Particle production as a function of UE activity and very forward energy with ALICE

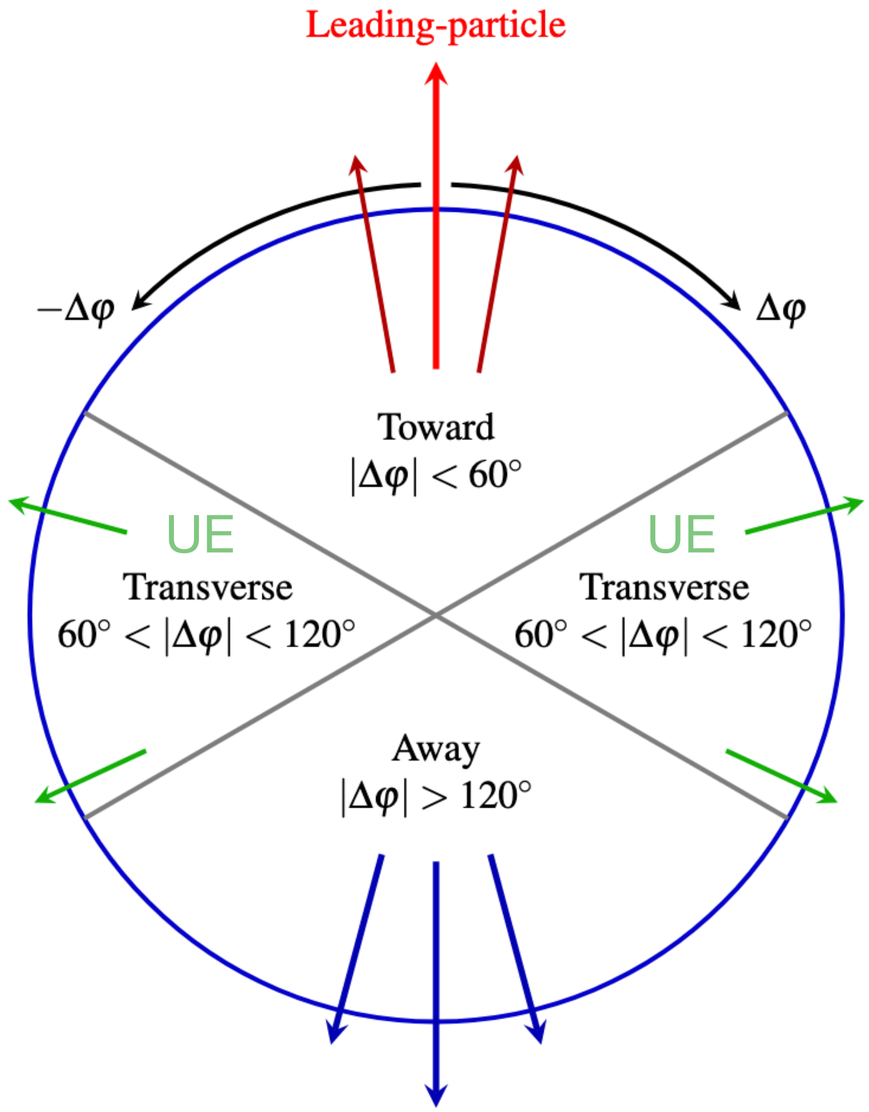
Feng Fan, for the ALICE collaboration

Introduction

- In pp collisions the underlying event (UE) is defined as the particle production which does not originate from the main parton-parton scattering

- Three azimuthal regions relative to the particle with the highest transverse momentum ($p_{\mathrm{T}}^{\mathrm{trig}}$) of the event are studied: toward, away, and transverse region CDF, PRD 65 (2002) 092002

- These three regions have been proposed to investigate the origin of the heavy-ion-like features discovered in small systems



T. Martin et al., EPJC 76 (2016) 5, 299 / A. Ortiz et al., PRD 99 (2019) 3, 034027 / S. Weber et al., EPJC 79 (2019) 1, 36

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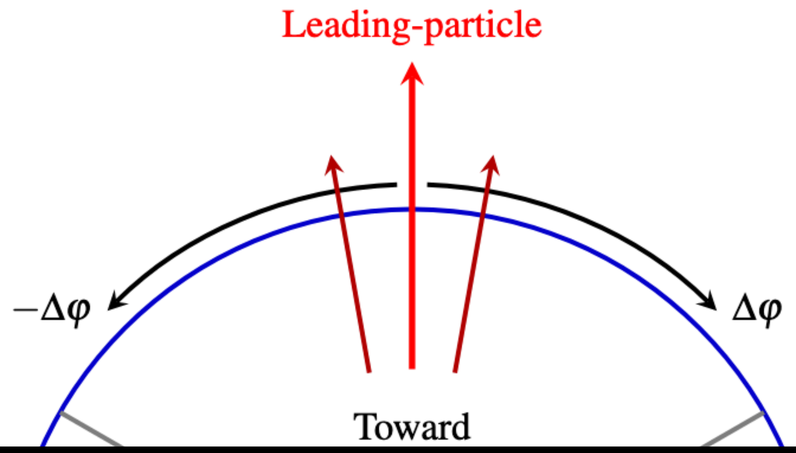
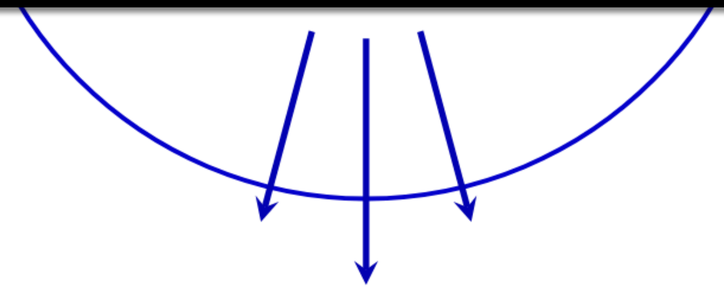


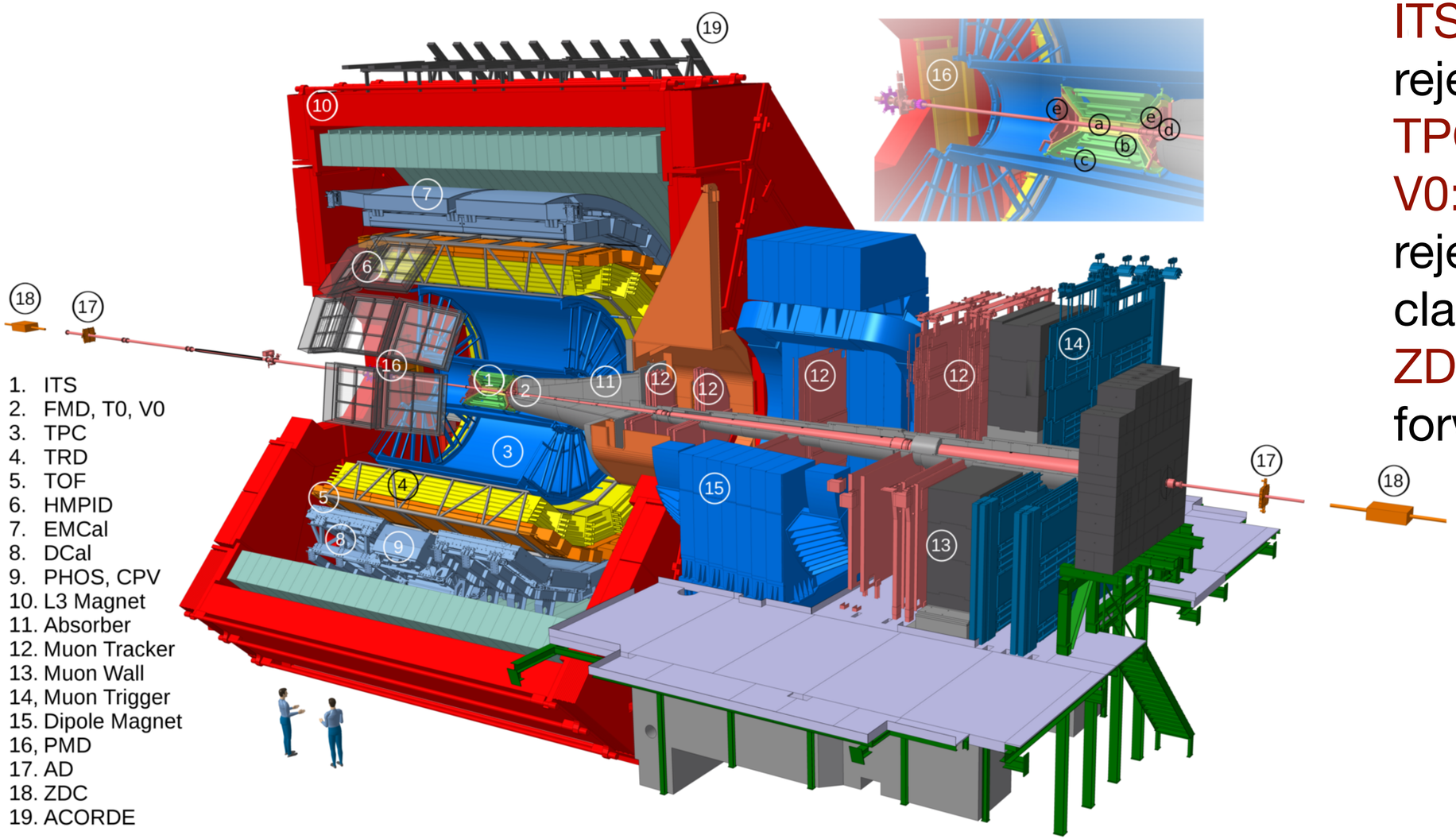
This presentation: results from UE-inspired techniques and very forward energy applied to different systems



- These three regions have been proposed to investigate the origin of the heavy-ion-like features discovered in small systems

T. Martin et al., EPJC 76 (2016) 5, 299 / A. Ortiz et al., PRD 99 (2019) 3, 034027 / S. Weber et al., EPJC 79 (2019) 1, 36

The ALICE detector



Relevant detectors for the present analysis:

ITS: primary vertex, pile up rejection, and tracking

TPC: tracking

V0: triggering, background rejection, and event classification

ZDC: detecting the very forward energy

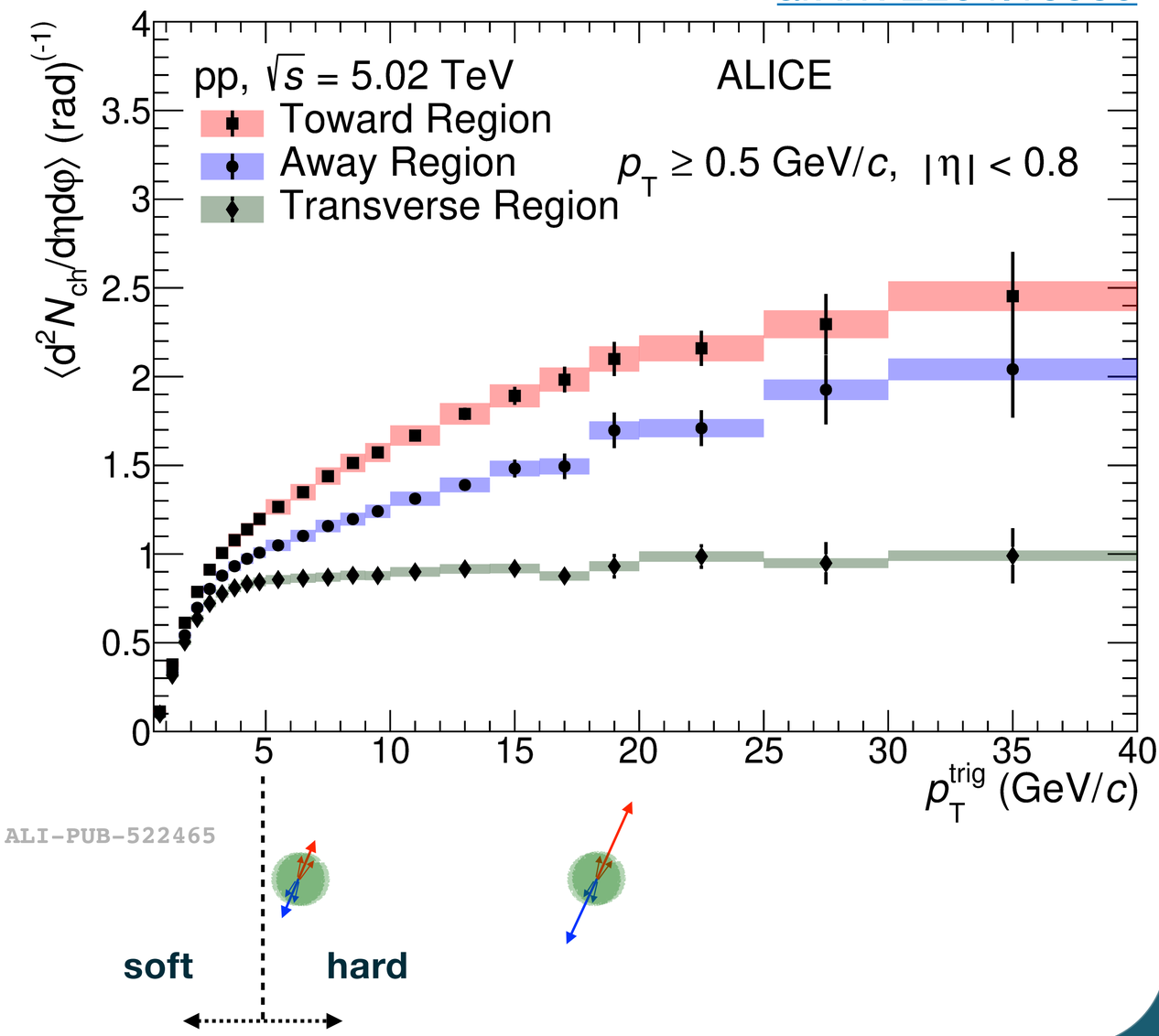
Analysis as a function of leading transverse momentum ($p_{\mathrm{T}}^{\mathrm{trig}}$)

UE in pp at $\sqrt{s} = 5.02$ TeV

arXiv: 2204.10389

Average charged-particle density (event activity) as a function of $p_{\mathrm{T}}^{\mathrm{trig}}$:

- $p_{\mathrm{T}}^{\mathrm{trig}} < 5$ GeV/c: in the toward, away, and transverse regions the activity increases by a factor ~10 relative to very low $p_{\mathrm{T}}^{\mathrm{trig}}$
- $p_{\mathrm{T}}^{\mathrm{trig}} > 5$ GeV/c: in the transverse region the activity saturates which is interpreted as due to MPI saturation. For the toward and away regions, still increases

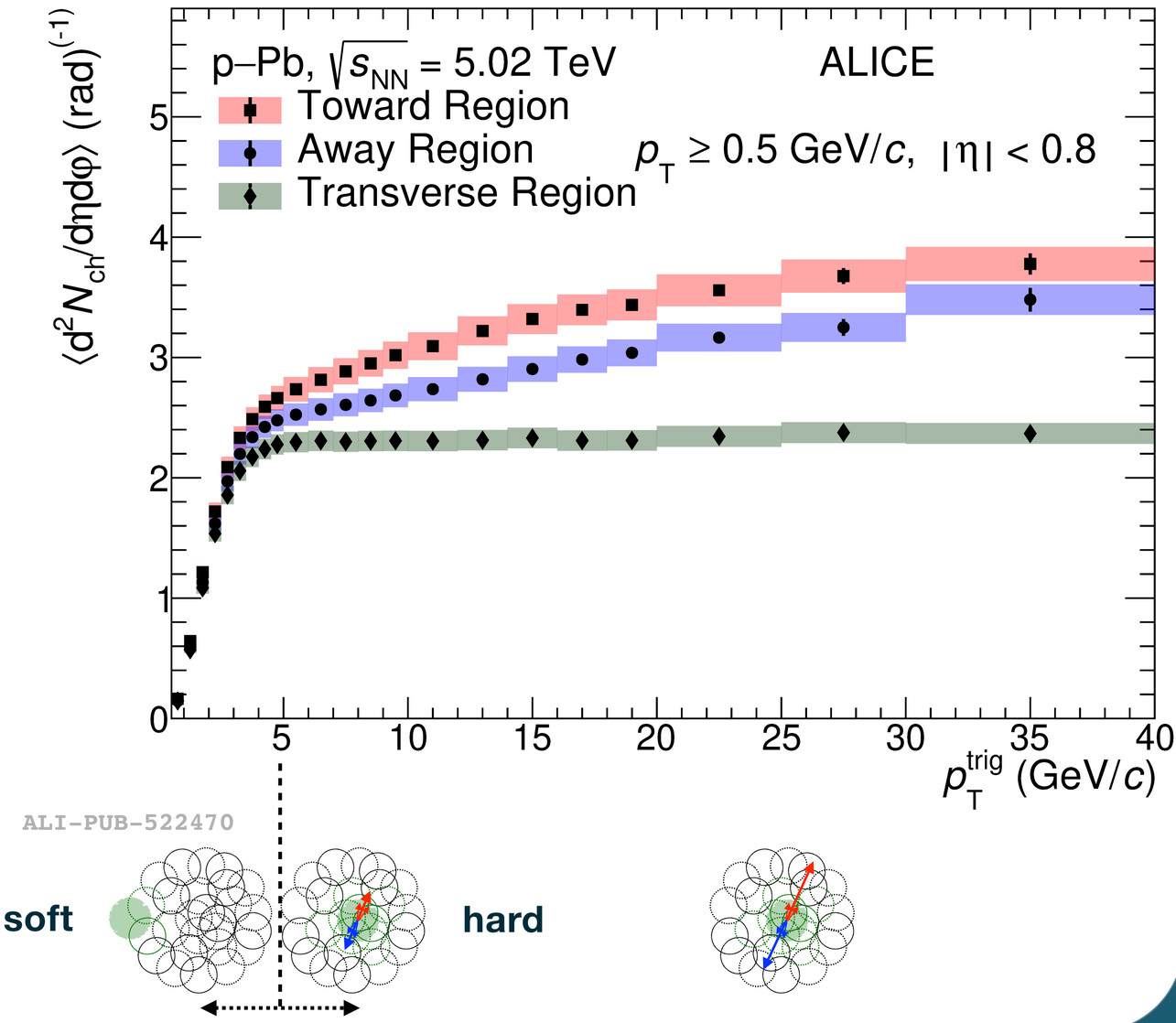


UE in p-Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

- Also in p-Pb collisions the activity in the transverse region saturates for $p_{\mathrm{T}}^{\mathrm{trig}} > 5$ GeV/c

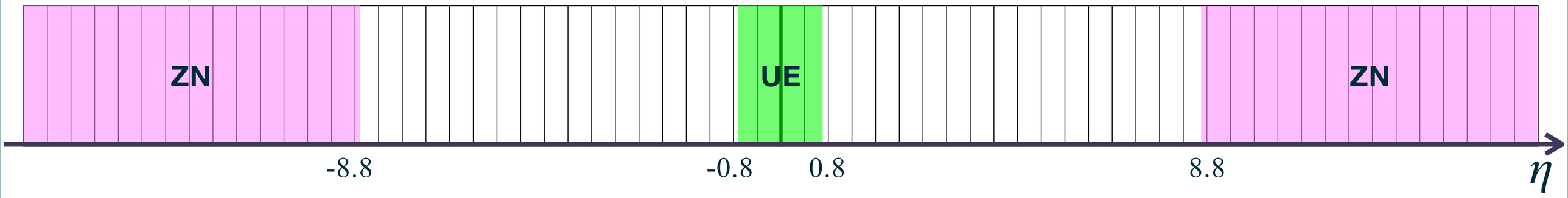
- However, the relative contribution of the underlying event to the toward and away regions is bigger in p-Pb collisions than in pp collisions

arXiv: 2204.10389



Very forward energy

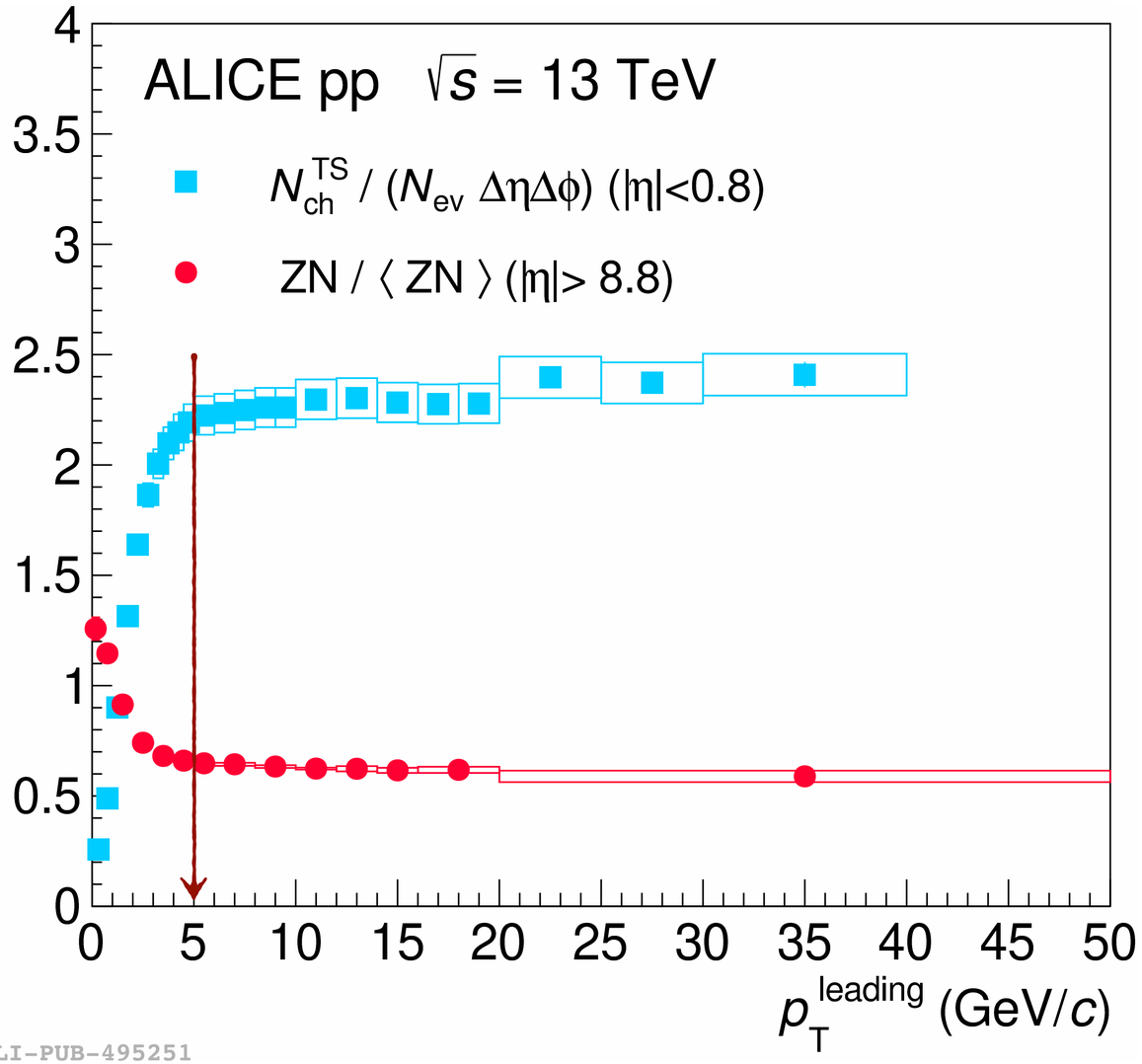
Another way to characterise the event is to look into a region which is separated in very forward pseudorapidity ($|\eta| > 8.8$), looking into the energy detected by the ZDC, which measures the beam remnants



The UE (at midrapidity) is studied using region that is separated in azimuth from the hard partonic scattering

UE vs ZN signals: pp

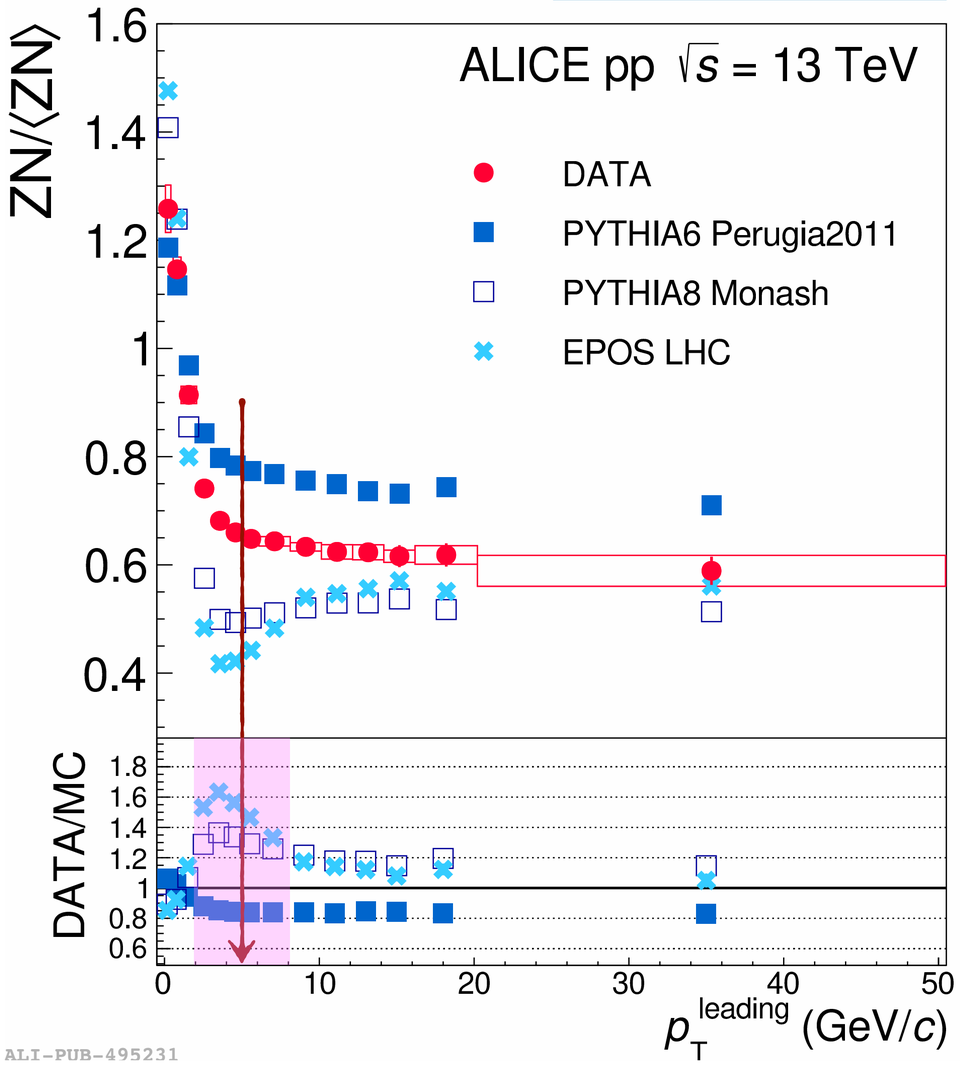
arXiv: 2107.10757



- The self-normalised ZN signals measure the beam remnants for $|\eta| > 8.8$
- The saturation in UE and in ZN energy occur at the same leading particle p_{T} scale, around $p_{\mathrm{T}} \sim 5\,\mathrm{GeV}/c$
- The result for the very forward energy corroborates the properties of UE activity since the correlation between central and forward rapidity can only be attributed to the initial stage of the collisions

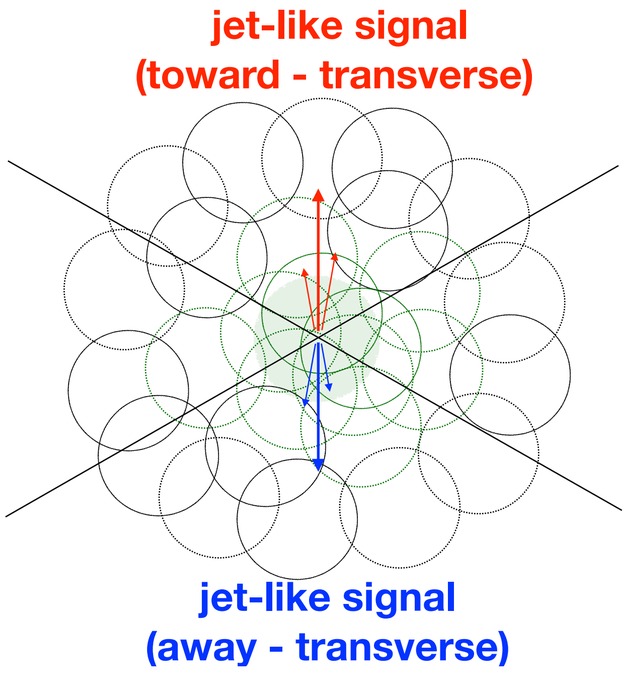
ZN signals: pp

arXiv: 2107.10757

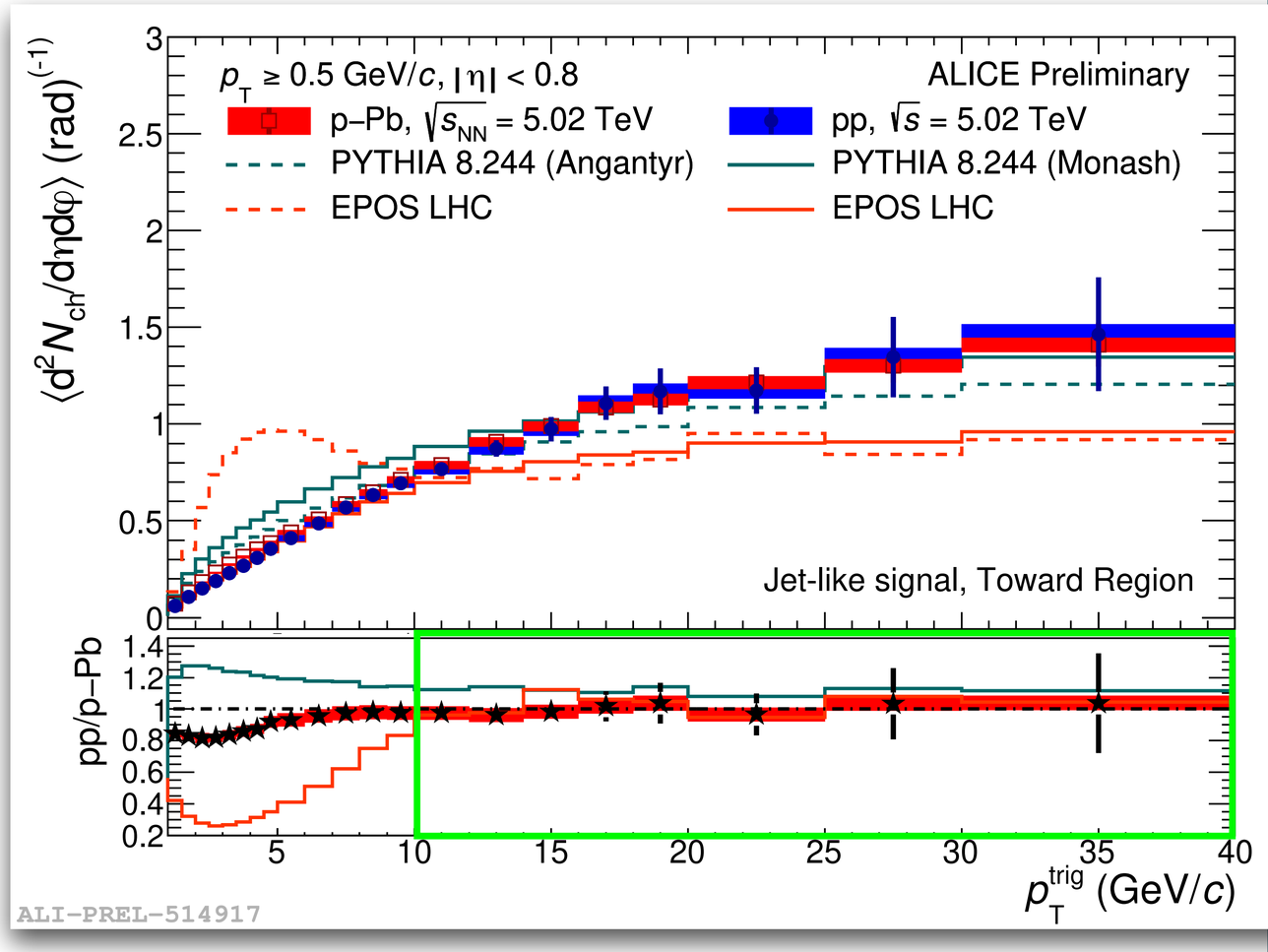


- Qualitatively, PYTHIA 6 is in agreement with data
- It seems to indicate that the treatment of colour reconnections and beam remnants in the Perugia tunes of PYTHIA 6 is more realistic than the one in the default Monash tune of PYTHIA 8
- Even EPOS LHC does not reproduce the measurements vs. very forward energy for intermediate $p_{\mathrm{T}}^{\mathrm{leading}}$ values $(2 - 8\,\mathrm{GeV}/c)$

Jet-like signals: pp vs p-Pb



arXiv: 2204.10389

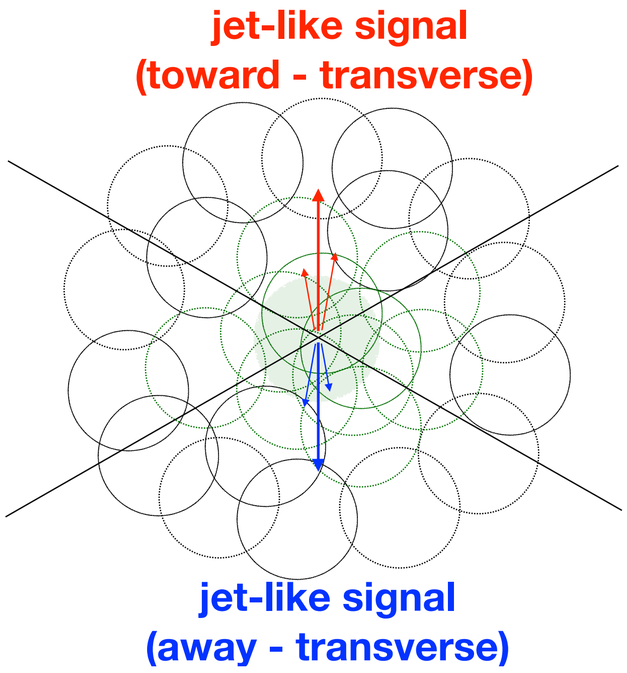


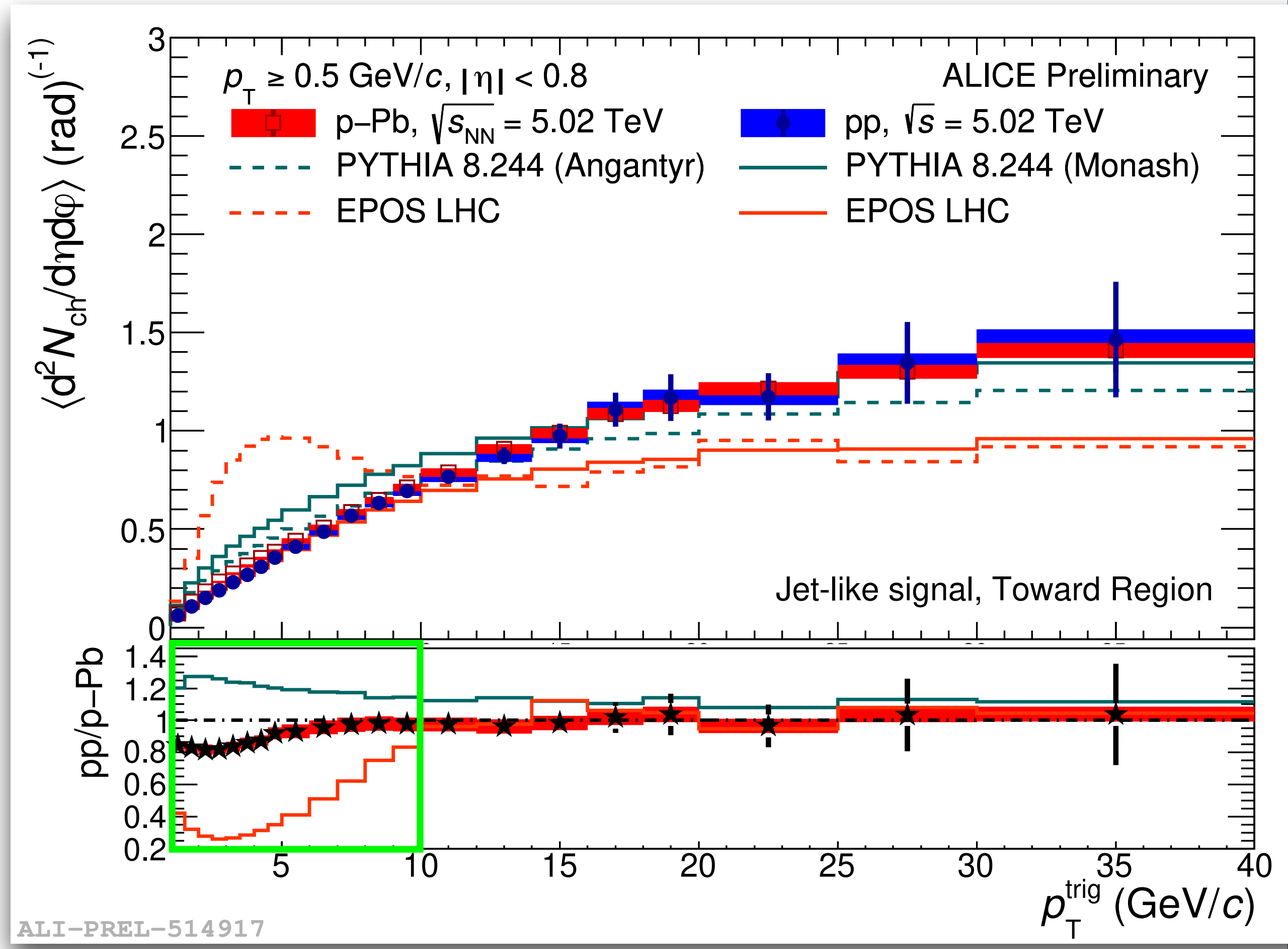
Toward region $p_{\mathrm{T}}^{\mathrm{trig}} > 10$ GeV/c:

- No jet-like modifications are observed
- Within 10%, models describe the data

Jet-like signals: pp vs p-Pb

arXiv: 2204.10389





Toward region $p_{\mathrm{T}}^{\mathrm{trig}} < 10$ GeV/c:

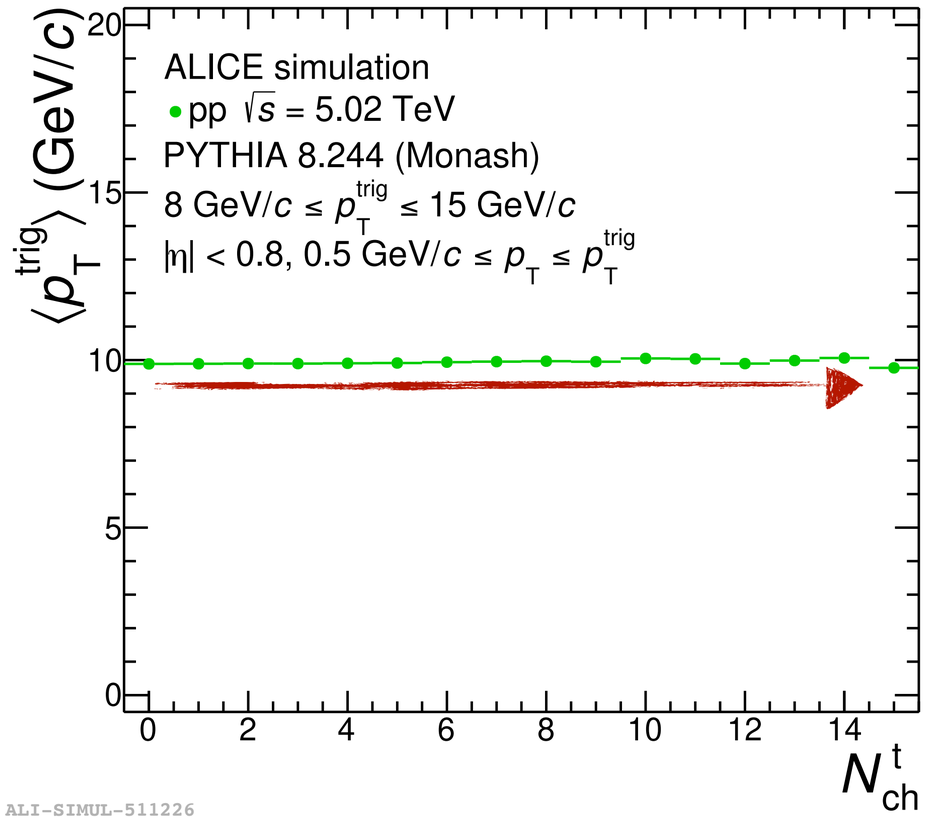
the activity is up to 20% higher in p-Pb than in pp collisions

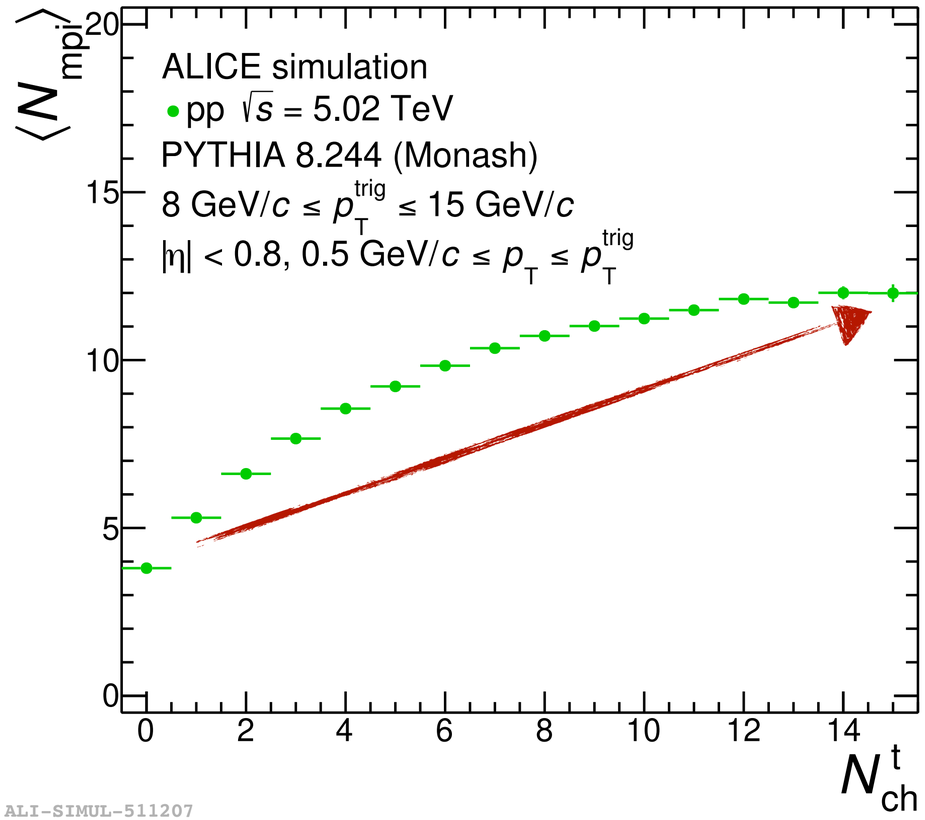
- PYTHIA 8 shows the opposite behaviour. However, EPOS LHC shows the same shape as the data, and the effect could be attributed to larger flow in p-Pb relative to pp collisions

UE as a function of multiplicity in the transverse region, N_{ch}^{t}

Event properties as a function of N_{ch}^{t}

multiplicity in the transverse region





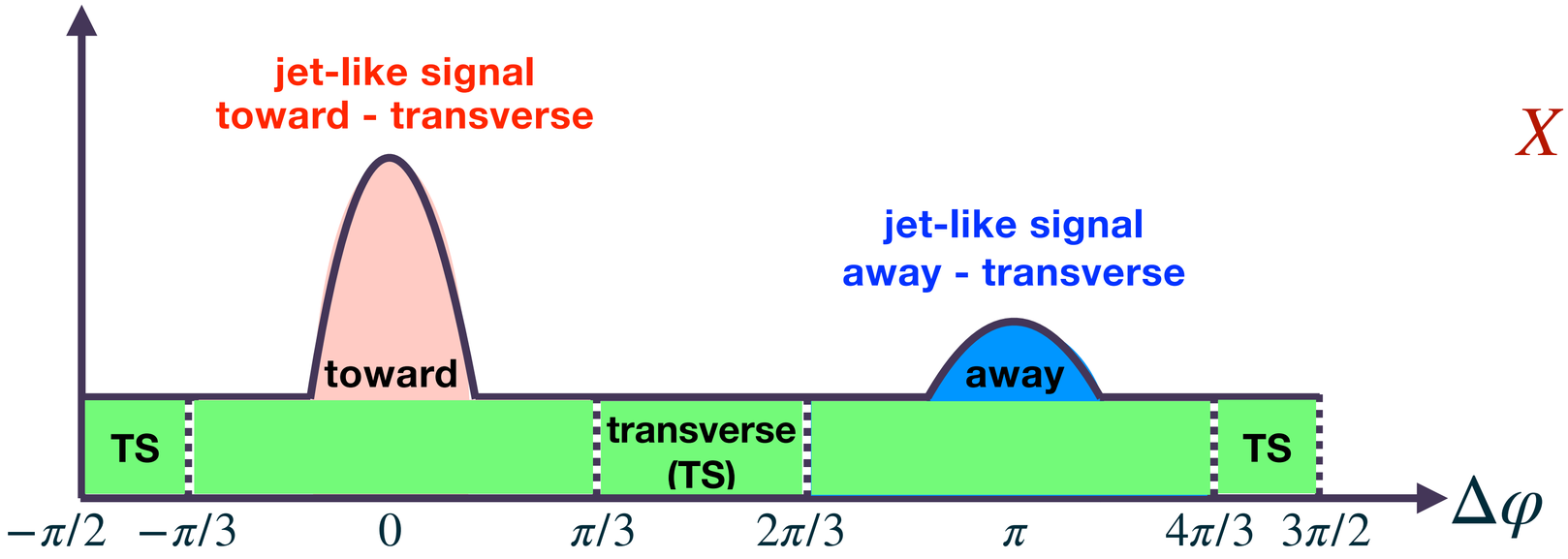
- $\langle p_{\mathrm{T}}^{\mathrm{trig}} \rangle$ is independent of N_{ch}^{t}, but $\langle N_{\mathrm{mpi}} \rangle$ in PYTHIA drastically increases with increasing $N_{\mathrm{ch}}^{\mathrm{t}}$
- We can study the jet-like signals as a function of $N_{\mathrm{ch}}^{\mathrm{t}}$ in order to search for any jet-like modification in events with large UE

Jet-like modifications

The high-p_{T} yields (4-6 GeV/c) as a function of the activity in the V0 detector were normalised to same quantity measured in minimum-bias pp collisions:

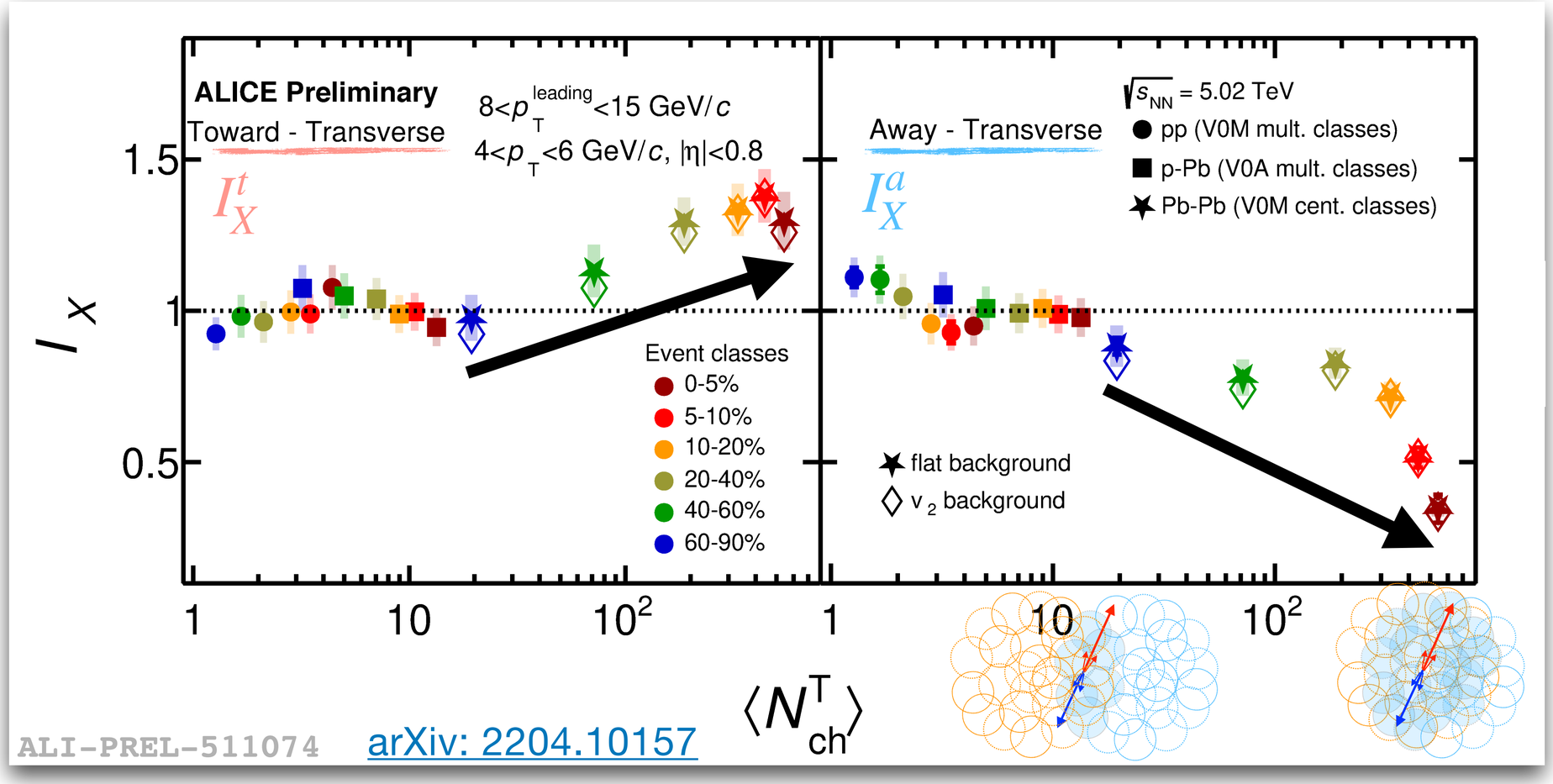
$$I_X = \frac{\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}p_{\mathrm{T}}^{\text{jet-like signal in } X}}{\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}p_{\mathrm{T}}^{\text{jet-like signal in MB pp}}}$$

X : multiplicity classes in pp, p-Pb and Pb-Pb collisions



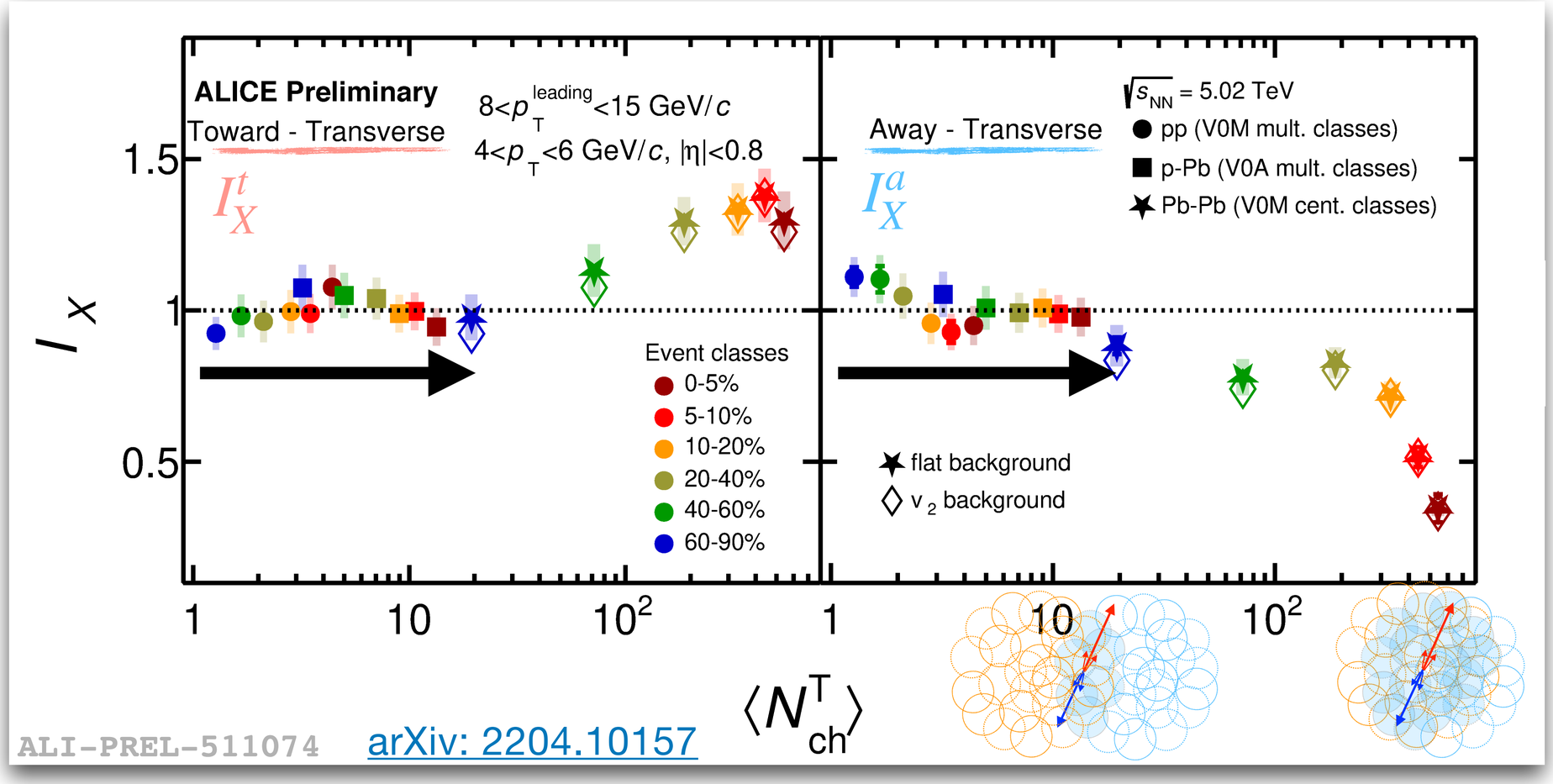
The toward and away regions are not only dominated by particle production from the hard process but also from the UE

pp, p-A, and A-A relative to MB pp



Pb-Pb: in toward (away) there is a enhancement (suppression) with increasing event activity, similar results were obtained for Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV ALICE, PRL 108 (2012) 092301

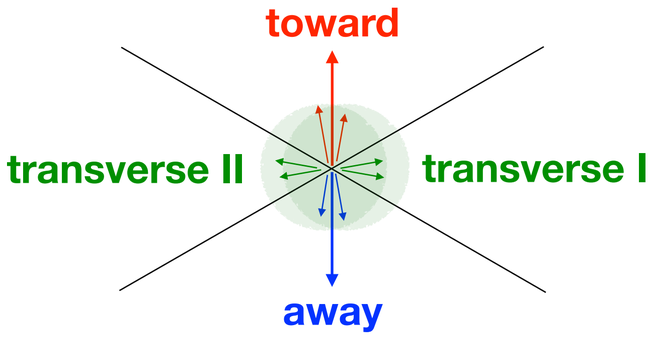
pp, p-A, and A-A relative to MB pp



Absence of jet-like modifications in **pp** and **p-Pb** collisions as a function of the activity in the forward region (V0 detector)

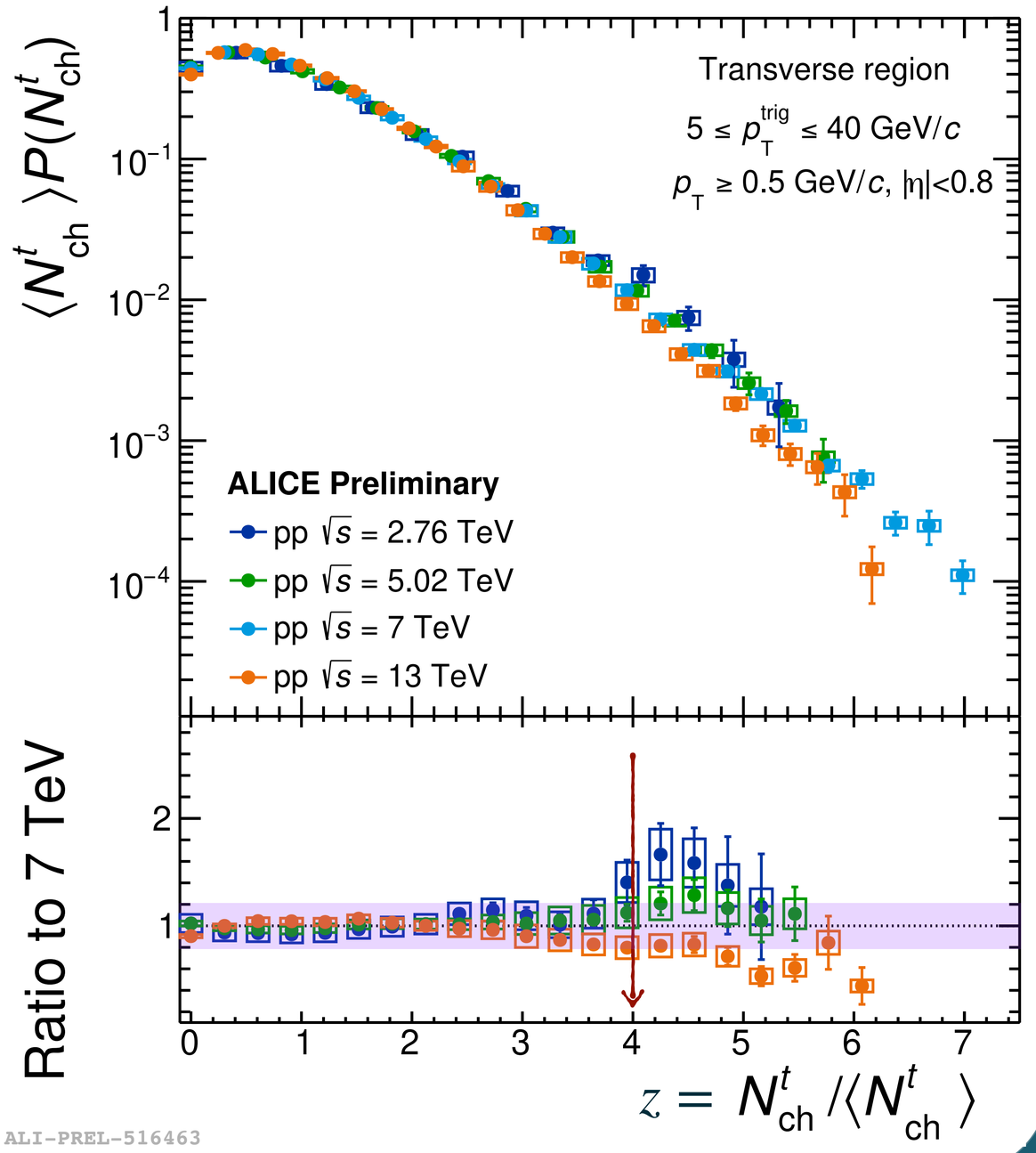
KNO-like scaling

trans-max (trans-min) refers to the sub-transverse region (I or II) with the largest (smallest) number of charged particles



Transverse region

- The KNO-like scaling holds for $0 < z < 4$
- MPI can explain the scaling, which suggests a single pp collision results from the superposition of a given number of elementary partonic collisions emitting independently



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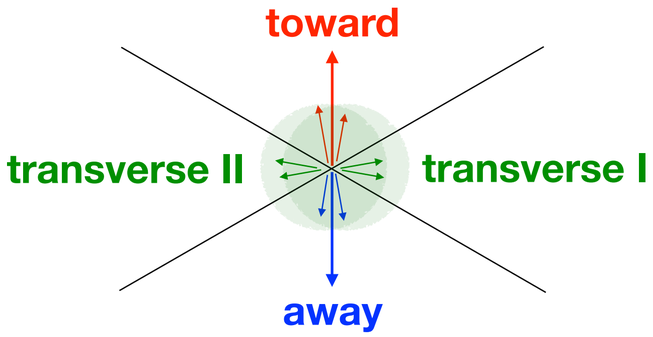
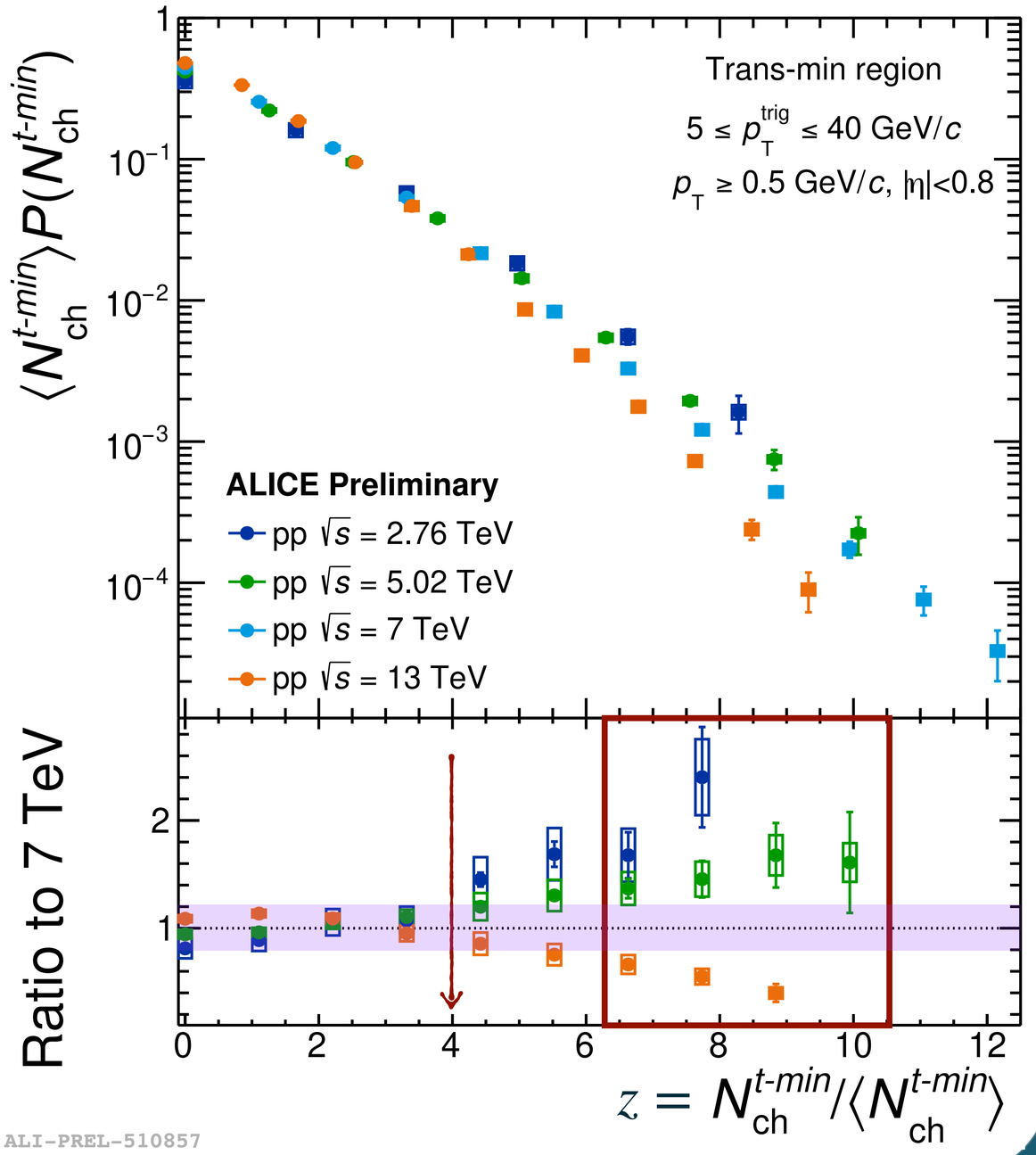


Trans-min region

- The KNO-like scaling also holds for $0 < z < 4$, and a better agreement is seen
- A higher z reach is achieved, especially for $z > 6$, there is a larger deviation which may be attributed to high multiplicity mini-jets



Conclusion

UE characteristics:

- Data suggests the same UE structure in pp and p-Pb collisions. The saturation effect, in the transverse region, comes from the initial stage, which can be corroborated by the correlation between $p_{\mathrm{T}}^{trig}(|\eta| < 0.8)$ and very forward energy ($|\eta| > 8.8$)
- KNO-like scaling holds for $0 < z < 4$ and it is broken above 4. However in the trans-min region for $z > 6$, a larger violation of the KNO scaling is observed, maybe due to high multiplicity mini-jets

Jet-like modifications:

- For $p_{\mathrm{T}}^{\mathrm{trig}} < 10$ GeV/c, the activity in jet-like signals is larger in p-Pb than in pp collisions, presumably due to flow.
- The I_X values, as a function of $\langle N_{\mathrm{ch}} \rangle$ in V0, suggest the absence of jet-like modifications in pp and p-Pb collisions. In contrast, for Pb-Pb data jet quenching effects are observed

Backup

Data analysis

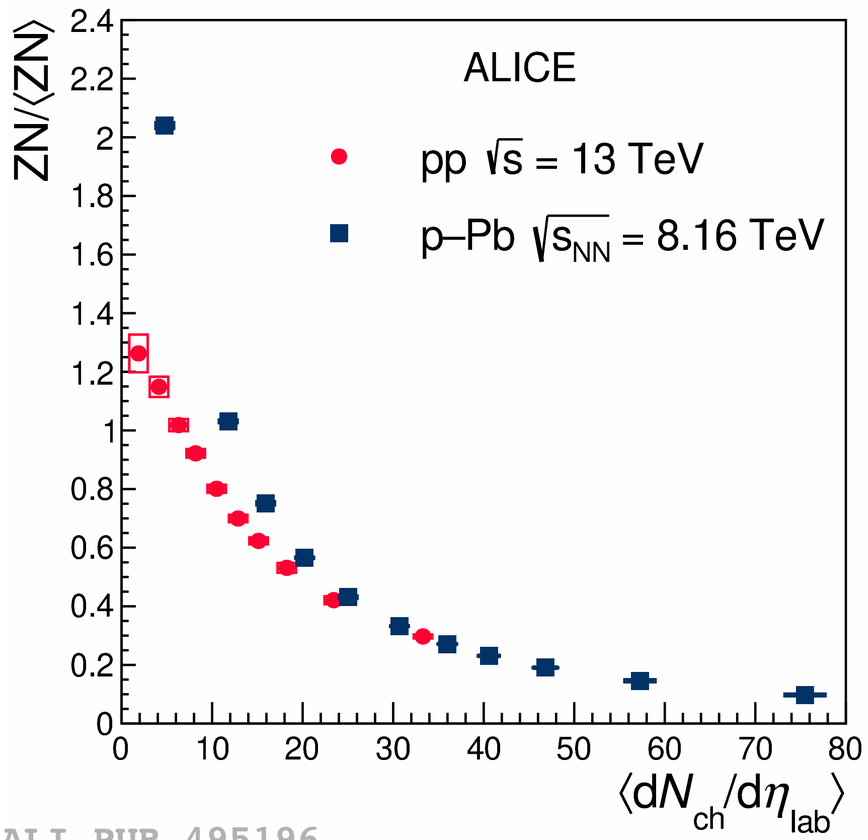
The p_{T} spectra as a function of either $p_{\mathrm{T}}^{\mathrm{trig}}$ or the particle multiplicity registered in the V0 detector are corrected for detector effects, the relevant corrections are:

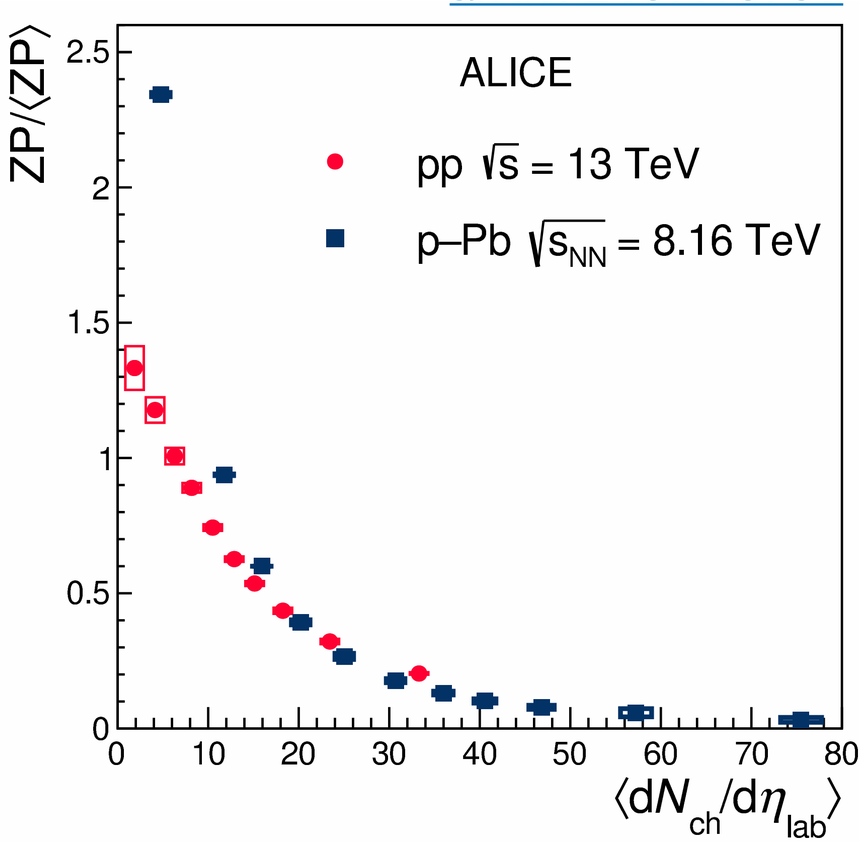
- Tracking efficiency: this correction considers the real particle composition measured at the LHC energies
- Contamination from secondary particles: this correction is estimated using a multi-template model which is fitted to the distance-of-closest approach distributions measured in data
- For the UE analysis a correction which takes into account the leading track misidentification is implemented. This correction is relevant for $p_{\mathrm{T}}^{\mathrm{trig}} < 5$ GeV/c

In addition, for the transverse momentum spectra in the toward, away, and transverse regions, as a function of the charged particle multiplicity in the transverse region (N_{ch}^{t}), a Bayesian unfolding technique is implemented in order to correct for the N_{ch}^{t} selection

ZN and ZP signals: pp vs p-Pb

arXiv: 2107.10757





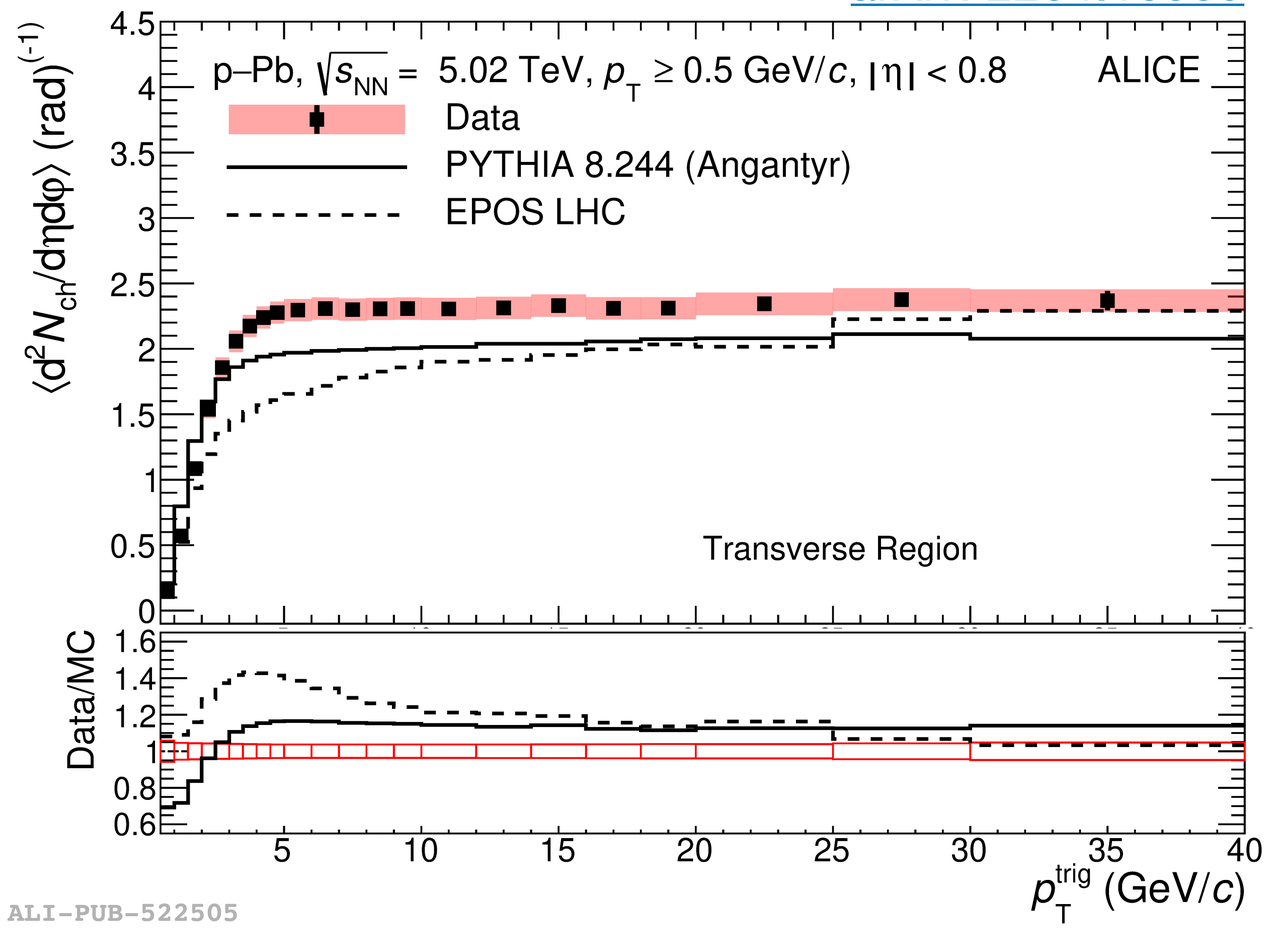
The self-normalised forward energy decreases with increasing charged-particle multiplicity at midrapidity, both in pp and in p-Pb collisions with the same proton beam energy.

UE in p-Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV

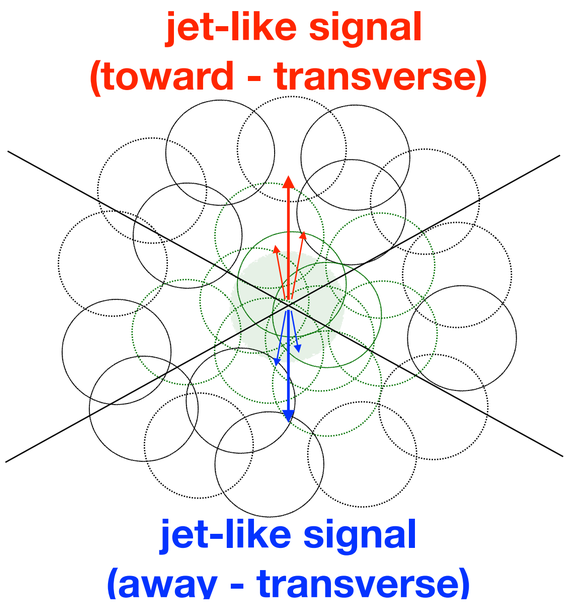
Data suggest the same UE structure in pp and p-Pb collisions

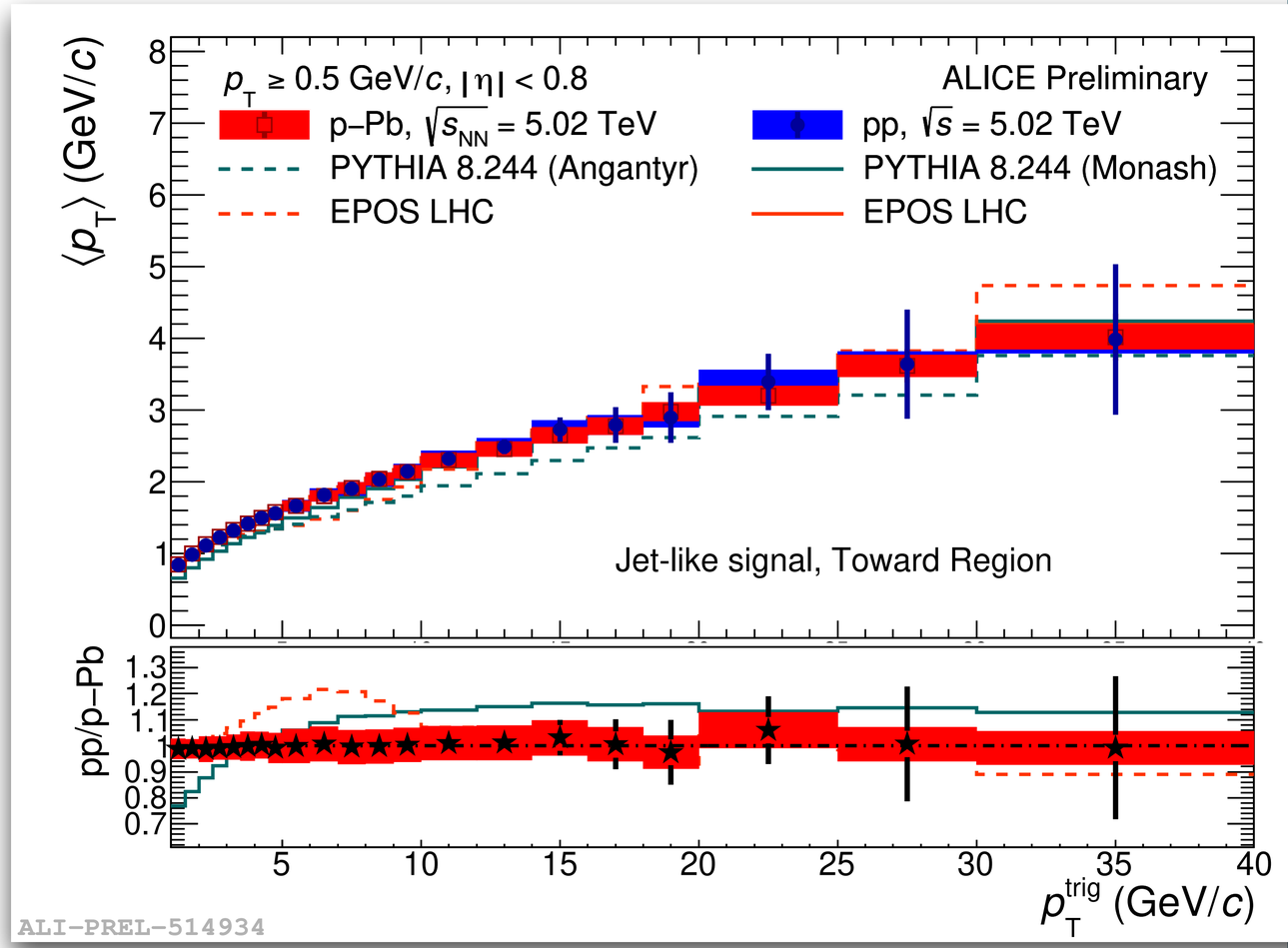
- This picture is supported by PYTHIA 8 (Angantyr) C. Bierlich et al., JHEP 10 (2018) 134
- EPOS LHC does not reproduce the saturation

arXiv: 2204.10389



Jet-like signals: pp vs p-Pb



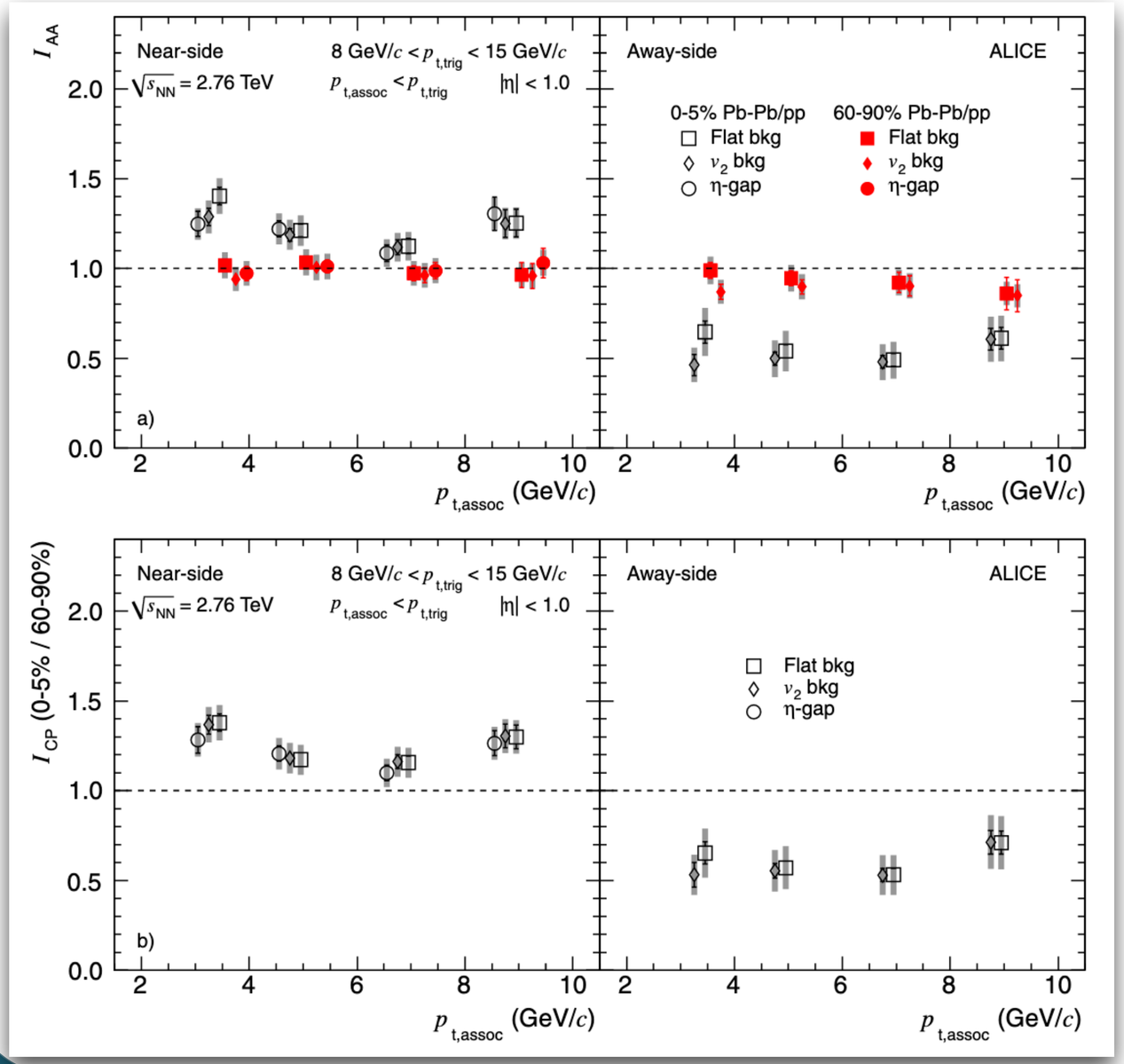


Within uncertainties, the average transverse momentum is the same in pp and p-Pb collisions within the full $p_{\mathrm{T}}^{\mathrm{trig}}$ interval

- Within 20% PYTHIA 8/Angantyr and EPOS LHC describe the data
- A similar behaviour is seen in both the toward and away regions

arXiv: 2204.10389

I_{AA} in Pb-Pb at $\sqrt{s} = 2.76$ TeV

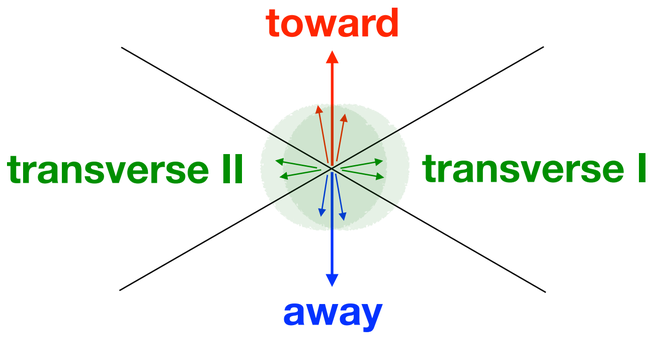


If the fragmentation function is softened in the medium, hadrons carry a smaller fraction of the initial parton momentum in Pb-Pb collisions as compared to pp collisions. Therefore, hadrons with a given p_{T} originate from a larger average parton momentum which may lead to more associated particles and $I_{\mathrm{AA}} > 1$

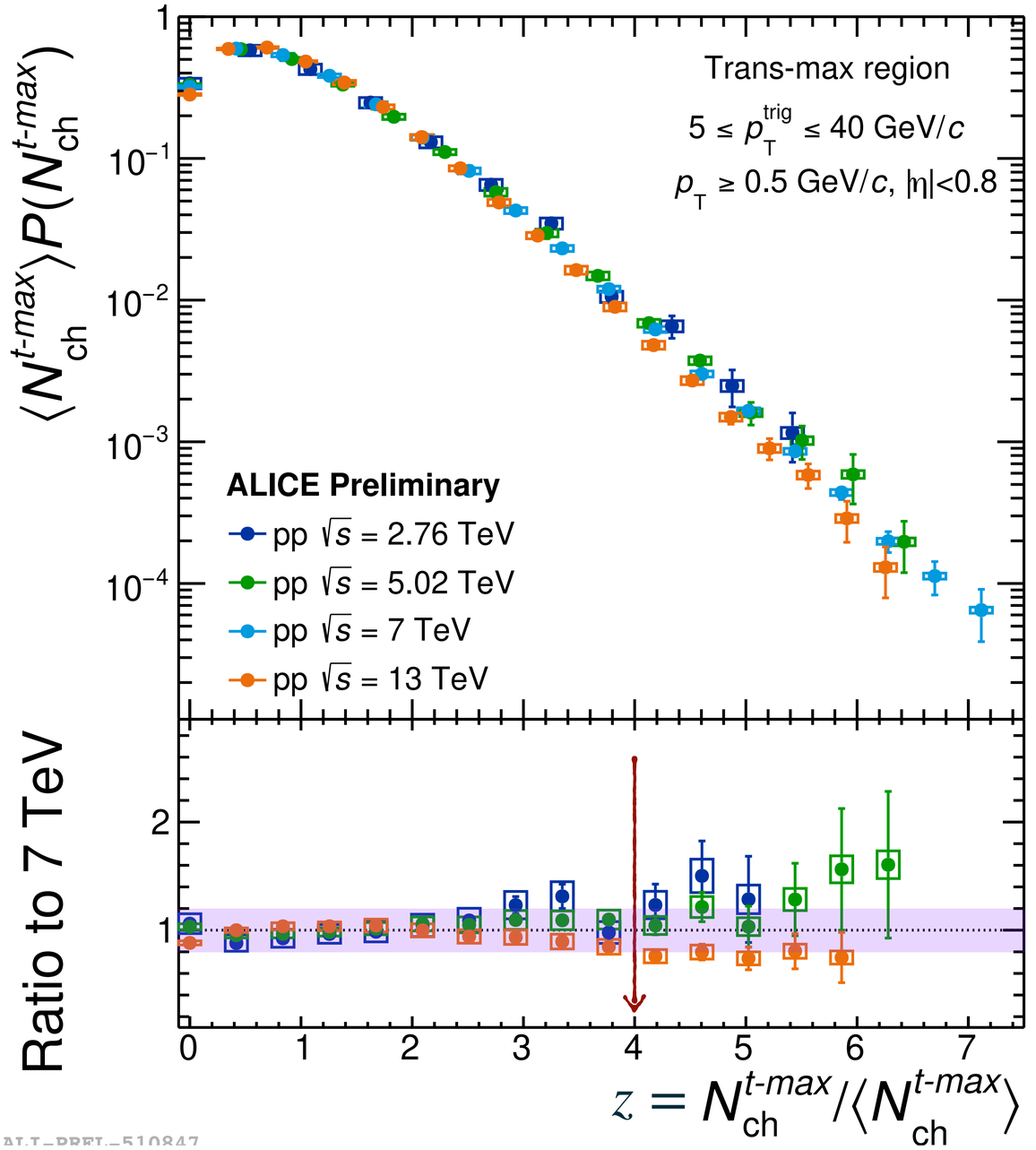
ALICE, PRL 108 (2012) 092301

KNO-like scaling

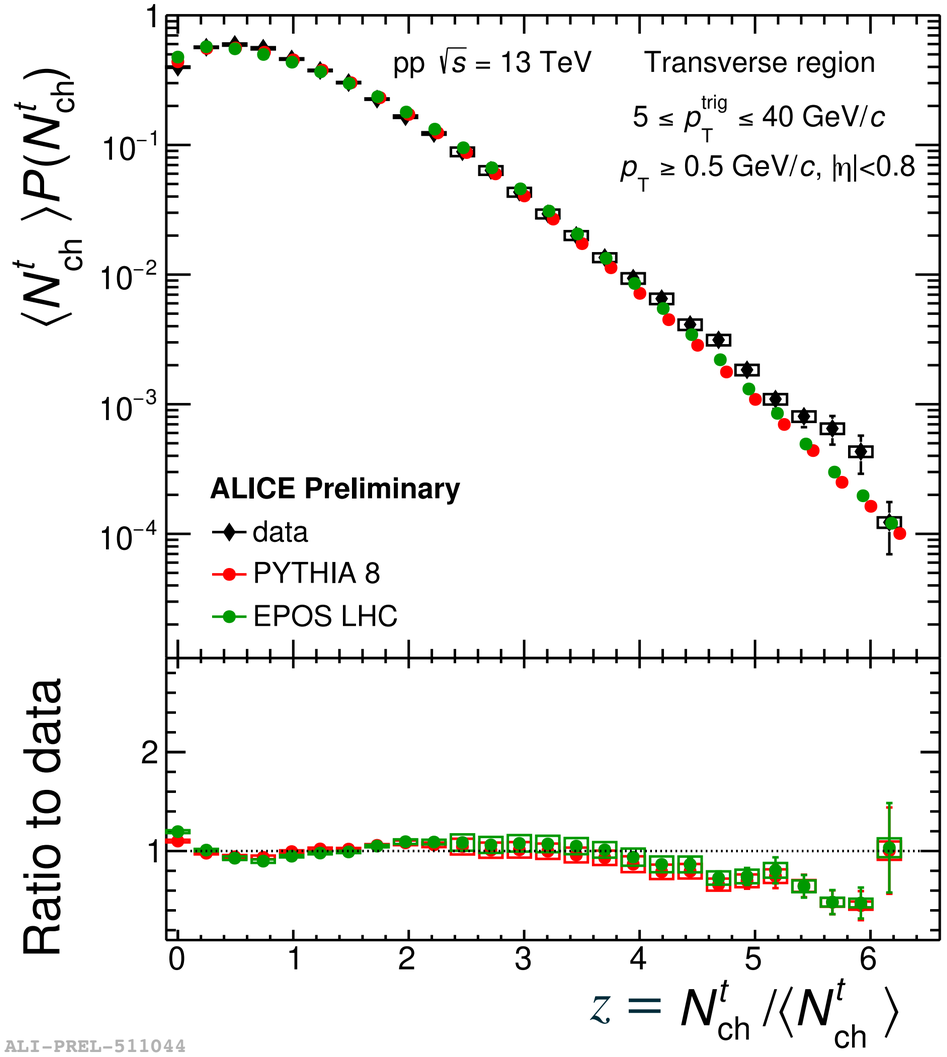
trans-max (trans-min) refers to the sub-transverse region (I or II) with the largest (smallest) number of charged particles



- In the trans-max region the KNO-like scaling holds for $0 < z < 4$, and it is broken for $z > 4$



KNO-like scaling



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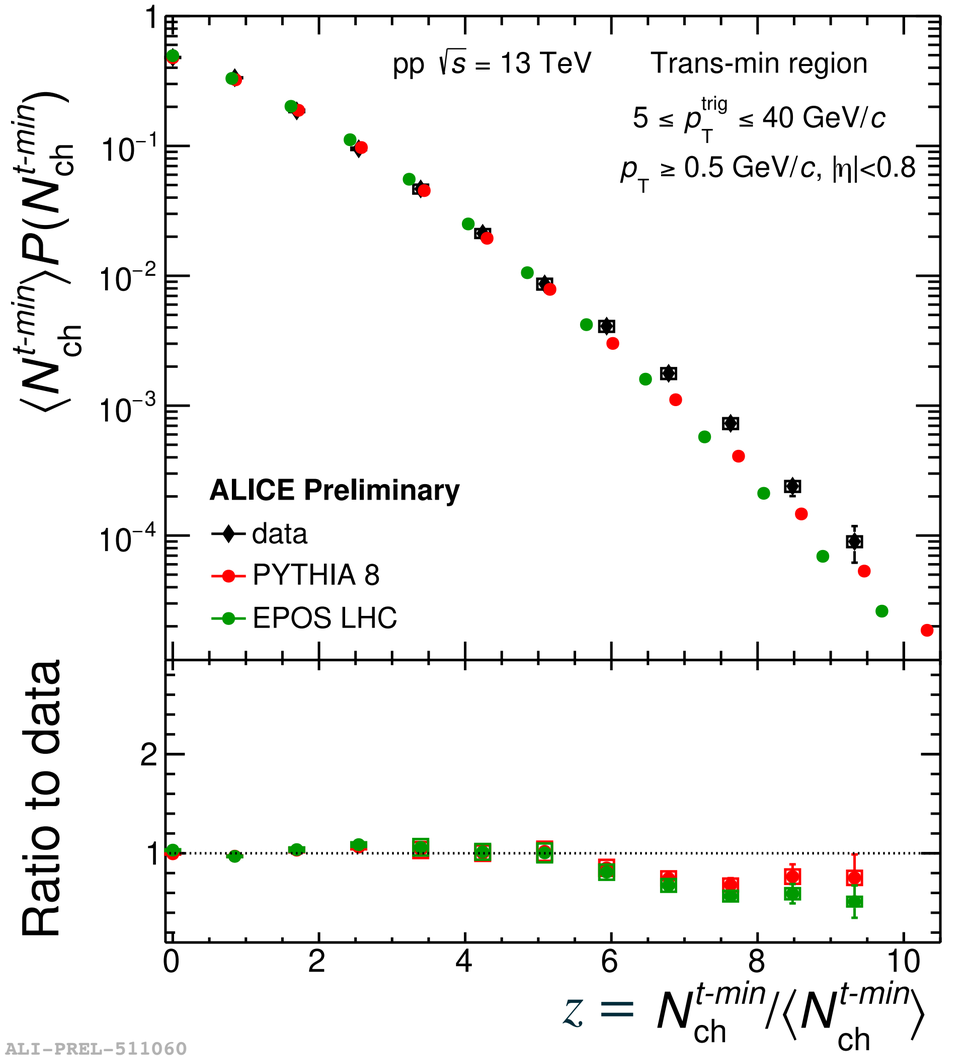


ALI-PREL-511060

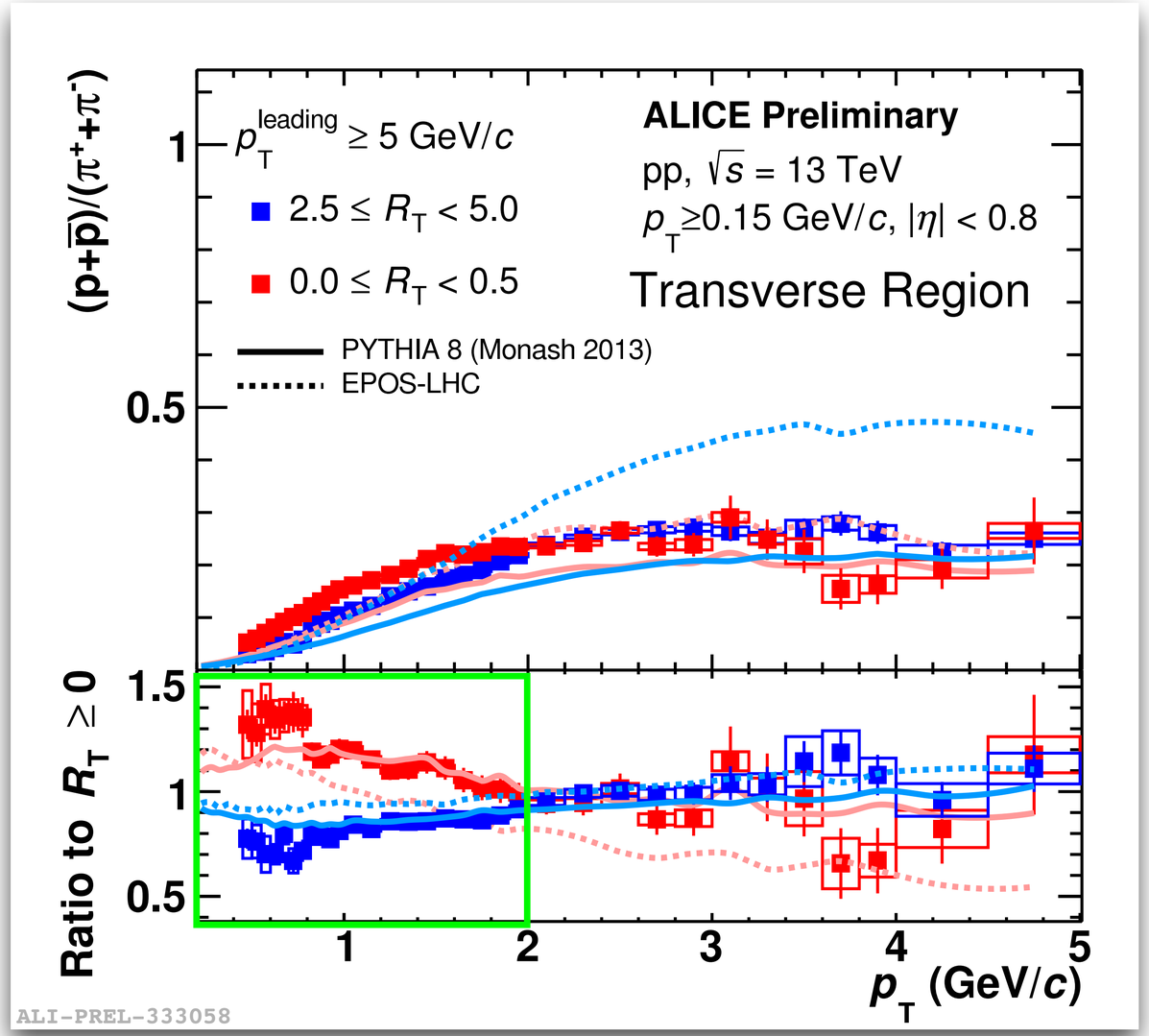
- In the transverse region, a similar behavior was reported in pp collisions at $\sqrt{s} = 13$ TeV

- PYTHIA 8 and EPOS LHC reproduce the distribution at low values of z, and for higher z values they underestimate data

p/π ratio as a function of R_T

self-normalised N_{ch}^{t}:

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



No UE activity ($R_T \to 0$)

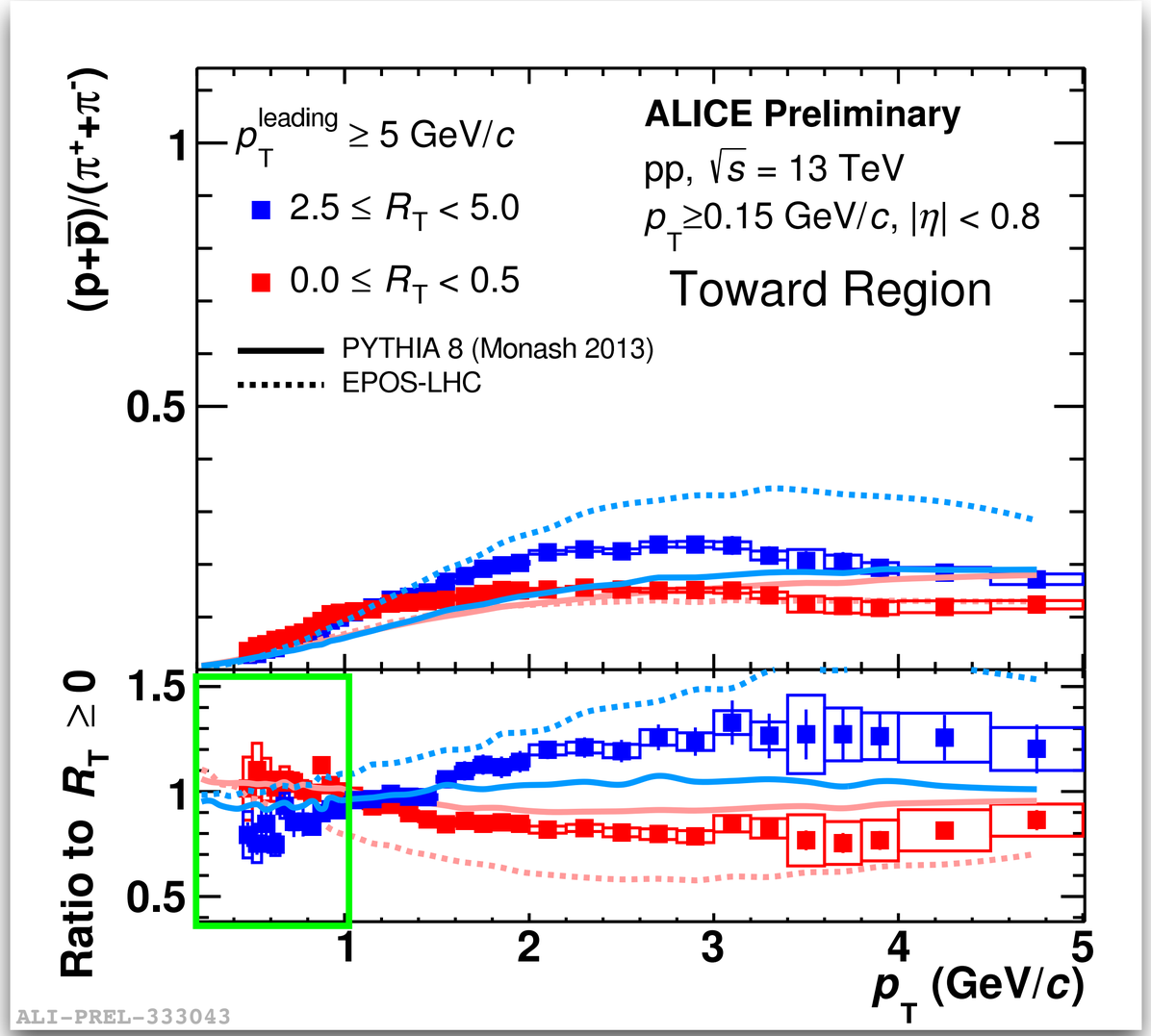
High UE activity (high R_T)

Transverse region

- $p_T < 2$ GeV/c: the ratio exhibits a depletion going from low to high R_T
- $p_T > 2$ GeV/c: the particle ratios are almost R_T independent

- Qualitatively, PYTHIA 8 reproduces the behaviour of the data

p/π ratio as a function of R_T



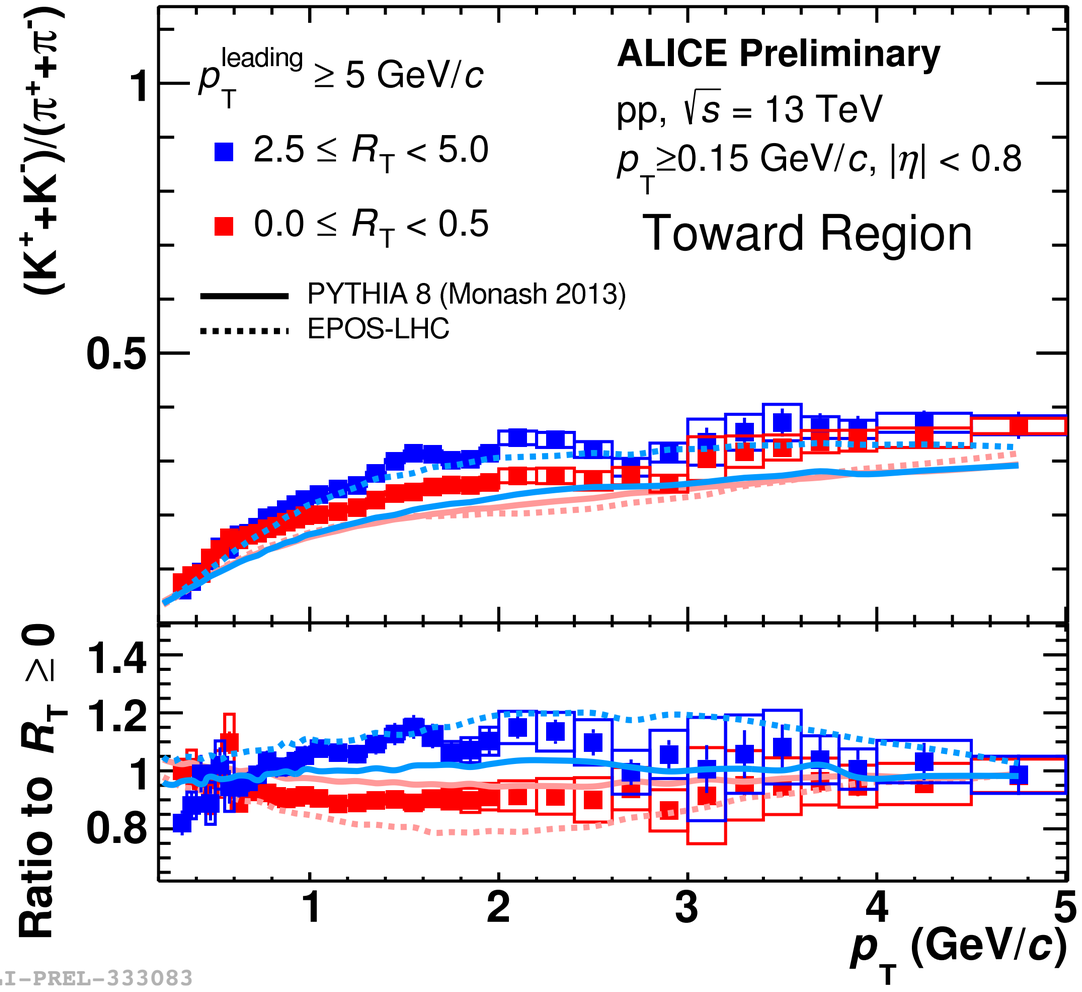
No UE activity ($R_T \to 0$)

High UE activity (high R_T)

Toward region

- Low p_T: the ratio exhibits a depletion going from low to high R_T
- Intermediate p_T: the ratio exhibits an enhancement going from low to high R_T
- Qualitatively, both PYTHIA 8 and EPOS LHC reproduce the behaviour of the data

Particle ratio as a function of R_T



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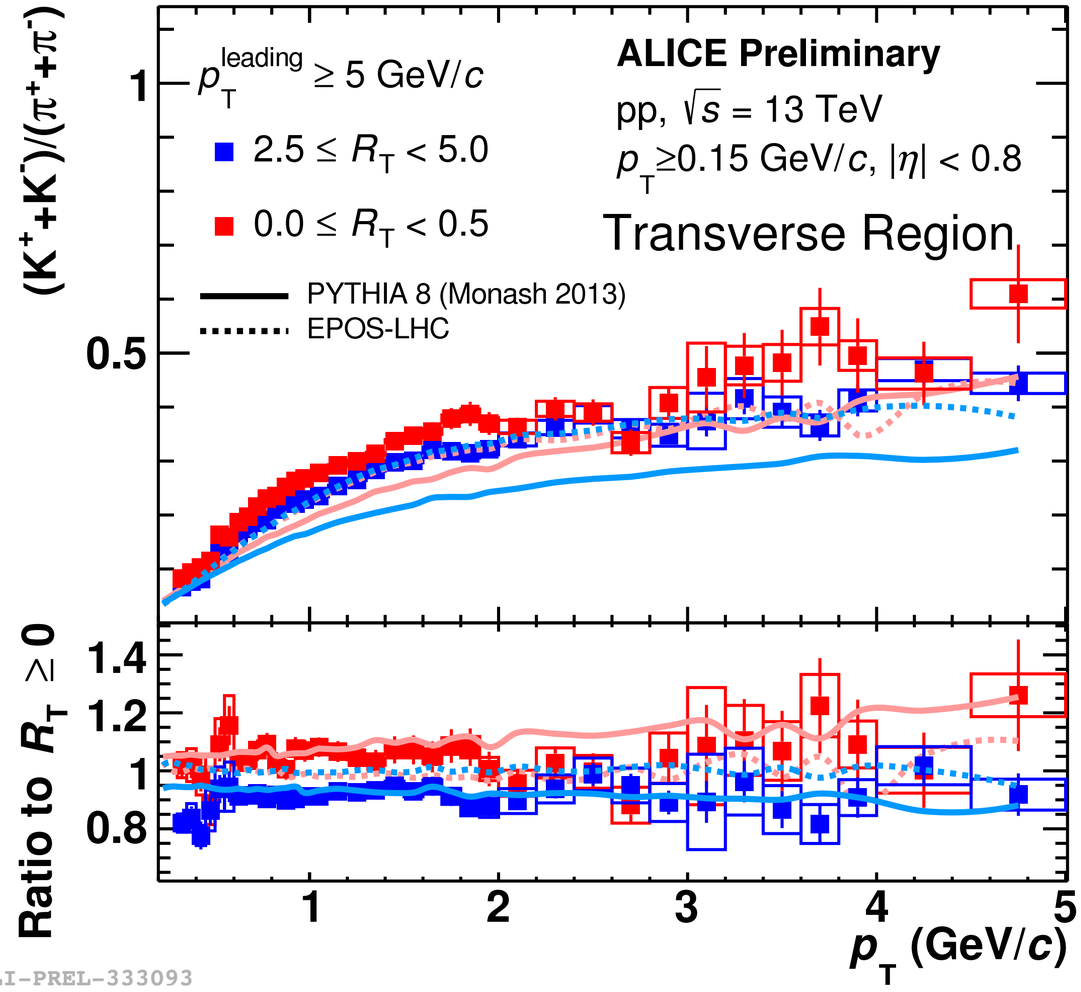

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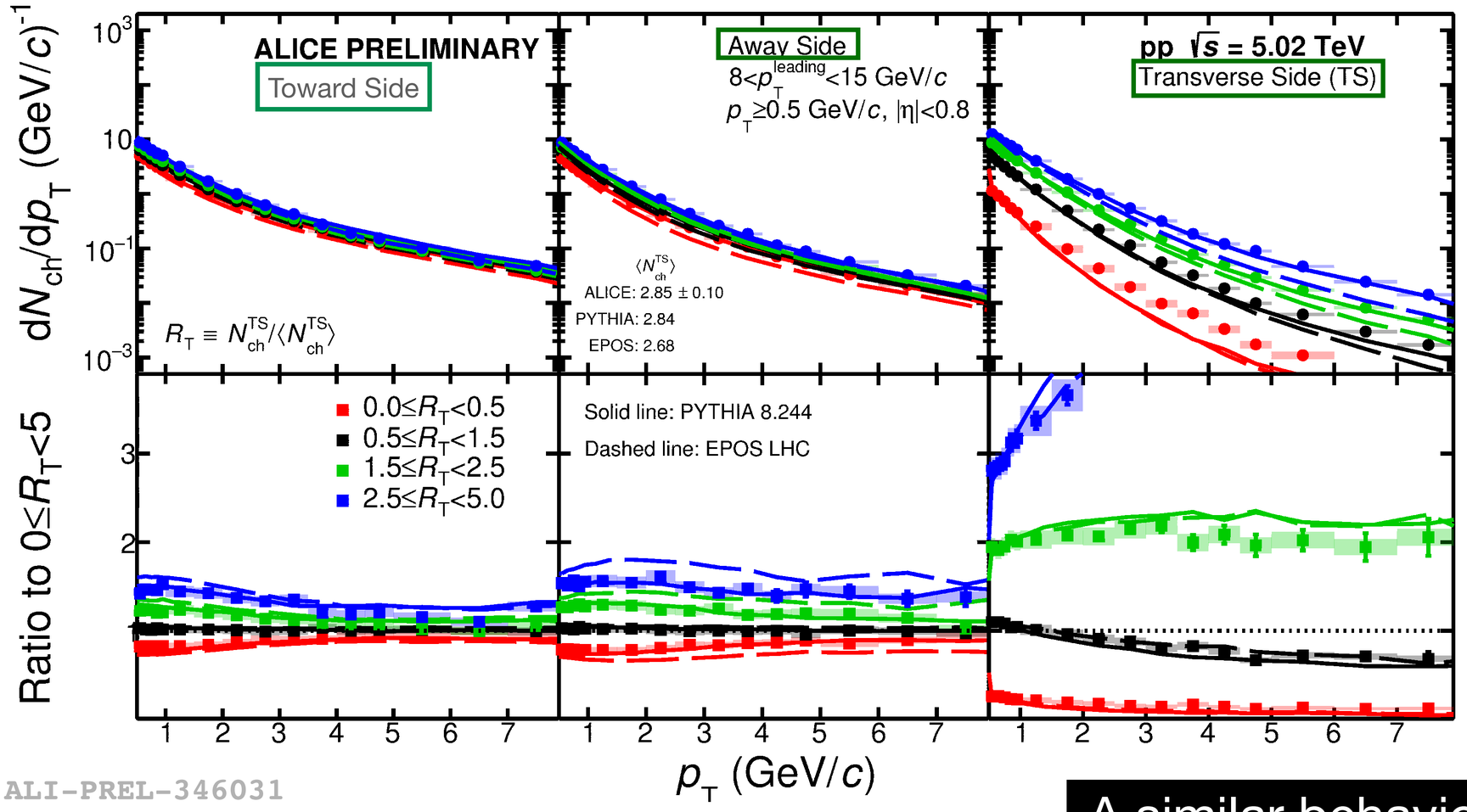
p_T spectra as a function R_T (pp)



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$p_T > 4$ GeV/c:

- For the toward and away regions, the yields approach to the values measured for the R_T -integrated case. This behaviour is reproduced by MC generators. **This suggests the absence of jet-like modifications**

A similar behaviour is found for p-Pb collisions

- For the transverse region, the high-p_T yield exhibits a fast increase with increasing R_T due to the selection bias. The effect is reproduced by MC generators