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CERN claims first experimental creation of quark-gluon plasma

Munich

The European Laboratory for Particle Physics (CERN) plans to announce today (10 February) that it has "compelling evidence" that its scientists have created the quark-gluon state of matter predicted to have existed shortly after the Big Bang.

If confirmed, this would be the first time that conditions within the first three minutes after the Big Bang — the point at which the protons and neutrons that make up atomic nuclei came into being — have been observed under experimental conditions.

Such 'nucleons' are made up of two types of elementary particle: quarks and the carriers of forces that bind them, gluons. But free quarks have never been detected — theory predicts that they exist only in an unconfined state either during this short window of time, or at energy densities encountered in very energetic heavy-ion collisions.

The theory of these particles, quantum chromodynamics, predicts that, at such energies, quarks and gluons coexist unbound within a plasma. Scientists have tried for years to find such a plasma, but the complexity of the phenomena produced by high-energy collisions of massive ions has made it impossible.

CERN scientists now say they have created quark-gluon matter in a series of experiments begun in 1994, in which CERN's Super Proton Synchrotron (SPS) fired very-high-energy beams of lead ions into gold or lead targets.

The collisions create temperatures 100,000 times hotter than the centre of the Sun, and the highest energy densities (3–4 GeV per cubic femtometre) ever reached over a large volume in laboratory experiments. Such collisions should be sufficient to break down the forces that confine quarks inside nucleons.

As the energy levels in the CERN experiment, known as the SPS Heavy Ion Programme, were insufficient to allow free quarks to be detected directly through electromagnetic radiation emitted in the form of photons, CERN scientists also searched for indirect evidence of quark matter.

Detectors in other experiments were optimized for measuring signals from the hadrons, such as protons, neutrons and mesons, that form as the plasma expands and

Detector work: CERN's NA45 experiment has contributed to evidence of quark matter creation.

cools, and the quarks and gluons coalesce.

One experiment was designed to detect the rare J/Ψ meson, made of a charm quark and a charm antiquark. Charm quarks are very heavy, and can be produced only immediately after the lead ion beam hits its target.

Theoretically, the formation of J/Ψ mesons is suppressed by quark-gluon matter, which reduces the interaction between charm quarks and antiquarks. The J/Ψ experiment actually measured a dip in the number of J/Ψ mesons reaching the detector, suggesting that a quark-gluon plasma had been created.

At a conference on quark matter held in Turin last May, the 600 or so physicists from 22 countries involved in the CERN programme decided that their combined results support the theory that quarks are freed up (or 'deconfined') at high energy densities.

They chose to announce their results before the experiments start at the Relativistic Heavy Ion Collider (RHIC), a dedicated quark-gluon plasma factory at the US Brookhaven National Laboratory. When it starts operation in the next couple of months, RHIC's higher energy capacity will allow it to create long-lived quark-gluon

plasma (see *Nature* **400**, 303; 1999).

The announcement appears to be intended to ensure that CERN receives credit for the initial creation of quark matter before the European laboratory's US counterpart announces its own results, which are likely to be more clear-cut.

"Even if the interpretation of some of the individual observations, taken on their own, is controversial, when they are all put together, the evidence that we have been able to create deconfined quark-gluon matter is overwhelming," says Federico Antinori, a particle physicist from Padua, Italy, who is spokesman for one of the CERN experiments.

Reinhard Stock, professor of nuclear physics at the University of Frankfurt, and head of another of the experiments, adds that CERN researchers were able not only to create the quark-gluon matter, but also to observe its decay into protons and neutrons.

CERN's achievement has been welcomed by scientists at RHIC. This facility will begin generating results in early summer, and will study the properties of quark-gluon plasma itself, rather than just its decay. The Brookhaven collider will generate centre-of-mass energies of 200 GeV by colliding two heavy-ion beams, rather than firing one beam onto a fixed target, as occurs at CERN.

Physicists expect that long-lived plasmas will be generated, and that it will be possible to measure the photons generated by free quarks directly. Tom Ludlam, associate director of the RHIC project, says he "agrees completely" that CERN scientists' conclusions that their evidence for a quark-gluon plasma is "very compelling". But he adds that direct measurement of free quarks, as RHIC should allow, would remove any doubts.

CERN will take over from the RHIC experiment when its ALICE experiment (A Large Ion Collider Experiment) begins in 2005. Exploiting CERN's new accelerator, the Large Hadron Collider, ALICE will be able to generate collision energies of 5.5 TeV per nucleon centre-of-mass energy — nearly 30 times that of RHIC.

Alison Abbott

Further reading:

Wilczek, F. Liberating quarks and gluons. *Nature* **391**, 330–331 (1998).