Characterization of particle production through UE and very forward energy in hadronic collisions with ALICE

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for the ALICE Collaboration

pp and p-Pb collisions at LHC

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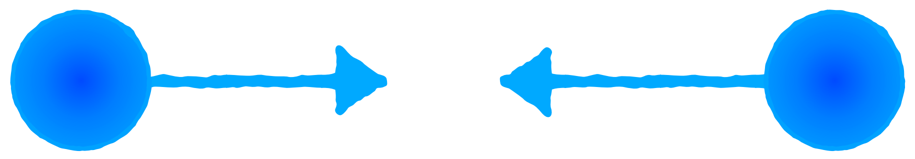
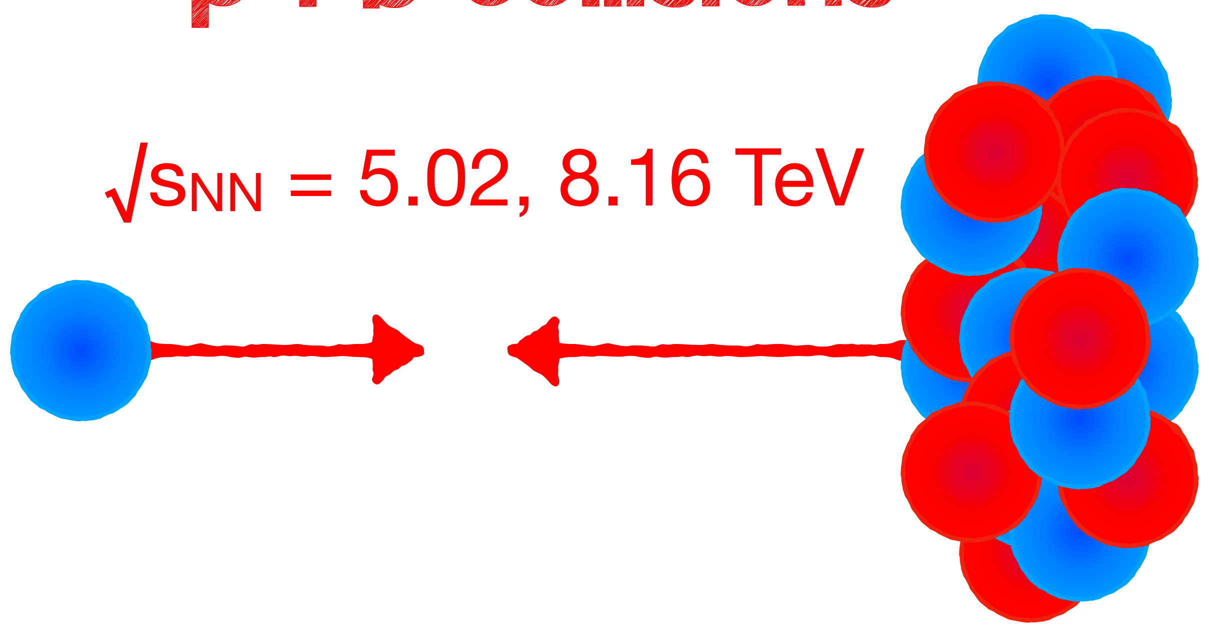
pp collisions

$\sqrt{s}$ = 5.02, 13 TeV

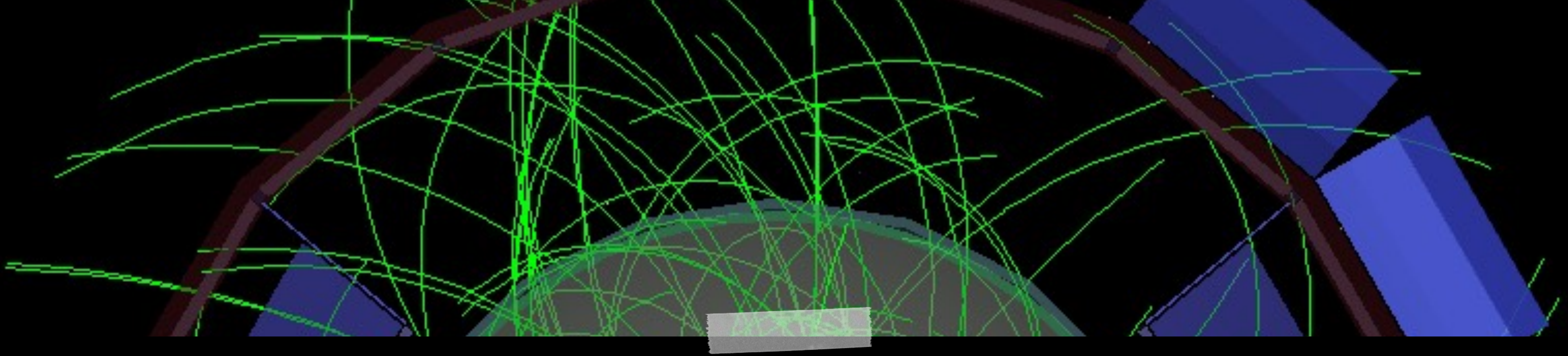


p-Pb collisions

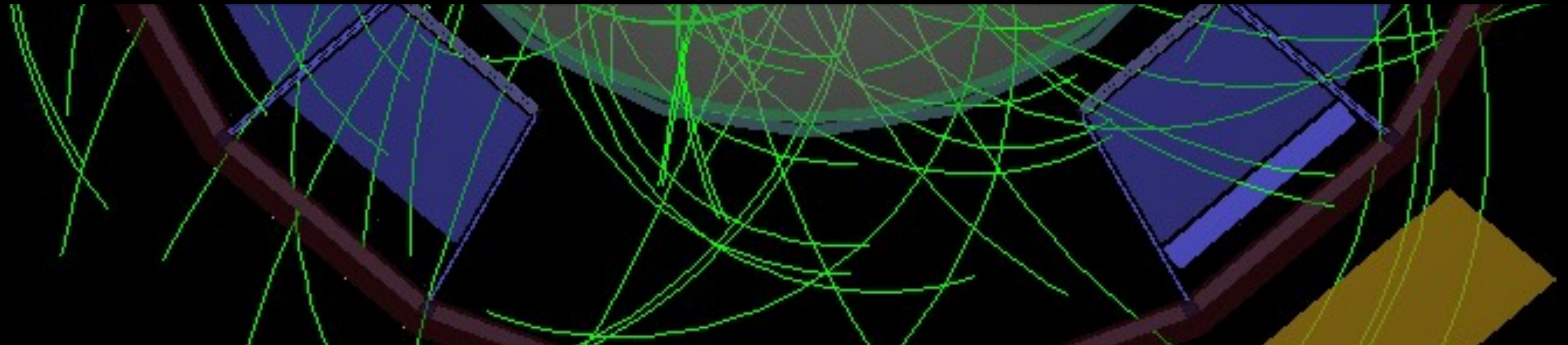
$\sqrt{s_{NN}}$ = 5.02, 8.16 TeV



- expected to provide a benchmark for AA collisions and to quantify the Cold Nuclear Matter effects
- showed QGP-like behaviour in the soft sector (strangeness enhancement, long-range angular correlations and collectivity) but no modifications of hard probes (no energy loss for high p_T particles)



pp and p-Pb collisions: what we know, what can we look for and which tools we use



What can we learn from small systems?

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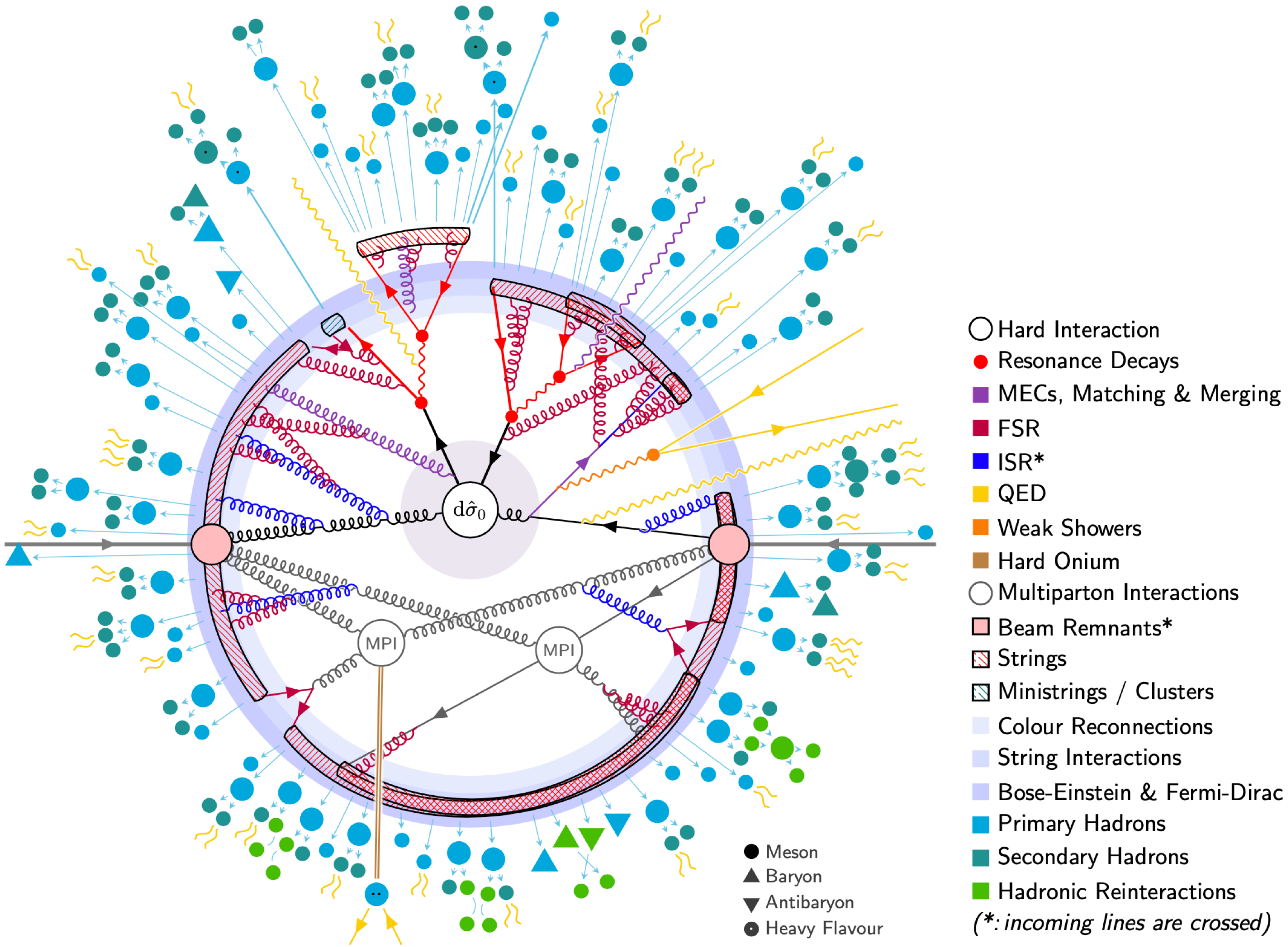
COLLISION STAGES

- early times dominated by hard probes
- relevance of Multiple Parton Interaction (MPI) at semi-hard scale
- hadronization at later stages

MECHANISMS AT PLAY

- role of different mechanisms used by event generators (color reconnection, hadronization…)
- what is the mechanism originating the collective-like behaviour? Is it the same occurring in Pb-Pb?
- what drives the observed strangeness enhancement? Is it the final state multiplicity?



Underlying Event (UE)

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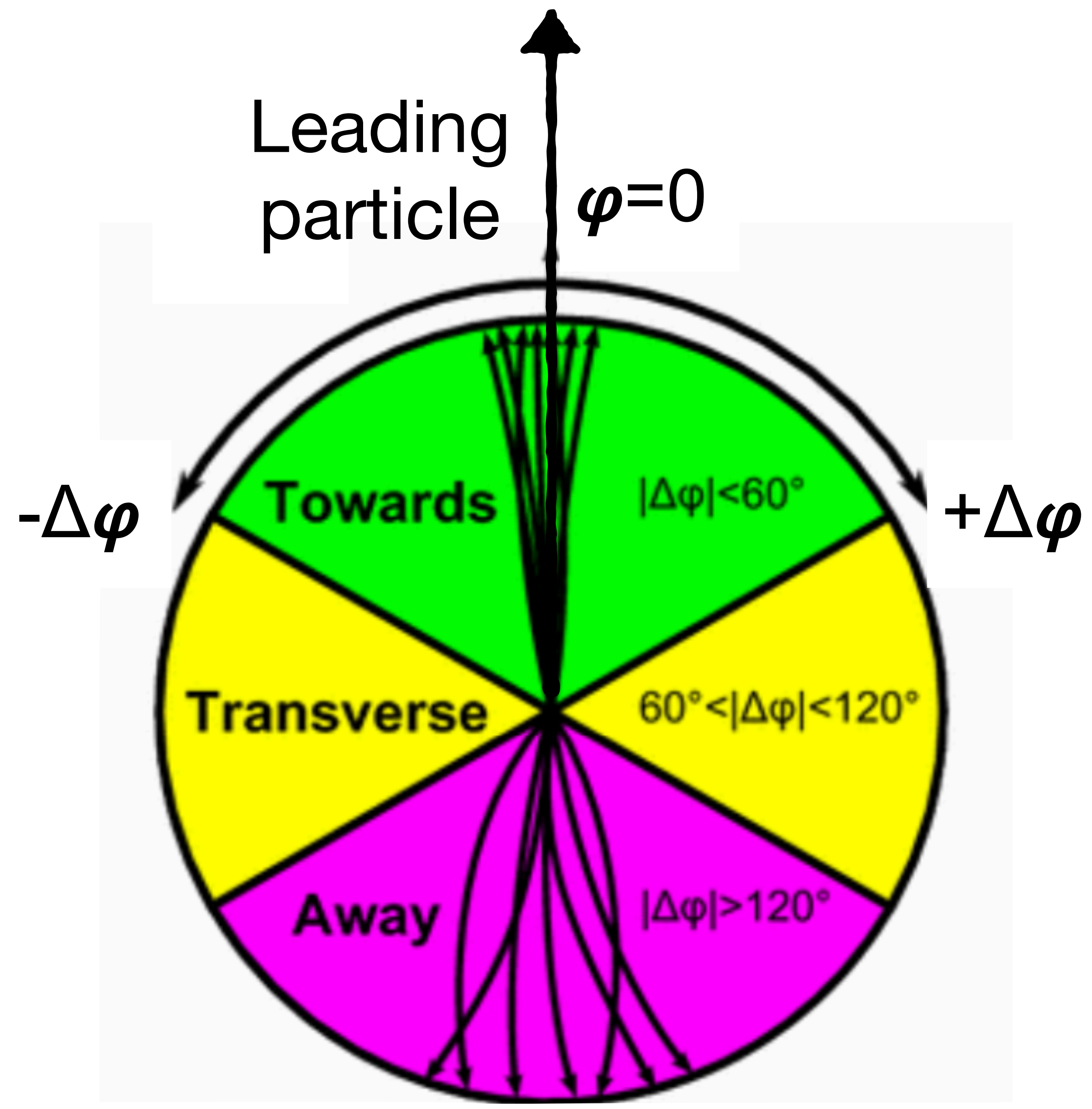
Underlying Event = particle production NOT originating from primary hard parton-parton scattering

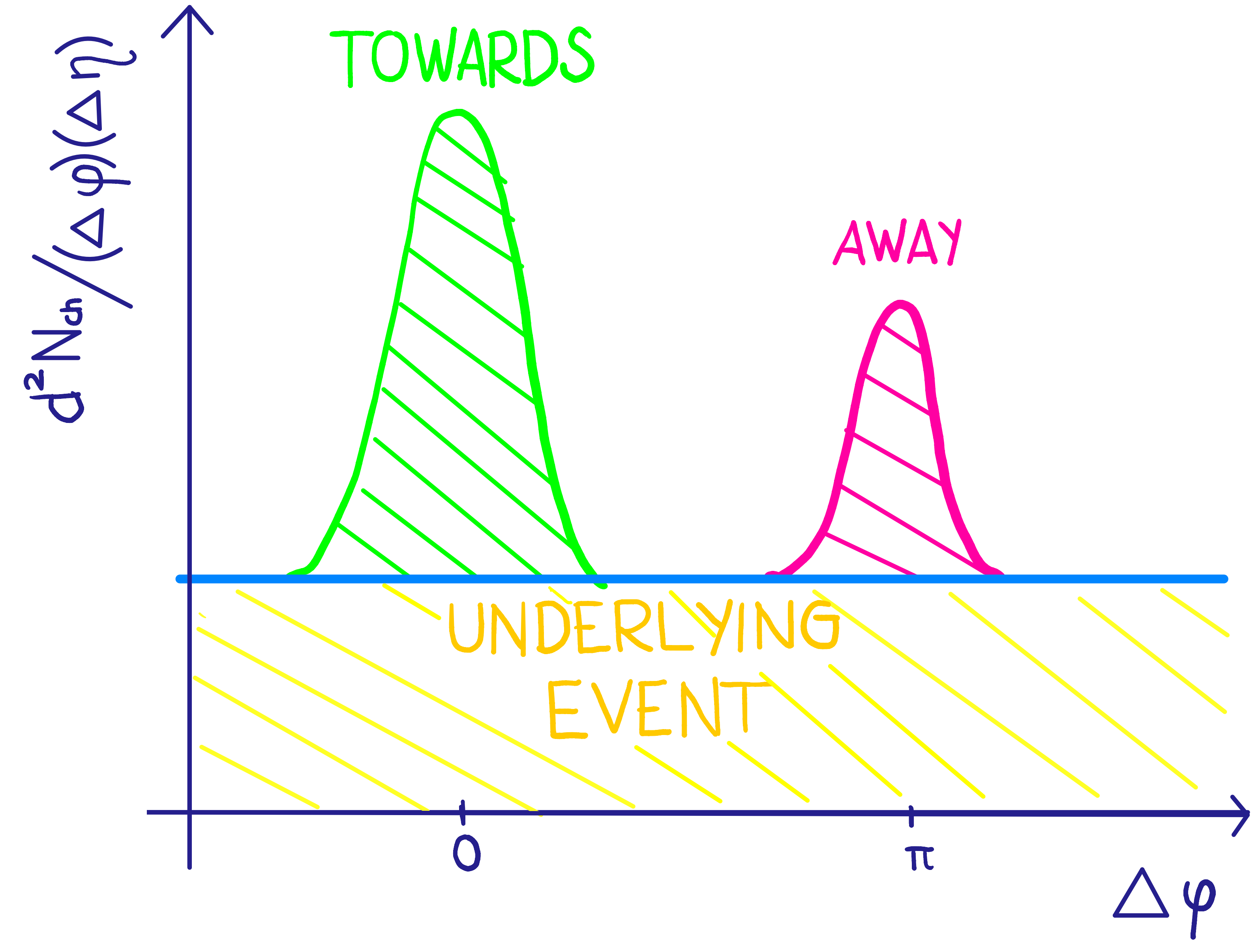
pp collisions ➧ in presence of a leading particle (hard scattering), particle production can be studied in 3 different topological regions:

TOWARDS REGION ($|\Delta\varphi|<60^{\circ}$)

TRANSVERSE REGION ($60^{\circ}<|\Delta\varphi|<120^{\circ}$)

AWAY REGION ($|\Delta\varphi|>120^{\circ}$)





➧ Disentangle and correlate HARD from SOFT contributions:

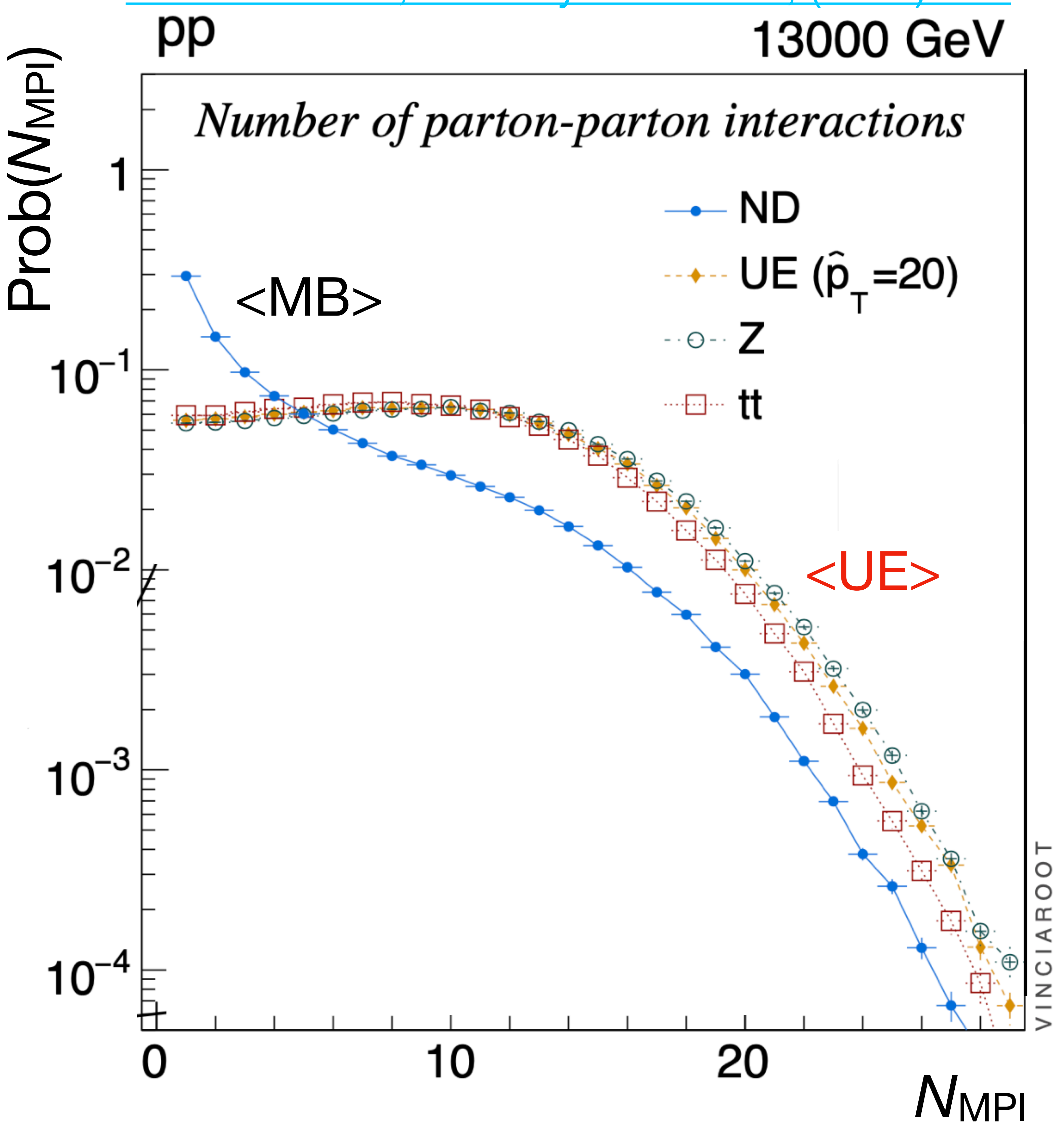
Fragmentation from parton hard scattering

UE ➧ MPI, ISR/FSR, beam remnants

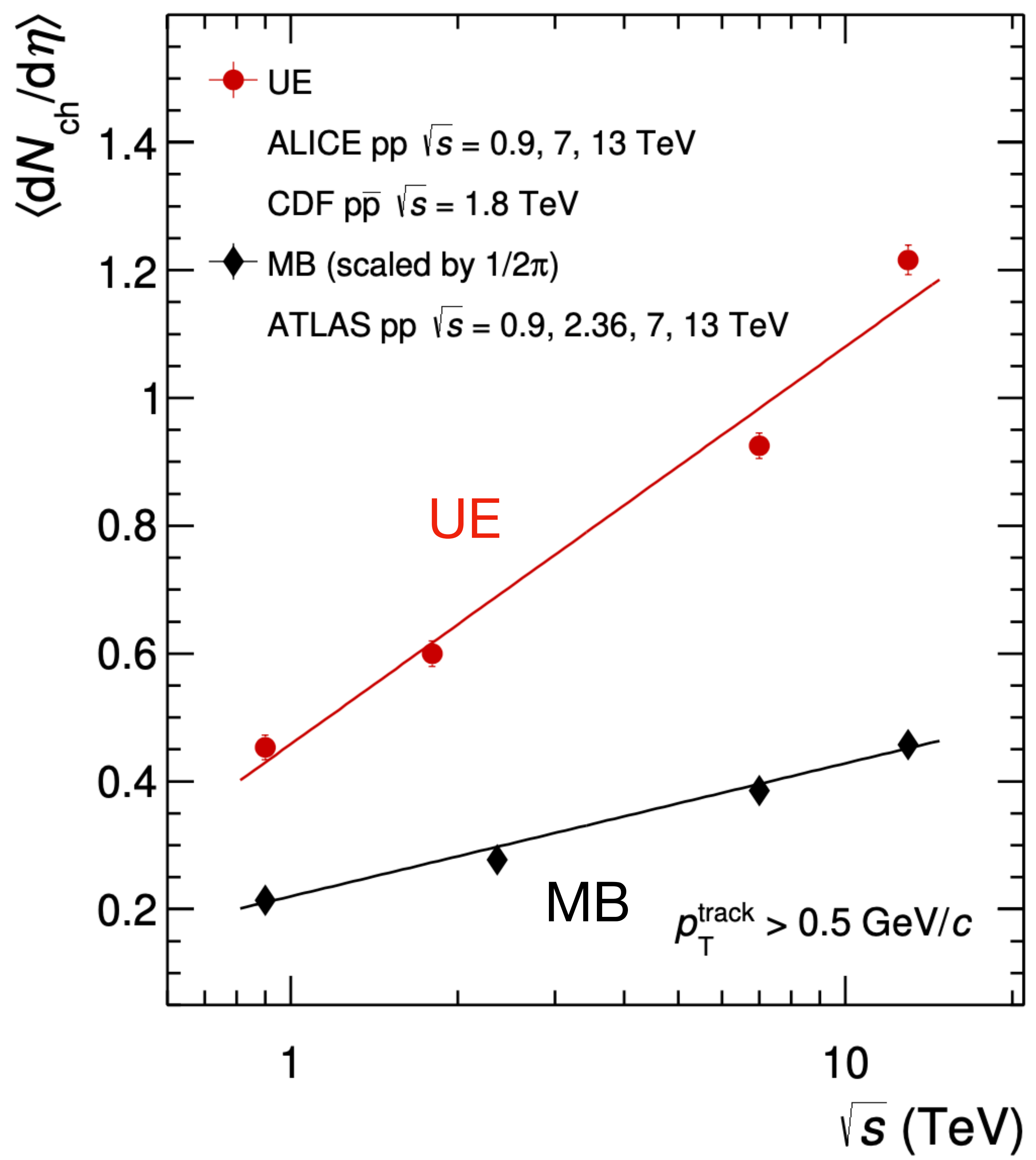
UE & MPI

- requesting a high p_T particle at midrapidity biases the event towards a larger activity than in MB collisions
- in models including MPIs with an impact parameter dependence, this is explained as a bias towards events with smaller b and larger number of MPI than in MB

T. Martin et al., Eur. Phys. J. C76 5, (2016) 299

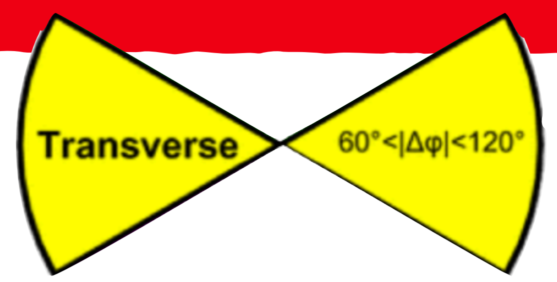


ALICE Coll., JHEP 04 (2020) 192

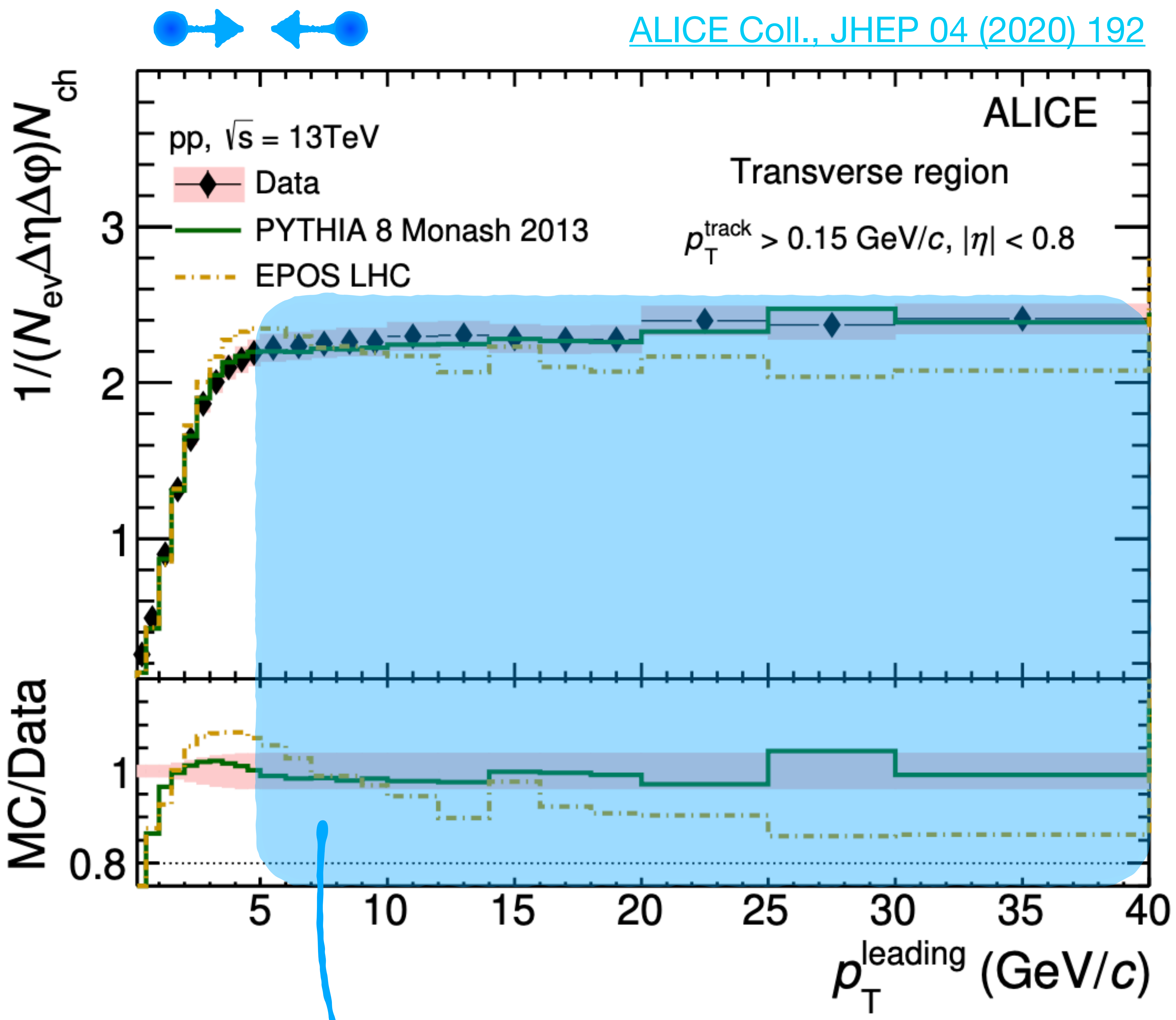


UE ➧ phase-space region exhibiting high-multiplicity MB-like features ➧ larger number of MPI, higher multiplicity

Relative transverse activity classifier



[ALICE Coll., JHEP 04 (2020) 192](#)



leading particles dominantly produced by hard scatterings

TRANSVERSE REGION:

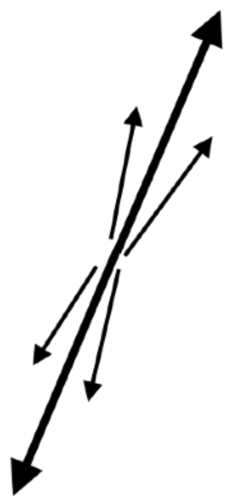
- Smaller b ➧ large matter overlap ➧ larger N_{MPI} ➧ higher probability of hard scattering
- Saturation for $p_T^{leading}$ >5 GeV/c ➧ multiplicity in the transverse region is largely independent on leading particle p_T when it is produced in a hard partonic scattering

➧ Define a "KNO-like" variable R_T for $p_T^{leading}$ >5 GeV/c

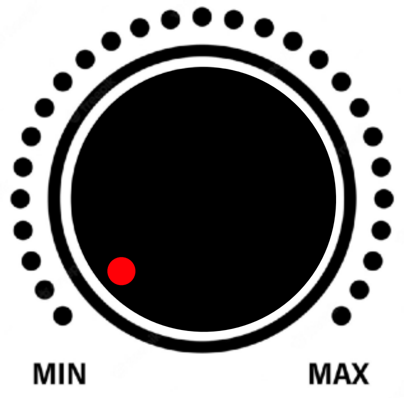
$$\boxed{R_{\mathrm{T}} = N_{\mathrm{ch}}^{\mathrm{T}} / \langle N_{\mathrm{ch}}^{\mathrm{T}} \rangle}$$

Use R_T to classify events ➧ characterisation as function of event-by-event UE level

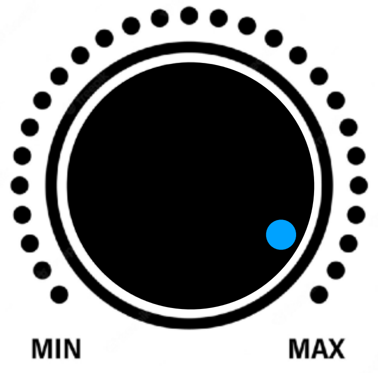
MPI & R_T



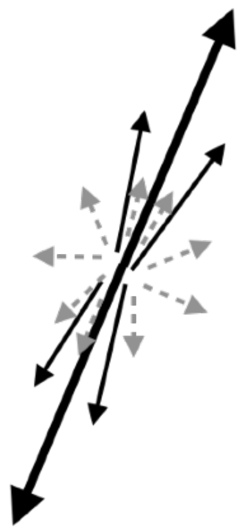
Small R_T ➧ e^+e^--like
➧ low-UE, low N_{MPI}



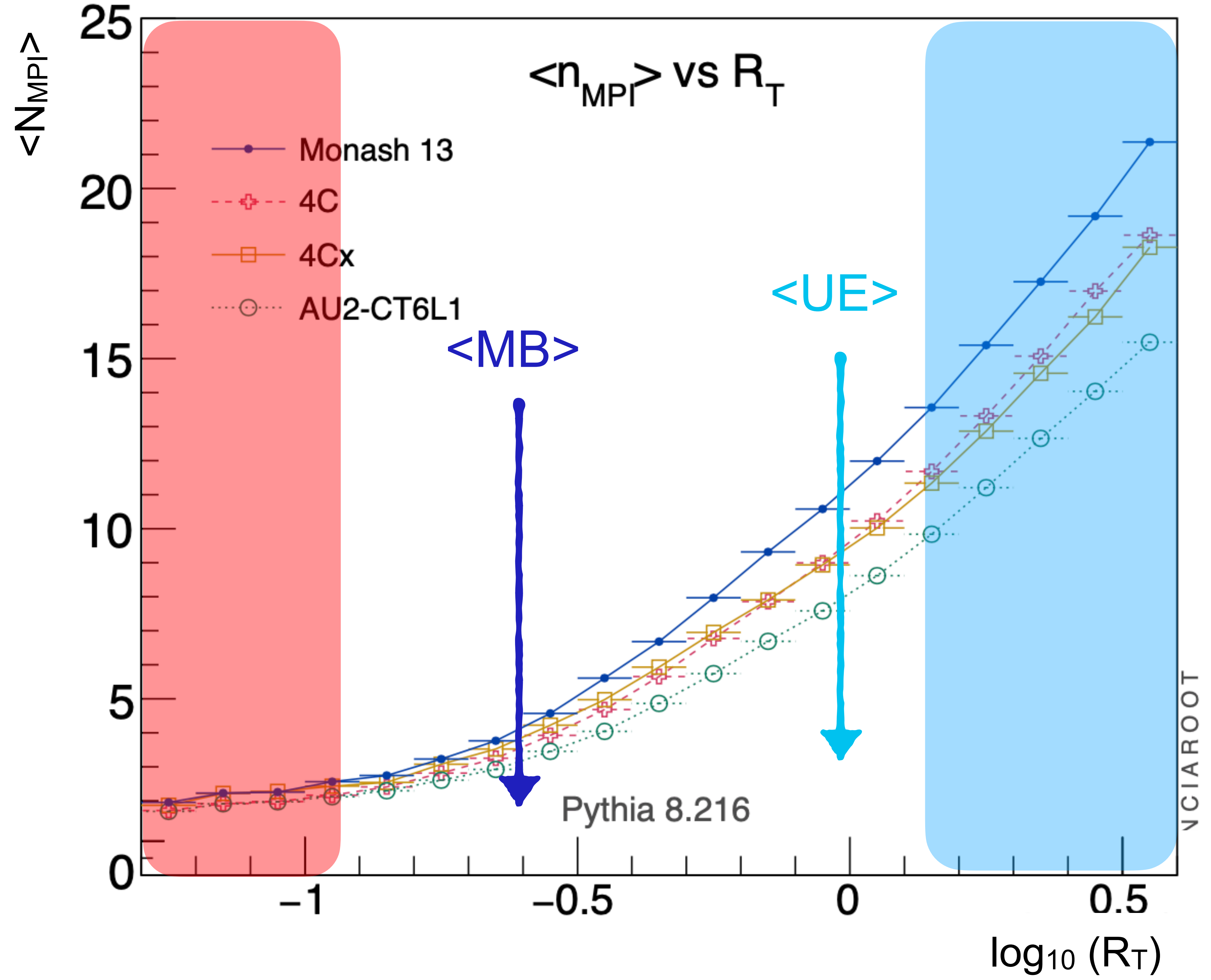
Increasing R_T



large R_T
➧ high-UE, high N_{MPI}



T. Martin et al., Eur. Phys. J. C76 5, (2016) 299



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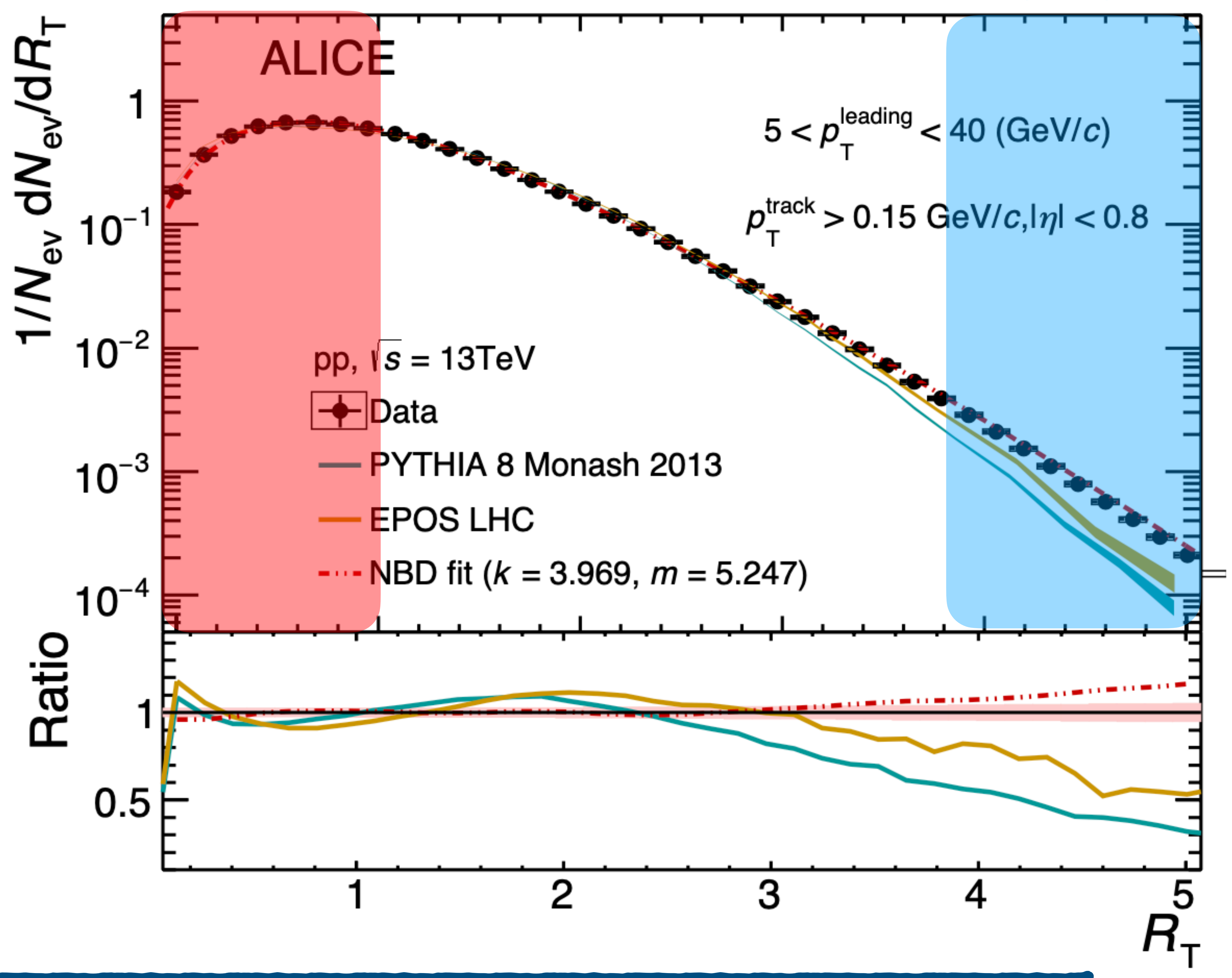
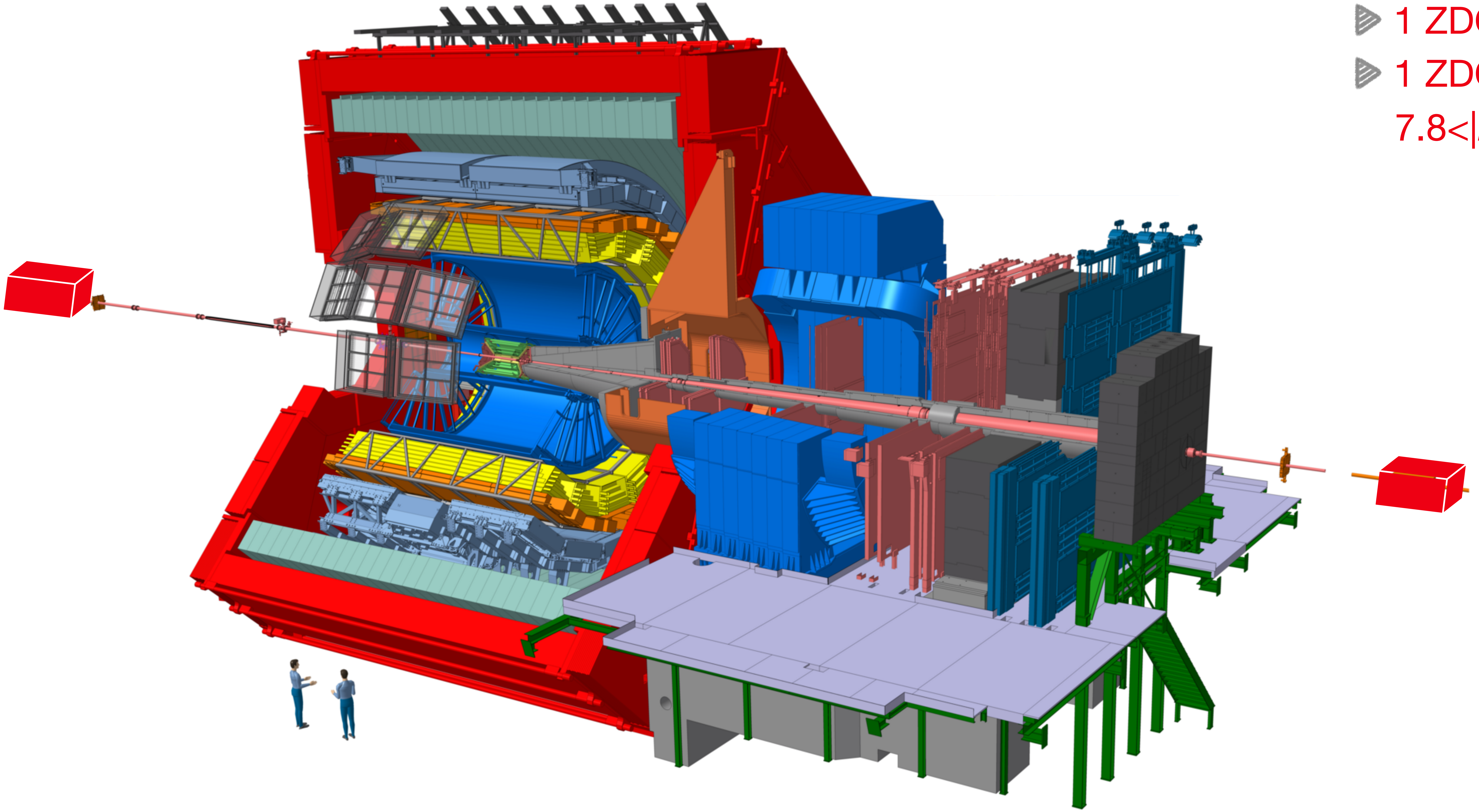


Going very forward

Beam remnants can be studied in ALICE using the Zero Degree Calorimeters (ZDC), placed at 112.5 m from IP



- 1 ZDC for forward neutrons (ZN) $|\eta|>8.7$
- 1 ZDC for forward protons (ZP) $7.8<|\eta|<12.9$ for pp collisions at 13 TeV

➧ opportunity to study the proton fragmentation region in the interaction with a p and with a Pb nucleus

Complementary perspectives

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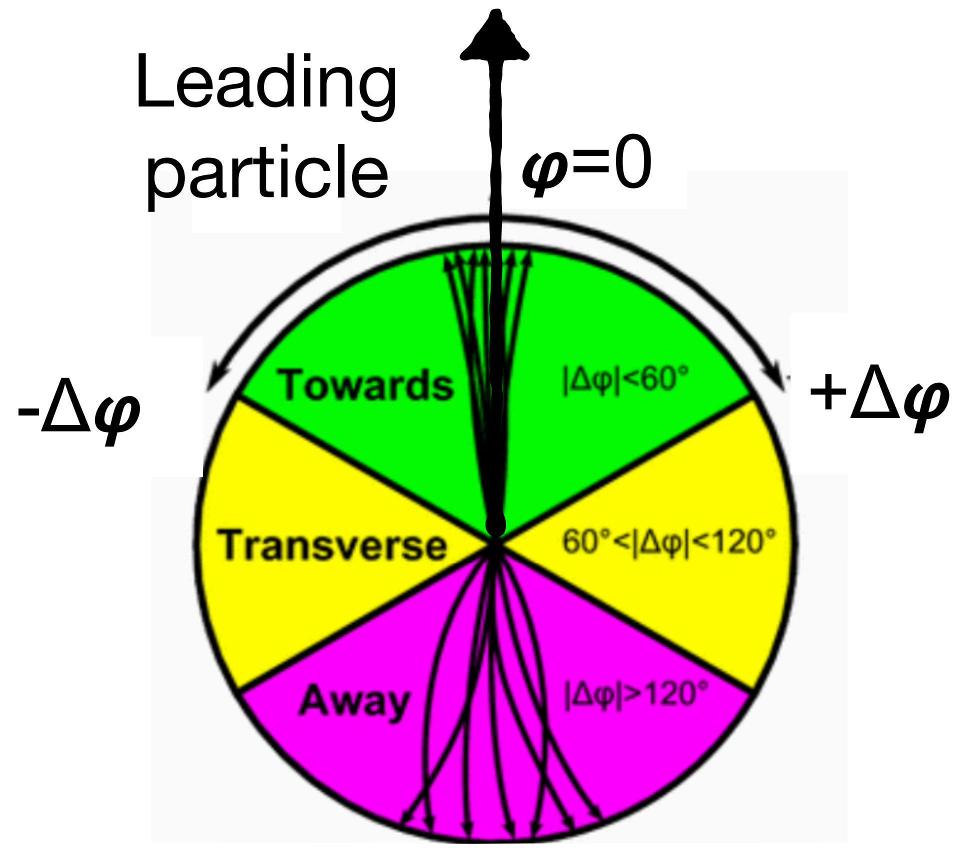
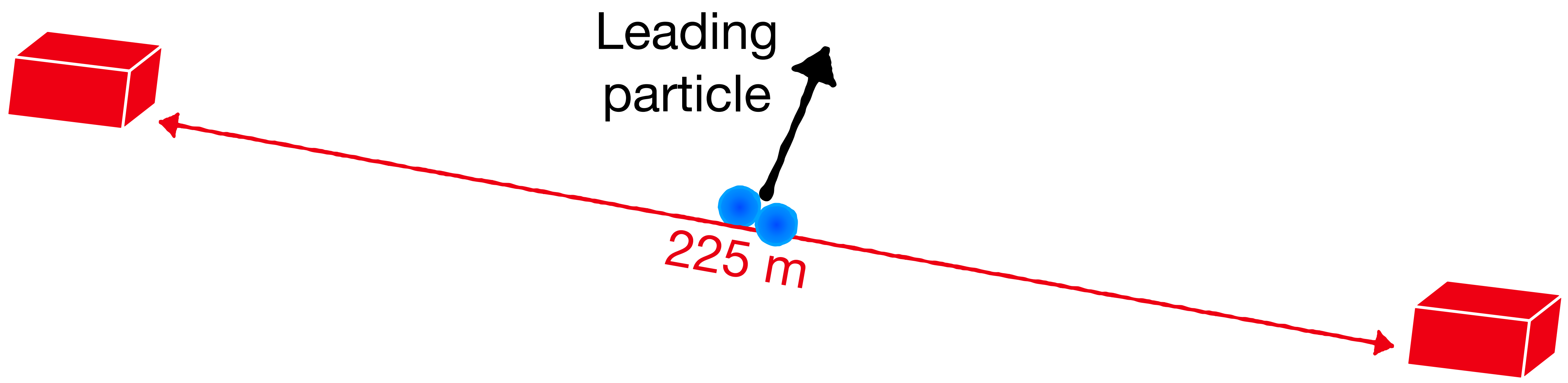
Midrapidity



Transverse region ➧ study particle emission in a region azimuthally separated from the hard scattering fragmentation

Very forward rapidity



ZDC energy ➧ study beam remnants in a region separated in pseudorapidity from the hard scattering fragmentation

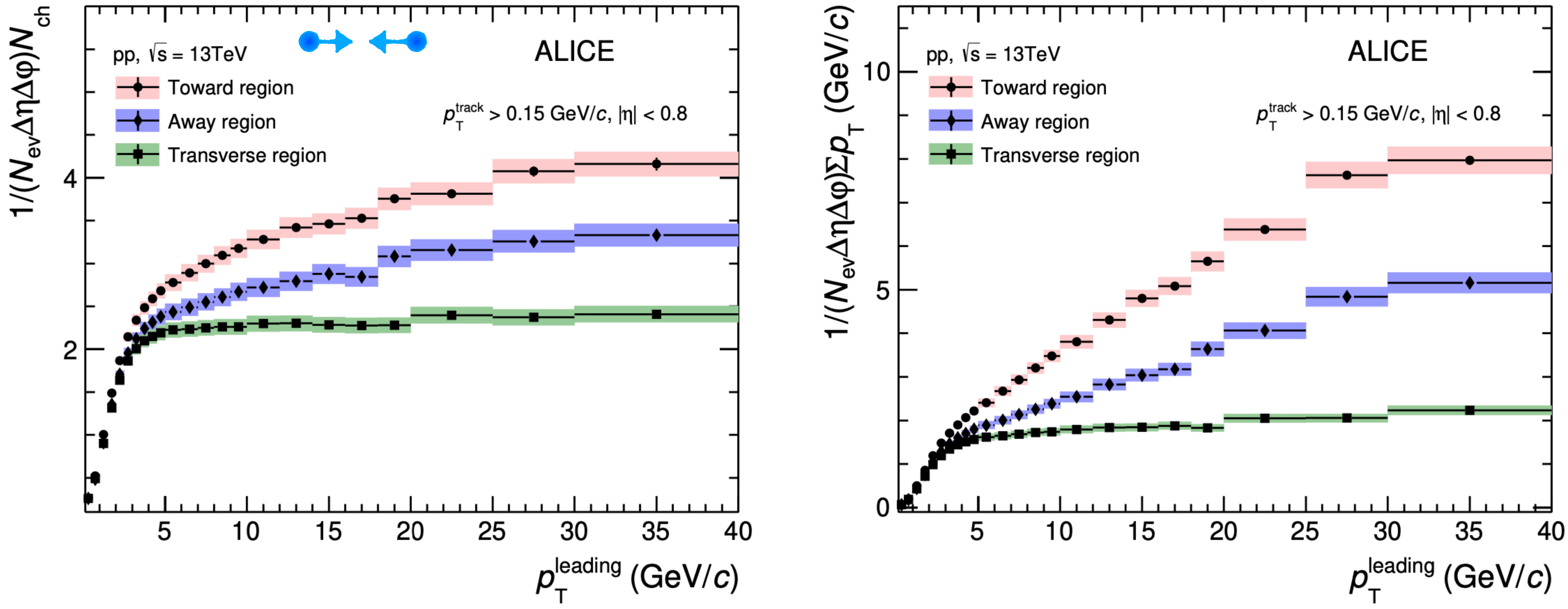
Midrapidity and very forward rapidity observables are causally disconnected after the collision
➧ any correlation in the final state must have been built during the initial stages of the collision

Event characterization at midrapidity

UE analysis

➧ Number (N_{ch}) and summed transverse-momentum densities (Σp_T)

ALICE Coll., JHEP 04 (2020) 192

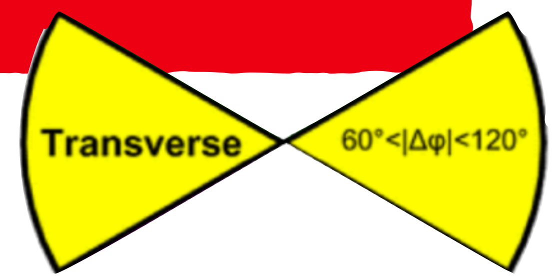


Toward and away regions ➧ UE + JET ➧ contribution from fragments increases with $p_T^{leading}$

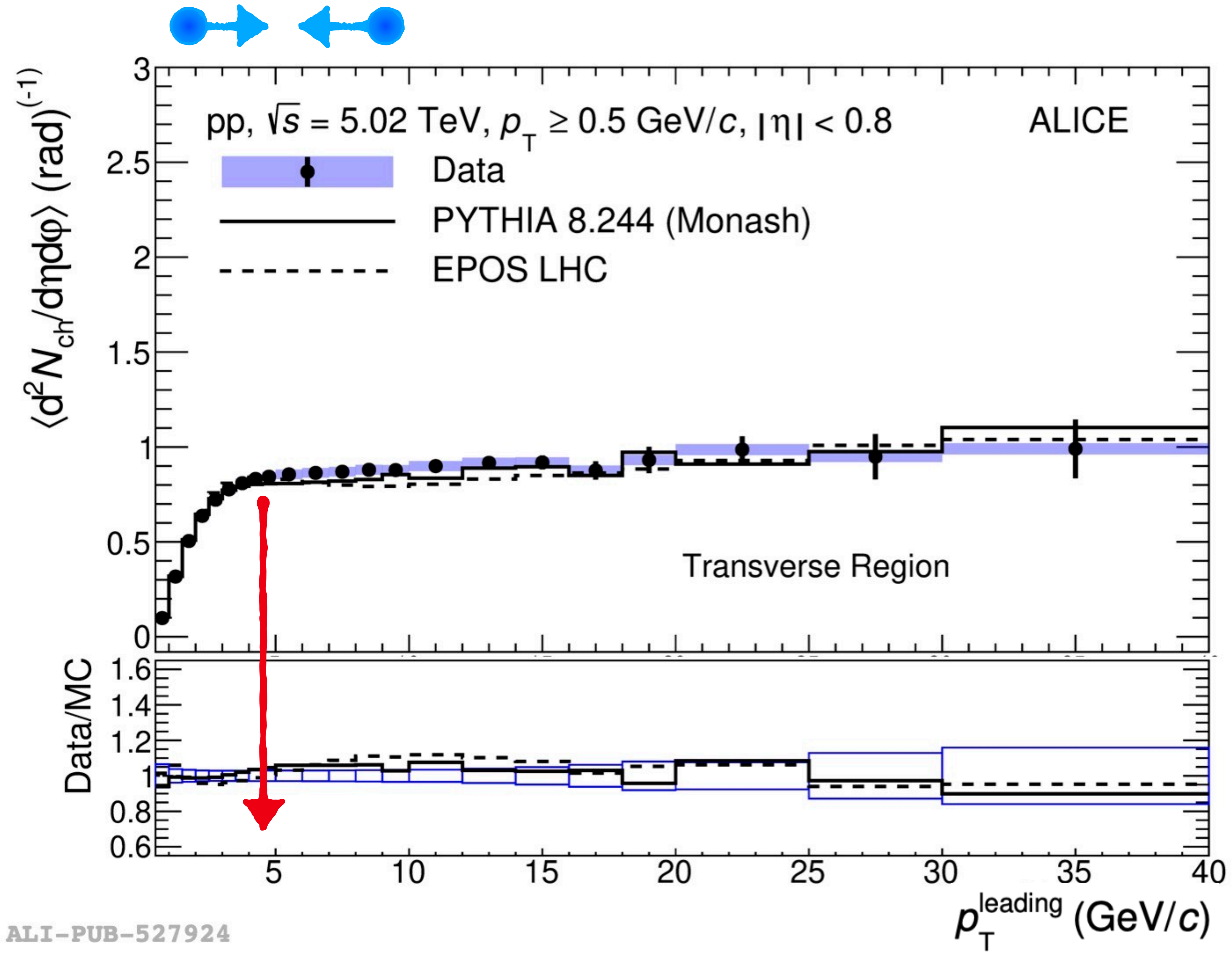
Transverse region ➧ UE ➧ MPI, ISR/FSR and beam remnants are not affected by increasing $p_T^{leading}$

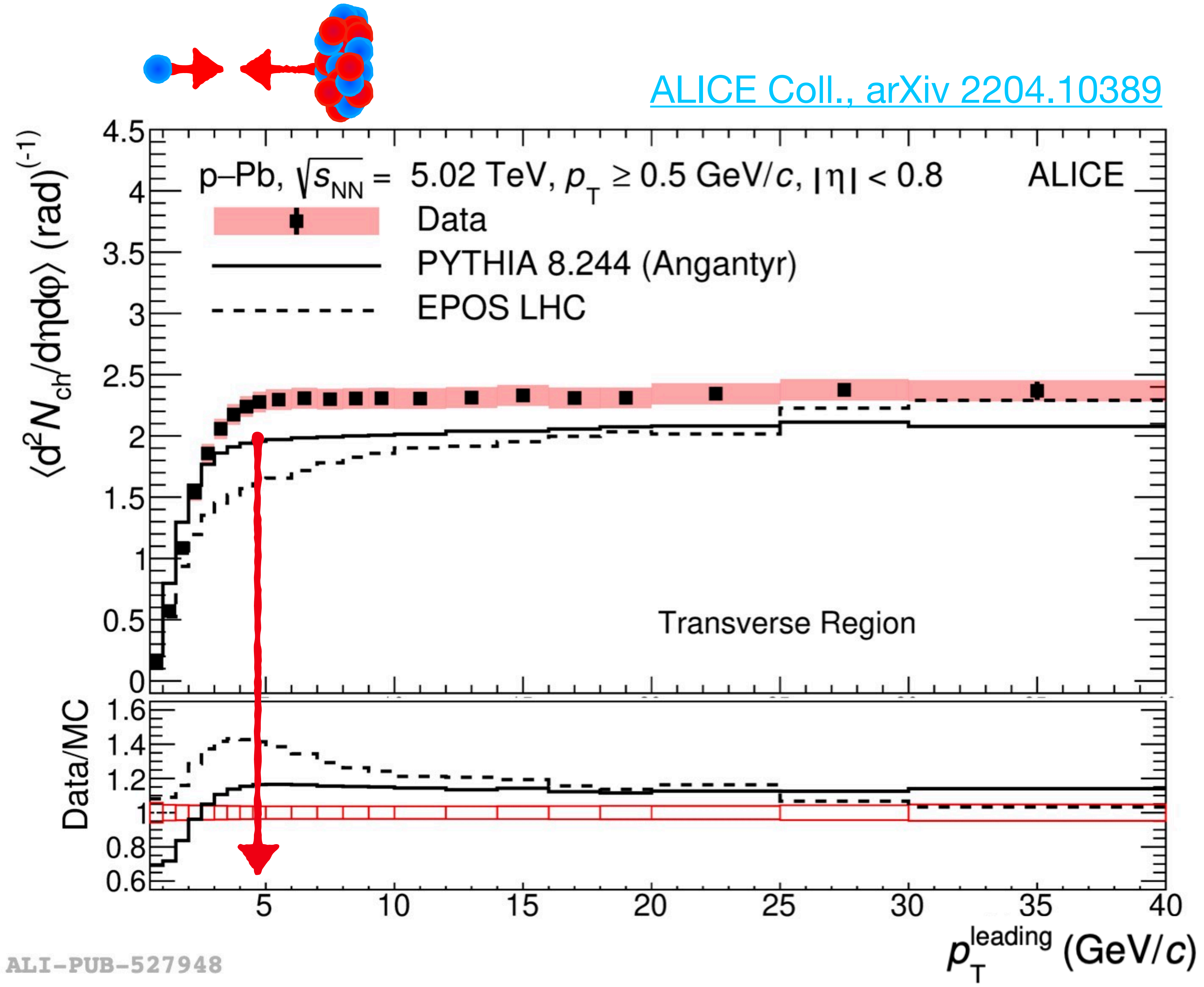
UE in pp and p-Pb collisions

ALICE characterized the UE in pp and in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV



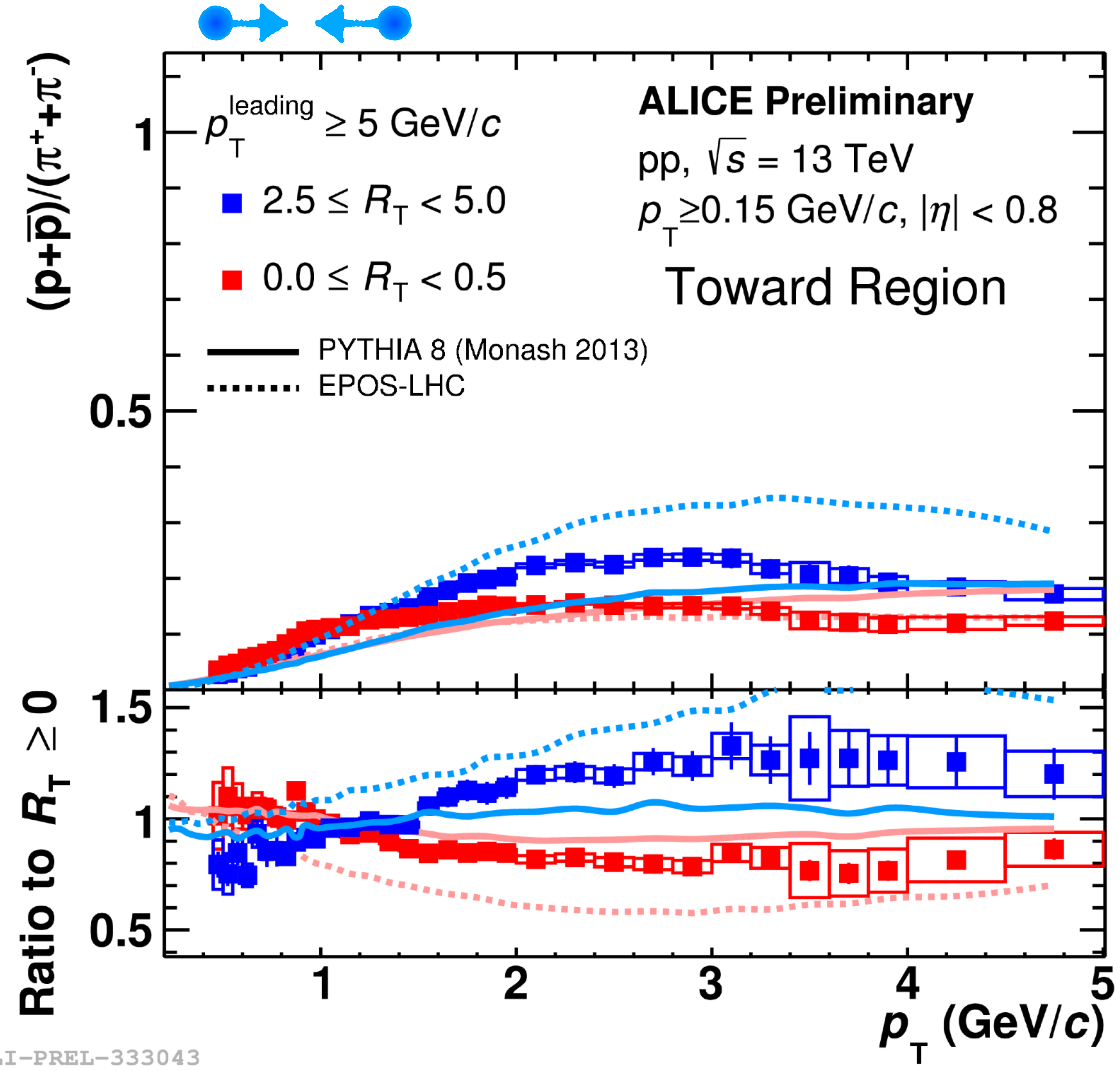
ALICE Coll., arXiv 2204.10389

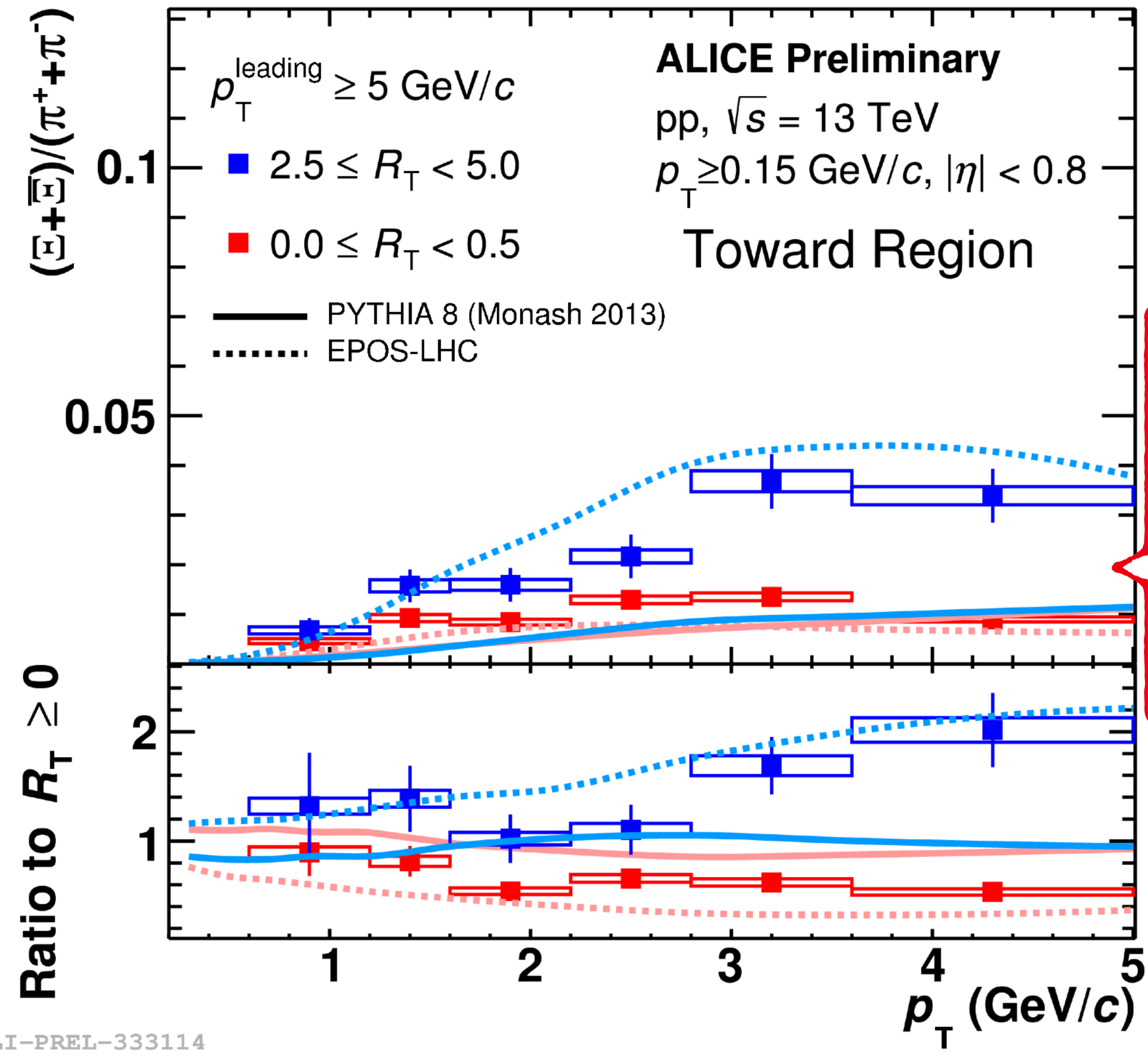


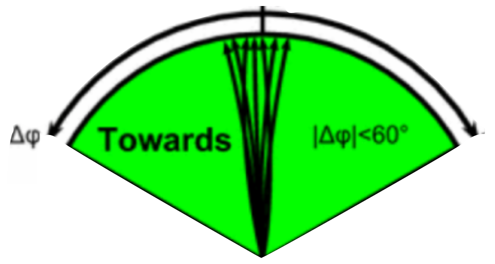


- saturation in particle production in the transverse region observed also in p-Pb collisions, occurs nearly at the same leading particle p_T scale ($p_T^{leading}$ ~ 5 GeV/c) as in pp collisions

Particle ratios in toward side vs. R_T



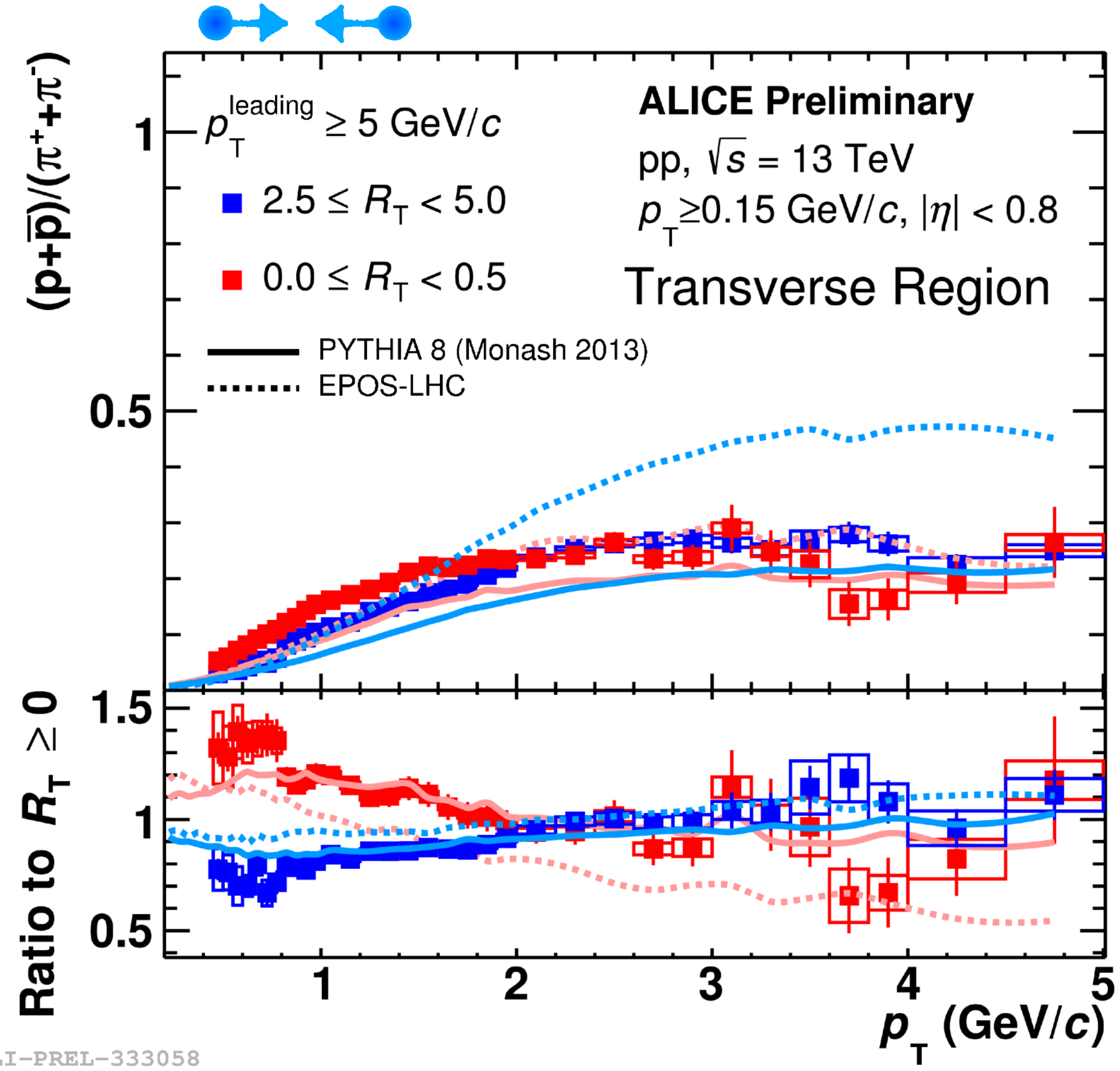


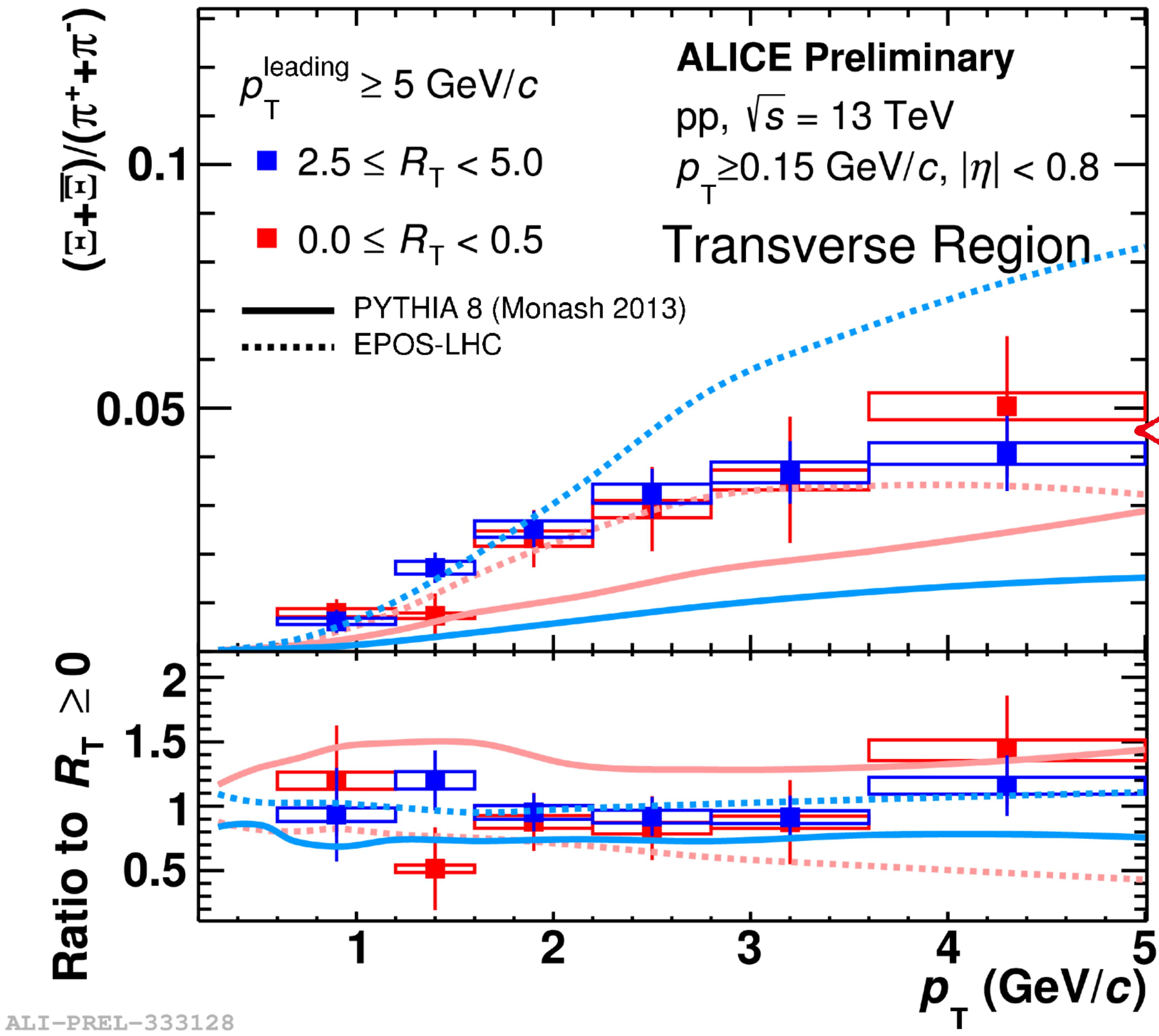


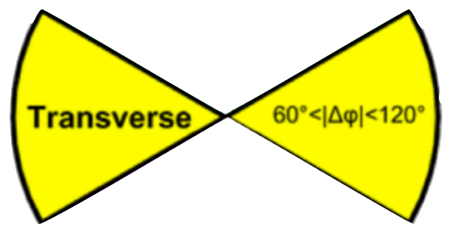
Strangeness enhancement with increasing R_T in toward region (JET+UE)

- evolution of ratios in the toward region as a function of R_T
- both PYTHIA (underpredicts baryon fractions, especially Ξ, at high R_T) and EPOS-LHC (overpredicts high-p_T baryon fractions at high R_T) predictions fail to describe the ratios

Particle ratios in transverse side vs. R_T





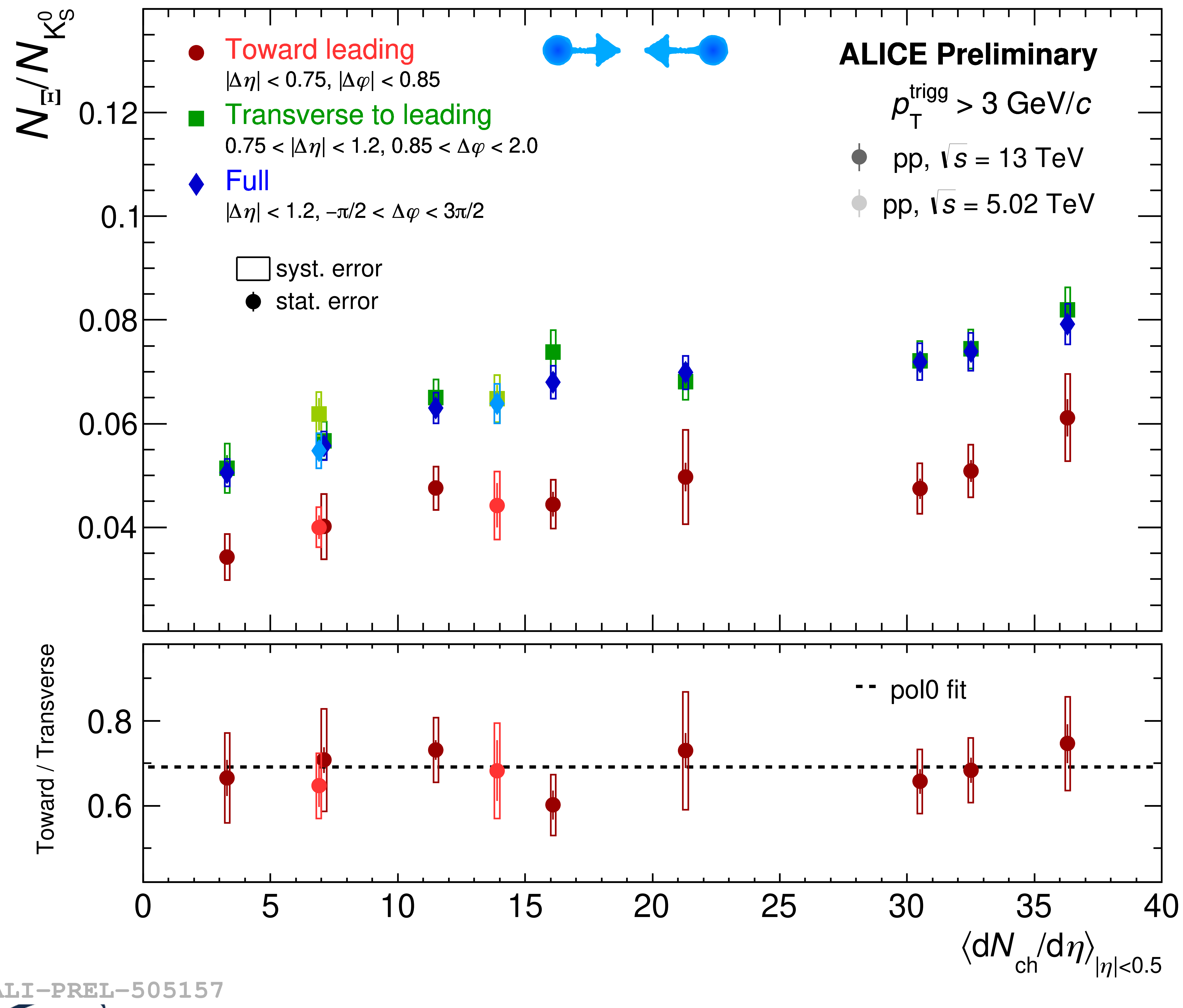


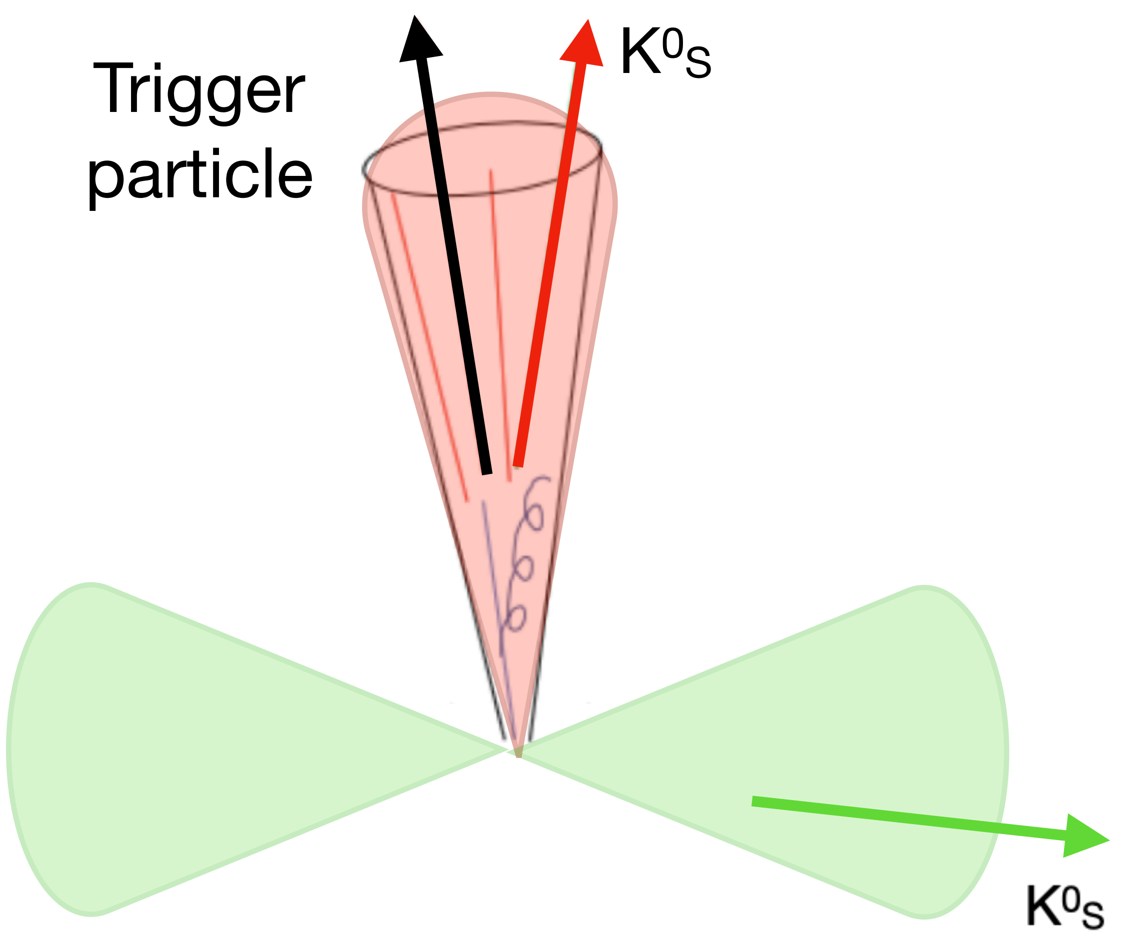
No hint of strangeness enhancement in transverse region (UE)

- no significant dependence of high-p_T particle production on R_T in the transverse region (but not easy to assess the ISR and FSR contributions)
- models fail to predict the UE activity in the transverse region

Angular correlation of strangeness production

Strangeness production is studied in toward and transverse regions relative to a trigger particle (with $p_T^{TRIGGER}$ >3 GeV/c) to gain insight into production mechanism ➧ soft vs. hard production





➧ strangeness production mainly comes from transverse to leading particle (soft production)

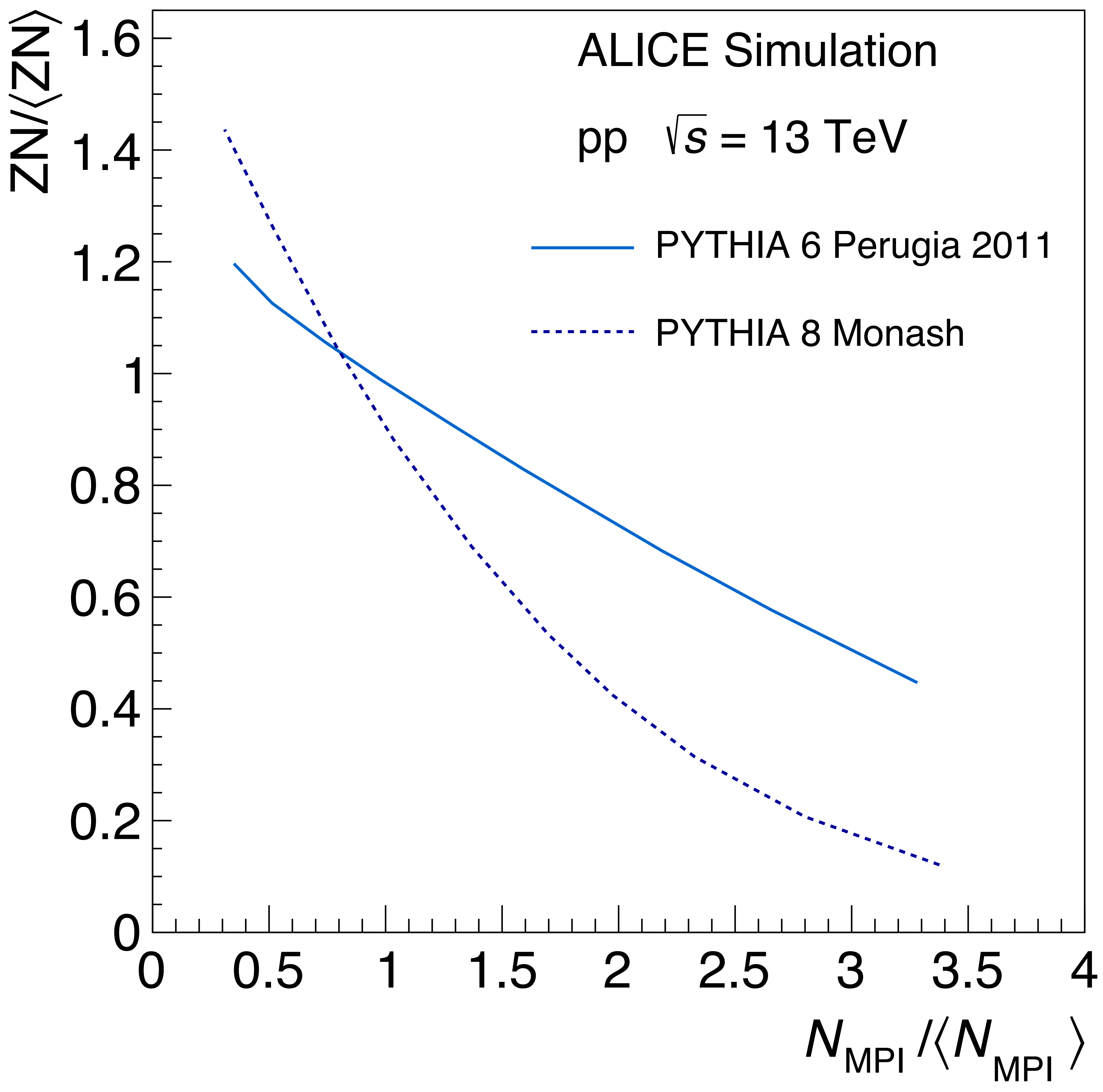
➧ BUT toward/transverse yield is flat vs. multiplicity
➧ no different evolution vs. multiplicity in the 2 regions

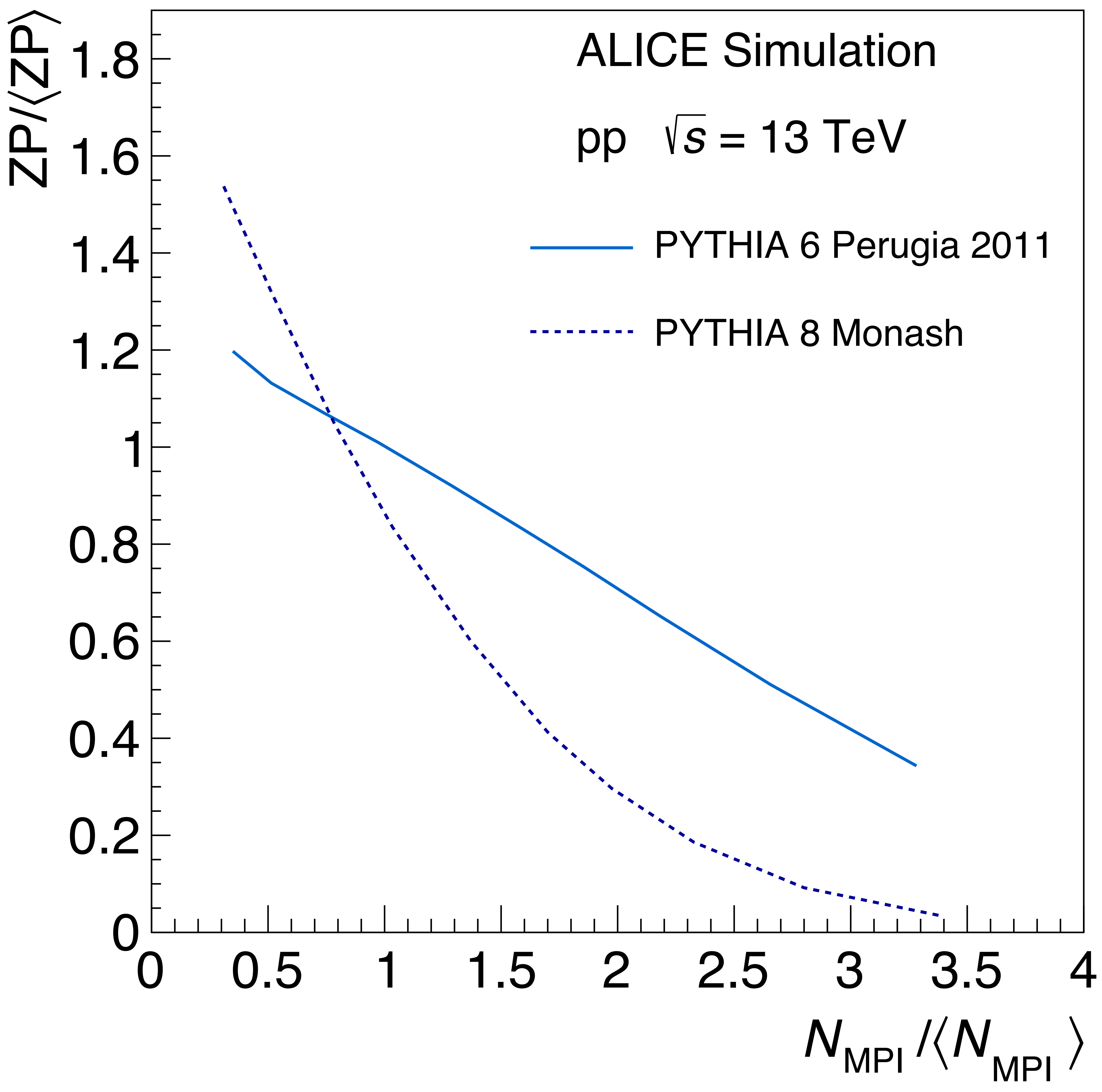

Event characterization
at very forward rapidities

ZDC energy and MPIs in pp collisions

- PYTHIA models (MPI with impact parameter dependence) predict a decrease of very forward energy with increasing number of MPIs

ALICE Coll., JHEP08 (2022) 086



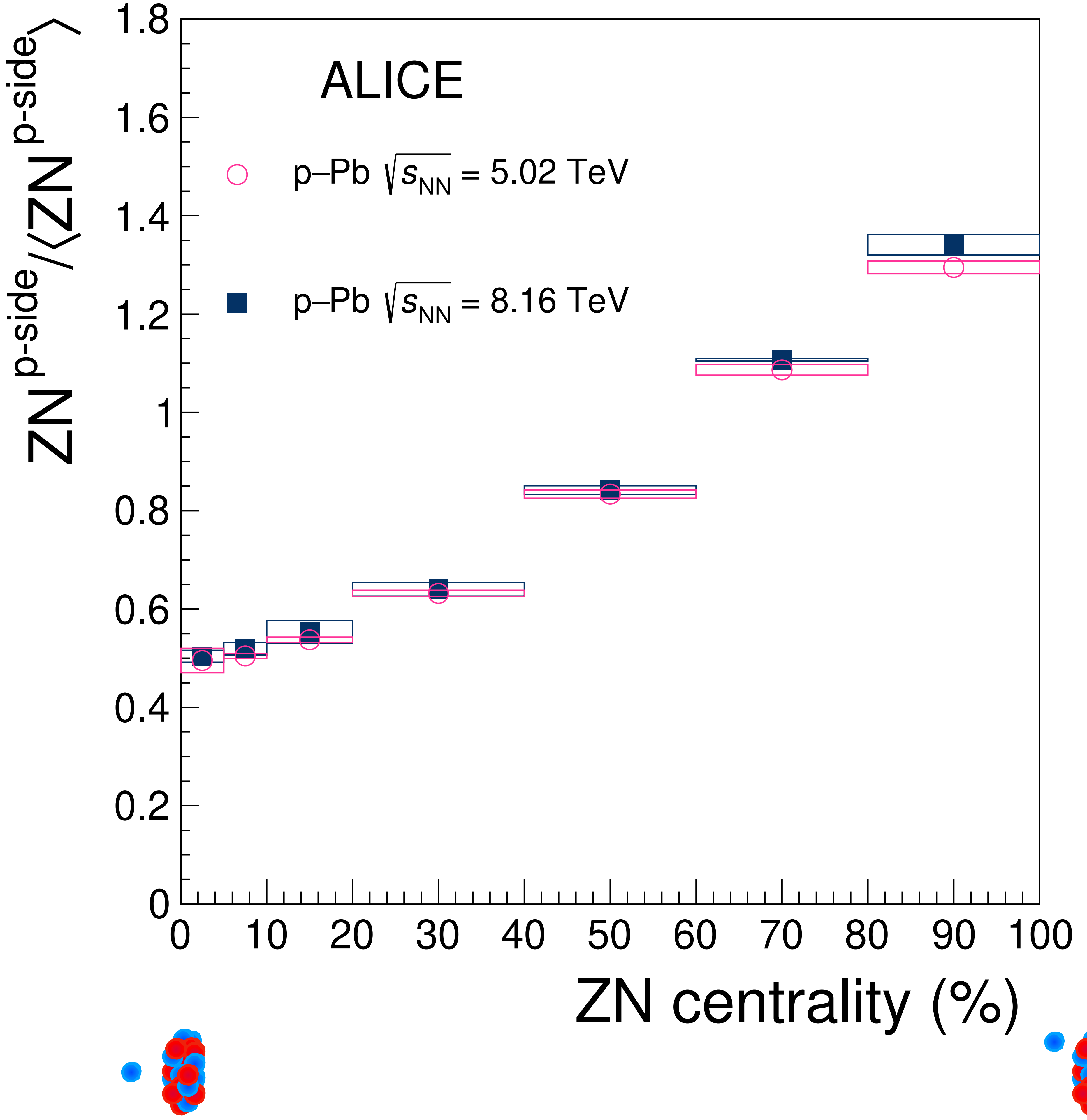


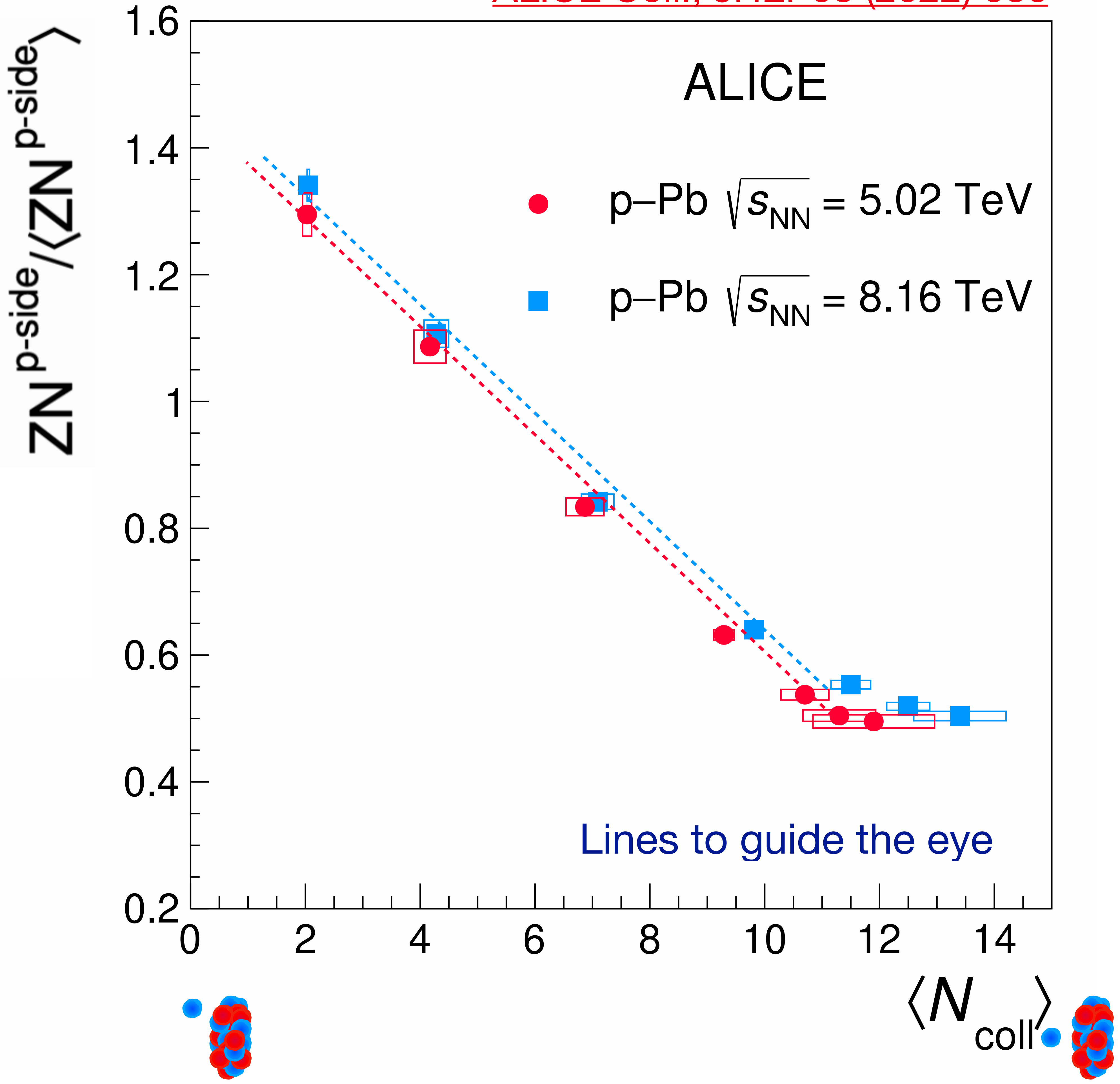
Forward energy in p-Pb collisions

Forward energy measured by ZN in the p fragmentation region:

- decreases with the centrality of the collisions, linear anti-correlated with N_{coll} over a wide centrality range
- consistent with an energy transfer from the proton proportional to N_{coll}

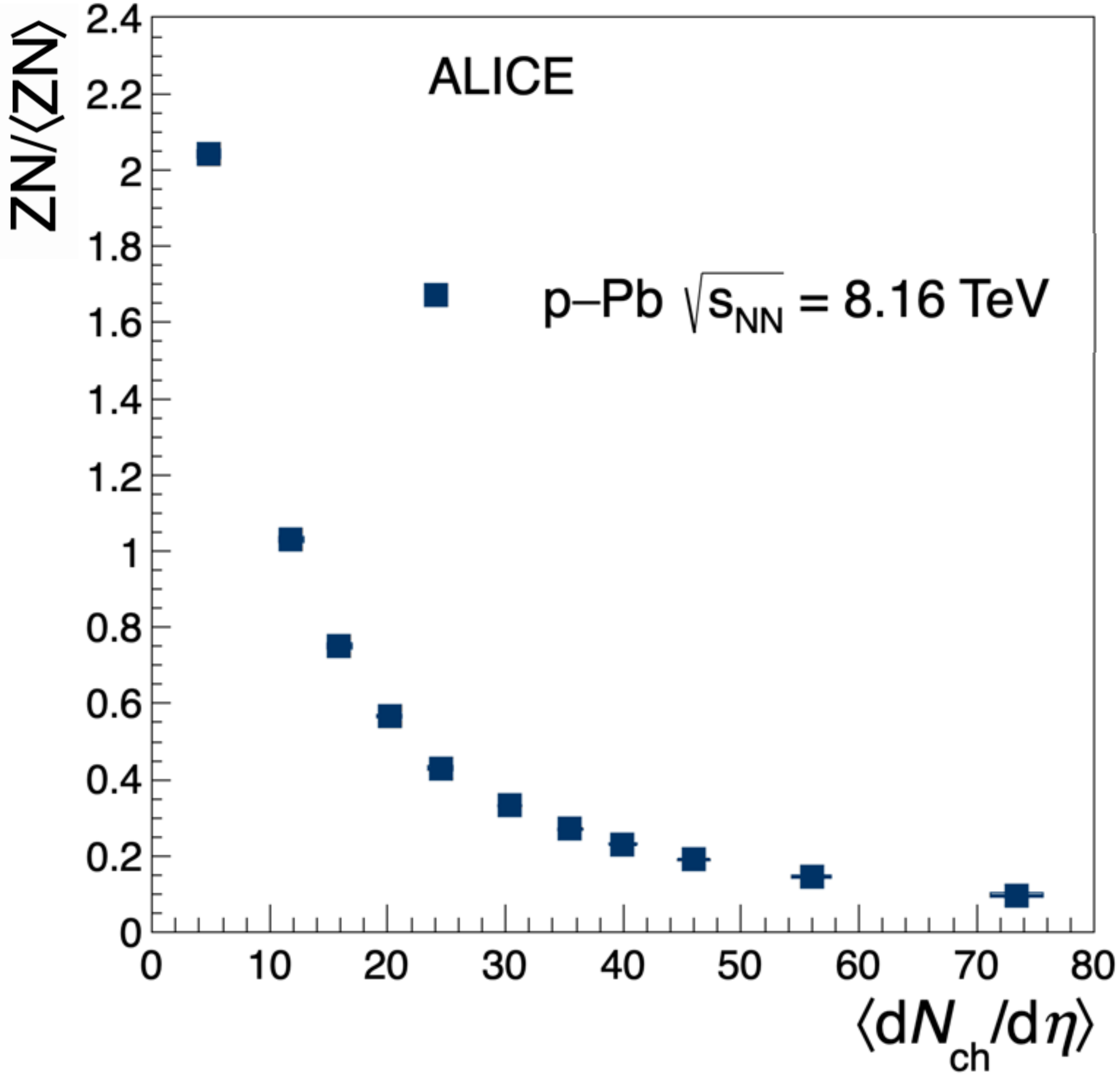
ALICE Coll., JHEP08 (2022) 086

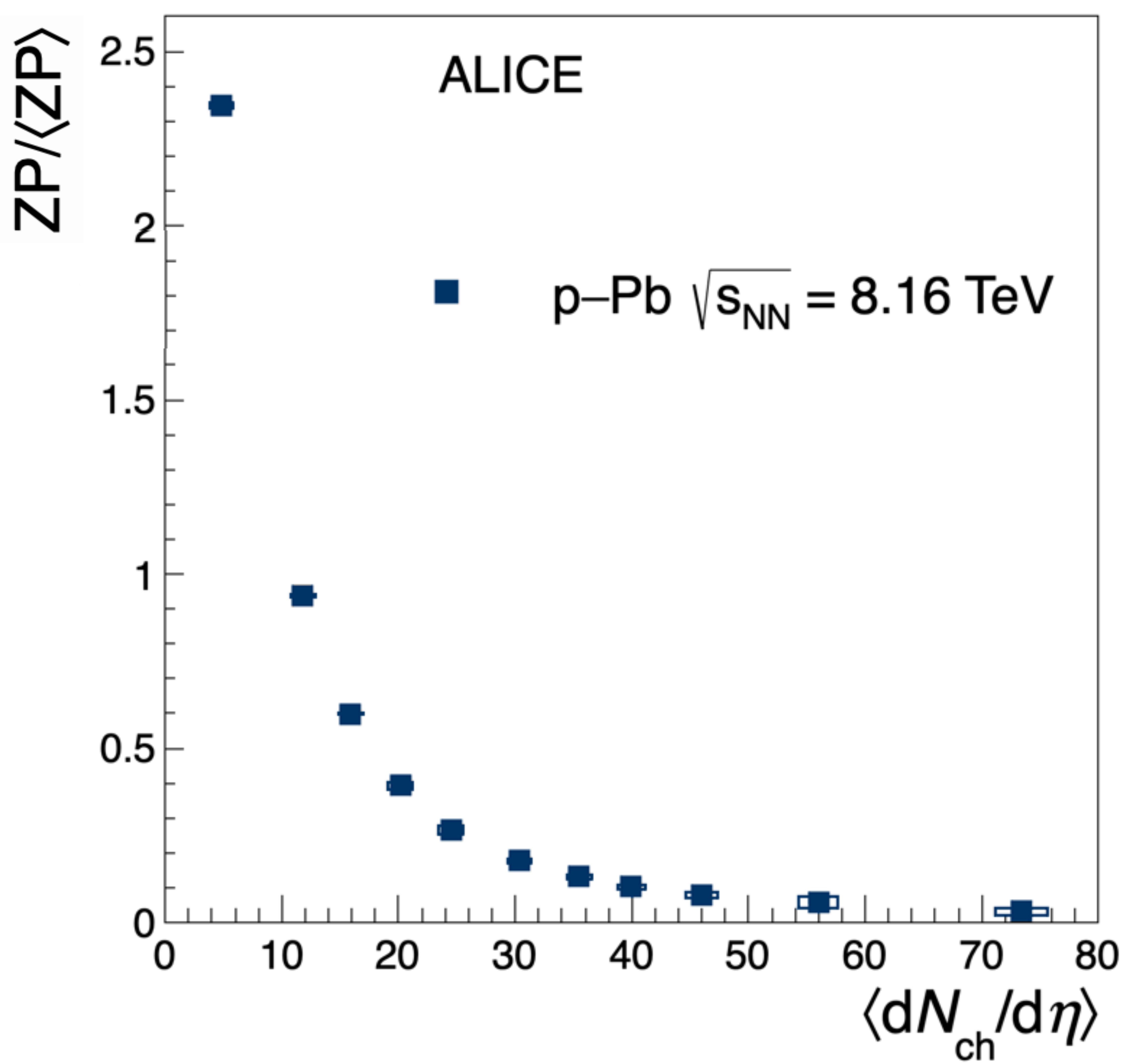




Dependence on multiplicity at midrapidity in p-Pb

ALICE Coll., JHEP08 (2022) 086





- very forward energy decreases with increasing multiplicity produced at midrapidity in |η|<1

Dependence on multiplicity at midrapidity

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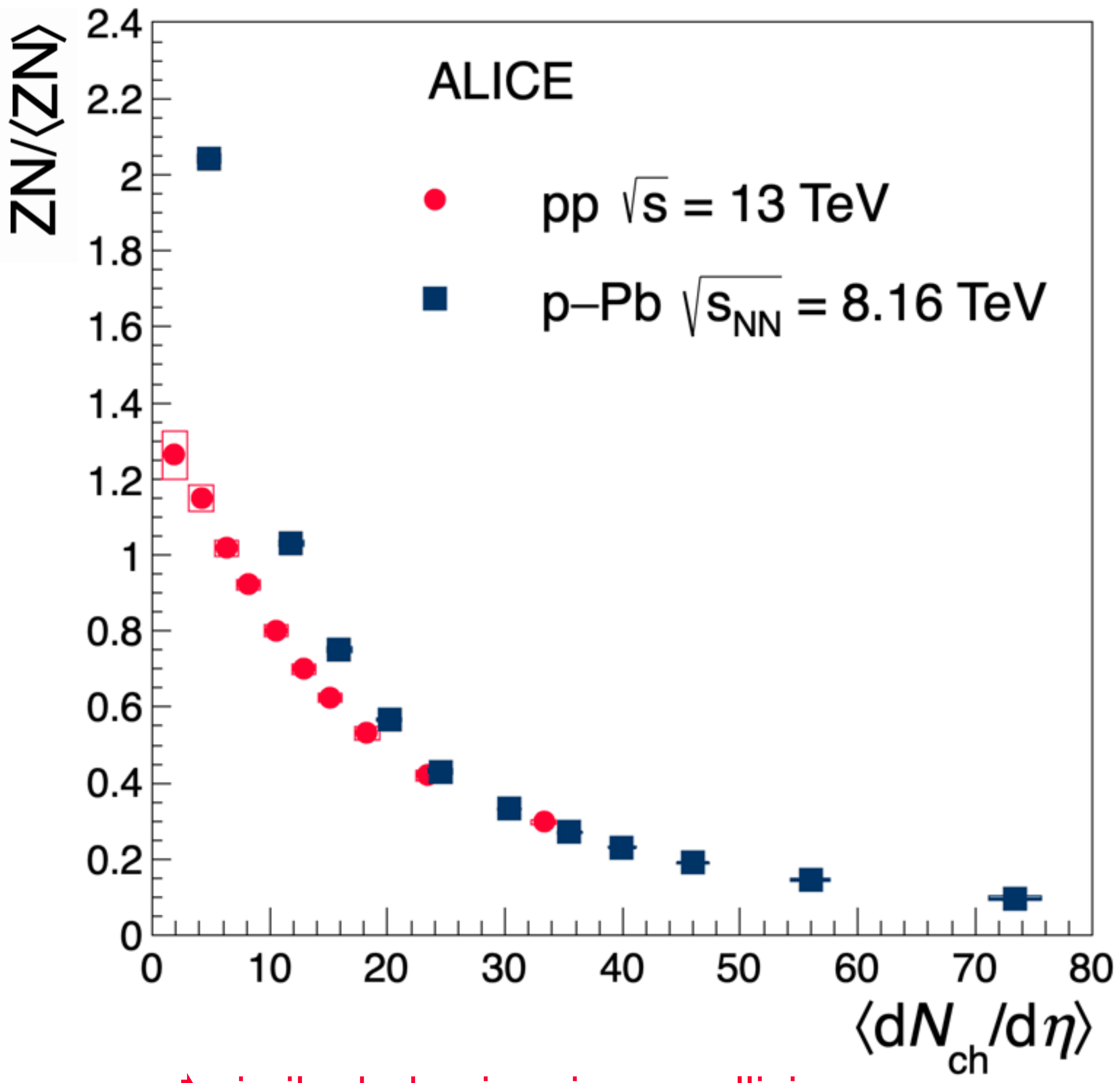
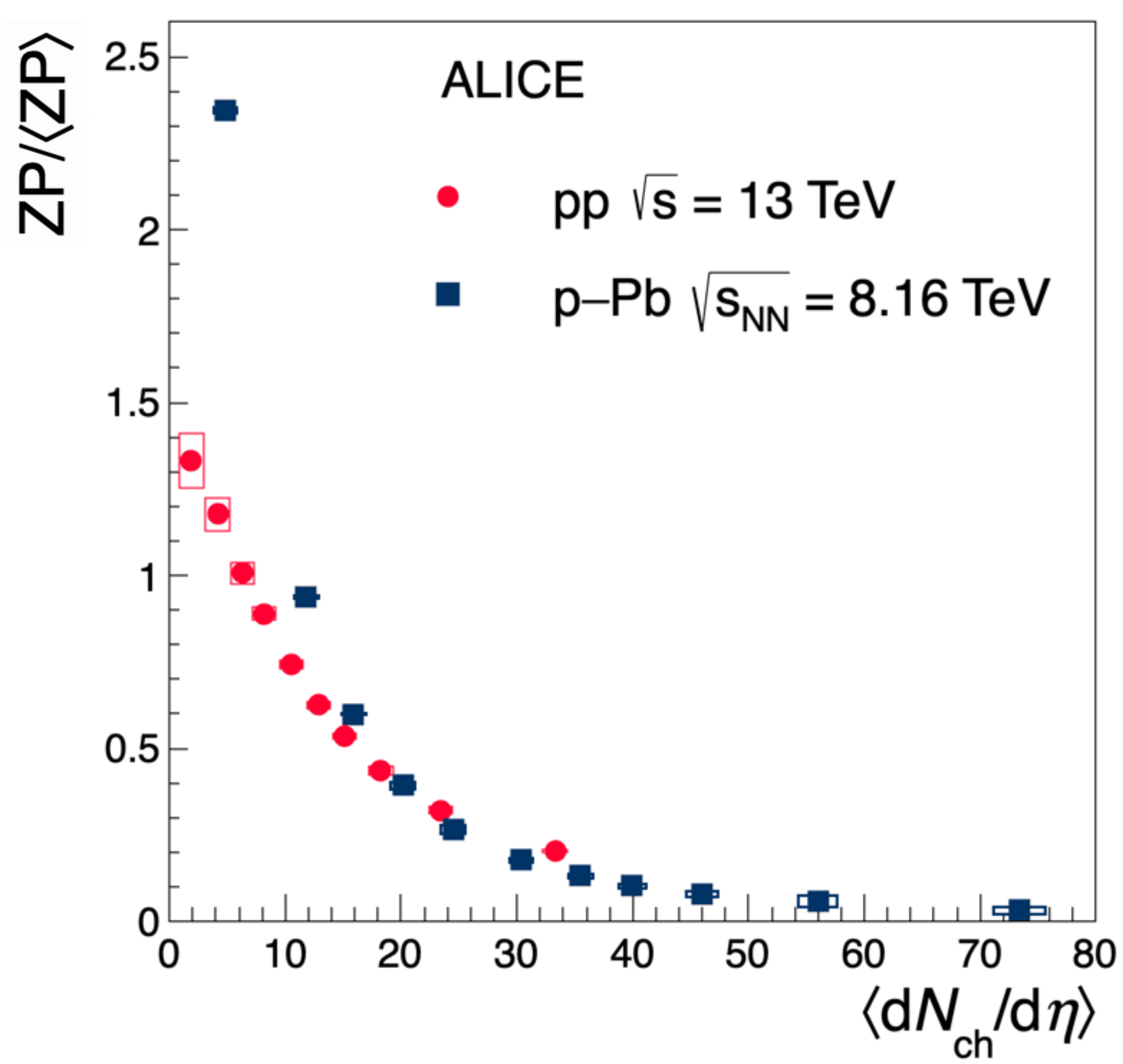
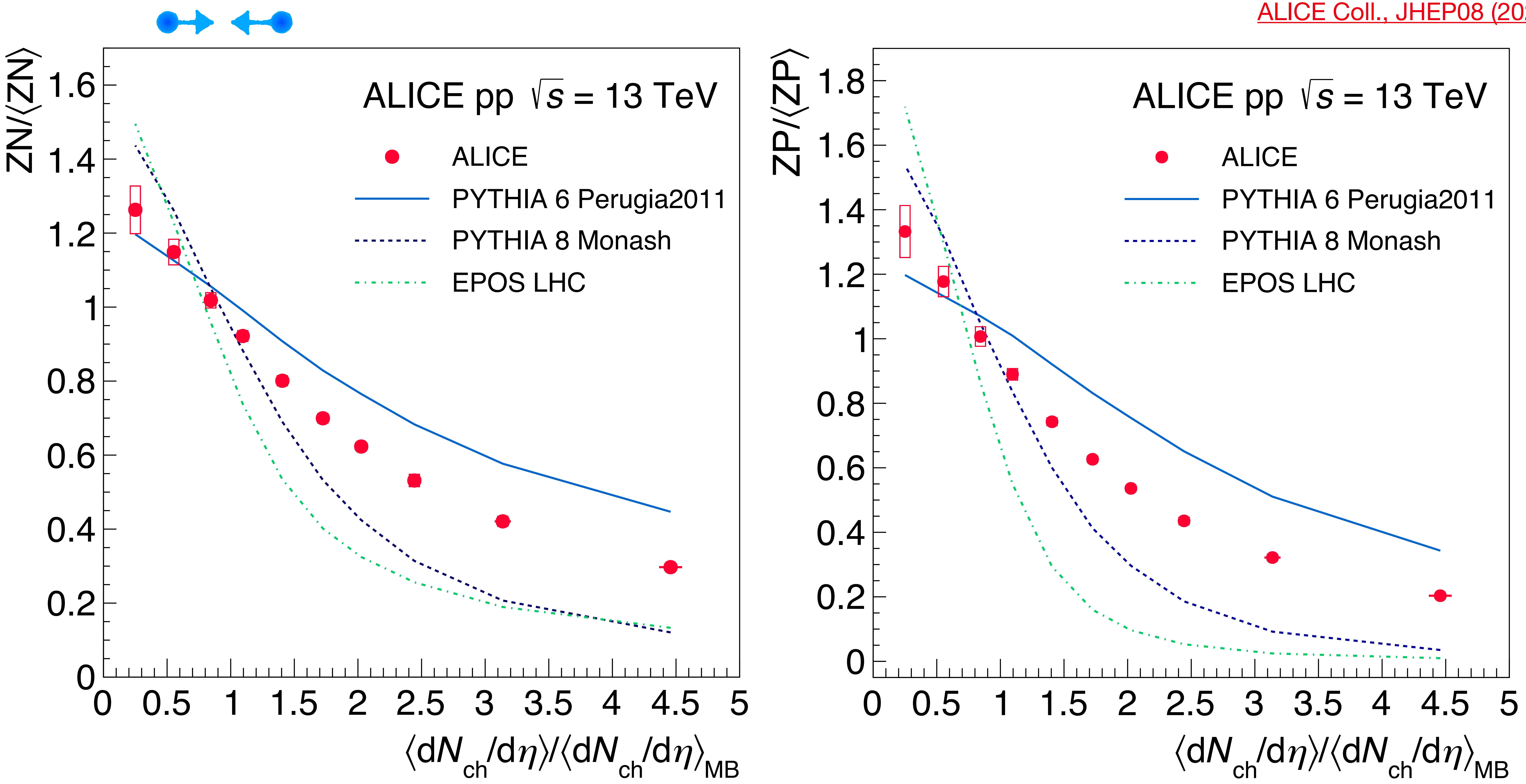




- similar behaviour in pp collisions

Dependence on multiplicity at midrapidity in pp

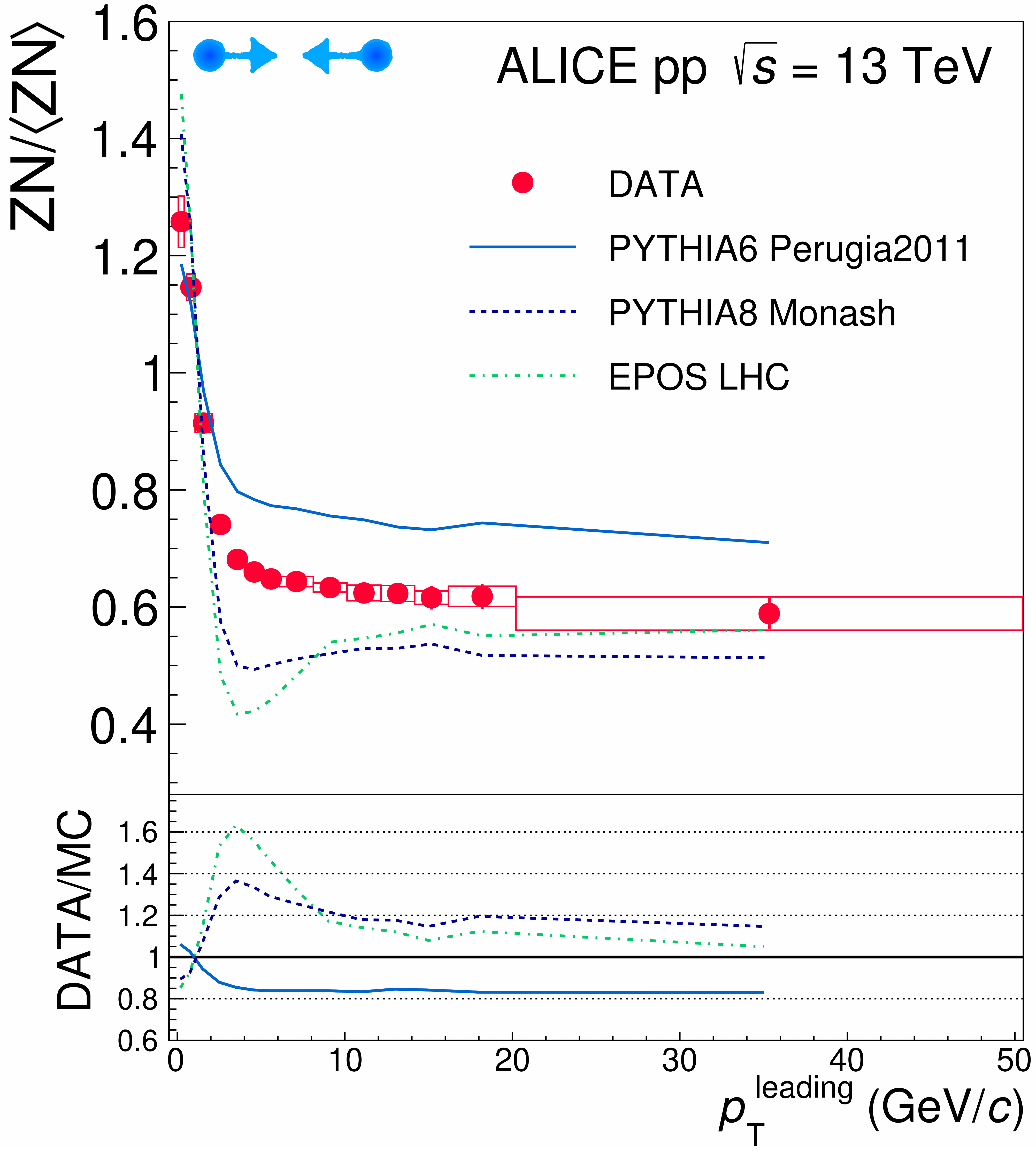
ALICE Coll., JHEP08 (2022) 086

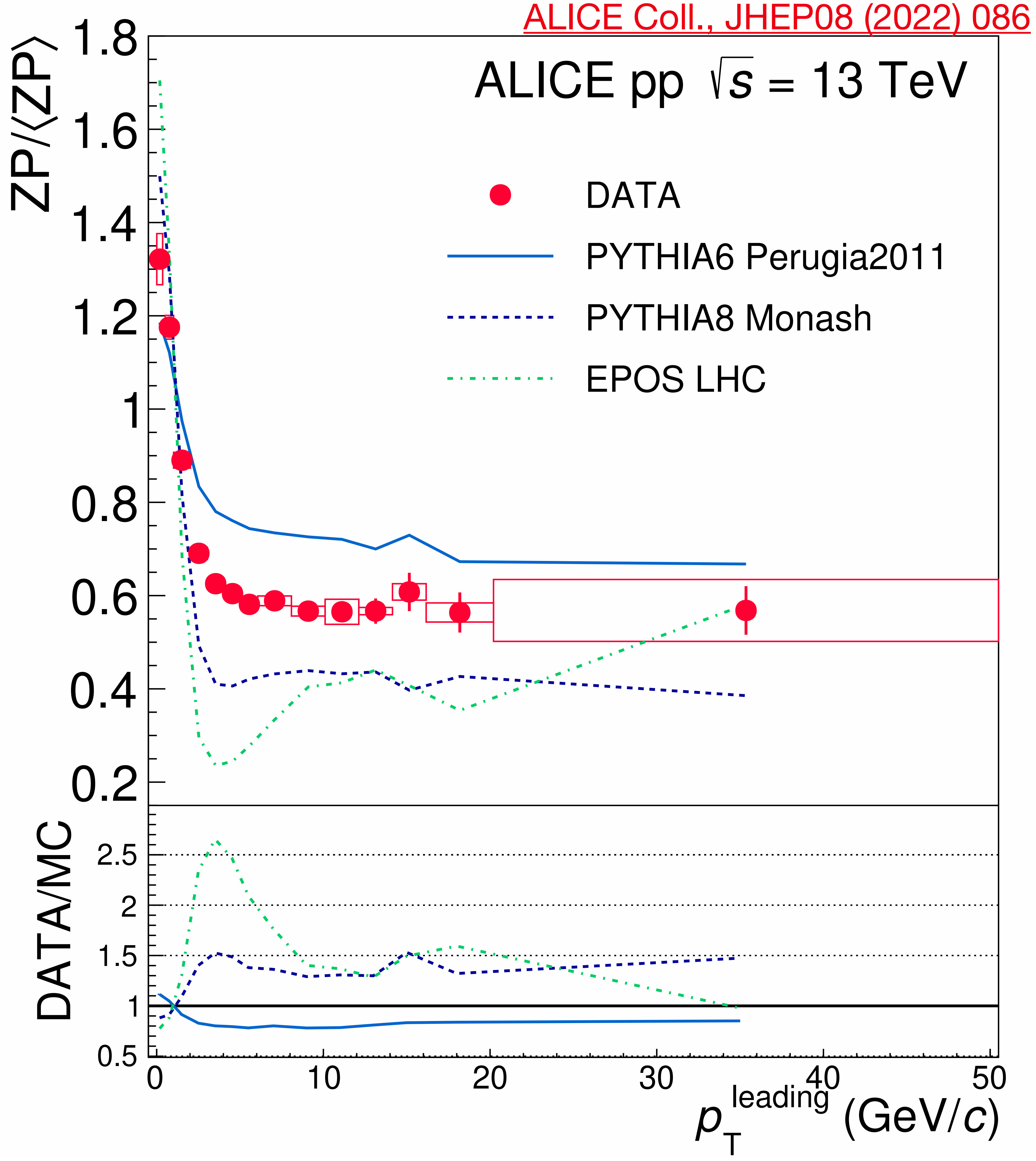


➧ the models used for comparison do not reproduce very forward vs. midrapidity measurements

Forward energy vs. leading p_T

ALICE Coll., JHEP08 (2022) 086

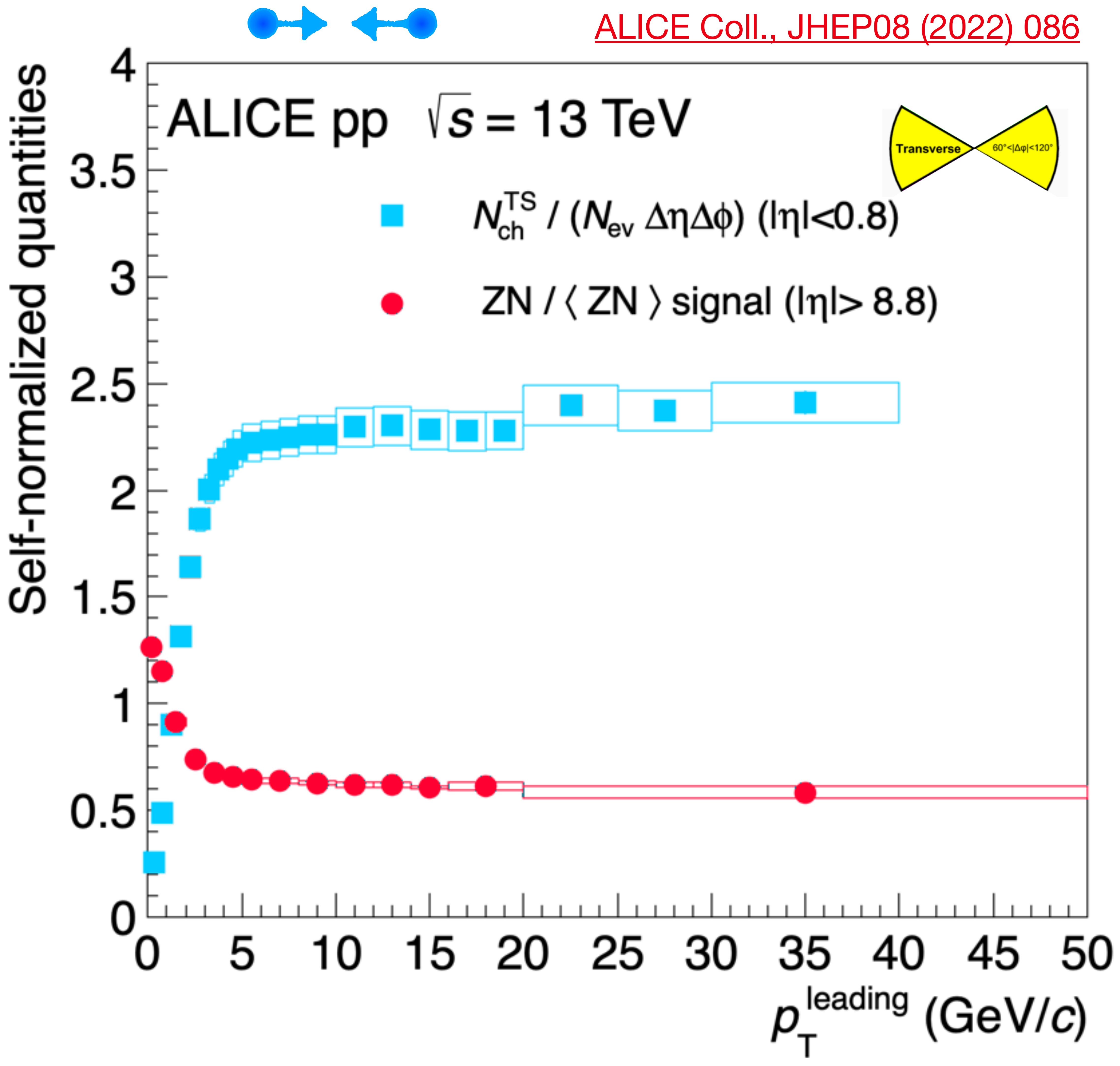




- very forward energy saturates with increasing hardness of the collision at midrapidity

UE and forward energy

ALICE Coll., JHEP08 (2022) 086



UE ➧ multiplicity in transverse region is constant in events with a larger than average number of MPIs

Very forward energy ➧ shows saturation with increasing $p_T^{leading}$ in a complementary way to UE

➧ saturation occurs at the same scale: $p_T^{leading}$ > 5 GeV/c

➧ saturation observed in transverse region at midrapidity and in very forward energy must be built in the initial stages of the collision

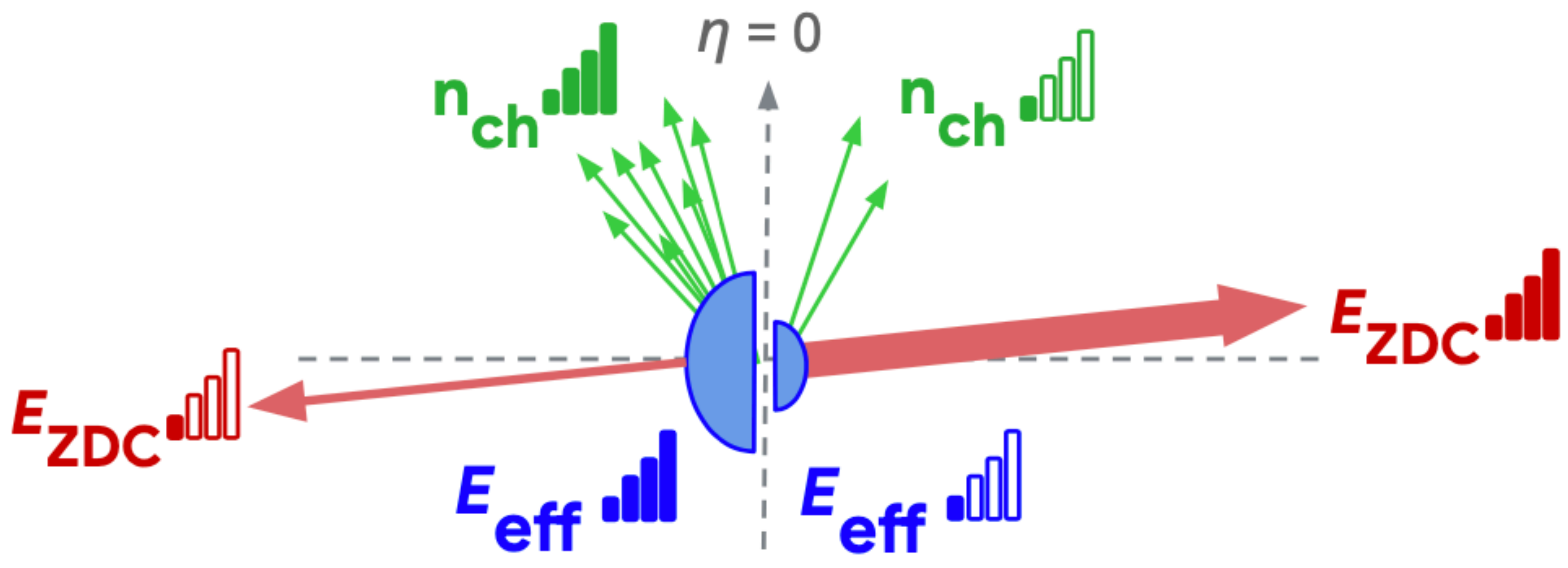
Strangeness enhancement vs. effective energy

What is the origin of strangeness enhancement observed in small systems?

- study of (multi) strange baryon production vs. multiplicity and effective energy

Effective energy = energy in the initial phase of a pp collision available for particle production. Reduced relative to centre-of-mass energy due to leading baryon production.

$$E_{\mathrm{eff}} = \sqrt{s} - E_{\mathrm{leading\ baryons}} \sim \sqrt{s} - E_{\mathrm{ZDC}}$$



Ratio of strange to non-strange hadron yields increases with charged-particle multiplicity.
The multiplicity distribution of charged particles is:

- characteristic of the final state of the collision
- strongly correlated to the initial effective energy

Strangeness enhancement vs. effective energy

- strange baryon over charged particle production increases with forward event activity at fixed multiplicity but also with increasing effective energy
- initial stages play a role in strangeness enhancement

Wrap up

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Several observables are used to characterise pp and p-Pb collisions and new developments aim at exploring multi-differential analyses ➧ UE, ZDC energy, effective energy
➧ Results provide useful inputs and constraint for existing models

➧ analyses vs. R_T revealed UE increasing contribution in toward region
➧ strangeness production studied in azimuthal regions and as a function of effective energy: regions transverse and toward the leading p_T particle show the same multiplicity dependence, hint for dependence of strangeness production on initial stages of the collisions

➧ first analysis correlating beam remnants and particle production at midrapidity: events with larger N_{MPI} are characterized by higher multiplicity and smaller forward energy, both UE and very forward energy saturates at the same p_T^{leading} scale ➧ initial stage effect

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Pb-Pb 5.36 TeV

LHC22s period

18th November 2022

16:52:47.893

New results soon!

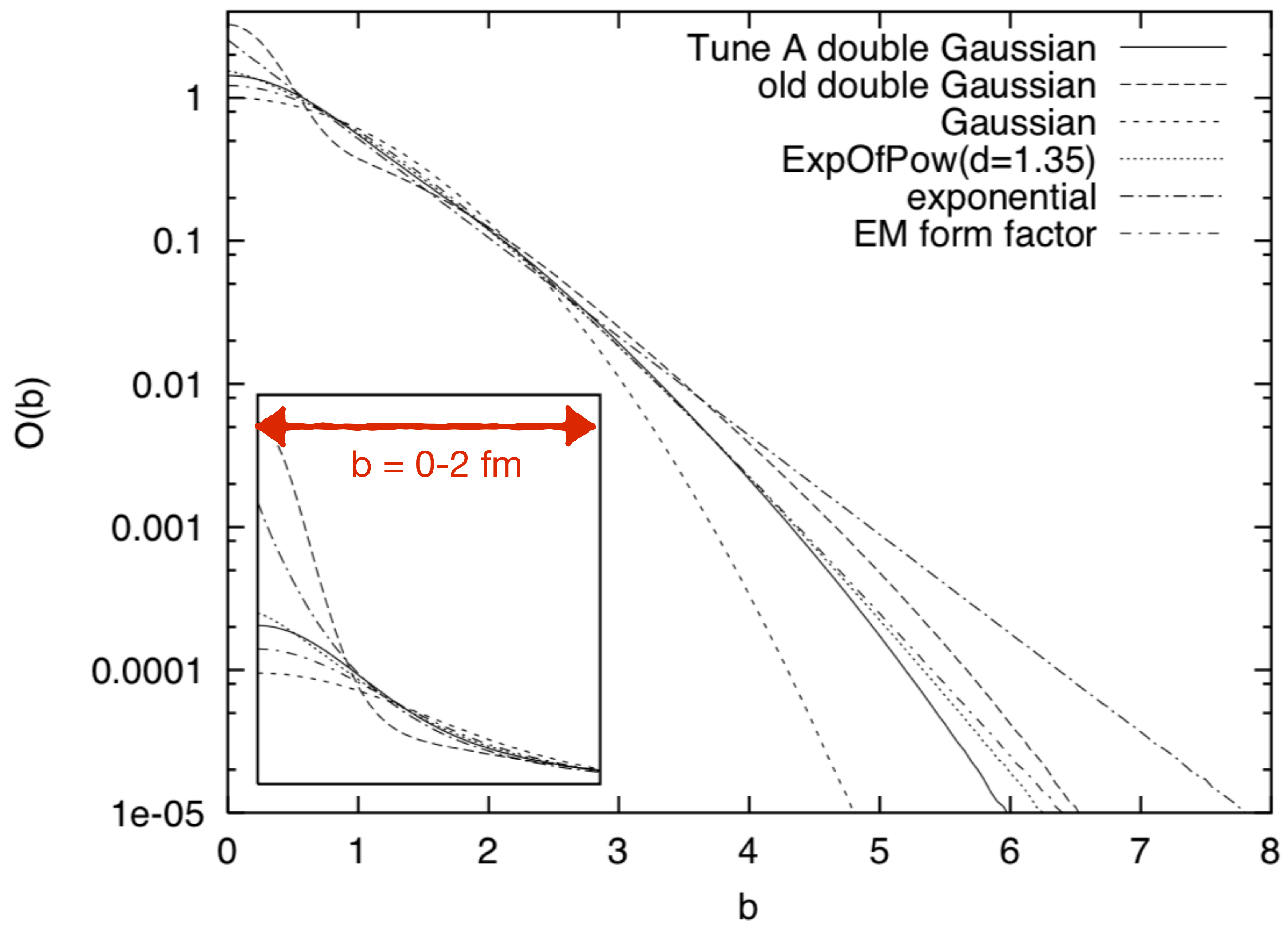
Thanks
for your
attention

Impact parameter dependence

- bulk properties are usually studied as function of final state charged-particle multiplicity measured at midrapidity

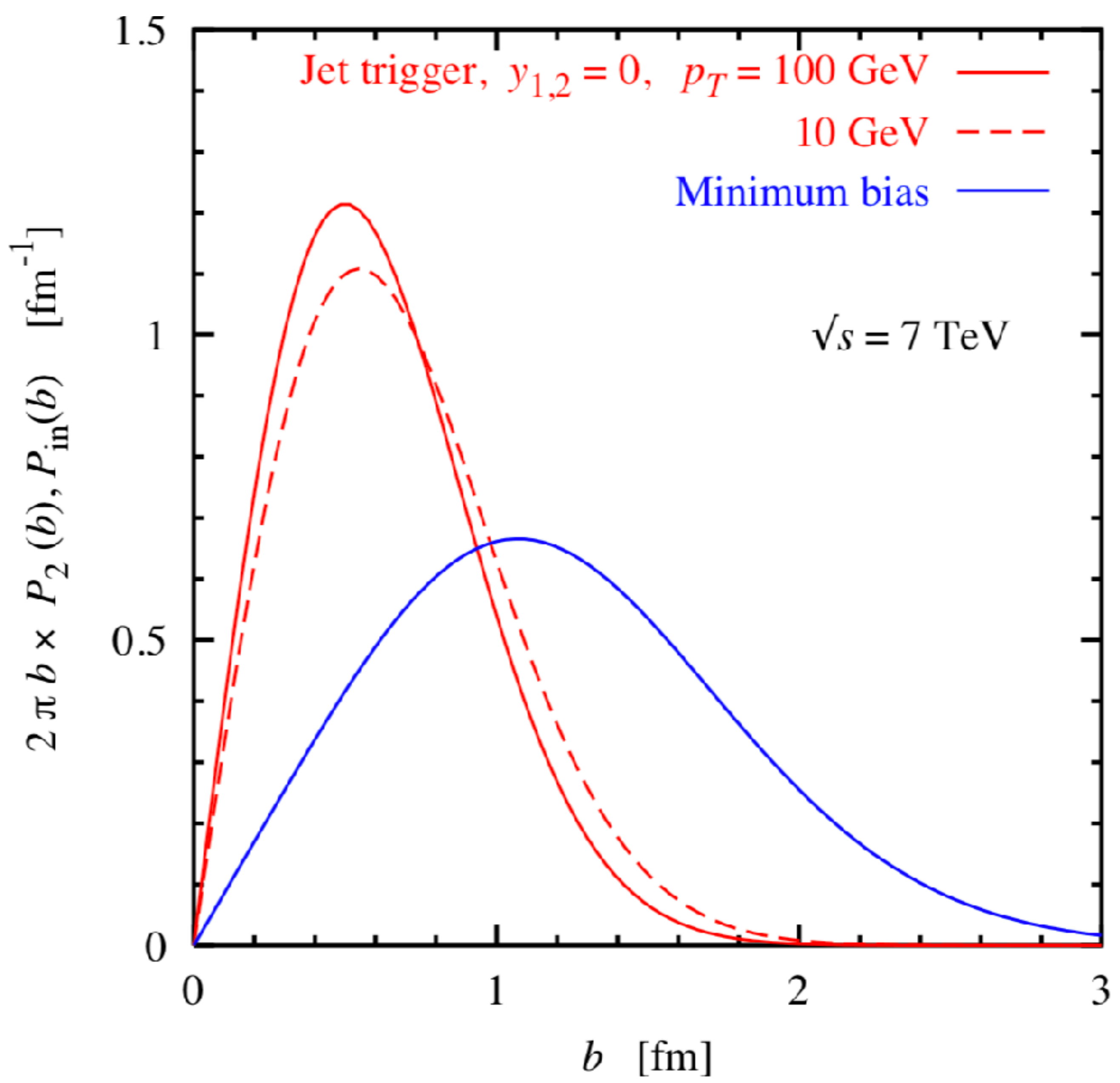
Final state observables depends on collision impact parameter: smaller b ➧ larger matter overlap ➧ larger probability of hard partonic processes ➧ a larger number of MPIs and higher multiplicity

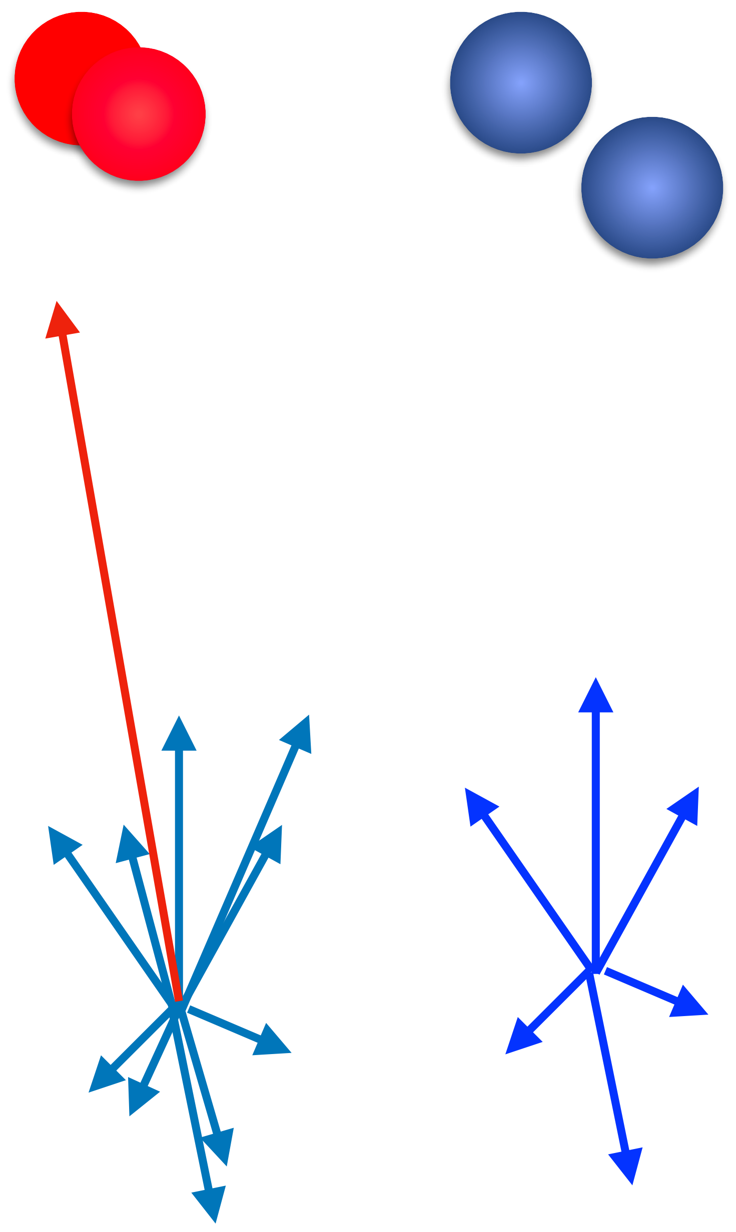
T. Sjostrand, arXiv 1706.02166



Impact parameter dependence of MPI model implemented in PYTHIA ➧ central collisions (small b) have a larger matter overlap and an enhanced probability to have multi parton interactions

M. Strikman et al., PRD 83 054012 (2011)



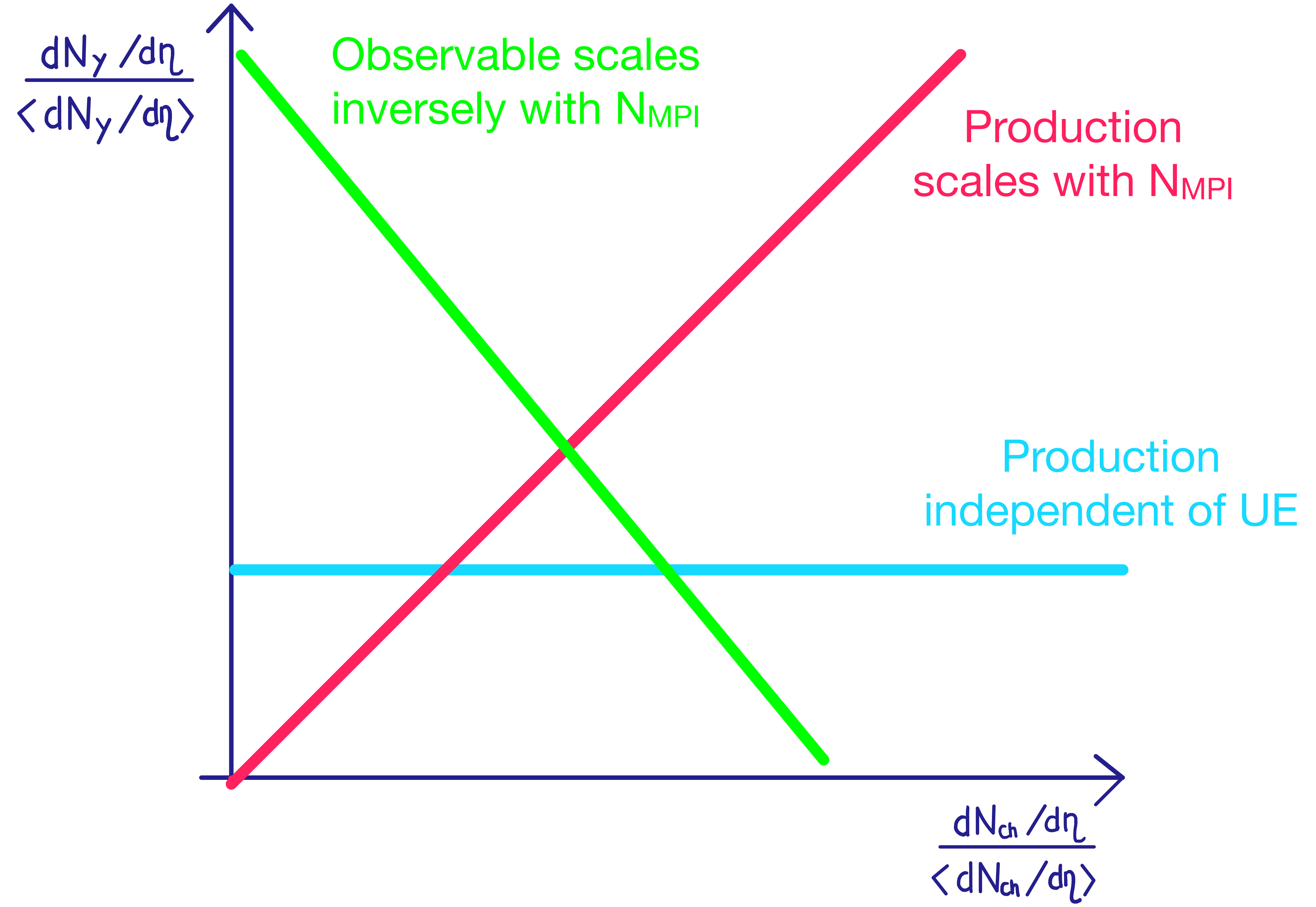


impact parameter distributions for inelastic pp collisions at $\sqrt{s}$ = 7 TeV

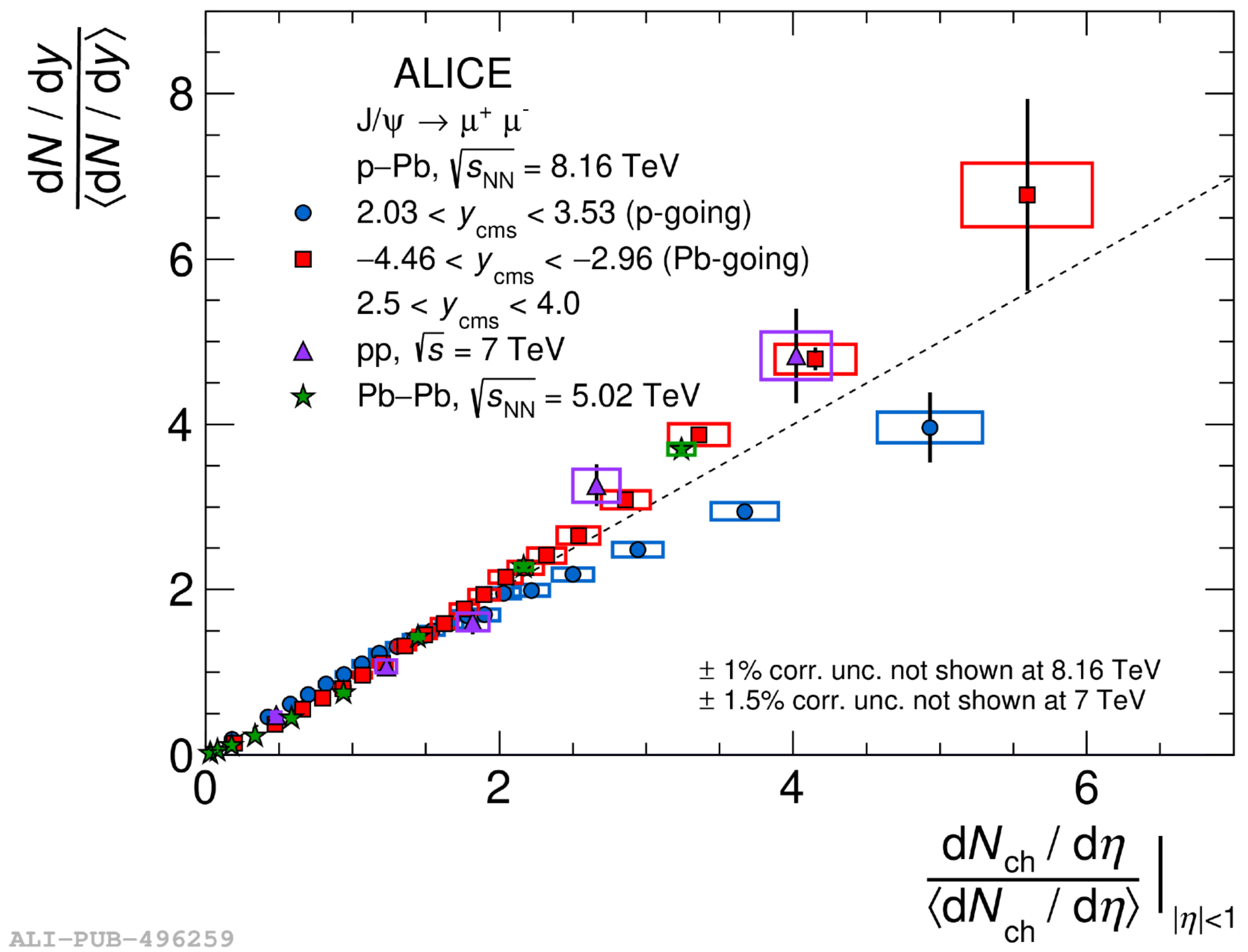
Hard vs. soft production

Charged particle multiplicity is connected to the number of MPI, N_{MPI}

➧ study hard probe production as a function of charged particle multiplicity



ALICE Coll., JHEP 09 (2020) 162

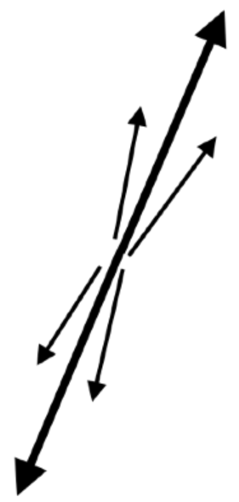


Self-normalized variables are used

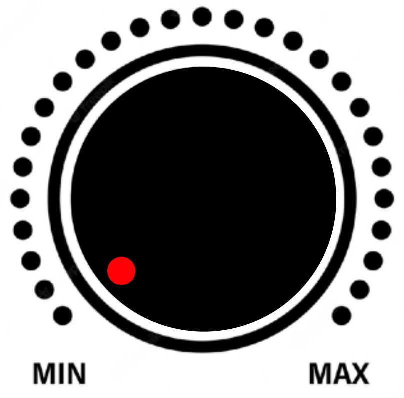
➧ reduce systematic uncertainties

➧ allows comparison of different systems and energies

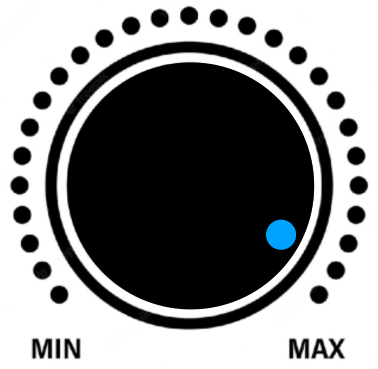
MPI & R_T



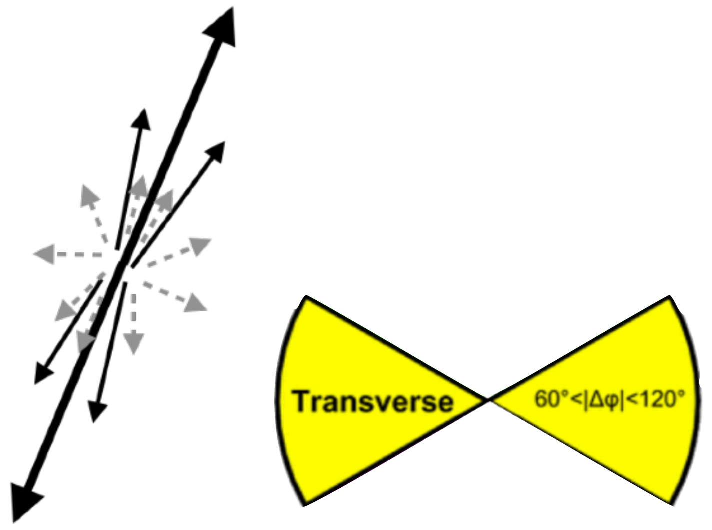
Small R_T ➧ e^+e^--like
➧ low-UE, low N_{MPI}



Increasing R_T



large R_T
➧ high-UE, high N_{MPI}



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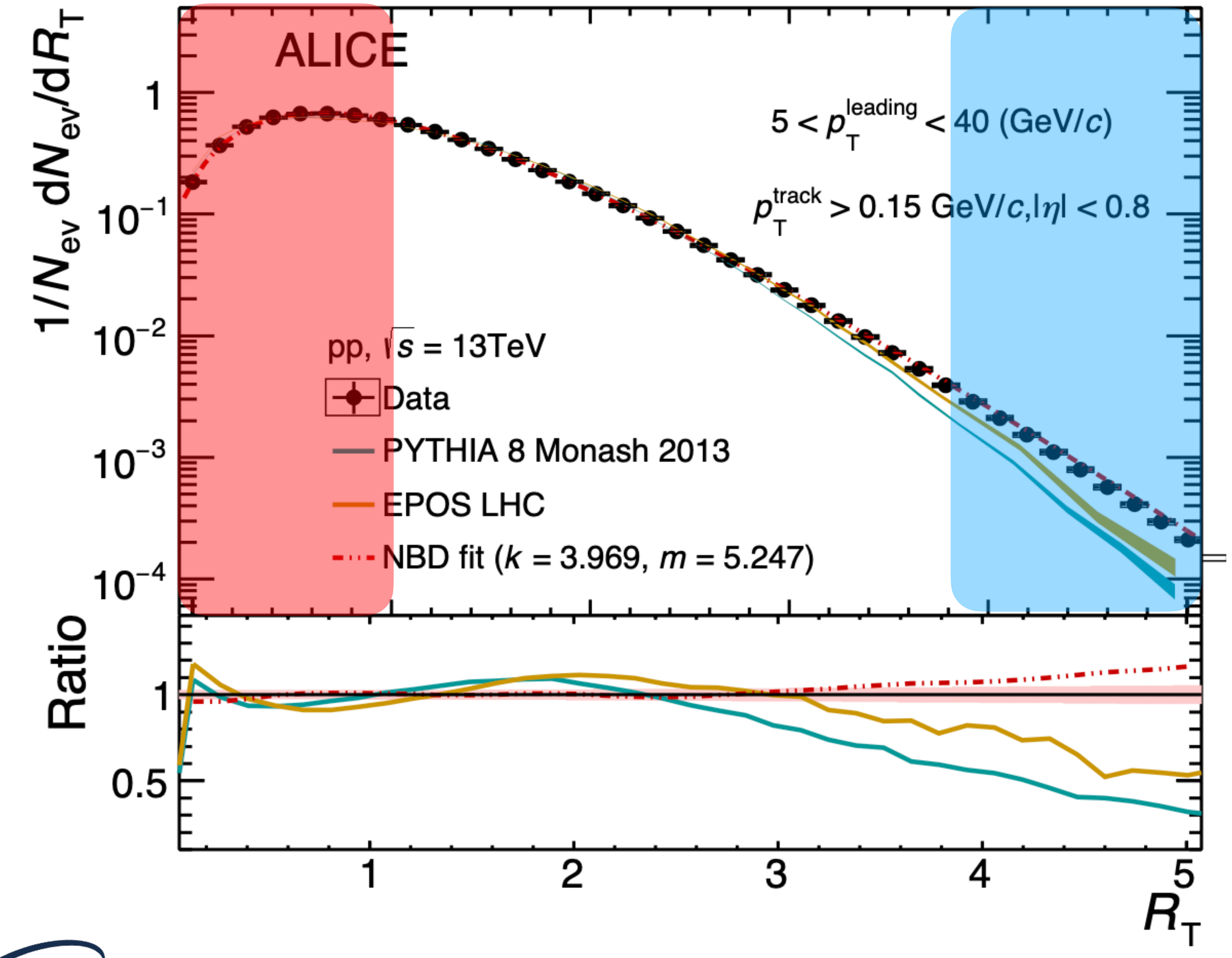
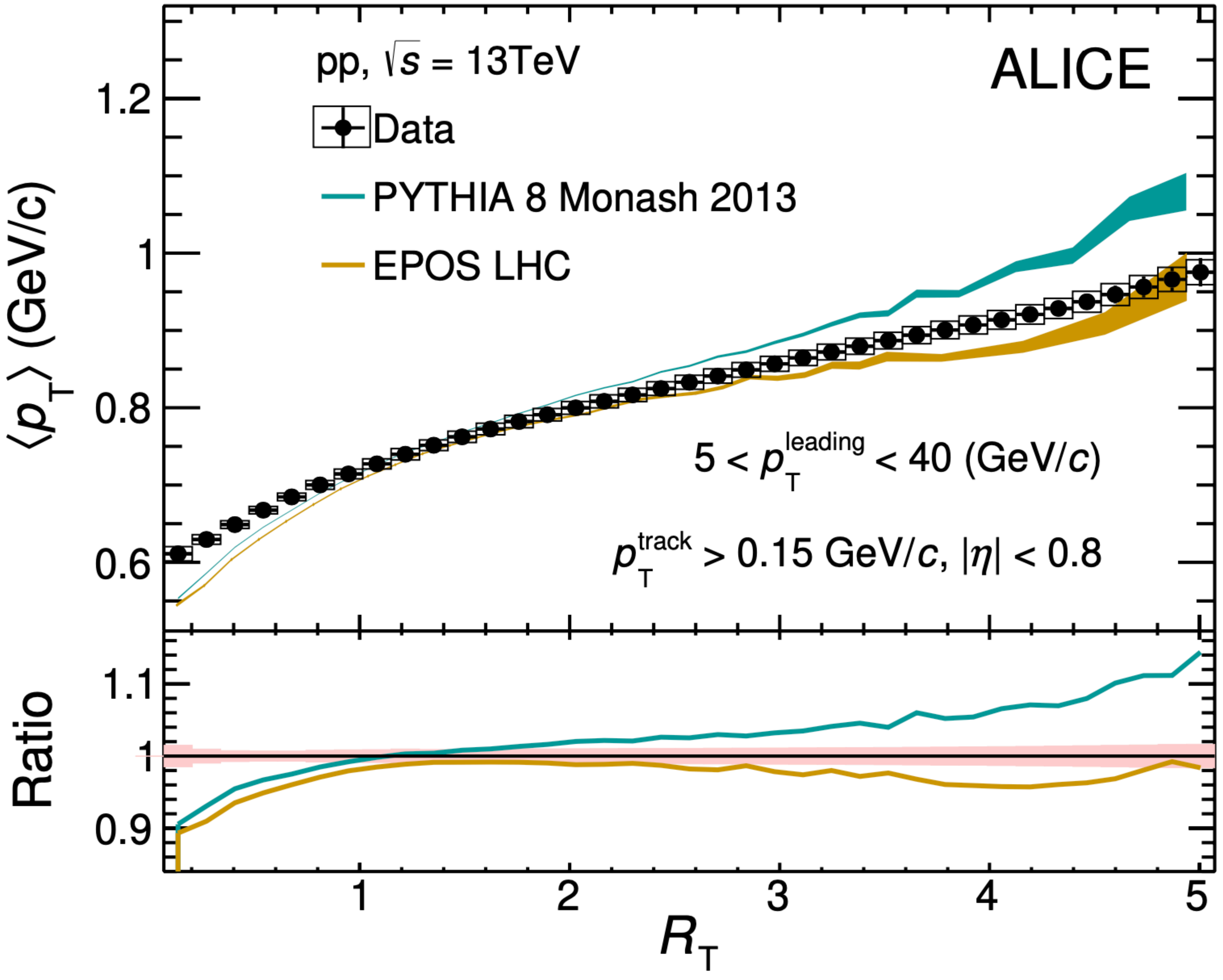




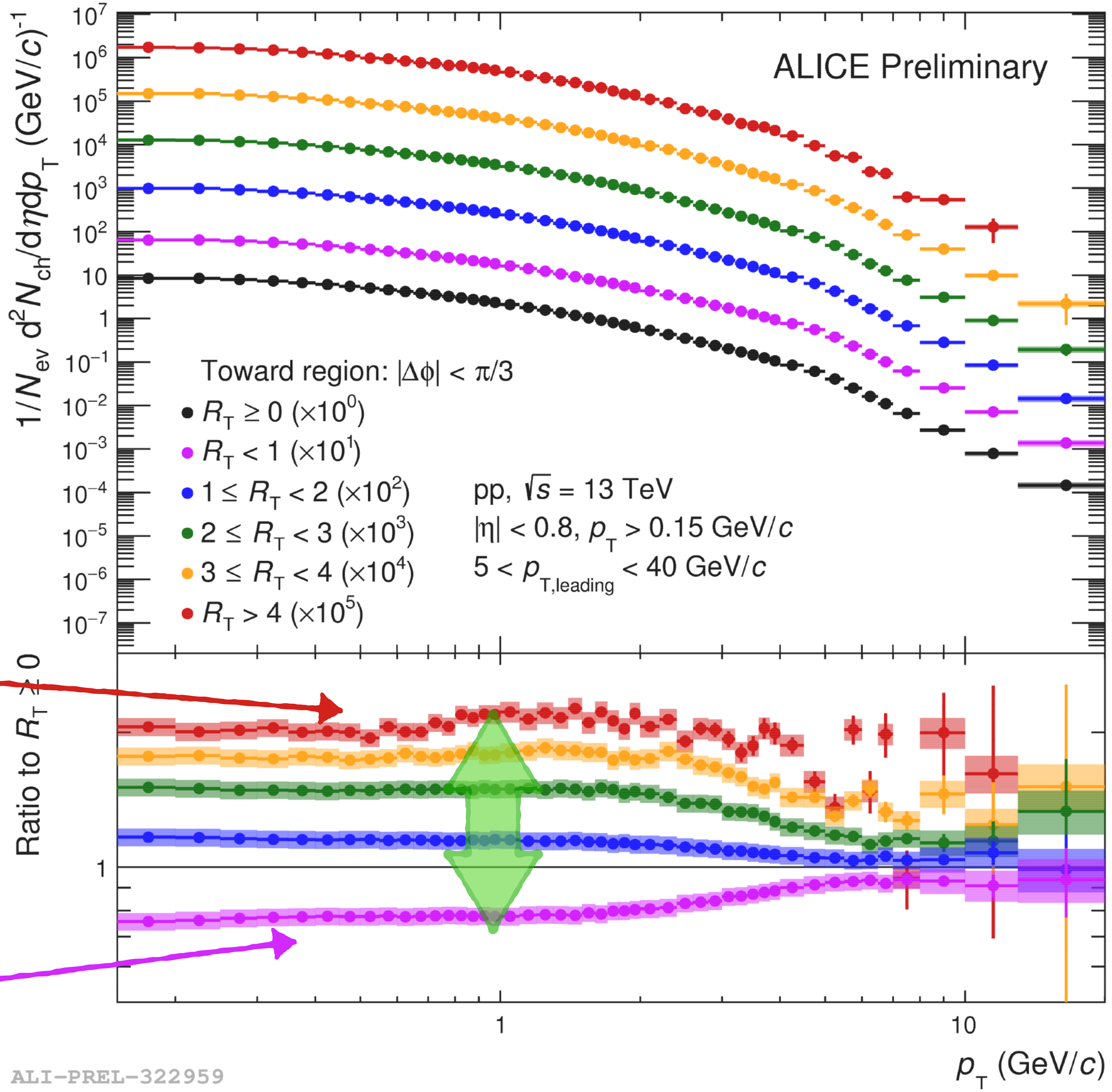
Spectra in toward region vs. R_T

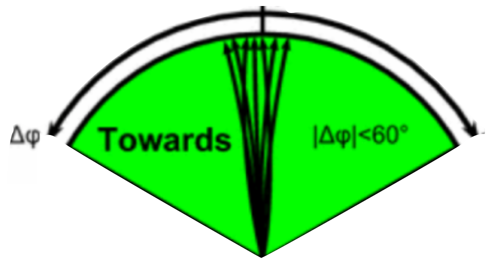
TOWARD REGION

- soft "jet pedestal" from UE whose relevance varies with R_T
- UE does not affect the hard part of the jet

High UE ➧ UE dominate the yields ("polluted" jets)

Small UE ➧ UE not contributing ("clean" jets)

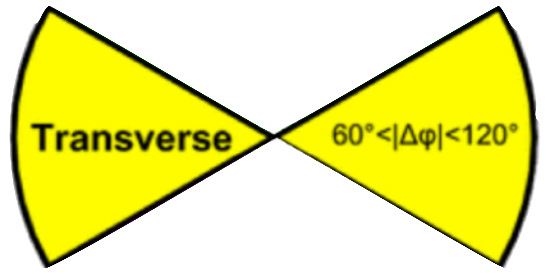


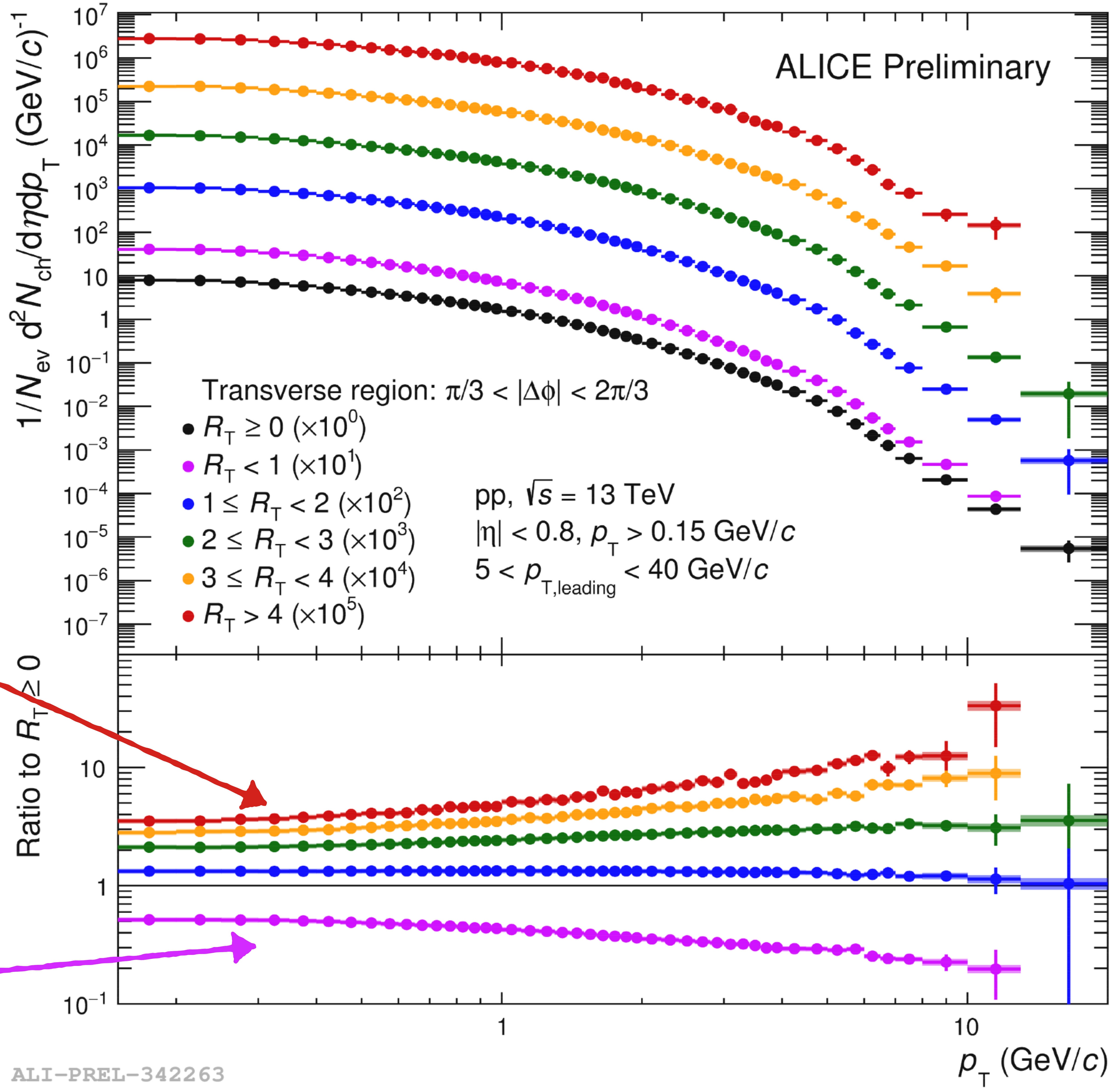


Spectra in transverse region vs. R_T

TRANSVERSE SIDE

- $\langle p_T \rangle$ increases with UE (as in MB)

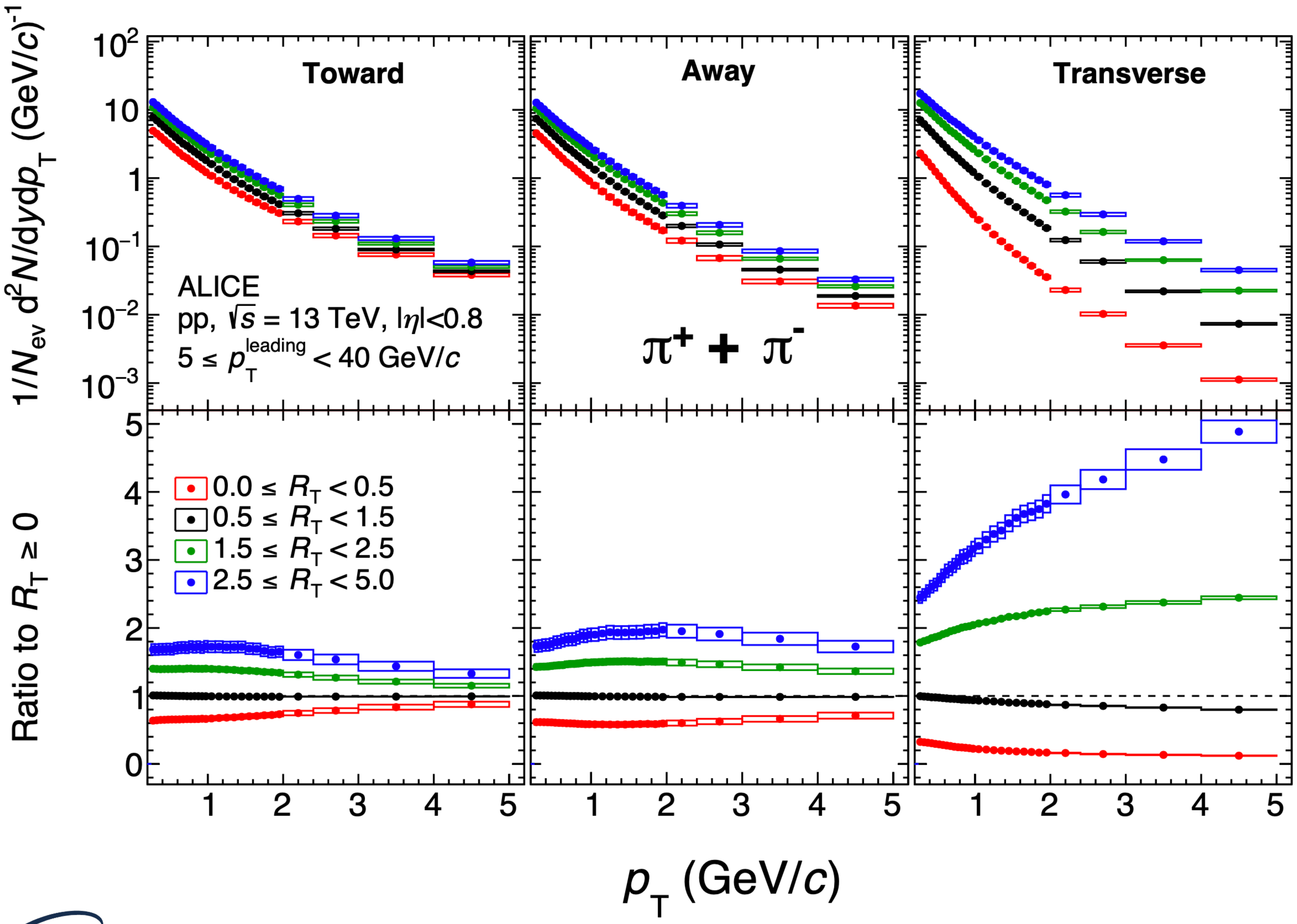




High UE ➧ harder spectra

High UE ➧ softer spectra

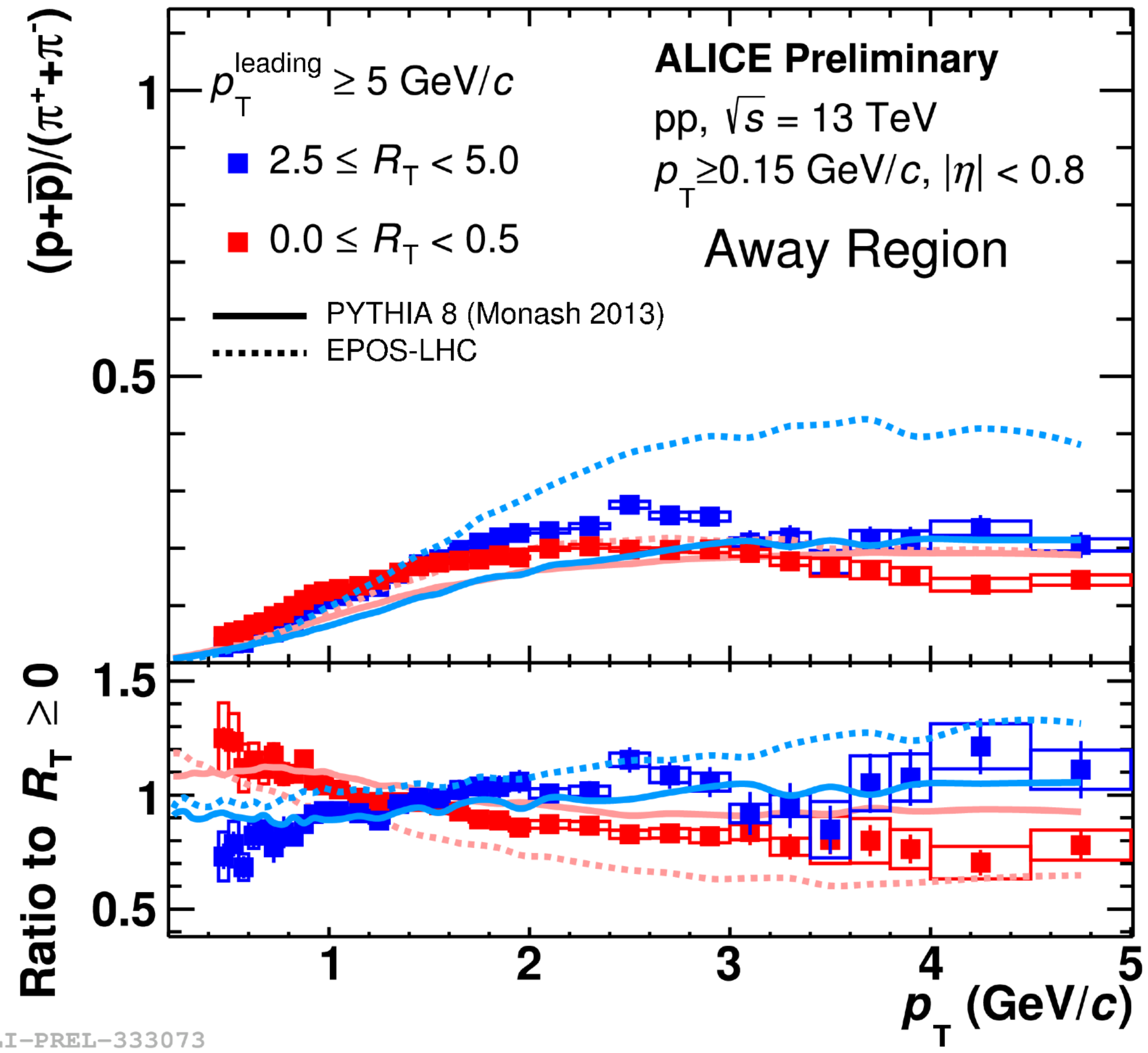
Particle spectra vs. R_T

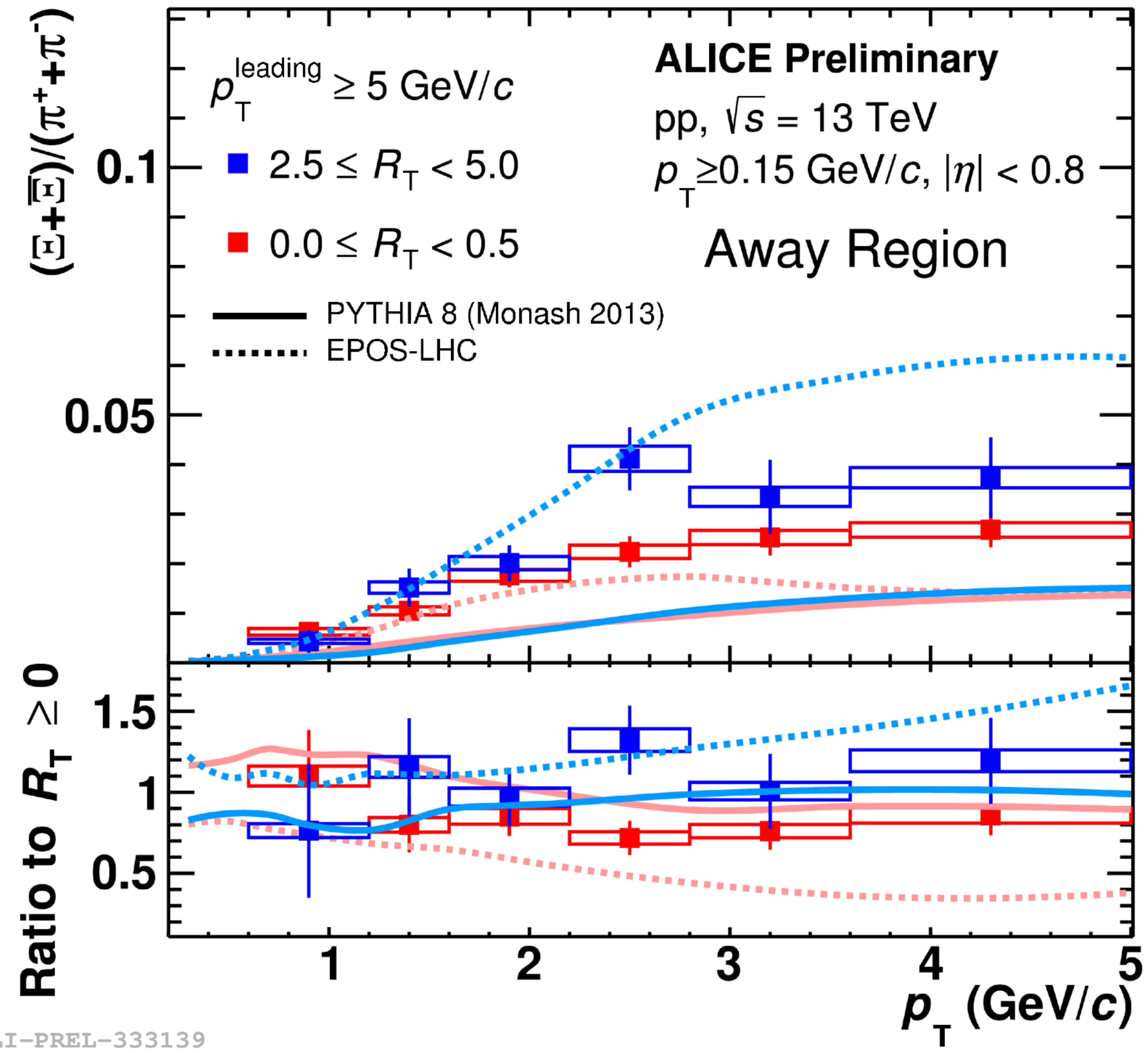


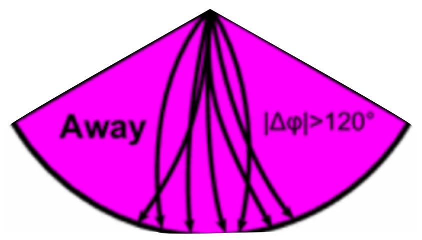
Yield of high p_T particles relative to the R_T-integrated measurement in TOWARD and AWAY regions decreases with increasing R_T

➧ UE dominates for large R_T values

Particle ratios in away side vs. R_T

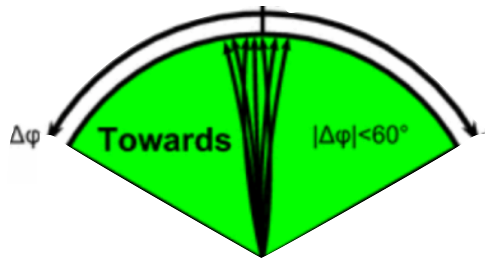


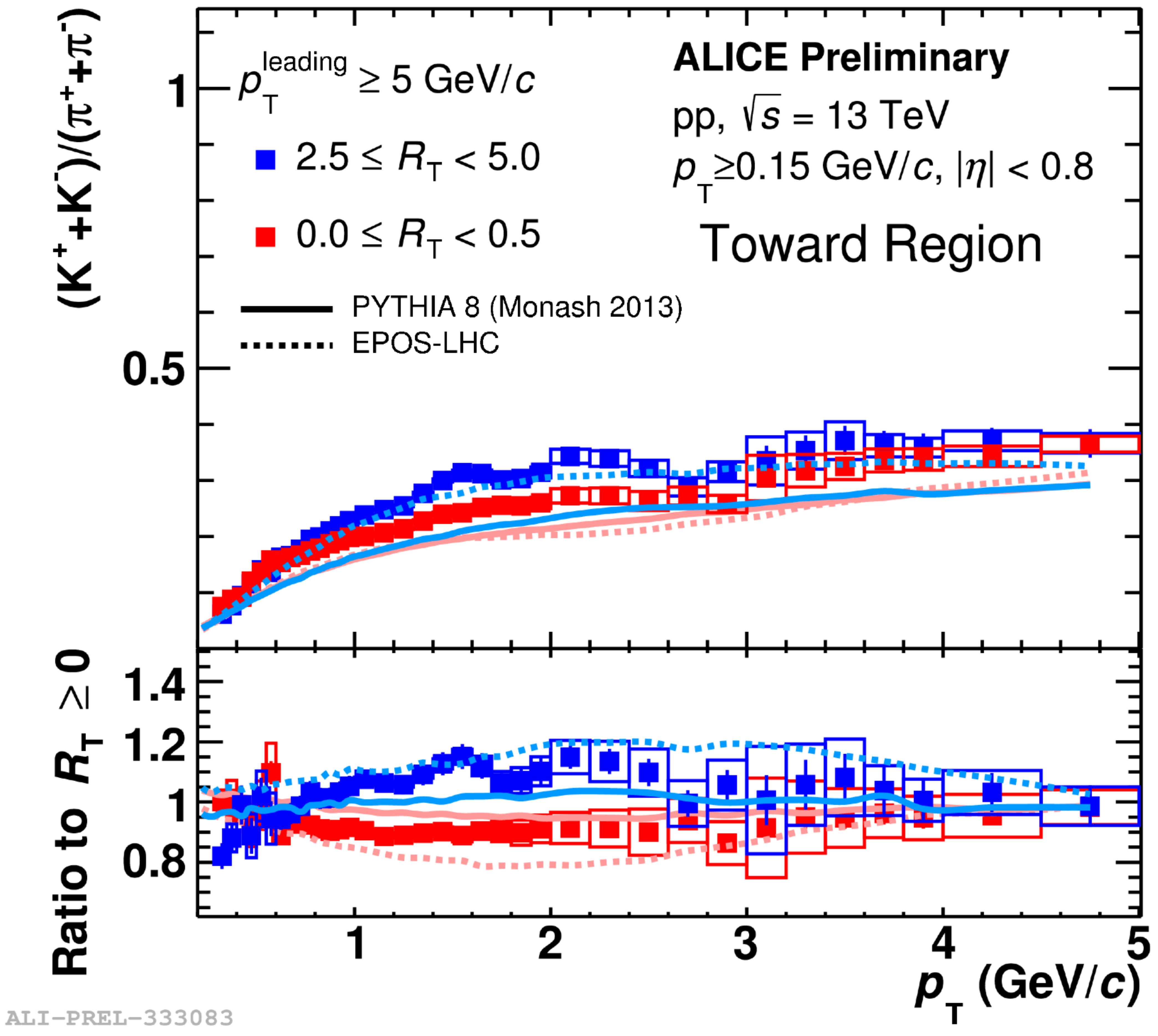


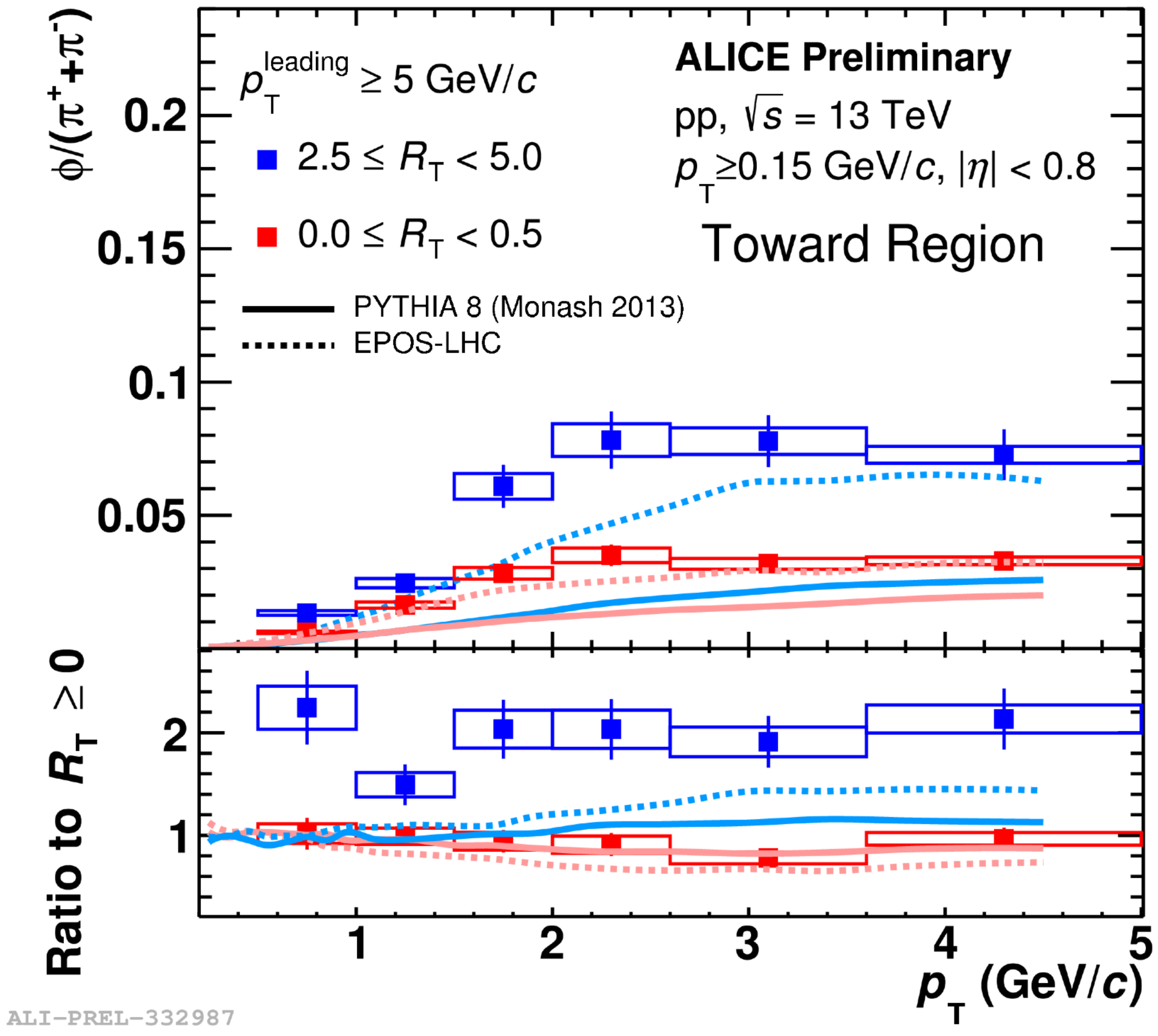


- milder R_T dependence in the away region
- both PYTHIA (underpredicts baryon fractions, especially Ξ, at high R_T) and EPOS-LHC (overpredicts high-p_T baryon fractions at high R_T) predictions fail to describe the ratios

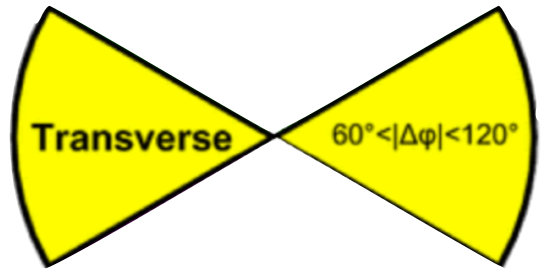
Particle ratios in toward side vs. R_T

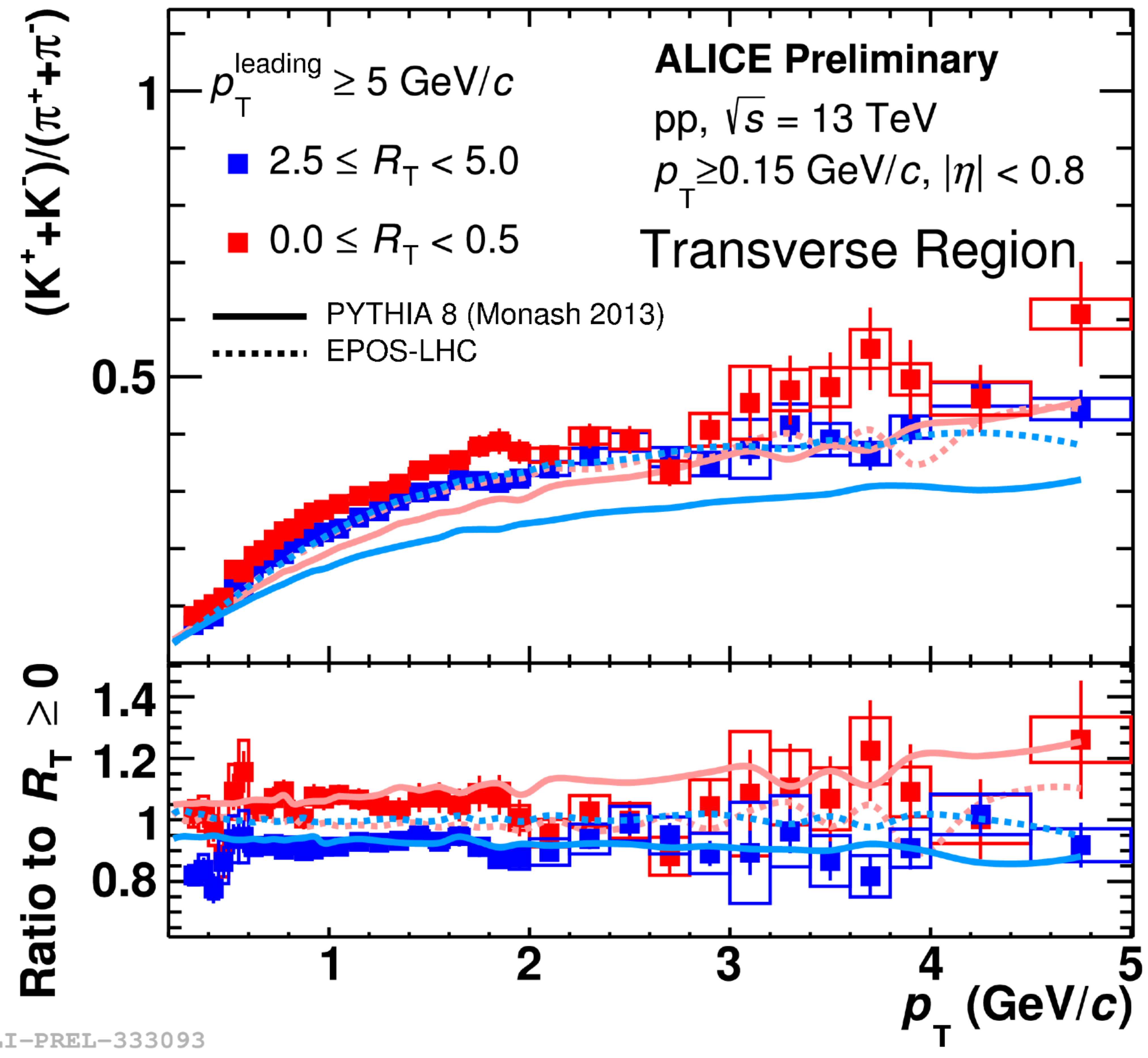


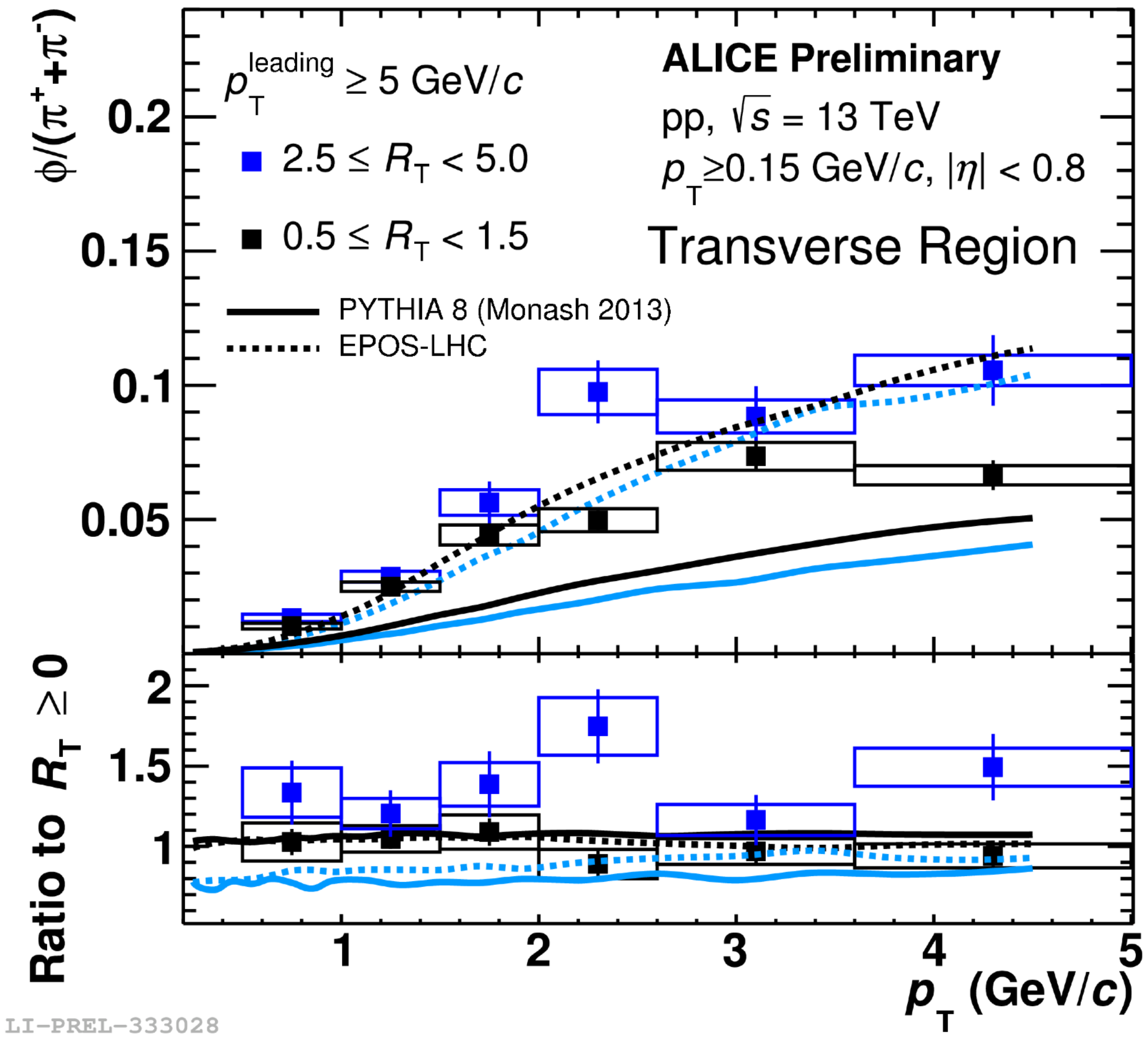


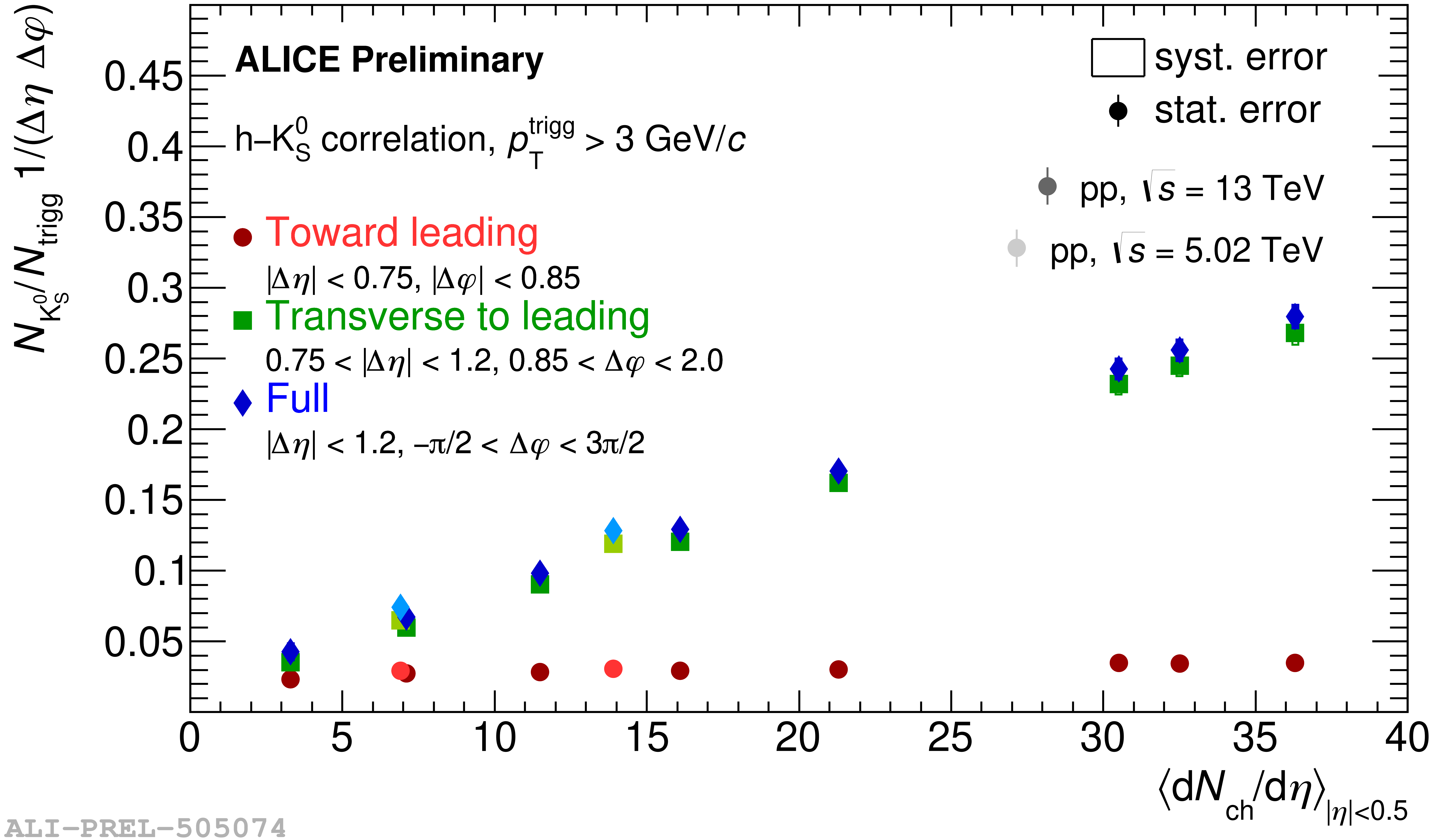


Particle ratios in transverse side vs. R_T

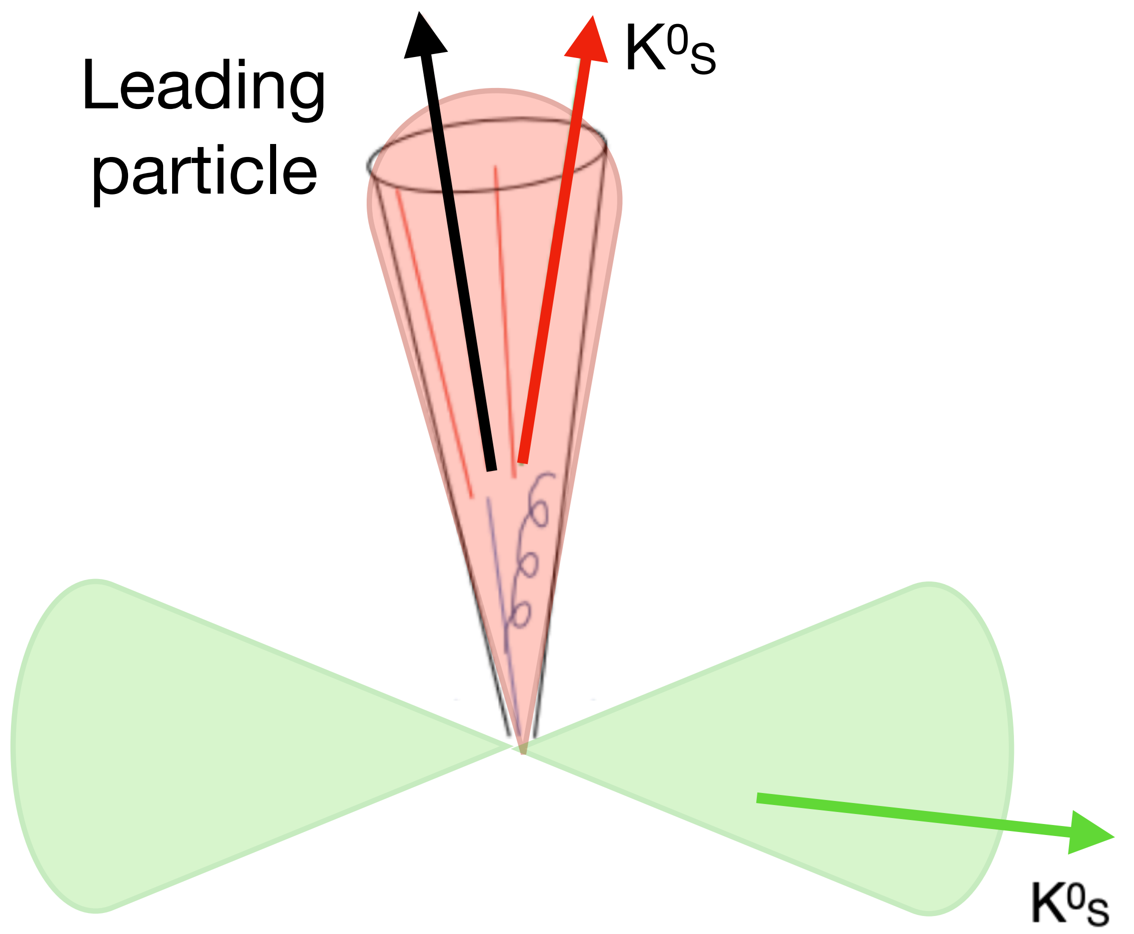




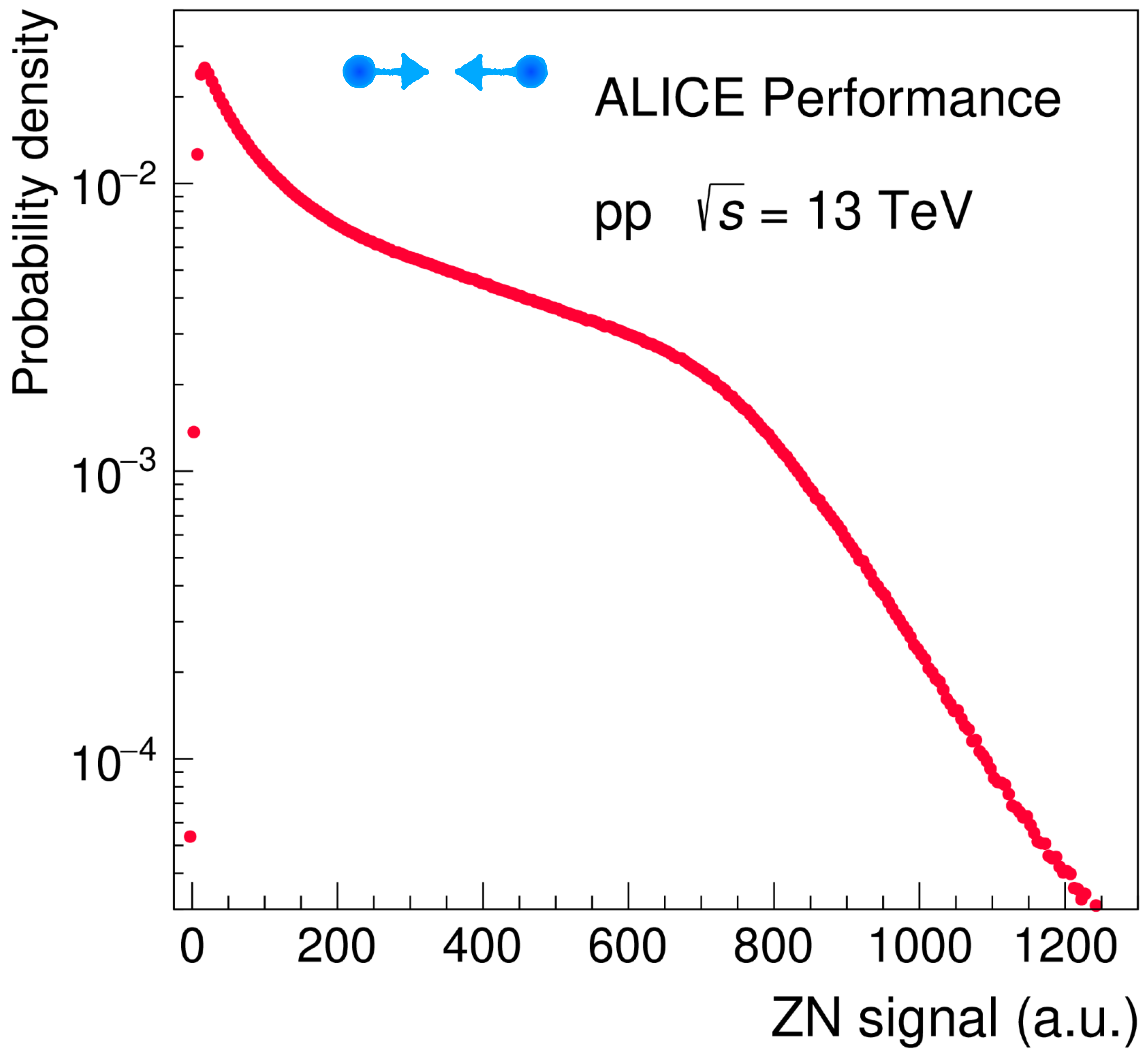




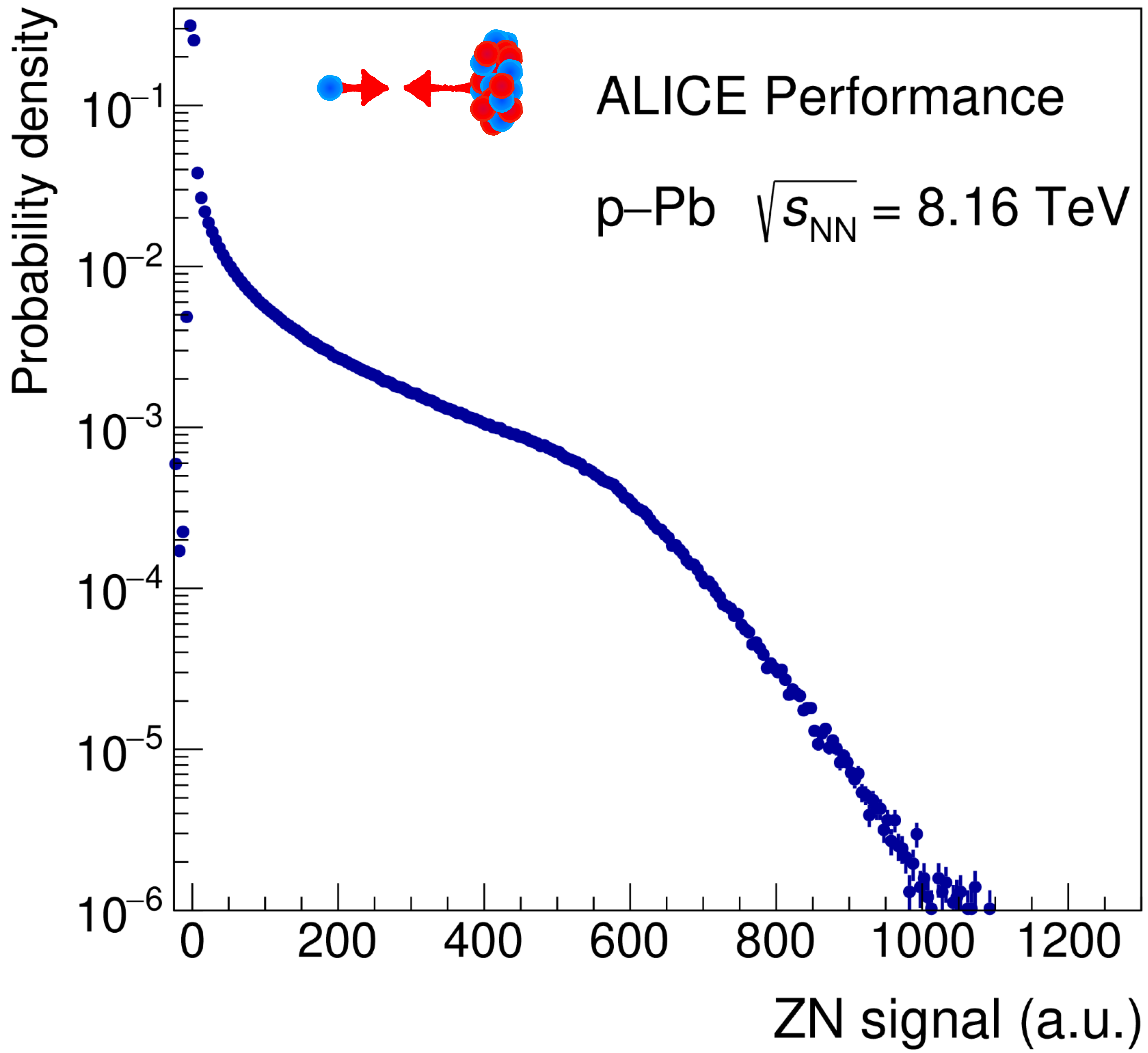
ALI-PREL-505074



ZN spectra in p fragmentation region



ALI-PERF-365696



ALI-PERF-365712

Very similar features in spectra from the p-fragmentation region

Different fraction of MB events with a signal in ZN: 43% in p-Pb 61% in pp

ZP spectra in p fragmentation region

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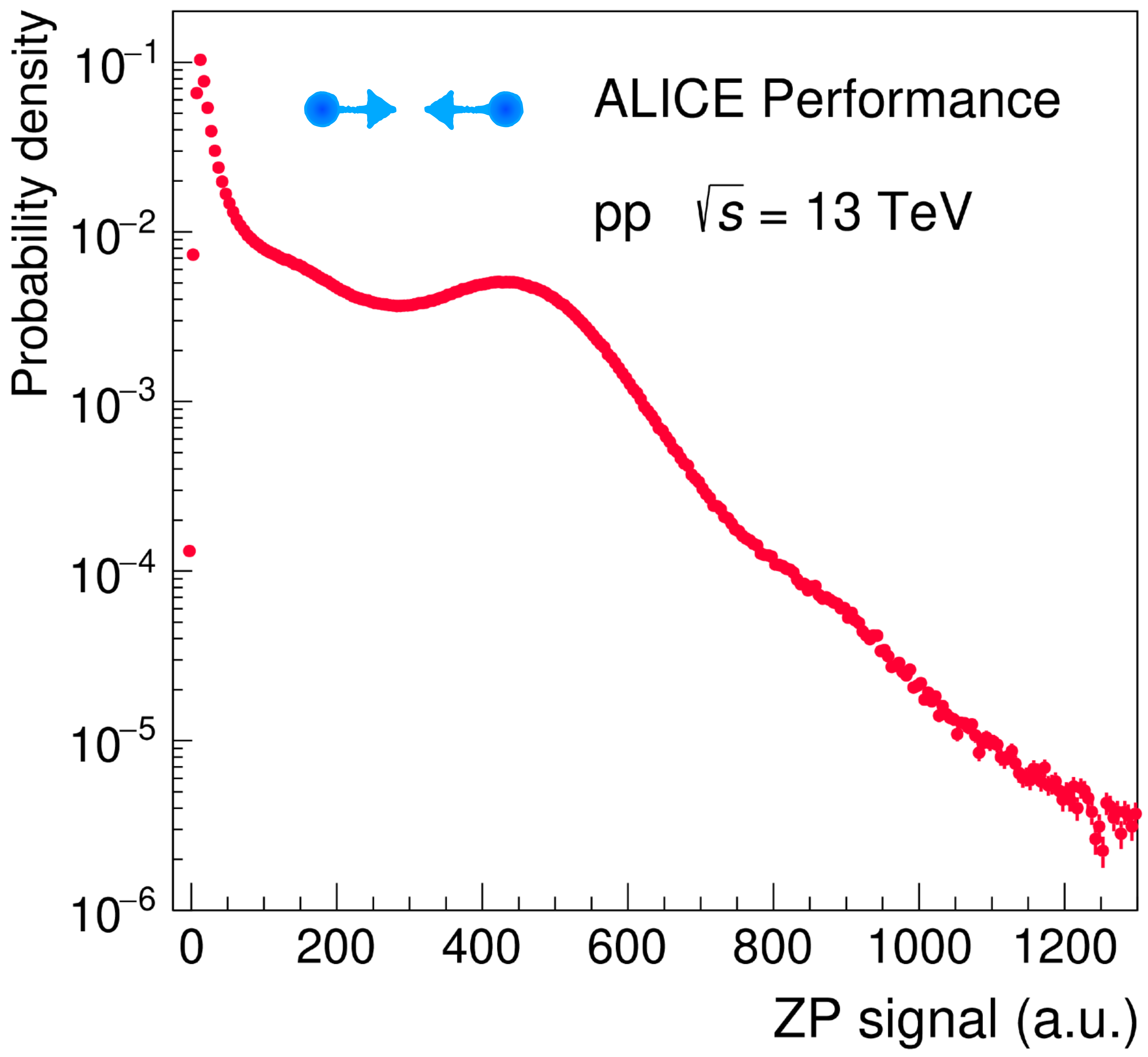
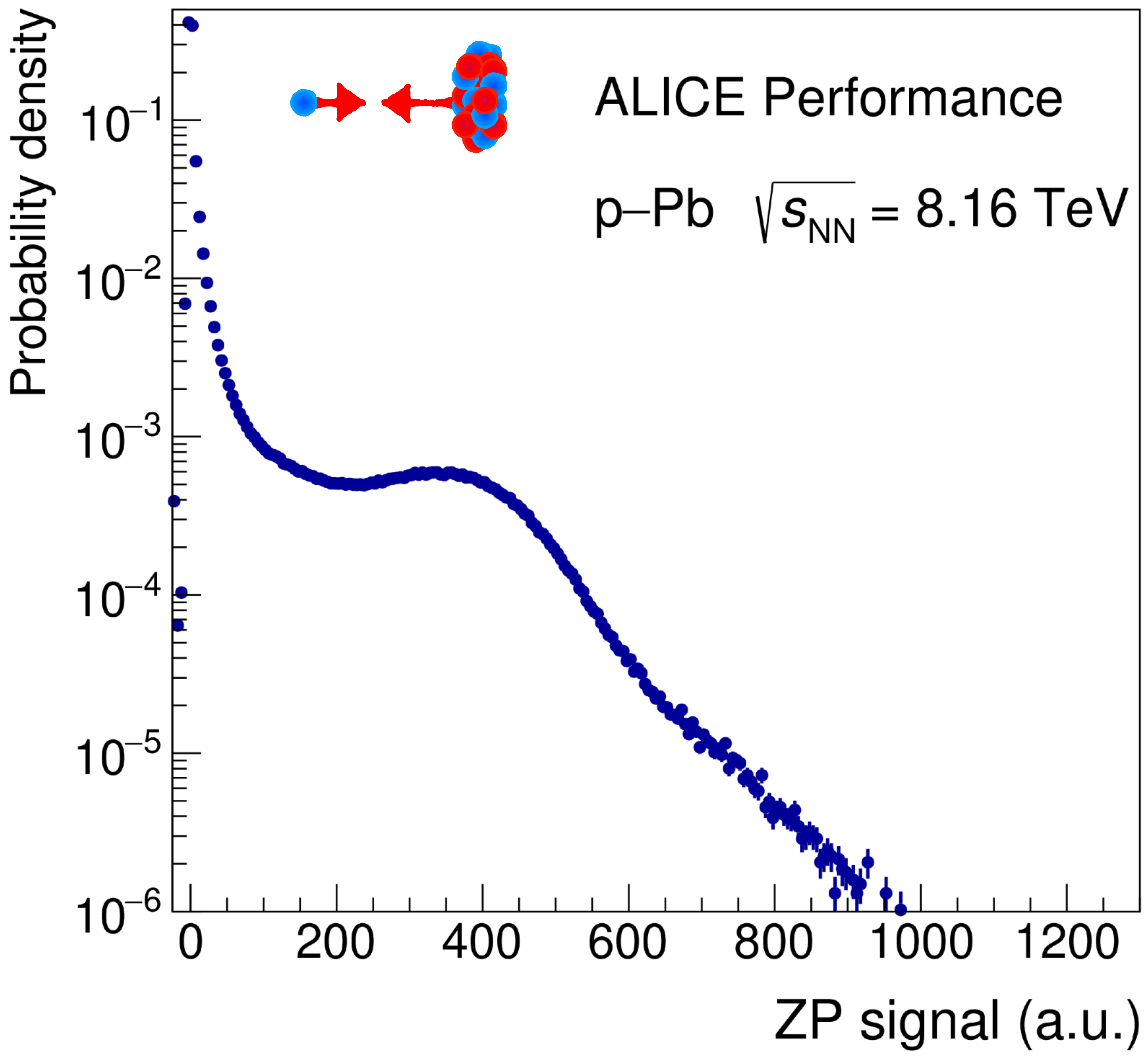


ALI-PERF-365704



ALI-PERF-365720

Very similar features in spectra from the p-fragmentation region

Different fraction of MB events with a signal in ZP: 15% in p-Pb 23% in pp

Strangeness enhancement in small systems

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