Focus on extra space dimensions

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New Journal of Physics 12 (2010) 075010 (3pp)
Received 15 June 2010
Published 16 July 2010
Online at http://www.njp.org/
doi:10.1088/1367-2630/12/7/075010

Abstract. Experiments at the Large Hadron Collider (LHC) have just started. In addition to verifying the Standard Model (SM) of particle physics, these experiments will probe a new energy frontier and test extensions of the SM. The existence of extra dimensions is one of the most attractive possibilities for physics beyond the SM. This focus issue contains a collection of articles addressing both theoretical and phenomenological aspects of extra-dimensional models.

The idea of introducing extra dimensions in the context of particle physics dates back to the 1920s and the work of Kaluza and Klein [1]. These authors attempted to unify the theory of gravity (general relativity) and electrodynamics (Maxwell theory) by enlarging space dimensions. Although their initial motivation did not become viable, the formalism that they and others developed is still useful. The next incarnation of extra dimensions came around 1980, when string theory was developed as a theory of quantum gravity. It was shown that string theory could only be made consistent if the spacetime dimensions were larger than four. The extra dimensions were supposed to be compactified close to the Planck scale, and therefore not testable in near-future experiments.

It was not until 1998 that it was realized for the first time that extra dimensions could also have an important impact in open problems in particle physics at low-energies (at/below $\sim$TeV). The first breakthrough came from a seminal paper by Arkani-Hamed, Dimopoulos and Dvali (ADD) [2], where it was shown that the hierarchy problem of the Standard Model (SM) of elementary particles could be solved by postulating two or more extra dimensions in which only gravity could propagate. These extra dimensions could be as large as (approximately) a millimeter, and thus observable in future experiments. A year later, Randall and Sundrum (RS) [3] discovered a new possibility for solving the hierarchy problem. They postulated a five-dimensional (5D) space with anti-de Sitter (AdS) geometry compactified at the TeV scale.
The origin of the smallness of the electroweak scale versus the Planck scale was explained by the gravitational redshift factor present in warped AdS metrics. The stability of this extra dimension was a crucial issue for assuring a true solution to the hierarchy problem, and this was subsequently proved in [4]. As in the ADD model, only gravity was assumed to exist in extra dimensions, although it was soon clear that this was unnecessary in the RS model, and also that the SM gauge fields and fermions could propagate in 5D space [5, 7]. Experiments can validate this approach in the near future, since Kaluza–Klein resonances for the SM fields, whose masses can be around the TeV scale, are accessible in present colliders. The physical consequences of the RS models today find an alternative interpretation by means of the AdS/CFT correspondence [6]. Models in warped extra dimensions are related to 4D strongly-interacting theories, and the properties of the 5D fields can be understood as properties of 4D composite states.

Subsequently, extra dimensions were also used to tackle other open questions in particle physics, offering a new perspective. For example, extra dimensions were proposed to explain the disparate fermion-mass spectrum [7, 8], to address the embedding of the SM in a Grand Unified Theory [9], and, more extensively, to explain the origin of electroweak symmetry breaking [10] and supersymmetry breaking [11], including addressing the flavor problem of SUSY [12]. The field of extra dimensions has flourished since then, and continues to influence many aspects of particle physics and cosmology.

The focus issue presented here combines review articles on some of the above mentioned theoretical fields, together with research articles addressing new directions in the field of extra dimensions.

The issue starts with an article by Bayntun, et al on ADD scenarios and how they could arise from string theory [13]. K. Benakli discusses possible new implications of supersymmetry-breaking by extra dimensions [14], and the article of Cabrer et al addresses the problem of stabilization in warped extra dimensions with soft-walls [15]. An extended review and new directions in the field of gauge-coupling unification in warped extra dimensions is given in the article of Choi et al [16].

The first part of the article by Davoudiasl et al provides a review of the model-building (including consistency with precision tests) of the RS models and other warped extra dimensions, while the second part discusses the associated collider phenomenology [17]. Finally, TeV−1-size flat extra dimensions are discussed in two articles: the model motivated (mainly) from the perspective of dark matter, called universal extra dimensions [18] by Datta et al [19], and a scenario providing a mechanism for electroweak symmetry breaking by M. Serone [20].

In summary, some of the ideas discussed will be tested in the coming years by a variety of experiments in particle physics, in particular associated with the ongoing program at the Large Hadron Collider and those for dark matter detection. This focus issue will be a useful reference during this endeavor.

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3 For an earlier work, see Antoniadis [11].

New Journal of Physics 12 (2010) 075010 (http://www.njp.org/)
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New Journal of Physics 12 (2010) 075010 (http://www.njp.org/)