QCD Phase Diagram and thermodynamics

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LBL

Introduction

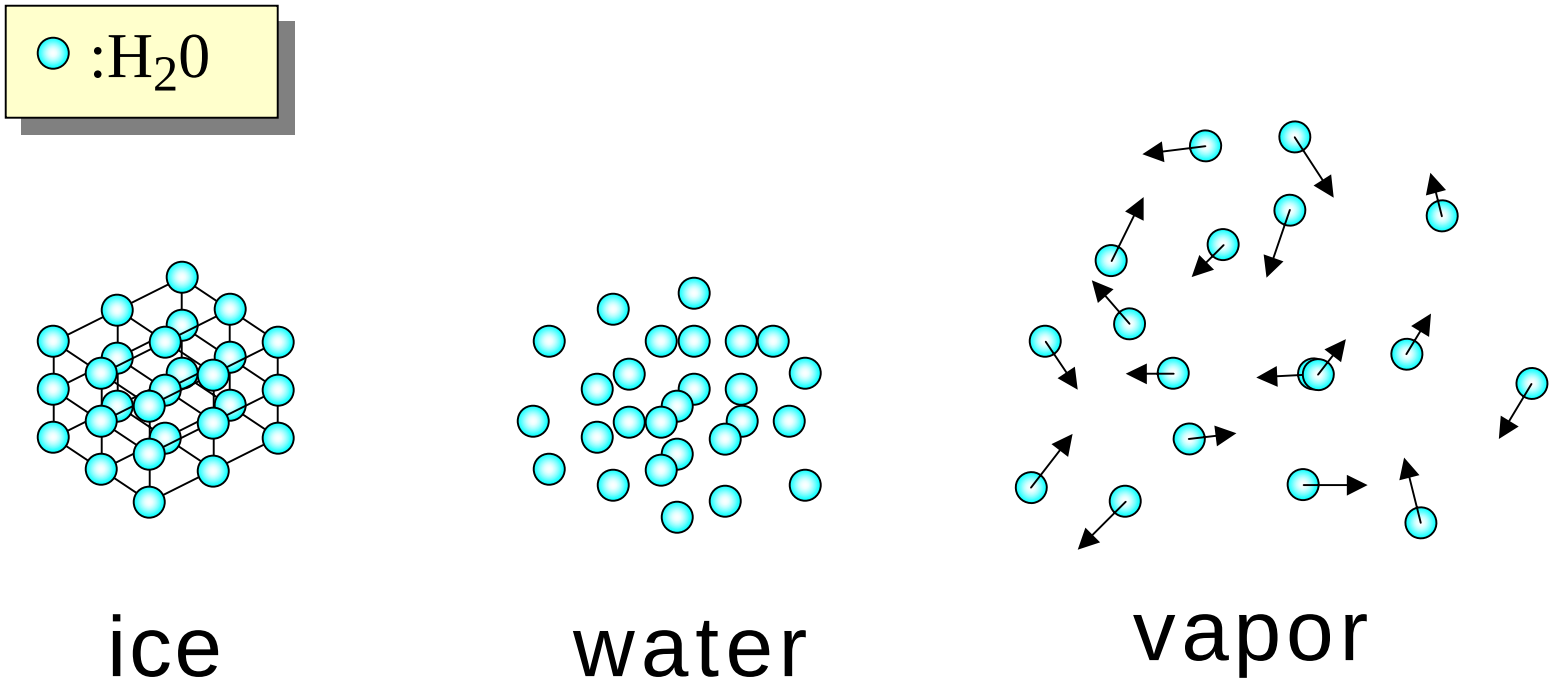
- Goal of High Energy Heavy Ion collisions
  - Study multi-body system in high energy
  - Observe Quark Gluon Plasma (QGP)
- QGP?
  - Our world consist from hadrons and leptons
  - In hot and/or dense matter, a phase transition

    hadron $\rightarrow$ Quark gluon plasma

    is predicted

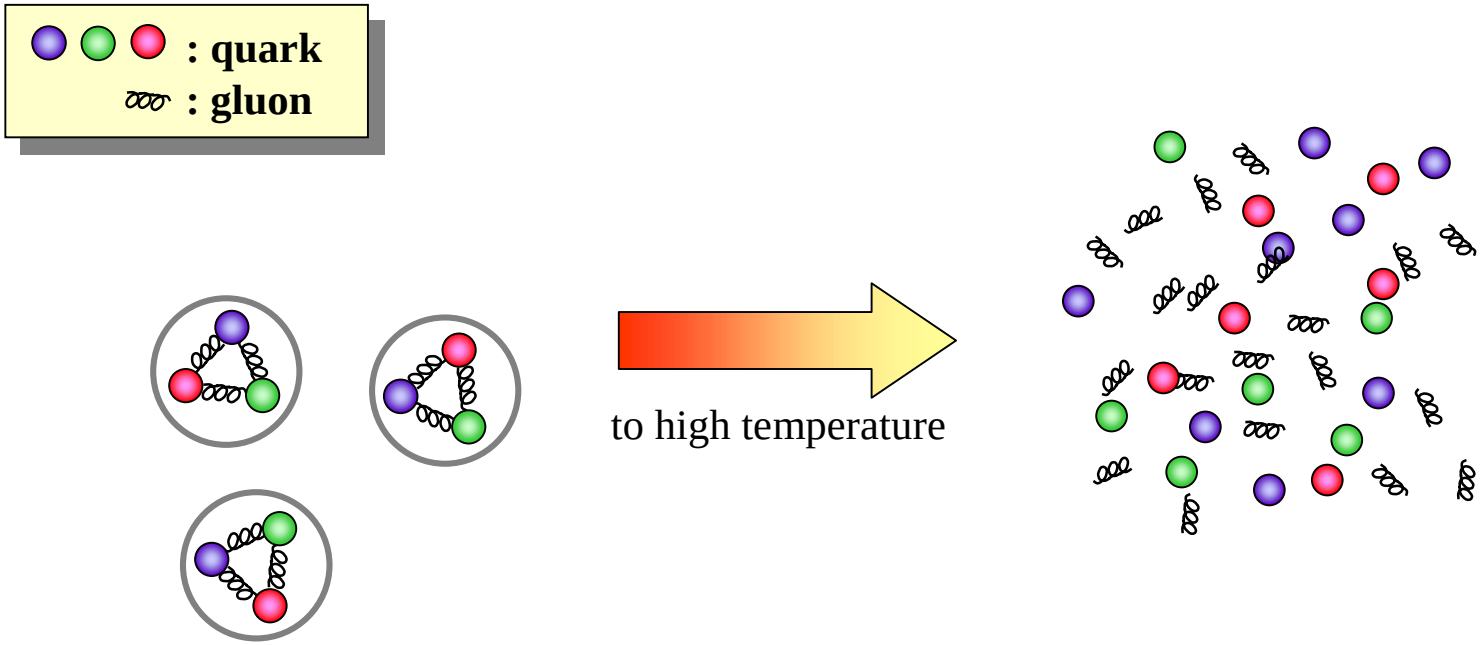
Phase transition

- In case of ice-water-vapor
  - heating give molecule kinetic (thermal) energy



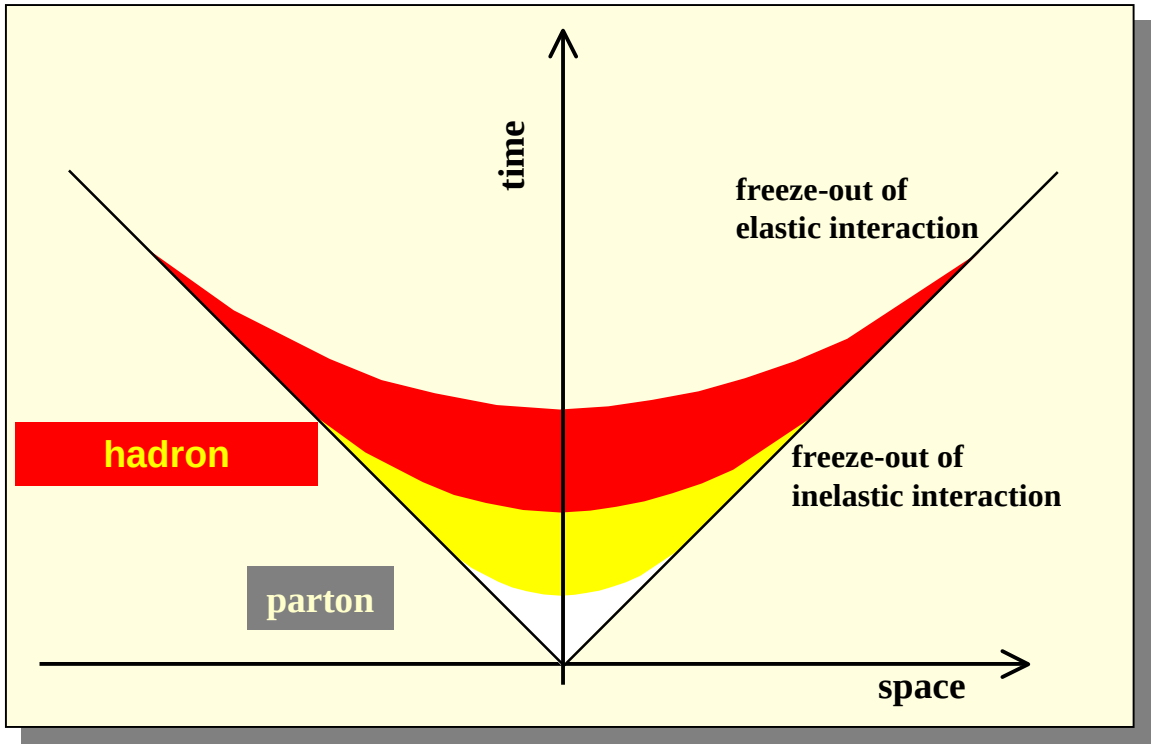
Phase transition hadron to QGP

- QGP
  - Quantum chromodynamics (QCD) predict a phase where quark and gluon can move like free particles in hot and/or dense matter



Heavy ion collisions

- Space expansion and time evolution of particle gas



Thermodynamics

- Thermodynamics describes many-body system
  - Energy distribution, particle density can be described by thermo dynamical parameters (temperature, potential, and etc)
- For example,
  - energy (momentum) distribution for temperature *T*

$$\frac{d^3n}{dp^3} = \frac{V}{(2\pi)^3} e^{-(E-\mu)/T}$$

Applications

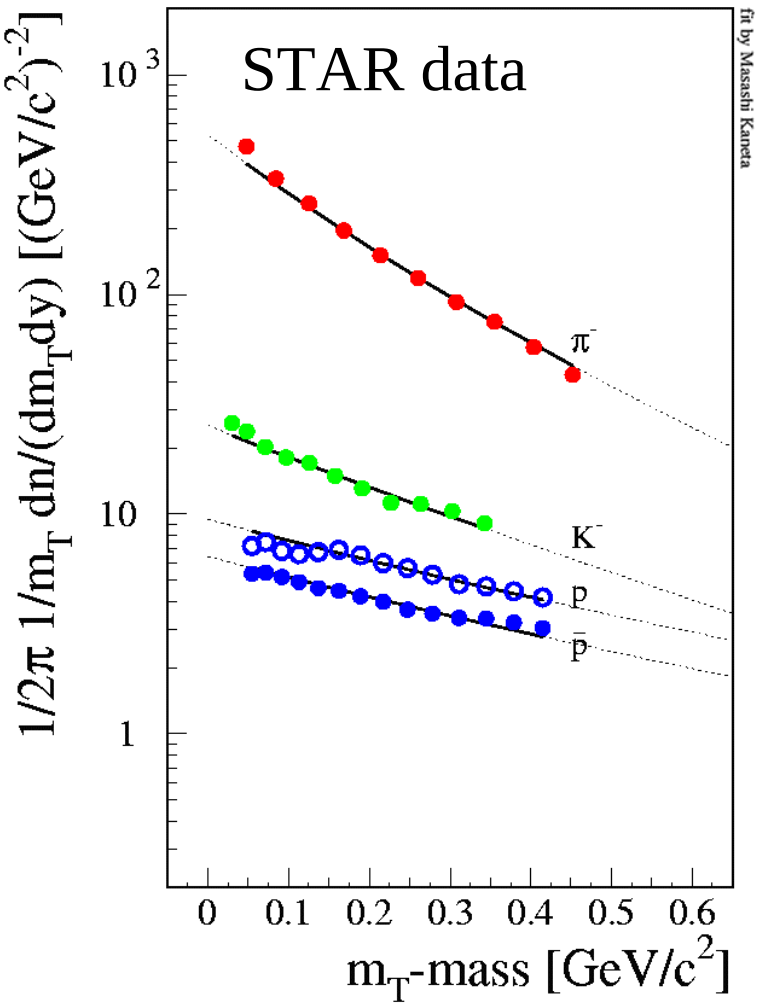
- Heavy ion collisions generate many hadrons (100~3000)
- Fact:
  - momentum distribution of hadrons can be described by thermal distribution

$$E\frac{d^3n}{dp^3} = \frac{1}{p_T}\frac{d^3n}{dp_T\,dy\,d\phi} = \frac{1}{m_T}\frac{d^3n}{dm_T\,dy\,d\phi} = \frac{V}{(2\pi)^3}E\,e^{-(E-\mu)/T}$$

$$m_T = \sqrt{m^2 + p_T^{\,2}}$$

$$\frac{1}{m_T}\frac{dn}{dm_T} \propto m_T\,K_1(m_T/T) \underset{m_T >> T}{\rightarrow} \sqrt{m_T}\,e^{-m_T/T}$$

$m_T(p_T)$ distributions



- m_T distribution can be described by Boltzmann-distribution + expansion effect

Inverse slope parameter

$$= T_{th} + m < \beta_r >^2$$

$$(p_T \lesssim m)$$

Ref.: I.G.Bearden et al (NA44), PRL78 2080 (1997)

particle ratios

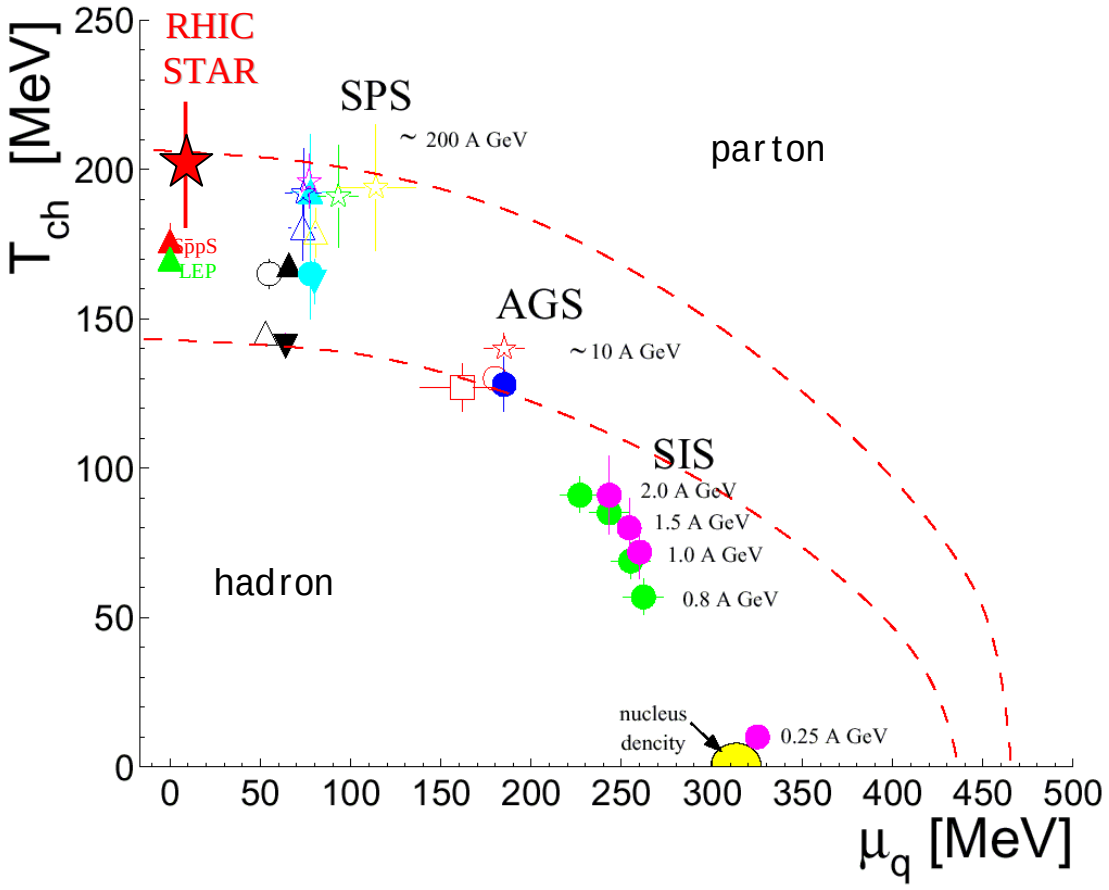
- If the system is in chemical equilibration
  - written by temperature and potentials
- focusing ratio (=particle number)
  - integrated momentum

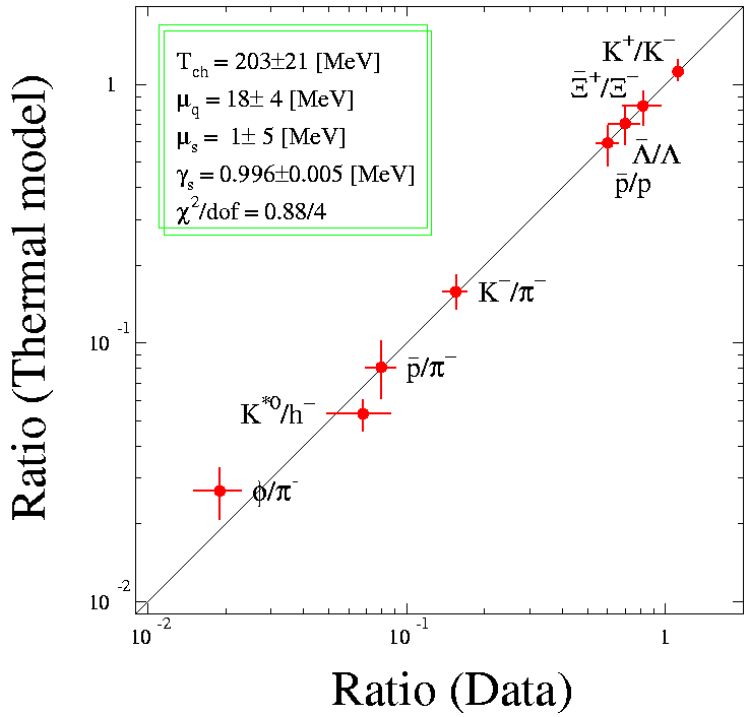
- particle density for the particle is

$$\rho = \frac{g}{2\pi^2} m_T \; T^2 \; K_2(m_T / T) \, e^{\mu / T}$$

- considered spin, isospin freedom, resonances effect

Where are we?





←related baryon density

parton-hadron phase boundary

Summary

- RHIC experiment make a phase which is close to QCD phase transition