Thermodynamics of nuclear matter at high energy nuclear reactions.

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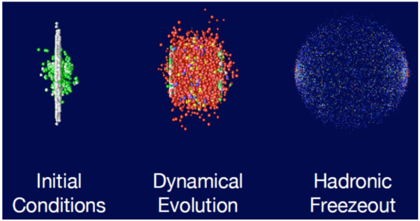
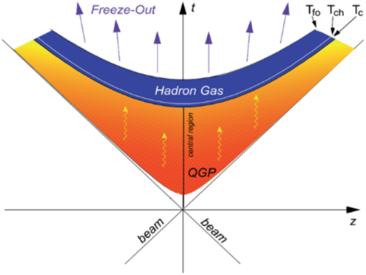
Outline

Introduction

The main three stages of high-energy nuclear collisions had to be treated with certain theoretical models





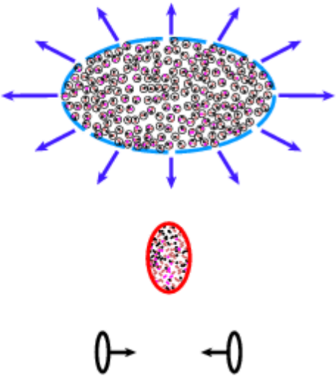
Introduction

There are several theoretical models, which are proposed to explain the characteristics of multi-particle production through nuclear collisions at high energies ,such as:

- Wounded Nucleon Model
- **Fermi-landau model**
- Bjorken– McLerran model
- Hydrodynamical model
- **Thermo-statistical models**

Outline

Fermi-landau model



The two incoming ions (traveling at speed ~ c)look like two flying disks toward each other, creating a cloud of hadrons. The cloud is assumed to have a spherical shape.

Fermi-landau model

The energy density of the drop will approximately be given by the macroscopic observables such as the volume, the multiplicity distribution and the transverse momentum, as:

$$\epsilon \simeq \frac{\frac{3}{2}\frac{dN_{ch}}{d\eta} < P_T >}{V}$$

The initial entropy density of produced charged hadrons produced in p-p collision at central rapidity range has been estimated based on fermi-landau model:

$$\sigma_s = \frac{\frac{3}{2}\frac{dN_{ch}}{d\eta}}{s}$$

Thermo-statical models

Macroscopic models that describe the particle production through the nuclear collisions based on several assumptions as follows:

- In the initial collision a large amount of the kinetic energy of the colliding nuclei is used to create a large number of secondary particles in a small volume.
- These particles will subsequently collide with each other to reach a state of local thermal equilibrium.
- When the system has reached local equilibrium, it can be characterized by following parameters:
  i) Temperature
  ii) Entropy
  iii) chemical potential

The transverse momentum distribution could be described by exponential thermal distribution as follows :

$$f(P_t) = \frac{1}{P_t}\frac{dN}{dP_t} \approx A e^{-\frac{P_t}{T_{eff}}}$$

then ,The effective temperature of the system can be estimated using the average of the transverse momentum for the finite range as following:

$$< P_t >= \frac{\int_a^b P_t \; dP_t \; P_t \; f(P_t)}{\int_a^b dP_t \; P_t \; f(P_t)}$$

$$< P_t >= 2\,T_{eff} + \frac{a^2\, e^{-\frac{a}{T_{eff}}} - b^2\, e^{-\frac{b}{T_{eff}}}}{(a + T_{eff})\, e^{-\frac{a}{T_{eff}}} - (b + T_{eff})\, e^{-\frac{b}{T_{eff}}}}$$

Thermo-statistical models

The Tsallis' distribution is describing the thermal fluctuation of the system especially when this system has several equilibrium sources:

$$f(P_t, y) = CP_t\sqrt{{P_t}^2 + {m_o}^2}\cosh(y)[1+\frac{q-1}{T}(\sqrt{{P_t}^2 + {m_o}^2}\cosh(y)-\mu)]^{-\frac{1}{q-1}}$$

T : the freeze-out temperature representing the average temperature in a few sources which can describe as local equilibrium states,

q : represents the degree of non-equilibrium among different states,

μ : the chemical potential and can regarded as zero in each local equilibrium state during it, the yield particles released from their sources,

m_o: the rest mass of the considered particle due to each interaction.

Tsallis' distribution could be formulated from several standard distributions and The used Tsallis' form is non-extensive formula to describe the pseudorapidity distribution of produced charged hadrons :

$$\frac{dN}{d\eta} = N_o \frac{\cosh(\eta)}{\sqrt{m^2 {P_t}^{-2} + cosh^2(\eta)}} [1 + (q-1) \frac{\sqrt{m^2 + {P_t}^2 cosh^2(\eta)}}{T}]^{\frac{1}{q-1}}$$

T : is the average kinetic freeze-out temperature in a few sources which can describe local equilibrium states,

P_t : is the average transverse momentum of produced charged particle ,

q : represents the degree of non-equilibrium among different states,

N_o : is a normalization factor.

Outline

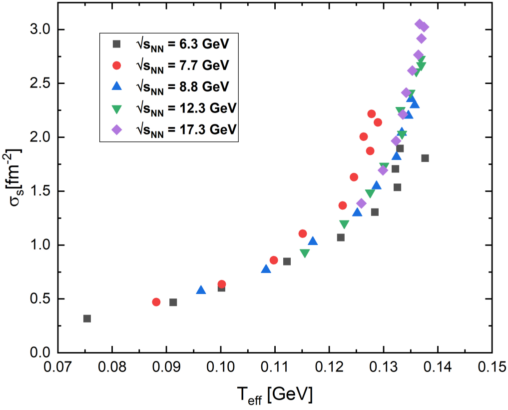
Results

Studying the properties of the produced charged particles through different proton-proton and nucleus-nucleus collisions in the following collisions;

- **Proton-Proton collisions:**
  - Transverse momentum spectra of produced charged hadrons through inelastic pp interactions at the center of mass energies per nucleon pair =6.3 ,7.7,8.8, 12.3 and17.3 GeV at rapidity ranges y from 0.0 to 2.0 .
  - The transverse momentum distributions of the produced charged hadrons through proton-proton collision at different energies = 0.9, 2.36, 7 Tev at Mid rapidity range.
- **Nucleus-nucleus collisions:**
  - Psudo-rapidity distribution of the shower particles emitted in 4.5 A GeV/c 28-Si interactions with emulsion.
  - The transverse momentum distributions of the produced charged hadrons through different A-A collision at different energies in the GeV and TeV region at Mid rapidity range.

Proton-proton collisions

The correlation between the effective temperature and entropy density through p-p collisions at the centre of mass energies equals to 6.3,7.7,8.8 ,12.3,17.3 GeV at central rapidity range(y=0.0-2.0)



Proton-proton collisions

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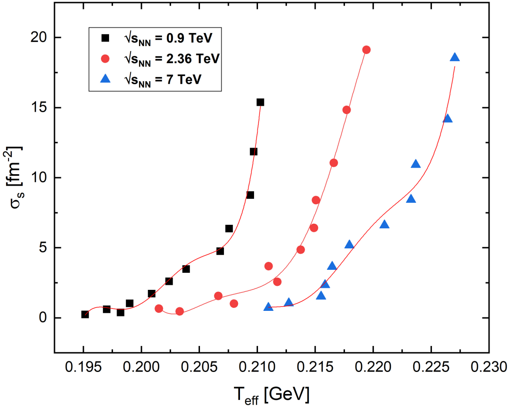
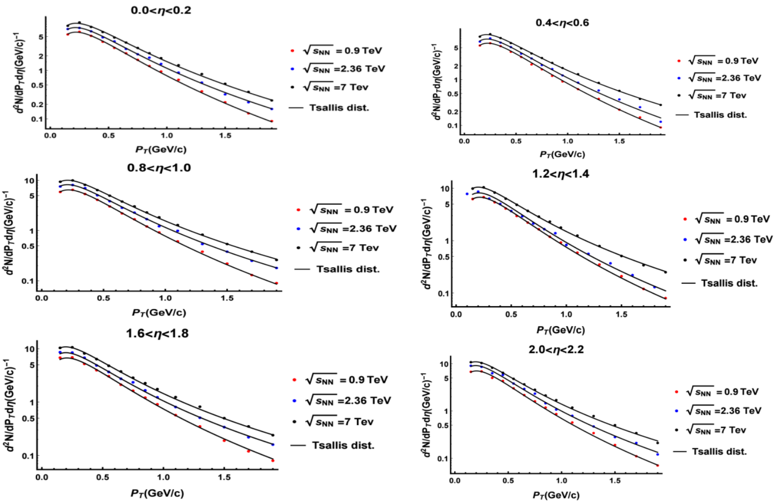


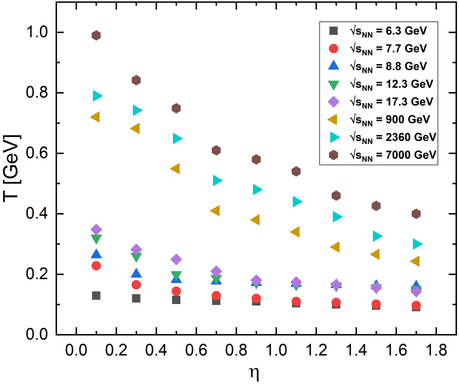
Proton-proton collisions

The transverse momentum distribution of the produced hadrons through the p-p collisions which has fitted using the Tsallis distribution function.



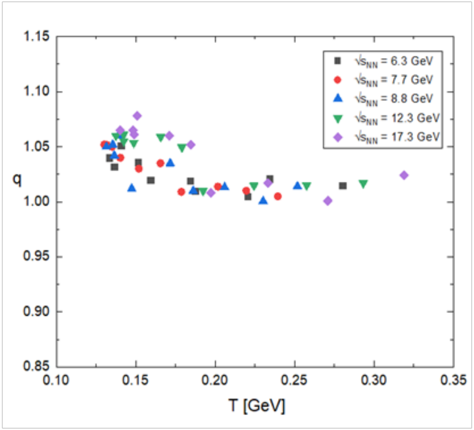
Proton-proton collisions

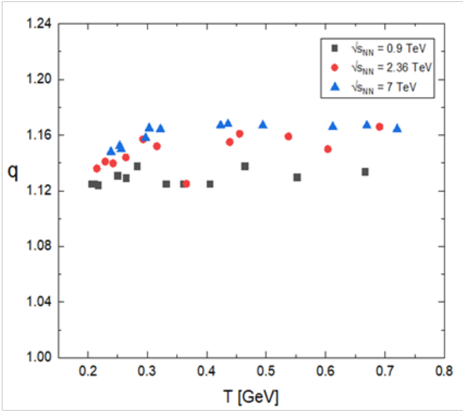
The variation of the extracted freeze out temperature with the rapidity interval of particles produced in p-p collision for the GeV and TeV groups as shown.



Proton-proton collisions

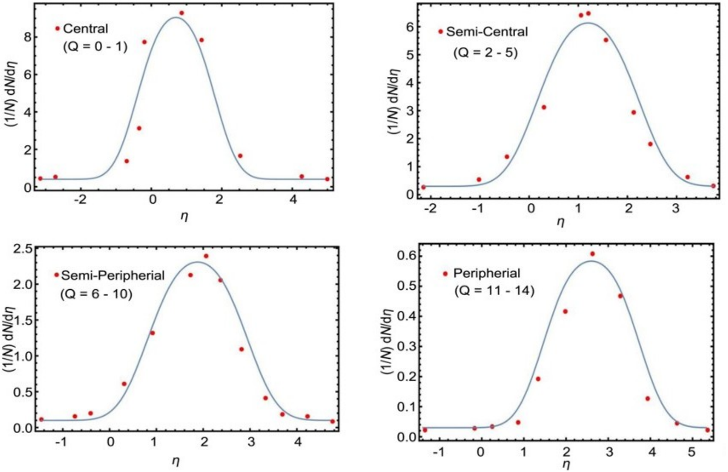
The correlation plot between the non-equilibrium index q and the temperature diagram in different proton - proton collisions:



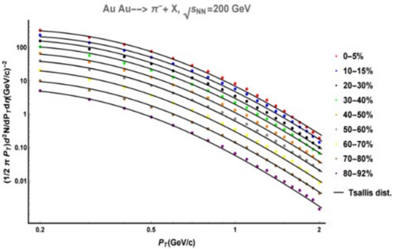


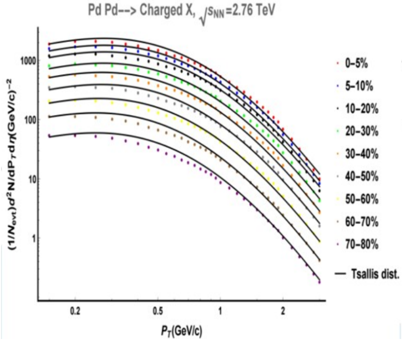
Nucleus-nucleus collisions

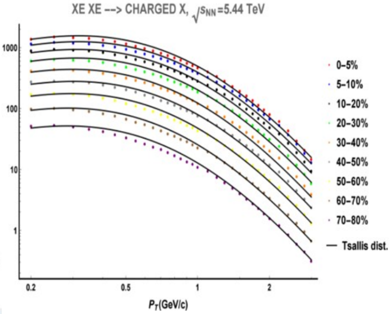
Pseudo-rapidity distribution of the shower particles emitted in 4.5A GeV/c ^{28}Si interactions with emulsion plate. Fitted by the Tsallis distribution function.



- Samples of the transverse momentum distribution of the produced hadrons through the A-A collisions which has fitted using the Tsallis distribution function.

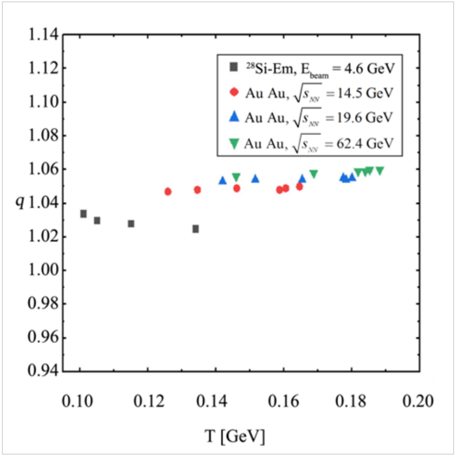


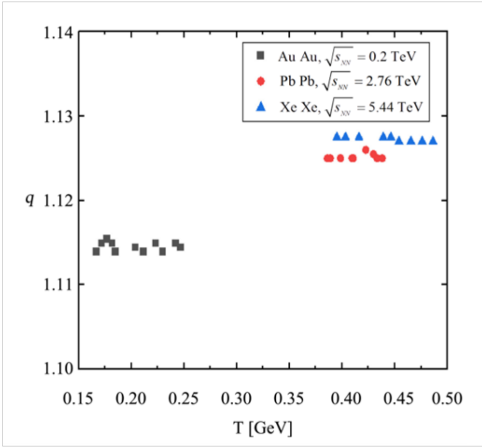




Nucleus-nucleus collisions

The correlation between the non-equilibrium index and the temperature through different nucleus-nucleus collisions.





Outline

Conclusion

According to the thermodynamic features revealed by the experimental data investigated in view of related theoretical models, can be summarized as follows:

- The produced particles in the tens GeV of p-p collision energy probably follow one mechanism of production, where the nuclear medium stays in one phase.
- At higher ranges of energy through p-p collisions, there are several sources of particle production that indicate passage of the nuclear matter through different states.
- According to the fermi-landau model, the critical temperature between the quark gulon plasma phase and the hadron phase is around 0.130 GeV through p-p collision at the GeV region, while it is around 0.207 - 0.225 GeV through p-p collision at the TeV region.

Conclusion

The Tsallis statistics describes effectively the distribution of experimental quantities of produced charged particles produced through different p-p and A-A collisions to extract the thermodynamic script as follows:

- Tsallis statistics show that the critical temperature between the quark gulon plasma phase and the hadron phase is between 0.130 and 0.15 GeV for a p-p collision in the GeV region and between 0.25 and 0.30 GeV for a p-p collision in the TeV region.
- The non-equilibrium parameter shows small bits of decrease with centrality approaching equilibrium in a few tens of GeV of A-A interaction energy that keeps the systems close to the border of equilibrium.
- In the TeV range of A-A collisions , the non-equilibrium parameter has shown different levels of saturation that are far away from equilibrium that could be interpreted by the interplay between the two crucial characters of the QCD: the color confinement and the asymptotic freedom.

References

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