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Exclusion of black hole disaster scenarios at the LHC

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ABSTRACT

The upcoming high energy experiments at the LHC are one of the most outstanding efforts for a better understanding of nature. It is associated with great hopes in the physics community. But there is also some fear in the public, that the conjectured production of mini black holes might lead to a dangerous chain reaction. In this Letter we summarize the most straightforward arguments that are necessary to rule out such doomsday scenarios.

1. Motivation

As an explanation for the large hierarchy between the Planck scale and the electroweak scale some authors postulated the existence of additional spatial dimensions [1–5]. One exciting consequence of such theories is that they allow for the production of black holes in highly energetic particle collisions [6–13]. It was further conjectured that black holes could have a stable final state. This lead to a public discussion whether such mini black holes once they are produced at the large hadron collider (LHC) could be growing dangerously inside the earth [14]. There is to our knowledge no scientific work that predicts that the remnants (if they exist) of such mini black holes (if they exist) could be stable at masses far above the Planck scale M_f. However, given the public alarm over the subject, we want to go further and also exclude danger from scenarios which are to the present understanding of the physics of mini black holes not well motivated. A number of counter arguments disfavor such disaster scenarios. Recently those arguments have been summarized and discussed by a group [15] who comes to the conclusion that "there is no risk of any significance whatsoever from such black holes". In this Letter we independently present a short coherent argument why there is no risk due to mini black holes from TeV particle collisions. First we look at the logically possible black hole evolution paths. After this we show for every endpoint of the paths, why mini black holes cannot be dangerously growing. For this we use arguments which are already present in [15], but we also bring forward new arguments such as the influence of a strongly growing black hole mass on the escape velocity of the mini black hole.

2. Black holes in large extra dimensions

High energy experiments like those at the large hadron collider (LHC) play a crucial role for a better understanding of the fundamental laws of physics. One hope is that those experiments can discriminate between several approaches that try to extend the physical framework of the standard model [9,16–22]. In some models [1–5] it was conjectured that the hierarchy problem between the Planck scale, $m_{\text{Planck}} \approx 10^{19}$ GeV, and the electroweak scale, $m_{\text{EW}} \approx 100$ GeV, can be solved by postulating the existence of additional spatial dimensions. In Refs. [1–3] this is done by assuming that the (d) additional spatial dimensions are compactified on a small radius R and further demanding that all known Standard Model particles exist on a $(3+1)$-dimensional sub-manifold (3-brane). They find that the fundamental mass M_f and the Planck mass m_{Planck} are related by

$$m_{\text{Planck}}^2 = M_f^{d+2} R^d. \tag{1}$$

Within this approach it is possible to have a fundamental gravitational scale of $M_f \sim 1$ TeV. The huge hierarchy between m_{EW} and m_{Planck} would then come as a result of our "ignorance" regarding extra spatial dimensions. Due to the comparatively low fundamental scale $M_f \sim$ TeV and the hoop conjecture [23], it might

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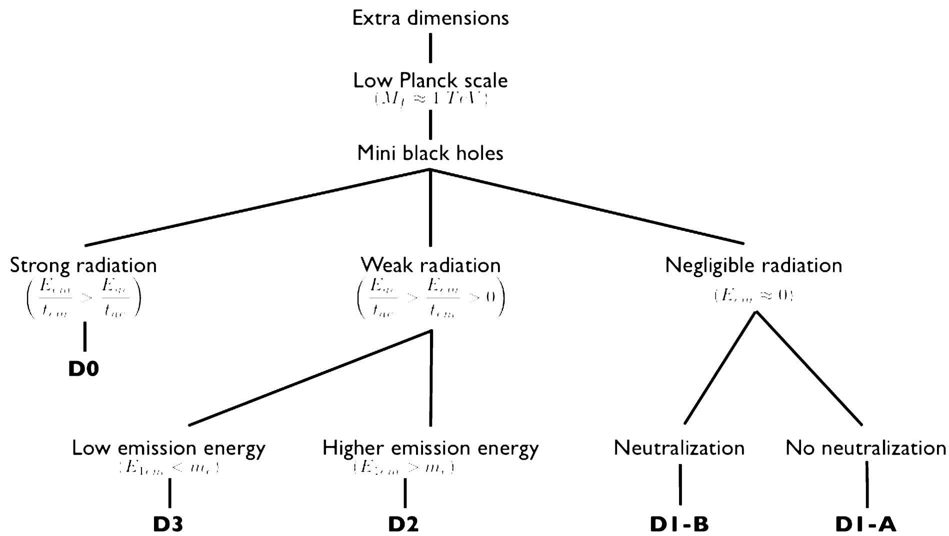

Fig. 1. Possible black hole evolution paths.

be possible to produce mini black holes with masses of approximately 1 TeV in future colliders [6–13]. This can only be the case when the invariant scattering energy $\sqrt{s}$ reaches the relevant energy scale M_f. The higher dimensional Schwarzschild radius [8,24] of these black holes is given by

$$R_H^{d+1} = \frac{16\pi(2\pi)^d}{(d+2)A_{d+2}}\left(\frac{1}{M_f}\right)^{d+1}\frac{M}{M_f}, \tag{2}$$

where A_{d+2} is the area of the $(d+2)$-dimensional unit sphere

$$A_{d+2} = \frac{2\pi^{(3+d)/2}}{\Gamma(\frac{3+d}{2})}. \tag{3}$$

A semi-classical approximation for the mini black hole production cross section is given by

$$\sigma(M) \approx \pi R_H^2 \xi(\sqrt{s} - M_f), \tag{4}$$

where the function ξ ensures that black holes are only produced above the M_f threshold. The function ξ is one for $\sqrt{s} \gg M_f$ and zero for $\sqrt{s} \approx M_f$. In many simulations ξ is replaced by a theta function. The validity of this approximation has been debated in [25–35] and the observable formation of an event horizon has been questioned [36,37]. However, other improved calculations including the diffuseness of the scattering particles (as opposed to point particles) and the angular momentum of the collision (as opposed to head on collisions) as well as string inspired arguments only lead to modifications of (4) which are of the order of one [38–41]. This would open up a unique possibility of studying gravitational effects at very small distance scales in the laboratory. Such observations of gravitational physics at the tiny scales of the quantum world may provide access to the presently biggest question of theoretical physics: A unified description of quantum physics and gravity.

At the same time there is a growing concern in the public. “Could such monstrous objects like mini black holes (once they are produced at LHC) eat up the entire world?” This question is controversially discussed in blogs and online-video-portals [14]. Similar anxieties (with strangelets instead of black holes) have already been stirred up when the previous generation of collider was built [42]. Fears of possibly dangerous mini black holes have been augmented by the idea of a quasi stable black hole final state. A quasi stable black hole final state has been frequently studied in the literature [43–68] which partially refer to astrophysical black holes and partially refer to mini black holes. Instead of ignoring this concern we take it serious and try to discuss the issue without provoking an emotional palaver. We explain from theoretical arguments why such a disaster is generally believed to be impossible. But we even go one step further and discuss the question: “What if the theory is wrong?” We show that even if the current theories are wrong, there is no danger as long as the “true theory” is not completely unphysical [69]. By mostly using arguments that are based on black hole production in highly energetic cosmic rays [70], a recent and extensive study on the (im) possibility of dangerous mini black holes has been given in [15]. However, in this Letter we want to concentrate on a short but convincing argument.

3. Possible black hole evolution paths

The logical structure of the assumptions that are relevant for this study is shown in Fig. 1. We will now discuss the tree structure in Fig. 1 step by step. Every branch of the tree ends with a discussion (D0–D3) which can be found in the next section. In those discussions we explain with either theoretical or experimental arguments why the discussed branch cannot have any disastrous consequences. Therefore, we define the average energy (E_{em}) as the energy which is emitted in the rest frame of the mini black hole in the average time scale (t_{em}). The corresponding definition for accretion gives the average energy (E_{ac}) as the energy which is accreted in the rest frame of the mini black hole in the average time scale (t_{ac}). If not explicitly stated otherwise, accretion times and energies are those for relativistic mini black holes from highly energetic cosmic rays. In order to open up the possibility of producing mini black holes in a 14 TeV collider, one has to assume the existence of extra dimensions with a fundamental mass scale in the $\sim$TeV range. Next one has to assume that quantum gravity effects do not spoil the conjecture that classical closed trapped surfaces lead to the formation of a black hole event horizon. If all this is given then the mini black hole could in principle follow three different paths in its further development. First, it could emit highly energetic radiation (E_{em}) in a short time scale (t_{em}) such that a comparison to the accretion energy (E_{ac}) and accretion time (t_{ac}) shows a net emission ($E_{em}/t_{em} > E_{ac}/t_{ac}$). This is what most theoreticians predict and it would be the case for both, the balding phase and the Hawking phase. In the tree Fig. 1 this possibility is denoted as “*Strong radiation*”. As discussed in (D0) such a black hole cannot cause any danger.