CYCLOTRON INSTITUTE
TEXAS A&M UNIVERSITY

Mass Melting at a Trillion Degrees

Dilepton radiation from high-energy heavy-ion collisions reveals how the mass of hadrons dissolves at high temperatures

THE SCIENCE

In the first few microseconds of its existence, the early universe was filled with a hot plasma of quarks and gluons. At about 2 trillion degrees Kelvin (or ~200 MeV/k_B), these particles condensed into hadrons, including the protons and neutrons which later formed atomic nuclei. In this transition, more than 98 percent of the visible mass in the universe was created. By colliding heavy atomic nuclei at high energies, modern-day experiments aim at re-creating the quark-gluon plasma (QGP) in the laboratory. Of particular interest are dilepton spectra (electron-positron or muon-antimuon pairs), which can reveal how the mass distributions of ρ mesons (quark-antiquark bound states) change when they decay inside the hot and dense fireball. Scientists at Texas A&M have calculated the in-medium modifications of the ρ-meson mass spectrum and tested their predictions in heavy-ion collisions experiments.

THE IMPACT

Dileptons, once produced, can escape the strongly interacting fireball created in heavy-ion collisions without further rescattering; they are the only known observable to give direct access to an in-medium spectral function of hot and dense QCD matter. Theoretical analyses of measured dilepton spectra provide unique information on how mass distributions of hadrons change and eventually dissolve into quark-gluon degrees of freedom [1], and on the temperature and lifetime of the exploding fireball formed in heavy-ion collisions [2].

SUMMARY

Quantum many-body calculations of the ρ-meson spectral function in hot and dense hadronic matter [1] have found that its average mass changes rather little. However, intense interactions with the hot medium lead to a dramatic increase of the spectral width of the ρ-meson. Close to the transition temperature into the QGP the ρ width becomes comparable to its mass, i.e., the quark-antiquark bound state dissociates. Its spectral mass distribution approaches that of a quark-antiquark continuum, suggesting that the melting of hadronic masses induces a transition to partonic degrees of freedom. The pertinent dilepton emission spectra from ρ-meson decays, together with the radiation from the QGP at high temperatures, have been implemented into a fireball simulation of heavy-ion collisions, see Fig. 1. The calculated spectra agree well with experiment, confirming the melting of the ρ-meson at low mass (M<1GeV) and radiation from the QGP at higher masses, see Fig. 2. Similar measurements at lower collision energies show the ρ-mass also melts in the high-density matter at relatively low temperatures [3] that occurs in mergers of neutron stars.

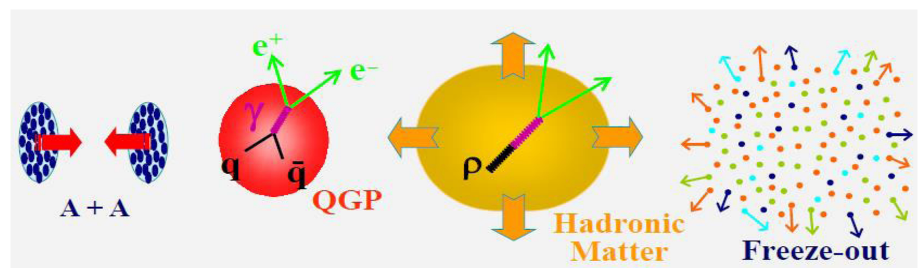

Fig. 1: Schematic view of a fireball evolution in high-energy heavy-ion collisions with pertinent thermal radiation of dileptons from QGP and hadronic matter.

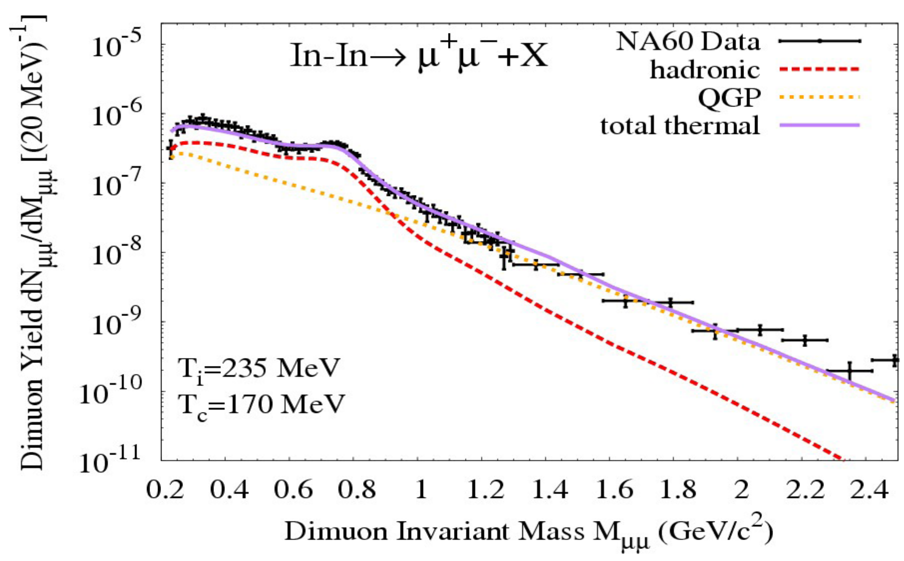

Fig. 2: Theoretical calculations of thermal dilepton radiation (solid line) from the quark-gluon plasma (orange dotted line) plus hadronic matter (red-dashed curve), compared to data from the NA60 collaboration (black symbols).

Ralf Rapp

Hendrik van Hees

PUBLICATIONS

[1] R. Rapp, J. Wambach and H. van Hees, "The Chiral Restoration Transition of QCD and Low-Mass Dileptons", Landolt Börnstein 23 (2010) 134-181.

[2] R. Rapp and H. van Hees, "Thermal Dileptons as a Fireball Thermometer and Chronometer", Physics Letters B 753 (2016) 586-590.

[3] R. Rapp, "Fireball Spectroscopy", Nature Physics (2019); https://www.nature.com/articles/s41567-019-0614-5.

FUNDING

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ABOUT THE CYCLOTRON INSTITUTE: *Dedicated in 1967, the Cyclotron Institute serves as the core of Texas A&M University's accelerator-based nuclear science and technology program. Affiliated faculty members from the Department of Chemistry and the Department of Physics and Astronomy conduct nuclear physics- and chemistry-based research and radiation testing within a broad-based, globally recognized interdisciplinary platform supported by the United States Department of Energy (DOE) in conjunction with the State of Texas and the Welch Foundation. The facility is one of five DOE-designated Centers of Excellence and is home to one of only five K500 or larger superconducting cyclotrons worldwide.*