CETHEP Symposium, 2022, VECC, Kolkata

Possibility of a QCD medium formation in LHC proton+proton collisions: A Color String Percolation Approach

Dushmanta Sahu

Indian Institute of Technology Indore, India

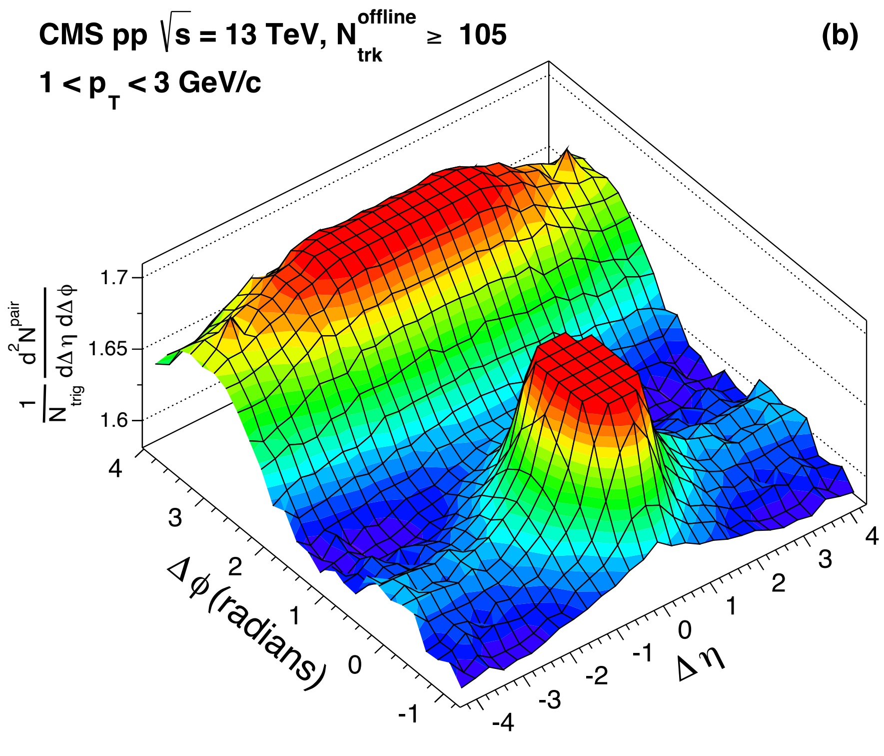
Email : Dushmanta.Sahu@cern.ch

Contents

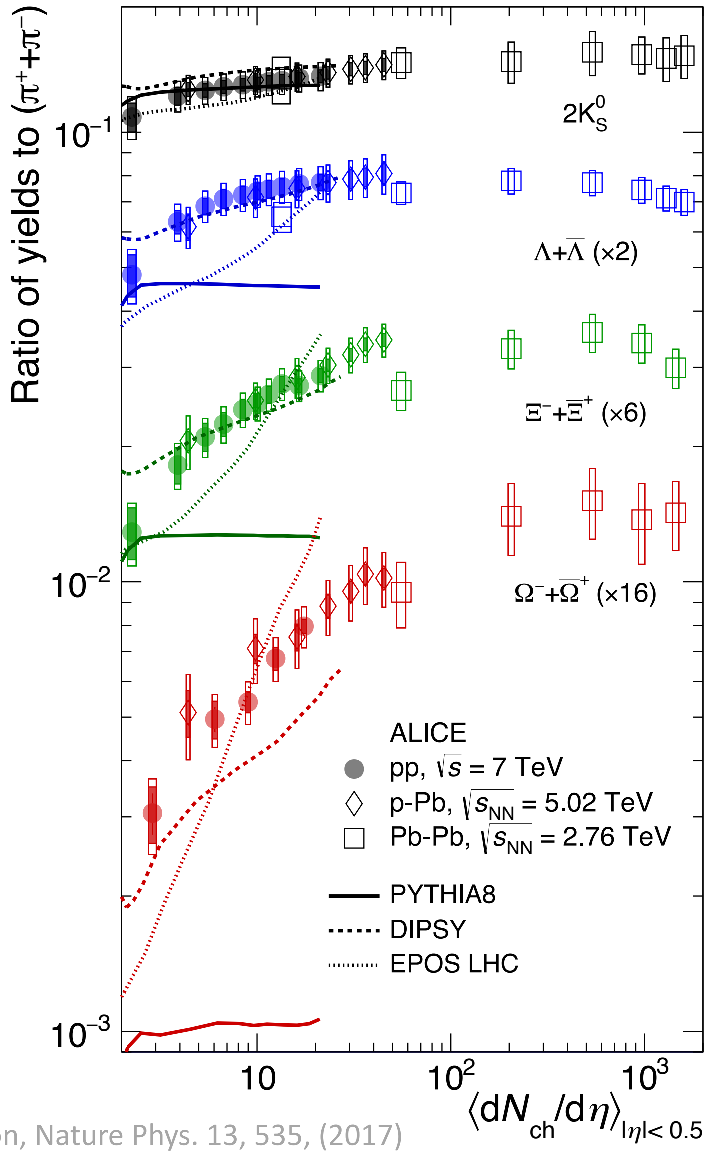
- Introduction
- Color String Percolation Model (CSPM)
- Transport properties
  - Shear viscosity to entropy density ratio (η/s)
  - Bulk viscosity to entropy density ratio (ζ/s)
  - Jet quenching parameter ($\hat{q}$)
  - Charm quark diffusion coefficient (D_s)
- Summary

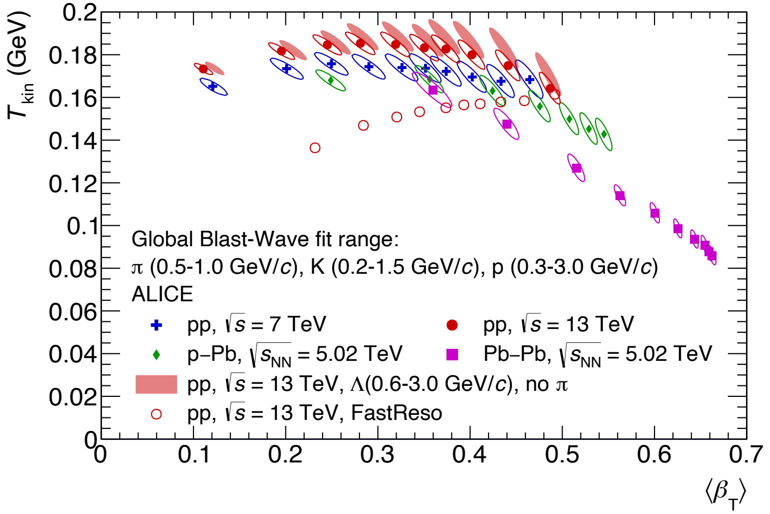
Introduction

- QGP formation in heavy-ion collisions
- Possibility of QGP droplets in high-multiplicity pp collisions
  - Strangeness enhancement
  - Ridge like structure formation
  - Radial flow



CMS Collaboration, Phys. Rev. Lett. 116, 172302 (2016)

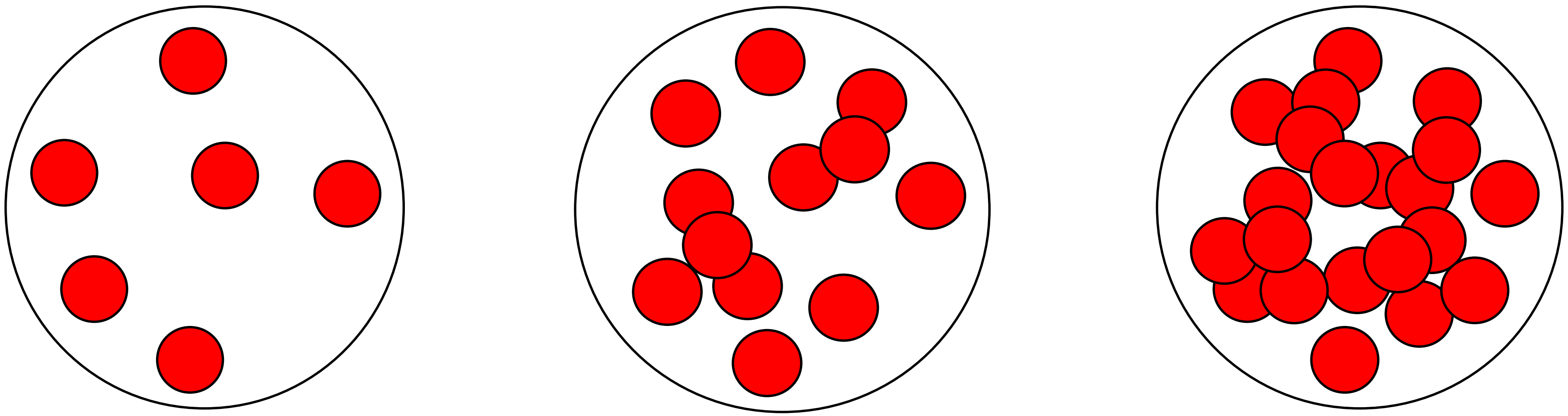




ALICE Collaboration, Eur. Phys. J. C 80, 693 (2020)

ALICE Collaboration, Nature Phys. 13, 535, (2017)

Color String Percolation Model (CSPM)



- What is color string percolation?
- Color strings are stretched between the partons of the target and the projectile
- Number of color string grows with increase in energy and with increase in number of colliding partons
- String density increases
- After a critical percolation density, a macroscopic cluster appears, which marks the percolation phase transition

Color String Percolation Model (CSPM)

- In the thermodynamic limit, the color Suppression Factor can be expressed in terms of the string percolation density ξ as, $F(\xi) = \sqrt{\frac{1-e^{-\xi}}{\xi}}$

- We fit the p_T spectra of the lower energy pp collisions at $\sqrt{s} = 200$ GeV with the function,

$$\frac{d^2N_{ch}}{dp_T^2} = \frac{a}{(p_0 + p_T)^\alpha}$$

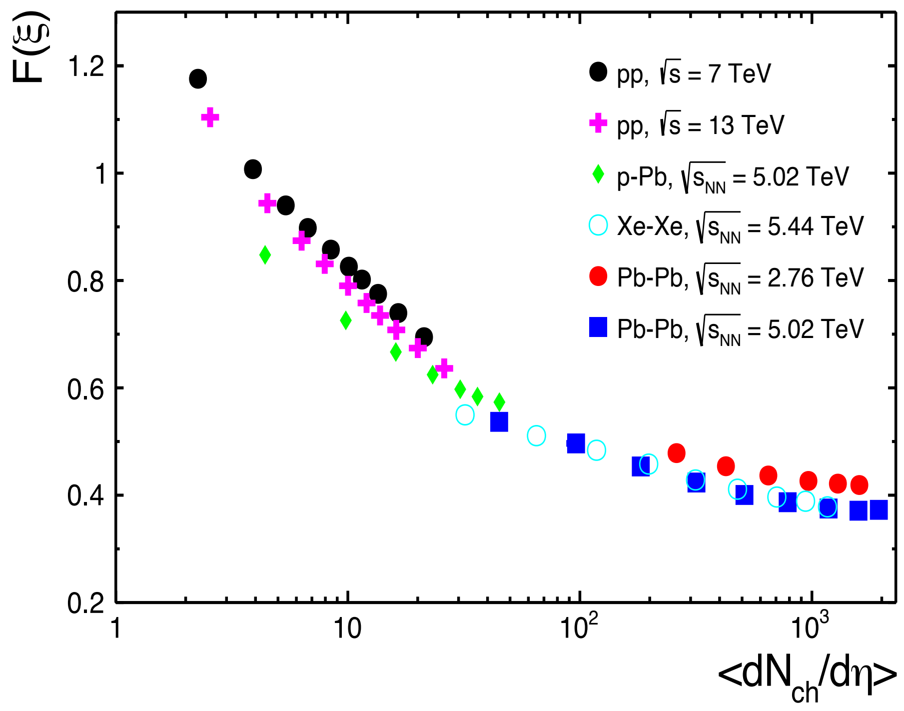
  where, p_0 and α are fitting parameters with the values $p_0 = 1.98$ and $\alpha = 12.87$

- For higher energy pp collisions and heavy ion collisions, we update the parameter as,

$$p_0 \rightarrow p_0 \left(\frac{\langle NS_1/S_N \rangle_{pp,pA,AA}}{\langle NS_1/S_N \rangle_{pp,\sqrt{s}=200\ \mathrm{GeV}}} \right)^{1/4}$$

- Now the fitting function becomes,

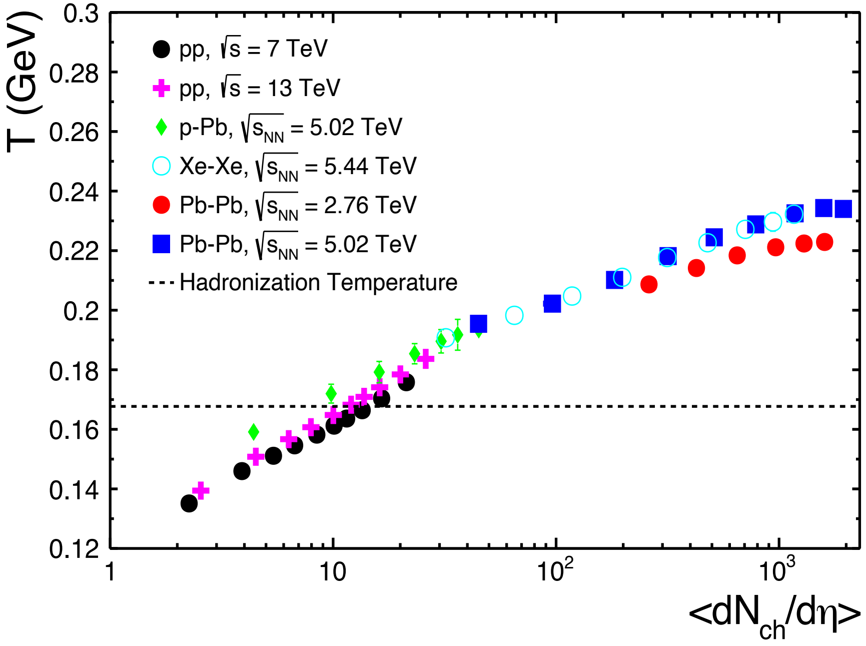
$$\frac{d^2N_{ch}}{dp_T^2} = \frac{a}{(p_0\sqrt{F(\xi)_{pp,\sqrt{s}=200\ \mathrm{GeV}}/F(\xi)_{pp,pA,AA}} + p_T)^\alpha}$$

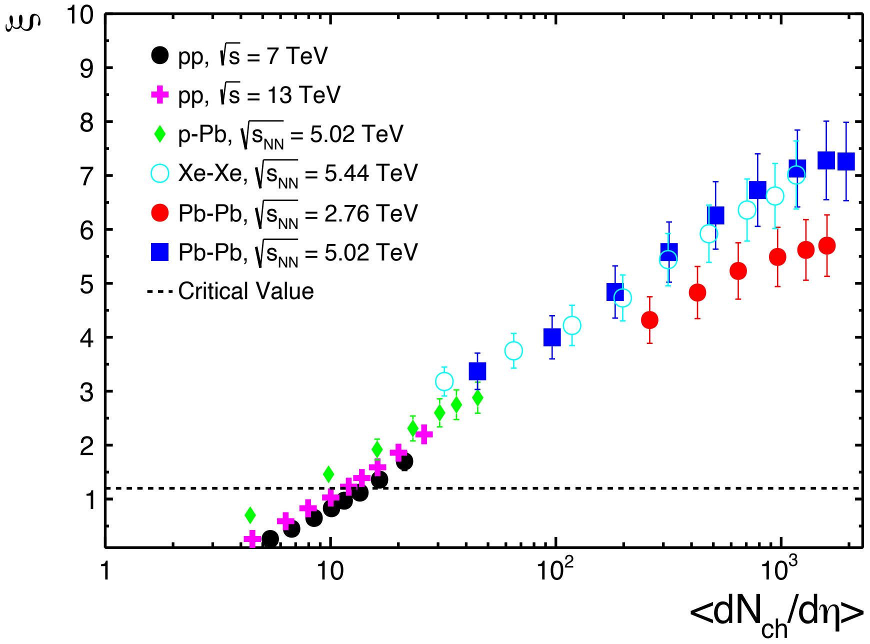


D. Sahu and R. Sahoo, J. Phys. G 48, 125104 (2021)

Color String Percolation Model (CSPM)

- The initial percolation temperature is related to the color suppression factor by the relation, $T = \sqrt{\frac{\langle p_{\mathrm{T}} \rangle_1}{2F(\xi)}}$
- We observe that after $\langle dN_{\mathrm{ch}}/d\eta \rangle \simeq 10$, the temperature is higher than the hadronization temperature regardless of the collision systems
- The percolation density parameter ξ is given by $\xi = \frac{N_{\mathrm{s}} S_1}{S_{\mathrm{N}}}$





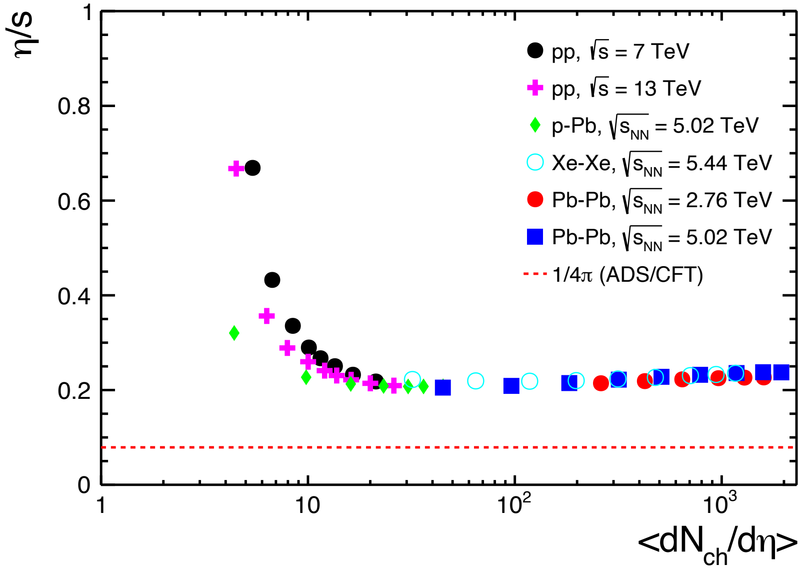
D. Sahu, S. Tripathy, R. Sahoo and S. K. Tiwari, Eur. Phys. J. A 58, 78 (2022)

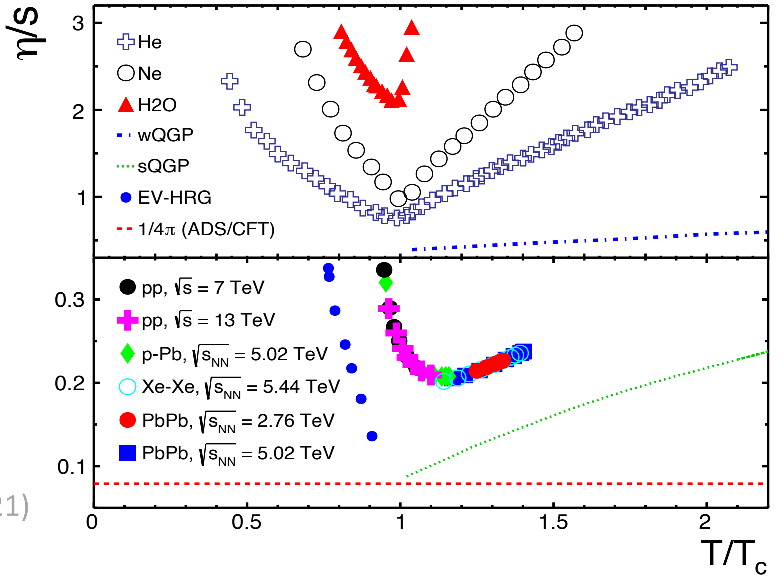
Shear Viscosity to entropy density ratio

- From the relativistic kinetic theory, the shear viscosity to entropy density ratio is given by, $\frac{\eta}{s} \simeq \frac{T\lambda}{5}$
- Using the value of mean free path, we get the final expression of shear viscosity to entropy density ratio as,

$$\frac{\eta}{s} \simeq \frac{TL}{5(1-e^{-\xi})}$$

- For the matter formed in ultra-relativistic collisions at LHC energies, the value of η/s is the lowest as compared to any other known material
- We observe that η/s approaches the KSS bound value and becomes minimum at $\frac{dN_{ch}}{d\eta} \leq 10-20$
- This hints that the matter behaves almost like a perfect fluid

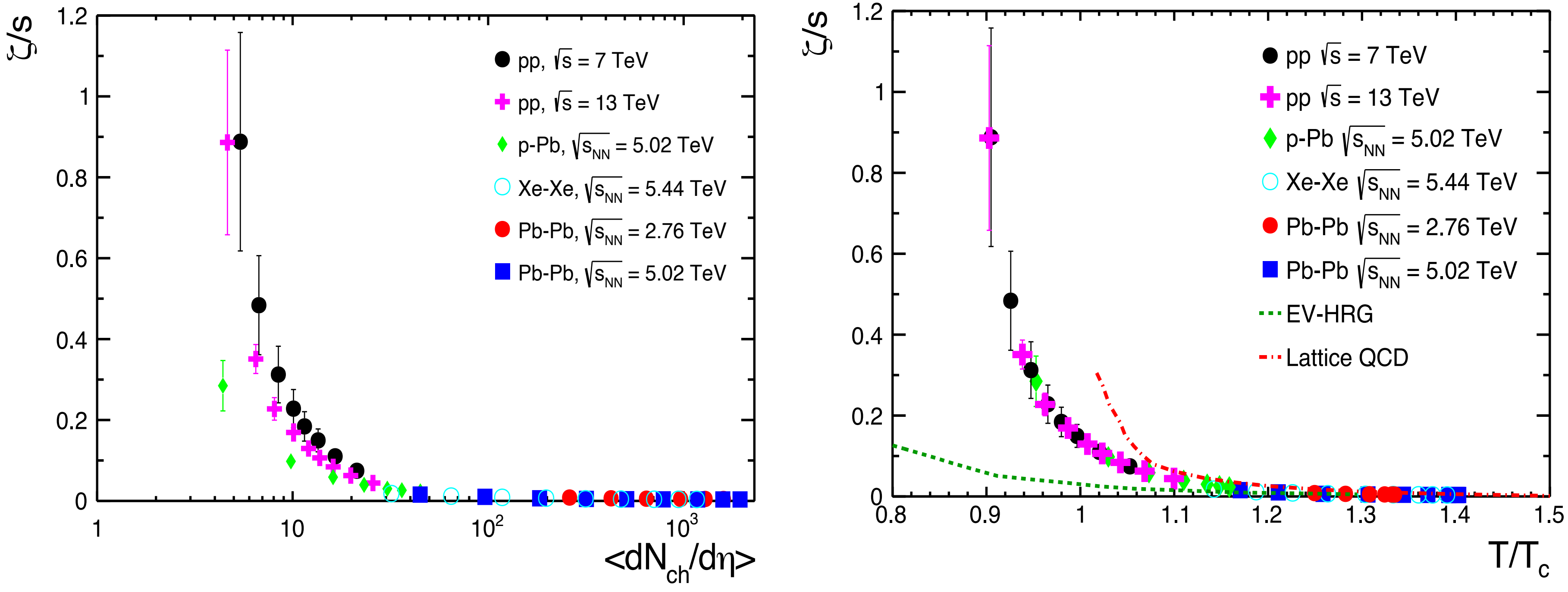




D. Sahu and R. Sahoo, J. Phys. G 48, 125104 (2021)

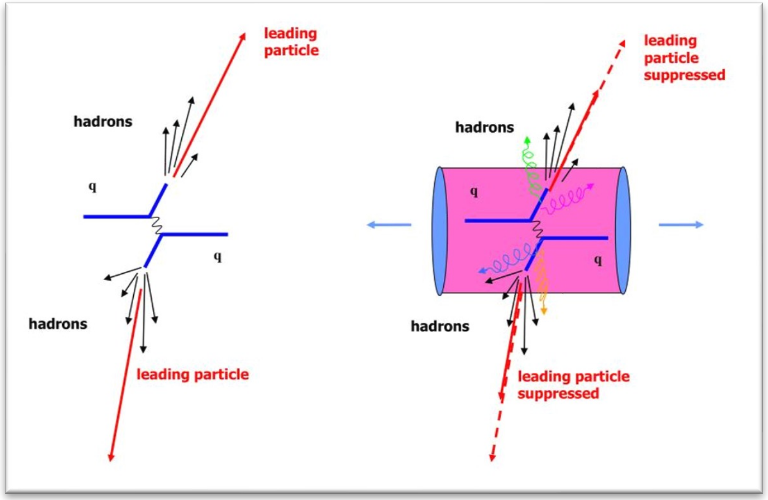
Bulk Viscosity to entropy density ratio (ζ/s)

- From the relaxation time approximation (RTA), the bulk viscosity of a system is given as, $\zeta = 15\eta\left(\frac{1}{3} - c_s^2\right)^2$
- So, the bulk viscosity to entropy density ratio becomes, $\zeta/s = 15\frac{\eta}{s}\left(\frac{1}{3} - c_s^2\right)^2$
- After $\langle dN_{ch}/d\eta\rangle \geq 10 - 20$, the value of ζ/s becomes minimum and approaches zero



D. Sahu and R. Sahoo, J. Phys. G 48, 125104 (2021)

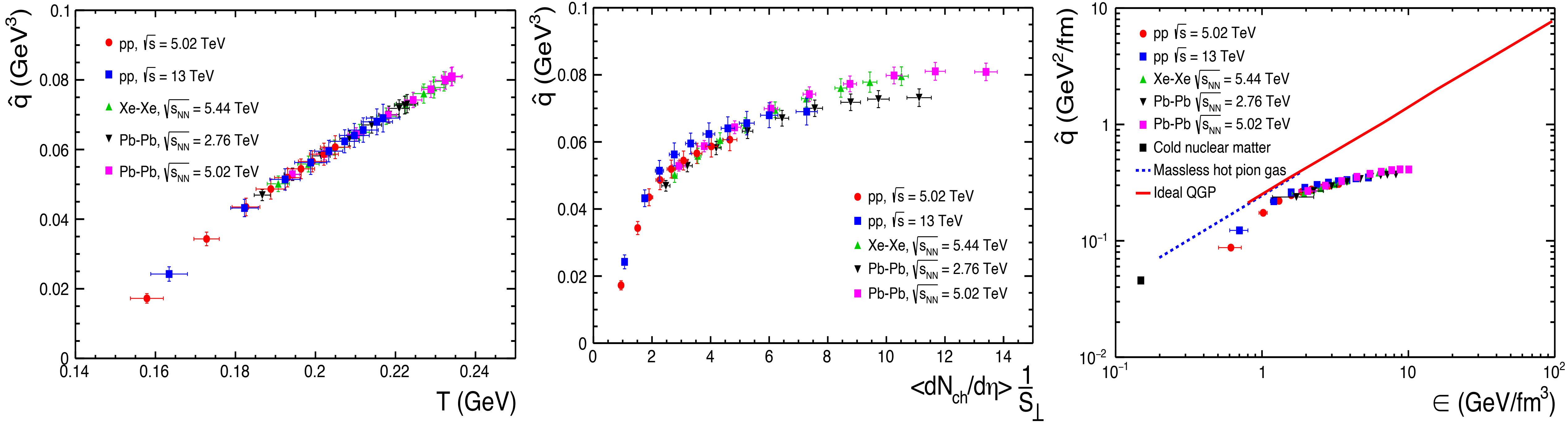
Jet transport coefficient ($\hat{q}$)



- Jets are collimated beams of multitude of hadrons originating from the hard partonic scattering
- They lose their energy through medium-induced gluon radiation and collisional energy loss, because of which we observe suppression of high transverse momentum particles (jet quenching)
- In kinetic theory framework, $\hat{q}$ can be estimated by the formula, $\hat{q} = \rho \int d^2q_\perp \; q_\perp^2 \frac{d\sigma}{d^2q_\perp}$, where ρ is the number density of the medium and $d\sigma/d^2q_\perp$ is the differential scattering cross-section of the particles in the medium
- The jet transport parameter and the shear viscosity to entropy density ratio are related as, $\frac{\eta}{s} \approx \frac{3}{2}\frac{T^3}{\hat{q}}$

$$\boxed{\hat{q} \approx \frac{3}{2}\frac{T^3}{\eta/s} \approx \frac{15}{2}\frac{T^2(1-e^{-\xi})}{L}}$$

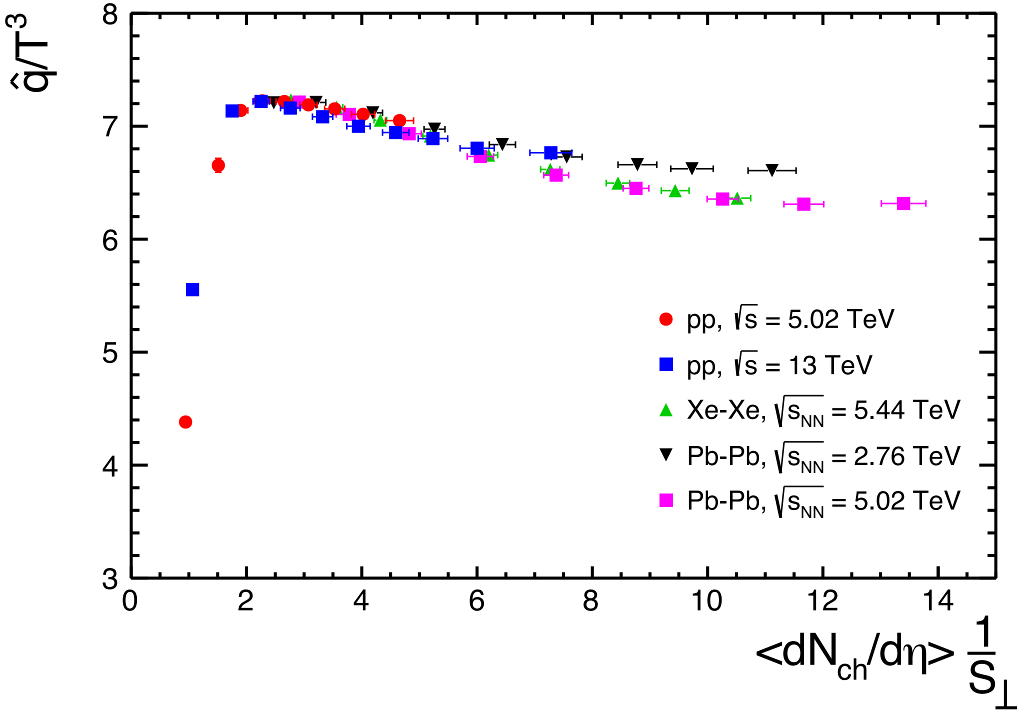
Jet transport coefficient ($\hat{q}$)

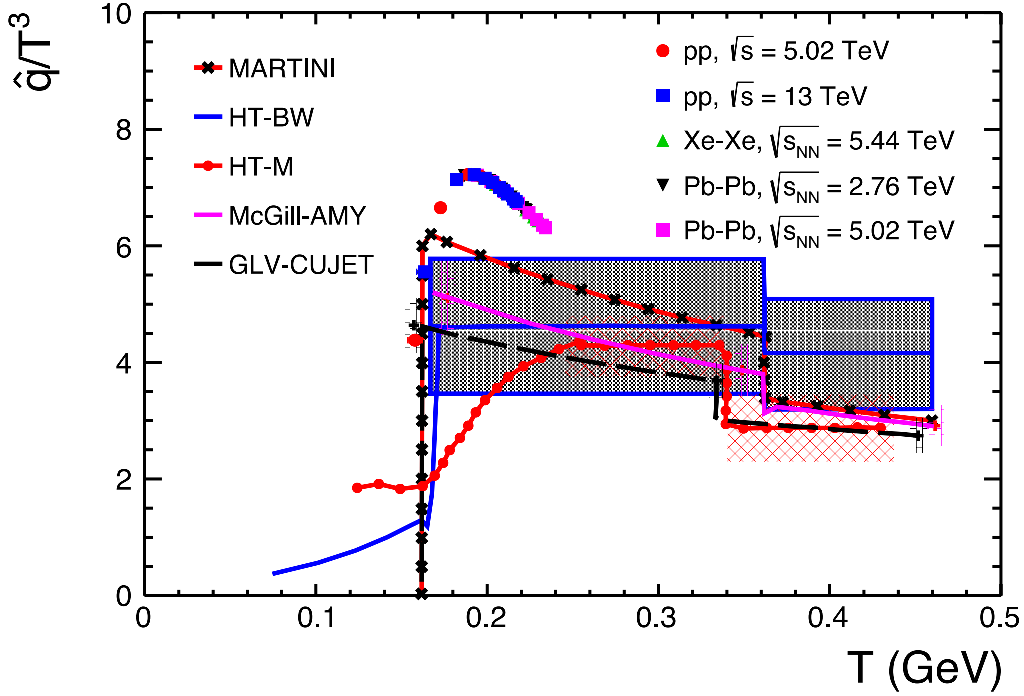


- At lower multiplicity the system is not dense enough to highly quench the partonic jets, whereas with increase in multiplicity the quenching of jets becomes more prominent
- In the low energy density regime, the system behaves almost like a massless hot pion gas
- As initial energy density increases, $\hat{q}$ values deviate from the ideal QGP values because systems produced in high multiplicity events are viscous and are not exactly ideal

A. N. Mishra, D. Sahu and R. Sahoo, MDPI Physics 4, 315 (2022)

Jet transport coefficient ($\hat{q}$)





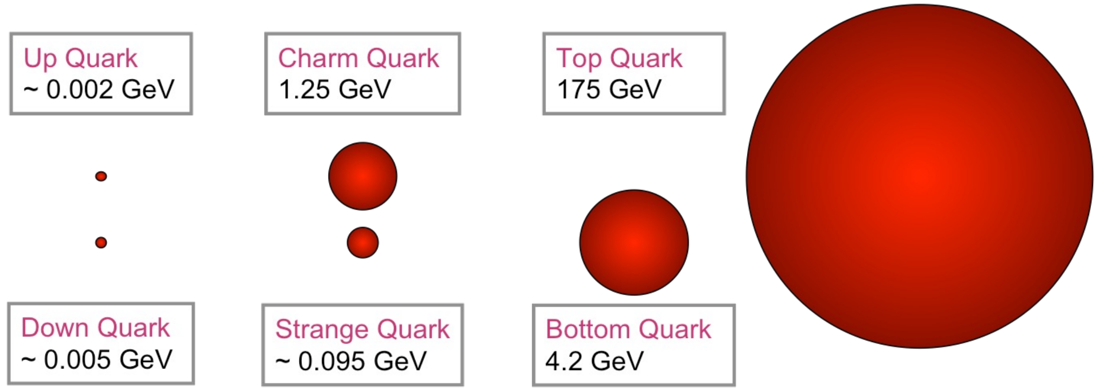
- $\hat{q}/T^3$ as a function of scaled charged particle multiplicity shows a sudden increase and reaches to a maximum at $\frac{dN_{ch}}{d\eta} 1/S_\perp \leq 2$, then it starts decreasing regardless of the collision system

- The $\hat{q}/T^3$ obtained from CSPM approach as a function of temperature has similar kind of behavior as observed by the JET collaboration

A. N. Mishra, D. Sahu and R. Sahoo, MDPI Physics 4, 315 (2022)

Diffusion of charm quark

- Heavy quarks are produced early in the evolution of the system, hence are better probes
- They interact with the medium and their momentum spectra gets modified
- Interaction of charm quark with the lighter quarks and gluons will lead to Brownian motion, which can be explained by Fokker-Planck transport equation
- The information about the interaction of heavy quarks within the QGP medium is embedded within the drag and diffusion coefficients

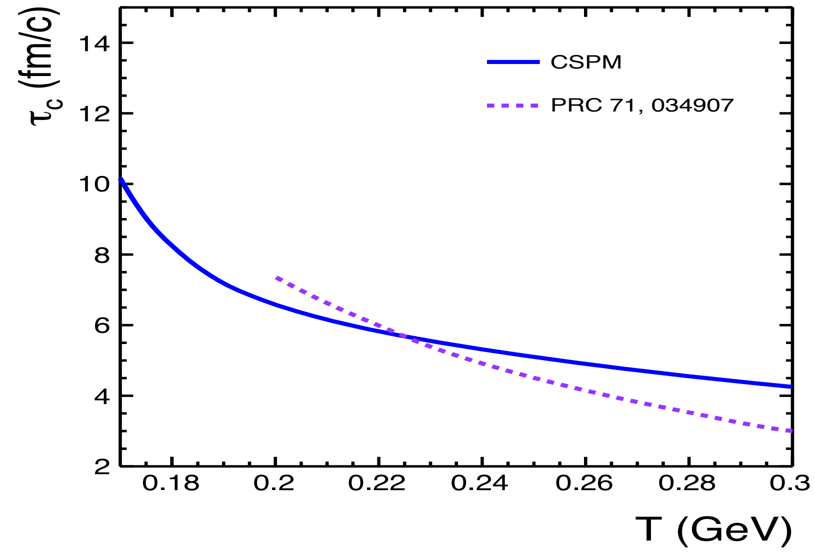


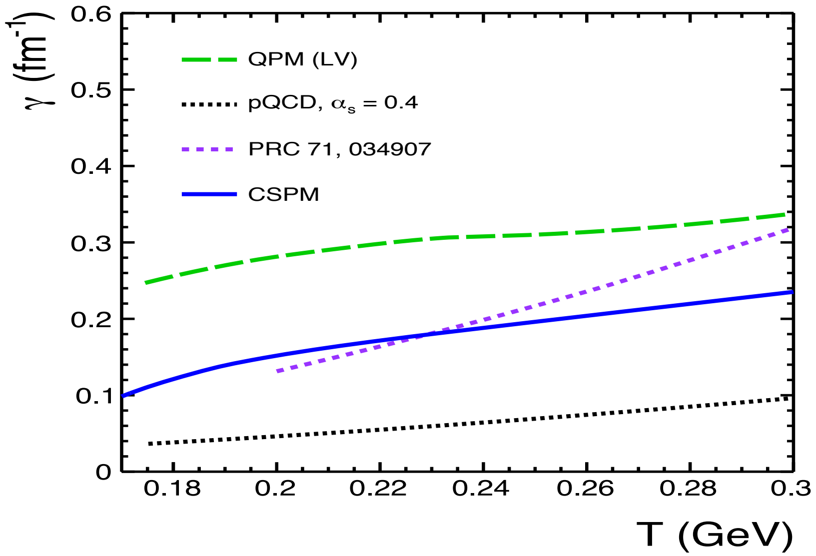
$$\frac{\partial f(t,p)}{\partial t} = \frac{\partial}{\partial p_i}\left\{A_i(p)f(t,p) + \frac{\partial}{\partial p_j}[B_{ij}f(t,p)]\right\}$$

Diffusion of charm quark

- Relaxation time of a quark is defined as the time accounting for the exponential decay of its average transverse momentum
- For a lighter quark, the relaxation time is given by, $\tau \simeq \frac{5\eta/s}{T}$
- In CSPM formalism, $\frac{\eta}{s} = \frac{TL}{5(1-e^{-\xi})}$
- For heavier quarks (charm and bottom quarks), the particle dependent relaxation time is expressed as, $\tau_R = \frac{m\tau}{T}$
- Relaxation time of charm quark is higher in smaller system because of less dense medium
- Drag coefficient is the inverse of the relaxation time, $\gamma \simeq \frac{1}{\tau_R}$

K. Goswami, D. Sahu and R. Sahoo, arXiv:2206.13786

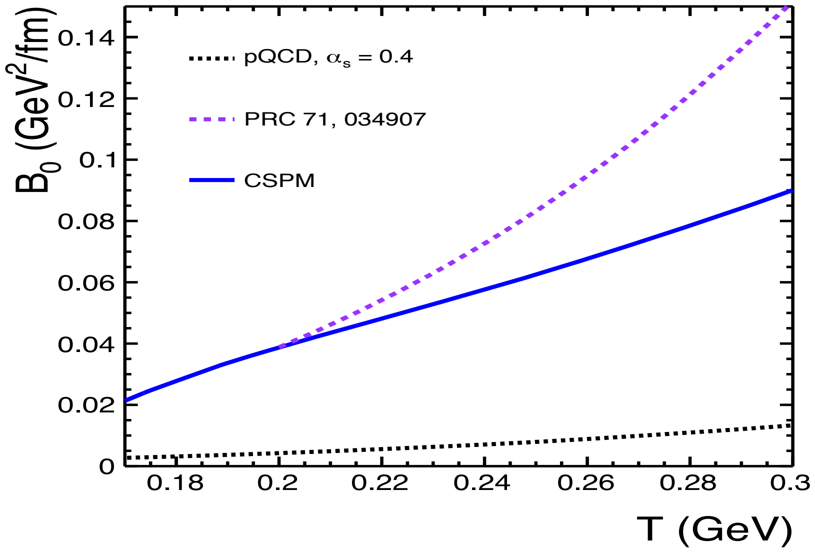


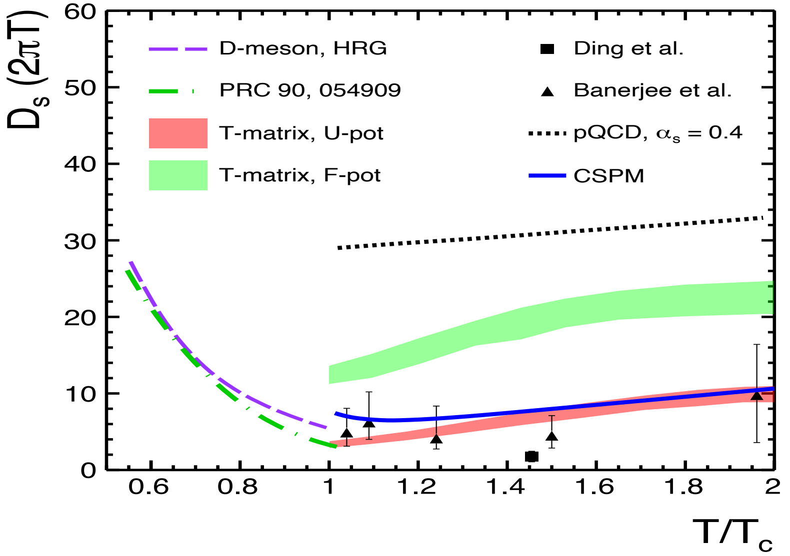


Diffusion of charm quark

- From Einstein's relation, the drag and transverse momentum diffusion coefficient are related as, $B_0 = \gamma T(m_c + T)$

  Where, $m_c = 1.275$ GeV is the mass of charm quark
- The spatial diffusion coefficient (D_s) can be estimated by starting a particle at position and time x = 0 and t = 0 and finding the mean squared position at a later time, $\left\langle \left(x(t) - x(0)\right)^2 \right\rangle = 2D_s t$
- In static limit, the spatial diffusion coefficient is given by the expression, $D_s = \frac{T}{m_c\gamma}$
- ADS/CFT calculation gives a minimum for this parameter ~ 1





K. Goswami, D. Sahu and R. Sahoo, arXiv:2206.13786

Summary

- QGP is closest to a perfect fluid found in nature
- Observed a threshold of charged particle multiplicity, $\langle\frac{dN_{ch}}{d\eta}\rangle \leq 10 - 20$ after which we see a change in the dynamics of the systems
- Possibility of observing jet quenching in high multiplicity pp collisions
- Studied diffusion of charm quark in the deconfined medium within CSPM
- Hints of possible formation of QGP droplets in high multiplicity pp collisions

THANK YOU