Potential for detection of graviton resonances from the process $G^* \rightarrow Z^0 Z^0 \rightarrow e^+e^-e^+e^-$ with ATLAS

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Abstract

The ATLAS detector will allow us to observe narrow graviton resonances, as predicted by the Randall-Sundrum model, which relys on a small extra dimension to reconcile the electroweak scale and the Plank scale. This analysis showed that gravitons in the decay channel $pp \rightarrow G* \rightarrow Z^0 Z^0 \rightarrow e^+e^-e^+e^-$ may be seen at ATLAS with masses up to 700GeV, assuming a luminosity of $100fb^{-1}$.

1 Introduction

The forthcoming ATLAS detector at the LHC will allow us to explore particle physics on the TeV scale. Major motivation in the search for graviton resonances has been caused by ideas put forth by Randall and Sundrum suggesting a 5-dimensional non-factorizable geometry between the weak and plank scales [1]. A graviton Kaluza-Klein spectrum is created with a scale:

$$\Lambda_{\Pi} = \overline{M_{Pl}} e^{-kr_c\pi} \tag{1}$$

where $\overline{M_{Pl}}$ is the effective Plank scale, k is on the order of the Plank scale, and r_c is the compactification radius. This theory is unique in its inclusion of the kr_c 'warp factor', which solves the hierarchy problem between the Plank and electroweak scales. Resonance masses are given by

$$m_n = x_n(\frac{k}{\overline{M_{Pl}}})\Lambda_\Pi \quad (2)$$

where x_n are the roots of the Bessel function. In this analysis we have chosen the ratio $\frac{k}{\overline{M_{Pl}}} = 0.01$, which leads to narrow resonances and allows us to see exitations of the graviton at the TeV scale in the ATLAS detector.

Because the graviton couples universally, it is important to study the behavior of all the possible decay channels which may be seen in the ATLAS detector. In this paper we will explore the decay channel $G^* \to Z^0Z^0 \to e^+e^-e^+e^-$ against a background of Standard Model events $q\overline{q} \to Z^0Z^0 \to e^+e^-e^+e^-$.

2 Signal and Background Simulation

The simulation of the signal process $G^* \to Z^0Z^0 \to e^+e^-e^+e^-$ involved events created through the Pythia event generator for five mass points between 300GeV and 1.5TeV. Data from each event was then reconstructed using the Geant4 full simulation of the ATLAS detector response. In the case of $G^* \to Z^0Z^0 \to e^+e^-e^+e^-$, information obtained in the EM calorimeter and the inner detector are used to reconstruct the energy and direction of each electron. The invariant mass of the graviton is then reconstructed using this information. The cross-section for this interaction to occur decreases for increasing energies. Standard model background events from the process $q\overline{q} \to Z^0Z^0 \to e^+e^-e^+e^-$ not involving the graviton must also be considered within the analysis. Properties of the signal and background samples used in the analysis are summarized in Table 1. The number of events from the graviton must be significant compared to the Standard Model background in order for the signal to be detectable by ATLAS. The number of events is a function of the cross-section times branching ratio and the beam luminosity:

$$N_{Ev} = (\sigma \cdot B_r) \cdot L \quad (3)$$

The number of entries from the simulation must then be scaled according to cross-section times branching ratio and the beam luminosity, assuming

Process	$m_{G*}(GeV)$	$(\sigma B_r)_{sig}(fb)$	N_{Ev}
$G^* \to Z^0 Z^0 \to e^+e^-e^+e^-$	300	4.807	1675
$G^* \to Z^0 Z^0 \to e^+e^-e^+e^-$	500	0.7347	1918
$G^* \to Z^0 Z^0 \to e^+e^-e^+e^-$	700	0.0972	1677
$G^* \to Z^0 Z^0 \to e^+e^-e^+e^-$	1000	0.0167	1999
$G^* \to Z^0 Z^0 \to e^+e^-e^+e^-$	1500	0.001918	1899
$q\overline{q} \to Z^0 Z^0 \to e^+e^-e^+e^-$	200	9.068	1480
$q\overline{q} \to Z^0 Z^0 \to e^+e^-e^+e^-$	400	1.527	1000
$q\overline{q} \to Z^0 Z^0 \to e^+e^-e^+e^-$	500	0.7347	1918
$q\overline{q} \to Z^0 Z^0 \to e^+e^-e^+e^-$	800	0.167	1678
$q\overline{q} \to Z^0 Z^0 \to e^+e^-e^+e^-$	1200	0.03684	1876

Table 1: Properties of simulated data for signal and background processes: cross-section times branching ratio and number of events generated for each mass point

luminosity of $100fb^{-1}$ which corresponds to one year of the LHC running at design luminosity. This is then compared to the number of events generated at that mass point, and a weight is added to approximate the number of events expected at that energy.

3 Event Selection and Reconstruction

Since there is the possibility for particles to be produced which did not decay from the graviton but from other processes, all particles were checked for characteristics of high-energy electrons which most likely would have decayed from a graviton. Falsely identified pions were reduced by ignoring all particles with a probability of less than .9 of being an electron rather than a pion. Additionally, electrons with transverse energies less than 20GeV were not considered in the reconstruction of the graviton invariant mass, as they do not have high enough energy to have decayed from a graviton. The selection process within each event of the remaining electrons and positrons initially matches each particle with every other particle and calculates the invariant mass of two Z^0 bosons using the four-vector information provided by the reconstructed data. At this point, the four-vectors of each possible electron-positron pairs were used to compute the combined invariant mass of that pair. This result was compared to the known Z^0 mass of 91.1GeV. Selecting the

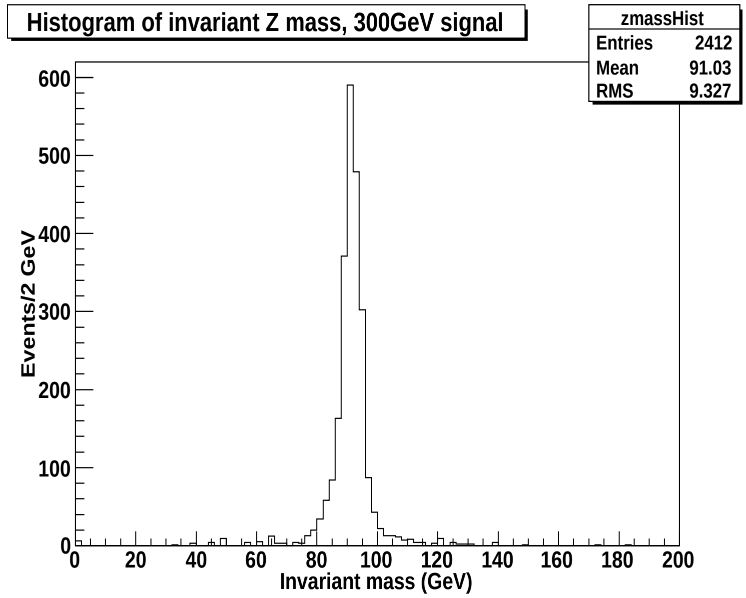

Figure 1: Invariant mass of the Z^0 bosons in the decay process $q\overline{q} \rightarrow Z^0 Z^0 \rightarrow e^+e^-e^+e^-$.

two electron-positron pairs with the least combined difference between the reconstructed Z mass and the known Z^0 mass (Figure 1) allows us to choose the electrons that decayed from the process $G^* \rightarrow Z^0 Z^0 \rightarrow e^+e^-e^+e^-$.

Once the two electron-positron pairs were selected as the pairs having decayed from the Z^0, the four-vectors of all four particles were used to calculate the invariant mass of the graviton.

The signal was fit to a guassian disribution (Figure 2), giving the standard deviation σ from the mean of the signal for each mass point, which is used to define a mass window of $\pm 3\sigma$. As energy increases, the number of background events decreases exponentially (Figure 3). The number of signal events and background events were counted within the window to determine the significance $\frac{N_{sig}}{\sqrt{N_{bg}}}$ of the signal. By requiring a significance greater than 5 as well as a minimum number of signal events $N_{sig} > 10$, the minimum luminosity needed to detect graviton resonances various mass points was determined.

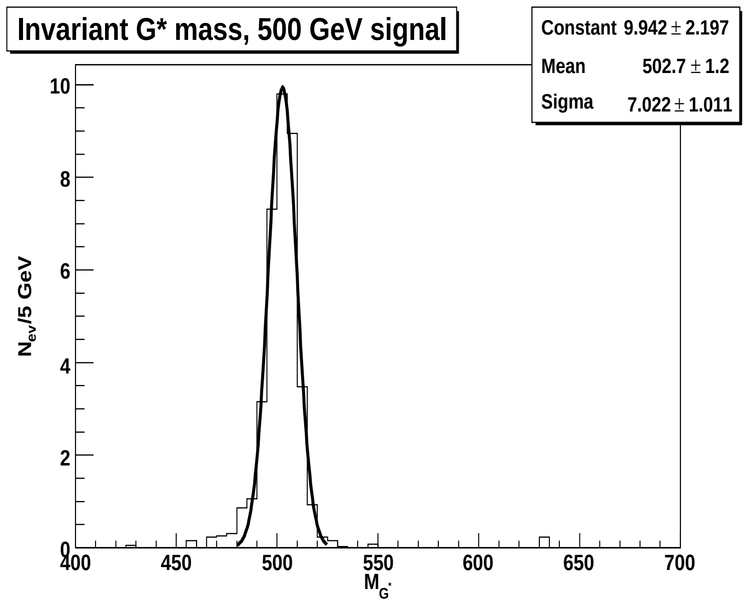

Figure 2: Signal at $M_{G^*} = 500GeV$, with a Gaussian fit

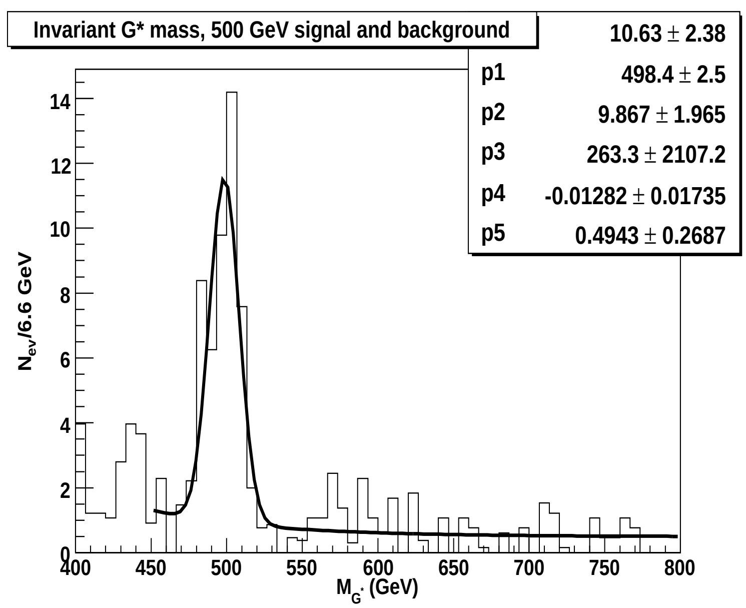

Figure 3: Signal and background at $M_{G^*} = 500GeV$, fit with $[p0]e^{\frac{(-(x-[p1])^2}{2[p2]^2}} + [p3]e^{([p4]x+[p5])}$

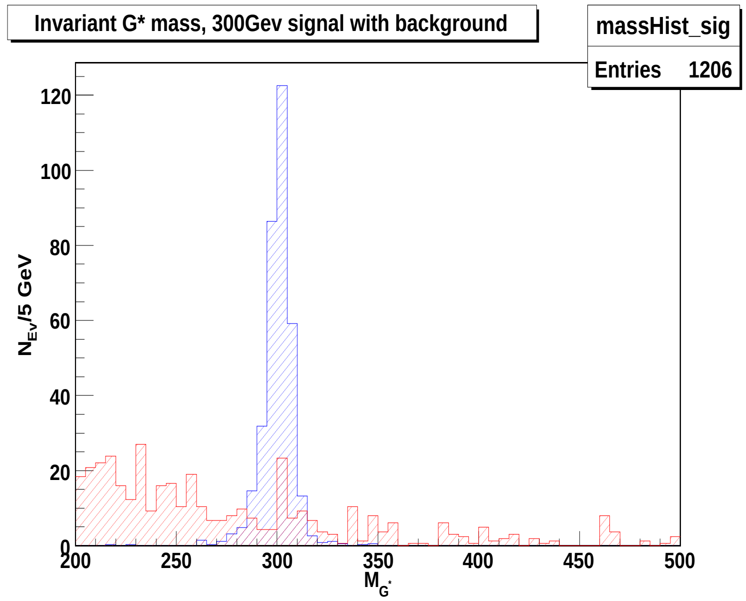

Figure 4: Signal(blue) with background(red) for $M_{G^*} = 300GeV$ with luminosity $L = 100fb^{-1}$

4 Results

The luminosity needed for statistical significance $N_{sig} \geq 5\sqrt{N_{bg}}$ and $N_{sig} \geq 10$ for each mass point was determined using equation (1). At luminosity 100fb-, we can see that signals with energy higher than about 700GeV the significance of the signal processes with respect to the background processes begins to fall. The reconstructed signal with background for each mass point can be seen in figures 4-7.

A main goal of this analysis was to determine the luminosity needed to detect signals of statistical significance at various energies. Since the cross-section times branching ratio decreases with energy, detecting gravitons of higher energy requires a higher luminosity for a significant number of signal events to be seen. Based on the five simulated mass points taken, we can see the minimum luminosity needed to see the number of signal events greater than $5 * \sqrt{N_b g}$ or 10 events in(Figure 8).

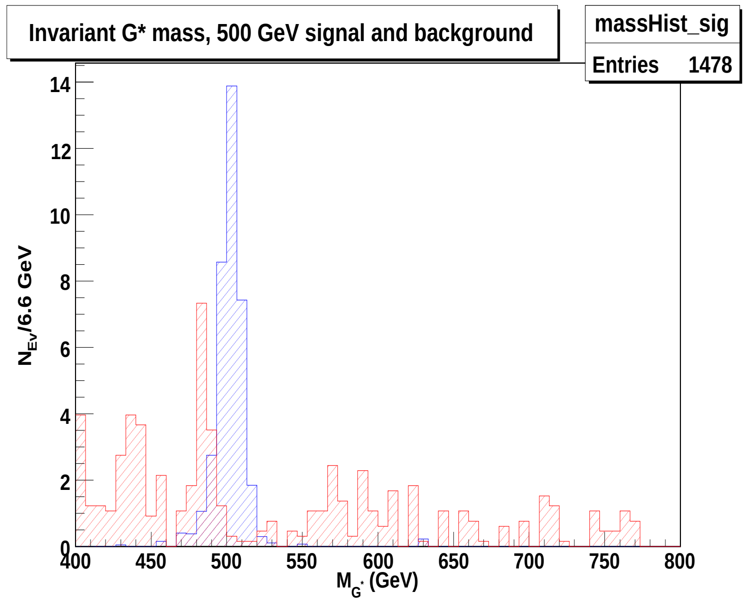

Figure 5: Signal(blue) with background(red) for $M_{G^*} = 500GeV$ with luminosity $L = 100fb^{-1}$

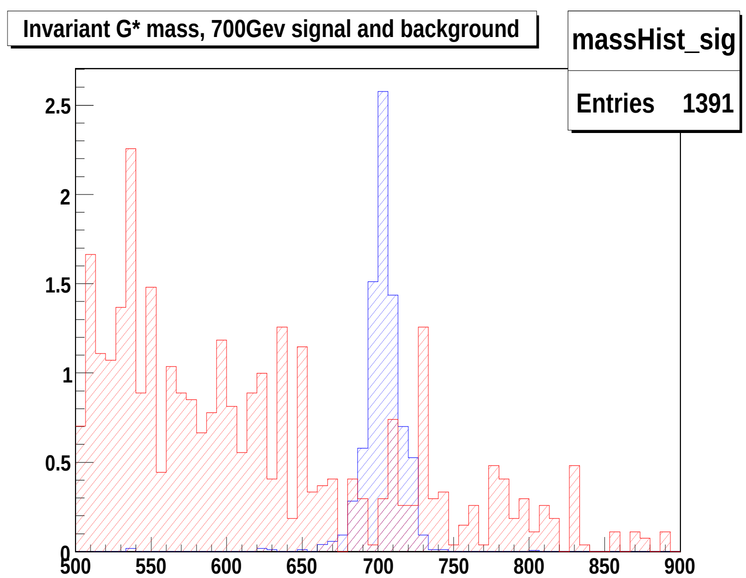

Figure 6: Signal(blue) with background(red) for $M_{G^*} = 700GeV$ with luminosity $L = 100fb^{-1}$

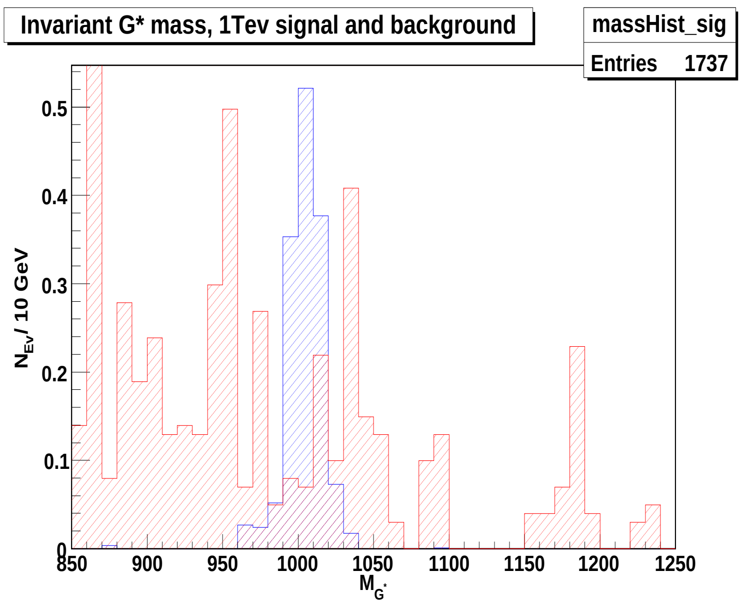

Figure 7: Signal(blue) with background(red) for $M_{G^*} = 1000GeV$ with luminosity $L = 100fb^{-1}$

M_{G^*} (GeV)	N_{sig} in $\pm3\sigma$	N_{BG} in $\pm3\sigma$	$S = \frac{N_{sig}}{sqrtN_{bg}}$
300	323.4	64.98	40.12
500	36.54	15.73	9.21
700	7.54	2.18	5.107
1000	1.34	7.317	.495
1500	.142	.192	.324

Table 2: Statistics on the expected number of events detected at each mass point with a luminosity of $100fb^{-1}$; Number if signal events N_{sig} within the mass window; number of background events N_{BG} within the mass window; Significance (S) of the signal

5 Conclusions

Assuming a beam luminosity of $100 fb^{-1}$, graviton resonances detected in the decay channel $G^* \rightarrow Z^0 Z^0 \rightarrow e^+e^-e^+e^-$ will only be significant compared to the Standard Model background produced by $q\overline{q} \rightarrow Z^0 Z^0 \rightarrow e^+e^-e^+e^-$ for signals below 700GeV. Additionally, the number of signal events N_{EV} within a the mass window of 3σ falls below 10 at these energies. Increasing the luminosity by several years would produce more signal events at higher energies, allowing a possible signal to be discovered. Discoveries through other couplings with higher discovery potential such as $G^* \rightarrow e^+e^-$ could provide a signal at a certain mass, which would also produce the four electrons in the final state as studied in this analysis. It would be interesting to compare this upper mass limit with those of other graviton processes to determine the overall the range for possible graviton resonance detection.

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References

[1] L. Randall and R. Sundrum, *Phys. Rev. Lett.* **83** (1999) 3370-3373, hep-th/9905221