Important heavy-ion results from CMS

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The CMS experiment has made several unique measurements using data from LHC collisions of lead nuclei (PbPb, November 2010) at centre-of-mass energies of 2.76 TeV per nucleon pair.

Phenomena measured for the first time in nucleus-nucleus collisions include: very energetic jets; energetic bottom or b-quarks through secondary J/Ψ mesons (comprising a charm or c-quark and its anti-quark); the full family of Υ (Upsilon) mesons (comprising a b-quark and its anti-quark); W and Z bosons; and isolated photons.

The CMS results include the comparison of the production rates of various particles including strongly-interacting heavy-quark bound states, energetic light-quark and gluon jets, and heavy-quark jets as well as weakly-interacting particles such as prompt photons, which are produced directly from the interaction of quarks rather than in particle decays, and W and Z bosons.

A particularly important observation is that production of strongly-interacting particles is suppressed in PbPb collisions, compared to pp collisions. No such suppression was observed for weakly-interacting particles. It is thought that the hot, dense, soup-like medium called quark-gluon plasma (QGP), which is expected to be produced in collisions of heavy nuclei, suppresses the production of particles that interact strongly with it.

The properties of the medium in PbPb and pp collisions have been investigated via measurements of the total hadron multiplicity, transverse energy densities, and angular correlations between particles in high-multiplicity events.

All these data provide unprecedented insights into the nature of strongly-interacting matter at the highest energy densities ever studied in the laboratory. First estimates show that the energy density is more than three times that obtained at the RHIC collider at the Brookhaven laboratory in the USA.

CMS has unparalleled muon detection and measurement capabilities that make it possible to measure precisely J/Ψ and Υ “quarkonia” mesons, through their decays to a pair of muons. Such quarkonia states are expected to “melt” in the QGP medium at temperatures that depend on how tightly the quark-antiquark pair is bound.

CMS measured the charm-anticharm state, J/Ψ, and the bottom-antibottom Υ family and observed for the first time ever that the excited, loosely-bound Υ states disappear relative to the more tightly-bound ground-state Υ.

CMS was also able to separate the J/Ψs produced by b-quark decays from those produced in the PbPb collision itself. In both cases production appears to be suppressed, pointing to the “melting” of J/Ψ in the QGP medium. A first measurement of energetic b-quark quenching in the QGP medium was also made.
Invariant mass spectrum of pairs of oppositely-charged muons produced in lead-lead collisions, showing clear peaks due to $J/\Psi$, $\Upsilon$ and $Z$ production.

Following a previous measurement of a di-jet imbalance in December 2010 [arXiv:1102.1957], jets have been extensively studied. CMS measured the spectrum of charged hadrons and prompt photons up to 100 and 80 GeV/c respectively. On the one hand, the observed suppression of charged hadrons in the medium extends to much higher momenta – the RHIC experiments observed it at lower energies of up to 20 GeV/c. The CMS observation provides strong constraints on models of parton (quark or gluon) energy loss in the QGP. On the other hand, isolated photons as well as $Z$ bosons [PRL to appear soon], which do not interact strongly, appear to be unaffected by the QGP medium.

CMS has also been able to measure for the first time the parton “fragmentation functions” in PbPb collisions, by correlating single particles to fully reconstructed jets. This provides detailed information on how energetic partons fragment into hadrons within and beyond the QGP medium.

Other studies carried out include: the azimuthal anisotropy (elliptic flow) of the produced hadrons, a quantity that is sensitive to the viscosity of the QGP; the total hadron multiplicity and transverse energy densities (reaching about 2 TeV per unit of rapidity, which is almost 4 times higher than that measured at RHIC); as well as long-range angular correlations of the produced particles – an effect that was also observed by CMS in pp collisions [JHEP 1009 (2010) 091] – indicative of strong collective flows present in the final-state of the system.

The richness of the new physics studies opened-up by the high-energy and high-rate heavy ion collisions provided by the LHC is being fully exploited by the CMS
detector. This is just the beginning of a long and fruitful voyage at the frontier of particle physics.

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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