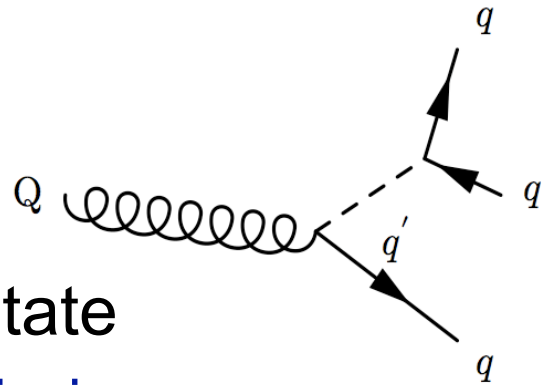
Search for New Physics in Multi-jet Final States at CDF

Boost 2011
May 25, 2011

Eva Halkiadakis
for the CDF Collaboration

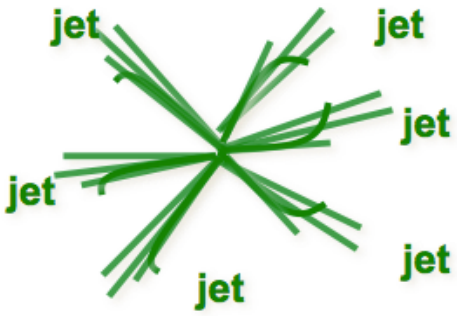
with
Amit Lath, Claudia Seitz, and Scott Thomas
Rutgers, the State University of NJ

Introduction

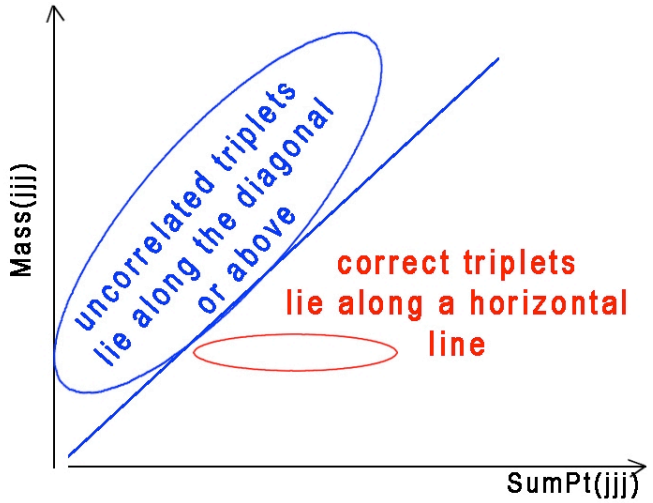


- New Physics Search in Multijet final state
  - Most searches require leptons and/or missing energy
  - What if new physics is hidden behind a strong coupling?
- Search for:
  - $p\,\bar{p} \rightarrow X\,X'$, where $X, X' = \tilde{g}, \tilde{q}, \bar{\tilde{q}}$
  - R-parity violating decay into 3 jets (no MET)
  - Signal similar to SM ttbar to all hadronic decay
- Challenge
  - Large QCD background
  - Make use of kinematic features and an ensemble of jets

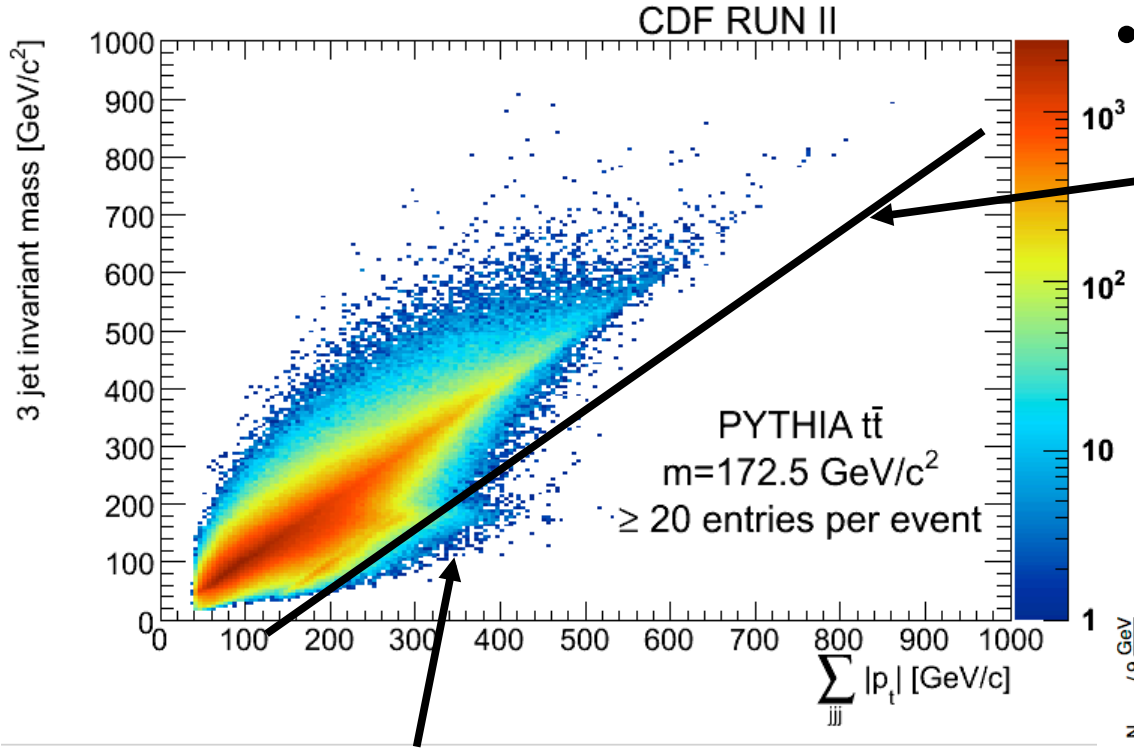
Jet Ensemble Method



- We use an **ensemble** of jet combinations
- We have at least $\binom{6}{3} = 20$ combinations
- **Strategy:**
  - Build triplets out of all final state jets and calculate
    - Invariant mass M_{jjj}
    - Scalar sum p_T $\Sigma|p_T|_{jjj}$
  - Plot one vs. the other for each combination (at least 20 combinations for each event)



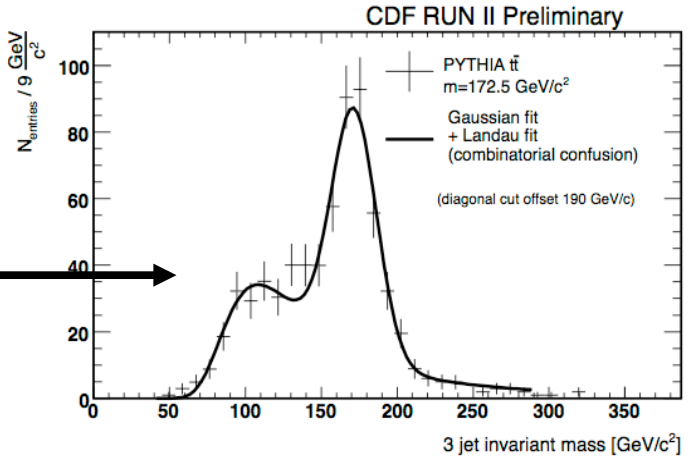
Jet Ensemble Method Example: ttbar Monte Carlo



- Diagonal cut:
  - For any triplet require: $M_{jjj} < \Sigma|p_T|_{jjj}$ – diagonal offset
  - Reduces background from combinatorial confusion and QCD

- Projection on to mass axis
  - Signal still contains jet combinatorial confusion
  - QCD has a similar shape

Offset 190 GeV

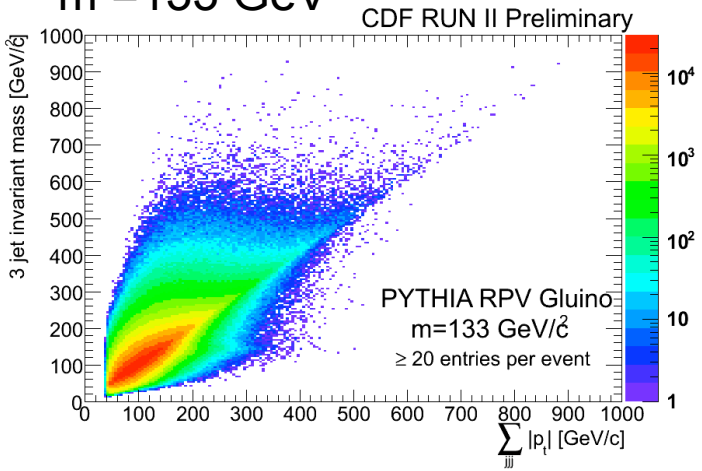


$\sigma(p\bar{p} \to XX') \times BR(\tilde{g}\tilde{g} \to 3jet + 3jet)$

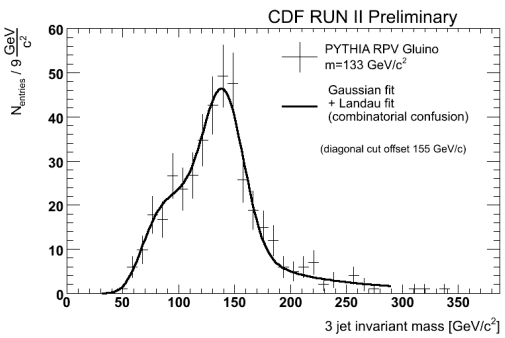
where $X, X' = \tilde{g}, \tilde{q}, \bar{\tilde{q}}$ with $\tilde{q}, \bar{\tilde{q}} \to \tilde{g} + jet$

Diagonal cut: Optimized vs. Mass

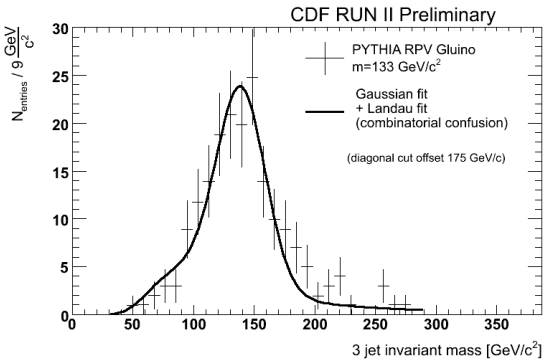
m =133 GeV



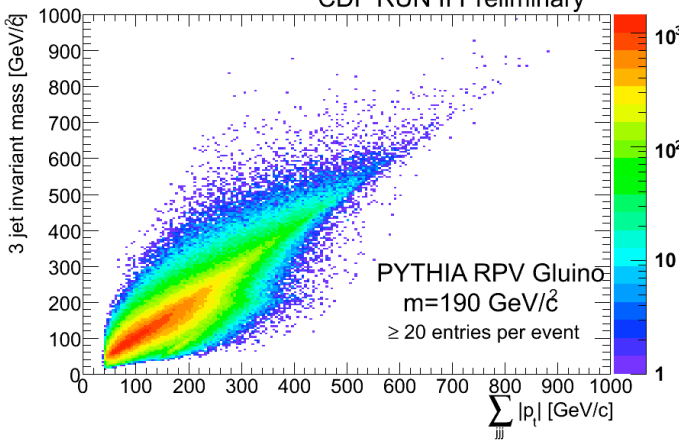
Offset 155 GeV



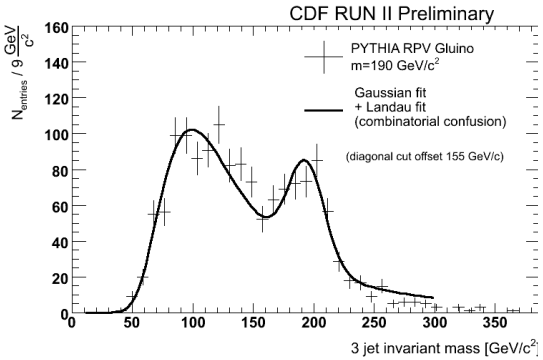
Offset 175 GeV



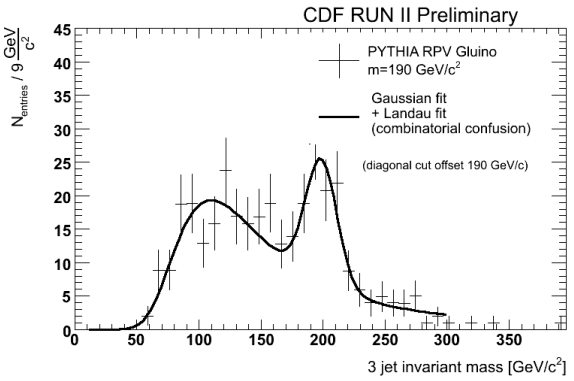
m =190 GeV



Offset 155 GeV



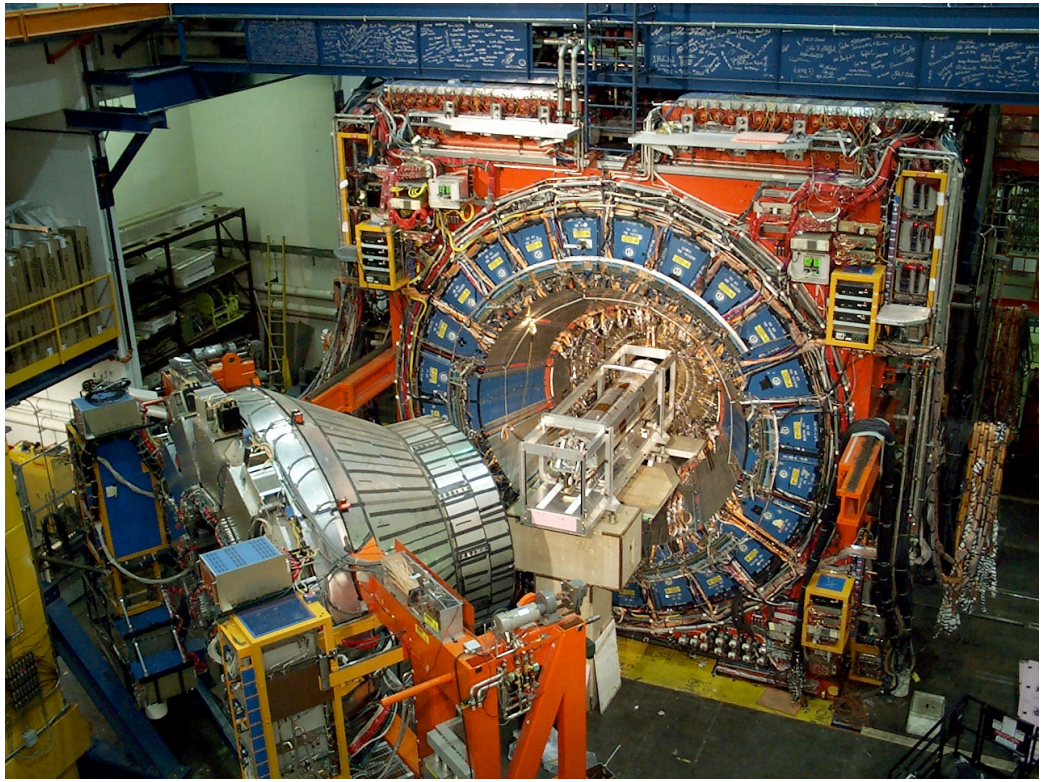
Offset 190 GeV



A few comments on the technique

- We look for just one 3-jet mass resonance in a multi-jet environment.
  - No attempt to fully reconstruct both decays.
  - Nothing model dependent: no b-quarks, no internal resonances, no requirements on geometry (hemisphere, ΔR, etc.)
- New physics with strong couplings will have large cross sections.
  - Recall ttbar production is ~7 pb.
  - RPV gluinos are similar
    - ~2.3 x σ_{ttbar} at m_{top}
  - The power of this technique is in the focus on boosted decays. Reduces QCD and combinatoric backgrounds.

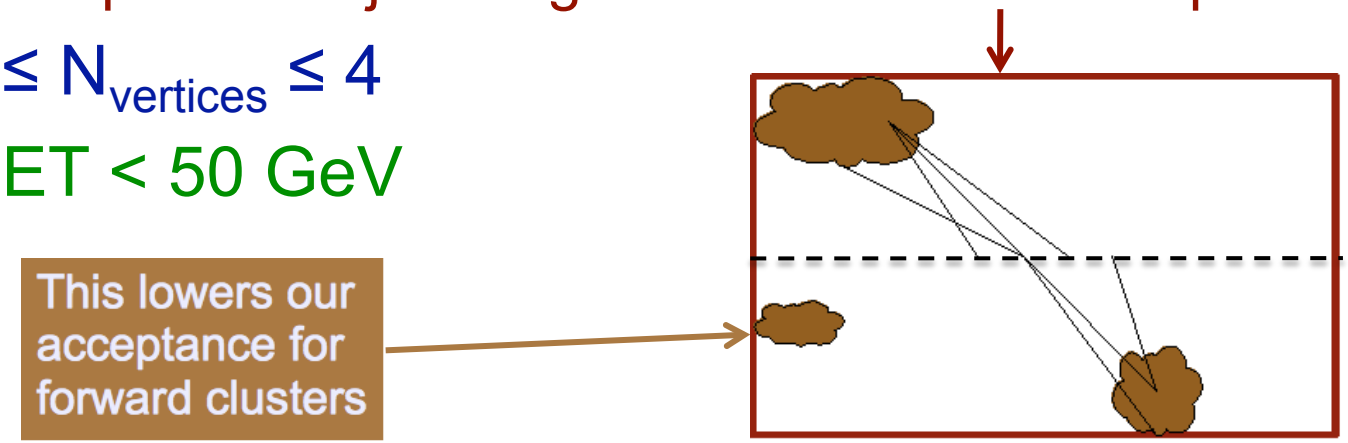
CDF Detector



- Multipurpose detector:
  - Tracking system
  - ~2 Tesla field
  - Electromagnetic and Hadronic calorimeters
  - Muon System

Event Selection

- **Dataset:** 3.2 fb^{-1} of CDF data
  - Trigger: 4 jets p_T>15GeV (raw) and SumE_T>175GeV (raw)
- $N_{jets} \geq 6$
  - Jet p_T>15 GeV, $|\eta| < 2.5$
  - $|z_0| \leq 60$ cm
  - $\Sigma_{6jets}\ p_T > 250$ GeV for 6 highest p_T jets
  - Request that jets originate from the same z position
- $1 \leq N_{vertices} \leq 4$
- MET < 50 GeV

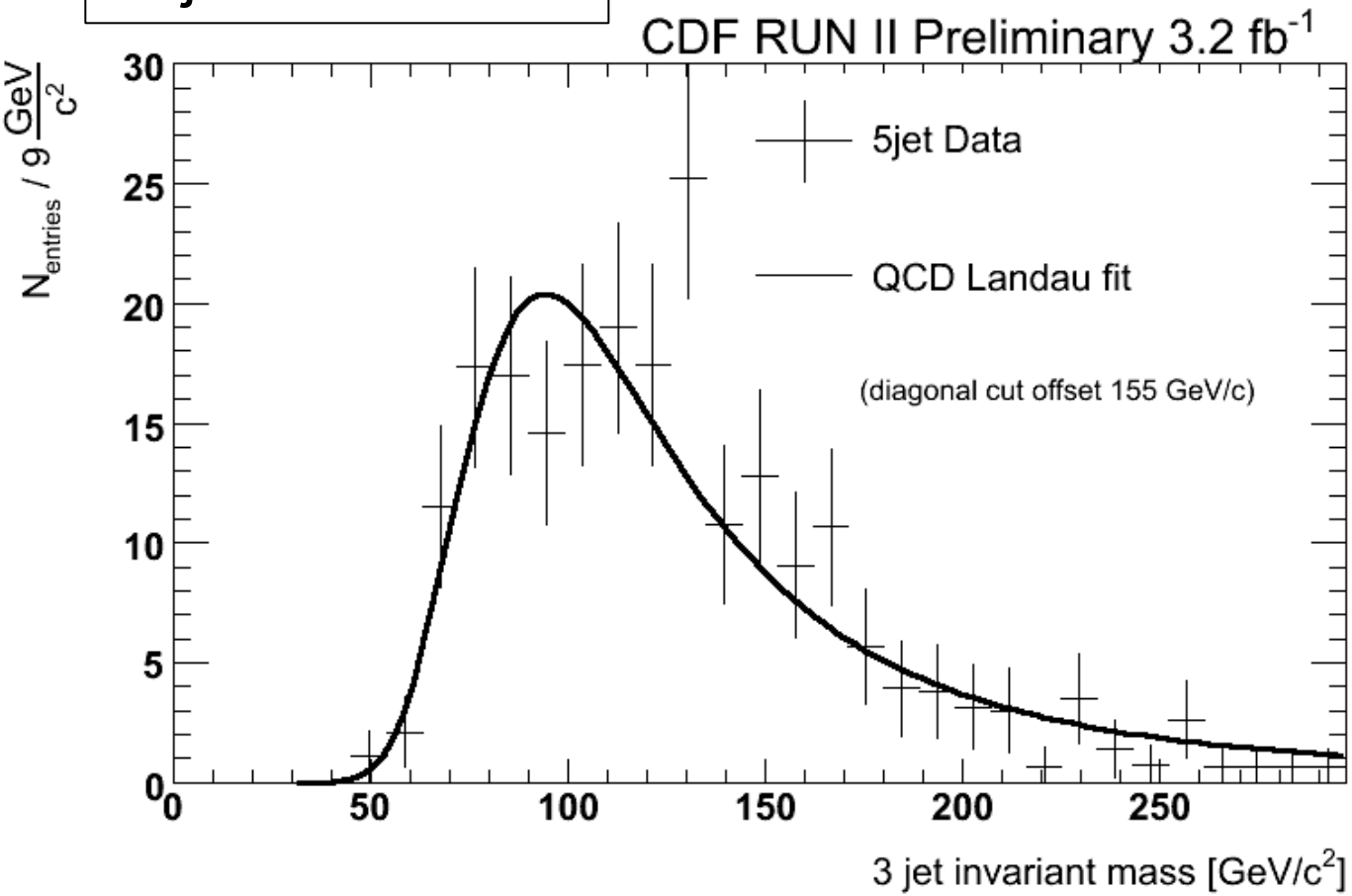


QCD Background Estimate

- Use Monte Carlo Simulation?
  - Difficult to calculate → not well understood
  - Would take a long time to generate a large enough sample
- **Data-driven method**
  - Estimate QCD shape from exclusive 5-jet sample
  - Rescale 5-jet triplet $\Sigma|p_T|$ distribution to match triplets in the 6-jet sample
  - Use Landau function to parameterize background
  - Use as input parameters for similar fits in the 6-jet sample
  - Landau parameters vary smoothly as a function of diagonal cut

QCD Background Estimate: 5-jet Data

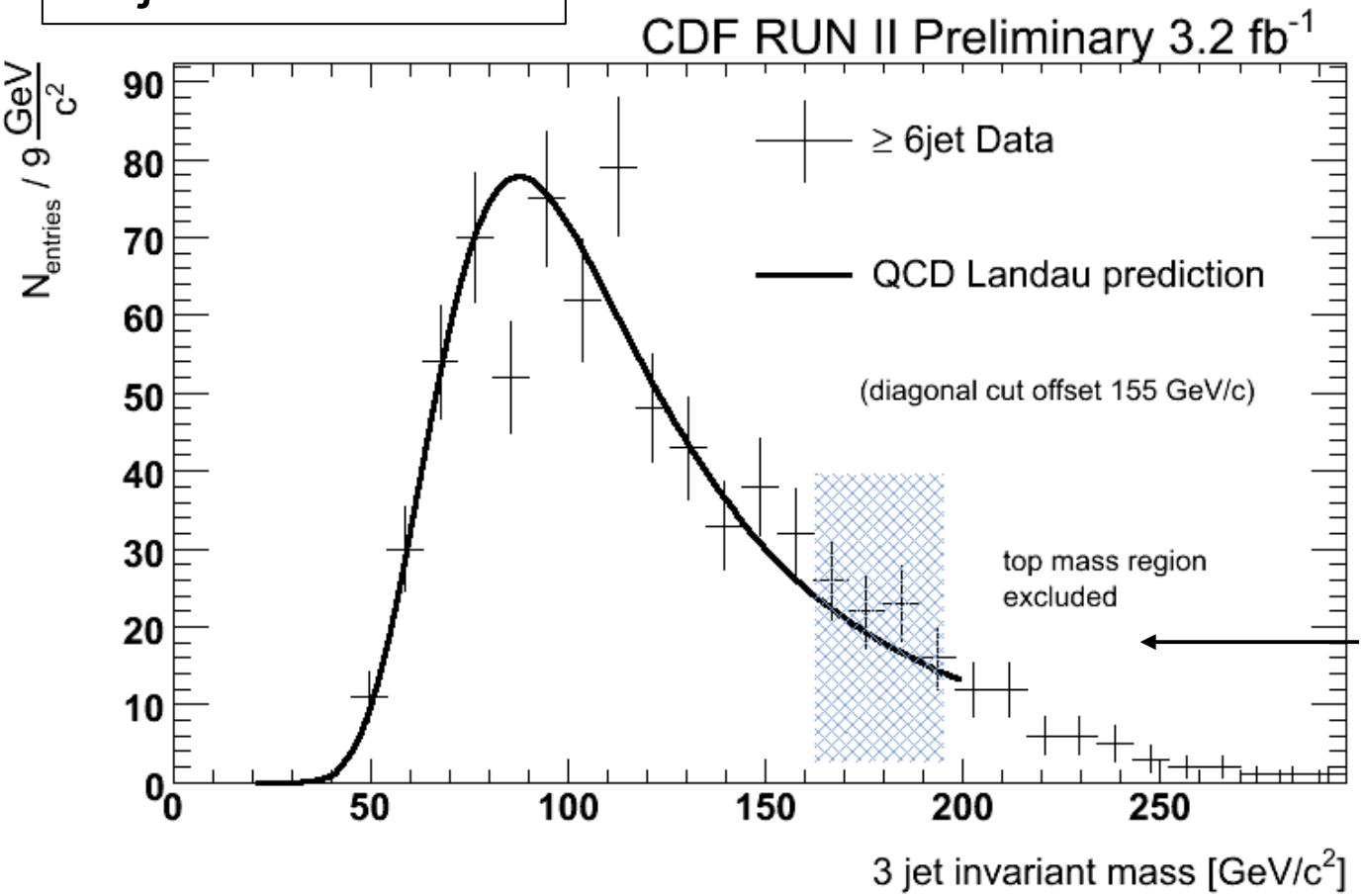
5-jet Landau Fit



We use 5-jet fit parameters as input for 6-jet fit.

QCD Background Estimate: 6-jet Data

6-jet Landau Fit

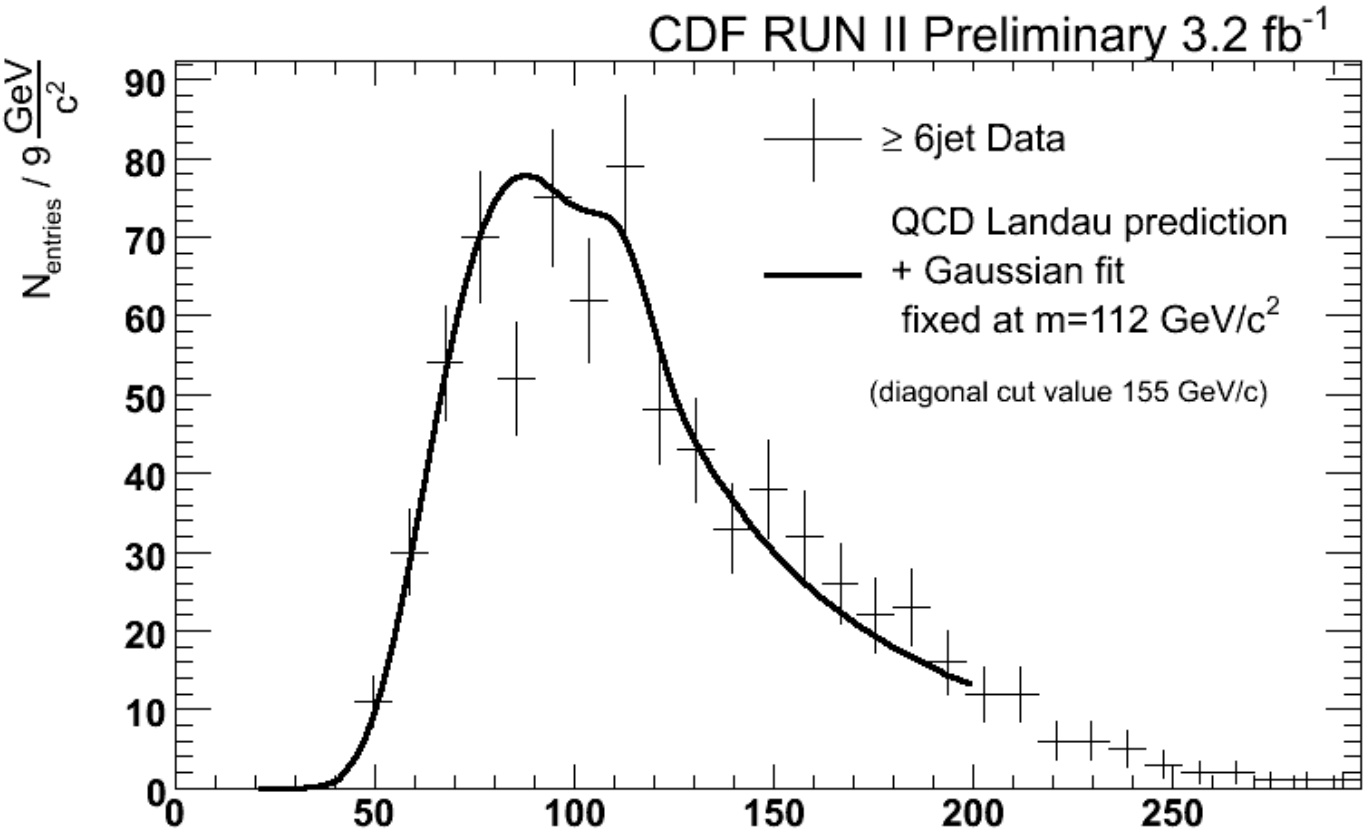


Top quark mass region is blinded in the fit

We use 5-jet fit parameters as input for 6-jet fit.

Fitting for signal in data

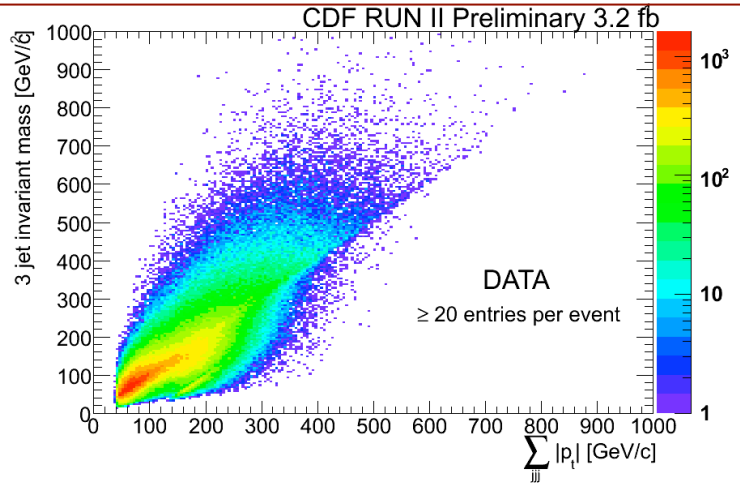
Fit for possible signal with Landau + Gaussian

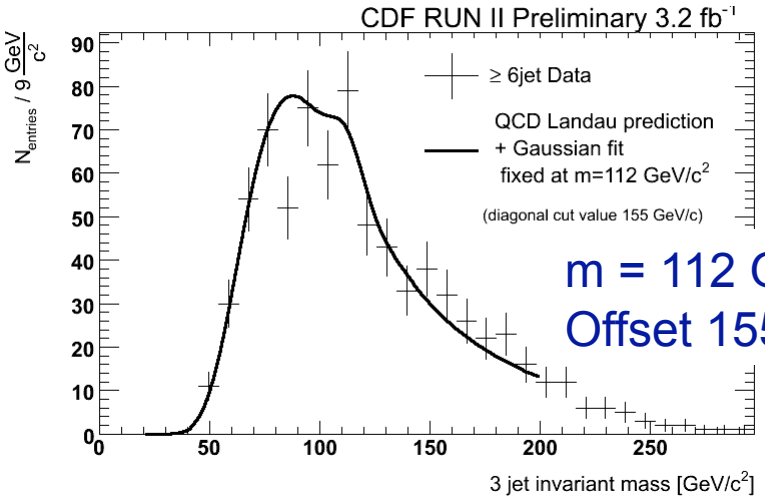


Diagonal cut = 155 GeV
Mass = 112 GeV

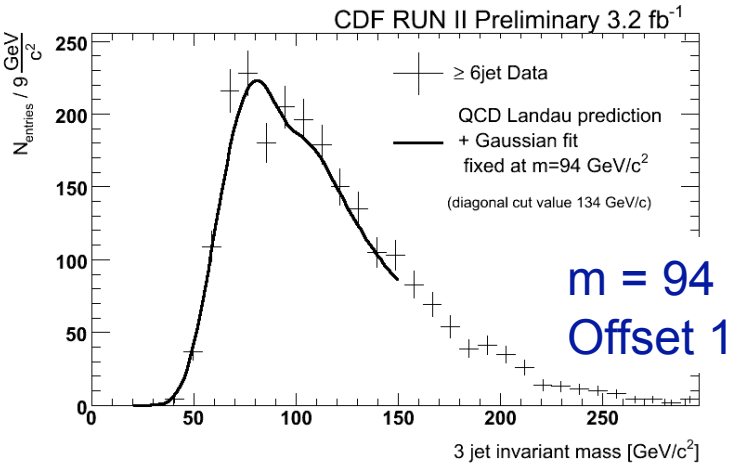
Fitting for signal in data

Search in the range of 77 – 240 GeV

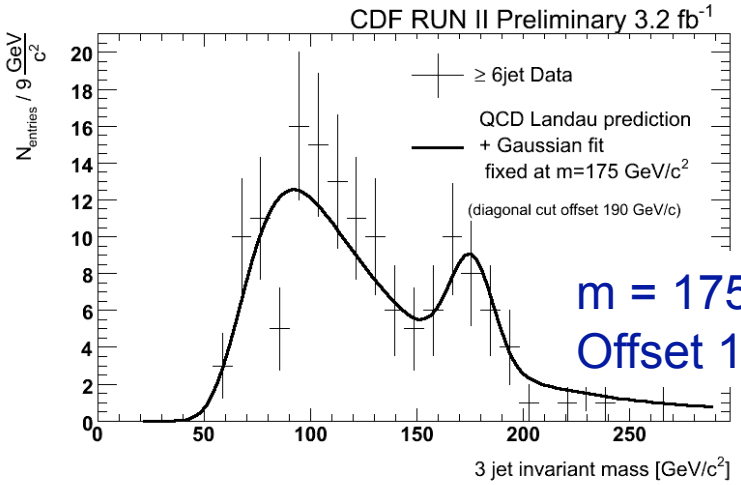




m = 112 GeV
Offset 155 GeV



m = 94 GeV
Offset 134 GeV



m = 175 GeV
Offset 190 GeV

Largest excess near m_{top}: 2 σ
More on this later.
No evidence for new physics above SM background

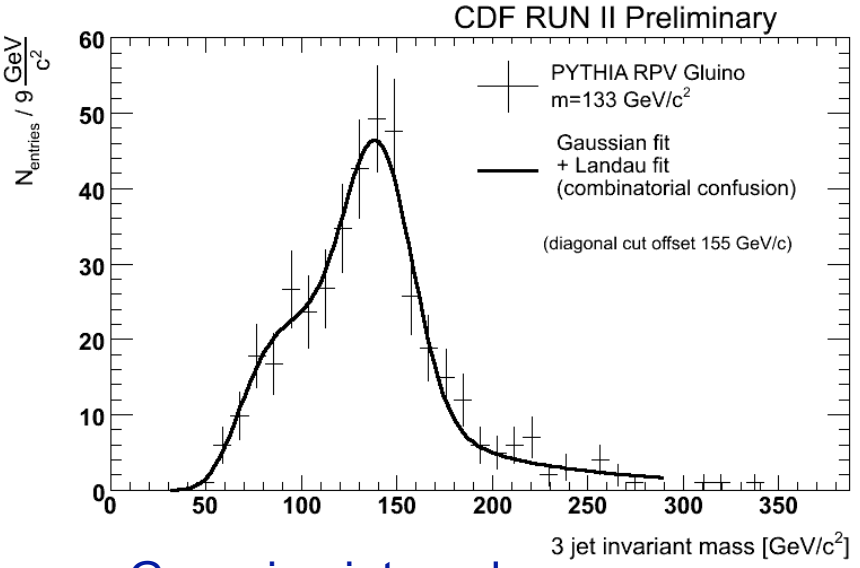
Signal: RPV Gluino

- **Monte Carlo simulation (PYTHIA) for the process:**

$$\sigma(p\bar{p} \to XX') \times BR(\tilde{g}\tilde{g} \to 3jet + 3jet)$$

$$\text{where } X, X' = \tilde{g}, \tilde{q}, \bar{\tilde{q}} \text{ with } \tilde{q}, \bar{\tilde{q}} \to \tilde{g} + \text{jet}$$

- **Acceptance:**
  - $a = N_{selected} / N_{generated} = (4.9 \pm 1.9) \times 10^{-5}$
  - Observed to be roughly independent of mass

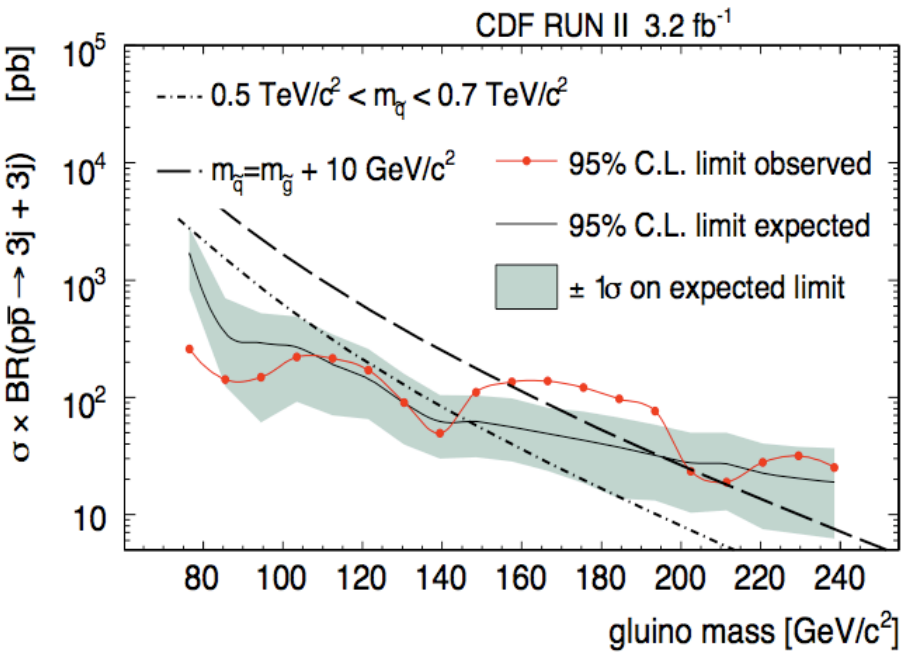


Gaussian integral
(after all analysis cuts)

Limits on Hadronic Resonances

- We translate observed events into cross section
- **Bayesian** method to calculate 95% C.L. limits
- **Systematic Uncertainties**
  - Acceptance Uncertainty
    - Jet Energy Scale
    - ISR & FSR
    - Parton Distribution Functions
    - Luminosity
  - Background Shape Uncertainty
- Consider **two different models** for gluino production
  - Heavy intermediate squark $0.5\ \text{TeV} < m_{\tilde{q}} < 0.7\ \text{TeV}$
  - Nearly degenerate squark mass $m_{\tilde{q}} = m_{\tilde{g}} + 10\ \text{GeV}$

Limits on Hadronic Resonances

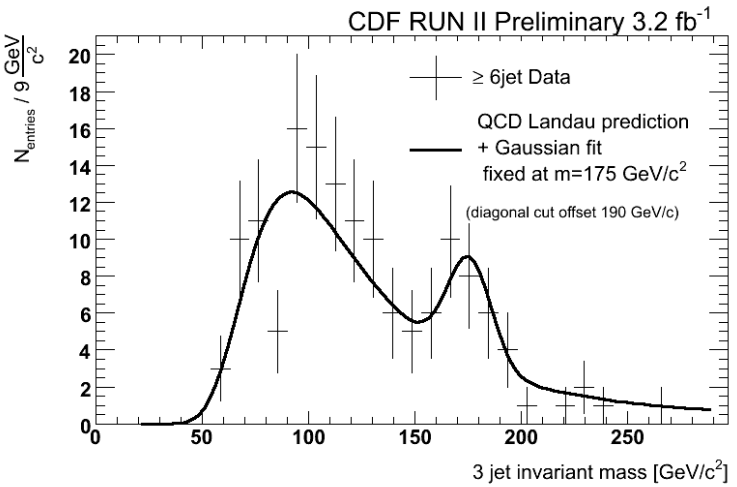


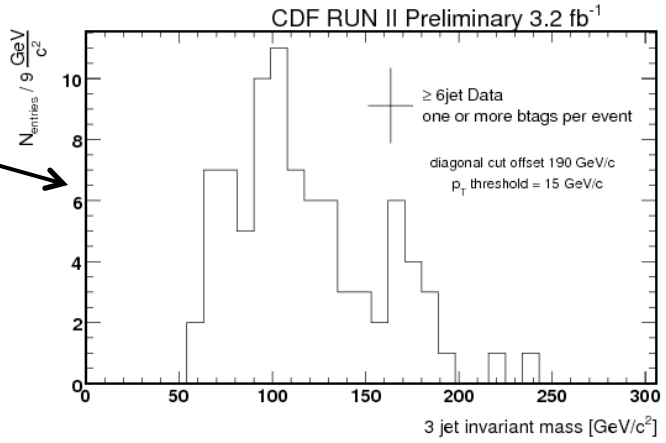
Model cross sections from Pythia, corrected with NLO k-factors from Prospino

- **Limits on gluino pair production:**
  - Heavy intermediate squark
    - 144 GeV
  - Nearly degenerate squark mass
    - 154 GeV
- **Largest excess around m_{top}**
  - Expectation ~ 1 triplet
  - Observation 11 ± 5 triplet
  - Significance of 2 σ

Cross Checks on ttbar contribution

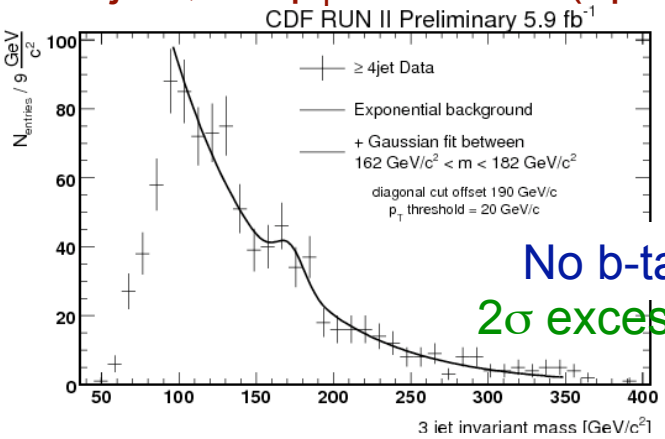
- Noticeable (2σ) excess near m_{top}
- MC expectation for known SM process ttbar ~ 1 triplet for diagonal cut = 190 GeV
  - Cross checked with MC@NLO, Alpgen, varied ISR/FSR, varied PDFs: expectation between 0.5 -1.1 triplets
  - Also cross checked with b-tagging, dijet mass of non-btagged jets
- Fit gives 11 ± 5 triplets in $\pm 1\sigma$ window around Gaussian
  - QCD Landau fit in same window gives 8 ± 1 triplets



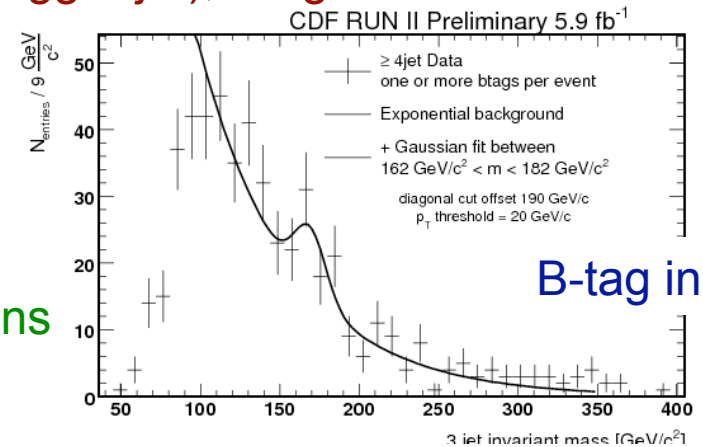


Cross Check with more data: 5.9 fb^{-1}

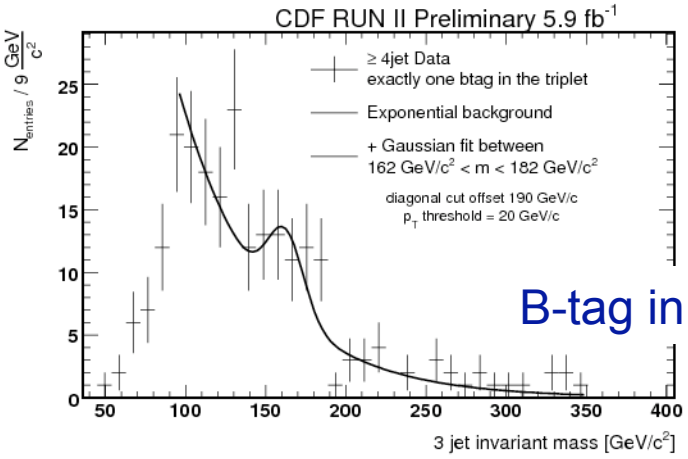
- Used Jet100 trigger
- ≥ 4 jets, Jet p_T > 20 GeV (apart from trigger jet), Diagonal cut = 190 GeV



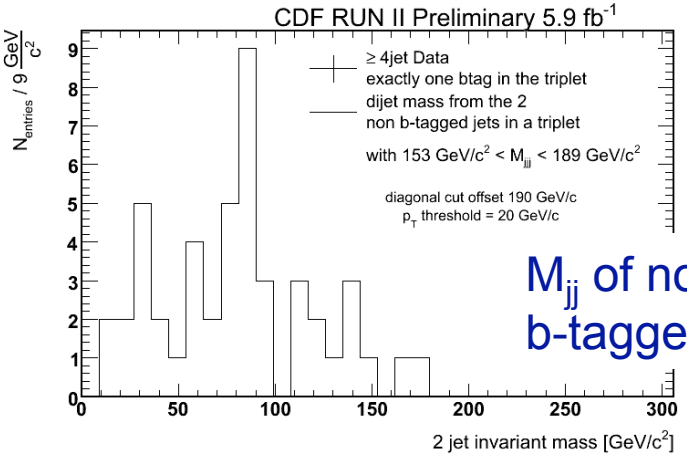
No b-tagging
2σ excess remains



B-tag in event



B-tag in triplet



M_{jj} of non b-tagged jets

Summary

- **Jet ensemble** technique works to extract boosted hadronic resonances from QCD background
- Performed a search for such resonances related to possible new physics scenarios
- **Set limits** on $\sigma(p\bar{p} \to XX') \times BR(\tilde{g}\tilde{g} \to 3jet + 3jet)$ where $X, X' = \tilde{g}, \tilde{q}, \bar{\tilde{q}}$ with $\tilde{q}, \bar{\tilde{q}} \to \tilde{g} + jet$
- Largest excess around the top quark mass ~2σ
  - Many cross checks performed
- Result submitted to PRL
  - http://arxiv.org/abs/1105.2815
  - FERMILAB-PUB-11-220-E-PPD
- More information about this analysis:
  - http://www-cdf.fnal.gov/physics/exotic/r2a/20110203.multijets/
  - FERMILAB-MASTERS-2011-01
- Amit Lath presenting similar search at CMS next
- Also see talk by Scott Thomas for critical perspective