ADD Extra Dimensional Gravity and Di-Jet Production at Hadron Colliders

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We re-analyze dijet production at hadron colliders (the Tevatron at Fermilab and the Large Hadron Collider, LHC, at CERN), to determine the potential limits on Planck mass in ADD type extra dimensional gravity scenarios. We try a variety of experimental observables in order to maximize the exclusion limits; we find that the p_T, p_T^2 and τ distributions give the highest search limits, and these observables provide comparable reaches.

1. Introduction

Conventional wisdom tells us that gravity is the weakest, by far, of the four fundamental forces of the universe. However, the possibility of large extra dimensions [1, 2] where gravity becomes strong at scales of order a TeV, may lead to a complete revision of conventional wisdom. This possibility has spawned a great deal of research, both phenomenological and experimental, into the discovery or exclusion of extra dimensional gravity scenarios.

The first such scenario [1], commonly known as ADD extra dimensional gravity, suggests that extra spatial dimensions (the bulk) beyond the usual 3 (the wall) exist in which gravity operates. For distances larger than the extra dimension length scale, the effective Planck mass is large, $M_P \sim 10^{19}\ GeV$, while for distances smaller than the extra dimension length scale, the true Planck mass is small, $M_S \sim \mathcal{O}(1\ TeV)$. The attractiveness of ADD and other extra dimensional gravity scenarios is that they solve the hierarchy and naturalness problems by moving the scale of gravity to something near the electroweak scale.

The phenomenology of the ADD model has been studied extensively; the Feynman rules are given in Ref. [3]. Among the many processes studied to date, Atwood, Bar-Shalom and Soni [4] recently studied the effect of graviton tower exchange to dijet production at hadron colliders. Unlike a direct graviton production process, where the graviton produced appears as a missing E_T signature, dijet production is sensitive to virtual graviton exchange in the s, t and/or u channels (depending on the subprocess). Virtual graviton exchange can modify various experimental observables to be significantly different than Standard Model (SM) predictions, and ADD scenarios can be discovered or excluded based on measured deviations from SM predictions. Similar analyses are possible under other extra dimensional gravity scenarios, such as Randall-Sundrum [2], but those analyses are beyond the scope of this study.

2. Calculation

In Ref. [4], equations for all the necessary parton level subprocesses are given. The authors of Ref. [4] reported exclusion limits at the Tevatron and LHC based on deviations from the SM τ distribution, where τ is the usual product of parton momentum fractions

$$\tau = xy = \frac{M_{jj}^2}{s} \tag{1}$$

but can also be expressed in terms of experimental observables M_{jj} (the jet-jet invariant mass) and s (the square of the center of mass energy).

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Based on recent compositeness searches by the CDF and D0 [5] collaborations, we felt that alternate experimental observables could improve the search reach here. One favorite observable is transverse momentum; p_T and p_T^2 are natural choices. Psuedorapidity,

$$\eta = \log \frac{1 + \cos\theta}{1 - \cos\theta} \tag{2}$$

is another commonly used observable. Related to η is

$$\chi = \frac{1 + \cos\theta}{1 - \cos\theta}. \tag{3}$$

In addition, a ratio of M_{jj} distribution with $\eta > \eta_0$ to M_{jj} distribution with $\eta < \eta_0$ was found to be useful in compositeness searches.

In order to simulate detector acceptance, we count jets only when $|\eta| < 1$ and $p_T > 10\ GeV$. Furthermore, we assume an integrated luminosity of $2\ fb^{-1}$ for the Tevatron and $30\ fb^{-1}$ for the LHC. With these acceptance cuts and integrated luminosities, the event rates are large, leading to a high level of sensitivity to deviations from the SM predictions. As will be clear below, this analysis will not depend strongly on the value of the p_T cut; the strongest deviation from SM occurs at p_T significantly higher than $10\ GeV$. For our analysis, CTEQ5M [6] distributions are used.

For all observables, a χ^2 analysis was performed, where

$$\chi^2 = \sum \left(\frac{\mathcal{N}_i - \mathcal{N}_i^{\mathrm{SM}}}{\delta \mathcal{N}_i^{\mathrm{SM}}} \right)^2 \tag{4}$$

where $\mathcal{N}_i$ is the event number in a specific bin, and only statistical errors were considered, so that the uncertainty in $\mathcal{N}_i$, $\delta\mathcal{N}_i$, equals $\sqrt{\mathcal{N}_i}$. $\chi^2 = 4$ corresponds to a 95% C.L. deviation from the SM. We chose the number of bins to be 50 for the Tevatron and 100 for the LHC; this corresponds to p_T bin sizes of $20\ GeV$ and $70\ GeV$, respectively.

A comparison of the p_T distribution, $d\sigma/dp_T$, is shown in Figure 1, for both the Tevatron and the LHC; the SM (solid line) is compared with extra dimensional gravity predictions for the number of extra dimensions δ of 3 and 4, as indicated on the figures. The extra dimensional gravity points include statistical uncertainty only, and the horizontal dashed line indicates 1 event/bin. The other extra dimensional gravity parameter, the Planck mass M_S, is chosen to be $1\ TeV$ for the Tevatron and $7\ TeV$ for the LHC. There is a large excess of events at high p_T, and it is clear that the exclusion limits possible far exceed the values of M_S chosen to produce Figure 1.

The search/exclusion limits possible at the Tevatron are $M_S = 3.1\ TeV$ ($2.6\ TeV$) for $\delta = 3$ (4), while the limits at the LHC are $20.8\ TeV$ ($17.4\ TeV$). Similar limits are possible using p_T^2 and τ distribution; the limits for these observables are only a few 10s of GeV lower. The other observables mentioned above (χ, η, M_{jj}, *etc.*) provide limits that are significantly lower than those from the p_T distribution. The authors of Ref. [4] chose one of the best possible observables on which to base their analysis.

The exclusion limits reported here are slightly higher than those in Ref. [4], even for the τ distribution. This is almost certainly due to our use of a finer binning of observables in the distributions. Just as a distribution will give a higher χ^2 than a total cross section, a more finely binned distribution will give a higher χ^2 than a coarser binning, assuming sufficient event numbers. The binning used here for the p_T distribution is rather coarse, so our results are, in a sense, conservative.

3. Conclusions

Due to the extremely high event rate, dijet production at hadron colliders is a favorite for searches for Physics Beyond the Standard Model. As shown originally by the authors of Ref. [4], dijet production at the Tevatron and the LHC is very sensitive to virtual graviton exchange effects, as provided by extra dimensional gravity scenarios.

In this re-analysis, we studied a number of observables related to dijet production, and found that the p_T distribution was more sensitive to virtual graviton effects than the τ distribution

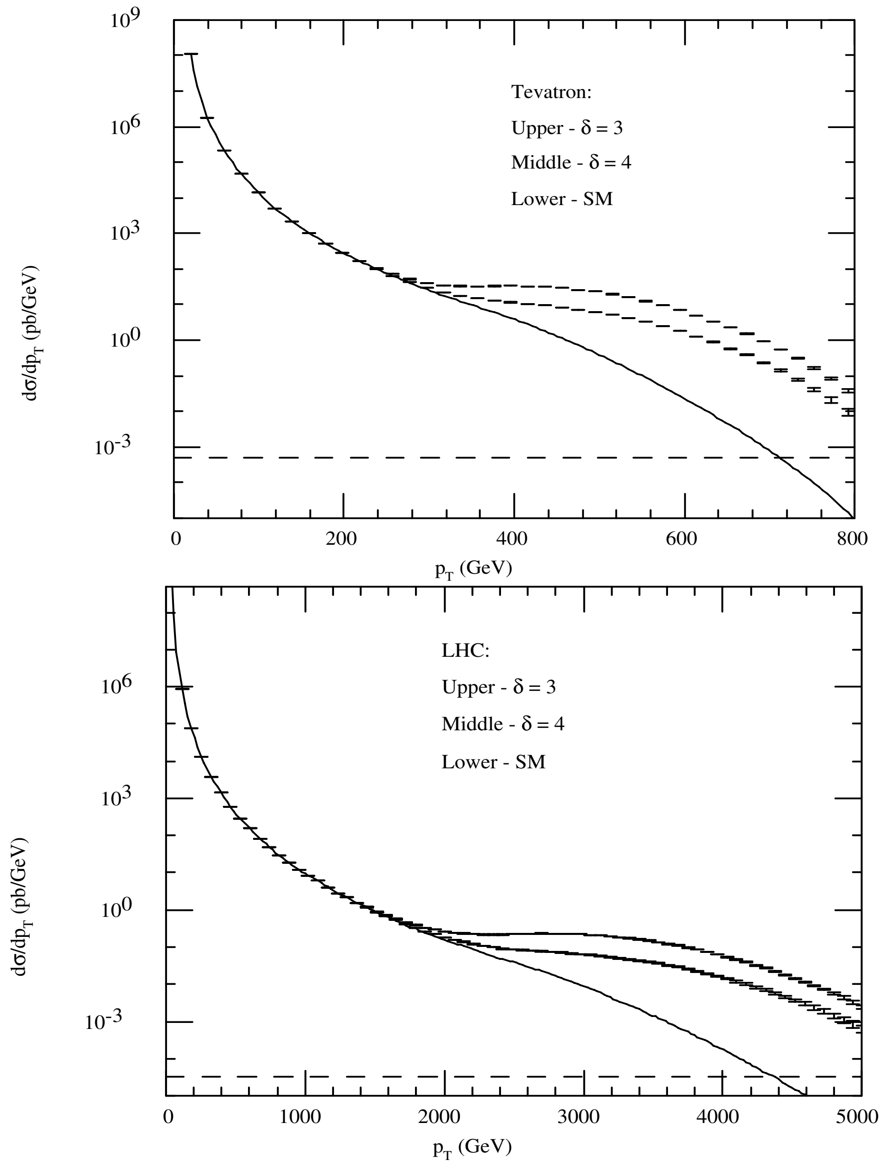

Figure 1: (a) $d\sigma/dp_T$ vs. p_T for the for the SM (solid lines) and with extra dimensional gravity ($\delta = 3, 4$ as indicated on the figures) for the Tevatron and LHC respectively. The error bars correspond to 1 σ statistical uncertainties only; an integrated luminosity of 2 fb^{-1} (30 fb^{-1}) and $M_S = 1.0\ TeV$ ($7.0\ TeV$) is assumed for the Tevatron (LHC). The horizontal dashed line indicates 1 event per bin.

proposed by the authors of Ref. [4], but only slightly more sensitive. A more thorough analysis, including a more realistic detector simulation and systematic effects, is required, but the more careful analysis will not change the fact that dijet production at hadron colliders will be an important probe of extra dimensional gravity models.

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References

[1] N. Arkani-Hamed, S. Dimopoulos and G. Dvali, Phys. Lett. **B429**, 263 (1998) and Phys. Rev. **D59**, 086004 (1999); I. Antoniadis, N. Arkani-Hamed, S. Dimopoulos and G. Dvali, Phys. Lett. **B436**, 257 (1998).
[2] L. Randall and R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999) and *ibid.*, 4690 (1999).
[3] T. Han, J. D. Lykken, R.-J. Zhang, Phys. Rev. **D59**, 105006 (1999); G. F. Giudice, R. Rattazzi, J. D. Wells, Nucl. Phys. **B544**, 3 (1999).
[4] D. Atwood, S. Bar-Shalom and A. Soni, Phys. Rev. **D62**, 056008 (2000).
[5] G. Landsburg, `hep-ex/9910034`; D0 Collaboration (B. Abbott *et al.*), Phys. Rev. **D64**, 032003 (2001); Phys. Rev. Lett. **82**, 2457 (1999).
[6] CTEQ Collaboration (H.L. Lai, *et al.*), Eur. Phys. J. **C12**, 375 (2000).