Exploring inelastic and elastic parton interactions and transport properties of the strongly interacting quark-gluon plasma

Ilia Grishmanovskii[1], Olga Soloveva[1], Taesoo Song[2], Carsten Greiner[1], and Elena Bratkovskaya[2,1]

[1]Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH

SQM Strasbourg 2024

MOTIVATION

An understanding of the properties of the sQGP by employing an effective quasiparticle model

DYNAMICAL QUASIPARTICLE MODEL (DQPM)

- Effective model for the description of non-perturbative QCD based on lQCD EoS [1]
- The QGP phase is described in terms of interacting quasiparticles, massive quarks and gluons, with Lorentzian spectral functions

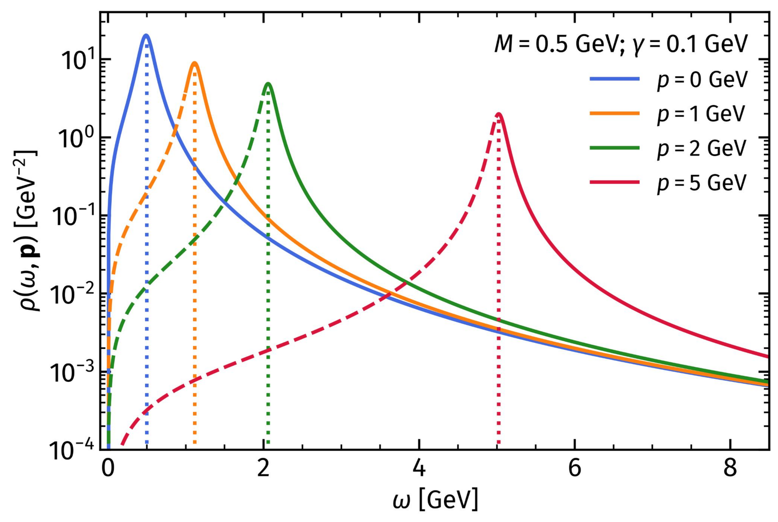
$$\rho_j(\omega,\mathbf{p}) = \frac{4\omega\gamma_j}{\left(\omega^2-\mathbf{p}^2-M_j^2\right)^2+4\gamma_j^2\omega^2}$$

- Theoretical basis: "resummed" single-particle Green's functions → quark (gluon) propagator (2PI)

gluon propagator: $\Delta^{-1} = P^2 - \Pi$;
gluon self-energy: $\Pi = M_g^2 - 2i\gamma_g\omega$;

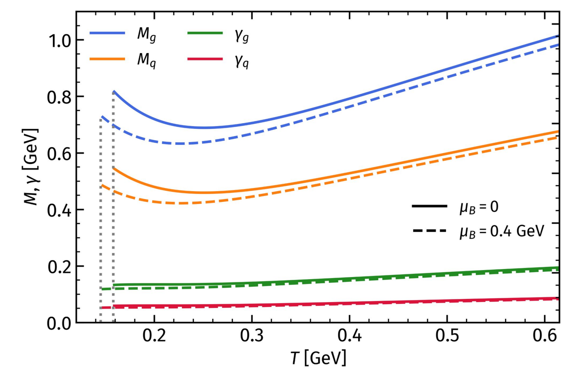
quark propagator: $S_q^{-1} = P^2 - \Sigma_q$
quark self-energy: $\Sigma_q = M_q^2 - 2i\gamma\omega$

- Real part of the self-energy – thermal masses
- Imaginary part of the self-energy – interaction widths



DQPM INGREDIENTS

- Masses and widths of quasiparticles depend on T and μ_B

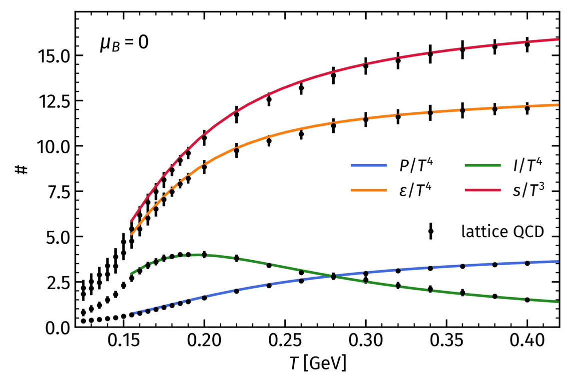


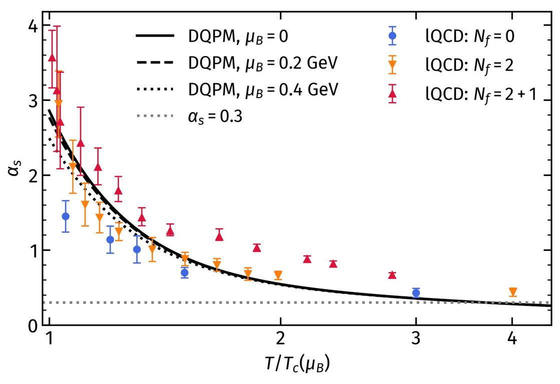
$$m_g^2(T,\mu_B) = C_g\frac{g^2(T,\mu_B)}{6}T^2\left(1+\frac{N_f}{2N_c}+\frac{1}{2}\frac{\sum_q\mu_q^2}{T^2\pi^2}\right)$$

$$m_{q(\bar{q})}^2(T,\mu_B) = C_q\frac{g^2(T,\mu_B)}{4}T^2\left(1+\frac{\mu_q^2}{T^2\pi^2}\right)$$

$$\gamma_j(T,\mu_B) = \frac{1}{3}C_j\frac{g^2(T,\mu_B)T}{8\pi}\ln\left(\frac{2c_m}{g^2(T,\mu_B)}+1\right)$$

- Input: entropy density vs T for μ_B=0 → fix DQPM parameters by comparison of the DQPM entropy density to lQCD at μ_B =0





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

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

2 → 2 (ELASTIC) PARTONIC INTERACTIONS

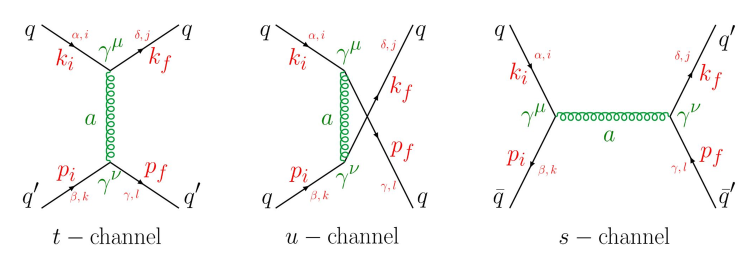
- DQPM partonic cross sections → leading order diagrams

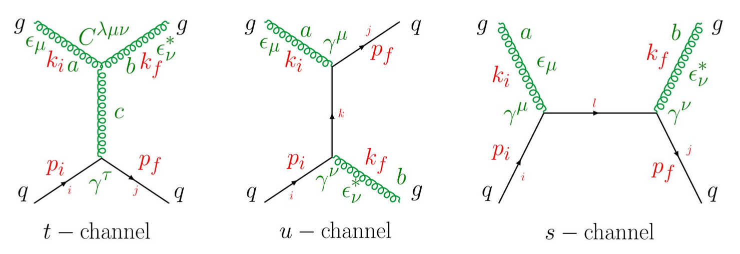
quark propagator:

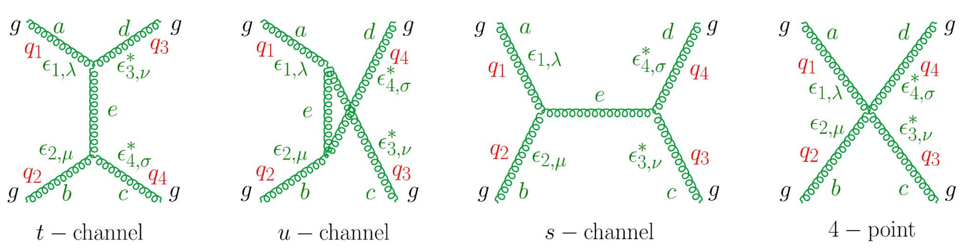
$$= i\delta_{ij}\frac{\not{q}+M_q}{q^2-M_q^2+2i\gamma_q q_0}$$

gluon propagator:

$$= -i\delta_{ab}\frac{g^{\mu\nu}-q^\mu q^\nu/M_g^2}{q^2-M_g^2+2i\gamma_g q_0}$$

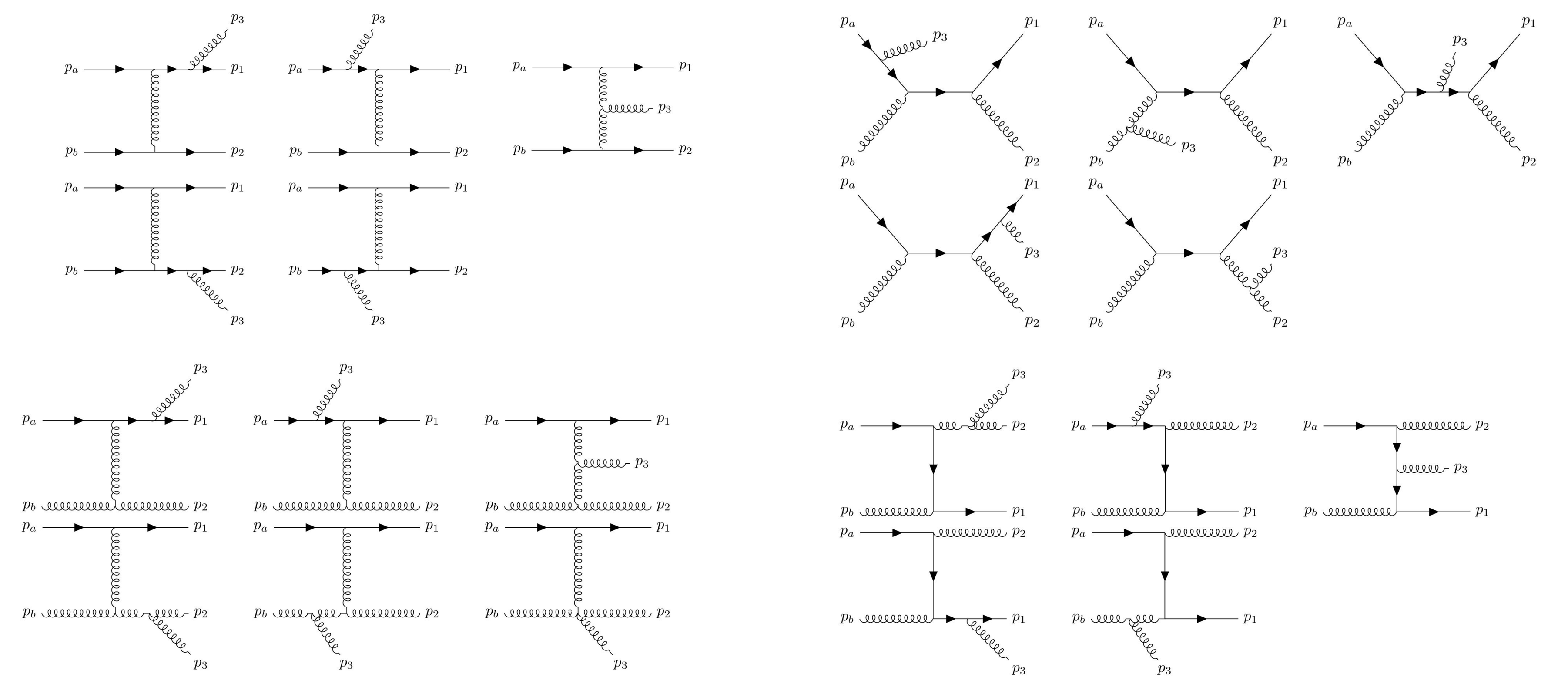






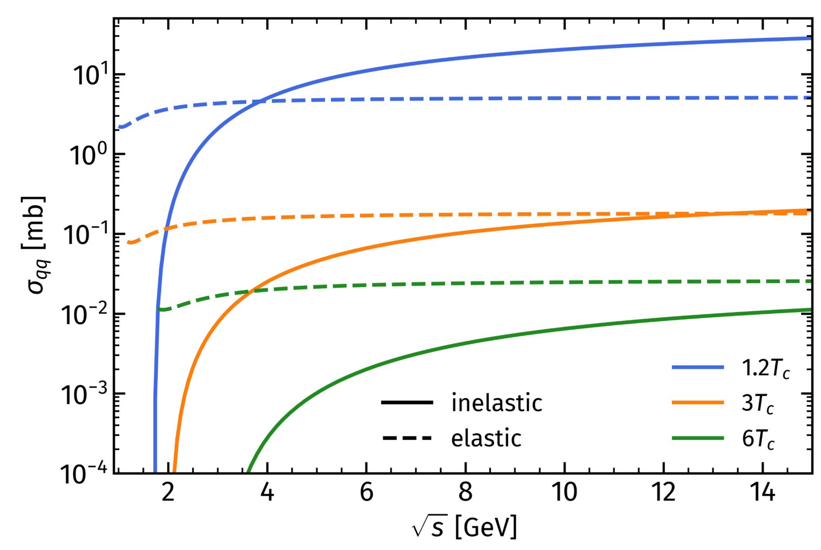
- No approximations applied
- All interference terms included

2 → 3 (INELASTIC) PARTONIC INTERACTIONS



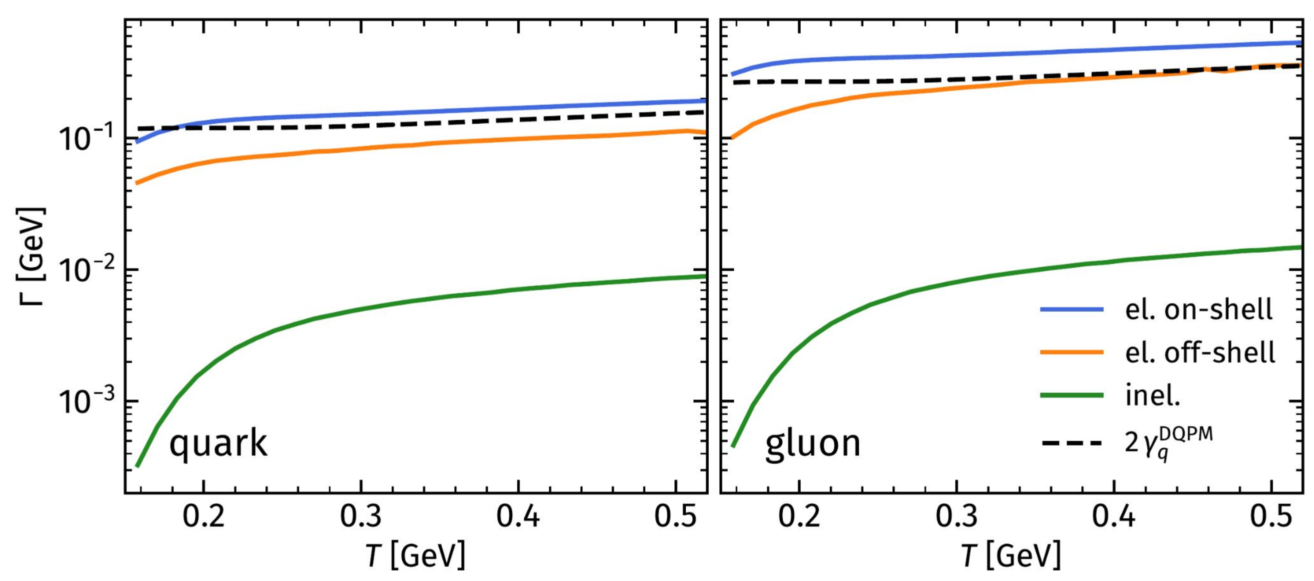
- Emitted gluon is massive

RESULTS: CROSS SECTIONS



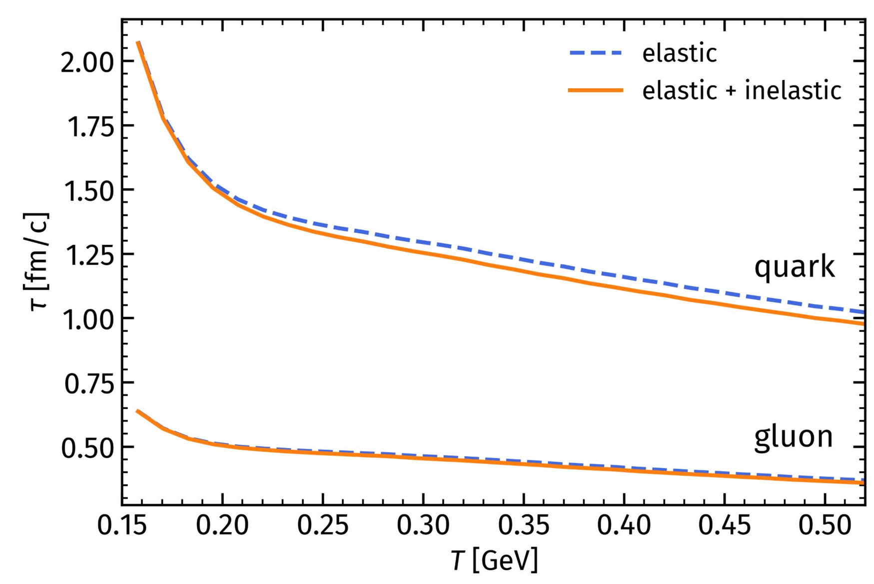
- Suppression of radiative cross section for small energies
- Enhancement of radiative cross section for small temperatures

RESULTS: PARTON INTERACTION RATES



- Inelastic interaction rates of thermal light quarks and gluons are strongly suppressed at all temperatures

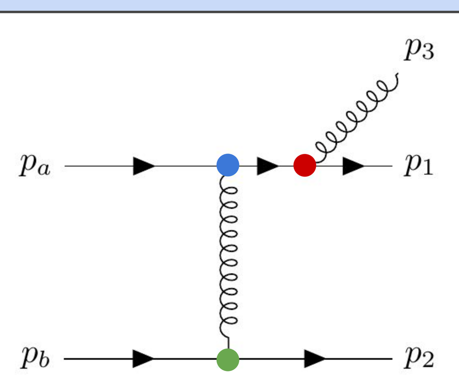
RESULTS: QGP RELAXATION TIME



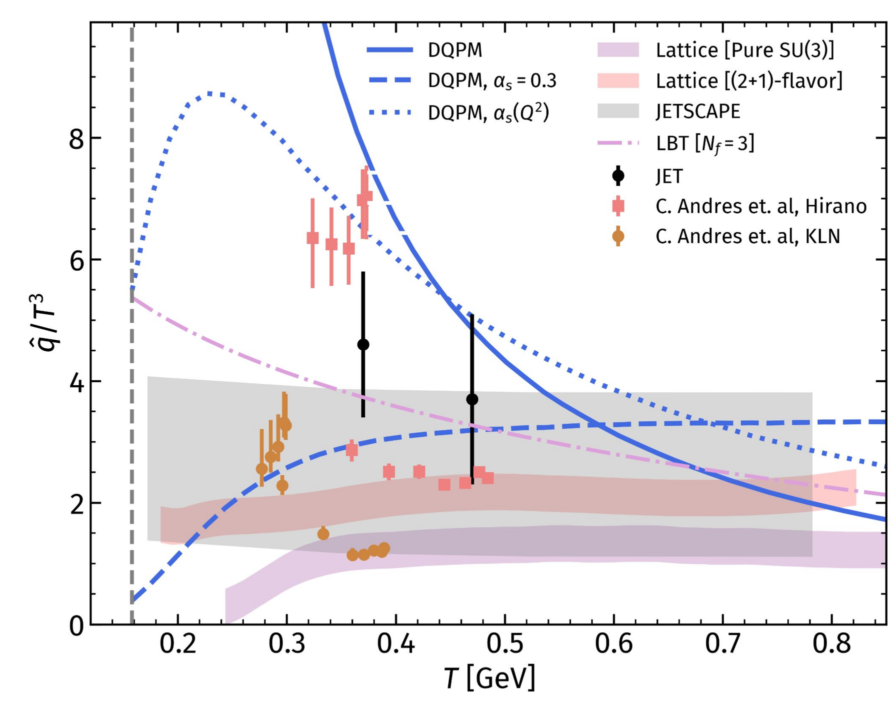
- Accounting for inelastic processes only slightly shortens the relaxation time of thermal sQGP

RESULTS: JET TRANSPORT COEFFICIENTS

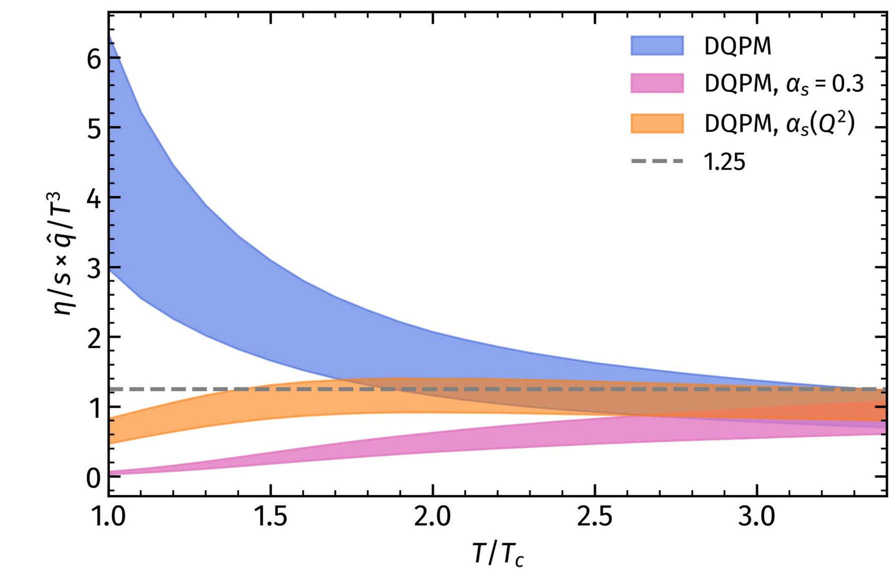
- Employing different strong couplings in thermal, jet, and radiative vertices



Model	Vertex		
	● thermal parton	● jet parton	● emitted gluon
DQPM	$\alpha_s(T)$		
DQPM, α_s = 0.3	α_s = 0.3		
DQPM, $\alpha_s(Q^2)$	$\alpha_s(T)$	$\alpha_s(Q^2)$	$\alpha_s(k_t^2)$



- Strong dependence on the choice of α_s



- Consistency with the weak-coupling limit at high temperatures
- Strong deviation from the weak-coupling limit at low temperatures

OUTLOOK

- Implementation of inelastic 2→3 cross sections into full transport simulation (PHSD)
- Study the full jet evolution within transport simulations
- Implementation of the LMP effect

REFERENCES

[1] W. Cassing, Eur.Phys.J.ST 168 (2009) 3-87
[2] I. Grishmanovskii et al, Phys.Rev.C 109 (2024) 2, 024911
[3] I. Grishmanovskii et al, Phys.Rev.C 106 (2022) 1, 014903
[4] I. Grishmanovskii et al, arXiv:2402.04923

FUNDING

GOETHE UNIVERSITÄT FRANKFURT AM MAIN
CRC-TR 211 Strong-interaction matter under extreme conditions
HFHF Helmholtz Forschungsakademie Hessen für FAIR
GSI