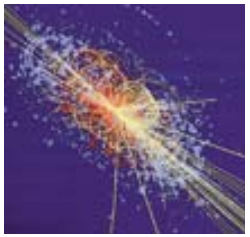


Multijet Resonances

or

how we could totally miss the new physics

Amitabh Lath

Rutgers, The State University of New Jersey

with

Sunny Chuang, Rouven Essig, Eva Halkiadakis, Tim Lou, Scott Thomas

What do all searches assume?

New physics will have one or more of the following:

- Leptons (including taus)
- Missing energy
- B

In other words, new physics couples to **Weak sector** (or photons)

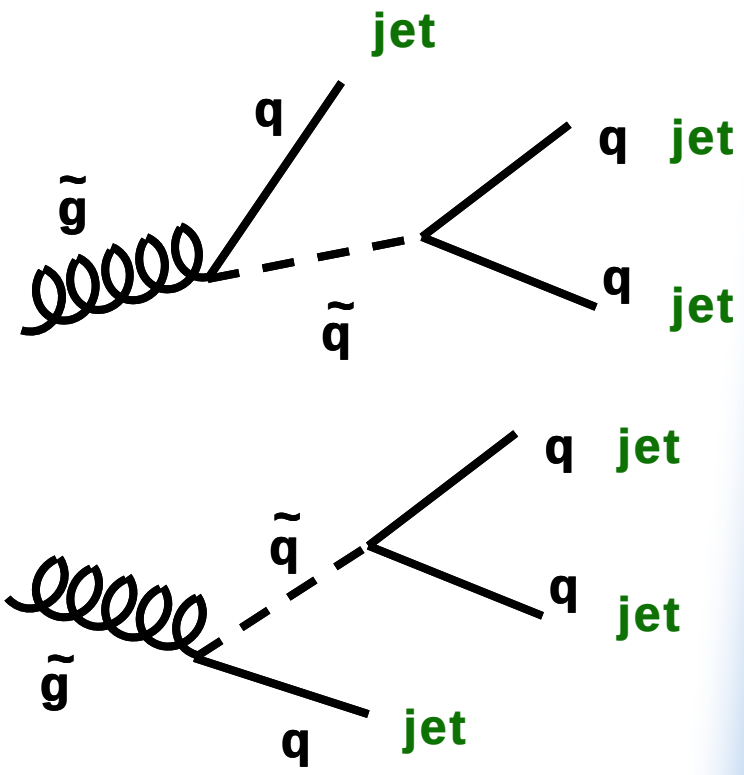
Exception: Dijet searches! (Rob and crew)

What if new physics has color?

- Colored like a quark or gluon.
- Would be pair-produced.
  - Final state of 4 jets if quark-like
  - Final state of 6 jets if gluon-like
- QCD multijet background horrendous.
- So what can we do?

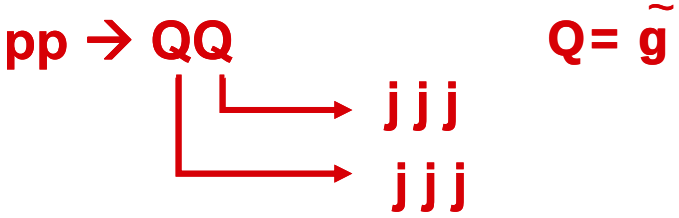
New Physics in Multi-Jets

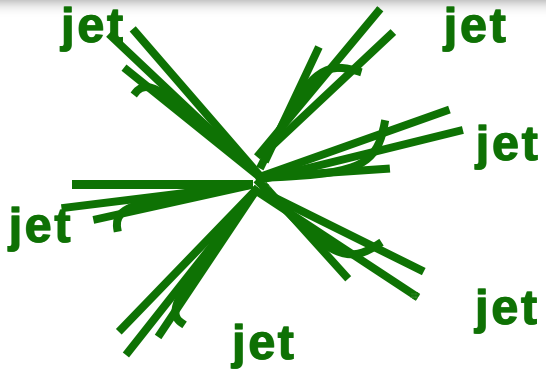
- Model this using Pythia SUSY
- Studying pp→QQ → 3j+3j = 6j
  - **Q= gluino** = $SU(3)_C$ Adjoint Majorana Fermion
  - R-Parity violating (so no MET)
- How do all-hadronic top guys do this?
  - *Make use of kinematic features and correlations*
- ***Our own trick**: Use an ensemble of jet combinations*



NO MISSING ET

Details: Signal & Background





Signal: **PYTHIA** RPV (uud Yukawa) gluino
MSbar masses 200 GeV (real mass 290 GeV) and up

6 Jet Background: **ALPGEN** 6j CSA07 samples (pt leading parton 20-100, 100-180, 180-250, 250-400, 400-5600)
https://twiki.cern.ch/twiki/bin/view/Main/AlpgenSummer07
Validation plots in past Generators/QCD meetings.

CMS NOTE: CMS AN-2008/068

No leptons, No MET, No W resonance, No b

Cuts: Trigger Level

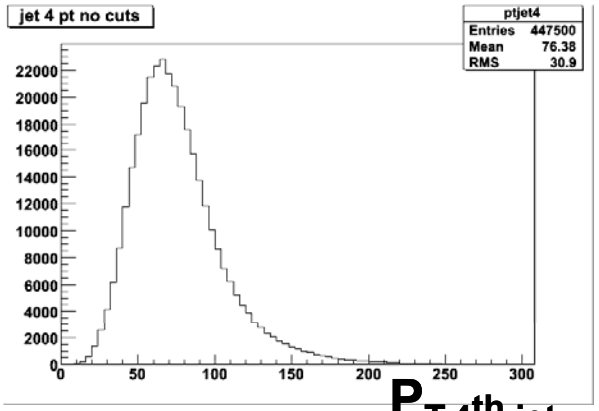
- $|\eta| < 3$ of the first 6 jets

- (1st jet > 400 GeV .OR.
  2nd jet > 350 GeV .OR.
  3rd jet > 195 GeV .OR.
  4th jet > 80 GeV .OR.
  sum had > 1000 GeV)

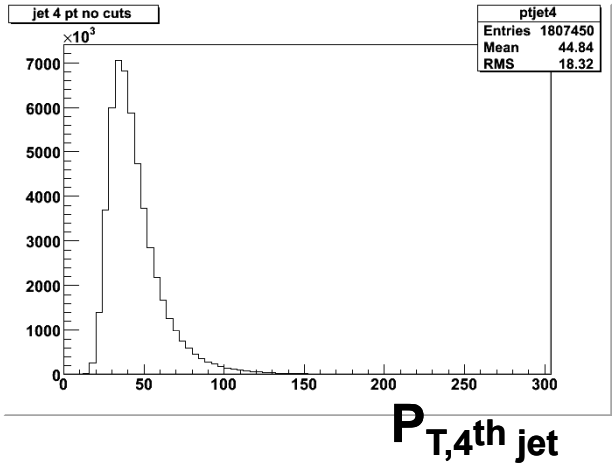
This is dominated by the 4th jet trigger.

Note: In this analysis, we are using cone 0.5 reconstructed jets.
Also note: ALPGEN QCD samples generated with deltaRmin>0.7. Bad?

Signal M_Q = 290 GeV



Hadronic Background



Cuts: Analysis Level

- **USEFUL VARIABLE 1**: SCALAR Sum p_T of the 1st 6 jets:

  $\sum_{i=1}^{6} |p_{T,}|$

  - gluino200 600 GeV
  - gluino300 700 GeV
  - gluino500 1100 GeV

- **USEFUL VARIABLE 2:** 6th jet p_T
  - 30 GeV, 60 GeV, 90 GeV, 120 GeV

Try different cuts to optimize signal vs. background

Sum $P_{T,jets}$ vs. $P_{T,6th\ jet}$

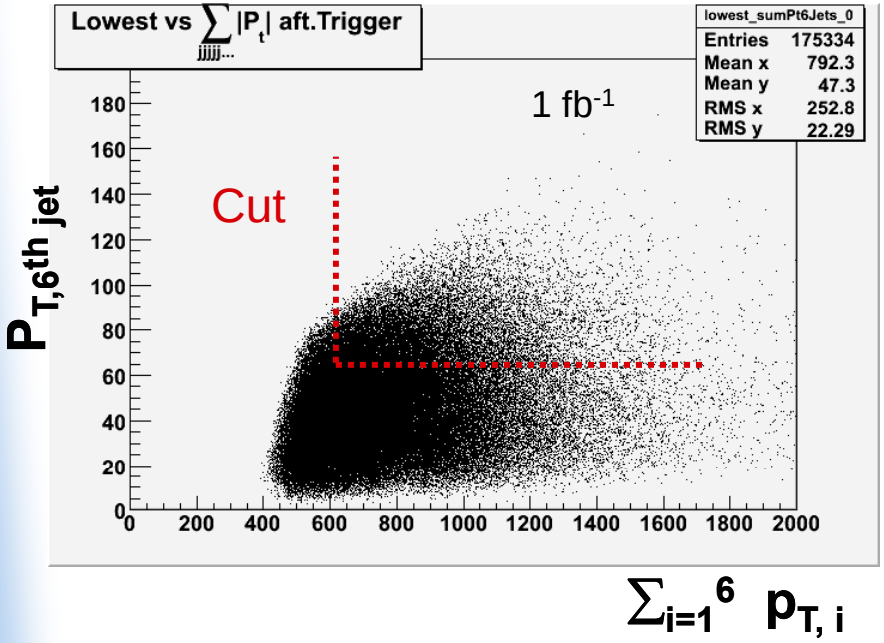
pp → QQ → j j j j j j

$N_{jet} \geq 6$

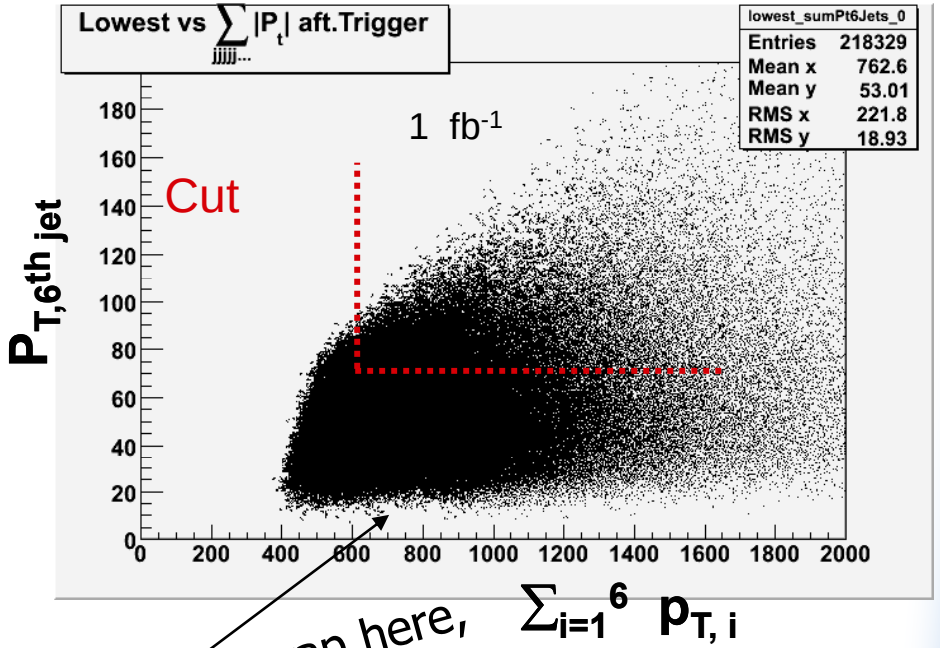
Example

Cuts: $\sum_{i=1}^{6} p_{T,i} > 600$ GeV, $p_{T,6th\ jet} > 60$ GeV

Signal $M_Q = 290$ GeV



Hadronic Background



Selecting Jet Triplets:
Ensemble of Jet Combinations

Which Combination?

There are 20 possible triplets among 6 jets.

Tried looking at pairs of mjjj closest to each other. Did not work.

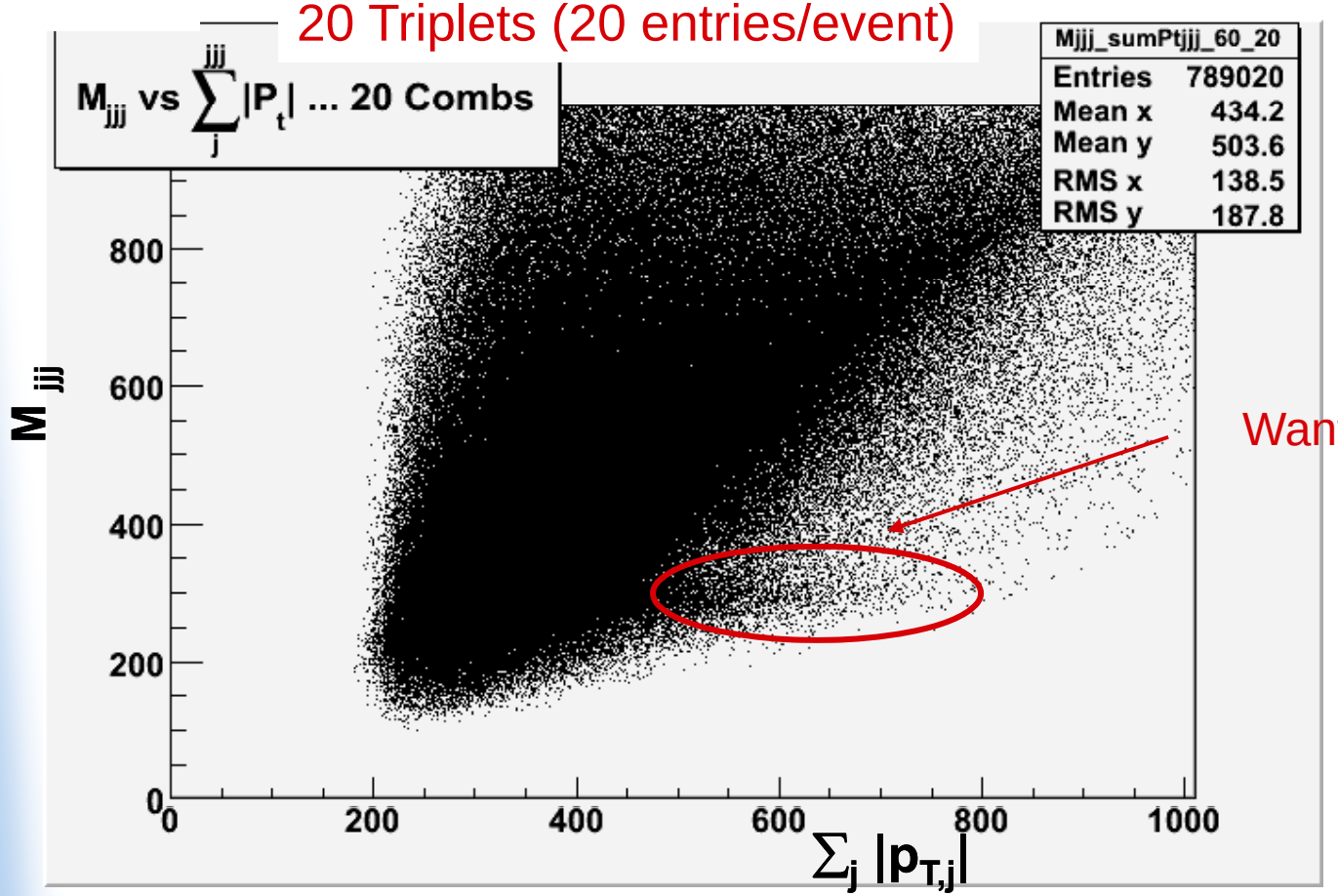
Use all 20.

Multiple entry plot.

Using Kinematic Correlations: Mass vs. Sum P_T

Extract Kinematic Features from Combinatoric Confusion

20 Triplets (20 entries/event)



Signal

M_Q=290

1 fb^{-1}

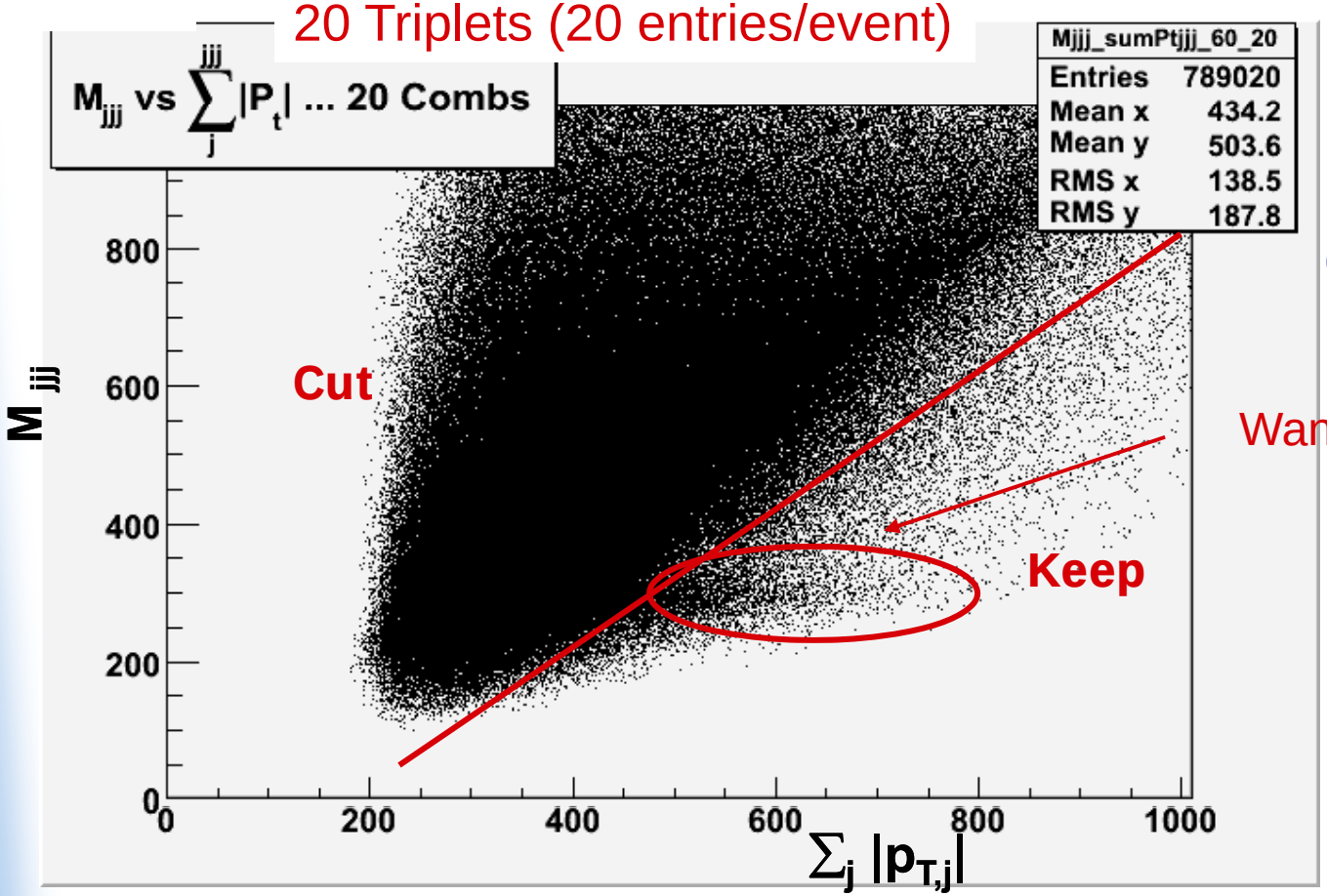
Want to isolate good triplets

Horizontal Branch: Region of high signal to combinatoric background contrast

Using Kinematic Correlations: Mass vs. Sum P_T

Extract Kinematic Features from Combinatoric Confusion

20 Triplets (20 entries/event)



Signal

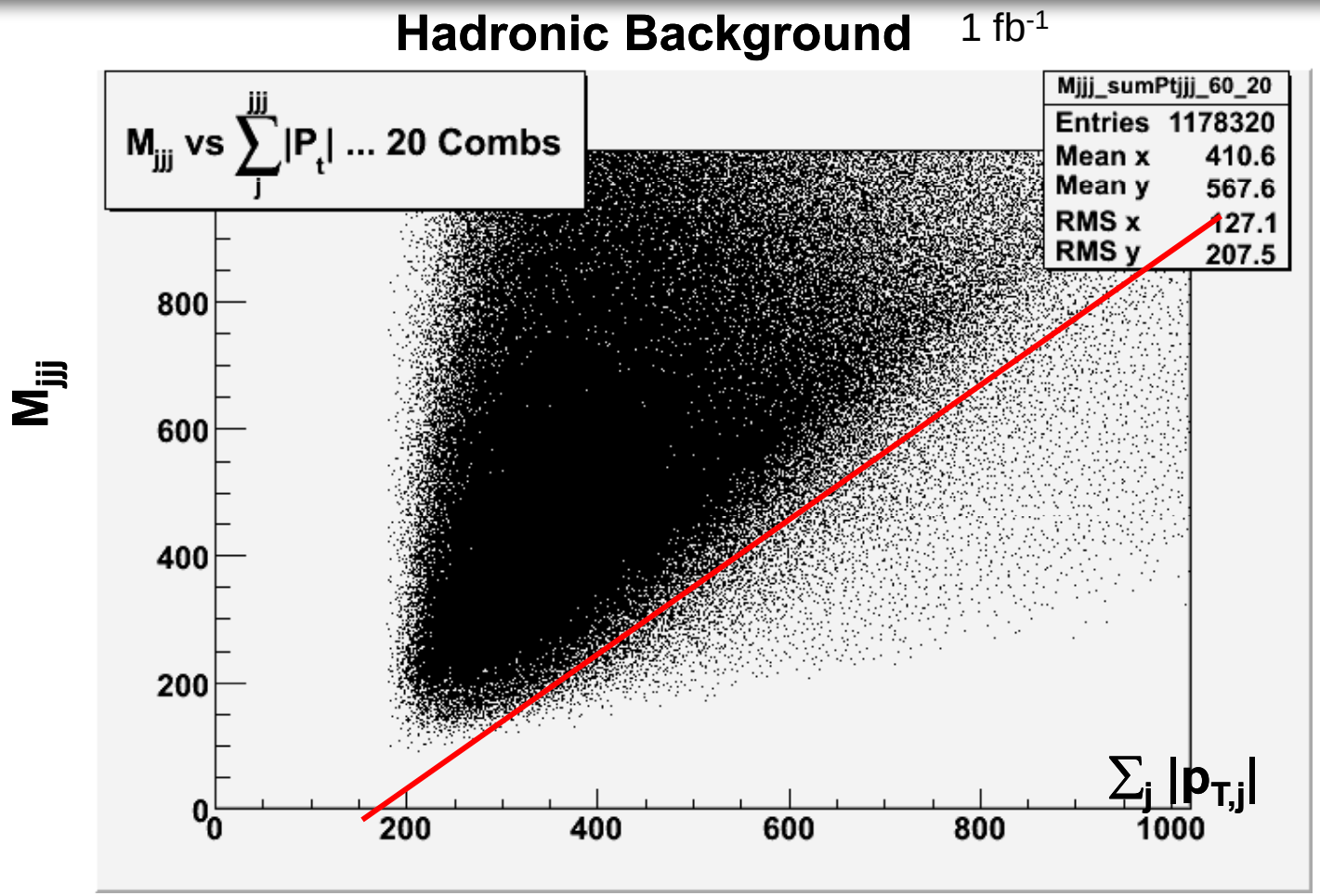
M_Q=290 1 fb^{-1}

Cut: $M_{jjj} < \sum|p_{T,j}|$ - offset

Want to isolate good triplets

Horizontal Branch: Region of high signal to combinatoric background contrast

Mass vs. Sum P_T for Background

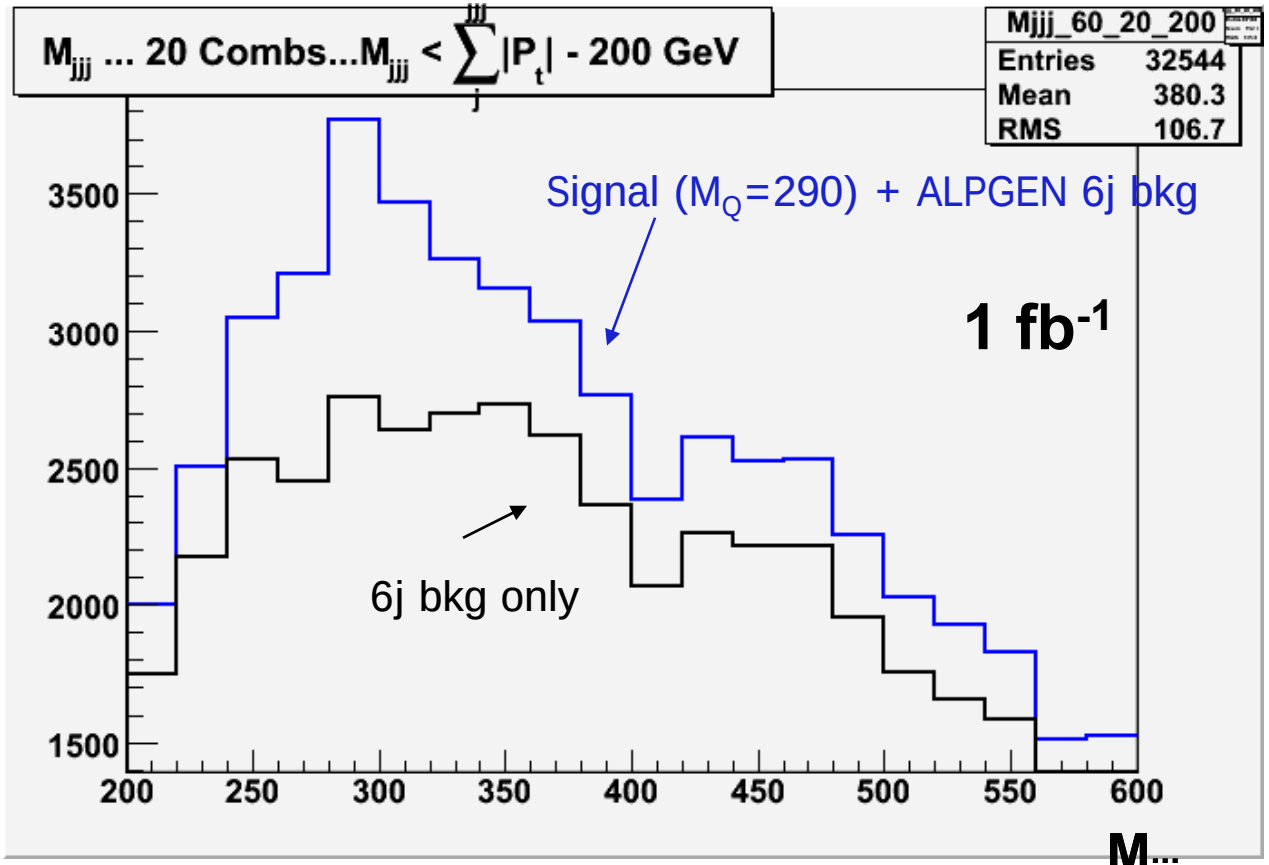


Cuts: Analysis Level

- For ANY triplet of jets from the set of 20 require:
  $M_{jjj} < \sum|p_{T,j}|$ - **OFFSET (USEFUL VARIABLE 3)**
  - M_{jjj} = invariant mass of the 3 jets
  - OFFSET is either
    100 GeV ,200 GeV ,300 GeV or 400 GeV

Isolate horizontal branch with "correct" invariant mass.
Remove QCD and combinatoric background.

Result?



Cuts: **600,** **60,** **200**

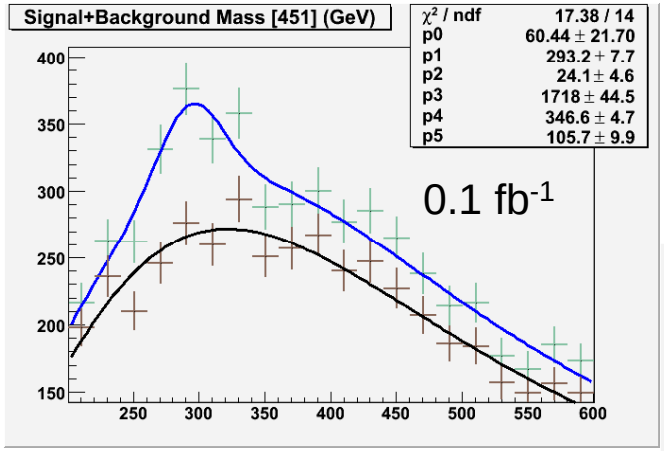
Sum6$|P_T|$, $P_{T,6th\ jet}$**, Diagonal cut offset**

Cuts: 600, 60, 200

Sum6$|P_T|$, $P_{T,6th\ jet}$, Diagonal cut offset

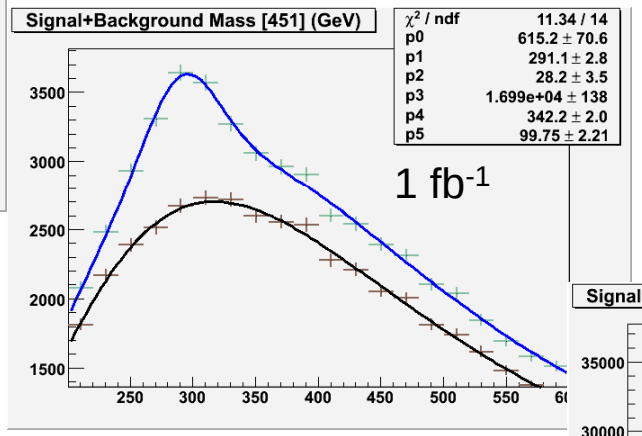
Pseudo-experiments
$0.1fb^{-1}$, $1fb^{-1}$, $10\ fb^{-1}$

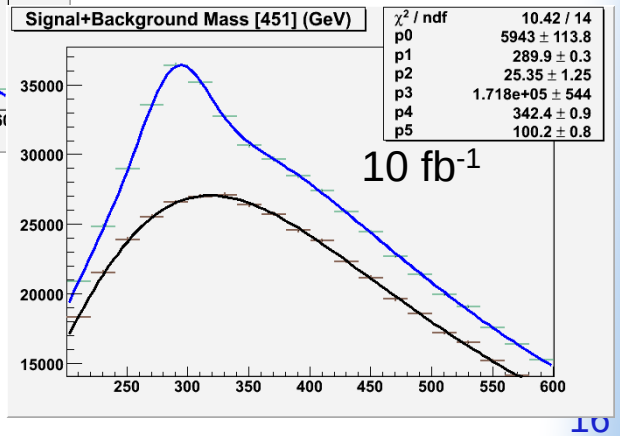
Throw 1000 PSE's for each of these luminosities and a variety of cuts.
Optimize based on S/sqrt(B).



M_Q=290

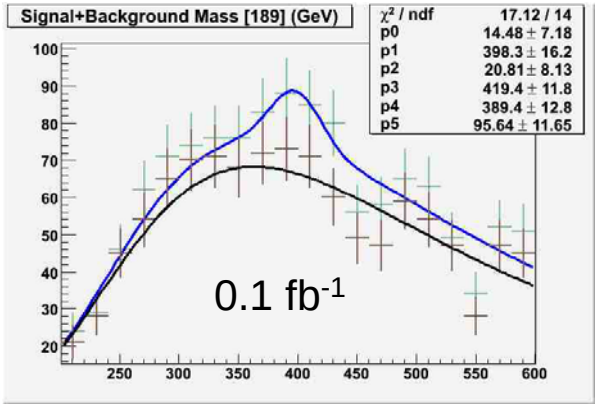
Cuts: 600_60_200

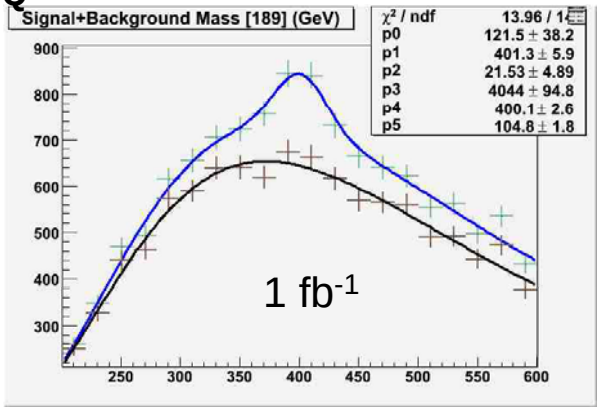


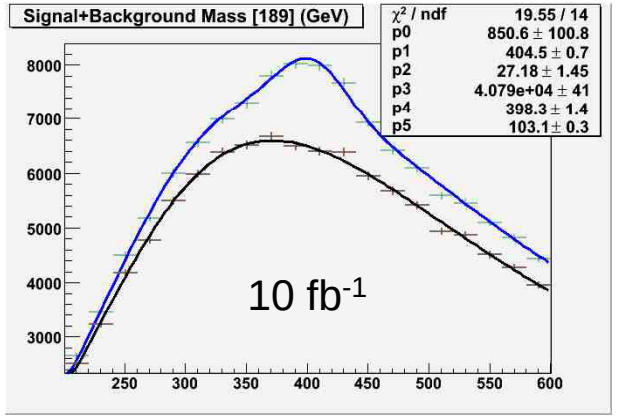


Same but for higher masses

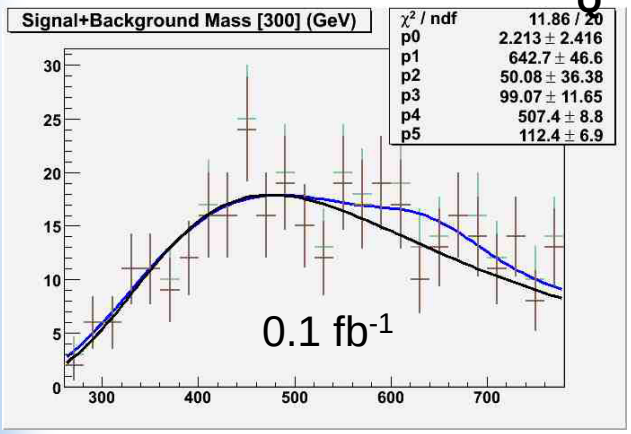
M_Q=420 Cuts: 700_90_200

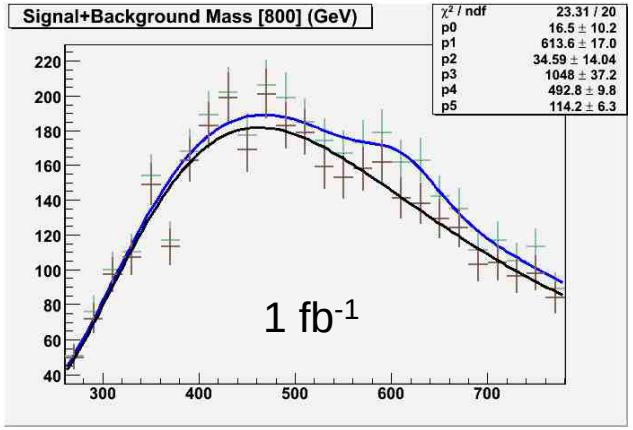


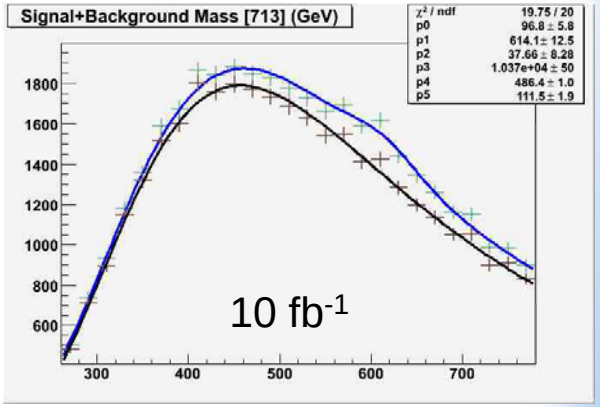




M_Q=660 Cuts: 1100_90_300

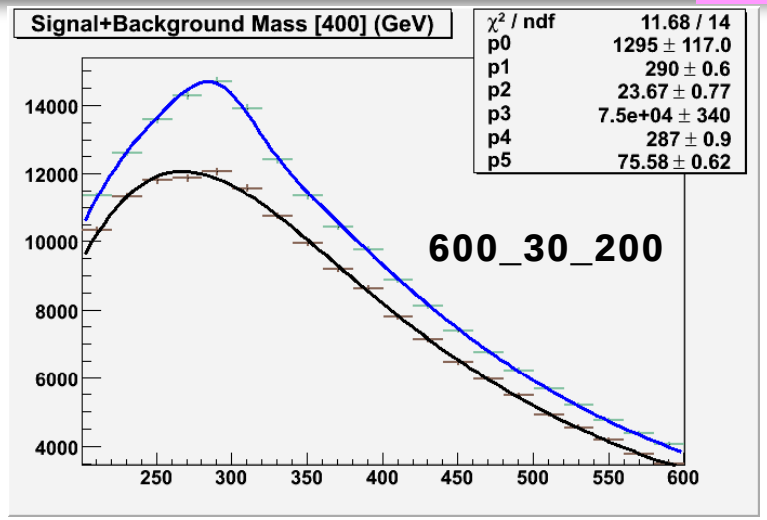


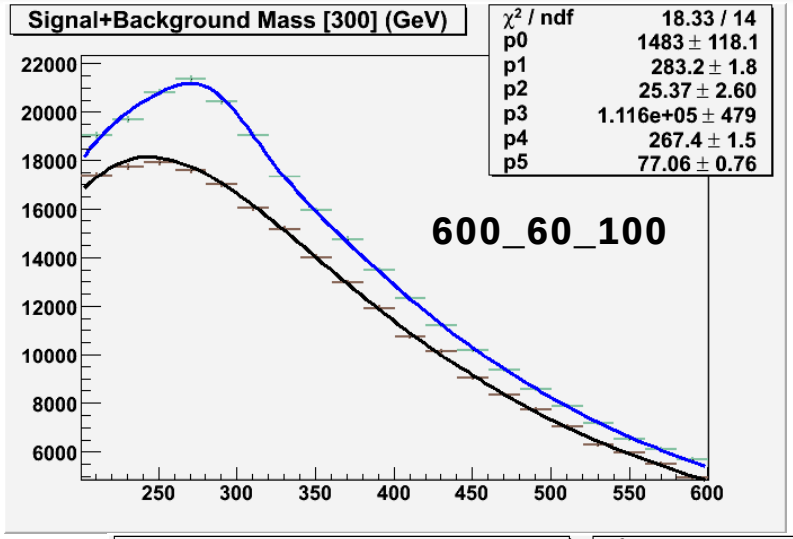


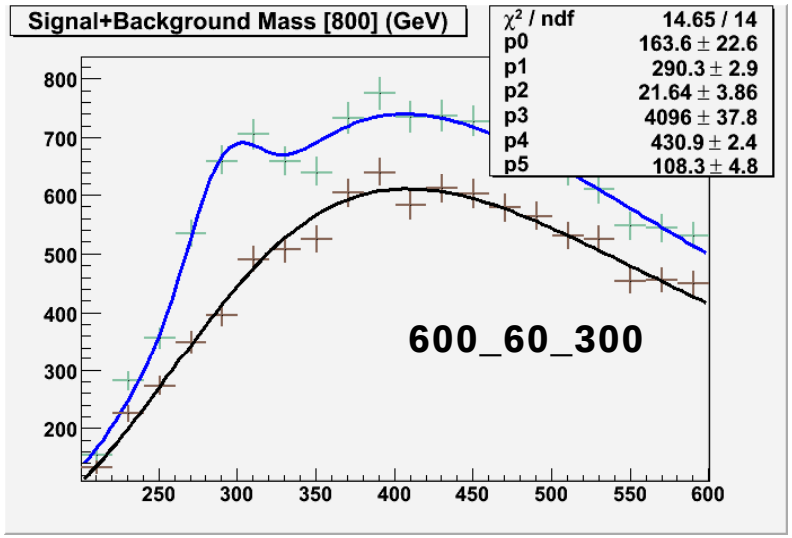


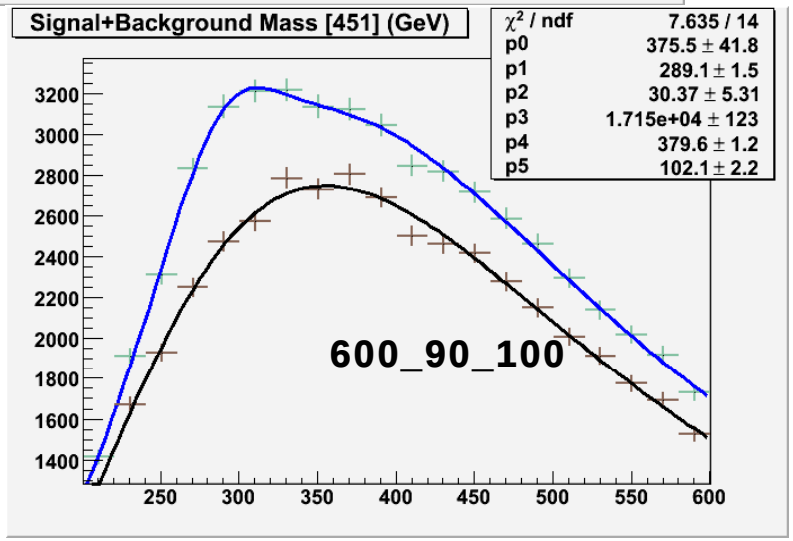
$1fb^{-1}$ pseudo-experiments varying cuts

M_Q=290









PSE Fit Results for 0.1fb^{-1}, 1fb^{-1}, 10 fb^{-1} scenarios

These are avg. values from 1000 PSE

Mass (GeV)	Cuts	S/√B 0.1 fb^{-1}	S/√B 1 fb^{-1}	S/√B 10 fb^{-1}
290	600_30_0_-100	4.3	14	44
290	600_60_0_-100	4.7	15	49
290	600_90_0_-100	3.7	11	34
290	600_30_0_-200	4.3	14	44
290	600_60_0_-200	4.9	15	46
290	600_90_0_-200	3.3	8.6	26
290	600_60_0_-300	3.1	9.4	31
290	600_90_0_-300	3.2	6.8	20

CMSSW studies show that we *can* do this search with ~1fb^{-1} (0.1 fb^{-1} looks hard).
Consistent with our PGS study conclusions.
We could optimize further...

Rouven's thesis

Same but for higher masses

Mass (GeV)	Cuts	S/√B 0.1 fb^{-1}	S/√B 1 fb^{-1}	S/√B 10 fb^{-1}
420	700_30_0_-100	2.9	8.9	28
420	700_60_0_-100	2.3	7.3	22
420	700_90_0_-100	1.6	4.5	14
420	700_30_0_-200	2.1	6.4	19
420	700_60_0_-200	1.9	5.5	17
420	700_90_0_-200	1.8	4.8	15
420	700_60_0_-300	1.4	3.9	12
420	700_90_0_-300	1.9	4.3	14
660	600_30_0_-100	0.6	1.5	4.7
660	600_60_0_-100	0.7	1.6	4.9
660	600_90_0_-100	0.7	1.6	4.9
660	600_30_0_-200	0.5	1.2	3.6
660	600_60_0_-200	0.6	1.4	4.0
660	600_90_0_-200	0.7	1.5	4.3
660	600_60_0_-300	0.7	1.3	3.5
660	600_90_0_-300	0.8	1.3	3.8

More difficult for higher masses but still doable

Systematic Uncertainty: Jet Resolution

Jet resolution.

- Procedure (Ref. CMS Physics TDR):
  - Add an additional smearing to the jet energy which broadens the overall jet resolution by 10%.
  - Done by throwing a Gaussian random number and adding an energy term which is 46% of the jet resolution (to get overall widening of 10%).

- Jet-by-jet, event-by-event smearing:

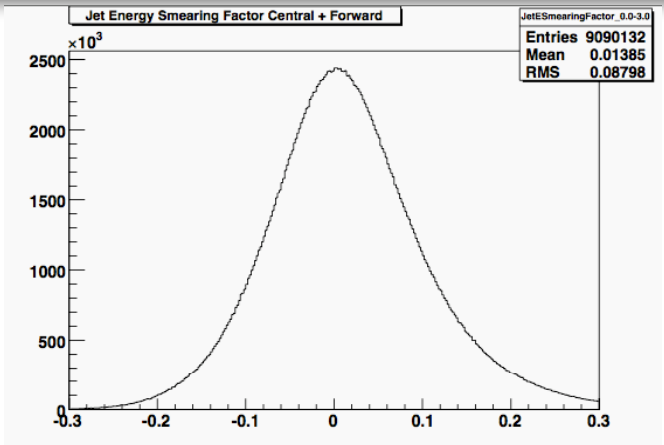
$$E'^{\text{jet}}_{\text{T}} = E^{\text{jet}}_{\text{T}} + \text{Gaus}[0,\ 0.46 * \sigma(E_{\text{T}}, \eta)]$$

$$\sigma(E^{\text{jet}}_{\text{T}}, |\eta| < 1.4) = (5.8\ \text{GeV}) \oplus \left(1.25 * \sqrt{E^{\text{jet}}_{\text{T}}}\right) \oplus 0.033 * E^{\text{jet}}_{\text{T}}$$ Central jets

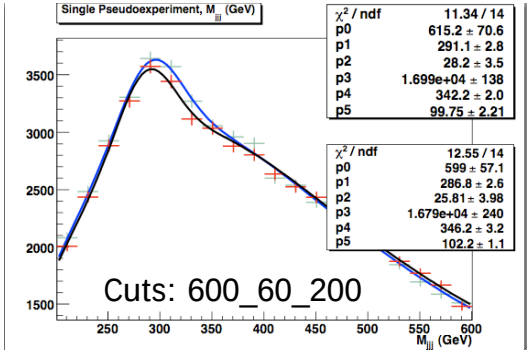
$$\sigma(E^{\text{jet}}_{\text{T}}, 1.4 < |\eta| < 3.0) = (4.8\,\text{GeV}) \oplus (0.89 * \sqrt{E^{\text{jet}}_{\text{T}}}) \oplus 0.043 * E^{\text{jet}}_{\text{T}}$$ Forward jets

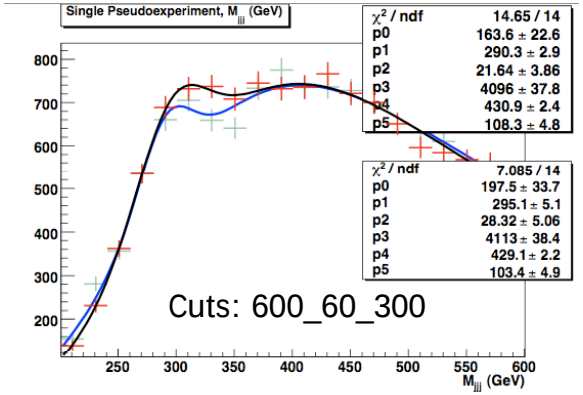
Jet Energy Smearing Systematic

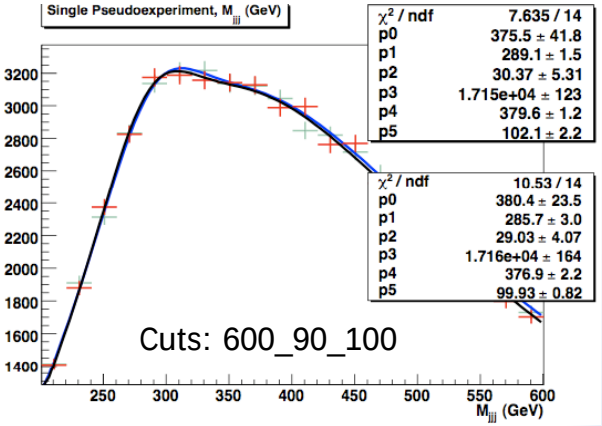
Total smearing factor:



Effect of smearing on M_{jjj} for M_Q=290GeV and a variety of cuts for 1fb^{-1} data:







Effect of Jet smearing

These are avg. values from 1000 PSE for M_Q=290GeV for 1fb^{-1} data

Mass (GeV)	Cuts	S/√B 1 fb^{-1} No smearing	S/√B 1 fb^{-1} With smearing
290	600_30_0_-100	14	12
290	600_60_0_-100	15	14
290	600_90_0_-100	11	11
290	600_30_0_-200	14	14
290	600_60_0_-200	15	14
290	600_90_0_-200	8.6	9.1
290	600_60_0_-300	9.4	10
290	600_90_0_-300	6.8	8.9

Jet resolution is not a big effect

Similar results for other lumi and higher masses (see CMS note)

Background Scale Systematic

- Since the six-jet cross section at 14TeV is not well known, we repeated the analysis but now scaling the QCD background up by 50%
  - Yes, we picked +50% out of a hat.
- How does this affect our significance tables?

Background scale systematic

These are avg. values from 1000 PSE for M_Q=290GeV for 1fb^{-1} data

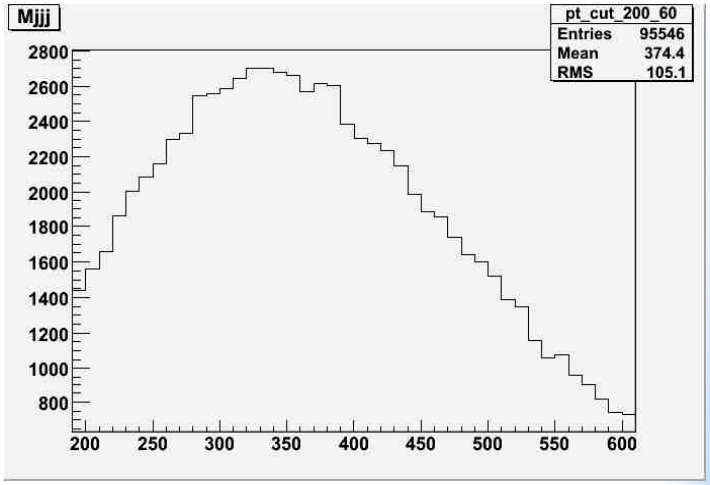
Mass (GeV)	Cuts	S/√B 1 fb^{-1} Default bkg normalization	S/√B 1 fb^{-1} Bkg scaled up by 50%
290	600_30_0_-100	14	11
290	600_60_0_-100	15	13
290	600_90_0_-100	11	9
290	600_30_0_-200	14	12
290	600_60_0_-200	15	12
290	600_90_0_-200	8.6	7.4
290	600_60_0_-300	9.4	8.7
290	600_90_0_-300	6.8	5.8

Increasing the bkg by 50% has an effect on the significance - obviously

We're all looking forward to ditching ALPGEN and getting at data...

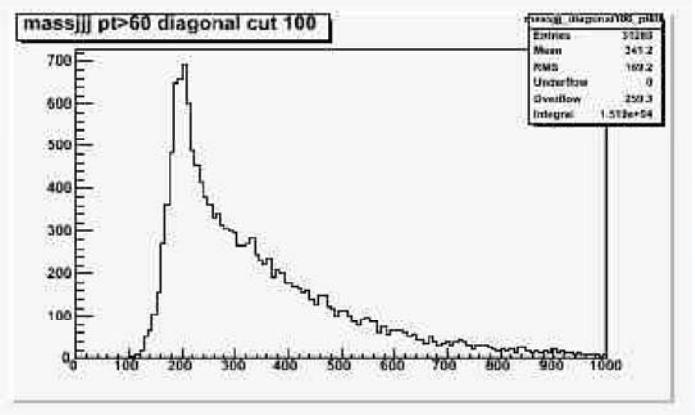
Jet Scrambling

- Can we get QCD background *shape* from DATA?
- Hypothesis: QCD jets are uncorrelated
- To understand the shape, construct 6-jet events by selecting 6 jets from **different events**
  - i.e. **scramble** the jets
- Plot shows Madgraph QCD.
- Being studied…



A few words on applying technique to top all hadronic

- We are beginning a parallel analysis to used this technique for finding the top quark in the all hadronic channel.
- Plot shows a similar event selection applied to the chowder sample
  - No QCD yet



- We are also doing this analysis with CDF data. (VEP group). Looks REALLY promising.

(CDF people: I've got cool plots to show you in my notebook !)

Summary

- Looked for difficult (but doable) new physics signature.
- PGS/CMSSW studies look promising.
  - We're calling it the "ensemble" method.
  - Of course, we have a twiki!
    https://twiki.cern.ch/twiki/bin/view/CMS/ExoticaSixJets
- Testing method with all-hadronic t-tbar
  (at CMS and CDF)
- To do:
  - Finish up systematic uncertainties
  - Try to turn results into a "reach" plot?
  - Update CMS note.

How well do we fit for the signal+bkg vs. bkg only?

Diagonal cut offset

100 200 300 400

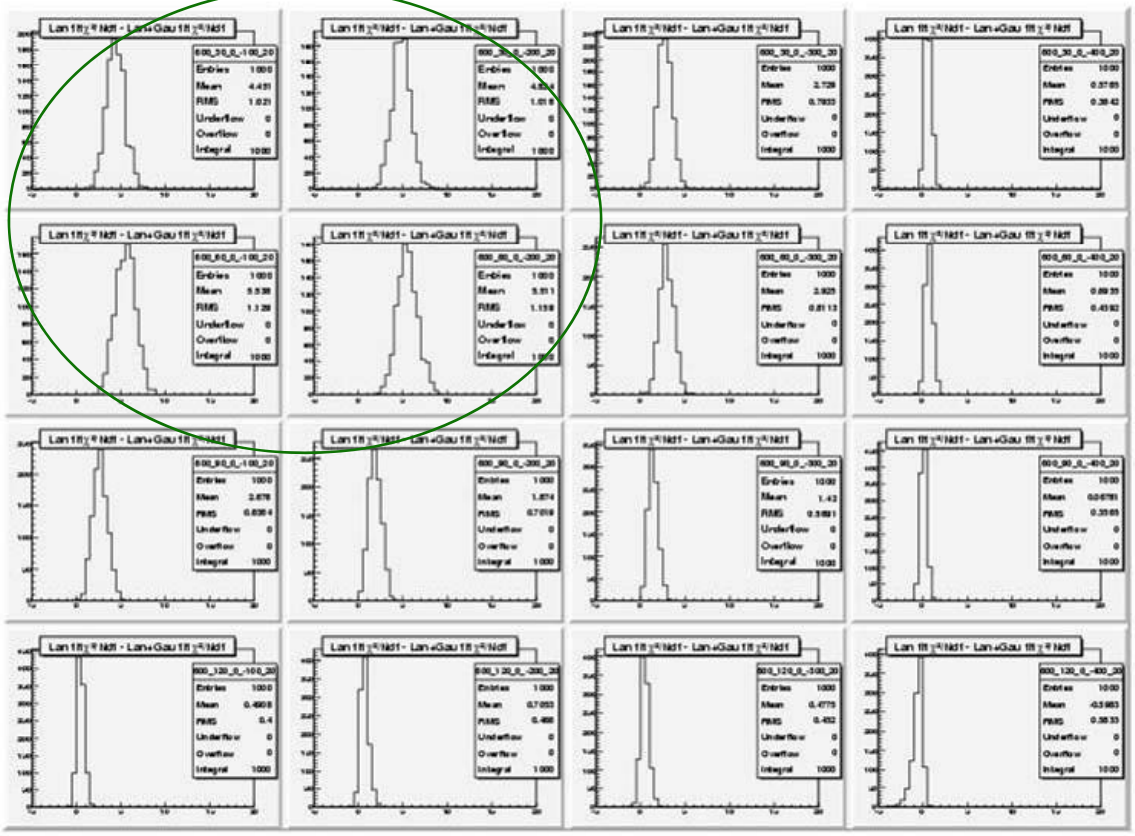
1 fb^{-1}

$P_{T,6th\ jet}$ 30GeV

$P_{T,6th\ jet}$ 60GeV

$P_{T,6th\ jet}$ 90GeV

$P_{T,6th\ jet}$ 120GeV



Plots of $\Delta\chi^2$ of fitting for:

Sig+bkg= Gaussian+Landau

and

Bkg only= Landau

Best fits for signal for $P_{T,6th\ jet}$ 30, 60GeV and diag cut 100, 200

How well do we fit for the Gaussian peak?

1 fb^{-1}

Diagonal cut offset

100 200 300 400

$P_{T,6th\ jet}$ 30GeV

$P_{T,6th\ jet}$ 60GeV

$P_{T,6th\ jet}$ 90GeV

$P_{T,6th\ jet}$ 120GeV

Look at ratio of Gaussian fit amplitude/error

Best fits for signal peak for $P_{T,6th\ jet}$ 30, 60GeV and diag cut 100, 200