Event-by-event mean transverse momentum fluctuations in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE

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Introduction: Mean p_T fluctuations

- Fluctuations of a thermal system are directly related to its various susceptibilities.
- *The extraction of the system heat capacity from temperature fluctuations,*

$$\frac{1}{C} = \frac{(\Delta T^2)}{T^2}$$

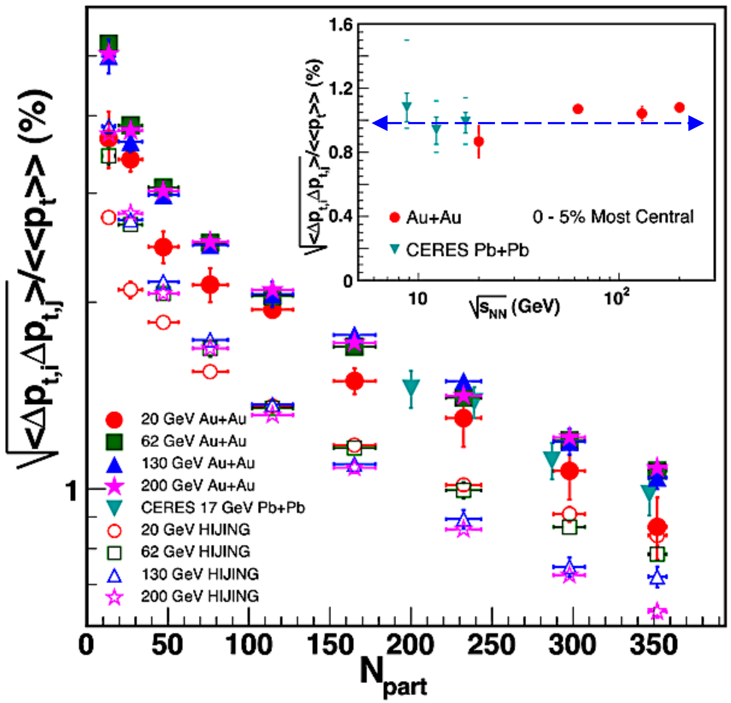
- The p_T correlations can be formulated in terms of the fluctuations in the effective temperature as,

$$\langle \Delta p_T \Delta p_T \rangle \approx \left[\frac{d\langle p_T \rangle}{dT} \right]^2 \Delta T^2$$

- Non-monotonic changes in p_T correlations with beam energy or centrality can be identified as a possible signal of QGP formation.

STAR Collboration, Phys. Rev. C87, (2013) 064902; Sumit Basu et al, Phys. Rev. C94 (2016) 044901; B-H Sa et al, Phys. Rev. 75 (2007) 054912

Mean p_T fluctuations



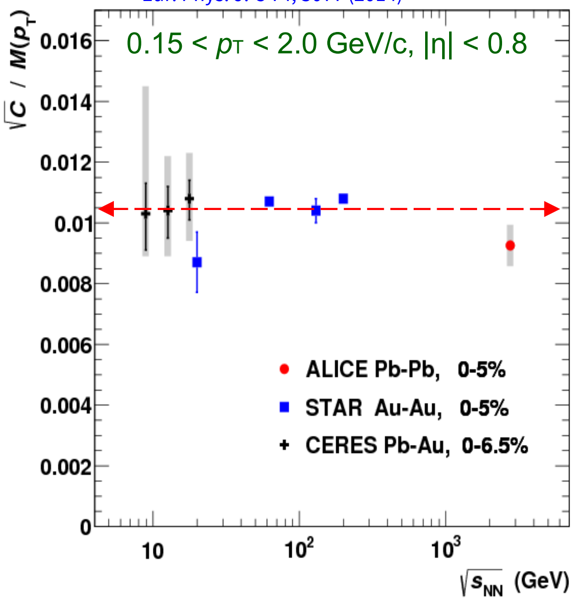
- Significant dynamical mean p_T fluctuations are observed in heavy-ion collisions.

STAR Coll., Phys. Rev. C 72, 044902 (2005)

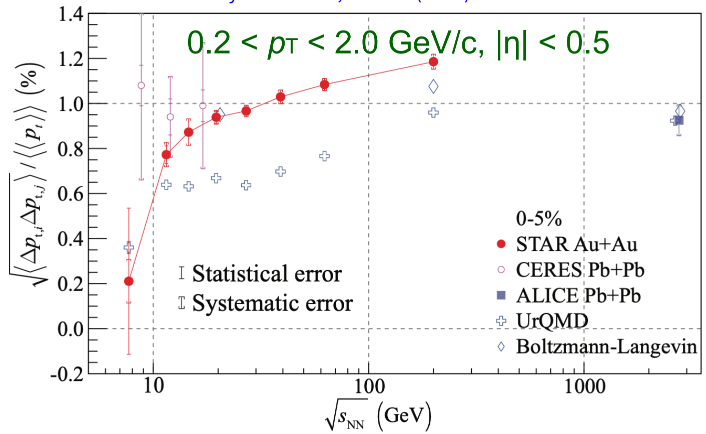
Kinematic acceptance:
$0.15 < p_T < 2.0$ GeV/c, $|\eta| < 1.0$

Mean p_T fluctuations

Eur. Phys. J. C 74, 3077 (2014)



Phys. Rev. C 99, 044918 (2019)



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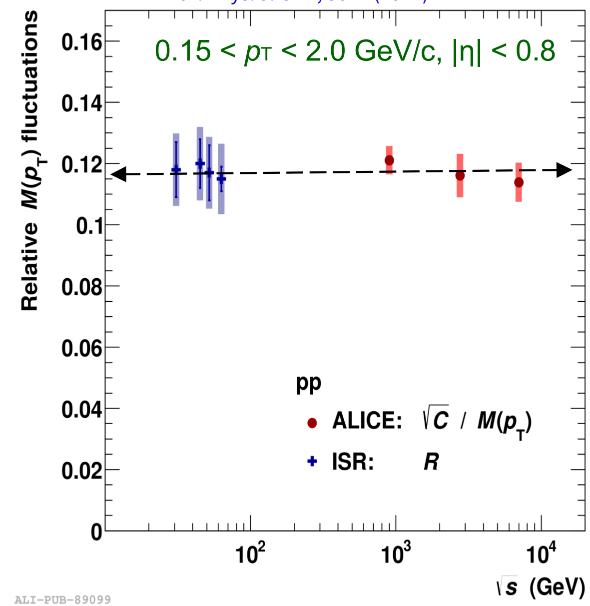
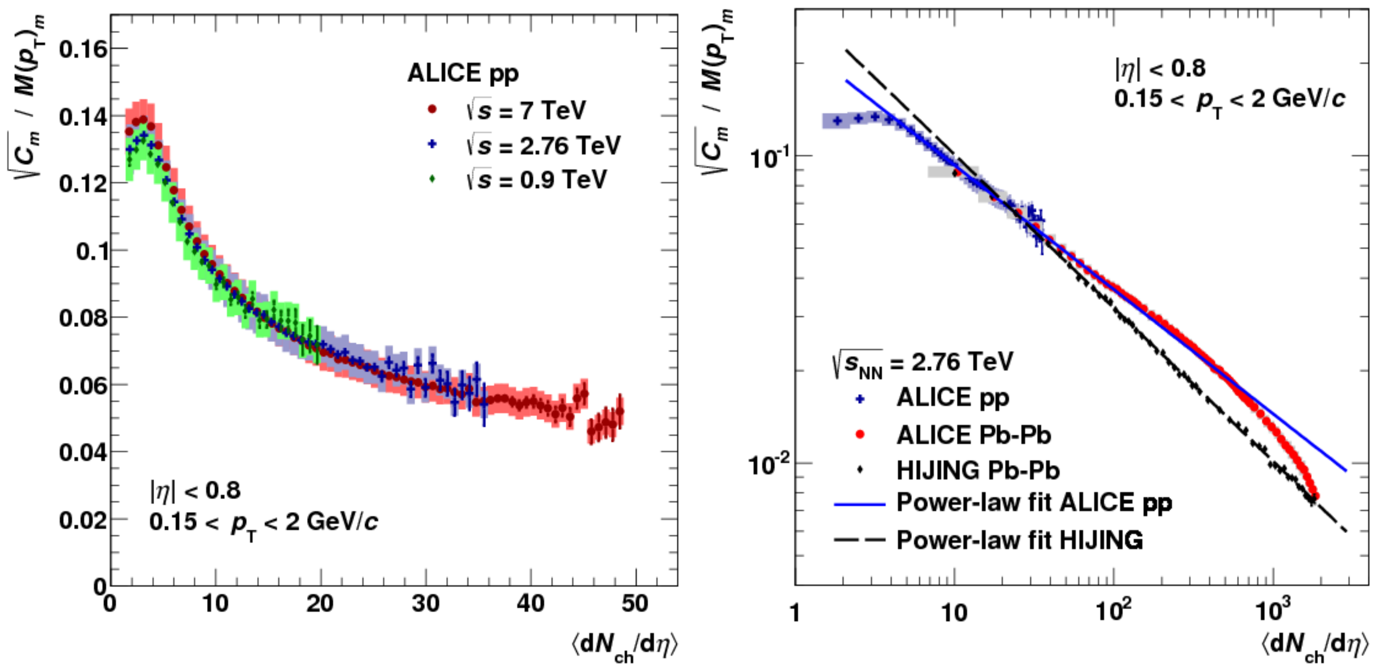


- In heavy-ion collisions, the mean p_T fluctuation strength is observed to be ~ 1%
- In pp collisions the strength is ~ 11%

Fun Fact
CMBR temperature fluctuations (ΔT/T) is 2.7K ± 3mK about 0.01%

Mean p_T fluctuations



Eur. Phys. J. C 74, 3077 (2014)

- The correlation strength is inversely proportional to the number of sources;
- A similar trend is observed from pp to Pb–Pb collisions;
- Motivated to look at high-multiplicity pp events.

The two-particle p_T correlator

The two-particle correlator C measures the dynamic component of mean transverse momentum fluctuations.

In multiplicity class m, given as:

$$C_m = \frac{1}{\sum_{k=1}^{n_{evt},m} N_k^{pairs}} \sum_{k=1}^{n_{evt},m} \sum_{i=1}^{N_{acc},k} \sum_{j=i+1}^{N_{acc},k} \left(p_{T,i} - M(p_T)_m\right) * \left(p_{T,j} - M(p_T)_m\right)$$

$$M(p_T)_m = \frac{1}{\sum_{k=1}^{n_{evt},m} N_{acc,k}} \sum_{k=1}^{n_{evt},m} \sum_{i=1}^{N_{acc,k}} p_{T,i}$$

Mean p_T of the sample

The two-particle p_T correlator

The two-particle correlator *C* measures the dynamic component of mean transverse momentum fluctuations.

In multiplicity class *m*, given as:

$$C_m = \frac{1}{\sum_{k=1}^{n_{evt,m}} N_k^{pairs}} \sum_{k=1}^{n_{evt,m}} \sum_{i=1}^{N_{acc,k}} \sum_{j=i+1}^{N_{acc,k}} \left(p_{T,i} - M(p_T)_m\right) * \left(p_{T,j} - M(p_T)_m\right)$$

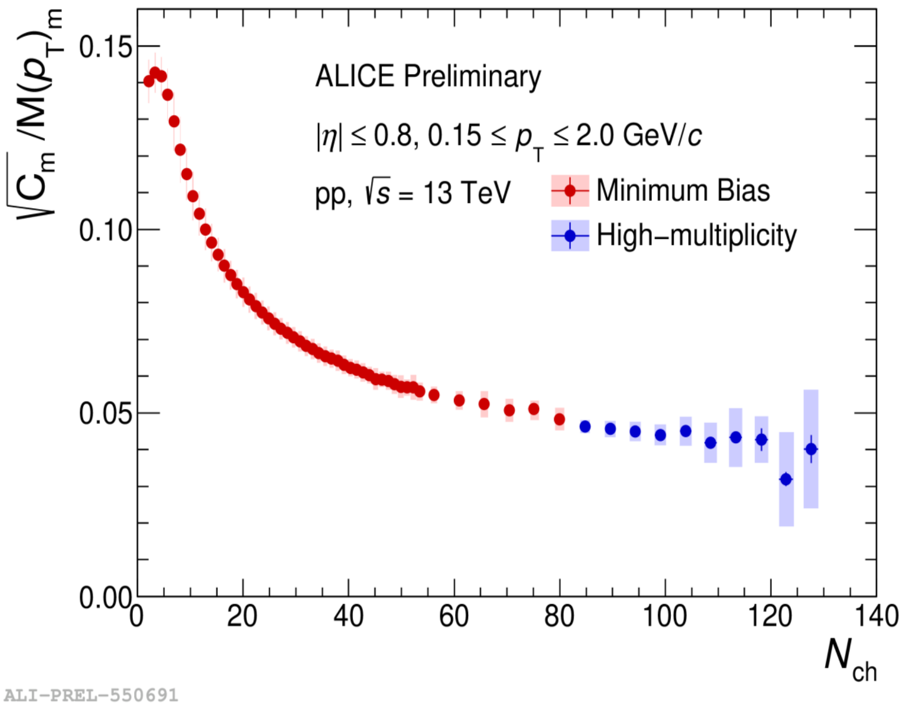
→ C_m vanishes for uncorrelated production, where only statistical fluctuations are present.

ALICE	STAR
$\sqrt{C_m}/M(p_T)_m \approx$	$\sqrt{\langle\Delta p_{T,i}\Delta p_{T,j}\rangle}/\langle\langle p_T\rangle\rangle$

Equivalent to *R*

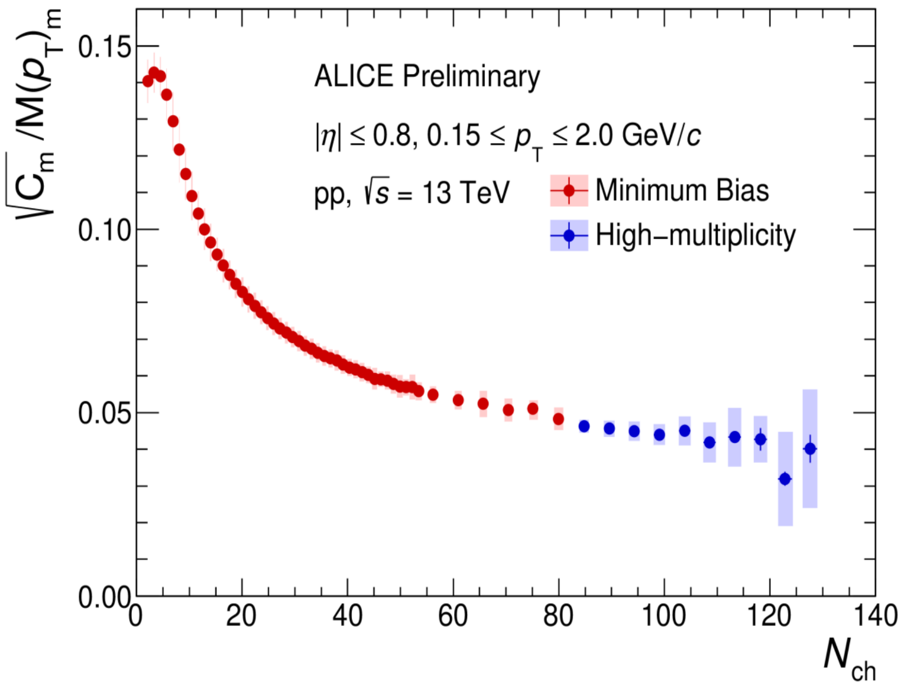
Relative fluctuation measure used at ISR energies

Results: $\sqrt{C_m}/M(p_T)_m$ as a function of multiplicity



- $\sqrt{C_m}/M(p_T)_m \rightarrow$ dimensionless ratio, quantifies the strength of correlations in units of $M(p_T)$.
- The systematic errors are shown by boxes and statistical errors by bars.

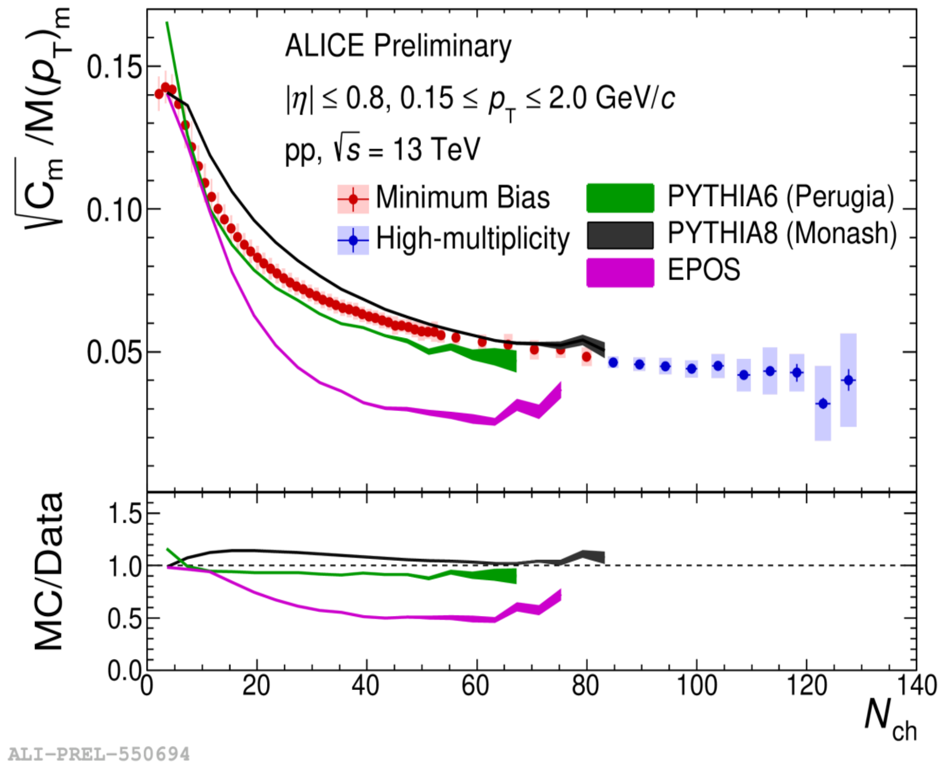
Results: $\sqrt{C_m}/M(p_T)_m$ as a function of multiplicity



ALI-PREL-550691

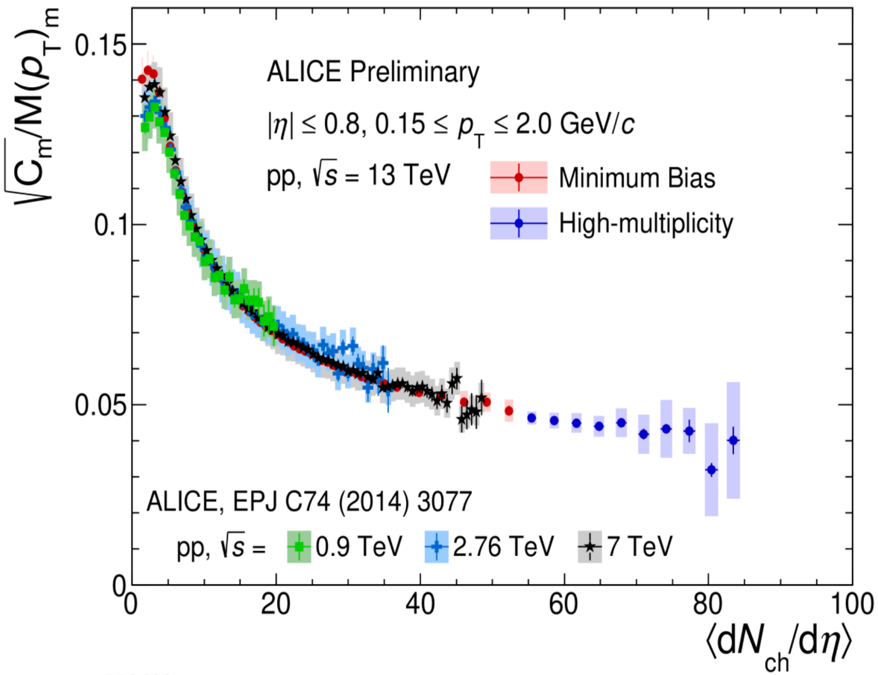
- A threshold is defined at N_{ch} = 85 → such that results from HM events are presented beyond this value.
- Non-zero mean p_T fluctuation.
- Normalized correlator decreases with multiplicity.
- This trend is nicely followed by *HM events*.

Results: Model predictions



- The MC models PYTHIA (both tunes) and EPOS give qualitative description of the data.
  - ✓ PYTHIA6 predicts slightly lower values,
  - ✓ PYTHIA8 gives significantly larger values,
  - ✓ EPOS predicts significantly lower values of normalized correlator.

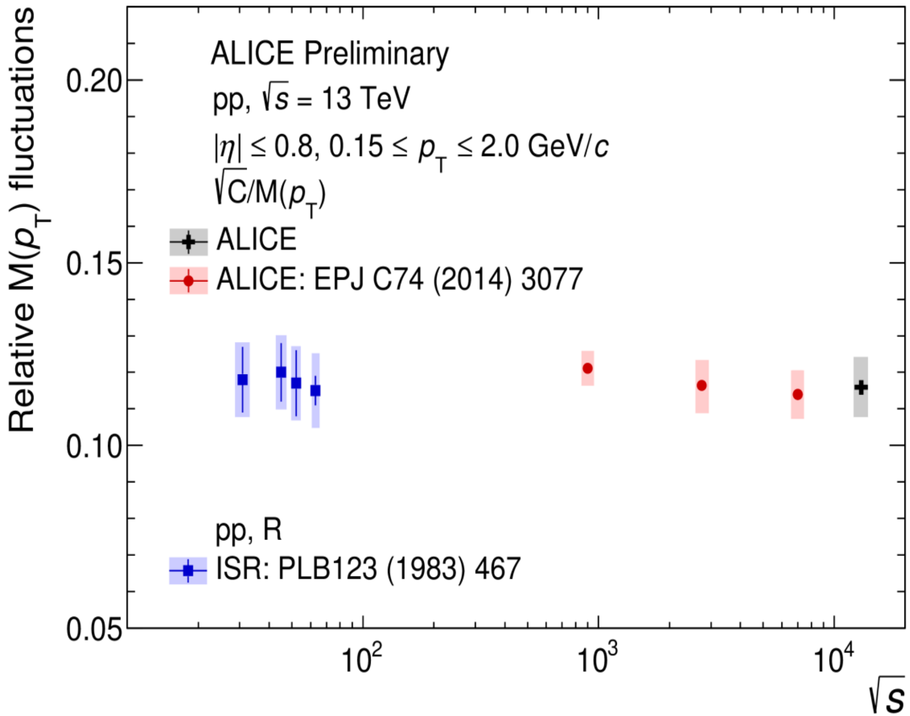
Results: Comparison with lower energy datasets



ALI-PREL-550688

- Relative mean p_T fluctuations in pp collisions at $\sqrt{s}$ = 0.9, 2.76, 7 and 13 TeV.
- *No significant energy dependence.*

Results: Inclusive mean p_T fluctuations

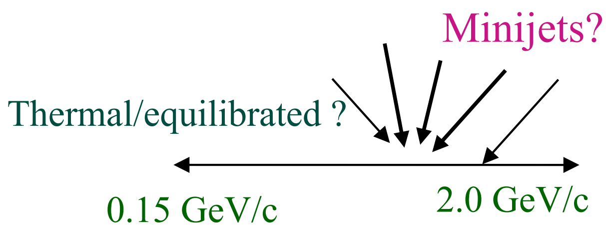


ALI-PREL-550685

- Relative fluctuations from ISR to ALICE shows no significant energy dependence.
- *The relative fluctuation strength ~ 11%*

Motivation towards higher p_T

A study of soft, intermediate and hard p_T would significantly impact on understanding the equilibrations and thermal (radial flow) - non thermal (jets/minijets) sources for p_T fluctuations.



Various collision systems at different energies were studied...

Motivation towards higher p_T

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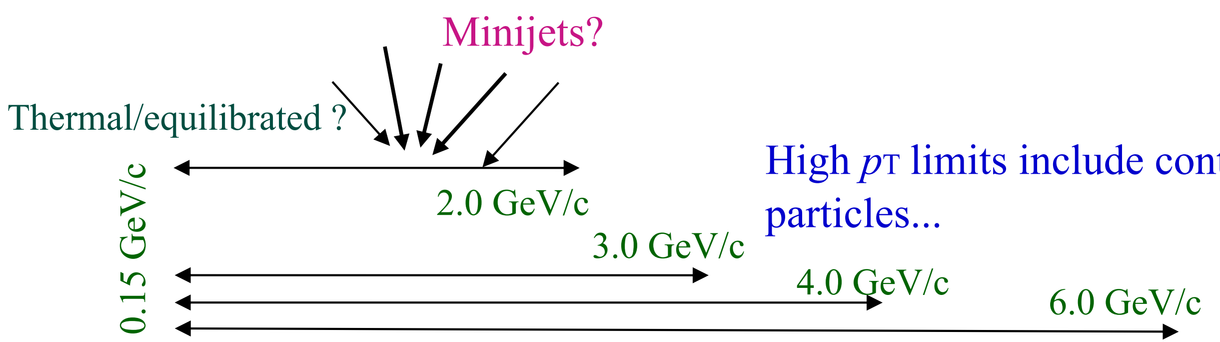
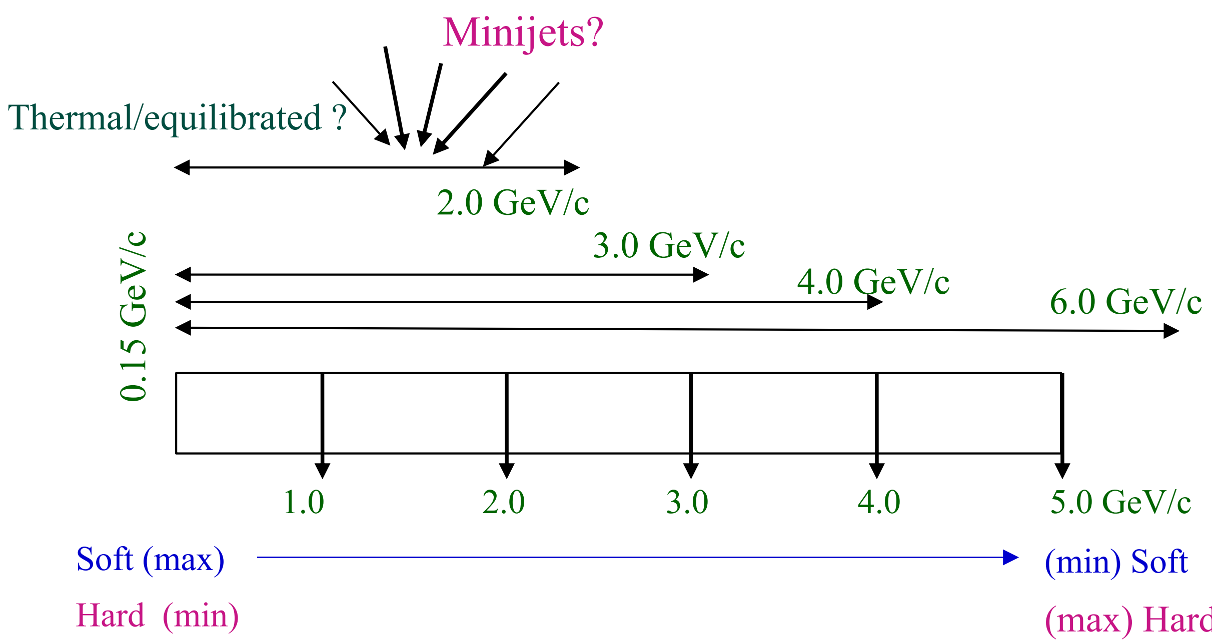


High p_T limits include contributions from hard particles...

Motivation towards higher p_T

A study of soft, intermediate and hard p_T would significantly impact on understanding the equilibrations and thermal (radial flow) - non thermal (jets/minijets) sources for p_T fluctuations.



PYTHIA - pQCD-inspired
- Hard interactions ?

EPOS - core + corona
- soft + hard interactions?

Motivation towards higher p_T

Charged particles in kinematical acceptance;

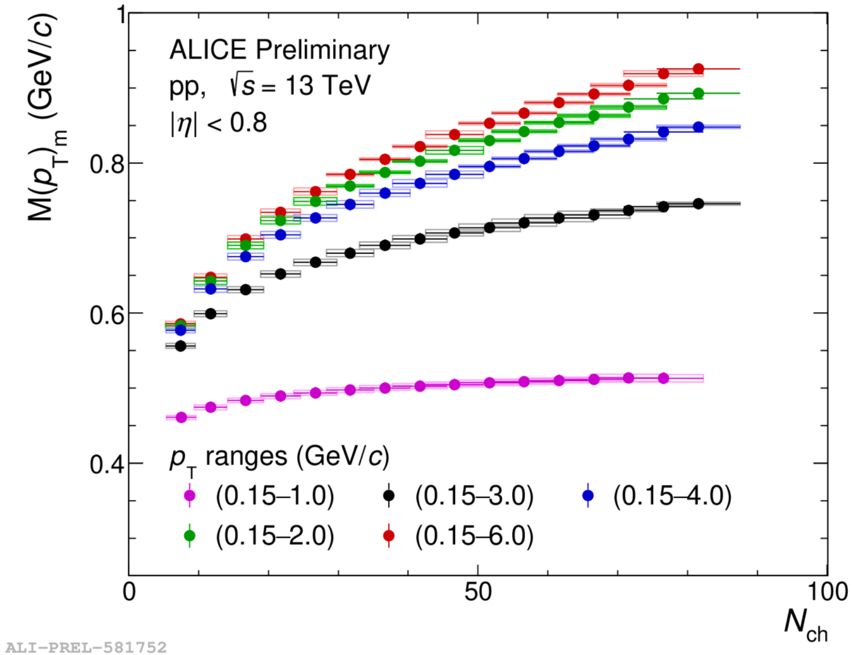
Psuedo-rapidity cut: $-0.8 \leq \eta \leq 0.8$
Transverse momentum acceptnaces:
as shown in the table

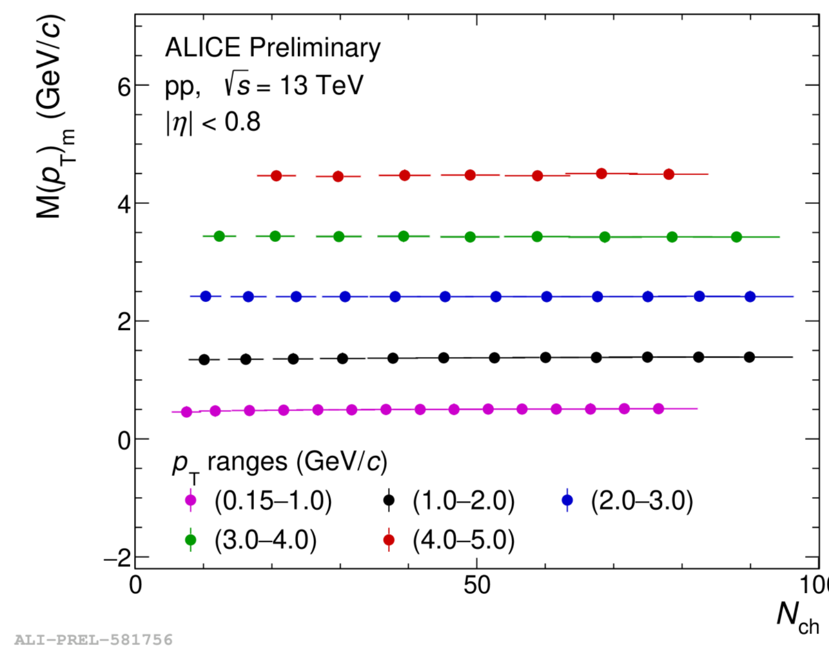
p_T ranges (GeV/c);	
Case 1	Case 2
[0.15, 1.0]	[0.15, 1.0]
[0.15, 2.0]	[1.0, 2.0]
[0.15, 3.0]	[2.0, 3.0]
[0.15, 4.0]	[3.0, 4.0]
[0.15, 6.0]	[4.0, 5.0]

Fixed δp_T

The range used in previous results, STAR/PHENIX/ALICE

Results: Dependence of M(p_T) on N_{ch}

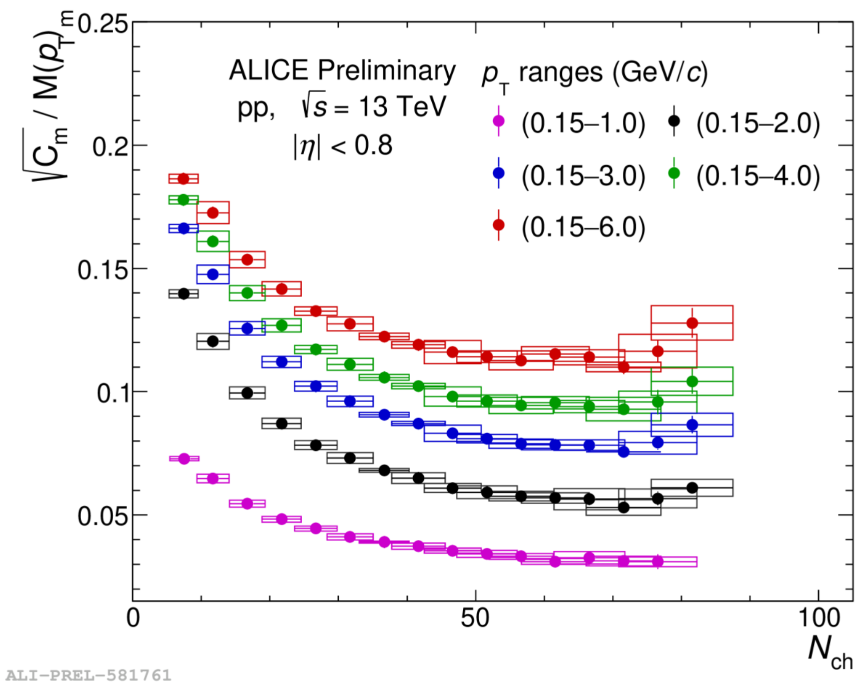




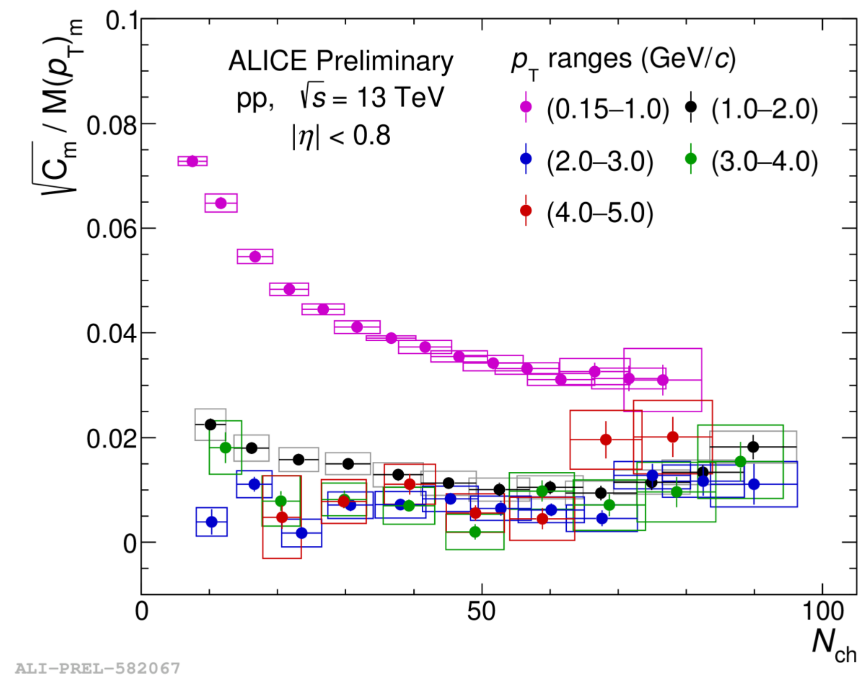
Case 1
[0.15, 0.15+Δp_T]

Case 2
Fixed δp_T

Results: Variations of $\sqrt{C_m}/M(p_T)_m$ with N_{ch}

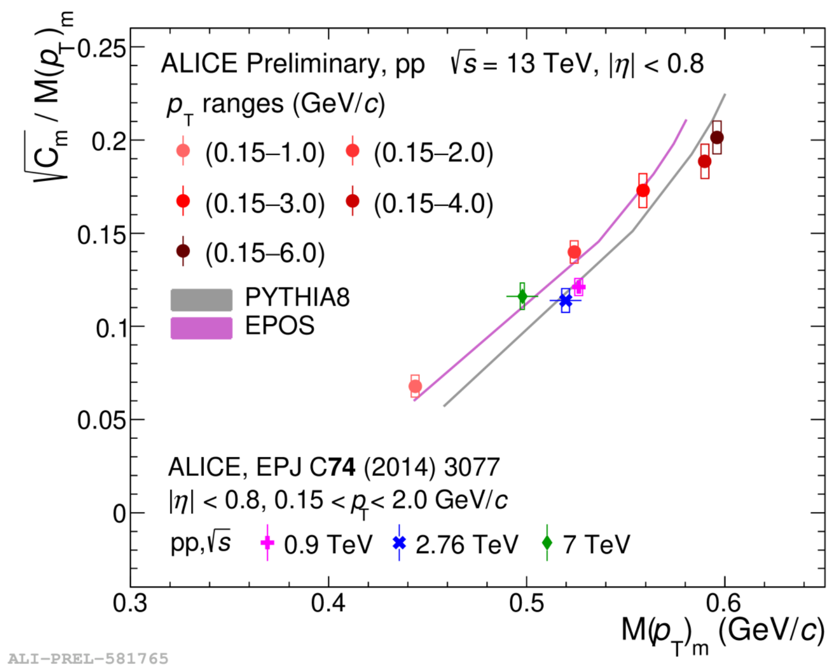


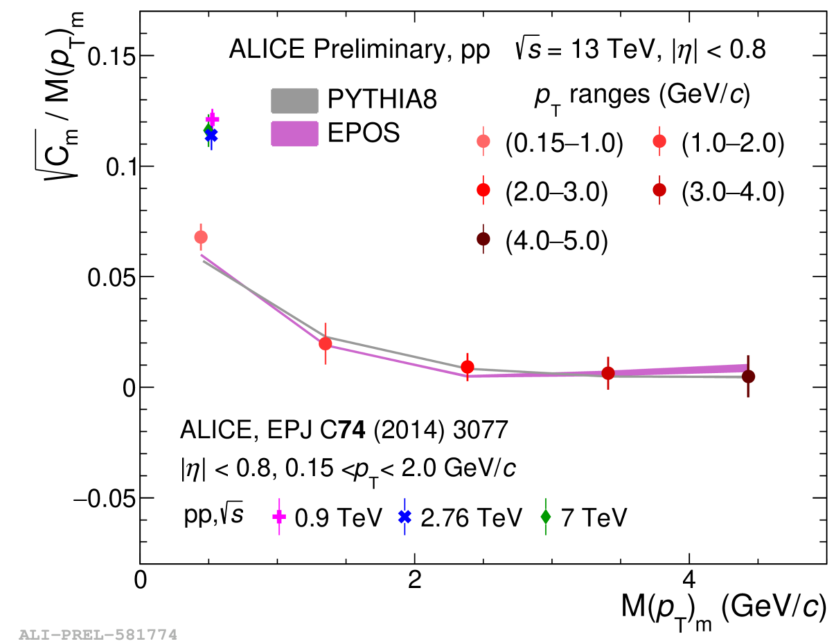
Case 1
[0.15, 0.15+Δp_T]



Case 2
Fixed δp_T

Results: Variations of $\sqrt{C_m}/M(p_T)_m$ with N_{ch}

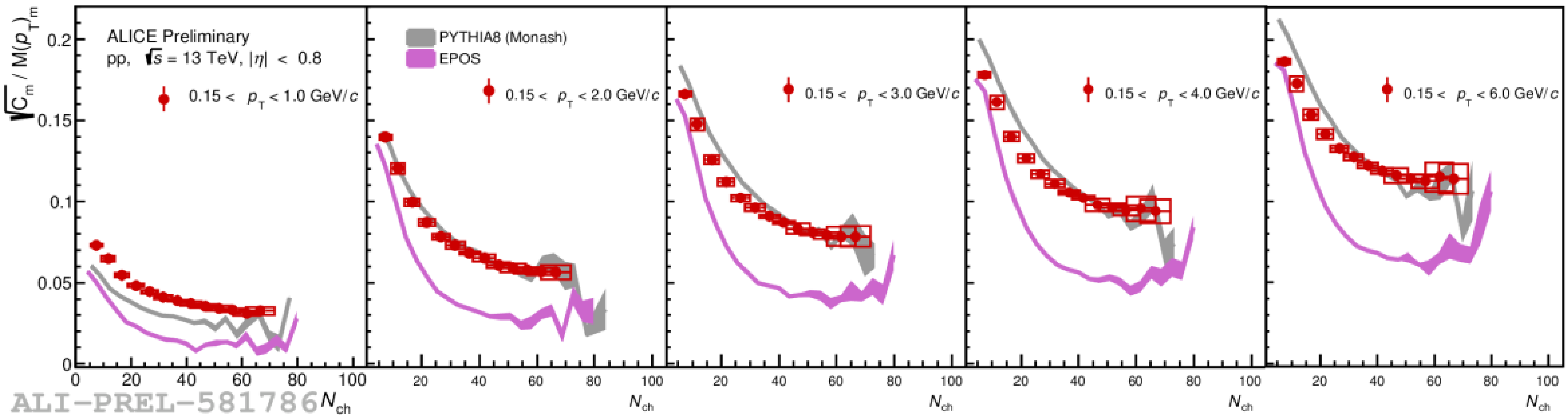




Case 1
[0.15, 0.15+Δp_T]

Case 2
Fixed δp_T

Results: PYTHIA and EPOS comparison

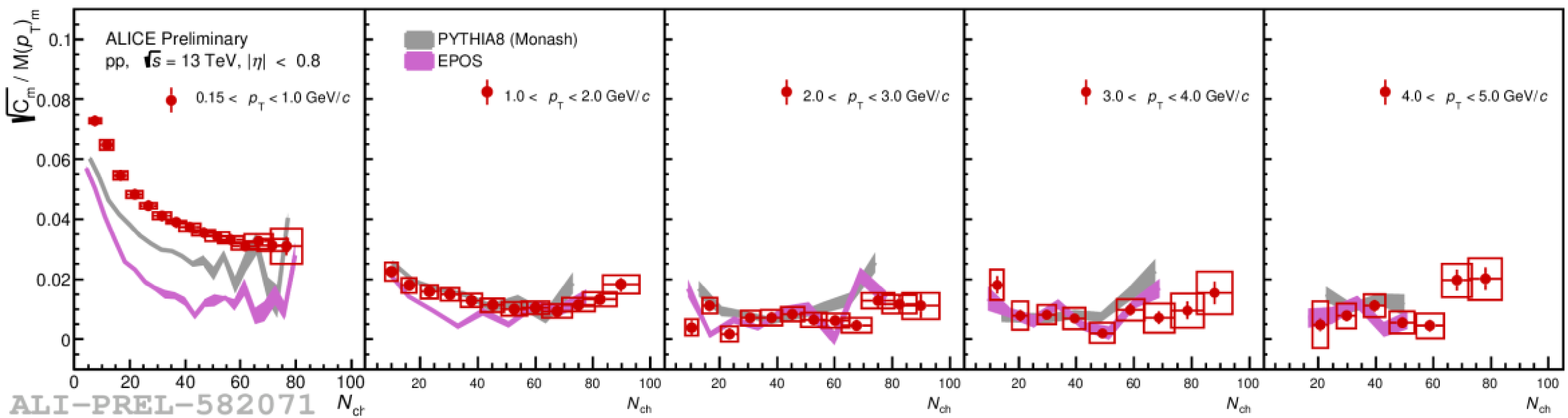


Case 1
[0.15, 1.0]
[0.15, 2.0]
[0.15, 3.0]
[0.15, 4.0]
[0.15, 6.0]

[0.15, 0.15+Δp_T]

- PYTHIA8 (Monash) and EPOS describe the data qualitatively.
- As the p_T window is increased, PYTHIA agrees qualitatively with the data.
- EPOS, with increasing p_T window, tends to show qualitative disagreement with data.

Results: PYTHIA and EPOS comparison

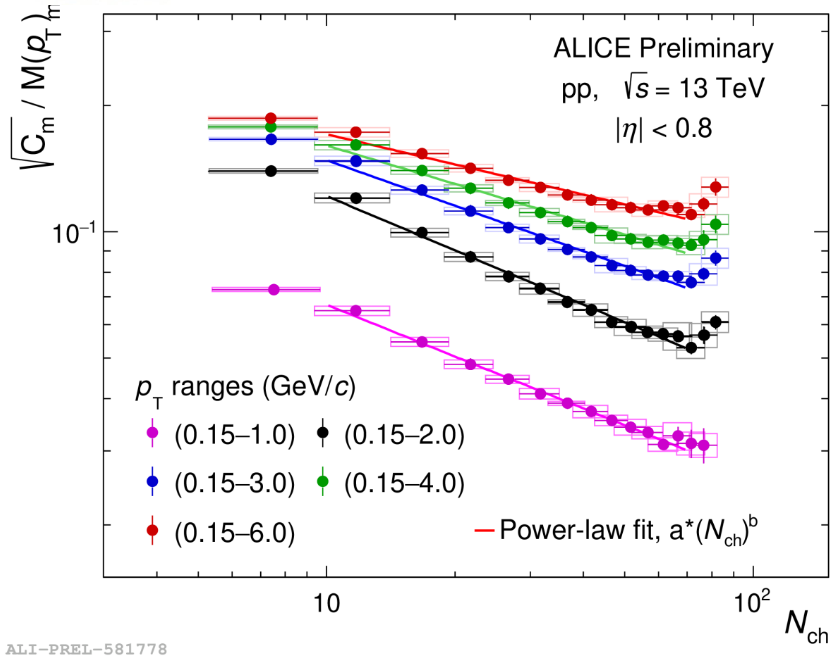


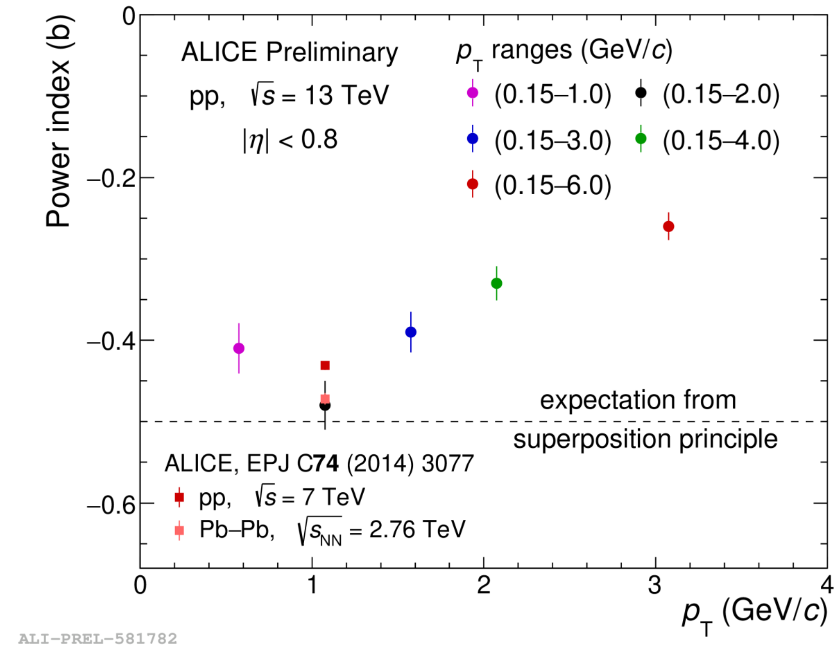
Case 2
[0.15, 1.0]
[1.0, 2.0]
[2.0, 3.0]
[3.0, 4.0]
[4.0, 5.0]

Fixed δp_T

- Statistically challenging to draw conclusion.
- With high p_T acceptance, better agreement between the data and models.

Results: Comparison with superposition principle





- Power-law fit of the form $a*(N_{ch})^b$ is performed.
- Increasing the p_T window, the system tends to depart from the superposition scenario.
  - For pp at $\sqrt{s}$ =13 TeV (with HM triggered events), b = −0.404 ± 0.001 (stat.)
  - ALICE Published values from *Eur. Phys. J. C 74 (2014) 3077*

Summary

- Mean p_T correlation strength (~ 1/number of sources) for pp collision at $\sqrt{s}$ = 13 TeV for both minimum bias and high-multiplicity triggered events are presented, which decreased with increasing multiplicity.

- For a given N_{ch}, correlator values increase when the p_T acceptance window is widened but decrease when p_T window is placed in high p_T limits.

- PYTHIA (pQCD-inspired) describes the data more accurately, *suggesting hard processes are the dominant sources for mean p_T fluctuations.*

- For a wider range of p_T windows (0.15 ↔ 0.15+Δp_T), the variations of b (power index parameter) show that the system moves farther away from expectation from superposition principle (independent sources).

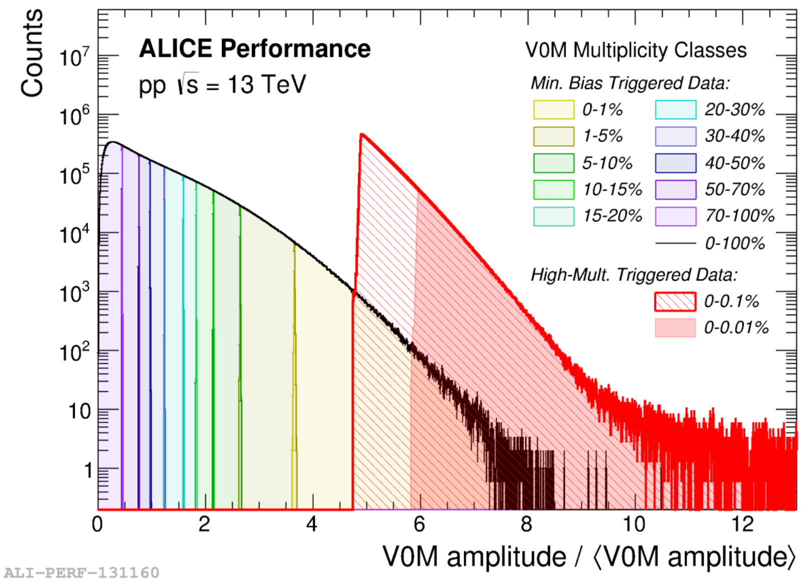
- To further understand the factors affecting correlation strength, future investigations could compare the correlator across various systems (pp, p–Pb, Xe–Xe, and Pb–Pb) at matched multiplicities, helping to discern the roles of mean p_T and multiplicity

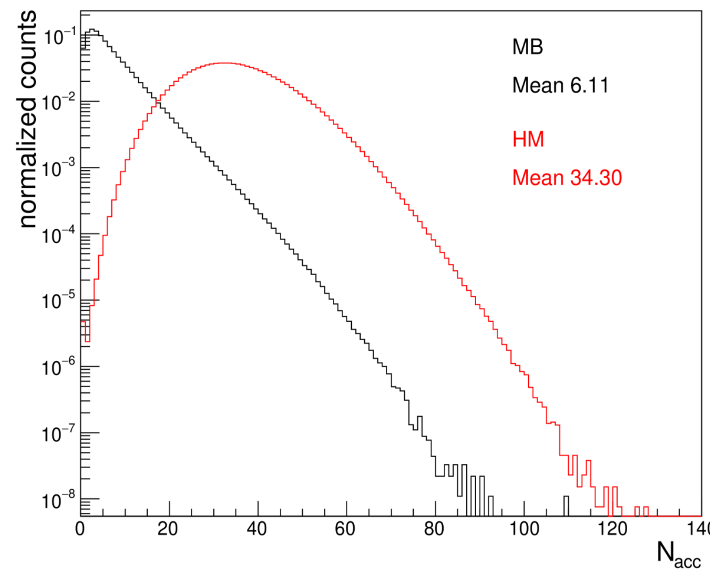
Thank you

Back Ups...

The High-multiplicity trigger

Trigger is a bais introduced during data collection.

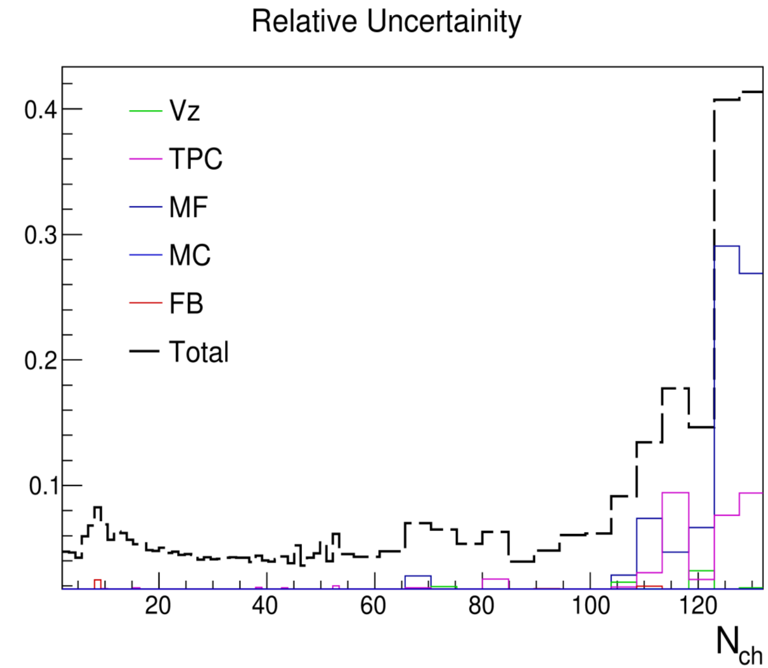




- The **kHighMultV0** trigger is based on the average V0 amplitude ➛ tuned such that only 0.1% central minimum bias events are recorded.
- *Why do we need it?* → to enhance high multiplicity region.

Systematic uncertainties

Variable	Default	Var1	Var2
VertexZ	10	8	[-10, 0], [0,10]
MF polarity	Both	++	--
TPC Crossed Rows	70	80	100
FB	96	768	32
MC non-closure			



- Total systematic error is calculated by adding the ;
  - quadratic sum of errors from TPC crossed rows and filter bits.
  - Direct sum of errors from vertex variations, MF polarity and MC non-closure.