XIth Quark Confinement and the Hadron Spectrum

VECC

Mapping the Little Bangs Through Energy Density and Temperature Fluctuations

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OUTLINE

① Prelude & Motivation

② Methodology

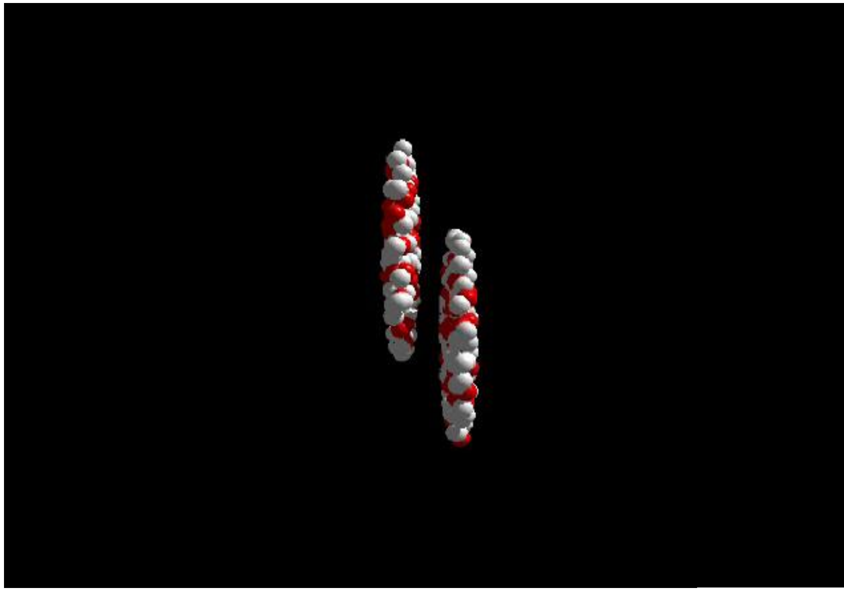
③ Hydro Prediction

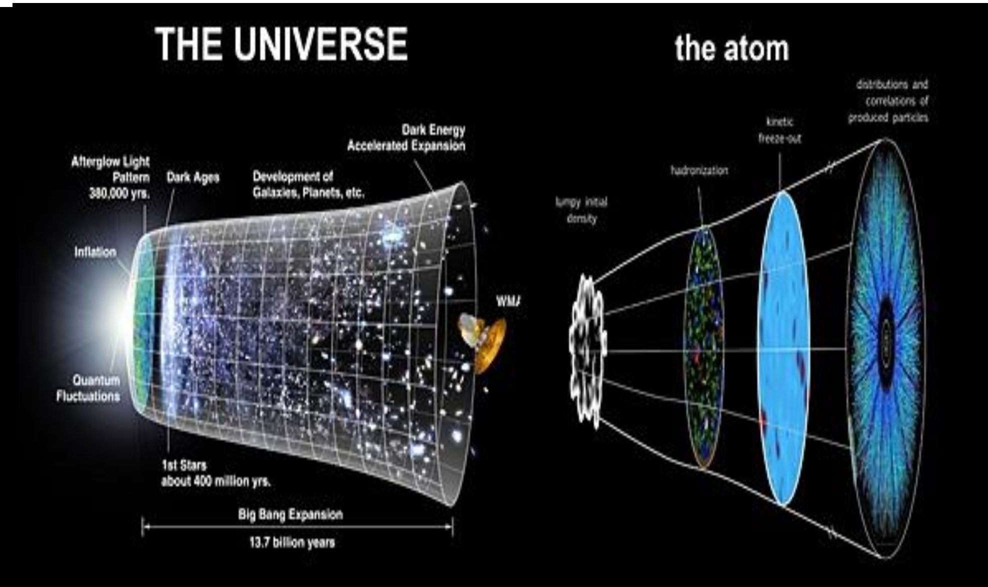
④ Event By event : Global Fluctuation

⑤ Within The Event : Local Fluctuation

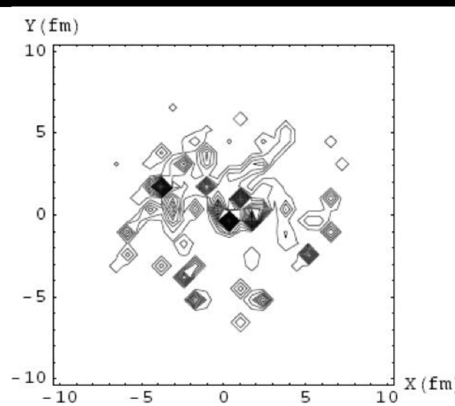
⑥ Summary & Conclusion

Prelude

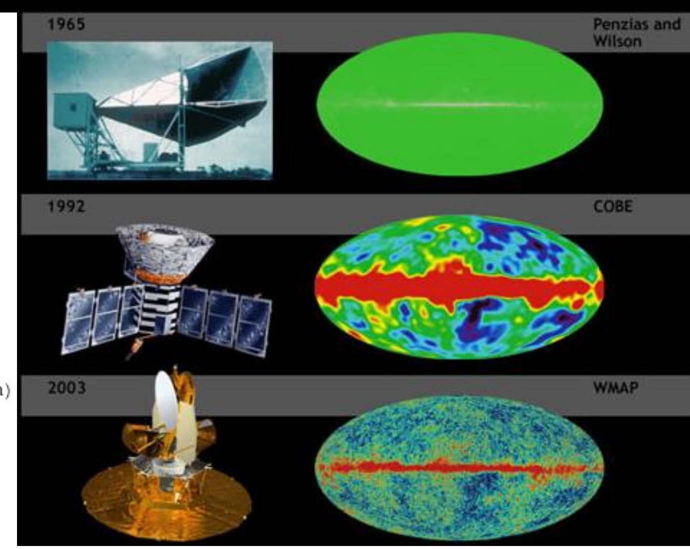




Ajit Srivastava et. al



Central Au - Au Collision
C M Energy 200 GeV



Why Not photons?
Why We are not following direct methodology like in Astrophysics?

Why it is important?

Prelude -> Motivation

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Uli Heinz, arXiv:1304.3634v1 [nucl-th] 11 Apr 2013

- Weather there is spatial patches in the temperature distribution?
- Indicating local fluctuation or hot spot position?
- Is it 1 to 1 corresponds?
- Unlike to Big Bang what is the event-to-event fluctuation?
- how fluctuation really transferred? what is the width?

$$\frac{1}{C_V} = \left(\mathrm{D} T_{eff}^{ebye} / \left\langle T_{eff}^{ebye} \right\rangle\right)^2$$

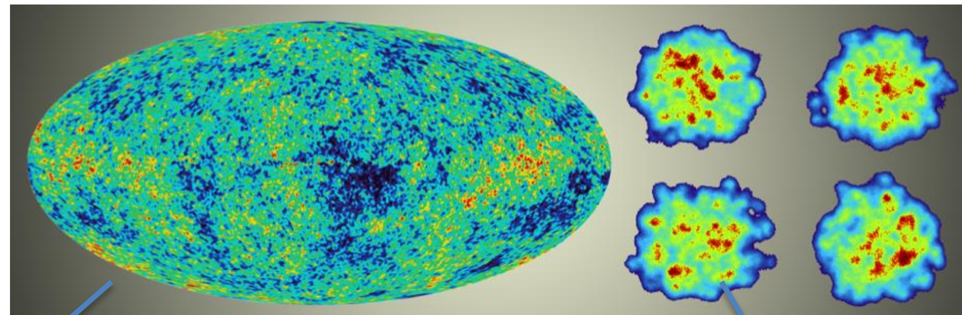
- How much initial fluctuation retains ?
- Isothermal compressibility

$$\langle (N - \langle N \rangle)^2 \rangle = var(N) = \frac{k_B T \langle N \rangle^2}{V} k_T$$

$$k_T \propto \left(\frac{T - T_C}{T_C}\right)^{-\gamma} \propto \epsilon^{-\gamma}$$

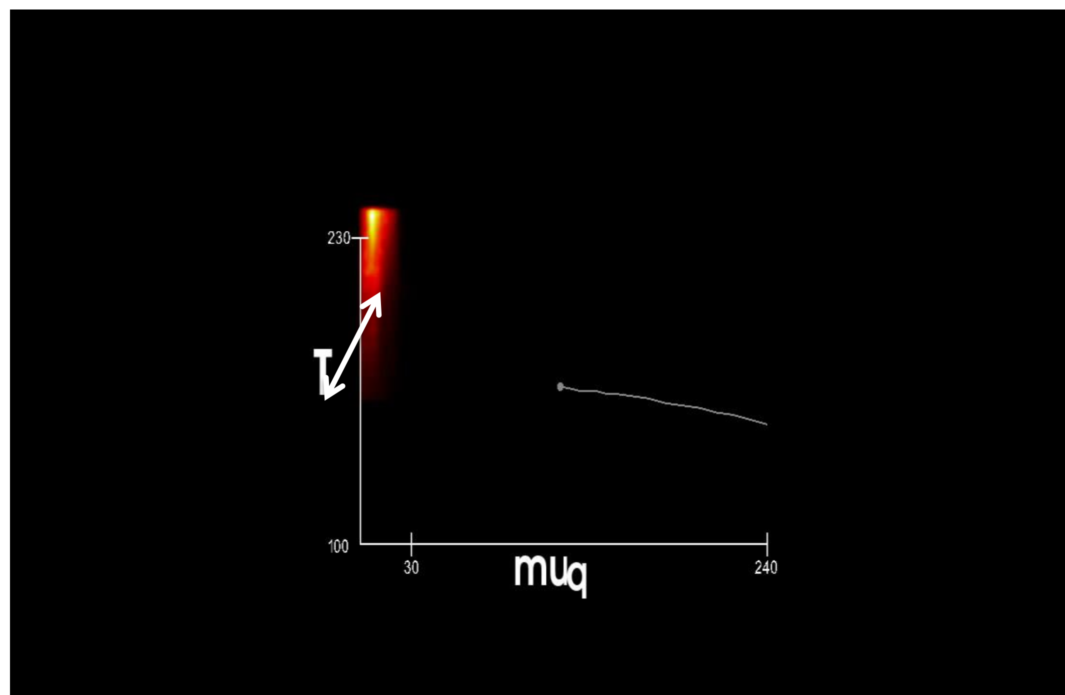
- Speed of Sound (c_s)

arXiv: 0805.1521



WMAP

Pb-Pb collisions at the LHC after 0.2 fm/c



METHODOLOGY

TEMPERATURE FLUCTUATION

Ways

From Fitting Particle Spectra

Methodology

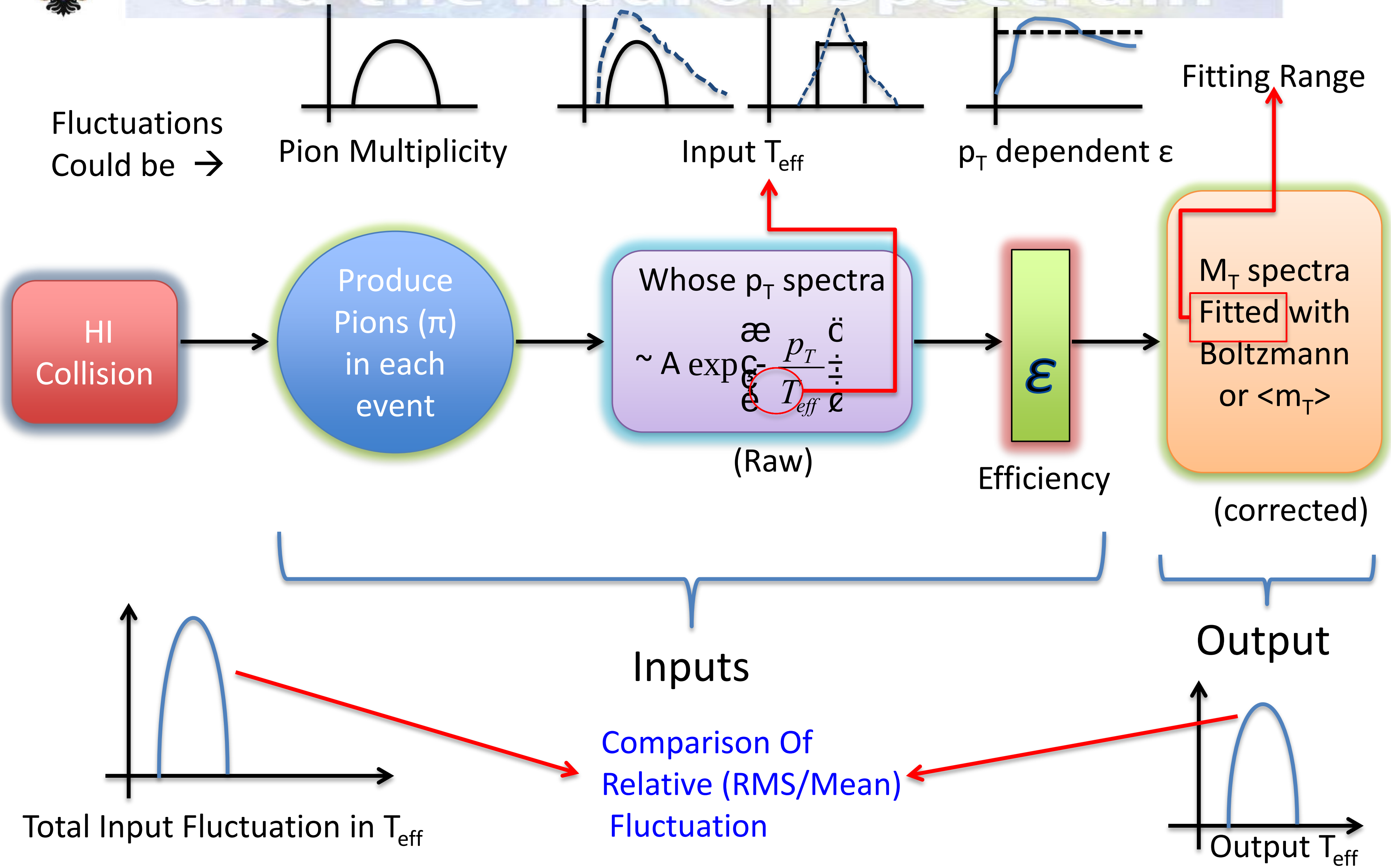
1. Event by Event basis
2. $y - \varphi$ bin wise

From Mean m_T

Identified Particle Spectra

So We Need

Methodology



How to Measure Temperature

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$$\langle m_T \rangle = \frac{\int_0^\infty p_T\, dp_T\, m_T\, exp.(-m_T/T_{eff})}{\int_0^\infty p_T\, dp_T\, exp.(-m_T/T_{eff})} = \frac{2T_{eff}^2 + 2m_0 T_{eff} + m_0^2}{m_0 + T_{eff}}$$

$$f(p_T) = \frac{1}{p_T}\frac{dN}{dp_T} \simeq C\, e^{-m_T/T_{eff}}.$$

$$\langle A \rangle = \frac{\int A\, f(A)\, dA}{\int f(A)\, dA}.$$

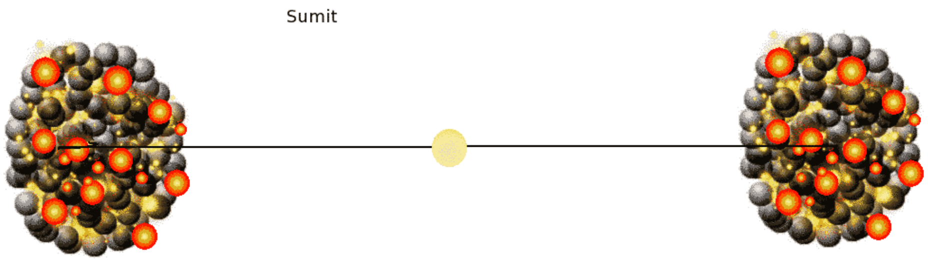
$$\langle m_T \rangle \rightarrow \langle p_T \rangle \cong 2T_{eff}.$$

$$\langle p_T \rangle = \frac{\int_0^\infty p_T\, (\frac{dN}{dp_T})\, dp_T}{\int_0^\infty (\frac{dN}{dp_T})\, dp_T} = \frac{\int_0^\infty p_T\, dp_T\;\; p_T(\frac{dN}{p_T dp_T})}{\int_0^\infty p_T\, dp_T(\frac{dN}{p_T dp_T})} = \frac{\int_0^\infty p_T\, dp_T\;\; p_T\, f(p_T)}{\int_0^\infty p_T\, dp_T f(p_T)}$$

$$\langle m_T \rangle = \frac{2T_{eff}^2 + 2m_0 T_{eff} + m_0^2}{m_0 + T_{eff}} \longrightarrow (1)$$

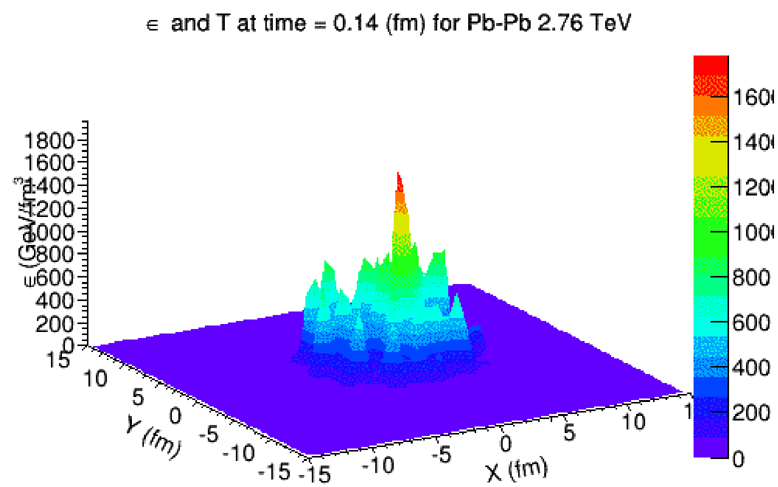
$$\frac{d\langle m_T \rangle}{dT_{eff}} = 1 + \frac{2T_{eff}}{m_0 + T_{eff}} - 2\left(\frac{T_{eff}}{m_0 + T_{eff}}\right)^2 \longrightarrow (2)$$

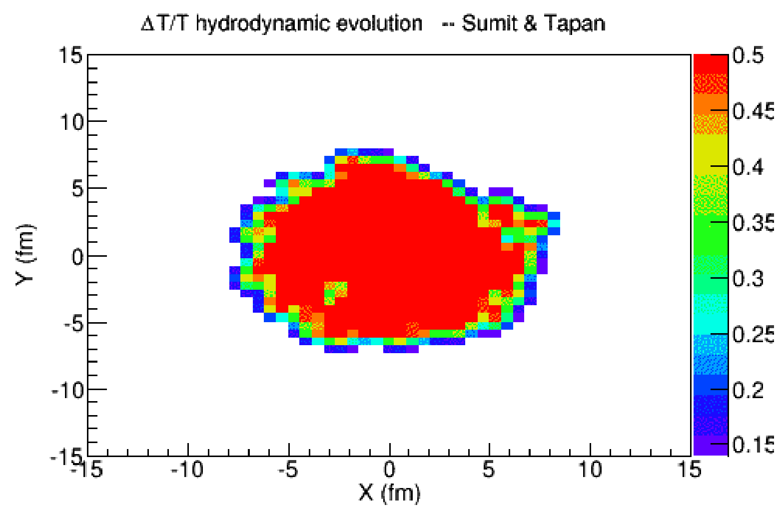
Hydro Prediction



- The Yield and pT spectra matches well
- Drastic Energy dissipation in phase space
- The dilution of fluctuation will be large if one look for same study with viscous hydro
- 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.

Collision ==> microscopic





Hydro Prediction

Energy density and Temperature:

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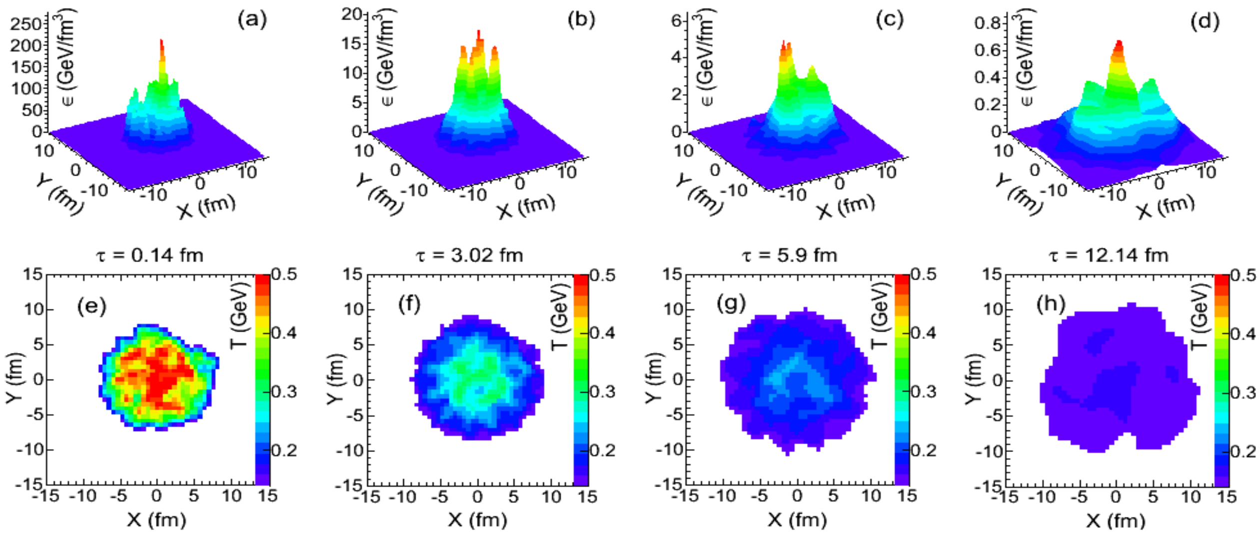
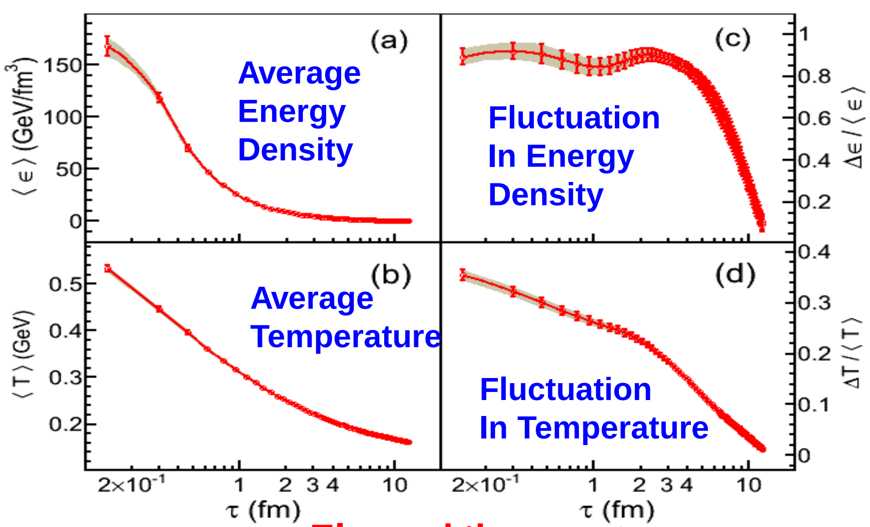


Observations from hydrodynamic calculations:

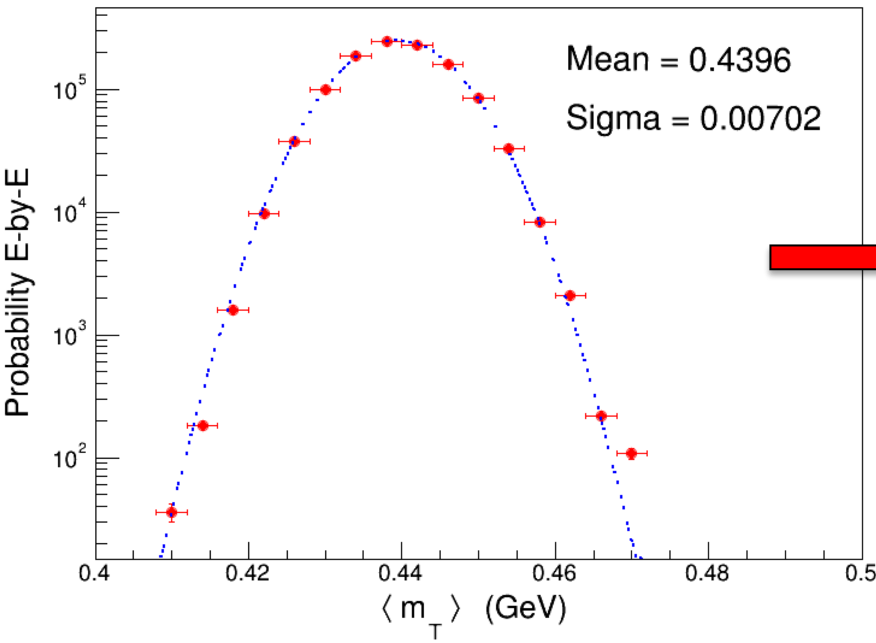
- At early times system is inhomogeneous and quite violent:
  - ➢ sharp and pronounced peaks in energy densit & hotspots in temperature
  - ➢ Extremely large fluctuations (~90%) in energy density
- With time, the system cools, expands and bin-to-bin variations smoothens
- Energy density drops fast, the 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

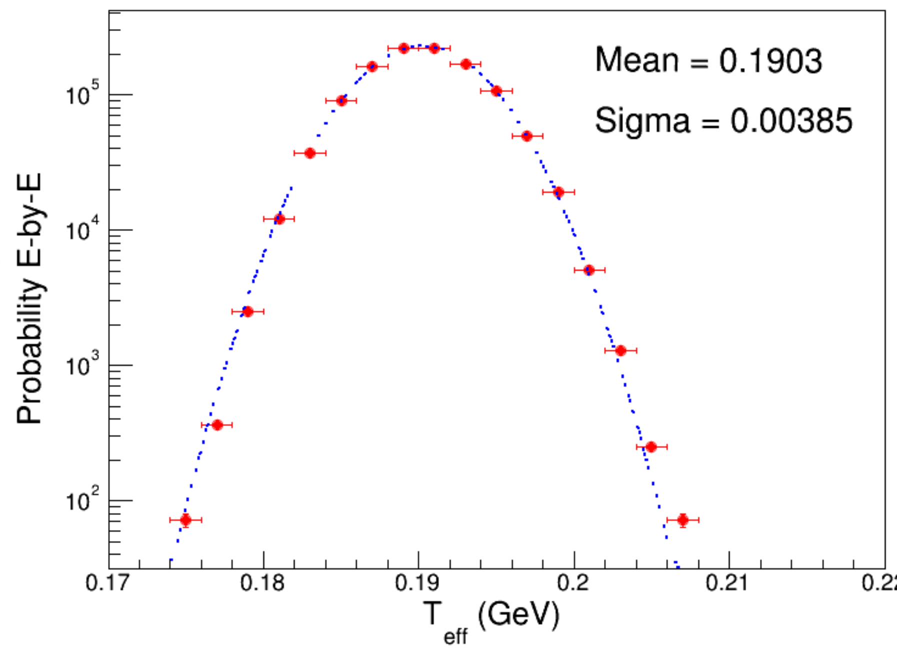
Temporal Evolution:

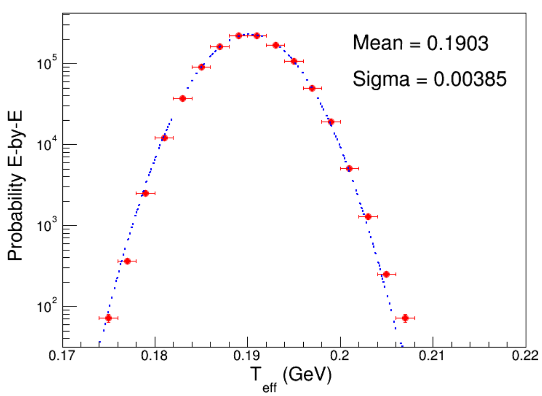


Elapsed time ⟶

Event-by-Event : Global Fluctuation







$$\frac{1}{C_V} = \left(\Delta T_{eff}^{ebye} / \left\langle T_{eff}^{ebye} \right\rangle \right)^2$$

$\Rightarrow$ Heat Capacity, C_V = **2450**

Within The Event : Local Fluctuation

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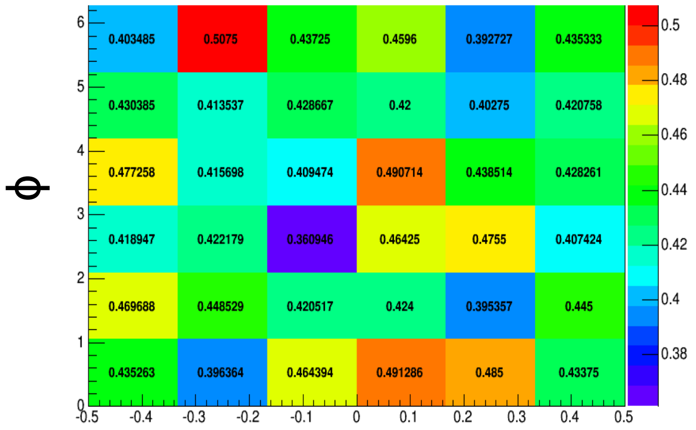
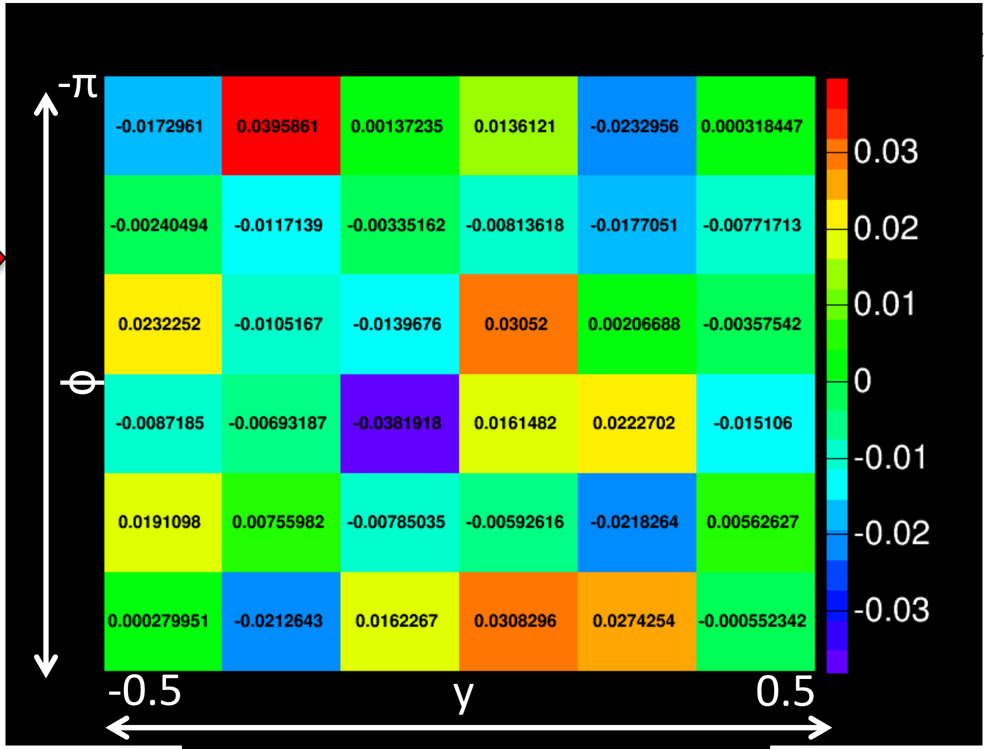
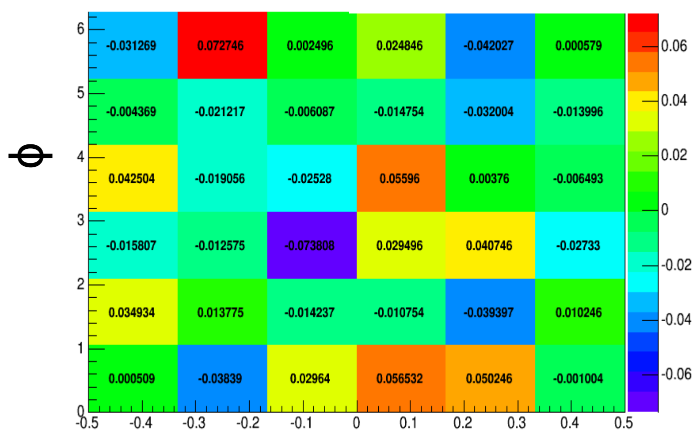
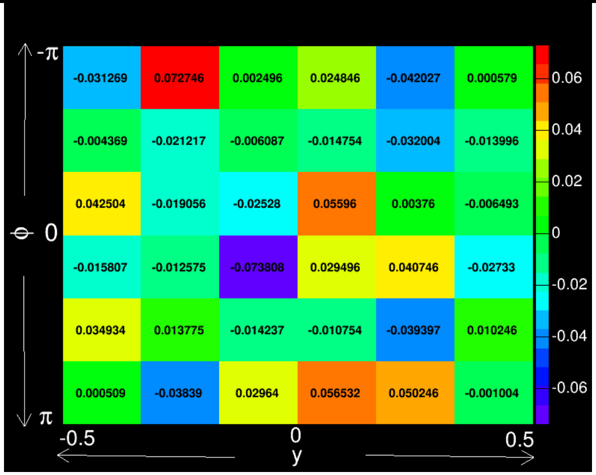
Map of $<m_T>$





Fluctuation: $(\overline{m}_{\mathrm{T}}^{\mathrm{bin}} - \langle m_{\mathrm{T}} \rangle)/\langle m_{\mathrm{T}} \rangle$





Derived Map of Temperature Fluctuation

Within The Event : Local Fluctuation

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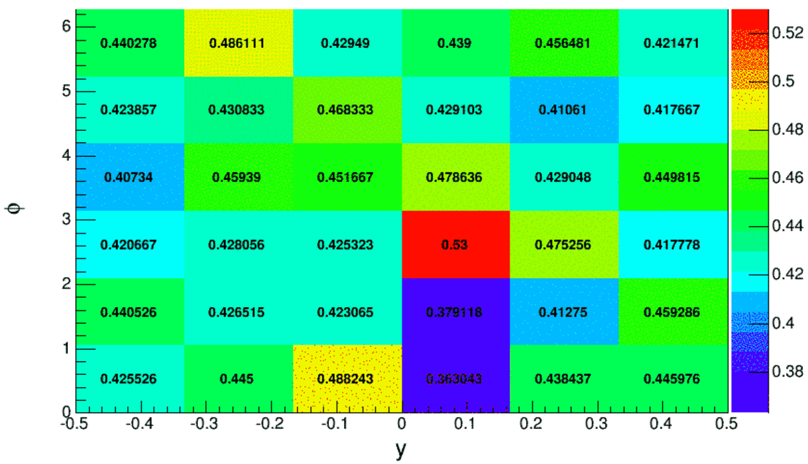
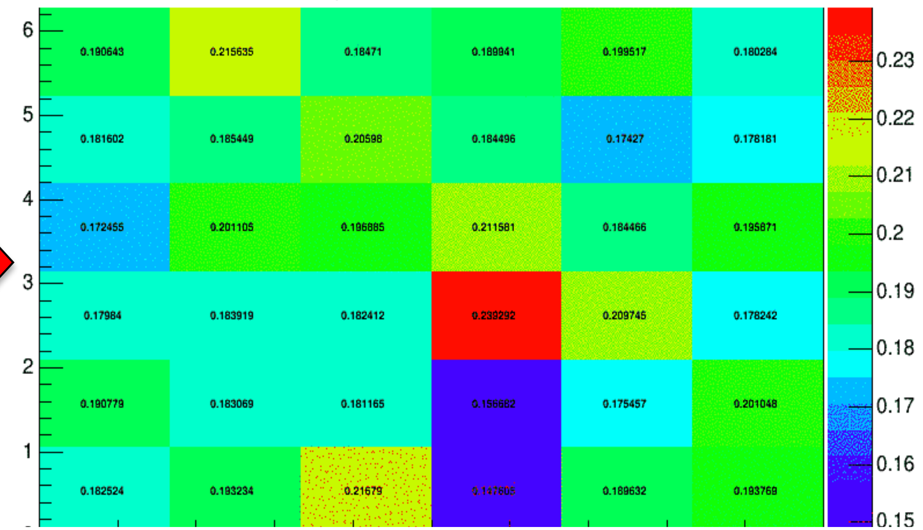
< m_T > Distribution

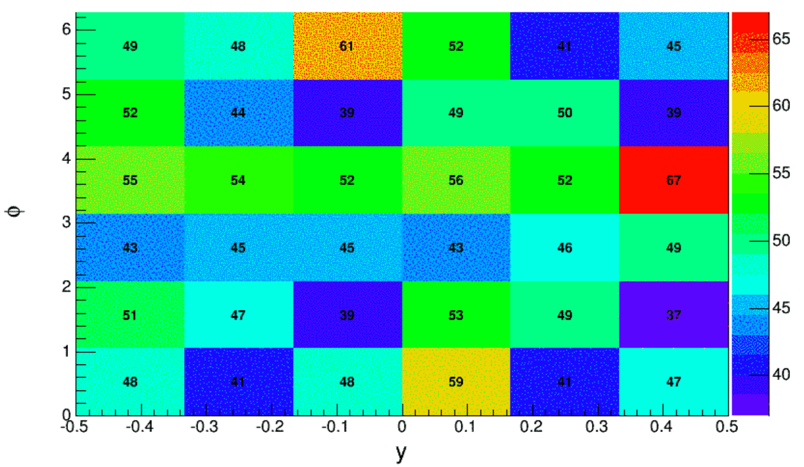


T_{eff} Distribution

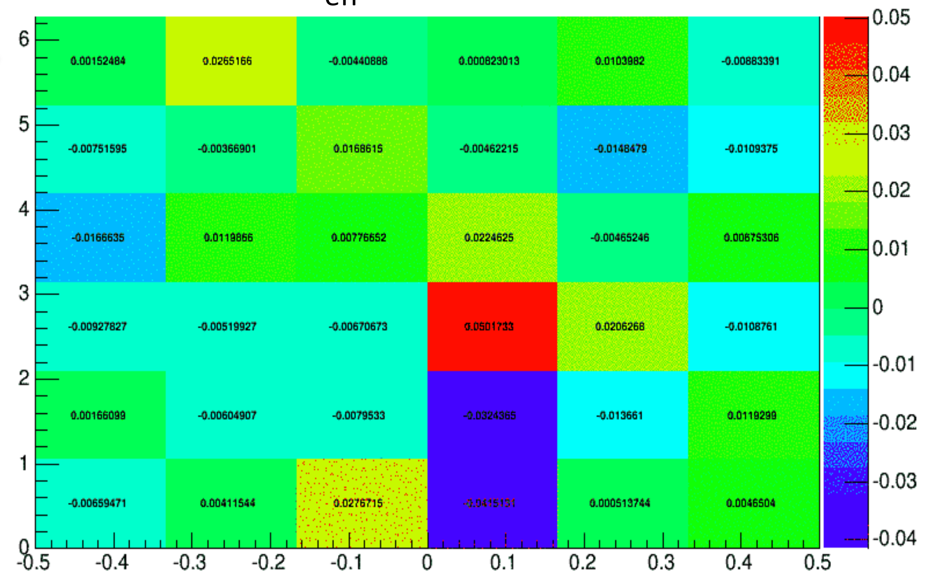


Pion No Distribution

???



T_{eff} Fluctuation



Within The Event : Local Fluctuation

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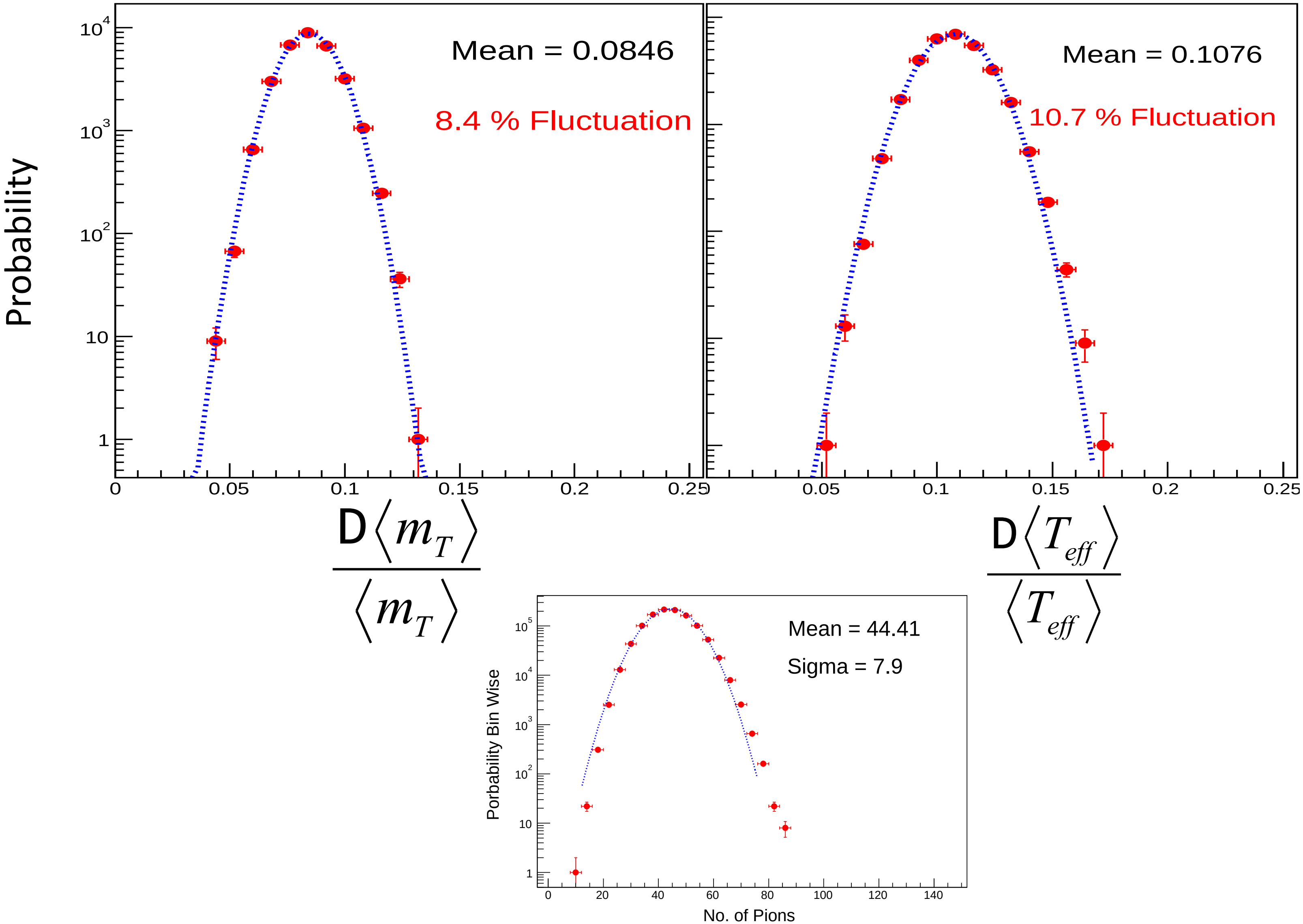
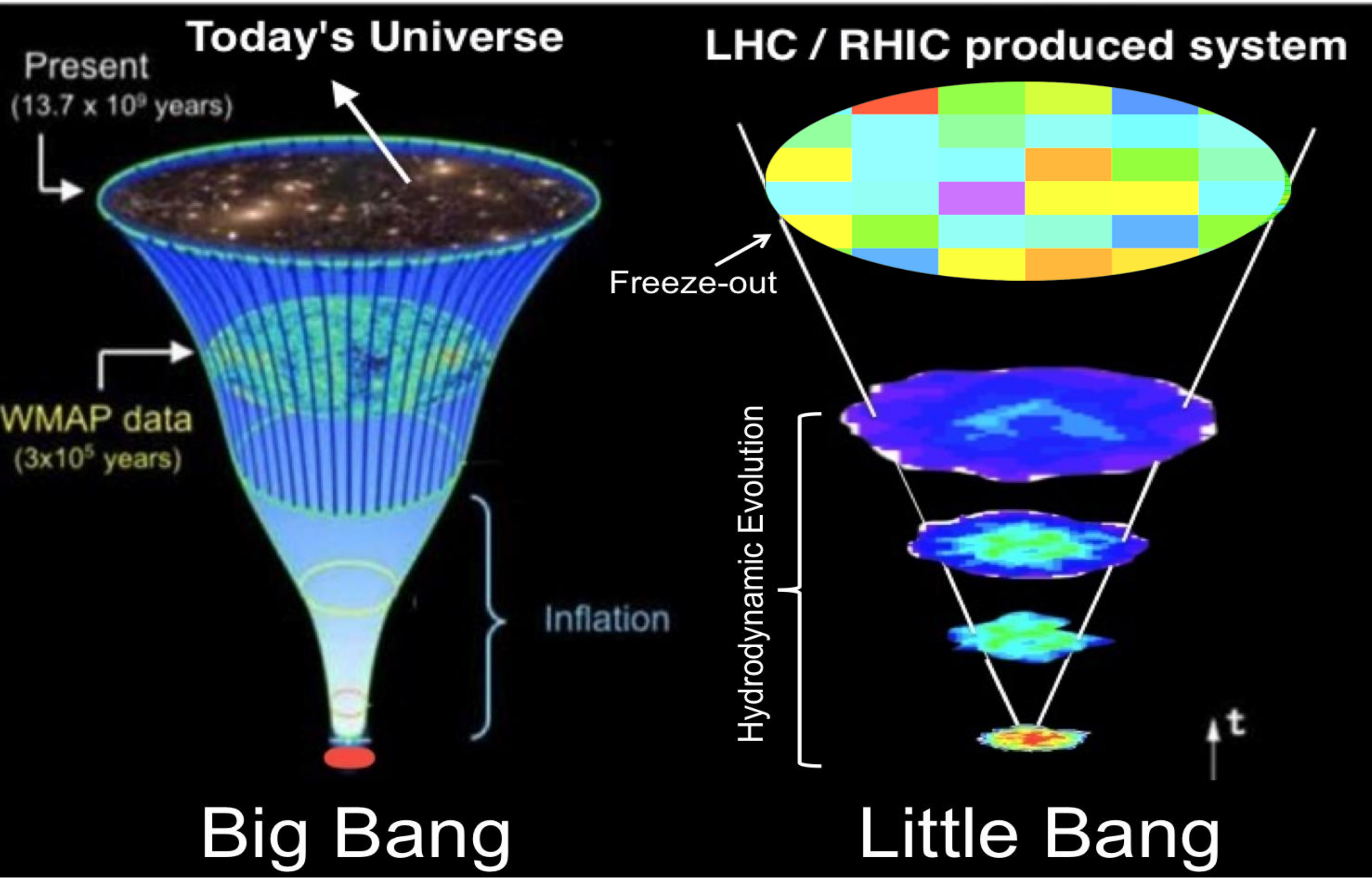


Summary -1


Today's Universe
Present
(13.7 x 10⁹ years)
WMAP data
(3x10⁵ years)
Inflation
LHC / RHIC produced system
Freeze-out
Hydrodynamic Evolution
t
Big Bang
Little Bang

Summary - 2

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PbPb Collisions at the LHC energy for central collisions:

- Global Temperature Fluctuations are about 2%.
- This corresponds to heat capacity of 2450.
- Local Temperature Fluctuations within a given event are about 10%.
- The Local fluctuations may be remnants of the early temperature fluctuations which are seen in hydrodynamic fluctuations.
- This is for the 1st time direct approach to characterize and make a connection of Little bangs to the Big Bang.

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Saint-Petersburg State University, Russia

THANK YOU ALL