Unveiling the origin of QGP-like effects in pp and p-Pb collisions using flattenicity

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Workshop on Advances, Innovations, and Future Perspectives in High-Energy Nuclear Physics

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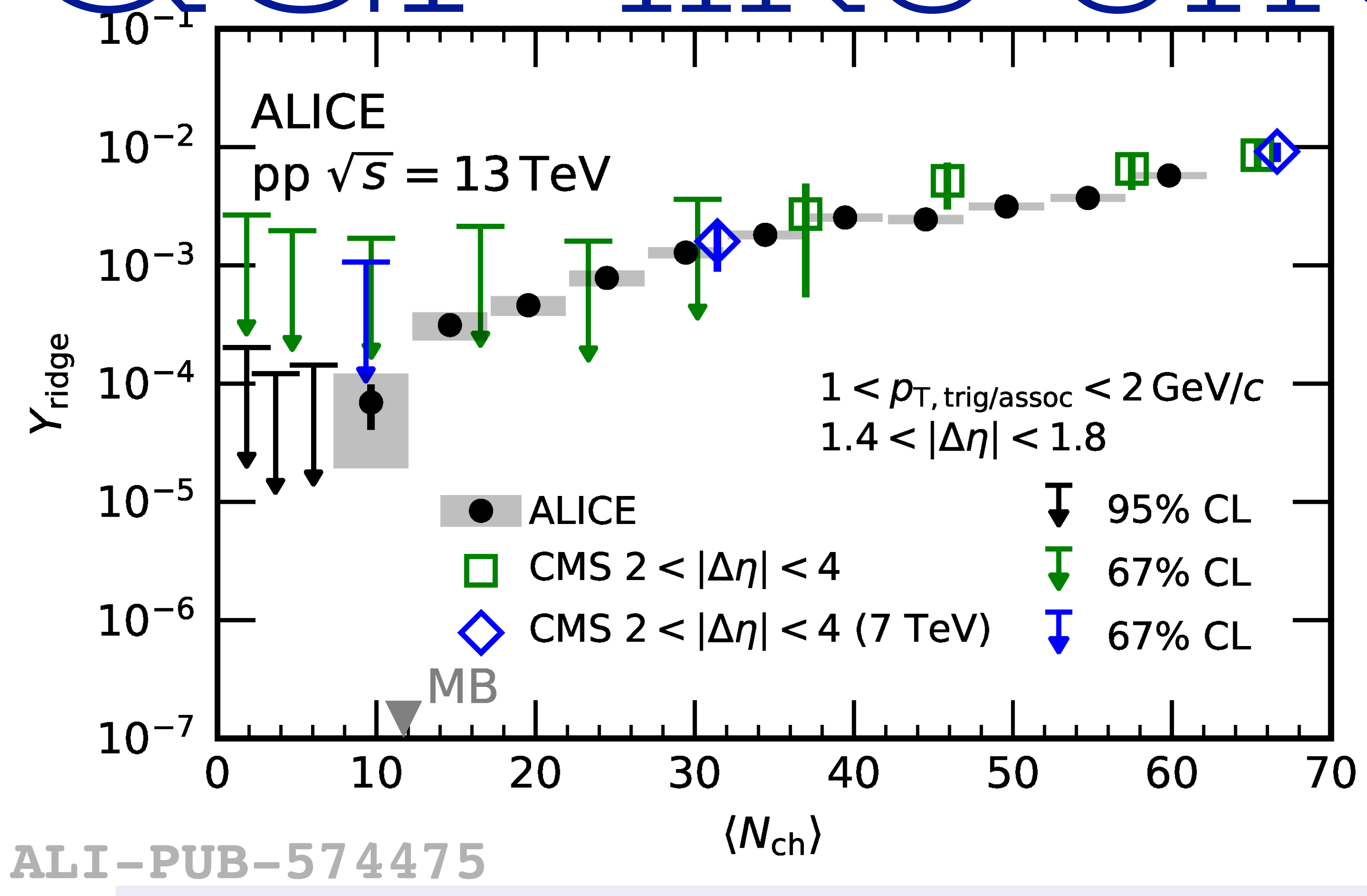
OUTLINE

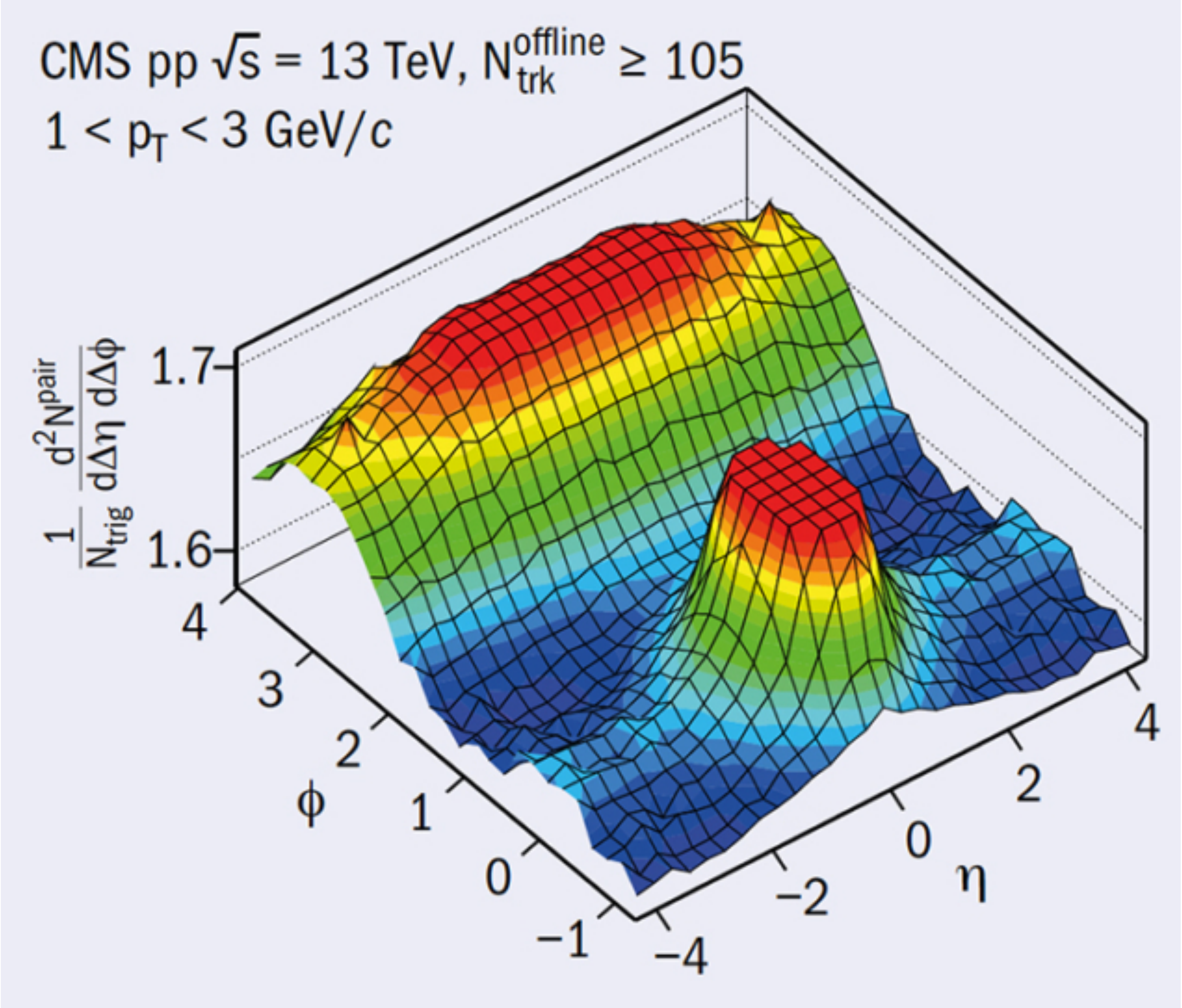
- Heavy-ion-like effects in pp and p-Pb collisions
- Selection biases in small systems
- Flattenicity in pp: data vs PYTHIA, EPOS LHC and EPOS 4 (new)
- Flattenicity in p-Pb collisions
- Conclusions

QGP-like effects in small systems

ALICE, PRL 132 (2024) 17, 172302



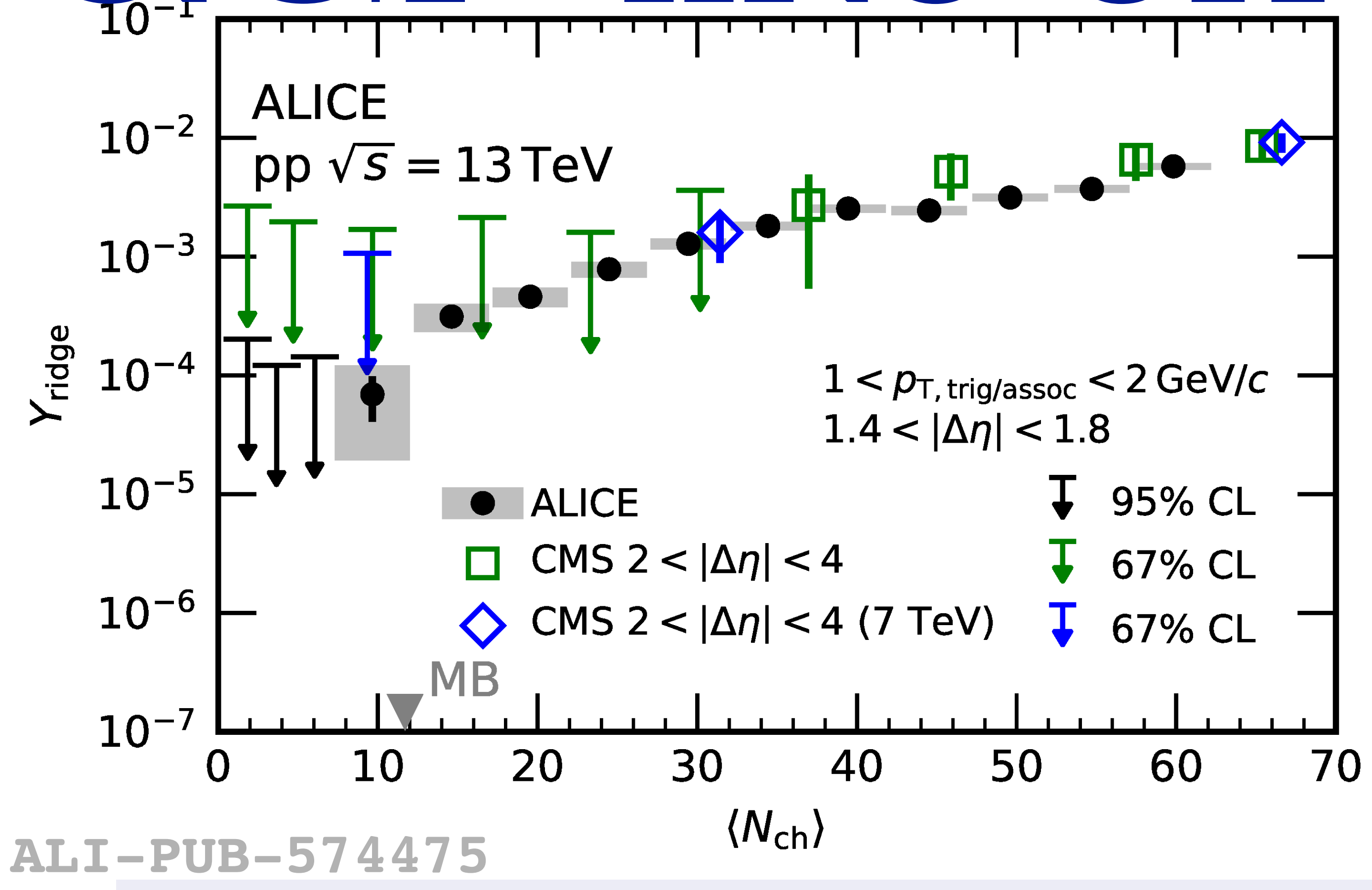
CMS, JHEP (2019) 1009:091



- Long range angular correlations in low- and high-multiplicity (HM) pp collisions

QGP-like effects in small systems

ALICE, PRL 132 (2024) 17, 172302



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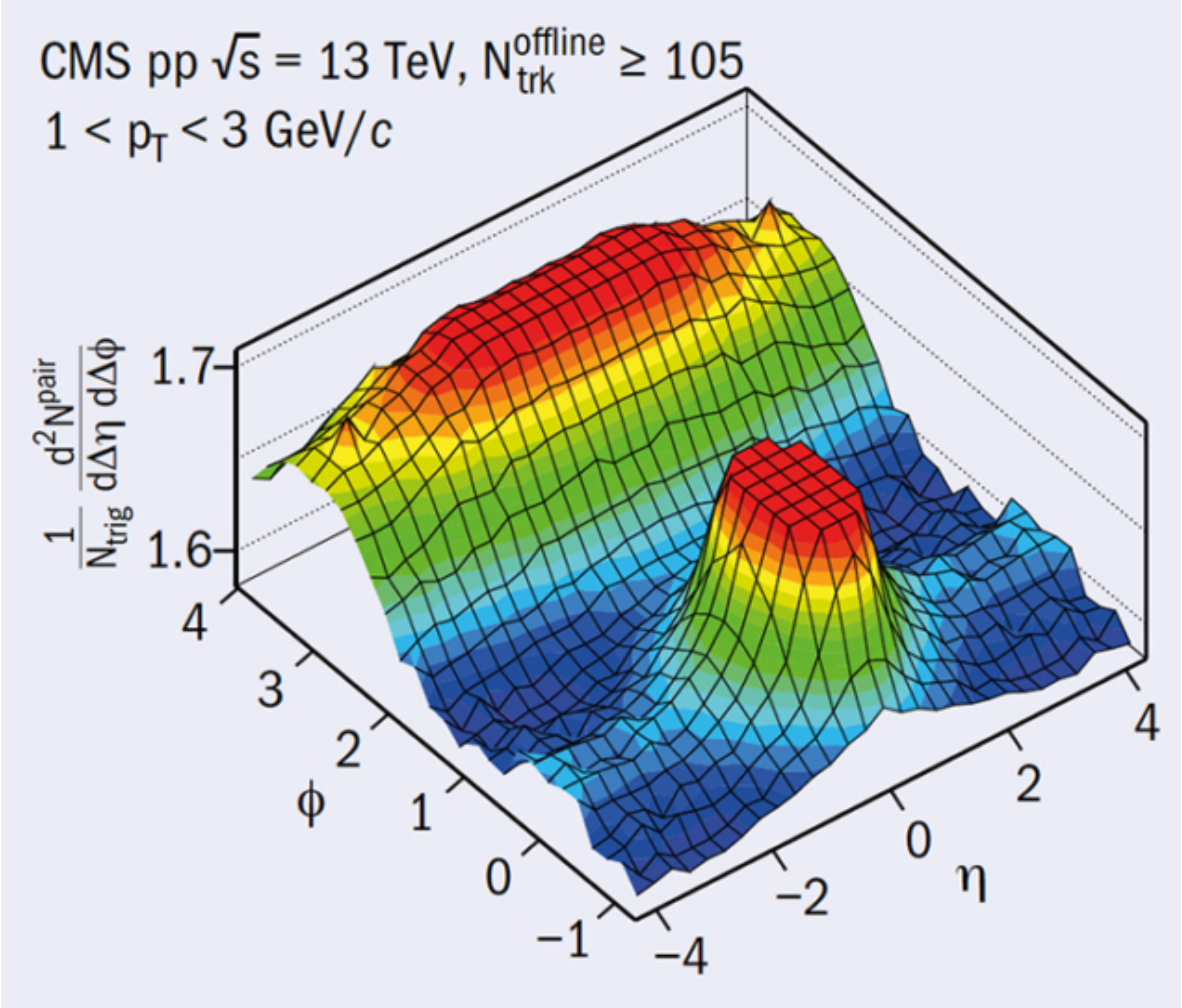
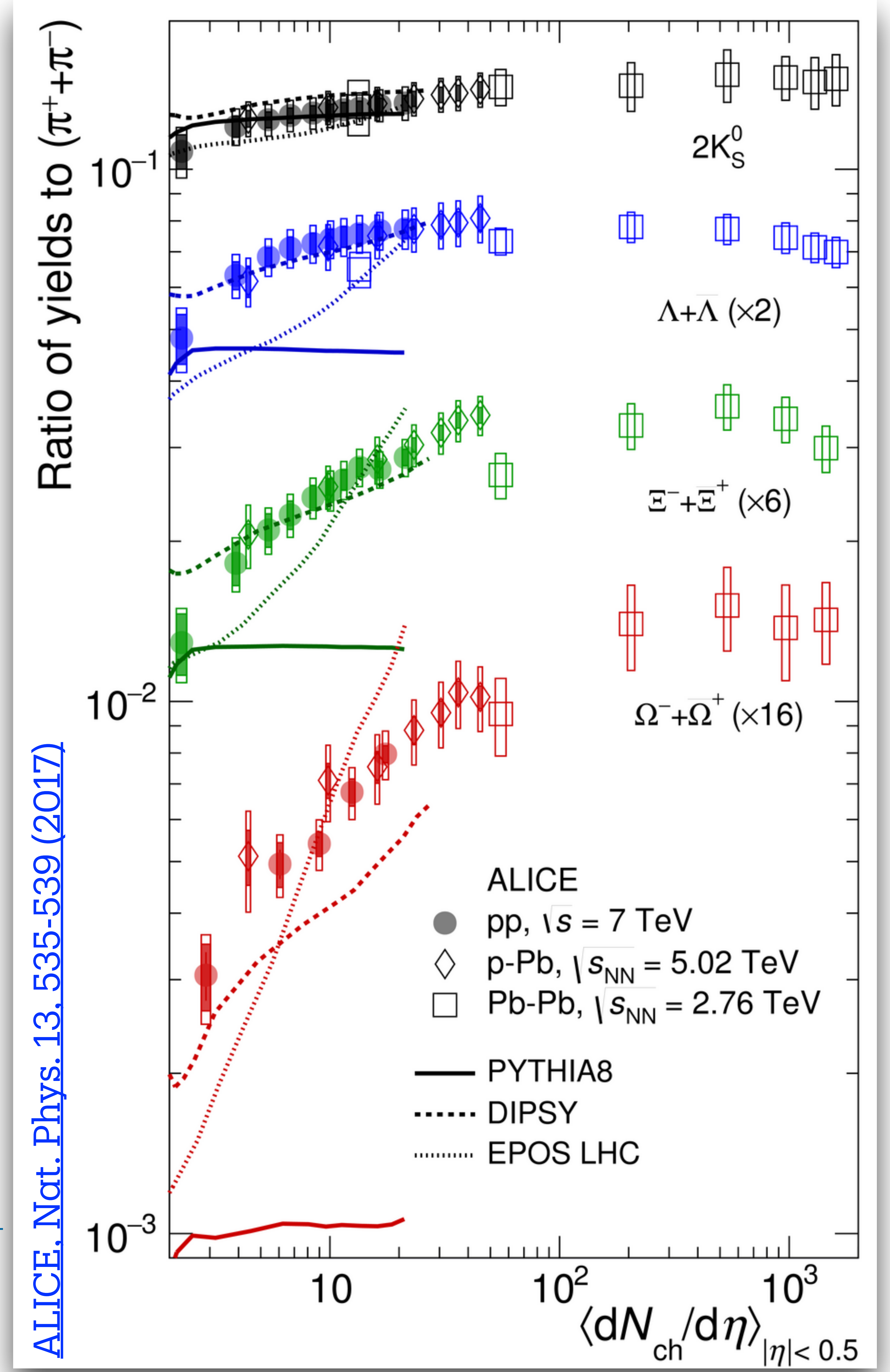


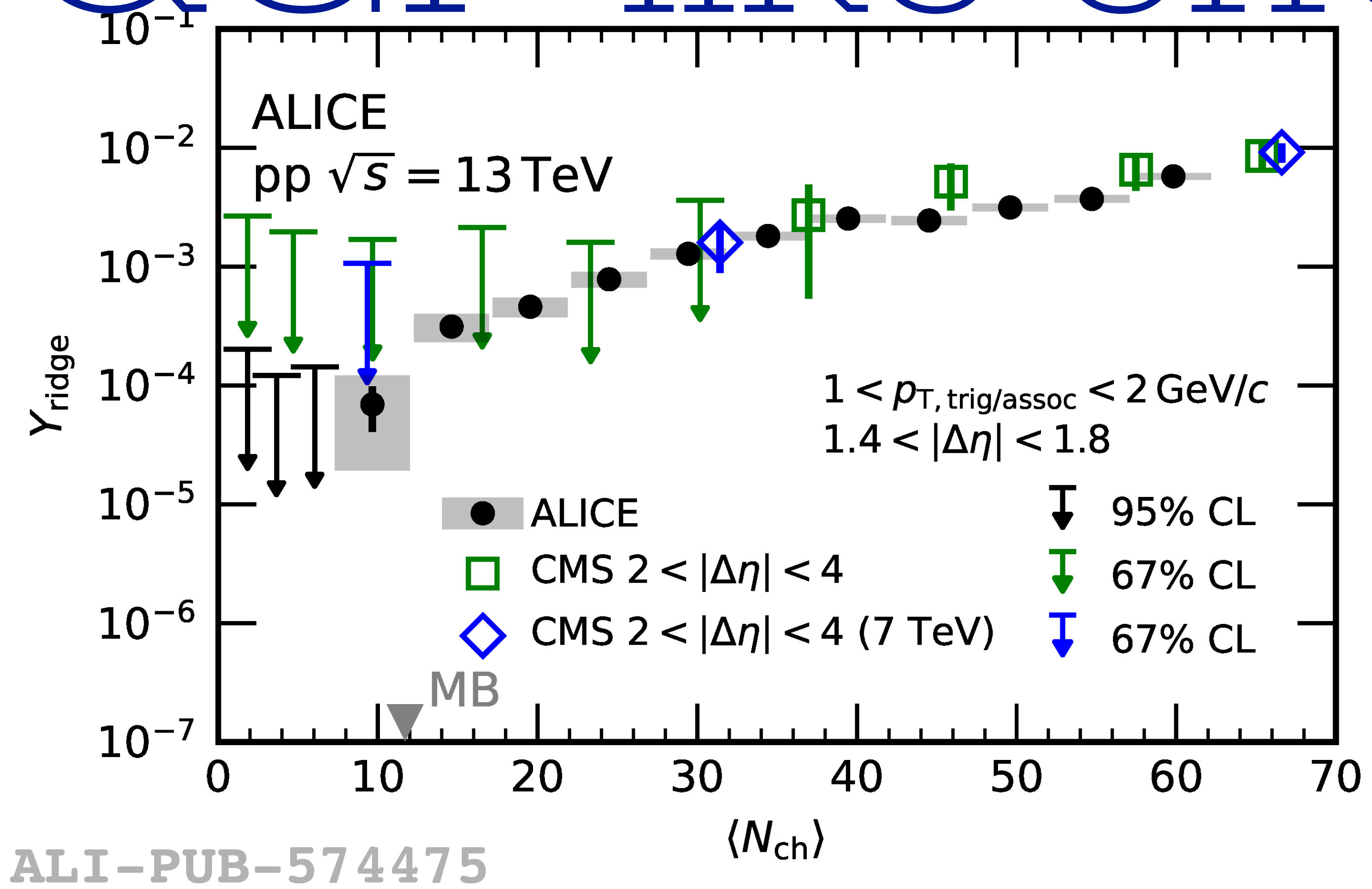
- Long range angular correlations in low- and high-multiplicity (HM) pp collisions

- Strangeness enhancement

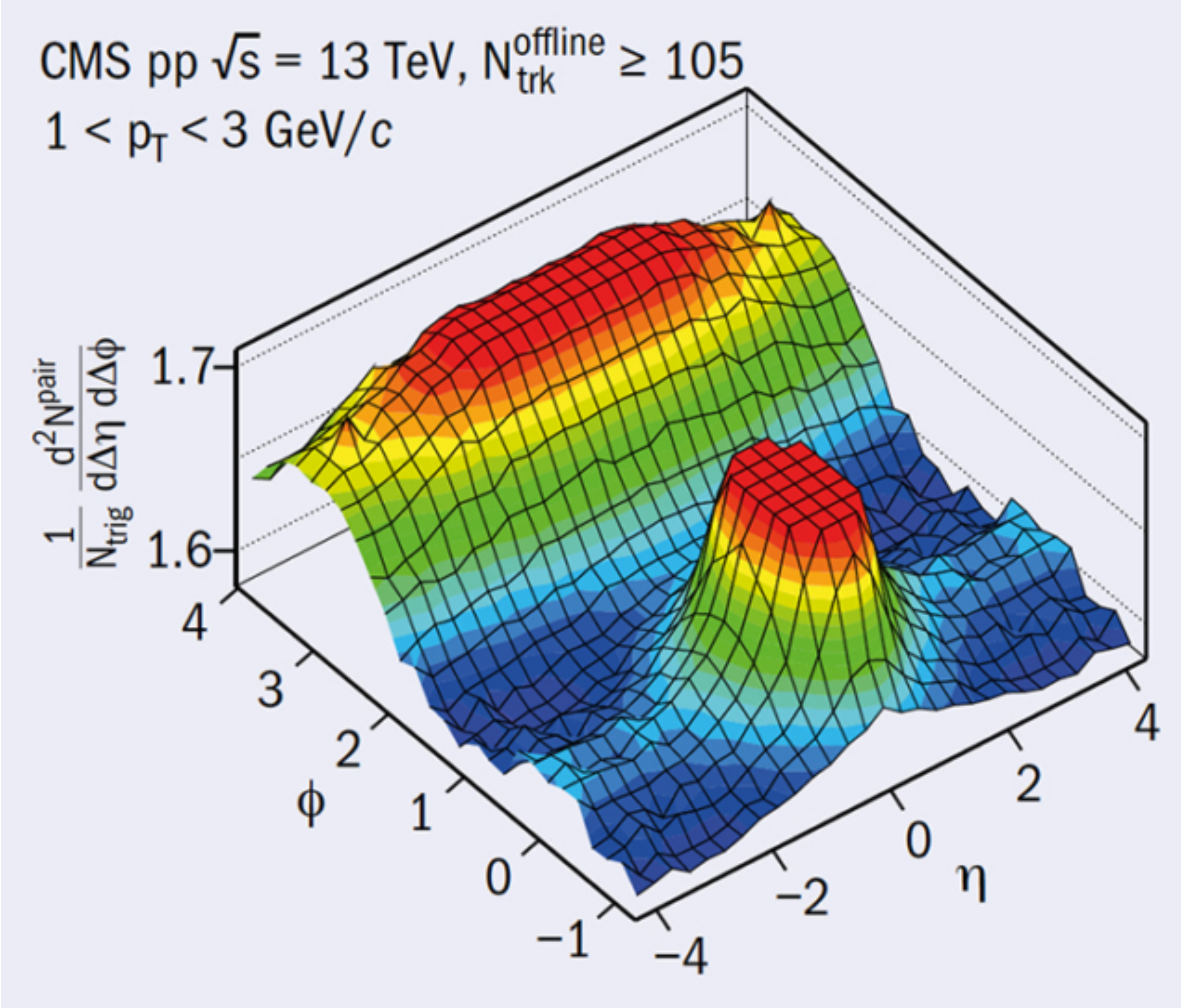
ALICE, Nat. Phys. 13, 535-539 (2017)



QGP-like effects in small systems



ALICE, PRL 132 (2024) 17,172302



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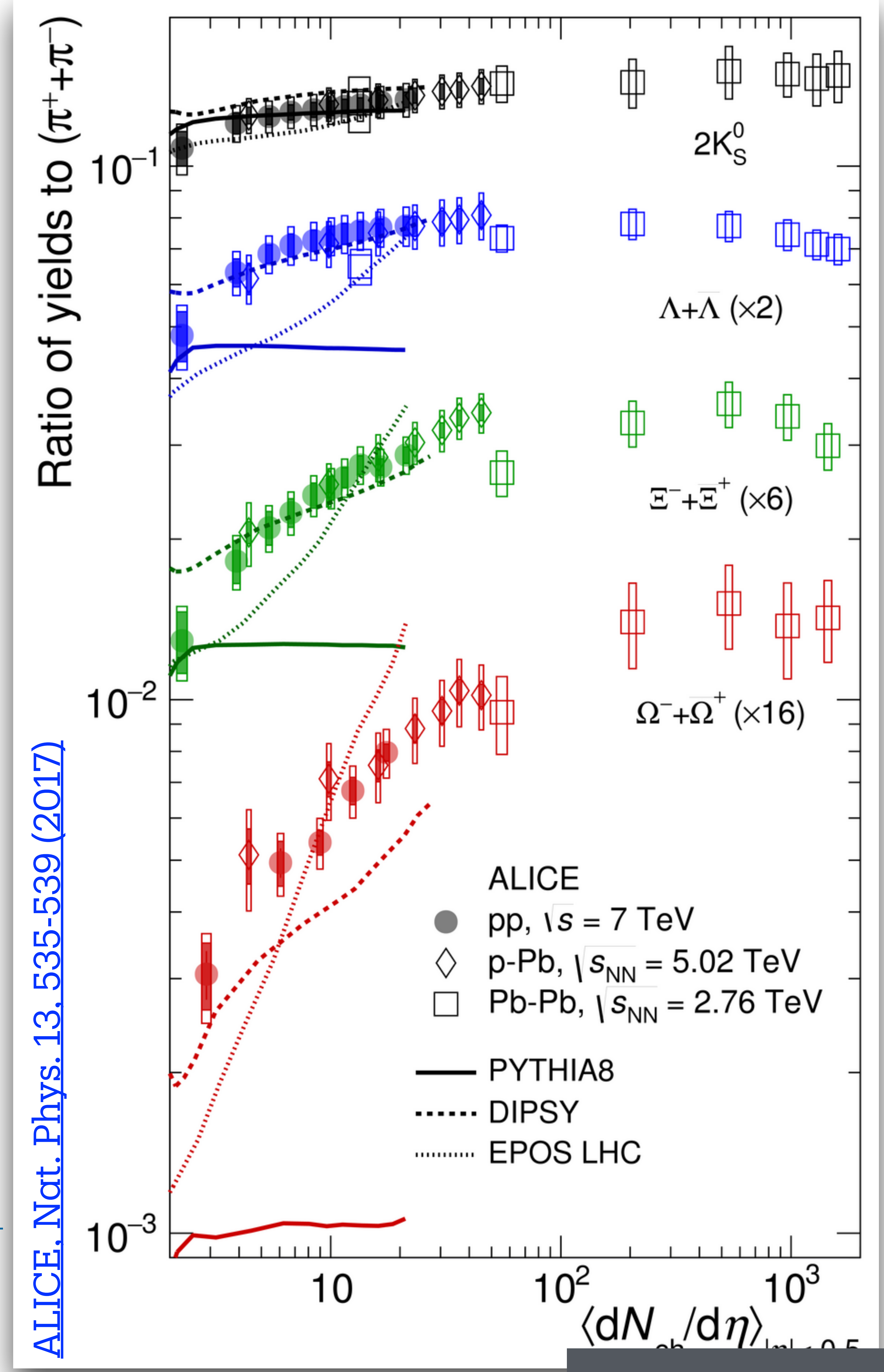
Long range angular correlations in low- and high-multiplicity (HM) pp collisions

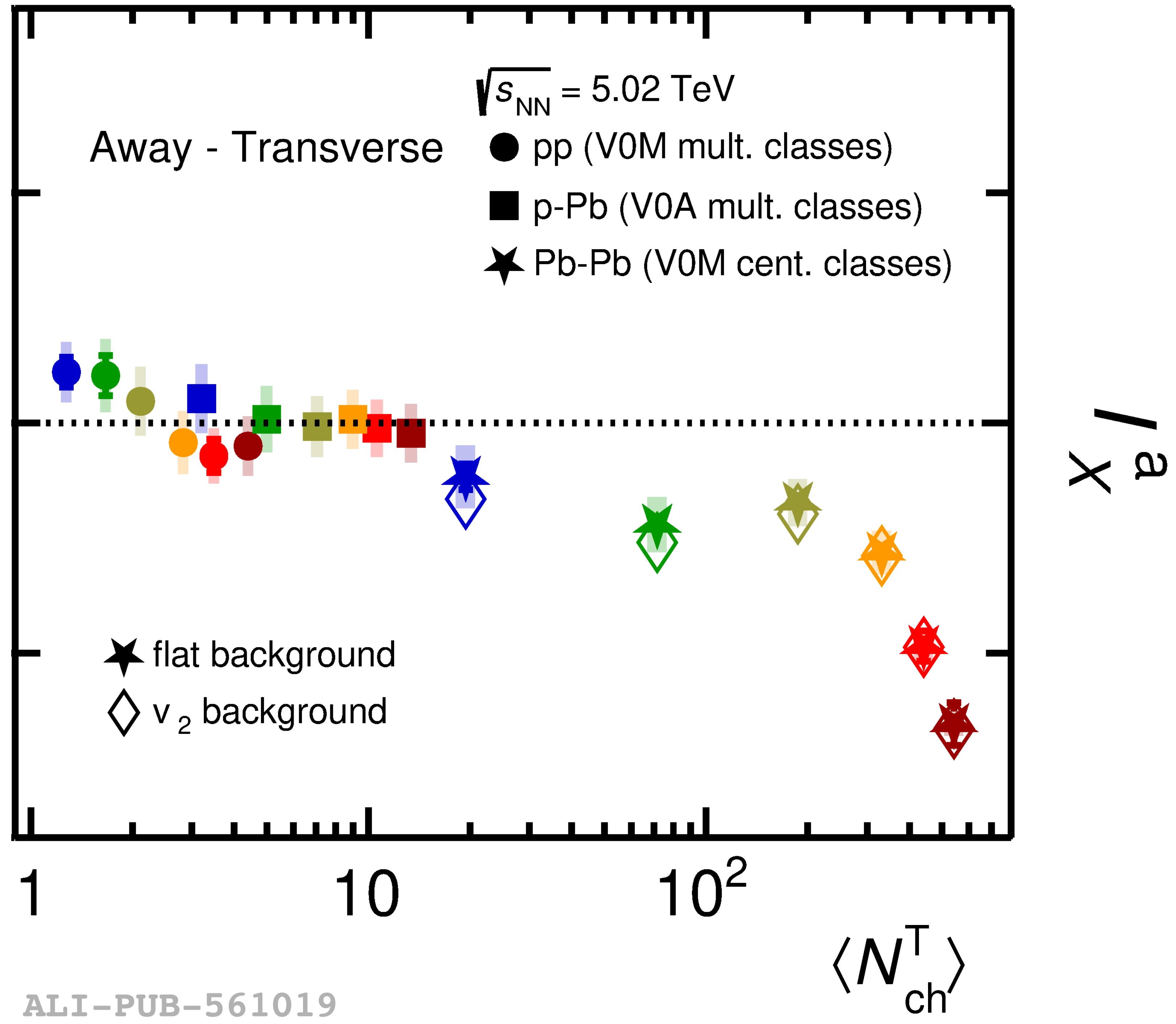
Strangeness enhancement



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

$$8 < p_T^{trig} < 15\,\text{GeV}/c$$

Jet quenching?



ALICE, PLB 843 (2022) 137649

pp and p-Pb collisions: small effect is driven by a bias (search is ongoing)

More about small systems, Jurgen Schukraft talk, 20/10/24

Bias due to local mult. fluctuations

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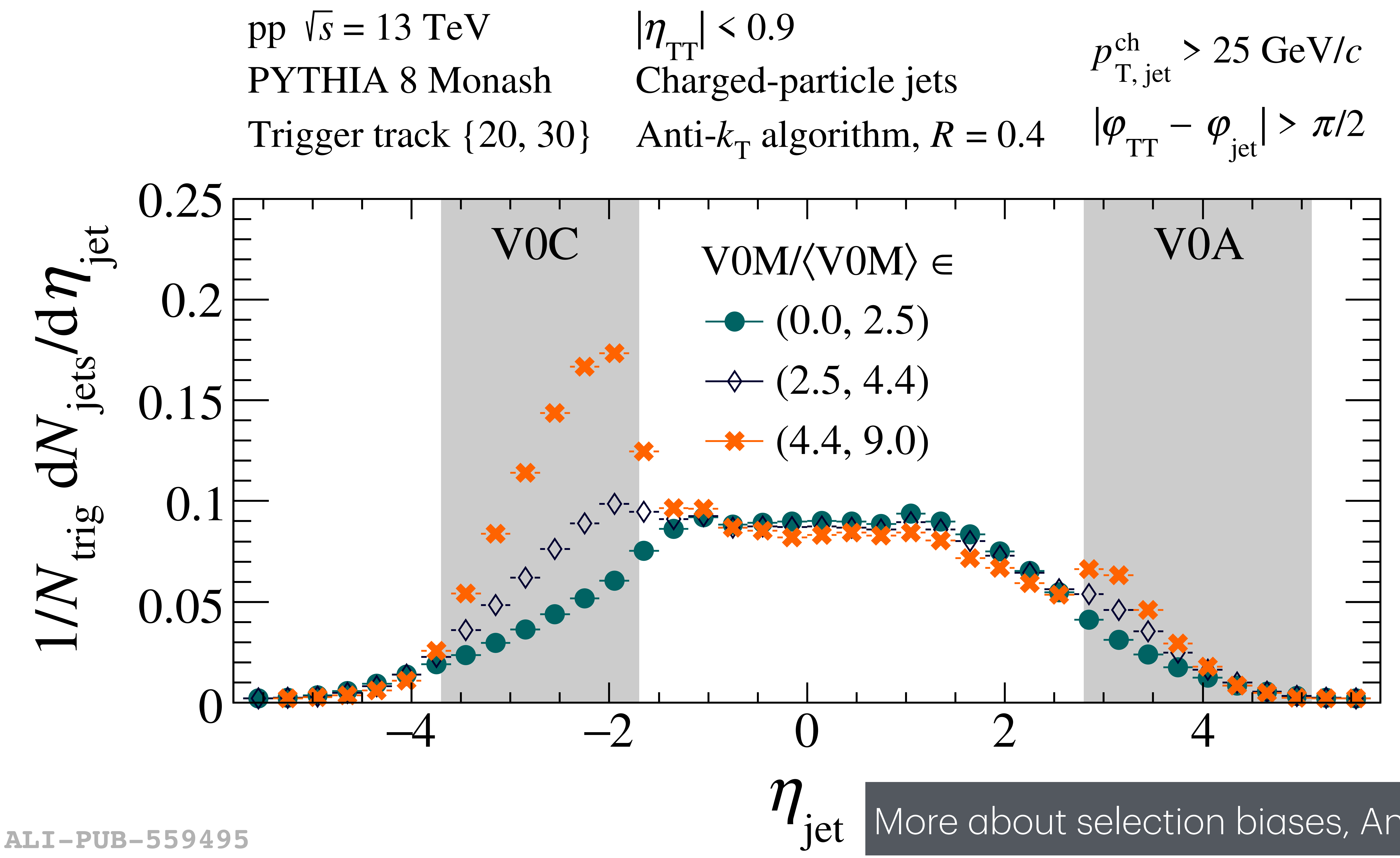

More about selection biases, Andreas Morsch talk, 21/10/24

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

ALICE, JHEP 05 (2024) 229   ALICE, Phys. Lett. B 843 (2022) 137649

Bias due to local mult. fluctuations

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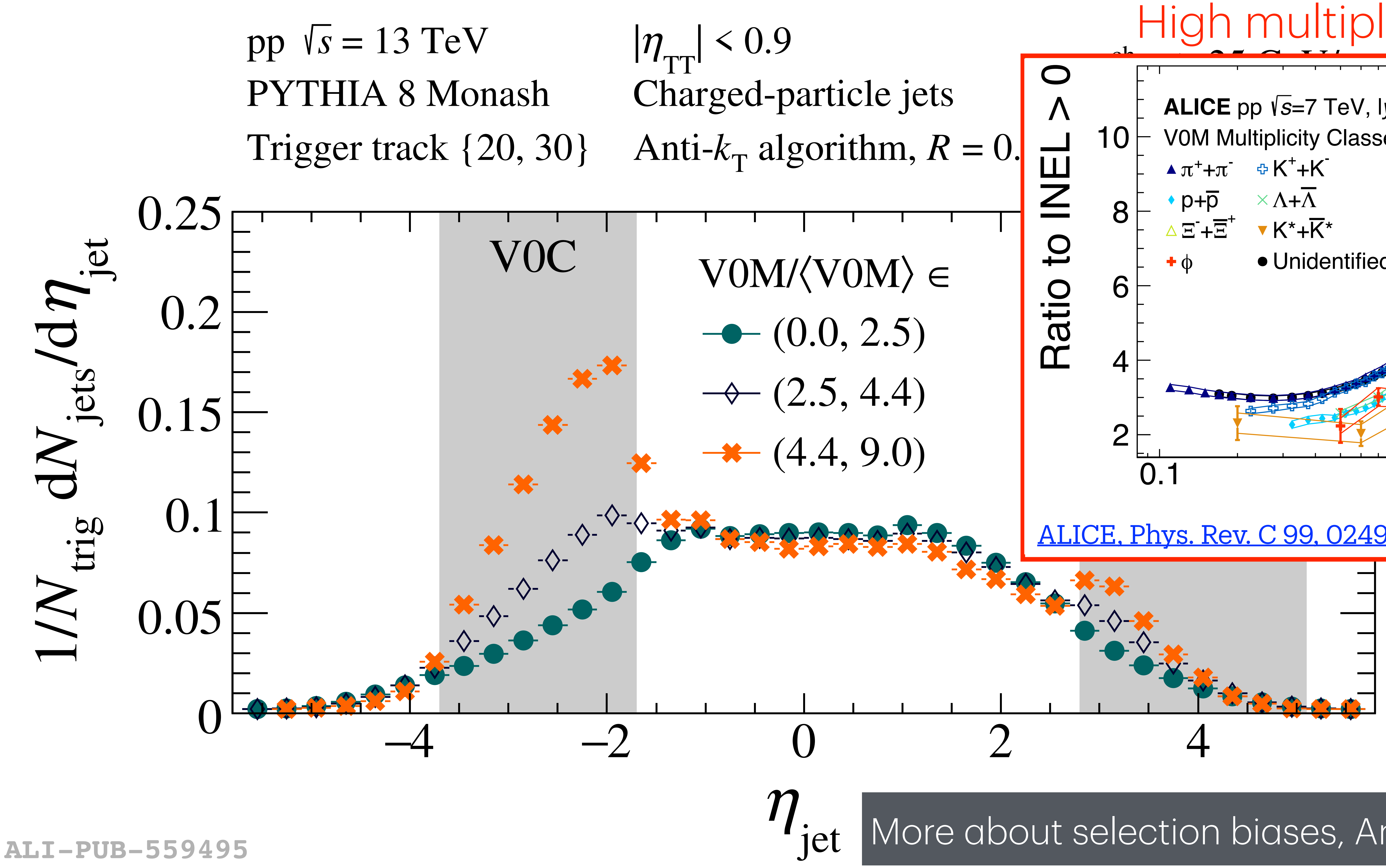
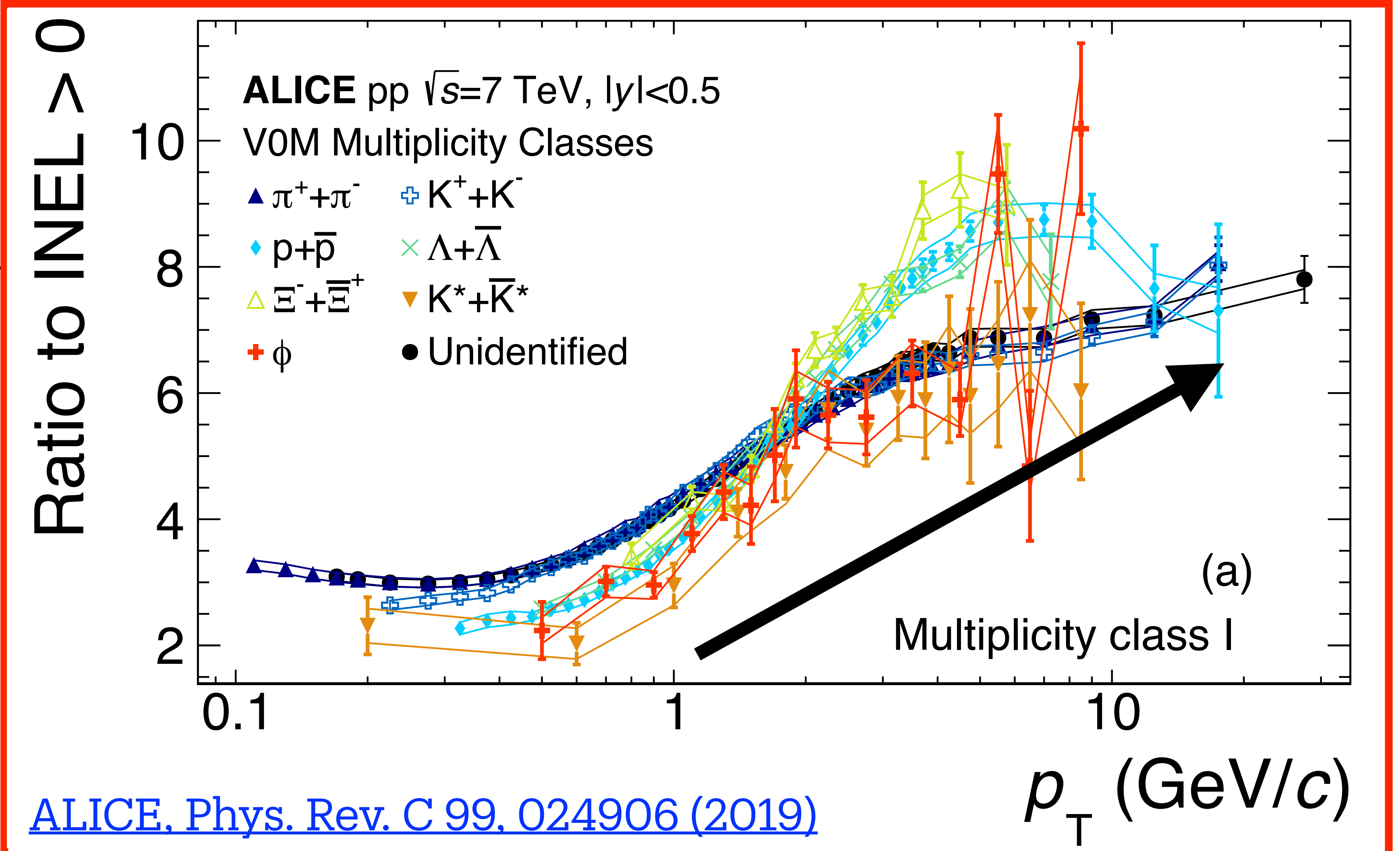


High multiplicity V0M events



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

More about selection biases, Andreas Morsch talk, 21/10/24

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

ALICE, JHEP 05 (2024) 229 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

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

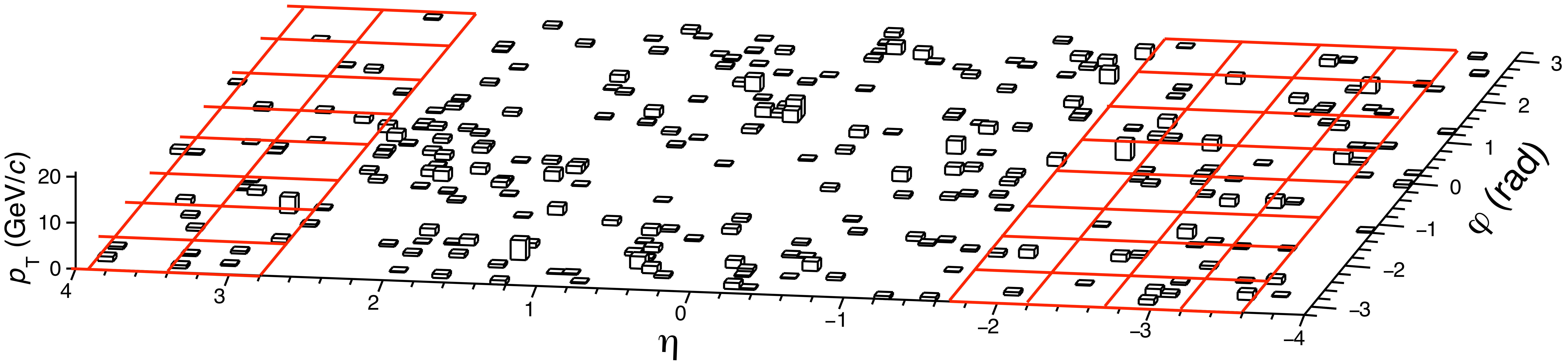
Flattenicity

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](#)

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

PYTHIA 8.303 (Monash 2013), pp $\sqrt{s}$ = 13 TeV, N_{mpi}=24



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, $N^{(\mathrm{ch.}\,i)}$

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

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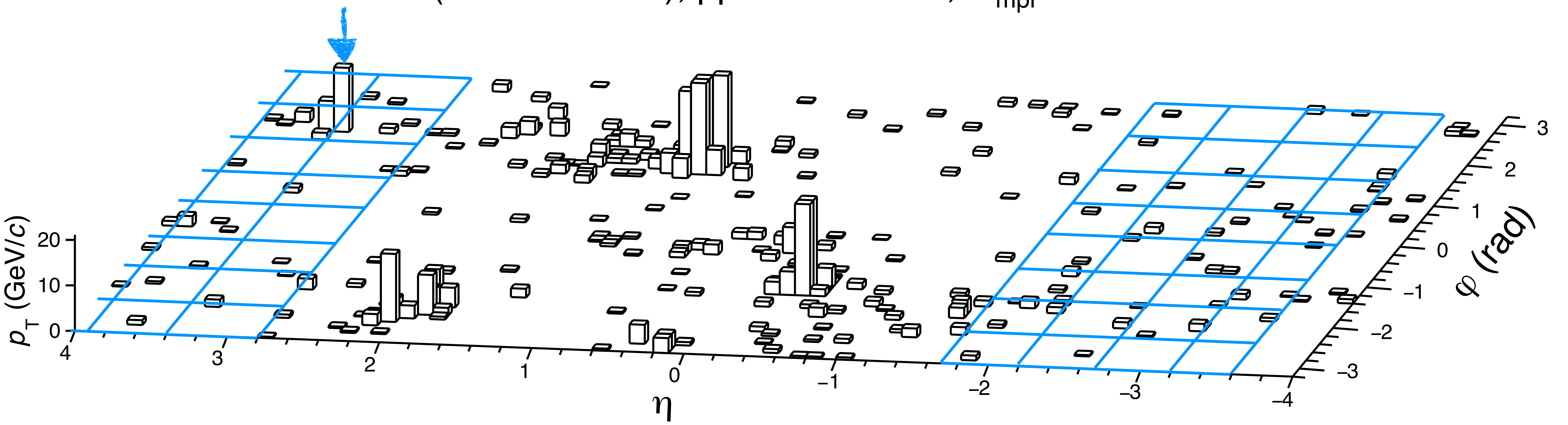
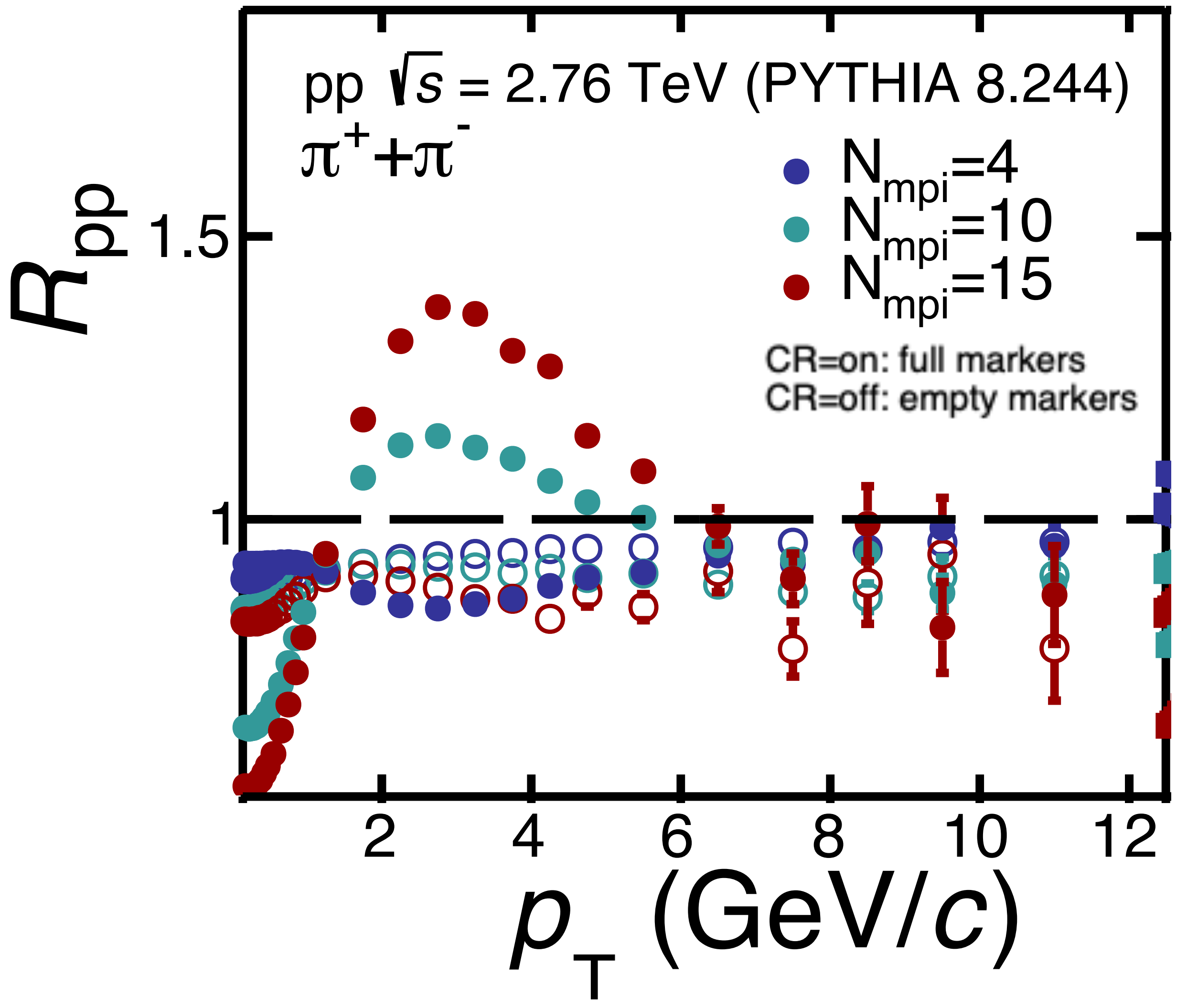


Large local $N^{(\mathrm{ch.}\,i)}$ fluctuations in the V0 acceptance: large flattenicity values

- jet structures, small multiplicity

High-p_T physics: V0M vs flattenicity

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 flattenicity

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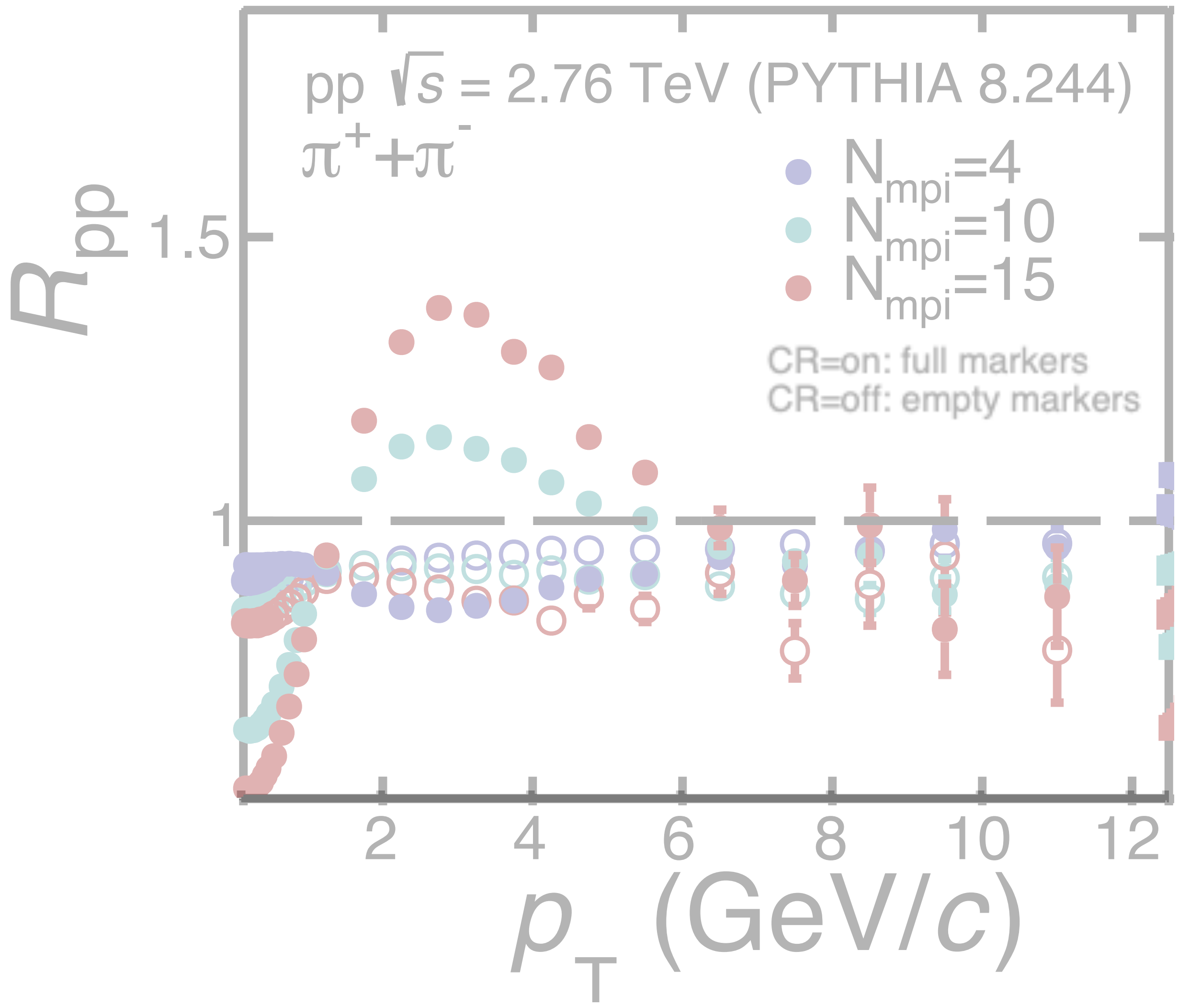
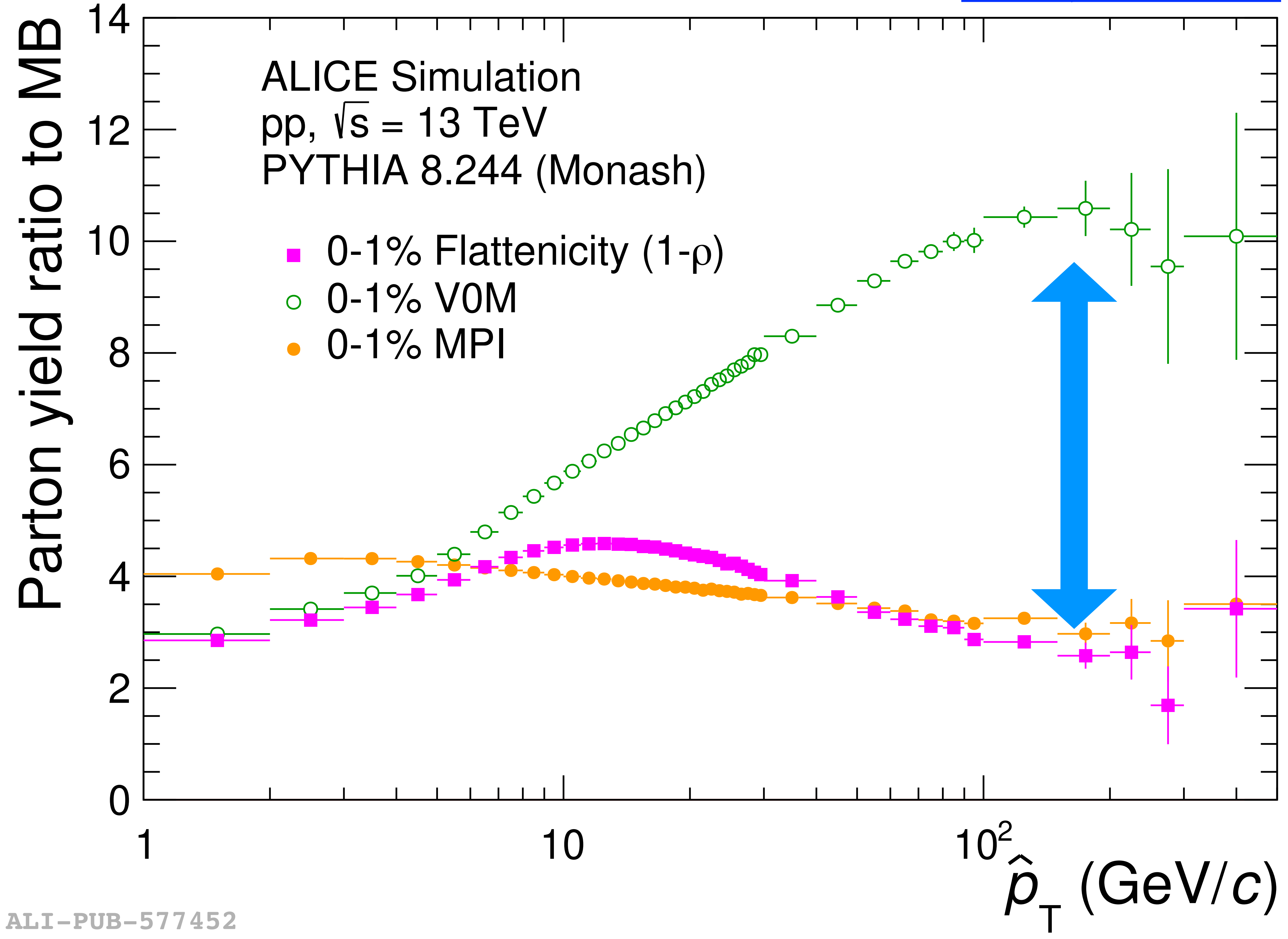
A. Ortiz et al., Phys. Rev. D102 (2020) 7, 076014



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

$${\rm ratio}(\hat{p}_{\rm T}) = \frac{\left.\frac{1}{N_{\rm ev}}\frac{{\rm d}N_{\rm parton}}{{\rm d}\hat{p}_{\rm T}}\right|_{1\%\,{\rm xsec}}}{\left.\frac{1}{N_{\rm ev}}\frac{{\rm d}N_{\rm parton}}{{\rm d}\hat{p}_{\rm T}}\right|_{\rm MB}}$$

ALICE, 2407.20037



High-p_T physics: V0M vs flattenicity

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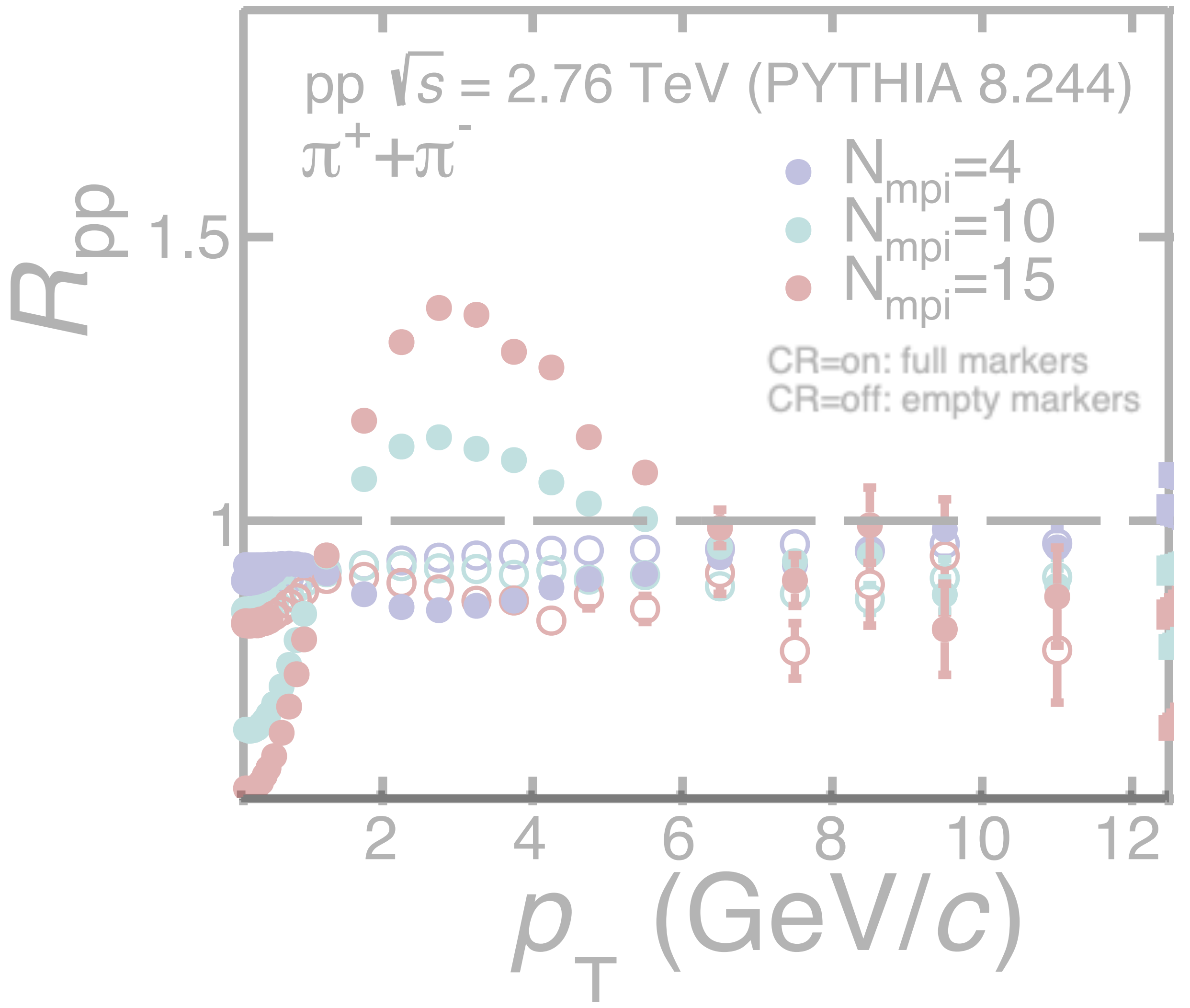
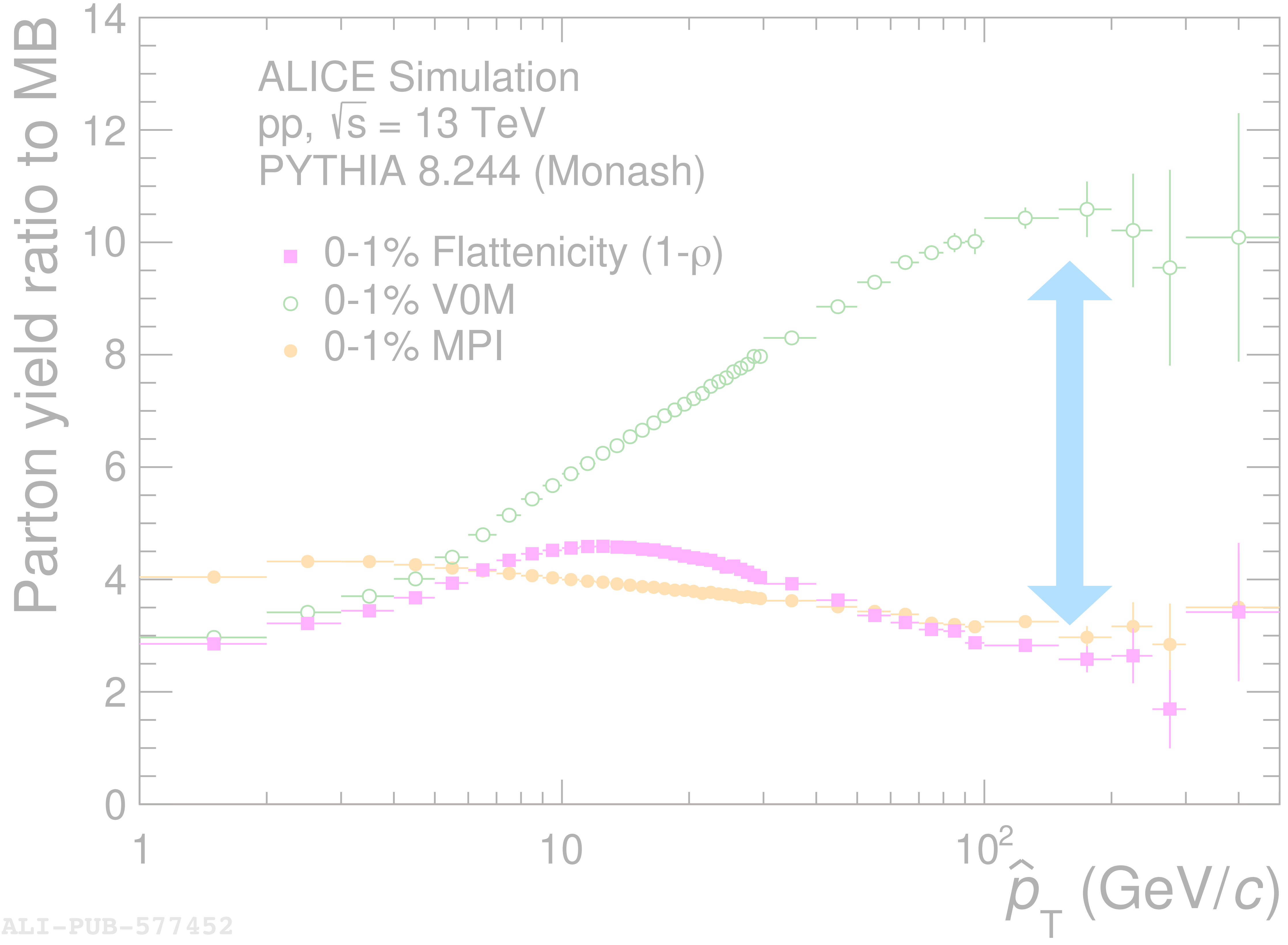


$$R_{pp}(p_T) = \frac{\frac{1}{N_{ev}}\frac{dN_{ch}}{dp_T}\frac{1}{\langle N_{mpi}\rangle}\Big|_{\text{high MPI}}}{\frac{1}{N_{ev}}\frac{dN_{ch}}{dp_T}\frac{1}{\langle N_{mpi}\rangle}\Big|_{\text{MB}}}$$

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



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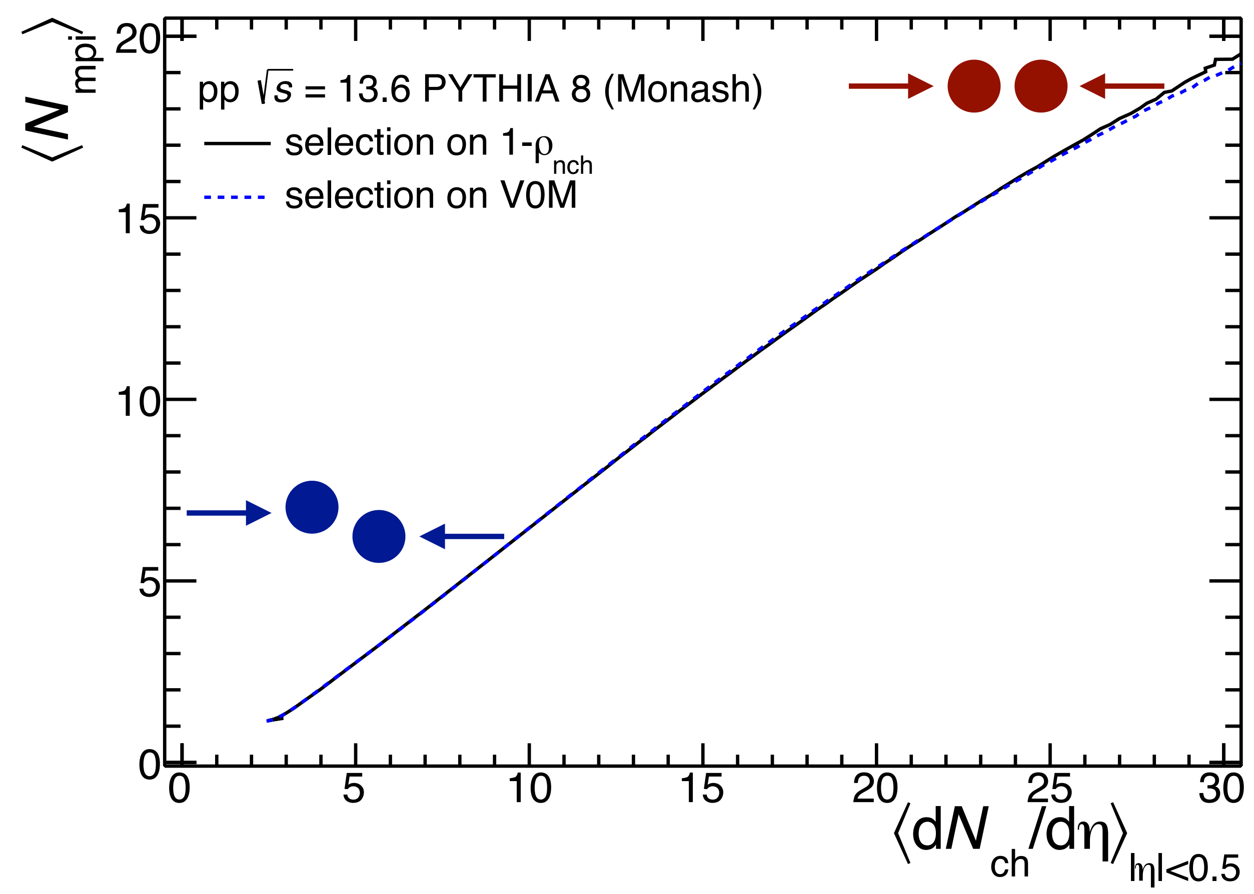


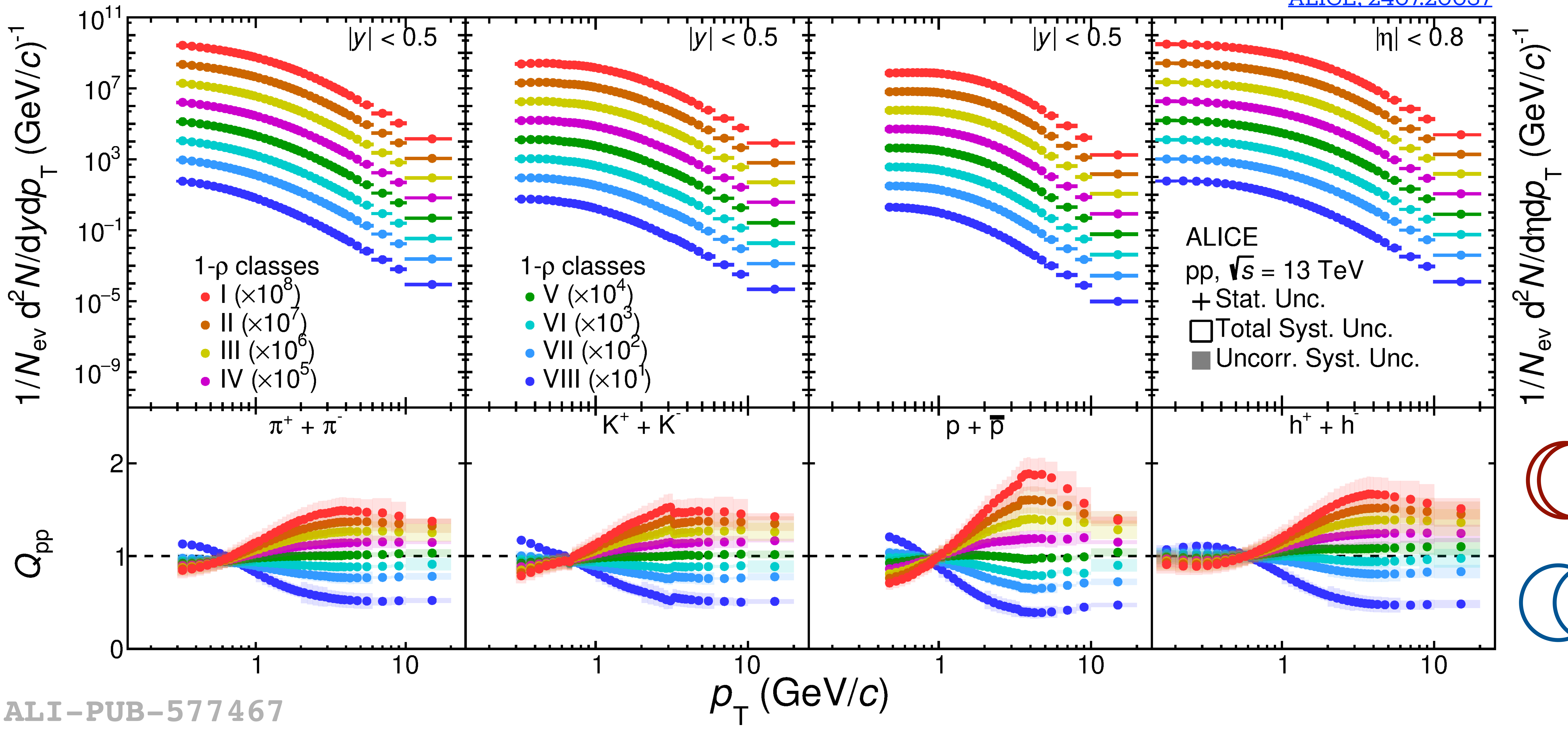
$$\left\langle \frac{dN_{ch}}{d\eta} \right\rangle \propto \langle N_{mpi} \rangle$$

Experimentally:

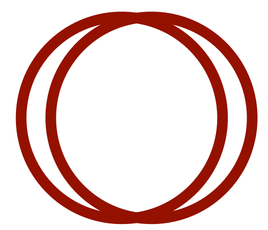
$$Q_{pp}(p_T) = \frac{\frac{1}{N_{ev}}\frac{dN_{ch}}{dp_T}\frac{1}{\langle N_{ch}\rangle}\Big|_{\text{HM}}}{\frac{1}{N_{ev}}\frac{dN_{ch}}{dp_T}\frac{1}{\langle N_{ch}\rangle}\Big|_{\text{MB}}}$$

Q_{pp} as a function of p_T

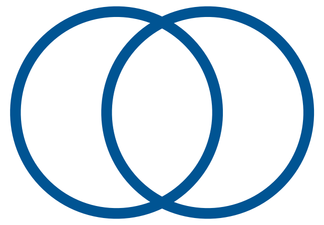
ALICE, 2407.20037



$\langle \frac{dN_{ch}}{d\eta} \rangle \approx 22$



$\rho \to 0$



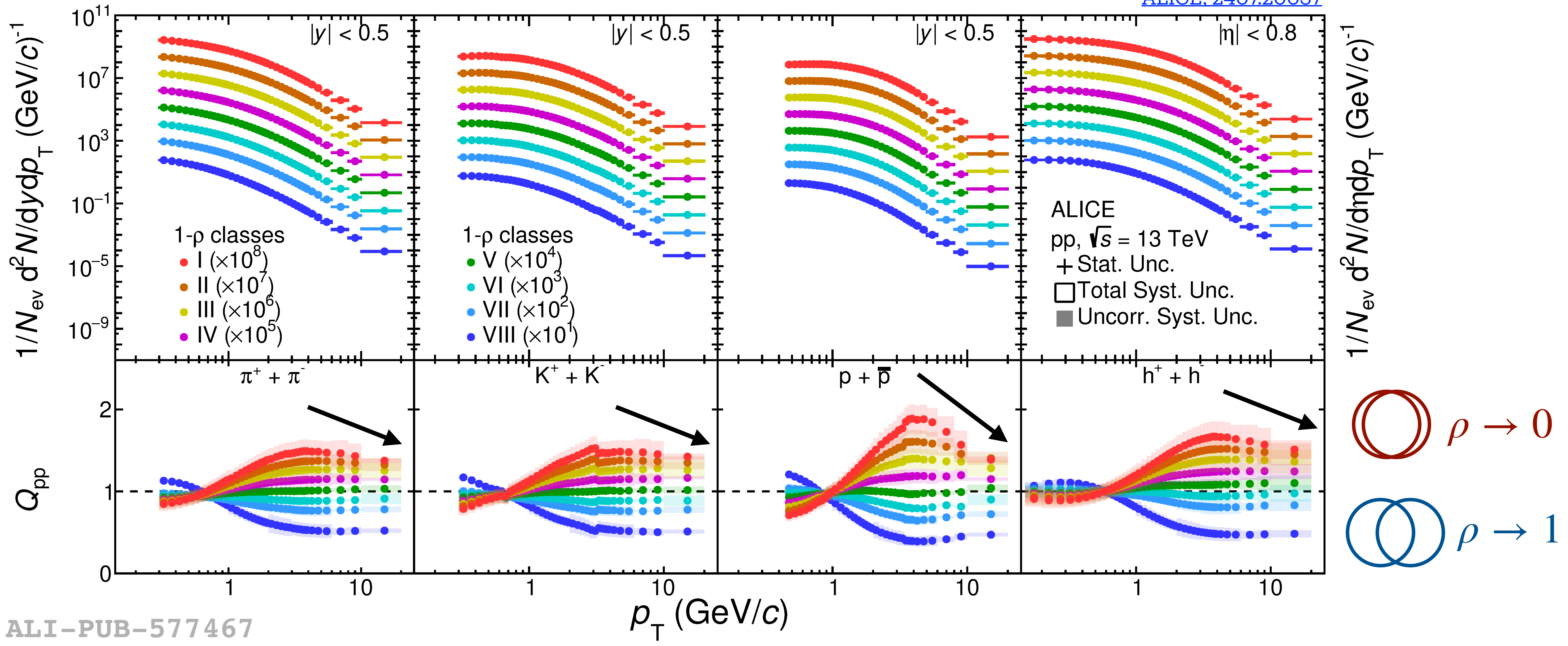
$\rho \to 1$

$\langle \frac{dN_{ch}}{d\eta} \rangle \approx 3$

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

Q_{pp} as a function of p_T

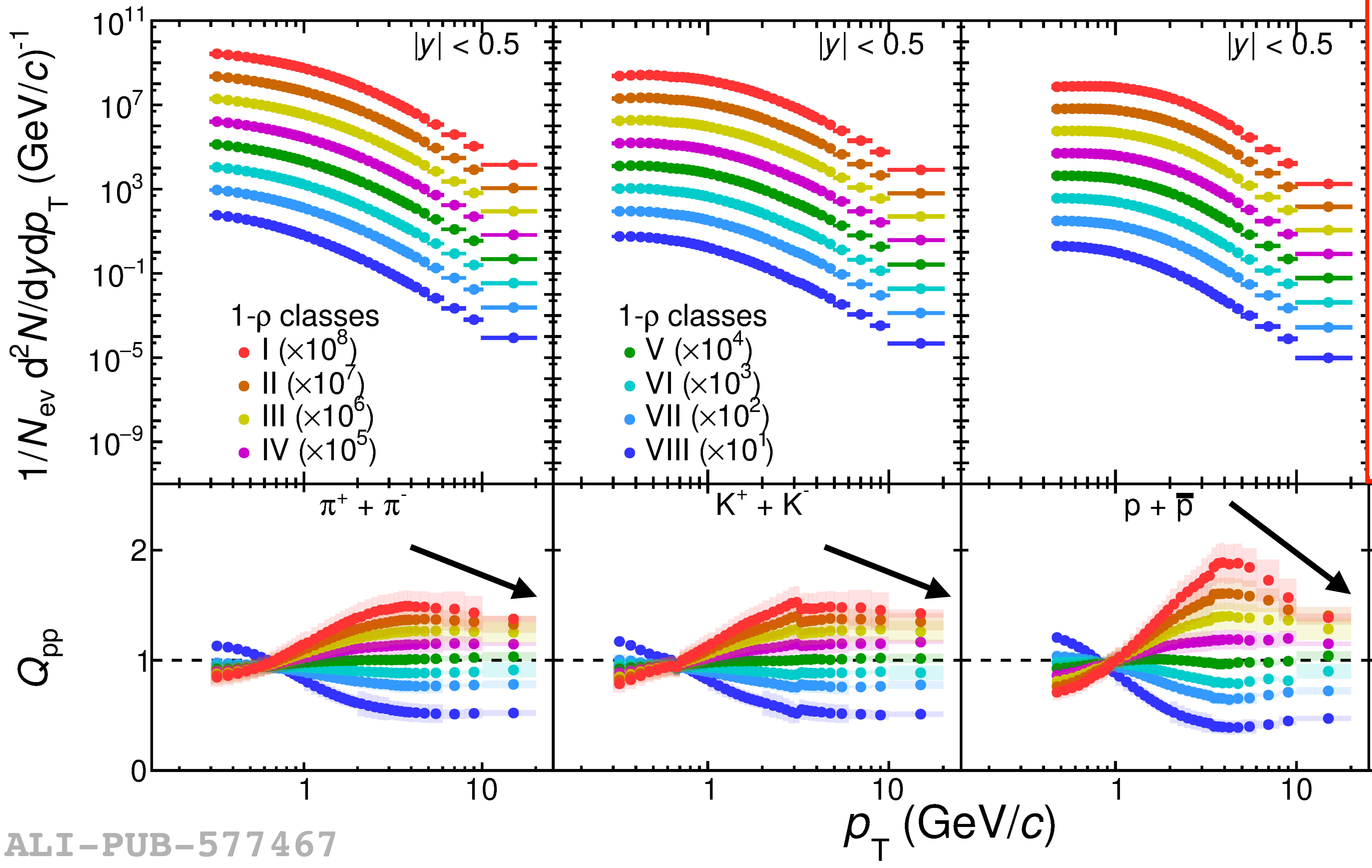
ALICE, 2407.20037

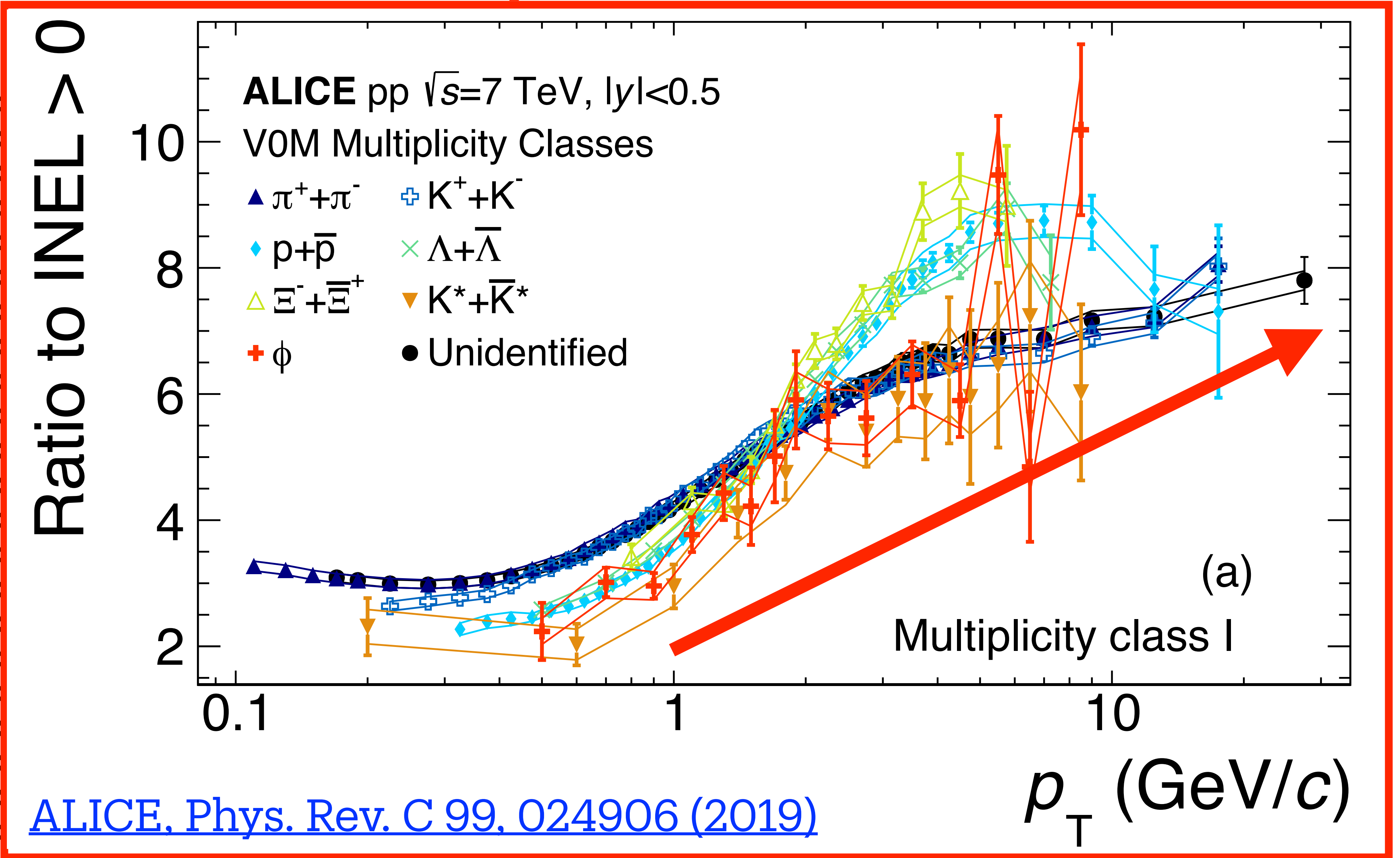


- Intermediate p_T: a bump structure is developed with increasing multiplicity
- High p_T: Q_{pp} seems to approach to the vicinity of one

Q_{pp} as a function of p_T

The effect is not seen in the V0M analysis!





[ALICE, Phys. Rev. C 99, 024906 (2019)](#)

- 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

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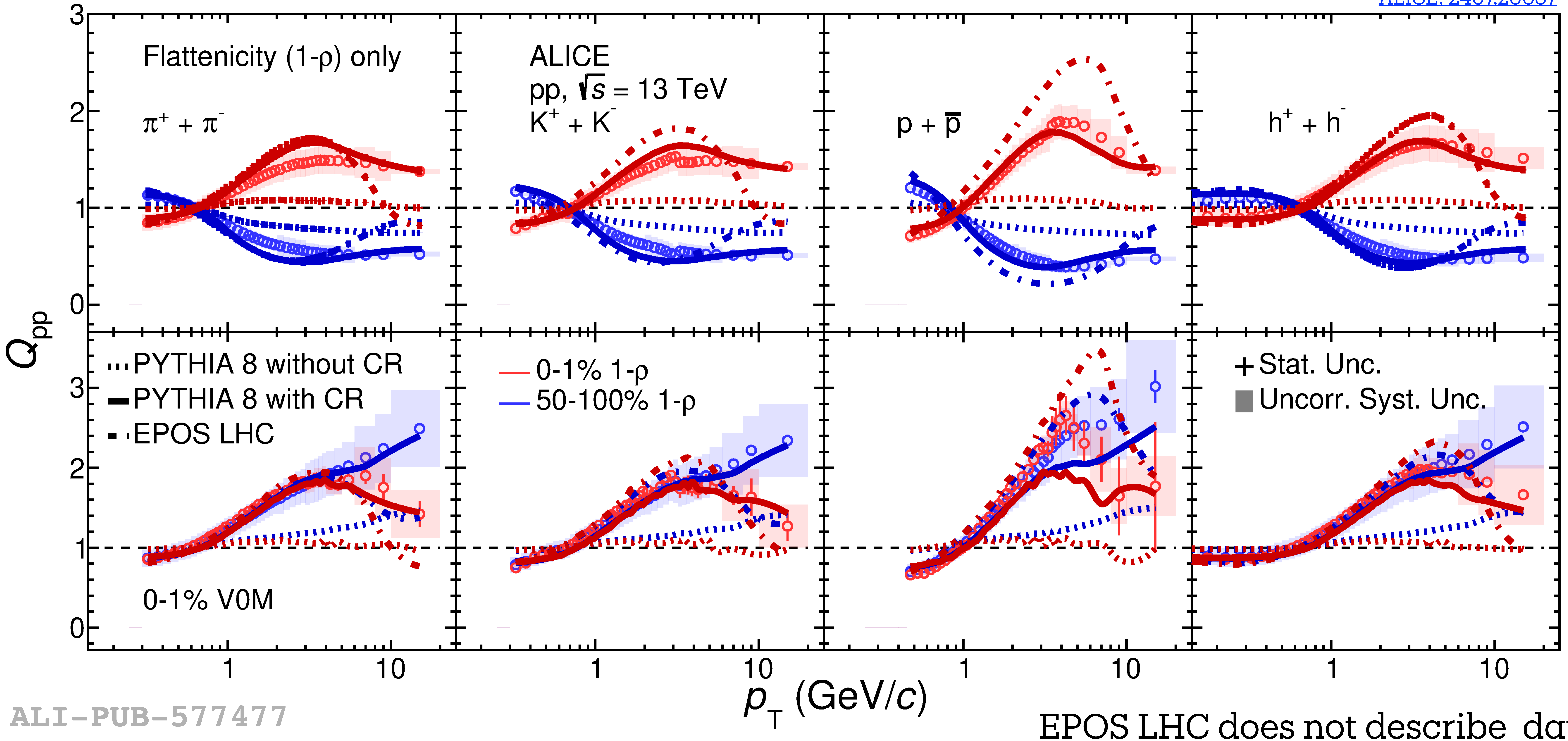

EPOS LHC does not describe data

Q$_{pp}$: data vs MC models

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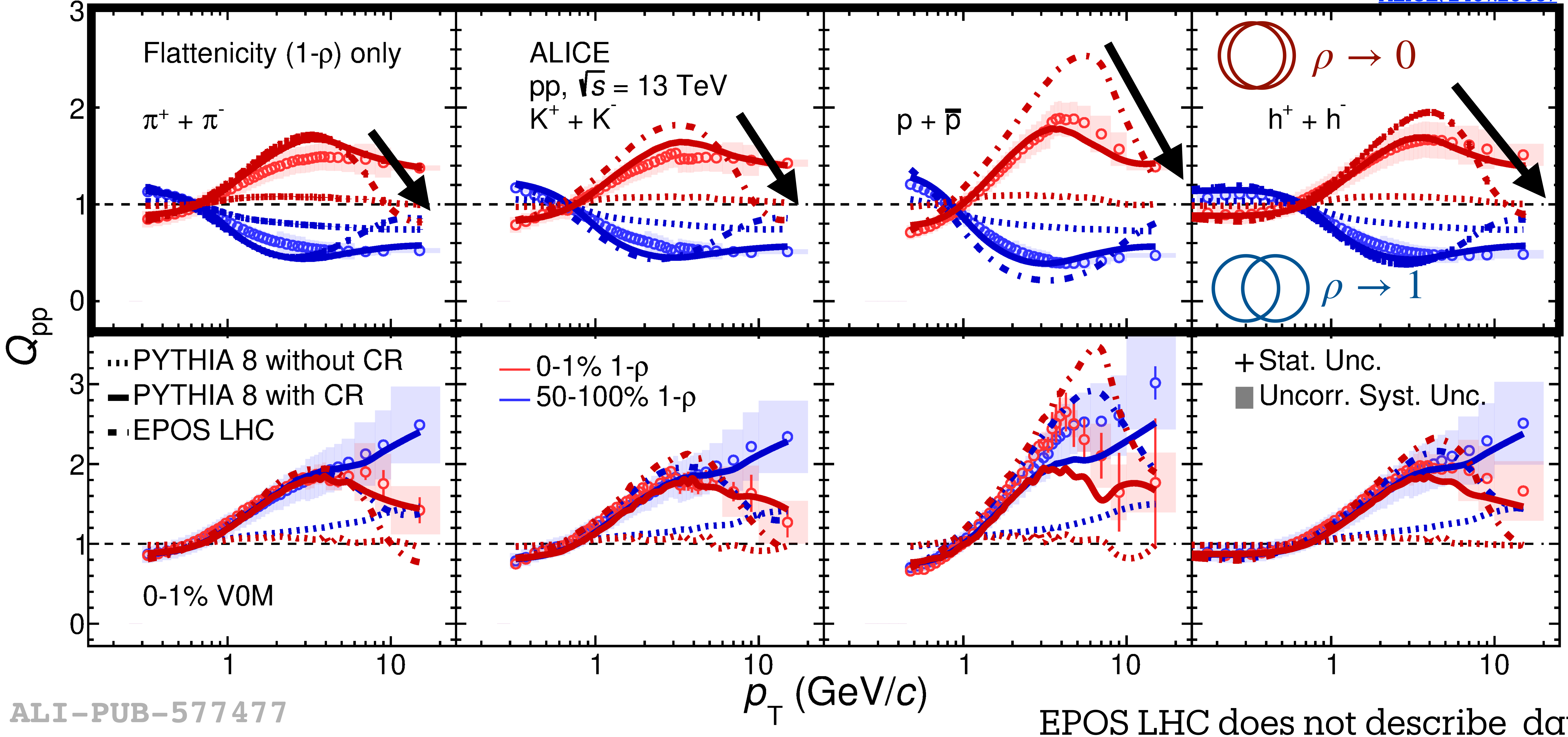

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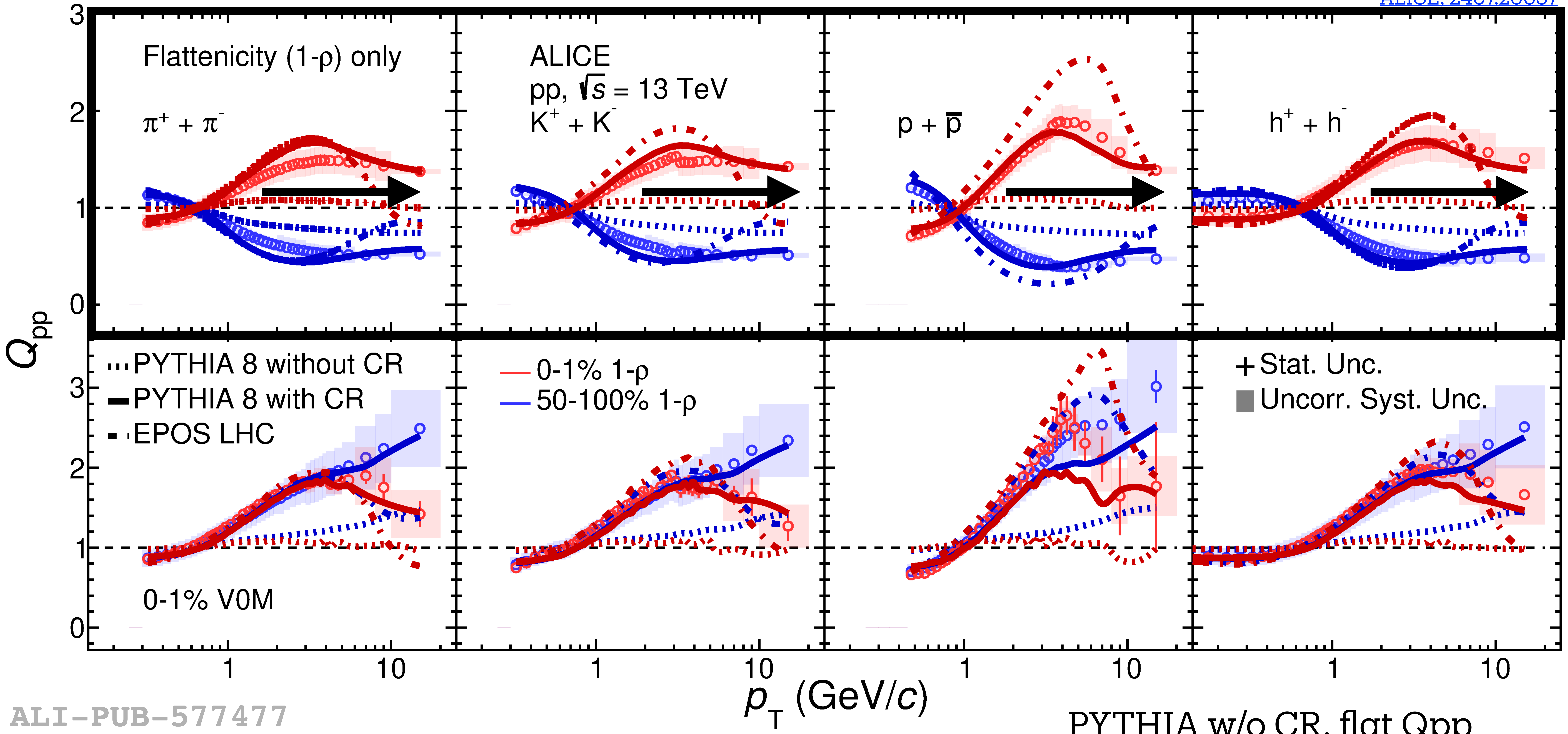

PYTHIA w/o CR, flat Qpp

Qpp: data vs MC models

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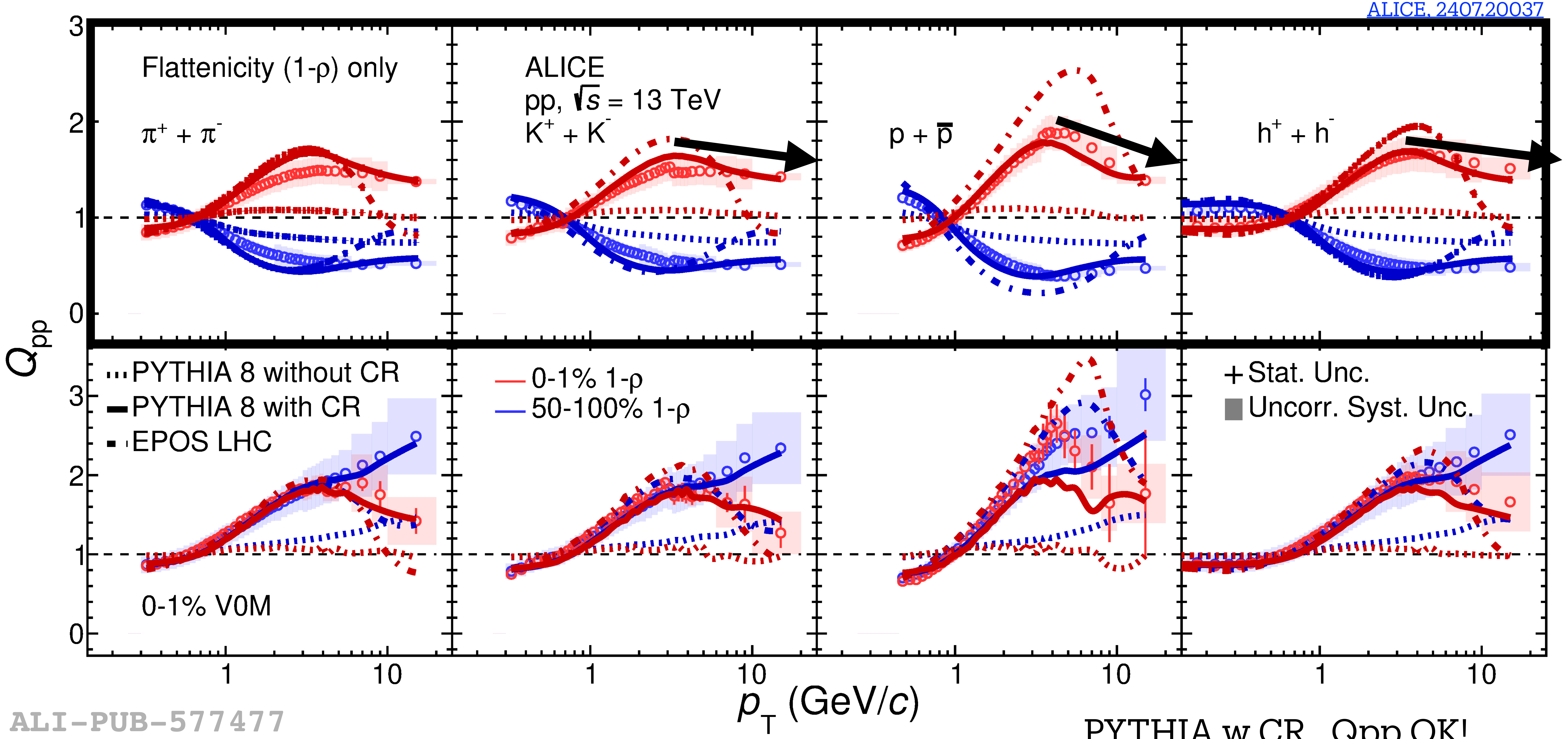

PYTHIA w CR, Qpp OK!

Qpp: data vs MC models

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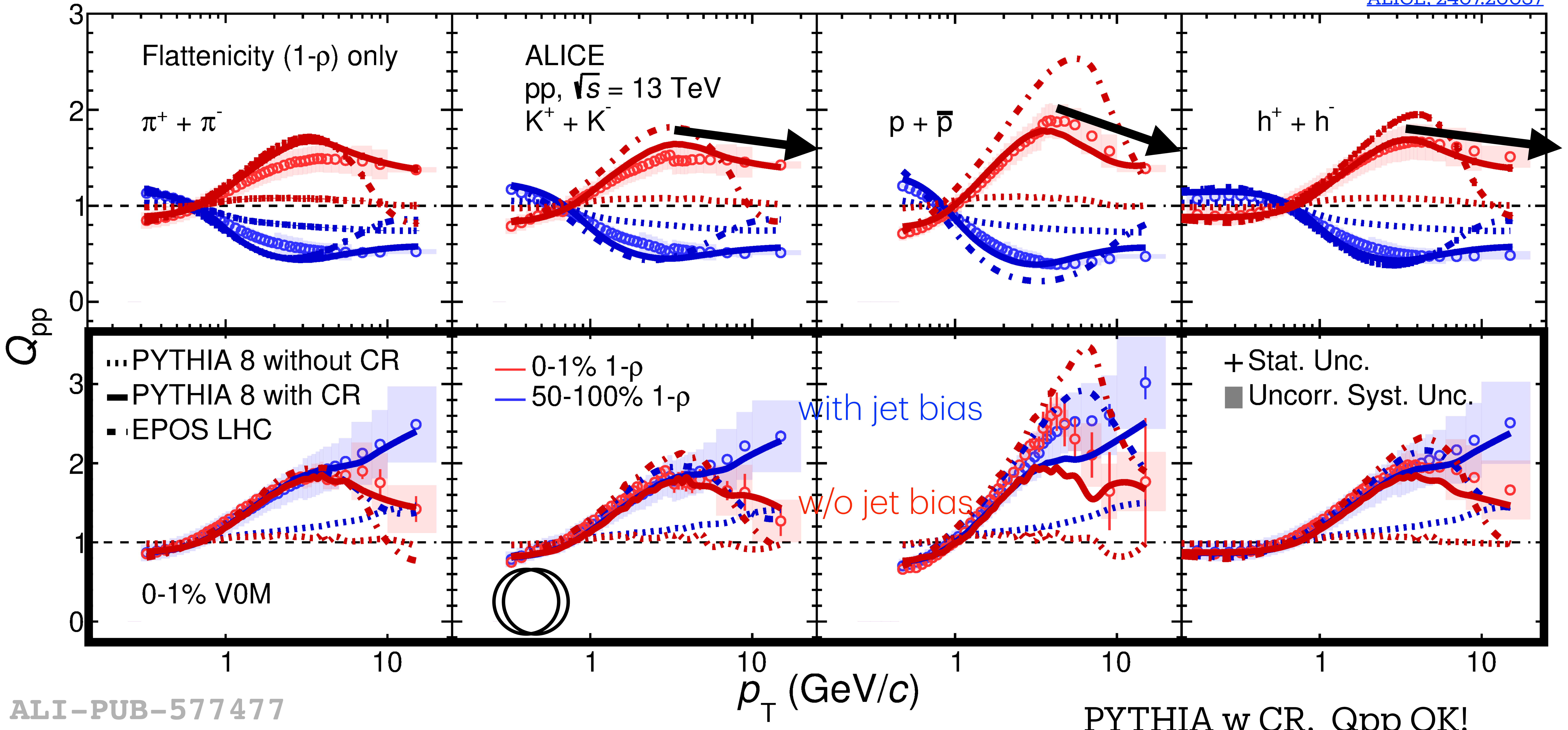
ALICE, 2407.20037



PYTHIA w CR, Qpp OK!

Q_{pp}: EPOS 4 (flattenicity)

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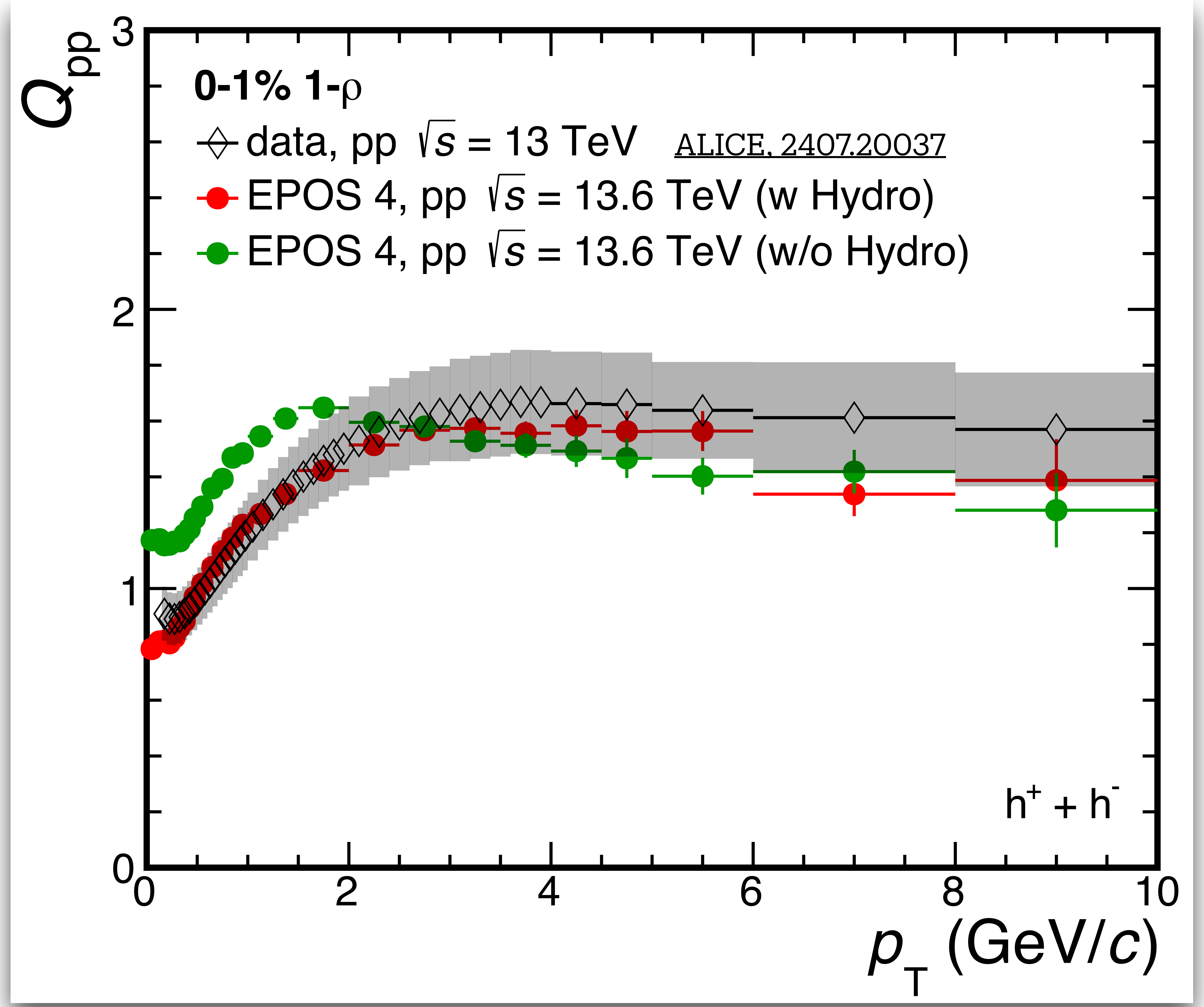

EPOS 4 from: https://klaus.pages.in2p3.fr/epos4

Primary (multiple parallel scatterings happening instantaneously) and secondary interactions (subsequent interactions of the string decay products)

Core-Corona: the collision system is separated into a high-density (core), which evolves hydrodynamically, and a low-density (corona), which hadronizes without hydro behavior

Epos 4 with hydro: better description of data than EPOS LHC. Better statistics needed

Q_{pp}: EPOS 4 (charged particles)

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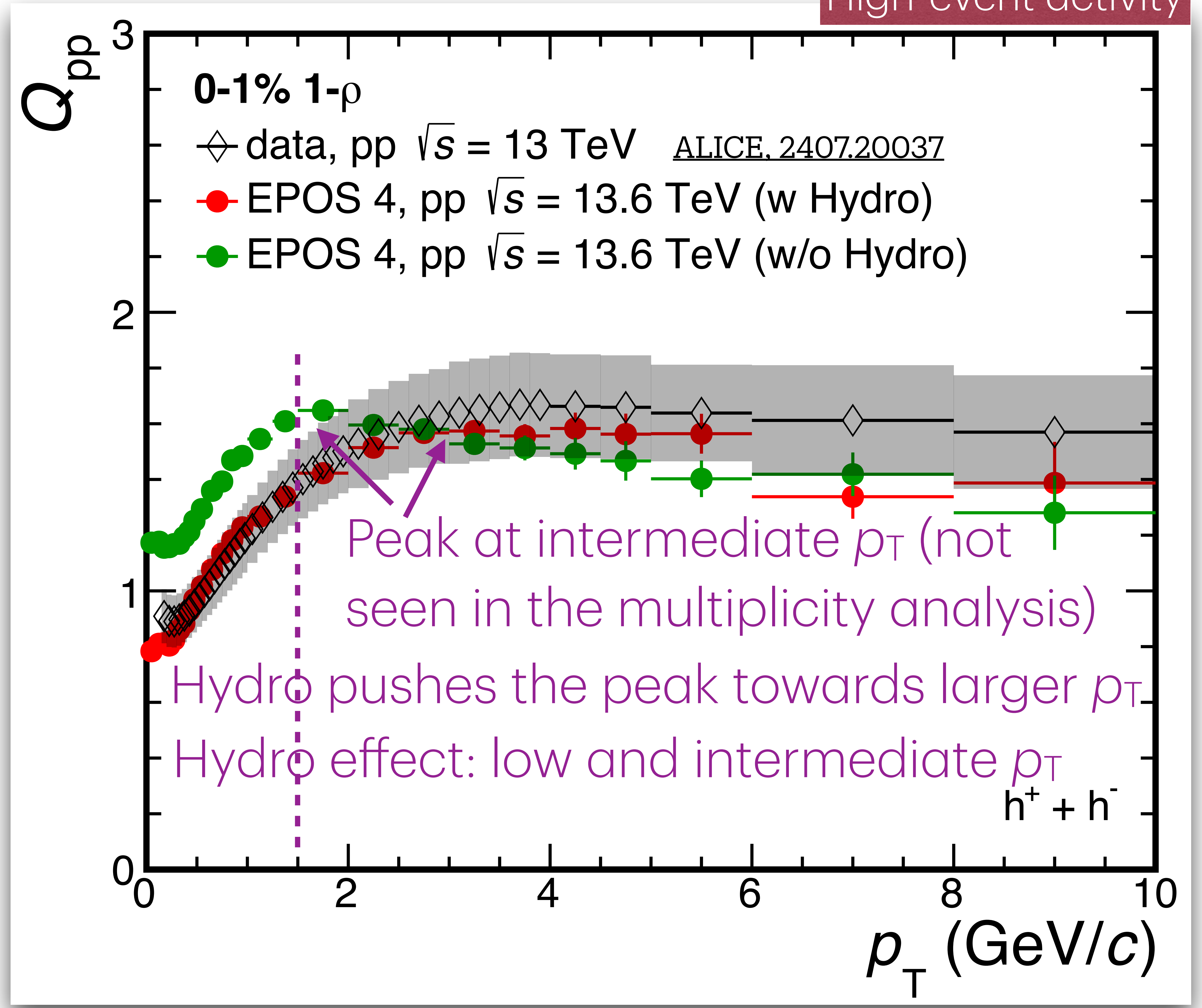
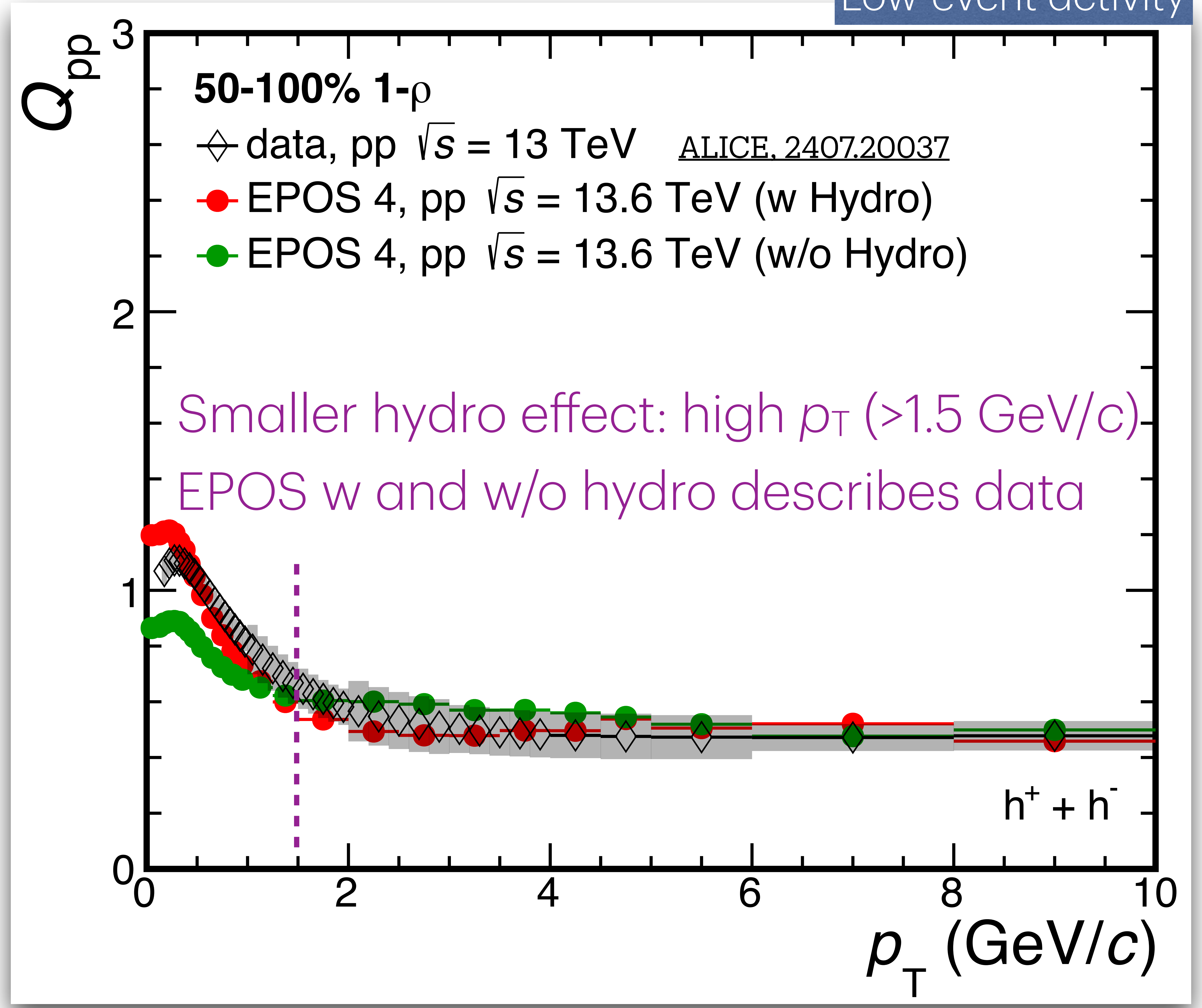
High-event activity



Low-event activity



$\rho \to 0$ $\rho \to 1$

Q_{pp}: EPOS 4 (pions)

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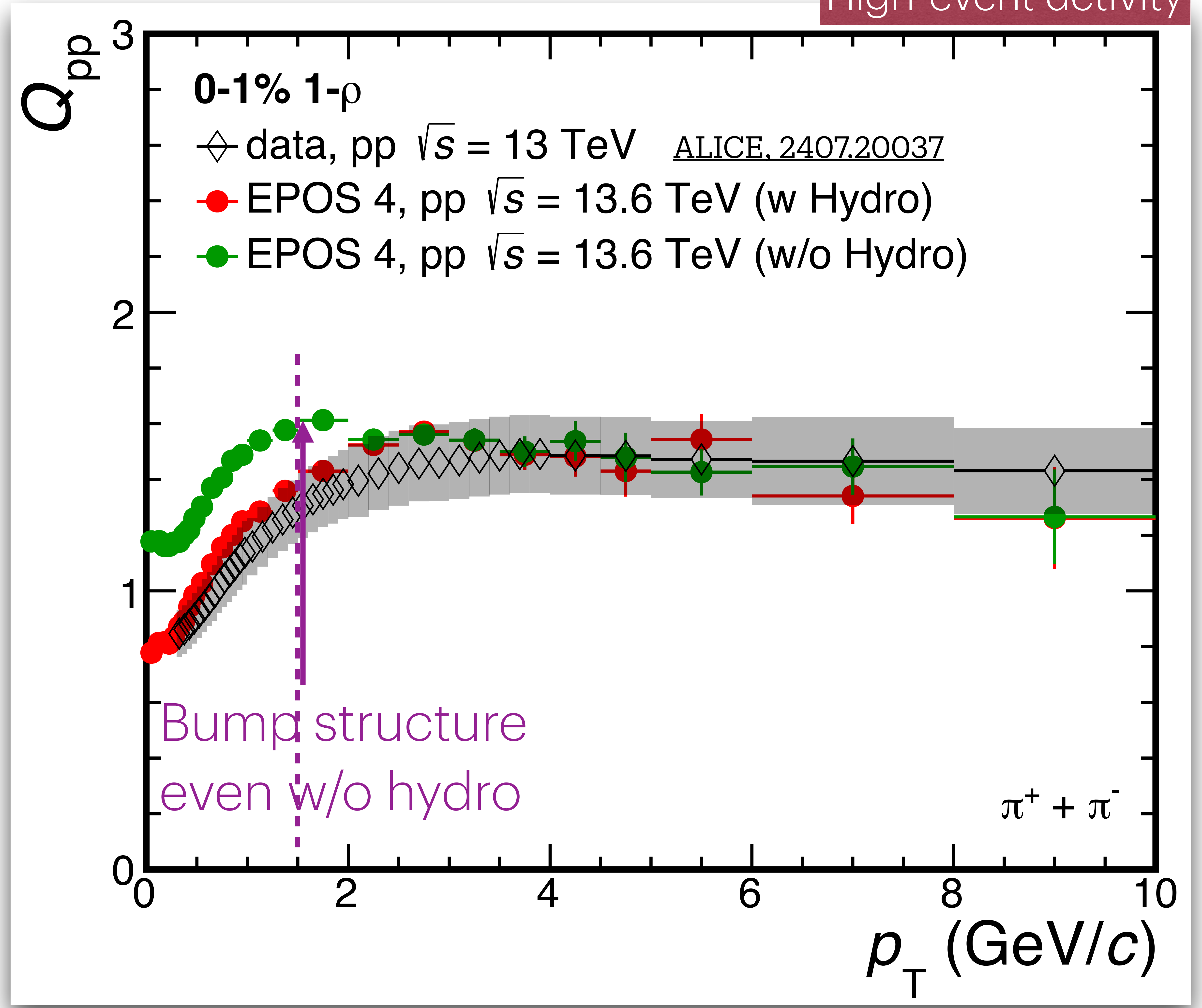
High-event activity



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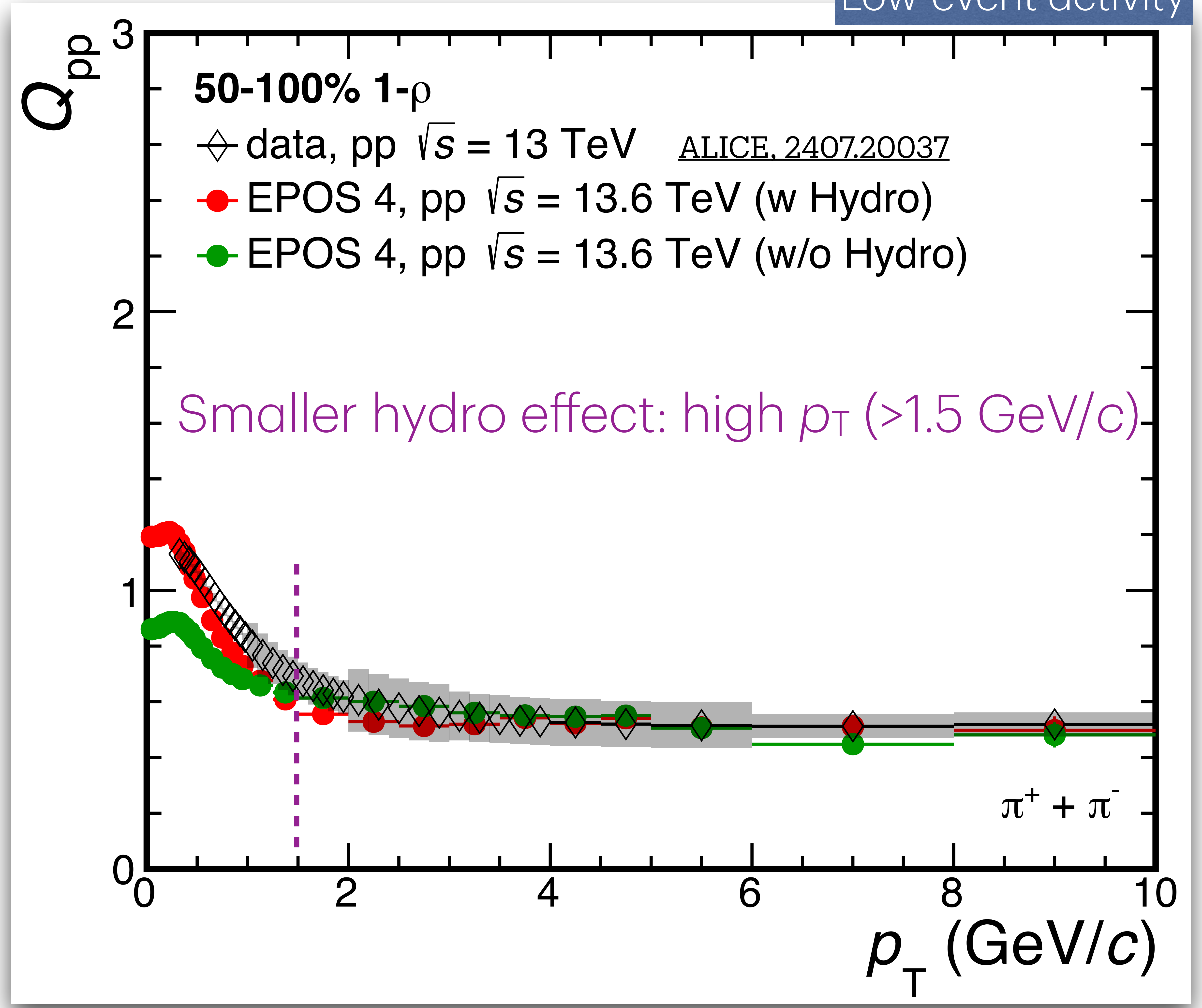
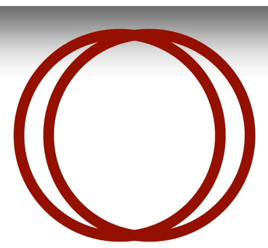
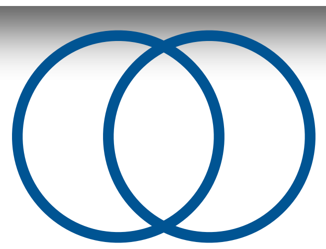




$\rho \to 0$



$\rho \to 1$

Q_{pp}: EPOS 4 (kaons)

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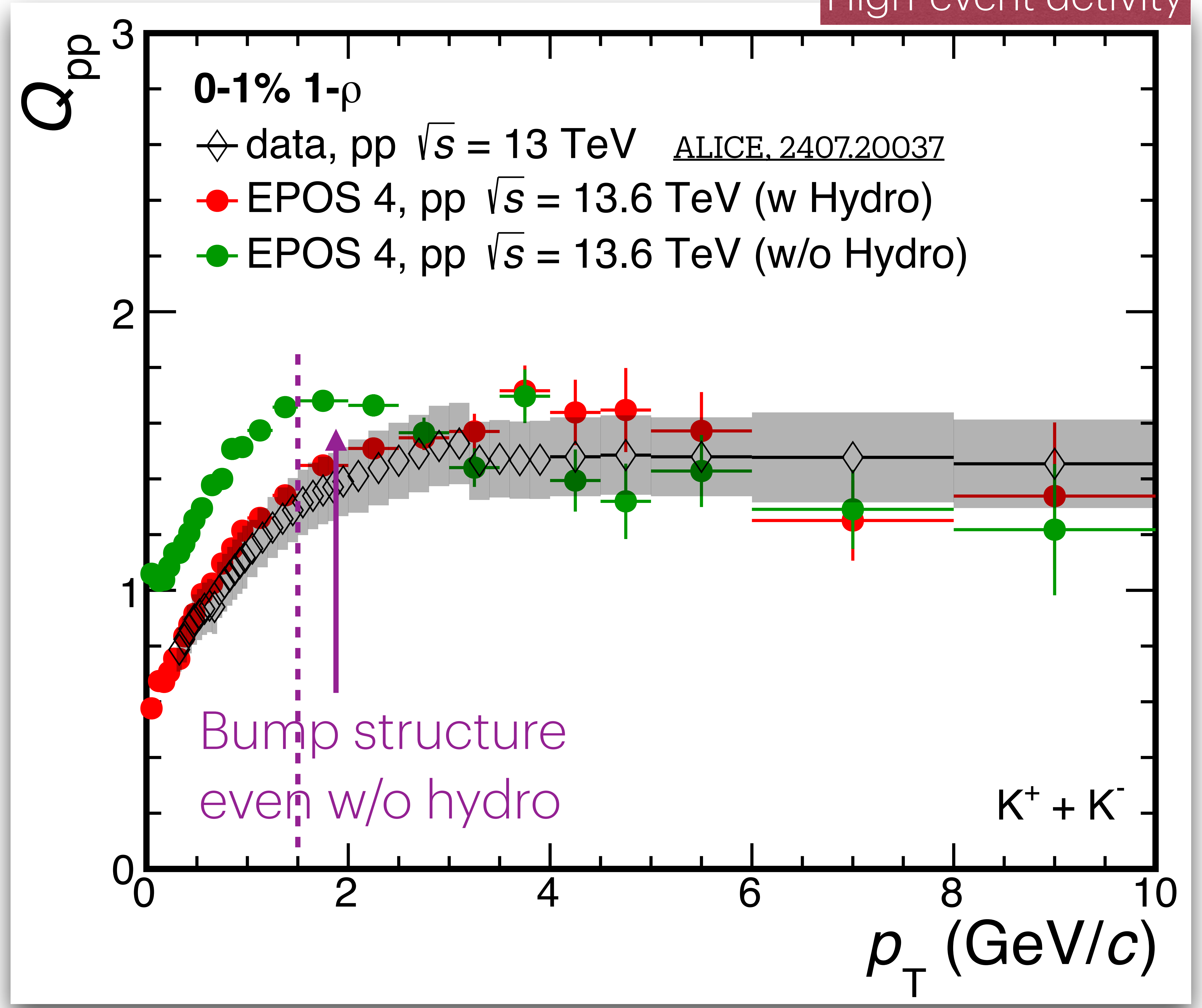
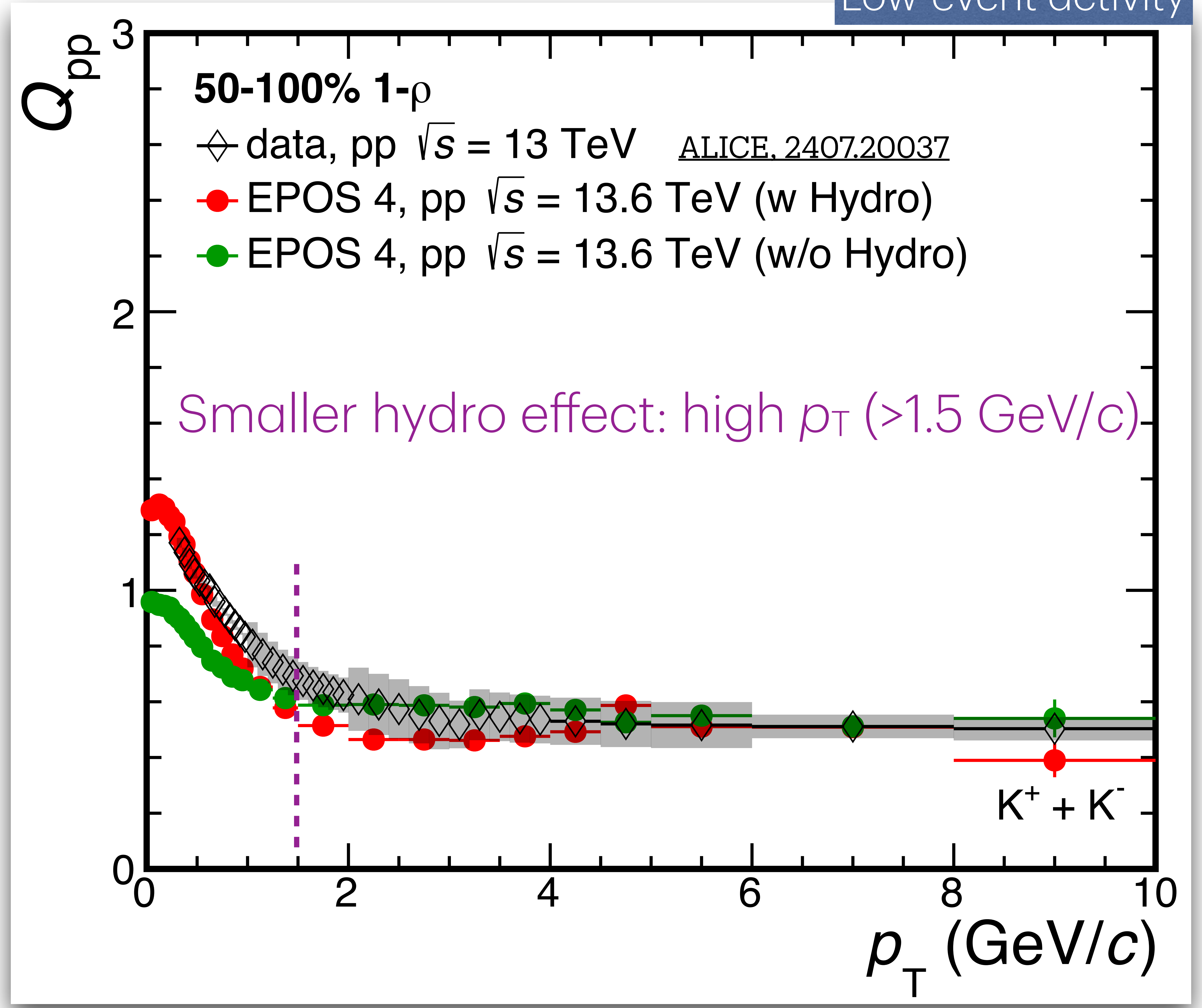
High-event activity



Low-event activity



$\rho \to 0$ $\rho \to 1$

Q_{pp}: EPOS 4 (protons)

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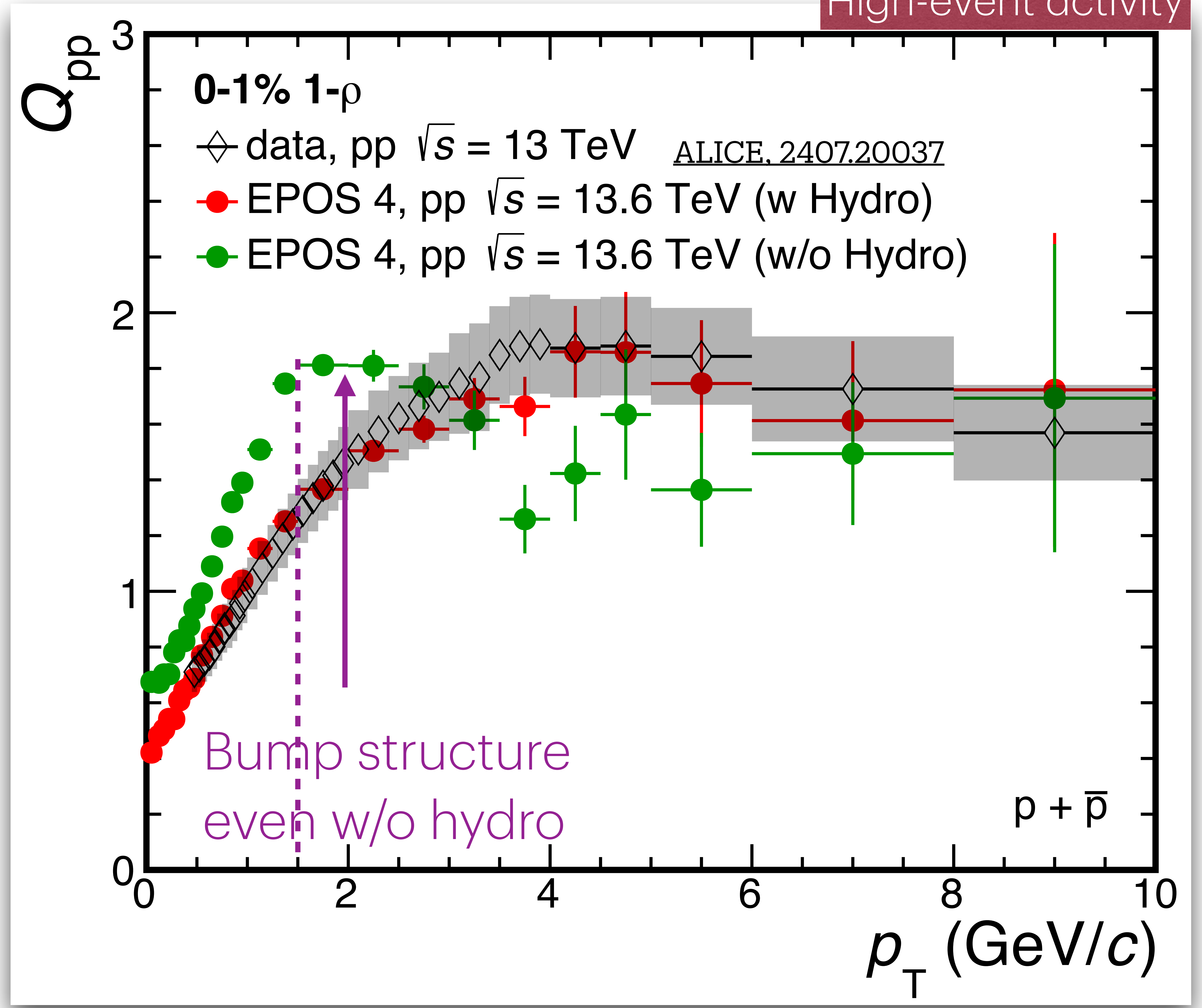
High-event activity



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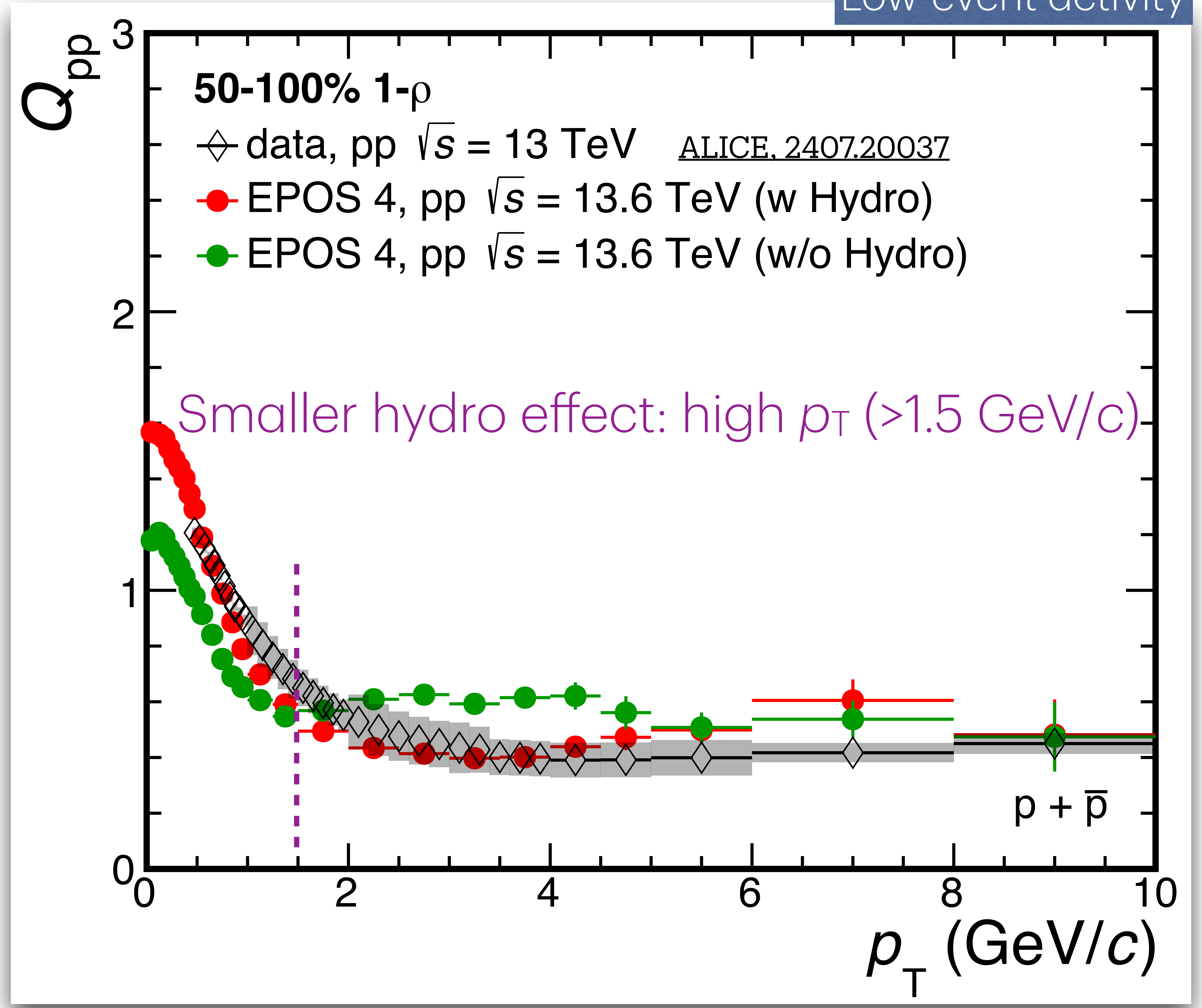

$\rho \to 0$ $\rho \to 1$

Q_{pp}: EPOS 4 (protons)

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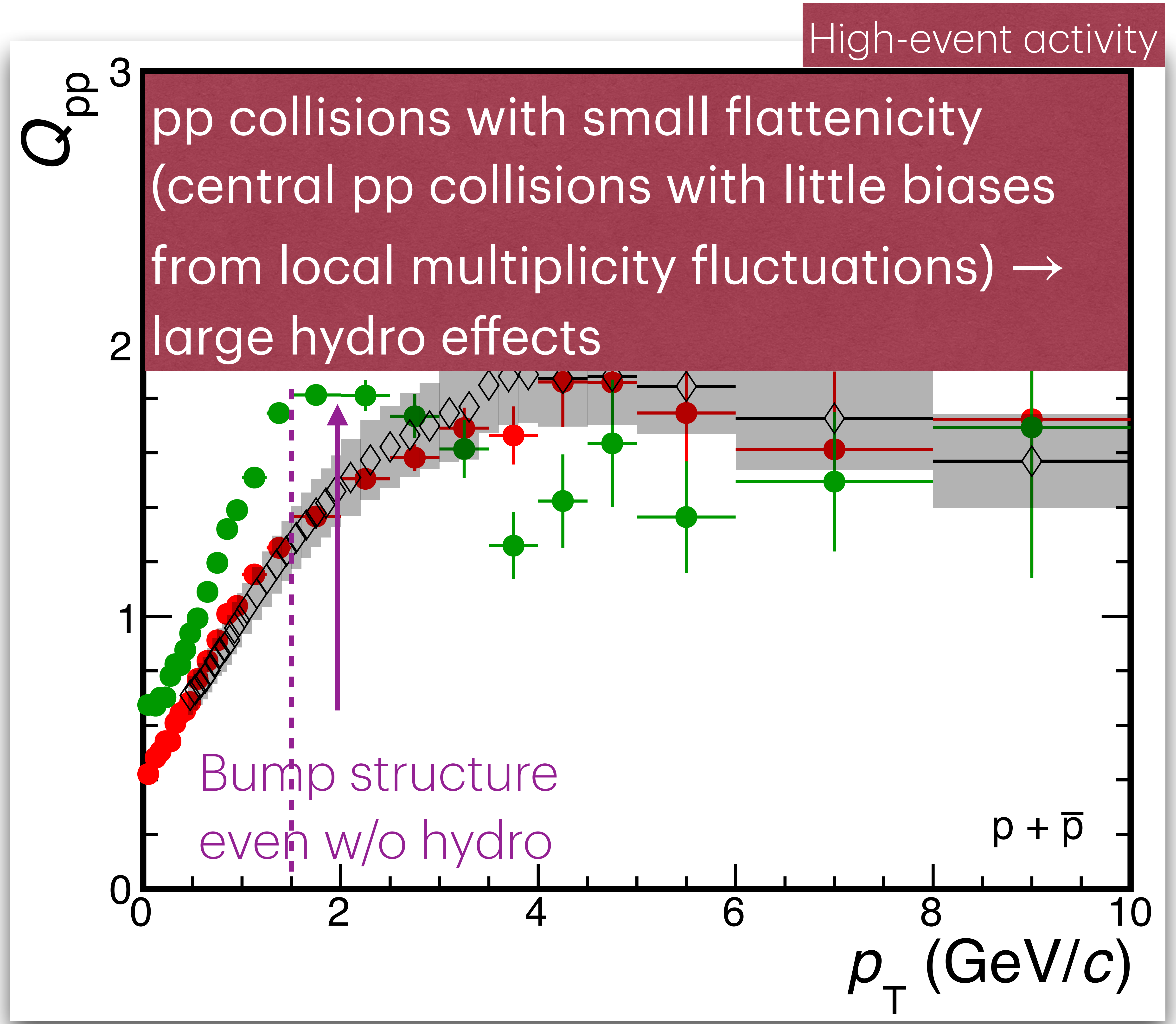

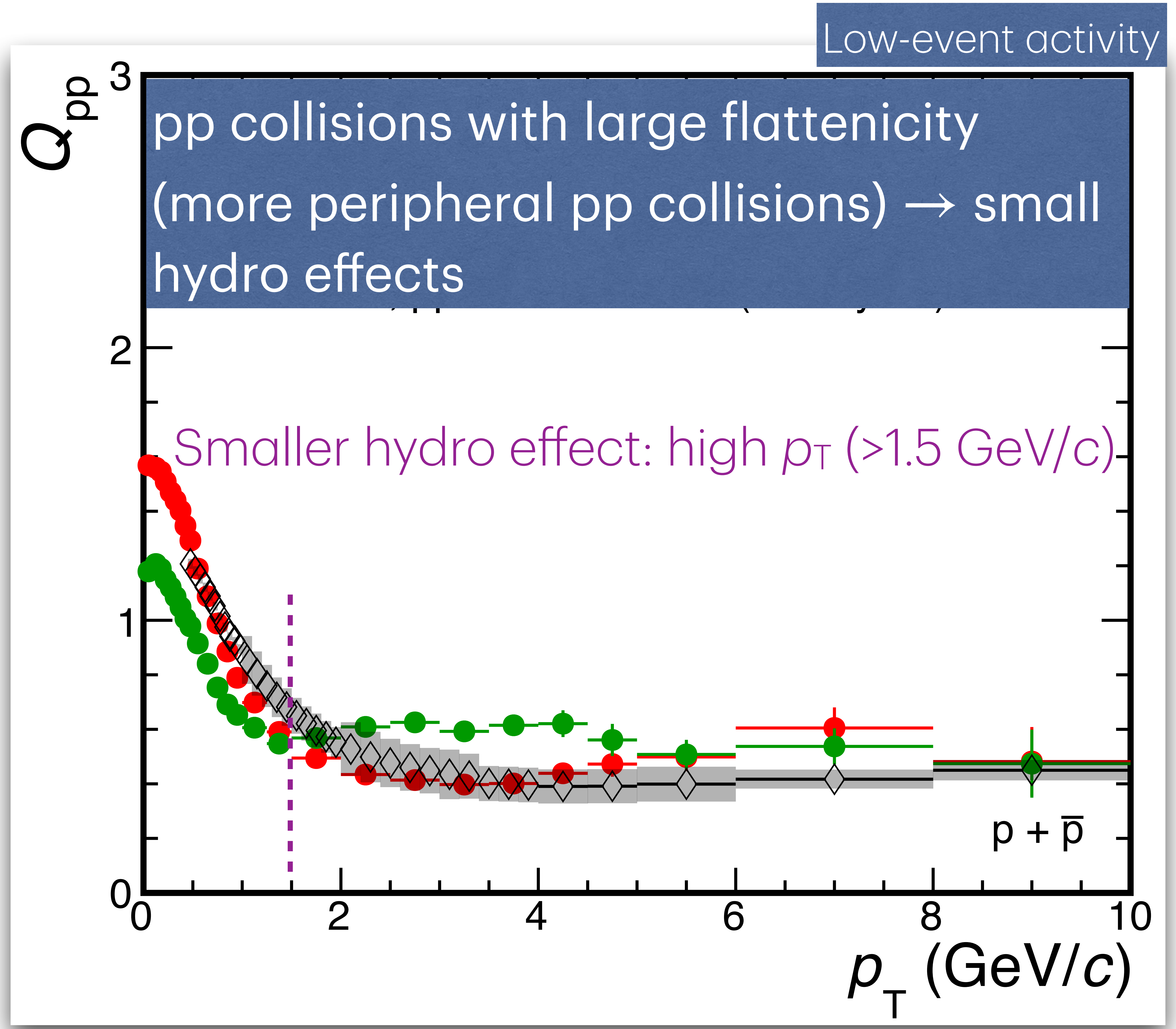

$\rho \to 0$ $\rho \to 1$

Particle ratios: EPOS 4

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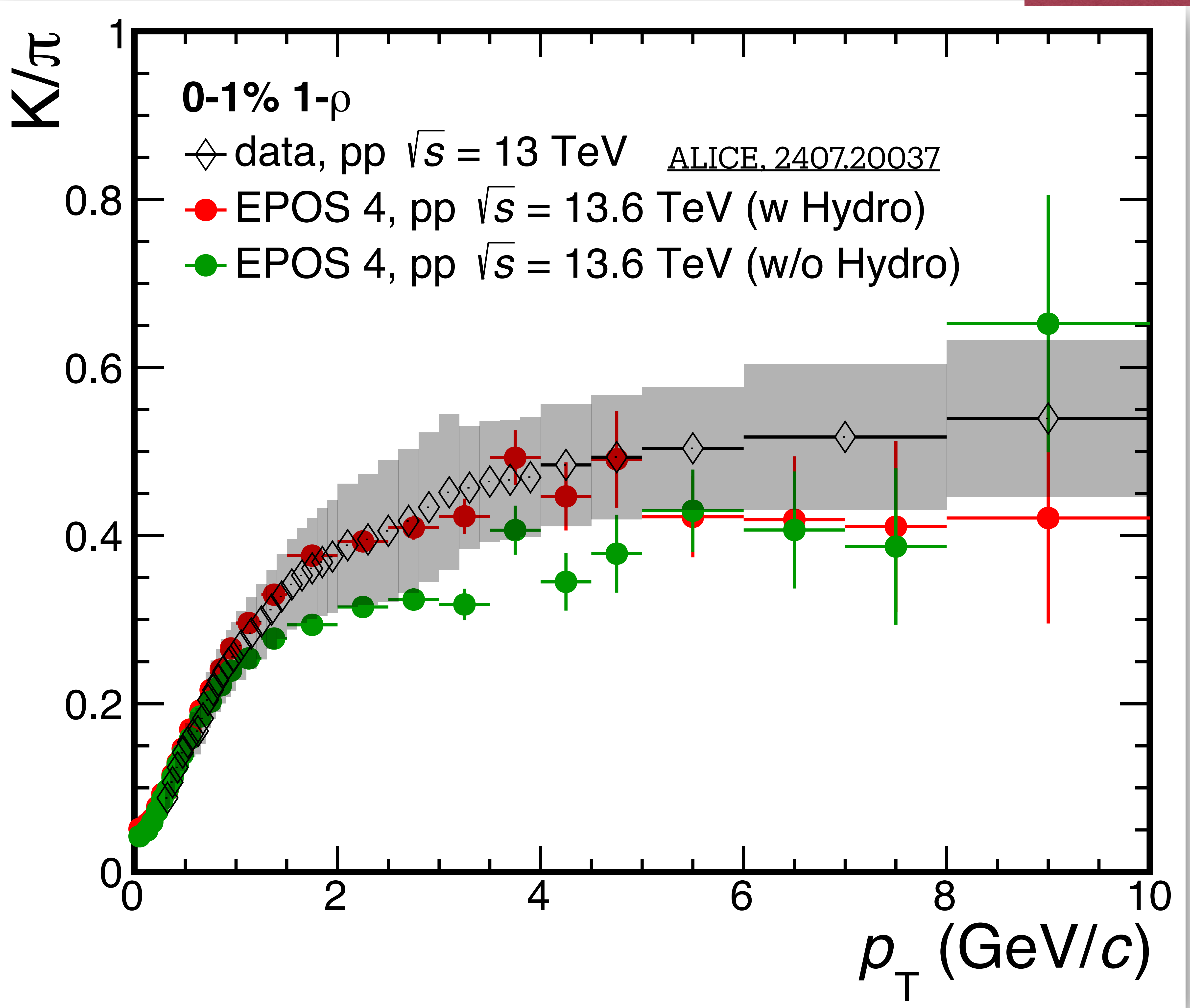
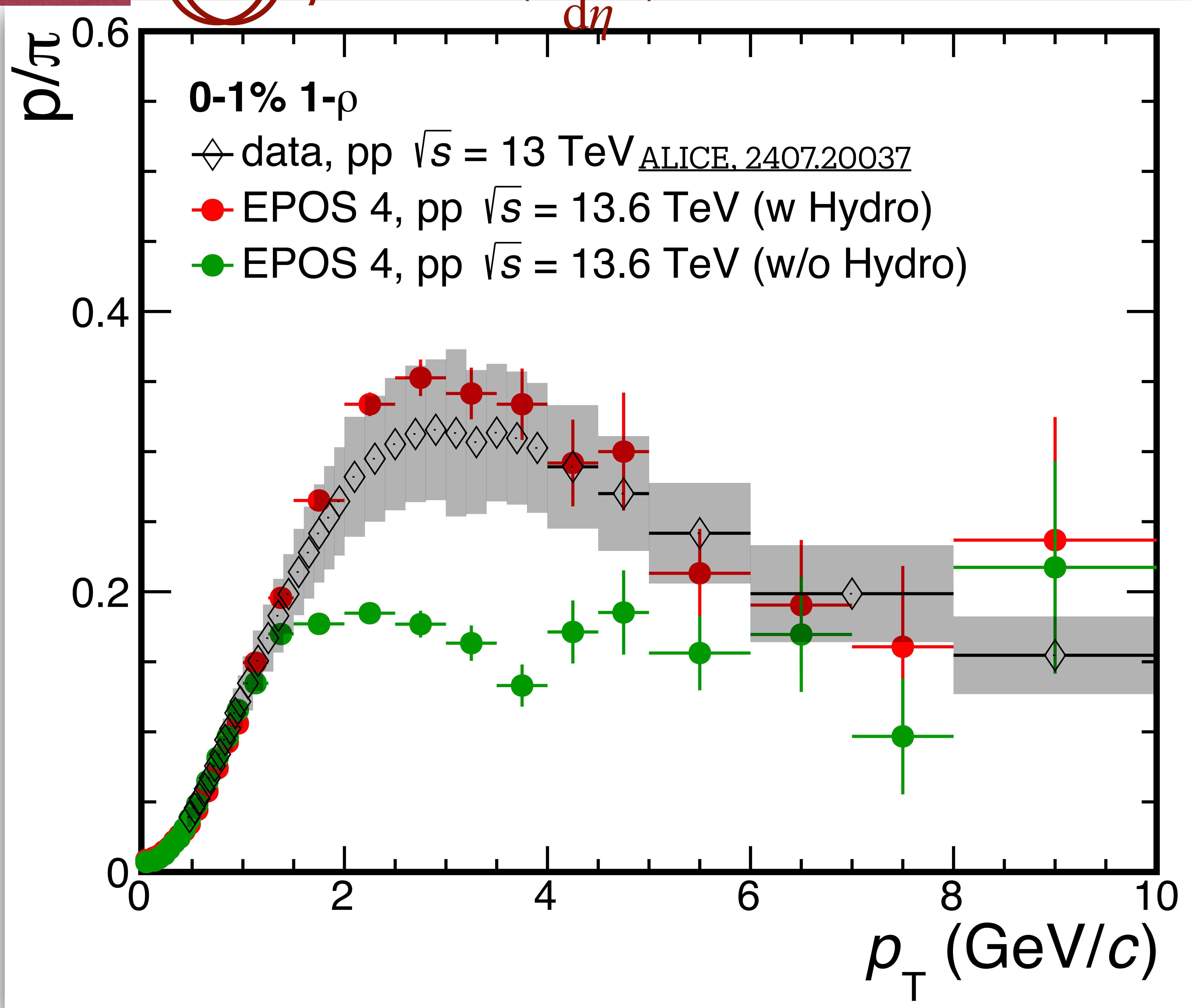
High-event activity

$\rho \to 0 \quad \langle \frac{dN_{ch}}{d\eta} \rangle \approx 22$



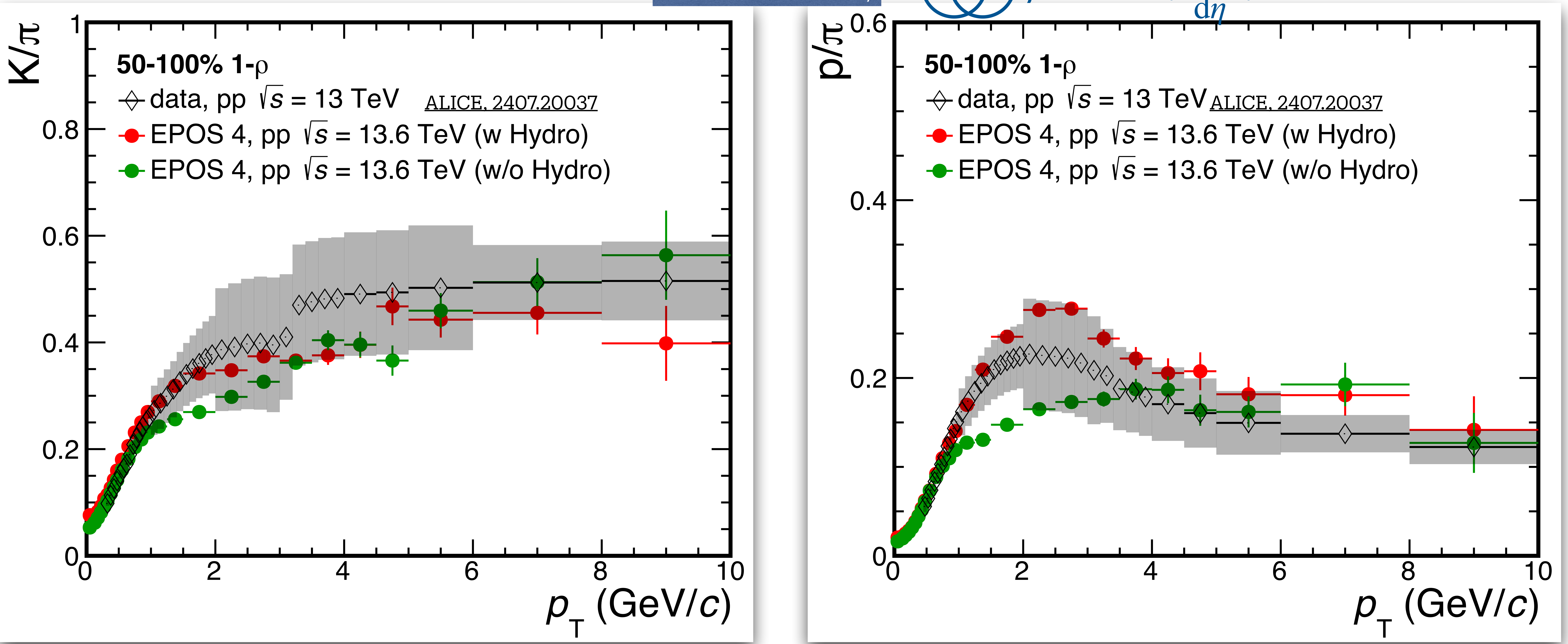


Large hydro effects

Particle ratios: EPOS 4

Low-event activity

$\rho \to 1 \quad \langle \frac{dN_{ch}}{d\eta} \rangle \approx 3$



Low multiplicity pp collisions with fluid behaviour (keep in mind that we have measured a non zero v2 in low multiplicity pp)

Flattenicity in p-Pb?

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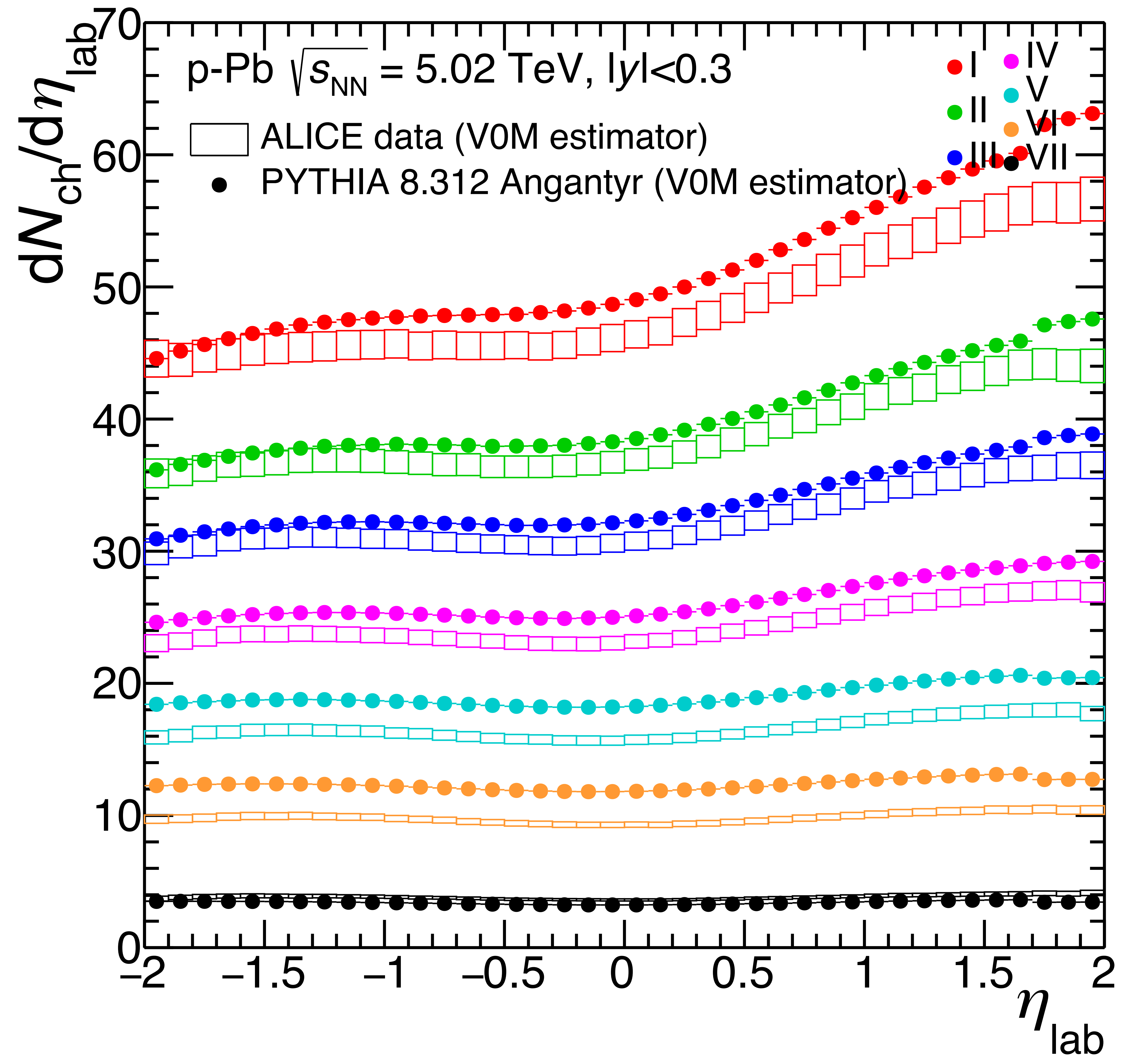
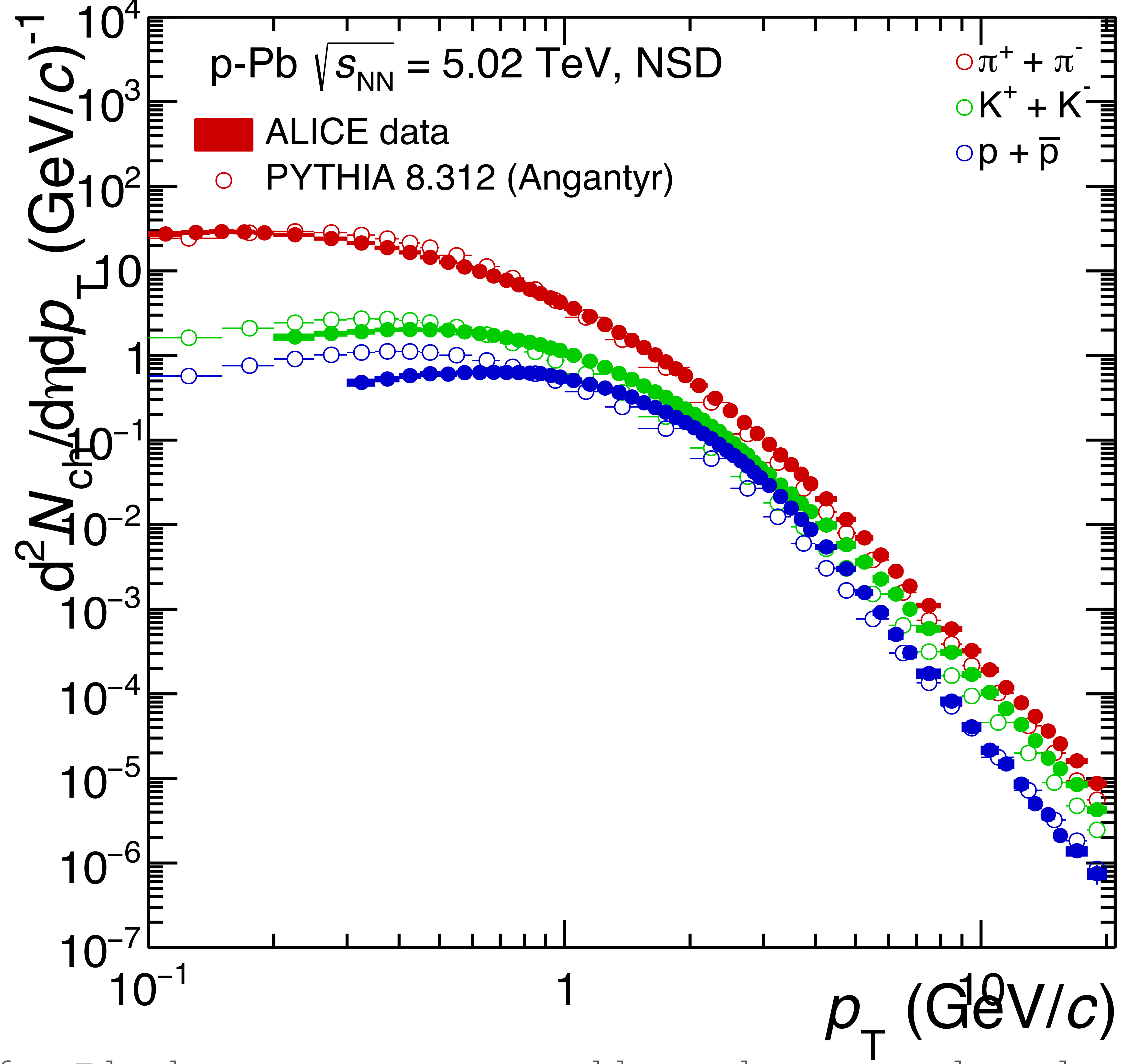
G. Bencedi, F. Fan, AO , 2407.07724

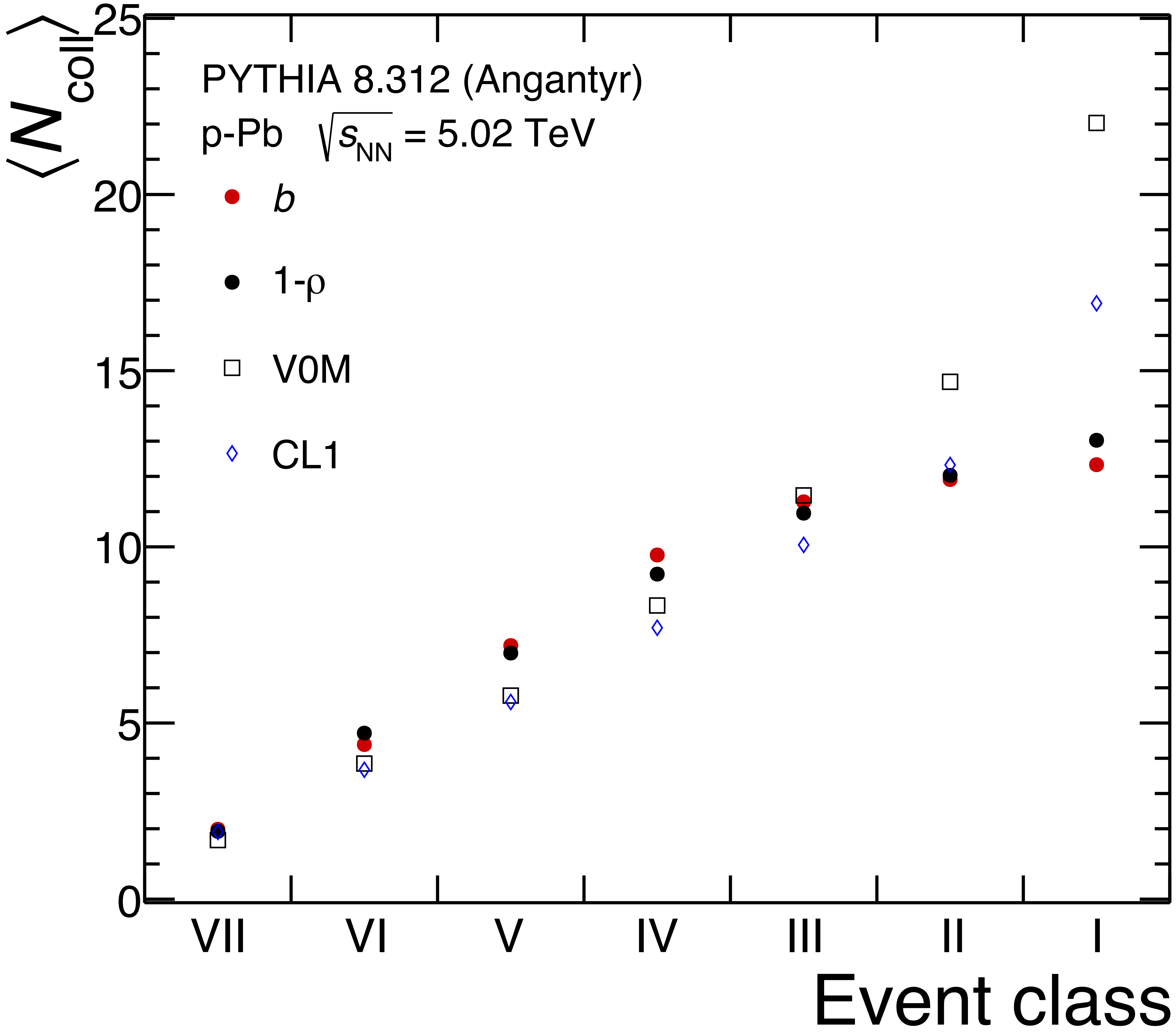




First studies using PYTHIA Angantyr: description of p-Pb data is not optimal but ok to test the idea

Flattenicity in p-Pb?

G. Bencedi, F. Fan, AO , 2407.07724



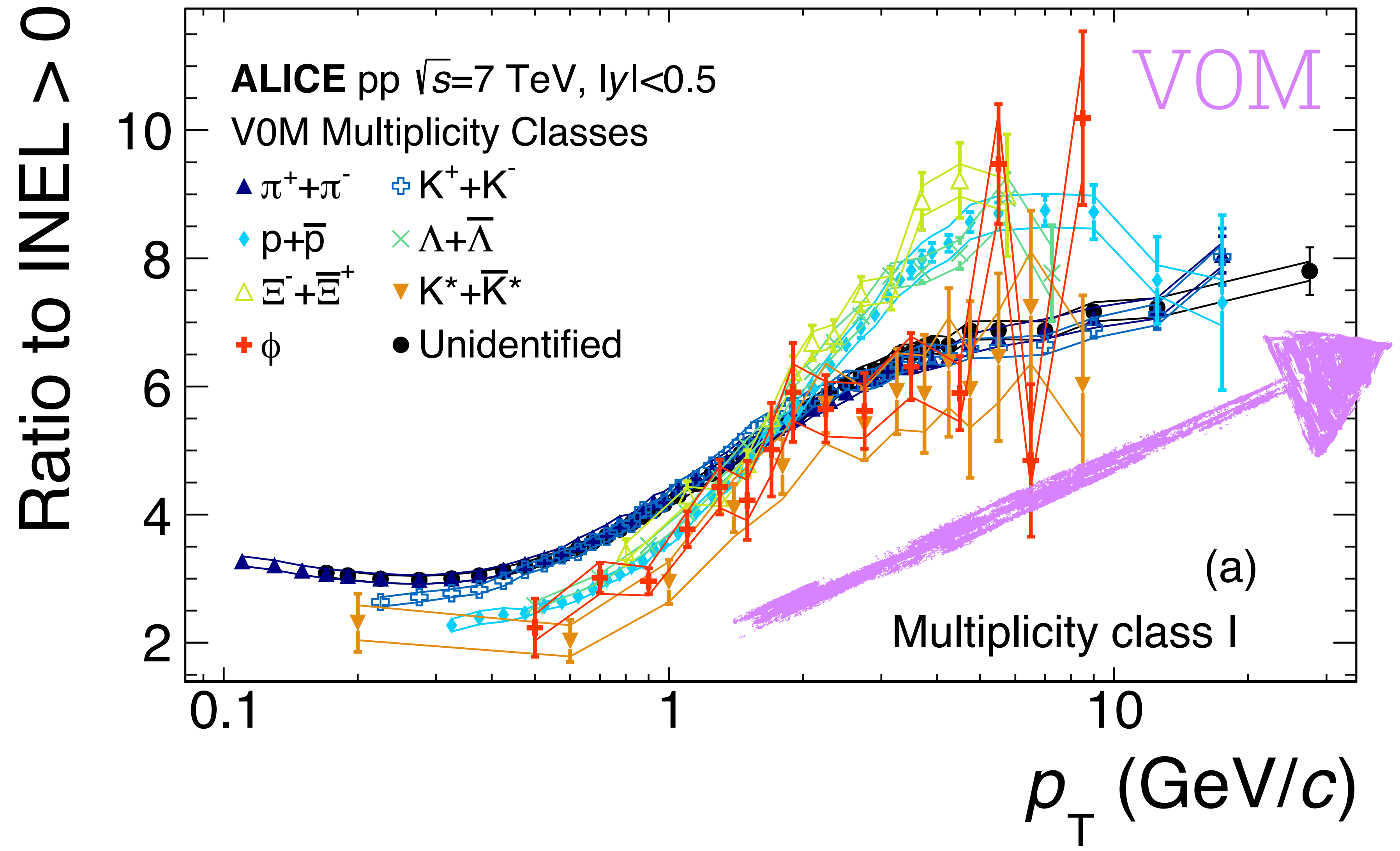
Flattenicity in p-Pb seems to be a good candidate to classify the collisions in terms of the centrality

More studies will come

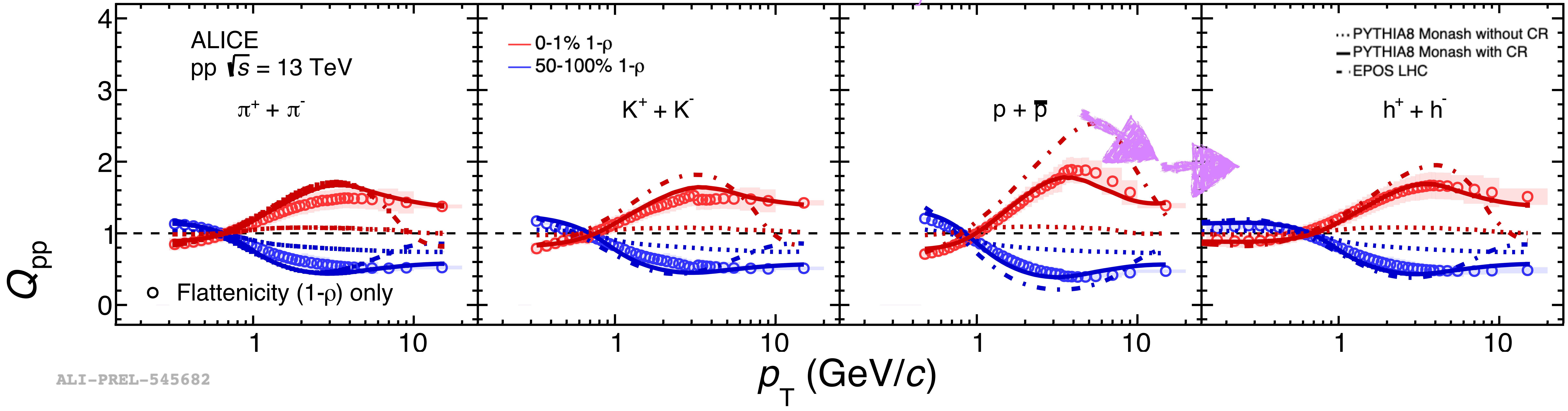
Summary

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

Promising tool to study particle production in small systems



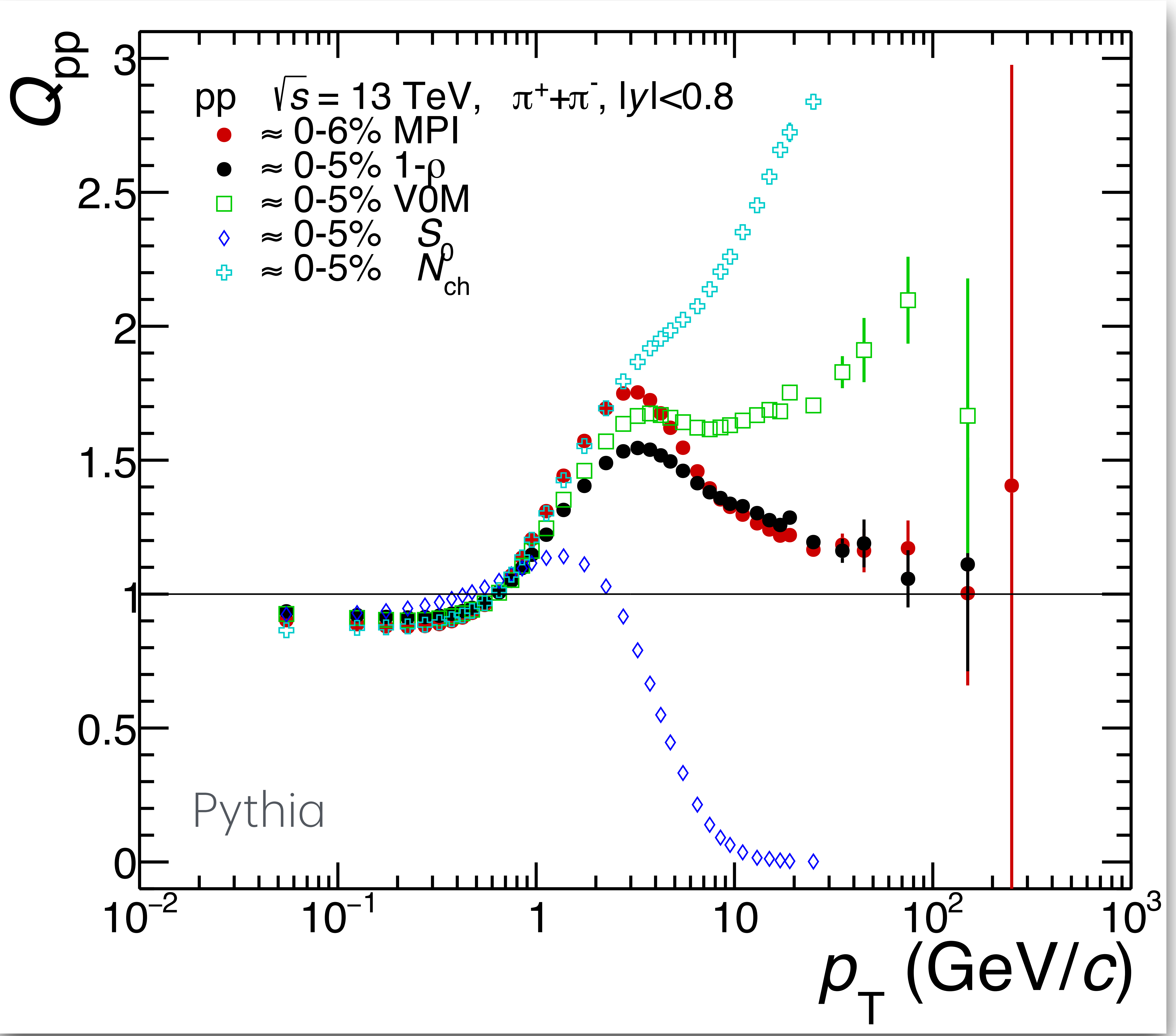
Flattenicity



Thank you!

backup

Flattenicity vs other estimators



Q_{pp}: EPOS 4 (V0M)

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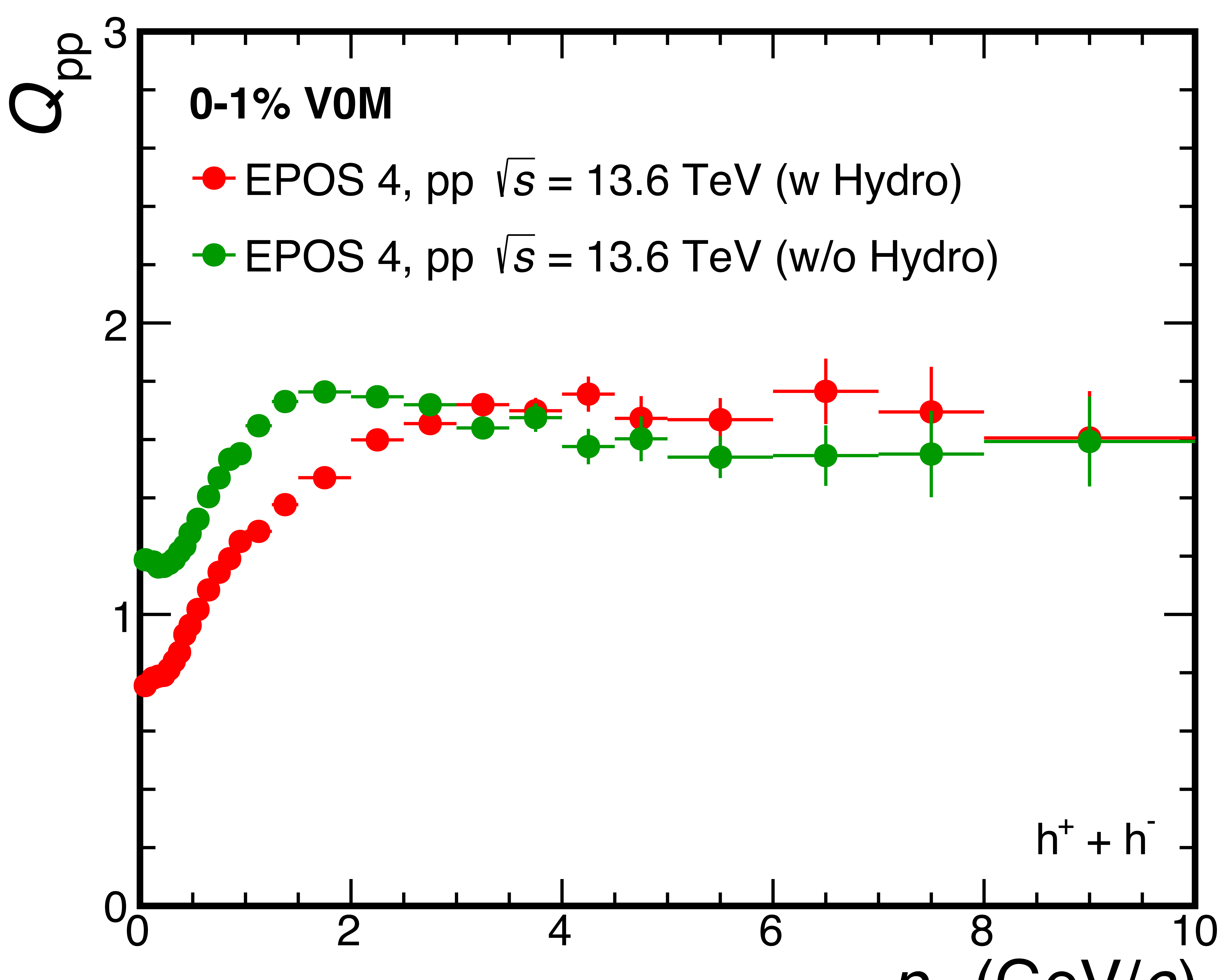

Plot made by Feng Fan (CCNU)

EPOS 4 from: https://klaus.pages.in2p3.fr/epos4

Primary (multiple parallel scatterings happening instantaneously) and secondary interactions (subsequent interactions of the string decay products)

Core-Corona: the collision system is separated into a high-density (core), which evolves hydrodynamically, and a low-density (corona), which hadronizes without collective behavior

Epos 4 with hydro: adequate description of data

Particle ratios: EPOS 4 (flattenicity)

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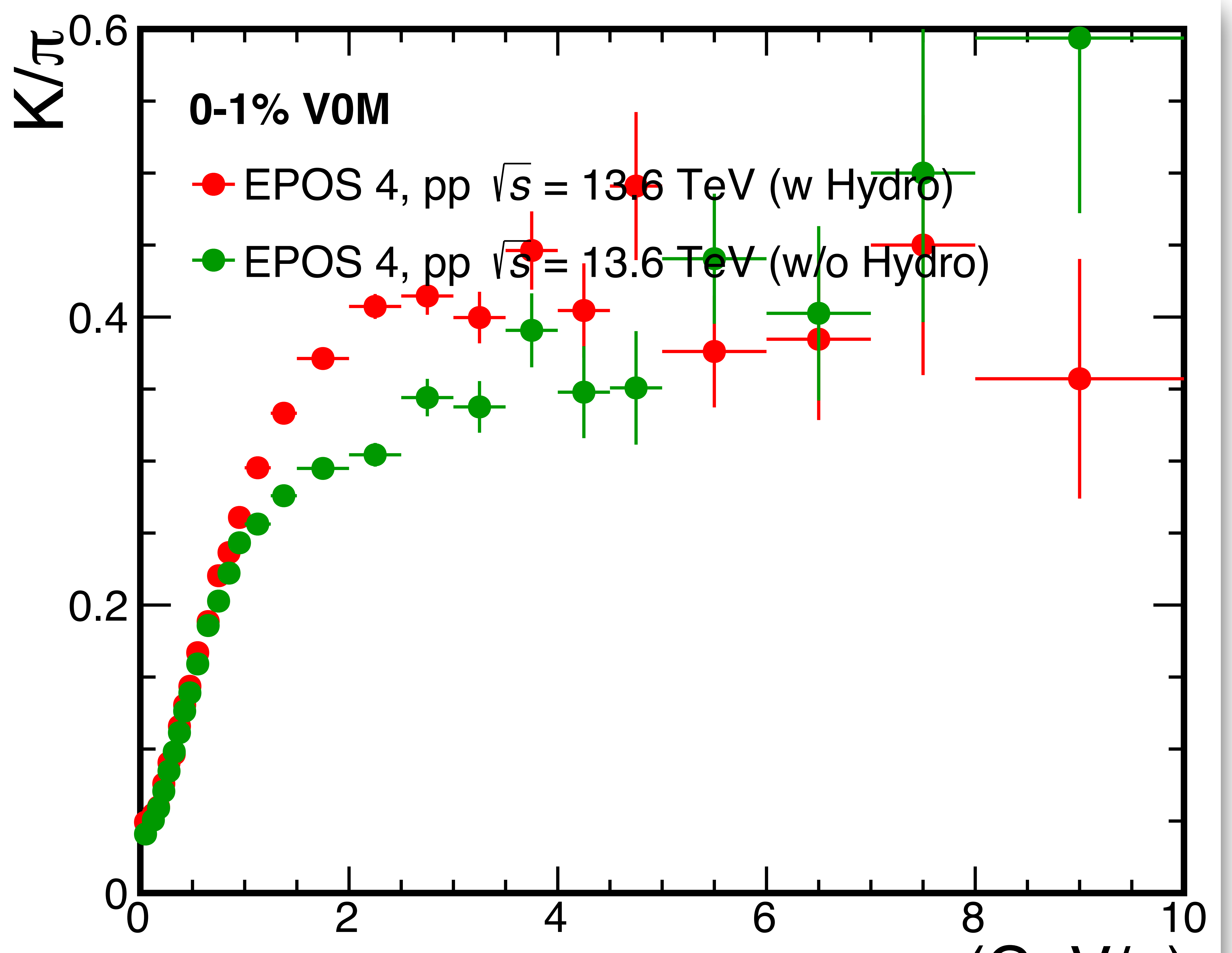
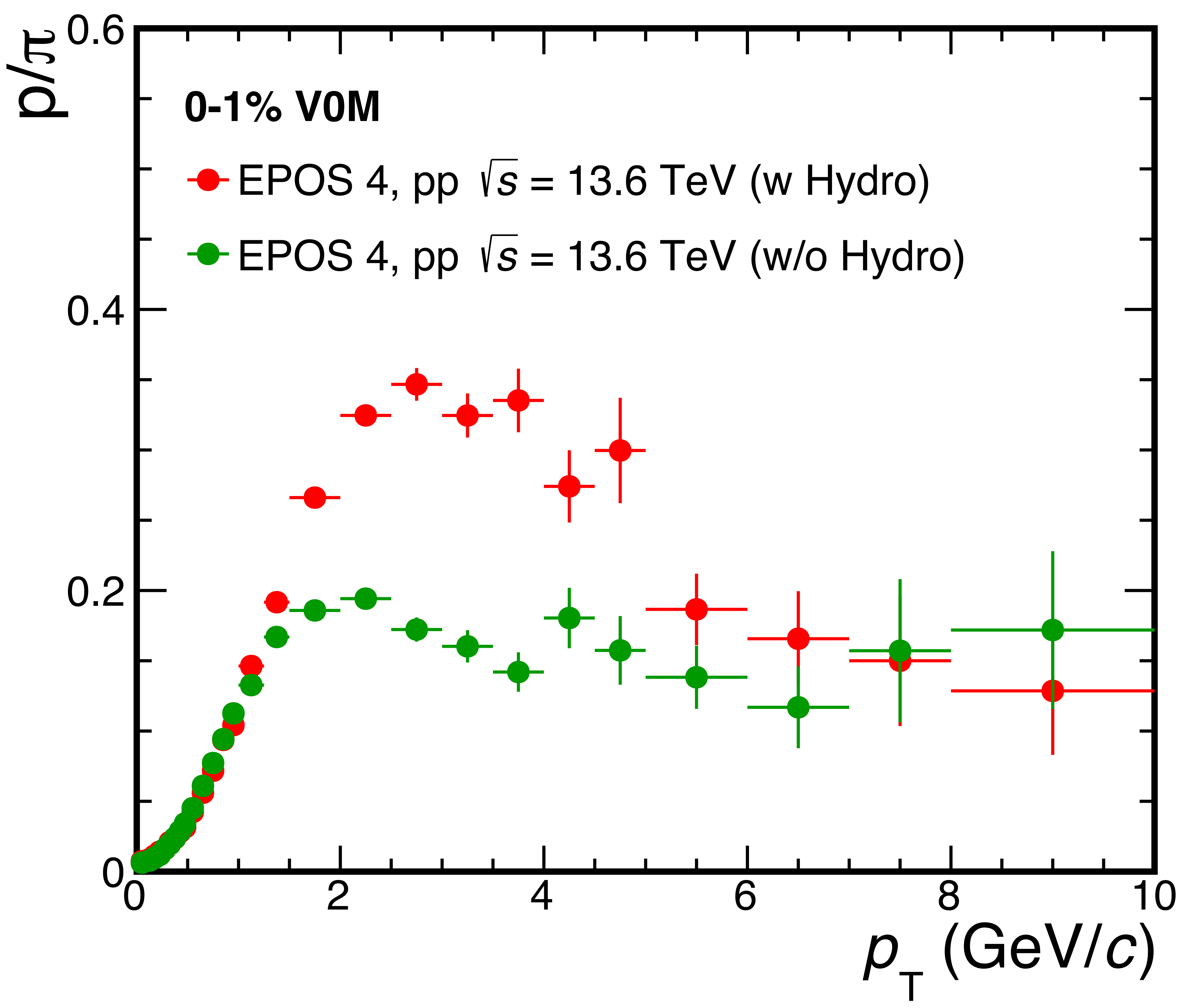
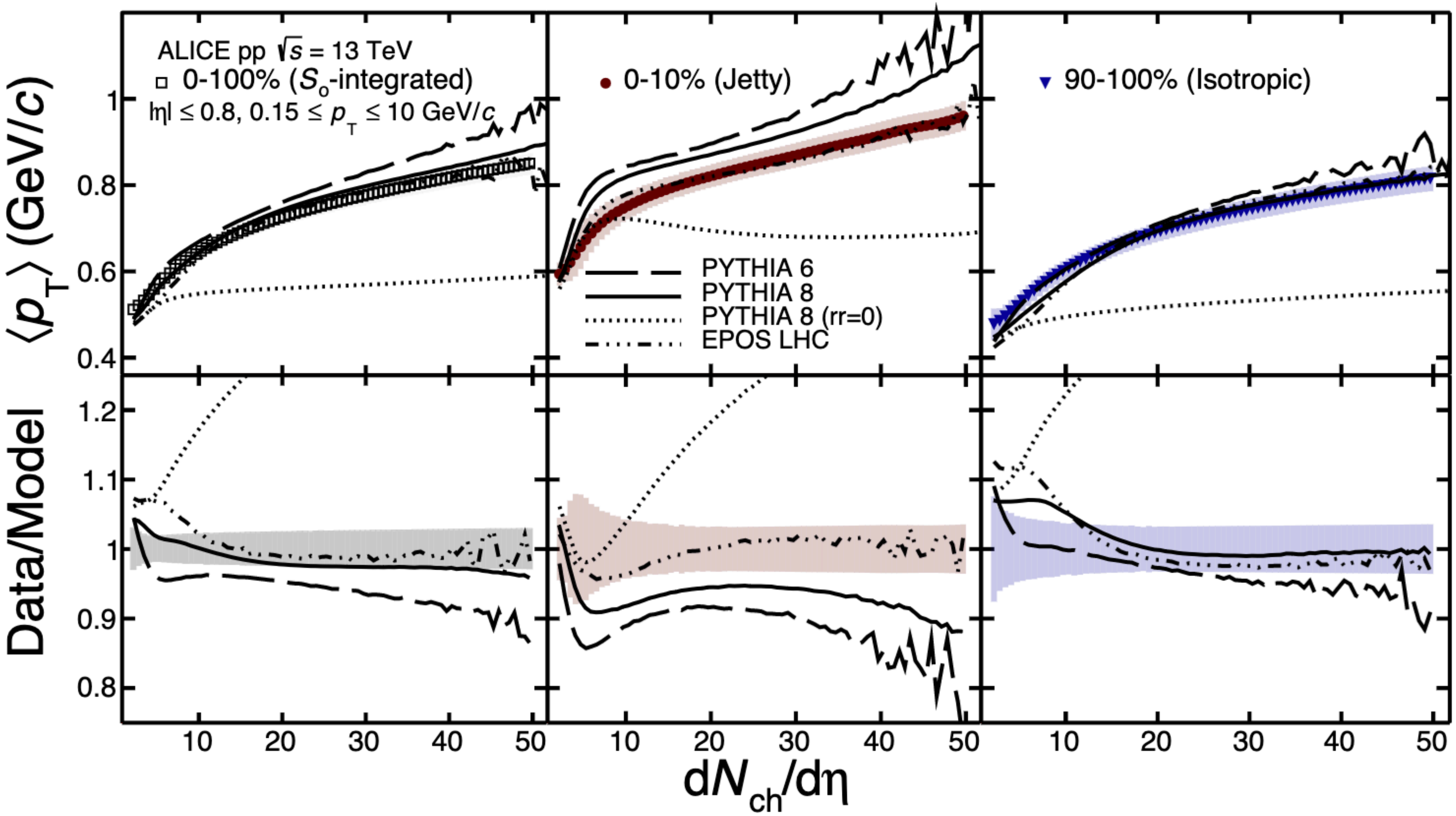
EPOS 4 from: https://klaus.pages.in2p3.fr/epos4



Plot made by Feng Fan (CCNU)



Epos 4 with hydro: adequate description of data



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

MPI

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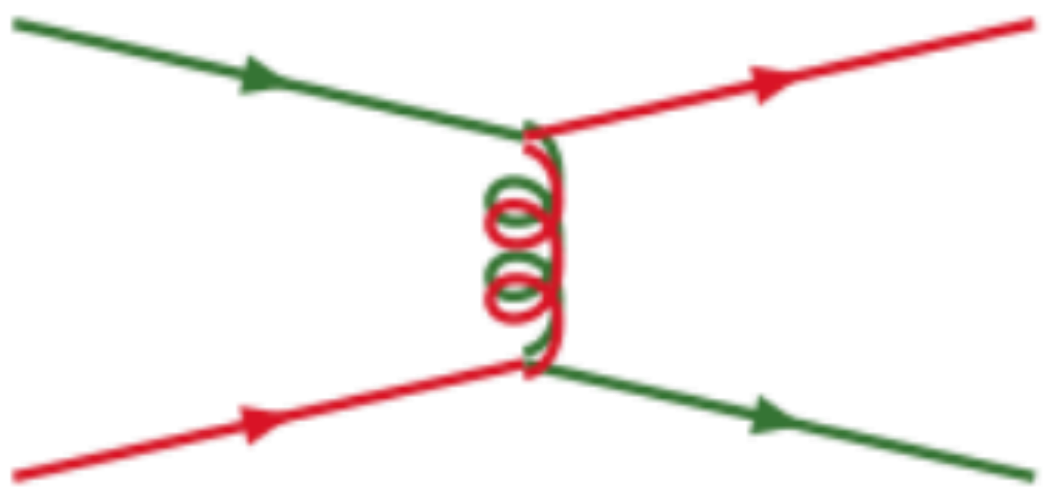
At high energies, the leading order cross-section for $2 \rightarrow 2$ parton scatterings with momentum transfer $Q > Q_{\text{min}} \gg \Lambda_{\text{QCD}}$ exceeds the total pp cross-section at a range of Q_{min}-values where perturbative QCD is applicable (at LHC, $Q_{\text{min}} \approx 4$ GeV/c)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

T. Sjöstrand, 6th MPI @ LHC Workshop



Integrate QCD $2 \rightarrow 2$

$qq' \rightarrow qq'$

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

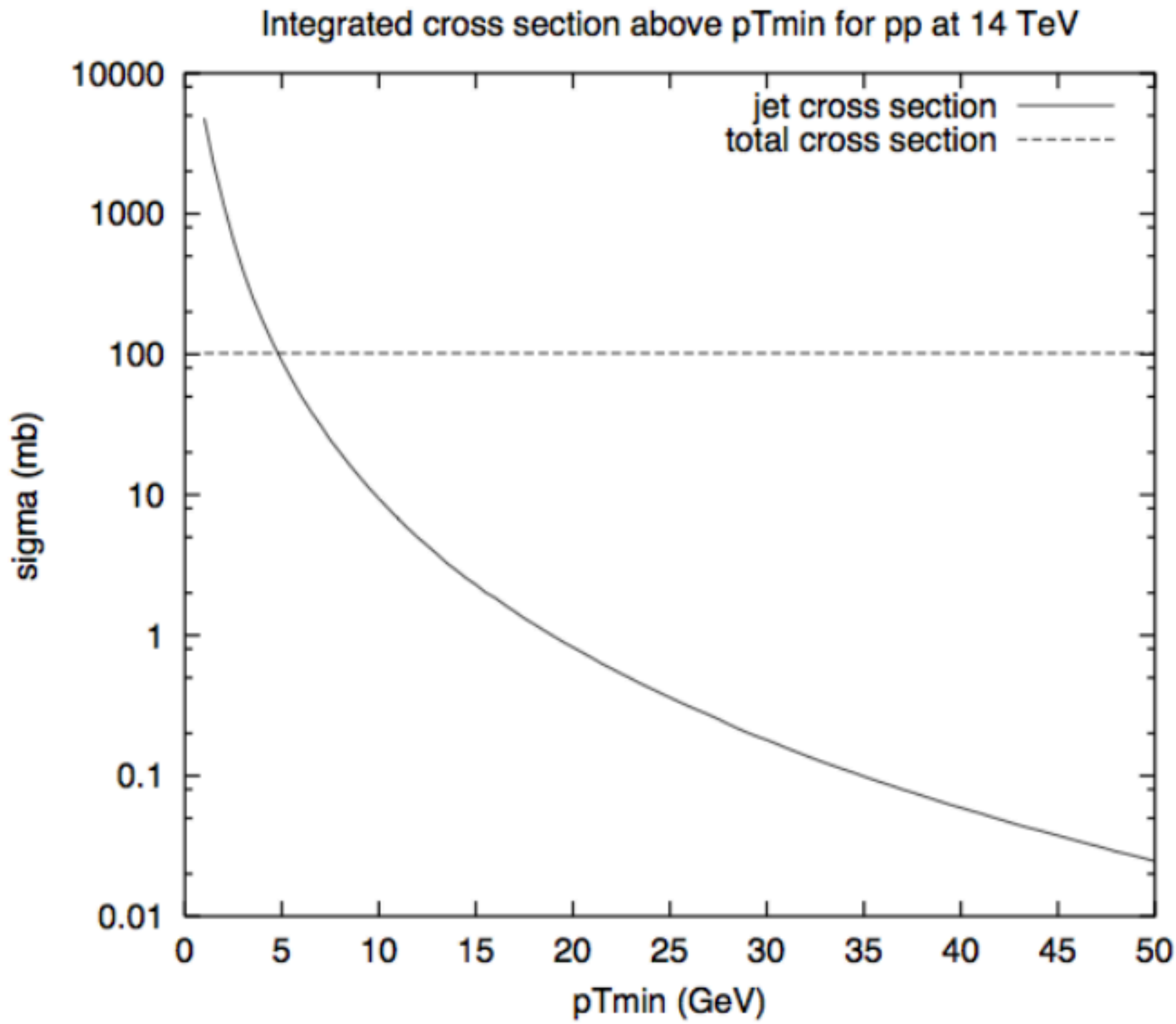
$q\bar{q} \rightarrow gg$

$qg \rightarrow qg$

$gg \rightarrow gg$

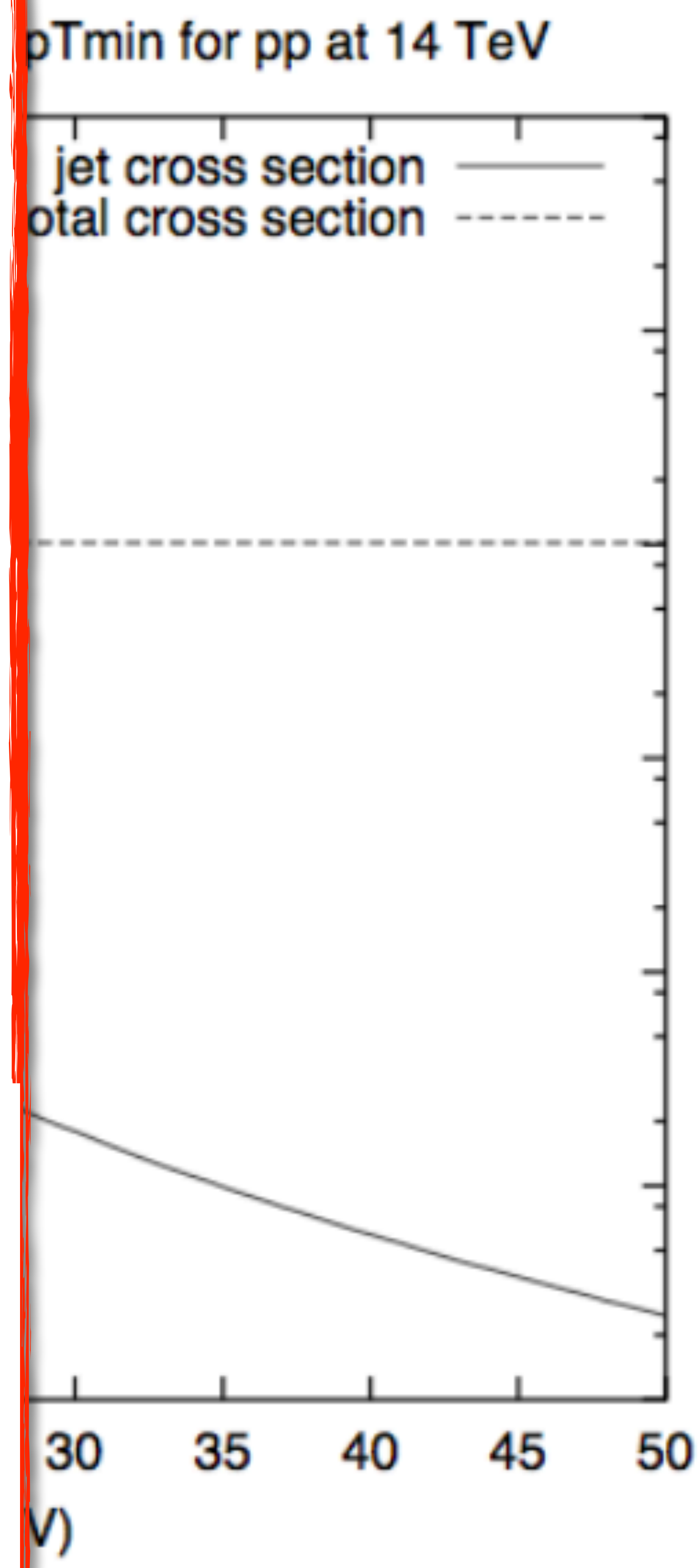
$gg \rightarrow q\bar{q}$

(with CTEQ 5L PDF's)



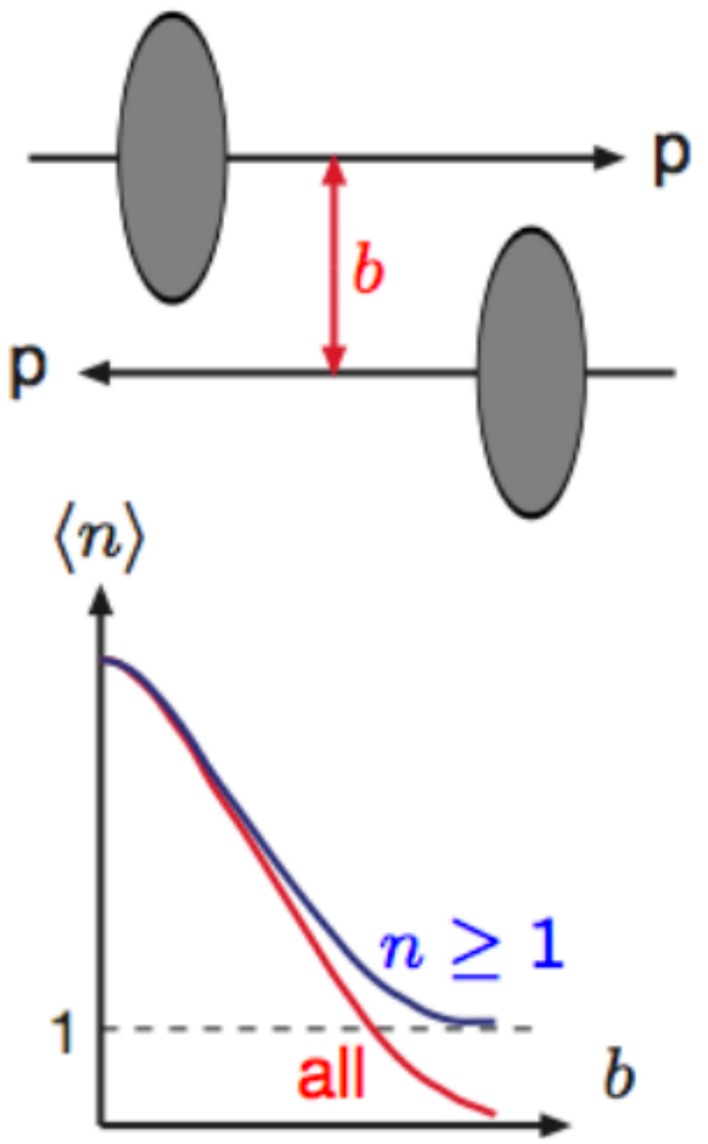
MPI

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

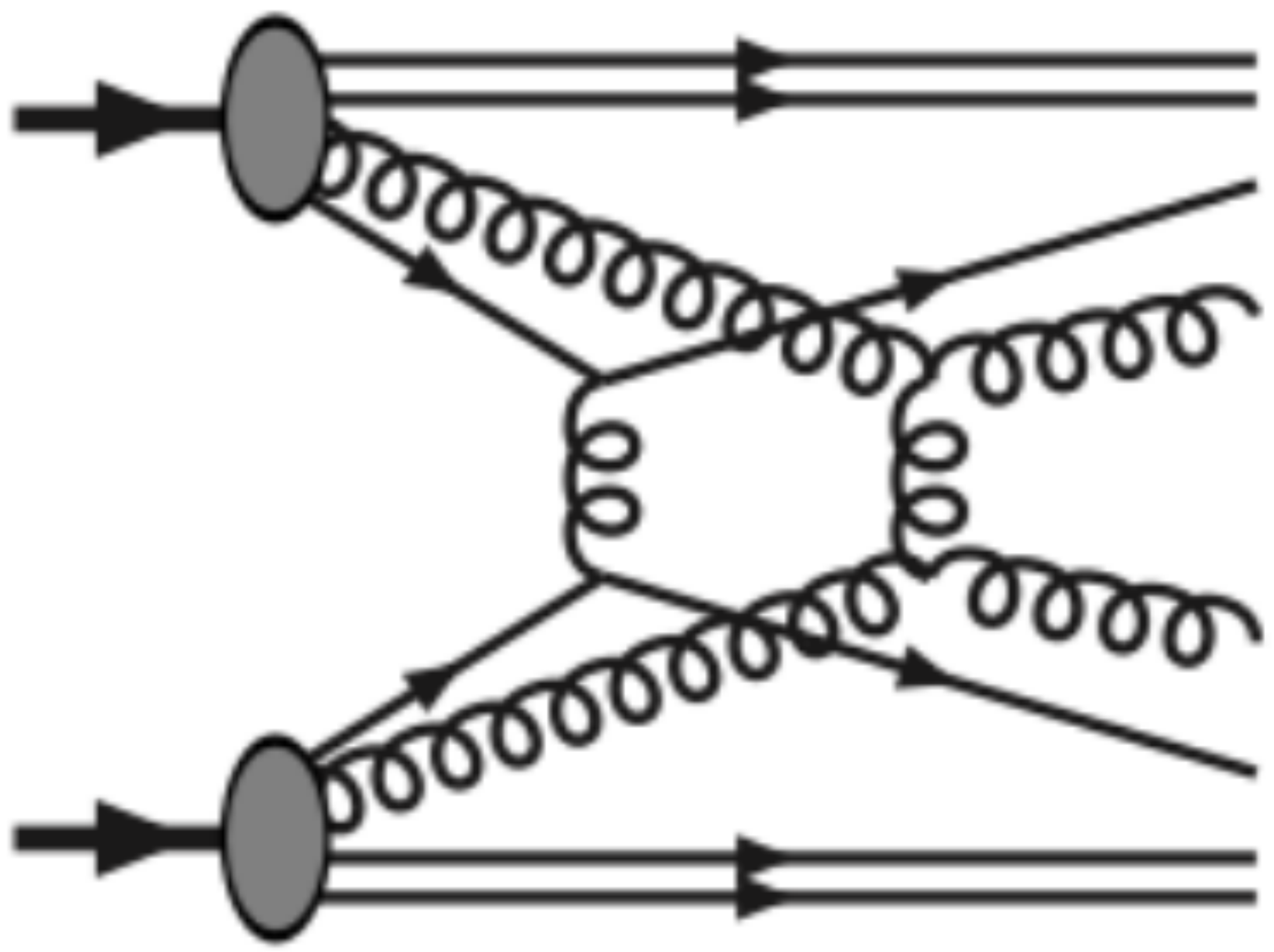


Interpretation: Many partonic scatterings per event: (MPI)

- 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

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

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

T. Sjöstrand, ISAPP 2018

MPI

Interpretation: Many partonic scatterings per event: (MPI)

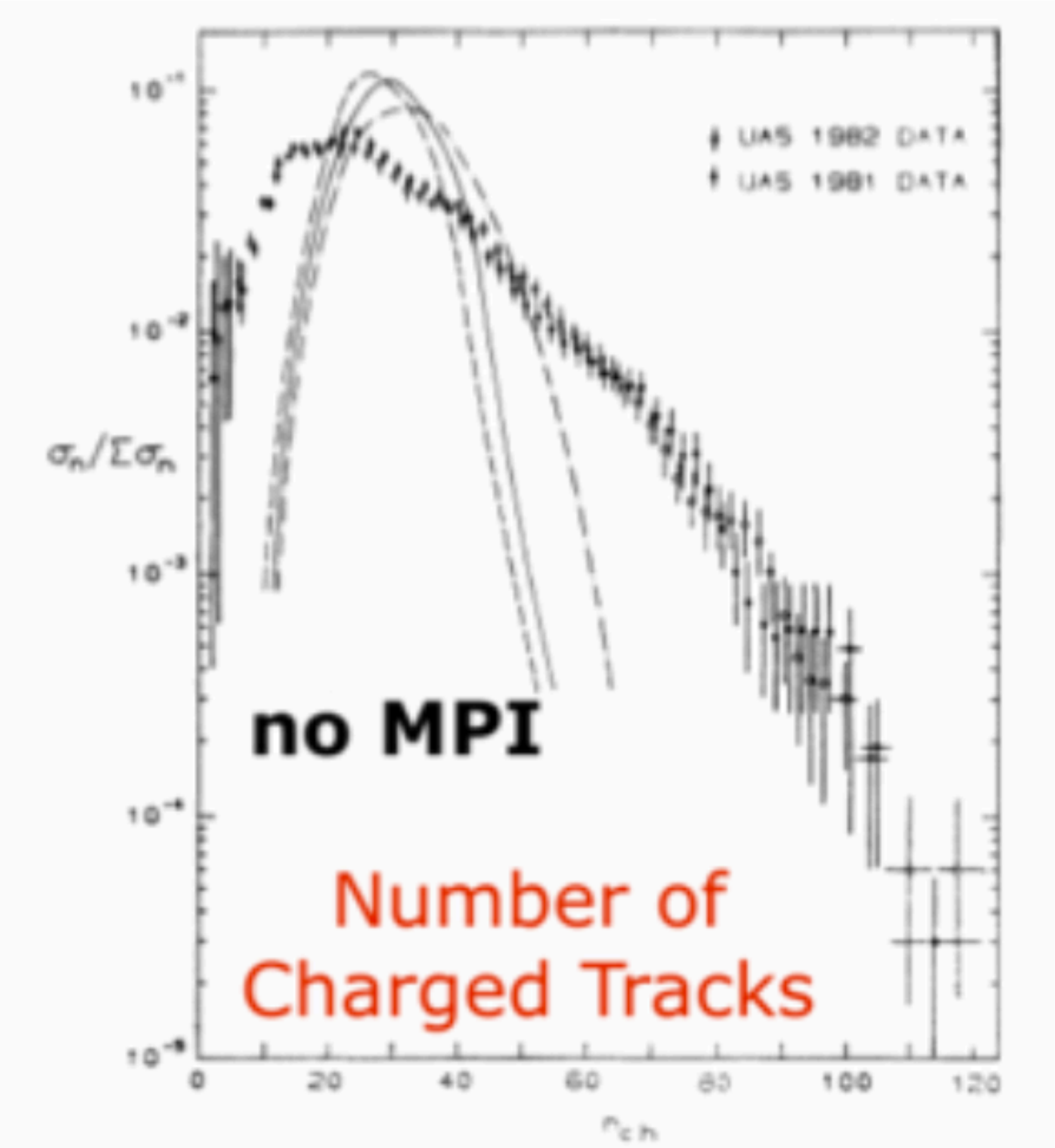


FIG. 3. Charged-multiplicity distribution at 540 GeV, UA5 results (Ref. 32) vs simple models: dashed low p_T only, full including hard scatterings, dash-dotted also including initial- and final-state radiation.

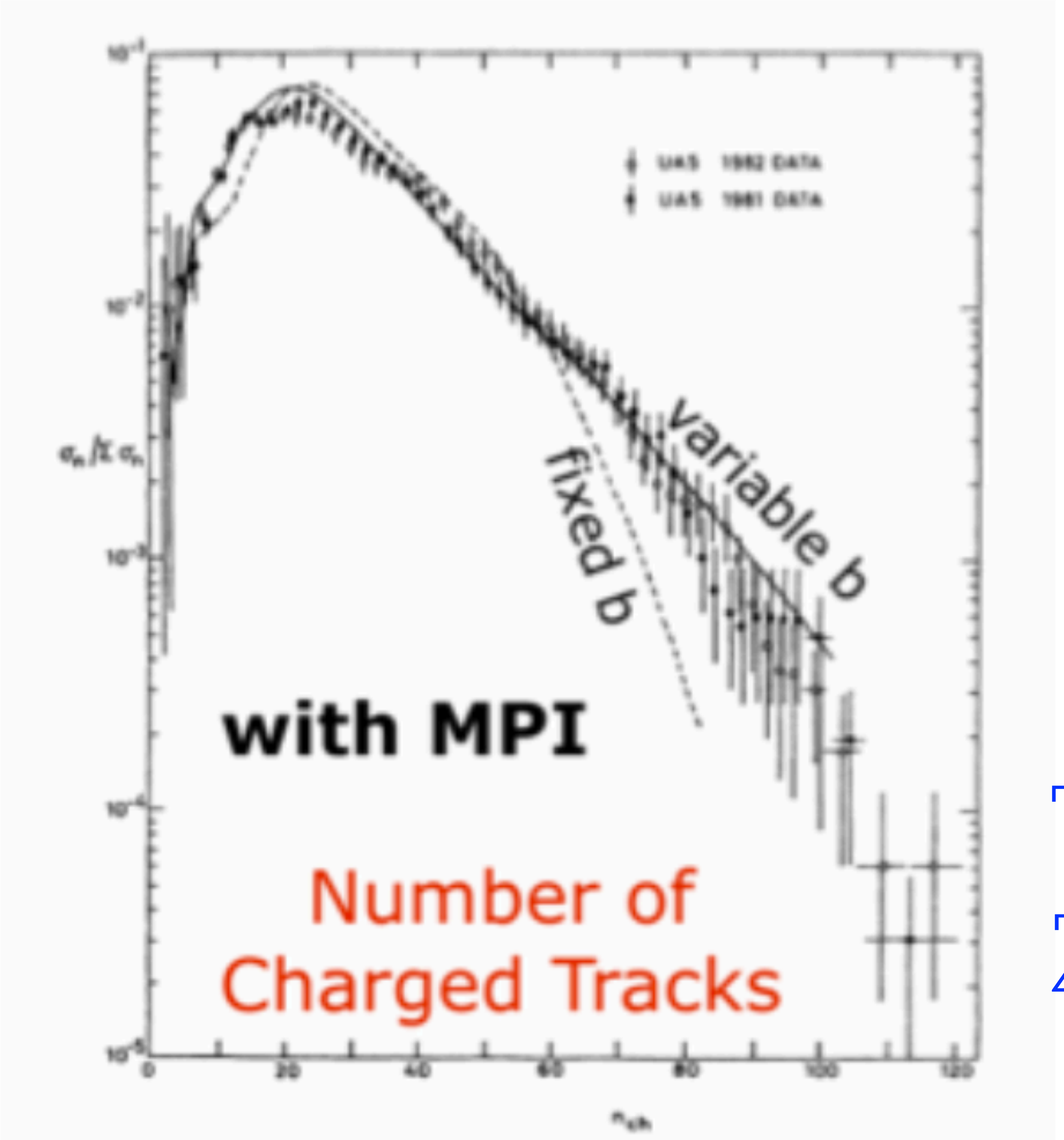


FIG. 12. Charged-multiplicity distribution at 540 GeV, UA5 results (Ref. 32) vs multiple-interaction model with variable impact parameter: solid line, double-Gaussian matter distribution; dashed line, with fix impact parameter [i.e., $\tilde{O}_0(b)$].

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

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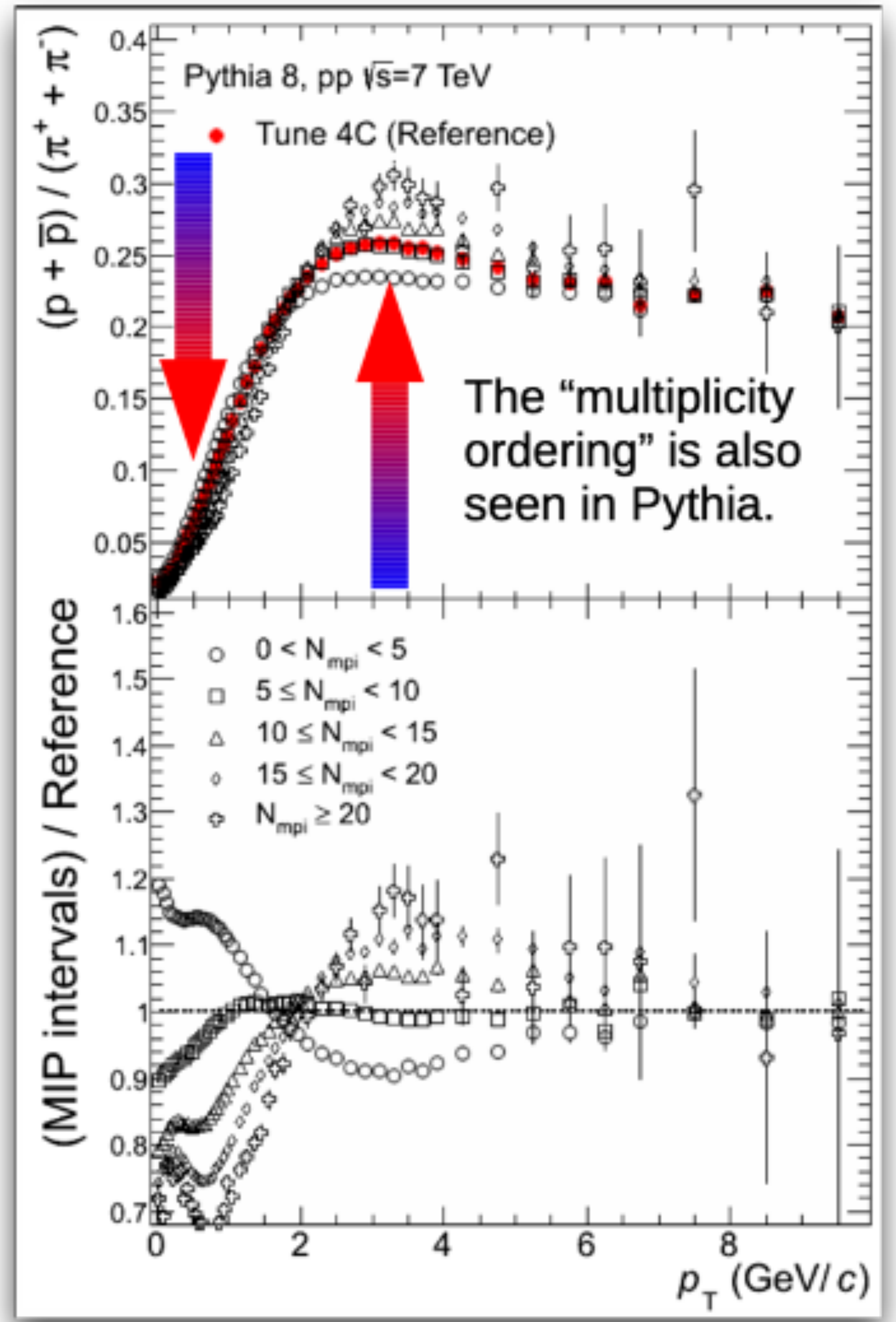
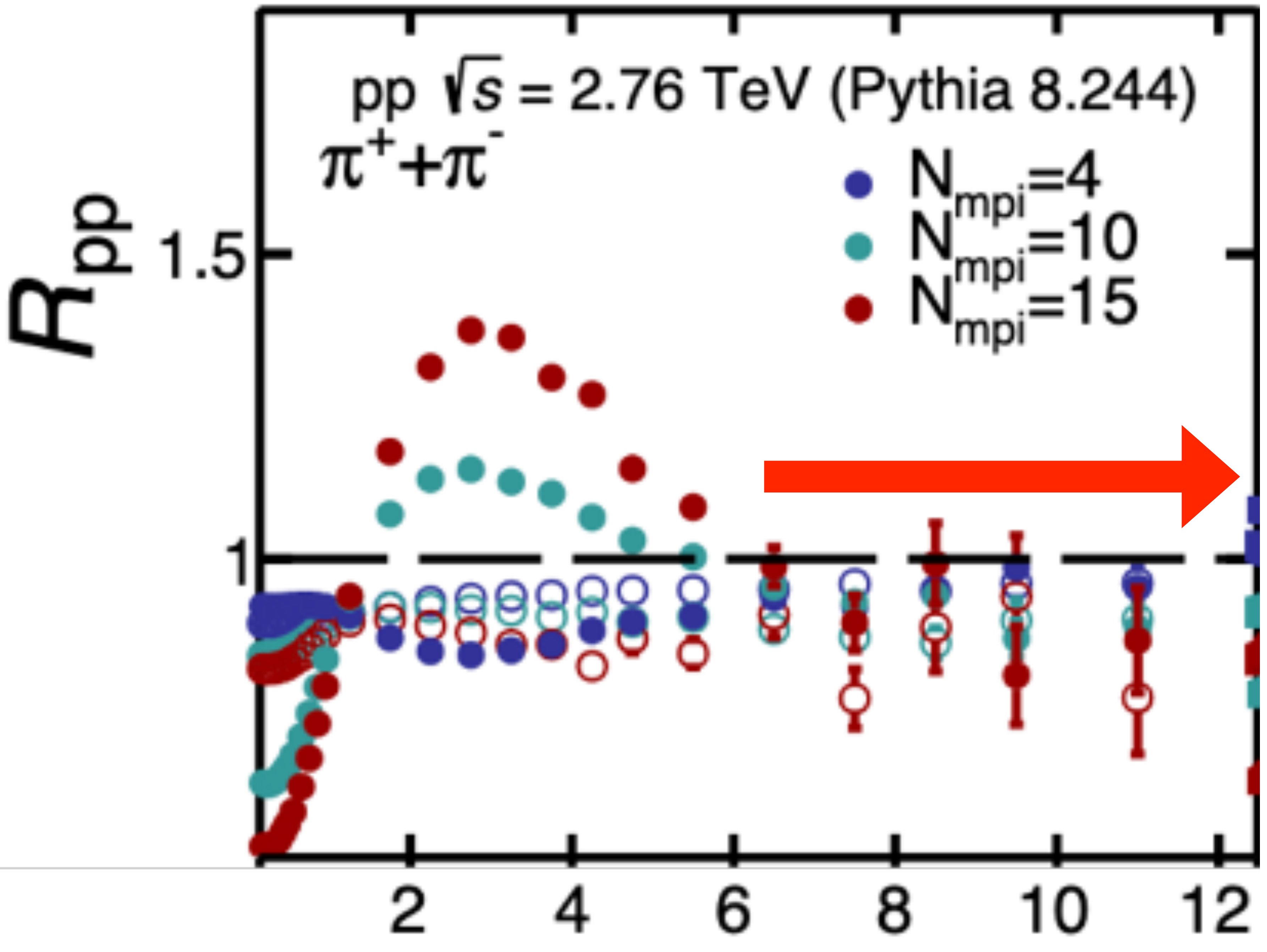
Phys. Rev. Lett. 111, 042001 (2013)



Radial flow-like behaviour



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

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

Scaling with number of parton-parton interactions at high p_T

High energy heavy-ion collisions

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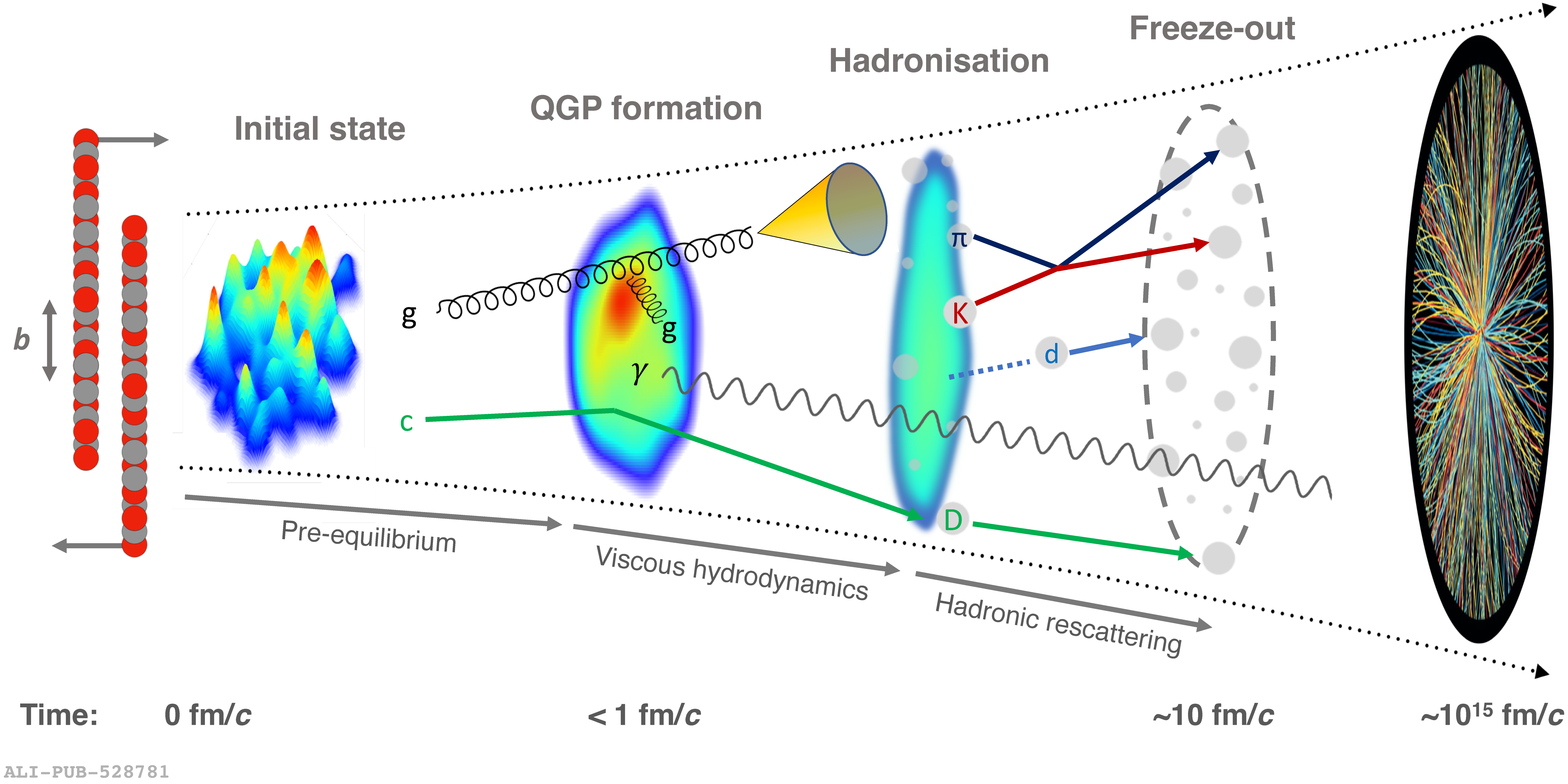

High-p_{T} physics: V0M vs flattenicity

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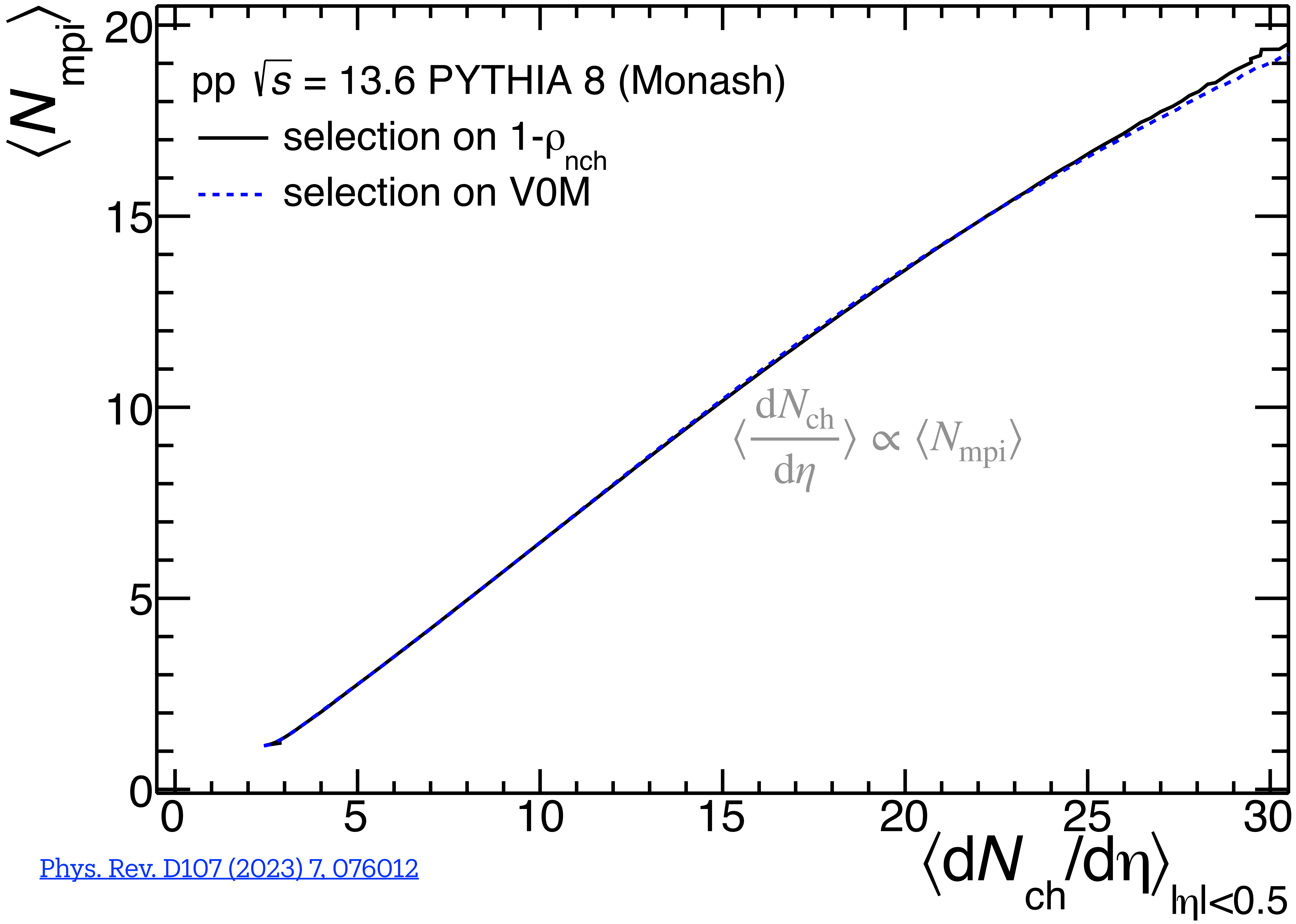
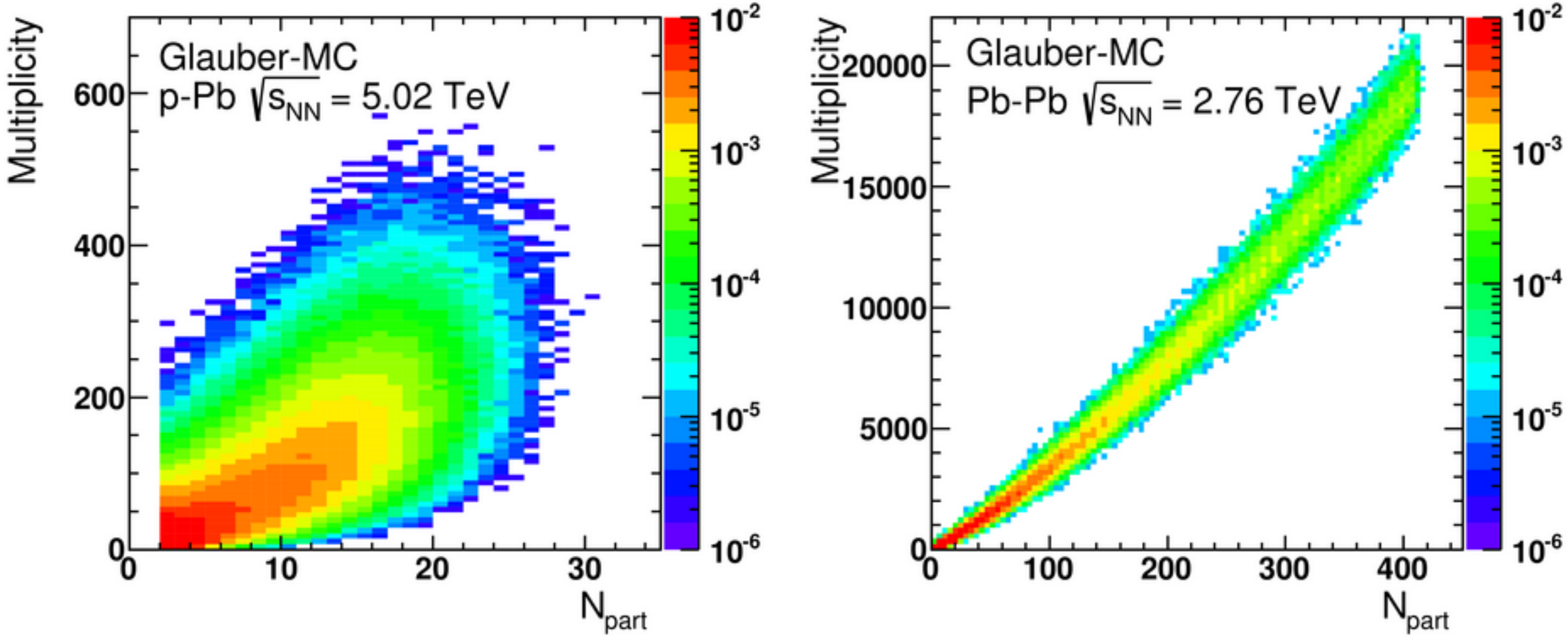


Phys. Rev. D107 (2023) 7, 076012

Centrality in small systems (p-Pb)

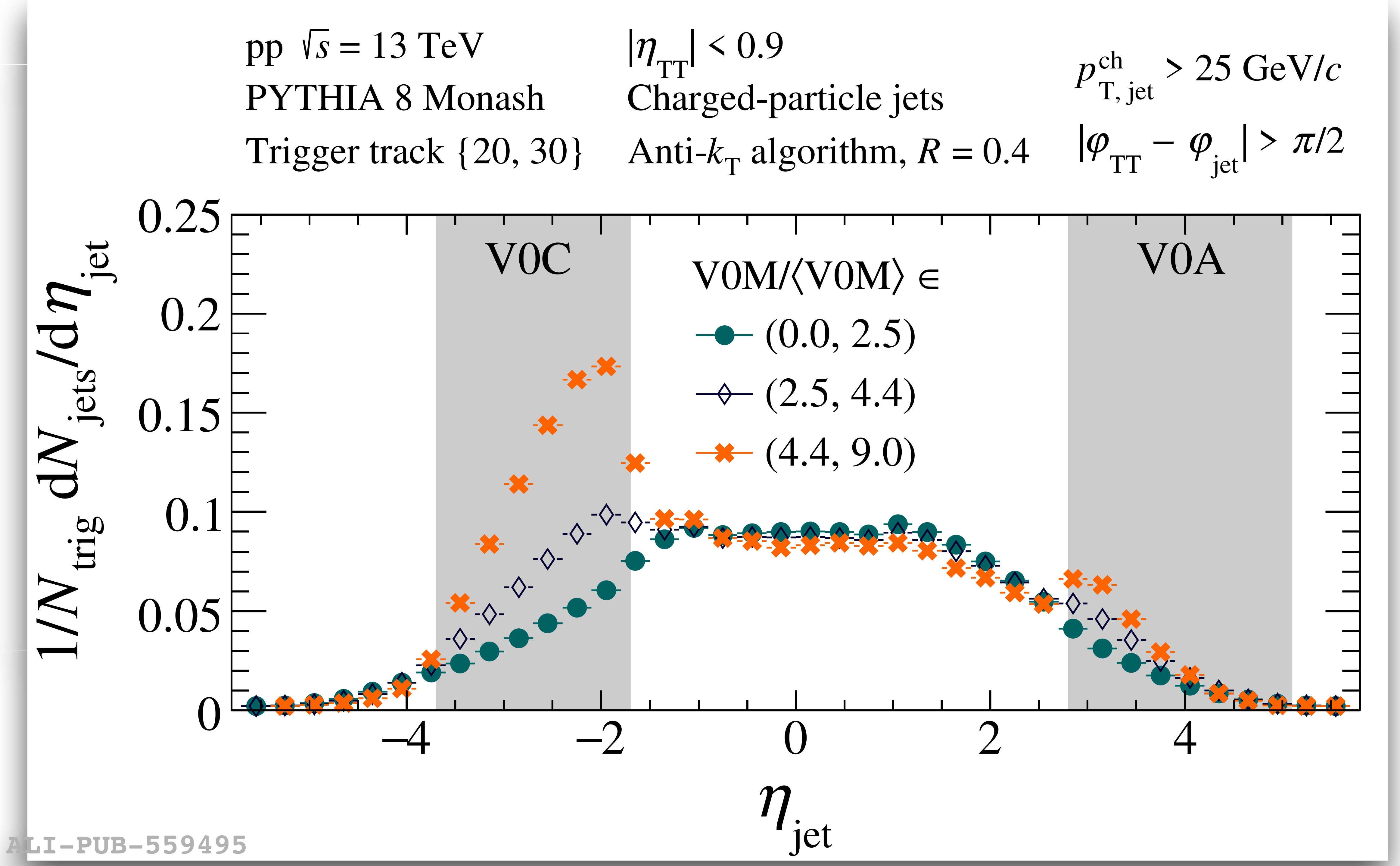
In contrast to Pb–Pb collisions, for p–Pb collisions the multiplicity (V0A) fluctuations are sizeable compared to the width of the N_{part} distribution

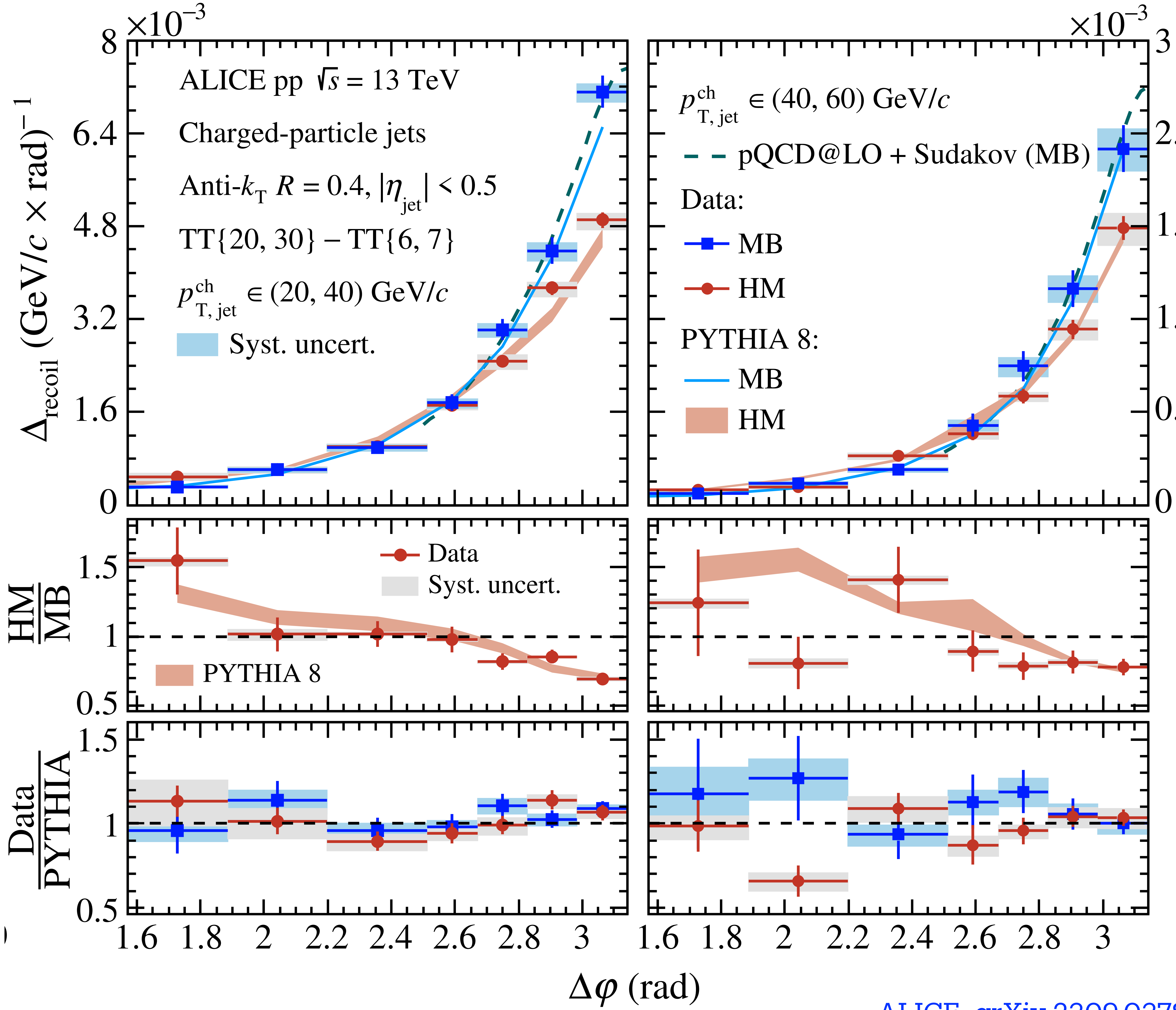


Phys. Rev. C 91 (2015) 064905

Weak correlation between geometry and event activity

Issues to search for jet quenching

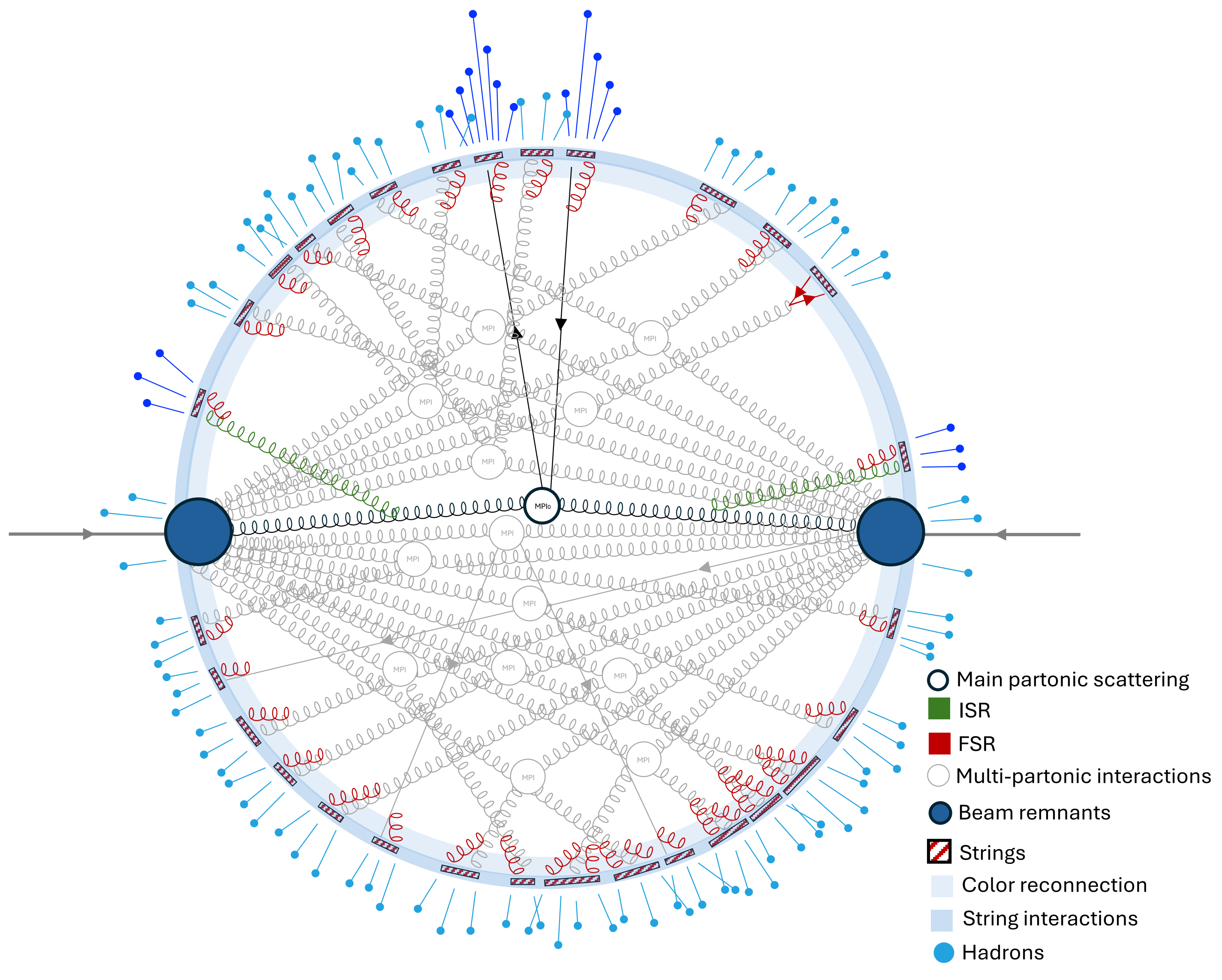




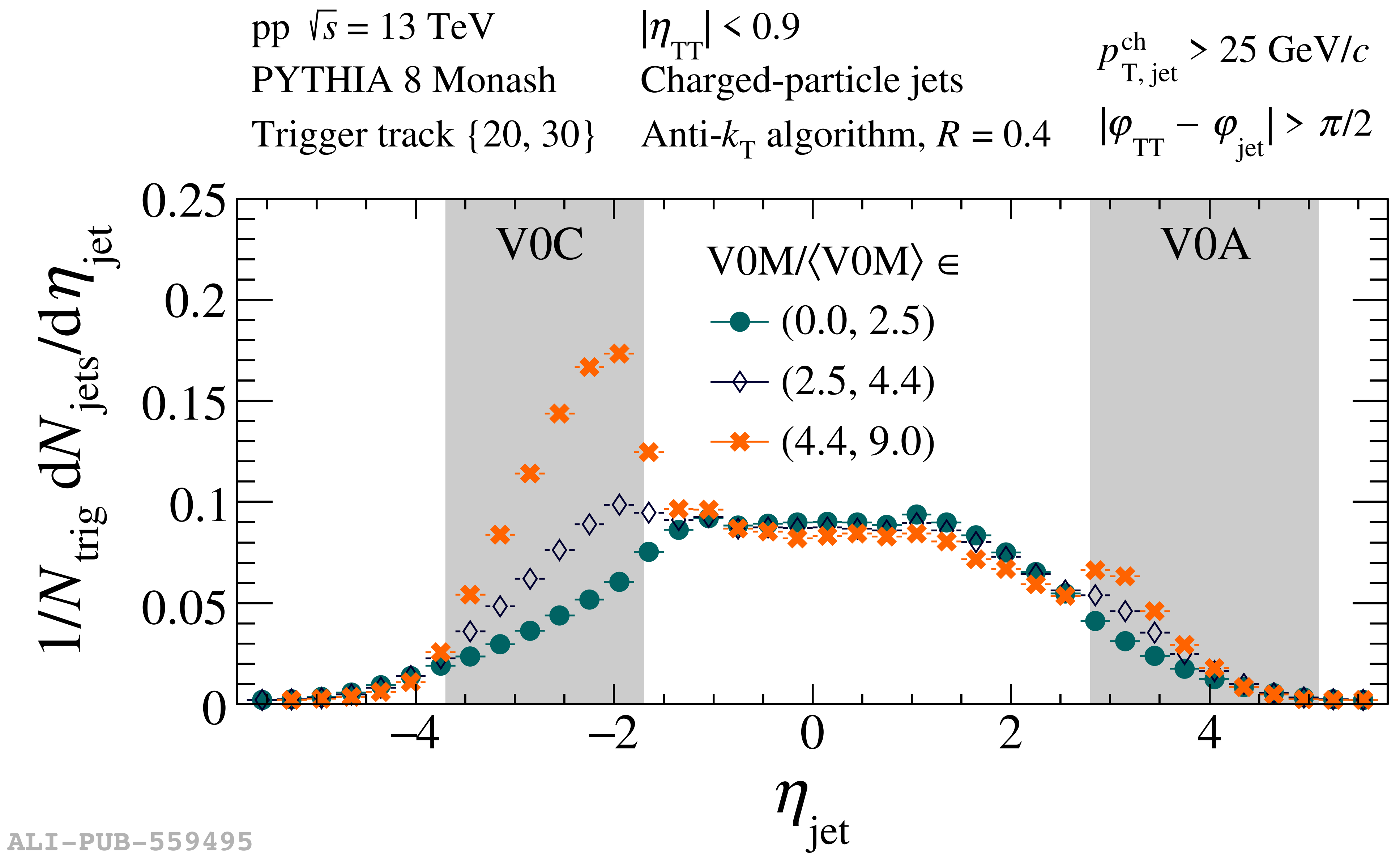
ALICE, arXiv:2309.03788

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

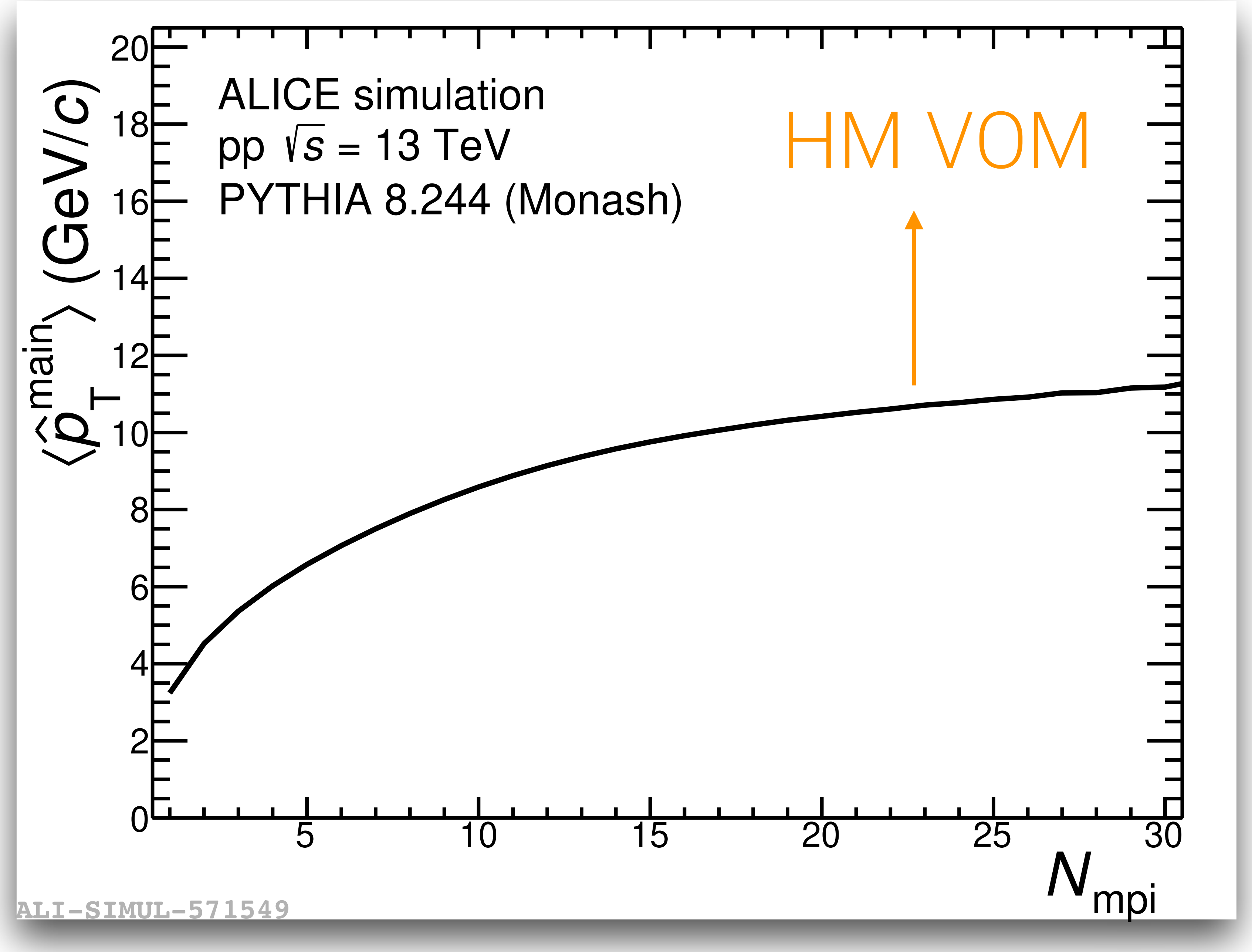
Bias due to local mult. fluctuations



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



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



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

ALICE, JHEP 05 (2024) 229   ALICE, Phys. Lett. B 843 (2022) 137649