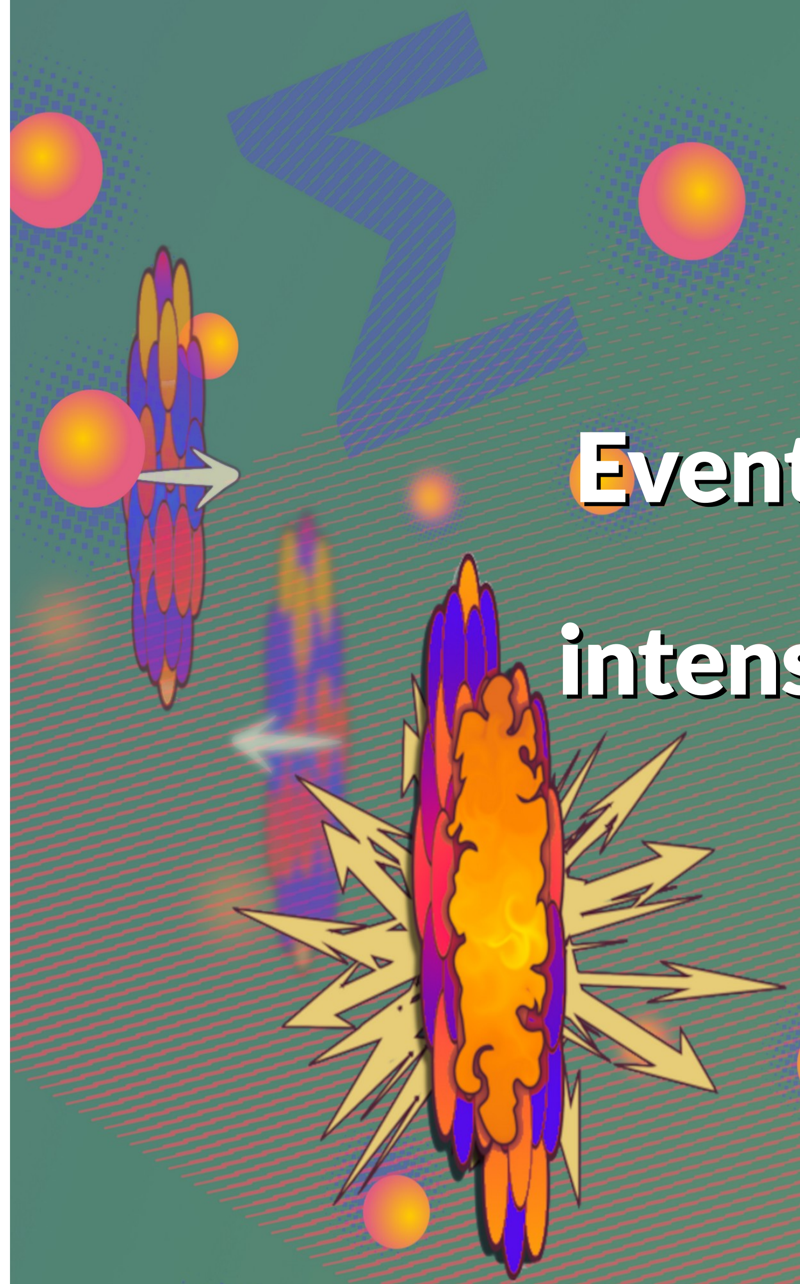
Seminarium HEP Białasówka
AGH, 4 November, 2022



Event-by-Event correlations and fluctuations with strongly intensive quantities in heavy-ion collisions with ALICE

IWONA SPUTOWSKA

Institute of Nuclear Physics
Polish Academy of Sciences

Outline

Overview of the ALICE measurement of the **strongly intensive quantity Σ** in terms of forward-backward correlations analysis...

...in various colliding systems and energies.

Plan:

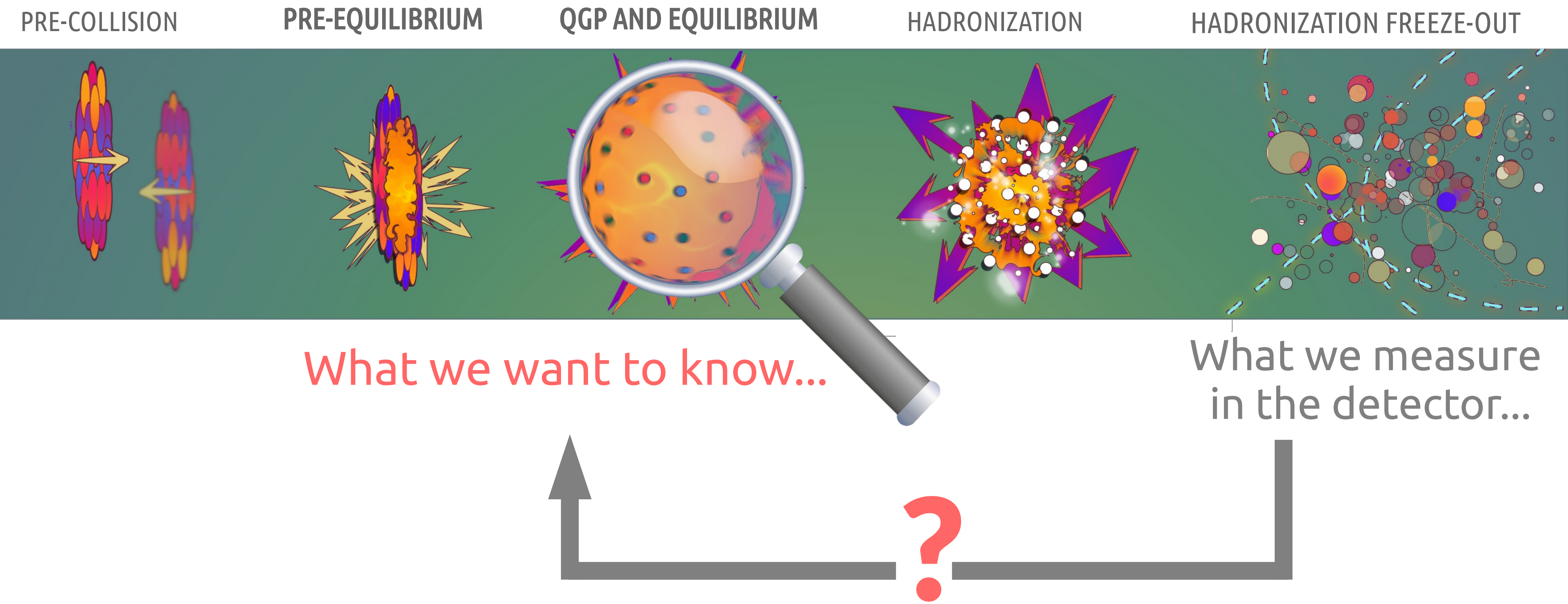
1. Motivation;

2. Analysis;

3. Results;

4. Summary.

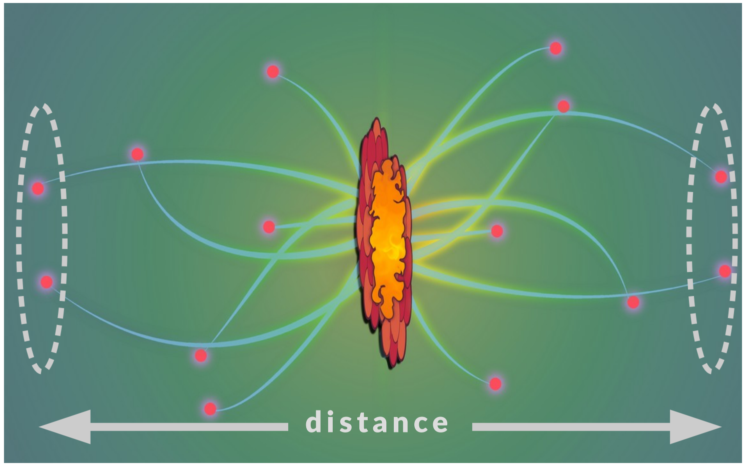
Motivation: Why do we study correlations and fluctuations?



Analysis of correlations and fluctuations can provide information about **the early stages of heavy-ion collisions.**

Motivation: Why do we study correlations and fluctuations?

1. Study of **Long-Range Correlations** (LRC):

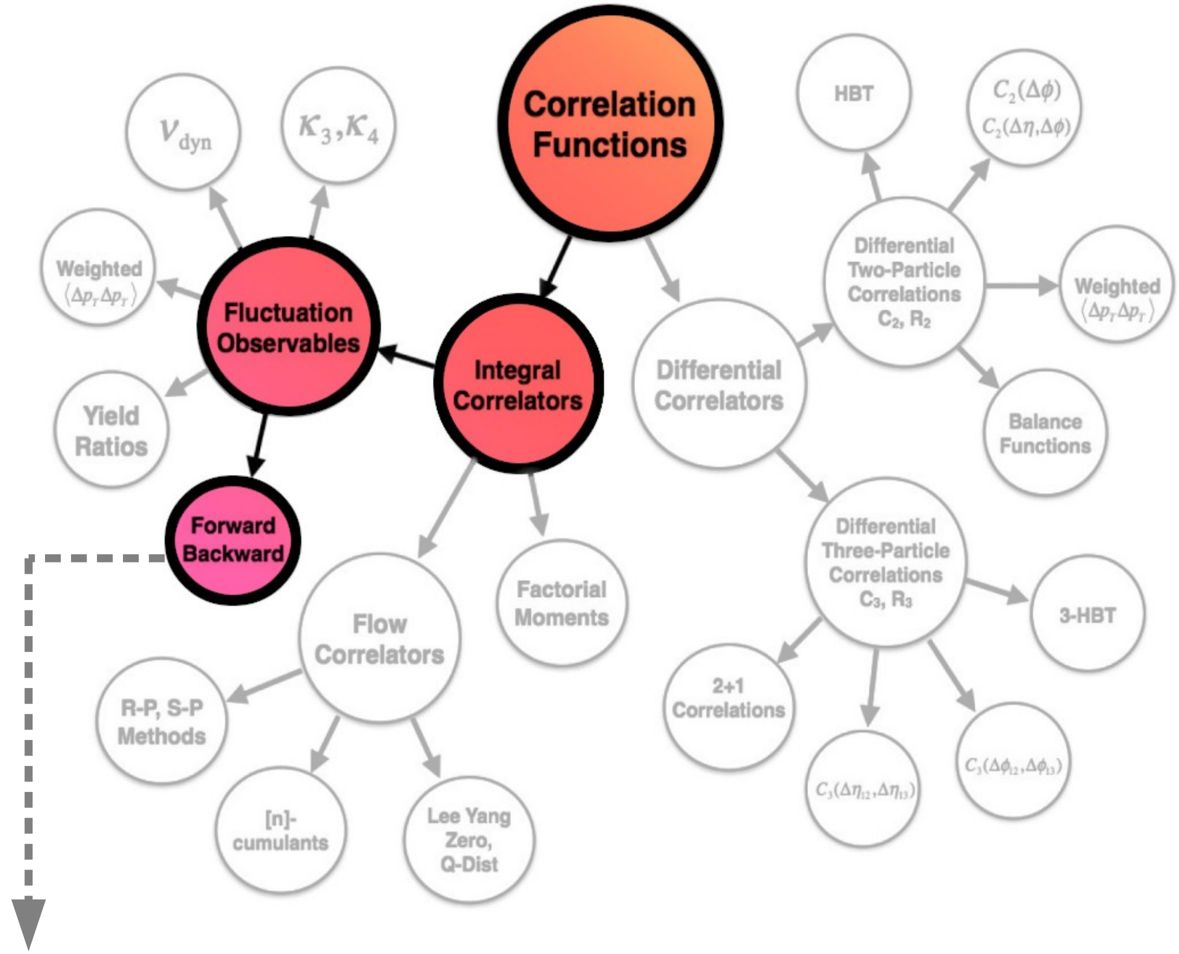


- LRC carry **information** on the **early dynamics** of the nuclear collision.

2. Analysis of **fluctuations** in the number of particles produced in A–A collisions:

   - A good way to check dynamical models of particle production.
   - Gives a chance to study observables sensitive to the early dynamics of the collision, independent of trivial fluctuations of the volume of the system.

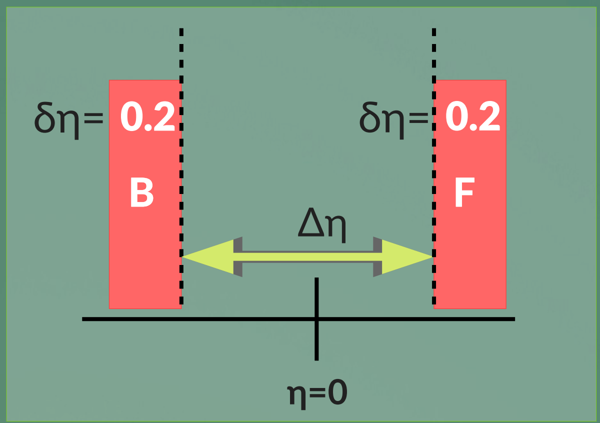
The Analysis: How do we study correlations and fluctuations?



We are here!

Picture from: Claude A. Pruneau, Data Analysis Techniques for Physical Scientists, 2017, Cambridge University Press.

The forward-backward (FB) correlation:



A popular technique:

The FB **correlation coefficient b_{corr}** is:

$$b_{corr} = \frac{\mathrm{Cov}(n_F, n_B)}{\sqrt{\mathrm{Var}(n_F)\,\mathrm{Var}(n_B)}}$$

- largely influenced by **geometrical (volume) fluctuations.**
- dependent on **centrality estimator.**

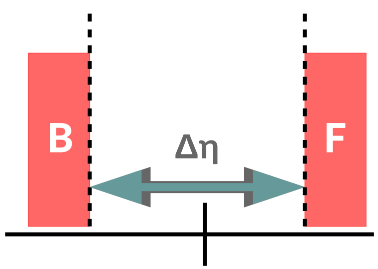
The Analysis: FB correlations with strongly intensive quantity Σ

- **Strongly intensive quantities** do not depend on system volume nor system volume fluctuations.

Gaździcki, Gorenstein, Phys.Rev. C84 (2011) 014904

STRONGLY INTENSIVE QUANTITY Σ:

$$\Sigma = \frac{\langle n_F \rangle \omega_B + \langle n_B \rangle \omega_F - 2Cov(n_F, n_B)}{\langle n_F \rangle + \langle n_B \rangle}$$



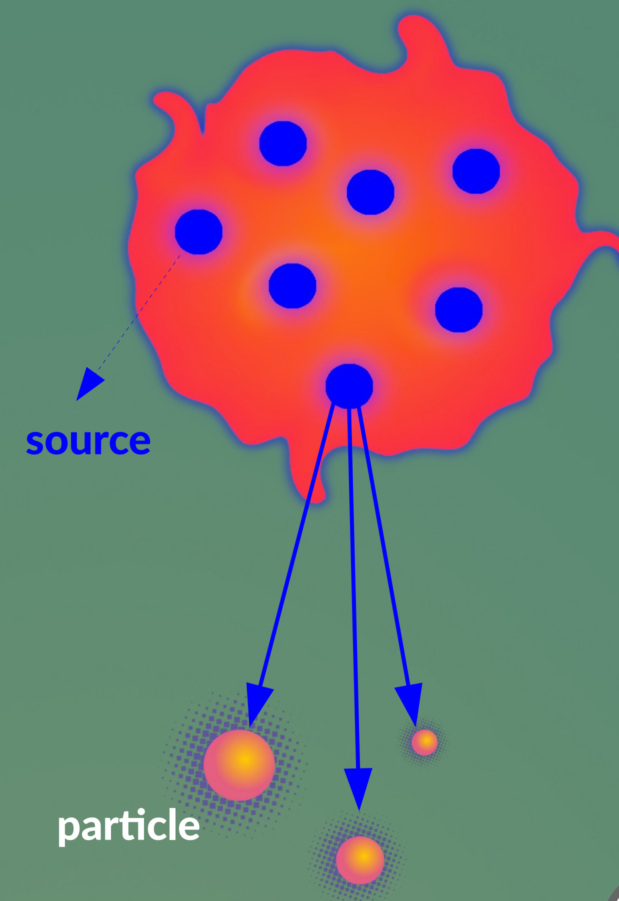
- For a symmetric collision $\omega_B = \omega_F$ and $\langle n_F \rangle = \langle n_B \rangle$,

$$\Sigma \approx \omega(1 - b_{corr}).$$

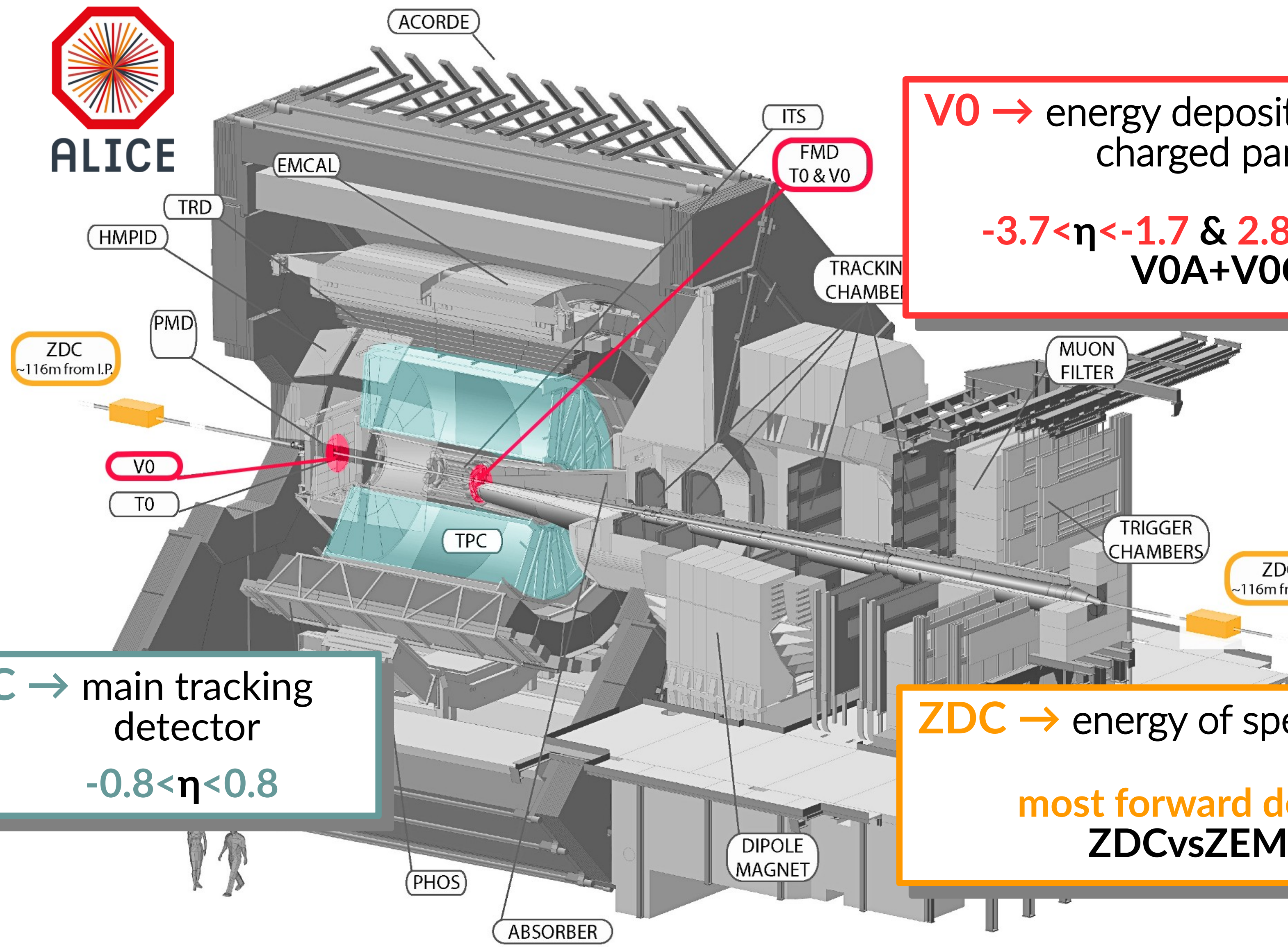
For Poisson distribution: $\omega=1$ & $b_{corr}=0 \rightarrow \Sigma=1$

Independent source model:

Σ → gives direct information about characteristics of **single source distribution!**



The Analysis: ALICE experiment



V0 → energy deposition by charged particles

-3.7<η<-1.7 & 2.8<η<5.1

V0A+V0C

TPC → main tracking detector

-0.8<η<0.8

ZDC → energy of spectators

most forward detector

ZDCvsZEM

The Analysis: Data Sample

Experimental data:

→ **Pb−Pb @ $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV**

→ **Xe−Xe @ $\sqrt{s_{NN}}$ = 5.44 TeV**

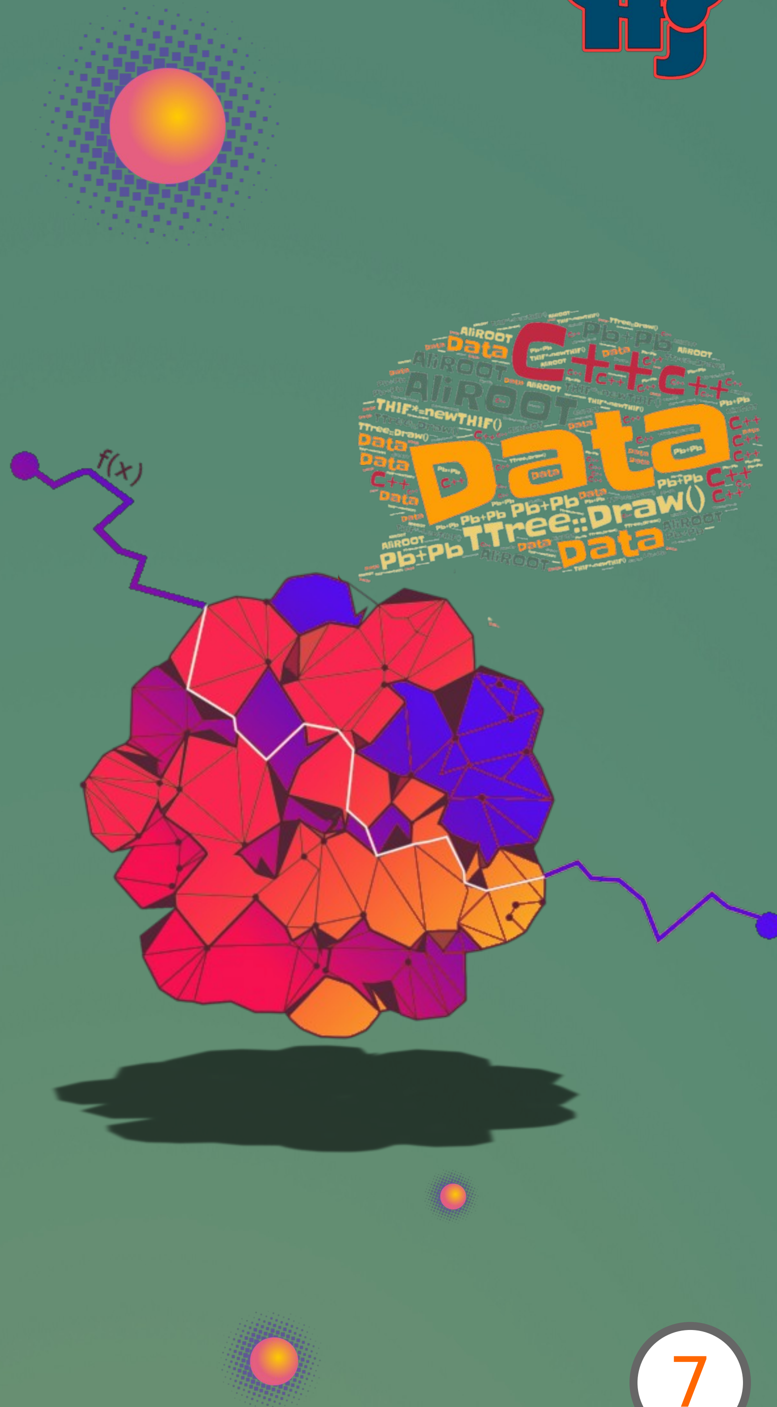
→ **pp @ $\sqrt{s}$ = 0.9, 2.76, 5.02, 7, 13 TeV**

Tracks: **-0.8<η<0.8,**

pp analysis→ **$0.2 < p_T < 2$ GeV/c**

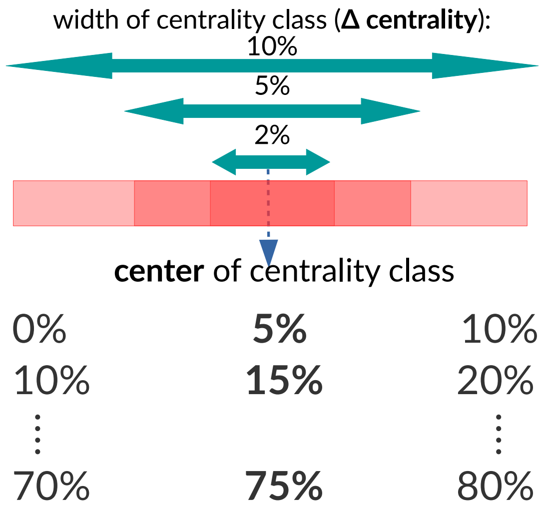
A-A analysis→ **$0.2 < p_T < 5$ GeV/c**

Centrality estimators: **V0 ($N_{charged}$),**
ZDC ($N_{spectators}$)

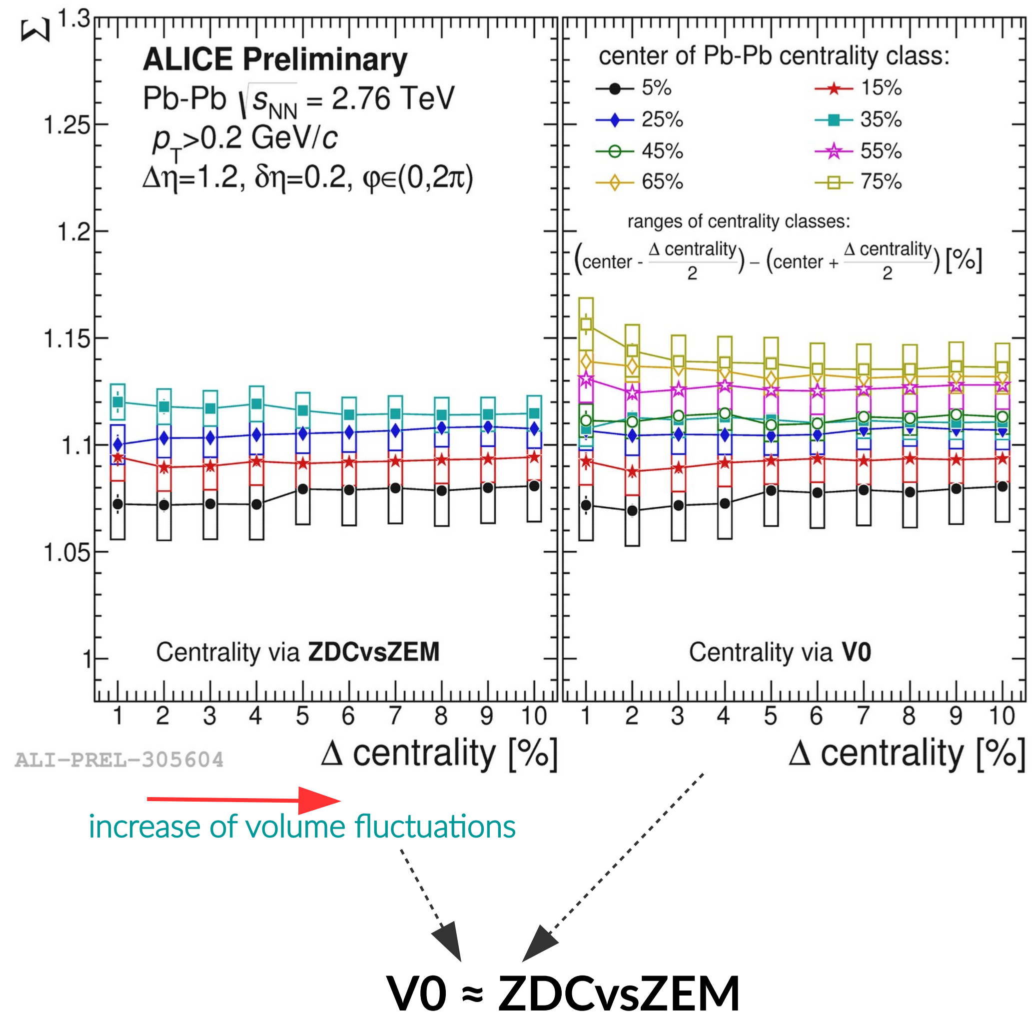


Results: Σ as a function of centrality bin width

Pb-Pb collisions



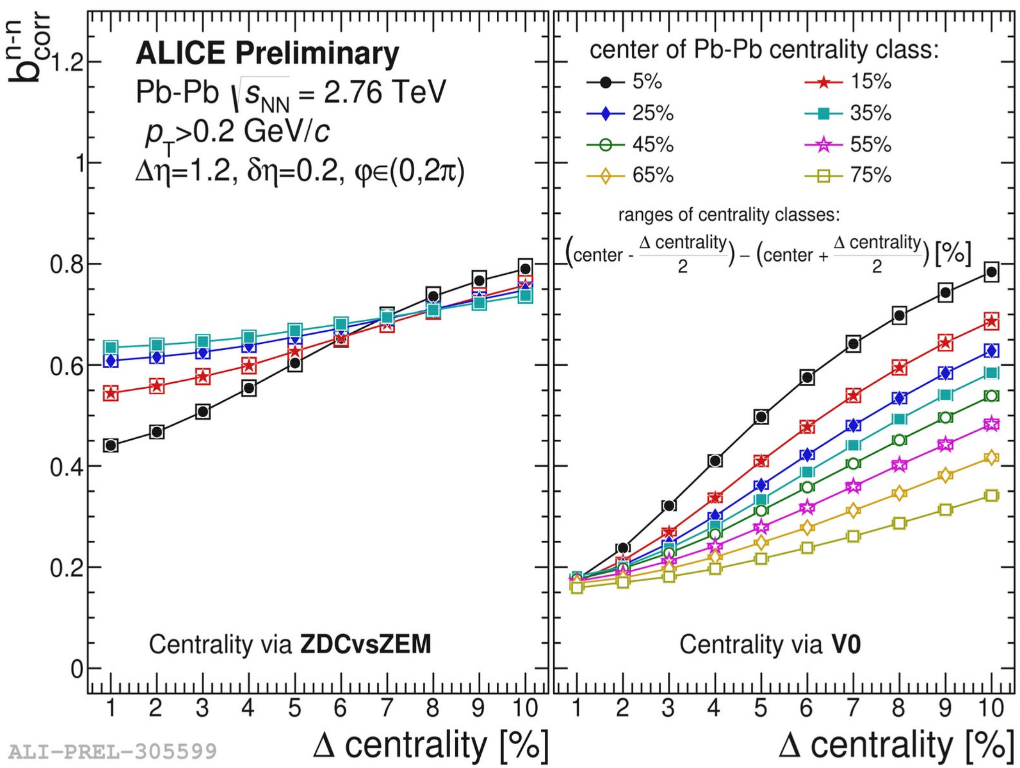
The strongly intensive quantity Σ



- **Σ does not** depend on centrality bin width (volume fluctuations).
- **Σ does not** depend on centrality estimator!

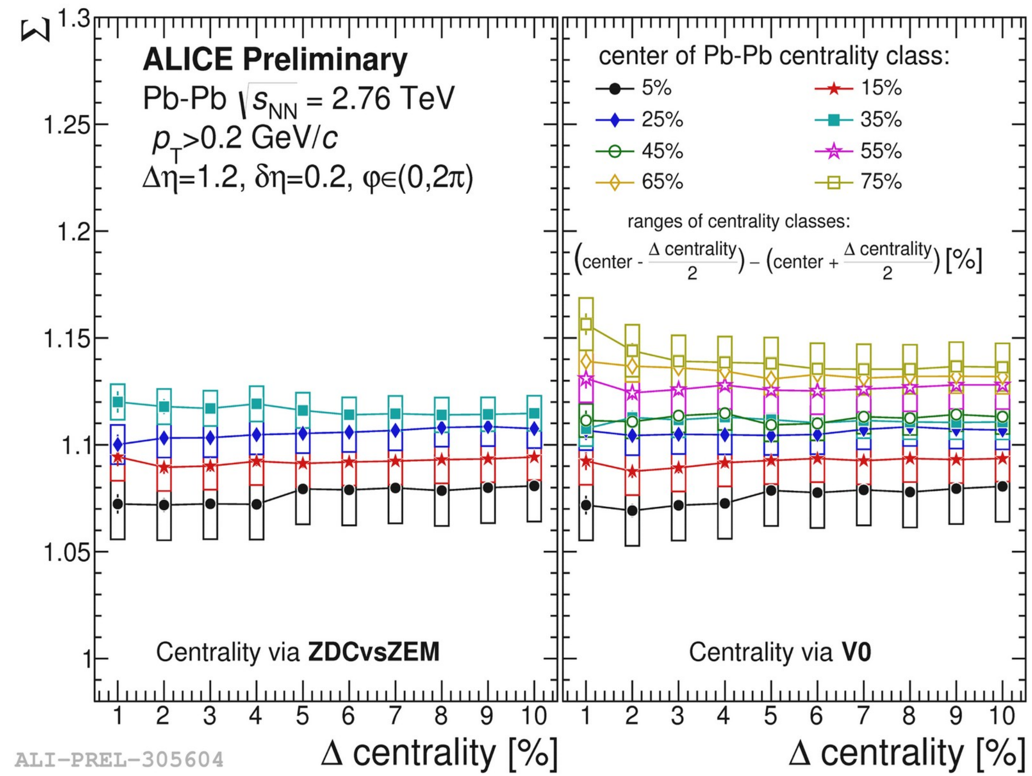
Results: Σ as a function of centrality bin width

The FB **correlation coefficient** b_{corr}



increase of volume fluctuations

The strongly intensive quantity Σ



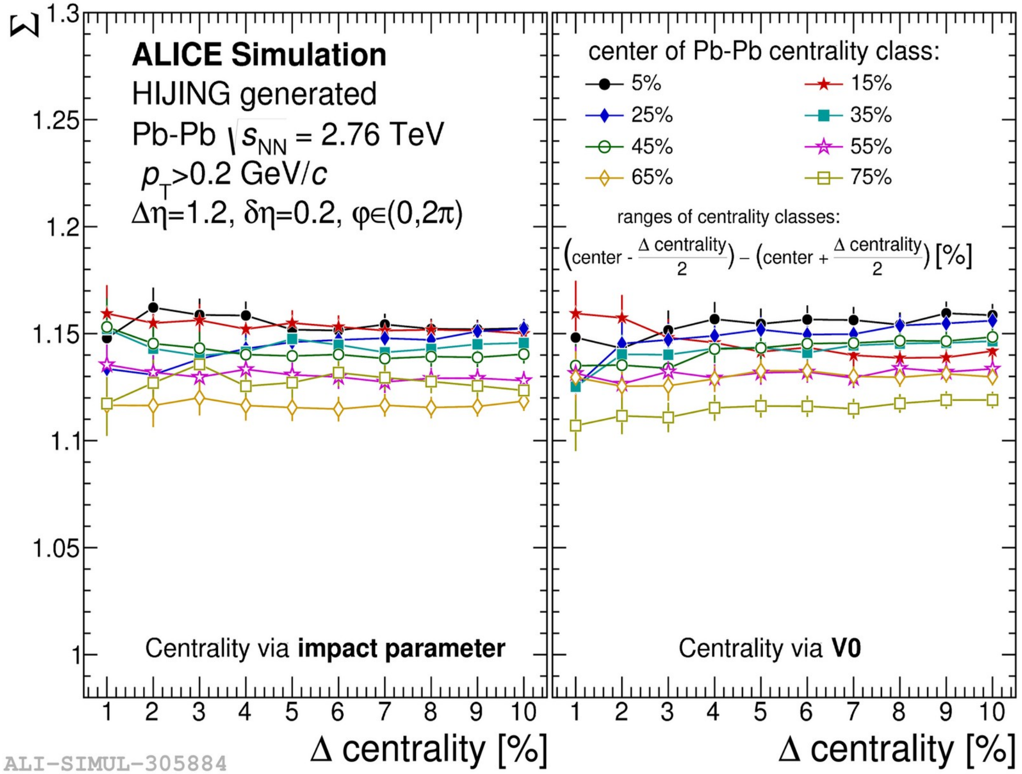
increase of volume fluctuations

- **Σ does not** depend on centrality bin width (volume fluctuations).
- **Σ does not** depend on centrality estimator!

→ contrary to many other observables such as b_{corr}, ω, etc.

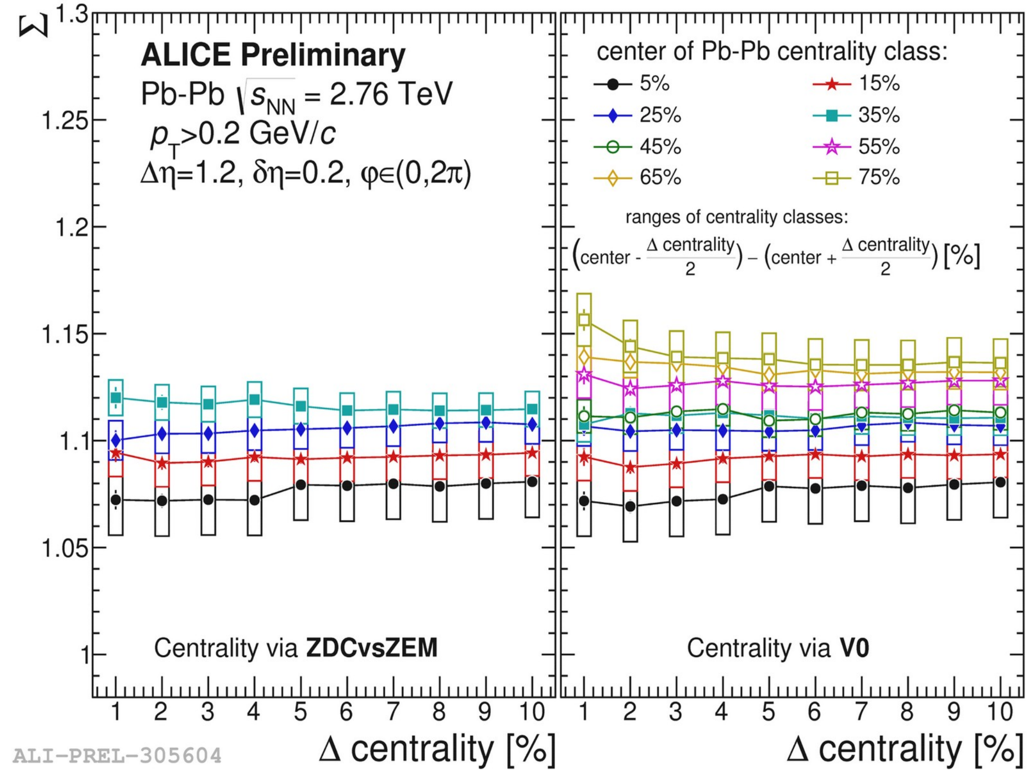
Results: Σ as a function of centrality bin width

MC simulations



increase of volume fluctuations

Experimental data

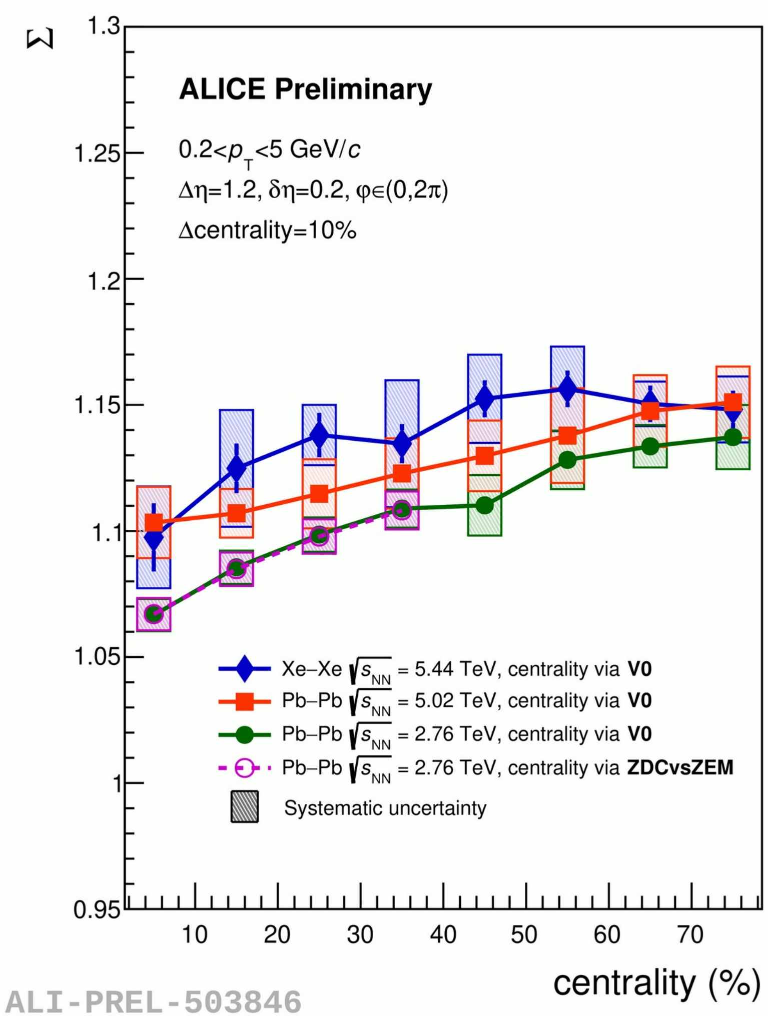


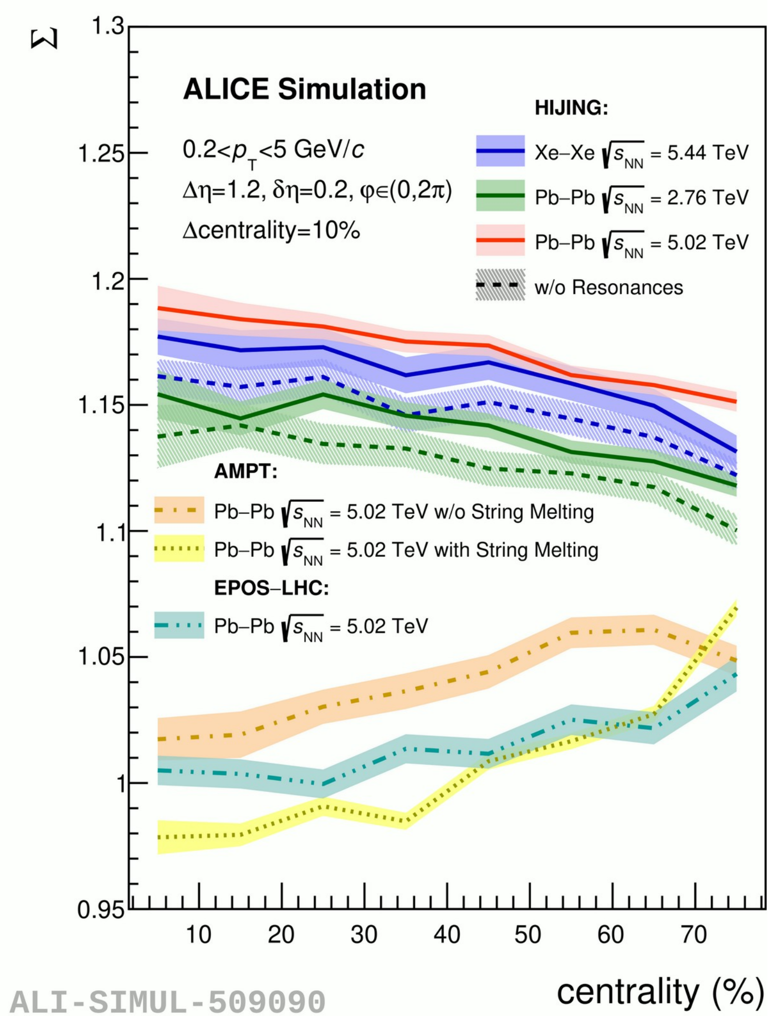
increase of volume fluctuations

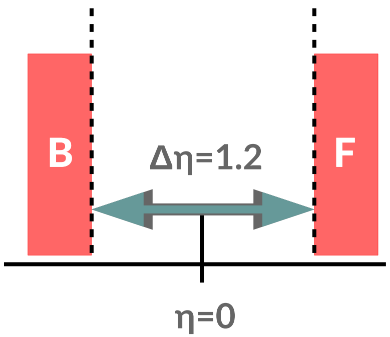
- **Σ does not** depend on centrality bin width (volume fluctuations).
- **Σ does not** depend on centrality estimator!

Σ indeed shows the properties of a strongly intensive quantity

Results: Σ as a function of centrality







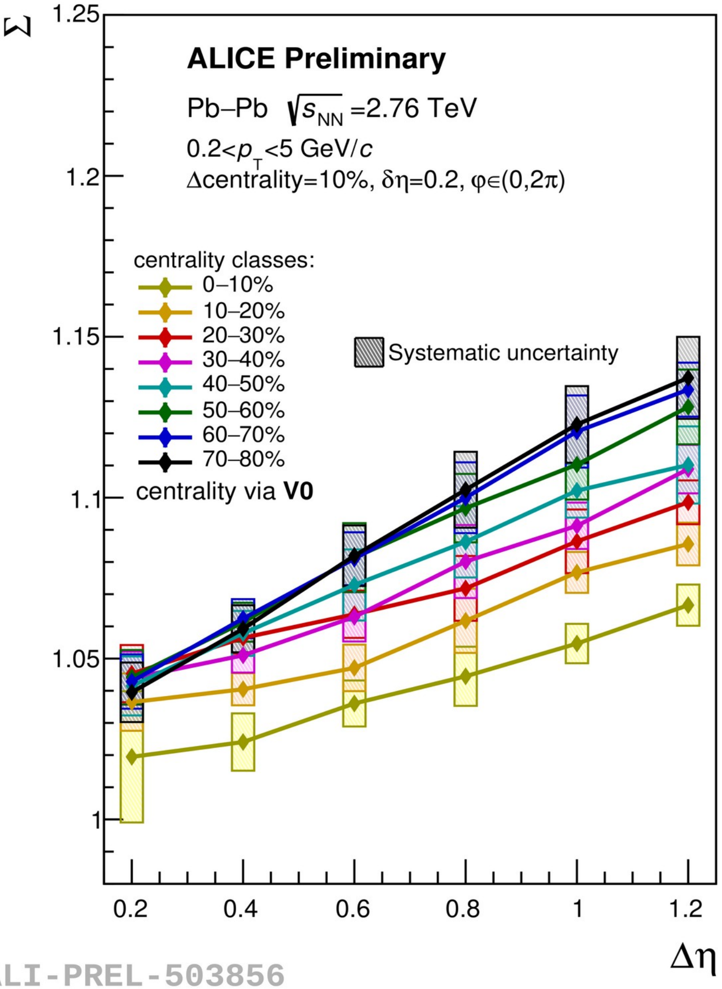
V0 ≈ ZDCvsZEM

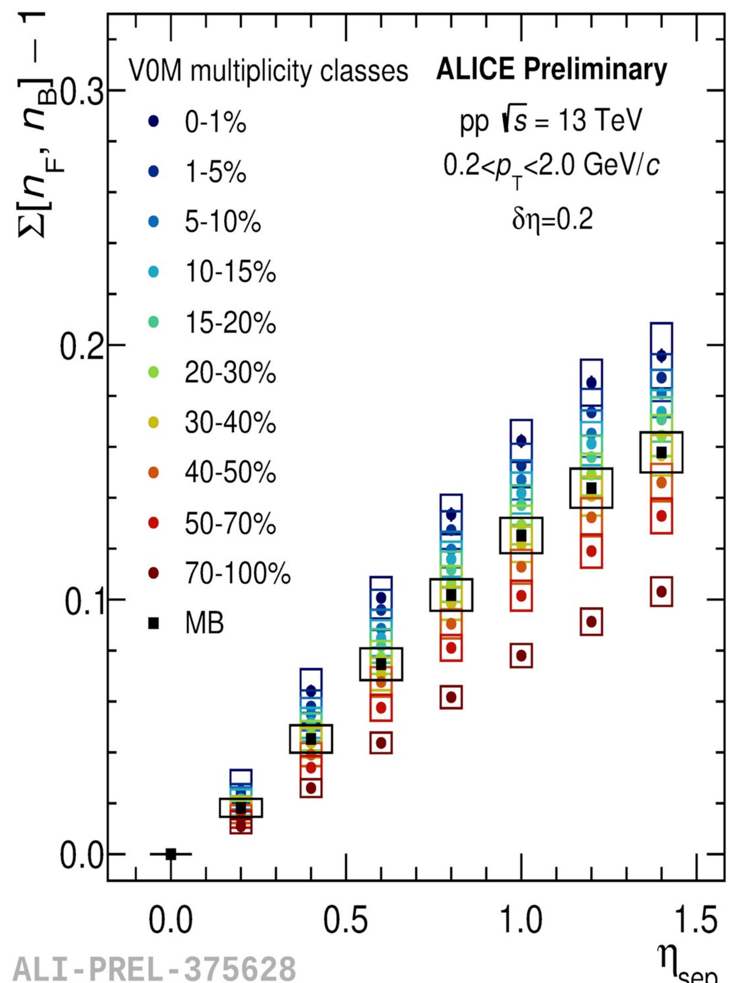
→ no dependence

on centrality estimator!

- Values of Σ **increase with energy** and **increase with decreasing centrality** in experimental data, contrary behavior noted for MC HIJING results.
- MC AMPT and MC EPOS reproduce dependence on centrality qualitatively but not quantitatively.
- From results for MC AMPT it is evident that Σ is sensitive to the mechanism of particle production.

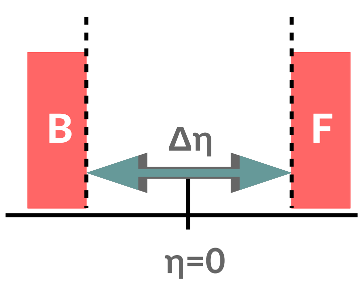
Results: Σ as a function of Δη



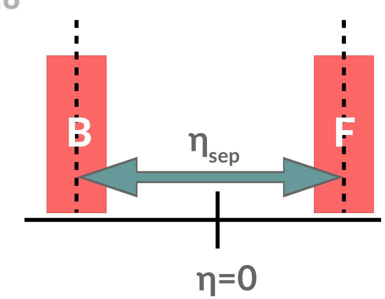


- **increase** with Δη;
- **Pb–Pb: decrease** of Σ with increasing centrality class;
- **pp:** Σ **grows** with the increase of forward event multiplicity; **contrary to Pb–Pb.**

Different ordering of Σ with centrality for Pb–Pb and pp.

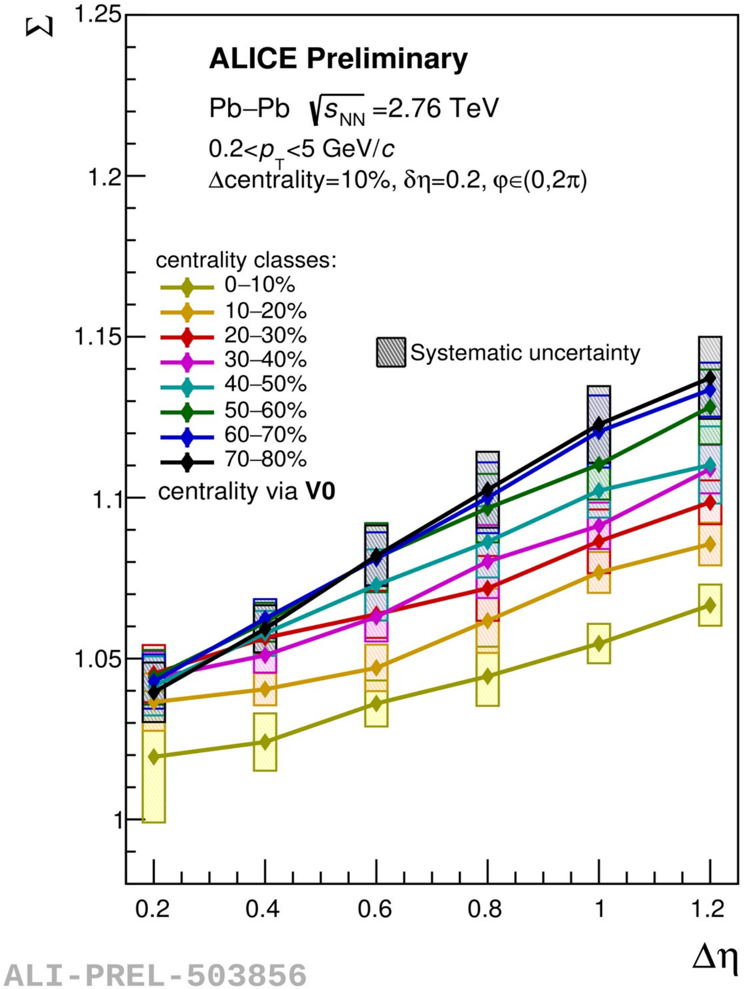


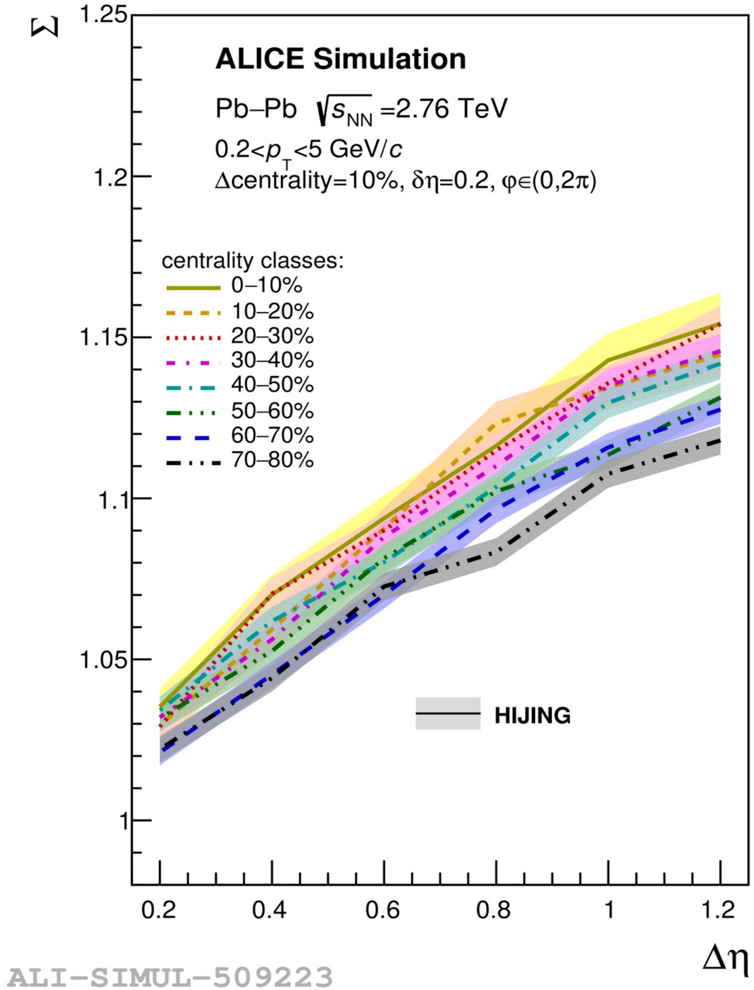
$$\eta_{sep} = \Delta\eta + 0.2$$



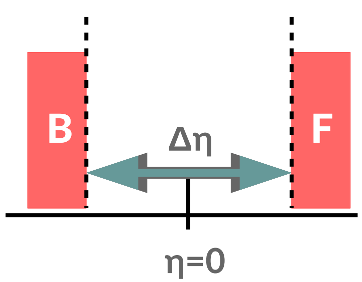
$$\Sigma \approx \omega(1-b_{corr})$$

Results: Σ as a function of Δη



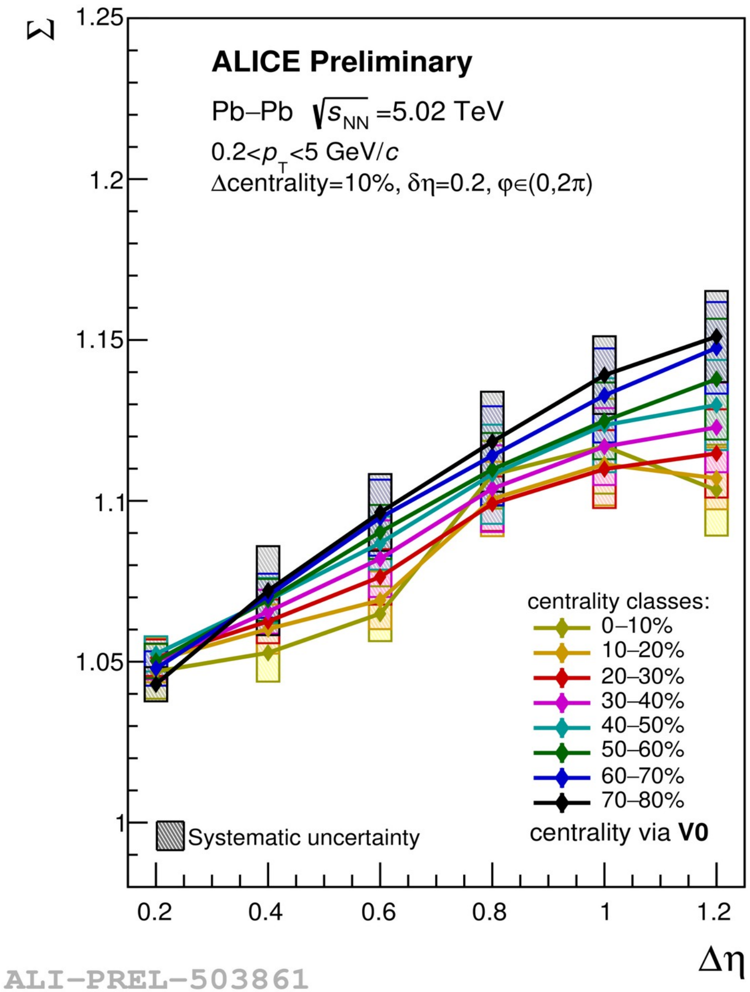


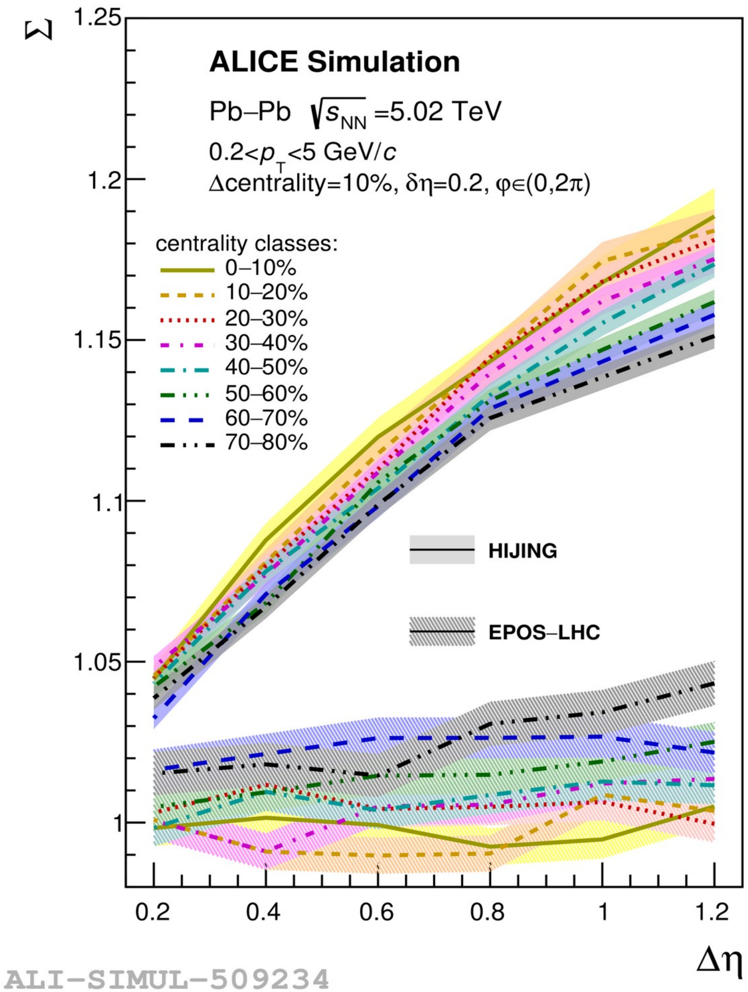
- **increase** with Δη;
- **experimental data: decrease** of Σ with increasing centrality class;
- **MC HIJING:** Σ **grows** with with increasing centrality class.



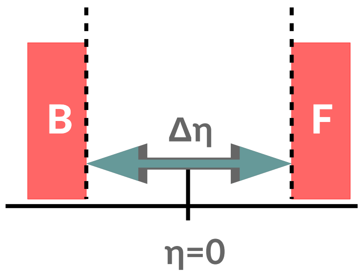
$$\Sigma \approx \omega(1-b_{corr})$$

Results: Σ as a function of Δη



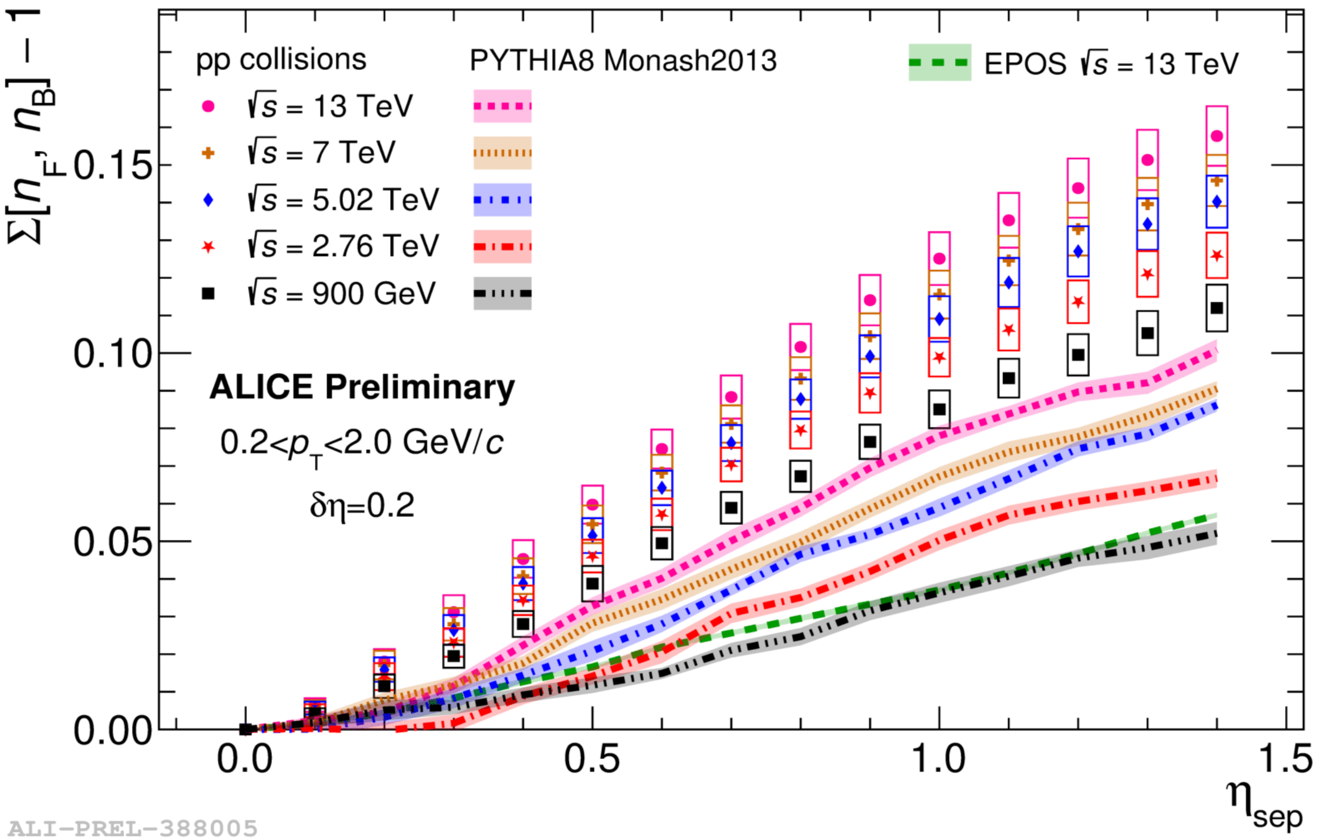


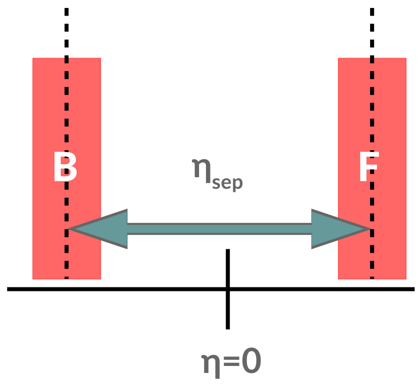
- **increase** with Δη;
- **experimental data: decrease** of Σ with increasing centrality class;
- **MC HIJING:** Σ **grows** with with increasing centrality class;
- **MC EPOS: decrease** of Σ with increasing centrality class;
- **MC EPOS:** reproduces dependence on centrality **qualitatively** but **not quantitatively.**



$$\Sigma \approx \omega(1-b_{corr})$$

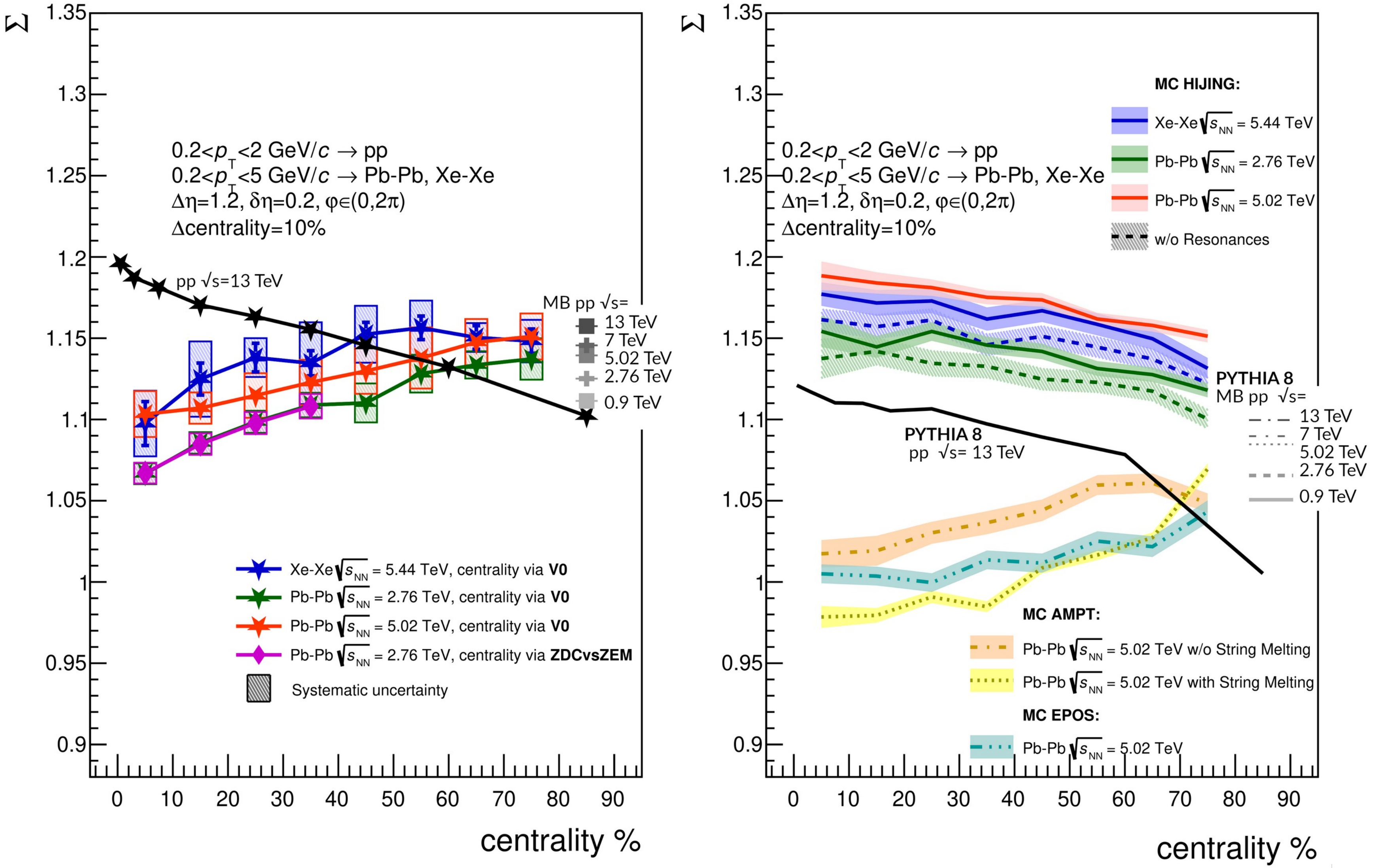
Results: Σ as a function of Δη





- The value of Σ **grows with collision energy.**
- PYTHIA8 is not able to reproduce this behavior quantitatively.
- EPOS is not able to reproduce this behavior quantitatively.

Results: Overview



Summary

New results for measurement of the FB correlation with the strongly intensive quantity Σ have been presented:

- Σ **increases with energy and with decreasing centrality** in experimental data, **contrary** behavior noted for MC HIJING results and experimental pp collisions.
- Removal of the resonance contribution does **not** change the dependence (ordering) of Σ with centrality.
- AMPT and EPOS reproduce the dependence on centrality **qualitatively** but **not quantitatively**.
- From results for AMPT it is evident that Σ is sensitive to the mechanism of particle production.
- The comparison of **centrality ordering** in A−A reactions versus theoretical models, and experimental pp data, may provide new insight into the underlying dynamics of the collision.
- **What model can reproduce Σ behavior?**

This work was supported by the National Science Centre, Poland (grant No. 2021/43/D/ST2/02195).

LEARN MORE ABOUT Σ:
with one "click"

Strongly Intensive Quantities

Σ in pp with ALICE

Dependence on centrality selection and volume fluctuations

Σ in A-A with ALICE