Constraining the QCD equation of state with identified particle spectra

Akihiko Monnai[1,2] and Jean-Yves Ollitrault[1]

[1] Institut de Physique Théorique, CNRS, CEA/Saclay, F-91191 Gif-sur-Yvette, France

[2] KEK Theory Center, Institute of Particle and Nuclear Studies, KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

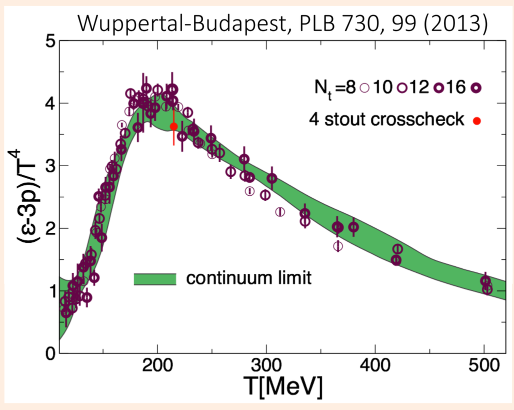
Reference: AM and J. Ollitrault, Phys. Rev. C 96, 044902 (2017)

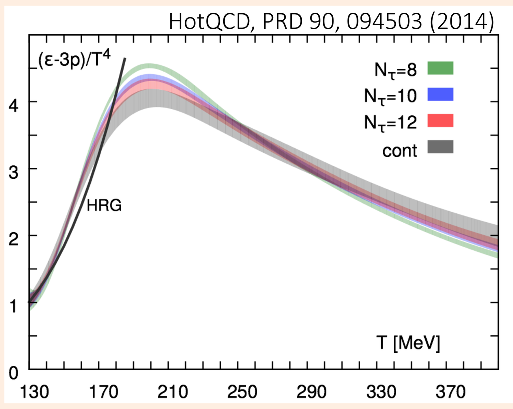
Abstract

The fluidity of the quark-gluon plasma allows one to experimentally explore QCD thermodynamics. We study how different the equation of state (EoS) in a heavy-ion collision can be from the one by lattice QCD. We find in hydrodynamic simulation that the EoS with the effective number of degrees of freedom equal to or larger than that of lattice QCD are favored.

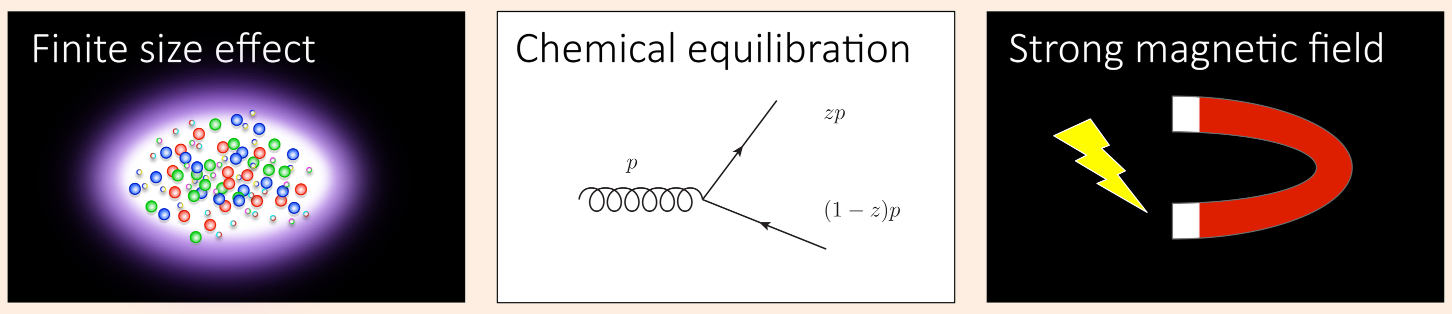
1. Introduction

- Equation of state: static relation among thermodynamic variables
- State-of-art lattice QCD calculations provide the EoS at vanishing density
  - ϵ : energy density
  - P : pressure
  - T : temperature





- We may see a different EoS in nuclear collisions for various reasons:



We extract information of the EoS from experimental data at RHIC and LHC using a relativistic hydrodynamic model

2. Thermodynamic quantities and observables

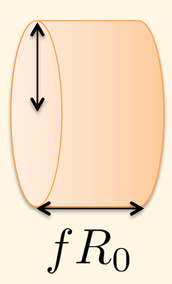
- Entropy density vs. Particle number

Effective entropy per volume

$$s(T_{\rm eff}) = a\frac{1}{R_0^3}\frac{dN}{dy}$$

Particle number at T_f

$$\frac{S(T_f)}{N(T_f)} \times \frac{1}{V(T_{\rm eff})}$$



R_0, fR_0, $V \sim f\pi R_0^3$

*Total entropy conservation $S(T_f) = S(T_{\rm eff})$

- $T_{\rm eff}$: effective temperature when transverse expansion starts
- R_0 : effective radius of the medium where $R_0^2 = 2(\langle|\mathbf{x}(\tau_0)|^2\rangle - |\langle\mathbf{x}(\tau_0)\rangle|^2)$
- T_f : freeze-out temperature
- a : dimensionless constant factor

- Energy density over entropy density vs. Mean transverse mass

Effective energy per entropy

$$\frac{\epsilon(T_{\rm eff})}{s(T_{\rm eff})} = b\langle m_T\rangle$$

Energy per number at T_f

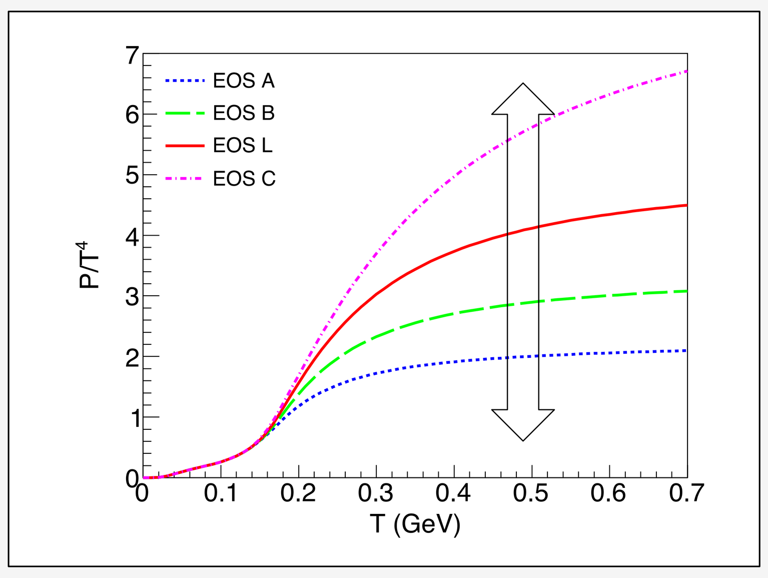
$$\frac{N(T_f)}{S(T_f)}$$

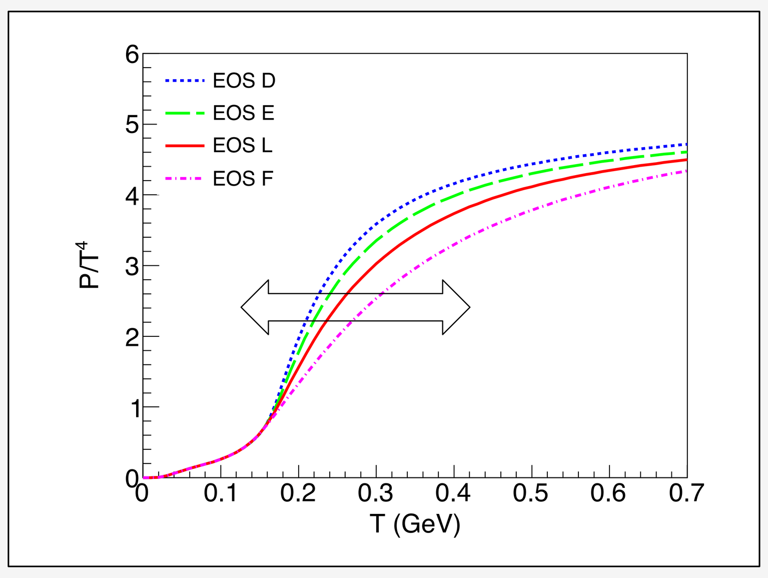
*Once transverse expansion sets in ($T \sim T_{\rm eff}$), longitudinal work becomes smaller and total energy is conserved $E(T_f) \sim E(T_{\rm eff})$

- b : dimensionless constant factor

3. Equation of state

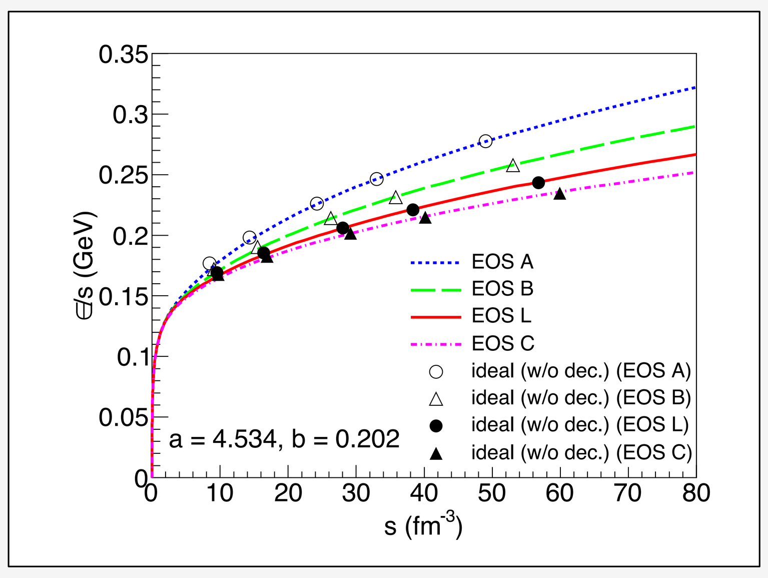
- Starting from lattice QCD (EOS L), we vary the number of degrees of freedom (EOS A-C) and the crossover temperature (EOS D-F)

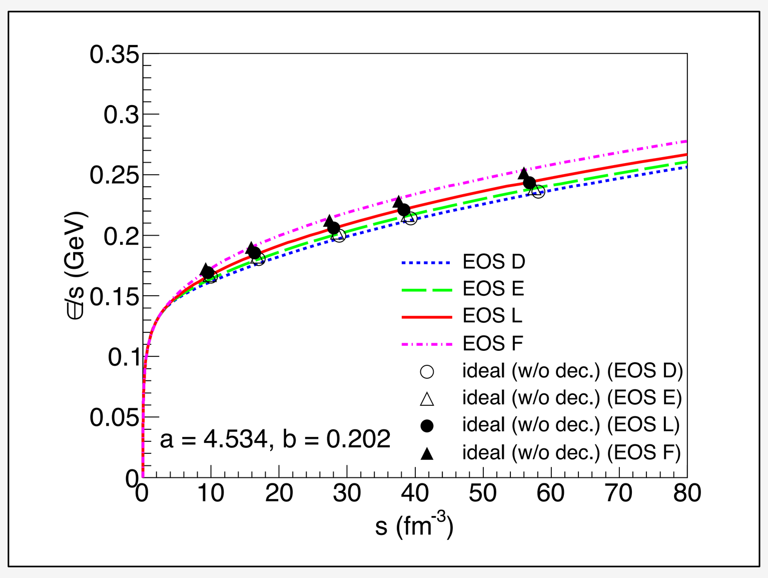




*Fixed at lower T by hadron resonance gas for energy-momentum conservation at freeze-out

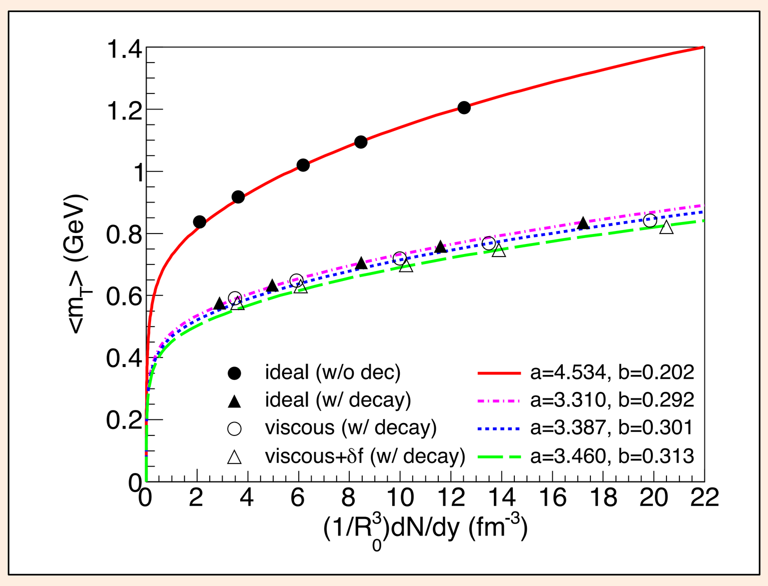
- Determine a and b from Sec. 2 theoretically using a hydrodynamic model (Au-Au, 0-5 %) with different EoS and collisions energies



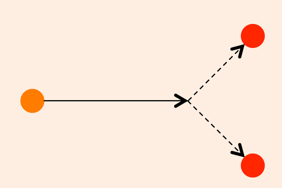


4. Corrections for viscosity and decay

- Non-equilibrium processes play important roles in heavy-ion collisions



- Hadronic decay
  - $\langle m_T\rangle$: decreased
  - dN/dy : increased



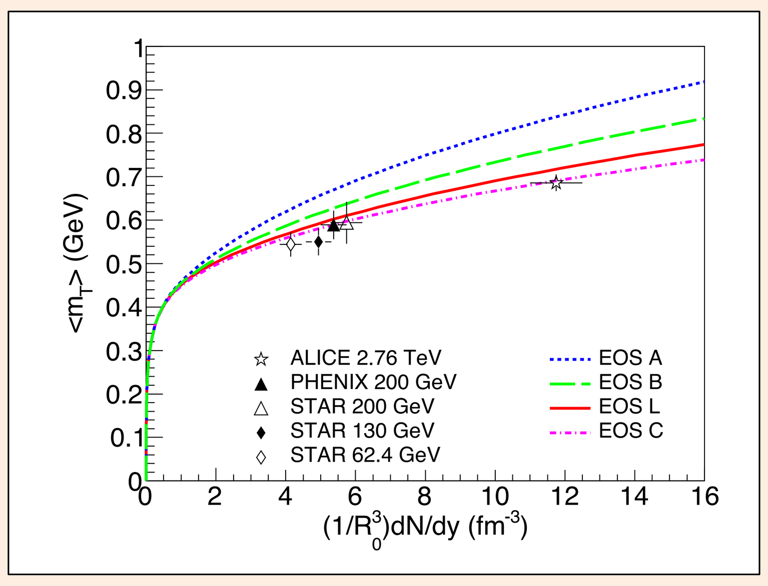
- Shear and bulk viscosity
  - $\langle m_T\rangle$: cancellation of shear & bulk
  - dN/dy : increased

5. Results

- Viscous hydrodynamic results with hadronic decay compared to RHIC & LHC experimental data

⇨ Compatible with the lattice QCD EoS within the error

⇨ A larger number of degrees of freedom is allowed by the data



- $d\ln\langle m_T\rangle/d\ln dN/dy = P/\epsilon|_{T_{\rm eff}} = 0.21 \pm 0.10$ where $P/\epsilon|_{\rm lattice} = 0.23$

6. Summary and outlook

- QCD equation of state is constrained using $\langle m_T\rangle$ and dN/dy at various collision energies
- The equation of state with the effective number of degrees of freedom equal to or larger than that of lattice QCD is found to be favored
- Future prospects include extraction of the QCD equation of state at finite density from the experimental data of Beam Energy Scan programs

Contact address: akihiko.monnai@kek.jp