Searches for Electroweak Production of Supersymmetric Gauginos and Sleptons with the ATLAS Detector

Large Hadron Collider Physics Conference 2014 - New York

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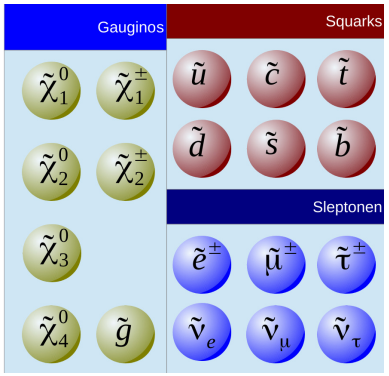
Outline

Introducing Electroweak (EW) SUSY:

- Comparison to "*strong production*"
- Few phenomenology items
- Search strategies

sparticles examples



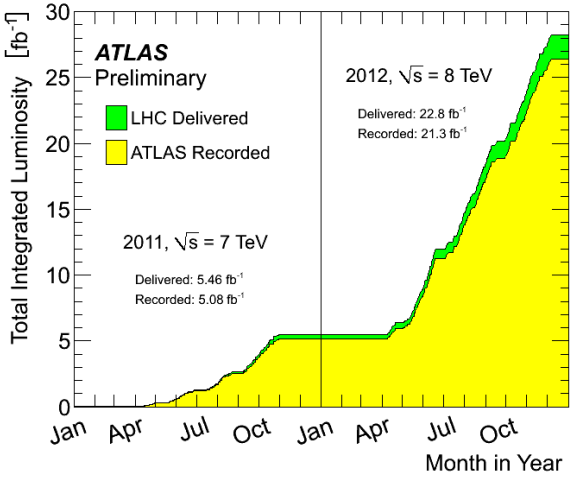
ATLAS searches based on lepton signatures

- Recent EW SUSY results:

$\Rightarrow$ 1, 2, 3, 4 leptons (plus $\not{E}_T$)

- The global picture and the future prospects

LHC Run 1 over from > 1 years



Data may still hide surprises...

Introduction to Electroweak SUSY

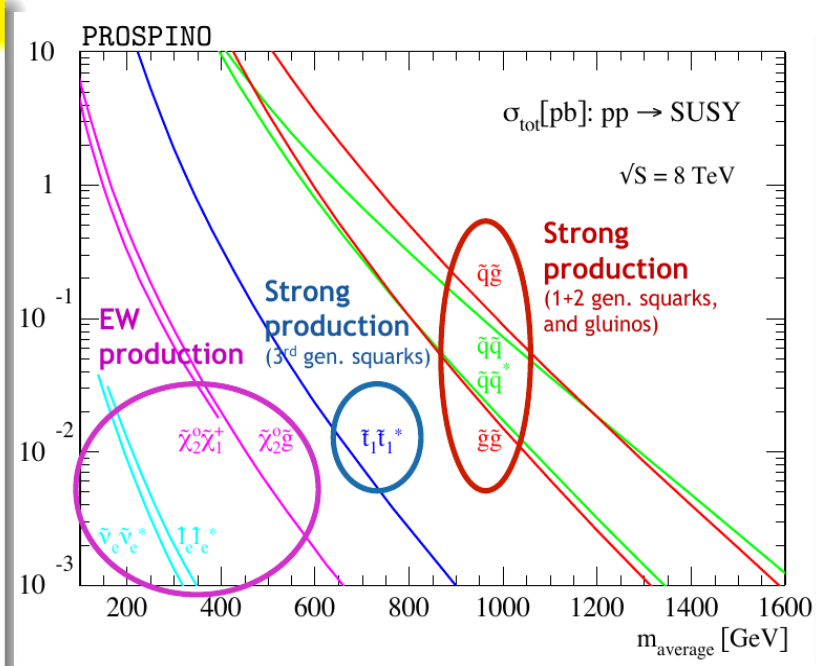
SUSY prediction of partners of SM particles at 1 TeV scale still appealing:

- possible solution to "hierarchy problem"
- may hint to gauge coupling unification
- neutral LSP *may* be a Dark Matter candidate

But...

- *strong production* (squarks and gluinos):
  - ⇒ was expected to dominate at LHC
  - ⇒ exclusion limits already stringent
- Characteristics of EW SUSY production:
  - ⇒ rarer because of smaller cross sections
  - ⇒ charginos ($\tilde{\chi}^{\pm}$), neutralinos ($\tilde{\chi}^{0}$), and sleptons ($\tilde{\ell}$) favor leptonic final states
  - ⇒ signatures with small SM background

Can EW production lead to discover SUSY if squarks/gluinos are much heavier?



EW SUSY Phenomenology

Under some assumptions, all EW SUSY sector is defined by 9 parameters:

- for the *sleptons*: 4 masses ($m^2_{\tilde{e}_L}$, $m^2_{\tilde{e}_R}$, $m^2_{\tilde{\tau}_L}$, $m^2_{\tilde{\tau}_R}$) plus 1 mixing angle ($\theta_{\tilde{\tau}}$)
- 4 parameters (M_1, M_2, μ, $\tan\beta$) of *gauginos/higgsinos* mixing matrices:

$$\begin{pmatrix} M_1 & 0 & -c_\beta s_W M_Z & s_\beta s_W M_Z \\ 0 & M_2 & c_\beta c_W M_Z & -s_\beta c_W M_Z \\ -c_\beta s_W M_Z & c_\beta c_W M_Z & 0 & -\mu \\ s_\beta s_W M_Z & -s_\beta c_W M_Z & -\mu & 0 \end{pmatrix}$$

Neutral: Bino, Wino, Higgsino
$\Rightarrow$ 4 Neutralinos ($\tilde{\chi}^0_1$- $\tilde{\chi}^0_4$, or N1-N4) eigenstates

$$\begin{pmatrix} M_2 & \sqrt{2} s_\beta m_W \\ \sqrt{2} s_\beta m_W & \mu \end{pmatrix}$$

Charged: Wino, Higgsino
$\Rightarrow$ 2 Charginos ($\tilde{\chi}^\pm_1$, $\tilde{\chi}^\pm_2$, or C1,C2) eigenstates

How to study this?

- Phenomenological constrained MSSM (pMSSM) with lightest $m_H = 125$ GeV
- Or simplified models:
  - pure states $\Rightarrow$ no mixing of wino, bino, and higgsinos
  - gluino and squarks masses above TeV scale, decoupled heavy higgses
  - one decay considered each time $\Rightarrow$ es. $\mathcal{BR}(\tilde{\ell} \to \ell \tilde{\chi}^0_1) = 100\%$

Recent ATLAS Searches based on Lepton Signatures

Recipe for a successful SUSY analysis:

- Well defined final state depending on multiplicity of physics objects:
  - light leptons, hadronic τ (τ^{had}), photons, jets, $b-$jets, $\not{E}_T$
  - *Common identification criteria* within ATLAS SUSY group
- Define kinematic regions (3 possible kind):

  SR Signal Region with maximal sensitivity to specific models/parameter spaces
  VR Validation Region dominated by SM backgrounds, used to test analysis robustness
  CR Control Region in phase space close to SR $\Rightarrow$ used to help background estimate by extrapolation to SR (systematic uncertainty reduction)
- Background estimate (analysis dependent): fully or partially MC-based for well defined SM processes, completely data-driven for components hard to simulate (e.i. multi-jet or fake lepton ID)

Recent ATLAS results, according to lepton multiplicity:

1 lep. $+b\bar{b}+\not{E}_T$	ATLAS-CONF-2013-093	8-2013
2 lep. $+2jets+\not{E}_T$	JHEP 05 (2014) 071	3-2014
3 lep. $+\not{E}_T+(0-2\tau^{had})$	JHEP 04 (2014), 169	2-2014
4 lep. $+\not{E}_T+(0-2\tau^{had})$	CERN-PH-EP-2014-074 (PRD submitted)	5-2014, New!
	See M. Goblirsch contribution	
2 $\tau^{had}+\not{E}_T$	ATLAS-CONF-2013-028 (available in backup)	3-2013

1 Lepton, $\not{E}_T$ and $H \to b\bar{b}$ Analysis

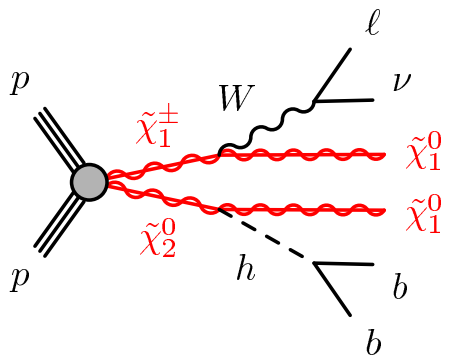
ATLAS-CONF-2013-093:

- First analysis exploiting $m_h = 125$ GeV (with $H \to b\bar{b}$)
- Two SRs optimized for low (high) Δm of $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^0$
- Main backgrounds ($t\bar{t}$, W+jets) reduced using:

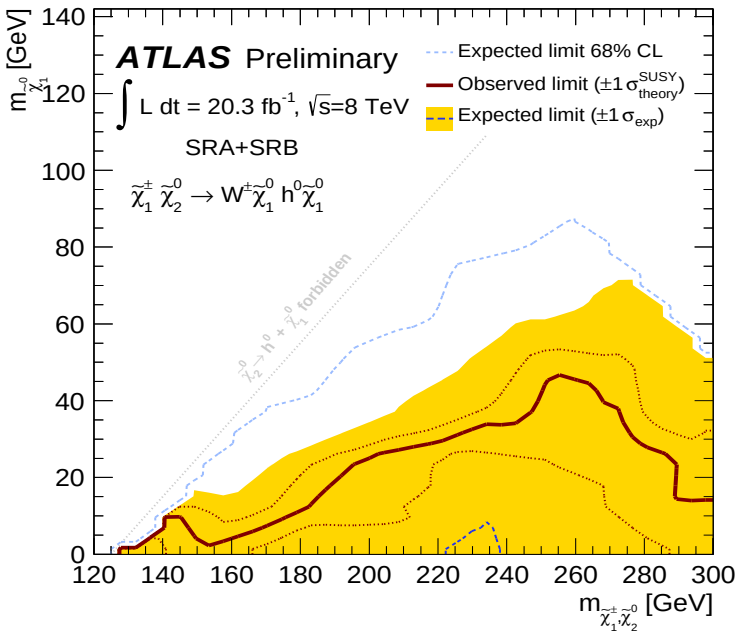
$$m_{cT} \approx \sqrt{2 p_T^{b1} p_T^{b2} (1 + \cos\phi_{bb})}$$

mass of pair produced particles with semi-invisible decay

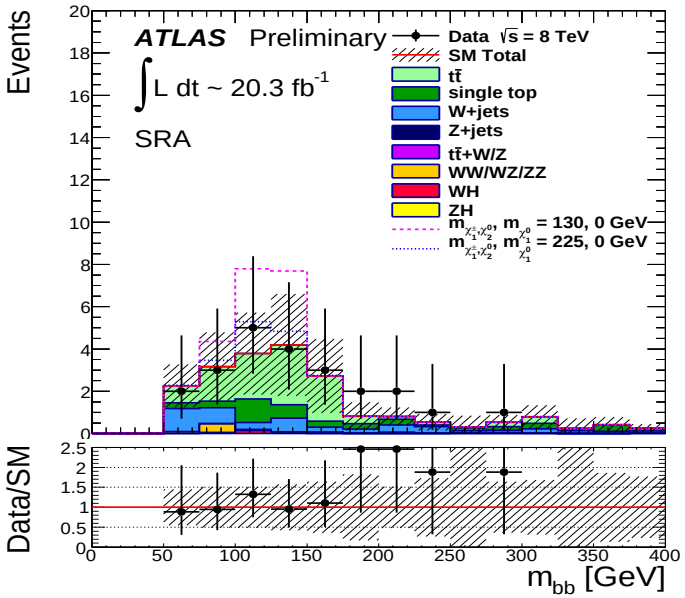
$\Rightarrow$ 95% CL limit on $\sigma_{obs}/\sigma_{theo}$ for $m_{\tilde{\chi}_1^{\pm}}$ *vs* $m_{\tilde{\chi}_1^0}$ (C1 *vs* N1):



SUSY on WH production



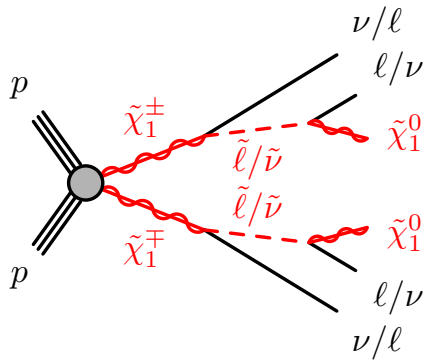
$m_{b\bar{b}}$ in SRa:



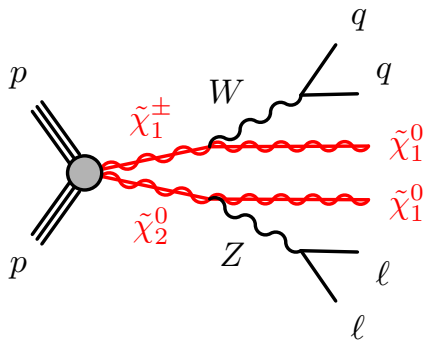
2 Leptons, $\not{E}_T$ (+*jets*) Analysis

JHEP 05 (2014) 071:

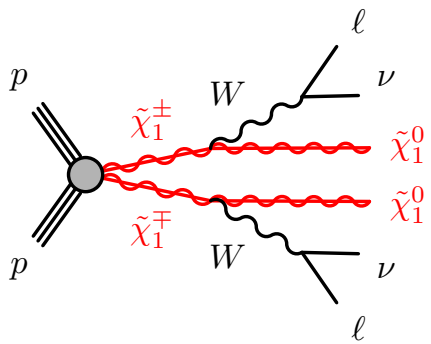
⇒ More complex analysis with **7 SRs** specifically optimized:



3 SRs: slepton mediated



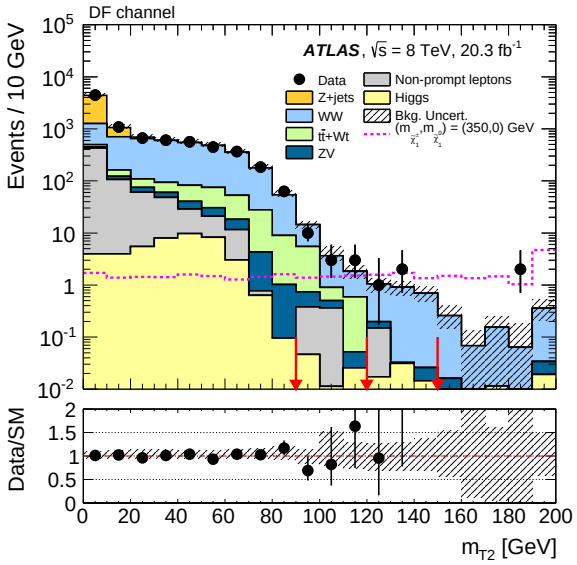
1 SRs: *WZ* mediated



3 SRs: *WW* mediated

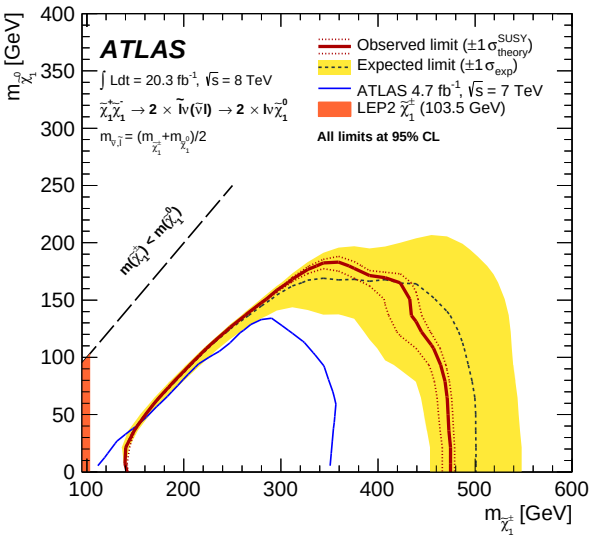
SRs optimization according to:

- Same-Flavor (SF), Different-Flavor (DF) leptons
- use of s-transverse mass:
  $m_{T2} = \min_{\mathbf{q_T}} \left[\max\left(m_T(\mathbf{p_T}^{\ell 1}, \mathbf{q_T}), m_T(\mathbf{p_T}^{\ell 2}, \not{E}_T - \mathbf{q_T})\right)\right]$
- m_{T2} end-point used to reduce main backgrounds ($t\bar{t}$, *WW*)

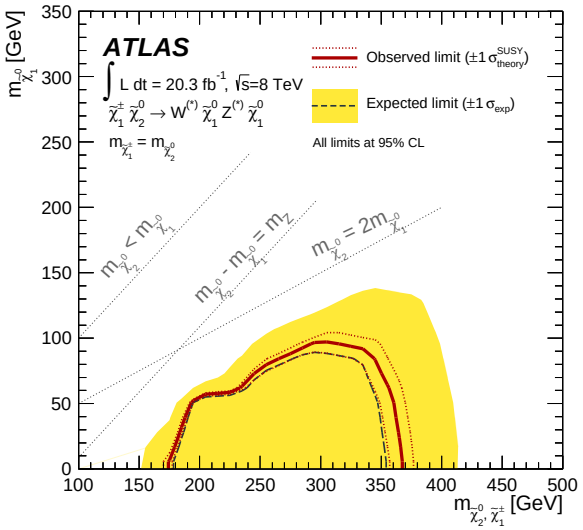


95% Exclusion Limits on Several Models

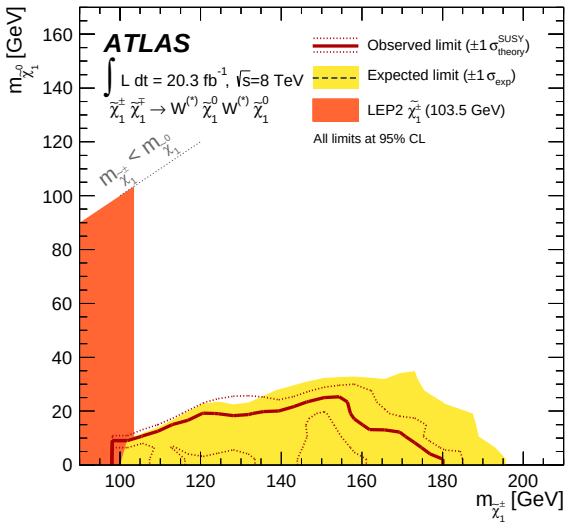
slepton mediated (C1C1)



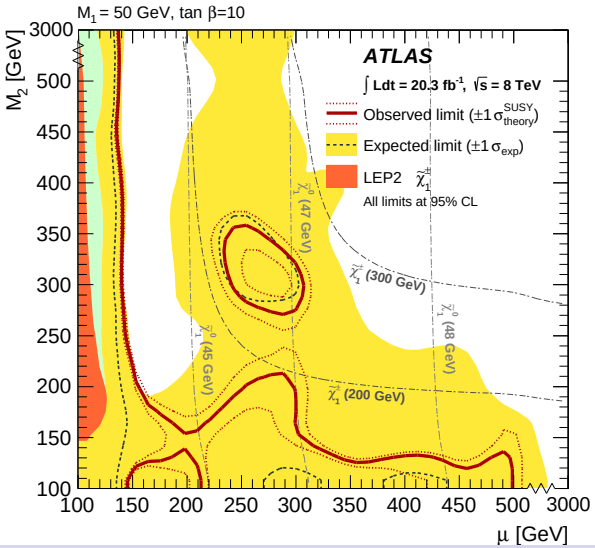
WZ mediated (C1N2)



WW mediated (C1C1)



pMSSM, large $m_{\tilde{\ell}}$, $\tan\beta = 10$



⇒ No excess with respect to SM predictions

- $\Delta m_{\tilde{\chi}_1^\pm} = 200$ GeV improved exclusion with respect to 7 TeV (blue line)
- *WZ* mediated models difficult for $m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^\pm} = m_Z$
- Results interpreted in pMSSM phase space exclusions

3 Leptons, $\not{E}_T$ $(0 - 2\ \tau^{had})$ Analysis

JHEP 04 (2014), 169:

- Combined use of SF/DF, Opposite Sign (OS), m_T cuts, high $\not{E}_T$, $\Delta\phi_{\ell\ell}$, etc ...

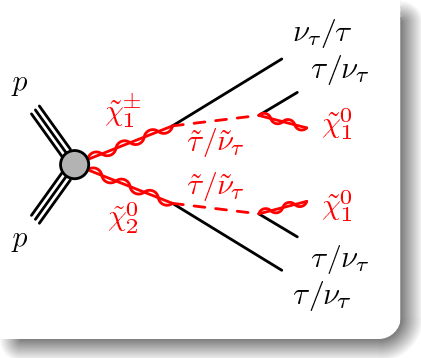
⇒ *SR characterized by 20 independent bins targeting $\tilde{\ell}$ and WZ mediated scenarios*

⇒ 1 specific SR optimized for *WH* mediated scenarios

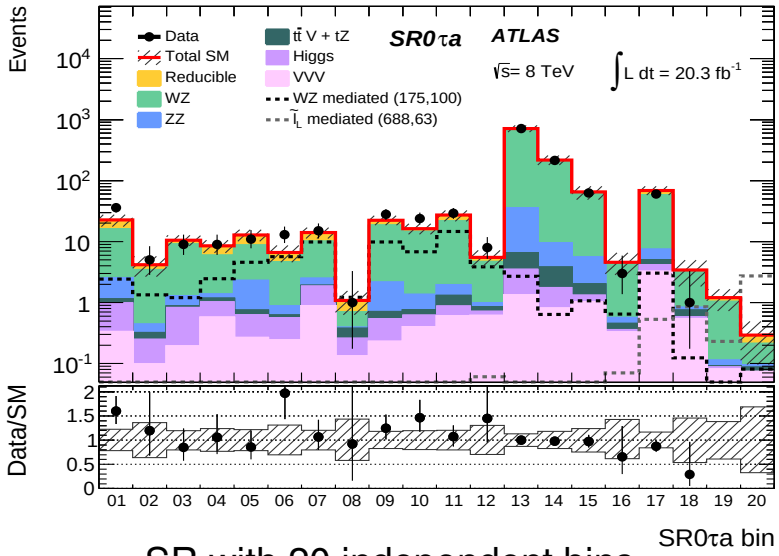
- 3 SRs with 1, or 2 τ^{had}:

⇒ improved sensitivity to $\tilde{\tau}$ mediated scenarios

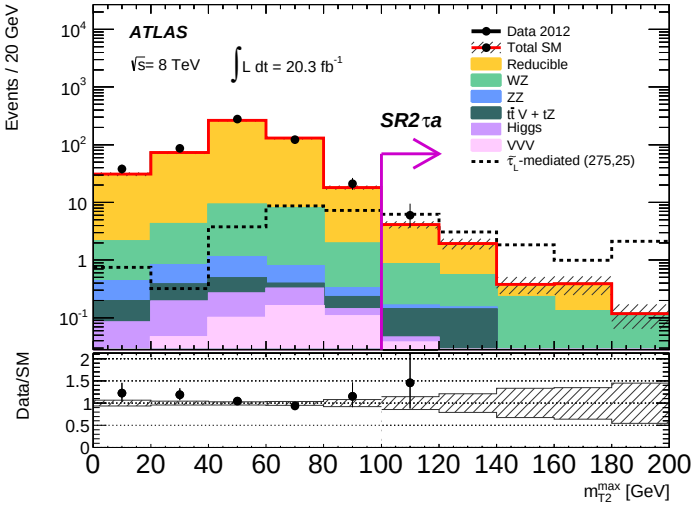
⇒ with relevant fraction of reducible backgrounds



- Relevant background components from rare SM processes such *VVV* and $t\bar{t}V$



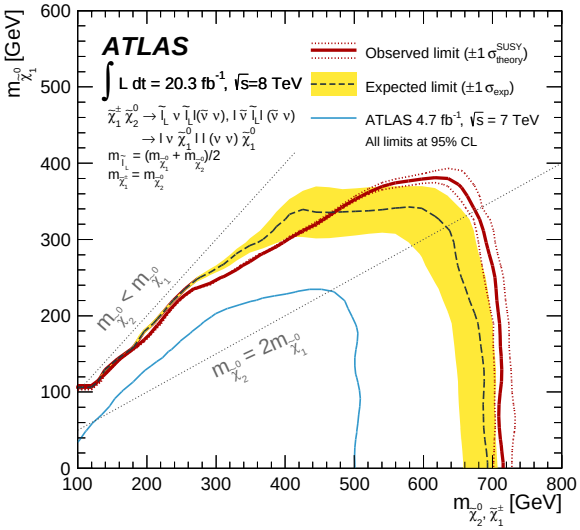
SR with 20 independent bins



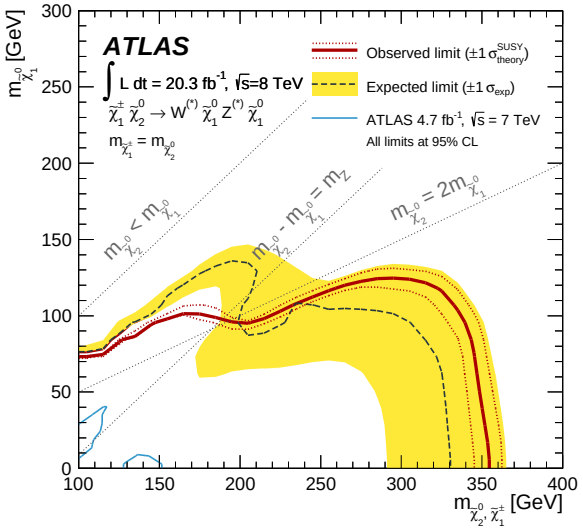
m_{T2} cut on 2 τ^{had} SR

Exclusion Results on Target models

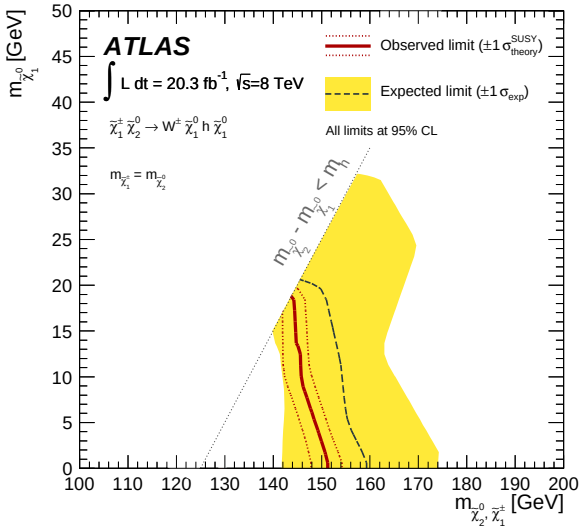
slepton mediated (C1N2)



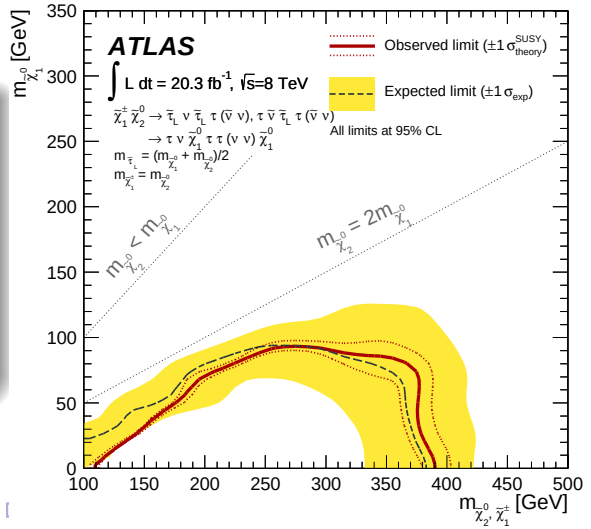
WZ mediated (C1N2)



WH mediated (C1N2)



$\tilde{\tau}$ mediated (C1N2)



⇒ No excess with respect to SM predictions

- Very powerful constraint from binned SR: large improvement in challenging *WZ* mediated region
- Models common to other analysis may be used for combined exclusions

Combination of $2\ell+\not{E}_T$ and $3\ell+\not{E}_T$ Analyses

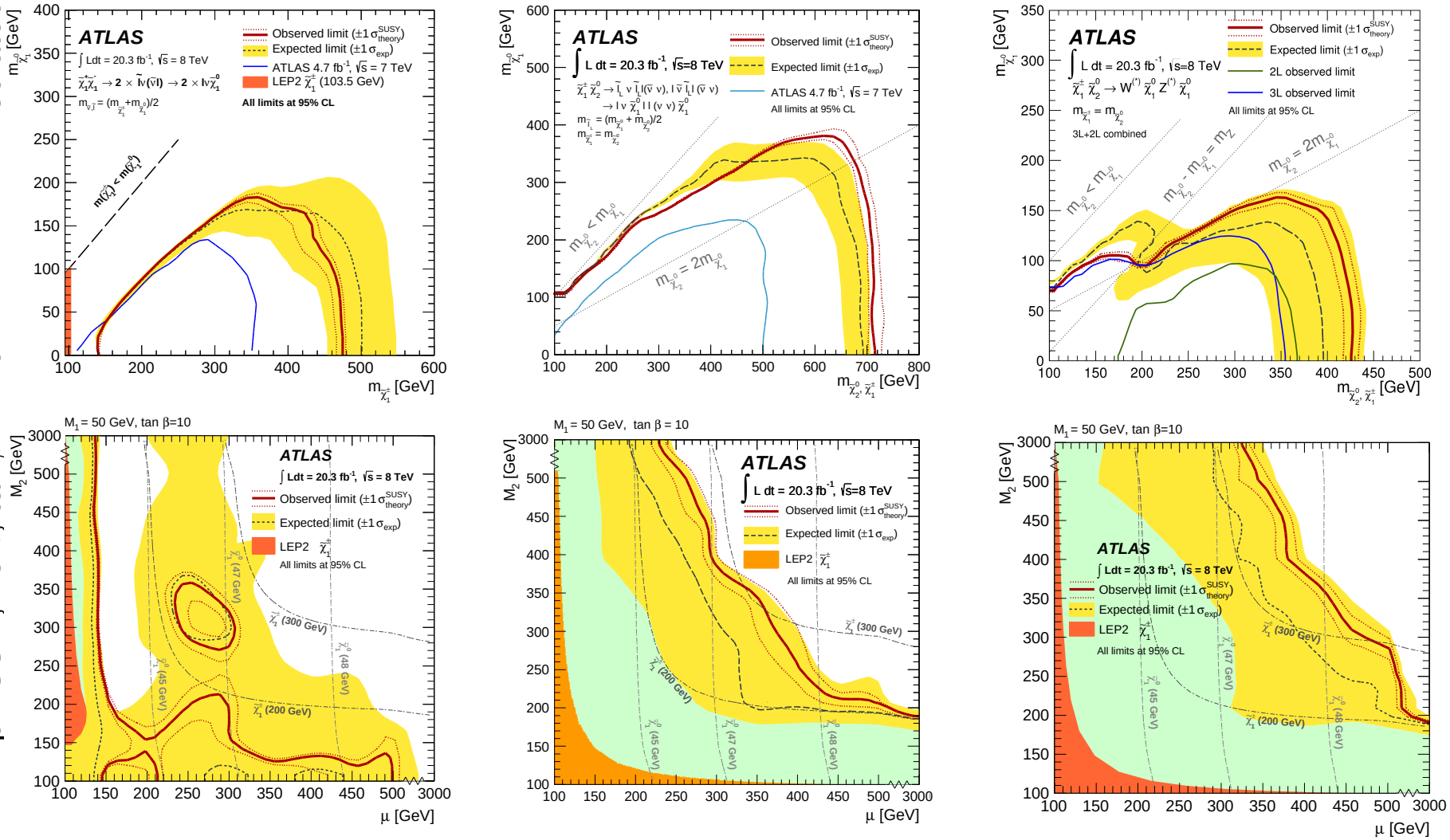
2 plus 3 lepton combination:

2 leptons results

3 leptons results

WZ Mediated

pMSSM, no $\tilde{\ell}$, $\tan\beta = 10$



$\Delta m \gtrsim 70$ GeV improved exclusion combining orthogonal SRs!

4 Leptons, $\not{E}_T$ $(0 - 2\ \tau^{had})$ Analysis - New!

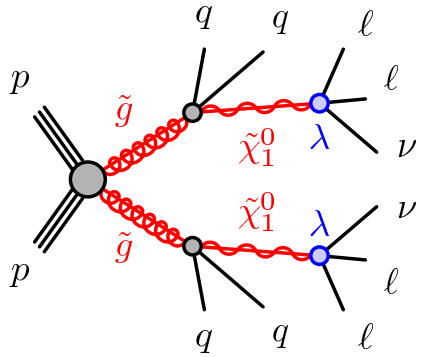
CERN-PH-EP-2014-074 $\Rightarrow$ *targets scenarios with both R-Parity Violation & Conservation*

- R-Parity Violating (RPV) SUSY potential:

  $$W_{\mathrm{RPV}} = \lambda_{ijk} L_i L_j \bar{E}_k$$

  with L_i, L_j, $\bar{E}_k$ supermultiplets with SM and SUSY fields
- RPV simplified models:
  - $\Rightarrow$ if $\lambda_{ijk} \neq 0$, LSP decay $\tilde{\chi}_1^0 \to 2\ell + 1\nu$
  - $\Rightarrow$ lepton-flavor signature depends on i, j, k
  - $\Rightarrow$ cross section depends by NLSP (4 topologies investigated)
- High multiplicity of objects from RPV cascade, *not only leptons*

Example of RPV cascade with gluino NLSP:



9 SR optimized for RPV or RPC signals:

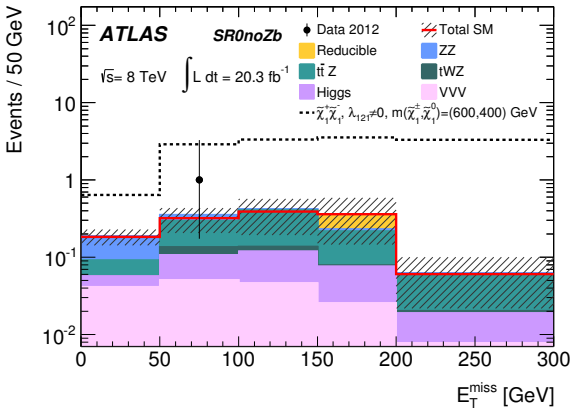
- SM reduction with SFOS veto, high m_{eff} $(= \sum_{\text{all obj.}} |\mathbf{p_T}|)$ and/or high $\not{E}_T$ (useful for RPC scenarios)
- 6 SRs with 1, 2 τ^{had} $\Rightarrow$ sensitive to all λ_{ijk}
- Boosted topology from light LSP $\Rightarrow$ lepton isolation corrected for close by tracks
- Rare SM processes (VVV and $t\bar{t}Z$) may be source of relevant background fractions

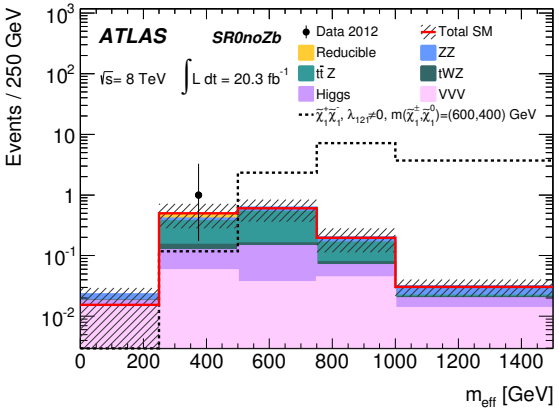
RPV Up-sides:
$\Rightarrow$ almost un-explored phase space
$\Rightarrow$ clean signature

RPV Down-sides:
$\Rightarrow$ need additional symmetry for p^+ stability
$\Rightarrow$ no Dark Matter candidate from LSP

Exclusion Results from 4 Leptons, $\not{E}_T$ $(0 - 2\ \tau^{had})$ Analysis

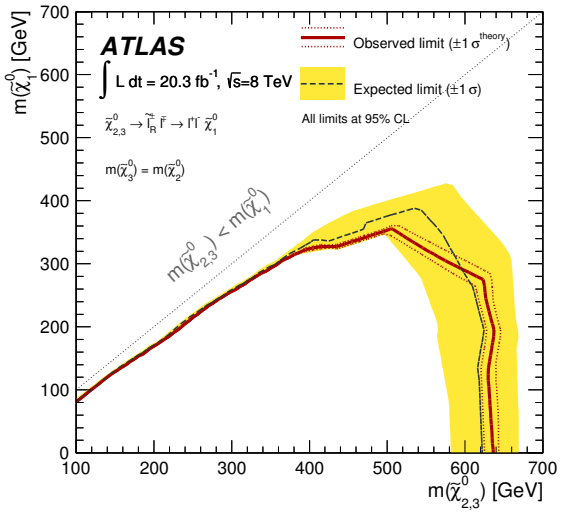
Examples of $\not{E}_T$ and m_{eff} distributions in signal regions with no τ^{had} and Z-veto:



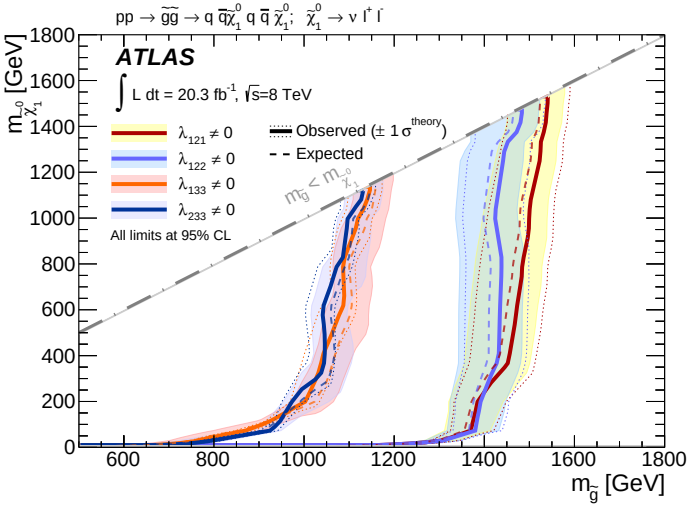


- No excess with respect to SM predictions
- RPC constraints in models with sleptons
- powerful constraints on all λ_{ijk} leptonic flavours

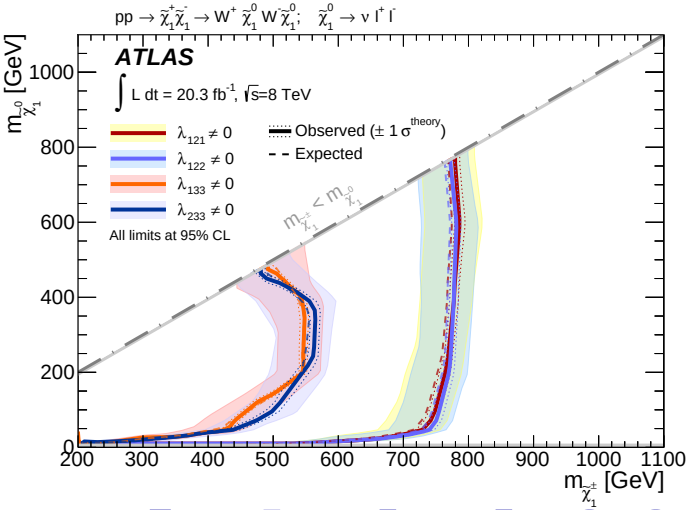
$\tilde{\ell}$ mediated RPC (N2N3)



λ_{ijk} exclusion, gluino NLSP



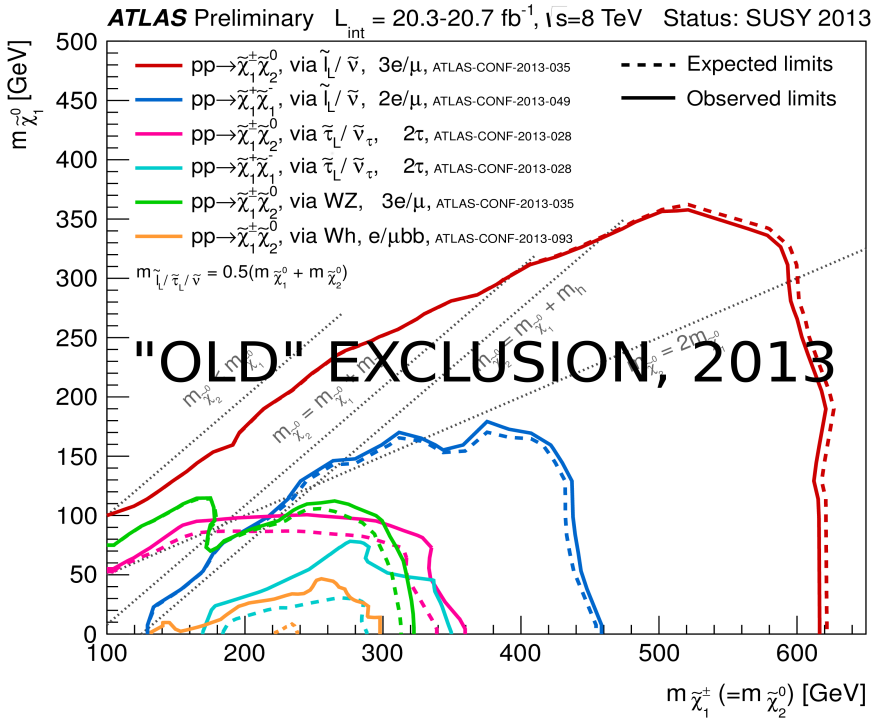
λ_{ijk} exclusion, Wino NLSP



Conclusions

The ATLAS collaboration presented several *recent* searches for EW SUSY scenarios characterized by leptons in the final state:

The global picture at the end of Run 1, 2013:

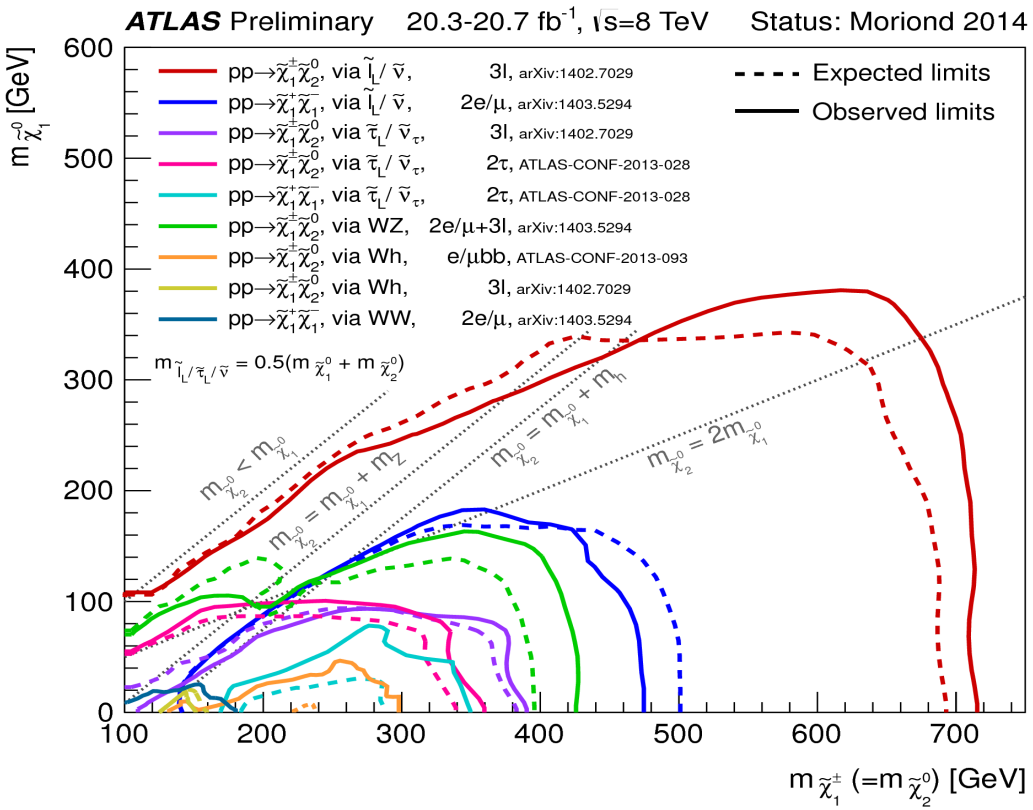


Summary of chargino (C1), neutralino (N1 or N2) exclusion

Conclusions

The ATLAS collaboration presented several *recent* searches for EW SUSY scenarios characterized by leptons in the final state:

The global picture now, 2014, same dataset but improved analysis



Summary of Chargino (C1), neutralino (N1 or N2) exclusion
(**4 lep. result not included yet**)

Prospects

$\Rightarrow$ No surprises yet with current dataset... *what to do next??*

$\Rightarrow$ Keep improving: more advanced analysis techniques, combination of different channels

Prospects

⇒ No surprises yet with current dataset... *what to do next??*

⇒ Keep improving: more advanced analysis techniques, combination of different channels

Prepare for discovery in Run 2!

THANKS FOR YOUR KIND ATTENTION!

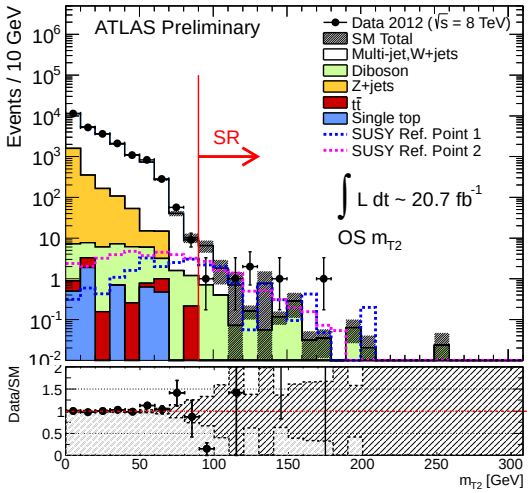
Back Up Slides

$2\,\tau^{had} + \not{E}_T$

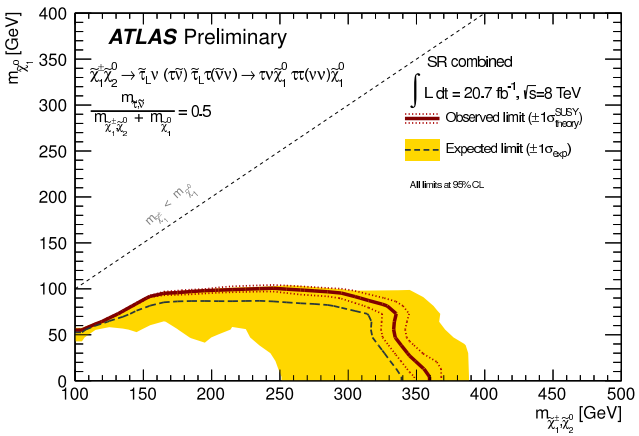
ATLAS-CONF-2013-028:

- combined use of di-tau trigger and $\not{E}_T$ trigger
- SR optimized with OS, $\not{E}_T$ and m_{T2}
- Fake-τ with ABCD method: τ_{ID} *vs* m_{T2}
- No excess over SM expectations

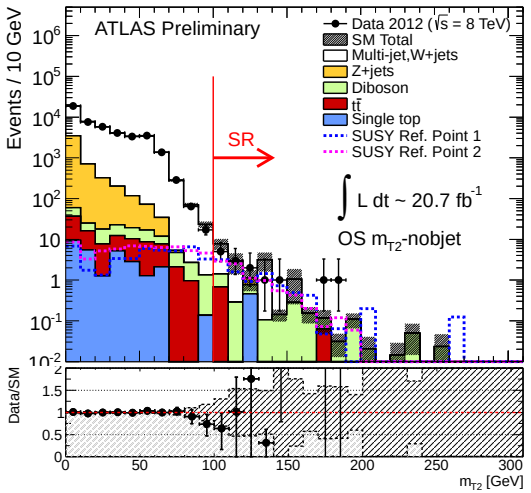
OS SR m_{T2}



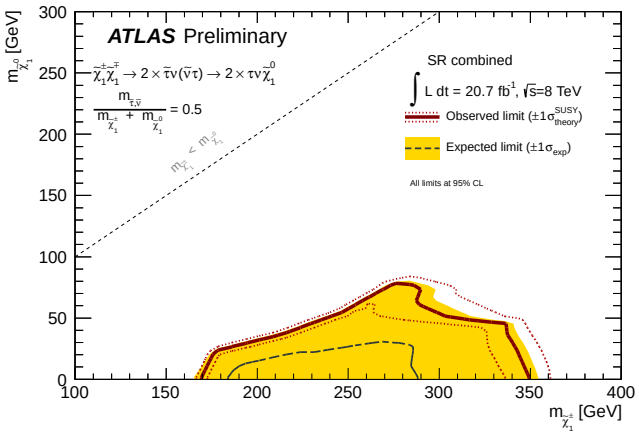
C1N2 via $\tilde{\tau}$ exclusion



OS SR m_{T2}, $b-$veto



C1C1 via $\tilde{\tau}$ exclusion



The Atlas Detector