Boosted RPV Gluinos

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arXiv: 1208.????

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PRELIMINARY!! **PRELIMINARY!!**

SUSY is hiding!

- Limits on the production of strongly coupled particles + MET already pushed beyond TeV.
- If supersymmetry is realized in nature, then it is not the 'vanilla' scenario envisioned before the LHC.
- How could SUSY be hiding?
  - It could be hidden in SM measurements, e.g. charginos in WW.
  - Stealth SUSY, Compressed/Squeezed SUSY, ... (reduce MET)
  - ...

  $\rightarrow$ **RPV!!** Generically no MET signature, possibly no interesting leptonic final state either.

$\rightarrow$ **This is preliminary work in progress!!** $\leftarrow$

RPV Gluinos

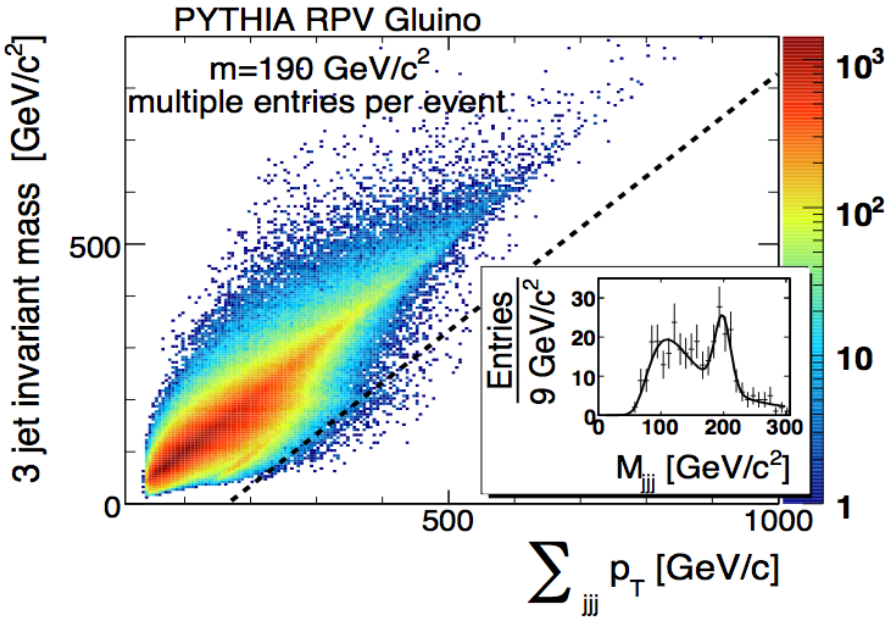
- Gluinos have large pair-production cross section.
- In normal SUSY, phenomenology depends on identity of LSP. Now it also depends on which of the many allowed RPV couplings is realized.
- We assume gluino LSP with B-violating decay: $\tilde{g} \to qqq$.
- Furthermore, let's be pessimistic and assume qqq = all light quarks. (Could also include b or t, under investigation.[1])

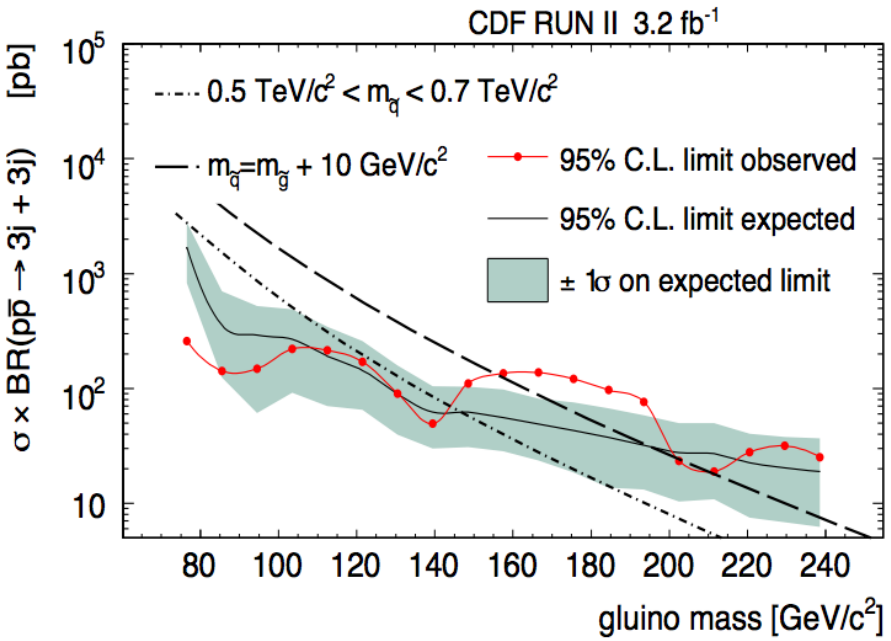
$\Rightarrow$ **$gg \to 6j$: Extremely challenging signature: combinatorics, QCD background, no leptons or MET.**

[1] For a recent example of RPV stop searches, see Brust, Katz, Sundrum 1206.2353

Tevatron search for RPV gluinos

- 3.2/fb $\sqrt{s} = 1.96\,\mathrm{TeV}$ search: arxiv:1105.2815
- Search for 6 cone(0.4) jets from low-mass RPV gluino pairs.
- Main background is QCD multi-jet. Reduce QCD and combinatorics background with diagonal $p_{Tjjj} - M_{jjj}$ cut:

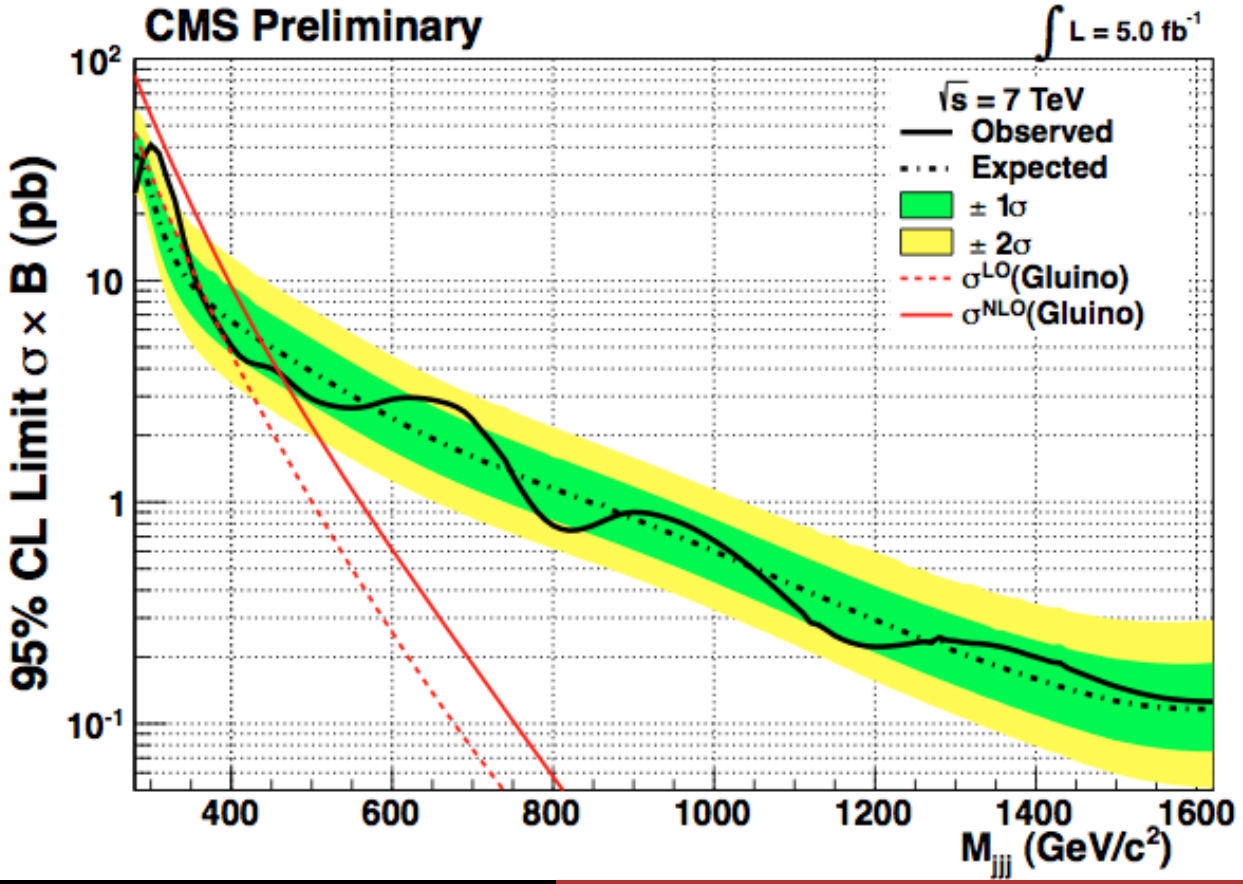




- **Exclude** $m_{\tilde{g}} \lesssim 160\,\mathrm{GeV}$**.**

CMS Search for RPV gluinos

- arXiv:1107.3084 (36/pb), which has been updated with 2011 5/fb data.
- Similar method to Tevatron search, now looking for 6 anti-$k_T(0.5)$ jets. Excludes $m_{\tilde{g}} \in 200 - 460\,\mathrm{GeV}$:



Can we do better?

- S/B is small for performed searches.
- Not clear how these previously used methods scale to higher gluino masses with lower σ...do we understand the QCD background sufficiently? Would like complementary search strategy!
- Raklev, Salam Wacker showed in 2010 that the Tevatron might have excluded gluinos up to $m_{\tilde{g}} \sim 250\,\mathrm{GeV}$ using simple substructure methods.
- **Let's see what we could do at the LHC today by looking for boosted RPV gluinos!**

Substructure Strategy

- Two interesting regimes that are not yet excluded: gluino near the top mass and heavy gluinos > 450 GeV.
  - Top-mass gluinos would be interesting to look for, seems possible with aggressive top-veto and over-tuned b-tagger.
    $\Rightarrow$ Under Investigation!
    Trigger might leave no choice but to look for boosted signal!

  $\rightarrow$ Examine heavy gluino case!

- Boosted fractions are small, backgrounds are huge (many nb from QCD multi-jet), will need extremely powerful background discrimination.

- Use N-subjettiness[2]: Probes substructure in many different ways.

$$\tau_N = \frac{1}{d_0} \sum_k p_{Tk} min_A \{\Delta R^{\beta}_{A,k}\}$$

[2]Thaler, van Tilburg 1011.2268

Signal and Background

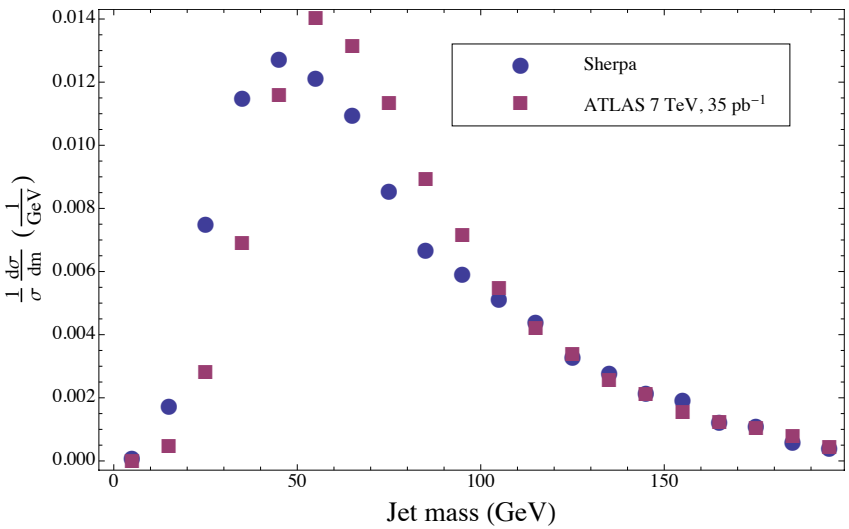
- Consider LHC8 with 20/fb
- Look for boosted $\tilde{g} \to qqq$ by looking for very hard ($p_T > 450$+ GeV) 3-pronged anti-$k_T(1.5)$ fat jets.
  - For 600/800 GeV gluinos, $\sigma_{\tilde{g}\tilde{g}} \approx$ 1pb / 100 fb.
  - Boosted fraction with decay products in fat jet $\sim$ %
    $\to$ looking for $\sim 10 - 200$ boosted gluino events.
- Backgrounds:
  - QCD multi-jets. Requiring two $p_T > 450\,\mathrm{GeV}$ fat jets still gives a few *nb* $\to \sim 8 \times 10^6$ events
  - Hadronic $t\bar{t}$ can also generate two 3-pronged fat jets: $\sim$ pb.
  - Other backgrounds *much* smaller, not considered at this stage.

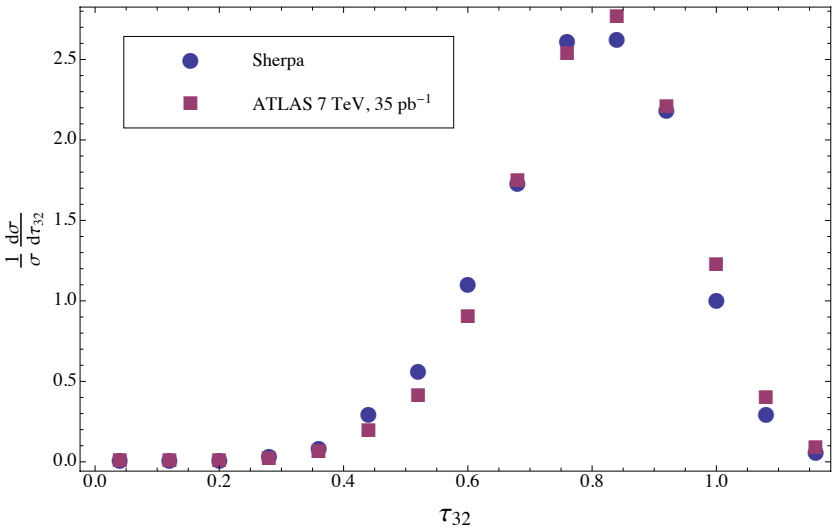
Monte Carlo Event Generation

- Use `Pythia` 6.4 to generate signal (hard process, showering, hadronization): gluino pair production with off-shell heavy intermediate squarks, decay to qqq.
  - $\rightarrow$ should handle hadronization & decay of $\tilde{g}$ correctly.
  - $\rightarrow$ Important for color connections.
- Use `Sherpa` 1.4 to generate fully matched LO background samples
  - QCD: $2j + (4j)$, hadronic $t\bar{t} + (2j)$
  - We care about extreme corners of phase space: use weighted generation that overproduces such events.
  - Generator-level cut: two parton-level fat-jets with $p_T > 400\,\mathrm{GeV}$.
- Rescale background cross section using experimental measurements.

Verification of Background Samples

- ATLAS performed comparisons of substructure observables in data vs various MC generators: 1203.4606.
- Our Sherpa samples matched the shape data well:



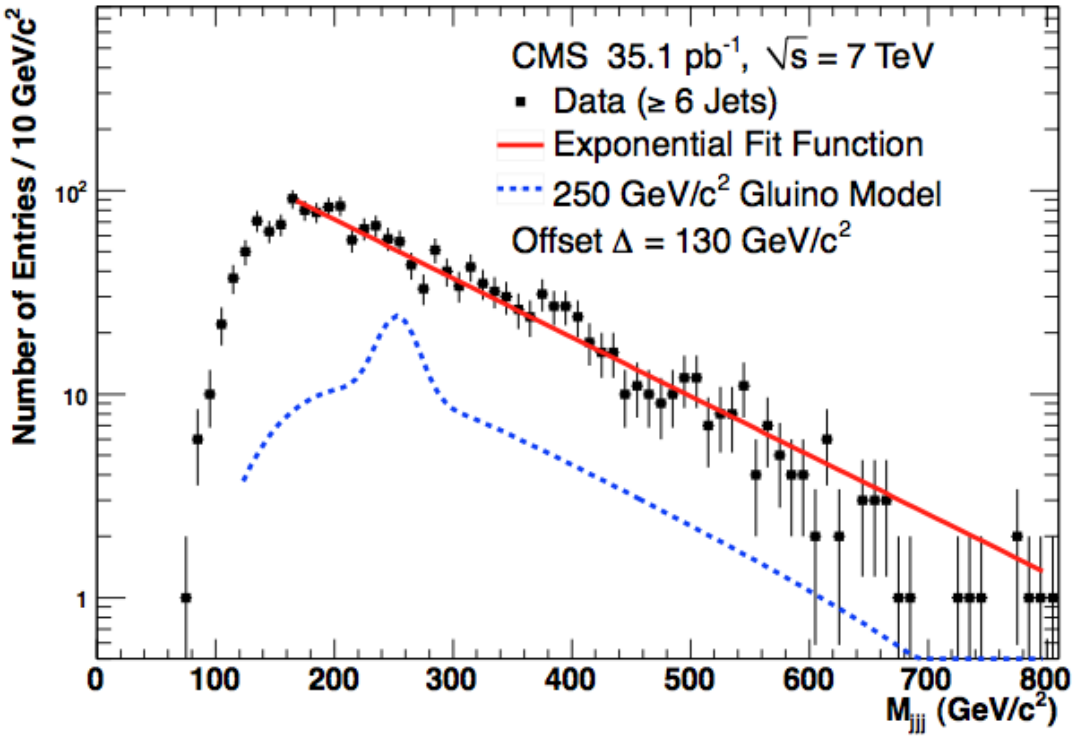


- Obtain 'K-factor' from data: Scale our sample up by a factor of 2.

  → Constant renormalization of shape suggests this is OK for our multijet sample.

Verification of Background Samples

- Orthogonal check with different sample: Reproduce BG + signal predictions from CMS 36/pb search:



- Also works well (shape + normalization after *K*-factor correction).

Analysis Framework

- Analyze events in `FastJet 3.0.2` & `Mathematica` based codes.
- Rudimentary detector simulation: geometric acceptance, detection efficiencies.
  - $\rightarrow$ No UE, PU, detector resolution effects.
    - This should not invalidate results (PU can be managed & our signal events are very hard.)
- Use `N-jettiness plugin`[3] `0.4.1` to compute τ_N with optimized axes.

[3] Jesse Thaler, Ken Van Tilburg, and Christopher K. Vermilion

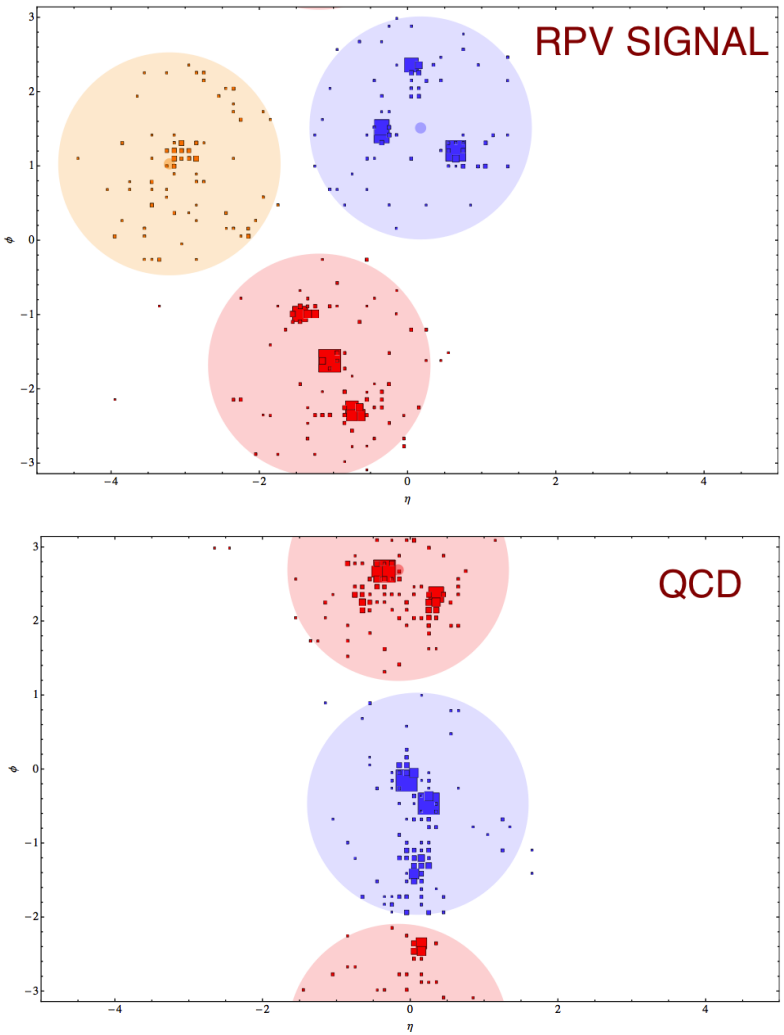
Cuts

- Characteristics of boosted RPV gluino signal suggest extremely obvious set of cuts for fully exclusive analysis (both gluinos boosted):

	QCD	ttbar	Total BG	gluino600	gluino700	gluino800
BEFORE ANY CUTS	1.76748×10^{7}	21410.3	1.76962×10^{7}	23600.	7640.	2700.
				S/B 0.00133	S/B 0.000432	S/B 0.000153
HT trigger (> 850 GeV)	1.70633×10^{7}	20992.2	1.70843×10^{7}	23323.1	7616.13	2697.69
				S/B 0.00137	S/B 0.000446	S/B 0.000158
two antikT(1.5) fat jets with pT > 800 GeV	202727.	371.392	203098.	493.83	292.221	168.733
				S/B 0.00243	S/B 0.00144	S/B 0.000831
max[T3/T2] < 0.5	743.191	11.8335	755.025	54.28	36.2485	20.5357
				S/B 0.0719	S/B 0.0480	S/B 0.0272
|M1+M2|/Avg[M1,M2] < 0.1	140.37	2.13274	142.503	23.4033	13.3379	5.55938
				S/B 0.164	S/B 0.0936	S/B 0.0390
Min[pT_sjet3/pT_sjet1] > 0.2	12.9686	0.0640776	13.0326	11.8	7.53049	3.44909
				S/B 0.905	S/B 0.578	S/B 0.265
Mj > 500 GeV	10.7285	0.0101477	10.7387	11.6033	7.53049	3.33563
				S/B 1.08	S/B 0.701	S/B 0.311
				$S/\sqrt{B}$ 3.54	$S/\sqrt{B}$ 2.30	$S/\sqrt{B}$ 1.02

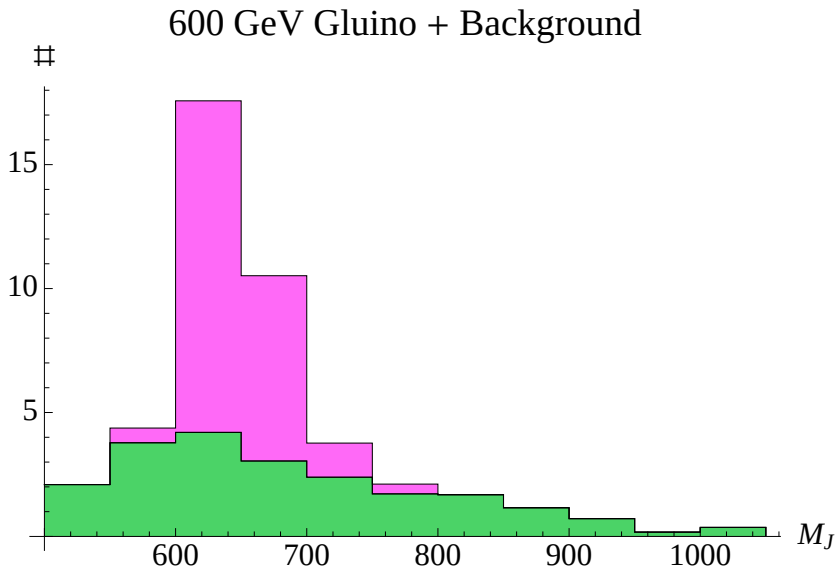
- τ_{32} cut is extremely powerful at rejecting lower (thin-)jet multiplicities without additional reclustering!
- QCD Background reduced by 6 orders of magnitude, $S/B \sim 1$.
- Signal Efficiency of boosted fraction $\sim 10\%$.

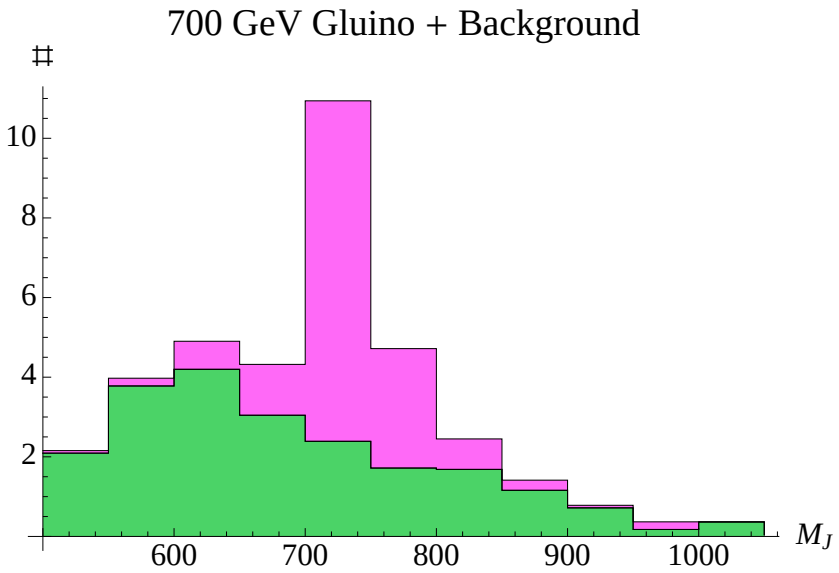
Cuts

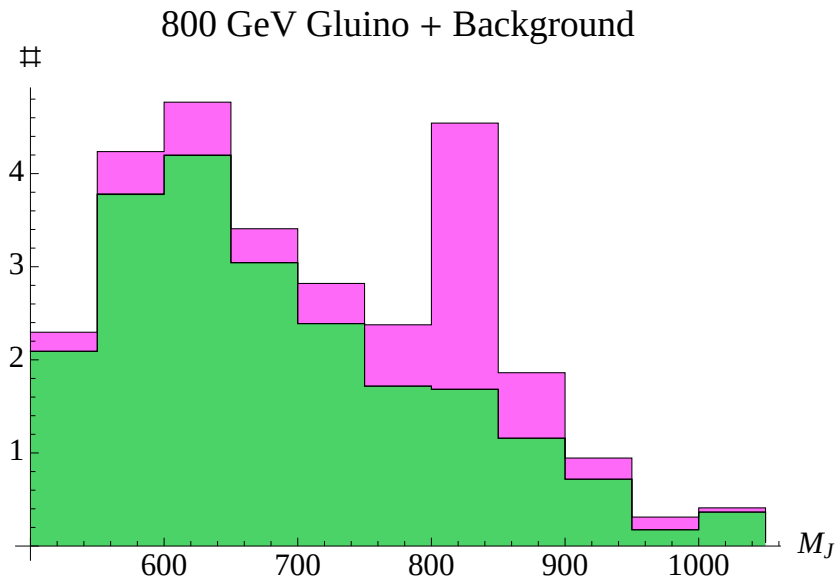


- Boosted gluino fat jets have less hierarchical subjets than QCD. Improves S/B by x 10.
- There seems to be more radiation between subjets in QCD than signal.
  - → Additional improvements might be obtained by looking at girth, flow, . . .
- **Some of this information might be accessed by looking at β-dependence of τ_N ratios!**
  - We are still investigating this.
  - Naive applications not helpful for boosted analysis, but might help with resolved searches (!!).

Final Jet Mass Distributions

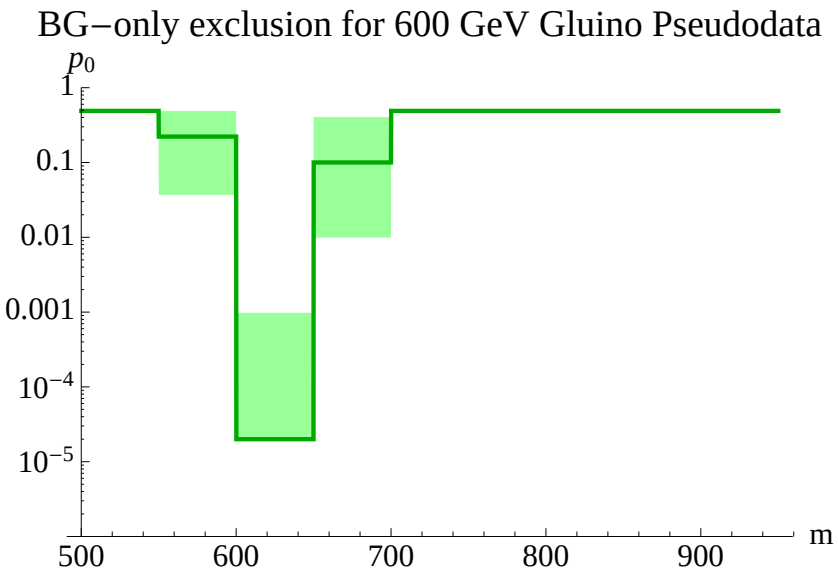


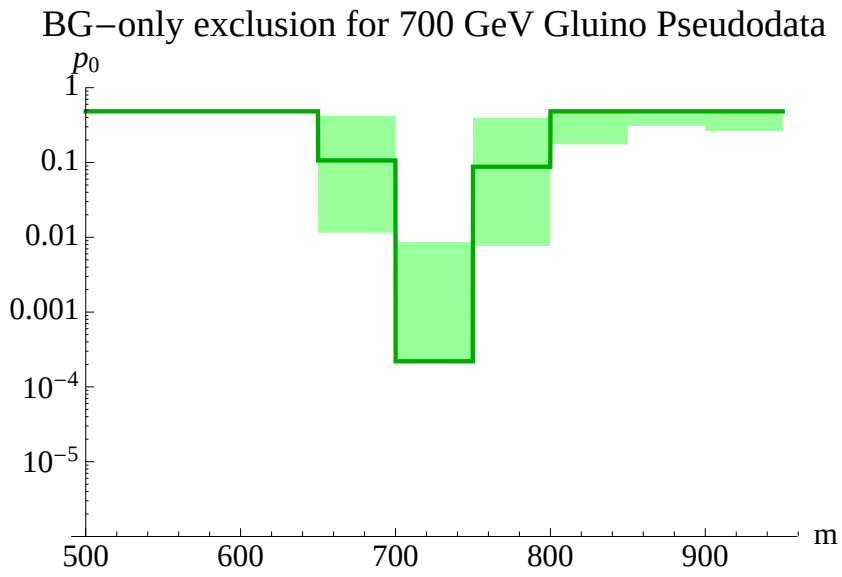


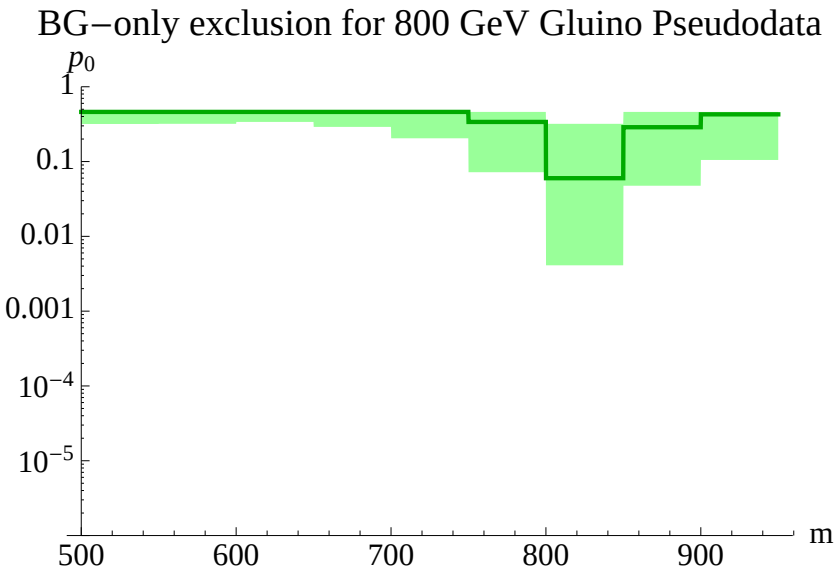


- Resonance peaks well reconstructed for $m_{\tilde{g}} = 700\,\mathrm{GeV}$ @ LHC8, 20/fb.
- $800\,\mathrm{GeV}$ might be possible with more luminosity. (Extended 2012 run?)
- Shape analysis seems much more reliable than counting experiment.

Mass Reach







- 4/3.5 σ background exclusion for 600/700 GeV Gluino @ LHC8, 20/fb
- $2 \pm 1\sigma$ background exclusion for 800 GeV gluino. . . might get lucky? ;)
- Very high mass reach for a boosted search!

Counting Analysis

- Could we extend the mass reach by relaxing cuts to increase $S/\sqrt{B}$?
- Effectively do counting experiment (no longer reconstruct mass peak).
  - Relies on known background normalization. Can do data-driven background, but intrinsically less reliable than shape analysis.
  - Systematic errors more dangerous.
  - Why use substructure and not multi-jet search? Looking for a small number of fat jet has advantages (see Jay Wacker's talk).
  - **Our analysis strategy not optimized for this**, but worth exploring.

Counting Analysis

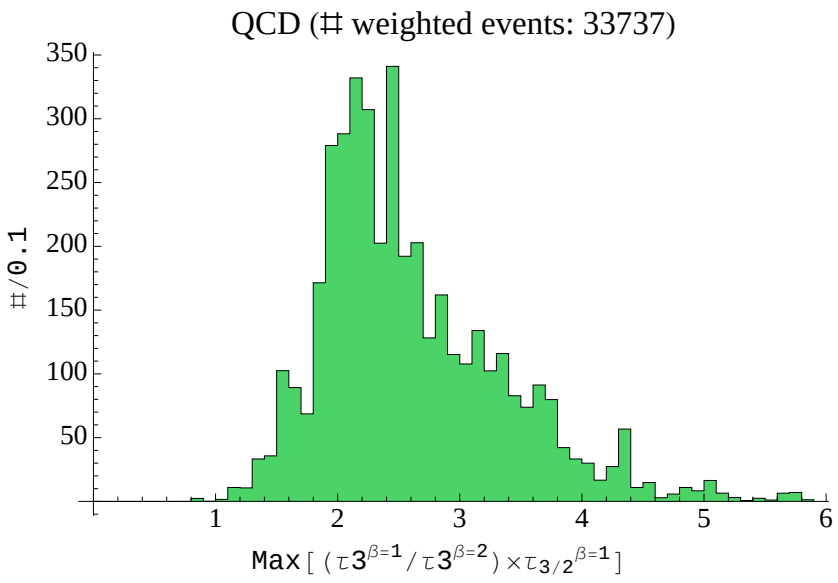
- Very loose cuts:

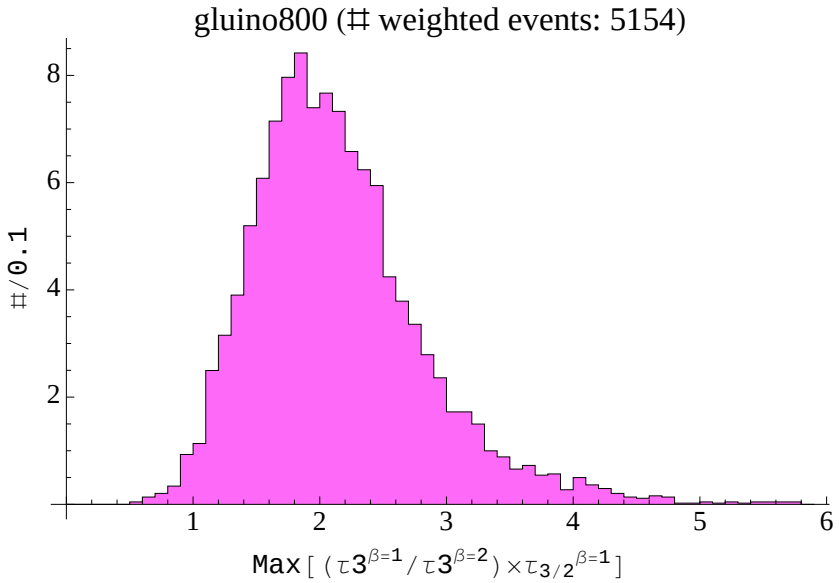
	QCD	ttbar	Total BG	gluino800
BEFORE ANY CUTS	1.76748×10^7	21410.3	1.76962×10^7	2700. S/B 0.000153
HT trigger (> 850 GeV)	1.69917×10^7	20919.9	1.70126×10^7	2697.69 S/B 0.000159
two antikT(1.5) fat jets with pT > 450 GeV	8.5076×10^6	10272.6	8.51788×10^6	1754.66 S/B 0.000206
max[T3/T2] < 0.7	685972.	4925.66	690898.	724.422 S/B 0.00105
Avg[M1,M2] > 520 GeV	6920.86	29.6344	6950.5	198.549 S/B 0.0286
$\mathrm{Max}[(\tau 3^{\beta=1}/\tau 3^{\beta=2}) \times \tau_{3/2}{}^{\beta=1}] < 2$	1060.66	5.92857	1066.59	96.0299 S/B 0.0900 $S/\sqrt{B}$ 2.94

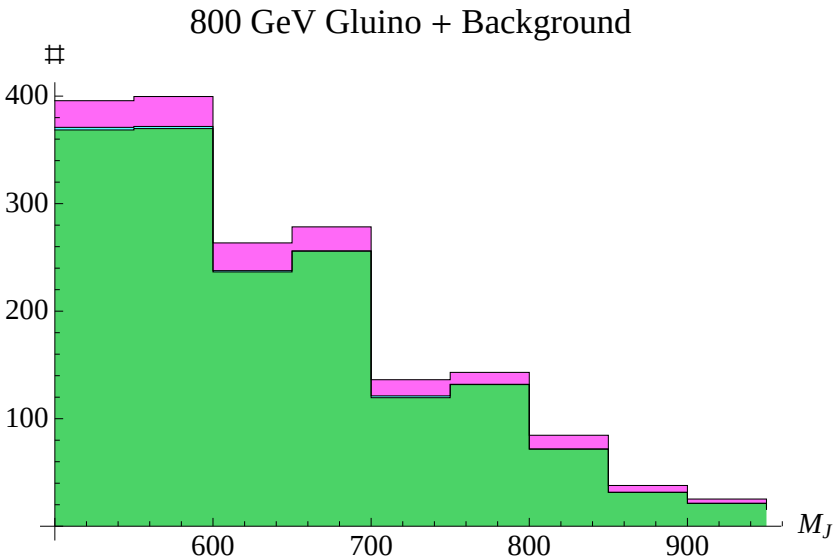
- Can achieve $S/\sqrt{B} = 3$. (Systematics?)
- **Might do much better by vetoing events with fewer than 6 thin jets?** (τ_{32} cut not very aggressive here.)
- Interesting β-dependent cut!

$$\tau_N = \frac{1}{d_0} \sum_k p_{Tk} min_A \{\Delta R^{\beta}_{A,k}\}$$

Interesting β-dependent Cut







- $\text{Max}\left[\frac{\tau_3^{\beta=1}}{\tau_3^{\beta=2}} \times \frac{\tau_3^{\beta=1}}{\tau_2^{\beta=1}}\right]$ has excellent S/B discrimination! Much better than either by itself.
- Does not select 'complete' gluino fat jets!
- β-variation could contain a lot of information: under Investigation!

Conclusions & Future Work

PRELIMINARY!

- We have shown that boosted gluino searches @ LHC8 have very high mass reach, up to maybe 800 GeV.
- Information contained in β-variation of τ_N could help in this and other searches. **Under Investigation!** (See also Marat Freytsis' talk.)
- Lots more to do:
  - Further optimization of heavy boosted RPV gluino search might be possible.
  - Gluino on the top mass is an interesting special case that has not been excluded yet. Triggers might force boosted search.
  - RPV gluino with intermediate on-shell squark: additional handle on signal. (Small mass gap could also reduce subjet p_T.)
  - RPV gluino decaying to b or t. **Stay Tuned!**