Photon radiation from thermally anisotropic nuclear matter produced from Fermi-energy

T.J. Onyango and R. Rapp

I am a fifth-year graduate student. I started at Texas A&M University and the cyclotron in August 2018. I did my preliminary exam in January 2023 and am anticipating defending in October 2023. I work with Dr. Rapp to study nuclear collisions at Fermi energies. The goal of my project is to create a systematic method to correlate temperature and collective-flow extractions with photon production in these collisions. This will be done by first devising a method to accurately extract the time evolution of temperature and chemical potential from a collision in order to properly identify if and when the fireball has thermalized. This thermalization time is important because it signifies the transition between primordial photon production and thermal photon production. Primordial photons are produced from the initial contact between the nuclei. Once the nuclei start to overlap and form a fireball, then thermal photons, which are related to the fireball's temperature distribution in space, are expected to be produced. The impact of this work will be the quantification of the contributions of the different photon production mechanisms present during nuclear collisions at Fermi energy as well as the opportunity to give experimental colleagues an effective tool to interpret data from nuclear collisions. I have been analyzing central collisions of ^{40}Ca nuclei at 35A•MeV lab energy, but this process should be applicable to other collision energies and nuclei of any size.

Since beginning this project, I have learned and modified the Constrained Molecular Dynamics (CoMD) simulation code [1] created by Dr. Bonasera in order to extract the positions and momenta of the individual nucleons involved in the collision. The transport code creates a nucleus by calculating the positions and momenta of nucleons based on prescribed input parameters for the intranuclear interactions. The transport code also collides the nuclei in the center-of-mass reference frame based on a range of specified impact parameters. The transport code then yields the positions and momenta of the center of the gaussian wave packets of the nucleons.

Using the positions and momenta produced by the transport code, I produce density evolutions and localized momentum distributions. From the momentum distributions, I create fit functions using Fermi-Dirac statistics based on the momentum distributions in order to extract time evolutions of chemical potential and temperature. The extracted density is compared to the raw transport density obtained from the transport data of positions and momenta as a constraint when calculating the thermodynamic properties. The momentum distributions along the beam axis require fit functions with more parameters to account for the residual motion of the two independent nuclei entering the cells at different times. The chemical potentials and temperatures extracted from the transverse direction are imported into the longitudinal fit functions. Evolutions of centroidal motion and thermal anisotropy along the longitudinal are produced.

We then calculate the photon production rate from nucleon-nucleon bremsstrahlung [2]. We have replicated a photon emissivity from established literature [3] to establish consistency with the literature. Our current estimates are based on the dipole contribution and therefore assume that every collision is between a proton and a neutron. We find that the photon rate for thermalized nuclear matter is more sensitive to temperature as compared to density. We then started to investigate the roles off-equilibrium

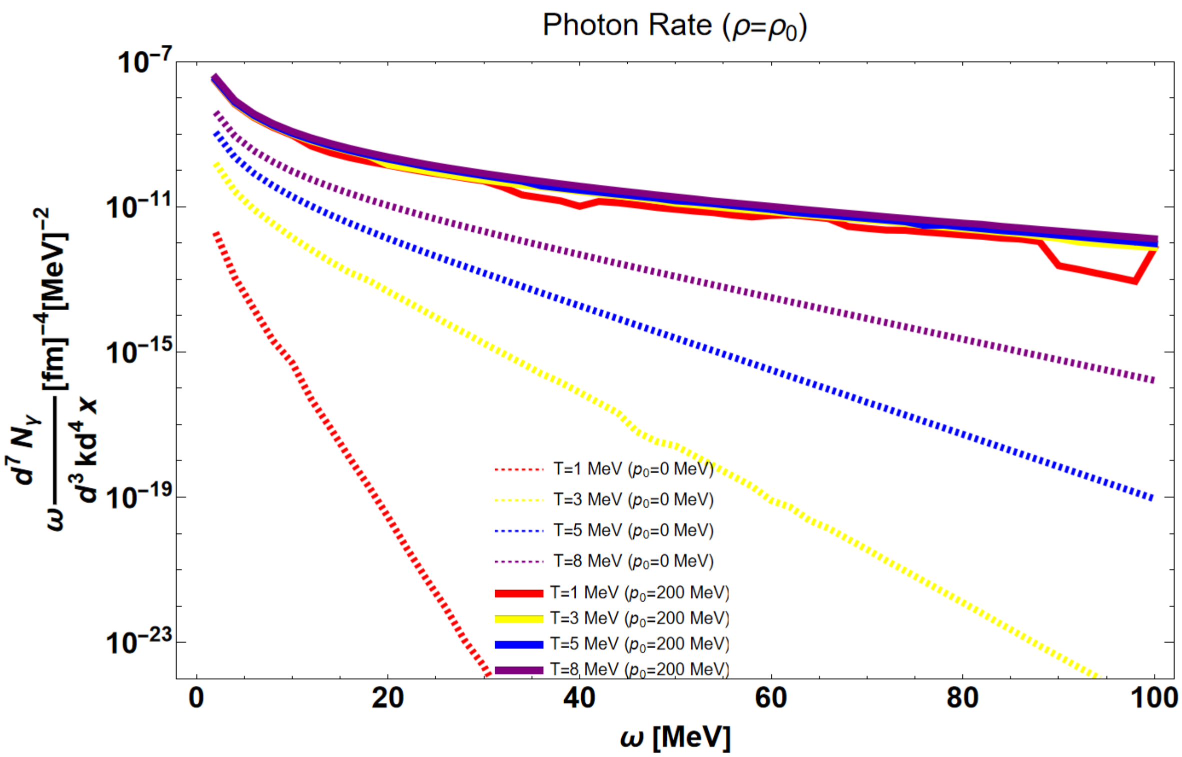

Fig. 1.

effects play in the shape of the photon rate. We incorporate the initial collective nuclear motion by including the centroid momenta in the nucleon distribution functions in the photon rate. We observe a significant increase in the overall yield. We also observe that the photon rate depends more strongly on the centroid momenta than on the temperature. The sensitivity of the photon rate to temperature is very weak in the presence of large centroid momenta.

From the photon rate we have calculated photon energy spectra with and without centroid motion and compared them to what has been experimentally produced. We see a significant increase in the production of high energy ($E_\gamma > 30$ MeV) photons when accounting for the energy of the initial longitudinal motion.

The plan for the near future is to finish implementing the off-equilibrium parameters, specifically the thermal anisotropy parameter. After that we will comment on the significance of isospin dependence by comparing the dipole and quadrupole contributions to the photon rate. Then we will implement realistic characteristics (such as angular cuts representative of the placement of experimental detectors) so that our calculations more accurately reflect experimental conditions.

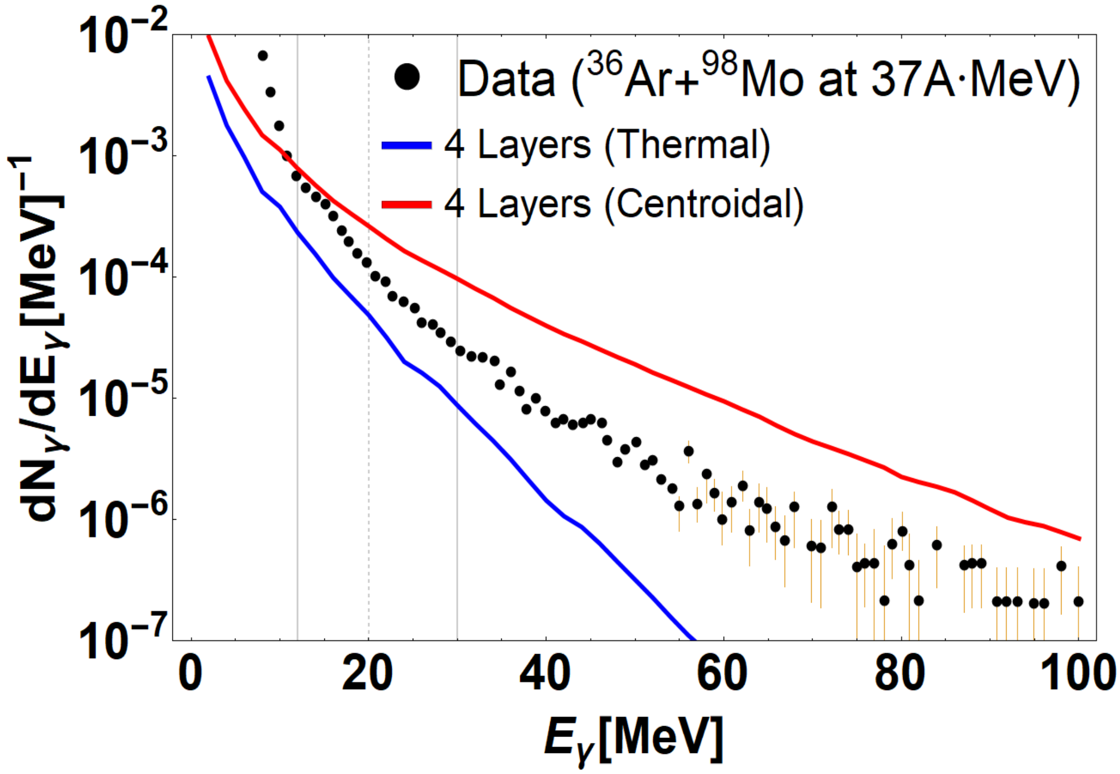

Fig. 2.

[1] H. Zheng, G. Bonasera, J. Mabiala, P. Marini, and A. Bonasera, Eur. Phys. J. A **50,** 167 (2014).

[2] J. H. Chang, R. Essig, and S. McDermott, JHEP **01,** 107 (2017).

[3] E. Rrapaj, S. Reddy, Phys. Rev. C **94**, 4 (2016).