Nucleon-nucleon Bremsstrahlung in heavy-ion collisions at Fermi energies

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In this work we continue our investigation of nuclear matter formed in heavy-ion collisions (HICs) at low beam energies, specifically E_{lab} = 35 MeV/A. In our previous work we employed a coarse-graining procedure to extract the time evolution of the thermodynamic properties of $^{40}Ca + ^{40}Ca$ collisions in local cells of $(2fm)^3$ [1]. In particular, we found that while the transverse-momentum spectra are amenable to a description with thermal Fermi distribution functions, the energy related to the initial centroid motion of the incoming nuclei (z-direction) undergoes a gradual dissipation on a timescale of about 100 fm/c. In the present work we employ these results to convolute thermal photon rates over the space-time evolution and compare the pertinent spectra to experiment.

Under the present conditions, the local emission of photons is dominated by nucleon-nucleon (NN) Bremsstrahlung. We calculate the photon emission rate per unit 3-momentum and 4-volume in a quantum field theoretical framework by folding the NN Bremsstrahlung's cross section [2,3] over the nucleon distribution functions obtained from the coarse graining, including non-thermal longitudinal motion. Specifically, we employ an energy-dependent NN cross-section (assumed to be S-wave) fitted to experimental data and relax the soft photon approximation by considering the energy of the emitted photon in the final state. A comparison between our calculated photon energy spectra from $^{40}Ca + ^{40}Ca$ at 35 MeV/A and a relevant experiment [4] is shown in Fig. 1. To match the centrality selection in the Ar+Mo system, we apply a NN collision scaling to our calculated spectra. We also account for exeperimental detector accpetance, thereby including the boost from the transverse and longitudinal center-of-mass motion of the local cells into the laboratory frame.

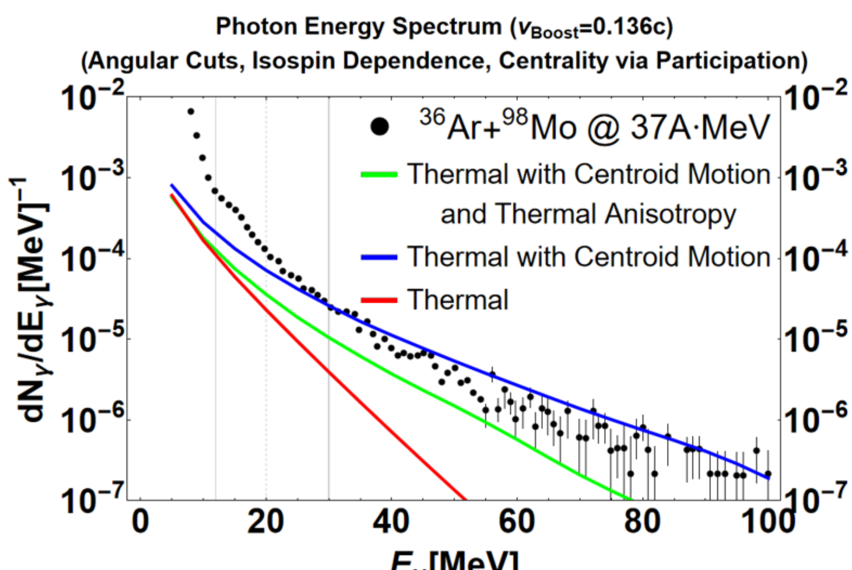

Fig. 1. Photon spectra calculated from a rate convoluted over coarse-grained thermodynamics of 35 A·MeV $^{40}Ca + ^{40}Ca$ collisions, compared to experimental data [4] of a comparable collision system ($^{36}Ar + ^{98}Mo$ at 37 A·MeV), using purely thermalized nucleon distributions (red line), including centroid motion (blue line) and temperature anisotropy (green line).

In a purely thermal approximation, where the centrod motion of the incoming nuclei within the cells is neglected, the data are underestimated. The inclusion of the centroid motion much enhances the yield which now lies slightly above the data for photon energies above ~40 MeV. This demonstrates the importance of the longitudinal motion in the early NN collisions upon nuclear impact (and justifies the collision scaling assumed above). However, when additionally implementing a temperature anisotropy (implying a slightly smaller temperature in the longitudinal direction), the yield reduces again and falls somewhat below the data. We also see that the low-energy data, below ~20 MeV, are beyond the reach of our local emission sources, indicating the presence of a giant-dipole contribution as well as late-stage fragment decays.

In future studies we plan improve our paramterization of the NN cross section by including higher partial waves, additional high-energy sources (e.g., D(1232)-resonance contributions) and in-medium effects through a microscopic model calculation.

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