Event-by-event mean transverse momentum fluctuations in pp collisions at √s=13 TeV using PYTHIA8 and HERWIG7 models

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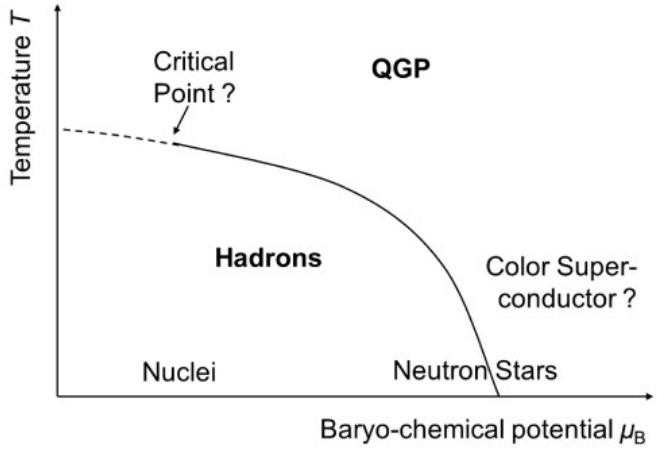
$\langle p_T \rangle$ fluctuations in heavy-ion collisions

Fluctuations

Statistical
(due to finite sample size)

Dynamical
(reflects the dynamics)

Fig: T. Heckel



- $\langle p_T \rangle$ fluctuations is sensitive to the temperature fluctuations
- Temperature (T) correspondingly, $\langle p_T \rangle$ fluctuations exhibits info on the phase transition

L. Stodolsky, Phys. Rev. Lett. 75, 1044 (1995).

Observables

- Event-by-event mean transverse momentum

$$\langle p_{\mathrm{T}} \rangle = \frac{\sum_{i=1}^{N_{\mathrm{ch}}} p_{\mathrm{Ti}}}{N_{\mathrm{ch}}}$$

- $\langle p_{\mathrm{T}} \rangle$ in a specific multiplicity class

$$\langle\langle p_{\mathrm{T}} \rangle\rangle = \left\langle \frac{\sum_{i=1}^{N_{\mathrm{ch}}} p_{\mathrm{T}}}{N_{\mathrm{ch}}} \right\rangle$$

$\langle \ldots \rangle$ denotes average of $\langle p_{\mathrm{T}} \rangle$ performed over the events

- The fluctuations of $\langle p_{\mathrm{T}} \rangle$ are quantified using

$$\sqrt{\langle\langle \Delta p_{\mathrm{T1}} \Delta p_{\mathrm{T2}} \rangle\rangle} / \langle\langle p_{\mathrm{T}} \rangle\rangle$$

where $\Delta p_{\mathrm{T}i} = p_{\mathrm{T}i} - \langle\langle p_{\mathrm{T}} \rangle\rangle$

with $i = 1, 2$

- Measurement of the Skewness of $\langle p_{\mathrm{T}} \rangle$ distributions

$$\gamma_{\langle p_{\mathrm{T}} \rangle} = \frac{\langle \Delta p_{\mathrm{Ti}} \Delta p_{\mathrm{Tj}} \Delta p_{\mathrm{Tk}} \rangle}{\langle \Delta p_{\mathrm{Ti}} \Delta p_{\mathrm{Tj}} \rangle^{3/2}}$$

This version of skewness has $1/\sqrt{N_{\mathrm{part}}}$ Dependency on the participant nucleons

- Intensive skewness

$$\Gamma_{p_t} \equiv \frac{\langle \Delta p_i \Delta p_j \Delta p_k \rangle \langle\langle p_t \rangle\rangle}{\langle \Delta p_i \Delta p_j \rangle^2}$$

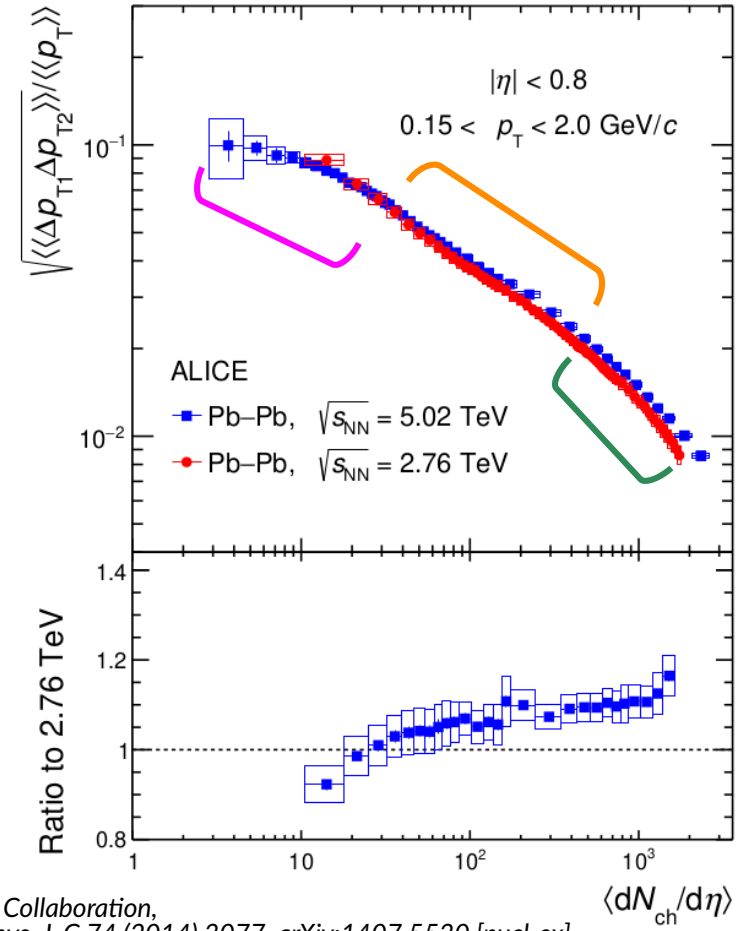
Independent of participant nucleons

Skewness can serve as an essential probe of the hydrodynamic behaviour of the system

G. Giacalone, F.G. Gardim, J. Noronha-Hostler, J.-Y. Ollitrault, Skewness of mean transverse momentum fluctuations in heavy-ion collisions, Phys. Rev. C 103 (2021) 024910, arXiv :2004 .09799 [nucl -th].

$\langle p_T \rangle$ fluctuations studies

- Finite dynamical $\langle p_T \rangle$ fluctuations are observed
- Follow different power law in three distinct regions $3 < \langle dN_{ch}/d\eta \rangle < 20$, $20 < \langle dN_{ch}/d\eta \rangle$ and $\langle dN_{ch}/d\eta \rangle > 300$
- Indications that the correlator is influenced by distinct mechanism from peripheral to central collisions
- Number of mechanisms like the onset of collectivity and thermalization, initial energy density etc.
- The interpretation of the observed fluctuations in terms of temperature fluctuations is, however, yet challenged by the mentioned processes



ALICE Collaboration, arXiv:2411.09334 [nucl-ex]

ALICE Collaboration, Eur. Phys. J. C 74 (2014) 3077, arXiv:1407.5530 [nucl-ex].

$\langle p_T \rangle$ fluctuations in pp collisions using PYTHIA8 and HERWIG7

- $\langle p_T \rangle$ fluctuations in pp collisions has contributions from jets, resonance decays and string fragmentation
- Investigations using two different underlying processes of hadronization
- Separate the contributions from jets and underlying soft processes of particle production [Event shape analysis]

PYTHIA8 Vs. HERWIG7

- **PYTHIA8 : Implement Lund String Model based on the dynamics of relativistic strings**

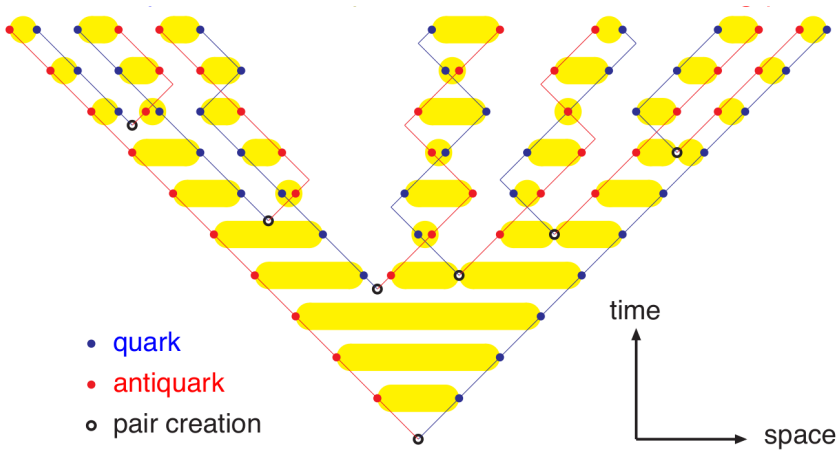
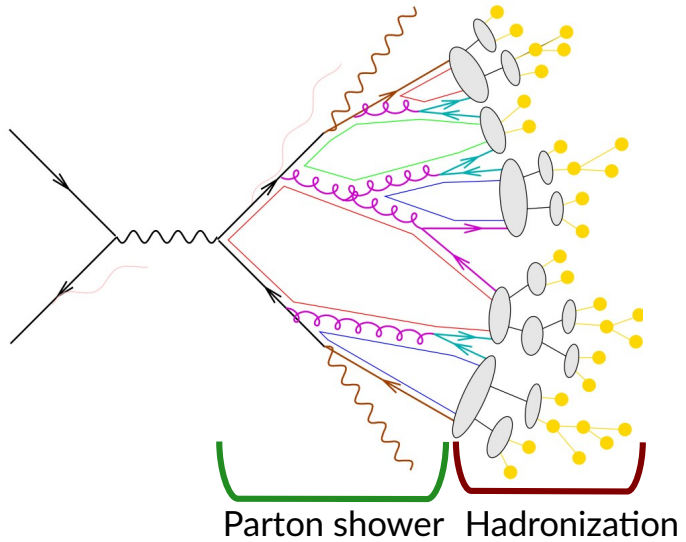


Fig: Torbjörn Sjöstrand

➲ A q from one string break combines with a $\bar{q}$ from an adjacent one

Torbjörn Sjöstrand, Stefan Ask, Jesper R Christiansen, Richard Corke, Nishita Desai, Philip Il-ten, Stephen Mrenna, Stefan Prestel, Christine ORasmussen, and Peter Z Skands, Comput. phys. commun. 191, 159–177 (2015).

- **HERWIG7 : Implements cluster-hadronization model based on the so-called preconfinement property of QCD**

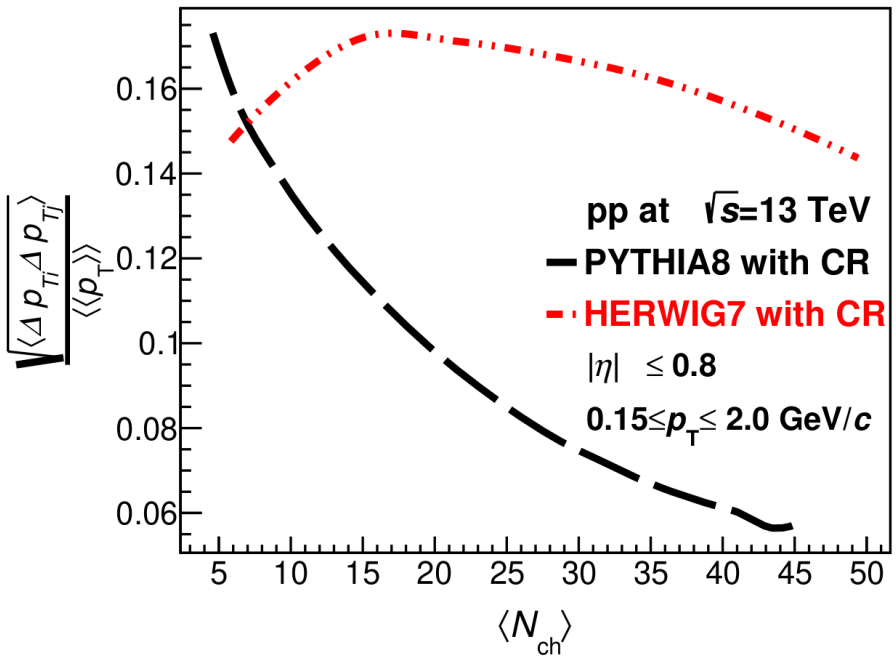


➲ Form colour singlet clusters

➲ Decay high-mass clusters to smaller clusters

Bahr, M., Gieseke, S., Gigg, M., Grellscheid, D., Hamilton, K., Latunde-Dada, O., Platzer,S., Richardson, P., Seymour, M., Sherstnev, A.& Others Herwig++ physics and manual. ArXiv Preprint ArXiv:0803.0883. (2008)

Comparison of the fluctuations

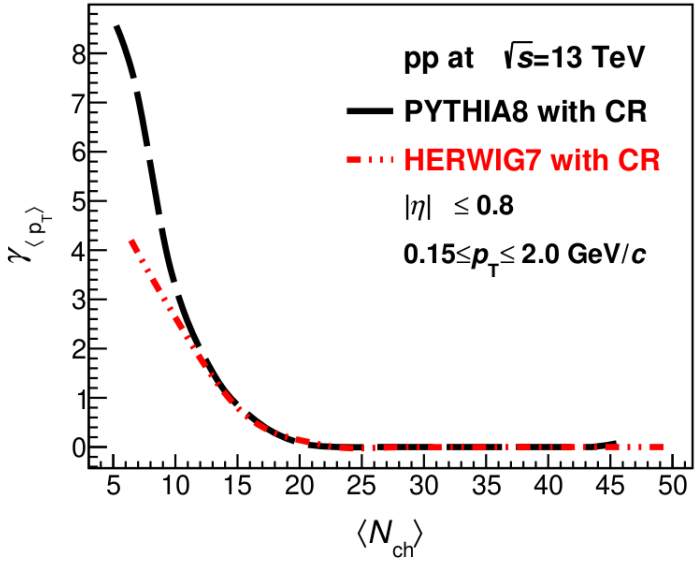


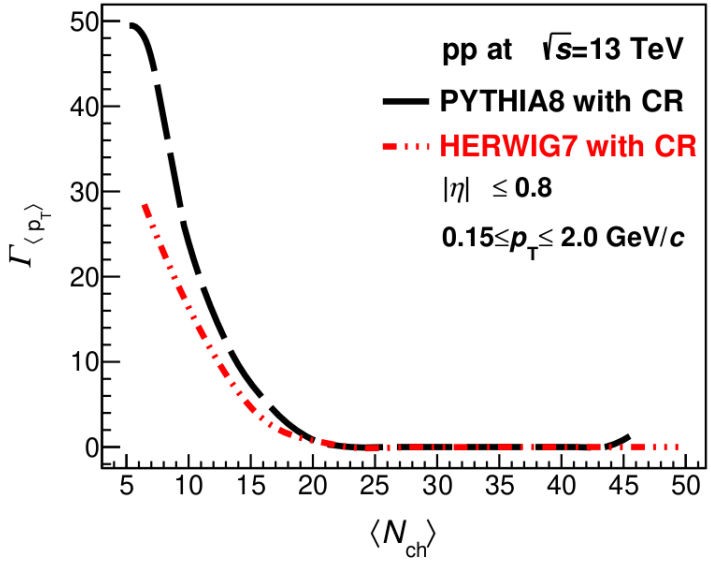
- Quantifies the strength of the dynamical fluctuations
- Indicative of the correlated particle emissions
- Cluster hadronization leads to greater fluctuations
- **String fragmentation** picture produces similar qualitative trend as data, observed by the various LHC experiments

Skewness

Standardized skewness : $\gamma_{\langle p_T \rangle} = \frac{\langle \Delta p_{Ti} \Delta p_{Tj} \Delta p_{Tk} \rangle}{\langle \Delta p_{Ti} \Delta p_{Tj} \rangle^{3/2}}$

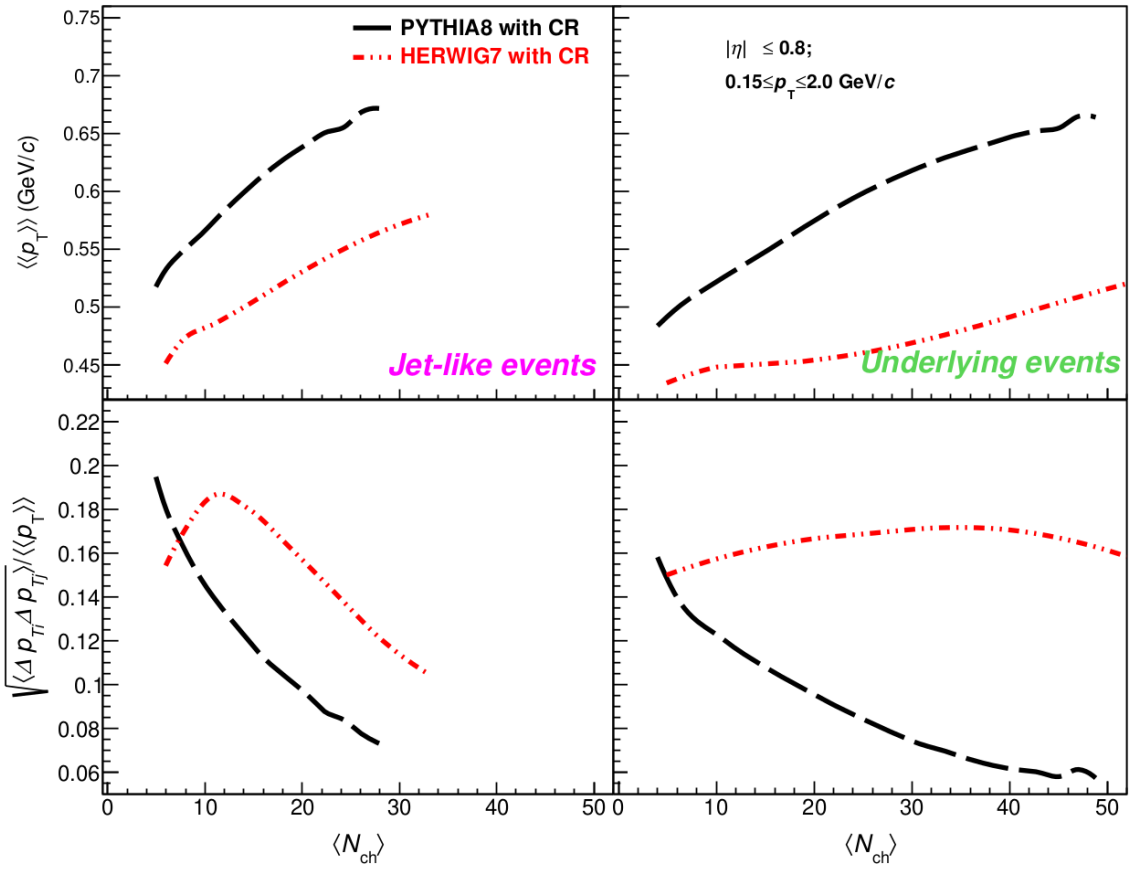
Intensive skewness : $\Gamma_{\langle p_T \rangle} = \frac{\langle \Delta p_{Ti} \Delta p_{Tj} \Delta p_{Tk} \rangle \langle\langle p_T \rangle\rangle}{\langle \Delta p_{Ti} \Delta p_{Tj} \rangle^{2}}$





- Both versions of skewness follow similar trends
- **String fragmentation** leads to enhanced skewness in the distributions

Understanding the jet contributions



- In jet reached samples, the slopes of the distributions almost **insensitive** to the cluster and string fragmentation
- Fluctuations are almost independent with multiplicity for Cluster hadronizations for the isotropic events
- Significant deviations in **isotropic** events reflect the difference in the sampling of various soft process in the Models

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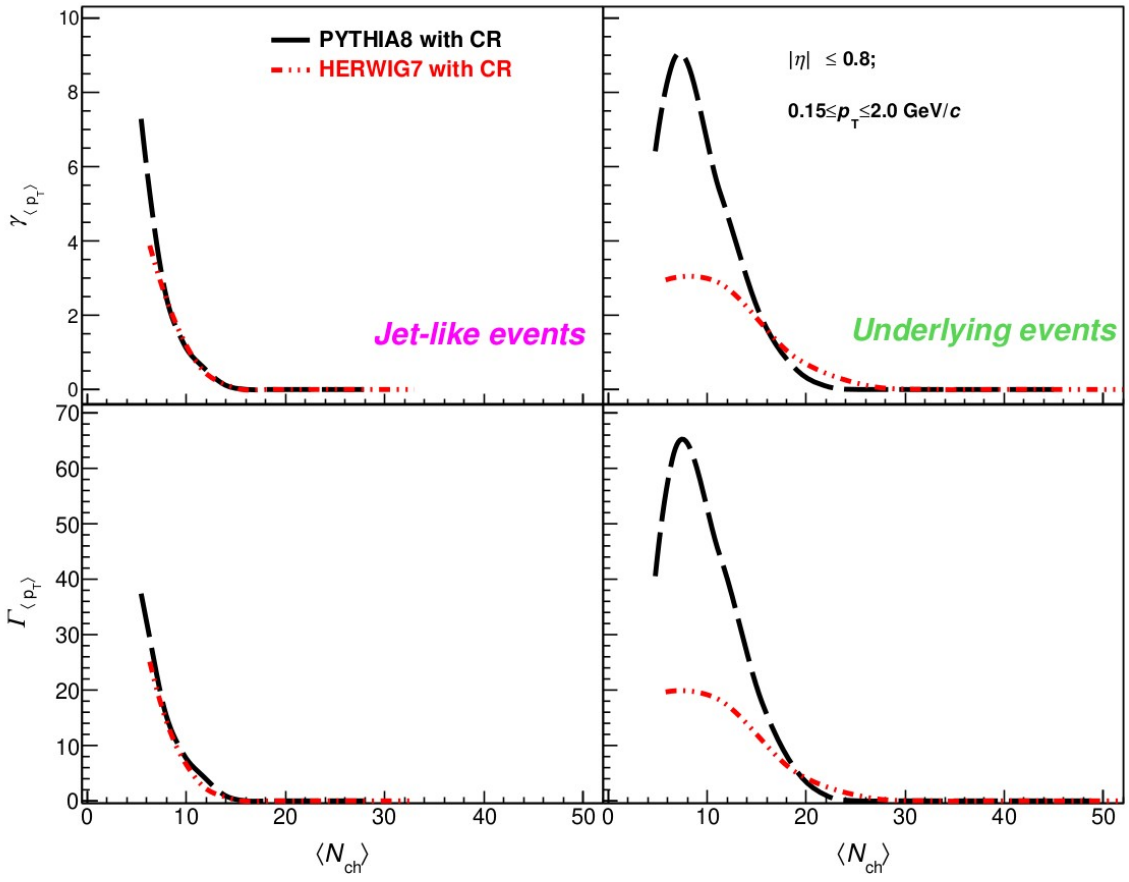

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Summary

- A comparative measurement of the $\langle p_T \rangle$ fluctuations is presented using different dynamics of hadron productions
- HERWIG7 produces greater dynamical fluctuations compared to PYTHIA8
- For jet reached samples the fluctuations are driven by similar mechanisms (jet fragmentation)
- The difference in the fluctuation trends essentially comes from the sampling of the underlying events in these models

Thank you!