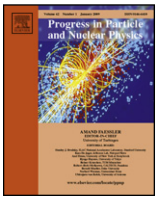
Progress in Particle and Nuclear Physics 67 (2012) 617–650

Contents lists available at SciVerse ScienceDirect

Progress in Particle and Nuclear Physics

journal homepage: www.elsevier.com/locate/ppnp



Review

Black holes and the LHC: A review

Seong Chan Park

Department of Physics, Sungkyunkwan University, Suwon 440-746, Republic of Korea

ARTICLE INFO

Keywords:
Black hole
Extra dimension
LHC
Hawking radiation
Trans-Planckian scattering

ABSTRACT

In low-scale gravity models, a particle collider with trans-Planckian collision energies can be an ideal place for producing black holes because a large amount of energy can be concentrated at the collision point, which can ultimately lead to black hole formation. In this article, the theoretical foundation for microscopic higher dimensional black holes is reviewed and the possible production and detection at the LHC is described and critically examined.

© 2012 Elsevier B.V. All rights reserved.

Contents

E-mail address: s.park@skku.edu.

0146-6410/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.ppnp.2012.03.004

1. Introduction

A long standing problem in high energy physics is understanding the quantum nature of gravity. The problem is often defined in terms of the Planck scale, M_P, which characterizes the strength of the gravitational interaction and sets the cut-off scale of the effective quantum field theoretic formulations for the strong, weak nuclear and electromagnetic interactions. Over the past several decades, the Planck scale has been regarded as a fundamental scale of physics, but the highness of the scale has been also known to lead to the notorious hierarchy problem. The big hierarchy between the Planck scale ($\sim 10^{19}$ GeV) and the electroweak scale ($\sim 10^{3}$ GeV) can be translated into the extreme ratio between the gravitational constant, $G_N = 1/M_P^2$, and the Fermi coupling constant, G_F, which represents the relative weakness of the gravitational interaction compared to the weak nuclear interaction, as follows:

$$\frac{G_N}{G_F} = \frac{6.709 \times 10^{-39}\ \mathrm{GeV}^{-2}}{1.166 \times 10^{-5}\ \mathrm{GeV}^{-2}} \sim 10^{-34}. \tag{1}$$

The presence of a high scale is problematic particularly in the scalar sector since there is a large quantum quadratic correction, $\delta m^2_{\text{1-loop}} \sim \Lambda^2$. The Higgs sector of the standard model thus suffers from a fine-tuning problem at an extremely high level,

$$\Delta_{\text{tuning}} \equiv \frac{m^2_{\text{tree}} + \delta m^2_{\text{1-loop}}}{\Lambda^2} \sim \frac{(100\ \mathrm{GeV})^2}{(10^{19}\ \mathrm{GeV})^2} \sim 10^{-34}, \tag{2}$$

when $\Lambda \sim M_P$. It is evident that the level of fine tuning, Δ_{tuning}, is essentially given by the ratio in Eq. (1). The technical aspect of the fine-tuning problem is known to be resolved in the presence of additional symmetries such as supersymmetry and conformal symmetry provided that their breaking scales are close to the physical Higgs mass, which still demands additional (dynamical) explanations.

In the past decade or so a new field has emerged in high energy physics and has expanded to other fields including quantum and classical gravity, cosmology, astrophysics and numerical relativity based on the realization that extra dimensions can lead to "low scale gravity" and "brane world" models. A higher dimensional brane world model with large, flat, extra dimensions [1–3] and a five-dimensional model with a part of highly warped AdS$_5$ space [4] have catalyzed an entirely new approach to the hierarchy problem. In these new higher dimensional models, a brane, like an ordinary domain wall, soliton or D-brane in string theory, is introduced to confine a subset or entire fields of the standard model. Gravitons, on the other hand, can propagate through the higher dimensional bulk and the effective strength of the gravitational interaction for a brane-localized field is diluted by the large volume of extra dimensions or red-shifted by the 'warp factor' along extra dimension(s). As a result, gravity becomes weak as has been observed in ordinary experiments. The true strength of gravity can only be measured at small distance scales below the compactification radius or the size of extra dimensions, but can cause interesting phenomenological consequences. On the true gravity scale, M_D, can be as low as the electroweak scale then the hierarchy problem does not exist.[1]

The most striking prediction in low-scale gravity models is the production and decay of higher dimensional rotating black holes at the CERN Large Hadron Collider (LHC). Indeed, back in 1974 Penrose first showed that a black hole can be formed in classical high energy head-on collisions [8] and in 1987 't Hooft [9] made preliminary arguments for graviton dominance and black hole formation in the trans-Planckian domain, which has been clarified by many subsequent studies. The production of a black hole during particle collision can be easily understood when we accept the hoop conjecture suggested by Thorne in 1972 [10]. The hoop conjecture essentially states that a black hole forms if and only if a large amount

---

[1] To be fair, one should provide the mechanism to stabilize the 'radion' or geometry to completely solve the hierarchy problem. See [5] for this mechanism. There is now a wide class of string scenarios, including the "flux compactifications" (2001) of Giddings et al. [6] and of Kachru et al. [7] and other general warped compactifications, which make the distinction between large volume and large warping less clear-cut. One can have either, or a combination of both, in more complete scenarios.

Download English Version:

https://daneshyari.com/en/article/1854449

Download Persian Version:

https://daneshyari.com/article/1854449

Daneshyari.com