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

Boost 2011
May 25, 2011

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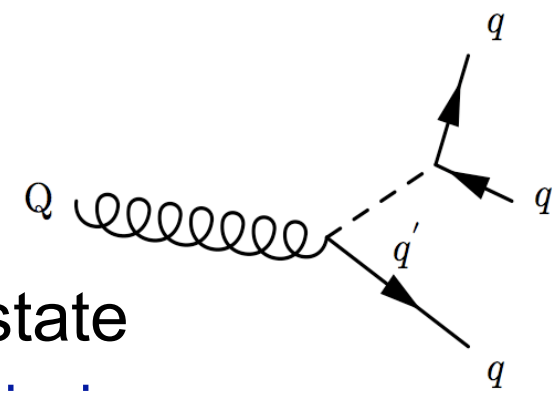
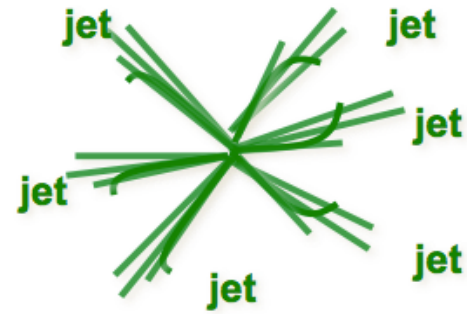
Introduction

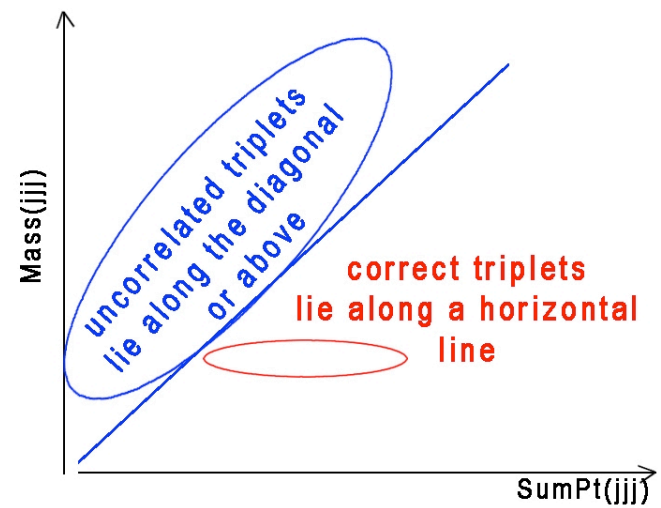


- New Physics Search in Multijet final state
  - Most searches require leptons and/or missing energy
  - What if new physics is hidden behind a strong coupling?
- Search for:
  - $p\,\bar{p} \rightarrow X\,X'$, where $X, X' = \tilde{g}, \tilde{q}, \bar{\tilde{q}}$
  - R-parity violating decay into 3 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

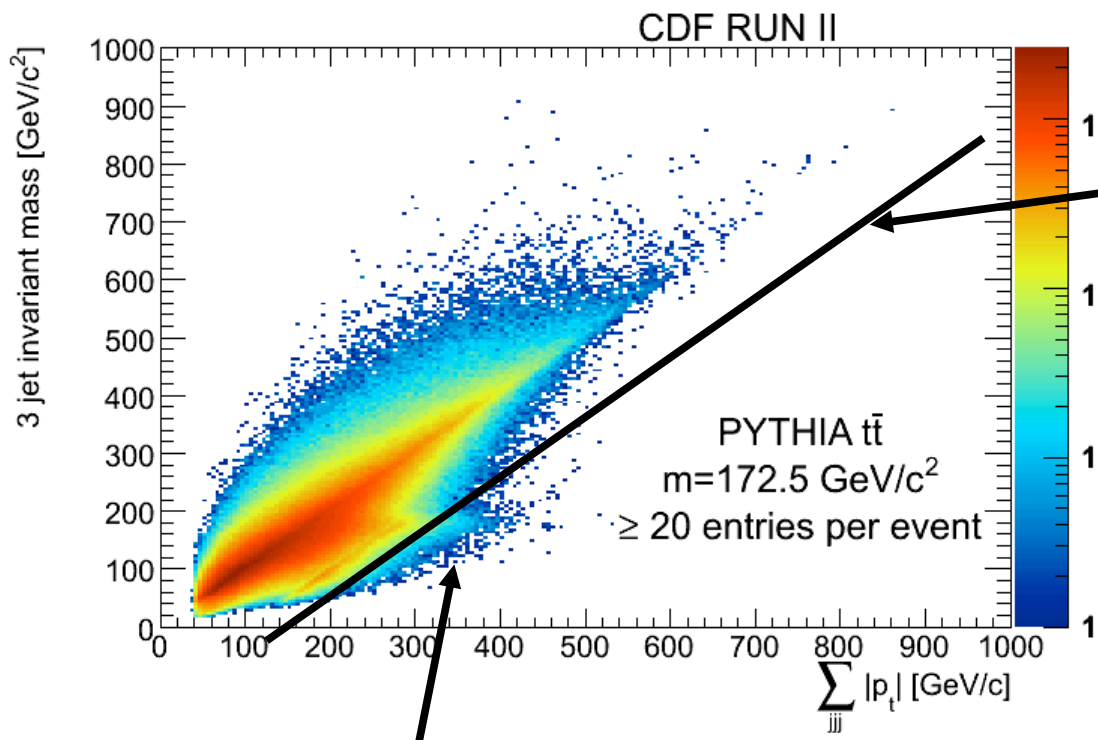
Jet Ensemble Method



- 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)

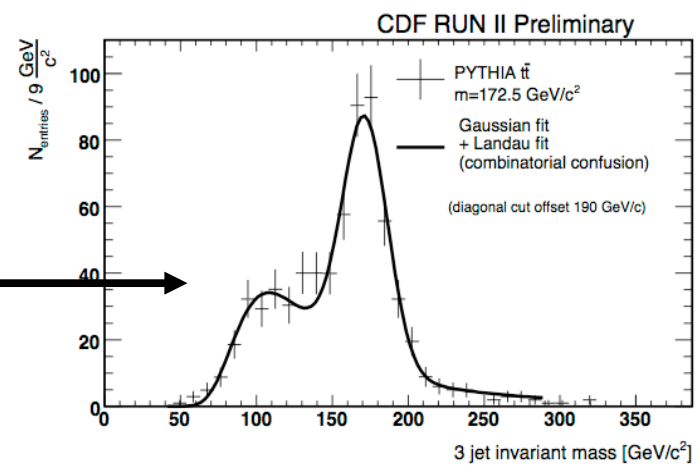


Jet Ensemble Method Example: ttbar Monte Carlo



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

Offset 190 GeV



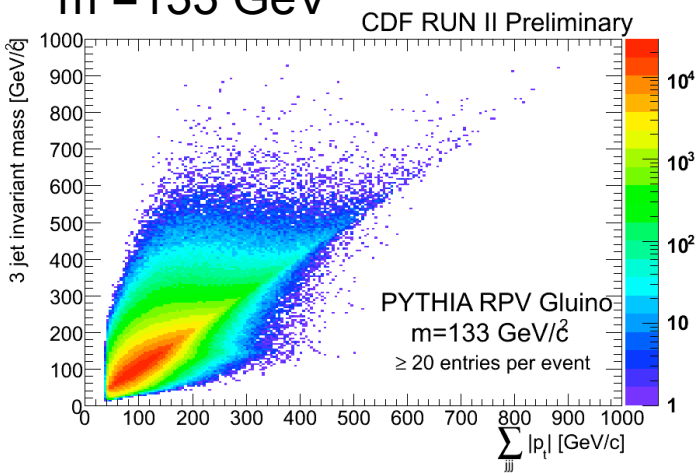
- Projection on to mass axis
  - Signal still contains jet combinatorial confusion
  - QCD has a similar shape

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

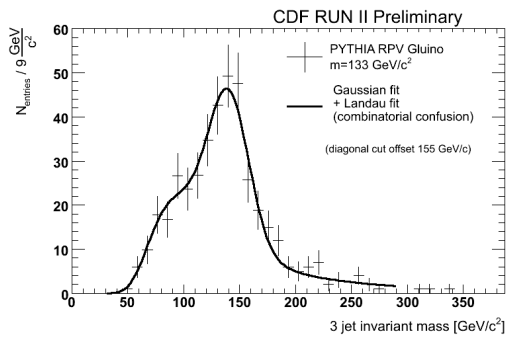
where $X, X' = \tilde{g}, \tilde{q}, \bar{\tilde{q}}$ with $\tilde{q}, \bar{\tilde{q}} \to \tilde{g} + jet$

Diagonal cut: Optimized vs. Mass

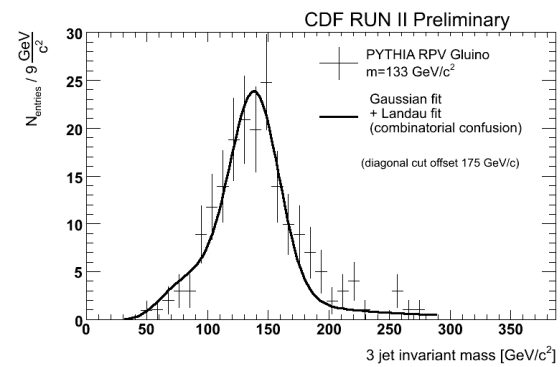
m =133 GeV



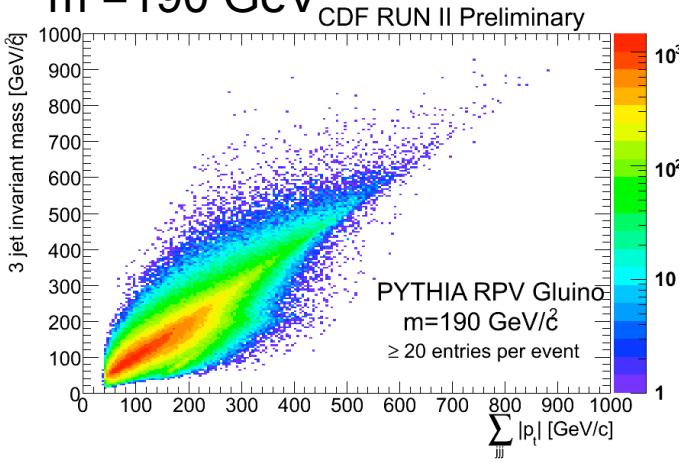
Offset 155 GeV



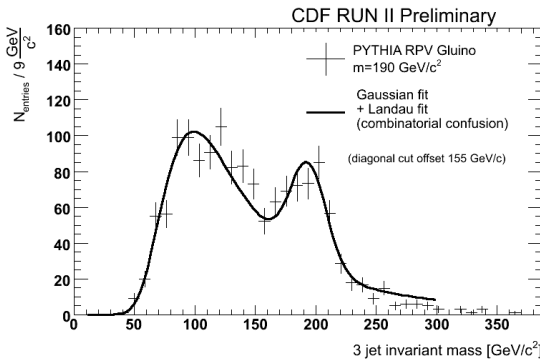
Offset 175 GeV



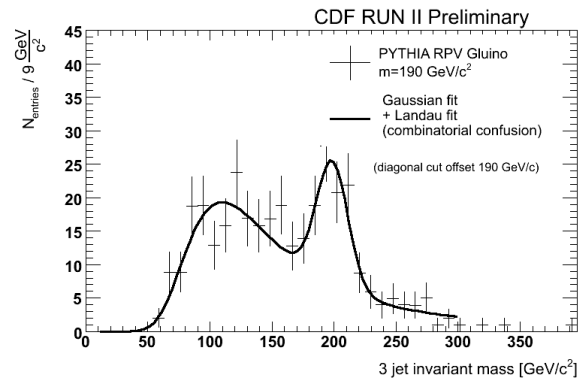
m =190 GeV



Offset 155 GeV



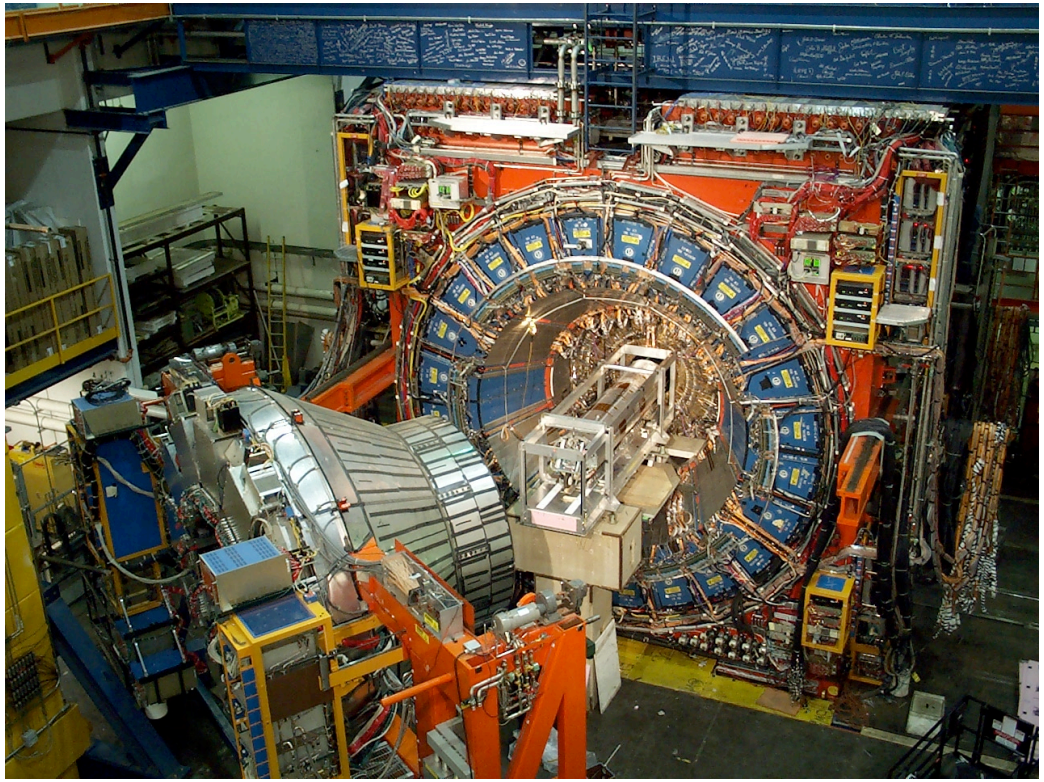
Offset 190 GeV



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

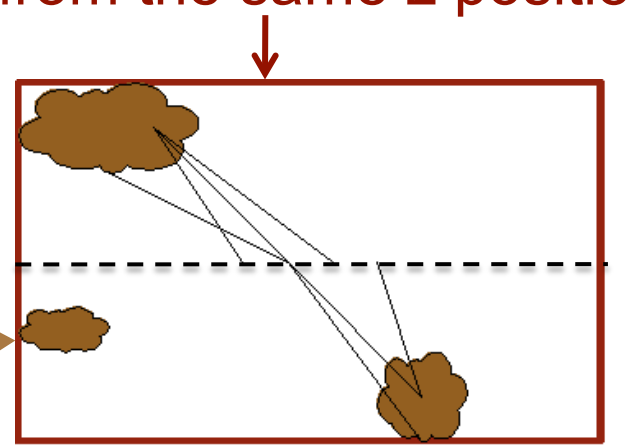


- Multipurpose detector:
  - Tracking system
  - ~2 Tesla field
  - Electromagnetic and Hadronic calorimeters
  - Muon System

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

This lowers our acceptance for forward clusters

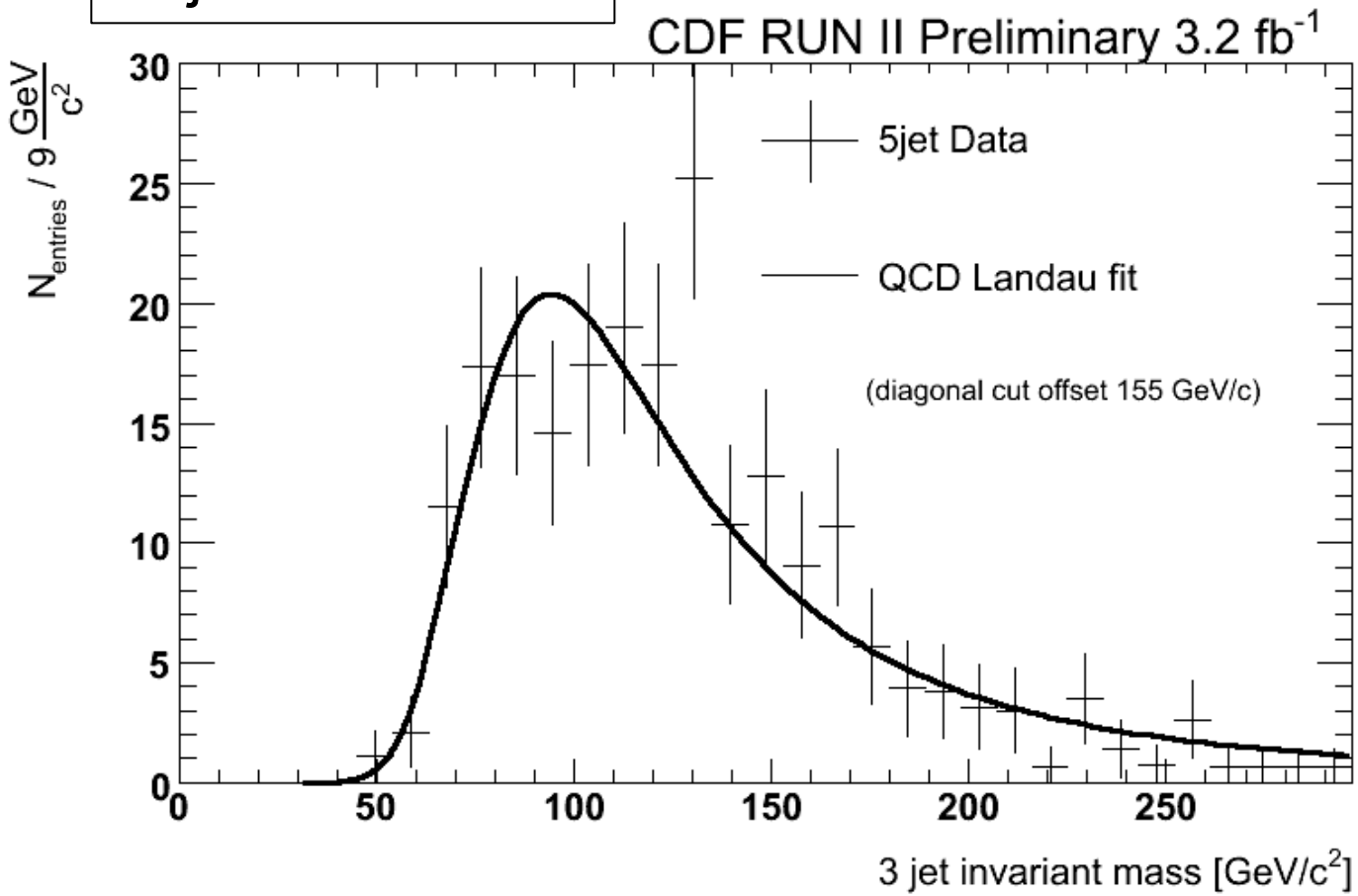


QCD Background Estimate

- 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

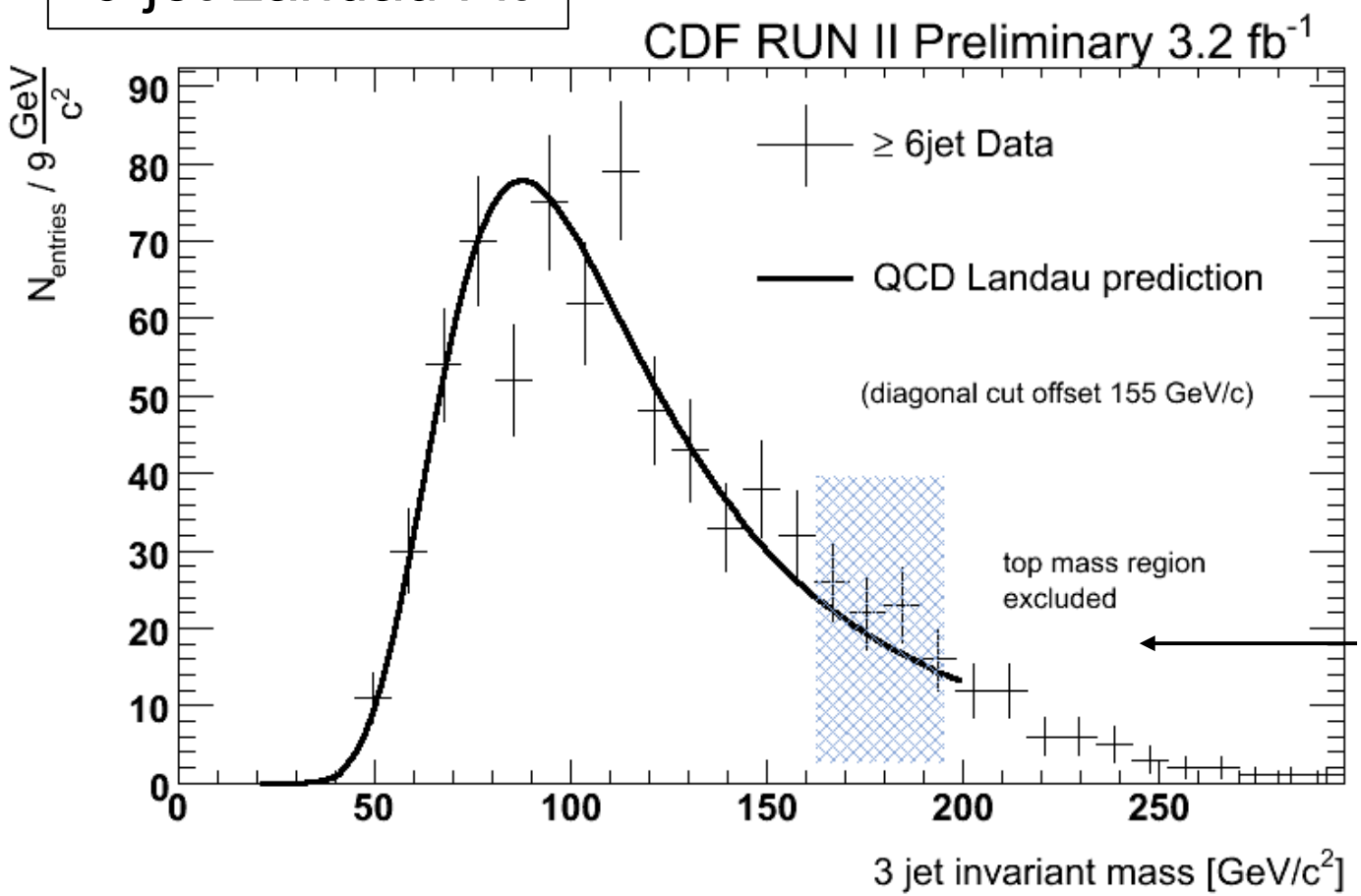
5-jet Landau Fit



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

QCD Background Estimate: 6-jet Data

6-jet Landau Fit

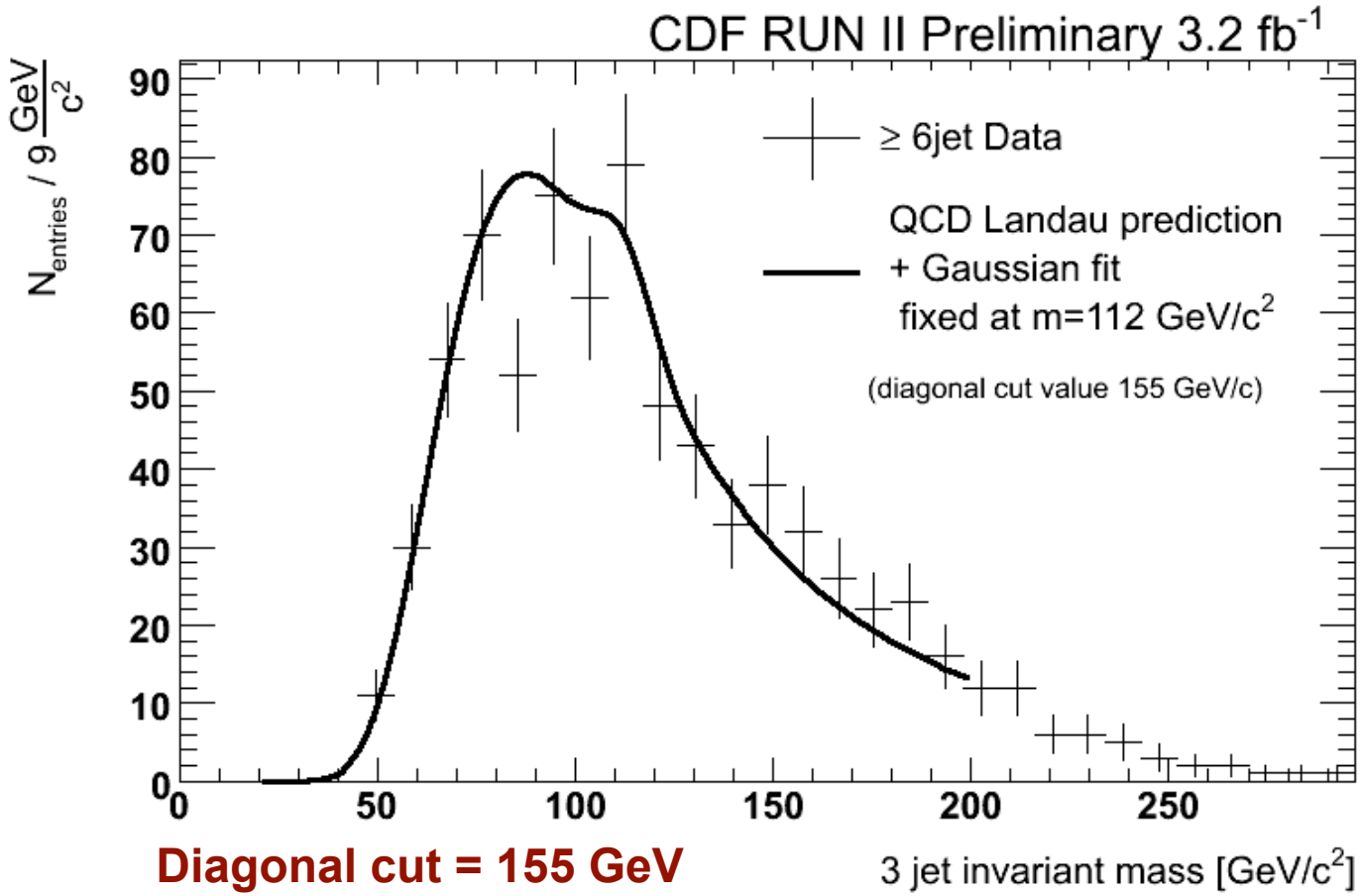


Top quark mass region is blinded in the fit

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

Fitting for signal in data

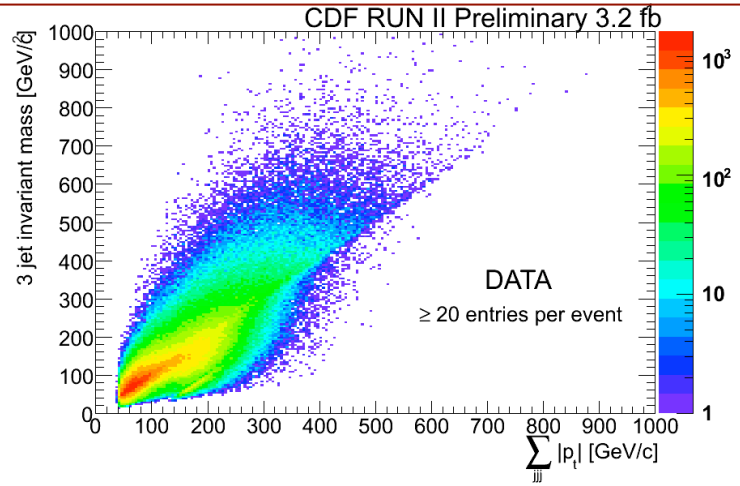
Fit for possible signal with Landau + Gaussian

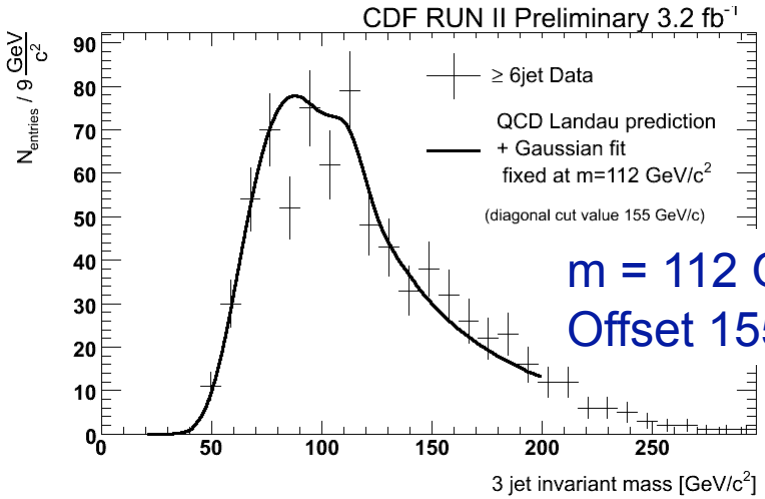


Diagonal cut = 155 GeV
Mass = 112 GeV

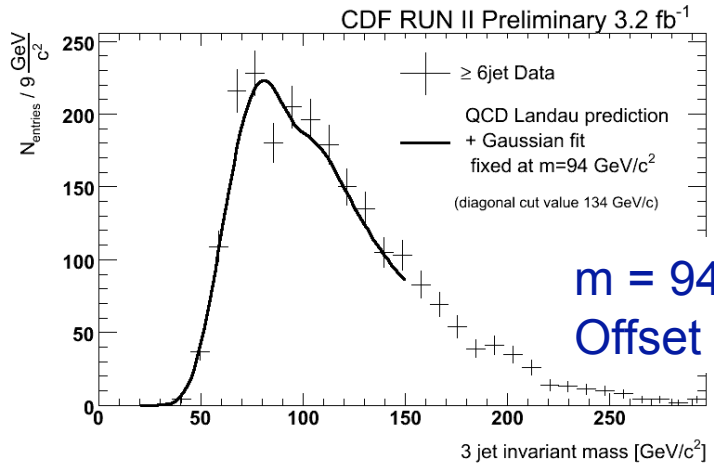
Fitting for signal in data

Search in the range of 77 – 240 GeV

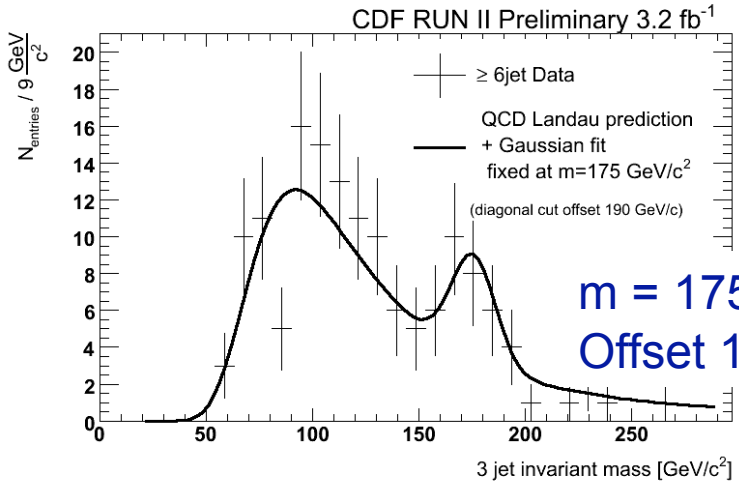




m = 112 GeV
Offset 155 GeV



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

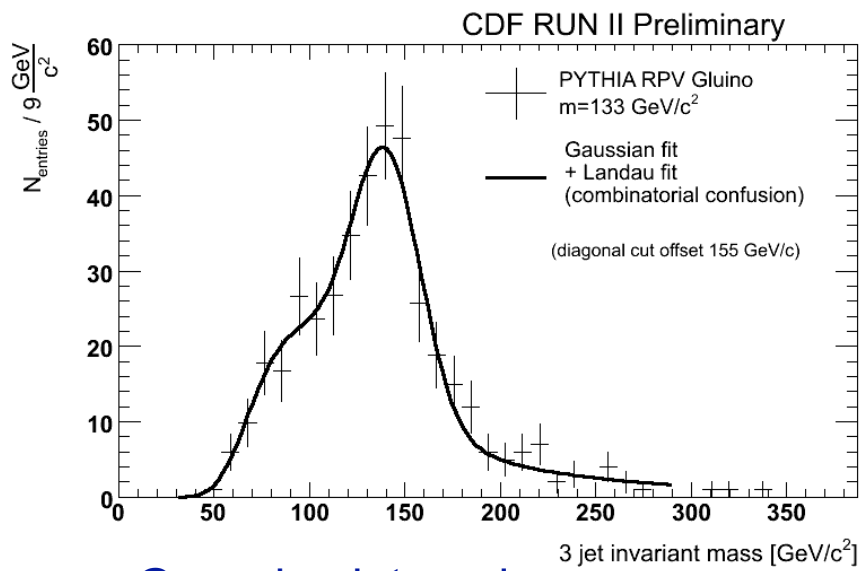
Signal: RPV Gluino

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

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

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

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

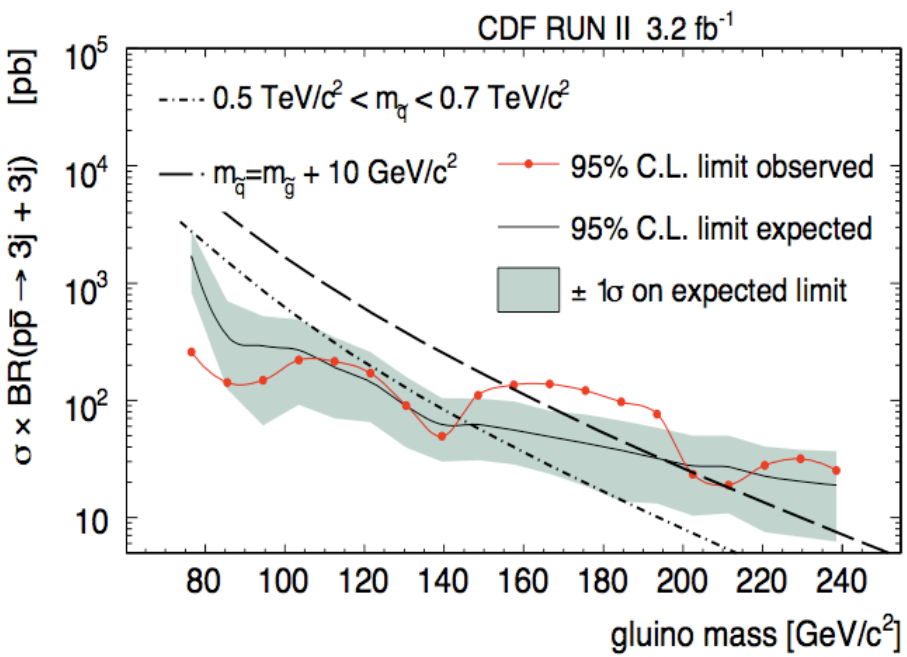


Gaussian integral
(after all analysis cuts)

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

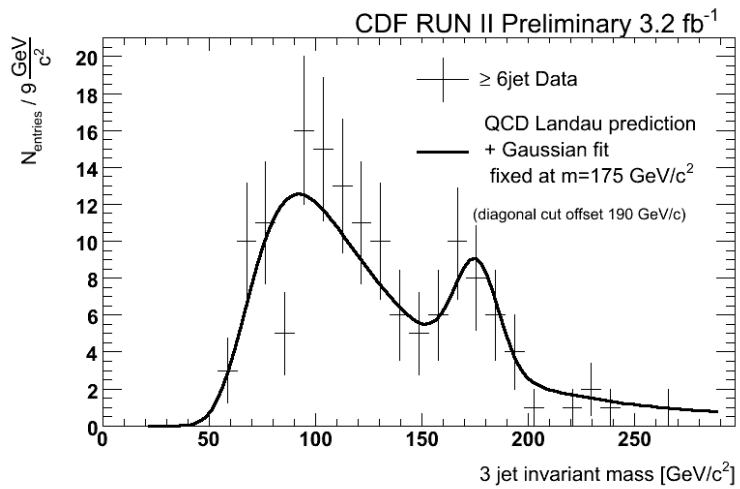


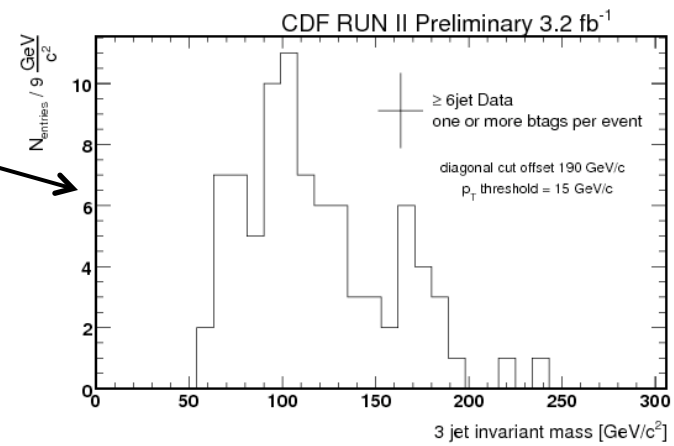
Model cross sections from Pythia, corrected with NLO k-factors from Prospino

- **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

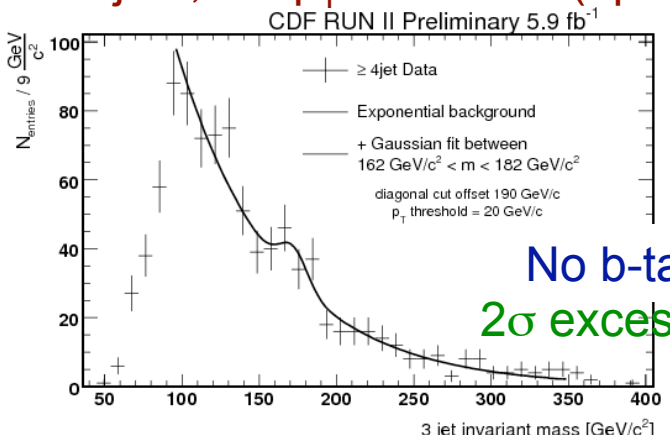
- Noticeable (2σ) excess near m_{top}
- MC expectation for known SM process ttbar ~ 1 triplet for diagonal cut = 190 GeV
  - Cross checked with MC@NLO, Alpgen, varied ISR/FSR, varied PDFs: expectation between 0.5 -1.1 triplets
  - Also cross checked with b-tagging, dijet mass of non-btagged jets
- Fit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



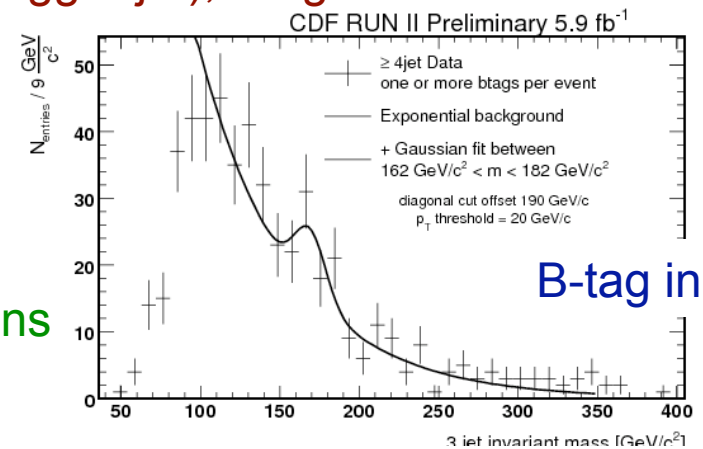


Cross Check with more data: 5.9 fb^{-1}

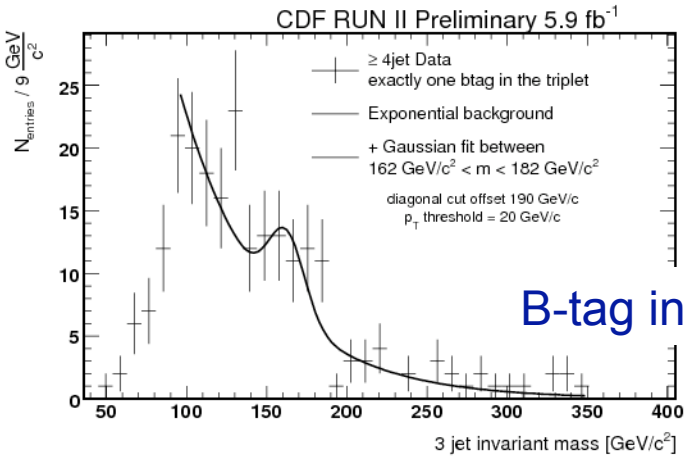
- Used Jet100 trigger
- ≥ 4 jets, Jet p_T > 20 GeV (apart from trigger jet), Diagonal cut = 190 GeV



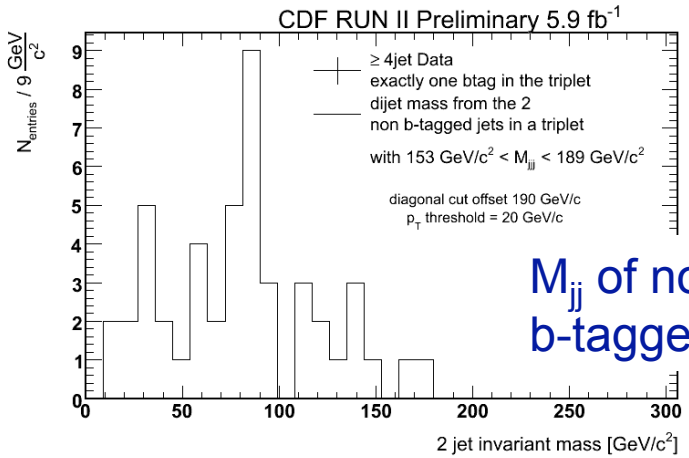
No b-tagging
2σ excess remains



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