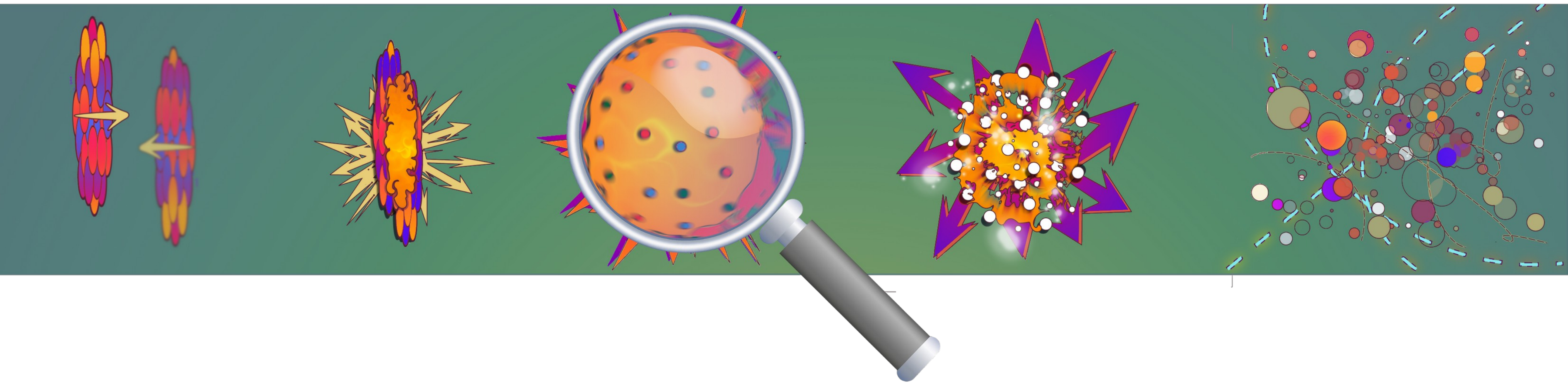
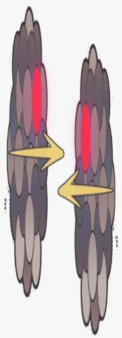
Heavy-ion collisions

PRE-COLLISION | PRE-EQUILIBRIUM | QGP AND EQUILIBRIUM | HADRONIZATION | HADRONIZATION FREEZE-OUT



ENERGY OF THE COLLISION
IN THE C.M.S.

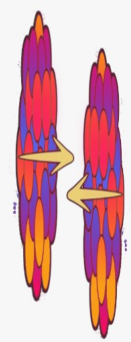
PER NUCLEON PAIR



Pb-Pb

$\sqrt{s_{NN}} = 2.76$ TeV

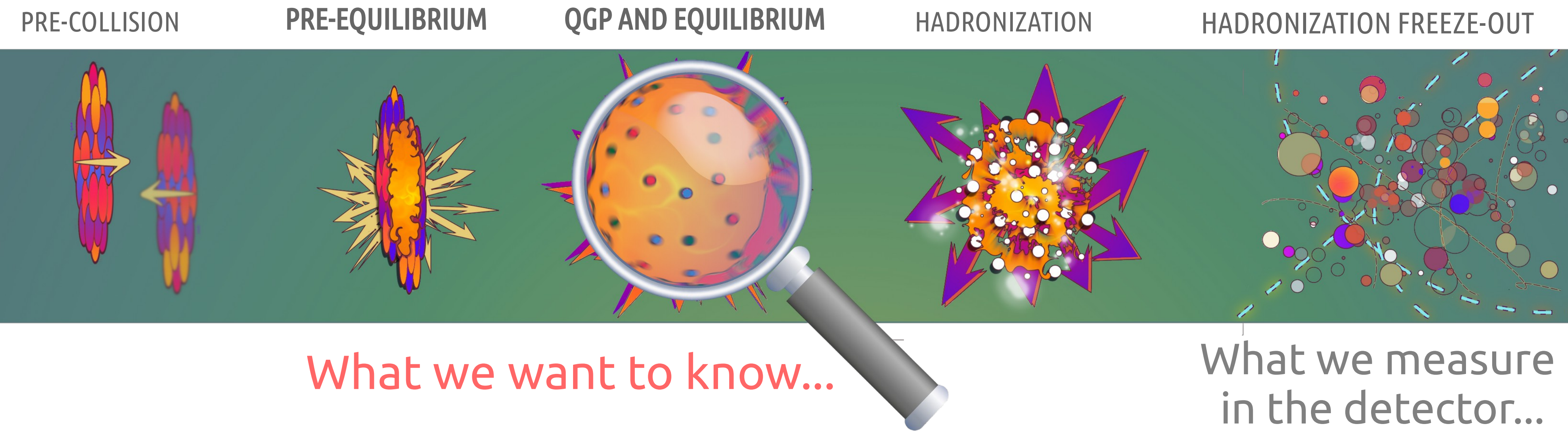
PER NUCLEUS



Pb-Pb

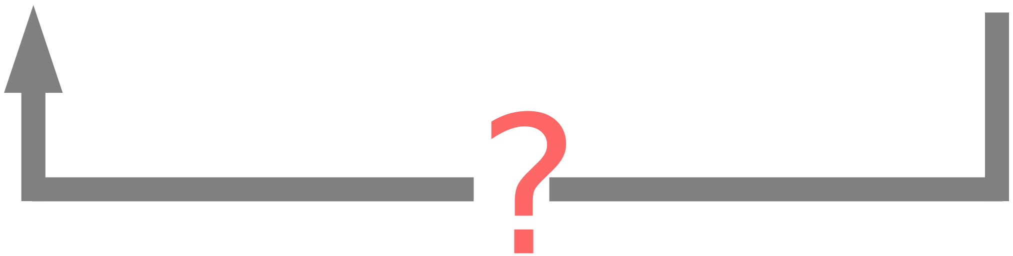
$\sqrt{s} = \underline{574}$ TeV $= 574 \cdot 10^{6}$ MeV

Heavy-ion collisions



What we want to know...

What we measure in the detector...



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

Motivation: Why do we study correlations and fluctuations?

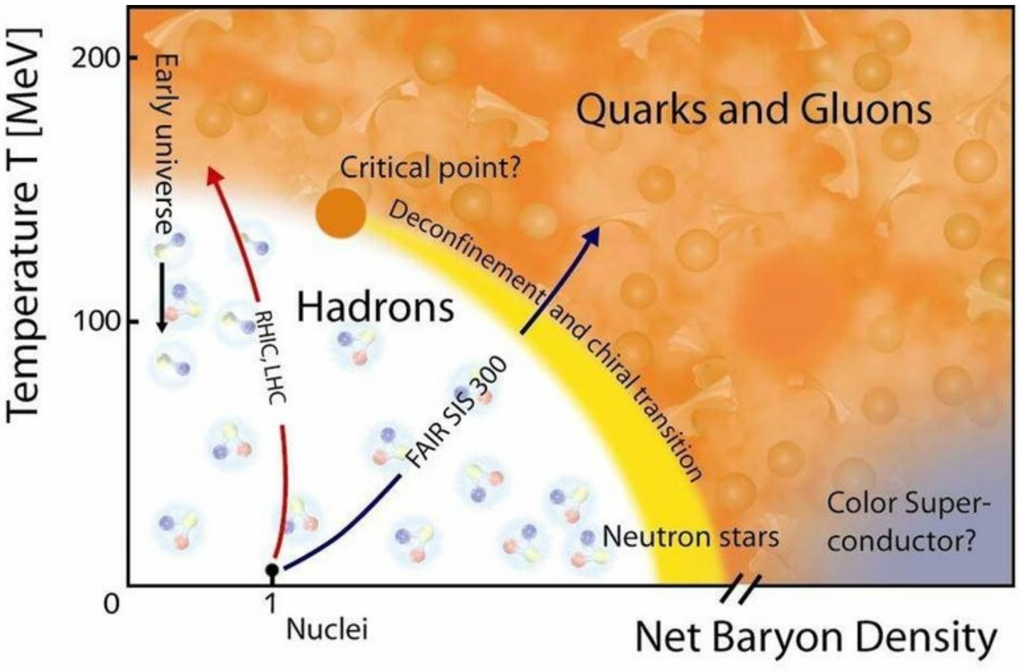
- Analysis of correlation and fluctuatation can provide information about **early stages of collsions.**

- Provide information about **properties of quark-gluon plasma.**

- Sensitive to **phase transition**:
  → insights into phase transitions between hadronic and partonic matter.

- Provide insights to understanding the **initial conditions** and **geometry** of the colliding nuclei.

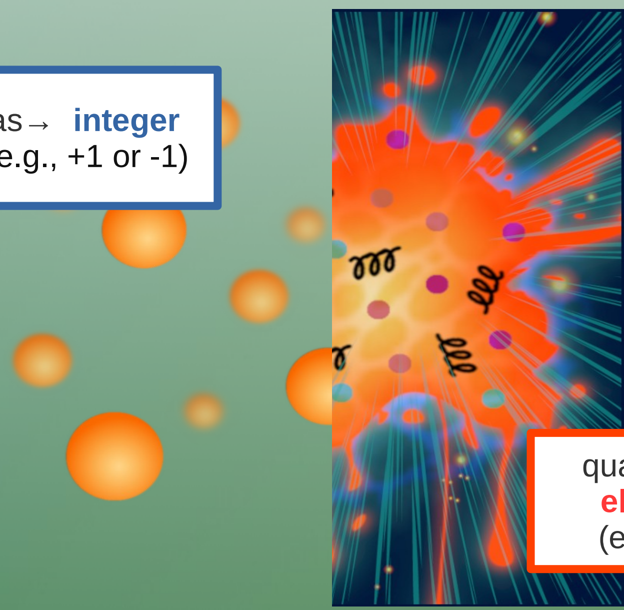
- Validation of **theoretical models of particle production**.



Motivation: Why do we study correlations and fluctuations?

Net-charge fluctuations

hadron gas → **integer charges** (e.g., +1 or -1)

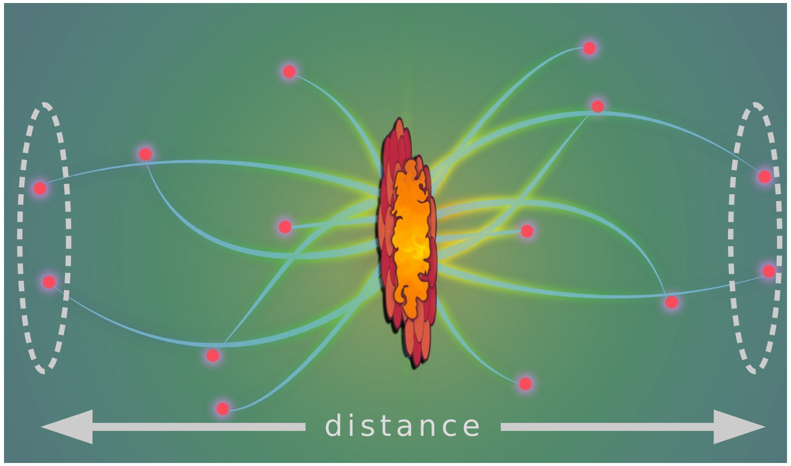


quarks → **fractional electric charges** (e.g., +2/3 or -1/3)

- Charge fluctuations are sensitive to the square of the charges of particles in the medium.

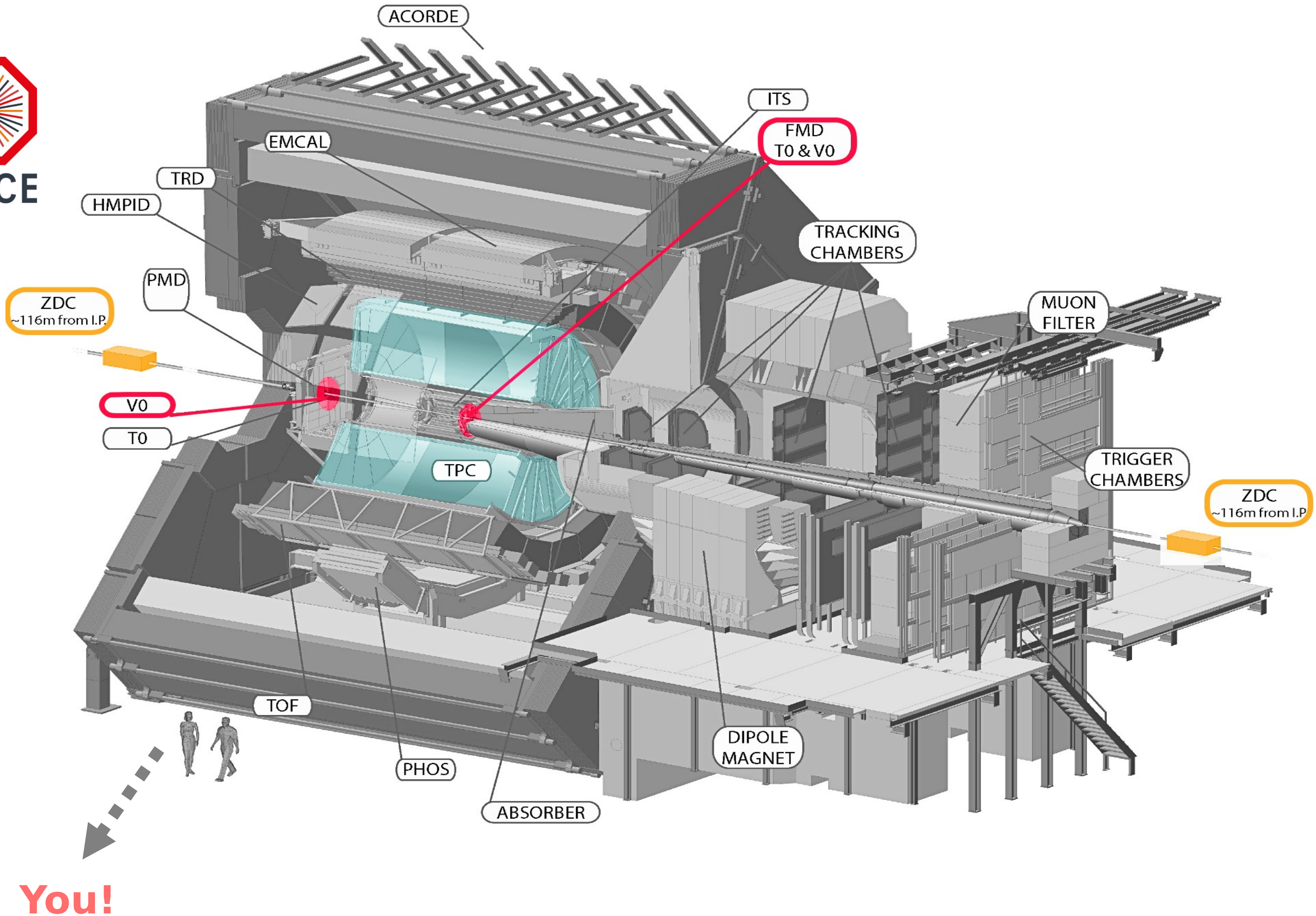
hadron gas > QGP

Long-Range Correlations (LRC):



- LRC carry **information** on the **early dynamics** of the nuclear collisio

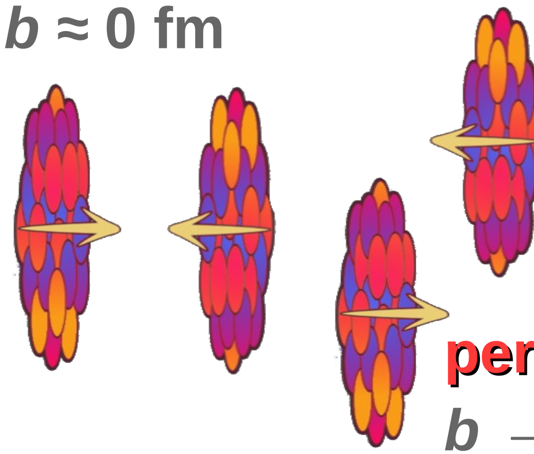
TheAnalysis: How do we study correlations and fluctuations?



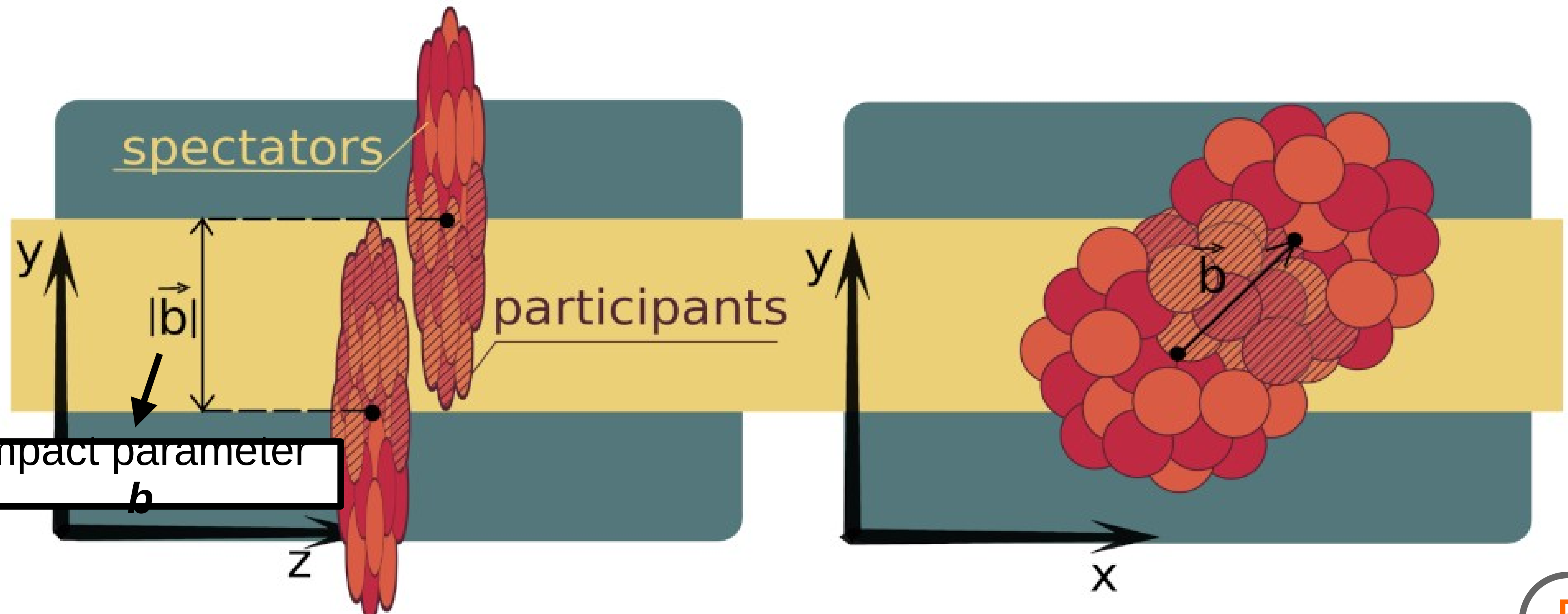
Geometry of collision & the concept of centrality

- Heavy-ions are **extended objects**;
- Systems created in **central head-on collisions** are different from those in **peripheral collisions**;
- Geometry of the collision = initial **overlap region** of the colliding nuclei → defined by **the impact parameter, *b*;**
- Impact parameter challenges: not directly measurable in experiments...neither **number of participants**.

central:
b **≈ 0 fm**



peripheral:
b **→ large**



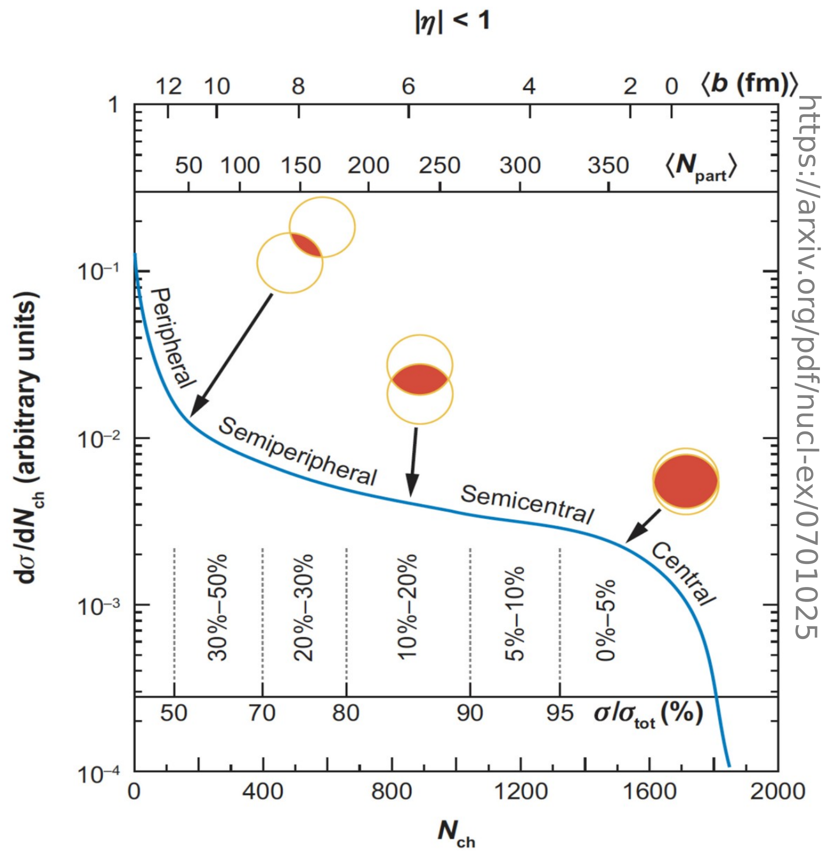
impact parameter
b

Geometry of collision & the concept of centrality

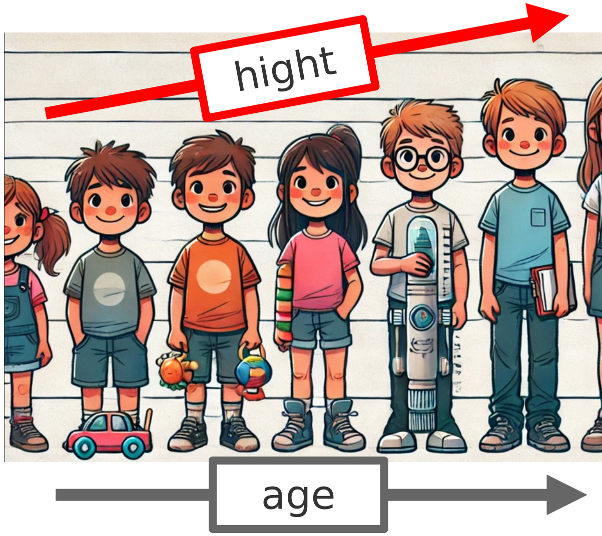
How to classify geometry in the experiment?

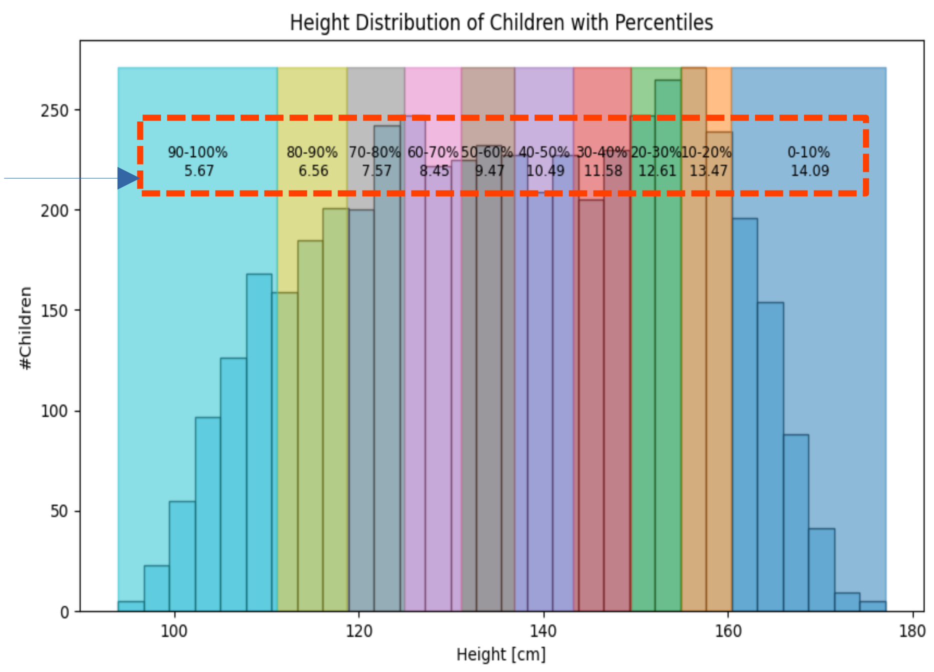
Use observable that **scales monotonically with impact parameter** like particles multiplicty, energy of the spectator system...

Centrality[%] → fraction of the total cross section, **percentile** of events with the highest multiplicity or with the highest number of participants.

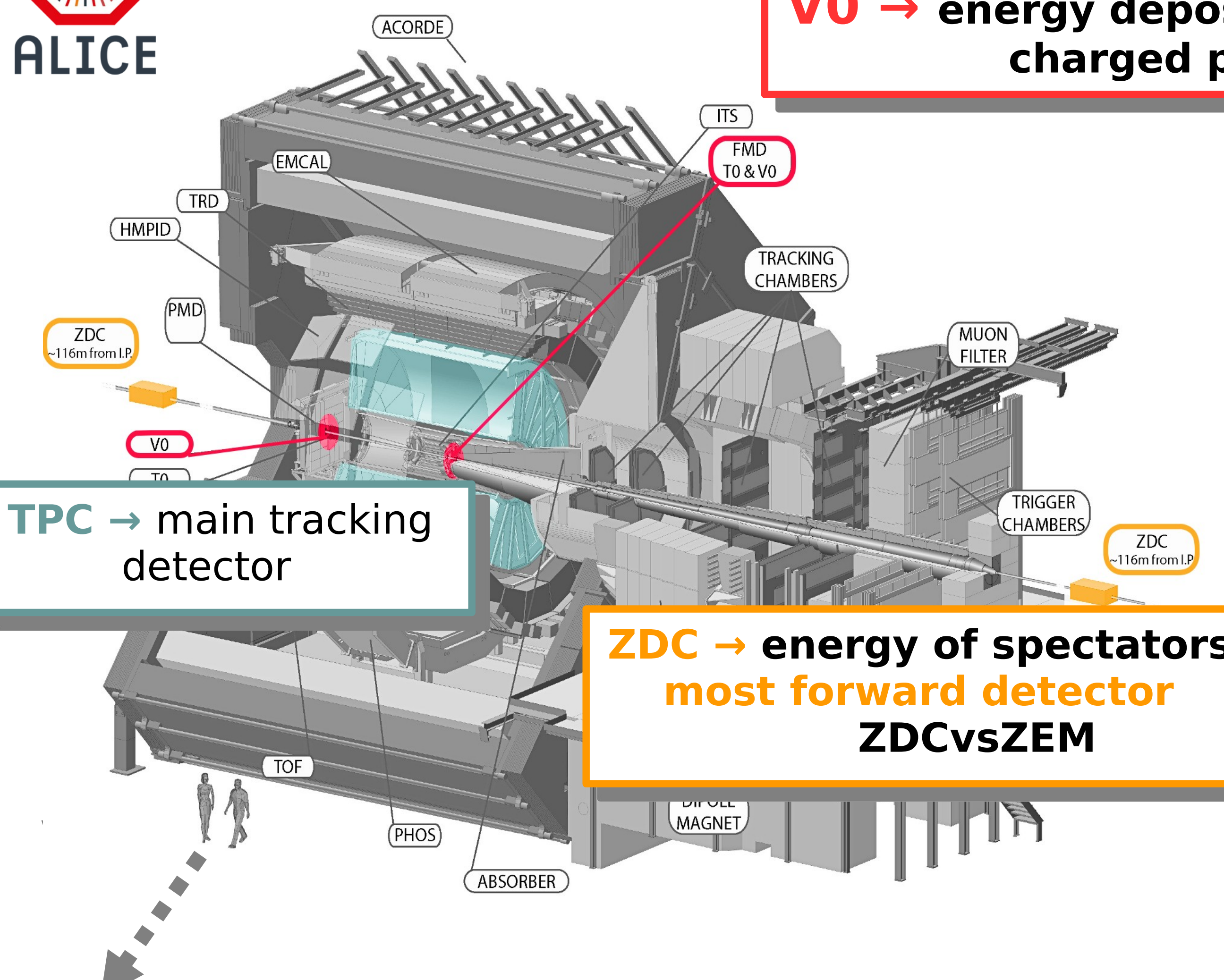


Centrality Analogy:
Classifying Children by Height Percentiles





How do we study correlations and fluctuations?

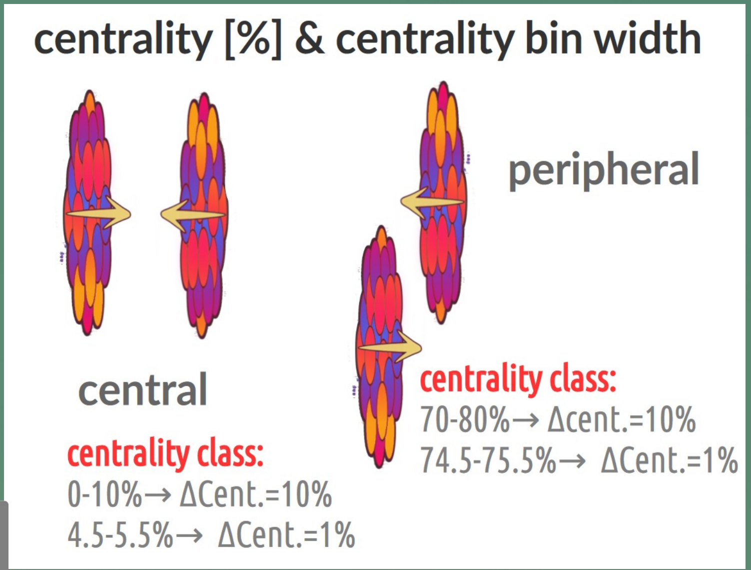


V0 → **energy deposition by charged particles**

TPC → main tracking detector

ZDC → **energy of spectators**
most forward detector
ZDCvsZEM

You are here!

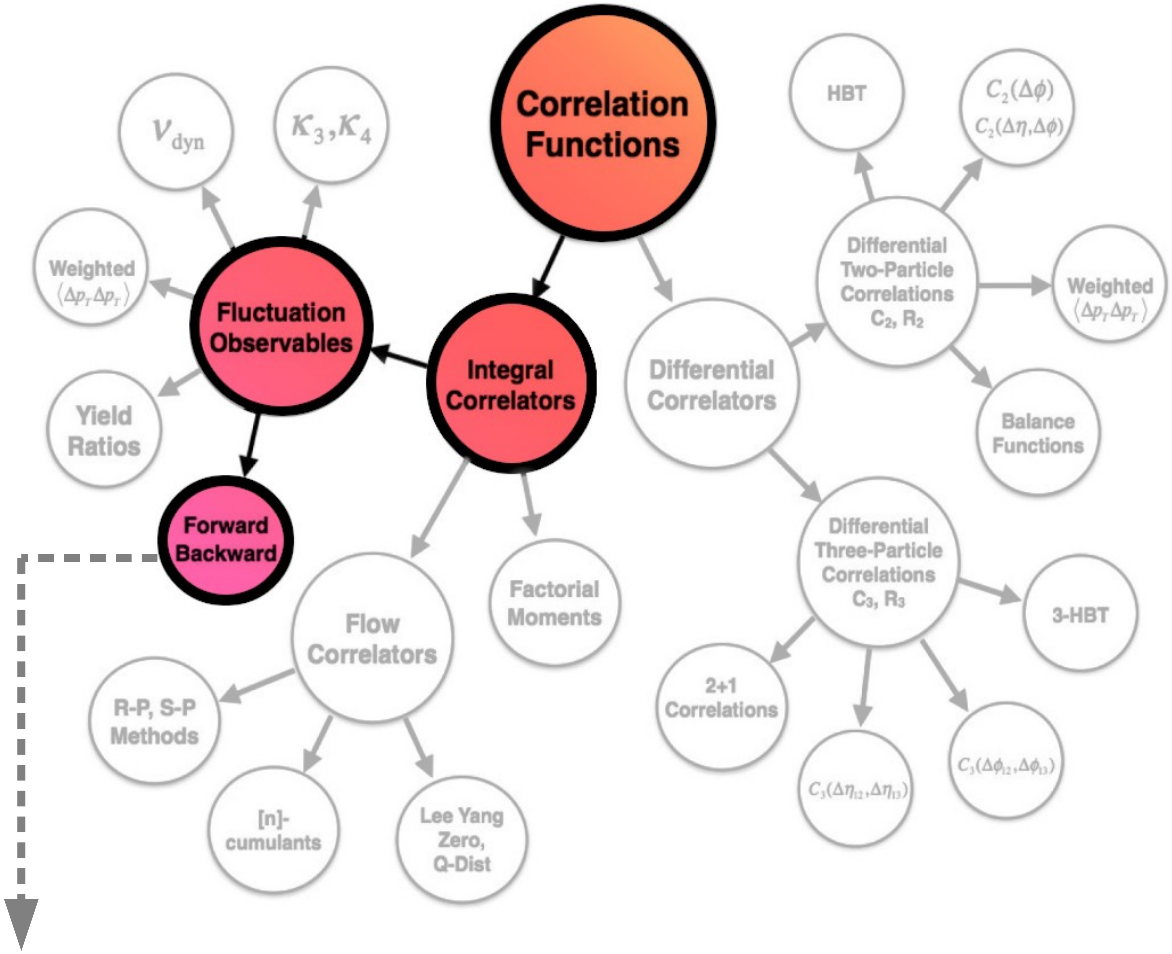


Experimental data:

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

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

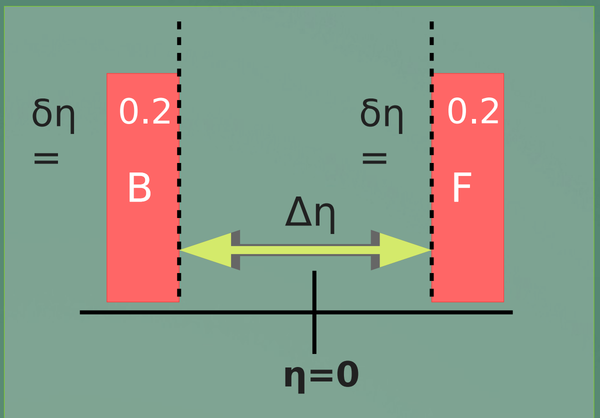
The Analysis: How do we study correlations and fluctuations?

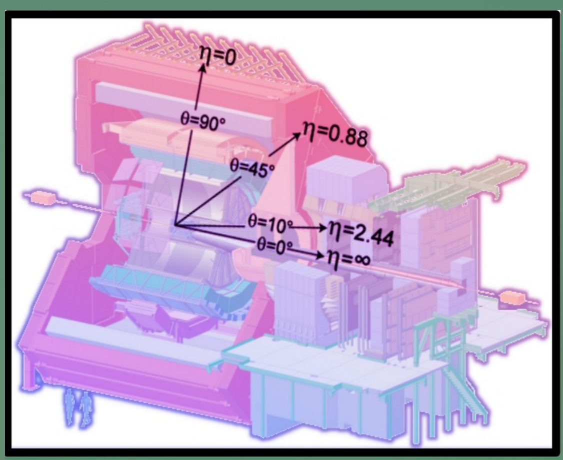


We are here!

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

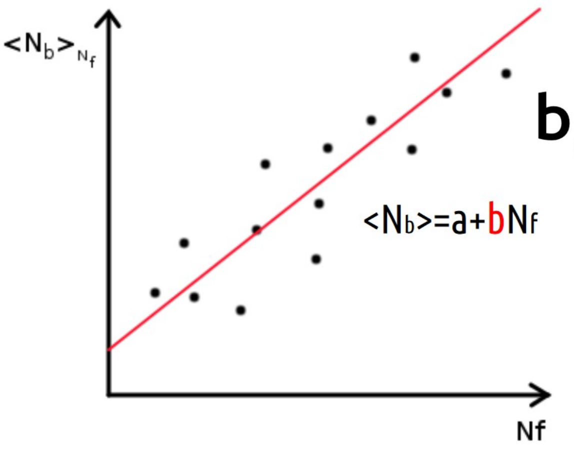
The forward-backward (FB) correlation:





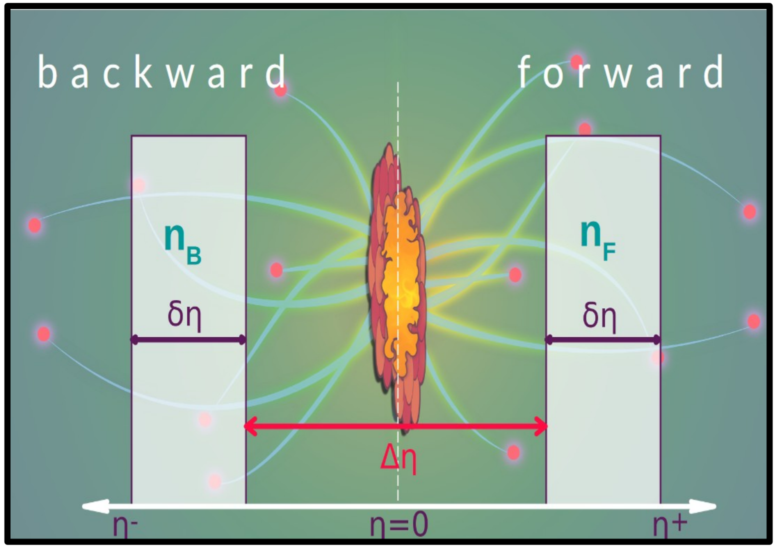
The Analysis: FB correlations

Correlation coefficient:

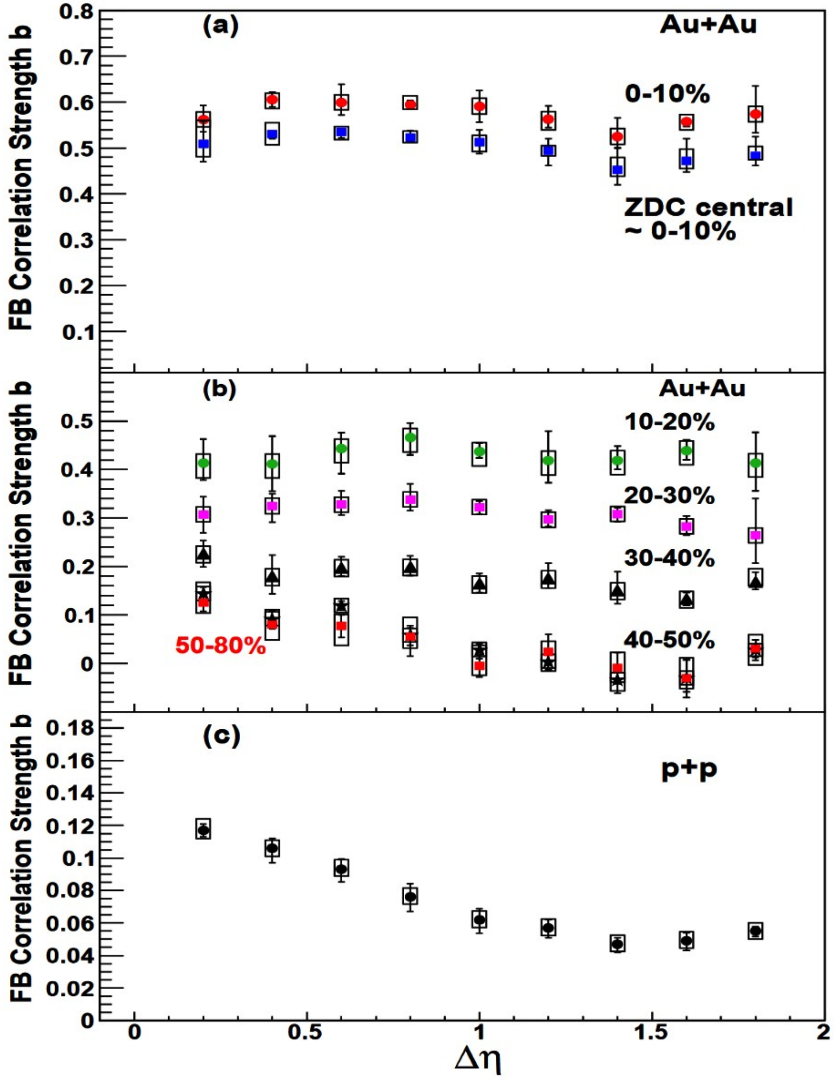


$$b_{corr} = \frac{Cov(n_F, n_B)}{\sqrt{Var(n_F) Var(n_B)}}$$

central



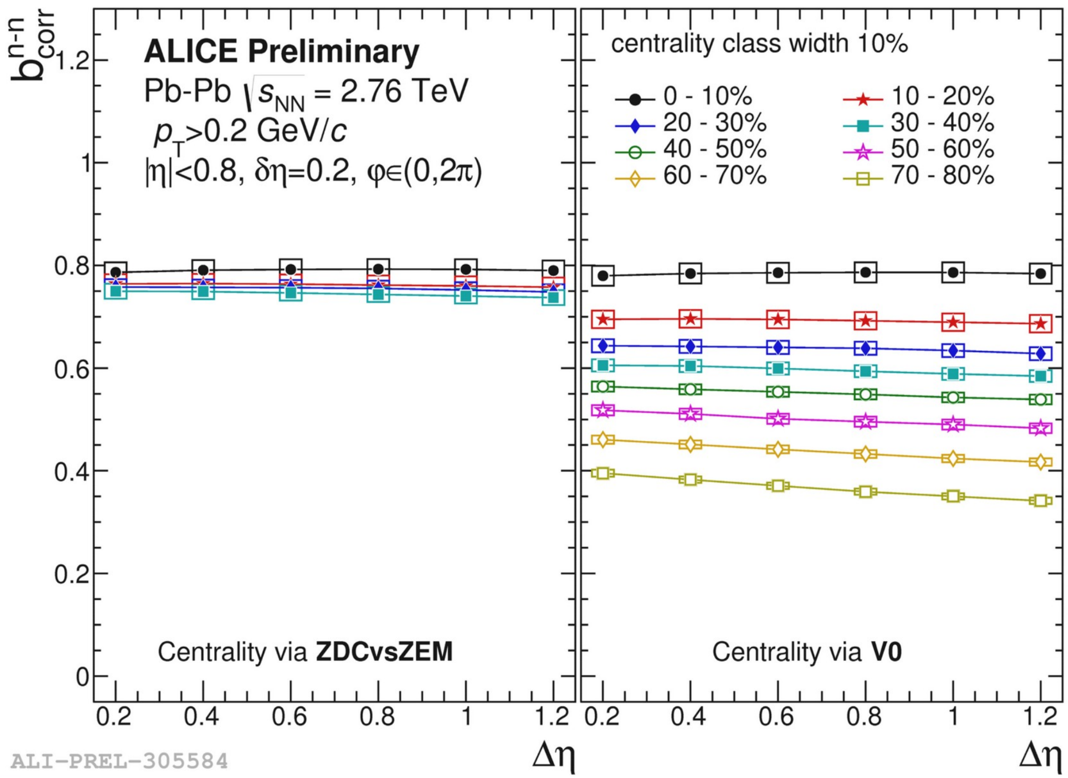
First results on FB correlation in ultrarelativistic heavy-ion colisions, STAR Collaboration



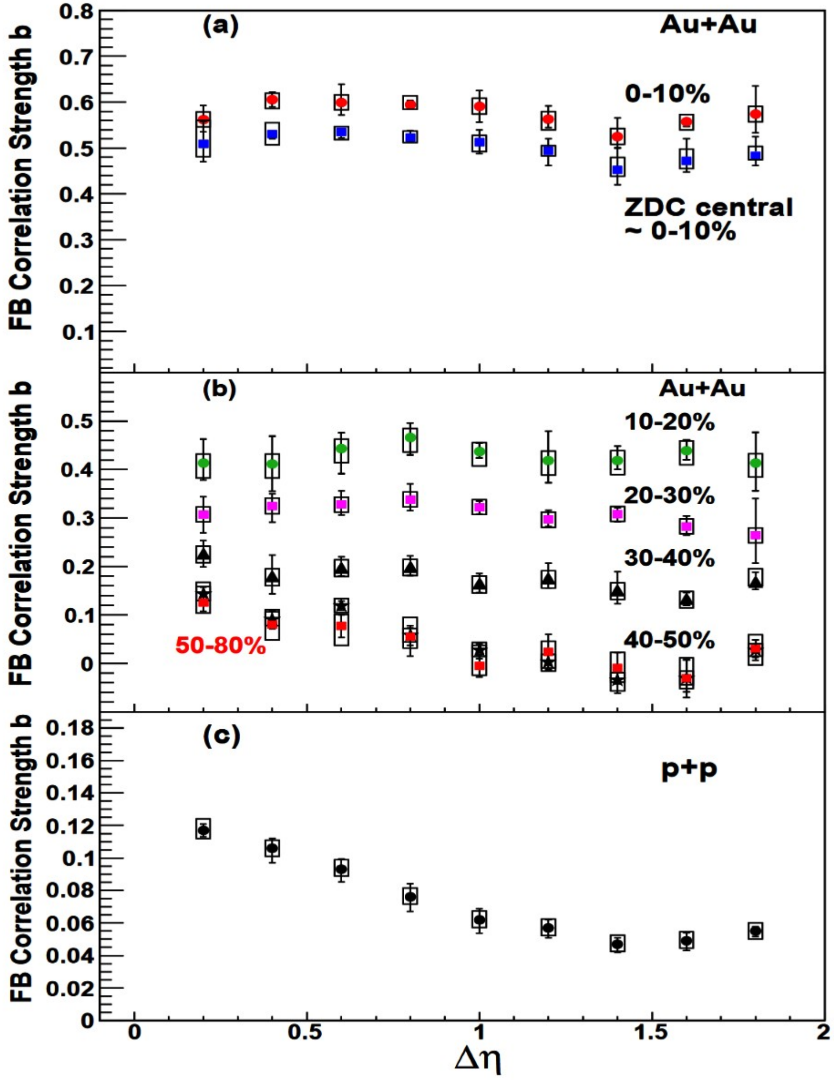
STAR Collaboration, Phys.Rev.Lett. 103 (2009) 172301

The Analysis: FB correlations

ALICE:



First results on FB correlation in ultrarelativistic heavy-ion colisions, STAR Collaboration



STAR Collaboration, Phys.Rev.Lett. 103 (2009) 172301

- Large values of b_{corr} for 10% (large) intervals of centrality classes,
- b_{cor} in central AA colisions > pp
- Evident dependence on centrality estmator.

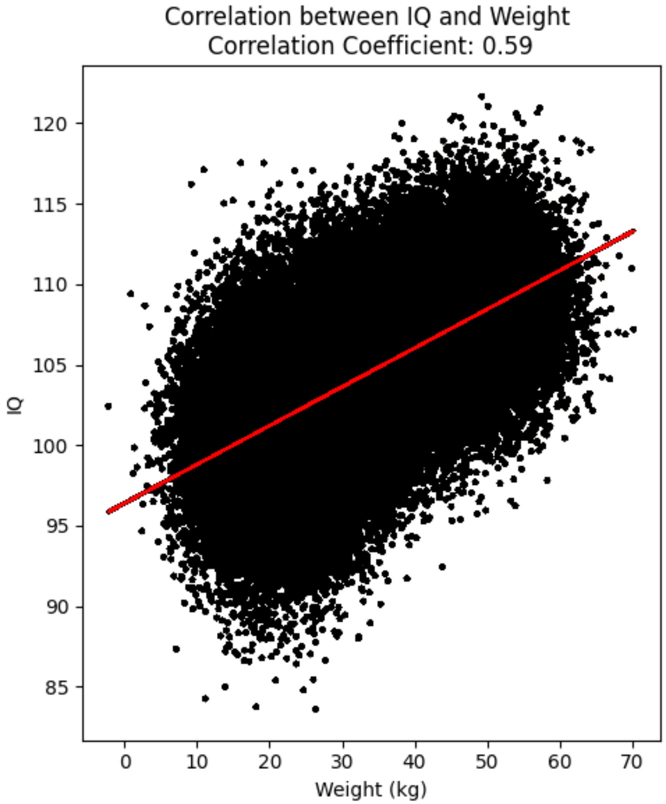
The Analysis: FB correlations

Schoolchildren

W. Krzanowski,Principles of Multivariate Analysis, Oxford U. Press, 2000

$b_{corr}(\textbf{weight}, \textbf{IQ}) \approx \textbf{0.6}$

Large correlations



The Analysis: FB correlations

Schoolchildren

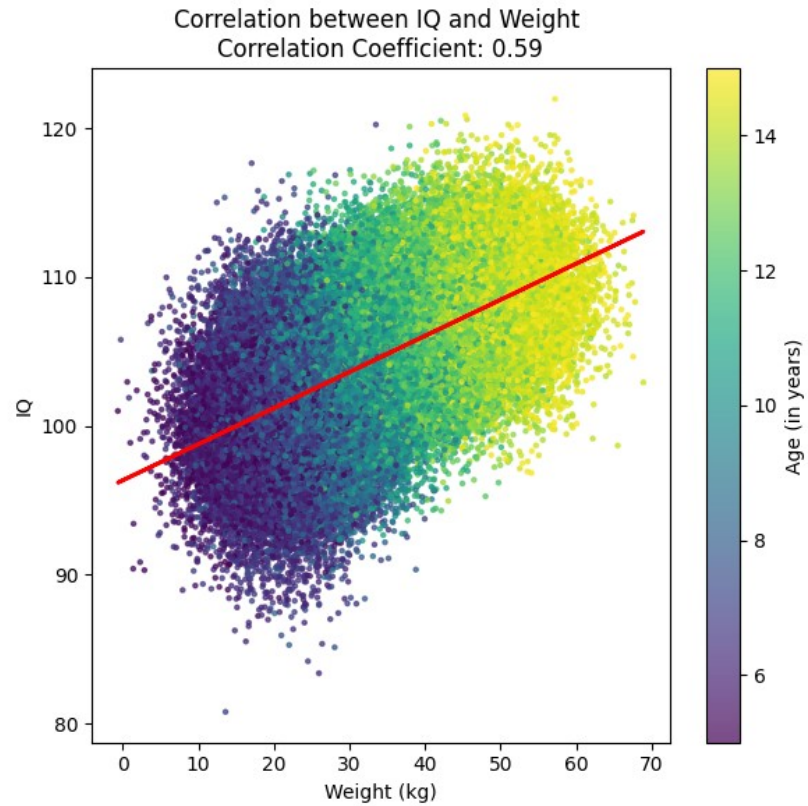
W. Krzanowski,Principles of Multivariate Analysis,
Oxford U. Press, 2000

b_{corr}(**weight**, **IQ**) ≈ **0.6**

age fluctuation

Large correlations

Spurious effect of external variable leads to absurd conclusions!



The Analysis: FB correlations

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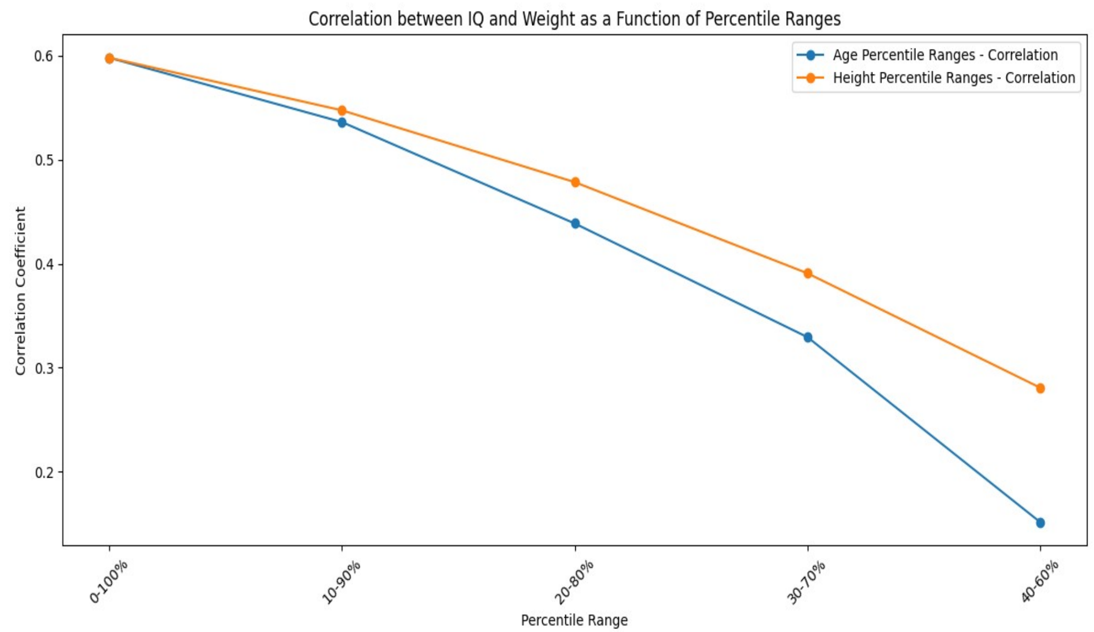
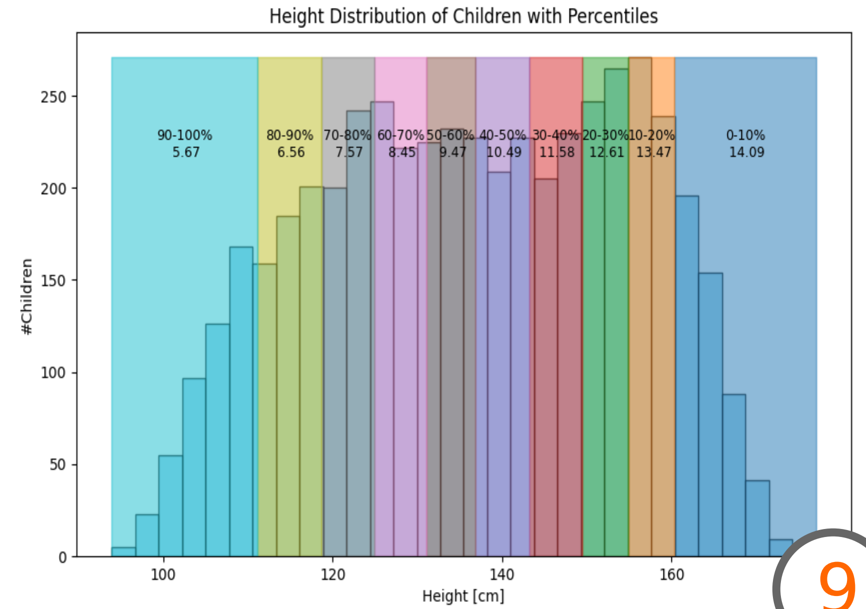
strict age selection





Schoolchildren

W. Krzanowski, Principles of Multivariate Analysis, Oxford U. Press, 2000

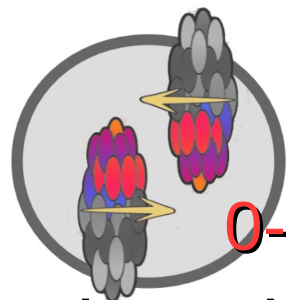
b_{corr}(**weight**, **IQ**) ≈ **0.6**

age fluctuation

Heavy-ion collisions

sample of most central Pb--Pb events

b_{corr}(**nF**, **nB**) ≈ **0.8**

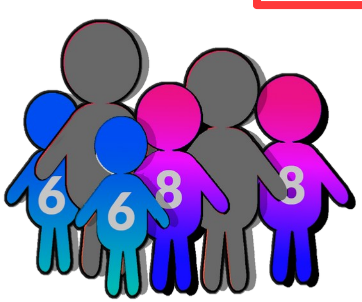


0-10%

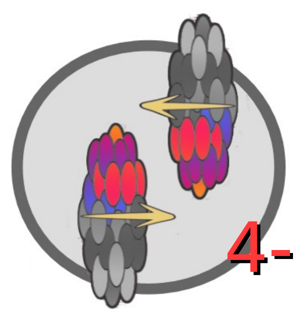
event geometrical fluctuation

Large correlations

Spurious effect of external variable leads to absurd conclusions!



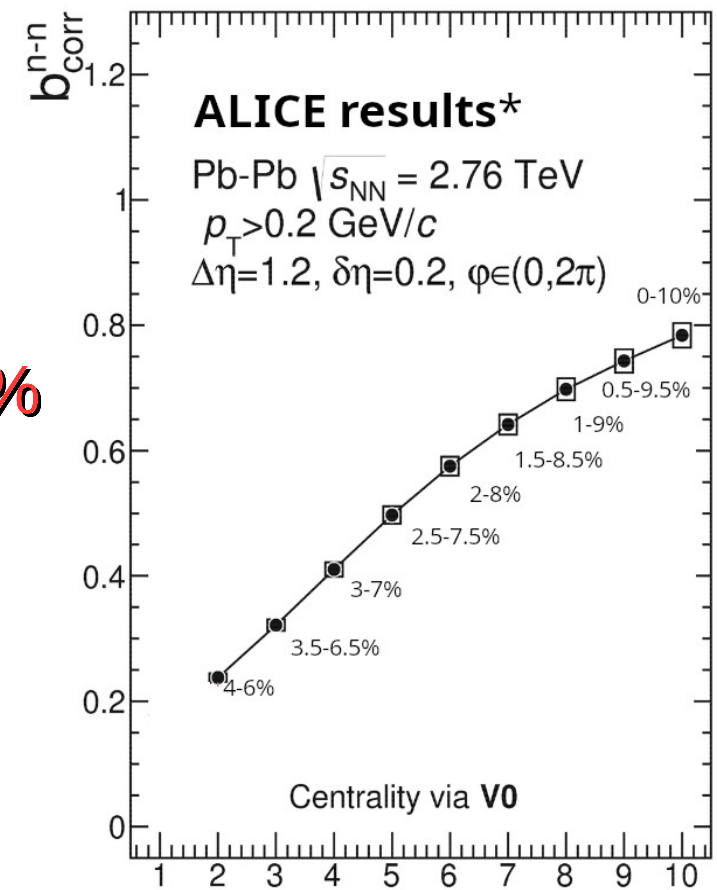
strict age selection



4-6%

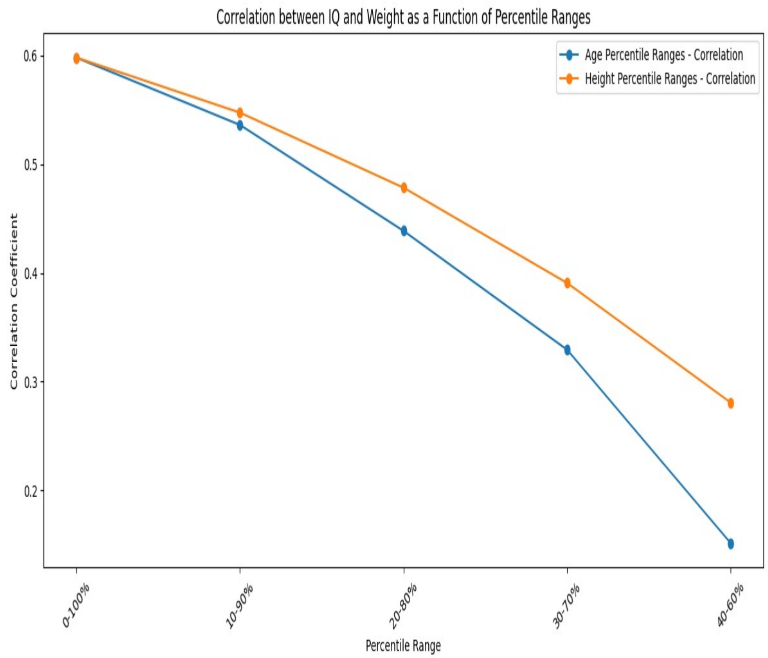
narrow centrality classes

*redrawn form
I.Sputowska. [ALICE], MDPI Proc. 10 (2019) 1, 14
DOI: 10.3390/proceedings2019010014

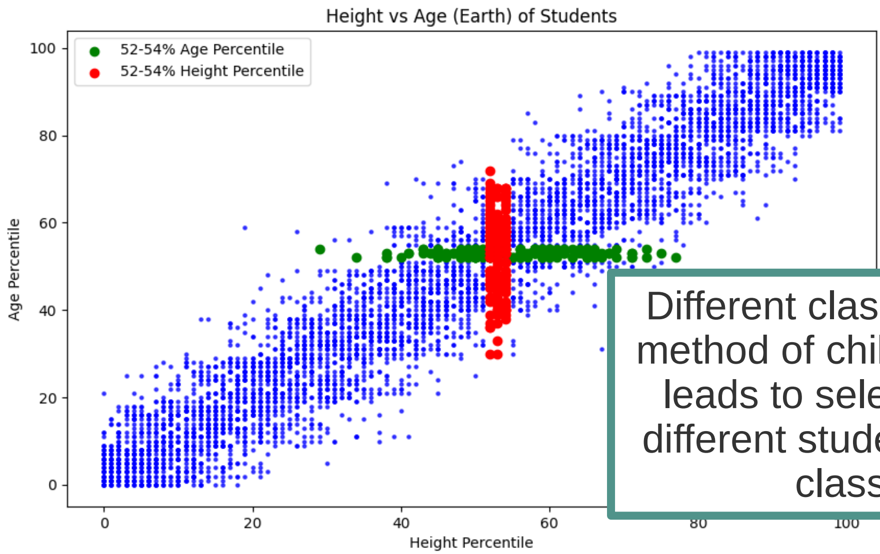


centrality bin width %

The Analysis: FB correlations



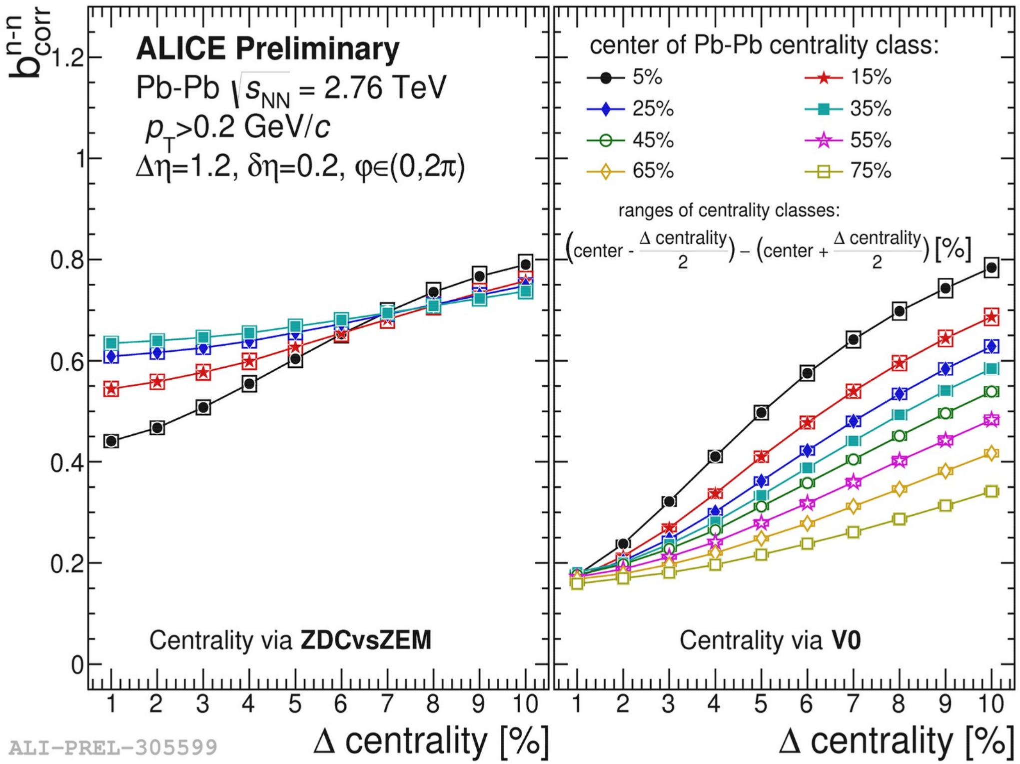
How to explain dependence on cetrality estimator?



Different classification method of children age leads to selection of different student in the class

Centrality estimator: spectators in ZDC

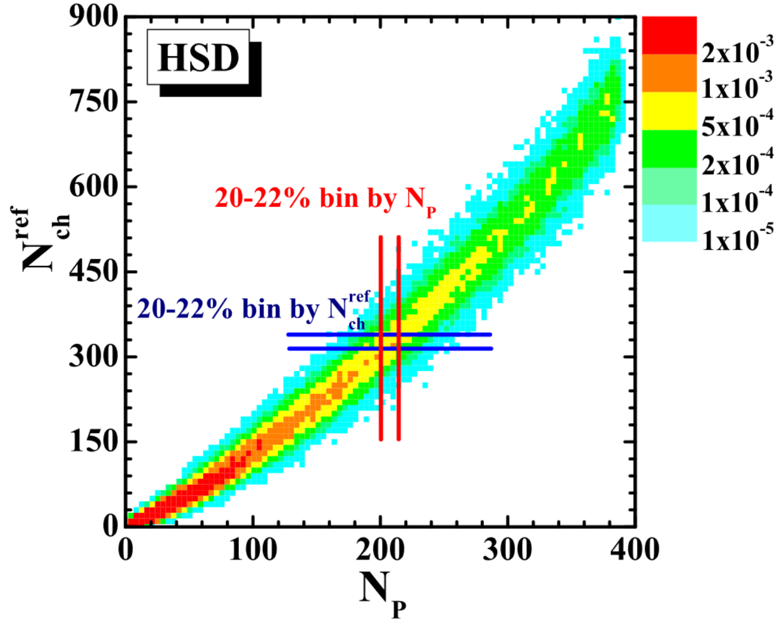
Centrality estimator: charged particles in V0



increase of volume fluctuations

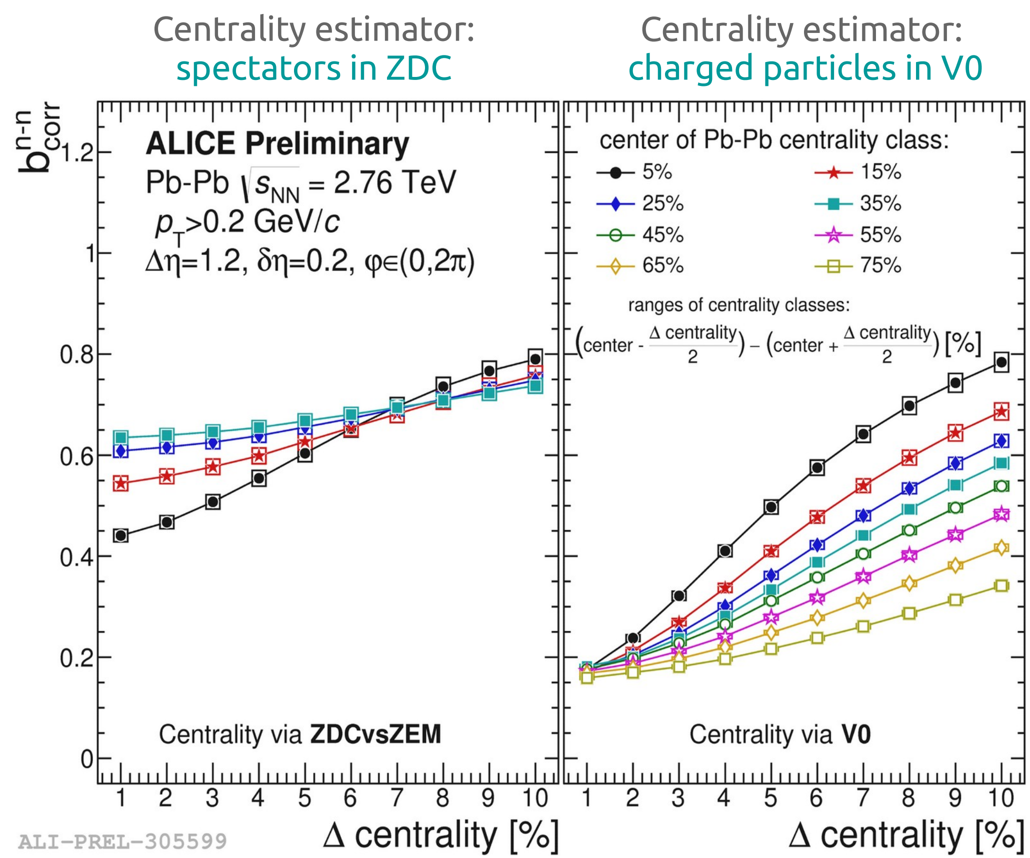
- Dependence on centrality estimator;
- Drop of the value of b_{corr} (**reduced volume fluctuations**).

The Analysis: FB correlations



How to explain dependence on cetrality estimator?

- Different centrality selection methods lead to varying in events entering the data samples.
- More evident for narrow centrality class.
- Aslo different events in data sample → different contribution form volume fluctuations



increase of volume fluctuations

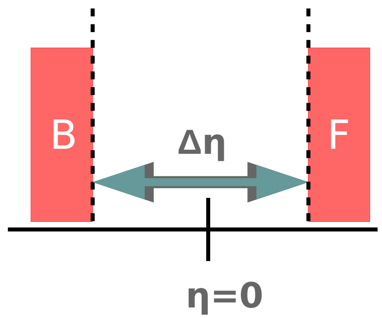
- Dependence on centrality estimator;
- Drop of the value of b_{corr} (**reduced volume fluctuations**).

Introduction: 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:



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

where ω is scaled variance: ω=Var(n)/<n>

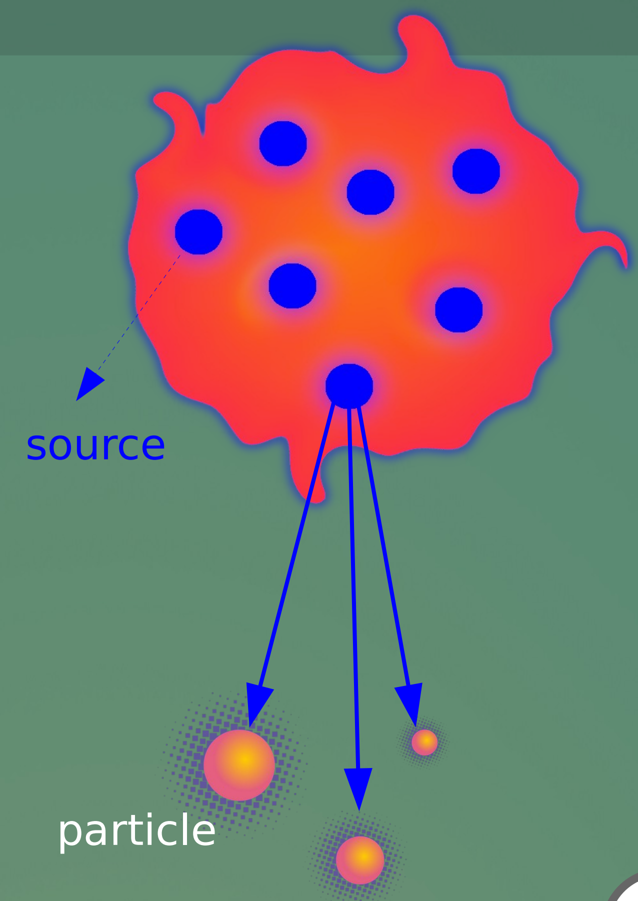
- For a symmetric collision $\boldsymbol{\omega_B = \omega_F}$ and $\boldsymbol{\langle n_F\rangle = \langle n_B\rangle}$,

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

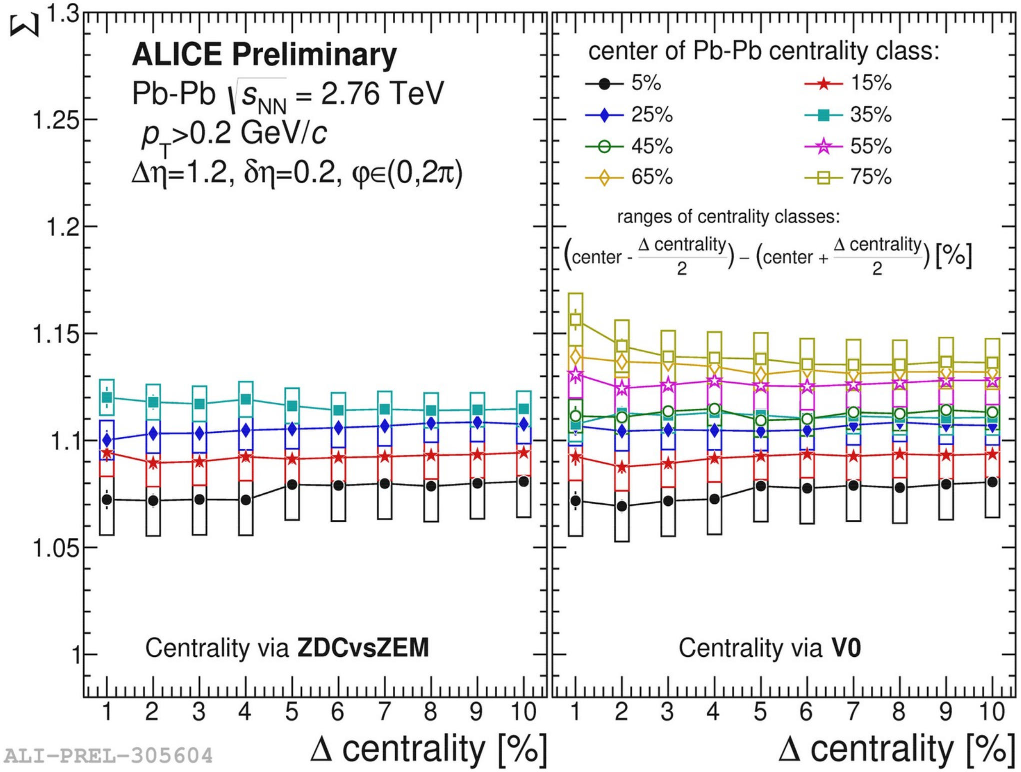
For Poisson distribution: $\omega=1$ & $b_{corr}=0 \rightarrow \Sigma=1$

Independent source model:

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

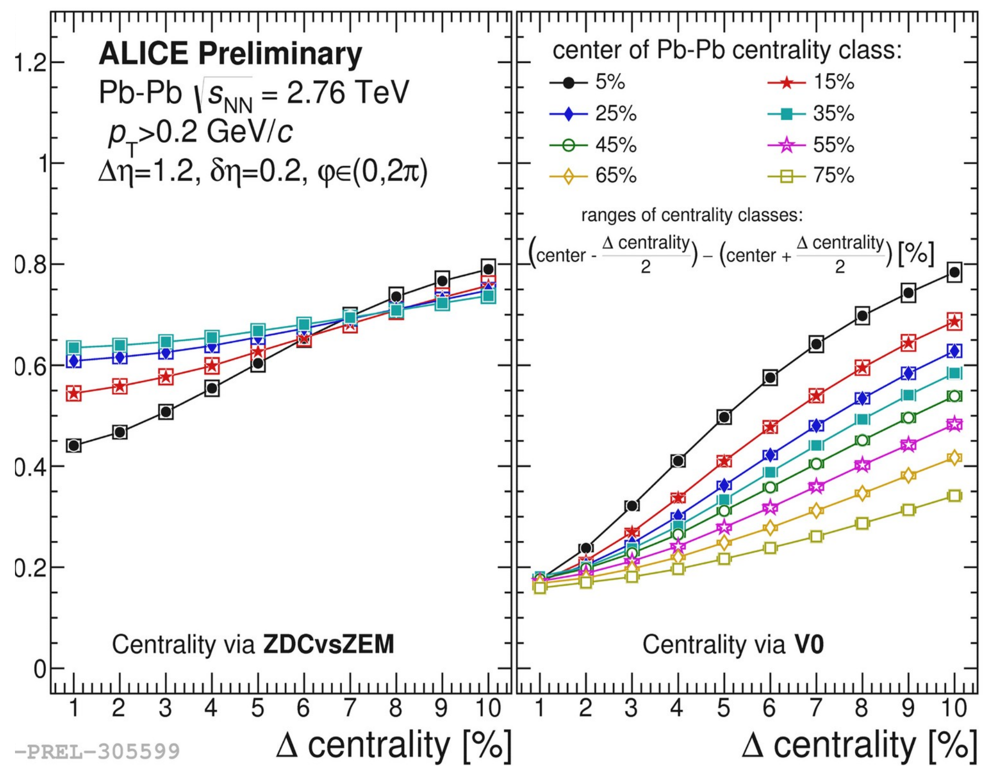


The Analysis: FB correlations



Centrality estimator: spectators in ZDC

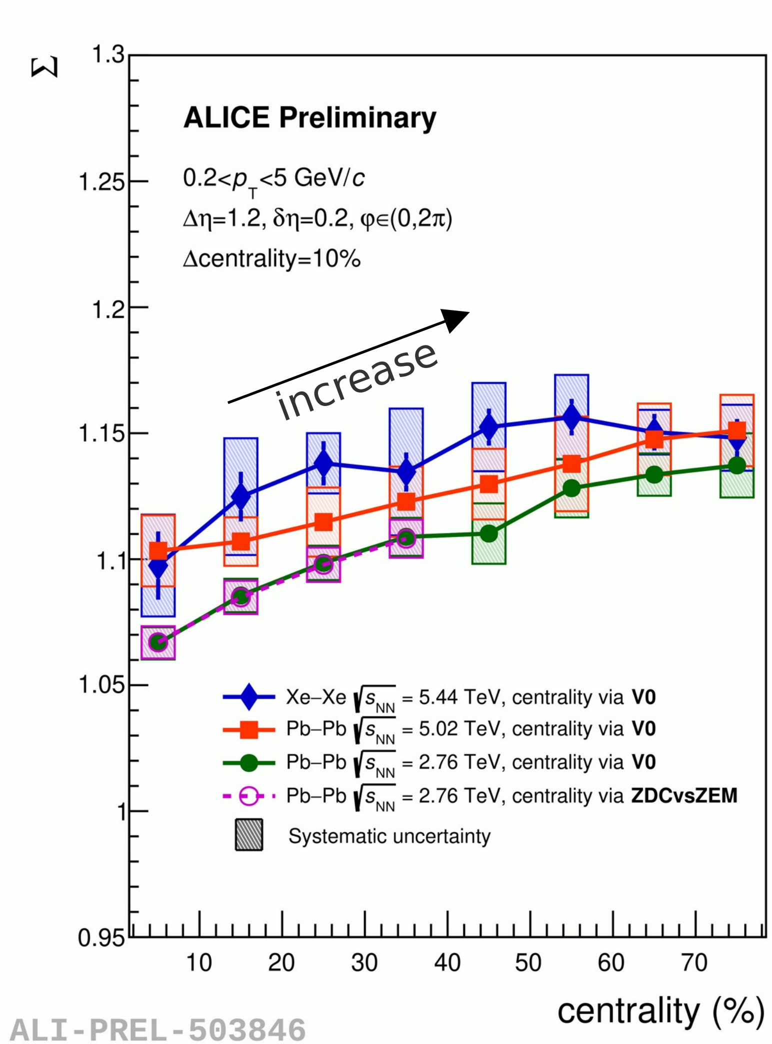
Centrality estimator: charged particles in V0

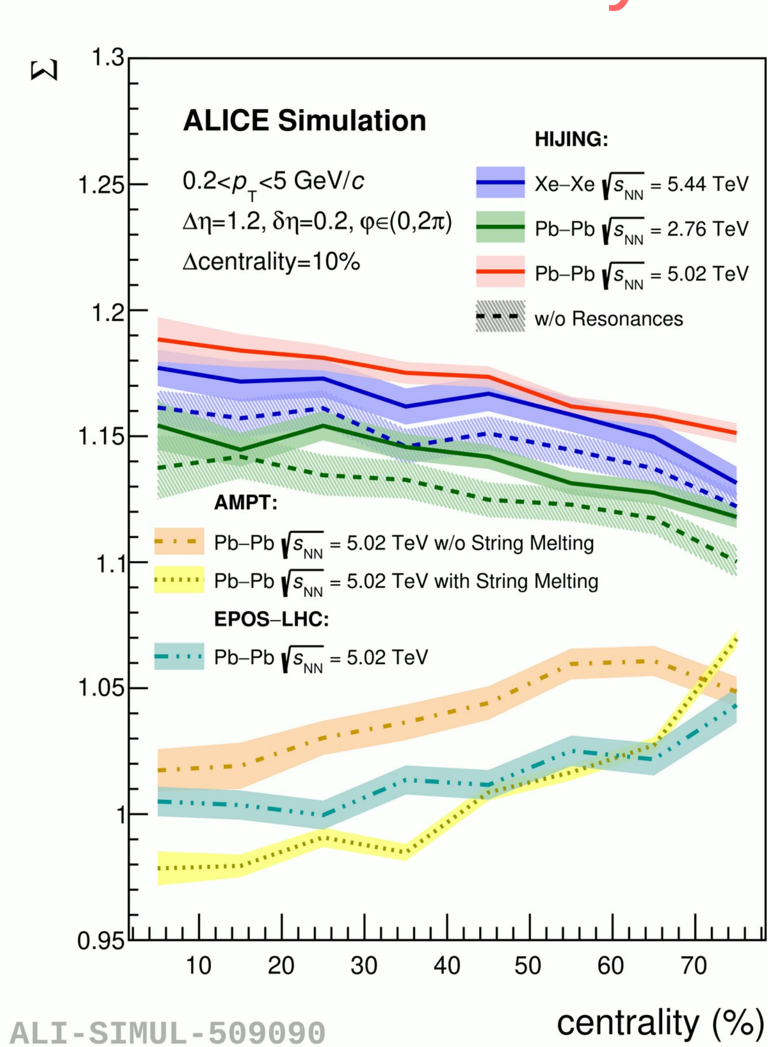


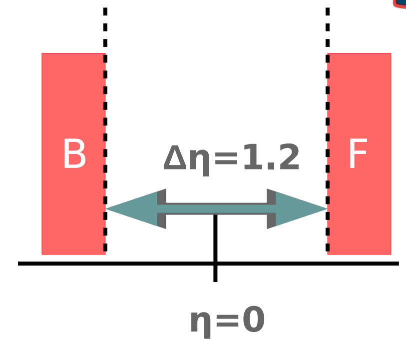
increase of volume fluctuations

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

Results: Σ as a function of centrality







- **Σ increases with energy;**
- **Σ increases 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.