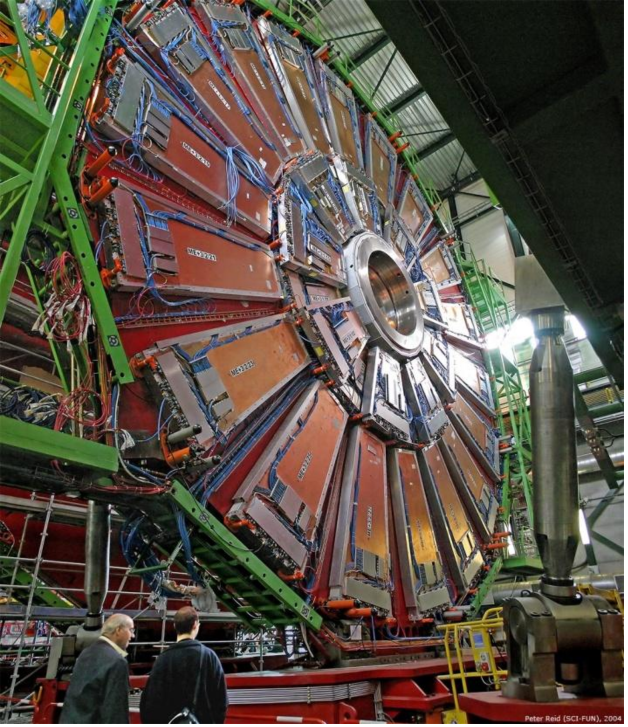
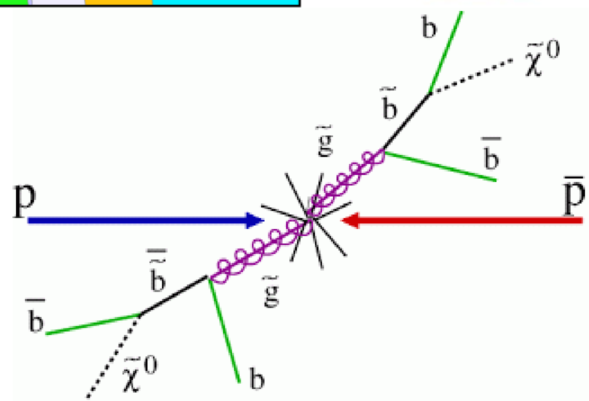
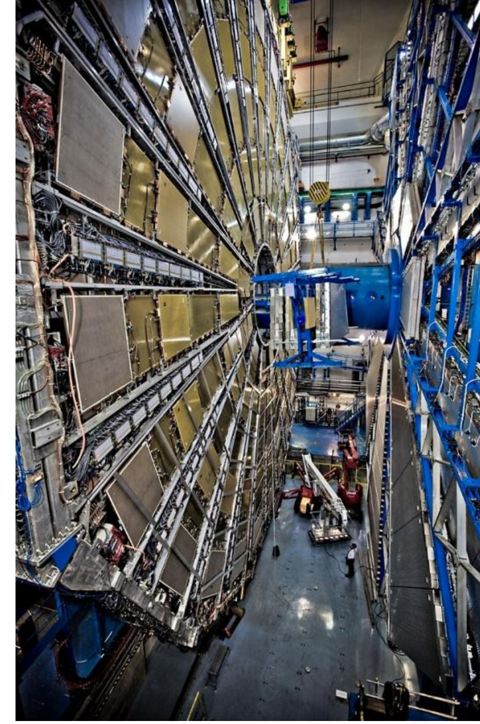






Overview of gluino-mediated stop/sbottom searches

Joshua Thompson, Cornell University

12 Nov 2013

SUSY at the Near Energy Frontier

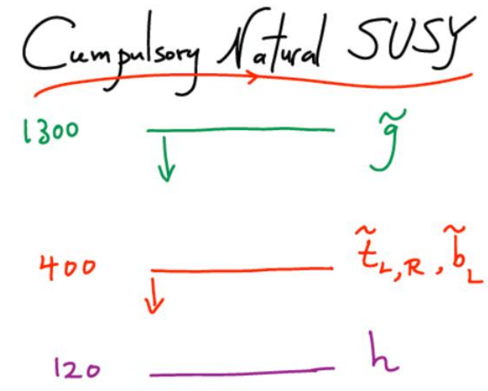
Fermilab

Brief outline

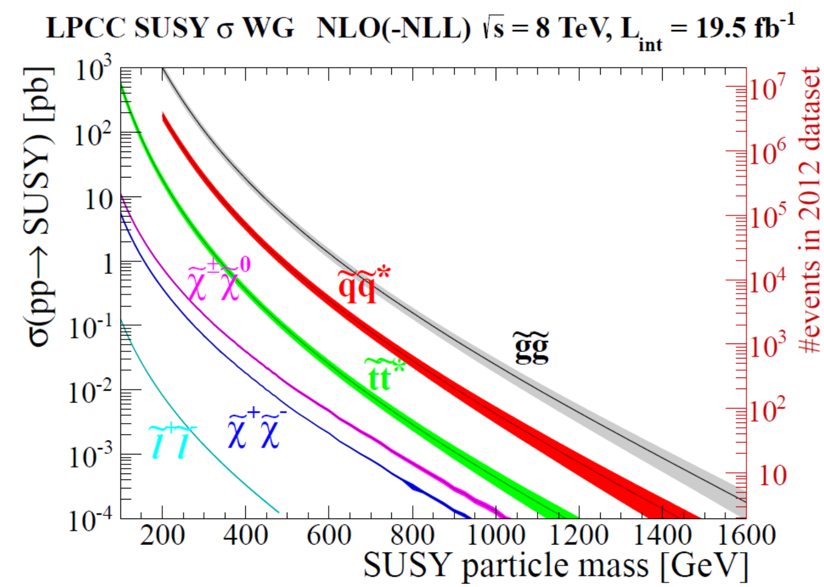
- Gluinos in natural SUSY: motivation and introduction
- Search signatures
- Backgrounds
- Analyses and interpretations:
  - Gluino-mediated sbottom production
    - 0-1 leptons
  - Gluino-mediated stop production with stop → top+LSP
    - 0-3 leptons
    - High jet multiplicity
  - Gluino-mediated stop production with stop → charm+LSP
    - 0 leptons

Why gluinos?

- Naturalness
  - As you know (see yesterday's talks), gluinos are a key player in the naturalness story
  - Constrained to 1-2 TeV in natural SUSY scenarios
- High production cross section
  - Sensitivity to highest masses
  - Most dramatic signatures
    - Heavy SUSY parents→lots of (missing) energy in the detector
  - Searches for the heaviest particles gain the most from increases in CM energy

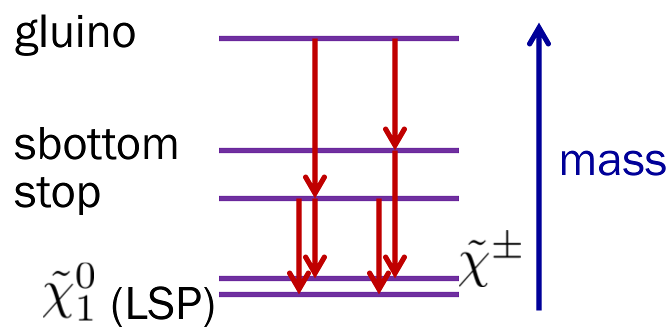


N. Arkani-Hamed



Decay topologies and signatures

Hypothetical SUSY spectrum



Typical decay chains

$$\tilde{g} \to b\tilde{b} \to b\bar{b}\tilde{\chi}_1^0$$

$$\tilde{g} \to t\tilde{t} \to tb\tilde{\chi}^+$$

$$\tilde{g} \to b\tilde{b} \to bt\tilde{\chi}^-$$

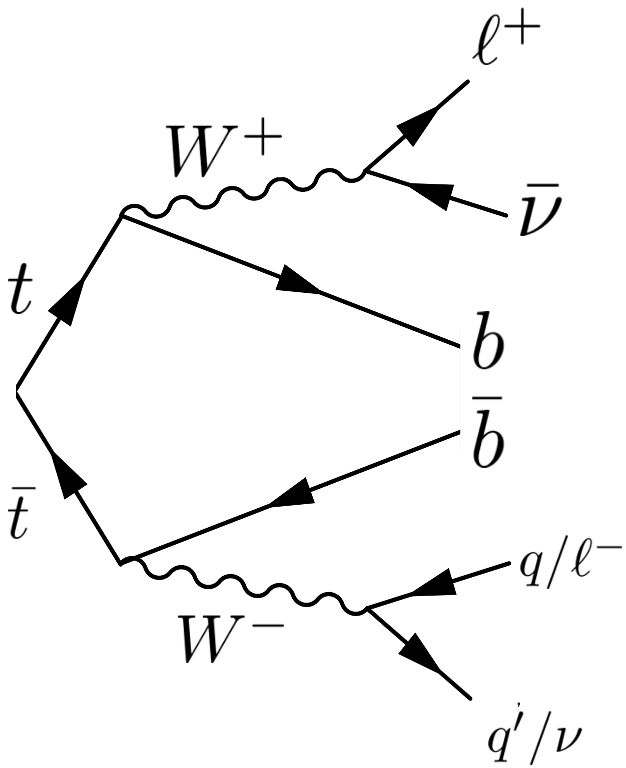
$$\tilde{g} \to t\tilde{t} \to t\bar{t}\tilde{\chi}_1^0$$

$$\tilde{g} \to t\tilde{t} \to tc\tilde{\chi}_1^0$$

- What signatures are we looking for?
  - bbbb+MET
  - ttbb+MET
  - tttt+MET
  - ttcc+MET

- Final states: **4 b-quarks and 0-4 W's**
- Final states with many W's give rise to (depending on the W decay) a combination of
  - **High jet multiplicity**
  - **Potential for many leptons**
- LSP escapes undetected
  - **Large missing transverse energy (MET)**

Main backgrounds



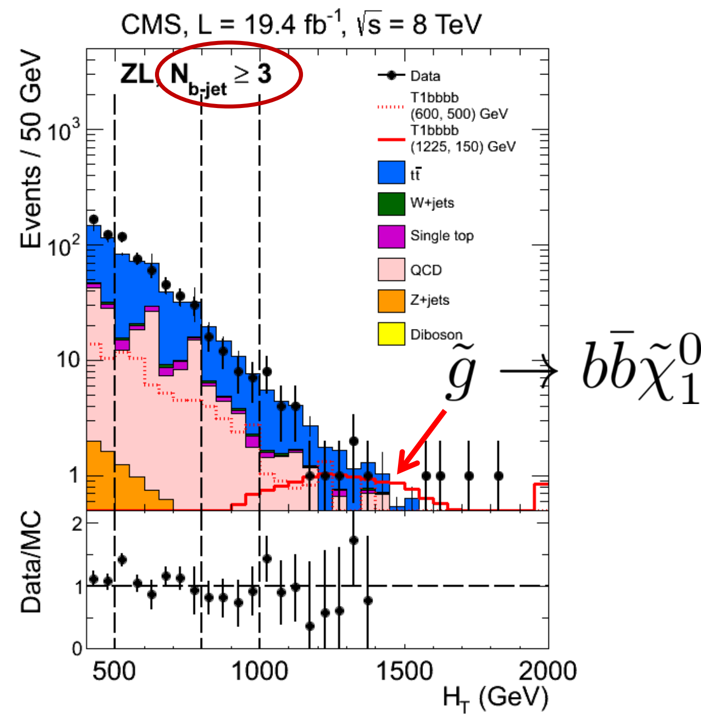
- Signal signature: jets, MET, 0-3 leptons, b-tags
- Main background usually ttbar (semi or fully leptonic)
  - Neutrino(s) give real MET
  - 2 b-jets from top decays
    - 3rd b-tag can come from W→cs , radiated b-jet, (etc)
  - 0 lepton searches:
    - Leptons can evade vetoes (especially tau→hadrons)
  - 1 lepton searches:
    - 1l ttbar can be reduced with MT and related quantities
  - 2 same-sign lepton and 3 lepton searches:
    - Jets can be a source of non-prompt leptons, especially from semileptonic B decays
- Other backgrounds depend on search
  - W+jets, Single top production
  - 0 lepton searches:
    - Z→νν+jets
    - QCD
  - Rare processes such as diboson, ttW, ttZ, and ttH

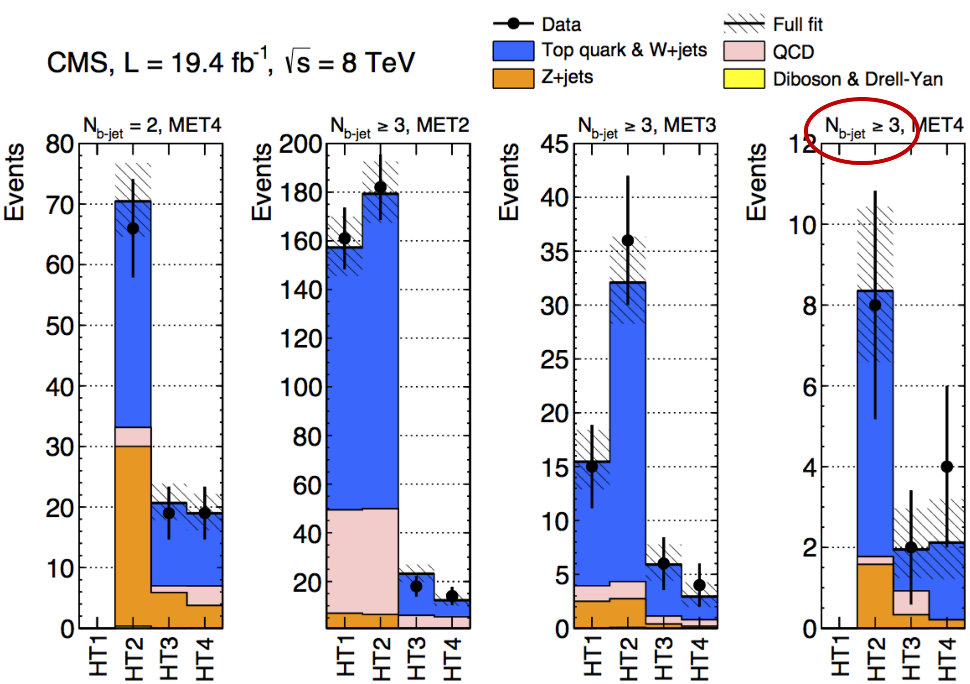
CMS-SUS-12-024

PLB 725, 243 (2013)

0 lepton, multiple b-tags

- Discriminating variables:
  - MET, HT=$\Sigma_{jets}|p_T|$, number of b tags
  - QCD rejection: variant of $\Delta\phi$(jet,MET)
  - Lepton and isolated track vetoes





Data agrees with background prediction

- Background determined in 3-d binned fit
  - Control sample defined for each background:
    - ttbar: 1-lepton sample
    - Z→νν: Z→ll samples
    - QCD: inverted $\Delta\phi$ cut
  - Simultaneous fit to MET/HT/nb shape in control and signal samples

Also see: α_T analysis,SUS-12-028/EPJC 73 (2013) 2568

Razor analysis

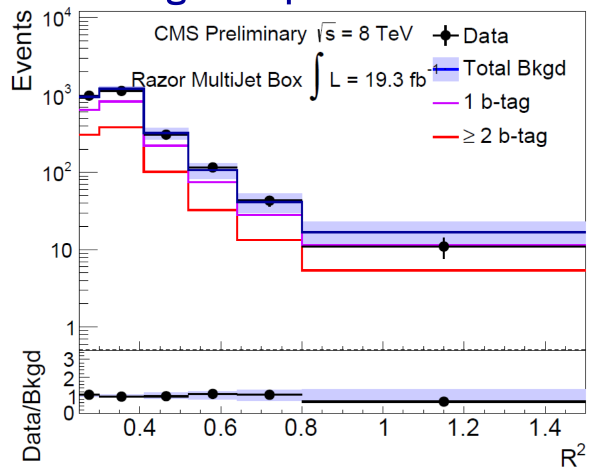
- Analysis binned in lepton, jet, b-tag multiplicities
  - 0+1 lepton categories used in current results
  - 1,2, ≥3 b-tags
- 2-d fit to shape of background and signal in the plane of the "Razor" variables: *C. Rogan, arXiv:1006.2727*

$$M_R \equiv \sqrt{(p_{j_1} + p_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2} \quad \text{and} \quad R \equiv \frac{M_T^R}{M_R}$$

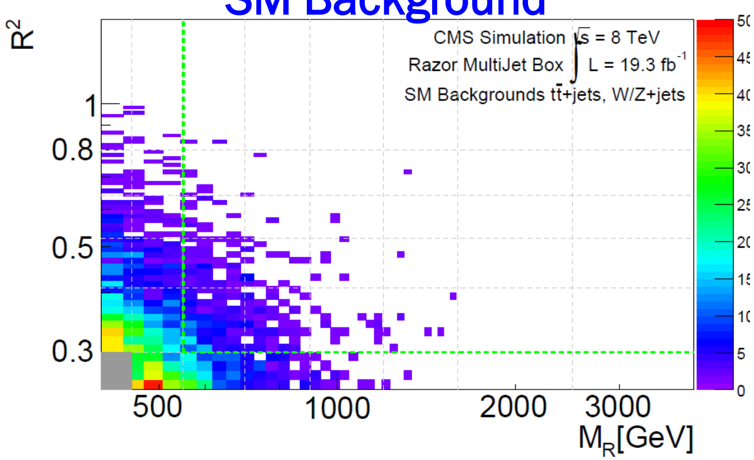
where $$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2})}{2}}$$

- Variables are defined in terms of a dijet topology
  - For higher jet multiplicity, cluster jets into two "megajets"

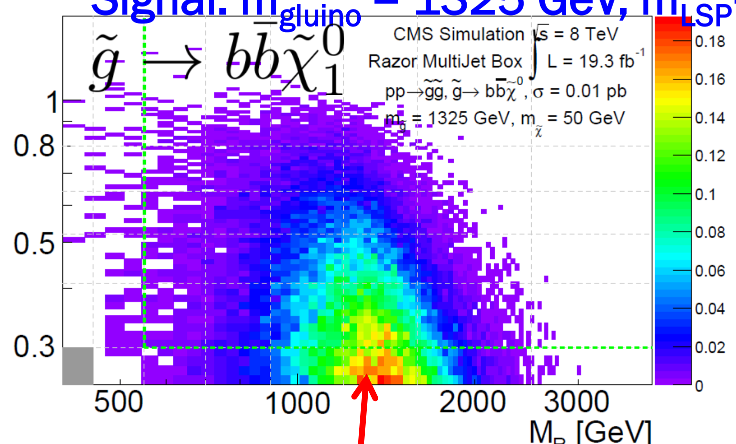
Data agrees with background prediction



SM Background



Signal: m_{gluino} = 1325 GeV, m_{LSP}=50 GeV

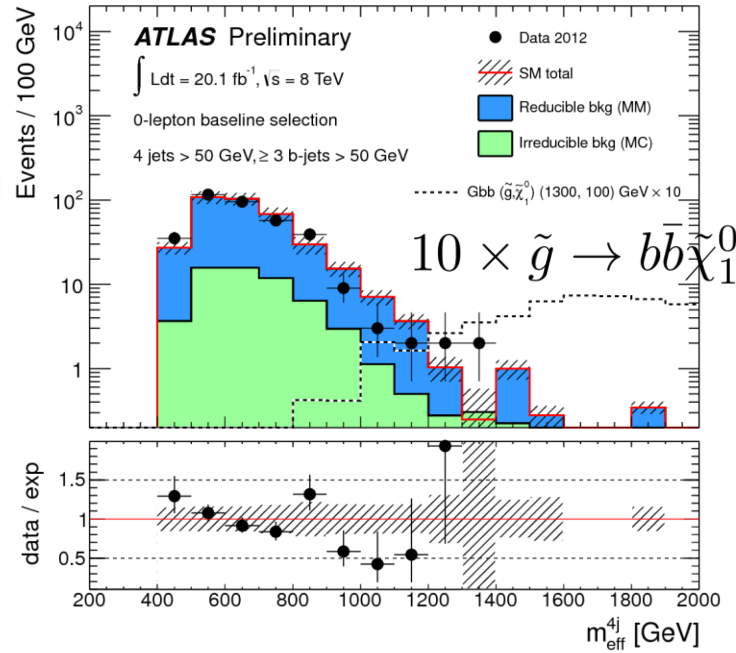


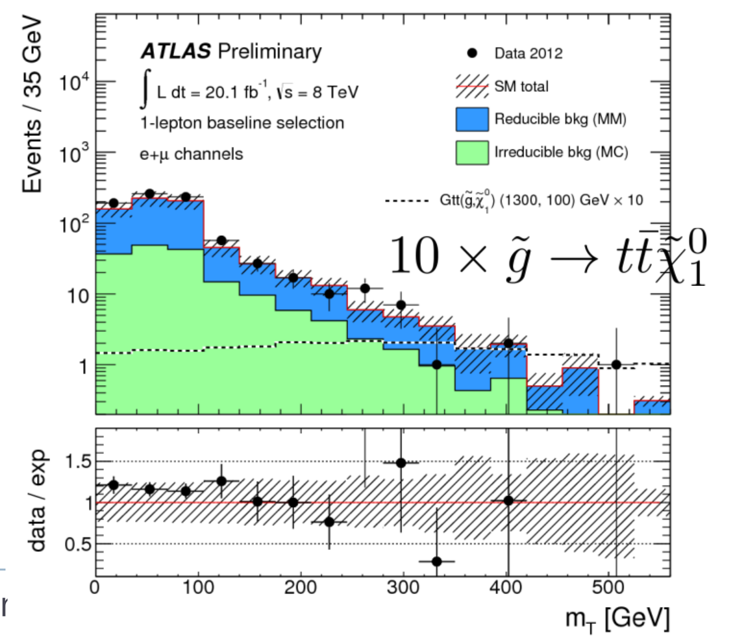
Signal has tail at high R^2

M_R peaks at ~ $M_\Delta = \frac{M_{\tilde{g}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{g}}}$

0-1 leptons, ≥3b-tags

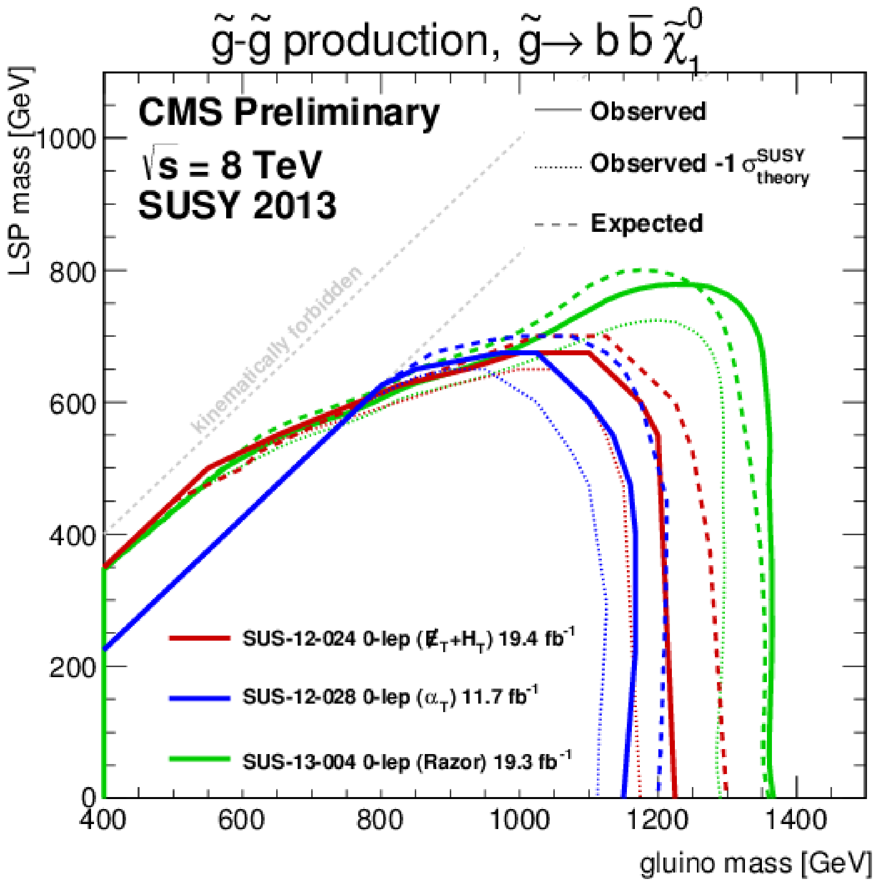
- Discriminating variables:
  - Signal regions defined using:
    - Number of leptons (e/mu): 0 or 1
    - Meff = Σ^{N}_{jets} $|p_T|$ + MET (+ lepton pT)
      - Where N = 4 or all, depending on signal region
    - Jet multiplicity
      - ≥4, ≥7 jets for 0 lepton search
      - ≥6 jets for 1 lepton search
    - Varying MET selections
    - MT selection for 1 lepton search
  - Require ≥3 b-tags
  - Reject QCD with $\Delta\phi$(jet,MET) for 0 lepton search
- Backgrounds:
  - Reducible backgrounds (<3 real b jets) estimated from pre b-tag data by solving a system of equations with the b-tag efficiency and mistag rates as input
    - Dominated by ttbar
  - Irreducible backgrounds (≥3 b jets) taken from MC:
    - tt+b, tt+bb, ttZ/H
- Data compatible with background predictions



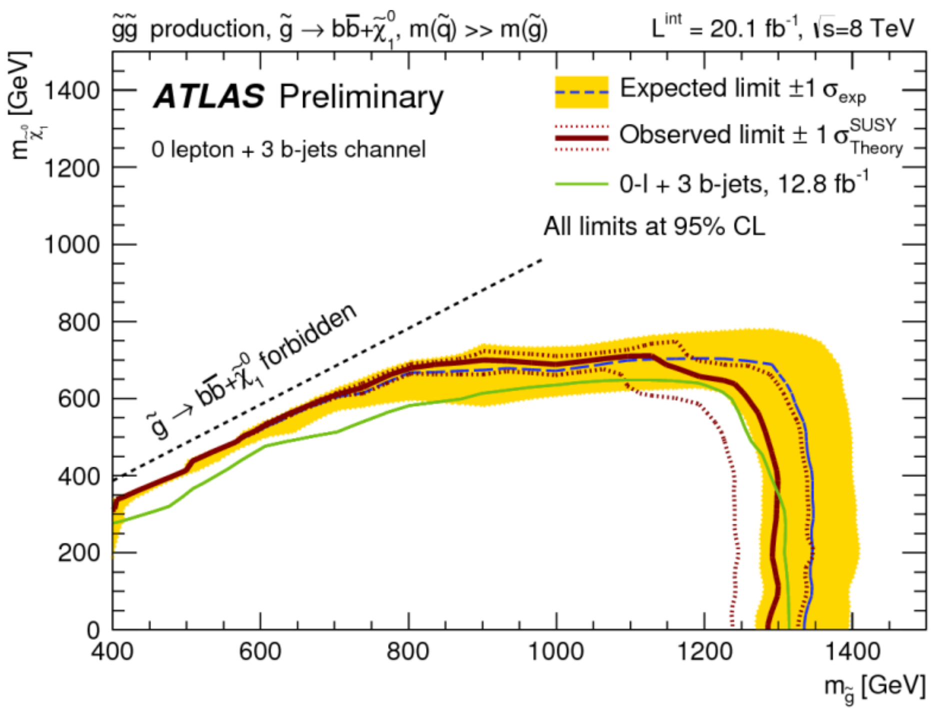


Limits on the $\tilde{g} \to b\bar{b}\tilde{\chi}_1^0$ topology

- Interpretation of 0-lepton searches
- Sensitivity to gluinos as heavy as ~1350 GeV for light LSP

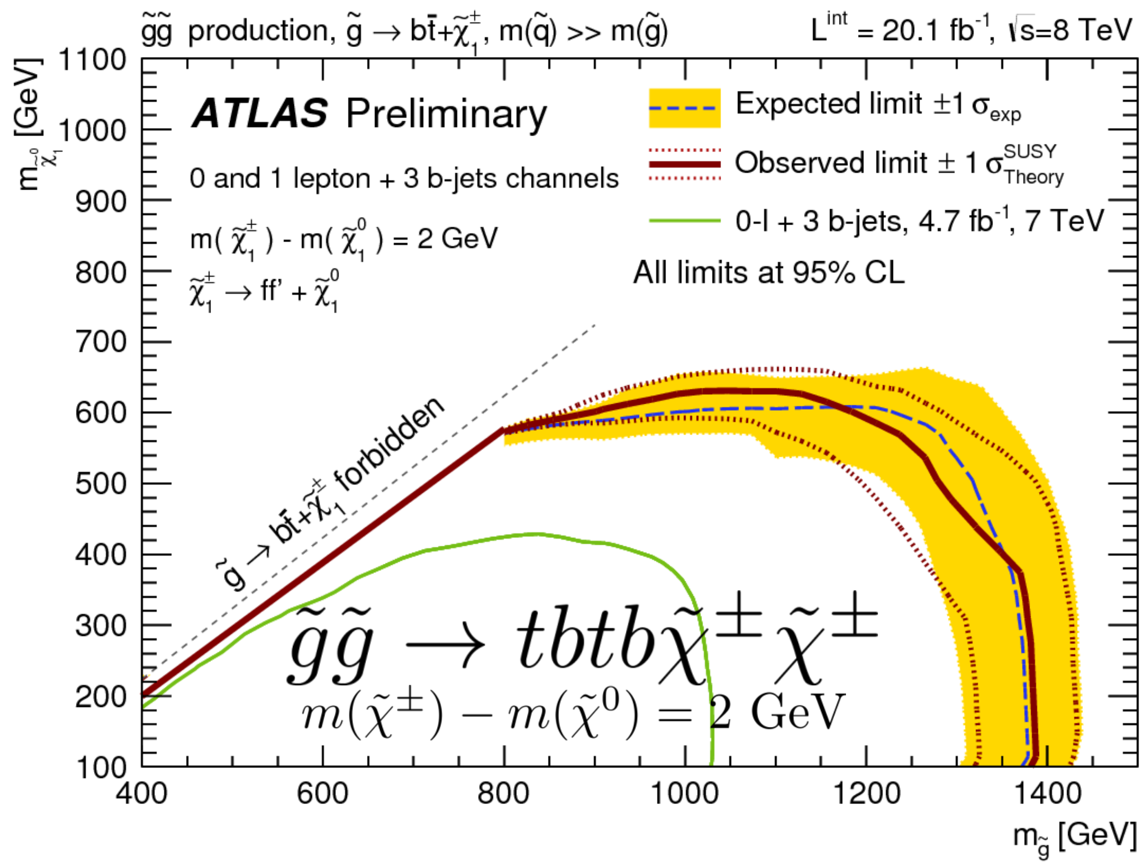


ATLAS CONF-2013-061



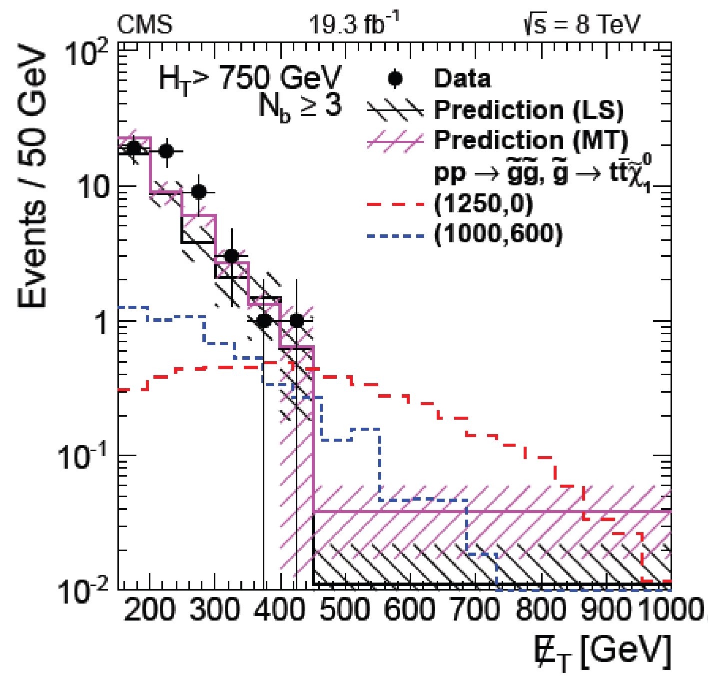
Additional interpretation

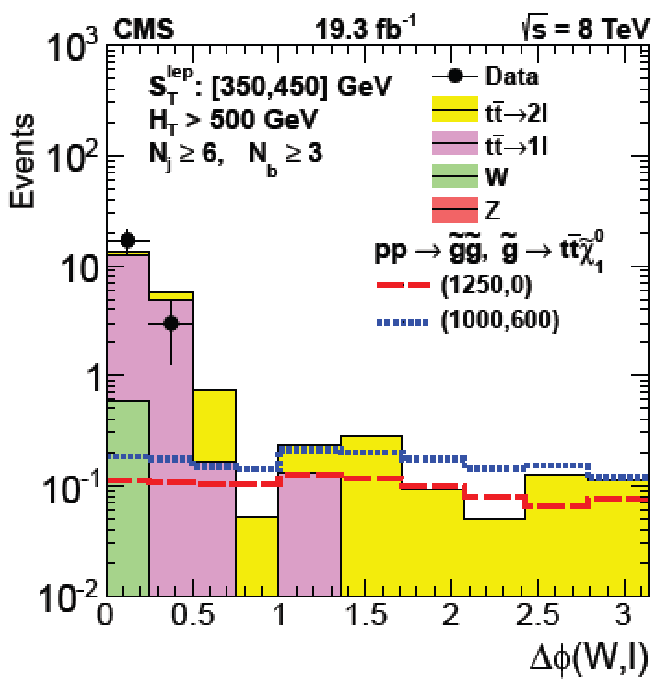
- Combined 0 and 1 lepton search provides good sensitivity to models with tops in the final state
  - Shown here: ATLAS results for $\tilde{g} \rightarrow tb\tilde{\chi}^{\pm}$
  - Results for $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ shown later



1 lepton, multiple b-tags

- Independent searches in 2 sets of kinematic variables:
  - HT, MET
  - HT, (MET+lepton pT), Δϕ(l,W)
    - Δϕ is related to MT(l,MET). Reduces semileptonic ttbar background
  - Both versions require ≥6 jets
    - Optimized for $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$



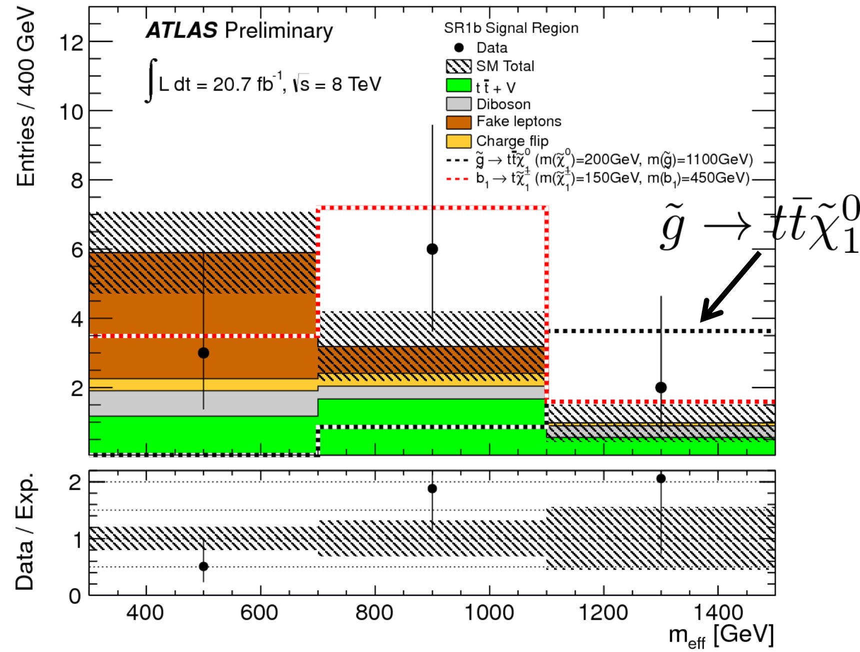


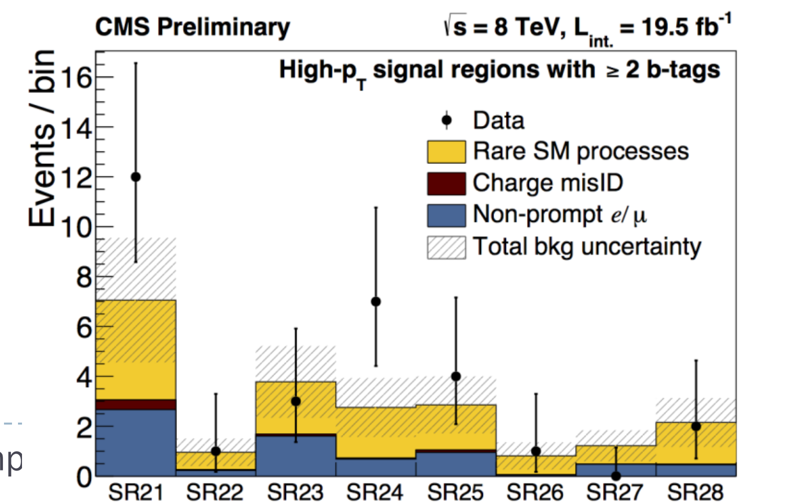
- 3 background estimation methods
  - Estimations of background MET spectrum:
    - From spectrum of measured leptons
    - Fit to parameterization of MET shape
  - Extrapolation from low Δϕ(l,W) control sample
    - Uses lower b-tag sample as ttbar control sample
- Data agrees with predicted backgrounds in all cases

ATLAS CONF-2013-007
CMS PAS SUS-13-013

2 Same sign leptons + b-tags

- Powerful signature:
  - 4 W final states from SUSY naturally produce same-sign leptons
  - Real same-sign leptons very rare in SM
    - TTZ/W, diboson
- Experimental challenge:
  - Understand "fake" leptons (mostly from B decays)
    - Fake rate estimated using control samples in data
- Sensitive variables:
  - ATLAS: N_{jets}, $N_{b\text{-}tags}$, MET, M_T, M_{eff}
  - CMS: N_{jets}, $N_{b\text{-}tags}$, MET, HT
    - *(details of search regions in backup)*

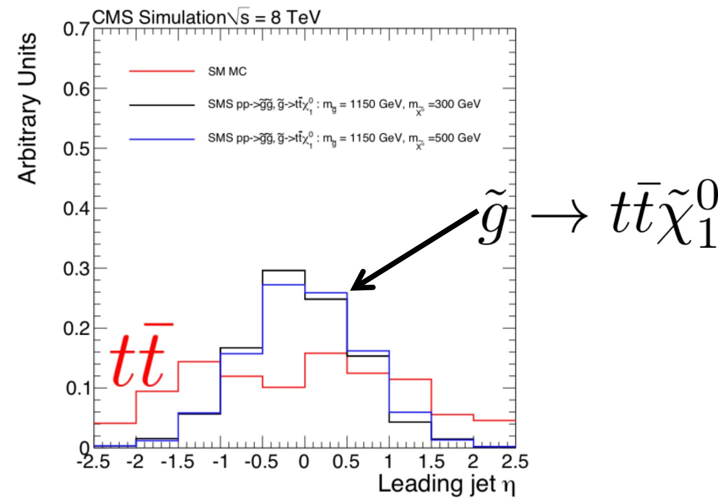


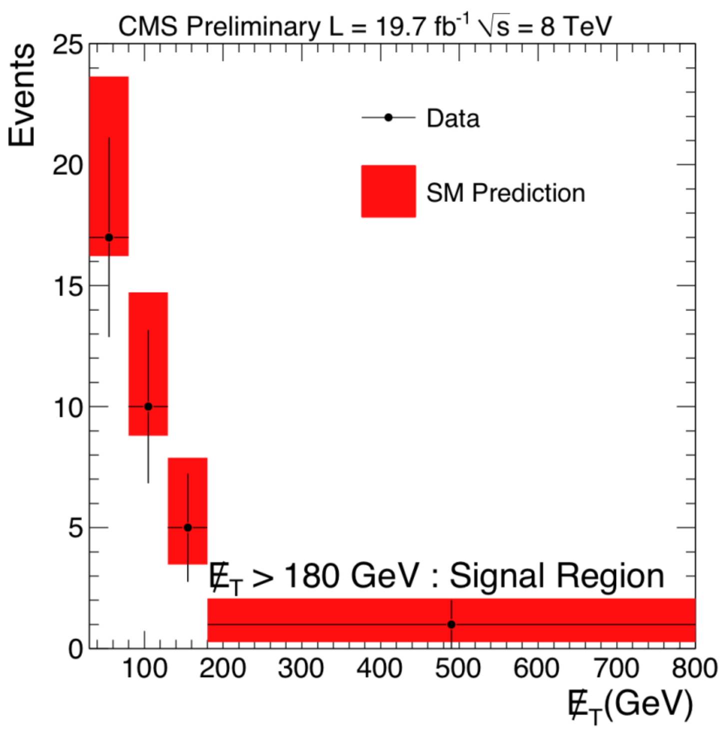


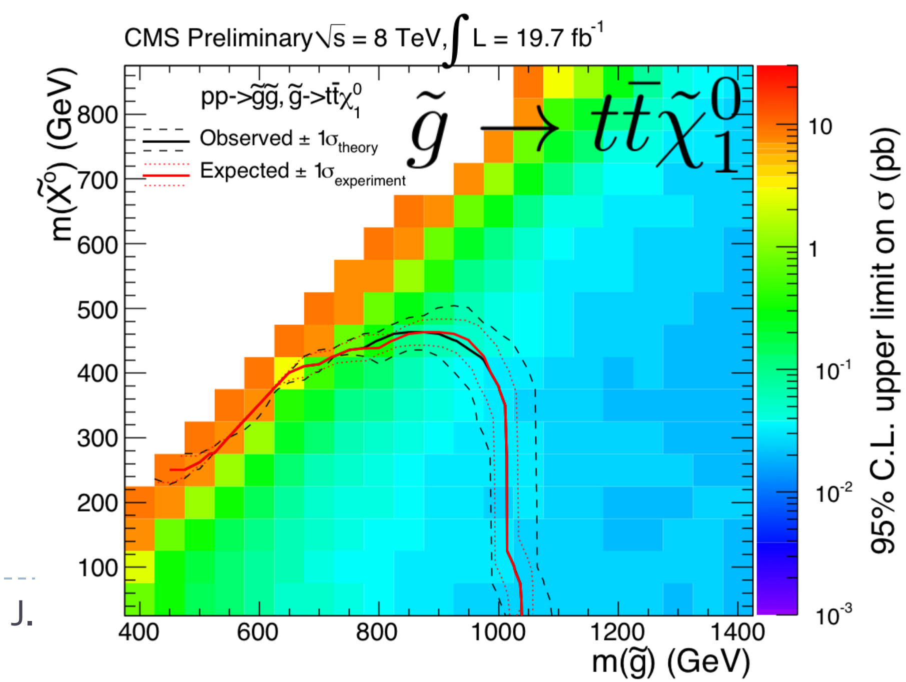
NEW

2 opposite-sign leptons + b-tags

- Mutually exclusive from same-sign analysis
  - Allows us to catch signal not included in other searches
  - ttbar background much larger, however
- Suppress ttbar with the usual properties of 4-top signal:
  - $N_{jets} \geq 5$
  - $N_{b\text{-}tag} \geq 3$
  - MET>180 GeV
- Also use the fact that SUSY tends to be central in eta
  - ttbar control region defined as one of leading jets with |η|>1





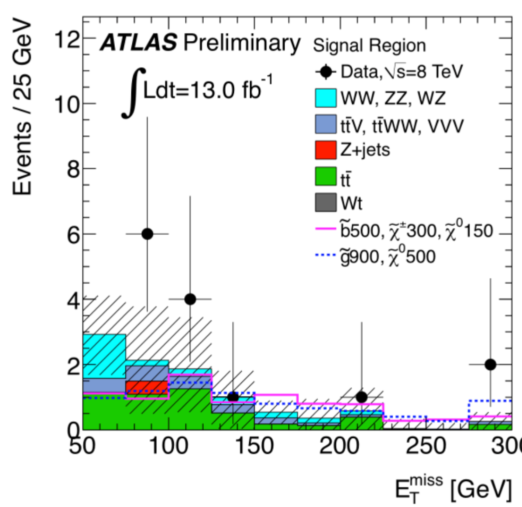


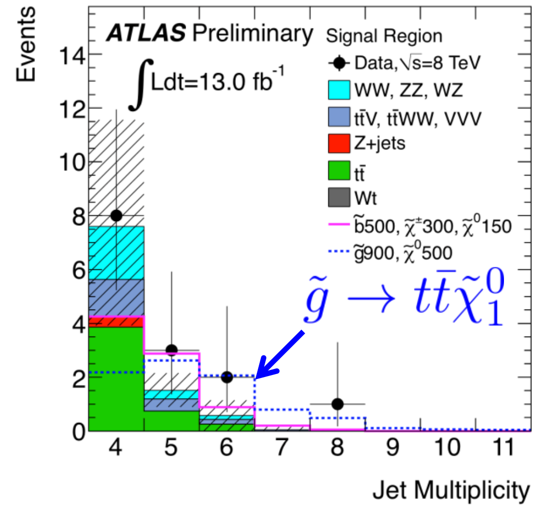
J.

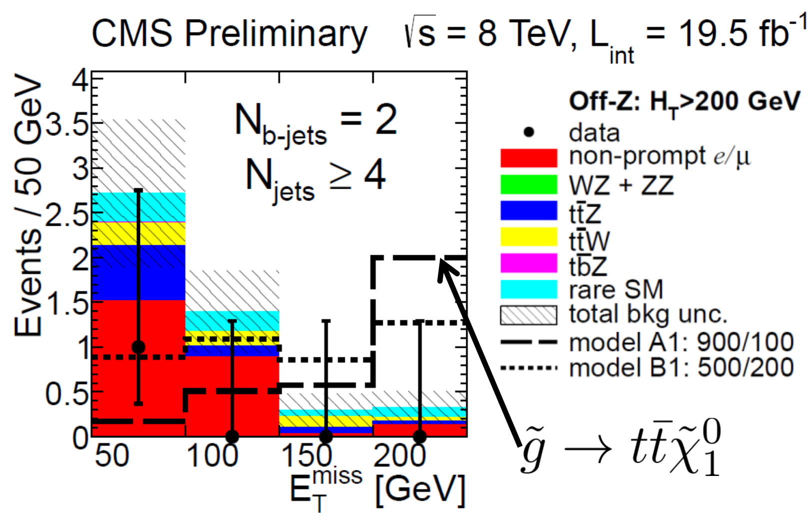
ATLAS CONF-2012-151
CMS PAS SUS-13-008

3 leptons

- ≥3 leptons possible in 4 top SUSY signal but very rare in SM
  - WZ, ttV, triboson, lepton fakes
- ATLAS Selection:
  - e/μ p_T>15 GeV
    - With one >20 GeV
    - Veto Z mass window
  - ≥4 Jets (p_T>30 GeV)
  - MET>50 GeV
- CMS Selection:
  - e/μ p_T>10 GeV
    - With one >20 GeV
    - Divide into "on-Z" and "off-Z"
  - Bins of jet multiplicity (p_T>30 GeV)
    - Bins of b-tag multiplicity (1,2, ≥3)
  - Bins of MET and HT

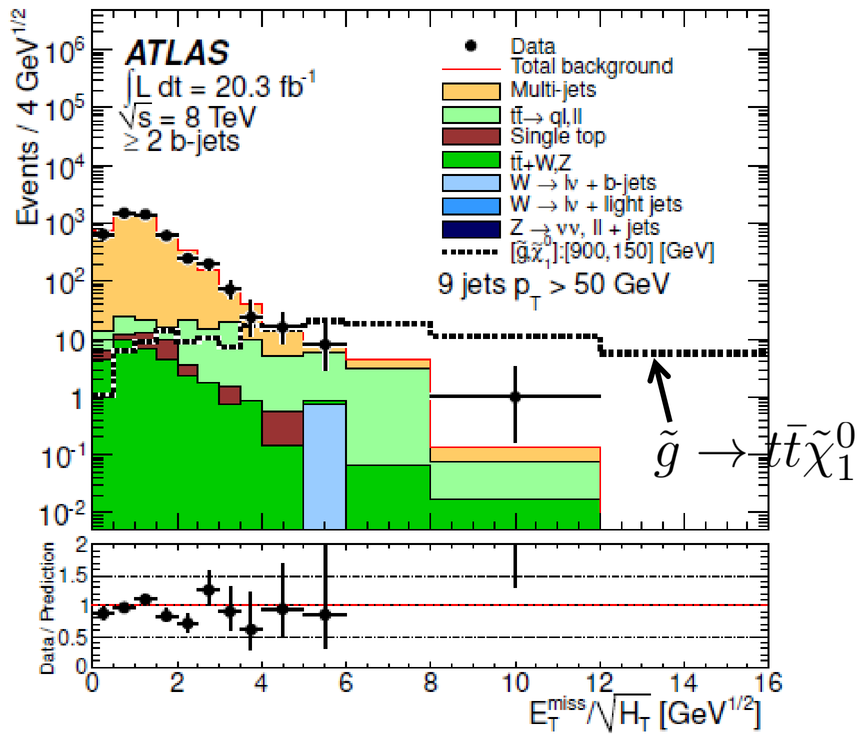






High jet multiplicity

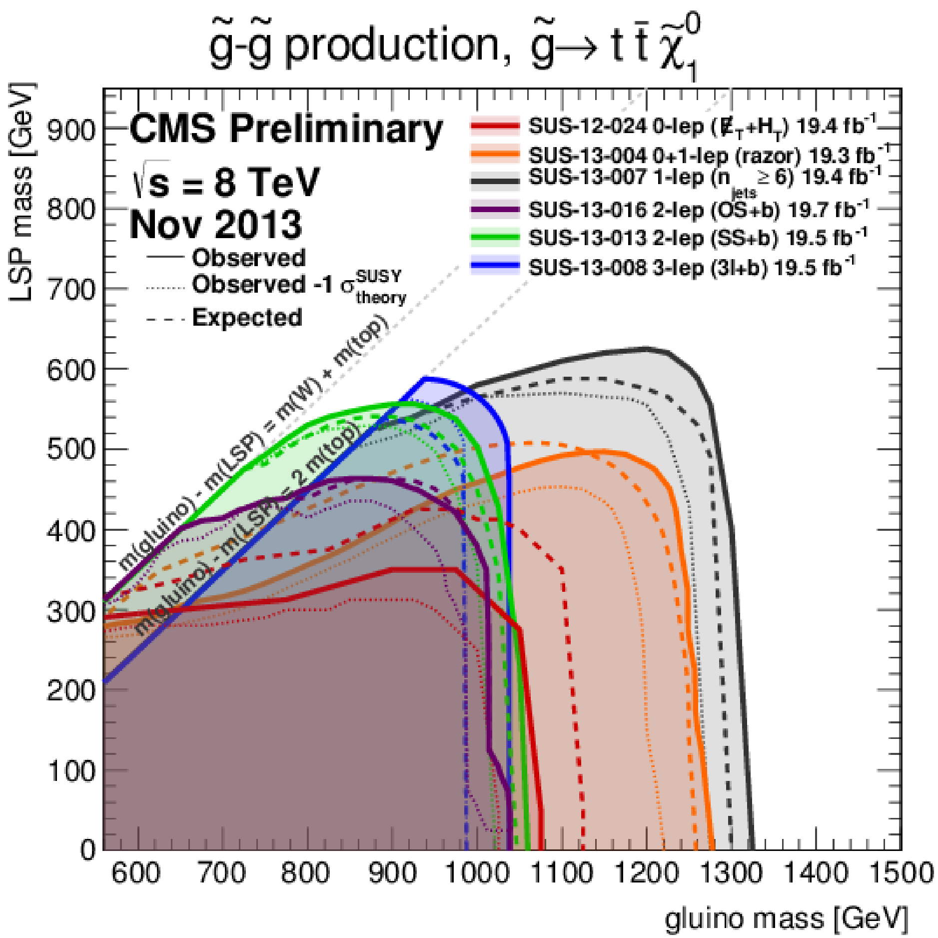
- Veto leptons, look for very high jet multiplicity from 4 hadronically-decaying tops
- Selection:
  - Bins of jet multiplicity
    - [8,9, ≥10] or [7, ≥8] depending of pT threshold
  - Bins of number of b-tagged jets
    - [0,1, ≥2]
  - MET/√HT > 4 √GeV

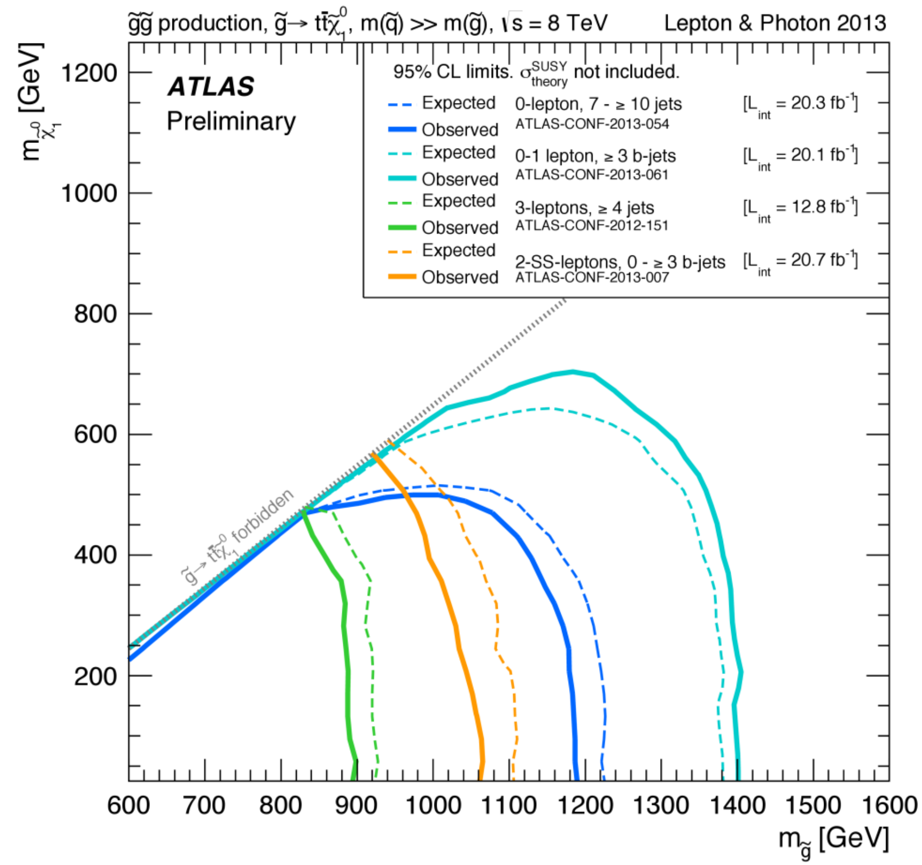


(Just one of many signal regions)

Limits in the $\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$ topology

- All lepton multiplicities are relevant
  - Limits up to 1400 GeV for light LSP





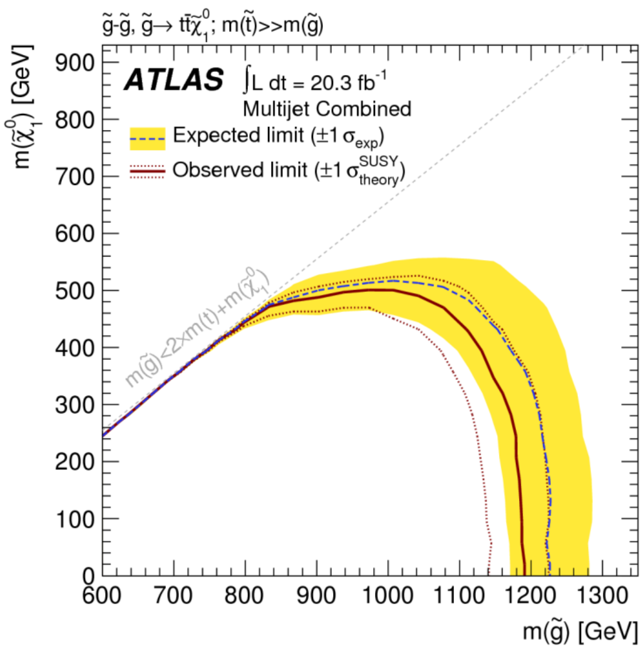
Off-shell versus on-shell

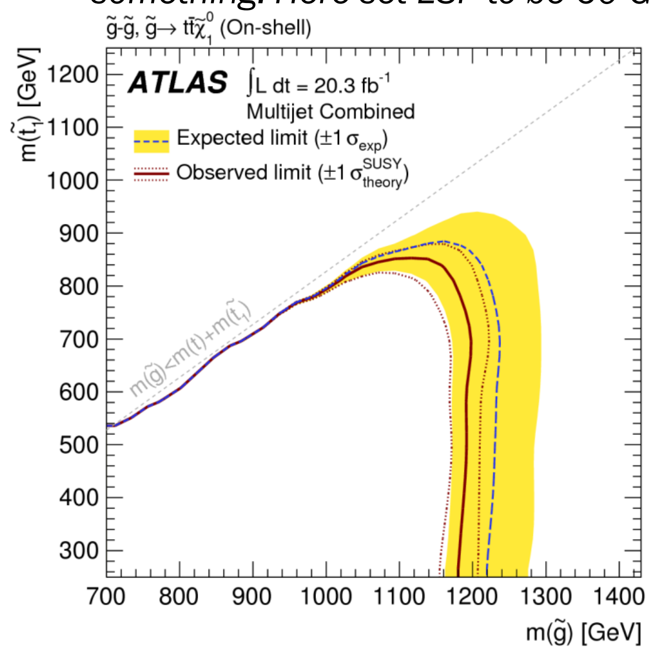
- Natural SUSY motivates simplified models with on-shell stop/sbottom
  - $m_{gluino} > m_{sbottom} \sim m_{stop}$
  - For example $\tilde{g} \rightarrow t\tilde{t} \rightarrow t\bar{t}\tilde{\chi}_1^0$
- I have shown the interpretations that ignore the intermediate decay and instead use a direct 3-body decay, for example $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$
  - reduces the number of parameters to 2 (gluino, LSP masses)

$$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$$

$$\tilde{g} \rightarrow t\bar{\tilde{t}} \rightarrow t\bar{t}\tilde{\chi}_1^0$$

For on-shell model, need to fix something. Here set LSP to be 60 GeV





→kinematics of the event do depend on the intermediate mass
→However, most analyses find limits on the gluino mass that are largely independent of the intermediate mass

ATLAS-CONF-2013-047

0-lepton, 2-6 jets

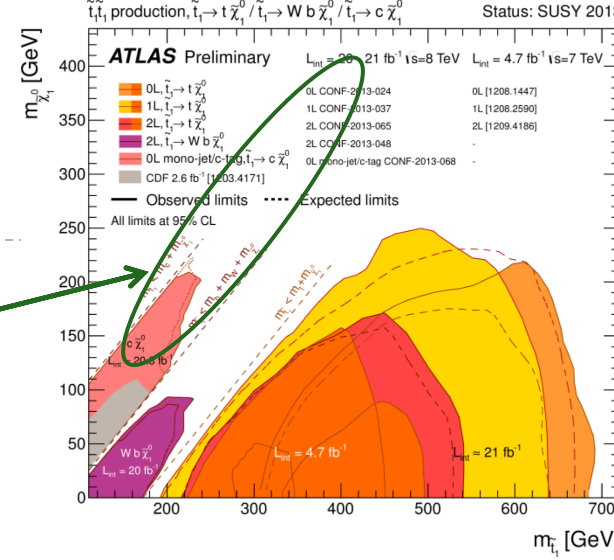
- Direct stop searches have limited sensitivity when ΔM(stop, LSP) is small

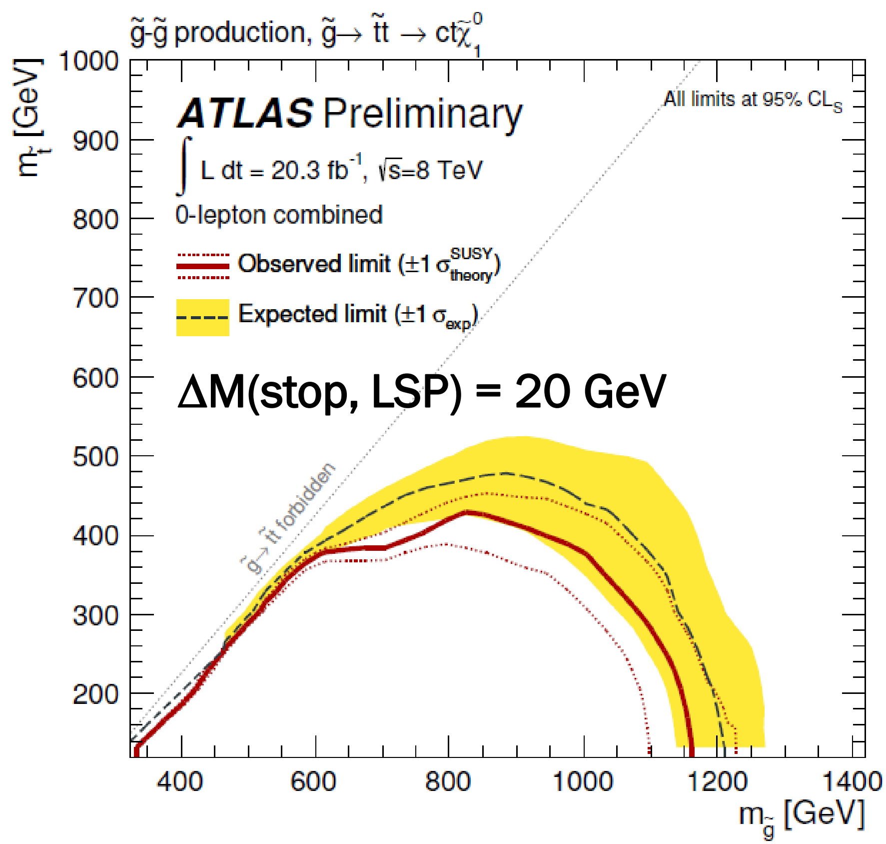
$$\tilde{t} \to c\tilde{\chi}_1^0$$

  - Soft jets, small MET
    - (some sensitivity from monojet search)
- Gluino production opens a back door to discovery:

$$\tilde{g} \to \tilde{t}t \to ct\tilde{\chi}_1^0$$

  - Stop produced in gluino decay gets boosted: enhances jet p_T and MET
- Generic search for new physics in jets+MET provides sensitivity to this scenario using ≥6-jet signal regions





Summary

- Thorough program at both experiments to search for gluinos in the context of natural SUSY
  - 0, 1, 2 (same sign and opposite sign), ≥3 lepton signatures covered
  - Many variations on background techniques, kinematic variables, etc
  - Same story in all analyses: data consistent with background predictions
- Sensitivity out to nearly 1.4 TeV for light LSP
    - (And to LSP masses of ~700 GeV)
  - Keep in mind that if such a gluino exists, only ~17 pairs of them (per experiment) were produced last year!
  - Starting to see gains from combinations of searches; expect more of that in the future
- There is a lot more activity in reinterpretation than I have shown here. Many of these analyses are sensitive to many different models. See experiments' twikis for all the details:
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
- Gluino searches will have the most to gain from energy increase to 13 TeV
  - Cross your fingers!

Backup

CMS-SUS-12-024: more details

- Mutually exclusive search bins:

Bin	H_T (GeV)	E_T^{miss} (GeV)
1	400 – 500 (HT1)	125 – 150 (MET1)
2	500 – 800 (HT2)	150 – 250 (MET2)
3	800 – 1000 (HT3)	250 – 350 (MET3)
4	> 1000 (HT4)	> 350 (MET4)

Results in most sensitive bins

Observed number of events					
$N_{b\text{-jet}} \geq 3$	HT1	HT2	HT3	HT4	HT1-4
MET2	161	182	18	14	375
MET3	15	36	6	4	61
MET4	—	8	2	4	14
MET2-4	176	226	26	22	450

SM background estimates from fit					
$N_{b\text{-jet}} \geq 3$	HT1	HT2	HT3	HT4	HT1-4
MET2	157^{+13}_{-12}	179^{+13}_{-12}	$23.2^{+3.8}_{-3.4}$	$12.3^{+2.7}_{-2.3}$	372^{+19}_{-18}
MET3	$15.5^{+3.0}_{-2.6}$	$32.1^{+4.3}_{-3.8}$	$5.9^{+1.9}_{-1.5}$	$2.9^{+1.3}_{-1.0}$	$56.5^{+5.7}_{-5.4}$
MET4	—	$8.4^{+2.1}_{-1.8}$	$2.0^{+1.0}_{-0.7}$	$2.1^{+1.1}_{-0.9}$	$12.4^{+2.5}_{-2.2}$
MET2-4	173^{+13}_{-12}	220^{+14}_{-13}	$31.0^{+4.3}_{-3.8}$	$17.3^{+3.1}_{-2.8}$	441^{+20}_{-19}

SM background predictions from simulation					
$N_{b\text{-jet}} \geq 3$	HT1	HT2	HT3	HT4	HT1-4
MET2	127 ± 8	180 ± 12	27 ± 2	13 ± 1	347 ± 14
MET3	14.7 ± 0.7	30.9 ± 0.7	7.5 ± 0.4	3.9 ± 0.2	56.9 ± 2.6
MET4	—	6.1 ± 0.2	2.6 ± 0.2	2.6 ± 0.2	11.3 ± 0.3
MET2-4	141 ± 8	217 ± 12	37 ± 2	20 ± 1	415 ± 15

SM background estimates from sideband fit					
$N_{b\text{-jet}} \geq 3$	HT1	HT2	HT3	HT4	HT1-4
MET2	119^{+32}_{-19}	158^{+36}_{-24}	$28.2^{+6.9}_{-5.7}$	$10.2^{+3.5}_{-2.7}$	316^{+49}_{-37}
MET3	$15.2^{+4.3}_{-3.5}$	$27.7^{+5.8}_{-4.9}$	$5.6^{+2.6}_{-1.9}$	$2.0^{+1.5}_{-0.9}$	$50.5^{+8.2}_{-7.3}$
MET4	—	$8.3^{+2.9}_{-2.2}$	$1.9^{+1.3}_{-0.8}$	$0.4^{+0.6}_{-0.2}$	$10.5^{+3.2}_{-2.5}$
MET2-4	134^{+32}_{-20}	194^{+36}_{-26}	$35.7^{+7.5}_{-6.3}$	$12.6^{+3.8}_{-3.0}$	377^{+51}_{-42}

CMS PAS SUS-13-004: more details

- Selection details:
  - Events are categorized into mutually exclusive "boxes"

Table 1: Lepton, b-tag, kinematic, and jet multiplicity requirements for each of the ten boxes in the razor analysis. The boxes are listed in decreasing hierarchy rank. The ranking is introduced to unambiguously associate an event to a box.

	Requirements			
Box	lepton	b-tag	kinematic	jet
Dilepton Boxes				
MuEle	≥ 1 tight electron and ≥ 1 loose muon	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	≥ 2 jets
MuMu	≥ 1 tight muon and ≥ 1 loose muon	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	≥ 2 jets
EleEle	≥ 1 tight electron and ≥ 1 loose electron	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	≥ 2 jets
Single Lepton Boxes				
MuMultiJet	≥ 1 tight muon	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	≥ 4 jets
MuJet	≥ 1 tight muon	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	2 or 3 jets
EleMultiJet	≥ 1 tight electron	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	≥ 4 jets
EleJet	≥ 1 tight electron	≥ 1 b-tag	($M_R > 300$ GeV and $R^2 > 0.15$) and ($M_R > 450$ GeV or $R^2 > 0.2$)	2 or 3 jets
Hadronic Boxes				
MultiJet	none	≥ 1 b-tag	($M_R > 400$ GeV and $R^2 > 0.25$) and ($M_R > 550$ GeV or $R^2 > 0.3$)	≥ 4 jets
2b-Jet	none	≥ 2 b-tag	($M_R > 400$ GeV and $R^2 > 0.25$) and ($M_R > 550$ GeV or $R^2 > 0.3$)	2 or 3 jets

- Each of the boxes is further subdivided in bins of b-jet multiplicity
  - =1b, =2b, ≥3b

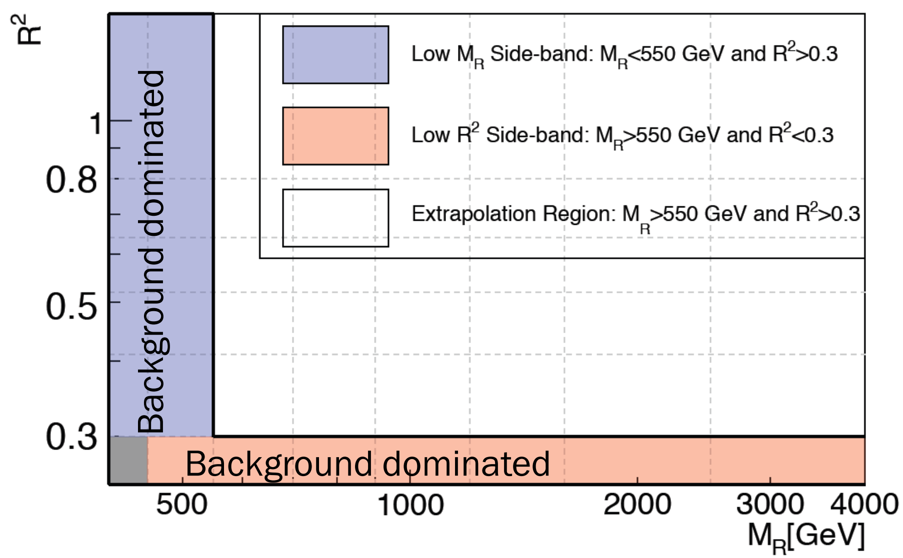
Razor analysis background estimate

- Backgrounds are parameterized using 2-d exponential:

$$f_{SM}(M_R, R^2) = [b(M_R - M_R^0)^{1/n}(R^2 - R_0^2)^{1/n} - 1]e^{-bn(M_R - M_R^0)^{1/n}(R^2 - R_0^2)^{1/n}}$$

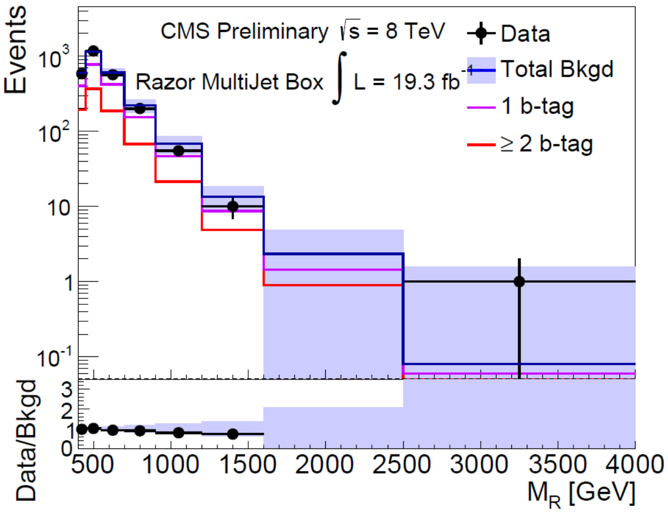
- Each "box" is analyzed independently
  - Simultaneous fit across b-tag multiplicity within a "box"
  - =2b and ≥3b bins constrained to share the same background shape

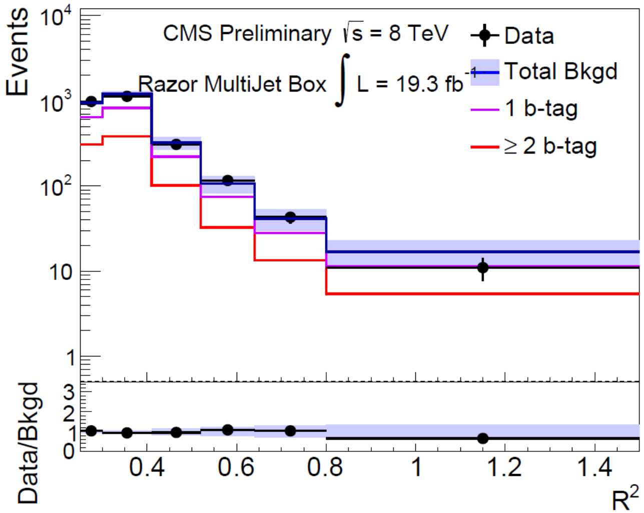
- Two types of fits:
  - Sideband fit to red/blue regions, with extrapolation to white region
    - Better for theorist reinterpretation
  - Full fit to whole plane
    - used in setting CL_s limits



Razor analysis: Example fit results

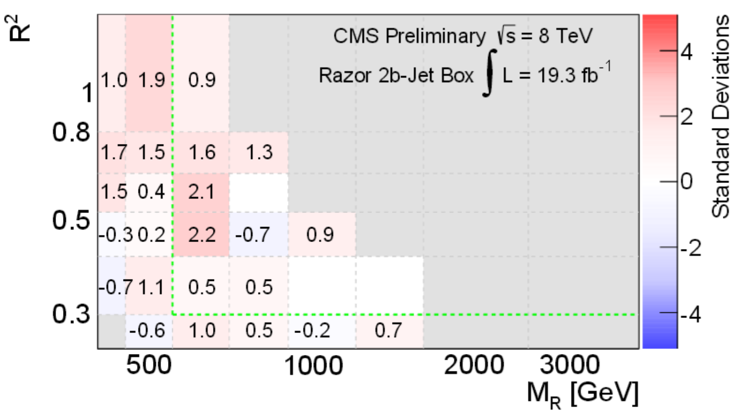
- Projections of the sideband fit, extrapolated to the full analysis region, for the multijet box

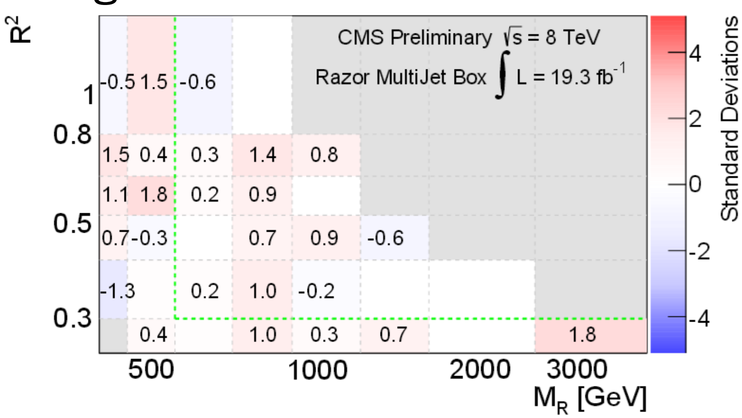




Data in agreement with predicted background

- P-values quantifying agreement of background model and data, translated into number of sigma





ATLAS CONF-2013-061: selection details

baseline selection: baseline lepton veto, $p_T^{j_1} > 90$ GeV, $E_T^{miss} > 150$ GeV, ≥ 4 jets with $p_T > 30$ GeV, $\Delta\phi_{min}^{4j} > 0.5$, $E_T^{miss}/m_{eff}^{4j} > 0.2$, ≥ 3 b-jets with $p_T > 30$ GeV

0-ℓ region	N jets	p_T jets [GeV]	E_T^{miss} [GeV]	m_{eff} [GeV]	$E_T^{miss}/\sqrt{H_T^{4j}}$ [GeV$^{\frac{1}{2}}$]
VR-0l-4j-A	≥ 4	> 30	> 150	-	< 16
VR-0l-4j-B	≥ 4	> 50	> 150	$m_{eff}^{4j} < 1000$	-
VR-0l-7j-A	≥ 7	> 30	> 150	$m_{eff}^{incl} < 1000$	-
VR-0l-7j-B	≥ 7	> 30	$150 < E_T^{miss} < 350$	$m_{eff}^{incl} < 1500$	-
SR-0l-4j-A	≥ 4	> 30	> 200	$m_{eff}^{4j} > 1000$	> 16
SR-0l-4j-B	≥ 4	> 50	> 350	$m_{eff}^{4j} > 1100$	-
SR-0l-4j-C	≥ 4	> 50	> 250	$m_{eff}^{4j} > 1300$	-
SR-0l-7j-A	≥ 7	> 30	> 200	$m_{eff}^{incl} > 1000$	-
SR-0l-7j-B	≥ 7	> 30	> 350	$m_{eff}^{incl} > 1000$	-
SR-0l-7j-C	≥ 7	> 30	> 250	$m_{eff}^{incl} > 1500$	-

baseline selection: $\geqslant 1$ signal lepton (e,μ), $p_T^{j_1} > 90$ GeV, $E_T^{miss} > 150$ GeV, ≥ 4 jets with $p_T > 30$ GeV, ≥ 3 b-jets with $p_T > 30$ GeV

1-ℓ region	N jets	E_T^{miss} [GeV]	m_T [GeV]	m_{eff}^{incl} [GeV]	$E_T^{miss}/\sqrt{H_T^{incl}}$ [GeV$^{\frac{1}{2}}$]
VR-1l-4j	≥ 4	> 150	> 100	-	-
VR-1l-6j	≥ 6	> 150	$100 < m_T < 140$	> 600	> 5
SR-1l-6j-A	≥ 6	> 175	> 140	> 700	> 5
SR-1l-6j-B	≥ 6	> 225	> 140	> 800	> 5
SR-1l-6j-C	≥ 6	> 275	> 160	> 900	> 5

CMS PAS SUS-13-007: more details

- ST_{lep} + $\Delta\phi(W,l)$ search

Table 12: Event yields in 19.4 fb^{-1} of data with $N_{jet} \geq 6$: the columns list the numbers of events observed in the control region, while for the signal region both the numbers of events expected and the numbers of events observed are listed. The uncertainty reflects the total uncertainty, while the number in parenthesis the statistical uncertainty stemming from the number of events in the control regions.

		S_T^{lep} [GeV]	control reg. data	prediction	observation
N_b=2	Muons	[250,350]	141	6.00 ± 2.40 (2.23)	9
		[350,450]	24	1.37 ± 1.19 (1.12)	2
		>450	9	0.0 ± 0.66 (0.66)	0
	Electr.	[250,350]	112	3.83 ± 1.84 (1.75)	9
		[350,450]	28	2.74 ± 2.02 (1.86)	2
		>450	9	0.0 ± 0.42 (0.42)	0
$N_b \geq 3$	Muons	[250,350]	28	1.92 ± 0.95 (0.84)	0
		[350,450]	13	0.57 ± 0.58 (0.52)	0
		>450	2	0.0 ± 0.22 (0.22)	0
	Electr.	[250,350]	45	1.89 ± 1.03 (0.94)	4
		[350,450]	7	0.85 ± 0.80 (0.70)	0
		>450	0	0.0 ± 0.08 (0.08)	0

MET+HT search

presence of four top quarks, signal events have high jet and b-jet multiplicities, so the search region is $N_{jet} \geq 6$ and $N_b \geq 2$, while the $N_{jet} \geq 4$ region provides a background enriched validation sample. In both cases, we consider three different H_T requirements, $H_T > 500, 750$, or 1000 GeV, each of which provides sensitivity to different mass ranges. The $\not{E}_T$ spectrum in these samples is divided into three search regions, [250, 350), [350, 450), and $\geq$ 450 GeV, plus a lower bin of $150 \leq \not{E}_T < 250$ GeV, which is used for additional validation.

ATLAS CONF-2013-007: more details

- Search regions

Signal region	N_{b-jets}	Signal cuts (discovery case)	Signal cuts (exclusion case)
SR0b	0	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV $m_T > 100$ GeV, $m_{eff} > 400$ GeV	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV, $m_T > 100$ GeV, binned shape fit in m_{eff} for $m_{eff} > 300$ GeV
SR1b	≥ 1	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV $m_T > 100$ GeV, $m_{eff} > 700$ GeV	$N_{jets} \geq 3$, $E_T^{miss} > 150$ GeV, $m_T > 100$ GeV, binned shape fit in m_{eff} for $m_{eff} > 300$ GeV
SR3b	≥ 3	$N_{jets} \geq 4$ -	$N_{jets} \geq 5$, $E_T^{miss} < 150$ GeV or $m_T < 100$ GeV

Table 1: Definition of the signal regions. The cuts for the discovery and exclusion cases are shown separately. For all signal regions, two leading leptons with $p_T > 20$ GeV and of the same electric charge are required. Jets are selected with $p_T > 40$ GeV while b-jets are required to have $p_T > 20$ GeV.

CMS PAS SUS-13-013

- Same-sign dileptons

Table 1: Kinematic requirements on leptons and jets that are used to define the low-p_T (high-p_T) analysis.

	$p_T(GeV)$	$\|\eta\|$
electrons	$> 10(20)$	< 2.4 and $\notin [1.442, 1.566]$
muons	$> 10(20)$	< 2.4
jets	> 40	< 2.4
b-tagged jets	> 40	< 2.4

$N_{\text{b-jets}}$	E_T^{miss} (GeV)	N_{jets}	$H_T \in [200, 400]$ (GeV)	$H_T > 400$ (GeV)
$= 0$	50-120	2-3	SR01	SR02
		≥ 4	SR03	SR04
	> 120	2-3	SR05	SR06
		≥ 4	SR07	SR08
$= 1$	50-120	2-3	SR11	SR12
		≥ 4	SR13	SR14
	> 120	2-3	SR15	SR16
		≥ 4	SR17	SR18
≥ 2	50-120	2-3	SR21	SR22
		≥ 4	SR23	SR24
	> 120	2-3	SR25	SR26
		≥ 4	SR27	SR28

ATLAS CONF 2012-151

6 Signal and control regions

The tri-lepton events are divided into four non-overlapping kinematic regions, consisting of three control regions and a signal region. The control regions are used to estimate the SM backgrounds in the signal region. The regions are:

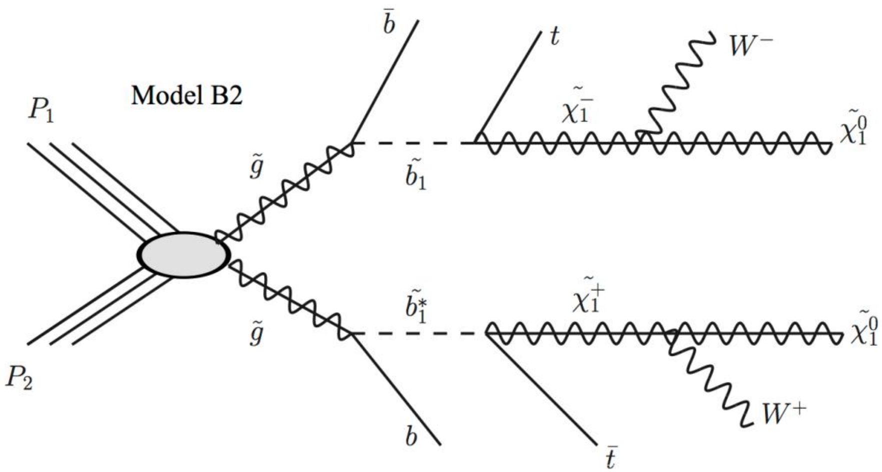
- ***Z*-boson control region** - Events have a pair of leptons with opposite charge, same flavor, and $81 < m(\ell^+\ell^-) < 101$ GeV.
- **Low-$E_{\mathrm{T}}^{\mathrm{miss}}$ control region** - Events have $E_{\mathrm{T}}^{\mathrm{miss}} < 50$ GeV and are not in the Z-boson control region.
- **$t\bar{t}$ control region** - Events have fewer than four jets, $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV, and are not in the Z-boson control region.
- **Signal region** - Events have four or more jets, $E_{\mathrm{T}}^{\mathrm{miss}} > 50$ GeV, and are not in the Z-boson control region.

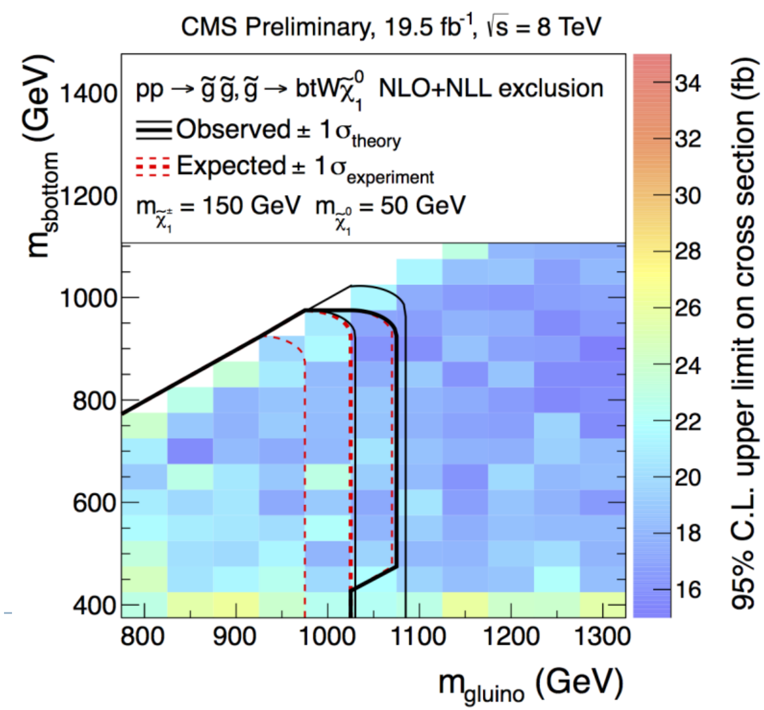
CMS SUS-13-008

- All the combinations of these requirements are used to create the 60 search regions
  - (for nb>=3, no extra jet multiplicity binning is used)

Variable	Baseline	Search Regions			
Sign/Flavor	3 e/μ	On-Z		Off-Z	
$N_{\text{b-jets}}$	≥ 1	1	2		≥ 3
N_{jets}	≥ 2	2–3		≥ 4	
H_T (GeV)	≥ 60	60–200		≥ 200	
E_T^{miss} (GeV)	≥ 50	50–100	100–200		≥ 200

Example of additional interpretation





ATLAS JHEP10 (2013) 130

- Definition of search regions

<table>
<tr><td></td><td colspan="13">Multi-jet + flavour stream</td><td colspan="3">Multi-jet + M_J^{Σ} stream</td></tr>
<tr><td>Identifier</td><td colspan="3">8j50</td><td colspan="3">9j50</td><td>$\geq$ 10j50</td><td colspan="3">7j80</td><td colspan="3">$\geq$ 8j80</td><td>$\geq$ 8j50</td><td>$\geq$ 9j50</td><td>$\geq$ 10j50</td></tr>
<tr><td>Jet $|\eta|$</td><td colspan="7">< 2.0</td><td colspan="6">< 2.0</td><td colspan="3">< 2.8</td></tr>
<tr><td>Jet p_{T}</td><td colspan="7">> 50 GeV</td><td colspan="6">> 80 GeV</td><td colspan="3">> 50 GeV</td></tr>
<tr><td>Jet count</td><td colspan="3">$= 8$</td><td colspan="3">$= 9$</td><td>≥ 10</td><td colspan="3">$= 7$</td><td colspan="3">≥ 8</td><td>≥ 8</td><td>≥ 9</td><td>≥ 10</td></tr>
<tr><td>b-jets
($p_{\mathrm{T}} > 40$ GeV, $|\eta| < 2.5$)</td><td>0</td><td>1</td><td>≥ 2</td><td>0</td><td>1</td><td>≥ 2</td><td>—</td><td>0</td><td>1</td><td>≥ 2</td><td>0</td><td>1</td><td>≥ 2</td><td colspan="3">—</td></tr>
<tr><td>M_J^{Σ} [GeV]</td><td colspan="7">—</td><td colspan="6">—</td><td colspan="3">> 340 and > 420 for each case</td></tr>
<tr><td>$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$</td><td colspan="7">$> 4$ GeV$^{1/2}$</td><td colspan="6">> 4 GeV$^{1/2}$</td><td colspan="3">> 4 GeV$^{1/2}$</td></tr>
</table>

Table 1: Definition of the nineteen signal regions. The jet $|\eta|$, p_{T} and multiplicity all refer to the $R = 0.4$ jets. Composite jets with the larger radius parameter $R = 1.0$ are used in the multi-jet + M_J^{Σ} stream when constructing M_J^{Σ}. A long dash '—' indicates that no requirement is made.

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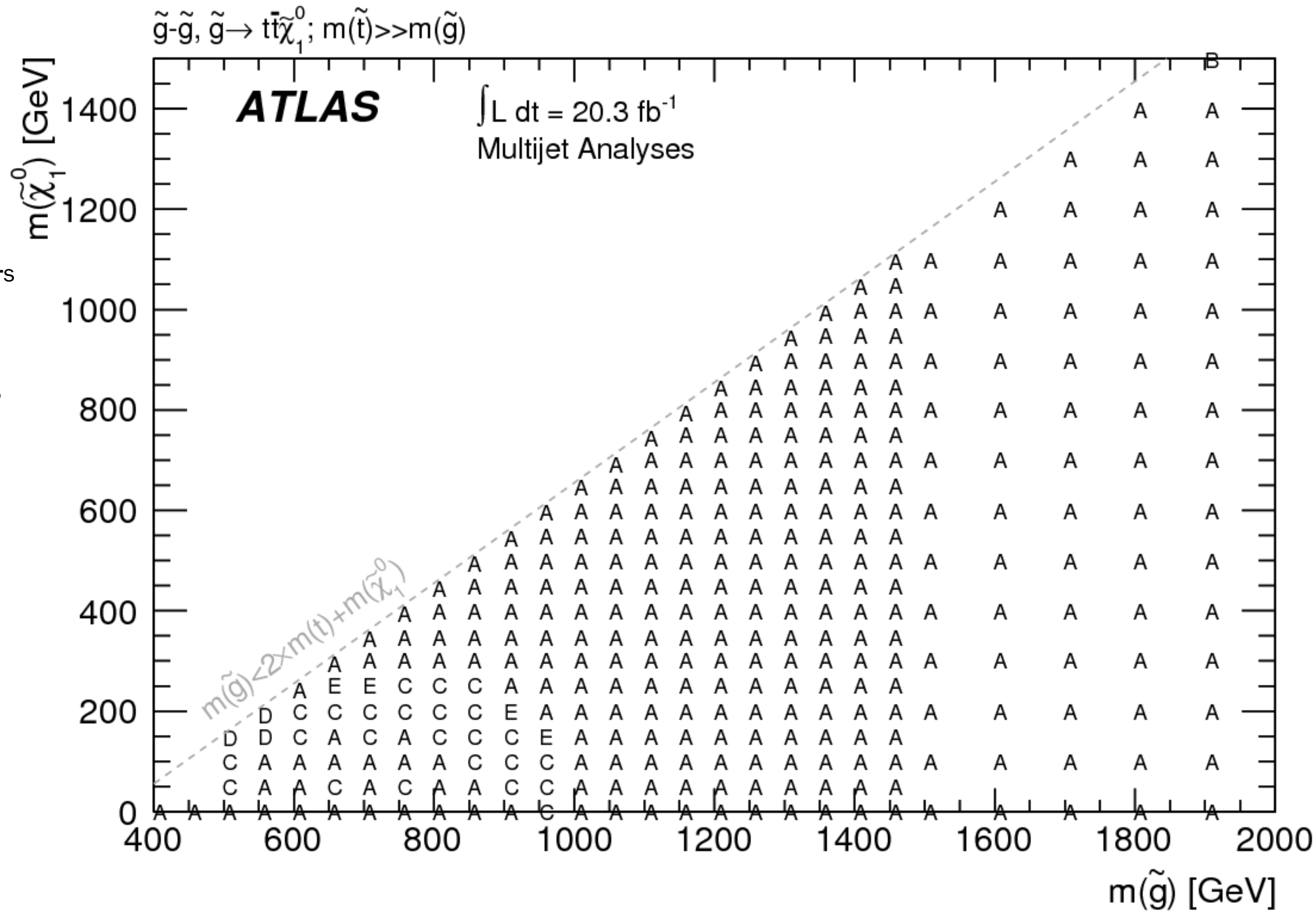
- Most sensitive search region

The SR with the best expected CL_s value for each of the interpretations. Each letter corresponds to a signal region as follows

A: j50 SRs of the flavour stream,
B: j80 SRs of the flavour stream,
C: 8j50 and M_J^{Σ}>340 GeV SR,
D: 8j50 and M_J^{Σ}>420 GeV SR,
E: 9j50 and M_J^{Σ}>340 GeV SR
F: 9j50 and M_J^{Σ}>420 GeV SR,
G: 10j50 and M_J^{Σ}>340 GeV SR,
H: 10j50 and M_J^{Σ}>420 GeV SR.



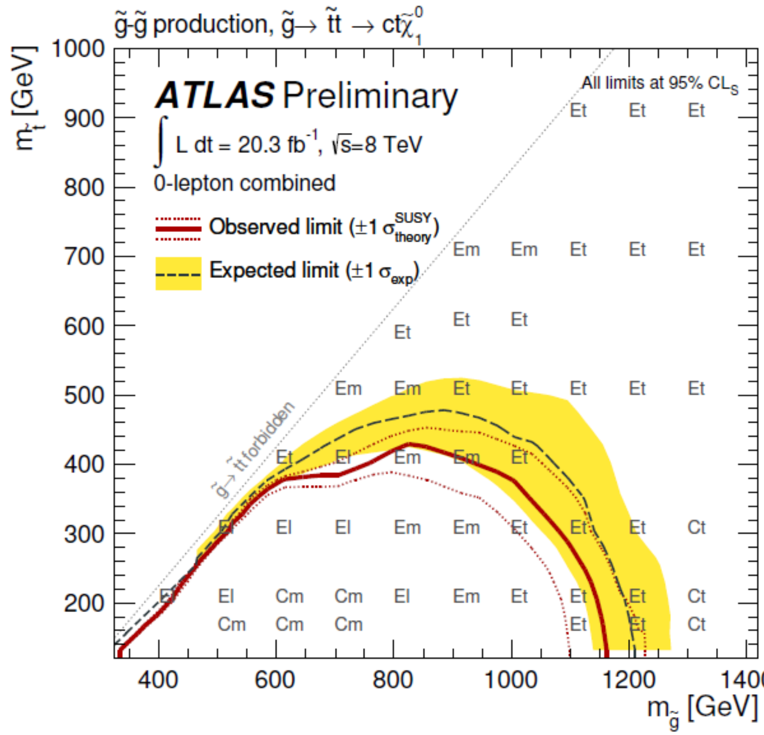
ATLAS-CONF-2013-047 details

- Search regions:

Requirement	A (2-jets)		B (3-jets)		C (4-jets)		D (5-jets)	E (6-jets)		
	L	M	M	T	M	T	–	L	M	T
E_T^{miss}[GeV] >	160									
$p_T(j_1)$ [GeV] >	130									
$p_T(j_2)$ [GeV] >	60									
$p_T(j_3)$ [GeV] >	–		60		60		60	60		
$p_T(j_4)$ [GeV] >	–		–		60		60	60		
$p_T(j_5)$ [GeV] >	–		–		–		60	60		
$p_T(j_6)$ [GeV] >	–		–		–		–	60		
$\Delta\phi(\text{jet}_i, E_T^{miss})_{min}$ >	0.4 ($i = \{1, 2, (3 \text{ if } p_T(j_3) > 40 \text{ GeV})\}$)				0.4 ($i = \{1, 2, 3\}$), 0.2 ($p_T > 40$ GeV jets)					
$E_T^{miss}/m_{eff}(Nj)$ >	0.2	–[a]	0.3	0.4	0.25	0.25	0.2	0.15	0.2	0.25
m_{eff}(incl.) [GeV] >	1000	1600	1800	2200	1200	2200	1600	1000	1200	1500

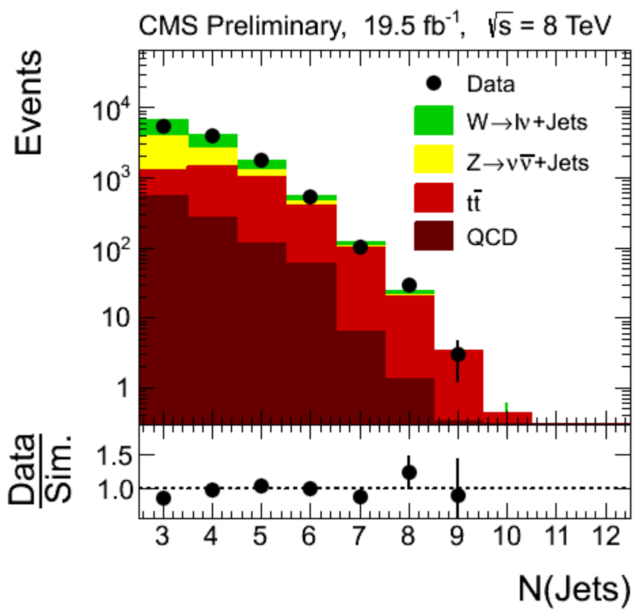
(a) For SR A-medium the cut on $E_T^{miss}/m_{eff}(Nj)$ is replaced by a requirement $E_T^{miss}/\sqrt{H_T} > 15$ GeV$^{1/2}$.

Search region with best expected sensitivity:



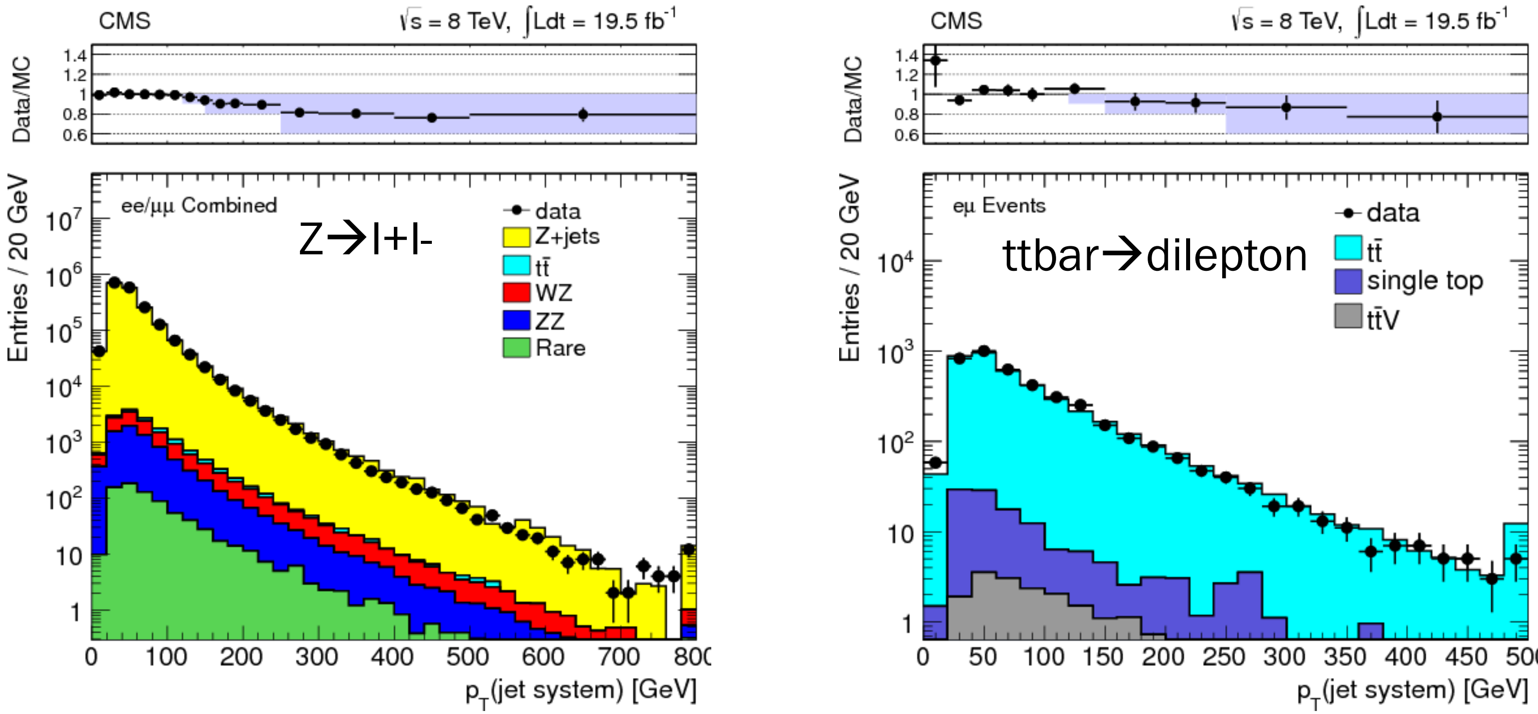
High jet multiplicity

- Veto leptons, look for very high jet multiplicity from 4 hadronically-decaying W's
- Selection:
  - Bins of jet multiplicity
    - [3-5], [6-7], [>=8]
  - Bins of MET, HT
  - (no b-tagging in this search)
- Interpretation in natural SUSY topology (4 tops) in progress....



Signal Simulation in CMS

- Signal Monte Carlo samples generated with Madgraph with up to 2 additional partons
  - Studies done using Z+jets and ttbar+jets control samples to quantify agreement of ISR radiation in data and MC
- Correction to/uncertainty on p_T spectrum of gen-level SUSY system derived from these comparisons
  - Correction from 0-20%
  - Uncertainty from 0-20%
- This (conservative) procedure allows us to interpret our results even in regimes where the boost of the SUSY system from ISR is important



Search using Jets+α_T

- α_T variable very effective at QCD rejection $\alpha_T = \frac{\sqrt{E_T^{J_2}/E_T^{J_1}}}{\sqrt{2(1-\cos\Delta\phi_{J_1 J_2})}}$

Randall, Tucker-Smith
*PRL **101** 221803, 2008*

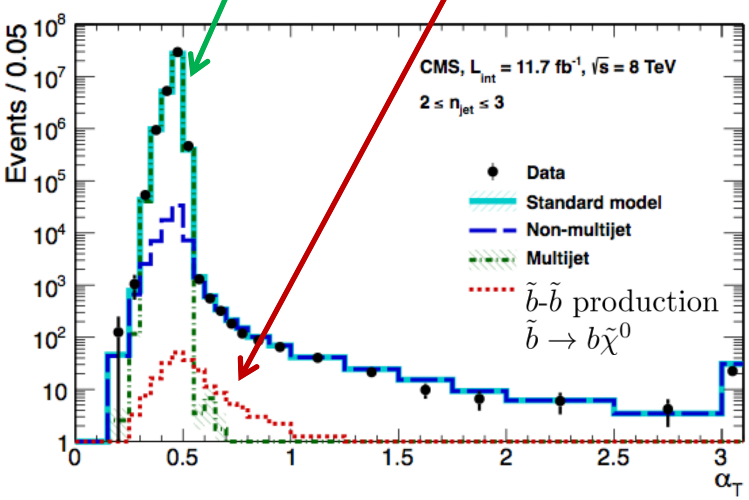
QCD

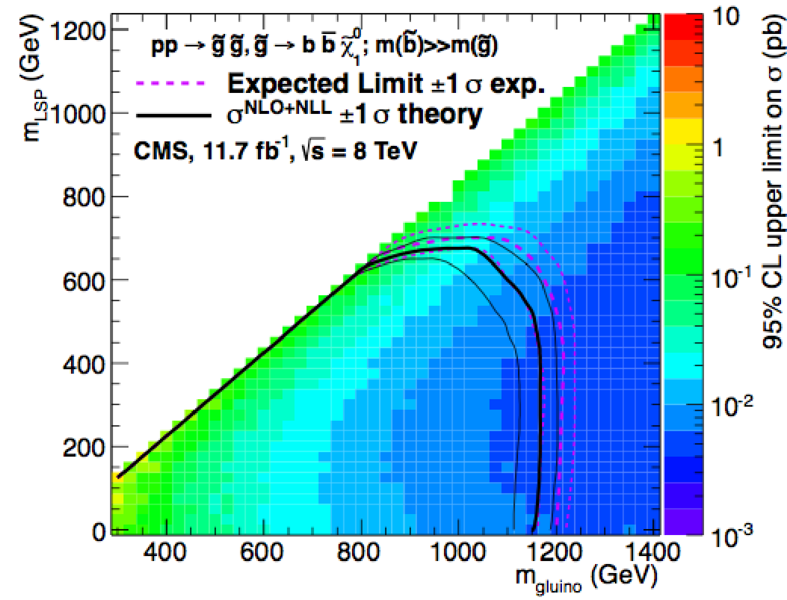
$$\alpha_T \approx \frac{\sqrt{E_T^{J_2}/E_T^{J_1}}}{2} \leq \frac{1}{2}$$

SUSY

$$\alpha_T \approx \frac{\sqrt{E_T^{J_2}/E_T^{J_1}}}{\Delta\phi_{J_1 J_2}}$$

For multijet events, form 2 pseudo-jets





- Inclusive search, binned in:
  - H_T, jet multiplicity (2-3, ≥4), n b-tags
- Many interpretations in squark and gluino production models
- 11.7 fb^{-1}: EPJC 73 (2013) 2568