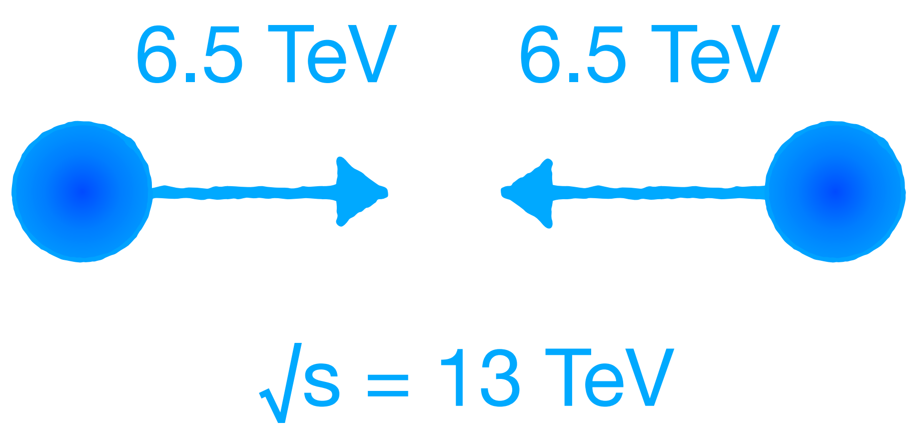
Shedding light on pp and p-Pb collisions through forward energy detection

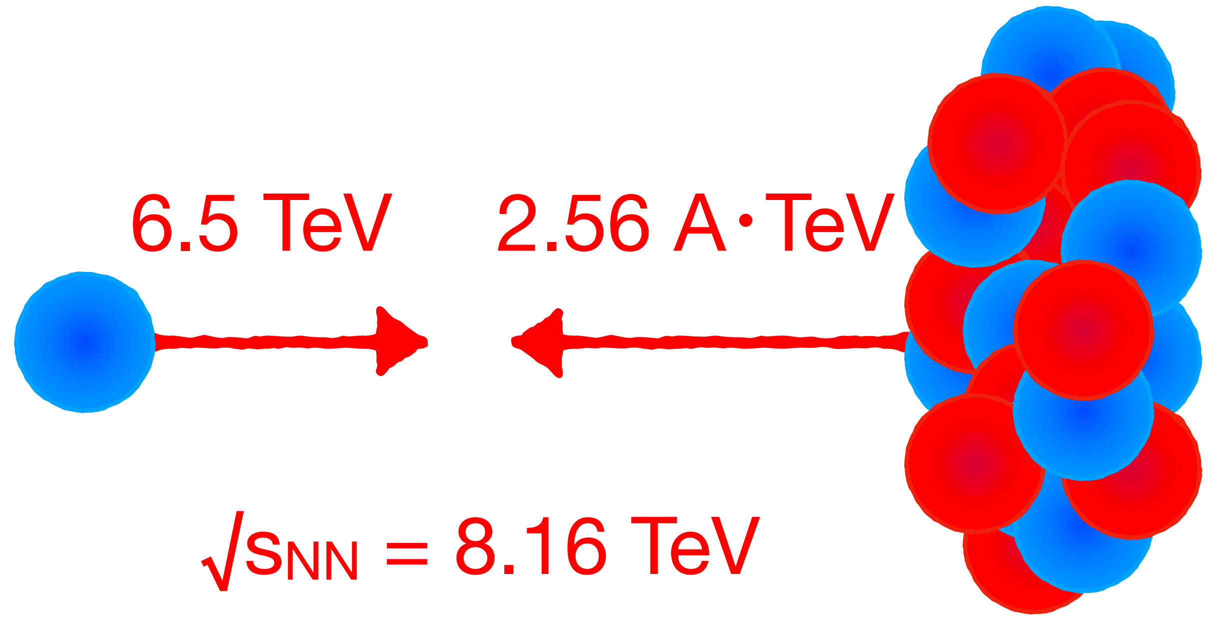
Chiara Oppedisano
INFN Torino

pp and p-Pb collisions at LHC

pp collisions



p-Pb collisions



Collective behaviour and strangeness enhancement in pp and in p-Pb collisions at LHC energies
➧ increasing interest in small collision systems

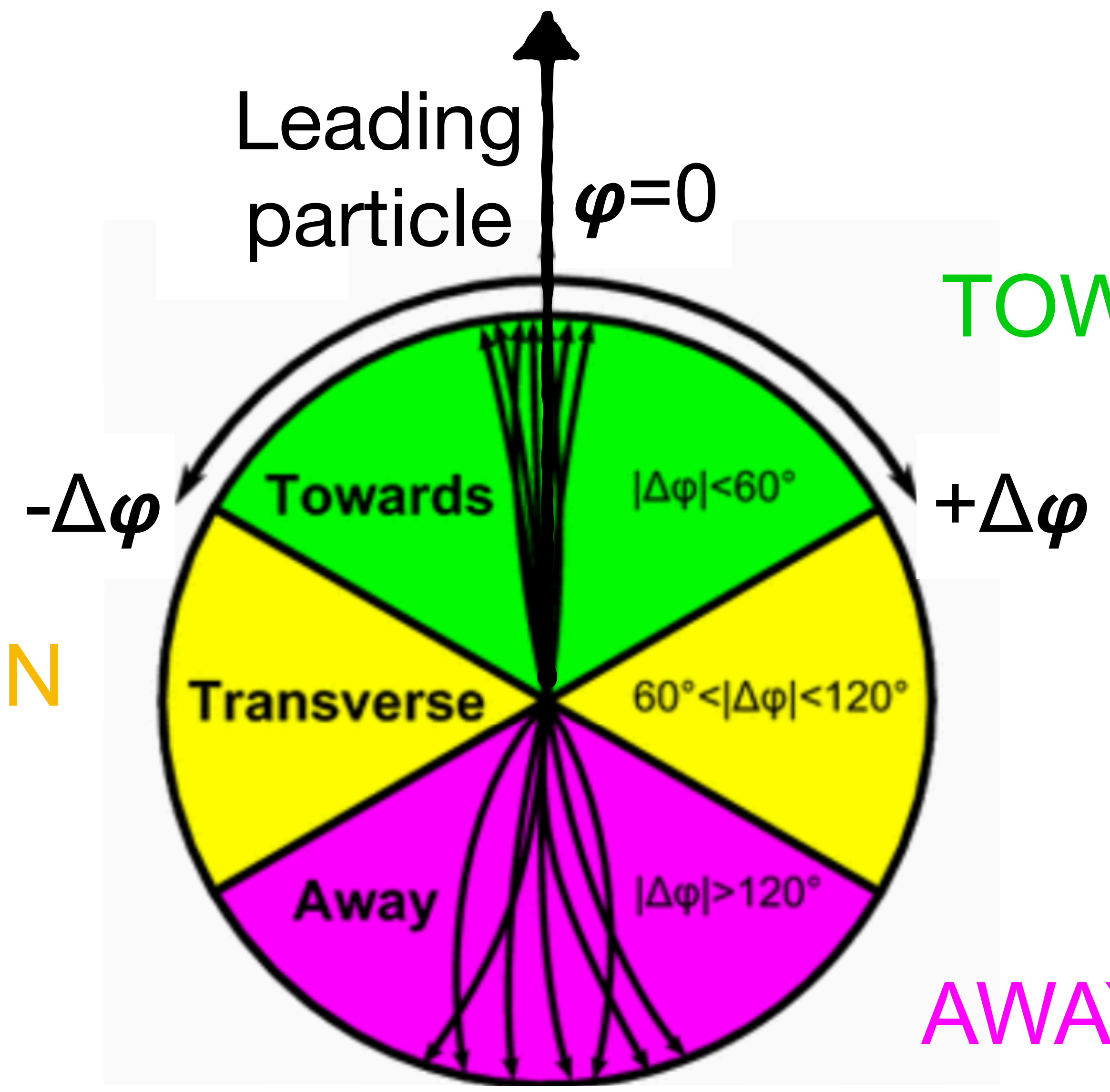
➧ bulk properties studied as function of final state charged-particle multiplicity measured at midrapidity

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

➧ opportunity to study what happens to the proton in the interaction with a proton and with a Pb nucleus

Underlying Event (UE)

At midrapidity particle production in presence of a leading particle (hard scattering) can be studied in 3 different topological regions:



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

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

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

Underlying Event (UE)

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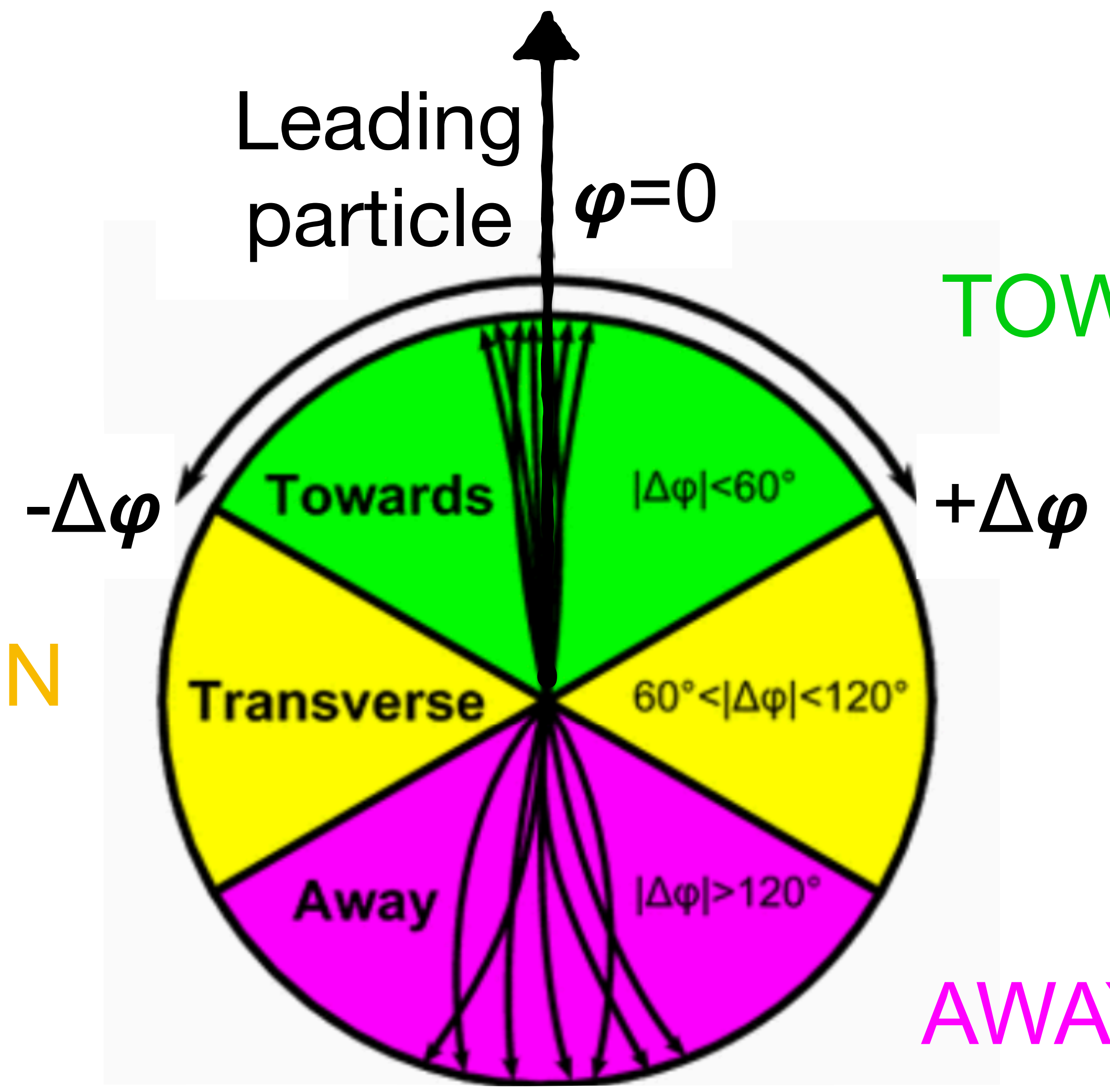


TOWARDS REGION

($|\Delta\varphi|<60°$)

TRANSVERSE REGION

($60°<|\Delta\varphi|<120°$)

AWAY REGION

($|\Delta\varphi|>120°$)

Fragmentation products from parton hard scattering

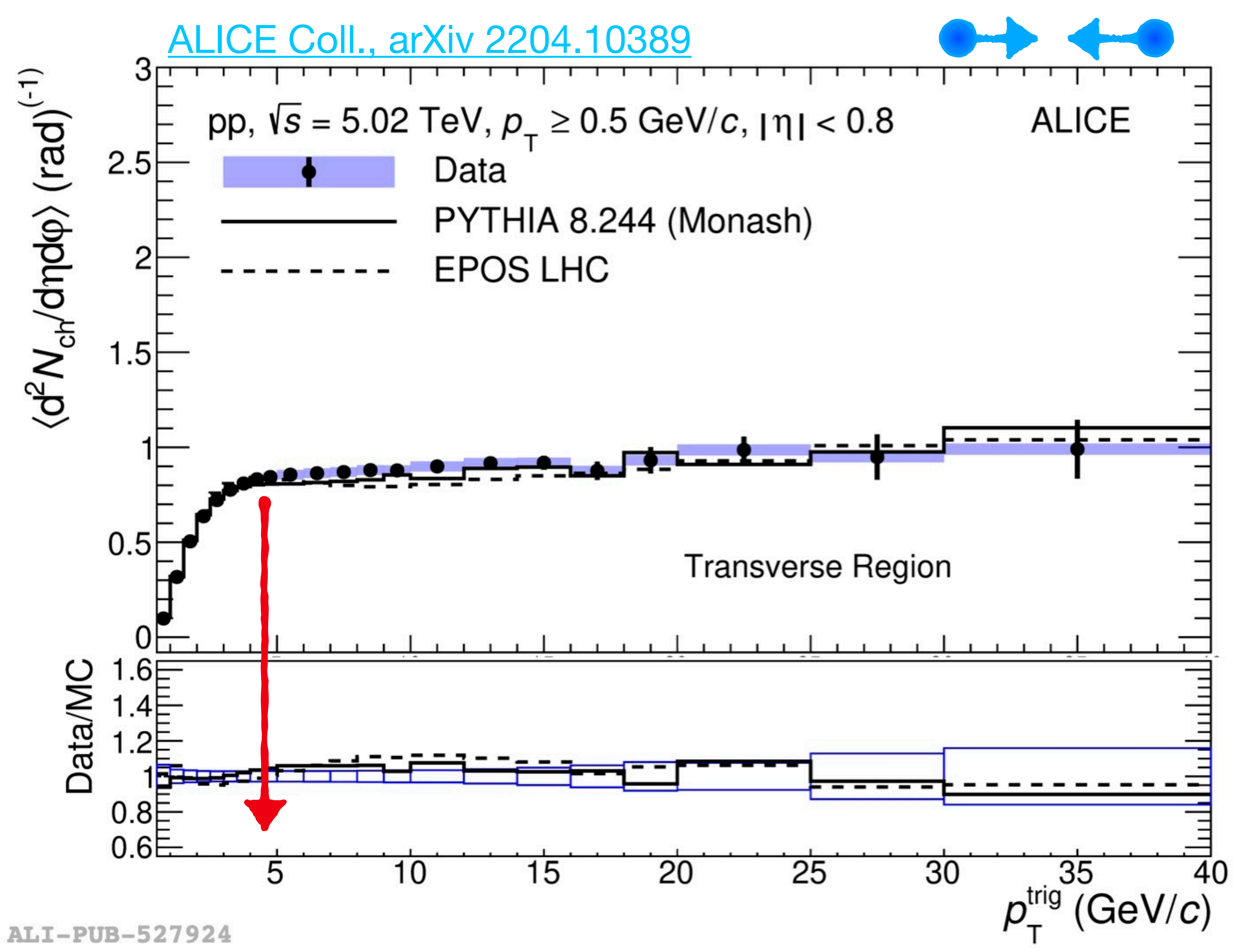
Particle production NOT originating from primary hard scattering: UE, MPIs, ISR/FSR, beam remnants

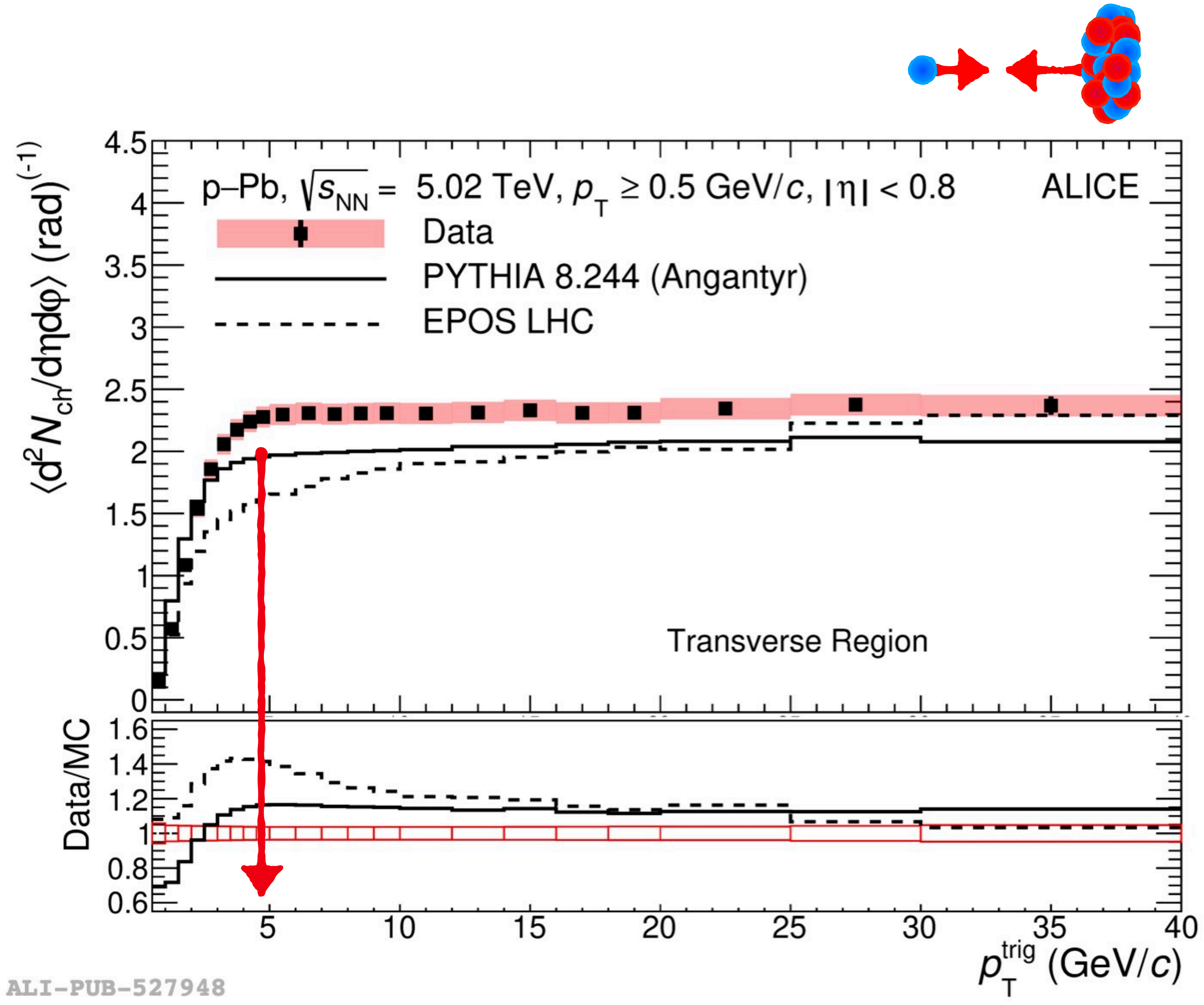
- the transverse region is the ideal place to study particle production mechanisms “outside” the jet
- multiplicity in the transverse region is largely independent on leading particle p_T when the trigger particle originates from a hard partonic scattering

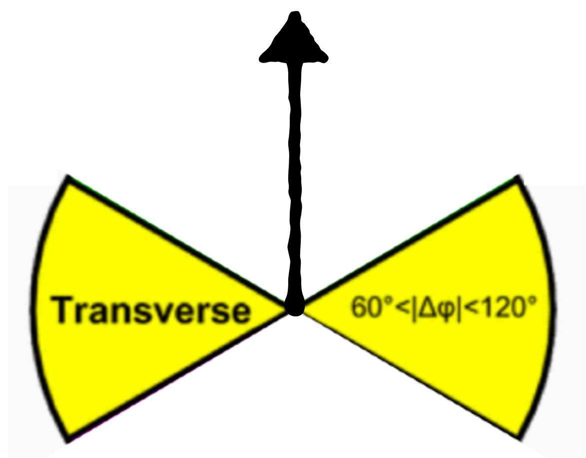
Underlying Event (UE)

ALICE characterized the UE in pp and in p-Pb collisions at √s = 5.02 TeV

ALICE Coll., arXiv 2204.10389





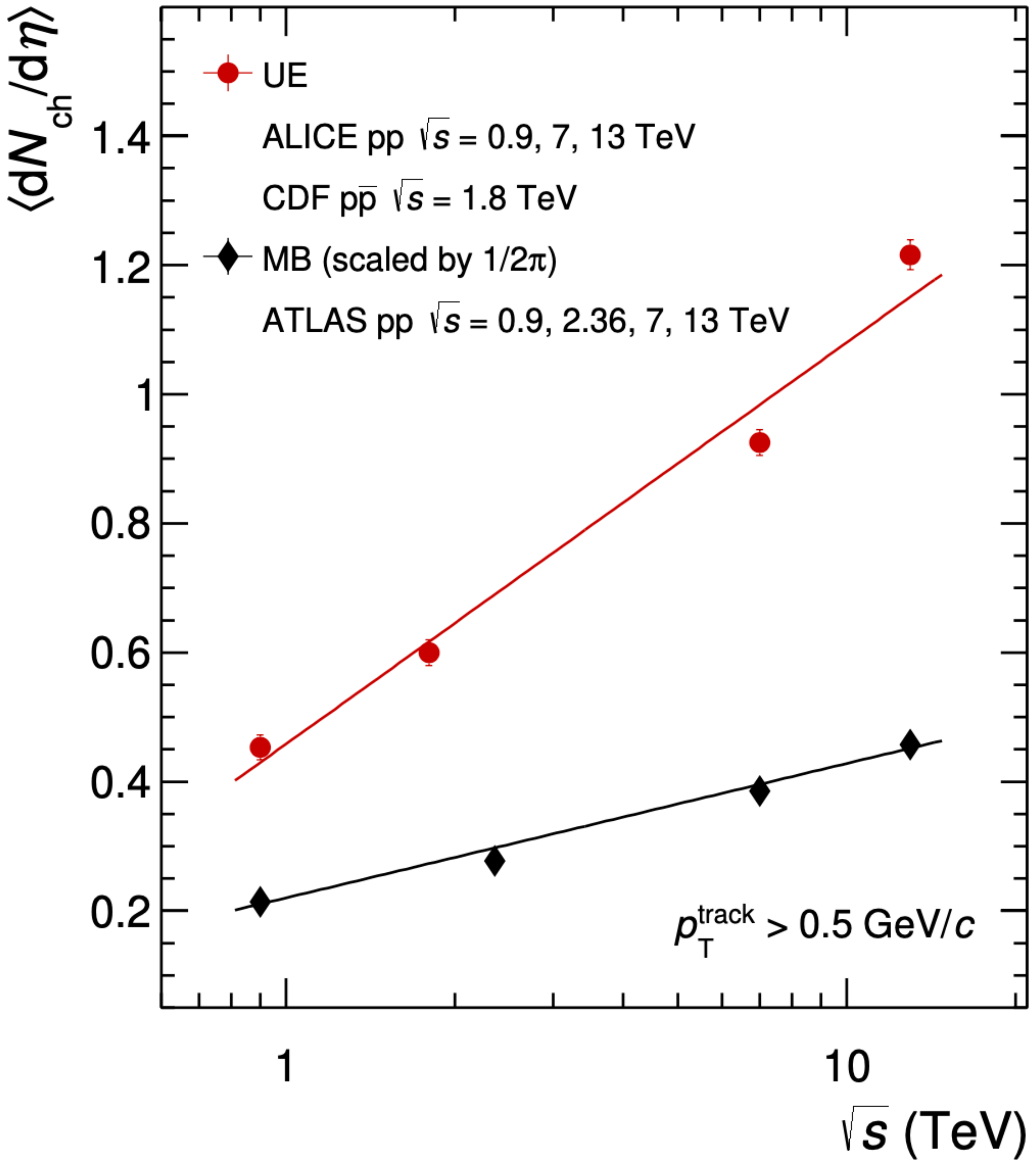


- saturation in particle production in the transverse region observed also in p-Pb collisions,
- saturation occurs nearly at the same leading particle p_T scale ($p_T^{leading}$ ~ 5 GeV/c) in pp and p-Pb collisions

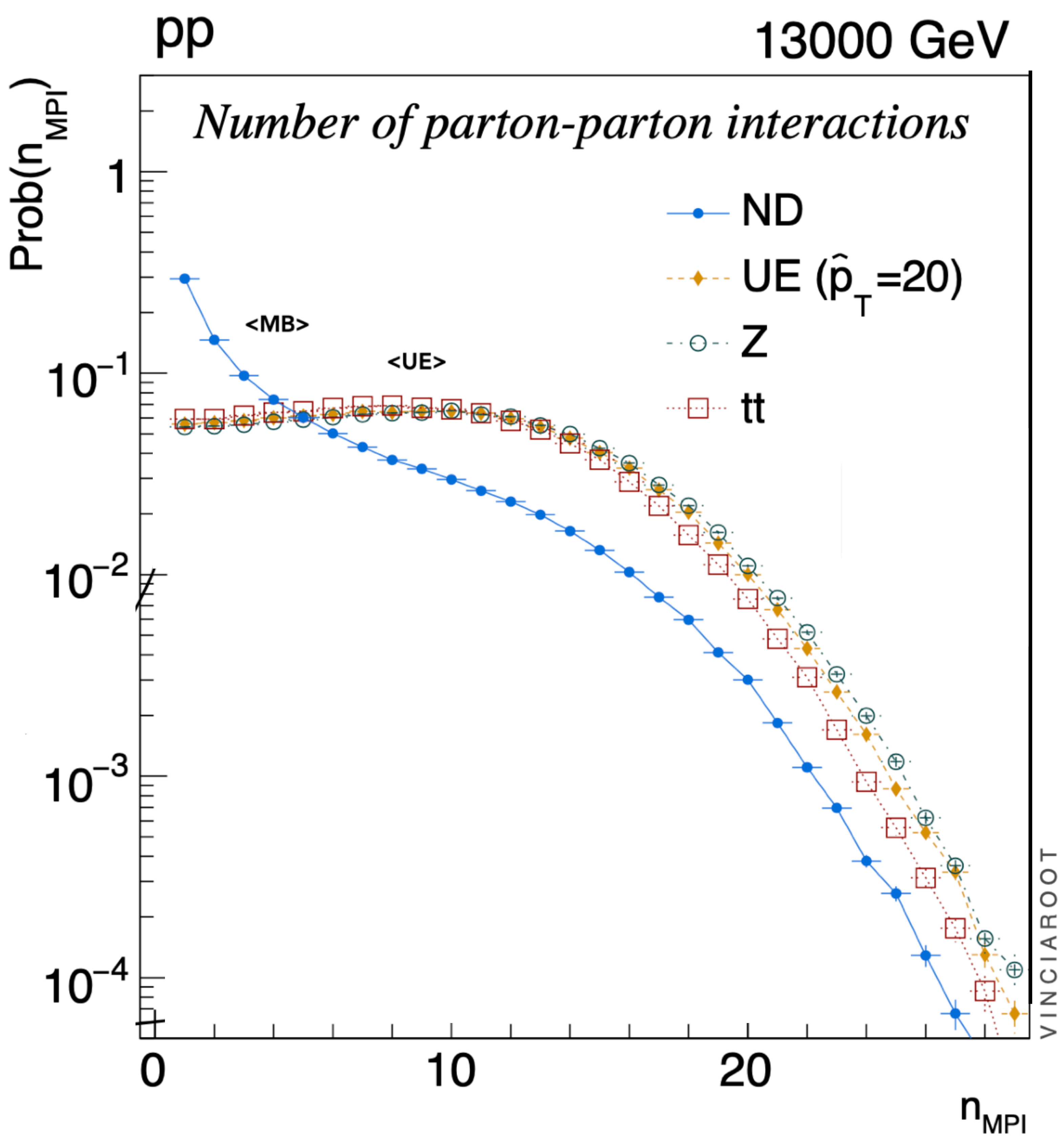
UE and MPIs

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

ALICE Coll., JHEP 04 (2020) 192



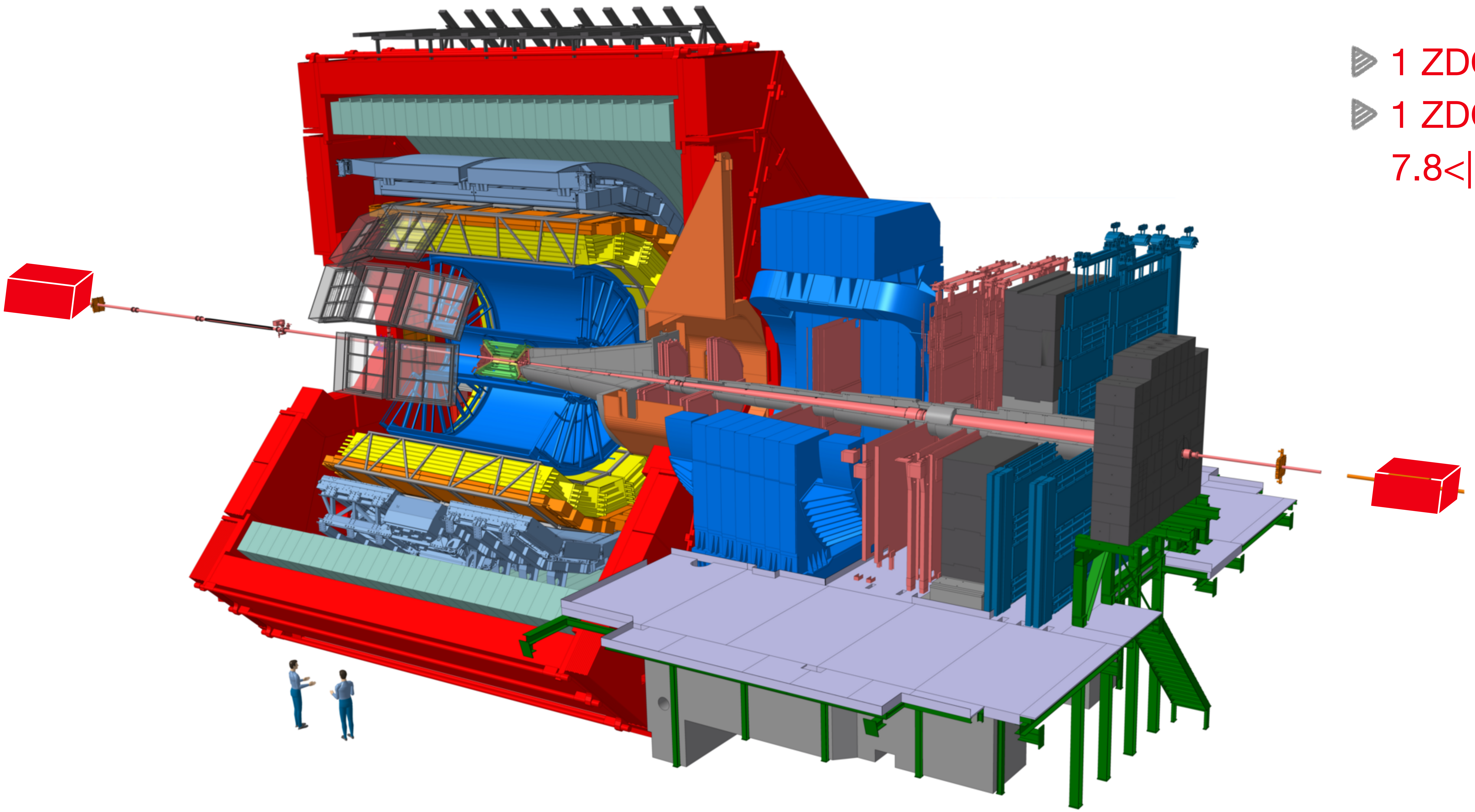
T. Martin et al., Eur. Phys. J. C76 5, (2016) 299



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

Going very forward

ALICE ➧ beam remnants can be studied 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

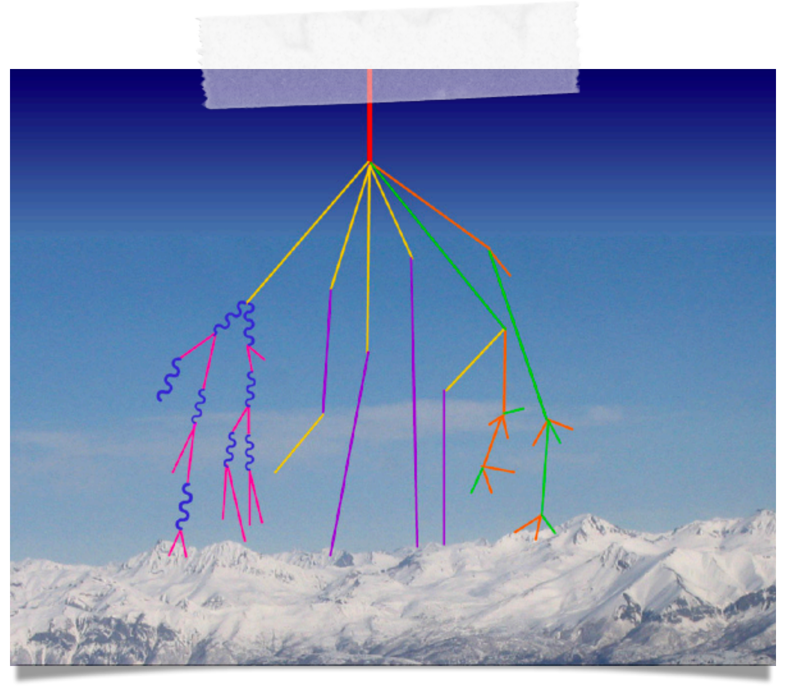
Beam remnants

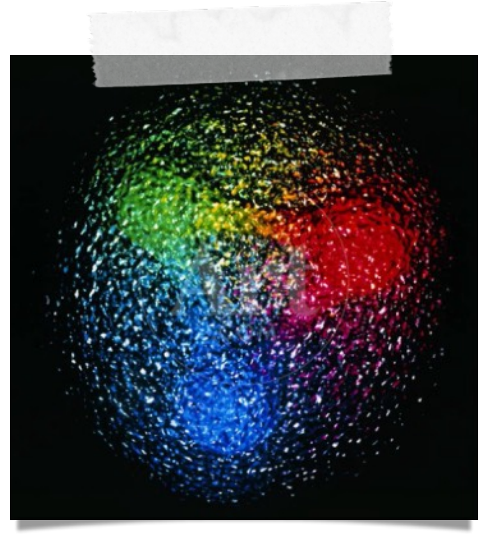
Proton fragmentation region is sensitive to beam remnants

At large rapidities in high energy hadronic collisions:

- leading baryon production (mostly neutrons and protons) from valence quarks
- sensitivity to high gluon density ➧ suppression of leading baryon production in small b events

➧ measurements of interest for simulations of high-energy cosmic-ray interaction

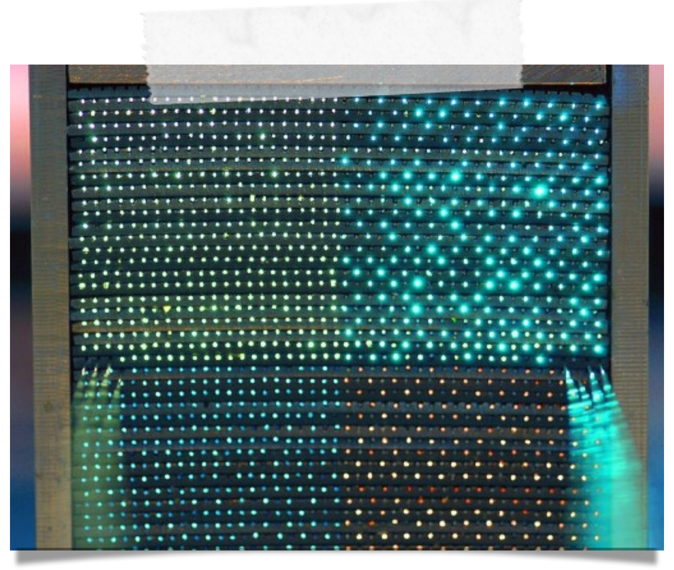




Colliding protons are color neutral ➧ color structure of beam remnants must be connected to that of initiator partons

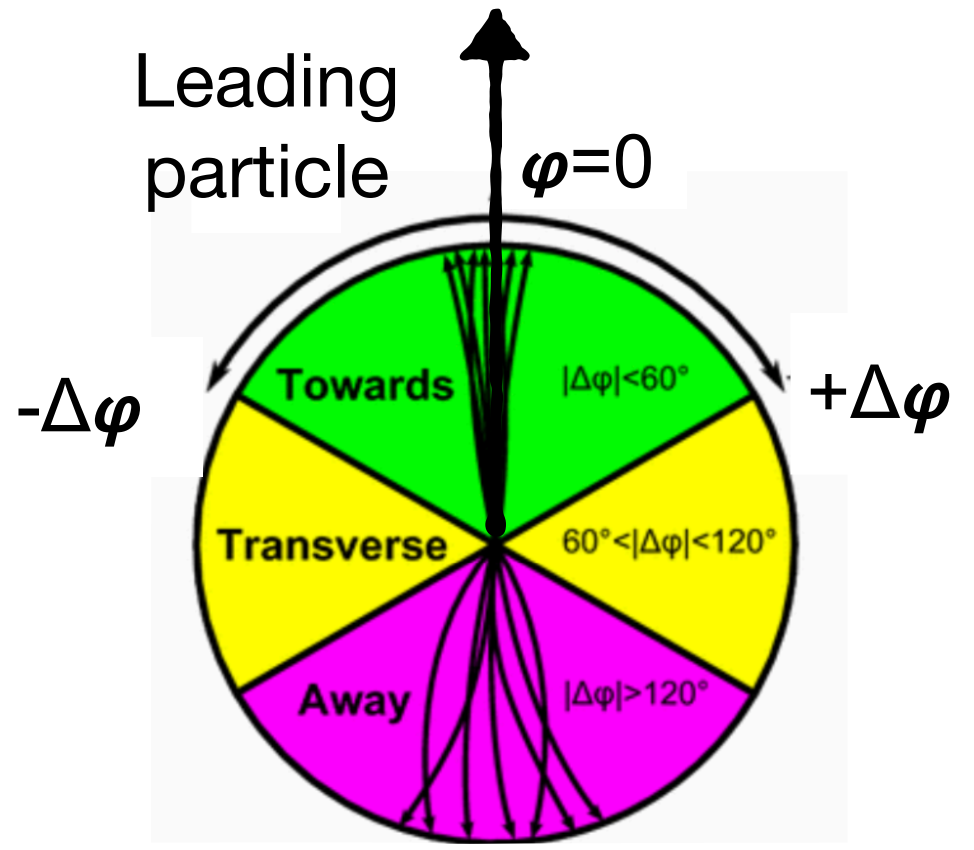
➧ beam remnant measurements can provide input and constraint for models

ALICE can detect both neutrons and protons at very large rapidities (0°) at LHC energies in all collision systems



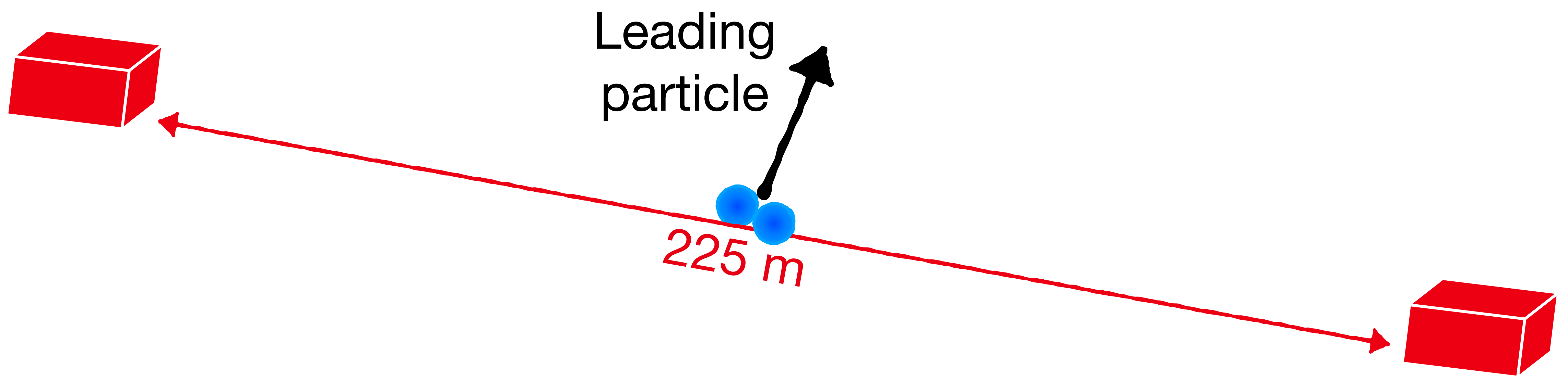
Going forward to gain a new perspective

Midrapidity



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

Very forward rapidity



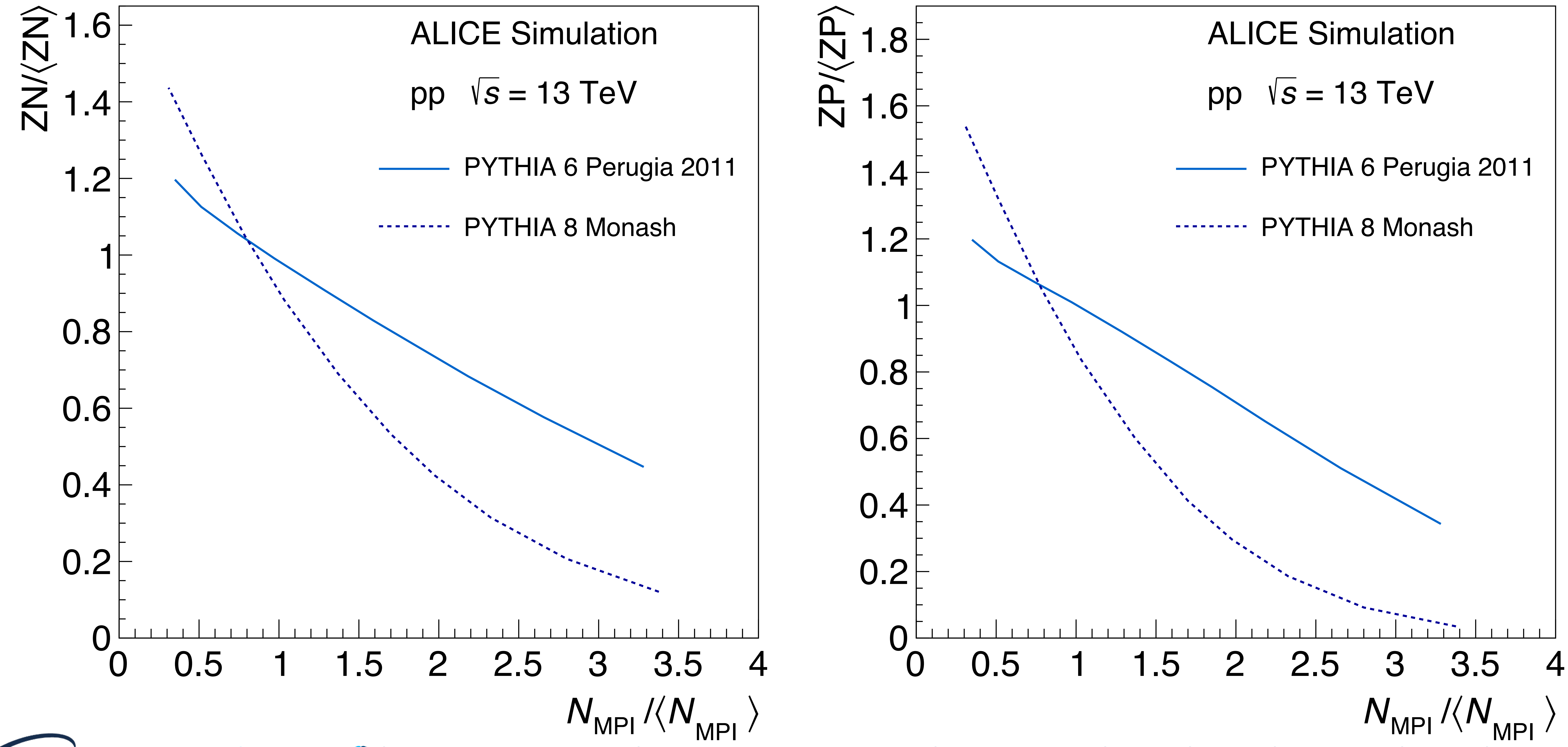
ZDC energy ➧ study beam remnants in regions separated in η from the hard scattering fragmentation

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

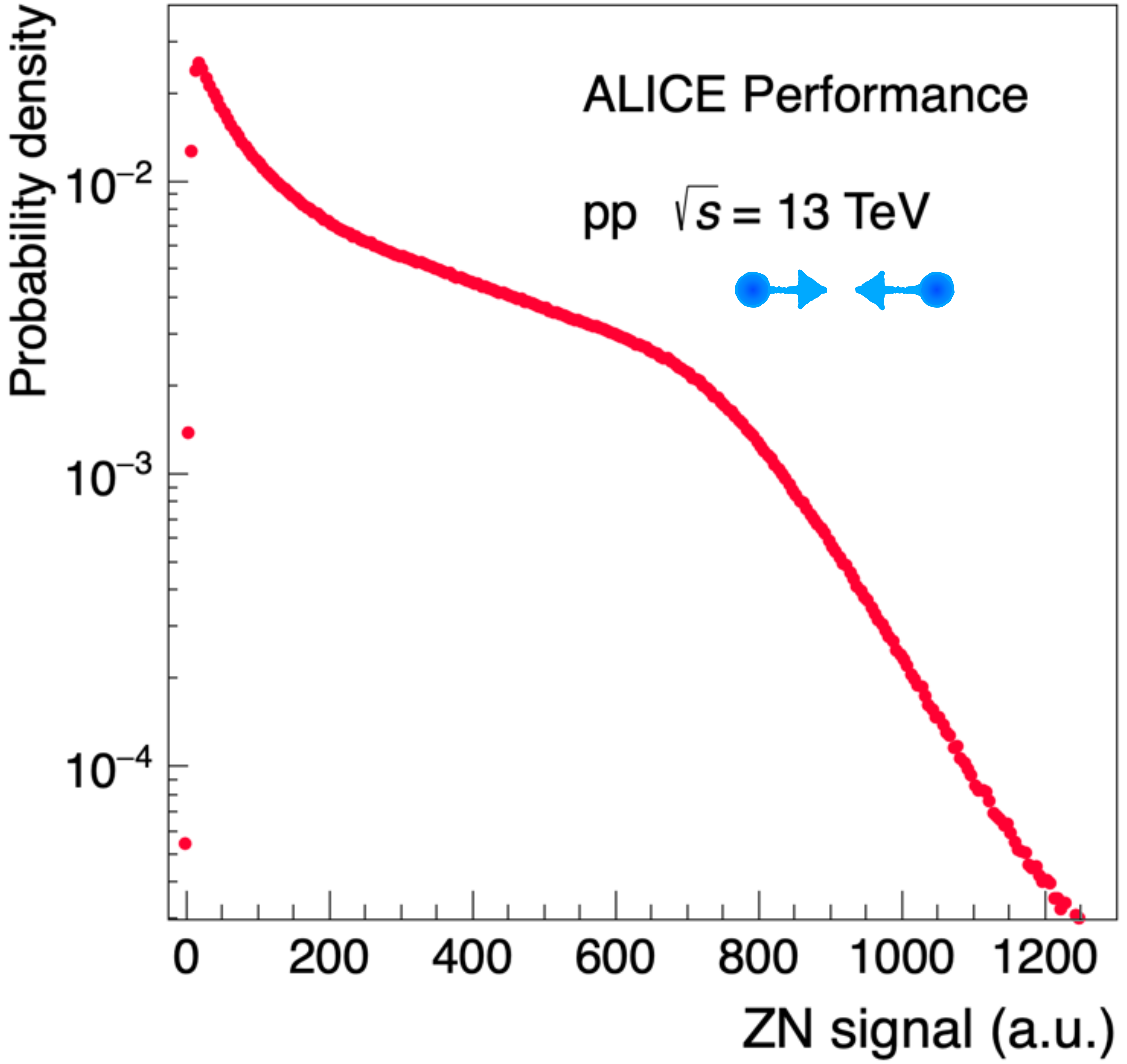
ZDC energy and MPIs in pp collisions

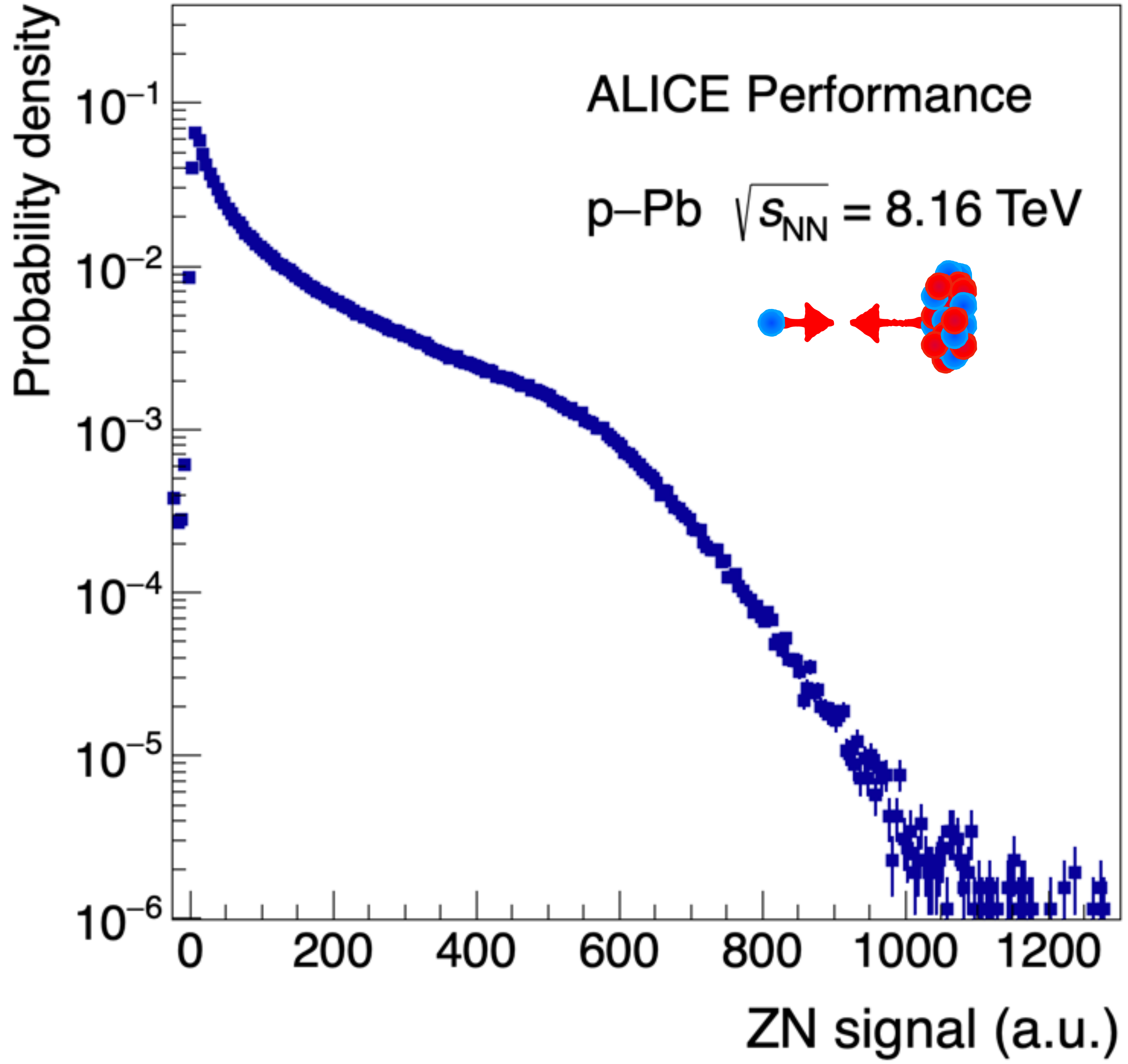
- PYTHIA models (MPI with impact parameter dependence) predict a decrease of very forward energy with increasing number of MPIs

ALICE Coll., JHEP08 (2022) 086



ZN spectra in p fragmentation region

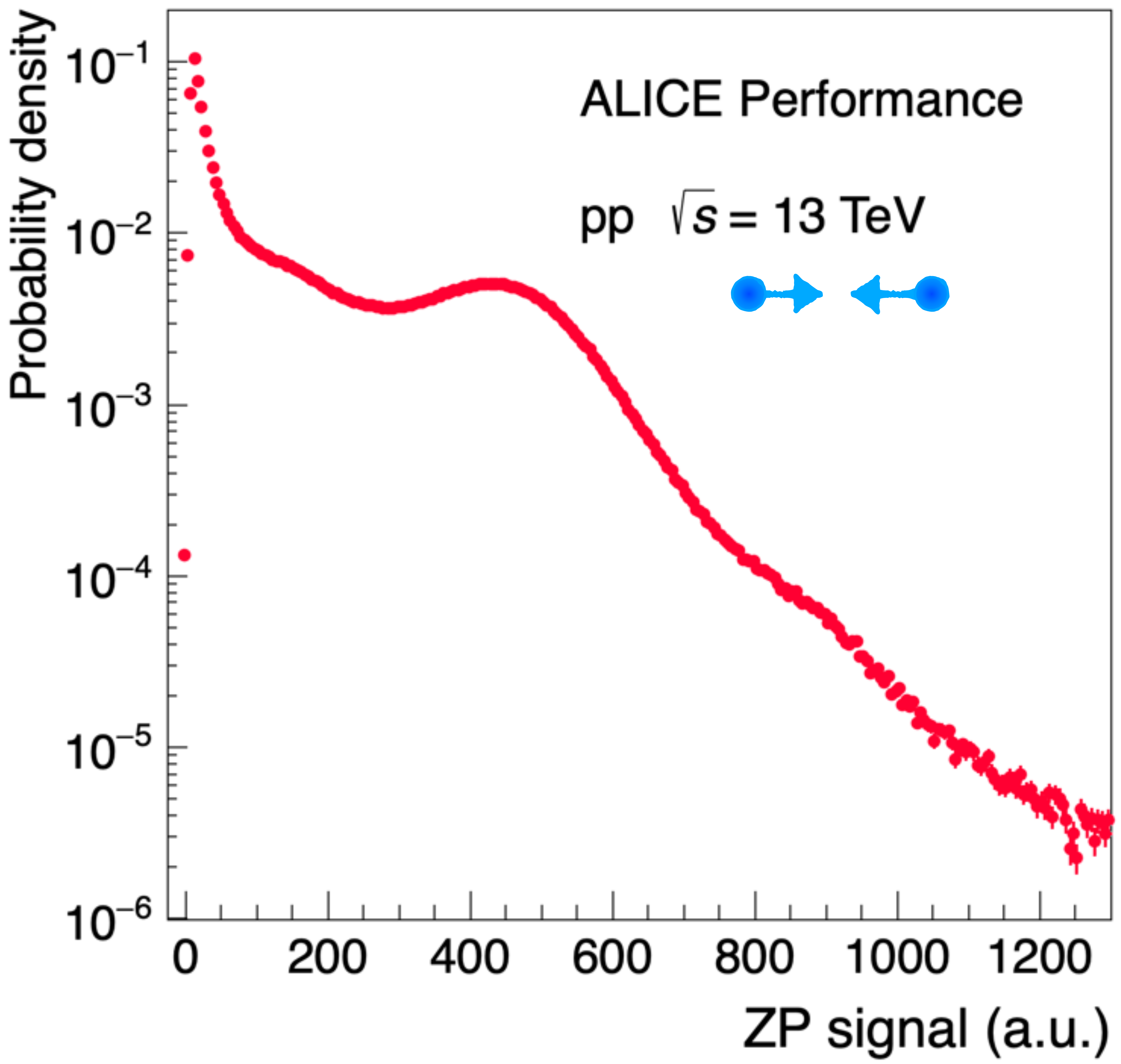


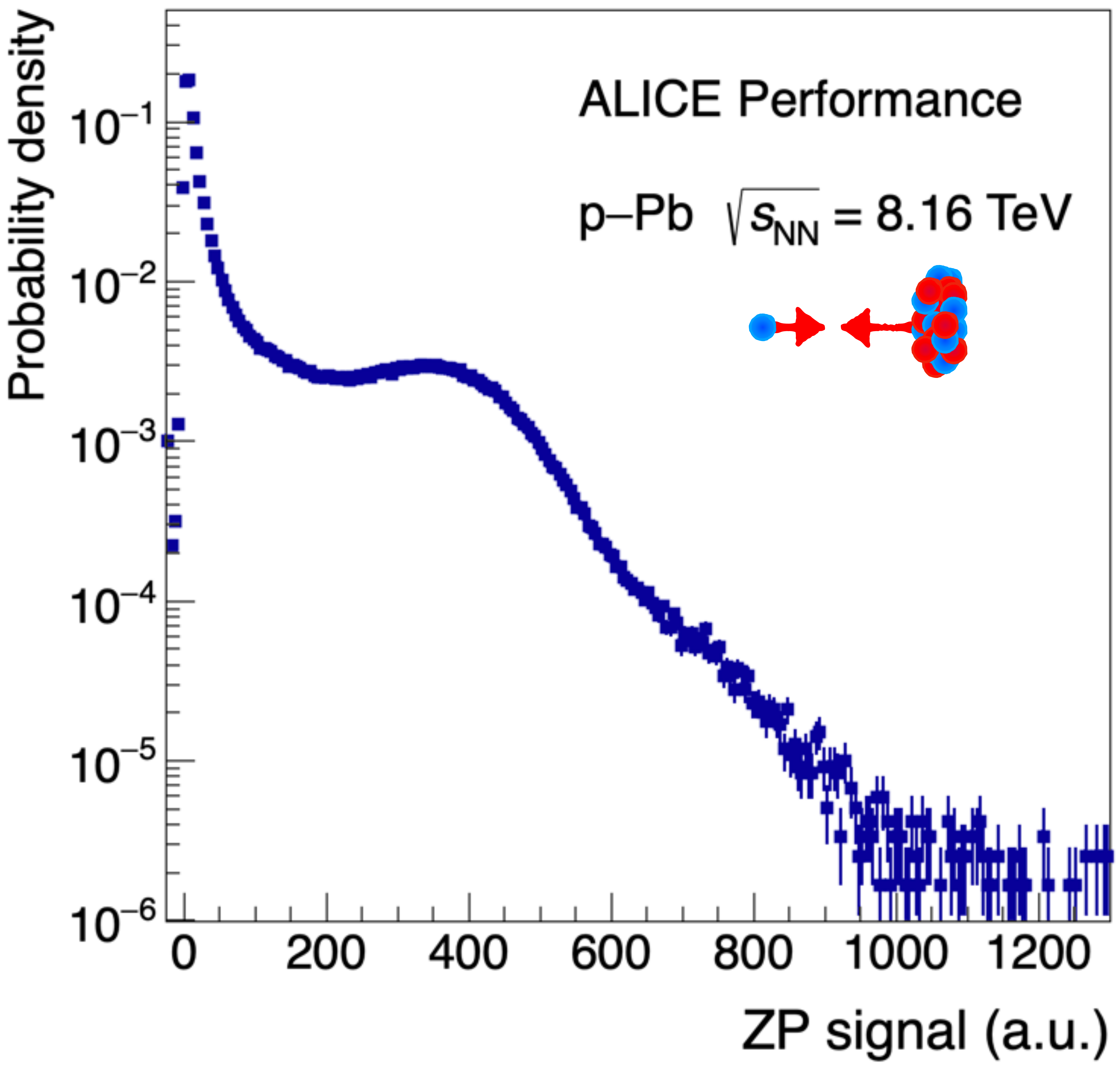


Very similar features in spectra from the p-fragmentation region

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

ZP spectra in p fragmentation region





Very similar features in spectra from the p-fragmentation region

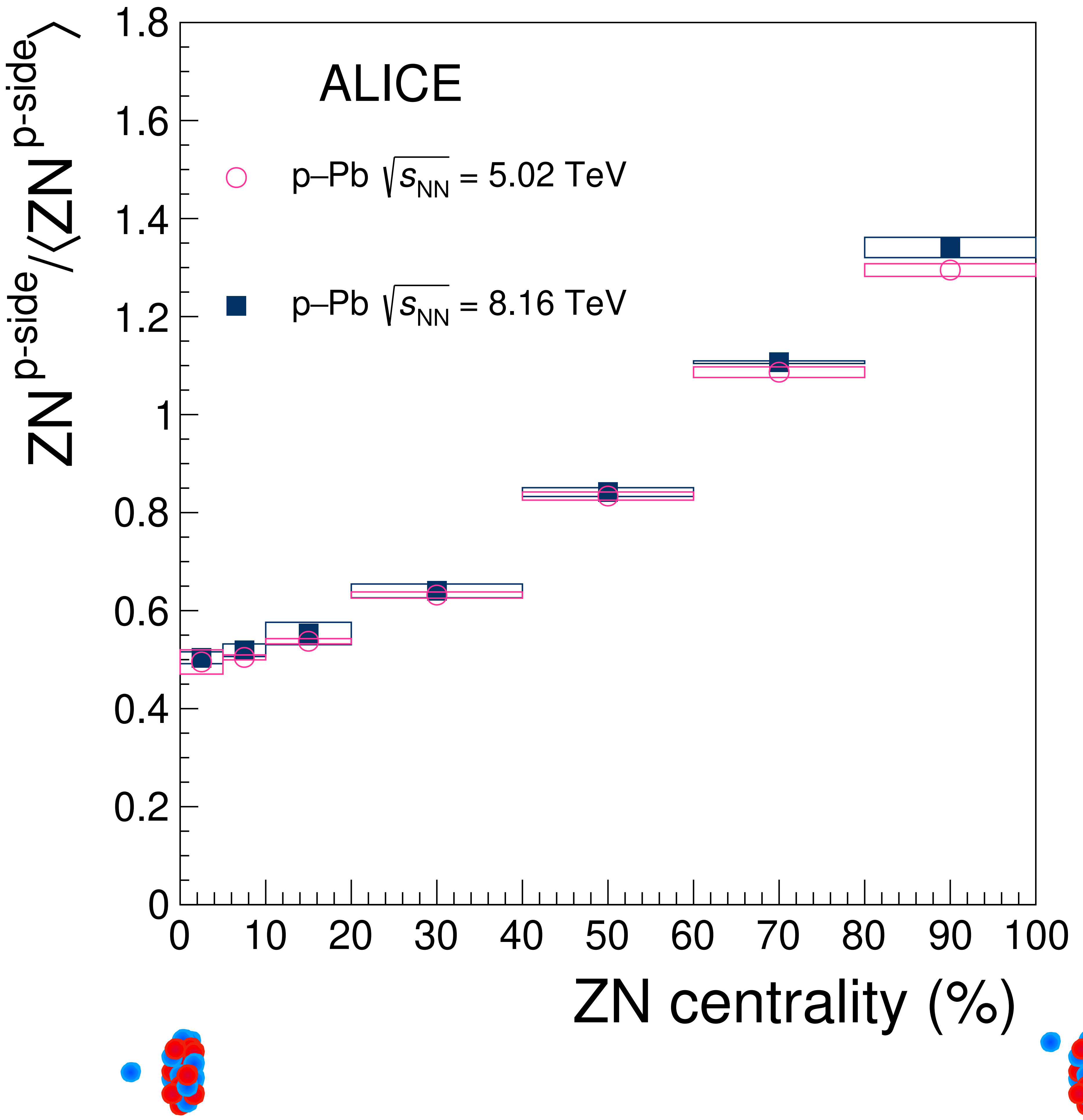
Different fraction of MB events with a signal in ZP: 15% in p-Pb 23% in pp

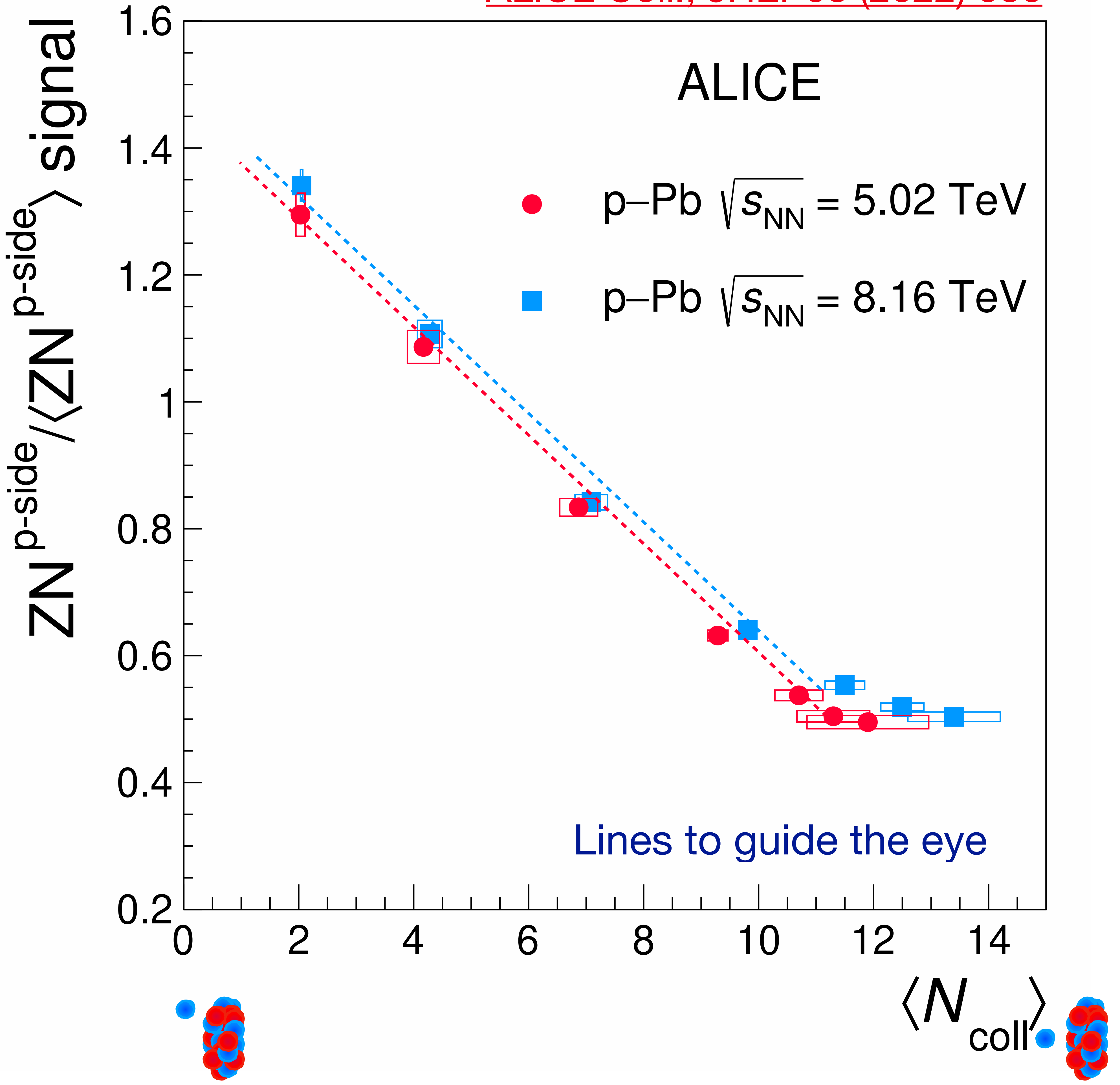
Forward energy in p-Pb collisions

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}

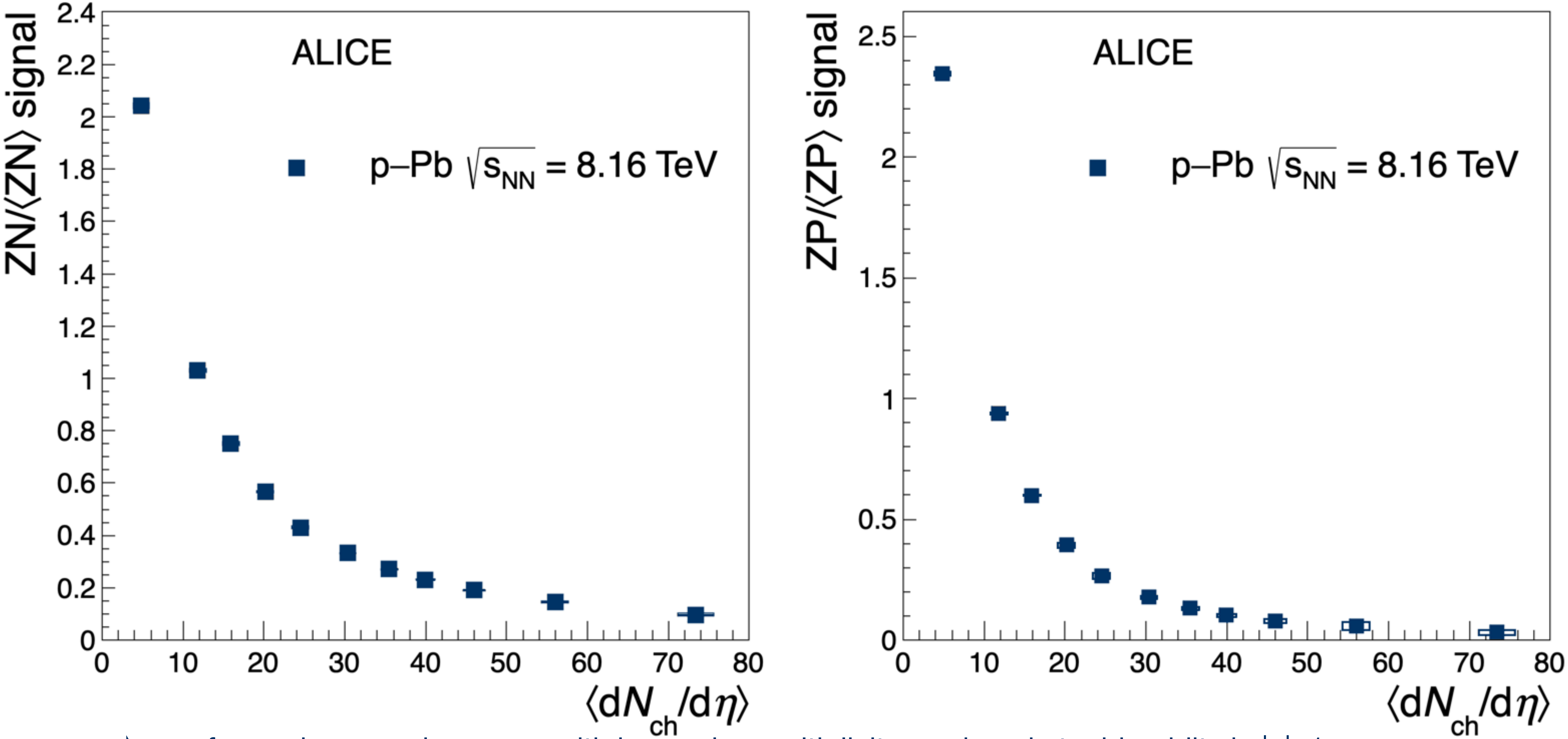
ALICE Coll., JHEP08 (2022) 086





Dependence on multiplicity at midrapidity in p-Pb

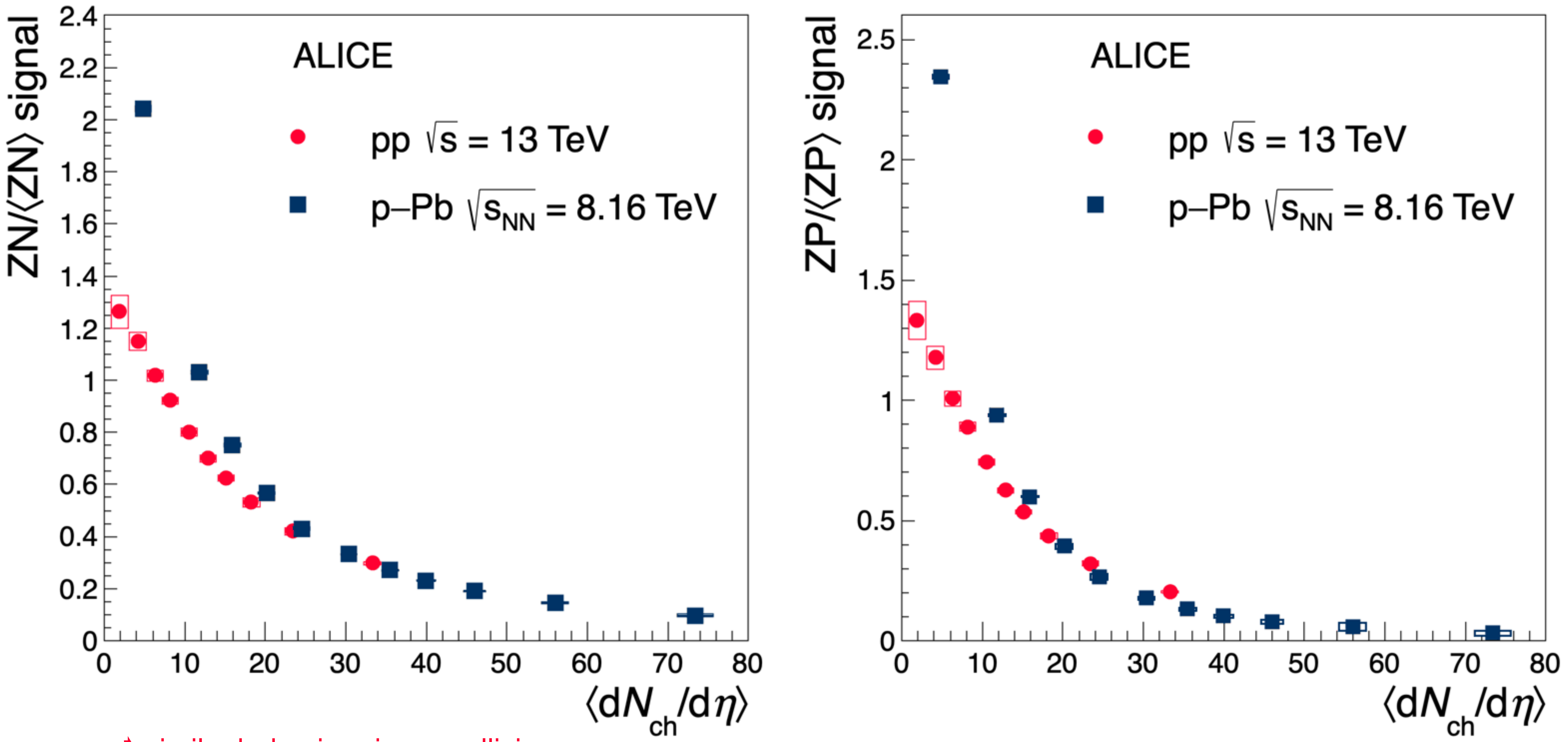
ALICE Coll., JHEP08 (2022) 086



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

Dependence on multiplicity at midrapidity

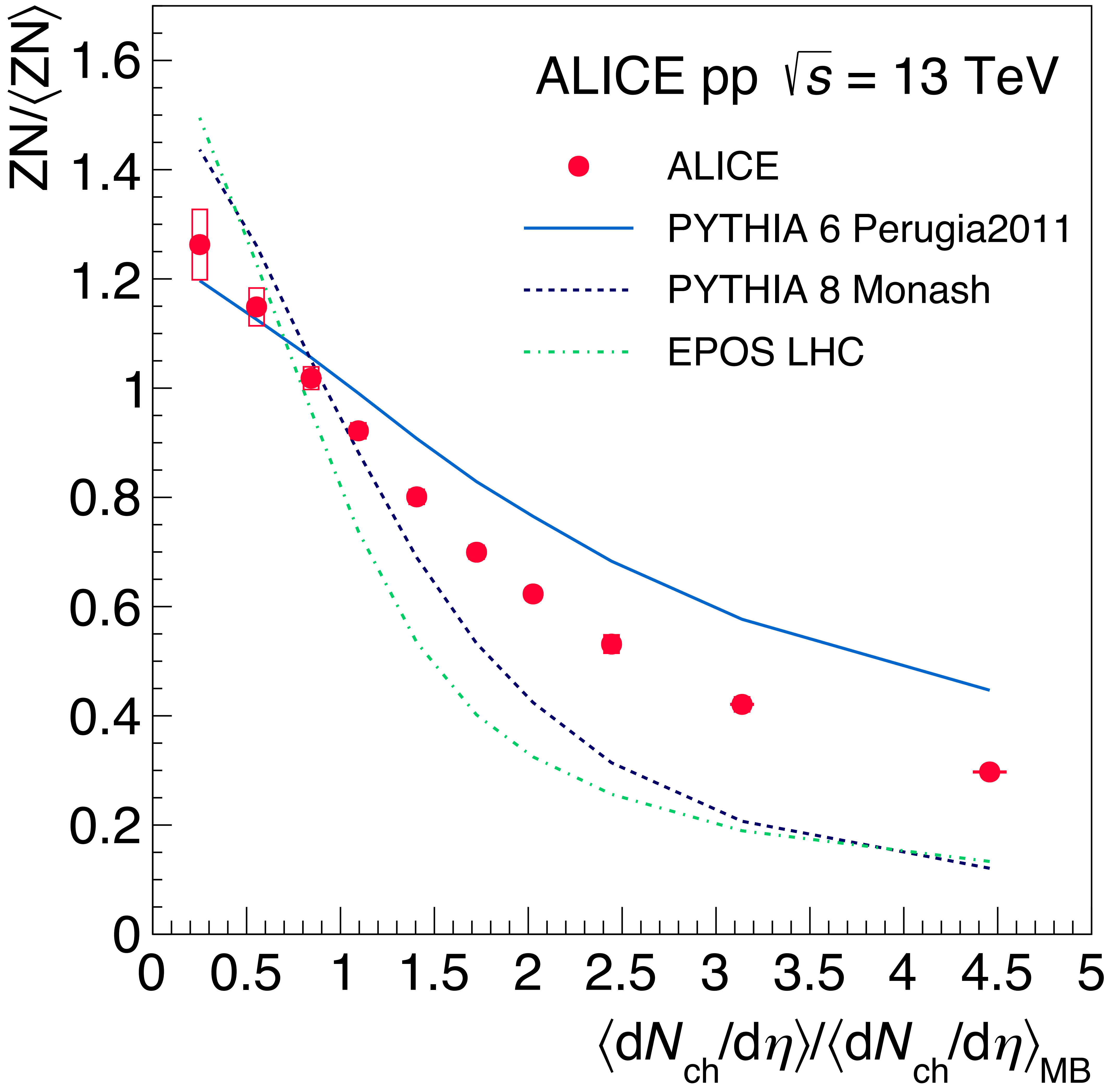
ALICE Coll., JHEP08 (2022) 086

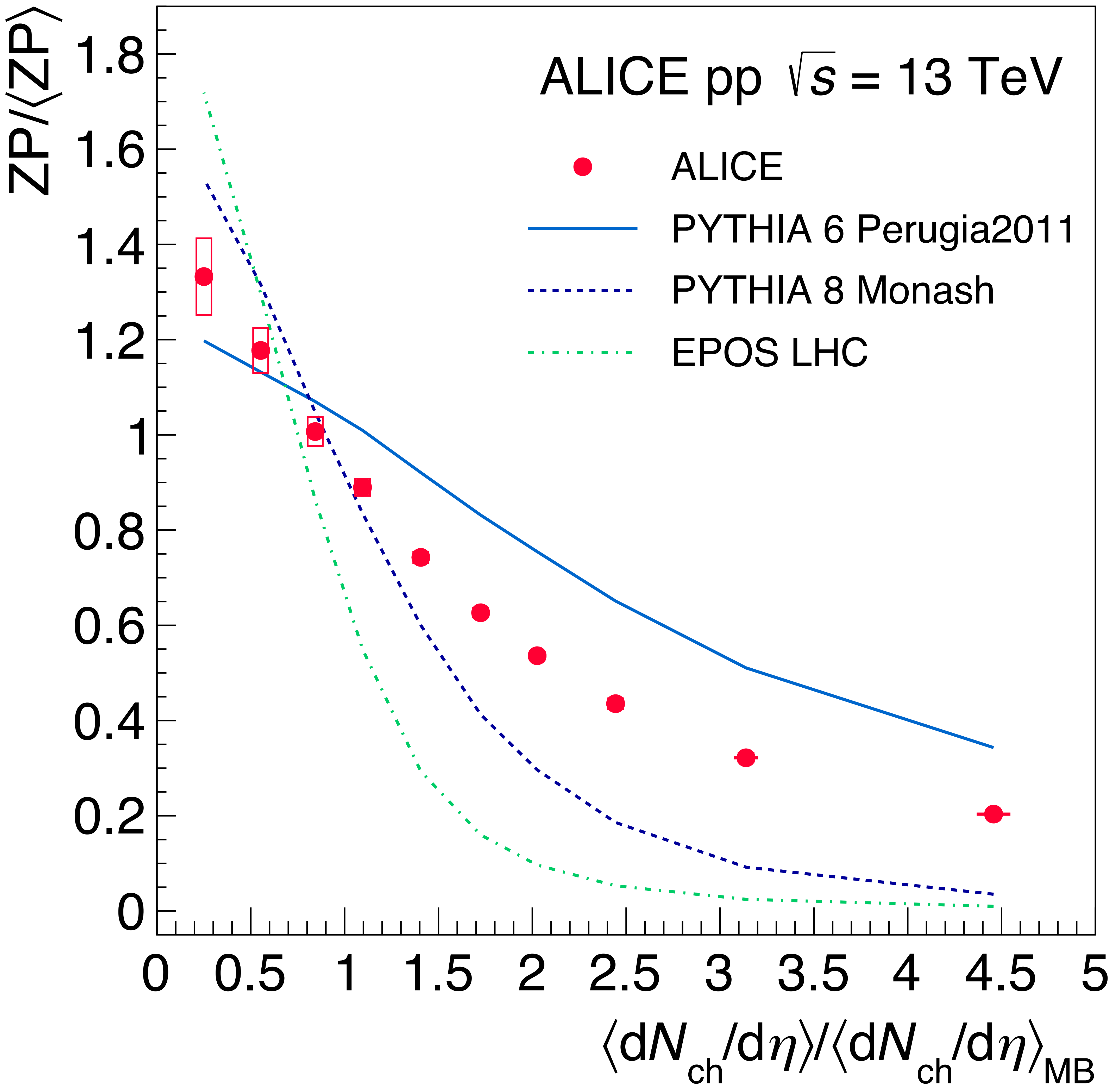


- similar behaviour in pp collisions

Dependence on multiplicity at midrapidity in pp

ALICE Coll., JHEP08 (2022) 086

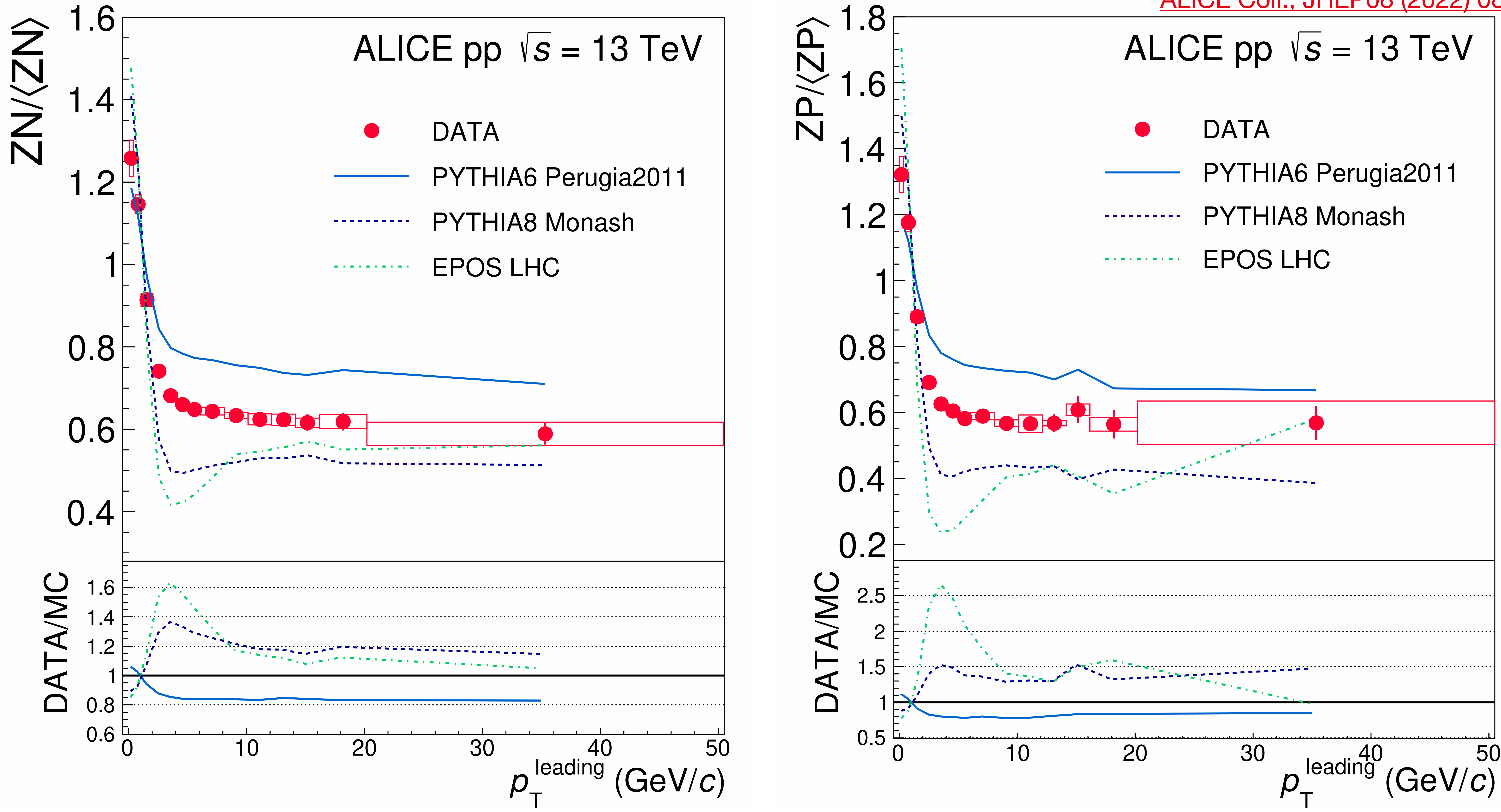




➧ the models used for comparison are not able to reproduce very forward vs. midrapidity measurements

Forward energy vs. leading p_T

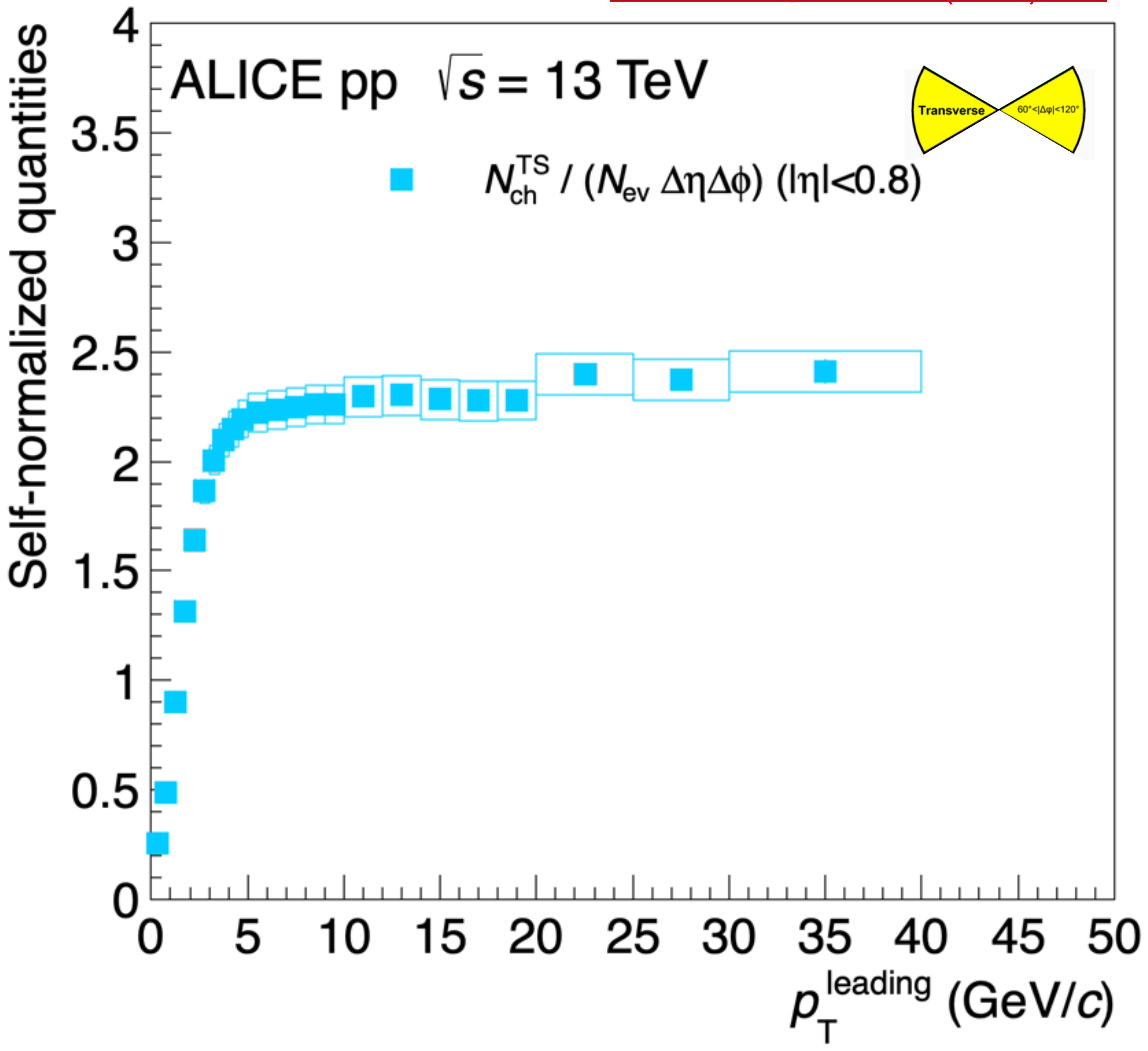
ALICE Coll., JHEP08 (2022) 086



- 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 constant in events with a larger than average number of MPIs

UE and forward energy

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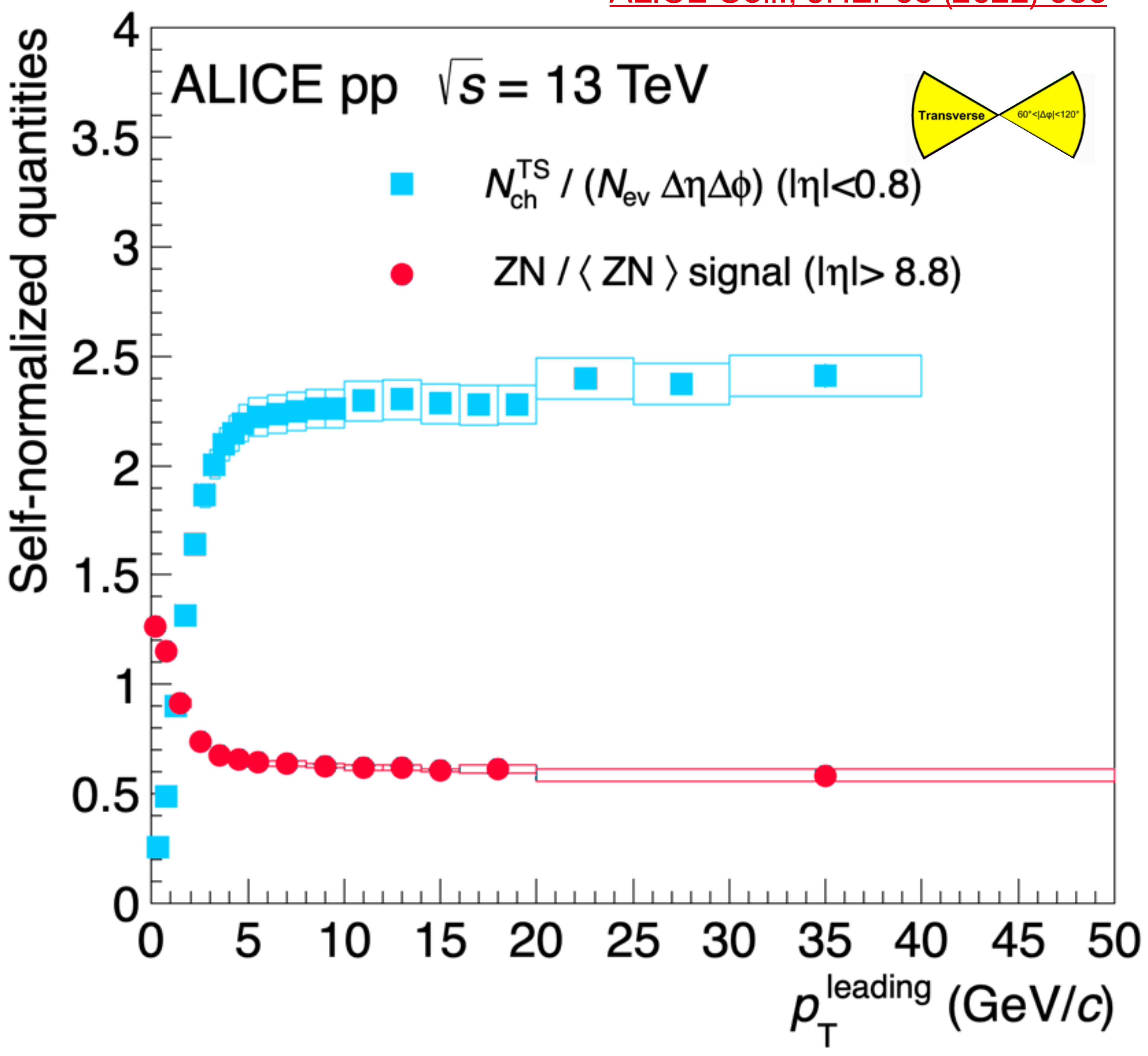

UE ➧ multiplicity in transverse region constant in events with a larger than average number of MPIs

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

Events without leading baryon production

H. J. Drescher, M. Strikman, PRL 100 (2008) 152002

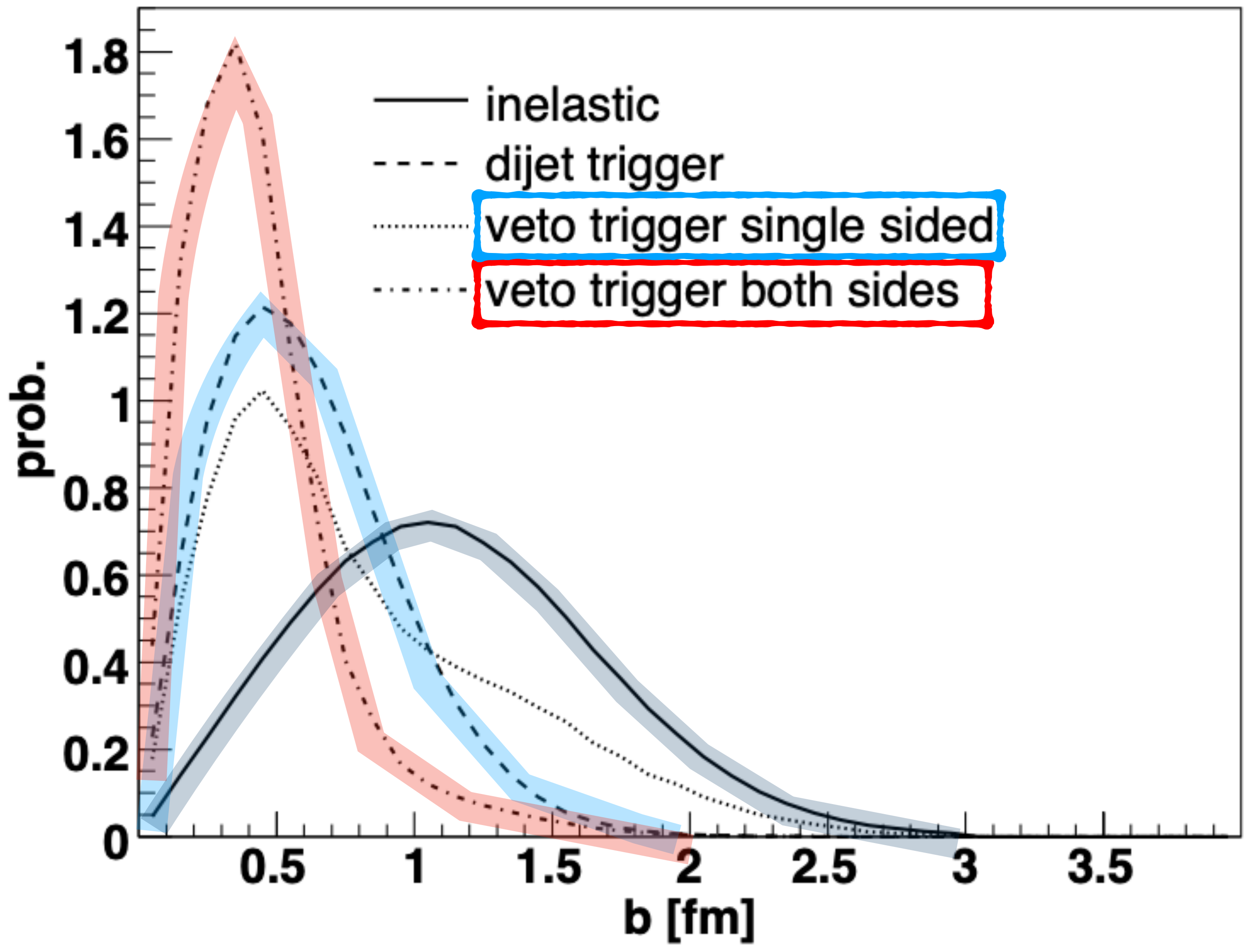

FIG. 5: Impact parameter distributions for inelastic events, the dijet trigger and single and double sided veto-trigger (no baryon in the region $x_F > 0.1$).

- model describing hadron production in p fragmentation region in the high gluon field density present in pp collisions at LHC energy

- effective way to select smaller impact-parameter distributions suggested: veto on leading baryon production

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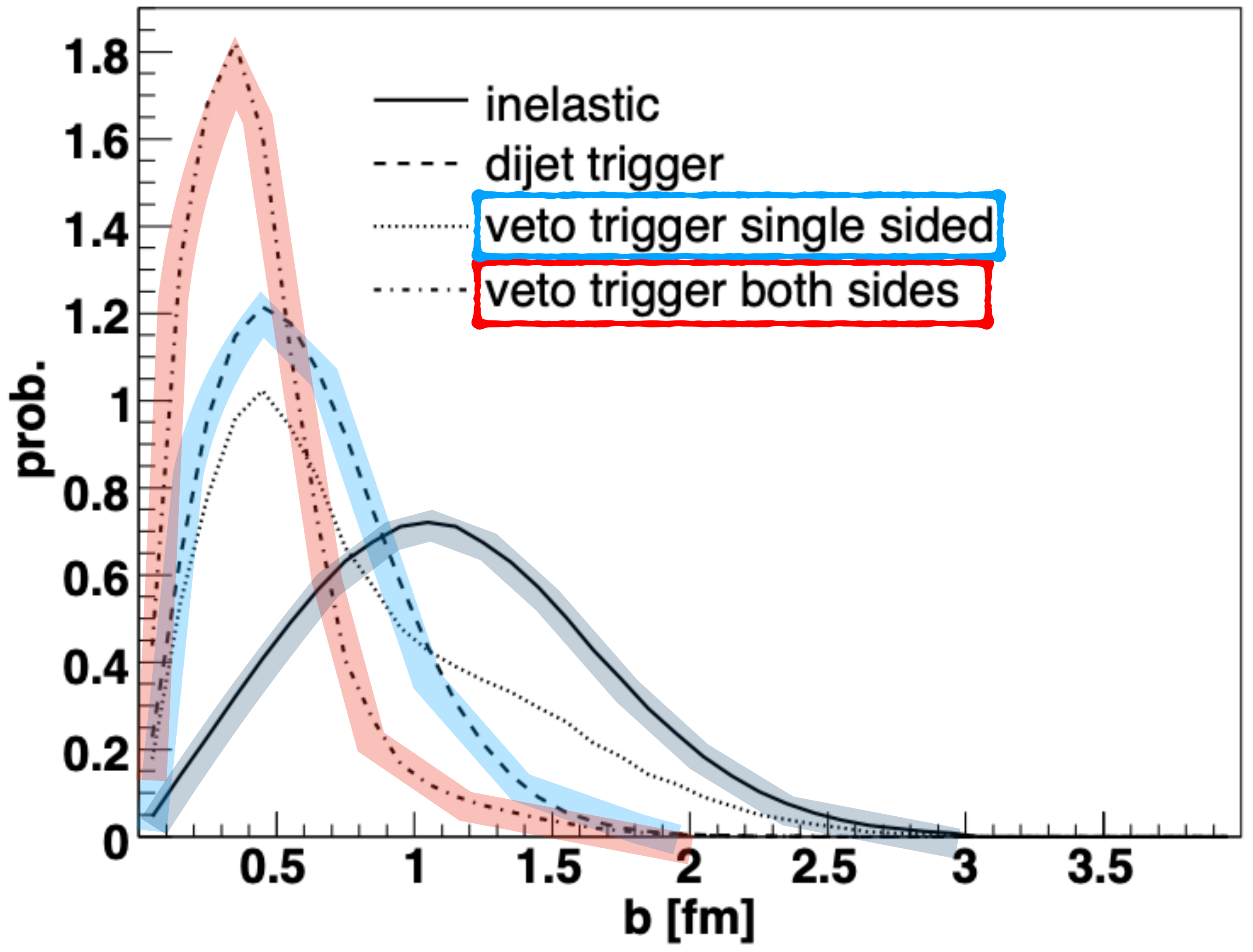

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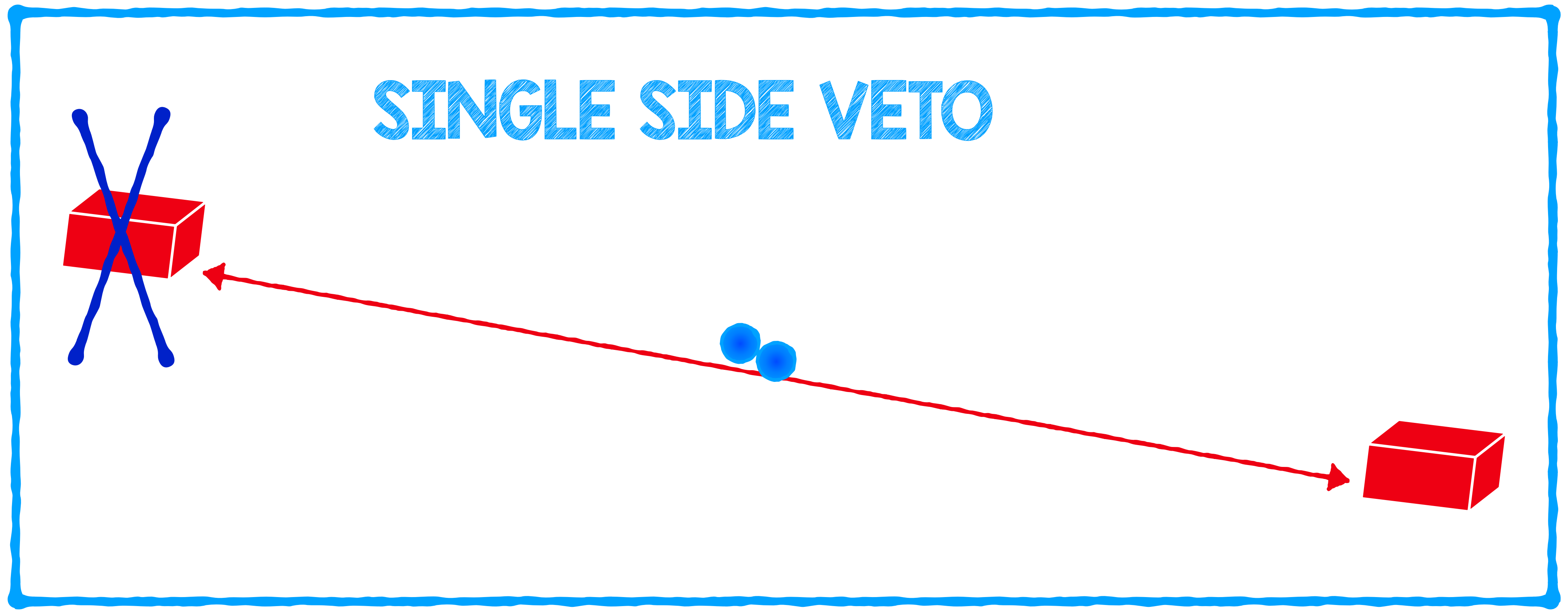
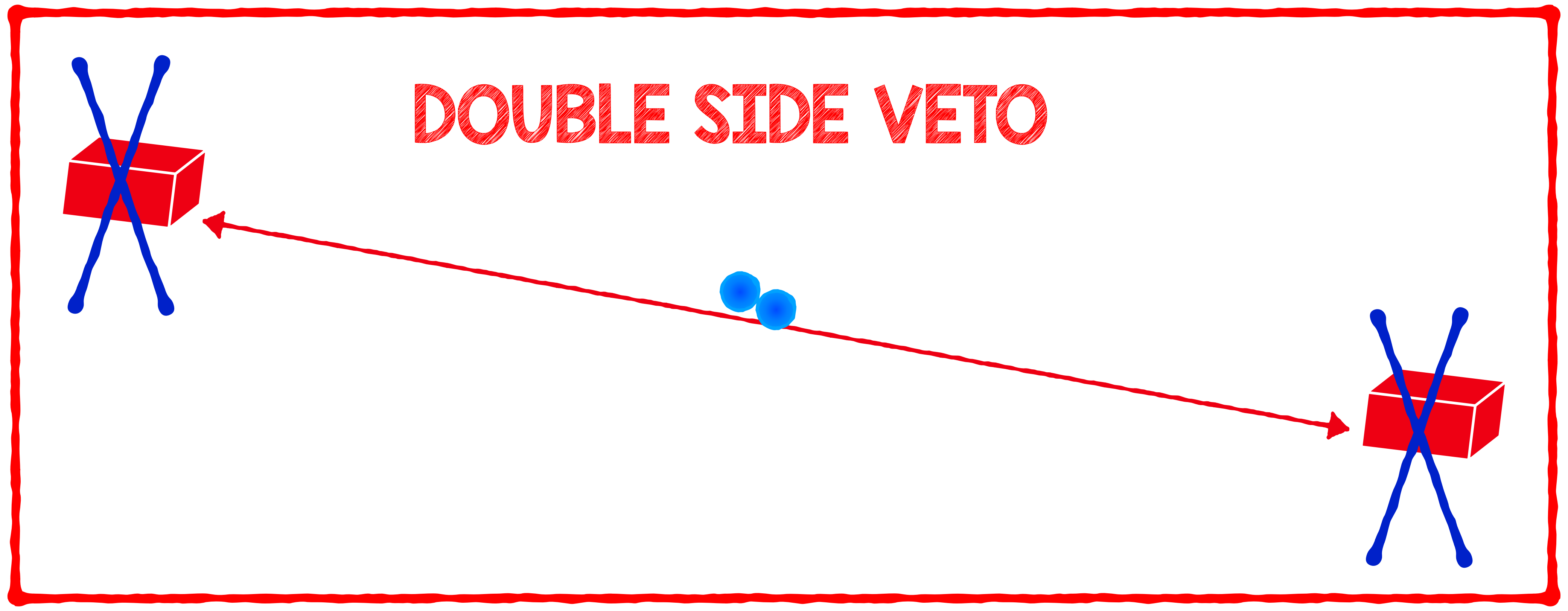
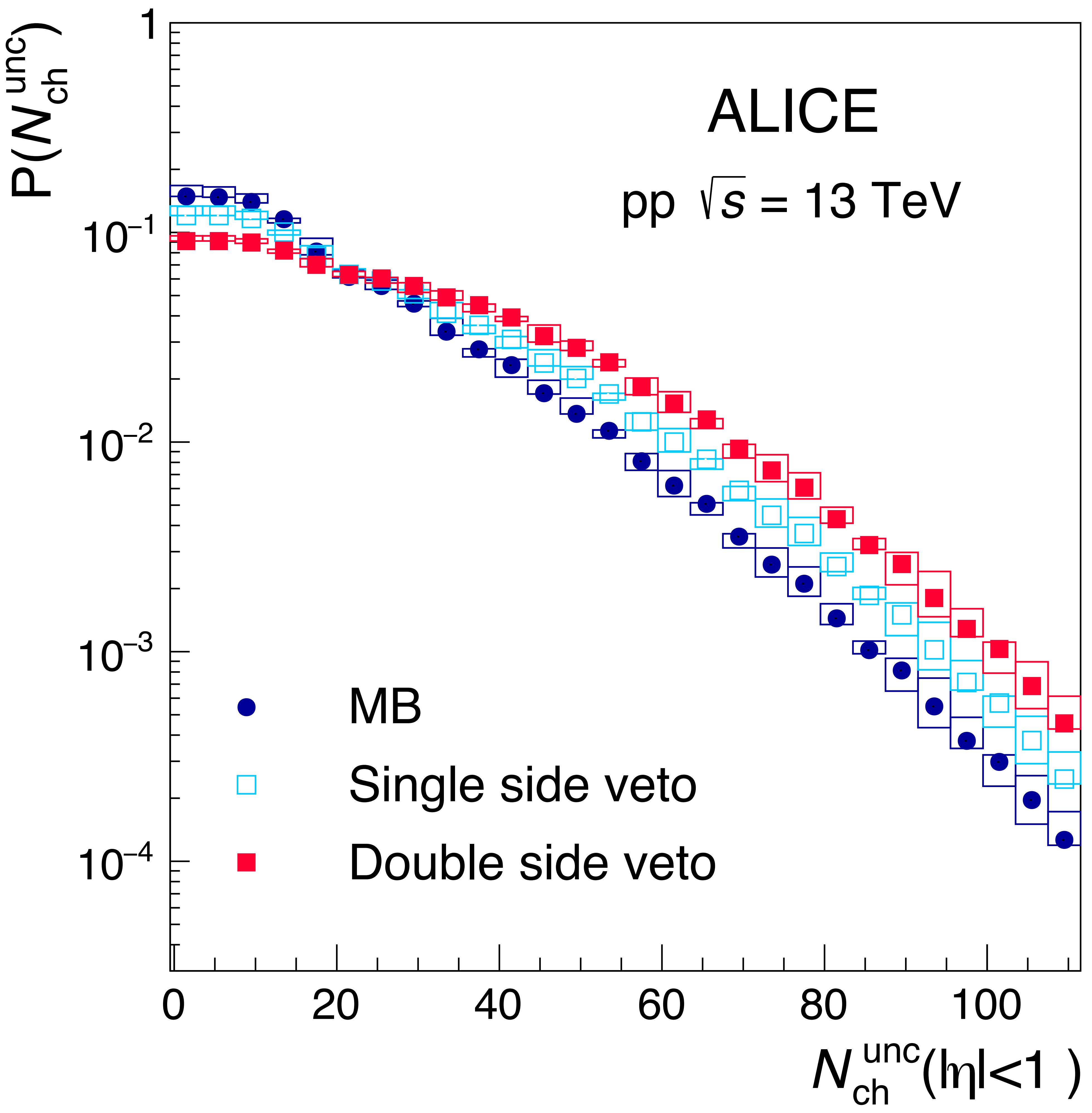
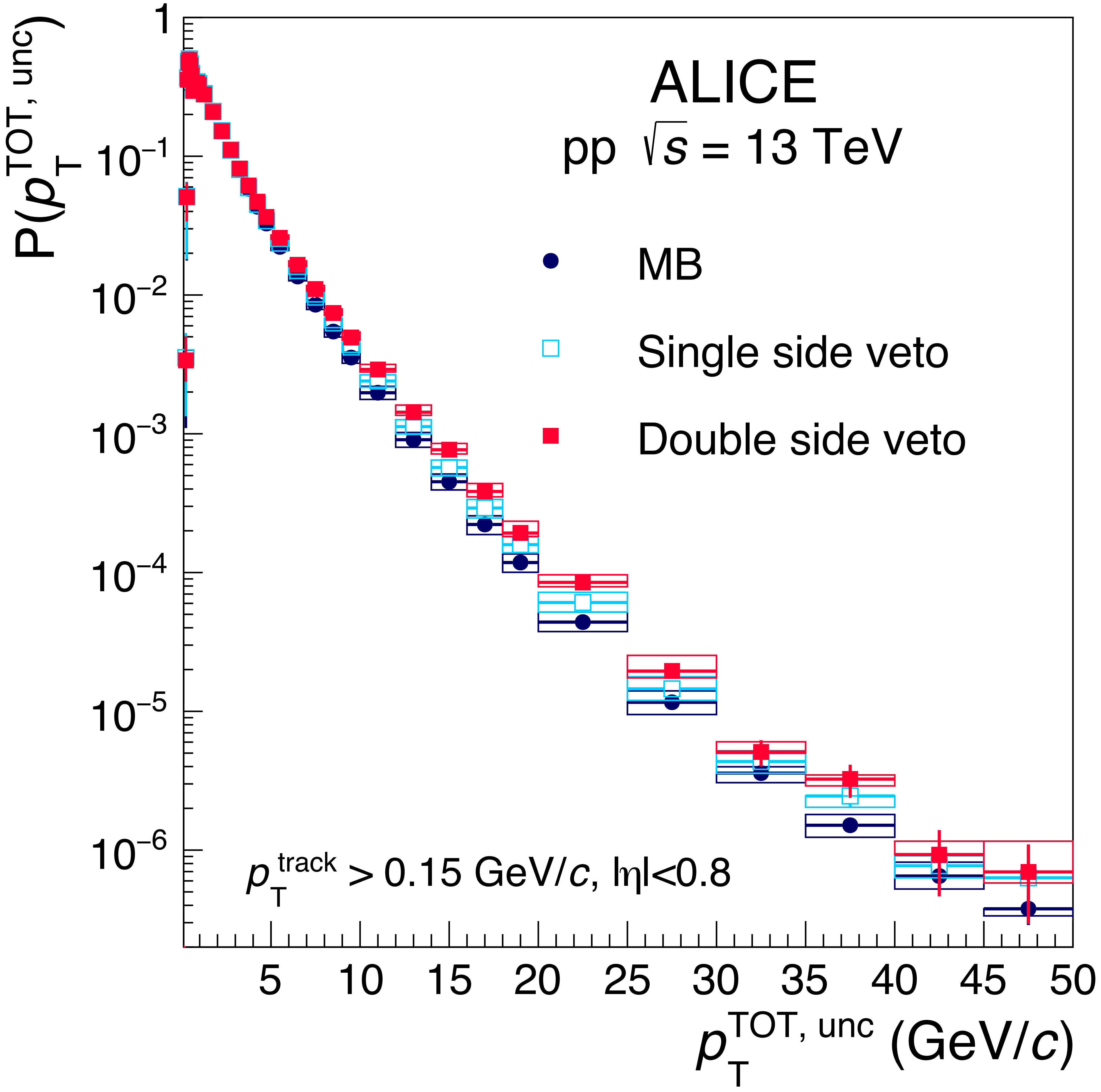




Double veto in action

ALICE Coll., JHEP08 (2022) 086



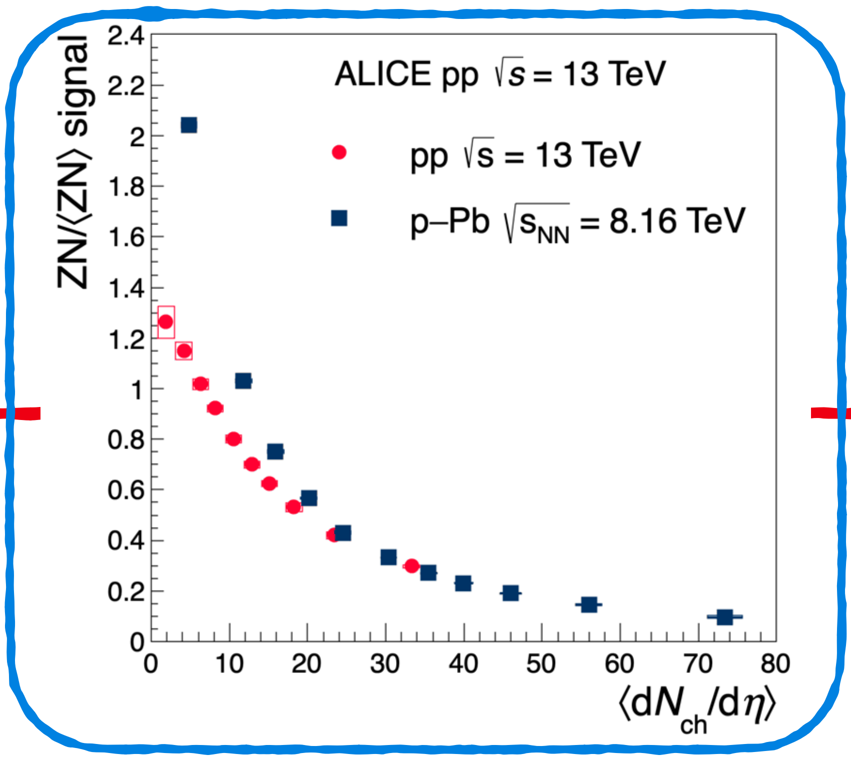


Distributions corrected only for inefficiencies, not for effects related to detector resolution

- N_{ch} in $|\eta|$<0.8 is on average a factor 1.2 (1.5) higher than in the MB sample for the (single) double veto selection
- predictions supported by experimental data

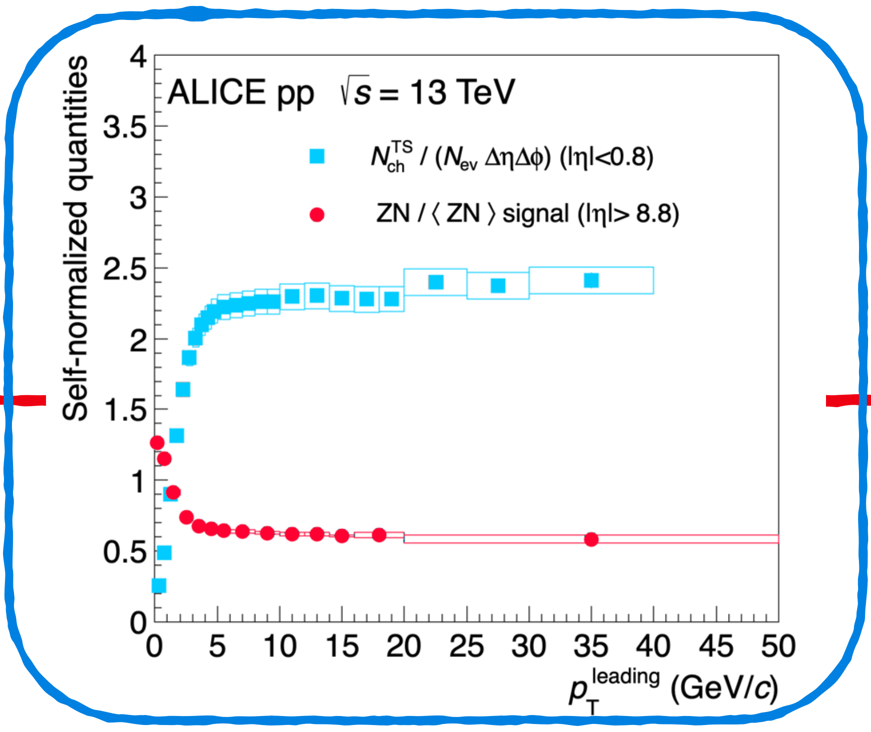
Wrap up

Similar features for pp and p-Pb collisions in p-fragmentation region measured for the first time at LHC energies



Events with larger N_{MPI} have higher multiplicity and smaller forward energy

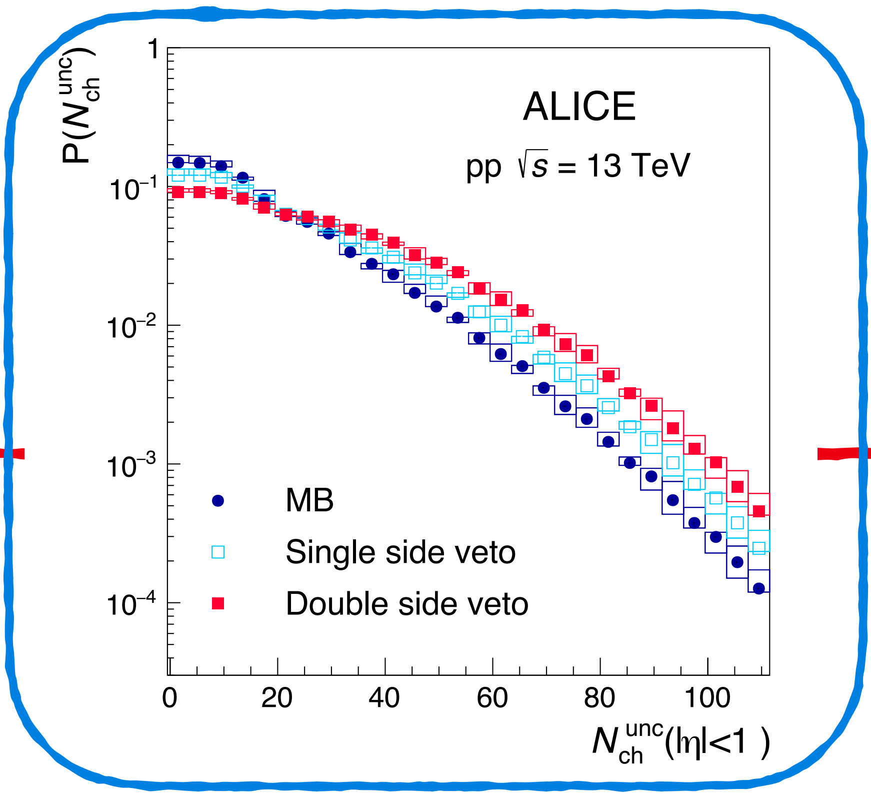
Beam remnants show features complementary to UE as function of leading particles p_T at midrapity



Both UE and very forward energy saturates at the same p_T ^{leading} scale

➧ initial stage effect

Vetoing leading baryon production selects higher than average multiplicity and harder spectra



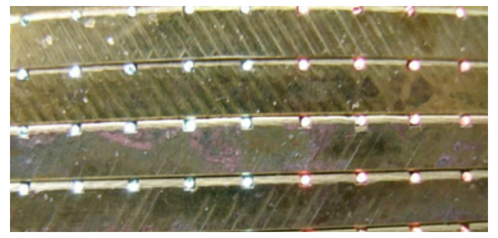
A double veto on leading baryon production in pp collisions selects events with larger overlap (smaller b)

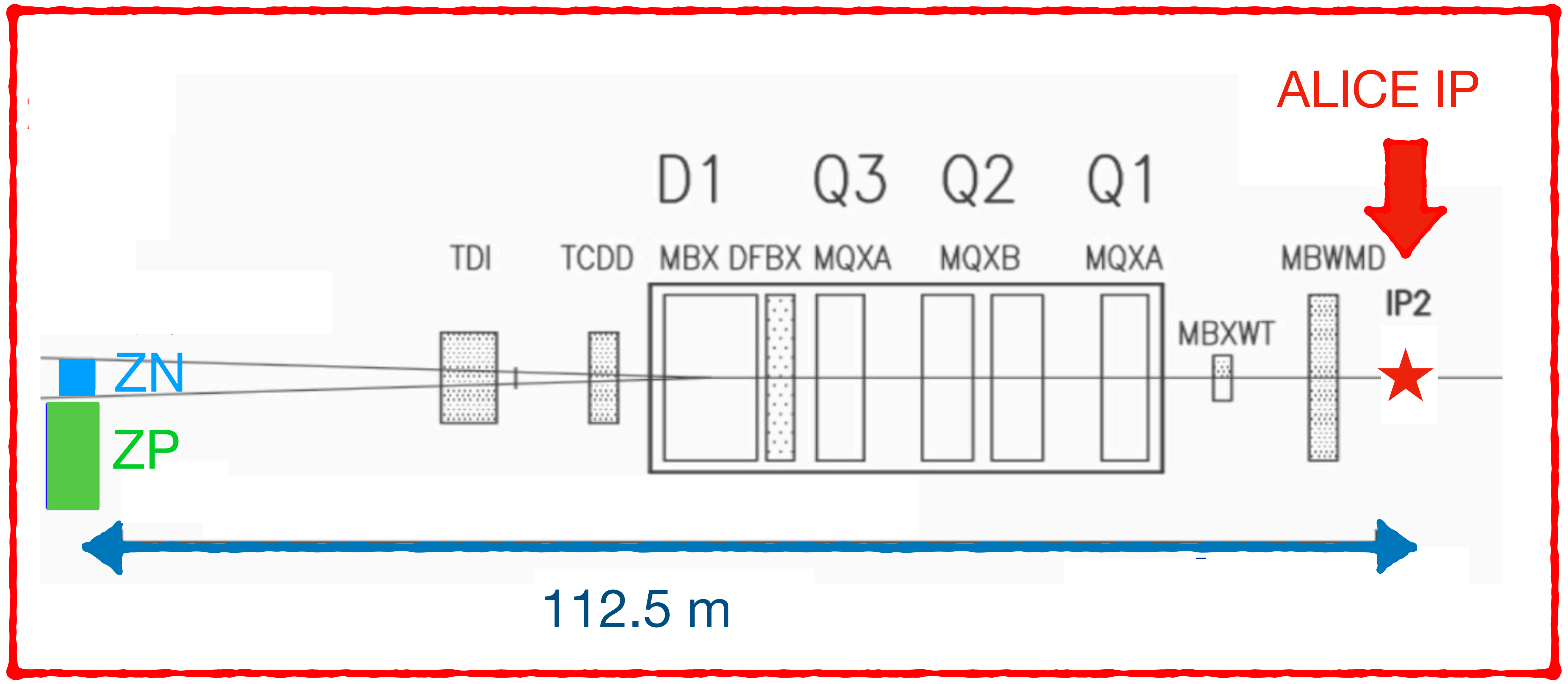
Picture by Klaus Barth

Thanks for your attention!

ALICE ZDC

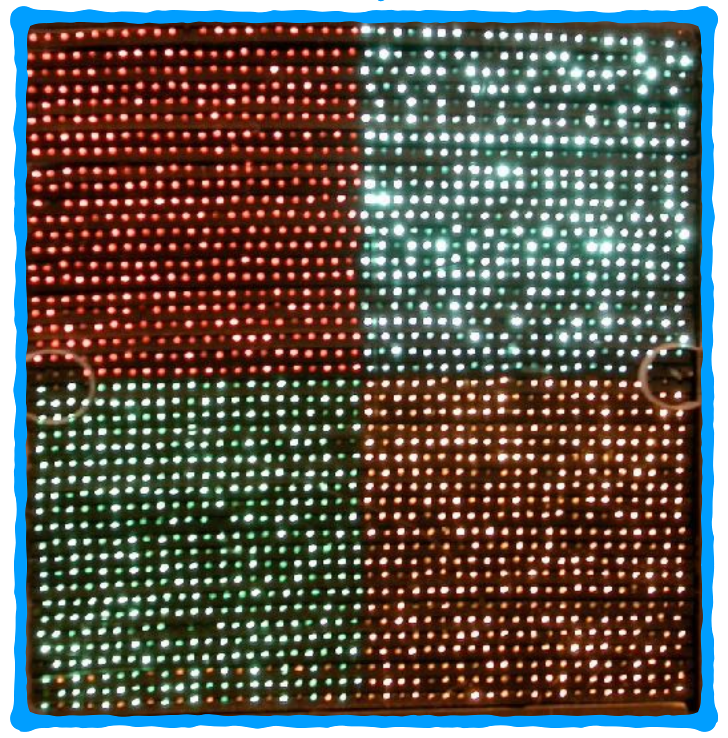
Quartz fibre spaghetti calorimeters
Cerenkov light produced of shower particles



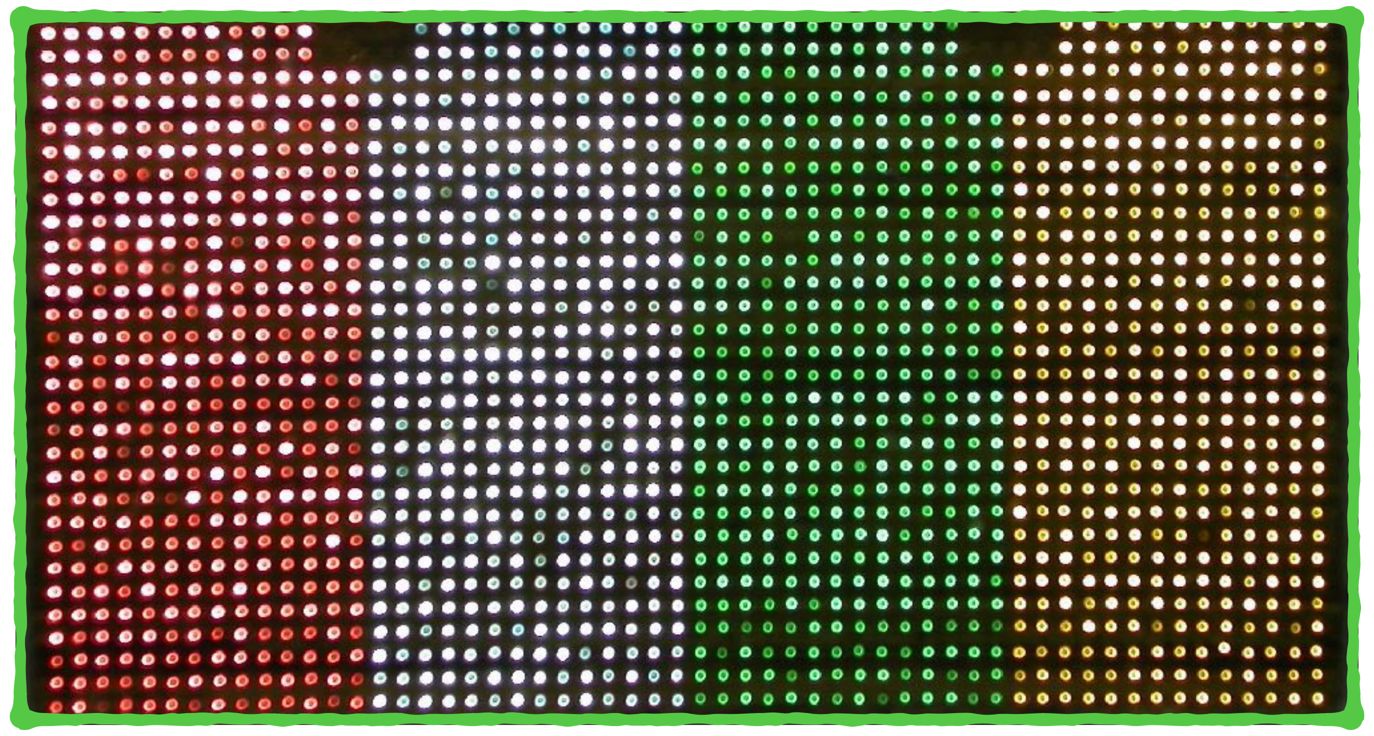


Two identical systems on both sides relative to IP, each made by:

- a neutron ZDC (ZN) at 0° w.r.t LHC axis, 7x7x100 cm^3 that detects neutral forward energy in $|\eta|>8.7$
- a proton ZDC (ZP) external to the beam pipe, 22.4x11.2x150 cm^3, detecting positively charged particles (mainly protons) in a pseudo rapidity range defined by the LHC magnetic beam settings



ZN



ZP

p-Pb collisions at √s = 5.02 TeV

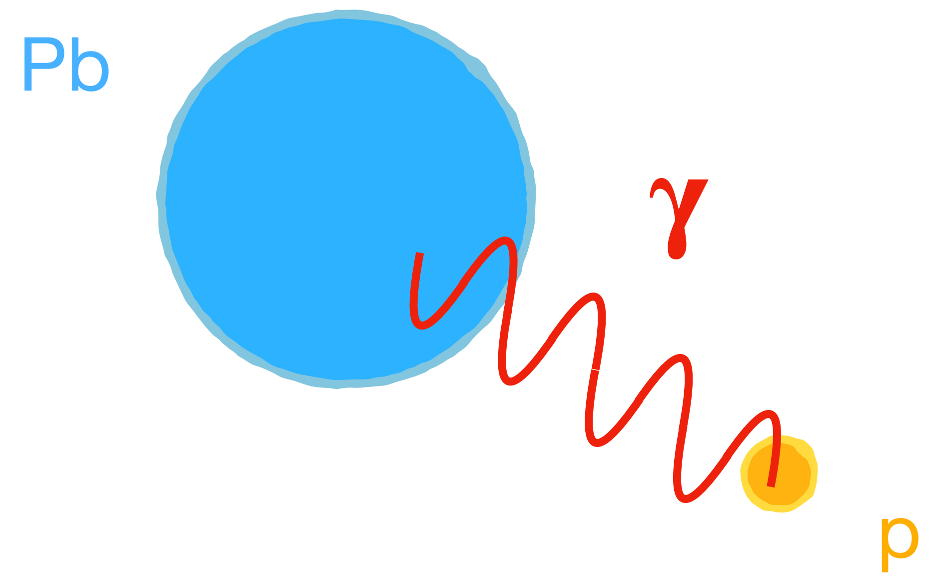
ALICE “visible” cross section of 2.09 ± 0.07 b measured in a van der Meer scan

Monte Carlo simulations ➧ the measured cross section consists mainly of non-single-diffractive (NSD) collisions and a negligible contribution of single-diffractive (SD) and electromagnetic events

Electromagnetic contribution evaluated using RELDIS model [1, 2]
for 4 TeV protons interacting with Pb nuclei of 1.57*A TeV

EM fragmentation of Pb nucleus
➧ cross section = 33.9 ± 2.0 mb (16.3 mb in neutron emission)

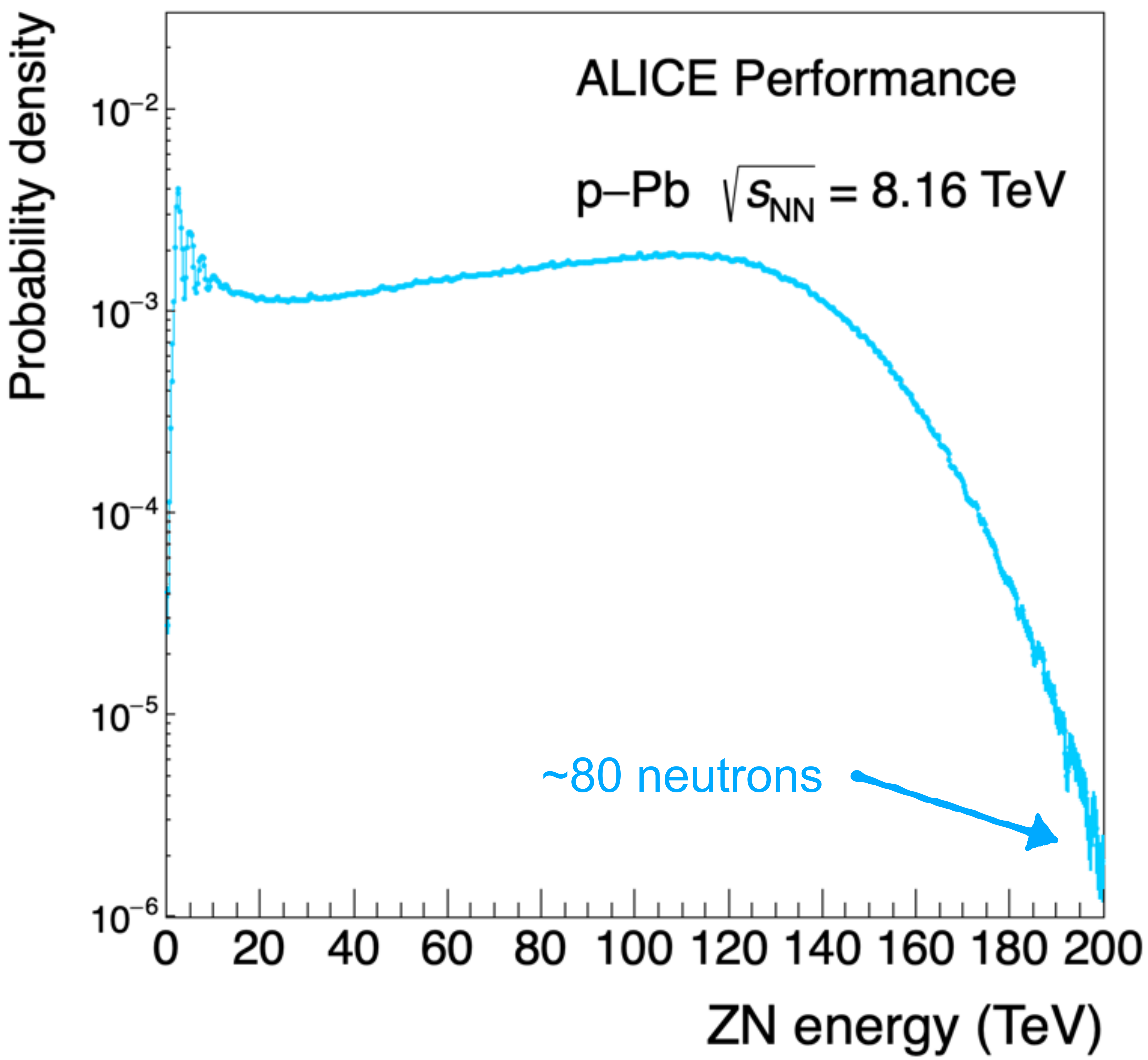
Excitation of proton by virtual photons from Pb nucleus
➧ cross section ~ 392 ± 118 mb (~200 mb in neutron emission)
(<1/5 of the visible cross section ➧ much less relevant than in Pb-Pb collisions!)



[1] I.A.Pshenichnov et al., Phys.Rev. C 60 044901 (1999)
[2] I.A.Pshenichnov, Phys. Part. Nuclei 42 215 (2011)

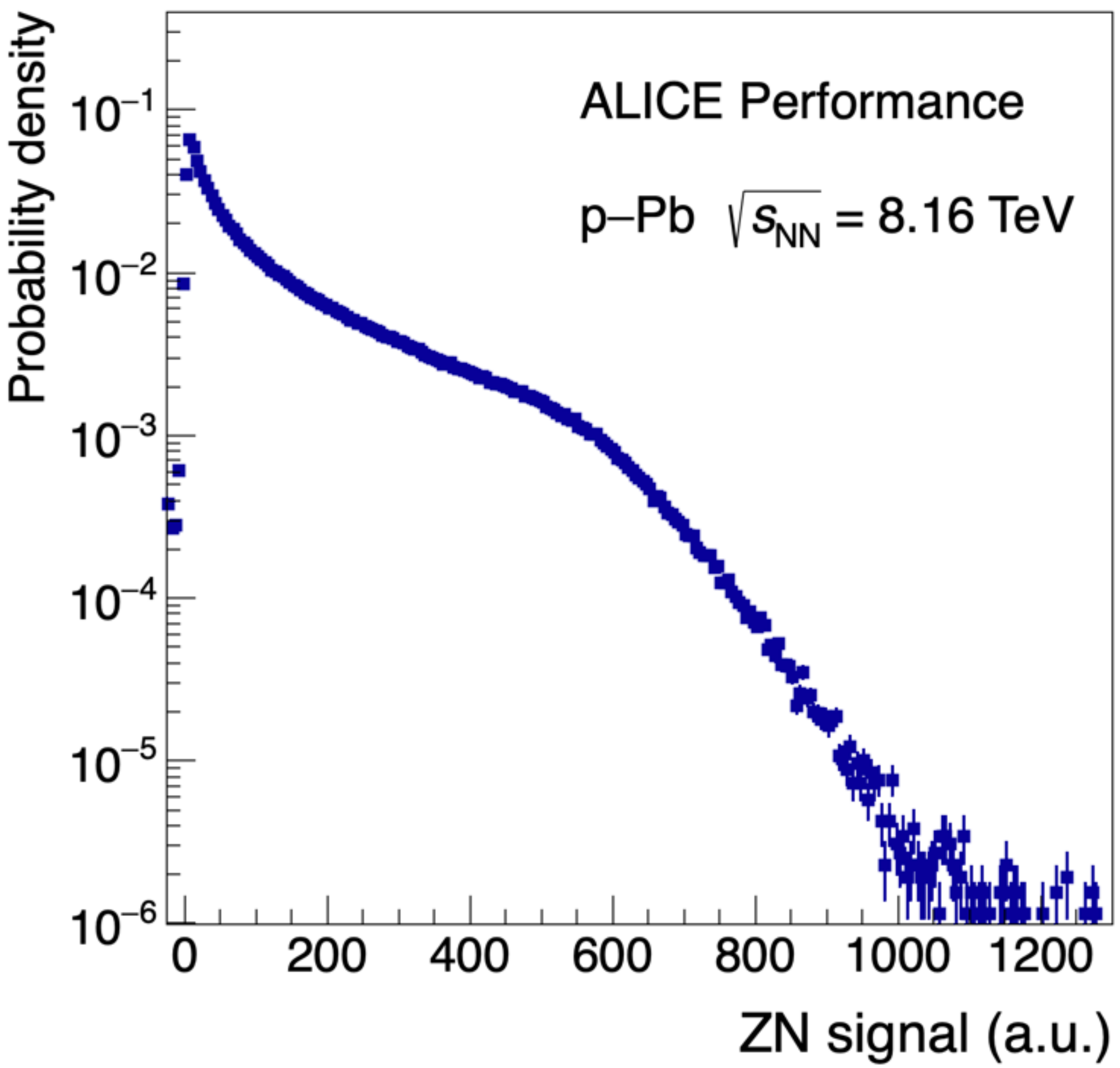
ZN spectra in p-Pb collisions

Pb fragmentation region ZDC



Pb fragmentation signal due to “slow” neutrons

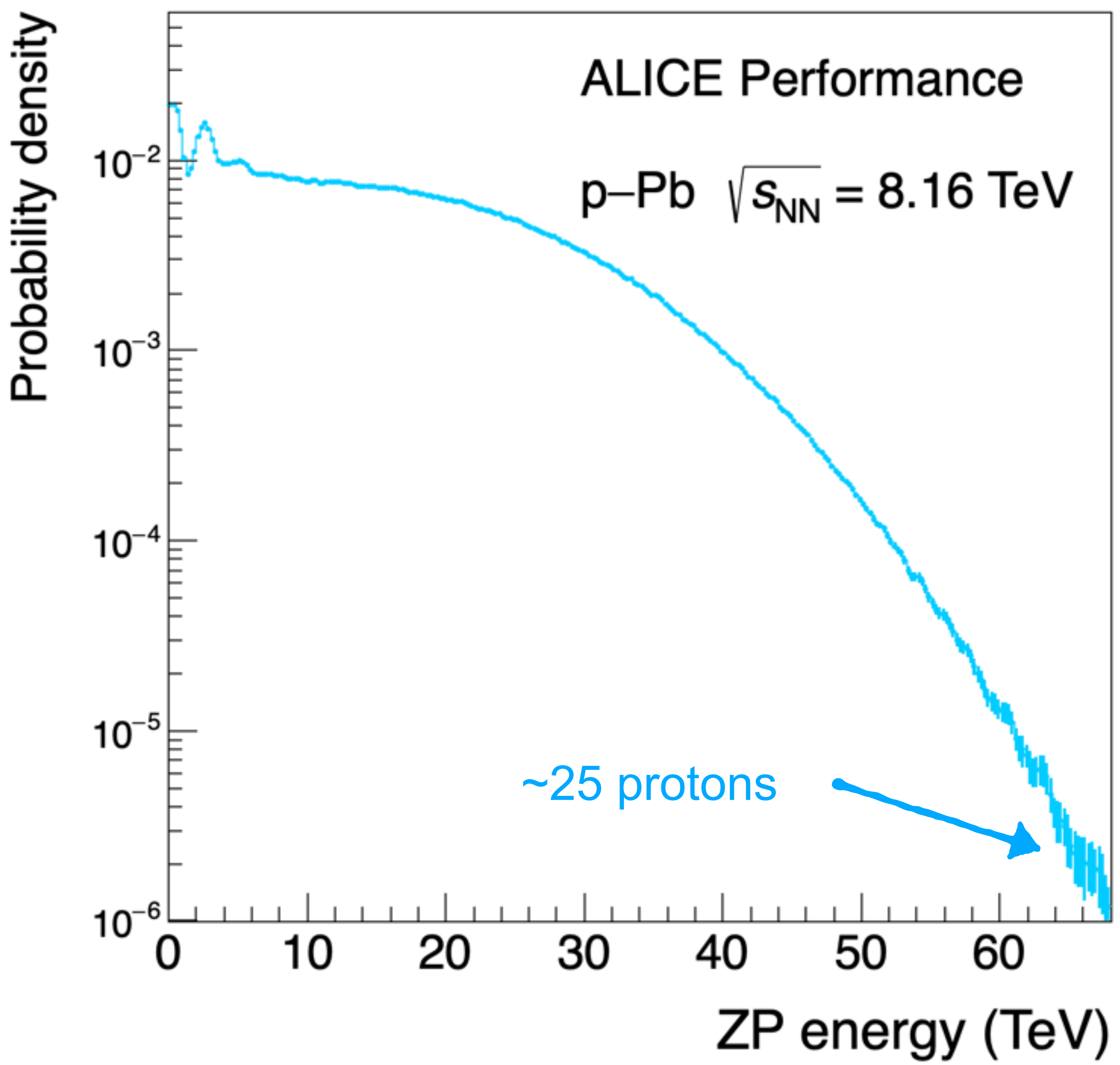
p fragmentation region ZDC



p fragmentation signal mainly due to leading n

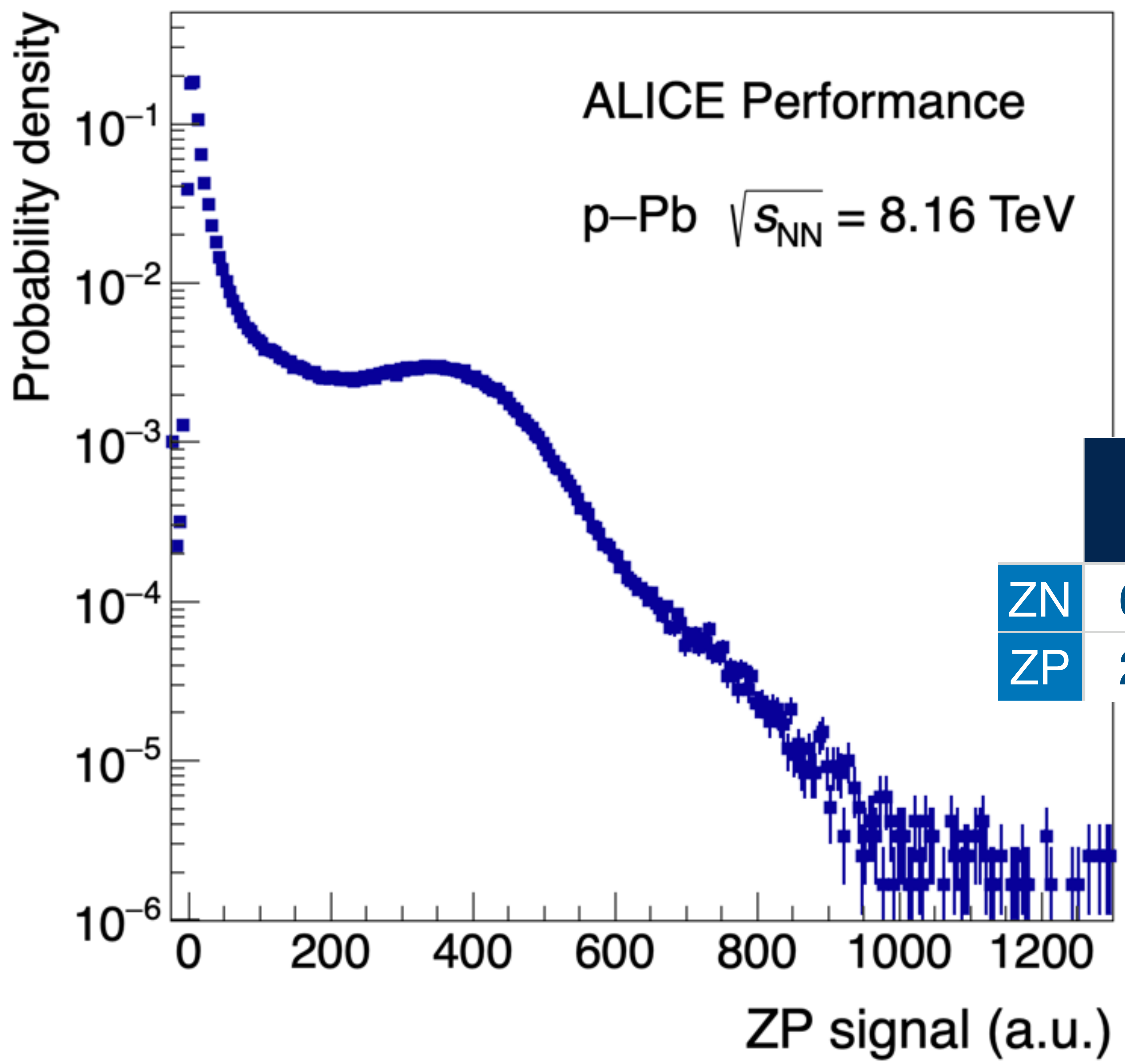
ZP spectra in p-Pb collisions

Pb fragmentation side ZDC



Pb fragmentation signal due to "slow" protons

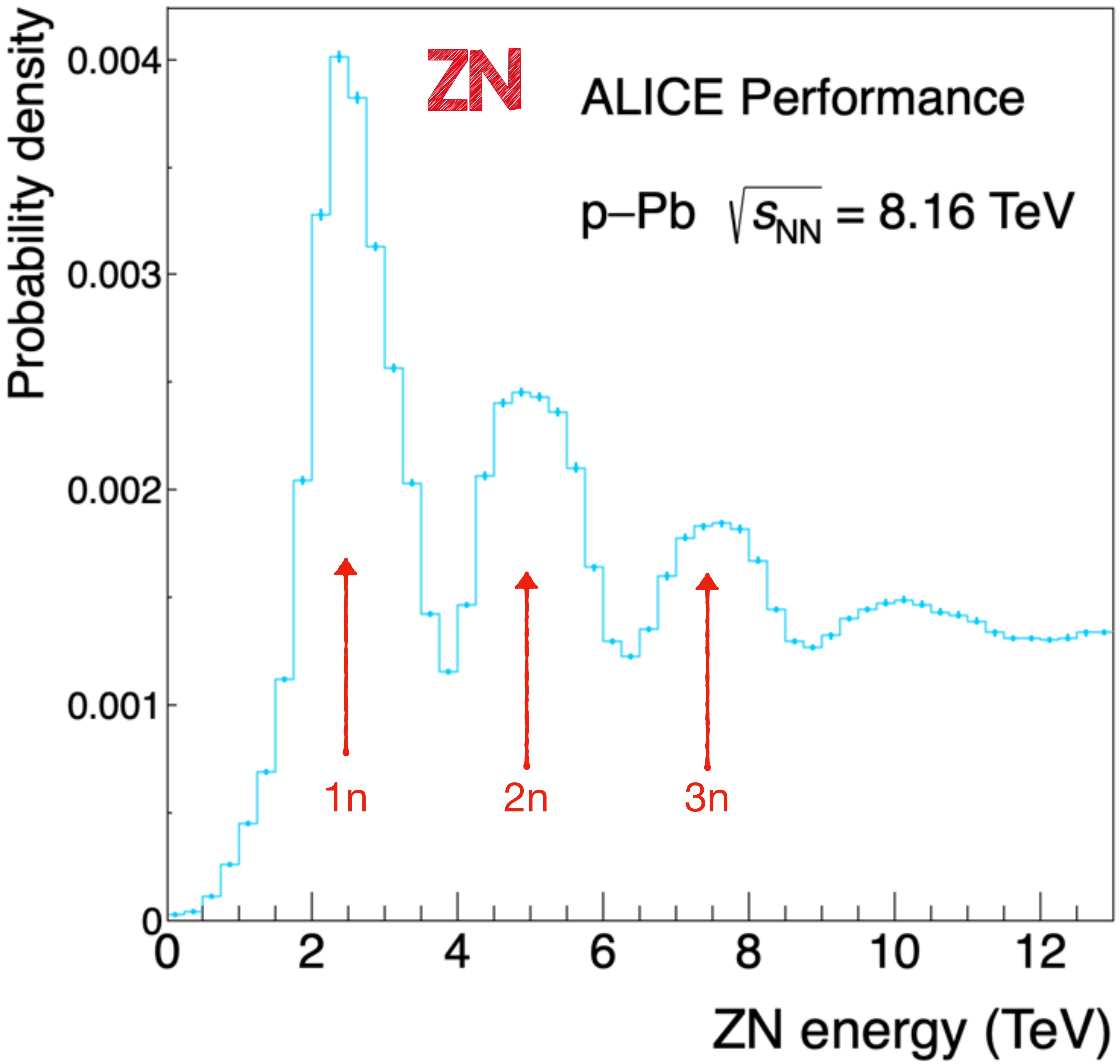
p fragmentation side ZDC

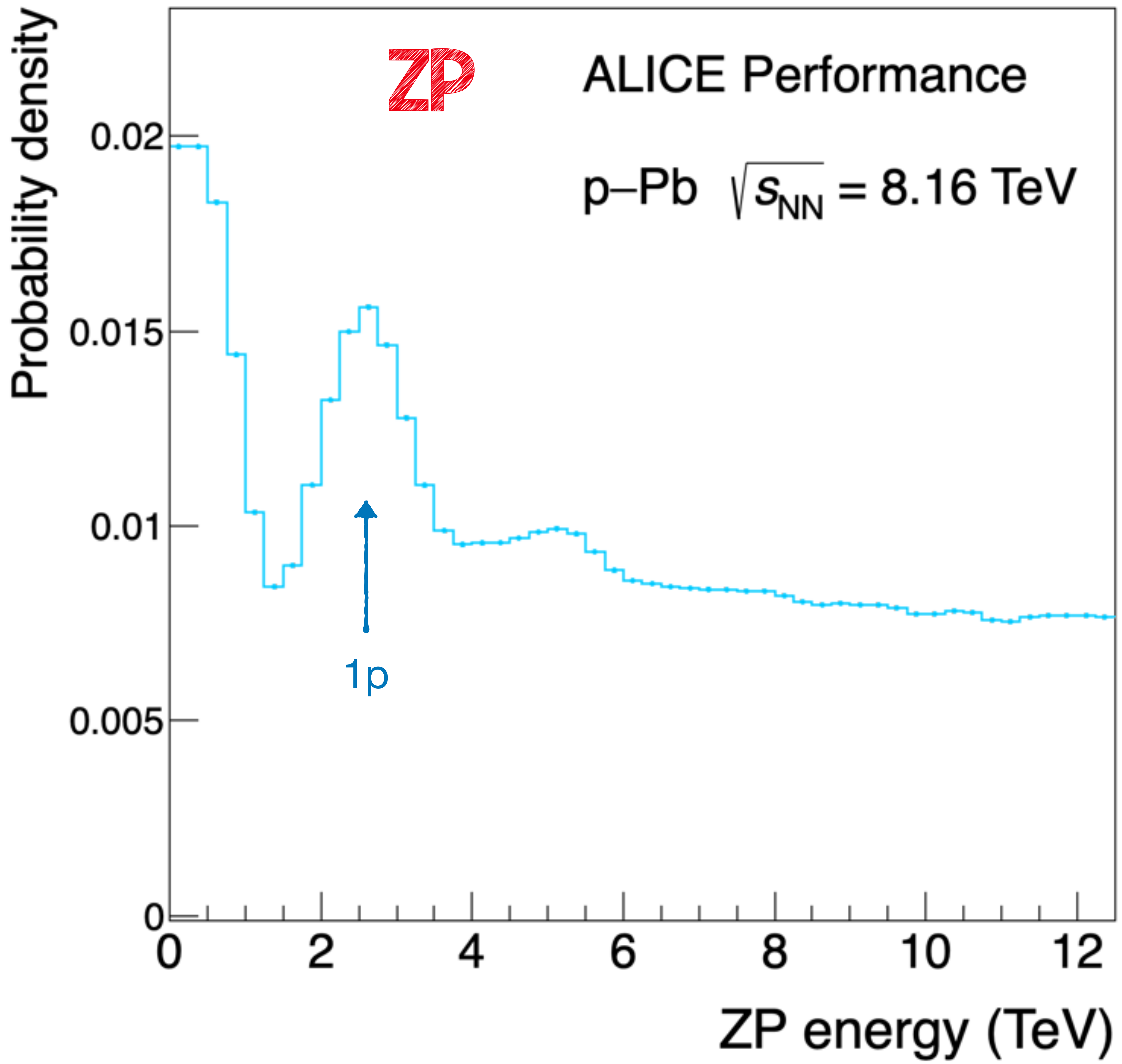


p fragmentation signal mainly due to protons

	pp	p-Pb (p side)	p-Pb (Pb side)
ZN	61%	43%	96%
ZP	23%	15%	82%

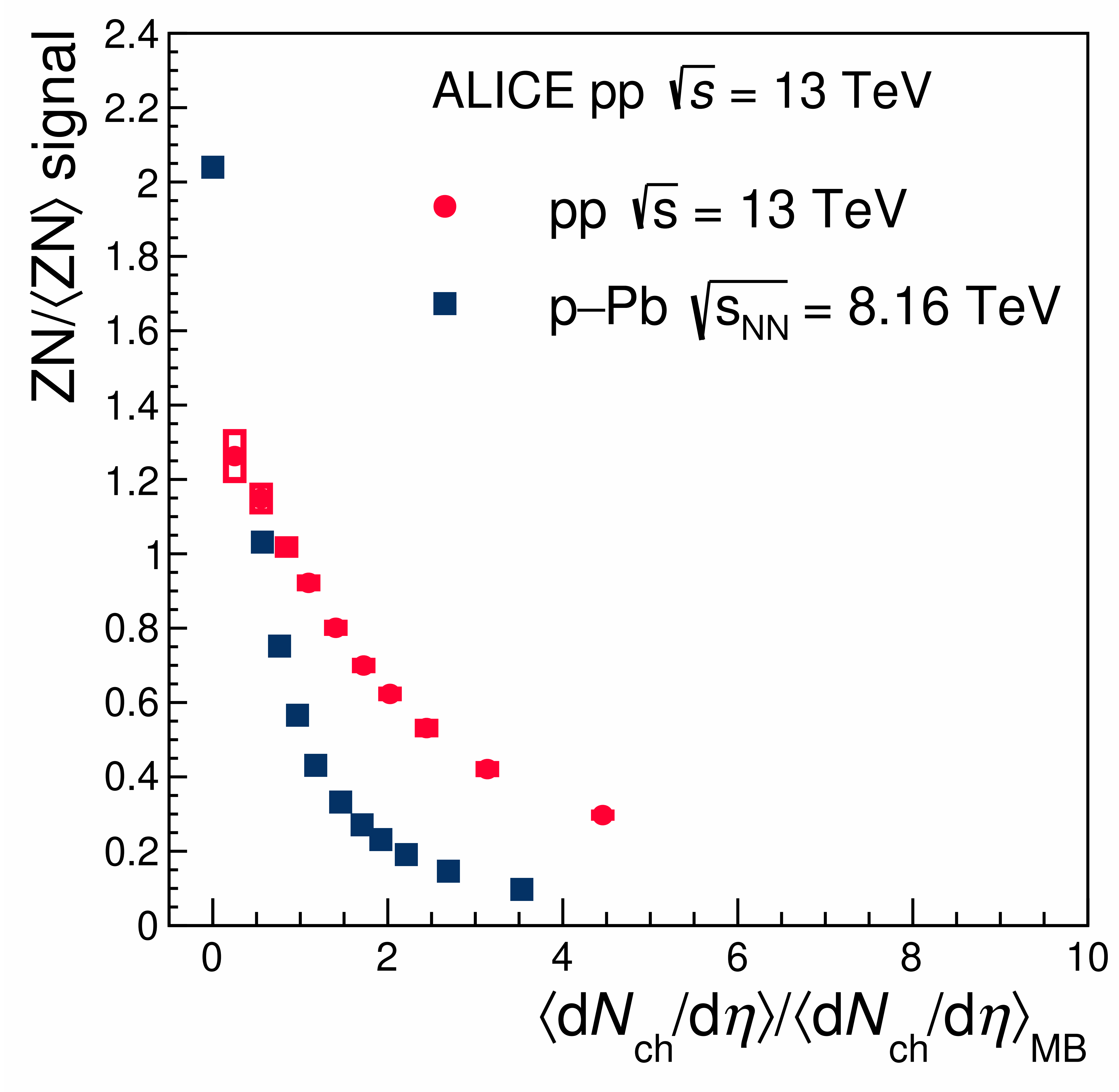
Energy calibration in the Pb-fragmentation region

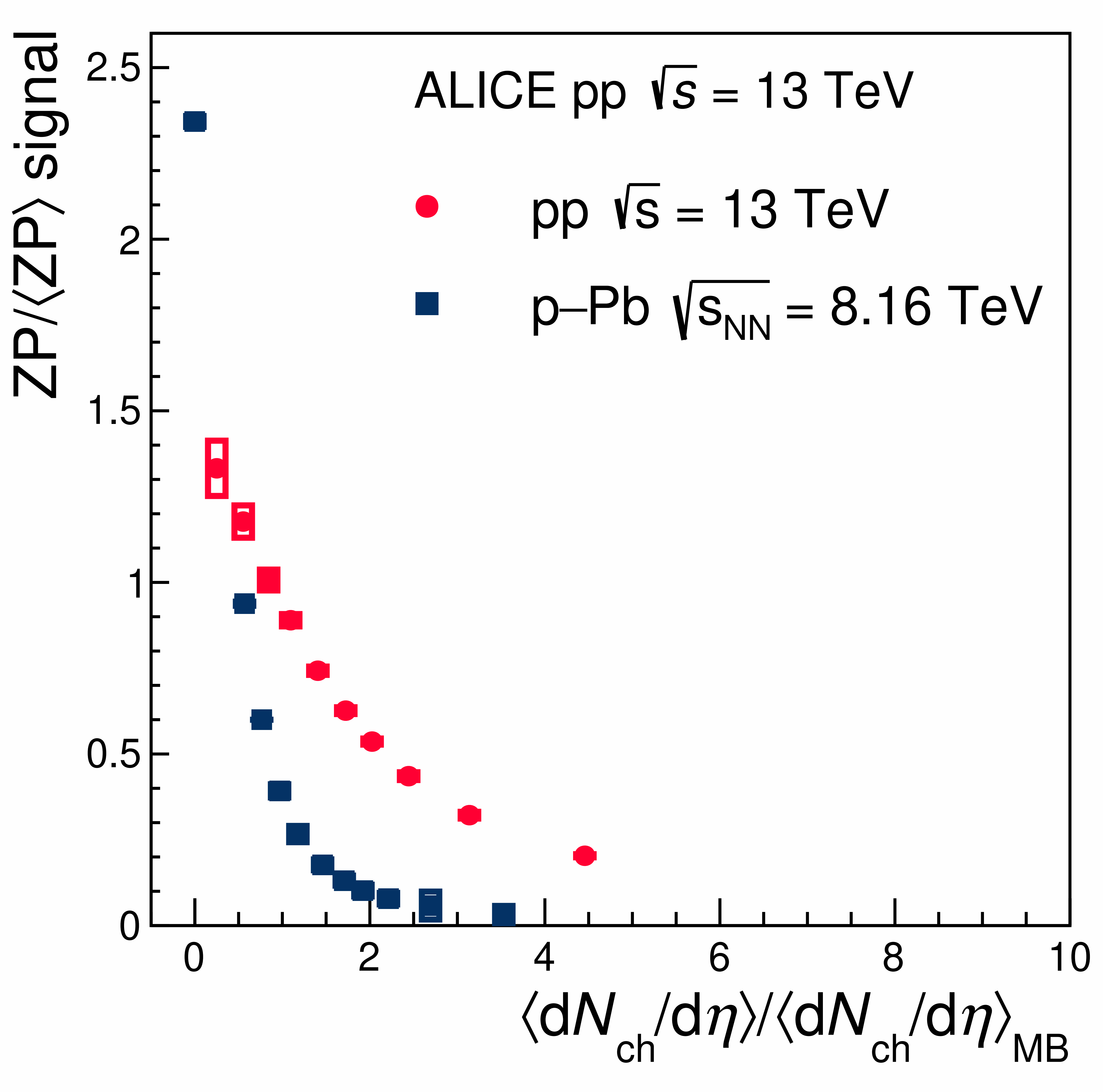




➧ Single nucleon peaks are used to calibrate in energy the ZN and ZP spectra on the Pb-fragmentation side

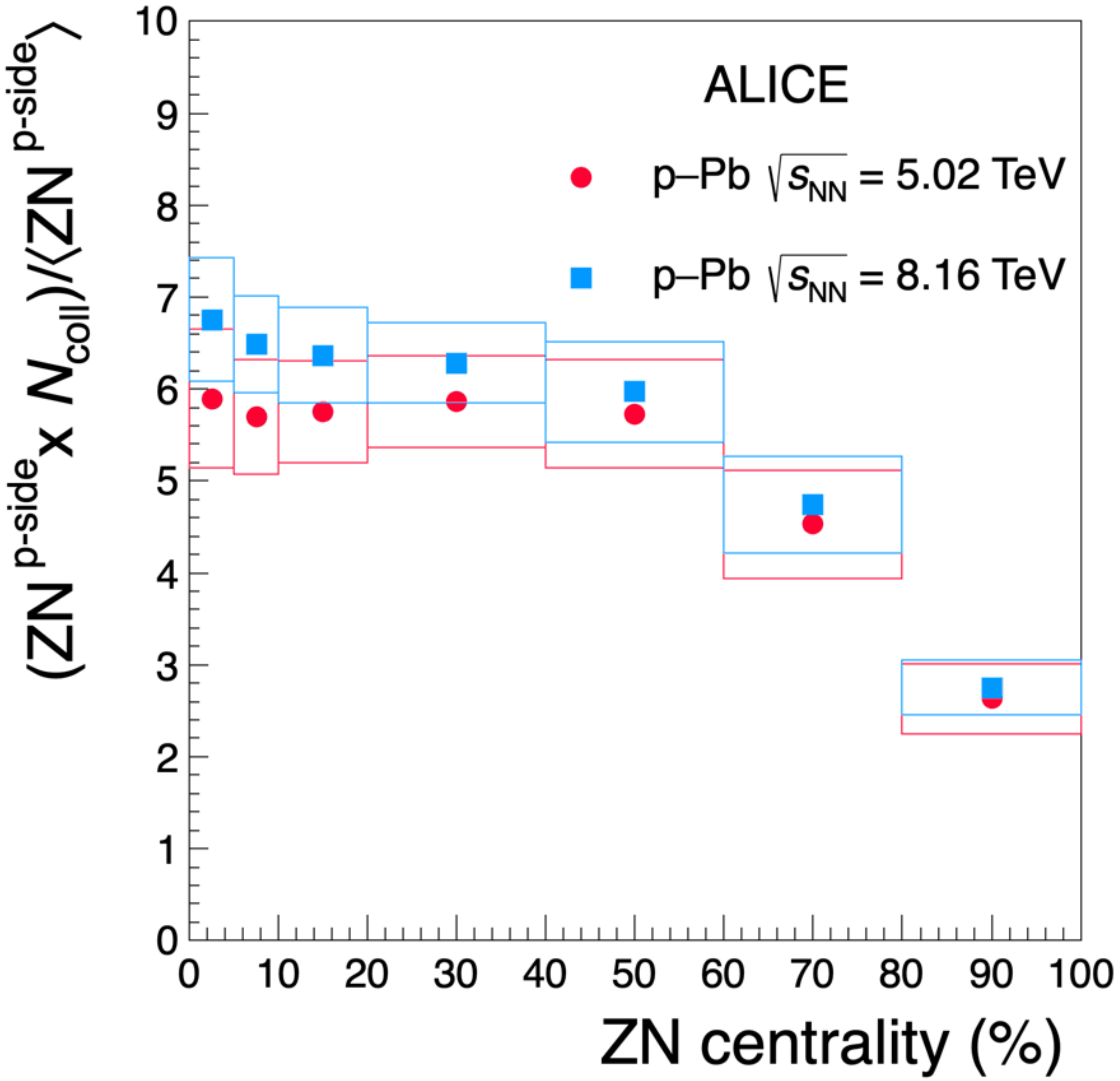
Very forward energy vs. Midrapidity multiplicity

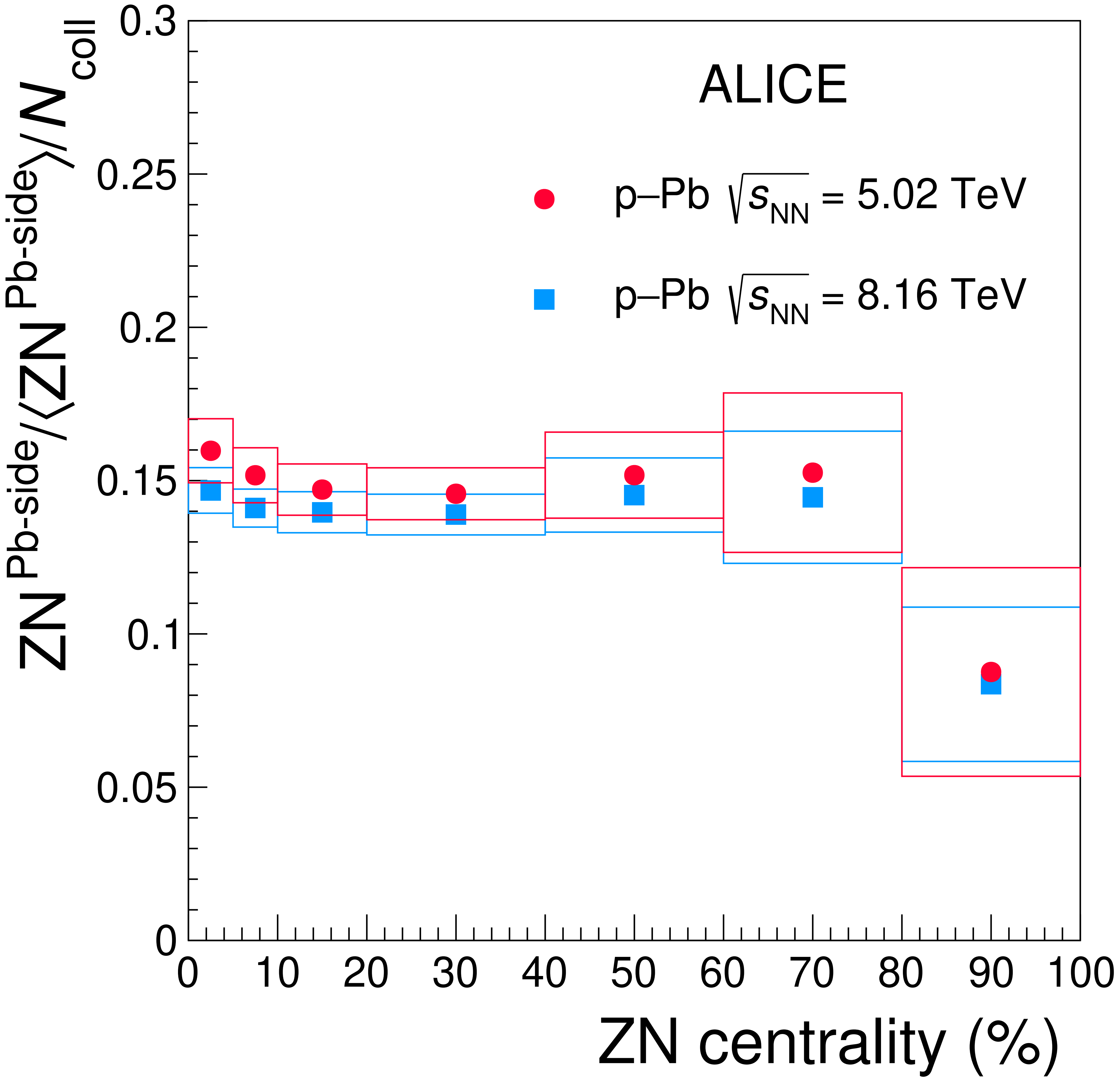




N_{coll} scaling in p-Pb collisions

- neutral forward energy in p-fragmentation region decreases with centrality ~$1/N_{coll}$ for central collisions
- neutral forward energy in Pb-fragmentation region increases with centrality ~N_{coll} over a wide centrality range

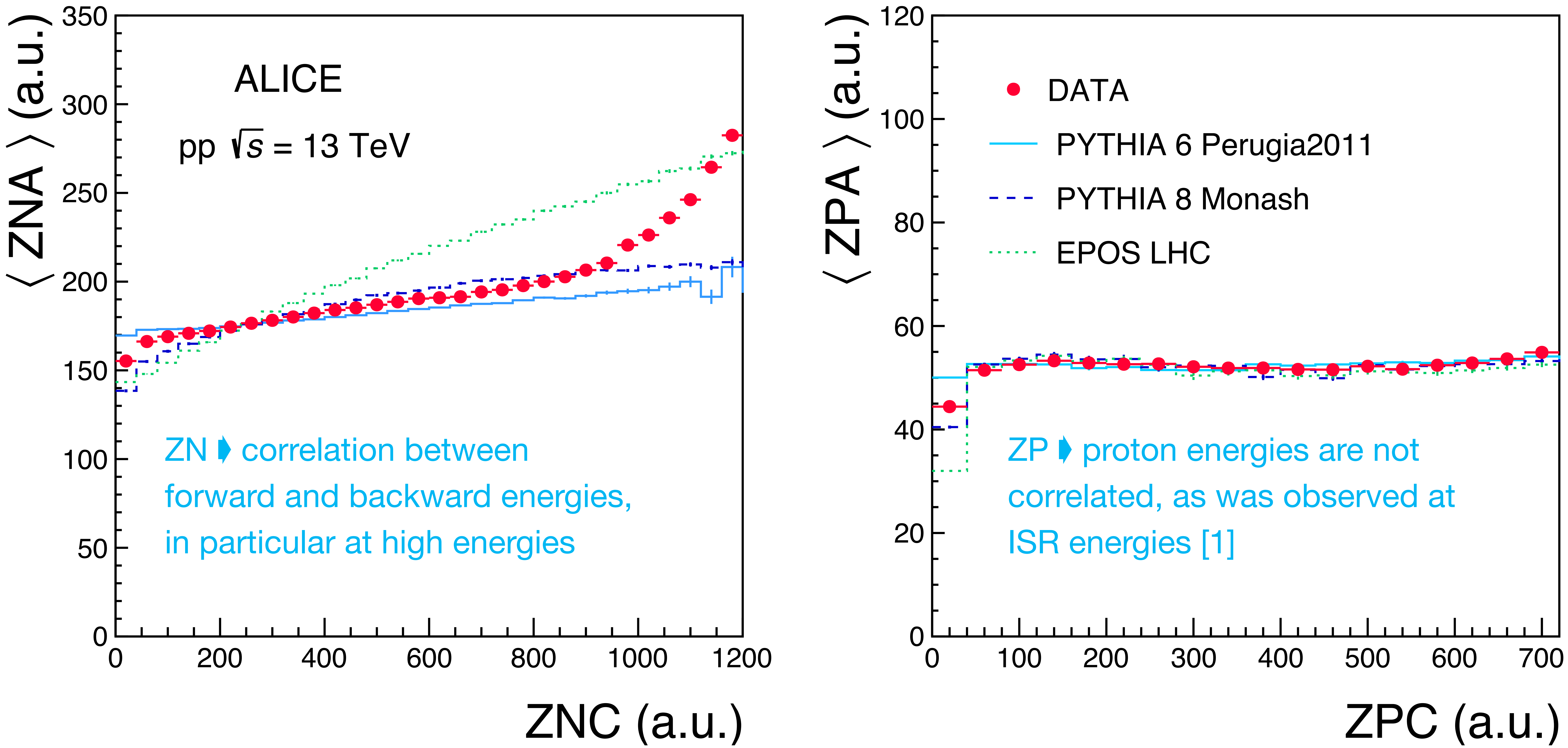




Forward-backward correlation in pp collisions

Average signal on one side as a function of the signal on the other side

ALICE Coll., JHEP08 (2022) 086



Models predict a flat behaviour for ZP in agreement with data, but are not able to reproduce quantitatively the measured ZN dependence over the whole range

[1] M. Basile et al., Nuovo Cim. 353 A 73 (1983) 329