SEARCH FOR EXTRA DIMENSIONS WITH ATLAS AT LHC

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Theories with extra space dimensions aiming at resolving the hierarchy problem have recently been developed. These scenarios have provided exciting new grounds for experimental probes. A review of some recent studies done by the ATLAS collaboration on the sensitivity of the detector to various extra dimension models is reported in this document.

1. Introduction

The complete unification of particle interactions might require the presence of additional spacial dimensions, three of which are within the reach of our senses and the others being compactified at distances of the order of 10^{-32} m. In a model inspired by string theory, Arkani-Hamed, Dimopoulos and Dvali (ADD) suggested that there is only one fundamental scale in nature; the electroweak scale ¹. In this setup gravity appears much weaker than other forces because it can propagate in extra spacial dimensions and hence its flux lines are diluted, while the standard model fields are confined to the three space dimensions. Since then, the idea of extra dimensions has been a subject of intense phenomenological studies.

2. ATLAS Studies

The sensitivity of the ATLAS detector to a number of phenomenological models has been studied. The results of some of these studies are reported in the following sections. Most of these studies have used a parameter-based fast Monte Carlo, ATLFAST, to simulate the effects related to the detector. ATLAS is expected to accumulate $100fb^{-1}$ data in a high luminosity run of the LHC per year.

2.1. Large Extra Dimension

In the presence of large extra dimensions, gravitons will appear as towers of massive Kaluza-Klein (KK) states from the 4-D point of view. Since the coupling of gravitons to matter is very weak, direct production of KK gravitons will result in signals with large missing transverse energy in the detector. Final states of jets plus missing energy and photons plus missing energy² have been simulated in the ATLAS detector. Figure 1 shows signal and background distributions. After one year of running at the design luminosity, the LHC can probe the mass scale of the theory up to 9, 7 and 6 TeV if there are respectively two, three or four extra dimensions. Running the LHC at different center-of-mass energies could help to find out the number of extra dimensions.

A virtual production of the KK gravitons will result in the modification of the Drell-Yan cross section. Studies have been done with photon and lepton pairs in the final state. A one year run at high luminosity should have sensitivity up to 8(7) TeV for a number of extra dimensions equal to 5(2)³.

Figure 1. Distribution of missing transverse energy for signal and background events

2.2. TeV^{-1} Extra Dimension

An interesting variation to the above scenario is the one in which only the standard model fermions are confined to the three space dimensions, while there can be Kaluza-Klein excitations of the gauge boson in the presence of small extra dimension. In ATLAS, we have performed a detailed study

of the leptonic signatures for the production of Kaluza-Klein excitations of the γ and Z in models with TeV-scale extra dimensions⁴. The production and decay of the excitations were fully simulated, and the resulting particles were passed through a parametrized simulation of the ATLAS detector. Figure 2 shows the invariant mass distribution of e^+e^- pairs for the standard model (full line) and for models M1 (dashed line) and M2 (dotted line) for which fermions lie at different fixed points on the wall. With an integrated luminosity of $100 fb^{-1}$ ATLAS will be able to detect a peak in the lepton-lepton invariant mass if the compactification scale (M_c) is below 5.8 TeV. In the absence of a peak, a detailed study of the shape of the lepton-lepton invariant mass will allow us to observe the interference effect up to $M_c \sim 13.5$ TeV.

Once a peak is observed, an important task is the assessment of the model which has produced the signal. With an integrated luminosity of $300 fb^{-1}$ and for resonances of mass up to 5 TeV, the KK excitations can be distinguished from mass peaks produced by SM-like Z' or graviton resonances from the study of the forward backward asymmetry of the leptons in the peak region.

Figure 2. Invariant mass distribution of e^+e^- for the standard model and for models M1 and M2. The mass of the lowest lying KK excitation is 4000 GeV. The histograms are normalized to $100 fb^{-1}$.

2.3. Randall-Sundrum Models

The Randall-Sundrum model postulates a universe with two 4-D surfaces (TeV and Planck brane) bounded by 5-D space-time. The SM fields are

assumed to be located on one of the two branes (the TeV brane), while gravity lies in the bulk. The fifth dimension is not large, but the metric is non factorisable, allowing for a resolution of the hierarchy problem, given an appropriate warp factor. The theory admits two types of four-dimensional massless excitations: the usual graviton and a graviscalar, the modulus or radion (ϕ). In order to stabilize the size of extra dimensions without fine tuning of parameters, Goldberger and Wise have proposed a mechanism by which the radion acquires a mass, expected to be smaller than the J=2 Kaluza-Klein excitations. The presence of the radion is one of the important phenomenological consequences of these theories of warped extra dimensions.

ATLAS has performed a model independent study of narrow graviton resonance signals⁵. Figure 3 shows the number of $G \rightarrow ee$ events per 4 GeV mass bin from a graviton resonance along with the expected standard model background. In the context of the RS model, we obtained a 5 sigma sensitivity up to 2.1 TeV of graviton mass in the di-electron production channel. Studies of the angular distribution of the polar angle of electrons show that a spin-2 resonance can be distinguished from a spin-1 resonance up to a mass of 1.7 TeV with 90 % CL.

ATLAS has also investigated the possibility of observing the radion via its decay into pair of Higgs scalars⁶. Two cases were examined: $\phi \rightarrow hh \rightarrow \gamma\gamma b\bar{b}$ and $\phi \rightarrow hh \rightarrow \tau\tau b\bar{b}$, for radion masses of 300 and 600 GeV, for $m_h = 125$ GeV and for an integrated luminosity of 30 fb^{-1} . Figure 4 shows the reconstructed mass of the radion for 30 fb^{-1} and for $\Lambda_\phi = 1 \text{ TeV}$, $\xi = 0$, where Λ_ϕ is the vev of the radion and ξ is a parameter describing mixing with the Higgs boson. Limits on the maximal reach in Λ_ϕ were obtained for these two channels. For the $\gamma\gamma b\bar{b}$ channel, the background is negligible and the reach in Λ_ϕ is 2.2 (0.6) TeV for $m_\phi = 300$ (600) GeV, when $\xi = 0$. For the $\tau\tau b\bar{b}$ channel, the reach for Λ_ϕ is about 1 TeV for both $m_\phi = 300$ GeV and $m_\phi = 600$ GeV, when $\xi = 0$, although in the first case, uncertainties in the background shape may result in large systematic errors.

3. Summary

The ATLAS collaboration has studied different phenomenological models with extra space dimensions. The experiment will be very sensitive to the presence of these extra dimension and will be able to probe mass scales of 5 to 10 TeV, depending on the model.

Figure 3. The number of events per 4 GeV mass bin from a graviton resonance, with $m_G = 1.5$ GeV, superimposed on the expected standard model background, for 100 fb^{-1} of integrated luminosity.

Figure 4. Reconstructed mass of the radion, for 30 fb^{-1} and $\Lambda_\phi = 1 \text{ TeV}$, $\xi = 0$. Left plot: expected signal (light) and $t\bar{t}$ background (dark). Right plot: $t\bar{t}$ background (dark), expected signal (light) and $Z + \text{jets}$ backgrounds (very light).

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