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Extra-dimensional physics with p+p in the ALICE Experiment

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Abstract

The concept of Large Extra Dimensions (LED) provides a way of solving the Hierarchy problem which concerns the weakness of gravity compared with the strong and electro-weak forces. A consequence of LED is that miniature Black Holes (mini-BHs) may be produced at the Large Hadron Collider in p+p collisions. The present work uses the CHARYBDIS mini-BH generator code to simulate the hadronic signal which might be expected in the ALICE detector from the decay of these exotic objects if indeed they are produced.

1 Introduction

The Hierarchy Problem in particle physics is concerned with the question of why gravity is so weak compared with the other forces in nature, or posed another way, why the scale for gravity, i.e. the Planck mass at $\sim 10^{19}$ GeV, is so much larger than the scales for the other forces in nature, the strong force with a Lund string model scale of $\sim$1 GeV/fm and the electro-weak force characterized by the mass of the W and Z bosons, $\sim$100 GeV. Several solutions have been proposed to solve this problem, such as 1) Supersymmetry in which bosons and fermions are symmetric and which unifies the strong and electro-weak forces at a scale just below the Planck scale, 2) String Theory in which elementary particles are represented by higher dimensional strings, e.g. 11 dimensional, and which is a theory of quantum gravity thought to be valid up to the Planck scale and beyond, and 3) the concept of Large Extra Dimensions (LED) which also assumes space-time has a higher dimensionality than the normal $3 + 1$ dimensions[1, 2]. The present study will be carried out in the framework of the LED model of Arkani-Hamed, Dimopoulos, and Dvali[1, 3], called the ADD model, so some further discussion of the model is given. This model has produced a great deal of interest in the literature, and there exist many papers that discuss it and its consequences, several of which are referenced here[4, 5, 6, 7].

The four main assumptions of the ADD model are: 1) space-time is higher dimensional, so introduce n extra spacial dimensions beyond our usual three such that space-time is $3 + 1 + n$ dimensional, 2) only allow gravity, i.e. gravitons, to propagate in all $3 + 1 + n$ dimensions, 3) assume the extra dimensions are "compact", i.e. finite, so they are too small to normally detect but large enough to impact physics, and 4) assume that Standard Model particles, e.g. quarks, gluons, photons, etc..., are confined to a $3+1$ dimensional "wall" or "brane" representing our normal world embedded in the higher dimensional space. The mechanism used in the ADD model to solve the Hierarchy Problem is to define that it doesn't exist: the reason gravity looks so weak in our $3 + 1$ dimensional world is that its force is diluted by existing in $3 + 1 + n$ dimensions, so the higher dimensional "true" Planck mass, M_P, is much lower than the "apparent" Planck mass we measure in our world. As will be shown below, by adjusting the number of extra dimensions and their size, the higher dimensional Planck mass can be brought down to a level low enough, i.e. $\sim$1 TeV, to eliminate the Hierarchy Problem.

In addition to resolving the Hierarchy Problem, the ADD model leads to other consequences which may be observed in nature. One of these is due to the compactification of the extra dimensions resulting in "towers" of new "particle-in-a-box" energy states called Kaluza-Klein states (named after the researchers who in the 1930's made an unsuccessful attempt to unify gravity with the electromagnetic force using extra dimensions)[7]. Kaluza-Klein states can be associated with a spectrum of graviton states which could influence hard scattering processes at the Large Hadron Collider (LHC) and could be Dark Matter candidates[3]. Another exciting consequence of the ADD model is that miniature Black Holes could exist at the greatly reduced Planck mass of around 1 TeV and thus might be produced in TeV-scale particle collisions, such as at the LHC[4, 5]. Of course, in order for the ADD model to be a viable solution to the Hierarchy Problem, none of its consequences are allowed to conflict with existing observations. It can be shown that for $n > 2$ and $M_P \sim 1$ TeV, the ADD model does not conflict with existing astrophysical observations, cosmology, or particle accelerator experiments[3] (some of these arguments will be presented later in this note). A very interesting feature of the ADD model is that it can be shown to be consistent with Type I String Theory[1], which is characterized by extra dimensions, open ended strings (SM particles) stuck to a $3+1$ dimensional brane, and closed strings (gravitons) which can move freely in the extra dimensions. Because of this, detection of unique signatures predicted by the ADD model would be a strong suggestion of the validity of String Theory and thus we might be able to experimentally study String Theory effects, such as supersymmetry[8], at the 1 TeV scale!

In this spirit, the goal of the present work is to study the possibility of detecting unique signatures of miniature Black Holes which may be created in LHC $p+p$ collisions. More specifically, quantitative calculations will be carried out for mini-BH production at the LHC using a code based on the ADD model, CHARYBDIS[9], and comparisons of charged hadron production from mini-BH decay will be made with charged hadron production from the PYTHIA QCD code[10] in the ALICE experiment tracking acceptance.

This note is organized as follows: Section 2 presents some qualitative derivations for the Planck mass and BHs in normal and extra-dimensional space-time, Section 3 presents quantitative calculations using CHARYBDIS and PYTHIA, and Section 4 gives a summary. Note that Section 2 can be skipped if the reader is already familiar with this subject and/or wants to immediately proceed to the results of this study.

2 Qualitative derivations for Large Extra Dimensions

Since the concepts of Large Extra Dimensions and Black Holes are less familiar than other aspects of LHC physics, it seems desirable to present some qualitative discussions of these concepts before proceeding to the results of the present study. Due to the geometrical and semi-classical assumptions that are used in carrying out calculations in the ADD framework, the subject lends itself well to obtaining a satisfactory qualitative picture of the concepts. Thus, what is presented in this section are "hand-waving" derivations of some of the more important ideas to give the reader a better feel for this subject. These derivations are taken from several references[1, 3, 4, 5, 11]. As mentioned above, this section can be skipped if the reader prefers to immediately proceed to the results of this study. Unless indicated otherwise, units in which $c = 1$ will be used below, but $\hbar$ will be explicitly included in the equations to assist in numerical evaluations.

2.1 Lowering the Planck Mass with Large Extra Dimensions

Geometric considerations alone are used to find the relationship between the Planck mass in $3+1+n$ dimensions, M_P, and the usual Planck mass in $3+1$ dimensions, M_{P0}. Consider the Newtonian gravitational potential energy, V, for a mass, m, in the field of another mass, M, separated by a distance, r, in normal space-time as shown in Figure 1:

$$V = -\frac{GMm}{r} \tag{1}$$

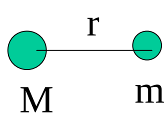

Figure 1: Two masses separated by a distance r in $3+1$ dimensional space-time.

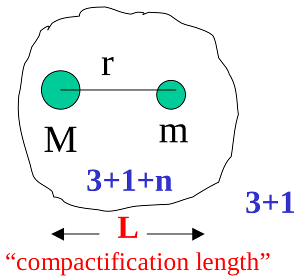

Figure 2: Two masses separated by a distance r in $3+1+n$ dimensional space-time.

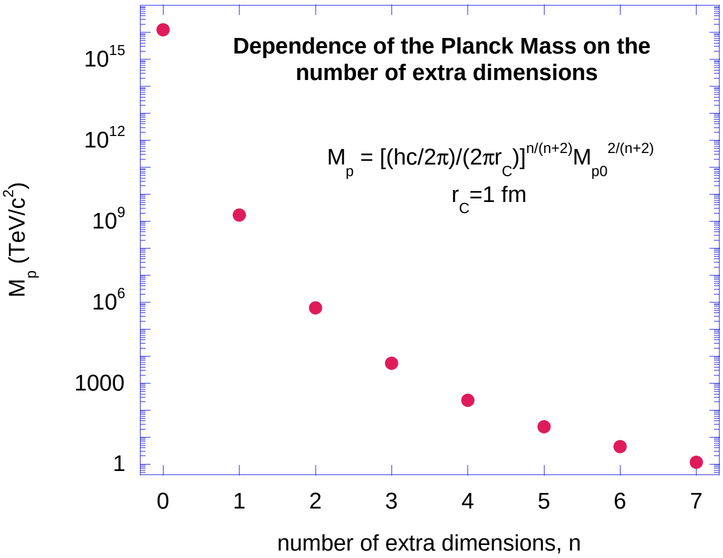

Figure 3: Dependence of M_P on the number of extra dimensions for $r_c = 1$ fm.

where $G =$ Newton's gravitational constant $= \frac{\hbar}{M_{P0}{}^2}$ and $M_{P0} = 1.22 \times 10^{19}$ GeV. Consider the analogous situation in a region of $3+1+n$ dimensional space of compactification length, L, as shown in Figure 2:

$$V_n = -\frac{G_n M m}{r^{n+1}} \tag{2}$$

where V_n is the extra-dimensional potential energy and $G_n =$ extra-dimensional gravitational constant $= \left(\frac{1}{M_P}\right)^{n+2} \hbar^{n+1}$. Assume that each of the n extra dimensions is compactified to the size L. To get the relationship between M_P and M_{P0}, use the requirement that at $r{\sim}L$ the potential energy must match in both spaces, i.e., $V_n{\rightarrow}V$, then, $-\frac{G_n M m}{L^{n+1}}{\rightarrow} - \frac{GMm}{L}$, and thus $G_n{\rightarrow}GL^n$. Using the convention that the n extra dimensions are each compactified into a circle of radius r_c on an n-torus such that $L = 2\pi r_c$ and from above the relationship $G_n{\sim}G(2\pi r_c)^n$ is obtained. Substituting for G and G_n from Equations 1 and 2, respectively, the desired relationship is obtained:

$$M_P{\approx}\left(\frac{\hbar}{2\pi r_c}\right)^{\frac{n}{n+2}} M_{P0}{}^{\frac{2}{n+2}} \tag{3}$$

From Equation 3 it is seen that $n > 0$ results in $M_P < M_{P0}$ as expected. The dependence of the Planck mass on the number of extra dimensions from Equation 3 is plotted in Figure 3 for the arbitrary case of setting $r_c = 1$ fm. It is seen that for this case, the Planck mass can be reduced to the desired level to solve the Hierarchy Problem, ${\sim}1$ TeV, for $n = 7$. Figure 4 shows the dependence of the compactification radius on the number of extra dimensions for the desired case of $M_P = 1$ TeV. The value $n = 1$ is excluded since

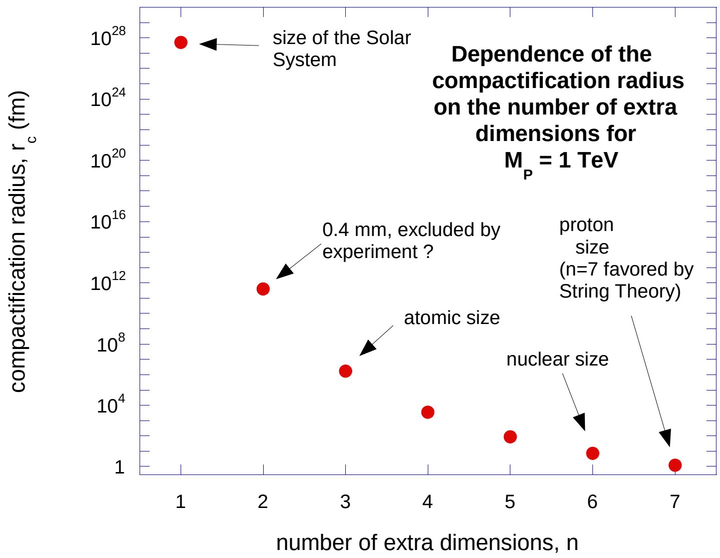

Figure 4: Dependence of r_c on the number of extra dimensions for $M_P = 1$ TeV.

it results in a r_c value of order of the size of the Solar System which would have a noticeable effect on the motions of the planets, and the value $n = 2$ is also excluded by direct measurements which have recently been made down to that level[3]. Even though any $n > 2$ is not excluded, one might be biased by String Theory which presently favors six or seven extra dimensions. For the present study $n = 7$ is used throughout.

2.2 Qualitative derivations for Black Holes in normal and extra-dimensional space-time.

Figure 5 shows a conceptual view of a higher-dimensional Black Hole in a Type I String Theory picture. The BH is fixed to the $3+1$ brane but exists in all dimensions, i.e. the "bulk." Standard Model particles such as quarks, gluons, muons, etc. are shown as open-ended strings with their ends stuck to the brane, whereas gravitons are shown as closed strings free to move anywhere in the bulk. Since no well-defined solution to String Theory currently exists which can be used to describe BHs quantitatively, the assumption is normally made to describe the properties of mini-BHs semi-classically, i.e. ignoring quantum gravity effects. This should be a good assumption for BHs with masses, M_{BH}, satisfying $M_{BH} >> M_P$[4]. In this semiclassical approximation, one assumes the static Schwarzschild solution from General Relativity describes the BHs. The procedure in what follows will be to carry out qualitative derivations of the Schwarzschild radius for BHs in $3+1$ and $3+1+n$ dimensions to get a feel for the dependencies involved, and then to compare these qualitative results with the exact expressions from General Relativity using the Einstein Equation to see how close one gets with the qualitative method.

First consider a static BH in $3+1$ dimensions. Figure 6 shows a BH of mass M_{BH} and Schwarzschild radius R_S with a test mass of relativistic mass m at a distance r. The total relativistic energy of m in a weak gravitational field (i.e. ignoring General Relativity), E can be estimated using Equation 1 as

$$E \approx m + V = m - \frac{G M_{BH} m}{r} \tag{4}$$

Estimate the Schwarzschild radius from the condition that the mass m is captured in the BH when it crosses the event horizon[11], i.e. $E < 0$ when $r < R_S$, so setting $E = 0$ in Equation 4 allows one to solve for $r \approx R_S$,

$$0 = m - \frac{G M_{BH} m}{R_S} \Longrightarrow R_S \approx \frac{M_{BH} \hbar}{{M_{P0}}^2} \tag{5}$$

The exact Schwarzschild solution for a BH from General Relativity is

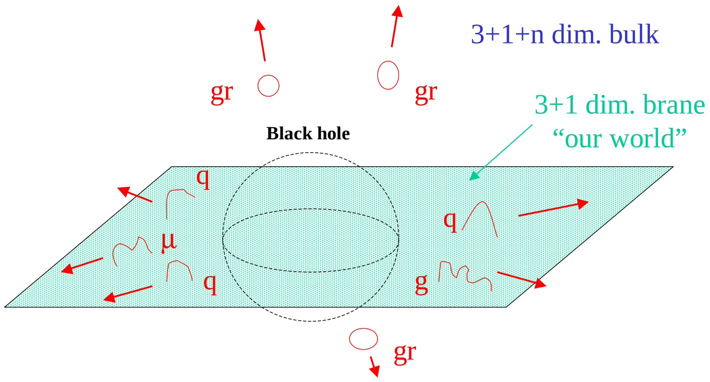

Figure 5: Schematic view of a $3 + 1 + n$ dimensional Black Hole in a Type I String Theory picture.

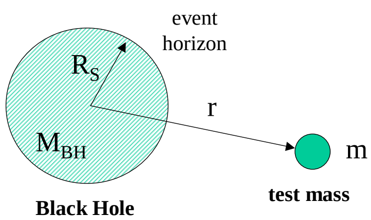

Figure 6: Black Hole with test mass in $3 + 1$ dimensions.

$$R_S = 2\frac{M_{BH}\hbar}{{M_{P0}}^2} \tag{6}$$

and the approximate expression for R_S in Equation 5 is seen to be within a factor of 2 of the correct expression given in Equation 6. As an exercise, one can calculate R_S for the Sun from Equation 6 using $M_{BH} = M_{Sun} = 2 \times 10^{30}$ kg $= 1.1 \times 10^{57}$ GeV which gives $R_S = 3$ km. Using "Thorne's hoop conjecture"[12] which states that if all of the mass of an object finds itself within its Schwarzschild radius it spontaneously becomes a BH, the Sun would become a BH if it were compressed down to a radius of 3 km (fortunately, this is unlikely to happen). Thorne's hoop conjecture will be used later in the discussion of calculating the cross section for BH creation in parton-parton collisions.

Now consider a static BH in $3+1+n$ dimensions. Figure 7 shows such a BH with a test mass m located at r all within a region of higher-dimensional space compactified to a radius r_c. It is assumed that both the higher-dimensional Schwarzschild radius, R_{Sn} and r are small compared to r_c so that boundary effects of the space are not important for calculations relating to the BH. Analogous to the method used above, estimate R_{Sn} from the condition that the total relativistic energy of m vanishes at R_{Sn}, i.e. using Equation 2,

$$E \approx m - \frac{G_n M_{BH} m}{{R_{Sn}}^{n+1}} = 0 \Longrightarrow R_{Sn} \approx \left(\frac{M_{BH}}{{M_P}^{n+2}}\right)^{\frac{1}{n+1}} \hbar \tag{7}$$

The exact $3 + 1 + n$ dimensional Schwarzschild solution for a BH from General Relativity[13] is

$$R_{Sn} = \left\{ \frac{1}{\sqrt{\pi}} \left[\frac{8}{n+2}\, \Gamma\left(\frac{n+3}{2}\right)\right]^{\frac{1}{n+1}} \right\} \left(\frac{M_{BH}}{{M_P}^{n+2}}\right)^{\frac{1}{n+1}} \hbar \tag{8}$$

Comparing Equations 7 and 8, the approximate solution differs from the exact solution by the term in the curly brackets which only depends on the dimensionality of the space. For the case of $n = 7$, it is found that $\{...\} \approx 1$ and the two expressions for R_{Sn} amazingly give about the same result. To get an idea of the scale of R_{Sn} in a possible LHC-like scenario, taking $n = 7$, $M_P = 1$ TeV and $M_{BH} = 10$ TeV, from either Equation 7 or 8 one obtains

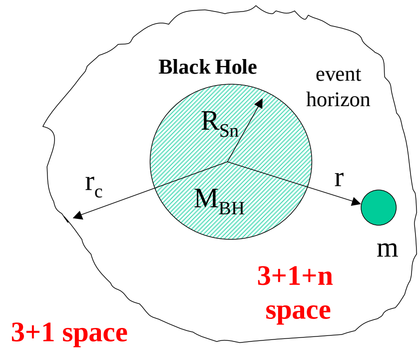

Figure 7: Black Hole with test mass in $3+1+n$ dimensions.

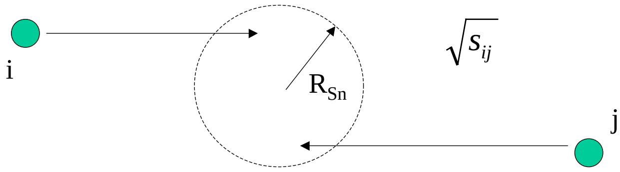

Figure 8: Schematic geometry for mini-BH production in a parton-parton collision.

$$R_{Sn} \approx 0.00026 fm << 1 fm \tag{9}$$

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Thus even for the case where $r_c \sim 1$ fm, the requirement that the BH be much smaller than the size of the space in which it is embedded in order to use Equations 7 or 8 is satisfied for this example.

2.3 Calculating the cross section for mini-BH production in a p+p collision

Continuing in the spirit of the semi-classical picture used above, one can estimate the cross section for a parton-parton scattering to form a mini-BH using Equation 8. Figure 8 shows the geometry of a parton-parton scattering in the c.m. frame of the partons with energy $\sqrt{s_{ij}}$. Invoking once again Thorne's Hoop conjecture, assume that a BH is immediately formed whenever the two colliding partons approach within a sphere defined by their Schwarzschild radius, where $M_{BH} = \sqrt{s_{ij}}$. Under this assumption and using Equation 8, the (semi-classical) cross section for BH formation in this case is[14]

$$\sigma_{BH}(ij) \approx \pi {R_{Sn}}^2 \approx \left[\frac{8}{n+2}\,\Gamma\left(\frac{n+3}{2}\right)\right]^{\frac{2}{n+1}} \left(\frac{\sqrt{s_{ij}}}{{M_P}^{n+2}}\right)^{\frac{2}{n+1}} \hbar^2 \tag{10}$$

Putting LHC-size numbers into Equation 10, i.e. $M_P = 1$ TeV, $n = 7$, and $M_{BH} = 10$ TeV, one obtains $\sigma \approx 2.2$ nb. This is a huge cross section by LHC standards since the integrated luminosity for one year is targeted to be about 30 fb^{-1} ! For comparison with the case of no extra dimensions, i.e. $M_P = 10^{16}$ TeV, $n = 0$, and $M_{BH} = 10$ TeV, one obtains $\sigma \approx 10^{-62}$ nb, which is certainly undetectable by any standards.

In a realistic LHC p+p collision, the partons are contained within the protons, as schematically depicted in Figure 9. To calculate the cross section for BH formation in the realistic case, it is necessary to integrate in Feynman-x and M_{BH} for the colliding partons over the parton distribution functions in the colliding protons, f_i and f_j, respectively, as shown in Equation 11[4],

$$\sigma_{BH}(pp) = \frac{1}{s_{pp}} \sum_{i,j} \int_{{M_{BHmin}}^2}^{s_{pp}} d{M_{BH}}^2 \int_{{M_{BH}}^2/s_{pp}}^{1} \frac{dx}{x} f_i(x) f_j(\frac{{M_{BH}}^2}{x s_{pp}}) \sigma_{BH}(ij) \tag{11}$$

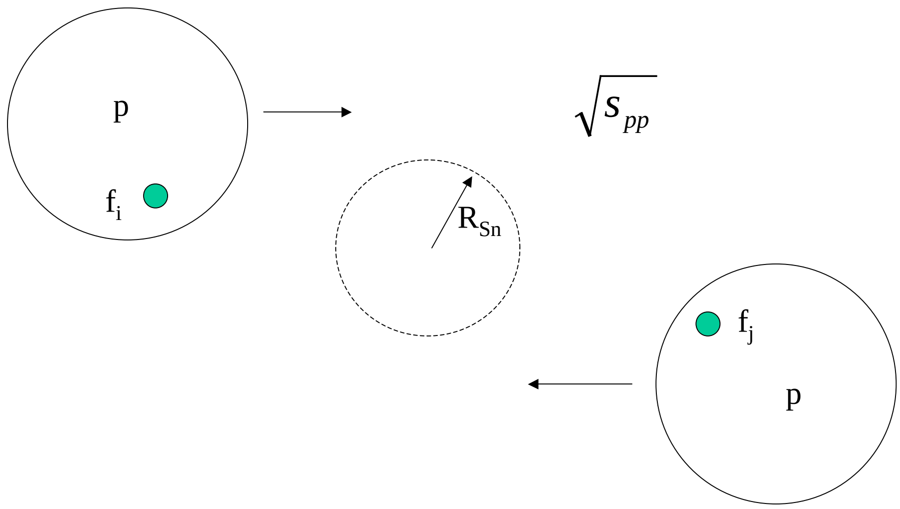

Figure 9: Schematic geometry for mini-BH production in a proton-proton collision (not to scale).

This expression is used in the code for the present study[9, 15].

2.4 Decay of the mini-BH via Hawking radiation

It is expected that if mini-BHs are created at the LHC, they will not be stable but will decay into Standard Model partons on the $3+1$ brane and gravitons in the $3+1+n$ bulk within a very short time. The decay is expected to proceed in the following time sequence[9]: 1) an initial "balding phase" during which asymmetry and moments acquired in the violent production process are lost, 2) a brief "spin-down phase" during which angular momentum is lost from the rotating Kerr BH, 3) a long "Schwarzschild phase" during which Hawking radiation is emitted, and finally 4) a "Planck phase" during which the mass of the BH approaches the Planck mass. Assuming that the decay is "democratic" such that there is equal probability for decay into any particle, most of the energy will go into the detectable Standard Model particles due to their larger multiplicity than that for gravitons in a fraction of roughly 5/1[4]. Most of the decay particles are expected to be emitted as Hawking radiation during the Schwarzschild phase and to follow a black-body spectrum such as[9]

$$\frac{dN_{slm}}{dEdt} = \frac{1}{2\pi}\frac{\Gamma_{slm}}{\exp\left(E/T_H\right) \pm 1} \tag{12}$$

where s, l, and m are the polarization spin and angular momentum quantum numbers of the emitted particle, respectively, Γ represents the "grey-body" factors and T_H is the Hawking temperature given by,

$$T_H = \frac{(n+1)\hbar}{4\pi R_{Sn}} \tag{13}$$

For the case used earlier of $M_P = 1$ TeV, $n = 7$, and $M_{BH} = 10$ TeV, Equation 13 gives $T_H = 370$ GeV. One can estimate the parton multiplicity, N, and BH lifetime, τ, from T_H assuming the average emitted particle energy is T_H and that the decay of the BH occurs such that one particle is emitted at a time each with timescale on the order of the size of the BH, giving

$$N \approx \frac{M_{BH}}{T_H} \approx 27 particles; \quad \tau \approx NR_{Sn}/c \approx 0.01 fm/c \tag{14}$$

From this it is seen that the lifetime of a mini-BH is very short compared with the characteristic timescale of a p+p collision of about 1 fm/c. This calculation also shows that a possible signature for BH formation and decay would be to look for events with a high multiplicity of high-p_T particles. Although not studied in the present work, another possible BH signature which has been proposed is to look for a "BH remnant"[16]

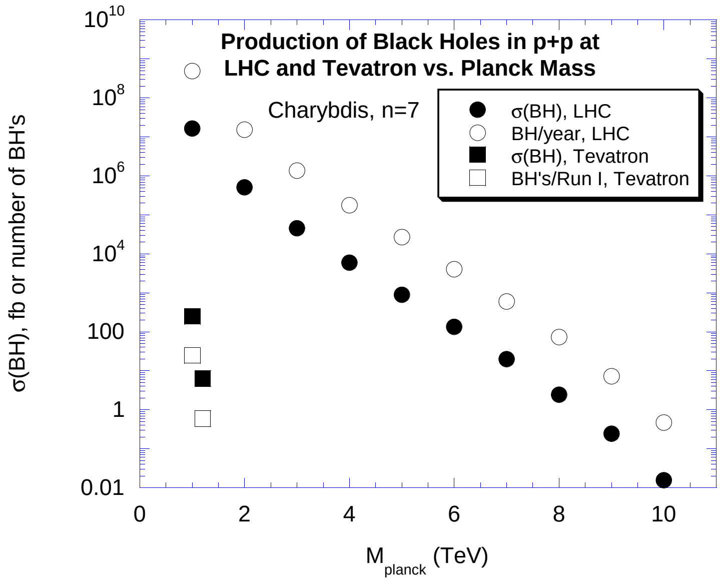

Figure 10: Cross section and yield for mini-BH production vs. M_P for the LHC (full luminosity and energy) and Tevatron (Run I) using CHARYBDIS.

which results if the BH does not further decay at the Planck phase. In this case one would look for events with a massive, ~ 1 TeV, charged particle.

3 Quantitative calculations of mini-BH production at the LHC and detection via the hadronic channel in the ALICE experiment

The previous section laid a qualitative groundwork for dealing with mini-BH production at the LHC. The present section describes quantitative calculations for BH production and detection in the LHC ALICE experiment for p+p collisions. Similar studies have been carried out by others for the LHC ATLAS experiment[17, 18]. In the present study the BH event generator code CHARYBDIS[9] is used. CHARYBDIS represents a quantitative treatment of BH formation and decay for p+p collisions. Three of its main features are 1) it integrates over parton distribution functions as in Equation 11, 2) it calculates BH decay incorporating "grey body" factors as in Equation 12, and 3) it is coupled to the PYTHIA QCD code[10] for parton evolution and hadronization.

Figure 10 shows the production cross section and number of BHs produced in a one-year running period at the LHC for p+p at a luminosity of $10^{34} cm^{-2} s^{-1}$, and similar numbers for Run I at the Tevatron, as a function of the Planck mass from CHARYBDIS+PYTHIA. As seen, at full luminosity at the LHC for one year there are about 10^9 BHs produced if the Planck mass is 1 TeV, exponentially decreasing to only 1 BH being produced in a year for 10 TeV. For the Tevatron, it is seen that only a few BHs are expected to have been produced during Run I if the Planck mass were exactly at 1 TeV, dropping to less than one BH for 1.1 TeV. Thus, it is not suprising that no evidence of BH formation has been reported so far at the Tevatron.

Figure 11 shows a comparison between transverse momentum distributions for charged hadrons at mid-rapidity at full LHC energy from CHARYBDIS+PYTHIA for two values of M_P with that from PYTHIA alone, labeled "QCD only" (this plot is patched together from various PYTHIA runs with increasing values for the hardness of the $2 \rightarrow 2$ parton collision, each run represented by a different color). As seen for $M_P = 1$ TeV, hadrons from BH decays dominate over QCD processes for $p_T > 100$ GeV/c, whereas for $M_P = 5$ TeV, BH decays only become important for $p_T > 1.2$ TeV. Since the ALICE experiment does not presently forsee having large-acceptance calomimetry capable of accurate particle p_T measurements to very high values, alternative observables which are sensitive to the possibility of $M_P > 1$ TeV are needed. Taking

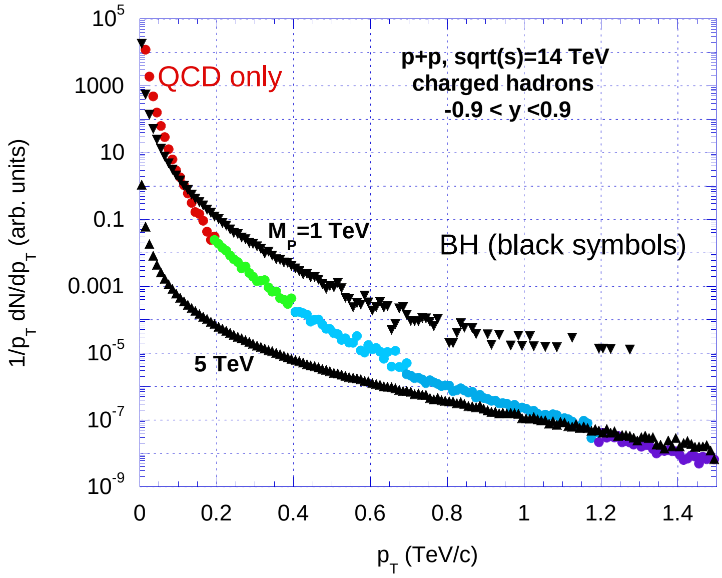

Figure 11: Transverse momentum distributions for charged hadrons from BH decay (CHARYBDIS) compared with $2 \to 2$ hard QCD processes (PYTHIA).

advantage of the large-acceptance precision tracking detectors available in ALICE, namely the combined Inner Tracking System (ITS), Time Projection Chamber (TPC) and Transition Radiation Detector (TRD) tracking, two event-by-event observables look promising for BH studies: charged multiplicity and summed p_T. The particle acceptance for charged multiplicity in rapidity and p_T is represented by $-2 < y < 2$ and $p_T > 0.1$ GeV/c, respectively. A reasonable acceptance which can be taken for summed p_T per event is represented by $-0.9 < y < 0.9$ and $0.1 < p_T < 300$ GeV/c. These observables will be studied below.

The strategy of the present study will be the following: a) compare charged hadron production from BHs using CHARYBDIS+PYTHIA with QCD high-p_T processes from PYTHIA alone, b) detect these hadrons in the ALICE ITS+TPC+TRD tracking acceptance with momentum resolution effects included and c) try to find a simple triggering scheme to use for this. For all of the plots shown below for the ALICE study, the LHC will be assumed to give $\sqrt{s} = 14$ TeV p+p collisions at a "year-1" luminosity of $10^{31} cm^{-2} s^{-1}$. A value for the number of extra dimensions will be taken to be $n = 7$. Note that for a given M_P the results from CHARYBDIS do not depend sensitively on the exact value of n used for values of this order, e.g. for $n = 6$ the BH production cross section is within 10% of the $n = 7$ case. The charged hadrons included in all plots are pions, kaons, protons, and their anti-particles. The ALICE tracking acceptance is simulated with rapidity and transverse momentum cuts, and momentum resolution effects are conservatively simulated assuming $\Delta p/p = 0.16p$, where p is the particle momentum.

Figures 12 and 13 show plots of charged hadron multiplicity per event and summed p_T per event, respectively, for BH and QCD events in the ALICE acceptances for running a minimum-bias trigger for four months of initial LHC luminosity. The maximum data acquisition rate for p+p in ALICE is taken to be 100 Hz. For these running conditions, it is seen that only a few BH events will be visible above the QCD background and only for $M_P = 1$ TeV, occuring for multiplicities greater than 200 and summed p_T greater than 0.5 TeV/c.

In order to improve this situation, assume it is possible to apply a simple charged multiplicity trigger to ALICE events in the tracking acceptance $-0.9 < y < 0.9$ where only events with multiplicity greater than 65 are accepted. Possible detectors which could be used to implement such a trigger are the TRD and ITS, but further study of the details of this is required. Figures 14 and 15 show plots corresponding to Figures 12 and 13 above except with this multiplicity trigger. The data rate for this trigger for the LHC luminosity used is only 1 Hz, which is 1% of the maximum data acquisition rate for ALICE p+p data and which would thus have only a small impact on the overall data-taking rate for ALICE. As expected, this trigger is seen to greatly reduce the QCD background allowing for significant BH signals to be detected

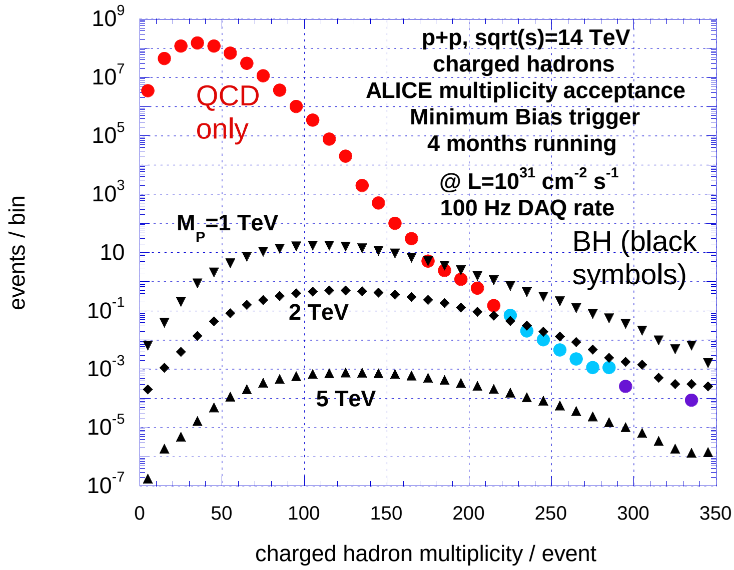

Figure 12: Multiplicity distributions for charged hadrons for minimum bias triggering in ALICE.

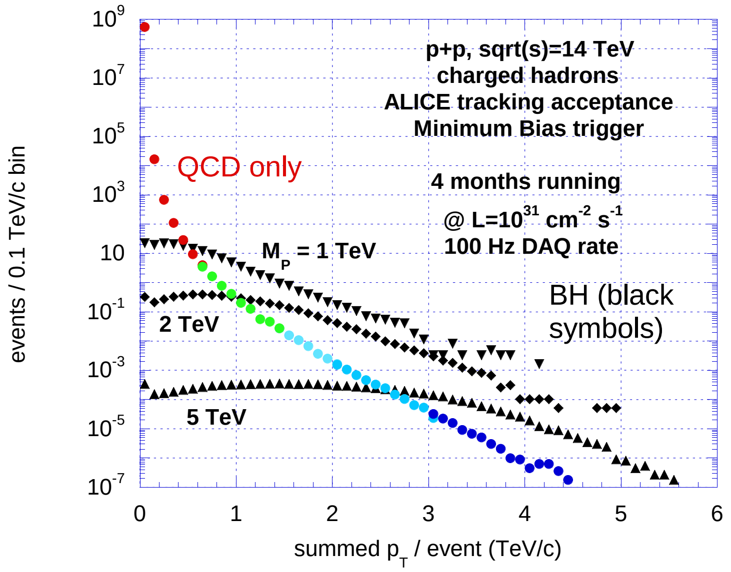

Figure 13: Summed p_T per event distributions for charged hadrons for minimum bias triggering in ALICE

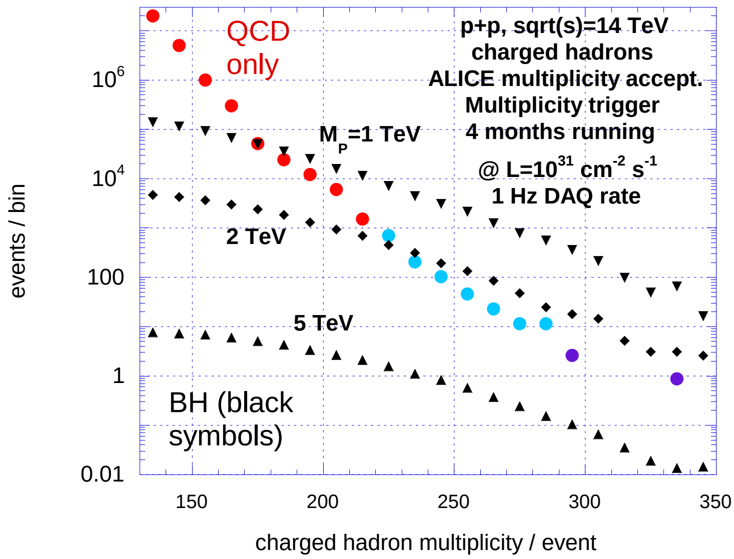

Figure 14: Multiplicity distributions for charged hadrons using a multiplicity trigger in ALICE.

during this short running period. For charged multiplicity, the sensitivity to M_P is raised to 2 TeV and hundreds of BH events above background corresponding to this case are seen for multiplicities greater than 250. The situation is seen to be even better for summed p_T, where tens of thousands of BH events are seen above background for the $M_P = 1$ TeV case, and tens of BH events may be seen above background even for the $M_P = 5$ TeV case in this running period. The signature for BH creation from these simple observables is seen to be an abrupt flattening of the slope of either distribution as the transition from pure QCD to BH dominated charged particle production takes place. For $M_P < 2$ TeV, this flattening should be seen in both distributions in ALICE giving a redundancy to this signature. The point in multiplicity and/or summed p_T where the flattening occurs would be related to the value of M_P which in principle could then be determined.

4 Summary

The model of Large Extra Dimensions has exciting consequences including the possible creation of mini-BHs at the LHC. Under the proper conditions the ALICE experiment has the capability to detect BHs from charged hadronic observables for higher-dimensional Planck masses ranging from 1 to 5 TeV within the first four months of LHC running. A simple method for triggering on charged particle multiplicity to enhance the BH signal is suggested, and further work should be carried out to study how to implement this in the ALICE triggering scheme.

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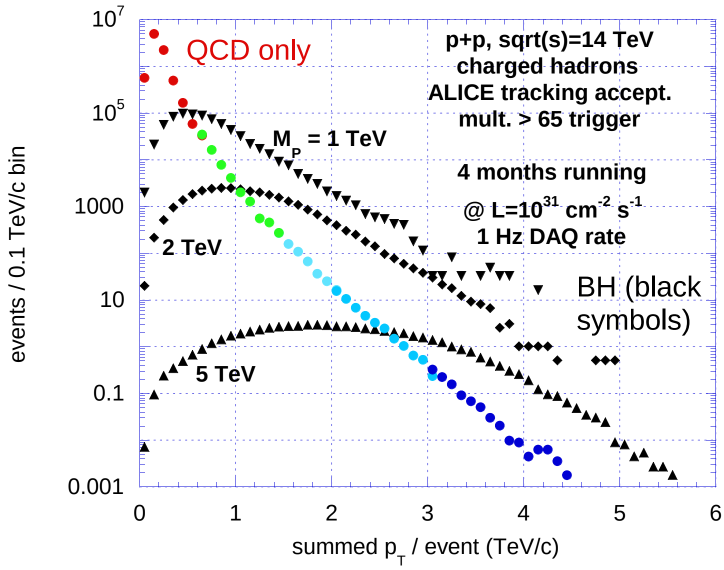

Figure 15: Summed p_T per event distributions for charged hadrons using a multiplicity trigger in ALICE.

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