CDF/PUB/EXOTIC/PUBLIC/7098

Search For a High-Mass Diphoton State and Limits on Randall-Sundrum Gravitons at CDF

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URL http://www-cdf.fnal.gov
(Dated: August 11, 2004)

The paper summarizes the CDF search for a high-mass state decaying to two photons. The sample corresponds to 345 pb^{-1} of Tevatron data taken at $\sqrt{s} = 1.96$ TeV between February 2002 and July 2004. We examine data with two photons in the central calorimeter ($|\eta| < 1.04$) with $E_t > 15$ GeV. Since the data are consistent with the Standard Model prediction, we place upper limits on the cross section times branching ratio of Randall-Sundrum graviton production and decay to diphotons. All results are preliminary.

Preliminary Results for Summer 2004 Conferences

I. INTRODUCTION

Searches for new particles decaying to two identical particles are broad, inclusive and sensitive. The production of the new particle may be direct or with associated particles, or in a decay chain. The discovery of a sharp mass peak over background would be compelling evidence of a new particle. The diphoton final state is important because the photons are bosons and the parent maybe fermiphobic. The photons have moderate signal–to–noise but good efficiency and mass peak resolution.

One model producing a diphoton mass peak is Randall-Sundrum gravitons [1]. Current string theory proposes that as many as seven new dimensions may exist and the geometry of these extra dimensions are responsible for why gravity is so weak. The Randall–Sundrum model has the property that a parameter, the warp factor, determines the curvature of the extra dimensions and therefore the mass of the Kaluza–Klein graviton resonances. In this case the resonances are narrow, smaller than our detector resolution, and decay to two bodies including two photons.

Searches in the final state with two electrons, muons, or jets are also being performed [2]. The CDF detector is described in detail elsewhere [3].

II. DATA SAMPLE & EVENT SELECTION

Our sample corresponds to 345 pb^{-1} of Tevatron data taken at $\sqrt{s} = 1.96$ TeV between February 2002 and July 2004. The data was collected using 4 triggers. The most restrictive cuts are applied at the 3rd trigger level where the diphoton triggers require two clusters, isolated in the calorimeter, with $E_t > 12$ or two clusters with $E_t > 18$ GeV regardless of isolation. The high-Et single photon triggers are $E_t > 50$ GeV with no isolation requirement, or $E_t > 70$ GeV with no other requirements at all. The combination of these triggers is 100% effective for a high-mass state. This dataset includes 48 pb^{-1} of data taken with the inner layers of the COT turned off to prevent aging (the detector has now been recovered and returned to full operation). This period has reduced tracking efficiency and resolution, which does not significantly effect this analysis.

We require that the data was taken under good detector conditions. There must be an event vertex with $|z| < 60$ cm, which is 95% efficient. In this analysis, we examine only events where both photons are in the central calorimeter (approximately $|\eta| < 1.04$), have $E_t > 15$ GeV and their invariant mass greater than 30 GeV/c^2. We require both photons pass standard photon cuts which include good shower shape in the shower max detector, no other significant clusters nearby in the shower max detector; less than 2 GeV of transverse energy in the calorimeter, in a cone of 0.4 around the candidate; and the scalar sum of the P_t of the tracks in the same cone size to be less than 2 GeV.

The final dataset consists of 3339 events. The data histogrammed with bins equivalent to one σ of resolution is shown in Figure 1. The highest mass events occur at masses of 207, 247, 304, 329, and 405 GeV/c^2, and they have the respective cosθ^* values -0.47, -0.09, -0.33, -0.08 and 0.52 (in the Collins-Soper rest frame [4].) We have scanned these events and concluded that they are also visually consistent with diphoton production. Figure 2 shows the Collins-Soper rest frame cosθ^* distribution for all of the events observed, compared to the expected distribution, whereas Figure 3 shows this distribution for events with an invariant mass above 200 GeV/c^2 and also the distribution for a Randall-Sundrum graviton of 500 GeV/c^2 and k/M_{Pl}=0.1.

III. BACKGROUNDS

There are two significant backgrounds to our sample. The first is Standard Model diphoton production which accounts for 30% of our events. We estimate this background using a NLO Monte Carlo, diphox [5]. We use this program to produce a cross section as a function of mass. We then correct this spectrum by an efficiency function derived from a Standard Model diphoton sample generated using Pythia [6] and our full GEANT–based detector simulation. The leading systematic uncertainty on this result is one half the difference between the central value of fragmentation scale ($m_{\gamma\gamma}/2$) and an extreme value ($m_{\gamma\gamma} * 2$).

The second background is from jets, primarily jets which fragment into a leading π^0. For a control sample, we loosen several cuts including relaxing the isolation cuts by 50%. We reject events in the signal sample and are left with 6552 events in this "photon sideband" sample. We then fit this sample to a sum of several exponentials to derive the shape in the mass distribution. We then normalize the fakes background to the data between 30 and 100 GeV/c^2, after subtracting the estimate from the Standard Model diphotons. The cuts on the photon sideband are varied and the shape is refit. This is the leading systematic on the jet background. The statistical uncertainty is also propagated.

Figure 4 shows the data mass spectrum compared to the Standard Model prediction. Table I displays the number of expected and observed in 345 pb^{-1} of data above particular mass thresholds.

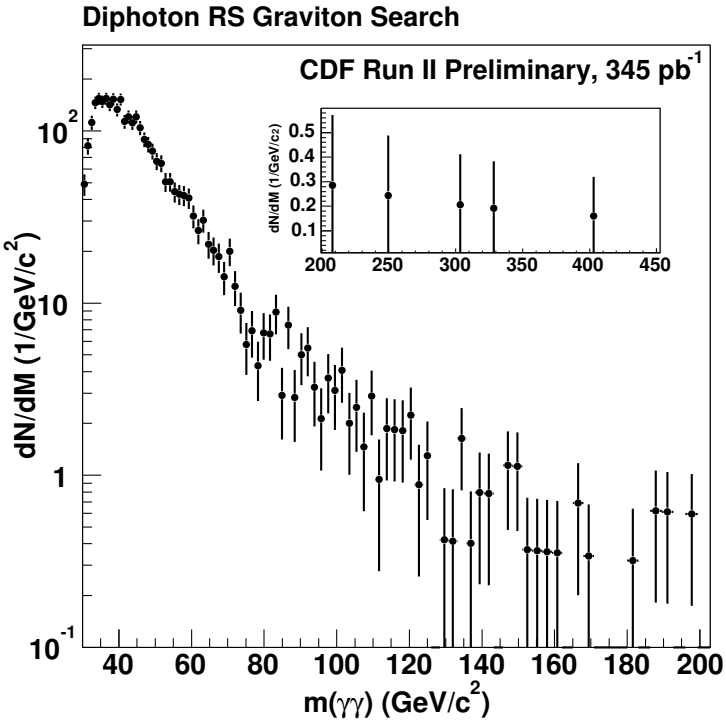

FIG. 1: The diphoton mass distribution histogrammed in bins of approxiamtely one σ of mass resolution.

CDF Run II Preliminary (345 pb^{-1})

Mass Threshold	Standard Model	Non-Photon Background	Total Background	Data
GeV/c^2	Number of Diphoton Events			
100	84.9 ± 20.4	12.0 ± 7.2	96.8 ± 21.6	87
150	27.9 ± 8.0	2.2 ± 2.6	30.1 ± 8.5	21
200	11.5 ± 4.2	0.82 ± 1.25	12.3 ± 4.4	5
250	5.3 ± 2.6	0.36 ± 0.71	5.9 ± 2.7	3
300	2.6 ± 1.7	0.17 ± 0.45	2.8 ± 1.8	1
350	1.3 ± 1.2	0.08 ± 0.30	1.4 ± 1.2	1
400	0.61 ± 0.80	0.04 ± 0.20	0.65 ± 0.82	1
450	0.29 ± 0.54	0.017 ± 0.130	0.30 ± 0.56	0

TABLE I: Number of diphotons expected and observed in 345 pb^{-1} of data above particular mass thresholds.

IV. EFFICIENCIES

We estimate efficiencies for Randall–Sundrum events with Pythia 6.223 [6] and the CTEQ5L PDF. We have reweighted the events for the $\cos\theta^*$ distribution which is not implemented in this version of Pythia. The events are simulated by the full CDF GEANT-based simulation. The acceptance for the central ($|\eta| < 1.04$) and $E_t > 15$ GeV cuts for Randall–Sundrum events increases from 0.246 ± 0.003 for 200 GeV/c^2 mass gravitons, to 0.565 ± 0.006 for 850 GeV/c^2 mass gravitons.

Small corrections to the efficiency are derived by comparing data and Monte Carlo detector response to electrons from Z decay. (The electron showers are very similar to photon showers.) We also make a small correction based on detector material studies which are important since material can cause photons to convert and therefore fail cuts.

The final acceptance times efficiency for model events is shown in Figure 5. This increases from 0.090 ± 0.016 for a graviton mass of 200 GeV/c^2, to 0.216 ± 0.032 for a graviton mass of 900 GeV/c^2.

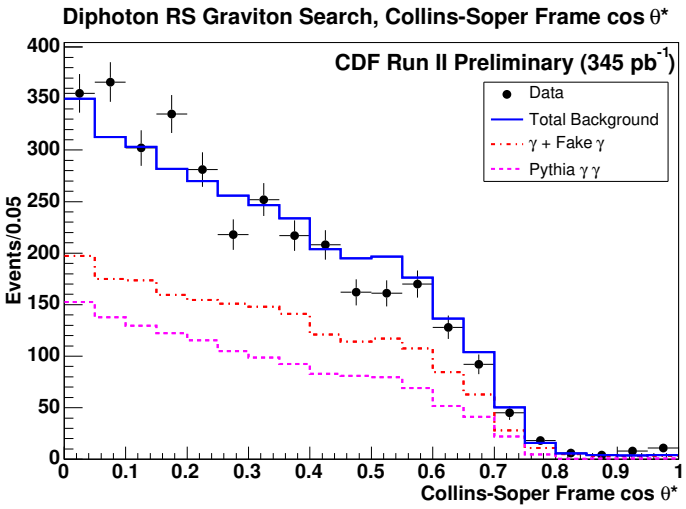

FIG. 2: Collins-Soper rest frame cosθ^* distribution for all of the events observed, compared to the expected distribution from the Standard Model (shape from Pythia (LO), but normalised to the number expected from diphox (NLO)), and that from sideband data sample (normalised in the low mass region).

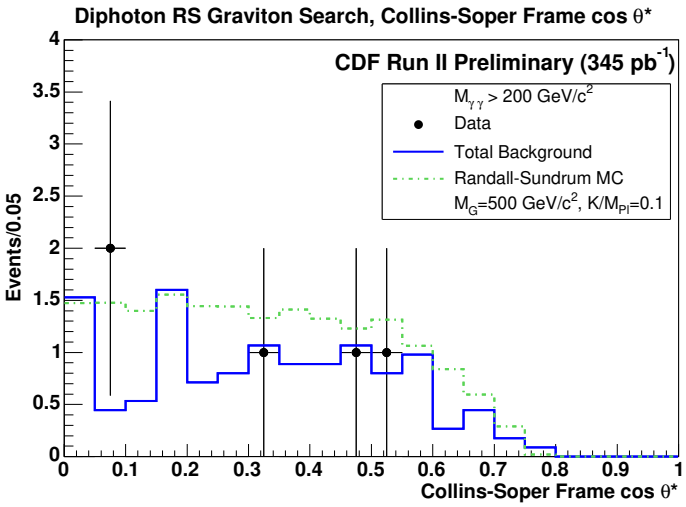

FIG. 3: Collins-Soper rest frame cosθ^* distribution for events observed with an invariant mass greater than 200 GeV/c^2, compared to the expected distribution from the Standard Model (shape from Pythia (LO), but normalised to the number expected from diphox (NLO)), and that from sideband data sample (normalised in the low mass region).

V. LIMITS

Since the data are consistent with the Standard Model prediction, we place upper limits on the cross section times branching ratio of Randall-Sundrum graviton production and decay to diphotons, for graviton masses between 200 and 900 GeV/c^2. The limits are computed using a Bayesian style program, which utilises the observed number of events in a 3σ mass window around each graviton mass, the background prediction in this window, the efficiency, and luminosity. These values for each graviton mass are summarized in Table II. The 95% upper limits are displayed in Figure 6 as function of the graviton mass. Also shown are the cross section predictions for several values of the warp factor. We can exclude gravitons as function of the warp factor and the graviton mass: this is shown in Figure 7. At k/M_{Pl}=0.1 gravitons with masses < 690 GeV/c^2 are excluded at 95% the confidence level.

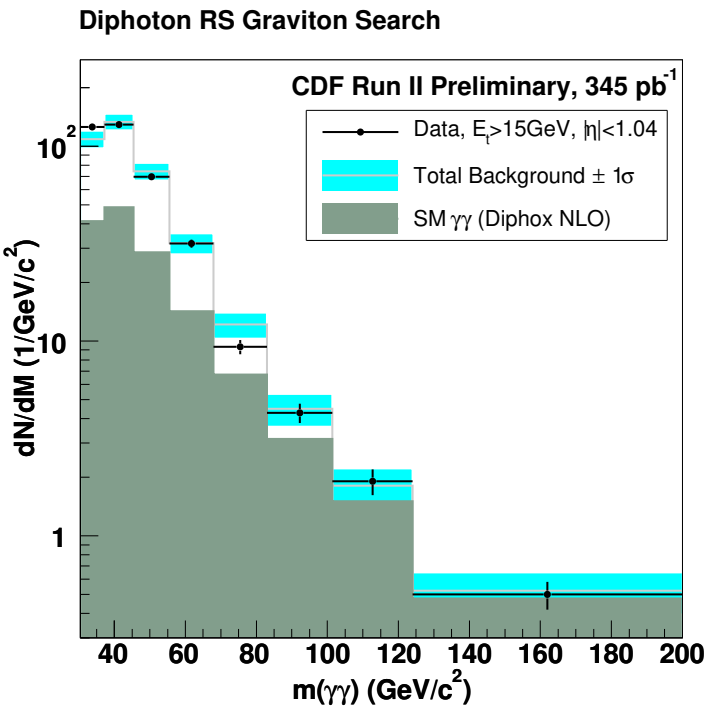

FIG. 4: The observed diphoton mass spectrum compared to the prediction.

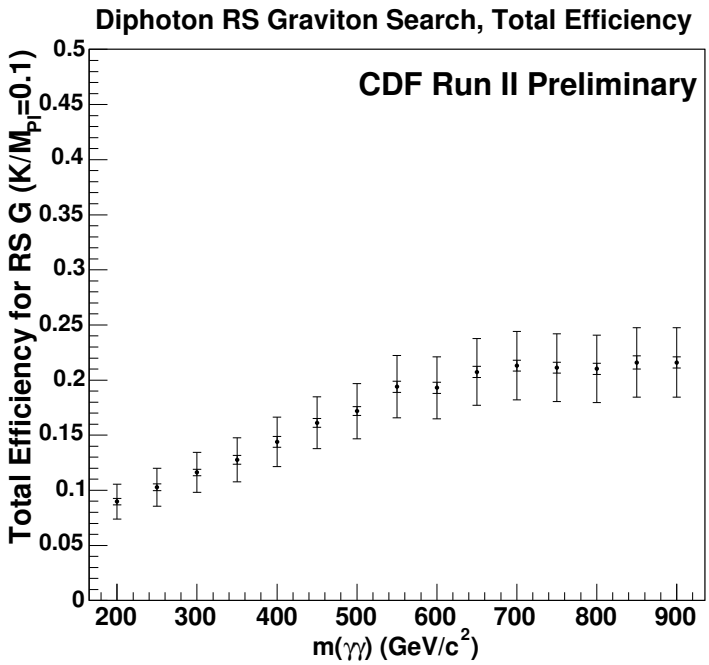

FIG. 5: The total acceptance times efficiency of the Randall-Sundrum model.

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m_G	Search window	N_{bkdg}	N_{data}	$N_{95\%}$	A*ϵ	$\sigma_{95\%}$
	GeV/c^2	Number of Diphoton Events				pb
200	184-218	10.5 ± 2.4	7	7.4	0.092 ± 0.02	0.23
250	232-272	5.4 ± 1.3	1	3.8	0.106 ± 0.02	0.10
300	278-328	4.2 ± 1.0	1	3.9	0.119 ± 0.02	0.093
350	324-382	1.5 ± 0.52	1	4.2	0.132 ± 0.02	0.093
400	370-434	0.93 ± 0.39	1	4.5	0.149 ± 0.02	0.087
450	416-490	0.84 ± 0.35	0	3.2	0.166 ± 0.02	0.055
500	460-544	0.51 ± 0.27	0	3.2	0.177 ± 0.02	0.052
550	506-598	0.41 ± 0.22	0	3.2	0.199 ± 0.03	0.046
600	552-652	0.38 ± 0.18	0	3.2	0.199 ± 0.03	0.046
650	596-704	0.20 ± 0.14	0	3.2	0.214 ± 0.03	0.043
700	642-758	0.018 ± 0.11	0	3.2	0.219 ± 0.03	0.042
750	684-812	0.048 ± 0.084	0	3.2	0.218 ± 0.03	0.042
800	732-864	0.039 ± 0.068	0	3.2	0.216 ± 0.03	0.042
850	776-916	0.060 ± 0.058	0	3.2	0.223 ± 0.03	0.041
900	820-968	0.051 ± 0.046	0	3.2	0.222 ± 0.03	0.041

TABLE II: The 95 % confidence level limits on the production cross-section times branching fraction of RS model graviton decaying to diphotons ($\sigma_{95\%}$·B(G $\rightarrow \gamma\ \gamma$)). These limits are calculated using the 95 % confidence level upper limit on the number of expected events ($N_{95\%}$), which depends on the background estimate (N_{bkdg}) and the number of events observed N_{data} in the search window; the acceptance and efficiency (A*ϵ); and the luminosity.

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium fuer Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comision Interministerial de Ciencia y Tecnologia, Spain; and in part by the European Community's Human Potential Programme under contract HPRN-CT-20002, Probe for New Physics.

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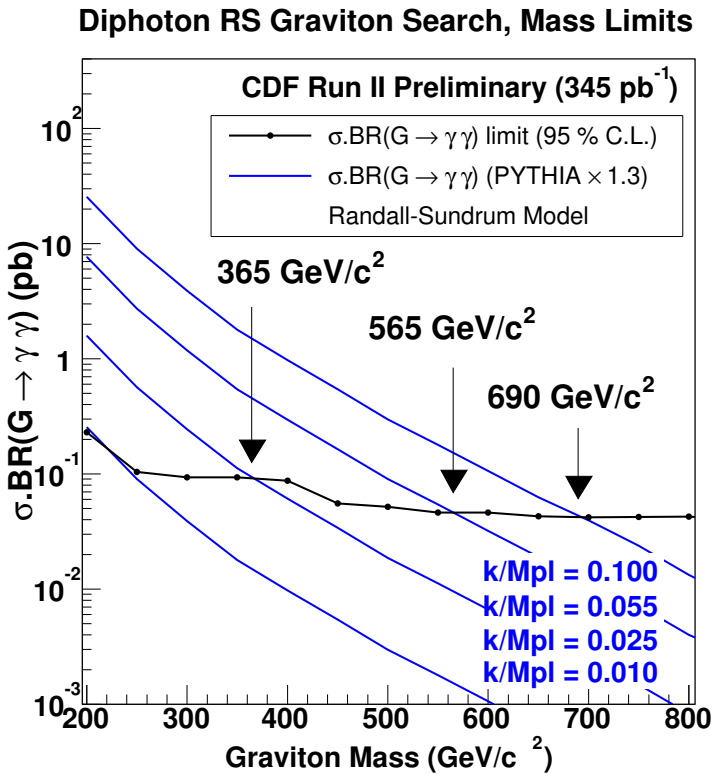

FIG. 6: The cross section limits from the data and the cross section of the Randall-Sundrum Model.

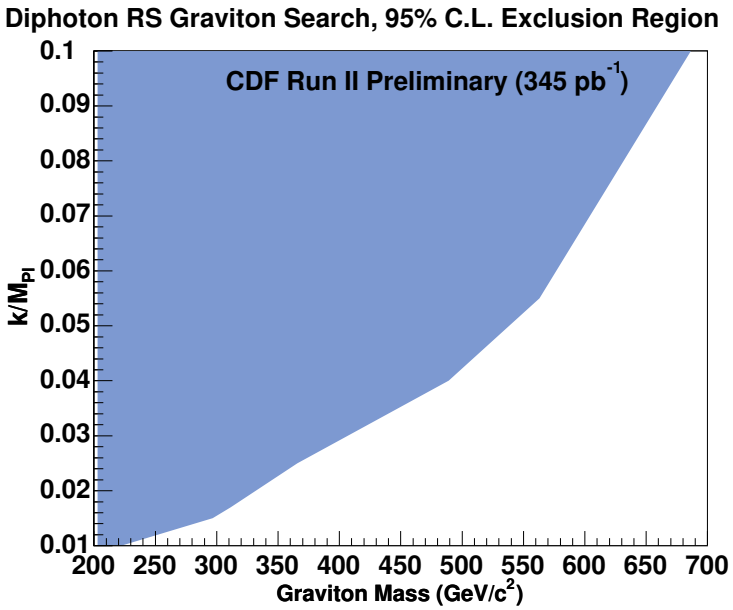

FIG. 7: The limits on the Randall-Sundrum graviton model displayed as a function of graviton mass and warp factor.