CDF note xxxx

A Search for Massive Gluon Decaying to Top Pair in Lepton+Jet Channel

The CDF Collaboration
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We present a result on the search for the new color-octet particle (*massive gluon*) decaying to top quark pair in proton-antiproton collisions with a center-of-mass energy of 1.96 TeV, based on 1.9 fb^{-1} of data collected by the CDF in the Tevatron Run II. The lepton+jet channel with at least one secondary vertex b-tagged jet are studied. The observed top quark pair invariant mass distribution is consistent with the standard model prediction within the explored parameter space. We set the 95 % confidence level limits on the coupling strength.

I. INTRODUCTION

The top quark is the heaviest elementary particle, which could be sensitive to the physics beyond standard model [1]. The search for the new color-singlet particle decaying the top pair have been performed at both CDF and DØ [2, 3]. In this analysis we search for the new color-octet particle, *"massive gluon (G)"*, based on the generic assumption. The top quark pairs are produced coherently in $q\bar{q}$ annihilation process in this case. The production matrix element can be written as,

$$|\mathcal{M}_{\rm prod.}|^2 = \frac{9}{2}g_s^4\hat{s}^2(2-\beta^2+\beta^2\cos^2\theta)(\Pi_g+\lambda\Pi_{\rm int.}+\lambda^2\Pi_G) \tag{1}$$

where the propagator factors are

$$\Pi_g = \frac{1}{\hat{s}^2},\ \Pi_G = \frac{1}{(\hat{s}-M^2)^2+M^2\Gamma^2},\ \Pi_{\rm int.} = \frac{2}{\hat{s}}\frac{\hat{s}-M^2}{(\hat{s}-M^2)^2+M^2\Gamma^2} \tag{2}$$

$\lambda \equiv \lambda_q\lambda_Q$. λ_q and λ_Q are the coupling strength of massive gluon to the light quark and heavy quark, relative to the strong coupling as shown in the figure1. There are 3 modeling parameters, λ (strength of coupling), mass, and the decay width. λ can be both positive and negative. We assume no parity violation.

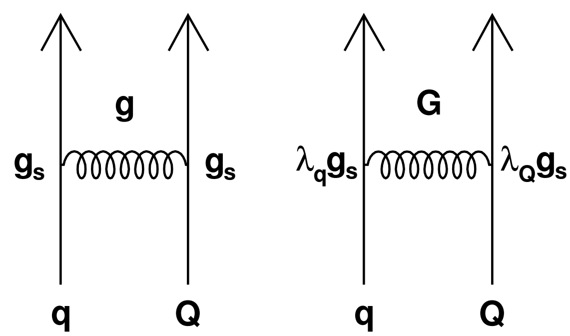

FIG. 1: Feynman diagram: Left diagram is SM $q\bar{q}$ annihilation process. Right diagram is Massive Gluon process. These processes interfere.

II. DATA SAMPLE & EVENT SELECTION

This analysis is based on an integrated luminosity of 1.9 fb^{-1} collected with the CDFII detector between March 2002 and May 2007. To select lepton+jets events, $t\bar{t} \to W^+W^-b\bar{b} \to l\bar{\nu}_l q\bar{q}'b\bar{b}$, we require one lepton ($p_T > 20$ GeV), high missing E_T (> 20 GeV) and exact 4 jets ($E_T > 20$ GeV and $|\eta| < 2.0$). Jets are reconstructed with the cone algorithm with a radius of 0.4 [4]. The SECTVX algorithm [5] based on the identification of secondary vertices inside jets is used to tag b-jets. The dataset with high-p_T lepton ($E_T > 18$ GeV for electron and $p_T > 18$ GeV for muon) collected in CDF are studied. The processes of $q\bar{q} \to g \to t\bar{t}$ and $q\bar{q} \to G \to t\bar{t}$ can not be treated separately due to the effect of the interference. So we treat $q\bar{q} \to t\bar{t}$ as signal, and the other processes are the backgrounds. The background processes are $gg \to t\bar{t}$, W boson + heavy flavor, W boson + light flavor (*Mistags*), QCD, diboson, Z boson production, and the single top productions. The way of background estimation is described in the reference [6]. The fraction of gluon fusion in the top pair production from the next-to-leading-order calculation [7] is assumed.

III. SEARCH METHODOLOGY

The $t\bar{t}$ invariant mass is reconstructed event-by-event using the Dynamical Likelihood Method (DLM) [8]. The production matrix element is not used for the reconstruction to avoid the bias by assuming the standard model or massive gluon production. After reconstructing the $t\bar{t}$ invariant mass, we perform the unbinned likelihood fit by scanning the mass and width of massive gluon to extract the coupling strength.

$$L(\boldsymbol{\alpha},\nu_s,\nu_b) \equiv G(\nu_b;\nu_b^{\exp},\sigma_b^{\exp})P(N;\nu)\prod_{i=1}^{N}\frac{\nu_s p_s(\sqrt{s_{t\bar{t}}}_r(i);\boldsymbol{\alpha})+\nu_b p_b(\sqrt{s_{t\bar{t}}}_r(i))}{\nu} \tag{3}$$

where, $\boldsymbol{\alpha}$ is massive gluon parameters: $\boldsymbol{\alpha} \equiv (\lambda, M, \Gamma)$. G is Gaussian and P is Poisson. $\nu_b^{\exp}$ is the central value of expected background number and $\sigma_b^{\exp}$ is the uncertainty of background estimation. N is the total number of event. $\sqrt{s_{t\bar{t}}}_r$ is the reconstructed $t\bar{t}$ invariant mass of i-th event. p_s (p_b) is the signal (background) $t\bar{t}$ invariant mass probability density function (p.d.f.). ν_s and ν_b are the signal and background numbers ($\nu \equiv \nu_s + \nu_b$).
The reconstructed signal $t\bar{t}$ invariant mass p.d.f. is defined by

$$p_s[\sqrt{s_{t\bar{t}}}_r;\boldsymbol{\alpha}] \equiv N(\boldsymbol{\alpha})\int\left[\frac{d\sigma}{d\sqrt{s_{t\bar{t}}}_p}\right]_{SM:q\bar{q}\to t\bar{t}}\epsilon(\sqrt{s_{t\bar{t}}}_p)R(\sqrt{s_{t\bar{t}}}_p;\boldsymbol{\alpha})f(\sqrt{s_{t\bar{t}}}_r-\sqrt{s_{t\bar{t}}}_p;\sqrt{s_{t\bar{t}}}_p) \tag{4}$$

where, $\sqrt{s_{t\bar{t}}}_p$ is the parton level $t\bar{t}$ invariant mass, $N(\alpha)$ is normalization factor, ϵ is acceptance, R is the (massive gluon)/(SM) differential cross section ratio and f is the resolution function (left plot of figure4).

$$N(\boldsymbol{\alpha})^{-1} = \int\left[\frac{d\sigma}{d\sqrt{s_{t\bar{t}}}_p}\right]_{SM:q\bar{q}\to t\bar{t}}\epsilon(\sqrt{s_{t\bar{t}}}_p)R(\sqrt{s_{t\bar{t}}}_p;\boldsymbol{\alpha})d\sqrt{s_{t\bar{t}}}_p \tag{5}$$

$$R(\sqrt{s_{t\bar{t}}}_p;\boldsymbol{\alpha}) \equiv \frac{[d\sigma/d\sqrt{s_{t\bar{t}}}_p]_{MG}}{[d\sigma/d\sqrt{s_{t\bar{t}}}_p]_{SM}} = \frac{|\mathcal{M}_{prod}(s_{t\bar{t}p};\boldsymbol{\alpha})|^2_{MG}}{|\mathcal{M}_{prod}(s_{t\bar{t}p})|^2_{SM}} \tag{6}$$

$$= 1+2\lambda\frac{s_{t\bar{t}p}(s_{t\bar{t}p}-M^2)}{(s_{t\bar{t}p}-M^2)^2+M^2\Gamma^2}+\lambda^2\frac{s_{t\bar{t}p}^2}{(s_{t\bar{t}p}-M^2)^2+M^2\Gamma^2} \tag{7}$$

In equation4 we use the differential cross section ratio to describe the massive gluon parton level $\sqrt{s_{t\bar{t}}}$, because by taking the ratio many factors are canceled, like PDFs, top propagators, decay matrix elements and the Jacobian's, and the differential cross section ratio is written by simple formula 7.
The right plot of the figure4 shows the background p.d.f.

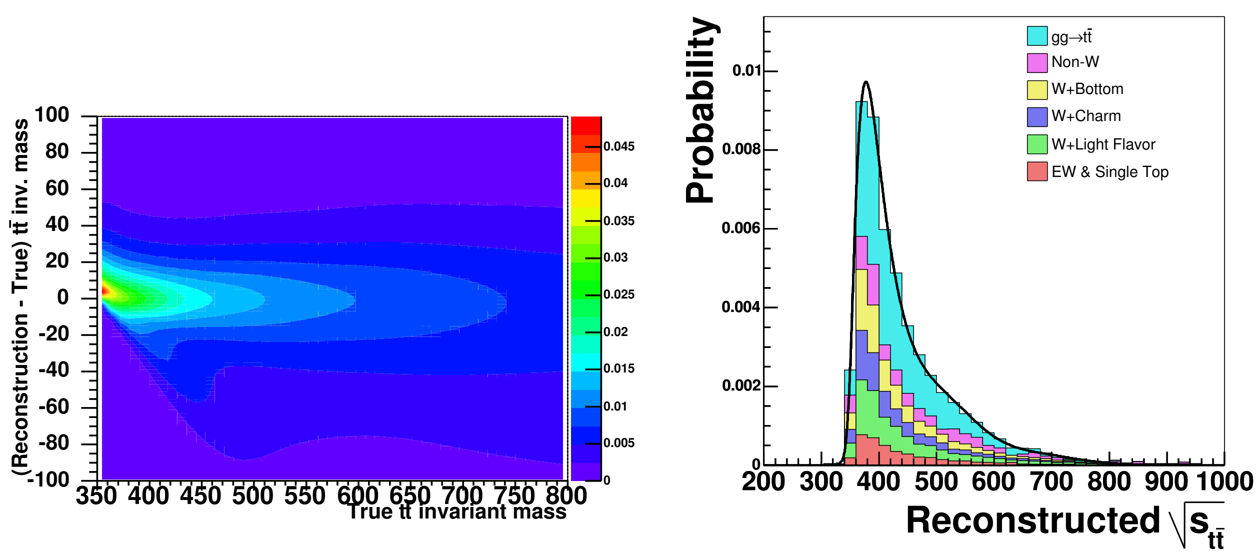

FIG. 2: The left plot is the resolution function in the $t\bar{t}$ invariant mass reconstruction normalized at the given true value. The right plot is the background probability density function.

IV. SYSTEMATIC UNCERTAINTIES

We briefly summarize the systematic uncertainties. The changes in the shape of $t\bar{t}$ invariant mass distribution affect the fitted coupling strength. The jet energy scale and top mass uncertainties are shifted $\pm 1\sigma$ simultaneously to account for the correlation. The uncertainties of the parton distribution function (PDF) are estimated by using different PDF sets (CTEQ5L vs MRST72), different values of Λ_{QCD} and varying the eigenvectors of the CTEQ6M set. The difference from the generators is estimated by using Pythia[9] and Herwig[10]. The uncertainties due to the next-to-leading-order is estimated by using the MC@NLO[11]. The initial and final state gluon radiation is estimated using Pythia by shifting the range of QCD parameters studied with Drell-Yan data. The uncertainty in the MC modeling of the multiple interaction and the b-tagging efficiency as a function of jet p_T are evaluated. These uncertainties are evaluated at the various coupling strengths, masses and decay widths, and incorporated in the likelihood function. The example of the systematic uncertainties is shown in figure3.

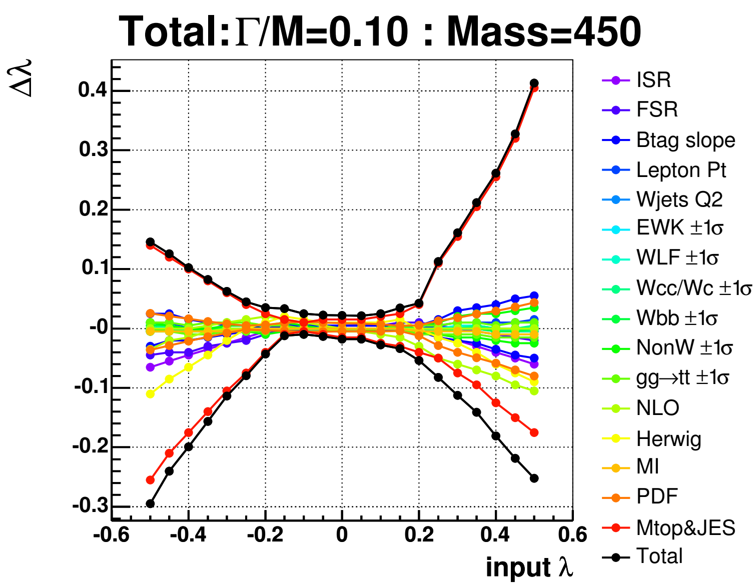

FIG. 3: The example of the systematic uncertainties at $\Gamma/M = 0.1$ and $M = 450$ GeV.

V. RESULTS

The $t\bar{t}$ invariant mass distribution is shown in figure4. The fitted coupling strengths are consistent with the standard model prediction within $\sim 1.7\sigma$ at the explored parameter range, as shown in the figure6. The 95% confidence level limits on the coupling strength are shown in the figure7, which are highly dependent on the decay width.
The top quark p_T distributions show no discrepancy with the standard model prediction as in figure5, which will reflect the secondary effect of the resonance.

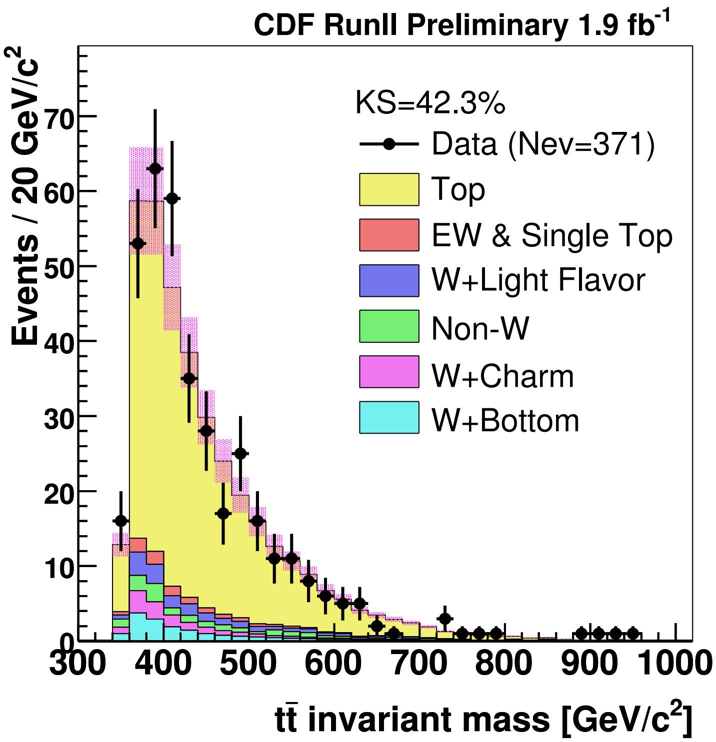

FIG. 4: The $t\bar{t}$ invariant mass distribution.

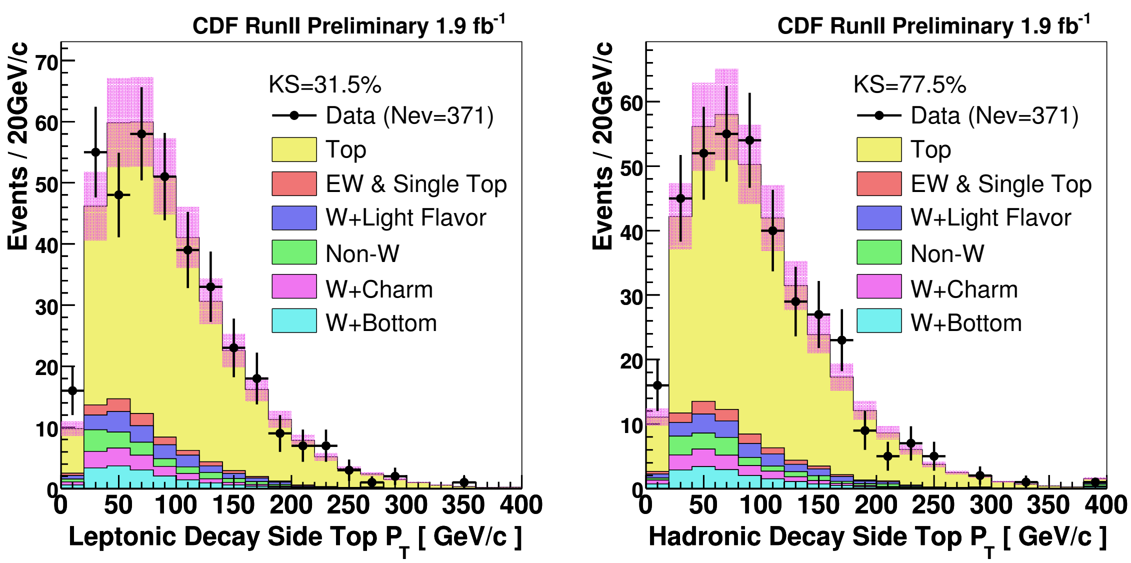

FIG. 5: The top quark p_T distribution of leptonic decay (left) and hadronic decay (right)

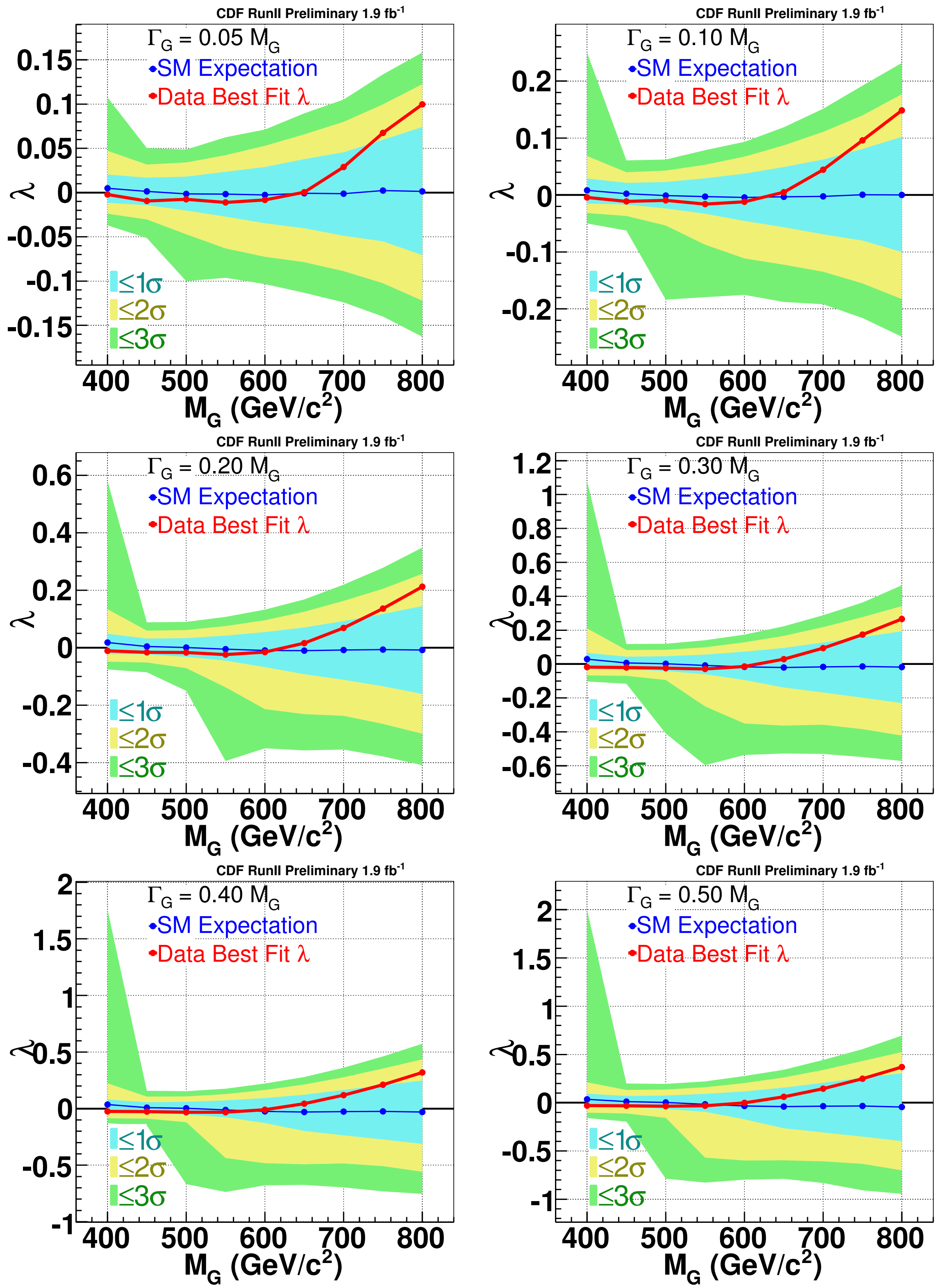

FIG. 6: The consistency with the standard model expectations. Each plot shows the fitted coupling strength as a function of mass of massive gluon from $\Gamma/M = 0.05$ to $\Gamma/M = 0.5$.

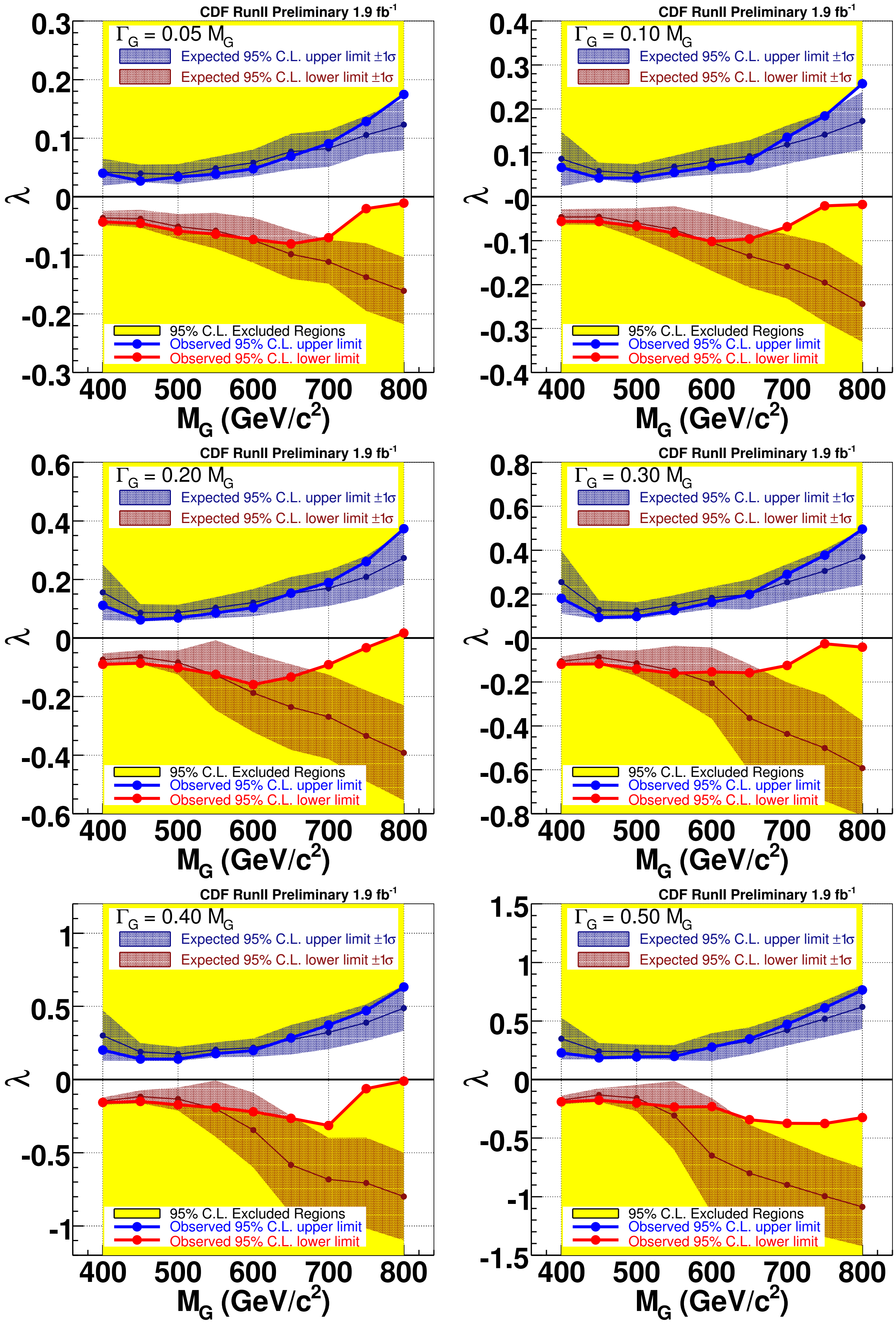

FIG. 7: The limits on the coupling strength as a function of mass from $\Gamma/M = 0.05$ to $\Gamma/M = 0.5$.

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