Extra dimensions and micro black holes at the LHC

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We present recent studies of the ATLAS and CMS Collaborations on the potential to discover extra dimensions and microscopic black holes in the forthcoming 2009-10 LHC run. We show that there is a good chance that with an integrated luminosity of ~ 100 pb^{-1} accumulated at a center-of-mass energy of 10 TeV the searches for such new physics will be extended beyond the existing limits.

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1. Introduction

Many theories beyond the Standard Model (SM) invoke extra dimensions (EDs) to explain why gravity is so much weaker than the other forces. The most popular scenarios of extra dimensions include ADD [1], in which the gravitational force is diluted by propagating through extra dimensions of macroscopic size, and RS [2], in which gravity originates on a hidden 4D brane and is suppressed away from the brane along the ED due to the warping of the brane. In these models, the strength of gravity is strongly increased at small distances, which opens up the possibility of observing quantum-gravity effects in the TeV energy range, in particular the production of microscopic black holes [3]. In this talk, we focus on the prospects to discover these phenomena in the ATLAS and CMS experiments [4] in the forthcoming 2009-10 LHC run, and on the main experimental challenges of such searches.

2. Search for dilepton decays of new high-mass resonances

Both the ADD and RS scenarios are expected to manifest themselves through modifications in the mass spectrum of high-mass dilepton pairs. While the closely-spaced Kaluza-Klein modes of the ADD model give rise to non-resonant distortions of the spectrum, the gravitons (G^*) of the RS scenario would be seen as narrow resonances. The dominant and irreducible background is the Drell-Yan production of lepton pairs. Other backgrounds can be subdivided into two categories: I) with two high-p_T isolated leptons ($t\bar{t}$, tW, WW); II) with one or more leptons produced in a jet (W+jets, dijets, γ+jets). Type-I backgrounds are expected to be measured from data, using samples of $e\mu$ and b-tagged events. Type-II backgrounds can be efficiently suppressed by isolation and kinematic cuts and their residual contribution evaluated from data, using the measured probability for a jet to fake a lepton as well as same-sign (e^+e^+, $\mu^-\mu^-$, etc.) events.

Figure 1a shows the simulated dielectron invariant-mass spectrum for the SM backgrounds and a 1 TeV resonance corresponding to an integrated luminosity of 100 pb^{-1} accumulated at a center-of-mass energy ($\sqrt{s}$) of 10 TeV. In order to minimize sensitivity to uncertainties in the expected signal and background levels, the fit to the data explores the difference *in shape* between the signal "bump" and the steeply-falling background. Evaluations of the statistical significance show that an integrated luminosity of 100 pb^{-1} at $\sqrt{s}$ = 10 TeV should be sufficient to probe the RS G^* mass region of up to 1.3-1.5 TeV in each leptonic decay channel [5, 6].

3. Search for extra dimensions in the diphoton channel

Since the graviton is a spin-2 particle, its decays to diphotons can proceed via an s-wave process, resulting in a larger branching ratio compared to that of difermion decays. The dominant and irreducible background is the SM production of diphotons, which mainly occur through t-channel processes. The shape of this background at high invariant masses is obtained from a detailed Monte Carlo (MC) simulation, whereas its absolute normalization comes from normalizing the MC-based spectrum to data at low diphoton masses, where the contribution from possible signal is negligible. Other backgrounds include jets faking photons in γ+jet and dijet events and electrons from Drell-Yan events misidentified as photons; their contributions can be measured in samples of identified jets and $Z \rightarrow ee$ events, respectively.
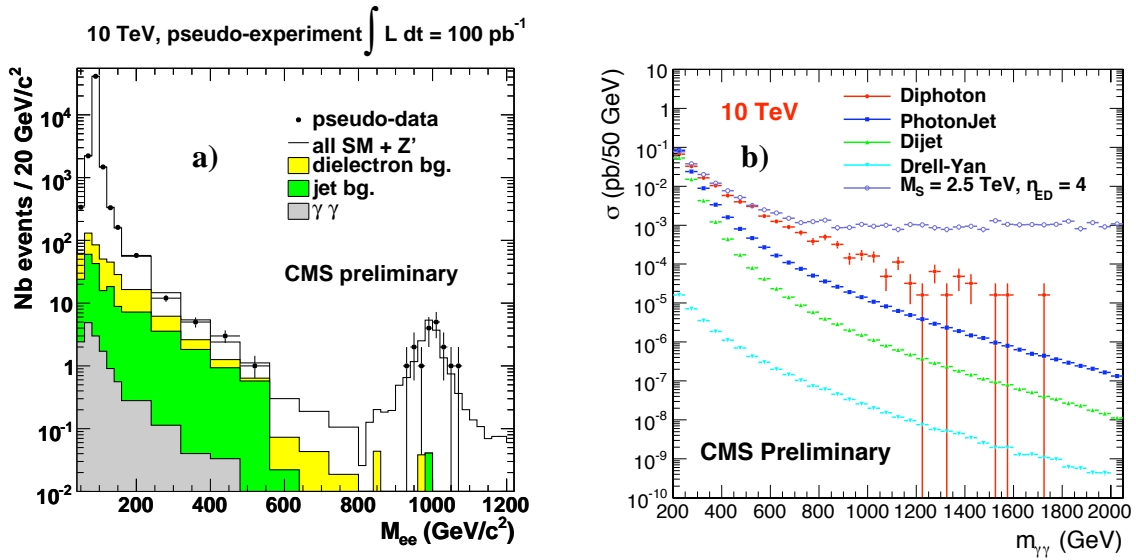
Figure 1: a) A simulated dielectron invariant-mass spectrum for an integrated luminosity of 100 pb^{-1} at $\sqrt{s}$ = 10 TeV. The shaded areas show contributions from various non-Drell-Yan backgrounds; the non-shaded histogram gives the sum of all SM backgrounds and the signal from an additional heavy neutral gauge boson of the Sequential Standard Model (Z_{SSM}) with a mass of 1 TeV; points with error bars show the outcome of a single signal-plus-background MC experiment. b) The expected composition of the diphoton invariant-mass spectrum at $\sqrt{s}$ = 10 TeV. The distribution at the top shows the sum of the ADD signal (in a model with ultraviolet cutoff value M_S of 2.5 TeV and with four EDs) and the SM direct diphoton background.

The optimal sensitivity to the ED signal is obtained by selecting events with two high-E_T photons, each in the pseudorapidity region of $|\eta_\gamma| < 1.5$. Figure 1b shows the expected contributions from various SM backgrounds as well as the ADD signal to the diphoton invariant-mass spectrum at $\sqrt{s}$ = 10 TeV, for events passing all selection criteria. One searches for an excess of signal over the background in the mass range above 700 GeV. Evaluations of the ADD discovery potential show that lower limits on the effective Planck scale of up to a factor of two higher than the current best limits can be obtained with an integrated luminosity of 100 pb^{-1} [7]. The sensitivity to the parameters of the RS model is expected to be similar to that in the dilepton channels [8].

4. Search for large extra dimensions in mono-jets

Another way to probe models of large EDs such as ADD, complementary to the searches for virtual graviton decays described above, is to look for real gravitons recoiling against a quark or a gluon. The signal signature consists of large missing E_T back-to-back to a high-p_T jet. The dominant SM backgrounds are Z+jets with the Z decaying into neutrinos, W+jets followed by a leptonic W decay, and QCD events. The main signal-background discriminator is the *MHT* variable, defined as the negative vector sum of p_T of all high-p_T jets. The optimal sensitivity to the ED signal is obtained by selecting events with no isolated leptons, one or two high-p_T jets with $|\eta_{jet}| < 1.7$, and $|MHT| > 250$ GeV. The projected discovery reach in this channel is about the same as in the diphoton channel [9].

5. Search for micro black holes

If microscopic black holes are produced at the LHC, they should undergo Hawking evaporation: particle pairs produced by vacuum fluctuations may be split, with one particle falling into the black hole and the other projected outward. This gives a very distinct signature characterized by a large number of high-p_T final-state particles and jets and large missing E_T. The main sources of the background are $t\bar{t}$, dijet and W+jet events. A pure sample of signal events can be obtained by selecting events containing at least one high-p_T lepton and with large $\sum |p_T|$ of all reconstructed objects. The generation of micro black holes involves many assumptions, but if the predicted signature is correct, it should be detectable at the LHC [10].

6. Conclusion

We presented some recent studies by the ATLAS and CMS Collaborations dedicated to searches for extra dimensions and micro black holes in the forthcoming 2009-10 LHC run. The focus of the analyses is currently on data-driven methods of estimating backgrounds and efficiencies, and on techniques to minimize systematic uncertainties. The scenario in which an integrated luminosity of ~ 100 pb^{-1} is accumulated at $\sqrt{s} = 10$ TeV offers good chances to go beyond the existing limits.

References

[1] N. Arkani-Hamed, S. Dimopoulos and G. Dvali, *The hierarchy problem and new dimensions at a millimeter*, *Phys. Lett. B* **429** (1998) 263.

[2] L. Randall and R. Sundrum, *Large mass hierarchy from a small extra dimension*, *Phys. Rev. Lett.* **83** (1999) 3370.

[3] S.B. Giddings and S.D. Thomas, *High energy colliders as black hole factories: The end of short distance physics*, *Phys. Rev. D* **65** (2002) 056010 [hep-ph/0106219].
S. Dimopoulos and G.L. Landsberg, *Black holes at the LHC*, *Phys. Rev. Lett.* **87** (2001) 161602 [hep-ph/0106295].

[4] ATLAS Collaboration, *The ATLAS experiment at the CERN LHC*, *JINST* **3** (2008) S08003.
CMS Collaboration, *The CMS experiment at the CERN LHC*, *JINST* **3** (2008) S08004.

[5] CMS Collaboration, *Search for new high-mass resonances decaying to muon pairs in the CMS experiment*, *CMS PAS* **SBM-07-002** (2008). This and other CMS notes cited here are available at https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults.

[6] CMS Collaboration, *Search for high-mass resonances decaying into an electron pair in CMS at 10 TeV with 100 pb^{-1}*, *CMS PAS* **EXO-09-006** (2009).

[7] CMS Collaboration, *Search for large extra dimensions in the diphoton final state*, *CMS PAS* **EXO-09-004** (2009).

[8] CMS Collaboration, *Search for Randall-Sundrum gravitons in the diphoton final state*, *CMS PAS* **EXO-09-009** (2009).

[9] CMS Collaboration, *Search for mono-jet final states from ADD extra dimensions at $\sqrt{s} = 10$ TeV*, *CMS PAS* **EXO-09-013** (2009).

[10] ATLAS Collaboration, *Expected performance of the ATLAS experiment: detector, trigger and physics*, *CERN-OPEN* **2008-020** (2008) [arXiv:0901.0512v4].