Intermittency analysis of charged particle production in Xe-Xe collisions at 5.44 TeV.

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AN: https://alice-notes.web.cern.ch/node/1423

ALICE-India Collaboration meeting
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Outline

- Physics Motivation & Methodology
- Observables used
- Data Sets and selection cuts
- Observations and Results
- Summary
- Backup slides

Motivation and Methodology

The exploration of the QCD phase diagram and the critical point search is one of the main goals in relativistic heavy-ion collisions.

Near critical temperature

There is tension between the collective interactions and thermal randomization results in clusters of all sizes.

↓

Large density fluctuations at the QCD phase transition.

↓

- R.C. Hwa and C. B. Yang, Acta Physica Polonica B . Jan 2017, Vol. 48 Issue 1, p23-52. 30p

To characterize the quark hadron phase transition and to understand the dynamics of the particle production mechanism, One of the proposed measures is to study the fluctuations in spatial patterns.

- To study the scaling behaviour of fluctuations in spatial patterns, scaling properties of multiplicity fluctuations over wide range of bin sizes using the normalized factorial moments (NFM) is made.

Intermittency Analysis

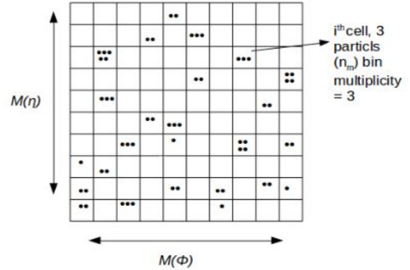
Motivation and Methodology

❑ Factorial Moment :

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

- ➢ $F_q(M)$ is the normalized factorial moment
- ➢ q is the order of the moment, q ≥ 2 and presently we are using q =2, 3, 4, 5
- ➢ n_{ie} is number of particle in a bin, and only $n_{ie} \geq q$ is counted.
- ➢ M : is number of bin and
- ➢ N : Number of events

Eta-phi phase space of an event is binned into M×M bins



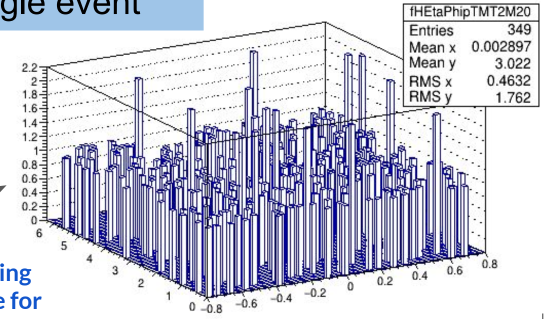
An event-by-event,

- ➔ two dimensional intermittency analysis in (η,φ) phase space
- ➔ Phase space (η,φ) is divided into a square lattice of M xM
- ➔ M(η) and M(Φ) : Number of bins along eta and phi axis respt.
  M : 4 – 82
- ➔ Charged particles in the selected phase space are mapped on to this 2D matrix so that

  Number of particles that go in each bin defines the bin multiplicity (n, that is used to determine the Normalized Factorial Moments)

- ➔ Here in this 10 × 10 matrix , each box represent a bin for M = 10

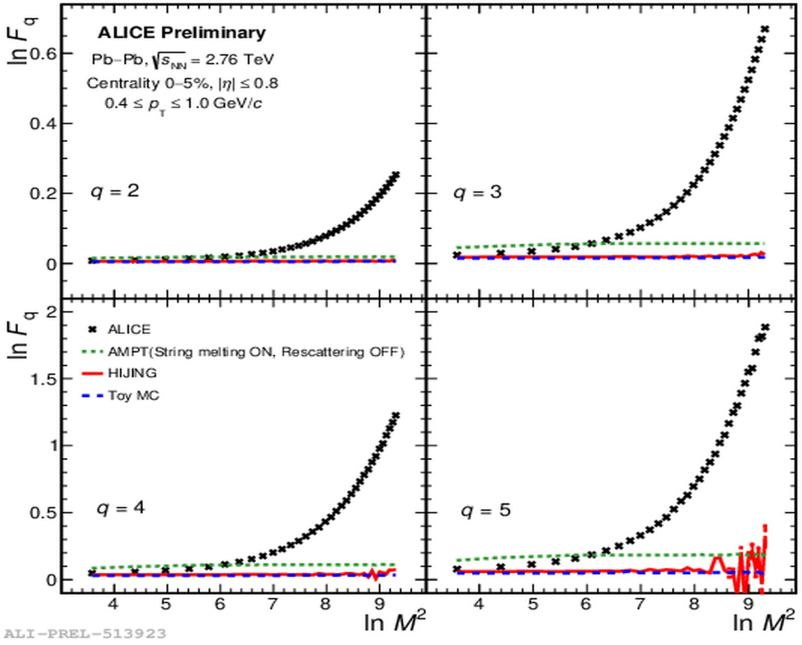
Single event



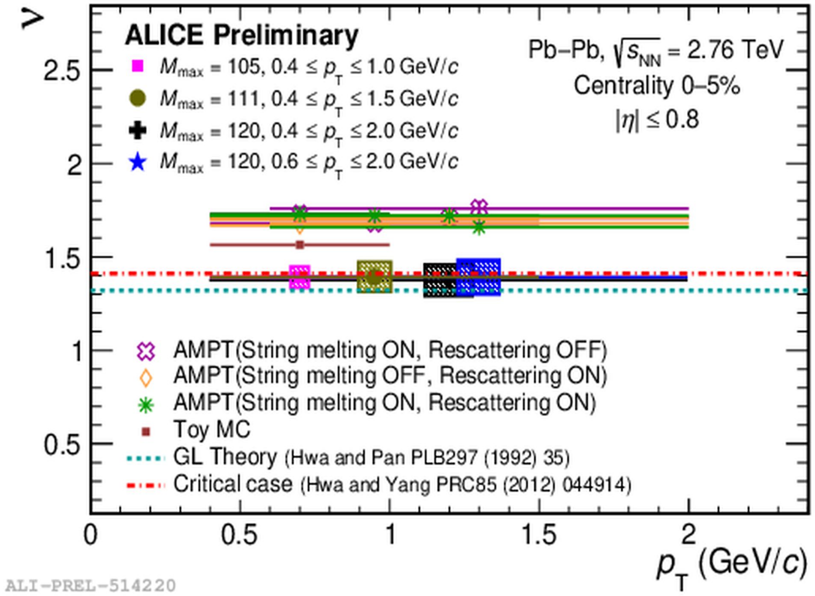
Lego plot of an event in the (η, φ) plane depicting the distribution of particles in the phase space for M = 63 in p_T bin 0.4 ≤ p_T ≤ 0.6 GeV/c.

ALICE: Measurements at $\sqrt{s_{NN}}$ = 2.76 TeV

Physics Forum Approval Link **(QM2022)**
https://indico.cern.ch/event/1135462/



M-Scaling: ALICE and MC comparison



Dependence of scaling exponent on p_T

Observables Studied

Intermittency refers to power-law growth of the Normalised Factorial Moment (NFM)

- with decrease of phase space bin
- increase in number of bins.

$$F_q(M) \propto (M)^{\phi_q}$$ → **M-scaling**

or

$$F_q(\delta) \propto (\delta)^{-\phi_q}$$

where $\varphi_q > 0$, a positive number and is known as intermittency index.

- If F_q is observed to follow power law such that

$$F_q(M) \propto F_2(M)^{\beta_q}$$ → **F-scaling**

$$\beta_q = \frac{\phi_q}{\phi_2}$$

β_q is quantitatively described by the scaling exponent, ν

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

- Scaling exponent (ν): quantifies the multiplicity fluctuations
  => can be used to investigate criticality in systems.

- R.C. Hwa and M.T. Nazirov, Phys. Lett. 69, 741 (1992).
- E.A. De Wolf et al., Phys Rep 270 (1996)1-141.
- R.C. Hwa and C. B. Yang, Acta Physica Polonica B . Jan 2017, Vol. 48 Issue 1, p23-52. 30P

Data sets and selection cuts.

Data sets

ALICE : LHC17j7n

Anchored MC : HIJING LHC17j7_3

Run no's: 280234, 280235

AOD Information

alienHandler->SetDataPattern("/pass1/AOD227/*AliAOD.root");

alienHandler->SetDataPattern("*/AOD226/*AliAOD.root")

Event Selection:

- ➢Triggers: kINT7 (Min. Bias trigger)
- ➢ Centrality estimator = “V0M”
- ➢ Centrality : 0 – 5 %
- ➢ |V z | < 10 cm

Statistical Uncertainties : Sub-sampling method

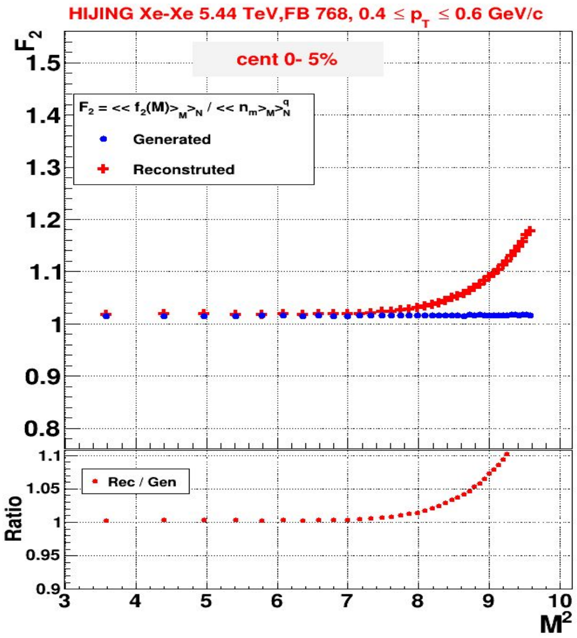
Track Selection:

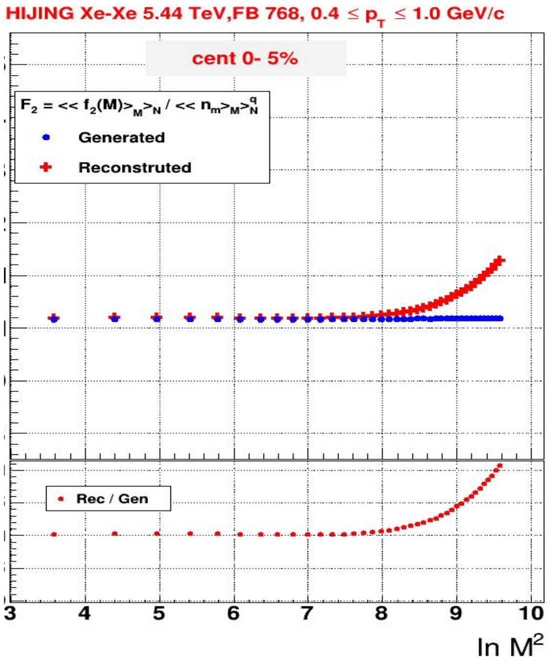
- ➢ FilterBit : 768 (Hybrid tracks)
- ➢ | η | < 0.8 , full azimuthal coverage
- ➢ **Wider p_T window** / **Narrow p_T window**

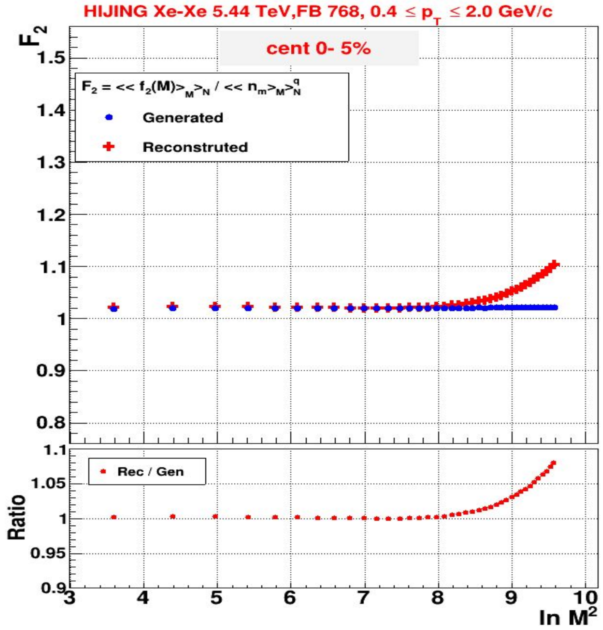
Wider p_T window	Narrow p_T window
➔ $0.4 \le p_T \le 1.0$ GeV/c	$0.4 \le p_T \le 0.6$ GeV/c
➔ $0.4 \le p_T \le 1.5$ GeV/c	$0.5 \le p_T \le 0.8$ GeV/c
➔ $0.4 \le p_T \le 2.0$ GeV/c	$0.6 \le p_T \le 1.0$ GeV/c
➔ $0.4 \le p_T \le 5.0$ GeV/c	

Observations and Results

MC Closure: HIJING LHC17j7_3 (wider overlapping p_T bins)



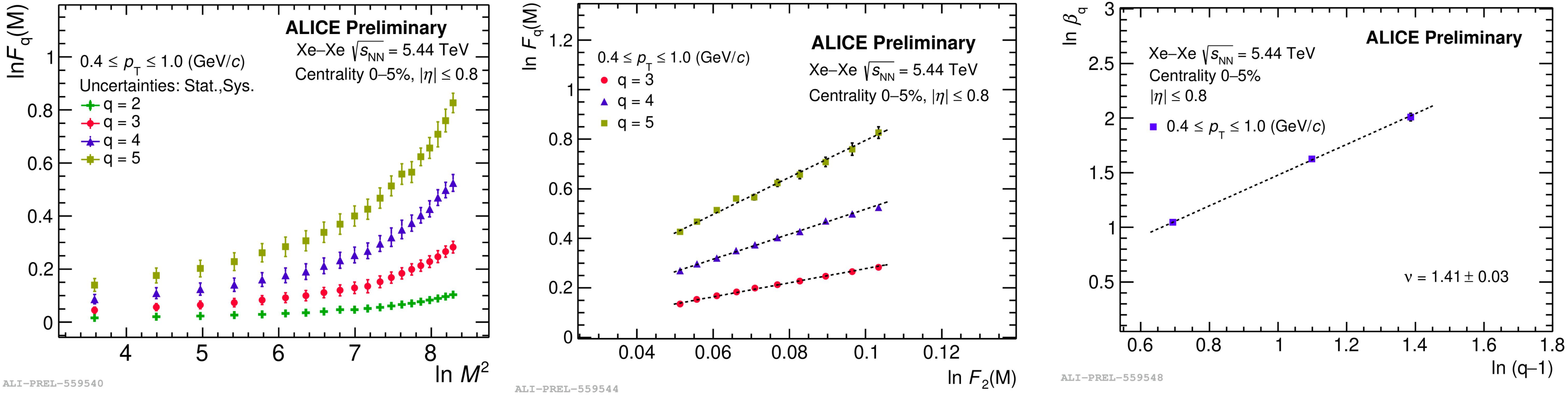




- ❖ The momentum resolution has an impact on the closure
- ❖ This is more dominant at low p_T and at the edges of the momentum acceptance.

ALICE: M-scaling , F-scaling and scaling exponent

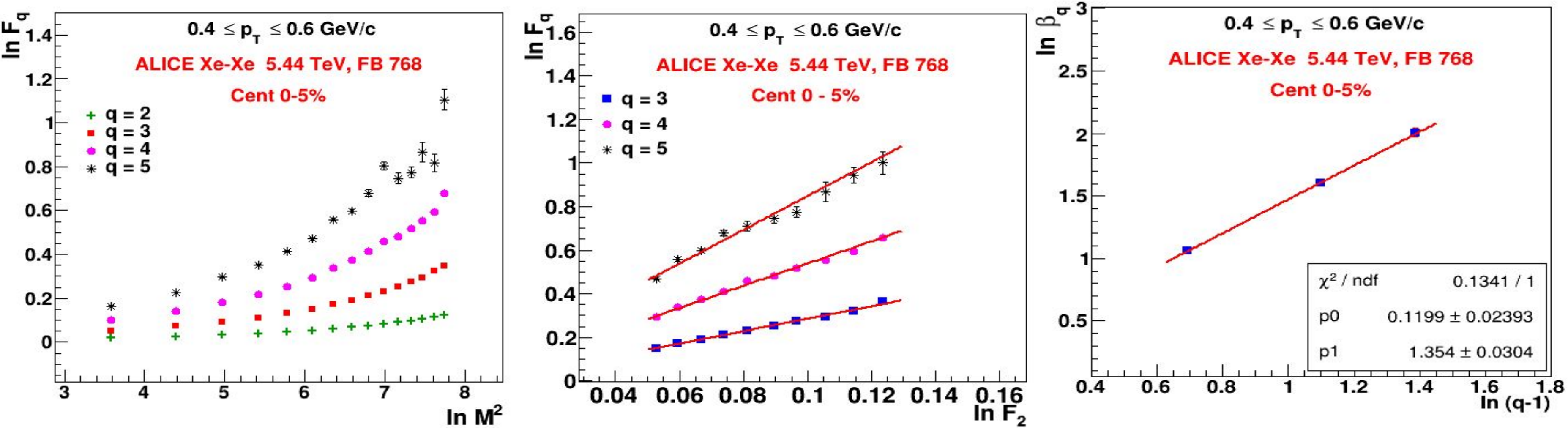
0.4 ≤ p_T ≤ 1.0 GeV/c



- Power law behaviour of NFM with the increasing number of bins.
  - **Intermittency (scale invariant fluctuations) in Data.**
- M-scaling and F-scaling observed for Data.
- Scaling exponent ~ 1.41 for p_T bin 0.4 ≤ p_T ≤ 1.0 GeV/c.

ALICE: M-scaling and F-scaling plots and scaling exponent

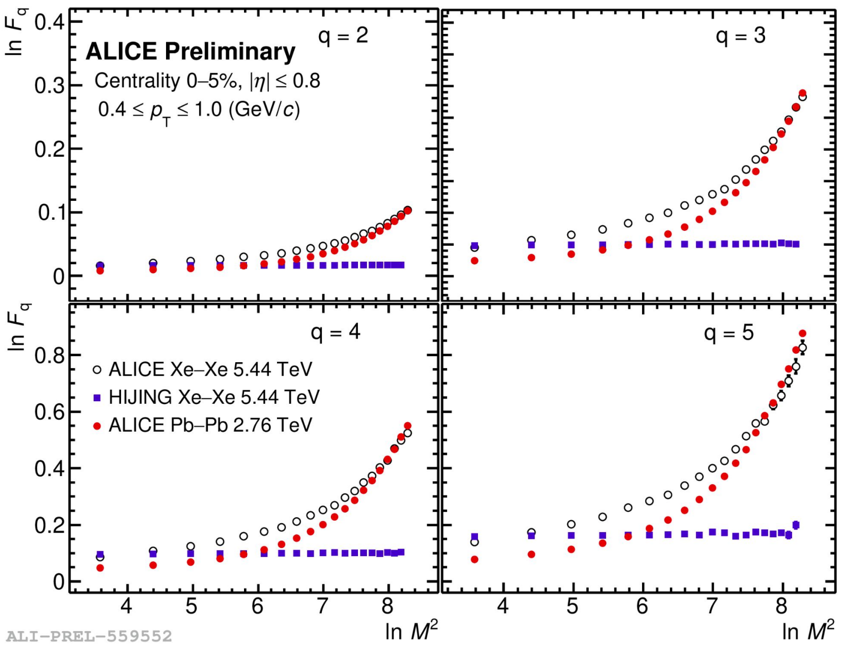
$0.4 \leq p_T \leq 0.6$ GeV/c



- M-scaling and F-scaling observed for Data.
- Scaling exponent ~ 1.35 for p_T bin $0.4 \leq p_T \leq 0.6$ GeV/c.

ALICE and HIJING (Gen) Comparison Plot

$0.4 \le p_T \le 1.0$ GeV/c

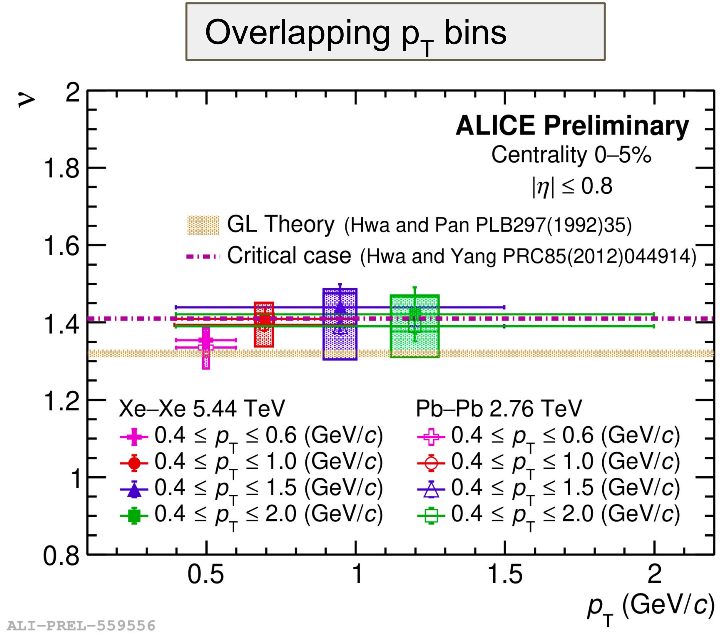


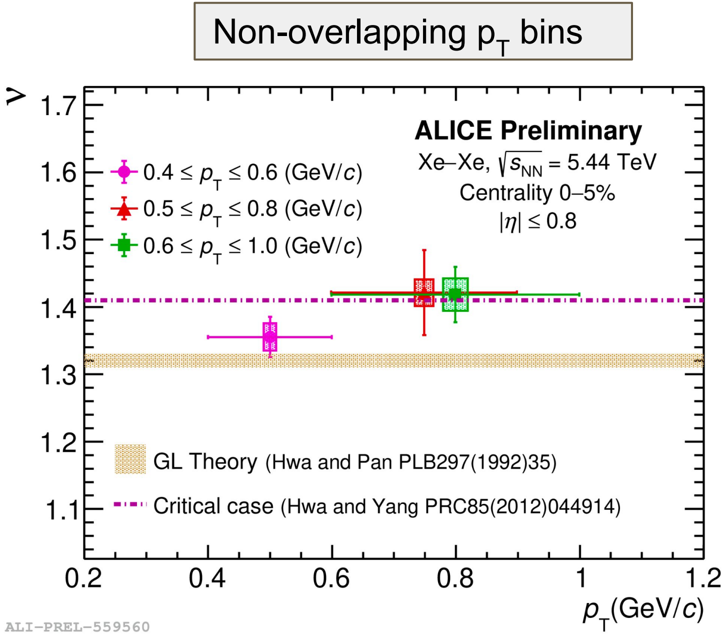
- Good power law growth of lnFq with lnM for all q in pb-pb 2.76 TeV and Xe-Xe 5.44 TeV .
- Quantitative Difference between pb-pb and Xe-Xe ALICE data is quite small.
- No power law growth of $\ln F_q$ with lnM in HIJING.
- HIJING far away from ALICE for all q and M
- This reveals that the particle density fluctuations that are there in data are not explained by HIJING.

Presence of intermittency in ALICE data

Dynamics of the system has self-similar Nature.

p_T bin width dependence of scaling exponent.





Observations:

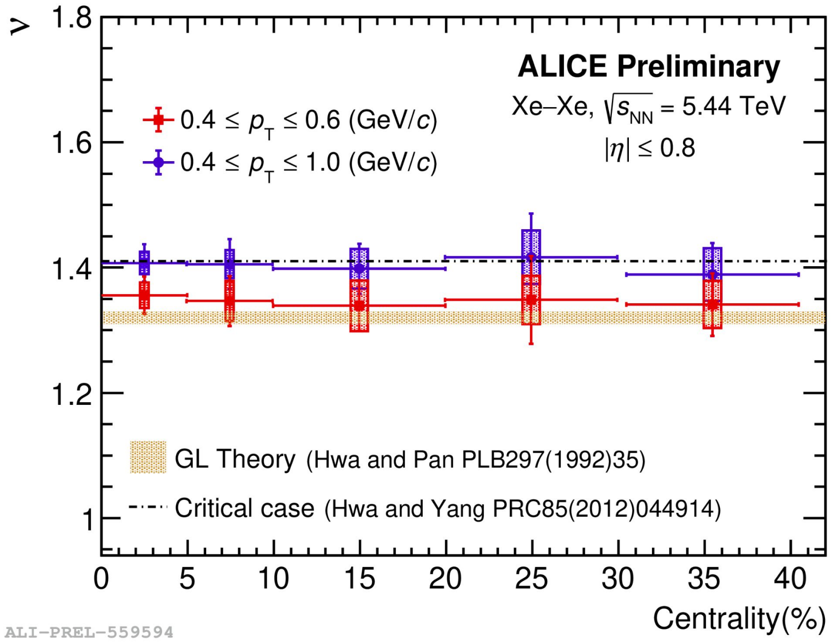
Within the Uncertainty scaling exponents

- **Independent of the p_T bin and p_T bin width.**
- **Close to the universal scaling exponent value predicted for system with critical fluctuation.**

Systematics Checks for different cut variables

Systematic observable	Standard	Variations
event vertex Z	10.0 cm	8.0 cm, 12cm
filterbit	768	32
Centrality estimator	V0M	CL0
min # of ITS cluster	2	3
min # of TPC clusters	70	80

Centrality dependence of scaling exponent (ν)



❖ The value of the scaling exponent(ν) for the p_T intervals **$0.4 \leq p_T \leq 0.6$** and **$0.4 \leq p_T \leq 1.0$** is calculated as a function of collision centrality.

❖ **Within the Uncertainty**

- Scaling exponents is weakly dependent of the centrality.
- close to the universal scaling exponent value predicted for system with critical fluctuation.

Summary

- Intermittency analysis for charged particles produced in Xe-Xe collisions at 5.44 TeV is performed.
- $|\eta| \leq 0.8$, full azimuth, different p_T bins

❖ **ALICE (LHC17n)**

- Good Power law growth at higher M. Thus Intermittency is observed in ALICE data
- F-scaling is observed for ALICE data in different p_T bins and the scaling exponent value is found to be less than 1.5 (i.e ν< 1.5)
- Scaling exponent (ν) is found to be independent of p_T bins and p_T bins width.
- Scaling exponent (ν) is found to be independent of centrality.

❖ **HIJING (LHC17j7_3)**

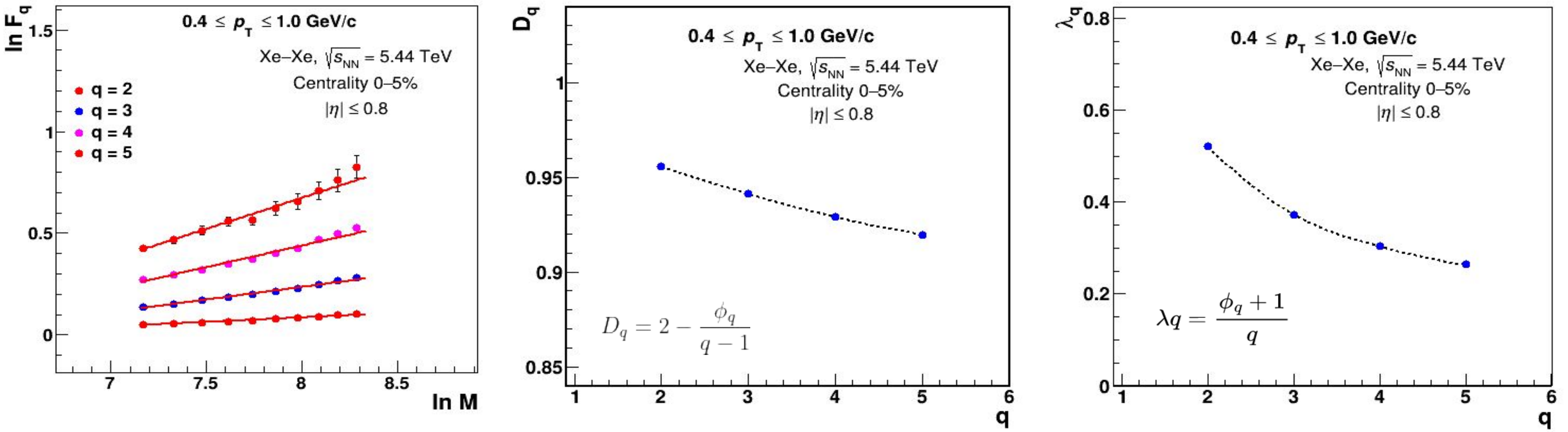
- No power law growth at higher M values. ~ No Intermittency
- HIJING doesn't explain data


THANK
YOU !

Backup slides……..

Fractals Parameters : D_q and λ_q dependence on q

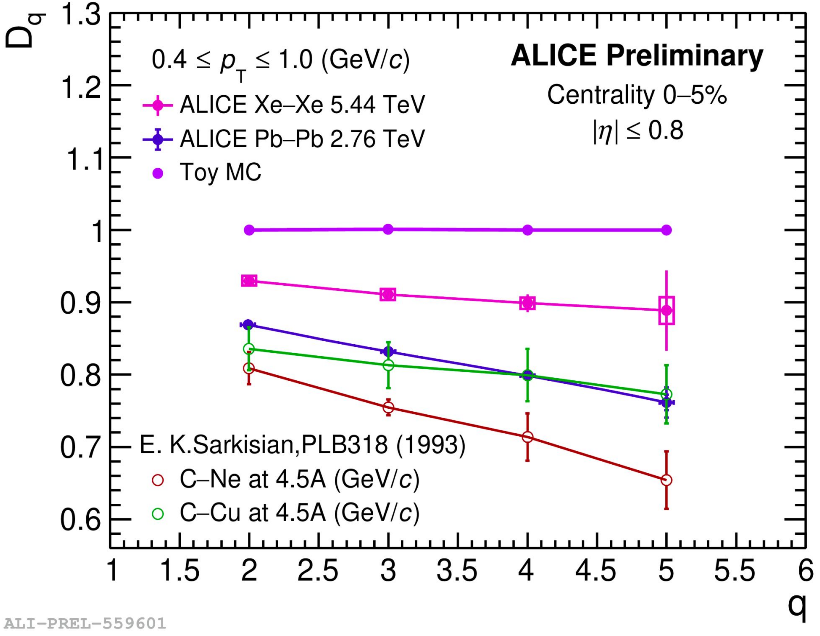
0.4 ≤ p_T ≤ 1.0 GeV/c



- Dependence of D_q on q, shows multifractal nature of the system at 5.44 TeV
- λ_q doesn't have any minima upto q = 5, thus indicates a single phase system.
- More statistics required to go beyond the q=5.

Fractal parameter D_q comparison

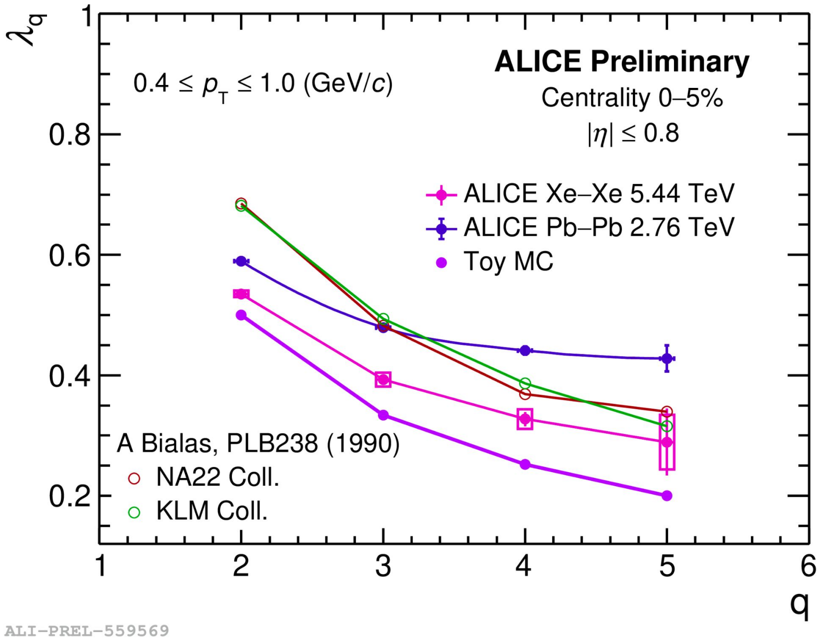
$0.4 \le p_T \le 1.0$ GeV/c



- ❖ **ALICE:**
  - Pb-Pb 2.76 TeV: D_q dependence on q
  - Xe-Xe 5.44 TeV: Weak dependence of D_q on q
- ❖ **Toy MC:** Monofractal behaviour

Fractal Parameter λ_q comparison

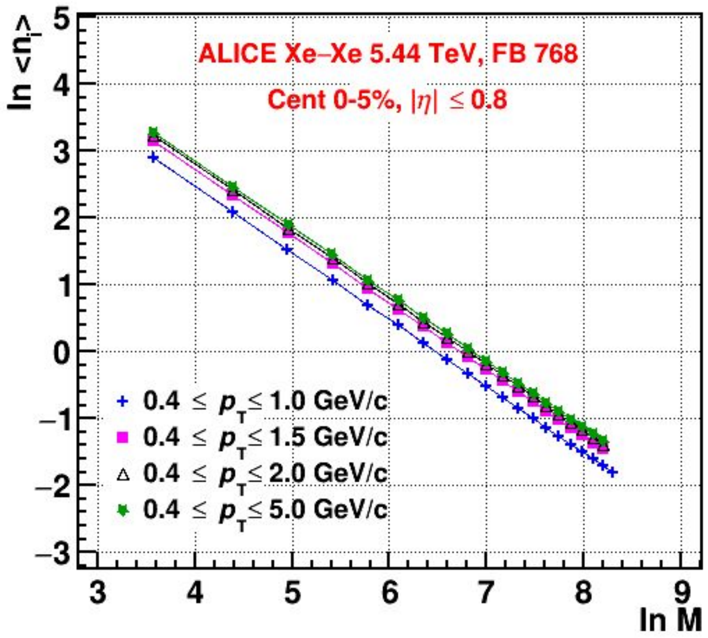
$0.4 \leq p_T \leq 1.0$ GeV/c

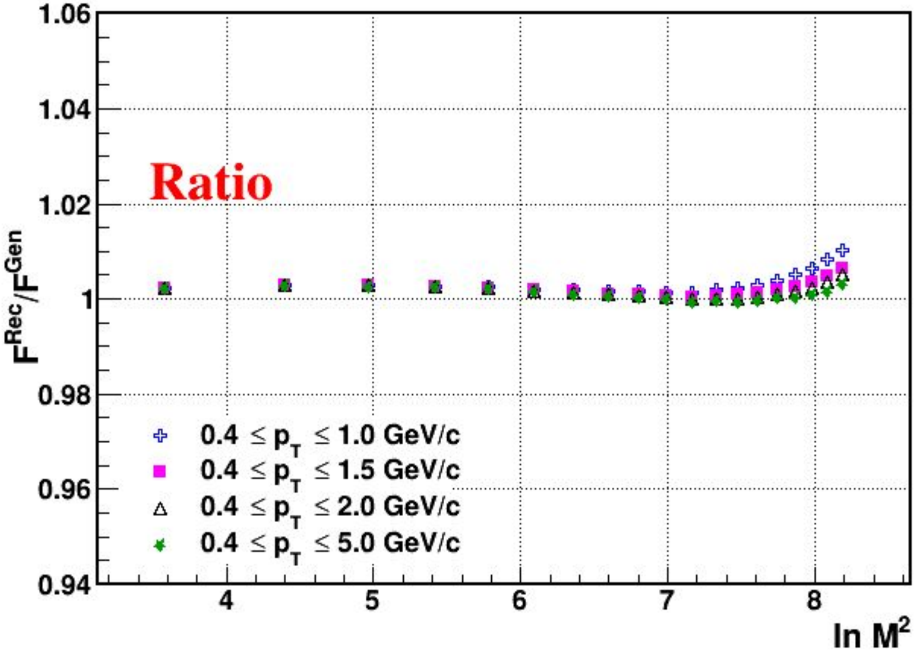


ALI-PREL-559569

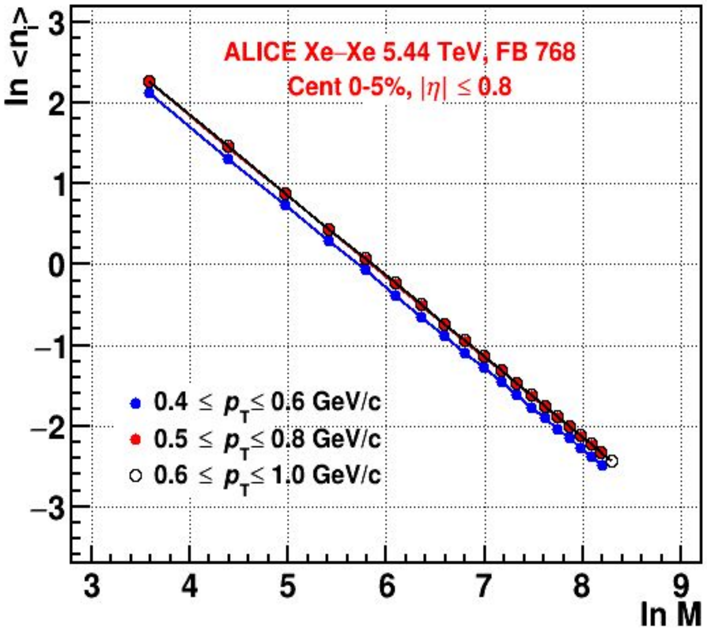
- ❖ λ_q doesn't have any minima upto q = 5, thus indicates a single phase system.
- ❖ More statistics required to go beyond the q=5.

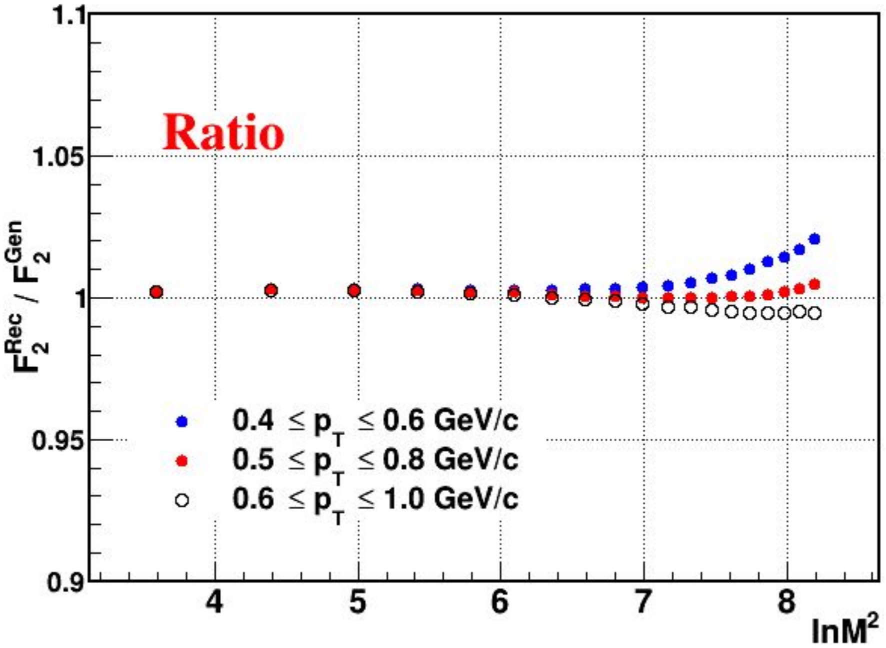
HIJING: Average bin content and Ratio plot (Wider p_T bins)



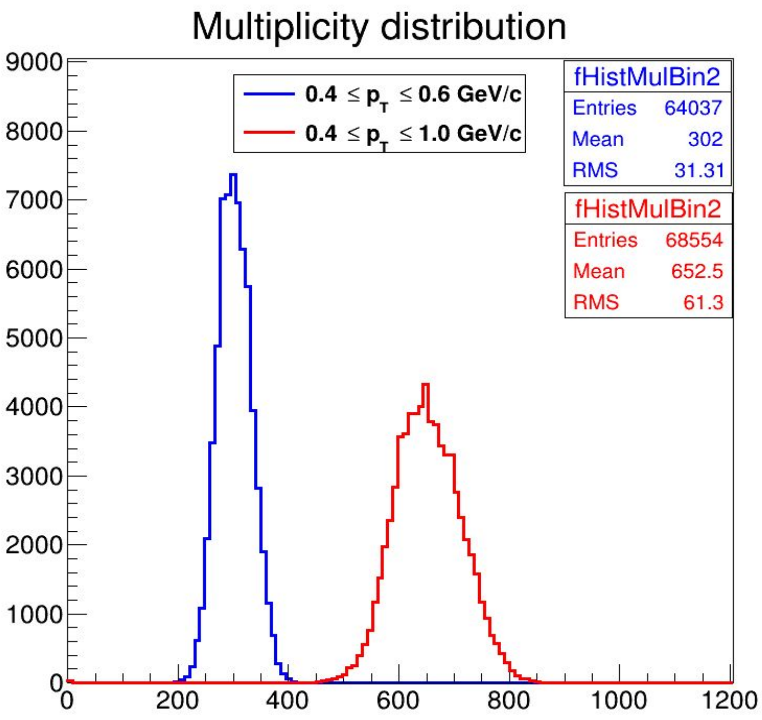


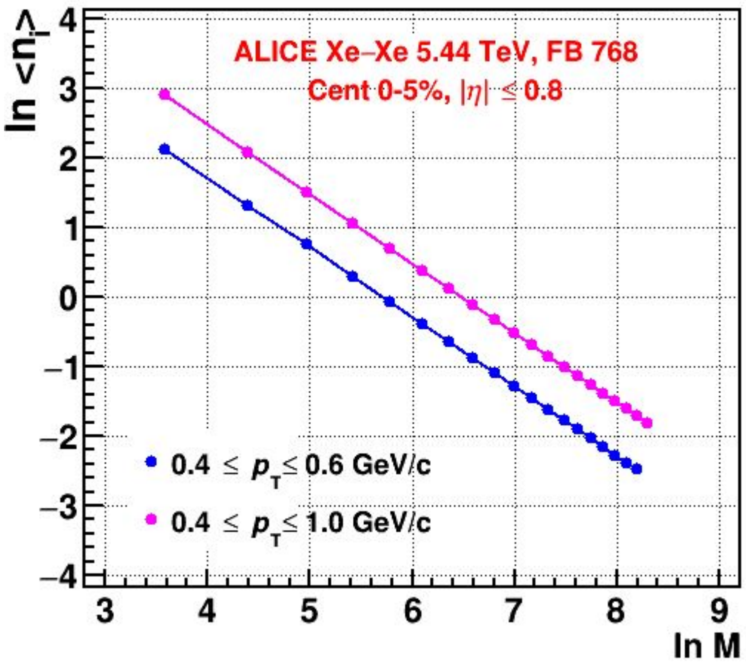
HIJING: Average bin content and Ratio plot (Narrow p_T bins)



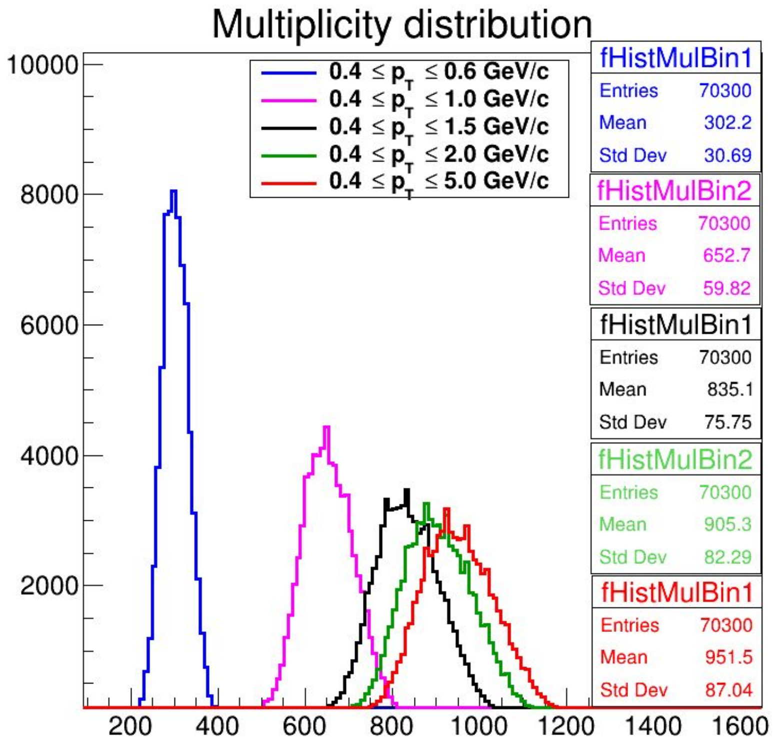


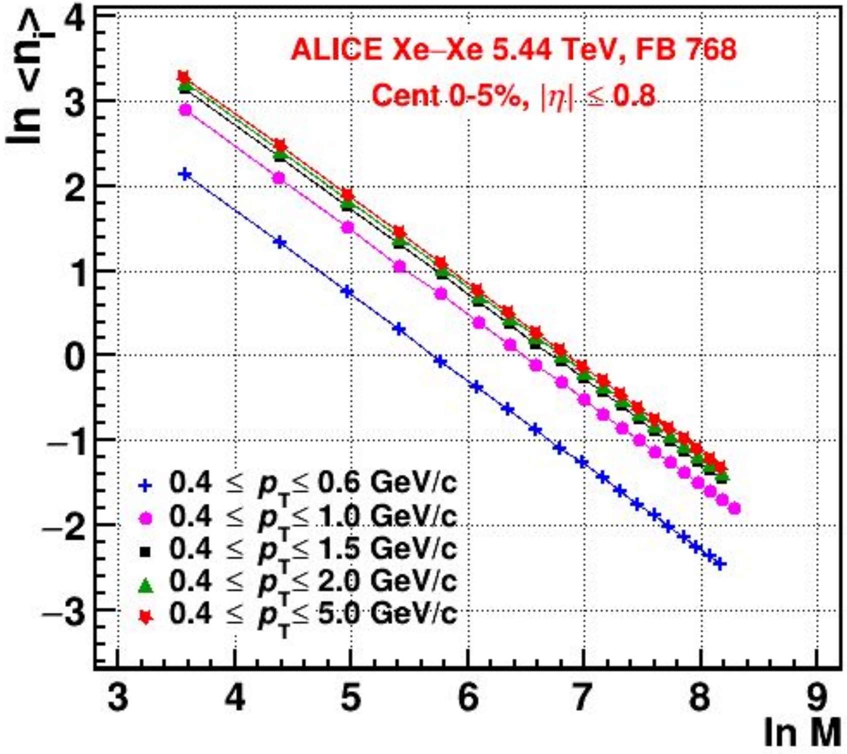
ALICE: Multiplicity Distribution and Average bin content Plots



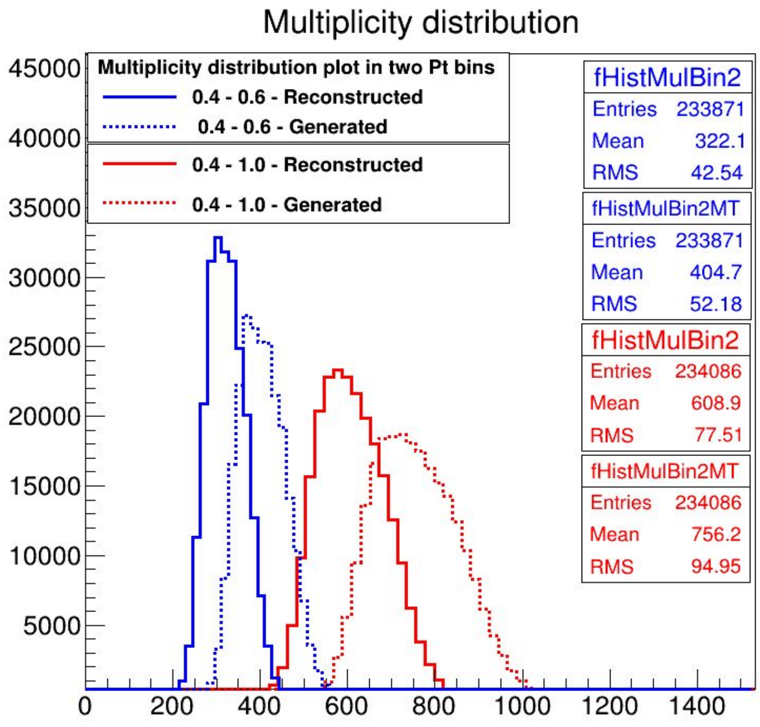


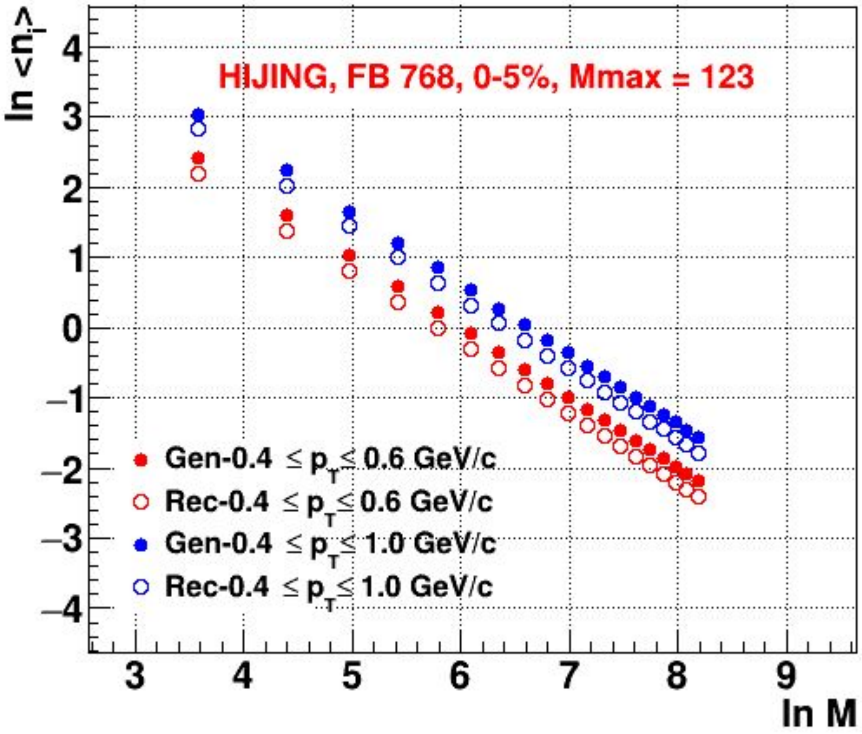
ALICE: Multiplicity Distribution and Average bin content for wider p_T bins



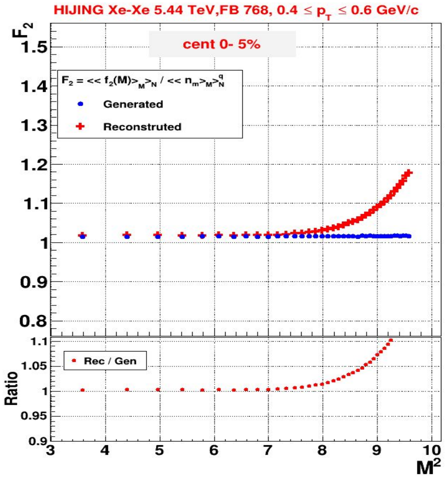


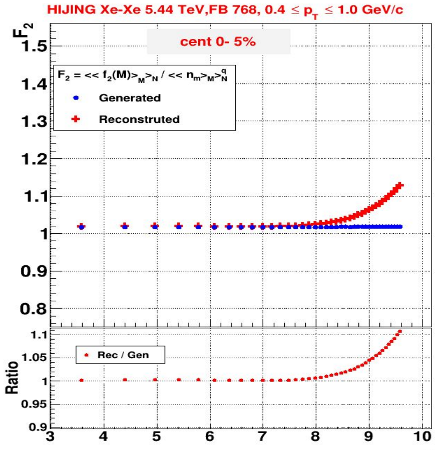
HIJING: Multiplicity Distribution and Average bin content(Rec) Plots

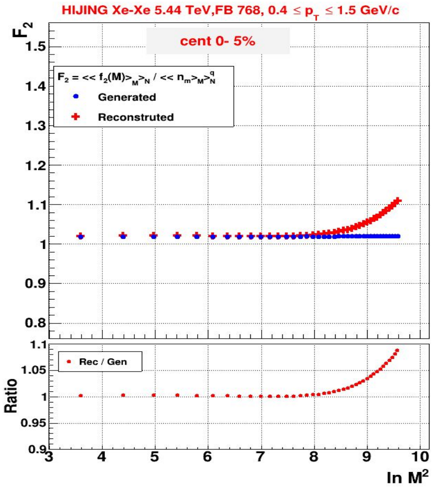


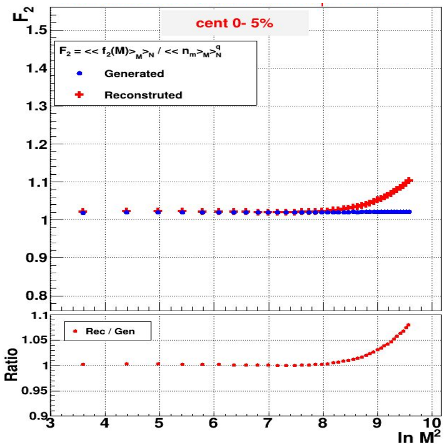


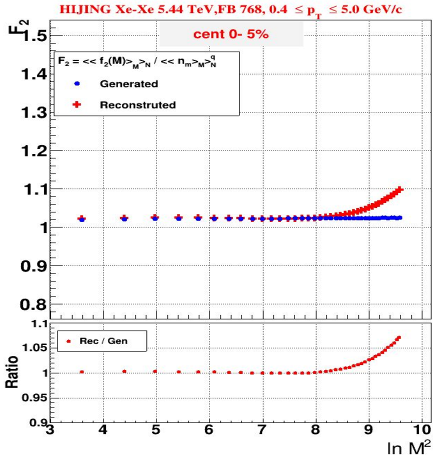
MC Closure: HIJING LHC17j7_3 (wider overlapping p_T bins)





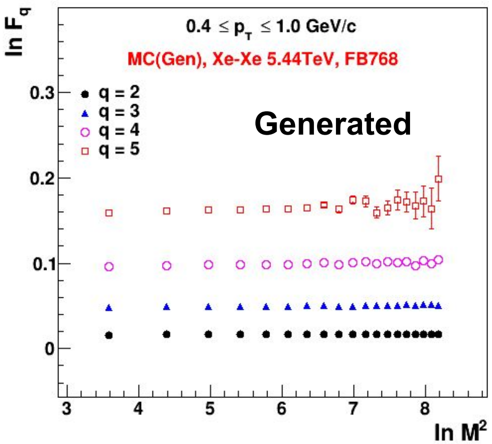


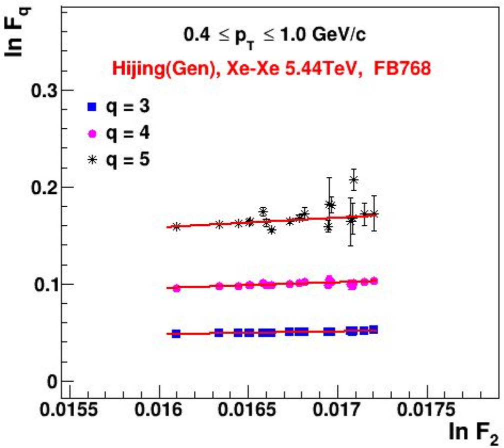


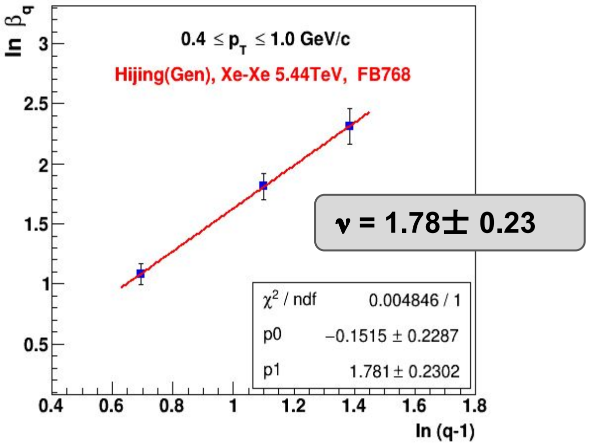


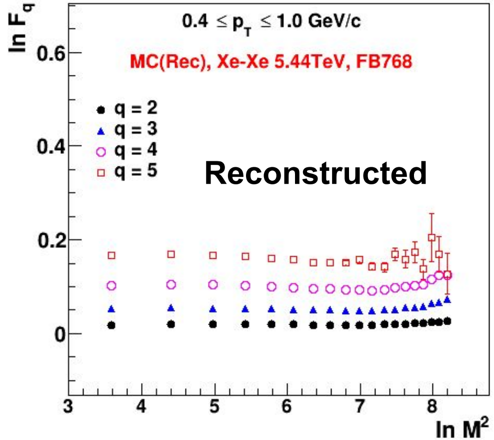
HIJING (Gen and Rec) : M-scaling and F-scaling plots

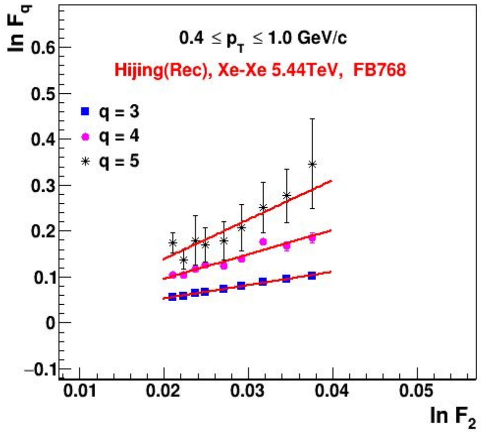
$0.4 \leq p_T \leq 1.0$ GeV/c

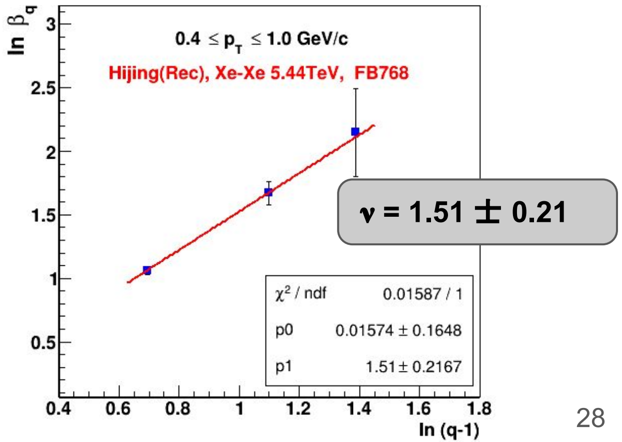




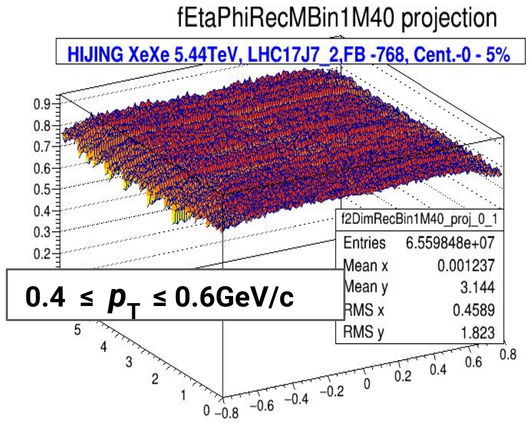


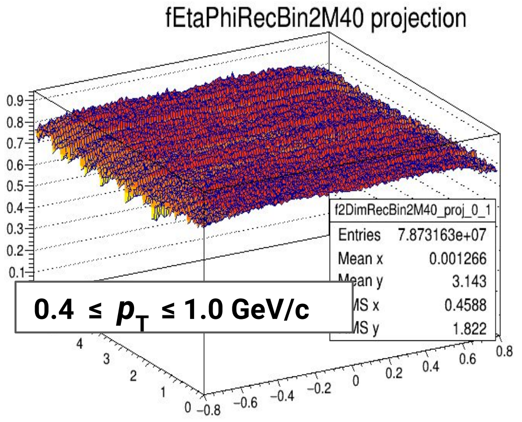


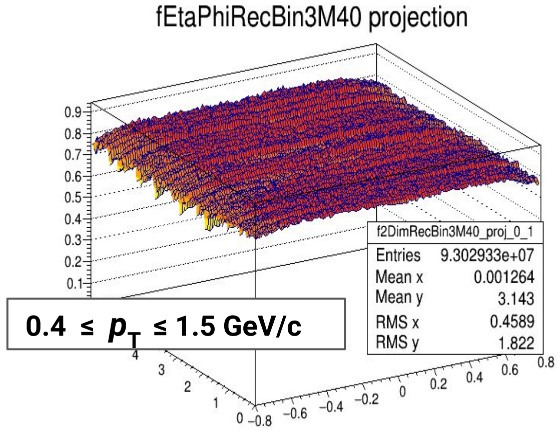


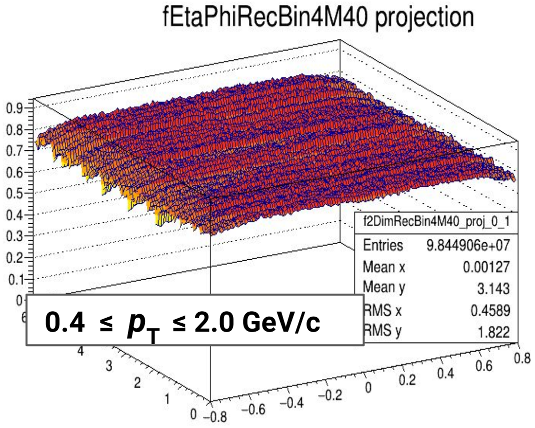


HIJING: 2D Efficiency Map for Bin1M40, Bin2M40, Bin3M40, Bin4M40









For same number of bins in the two Dimensional phase space, tracking efficiency maps for the Four p_T bins with M = 40 for 0-5% central events in | η | ≤ 0.8 region.

when efficiencies are uniform in the kinematical acceptance region

↓

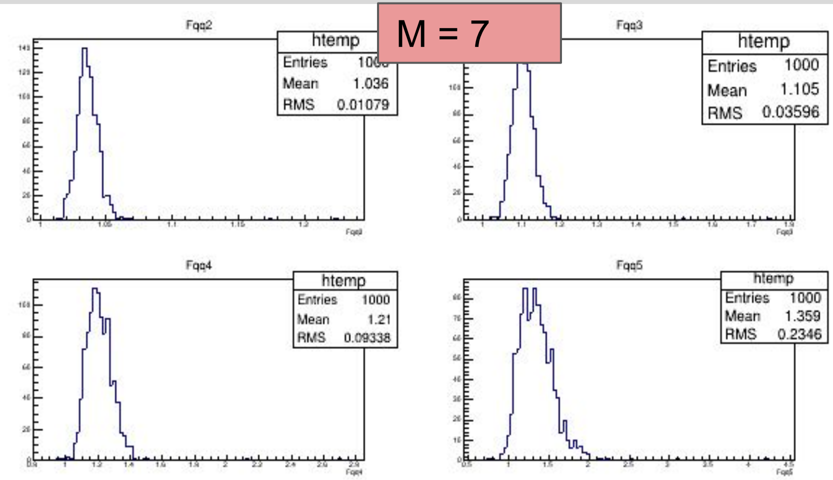
$$F_q^{uncorr} \approx F_q^{corr}$$

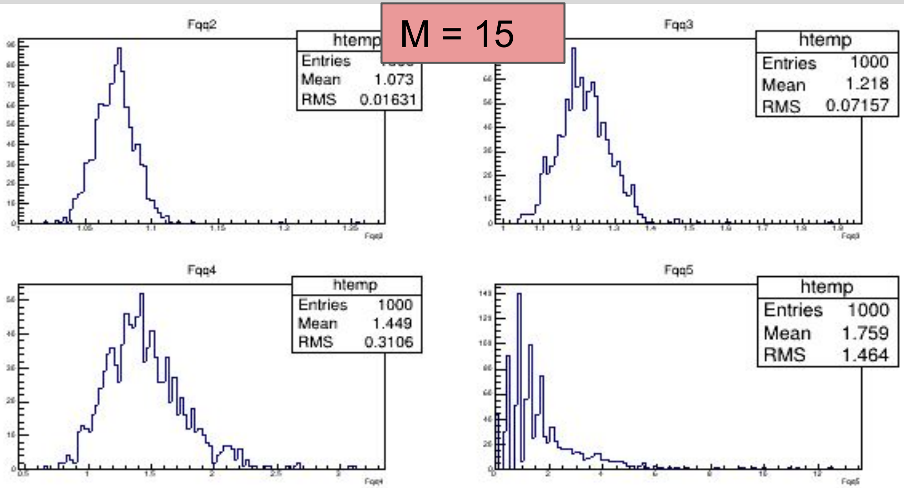
↓

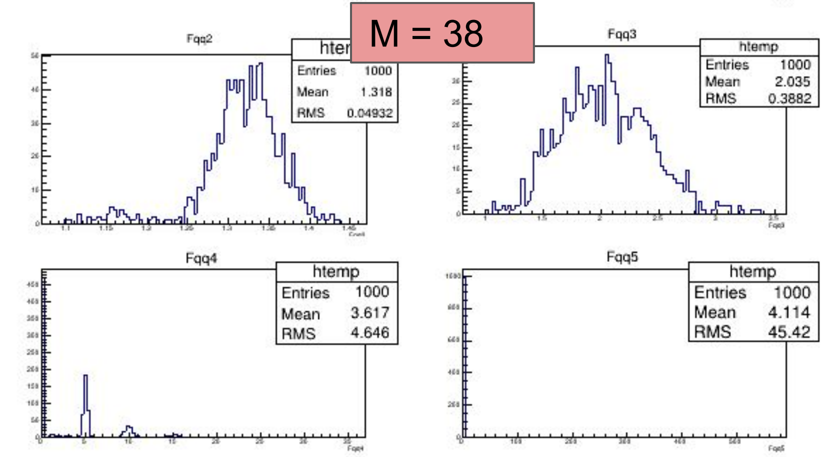
Normalized Factorial Moments are independent of efficiency corrections.

ALICE Data : F_q distributions of q = 2,3,4,5 ...... for some M values

$$\sum_{e=1}^{N} \frac{1}{M} \sum_{i=1}^{M} f_q(n_{ie})$$







- The empty bin effect arises when the bins reach a size where the average multiplicity per bin becomes significantly smaller than the order i of the factorial moment being determined.
- In such a situation most of the events of a given event sample do not contribute to the factorial moment.
- Thus the values of higher order moments at small bin sizes are determined only by a small fraction of the finite event sample of an experiment and consequently are subject to considerable sampling fluctuations

ALICE : QA Plots

LHC17n, FB 768, Cent 0-5%

$0.4 \leq p_T \leq 1.0$ GeV/c