# Extracting New Physics from Multi-Jet Signals

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Rutgers HEX (CMS) + HET

# Motivation

Many qualitatively different discovery signatures possible at LHC

New Physics Searches at Hadron Colliders involve

(Reconstructed) Objects

- Leptons
- Photons
- Missing Transverse Energy
- Jets

"Exotic" Objects (New Long Lived Particles)

- Leptons, Photons, or Jets from displaced vertices
- Kinks
- Late decays
- etc.

# Motivation

(Reconstructed) Objects

Leptons
Photons
Missing Transverse Energy
Jets

Strong Production Cross Section
Electroweak Decays
Background / Signal ***Suppressed***

$\sigma(pp \rightarrow QQ) \propto \sigma(pp \rightarrow Jets)$

$Q \rightarrow$ Leptons, Photons, MET

Searches at colliders (almost) always involve electroweak decays

# Motivation

(Reconstructed) Objects

Leptons
Photons
Missing Transverse Energy
Jets

Strong Production Cross Section $\sigma(pp \rightarrow QQ) \propto \sigma(pp \rightarrow Jets)$
Decay to Strongly Interacting States $Q \rightarrow Jets$
Background / Signal *Severe*

What if new physics appears in jets?

# New Physics Searches in Multi-Jets

- Challenging
- But Possible New Physics May be Hidden in Jets …..
- Techniques may be Useful for Multi-Jets in Association with Leptons, Photons, MET (e.g. also for SUSY signals with R-parity violation)
- Magnitude of Multi-Jet Backgrounds from High Order Processes is difficult to calculate a priori (O($\alpha_S^n$ ))

We have undertaken first studies in pp → QQ → 3j+3j = 6j

Q = $SU(3)_C$ Adjoint Majorana Fermion

- High Multiplicity-Jet Backgrounds, Lower Rate - More Tractable
- for 6j can get guidance from all-hadronic top studies (but no b-tagging or $m_W$ resonance!)
- Make use of *Kinematic Features* + *Correlations*

# How did we generate the events?

Signal: PYTHIA

MSSM: gluino production, -> 6 jets

with R-parity violation (UUD)

(all other sparticles heavy)

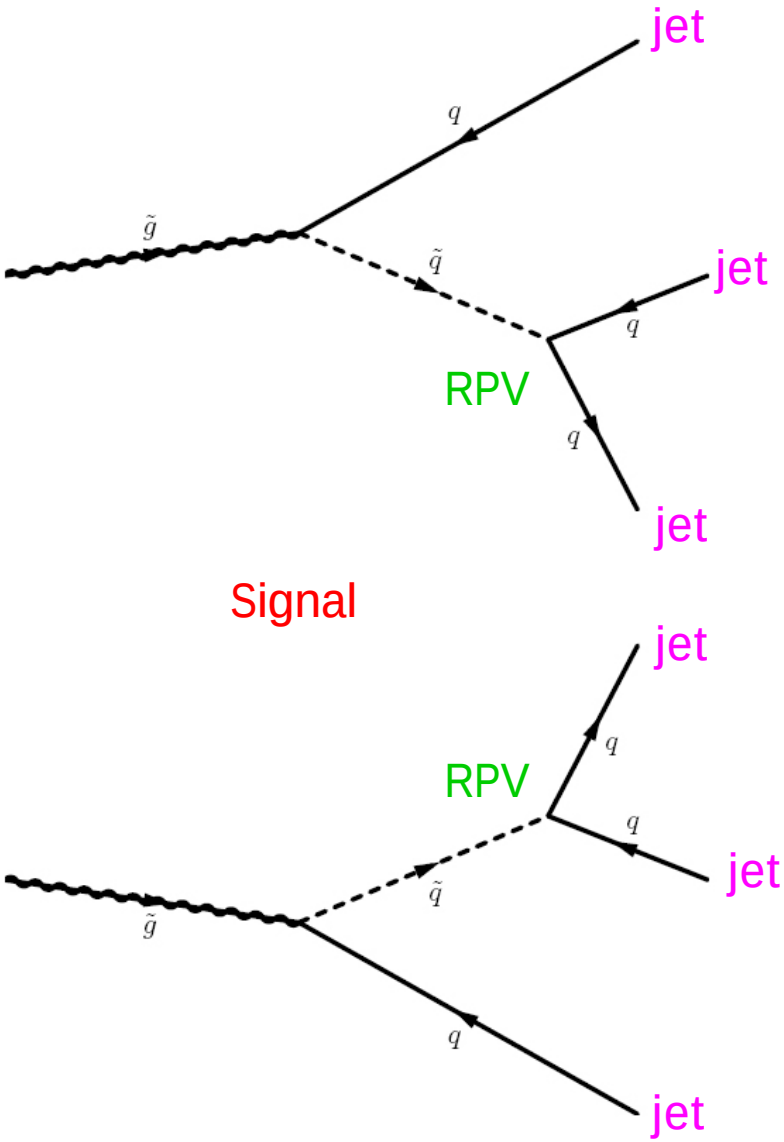
6 jet Background: ALPGEN -> PYTHIA

Hadronic top Background: PYTHIA

Detector Simulation: PGS (Conway, …)

Analysis: ChRoot+ (Braun, Ambroso;

+ additional functions from RE & P. Mosteiro)

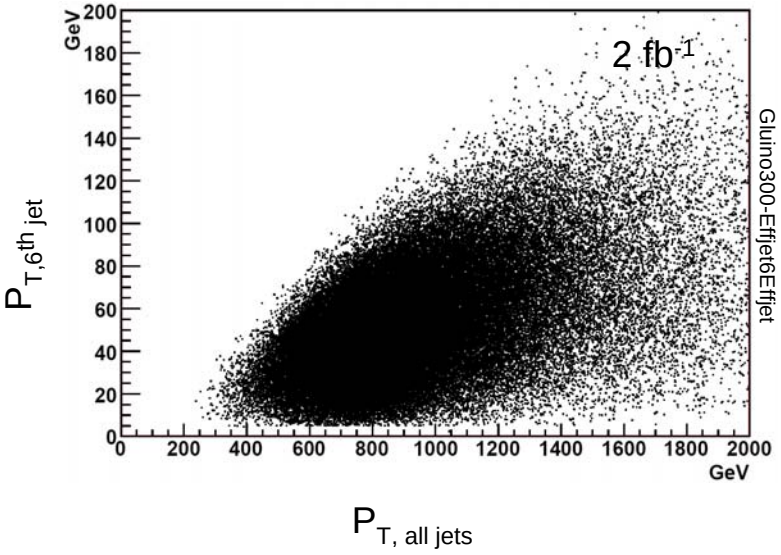


# pp → QQ → 6 jets

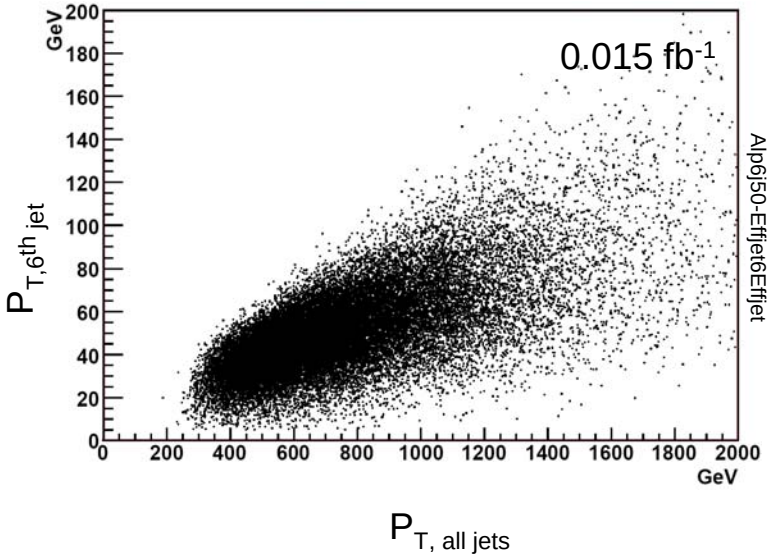
$N_{jet} \geq 6$

$m_Q$ = 420 GeV

Signal




Hadronic Background



# pp → QQ → 6 jets

$N_{jet} \geq 6$

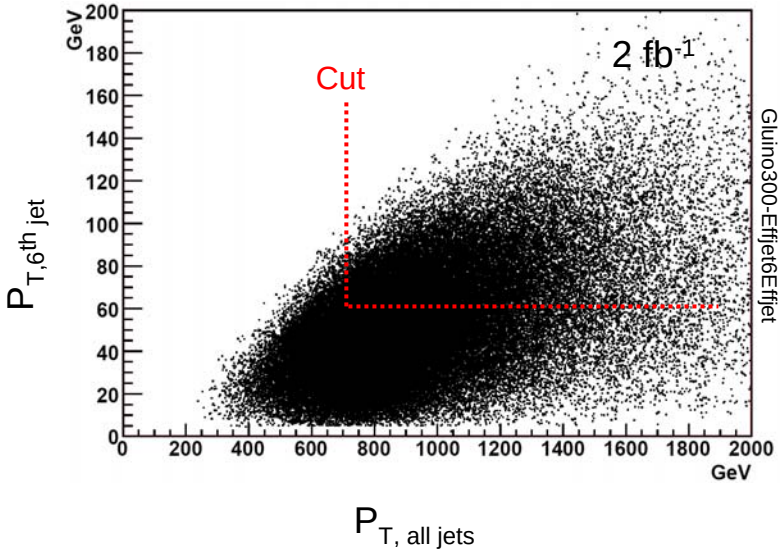
$m_Q = 420$ GeV

Cut :

$p_{T,\ all\ jets} \geq 700$ GeV

$p_{T,\ 6th\ jet} \geq 60$ GeV

Signal

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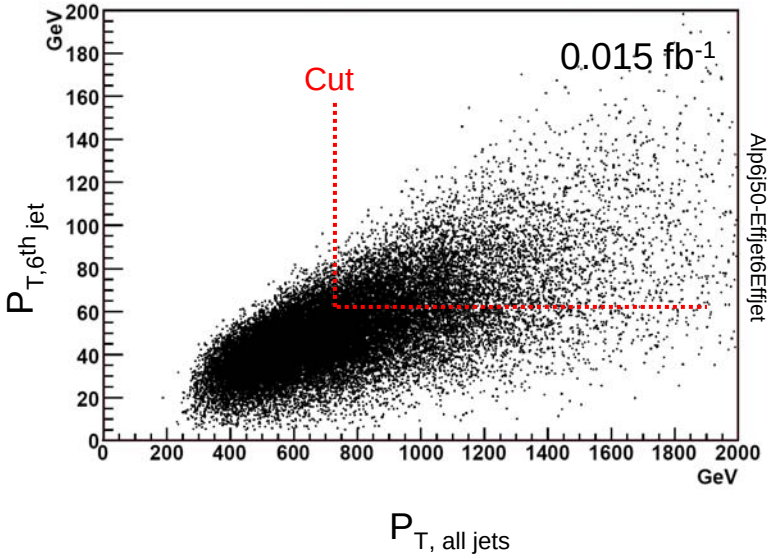



Signal Efficiency ≃ 0.25

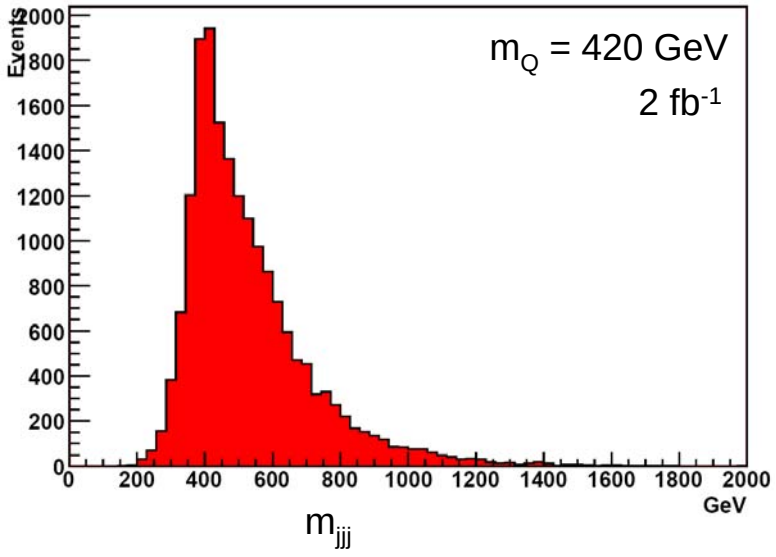
# pp → QQ → 6 jets

- Assume six hardest jets come from QQ decay
- Can form two Three-Body Resonances $m_{jjj} = m_{jjj'}$

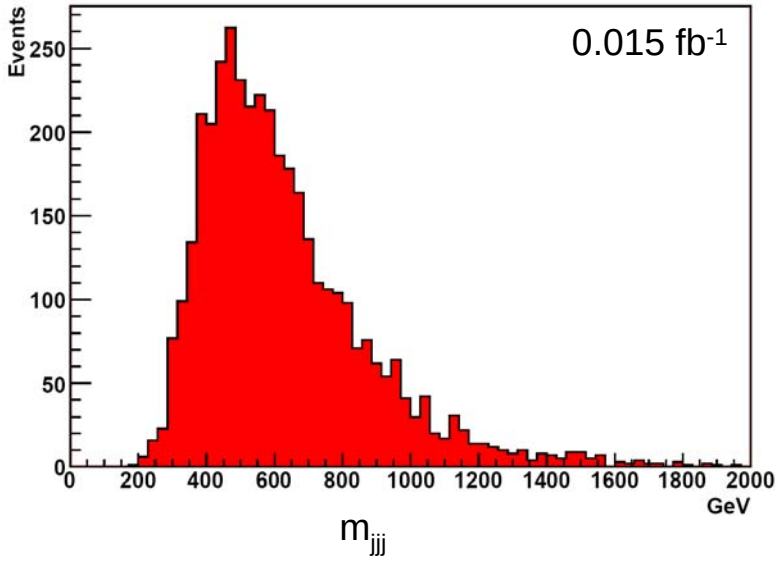
Choose Pair of Jet triplets (from 10 possibilities) with Smallest $|m_{jjj} - m_{jjj'}| < 60$ GeV

$|\Sigma_{i=1}^{6} \vec{p}_{T,i,\mathbf{jet}}| \leq 60$ GeV

Signal




Hadronic Background




- Cuts Necessarily Shape Background
- Magnitude of Background Uncertain -
  Use Signal + Background Distributions as Templates

# pp → QQ → 6 jets

Choose Scaled Cuts:

$p_{T,\text{ jets}} \geq 1.7\ m_Q$

$p_{T,\text{ 6th jet}} \geq 0.15\ m_Q$

$|\Sigma_{i=1}^{6} \vec{p}_{T,i,\mathbf{jet}}| \leq 0.15\ m_Q$

$|\ m_{jjj} - m_{jjj}\ | < 0.15\ m_Q$

| $M_Q$ (GeV) | S/B | S/ $B^{1/2}$ / $fb^{-1}$ | Signal Events / $fb^{-1}$ |
|---|---|---|---|
| 290 | 1/125 | 15 | 26500 |
| 420 | 1/29 | 17 | 9000 |
| 660 | 1/22 | 5 | 600 |
| 890 | 1/17 | 2 | 70 |

Note: Magnitude of Background Uncertain

# pp → QQ → 6 jets

- Assume six hardest jets come from QQ decay
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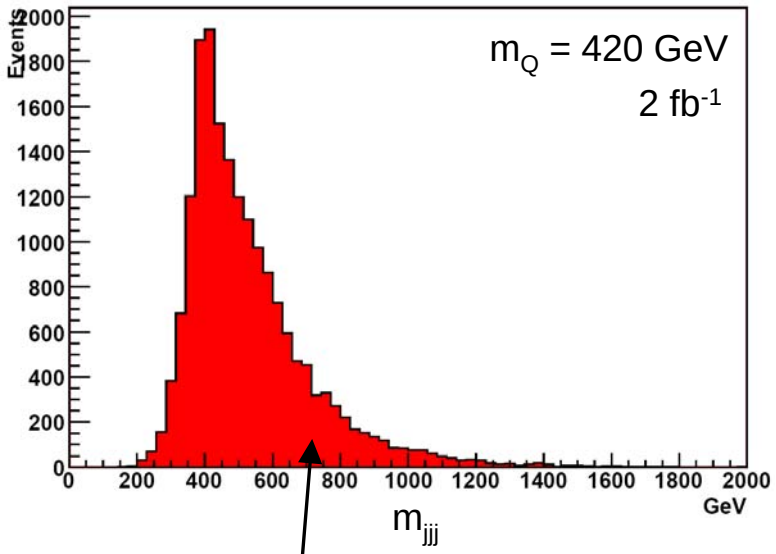
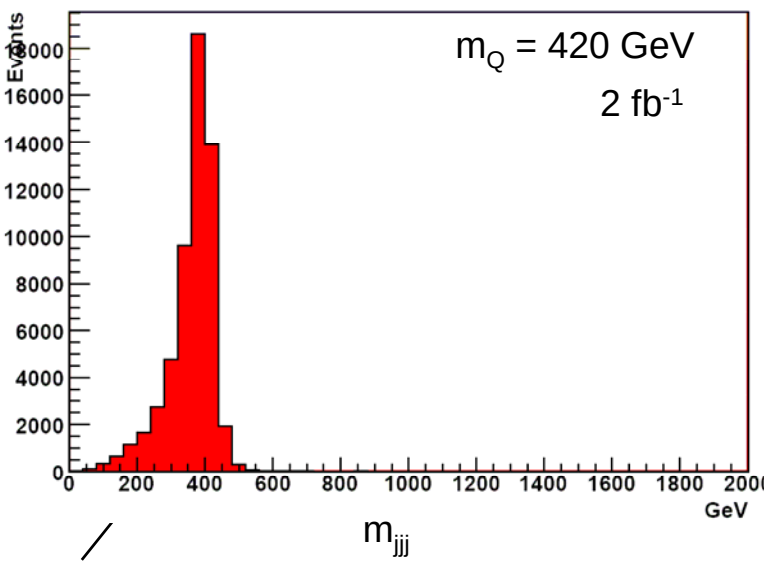
$|\Sigma_{i=1}^{6} \vec{p}_{T,i,\mathbf{jet}}| \leq 60$ GeV

Signal




Signal (using parton level information)
(no additional kinematic cuts)




-Tail much larger than Jet Resolution
- Mismatching of Jet Triplets
- Combinatoric Background Within Signal

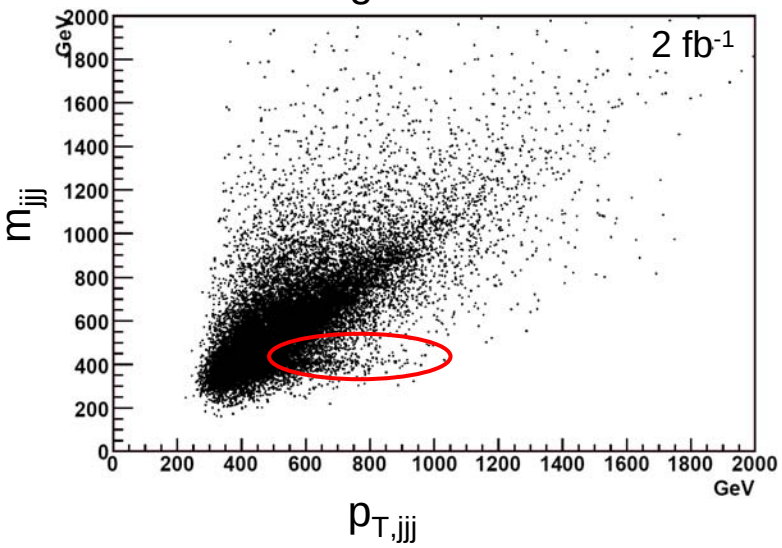
Improve Contrast Between Signal and Background

# pp → QQ → 6 jets

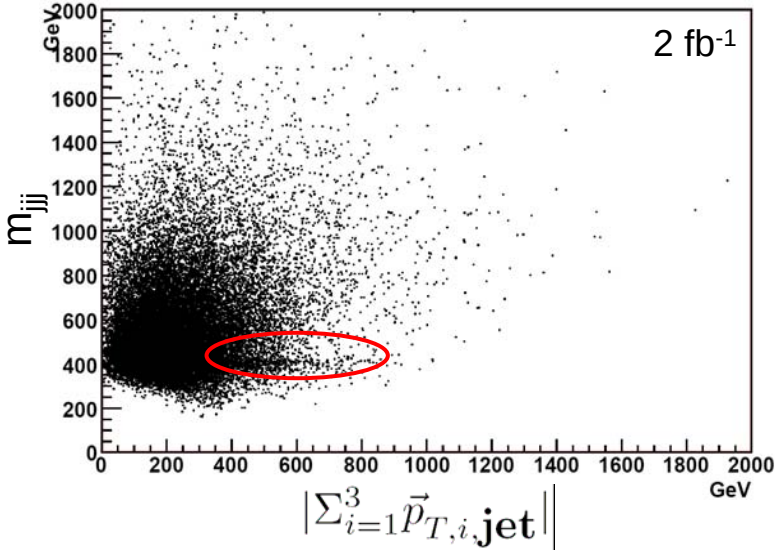
Use Kinematic Correlations to Separate Signal from Combinatoric Background

$m_Q$ = 420 GeV

Signal




Signal

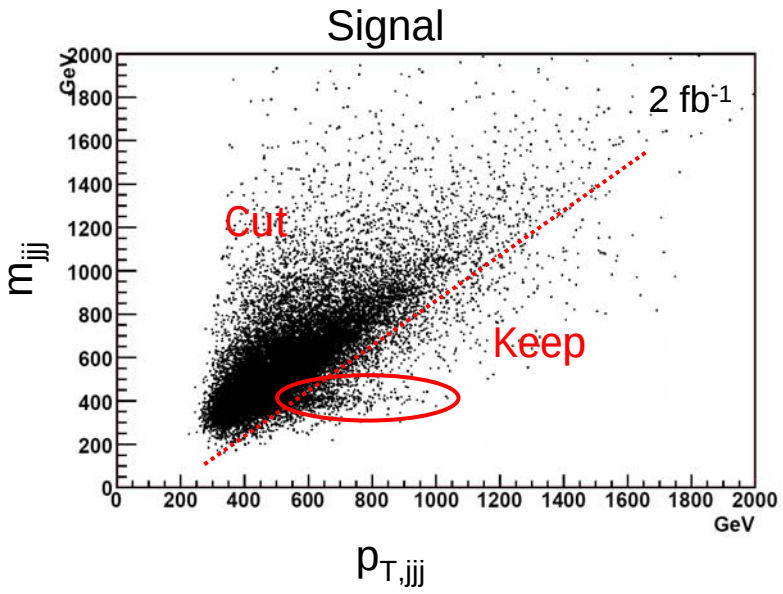


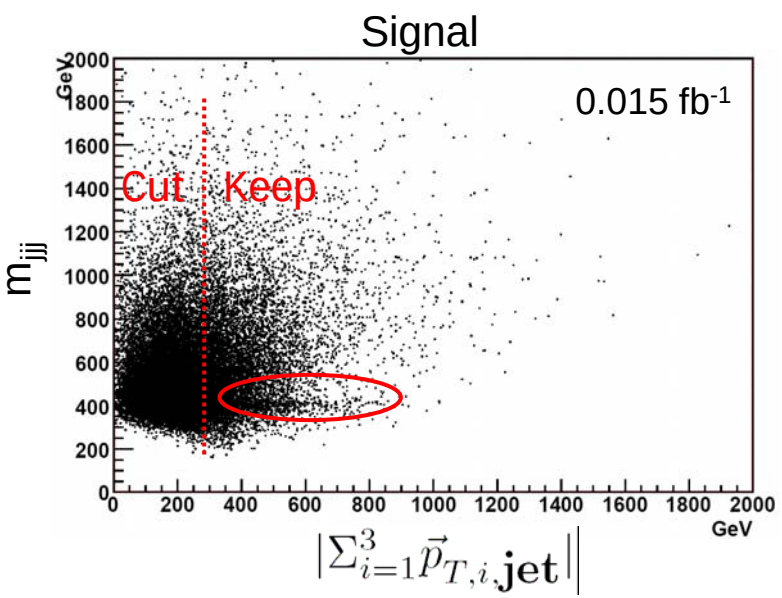

- Two Distributions of Events
- Three Body Resonance Jet Resolution Apparent on Horizontal Branch
- Most of the "Best" Pairs of Jet Triplets with small $|m_{jjj}-m_{jjj'}|$ are NOT the Correct Pairing (Random Choice of Triplet ~ Same Distribution)

# pp → QQ → 6 jets

## Remove Combinatoric Background with Cuts

$m_Q$ = 420 GeV




- Horizontal Branch - Region of High Signal to Combinatoric Background Contrast

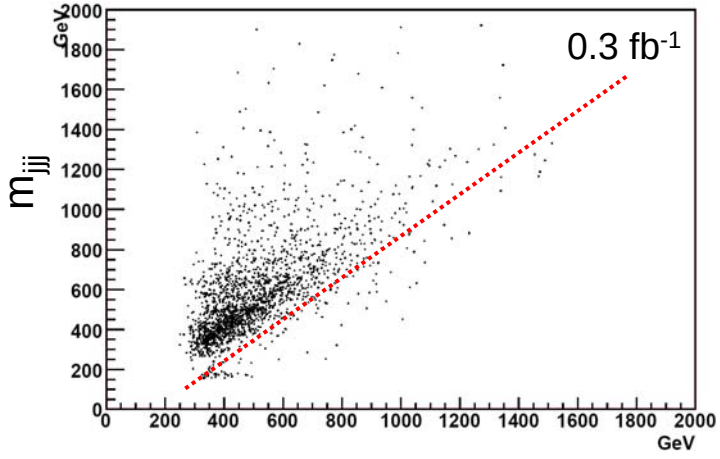
→ Increase Signal Efficiency by Including <u>All</u> 20 Jet Triplets

Remove $|m_{jjj} - m_{jjj'}| < 60$ GeV Cut

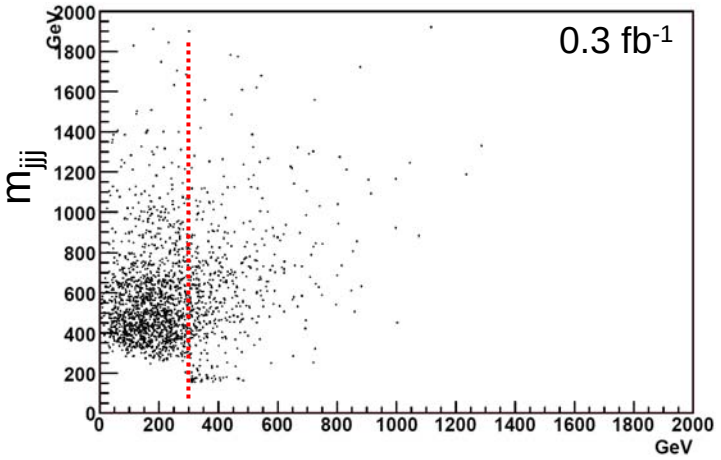
# pp → QQ → 6 jets

## Cuts on Background

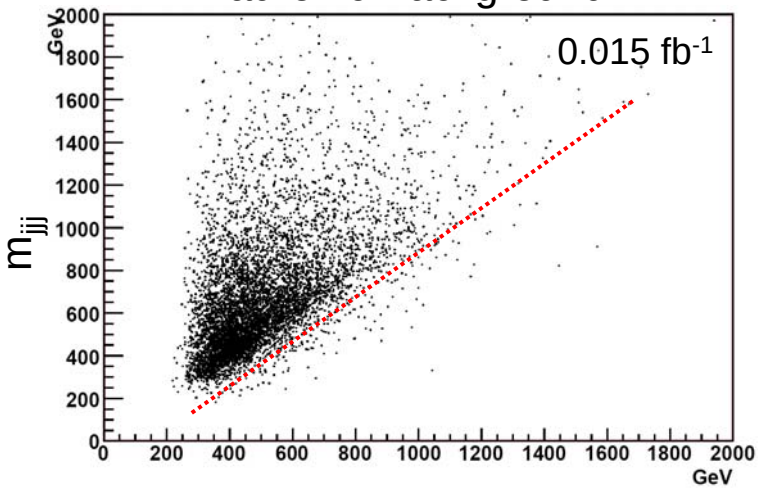
Top Background




Top Background




Hadronic Background

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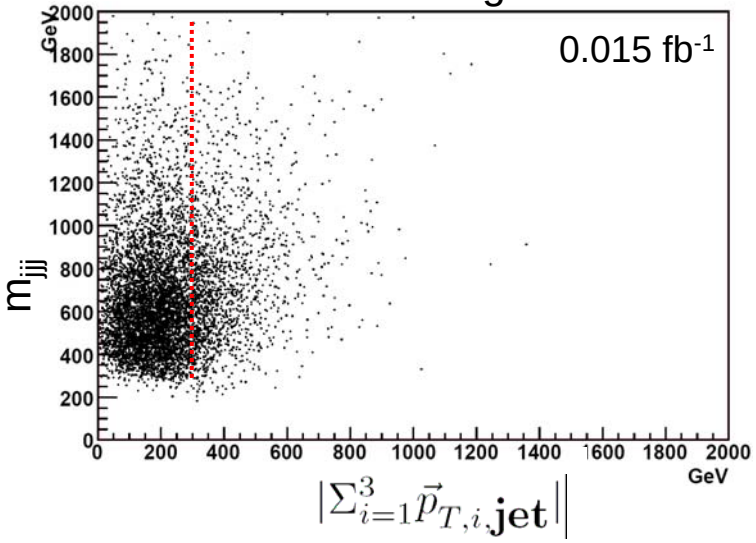
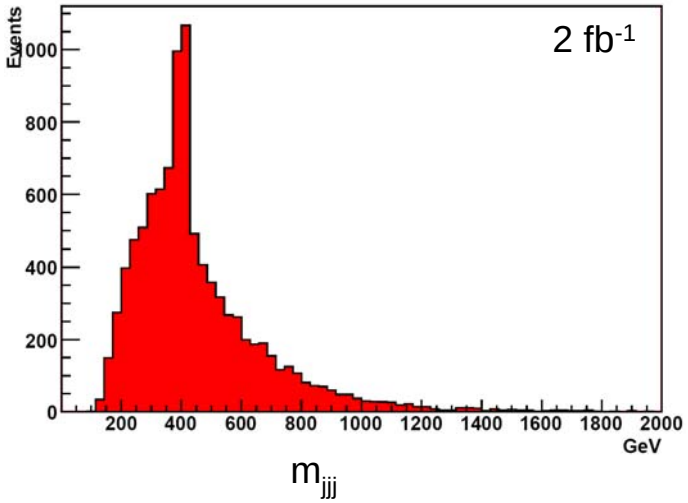


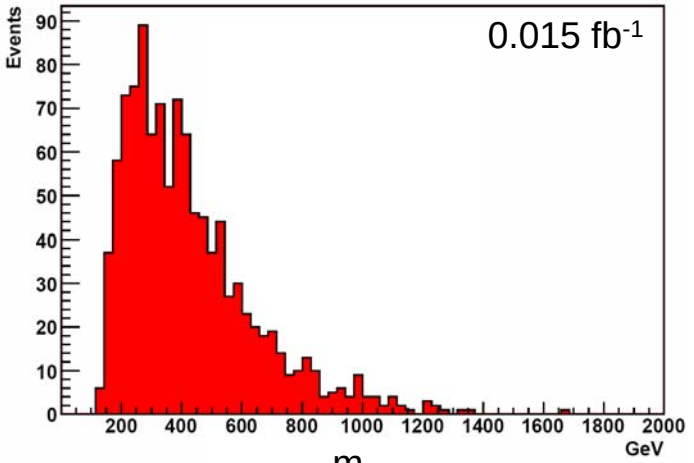
# pp → QQ → 6 jets

Signal



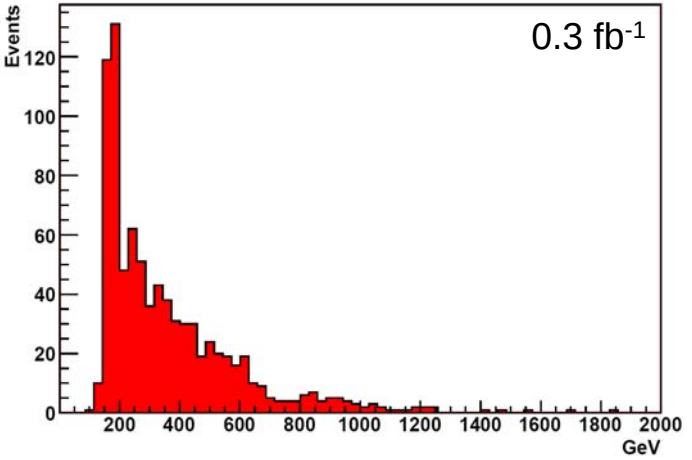

$m_{jjj}$

Hadronic Background




$m_{jjj}$

Top Background

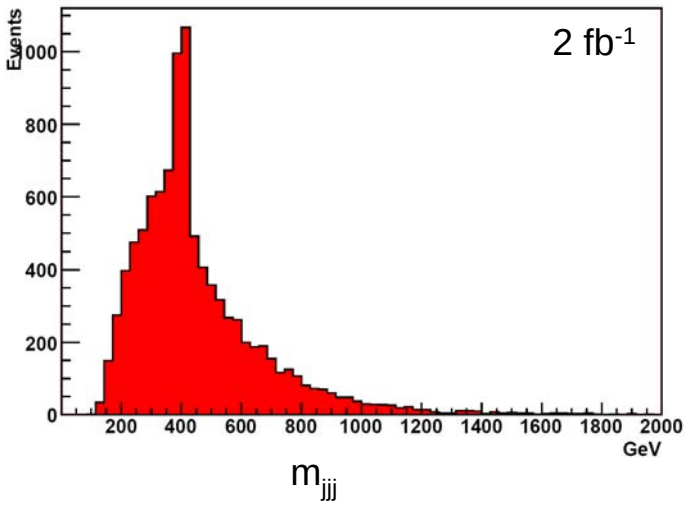



$m_{jjj}$

After cuts

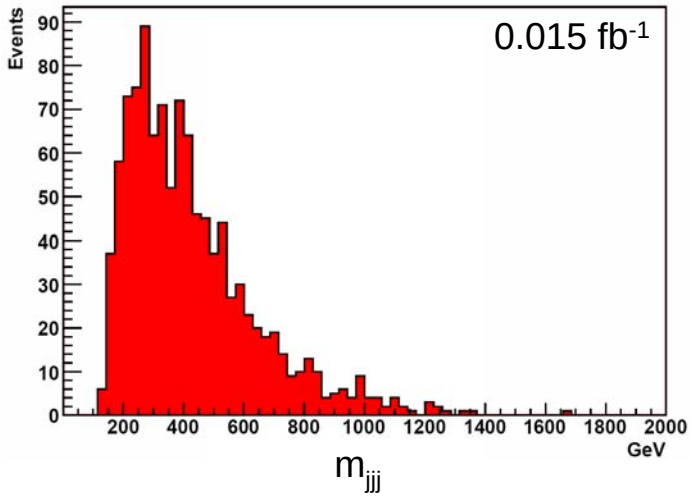
# pp → QQ → 6 jets

Signal




$m_{jjj}$

Hadronic Background




$m_{jjj}$

Picking out horizontal branch:

- Improves Constrast
- Improves S/B by 2
- Number of signal events smaller

| $M_Q$ (GeV) | S/B | S/ $B^{1/2}$ / $fb^{-1}$ | Signal Jet Triplets / $fb^{-1}$ |
|---|---|---|---|
| 420 | 1/15 | 18 | 4700 |

# Conclusions

- Using Correlations – Possible to Separate pp → QQ → 6 jets from Background
- Possible Reach (Preliminary) $m_Q \sim 600$ GeV with 1 $fb^{-1}$
  $\sim 800$ GeV with 10 $fb^{-1}$
- Study Template Fitting to Signal + Background
- Validate Background Templates and Magnitude with Data
- use HT300 trigger

## Further directions:

- Study parton level information
- Develop Kinematic Correlations for Other Multi-Jet Signatures (4j, …)
- Extend to Signatures that include other Objects (Leptons, Photons, MET)
- Rutgers HEX group is working on studies with full CMSSW