

Searches for electroweak production of supersymmetric gauginos and sleptons with the ATLAS detector

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on behalf of the ATLAS Collaboration

SUSY2015 - August 27, 2015

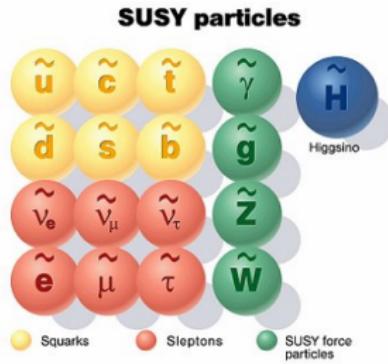


Introduction to EW SUSY

- Definition of the term 'electroweak SUSY'
- General analysis strategy
- Focus of this talk

New ATLAS EW SUSY Results

- Direct stau production
- Same-sign chargino pair production via vector boson fusion
- Compressed spectra in direct gaugino or slepton pair production
- *All results shown are part of a comprehensive 'summary' paper on EWK SUSY production to be submitted soon
(ATLAS-SUSY-2014-05)*



Introduction

Electroweak SUSY

Term: electroweak production of SUSY

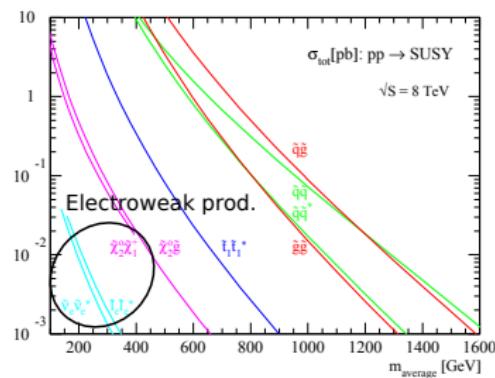
Production of colorless gauginos and/or sleptons

Why at LHC?

- Naturalness suggests low mass higgsinos and stops
- Stringent limits have already been put on strong production with masses above 1 TeV

Characteristics

- Lower σ at LHC than strong prod.
- Leptonic final states favored
- Clean signatures, small SM backgrounds



Here

- R-parity conserved
- LSP neutral and stable
- Optimization for simplified models

Searching for rare processes in a flood of SM processes.
SUSY searches rely on an accurate modelling of SM backgrounds.

Standard Model Backgrounds

Reducible

- E.g. fake taus in a di-tau analysis
- Analysis dependent data-driven estimation

Irreducible

- E.g. $Z \rightarrow \tau\tau$ in a di-tau analysis
- **Dominant sources:** normalised to data in dedicated **control regions** (CRs)
- **Sub-dominant sources:** estimated from MC only

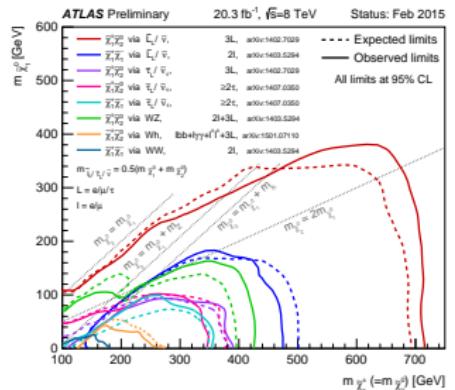
In addition predictions are validated in **validation regions** (VRs)
Signal regions (SRs) are defined to discriminate SUSY signal from background.

Introduction

Focus

Focus - ATLAS-SUSY-2014-05

- Lots of results have already been shown, focus here on new results:
 - Reoptimized search for direct stau prod.
 - Same-sign chargino pair production via vector boson fusion
 - Compressed spectra in direct production channels**

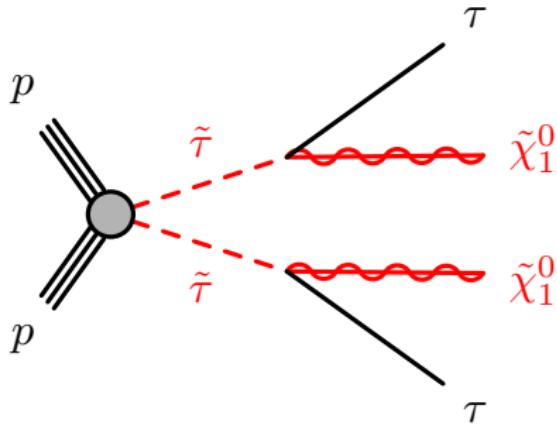


ATLAS SUSY Searches* - 95% CL Lower Limits

Status: July 2015

| Model | e, μ, τ, γ | Jets | E_T^{miss} | $\int L dt [\text{fb}^{-1}]$ | Mass limit | $\sqrt{s} = 7 \text{ TeV}$ | $\sqrt{s} = 8 \text{ TeV}$ | Reference |
|---|------------------------|----------|---------------------|------------------------------|--|----------------------------|----------------------------|--|
| $\tilde{t}_{1,R}\tilde{t}_{1,L}, \tilde{t} \rightarrow \tilde{e}\tilde{e}^0$ | $2 e, \mu$ | 0 | Yes | 20.3 | \tilde{t}_1^+ | 90-325 GeV | | $m(\tilde{t}_1^+) = 0 \text{ GeV}$ |
| $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \tilde{e}\tilde{e}^0$ | $2 e, \mu$ | 0 | Yes | 20.3 | \tilde{e}_1^+ | 140-465 GeV | | $m(\tilde{e}_1^+) = 0 \text{ GeV}$ |
| $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \tilde{\tau}\tilde{\tau}^0$ | 2τ | - | Yes | 20.3 | $\tilde{\tau}_1^+$ | 100-350 GeV | | $m(\tilde{\tau}_1^+) = 0 \text{ GeV}$ |
| $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \tilde{\ell}_1^-\tilde{\nu}_1^0 \tilde{\ell}_1^+\tilde{\nu}_1^0, \tilde{\ell}_2^-\tilde{\nu}_2^0 \tilde{\ell}_2^+\tilde{\nu}_2^0$ | $3 e, \mu$ | 0 | Yes | 20.3 | $\tilde{\ell}_1^+, \tilde{\ell}_2^+$ | 200-700 GeV | | $m(\tilde{\ell}_1^+) = m(\tilde{\ell}_2^+) = 0 \text{ GeV}$ |
| $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$ | $2-3 e, \mu$ | 0-2 jets | Yes | 20.3 | $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{\pm}$ | 250 GeV | 420 GeV | $m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_2^{\pm}) = 0 \text{ GeV}$ |
| $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow W\tilde{\chi}_1^0 h\tilde{\chi}_1^0, h \rightarrow b\bar{b}/WW/\tau\tau/\gamma\gamma$ | $4 e, \mu, \gamma$ | 0-2 b | Yes | 20.3 | $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{\pm}$ | 700 GeV | | $m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_2^{\pm}) = 0 \text{ GeV}$ |
| $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow l\tilde{l} \tilde{\ell}$ | $4 e, \mu$ | 0 | Yes | 20.3 | $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{\pm}$ | 620 GeV | | $m(\tilde{\chi}_1^{\pm}) = m(\tilde{\chi}_2^{\pm}) = 0 \text{ GeV}$ |
| GGM (wino-NLSP) weak prod. | $1 e, \mu + \gamma$ | - | Yes | 20.3 | W | 124-361 GeV | | $m(\tilde{e}_1^{\pm}) = m(\tilde{\chi}_1^{\pm}) = 0, m(\tilde{\ell}_1^{\pm}) = 0, m(\tilde{\chi}_2^{\pm}) = 0.5(m(\tilde{e}_1^{\pm}) + m(\tilde{\ell}_1^{\pm}))$ |

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.



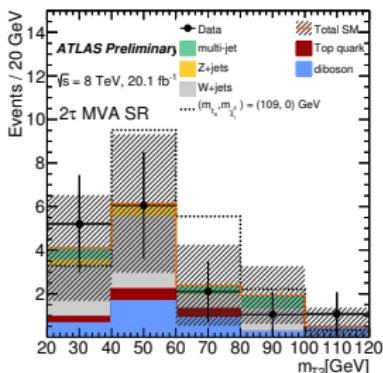
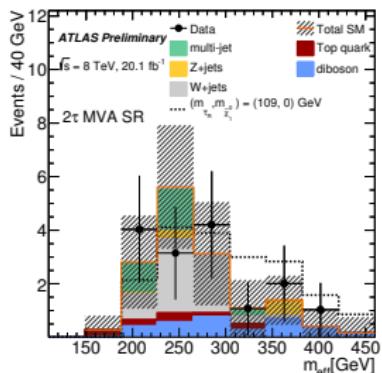
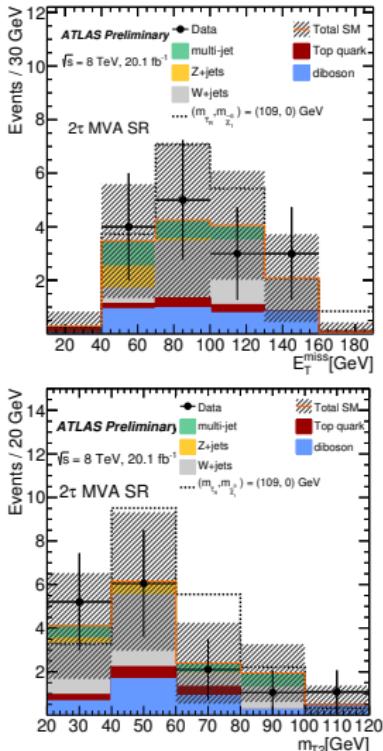
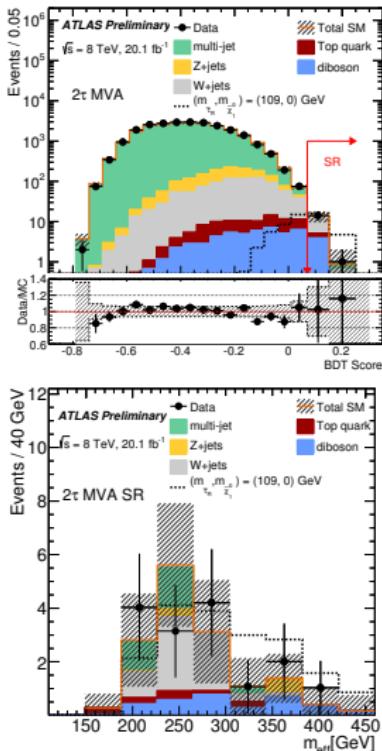
Backgrounds

- **Reducible:** bgs containing one or more 'fake' taus, e.g. $W+jets$, multi-jet
- **Irreducible:** two or more real prompt taus, e.g. dibosons, $t\bar{t}$, $Z+jets$

- Two opposite sign taus in the final state
- Veto light leptons
- $m_{T2} > 30\text{GeV}$
- Multi Variate Analysis (MVA) optimised to yield best exp. discovery sensitivity (using Boosted Decision Trees, BDTs)
- Update of: JHEP 1410 (2014) 96, arXiv:1407.0350 [hep-ex]

Recent Results

Direct stau prod.

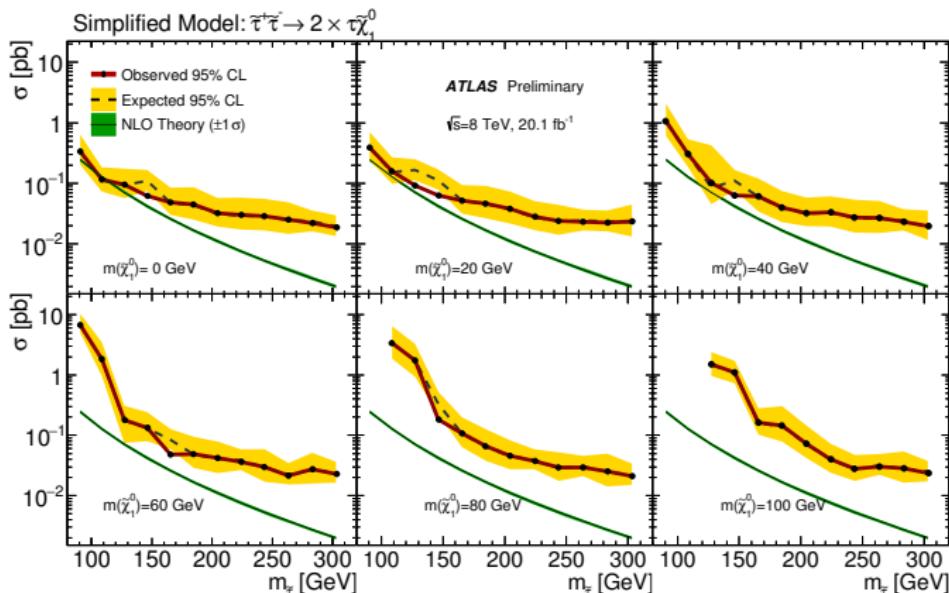


- No excess observed
- → Setting limits
- Dominant syst.: **Stat. MC uncert** $\approx 20\%$
MET soft-term resolution $\approx 20\%$
W+jets normalization $\approx 15\%$
- Total syst.: $\approx 35\%$

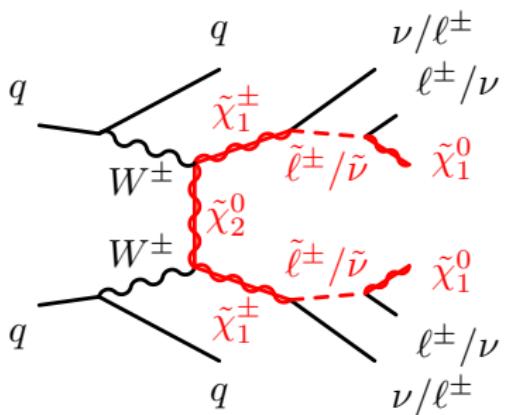
The upper limit on the combined production of $\tilde{\tau}_L \tilde{\tau}_L$ and $\tilde{\tau}_R \tilde{\tau}_R$ could be improved from 0.95 to 0.90 for one of the mass points.

Recent Results

Direct stau prod.



95% CL exclusion limits on the cross-section for combined production of left- and right-handed stau pairs with equal masses for various $\tilde{\chi}_1^0$ masses.



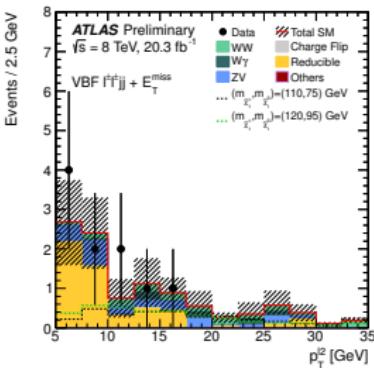
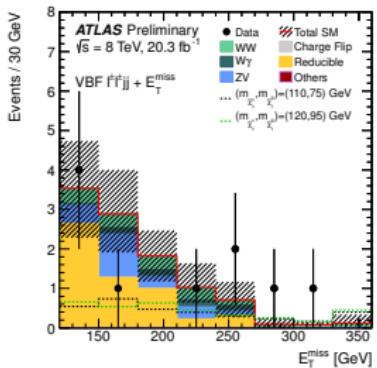
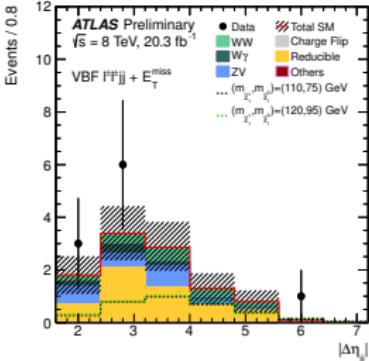
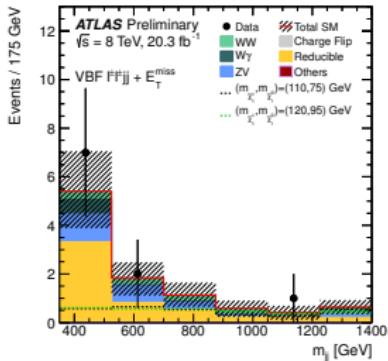
Backgrounds

- **Reducible:** bgs containing one or more 'fake' leptons, e.g. $W+\text{jets}$ and $t\bar{t}$
- **Irreducible:** two real prompt leptons, e.g. dibosons and Higgs
- **Charge flip:** one or more leptons have mis-measured charge (dedicated CR)

- Exactly two same sign light leptons, two or more jets, large MET
- Two leading jets well separated, from opposite sides of the detector and have high inv. mass, VBF-like topology
- Signal region is defined using a b -jet veto and a number of kinematic variables of leptons and jets

Recent Results

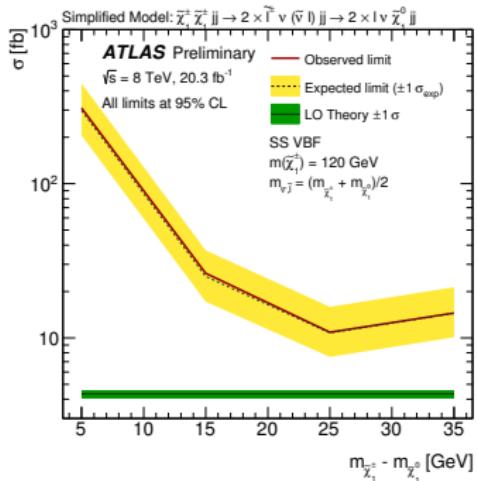
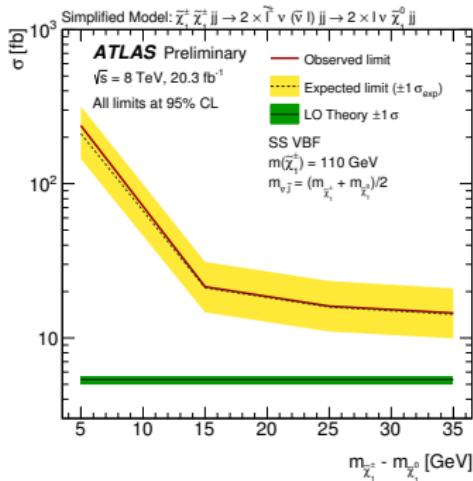
SS C1C1 prod. via VBF



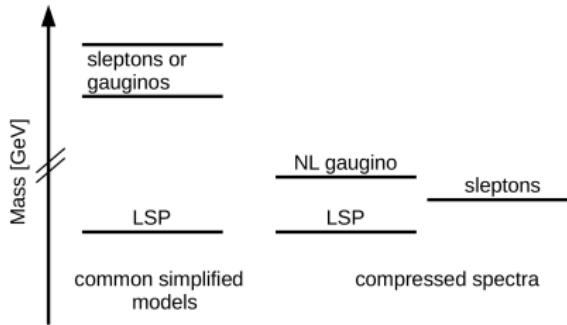
- No excess observed
- → Setting limits
- Dominant syst.: Fake factor closure test ≈ 13%
- Stat. uncert. on reducible bg ≈ 11%
- Total syst.: ≈ 21%

Recent Results

SS C1C1 prod. via VBF



95% CL upper limits on the cross-section for VBF production of $\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\pm}$.
 The limits have been set with respect to the mass difference between the $\tilde{\chi}_1^{\pm}$ and the $\tilde{\chi}_1^0$.
 Current analysis **cannot exclude** expected SUSY cross section, however an interesting approach has been developed for **probing compressed Electroweak SUSY** scenarios with more data in **Run-2**.



Reoptimized ATLAS analyses to target compressed spectra:

- Two OS Light Leptons
- Two SS Light Leptons
- Three Light Leptons

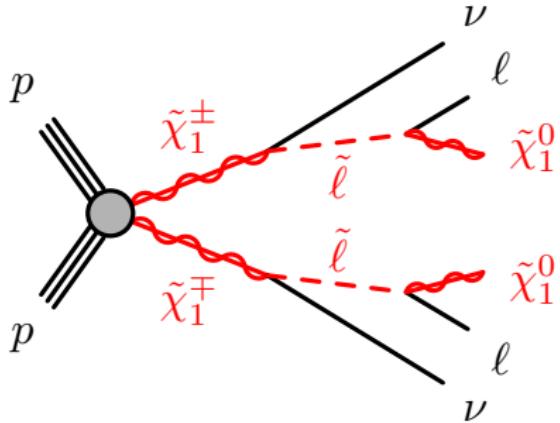
Motivation

Lots of SUSY models favor compressed sparticle mass spectra.

Difficulties

- Low mass splittings
- → soft decay products
- → SM-like

Compressed Scenarios



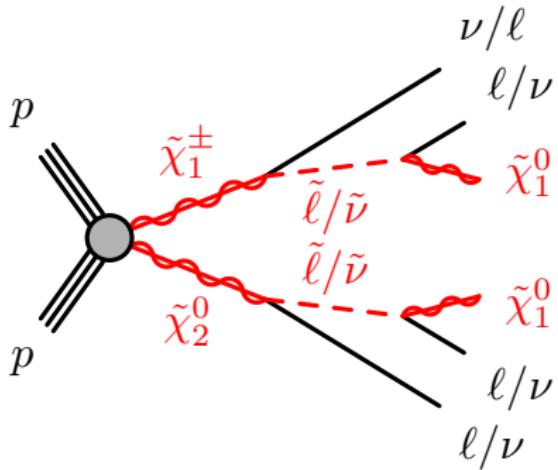
Two OS Light Leptons

Backgrounds

- **Reducible:** bgs containing one or more 'fake' leptons, e.g. $W+jets$
- **Irreducible:** two real prompt leptons, e.g. dibosons, Higgs, $Z+jets$

- Two opposite sign light leptons
- b -jet veto, Z veto using inv. mass of lept pairs
- Two SRs requiring a high p_T ISR jet, sensitive to small and moderate mass splittings
- Use 'super-razor' variables, sensitive to mass differences between sparticles

Compressed Scenarios

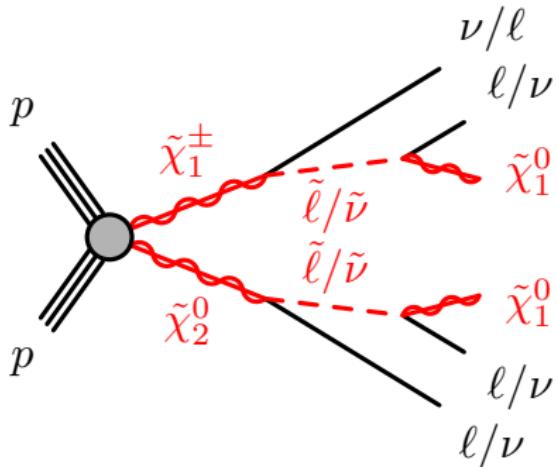


Two SS Light Leptons

Backgrounds

- **Reducible:** bgs containing one or more 'fake' leptons, e.g. $W+jets$
- **Irreducible:** two real prompt leptons, e.g. dibosons, triboson, Higgs
- **Charge flip:** one or more leptons have mis-measured charge (dedicated CR)

- Two same sign well isolated light leptons
- Eight BDTs are trained to cover four different mass splittings for $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 20, 35, 65, 100 \text{ GeV}$
- For each splitting: one region requiring one ISR jet and one applying a jet veto



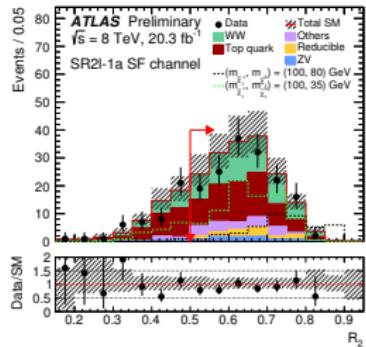
Backgrounds

- **Reducible:** bgs containing one or more 'fake' leptons, e.g. $W/Z + \text{jets}$, WW , top and $t\bar{t}$
- **Irreducible:** three real prompt leptons, e.g. WZ/ZZ , triboson, Higgs

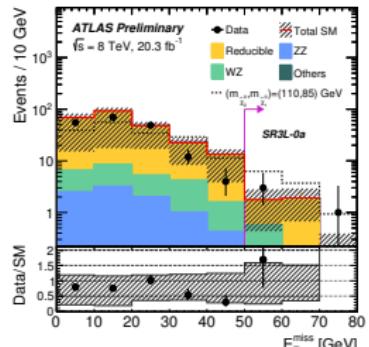
- Exactly three light leptons, one same flavor OS pair (SFOS)
- b -jet veto, Υ veto using mass of SFOS pair
- Two SRs use low p_T leptons to target mass splittings of 4-15 and 15-25 GeV, two further SRs request a jet with $p_T > 50\text{GeV}$ to target ISR events for both splitting regions

Compressed Scenarios

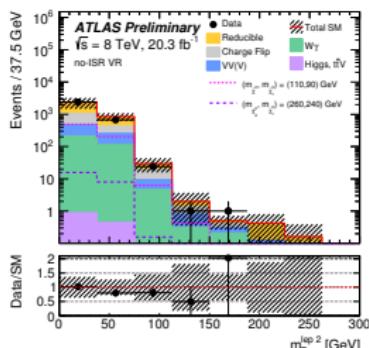
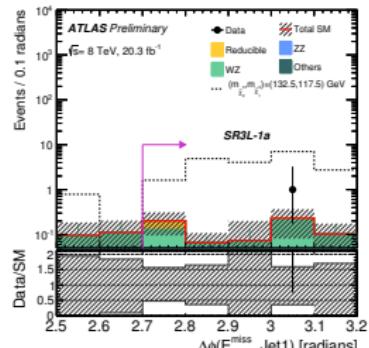
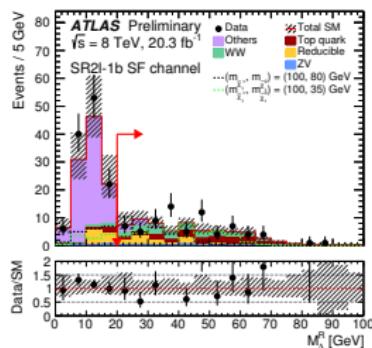
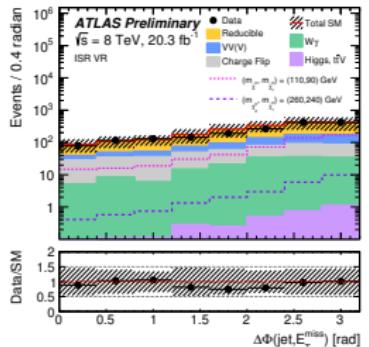
Two OS leptons



Three leptons

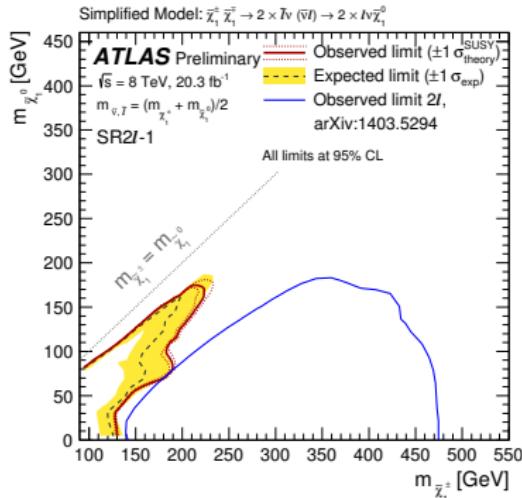
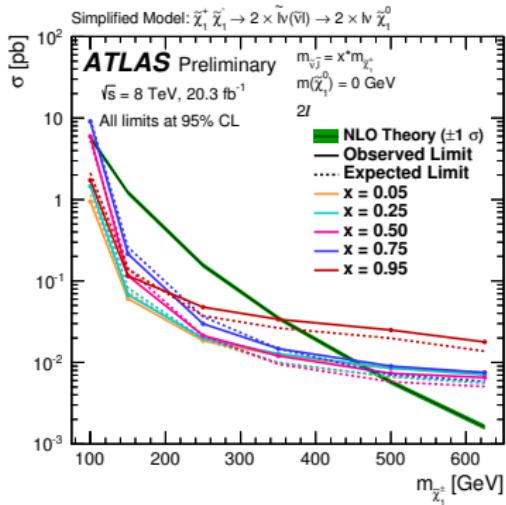


Two SS leptons



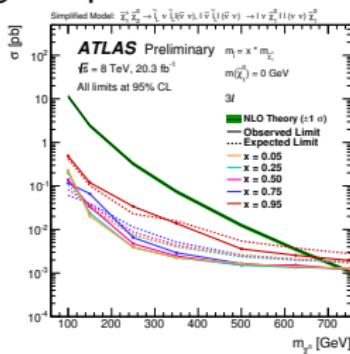
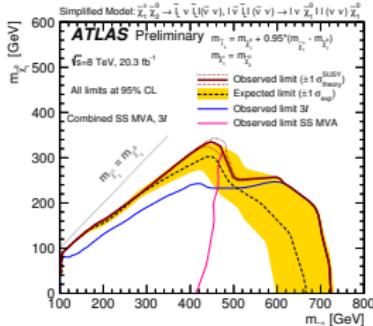
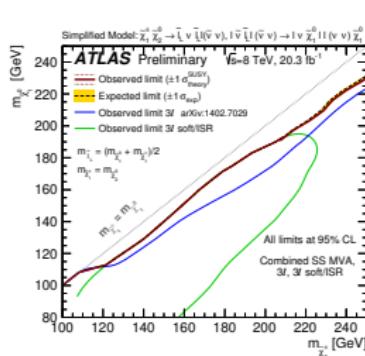
Results

Two OS light leptons



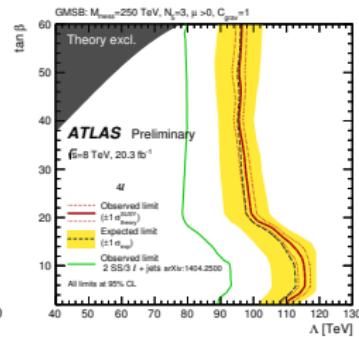
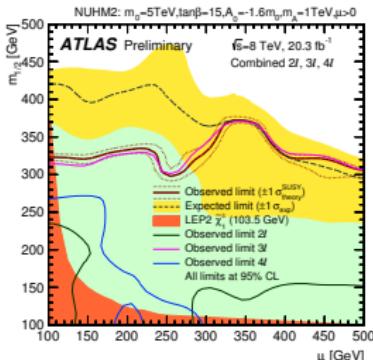
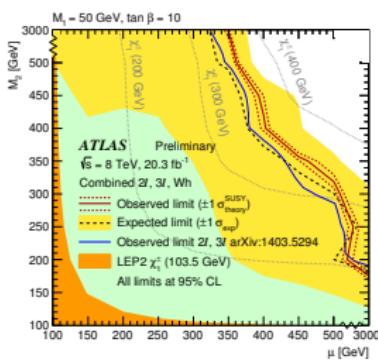
Reoptimized analysis nicely complements the already published one in the region of low mass splittings close to the diagonal :)

Two SS light leptons and three light leptons



Reoptimized analysis nicely complements the already published one in the region of low mass splittings close to the diagonal :)

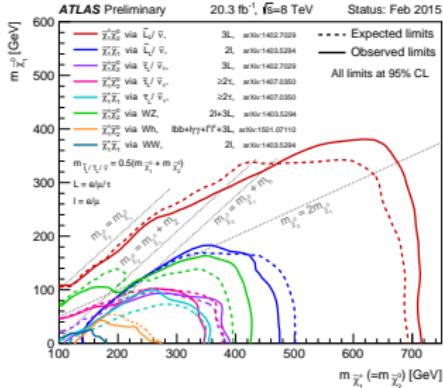
pMSSM, NUHM2, GMSB



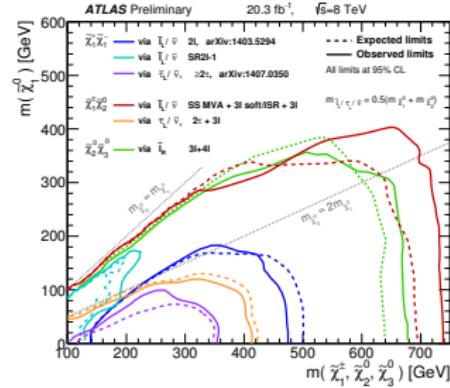
Combination (doing a combined fit) of existing, published, analyses shows a nice improvement in sensitivity :)

Conclusion and Outlook

Before



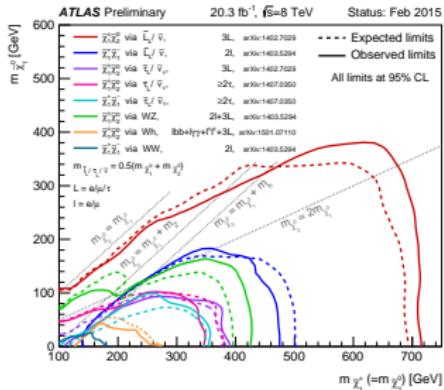
Now



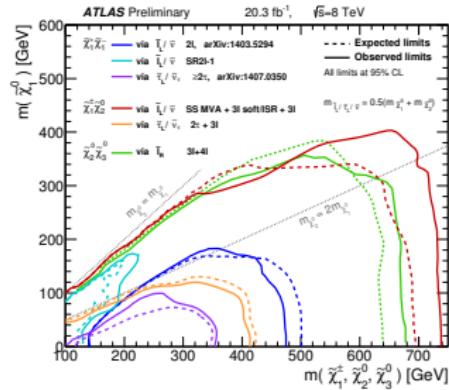
- Lots of effort has been put into searching for SUSY
- Many different methods have been developed
- Strong and ew. prod. of SUSY have not been observed, yet
- Limits have been set
- Time to unveil SUSY throughout run 2

Conclusion and Outlook

Before



Now



- Lots of effort has been put into searching for SUSY
- Lots of different methods have been developed
- Strong and ew. prod. of SUSY have not been observed, yet
- Limits have been set
- Time to unveil SUSY throughout run 2
- Thank you for your attention!

BACKUP

p_T^X The transverse momentum of a reconstructed object X .

$\Delta\phi(X, Y), \Delta\eta(X, Y)$ The separation in ϕ or η between two reconstructed objects X and Y , e.g. $\Delta\phi(E_T^{\text{miss}}, \ell)$.

$|\Delta\eta_{jj}|$ The separation in η between the leading two jets.

E_T^{miss} The magnitude of the missing transverse momentum in the event.

$E_T^{\text{miss,rel}}$ The quantity $E_T^{\text{miss,rel}}$ is defined as

$$E_T^{\text{miss,rel}} = \begin{cases} E_T^{\text{miss}} & \text{if } \Delta\phi(E_T^{\text{miss}}, \ell/j) \geq \pi/2 \\ E_T^{\text{miss}} \times \sin \Delta\phi(E_T^{\text{miss}}, \ell/j) & \text{if } \Delta\phi(E_T^{\text{miss}}, \ell/j) < \pi/2 \end{cases},$$

where $\Delta\phi(E_T^{\text{miss}}, \ell/j)$ is the azimuthal angle between the direction of E_T^{miss} and that of the nearest electron, muon, or central jet.

$p_T^{\ell\ell}$ The transverse momentum of the two-lepton system.

H_T The scalar sum of the transverse momenta of the leptons and jets in the event.

m_T The transverse mass formed using the $E_{\text{T}}^{\text{miss}}$ and the leading lepton or tau in the event

$$m_{\text{T}}(\vec{p}_{\text{T}}^{\ell/\tau}, E_{\text{T}}^{\text{miss}}) = \sqrt{2p_{\text{T}}^{\ell/\tau}E_{\text{T}}^{\text{miss}} - 2\vec{p}_{\text{T}}^{\ell/\tau} \cdot \vec{E}_{\text{T}}^{\text{miss}}}.$$

In the three-lepton analysis, the lepton not forming the SFOS lepton pair with mass closest to the Z boson mass is used. In cases where the second lepton or tau is used, the variable is labeled as m_{T}^X , where X is the object used with the $E_{\text{T}}^{\text{miss}}$ to form the transverse mass.

m_{SFOS} The invariant mass of the SFOS lepton pair in the event. In the three-lepton analysis, the SFOS pair with mass closest to the Z boson mass is used.

m_{SFOS}^{min} The lowest m_{SFOS} value among the possible SFOS combinations.

m _{$\ell\ell\ell$} The three-lepton invariant mass.

m _{$\tau\tau$} The two-tau invariant mass.

m_{T2} The “stransverse mass” is calculated as

$$m_{\text{T2}} = \min_{\vec{q}_{\text{T}}} \left[\max \left(m_{\text{T}}(\vec{p}_{\text{T}}^{\ell1/\tau1}, \vec{q}_{\text{T}}), m_{\text{T}}(\vec{p}_{\text{T}}^{\ell2/\tau2}, E_{\text{T}}^{\text{miss}} - \vec{q}_{\text{T}}) \right) \right],$$

where $\ell1/\tau1$ and $\ell2/\tau2$ denote the highest- and second-highest- p_{T} leptons or taus in the event, respectively, and \vec{q}_{T} is a test transverse vector that minimizes the larger of the two transverse masses m_{T} . The m_{T2} distribution has a kinematic endpoint for events where two massive pair-produced particles each decay to two objects, one of which is detected and the other escapes undetected [108, 109].

m_{eff} The scalar sum of the transverse momenta of the signal leptons, taus, jets and $E_{\text{T}}^{\text{miss}}$ in the event:

$$m_{\text{eff}} = E_{\text{T}}^{\text{miss}} + \sum p_{\text{T}}^{\text{leptons}} + \sum p_{\text{T}}^{\text{taus}} + \sum p_{\text{T}}^{\text{jets}}.$$

In the case of the two-tau analysis, only the sum of the $E_{\text{T}}^{\text{miss}}$ and two taus is used.

R_2 The quantity R_2 is defined as

$$R_2 = \frac{E_{\text{T}}^{\text{miss}}}{E_{\text{T}}^{\text{miss}} + p_{\text{T}}^{\ell 1} + p_{\text{T}}^{\ell 2}}.$$

The R_2 distribution is shifted towards unity for signal events compared to the background, due to the existence of the LSPs that results in a larger $E_{\text{T}}^{\text{miss}}$ fraction.

$M_{\Delta}^R, \Delta\phi_R^{\beta}$ The super-razor quantities M_{Δ}^R and $\Delta\phi_R^{\beta}$ are defined in Ref. [110]. These variables are motivated by the generic process of the pair production of two massive particles, each decaying into a set of visible and invisible particles (i.e. $\tilde{\chi}_1^{\pm} \rightarrow \ell\nu_{\ell}\tilde{\chi}_1^0$). Similar to m_{T2} , M_{Δ}^R is sensitive to the squared mass difference of the pair-produced massive particle and the invisible particle, via a kinematic endpoint. These two variables are expected to have a similar performance. For systems where the invisible particle has mass that is comparable to the pair-produced massive particle (i.e. compressed spectra), the variable $\Delta\phi_R^{\beta}$ has a pronounced peak near π . The effect is magnified as the spectrum becomes more and more compressed, making this variable a good discriminator for compressed spectra searches.

Ref 110: arXiv: 1310.4827

After applying the preselection listed above, both signal and background MC samples are split in two. Half is used for the BDT training and the other half for testing. Twelve variables with good discriminatory power are considered as input for the BDT training procedure: E_T^{miss} , m_{eff} , $m_{\tau 2}$, $m_{\tau \tau}$, $\Delta\phi(\tau, \tau)$, $\Delta\eta(\tau, \tau)$, $p_T^{\tau 1}$, $p_T^{\tau 2}$, $m_{\text{Tr}1}$, $m_{\text{Tr}2}$, $\Delta\phi(E_T^{\text{miss}}, \tau 1)$ and $\Delta\phi(E_T^{\text{miss}}, \tau 2)$. The MC simulation is compared to data for these variables and their correlations to ensure that they are modelled well.