TEXAS A&M UNIVERSITY
Cyclotron Institute

https://cyclotron.tamu.edu

Scientists Study How B_c Mesons Form to Gain More Information from Ultra-Relativistic Heavy-Ion Collisions

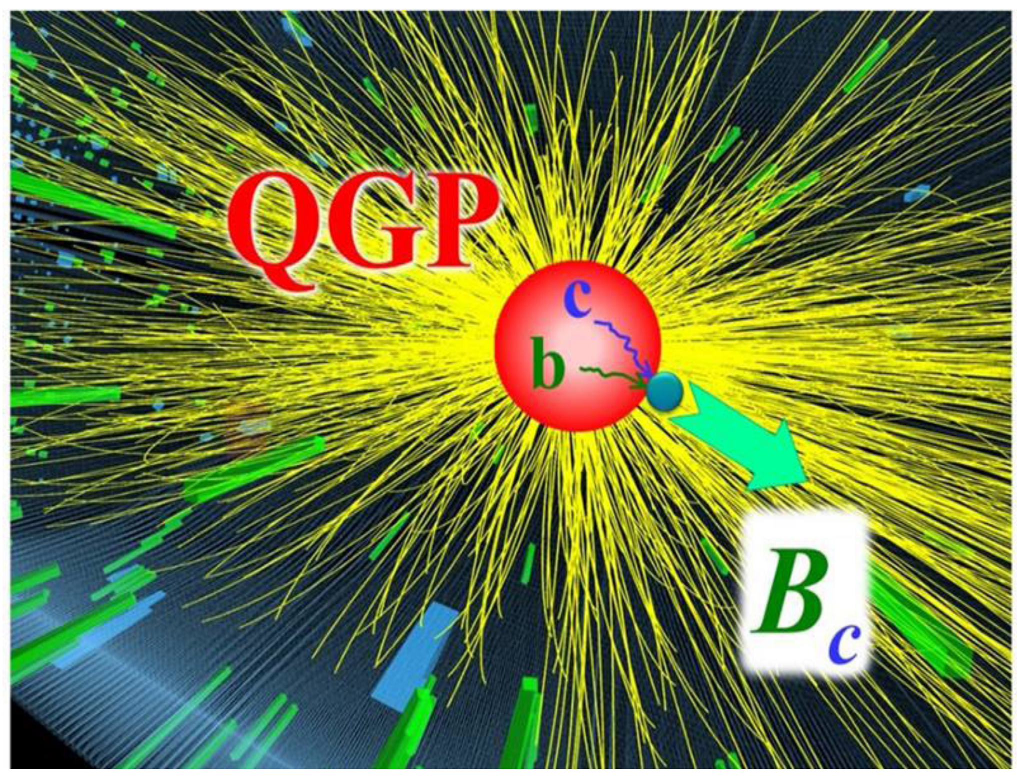
Evidence for quark-gluon plasma formation emerges from recombination of charm and bottom quarks into B_c mesons

THE SCIENCE
High-energy collisions of atomic nuclei provide a unique opportunity to recreate the quark-gluon plasma (QGP) in the laboratory, for a brief moment. The QGP is a fundamental, extremely hot form of nuclear matter in which protons and neutrons dissolve into quarks and gluons. It filled the early universe in the first few microseconds after the Big Bang. Scientists use collisions of heavy ions (particles with an electrical charge) to produce large numbers of the heavy charm and bottom quarks. These quarks are excellent probes of QGP formation. Specifically, the recombination of freely moving charm and bottom quarks facilitates the production of B_c mesons—particles made of an equal number of quarks and antiquarks—when the QGP decays.

THE IMPACT
A QGP formed in high-energy heavy-ion collisions only lasts for a short time before disintegrating into thousands of particles that can be observed in detectors. These detectors track signatures—the signals produced by specific types of particles. The discovery and study of QGP formation in heavy-ion experiments requires signatures that do not occur in other types of collisions, such as proton-proton collisions. In this study, researchers carried out theoretical simulations of charm and bottom quarks diffusing through the QGP. They found that the recombination of these quarks enhances the production of B_c mesons. This mechanism does not occur in proton-proton collisions and thus can serve as a clean signature of QGP formation.

SUMMARY
Researchers from the HEFTY Topical Collaboration investigated the recombination of charm and bottom quarks into B_c mesons in the QGP. They have developed a transport model that simulates the kinetics of heavy-quark bound states through the expanding QGP fireball formed in high-energy heavy-ion collisions. Previous research has successfully used this model to describe the production of charm-anticharm and bottom-antibottom bound states, and thus can provide predictions for B_c particles (charm-antibottom bound states). The researchers used realistic spectra of charm and bottom quarks, computed from their diffusion through the QGP, to evaluate their recombination processes. The results show a large enhancement of the B_c yield in collisions of lead (Pb) nuclei, relative to that in proton collisions. The largest effect is predicted for slow-moving B_c mesons in “head-on” collisions of the Pb nuclei, where a large QGP fireball with appreciable numbers of charm and bottom quarks is formed.

The theoretical calculations agree with pioneering data of the CMS collaboration at the Large Hadron Collider. However, the data are not yet sensitive to slow-moving B_c mesons; future data therefore will provide a critical test of this QGP signature.



Quark recombination in the quark-gluon plasma formed in high-energy nuclei collisions enhances the production of B_c mesons. These mesons consist of a charm quark and a bottom quark. Most of the quark-gluon plasma decays into thousands of other particles.
(Credit: CERN/CMS Collaboration: B. Wu, Z. Tang, M. He, and R. Rapp)

Ralf Rapp

Biaogang Wu

PUBLICATIONS
Wu, B., Tang, Z., He, M., and Rapp, R., "Recombination of B_c mesons in ultrarelativistic heavy-ion collisions," Physical Review C 109, 014906 (2024).

FUNDING
This work was supported by the Department of Energy Office of Science, Office of Nuclear Physics through the Topical Collaboration in Nuclear Theory on Heavy-Flavor Theory (HEFTY) for QCD Matter. Additionally, this research was funded by the National Science Foundation and the National Natural Science Foundation of China.

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.*