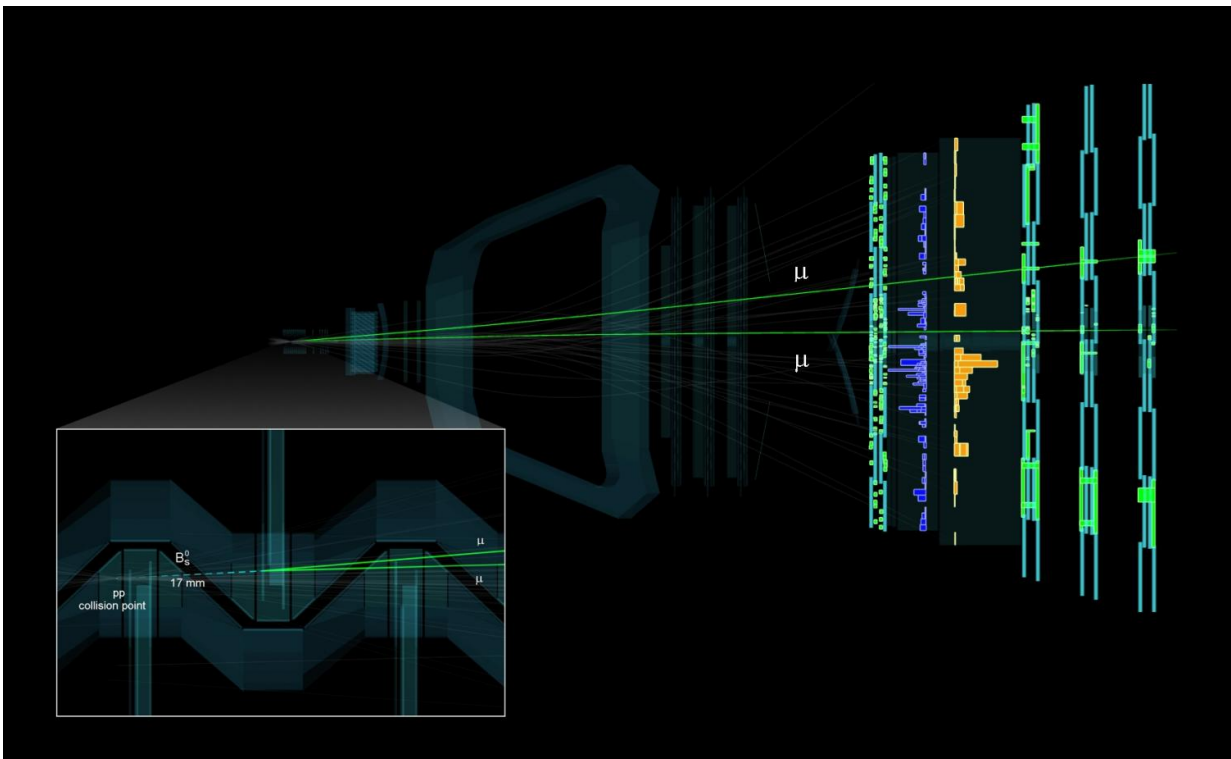


The most accurate measurement of rare meson decay confirms modern physics

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Extremely rare B_s^0 meson decay into two muons, registered in 2016 at the LHCb detector at CERN near Geneva. The enlargement at the bottom shows that the point of decay was 17 mm from the collision of two protons. Credit: IFJ PAN / CERN / The LHCb Collaboration

All physical theories are simplified representations of reality, and as a consequence, have a specified range of applicability. Many scientists

working on the LHCb experiment at CERN had hoped that the exceptional accuracy in the measurement of the rare decay of the B_s^0 meson would at last delineate the limits of the Standard Model, the current theory of the structure of matter, and reveal phenomena unknown to modern physics. But the spectacular result of the latest analysis has only served to extend the range of applicability of the Standard Model.

Mesons are unstable [particles](#) that arise as a result of proton collisions. Physicists are convinced that in some very rare decays of these particles, processes can potentially occur that may reveal physics, with the participation of previously unknown [elementary particles](#). Scientists at the LHC have been looking into the decay of the B_s^0 [meson](#) into a muon and an anti-muon. The most recent analysis, carried out for a much greater number of events than ever before, has achieved a result that shows excellent agreement with the predictions of the Standard Model.

Prof. Mariusz Witek from the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Cracow, says, "This result is a spectacular victory, only that it's slightly pyrrhic. It is, in fact, one of the few cases where experimentation agrees with theory, but still causes worry. Together with the improvement in the accuracy of measurement of the decays of B_s^0 mesons, we expected to see new phenomena beyond the Standard Model, which we know with all certainty is not the ultimate theory. But instead, we have only shown that the model is more accurate than we originally thought."

The Standard Model is a theoretical framework developed in the 1970s to describe phenomena occurring among elementary particles. The model describes matter as composed of elementary particles from a group called fermions, including quarks (down, up, strange, charm, true and beauty) and leptons (electrons, muons, tauons and their associated neutrinos). In the [model](#), there are also particles of antimatter associated

with their respective particles of matter. Intermediate bosons are responsible for carrying forces between fermions; photons are the carriers of electromagnetic forces; eight kinds of gluons are carriers of strong forces; bosons W^+ , W^- and Z^0 are responsible for carrying weak forces. The Higgs boson, recently discovered at the LHC, gives particles mass (all of them except for gluons and photons).

Muons are elementary particles with characteristics similar to those of electrons, only around 200 times more massive. In turn, B mesons are [unstable particles](#) made up of two quarks: a beauty anti-quark and a down, up, strange or charm quark. The decay of the B_s^0 meson into a muon and an anti-muon (endowed with positive electric charge) occurs extremely rarely. In the analyzed period of LHCb operation, there were hundreds of trillions of [proton collisions](#) during which whole cascades of disintegrating secondary particles were recorded. With such a large number of events in a multi-stage selection process, it was only possible to pick out a few cases of this decay. One of them can be viewed in 3-D [here](#).

In its most recent analysis, the LHCb experiment team took into account not only the first but also the second phase of operation of the LHC. The deeper statistics provided exceptional decay measurement accuracy of the beauty meson into a muon and anti-muon—up to 7.8 standard deviations (commonly denoted by the Greek letter sigma). In practice, this means that the probability of registering a similar result by random fluctuation is less than one to over 323 trillion.

"The spectacular measurement of the decay of the beauty meson into a muon-anti-muon pair agrees with the predictions of the Standard Model with an accuracy of up to up to nine decimal places," says Prof. Witek.

Despite the result, physicists are confident that the Standard Model is not a perfect theory. It does not take into account the existence of gravity, it

does not explain the dominance of matter over antimatter in the contemporary universe, it offers no explanation of the nature of dark matter, it gives no answers regarding why fermions are composed of three families. In addition, for the Standard Model to work, over 20 empirically chosen constants have to be accounted for, including the mass of each particle.

"The latest analysis significantly narrows down the values of the parameters that should be assumed by certain currently proposed extensions of the Standard Model—for example, supersymmetric theories. They assume that each existing type of elementary particle has its own more massive counterpart—its superpartner. Now, as a result of the measurements, theorists dealing with supersymmetry have a reduced possibility of adapting their theory to reality. Instead of coming closer, the new physics is again receding," concludes Prof. Witek.

Physicists plan to continue their studies of the decay of the B_s^0 meson into the muon and anti-muon pair. There is still a possibility that new, undiscovered effects are smaller than expected and continue to get lost in measurement errors.

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