Charged-particle production in different collision systems up to very high p_T measured with ALICE

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for the ALICE collaboration

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Introduction

recent ALICE publication:

- charged-particle production at LHC for most Run 1 & 2 collision systems: arXiv:2211.15326 (submitted to PLB)

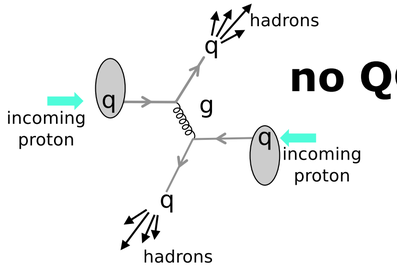
- fundamental observables:
  - multiplicity (N_{ch}) distributions
  - multiplicity dependent transverse momentum (p_T) spectra

MC event generators:

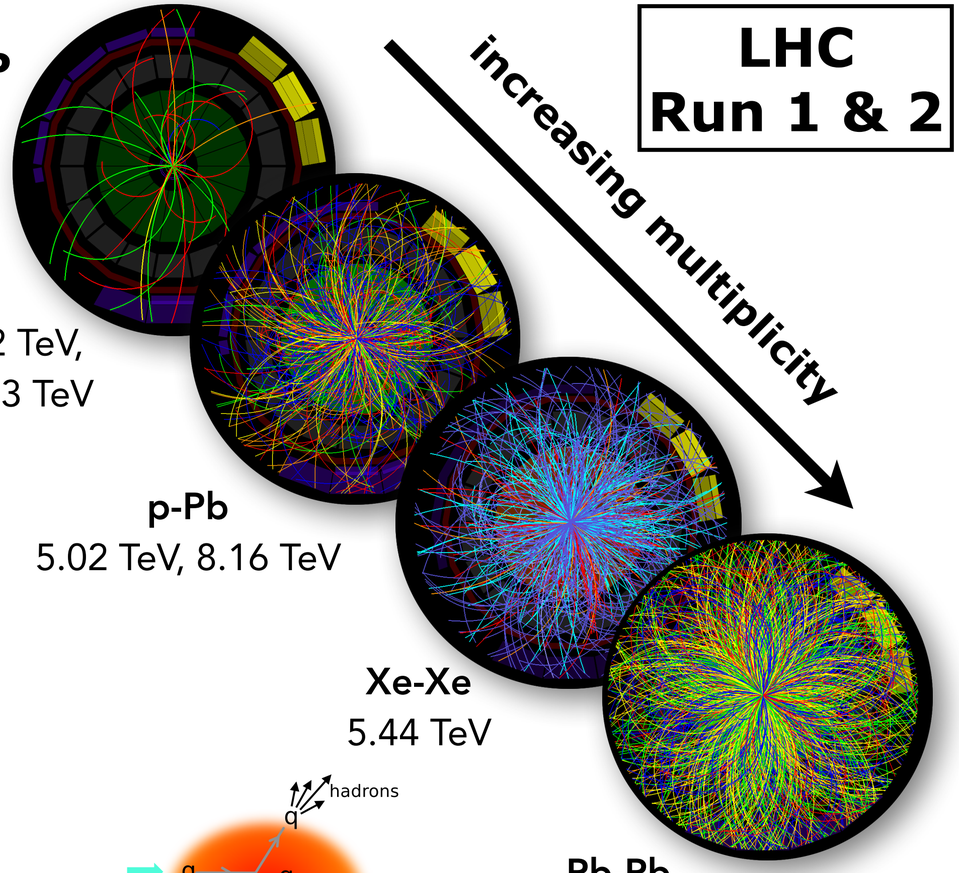
- alternative approaches:
  - strings and no QGP (PYTHIA)
  - QGP / hydro. flow also in small systems (EPOS)

- challenge to describe all systems in same framework

- need precise measurements for tuning



no QGP

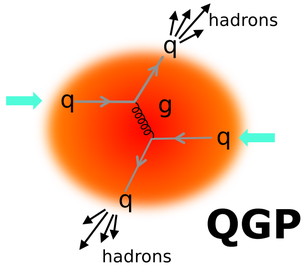


pp
2.76 TeV, 5.02 TeV,
8 TeV, 7 TeV, 13 TeV

p-Pb
5.02 TeV, 8.16 TeV

Xe-Xe
5.44 TeV

Pb-Pb
2.76 TeV, 5.02 TeV



QGP

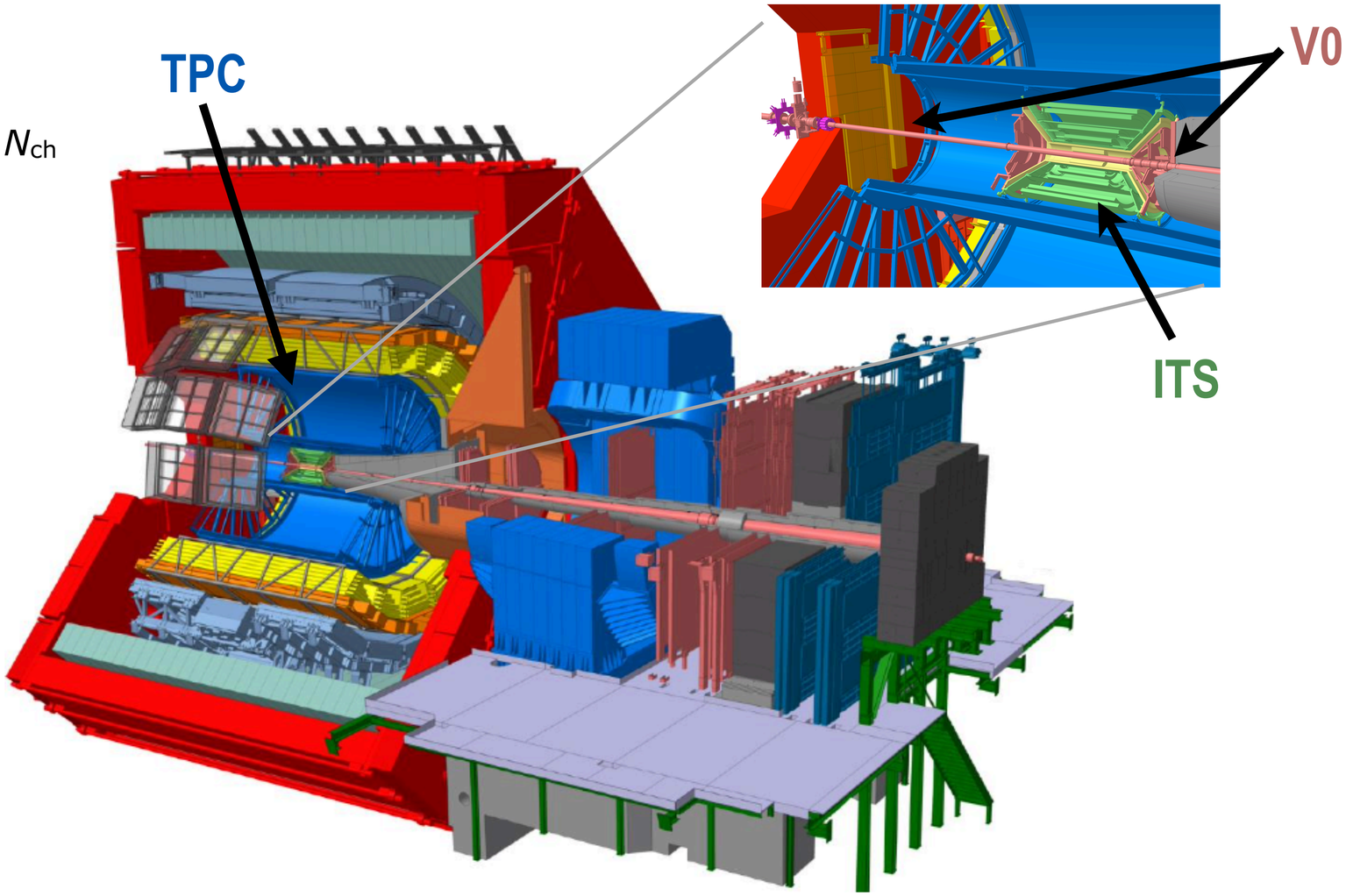
modified from A. Kalweit, QM18 ALICE plenary talk

ALICE Detector

- dedicated heavy-ion experiment with good p_T resolution also for large N_{ch}
- tracking capabilities in central barrel from very low to very high p_T (this work: 0.15 GeV/c — 10 GeV/c)

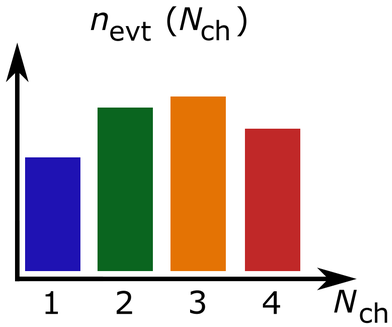
detectors used in this work:

- MB trigger:
  - V0 system
- charged-particle reconstruction:
  - Inner Tracking System (ITS)
  - Time Projection Chamber (TPC)



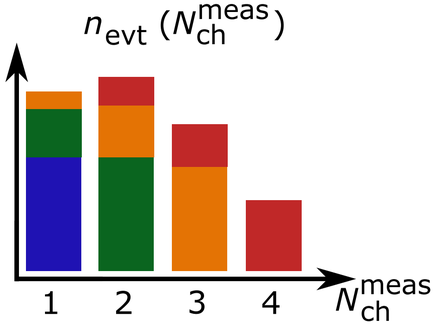
Experimental Challenge

- correlation of p_T spectra with true multiplicity cannot be measured directly due to detector effects
- idea: employ 2D-unfolding
- raw observable:
  track yield as a function of
  track multiplicity
- final observable:
  multiplicity and p_T-differential yield
  of primary charged particles

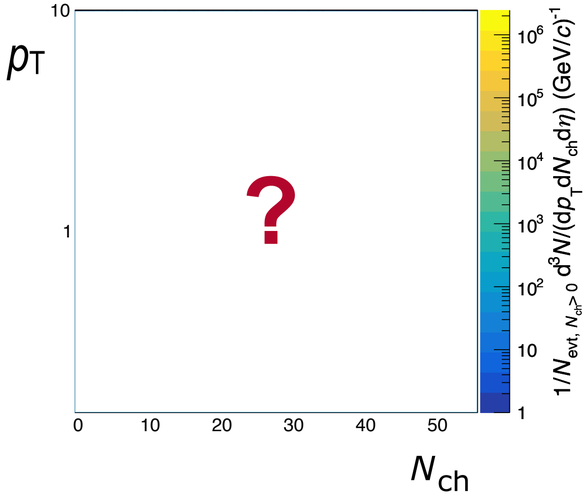


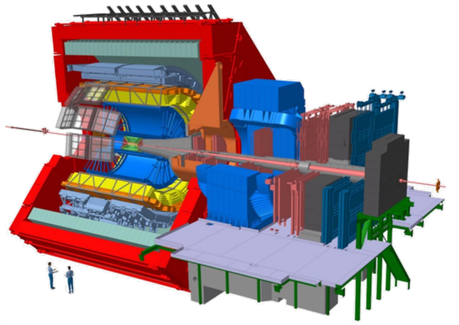
true

detector response

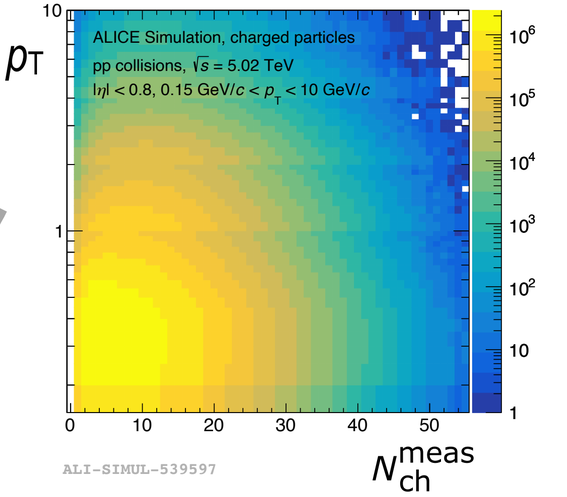


measured



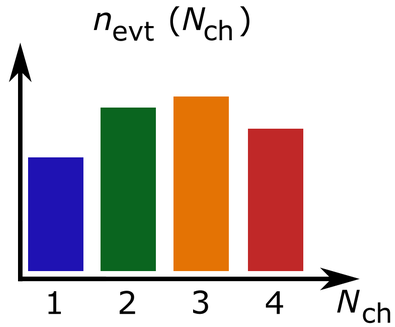


unfolding



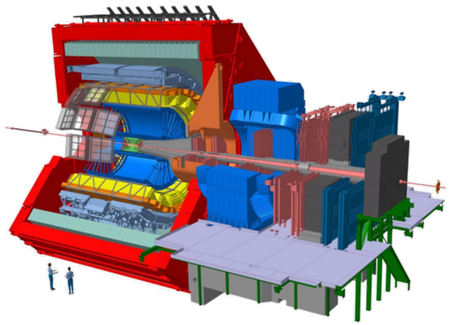
Experimental Challenge

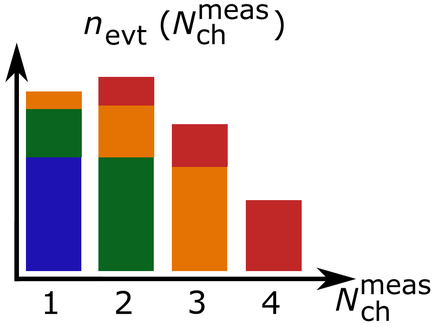
unfolding
multiplicity distributions



true

detector response





measured

unfolding

Iterative D`Agostini Unfolding

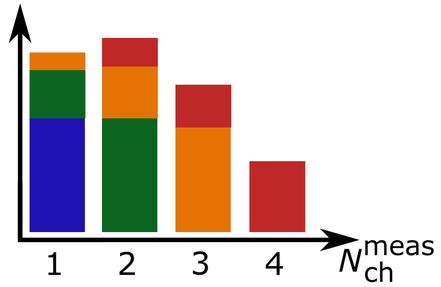
Detector response

$N_{\mathrm{ch}} \rightarrow N_{\mathrm{ch}}^{\mathrm{meas}}$

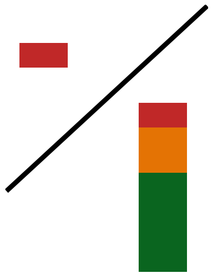
Initial guess for true distribution

Iteratively use Bayes' theorem

Measured distribution



Composition of measurement

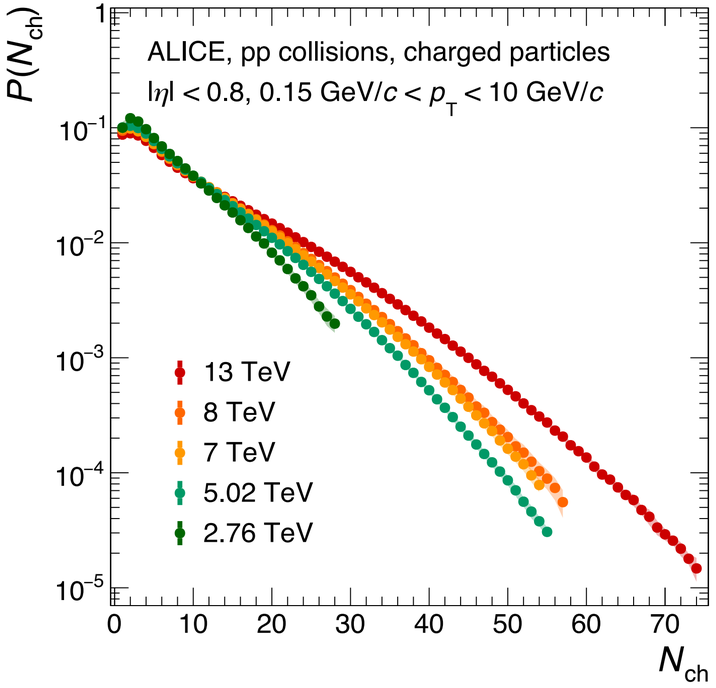


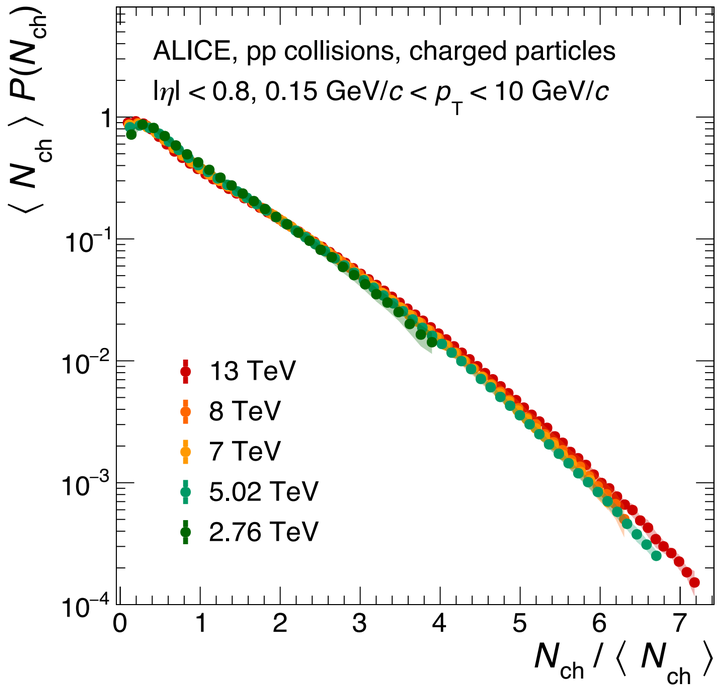
$N_{\mathrm{ch}}^{\mathrm{meas}} \rightarrow N_{\mathrm{ch}}$

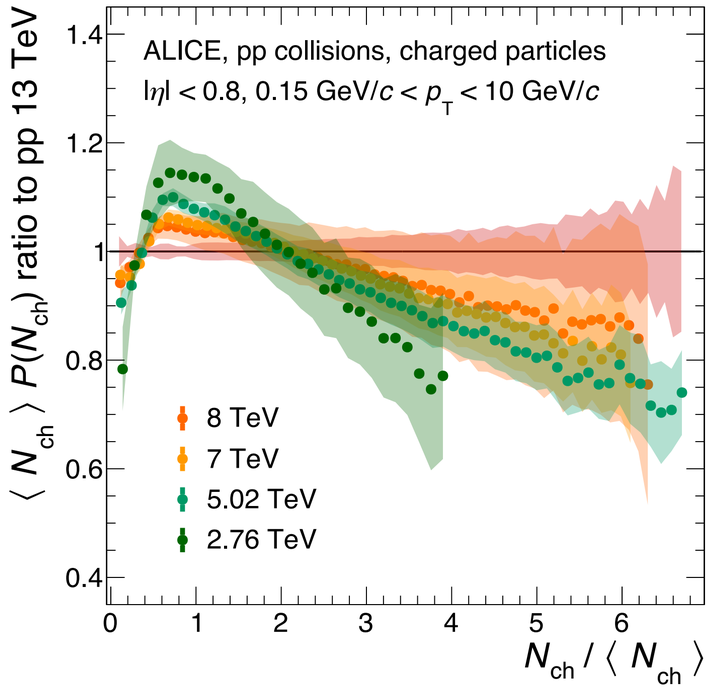
G D'Agostini, Nucl. Instr. Meth. Phys. Res. A 362 (1995) 487-498

Multiplicity Distributions in pp

arXiv:2211.15326







- clear centre-of-mass energy ordering of unfolded multiplicity distributions
- KNO-scaled distributions for the different energies align within 20%

KNO Scaling

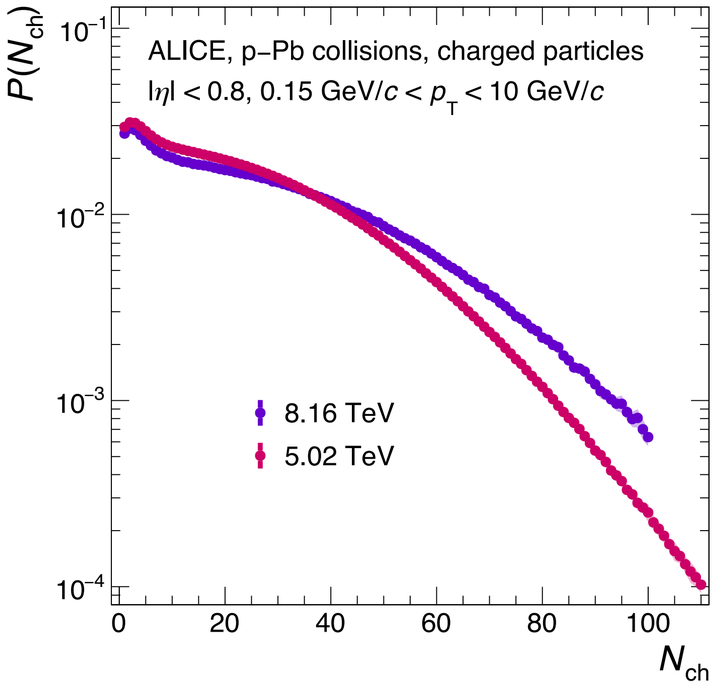
$$N_{ch} \rightarrow N_{ch} / \langle N_{ch} \rangle$$

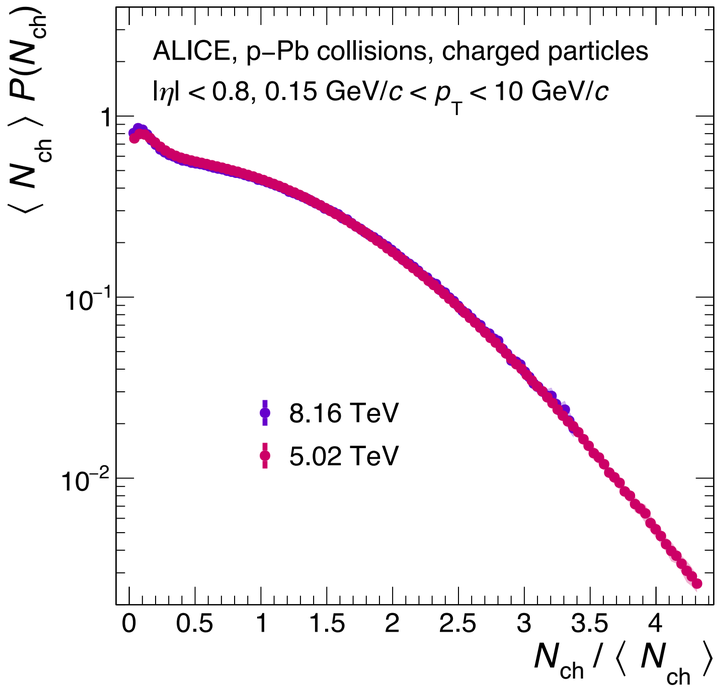
$$P(N_{ch}) \rightarrow \langle N_{ch} \rangle \cdot P(N_{ch})$$

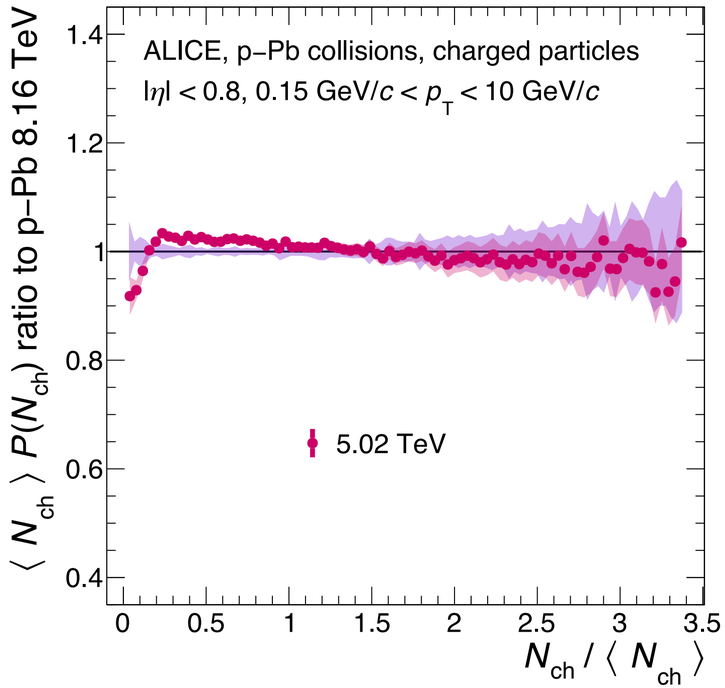
Koba Z., Nielsen H. B., Olesen P., Nuclear Physics B 40 (1972) 317

Multiplicity Distributions in p–Pb

arXiv:2211.15326







- first time to employ the KNO-scaling also in p–Pb
- KNO-scaled distributions for the two energies agree within 10%

KNO Scaling

$$N_{ch} \rightarrow N_{ch} / \langle N_{ch} \rangle$$

$$P(N_{ch}) \rightarrow \langle N_{ch} \rangle \cdot P(N_{ch})$$

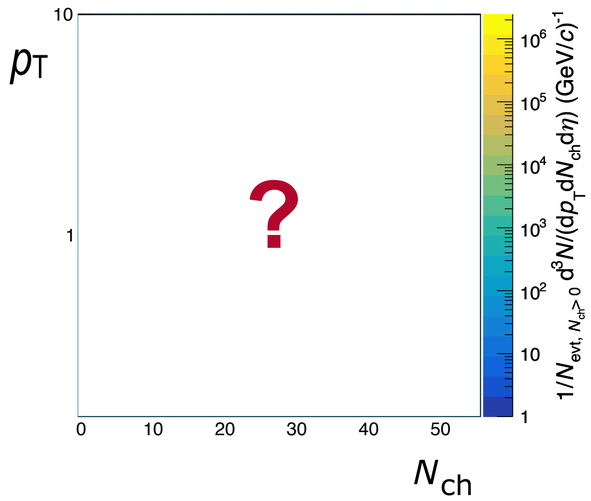
Koba Z., Nielsen H. B., Olesen P., Nuclear Physics B 40 (1972) 317

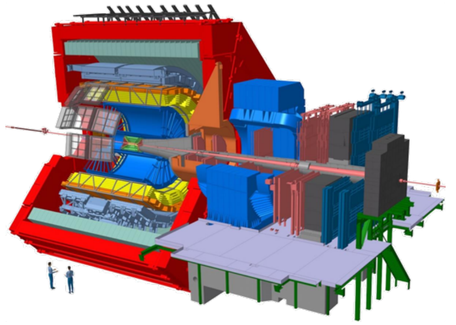
Experimental Challenge

unfolding
multiplicity dependent
p_T spectra

detector response

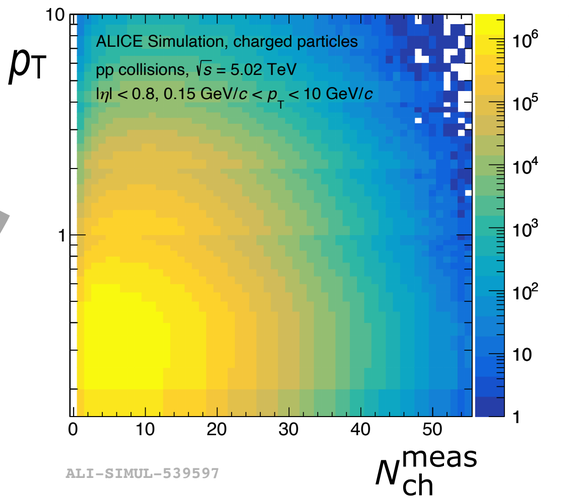
true



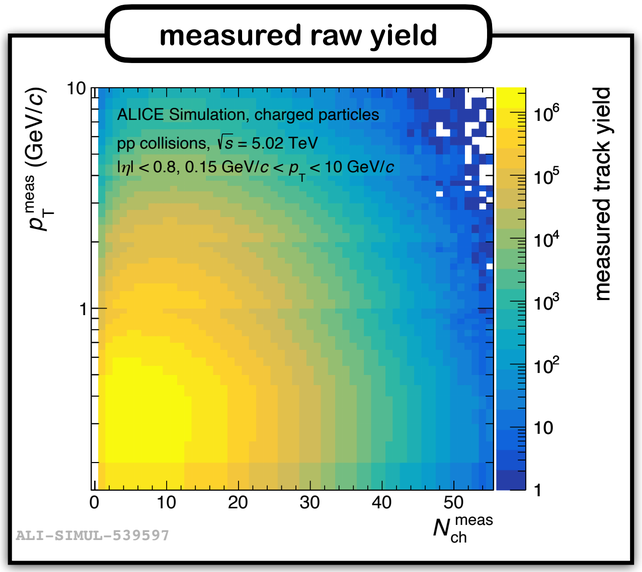


unfolding

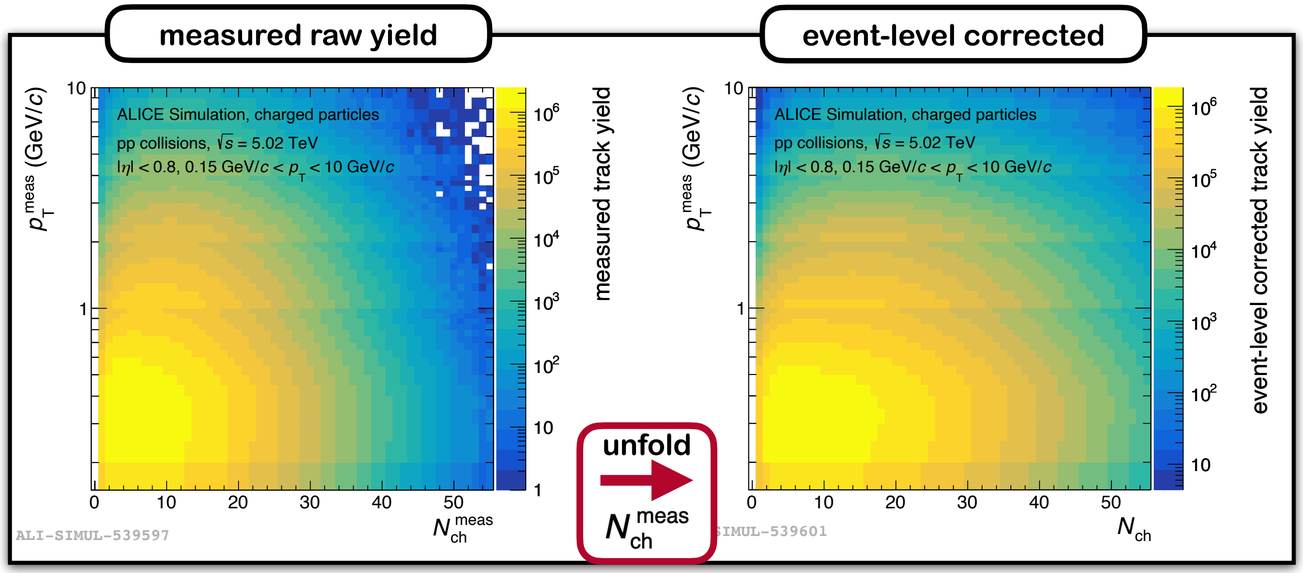
measured



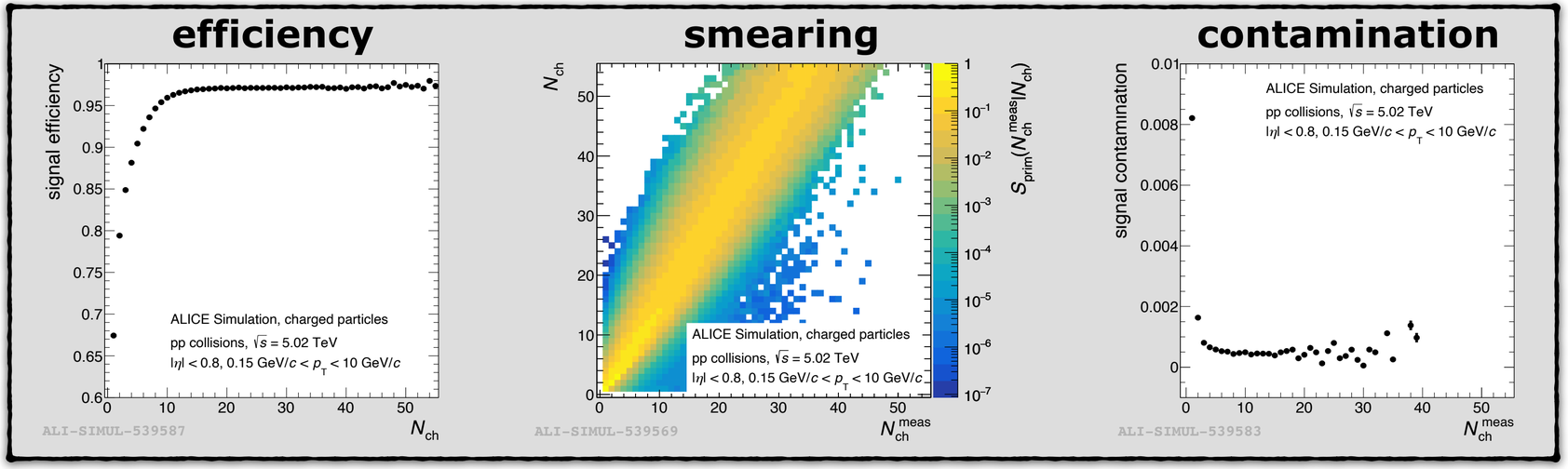
Sequential 2D Unfolding



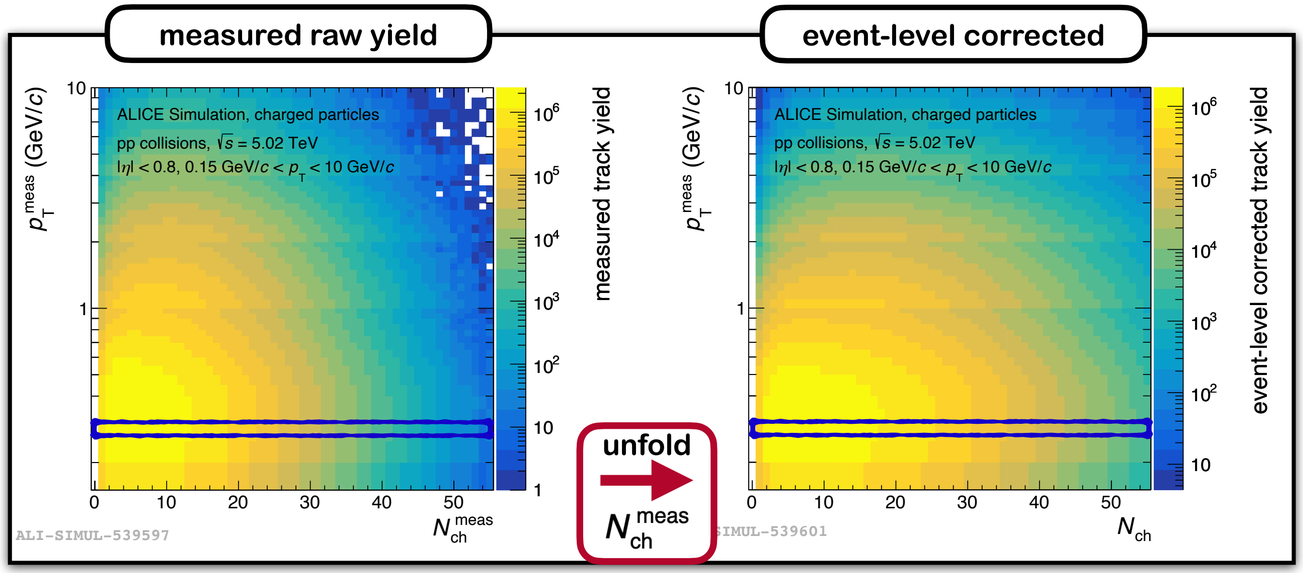
Sequential 2D Unfolding

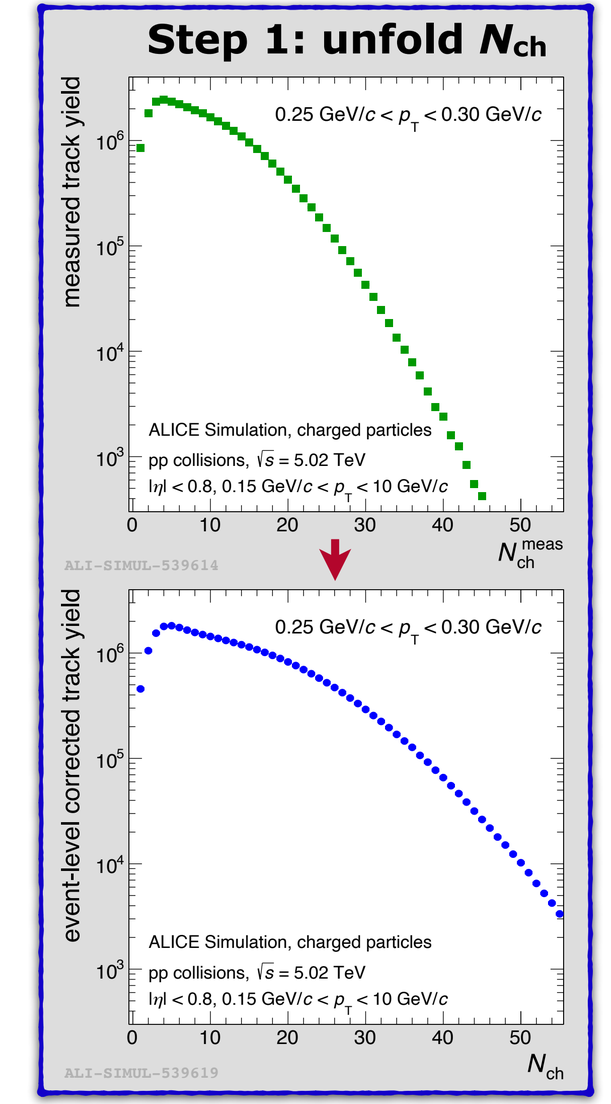


input for unfolding

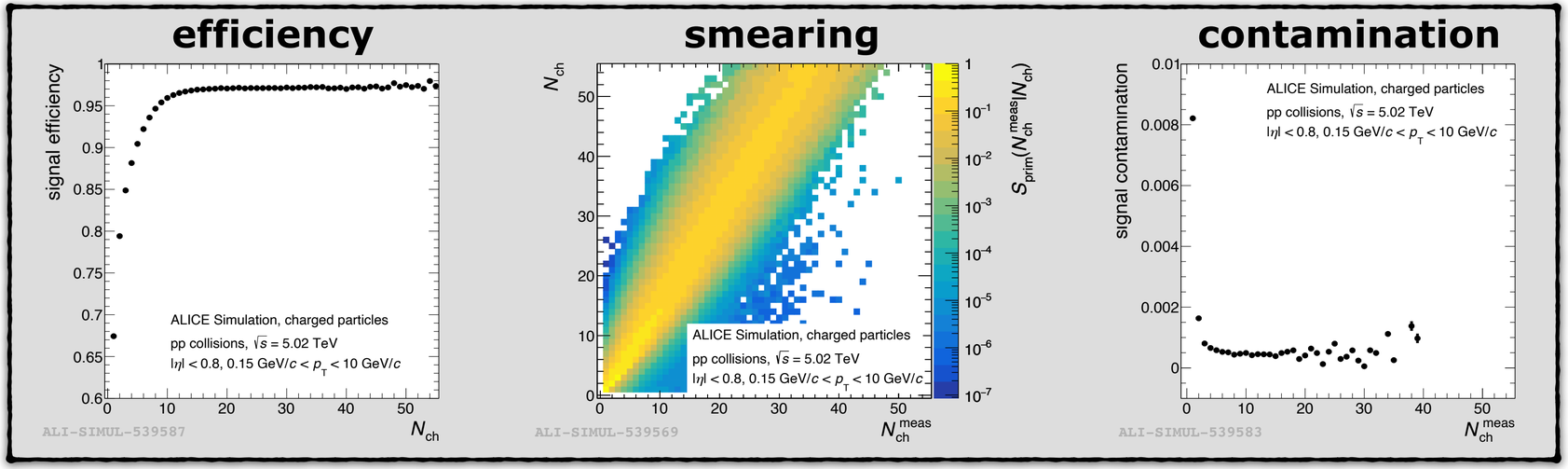


Sequential 2D Unfolding



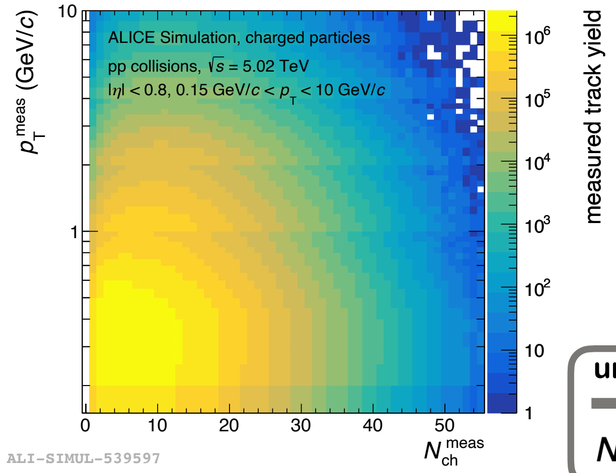


input for unfolding



Sequential 2D Unfolding

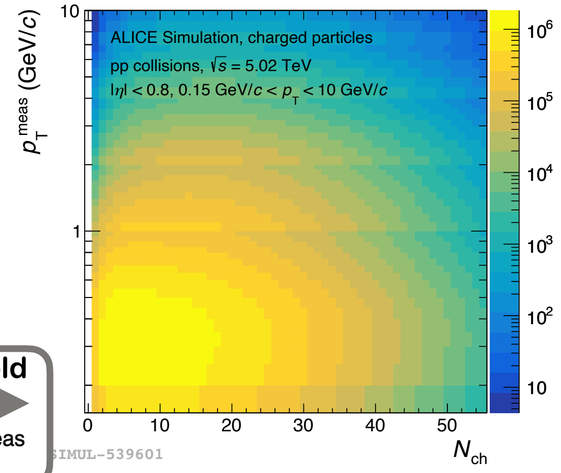
measured raw yield



measured track yield

unfold N_{ch}^{meas}

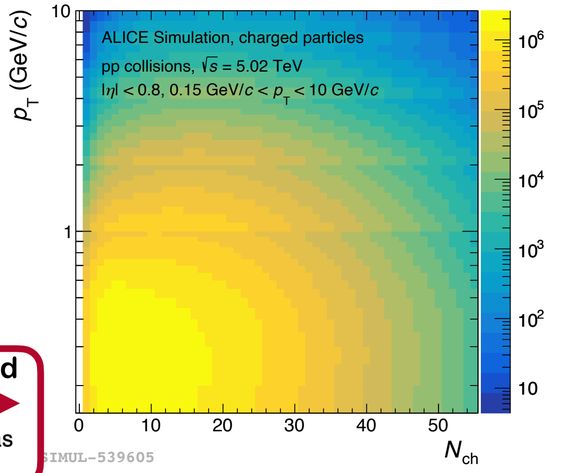
event-level corrected



event-level corrected track yield

unfold p_T^{meas}

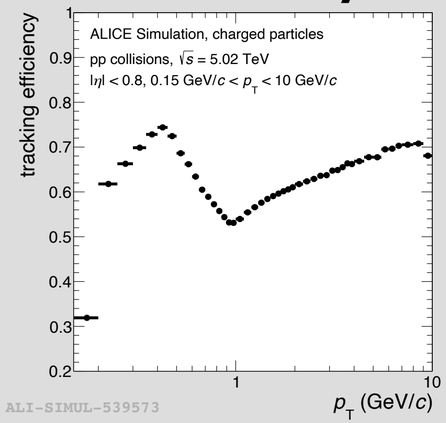
fully corrected



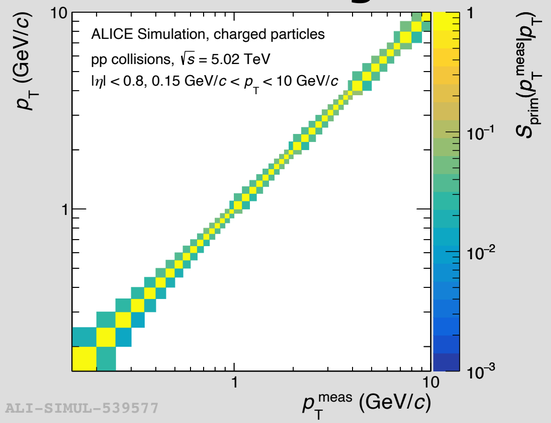
fully corrected yield

input for unfolding

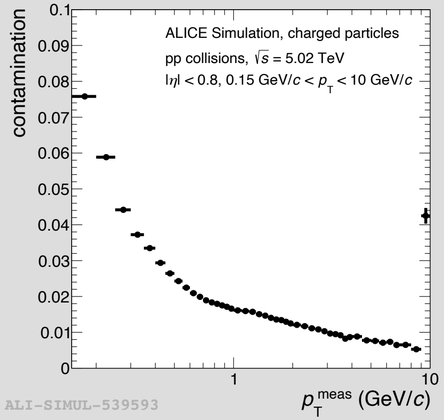
efficiency



smearing

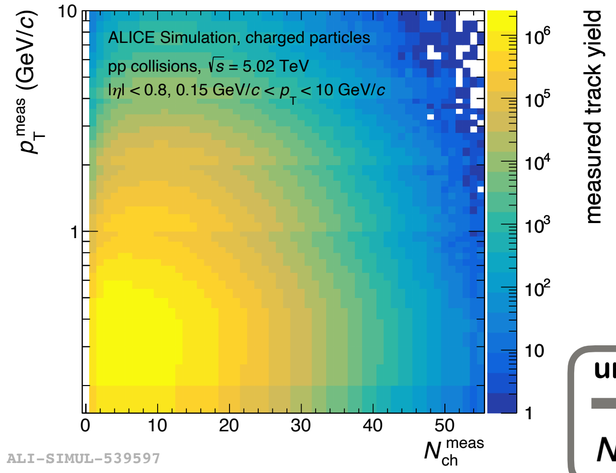


contamination



Sequential 2D Unfolding

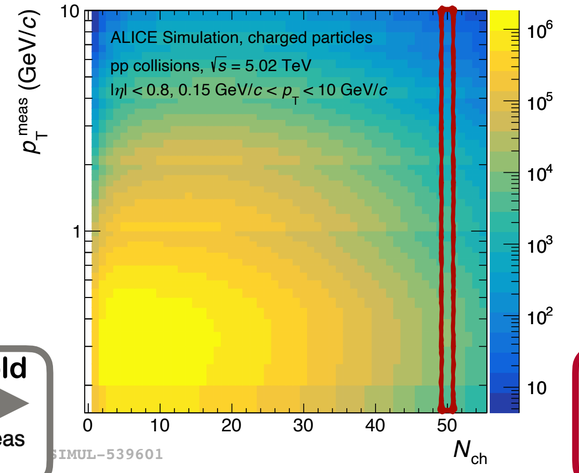
measured raw yield



measured track yield

unfold N_{ch}^{meas}

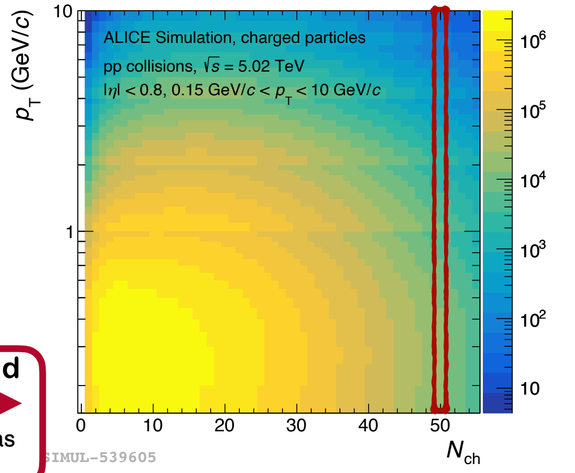
event-level corrected



event-level corrected track yield

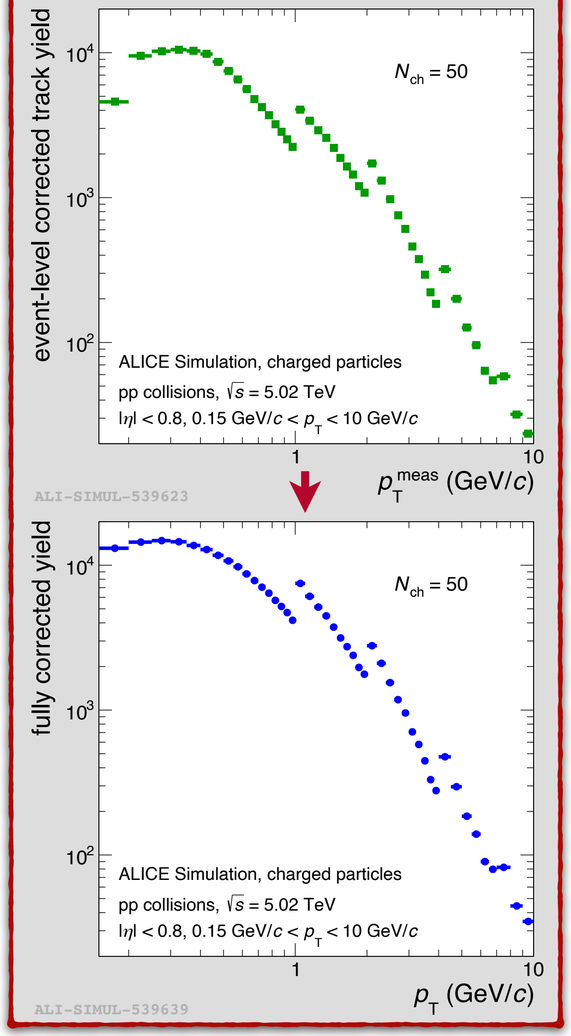
unfold p_T^{meas}

fully corrected



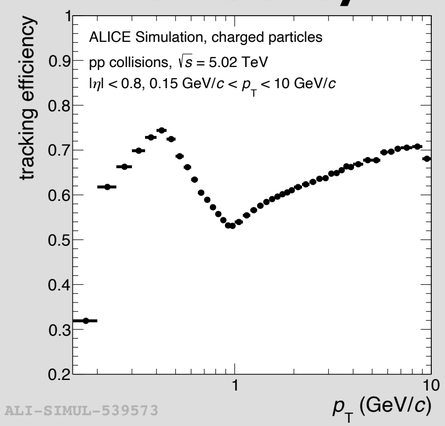
fully corrected yield

Step 2: unfold p_T

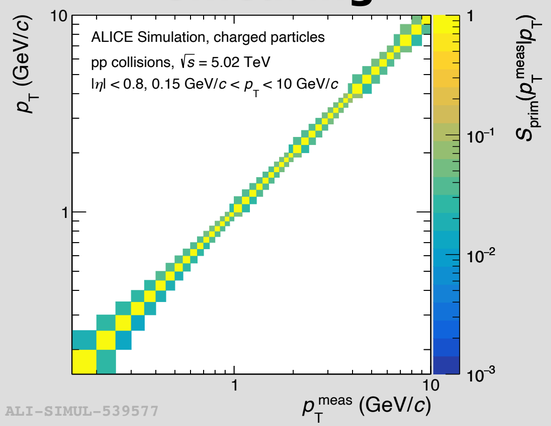


input for unfolding

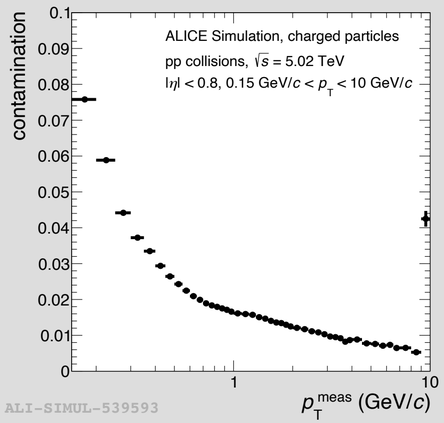
efficiency



smearing

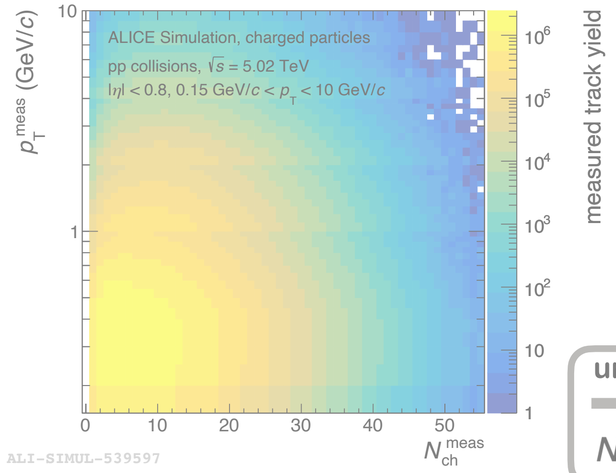


contamination



Sequential 2D Unfolding

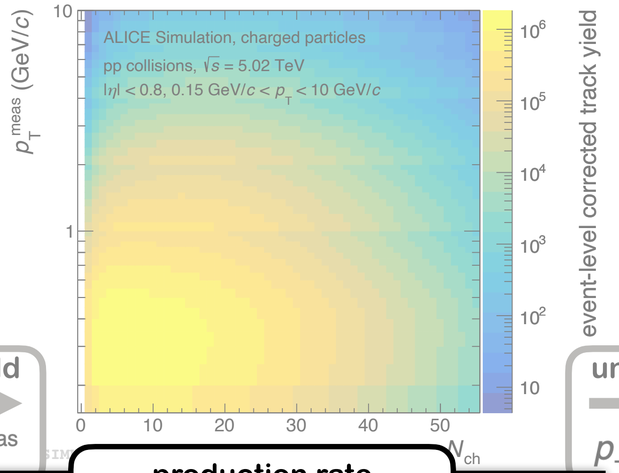
measured raw yield



unfold

N_{ch}^{meas}

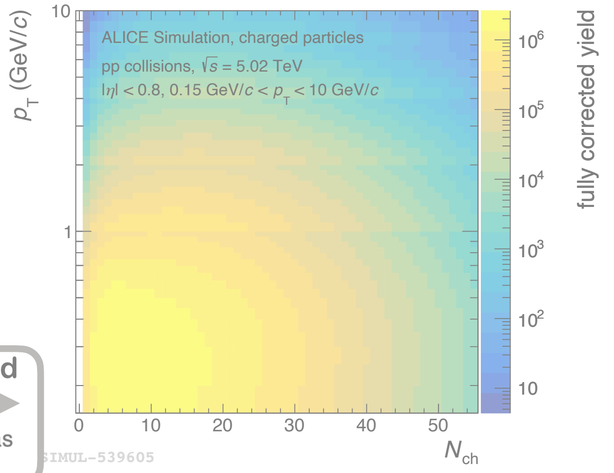
event-level corrected



unfold

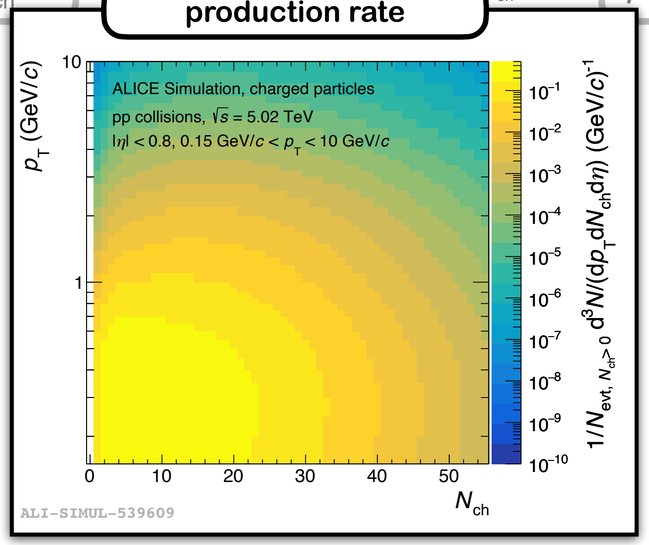
p_T^{meas}

fully corrected



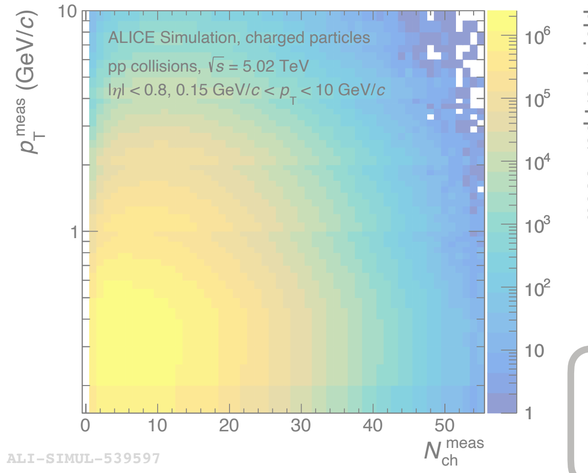
norm

production rate



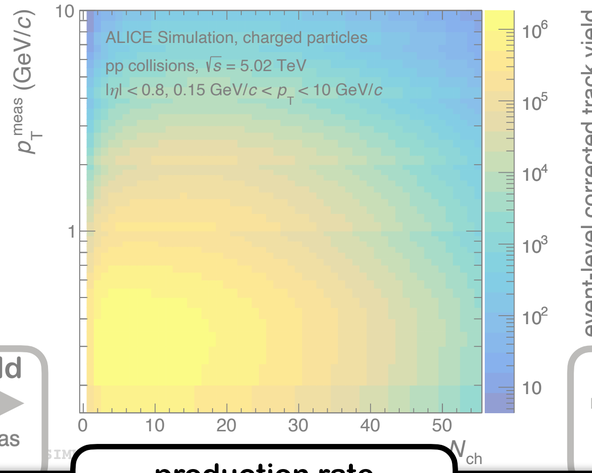
Sequential 2D Unfolding

measured raw yield



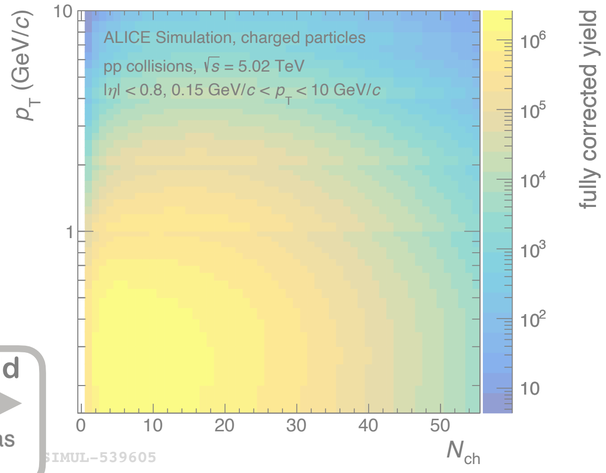
unfold → N_{ch}^{meas}

event-level corrected



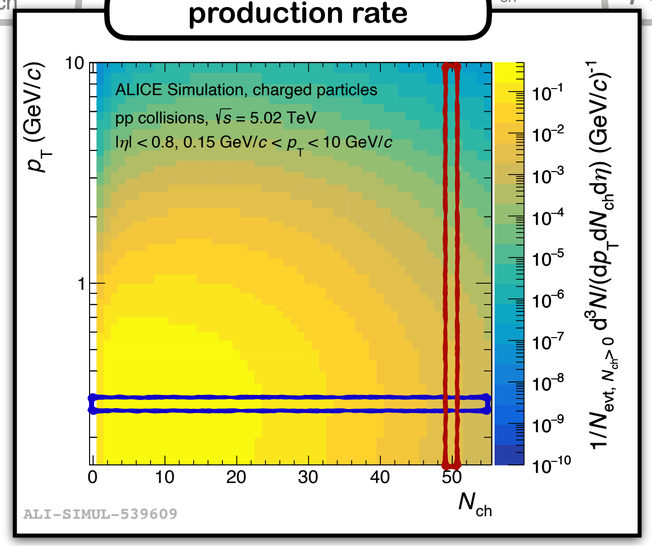
unfold → p_T^{meas}

fully corrected

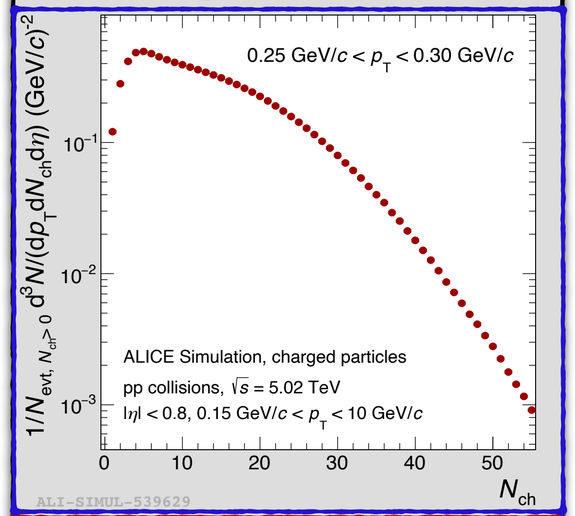


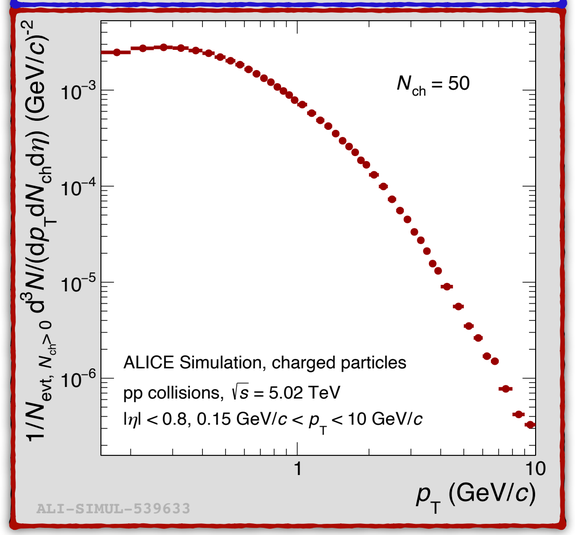
norm →

production rate

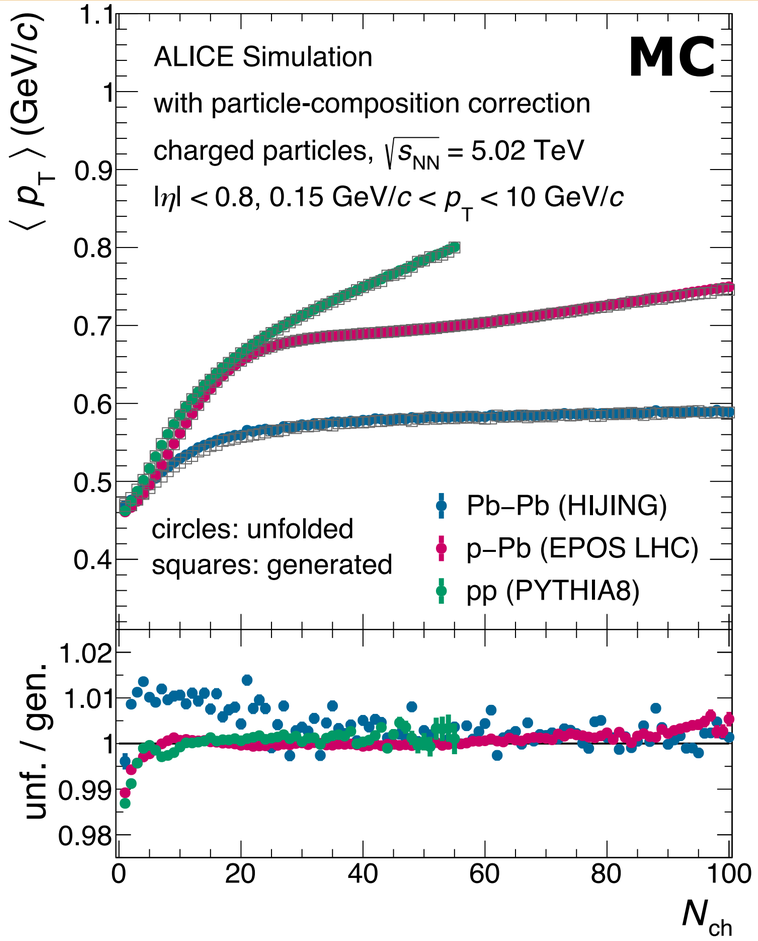


Step 3: normalize

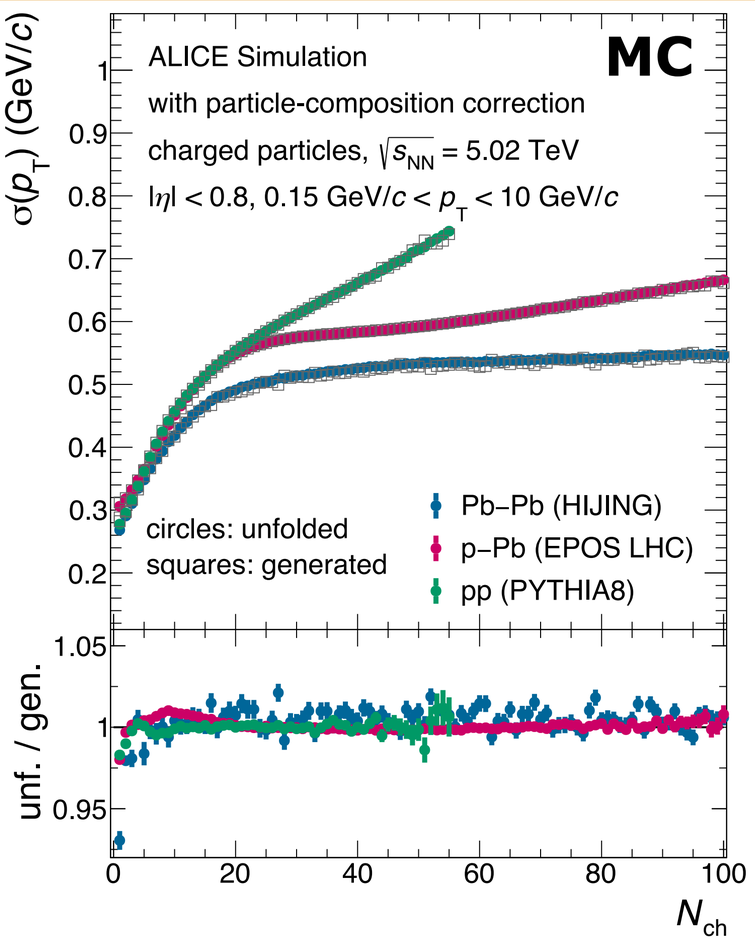




Method Validation — Closure Test



<p_T>

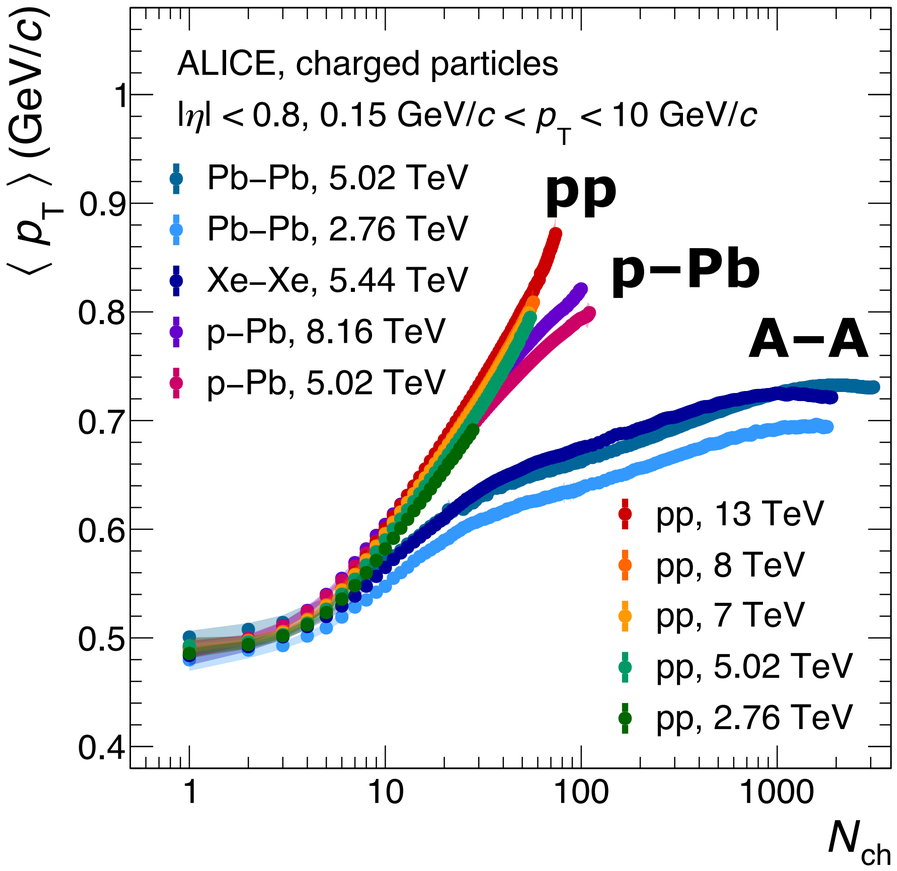


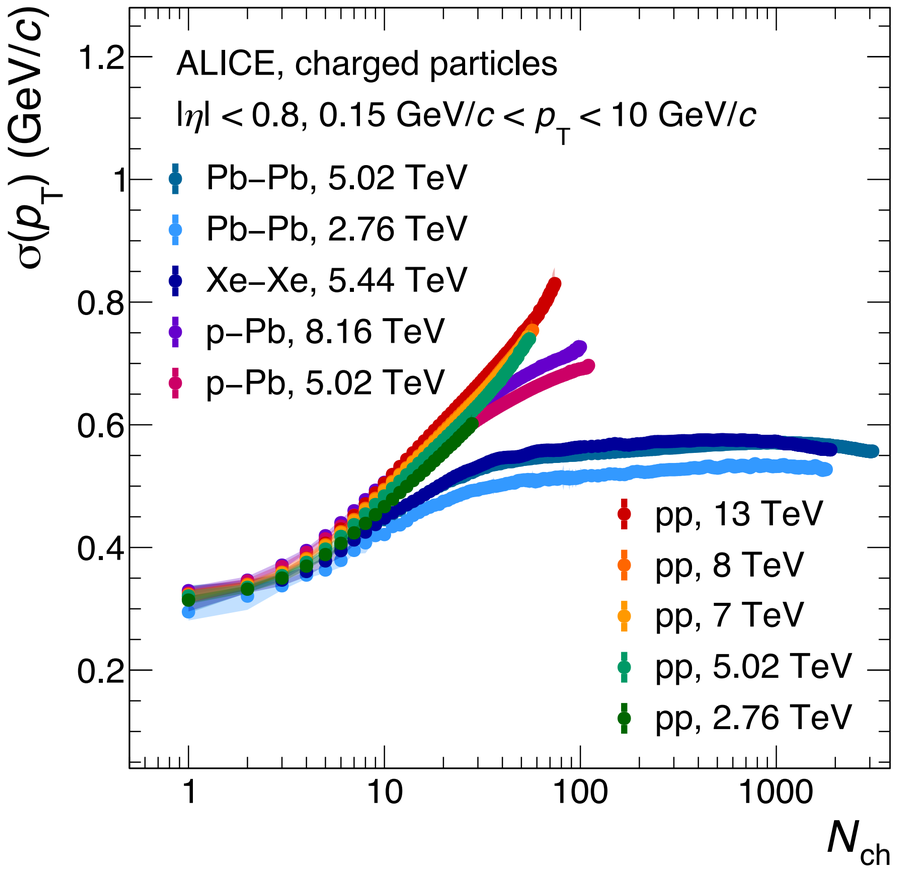
σ(p_T)

arXiv:2211.15326

- unfolding procedure applied to MC sample including transport of particles through detector
- results compared to generator-level expectation → deviations mostly well below 1-2%

Spectral Shape Evolution

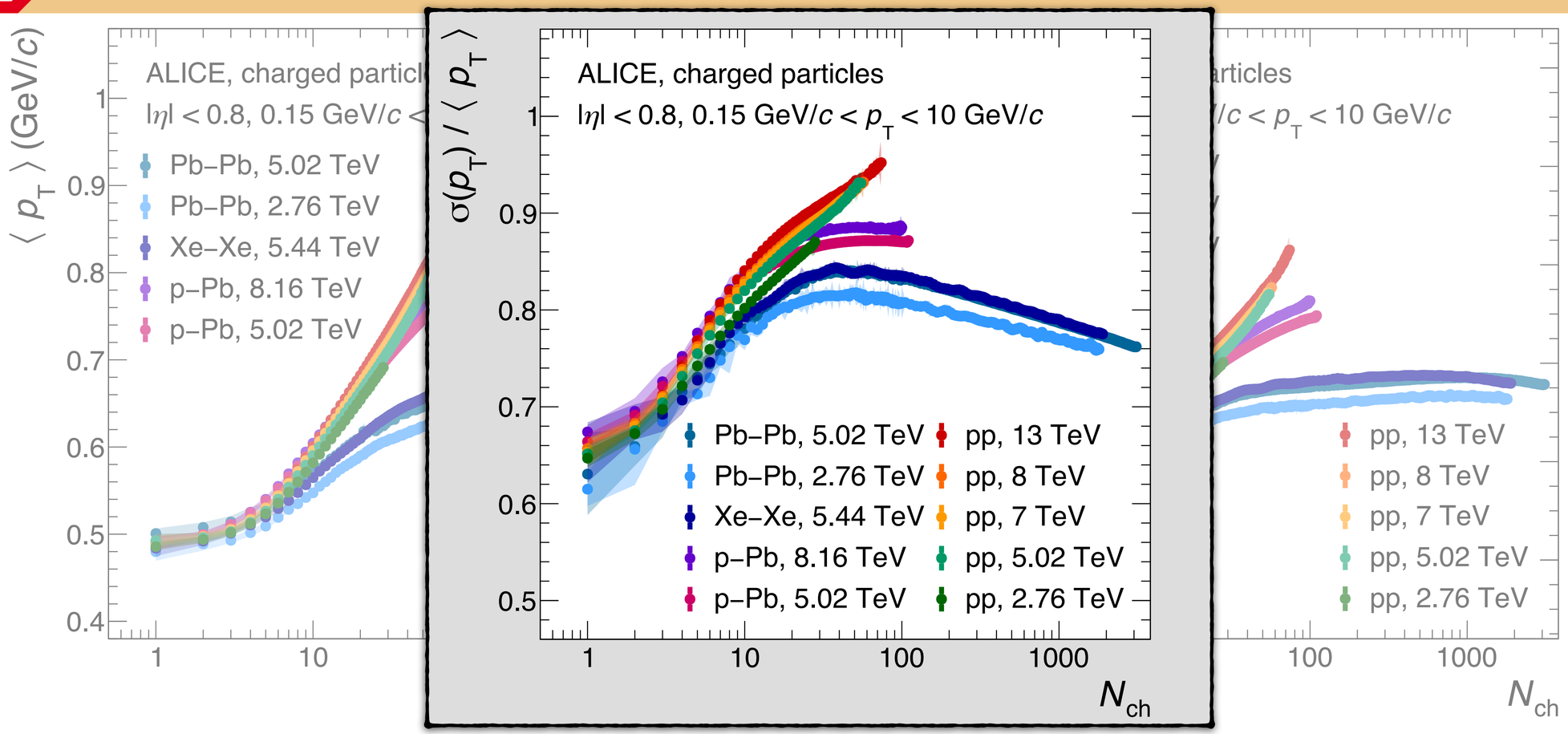




arXiv:2211.15326

- comprehensive measurement of mean and width of p_T spectra for most LHC Run 1&2 collision systems
- A–A collisions exhibit slower rise in width than in mean at high multiplicities
  (spectra stay narrow as a result of both jet quenching and radial flow?)

Spectral Shape Evolution



arXiv:2211.15326

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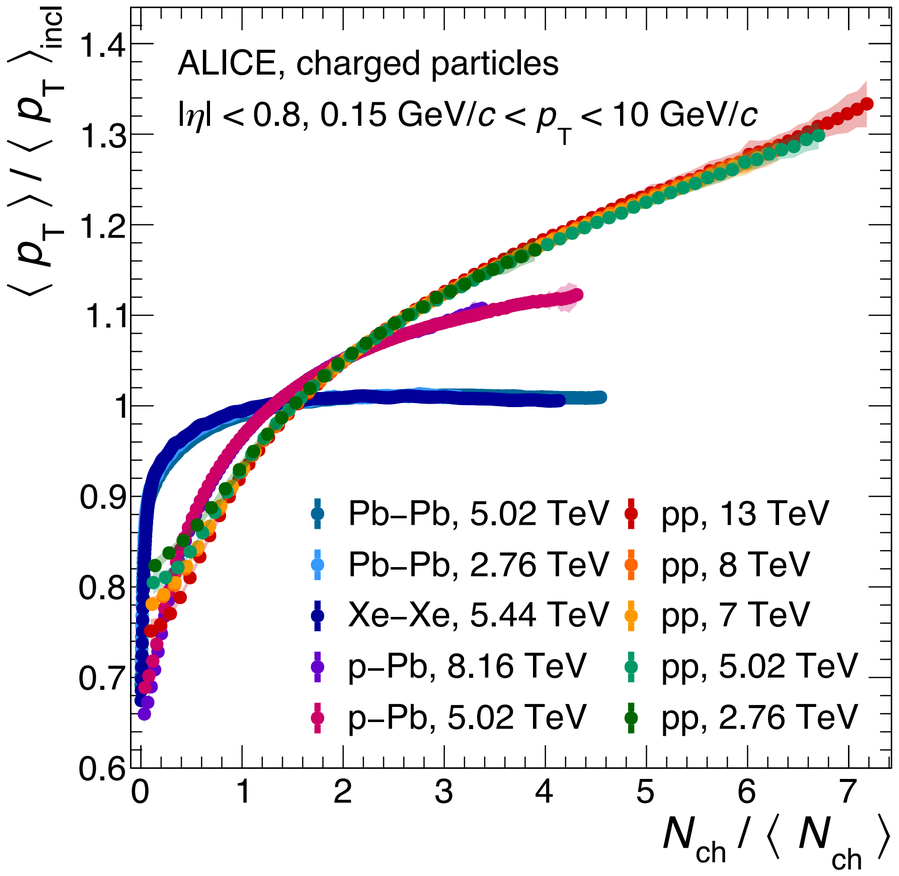
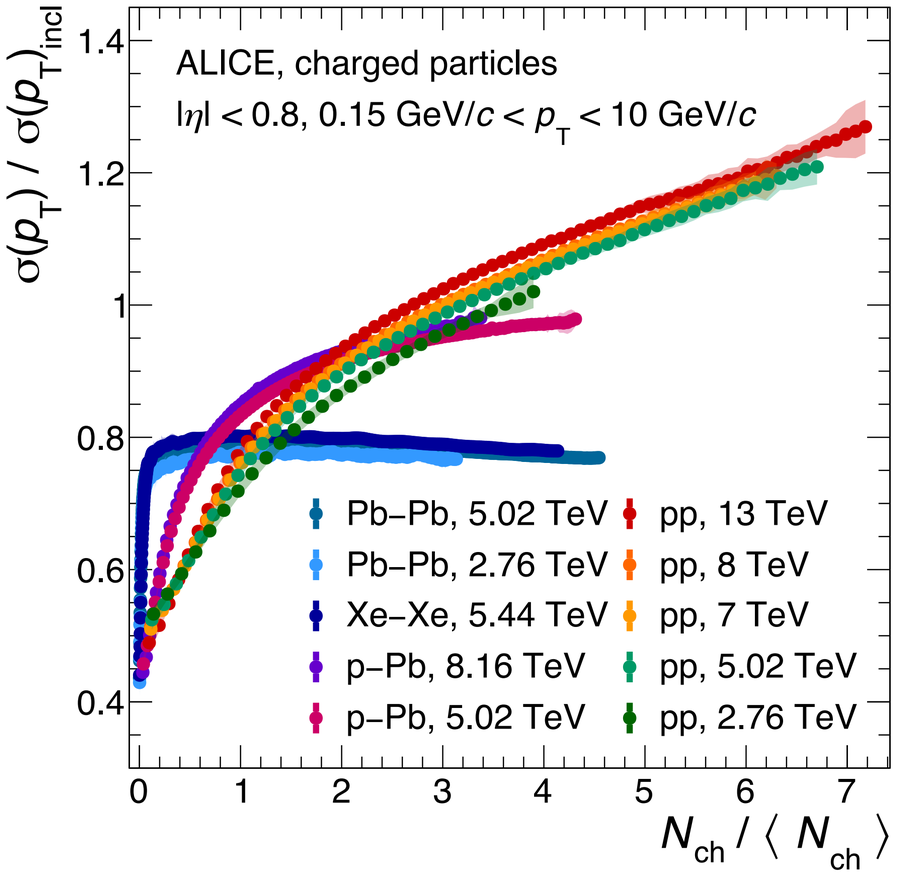
Self-Scaling Features





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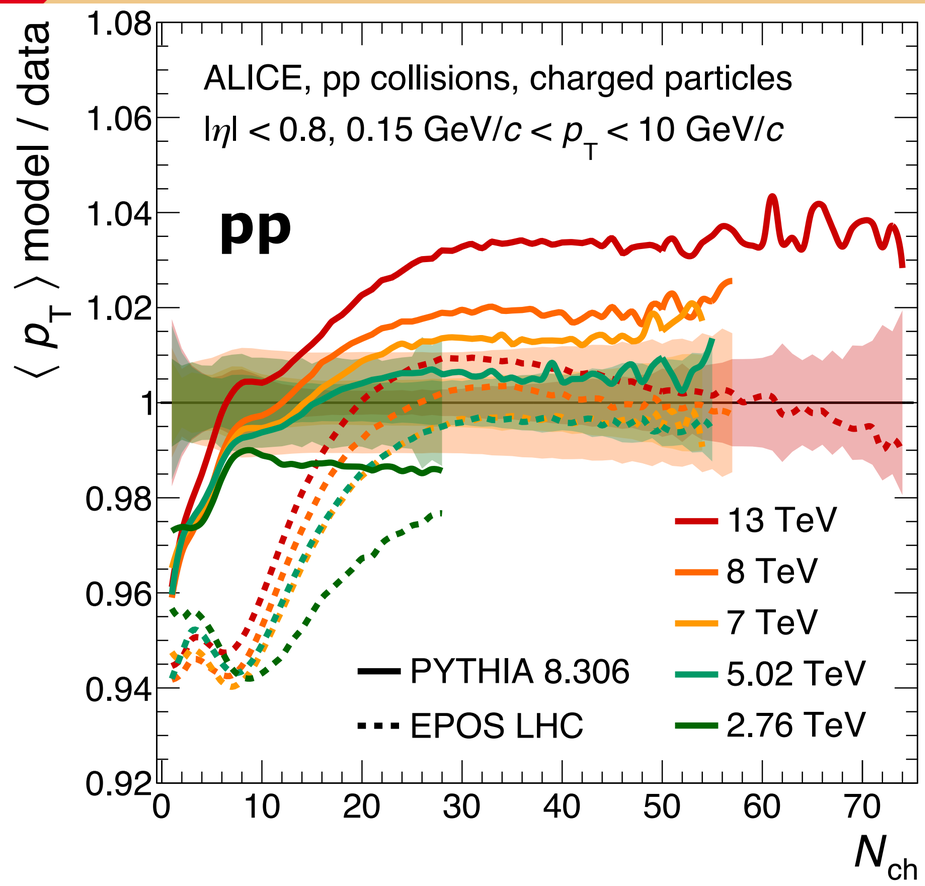
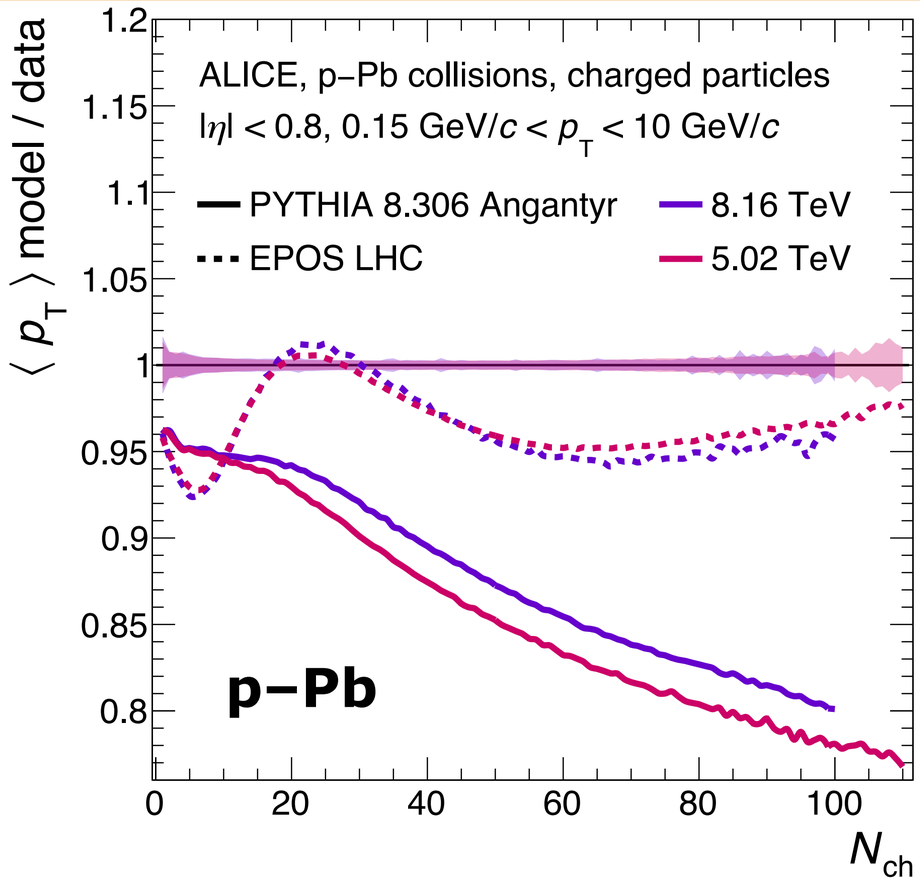
- common trend for each system (independent of collision energy)
- scaling better for mean than for width of spectra

Model Comparisons pp & p–Pb





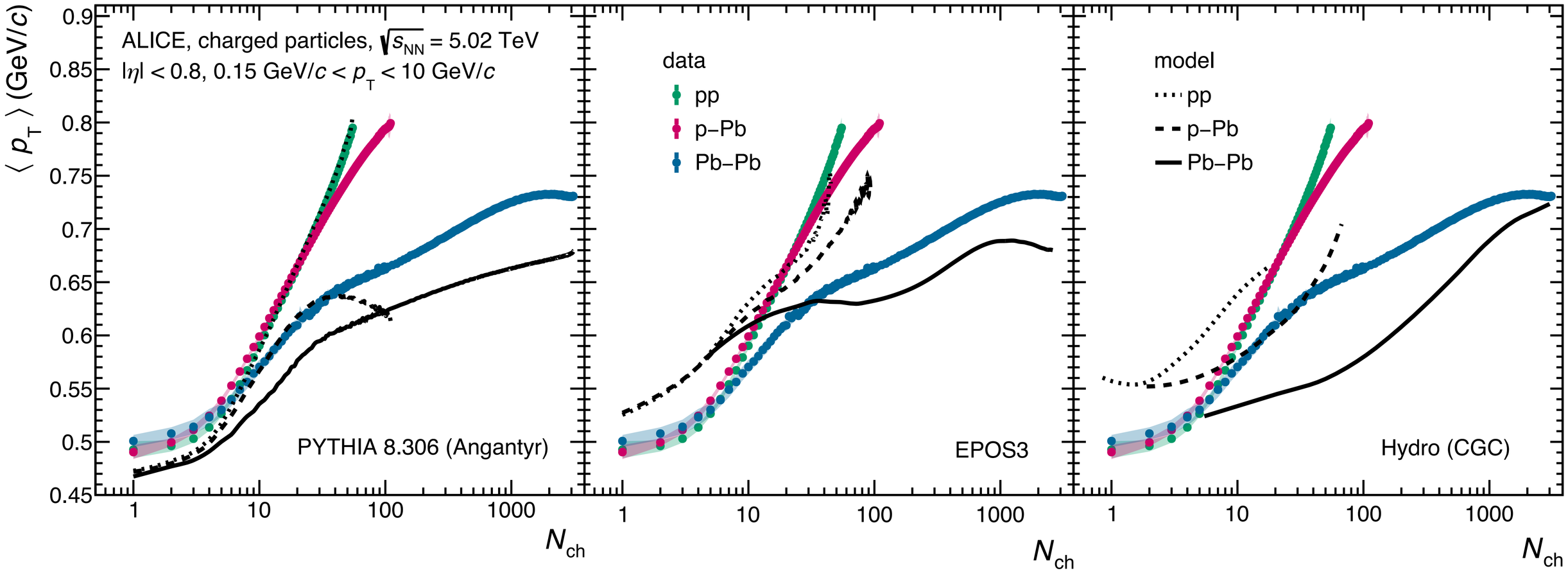
arXiv:2211.15326

- pp: both PYTHIA and EPOS LHC describe the trend of <p_T> vs. N_{ch} within few %
- p–Pb: EPOS LHC more accurate description of the data

EPOS LHC: Phys. Rev. C 92, 034906

PYTHIA: Comput. Phys. Commun. 191 (2015) 159–177

Model Comparisons all systems



- basic observable <p_T> vs. N_{ch} in all collision systems challenging for models
- pp best described by PYTHIA8, large systems difficult for all models

arXiv:2211.15326

EPOS: Phys. Rev. C89(2014) 064903

Conclusions

paper submitted to PLB
arXiv:2211.15326

- new analysis technique to measure spectral shape evolution with multiplicity with unprecedented precision
- comprehensive measurement of charged-particle production at LHC energies for most Run 1 & 2 data
- modelling of particle production through system sizes still challenging for all current theoretical approaches
- many HEP measurements rely on these models to correct their raw data (e.g. to extract detector efficiencies)

precise experimental data can help constrain model parameters