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Higgs Bosons, Electroweak Symmetry Breaking, and the Physics of the Large Hadron Collider

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The Large Hadron Collider, a 7⊕7 TeV proton-proton collider under construction at CERN (the European Laboratory for Particle Physics in Geneva), will take experiments squarely into a new energy domain where mysteries of the electroweak interaction will be unveiled. What marks the 1-TeV scale as an important target? Why is understanding how the electroweak symmetry is hidden important to our conception of the world around us? What expectations do we have for the agent that hides the electroweak symmetry? Why do particle physicists anticipate a great harvest of discoveries within reach of the LHC?

Keywords: Electroweak symmetry breaking; Higgs boson; Large Hadron Collider; 1-TeV scale; origins of mass

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1 Introduction

Electromagnetism and the weak interactions share a common origin in the weak-isospin and weak-hypercharge symmetries described by the gauge group $\mathrm{SU}(2)_\mathrm{L} \otimes \mathrm{U}(1)_Y$, but their manifestations are very different. Electromagnetism is a force of infinite range, while the influence of the charged-current weak interaction responsible for radioactive beta decay only spans distances shorter than about 10^{-15} cm, less than 1% of the proton radius. We say that the electroweak gauge symmetry is spontaneously broken—hidden—to the $\mathrm{U}(1)_\mathrm{em}$ phase symmetry of electromagnetism. How the electroweak gauge symmetry is hidden is one of the most urgent and challenging questions before particle physics.

The search for the agent that hides the electroweak symmetry is also one of the most fascinating episodes in the history of our quest to understand the material world. Over the next decade, experiments at the Large Hadron Collider (LHC) will lead us to a new understanding of questions that are both simple and profound: Why are there atoms? Why chemistry? What makes stable structures possible? Uncovering the answers to those questions may even bring new insight into "What makes possible the prerequisites for life?" A goal of this Article is to link these questions to the electroweak theory, and to the explorations soon to come at the LHC.

Within the standard electroweak theory, the agent of electroweak symmetry breaking is posited to be a single elementary scalar particle known as the Higgs boson, and so "the search for the Higgs boson" is a common token for the campaign to understand the origins of electroweak symmetry breaking. Such a shorthand is fine—so long as it is not taken to define a very limited menu of opportunities for discovery. As we embark upon the LHC adventure, we will need open and prepared minds!

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