Particle X in rare decay could belong to a new physics model

A particle that may mediate the rare decay of a Sigma-plus hyperon appears to have close affiliations with a light Higgs boson found in one supersymmetric model—an interpretation suggesting unambiguous evidence for physics beyond the standard model (SM), scientists say.

Xiao-Gang He of the National Taiwan University, Jusak Tandean of the University of La Verne, and German Valencia of Iowa State have investigated the so-called HyperCP result observed at Fermilab a little over two years ago. While the HyperCP Collaboration began as a search for CP symmetry violation, the rare decay of the Sigma-plus hyperon (made of a strange quark and two up quarks) opens the possibility for the existence of a new particle with unusual characteristics.

This unverified particle, which He and colleagues call particle X, would act as the intermediate state when the Sigma-plus decays to its final state, of a proton, muon-plus and muon-minus. With its extremely light mass (214.3 MeV), low energy, and smallest-ever branching ratio for a baryon decay, particle X would have less than a 1% chance of being accounted for within the SM.

Although He and colleagues showed in an earlier paper that the HyperCP result may be explained by the SM if there is no new particle, the implications of a new particle are considerable. If scientists find that particle X is indeed a new particle belonging to a different model, the breakdown of the SM would open up new doors for future investigations in many areas, and possibly answer many questions unanswered by the SM.

In their recent paper published in *Physical Review Letters*, He et al. turned their attention to a model called the “next-to-minimal sypersymmetric standard model” (NMSSM) that contains seven Higgs bosons. The scientists showed that the lightest one is the main component of a particle called A01, and that A01 satisfies all the constraints of particle X.

“If the existence of a very light A01 is confirmed, other models such as the SM, which do not have any light Higgs bosons, will be ruled out,” Tandean told *PhysOrg.com*.

Tandean also explained how, although the SM has withstood many experimental tests, there are some issues that the model doesn’t address.

“One issue is the so-called hierarchy problem: why the electroweak scale (represented by the W and Z boson masses, of order 100 GeV) is so much smaller than the Planck scale (1019 GeV), at which gravity becomes important for elementary particle interactions,” he said. “One aspect of this issue is that quantum corrections to the Higgs mass make its value arbitrarily large, up to the Planck scale. This clearly contradicts the requirement that the Higgs be lighter than a few hundred GeV.”

However, as Tandean explained, supersymmetric models (where every SM particle has a corresponding superpartner) can provide a natural solution to this problem.

”The presence of the superpartners results in the cancellation of the large quantum corrections, leading to a Higgs mass at the desired level,” he said. “The minimal version of such models is called the Minimal Supersymmetric Standard Model (MSSM). The MSSM is a very attractive model in many ways, but it does not address the question of why the electroweak scale is much smaller than the Planck scale to begin with—this is the so-called mu problem.

“Interestingly, the Next-to-Minimal Supersymmetric Standard Model (NMSSM) solves this problem by adding a set of two particles to the MSSM in such a way that the electroweak scale can be naturally small. The NMSSM has been extensively studied in the literature and has many other interesting features. It is therefore a well-motivated model.”

Among the constraints that the NMSSM’s A01 can satisfy include explaining why X is very light: the mass of A01 can be as low as 100 MeV, and when the mass is 214.3 MeV, the decay into a muon-anti-muon dominates over other possible modes. Secondly, the interactions of A01 can produce the same rate found in the HyperCP observation.

Thirdly, A01 explains why previous experiments with kaons and B-mesons that thoroughly explored the same regions where X exists never saw X. For these reasons, kaon and B-meson decays impose severe constraints on the properties of X, specifically regarding two-quark couplings. This means that, even though A01 could explain the new particle over a wide range of parameters, there are only narrow ranges for which the kaon constraints are also satisfied. However, the scientists also suggest that revisiting these constraints might reveal some overlooked data.

In the future, two new particle accelerators—the Large Hadron Collider (LHC) and International Linear Collider (ILC)—might shed more light on the Higgs hypothesis. Supersymmetry may determine some parameters of particle X, where investigations of squark and chargino intermediate states in the NMSSM might provide more evidence.

“The LHC and ILC have the capability of finding the charginos predicted by supersymmetric theories, depending on the chargino masses,” Tandean said. “In our study, we find that in order to explain the HyperCP results, the lighter chargino mass has to be around 100 GeV, which is within the range to be probed by the LHC and ILC. At the LHC and ILC, it is also possible to study the usual Higgs boson, h, in detail (or the one playing the role of h in NMSSM). If the A01 is the X particle, the process h --> XX can occur and may become the dominant decay mode if the h mass is relatively small (120 to 130 GeV). By studying the properties of h in detail, one may verify that X is the A01.”

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