CDF note 10256

Search for a New Hadronic Resonance using Jet Ensembles with CDF

The CDF Collaboration

URL http://www-cdf.fnal.gov

(Dated: August 6, 2010, revised February 3, 2011)

We performed an analysis to search for 3-jet hadronic resonances in 3.2 fb^{-1} of data at the CDF detector at Fermilab. This search is model independent. However, in order to model the new physics signatures, we choose R-parity violating supersymmetric gluinos produced in pairs and decaying into three partons. We use kinematic quantities and correlations to create an ensemble of jet combinations which allows us to extract signal from the multijet QCD background. We note that all-hadronic $t\bar{t}$ decays have a signature similar to our signal. We observe no significant excess in the data and place 95 % C.L. limits on $\sigma(p\bar{p} \rightarrow XX^{'}) \times \mathrm{BR}(\widetilde{\mathrm{g}}\widetilde{\mathrm{g}} \rightarrow 3\ \mathrm{jet} + 3\ \mathrm{jet})$ where $X = \widetilde{g},\ \widetilde{q},$ or $\widetilde{\widetilde{q}}$, versus gluino invariant mass.

I. INTRODUCTION

Typical searches for new physics require either leptons and/or missing transverse energy ($\not\!\!E_T$), however, they might be blind to new physics which have strong couplings and therefore decay into quarks and gluons. We present a search for a 3-jet hadronic resonance at the CDF detector at Fermilab. We use 3.2 fb^{-1} of data collected by CDF in $p\bar{p}$ collision at $\sqrt{s} = 1.96$ TeV at the Tevatron. This search is a model independent analysis that reconstructs hadronic resonances in multijet final states. We model the possible new physics with R-parity violating supersymmetric (RPV SUSY) gluino pairs, each decaying into three partons [1].

To extract signal from the multijet QCD background, we use kinematic quantities and correlations to create an ensemble of jet combinations. We note that all-hadronic $t\bar{t}$ decays have a signature similar to our signal. The biggest challenge of this analysis is the large QCD background that accompanies multijet resonances. We show a data driven approach to parameterize this background.

II. DATA SAMPLE

This analysis is based on an integrated luminosity of 3.2 fb^{-1} collected with the CDF II detector. The data was collected using a multijet trigger that requires at least four jets with a raw E_t >10 GeV and raw $\sum E_t > 175$ GeV [2].

III. ANALYSIS STRATEGY & EVENT SELECTION

In order to extract a possible new physics signal from the large multijet QCD background in this sample we use the kinematic quantities and correlations between them to create an "ensemble" of jet combinations. An ensemble consists of 20 (or more) possible jet triplets from the ≥ 6 hardest jets in the event. For every event, we calculate each jet triplet invariant mass, M_{jjj}, and scalar sum p_T, $\sum_{jjj} |p_T|$. Using the distribution of M_{jjj} vs. $\sum_{jjj} |p_T|$ ensures that we reconstruct the correct combination of jets in some kinematic regime, since the incorrect (uncorrelated) triplets tend to have $M_{jjj} = \sum_{jjj} |p_T|$. The correct (correlated) triplet produces a horizontal branch in the signal at approximately the invariant mass of the signal that is not present for the background, as seen in Figure 1.

A. Event Selection

1. Basic cuts

After passing the trigger cuts we apply some basics cuts to the event. Our events are initially selected using the following criteria: we remove any events with a missing transverse energy greater than 50 GeV; we only keep events that have between $1-4$ primary vertices; each event must have 6 or more jets; we require that the jets have $|z_0| < 60$ cm; finally, the sum p_T of the top six jets must be greater than 250 GeV. We select offline corrected jets [3] with transverse momentum greater than 15 GeV, and an $|\eta|$ smaller than 2.5. A summary of the cuts at this stage are listed here:

- $\not\!\!E_T \leq 50$ GeV
- 1$\leq$ Nvert ≤ 4
- Njets ≥ 6
- jet $|z_0| < 60$ cm
- $\sum_{6jet} p_T \geq 250$ GeV for six highest p_T jets

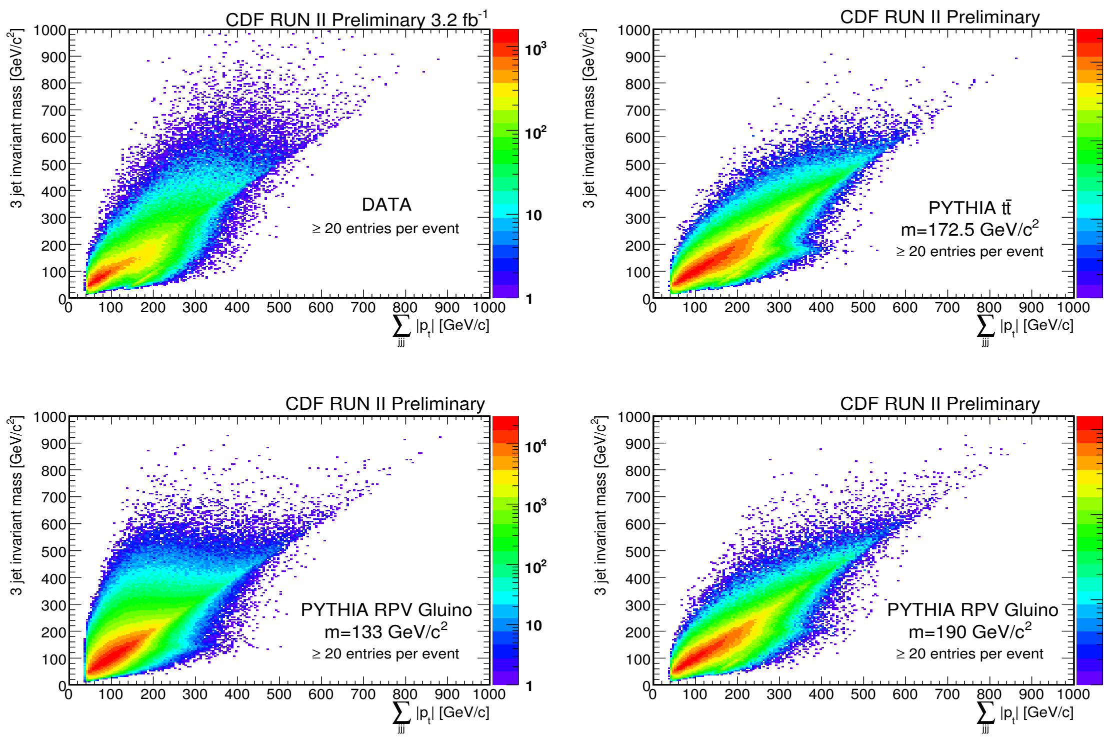

FIG. 1: Distributions of M_{jjj} versus $\sum_{jjj}|p_T|$ multiple entry (≥ 20). Top left: data, Top right: PYTHIA $t\bar{t}$ (m=172.5 GeV/c^2), Bottom left: PYTHIA RPV gluino (m=133 GeV/c^2), Bottom right: PYTHIA RPV gluino (m=190 GeV/c^2).

2. Final Selection

We demand the jets to come from the same z position by demanding a cutoff on $z_{\rm rms}$ over all jets. We define the mean $\bar{z_j}$ of all tracks within a jet as

$$\bar{z_j} = \frac{\sum\limits_{\rm tracks} z_0}{N_{tracks}}. \tag{1}$$

The *error* on z_j is defined as:

$$\delta(z_j) = \sqrt{\frac{\bar{z_j^2} - \bar{z_j}^2}{N_{tracks}}}. \tag{2}$$

At this point, each jet that has track information will have the z information above. Finally, we define $z_{\rm rms}$ as:

$$z_{\rm rms} = \sqrt{\frac{(\sum\limits_{\rm jets} \bar{z_j}^2)/N_{\rm jets} - \left(\sum\limits_{\rm jets} \bar{z_j}/N_{\rm jets}\right)^2}{N_{\rm jets}}} \tag{3}$$

Examples for M_{jjj} versus $\sum_{jjj}|p_T|$ scatter plots after different cuts for Monte Carlo and data can be seen in Figure 1.

3. Diagonal cut

We refer our final cut as the "diagonal cut", where we select events with $\sum_{jjj} p_T - M_{jjj} > offset$. This *offset* is optimized for each mass point separately. The background procedure and acceptance calculation is described in sections V and VI. We optimize by first throwing pseudoexperiments with the QCD background shape and an expected Gaussian signal. We then find the best signal/background ratio for each mass and each diagonal cut. As expected the optimal diagonal cut goes up as a function of gluino mass. We use a parameterization of diagonal cut versus mass to extrapolate between the mass points. Testing this procedure on $t\bar{t}$ Monte Carlo leads to an optimal diagonal cut of 190 GeV/c at the top quark mass.

IV. SIGNAL MONTE CARLO

We model the signal using PYTHIA, generating gluino pair produced events with hadronic RPV turned on (hadronic uud Matrix Element, which allows gluino decays to light jets) [4]. We produced samples with gluino pole masses ranging 73.7 GeV-225 GeV. Although the signal sample is generated assuming gluino decays, our analysis is not model dependent and assumes the signal is in the form of a heavy particle with strong coupling.

V. BACKGROUNDS

Since we are dealing with multijet events in this analysis, we expect large backgrounds from QCD. Estimating such a background from Monte Carlo is difficult. It is impractical to generate a large enough MC sample using a MC generator such as ALPGEN. Therefore, we use a data driven background method.

Our technique for estimating the QCD background comes directly from data. However, we need to be cautious about fitting for a signal and background in data at the same time, since statistical fluctuations can artificially inflate the signal, while deflating the background. To get around these problems, we use the (statistically independent) 5-jet data sample to parameterize the shape of the QCD background in the $\geq$ 6-jet sample (for brevity referred to as just 6-jet). Therefore, we rescale the 5-jet $\sum_{jjj}|p_t|$ distribution to the 6-jet sample. Although the statistics of the 5-jet sample is smaller, we use it to fit a Landau distribution which seems to describe the shape of the background well. For these fits we save the Most Probable Value (MPV) and Width of the Landau as a function of diagonal cut. Examples of the fit can be seen in Figure 2.

Scaling the 5-jet $\sum_{jjj}|p_t|$ to the signal 6-jet $\sum_{jjj}|p_t|$ leaves small residual discrepancies between the two samples. We correct for these by fitting the 5-jet Landau shape to the 6-jet sample. We allow the MPV and Width of the Landau to move within their uncertainties to account for the remaining shape differences. Since the Landau fit is meant to describe the QCD background, we blind the fit in the top mass region (153 GeV/c^2< M_{jjj} <189 GeV/c^2).

We save the Landau Amplitude, MPV, and Width from these fits. We note that the MPV and Width vary less than 2 GeV/c^2 from the values found in the 5-jet fit, indicating that the scaled 5-jet sample describes the background in the 6-jet sample reasonably well.

We now have a firm prediction for the QCD background (Landau Amplitude, MPV, an Width). We fix these values when we fit for signal. The QCD prediction for the 6-jet sample can be seen in Figure 3.

VI. ACCEPTANCE

To quantify our sensitivity to new physics we use signal Monte Carlo described in section IV. After applying all cuts we still need to extract signal from combinatorial background. Therefore we use a Landau + Gaussian fit and obtain the number of events that passed all cuts by integrating the Gaussian in a $\pm 1\sigma$ range. Examples of these final mass distributions for different diagonal cuts and gluino masses with fits can be seen in Figure 4. We have an optimal diagonal cut for each mass and note that the acceptance is constant for all gluino samples.

It should be noted that in addition to QCD background we also expect to see top events that are reconstructed from the all-hadronic channel. From the acceptance for a PYTHIA $t\bar{t}$ sample we expect to see $\sim$ 1 top event which we include into our background shape.

VII. SYSTEMATIC UNCERTAINTIES

We divide systematic uncertainties into two broad categories: uncertainties in the shape of the M_{jjj} distribution and uncertainties in the acceptance of the signal. We use pseudoexperiments to calculate an expected cross section considering background and acceptance systematics.

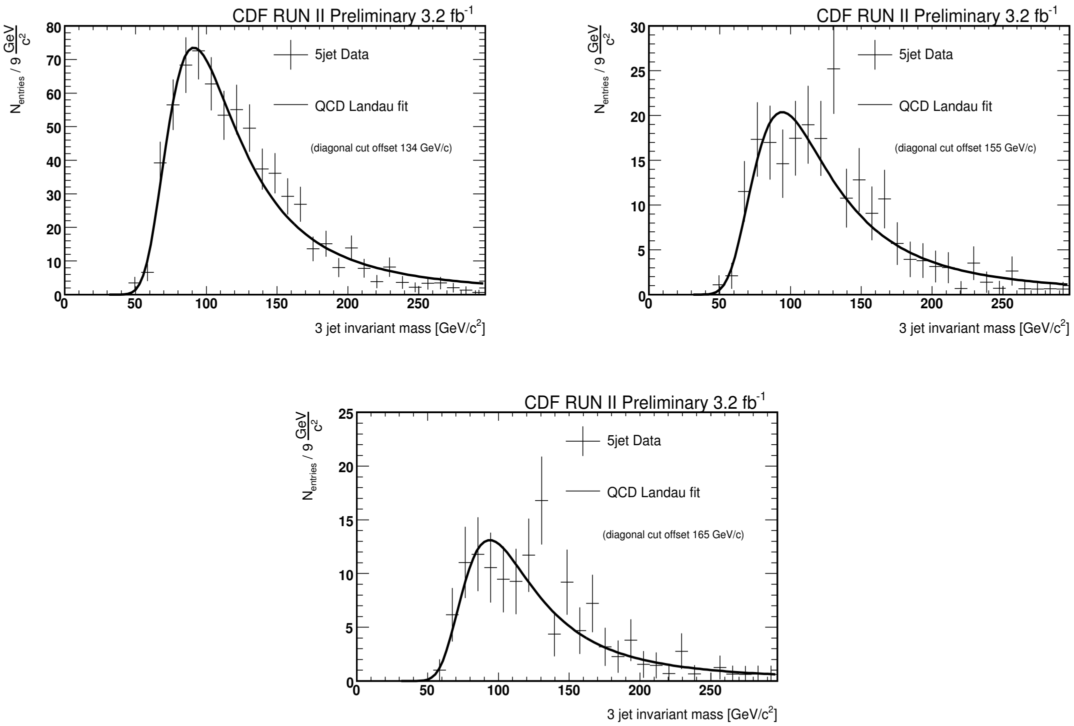

FIG. 2: These distributions show the scaled 5-jet background shape from the data for different diagonal cuts. The solid line is the fit to a Landau function. We save MPV and Width parameters of the Landau fit, to be used in the 6-jet analysis.

A. Background shape systematics

We are dealing with a data driven background which has a fixed parameterization as a function of diagonal cut. We use pseudoexperiments to factor in the uncertainties in our background estimate. We assume the QCD background is well described by a Landau. We add in the top quark background at its expected level (approximately 1 event). We generate one thousand pseudoexperiments per gluino mass point, allowing the background parameters to vary randomly within the range allowed by the background shape fits to the data. We fit each pseudoexperiment the same way we fit the data (fixing the background shape parameters and allowing the signal Gaussian to vary), and extract the number of signal events allowed for each pseudoexperiment.

B. Acceptance systematics

Acceptance systematics arise from modeling the signal Monte Carlo and include effects of ISR and FSR, PDF's and jet energy scale [3]. The change in acceptance is estimated by changing the above mentioned parameters in the modeling of the Monte Carlo signal. We assign an overall uncertainty due to these systematics of 38 %. The dominant uncertainty is due to the jet energy scale and contributes 31% in our multijet analysis.

VIII. SETTING LIMITS ON HADRONIC RESONANCES

Since we do not observe a significant excess in the data, we use a Bayesian approach to calculate the observed number of events at a 95% C.L. and obtain an observed cross section by dividing by acceptance and luminosity. We scan through a mass range of 76.5 GeV/c^2 to 238.5 GeV/c^2 in 9 GeV/c^2 steps and use the optimal diagonal cut and the associated QCD background prediction as described in section V. On top of the Landau QCD background we fit a Gaussian at each mass point and allow the amplitude and width to float within a range that we would expect from our Monte Carlo samples. After integrating Gaussian and Landau separately in a $\pm 1\sigma$ range of the Gaussian

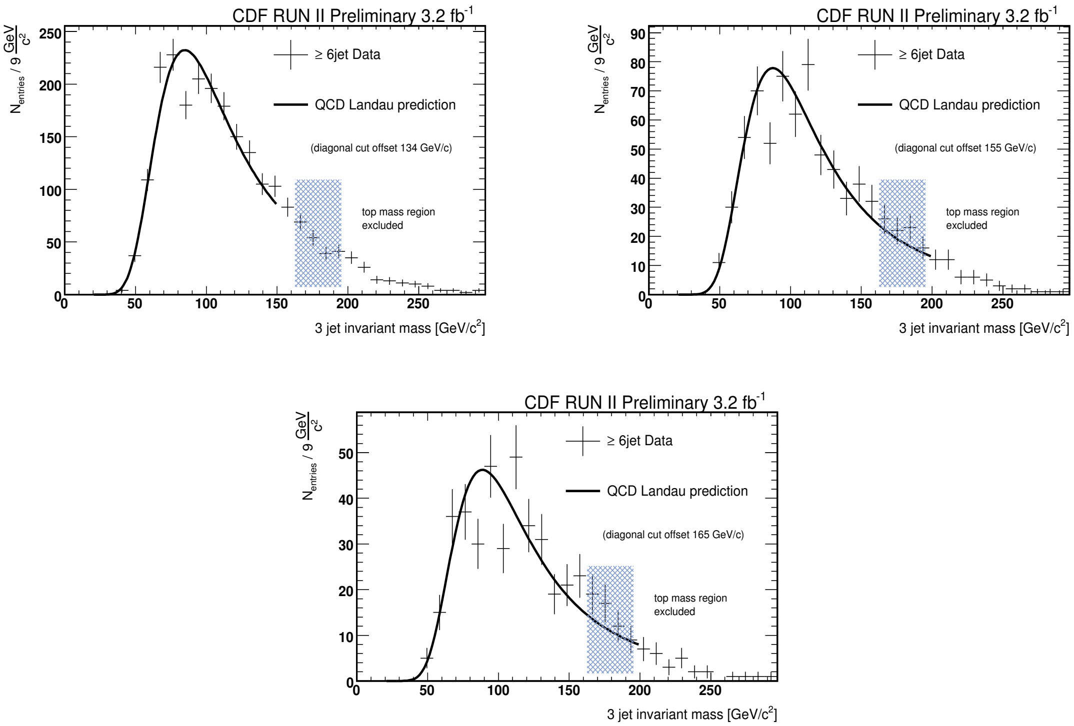

FIG. 3: These distributions show the 6-jet background shape from the data for different diagonal cuts. The solid line is the Landau QCD prediction.

we obtain the number of signal and number of background events for this bin. Two examples for fits at the mass points m=112.5 GeV/c^2 and m=175.5 GeV/c^2 can be seen in Figure 5. The expected cross section limit at a 95% C.L. is obtained by using pseudoexperiments of the QCD background parameterization including 1 top event at a mass of 172.5 GeV/c^2. The background shape systematic is incorporated into the pseudoexperiments as described in section VII A as well as the acceptance uncertainties. The result can be seen in Figure 6. We note that the largest excess observed is 2 σ and is located near the top quark mass and corresponds to a 2.27% probability.

IX. RESULTS

We observe no significant excess in the data and place 95 % C.L. limits on $\sigma(p\bar{p} \to XX') \times \mathrm{BR}(\tilde{g}\tilde{g} \to 3\ \mathrm{jet} + 3\ \mathrm{jet})$ where $X = \tilde{g}$, $\tilde{q}$, or $\tilde{\bar{q}}$ versus gluino invariant mass. We chose two different models where we change the mass of the intermediate $\tilde{q}$ from 0.5 TeV/c^2 $< m_{\tilde{q}} <$ 0.7 TeV/c^2 to $m_{\tilde{q}} = m_{\tilde{g}}$+10 GeV/$c^2$ The final limits, including the production cross section for both models $\sigma(p\bar{p} \to XX') \times \mathrm{BR}(\tilde{g}\tilde{g} \to 3\ \mathrm{jet} + 3\ \mathrm{jet})$ from PYTHIA corrected by an NLO k-factor, can be seen in Figure 7. We can exclude gluinos below a mass of 144 GeV/c^2.

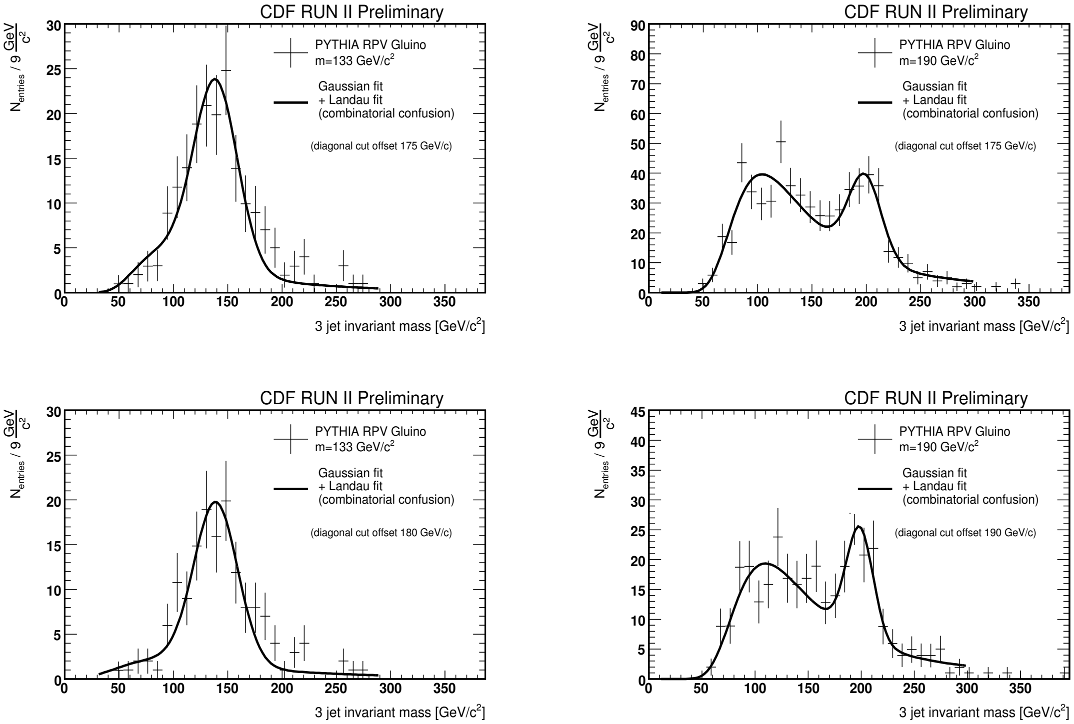

FIG. 4: We show the final mass distributions for two different gluino masses and diagonal cuts. The bottom distributions show the optimal diagonal cut for each mass. Left: For gluino with m=133 GeV/c^2 and the solid line is a fit to Gaussian + Landau (combinatorial confusion), Right: For gluino with m=190 GeV/c^2 and the solid line is a fit to Gaussian + Landau (combinatorial confusion).

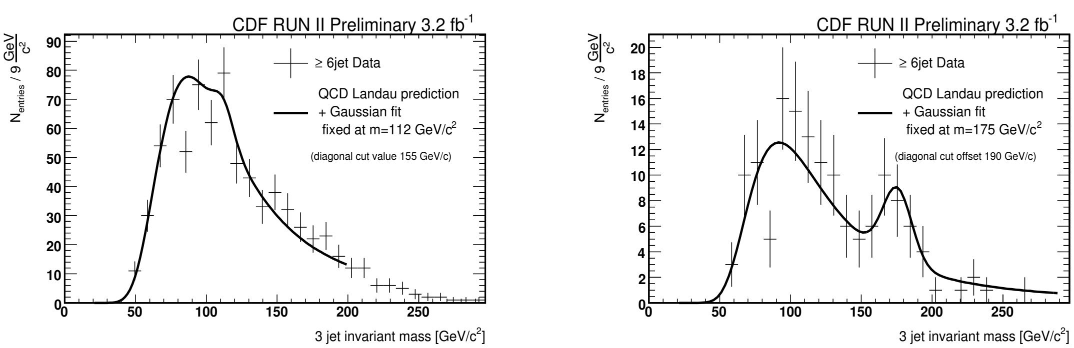

FIG. 5: Two examples for fits for the number of observed events at the mass points Left: m=112.5 GeV/c^2 and Right: m=175.5 GeV/c^2.

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

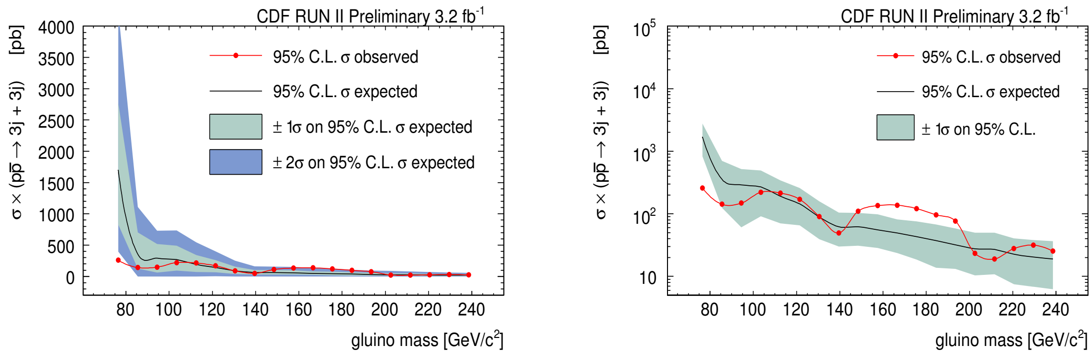

FIG. 6: The observed and expected limit including systematic uncertainties. Left:linear y-scale, Right:log y-scale.

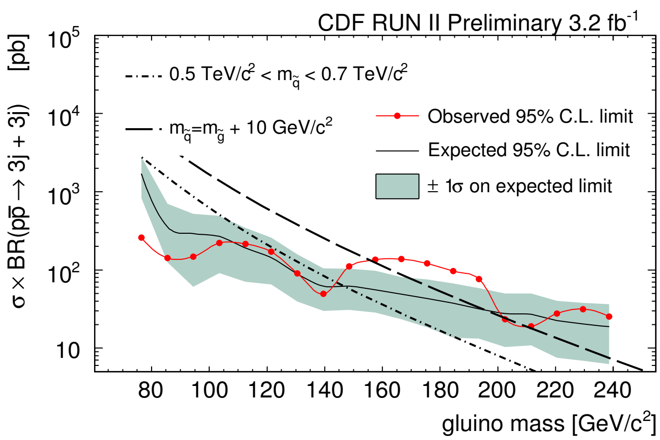

FIG. 7: The observed and expected limit including systematic uncertainties as well as the theory cross section for $\sigma(p\bar{p} \to XX^{'}) \times \mathrm{BR}(\widetilde{g}\widetilde{g} \to 3 \text{ jet} + 3 \text{ jet})$ where $X = \widetilde{g}$, $\widetilde{q}$, or $\widetilde{\bar{q}}$ from PYTHIA corrected by an NLO k-factor, on a log y-scale.

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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