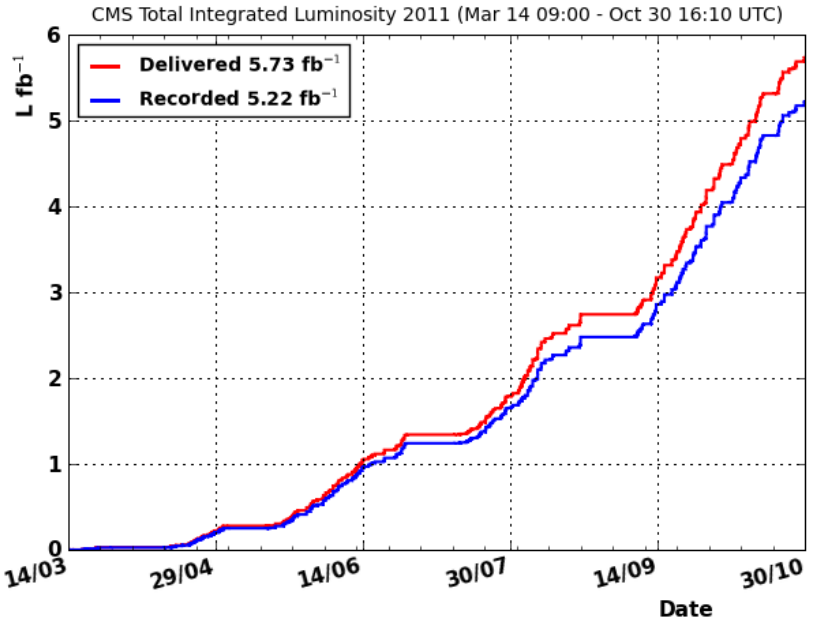
SUSY at 1 fb^{-1}

Josh Thompson
Cornell Theory/Exp discussion
11 Nov 11

Graphics stolen from Colin Bernet

LHC status

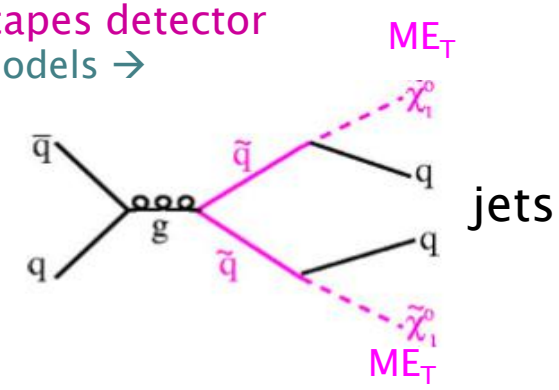
- The LHC is doing great (and so are the experiments)
- Most results are currently updated to the ~1 fb^{-1} dataset from early July
  - Expect updates to the full dataset ASAP



Usable for physics:
→~4.7 fb^{-1} (maybe more after rereco)
→ATLAS is probably similar

CMS Searches for Supersymmetry

- Hadron collider → production of colored objects (q~, g~) → decay to colored objects (jets)
- Lightest SUSY particle is stable and weakly interacting→ escapes detector
  - Provides universal signature of (R-parity conserving) SUSY models → missing transverse energy (ME_T)
- CMS emphasizes:
  - Complementary analyses
    - Signatures, background methods, kinematic variables
  - Data-driven background estimates



2011 CMS results (so far)

0 lepton	0 lep+b	1 lepton	OSDL	SSDL	Z	photon
MH_T, α_T, M_{T2}, Razor (approved Wednesday)	ME_T+b, M_{T2}+b	Lepton + jets + ME_T	Opposite-sign dilepton + jets + ME_T	Same-sign dilepton + jets + ME_T	Z + jets + ME_T	Photon + jets + ME_T

ATLAS has a similar program….

Not in this talk: monojet+ME_T

A word on triggers

- Collisions at 20 MHz
  - maybe 40 MHz next year, but in that case with lower pileup
- CMS writes ~300 Hz to disk (driven by offline)
  - ATLAS slightly higher???
- Trick is to throw out the massive QCD background, keep the interesting physics
  - Final states with e, μ are thus easier
    - Although single soft lepton is still hard
  - Triggers for hadronic searches are hard
    - Use variants on HT+MET, but PU has made the rates go up quickly….

Slightly dated numbers (September), but they give an idea

Lowest thresholds of unprescaled triggers @3e33

Single e/γ	32 GeV
Di-electron	10, 17/8 GeV
HT (total jet activity)	600 GeV
HT / MissingHT	350 / 90 GeV

Jets+Missing Energy

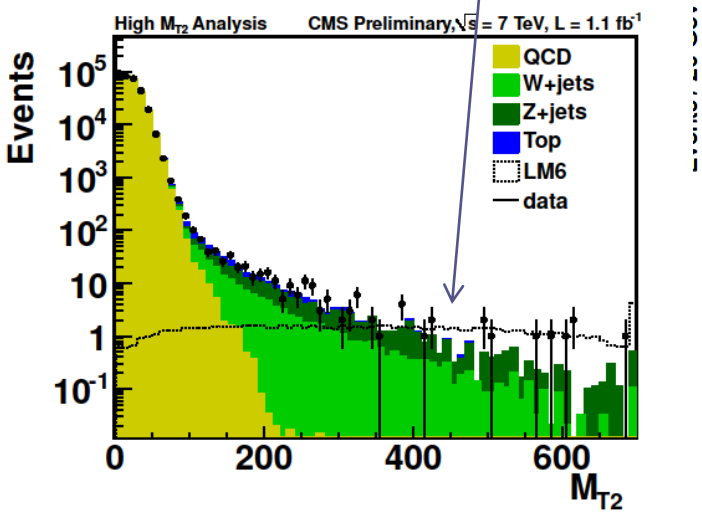
CMS PAS SUS-11-003
CMS PAS SUS-11-004
CMS PAS SUS-11-005

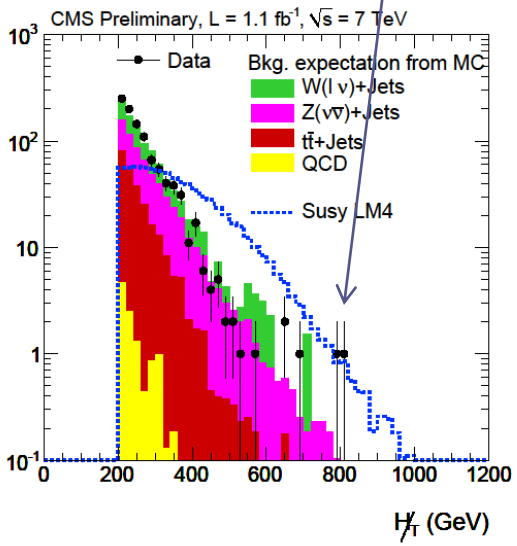
- Select events with large hadronic activity: $H_T = \sum_{jets} |\vec{p}_T|$
  - M_{T2}: H_T>600 GeV, >=2 jets
  - MH_T: H_T>350 GeV and up, >=3 jets
  - α_T: H_T>275 GeV (shape analysis), >=2 jets
- Veto leptons (ttbar, W+Jets rejection)
- Expect SUSY to show up in the tails of the various missing energy variables

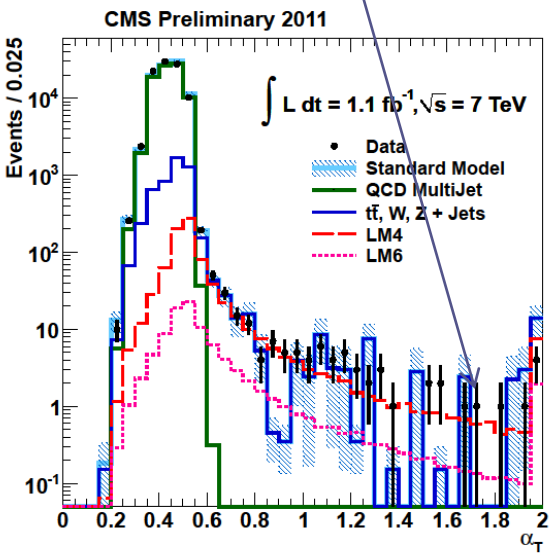
$$(M_{T2})^2 = 2A_T = 2p_T^{vis(1)} p_T^{vis(2)} (1 + cos\phi_{12})$$

$$MH_T = \left| \sum_{jets} - \vec{p}_T \right|$$

$$\alpha_T = \frac{\sqrt{E_T^{j2} / E_T^{j1}}}{\sqrt{2(1-\cos\Delta\varphi)}}$$







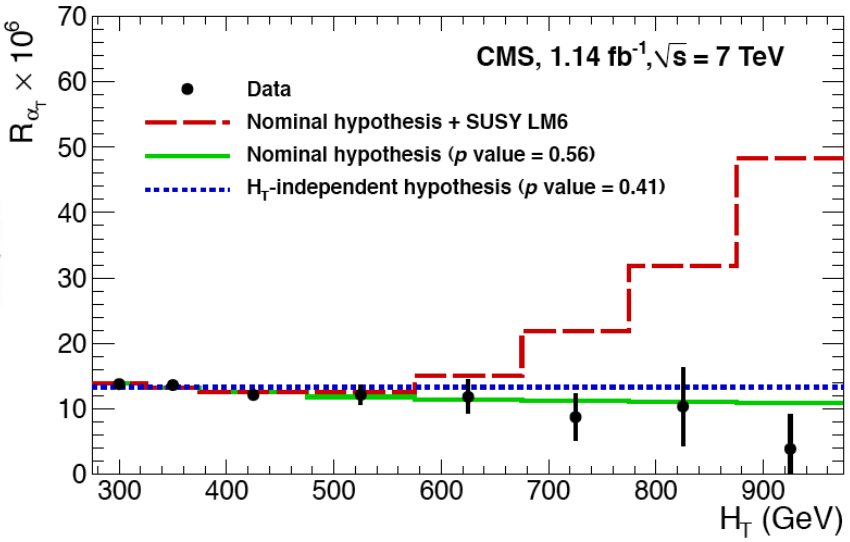
Moving to shape analysis

- Many analyses have multiple "search regions"
  - For example in the MHT analysis:

Baseline	Medium	High H_T	High $\not{H}_T$
(H_T >350 GeV)	(H_T >500 GeV)	(H_T >800 GeV)	(H_T >800 GeV)
($\not{H}_T$ >200 GeV)	($\not{H}_T$ >350 GeV)	($\not{H}_T$ >200 GeV)	($\not{H}_T$ >500 GeV)

    - Not mutually exclusive = hard to combine
- In α_T search, summer 2011 analysis is performed in (mutually exclusive) bins of HT
  - Significant gain in sensitivity
- Everybody will move in this direction
  - Requires correctly handling the correlated systematics between bins

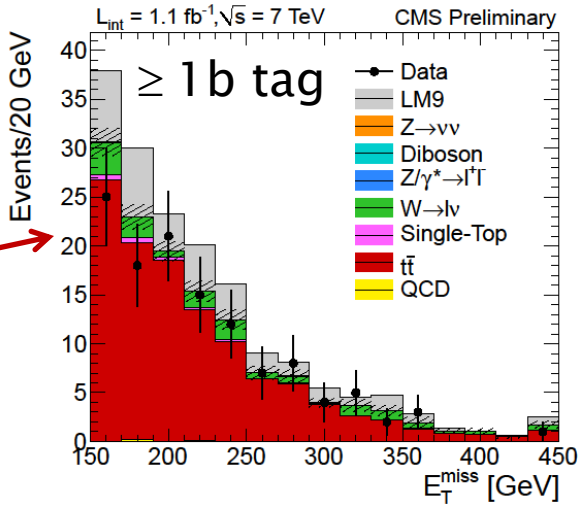
$$R_{\alpha_T} = \frac{\alpha_T > 0.55}{\alpha_T < 0.55}$$

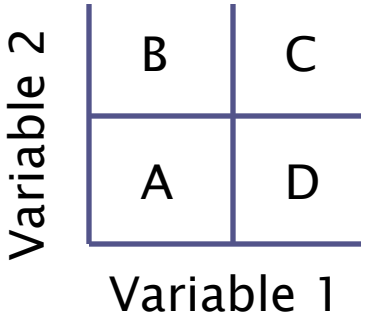


(Also, Razor analysis is a 2D(!) likelihood fit, not cut-and-count)

On background methods

- Data-driven background methods are various and can be quite elaborate
- CMS is very MC-phobic
  - ATLAS a bit less so
- Example control samples
  - QCD
    - Low MET and/or low $\Delta\phi$(jet, MET)
  - ttbar, W+Jets:
    - 1 lepton control sample (w, w/out b tag)
  - $Z\rightarrow\nu\nu$ + jets:
    - $Z\rightarrow ll$, $W\rightarrow l\nu$, γ+jets
- Trick is to get from control to nominal sample
  - Simplest: take "transfer factor" from MC
  - Simple data-driven technique: "ABCD method" (aka "matrix method", "factorization")
    - Requires 2 uncorrelated variables and 3 control regions
    - $N_C = N_D \times N_B/N_A$
  - Other examples:
    - Correct for efficiency difference between control/nominal using some combination of data and MC inputs
    - Jet smearing for QCD low MET/MHT→high MET/MHT



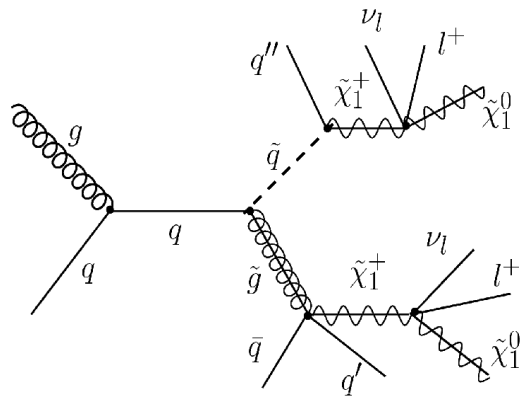


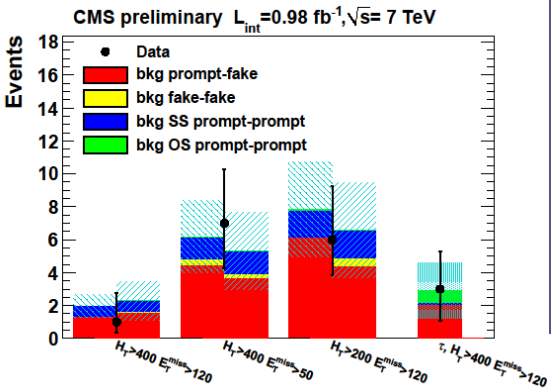
SUSY with leptons

- Leptons can originate from decays of charginos, or SM daughters of SUSY particles (W, top)
- Data agree with data-driven SM predictions

CMS PAS SUS-11-010

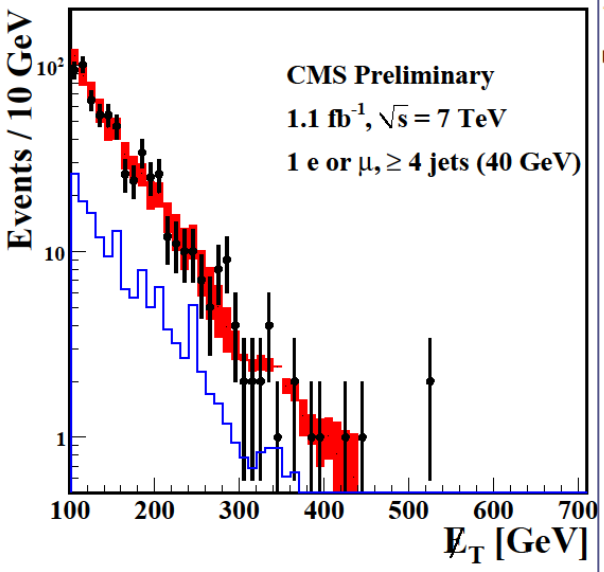
Same-sign dileptons





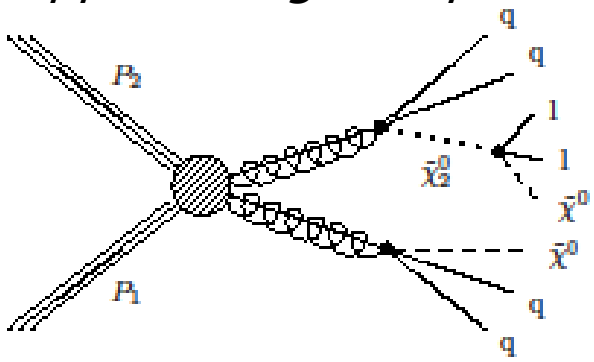
CMS PAS SUS-11-015

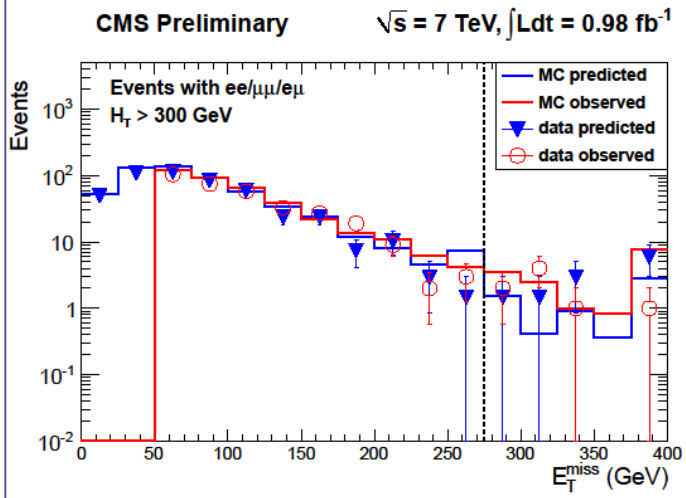
Single lepton



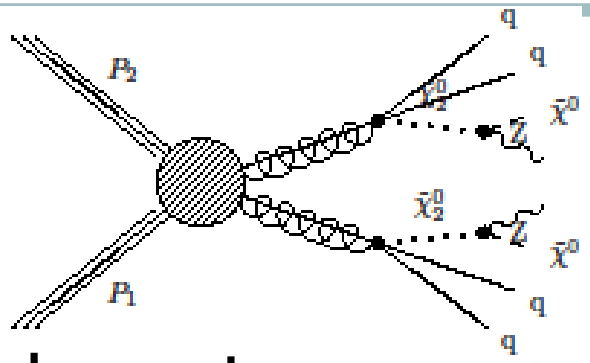
CMS PAS SUS-11-011

Opposite-sign dileptons



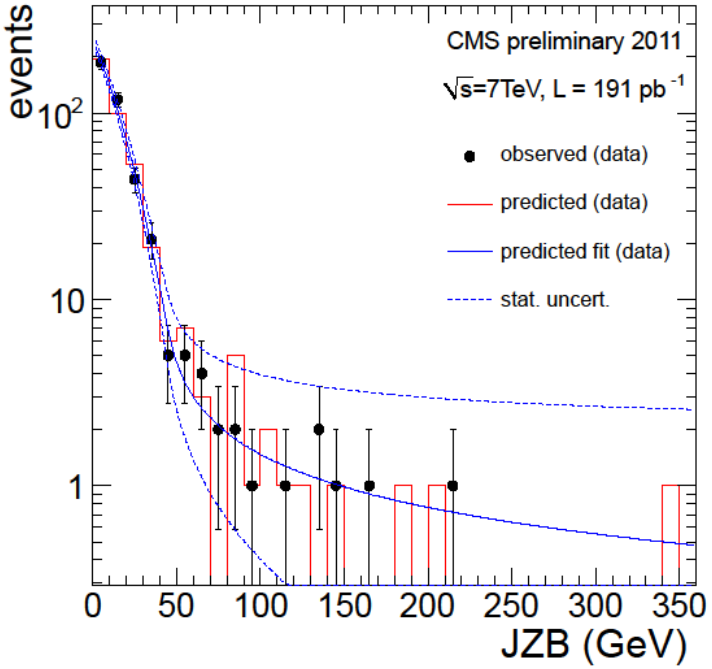


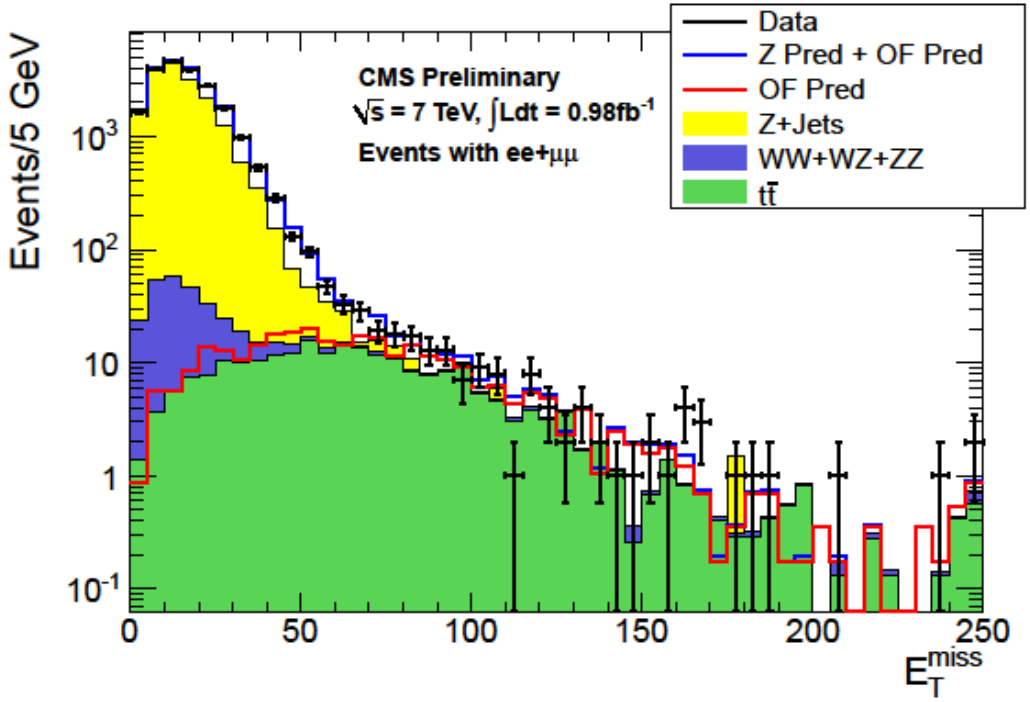
CMS PAS SUS-11-012
CMS PAS SUS-11-017



SUSY with Z

- Z→ll provides a clean search environment
- 2 complementary searches:
  - tail of jet–Z balance (JZB), ME_T tail





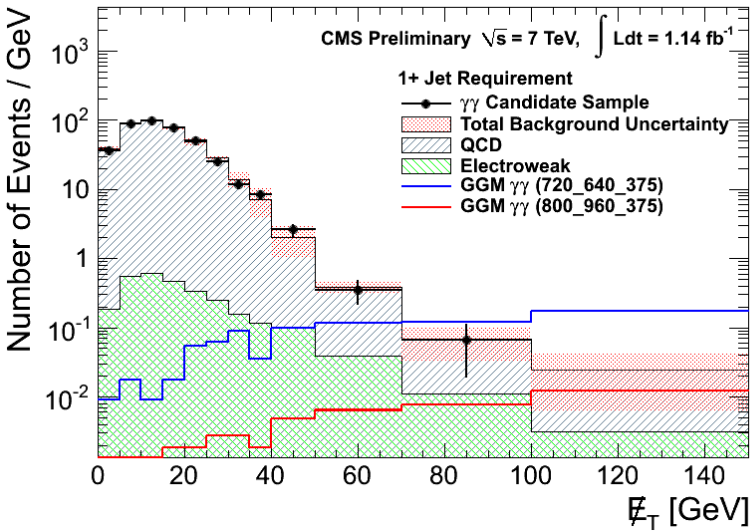
SUSY with photons

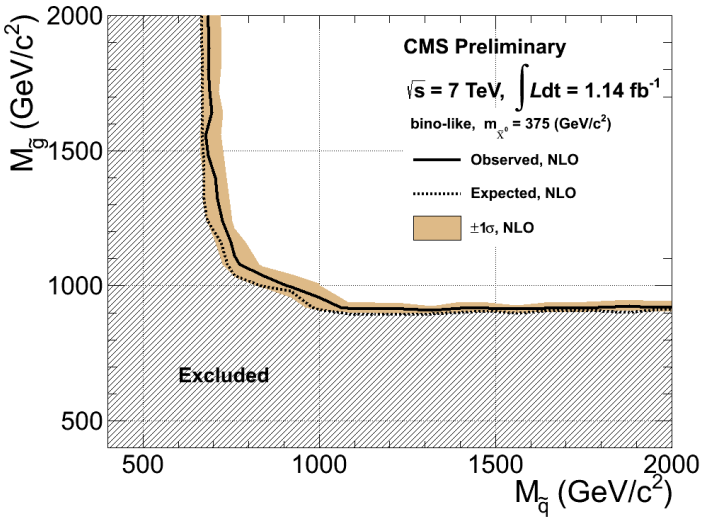
CMS PAS SUS-11-009

- gauge-mediated symmetry breaking scenario:
  - LSP is gravitino
  - Decay chain depends on NLSP type:

NLSP type	$\gamma + 3\,\text{jets} + E_T^{\text{miss}}$	$\gamma\gamma + \text{jet} + E_T^{\text{miss}}$
Bino	$\text{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \text{jets} + \gamma + Z + \tilde{G}\tilde{G}$	$\text{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \text{jets} + \gamma\gamma + \tilde{G}\tilde{G}$
Wino	$\text{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \text{jets} + \gamma + Z + \tilde{G}\tilde{G}$ $\text{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^{\pm} \rightarrow \text{jets} + \gamma + W^{\pm} + \tilde{G}\tilde{G}$	$\text{jets} + \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \text{jets} + \gamma\gamma + \tilde{G}\tilde{G}$

Di-photon analysis results





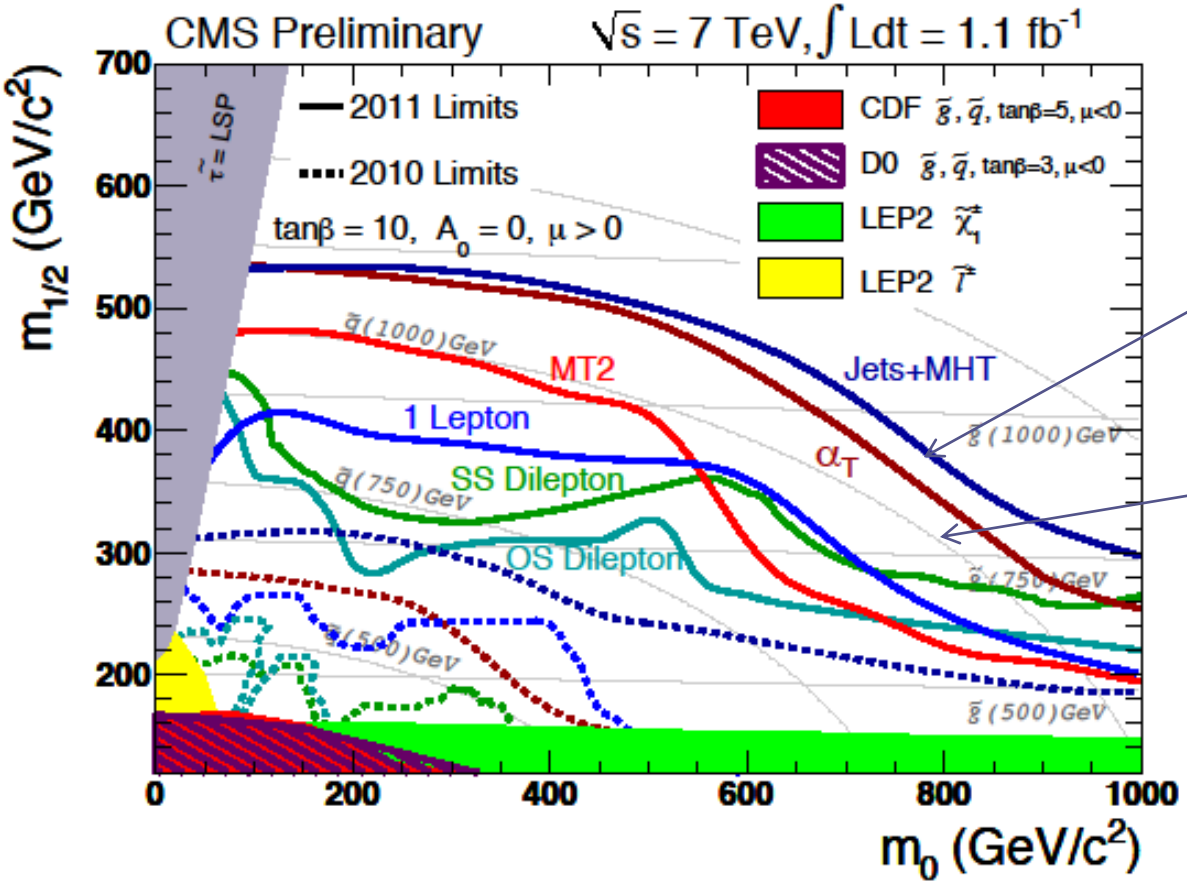
Interpretation in the CMSSM (aka mSugra)

All CMS tan β=10 results on one plot

→Hadronic searches are the most powerful for CMSSM exclusion

→Jets+MHT has best exclusion but α_T is similar

(watch for updated results from Razor analysis…)



Note that α_T was weaker in 2010. Nearly "caught up" to MHT by adding shape analysis

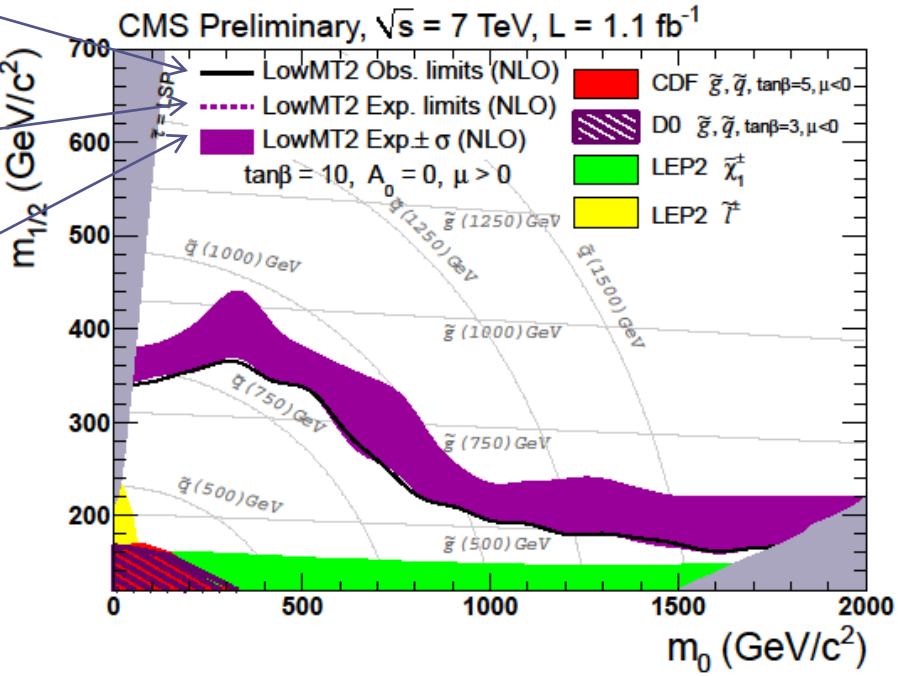
n.b.: Some people made a big deal about the fact that 1 TeV squarks are "eliminated" already….

About expected limits

For those who aren't familiar with the limit-setting business

Observed limit is what you get when you compare observed data to predicted background.
Expected limit is what you get if you had observed exactly the predicted background.
Error band on expected limit then reflects the size of the error on your predicted background.

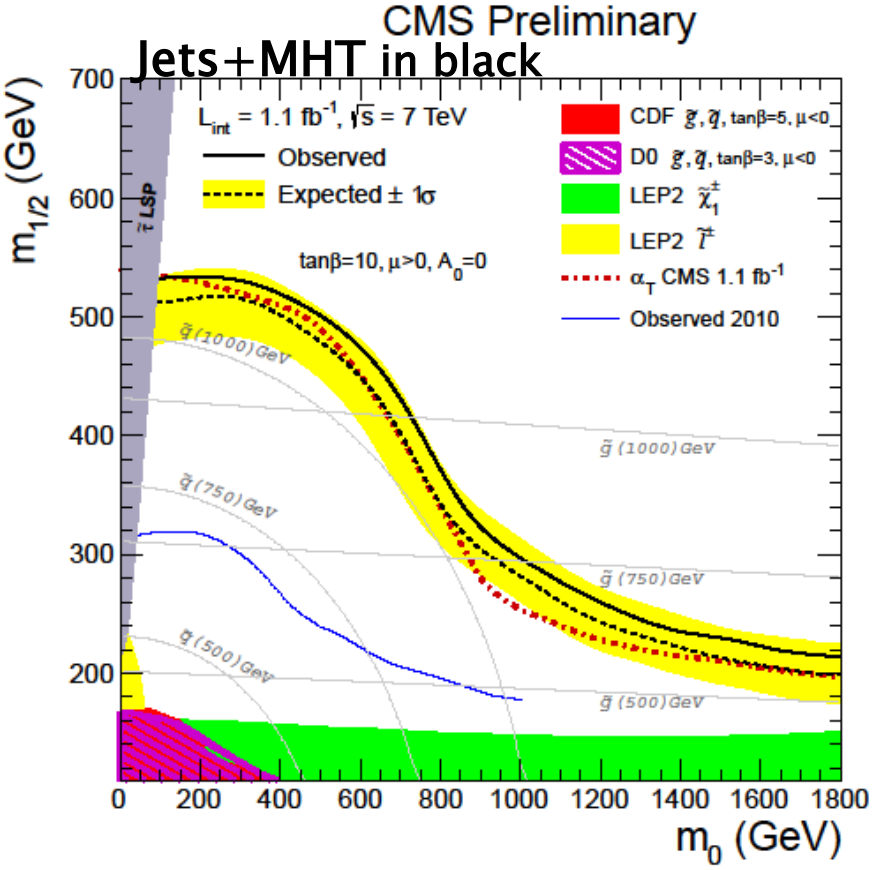
Example from MT2+b analysis

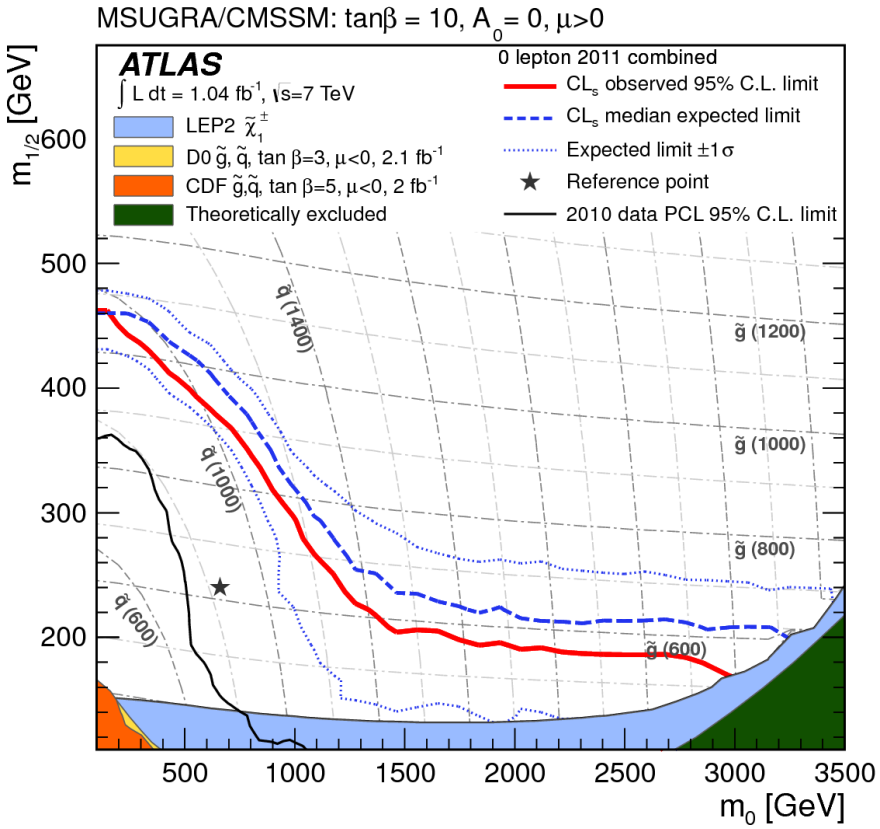


Predicted background: 10.6 ± 1.9 ± 4.8
Observed: 19 events

So they either got "unlucky", or they have the first hint of a signal! (Or their background estimate is biased…)

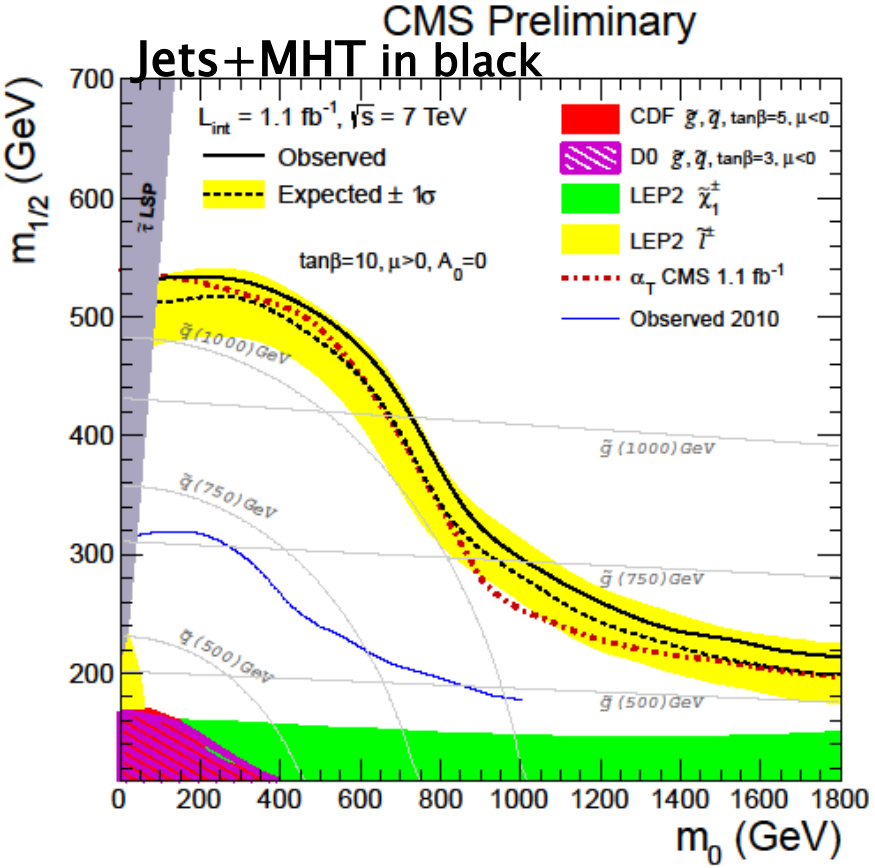
CMSSM: Summer 2011 ATLAS+CMS

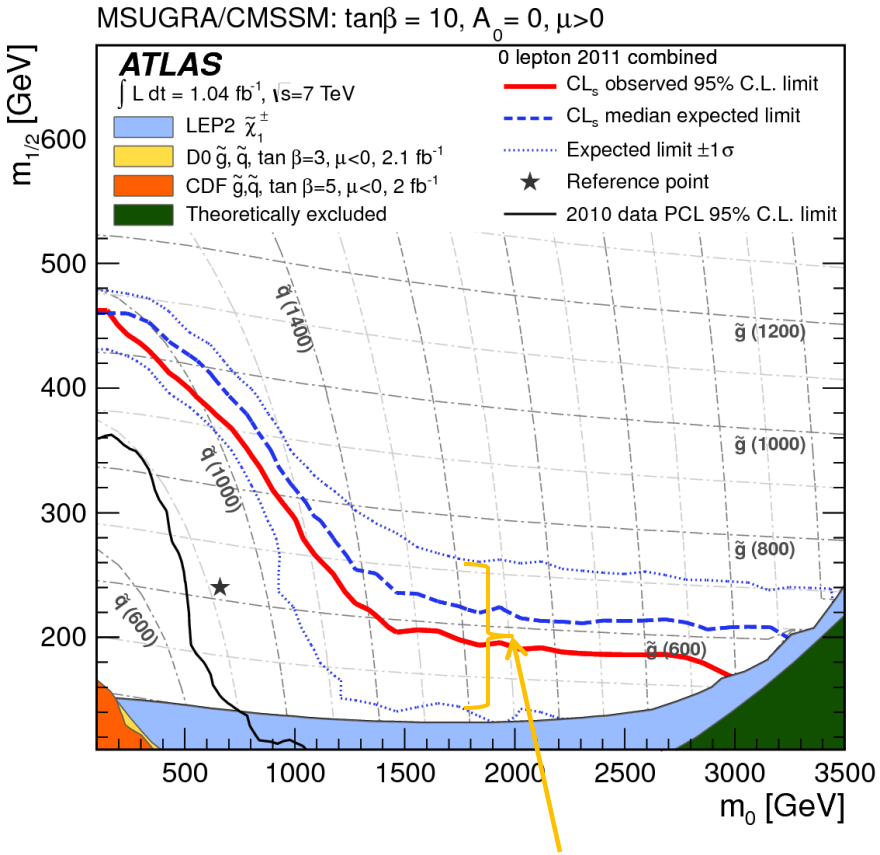




- CMS just a bit better at low m_0
- Similar at high m_0 (Razor result will be better here)
- ATLAS has more expansive MC generation than CMS (out to 3500 GeV!)

CMSSM: Summer 2011 ATLAS+CMS

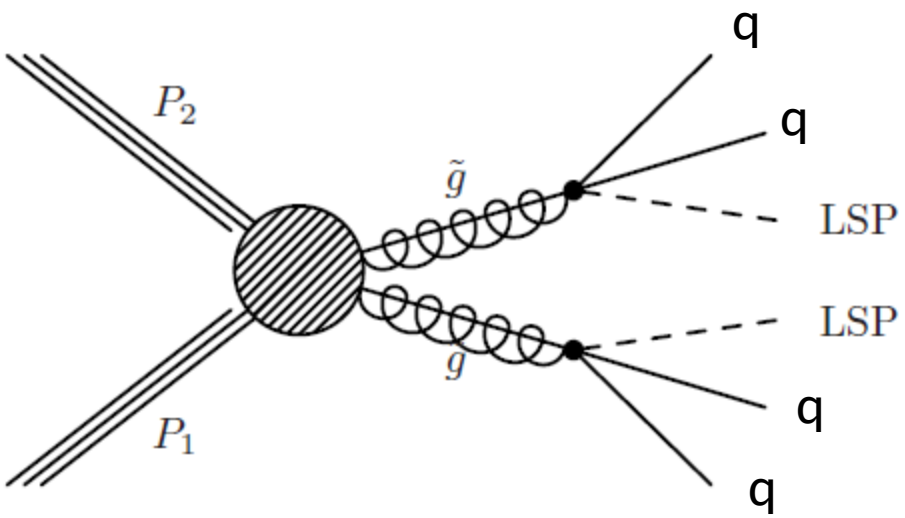




- Interesting note: there is some discussion about why ATLAS's ±1σ band on the expected limit expands so dramatically at high m_0, while CMS's does not. ATLAS suggests it is due to PDF uncertainties (gluon PDFs more important at high m_0). The only thing that is completely clear is that the experiments are doing something differently….

Interpretation in Simplified Models

- The CMSSM is not the only model of interest
  - CMSSM is somewhat "opaque"
    - Not trivial to see how masses, etc are changing as a function of the parameter space
  - CMSSM does not necessarily span a large range of kinematics across the phase space
- Broad push to interpret results in "Simplifed Models"
  - Not really "models", but rather extremely simple production and decay topologies

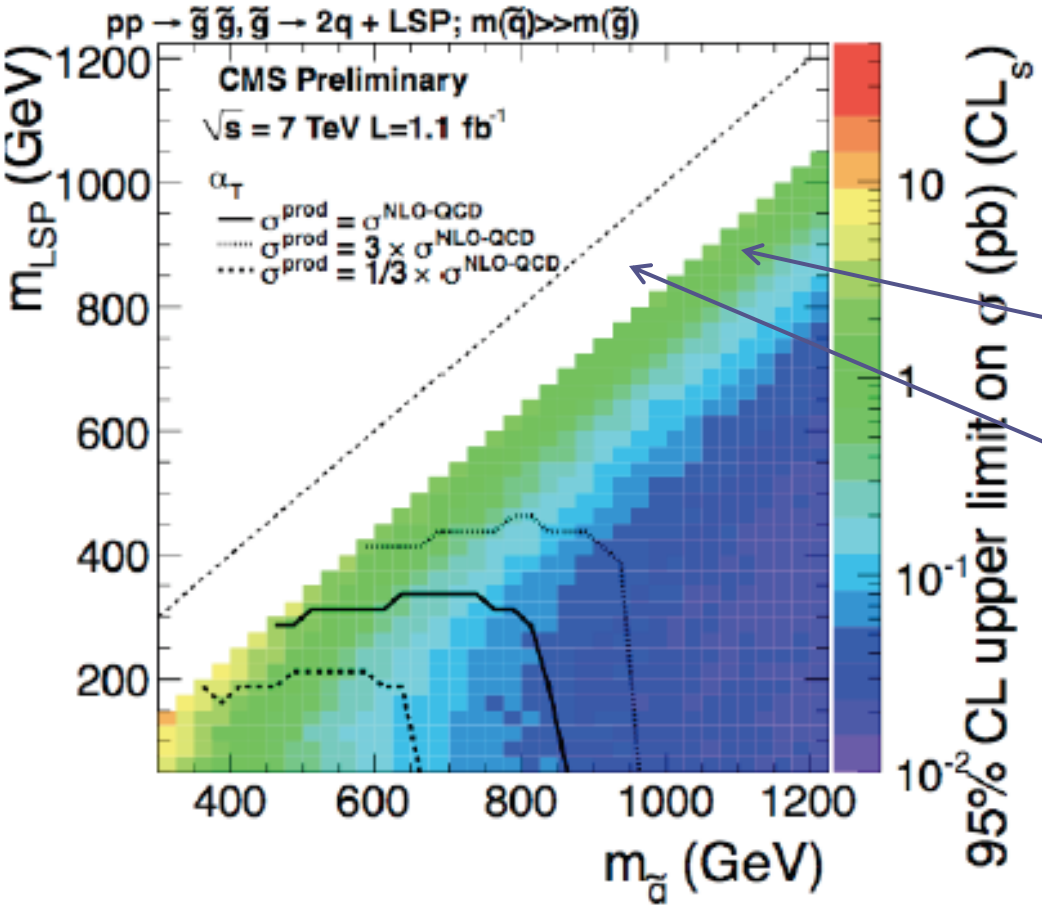


For example
Production: gluino-gluino
Decay: gluino → q q LSP

The only parameters are the masses of the gluino and LSP

Example results for Simplified Model

Limits on g~g~→qqX^0~ qqX^0~ model from α_T analysis

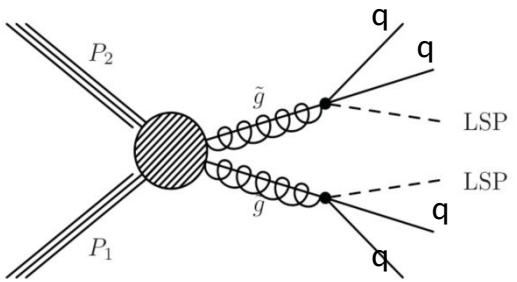


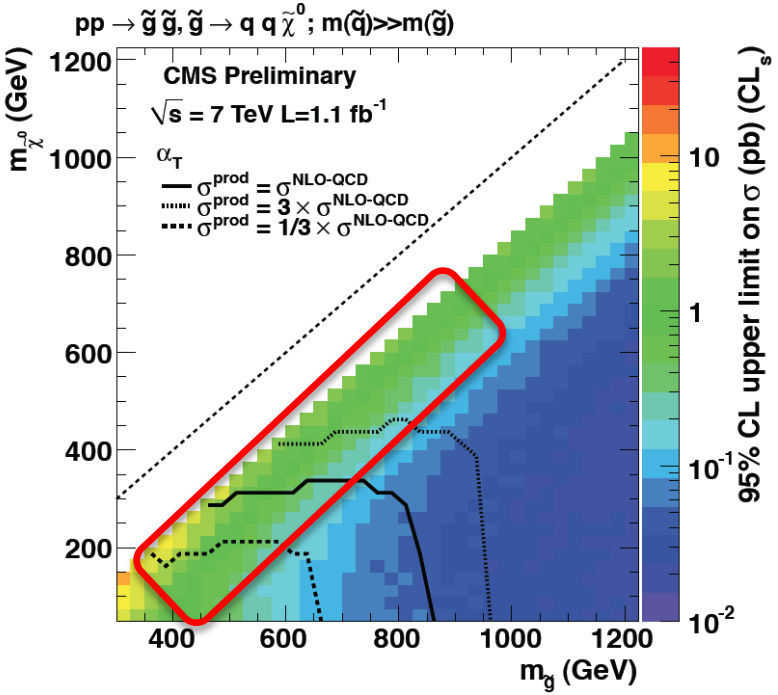
- Emphasis is on observed UL at each point in model space
  - Not so much on the "excluded" region
    - Although in practice people tend to look at the excluded region curve…
- By construction, model has widely varying kinematics across the plane
  - Immediately see that more degenerate splittings are hard
    - Squashed SUSY?
  - Very close to the diagonal, we don't even publish limits because of unmodeled (for now) ISR systematics
  - Reveals what kinematics our search cuts allow us to see and what kinematics they hide

Comparison with SS dilepton

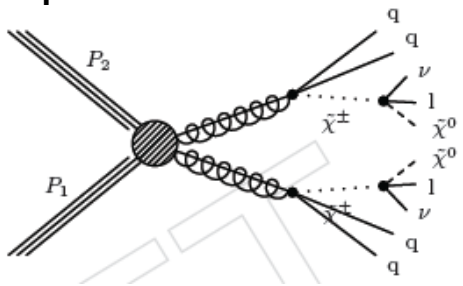
J. Thompson, Cornell — 11 Nov 11

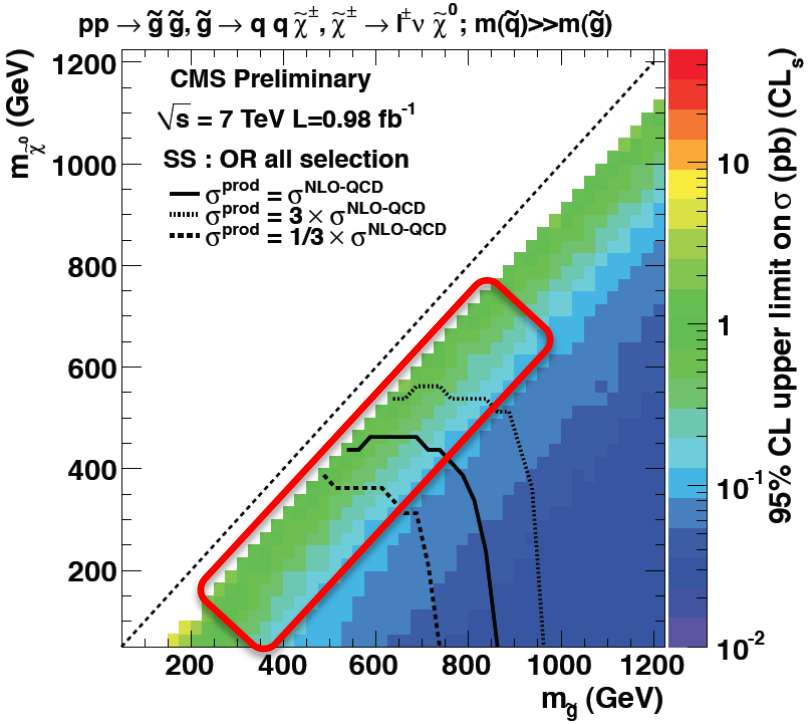
Jets + MET search with α_T





SS di-leptons + MET search





NB: chargino mass fixed to $(m_{g\sim}+m_{X0\sim})/2$

Leptonic searches can probe the compressed mass spectrum better than current hadronic analysis

1-lepton + MET in SMS (ATLAS)

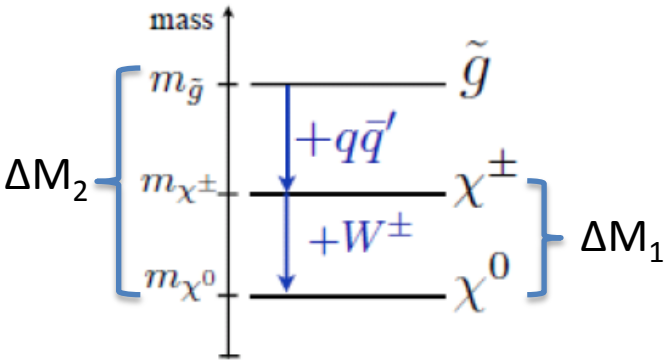
1 lepton + MET + ≥ 3,4 jets channel interpreted in simplified models

$M_{q\sim}$= 4.5 TeV

$$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^{\pm} \rightarrow q\bar{q}W\tilde{\chi}_1^0$$

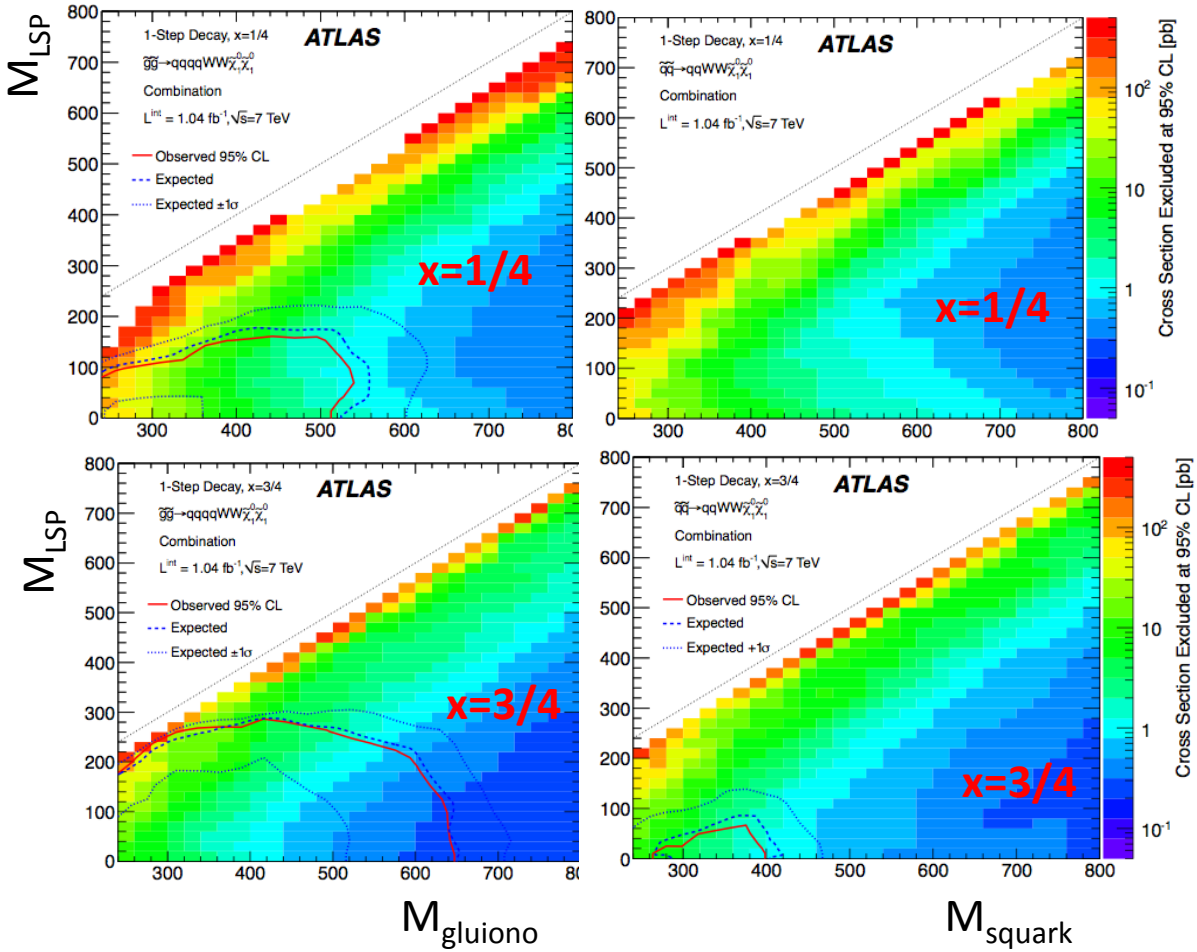
$M_{g\sim}$ / $M_{q\sim\text{-3rd Gen.}}$ = 4.5 TeV

$$\tilde{q} \rightarrow q'\tilde{\chi}_1^{\pm} \rightarrow q'W\tilde{\chi}_1^0$$



Note: less (no) sensitivity for x=1/4 -> Low pT leptons !

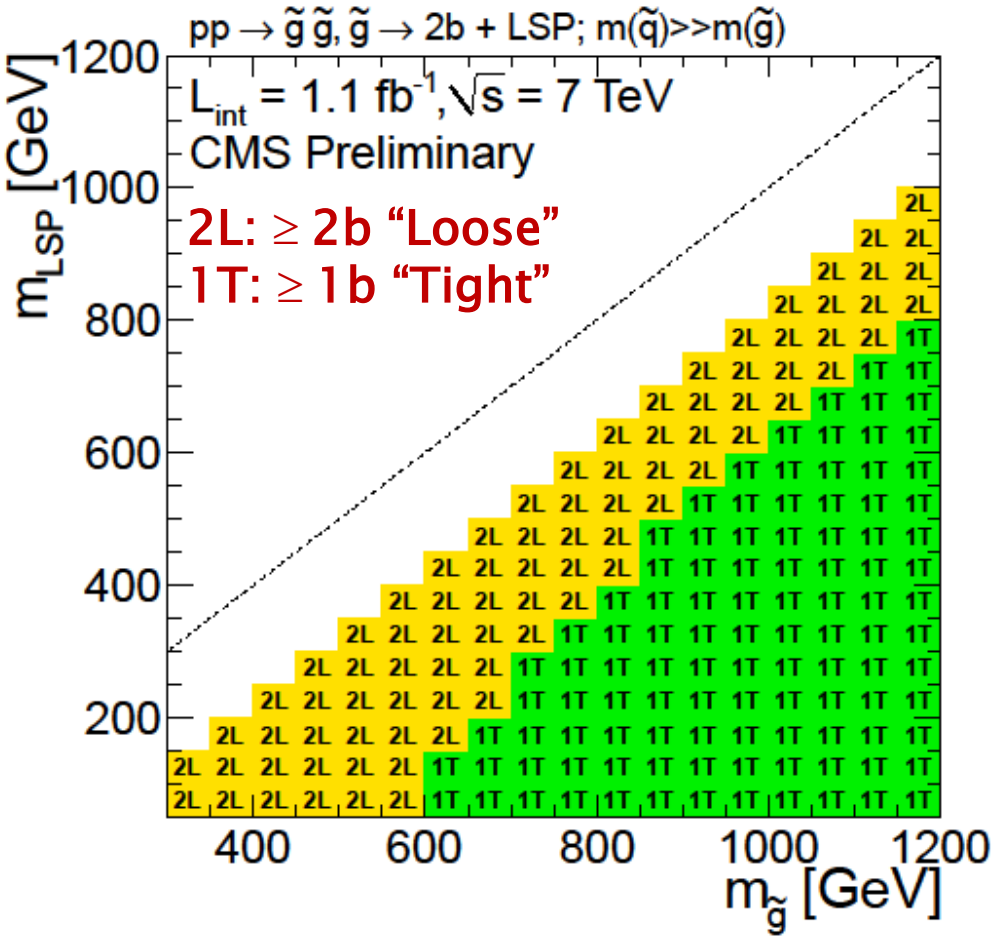
x= $\Delta M_1/\Delta M_2$

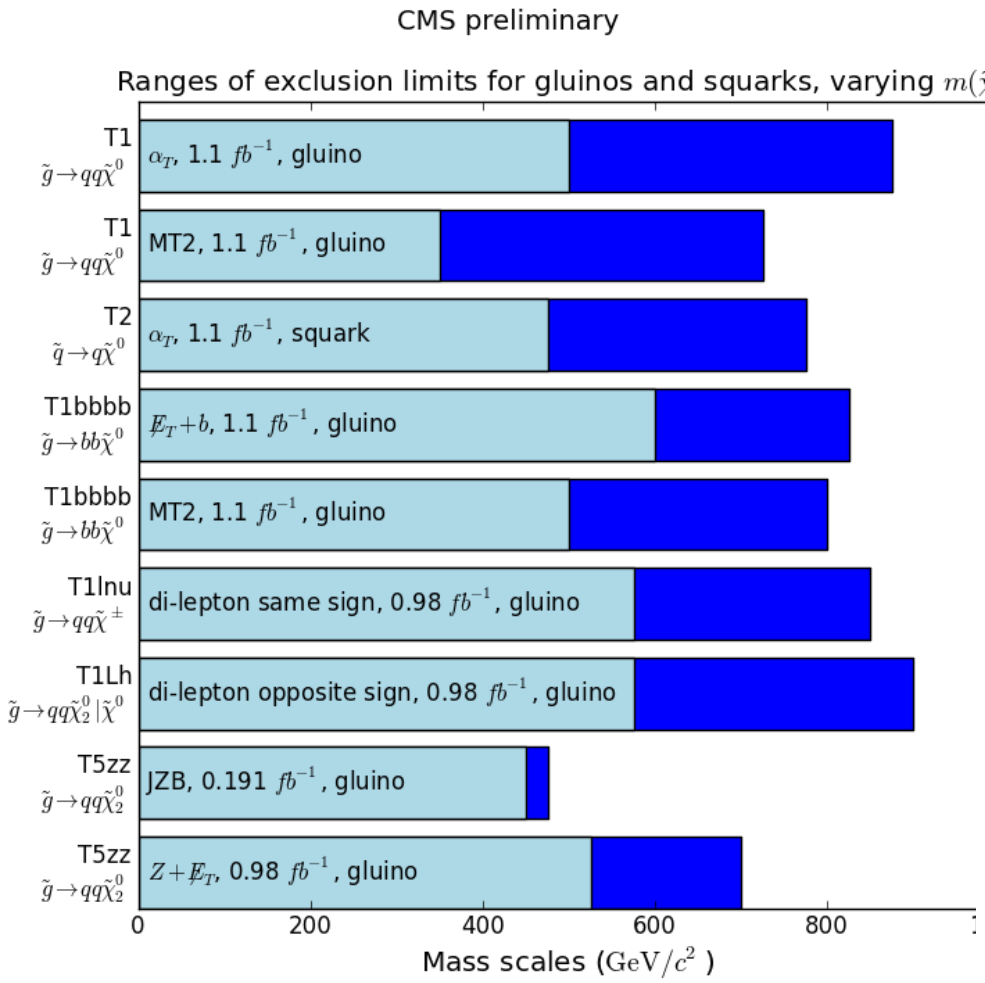


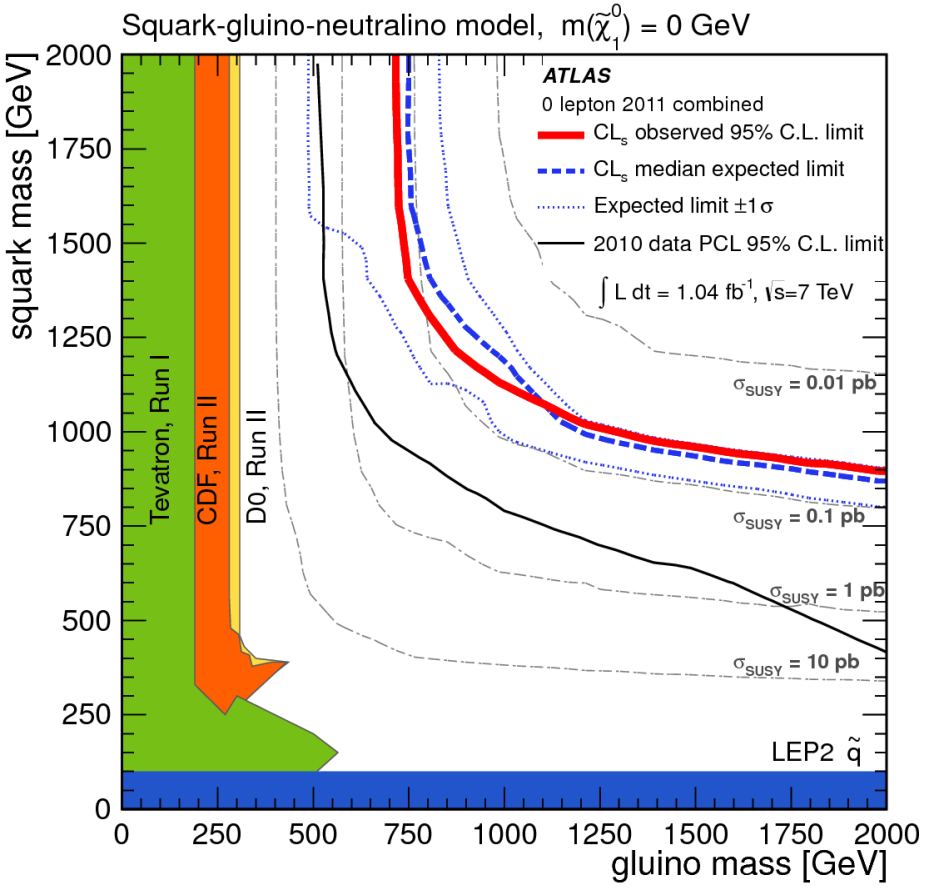
Illustrating the wide range of kinematics

- Jets+MET+b analysis has 4 selections:
  - (Loose, Tight) x (≥ 1b , ≥ 2b)
    - Loose = HT>350 GeV, MET>200 GeV
    - Tight = HT>500 GeV, MET>300 GeV
  - For each point in scan, decide which selection to use by the best *expected* limit
- Optimal selection changes with the varying kinematics of the model

MET+b: which selection is best







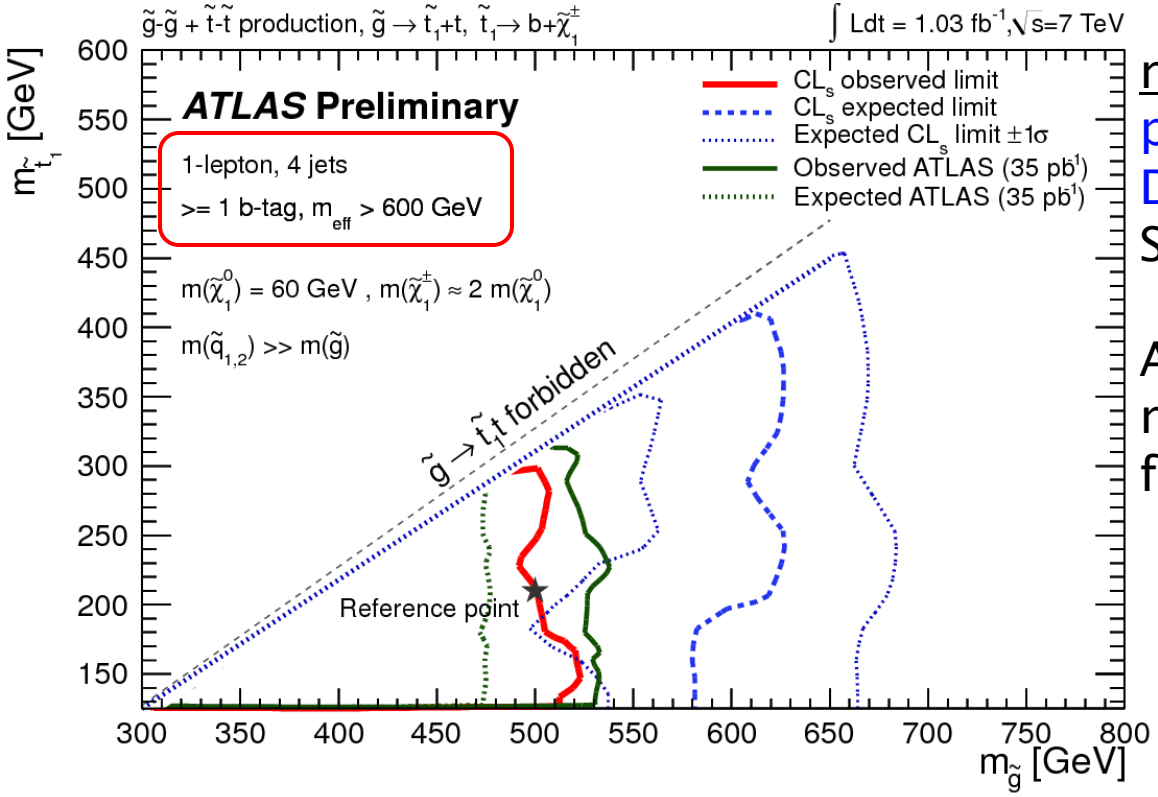
For limits on $m(\tilde{g}),m(\tilde{q})>>m(\tilde{g})$ (and vice versa). $\sigma^{\mathrm{prod}}=\sigma^{\mathrm{NLO-QCD}}$.

$m(\tilde{\chi}^\pm),m(\tilde{\chi}_2^0)\equiv\frac{m(\tilde{g})+m(\tilde{\chi}^0)}{2}$.

$m(\tilde{\chi}^0)$ is varied from 0 GeV/c^2 (dark blue) to $m(\tilde{g})-200$ GeV/c^2 (light blue).

Search for stop

- A lot of theory interest now in stop
  - Only ATLAS has a public result (for now)



<u>model</u>

production: g~ g~ and t~t~

Decay: g~ → t_1~ t, t_1~ → b$X_1^{\pm}$~

So final state like: 2 x ([t]b$\ell^{\pm}X_0$~)

Already 4 parameters in this model, so plot is made after fixing two of them arbitrarily

Note that Observed curve went the wrong way when going from 35 pb^{-1} to 1 fb^{-1}! Fluctuation? Signal? (error band on expected limit is quite big)

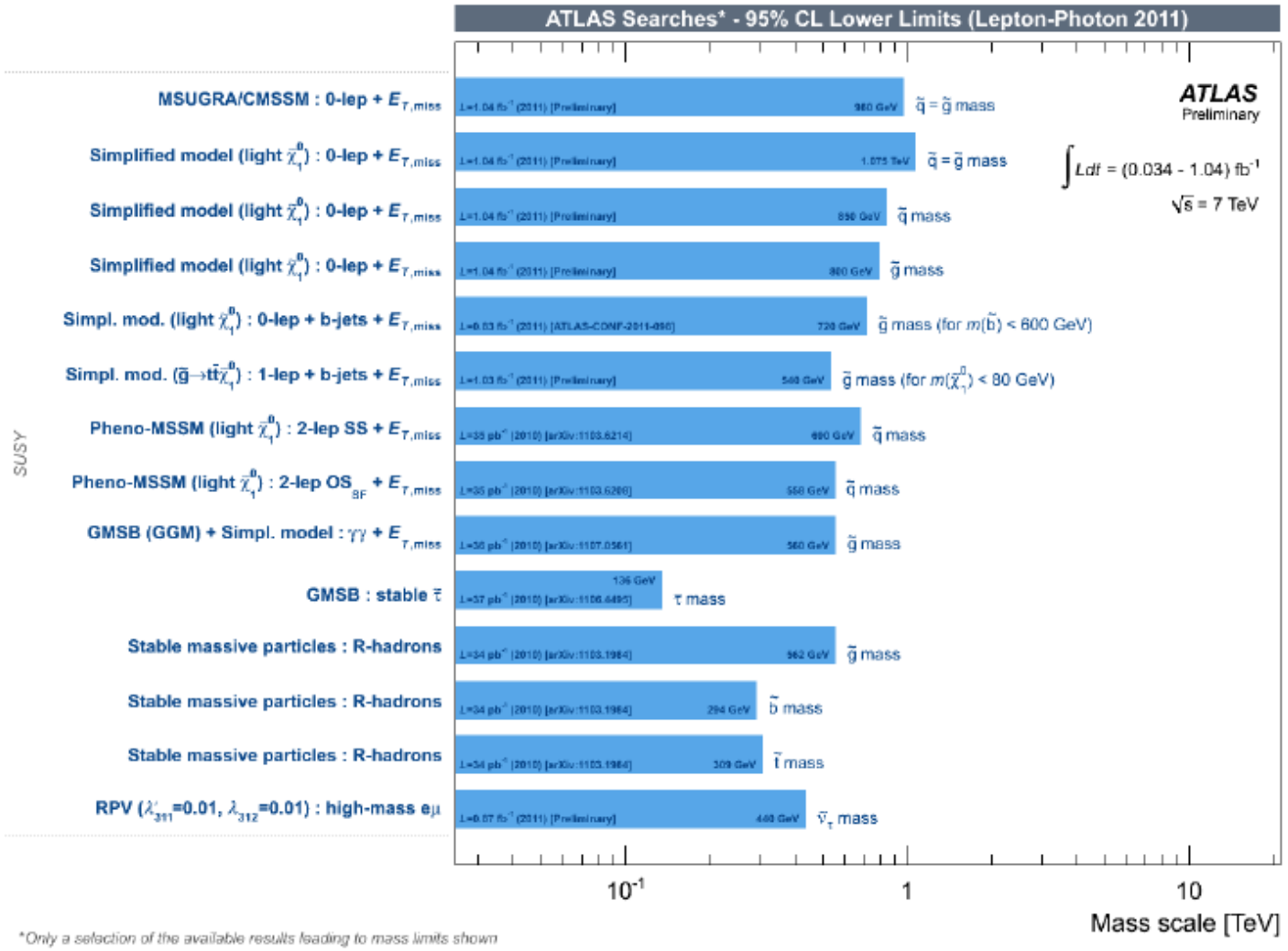
Summary

- Lots of signature-oriented searches going on now
  - Unfortunately all have the same results, as you know… (SM stands firm for now)
- There are some that I missed here
  - For example, ATLAS has a specific search for very high jet multiplicity (6-8 jets) + MET
- The thought that SUSY might be discovered early has been proven false, but there's a long road left
  - Experimentalists must now double down
    - Continue to improve/update current analyses with more data
    - Try to plug the holes that are left by current searches
      - Difficult spectra, etc

Graphics stolen from Colin Bernet

Extra slides and fun pictures

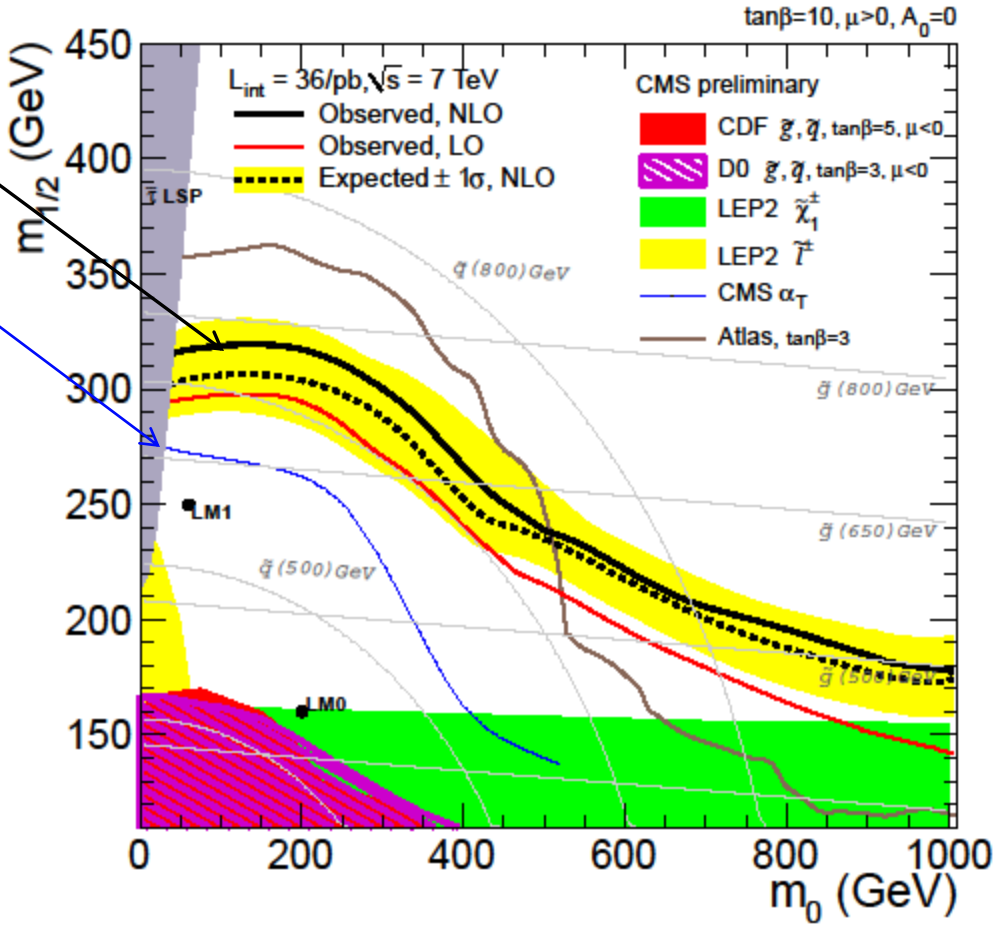
Backup



ATLAS SUSY searches typically probe masses ~ 500 – 1000 GeV

2010 limits in CMSSM

Black curve is Jets+MHT exclusion. Low-background α_T analysis was first, but sensitivity was exceeded Jets+MHT.



Tracking at high pileup

Recent event with >20 vertices