SQM DUBNA 2015

Presentation On

VECC

Beam Energy Scan of Specific Heat through Temperature Fluctuations

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OUTLINE

① Prelude & Motivation

② Definition : Temperature and Sp. Heat

③ Methodology

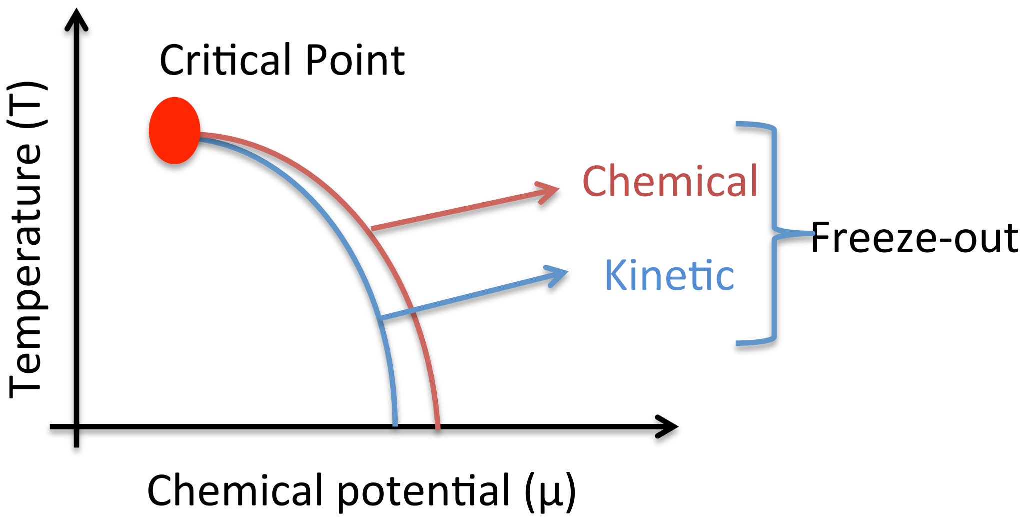
④ Event By event : Global Fluctuation

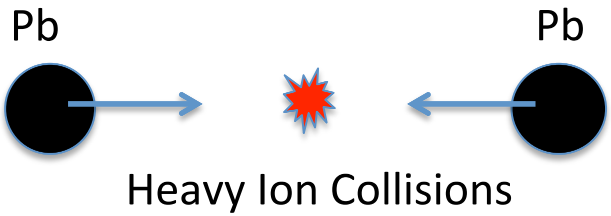
Result Data and Model 0-5% Central

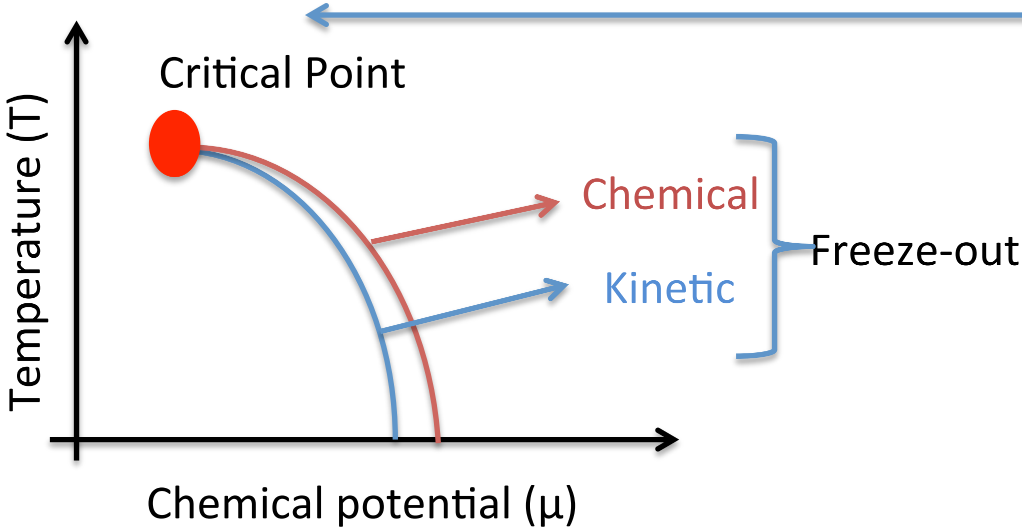
① Within The Event : Local Fluctuation

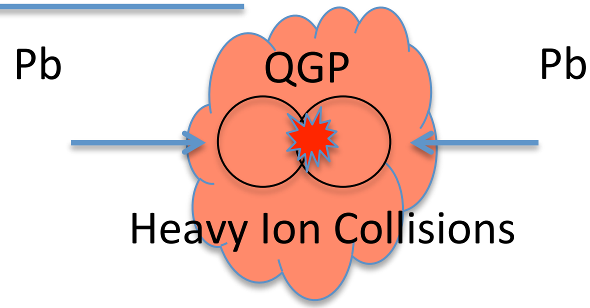
② Summary & Conclusion

Prelude

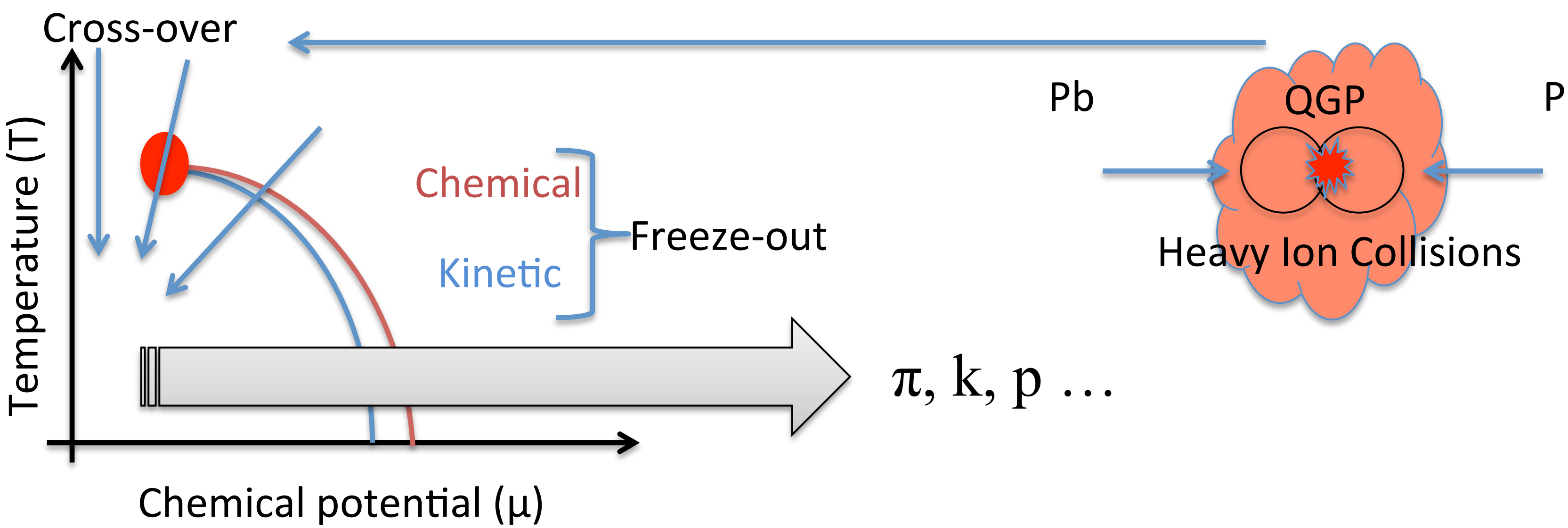

Critical Point
Chemical
Kinetic
Freeze-out
Temperature (T)
Chemical potential (μ)


Pb
Pb
Heavy Ion Collisions

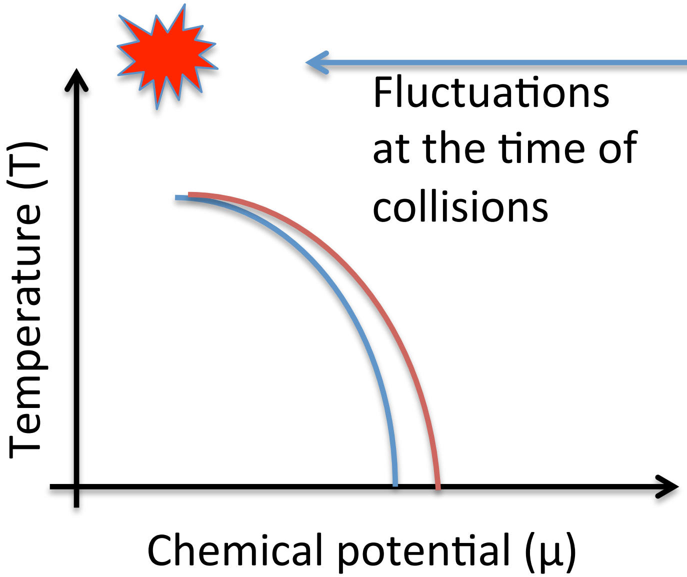

Critical Point
Chemical
Kinetic
Freeze-out
Temperature (T)
Chemical potential (μ)


Pb
QGP
Pb
Heavy Ion Collisions

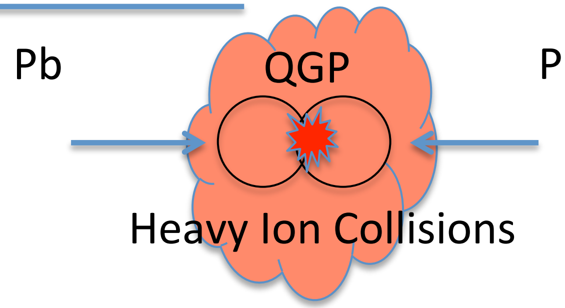
Prelude


Cross-over
Temperature (T)
Chemical potential (μ)
Chemical
Kinetic
Freeze-out
π, k, p …
Pb
QGP
Pb
Heavy Ion Collisions

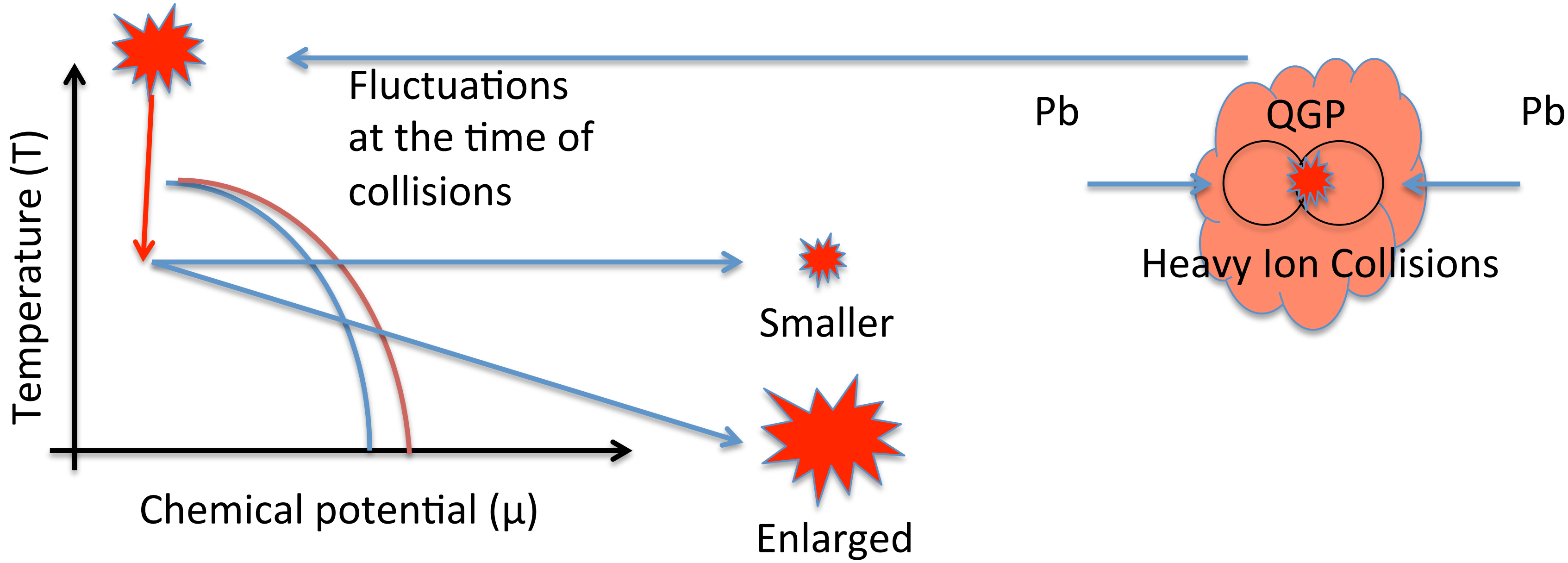
Prelude

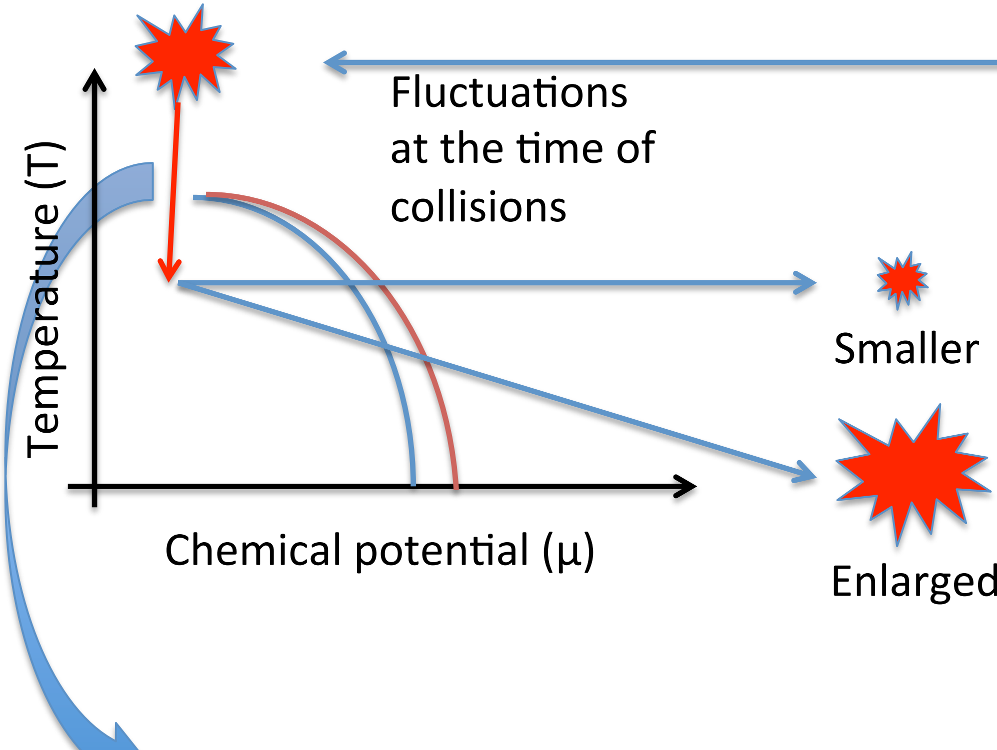


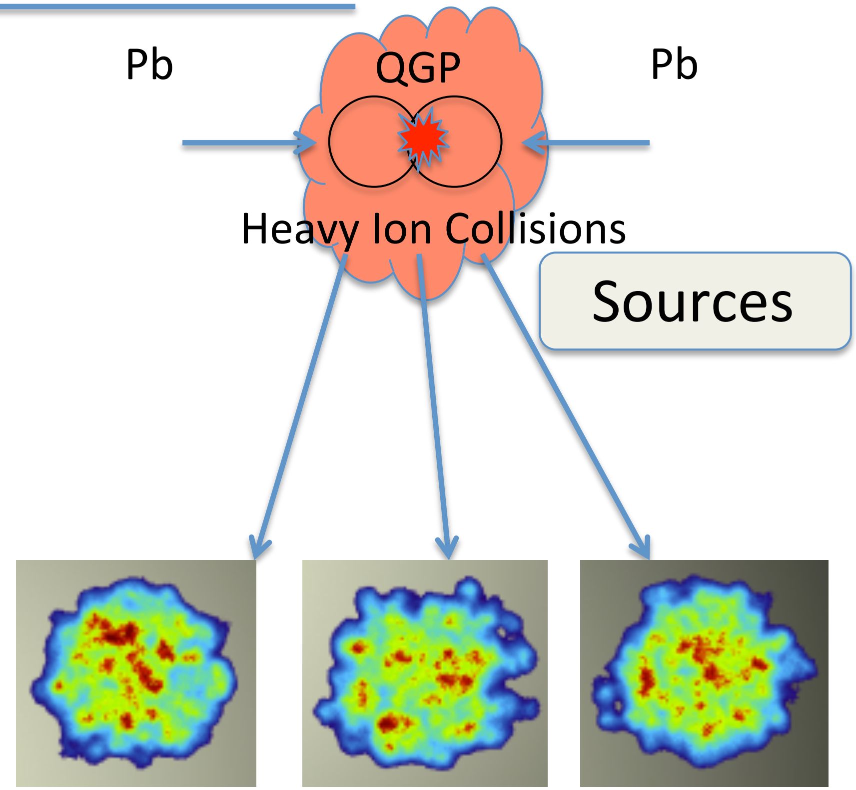
Fluctuations at the time of collisions



Prelude


Fluctuations
at the time of
collisions
Temperature (T)
Chemical potential (μ)
Smaller
Enlarged
Pb
QGP
Pb
Heavy Ion Collisions



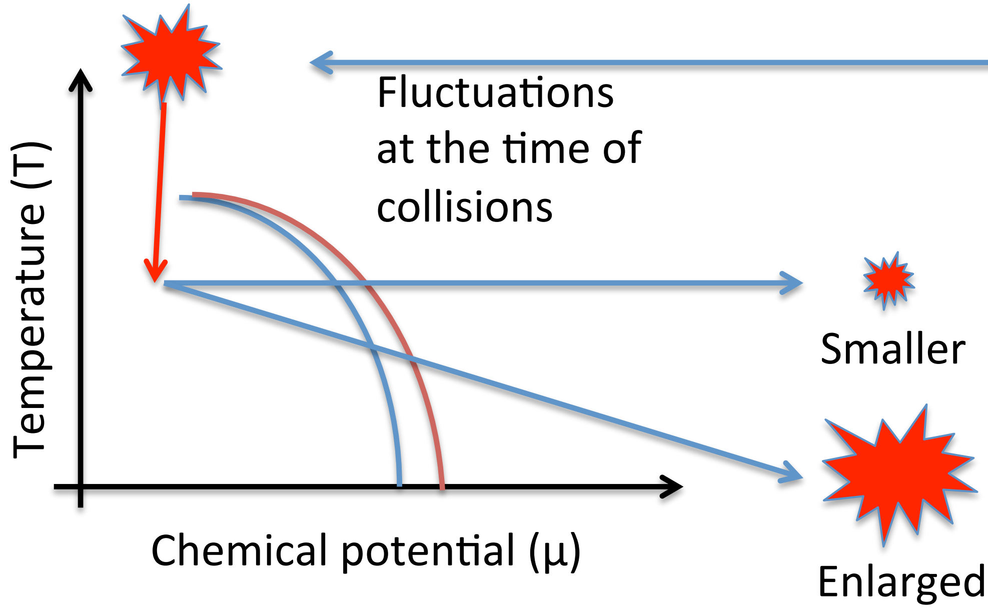


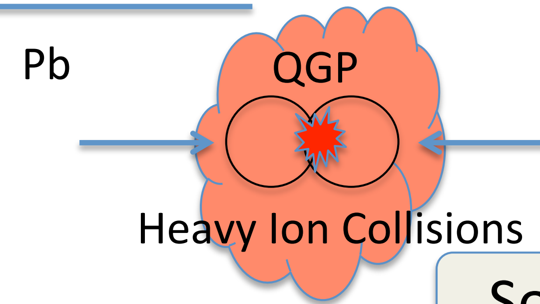
1. Initial State fluctuations
(Quantum fluctuations)

(Uli Heinz, arXiv:1304.3634)

2. During hadronization , Thermo-Dynamical Fluctuations

3. For finite multiplicity Statistical fluctuations

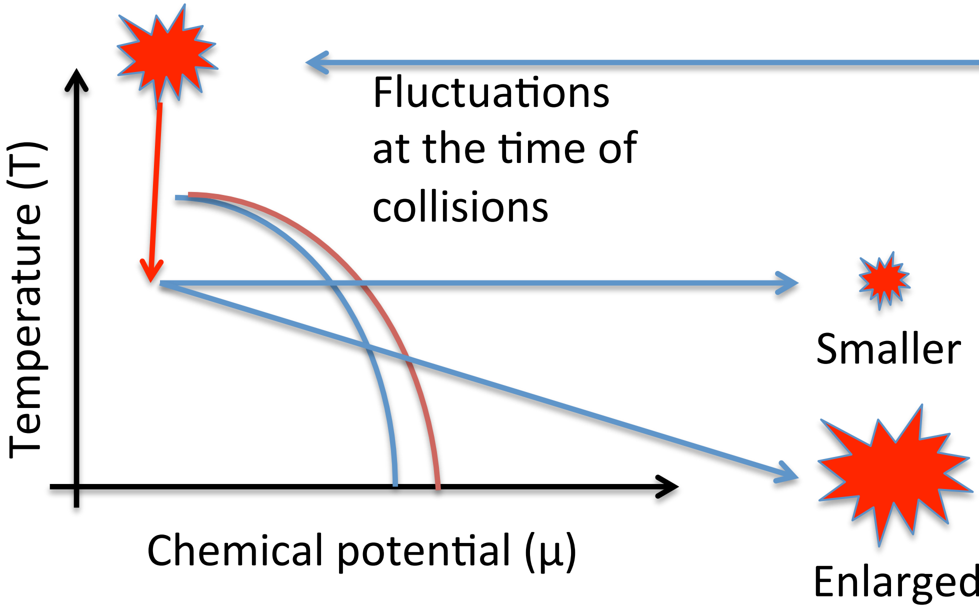


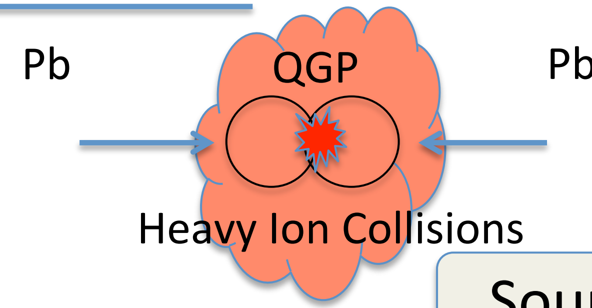


Sources

1. Initial State fluctuations
2. Thermodynamical fluctuations
3. Statistical fluctuations

Prelude





Sources

1. Initial State fluctuations
2. Thermodynamical fluctuations
3. Statistical fluctuations

$$\frac{1}{C_v} = \frac{(\langle T^2 \rangle - \langle T \rangle^2)}{\langle T \rangle^2}.$$

(L. Stodolsky, Phys. Rev. Lett. 75, 1044 (1995))

$$\frac{1}{C} = \frac{(\Delta T^2_{\text{kin}})}{T^2_{\text{kin}}} \approx \frac{(\Delta T^2_{\text{eff}})}{T^2_{\text{kin}}}$$

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

(arXiv: 0805.1521)

Def. Temperature & Sp. Heat

How to Measure Temperature?

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

$$\langle m_T \rangle = \frac{2T_{eff}^2 + 2m_0 T_{eff} + m_0^2}{m_0 + T_{eff}}$$

- But limit is the problem **: and fit as well**

$$\langle p_t \rangle = \frac{\int_a^b p_t^2 F(p_t) dp_t}{\int_a^b p_t F(p_t) dp_t} \quad \text{-->} \quad \langle p_t \rangle = 2T + \frac{a^2 e^{-a/T} - b^2 e^{-b/T}}{(a+T)e^{-a/T} - (b+T)e^{-b/T}}$$

Radial flow

Where, $f(\beta_T) \approx m_0 \langle \beta_T \rangle$

$$T\text{eff} = T_{\text{kin}} + f(\beta_T).$$

- We Define

Sp. Heat

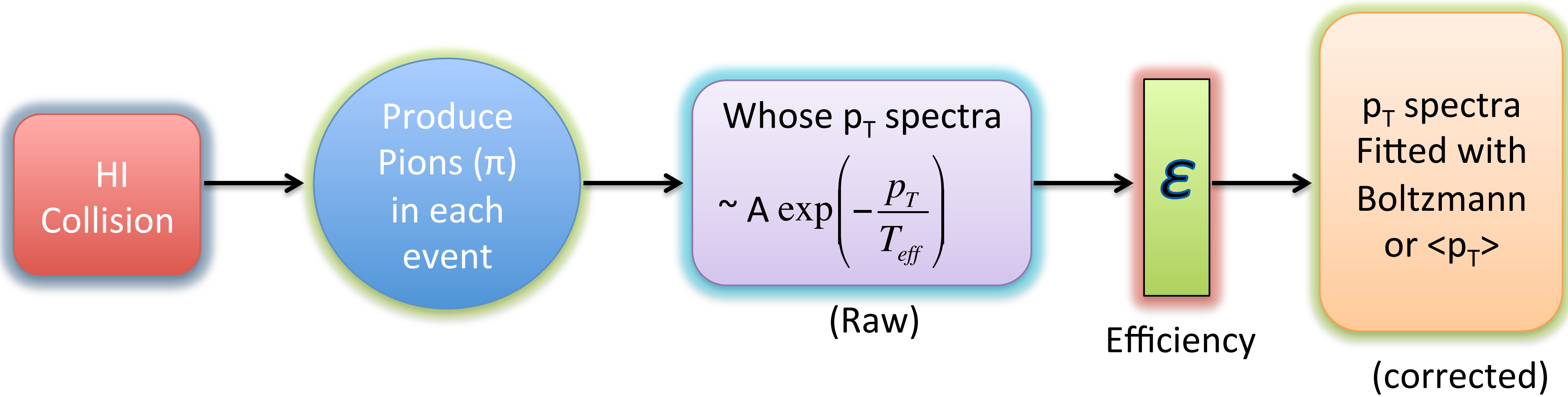
Dimensionless Quantity

$$\frac{1}{C} = \frac{(\Delta T_{\text{kin}}^2)}{T_{\text{kin}}^2} \approx \frac{(\Delta T_{\text{eff}}^2)}{T_{\text{kin}}^2}$$

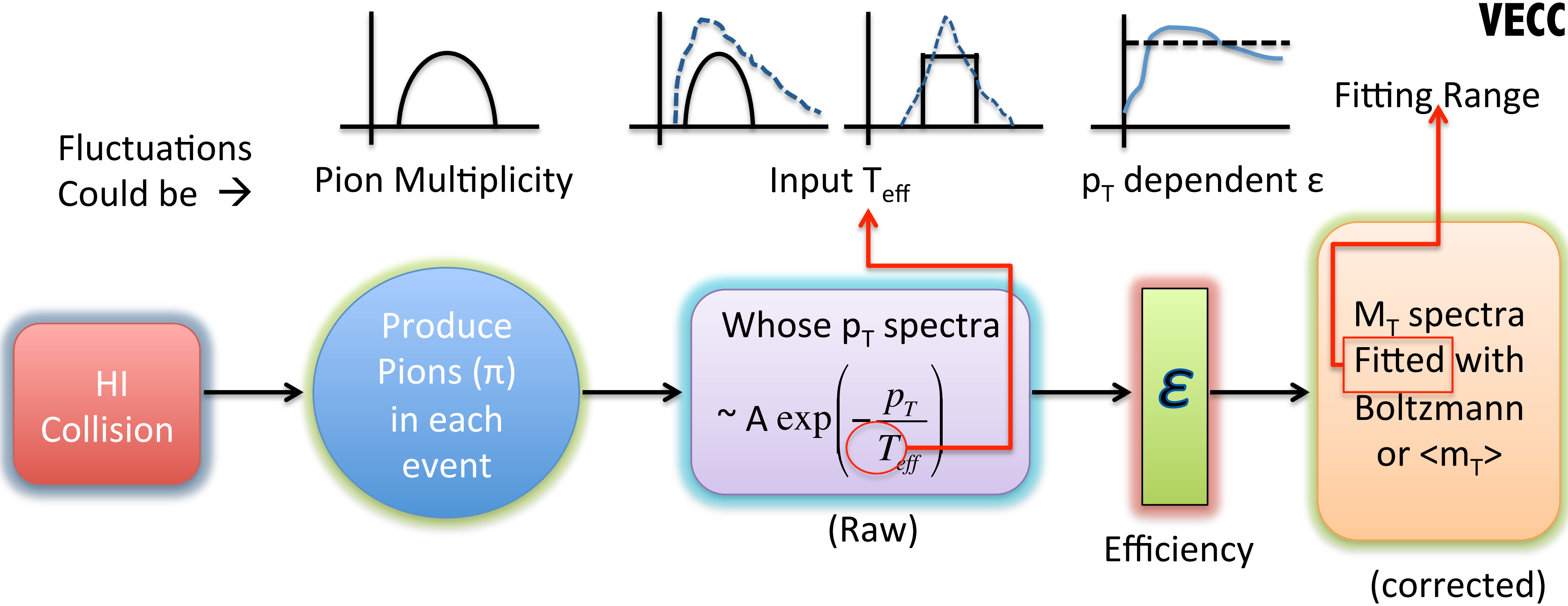
$$c_v = \frac{C}{\langle n \rangle}$$

$$\frac{c_v}{T_{Kin}^3}$$

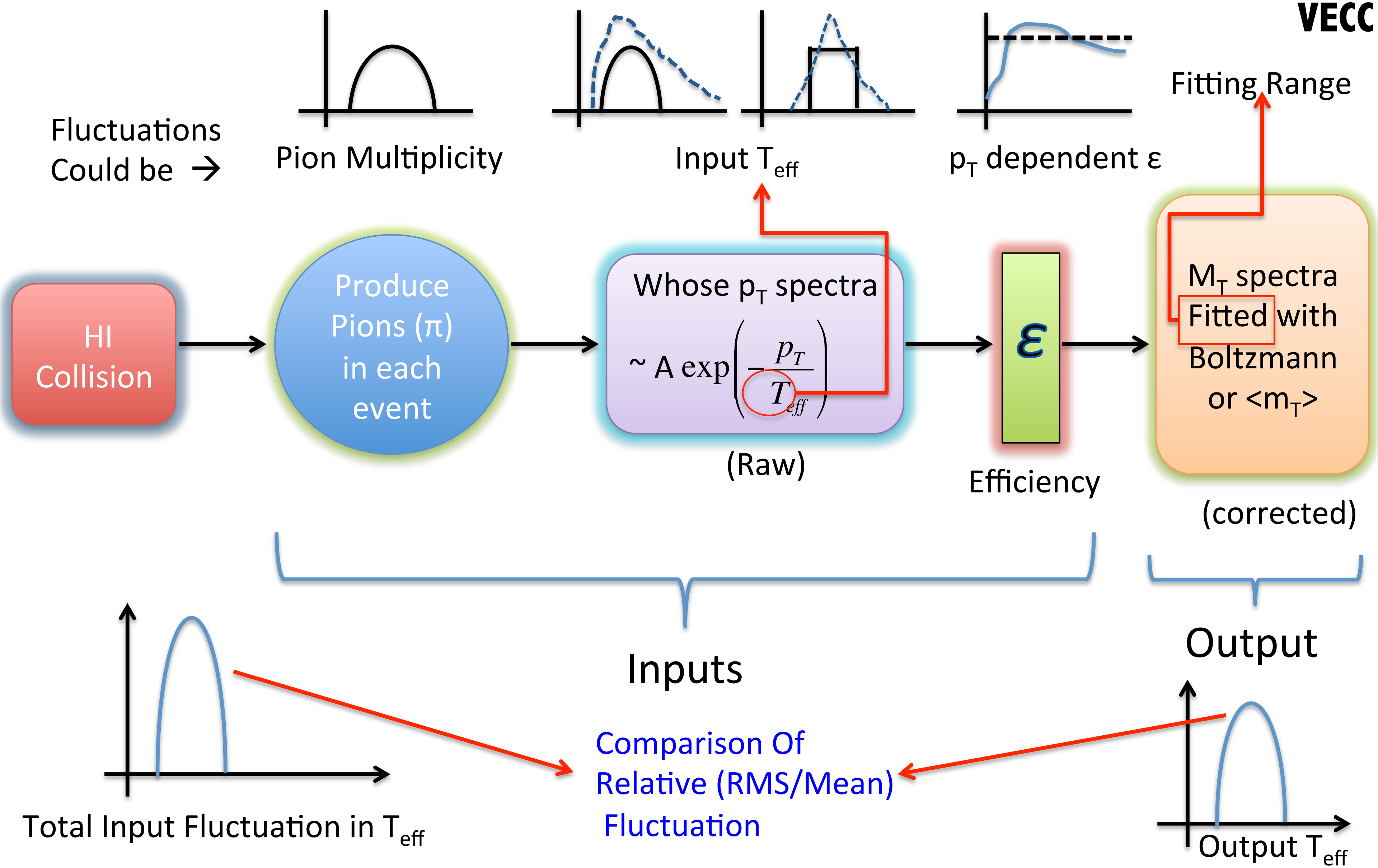
Methodology



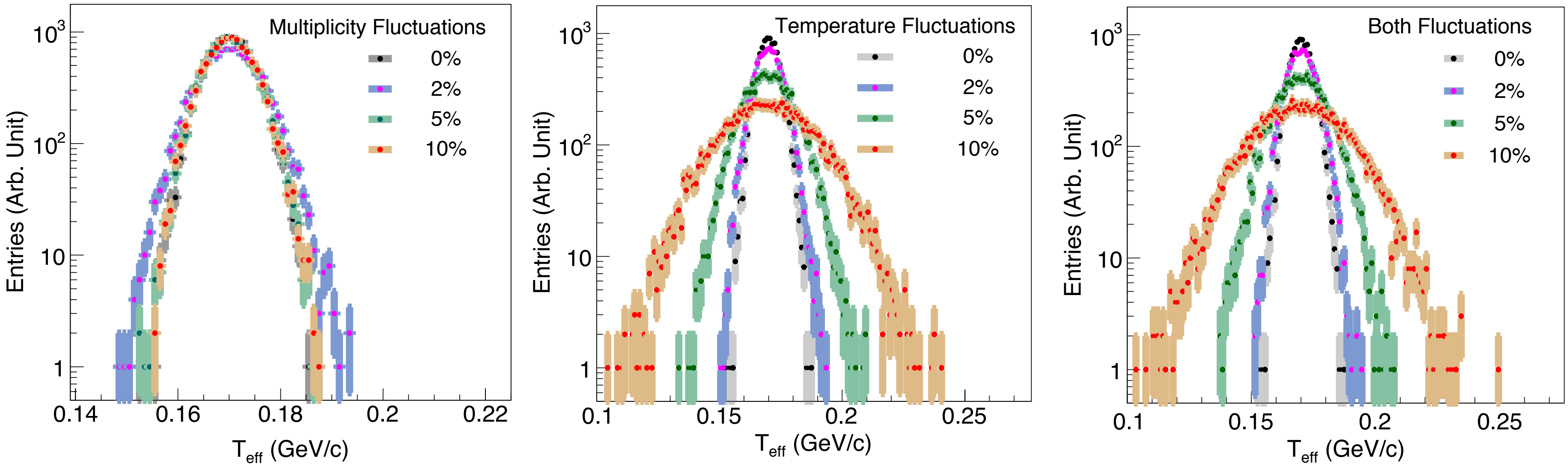
Methodology



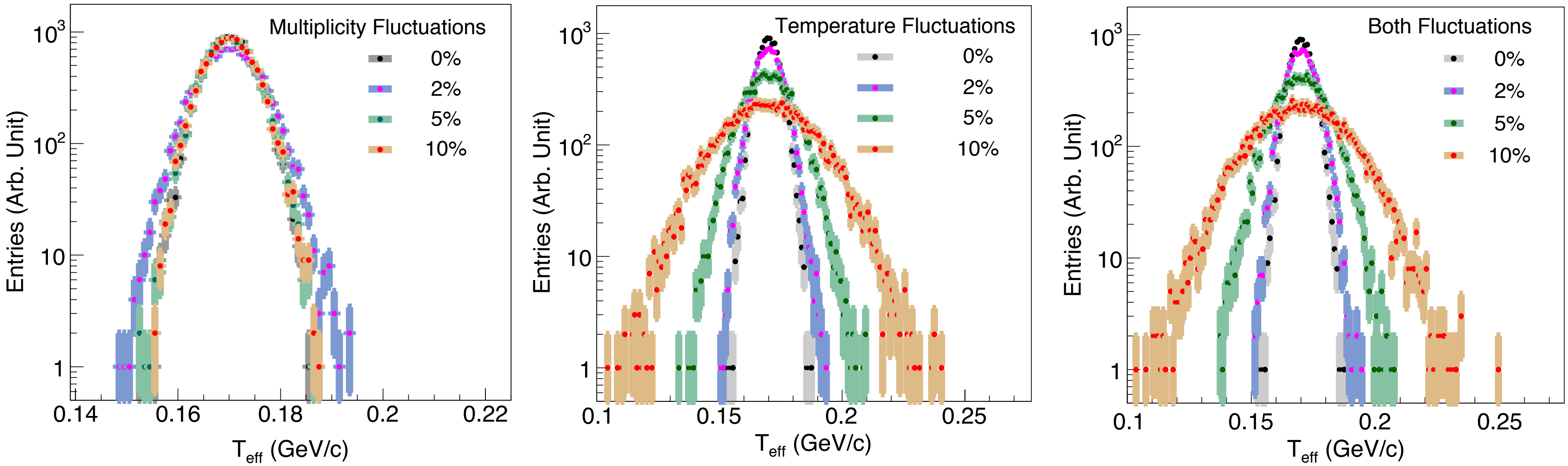
Methodology



Prelude


Multiplicity Fluctuations
0%
2%
5%
10%
Entries (Arb. Unit)
T_{eff} (GeV/c)
Temperature Fluctuations
0%
2%
5%
10%
Entries (Arb. Unit)
T_{eff} (GeV/c)
Both Fluctuations
0%
2%
5%
10%
Entries (Arb. Unit)
T_{eff} (GeV/c)

Prelude



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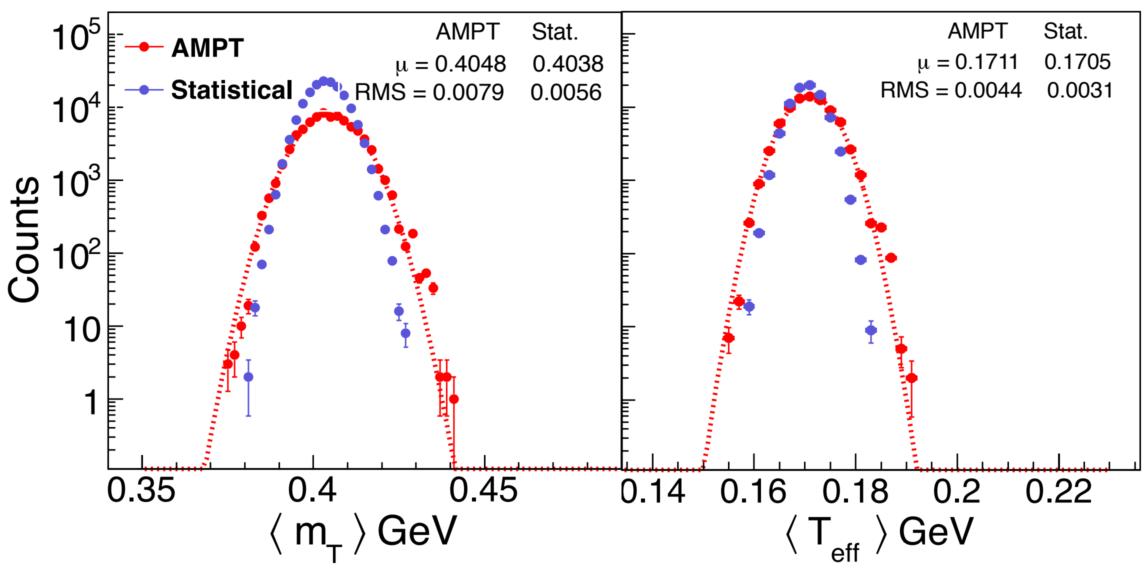
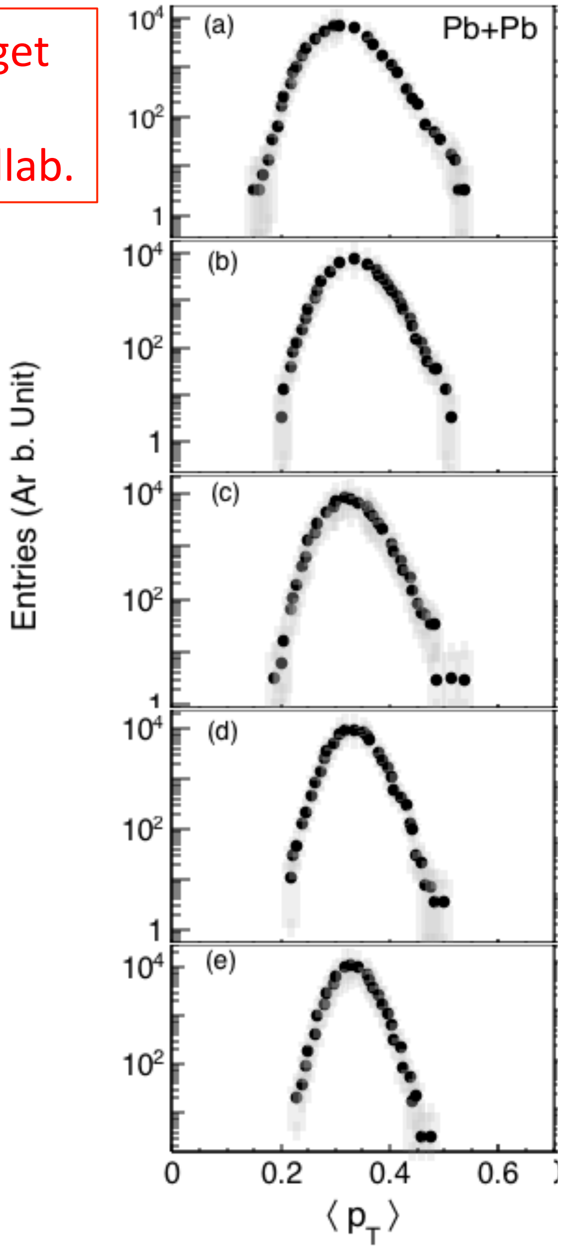


AMPT
Statistical
AMPT Stat.
μ = 0.4048 0.4038
RMS = 0.0079 0.0056
Counts
⟨ m_T ⟩ GeV
AMPT Stat.
μ = 0.1711 0.1705
RMS = 0.0044 0.0031
⟨ T_{eff} ⟩ GeV

Result : CERES

Fixed Target
Pb – Pb
CERES Collab.

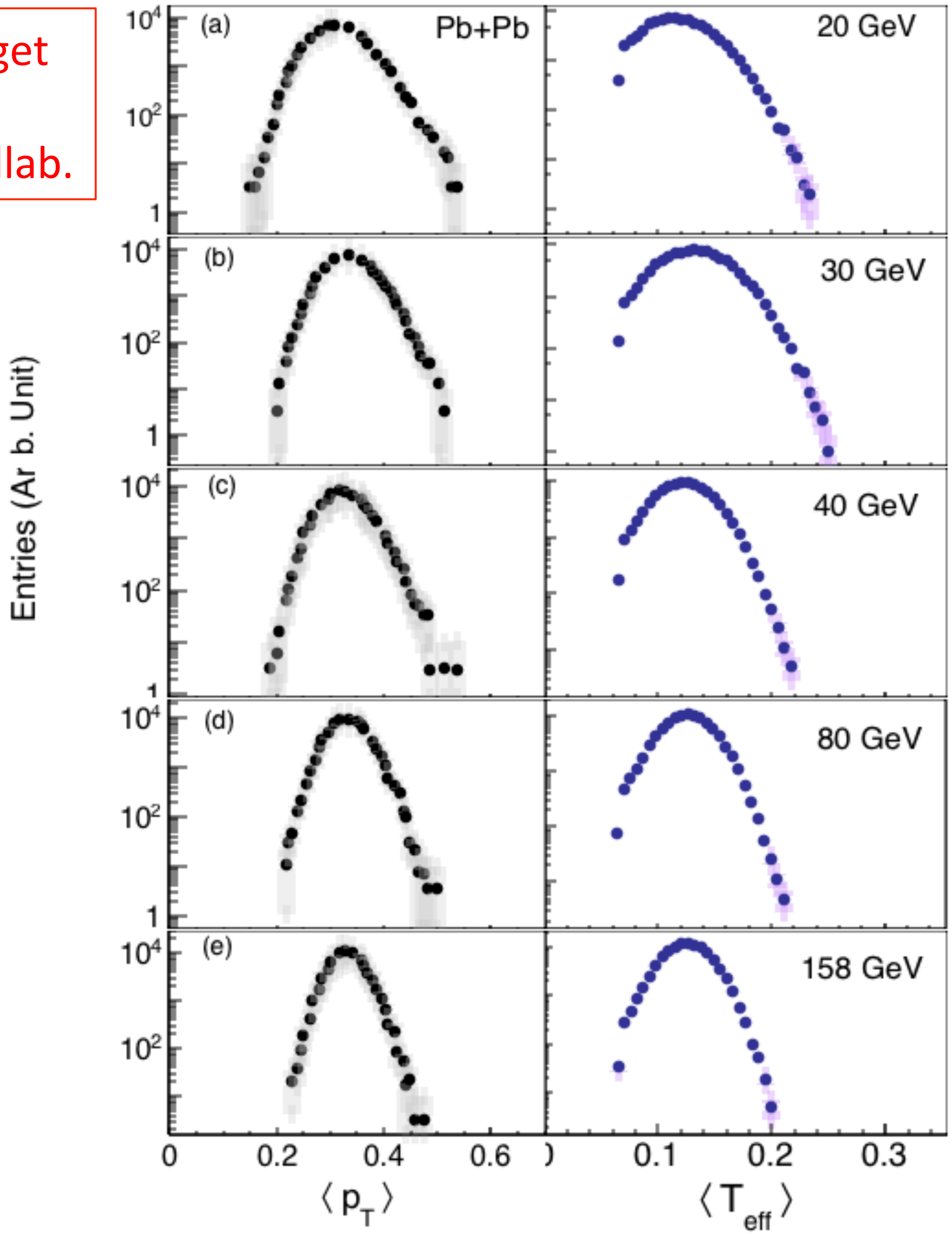


Collision energy (GeV)	$\sqrt{s_{NN}}$ (GeV)
20 A	6.27
30 A	7.62
40 A	8.73
80 A	12.3
158 A	17.3

$(1.1 < y^*_\pi < 2.6)$

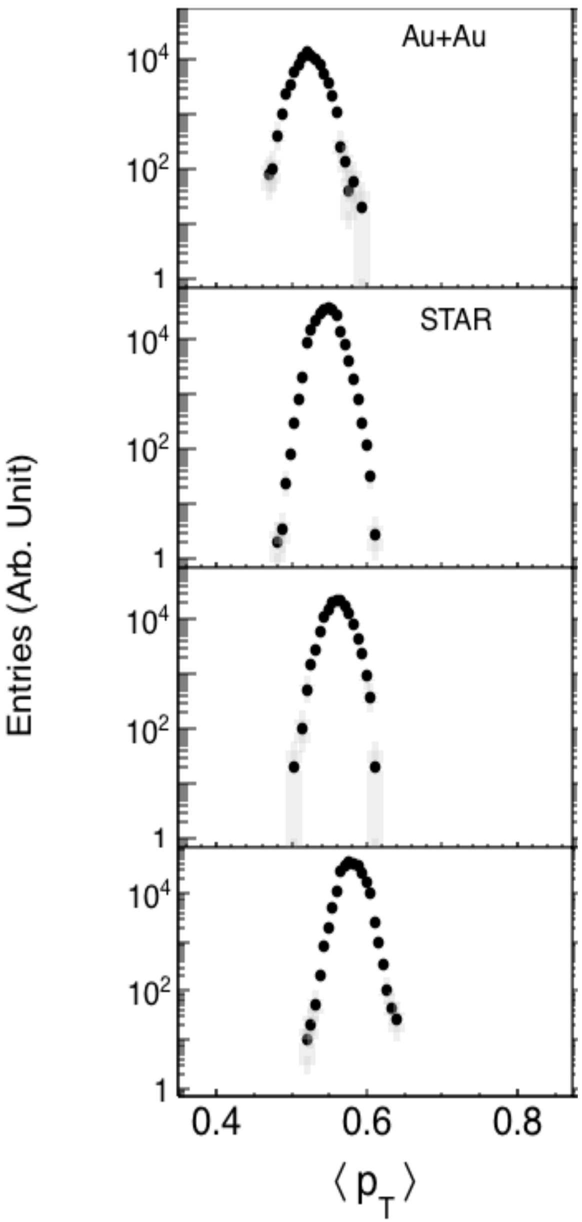
Result : CERES

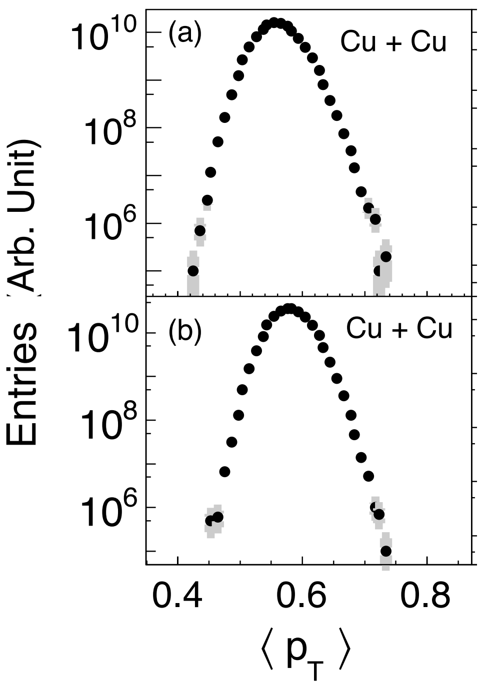
Fixed Target
Pb – Pb
CERES Collab.



Result : STAR

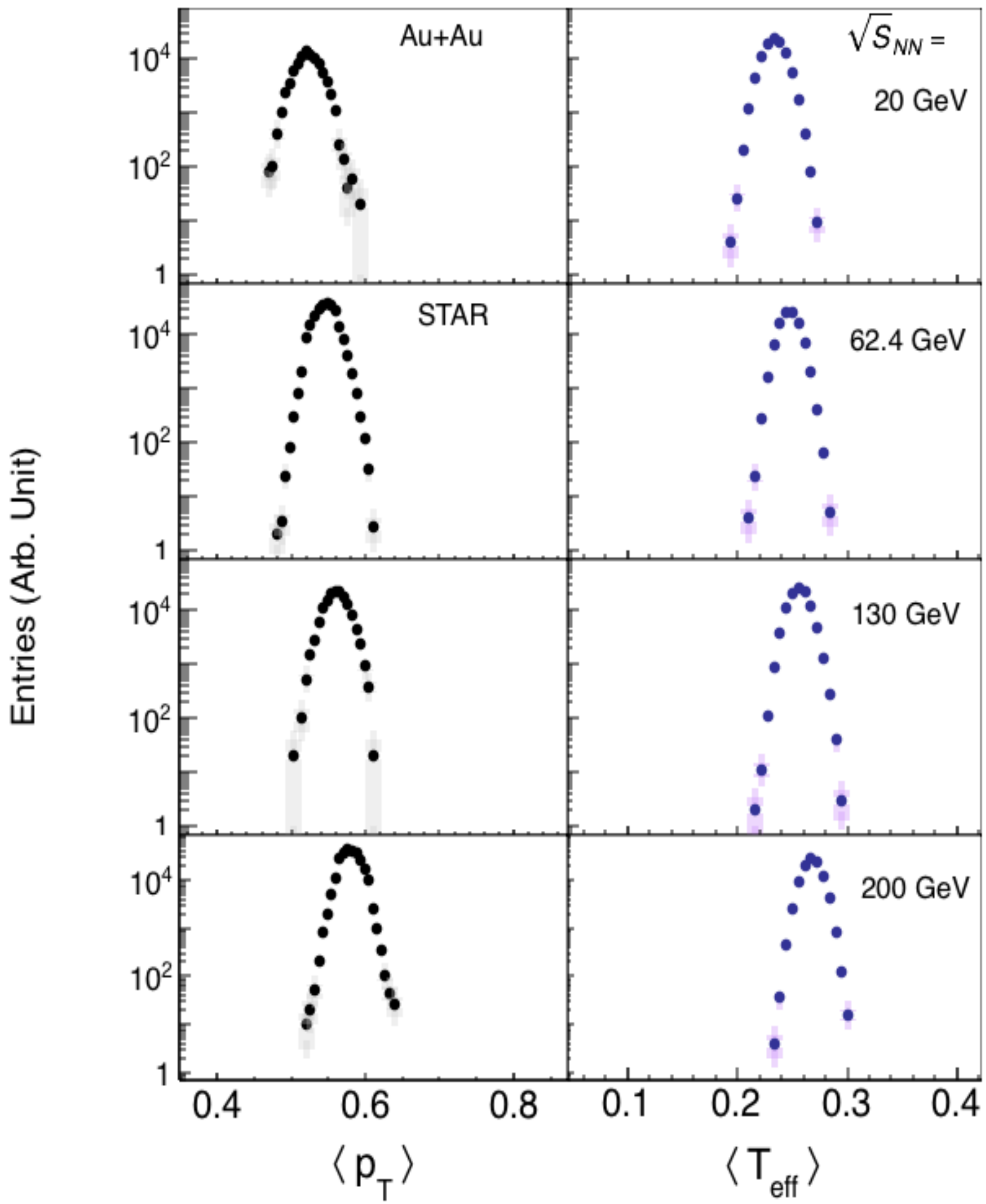
Collider Au –Au
STAR Collab.

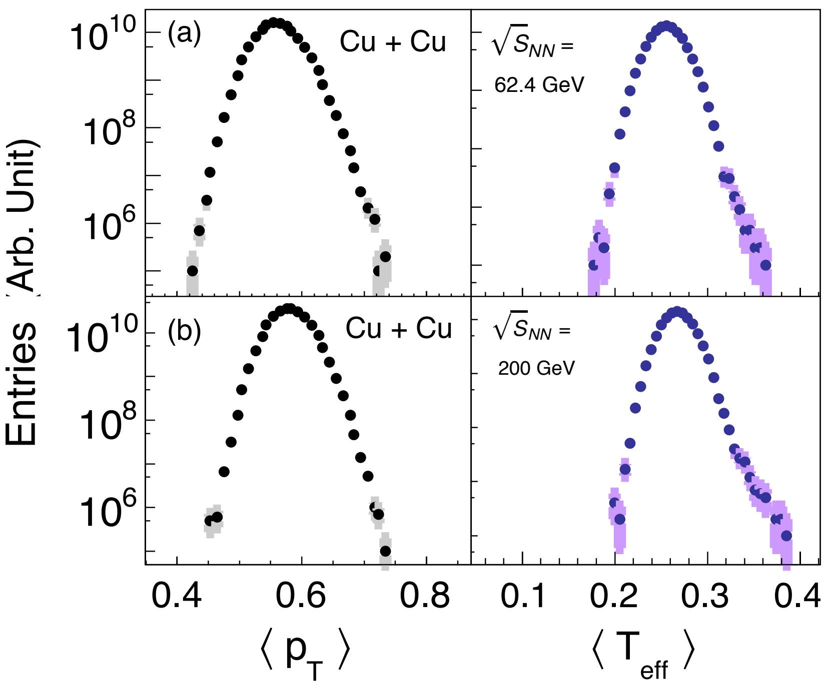




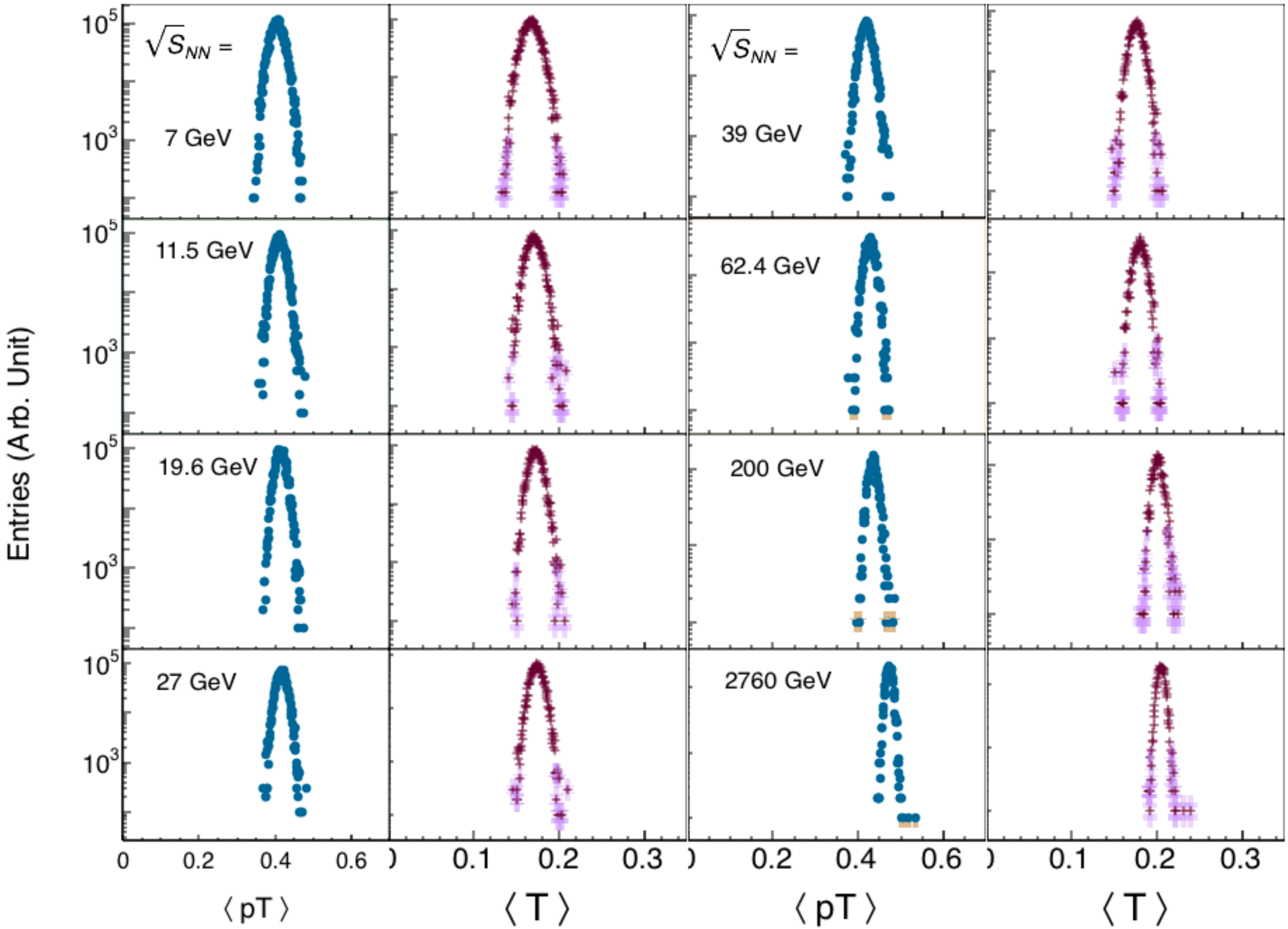
Result : STAR

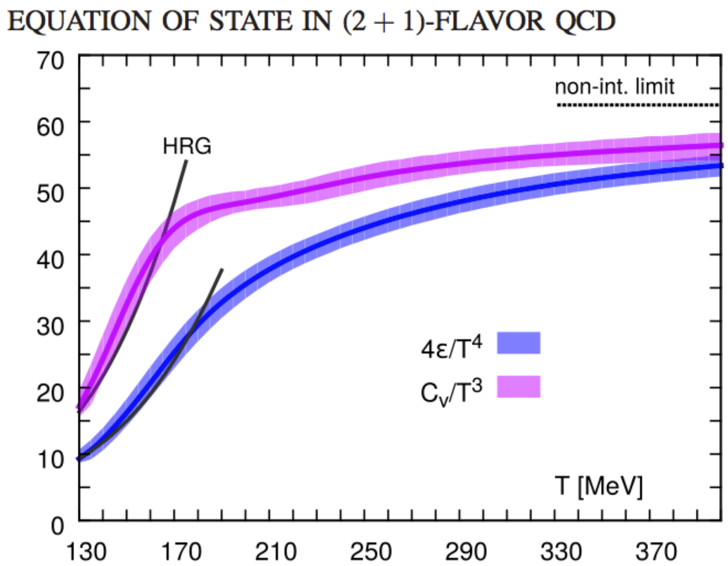
Collider Au –Au
STAR Collab.



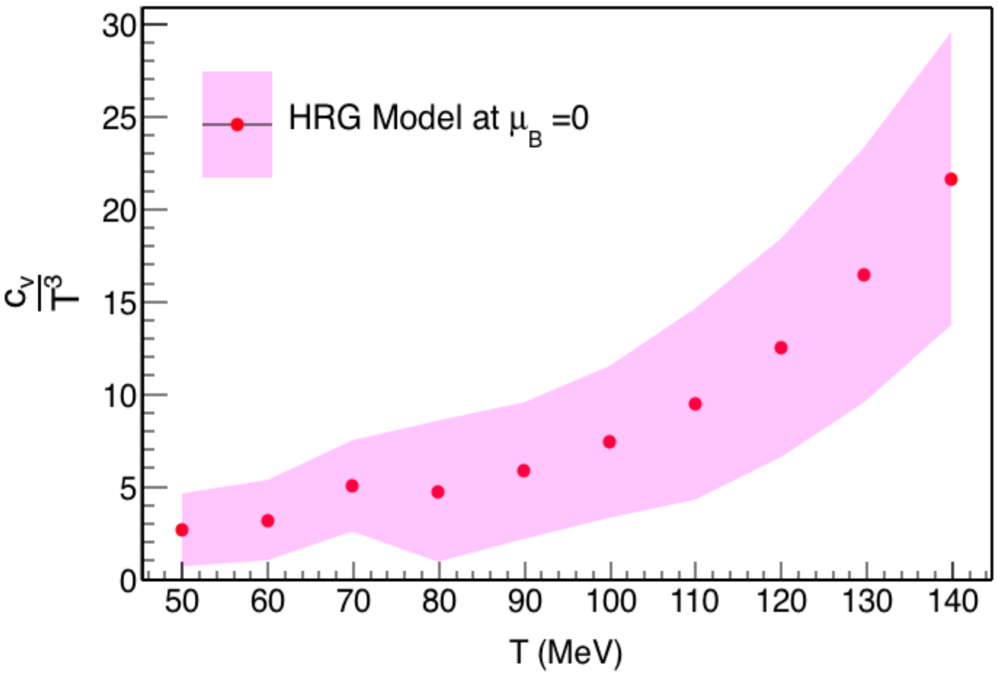


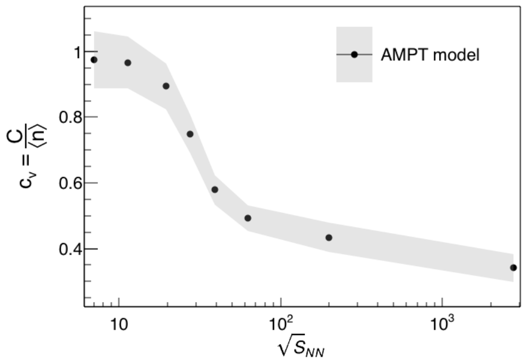
Result : AMPT


$\sqrt{S_{NN}}$ =
7 GeV
11.5 GeV
19.6 GeV
27 GeV
39 GeV
62.4 GeV
200 GeV
2760 GeV
Entries (Arb. Unit)
10^5
10^3
0
0.2
0.4
0.6
0.1
0.2
0.3
⟨pT⟩
⟨T⟩

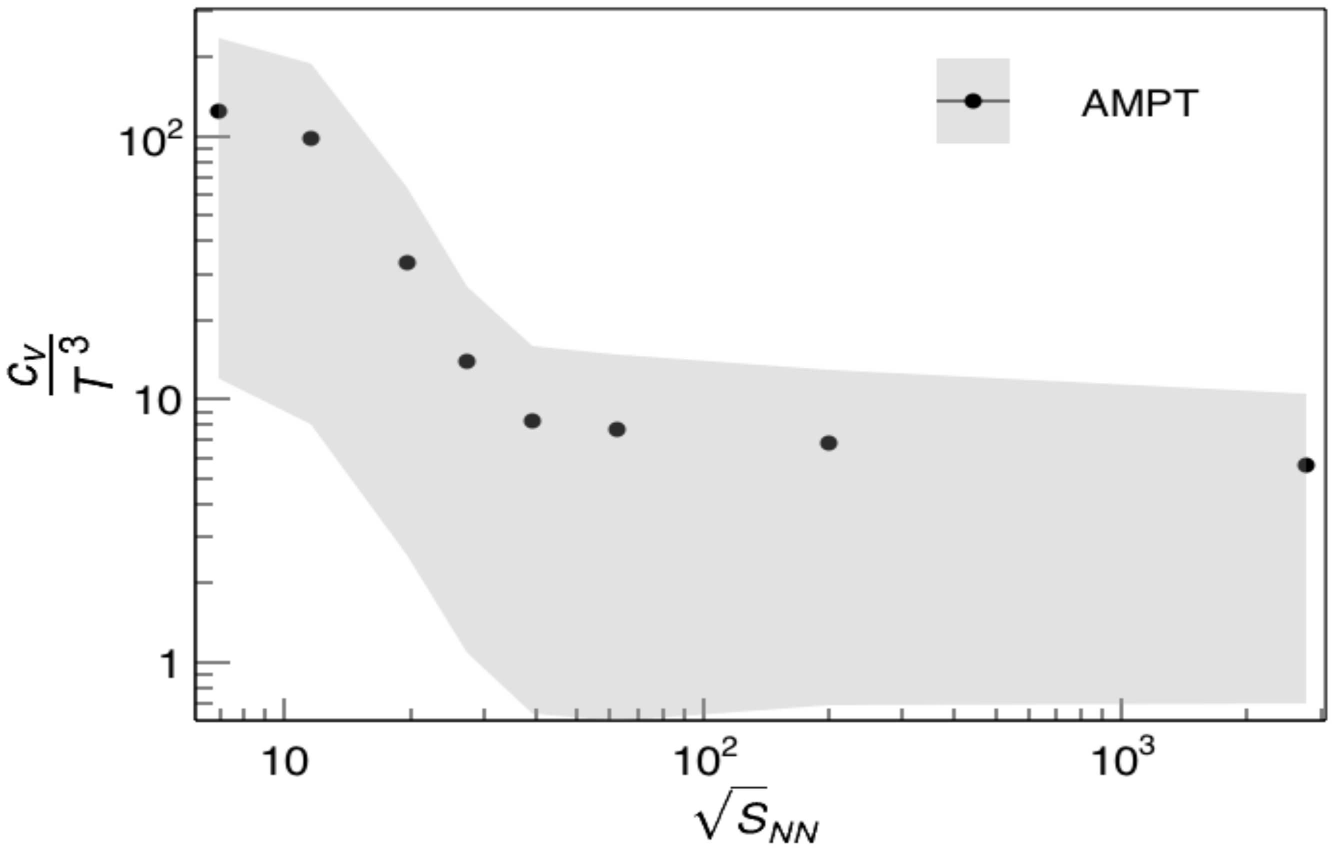


Swagato et. Al PhysRevD.90.094503

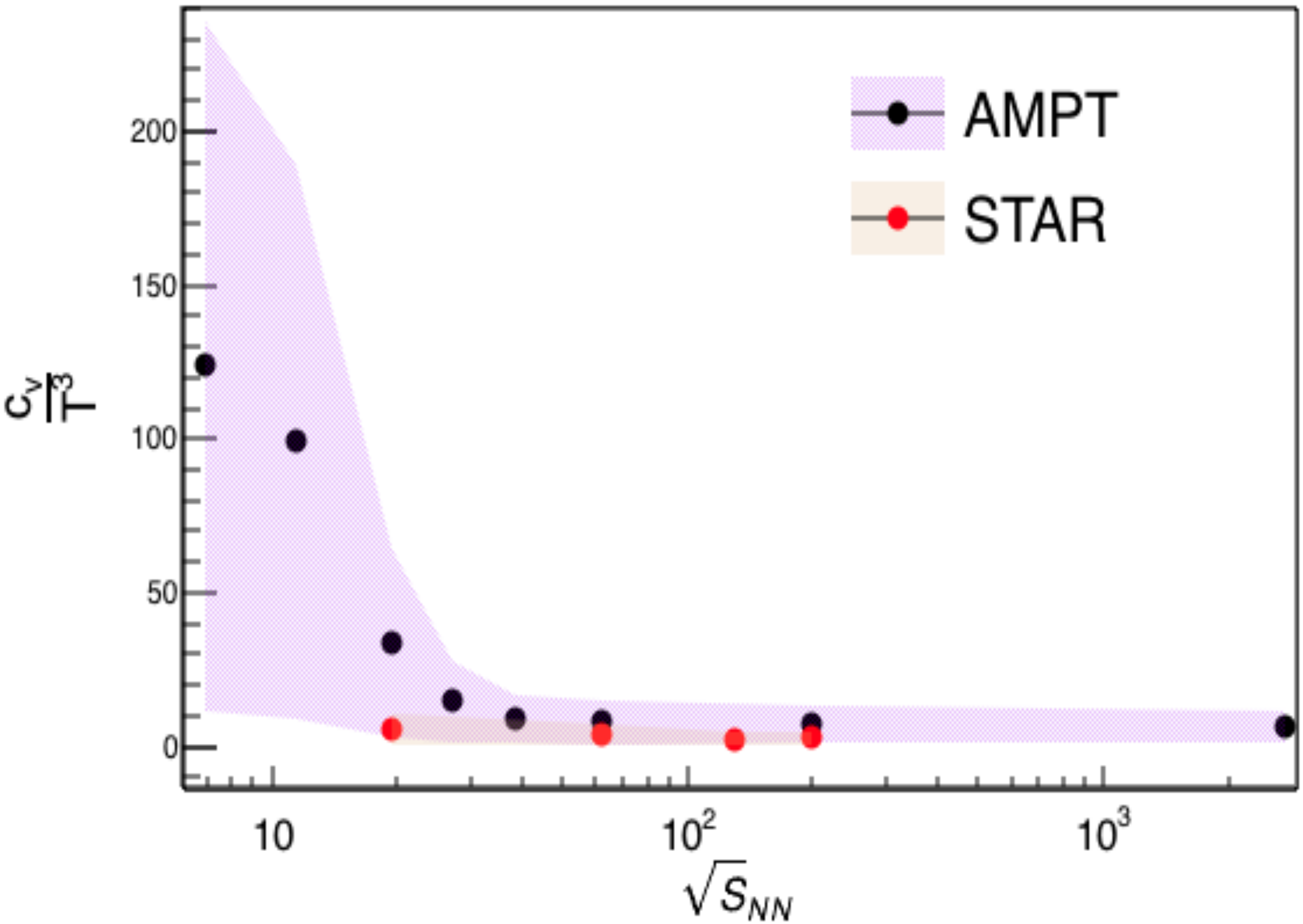




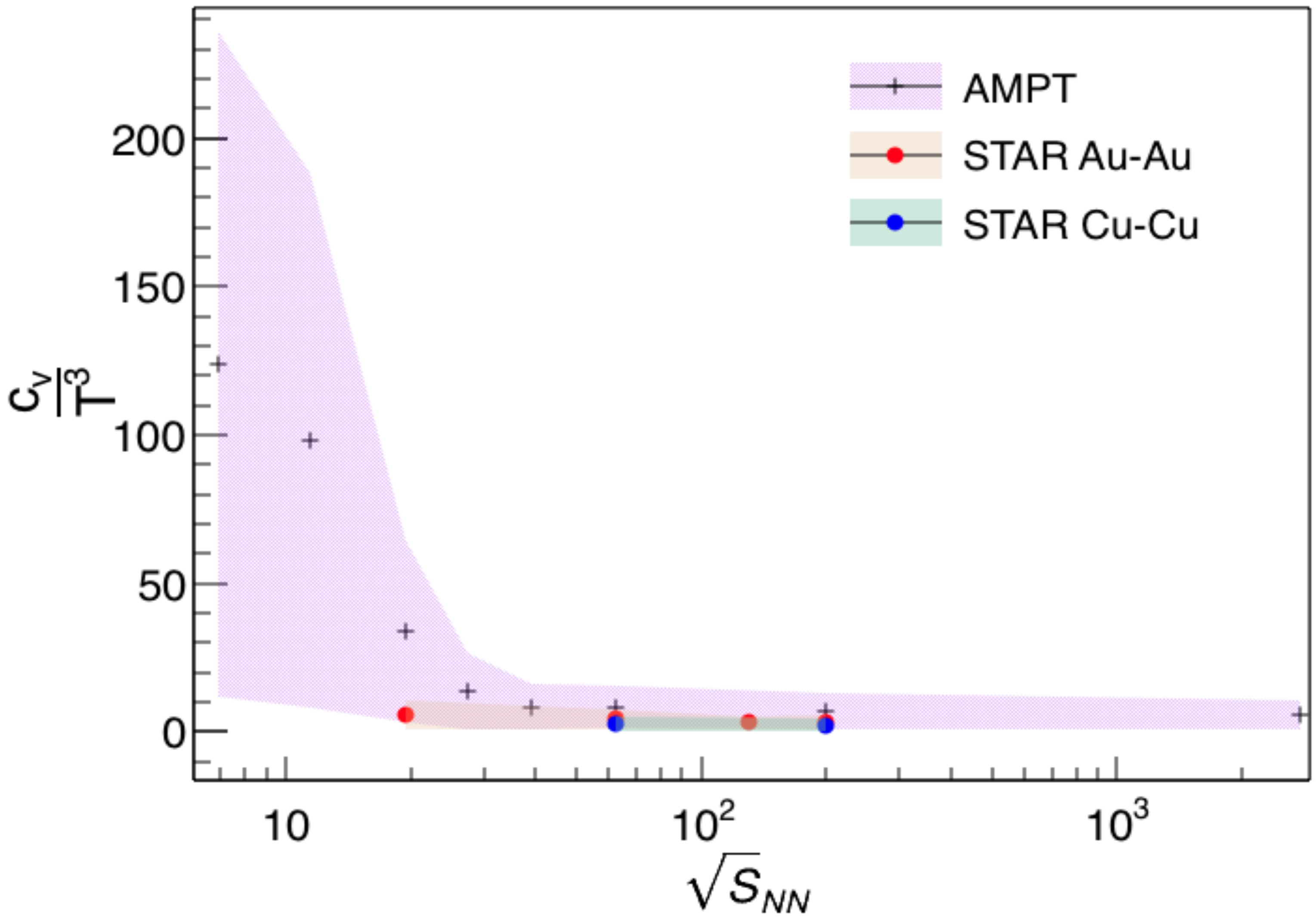
Result : c_V/T^3



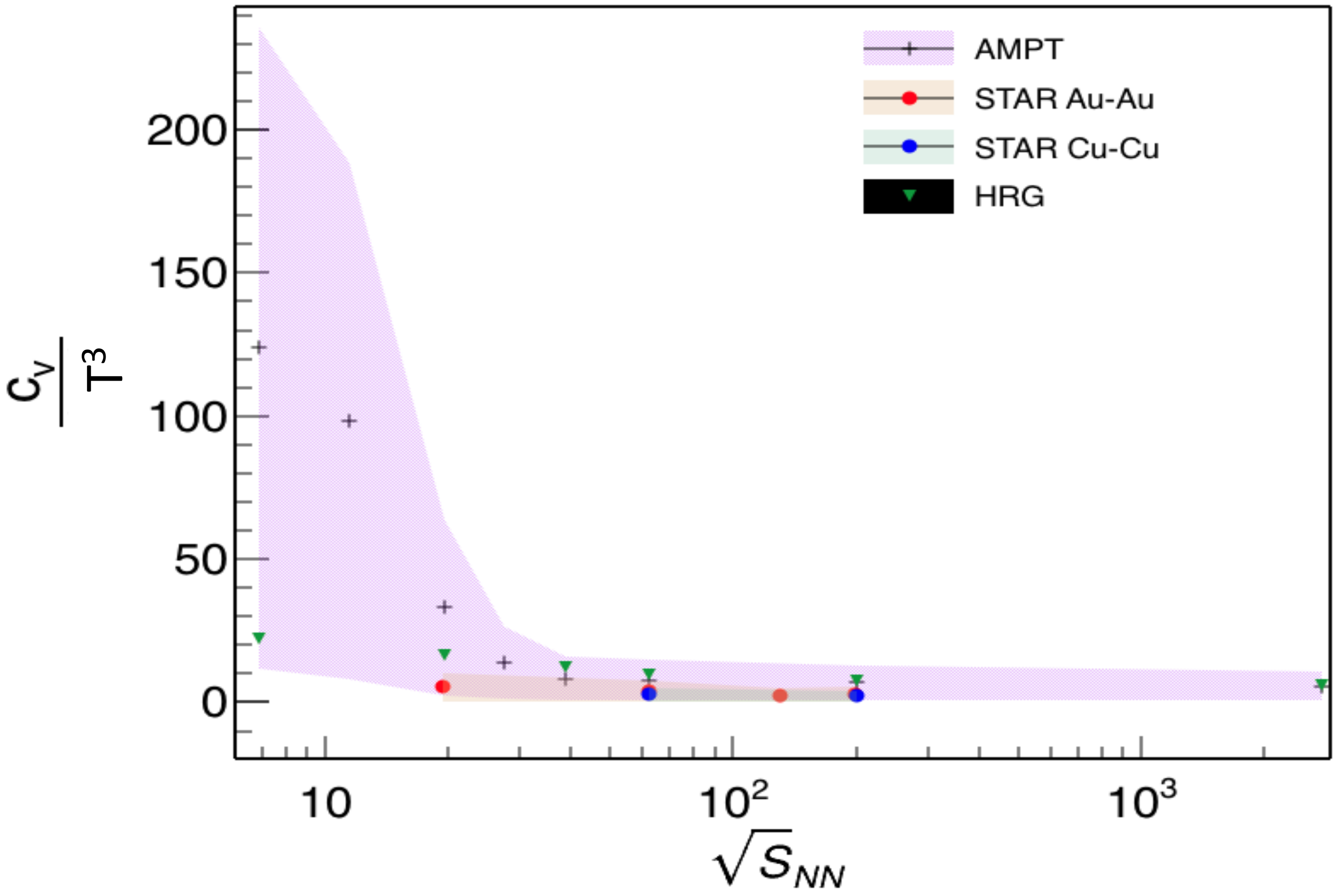
Result : c_V/T^3



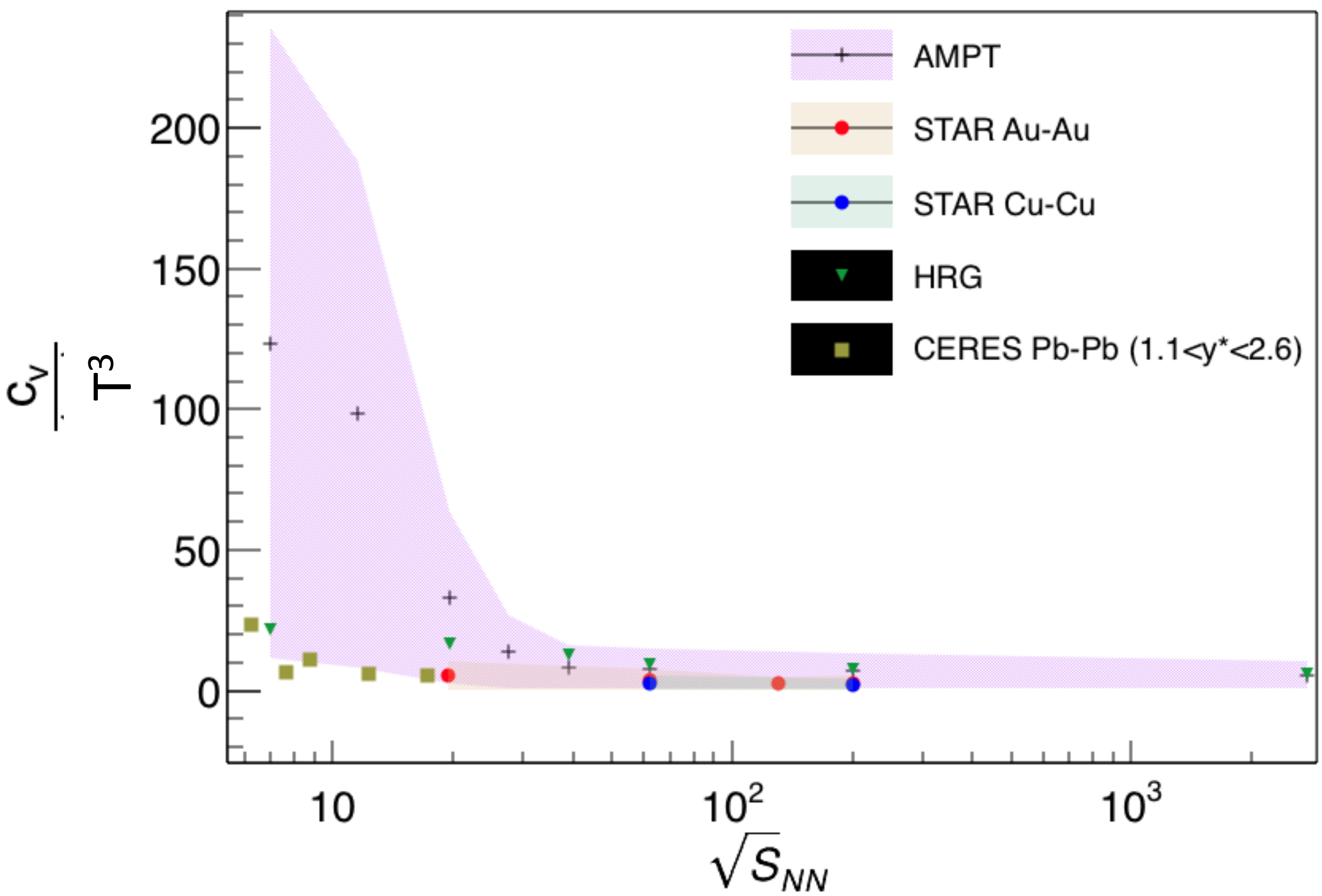
Result : c_V/T^3


AMPT
STAR Au-Au
STAR Cu-Cu
$\frac{c_V}{T^3}$
200
150
100
50
0
10
10^2
10^3
$\sqrt{s_{NN}}$

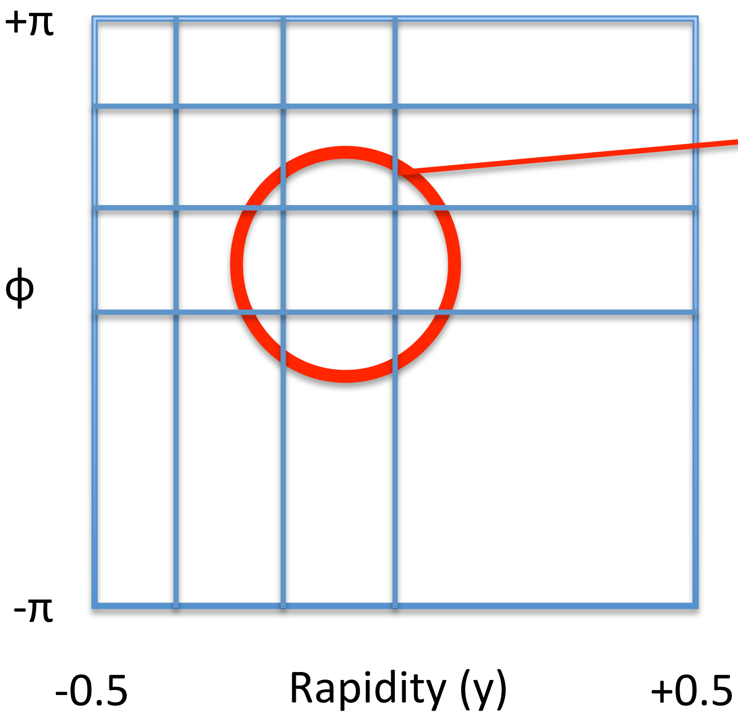
Result : c_V/T^3


AMPT
STAR Au-Au
STAR Cu-Cu
HRG
200
150
100
50
0
$\frac{c_V}{T^3}$
10
10^2
10^3
$\sqrt{S_{NN}}$

Result : c_V/T^3


AMPT
STAR Au-Au
STAR Cu-Cu
HRG
CERES Pb-Pb (1.1<y*<2.6)
200
150
100
50
0
10
10^2
10^3
$\frac{c_V}{T^3}$
$\sqrt{S_{NN}}$

Local Fluctuation



1. We Can construct pT Distribution

From where we have <pT> or <mT>

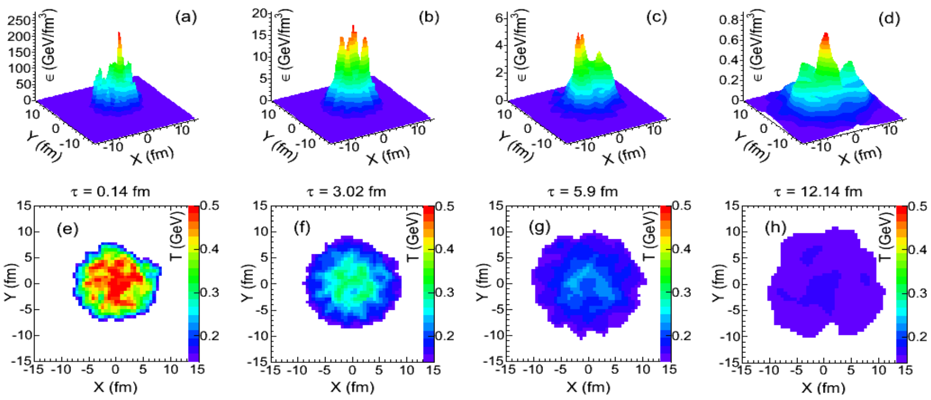
2. From there → Getting Teff is same like Global

3. For each Bin(y,ϕ) → We have 1 Teff value

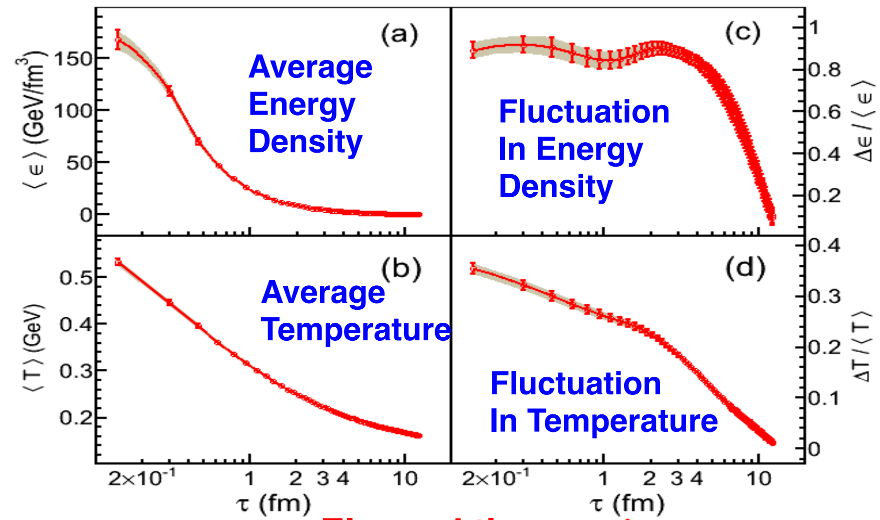
4. So, for each event
we have a local Teff distribution
→ Getting Mean and RMS

5. Event by Event We measure F_{bin} and it's Distribution.

Local Fluctuation

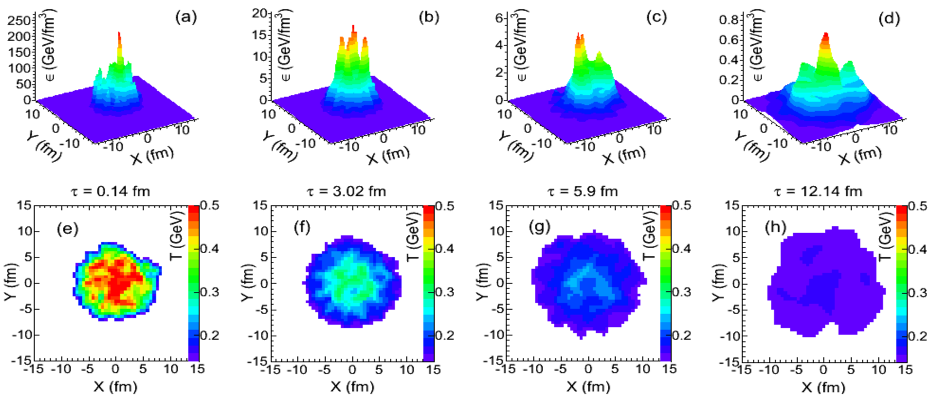


Temporal Evolution:

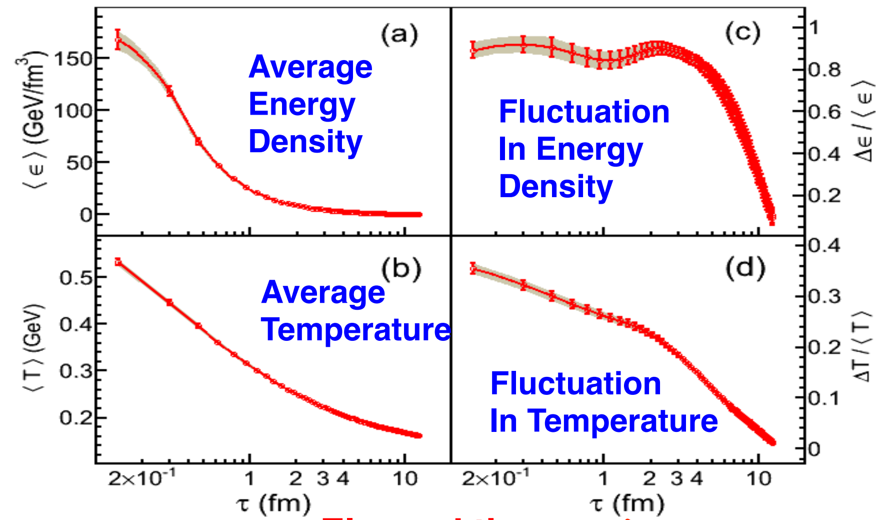


Elapsed time →

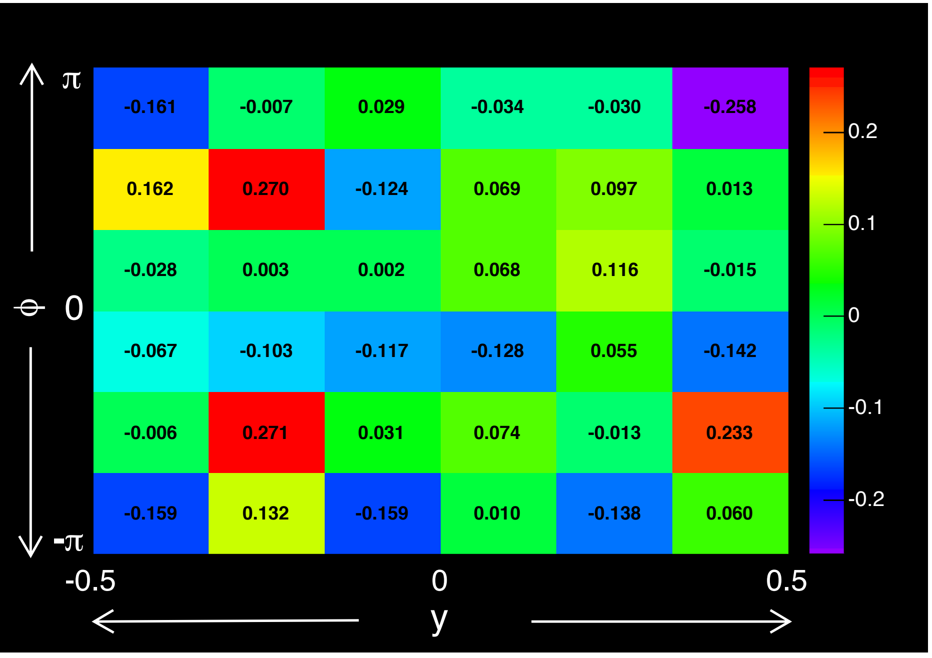
Local Fluctuation

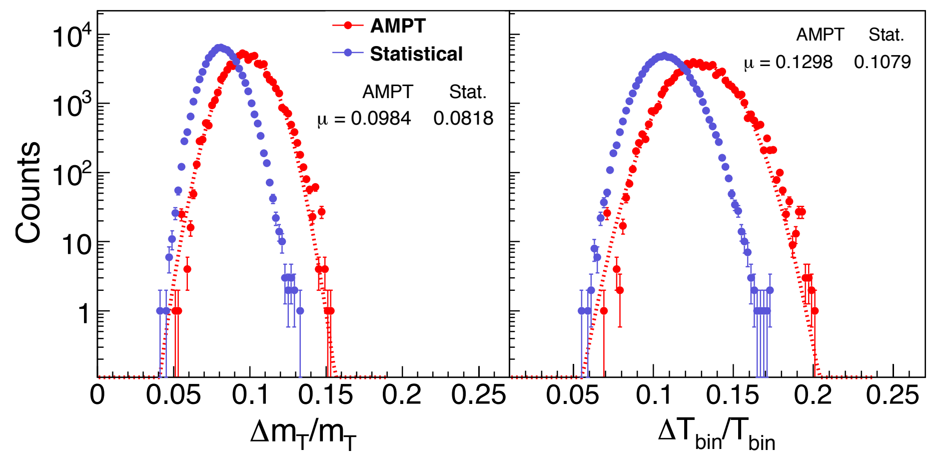


Temporal Evolution:



Elapsed time →





Summary

VECC

- ❖ Heat Capacity and Sp. Heat can be Calculated from Event-by-Event (E-by-E) Temperature Fluctuations:
  - Prospect for RHIC BES to calculate Specific Heat C_V/T^3 from Temperature fluctuations
  - A comparison with model and data with available theory is shown

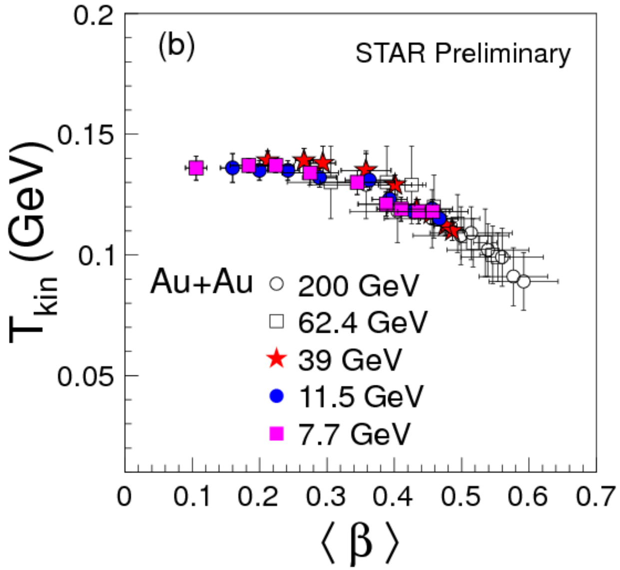
- ❖ Local Temperature Fluctuations map similar to CMBR
  - In 6x6 bins local fluctuations of temperature fluctuations in shown for model
  - Only possible in LHC energy, may be at Top RHIC energy.
  - ❖Weather there is spatial patches in the temperature distribution?
  - ❖Indicating local fluctuation or hot spot position?
  - ❖Is it 1 to 1 corresponds?

  Can We estimate??
  How to quantify ?
  Is that completely washed out?

- ❖ Open up a new avenue to characterize heavy ions collisions.

THANK YOU ALL

Back Up



STAR Collab. Nucl.Phys. A904-905 (2013)

PHYSICAL REVIEW C **79**, 034909 (2009)