A Large Ion Collider Experiment

ALICE

Particle Production in Small Systems

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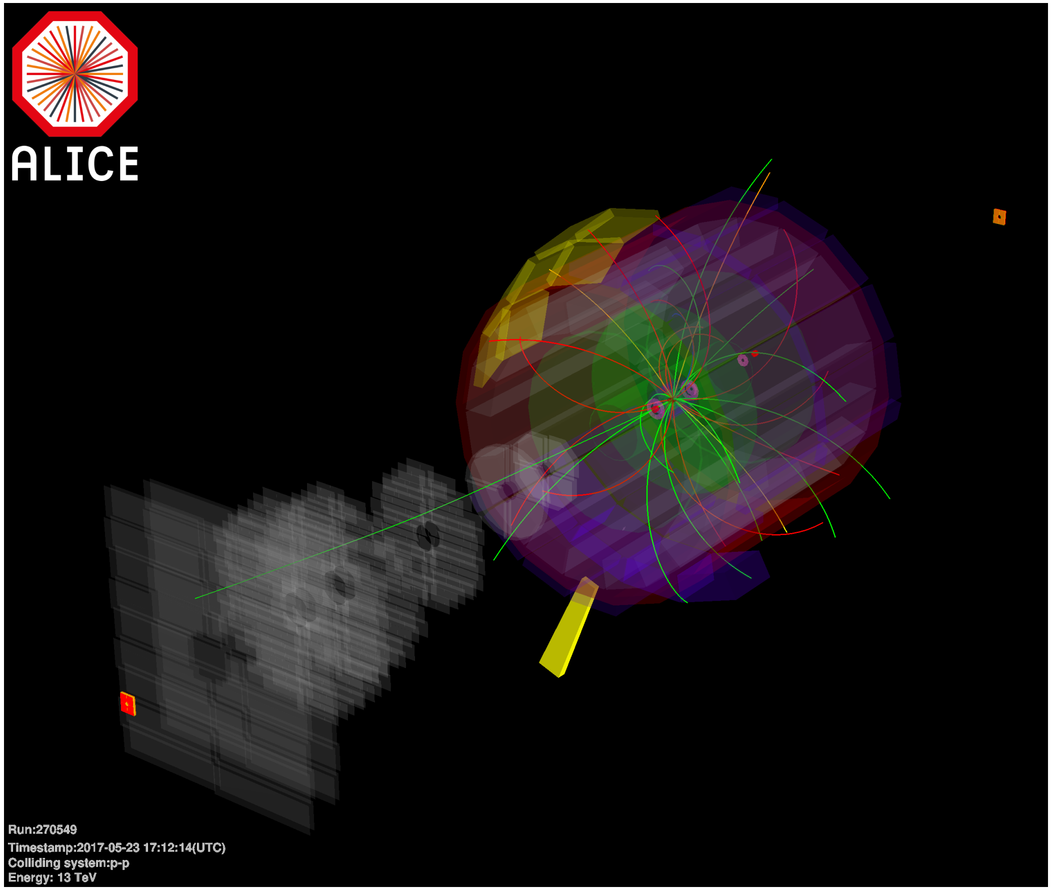
CSCS2018, Wuhan, China

Niels Bohr Institutet

centre for particle physics Discovery

Outline

- Motivation
- The ALICE detector: a dedicated heavy-ion experiment at the LHC
- Identified particle spectra and ratios
- Blast wave model fits
- Integrated particle yields and ratios
- Average transverse momenta
- (Un)identified particle production as a function of transverse spherocity
- Summary



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Recently, striking similarities between Pb-Pb and pp collisions have been observed in the soft-QCD sector. Two examples of the similarities are:

- p_T-differential baryon-to-meson ratios
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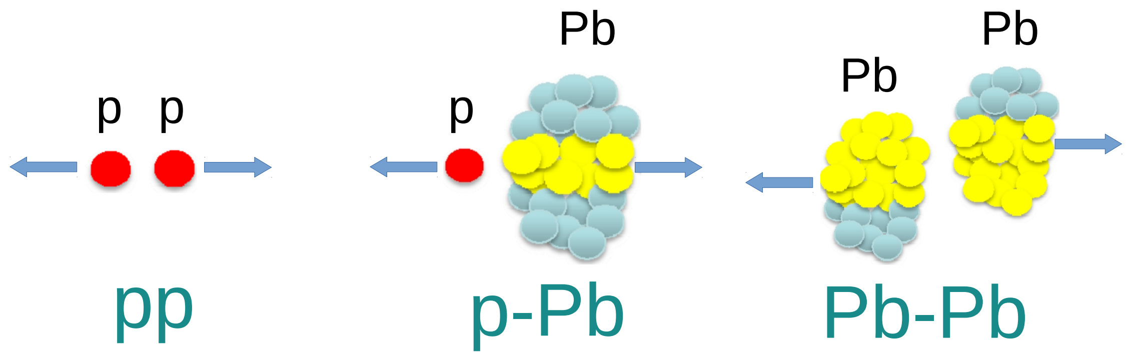
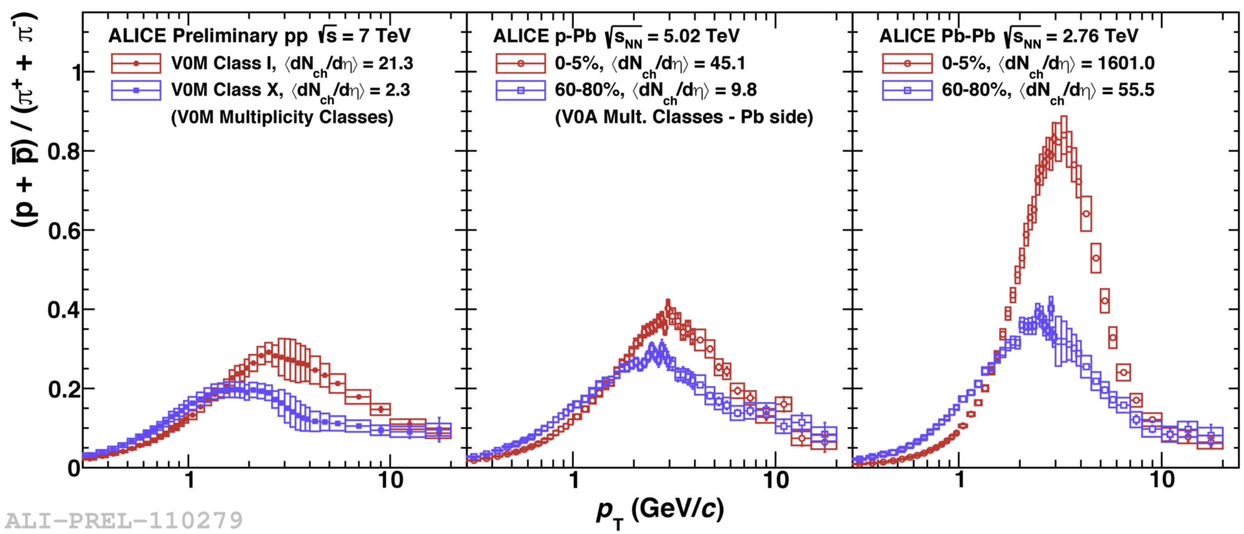
  - But also present in pp. Does that mean that Pb-Pb is just an extension of pp? Or vice versa?





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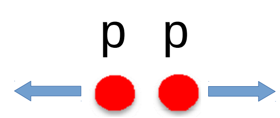
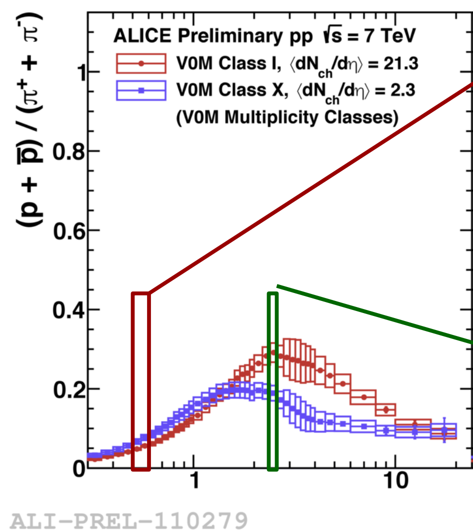
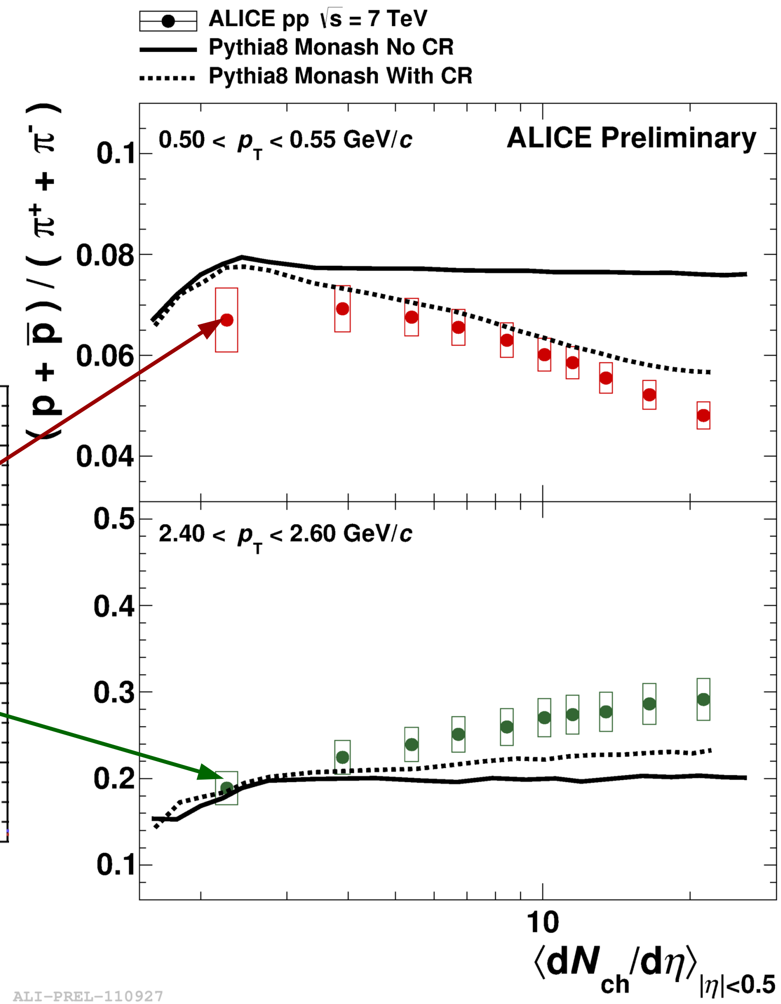


pp





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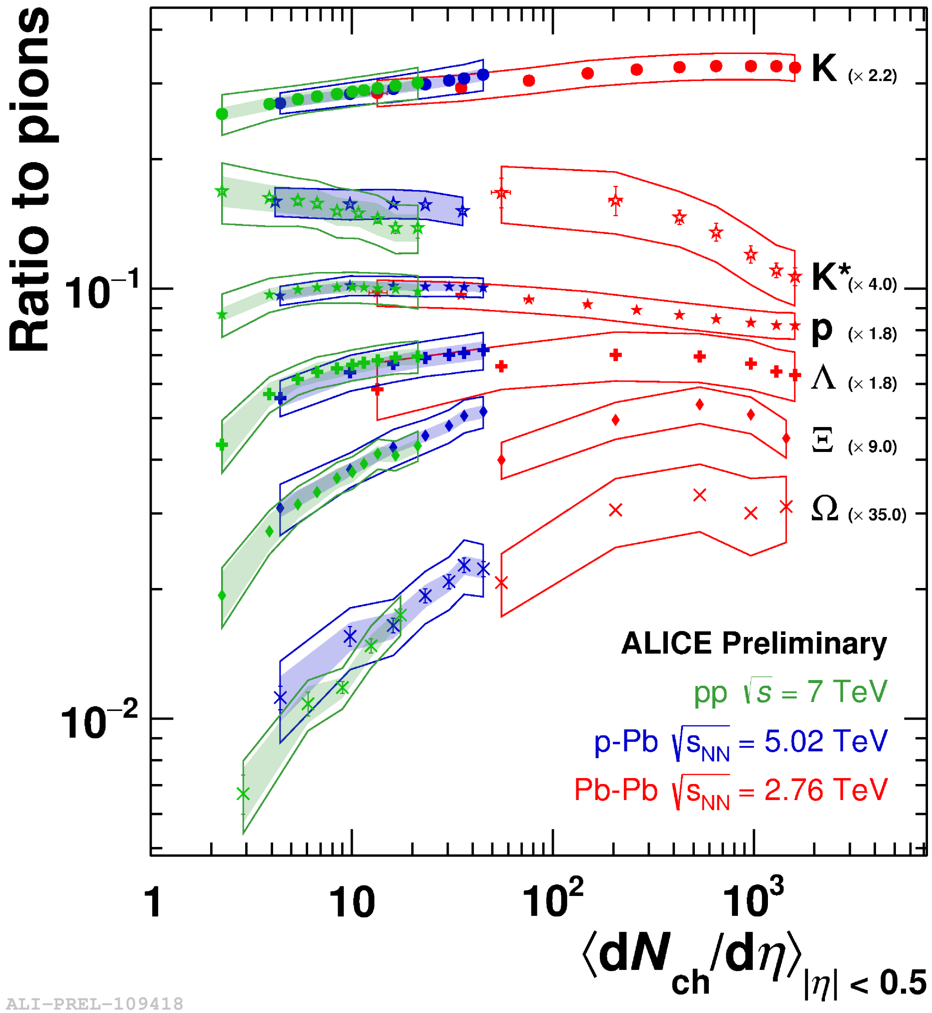
  - Similar particle yields at comparable multiplicities, different colliding systems



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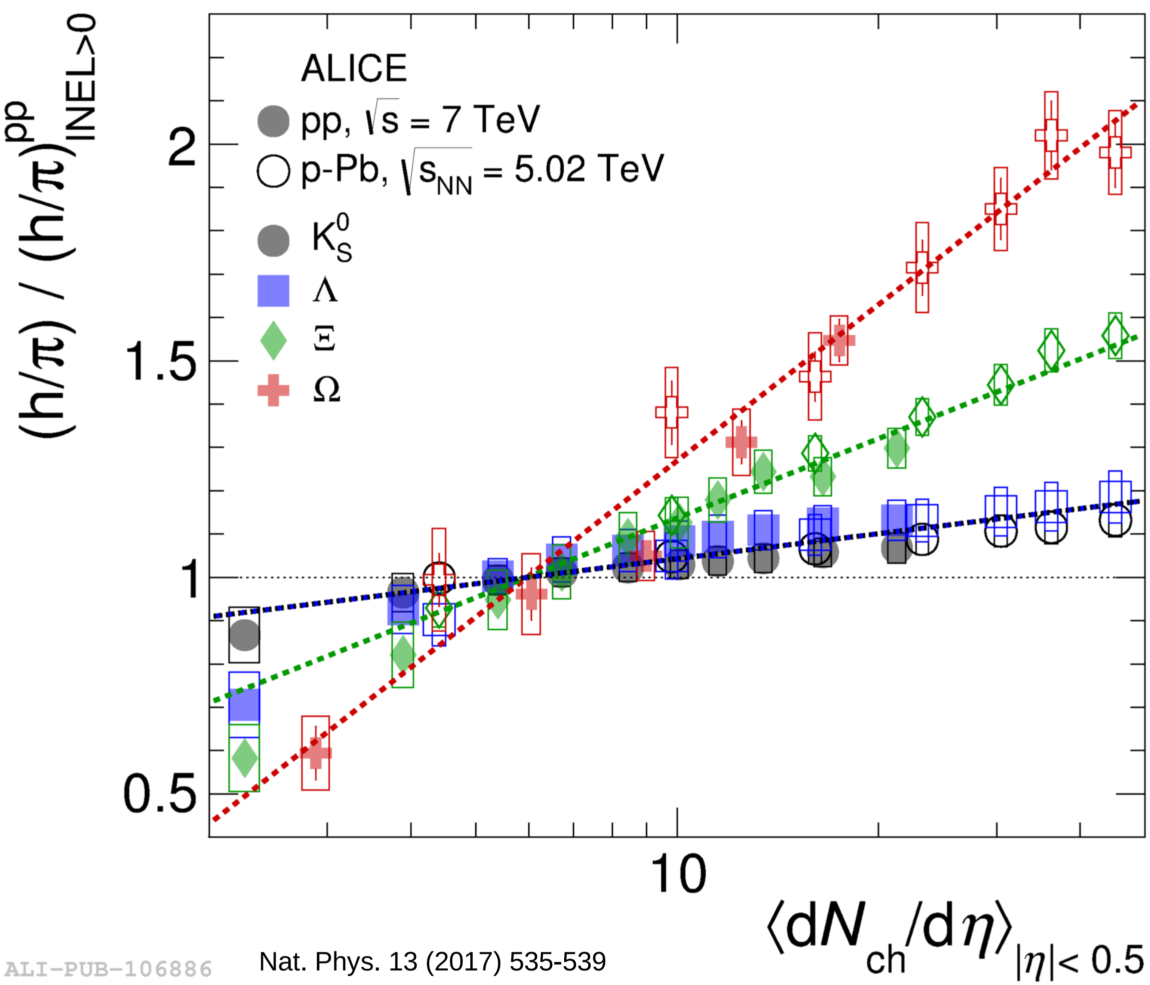
  - Enhanced production of strange hadrons



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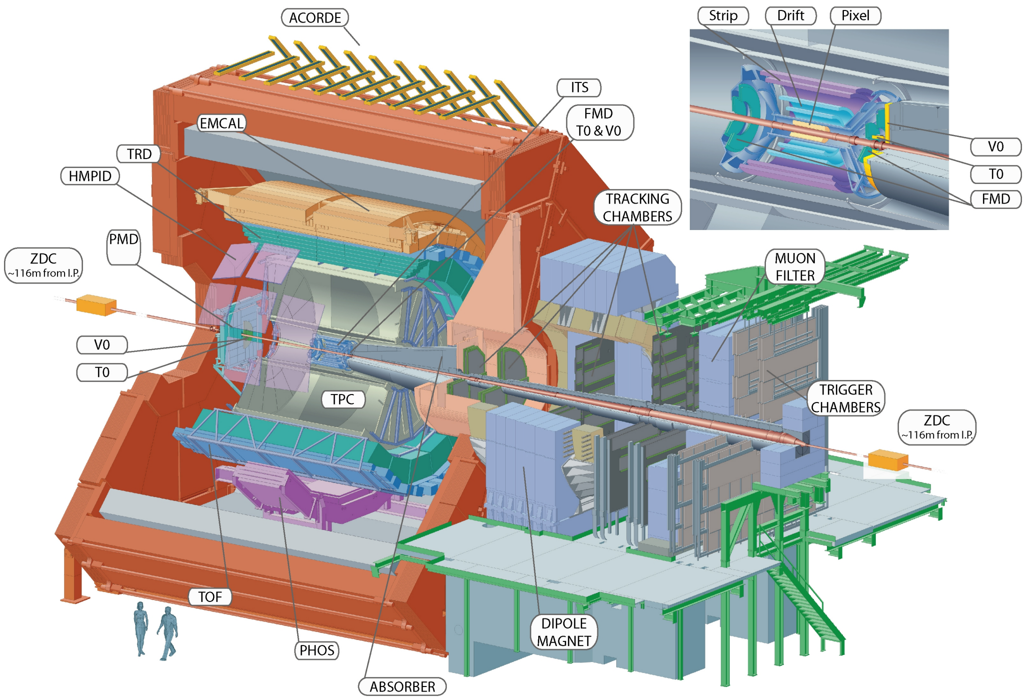
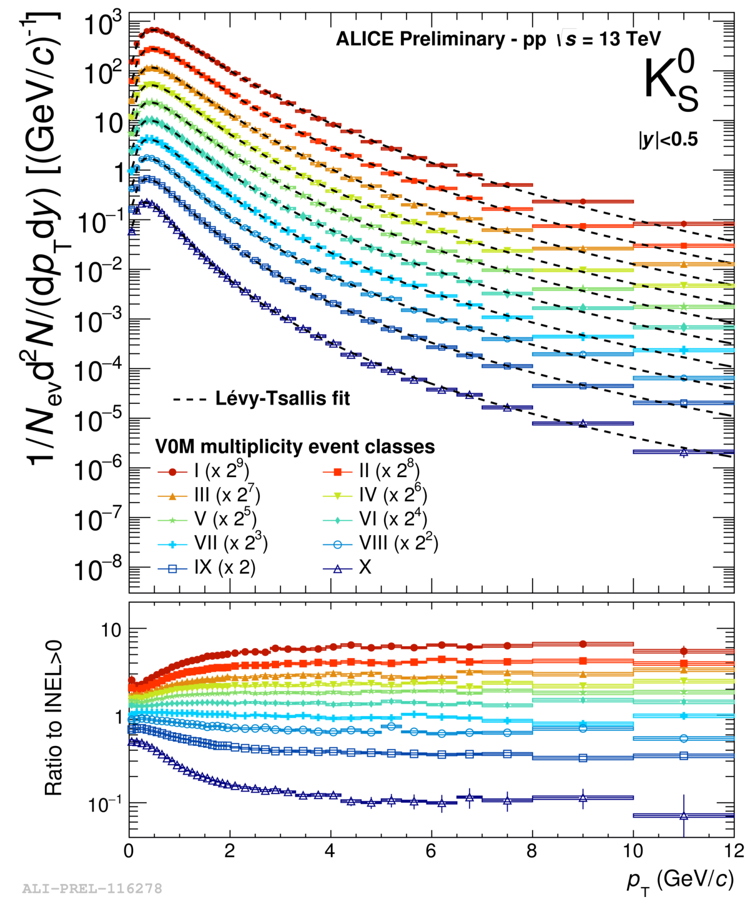
The ALICE Detector



Multiplicity estimation:

V0M – two arrays of plastic scintillators measuring multiplicities at forward rapidities:

V0M = V0A ($2.8 < \eta < 5.1$) + V0C ($-3.7 < \eta < -1.7$)



Excellent PID capabilities in a wide p_T range using:

- Inner Tracking System (ITS)
  - also: trigger, tracking, vertex
- Time Projection Chamber (TPC)
  - also: tracking
- Time-Of-Flight

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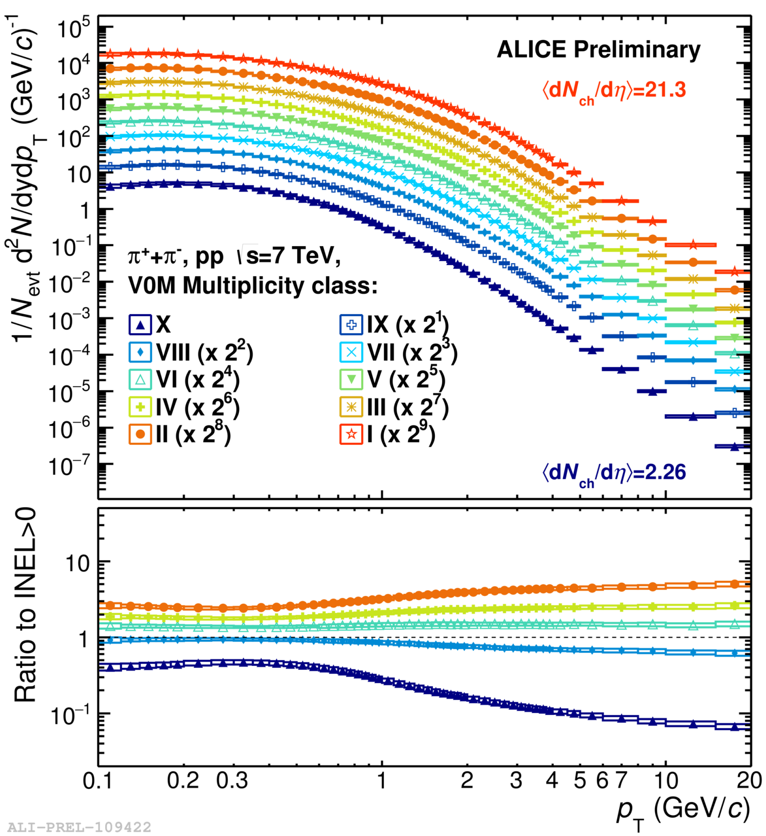
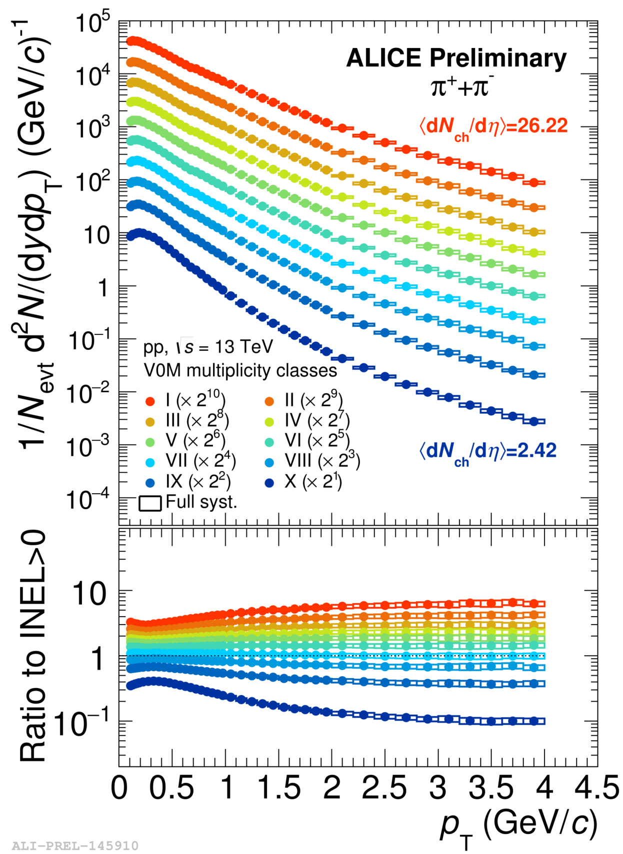
Identified particle spectra and ratios

Comprehensive set of light-flavoured hadrons has been measured as a function of multiplicity in pp collisions at different center-of-mass energies

→ $\sqrt{s}$ effects on particle production can be isolated from the multiplicity dependence





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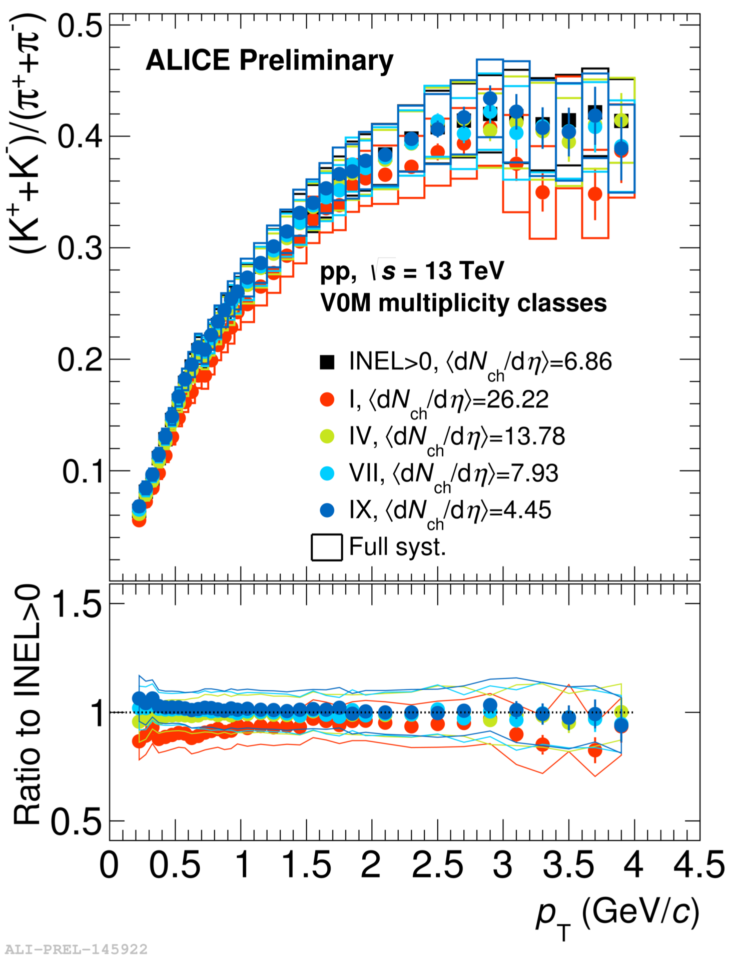

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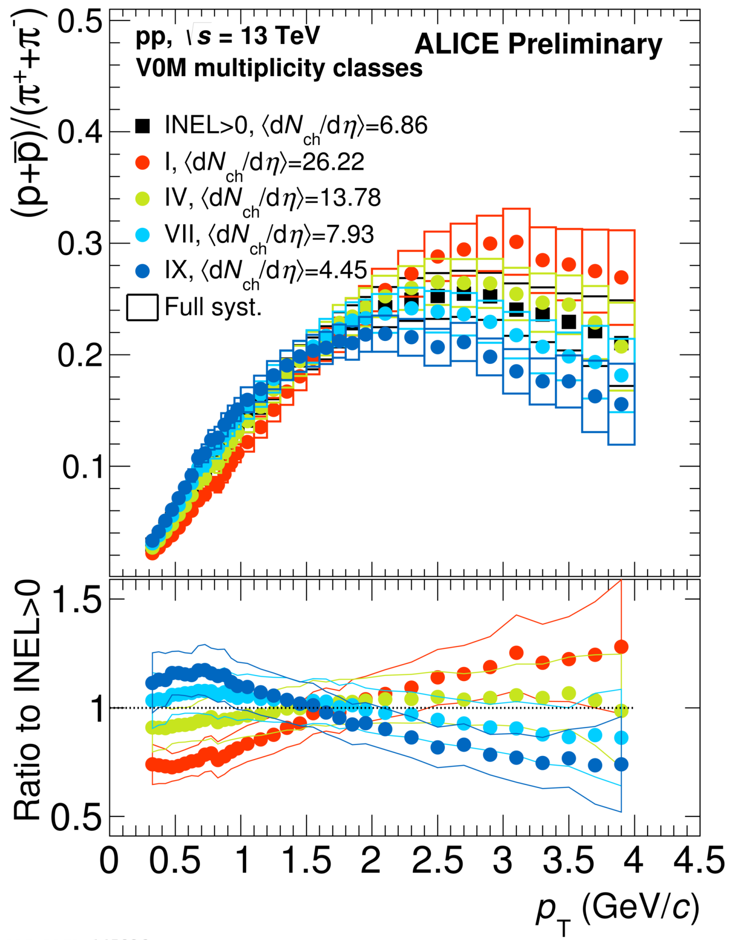

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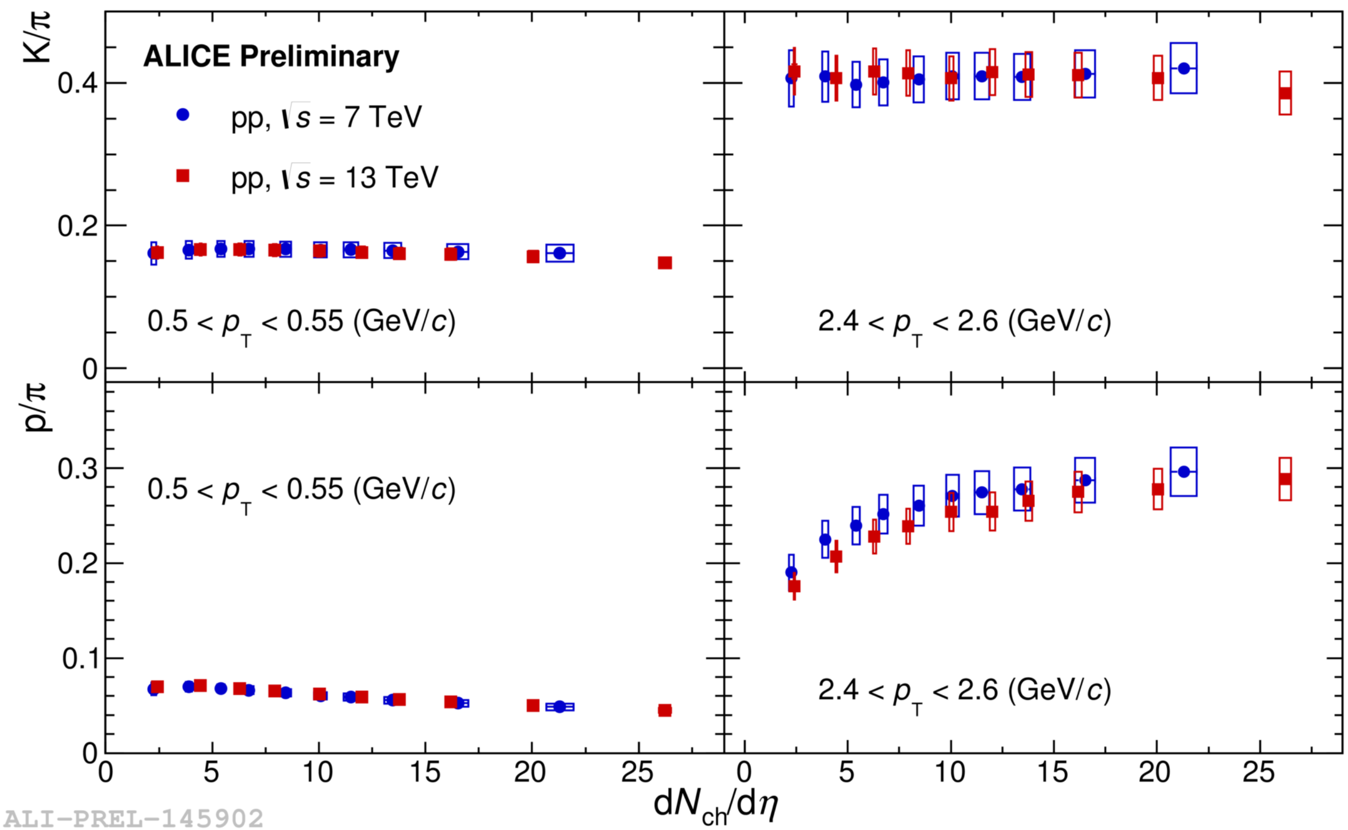
→K/π and p/π evolution with multiplicity is similar at different $\sqrt{s}$



Blast-Wave model fits

Multiplicity dependence of p_T-differential B/M ratios in Pb-Pb collisions can be explained by radial flow. In a simple way, this can be studied by the Blast-Wave model:

– Thermal production of particles at T_{kin} + boost of particles in the transverse direction by a common velocity field β_T

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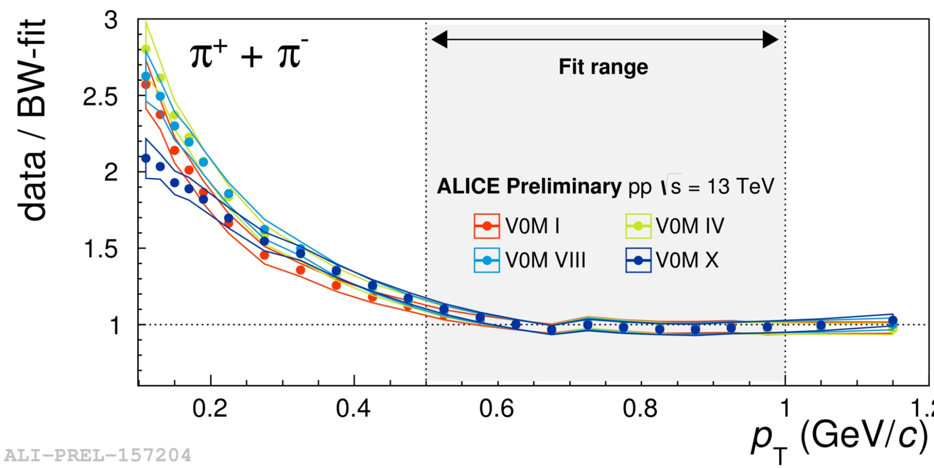
– Fit the model to the data

– In restricted ranges, spectra are described well



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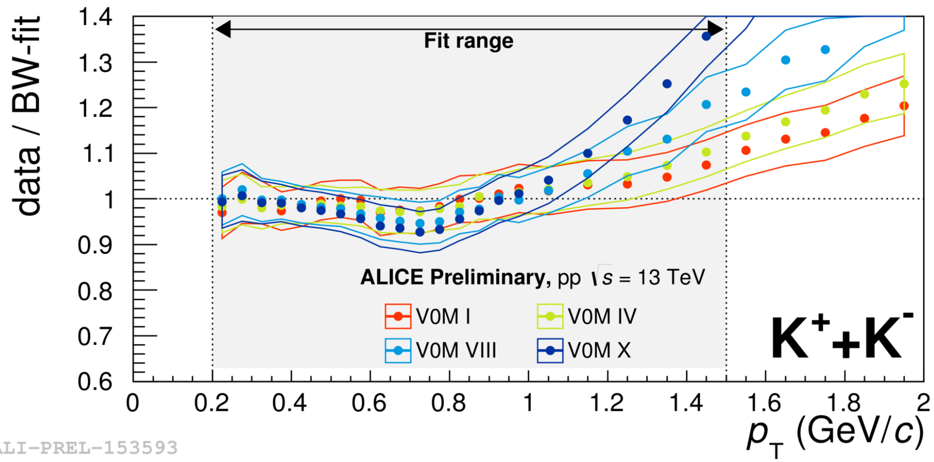

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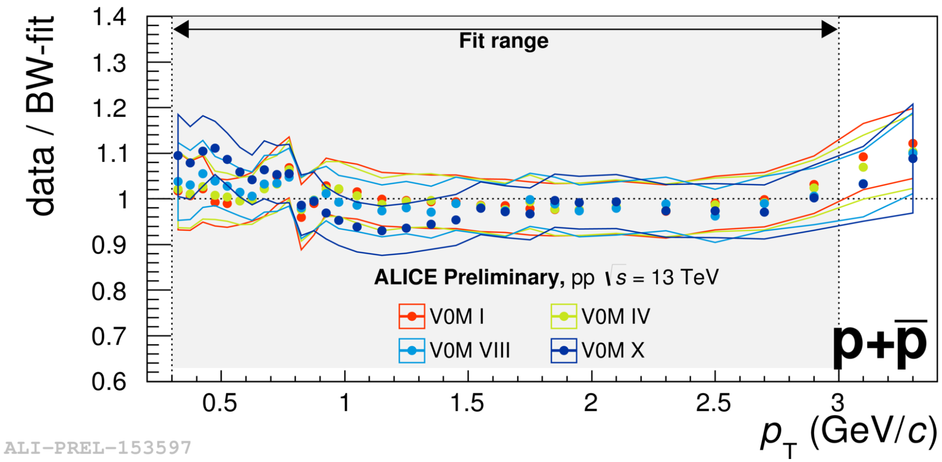

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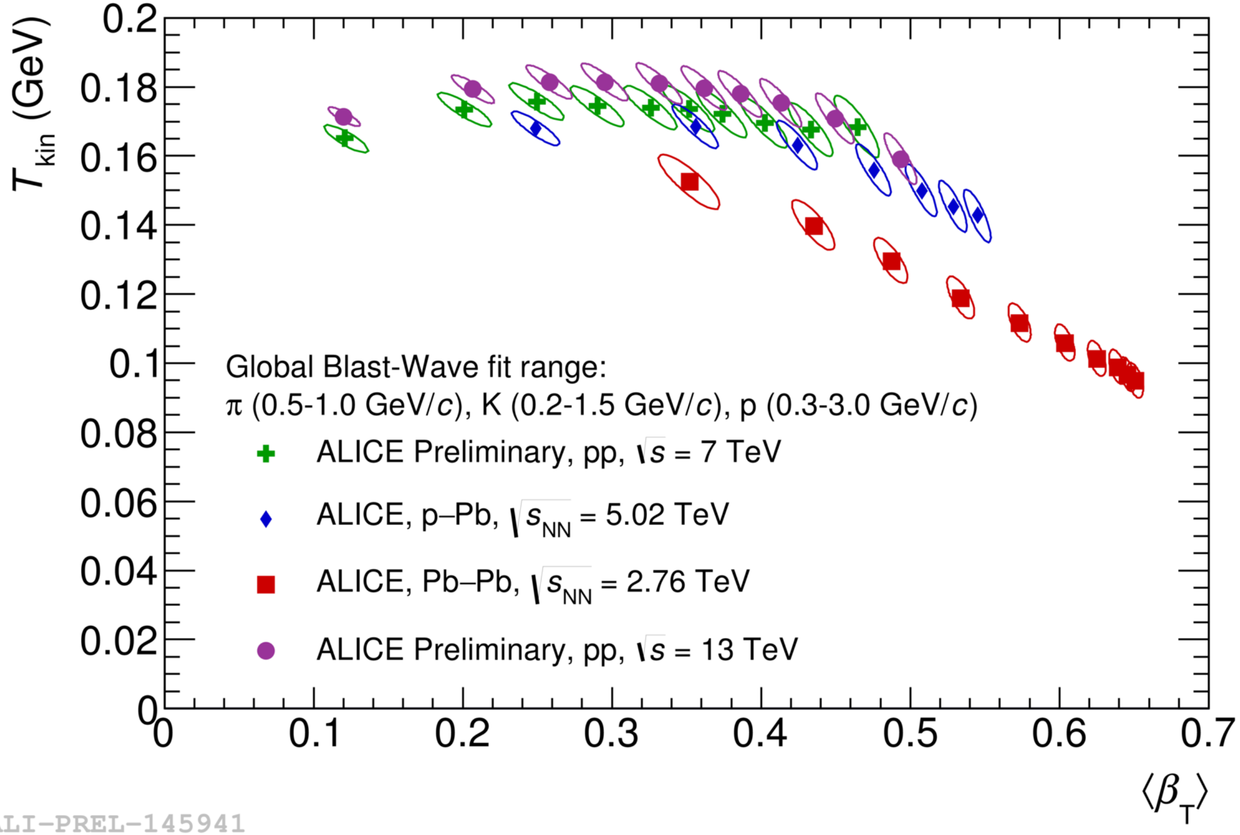
T_{kin}: larger at higher energies



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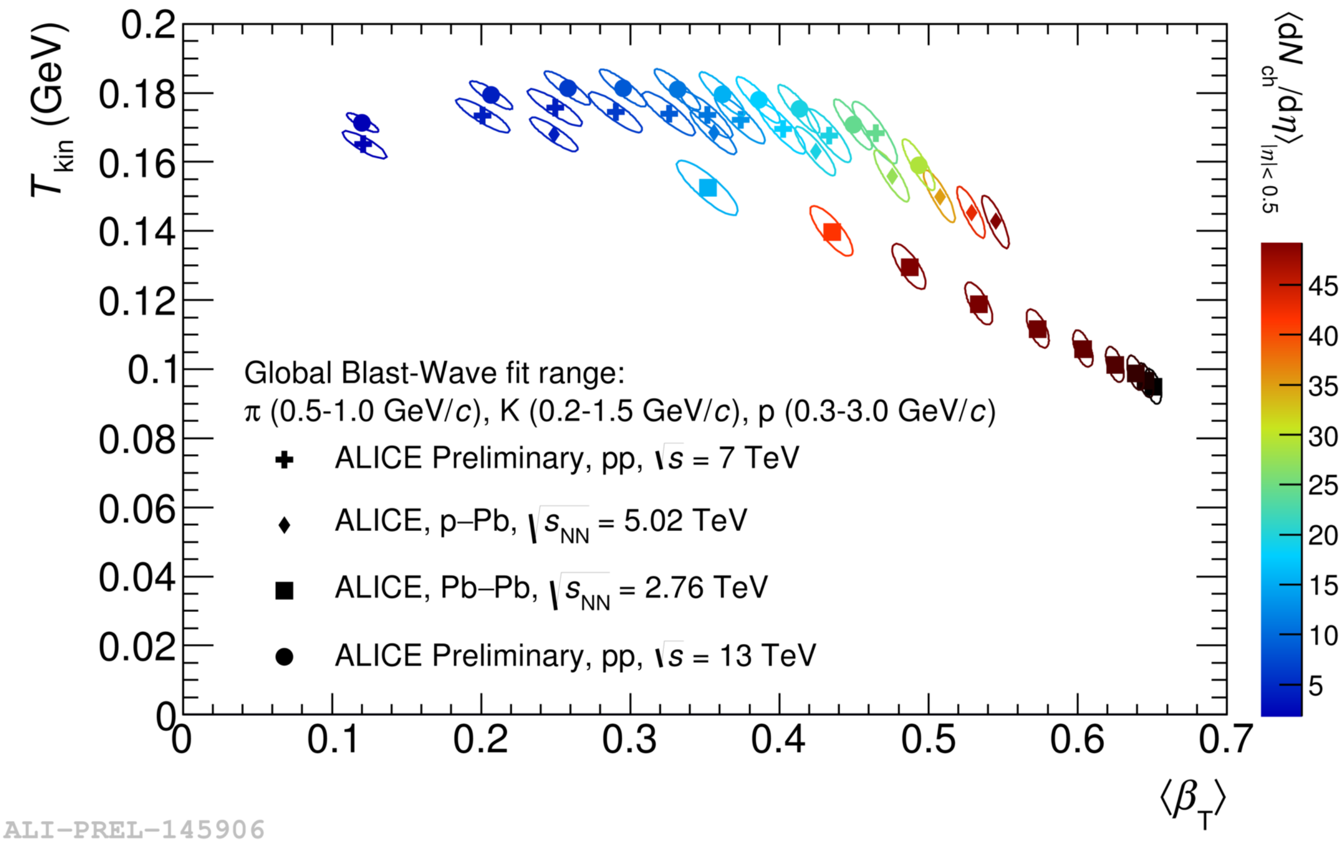
T_{kin}: larger at higher energies

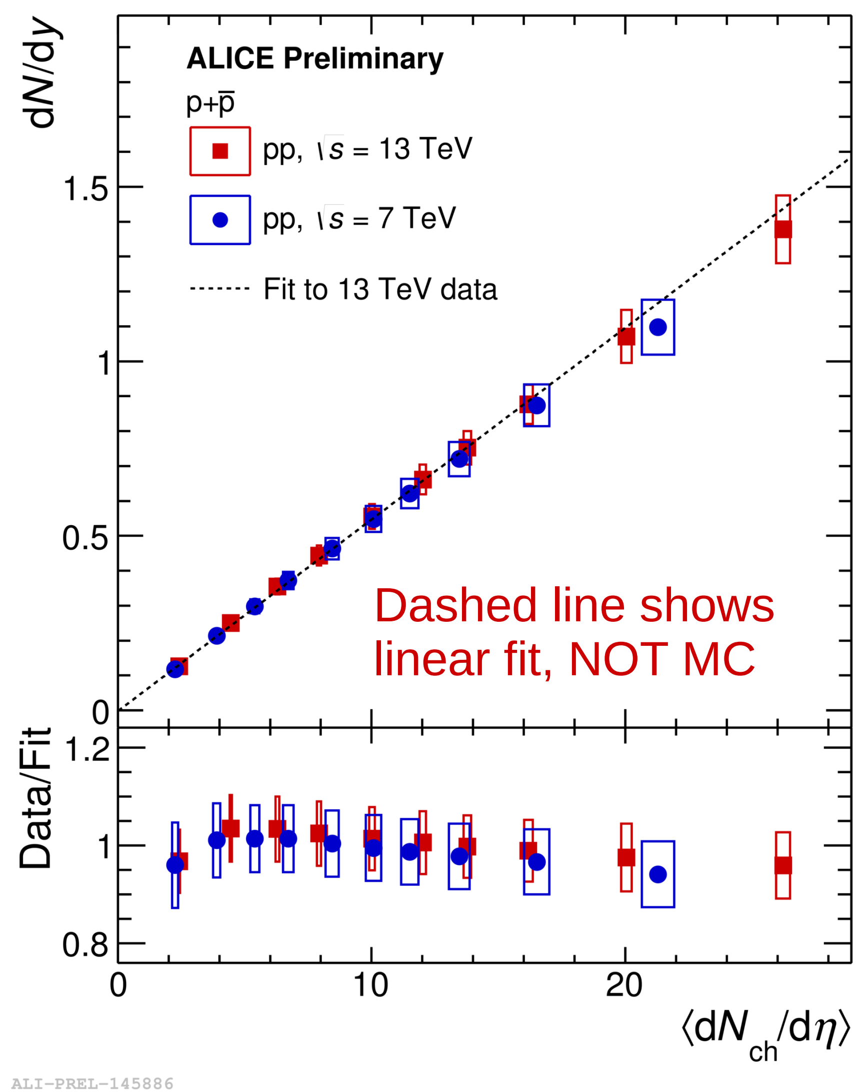
$\langle\beta_T\rangle$: in pp collisions, similar at comparable $\langle dN_{ch}/d\eta\rangle$, larger than in Pb-Pb at similar multiplicities



Integrated particle yields

Integrated particle yields:

– Similar at different $\sqrt{s}$ if comparable multiplicities are considered



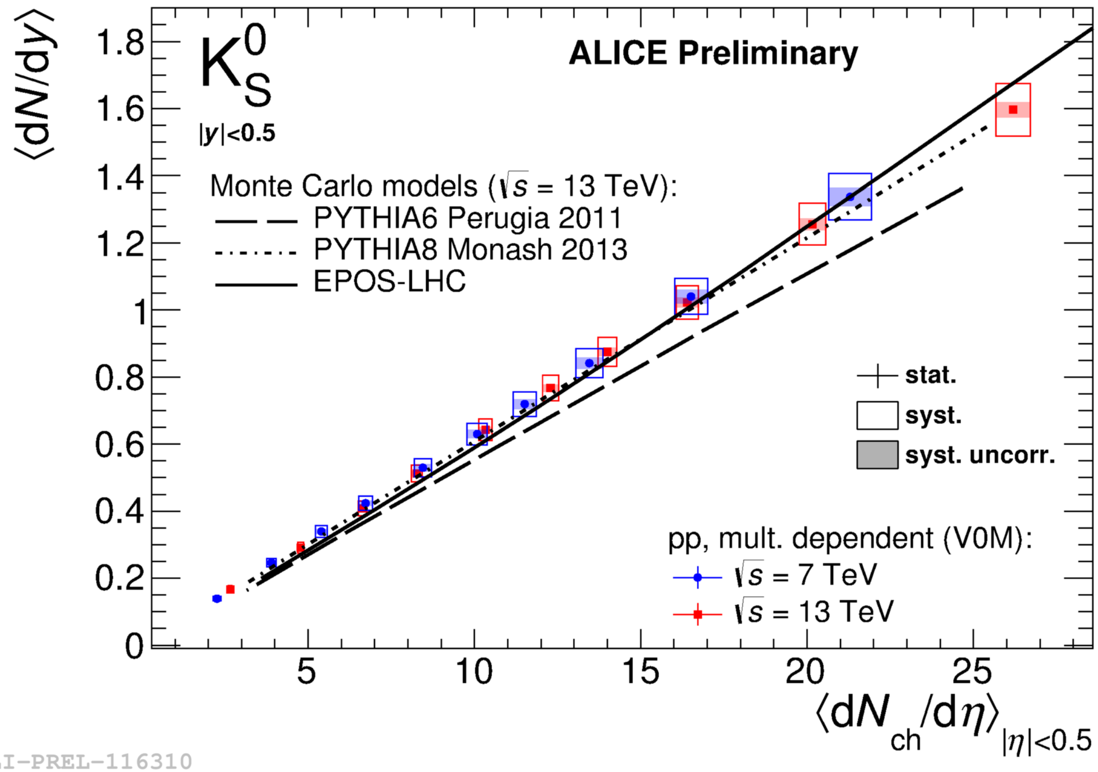
Integrated particle yields

Integrated particle yields:

– Similar at different √*s* if comparable multiplicities are considered

MC predictions:

- Strange hadrons are well described by PYTHIA8 and EPOS LHC



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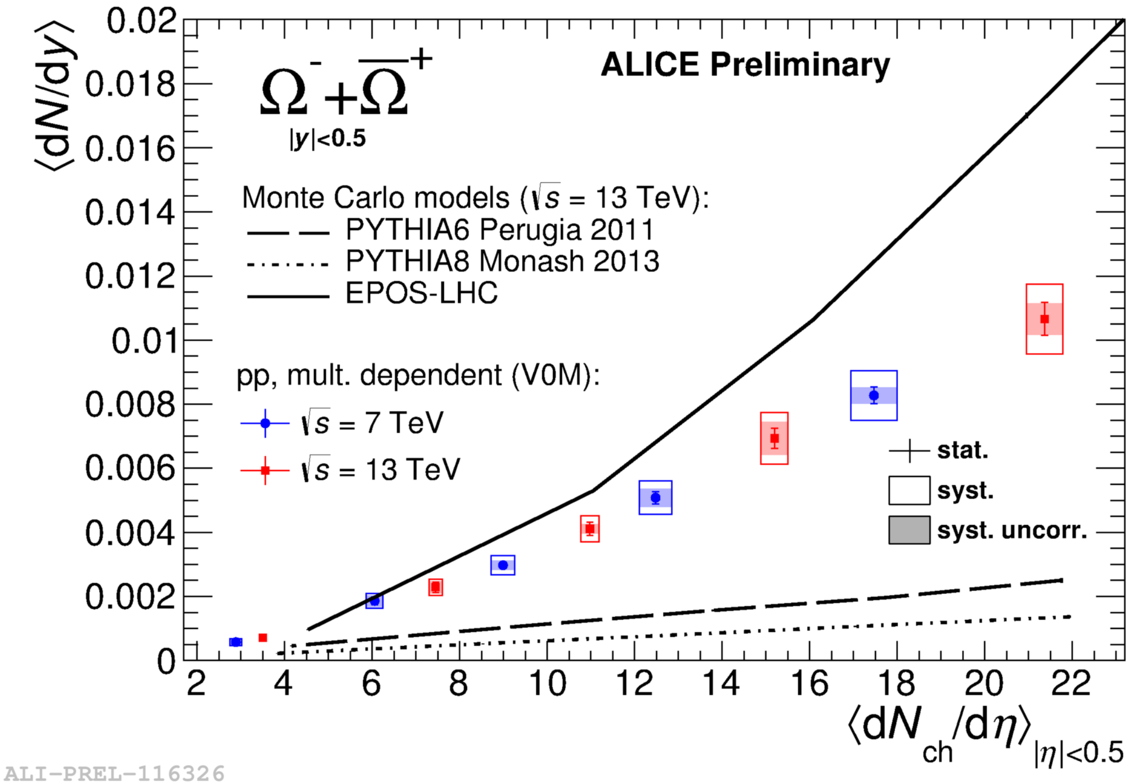
MC predictions:

- Strange hadrons are well described by PYTHIA8 and EPOS LHC
- But neither one describes the evolution of hyperons

What about particle ratios?



Integrated particle yield ratios in MC

PYTHIA8:
– Particle production via string fragmentation
  – No evolution with multiplicity

EPOS LHC:
– Collective hadronization, collective flow
  – Enhanced rates of strangeness production, larger than observed in the data

DIPSY:
– Rope hadronization
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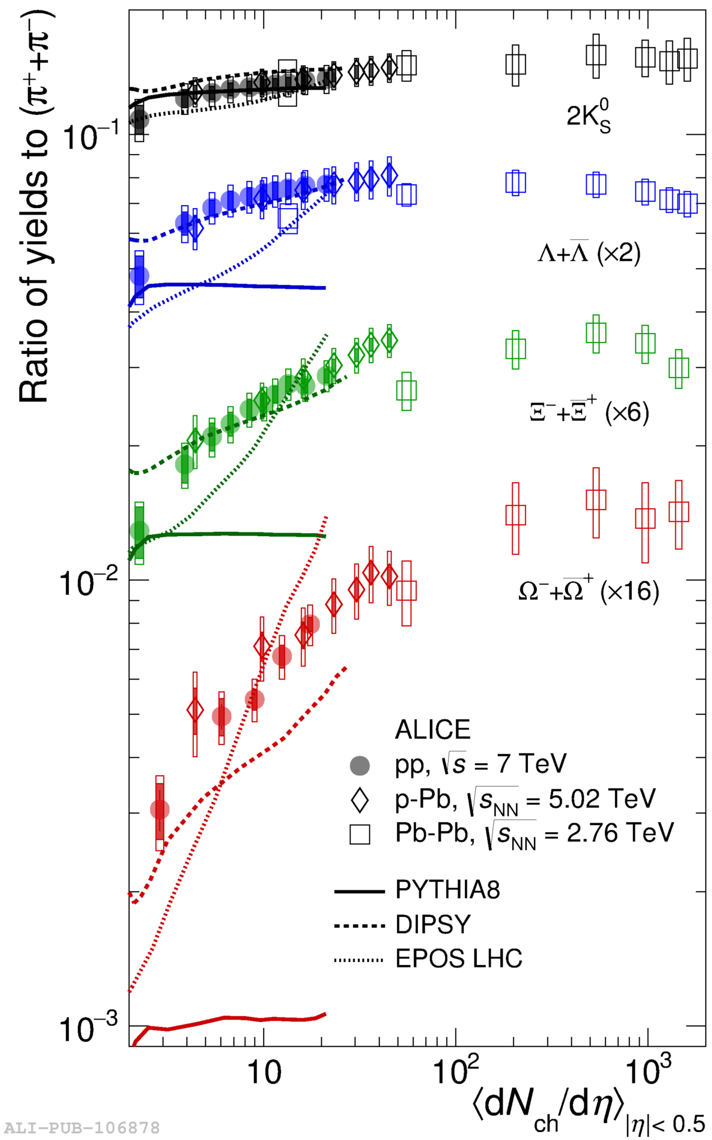

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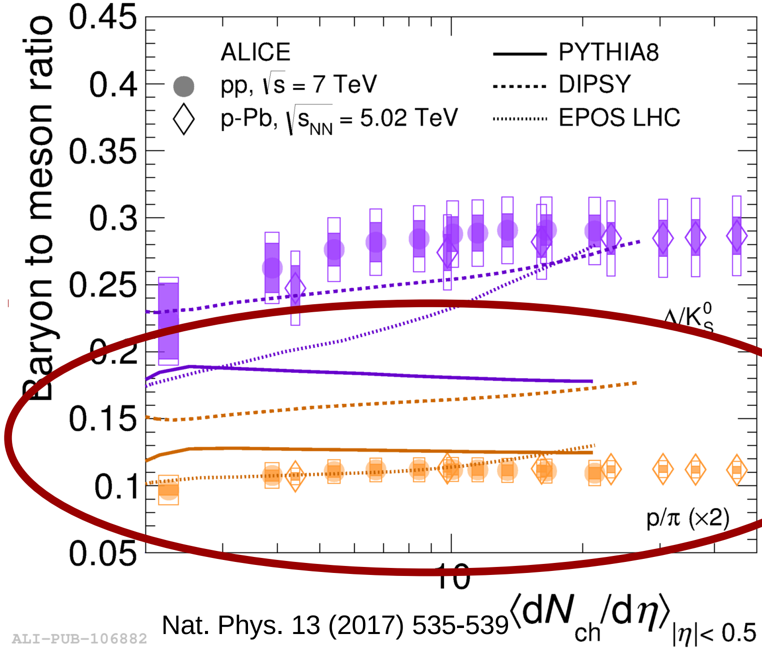

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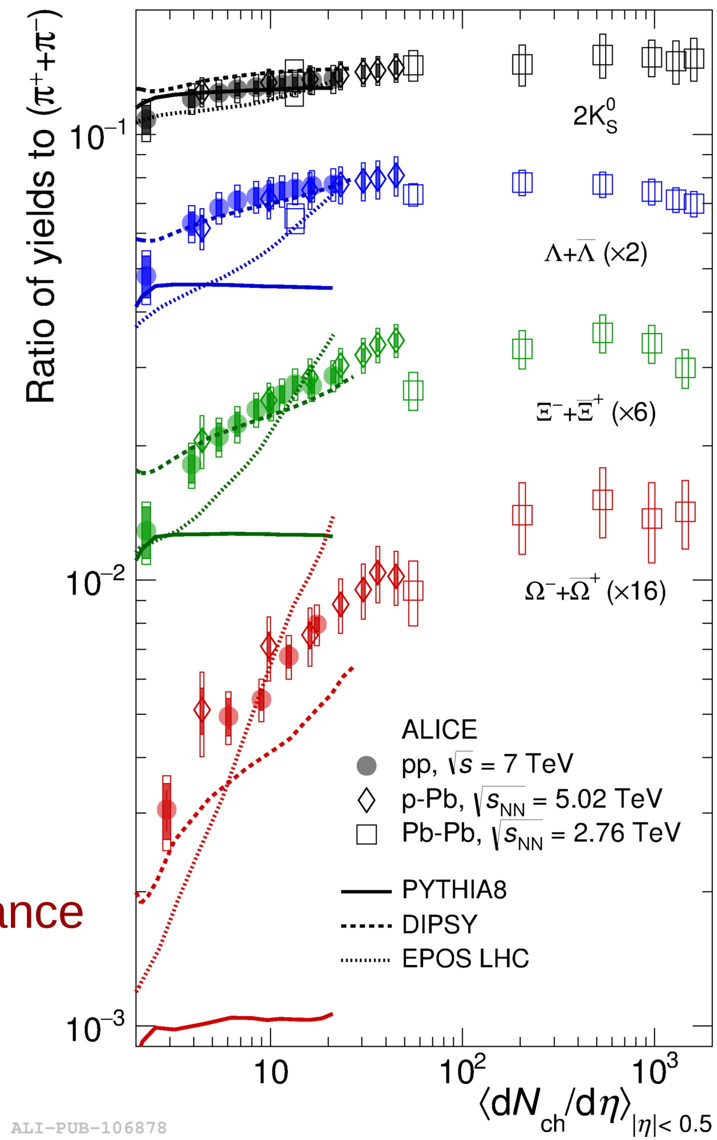
But ropes enhance all baryons!



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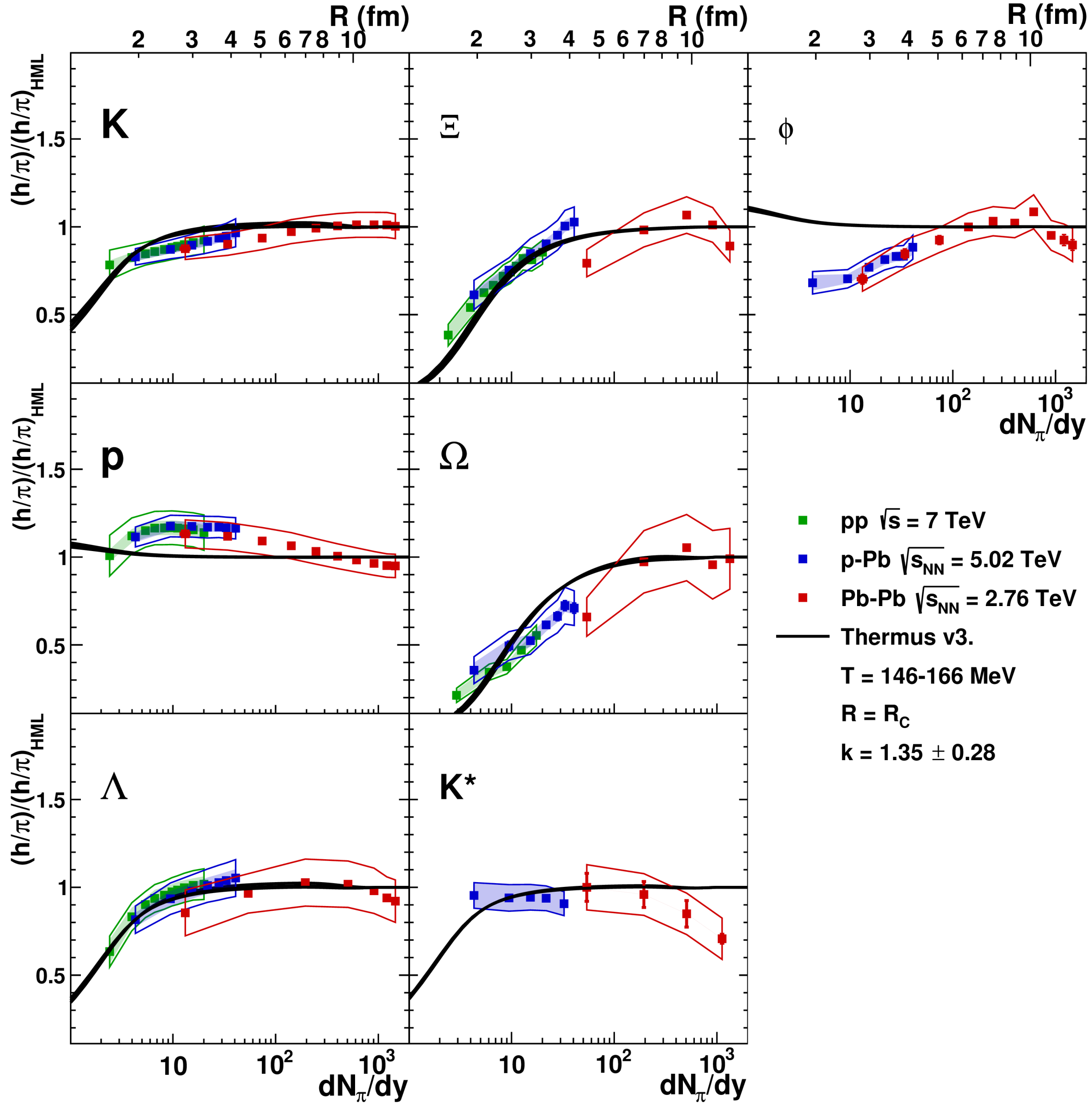
Integrated particle yield ratios in SHM

- Statistical (Thermal) model:
  – In equilibrium statistical-thermal models, strangeness enhancement is a result of the suppression of strange hadron production in small systems due to the local strangeness conservation



V.V., A. Kalweit, arXiv:1610.03001 [nucl-ex]

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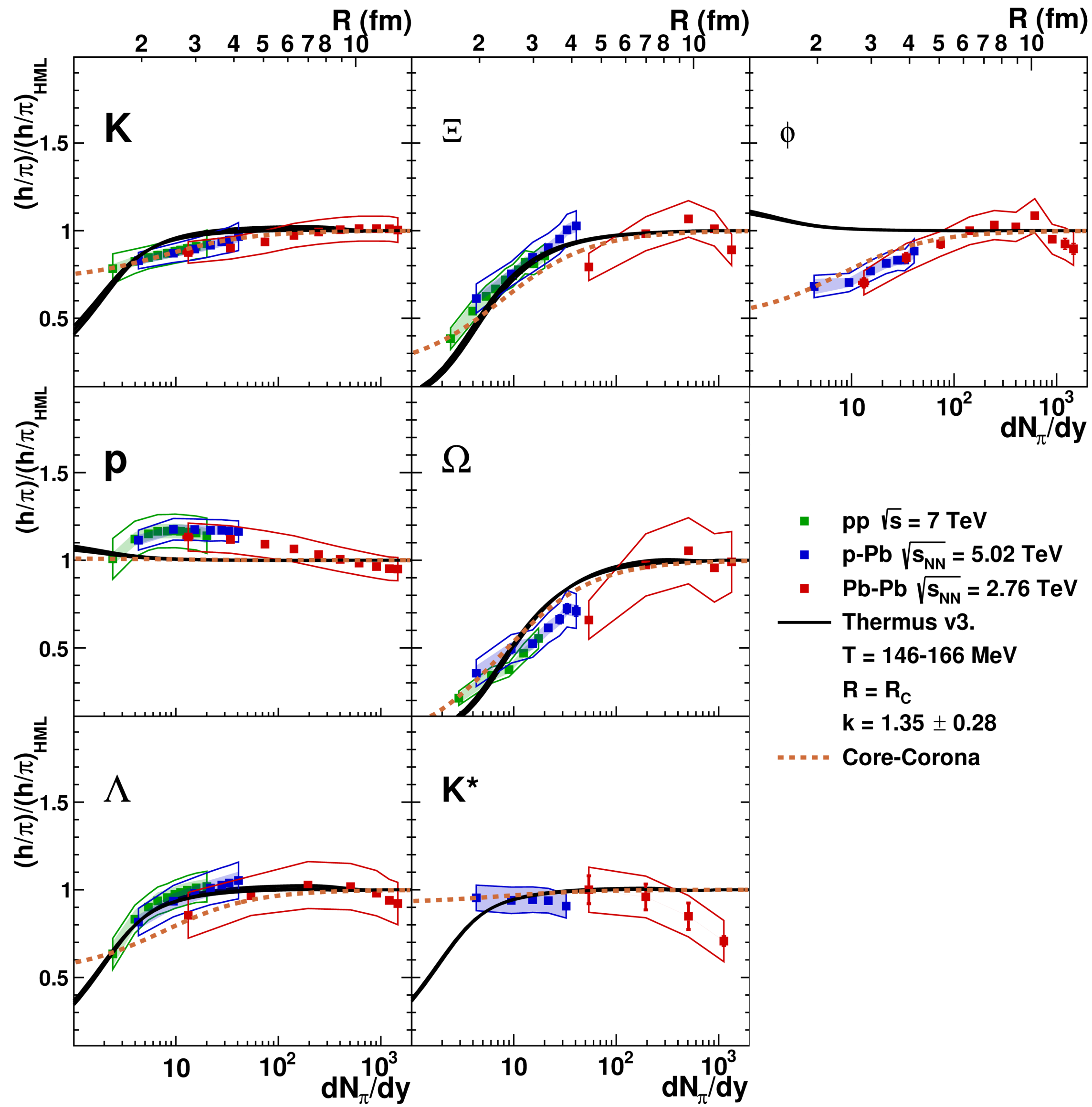

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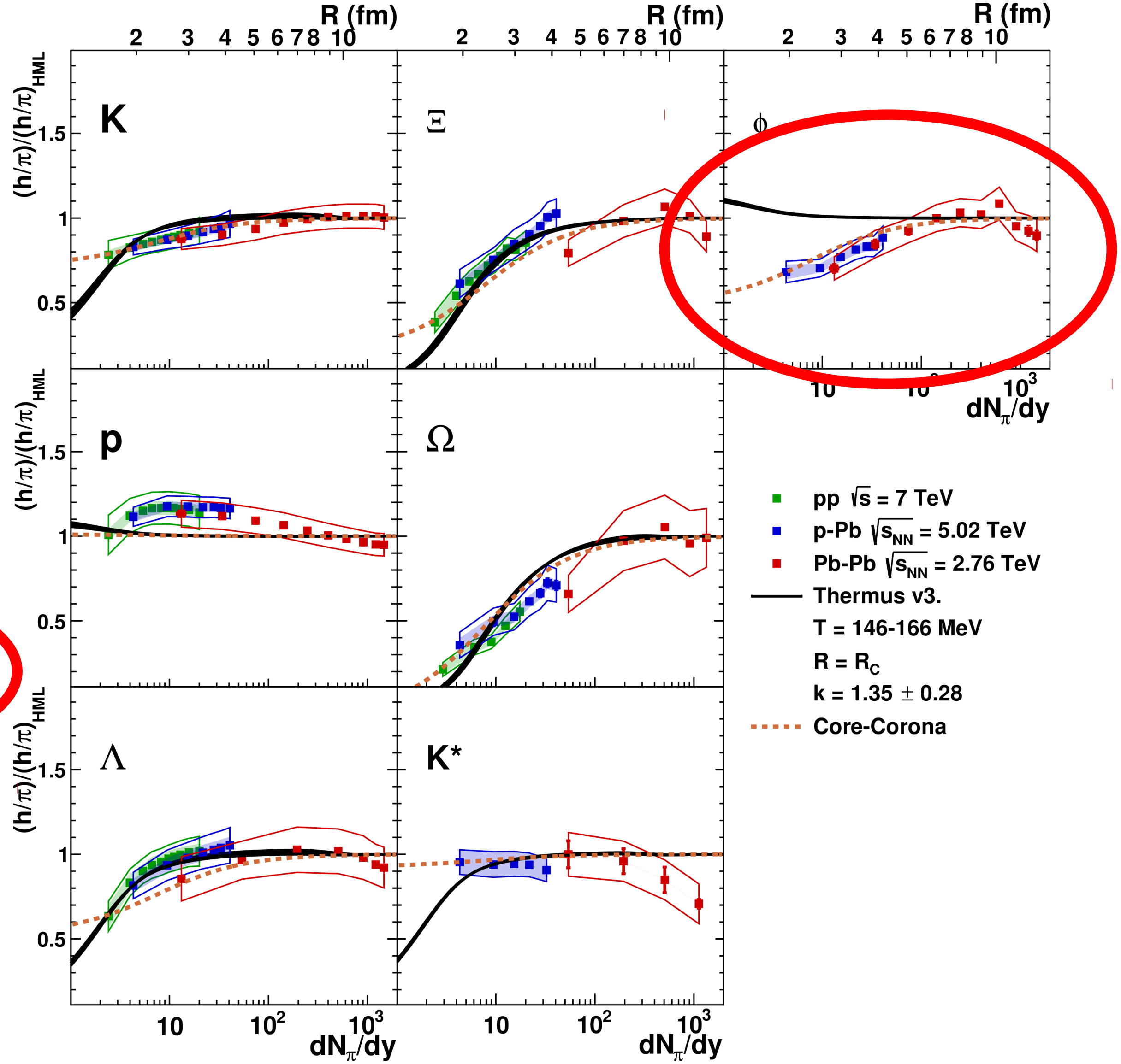
- Core-Corona: similar predictions
  – Model describes the data well for most particles, over-predicts for ϕ meson



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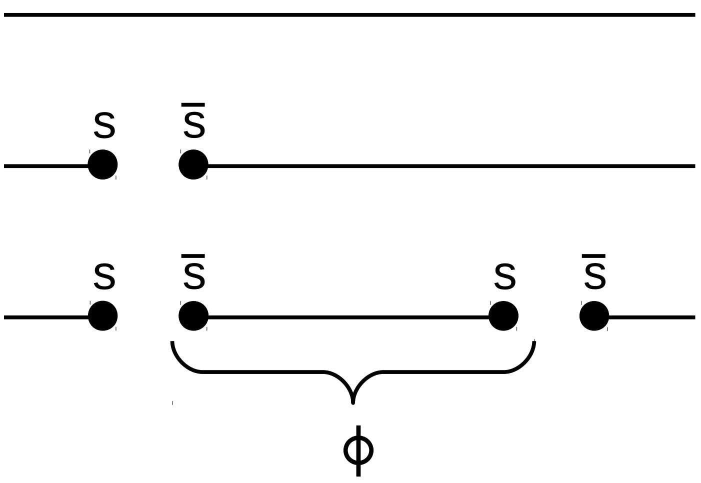
What happens to ϕ?

ϕ meson production

- String breaking: 2 strange quarks, need two string breakings to produce → double-suppressed
- Thermal production: overall strangeness *S* = 0, so should not be suppressed



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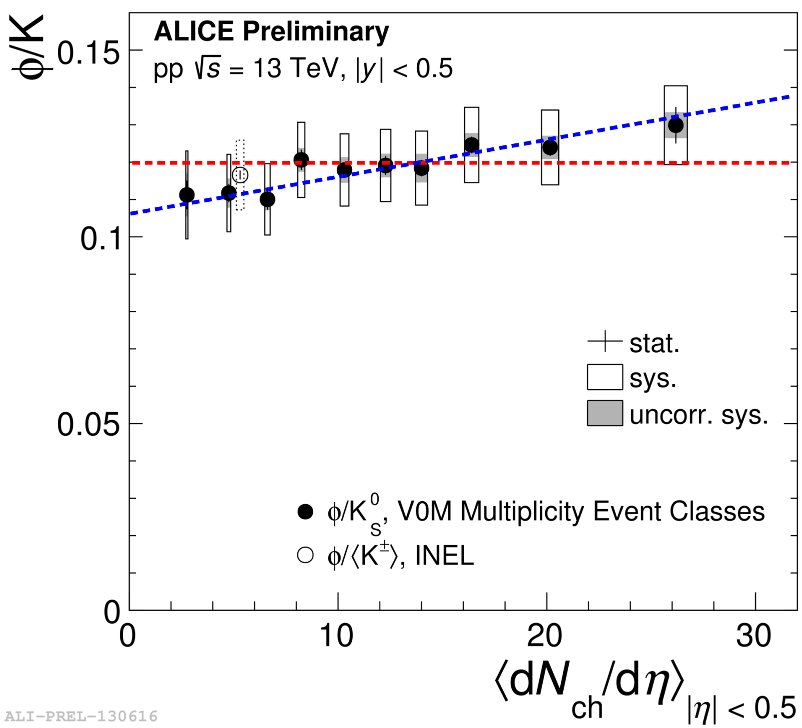

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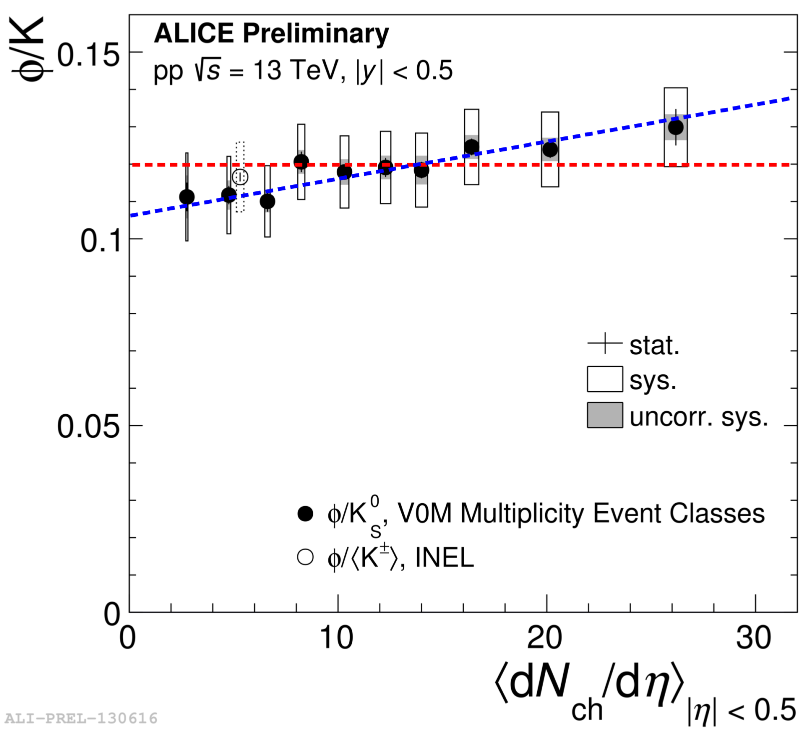
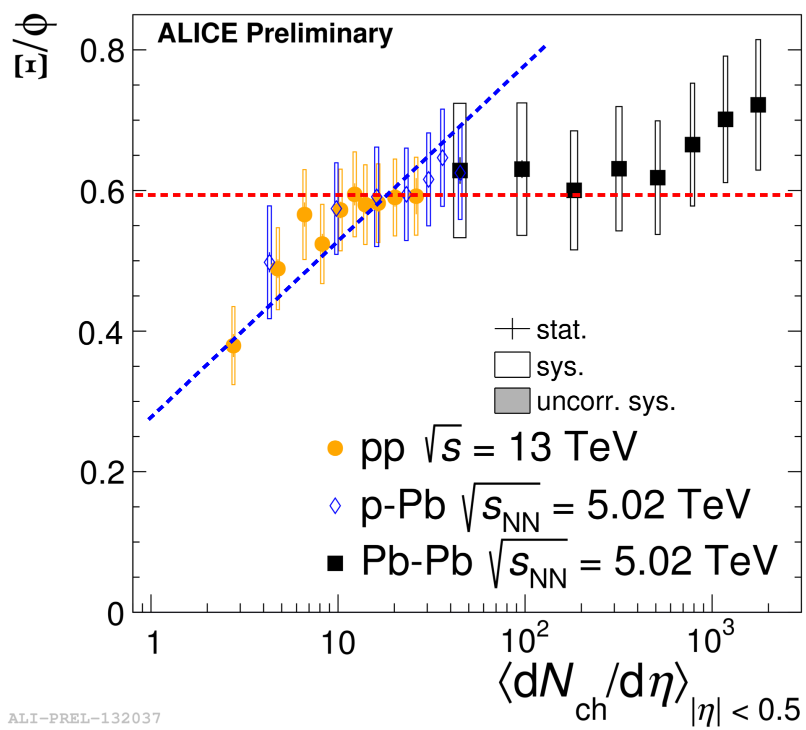
– Flat ($S(\Xi) = S(\phi)$) or increasing ($S(\Xi) > S(\phi)$)?

Overall: ϕ strangeness between 1 and 2?
Or do we measure both thermally (0) and string-produced (2) ϕ?





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Mean transverse momenta

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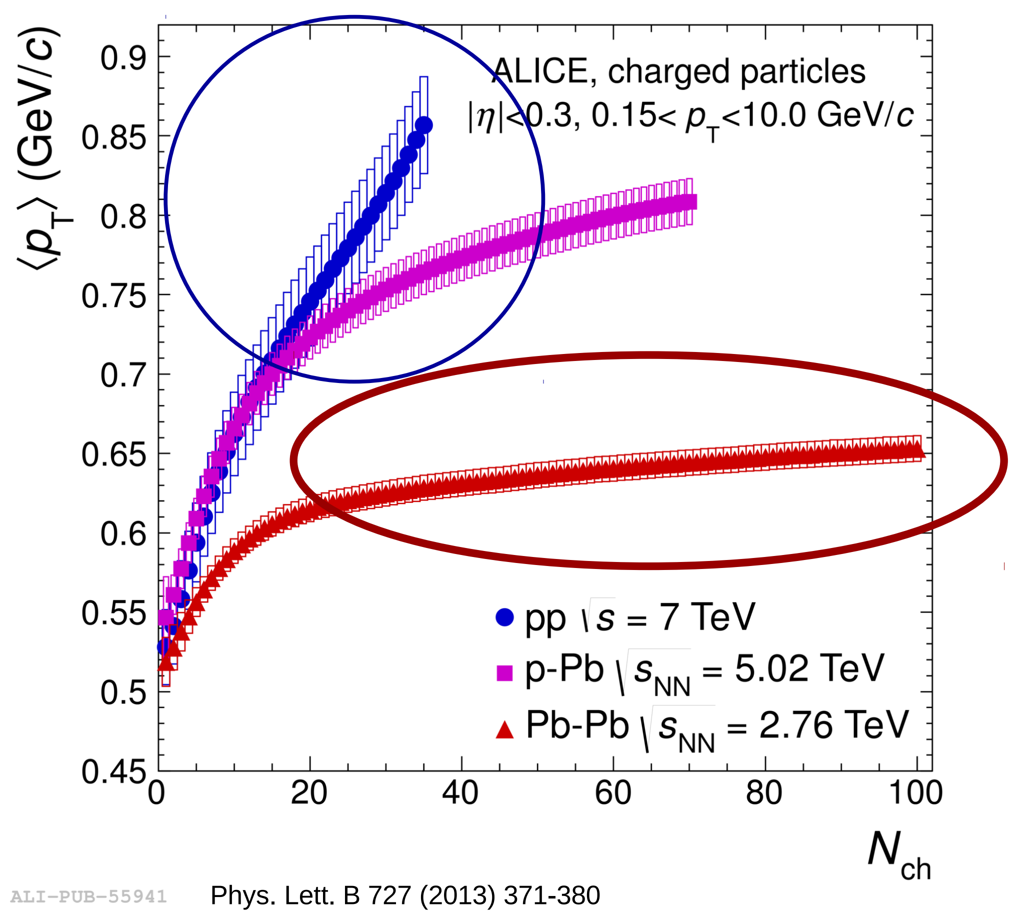
Different colliding systems → different underlying processes:

– Soft particle production (Pb-Pb)
– Hard processes (pp)



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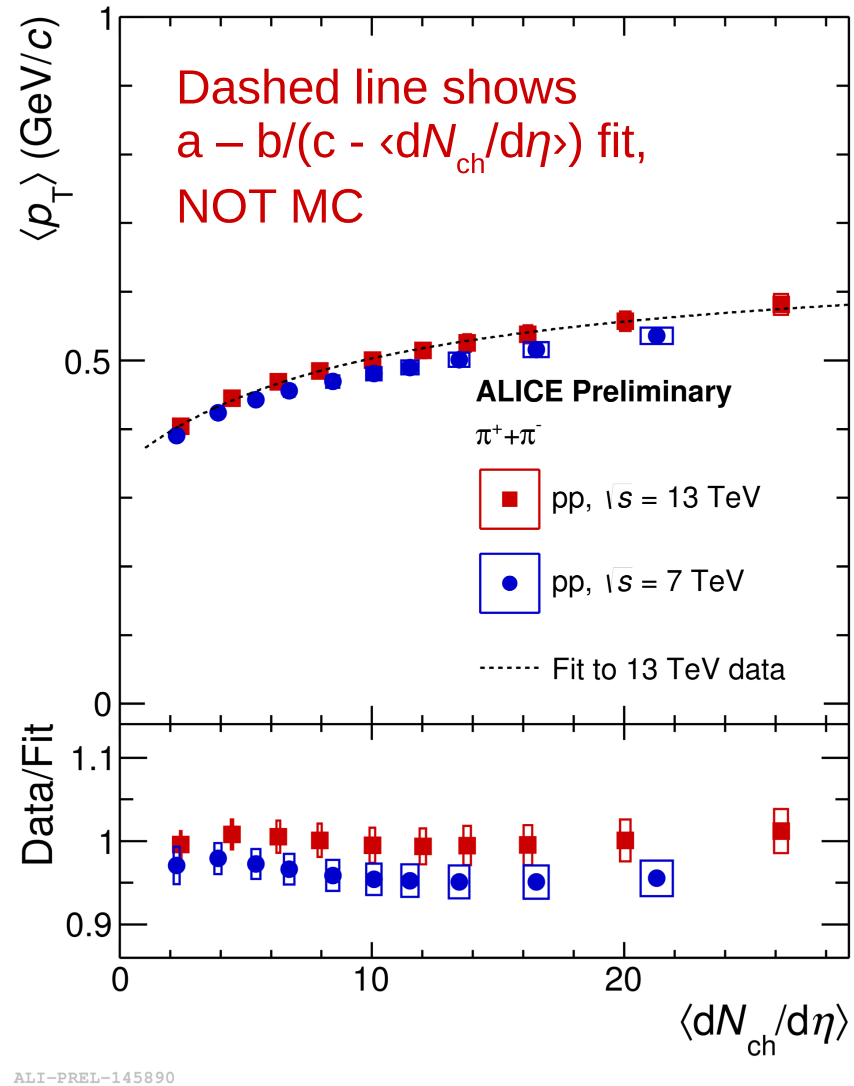

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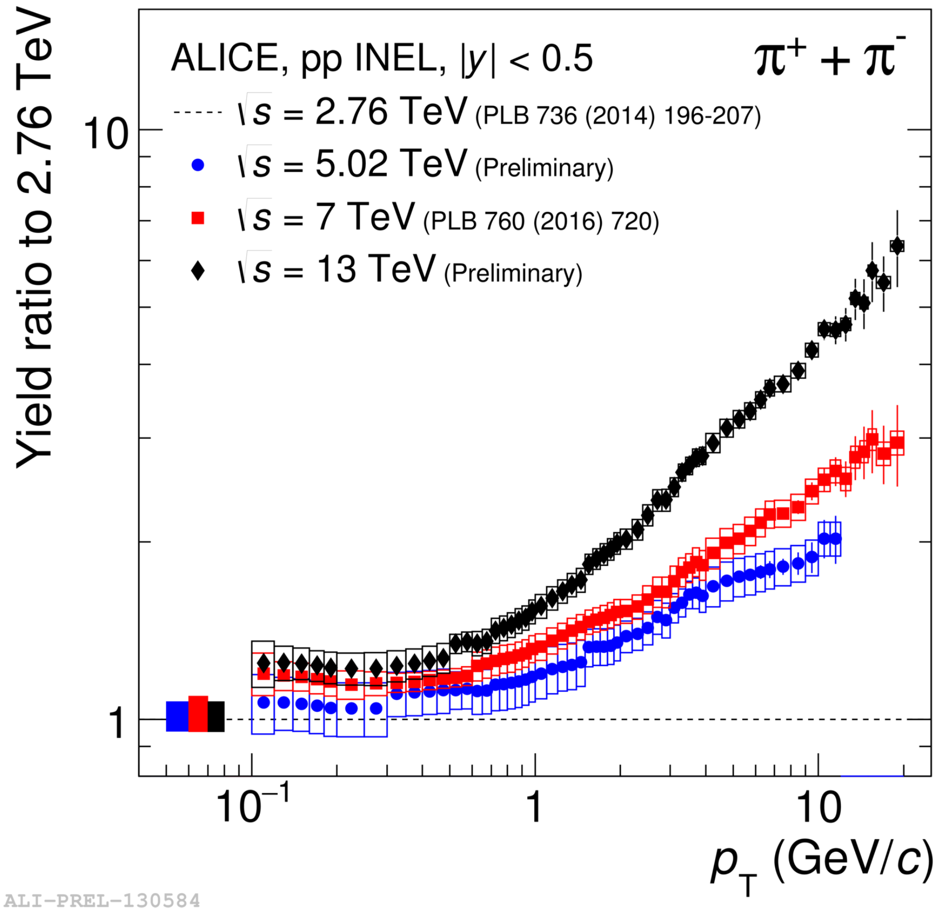
Moreover: at larger $\sqrt{s}$, we measure larger $\langle p_T \rangle$
– also seen in spectral ratios

Charged particle multiplicity drives hadrochemistry, *not the dynamics*



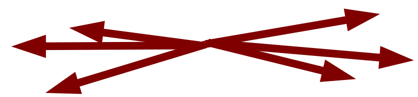
→ Can we select pp collisions with enhanced soft particle production?

Transverse spherocity

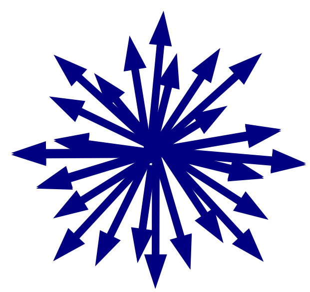
- Different underlying QCD processes result in different final state particle distributions

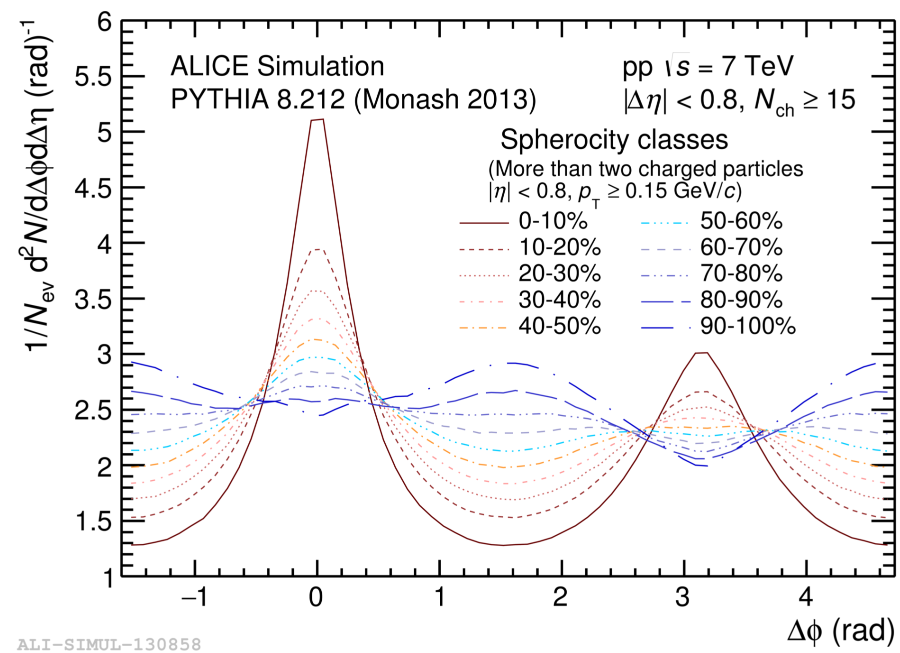
$$S_o = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\sum_i \vec{p}_{T,i} \times \hat{n}}{\sum_i p_{T,i}} \right)^2$$

- Hard QCD: e.g. dijets, toward/away regions
  $S_o \rightarrow 0$, "jetty" event



- Soft QCD: azimuthally isotropic particle distribution, enhanced underlying activity
  $S_o \rightarrow 1$, "isotropic" event





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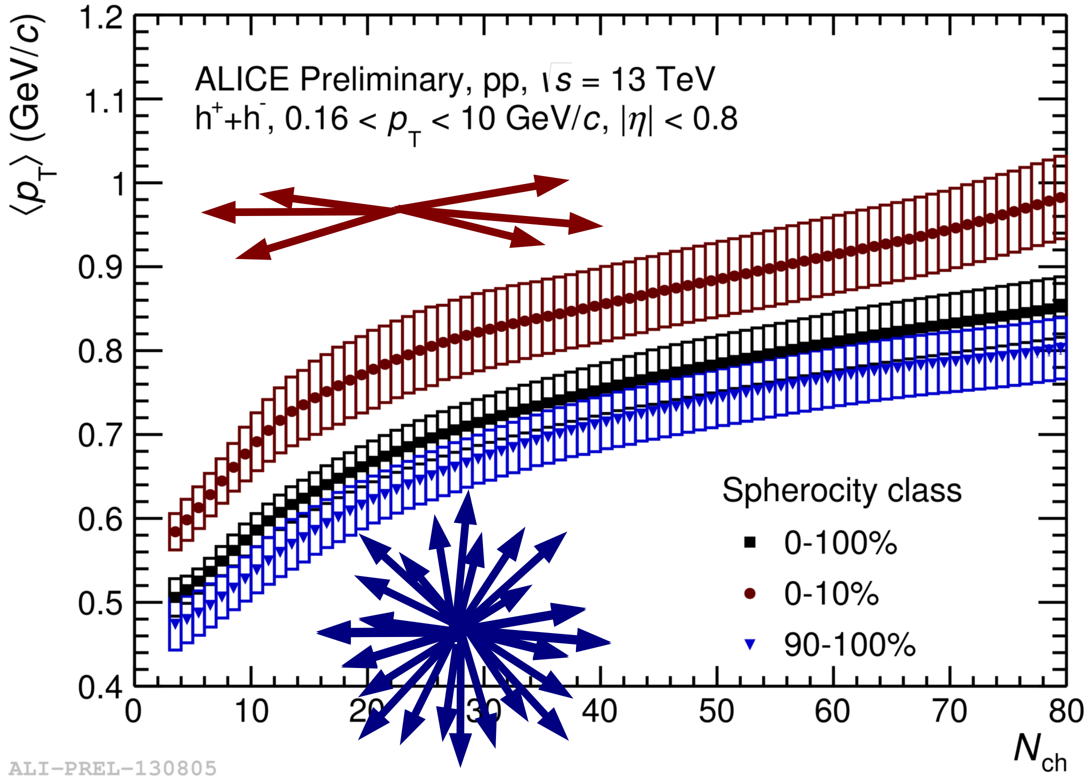
Yes we can!

$\langle p_T \rangle$ as a function of S_O

- Jetty collisions: *harder* spectra, more "pp"-like
- Isotropic collisions: *softer* spectra, more "Pb-Pb"-like

How does this compare to MC predictions?



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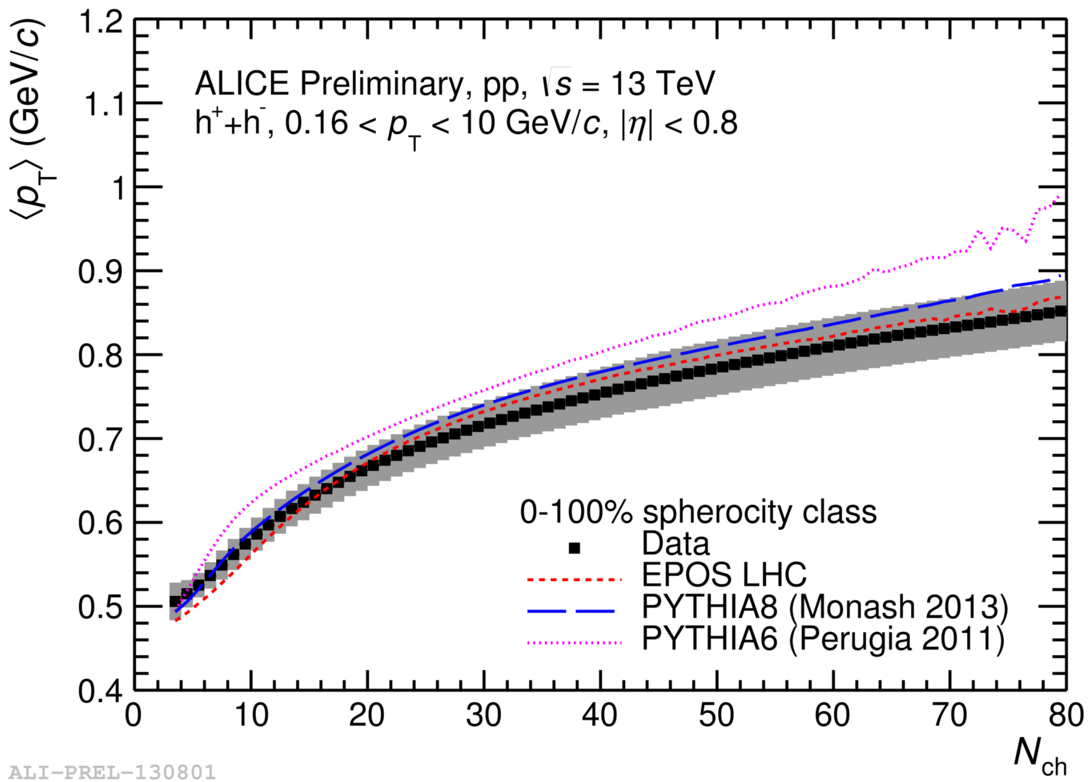

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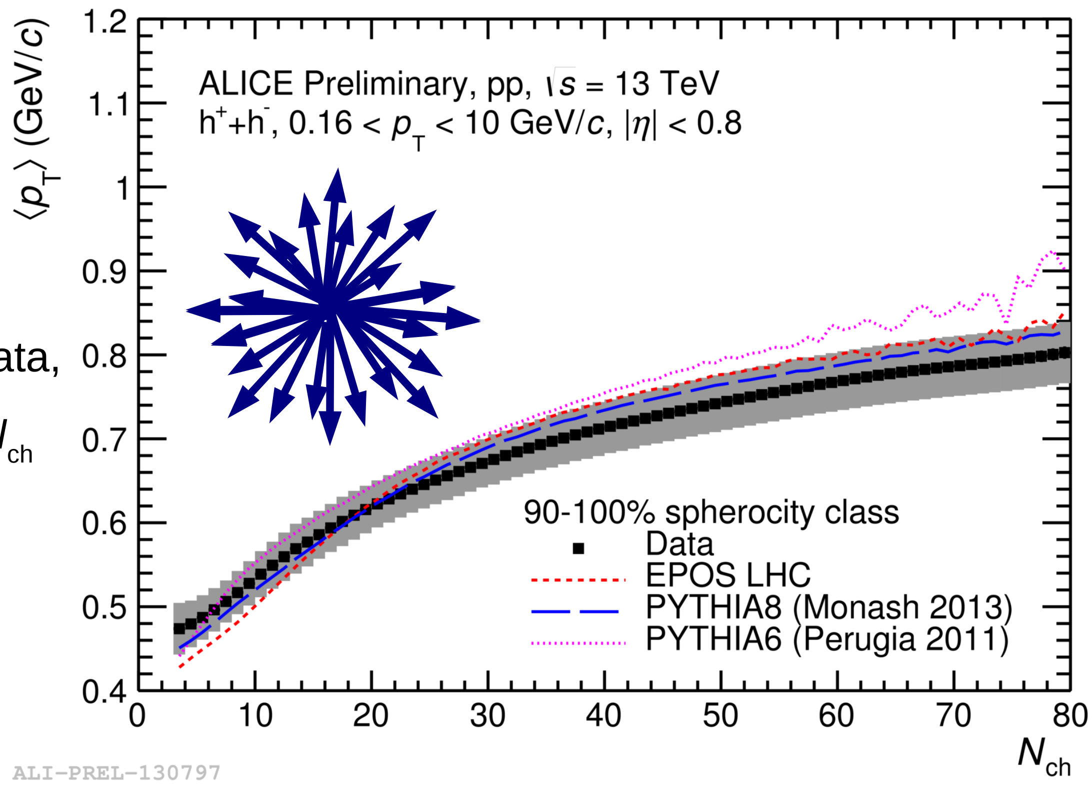

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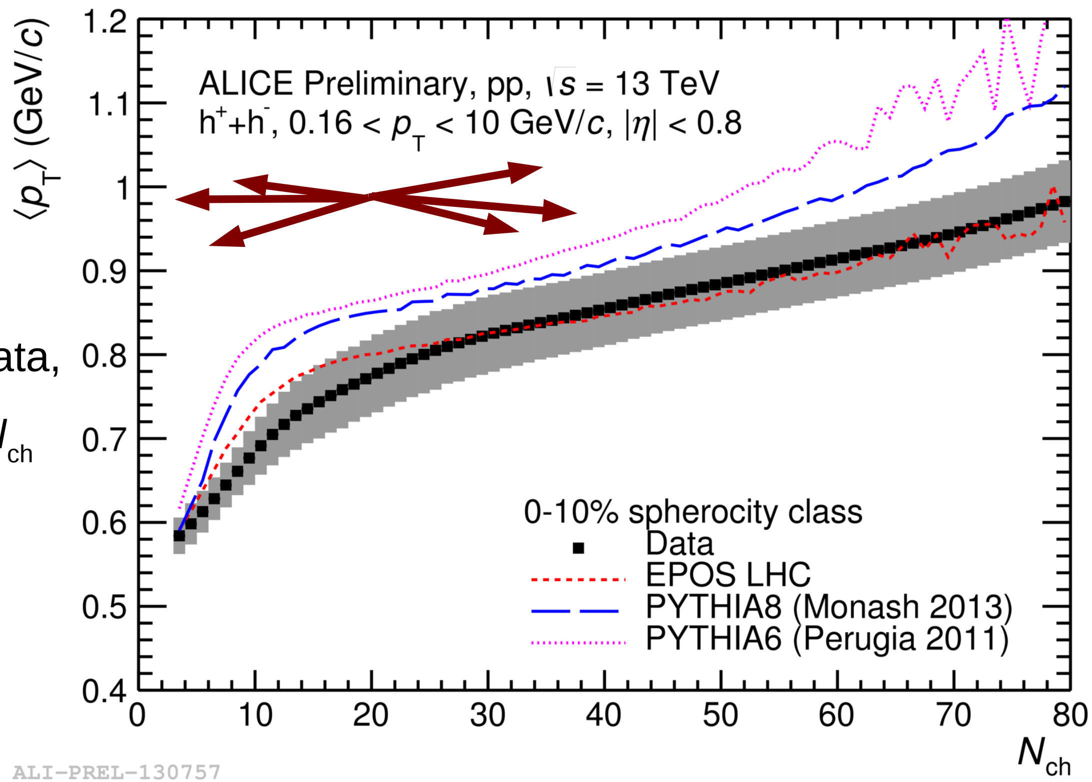
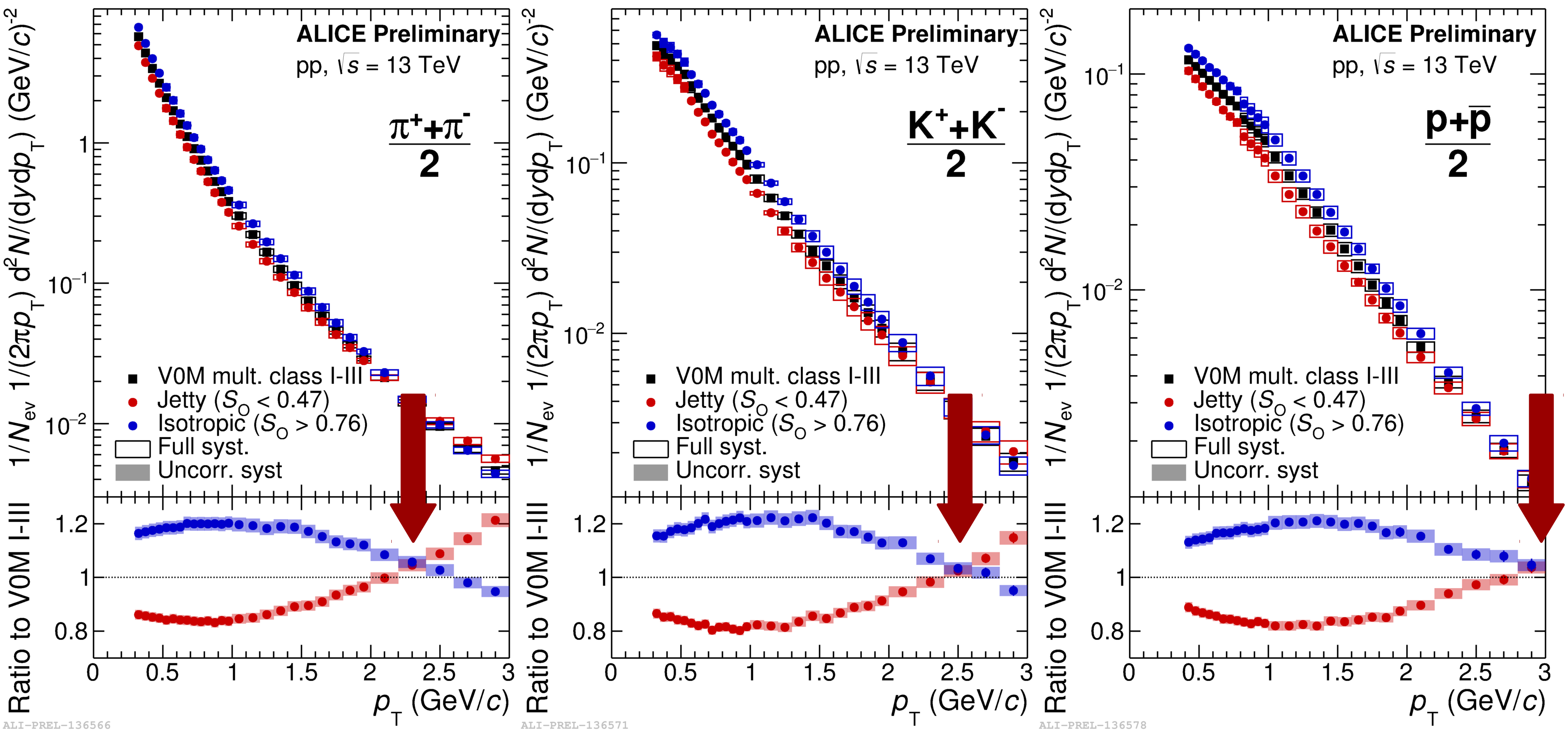
- Jetty collisions:
  – Tension with EPOS LHC at low N_{ch}
  – PYTHIA8 overestimates the $\langle p_T \rangle$
  → "Too little" of underlying event?



Identified particle spectra as a function of S_O

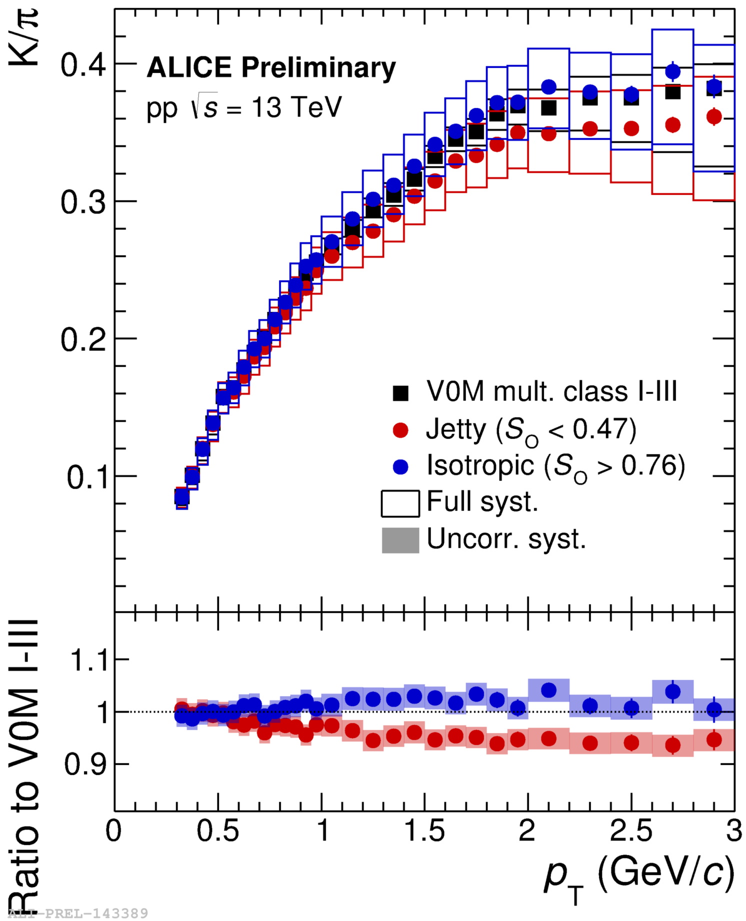
- Softer in isotropic
- Harder in jetty

- Crossing point shifter to larger p_T values for heavier particles
  → effect is mass-dependent (c.f. flow)

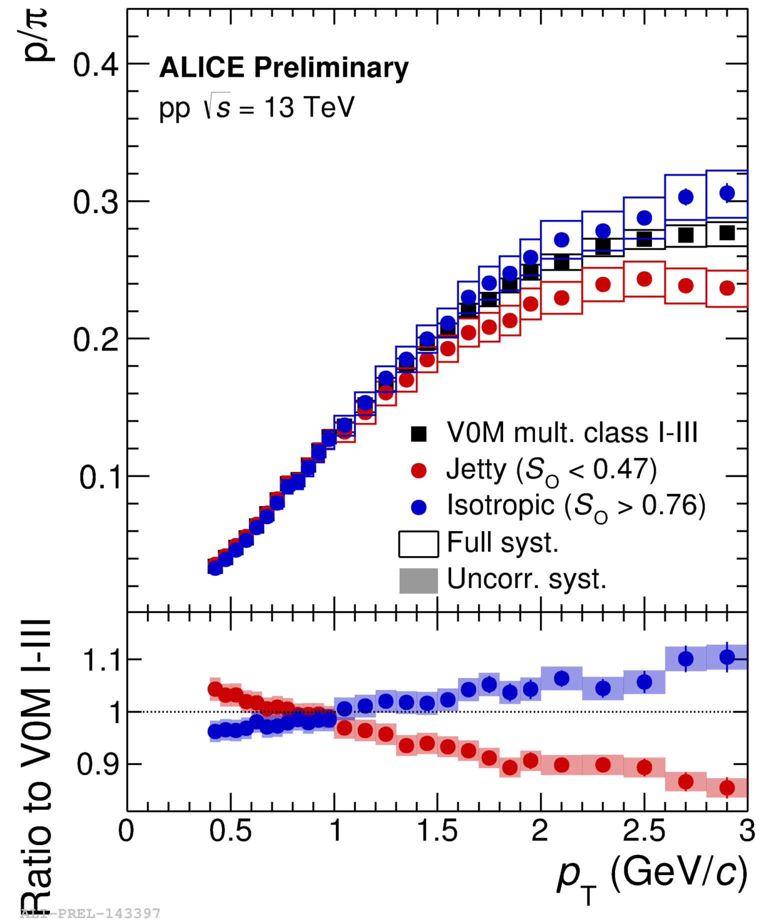


Identified particle spectra ratios as a function of S_O

Isotropic
- K/π: no (significant) modifications
- p/π: boosted towards higher p_T



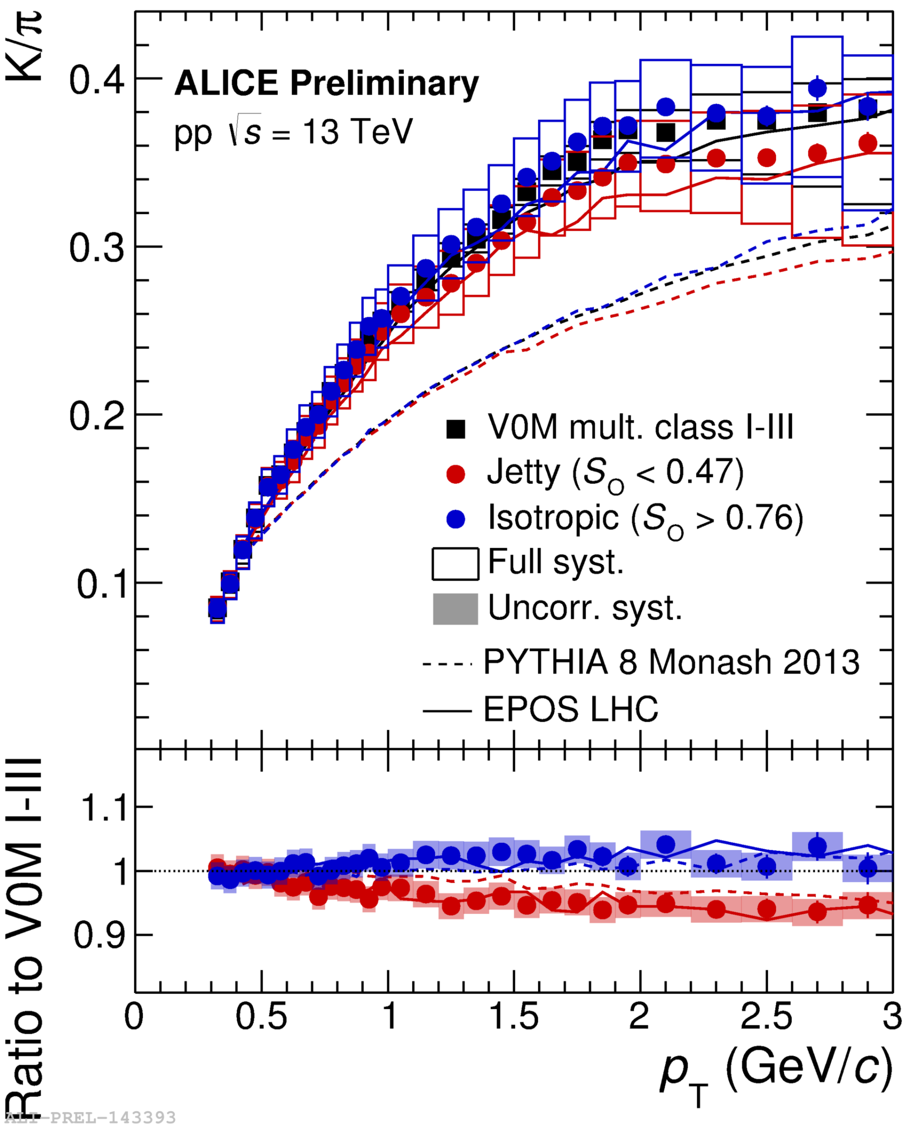
Jetty
- K/π: slightly shifted towards higher p_T
- p/π: shifted towards higher p_T



Identified particle spectra ratios as a function of S_O

K/π:

- PYTHIA8 underestimates the absolute values of the ratios, but double-ratios are consistent within systematic uncertainties
- EPOS LHC predicts the absolute values of the ratios and the double-ratios well



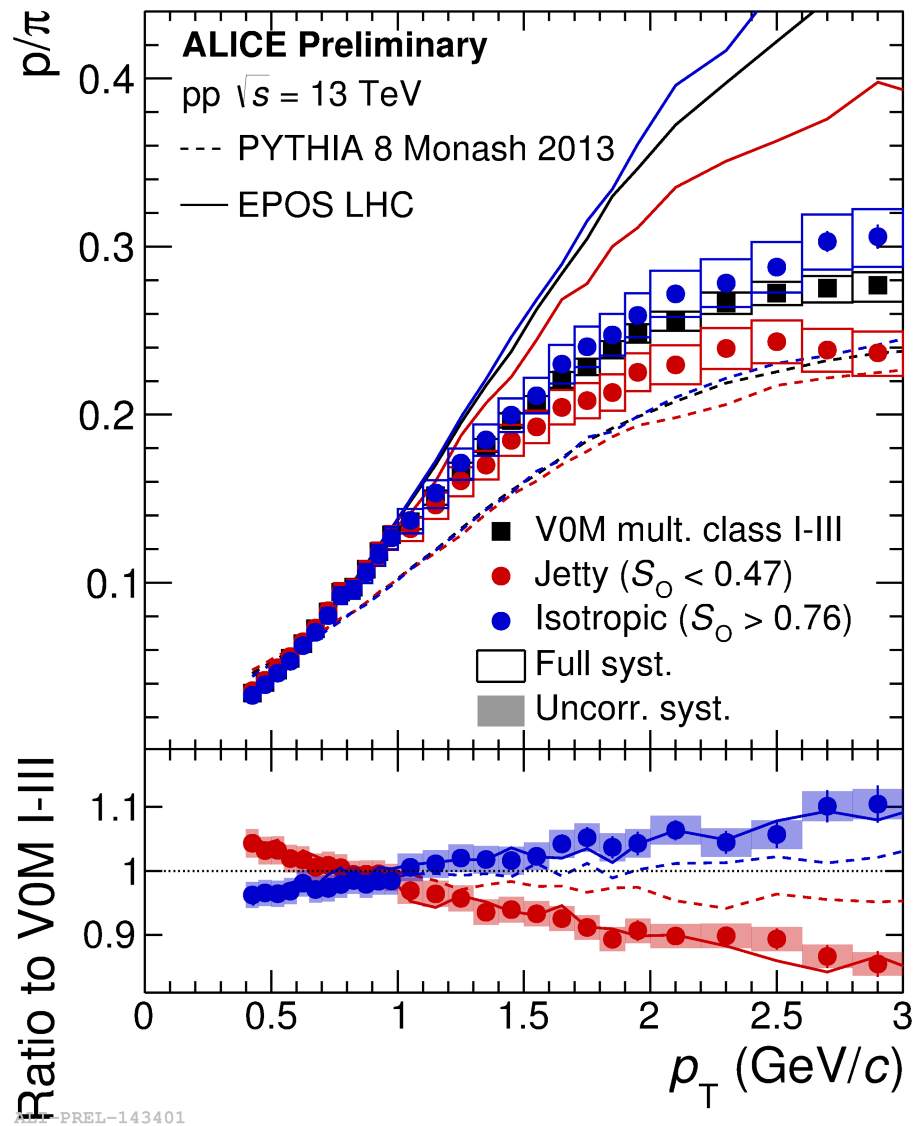
Identified particle spectra ratios as a function of S_O

K/π:

- PYTHIA8 underestimates the absolute values of the ratios, but double-ratios are consistent within systematic uncertainties
- EPOS LHC predicts the absolute values of the ratios and the double-ratios well

p/π:

- PYTHIA8 underestimates the absolute values of the ratios and their evolution with S_O
- EPOS LHC overestimates the absolute values of the ratios, but their evolution with S_O is predicted well



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Summary

The observed factorization of particle abundances with ‹dN_{ch}/dη› raised a question whether physics probed in Pb-Pb collisions are the same as in pp. To investigate this, hadron production as a function of multiplicity has been studied using several commonly-used Monte-Carlo generators. We found that:

- PYTHIA8 predicts *no evolution* of particle yield ratios and does not describe the observed trends
- EPOS LHC predicts the observed trends *qualitatively*, but overestimates the rates of strangeness enhancement
- DIPSY is in a good agreement with the measured strange hadron-to-pion ratios, but overestimates p/π

Studies of pp collisions at $\sqrt{s}$ = 13 TeV in context of different event shapes showed that:

- Soft- and hard-QCD dominated events can be separated with transverse spherocity
- Collective-like effects are enhanced in pp collisions that exhibit isotropic final-state particle distributions
- PYTHIA8 overestimates ‹p_T› as a function of N_{ch} in jetty collisions
- The evolution of p_T-differential K/π and p/π ratios with spherocity is well described by EPOS LHC, whereas PYTHIA8 predicts the trends only qualitatively