Transport coefficients of the hot and dense matter

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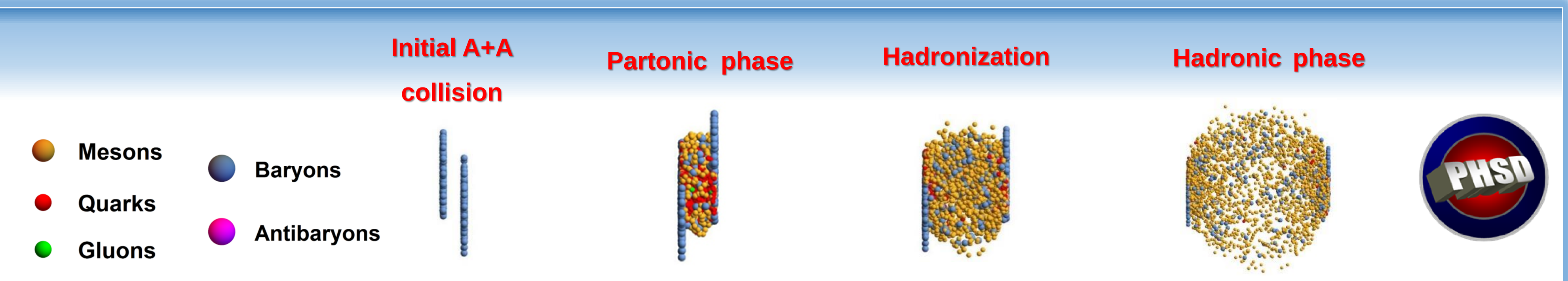
The goal:

- explore on a microscopic level the partonic phase at finite baryonic chemical potential μ_B and different temperatures T , and find traces of the μ_B dependence in observables, based on PHSD approach

PHSD : Parton-Hadron-String-Dynamics

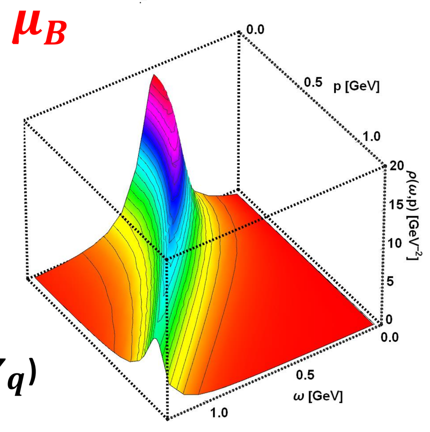
- Off-shell transport equations (on the basis of Kadanoff-Baym equations) in phase-space representation govern the time evolution of the system
- PHSD is a covariant dynamical approach for strongly interacting systems



Dynamical Quasi-Particle Model (DQPM)

- DQPM is an effective model describing the QGP at finite T and μ_B
- The d.o.f. are strongly interacting quasi-particles : q and g with Lorentzian spectral function

$$\rho_j(\omega,\mathbf{p}) = \frac{4\omega\gamma_j}{\left(\omega^2-\mathbf{p}^2-M_j^2\right)^2+4\gamma_j^2\omega^2}$$



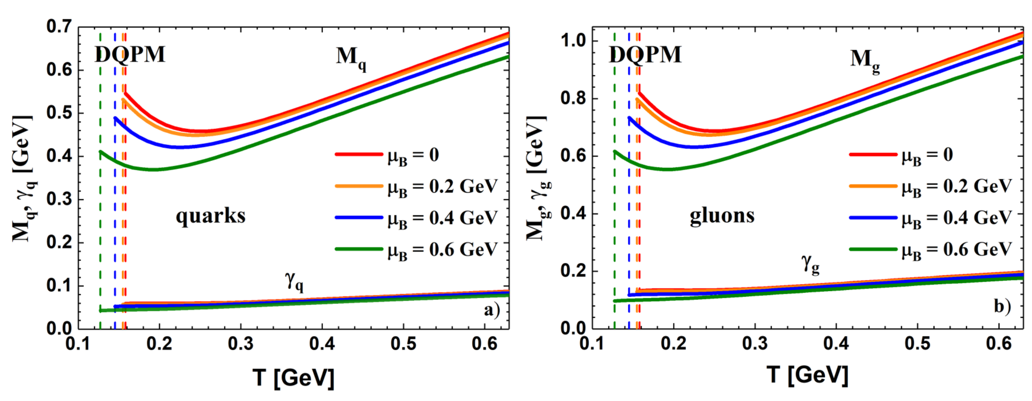
- Real part of the self-energy: thermal mass (M_g, M_q)
- Imaginary part of the self-energy: interaction width of partons (γ_g, γ_q)

$$M_g^2(T,\mu_B) = \frac{g^2(T,\mu_B)}{6}\left(\left(N_c+\frac{1}{2}N_f\right)T^2+\frac{N_c}{2}\sum_q\frac{\mu_q^2}{\pi^2}\right)$$

$$M_{q(\bar q)}^2(T,\mu_B) = \frac{N_c^2-1}{8N_c}g^2(T,\mu_B)\left(T^2+\frac{\mu_q^2}{\pi^2}\right)$$

$$\gamma_{q(\bar q)}(T,\mu_B) = \frac{1}{3}\frac{N_c^2-1}{2N_c}\frac{g^2(T,\mu_B)T}{8\pi}\ln\left(\frac{2c}{g^2(T,\mu_B)}+1\right)$$

$$\gamma_g(T,\mu_B) = \frac{1}{3}N_c\frac{g^2(T,\mu_B)T}{8\pi}\ln\left(\frac{2c}{g^2(T,\mu_B)}+1\right)$$



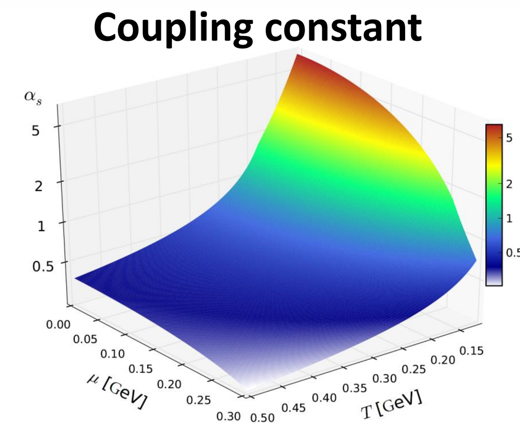
- Input: entropy density as a function of temperature for $\mu_B = 0$

$$g^2(s/s_{SB}) = d\left((s/s_{SB})^e-1\right)^f$$

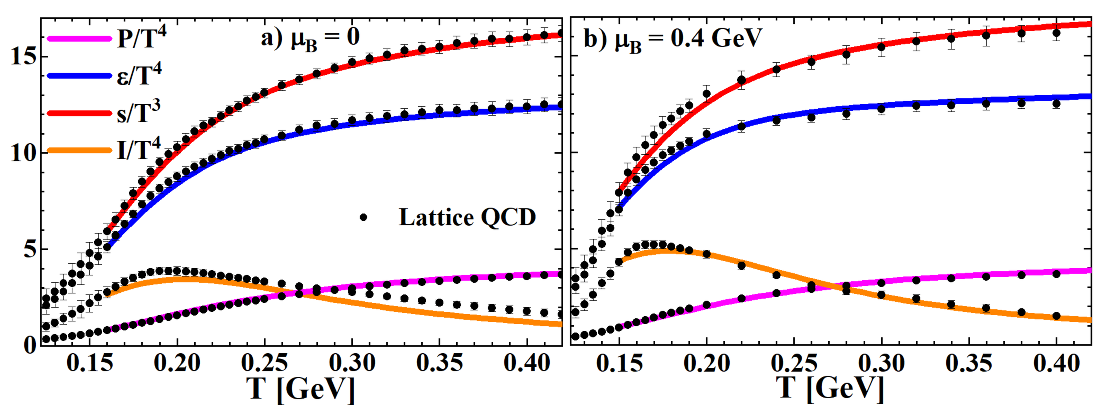
$$s_{SB}^{QCD} = 19/9\pi^2T^3$$

Scaling hypothesis: $g^2\left(\frac{T}{T_c}\right) \to g^2\left(\frac{T*}{T_c(\mu)}\right)$

Coupling constant



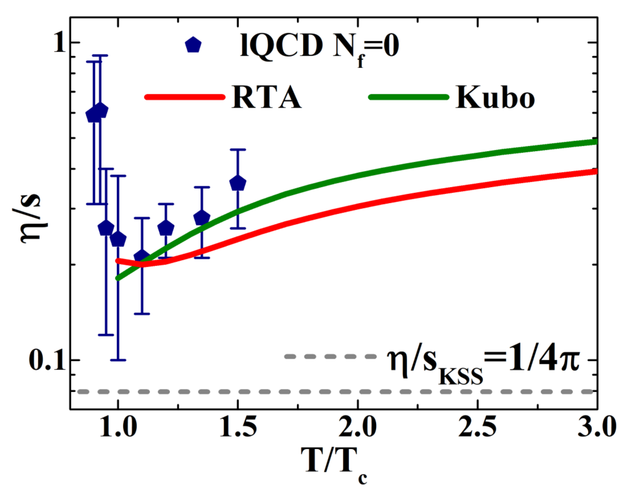
Input: lattice EoS $\mu_B = 0$

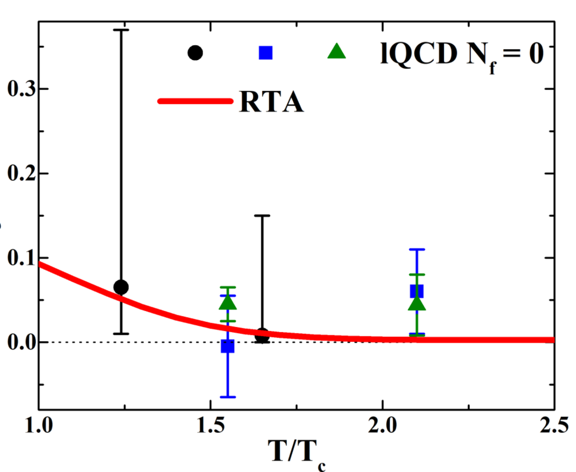


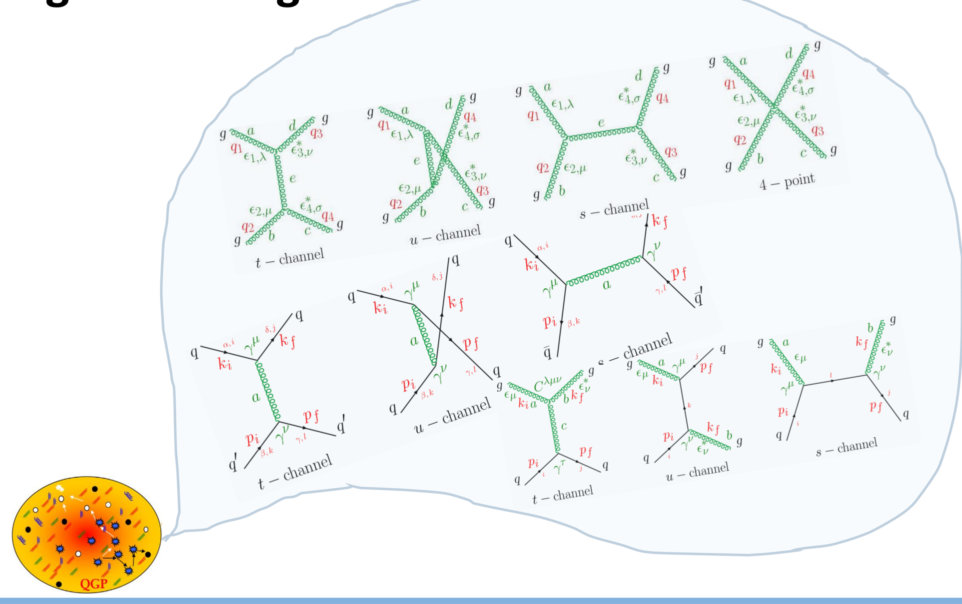
Output: DQPM EoS $\mu_B > 0$

DQPM transport coefficients: QGP in equilibrium

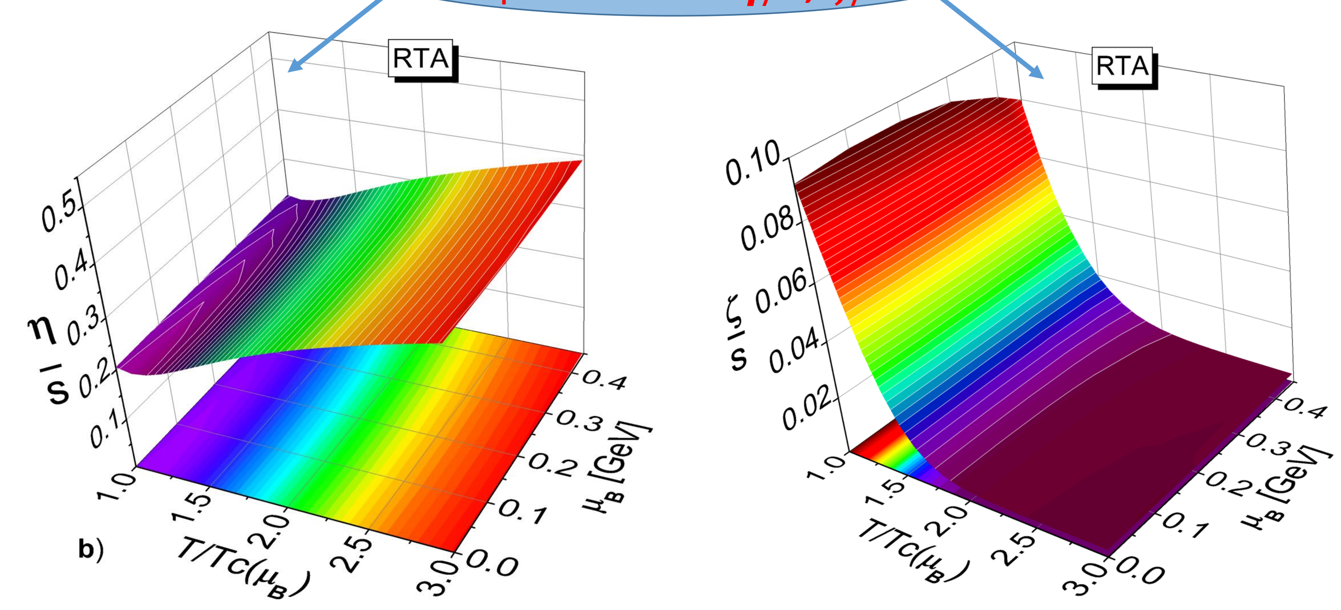
- Interactions between quasi-particles are calculated by leading-order diagrams
- Good agreement with lQCD







T, μ_B dependence of $\eta/s, \zeta/s$

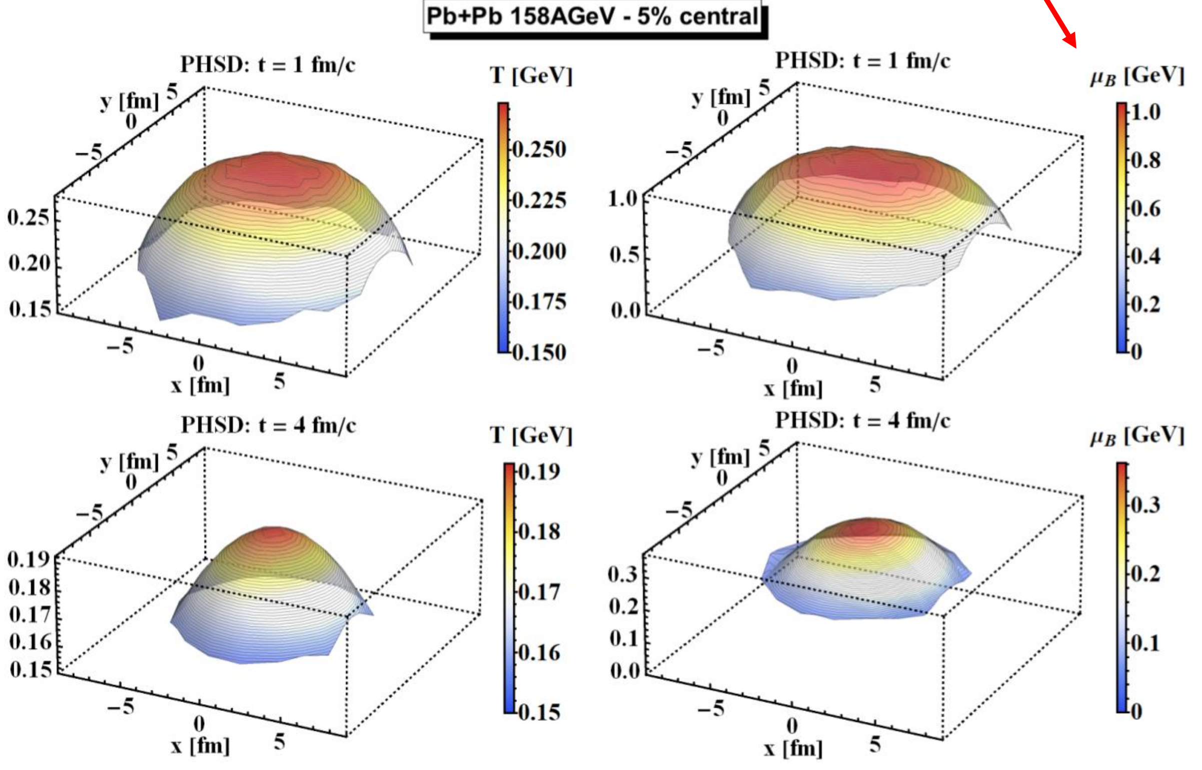


HIC: QGP off-equilibrium

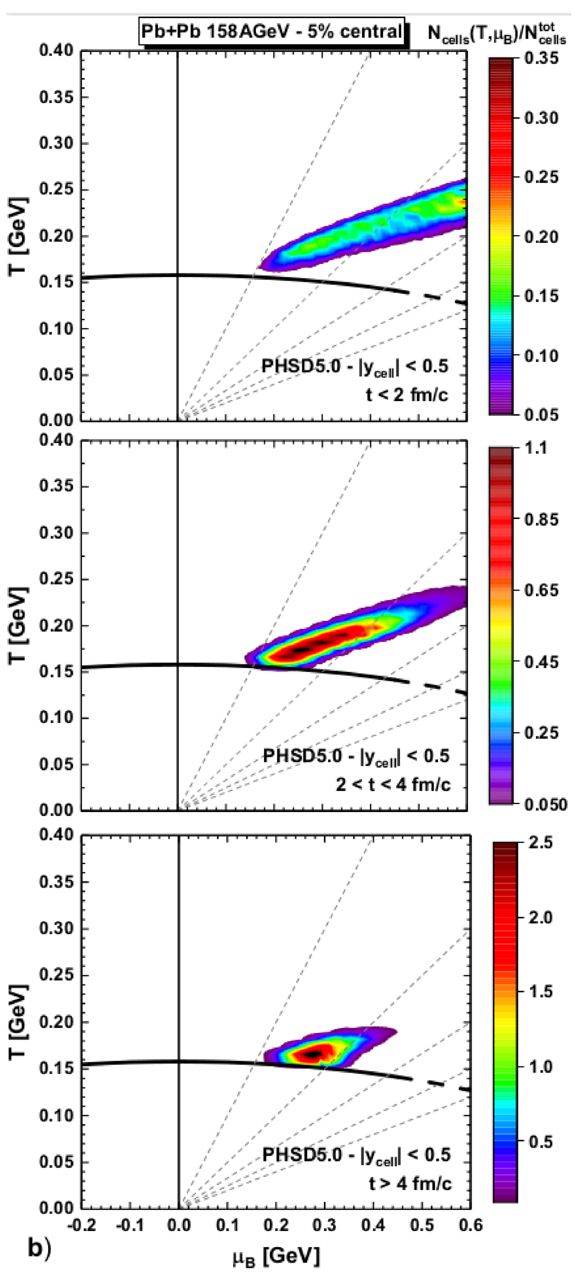
- The effect of finite μ_B in heavy-ion collisions is studied within PHSD:
  - Consistent description of the QGP dynamics for all bombarding energies
  - Extraction of (T, μ_B) in PHSD

$$\begin{cases}\epsilon^{\rm EoS}(T,\mu_B) = \epsilon^{\rm PHSD} \\ n_B^{\rm EoS}(T,\mu_B) = n_B^{\rm PHSD}\end{cases}$$

using Teylor expansion lQCD χ_n^B → (T, μ_B)

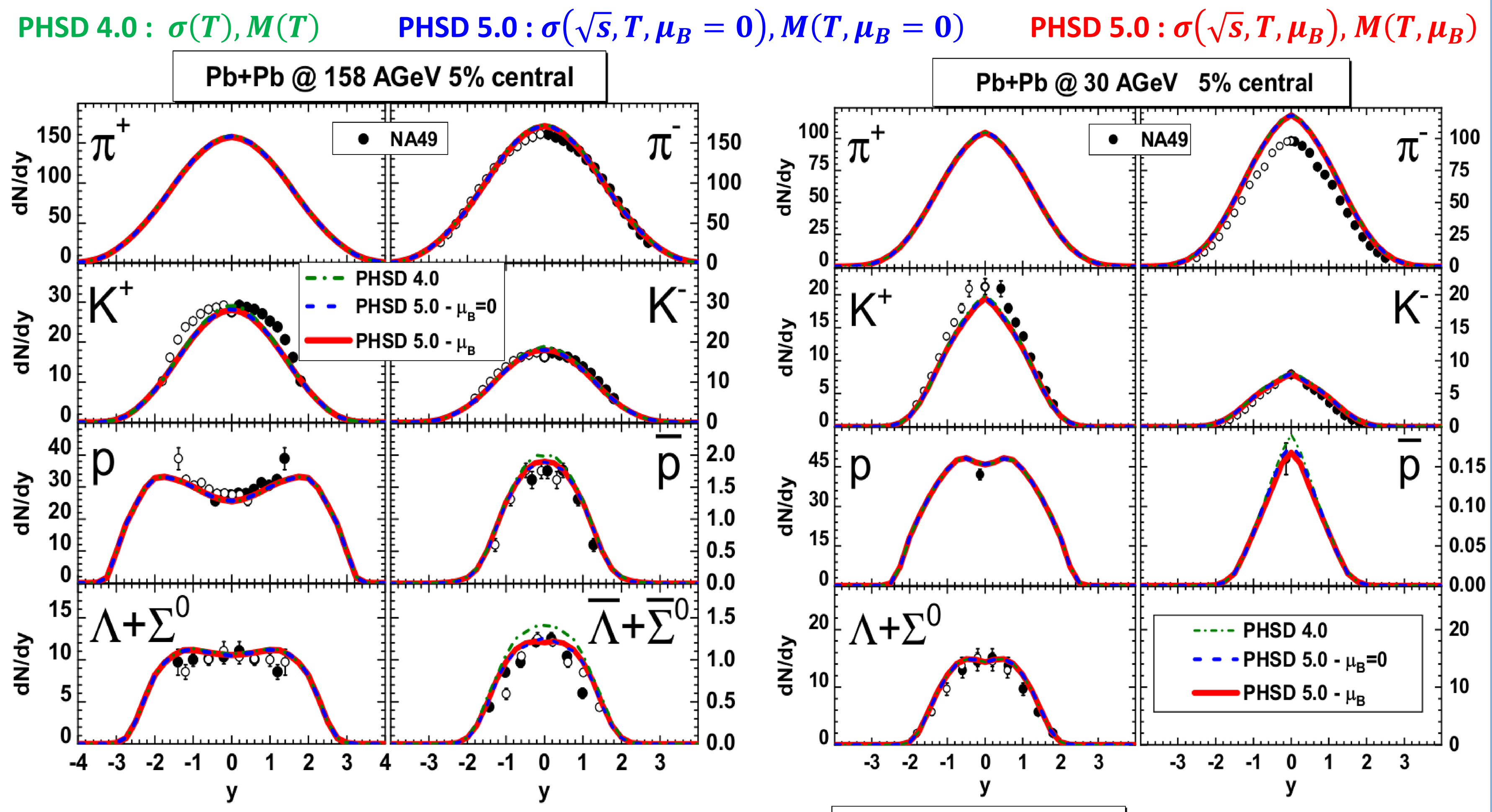


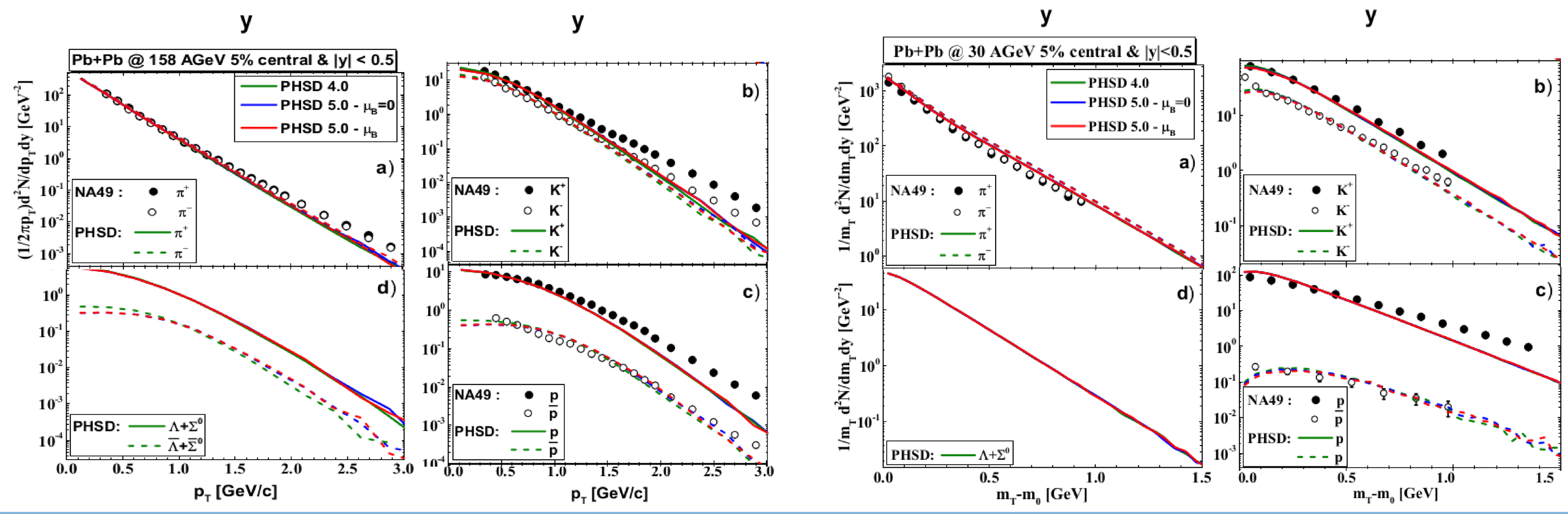
Distribution of (T, μ_B) for the central cells



Rapidity distributions of bulk particles including the new DQPM cross sections:

PHSD 4.0 : $\sigma(T), M(T)$ PHSD 5.0 : $\sigma(\sqrt{s}, T, \mu_B = 0), M(T, \mu_B = 0)$ PHSD 5.0 : $\sigma(\sqrt{s}, T, \mu_B), M(T, \mu_B)$





References

P. Moreau, O. Soloveva, L. Oliva , T. Song, W. Cassing, E. Bratkovskaya, arXiv:1903.10257, PRC (2019)

PHSD: W. Cassing, E.L. Bratkovskaya, Phys.Rev. C78 (2008) 034919; Nucl.Phys. A831 (2009) 215-242; W. Cassing, Eur. Phys. J. Spec. Top. (2009) 168: 3

DQPM: H. Berrehrah et al., Phys.Rev. C93 (2016), 044914; Int.J.Mod.Phys. E25 (2016), 1642003;

lQCD EoS: Sz. Borsanyi et al., JHEP 1208 (2012) 053

Conclusion / outlook

- High-μ_B regions are probed at low $\sqrt{s_{NN}}$ or high rapidity regions
- QGP fraction is small at low $\sqrt{s_{NN}}$: no effects seen in bulk observables
- Study more sensitive probes to finite-μ_B dynamics / more precise EoS finite/large μ_B
- 1st order phase transition?