S U M M A R Y (Theory)

Rajiv V. Gavai, IISER Bhopal

S U M M A R Y (Theory)

Rajiv V. Gavai, IISER Bhopal

- On the opening day, we heard about the goals that were set in the early times of this field for what we then expected from it.

S U M M A R Y (Theory)

Rajiv V. Gavai, IISER Bhopal

- On the opening day, we heard about the goals that were set in the early times of this field for what we then expected from it.

- Recall that it was sceptically said the A-A collisions ought to be simply superpositions of p-p collisions. So why bother?

S U M M A R Y (Theory)

Rajiv V. Gavai, IISER Bhopal

- On the opening day, we heard about the goals that were set in the early times of this field for what we then expected from it.

- Recall that it was sceptically said the A-A collisions ought to be simply superpositions of p-p collisions. So why bother?

- Theoretical expectations, on the other hand, were that quark-gluon plasma (QGP) may exist at sufficiently high temperatures/densities.

S U M M A R Y (Theory)

Rajiv V. Gavai, IISER Bhopal

- On the opening day, we heard about the goals that were set in the early times of this field for what we then expected from it.
- Recall that it was sceptically said the A-A collisions ought to be simply superpositions of p-p collisions. So why bother?
- Theoretical expectations, on the other hand, were that quark-gluon plasma (QGP) may exist at sufficiently high temperatures/densities.
- A-A collisions were thought to be capable of producing conditions which are ripe for QGP formation.

S U M M A R Y (Theory)

Rajiv V. Gavai, IISER Bhopal

- On the opening day, we heard about the goals that were set in the early times of this field for what we then expected from it.
- Recall that it was sceptically said the A-A collisions ought to be simply superpositions of p-p collisions. So why bother?
- Theoretical expectations, on the other hand, were that quark-gluon plasma (QGP) may exist at sufficiently high temperatures/densities.
- A-A collisions were thought to be capable of producing conditions which are ripe for QGP formation. Are they really able to do that ?

S U M M A R Y (Theory)

Rajiv V. Gavai, IISER Bhopal

- On the opening day, we heard about the goals that were set in the early times of this field for what we then expected from it.

- Recall that it was sceptically said the A-A collisions ought to be simply superpositions of p-p collisions. So why bother?

- Theoretical expectations, on the other hand, were that quark-gluon plasma (QGP) may exist at sufficiently high temperatures/densities.

- A-A collisions were thought to be capable of producing conditions which are ripe for QGP formation. Are they really able to do that ? How convincingly? Both from the A-A collisions data perspective and the (improved) current theoretical understanding perspective?

- Quantum chromodynamics (QCD) has now been established as the theory of the strong interactions, with Lattice QCD providing many inputs for QCD thermodynamics and transport coefficients.

- Quantum chromodynamics (QCD) has now been established as the theory of the strong interactions, with Lattice QCD providing many inputs for QCD thermodynamics and transport coefficients.

- The summary (theory), I felt, should therefore focus on such a broad picture while summarizing the talks presented here.

- Quantum chromodynamics (QCD) has now been established as the theory of the strong interactions, with Lattice QCD providing many inputs for QCD thermodynamics and transport coefficients.

- The summary (theory), I felt, should therefore focus on such a broad picture while summarizing the talks presented here.

- Including the keynote address 15 plenary and 38 parallel talks were presented at this conference, covering a wide variety of topics. While these exciting talks convey the vibrant nature of our field, both in India and worldwide, summarizing them adequately is a tough task for me.

- Quantum chromodynamics (QCD) has now been established as the theory of the strong interactions, with Lattice QCD providing many inputs for QCD thermodynamics and transport coefficients.

- The summary (theory), I felt, should therefore focus on such a broad picture while summarizing the talks presented here.

- Including the keynote address 15 plenary and 38 parallel talks were presented at this conference, covering a wide variety of topics. While these exciting talks convey the vibrant nature of our field, both in India and worldwide, summarizing them adequately is a tough task for me.

- Let me thank all those who sent me input on their work, and apologize in advance for any omissions from my presentation, inadvertently or far lack of time.

- Recall the classic paper of Bjorken (Phys. Rev. D 27, 140, 1983) already set stage for much of the later work :

PHYSICAL REVIEW D VOLUME 27, NUMBER 1 1 JANUARY 1983

Highly relativistic nucleus-nucleus collisions: The central rapidity region

J. D. Bjorken
Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510*
(Received 13 August 1982)

The space-time evolution of the hadronic matter produced in the central rapidity region in extreme relativistic nucleus-nucleus collisions is described. We find, in agreement with previous studies, that quark-gluon plasma is produced at a temperature $\gtrsim$200—300 MeV, and that it should survive over a time scale $\gtrsim$5 fm/c. Our description relies on the existence of a flat central plateau and on the applicability of hydrodynamics.

- Recall the classic paper of Bjorken (Phys. Rev. D 27, 140, 1983) already set stage for much of the later work :

PHYSICAL REVIEW D VOLUME 27, NUMBER 1 1 JANUARY 1983

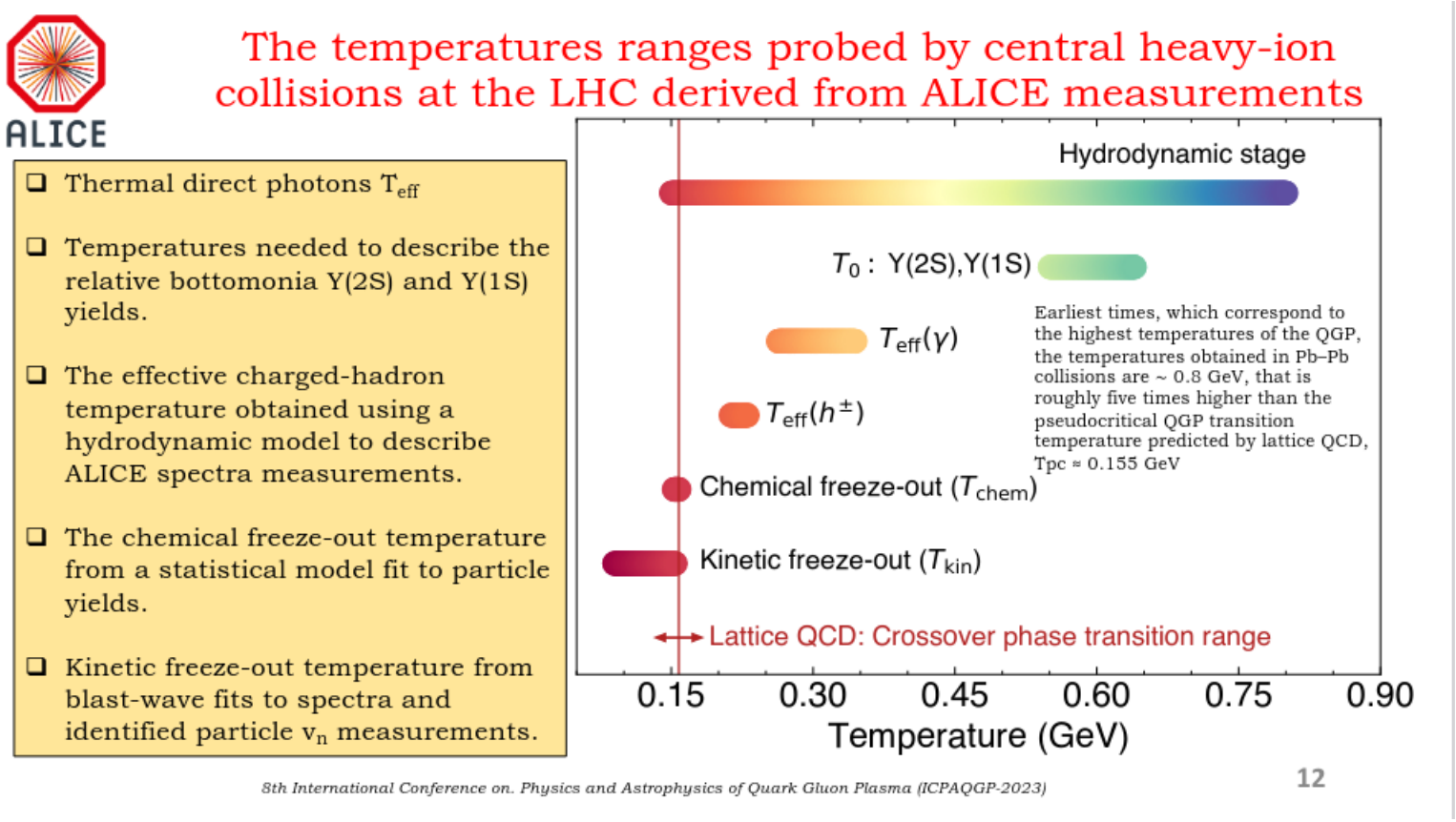
Highly relativistic nucleus-nucleus collisions: The central rapidity region

J. D. Bjorken
Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510*
(Received 13 August 1982)

The space-time evolution of the hadronic matter produced in the central rapidity region in extreme relativistic nucleus-nucleus collisions is described. We find, in agreement with previous studies, that quark-gluon plasma is produced at a temperature $\gtrsim$200–300 MeV, and that it should survive over a time scale $\gtrsim$5 fm/c. Our description relies on the existence of a flat central plateau and on the applicability of hydrodynamics.

- Remarkably, it gave us the famous energy density formula, taught us the application of boost invariant 1+1 D hydrodynamics and even provided quite a few estimates for QGP parameters.

- Relativistic hydrodynamics has been very successful in explaining the AA data, leading to the derivation of longest temperature range for QGP



From the talk of B. Mohanty

- What are the systematic errors on this result ? Thermalization time, Anisotropy of p_T and p_L, etc.

- What are the systematic errors on this result ? Thermalization time, Anisotropy of p_T and p_L, etc.

- Five plenary talks,
  - The initial state and thermalization in heavy-ion collisions – Raju Venugopalan (RV)
  - New theoretical developments towards understanding the early stages of HICs – Sören Schlichting (SS)
  - Latest developments in relativistic hydrodynamics – Wojciech Florkowski (WF)
  - Emergence of hydrodynamics attractors and fixed points – Jean-Paul Blaizot (JPB)
  - Taming instabilities in relativistic hydro and magnetic hydro – Victor Roy

  gave us glimpses of current theoretical ideas about these to some extent.

- What are the systematic errors on this result ? Thermalization time, Anisotropy of p_T and p_L, etc.

- Five plenary talks,
  - The initial state and thermalization in heavy-ion collisions – Raju Venugopalan (RV)
  - New theoretical developments towards understanding the early stages of HICs – Sören Schlichting (SS)
  - Latest developments in relativistic hydrodynamics – Wojciech Florkowski (WF)
  - Emergence of hydrodynamics attractors and fixed points – Jean-Paul Blaizot (JPB)
  - Taming instabilities in relativistic hydro and magnetic hydro – Victor Roy

  gave us glimpses of current theoretical ideas about these to some extent.

- In particular, RV advocated the saturation scale Q_S to be crucial in explaining the "Hydro for small systems" as well.

Bottom-up thermalization

Thermalized soft bath of gluons for $\tau > \frac{1}{\alpha_S^{5/2}} \frac{1}{Q_S}$

Thermalization temperature of $T_i = \alpha_S^{2/5} Q_S$

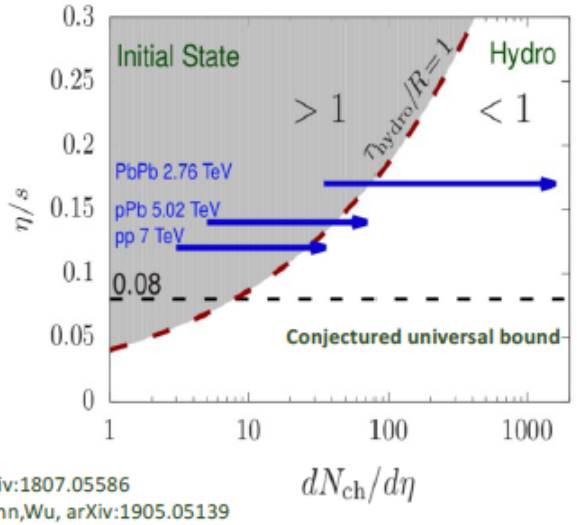
Since $\alpha_S \propto \frac{1}{\log Q_S}$

then $\tau_{\rm therm} \propto \frac{(\log Q_S)^{5/2}}{Q_S} \to 0$ as $Q_S \to \infty$

Matter thermalizes almost instantaneously at asymptotic energies

CGC naturally leads to hydro if $\tau_{\rm therm} \ll R$

Remarkably, in this picture, dominant feature of the entire dynamics of thermalization (across systems) is one semi-hard scale ...



Mazeliauskas, arXiv:1807.05586
Kurkela,Wiedemann,Wu, arXiv:1905.05139

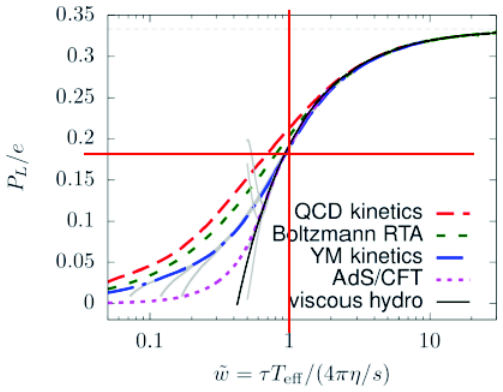
From the talk of R. Venugopalan

- SS, on the other hand, suggested that true thermal equilibrium is reached only asymptotically but a wide variety of different microscopic theories always lead to viscous hydrodynamics.

Hydrodynamic behavior

Effective description in viscous hydrodynamics becomes applicable on time scales Kurkela, Mazeliauskas, Paquet, SS, Teaney 1805.01604; 1805.00961

$$\tau_{\rm hydro} \approx \tau_R^{\rm eq}(\tau) \qquad \tau_R^{\rm eq}(\tau) = \frac{4\pi\eta/s}{T_{\rm eff}(\tau)} \qquad \tau_{\rm hydro} \approx 1.1\,{\rm fm}\left(\frac{4\pi(\eta/s)}{2}\right)^{\frac{3}{2}}\left(\frac{\langle \tau s\rangle}{4.1\,{\rm GeV}^2}\right)^{-1/2}$$



when the QGP is significantly out-of-equilibrium

$$Re^{-1} \sim 3(P_L/e - 1/3) \sim 1$$

Surprising effectiveness of viscous fluid dynamics also in a variety of different microscopic theories

BUT beware of high degree of symmetry in theor. calculations (conformal, no transverse expansion)

YM: Kurkela, Mazeliauskas, Paquet, SS, Teaney PRL 122 (2019) no.12, 122302; PRC 99 (2019) no.3, 034910 QCD: Kurkela, Mazeliauskas PRL 122 (2019) 142301; RTA: Strickland JHEP 12 (2018) 128; Kamata, Martinez, Plaschke, Ochsenfeld, SS PRD 102 (2020) 5, 056003
AdS/CFT: Romatschke PRL 120 (2018) no.1, 012301 Hydro vs. RTA: Strickland, Noronha, Denicol, PRD 97 (2018) 3, 036020

7

From the talk of S. Schlichting

- JPB showed that the apparent success of Israel- Stewart second order hydrodynamics in allowing early time description of matter expansion has nothing to do with "hydrodynamics". It results from a subtle property of IS equations that mimic the early time, collisionless, regime.

- JPB showed that the apparent success of Israel- Stewart second order hydrodynamics in allowing early time description of matter expansion has nothing to do with "hydrodynamics". It results from a subtle property of IS equations that mimic the early time, collisionless, regime.

- WF covered a broad spectrum of hydrodynamics approaches, pointing out in the commonly used Israel-Stewart theory "hydro equations are coupled to extra UV degrees of freedom, which in turn kill the unphysical UV modes" in a direct analogy with handling of UV behaviour of a QFT.

- JPB showed that the apparent success of Israel- Stewart second order hydrodynamics in allowing early time description of matter expansion has nothing to do with "hydrodynamics". It results from a subtle property of IS equations that mimic the early time, collisionless, regime.

- WF covered a broad spectrum of hydrodynamics approaches, pointing out in the commonly used Israel-Stewart theory "hydro equations are coupled to extra UV degrees of freedom, which in turn kill the unphysical UV modes" in a direct analogy with handling of UV behaviour of a QFT. He introduced the variety of relativistic spin hydrodynamics formalisms, explaining their qualitative differences.

- JPB showed that the apparent success of Israel- Stewart second order hydrodynamics in allowing early time description of matter expansion has nothing to do with "hydrodynamics". It results from a subtle property of IS equations that mimic the early time, collisionless, regime.

- WF covered a broad spectrum of hydrodynamics approaches, pointing out in the commonly used Israel-Stewart theory "hydro equations are coupled to extra UV degrees of freedom, which in turn kill the unphysical UV modes" in a direct analogy with handling of UV behaviour of a QFT. He introduced the variety of relativistic spin hydrodynamics formalisms, explaining their qualitative differences.

- Some architects of one of these
  - Avdesh Kumar
  - Samapan Bhaduri and
  - Amaresh Jaiswal

  presented their work in parallel session talks.

Summary : Spin-hydro

- Dissipative spin-hydro is built as a possible solution to the 'sign puzzle' in longitudinal spin-polarization.
- Need to introduce conservation law for angular momentum and a corresponding Lagrangian multiplier.

  [F. Becattini et. al. *PLB 789 (2019) 419-425*]
- Phase-space distribution is extended and classical treatment of spin is used.

  [W. Florkowski et. al., *PRC 97 (2018) 4, 041901*]
- Non-equilibrium corrections to the spin tensor contains multiple hydrodynamic gradients as:

$$\delta S^{\lambda,\mu\nu} = \tau_{\rm eq}\Big[B_{\Pi}^{\lambda,\mu\nu}\theta + B_{n}^{\phi\lambda,\mu\nu}(\nabla_{\phi}\xi) + B_{\pi}^{\alpha\beta\lambda,\mu\nu}\sigma_{\alpha\beta} + B_{\Sigma}^{\rho\gamma\phi\lambda,\mu\nu}(\nabla_{\rho}\omega_{\gamma\phi})\Big]$$

- Evolution of spin-polarization tensor is found as:

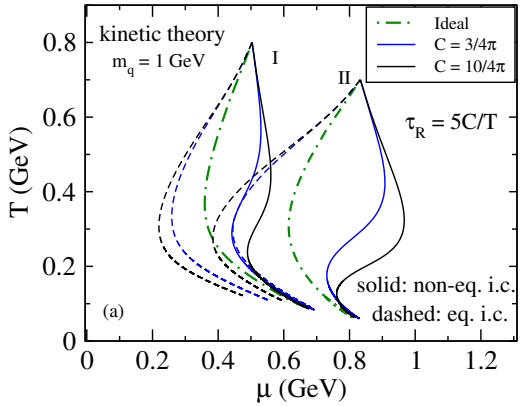
$$\dot{\omega}^{\mu\nu} = \mathcal{D}_{\Pi}^{\mu\nu}\theta + \mathcal{D}_{\rm n}^{\mu\nu\alpha}\left(\nabla_{\alpha}\xi\right) + \mathcal{D}_{\pi}^{\mu\nu\alpha\beta}\sigma_{\alpha\beta} + \mathcal{D}_{\Sigma}^{\lambda\mu\nu\alpha\beta\gamma}\left(\nabla_{\alpha}\omega_{\beta\gamma}\right),$$

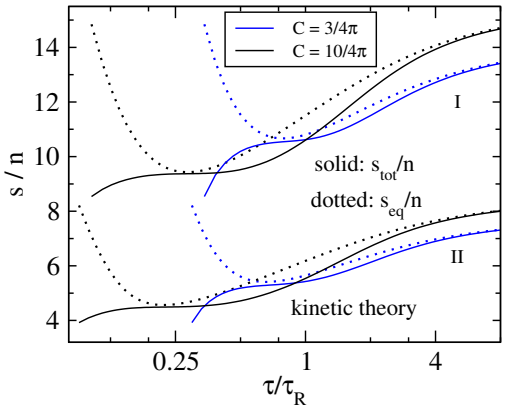
[S.B., W. Florkowski, A. Jaiswal, A. Kumar and R. Ryblewski, *PLB 814 (2021) 136096, PRD 103, 014030 (2021)*]

1

Far-from-equilibrium phase trajectories [Chattopadhyay, Heinz, Schäfer, arXiv:2209.10483]

- Top figure: Phase trajectories of a weakly interacting viscous quark-gluon gas obtained using kinetic theory; τ_R is time scale for local equilibration.
- Bottom figure: Evolution of entropy per baryon along the phase trajectories.
- Key conclusions:
  - Trajectories starting from same (T, μ) can be shuffled around substantially by dissipative effects (shear and bulk viscous pressure).
  - Along certain trajectories (blue and black solid lines) the equilibrium entropy per baryon, s_{eq}/n (dotted curves of lower fig.), may even decrease!
  - However, they do not violate the second law of thermodynamics as the total entropy per baryon, s_{tot}/n (obtained from Shannon's def. of entropy) never decreases.





- Parallel sessions on 07 February:
  - Evolution of dissipative stresses was found from the kinetic theory for both resistive and non-resistive MHD by Ankit Kumar Panda. Moving from flat space to curved space, new gaped modes arising due to gravity were found.

- Parallel sessions on 07 February:
  - Evolution of dissipative stresses was found from the kinetic theory for both resistive and non-resistive MHD by Ankit Kumar Panda. Moving from flat space to curved space, new gaped modes arising due to gravity were found.
  - Diffusion matrix in the baryon number, charge and strangeness space was estimated by Ranjita Kumari using ideal HRG and excluded volume HRG.

- Parallel sessions on 07 February:
  - Evolution of dissipative stresses was found from the kinetic theory for both resistive and non-resistive MHD by Ankit Kumar Panda. Moving from flat space to curved space, new gaped modes arising due to gravity were found.
  - Diffusion matrix in the baryon number, charge and strangeness space was estimated by Ranjita Kumari using ideal HRG and excluded volume HRG.
  - Pushpa Pandey calculated the momentum transport coefficients viz. shear and bulk viscosity in a weakly magnetized thermal medium. The medium generated mass were found to be different for left- and right-handed chiral modes of quarks in presence of a weak magnetic field. Both longitudinal and transverse components of bulk viscosity increase with B for L mode, while for the R mode a temperature dependent increase/decrease is found.

- Parallel sessions on 07 February:
  - Evolution of dissipative stresses was found from the kinetic theory for both resistive and non-resistive MHD by Ankit Kumar Panda. Moving from flat space to curved space, new gaped modes arising due to gravity were found.
  - Diffusion matrix in the baryon number, charge and strangeness space was estimated by Ranjita Kumari using ideal HRG and excluded volume HRG.
  - Pushpa Pandey calculated the momentum transport coefficients viz. shear and bulk viscosity in a weakly magnetized thermal medium. The medium generated mass were found to be different for left- and right-handed chiral modes of quarks in presence of a weak magnetic field. Both longitudinal and transverse components of bulk viscosity increase with B for L mode, while for the R mode a temperature dependent increase/decrease is found.
  - Nilanjan Chaudhuri obtained spectral functions in the scalar and pseudoscalar channels in presence of background magnetic field. They were seen to overlap with the corresponding chiral partners at high temperature values indicating restoration of the chiral symmetry.

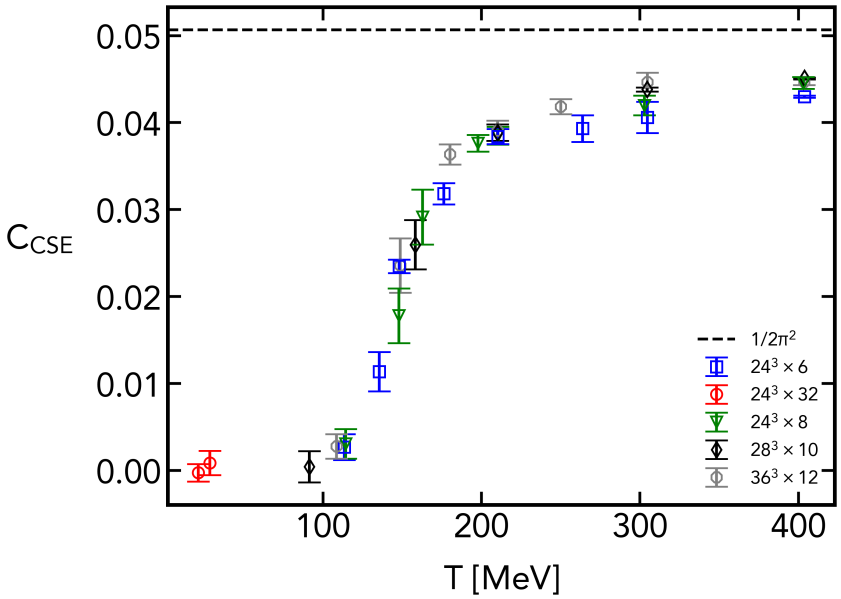
– Dilepton production rate (DPR) from hot and magnetized hadronic medium was studied by Rajkumar Mondal. A spike-like structure in DPR in the range 0-1 GeV^2 of invariant mass was found due to the Landau level quantization of pions in hadronic medium.

- Dilepton production rate (DPR) from hot and magnetized hadronic medium was studied by Rajkumar Mondal. A spike-like structure in DPR in the range 0-1 GeV^2 of invariant mass was found due to the Landau level quantization of pions in hadronic medium.
- Local NJL fails to reach the conformal limit for dense matter with velocity of sound approaching unity instead of the expected 1/3. Udita Shukla showed that a momentum-dependent gap equation (dressing the effective chemical potential) can resolve the issue.

- Dilepton production rate (DPR) from hot and magnetized hadronic medium was studied by Rajkumar Mondal. A spike-like structure in DPR in the range 0-1 GeV^2 of invariant mass was found due to the Landau level quantization of pions in hadronic medium.
- Local NJL fails to reach the conformal limit for dense matter with velocity of sound approaching unity instead of the expected 1/3. Udita Shukla showed that a momentum-dependent gap equation (dressing the effective chemical potential) can resolve the issue.
- Dipthi Godaba Venkata unified the crust-quake model (not compatible with large-size glitches) and vortex unpinning model (needs a trigger) by proposing crust-quake as a trigger for unpinning large number of vortices which then result in pulsar glitches. Large-size glitches can be produced in their picture with the inter-glitch time set by successive crust-quakes.

– Biswanath Layek and collaborators argue that formation of topological defects due to phase transition in the core of a neutron star can lead to prominent density fluctuations. These alter the moment of inertia tensor, affecting stars rotation and may account for glitches and anti-glitches of pulsars. High precision measurements of pulsar timings and intensity modulations may identify sources of fluctuations, thus the phase transition.

– Biswanath Layek and collaborators argue that formation of topological defects due to phase transition in the core of a neutron star can lead to prominent density fluctuations. These alter the moment of inertia tensor, affecting stars rotation and may account for glitches and anti-glitches of pulsars. High precision measurements of pulsar timings and intensity modulations may identify sources of fluctuations, thus the phase transition.
– Determination of the Chiral Separation Effect conductivity with Lattice QCD for the physical quark masses(Eduardo Garnacho).



- Assumptions used by Bjorken in his classic paper were a) rapidity plateau in the central region for pp and AA, and b) the leading baryon effect. Both of these become better as one increases the colliding energy $\sqrt{s} \to \infty$, e.g. top RHIC energy and/or the LHC energies.

- Assumptions used by Bjorken in his classic paper were a) rapidity plateau in the central region for pp and AA, and b) the leading baryon effect. Both of these become better as one increases the colliding energy $\sqrt{s} \to \infty$, e.g. top RHIC energy and/or the LHC energies.

- Unfortunately, we have no theoretical guidance yet as to what corrections would arise in relaxing them, as needed for even BES energies, let alone FAIR/NICA.

- Assumptions used by Bjorken in his classic paper were a) rapidity plateau in the central region for pp and AA, and b) the leading baryon effect. Both of these become better as one increases the colliding energy $\sqrt{s} \to \infty$, e.g. top RHIC energy and/or the LHC energies.

- Unfortunately, we have no theoretical guidance yet as to what corrections would arise in relaxing them, as needed for even BES energies, let alone FAIR/NICA.

- As we enter the era of "bright experimental future" (T. Galatyuk Erice 2021), I am afraid that we lack a similar bright outlook/guidance for a robust framework for formation of high baryon (quark?) density matter which we are expecting will lead us the QCD critical point. It is urgently needed.

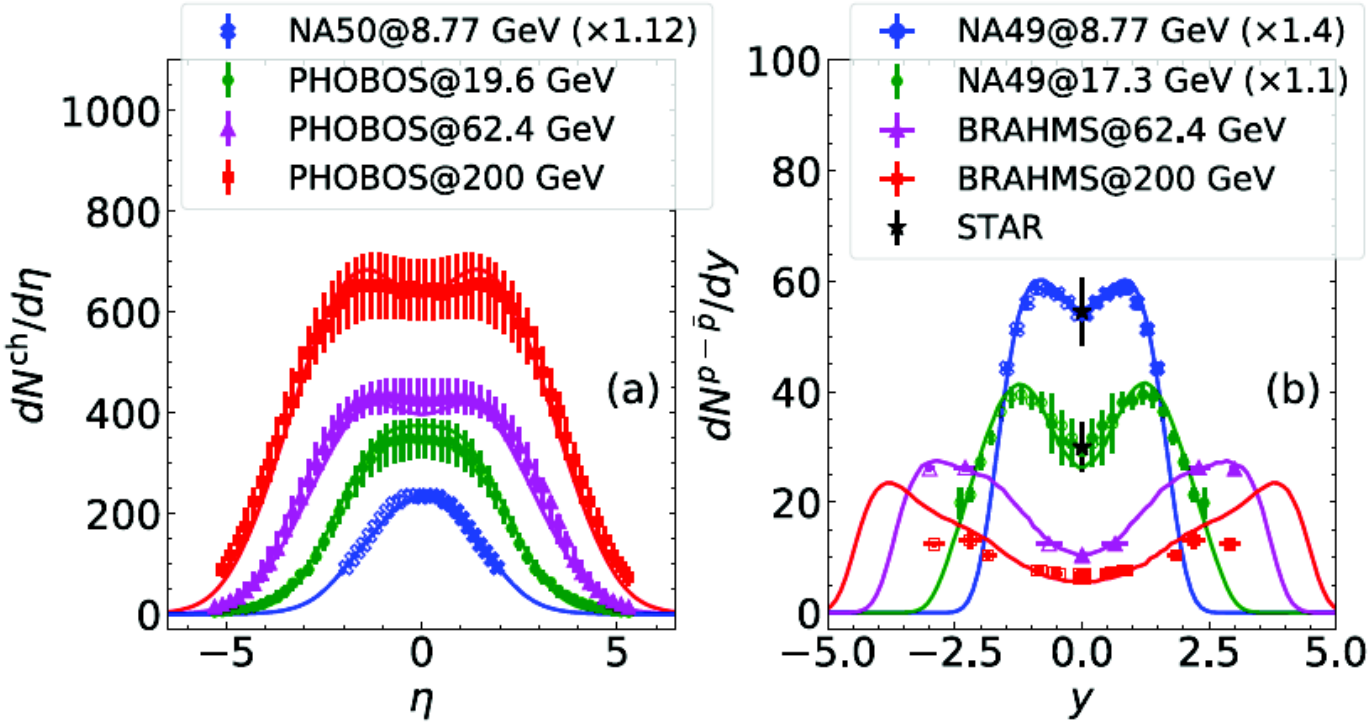
- Assumptions used by Bjorken in his classic paper were a) rapidity plateau in the central region for pp and AA, and b) the leading baryon effect. Both of these become better as one increases the colliding energy $\sqrt{s} \to \infty$, e.g. top RHIC energy and/or the LHC energies.

- Unfortunately, we have no theoretical guidance yet as to what corrections would arise in relaxing them, as needed for even BES energies, let alone FAIR/NICA.

- As we enter the era of "bright experimental future" (T. Galatyuk Erice 2021), I am afraid that we lack a similar bright outlook/guidance for a robust framework for formation of high baryon (quark?) density matter which we are expecting will lead us the QCD critical point. It is urgently needed.

- This was illustrated well by Sandeep Chatterjee in his talk on understanding rapidity dynamics in heavy ion collisions.

BES: a tale of 2 currents



arXiv: 2211.16408

As we go to lower energies, the baryon current plays an increasingly important role: essential to understand

How well do we understand the baryon current? In particular, directed flow.

From the talk of S. Chatterjee

Summarising..

A new Glauber based model of initial baryon deposition proposed

Qualitative agreement across beam energies with data on v_1

Helps in estimating background driven by baryon stopping across beam energies in signals of other physics like that of the EM field

To be further constrained from baryon - anti baryon splits in other observables like that of polarisation etc

Baryon diffusion may be constrained by proper treatment of the systematics of the parameter space

Independent Evolution of strangeness, electric charge seems important at $\sqrt{s_{NN}} \sim 10$ GeV

Baryon inhomogeneties in the bulk can produce flow patterns in nuclei that can discriminate between thermal vs coalescence picture-
Tribhuban's talk on Fri, 15:00 hrs, Hall 1

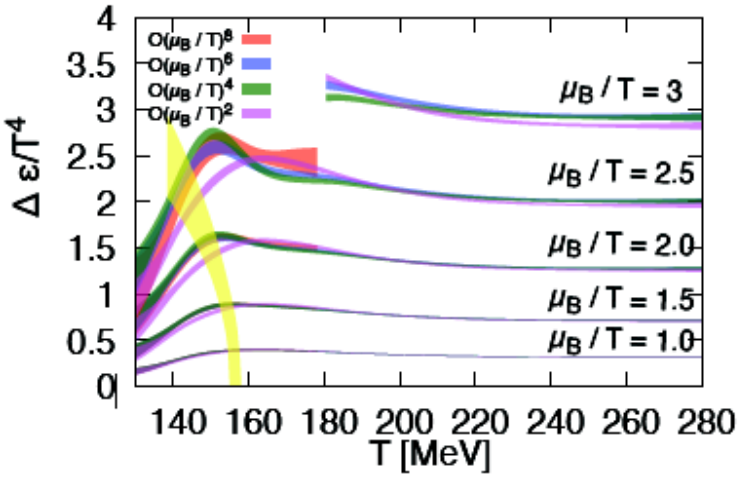
From the talk of S. Chatterjee

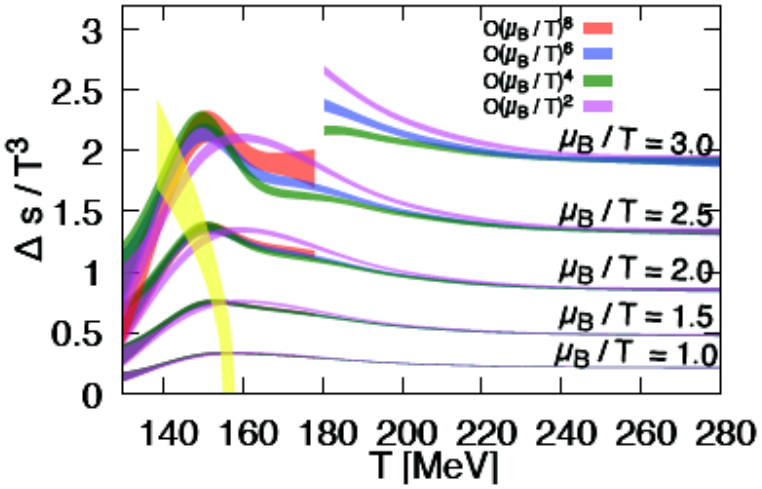
- Transport coefficients calculations in hot and dense matter as well as finite magnetic field were discussed by Sukanya Mitra and Sabyasachi Ghosh respectively. Two parallel methods - gradient expansion method and moment method were discussed to extract the values of transport coefficients by Sukanya. Due to magnetic field multi component transport coefficients structure is expected (Parallel, Perpendicular & Hall)

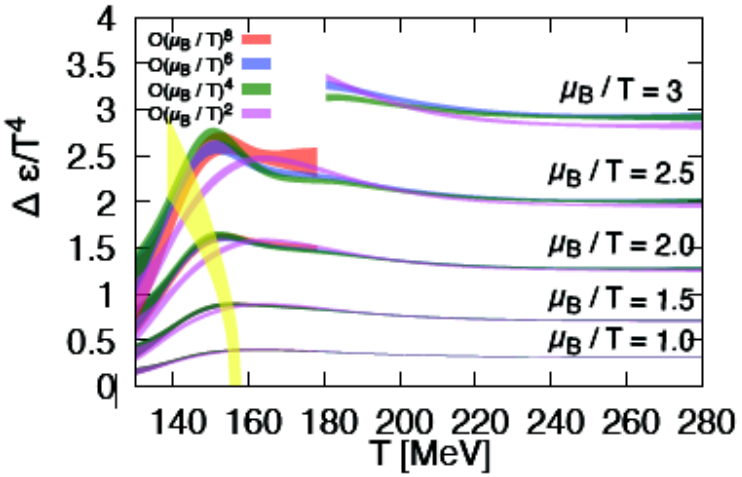
- Transport coefficients calculations in hot and dense matter as well as finite magnetic field were discussed by Sukanya Mitra and Sabyasachi Ghosh respectively. Two parallel methods - gradient expansion method and moment method were discussed to extract the values of transport coefficients by Sukanya. Due to magnetic field multi component transport coefficients structure is expected (Parallel, Perpendicular & Hall)

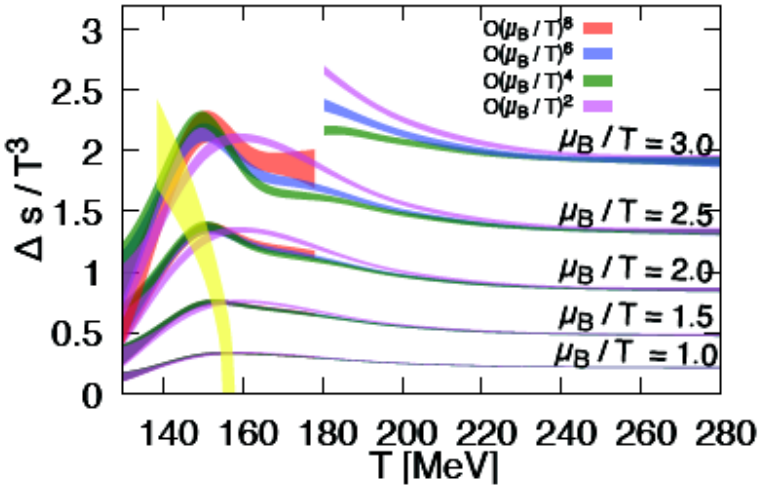
- From the imaginary chemical potential simulations, BI-Parma collaboration found that poles of the (multi-point) Pad limit the radius of convergence and show an apparent approach to the real axis. They might be identified with the Lee-Yang singularities, which show universal scaling

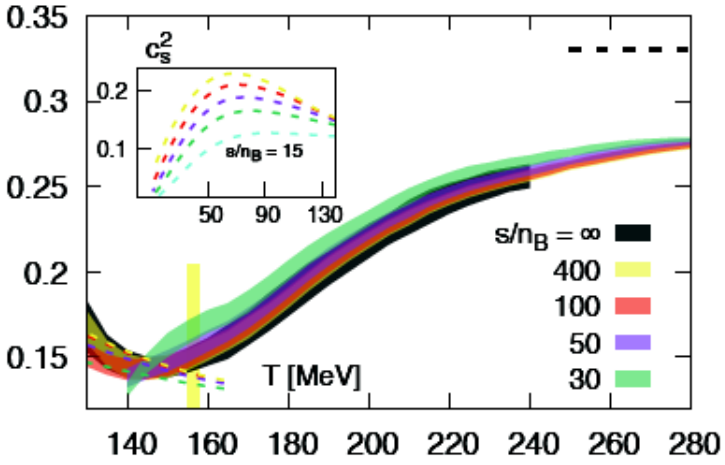
- Using Taylor expansion method, Christian Schmidt presented the latest HotQCD results for equation of state and the velocity of sound on isoentropes.


$\Delta\ \varepsilon/T^4$
$O(\mu_B/T)^8$
$O(\mu_B/T)^6$
$O(\mu_B/T)^4$
$O(\mu_B/T)^2$
$\mu_B/T = 3$
$\mu_B/T = 2.5$
$\mu_B/T = 2.0$
$\mu_B/T = 1.5$
$\mu_B/T = 1.0$
T [MeV]


$\Delta\ s/T^3$
$O(\mu_B/T)^8$
$O(\mu_B/T)^6$
$O(\mu_B/T)^4$
$O(\mu_B/T)^2$
$\mu_B/T = 3.0$
$\mu_B/T = 2.5$
$\mu_B/T = 2.0$
$\mu_B/T = 1.5$
$\mu_B/T = 1.0$
T [MeV]


$\Delta\ \varepsilon/T^4$
$O(\mu_B/T)^8$
$O(\mu_B/T)^6$
$O(\mu_B/T)^4$
$O(\mu_B/T)^2$
$\mu_B/T = 3$
$\mu_B/T = 2.5$
$\mu_B/T = 2.0$
$\mu_B/T = 1.5$
$\mu_B/T = 1.0$
T [MeV]


$\Delta\ s/T^3$
$O(\mu_B/T)^8$
$O(\mu_B/T)^6$
$O(\mu_B/T)^4$
$O(\mu_B/T)^2$
$\mu_B/T = 3.0$
$\mu_B/T = 2.5$
$\mu_B/T = 2.0$
$\mu_B/T = 1.5$
$\mu_B/T = 1.0$
T [MeV]


c_s^2
$s/n_B = 15$
$s/n_B = \infty$
400
100
50
30
T [MeV]

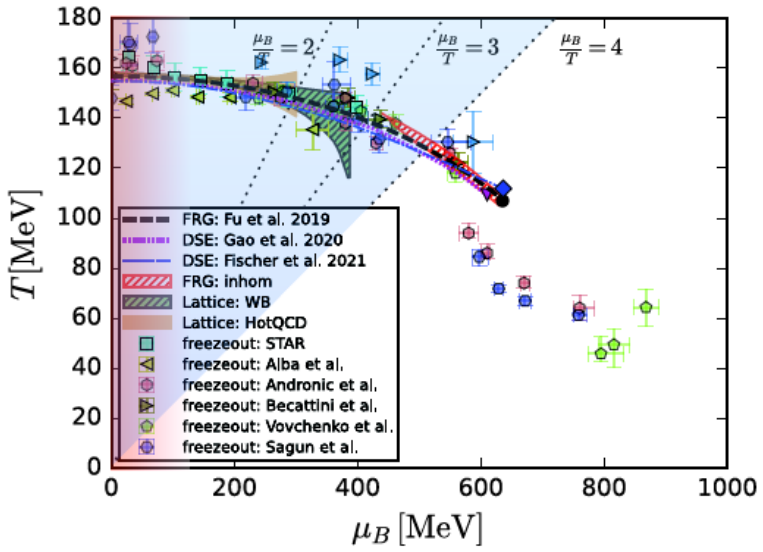
- Jan Pawlowski presented their fRG results on the phase diagram of strongly interacting matter.

Analyticity considerations at finite density

- **Self-consistent truncations to functional relations define analytic functions in μ_B, eg:**

$$\partial_t \Big\langle q(x)\bar{q}(y)\Big\rangle(\mu_B) = \text{Loop}\left[\Big\langle q(x)\bar{q}(y)\Big\rangle(\mu_B),\ \Big\langle q(x)A_\mu(y)\bar{q}(z)\Big\rangle(\mu_B), \cdots ;\ \mu_B\right]$$

- **Consequences for functional QCD predictions at finite density**



By now the best truncations to functional QCD pass lattice benchmark tests at vanishing and small chemical potential

Regime of reliability of current best truncation

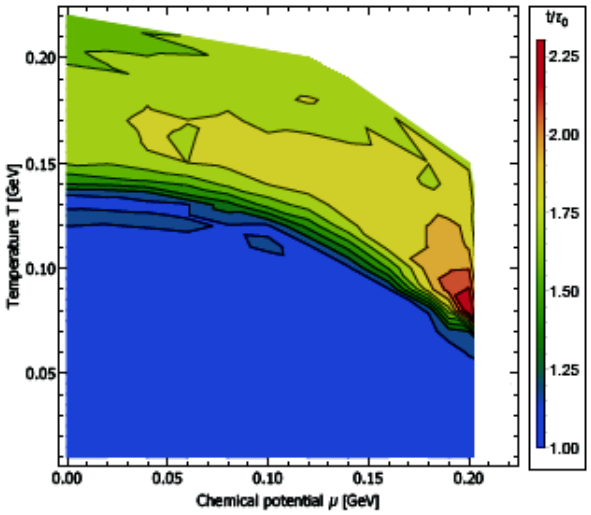
Dynamics and the size of the critical regime

fQCD

Showcases in linear sigma models

Transport with fRG spectral functions & effective potential

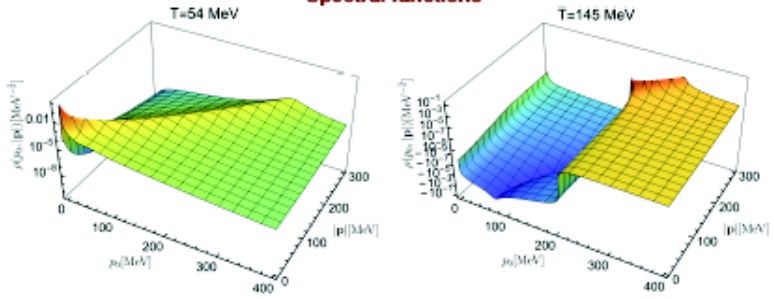
Equilibration time of sigma-kurtosis



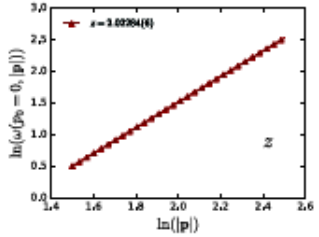
Blum, Jiang, Nahrgang, JMP, Rennecke, Wink, NPA 982 (2019) 871

Dynamical universality

Spectral functions



Dynamical O(4) critical exponent



$$\omega \propto (\vec{p}^{\,2})^{\frac{z}{2}}$$

Tan, Chen, Fu, SciPost Phys. 12 (2022) 026

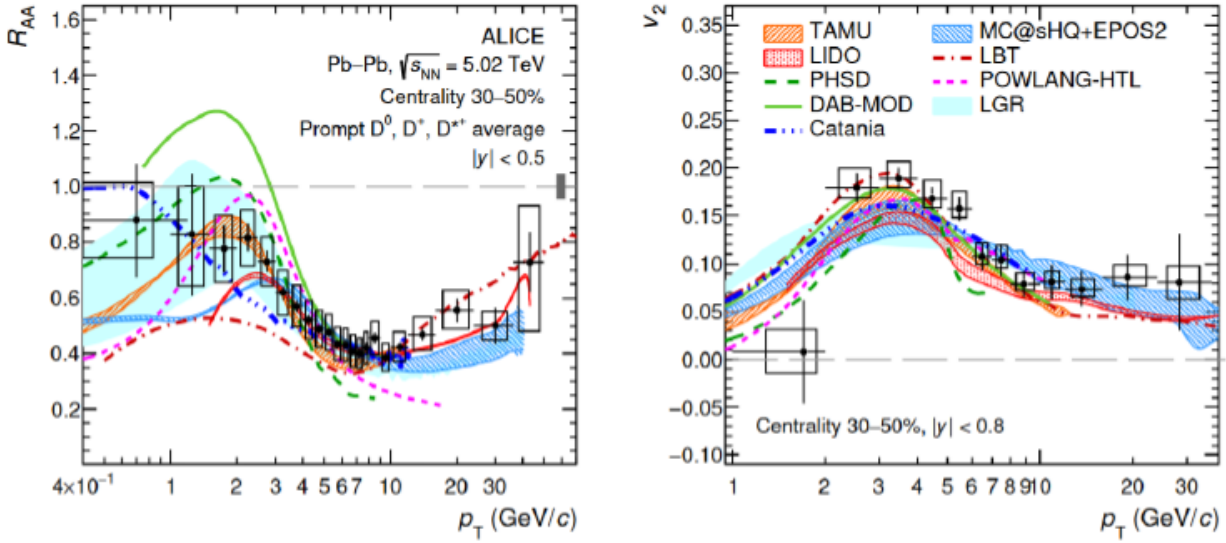
QM: Roth, Schweitzer, Rieke, von Smekal , PRD 105 (2022) 116017

- Rishi Sharma discussed various aspects of jet physics in AA collisions. From Δp_T of AA and pp data they find that both weak coupling and strong coupling dynamics of jets is consistent with the present data, with a minor preference for strong coupling. Observables that have the power to distinguish between models of jet quenching were discussed. More work is clearly needed in this direction to shed light on the nature of the medium.

- Rishi Sharma discussed various aspects of jet physics in AA collisions. From Δp_T of AA and pp data they find that both weak coupling and strong coupling dynamics of jets is consistent with the present data, with a minor preference for strong coupling. Observables that have the power to distinguish between models of jet quenching were discussed. More work is clearly needed in this direction to shed light on the nature of the medium.

- Santosh Das talked on the dynamics of heavy quark in AA collisions, covering a variety of topics from heavy quark diffusion to its hadronization models as well as its use as a probe of initial stages. His interesting conclusions were a) heavy quark diffusion in pre-equilibrium phase is crucial and b) coalescence and fragmentation both are required in hadronization of a heavy quark

R_{AA} and v_2
Comparison with models



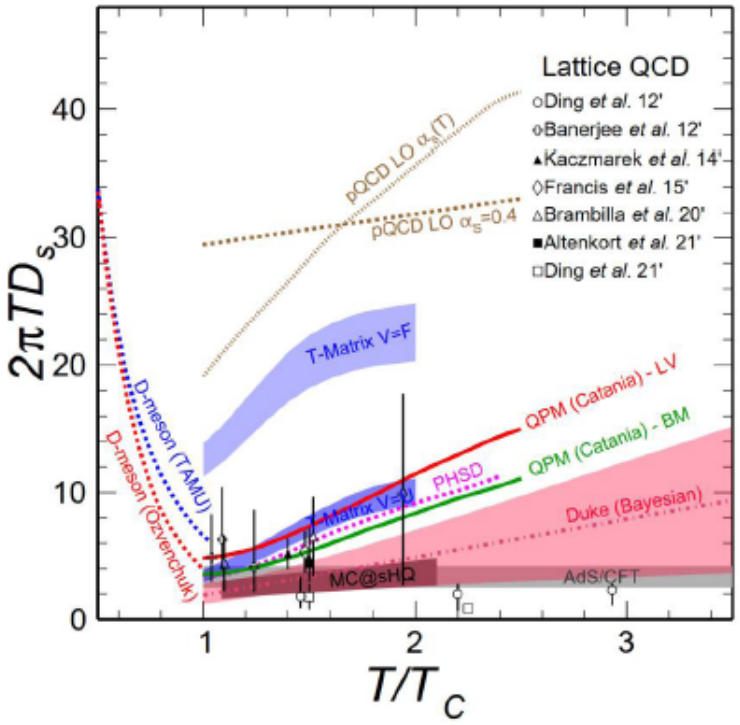
ALICE, JHEP 01 (2022) 174

Most of the models able to describe both R_{AA} and v_2 in certain p_T domain

Simultaneous description of R_{AA} and v_2 is still a challenge in the whole measured p_T and centrality ranges

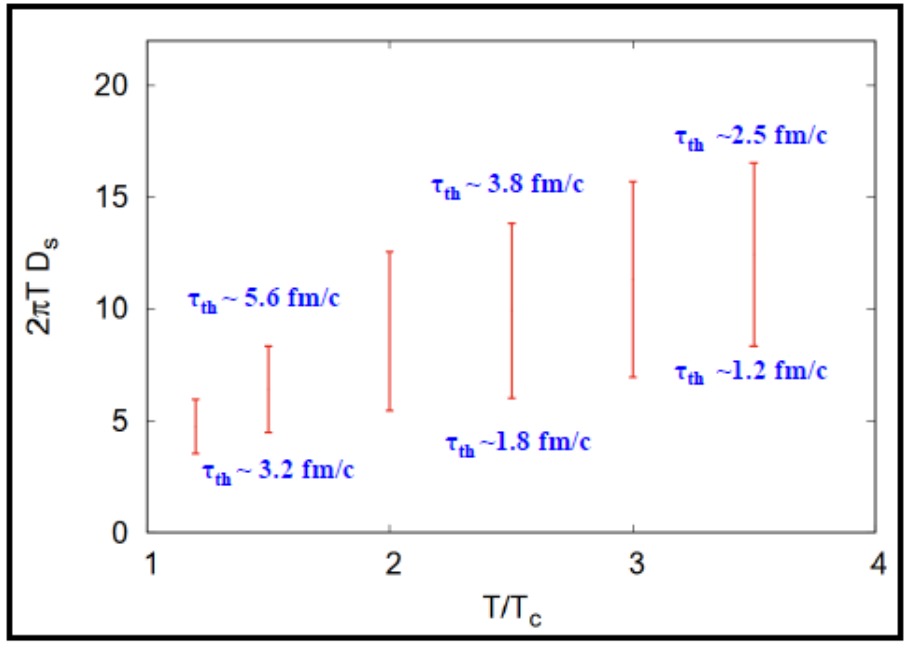
From the talk of S. K. Das

Heavy quark diffusion



$$D_s = T/M * \gamma(p \to 0)$$

He, Fries, Rapp, PRL,110, 112301 (2013)



Banerjee, Datta, Gavai, Majumdar
arxiv: 2206.15471 [hep-ph]

$$\tau_{\rm th} = \frac{M}{2\pi T^2}(2\pi T D_s) \cong 1.8 \frac{2\pi T D_s}{(T/T_c)^2}\ \text{fm/c}$$

Scardina, Das, Minissale, Plumari, Greco
PRC,96, 044905 (2017)

$2\pi T D_s \propto T^2$, corresponds to a constant thermalization time.

Memory effect can impact the HQ thermalization

Ruggieri, Pooja, Jai Prakash, Das, PRD, 106 (2022)

Summary

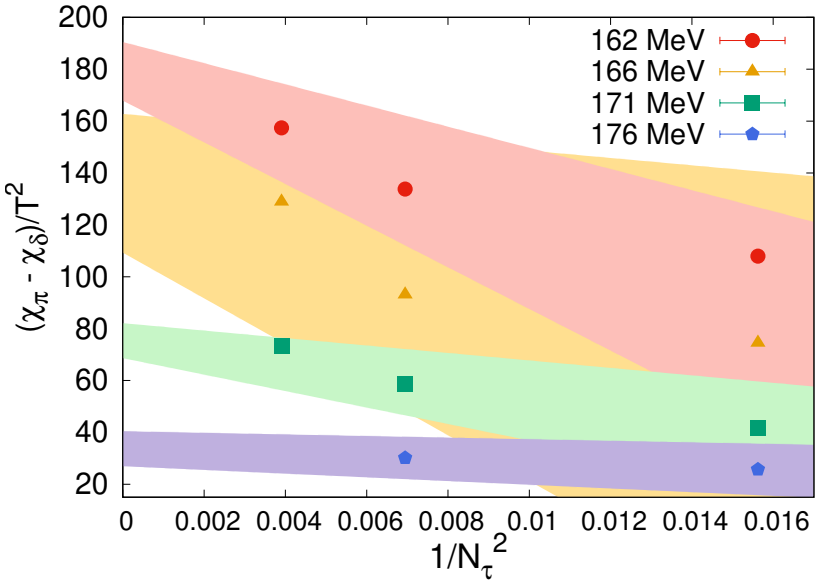
- The Clustering of Color Sources produced by overlapping strings has been applied to both A-A and *pp* collisions.
- The most important quantity in this picture is the multiplicity dependent interaction area in the transverse plane $S_\perp$
- The temperature from AA and *pp* scales as $\frac{dN_c}{d\eta}\left(\frac{1}{S_\perp}\right)$
- Quantum tunneling through color confinement leads to thermal hadron production in the form of Hawking-Unruh radiation. In QCD we have string interaction instead of gravitation.
- We observe for the first time a two-step behavior in the increase of DOF. Results for Pb-Pb and Xe-Xe collisions show a sharp increase in ε/T^4 above T ~ 210 MeV and reaching the ideal gas of quarks and gluons at T ~230 MeV.

34

From the talk of B. K. Srivastava

- Parallel sessions on 10 February:
  - Sipaz Sharma talked about her work on charm fluctuations in 2+1-flavour QCD for $T > T_{pc}$. Comparing her results with "PDG-HRG" she concluded that there ought to be many as yet undiscovered charm states.

- Parallel sessions on 10 February:
  - Sipaz Sharma talked about her work on charm fluctuations in 2+1-flavour QCD for $T > T_{pc}$. Comparing her results with "PDG-HRG" she concluded that there ought to be many as yet undiscovered charm states.
  - Using his studies of eigenvalue spectrum of 2+1-flavour HISQ QCD, Ravi Shanker obtained results for integrated π and δ meson correlators as a function of temperature in the continuum limit. From their difference, he obtains $1.14T_{pc}$ as the temperature where $U_A(1)$ is restored.



– Dean Valois showed that a richer scenario exists for inhomogeneous magnetic field such as dip in chiral condensate, electric currents etc. but CSE remains unchanged as a result of inhomogeneity.

– Dean Valois showed that a richer scenario exists for inhomogeneous magnetic field such as dip in chiral condensate, electric currents etc. but CSE remains unchanged as a result of inhomogeneity.

LATTICE APPROACH TO INHOMOGENEOUS MAGNETIC FIELDS AS PROBES OF QCD THERMODYNAMICS (DEAN VALOIS)

Chiral condensate

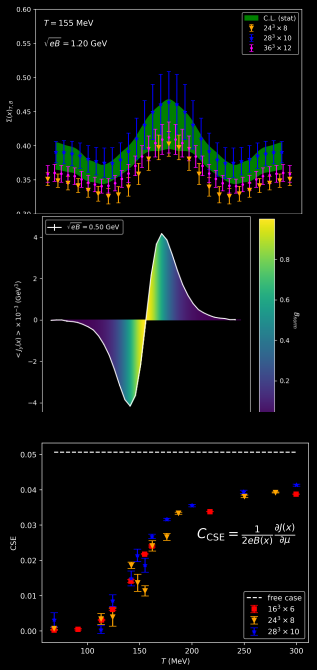
- Non-trivial features appear (dips due to interaction with Polyakov loop)
- The system could be in different phases at different points of the lattice.

Electric current

- We show the presence of electric currents flowing in equilibrium.
- They can be used to compute mag. susceptibility via Maxwell's equations.

Chiral Separation Effect (CSE)

- CSE doesn't feel the inhomogeneity of **B**: $\mathbf{B} = B\cosh((x - L_x/2)/\epsilon)^{-2}$
- Work in progress for CME!



2

– Saumen Datta presented his results on the heavy quark diffusion coefficients including those for the $1/M_Q$ term.

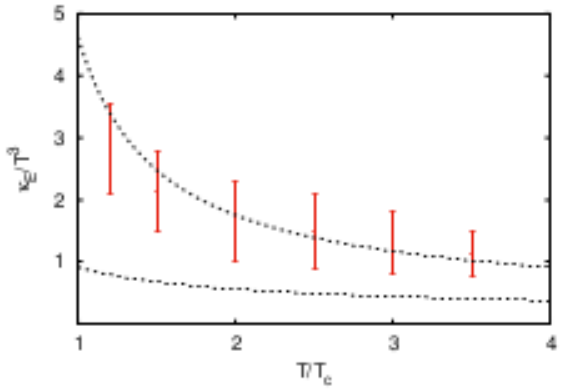
Heavy quark κ from lattice QCD

S. Datta (parallel session IVB)

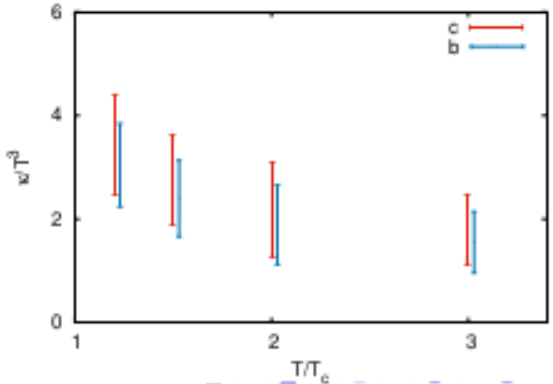
Results on κ_E, the static quark diffusion coefficient, for gluon plasma in the temperature range $T_c < T \lesssim 3.5 T_c$.

$1/m_Q$ correction calculated.
Can get $\kappa_{b,c}$

Banerjee, Datta, Gavai, Majumdar, 2206.14571



Banerjee, Datta, Laine, 2204.14075



Saumen Datta | Heavy quark diffusion coefficient from lattice QCD

– Pooja investigated anisotropic heavy quark diffusion in glasma. It is strongly affected by strong coherent gluon fields and memory effects become important. While spin fluctuations are suppressed by the M_Q, substantial anisotropic fluctuations are found in total angular momentum.

- Pooja investigated anisotropic heavy quark diffusion in glasma. It is strongly affected by strong coherent gluon fields and memory effects become important. While spin fluctuations are suppressed by the M_Q, substantial anisotropic fluctuations are found in total angular momentum.
- Adiba Shaikh studied the effect of including viscous corrections on the transport coefficients of heavy quarks, undergoing energy loss in QCD medium due to collision and radiation of soft gluon. The transition from collisional to radiative dominance of energy loss mechanism for charm quark was seen to occur at almost one order of magnitude less in initial momentum as compared to the bottom quark.

- Pooja investigated anisotropic heavy quark diffusion in glasma. It is strongly affected by strong coherent gluon fields and memory effects become important. While spin fluctuations are suppressed by the M_Q, substantial anisotropic fluctuations are found in total angular momentum.
- Adiba Shaikh studied the effect of including viscous corrections on the transport coefficients of heavy quarks, undergoing energy loss in QCD medium due to collision and radiation of soft gluon. The transition from collisional to radiative dominance of energy loss mechanism for charm quark was seen to occur at almost one order of magnitude less in initial momentum as compared to the bottom quark.
- Balbeer Singh investigated the relative contributions arising from Landau damping and gluo-dissociation to Upsilon 1S and 2S states. With the real part of the screened potential, he estimated the binding energies as a function of temperature for these states and found a behaviour as $\sim T$. This has consequences for $Q\bar{Q}$ evolution which should be non-local in time.

– Born-Oppenheimer EFT (BOEFT) provides a model-independent & systematic way to study heavy quark hybrids (exotic) and decays. Abhishek Mohapatra used the fact that results for hybrid-to-quarkonium transition widths sets lower-bounds on the inclusive rate of physical exotic states, if interpreted as pure hybrid states to identify possible hybrid states in the X,Y χ states in the charm sector.

- Born-Oppenheimer EFT (BOEFT) provides a model-independent & systematic way to study heavy quark hybrids (exotic) and decays. Abhishek Mohapatra used the fact that results for hybrid-to-quarkonium transition widths sets lower-bounds on the inclusive rate of physical exotic states, if interpreted as pure hybrid states to identify possible hybrid states in the X,Y χ states in the charm sector.
- Deepak Biswas studied chiral observables for physical hadrons within the HRG model. Precise values of σ terms for ρ,η, K, isoscalar mesons and ground state baryons were included for the first time. This successfully improved the Tc from HRG model to 161.2 ± 1.7 MeV, closer to the LQCD estimates. Similarly, curvature coefficients κ_2 and κ_4 are found to be closer to lattice results than previous estimates.

– Pracheta Singh discussed the formulation of relativistic dissipative hydrodynamics from BGK collision kernel. Unlike RTA, this collision kernel conserves number current by construction. The only matching condition necessary for energy momentum conservation is $\epsilon/\epsilon_0 = n/n_0$ The theory gives a set of physically consistent hydrodynamic descriptions classified by a free parameter (b_0) related to the freedom of choosing the 2nd matching condition.