A very rare decay has been seen by CMS

CMS Experiment, CERN
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CMS has seen an important rare decay predicted by the Standard Model of particle physics. Strong evidence for the decay of $B_s$ mesons (pronounced B-sub-s) to pairs of muons, which comes after a wait of roughly 25 years, will be announced later today at the biennial EPS-HEP Conference in Stockholm, Sweden.

For every billion $B_s$ mesons produced, only about three are expected to decay into two muons, heavier cousins of the electron. These decays are ideal processes in which to search for signs of new physics: a deviation from the precise predictions of the Standard Model (SM) would indicate the presence of physics “beyond the Standard Model” (BSM physics).

CMS reports a decay rate of $3.0^{+1.0}_{-0.9} \times 10^{-9}$ at $4.3 \sigma$ significance [1], consistent with the Standard Model’s prediction of $3.6\pm0.3 \times 10^{-9}$. The significance corresponds to a probability of only around 1 in 100,000 of obtaining an excess at least as large as that seen, in the absence of $B_s \rightarrow \mu\mu$ decays.*

Image 1: A candidate $B_s \rightarrow \mu\mu$ event recorded in the CMS detector in 2012, produced in proton-proton collisions at 8 TeV.

Looking for something new

For all its spot-on predictions over the years, we know that the extremely successful Standard Model of particle physics is incomplete: it offers no explanation for the cosmological evidence of dark matter, nor does it account for the dominance of matter over antimatter in the universe. If BSM physics lies within its grasp, the LHC
will show it to us, and CMS has been systematically searching for indications of various proposed extensions to the Standard Model.

The decay of B mesons (consisting of one bottom quark and a lighter quark) into two muons (μ) is an ideal place to search for indirect evidence for BSM physics. The decays of two types of B mesons – B^0 (made of a bottom quark and a down quark) and B_s (made of a bottom quark and a strange quark) – into pairs of muons are highly suppressed in the SM, yet several proposed extensions of the Standard Model predict either a significant enhancement or an even stronger suppression of these decays. If a measurement of the decay rates of either of these were to be inconsistent with the SM prediction, it would be a clear sign of BSM physics. Over nearly 25 years, a dozen experiments at many different particle colliders have searched for these elusive decays. The established limits have improved by four orders of magnitude in this time, as the sensitivities approach the values predicted by the SM. In the B_s → μμ case, LHCb showed the first clear evidence for the existence of the decay in November 2012, with a significance of 3.5σ.

Image 2: History of searches for decays of B_s and B^0 into pairs of muons at current and past colliders, showing an improvement of four orders of magnitude.

Identifying and counting the B’s

The experimental search for these rare processes requires one to find a few signal events among a potentially overwhelming number of background events: only three out of every billion B_s mesons are expected to decay into two muons, the rate being even lower for the B^0.

The first hurdle in finding the rare signal events is the identification of potential candidates produced in the proton-proton collisions inside the CMS detector. CMS selects around 400 of the most interesting collision events each second, of which roughly 10 events are for the B → μμ searches. These events are further classified
according to the properties of the two muons, to reject as much of the background as possible while retaining most of the signal events.

In addition to looking for the two muons produced from the B decays, CMS must also know to reasonably good precision how many B mesons were produced in total. These numbers are evaluated from counting other, well-studied decays of $B^0$ mesons.

**The first sight of an expected visitor**

![Image 3: The di-muon mass distribution. The purple and red curves show the $B^0$ and $B_s$ signals, respectively, while the dashed line, and the green and black shapes show three different types of background. The solid curve shows the sum of the fit components.](image)

Data collected by CMS in 2011 and 2012, corresponding to samples of 4.9 fb$^{-1}$ and 20.4 fb$^{-1}$ (inverse femtobarns [2]) respectively, were used for this search. The resulting di-muon mass distribution reveals an excess of $B_s \rightarrow \mu\mu$ events over the background-only expectation, corresponding, with a significance of 4.3$\sigma$, to a decay rate of $3.0^{+1.0}_{-0.9} \times 10^{-9}$, where the uncertainty reflects statistical and systematic effects. A paper reporting this result has been submitted to Physical Review Letters.

The CMS $B_s \rightarrow \mu\mu$ measurement is consistent with the prediction of $3.6\pm0.3 \times 10^{-9}$, showing that the SM continues its remarkable run of predictions. The $B^0 \rightarrow \mu\mu$ decay rates are also measured; no evidence of this decay is seen and an upper limit of $1.1 \times 10^{-9}$ is set at the 95% confidence level [3], also consistent with the SM.
Image 4: Two-dimensional contours showing the significance for the $B_s \rightarrow \mu\mu$ and $B_0 \rightarrow \mu\mu$ measurements. The insets show the one-dimensional projections where the curve minimum is the best-fit value for the decay rates and the intersection with zero on the X-axis shows the significance of the measurement.

Where do we go now?

The thrill of this remarkable measurement comes with some disappointment for those seeking new physics. Much of the appeal of the $B_s \rightarrow \mu\mu$ decay channel has been in its potential to reveal cracks in the Standard Model. However, the story is far from over. As the LHC continues to provide additional data, the precision with which CMS and other experiments can measure these key decay rates will steadily improve, and increased precision will be helpful in limiting the viable SM extensions and could point the way ahead to what might lie beyond today’s HEP horizon. Additionally, the next LHC run, starting in 2015, will provide the increase in sensitivity that CMS needs to measure $B_0 \rightarrow \mu\mu$ rates at the level of the SM prediction.

Seeing this rare $B_s$ decay marks a major milestone in a 25-year-long journey, but much uncharted territory lies ahead of us in the particle physics landscape.

About CMS

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 mass?” 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 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: 3275 physicists (including 1535 students) plus 790 engineers and technicians, from 179 institutions and research laboratories distributed in 41 countries all over the world.

More information: http://cern.ch/cms or contact: cms.outreach@cern.ch.

Footnotes

[1] The standard deviation describes the spread of a set of measurements around the mean value. It can be used to quantify the level of disagreement of a set of data from a given hypothesis. Physicists express standard deviations in units called “sigma”. The higher the number of sigma, the more incompatible the data are with the hypothesis. Typically, the more unexpected a discovery is, the greater the number of sigma physicists will require to be convinced.


[3] Confidence level is a statistical measure of the percentage of test results that can be expected to be within a specified range. For example, a confidence level of 95% means that the result of an action will probably meet expectations 95% of the time.

* This sentence was amended on 30 July to fix an incorrect expression of the significance in terms of probability.