0-Lepton SUSY analysis in ATLAS

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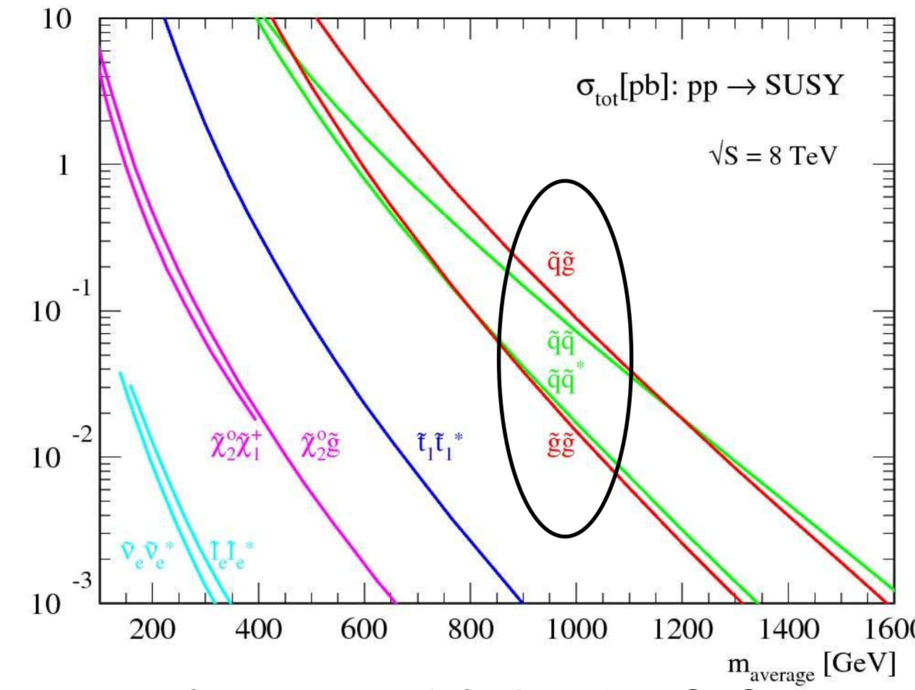
Results based on 2012 data set
collected by ATLAS at emc = 8 TeV
L = 20.3 fb^{-1}

Introduction

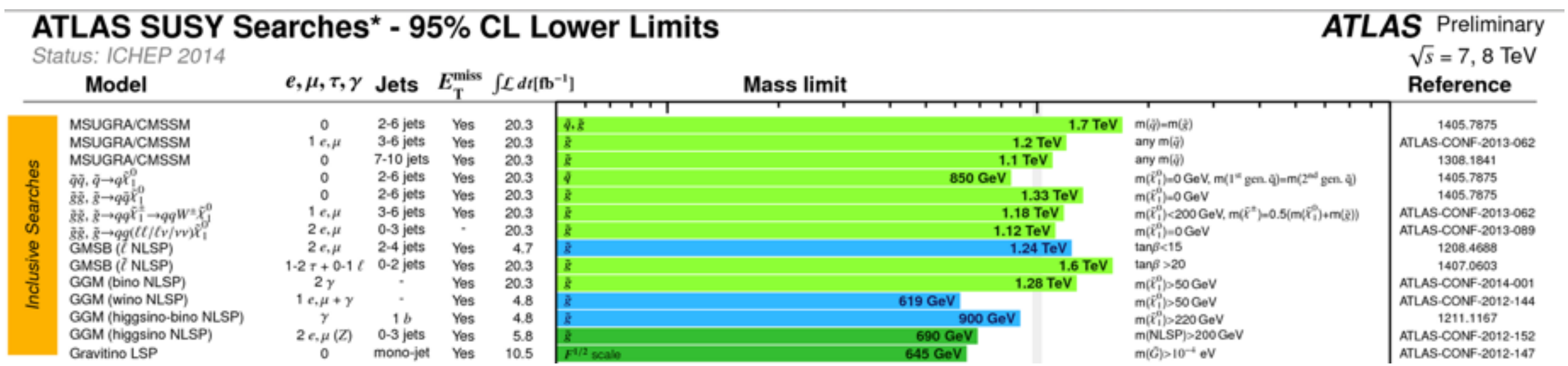
SUSY in strong production

If SUSY is present at TeV scale, squarks and gluinos may be produced at LHC

- Gluinos and squarks decay either directly or via a cascade into:
  - **Jets**, coming from gluinos and squarks decays
  - **LSP** (the Lightest Supersymmetric Particle), escaping the detector and resulting in MET (assuming R-parity conservation)
  - and **Leptons**, coming from chargino, neutrino or slepton decays



from Marc Hohlfeld's talk at SUSY13



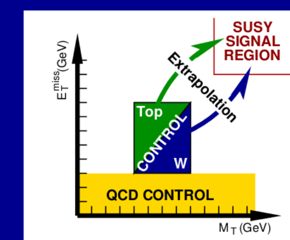
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/ATLAS_SUSY_Summary/ATLAS_SUSY_Summary.eps

Search Strategy (common for SUSY searches)

How do we search for SUSY?

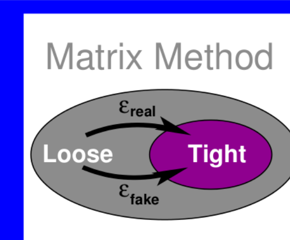
SM Backgrounds:
top pairs, single top, V+jets, dibosons, multijets,...

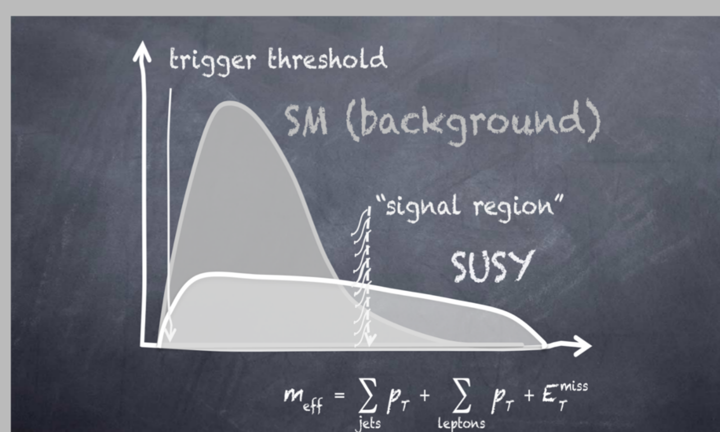
Main irreducible Backgrounds:
- Normalize MC prediction in dedicated Control Regions
- Extrapolate to Signal Regions using MC



Minor irreducible Backgrounds:
- Pure MC based prediction

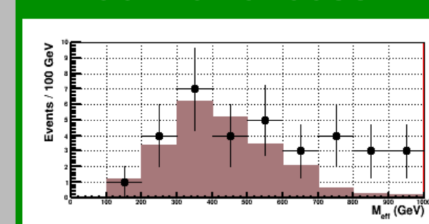
Reducible (fake) Backgrounds:
- Fully data driven method
  - Matrix method
  - Jet smearing
  - Templates





Validation Region:
- Cross check background predictions
- Closer to SR

Signal Region:
- Look for excess



Combined global fit:
Consider experimental and theoretical uncertainties

from Marc Hohlfeld's talk at SUSY13

Event Selection

0-Lepton + 2-6 jets

Very powerful analysis requiring 2-6 jets, MET and no leptons

Requirement	Signal Region					
	2jl	2jm	2jt	2jW	3j	4jW
E_T^{miss}[GeV] >	160					
$p_T(j_1)$ [GeV] >	130					
$p_T(j_2)$ [GeV] >	60					
$p_T(j_3)$ [GeV] >	–				60	40
$p_T(j_4)$ [GeV] >	–					40
$\Delta\phi(\text{jet}_{1,2,(3)}, \mathbf{E}_T^{miss})_{min}$ >	0.4					
$\Delta\phi(\text{jet}_{i>3}, \mathbf{E}_T^{miss})_{min}$ >	–					0.2
W candidates	–			$2(W \to j)$	–	$(W \to j) + (W \to jj)$
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] >	8	15		–		
$E_T^{miss}/m_{eff}(N_j)$ >	–			0.25	0.3	0.35
m_{eff}(incl.) [GeV] >	800	1200	1600	1800	2200	1100

Requirement	Signal Region								
	4jl-	4jl	4jm	4jt	5j	6jl	6jm	6jt	6jt+
E_T^{miss}[GeV] >	160								
$p_T(j_1)$ [GeV] >	130								
$p_T(j_2)$ [GeV] >	60								
$p_T(j_3)$ [GeV] >	60								
$p_T(j_4)$ [GeV] >	60								
$p_T(j_5)$ [GeV] >	–				60				
$p_T(j_6)$ [GeV] >	–					60			
$\Delta\phi(\text{jet}_{1,2,(3)}, \mathbf{E}_T^{miss})_{min}$ >	0.4								
$\Delta\phi(\text{jet}_{i>3}, \mathbf{E}_T^{miss})_{min}$ >	0.2								
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$] >	10		–						
$E_T^{miss}/m_{eff}(N_j)$ >	–		0.4	0.25	0.2			0.25	0.15
m_{eff}(incl.) [GeV] >	700	1000	1300	2200	1200	900	1200	1500	1700

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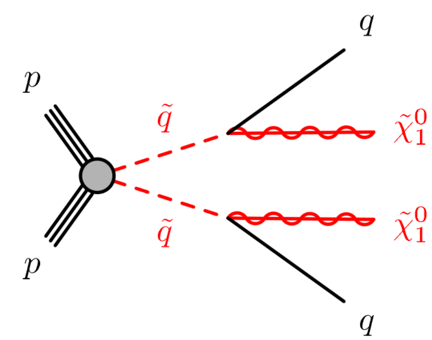
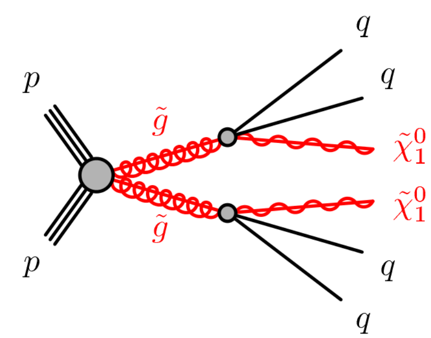


(Examples)



Main discriminating variables:

- $\Delta\phi(jet, E_T^{miss})$
- $m_{eff}(incl.)$
- $E_T^{miss}/\sqrt{H_T}$ or $E_T^{miss}/m_{eff}(N_J)$

$$m_{eff} \equiv \sum_{i=1}^{n} |p_T^i| + E_T^{miss}, \; H_T \equiv \sum_{i=1}^{n} |p_T^i|$$

Background Estimation

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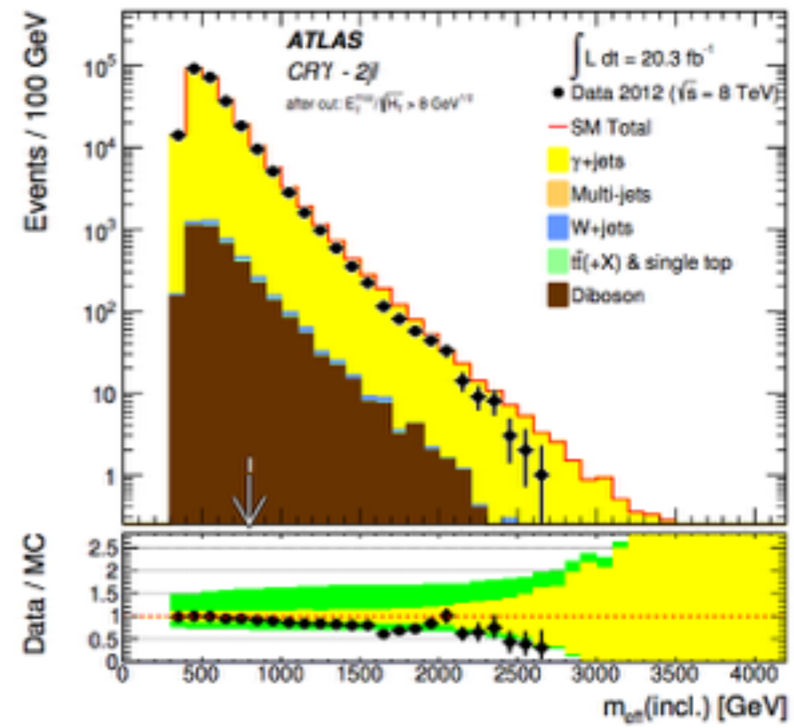

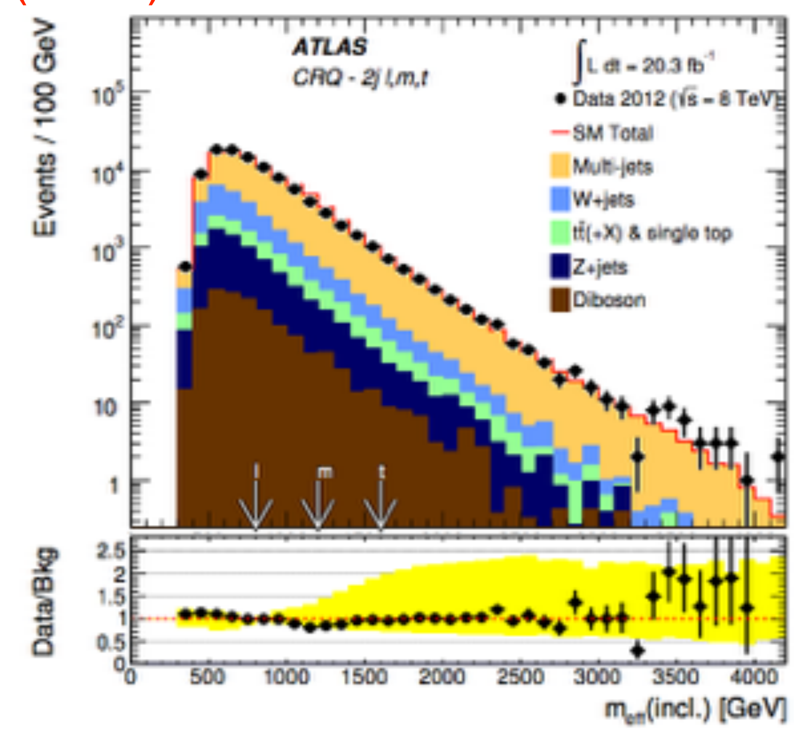

Main background sources:

- **Z+jets** with Z decaying in $\nu\nu$
- **W+jets**
- **ttbar**, **singletop**
- **QCD** multijets

4 Control Regions are assigned to each of the 15 Signal Regions to constrain background

CR	SR background	CR process	CR selection
CRγ	$Z(\rightarrow \nu\nu)$+jets	γ+jets	Isolated photon
CRQ	Multi-jets	Multi-jets	SR with reversed requirements on (i) $\Delta\phi(\text{jet}, \mathbf{E}_{\mathrm{T}}^{\mathrm{miss}})_{\min}$ and (ii) $E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}(N_{\mathrm{j}})$ or $E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$
CRW	$W(\rightarrow \ell\nu)$+jets	$W(\rightarrow \ell\nu)$+jets	$30\,\mathrm{GeV} < m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 100\,\mathrm{GeV}$, b-veto
CRT	$t\bar{t}$ and single-t	$t\bar{t} \rightarrow b\bar{b}qq'\ell\nu$	$30\,\mathrm{GeV} < m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) < 100\,\mathrm{GeV}$, b-tag

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Background Estimation & Results

Background Extrapolation to the SRs:

- MC predictions are normalised via a Likelihood fit in dedicated control regions (CRs)
- Number of expected events in each SR is extrapolated from the CR using a transfer factor

$$N(\mathrm{SR, scaled}) = N(\mathrm{CR, obs}) \times \left[\frac{N(\mathrm{SR, unscaled})}{N(\mathrm{CR, unscaled})}\right]$$

- Multijet events are estimated using a fully data-driven technique: the smearing method

Signal Region	2jl	2jm	2jt	2jW	3j
Total bkg	13000 ± 1000	760 ± 50	125 ± 10	2.3 ± 1.4	5.0 ± 1.2
Observed	12315	715	133	0	7
$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb]	60	4.3	1.9	0.16	0.40
$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb] (asymptotic)	62	4.0	1.8	0.12	0.40
S^{95}_{obs}	1200	90	38	3.2	8.2
S^{95}_{obs} (asymptotic)	1300	80	37	2.5	8.1
S^{95}_{exp}	1700^{+600}_{-500}	110^{+40}_{-30}	32^{+11}_{-10}	$4.0^{+1.7}_{-0.7}$	$6.4^{+2.9}_{-1.3}$
S^{95}_{exp} (asymptotic)	1600^{+600}_{-400}	110^{+40}_{-30}	31^{+12}_{-8}	$4.1^{+2.4}_{-1.4}$	$6.3^{+3.2}_{-2.0}$
p_0 (Z)	0.50 (0.0)	0.49 (0.0)	0.29 (0.5)	0.50 (0.0)	0.24 (0.7)

Signal Region	4jl-	4jl	4jm	4jt	4jW
Total bkg	2120 ± 110	630 ± 50	37 ± 6	2.5 ± 1.0	14 ± 4
Observed	2169	608	24	0	16
$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb]	13	4.5	0.52	0.15	0.68
$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb] (asymptotic)	13	4.3	0.45	0.12	0.63
S^{95}_{obs}	270	91	10	3.1	14
S^{95}_{obs} (asymptotic)	270	87	9	2.5	13
S^{95}_{exp}	240^{+90}_{-70}	103^{+34}_{-29}	16^{+6}_{-4}	$4.0^{+1.8}_{-0.9}$	11^{+5}_{-3}
S^{95}_{exp} (asymptotic)	240^{+90}_{-70}	97^{+35}_{-25}	15^{+6}_{-4}	$4.0^{+2.4}_{-1.4}$	11^{+5}_{-3}
p_0 (Z)	0.35 (0.4)	0.50 (0.0)	0.50 (0.0)	0.50 (0.0)	0.34 (0.4)

Signal Region	5j	6jl	6jm	6jt	6jt+
Total bkg	126 ± 13	111 ± 11	33 ± 6	5.2 ± 1.4	4.9 ± 1.6
Observed	121	121	39	5	6
$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb]	1.7	1.9	1.2	0.32	0.39
$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb] (asymptotic)	1.6	1.8	1.1	0.30	0.36
S^{95}_{obs}	35	39	25	6.6	7.9
S^{95}_{obs} (asymptotic)	32	37	22	6.1	7.3
S^{95}_{exp}	37^{+13}_{-10}	31^{+12}_{-6}	20^{+6}_{-4}	$6.2^{+2.6}_{-1.3}$	$6.6^{+2.6}_{-1.6}$
S^{95}_{exp} (asymptotic)	35^{+13}_{-10}	30^{+12}_{-8}	18^{+7}_{-5}	$6.3^{+3.1}_{-2.0}$	$6.4^{+3.2}_{-2.0}$
p_0 (Z)	0.50 (0.0)	0.27 (0.6)	0.25 (0.7)	0.50 (0.0)	0.36 (0.4)

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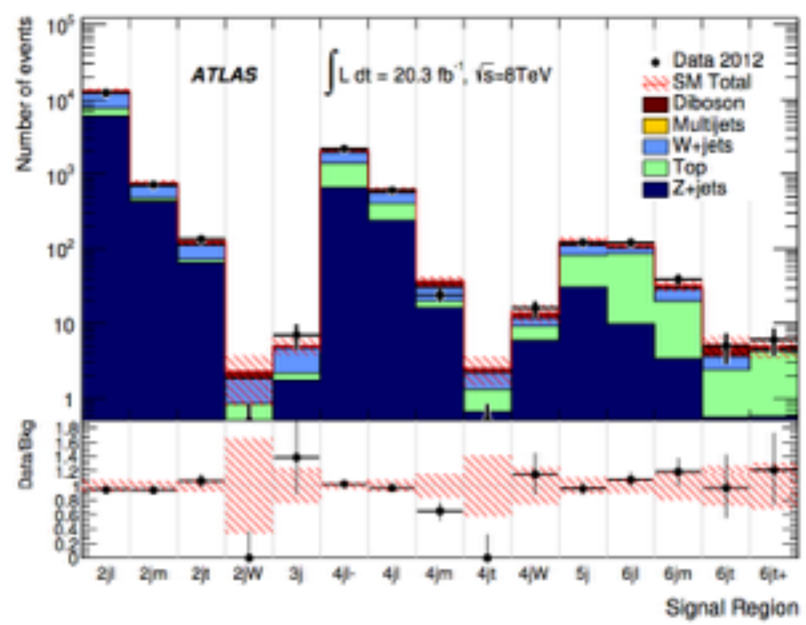
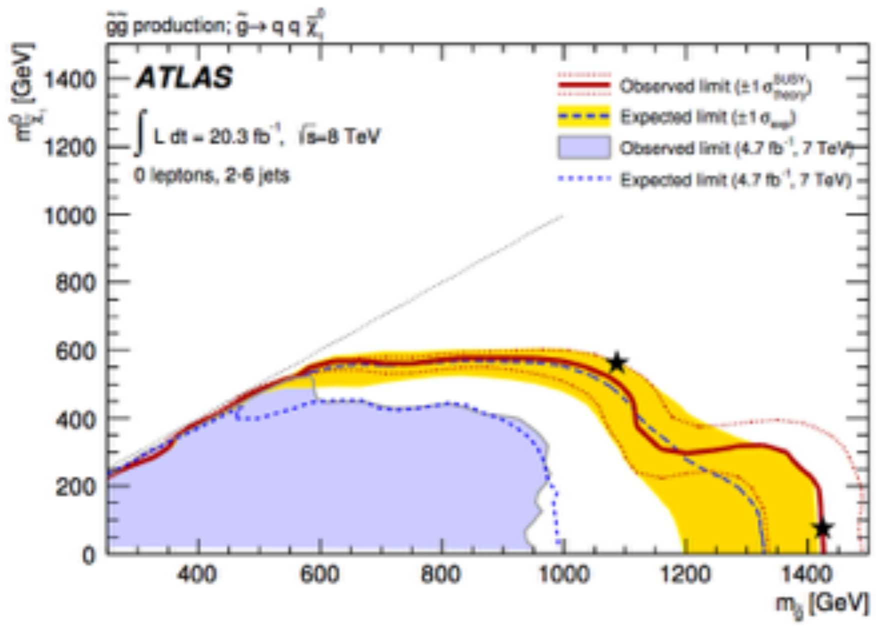


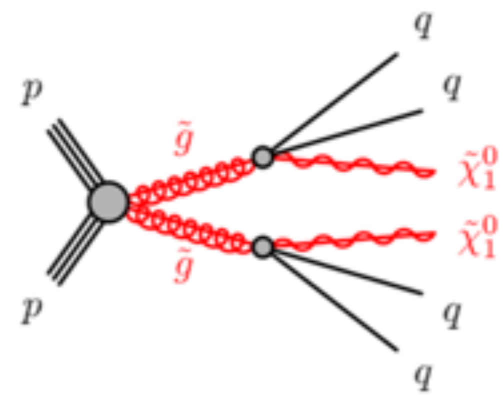
Interpretations - 1

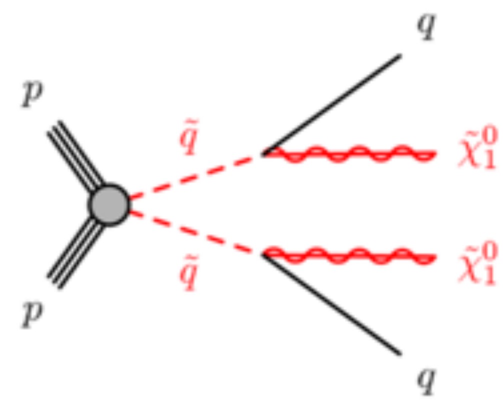
For each signal point, the signal region with the best expected sensitivity is used to set the exclusion limits. The expected and observed limits are shown at 95 % CL with 1 σ band due to experimental and theoretical uncertainties.

Simplified Models: direct decay of gluinos/squarks

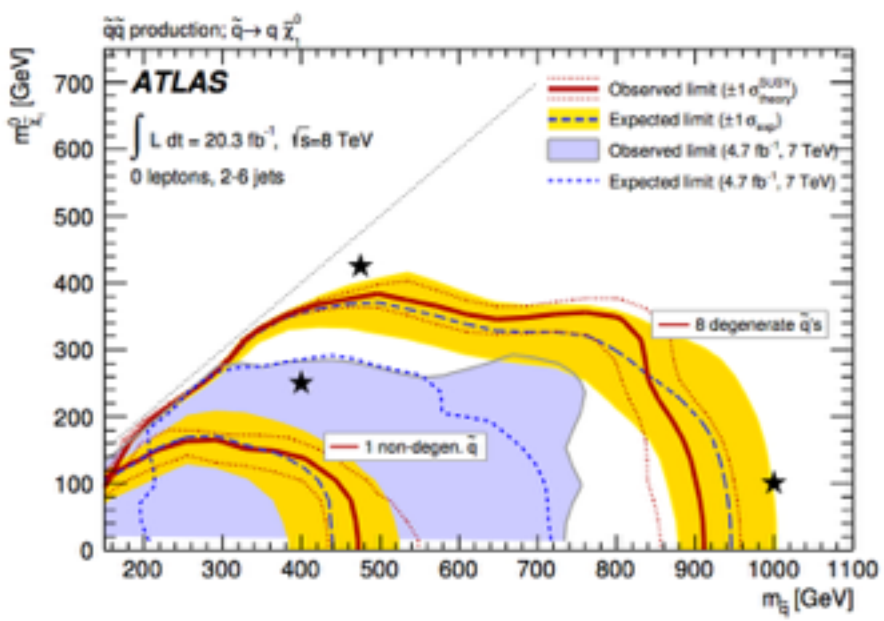


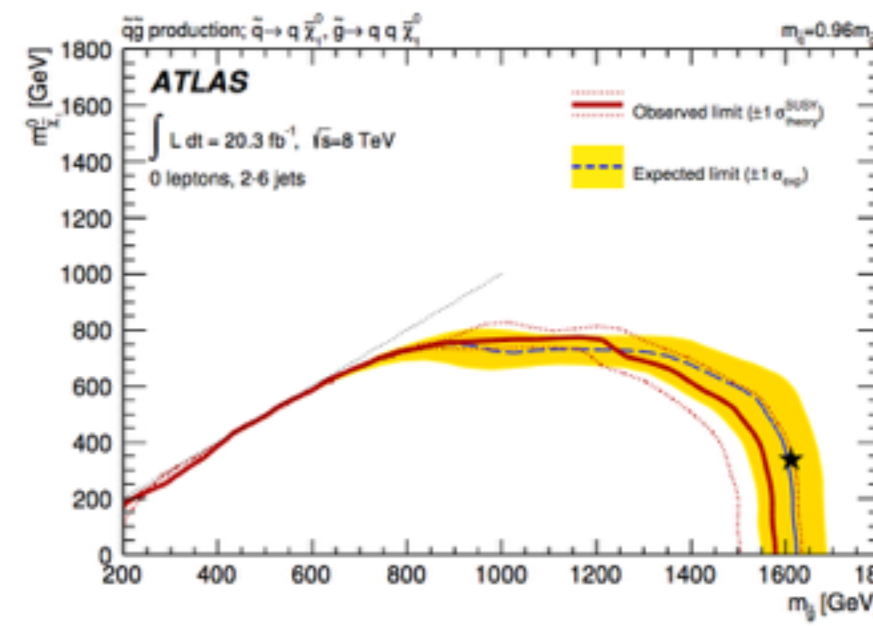
gluino pair-production





squark pair-production





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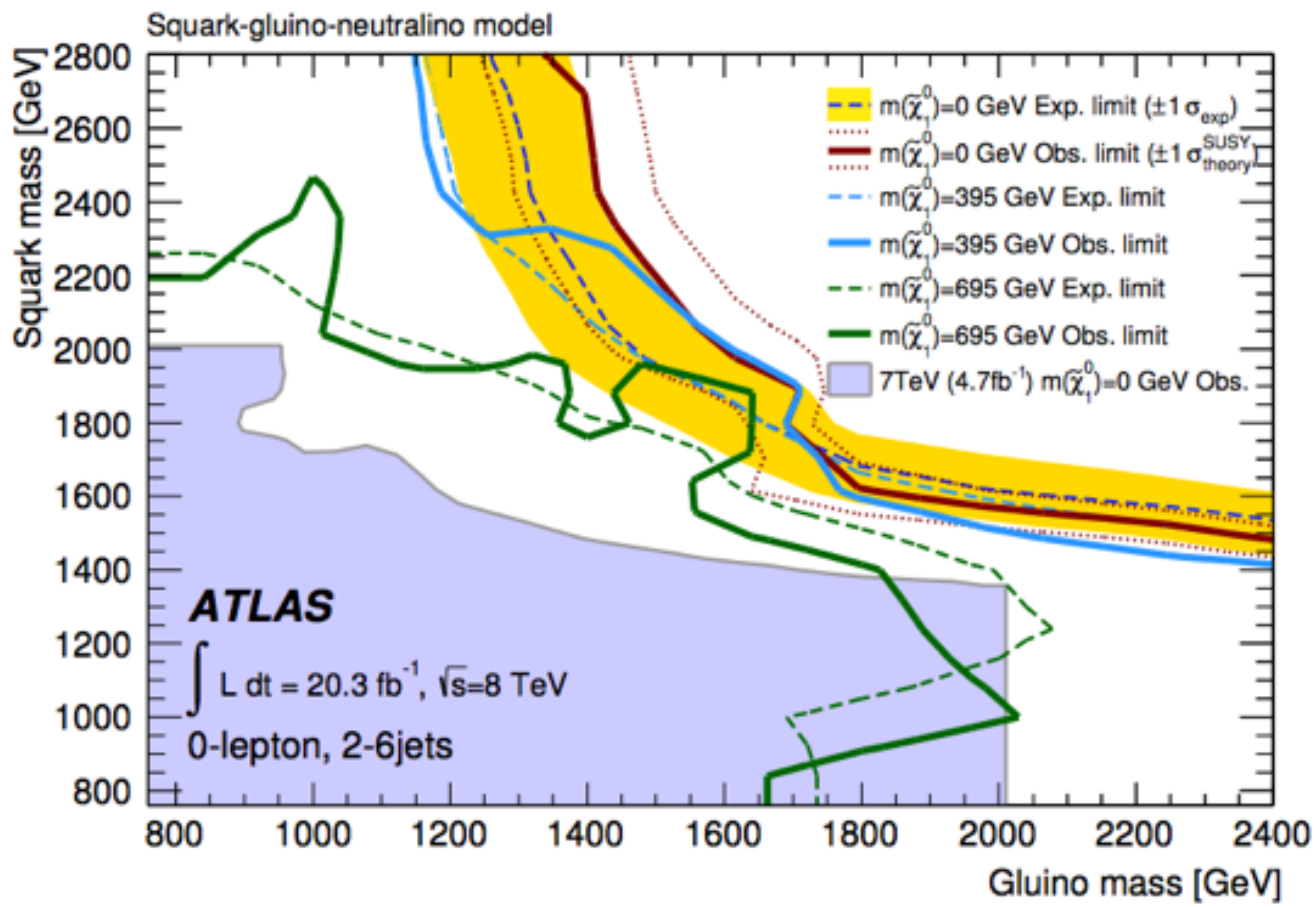
Interpretations - 2

Simplified Phenomenological MSSM



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Model with only strong production of $\tilde{g}$ and first- and second-generation $\tilde{q}$ with direct decays to jets and lightest $\tilde{\chi}^0_1$ (0.395 GeV, 695 GeV).

Metastable Gluinos

Motivation

- In some models of supersymmetry, the gluino is "metastable" and travels a measurable distance before decaying in the detector to quarks (or a gluon) and a neutralino.
  - ➡ The observed value of the Higgs boson mass indicates squark masses around 10^3–10^5 TeV for small values of tanβ
  - ➡ For these squark masses, a 1 TeV gluino could be metastable and decay within the detector with a visible decay length

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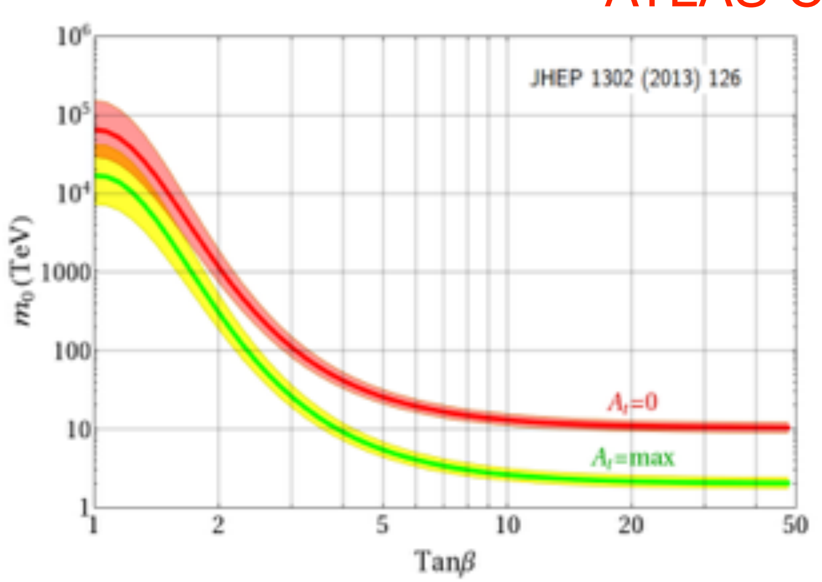
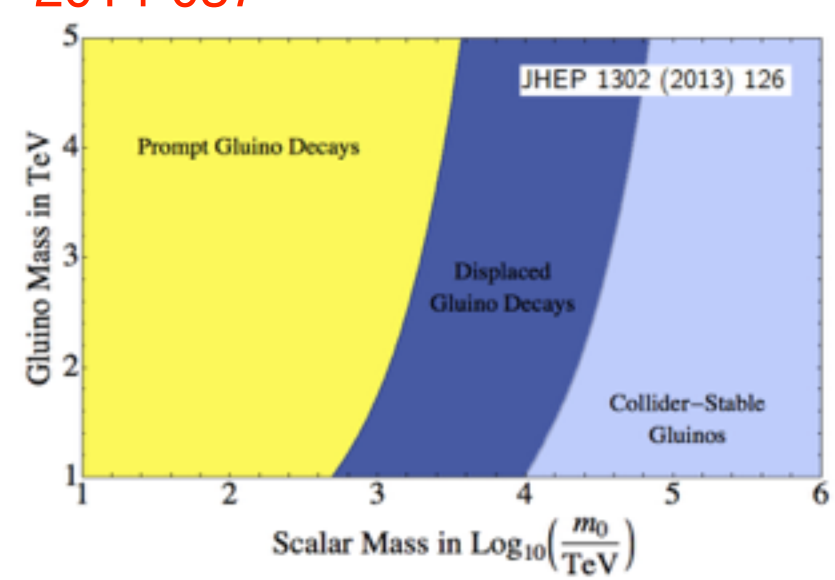
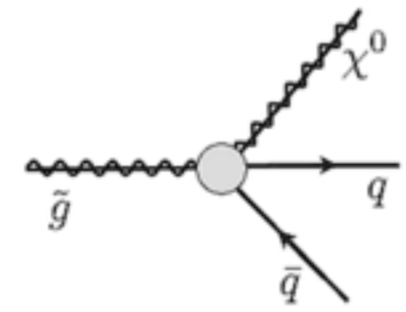


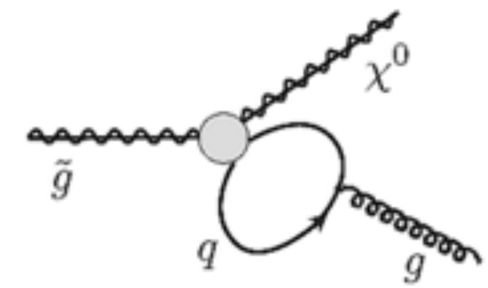


- Two ATLAS searches for promptly decaying SUSY are re-interpreted in the context of models with metastable (ps – ns lifetime) gluinos
  - ➡ 0Lepton (2-6 jets) analysis JHEP 09 (2014) 176: 15 signal regions based on: [2, 3, 4, 5, ≥6] jets,MET
  - ➡ 0Lepton (7-10 jets) analysis JHEP, 10 (2013) 130: 19 signal regions based on: [7, 8, 9, ≥10] jets, [0,1, ≥2] b-tagged jets , MET

Metastable Gluinos

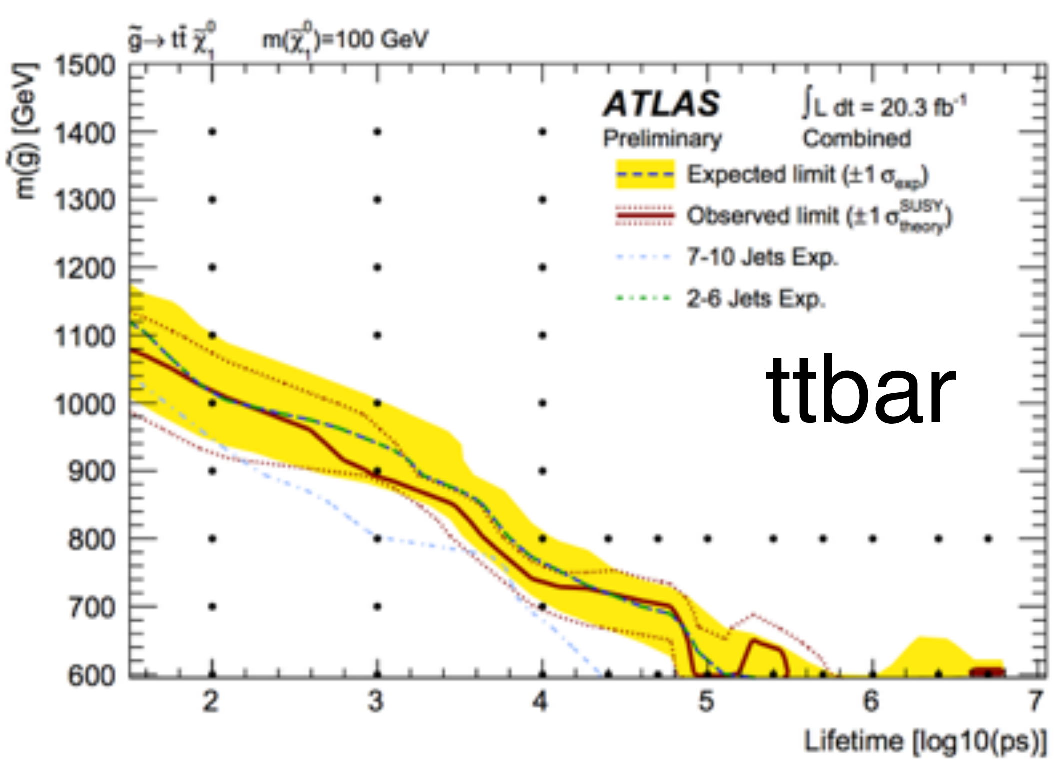
- Decay models considered:
  - ➡ stop as the lightest squarks: $\tilde{g} \to t\bar{t}\tilde{\chi}^0_1$.
  - ➡ mass-degenerate squark flavor scenario with equal branching ratios of the two decays: $\tilde{g} \to q\bar{q}\tilde{\chi}^0_1$, $\tilde{g} \to g\tilde{\chi}^0_1$.



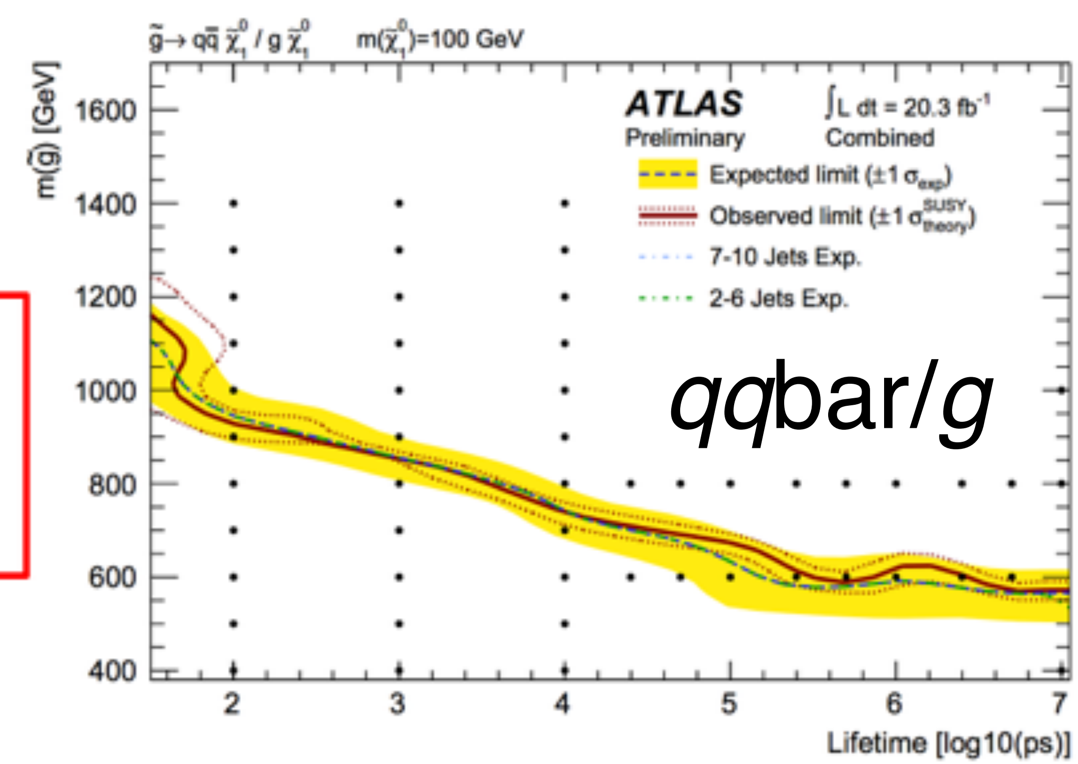


For ttbar decay model, both analyses can be used to set limits

For qqbar/g decay model the 7-10 jet analysis has no sensitivity



Excluded for τ=1ns, $m_{\tilde{\chi}^0_1}$ = 100GeV:
ttbar: $m_{\tilde{g}}$ < 900GeV
qqbar/g: $m_{\tilde{g}}$ < 850



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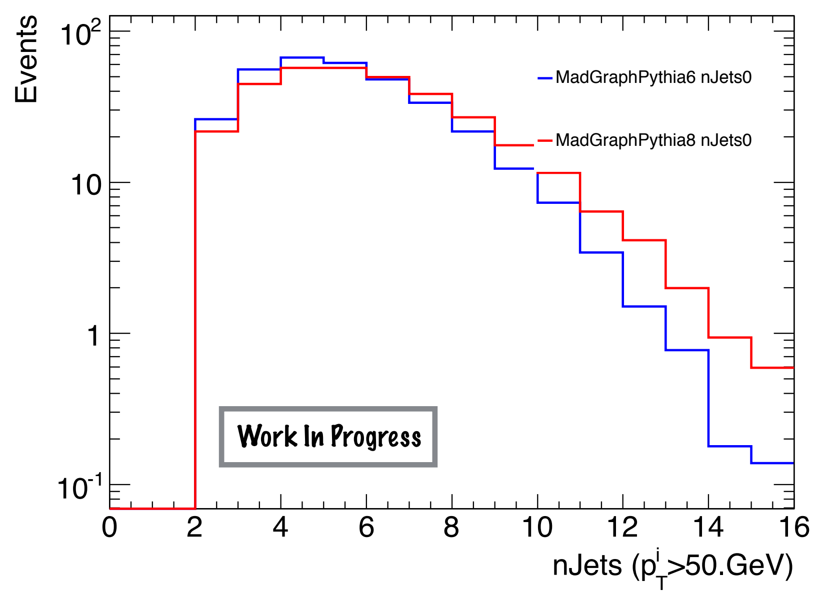
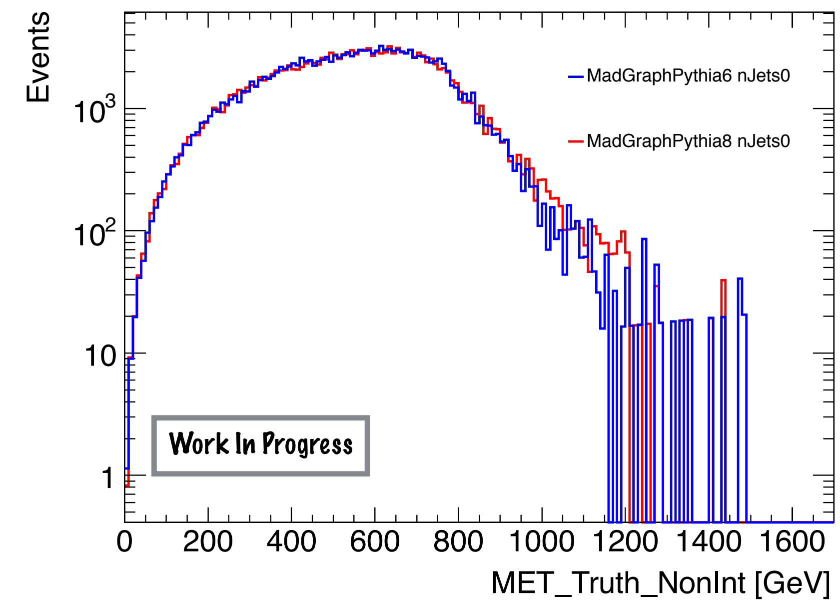
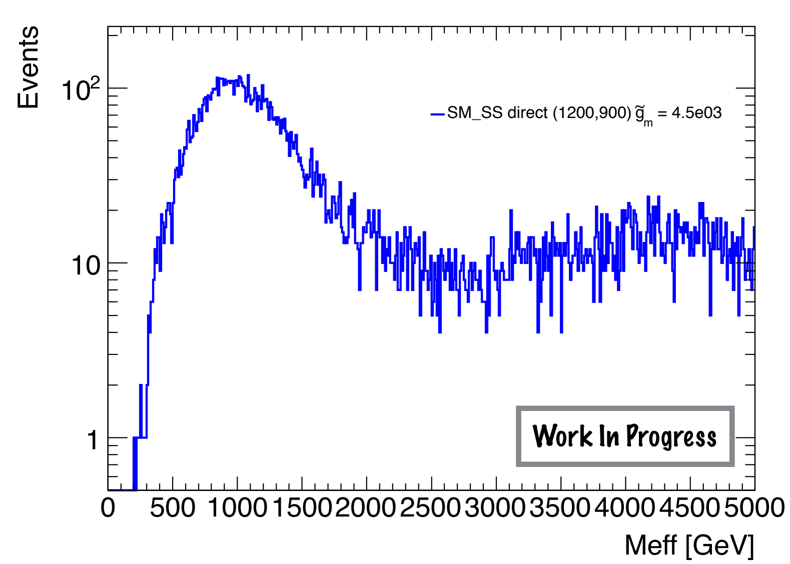
MC studies on SUSY signals

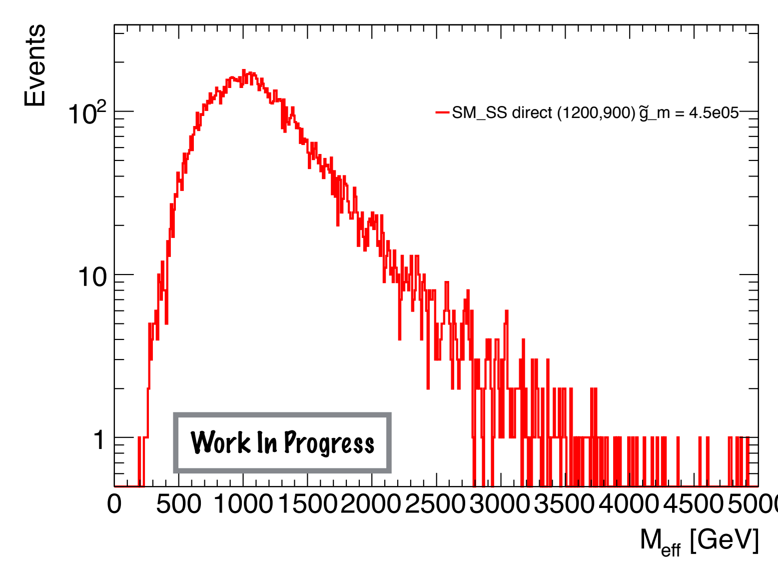
- Several studies are ongoing towards the RunII
- Signal modeling is crucial for robustness of the analysis
- Studies on MadGraph+Pythia6 or Pythia8 on SM_SS_direct (800,50) ecm= 8 TeV, truth level





- Studies on SM_SS_direct (1200,900) ecm= 14 TeV, truth level





Summary

- Presented the 0Lepton (2-6 jets) SUSY search in ATLAS data
- The analysis has been published
- No significant excess above SM has been found
- Limits are placed on gluino mass (up to 1350 GeV) and squark mass (up to 850 GeV), depending on the scenario
- Several reinterpretations has been performed: metastable gluinos have been publicly performed and presented
- Many studies are ongoing towards RunII! Presented a MC generators study
- Looking forward to 2015 new data!

Thank you for your attention!

BACKUP

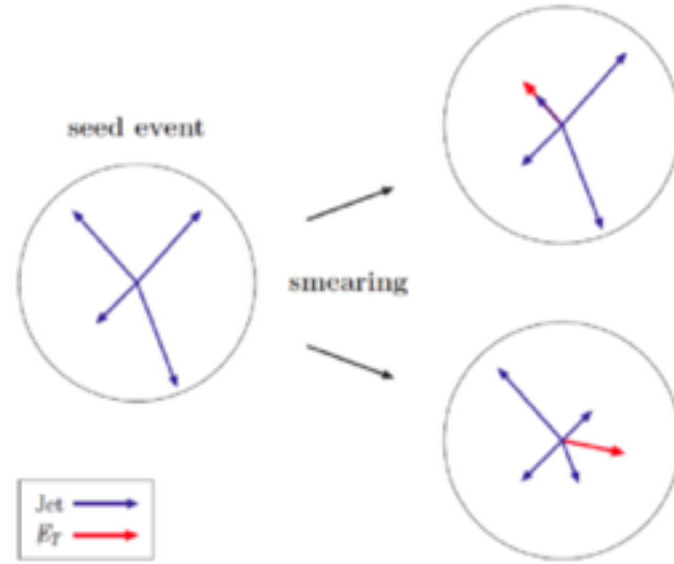
0-Lepton: Jet Smearing Method

- Select well measured seed events with low MET significance (S)

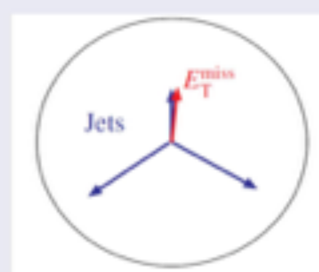
$$S = \frac{E_T^{miss}}{\sum |\vec{E}_T^{miss}|}$$

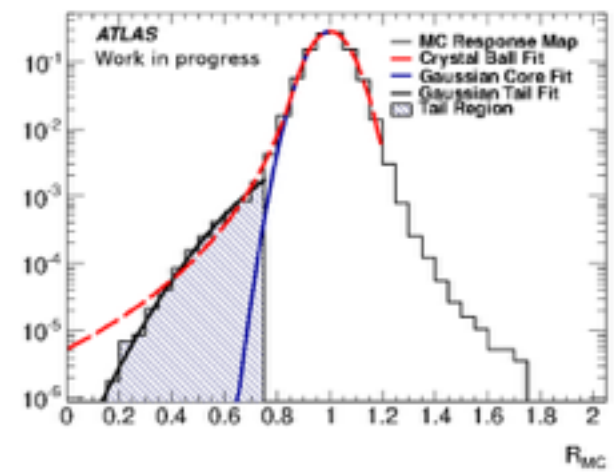
- *Smear* the jets in the seed event by multiplying the jet four vector by a random number from our jet response (R)

$$R_{MC} = \frac{p_T^{reco}}{p_T^{truth}}$$



An example Mercedes like event
where the MET is unambiguously associated with a jet in the event.





- Once the optimal jet response function has been found, the jet smearing method can then be applied to SUSY search channels to obtain:
  - Multijet distributions from pseudo-data sample;
  - estimate of the Multijet background for the Signal Regions via a Transfer Function

0-Lepton: W signal regions

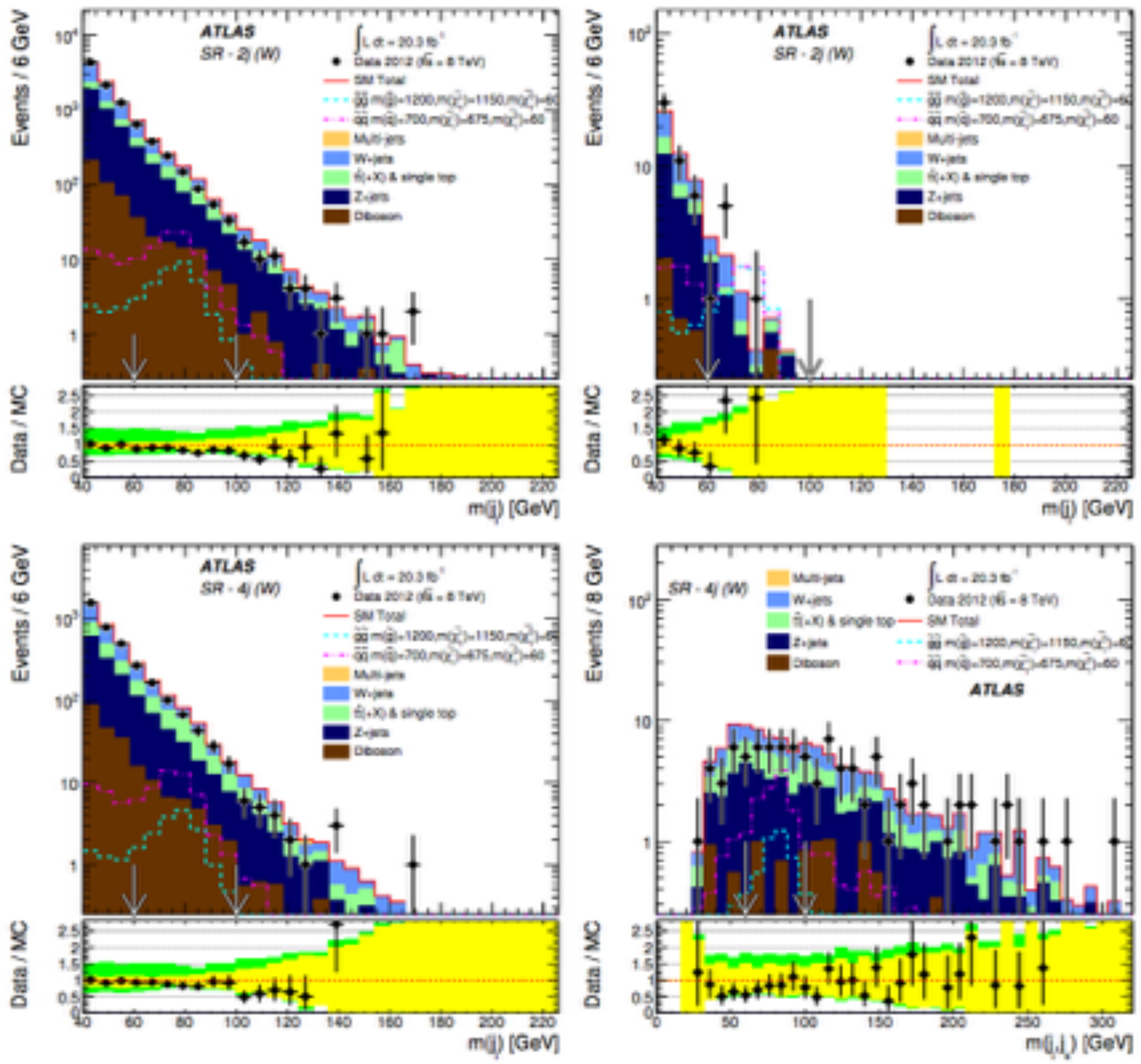
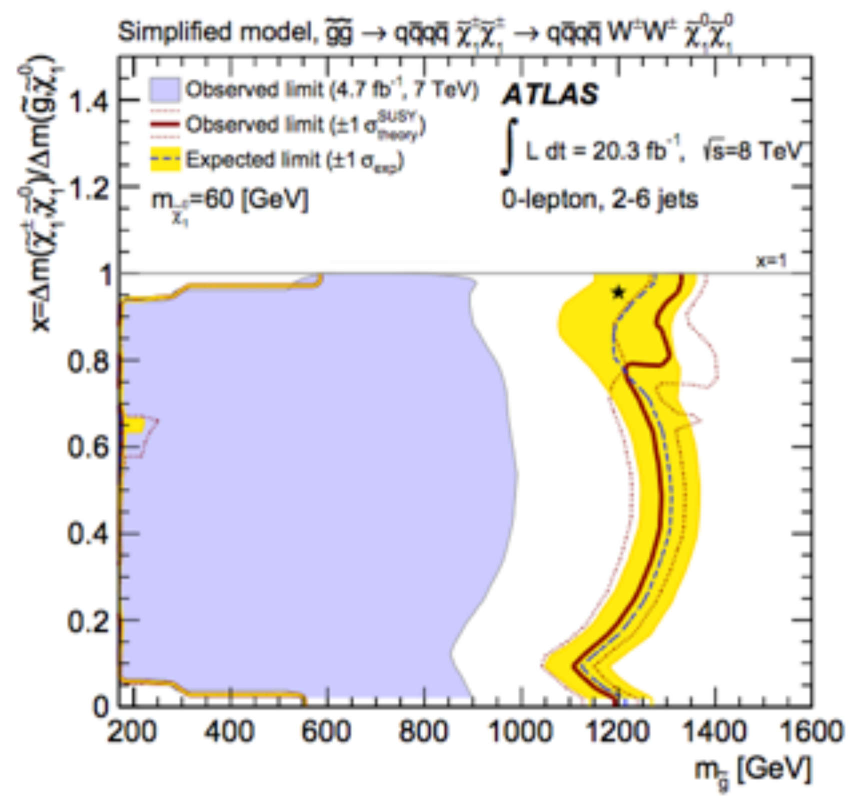
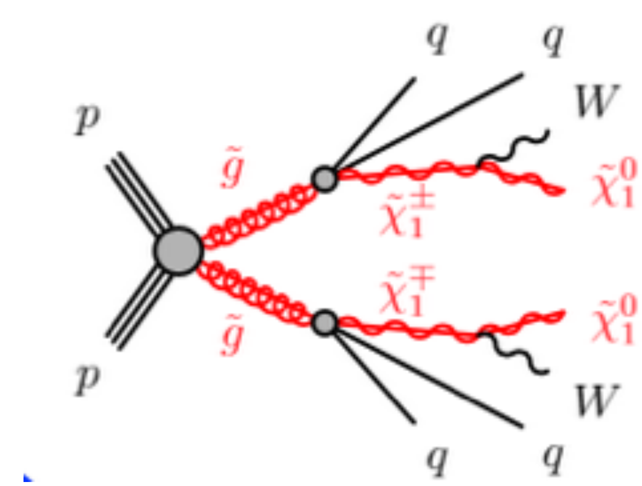


Figure 6. Observed jet and dijet mass distributions for the 2jW (top) and 4jW (bottom) signal regions for all unresolved W candidates (left) and for an additional W candidate after requiring at least one unresolved W candidate (right). The additional W candidate is unresolved (SR 2jW, top-right) or resolved (SR 4jW, bottom-right). With the exception of the multi-jet background (which is estimated using the data-driven technique described in the text), the histograms denote the MC background expectations prior to the fits described in the text, normalised to cross-section times integrated luminosity. In the lower panels the light (yellow) error bands denote the experimental systematic and MC statistical uncertainties, while the medium dark (green) bands include also the theoretical modelling uncertainty. Expected distributions for benchmark model points are also shown for comparison (masses in GeV). Arrows indicate the location of the mass window used in the final selection. See text for discussion of compatibility of data with MC background expectations.

Expected boosted W for large $\Delta m(\chi_1^{\pm}, \chi_1^{0})$





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Metastable Gluinos

Signal MC: Pythia6 for gluino production, hadronization and decay within R-hadron; dedicated Geant4 routine.

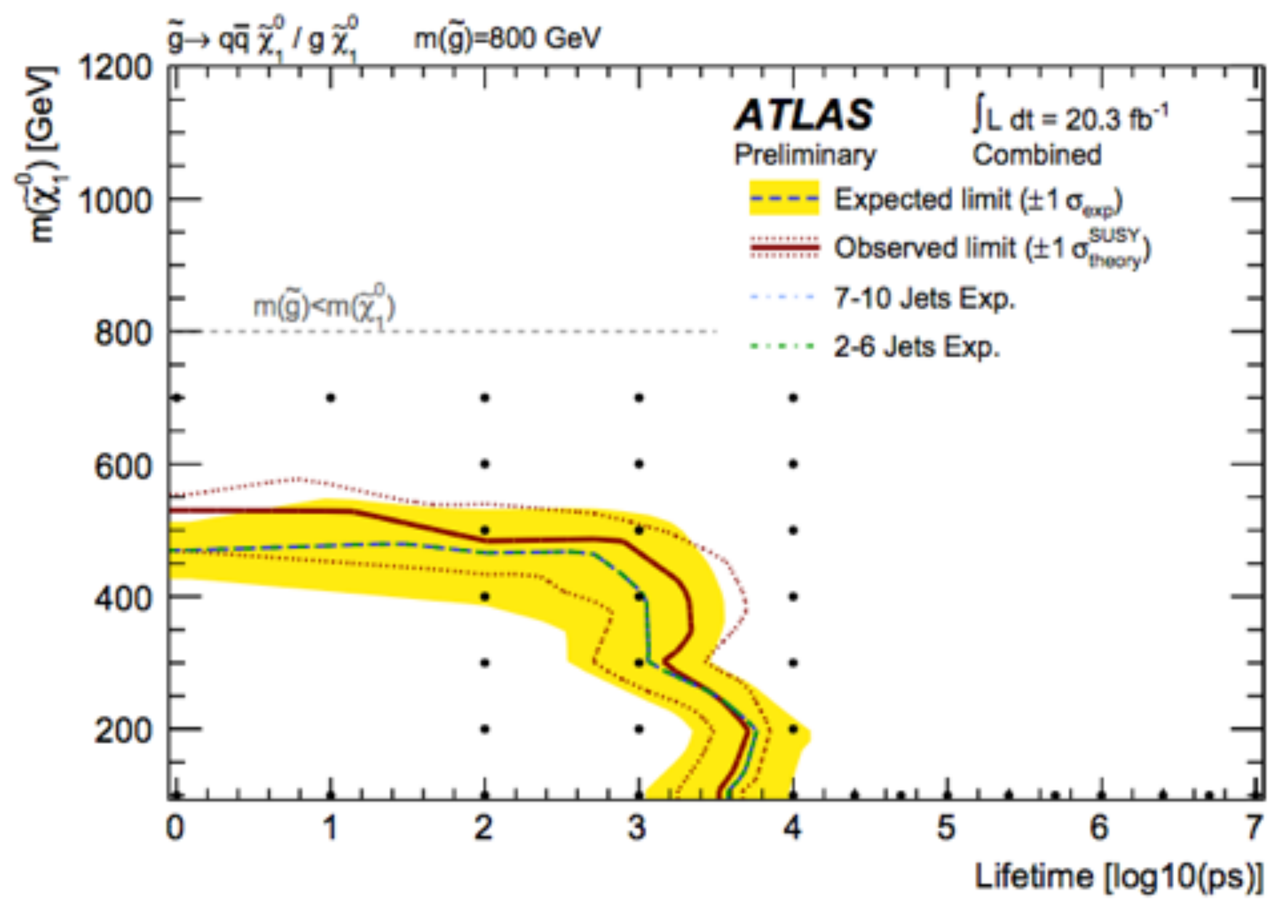

Figure 3: 95% CL excluded $\tilde{\chi}_1^0$ mass as a function of $\tilde{g}$ lifetime, for $m_{\tilde{g}}$ = 800 GeV and $\tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0/\ g\tilde{\chi}_1^0$ decays.

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Metastable Gluinos

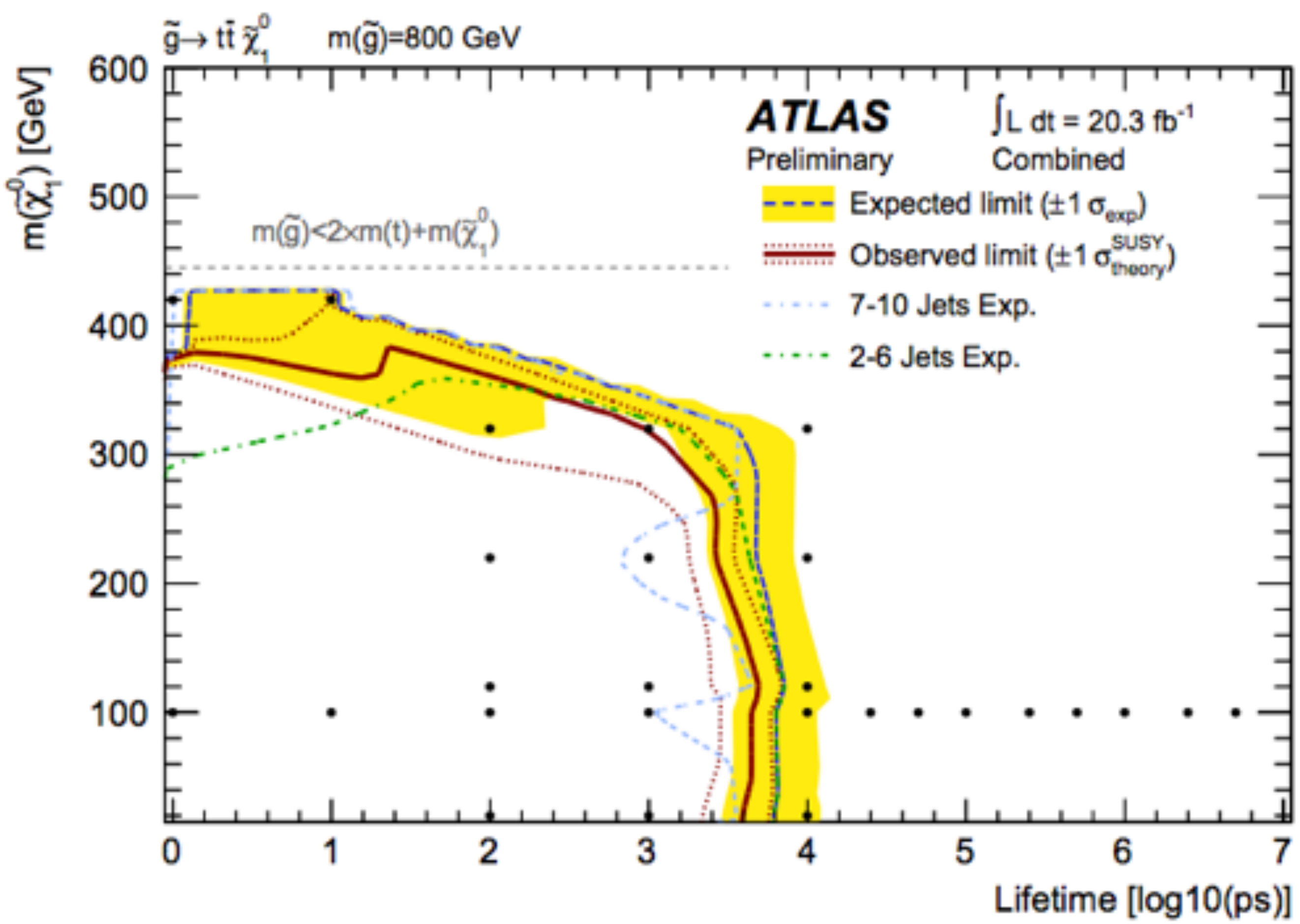

Figure 6: 95% CL excluded $\tilde{\chi}_1^0$ mass as a function of $\tilde{g}$ lifetime, for $m_{\tilde{g}}$ = 800 GeV and $\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ decays. At low lifetimes, the "7-10 jet" analysis has sensitivity beyond the "2-6 jets" analysis due to the use of b-tagging information.

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Metastable Gluinos

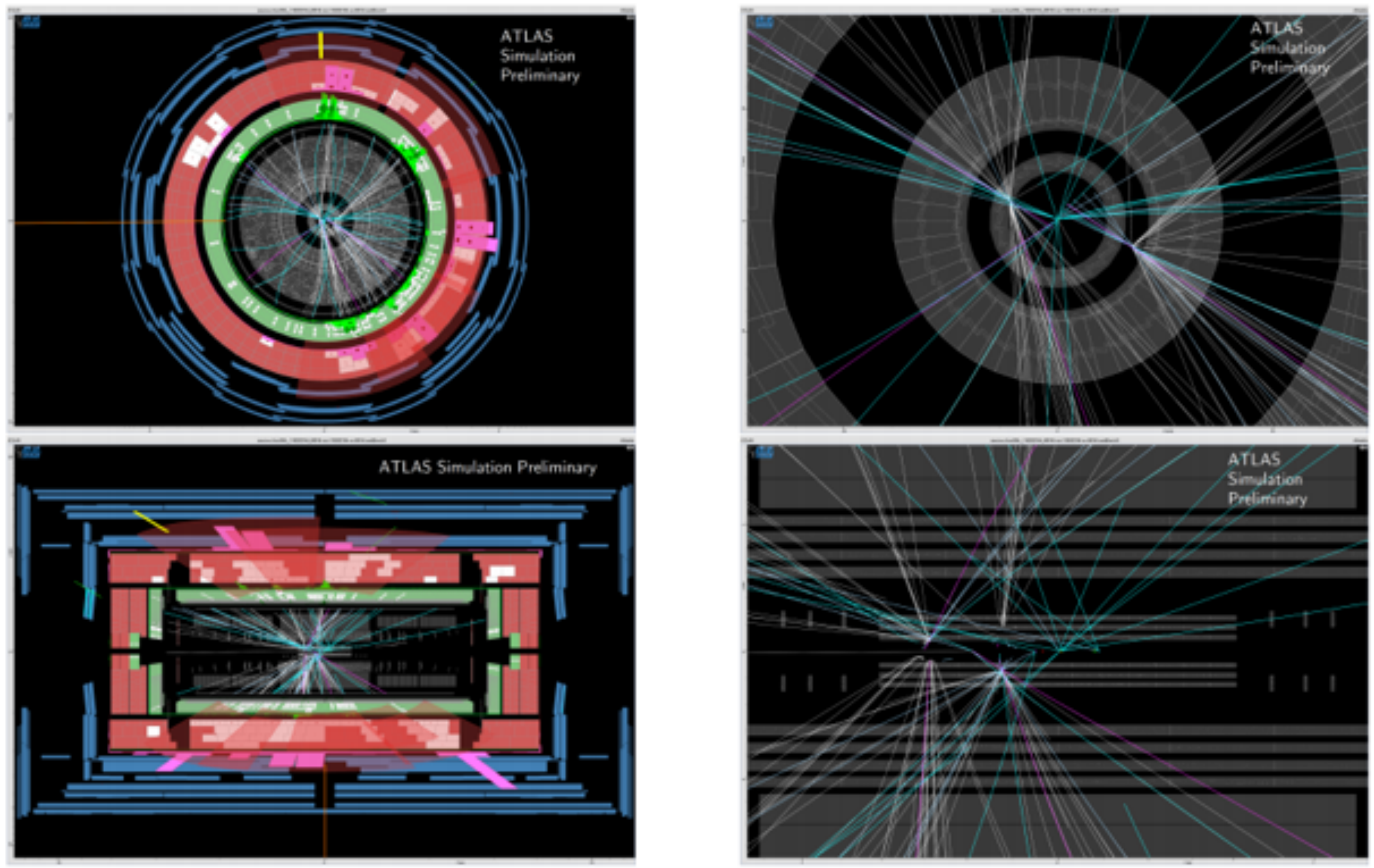

Figure 9: Displays of a simulated event with 600 GeV gluinos with 1 ns lifetime decaying to $t\bar{t}\tilde{\chi}^0$ with a 100 GeV $\tilde{\chi}^0$. Colored tracks are reconstructed, and white tracks are simulated charged tracks with p_T above 1 GeV.

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