

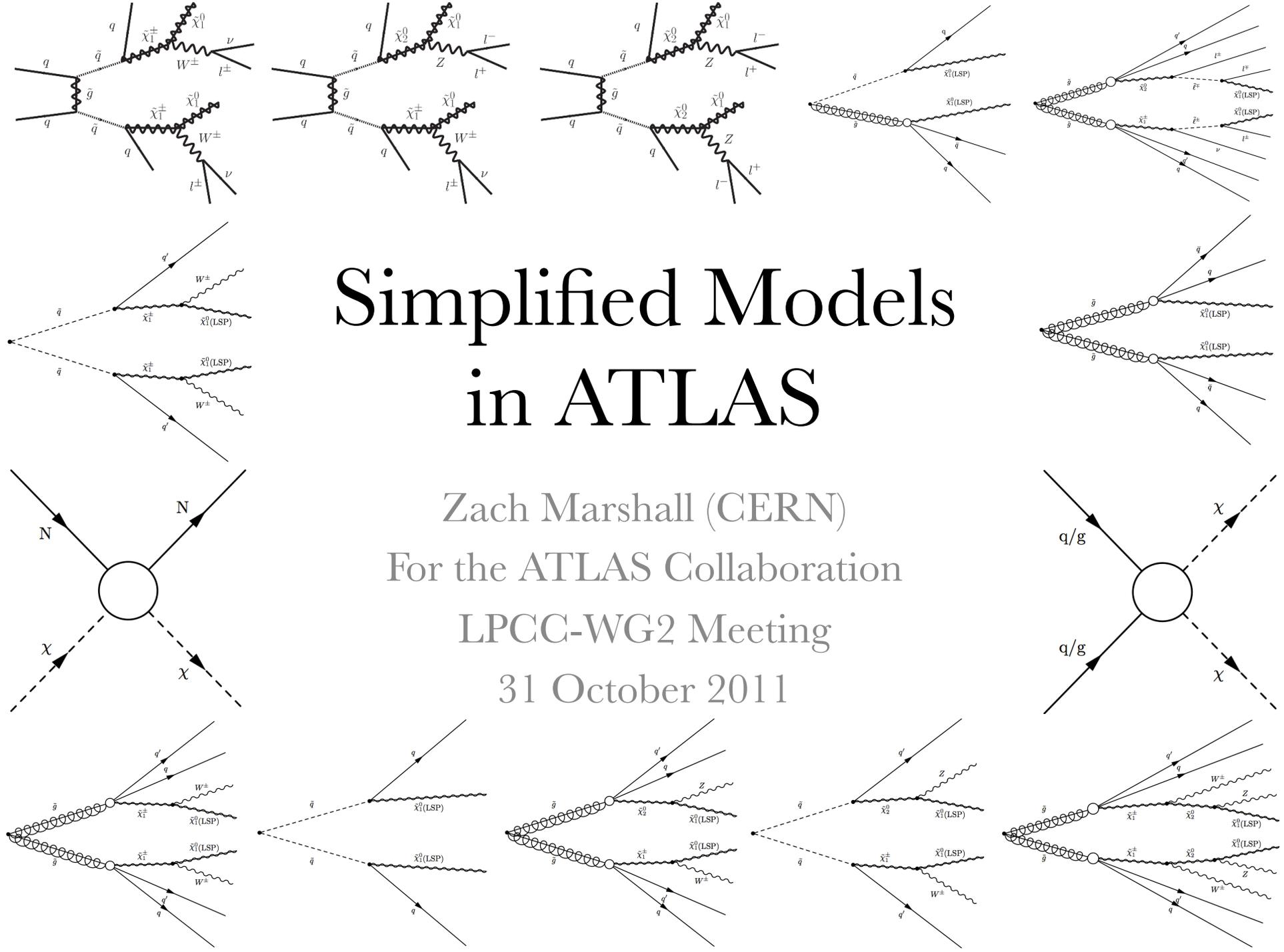
Simplified Models in ATLAS

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For the ATLAS Collaboration

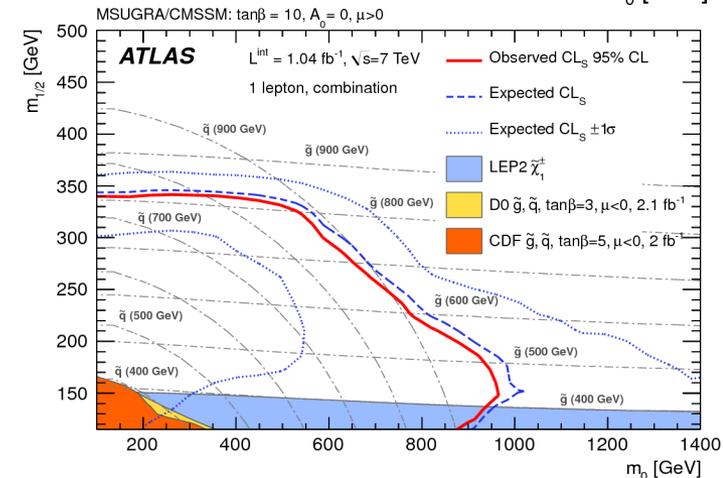
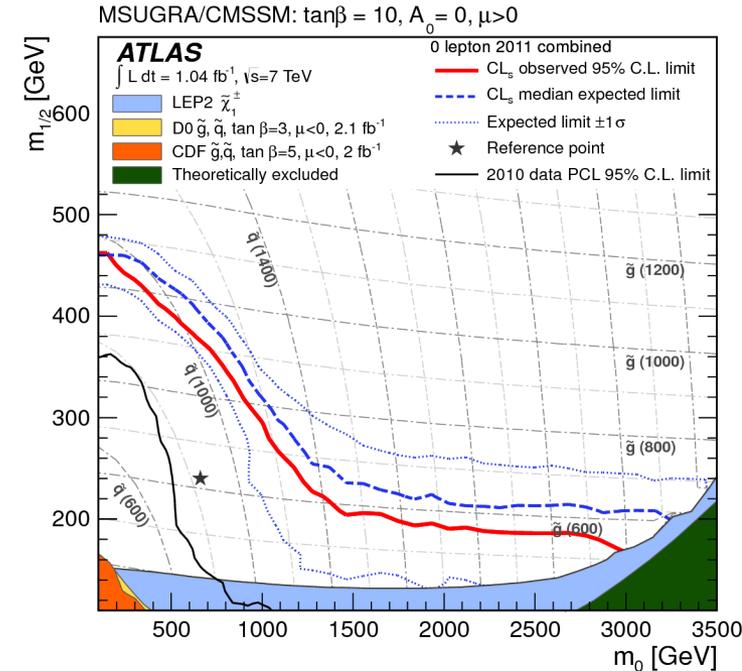
LPCC-WG2 Meeting

31 October 2011

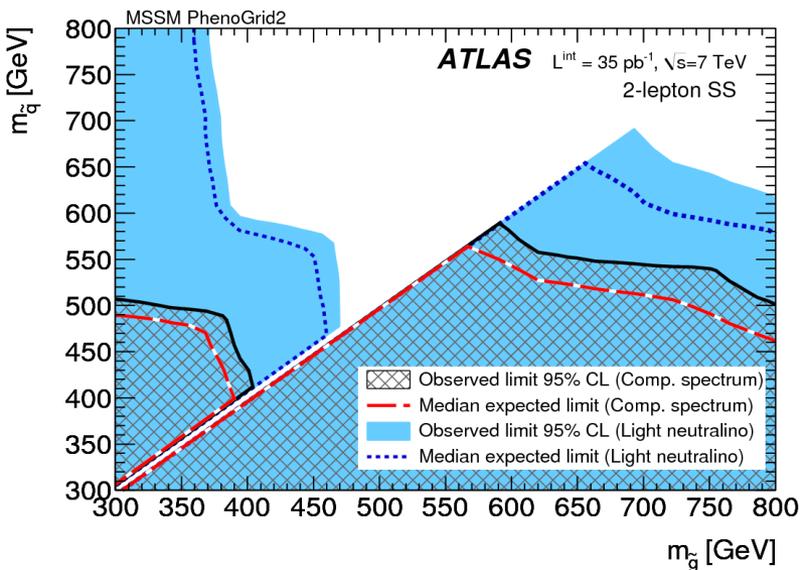
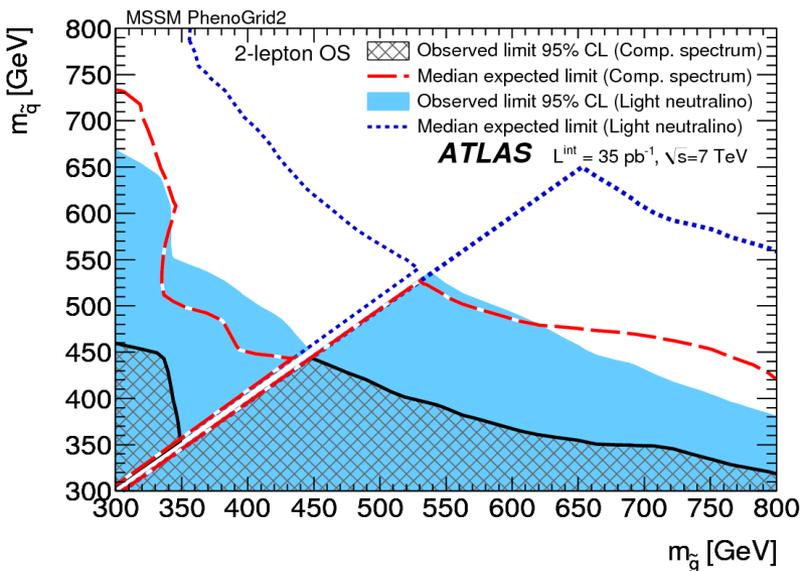


The (Well-Known) Problem

- Limits in mSUGRA (as with any many-dimensional theory) are rather hard to understand and clearly communicate
- Despite our best efforts, people still walk away with “ATLAS excluded SUSY below N GeV”
- We will continue to produce exclusions in mSUGRA planes, since they are familiar
- But we’ve also moved into the business of setting limits on *simplified models* in many of our searches
- Here I’ll show you what approaches we’ve taken, how our exclusions look, what caveats we’d like you to remember, and some of our plans for the (immediate) future
 - Focusing on SUSY simplified models, but I will say a word or two about others

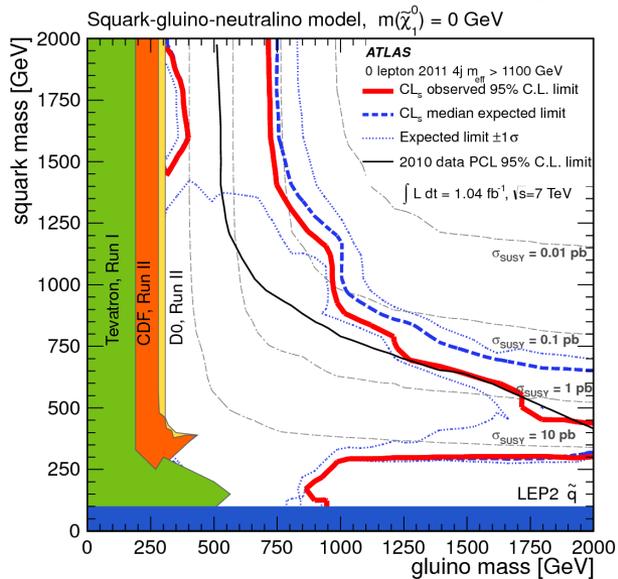
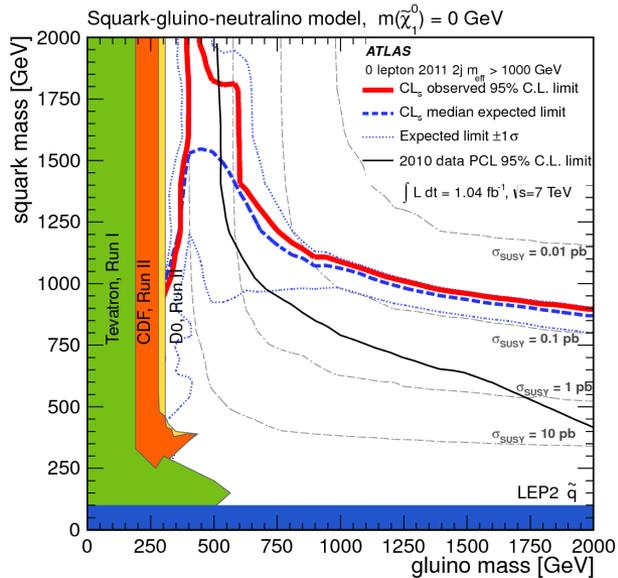


Transitioning to Simplified Models



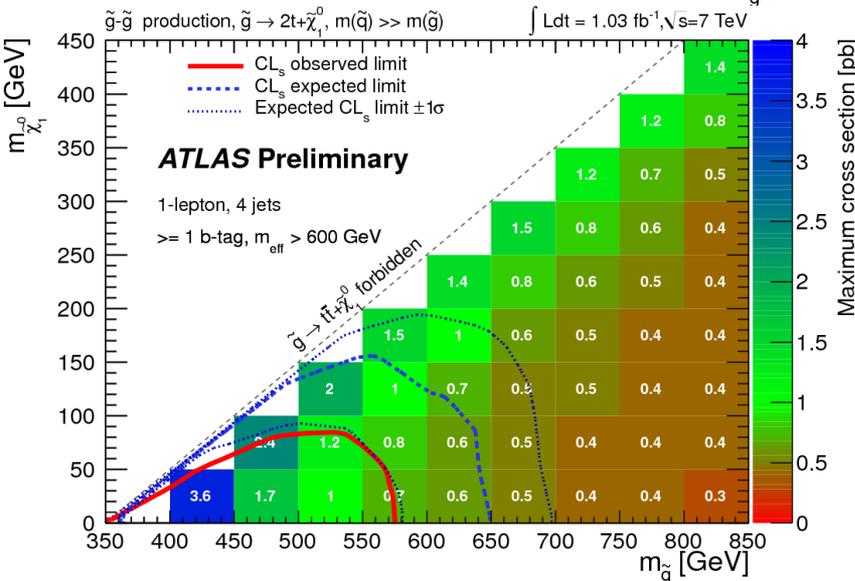
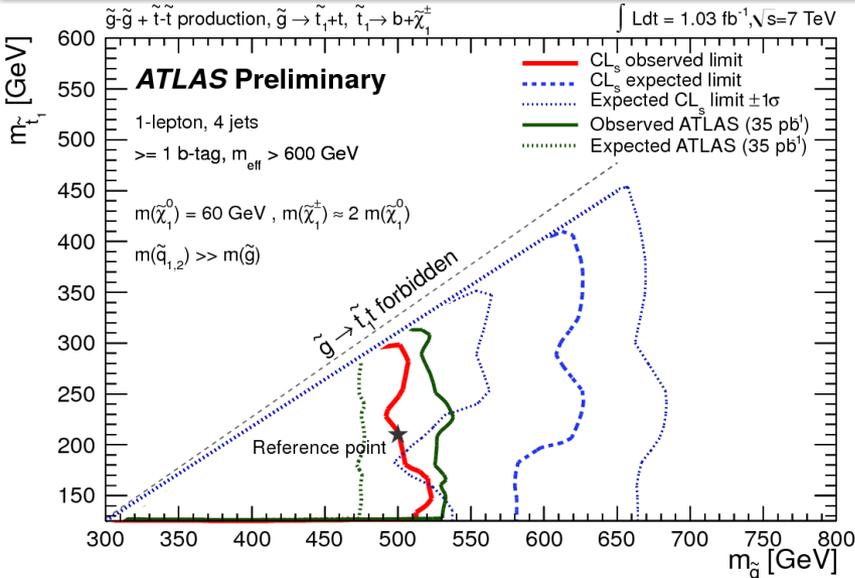
- Some of the first searches used ‘Pheno’ grids in an attempt to ease communication much like simplified models
 - <http://arxiv.org/abs/1103.6208>
- Used mostly in 2+ lepton searches, where simplified models can get rather more complicated (more on this later)
- Still full SUSY points, but with careful selection of parameters in order to give simpler couplings, branching ratios, etc
 - Means that each point is a real physical 24-parameter MSSM theory point – not an unphysical simplified model!
- Went some way to aiding understanding of the limits, but still a complicated parameter space (particularly for non-SUSY experts), and still difficult to understand the limits in terms of other theories

Zero-Lepton Models



- One of the first ATLAS analyses to adopt the use of simplified models was the zero-lepton search
 - Submitted to PLB: <http://arxiv.org/abs/1109.6572>
 - Also in our *first* 0-lepton paper: <http://arxiv.org/abs/1102.5290>
- Used ‘simple’ models with $m_{LSP}=0$
 - At left, two different signal regions’ exclusions
- Extending any 2D limit to the full SUSY space is not entirely trivial
 - Not obvious how things would change when giving the LSP a (significant) mass – but this works for light LSPs, up to almost 200 GeV
 - Including both squark and gluino masses makes things a bit more complicated – which process dominates the signal region? Several production modes and decays are allowed here; this also makes the theory more realistic / physical
- Still, cited as one of the most popular LHC SUSY result plots of the year (!!)
- Several more simplified models coming very soon
 - In line with, or even identical to, some of the models that I’ll describe in the next few slides

Simplified Models with b-jets



- ATLAS search using b-jet tagging has set simplified models limits
 - <http://cdsweb.cern.ch/record/1383833>
 - <http://arxiv.org/abs/1103.4344>
- One model including a gluino, stop, chargino, and LSP
 - LSP mass = 60 GeV (stable)
 - Chargino mass = 120 GeV ($\chi^\pm \rightarrow W^\pm \chi^0$)
 - Stop mass free ($st \rightarrow b \chi^\pm$)
 - Gluino mass free ($go \rightarrow t st$)
 - Limits in the stop-gluino mass plane
- One model including only a gluino and LSP (everything else heavy)
 - Gluino mass free ($go \rightarrow t t \chi^0$)
 - Limits in the gluino-LSP mass plane
- Focus on gluino production and decays including top quarks for now
 - Limits also available with sbottoms
 - In the future, more with direct stop and sbottom production likely!

One-Lepton Models

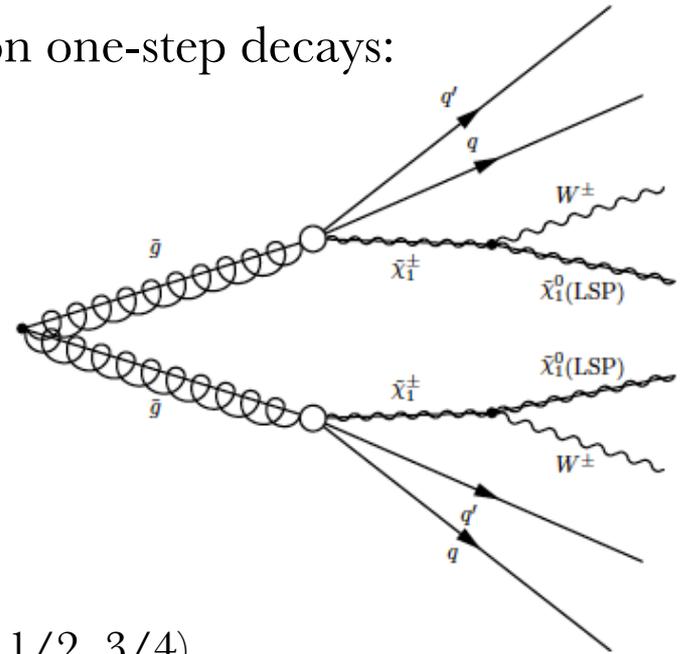
- One-lepton simplified models have focused on one-step decays:
 - Gluino or squark production
 - Decay to a chargino and 2/1 quarks
 - Chargino decay to LSP and a W

- Leaves a model with three parameters:
 - Gluino or squark mass
 - LSP mass
 - Mass of intermediate chargino, written as

$$x = (m_{\text{ch}^+} - m_{\text{LSP}}) / (m_{\text{heavy}} - m_{\text{LSP}})$$

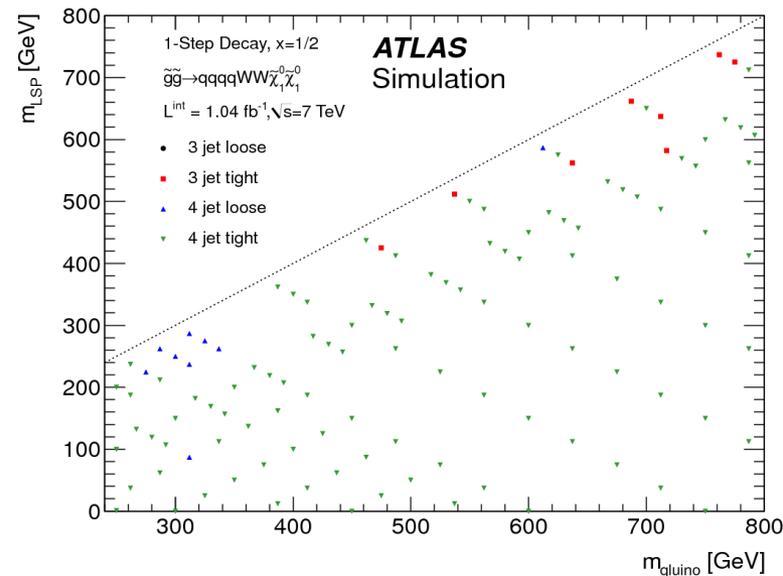
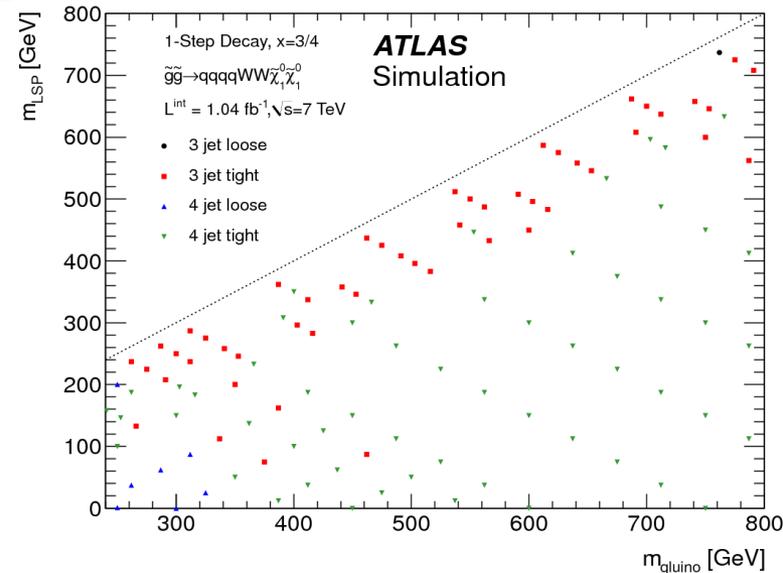
Using 2D grids with three values of x (1/4, 1/2, 3/4)

- Only *exclusion lines* include model-dependent uncertainties like PDFs and ISR uncertainty
 - In order to include these uncertainties in a reasonable way, one must assume some production diagram – which requires a model!
 - Production via quark vs gluon can change initial-state radiation by a factor of two, which can be very important for the search (more on this in a moment)
 - Here, SUSY limits being set, so using SUSY diagrams (caveat emptor)
- Paper now submitted to PRD: <http://arxiv.org/abs/1109.6606>

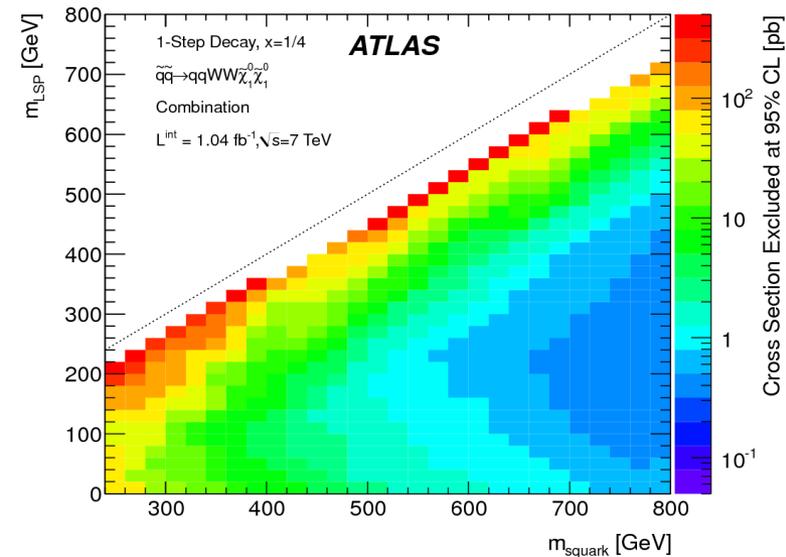


One-Lepton Optimization

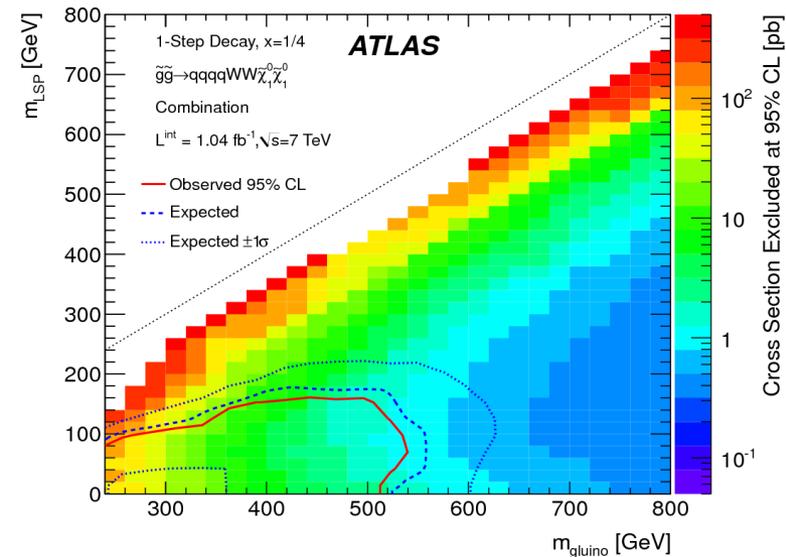
- One of the first analyses in ATLAS to be *re-optimized* based on examination of simplified models and missed parameter space
 - B-jet search also optimized using SMs
 - Many others now following suit!
- Using simplified models to ensure that we don't miss corners of parameter space / mass space
- Four signal regions included for one-lepton mode
 - The signal region that is optimal for a given point clearly depends on where you are in parameter space, as expected
 - One good for small splitting, one good for low mass, one good in the bulk
- Similar trends are showing up in other analyses – must have a few regions to cover everything
 - In general, we *weren't doing too badly* with the original signal selection, but some optimization was possible



One-Lepton Limits



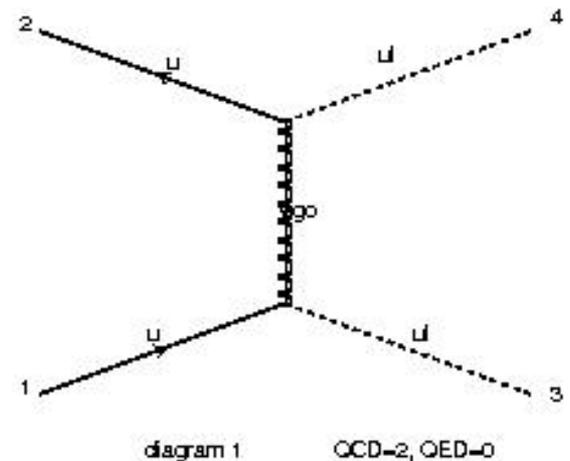
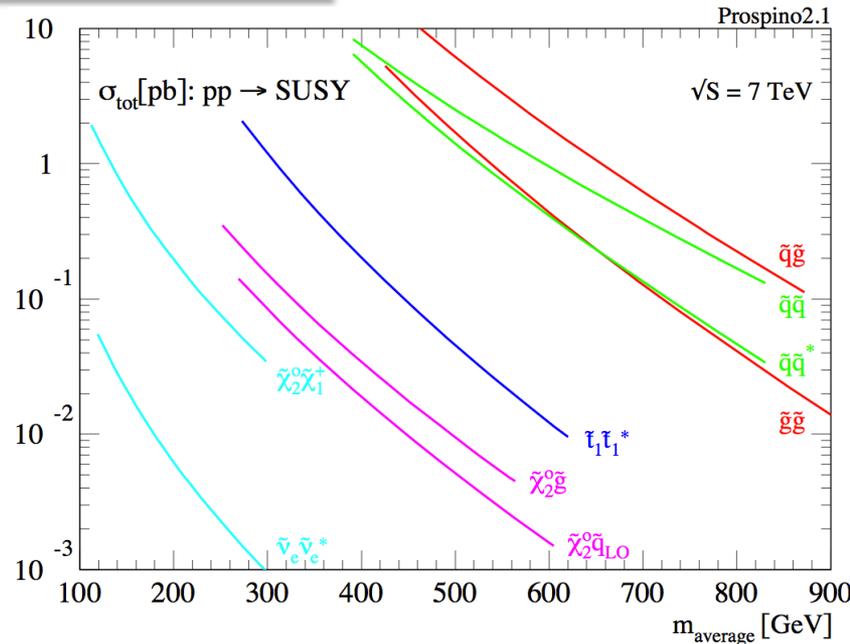
- Top, limits for squark-squark production
- Bottom, limits for gluino-gluino production
- All for 100% branching fractions
- Limits for squark-squark production appear *much* worse!
 - For simplified models these lines are not determinant – the color-coding of the plot carries a great deal of the information



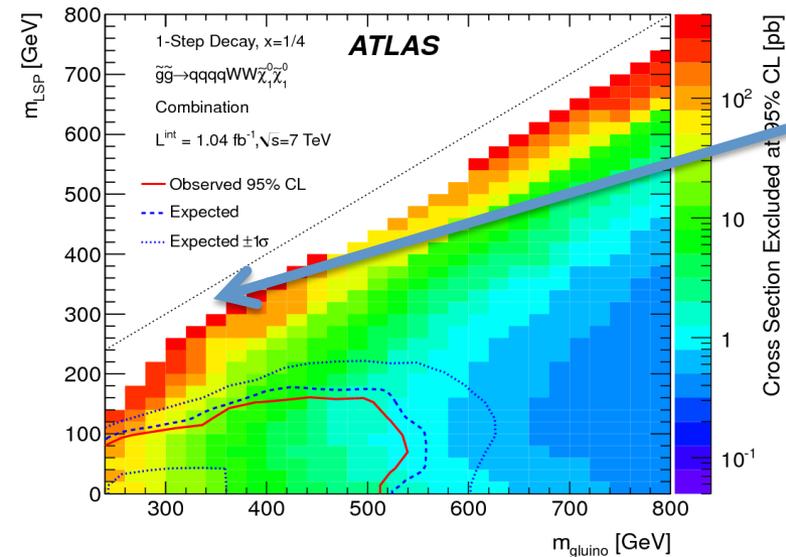
- Perhaps the lower multiplicity could hurt our acceptance * efficiency?
 - NO! In fact, the acceptance * efficiency is *very* similar for the two models!
- It is the *production cross-section* that differs most between the two!!
 - But Prospino's public plots show similar cross-sections, so what's going on?

Production Mechanisms

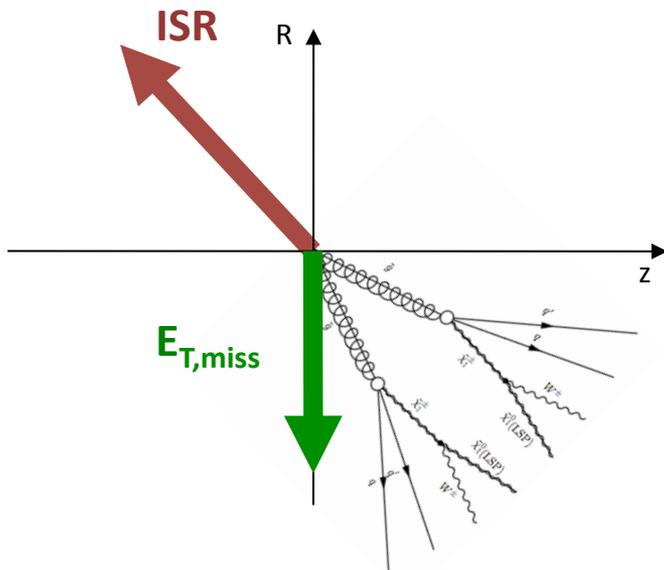
- Prospino publicity plots typically show the squark production cross section comparable to (or even higher than) the gluino production cross-section at 400-500 GeV
- But this is *not* a simplified model!
 - The critical *gluino exchange* diagram is turned off when the gluino is very heavy
 - Ignoring or disabling these diagrams leads to a significantly lower – albeit physically correct – cross-section for squark-squark production
 - Forcing a decay through a W means that we should only consider *left-handed* squarks
 - Simple sq-sq cross sections are an order of magnitude below ‘full’ sq-sq cross-sections
- Our acceptance*efficiency becomes that much more important when “model limits” are hard to draw



Approaching the Diagonal

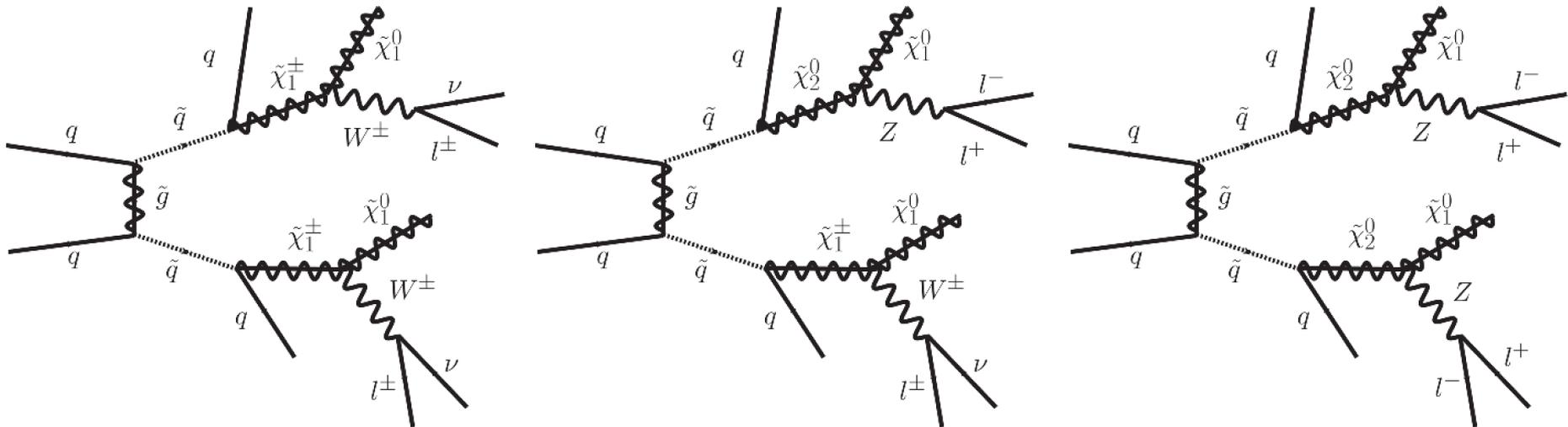


- As the search gets close to the diagonal of these simplified models, signal regions with jets depend increasingly on the modeling of initial state radiation
- How one sets a systematic uncertainty on that is not something well-established in the community (to say the least)
 - We have done some studies with MadGraph + Pythia, different matching scales, and different tunes, and tried to make some reasonable and conservative assumptions
 - Some guidance from the theory community or common agreement about how to treat this uncertainty would be welcome
 - Certainly the old trick of switching ISR off is *unacceptable* in this situation
- Jet kinematics of course change, but the missing E_T changes significantly as well!!

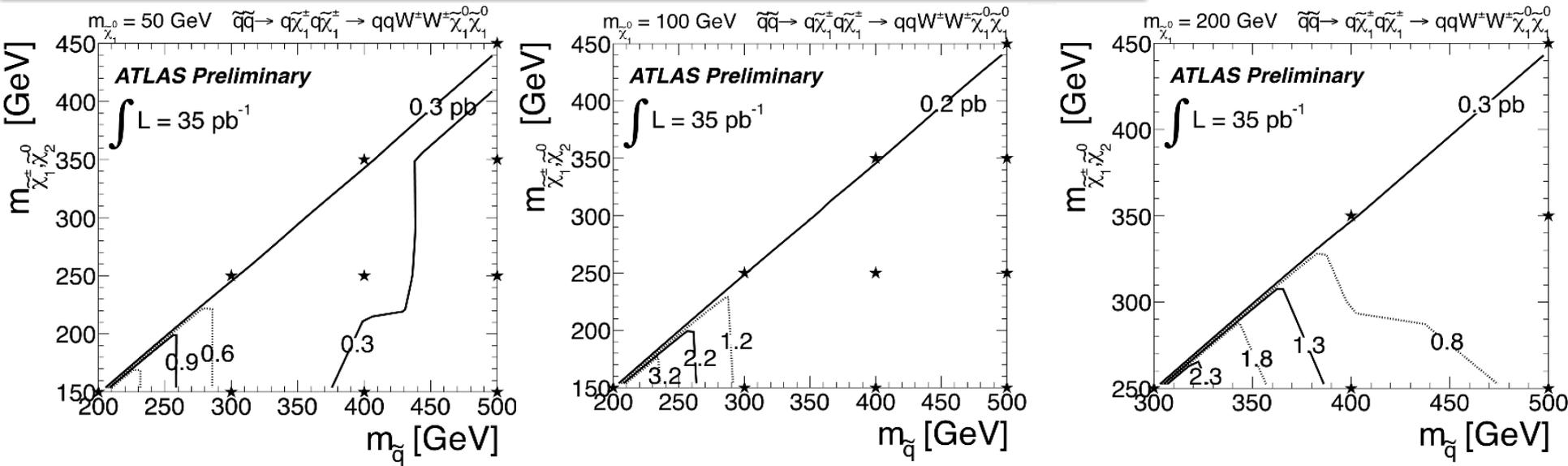


Multi-Leptons

- Multi-leptons give fairly background-light SUSY signals
- The more leptons we'd like to look at in the signal region, the more complicated the decay diagrams can get
- Becomes increasingly hard to judge what the best “simplified” models are for these modes, what is most interesting, and what is most meaningful
 - More grids mean more technical difficulties
- Our multi-lepton searches thus far have set limits on diagrams with a large number of charginos and neutralinos, rather than intermediate sleptons
 - More models to come, of course...



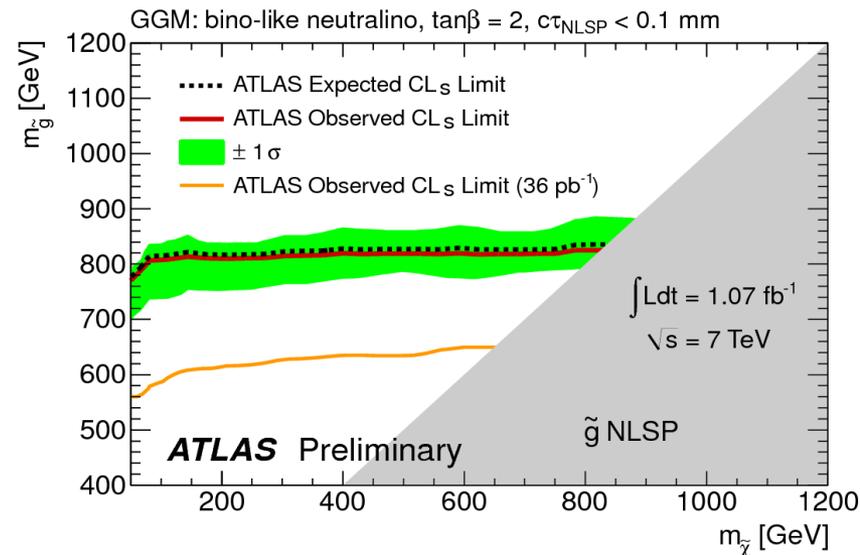
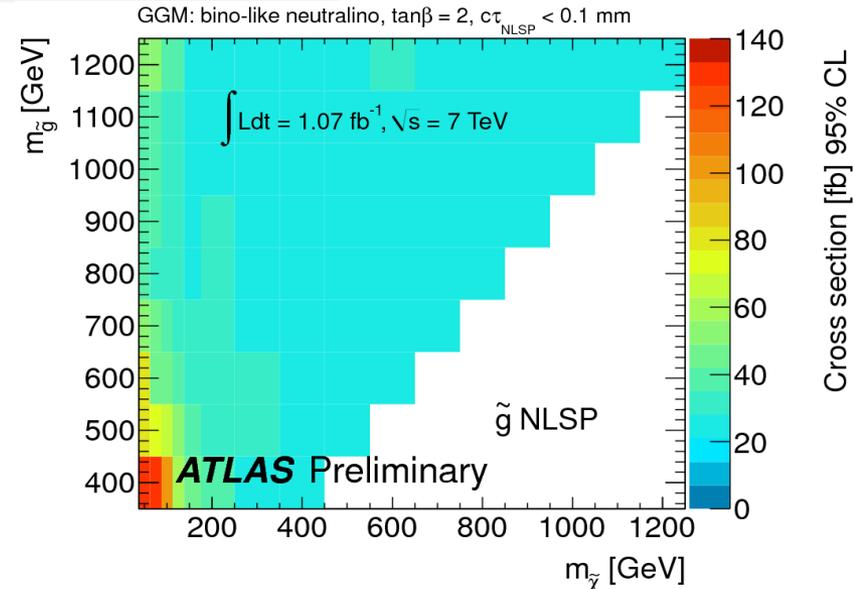
Multi-Lepton Exclusions



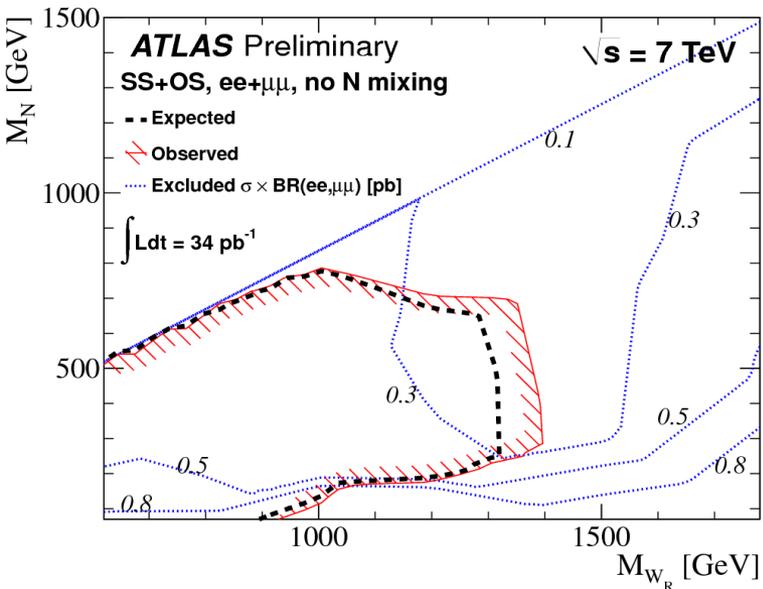
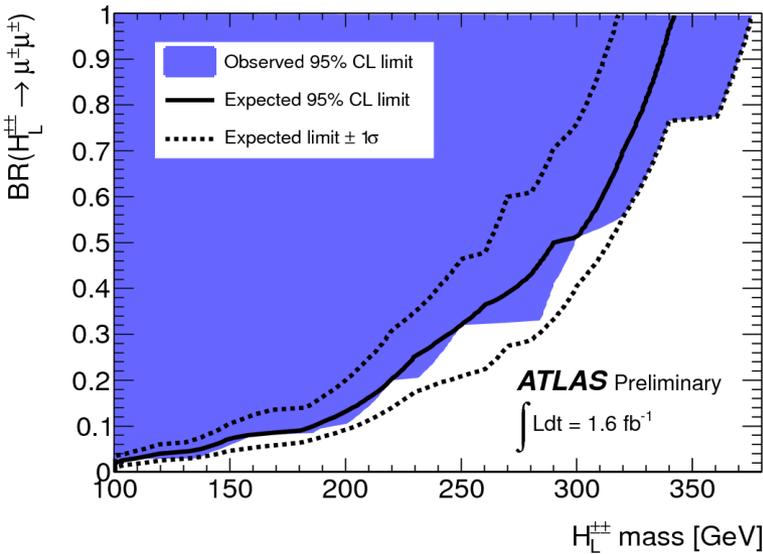
- Many public exclusion plots available
 - <http://cdsweb.cern.ch/record/1360190>
- Small number of grid points, large number of grids
 - Here three examples: squark production, decay through a chargino to qW LSP, with three different LSP masses
 - What is preferred in the end – a large number of grids with small number of points (lots of extrapolation), or a large number of points on a small number of grids (lots of uncovered topologies)?
 - Many more models coming with this year's papers in the multi-lepton channels

Photon Limits

- Also produced limits on simplified models with photons using the 2010 and 2011 data
 - <http://arxiv.org/abs/1107.0561>
 - Flipped x- and y-axes relative to the previous plots, and the χ^0 is unstable
 - Plots on the right are *hot off the presses*
- Dominant gluino production
 - Other masses 1.5 TeV (N.B. not enough to be decoupled)
- Decay mode: $g\tilde{g} \rightarrow X\chi^0, \chi^0 \rightarrow \gamma G$
- Limits set in gluino- χ^0 mass plane
 - Gravitino assumed to be light
- What alternate simplified models including photons would be interesting?
 - Some are covered in jet analyses, without photon ID (“just” jets without tracks)
 - But lose quite a bit of signal and gain background without photon identification



Exotic Simplified Models



- Simplified models show up more and more in our exotics searches
 - <http://cdsweb.cern.ch/record/1383792>
 - <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-115/>
- We know our limits will be applicable to a range of theories, so we're trying to make them as useful as possible!
 - Often that comes by weakening the assumptions about how Standard Model-like a particle's couplings are and providing fiducial cross-section limits
- Have to be a bit careful about this though!
 - Over-simplification can mean underestimation of signal contamination or overestimation of efficiency
- Setting 'full' model limits is important if we really want to exclude a theory and be sure that we're doing everything right

Summary and Conclusions

- Building up a nice dictionary of simplified model limits from ATLAS
 - Acceptance times efficiency plots are available on HepData (!!)
 - Certainly their use is becoming mainstream in setting BSM limits
- Some of these limits need some care in interpretation, particularly when one takes the “model lines” too seriously
 - Nature (and full models) tend to smear distributions out – this will be a serious concern when we start talking about analyses which *fit* for signals
- We remain open to feedback about how we might better present the limits to the community
 - How should we deal with initial state radiation uncertainties??
 - What lines are best to draw on the exclusion plots?
- New ‘high-multiplicity’ signal regions don’t use simplified models for limits
 - High-multiplicity == long decay chains != simple model
 - Similar concern for multi-lepton modes – what are the best models, and how do we best scan a 3(+) dimensional space? What about orthogonal 2D planes?
- Several more re-interpretations in simplified models on the way, both with already-published analyses and with upcoming analyses
- Coming soon to arXiv: the closed loop! Limits set on mSUGRA using simplified model exclusions (C. Gütschow and ZM, only public ATLAS results)