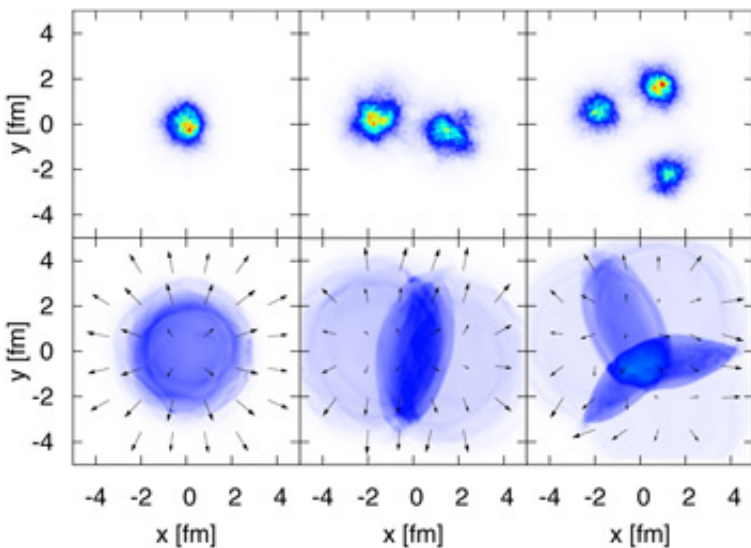


# Tiny drops of early universe 'perfect' fluid

September 1 2015



The upper panel of this image represents initial hot spots created by collisions of one, two, and three-particle ions with heavy nuclei. The lower panel shows the geometrical patterns of particle flow that would be expected if the small-particle collisions are creating tiny hot spots of quark-gluon plasma.

The Relativistic Heavy Ion Collider (RHIC), a particle collider for nuclear physics research at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory, smashes large nuclei together at close to the speed of light to recreate the primordial soup of fundamental particles that existed in the very early universe. Experiments at RHIC—a DOE Office of Science User Facility that attracts more than 1,000 collaborators from around the world—have shown that this primordial soup, known as quark-gluon plasma (QGP), flows like a nearly friction

free "perfect" liquid. New RHIC data just accepted for publication in the journal *Physical Review Letters* now confirm earlier suspicions that collisions of much smaller particles can also create droplets of this free-flowing primordial soup, albeit on a much smaller scale, when they collide with the large nuclei.

"These tiny droplets of [quark-gluon plasma](#) were at first an intriguing surprise," said Berndt Mueller, Associate Laboratory Director for Nuclear and Particle Physics at Brookhaven. "Physicists initially thought that only the nuclei of large atoms such as gold would have enough matter and energy to set free the quark and gluon building blocks that make up protons and neutrons. But the flow patterns detected by RHIC's PHENIX collaboration in collisions of helium-3 nuclei with gold ions now confirm that these smaller [particles](#) are creating tiny samples of perfect liquid QGP."

These results build on earlier findings from collisions of two-particle ions known as deuterons with gold ions at RHIC, as well as proton-lead and [proton-proton collisions](#) at Europe's Large Hadron Collider (LHC). They also set the stage for the current run colliding protons with gold at RHIC.

"The idea that collisions of small particles with larger nuclei might create minute droplets of primordial quark-gluon plasma has guided a series of experiments to test this idea and alternative explanations, and stimulated a rich debate about the implications of these findings," said University of Colorado physicist Jamie Nagle, a co-spokesperson of the PHENIX collaboration at RHIC. "These experiments are revealing the key elements required for creating quark-gluon plasma and could also offer insight into the initial state characteristics of the colliding particles."

## **Geometrical flow patterns**

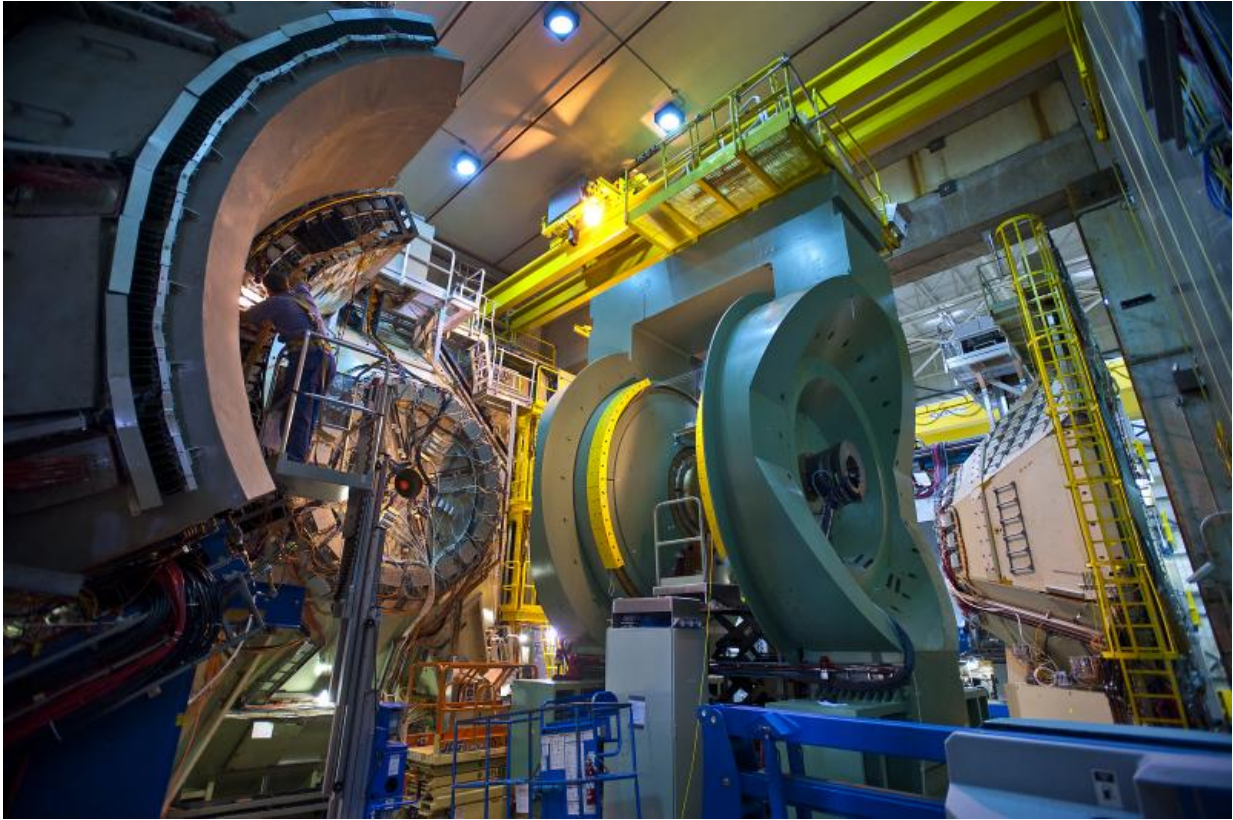
The discovery of the "perfect" liquid at RHIC, announced definitively in 2005, was largely based on observations of particles flowing in an elliptical pattern from the matter created in RHIC's most energetic gold-gold collisions. This flow was a clear sign that particles emerging from the collisions were behaving in a correlated, or collective, way that contrasted dramatically with the uniformly expanding gas the scientists had expected. Additional experiments confirmed that this liquid is indeed composed of visible matter's most fundamental building blocks, quarks and gluons, no longer confined within individual protons and neutrons, and that the flow occurs with minimal resistance—making it a nearly "perfect" liquid QGP.

"Experiments colliding smaller particles with the heavy ions were originally designed as control experiments because they weren't supposed to create the QGP," Nagle said. "But observations at the LHC of very energetic proton-proton collisions and later experiments there colliding protons with lead revealed hints that particles streaming from those tiny collisions were also behaving collectively and flowing. It looked a lot like some of the perfect liquid signatures originally discovered in gold-gold collisions at RHIC, and later in lead-lead collisions at the LHC."

When RHIC physicists checked data from the RHIC run of 2008, when deuterons (a nucleus made of one proton and one neutron) were smashed into gold ions, they saw a similar pattern.

"Since the deuteron is two particles, it creates two separate impacts on the nucleus—two hot spots that appear to merge and form an elongated drop of QGP," Nagle said.

## **Definitive tests**



Relativistic Heavy Ion Collider's PHENIX detector

Those observations triggered the idea of testing for flow patterns in a range of more tightly controlled experiments, which is only possible at RHIC, where physicists can collide a wide variety of ions to control the shape of the droplets of matter created. With additional deuteron-gold collisions already in hand, the RHIC scientists set out to collide three-particle helium-3 nuclei (each made of two protons and one neutron) with gold—and later, single protons with gold.

"The PHENIX detector can pick up particles coming out of collisions very far forward and backward from the collision point. This large angle coverage allows us to measure the flow in these small collision systems,"

said Shengli Huang, a PHENIX collaborator from Vanderbilt University who carried out the analysis. "PHENIX also has a trigger detector that picks up and records the most violent collisions—the ones in which the flow pattern is most apparent," he said.

The analysis of those events, as described in the new paper, reveals that the helium-gold collisions exhibit a triangular pattern of flow that the scientists say is consistent with the creation of three tiny droplets of QGP. They also say the data indicate that these small particle collisions could be producing the extreme temperatures required to free quarks and gluons—albeit at a much smaller, more localized scale than in the relatively big domains of QGP created in collisions of two heavy ions.

"This is a pretty definitive measurement," Nagle said. "The paper has a plot of elliptical and triangular flow that pretty much matches the hydrodynamic flow calculations we'd expect for QGP. We are really engineering different shapes of the QGP to manipulate it and see how it behaves."

There are other key signatures of QGP formation, such as the stopping of energetic particle jets, which have not been detected in the tiny droplets. And other theoretical explanations suggest the [flow patterns](#) resulting from some of the small particle-nucleus collisions could emerge from the interactions of gluons within the colliding particles, rather than from the formation of QGP.

"At this time, the only theoretical framework that reproduces the patterns we're observing in deuteron-gold and helium-3-gold collisions is fluid dynamics," said Bjoern Schenke, a nuclear theorist at Brookhaven Lab. "It remains to be seen if alternative models can describe these patterns as well."

If other models also turn out to be compatible with the helium-3-gold



data, physicists will want to explore whether these models make predictions that differ from those of the hydrodynamic flow model, and for which types of collisions.

"The good news is that RHIC, with its unrivaled versatility, will likely be able to study any system that can discriminate between different models," Mueller said.

## **RHIC's versatility, productivity key to discovery**

The versatility and productivity of RHIC as a collider were essential to all these experiments. The collisions of helium-3 with gold in 2014 were conducted almost as a bonus part of that run, Nagle explained.

"The collider's luminosity, or [collision](#) rate, was so high earlier in the run that we had collected almost 40 percent more data than we'd set as our goal a few weeks before the run was over," Nagle said. "That gave us the opportunity to do these tests for the remaining weeks."

RHIC's ability to collide a wide variety of ions, and easily switch the ion species fed into the accelerator, were also essential to this success. This versatility stems from innovative accelerator components, including the Electron Beam Ion Source and the Laser Ion Source.

Finally, thanks to a new configuration of certain magnets that make up the 2.4-mile-circumference RHIC accelerator, protons collided with gold nuclei for the first time during the 2015 run. Results from those collisions are in the very early stages of analysis.

"Thanks to these capabilities, RHIC is the only accelerator in the world where we can perform such a tightly controlled experiment, colliding particles made of one, two, and three components with the same larger nucleus, gold, all at the same energy," said Nagle. "This is the way to do

good basic science—change just one thing at a time, the number of particles in the ion smashing into the gold nucleus, to test for these interesting geometrical effects."

Provided by Brookhaven National Laboratory

Citation: Tiny drops of early universe 'perfect' fluid (2015, September 1) retrieved 24 April 2024 from <https://phys.org/news/2015-09-tiny-early-universe-fluid.html>

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.