Event-by-event multiplicity fluctuations in Pb–Pb collisions at 2.76 TeV with ALICE at the LHC

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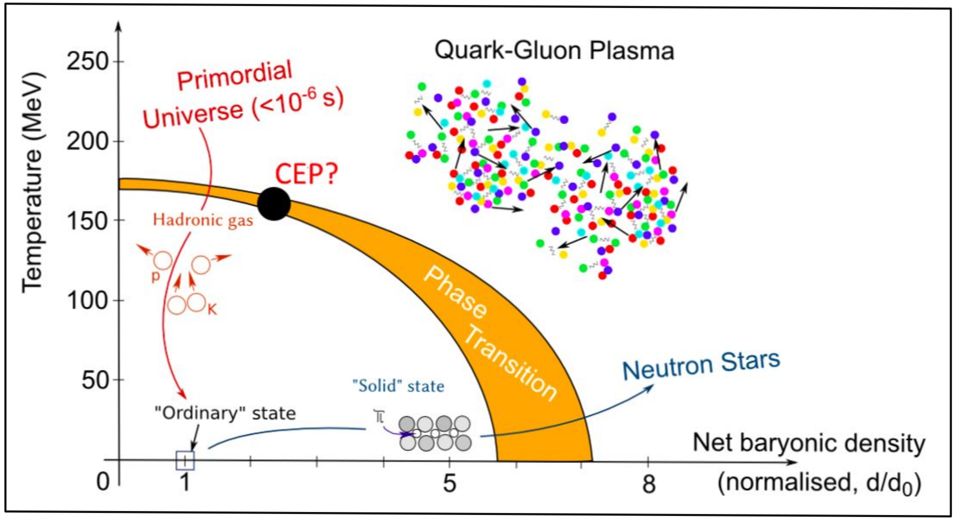
Introduction and motivation

The goals of heavy-ion collisions at RHIC and LHC are:

- to explore the QCD phase diagram,
- to locate the critical point,
- to search for quark-hadron phase transition.



Heavy ion collisions → Expected to produce large number of particles and thus provide the opportunity to analyze the data on an event-by-event basis.

Introduction and motivation

- As the system approaches critical temperature, the tension between the collective interactions and thermal randomization increases leading to the formation of clusters.

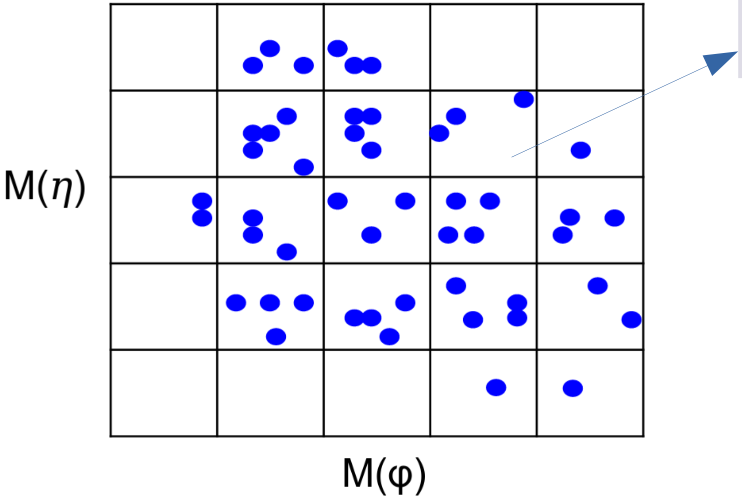
Clustering → **Fluctuations in the geometrical configurations (spatial patterns)** → **Criticality and quark-hadron phase transition**

- Multiplicity fluctuations are an important tool for understanding the dynamics of the produced particles and phase transition in heavy-ion collisions.
- These fluctuations are characterized by the moments of the particle density distribution within a given phase space.
- One of such moments to study the scaling properties of multiplicity fluctuations over a range of bin sizes is **Normalized Factorial Moment (NFM).**

Observables

Phase space (η, φ) is divided into a square lattice:

- Bin multiplicity is used to calculate the Normalized Factorial Moments (NFM).



i[th] cell, 3 particles (n_{ie})

$$f_q(n_{ie}) = n_{ie}(n_{ie}-1)(n_{ie}-2)........(n_{ie}-q+1)$$

$$F_q(M) = \frac{\frac{1}{N}\sum_{e=1}^{N}\frac{1}{M}\sum_{i=1}^{M} f_q(n_{ie})}{\left(\frac{1}{N}\sum_{e=1}^{N}\frac{1}{M}\sum_{i=1}^{M} f_1(n_{ie})\right)^q}$$

where **N** : number of events, **M** : number of bins, $\mathbf{n_{ie}}$: bin multiplicity, $n_{ie} \geq q$, q - order of the moment; $q \geq 2$

- F_q filters out statistical fluctuations.
- F_q is independent of the uniform detector efficiencies.

1. R.C. Hwa and C.B. Yang, PRC 85, 044914 (2012).

Observables

1. **M-Scaling** ⟶ $F_q(M) \propto M^{\varphi_q}$

Intermittency is observed if F_q shows a power law dependence on the number of phase space bins (M).

Observation of intermittency is related to self-similarity and fractal behavior of the particle production.

2. **F-Scaling** ⟶ $F_q(M) \propto F_2(M)^{\beta_q}$

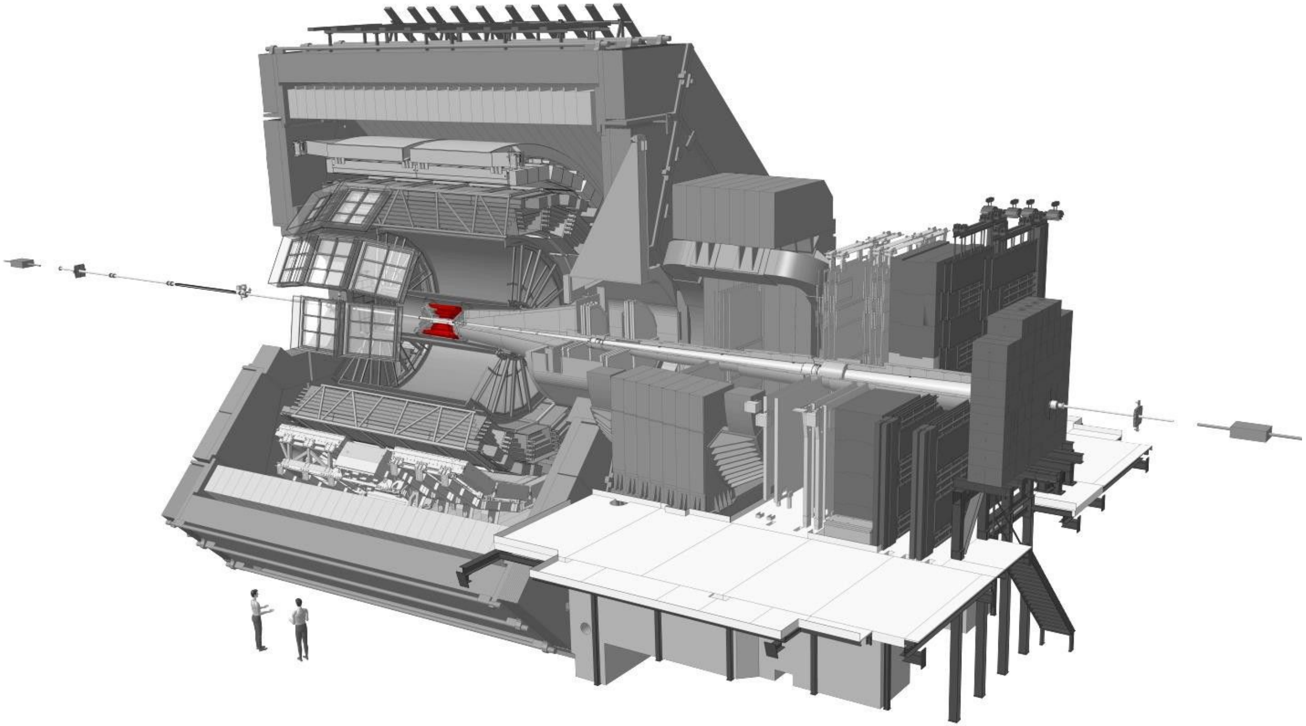
$$\beta_q \propto (q-1)^{\nu}$$

- **ν : is dimensionless scaling exponent** which characterizes the dynamics of the system under study.

ν ≅ **1.32** Ginzburg-Landau formalism[1] for the second- order phase transition
ν ≅ **1.41** Critical fluctuations in case of Successive Contraction and Randomization (SCR) Model[2]

1. R.C. Hwa and Jicai Pan, PLB 297, 35 (1992).
2. R.C. Hwa and C.B. Yang, PRC 85, 044914 (2012).

ALICE detector

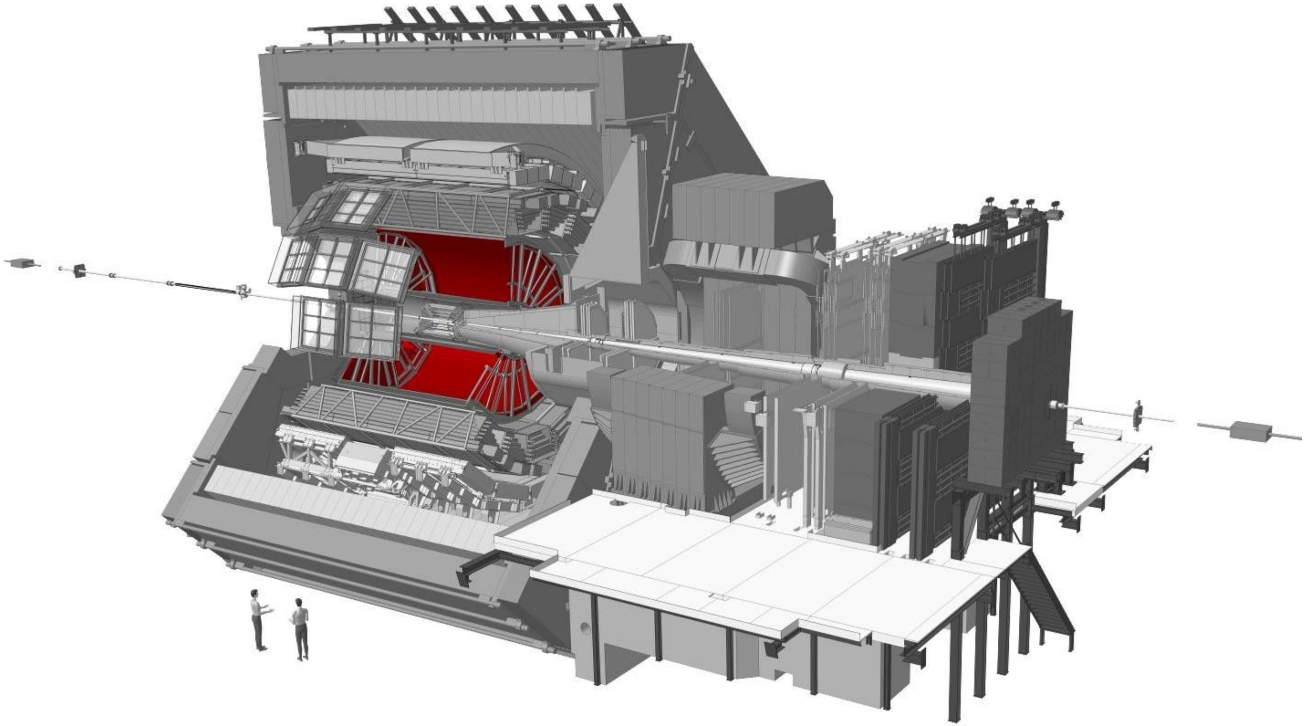


Detectors

ITS $|\eta| < 0.9$

Vertexing and tracking

ALICE detector

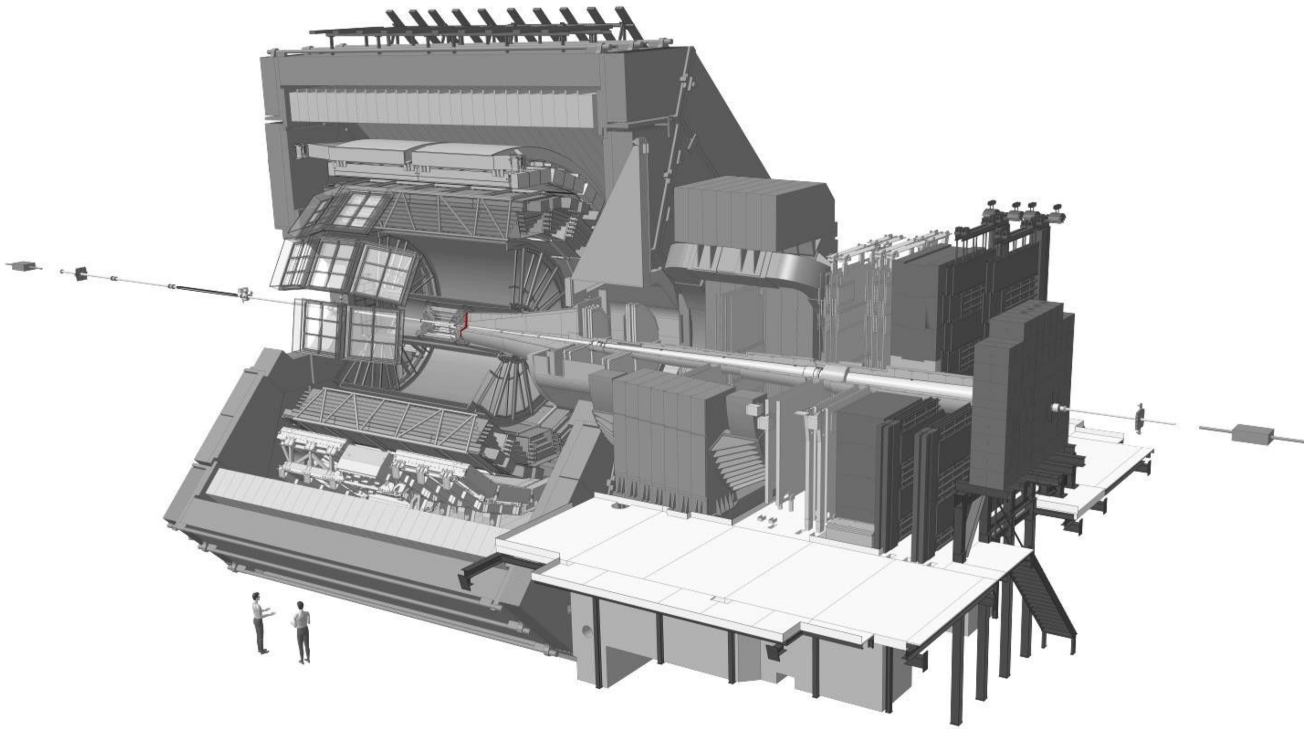


Detectors

ITS $|\eta| < 0.9$
Vertexing and tracking

TPC $|\eta| < 0.9$
Tracking and particle identification

ALICE detector



Detectors

ITS $|\eta| < 0.9$

Vertexing and tracking

TPC $|\eta| < 0.9$

Tracking and particle identification

V0

$3.7 < \eta < -1.7$

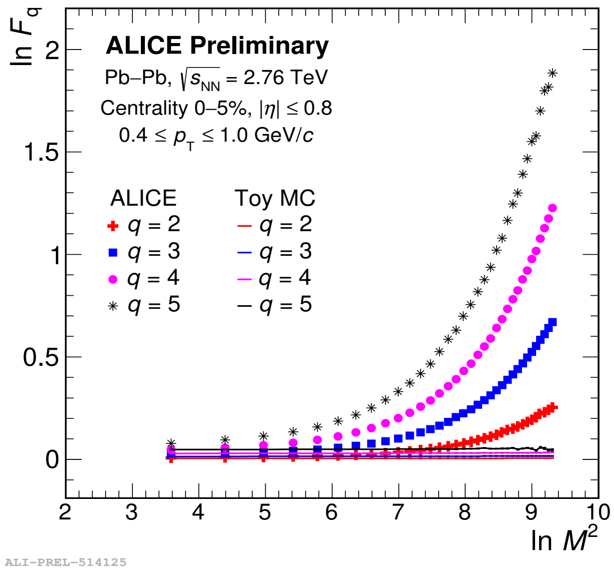
$2.8 < \eta < -5.1$

Trigger and centrality estimation

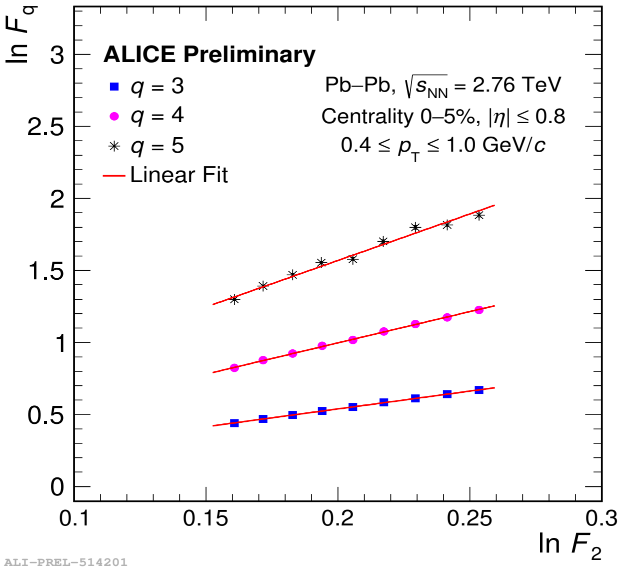
Results

M-scaling, F-scaling in ALICE data

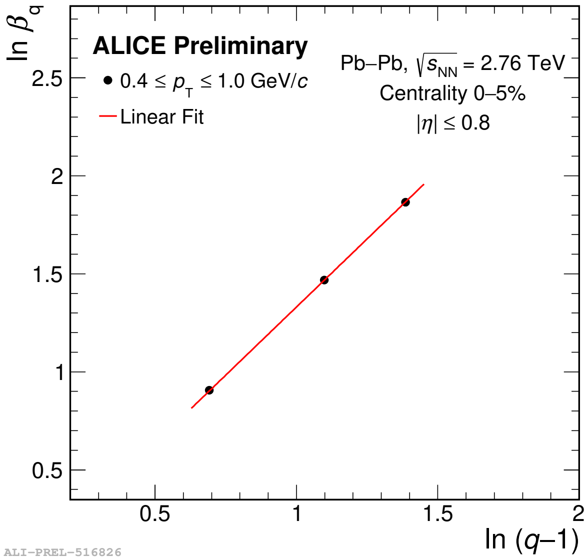
M-scaling



F-scaling

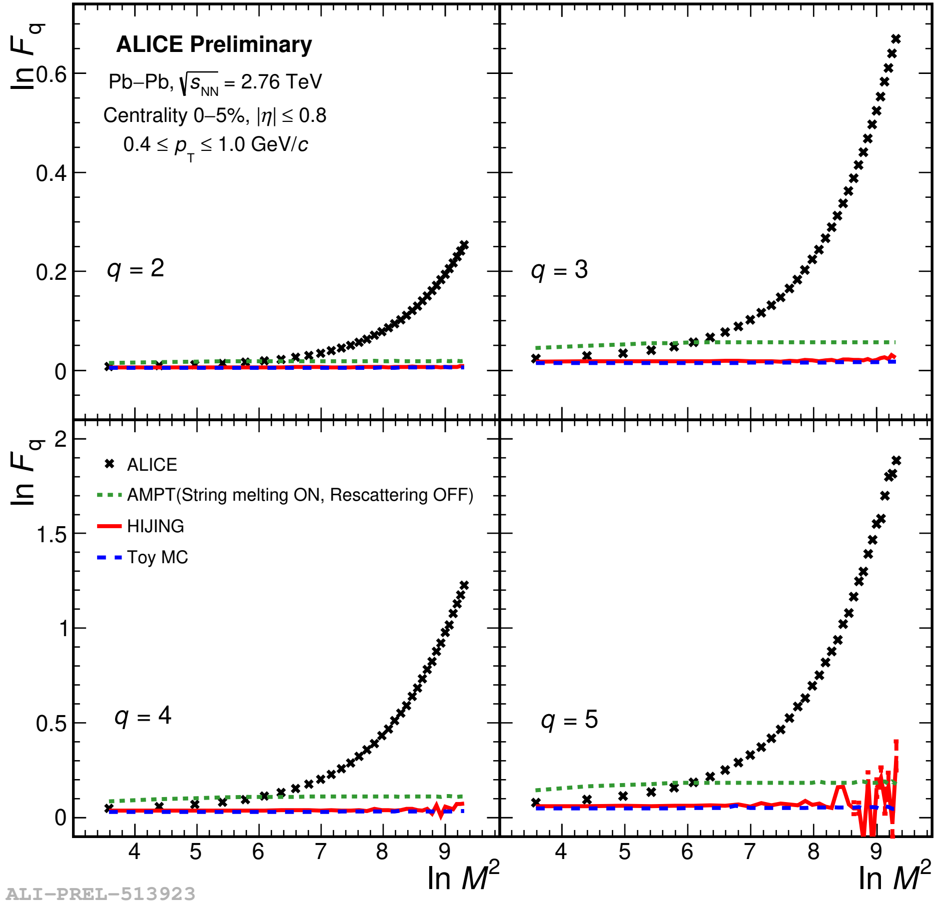


$$\beta_q \propto (q-1)^{\nu}$$



- Power-law growth of the NFM with the increase in the number of bins (M).
- Toy MC results, with statistical fluctuations only, do not describe the ALICE data.
- F-scaling observed in ALICE data and scaling exponent is calculated which gives information about the system under study.

M-scaling: comparison with models

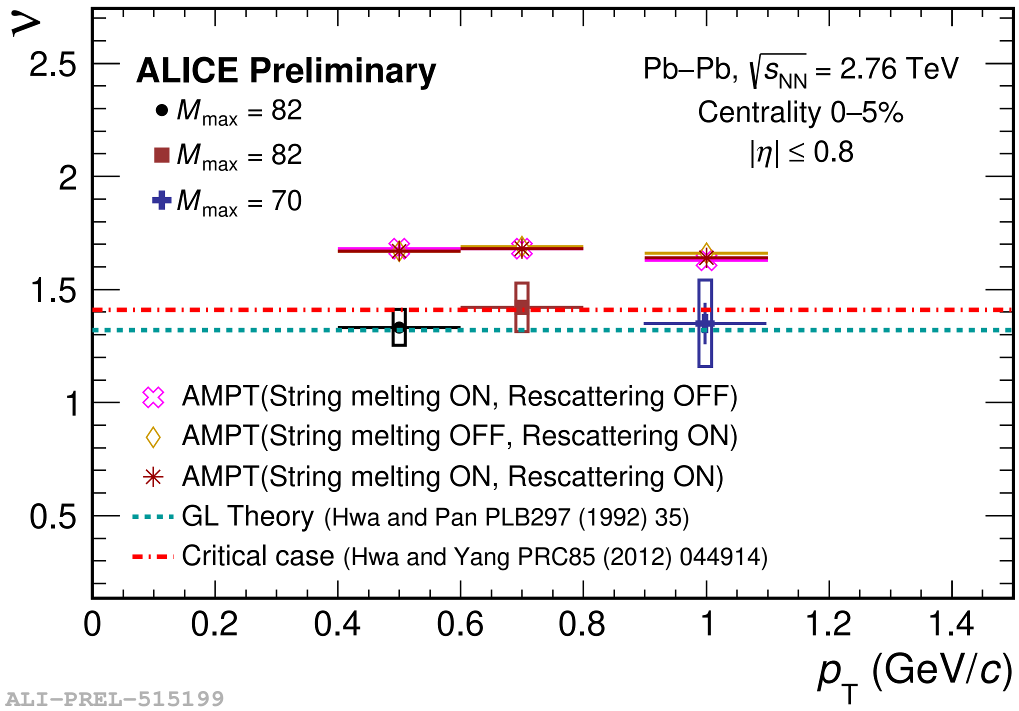


- Qualitative and quantitative difference are observed between data and MC.
- Observed difference in the scaling properties of charged particle multiplicity distributions as the binning resolution increases.

Scale-invariant density fluctuations observed in ALICE data but absent in MC
(HIJING, AMPT, Toy MC).

p_T bin width dependence of ν

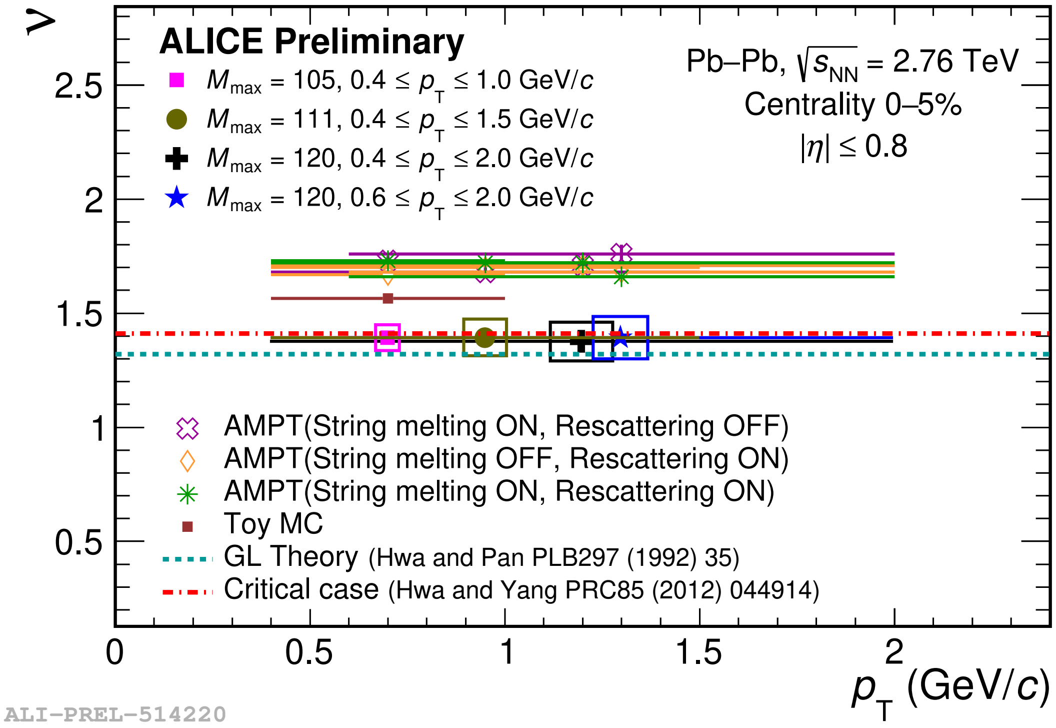
Narrow p_T intervals



- Scaling exponent (ν) is independent of p_T bin and p_T bin width within uncertainties.
- Scaling exponent values obtained from the ALICE data are in agreement with the predicted values for critical fluctuations and the GL formalism.

p_T bin width dependence of ν

Wide p_T intervals



- Scaling exponent (ν) is independent of p_T bin and p_T bin width within uncertainties.
- Scaling exponent values obtained from the ALICE data are in agreement with the predicted values for critical fluctuations and the GL formalism.

Analysis of the large statistics data from 2015 and 2018 is ongoing.

Summary

- Intermittency signal i.e. linear behaviour between ln F_q and ln M^2 is observed at higher bin resolution (M^2).
- F-scaling of moments of multiplicity fluctuations is observed in ALICE data.
- HIJING and AMPT models do not describe the linear behaviour of factorial moments with increase in the number of bins as observed in the ALICE data.
- Values of scaling exponent (ν) show no dependence on p_T bin width and agree with the models with critical fluctuations.