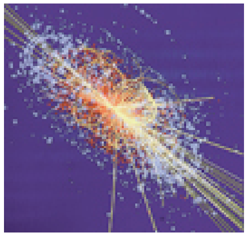

Extracting Hadronic Resonances using Jet Ensembles

LHC New Physics Signatures Workshop

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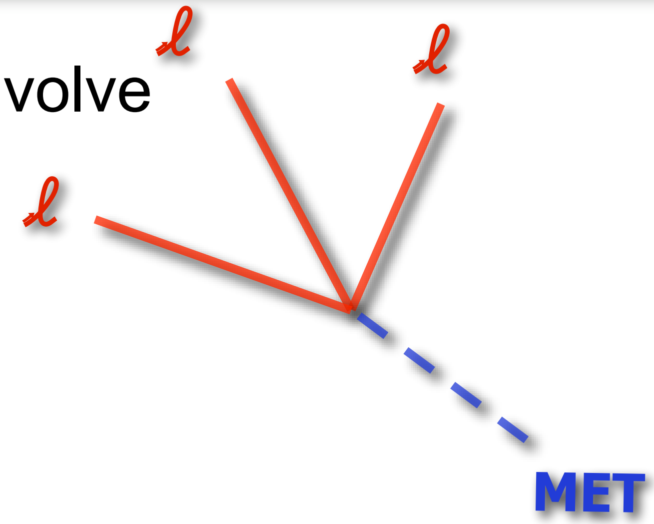
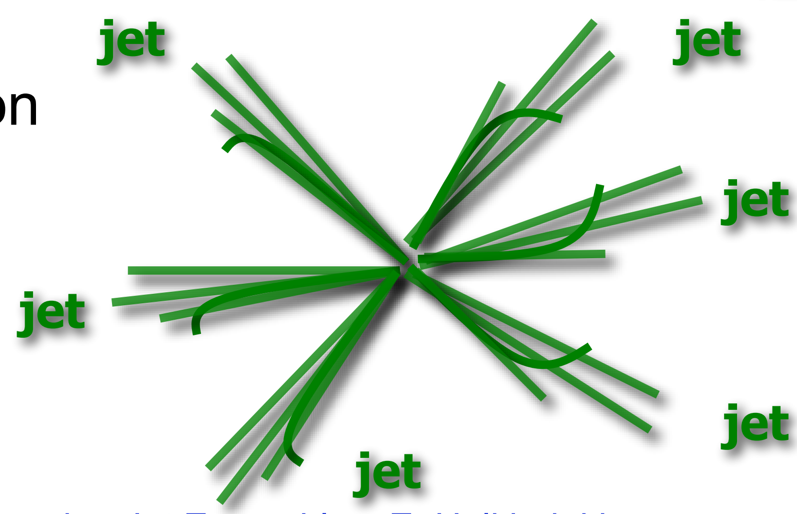
Motivation

- *Exotic* searches at colliders always involve MET or leptons/photons.
  - Strong production
  - ElectroWeak decays
  - Backgrounds suppressed

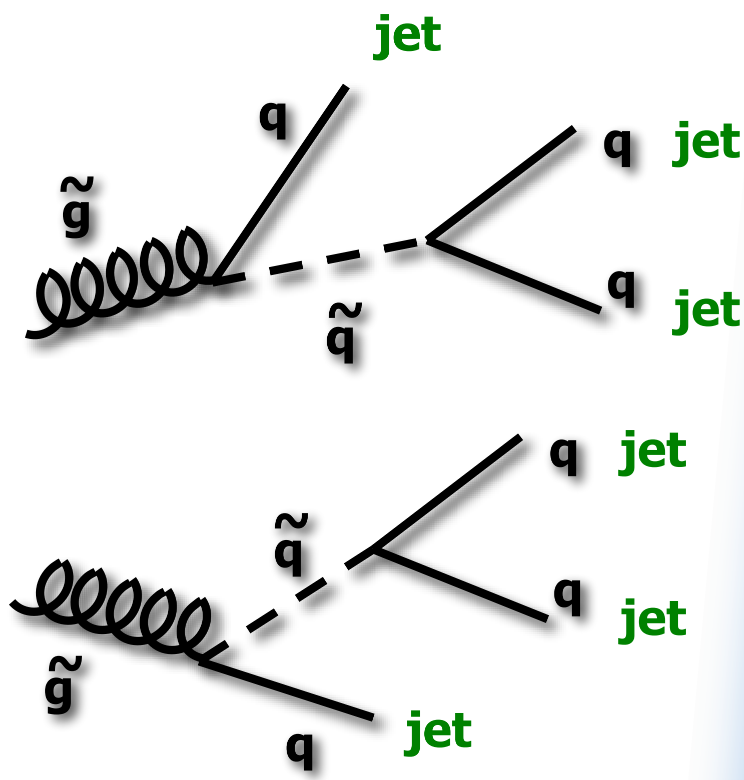


- New physics → Jets?
  - Strong production cross-section
  - Strong decays (multi-jet)
  - Backgrounds severe



New Physics in Multi-Jets

- Look for new physics in multi-jets
- Studying pp → QQ → 3j+3j = 6j
  - **Q= $\tilde{g}$** = SU(3)$_C$ Adjoint Majorana Fermion
- Challenging
  - Large backgrounds!
  - Magnitude of multi-jet backgrounds from higher order processes difficult to calculate a priori (α_s^n).
  - But possible new physics may be hidden in jets!
- Get guidance from all-hadronic top studies
- *Make use of kinematic features and correlations*
- *Use an ensemble of jet combinations*
- Techniques may also be useful for jets produced with leptons, MET, photons and we can study this later



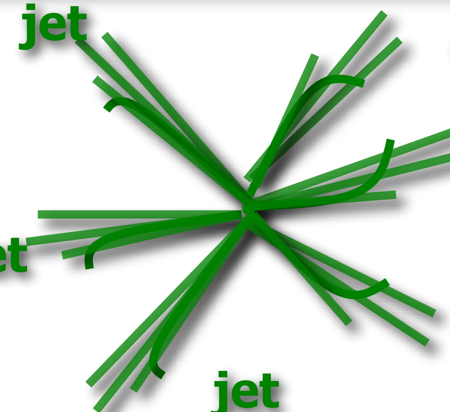
Signal & Background

pp → QQ

→ j j j

→ j j j

$Q = \tilde{g}$



Signal:	Pythia Model it as RPV (uud Yukawa) gluino MSbar masses 200 GeV (real mass 290 GeV) and up
6 Jet Background:	ALPGEN → Pythia
Hadronic Top Background:	Pythia
Detector Simulator:	PGS (fast simulation) Studies with full simulation CMSSW ongoing
Analysis:	(Ch)Root "Bump hunt"

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

Cuts: Trigger Level

- $|\eta| < 3$ of the first 6 jets
  (PGS requires a "jet" to have at least 5 GeV of p_T)

- (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.
  Adding the rest adds only a few percent.

Cuts: Analysis Level

- Cut on sum p_T of the 1st 6 jets:

  $\sum_{i=1}^{6} p_{T,i} >$
  - gluino200 600 GeV
  - gluino300 700 GeV
  - gluino500 1100 GeV
  - gluino700 1500 GeV

- Cut on the 6th jet p_T >
  - 30 GeV, 60 GeV, 90 GeV, 120 GeV

We are trying different cuts to optimize signal vs. background

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

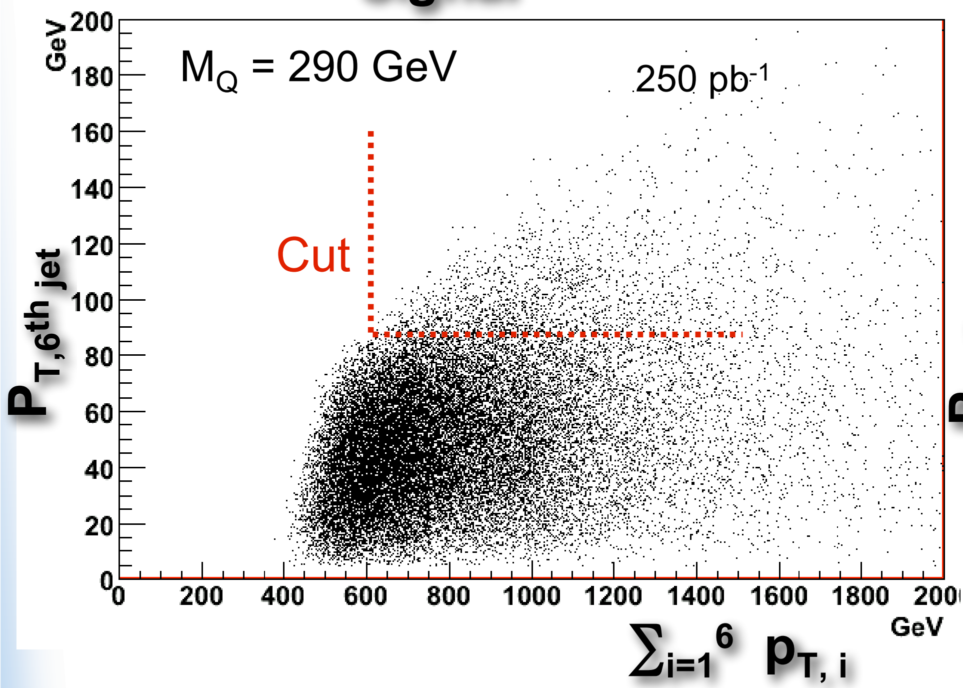
pp → QQ → j j j j j j

$N_{jet} \geq 6$

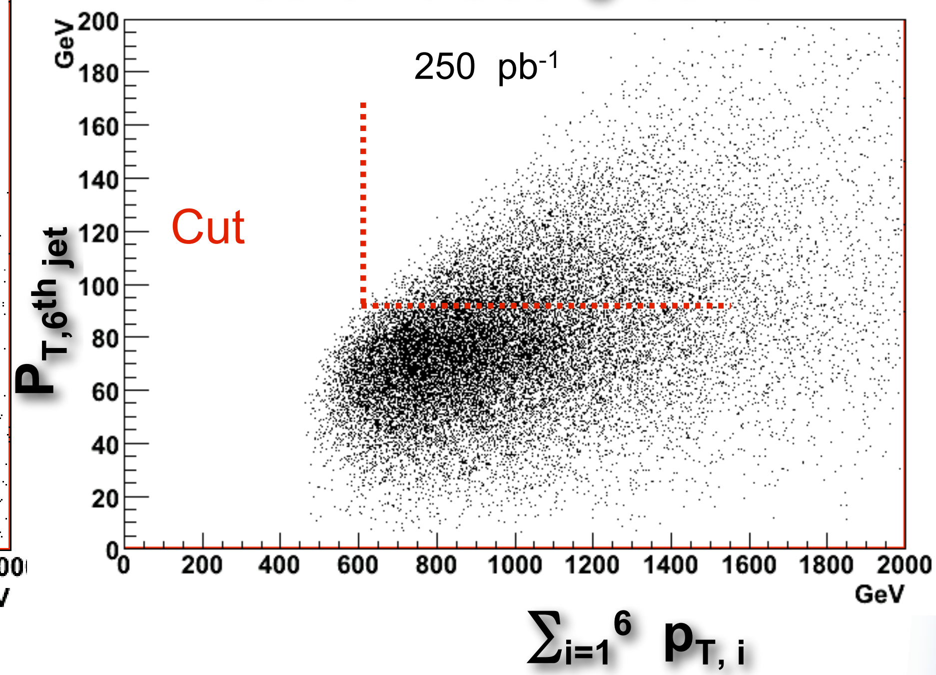
Example

Cuts: $\sum_{i=1}^{6} p_{T,i}$ > 600 GeV, $p_{T,\ 6th\ jet}$ > 90 GeV

Signal



Hadronic Background



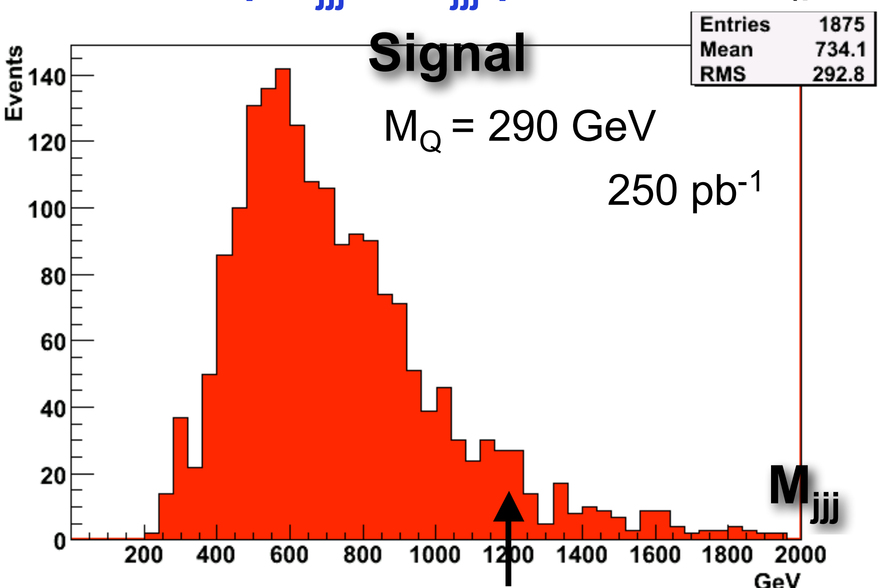
Signal Efficiency ~ 0.02

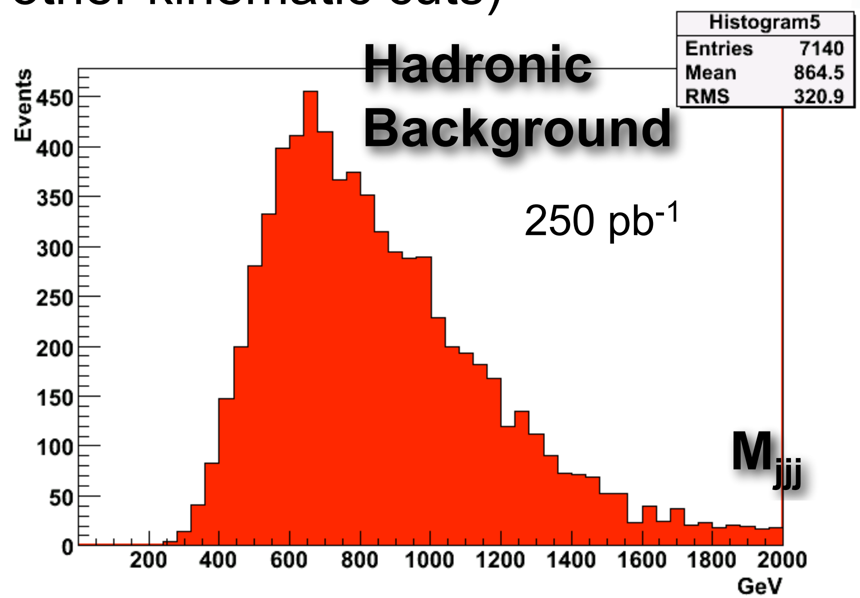
How To Select Jet Triplets?

pp → QQ → j j j j j j Assume six hardest jets come from QQ decay

Two Three-Body Resonances $M_{jjj} = M_{jjj}$

Choose Pair of <u>Jet triplets</u> (from 10 possibilities) with smallest **$| M_{jjj} - M_{jjj} | < 60$ GeV** (plus other kinematic cuts)





- Tail much larger than jet resolution
- Mismatching of jet triplets
- Combinatoric background within signal

Selecting Jet Triplets:
Ensemble of Jet Combinations

Which Combination?

There are 20 possible triplets among 6 jets.

Use MC matching info to find which triplets are correct most often:

Combo	%correct	Combo	%correct
235	5.3	246	3.0
234	4.7	135	2.9
236	4.3	345	2.6
245	4.3	256	2.0
145	4.2	134	2.0
146	4.0	126	1.7
156	3.4	346	1.6
136	3.2	125	1.4

Jets ordered in p_T
(e.g. 123 are three highest p_T jets)

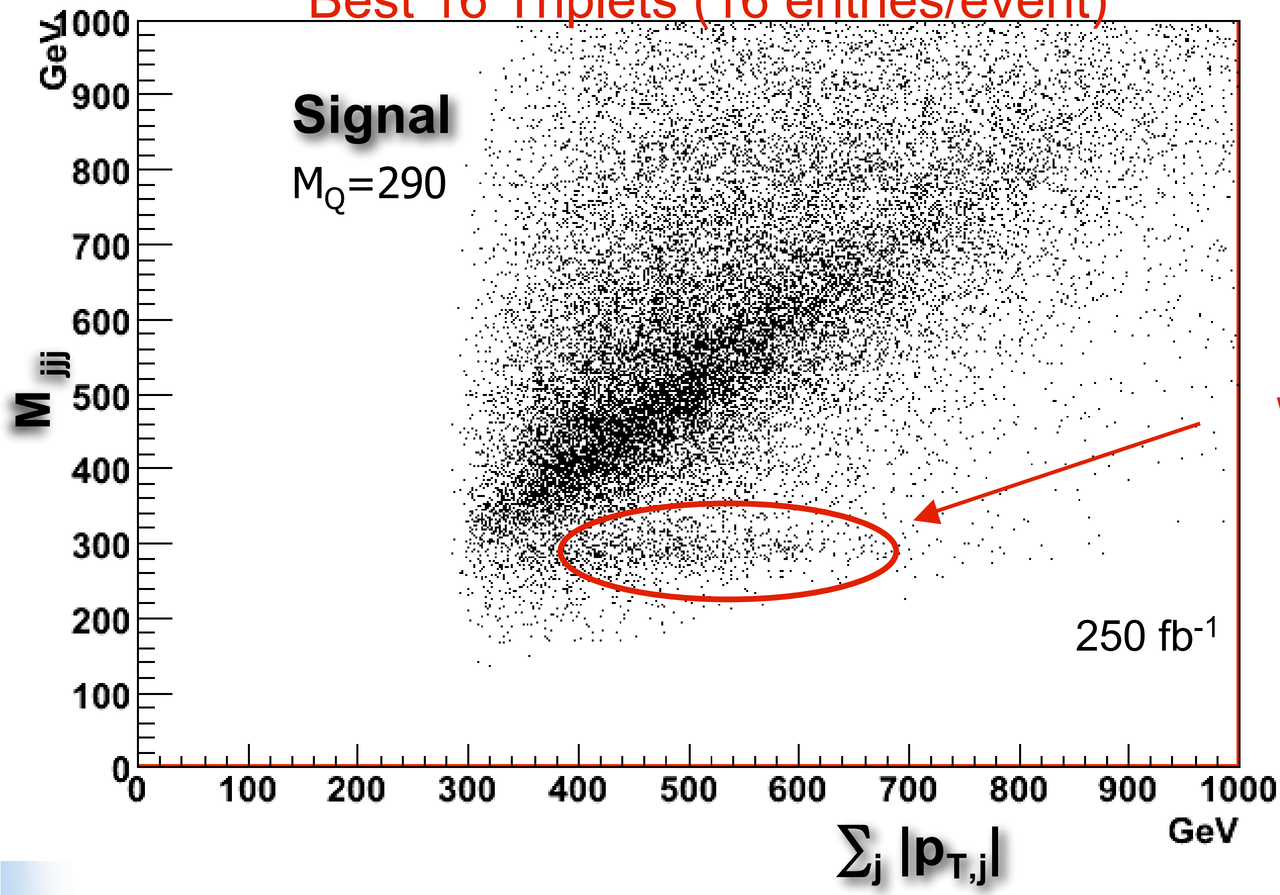
Combo 235 is correct
5.3% of the time.

Combo 123 is not among
the top 16 combinations.

Using Kinematic Correlations: Mass vs. Sum P_T

Extract Kinematic Features from Combinatoric Confusion

Best 16 Triplets (16 entries/event)

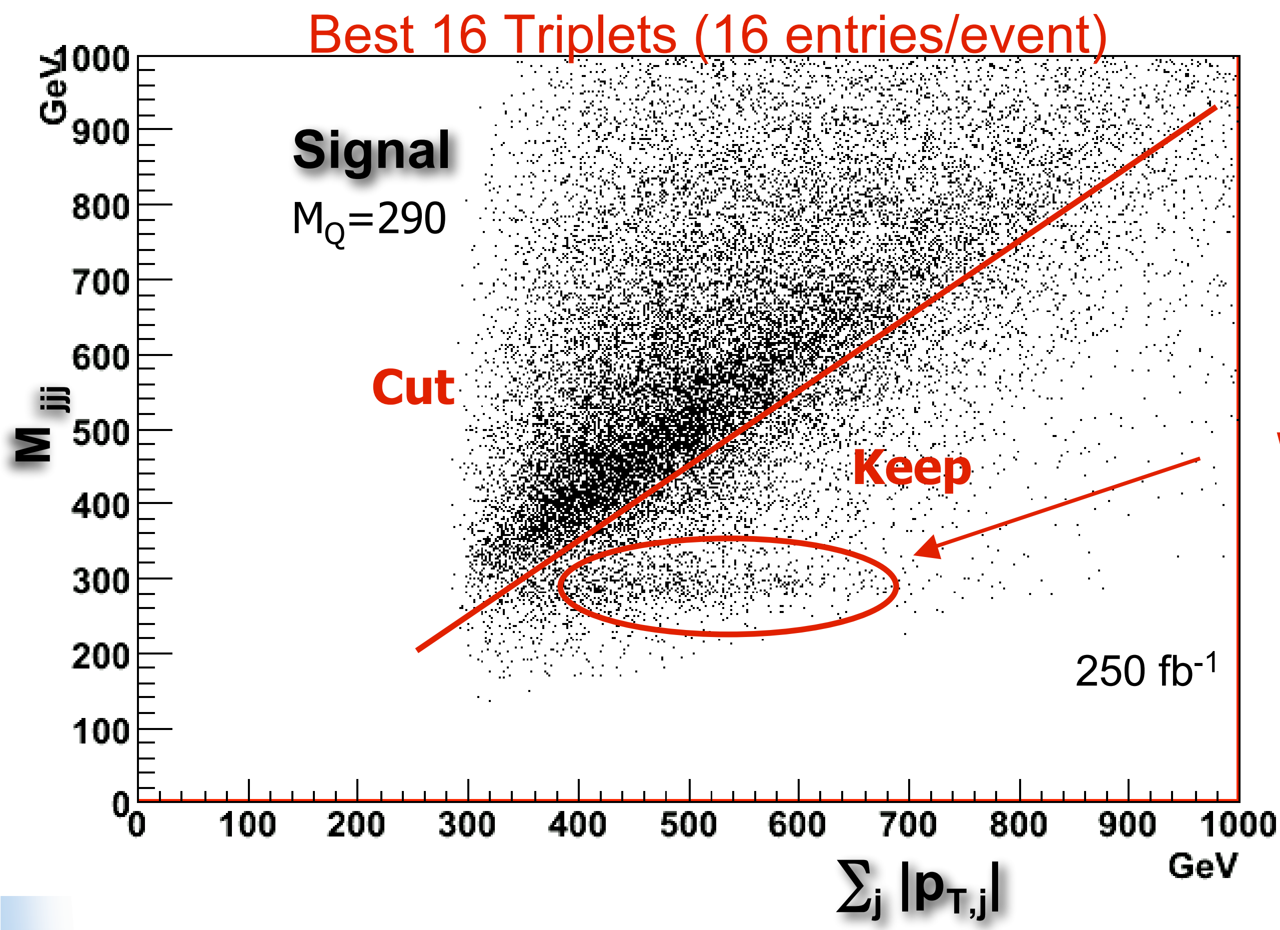


Want to isolate good triplets

Horizontal Branch: Region of high signal to combinatoric background contrast

Using Kinematic Correlations: Mass vs. Sum P_T

Extract Kinematic Features from Combinatoric Confusion



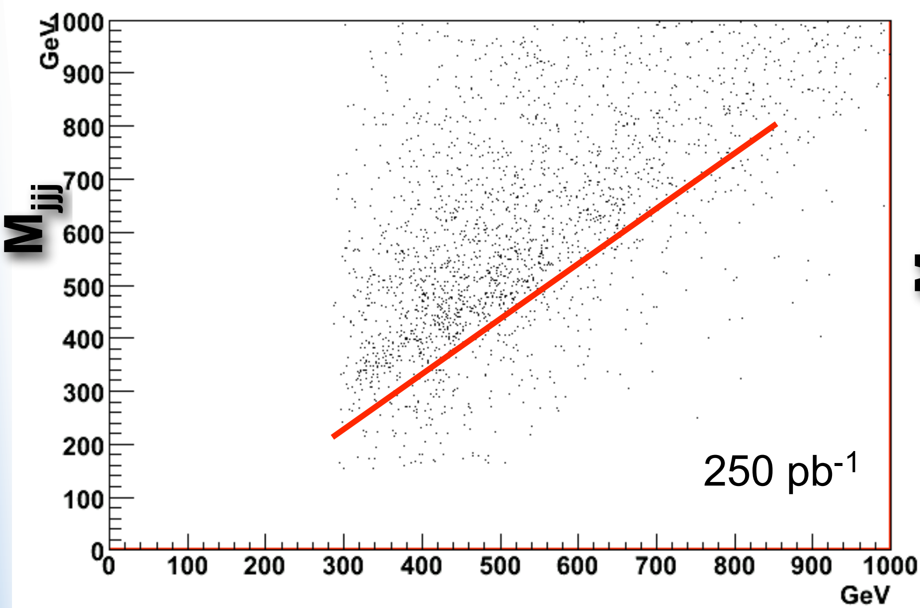
Cut: $M_{jjj} < \sum|p_{T,j}|$ - offset

Want to isolate good triplets

Horizontal Branch: Region of high signal to combinatoric background contrast

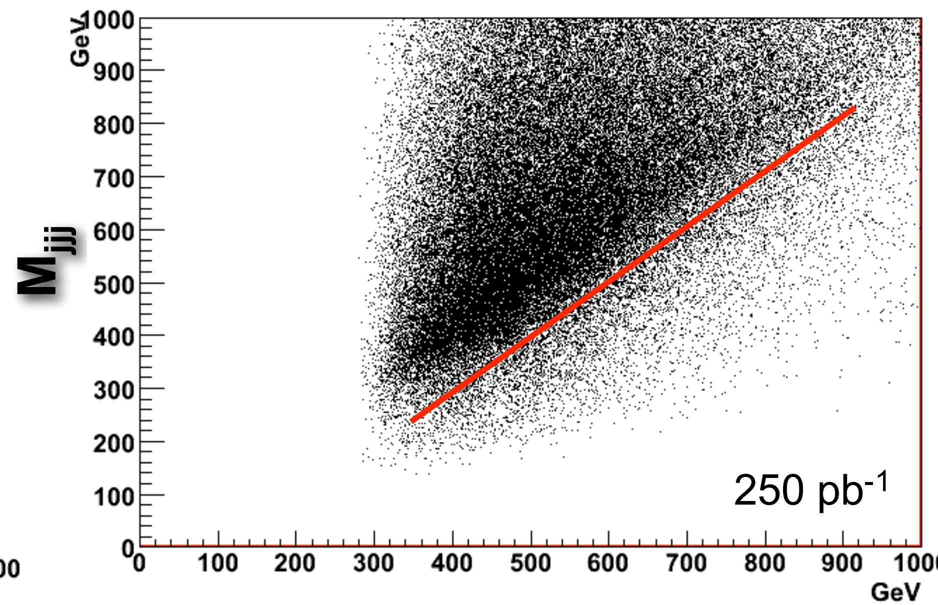
Mass vs. Sum P_T for Backgrounds

Hadronic Top Background



$\sum_j |p_{T,j}|$

Hadronic Background



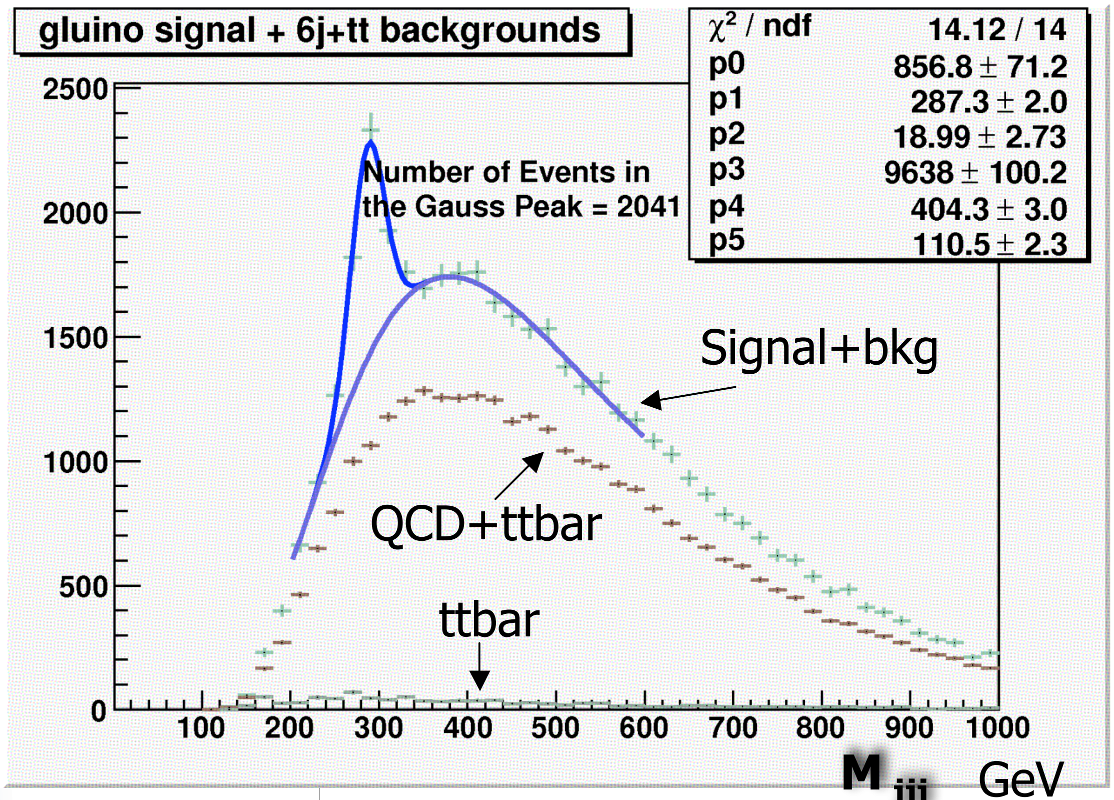
$\sum_j |p_{T,j}|$

Cuts: Analysis Level

- For ANY triplet of jets from the set of the “best” 16 require: $M_{jjj} < \sum|p_{T,j}|$ - offset
  - where M_{jjj} is the invariant mass of the 3 jets
  - $\sum|p_{T,j}|$ is the scalar sum $|p_T|$ of the 3 jets
  - offset is either infinity (i.e. no cut) or 0 GeV,100 GeV ,200 GeV ,or 300 GeV

This cut isolates the "horizontal branch” with the "correct" invariant mass, and removes a lot of background and combinatoric background within the signal.

Now Fit and Optimize Cuts



Signal: m=200 (m_Q=290)
+Alpgen 6j background
+ttbar background

Fit: Gaussian+Landau

Luminosity: $1fb^{-1}$

Note: Number of entries per event is between 0 and 16.
- Avg. for signal: 0.6 entries/event
- Avg. for bkg: 0.3 entries/event

Cuts: 600, 90, 0, 100
Sum6|P_T|, $P_{T,6th\ jet}$, SumVectorP_T, Diagonal cut offset

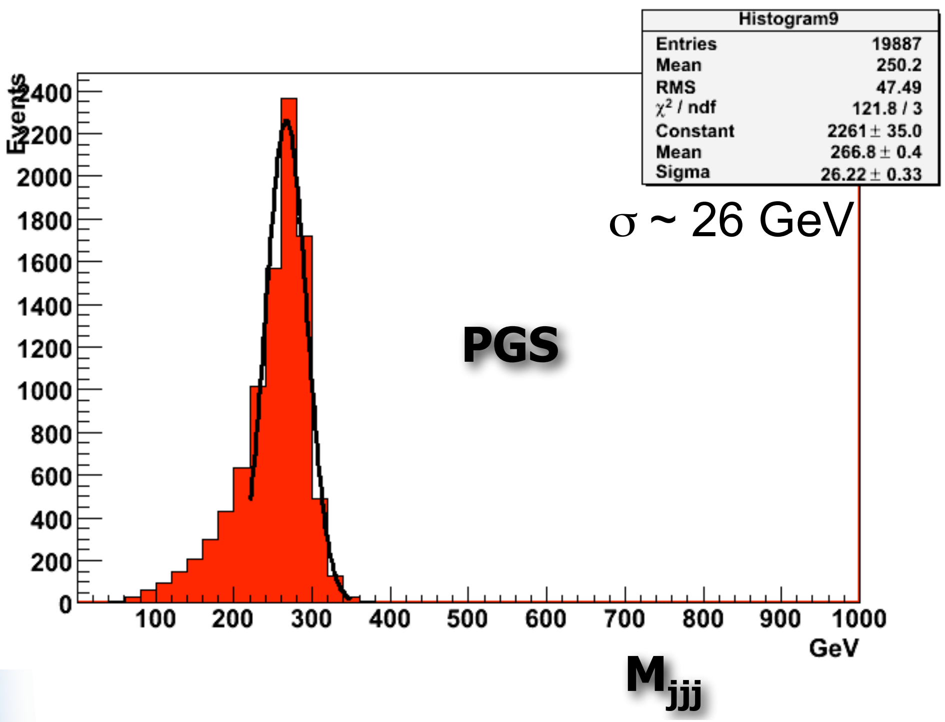
Fit Results

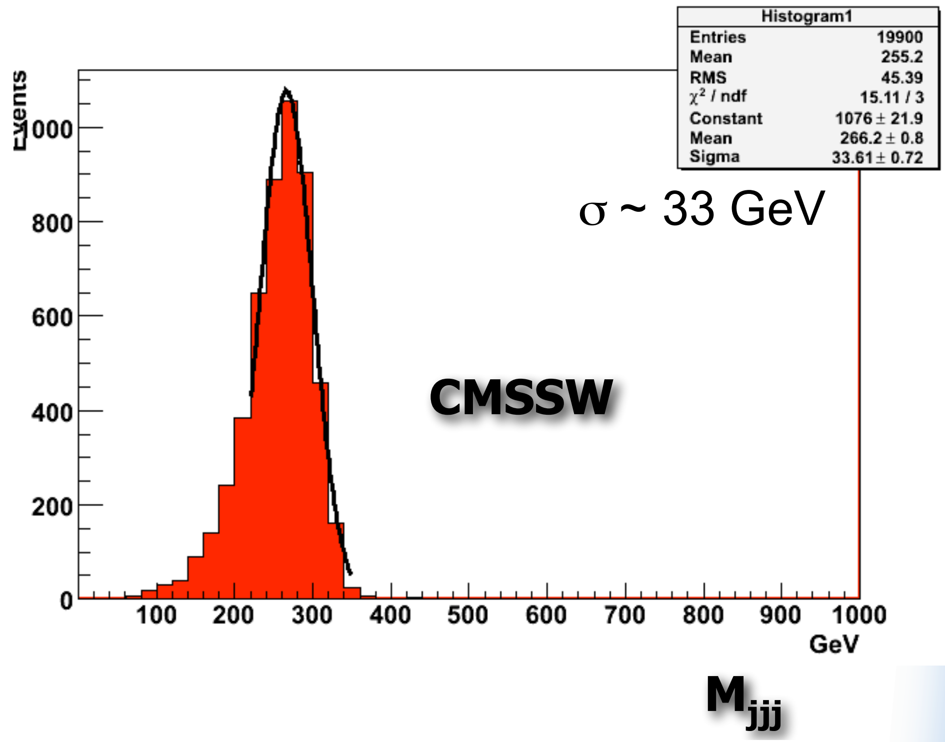
MSbar mass	cut set	eff_SG	eff_BG	peak mass (2σ)	nSG	nBG	S/B	S/Sqrt(B)
200	600__30_0_100	0.0960	0.0465	284.8	11514	1097865	0.01	10.99
200	600__60_0_100	0.0874	0.0477	285.3	4568	56161	0.08	19.27
200	600__90_0_100	0.1037	0.0642	285.2	2070	5558	0.37	27.77
200	600__30_0_200	0.0266	0.0095	286.0	3433	199651	0.02	7.68
200	600__60_0_200	0.0261	0.0121	286.6	1821	12848	0.14	16.07
200	600__90_0_200	0.0391	0.0224	288.2	1017	1917	0.53	23.23
200	600__60_0_300	0.0088	0.0033	287.8	891	3592	0.25	14.87
200	600__90_0_300	0.0145	0.0076	289.1	429	574	0.75	17.92
500	1100__60_0_200	0.0585	0.0378	638.5	185	10305	0.02	1.82
500	1100__90_0_200	0.0547	0.0341	643.0	110	1646	0.07	2.72
500	1100_120_0_200	0.0558	0.0374	646.0	52	344	0.15	2.78
500	1100__60_0_300	0.0212	0.0126	643.9	83	3019	0.03	1.52
500	1100__90_0_300	0.0208	0.0126	646.5	50	581	0.09	2.06
500	1100_120_0_300	0.0233	0.0158	650.2	26	125	0.20	2.28
500	1100__60_0_400	0.0081	0.0042	646.8	37	1018	0.04	1.17
500	1100__90_0_400	0.0084	0.0045	648.6	23	209	0.11	1.60
500	1100_120_0_400	0.0101	0.0064	652.2	13	46	0.29	1.95

S/sqrt(B) Looks good, Can be optimized Further.

Not so rosy for higher masses…

PGS vs. CMSSW





For MSbar mass 200 GeV.
Invariant mass of correct triplet (MC matched).

CMSSW is broader than PGS, but not too bad, can pull it out of background.

Systematic Uncertainty: Jet Resolution

- A good understanding of jets is important in this analysis.
- There are uncertainties in the 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:

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

Reference jet resolution the central jets:

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

Reference jet resolution the forward jets:

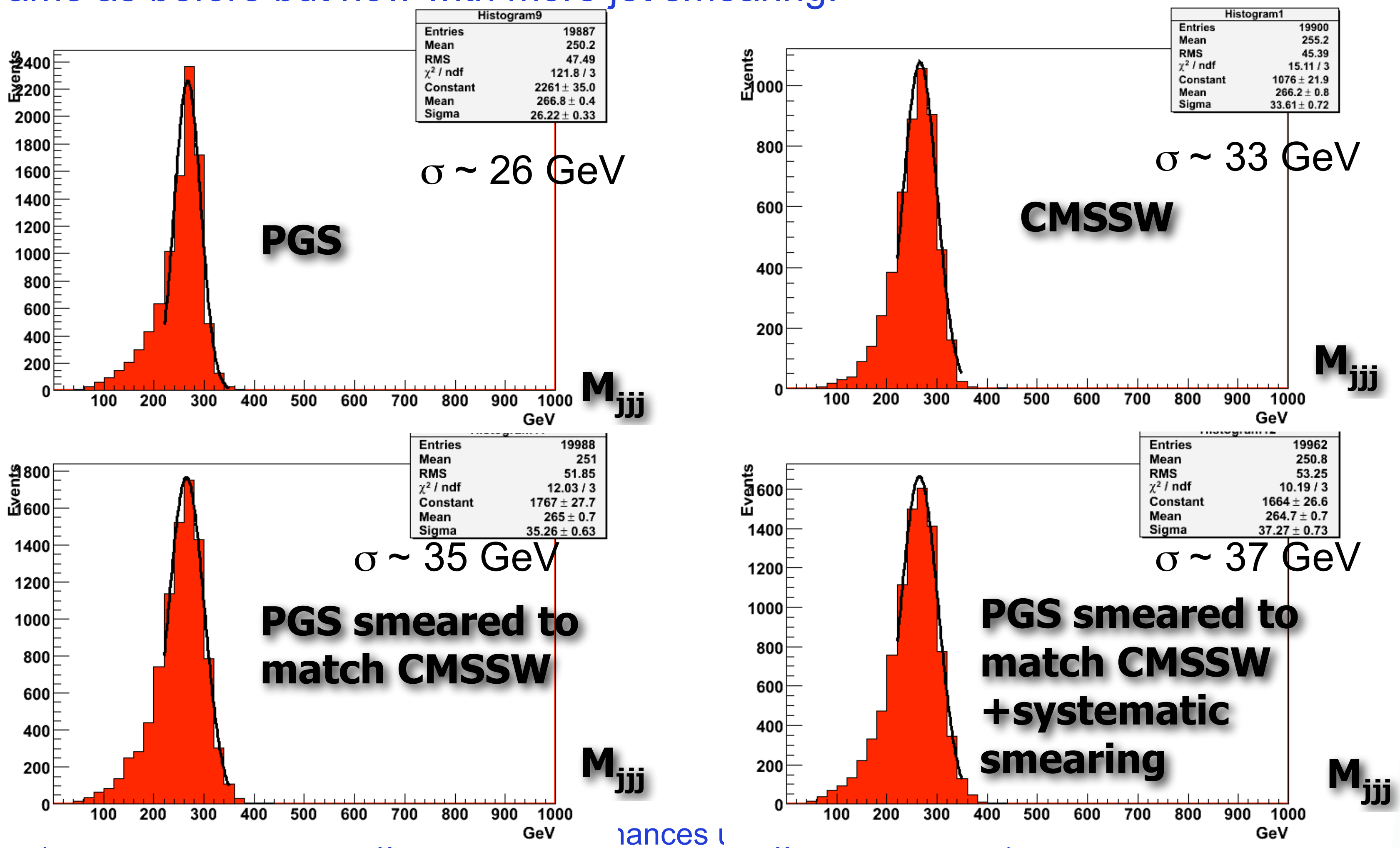
$$\sigma(E^{\mathrm{jet}}_{\mathrm{T}}, 1.4 < |\eta| < 3.0) = (4.8\,\mathrm{GeV}) \oplus (0.89 * \sqrt{E^{\mathrm{jet}}_{\mathrm{T}}}) \oplus 0.043 * E^{\mathrm{jet}}_{\mathrm{T}}$$

In CMS MC Simulation

In PGS: $\sigma(E_T^{jet}) \propto 0.8\sqrt{E_T^{jet}}$ (for HCAL)

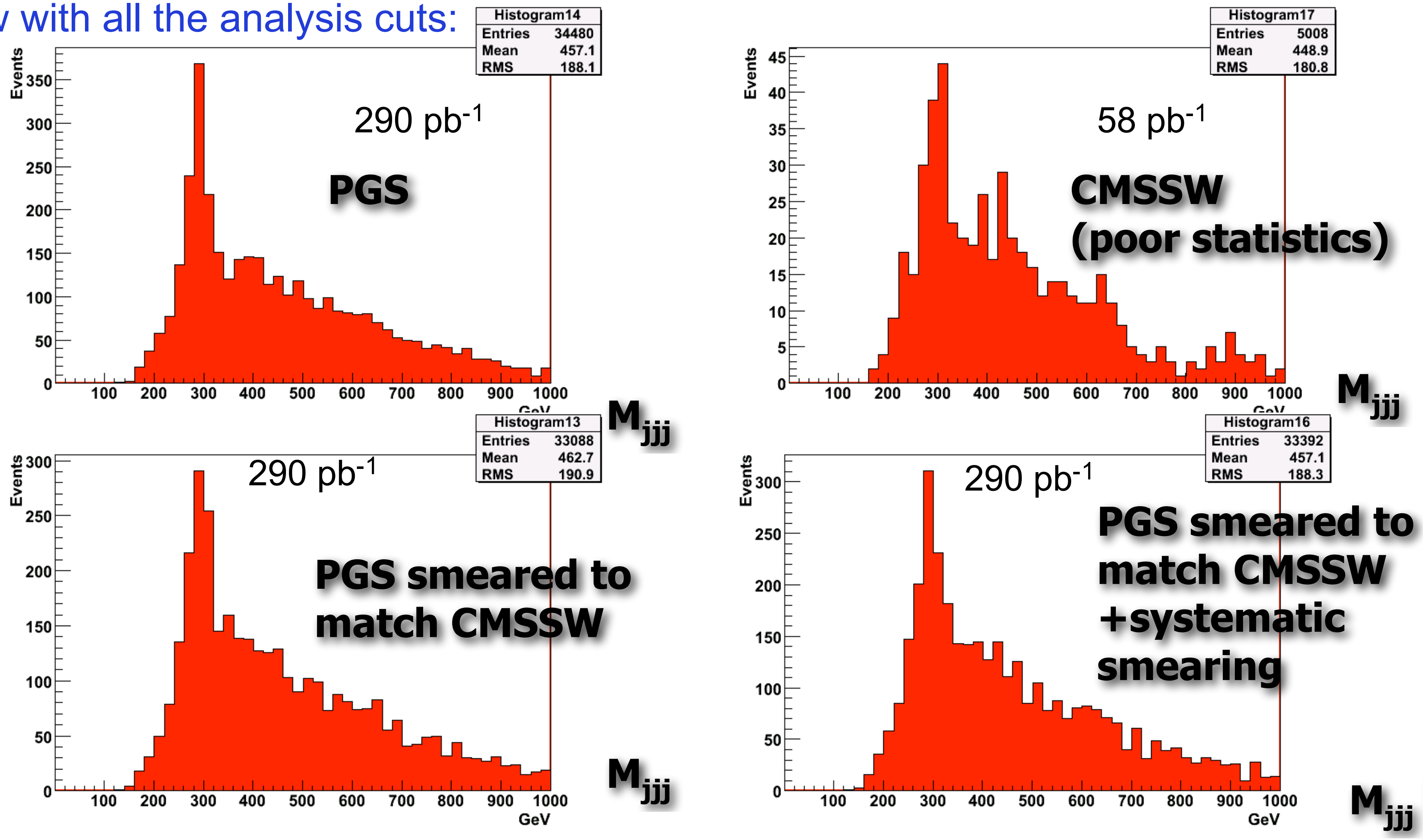
Jet Smearing

Same as before but now with more jet smearing:



Jet Smearing With Cuts

Now with all the analysis cuts:

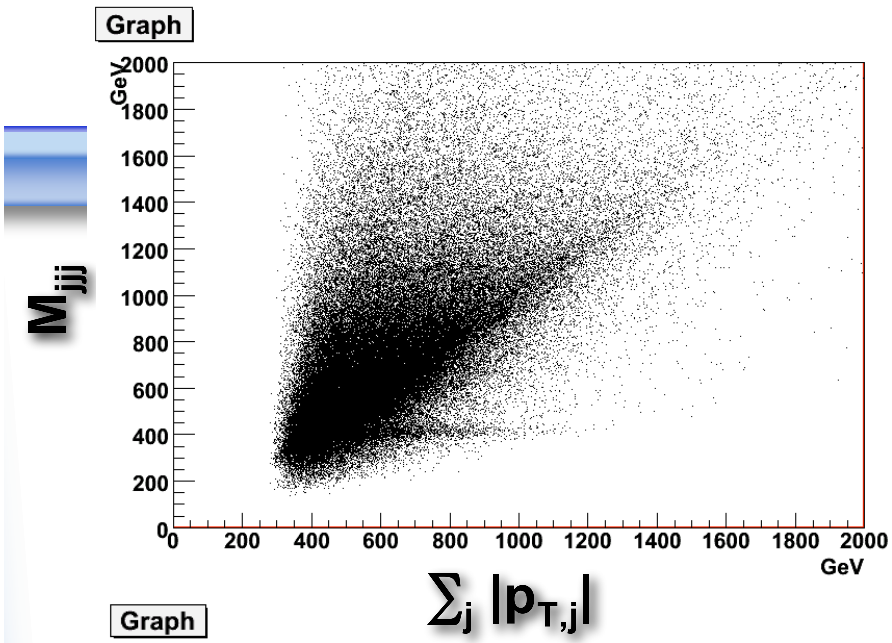


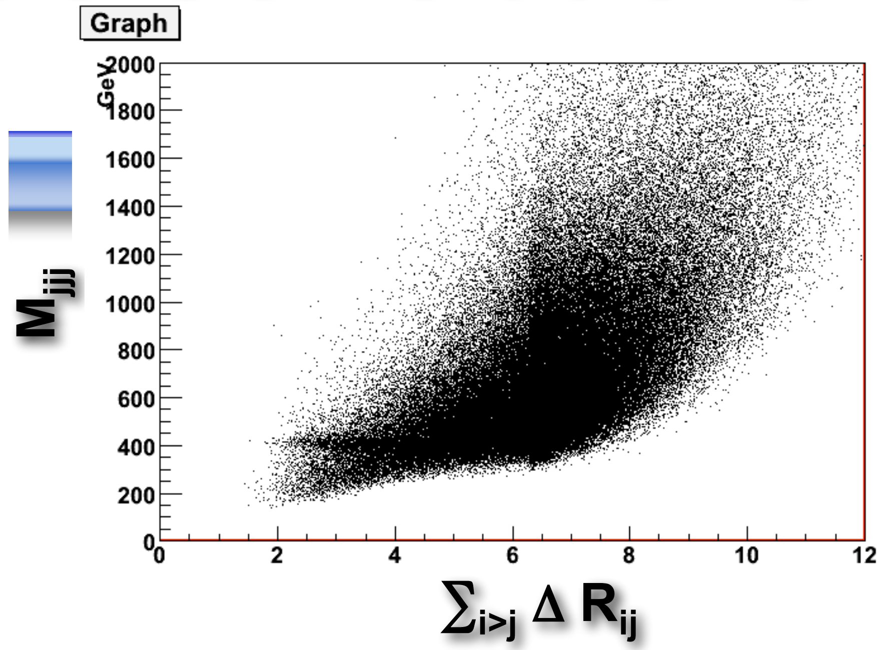
Summary

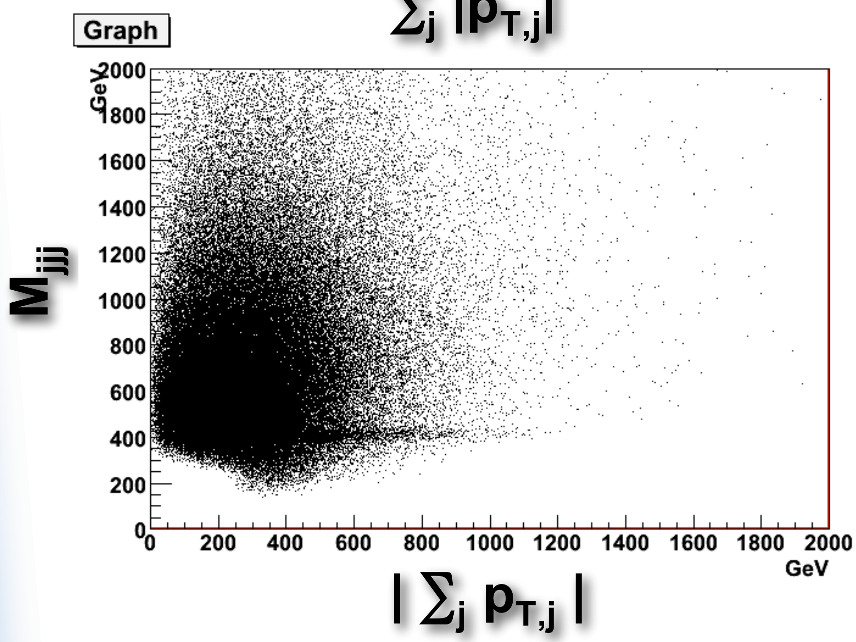
- We *can* do searches with jets
- Full CMSSW studies underway, encouraging
  - Responsible for large ALPGEN n-jet samples within CMS
  - Generating home-brewed CMSSW signal samples
  - Beginning studies on systematic uncertainties
- Ensemble techniques useful for other analyses as well
- Working closely with theorists can pay off handsomely!

Backup

More Kinematic Correlations







Note “Correct” Triplets – Horizontal Branch

Background is Very Similar to Combinatoric Confusion

Note Shaping from Cuts