaction model with variable impact parameter: solid line, double-Gaussian matter distribution; dashed line, with fix impact parameter [i.e., $\tilde{O}_0(b)$].

MPI help to describe particle multiplicities in MB events

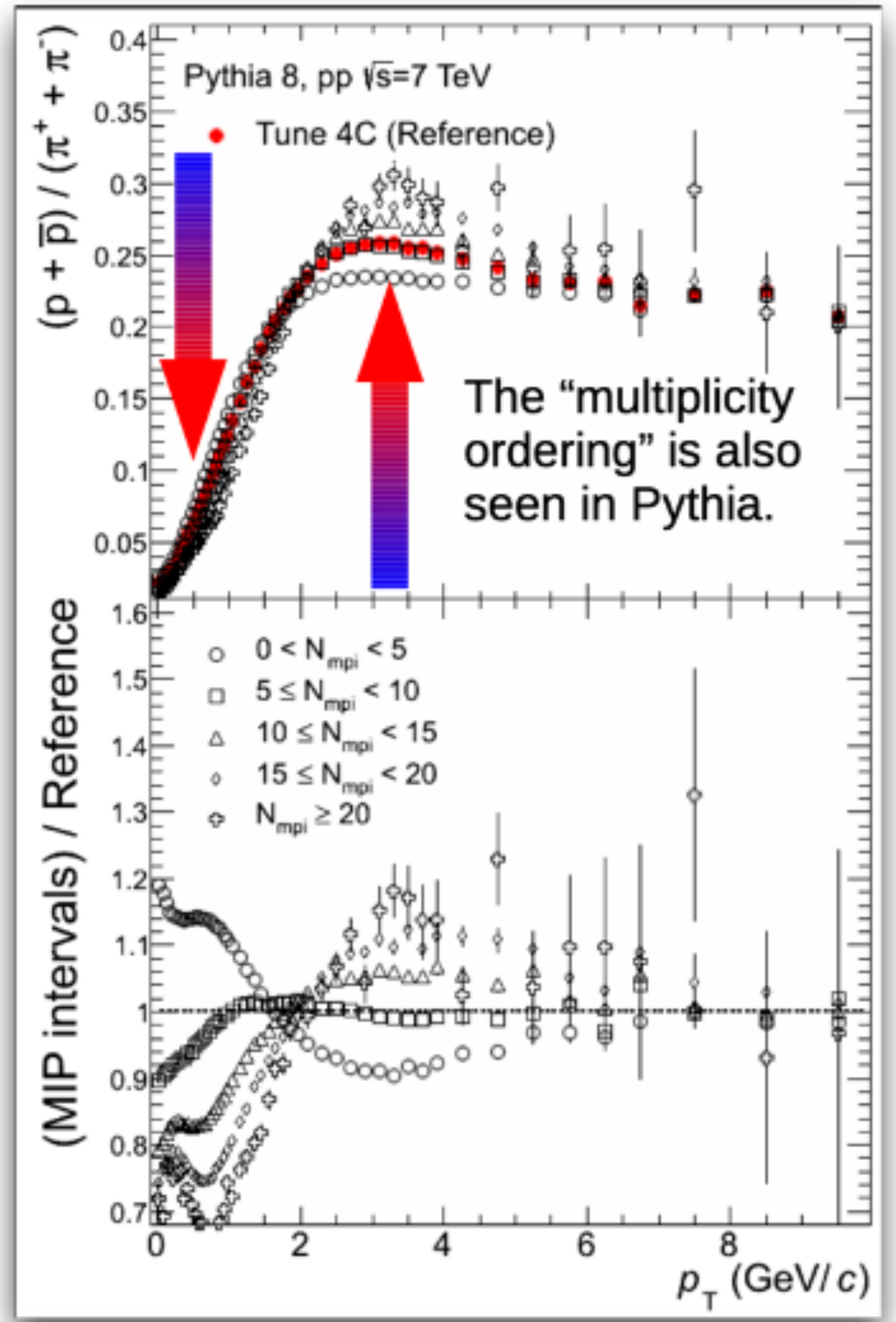
T. Sjöstrand and M. v. Zijl, PRD 36 (1987) 2019

Charged particle multiplicity is expected to be sensitive to MPI

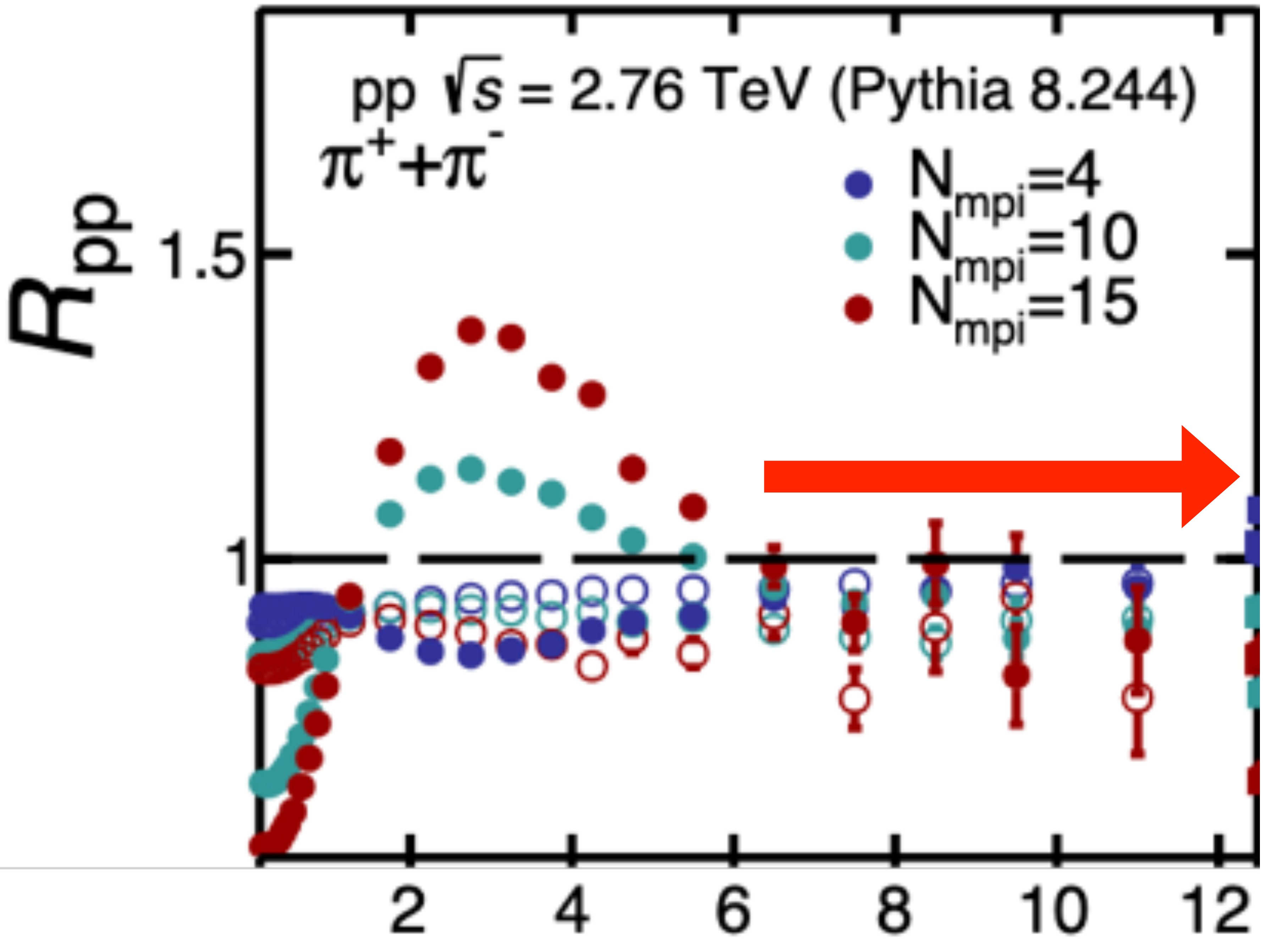
Data support the presence of MPI in high energy pp collisions, see e.g. these recent studies using ML: A. Ortiz et al., PRD 102 (2020) 7,076014, J. Phys. G: Nucl. Part. Phys. 48 (2021) 8, 085014

MPI+string interactions

Phys. Rev. Lett. 111, 042001 (2013)



Radial flow-like behaviour



$$R_{pp} = \frac{d^2N_{ch}^{mpi}/(\langle N_{mpi}\rangle d\eta dp_T)}{d^2N_{ch}^{MB}/(\langle N_{mpi}^{MB}\rangle d\eta dp_T)}$$

Phys. Rev.D 102 (2020) 7, 076014

Scaling with number of parton-parton interactions at high p_T

High energy heavy-ion collisions

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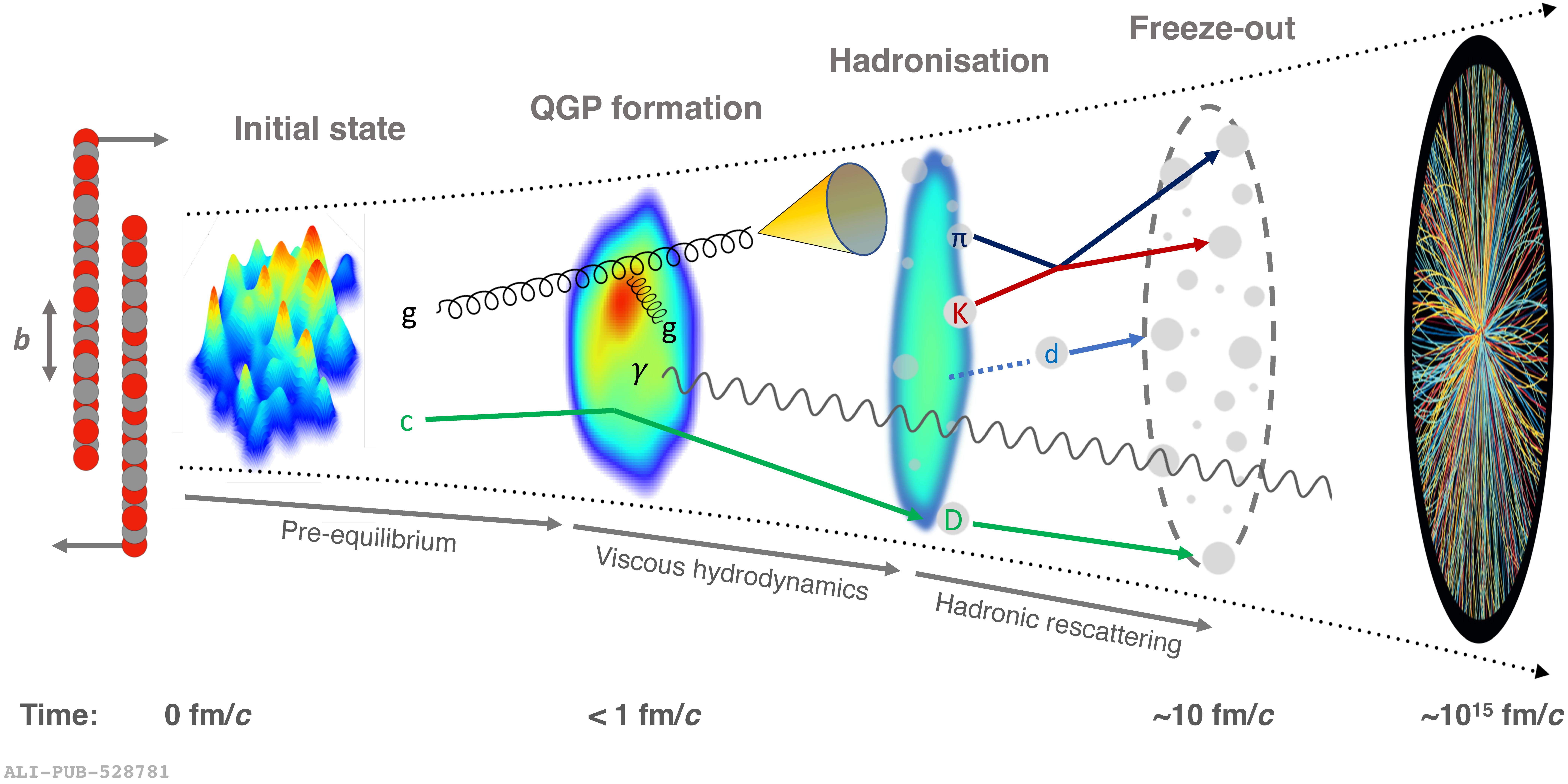

High-p_T physics: V0M vs flattenicity

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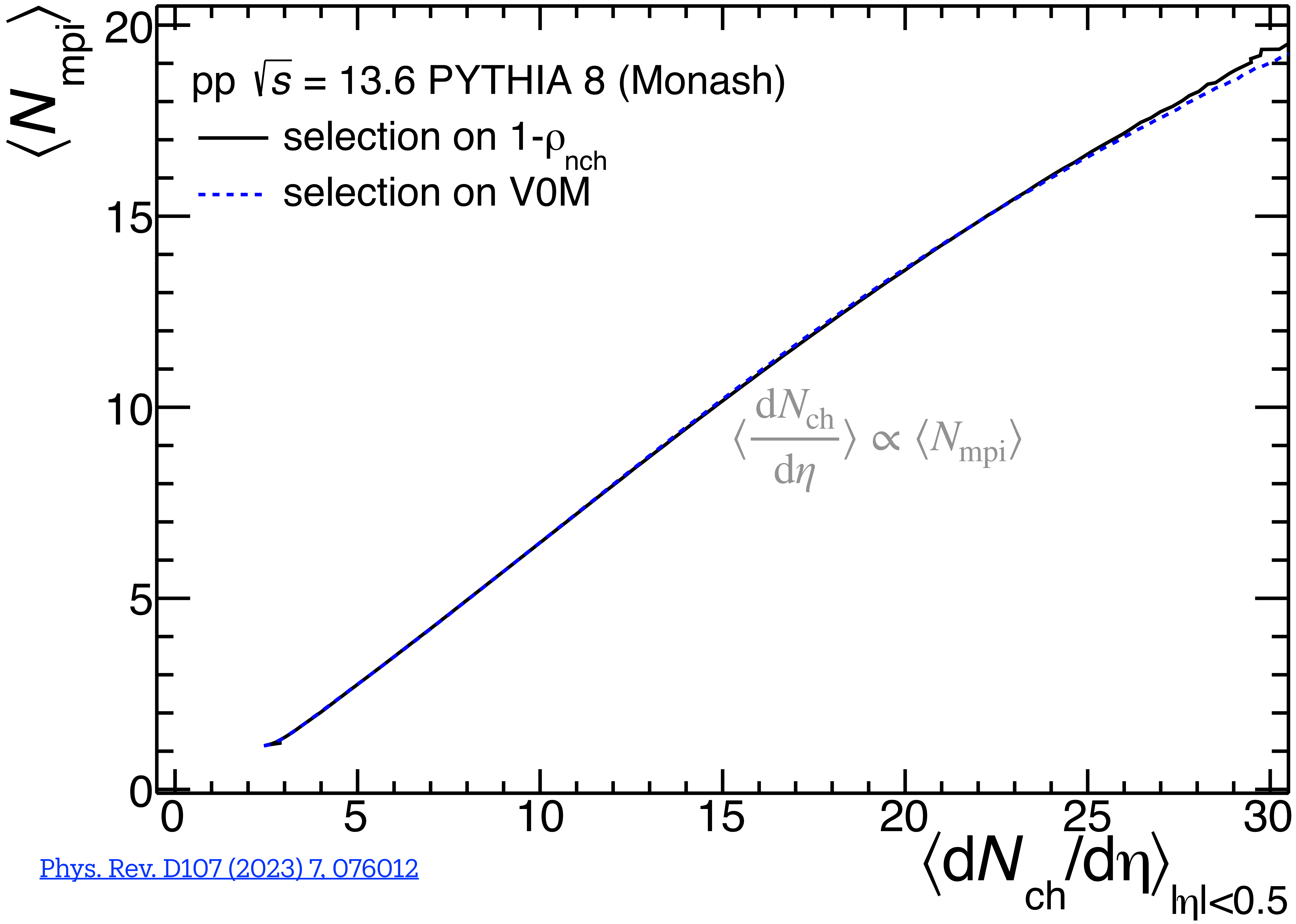

Phys. Rev. D107 (2023) 7, 076012

Centrality in small systems (p-Pb)

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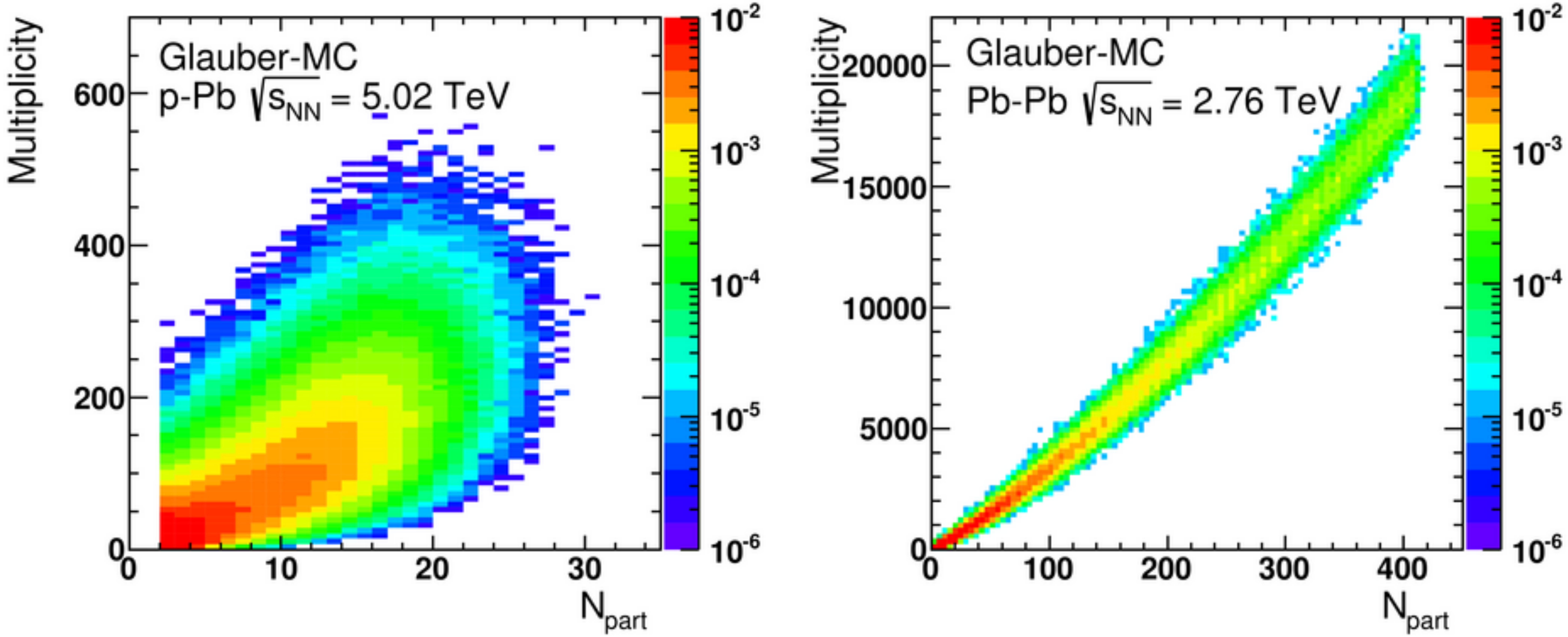
In contrast to Pb–Pb collisions, for p–Pb collisions the multiplicity (V0A) fluctuations are sizeable compared to the width of the N_{part} distribution



Phys. Rev. C 91 (2015) 064905

Weak correlation between geometry and event activity

Issues to search for jet quenching

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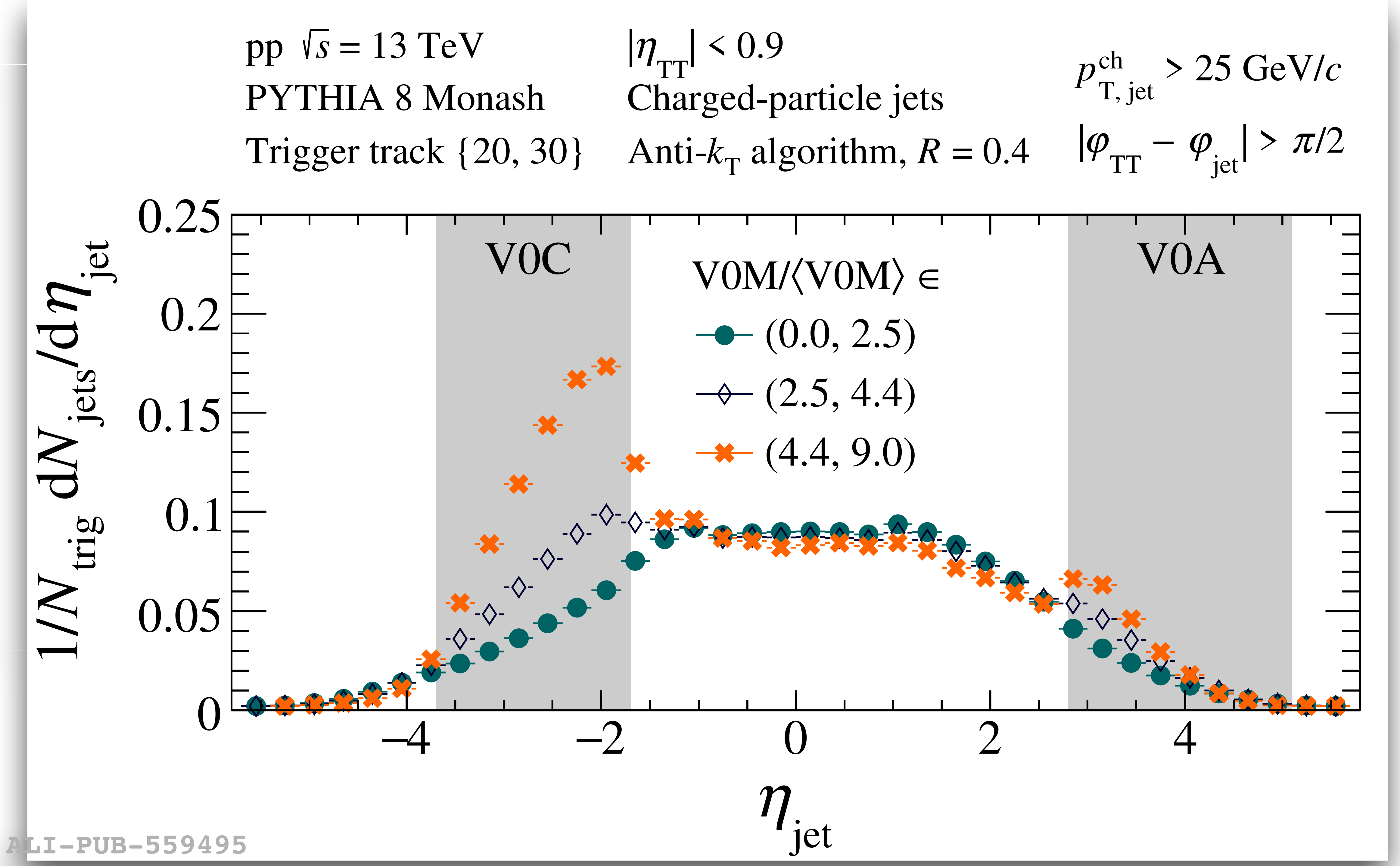
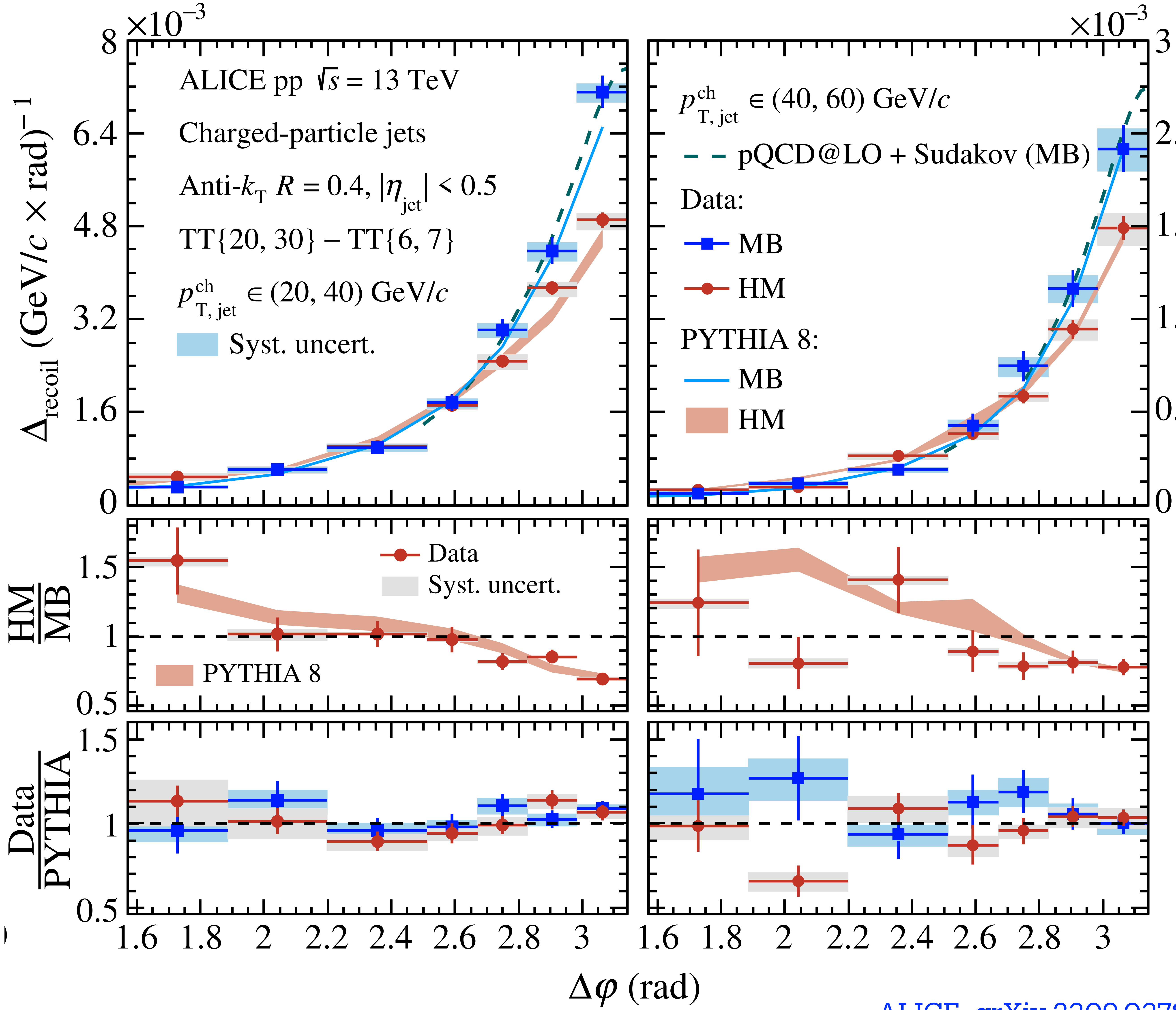


The HM V0M multiplicity class selects pp collisions with jets in the forward detector, consequently biasing the acoplanarity distribution measured in the central region



ALICE, arXiv:2309.03788