A study of local multiplicity fluctuations in Pb-Pb collisions

(Intermittency analysis)

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JIRA: https://alice.its.cern.ch/jira/browse/PWGCF-204
AN: https://alice-notes.web.cern.ch/node/1419

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Outline

- Physics Motivation & Observables
- Dataset
- Results
- Summary

Motivation & Observables

- Large density fluctuations -> final stage collective behaviour as QGP expands.
- Fluctuations => sensitive to the phase transition.
- These can be detected by performing intermittency analysis

  => works by measuring **Normalized Factorial Moments (NFM).**
- Suggested that the presence of intermittency:
  - dynamical fluctuations
  - self-similarity
- 2D phase space (η φ) is divided into MxM bins (self-similar)
- $F_q(M)$ => NFM are averaged over the bins to measure local fluctuations.

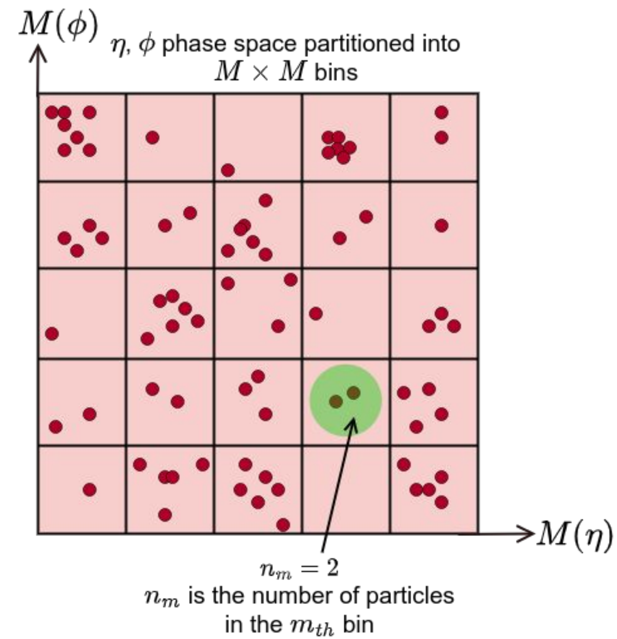
$$F_q(M) = \frac{\frac{1}{N}\sum_{e=1}^{N}\frac{1}{M}\sum_{m=1}^{M} f_q(n_{me})}{\left(\frac{1}{N}\sum_{e=1}^{N}\frac{1}{M}\sum_{m=1}^{M} f_1(n_{me})\right)^q}$$

$$f_q(n_{me}) = \prod_{j=0}^{q-1}(n_{me} - j)$$

q : order of the moment

e : *event*

$n_{ie} \geq q$



A. Bialas and R. Peschanski, Nucl. Phys. B, 273 (1986)
R.C. Hwa and C. B. Yang, Acta Physica Polonica B . Vol. 48 Issue 1 (2017)
R.C. Hwa & C.B. Yang, PRC 85, 044914 (2012), nucl-ex:1411.6083
R.C. Hwa and M.T. Nazirov, Phys. Lett. 69, 741 (1992).

Motivation & Observables

- NFM are sensitive to:
  - particle distribution in the bins
  - correlation between bins

- Scale-invariant form of particle distribution in the phase space
  => NFM scale with the number of bins M **(M-scaling)**

$$F_q \propto (M^2)^{\phi_q}$$

ϕ_q is the intermittency index

- Higher order NFM scale with second-order NFM **(F-scaling)**:

$$F_q(M) \propto F_2(M)^{\beta_q}$$

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

β_q is quantitatively described by the scaling exponent, ν

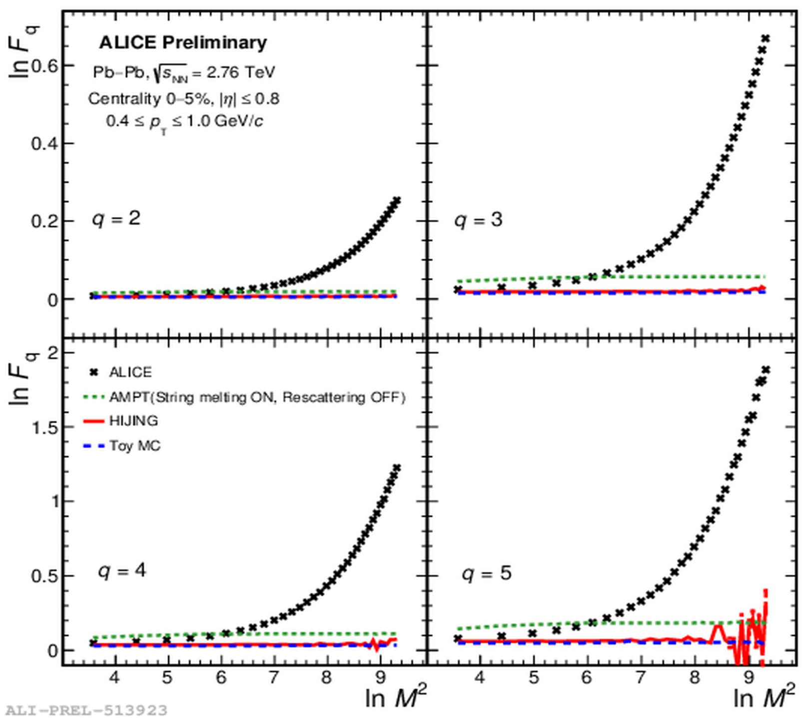
$$\beta_q \propto (q-1)^{\nu}$$

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

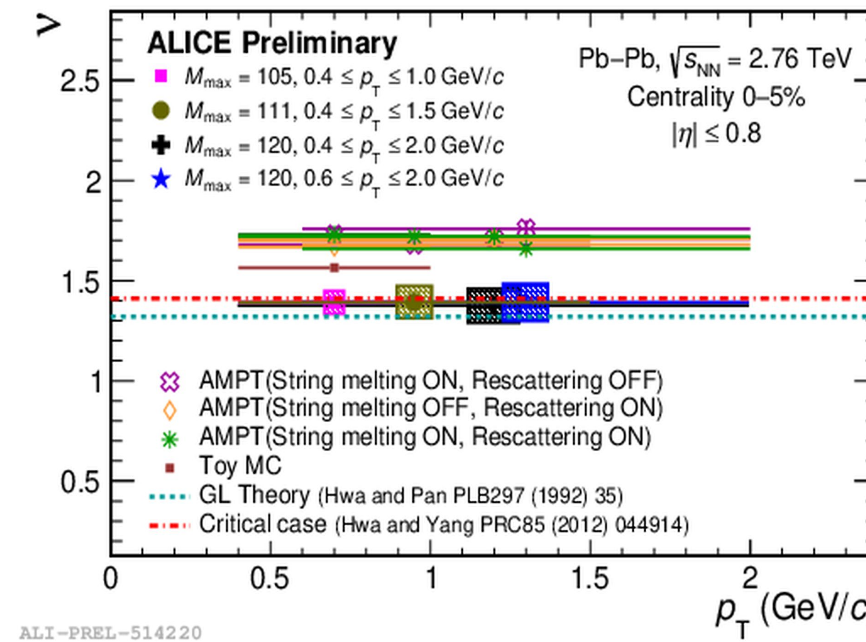
ν	Theory/Model
1.304	GL theory for 2nd order PT
1.0	Ising Model
1.41	SCR Model
1.79 ± 0.10	AMPT
1.743	UrQMD (RHIC en.)
1.75 ± 0.12	EPOS3 Hydro

ALICE: Measurements at 2.76 TeV

M-Scaling: Data and MC comparison



Scaling exponent independent of p_T bin width in the low p_T region



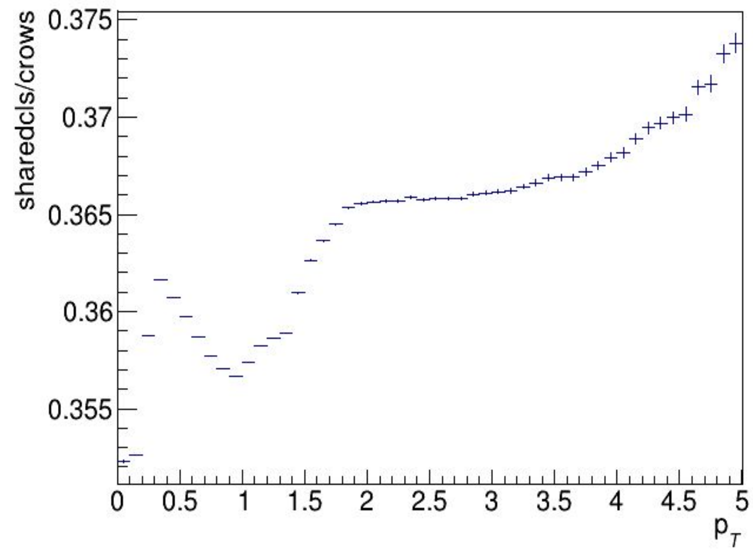
Analysis Note https://alice-notes.web.cern.ch/node/996

Datasets

- **Pb-Pb, 5.02 TeV**
  - **ALICE:** LHC15o_pass2, LHC18q,r_pass3:
  - **HIJING:** MB LHC20j6a, MB LHC20e3a
  - **EPOS_LHC:** LHC22d1d2, LHC22d1c2 (Gen)
  - **AOD252**
- **Track Cuts**
  - FilterBit: 768
  - Trigger bit: kINT7
  - sharedcls/ncrows < Mean values of shcls/ncrows vs p_T for $\Delta p_T = 0.1$
- **Pile Up Cuts:**
  - Data: Standard cut

```
fEventCuts.SetRejectTPCPileupWithITSTPCnCluCorr(kTRUE);
```

  - HIJING: Generated and out of bunch pileup cuts
    - => from twiki



Event Cuts

Centrality: 0-5%; Centrality estimator: V0M; **$|\eta| < 0.8$, full azimuth**

Statistical Uncertainties : Sub-sampling method

Datasets

- **Pb-Pb, 2.76 TeV**
  - **ALICE:** LHC10h AOD160
  - **HIJING:** MB LHC11a10a_bis
  - **AMPT:** LHC13f3a, LHC13f3b, LHC13f3c (Gen)

- **Track Cuts**
  - FilterBit: 768
  - Trigger bit: kMB

Systematic observable	Standard	Variations
event vertex Z	10.0 cm	**7.0 cm**
filterbit	768	**128**
B-field polarity	both	**positive, negative**
min # of crossed rows	80	**100**
min # of TPC clusters	70	**80**

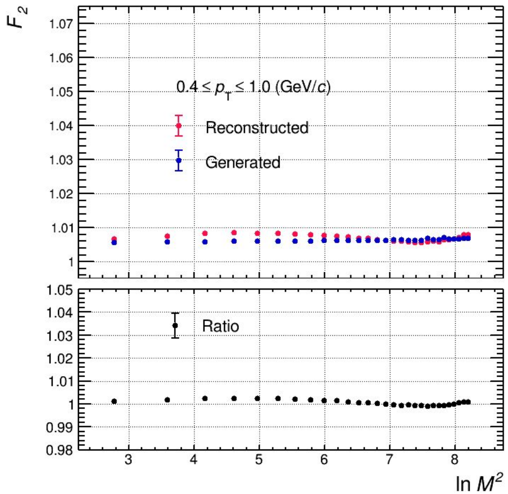
Event Cuts

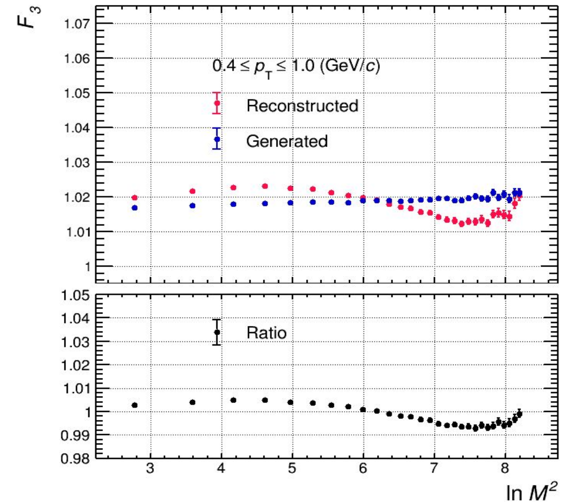
Centrality: 0-5%; Centrality estimator: V0M; $|\eta| < 0.8$, **full azimuth**

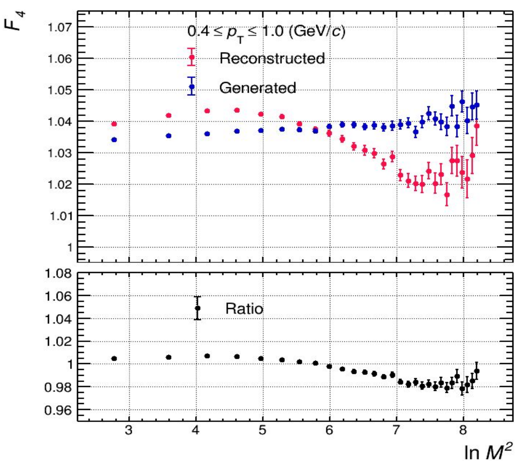
Statistical Uncertainties : Sub-sampling method

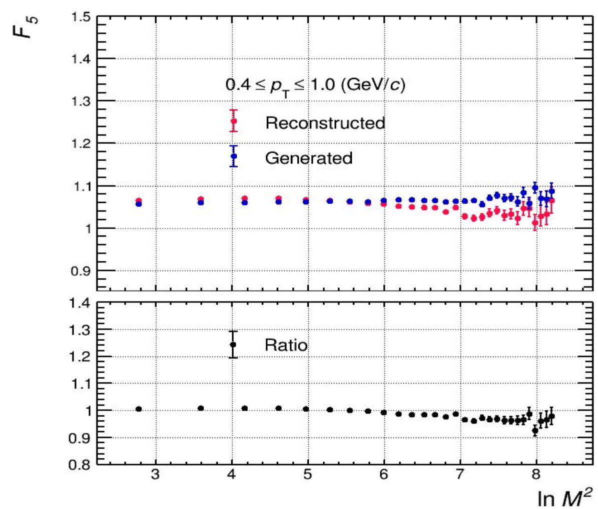
Closure of different orders

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





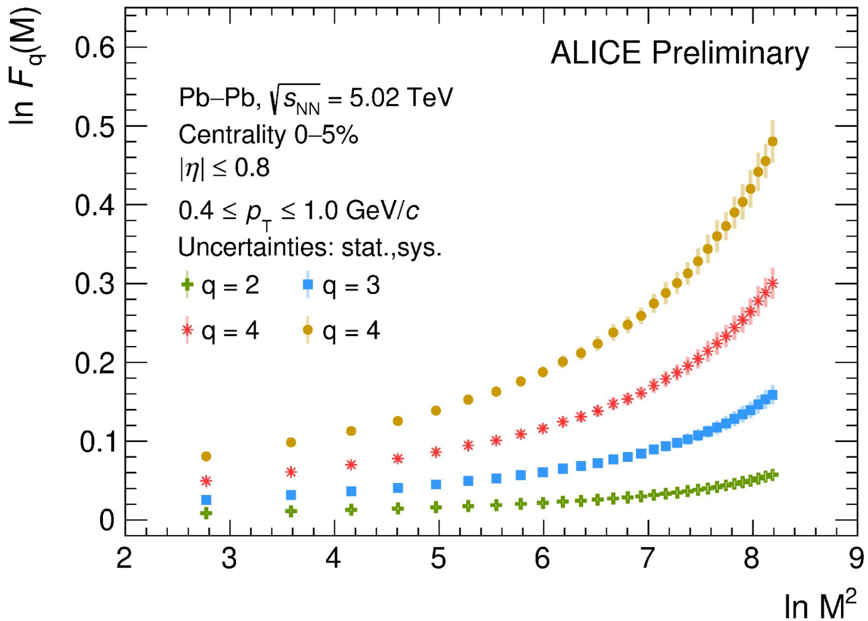




- Closure with HIJING shown for all the orders of F_q.

Results

M-scaling



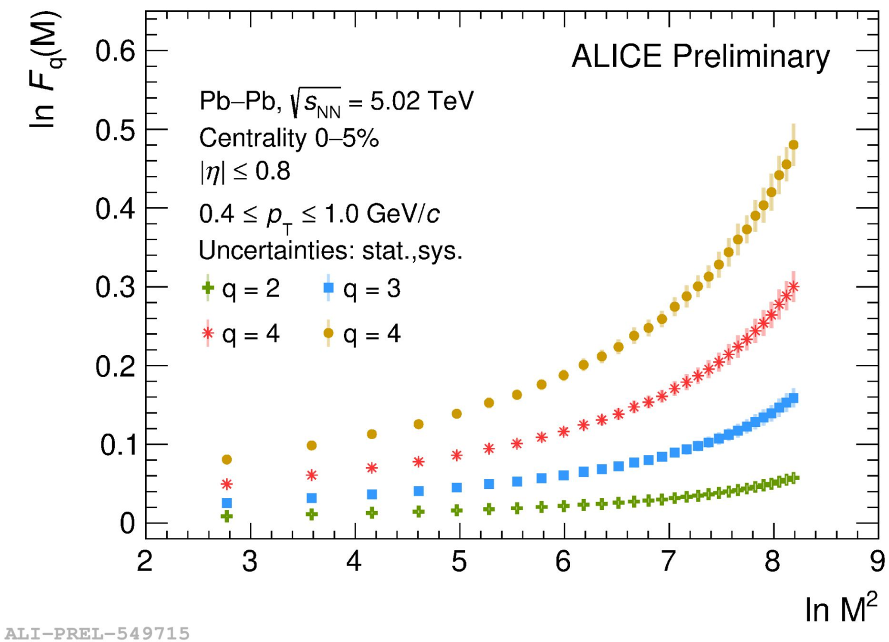
ALI-PREL-549715

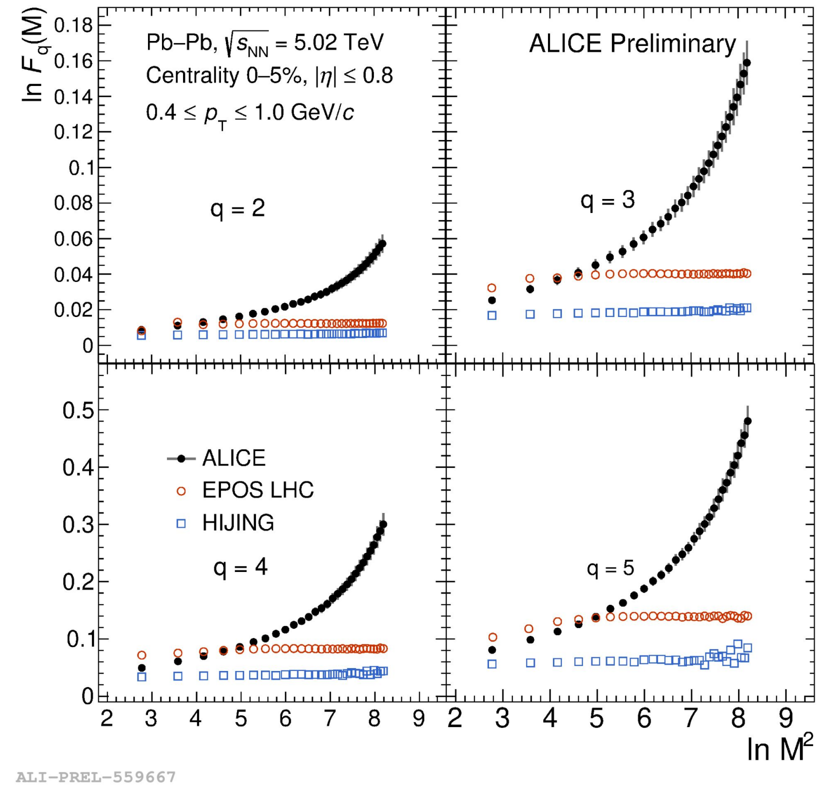
$$F_q \propto \left(M^2\right)^{\phi_q}$$

- Power-law growth of normalized factorial moments with increasing phase space bins (M) indicate scale-invariant pattern in the distribution of particles.

Results

M-scaling and comparison

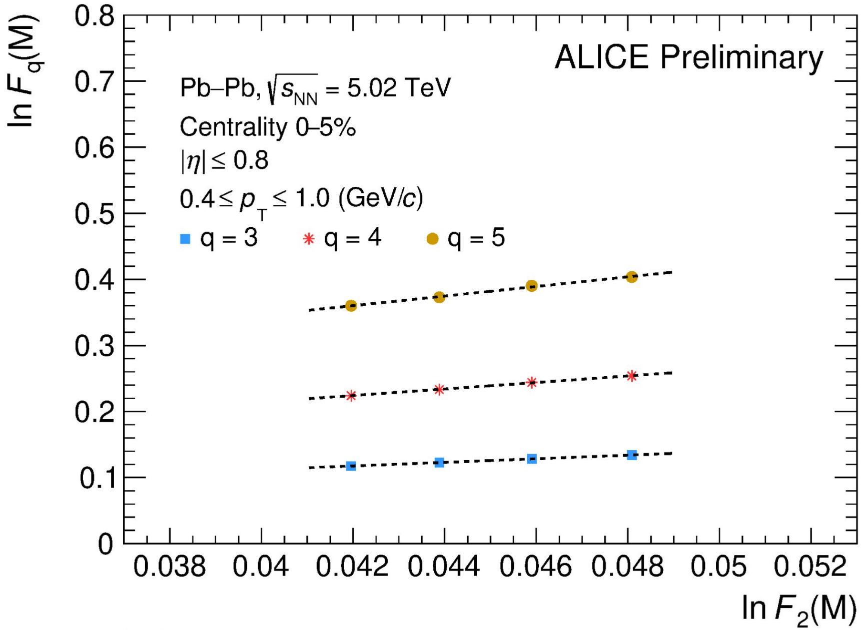




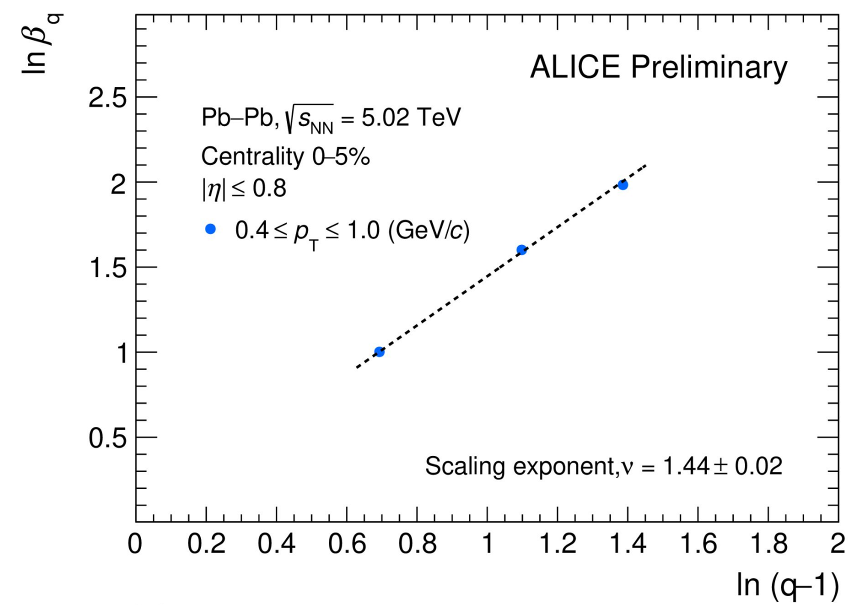
Significant difference between data and MC, similar to what was observed in 2.76 TeV
Scale-invariant density fluctuations in ALICE data but absent in MC (HIJING (non-collective), EPOS LHC (collective))

Results

F-scaling and scaling exponent



ALI-PREL-549719



ALI-PREL-549727

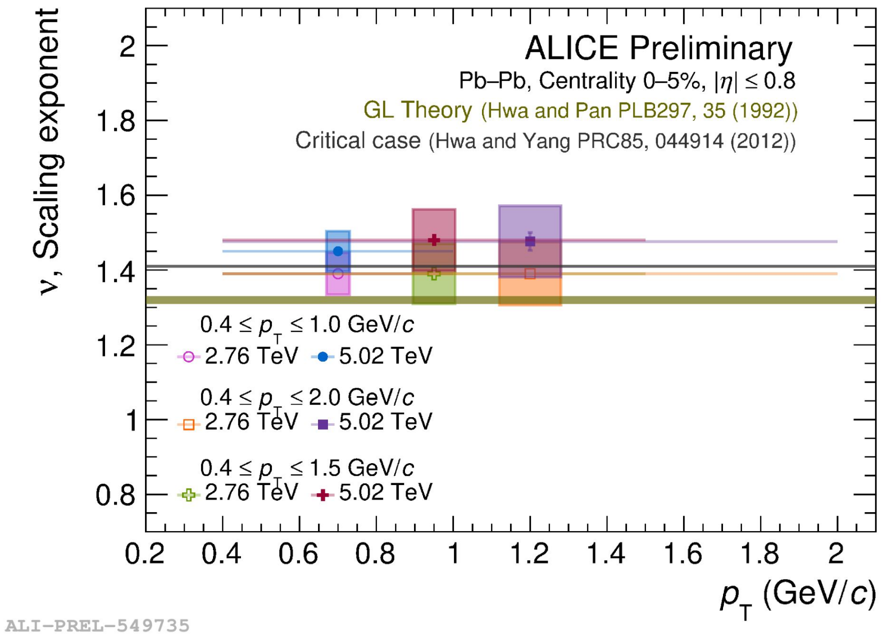
$$F_q(M) \propto F_2(M)^{\beta_q}$$

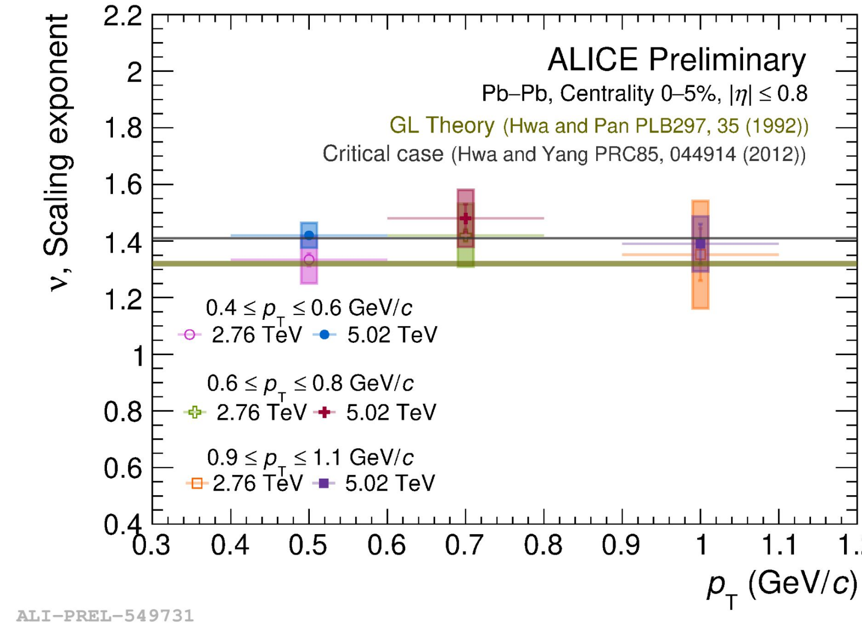
$$\beta_q \propto (q-1)^{\nu}$$

F-scaling observed in ALICE data and the resultant scaling exponent is calculated.

Results

Variation of scaling exponent with p_T

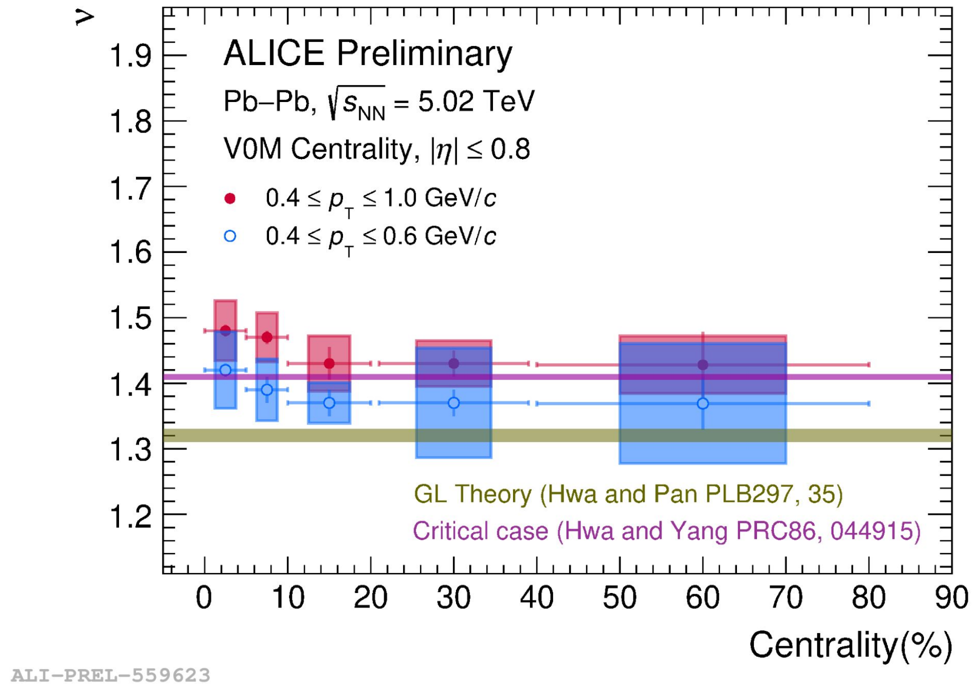




The scaling exponent is independent of p_T bin and p_T bin width within uncertainties
Scaling exponent values are close to the predicted values by theory of critical fluctuations.

Results

Variation of scaling exponent with centrality



A slight decrease in the values with increasing centrality for both the p_T bins.

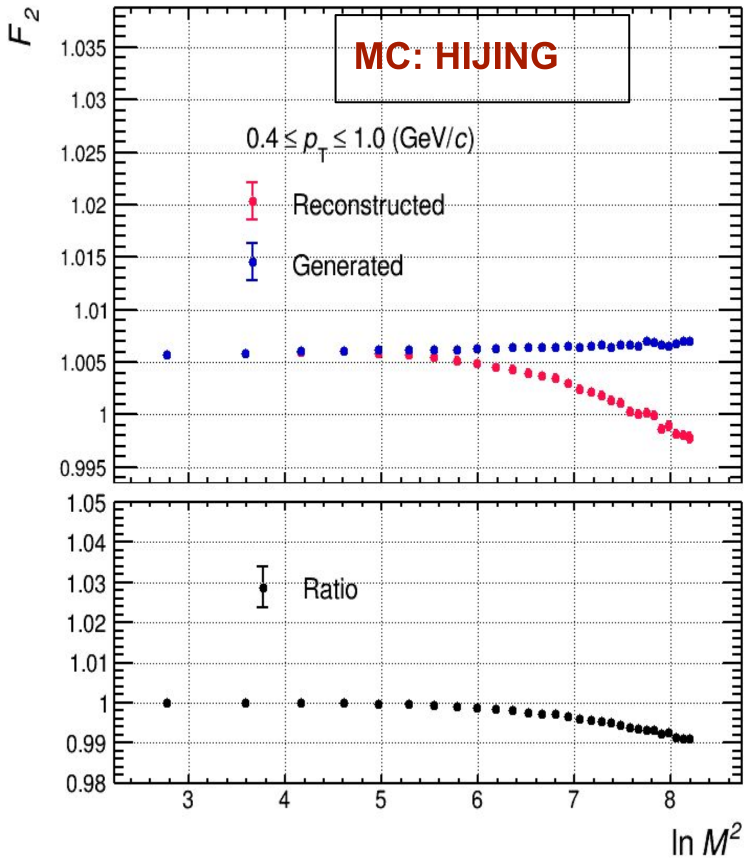
Summary

- Charged particle density fluctuations are studied in Pb-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV.
- *Intermittency* signal is observed at higher M (higher bin resolution).
- F-scaling observed at higher M and value of scaling exponent close to the predicted ones.
- Scaling exponent is independent of p_T and has a weak dependence on centrality.
- Difference in the scaling properties of charged particle multiplicity distributions between ALICE data and MC as the binning resolution increases.

THANK YOU

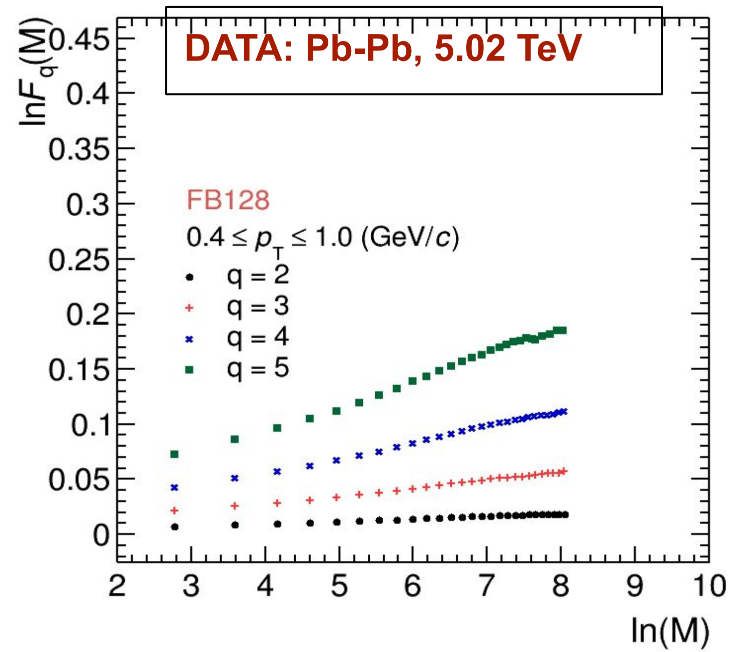
BACKUP

FB128



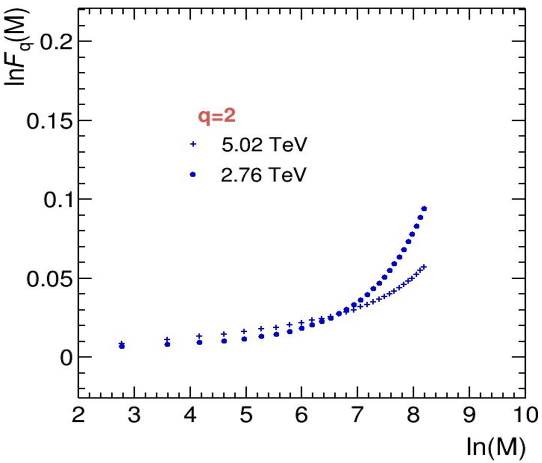
Pb-Pb, 5.02 TeV; $0.4 \leq p_T \leq 1.0$ GeV/c

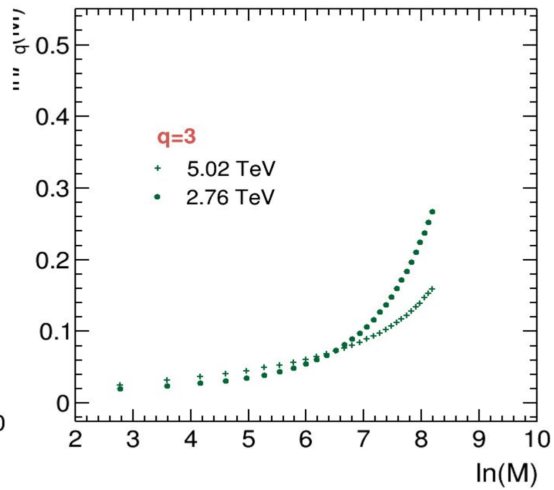
FlterBit 128

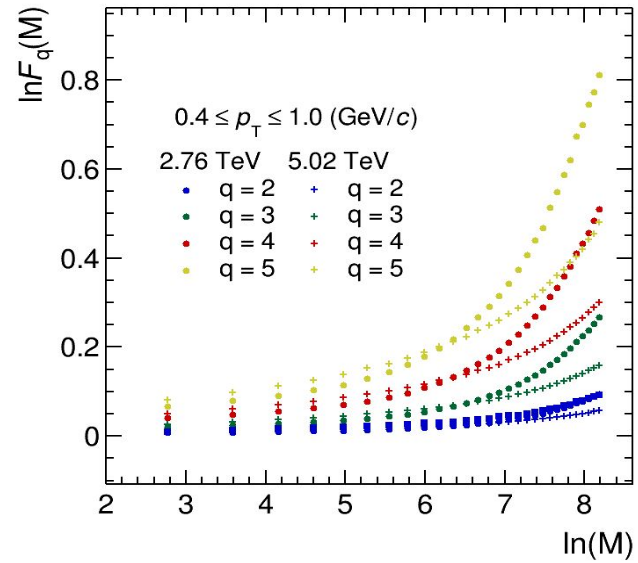


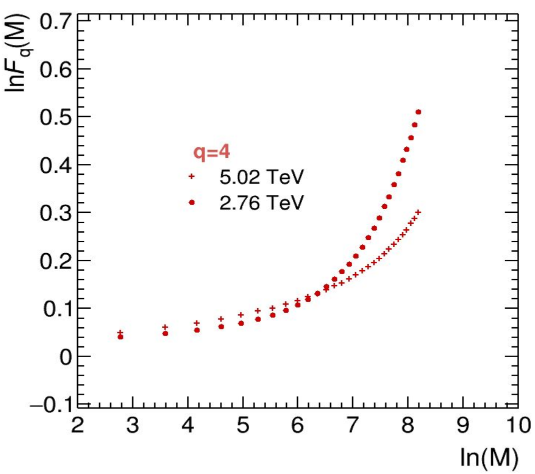
At higher M, saturation effect sets in (empty bin effect!)

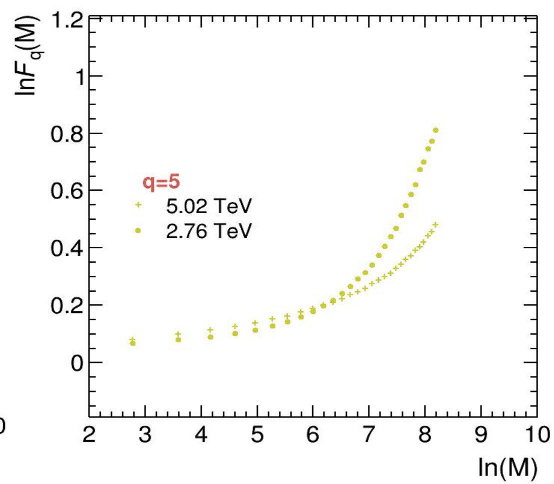
Difference between 2.76 TeV and 5.02 TeV (0.4 ≤ p_T ≤ 1.0 GeV/c)





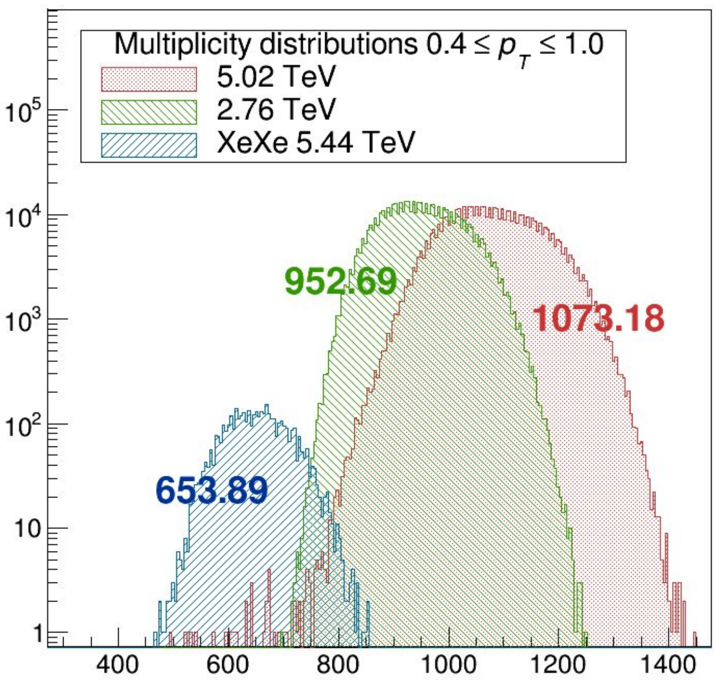




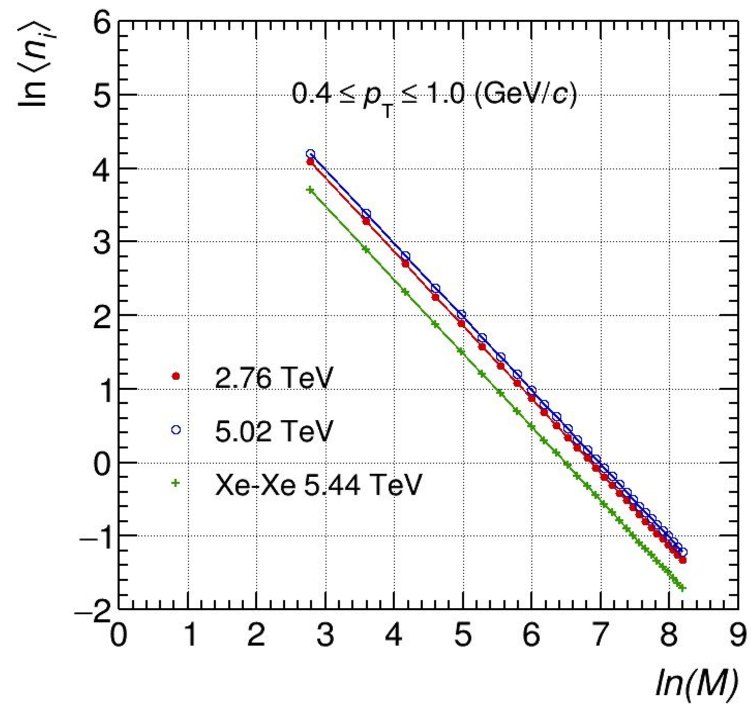


Multiplicity Distributions and average bin content

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



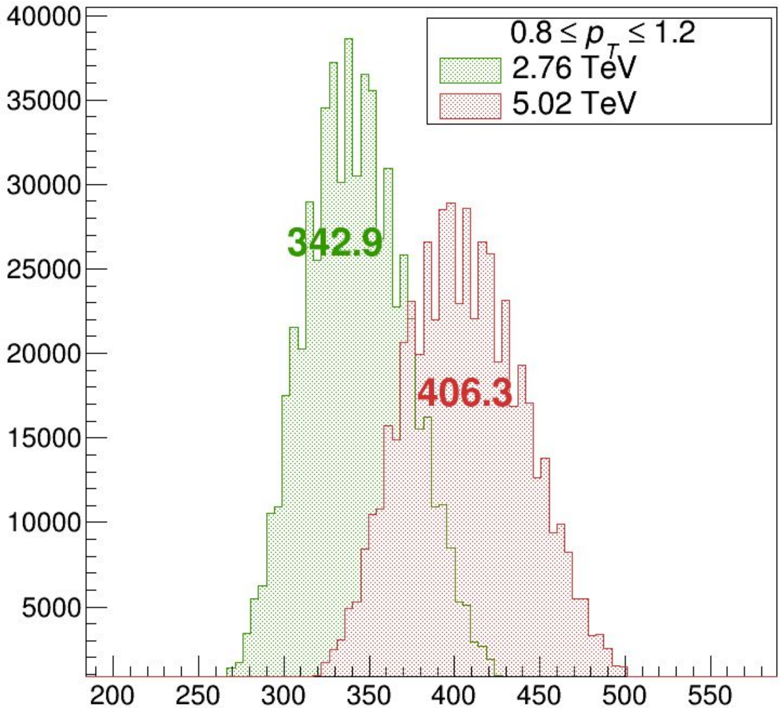
Charged particle Multiplicity distribution comparison

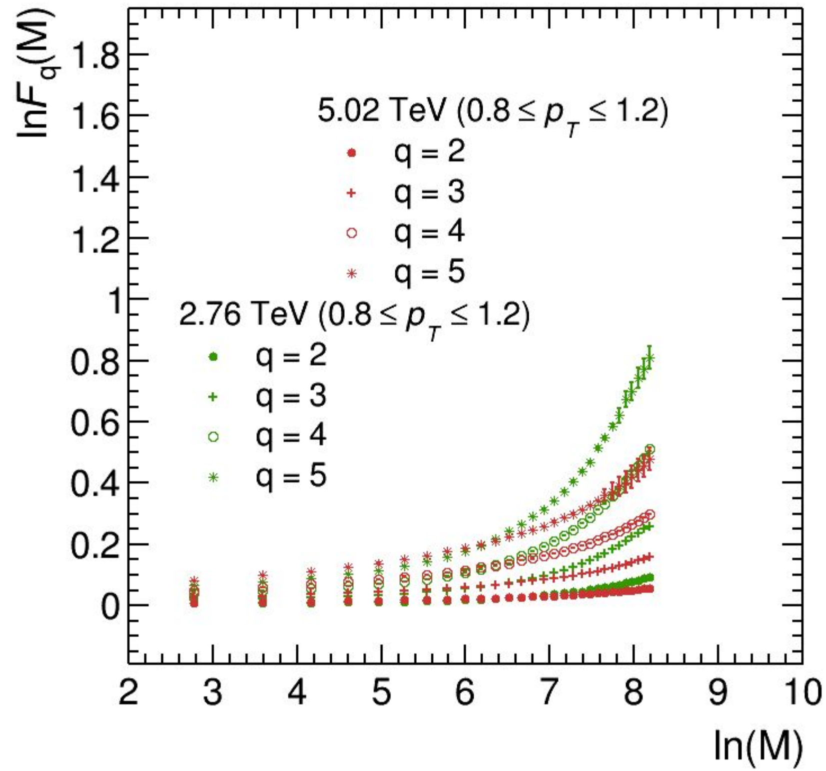


Average bin content as function of number of bins

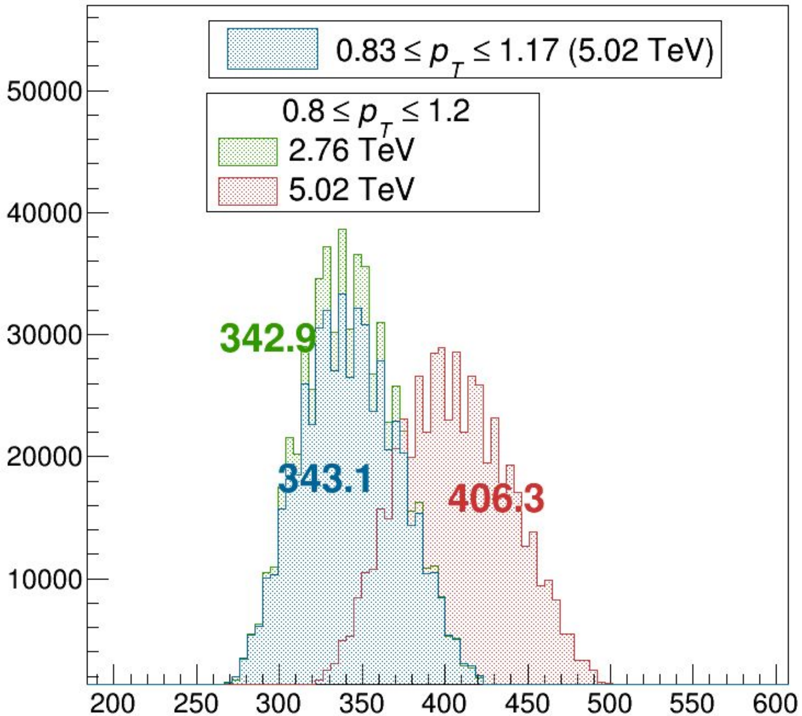
For datasets of Pb-Pb at 2.76 TeV, 5.02 TeV and Xe-Xe at 5.44 TeV in the accepted track cuts

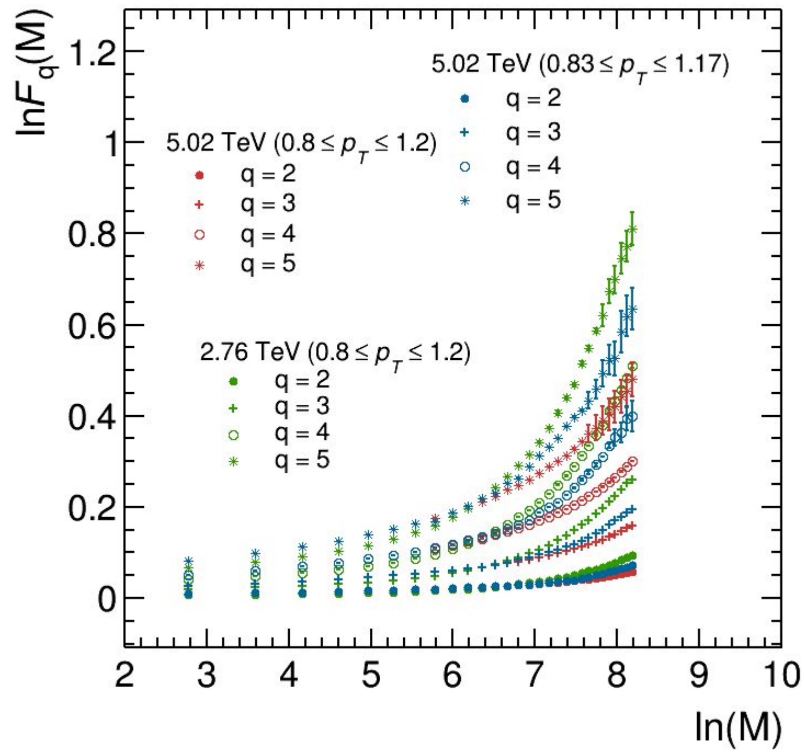
Multiplicity effect



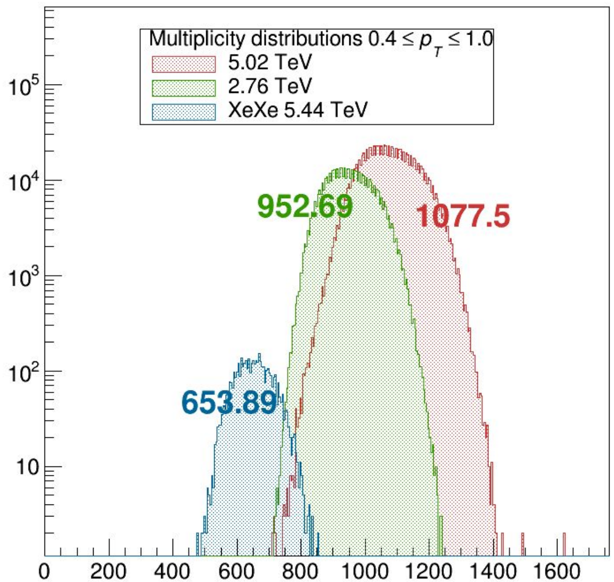


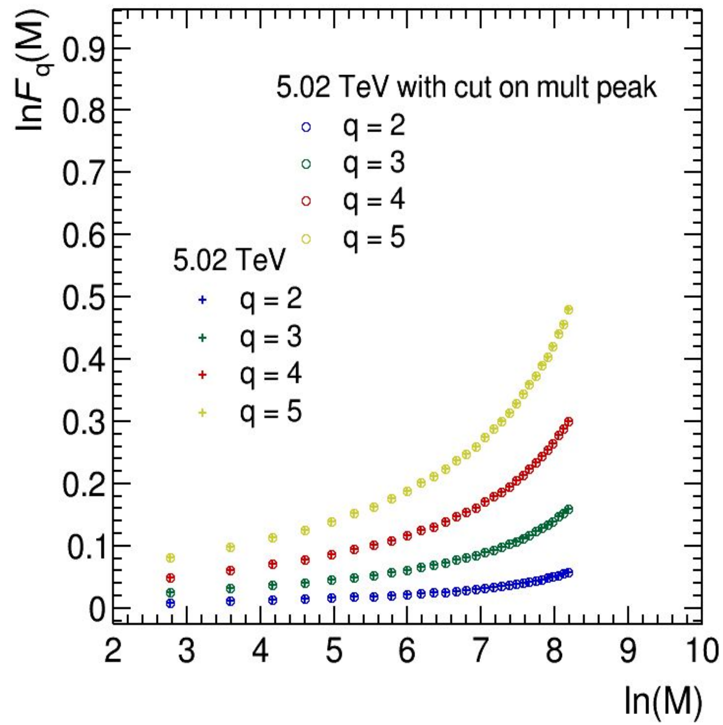
Multiplicity effect





Multiplicity tail effect





No Effect

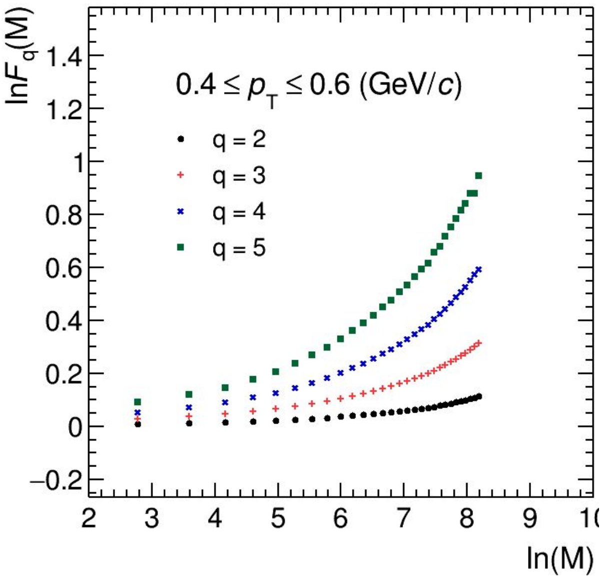
Systematics

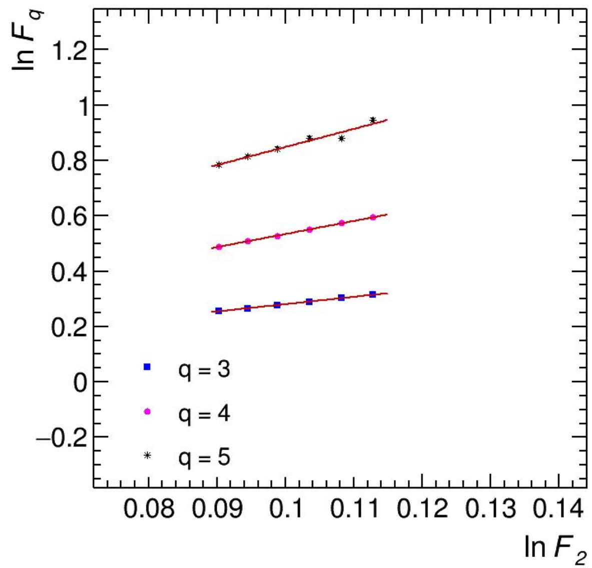
ALICE Pb-Pb, 5.02 TeV

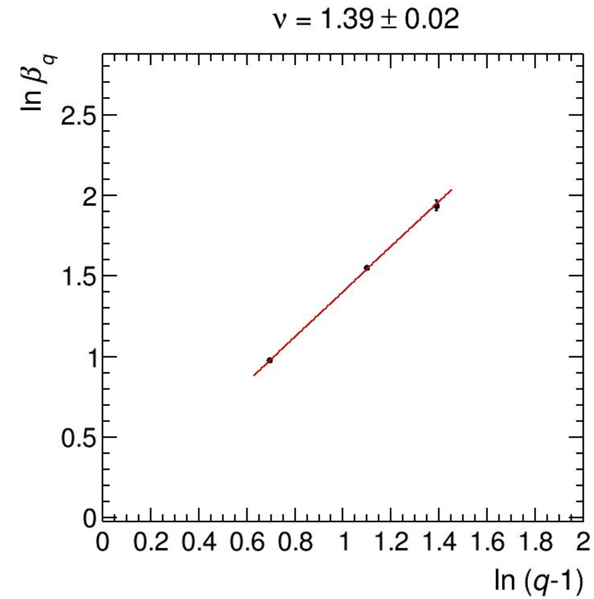
Systematic observable	Standard	Variations
event vertex Z	10.0 cm	**7.0 cm**
filterbit	768	**128**
B-field polarity	both	**positive, negative**
min # of crossed rows	80	**100**
min # of TPC clusters	70	**80**

Results (ALICE, Pb-Pb, 5.02 TeV)

0.4 ≤ pT ≤ 0.6 GeV/c





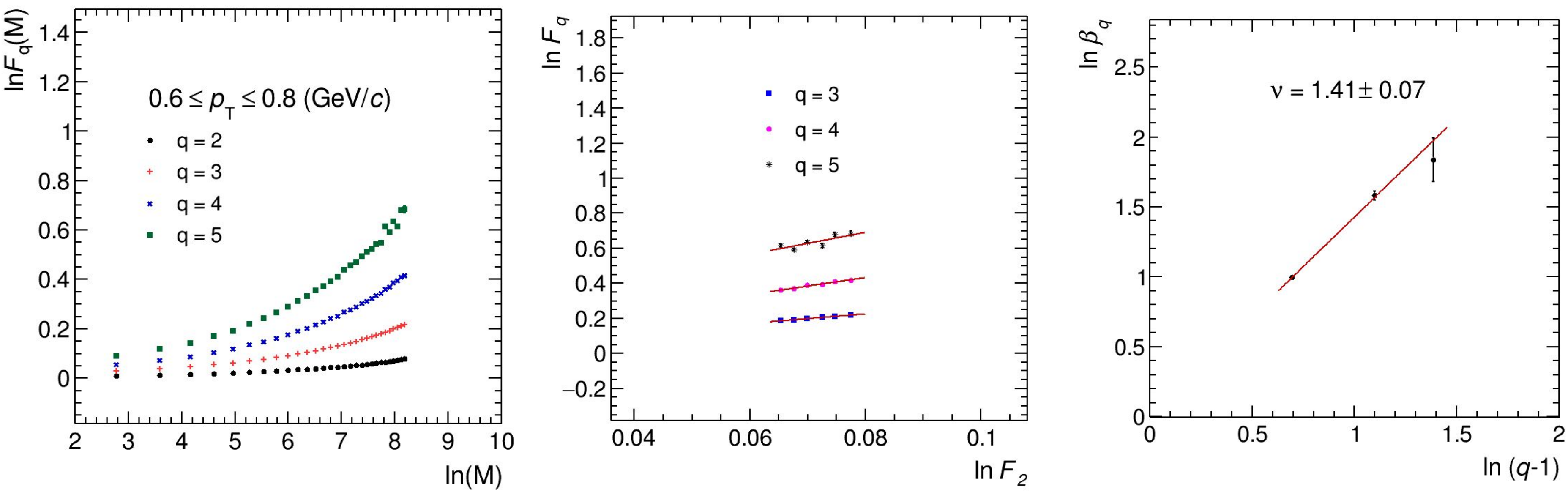


- M-scaling observed => Presence of intermittency
- F-scaling observed
- Scaling exponent different from 1.3 => system formed is not describable by GL theory

ν = 1.39 ± 0.02

Results (ALICE, Pb-Pb, 5.02 TeV)

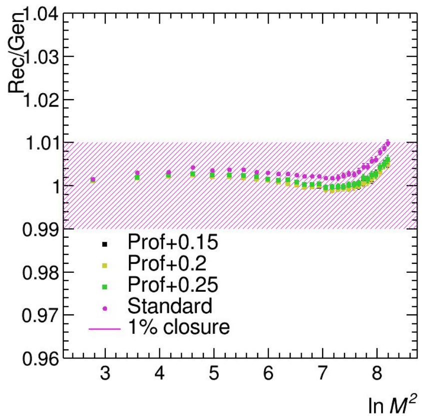
0.6 ≤ pT ≤ 0.8 GeV/c

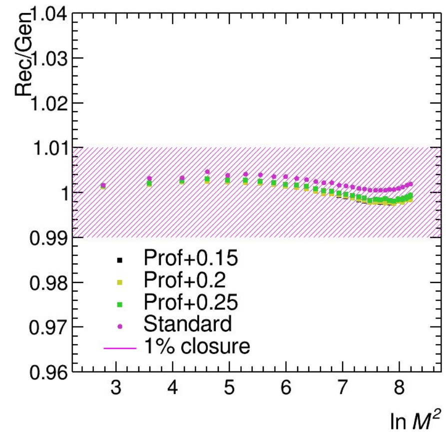


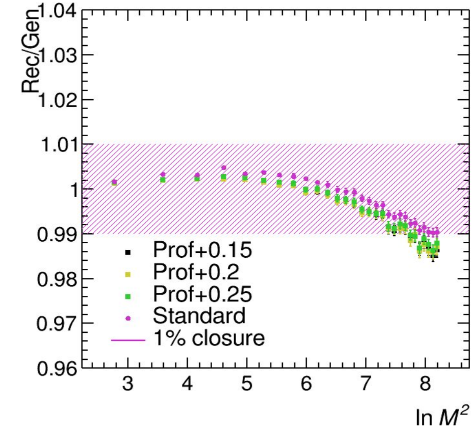
HIJING: MONTE Carlo closure,

$0.4 \leq p_T \leq 0.6$ GeV/c | **$0.4 \leq p_T \leq 1.0$ GeV/c** | **$0.6 \leq p_T \leq 0.8$ GeV/c**

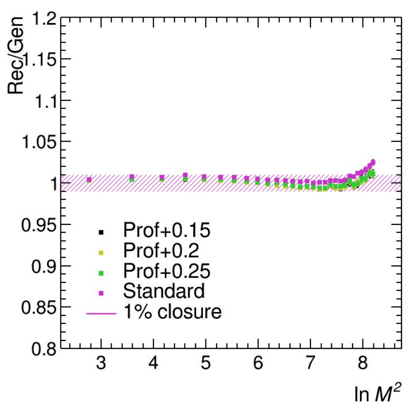
q=2

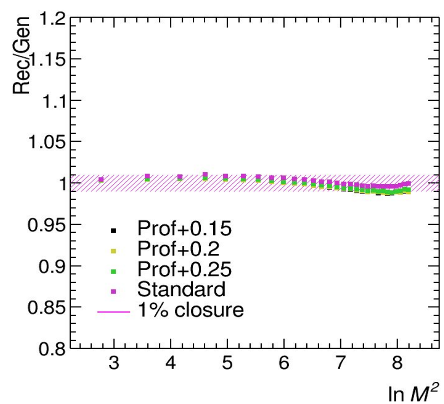


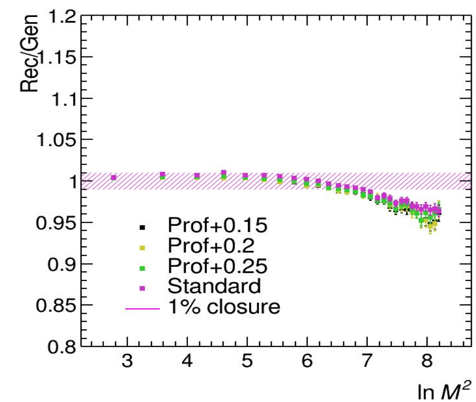




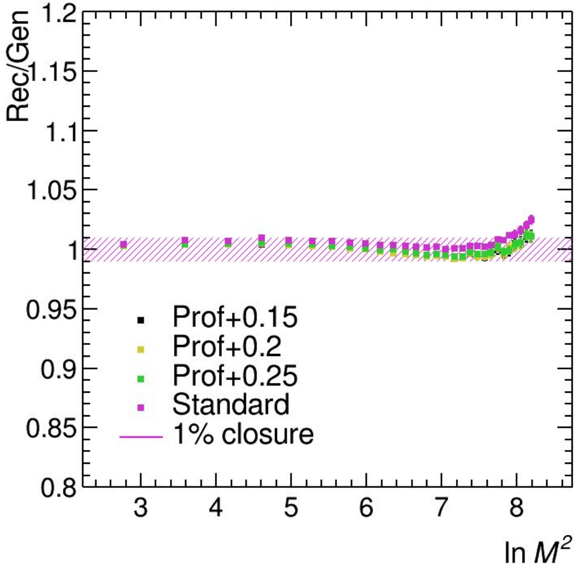
q=3



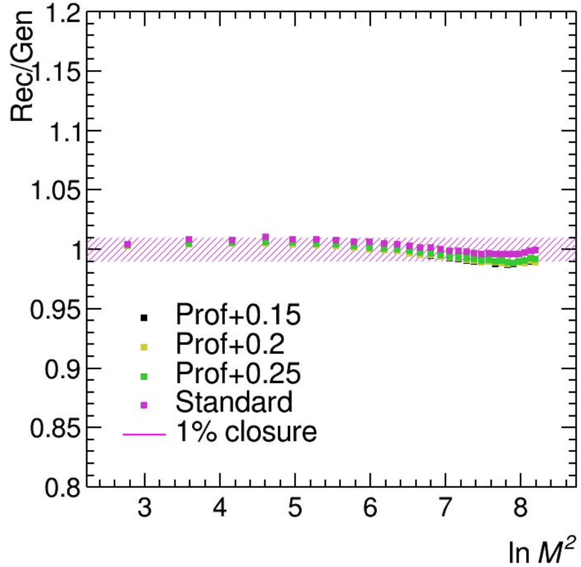




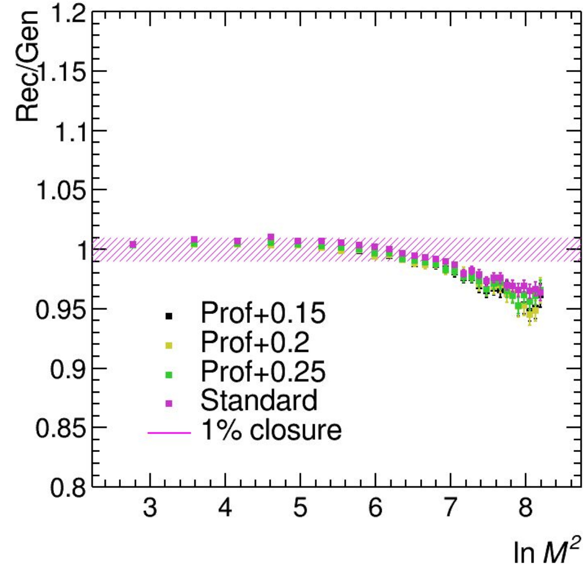
HIJING: MONTE Carlo closure, q=3



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

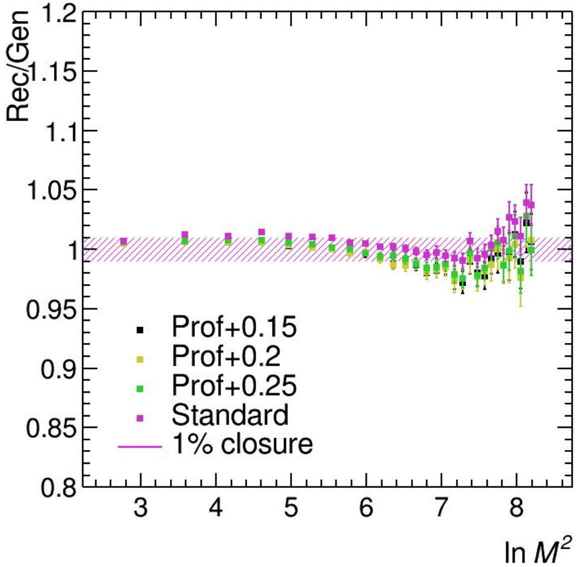


$0.4 \leq p_T \leq 1.0$ GeV/c

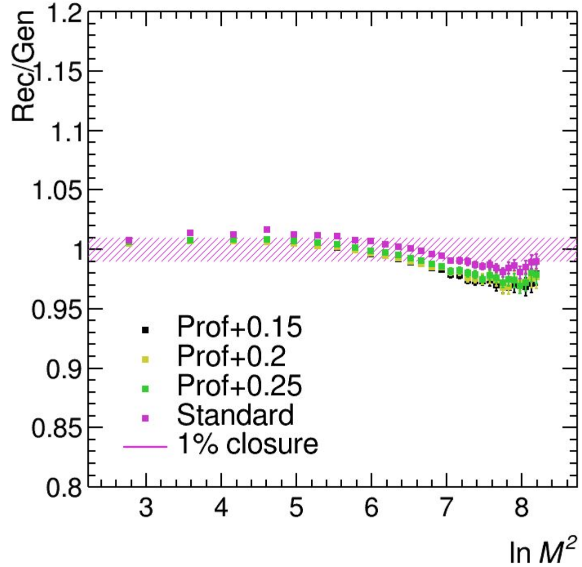


$0.6 \leq p_T \leq 0.8$ GeV/c

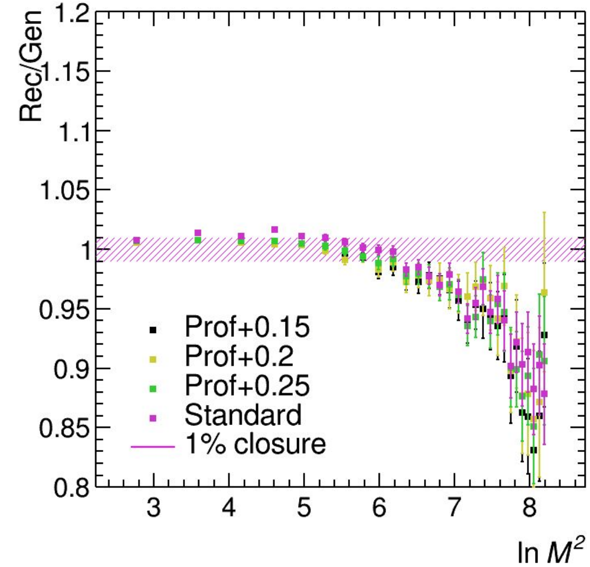
HIJING: MONTE Carlo closure, q=4



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

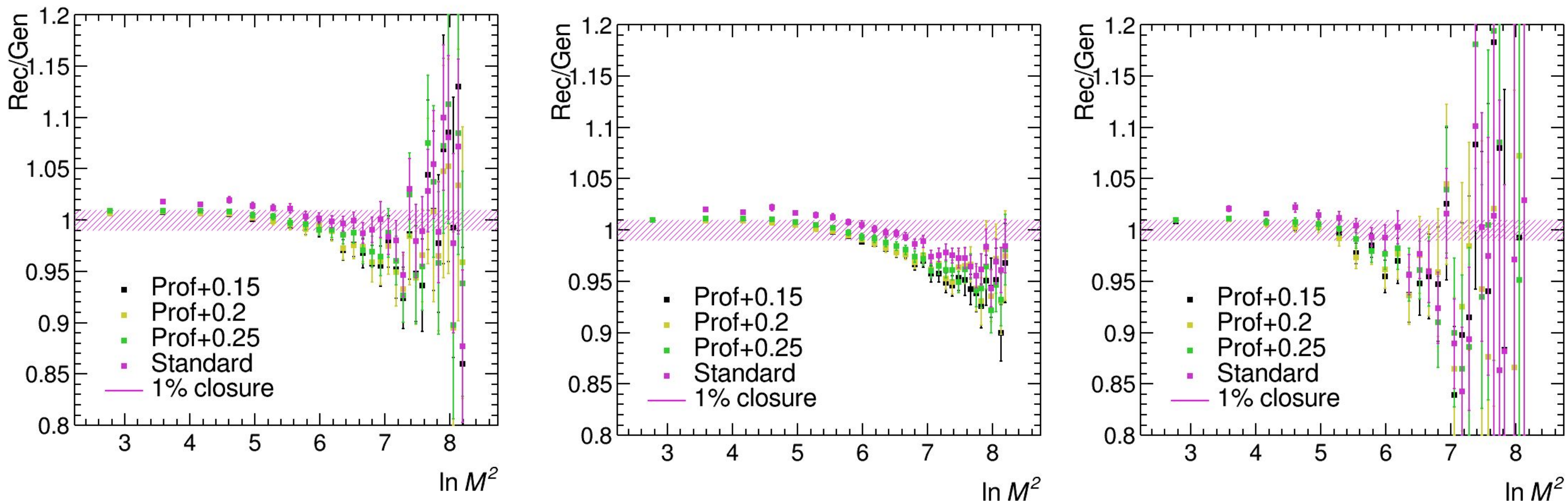


$0.4 \leq p_T \leq 1.0$ GeV/c



$0.6 \leq p_T \leq 0.8$ GeV/c

HIJING: MONTE Carlo closure, q=5

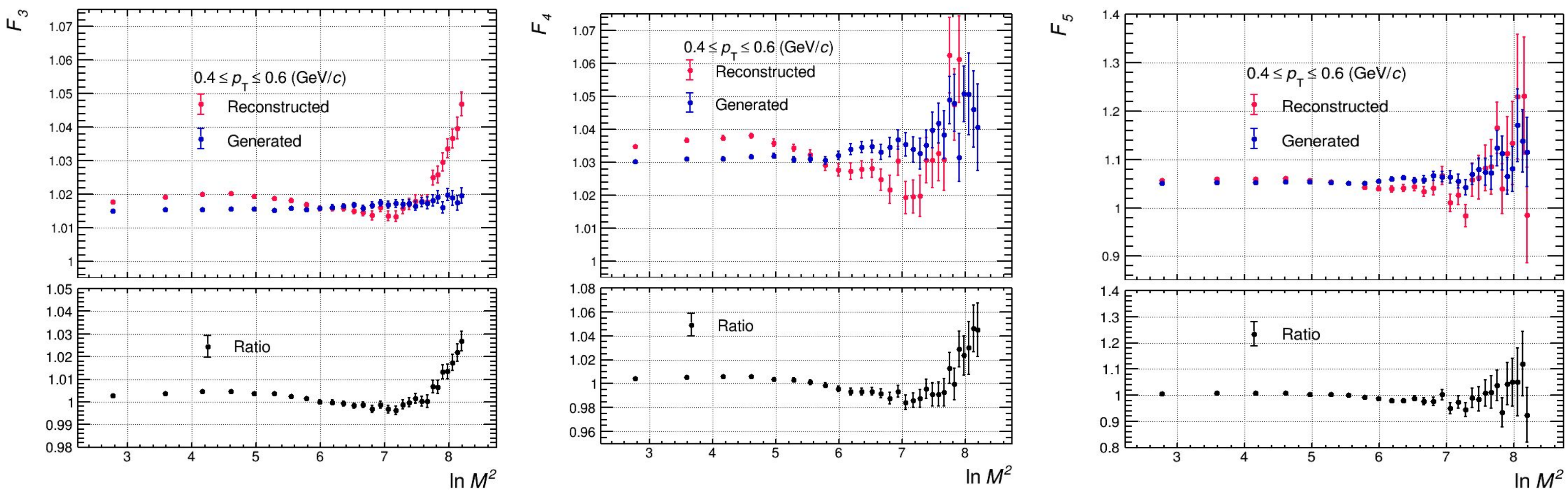


$0.4 \le p_T \le 0.6$ GeV/c

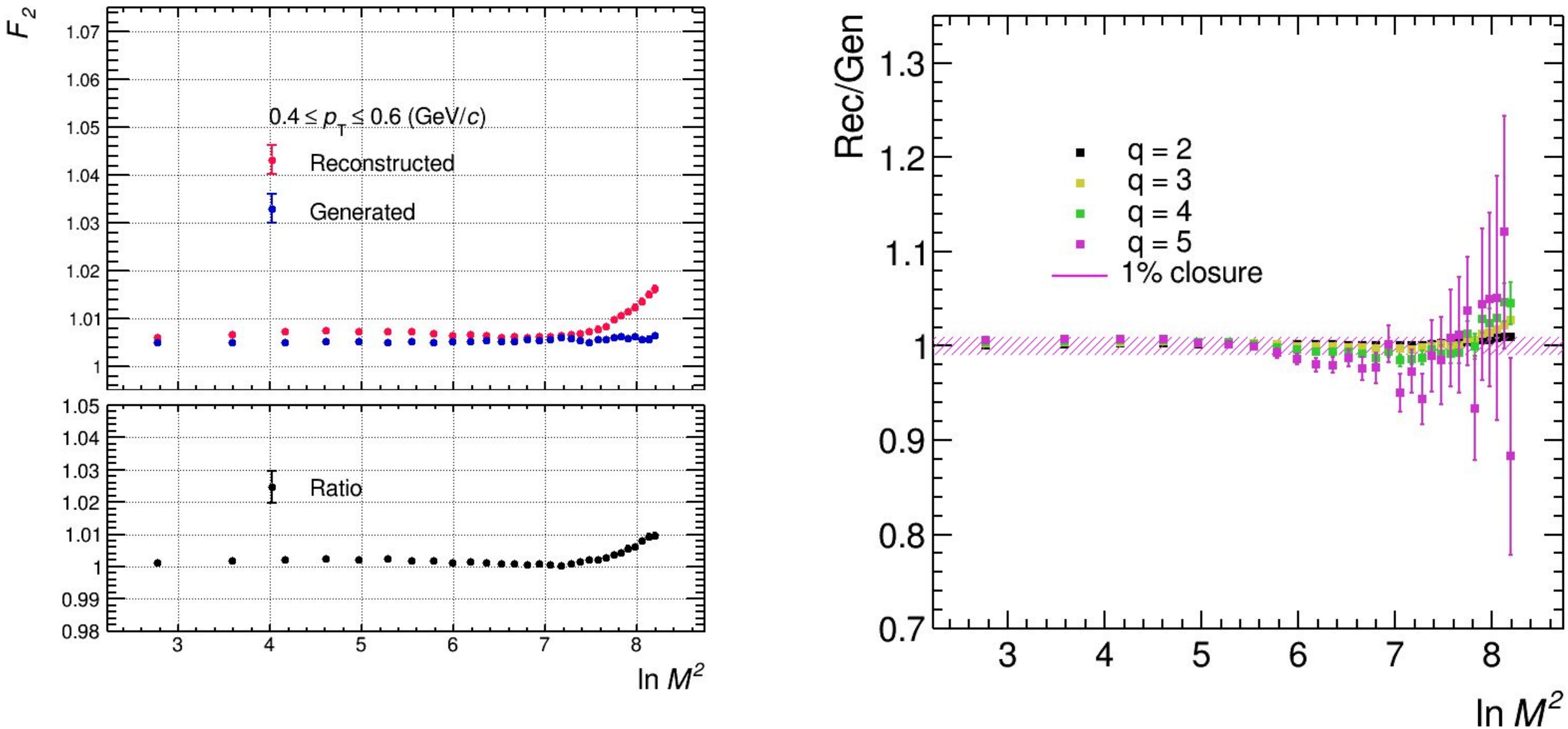
$0.4 \le p_T \le 1.0$ GeV/c

$0.6 \le p_T \le 0.8$ GeV/c

HIJING: MONTE Carlo closure, $0.4 \le p_T \le 0.6$ GeV/c

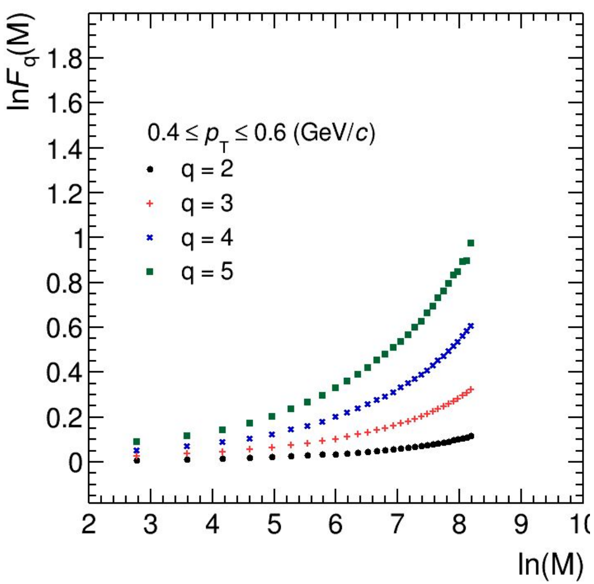


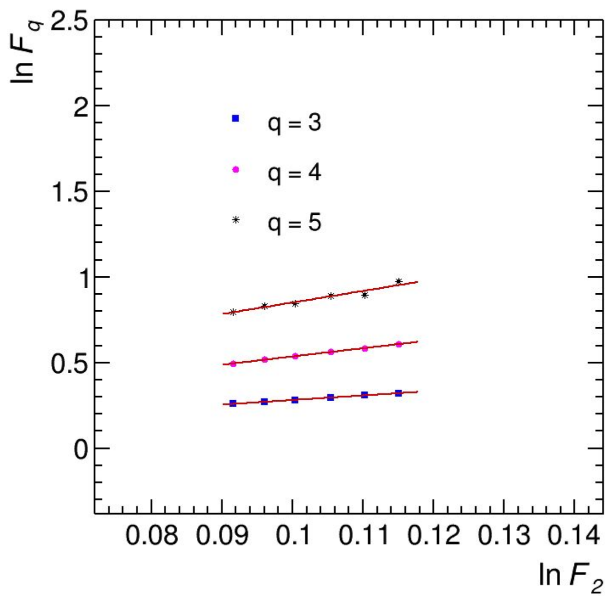
0.4 ≤ p_T ≤ 0.6 GeV/c

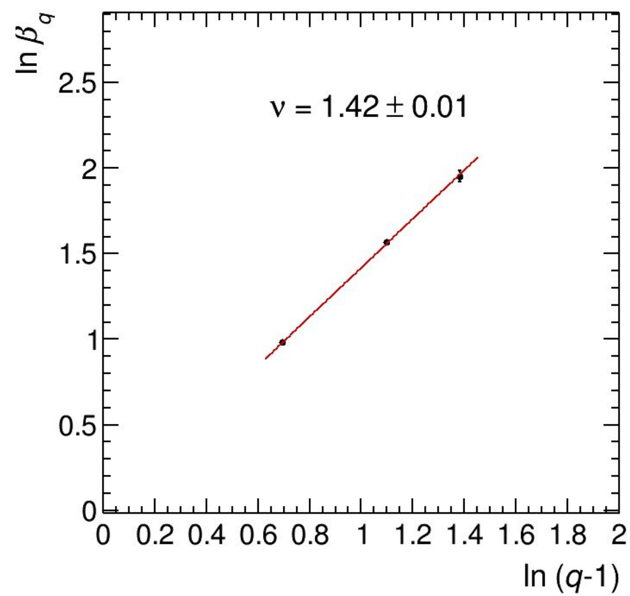


F_2
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1
0.4 ≤ p_T ≤ 0.6 (GeV/c)
Reconstructed
Generated
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
Ratio
3
4
5
6
7
8
ln M^2
Rec/Gen
1.3
1.2
1.1
1
0.9
0.8
0.7
q = 2
q = 3
q = 4
q = 5
1% closure
3
4
5
6
7
8
ln M^2

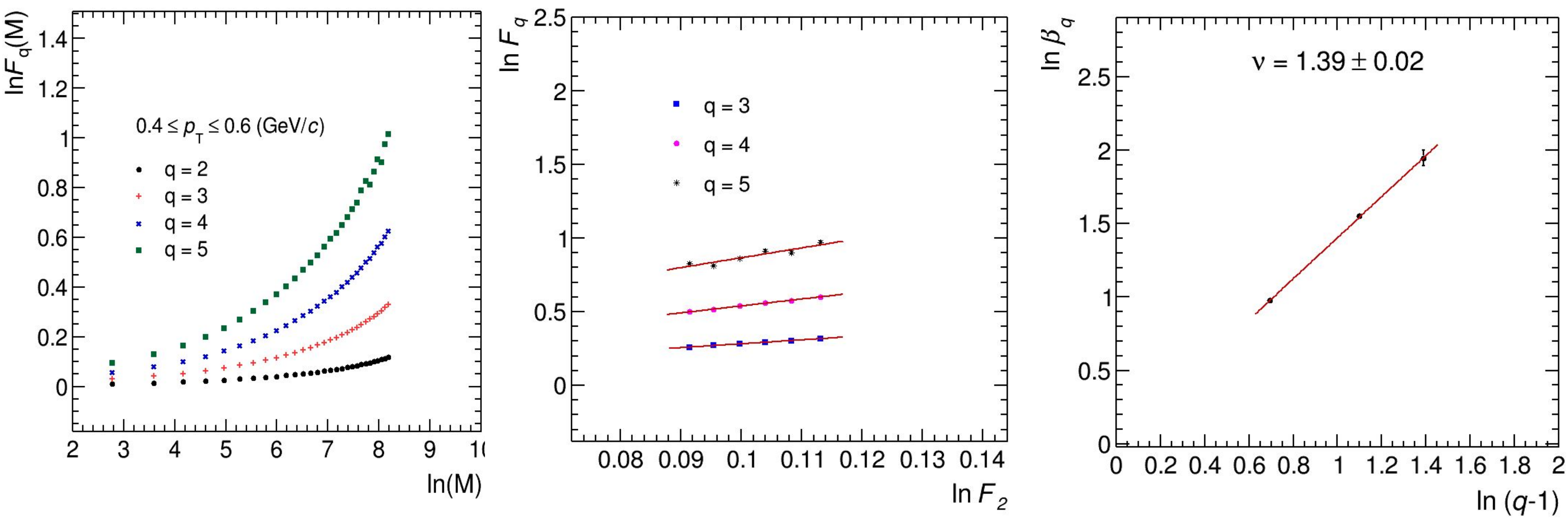
$0.4 \leq p_T \leq 0.6$ GeV/c
0-5% centrality



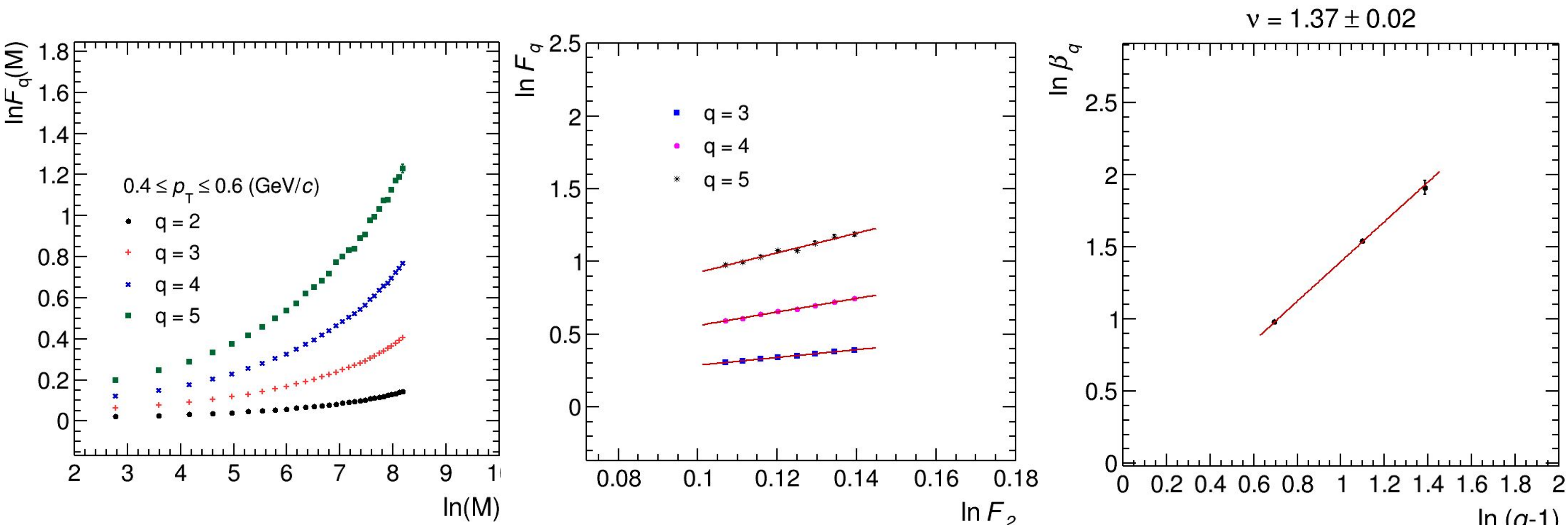




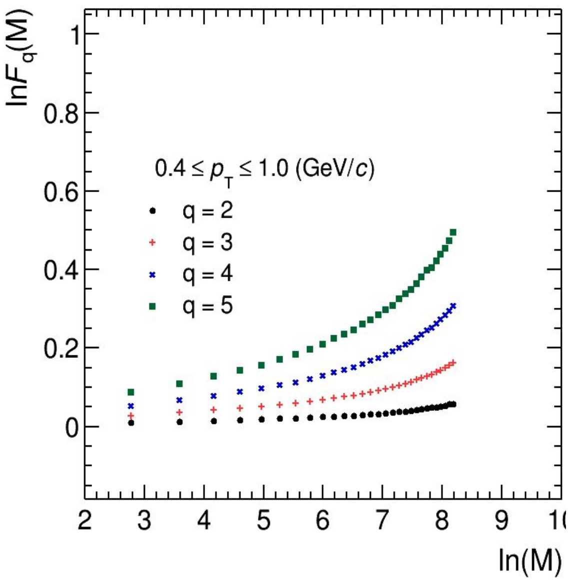
$0.4 \le p_T \le 0.6$ GeV/c
5-10% centrality

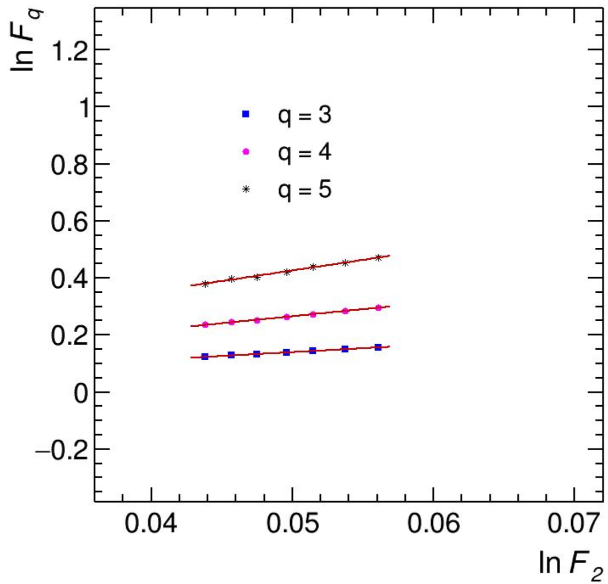


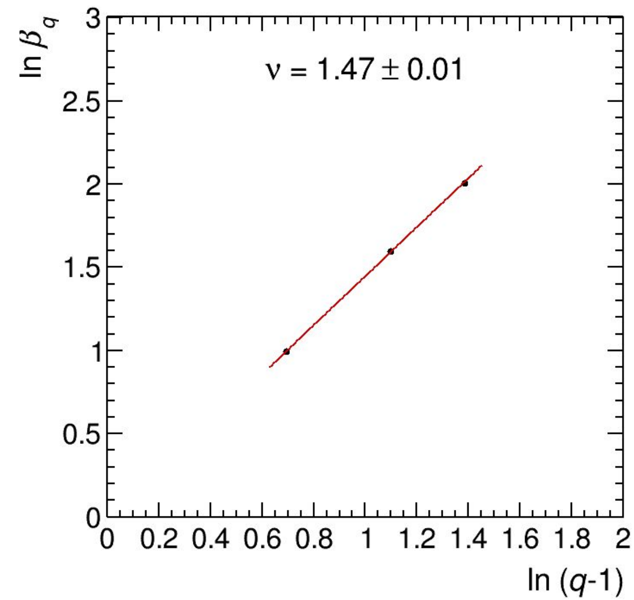
$0.4 \leq p_T \leq 0.6$ GeV/c
10-20% centrality



$0.4 \leq p_T \leq 1.0$ GeV/c
5-10% centrality







$0.4 \leq p_T \leq 1.0$ GeV/c
10-20% centrality