Searching for the supersymmetric bottom quark (and its friends)

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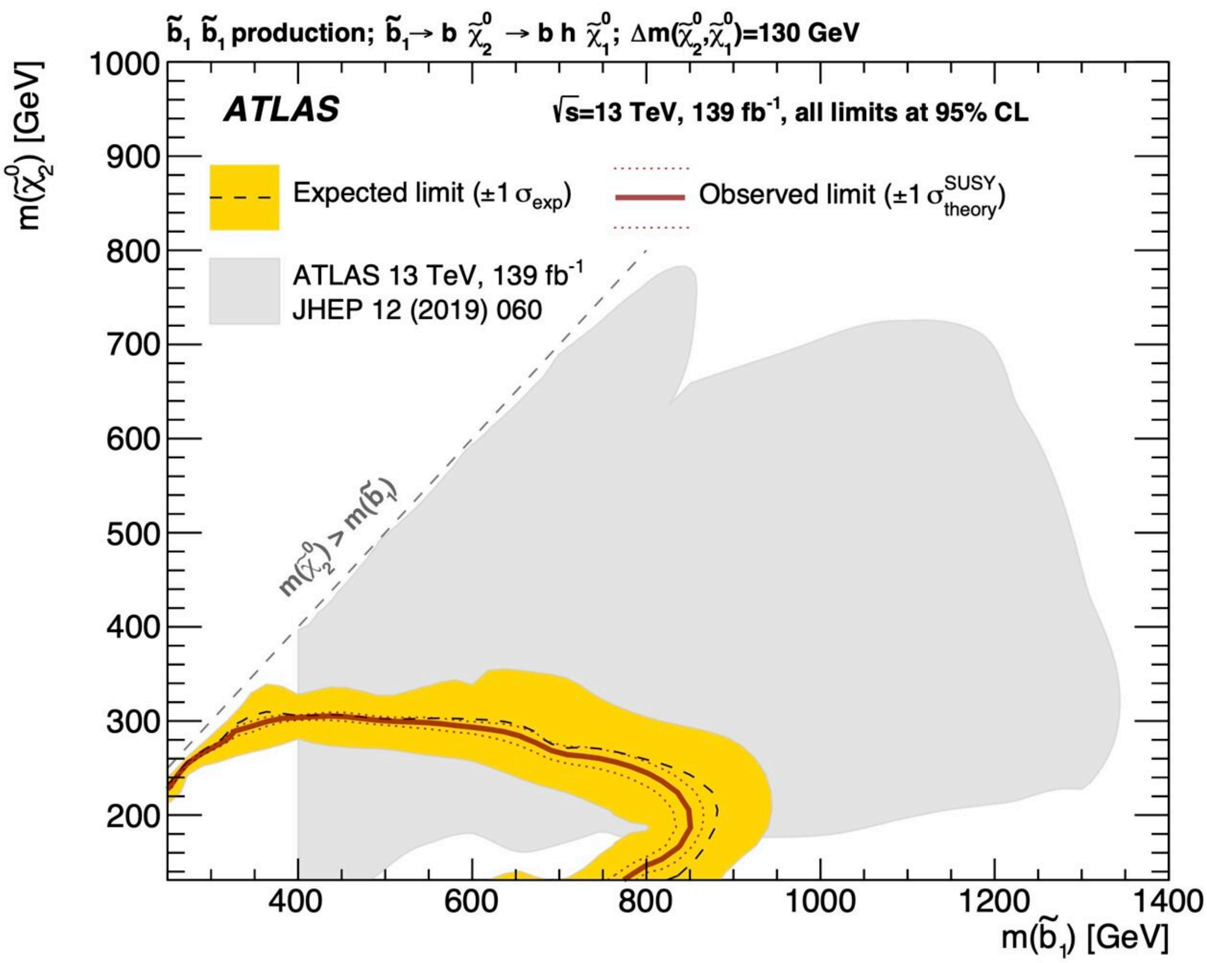

New exclusion limits on the scalar-bottom and heavy-neutralino masses. The hypotheses made on the specific scalar-bottom decay process and the mass hierarchy are reported outside the figure frame. The limits from a previous ATLAS search are also shown in grey. Credit: ATLAS Collaboration/CERN

When it comes to quarks, those of the third generation (the top and bottom) are certainly the most fascinating and intriguing. Metaphorically, we would classify their social life as quite secluded, as they do not mix much with their relatives of the first and second generation. However, as the proper aristocrats of the particle physics world, they enjoy privileged and intense interactions with the Higgs field; it is the intensity of this interaction that eventually determines things like the quantum stability of our universe. Their social life may also have a dark side, as they could be involved in interactions with dark matter.

This special status of third-generation quarks makes them key players in the search for phenomena not foreseen by the Standard Model. A new result released by the ATLAS Collaboration at CERN focuses on models of new phenomena that predict an enhanced yield of collision events with bottom quarks and invisible particles. A second new ATLAS search considers the possible presence of added tau leptons. Together, these results set strong constraints on the production of partners of the b-quarks and of possible dark-matter particles.

Searching for the supersymmetric bottom…

The supersymmetric partner of the bottom quark (the scalar bottom) is one of most sought-after new particles at the Large Hadron Collider (LHC). During Run 1 of the LHC (2010-2013), physicists were able to set strong constraints on the mass of the scalar bottom in its most natural decay modes. Those constraints have only grown stronger as scientists have studied data from Run 2 (2015-2018). The ATLAS Collaboration's newest results take the search one step further: not only have physicists examined the full set of collisions of Run 2, they've employed new techniques to target less common scalar-bottom decay modes and more difficult mass hierarchies.

ATLAS' first new result focuses on scalar-bottom decays that are not often investigated—namely, its decay into b-quarks, Higgs bosons and dark-matter candidate particles. Complementing a previous ATLAS study (see figure), the new result looks for a pair of tau leptons produced in the Higgs-boson decay. Identifying—or rather, mis-identifying—these tau leptons was one of the more challenging aspects of this study. To overcome this, ATLAS physicists developed a dedicated background estimation technique, based on the definition of a carefully designed set of control samples. This gave them a precise estimation of the difficult background component arising from mis-identifications of tau leptons.

In a second new study of scalar-bottom quarks, ATLAS researchers turned their focus to the decay of a pair-produced scalar bottoms to a b-quark and a candidate dark matter particle, resulting in two b-jets and missing transverse momentum in the final state. They paid particular attention to "compressed scenarios," that is, where the mass of the scalar bottom and that of the dark matter candidate are similar. In those cases, the b-quarks emitted in the scalar-bottom decay have very low momentum, making them hard to identify.

For the first time in ATLAS, physicists implemented machine learning techniques and dedicated reconstruction algorithms aimed at reconstructing the displaced bottom-hadron decay regardless of the presence of a jet. Together with the increased integrated luminosity of the LHC, these techniques have helped push the ATLAS Experiment's sensitivity to unprecedented levels.

… and its friends

One of the things that makes these final states so interesting is that they are also common to other new phenomena, such as leptoquarks. These are hypothetical particles whose decay would violate lepton and baryon number conservation, which could explain the observed matter–antimatter imbalance of our universe. A specific family of leptoquarks may decay at least partially in a b-quark and a neutrino, yielding once again a final state with two b-jets and missing transverse momentum. More generic models of dark matter, where b-jets are produced in association with the candidate dark matter particles, would also yield the same final state. ATLAS's new result sets competitive limits on these scenarios as well—a significant contribution to the search for dark matter or leptoquarks.

In conclusion

The investigation of the third-generation quark sector—both in terms of precision measurements and in terms of searches of new phenomena associated with it—is to be ascribed to the long list of triumphs of the LHC. This knowledge so far indicates that the third generation behaves as predicted by the Standard Model. Only further scrutiny and investigation will reveal new answers to the big questions raised by the third generation.

More information: Search for bottom-squark pair production in proton-proton collision events at 13 TeV with hadronically decaying τ-leptons, b-jets and missing transverse momentum using the ATLAS detector (arXiv: 2103.08189): arxiv.org/abs/2103.08189

Search for new phenomena in final states with b-jets and missing transverse momentum in 13 TeV proton–proton collisions with the ATLAS detector (arXiv: 2101.12527): arxiv.org/abs/2101.12527

Provided by ATLAS Experiment