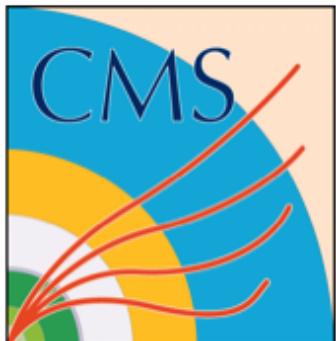




Supersymmetry: Experimental status

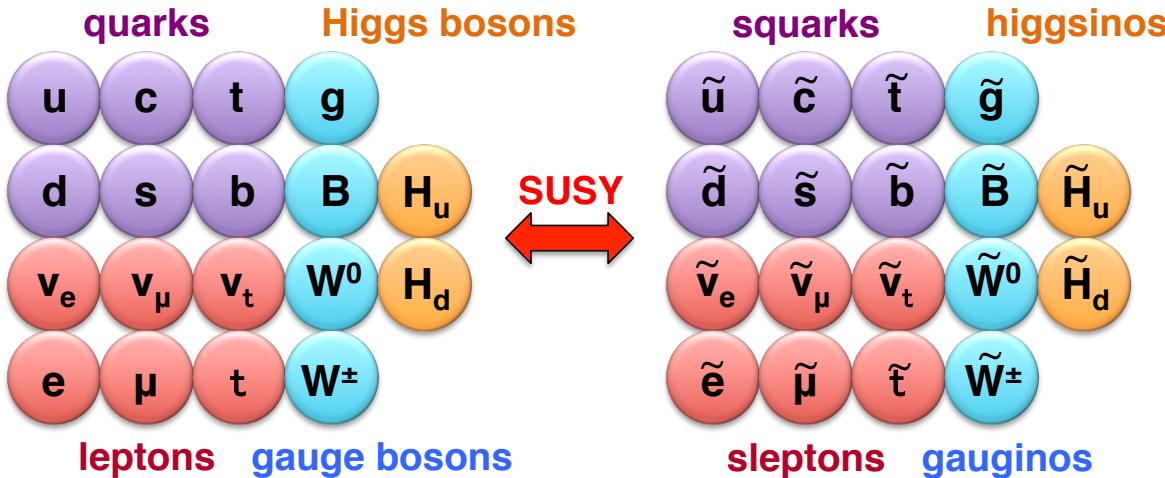
Keith Ulmer
Texas A&M University
for ATLAS and CMS



LHCP
St. Petersburg, September 2015

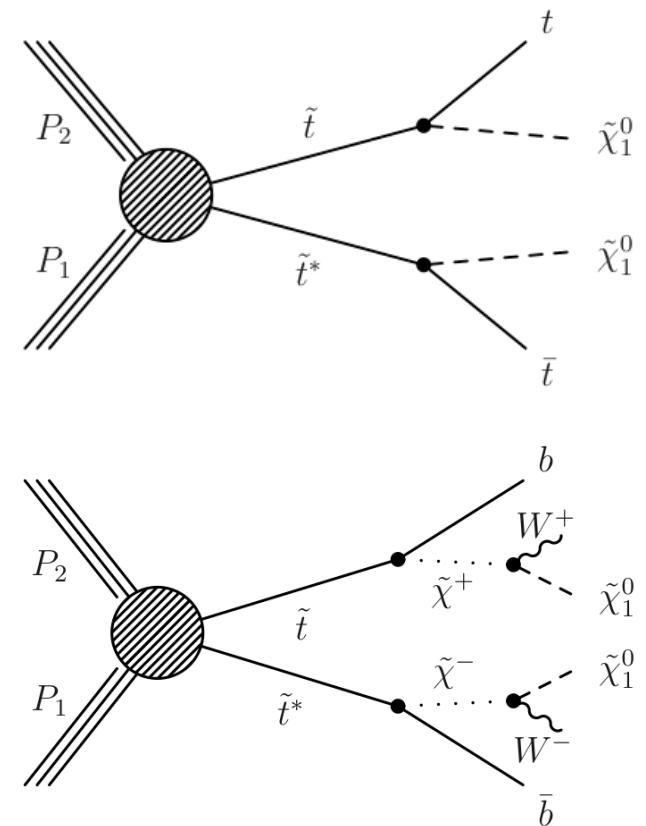
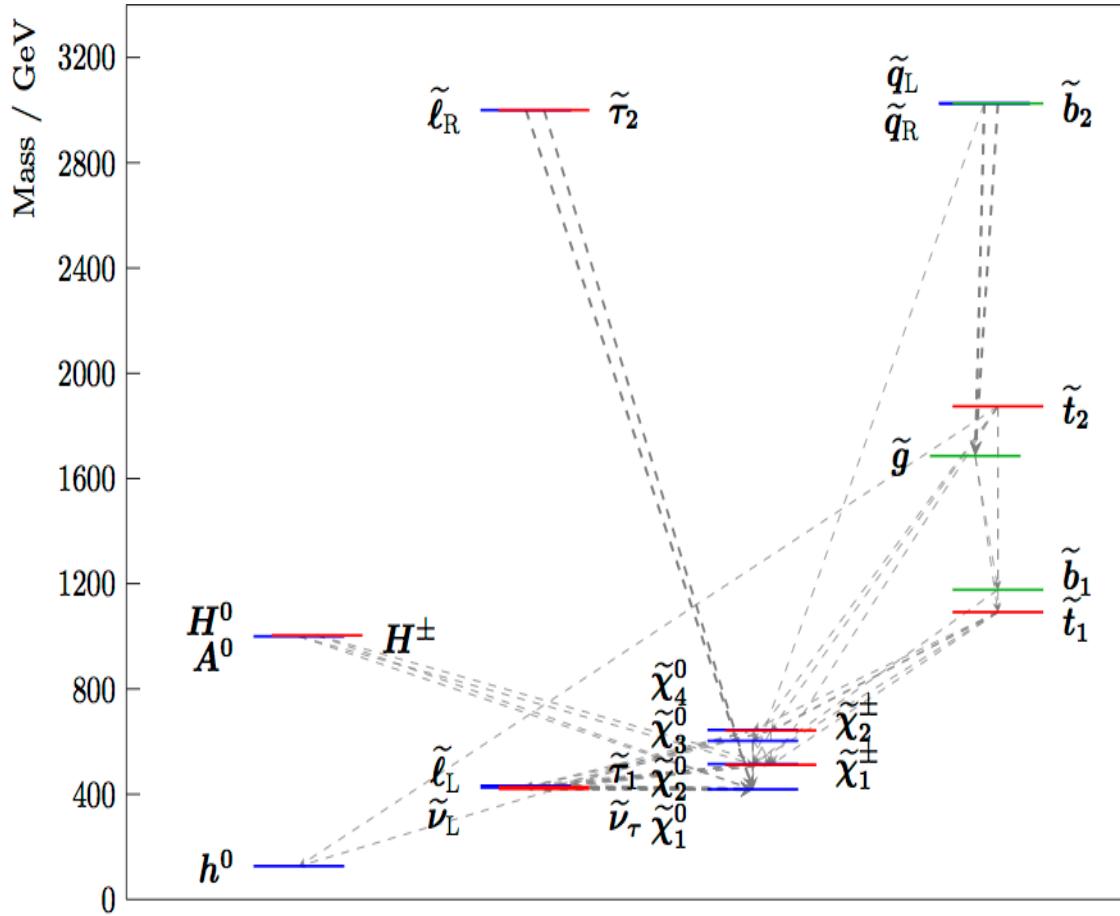


Supersymmetry



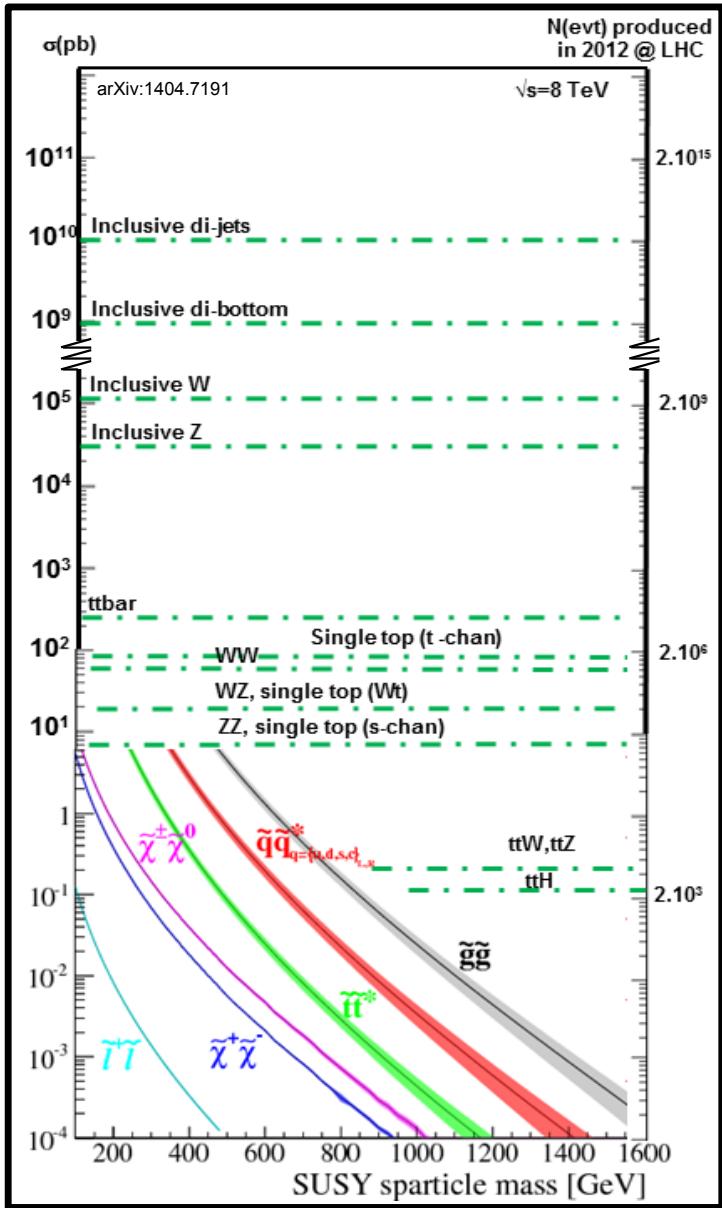
- ◆ SUSY offers eloquent solutions to many pressing issues in the SM
 - ◆ Natural cancelation of Higgs mass divergences
 - ◆ DM candidate with stable lightest SUSY particle (LSP)
 - ◆ Potential gauge coupling strength unification
- ◆ The experimentalist's note:
 - ◆ “SUSY” used as a proxy for a broader class of new physics models
 - ◆ Ex. Search for production of any new particles decaying to stable DM
 - ◆ Alternatively, see Annapaola De Cosa 8/31 for pure DM production

An Experimentalist's Playground



- Rich spectrum can be broken down into individual signatures

The Experimentalist's Challenge



- ◆ SUSY production buried under mountain of SM background
- ◆ Goal to accurately measure SM contributions in regions where new physics may have significant contributions
- ◆ This talk:
 - ◆ Give flavor of where we search and how we measure SM backgrounds
 - ◆ Can't possibly cover all results...

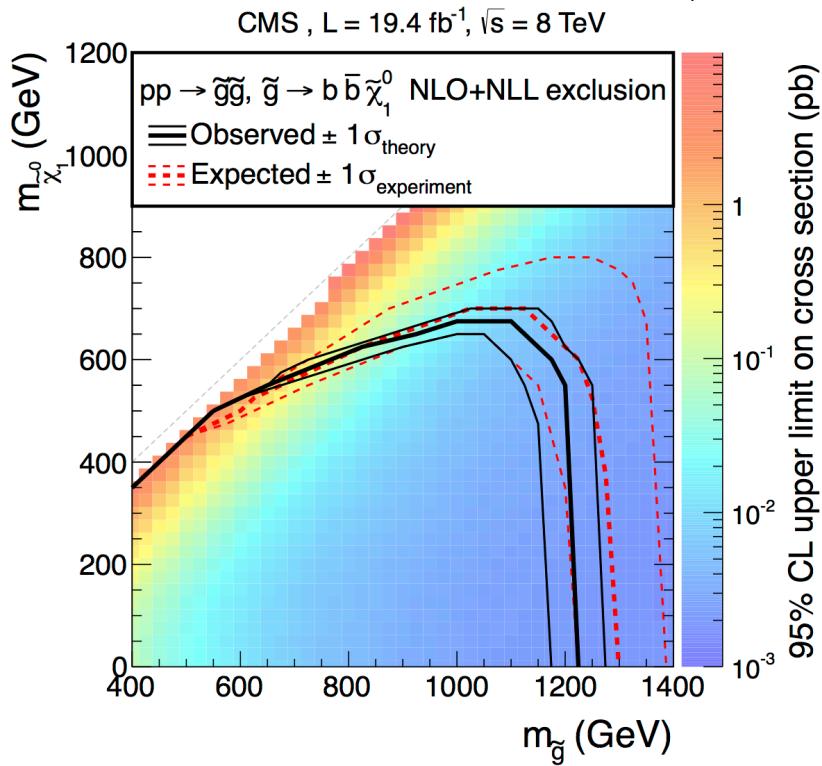
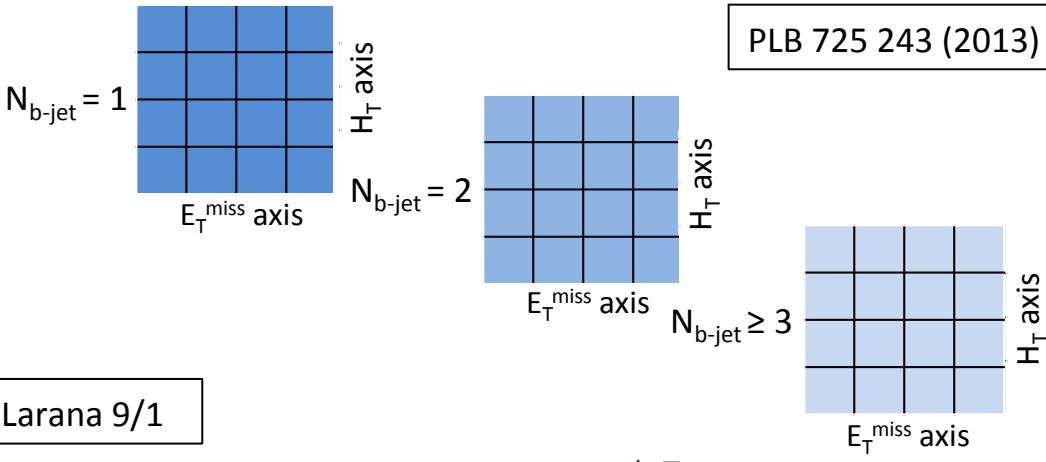
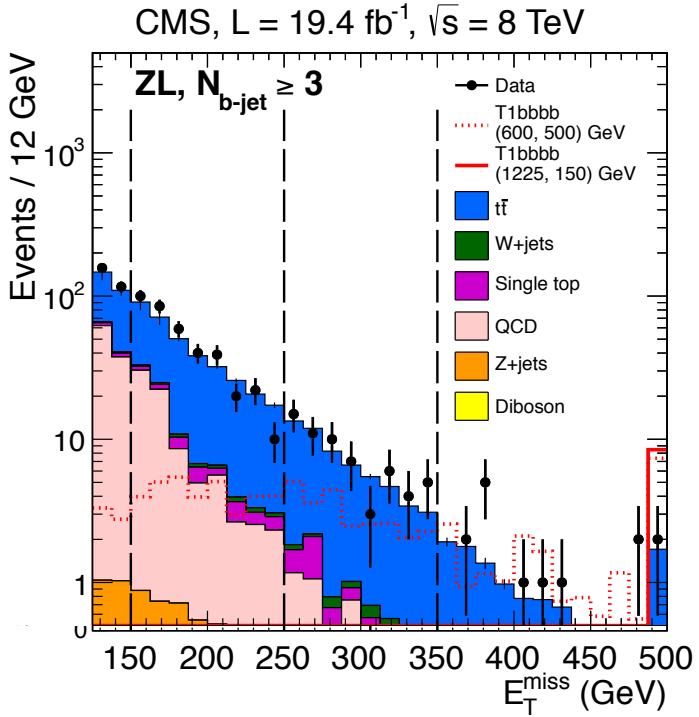
<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults>
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS>

Inclusive Searches

Inclusive Hadronic

- ◆ Select events with high p_T jets and no leptons
 - ◆ Search with 3D fit to MET, HT, and nB to capture broad sensitivity to many models

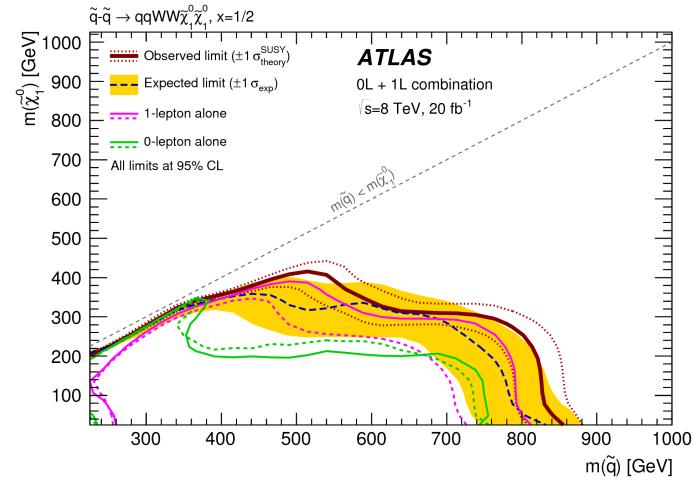
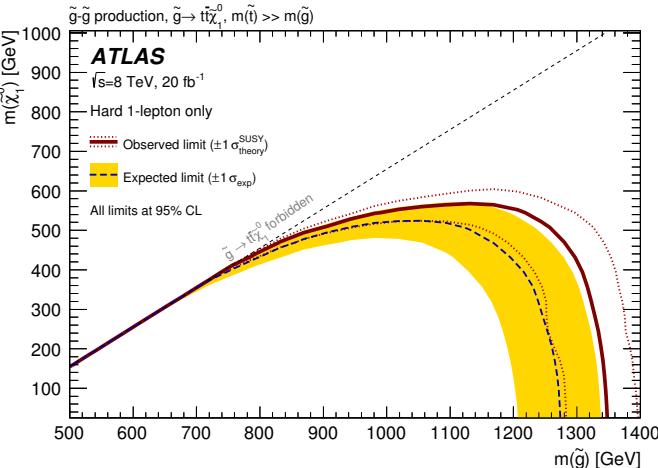
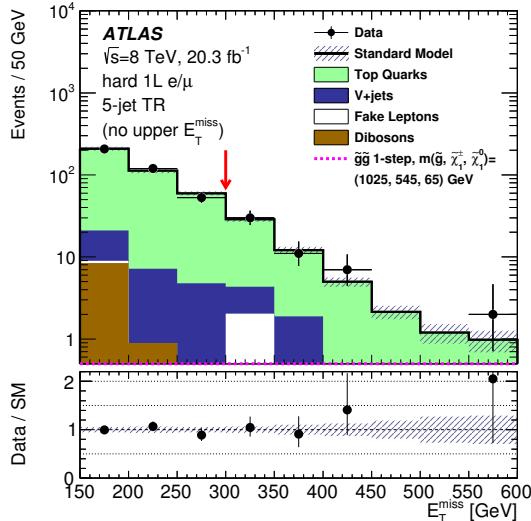
See also parallel talks by Julien Maurer, Bruno Casal Larana 9/1



Inclusive single lepton

- Search in soft and hard leptons
- With low and high jet multiplicities
- Background predictions from normalizing SM MC to control regions in data and extrapolating to signal regions
- Check accuracy of extrapolations with validation regions in data

JHEP 04 (2015) 116

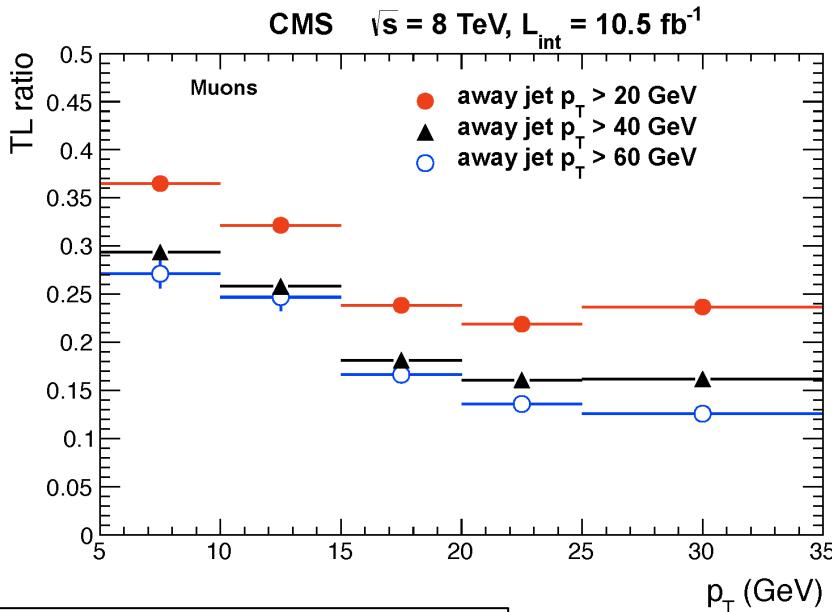


1507.05525 Inclusive summary paper

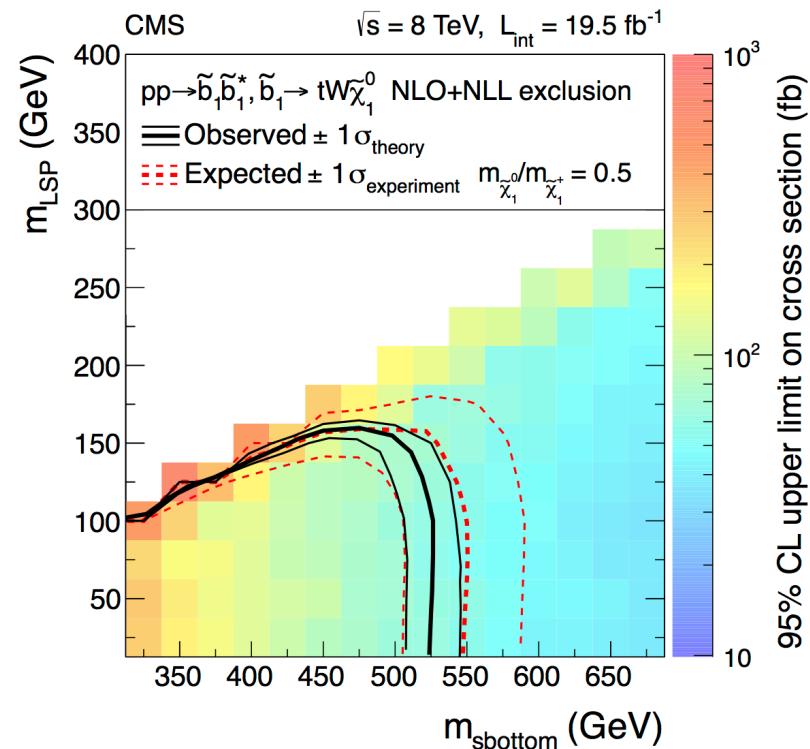
Inclusive same-sign dilepton

- ◆ Select events with two isolated like-charge e^- or μ^-
- ◆ Consider bins with low/high MET, HT, nJet, and nB
- ◆ Significant background from “fake” leptons
 - ◆ Measured with data-driven prediction of fake rate
 - ◆ Extrapolate from loose isolation sidebands to tight signal regions

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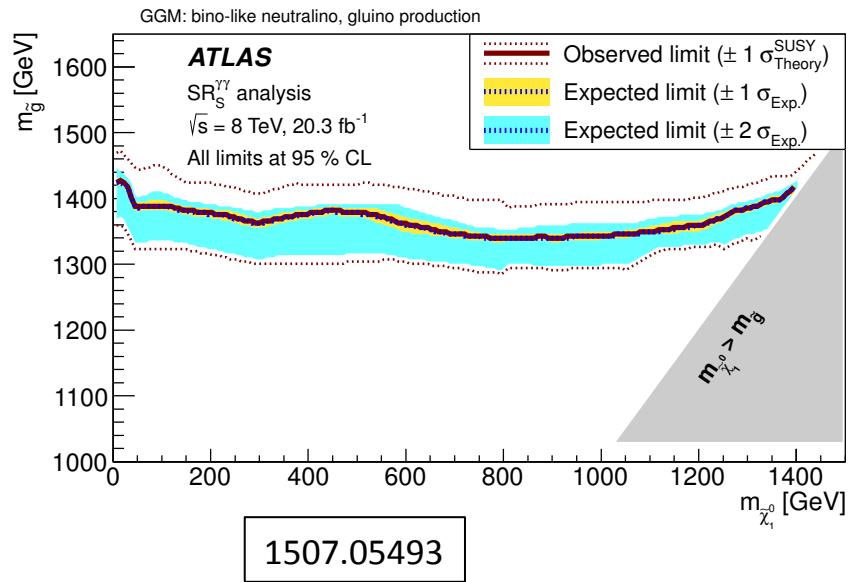
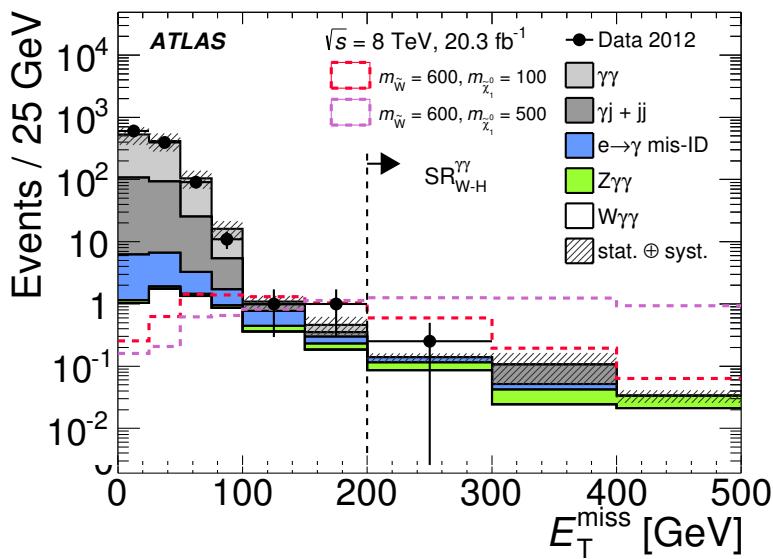
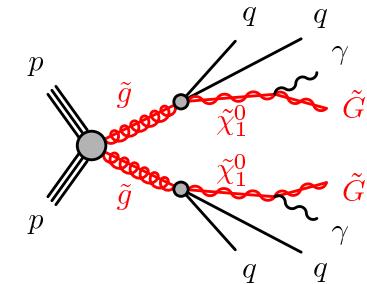


See also: Peter Thomassen 9/3



Inclusive with photons

- ◆ Select events with two isolated high p_T photons
- ◆ Generically present in many GMSB scenarios
- ◆ Signal regions targeting strong and weak production, and light and heavy LSP
- ◆ Isolation sidebands used to define proxy control sample to predict MET shape for $\gamma\gamma$ and γ ,jet backgrounds

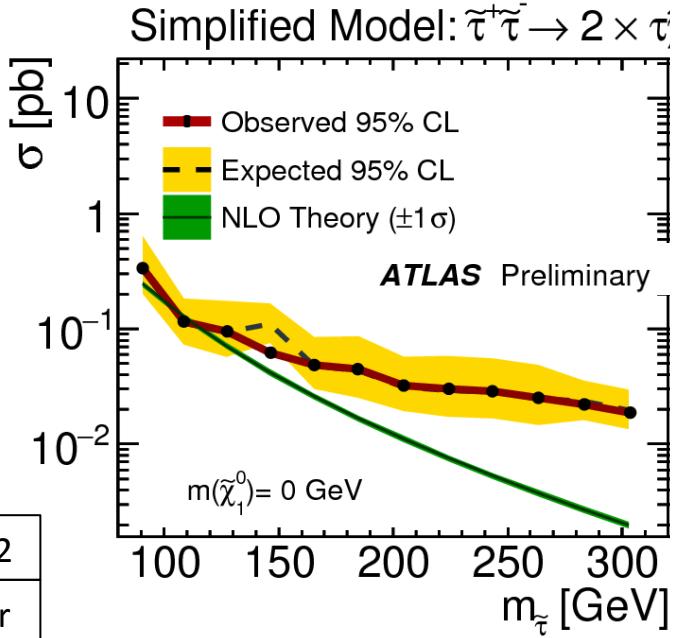
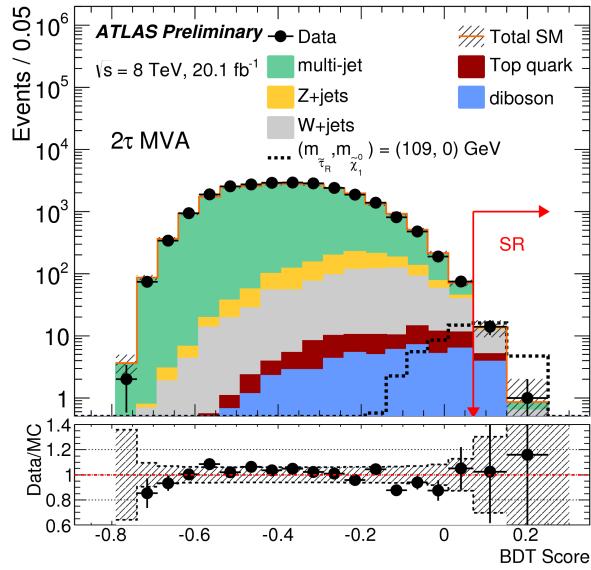
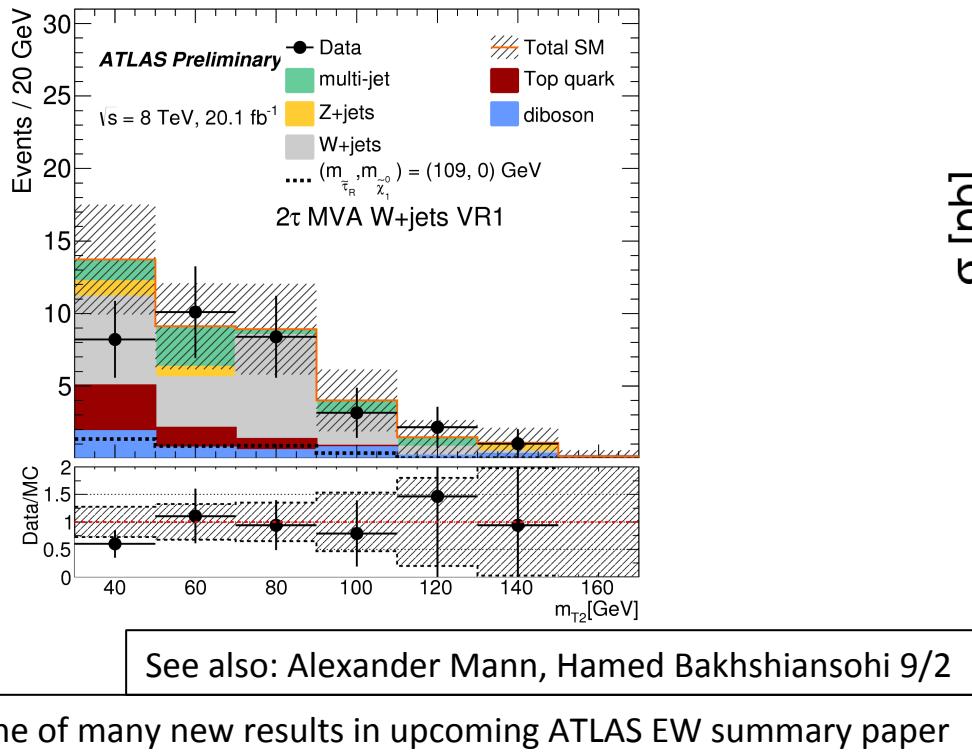


Summary photon paper including many final states

Targeted Searches

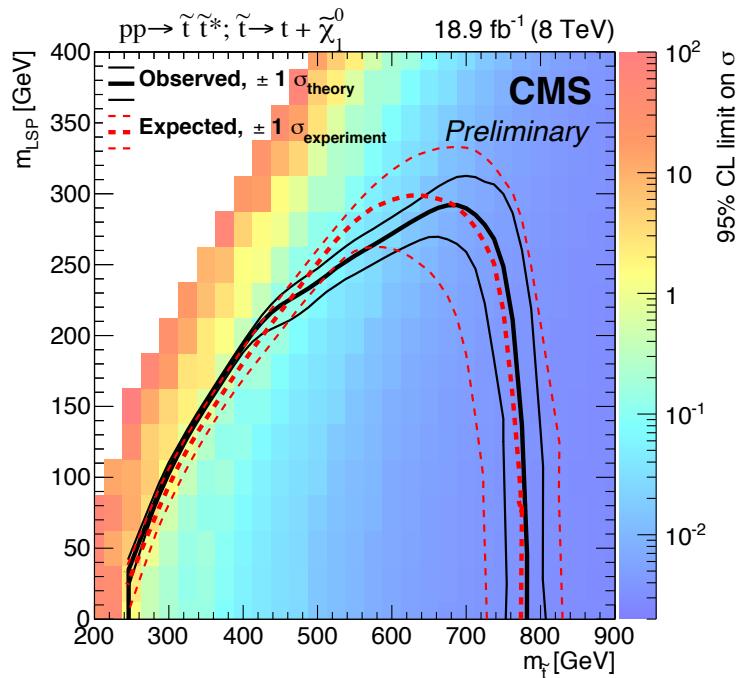
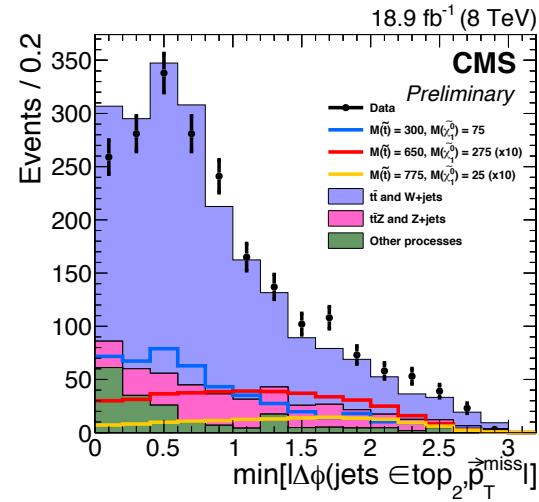
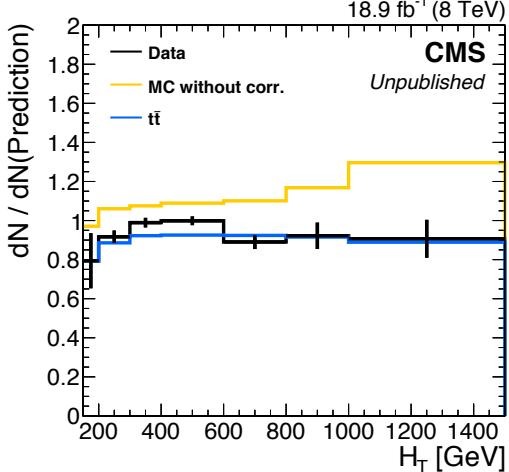
Direct stau pair production

- ◆ Select events with two hadronic tau candidates with opposite charge
- ◆ Veto b-jets and Z candidates
- ◆ Train Boosted Decision Tree to separate signal from backgrounds
- ◆ Backgrounds predicted by normalizing MC to data control regions in BDT sidebands



Direct stop production

- ◆ Search for hadronic stops
 - ◆ Veto events with isolated leptons
 - ◆ Custom variable-cone jet reconstruction for high top reconstruction efficiency
- ◆ BDT for signal selection
 - ◆ Including top kinematic variables
- ◆ MC reweighted in key variables for background predictions
 - ◆ MET resolution, W p_T , B-tag discriminant, etc.



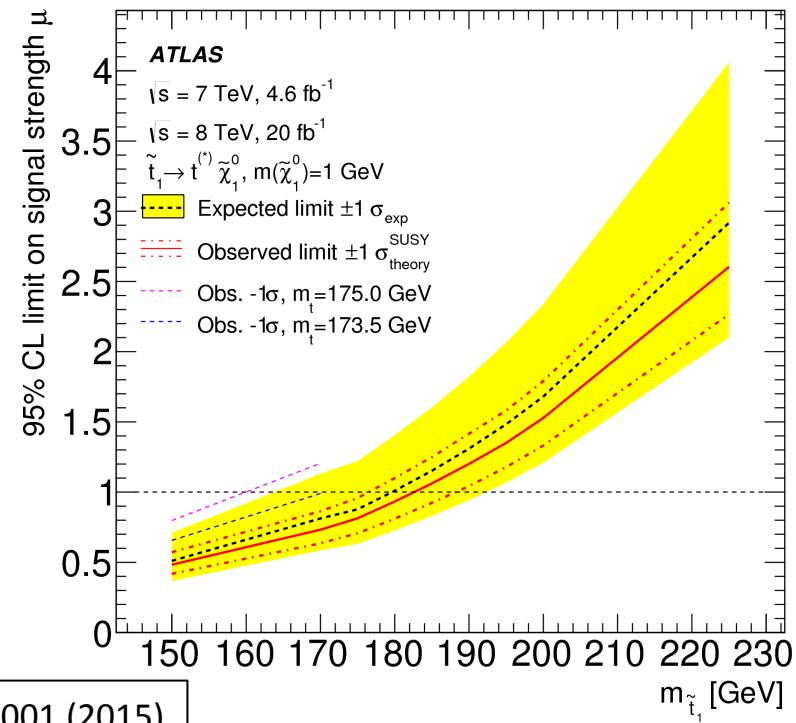
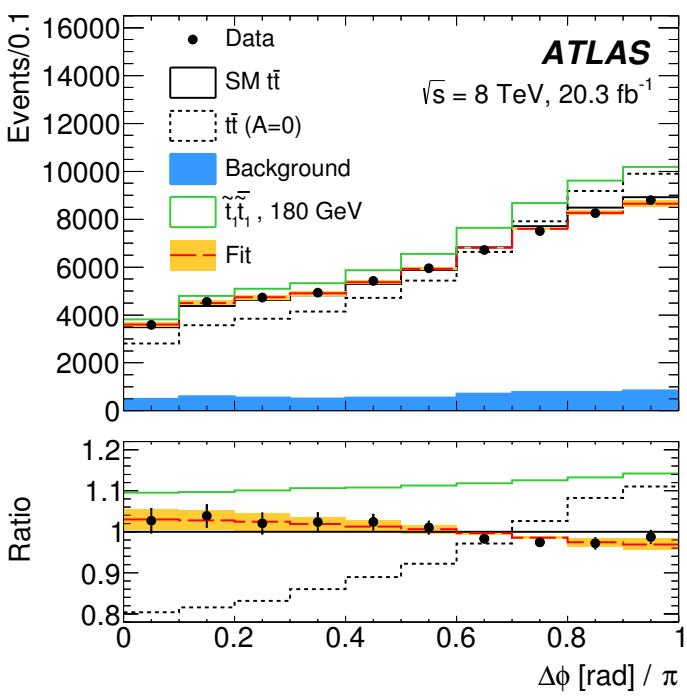
CMS-SUS-13-023

See also: Kerim Suruliz, Lara Lloret Iglesias 9/1

Exploring Gaps

Precision top as SUSY search

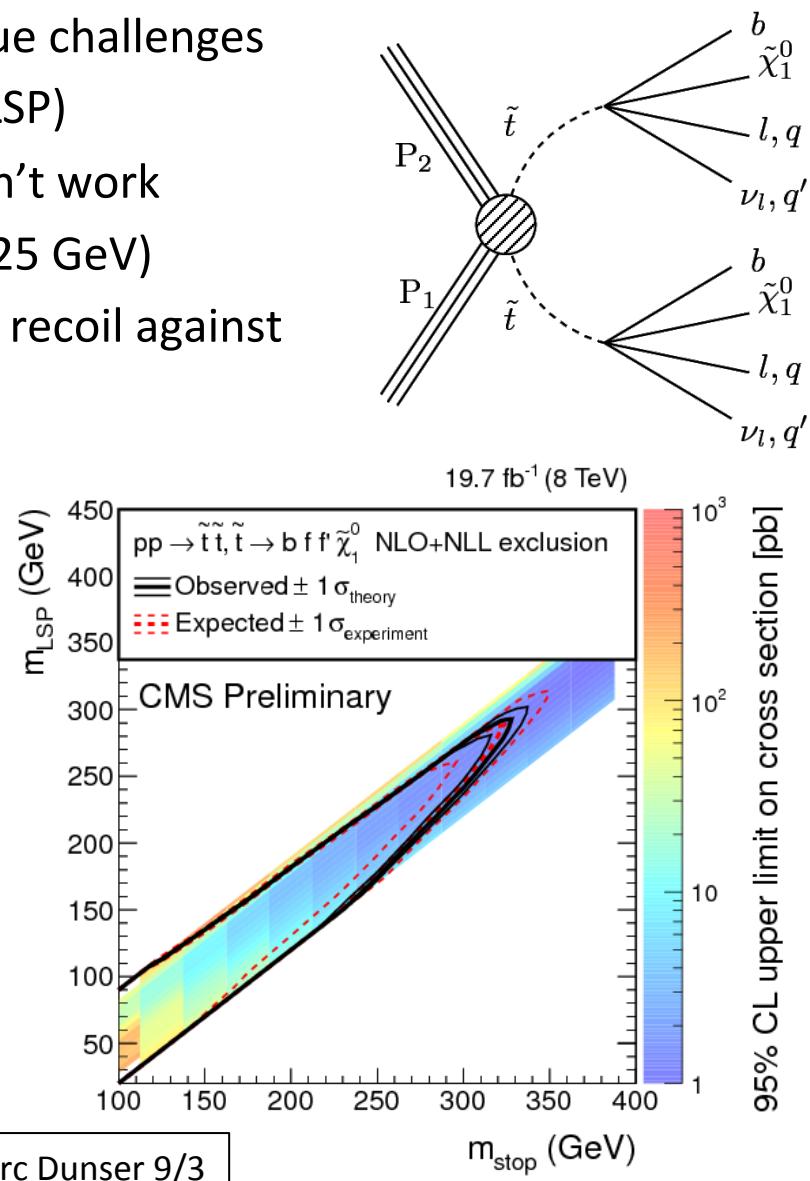
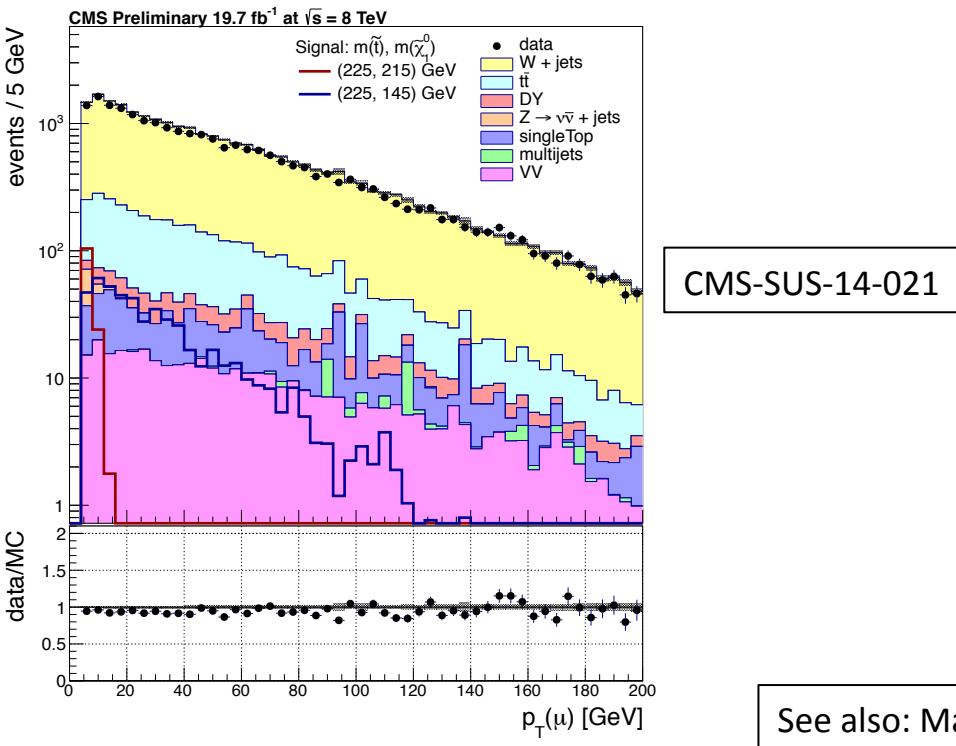
- ◆ Stop with mass equal to top, and $m(\text{LSP}) \sim 0$ presents a unique challenge
 - ◆ Dominant top background has identical decay products
- ◆ Measuring $\sigma(t\bar{t})$ with sufficient precision allows reinterpretation as limit on SUSY
- ◆ Subtle angular decay correlation differences exploited to squeeze further discrimination
- ◆ Included in new 3rd generation summary paper: 1506.08616



PRL 114, 142001 (2015)

Soft leptons with ISR

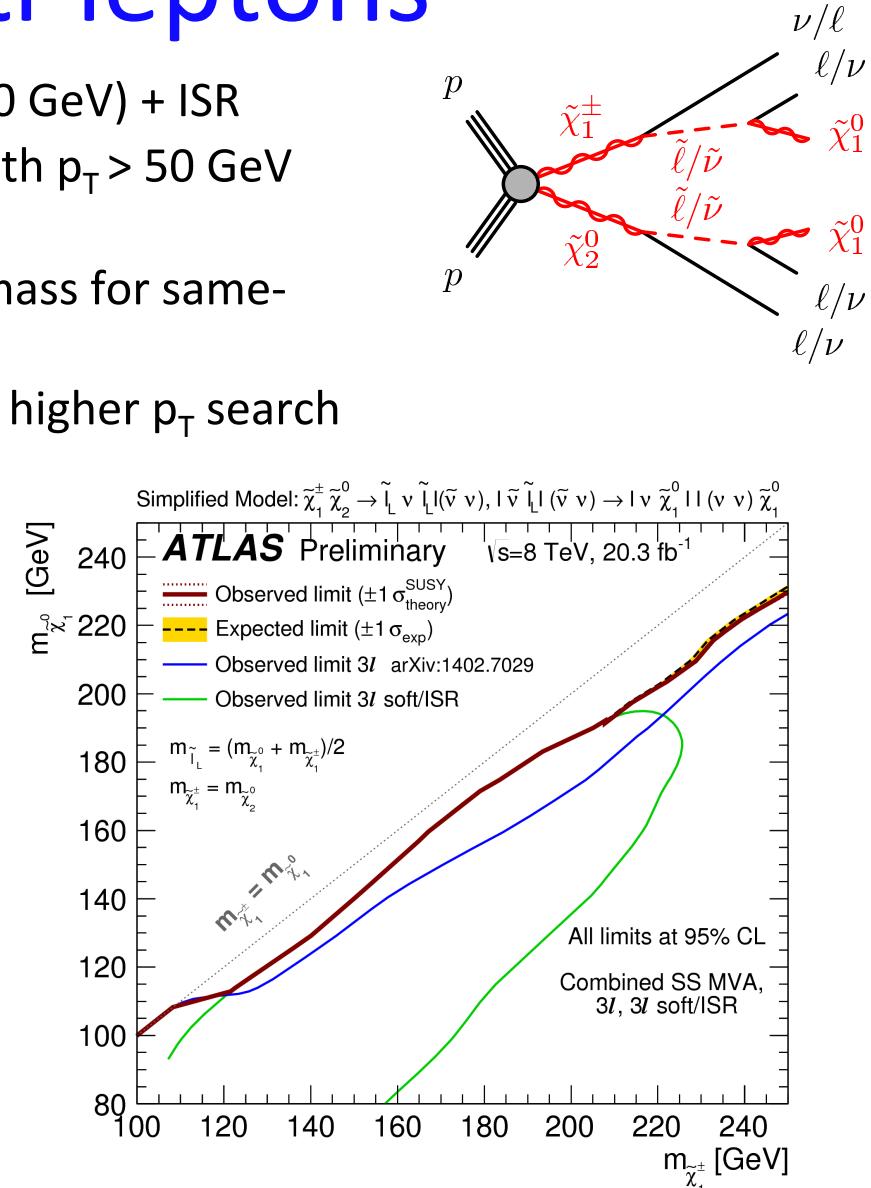
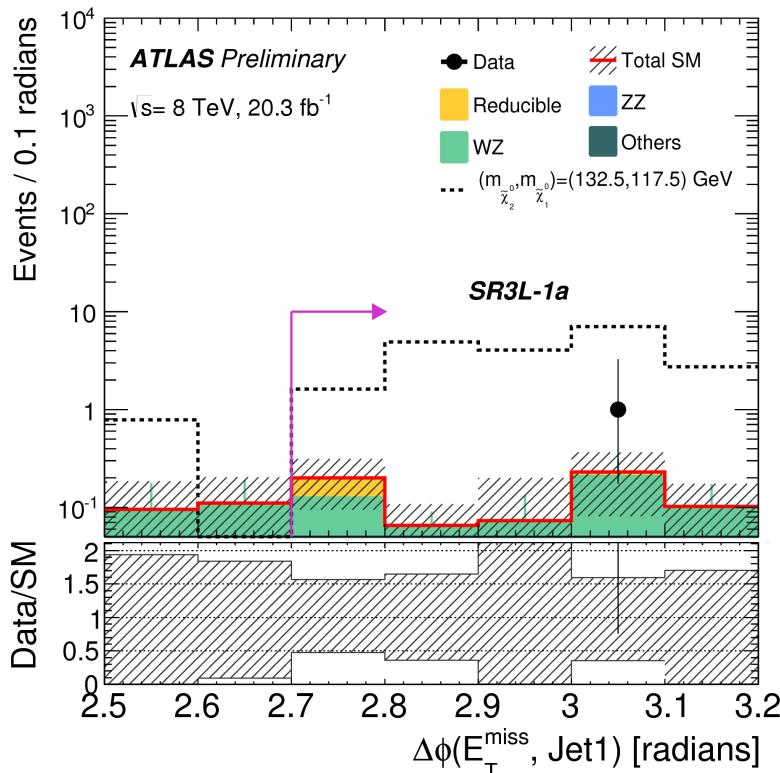
- ◆ Compressed stop decays also present unique challenges
 - ◆ Soft decay products with $m(\text{stop}) \sim m(\text{LSP})$
 - ◆ Conventional high p_T stop searches won't work
- ◆ Select events with 1 or 2 low p_T leptons (5-25 GeV)
- ◆ Boost SUSY system to give visible MET with recoil against an ISR jet a la "monojet" searches



See also: Marc Dunser 9/3

Soft multi-leptons

- Similarly, target 3 soft leptons ($p_T < 30$ GeV) + ISR
- Dedicated ISR regions require a jet with $p_T > 50$ GeV back-to-back with MET
- Target small mass splitting with low mass for same-flavor, opposite-charge lepton pair
- Soft lepton search complementary to higher p_T search

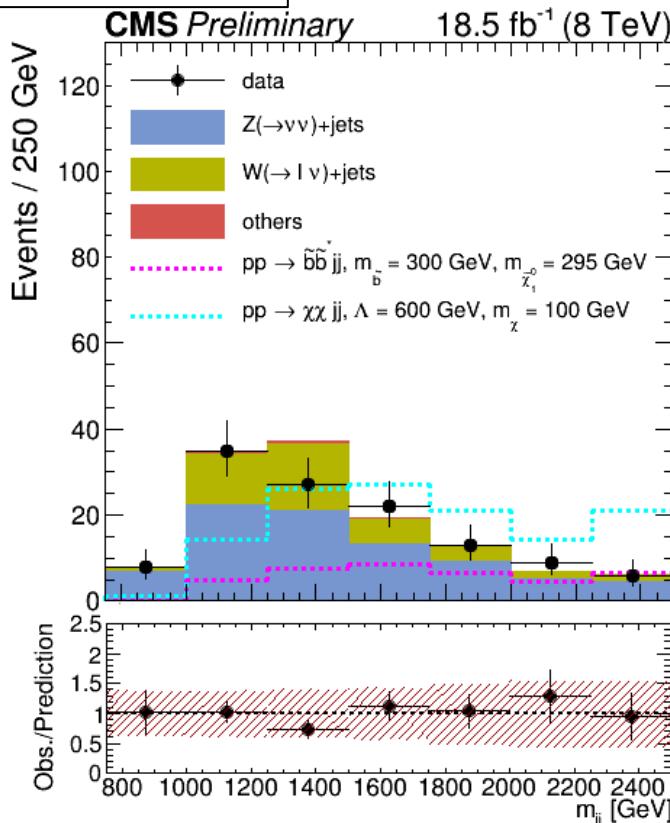


See also: Alexander Mann, Hamed Bakhshiansohi 9/2

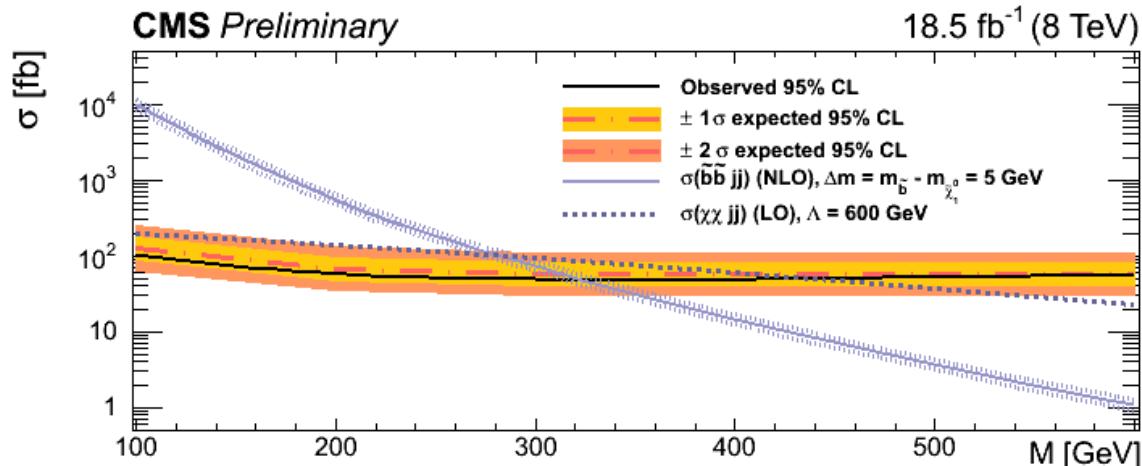
Compressed search with VBF

- Can also tackle compressed systems recoiling against VBF jets
 - Lower cross sections, but additional search variable with VBF di-jet mass
 - Also pick up efficiency from events with 2 ISR jets

CMS-SUS-14-019

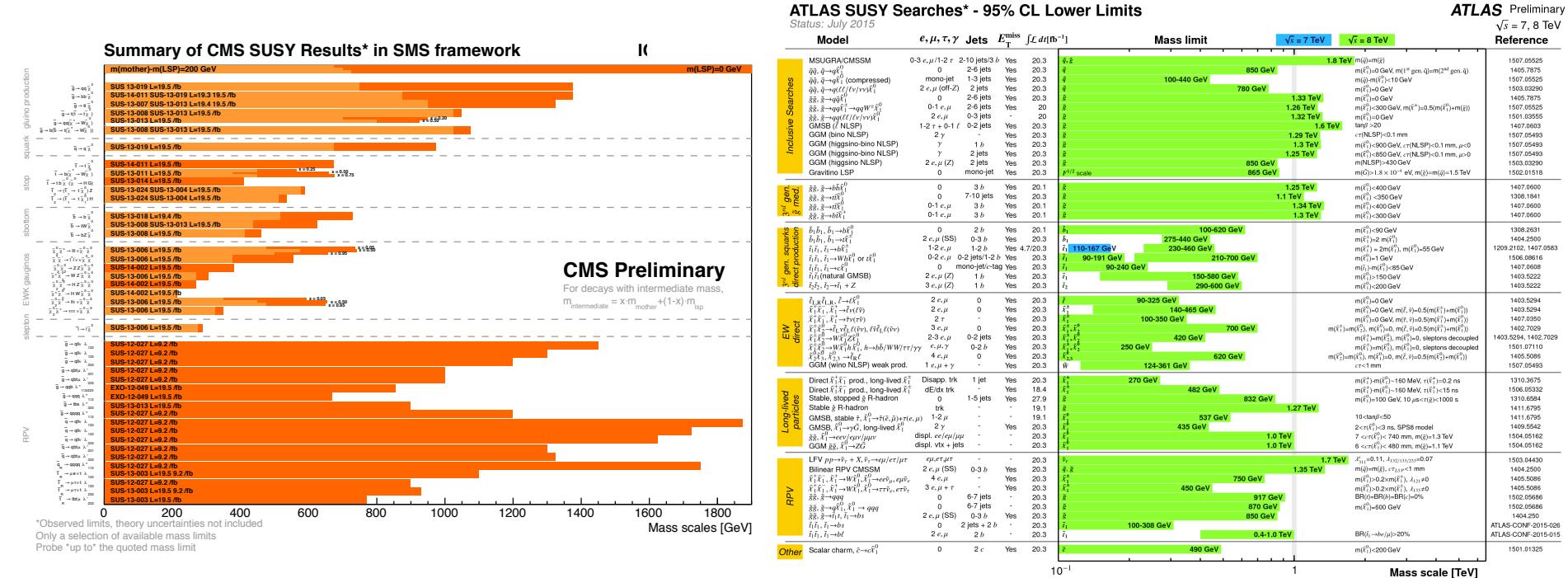


- Veto jets and leptons to search for very soft decay products completely missed by the detector
- VBF selection with 2 jets with $p_T > 50 \text{ GeV}$ and $\Delta\eta(jj) > 4.2$
- Fit shape of dijet mass to discriminate signal from background



Taking Stock

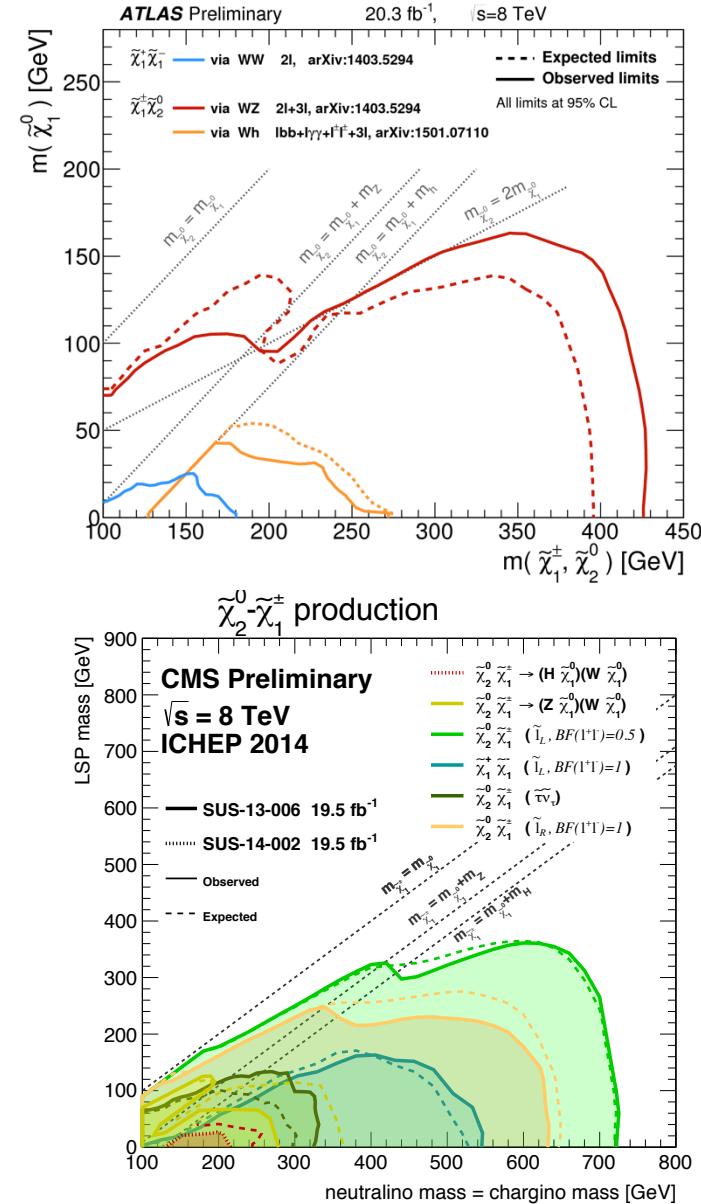
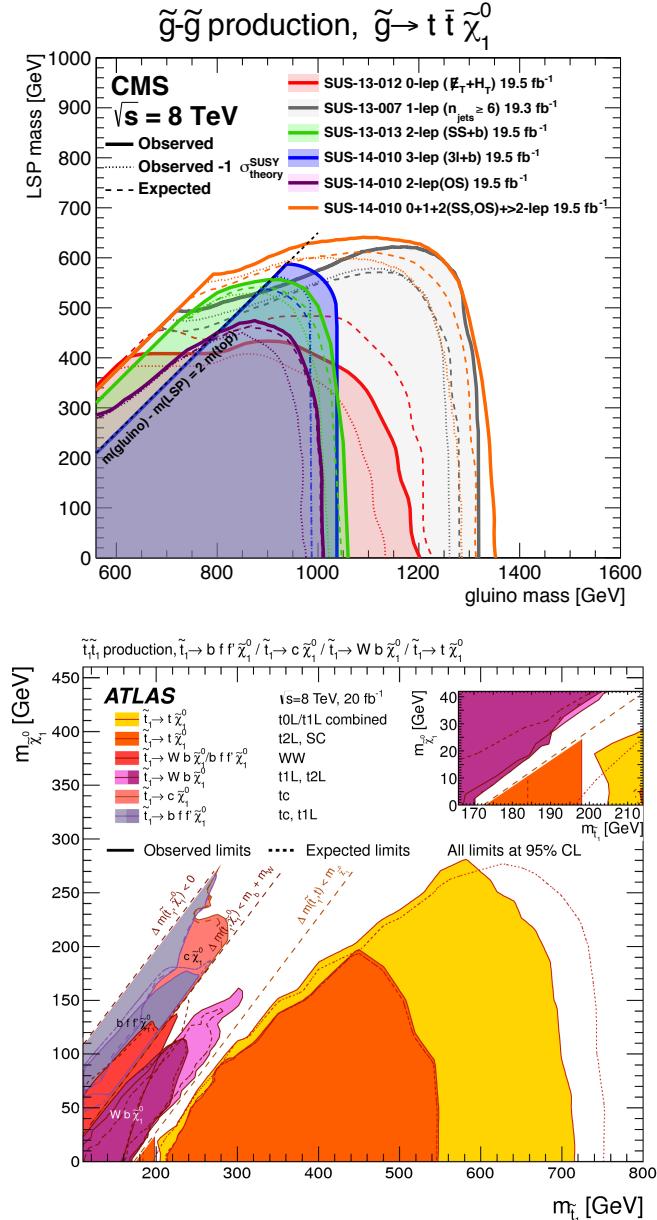
Summary of 8 TeV searches



- ◆ Dozens of searches completed at 8 TeV!
 - ◆ Final tail still in preparation

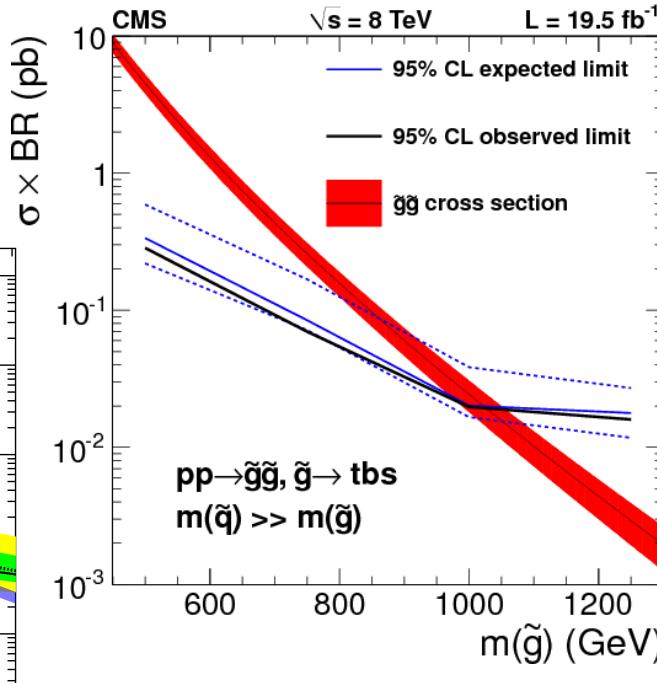
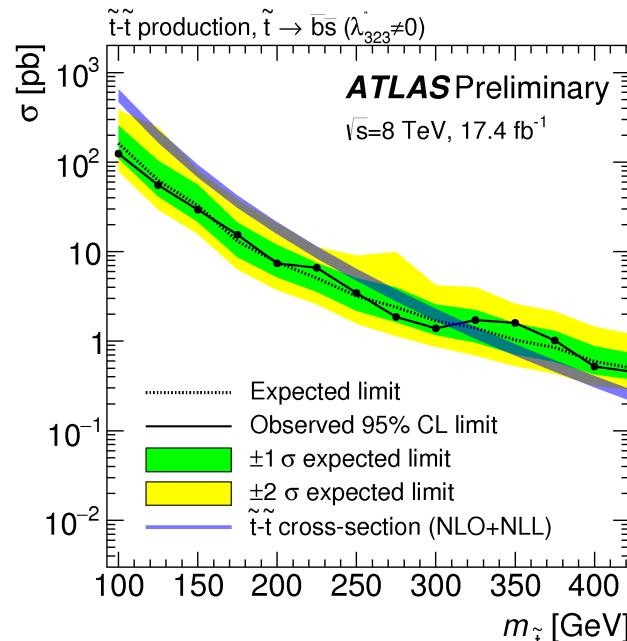
<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults>
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS>

8 TeV Summaries



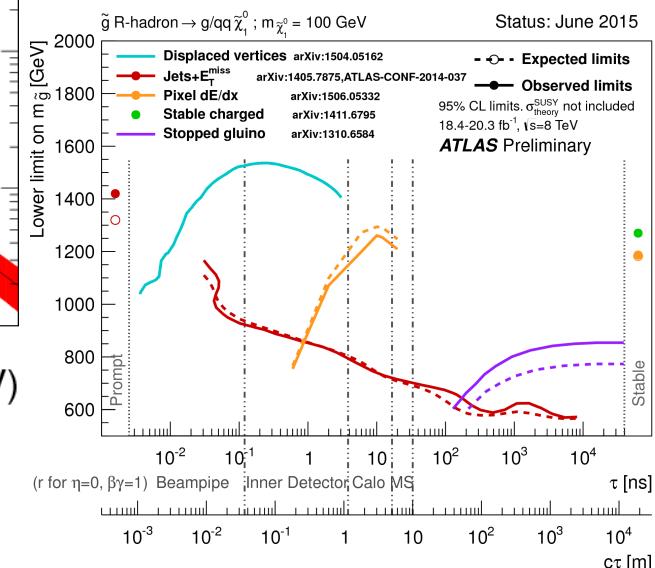
Long lived and RPV

- ◆ Summaries include entire topics not even touched in this talk...



CMS-SUS-14-003

ATLAS-CONF-2015-026



See also: Daniela Salvatore 8/31, Matgorzata Kazana 8/31, Junjie Zhu 8/31, Nora Emilia Pettersson 9/2

pMSSM: a Full Model

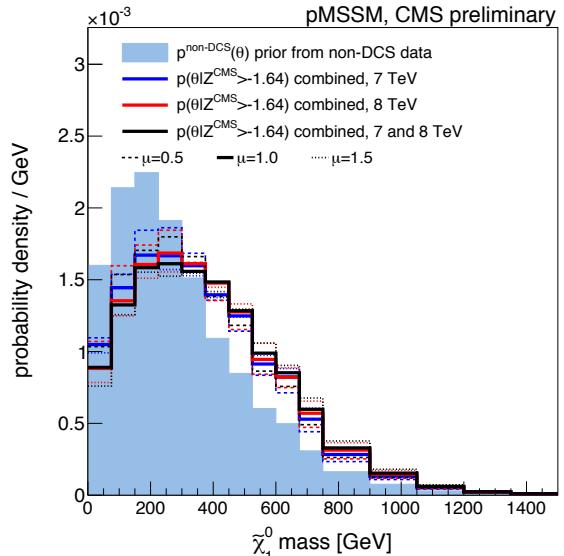
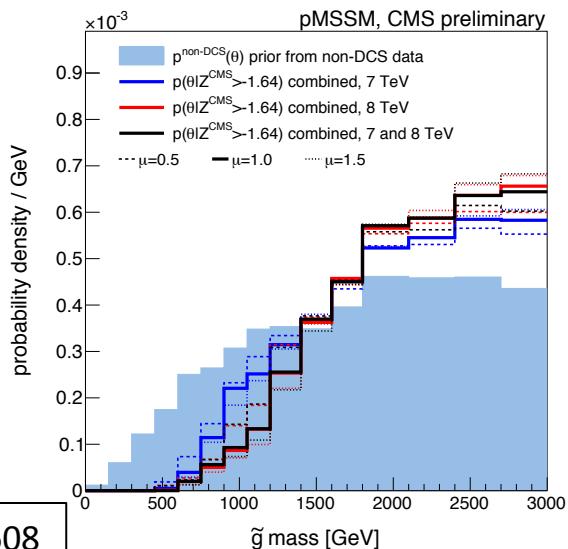
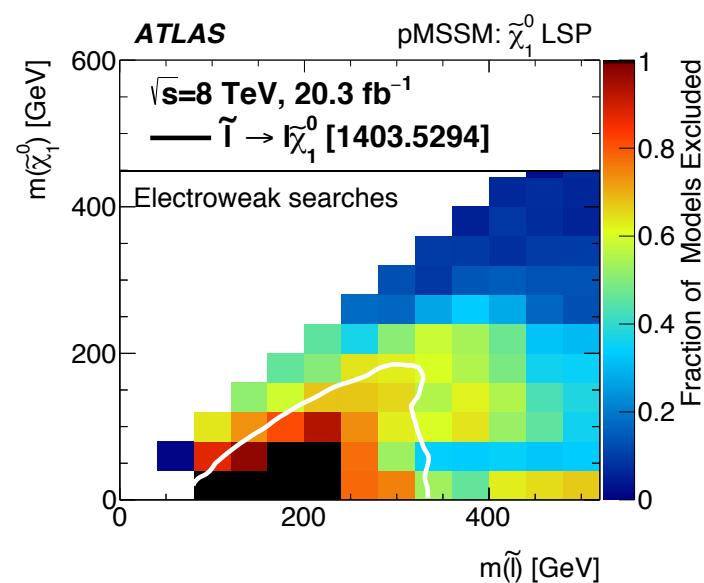
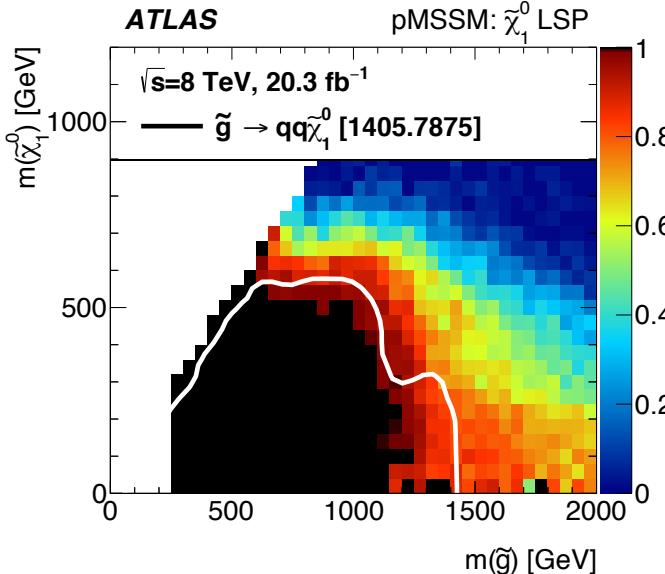
- ◆ phenomenological MSSM a 19 parameter characterization of minimal SUSY
 - ◆ Some assumptions: 1st and 2nd generations degenerate, R-parity conservation, no new CP-violation, ...
 - ◆ Much more flexible than 5 parameter CMSSM (MSUGRA)
- ◆ Allows for scans in parameter space to compare with experimental searches
 - ◆ Scan randomly across the 19 parameters to create many model points
 - ◆ Additional constraints applied based on external measurements: DM relic density, LEP, flavor, Higgs mass, ...
- ◆ Test each model point against a range of experimental searches
 - ◆ Hadronic, leptonic, Inclusive, 3rd generation, EW, ...
- ◆ Independent scans performed by ATLAS and CMS

CMS-SUS-15-010, ATLAS 1508.06608

See also: Brian Petersen 9/3

pMSSM Results

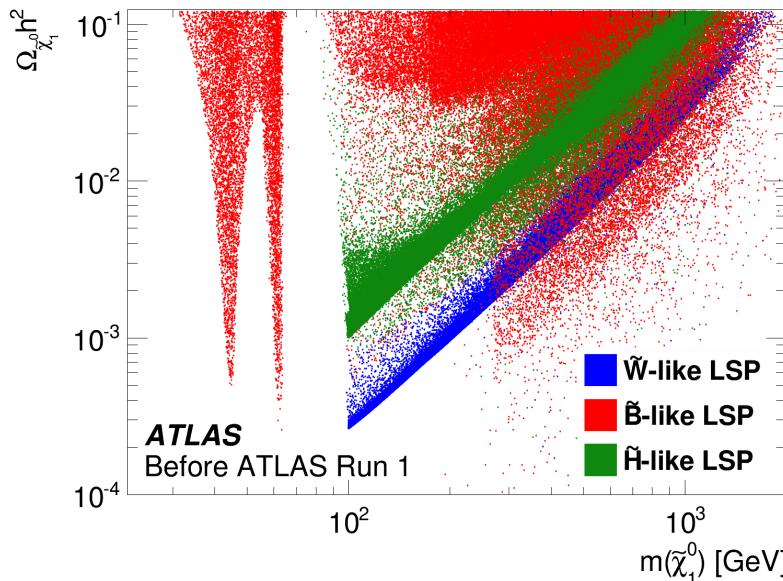
- Almost 100% exclusion with $m(\tilde{g}) < 1 \text{ TeV}$ and $m(\text{LSP}) < 500 \text{ GeV}$
 - Compares well with SMS exclusion for gluinos
- Much weaker EW limits
 - More detailed dependence on full spectrum
- Remaining allowed space moves to higher mass with new exclusions



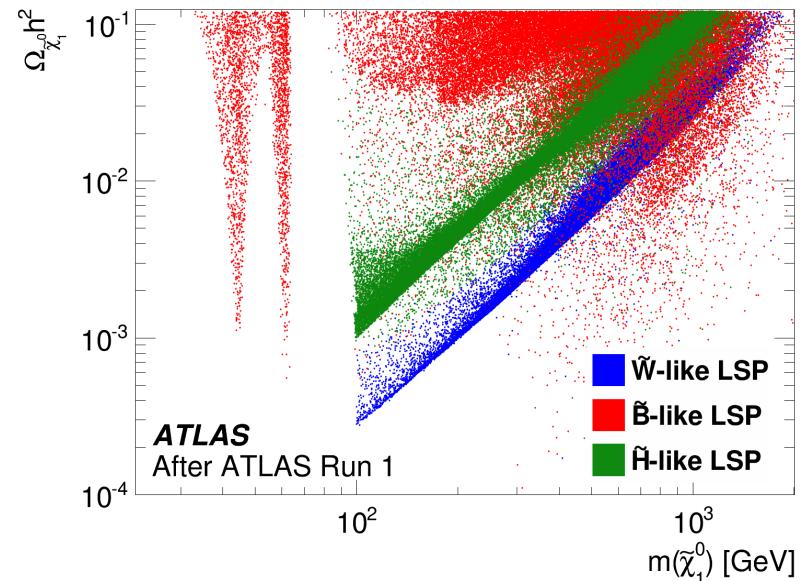
CMS-SUS-15-010, ATLAS 1508.06608

pMSSM Results

- Exclusion in relic density vs DM mass plane shows complementarity of collider and direct dark matter searches



(a) Before ATLAS Run 1



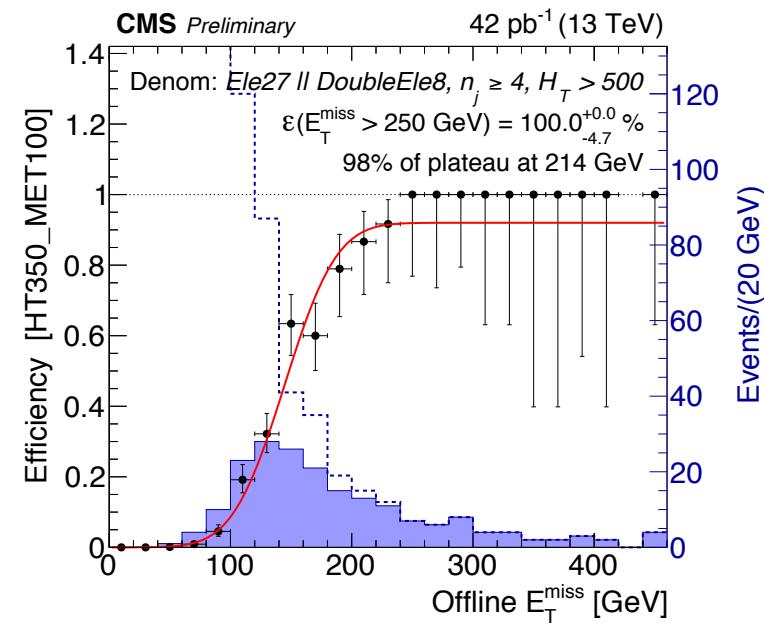
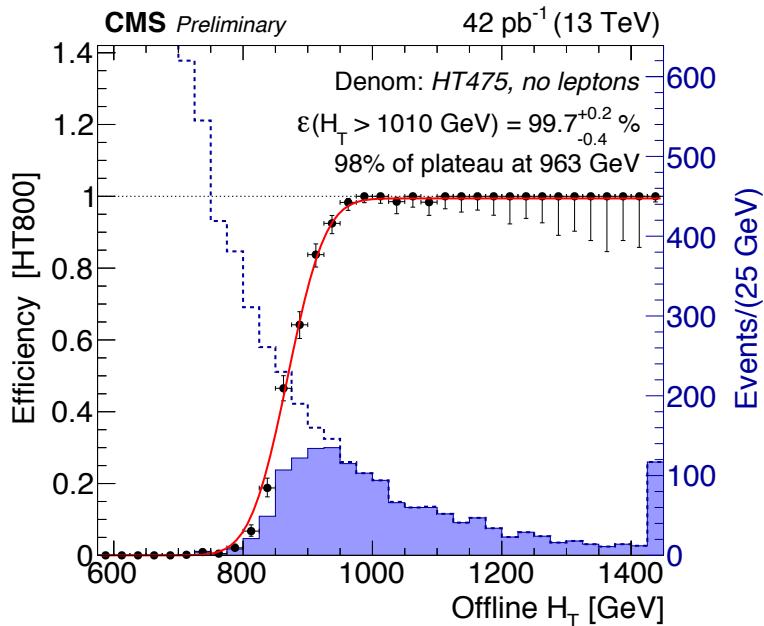
(b) After ATLAS Run 1

- Nature of LSP has strong effect on sensitivity
 - Wino-like and Higgsino-like LSPs have charged partners with strong limits from LEP
 - No a priori reason to expect a simple DM sector
- Exclusions strongest at low masses, but reach up to ~ 800 GeV

Preparation for 13 TeV

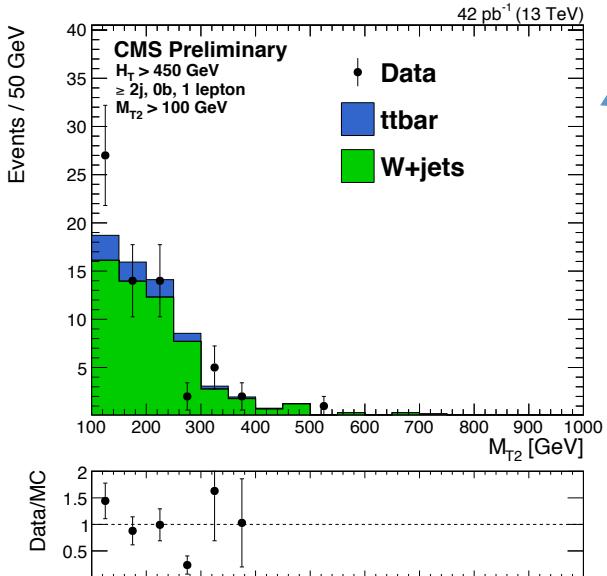
13 TeV data!

- Reconstruction performance being tested extensively for entire SUSY analysis decay chain with first 13 TeV data
 - Too early for competitive new physics results, but ATLAS and CMS on track for results when appropriate luminosity is available



- Sample trigger efficiency measurements from 50 ns data

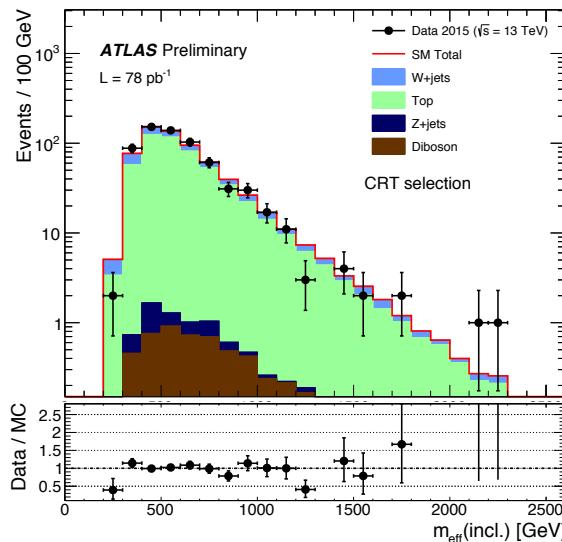
Top and W backgrounds



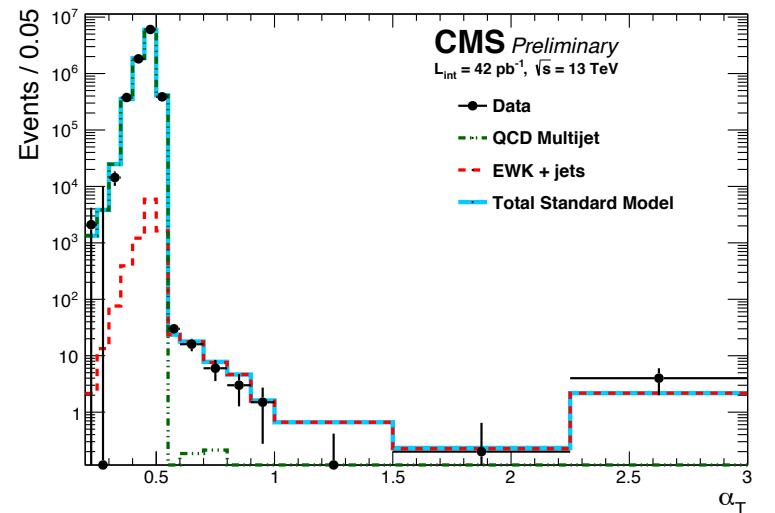
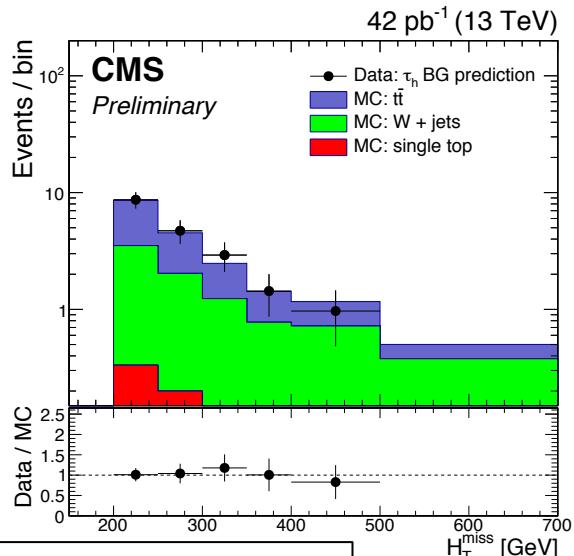
W+jets and $t\bar{t}$
dominated control
regions

Good data/MC shape
comparisons vs search
variables

MC normalized to
data

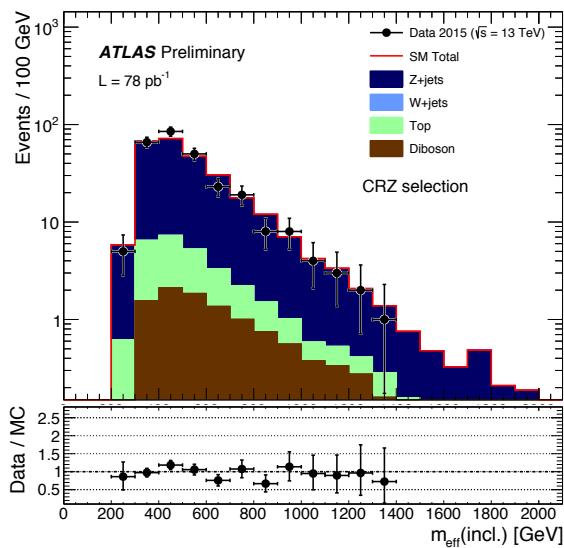


Hadronic tau
Background
prediction from
1 mu control sample

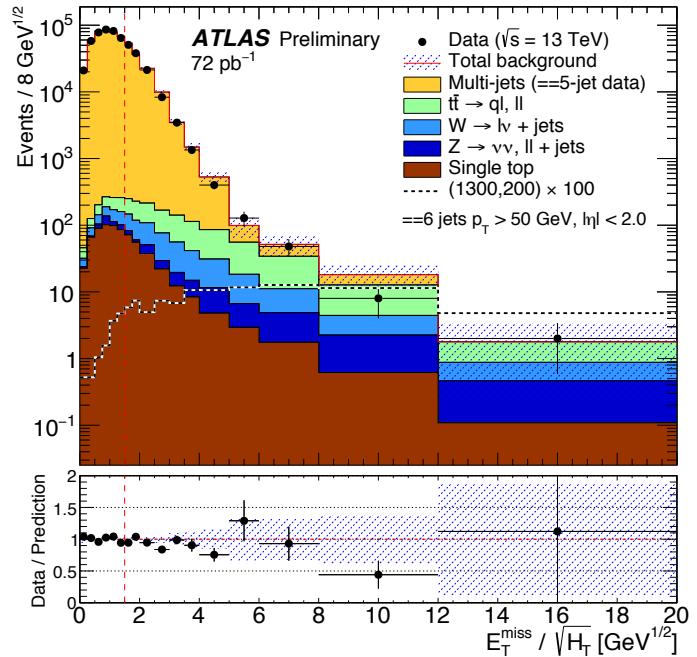
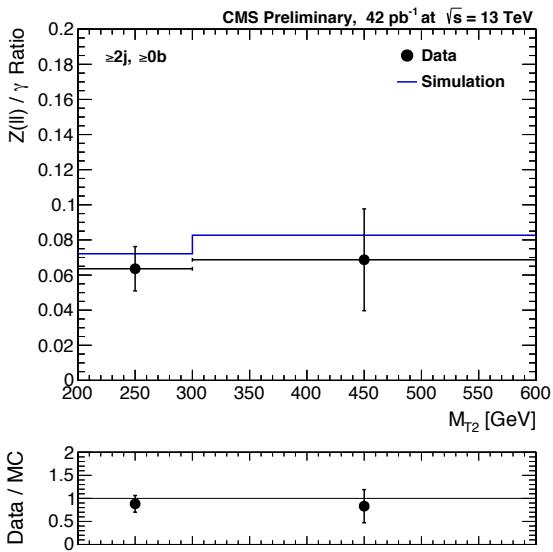


α_T search variable well modeled in MC

Z and QCD backgrounds

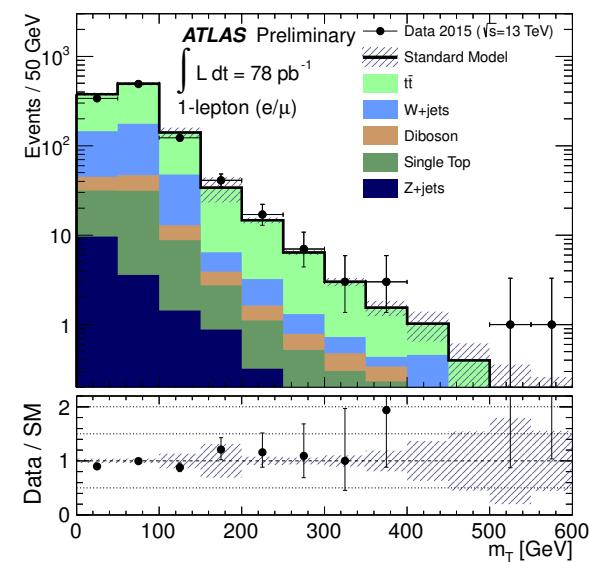


$Z \rightarrow l^+l^-$ control region
well modeled to predict
 $Z \rightarrow$ neutrino backgrounds

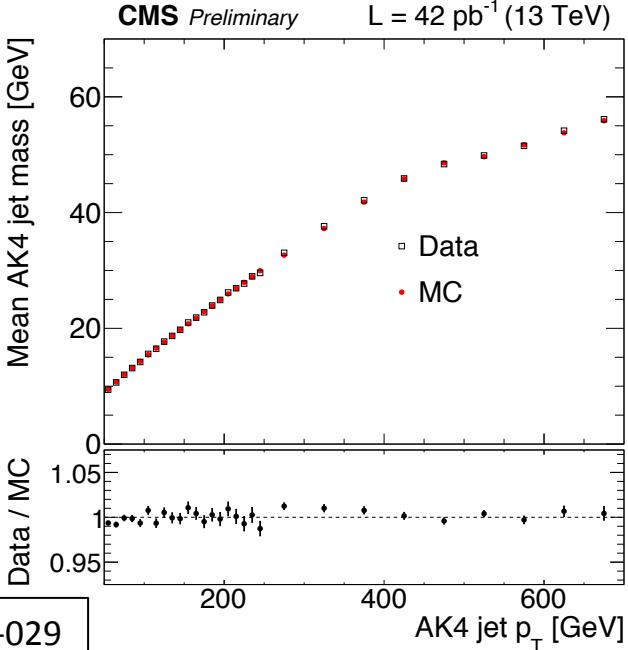


Multi-jet shape template from
5 jet data in
MET/VHT search variable
describes 6 jet data to predict
fake MET backgrounds

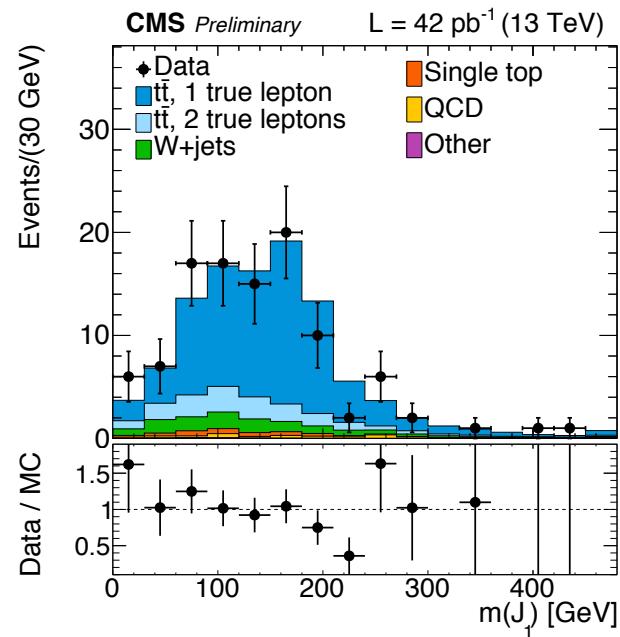
Single lepton searches



Transverse mass (M_T) search variable shape well modeled in MC for 1e and 1 μ events



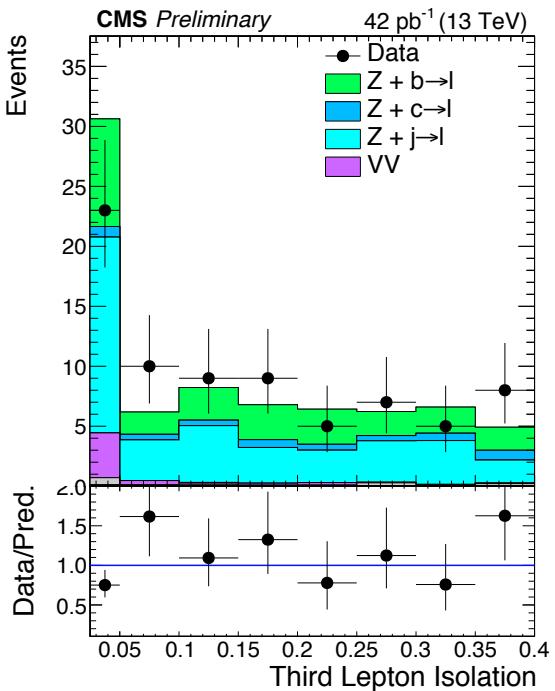
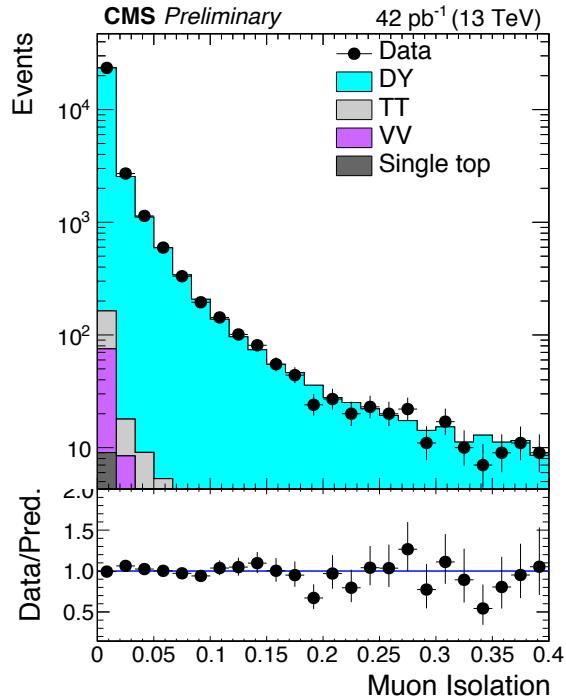
Utilize jet mass variables for signal/background discrimination in 1L gluino search



Masses for $\Delta R=0.4$ and $\Delta R = 1.2$ jets well described In simulation

Di-lepton and photon searches

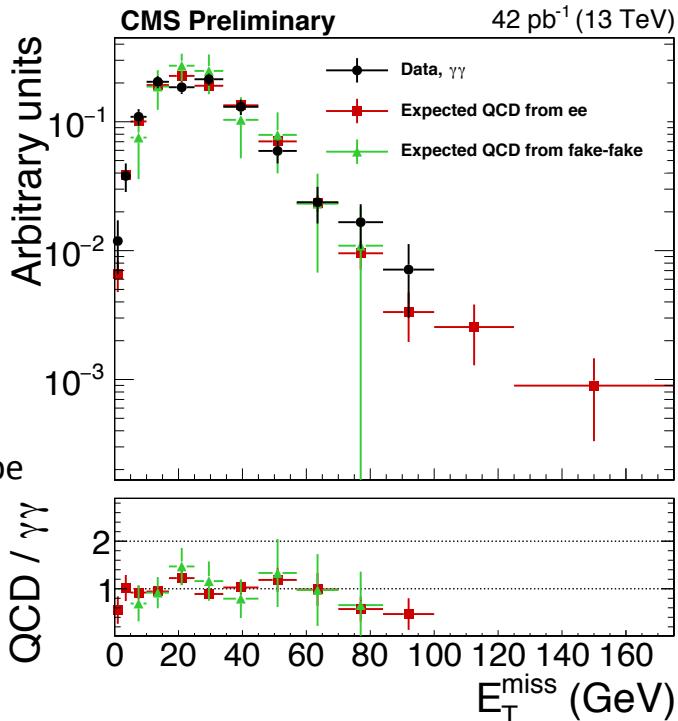
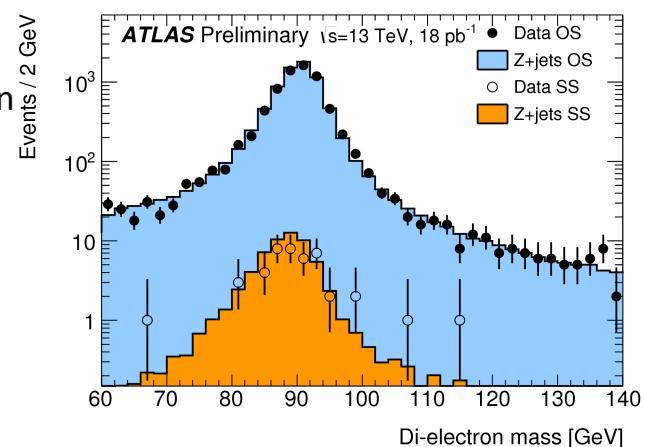
Z mass to measure wrong charge
Assignment fraction for SS search



Same-sign dilepton search utilizes isolation sidebands to predict fake prompt lepton backgrounds.

Isolation distributions well understood for prompt and non-prompt leptons

Di-photon MET shape well modeled by pT-reweighted control samples

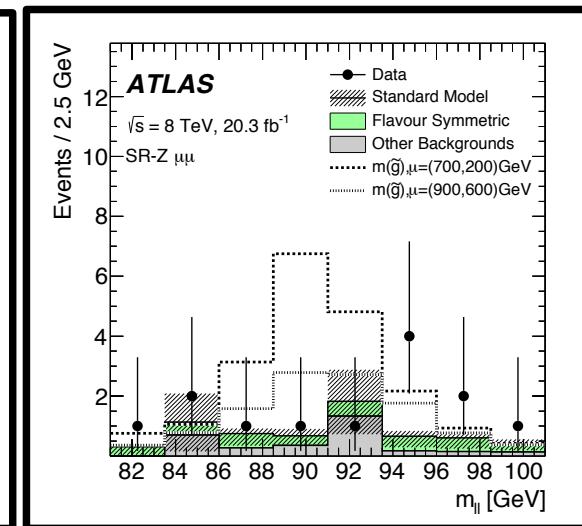
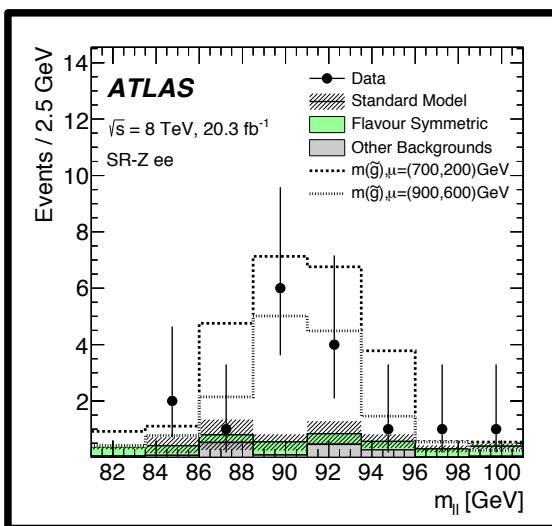
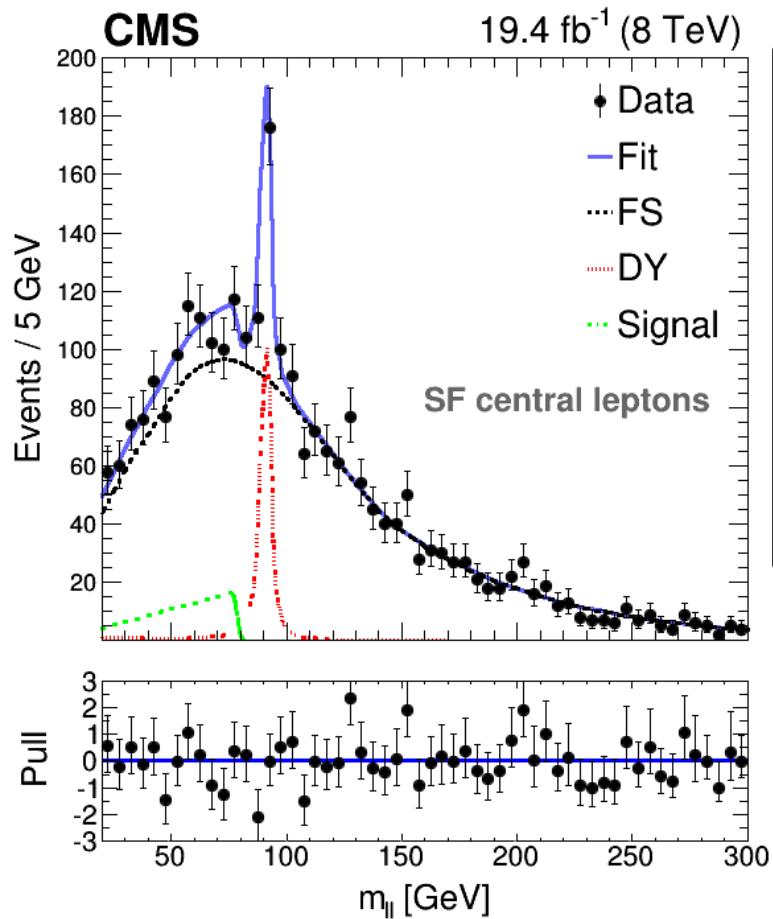


Summary

- ◆ Vast program of searches for Supersymmetry at ATLAS and CMS
 - ◆ Cover array of final states: jets, leptons, photons, missing energy, ...
 - ◆ Varied and robust methods to estimate SM background reliably
 - ◆ Searching for any deviation we might have access to
- ◆ Ready to do it all again at 13 TeV
 - ◆ Starting from a very strong base of experience from Run 1
- ◆ There are exciting times ahead!

Additional Slides

Dilepton excesses



1503.03290

- ◆ CMS has 2.6σ excess in non-resonant dilepton mass search
- ◆ ATLAS has $\sim 3\sigma$ excess in on-Z dilepton mass search
- ◆ No hints of either excess in the other experiment, though still something to watch at 13 TeV