Investigating The Soft And Hard Limits In Transverse Momentum Spectra In PP Collisions

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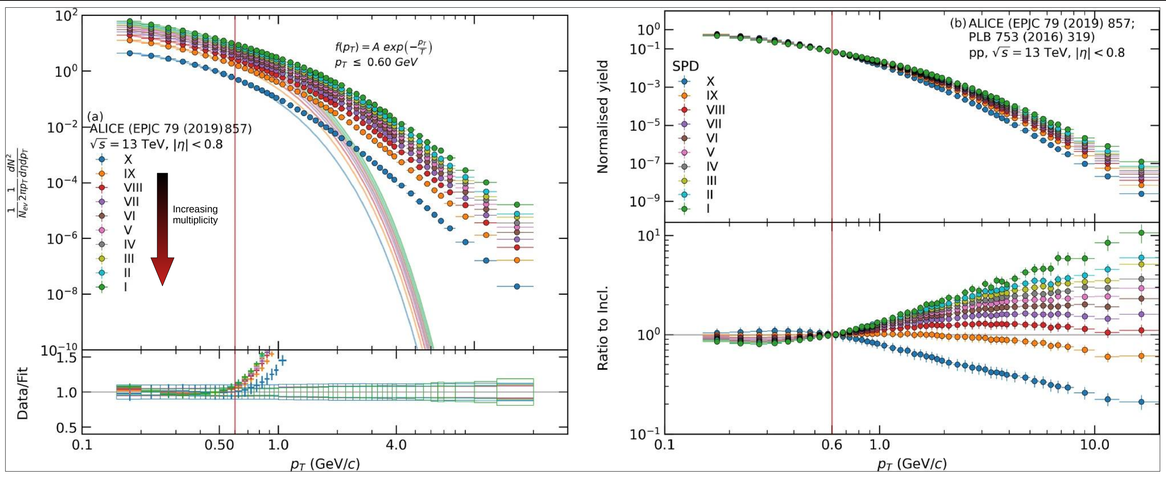
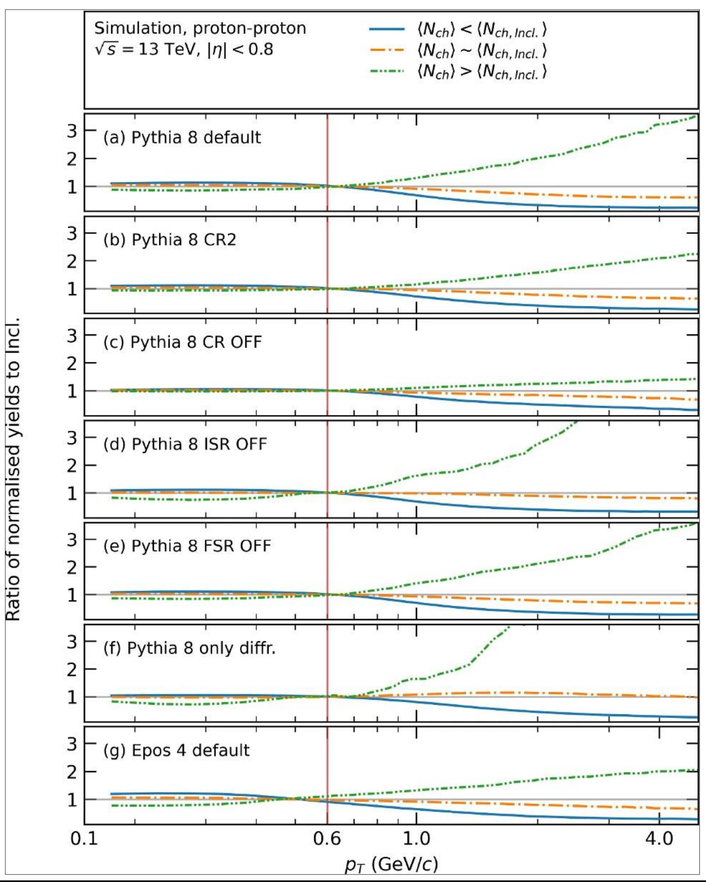
Introduction

- The transverse momentum spectra and their multiplicity dependence serve as key tools for extracting parameters to be compared with theoretical models.
- Recently, the possibility of a system analogous to quark-gluon plasma, in small systems has been investigated.
- We present the dependence of the mean transverse momenta obtained in the soft and soft+hard (mixed) parts.
- Finally, we also discuss possible refinements of the analyses concerning the use of statistical parameters of higher order, aimed at a more detailed way of comparing the models with data.

Experimental vs. Monte Carlo p_T Spectra



- Simple exponential fits (left) and normalized transverse momentum ratios with respect to the inclusive spectrum (right) at 13 TeV CM energy at various event multiplicity classes (X is the lowest, I is the highest)
- The spectra may be roughly separated into three regions:
  - the low p_T part representing purely soft interaction
  - an intermediate part where the hard interactions get mixed with soft ones
  - beyond ~4 GeV/c a region where we have contribution exclusively from hard interactions.

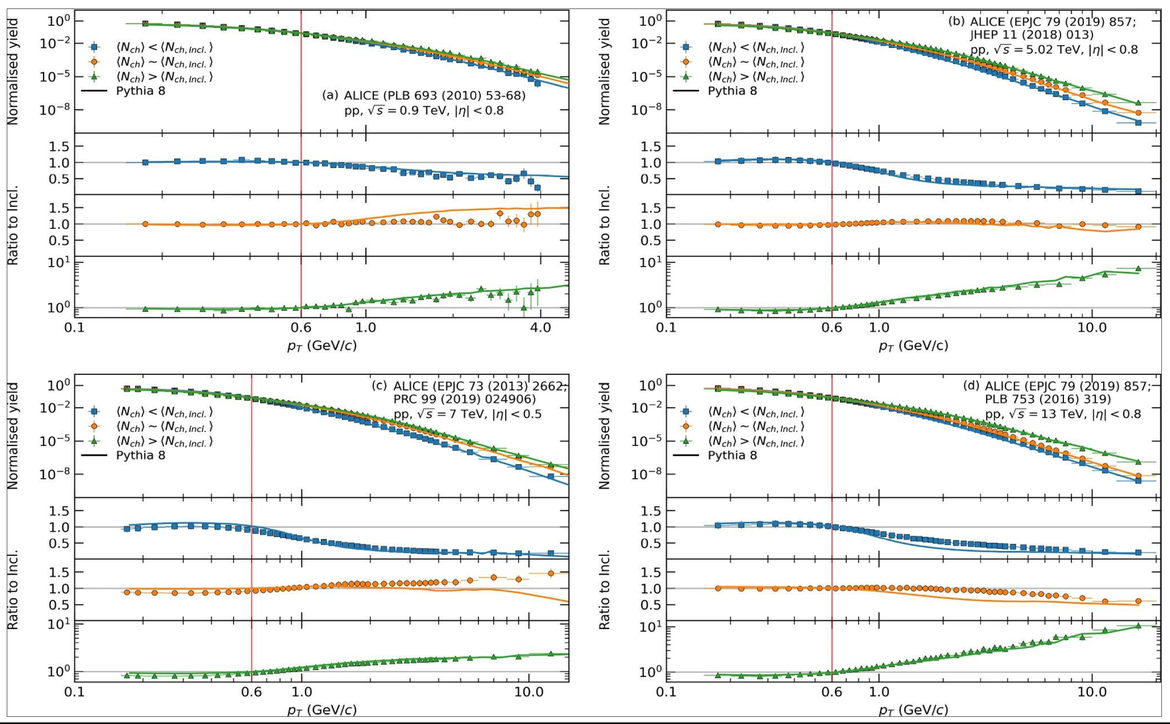


- MC comparisons with Rivet v3 analysis:
  - Pythia 8 with various settings
  - Epos 4 (version 4.0.0)
- Significant hardening of the distributions towards larger multiplicities
- The crossing point is independent of the different Pythia 8 settings
- The crossing-point is remarkably close to the breakdown of the naive exponential fit →
  - The spectra in a given multiplicity class stems from at least two different processes:
  - 1.Predominantly soft region (low-p_T):

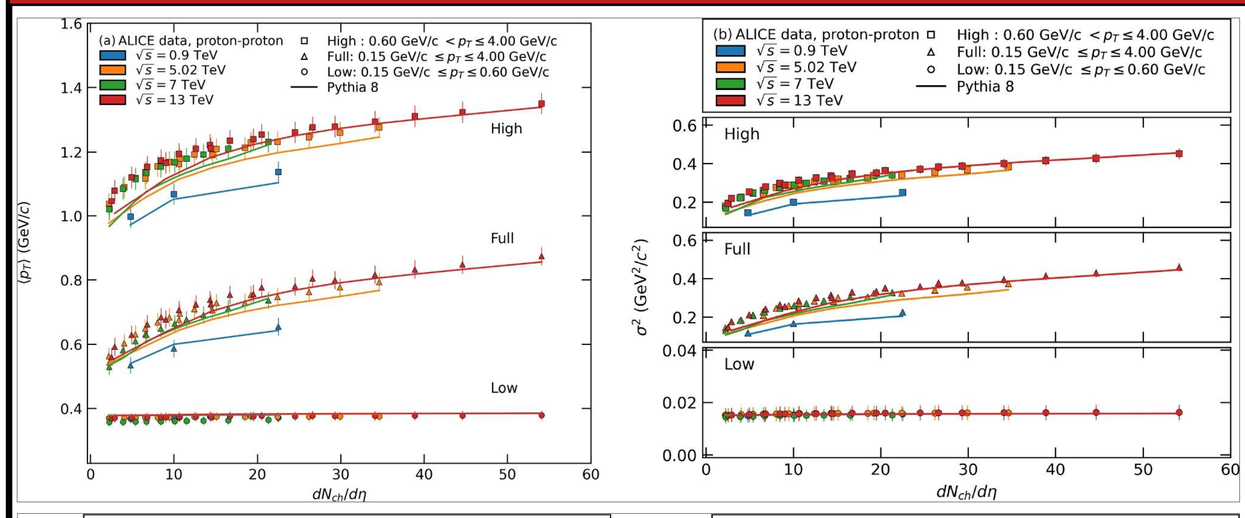
    0.15 GeV/c < $p_T \leq$ 0.6 GeV/c
  - 2.Mixed (soft and hard) region:

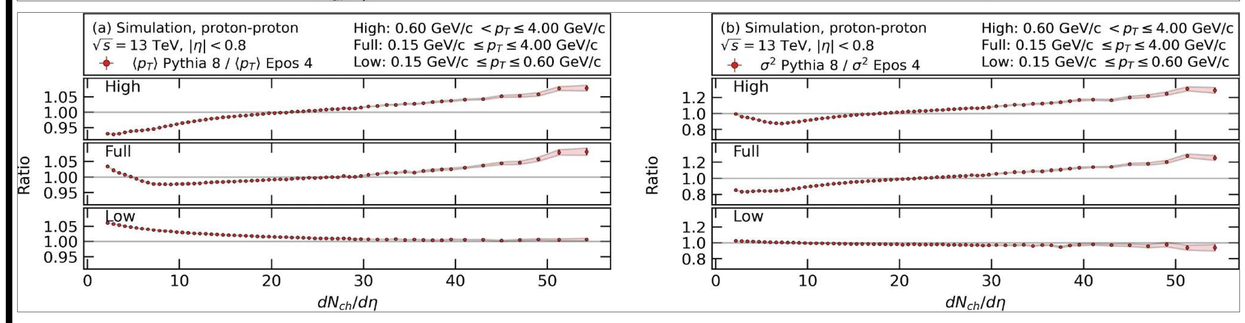
    0.6 GeV/c < $p_T \leq$ 4 GeV/c.

- By normalizing the spectra, the analysis isolates differences in the shape of the spectra, eliminating the influence of absolute particle yields.
- The centrality-class normalized yields select a natural value at 0.6 GeV/c at all studied energies.
- Pythia 8 (version 8.309) , Monash tune: successfully describe the qualitative features of the evolution of the spectra, in particular at low values.



Moments Of The p_T Spectra In Different Regions





- Mean transverse momentum and variance (variability within the data, deviation from the mean) for three p_T regions, compared to Pythia 8
- In the low-p_T region:
  - remain constant with respect to the multiplicity
  - no dependence on the centre-of-mass energy, spanning from 0.9 to 13 TeV
- Ratios between Pythia 8 and Epos 4 predictions: same independence of mean p_T and variance on mutliplicity within the low-p_T range

Discussion

- Consistent crossing-point at around $p_T \sim$ 0.6 GeV/c when comparing the ratio of the spectra to the inclusive distribution
  - This pattern observed across different classes and over a wide range of collision energies
  - Also present in the predictions from both Pythia 8 and Epos 4 models
  - Characteristic momentum scale → transition in the particle production mechanisms
- Absence of any variation with multiplicity and/or collision energy in the values of mean p_T and variance within the soft, low-p_T region
- Our results are consistent with the hypothesis of centre-of-mass energy invariance within the low-p_T part of the spectra
  - A phenomenon observed by the CDF collaboration in pp collisions at √s = 630 GeV and 1.8 TeV [2]
- This low-p_T region serves as an excellent laboratory for studying soft physics in pp collisions
- We advocate for the use of statistical parameters of higher order, such as variance and/or skewness to identify the differences between different models, Monte Carlo simulations, and experimental data
  - This is particularly important since the weight of soft and hard processes may differ in the models, and yet resulting in the same mean value

Summary

- The soft part of the interactions are reflecting a mode of interaction common to all collision energies and multiplicities at the LHC.
- Studies of collective effects that do extend the range of considered ranges well above the 0.6 GeV/c → risking important contributions of collisions of the hard nature.
- The selection of ranges in analyses demands greater scrutiny and justification to avoid potentially misleading conclusions.

Acknowledgement

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References

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