Event-by-event fluctuation and correlation measurements at the LHC energies in ALICE

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At high energy nuclear collisions, several observables could be studied on an Event-by-Event (E-by-E) basis.

**E-by-E fluctuations** → contain information on the dynamics and correlations in pp, p-A and A-A collisions.

ALICE experiment at LHC → small $\mu_B$ and high Temperature (T).

So → Possibility of chiral phase transition is in the crossover region.

→ Study of E-by-E fluctuations of conserved quantities

→ nature of matter produced at the collision and evolution of fluctuation.
◆ ALICE: Experimental Setup

◆ ALICE Results:
  □ Mean $p_T$ Fluctuations
  □ Net Charge Fluctuations
  □ Balance Function
  □ Multiplicity Fluctuations
  □ Particle Ratio Fluctuations
  □ Higher Moments Studies
  □ Temperature Fluctuations

◆ Summary and Outlook
Main Detectors used for E-by-E observables:
- TPC + ITS & TOF (For Tracking and PID)
- ITS (For Vertex)
- V0 (For Centrality)

Data Taken:
- Pb-Pb @ $\sqrt{S_{NN}} = 2.76$ TeV
- p-Pb @ $\sqrt{S_{NN}} = 5.02$ TeV
- pp @ $\sqrt{S} = 0.9, 2.76, 7$ TeV.
As the total energy is conserved and almost all the particles are produced in transverse directions, study of E-By-E mean $p_T$ fluctuations of charged particles $\rightarrow$ energy fluctuation

$$\sigma_{\text{total}}^2 = \sigma_{\text{stat}}^2 \pm \sigma_{pp}^2 \pm \sigma_{AA}^2$$

$$\sigma_{\text{dyn}}^2 = C_m = \langle \Delta p_{T,i}, \Delta p_{T,j} \rangle = \frac{1}{\sum_{k=1}^{n_{\text{ev}}} N_{\text{pairs}}^k} \cdot \sum_{k=1}^{n_{\text{ev}}} N_k \cdot \sum_{i=1}^{N_k} \sum_{j=i+1}^{N_k} (p_{T,i} - \langle p_T \rangle_m) \cdot (p_{T,j} - \langle p_T \rangle_m)$$

$C_m = 0$ for statistical fluctuations.

- Significant non-statistical fluctuations at low multiplicity
- Dynamical fluctuation “dilution” with multiplicity
- No significant collision energy dependence

Both in pp and heavy-ion data → No significant dependence on the collision energy is observed.

→ power law fit could describe both the pp and Pb-Pb data with same parameters.

→ Peripheral AA system in agreement with pp baseline.

→ Relative fluctuations for STAR and ALICE energies are described well by the pp baseline fit. Deviations are seen at higher multiplicities.

→ As a function of \(<N_{\text{part}}\>\), data from both experiments start to deviate from the power-law fit at the same centrality.

Net-Charge with full phase space $\rightarrow$ **ZERO** as charge is conserved.

**Hadron Gas**
- q = $\pm 1$

$\Rightarrow$ q$^2 = 1$

**QGP**
- q = $\pm 1/3$ or $\pm 2/3$

$\Rightarrow$ q$^2 = 1/9$ or $4/9$

How it behaves with limited rapidity window?

What will be the beam energy dependence?

What will be the centrality dependence?

**Definition $\rightarrow$ Dynamical charge fluctuations,**

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

$$D = 4 \frac{\langle (\delta Q)^2 \rangle}{N_{\text{ch}}} \approx \langle N_{\text{ch}} \rangle \langle \nu_{\text{dyn}} \rangle - 4 \approx \begin{cases} 4, (HG) \\ 3, (HRG) \\ 1 - 1.5, (QGP) \end{cases}$$

For, **Global Charge Conservation (GCC).**

$$\nu_{(+,-,\text{dyn})} = \frac{-2}{\langle N_+ \rangle} = \frac{-4}{\langle N_{\text{total}} \rangle}$$

So, $$\nu_{(+,-,\text{corr})} = \nu_{(+,-,\text{dyn})} + \frac{4}{\langle N_{\text{total}} \rangle}$$
Unlike sign pairs → more correlated
HIJING: little or no centrality dependence

The ‘function’ is according to M.A. Aziz and S. Gavin PRC 70, 034905 (2004).

Phys. Rev. Lett. 110, 152301
Beam energy dependence of net charge fluctuations
Creation of balancing charges in rapidly expanding medium

Definition used:

\[ B(\Delta \eta, \Delta \varphi) = \frac{S(\Delta \eta, \Delta \varphi)_{US}}{B(\Delta \eta, \Delta \varphi)_{US}} - \frac{S(\Delta \eta, \Delta \varphi)_{LS}}{B(\Delta \eta, \Delta \varphi)_{LS}} \]

Where, \[ US = + - / - + \]
\[ LS = + + / -- \]

Early stage creation: larger final separation, wider balance functions.
Late stage creation: pairs more correlated, narrower balance functions.

• But: stronger flow → pairs also more correlated, narrower balance functions.

S. Bass, P. Danielewicz and S. Pratt
Phys. Rev. Lett 85, 2689
→ Centrality dependence: both narrowing in $\Delta \eta$ and $\Delta \phi$ from peripheral to central =>
Suggests expanding/flowing medium.

→ Width remains almost similar in both RHIC and LHC energy.
System Size dependence

Centrality Dependence $\Delta \eta$

Narrowing of Balance function with increasing multiplicity in both $\Delta \eta$ and $\Delta \phi$ in low $p_T$ region.

ALICE Collaboration, arXiv:1509.07255
Characterized by scaled variances. So by definition,

$$\omega_{N_{ch}} = \frac{\langle N_{ch}^2 \rangle - \langle N_{ch} \rangle^2}{\langle N_{ch} \rangle} = \frac{\text{Var}(N_{ch})}{\langle N_{ch} \rangle}$$

Where, \( \langle N_{ch} \rangle = \frac{\sum N_{ch}}{n} \)

\( \text{Var}(N_{ch}) = \sigma_{ch}^2 = \langle N_{ch}^2 \rangle - \langle N_{ch} \rangle^2 \)

Dynamical fluctuations (other than the statistical fluctuation and fluctuation in the number of participants)

may provide insights on the intrinsic mechanisms of the particle production.

Selection of centrality window:

Bin-Width Correction

$$X = \frac{\sum_{i=1}^{k} n_i X_i}{\sum_{i} n_i} = \sum_{i} w_i X_i$$
The centrality dependence of scaled variance is shown, which decreases from peripheral to central.

The dynamical fluctuation for multiplicity, ranges within ~ 2-4.

Neither AMPT or HIJING is following the trend like data.
- Particle Ratio Fluctuations
  → See Mesut’s poster presentation.
  (New Results)

- Higher Moments Studies (of net-charge)
  → Results are almost final, coming soon.

- Temperature Fluctuations
  → Analysis ongoing, coming soon.
✧ We have presented recent results on Event-by-event correlation and fluctuations for ALICE experiment at LHC energy for different observables from different systems (from pp to p-Pb to Pb-Pb systems).

✧ Many more results for pp @ $\sqrt{S} = 8$ TeV and 13 TeV will come soon. We have collected a very good data set in recent runs.

✧ Data for Pb-Pb @ $\sqrt{S_{NN}} = 5$ TeV will be taken in November 2015. So, Stay tuned...
Assume the particle production increases monotonically with the overlap
→ categorize events in centrality percentiles through Glauber model, in which nuclear density profile and nucleon-nucleon cross section to link centrality to
→ number of participants \(N_{\text{part}}\)
\&
→ number of binary collisions \(N_{\text{coll}}\)

The centrality is selected using the VZERO amplitude as the default estimator

- Centrality bins: 0-5%, 5-10%, 10-20%,..., 70-80%
- Different centrality estimators (TPC tracks, SPD clusters).