Exploring jet transport coefficients in the strongly interacting quark-gluon plasma

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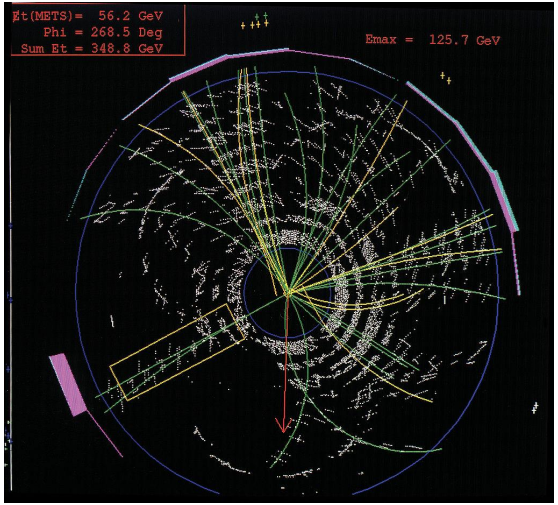
Outline

- Introduction
- Dynamical QuasiParticle Model (DQPM)
- Transport coefficients in kinetic theory
- Results:
    - q-hat coefficient
    - drag coefficient and energy loss
- Summary

Introduction

What is jet?

A jet is a collimated spray of hadrons generated via successive parton branchings, starting with a highly energetic and highly virtual parton (quark or gluon) produced by the collision



Why do we study jets?

- Early formation time
- Modify medium properties
- Modified by the medium

How do we study jets?

- Transport coefficients
- ...

Dynamical QuasiParticle Model (DQPM)

- DQPM – effective model for the description of non-perturbative (strongly interacting) QCD based on lQCD EoS

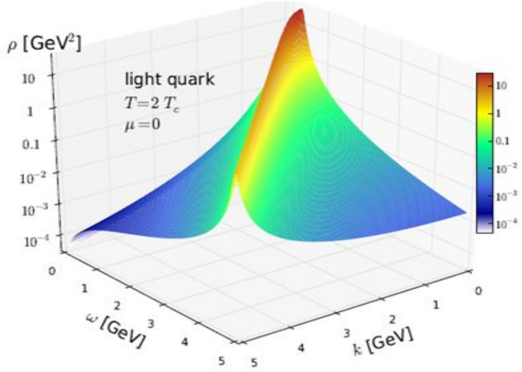
- The QGP phase is described in terms of interacting quasiparticles - massive quarks and gluons - with Lorentzian spectral functions:

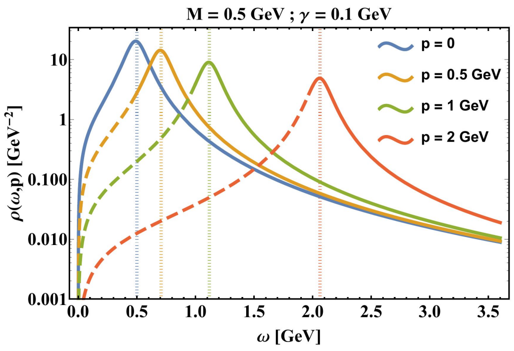
$$\rho_j(\omega, \mathbf{p}) = \frac{4\omega\gamma_j}{\left(\omega^2 - \mathbf{p}^2 - M_j^2\right)^2 + 4\gamma_j^2\omega^2}$$

- Field quanta are described in terms of dressed propagators with complex self-energies:

$$\text{gluon propagator: } \Delta^{-1} = P^2 - \Pi; \qquad \text{quark propagator: } S_q^{-1} = P^2 - \Sigma_q$$
$$\text{gluon self-energy: } \Pi = M_g^2 - 2i\gamma_g\omega; \qquad \text{quark self-energy: } \Sigma_q = M_q^2 - 2i\gamma\omega$$

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

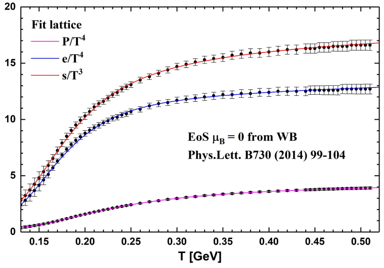




P. Moreau et al., 10.1103/PhysRevC.100.014911

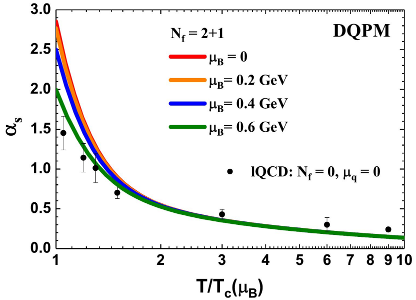
Dynamical QuasiParticle Model (DQPM)

Input: entropy density as a function of temperature for μ_B=0

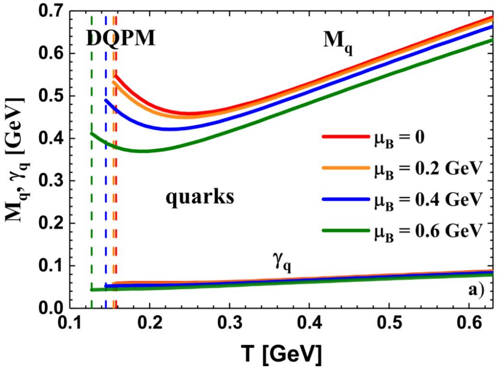


$$g^2(s/s_{SB}) = d((s/s_{SB})^e - 1)^f$$

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



Masses and widths of particles depend on the temperature of the medium and μ_B

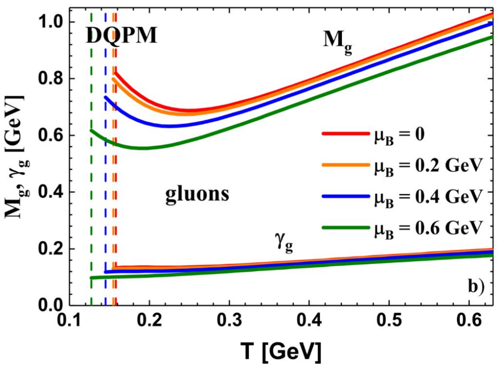


$$M^2_{q(\bar{q})}(T,\mu_q) = \frac{N_c^2-1}{8N_c} g^2(T,\mu_q)\left(T^2 + \frac{\mu_q^2}{\pi^2}\right)$$

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

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

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



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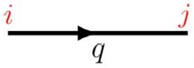
Partonic interactions in DQPM

DQPM partonic cross sections: leading order diagrams

quark propagator:

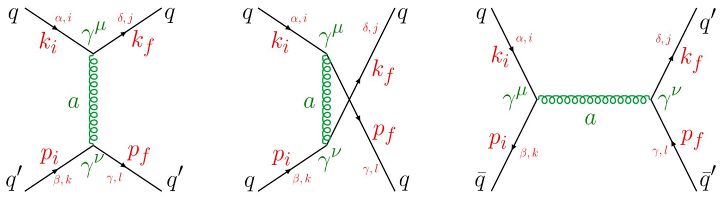


$$= i\delta_{ij}\frac{\not{q} + M_q}{q^2 - M_q^2 + 2i\gamma_q q_0}$$

gluon propagator:

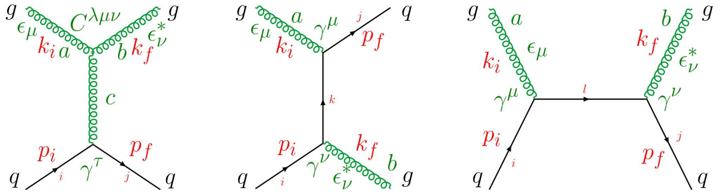
$$= -i\delta_{ab}\frac{g^{\mu\nu} - q^\mu q^\nu / M_g^2}{q^2 - M_g^2 + 2i\gamma_g q_0}$$

qq’ → qq’ scattering



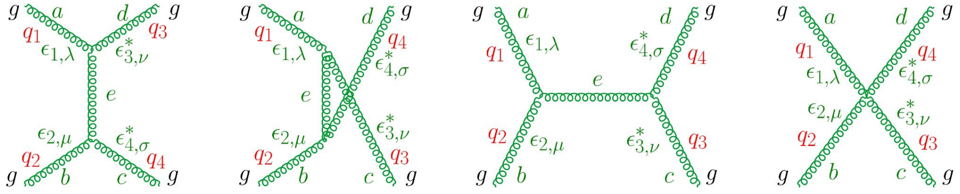
$t-$channel $u-$channel $s-$channel

qg → qg scattering



$t-$channel $u-$channel $s-$channel

gg → gg scattering

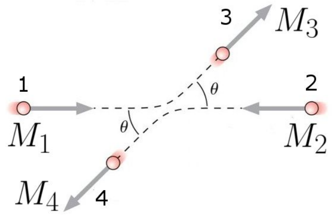


$t-$channel $u-$channel $s-$channel $4-$point

DQPM differential cross sections

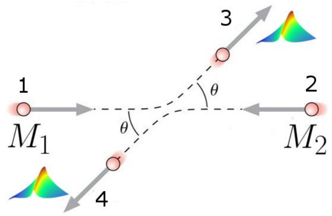
On-shell:

- final masses = pole masses

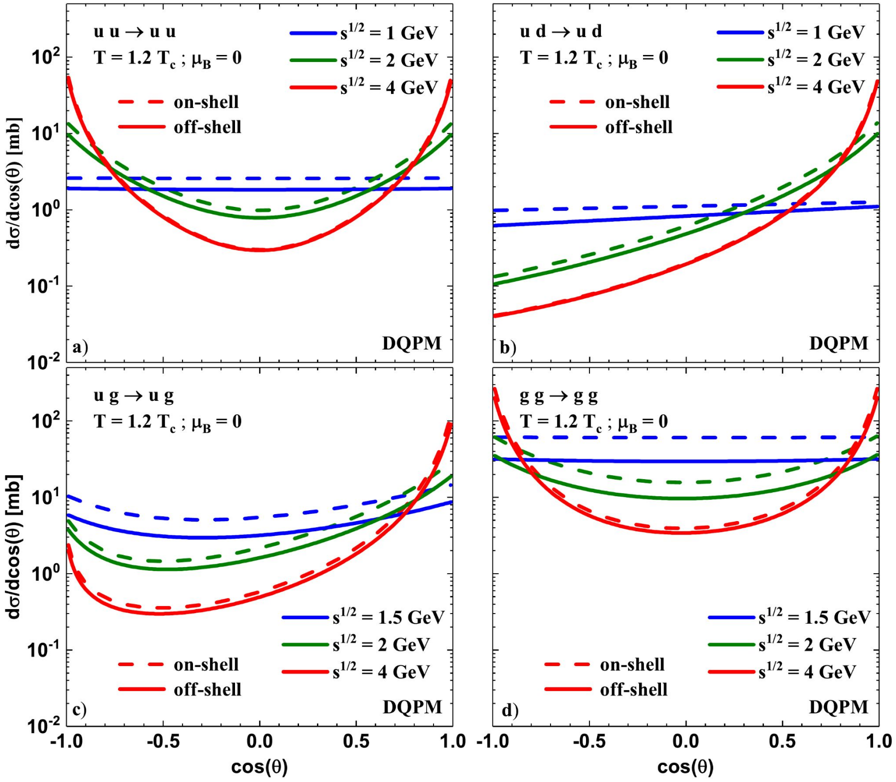


Off-shell:

- integration over final masses

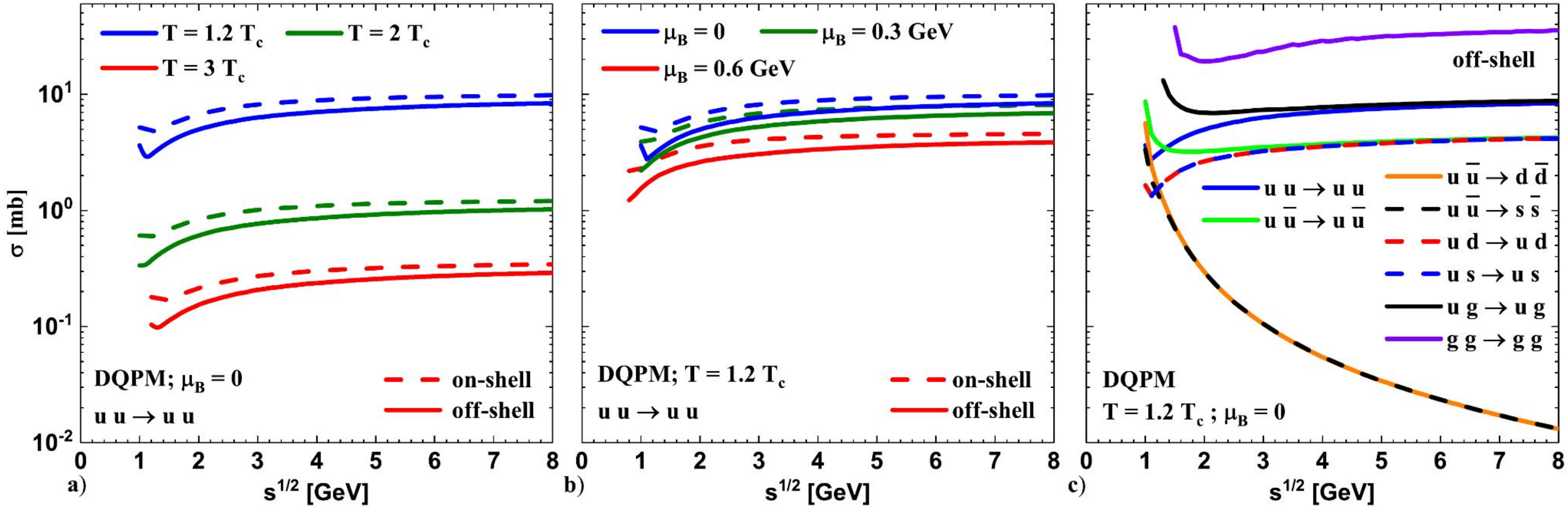


DQPM differential cross sections for different partons evaluated in the center of mass of the collision system



DQPM total cross sections

DQPM total cross sections for different partons evaluated in the center of mass of the collision system

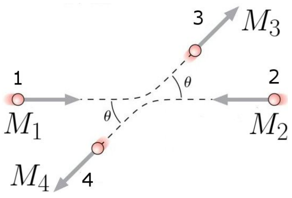


- strong T dependence
- weak μ_B dependence
- strong channel dependence

Transport coefficients in kinetic theory

On-shell

- integration over momentums



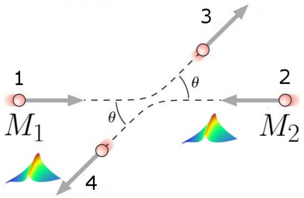
$$E^2 = m^2 + p^2$$

masses = pole masses

$$\langle \mathcal{O} \rangle^{\text{on}} = \frac{1}{2E_i} \sum_{j=q,\bar{q},g} d_j f_j \int \frac{d^3 p_j}{(2\pi)^3 2E_j}$$
$$\times \int \frac{d^3 p_1}{(2\pi)^3 2E_1} \int \frac{d^3 p_2}{(2\pi)^3 2E_2}$$
$$\times (1 \pm f_1)(1 \pm f_2) \mathcal{O} |\overline{\mathcal{M}}|^2 (2\pi)^4 \delta^{(4)}(p_i + p_j - p_1 - p_2)$$

Off-shell

- integration over momentums
- + two additional integrations over medium partons energy



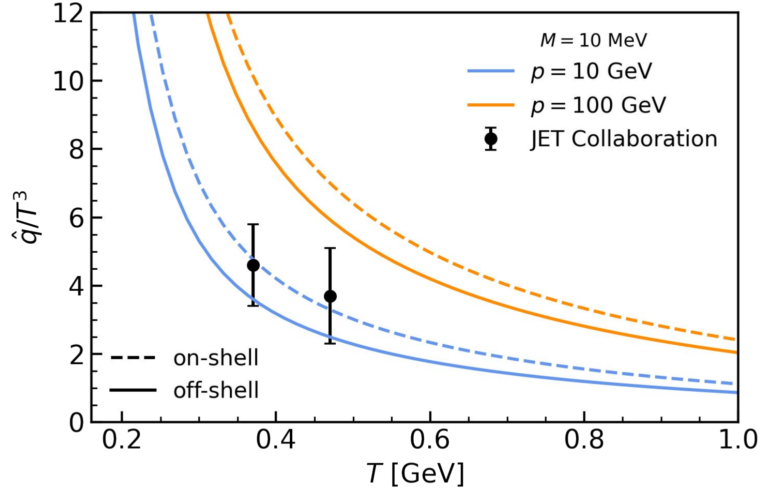
$$\frac{1}{2E} \to \int \frac{d\omega}{(2\pi)} \rho(\omega, \mathbf{p}) \theta(\omega)$$

$$\langle \mathcal{O} \rangle^{\text{off}} = \frac{1}{2E_i} \sum_{j=q,\bar{q},g} d_j f_j \int \frac{d^4 p_j}{(2\pi)^4} \rho(\omega_j, \mathbf{p}_j) \theta(\omega_j)$$
$$\times \int \frac{d^3 p_1}{(2\pi)^3 2E_1} \int \frac{d^4 p_2}{(2\pi)^4} \rho(\omega_2, \mathbf{p}_2) \theta(\omega_2)$$
$$\times (1 \pm f_1)(1 \pm f_2) \mathcal{O} |\overline{\mathcal{M}}|^2 (2\pi)^4 \delta^{(4)}(p_i + p_j - p_1 - p_2)$$

$$\langle \mathcal{O} \rangle = \begin{cases} \mathcal{A}, & \mathcal{O} = (\mathbf{p} - \mathbf{p}') \\ dE/d\tau, & \mathcal{O} = (E - E') \\ \hat{q}\,, & \mathcal{O} = (p_t^2 - p_t'^2) \end{cases}$$

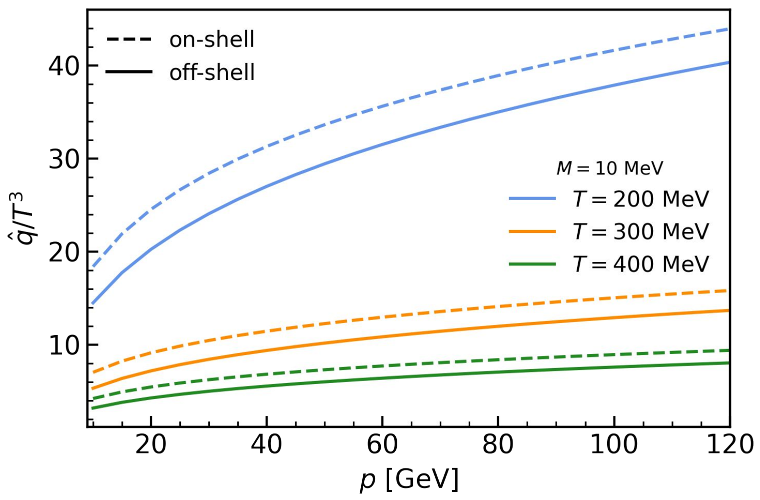
Results: q-hat, on-shell vs off-shell

Temperature dependence of the off-shell and on-shell scaled q-hat coefficient for the quark jet



- $\hat{q}_{\text{off-shell}} < \hat{q}_{\text{on-shell}}$

Momentum dependence of the off-shell and on-shell scaled q-hat coefficient for the quark jet

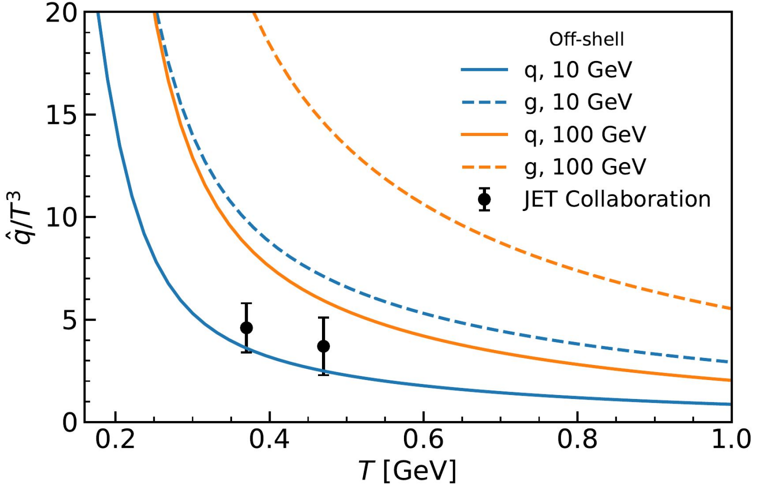


- $\hat{q}(p)/T^3 \sim \log(p)$

K. M. Burke et al. (JET), *Phys. Rev. C 90, 014909 (2014)*

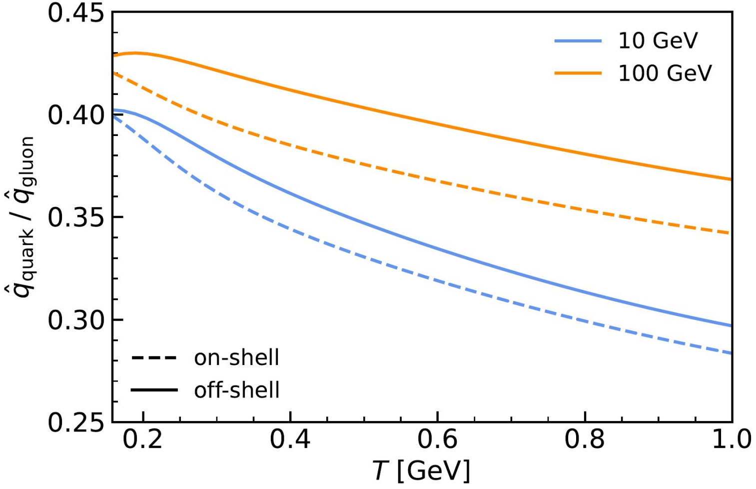
Results: q-hat, flavor dependence

Comparison between temperature dependent off-shell q-hat coefficients for the quark and gluon jets



- $\hat{q}_{\mathrm{quark}} < \hat{q}_{\mathrm{gluon}}$

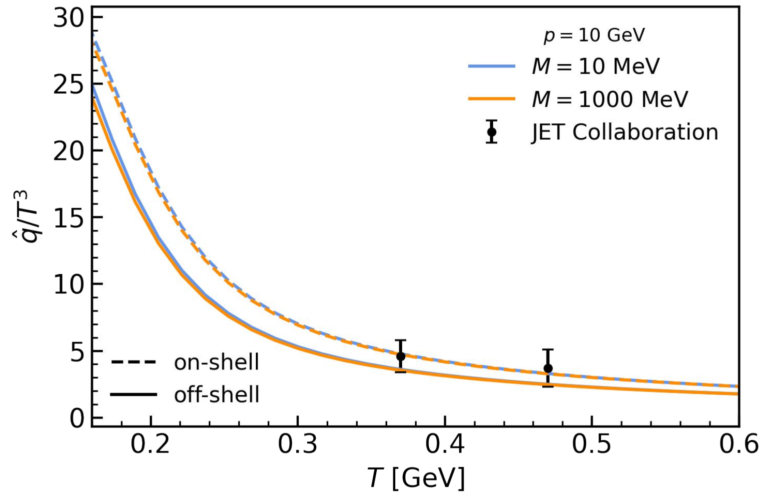
Ratio of q-hat between quark and gluon jets



- $\hat{q}_{\mathrm{quark}}/\hat{q}_{\mathrm{gluon}} \neq \mathrm{const}$

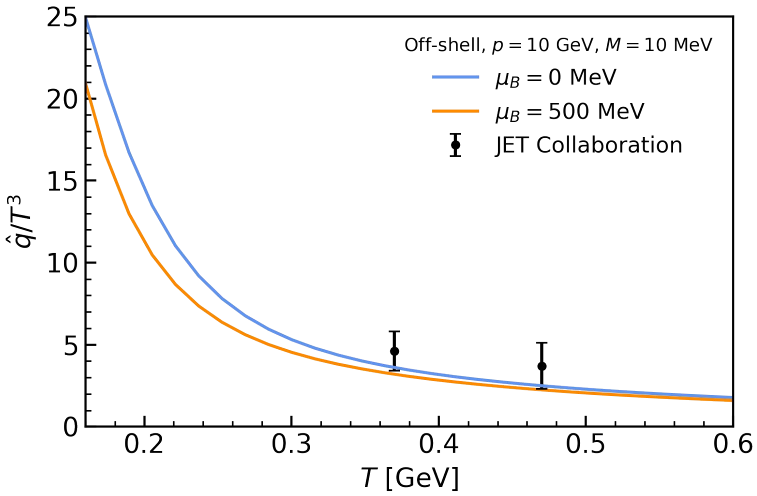
Results: q-hat, mass and chem. pot. dependence

Mass and temperature dependence of the scaled q-hat coefficient for a quark jet



- $p_{\mathrm{jet}} \gg M_{\mathrm{jet}} \rightarrow$ mass dependence is negligible

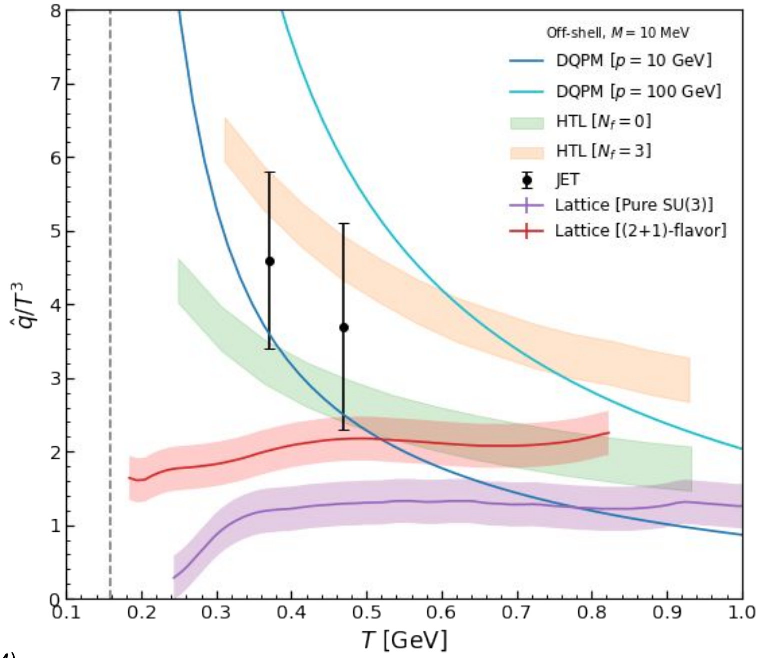
Chemical potential and temperature dependence of the scaled q-hat coefficient for a quark jet



- $\hat{q}_{\mu_B \neq 0} < \hat{q}_{\mu_B = 0}$

Results: q-hat

Comparison of the temperature dependent q-hat coefficients for a quark jet



JET: K. M. Burke et al. (JET), *Phys. Rev. C 90, 014909 (2014)*

lattice QCD: A. Kumar et al., *arxiv:2010.14463*

HTL: Y. He et al., *Phys.Rev.C 91 (2015)*

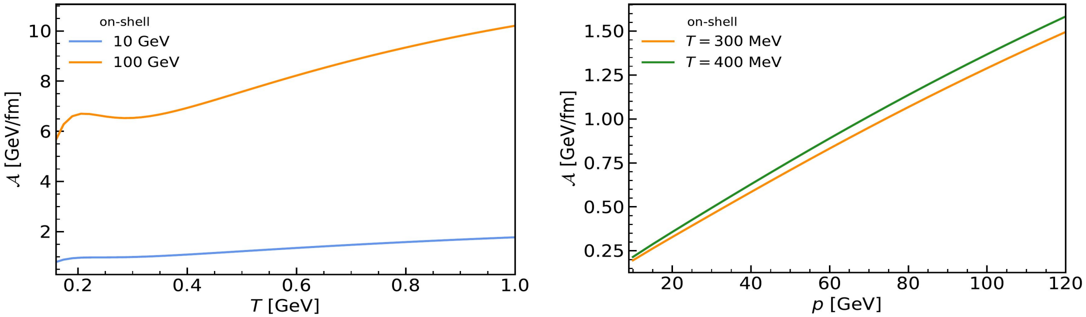
Results: drag coefficient and energy loss

$$\langle \mathcal{O} \rangle = \begin{cases} \mathcal{A}, & \mathcal{O} = (\mathbf{p} - \mathbf{p}') \\ dE/d\tau, & \mathcal{O} = (E - E') \\ \hat{q}, & \mathcal{O} = (p_t^2 - p_t'^2) \end{cases}$$

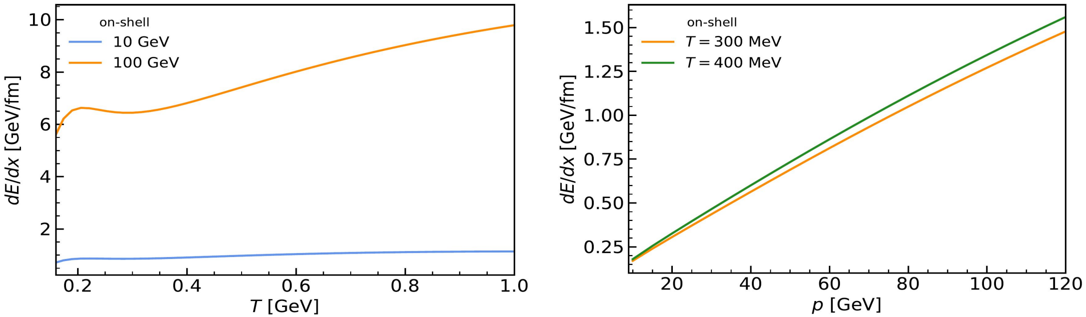
$$E = \sqrt{|p|^2 + m^2} \approx |p|$$

$$\Rightarrow \boxed{\mathcal{A} \approx dE/d\tau}$$

Temperature and momentum dependencies of the drag coefficient for a quark jet



Temperature and momentum dependencies of the energy loss for a quark jet



Summary and outlook

Summary:

- We have performed the evaluation of jet transport coefficients using Dynamical QuasiParticle Model
- q-hat coefficient is calculated as a function of
  - temperature
  - momentum of the jet
  - jet flavor
  - mass of the jet
  - chemical potential
- drag coefficient and energy loss are calculated as a function of
  - temperature
  - momentum of the jet

Future prospects:

- Investigate radiative processes

Thank you for your attention!