Thermal Photon Emission with PCE Equation of State

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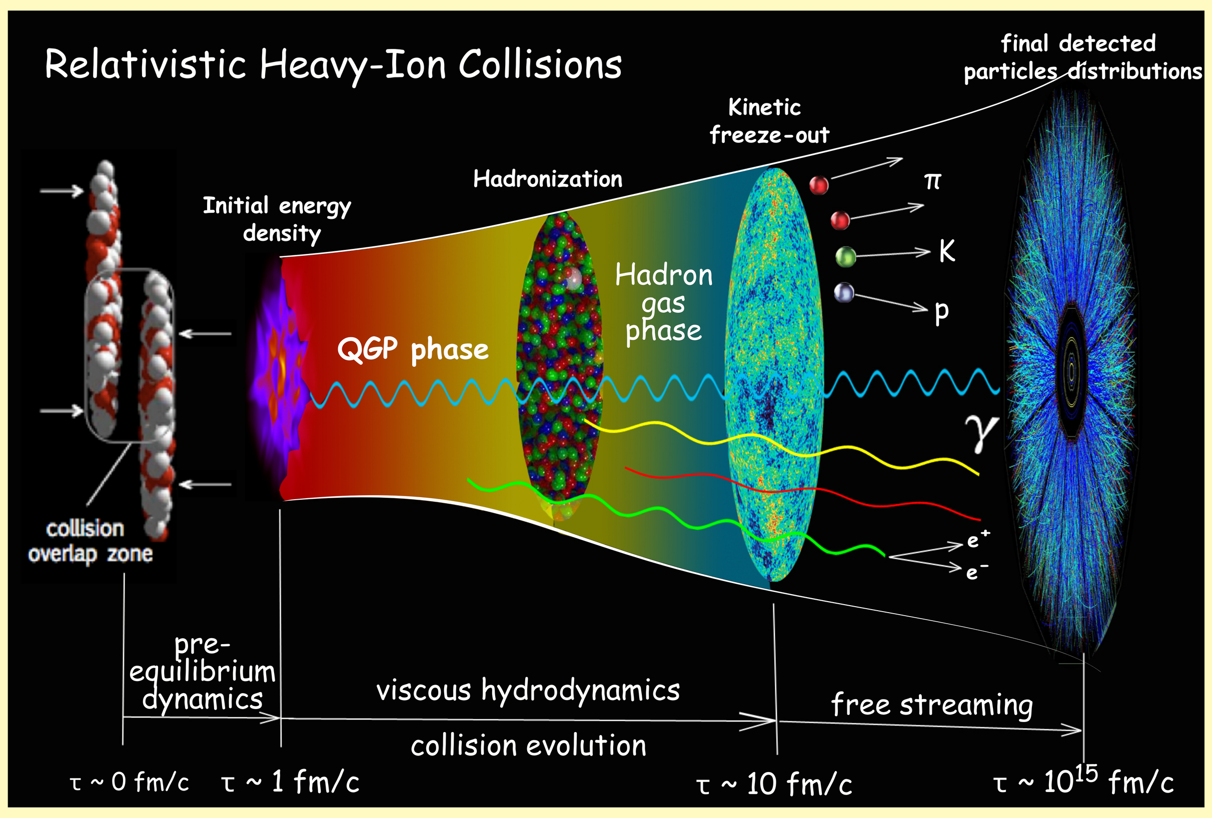
Abstract

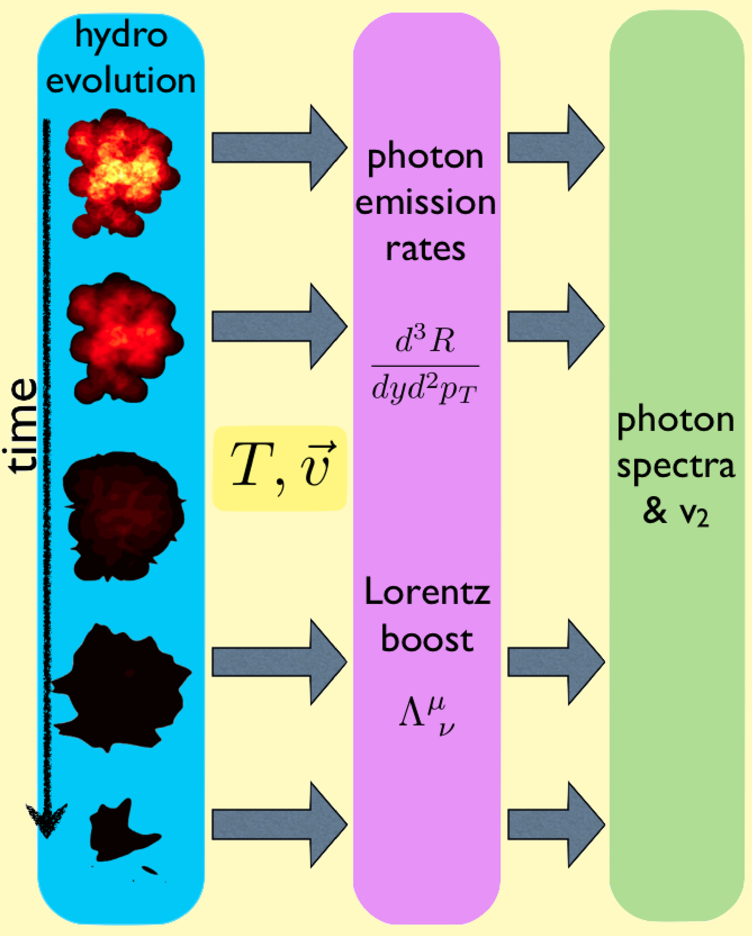
Photons are clean and penetrating probes of the medium created in ultra-relativistic heavy-ion collisions. To improve the hydrodynamic description of photon emission from the late hadronic stage, partial chemical equilibrium (PCE) is implemented in a realistic equation of state. Since the non-zero chemical potentials will enhance hadronic thermal photon production rates by their corresponding non-equilibrium fugacity factor $\sim e^{\mu/T}$, this might improve the agreement between theory and experimental measurements. We find, however, that it also shortens the lifetime of the hadronic phase. Using a realistically evolving hydrodynamic medium, we study PCE effects on the yields and the azimuthal anisotropies of produced thermal photons in heavy-ion collisions at RHIC energies. We observe a competition between the chemical potential enhancement in the thermal photon emission rates and faster cooling of the medium. We compare our calculations with PHENIX measurements at RHIC.

Introduction



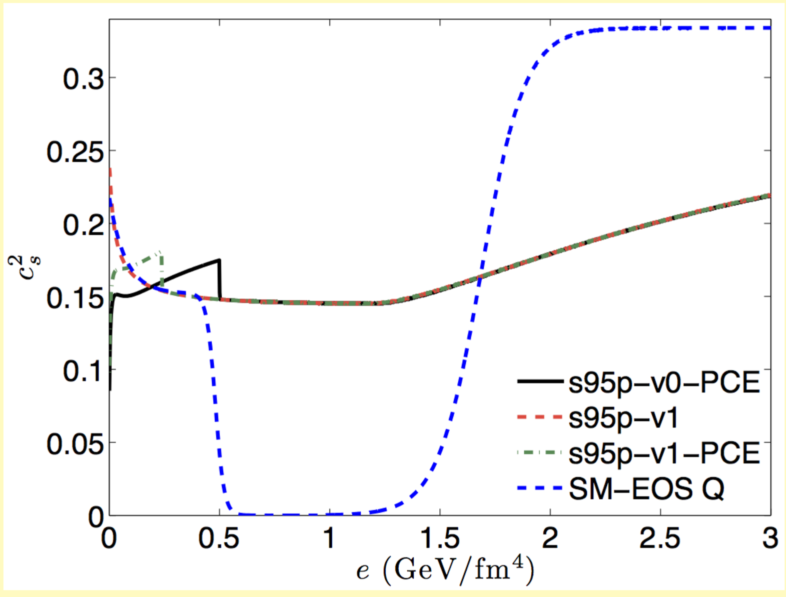
Thermal photons serve as messengers from all stages of the evolving medium created in ultra-relativistic heavy-ion collisions. The thermal photon spectra and their anisotropy are known to be very sensitive to the thermalization time, the specific shear viscosity, the equation of state of the produced matter, and initial state fluctuations.

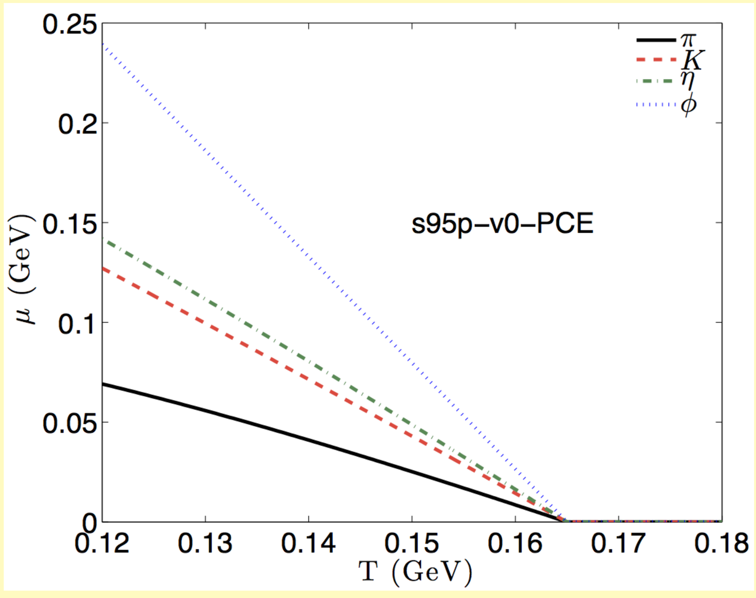
A numerical interface is developed to read in temperature and flow information from hydrodynamic evolution and fold them with photon emission rates to compute the emitted thermal photon spectra and their anisotropy.



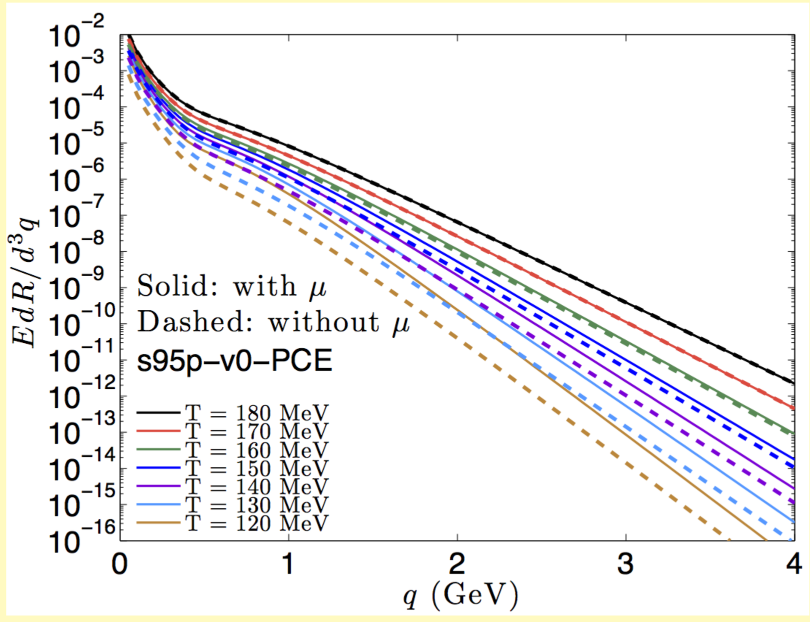
Ingredients

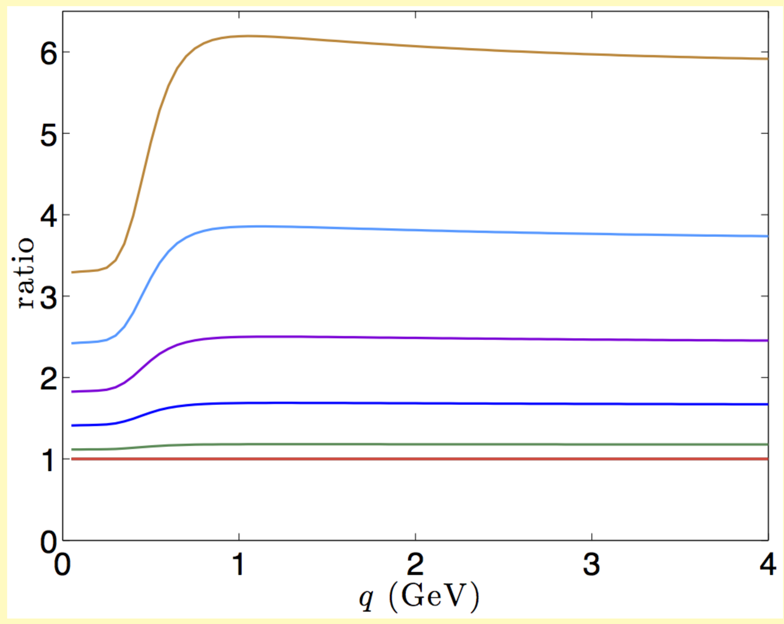
The lattice QCD based EOS has a large speed of sound in the transition region, but is softer at higher energy densities compared to an ideal massless gas. s95p-v0-PCE implements partial chemical equilibrium below $T_{\rm chem} = 165\,{\rm MeV}$[1]. Below $T_{\rm chem}$, the chemical potentials for stable mesons increase almost linearly as temperature decreases, with slopes that increase with hadron mass.



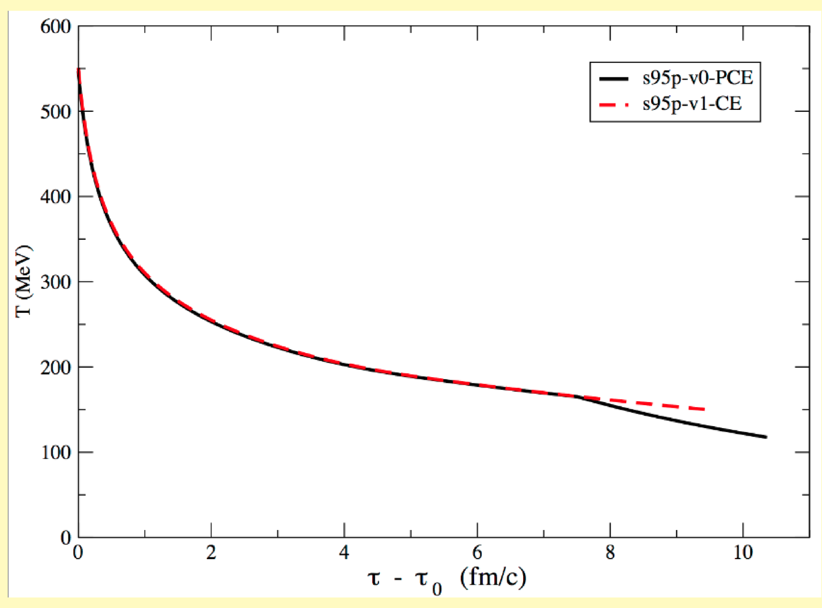


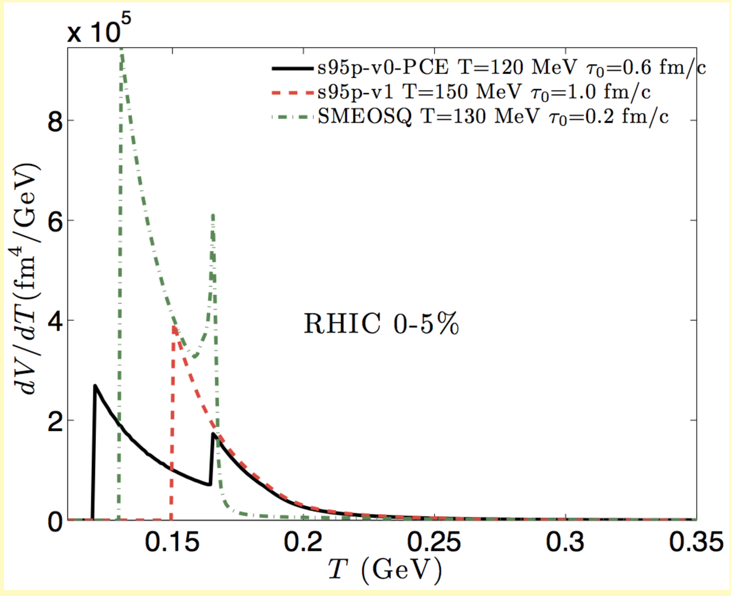
Hadronic thermal photon emission rates are enhanced by their corresponding non-equilibrium fugacity factors $\sim e^{\mu/T}$. At the kinetic freeze-out temperature, $T_{\rm dec} = 120\,{\rm MeV}$, the enhancement reaches $\sim$600%. The momentum dependence of the enhancement factor comes from the fact that $\pi + \pi \to \rho + \gamma$ dominates the low q region, while $\rho + \pi \to \pi + \gamma$ dominates at high momenta.





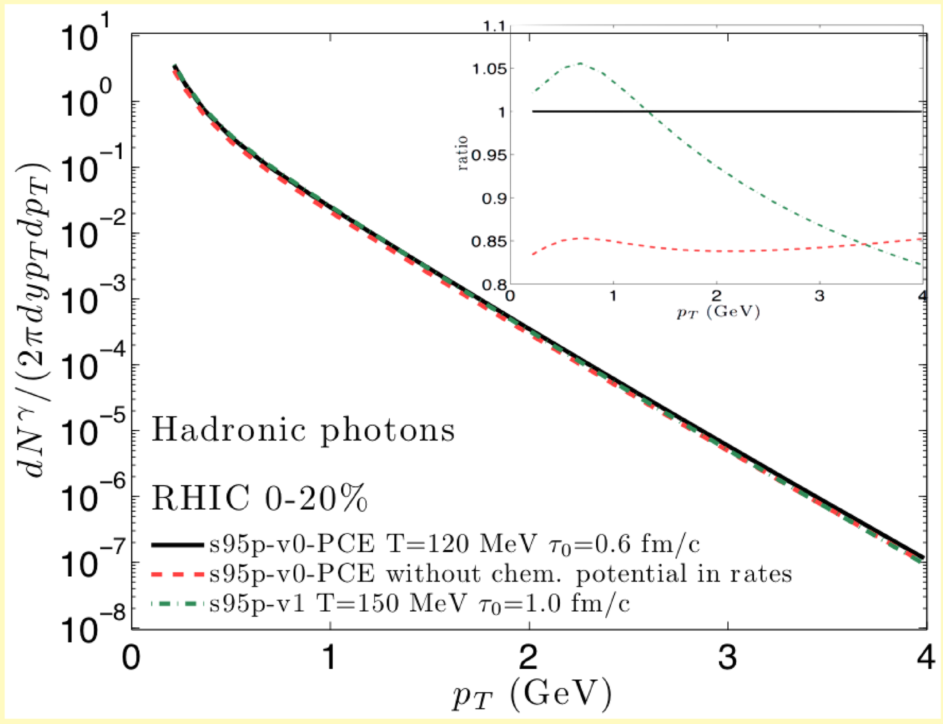
The breaking of chemical equilibrium below the quark-hadron phase transition also changes the relation between temperature and energy density, which results in faster cooling during the hadronic phase. This reduces the space-time volume for photon emission from the hadronic phase.

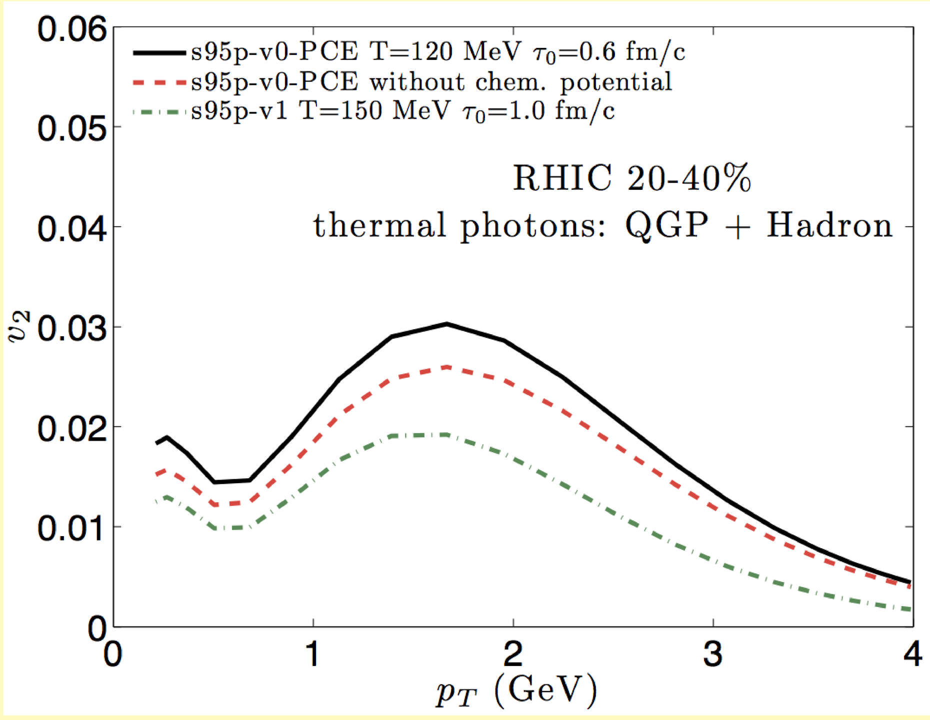




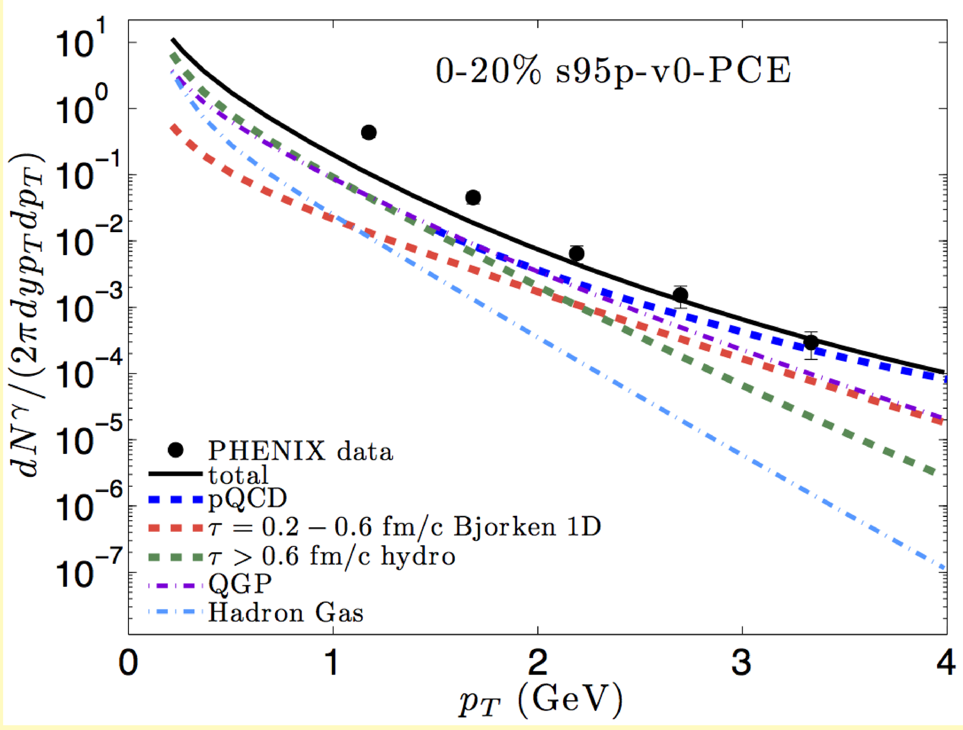
Results and Conclusions

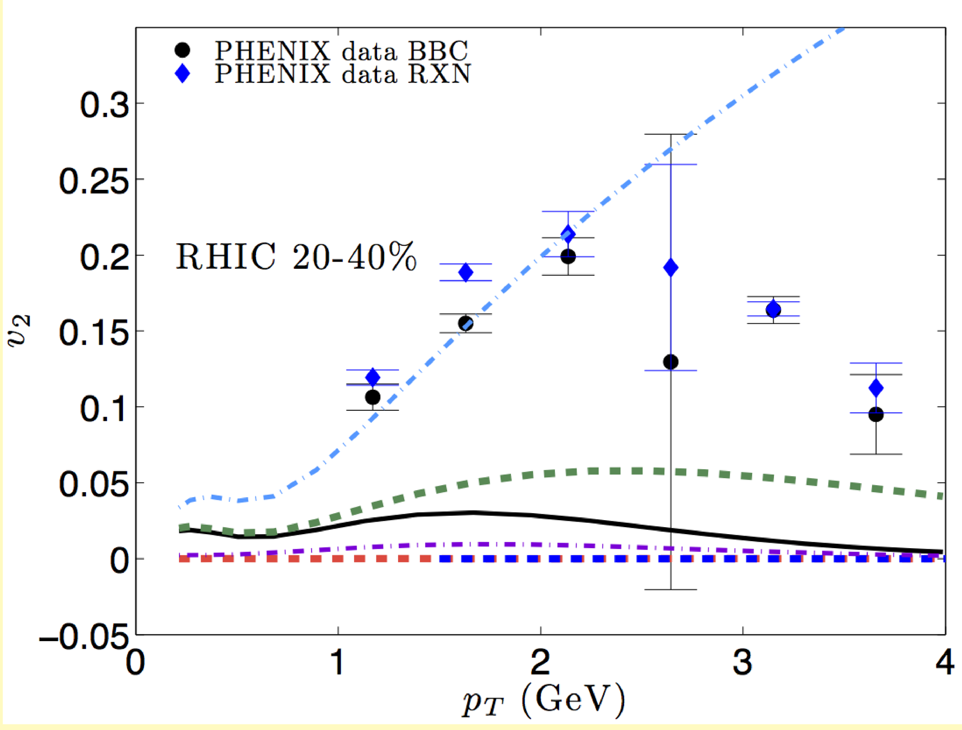
The non-vanishing chemical potentials increase the hadronic photon yield by $\sim$15%. s95p-v0-PCE results in flatter photon spectra compared to s95p-v1, due to stronger radial flow developed in the hadronic phase. The total yields from these two EOS are similar. The total thermal photon $v_2(p_T)$ is increased $\sim$15% by the chemical potentials in the photon emission rates. s95p-v0-PCE results in larger $v_2(p_T)$ due to earlier starting time for hydrodynamic evolution, which is tuned to fit hadron observables.





Photon spectra and $v_2(p_T)$ from different evolution stages are shown. With chemical potentials in the hadronic phase, theory still underestimated the photon spectra [2] for $p_T < 2.5\,{\rm GeV}$.
Although hadronic photon $v_2(p_T)$ are close to the experimental measured values [3] for $p_T < 2\,{\rm GeV}$, the total photon $v_2(p_T)$ remains small due to the large fraction of thermal photons coming from the QGP phase, where the anisotropic flow is still small.





References

[1] P. Huovinen and P. Petreczky, *QCD Equation of State and Hadron Resonance Gas*, *Nucl. Phys. A* **837**, 26 (2010)

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[3] A. Adare *et al.* (PHENIX Collaboration), *Observation of direct-photon collective flow in $\sqrt{s_{\rm NN}} = 200\,{\rm GeV}$ Au+Au collisions*, arXiv:1105.4126 [nucl-ex].

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