Exploring Event-by-Event p_T Fluctuations in pp Collisions at $\sqrt{s}$=13 TeV: Insights from 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*

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

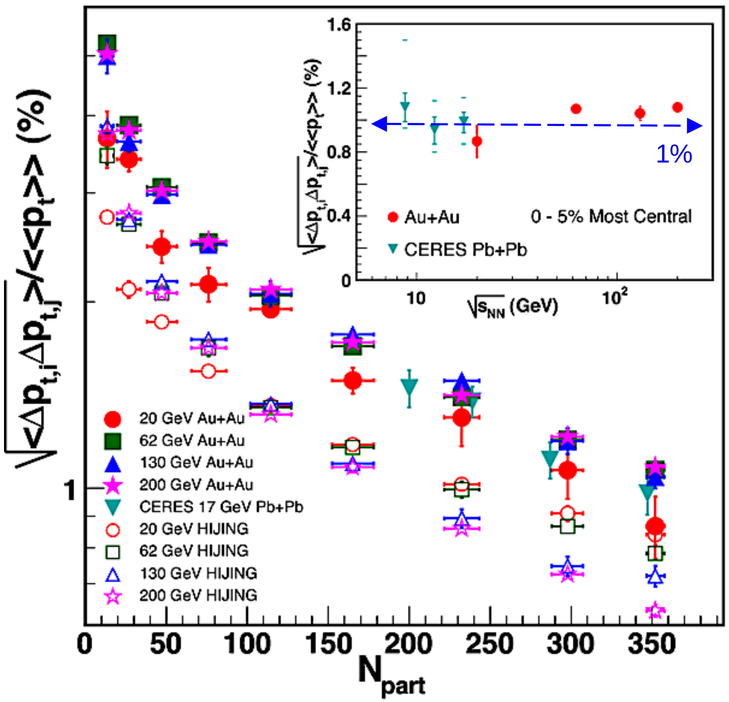
- The p_T correlations can be formulated in terms of the fluctuations in the effective temperature as

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

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

STAR Collaboration, 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
(centrality and collision energy dependences)



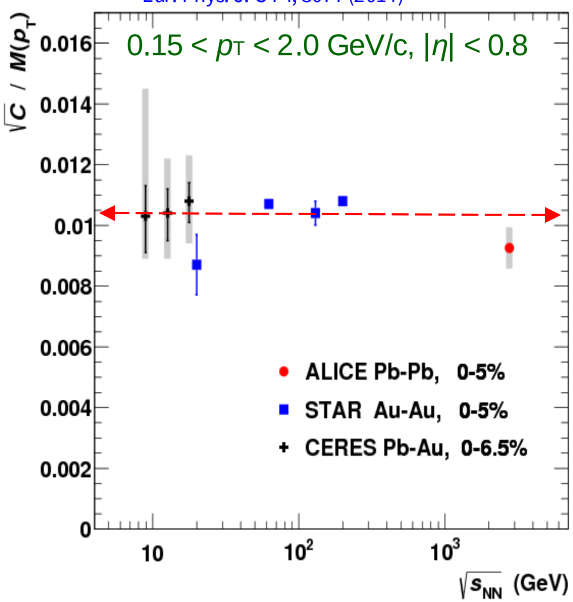
- Significant dynamical mean p_T fluctuations are observed in heavy-ion collisions.

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

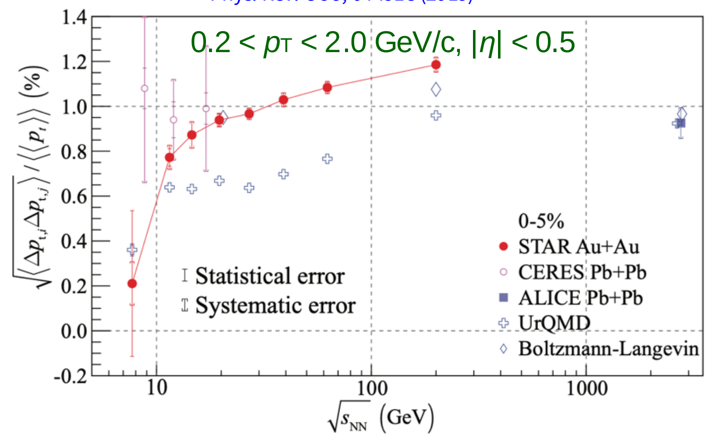
Kinematic acceptance:
$0.15 < p_T < 2.0$ GeV/c, $|\eta| < 1.0$

Mean p_T fluctuations
(System size and collision energy dependences)

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



Phys. Rev. C 99, 044918 (2019)



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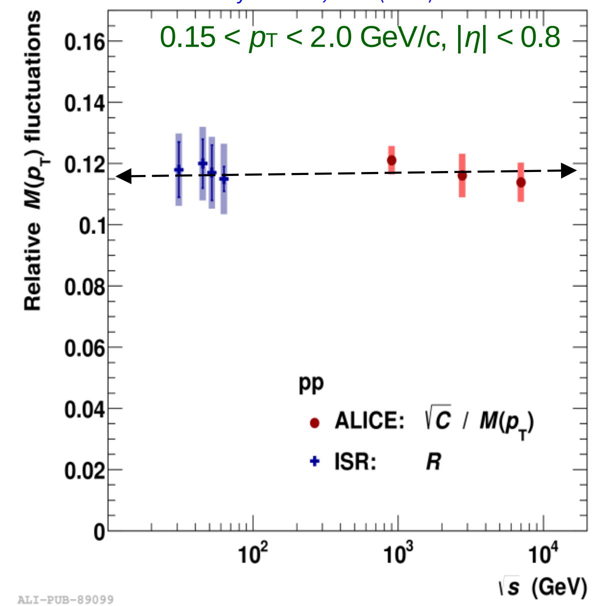
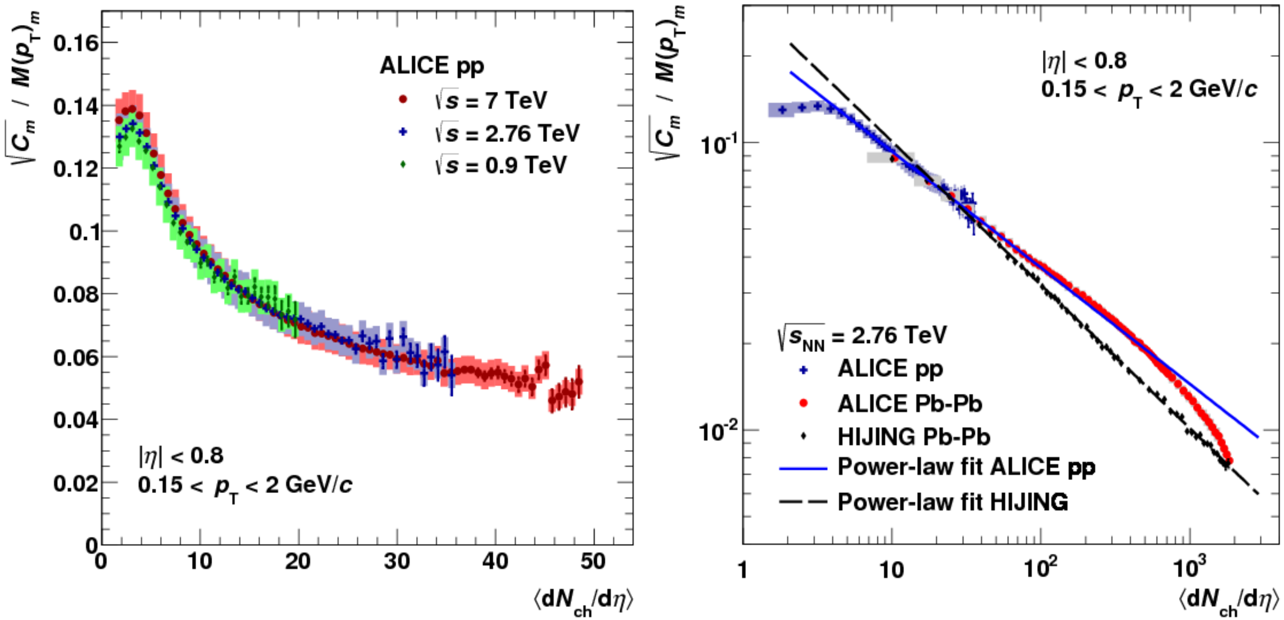


- In heavy-ion collisions, the mean p_T fluctuation strength is observed to be ~ 1%
- In pp collisions, the strength is ~ 11%

Mean p_T fluctuations

(as a function of multiplicity)



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;
- **Motivation (I): to look at high-multiplicity pp events.**

C_m : The two-particle p_T correlator

ALICE

The two-particle correlator *C* measures the dynamic component of mean transverse momentum fluctuations. In a multiplicity class *m*, the correlator is expressed as:

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

Mean p_T of the sample:

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

Terminology:

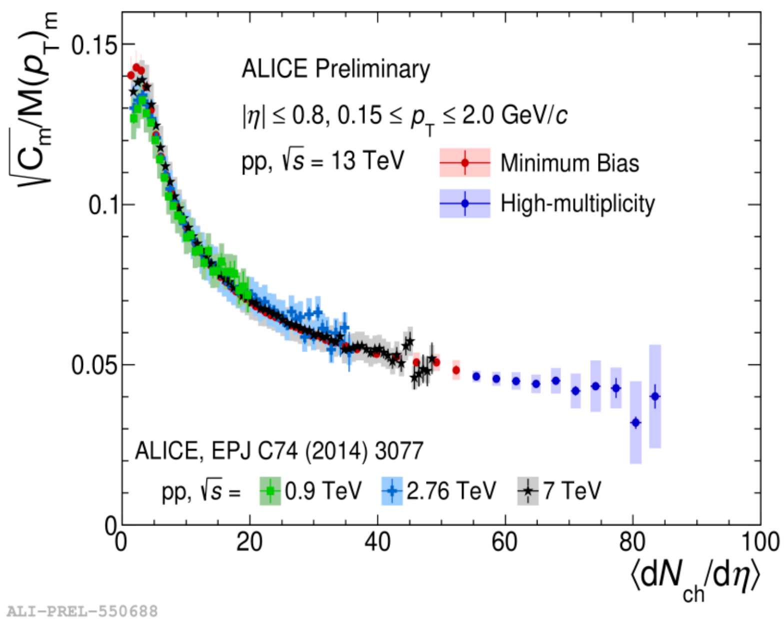
ALICE		STAR
$\sqrt{C_m}/M(p_T)_m$	$\approx$	$\sqrt{\langle \Delta p_{T,i} \Delta p_{T,j} \rangle} / \langle\langle p_T \rangle\rangle$

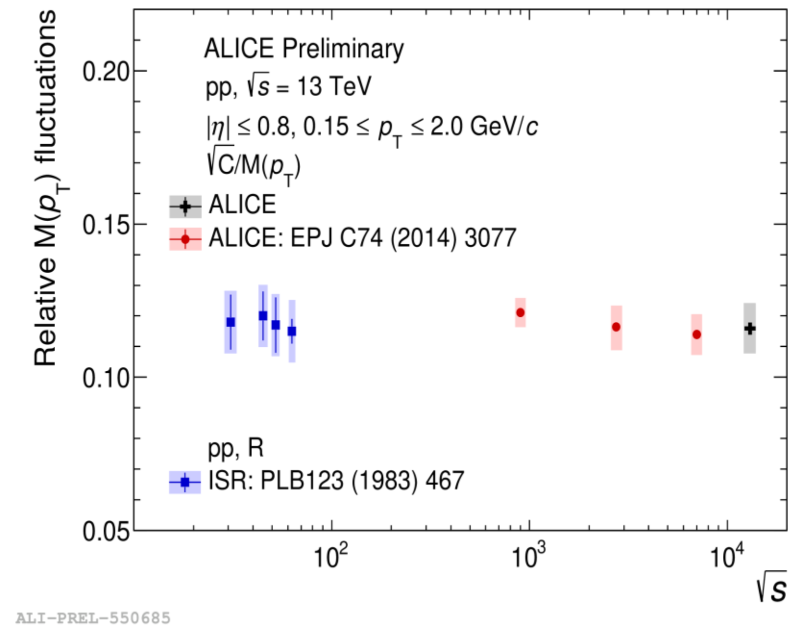
Equivalent to *R*

Relative fluctuation measure used at ISR energies

C_m : high multiplicity pp events at 13 TeV (LHC)

Comparison with lower energy datasets

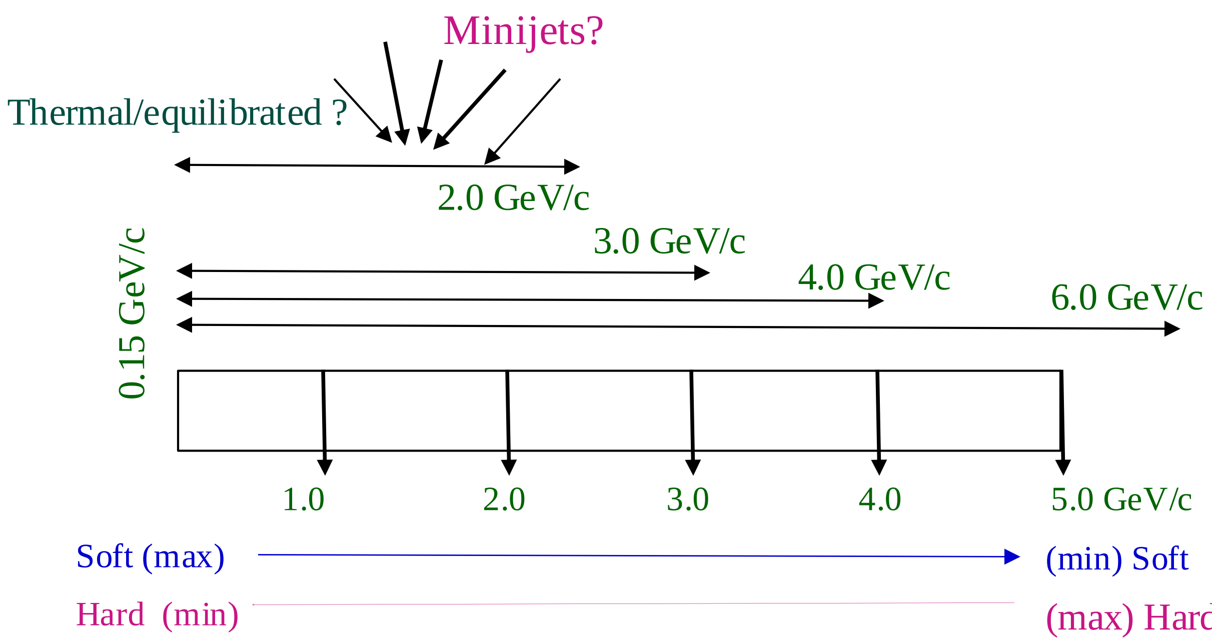




- *No significant energy dependence*
- *The relative fluctuation strength ~ 11%*

C_m : The two-particle p_T correlator at 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.

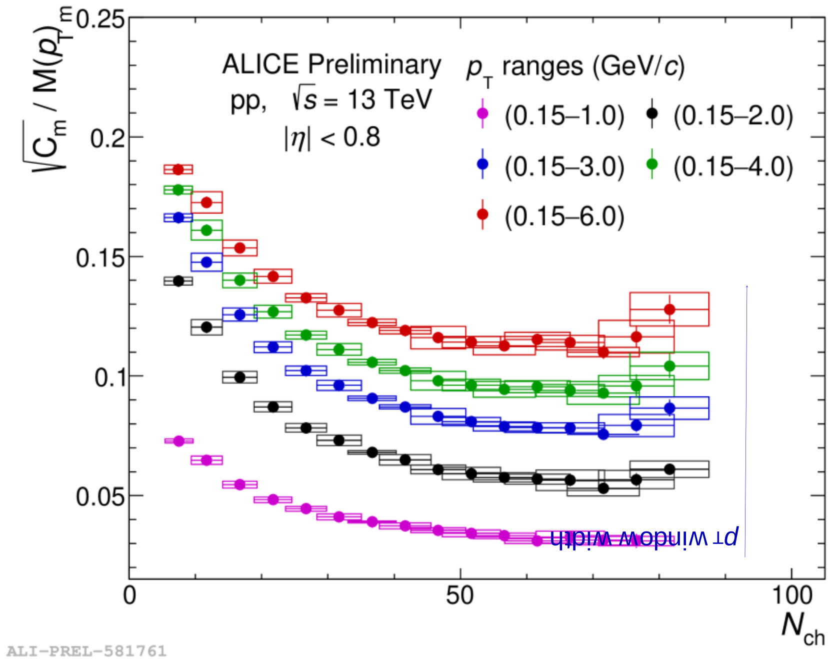


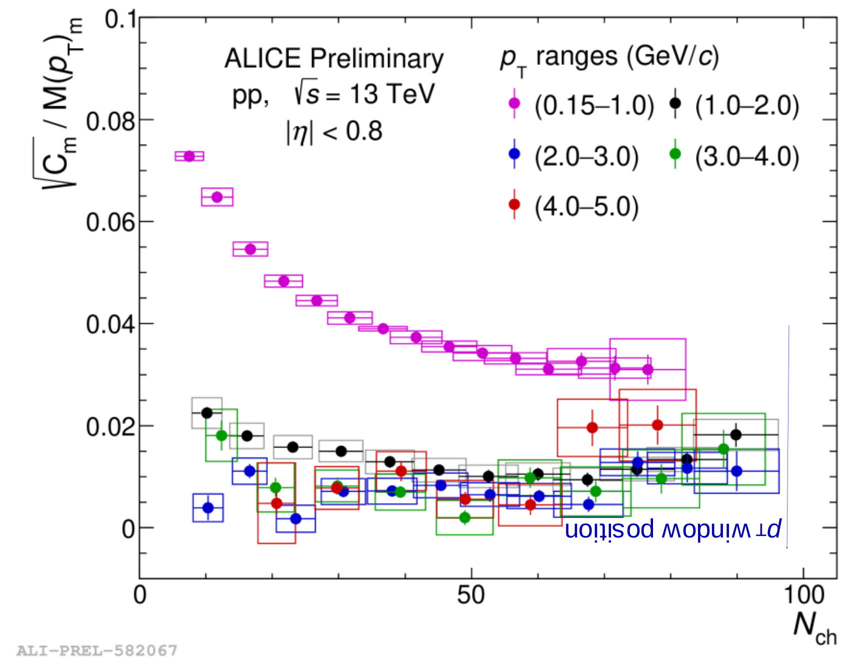
PYTHIA - pQCD-inspired
- Hard interactions?

EPOS - core + corona
- soft + hard interactions?

Correlator for higher p_T (and p_T windows)

(as a function of multiplicity)





Case 1

[0.15, 0.15+Δp_T]

Increase in correlation by including higher p_T particles

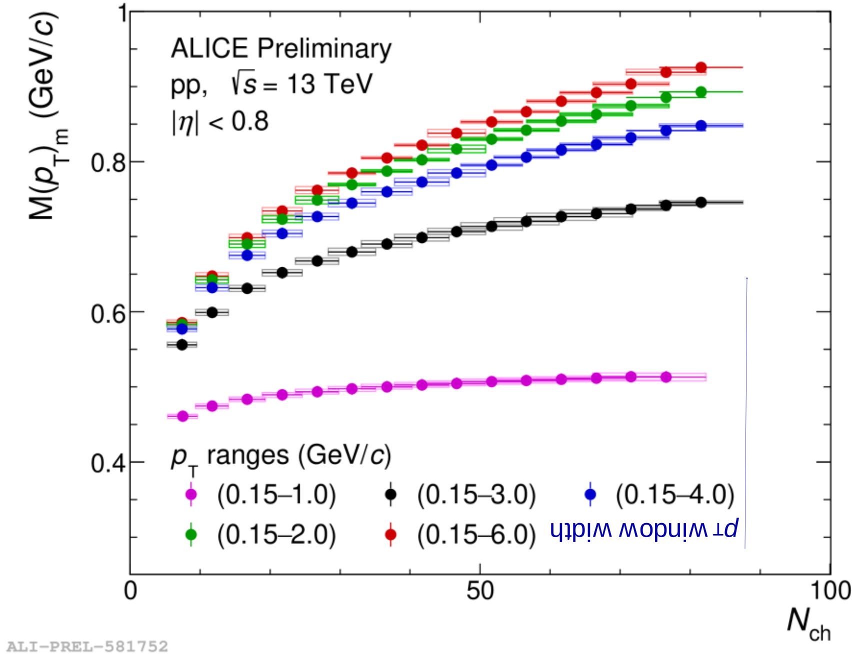
Case 2

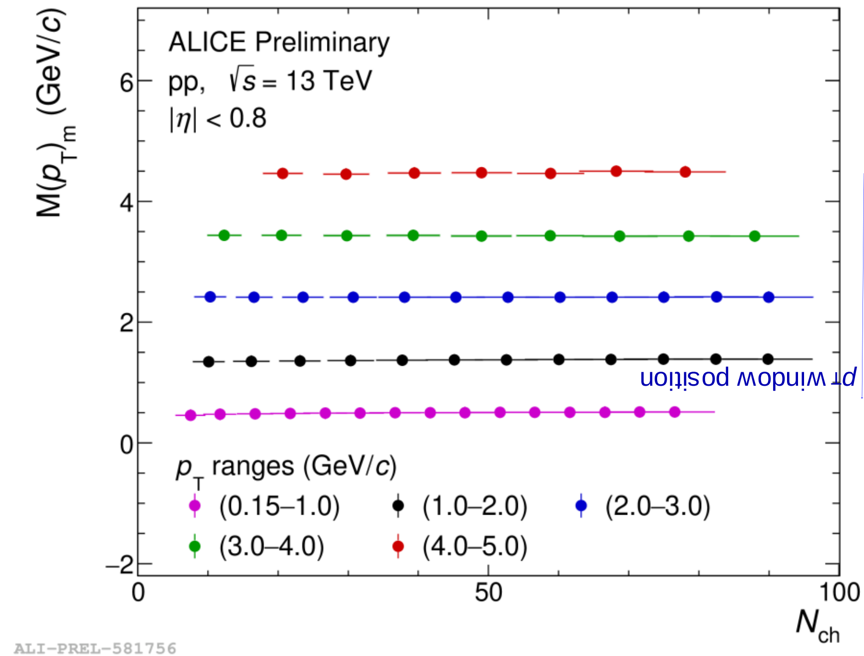
Fixed δp_T

- **Effect of minijets show up in larger p_T windows**

Mean p_T

(as a function of multiplicity)

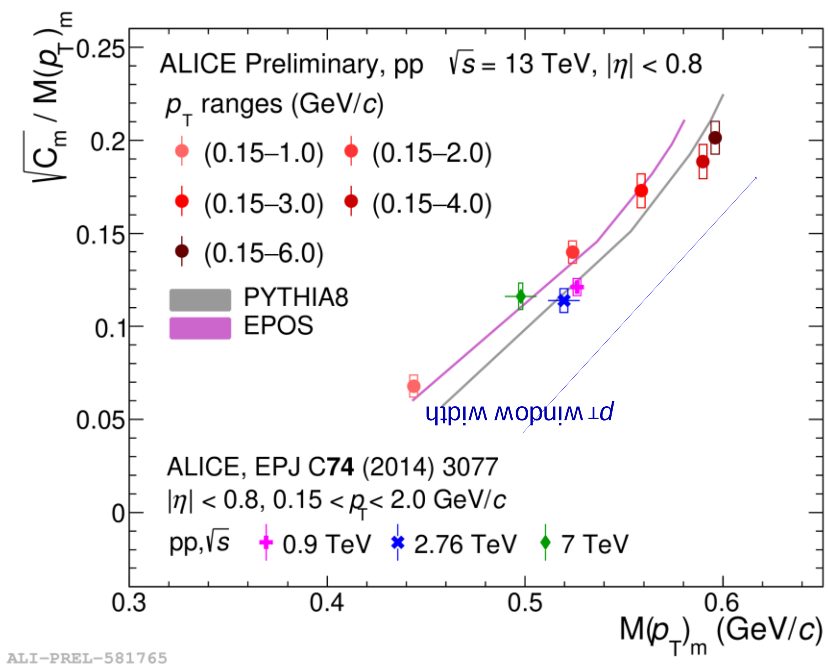


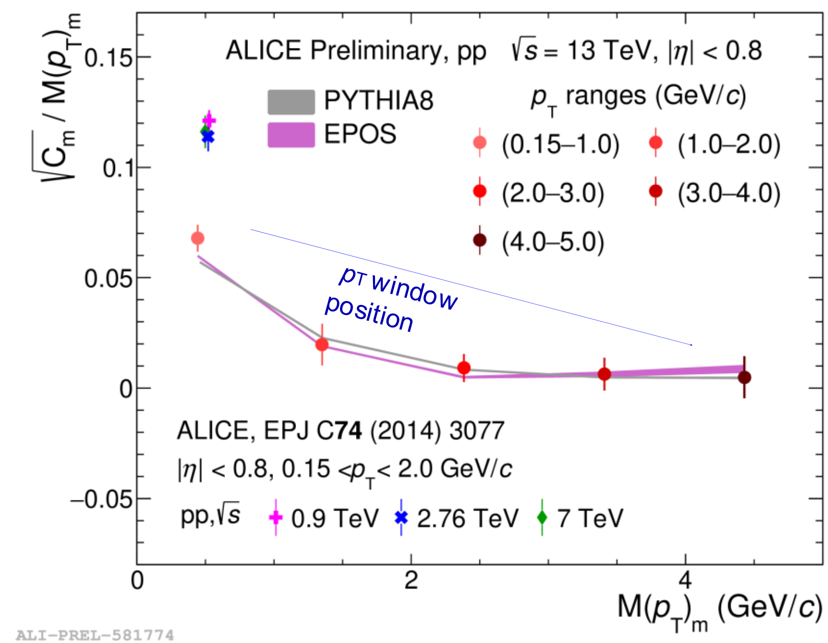


Case 1
$[0.15, 0.15+\Delta p_T]$

Case 2
Fixed δp_T

Correlator with respect to mean p_T





Case 1

[0.15, 0.15+Δp_T]

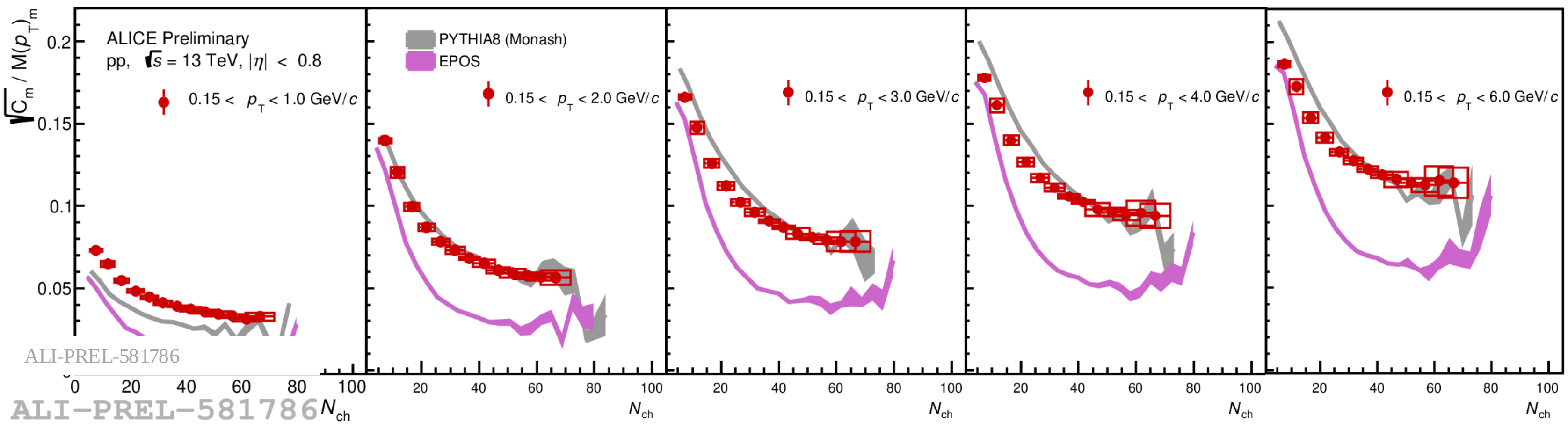
Increase in correlation with increase in mean p_T

Case 2

Fixed δp_T

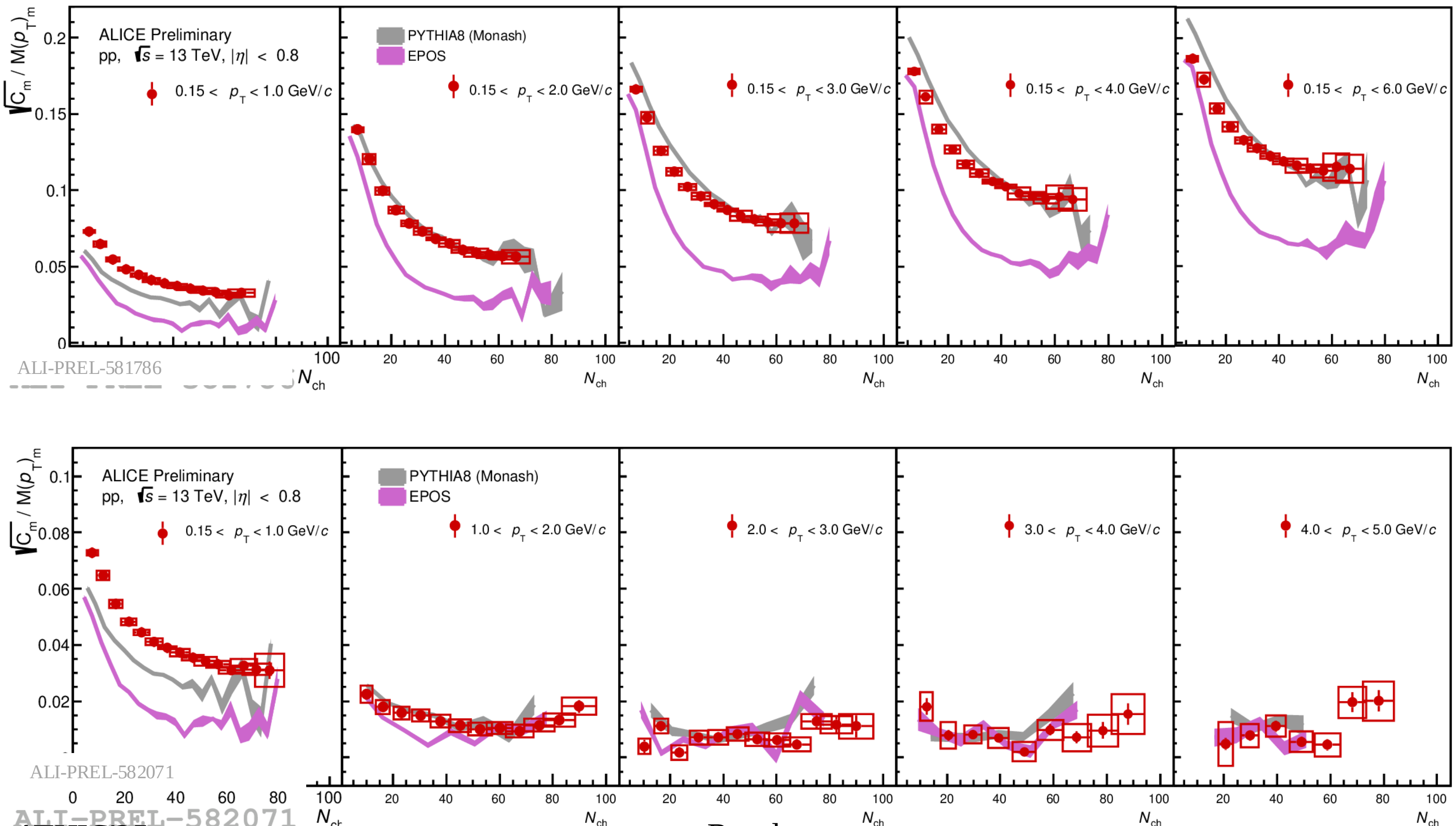
- **Correlation goes down with increase of p_T**

Correlator for higher p_T windows:
PYTHIA and EPOS comparison



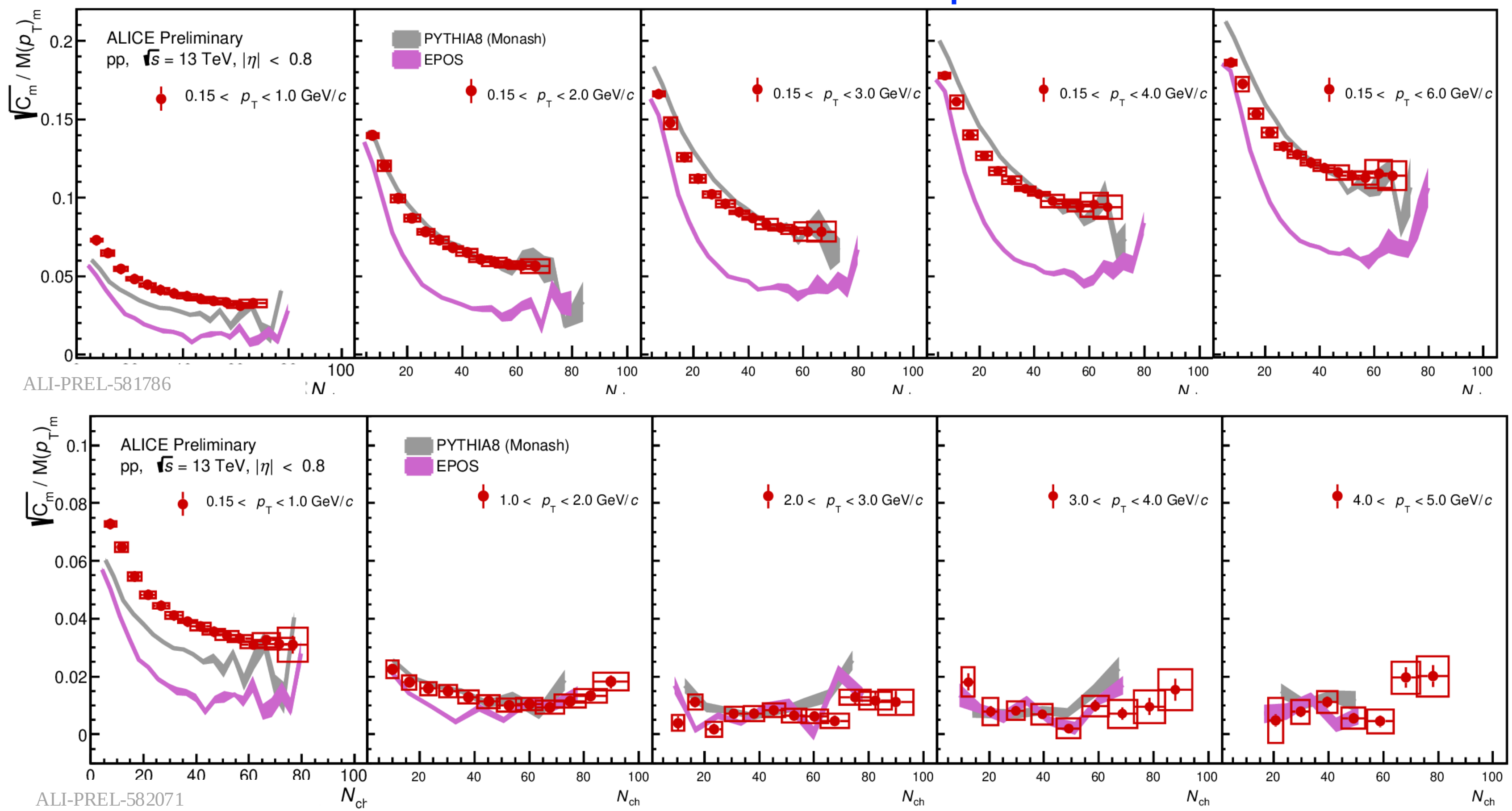
- PYTHIA8 (Monash) and EPOS describe the data qualitatively.
- As the p_T window increases:
    - PYTHIA agrees qualitatively with the data.
    - EPOS show qualitative disagreement with data.

Correlator for higher p_T windows:
PYTHIA and EPOS comparison



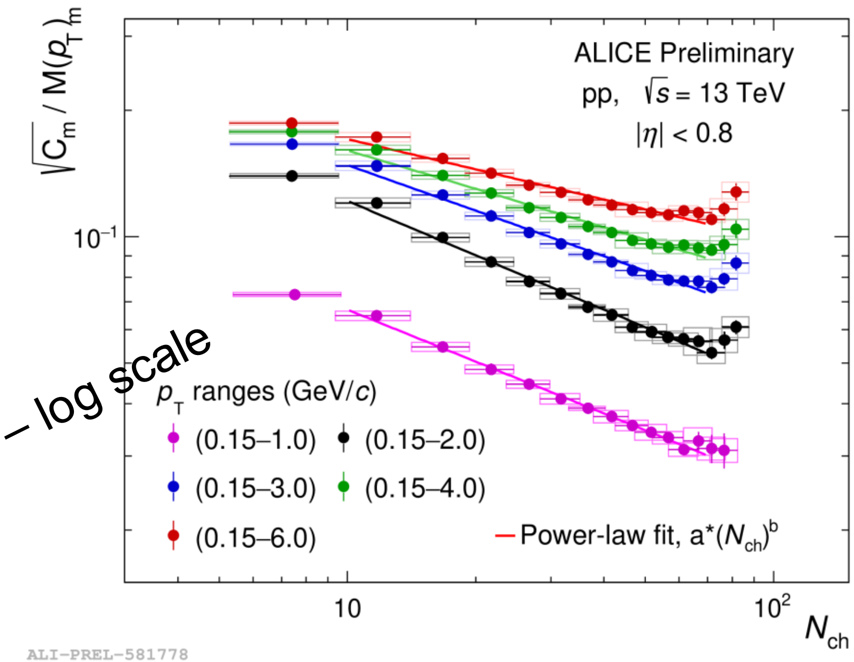
Correlator for higher p_T windows:

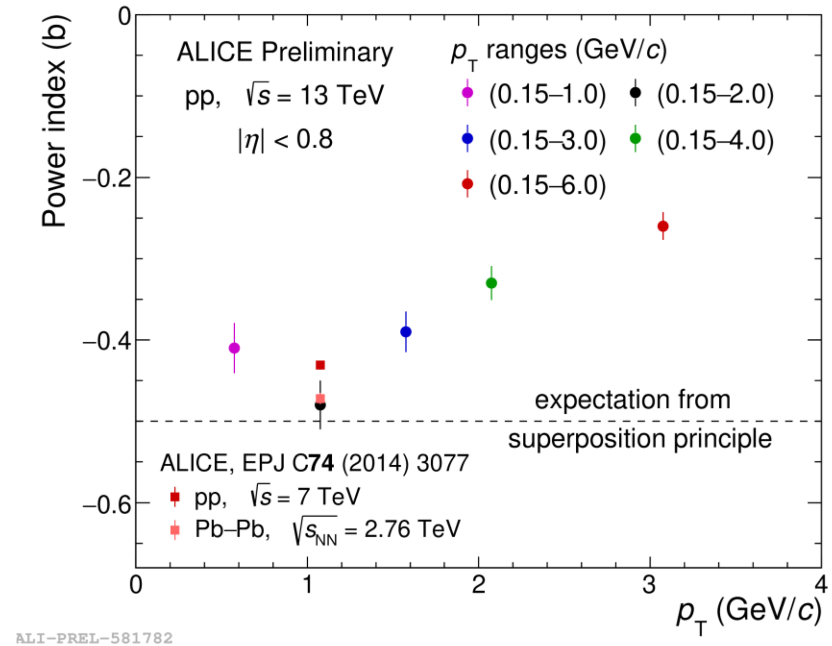
PYTHIA and EPOS comparison



→ In high p_T acceptance, better agreement between the data and models.

Comparison with superposition principle





b = -0.5: Poission, no correlation, superposition

- 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), $b = -0.404 \pm 0.001$ (stat.)

Summary and outlook

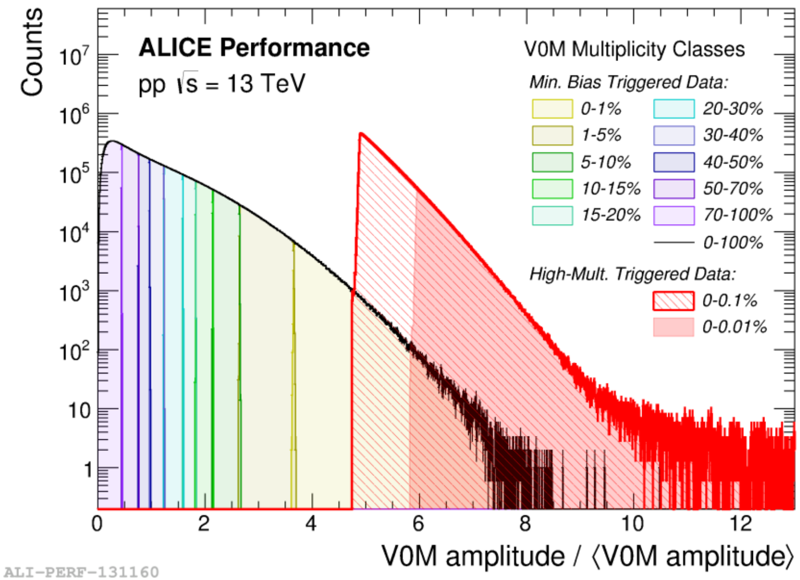
- Mean p_T correlation strength for pp collisions at $\sqrt{s}$ = 13 TeV: for both minimum bias and high-multiplicity triggered events show **decrease in correlation with increasing multiplicity.**
- For a given N_{ch}, **correlator increases with widening of the p_T acceptance window but decreases when p_T window is within high p_T limits**.
- PYTHIA (pQCD-inspired) describes the data quantitatively, ***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 the superposition principle** (independent sources).
- **Outlook**: 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 common multiplicity ranges, helping to **discern the roles of mean p_T and multiplicity**.

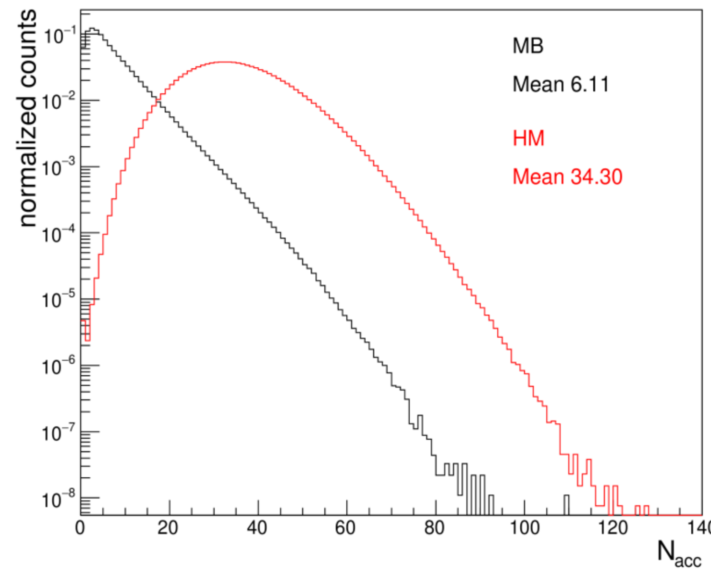
Thank you for your attention

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.