Electromagnetic emission from strongly interacting hadronic and partonic matter created in heavy-ion collisions

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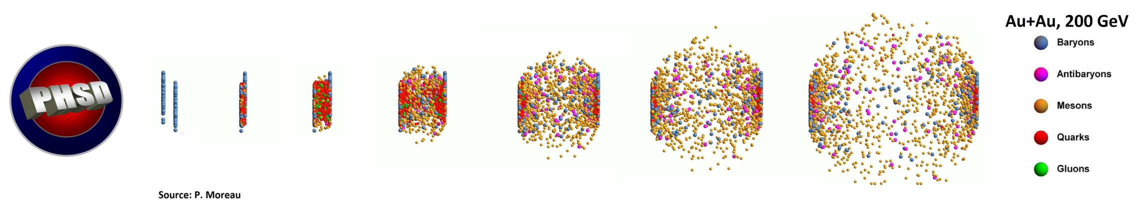
1. Motivation

Dileptons serve as key probes that provide crucial insights into both the partonic and hadronic stages of heavy-ion collisions, enabling the study of in-medium effects—such as the collisional broadening of vector meson spectral functions—and the investigation of various QGP phases, thereby deepening our understanding of strongly interacting matter.

2. PHSD Transport Approach

Parton-Hadron-String Dynamics (PHSD) is a non-equilibrium microscopic transport approach that describes the full evolution of heavy-ion collisions—from initial nucleon-nucleon interactions, through QGP formation (described in terms of the DQPM model) and interactions, to hadronization and final-state interactions—using generalized off-shell transport equations based on the Kadanoff-Baym theory [1].



3. DQPM (T, μ_B)

Dynamical QuasiParticle Model (DQPM) is an effective model for the description of non-perturbative (strongly interacting) QCD based on the lQCD EoS [2].

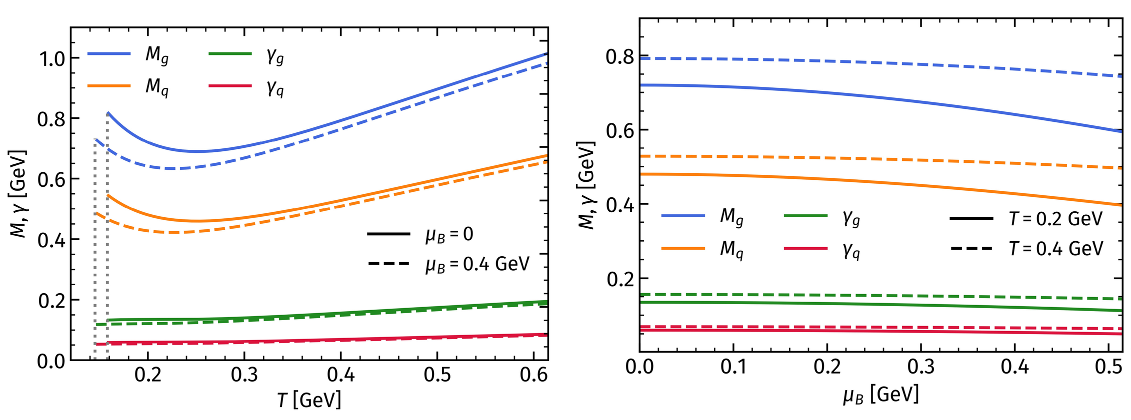
- Quasiparticles are described in terms of dressed quark (gluon) propagators (2PI) with complex self-energies.

gluon propagator:	$\Lambda^{-1} = \boldsymbol{P}^2 - \Pi$
quark propagator:	$S_q^{-1} = \boldsymbol{P}^2 - \Sigma_q$
gluon self-energy:	$\Pi = M_g{}^2 - i2\gamma_g\omega$
quark self-energy:	$\Sigma_q = M_q{}^2 - i2\gamma_q\omega$

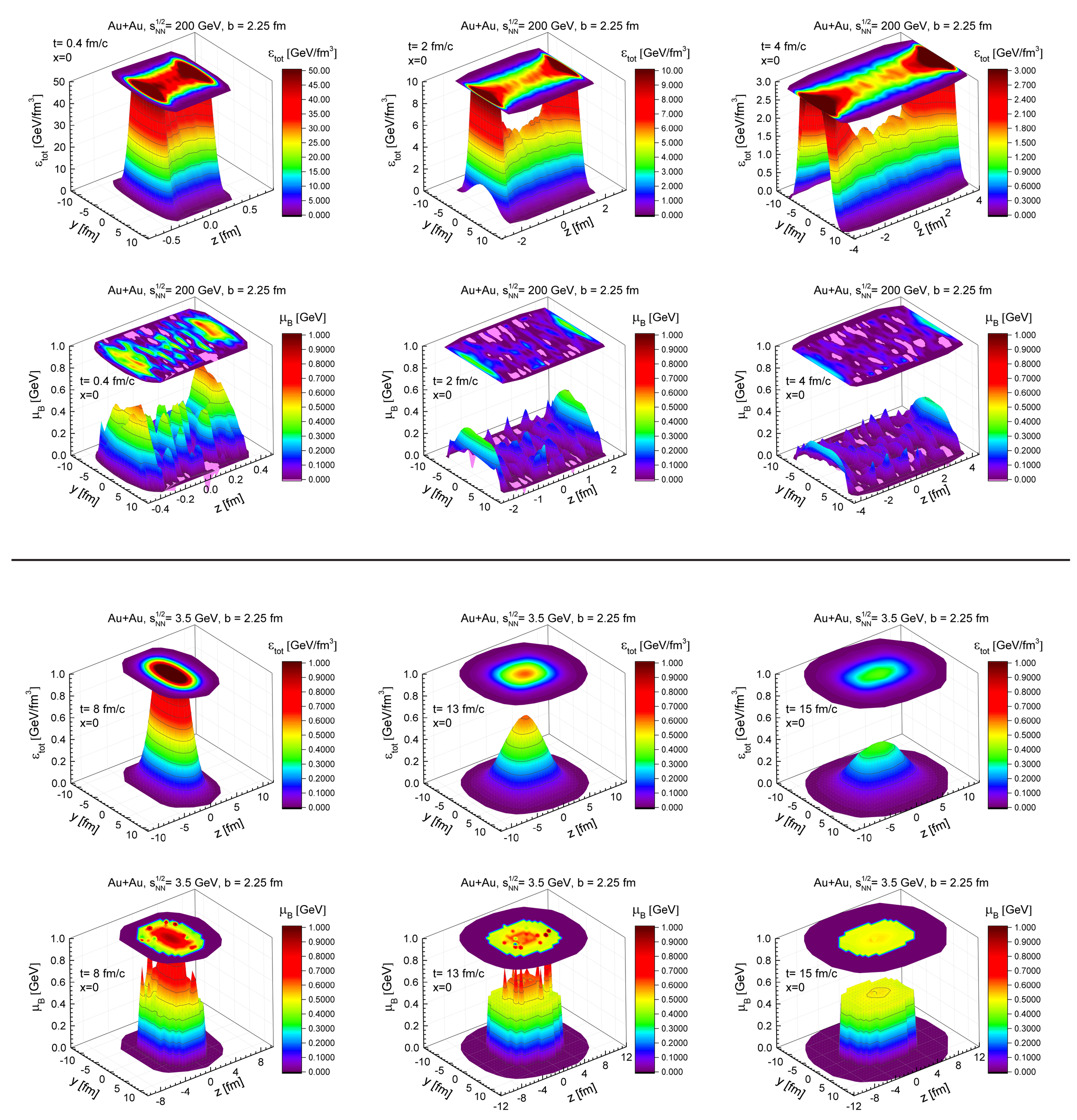
$$\begin{cases} \text{Re: } \Sigma_q : \text{thermal masses } (M_g, M_q) \\ \text{Im } \Sigma_q : \text{interaction widths } (\gamma_g, \gamma_q) \end{cases}$$

- Spectral functions with Lorentzian form,

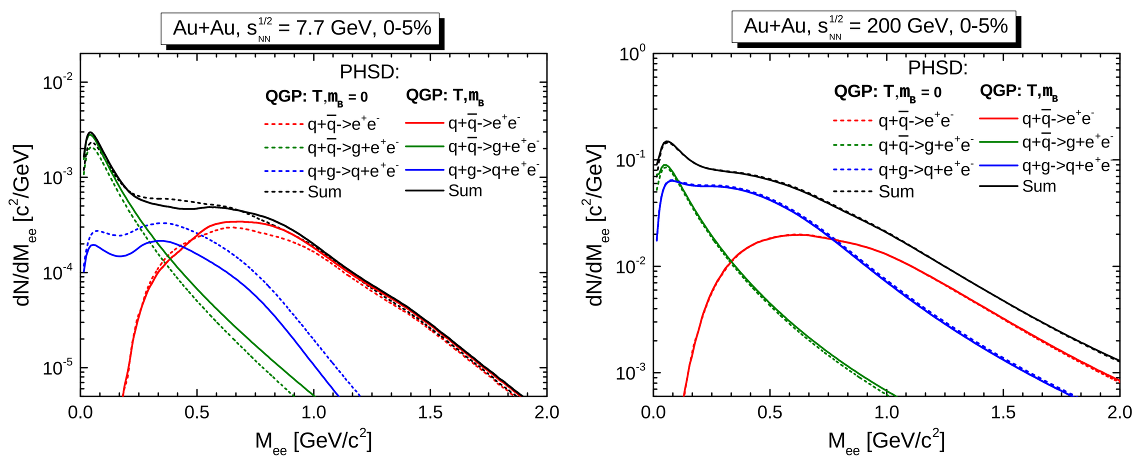
$$\rho_j(\omega, \mathbf{p}) = \frac{4\omega\,\gamma_j}{\left(\omega^2 - \mathbf{p}^2 - M_j^2\right)^2 + 4\gamma_j^2\,\omega^2}.$$



4. Time evolution of the fireball: ε_{tot} and μ_B

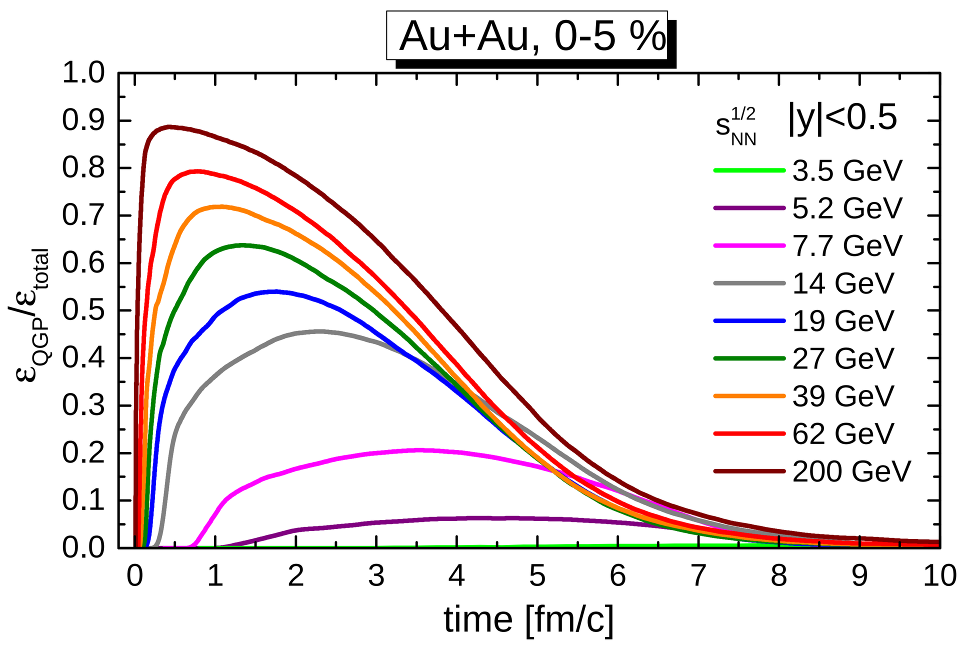


5. (T, μ_B)-dependent EoS on QGP dileptons



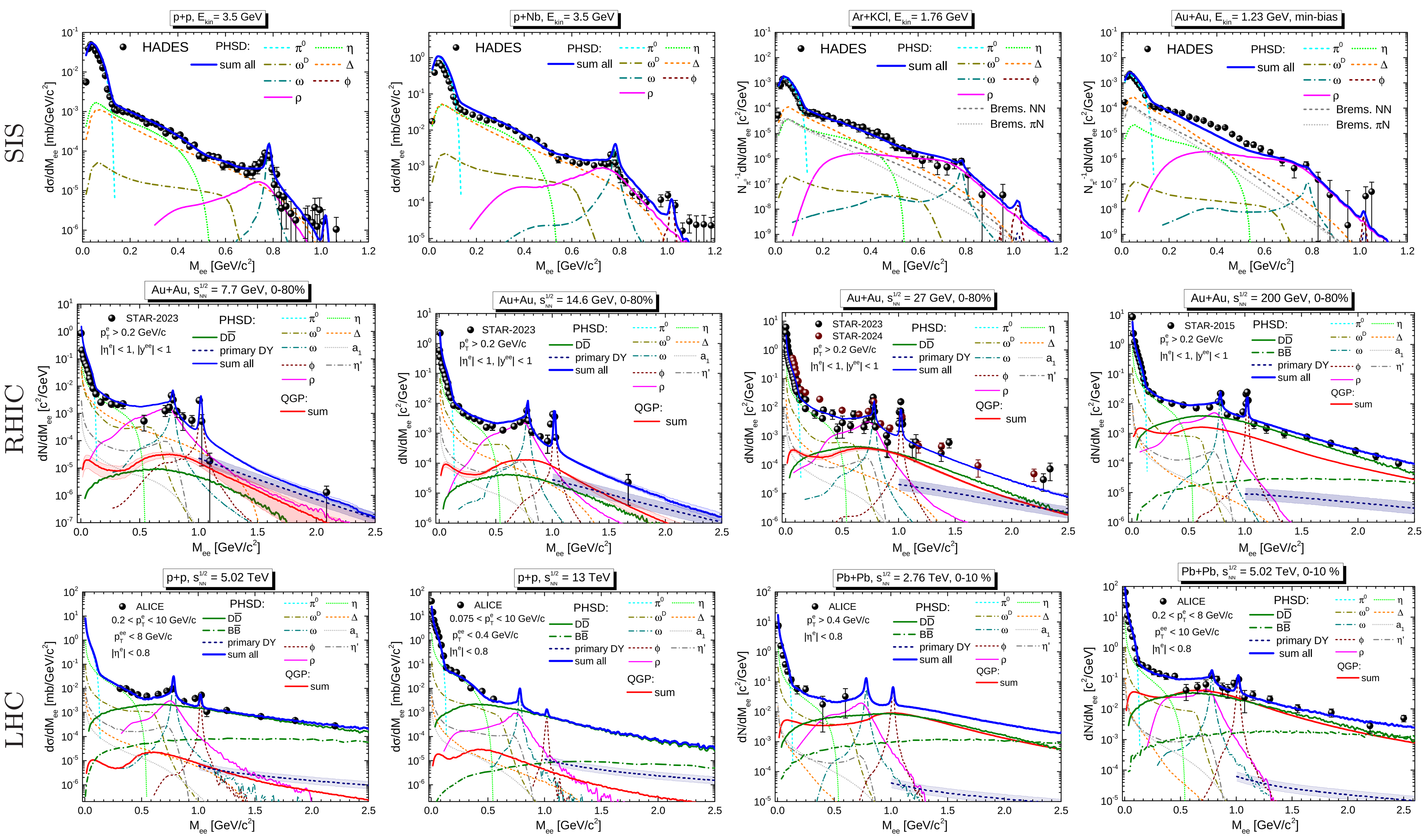
- Incorporating μ_B dependence into the QGP EoS leads to a weak impact on the total yield [3].

6. The fraction of energy in the QGP phase



- QGP dominates at high energy Au+Au collisions.
- QGP fraction decreases with decreasing collision energy.

7. Invariant Mass Spectra of Dielectrons in PHSD: From SIS to LHC Energies



Dileptons (e^+e^- and $\mu^+\mu^-$ pairs) are produced during the whole time evolution in heavy-ion collisions via:

Hadronic sources:

- Dalitz decays of $\pi^0, \eta, \Delta, a_1, \omega, \eta'$.
- Vector-meson decays $\rho, \omega, \phi \rightarrow e^+e^-$ (with in-medium broadening spectral functions) .
- $NN \rightarrow NN\,e^+e^-$ and $\pi N \rightarrow \pi N\,e^+e^-$ bremsstrahlung (low energies).
- Correlated charm/bottom meson decays ($D\bar{D}$, $B\bar{B}$).

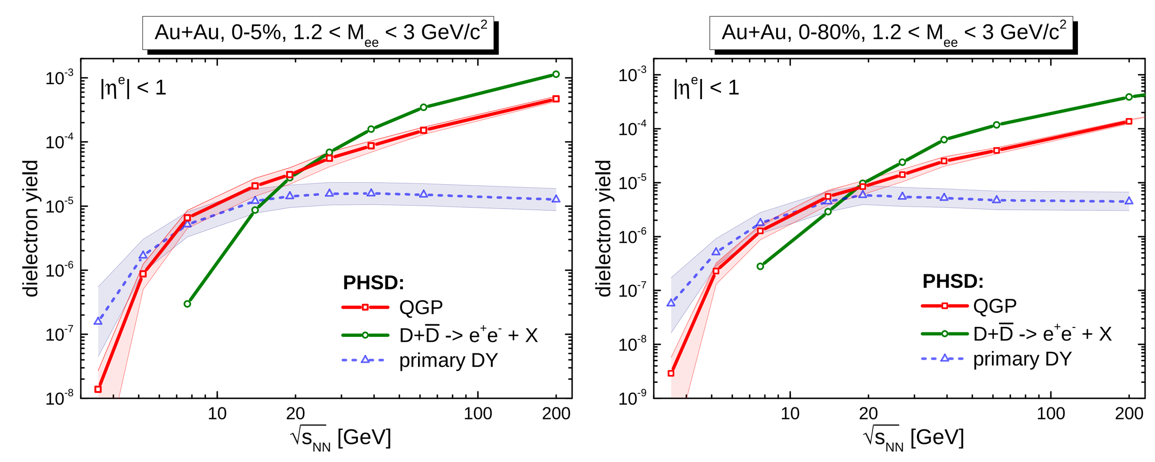
Partonic sources (QGP):

- $q\bar{q} \rightarrow e^+e^-$, $q\bar{q} \rightarrow g\,e^+e^-$, $q\,g \rightarrow q\,e^+e^-$, $\bar{q}\,g \rightarrow \bar{q}\,e^+e^-$.
- Off-shell cross sections from DQPM, including (T, μ_B) dependence.

Primary Drell-Yan (DY):

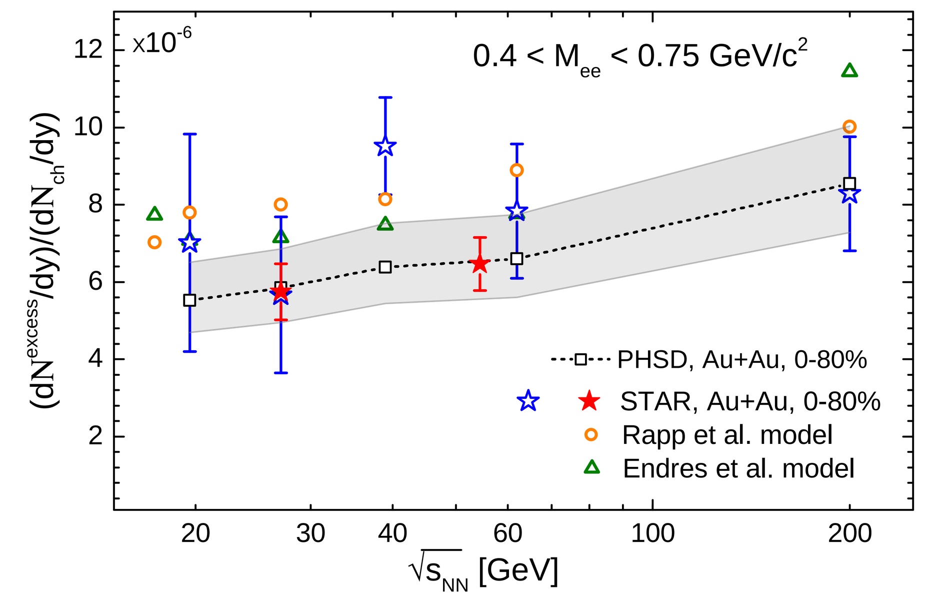
- $q\bar{q} \rightarrow e^+e^-$ in initial hard scatterings.

8. Excitation Function of Dielectron Yields



- Dileptons from QGP overshine dileptons from correlated charm for $\sqrt{s_{NN}} \simeq 30$ GeV (in line with Ref. [4]).
- Subtracting the Drell–Yan contribution would allow to access the thermal QGP dileptons at $\sqrt{s_{NN}} \simeq 20$ GeV.

9. Dilepton Excess Yields



- The low-mass dilepton excess yield increases with collision energy. STAR data from [5, 6].
- The dilepton excess yield includes the ρ-meson contribution, QGP, Dalitz decays of Δ-resonances and a_1 mesons.

10. Conclusions

- **Low energies (SIS):** Bremsstrahlung, Dalitz, and in-medium vector meson decays dominate, while QGP "hot spots" appear even at $\sqrt{s_{NN}} \sim 3.5$ GeV, potentially observable once Drell–Yan contribution is subtracted.
- **High energies (RHIC, LHC):** Partonic processes (QGP) and heavy flavors govern the intermediate-mass region.
- Small influence of μ_B dependence of QGP EoS on dilepton mass spectra is found.
- QGP radiation overshines charm contributions at $\sqrt{s_{NN}} \simeq 25 - 30$ GeV in central Au+Au collisions, providing access to thermal QGP dileptons at BES RHIC and FAIR.

KEY REFERENCES

[1] Cassing et al. (2008), PRC 78, 034919.
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[3] Romero Jorge et al. (2025), arXiv:2503.05253.
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[6] STAR Coll. (2024), arXiv: 2402.01998.

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