Global and Local Temperature Fluctuations in High Energy Heavy-ion Collisions

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Abstract: Temperature fluctuations have been discussed in the literature as a means of characterizing the evolving system. The fluctuations may have two distinct origins, first, quantum fluctuations that are initial state fluctuations, and second, thermodynamical fluctuations. We discuss a method of extracting the thermodynamic temperature from the mean transverse momentum of pions, by using controllable parameters such as centrality of the system, and range of the transverse momenta. Event-by-event fluctuations in global temperature over a large phase space provide the specific heat of the system. We present Beam Energy Scan of sp. heat from data, AMPT and HRG model prediction. For Pb-Pb collisions at the Large Hadron Collider (LHC) energies, because of the production of a large number of particles in every event, it is possible to divide the phase space into small bins and obtain local temperature for each bin. Event-by-event fluctuations in local temperature can be obtained by following a novel procedure of making fluctuation map of each event

Introduction:

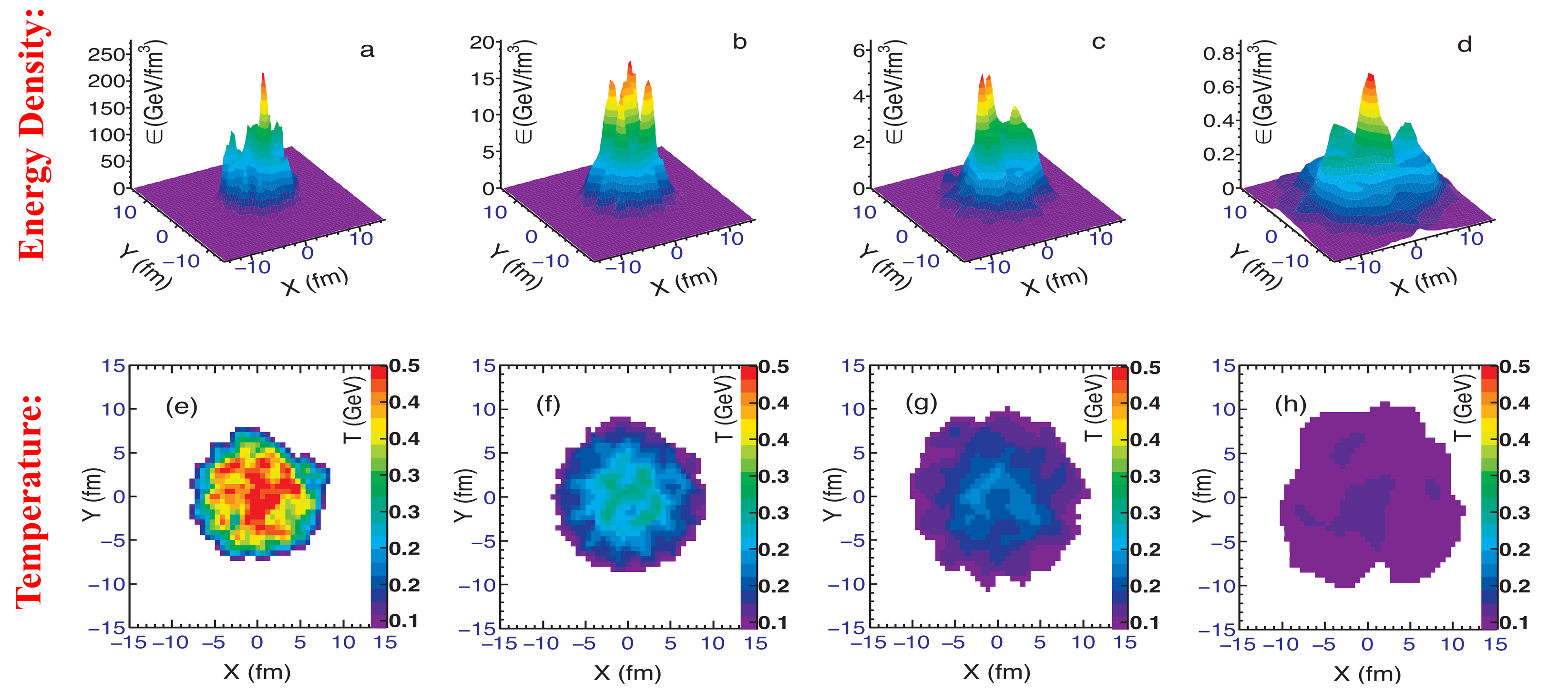
=> The physics of heavy-ion collisions at ultra-relativistic energies, popularly known as little bangs, has often been compared to the early Universe Big Bang phenomenon. We propose to make maps of the little bang, analogous to the CMBR maps, and use fluctuation measures to quantitatively probe the early stages of the heavy-ion collisions.

=> Fluctuation maps in bins of rapidity (y) and azimuthal angle (φ) are made from AMPT event generator which can be a proxy for experimental data.

=> A (2+1)-dimensional event-by-event ideal hydrodynamical framework to model the evolution of the produced system and make maps of ε and T from initial time to freeze-out, and estimate their relative fluctuations.

=> By making a correspondence of measured fluctuations with the time evolution profiles of the fluctuations from hydrodynamic calculations, we show that it is possible to visualize the thermodynamic conditions which presumably existed at different stages of evolution.

Energy density and Temperature:



Elapsed time ⟶

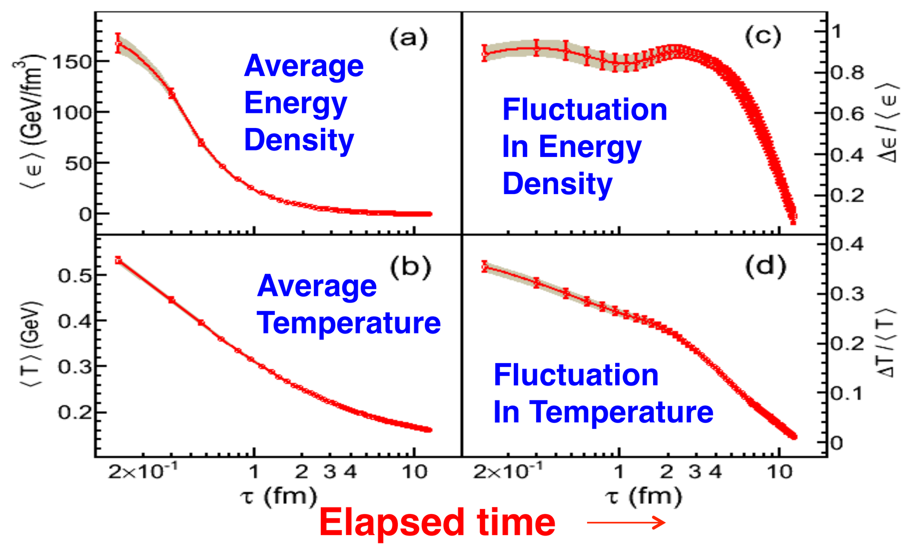
Observations from hydrodynamic calculations:

- At early times system is inhomogeneous and quite violent:
  - ➢ sharp and pronounced peaks in energy densit & hotspots in temperature
  - ➢ Extremely large fluctuations (~90%) in energy density
- With time, the system cools, expands and bin-to-bin variations smoothens
- Energy density drops fast, the fluctuation in energy density remains almost constant up to τ~2.5 fm, then falls rapidly.
- A kink in fluctuation of temperature observed around same time

Hydrodynamics Framework:

- (2+1)dimensional event-by-event ideal hydrodynamical framework is used in the present work to model the space-time evolution
- Lattice Equation of State with Transition temperature 170 MeV
- An wounded nucleon (WN) profile is considered where the initial entropy density is distributed around the WN using a 2-dimensional Gaussian distribution function.

Temporal Evolution:

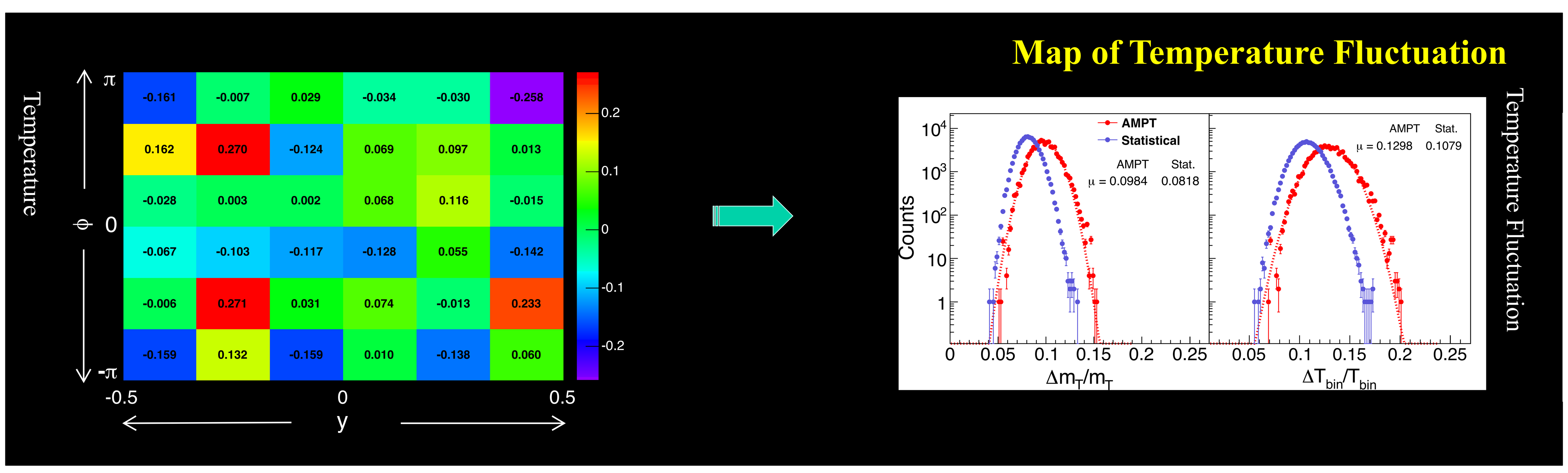


Elapsed time ⟶

Temperature Map:

- AMPT (String Melting)
- Phase space in rapidity: -0.5<y<0.5 and full azimuth
- Phase space is divided to a grid of 6x6 bins
- p_T spectra of pions are constructed for each y−φ bin by combining large number of events.
- Each p_T spectrum is fitted by a Maxwell-Boltzmann function within p_T window of 0.5 to 1 GeV.
- T_{eff} obtained for each bin and plotted in the temperature map.

Central Pb-Pb Collisions at $\sqrt{S_{NN}}$ = 2.76 TeV



Construction of Fluctuation Map:

- Distribution of Teff for all bins are made (shown in middle panel)
- Calculate Temperature Fluctuation: $(\langle T_{eff}\rangle - T_{eff}) / \langle T_{eff}\rangle$
- Make a temperature fluctuation map in y−ϕ

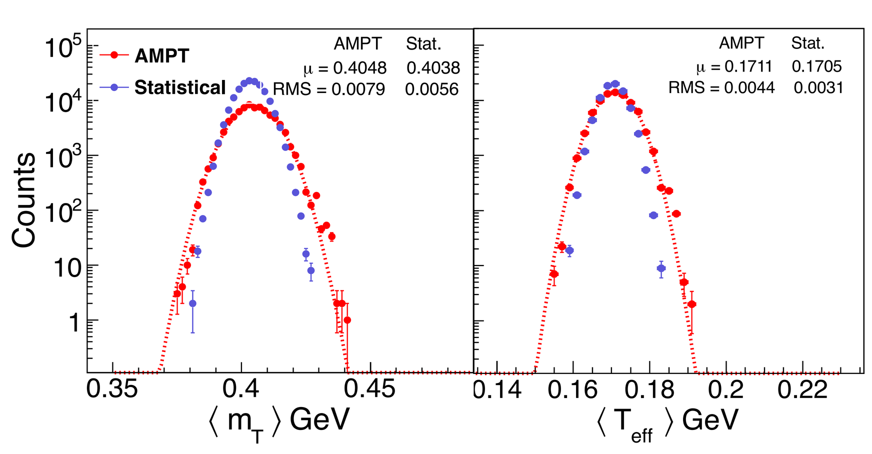
Observations from Fluctuation maps:

- Temperature Fluctuation map is a novel way of representing data from the Little Bang.
- For majority of the bins – the fluctuations are close to zero
- Map shows several hot spots (red) and cold zone (blue)
- Observed fluctuations may be remnants of the initial energy density fluctuations and are not washed out even till freeze-out.

Temperature Fluctuations: Event-by-Event

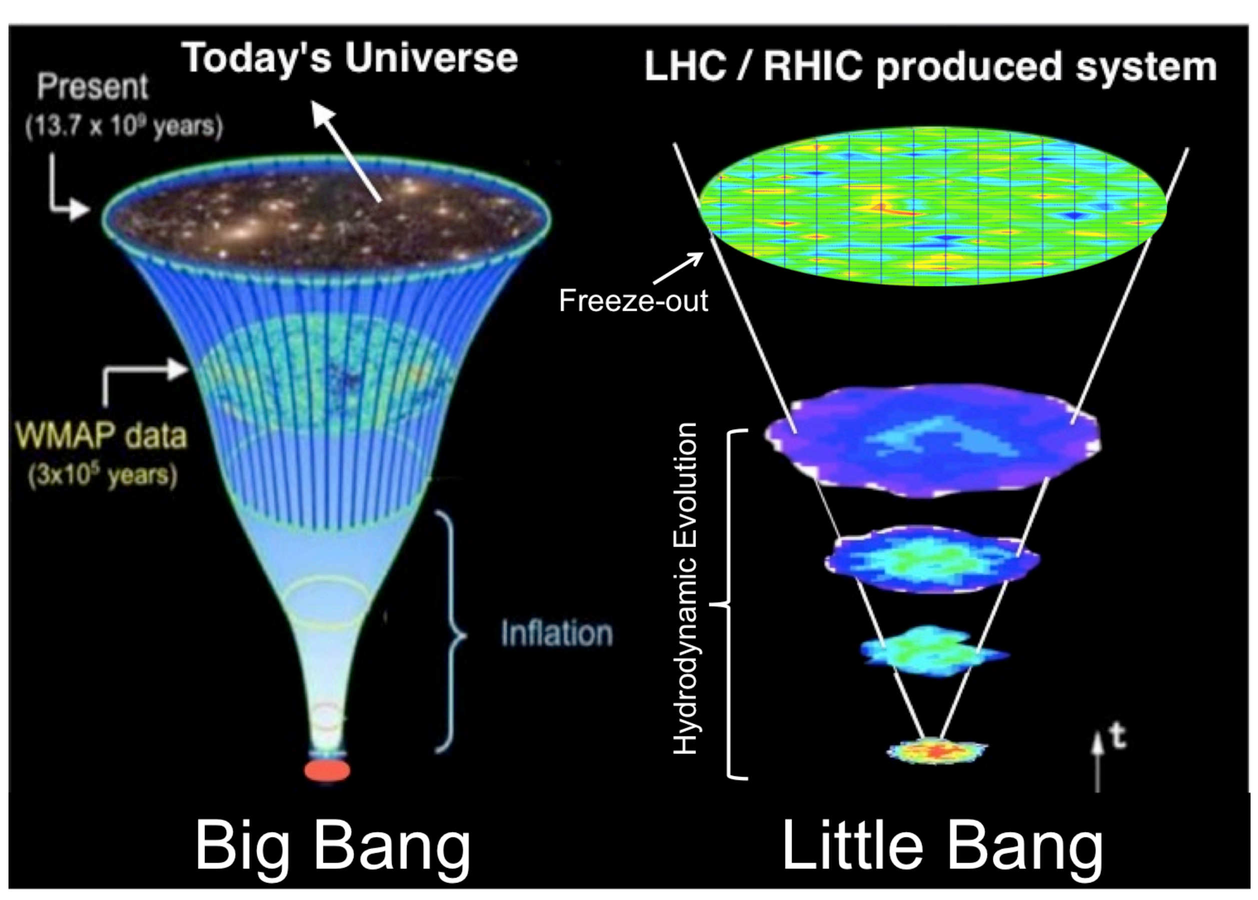
- Event-by-event Temperature Fluctuations is sensitive to the changes of the state of the matter, and give additional thermodynamic information.
- Event-by-event temperature fluctuations are related to the heat capacity and sp. heat of the system:

$$\frac{1}{C} = \frac{\langle(\Delta T_{\rm kin}^2)\rangle}{T_{\rm kin}^2} \approx \frac{\langle(\Delta T_{\rm eff}^2)\rangle}{T_{\rm kin}^2}.$$



◆ In LHC as the particle production is large ~ 1600, so event-by-event by p_T distribution is possible, and we are doing it for pions and have the inverse slope parameter as $T_{\rm eff}^{\rm ebye}$, by fitting it through Maxwell Boltzmann distribution.

Big Bang *vs.* Little Bang:



Summary and Outlook:

- ❖ The mean and its sigma of the distribution of Temperature Fluctuations are 171 MeV and 3 MeV respectively, which represents a fluctuation of 10.79% over all the bins in y-ϕ.
- ❖ This may indicate that the observed fluctuations are remnants of the initial energy density fluctuations and are not washed out even till the freeze-out stage.
- ❖ The amount of these fluctuations are similar to those from hydrodynamic calculations at τ ~12 fm. Thus within the present theoretical framework, we can make a correspondence to the early stage of the collision through the hydro calculations.
- ❖ Important information like speed of sound(c_s), C_V, etc., can be extracted from event-by-event temperature fluctuations.
- ❖ this novel way of studying temperature fluctuations will open up new avenues of studying the heavy-ion collisions and will be useful to get proper insight into the little bang and the QGP matter.