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Review

Experimental status of supersymmetry after the LHC Run-I

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ABSTRACT

The ATLAS and CMS experiments at the Large Hadron Collider (LHC) at CERN have searched for signals of new physics, in particular for supersymmetry. The data collected until 2012 at center-of-mass energies of 7 and 8 TeV and integrated luminosities of 5 fb^{-1} and 20 fb^{-1}, respectively, agree with the expectation from standard model processes. Constraints on supersymmetry have been calculated and interpreted in different models. Limits on supersymmetry particle masses at the TeV scale have been derived and interpreted generally in the context of simplified model spectra. The constrained minimal supersymmetric standard model is disfavored by the experimental results. Natural supersymmetry scenarios with low supersymmetry particle masses remain possible in multiple regions, for example in those with compressed spectra, that are difficult to access experimentally. The upgraded LHC operating at $\sqrt{s} = 13$ TeV is gaining sensitivity to the remaining unexplored SUSY parameter space.

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1. Introduction

A major motivation for the largest experiment ever built, the Large Hadron Collider (LHC) at CERN, is the search for new physics beyond the standard model. In particular after the standard model (SM) Higgs boson has been discovered [1,2], the experiments focus on searches for new physics, that are expected to explain some of the open questions of the standard model, like the so-called gauge hierarchy problem or the nature of the dark matter in the universe. While the standard model is a remarkably successful theory, it has multiple free parameters with values constrained only by experimental observations. A grand unified theory (GUT) could reduce the number of free parameters by virtue of a larger symmetry.

In this article the experimental results of searches for supersymmetry (SUSY) at the LHC with the ATLAS and the CMS experiments are discussed. Supersymmetry is one of the most popular theories for physics beyond the standard model, and can solve some of the open questions. The implications for the excluded SUSY mass-ranges and the still allowed SUSY phase space regions are reviewed. The experimental methods are summarized, focusing on the latest published results with the dataset collected until 2012 at a center-of-mass energy of 8 TeV, corresponding to an integrated luminosity of about 20 fb^{-1} per experiment.

Supersymmetry [3–12] is a space-time symmetry developed since the 1970s, relating fermions and bosons. SUSY multiplets contain particles differing in spin by 1/2, but having otherwise the same properties, as for example the Yukawa coupling $\lambda_S = |\lambda_f|^2$ to the Higgs field. The masses of the superpartners differ, because SUSY is a broken symmetry. The minimal supersymmetric standard model (MSSM) [13,14] contains chiral supermultiplets, e.g. a spin-1/2 fermion and two scalar bosons. The fermion, e.g. a standard model quark or lepton, has two spin helicity states, therefore two real scalar bosons have the same number of degrees of freedom. Other vector supermultiplets contain spin-1 vector bosons and spin-1/2 fermions, both having two helicity states. In extended supersymmetry $N > 1$ models the supermultiplets are enlarged. These extended theories are not considered in the following interpretations of the experimental results.

1.1. The particle content of supersymmetry

The MSSM is minimal with respect to the field content by which the standard model is extended. The particle content in the MSSM more than doubles the number of SM particles. No known particle of the standard model can be the superpartner of another SM particle, and in contrast to the standard model two electroweak Higgs doublets are necessary to keep the theory free of anomalies and to generate the masses of up-type and down-type fermions. Additional CP and flavor violating couplings are assumed to be negligible. In the standard model the masses are generated by Yukawa couplings to the Higgs field Φ and Φ^*, but complex-conjugate fields are not allowed in the superpotential. Therefore, at least two Higgs doublets H_u and H_d are required in supersymmetric theories, that have together eight degrees of freedom. When the Z^0 and $W^{\pm}$ bosons have acquired mass, the remaining five degrees of freedom generate the spin-0 Higgs bosons h, H, A, and $H^{\pm}$.

The Higgs bosons and all other particles of the standard model get supersymmetric partner “sparticles”. The sparticle names refer to the SM partner with prefix “s” for bosonic superpartners and suffix “ino” for fermionic superpartners. The supersymmetric particle content is summarized in Table 1. The superpartner gauge eigenstates of each line can mix, i.e. the mass eigenstates are linear combinations of the gauge eigenstates. The neutral gauginos $\tilde{B}$, $\tilde{W}^0$, i.e. the SUSY partners of the standard model U(1) and the neutral SU(2) gauge bosons respectively, and the neutral higgsinos mix to form four neutralinos $\tilde{\chi}^0_{1,2,3,4}$, where the mass increases with respect to the lower index. Similarly, the charginos $\tilde{\chi}^{\pm}_{1,2}$ are mixings of the charged gauge eigenstates $\tilde{W}^{\pm}$ and the charged higgsinos. The gluinos $\tilde{g}$ do not mix, and for the sleptons and squarks the mixing of the first and second generation sparticles is usually assumed to be small. The so-called left- and right-handed third generation squarks, e.g. $\tilde{t}_{L,R}$ where the name refers to the chirality of the standard model spin-1/2 partner, mix to form two mass-eigenstates $\tilde{t}_1$ and $\tilde{t}_2$, and similarly for the sbottom $\tilde{b}_{L,R}$ and the stau $\tilde{\tau}_{L,R}$.

When supersymmetry is imposed as a local symmetry, than gravity is naturally included. This constitutes another theoretical motivation for SUSY. In this case, the MSSM can contain the spin-2 graviton and its supersymmetric partner the spin-3/2 gravitino $\tilde{G}$. The graviton is massless and the gravitational coupling is suppressed by the Planck mass.