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Observing higher-dimensional black holes at the LHC

S. Sekmen[a], M.T. Zeyrek

Physics Department, Middle East Technical University, Ankara 06531, Turkey

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Abstract. A new approach to spacetime proposing the existence of n compactified large extra dimensions predicts the creation of higher-dimensional black holes at the LHC of CERN. In case they form, signatures of such black holes at accelerators would be quite significant and black hole decay products would carry valuable information for particle physics and cosmology. In this study we first make a short theoretical introduction, then present the results of an analysis made on a Monte Carlo simulation modeling black hole production and decay at the LHC. This analysis includes the examination of the lepton case in black hole to Higgs decay channels, reconstruction of the black hole masses, a calculation of the Hawking temperature and a determination of the radiated jets/leptons multiplicity ratio.

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1 Theoretical introduction

1.1 Large extra dimensions – the ADD model

According to recent theoretical arguments, LHC of CERN might host some interesting events like the formation of the first Earthly black holes when it starts operating in 2007. Yet this certain possibility of creating black holes on Earth is not mainly due to the high center of mass energy of LHC, but rather to a new idea that suggests a modification in the structure of spacetime by assuming the existence of n compactified large extra dimensions.

The primary motivation behind introducing large extra dimensions was to find a satisfactory solution to the hierarchy problem existing between the electroweak and Planck scales caused by the weakness of gravitational interactions. Yet this hierarchy is only valid when the gravitational coupling is considered to be constant in all distance scales. However in 1998, Arkani-Hamed, Dimopoulos and Dvali proposed that gravitational coupling might increase by decreasing scales if n large extra dimensions exist below a certain distance scale $\sim R$, where $n = 1, ..., 6$ [1–3]. According to this idea which is referred to as the ADD model, the bulk world created by large extra dimensions is only open to gravitational interactions while gauge interactions are localized to the "3-brane". Therefore contributions coming from the components of gravity in the extra dimensions enhance the gravitational coupling. Such an increase results in a decrease in the unification scale whose value then would be determined by the number and geometry of the large extra dimensions. At this point the ADD model proposes that unification occurs at the electroweak scale $M_{\mathrm{EW}} \sim$ TeV, which should be defined as the true fundamental Planck scale $M_{(4+n)}$ while the effective 4-dimensional Planck scale $M_{(4)} \sim 10^{19}$ GeV valid in the absence of large extra dimensions is considered as an ordinary energy scale. To find the relation between $M_{(4)}$ and $M_{(4+n)}$, we can compare the expressions of Newton's third law in 4 and $4 + n$ dimensions. In the presence of large extra dimensions, Newton's law is found by using the $(4 + n)$-dimensional Gauss law and is given for distances $r \ll R$ (where R is the common radius of n large extra dimensions) as

$$F(r) = G_{N(4+n)} \frac{m_1 m_2}{r^2} = \frac{1}{M_{(4+n)}^{n+2}} \frac{m_1 m_2}{r^{n+2}} \tag{1}$$

and for distances $r \gg R$ as

$$F(r) = \frac{1}{M_{(4+n)}^{n+2} R^n} \frac{m_1 m_2}{r^2}. \tag{2}$$

Here, the strength of the gravitational interactions, and therefore Newton's force law, is modified only at the domain of large extra dimensions, that is, at distances $r \ll R$. This modified version of Newton's law under the effect of extra dimensions is stated in (1). On the other hand, at distances $r \gg R$, where gravitation cannot penetrate the large extra dimensions, the strength of gravitation, and therefore the force between two masses given by Newton's third law, does not change. Only a change occurs in the mathematical expression of Newton's law: The familiar expression $F(r) = m_1 m_2 / M_{(4)} r^2$ in terms of $M_{(4)}$ is replaced by a new expression in terms of $M_{(4+n)}$ and R, given by (2). This means that we can compare (2) with the original Newton's third law $F(r) = m_1 m_2 / M_{(4)} r^2$ to find the relation between the two Planck scales $M_{(4)}$ and

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[a] *Corresponding author:* e-mail: ssekmen@aegee.metu.edu.tr

$M_{(4+n)}$ to be

$$M^2_{(4)} \sim M^{2+n}_{(4+n)} R^n. \tag{3}$$

For $n = 1$, R is found to be 10^{11} m which is strictly impossible, but for $n = 2$, $R \sim 100\,\mu\mathrm{m}$–$1\,\mathrm{mm}$, which is a distance scale that could be probed at the future particle accelerators. In any case the amount of modification in the gravitational coupling could be found by comparing Newton's laws at $r \ll R$, in the presence and absence of extra dimensions, which gives

$$\frac{F_{(4+n)}}{F_{(4)}} \sim \frac{R^n}{r^n}. \tag{4}$$

1.2 Higher-dimensional black holes

In a 4-dimensional world, the smallest black hole to be formed via proton–proton collision would require an accelerator with a center of mass energy about $\sim 10^{20}$ GeV. However, the new theory of large extra dimensions which assumes a gravitational coupling that gets stronger by decreasing distance scales foresees black hole formation at the $\sim$ TeV scale. The Schwarzschild radius of such a $(4+n)$-dimensional black hole is calculated formally by solving the $(4+n)$-dimensional Einstein field equations and is found to be [4]

$$r_{\mathrm{s}(4+n)} = \frac{1}{\sqrt{\pi} M_{(4+n)}} \left(\frac{M_{\mathrm{BH}}}{M_{(4+n)}} \left(\frac{8\Gamma((n+3)/2)}{n+2} \right) \right)^{\frac{1}{n+1}}. \tag{5}$$

Comparing $r_{\mathrm{s}(4+n)}$ with $r_{\mathrm{s}(4)}$ being the Schwarzschild radius of a black hole living in 4 dimensions, gives the relationship

$$r_{\mathrm{s}(4)} < r_{\mathrm{s}(4+n)} < R, \tag{6}$$

which clearly shows that a black hole with mass M_{BH} has a bigger Schwarzschild radius in the presence of n large extra dimensions, and therefore is easier to produce than a 4-dimensional black hole [5]. In fact, the true nature of black hole formation via particle collisions could only be understood through examining the detailed theories of high energy scattering process. Since such an effort requires a total formulation of quantum gravity, which still does not exist today, we need to be content with a semi-classical description, which was presented by Banks and Fischer in [6]. This approach states that at impact parameters smaller then the $(4+n)$-dimensional Schwarzschild radius and at CM energies greater then $M_{(4+n)}$, the proton–proton collision cross section is dominated totally by inelastic black hole production. The parton level black hole production cross section is calculated via geometrical assumptions and is given as [7,8]

$$\begin{aligned} \sigma(M_{\mathrm{BH}}) &= \pi r^2_{\mathrm{s}(4+n)} \\ &= \frac{1}{M^2_{(4+n)}} \left(\frac{M_{\mathrm{BH}}}{M_{(4+n)}} \left(\frac{8\Gamma((n+3)/2)}{n+2} \right) \right)^{\frac{2}{n+1}}. \end{aligned} \tag{7}$$

This cross section increases with increasing mass and decreases with increasing Planck scale. However in case of high energy scattering, partons with any gauge and spin quantum numbers could combine to form a black hole, so in order to find the differential black hole production cross section, every combination of two partons should be taken into account. Such a cross section could be calculated using the parton luminousity approach to be

$$\frac{\mathrm{d}\sigma(pp \to \mathrm{BH} \to X)}{\mathrm{d}M_{\mathrm{BH}}} = \frac{\mathrm{d}L}{\mathrm{d}M_{\mathrm{BH}}} \sigma(ab \to \mathrm{BH}) \Big|_{s=M^2_{\mathrm{BH}}}, \tag{8}$$

where

$$\frac{\mathrm{d}L}{\mathrm{d}M_{\mathrm{BH}}} = \frac{2M_{\mathrm{BH}}}{s} \sum_{a,b} \int_{M^2_{\mathrm{BH}}/s}^{1} \frac{\mathrm{d}x_a}{x_a} f_a(x_a) f_b(M^2_{\mathrm{BH}}/sx_a) \tag{9}$$

is the sum over all types of initial leptons and the $f_i(x_i)$ are the parton distribution functions. Integrating (8) leads to the total black hole production cross section. Some calculated integrated cross sections at LHC CM energies for BH masses above the given Planck scales are $\sigma \sim 430$ pb for $M_{(4+n)} = 2$ TeV, $n = 3$; $\sigma \sim 0.5$ nb for $M_{(4+n)} = 2$ TeV, $n = 7$; $\sigma \sim 120$ fb for $M_{(4+n)} = 6$ TeV, $n = 3$ and $\sigma \sim 6.9$ fb for $M_{(4+n)} = 10$ TeV, $n = 4$ [7,8]. These cross sections multiplied by the integrated luminosity of LHC give a considerably dominant BH production at LHC. A 430 pb cross section corresponds to 4.3×10^6 black hole events per year at low luminosities of LHC operation.

After being produced, these black holes would decay via Hawking radiation [9]. The Hawking temperature for a black hole in $4+n$ dimensions is

$$\begin{aligned} T_{(4+n)} = M_{(4+n)} &\left(\frac{M_{(4+n)}}{M_{\mathrm{BH}}} \right)^{\frac{1}{n+1}} \\ &\times \left(\frac{(n+1)^{n+1}(n+2)}{2^{2n+5}\pi^{(n+1)/2}\Gamma((n+3)/2)} \right)^{\frac{1}{n+1}}. \end{aligned} \tag{10}$$

Then the lifetime is calculated from the Hawking teperature and is found to be

$$\tau_{(4+n)} \sim \frac{1}{M_{(4+n)}} \left(\frac{M_{\mathrm{BH}}}{M_{(4+n)}} \right)^{\frac{n+3}{n+1}}. \tag{11}$$

Comparing (8) and (9) with their 4-dimensional equivalents show that a $(4+n)$-dimensional black hole is colder and it decays slower than a 4-dimensional black hole with the same mass [5]. Black holes formed via particle collisions would have charge and spin, so this would lead to a particle radiation in four phases, which are consequently the balding phase, where the black hole sheds the asymmetry of its charge, the spin-down phase, where the black hole sheds its angular momentum, the Schwarzschild phase, where the black hole evaporates via Hawking radiation and finally, the Planck phase, where the black hole ends by emitting a few particles having energies around the Planck scale [8].

An important question here is the destination and type of radiated particles. Since Hawking radiation is a thermal process, the nature of decay is democratic and the black hole emits every brane and bulk field with an equal probability. Since there are an infinite number of Kaluza–Klein modes, most of the radiation should go to the bulk. However, an argument in [10] shows that the total radiation emitted by all Kaluza–Klein modes is equivalent to radiation that should come from a single bulk field, and that radiation is dominated by the brane fields. As a result, a black hole decays mainly to the brane fields, and to each of them, including Higgs, with the same ratio [7].

Such black holes to be seen at LHC would reveal themselves through the structure of their decay products. Direct proofs of the existence of black holes could be listed as high multiplicity, spherical distribution, democratic decay[1], high transverse energies and particle energies which can reach up to $M_{(4+n)}$. Such observations would provide direct information on the nature of black holes, on Hawking radiation and on the structure and dimensionality of spacetime.

2 A virtual "black hole analysis"

2.1 Monte Carlo event definitions

The theoretical formulations that foresee higher-dimensional black hole creation at particle accelerators are reasonable but still not perfectly accurate. The true nature of such theories could only be revealed and the indefinite parts could only be cleared through facts offered by collision experiments with sufficient CM energy, which await the operation of LHC in 2007. As stated before, in case large extra dimensions exist, black hole formation is likely to be observed in such experiments. Our present study is based on an analysis of a simulation that models such a black hole production and consequent decay that might be possible at the LHC. The 50 K black hole event sample used was generated using TRUENOIR Monte Carlo by Dimopoulos and Landsberg [17] and it assumes that black holes are Schwarzschild type – having no charge and spin –, small couplings are absent, black hole decay is democratic[2] and time evolution is ignored during decay. Important parameters defined for this simulation are listed in Table 1. To simulate a detector and for jet and missing energy reconstructions at the LHC we used the fast detector simulation package CMSJET [16] as an example.

Using the data from the above simulation, black hole to Higgs decay channels were examined, black hole mass reconstructions were made, a general Hawking temperature was calculated, and the ratio of radiated jets to leptons was found.

Table 1. Parameters used in TRUENOIR Monte Carlo generation

Name of parameter	Value
Total number of spacetime dimensions	7
Number of large extra dimensions (n)	3
Fundamental Planck scale (M_{4+n})	2 TeV
pp CM energy	14 TeV
BH production cross section	430 pb
Higgs mass	130 GeV
Higgs production probability	1%

During this analysis, several particle multiplicity and energy cuts were applied such as follows: In black hole events, the average multiplicity for particles should be very much larger than 1, since otherwise the energy of the decay products would approach the kinematic limit for pair production (which is $M_{\mathrm{BH}}/2$) and the shape of the energy spectrum would depend on the details of the black hole decay model. Therefore the total number of jets + leptons + photons was required to be at least 4. Also events have to include either a lepton or a photon, because these have a considerably low background at high CM energies. All lepton and photon energies in selected events should be greater than 100 GeV, all lepton and photon transverse energies should be greater than 50 GeV and all jet transverse energies should be greater than 25 GeV. Furthermore, all particle energies have to be less than $M_{\mathrm{BH}}/2$ so that they do not approach the kinematic limit for pair production [7]. In order to get a clearer view among a high multiplicity of energetic jets, the cone radii of jets were taken to be 0.4. Such a selection reduces the original Monte Carlo event sample to 8960 black hole events, or to 17.9% of the total.

2.2 Black hole → Higgs decay channels

The democratic nature of Hawking radiation requires that there is approximately 1% probability of Higgs emission in black hole decays. The presence of Higgs particles could be checked by making invariant mass reconstructions from possible Higgs decay products. Among the Higgs decay channels for a 130 GeV Higgs, we have examined the following three ones whose branching ratios are (by HDECAY calculations [15]) $\mathrm{BR}(H \to bb) = 0.5254$, $\mathrm{BR}(H \to WW) = 0.2893$ and $\mathrm{BR}(H \to ZZ) = 0.0383$. Here the W decay further to $l\nu$ or jj and the Z decay to ll or $\nu\nu$. Overall, three channels with highest branching ratios are $\mathrm{BH} \to H \to bb$, $\mathrm{BH} \to H \to WW \to l\nu jj$ and $\mathrm{BH} \to H \to WW/ZZ \to l\nu l\nu$. The dominant channel $\mathrm{BH} \to H \to bb$ was already examined widely in [16, 17]. Although the lepton channels with their extremely low branching ratios do not provide much hope for observation of Higgs, our present study still analyses such channels, mostly in order to visualize the possible mass

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[1] In a more realistic approach, the geometry near the BHs event horizon creates a potential barrier which causes a part of the radiated particles to scatter back into the BH. This effect modifies the blackbody spectrum of the BH decay products. This modification is expressed by the "greybody factors", which are present in the definition of the BH radiation spectrum. A recent review and an extensive list of references on this subject could be found in [11].

[2] There is a more recent event generator (CHARYBDIS) which includes full greybody effects and also allows Hawking radiation to vary as the BH decay processes [12].

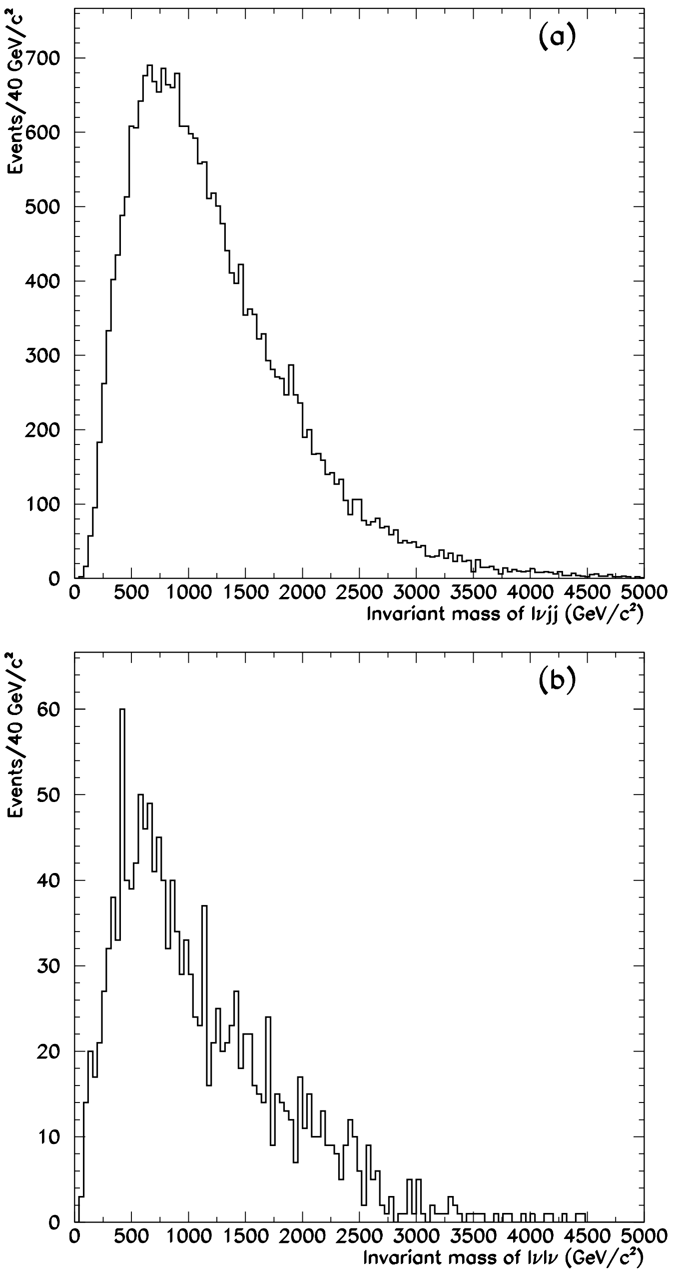

Fig. 1. Invariant mass distributions for (a) BH $\to H \to l\nu jj$ and (b) BH $\to H \to l\nu l\nu$

distribution in case of black hole presence. In every selected event, invariant masses were reconstructed by using a lepton + total missing energy + two jets for the $l\nu jj$ case and by using two leptons (with opposite charges) + total missing energy in the $l\nu l\nu$ case. Here the total missing energy counts for neutrinos. The results are shown in Figs. 1a,b.

As seen from those figures, tracing Higgs bosons at the lepton decay channels is almost impossible, since even those Higgses that might have come out from black hole decay are lost in an overwhelming background created by both missing energy and jet reconstruction uncertainties and also of high energetic leptons and jets coming directly from Hawking radiation. According to the democratic nature of Hawking radiation, lepton and neutrino emission rates are each $\sim 5\%$, while the jet emission rate is $\sim 70\%$. On the other hand, Higgs emission is only $\sim 1\%$, and BH $\to H \to WW/ZZ$ channels theoretically make up $\sim 0.34\%$ of black hole decays, which makes those channels very sensitive. Especially the largeness of the missing energy emission by a factor of ~ 15 compared to Higgs emission creates great uncertainities in the reconstructed Higgs masses.

2.3 Black hole mass

A black hole mass distribution could be found by making invariant mass reconstructions using all leptons, photons, jets and missing energy in each selected black hole event. Figure 2 shows the black hole mass distribution for the above event selection in Sect. 2.1.

In the case of higher-dimensional black holes, a semi-classical approximation of the theories defining black hole properties work best when the black hole mass is much higher than the Planck scale ($M_{\mathrm{BH}} \gg M_{(4+n)}$), whereas for lower black hole masses, stringy effects interfere. In our case, the mean black hole mass is 2924 GeV and is only slightly greater than $M_{(4+n)}$, which is 2 TeV in this simulation. Such a mean mass (and even the largest black hole masses accessible at the LHC) are far from satisfying $M_{\mathrm{BH}} \gg M_{(4+n)}$ and this will cause problems in the experimental research, especially in Hawking temperature reconstructions in lower masses as will be explained in next section. Here, those entries with masses below 2 TeV might be a question but this should not be considered as an inconsistence. Such low black hole masses would occur due to detector sensitivity.

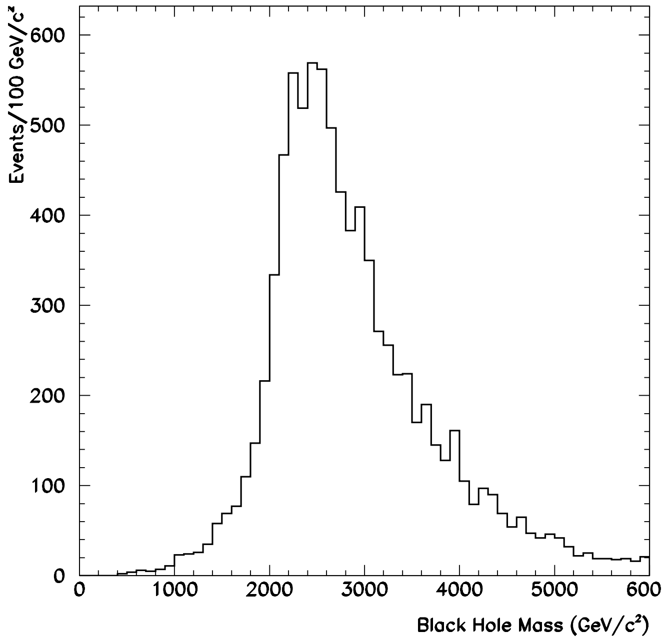

Fig. 2. Black hole mass distribution. The average black hole mass is 2924 GeV

The black hole mass distribution is asymmetrical about its maximum at 2.4 TeV, which is very close to $M_{(4+n)}$. This asymmetry is such that black hole mass entries to the right of the maximum black hole mass are more than the black hole mass entries to the left. Such a distribution happens because the entries to the left consist of only those masses measured due to detector sensitivity, while on the other hand entries to the right consist of those masses both due to detector sensitivity plus those black hole masses allowed by the theory and should normally be there. The discussion above shows that the shape of the black hole mass plot to be seen at the experiment in LHC could give us a bare idea about the value of the Planck scale. Information on the black hole mass, combined with the experimental value of the Hawking temperature could also be used to estimate the number of extra dimensions in spacetime as is explained in the following section.

2.4 Hawking temperature

The equation for Hawking temperature was already given in (10). When the black hole mass, the number of large extra dimensions n and the Planck scale $M_{(4+n)}$ are known simultaneously, the theoretical Hawking temperature could be found using that equation. For example, the Hawking temperature for a black hole having a mass of 2924 GeV (which is the average mass calculated in the previous section) with $n = 3$ and $M_{(4+n)} = 2\,\mathrm{TeV}$ corresponds to 767 GeV (8.9×10^{15} K).

On the other hand, the Hawking temperature could also be found experimentally by fitting the energy distribution of the black hole decay products to the Planck formula $\frac{\mathrm{d}f}{\mathrm{d}x} \sim \frac{x^3}{\mathrm{e}^x \pm c}$ with $x = E/T_{\mathrm{H}}$ where $c = -1$ for bosons, $+1$ for fermions and 0 for Boltzmann statistics, and then extracting the Hawking temperature by using the relation $\langle 1/E \rangle = a/T_{\mathrm{H}}$, where a is 0.46 for bosons, 0.68 for fermions and 1/2 for Boltzmann statistics.

For our case, we calculated a general Hawking temperature from all events seen in the black hole mass distribution, which would represent a black hole with an average mass of 2924 GeV. This was done by plotting energies of all particles emitted via Hawking radiation (which are leptons, jets, photons, W/Zs, Higgses and tops) for all selected events. Leptons or jets coming directly from black hole decay were determined by first making all possible invariant mass reconstructions from each lepton or jet, and then selecting those leptons or jets none of whose reconstructed invariant masses are in the energy range of W/Z, Higgs or top signals. The energy distribution of such selected black hole decay products were fitted to the Planck curve. The results are shown in Figs. 3a where the Planck curve was fitted starting from 100 GeV and b where the Planck curve was fitted starting from 750 GeV according to the χ^2 method. The distribution in the energy range of Fig. 3b is seen to fit better to the Planck formula. This result points out that particles in the lower energies make up the background while particles in the higher energy range do present the real energy distribution of Hawking radiation.

Then the Hawking temperature corresponding to Fig. 3b was calculated from $\langle 1/E \rangle$ as explained above, along the curve for an energy range of 100–3000 GeV, and was found to be ~ 304.7 GeV (3.54×10^{15} K). Putting this and also the average black hole mass into (10), we can find the number of extra dimensions n to equal ~ 1.1. Both the values of T_{H} and n are very low compared to the theoretically expected values. This is because the energy distribution is situated at lower energies than it should actually be. At a first glance, this could be related to the high background at low energies mostly due to detector resolution or uncertainities in jet or missing energy reconstructions, but the main problem lies in the fact that the black hole mass is very close to $M_{(4+n)}$. Theoretically, at such low masses, the emitted particle multiplicity $\langle N \rangle = M_{\mathrm{BH}}/2T_{\mathrm{H}}$ is also very low (e.g. $\langle N \rangle = 2$ for $M_{\mathrm{BH}} = 3\,\mathrm{TeV}$), leading to particle emission at the kinematic limit $M_{\mathrm{BH}}/2$, which would cause a model-dependent energy spectrum for the decay. To examine such a situation, we need the exact formulation for low mass theories. Of course $M_{(4+n)} \sim 1$ could as well provide more accurate estimations of T_{H} and n at the LHC energies. In any case, the results could be improved by examining only the decay products of black holes within the highest mass ranges. To see that, we analysed events only with $M_{\mathrm{BH}} > 4\,\mathrm{TeV}$. Here the average M_{BH} is 4890 GeV, the theoretical value of T_{H} is 674 GeV (7.82×10^{15} K) and the average multiplicity is ~ 4. The energy distribution is given in Fig. 3c. The resulting Hawking temperature is 464 GeV (5.39×10^{15} K) and n is ~ 2.1, values which are slightly better than previously obtained results, but still far away from satisfying the theory at hand.

2.5 Jets/leptons ratio

The democratic nature of Hawking radiation points out that the ratio of hadronic to leptonic activity in black hole decays is about $36/4 = 9$. However in our case we do not consider the top quark among the jets and the tau among the leptons, so this ratio reduces to $30/4 = 7.5$. To find the observed jets/leptons ratio, we counted all jets and leptons in the selected black hole events which directly come from Hawking emission, or in other words, which do not come from the decays of W/Z, Higgs or top. However, this time we did not require a lepton or photon during event selection, since such a choice would change the statistics in favor of leptons. The only restriction concerning the particle numbers was the total multiplicity cut which requires the number of leptons + jets + photons to be at least 4.

Leptons and jets coming from black hole decay were found as in the previous section, by making all possible invariant mass reconstructions, and then only taking those leptons and jets none of whose reconstructed invariant masses are in the energy ranges of W/Z, Higgs or top peaks. However, ignoring all the leptons or jets in the energy range of the signals would also not be correct, since not all leptons or jets in the energy range of W/Z, Higgs or top signals are W/Zs, Higgses or tops, but

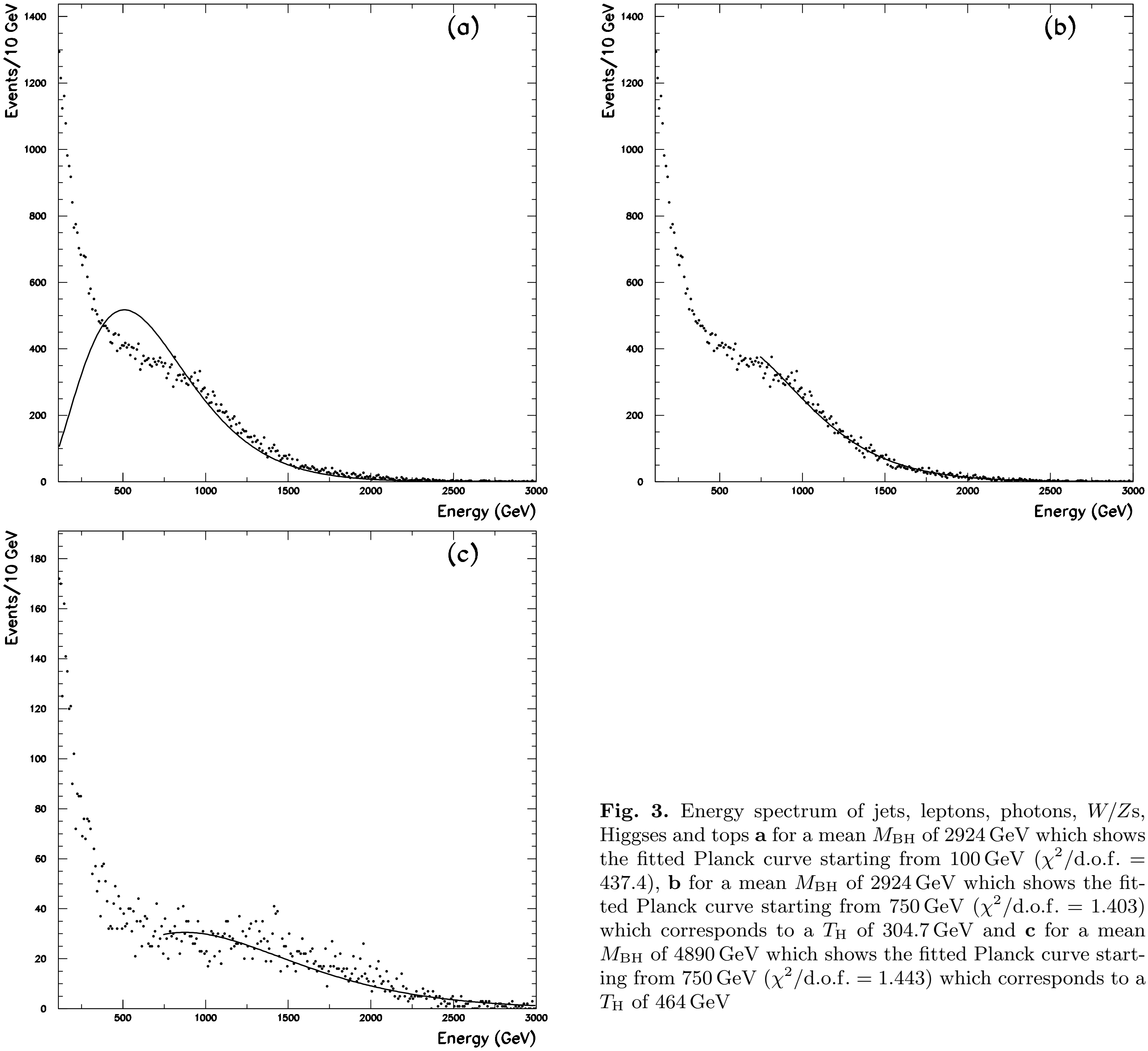

Fig. 3. Energy spectrum of jets, leptons, photons, W/Zs, Higgses and tops **a** for a mean M_{BH} of 2924 GeV which shows the fitted Planck curve starting from 100 GeV (χ^2/d.o.f. = 437.4), **b** for a mean M_{BH} of 2924 GeV which shows the fitted Planck curve starting from 750 GeV (χ^2/d.o.f. = 1.403) which corresponds to a T_{H} of 304.7 GeV and **c** for a mean M_{BH} of 4890 GeV which shows the fitted Planck curve starting from 750 GeV (χ^2/d.o.f. = 1.443) which corresponds to a T_{H} of 464 GeV

rather some constitute the background. Those particles within the background should also be counted among the black hole decay products. So, to achieve a more precise total number of jets and leptons, jet or lepton backgrounds should also be known and added to the total of particles which lie out of signal energy ranges. For jets, the signal to background ratio was estimated from the jj mass reconstruction made in a previous study [17]. Signal peaks in the jj mass distribution lie over a flat background. Both signal and background events were counted in a 2σ range. At the Higgs peak, this gives $S/B = 0.82$. An average S/B value of $\sim 1/1$ was estimated also with considering W/Z and top peaks. For leptons, the background was estimated from the $ll \to Z$ and $l\nu \to W$ invariant mass reconstructions. In the ll case the background is very low while in the ln case, because of the uncertainities in the missing energy definitions, the background is relatively high. From a combination of these two channels, we estimated the signal to background ratio for leptons to be 2/1. Table 2 summarizes the radiated jet and lepton multiplicities and totals.

As seen in Table 2, the jets/leptons multiplicity ratio turns out to be 6.82 and this result is quite close to the theoretical value. Such a jets/leptons ratio is a very characteristic signature of Hawking radiation and is, along with such properties as high sphericity, high multiplicity and high transverse energy of the decay products, a relatively reliable way to observe the black hole presence.

Table 2. Hawking radiation decay product multiplicities: jets and leptons

Jets or leptons per event	Events with jets	Events with leptons	Jets	Leptons
1	726 (6.9%)	2374 (65.9%)	726	2374
2	2933 (28.1%)	1047 (29.0%)	5865	2094
3	1761 (16.9%)	145 (4.0%)	5282	434
4	3711 (35.6%)	31 (0.9%)	14842	125
5	632 (6.0%)	2 (0.06%)	3158	12
6	390 (3.7%)		2340	
7	172 (1.6%)		1204	
8	72 (0.7%)		576	
9	24 (0.2%)		216	
10	14 (0.1%)		135	
Total	10432	3599	34343	5039

3 Conclusions

Our analysis was an attempt to visualize the outcome of a high energy collision experiment resulting with formation of higher-dimensional black holes in case the ADD model happens to be the theory describing the universe. Although reached through only a theory based simulation, our results still could lead to several useful conclusions which we will restate here. In the first place, the long-expected Higgs boson could only be observed in jet channels. On the other hand lepton channels would not be approppriate for tracing Higgs particles since they have extremely low branching ratios, and also since the background in lepton channels created by high energetic leptons and jets coming directly from Hawking radiation is high enough to overtake the only slightly possible signal.

Another idea would be to reconstruct the black hole mass from all black hole decay products, since knowing the black hole mass and combining it with other experimental findings could help to verify some parts of the present higher-dimensional theories and might even lead to interesting clues concerning the true nature of such theories or values of undefined parameters in them. A good example studied here is the attempt to estimate the number of extra dimensions from the observed Hawking temperature values. However, in order to achieve both more realistic and accurate results, the exact Hawking radiation theories should be constructed, especially for low masses, and the experimental analysis should consider the detailed properties of these theories, such as greybody factors and the time dependence of the Hawking radiation. Further improvements could be made by also considering all other black hole phases and also black hole decay modes to bulk fields.

Finally, examination of black hole decay product multiplicities and the radiated jets/leptons ratio would verify the presence of black holes if a democratic distribution among the examined decay products is observed. As a matter of fact, LHC could only hope to host higher-dimensional black holes if both the Planck scale and number of large extra dimensions are low, and such black holes could only be analysed precisely if the experimental expectations are defined throughly via constructing the more realistic low black hole mass theories.

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