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

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Outline

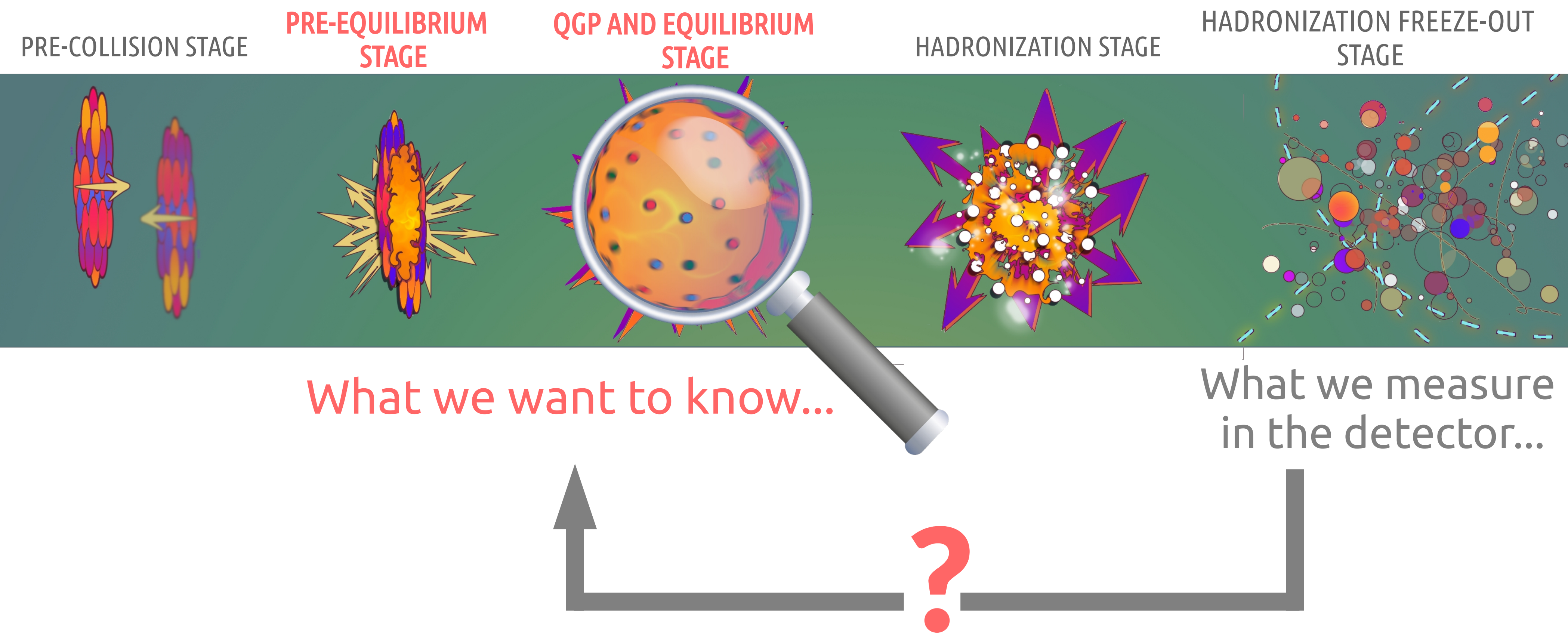
Overview of the ALICE measurement of the **strongly intensive quantity Σ and ν_{dyn} observables** in terms of forward-backward correlations and net-charge fluctuations analysis...

...in various colliding systems and energies.

Plan:

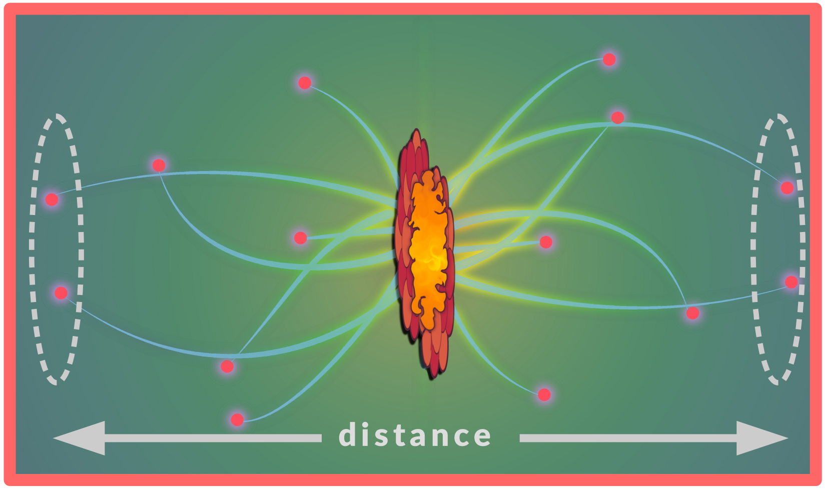
1. Motivation
2. Analysis
3. Results
4. Summary.

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?

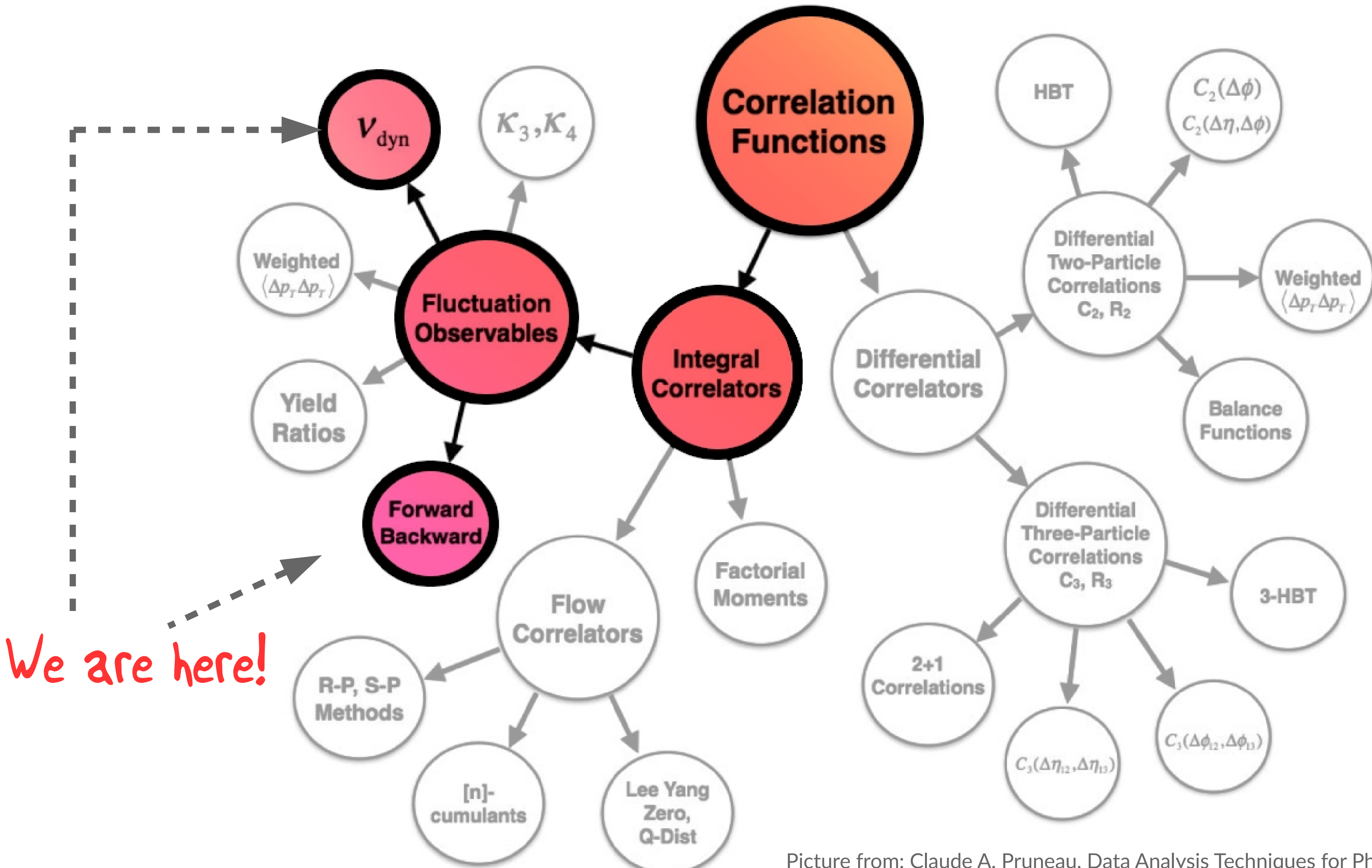


1. Study of **Long-Range Correlations** (LRC):
    - LRC carry **information** on the **early dynamics** of the nuclear collision.

2. Analysis of **fluctuations** in the number of particles produced in nucleus-nucleus 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.

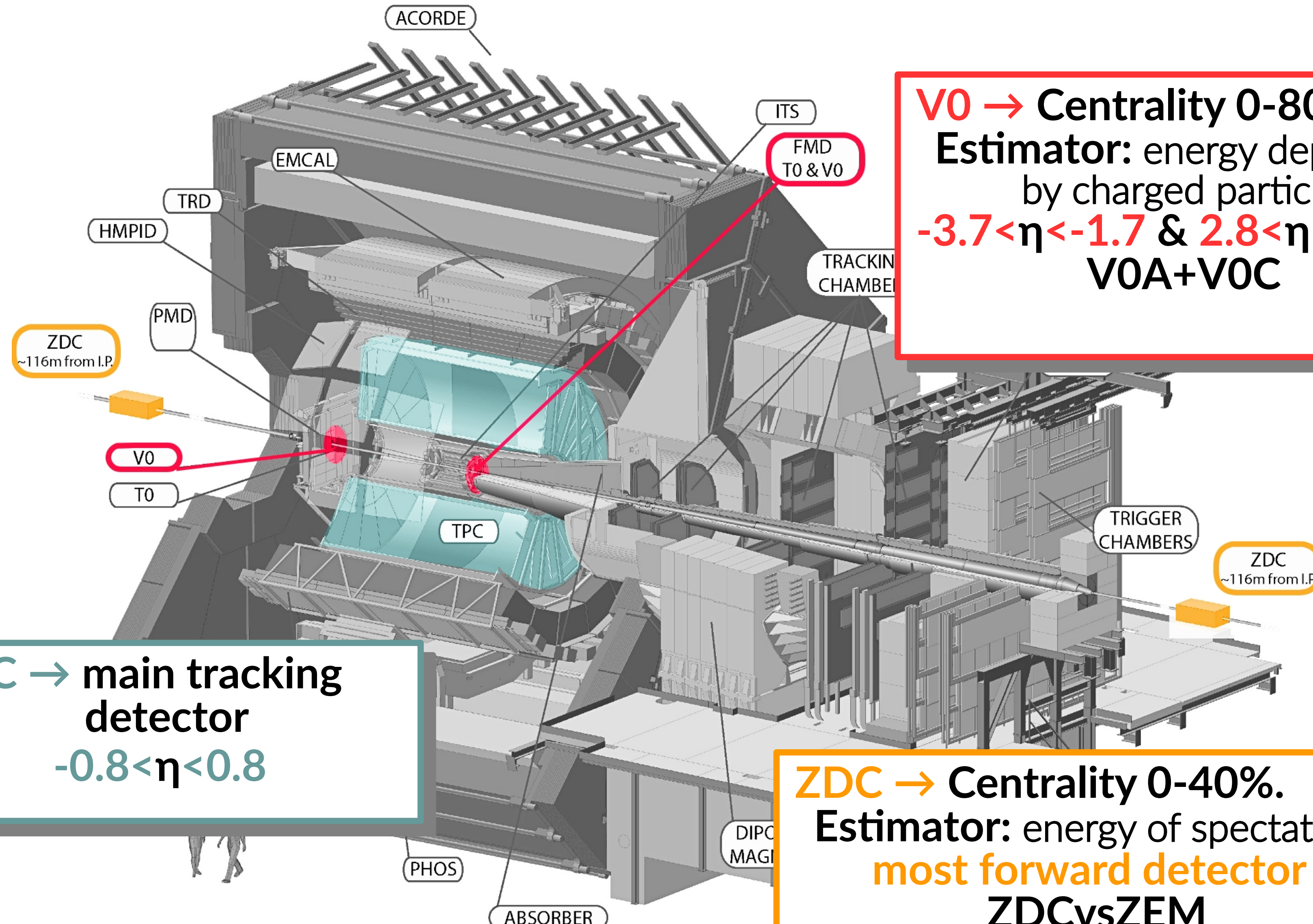
3. Fluctuations of **globally conserved quantities** → sensitive to the composition of hot and dense matter in the early stages of collision.

The Analysis: How do we study correlations and fluctuations?



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

The Analysis: ALICE experiment



V0 → Centrality 0-80%.
Estimator: energy deposition by charged particles
$-3.7<\eta<-1.7$ & $2.8<\eta<5.1$
V0A+V0C

TPC → main tracking detector
$-0.8<\eta<0.8$

ZDC → Centrality 0-40%.
Estimator: energy of spectators
most forward detector
ZDCvsZEM

The Analysis: Data Sample

Experimental data:

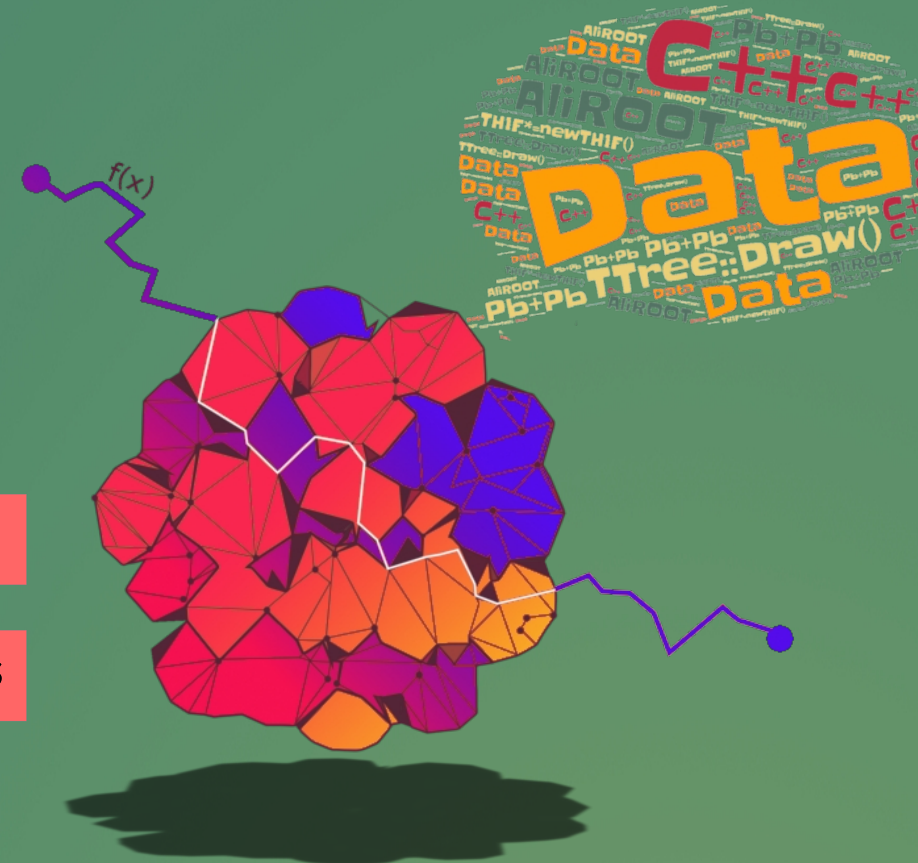
- → Pb-Pb @ $\sqrt{s_{NN}}$= 2.76, 5.02 TeV
- → Xe-Xe @ $\sqrt{s_{NN}}$ = 5.44 TeV
- → p-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV
- → pp @ $\sqrt{s}$ =0.9, 2.76, 5.02, 7 and 13 TeV

Tracks: $-0.8<\eta<0.8$, $p_T>0.2$ GeV/c

$0.2 < p_T < 2$ GeV/c } **Σ analysis**

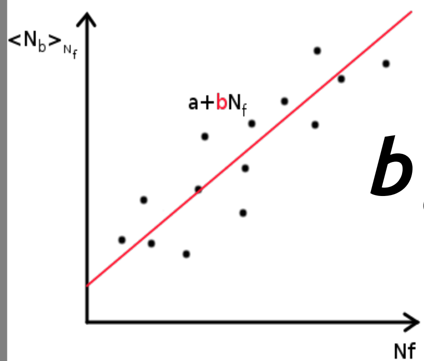
$0.2 < p_T < 5$ GeV/c } **ν_{dyn} analysis**

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

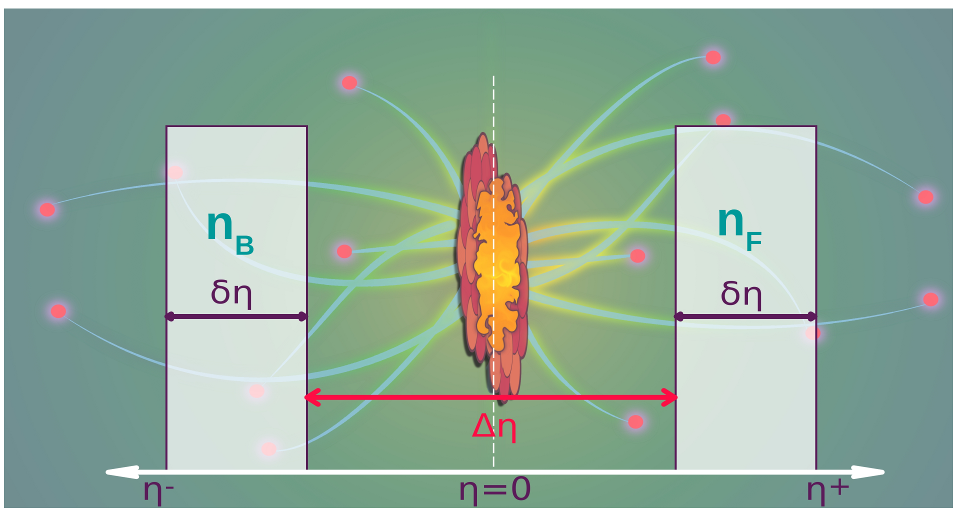


Forward-Backward Correlations

Pb-Pb collisions

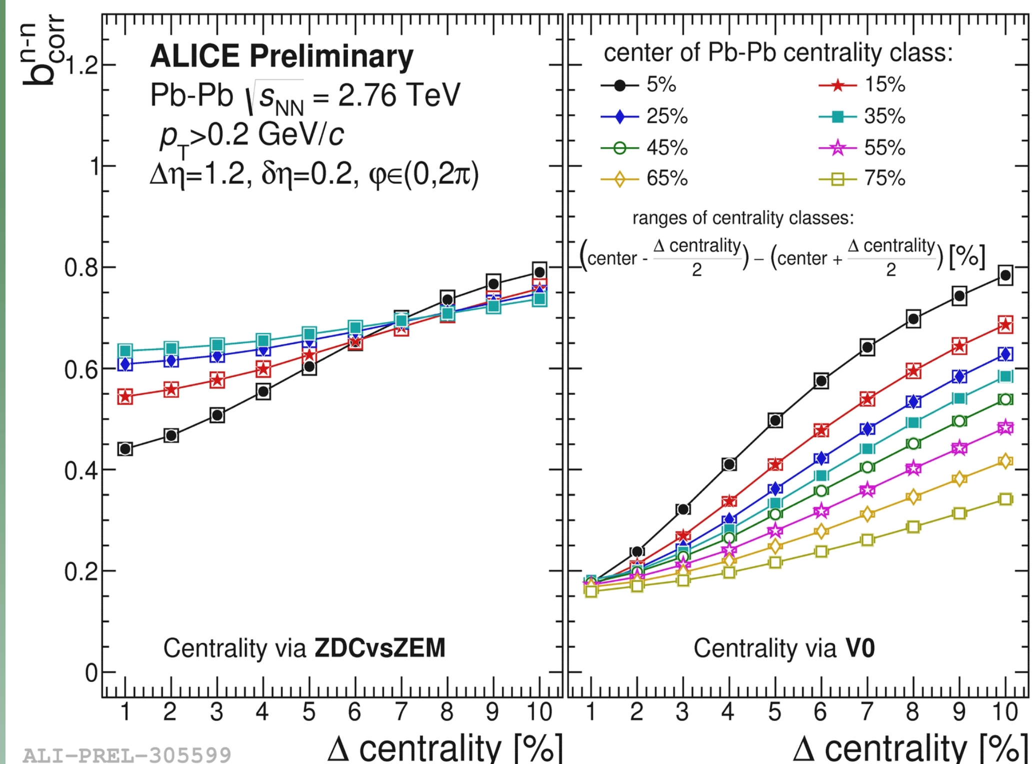


$$b_{corr} = \frac{\mathrm{Cov}(n_F, n_B)}{\sqrt{\mathrm{Var}(n_F)\,\mathrm{Var}(n_B)}}$$

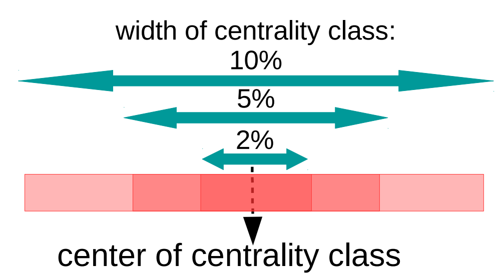


Centrality estimator: spectators in ZDC

Centrality estimator: charged particles in V0



increase of volume fluctuations



- Dependence on centrality estimator;
- Drop of the value of b_{corr} (**reduced fluctuations of N_{part}**).

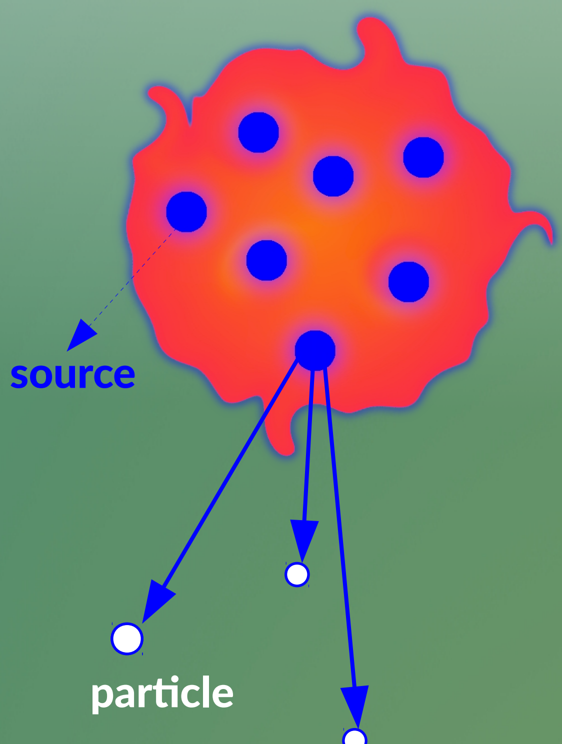
Strongly intensive quantities

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

Intensive quantities do not depend on system volume.

Scaled variance: $\omega_{B(F)} = \frac{Var(n_{B(F)})}{\langle n_{B(F)} \rangle}$

Independent source model:



Strongly Intensive quantities do not depend on system volume nor system volume fluctuations (i.e. $Var(N_s)$, ω_s) → Σ

$$\Sigma = \frac{1}{\langle n_B \rangle + \langle n_F \rangle} \left[\langle n_F \rangle \omega_B + \langle n_B \rangle \omega_F - 2\, Cov(n_F, n_B) \right]$$

For a symmetric collision, like Pb-Pb:

$\omega_B = \omega_F$ and $\langle n_F \rangle = \langle n_B \rangle$

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

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

Strongly intensive quantities

Pb-Pb collisions

→ Σ **does not depend** on centrality estimator;

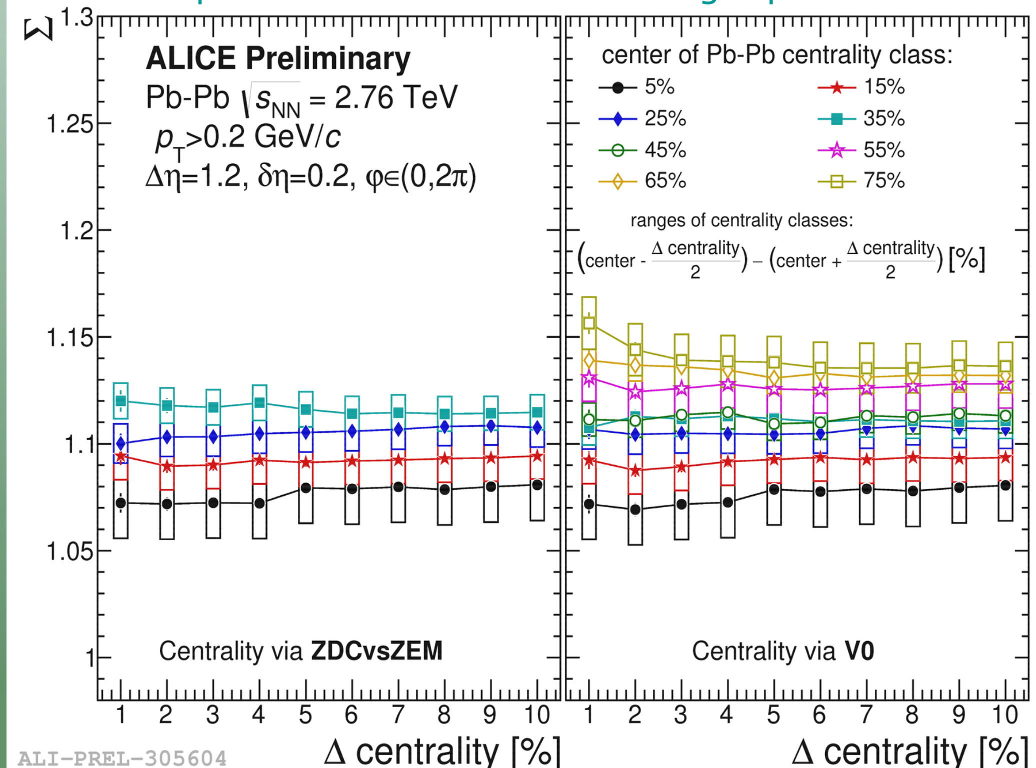
+

→ Σ **does not depend** on centrality bin width;

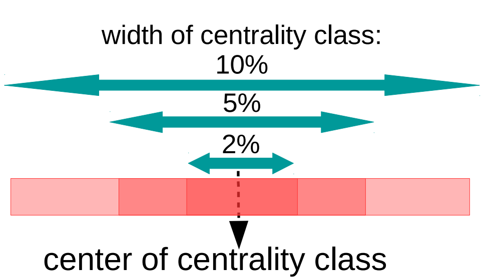
Σ indeed shows the properties of a strongly intensive quantity!

Centrality estimator: spectators in ZDC

Centrality estimator: charged particles in V0



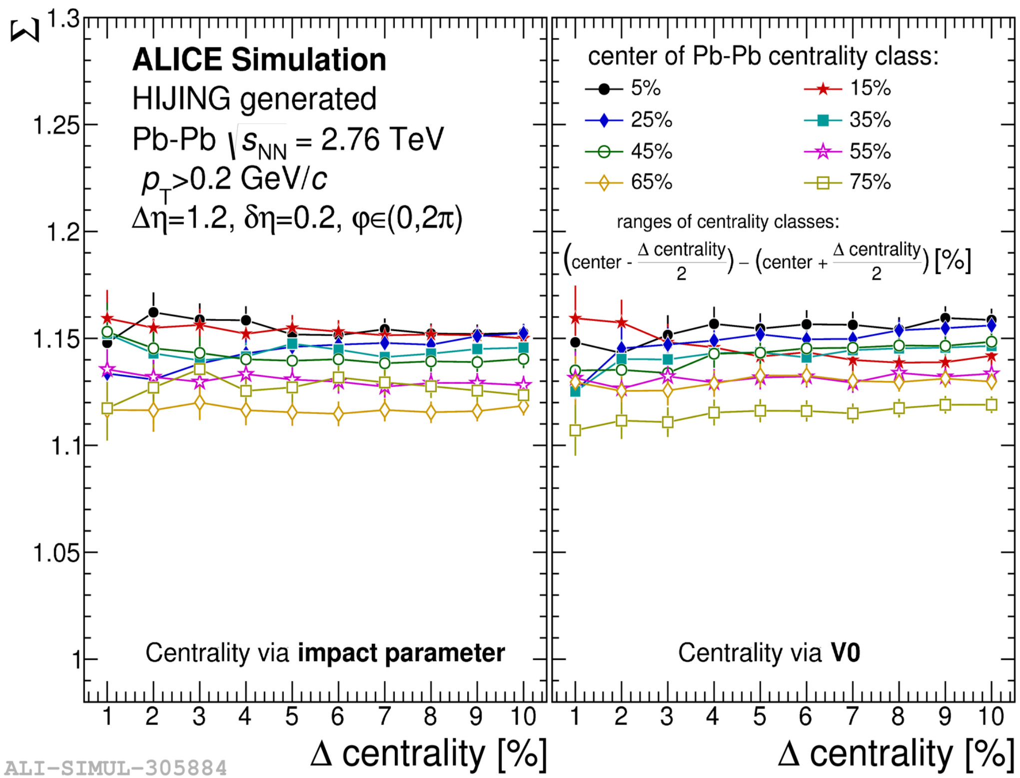
increase of volume fluctuations



Strongly intensive quantities

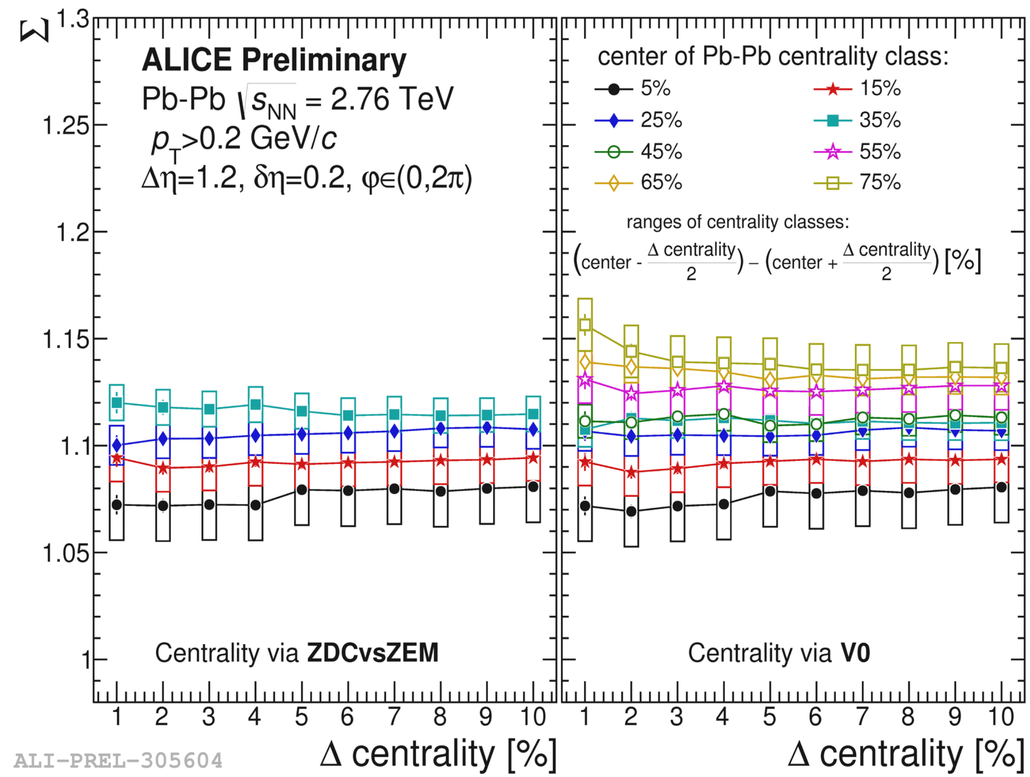
Pb-Pb collisions

MC simulations



increase of volume fluctuations

Experimental data

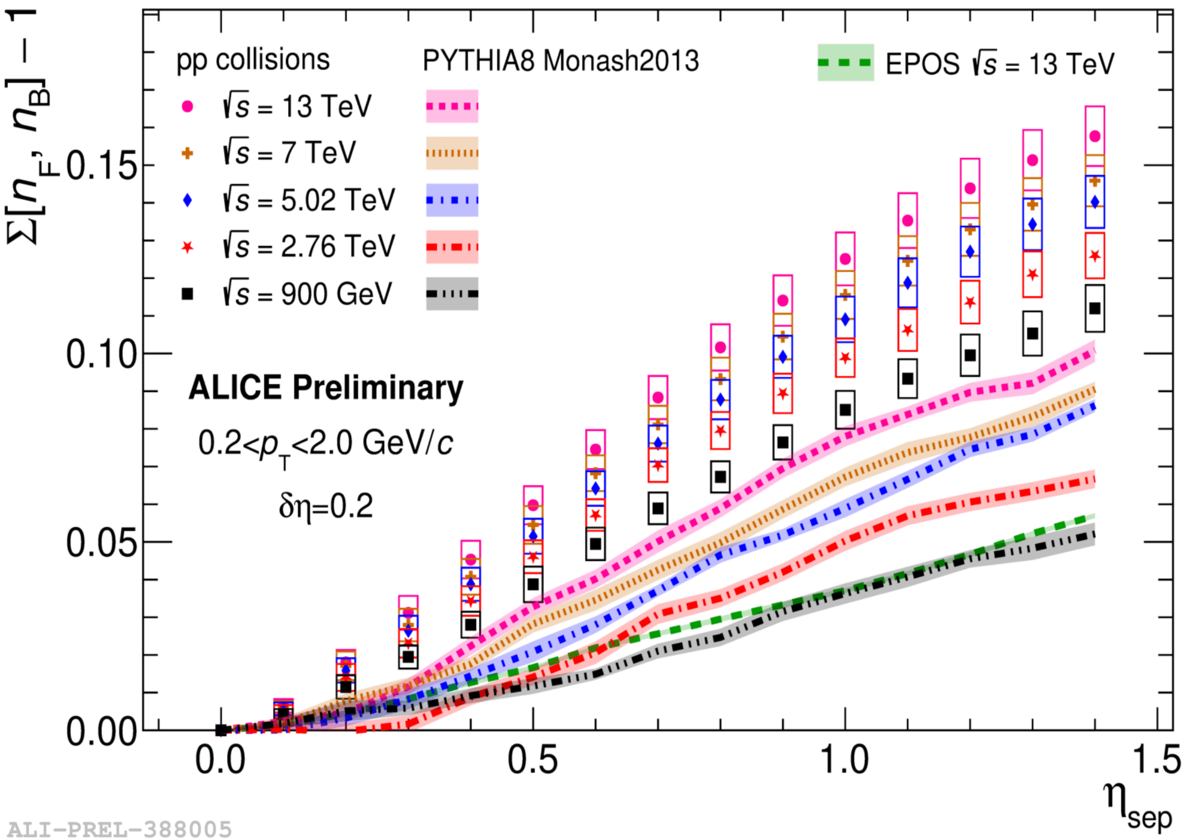


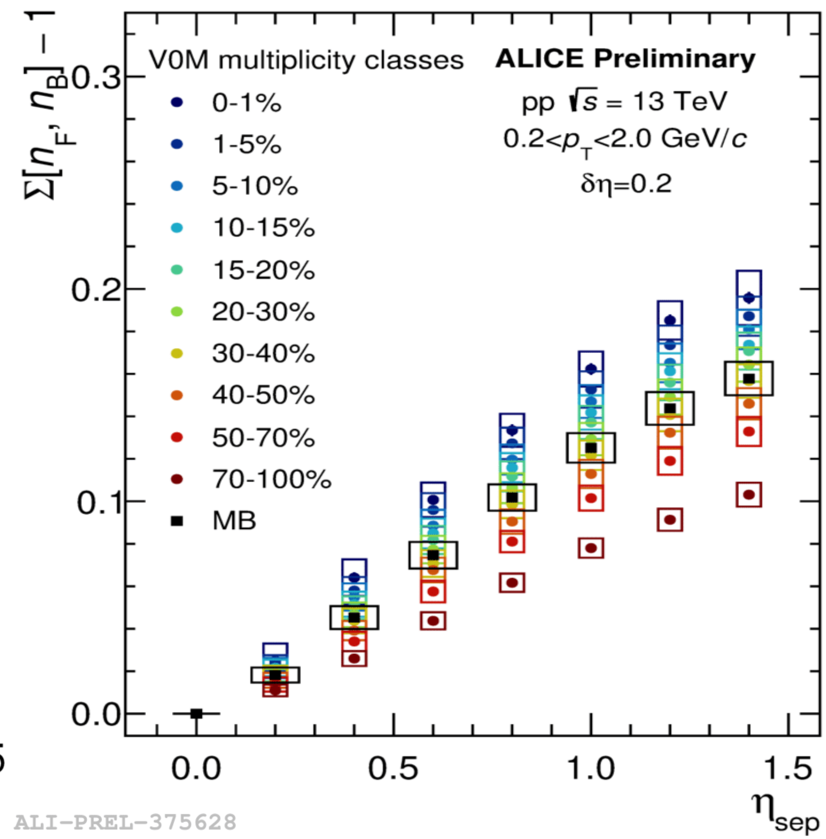
increase of volume fluctuations

- Σ provides direct information about particle production from single averaged source;
- Different ordering of the values of Σ with centrality→ possible hint about the early dynamics?

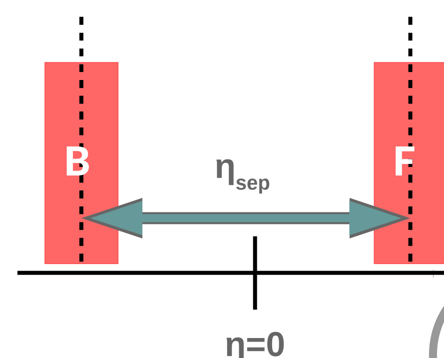
Strongly intensive quantities

pp collisions





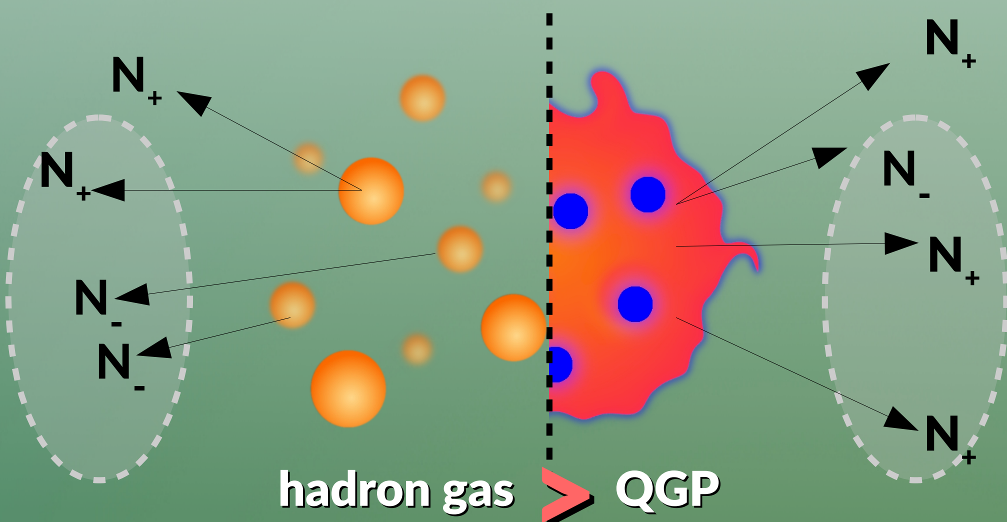
- The value of Σ **grows with collision energy.**
- PYTHIA8 is not able to reproduce this behavior quantitatively.
- For pp collisions Σ grows with the increase of forward event multiplicity, contrary to the behavior observed in Pb-Pb collisions.



Net-charge fluctuations with $\nu_{dyn}[+,-]$

ALICE

- The net-charge is a **globally conserved quantity** in nucleus-nucleus collisions → it **fluctuates** in a limited phase space window.



- **Net-charge fluctuations** → sensitive to the matter composition→ **differ** between confined and de-confined phases.

- Decrease of net-charge fluctuation → **signal of QGP.**

Dynamic net-charge fluctuations observable ν_{dyn}:

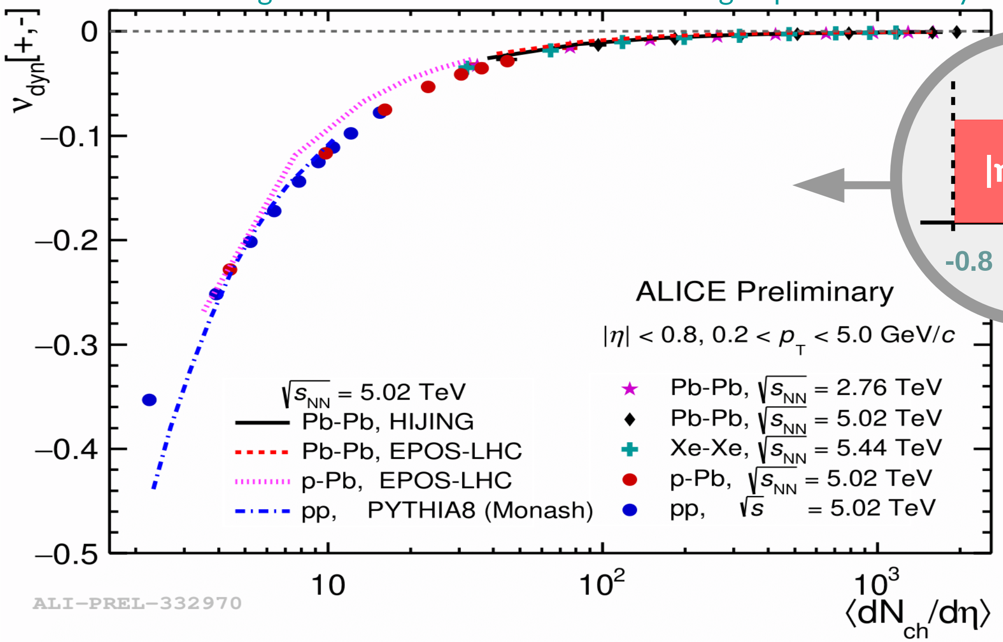
$$\nu_{dyn} = \frac{\langle N_-(N_- - 1)\rangle}{\langle N_-\rangle^2} + \frac{\langle N_+(N_+ - 1)\rangle}{\langle N_+\rangle^2} - 2\frac{\langle N_- N_+\rangle}{\langle N_-\rangle\langle N_+\rangle}$$

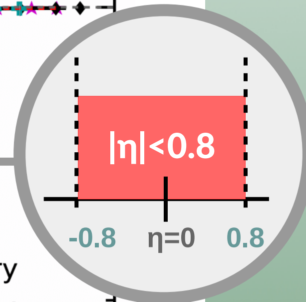
- → Robust against detection efficiency losses;
- → **Not** strongly intensive, scales as $\nu_{dyn} \sim \mathbf{1/N_{sources}}$;
- → Related to strongly intensive quantity **Σ:**

$$\nu_{dyn} = \frac{\langle N_- + N_+\rangle}{\langle N_-\rangle\langle N_+\rangle}\left[\Sigma^{N_- N_+} - 1\right]$$

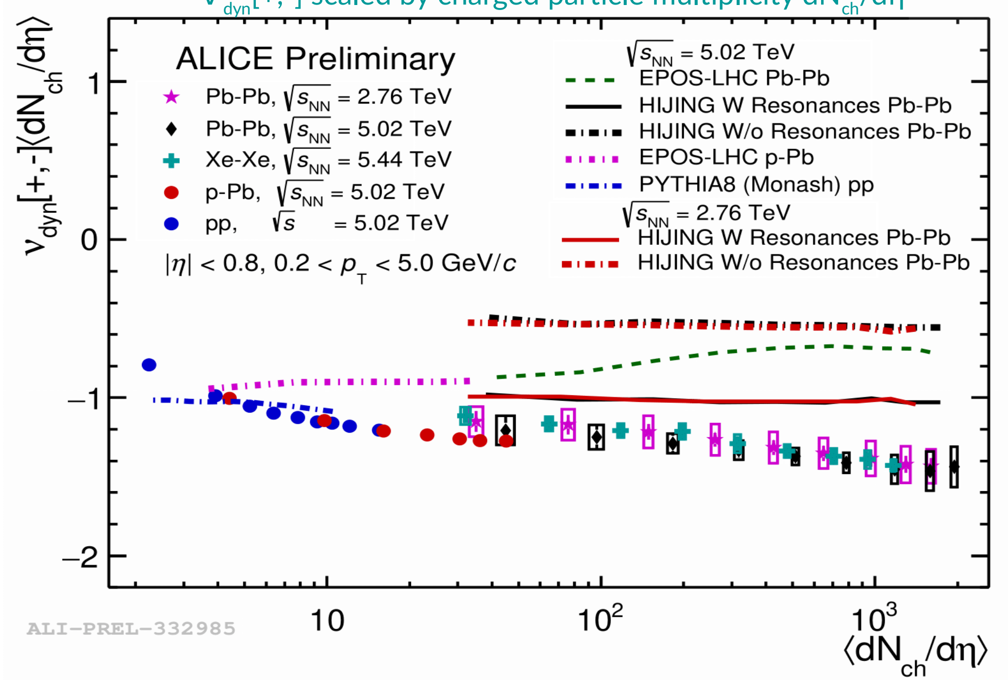
Net-charge fluctuations with $\nu_{dyn}[+,-]$

Net-charge fluctuations as a function of charged particle density





$\nu_{dyn}[+,-]$ scaled by charged particle multiplicity $dN_{ch}/d\eta$



Negative values of $\nu_{dyn}[+,-]$, indicate the dominance of the correlation between oppositely charged particles.

A **smooth evolution** of net-charge fluctuations is observed from smaller to larger collision systems → scaling $\nu_{dyn}[+,-]$.

Scaled $\nu_{dyn}[+,-]$ **:**

- Dependence on centrality→ not reproduced in MC HJING and EPOS-LHC;
- PYTHIA8 (Monash tune) ~agrees with experimental data;
- Significant contribution from the resonance decays.

Summary

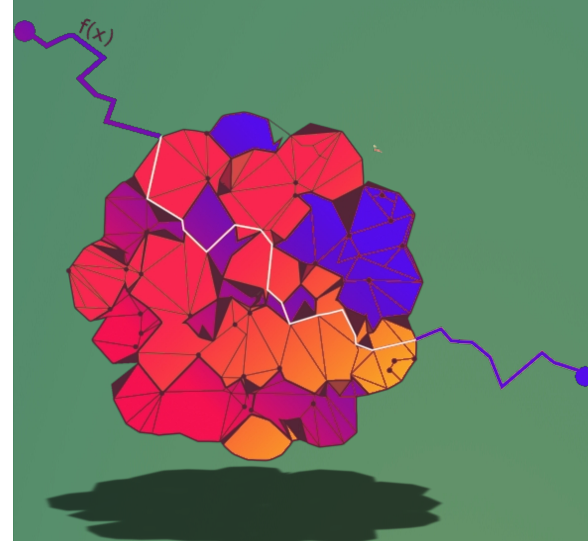
We obtained new data on net-charge fluctuations (ν_{dyn}) and first experimental data on forward-backward correlations with strongly intensive quantity Σ:

1. The Σ observable was studied in Pb-Pb and pp collisions:

- → it shows a deviation from unity → non-Poissonian particle emission;
- → in Pb-Pb collisions the Σ observable does not depend on the centrality bin width and centrality estimator, contrary to b_{corr} coefficient;
- → **exhibits properties of strongly intensive quantity;**
- → independent source model? → info about average source → direct probe for phenomenological models;
- → in pp collisions, the values of Σ grow with collision energy and increase with forward multiplicity.

2. Net-charge fluctuations ν_{dyn}:

- → have been studied in pp, p-Pb, Pb-Pb and Xe-Xe collisions;
- → a smooth evolution of net-charge fluctuations has been observed from smaller to larger collision systems;
- → the largest contribution to measured values of ν_{dyn} comes from resonance decays.



THANK YOU!

Acknowledgments

Many thanks to Andrzej Rybicki for his continuous contribution to the analysis of SI variables in Pb-Pb collisions.

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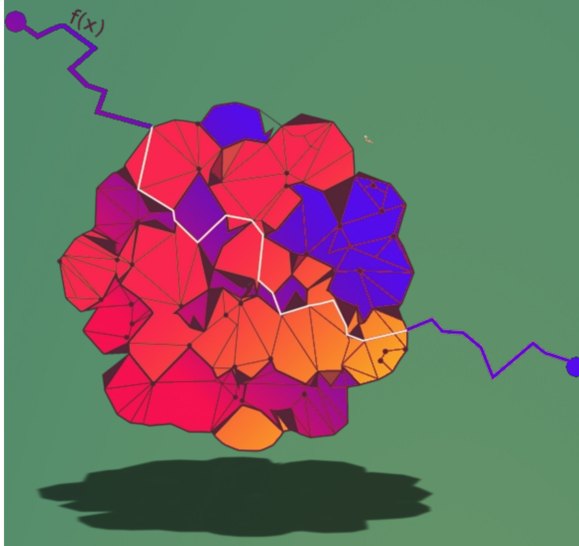
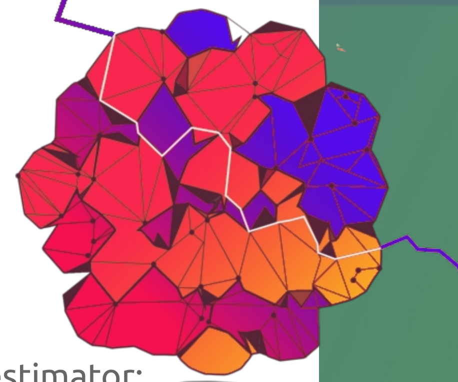
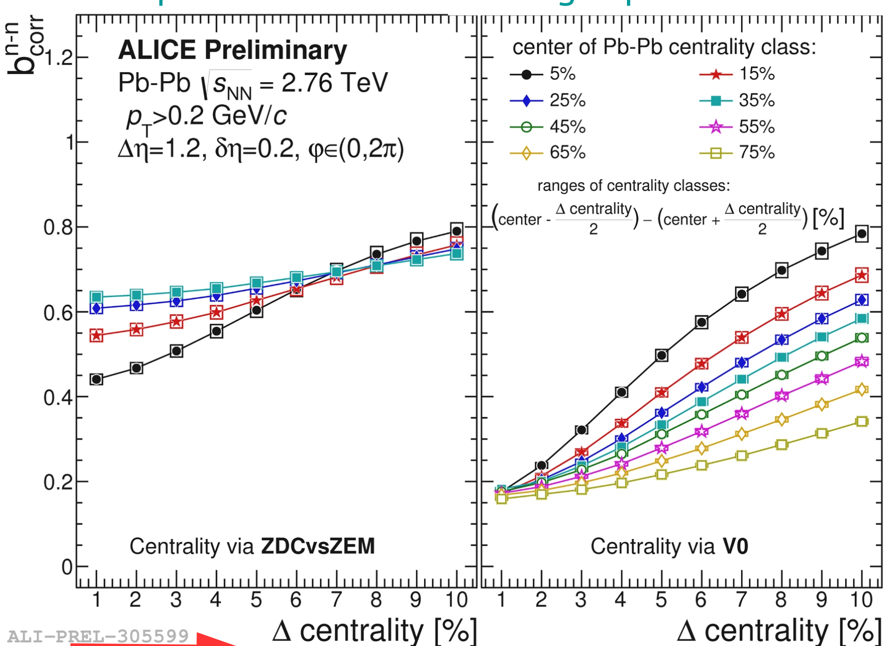


Backup

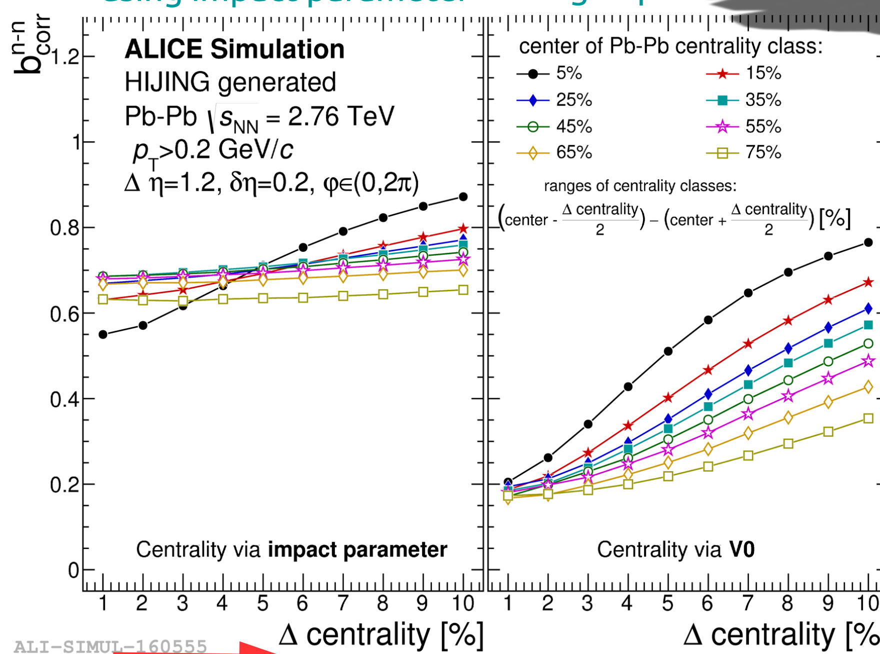


Centrality estimator: spectators in ZDC | Centrality estimator: charged particles in V0



geometrical fluctuations

Centrality determined using impact parameter | Centrality estimator: charged particles in V0



geometrical fluctuations

- **Large values of b_{corr}** but large centrality bin width **→ large geometrical (N_{part}) fluctuations** within a single bin of selected centrality.
- Theoretical predictions:

$$b = 1 - \left[1 + \frac{\bar{n}}{4}\left(\frac{2}{k} + \frac{\langle w^2\rangle - \langle w\rangle^2}{\langle w\rangle}\right)\right]^{-1}$$

Scaled variance of number of participants ω_{part}

A. Bzdak, Phys. Rev. C 80 (2009) 024906