CMS observes hints of melting of Upsilon particles in lead-nuclei collisions

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In our Universe today, quarks are always bound together by gluons to form “composite” particles such as protons and neutrons. The Quark-Gluon Plasma, or QGP, often described as a soup-like medium, is a hot, dense state in which these quarks and gluons exist freely, unbound. This is thought to have been the situation a few millionths of a second after the Big Bang.

It is thought that this medium can be produced in collisions of heavy ions such as lead nuclei, which are collided by the LHC in addition to protons. If produced, QGP can appear in a variety of ways, and can affect particles produced in these highly energetic collisions. This is helpful, because while it isn’t possible to observe the QGP directly, its presence can be inferred based on the expected behaviour of particles that interact with it.

One of the predicted characteristics of the QGP is that its high temperature causes the “melting” of quarkonia – bound states of a quark and its anti-quark. This melting manifests itself as the suppression of quarkonia production in heavy-ion collisions, compared to the number of quarkonia produced in collisions between protons.

The Υ (Upsilon) particle, a quarkonium consisting of a bottom and an anti-bottom quark, exists in three states known as 1S, 2S and 3S, in decreasing order of how tightly the quarks are bound. (1S is the ground state of the Υ, while the others are excited states.) Because they are more loosely bound, the 2S and 3S states will melt more readily in the QGP. This means that the number of Υ(2S) and Υ(3S) particles produced relative to Υ(1S) in heavy-ion collisions should be less than corresponding numbers from proton collisions.
Candidate Upsilon decay to two muons observed in a lead-lead collision at the LHC. The two red lines (tracks) are the two muons, the mass of orange lines are tracks from other particles produced in the collision, whose energy is measured in the electromagnetic calorimeter (red cuboids) and the hadron calorimeter (blue cuboids).

CMS studied pairs of muons that are part of the post-collision debris in the detector. Pairs of muons produced from the decay of particles such as the Y will outnumber those pairs that are created by random processes. Thanks to the excellent momentum resolution of the CMS detector, a spectrum can be produced from the masses of each pair, with clear peaks corresponding to the masses of particles from which they decayed.

CMS observed a dramatic difference in the number of Y(2S) and Y(3S) produced in the heavy-ion and proton collisions, as expected in case their production is suppressed by the QGP. From the data collected from both 2.76 TeV runs, CMS has observed that the relative production of the excited states of the Y particle in heavy-ion collisions is only about 30% that of the comparative rates from proton collisions (± about 20%).

Comparison of the number of Upsilons generated in PbPb collisions (blue line) and pp collisions (red dashed line), clearly showing the suppression of the excited Y states (the smaller peaks). Note that a normalisation factor was introduced in order to compare the results.

The probability of obtaining the measured value, or lower, if the true double ratio is unity, has been calculated to be less than 1%. The collaboration is looking
forward to the next PbPb run later this year when more data will allow study of the suppression of the excited Y states with even higher statistics.

More information, including images and animations of CMS collision events, may be found on the CMS web site: http://cms.cern.ch.

CMS is one of two general-purpose experiments at the LHC that have been built to search for new physics. It is designed to detect a wide range of particles and phenomena produced in the LHC’s high-energy proton-proton and heavy-ion collisions and will help to answer questions such as: “What is the Universe really made of and what forces act within it?” and “What gives everything substance?” It will also measure the properties of well-known particles with unprecedented precision and be on the lookout for completely new, unpredicted phenomena. Such research not only increases our understanding of the way the Universe works, but may eventually spark new technologies that change the world in which we live as has often been true in the past.

The current run of the LHC is expected to last eighteen months. This should enable the LHC experiments to accumulate enough data to explore new territory in all areas where new physics can be expected.

The conceptual design of the CMS experiment dates back to 1992. The construction of the gigantic detector (15 m diameter by nearly 29 m long with a weight of 14000 tonnes) took 16 years of effort from one of the largest international scientific collaborations ever assembled: more than 3100 scientists and engineers from 169 institutions and research laboratories distributed in 39 countries all over the world.

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