Searches for electroweak production of SUSY particles with the ATLAS detector

SUSY 2016

Melbourne, Australia

July 3rd – 8th 2016

Matthew Gignac on behalf of the

ATLAS Collaboration

Outline

Overview of recent electro-weakino searches with ATLAS

- Analysis based on $\sqrt{s}$ = 8 TeV of 20.3 fb^{-1} from Run-1 of the LHC

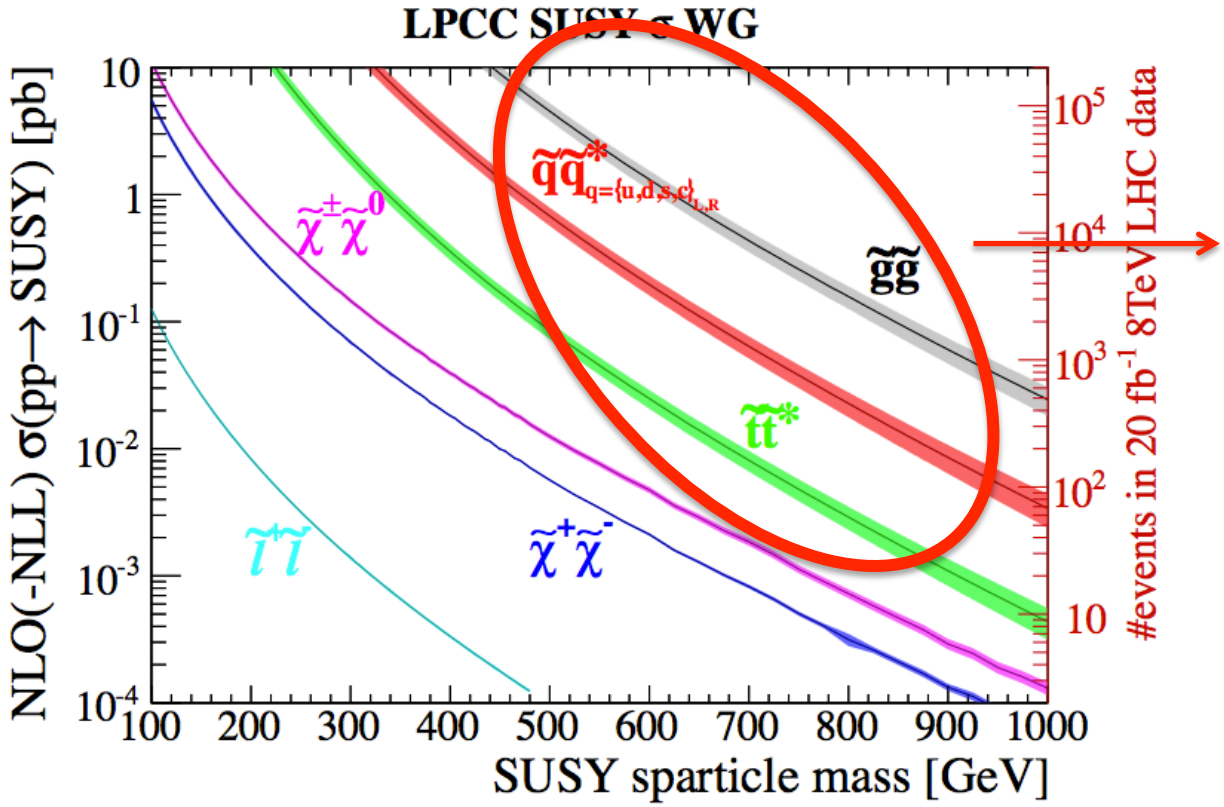
1. Explored experimentally challenging SUSY scenarios
2. Interpretations of Run-1 searches in phenomenological models

<u>Relevant papers:</u>

- EW summary paper: Phys. Rev. D 93, 052002 (2016)
- GGM Interpretations: CONF note to appear

All results available via ATLAS SUSY summary twiki:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Motivation



Strongly produced SUSY

- ✓ Largest cross section
- x TeV-scale mass limits
- x **No signs yet…!**

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections arXiv:1206.2892

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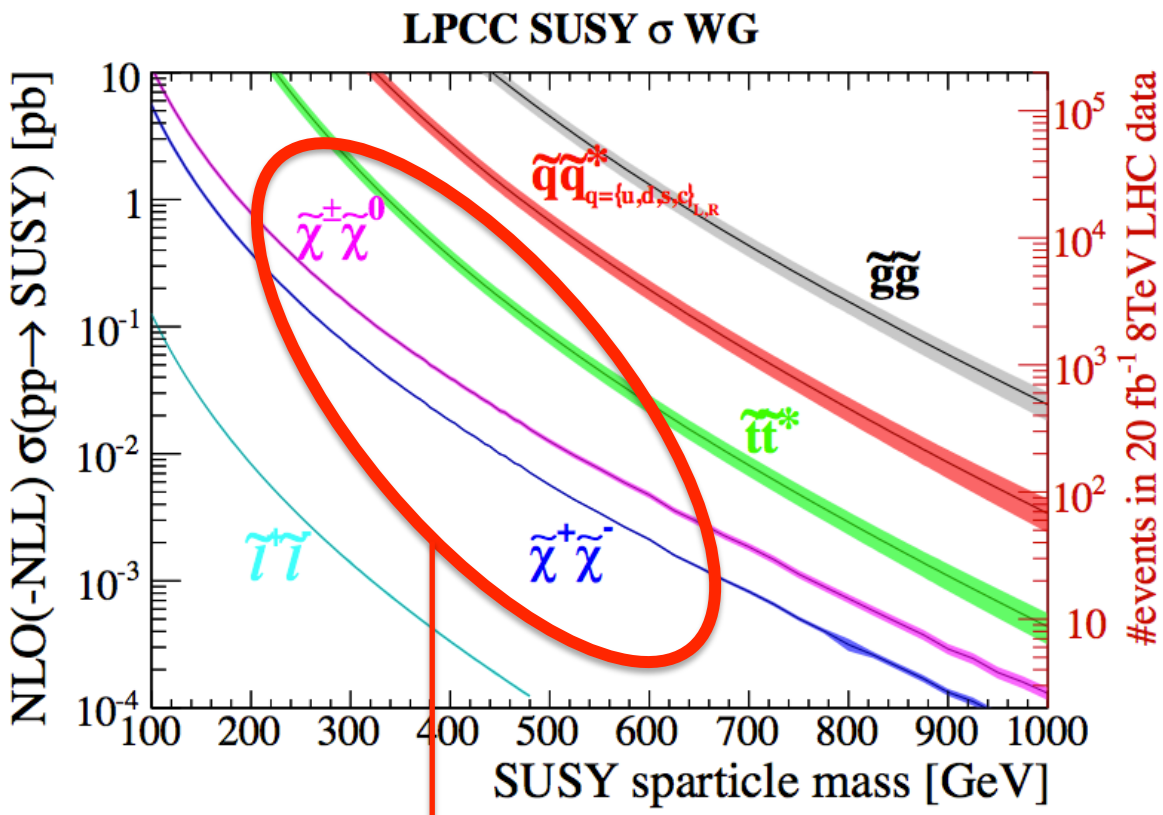

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Strongly produced SUSY

- ✓ Largest cross section
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Electroweak SUSY

- ✓ Small cross section but distinct leptonic signature

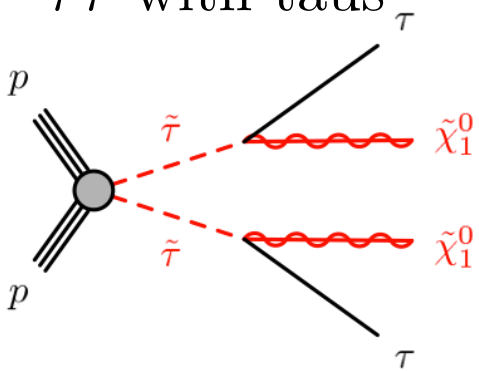
→ **<u>Topic of todays talk!</u>**

Simplified SUSY scenarios

Simplified models

- Masses and decay modes are the only free parameters
- Assumed 100% BR of sparticles

$\tilde{\tau}\tilde{\tau}$ with taus



→Di-hadronic tau

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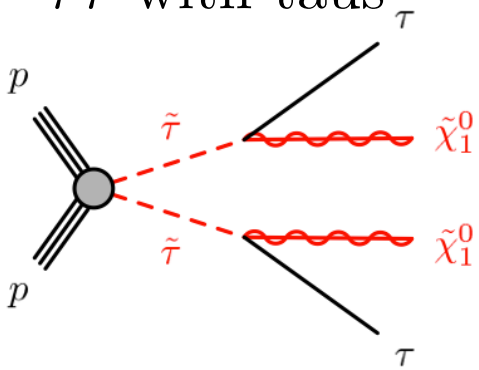
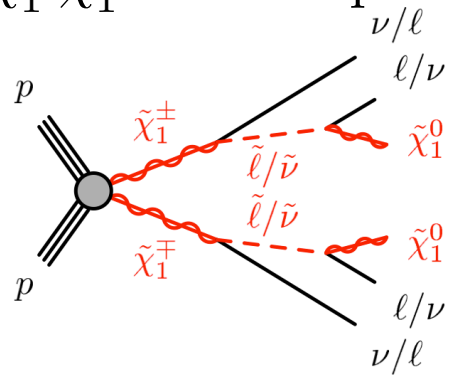


→Di-hadronic tau

$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ with sleptons



→ 2 OS light leptons

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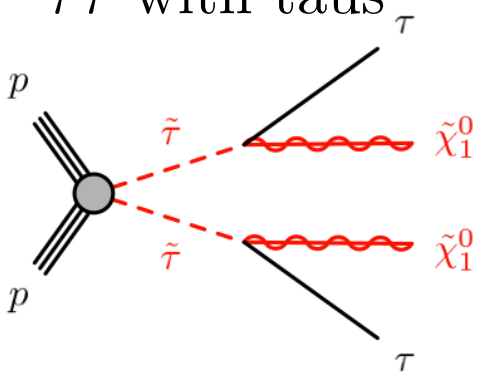

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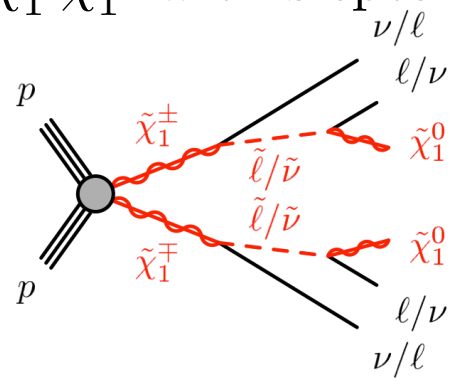
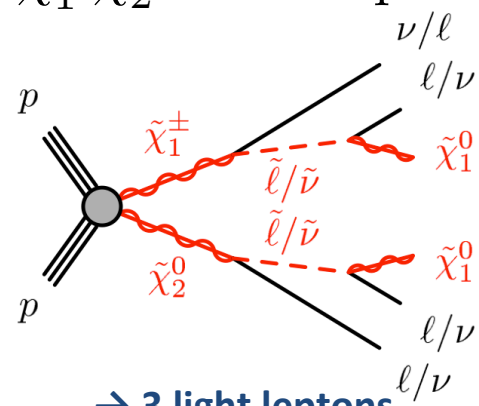


→ 2 OS light leptons

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ with sleptons



→ 3 light leptons
→ 2 SS light leptons

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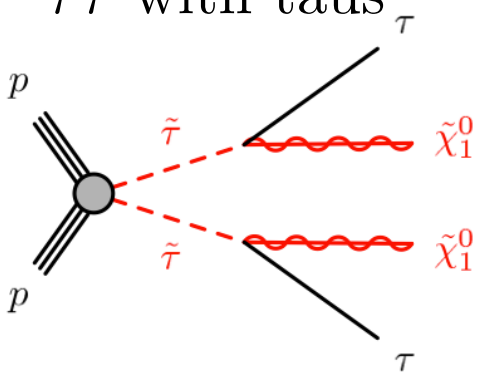

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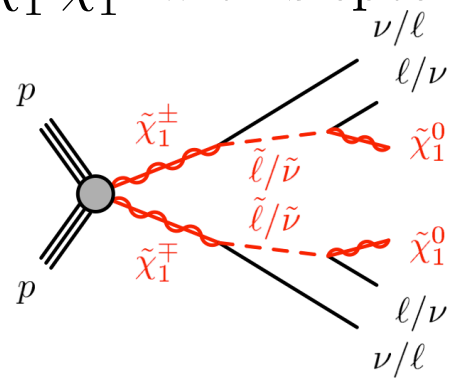

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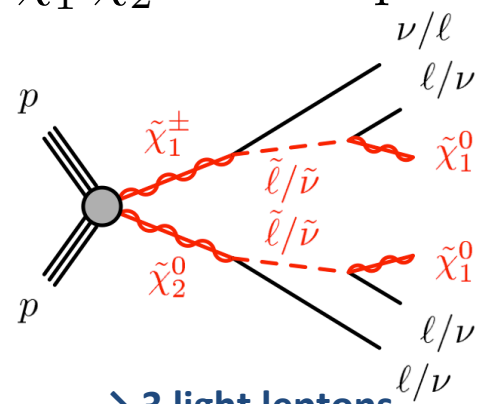
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ with sleptons



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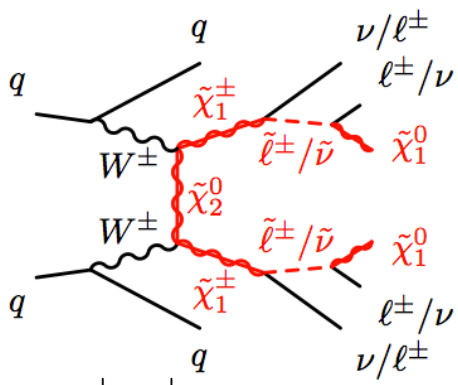


$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ via VBF

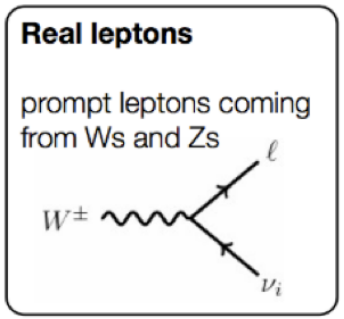
→ 2 SS light leptons
→ Forward jets

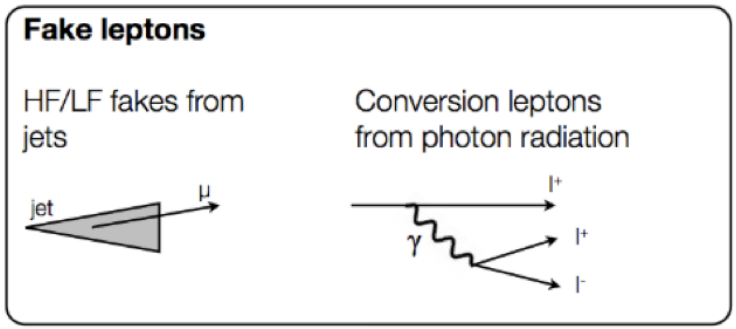
Standard Model background modelling

Several SM backgrounds mimic the SUSY signatures

- Single/di-/tri-bosons, top-quark(s) and multi-jet
- Need to understand and accurately model these backgrounds!

1. **<u>Irreducible backgrounds: MC simulation</u>**
   - Sources of real, prompt leptons
   - Control regions (CRs) used to normalize dominant contributions
   - Shapes of kinematic variables taken from MC simulation
2. **<u>Reducible backgrounds: Data-driven estimate</u>**
   - One or more fake, non-prompt leptons
   - Non-prompt backgrounds estimated with the **<u>matrix method</u>**
   - Multi-jet production estimated with the **<u>ABCD method</u>**





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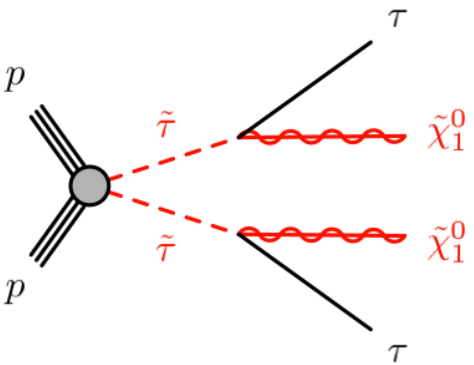
OS ditau channel

Di-hadronic tau final state, very challenging:

- Difficult to trigger and separate from SM backgrounds
- Previous ATLAS results[1] not sensitive to stau production

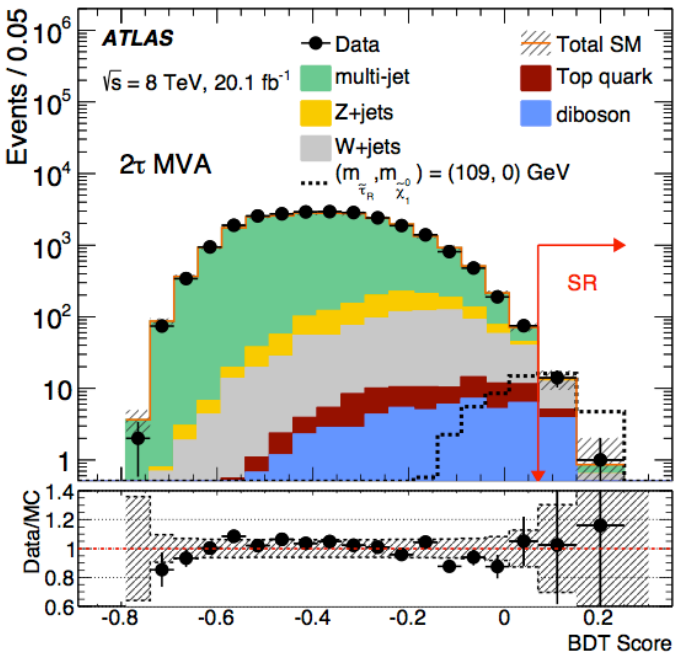


Event selection:

- SR defined with a multivariate technique
- Z-veto: reduce Z → $\tau\tau$ events
- B-veto: reduce di-tau tt events

Background estimation:

- W →τν+ mis-identified tau → normalized in CRs
- Diboson and top estimated using MC simulation
- Multi-jet background: data-driven ABCD method



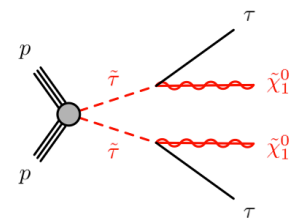
Data consistent with <u>background only</u> predictions

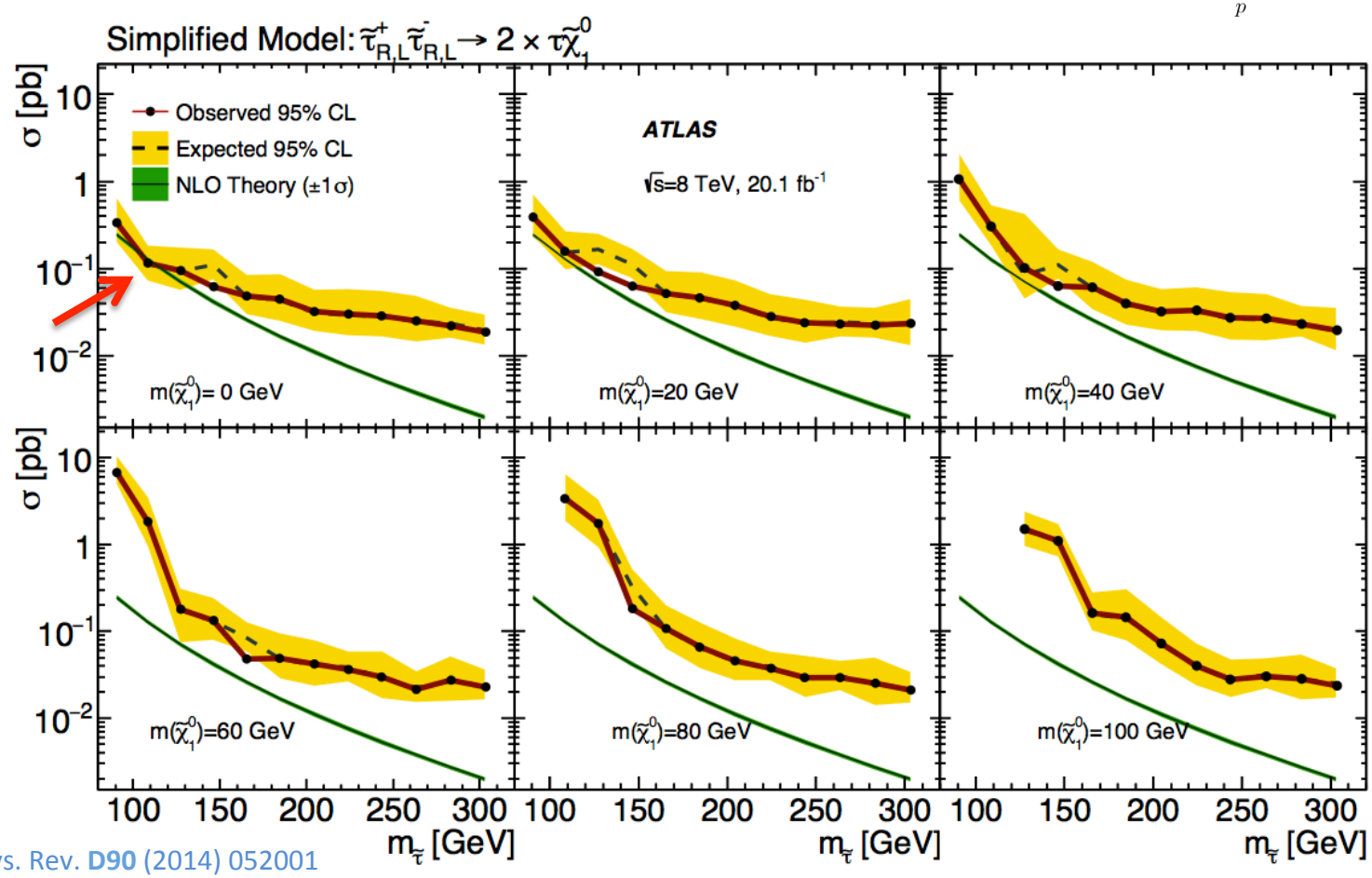
[1] Phys. Rev. **D90** (2014) 052001

OS ditau channel: interpretation

Improved sensitivity compared previous ATLAS result[1]

✓ Exclude one scenario where: $m_{\tilde{\tau}_R} = 109$ GeV and $m_{\tilde{\chi}_1^0} = 0$ GeV

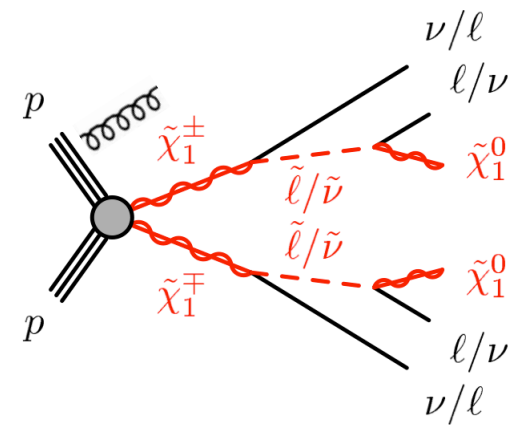




[1] Phys. Rev. **D90** (2014) 052001

OS dilepton channel

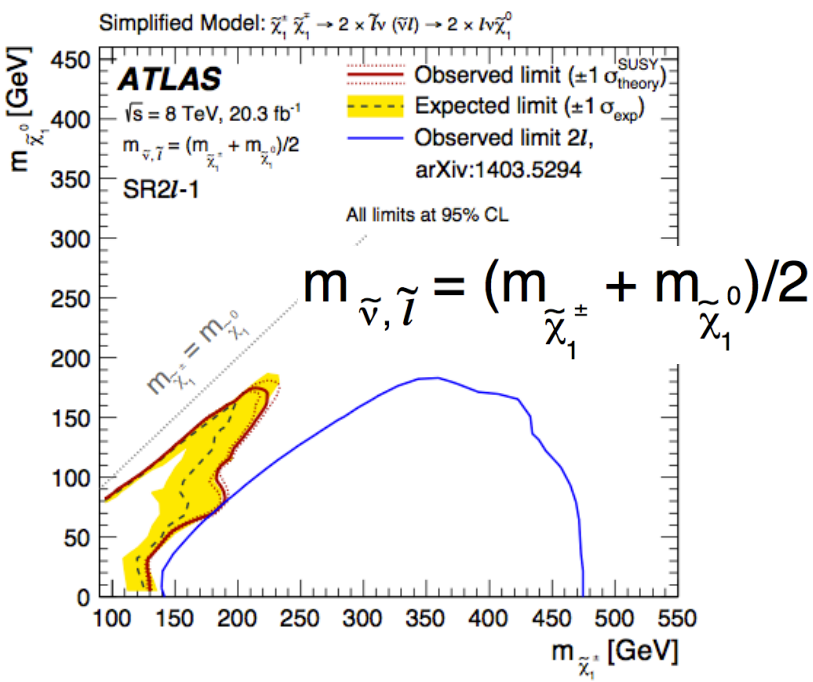
Improve previous 2-lepton results[2] for $\tilde{\chi}_1^{\pm} - \tilde{\chi}_1^0 < 100$ GeV



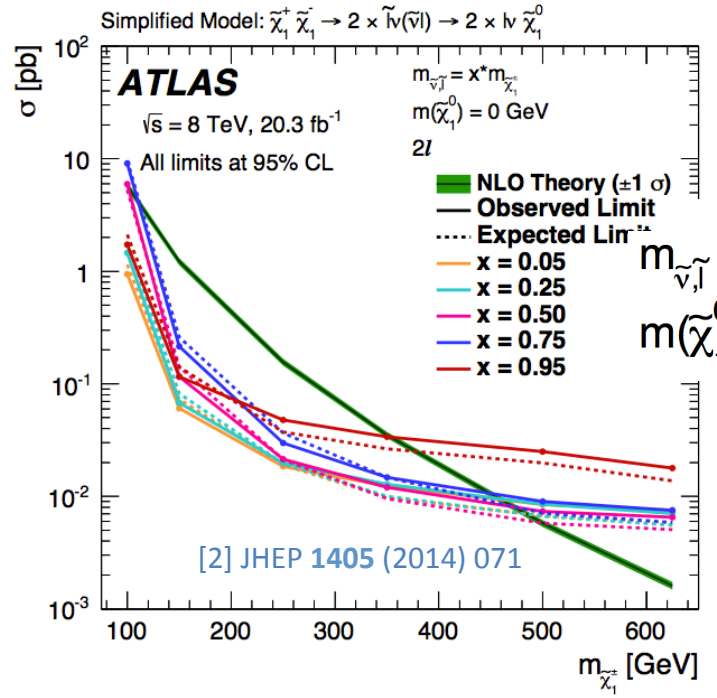
Event selection

- Exactly two oppositely-charged leptons with $p_T > 10$ GeV
- At least one hard ISR jet → boosts the leptons
- Suppress top quark(s) background with b-jet veto

Data consistent with <u>SM backgrounds only</u>



$$m_{\tilde{\nu},\tilde{l}} = (m_{\tilde{\chi}_1^{\pm}} + m_{\tilde{\chi}_1^0})/2$$



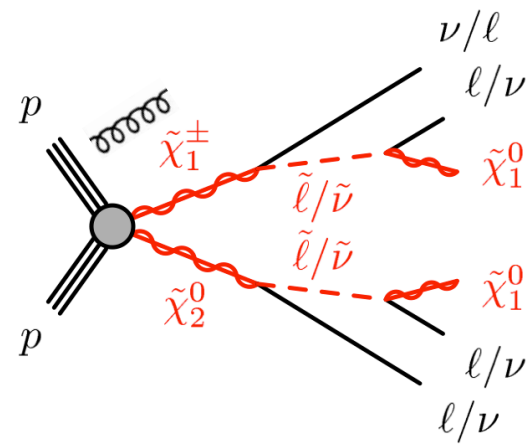
$$m_{\tilde{\nu},\tilde{l}} = x^* m_{\tilde{\chi}_1^{\pm}}$$

$$m(\tilde{\chi}_1^0) = 0 \text{ GeV}$$

[2] JHEP **1405** (2014) 071

3ℓ channel

Improve previous 3-lepton results[3] for $\tilde{\chi}_2^0 - \tilde{\chi}_1^0 < 20\ \mathrm{GeV}$



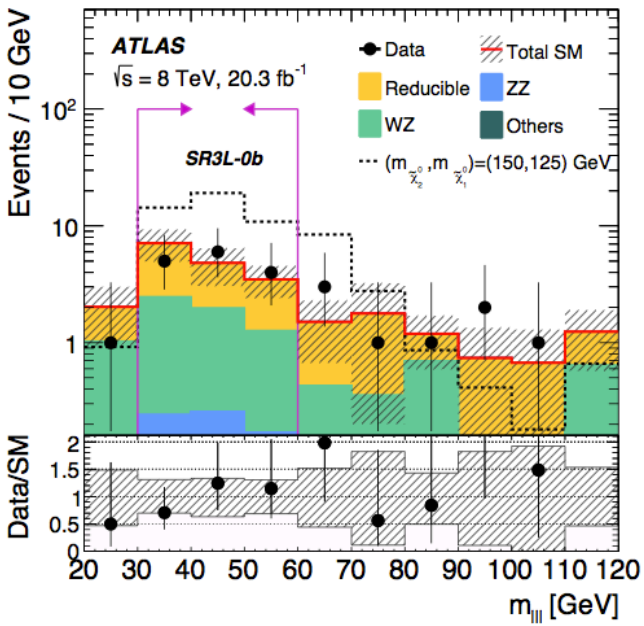
Event selection

- Three leptons with muon (electron) 6(7) < p_T < 30 GeV
- SRs to target ISR scenarios → jet with p_T > 50 GeV

Background estimation:

- WZ and ZZ estimated taken from MC → validated in VRs
- Reducible backgrounds: data driven matrix method

Data consistent with <u>SM only predictions</u>



			ISR scenarios	
	SR3ℓ-0a	SR3ℓ-0b	SR3ℓ-1a	SR3ℓ-1b
WZ	$0.59^{+0.47}_{-0.32}$	$5.0^{+1.5}_{-1.2}$	$0.54^{+0.20}_{-0.19}$	1.6 ± 0.4
ZZ	$0.23^{+0.09}_{-0.07}$	0.66 ± 0.16	0.024 ± 0.013	$0.10^{+0.05}_{-0.04}$
Reducible	$2.8^{+1.5}_{-2.2}$	$9.7^{+3.1}_{-3.6}$	0.09 ± 0.08	$1.4^{+1.0}_{-1.1}$
Others	$0.0033^{+0.0036}_{-0.0033}$	0.07 ± 0.05	0.013 ± 0.010	0.038 ± 0.021
Total SM	$3.7^{+1.6}_{-2.2}$	$15.4^{+3.5}_{-3.9}$	$0.67^{+0.22}_{-0.21}$	$3.1^{+1.1}_{-1.2}$
Data	4	15	1	3

[3] JHEP **1404** (2014) 169.

SS dilepton channel

Target compressed scenarios when one lepton is lost

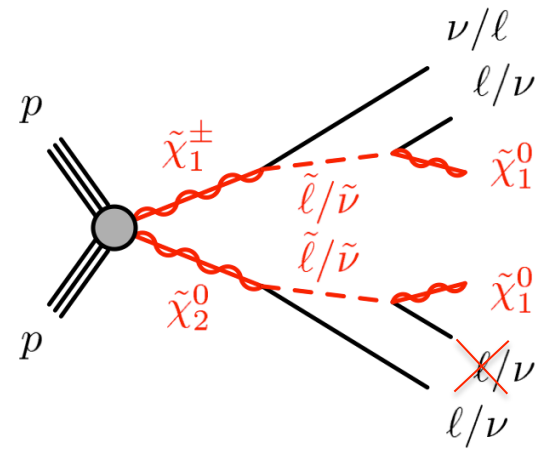
Event selection:

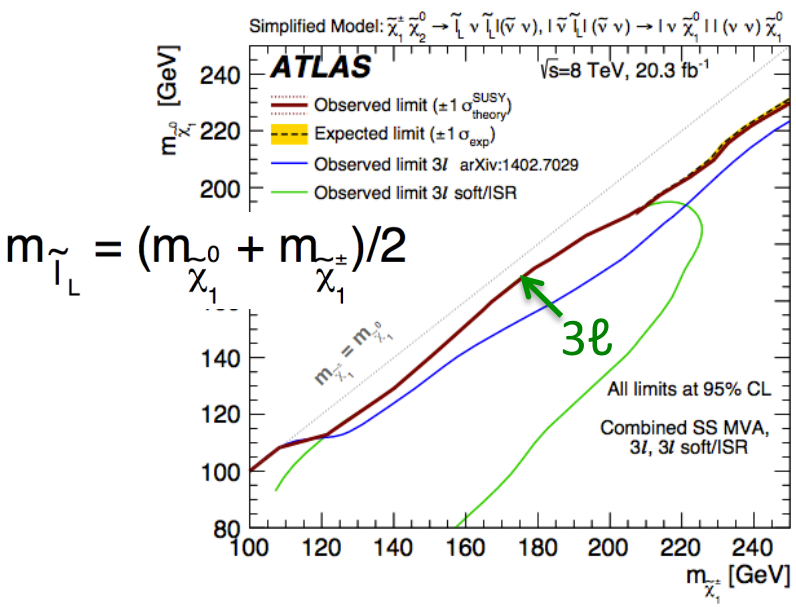
- Two light leptons with same charge: $e^{\pm}e^{\pm}$, $\mu^{\pm}\mu^{\pm}$, or $e^{\pm}\mu^{\pm}$
- BDTs trained and optimized for $\tilde{\chi}_1^{\pm} - \tilde{\chi}_1^0 < 100$ GeV

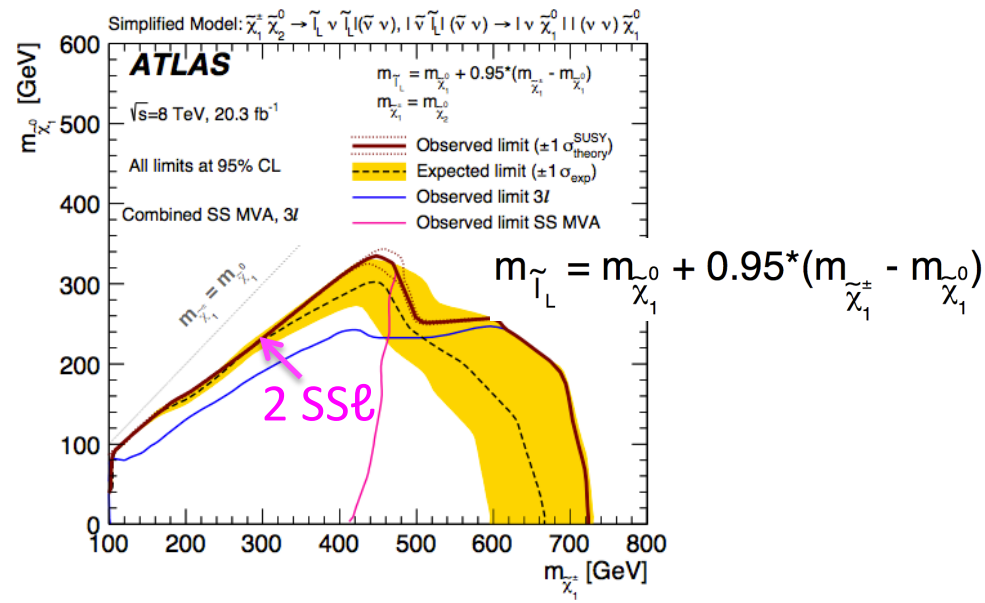
Background estimation:

- Charge flip (Z,tt, W^+W^-) estimated in $Z \rightarrow e^{\pm}e^{\pm}$
- $W^{\pm}W^{\pm}$, WZ and ZZ taken from MC simulation

Data consistent with <u>SM only predictions</u>







Chargino-pair production via VBF

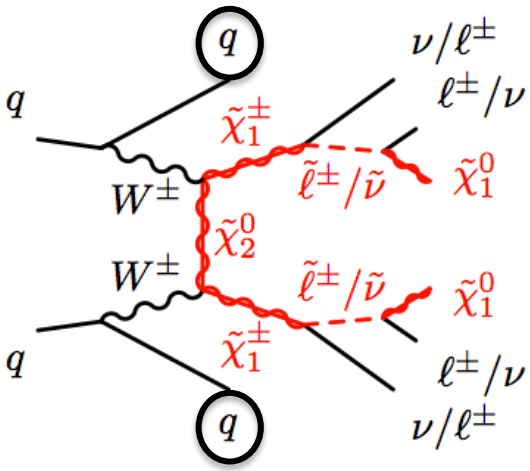
Explore highly compressed SUSY with VBF

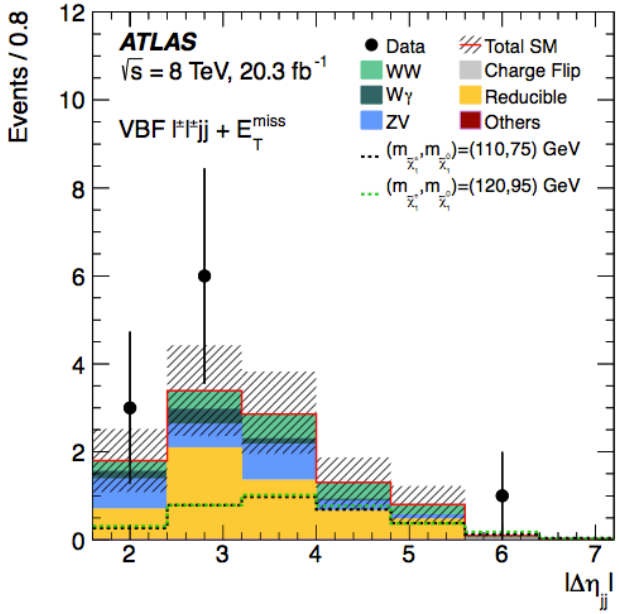
- Smaller cross section than direct production
- Forward jets give distinct signature from the SM

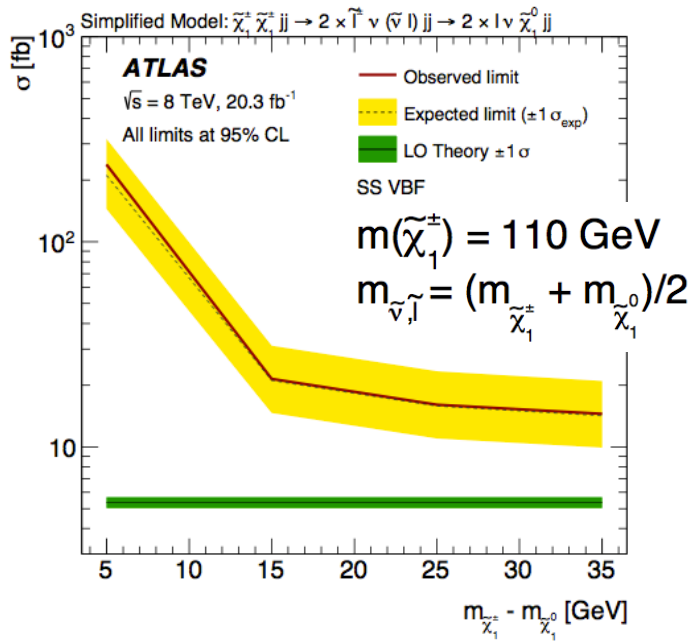
Event Selection

- Exactly two same sign leptons
- At least two jets with $m_{jj} > 350$ GeV & $|\Delta\eta_{jj}| > 1.6$

Data consistent with <u>SM only predictions</u>







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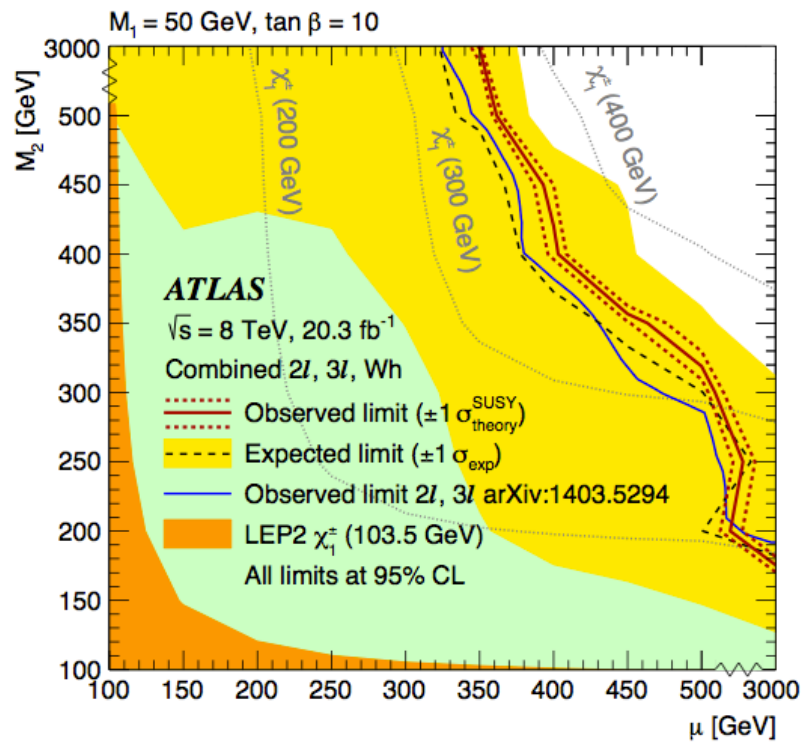
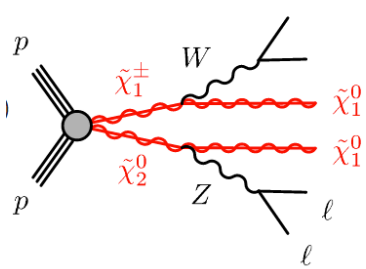
Phenomenological MSSM

Re-interpretation in the context of a pMSSM

- sfermions, gluinos and CP-odd Higgs are decoupled
- Four dimensional parameter space:
  - M1 = 50 GeV to satisfy dark matter cosmological bounds; tanβ= 10
  - Interpretation in M2 vs μ plane
- Direct production of charginos and neutralinos dominant
  - Decays through SM gauge bosons and the lightest higgs boson

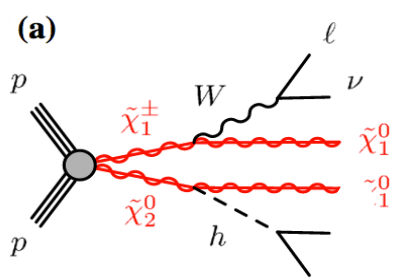


WZ → 2ℓ or 3ℓ



JHEP **1405** (2014) 071

Wh → 1ℓ + bb, ⤫⤫, WW

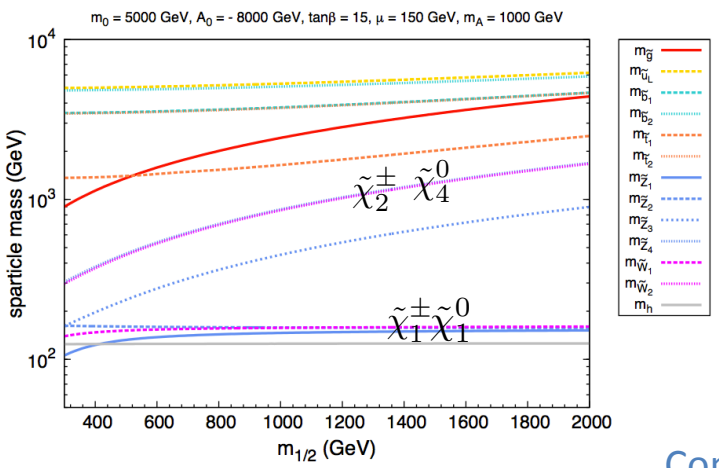


Eur. Phys. J. **C75** (2015) 208.

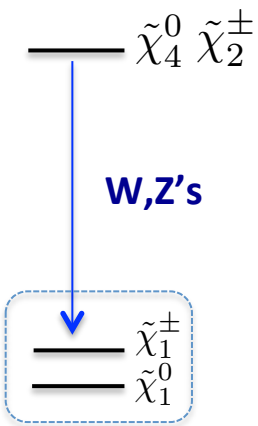
Two-parameter NUHM model (NUHM2)

Radiatively-driven Natural SUSY

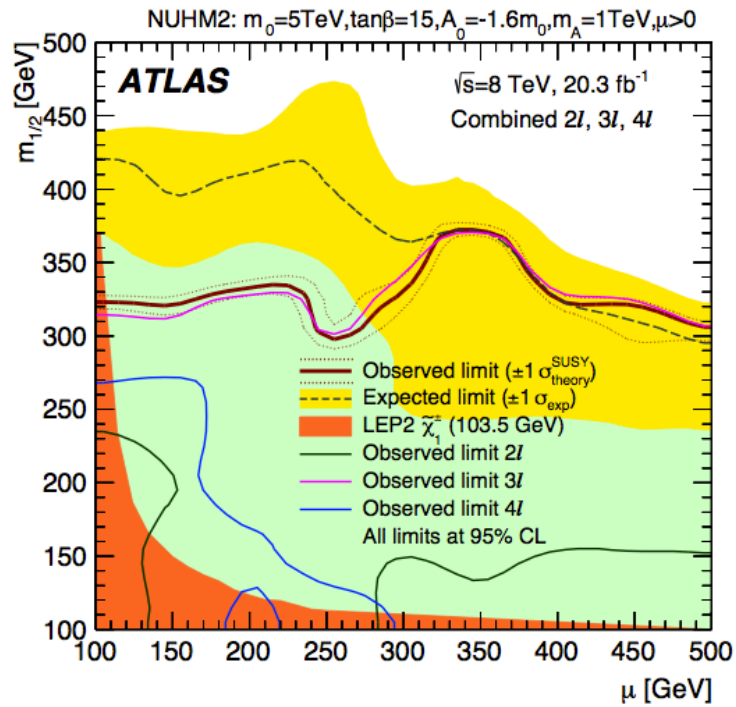
- Low-level of electroweak fine-tuning, allows SM h and Z-boson ~O(100) GeV
- Light higgsinos |μ| ~ 100 – 300 GeV
- Squarks and gluinos all at the TeV-scale
- Production of heavier Wino-like gauginos
  - Distinct multi-lepton signature
  - Sensitivity with existing 2ℓ,3ℓ and 4ℓ EW searches!



JHEP 1312 (2013) 013.



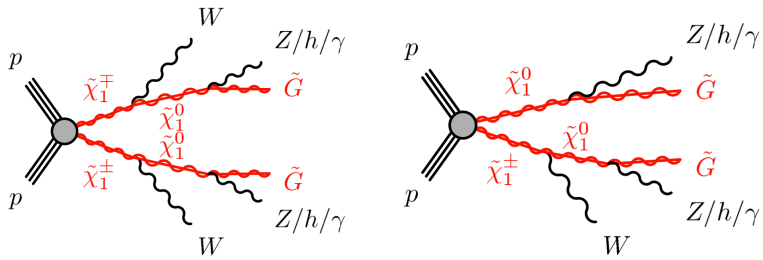
Compressed higgsinos

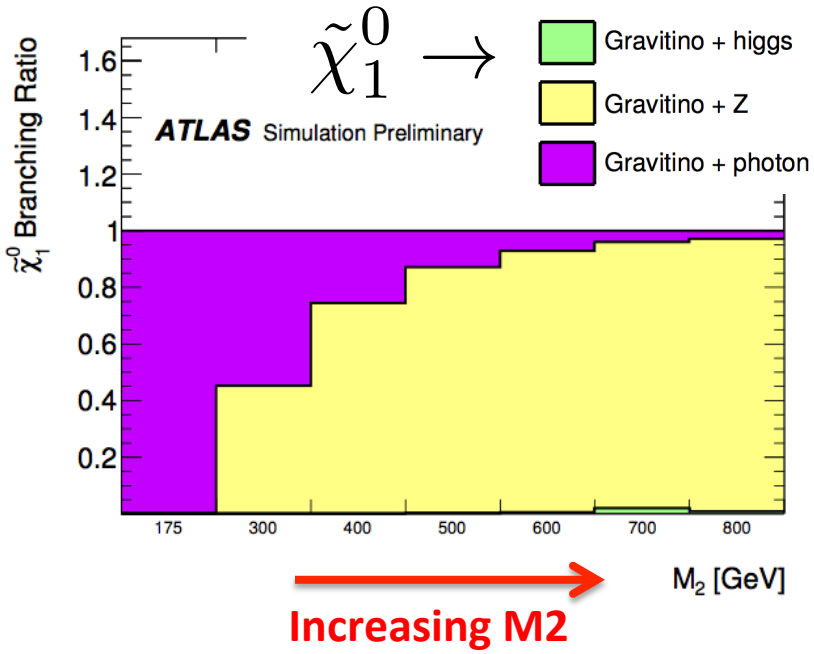


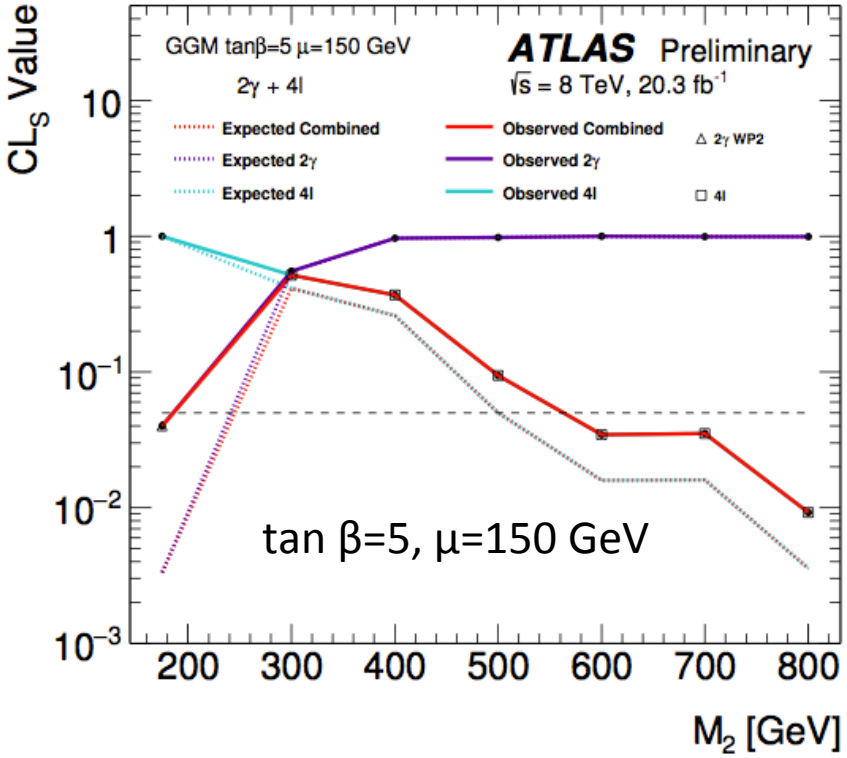
General Gauge Mediated (GGM) Model

Gauge mediated SUSY breaking model with SM Higgs mass constraint

- Wino-higgsino electroweakino production
- Decays via W,Z,h and photons; gravitino LSP







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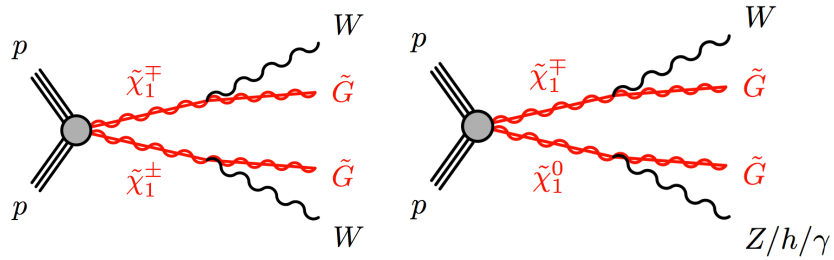
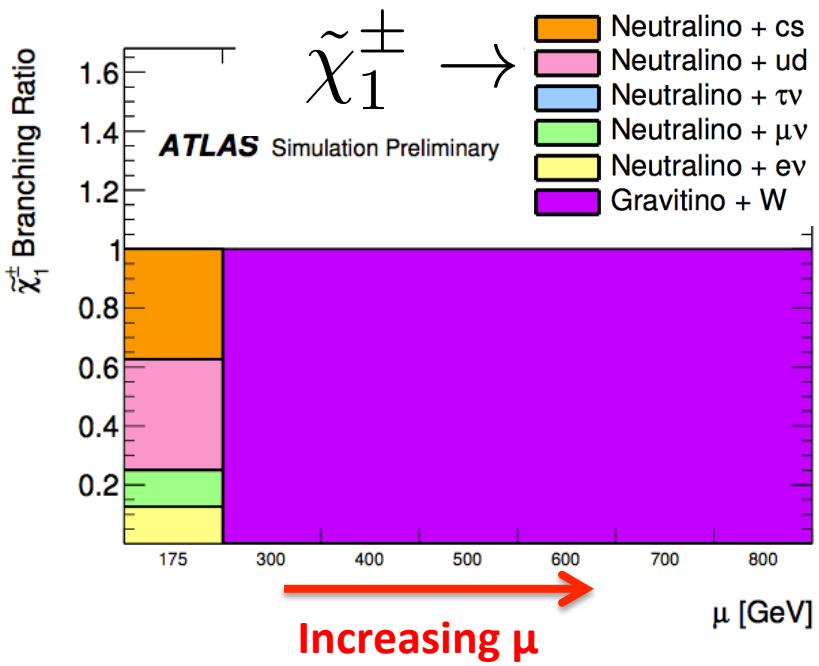
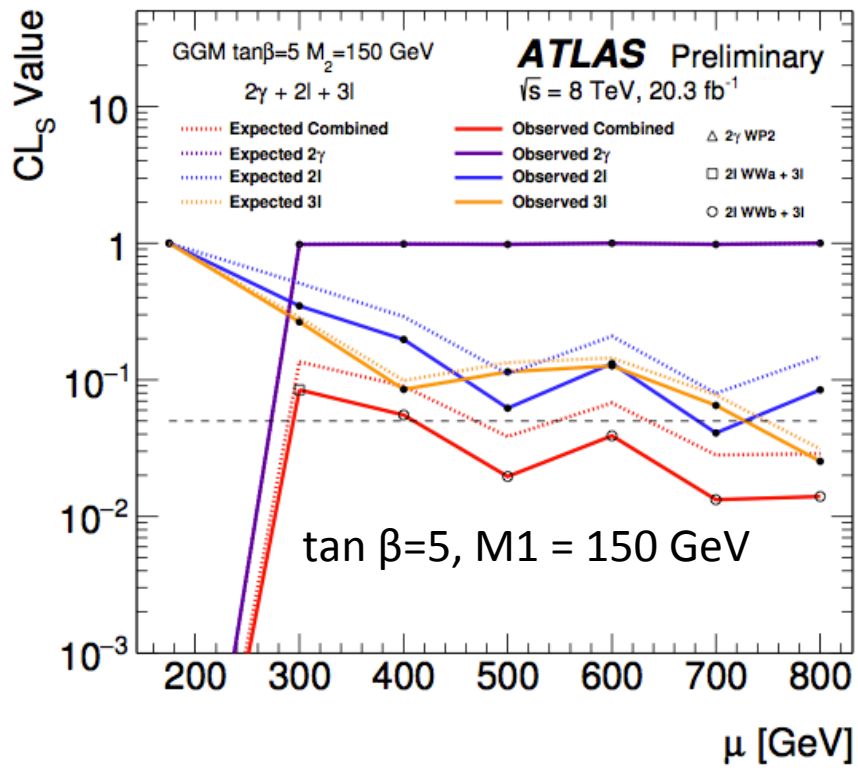


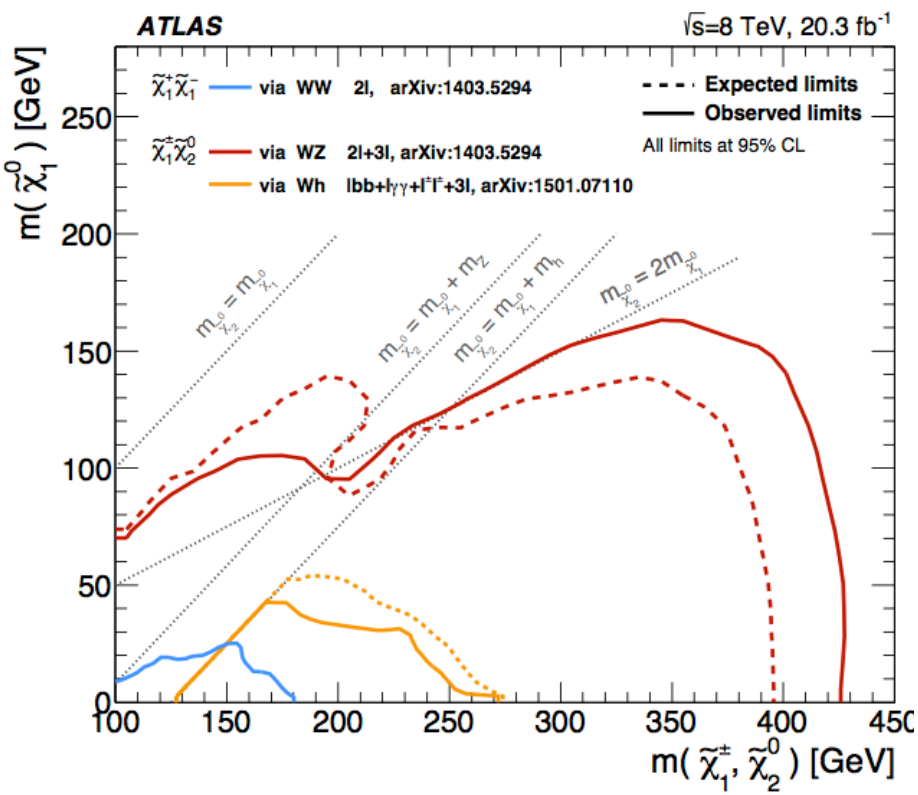


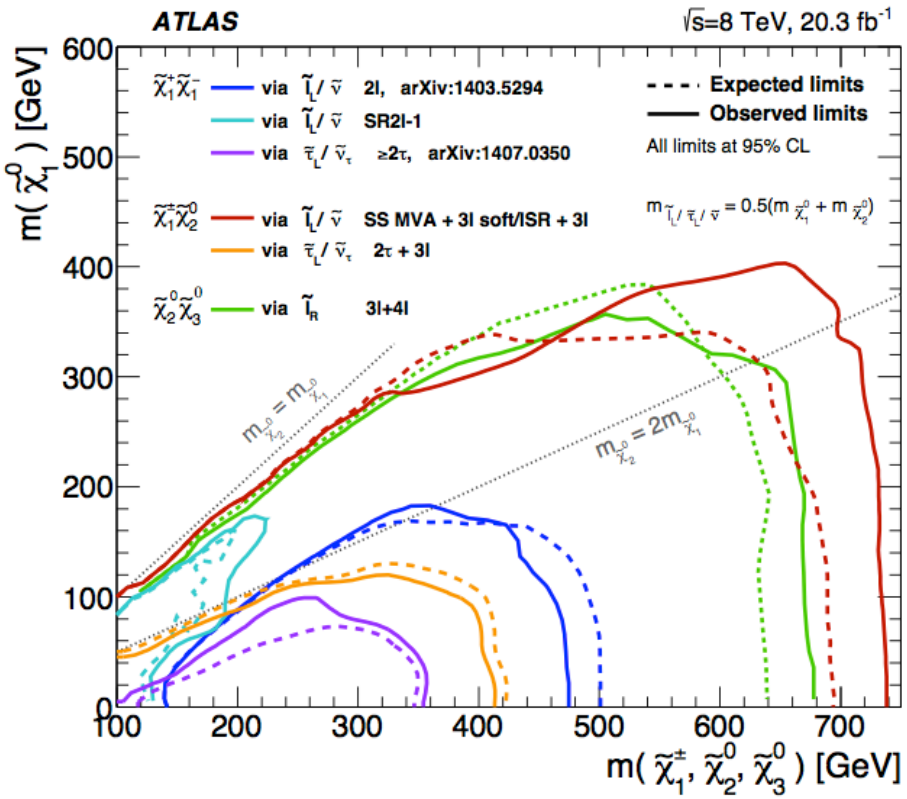


Conclusions

ATLAS has a rich SUSY program to explore electroweak SUSY

- No evidence for electro-weak SUSY at 8 TeV
- **Stay tuned for results at 13 TeV!**





Backup slides

Matrix method: overview

Relates tight (T) and loose (L) leptons to real (R) and fake (F) objects

- In 3ℓ events, leading lepton was shown to be real 99% of the time
- For 2ℓ events, we have a 4x4 matrix

$$\begin{pmatrix} N_{TT} \\ N_{TL'} \\ N_{L'T} \\ N_{L'L'} \end{pmatrix} = \begin{pmatrix} \epsilon_1\epsilon_2 & \epsilon_1 f_2 & f_1\epsilon_2 & f_1 f_2 \\ \epsilon_1(1-\epsilon_2) & \epsilon_1(1-f_2) & f_1(1-\epsilon_2) & f_1(1-f_2) \\ (1-\epsilon_1)\epsilon_2 & (1-\epsilon_1)f_2 & (1-f_1)\epsilon_2 & (1-f_1)f_2 \\ (1-\epsilon_1)(1-\epsilon_2) & (1-\epsilon_1)(1-f_2) & (1-f_1)(1-\epsilon_2) & (1-f_1)(1-f_2) \end{pmatrix} \cdot \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

  - ε: probability a real lepton passes signal loose to tight selection
  - f : probability a fake lepton passes signal loose to tight selection
  - εand f measured in MC close to SR, corrected by data-driven measurements of ε and f further from the SR
- Invert the matrix, solve for the number of fake leptons passing tight selection

$$N_{Fake \to TT} = \epsilon_1 f_2 \times N_{RF} + f_1 \epsilon_2 \times N_{FR} + f_1 f_2 \times N_{FF}$$

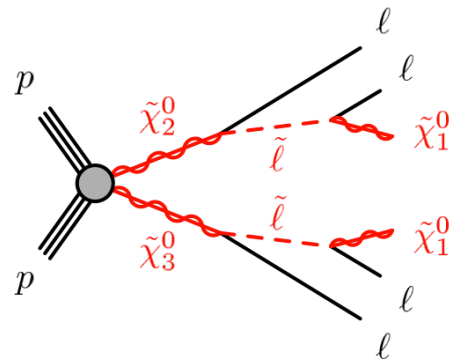
Triggers

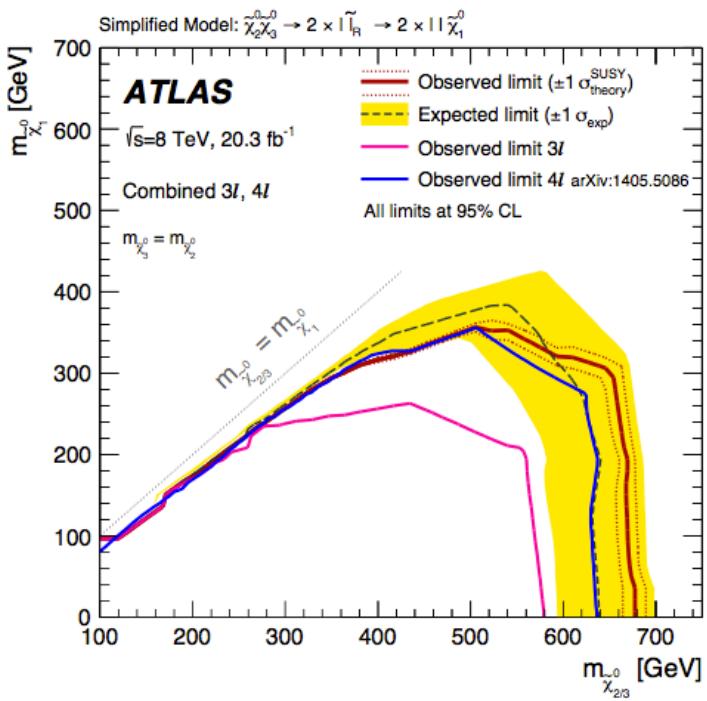
Trigger	p_T threshold [GeV]	Analysis
Single τ Double τ	150 40,25	Direct stau production
Single Isolated e Single Isolated μ	25 25	Compressed spectra $\ell^+\ell^-$, 3ℓ
Double e	14,14 25,10	Compressed spectra $\ell^+\ell^-$, $\ell^\pm\ell^\pm$, 3ℓ
Double μ	14,14 18,10	Compressed spectra $\ell^+\ell^-$, $\ell^\pm\ell^\pm$, 3ℓ
Triple e	20,9,9	Compressed spectra 3ℓ
Triple μ	7,7,7 19,5,5	Compressed spectra 3ℓ
Combined $e\mu$	14(e),10(μ) 18(μ),10(e) 9(e),9(e),7(μ) 9(e),7(μ),7(μ)	Compressed spectra 3ℓ
E_T^{miss}	120	Chargino production via VBF

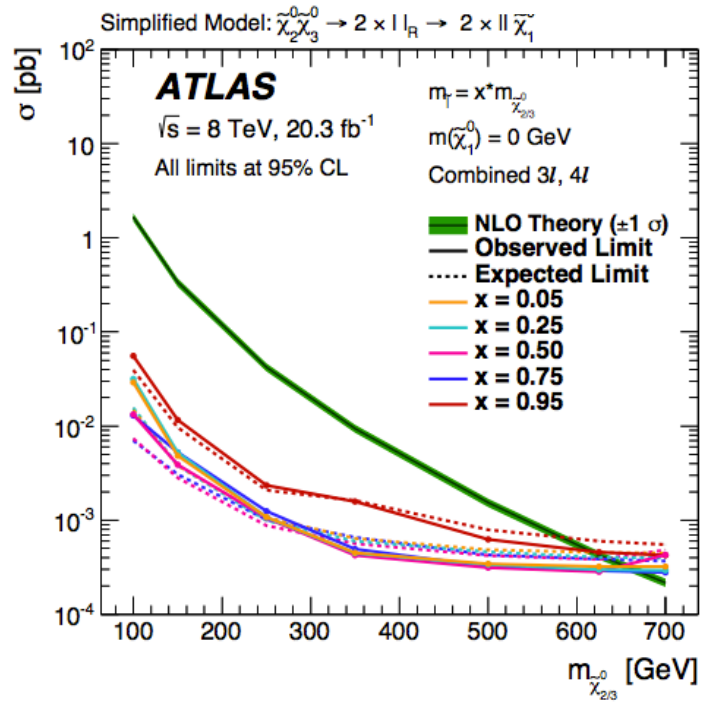
Heavier electroweakino states

Combination 3ℓ and 4ℓ analyses

- Overall improved sensitivity
- Limits robust against slepton mass



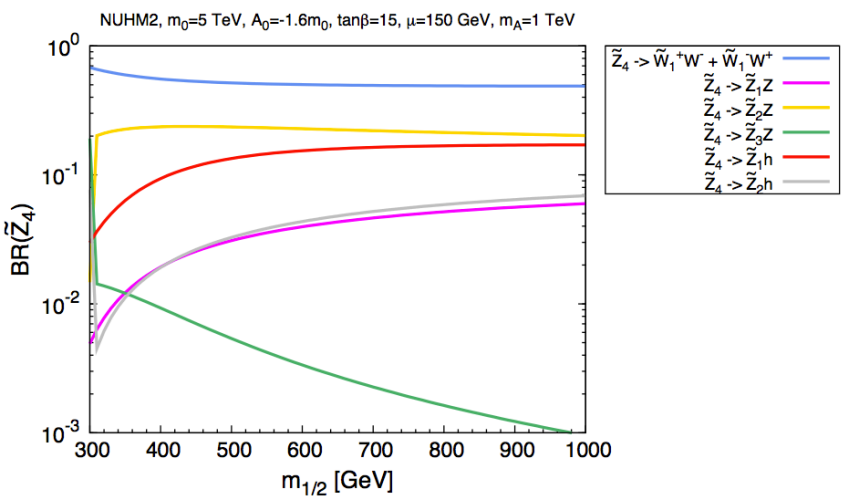


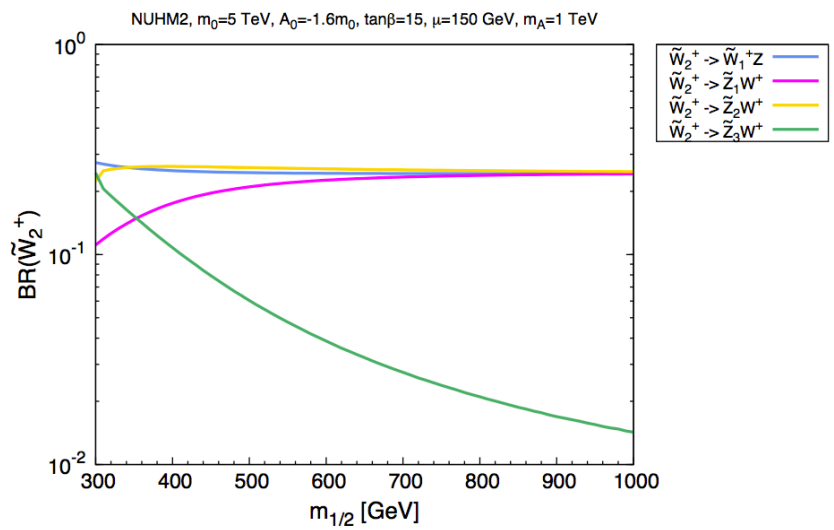


Two-parameter NUHM model (NUHM2)

$$\frac{M_Z^2}{2} = \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2,$$

$$\Delta_{\rm EW} \equiv max_i \left|C_i\right| / (M_Z^2/2).$$





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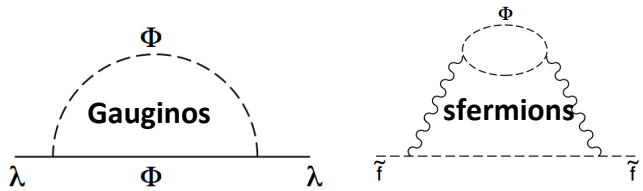
Gauge-Mediated SUSY Breaking model

Mechanism of SUSY breaking unknown

- SUSY particle masses arise from couplings to the messenger fields Φ:



- Parameters of the theory:
  - Messenger mass scale (M_{mess})
  - Number of SU(5) messenger fields (N_5)
  - SUSY-breaking mass scale (Λ)
  - tanβand μ

High Λ → EW production of sparticles

- stau NLSP; gravtino LSP
- Final states with 2-4 tau-leptons
  - **Sensitivity with 4ℓ EW search!**