Proton-ion collisions: Behind the scenes of a hybrid interaction

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Protons to the right, ions to the left: the basic principle of proton-ion collisions at the LHC might seem straightforward. However, this is an almost unprecedented mode of collider operation, certainly unique at the energy provided by the LHC. In addition to being a remarkable technical achievement, this interaction between a proton and an ion can potentially contribute a lot to the understanding of the properties of matter in its primordial state.

Prior to last week, the LHC had only collided protons with protons and lead ions with lead ions. These were indeed the two operational schemes the LHC was designed for. However, since science can often evolve in directions that were not necessarily expected at the beginning of a project, over the years the scientific community has become more and more interested in the hybrid type of interaction – that between protons and ions. Last week's collisions were only a test for the teams involved in the operation of the LHC, in preparation for the four week run in 2013. But why are these collisions so interesting to physicists?

"The relevance of studying this type of interaction is twofold," replies Urs Wiedemann from CERN's Theory Unit. "In addition to being a benchmark for ion-ion collisions, proton-ion collisions could provide valuable insights into a so-far unexplored region of QCD, the model that describes the behaviour of, among other things, nuclei, protons and quarks, in which novel phenomena are expected to occur."

From observations at the LHC and in other colliders we already know that when two ion beams are collided, a new state of matter is formed: the quark-gluon plasma (QGP). This is the hot and dense matter that existed in the initial moments of the Universe. At the LHC, the properties of this state can be probed by studying how high-energy particles produced in the collision are stopped inside this matter. "To better understand what this quenching of high-energy particles can tell us about the QGP properties, we want to study how the same processes are attenuated when they occur in the cold nuclear matter present in proton-ion collisions," explains Urs Wiedemann. "The quenching of high-energy particles is only one of several measurements where cold nuclear matter effects can provide the benchmark information needed to improve our understanding of heavy ion collisions."

For the first time last week, a beam of high-energy protons was collided with a beam of lead ions in the LHC. The collision energy was more than ten times higher than that of previous experiments. The hope of the scientific community is that these collisions will also provide insight into a phenomenon known as "parton saturation" in QCD. "From the theory we know that, when we look inside a particle composed of quarks and gluons, such as the proton, the number of its basic constituents varies depending on the magnifying lens with which we observe it, that is, the physical scale given by the momentum transfer," says Urs Wiedemann. "And if one keeps the magnification scale constant and increases the energy of the particle, theory tells us that the number of constituents (partons) seen at this scale increases. But at a still-unknown high energy, there are fundamental reasons to expect that this growth of the number of constituents with energy must be saturated."

"This saturation happens," he continues, "when the density of partons becomes so large that any further growth in density is compensated by the probability that these partons meet and recombine. This saturation phenomenon is expected to set in earlier in lead nuclei than in protons, simply because they contain more partons. In the absence of an electronion collider, proton-nucleus collisions are our best choice for making progress on the question of at what scale this parton saturation phenomenon arises in QCD. And by increasing the centre-of-mass energy of proton-nucleus collisions by more than a factor 10 over previous experiments, we open up a wide, previously unexplored energy range relevant for addressing this question."

Thanks to the proton-lead collisions at very high energy, the LHC experiments could be the first to observe this phenomenon. A first physics run with regular proton-lead collisions will start in January 2013.

Provided by CERN