

Searches for electroweak production of supersymmetric charginos, neutralinos and sleptons with the ATLAS detector

Ryo Nagai

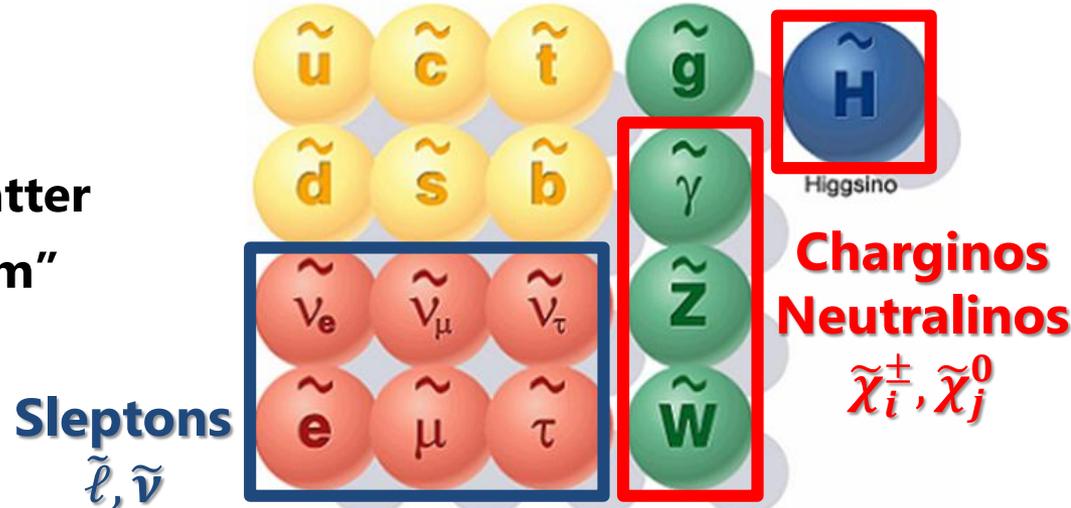
Tokyo Institute of Technology

on behalf of the ATLAS Collaboration

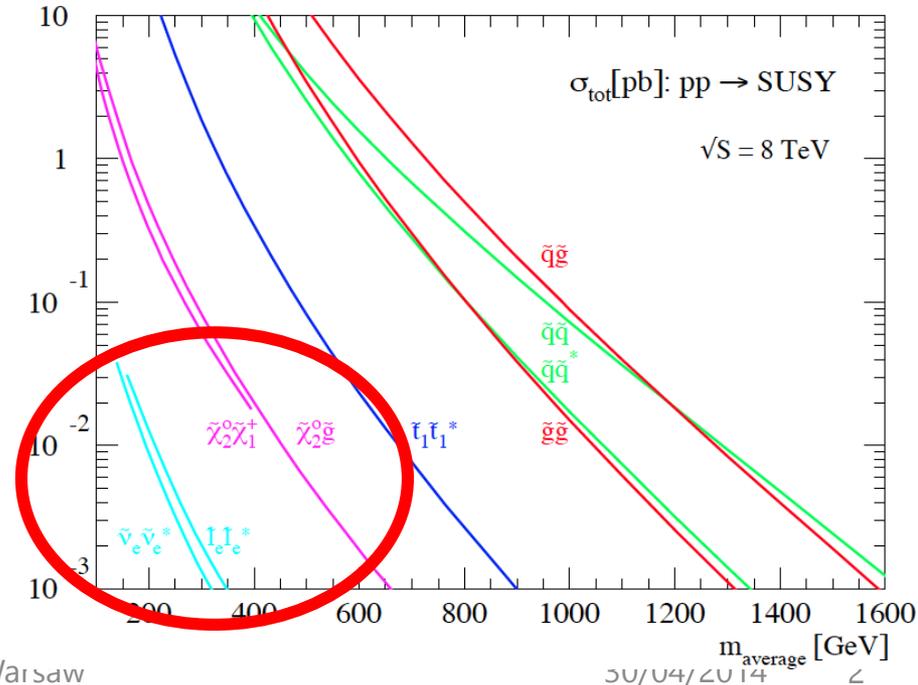
DIS2014, Univ. of Warsaw

Introduction

- ▶ Supersymmetry (SUSY)
 - **boson** \Leftrightarrow **fermion** symmetry
 - **good candidate** for **Dark Matter**
 - **can solve “hierarchy problem”**
 - Naturalness predicts light higgsinos and stops



- ▶ SUSY searches in ATLAS
 - Large Hadron Collider (LHC)
 - $\sqrt{s} = 8 \text{ TeV}, 20.3 \text{ fb}^{-1}$ (data in 2012)
 - If gluinos & squarks are *massive*
 - **Direct production of EW SUSY may be dominant process!**
 - Detectable up to SUSY mass of $m_{\text{SUSY}} \sim \mathcal{O}(100 \text{ GeV})$ in ATLAS



Analysis strategy

- ▶ Assuming R -parity conserving SUSY
 - lightest SUSY particle (LSP) is neutral and stable : usually neutralino $\tilde{\chi}_1^0$
→ **larger missing energy than Standard Model**

- ▶ Charginos, neutralinos and sleptons decay chain:

- $\tilde{\chi}_i^\pm \rightarrow W^\pm + \tilde{\chi}_j^0 \rightarrow \ell^\pm \nu + \tilde{\chi}_j^0$
- $\tilde{\chi}_i^\pm \rightarrow \ell^\pm + \tilde{\nu} \rightarrow \ell^\pm \nu + \tilde{\chi}_j^0$
- $\tilde{\chi}_i^0 \rightarrow Z/h + \tilde{\chi}_j^0 \rightarrow \ell^\pm \ell^\mp + \tilde{\chi}_j^0 (+X)$
- $\tilde{\chi}_i^0 \rightarrow \ell^\pm + \tilde{\ell}^\mp \rightarrow \ell^\pm \ell^\mp + \tilde{\chi}_j^0$
- $\tilde{\ell}^\pm \rightarrow \ell^\pm + \tilde{\chi}_j^0$
- $\tilde{\chi}_i^0 \rightarrow h + \tilde{\chi}_j^0 \rightarrow b\bar{b} + \tilde{\chi}_j^0$

There can be **many leptons**
& **less QCD contribution**
→ should be clean signature!

- ▶ We have **1L(+bb), 2L/2 τ , 3L(e, μ, τ), 4L*** signature based analyses

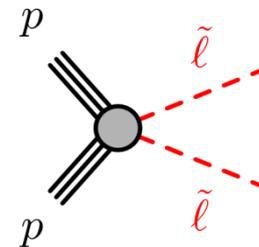
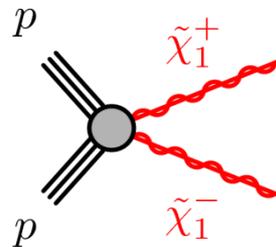
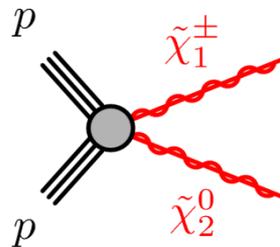
* Covered in Sofia's talk

➤ 2 LEPTONS + MET SEARCH

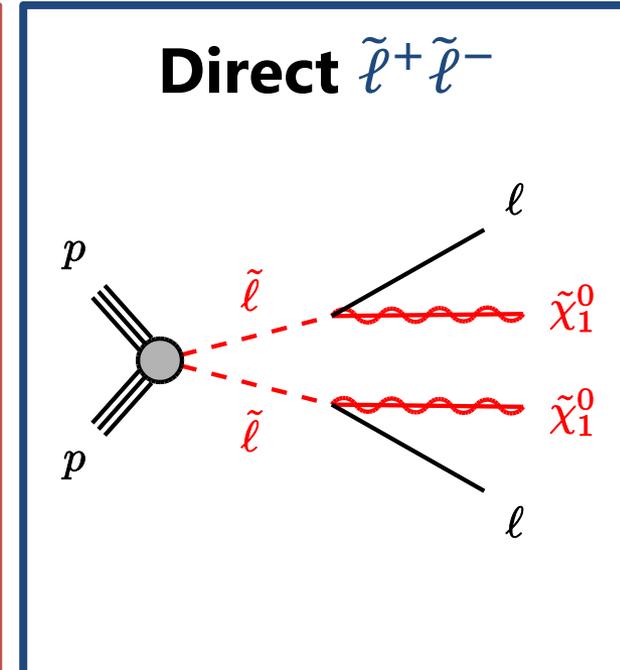
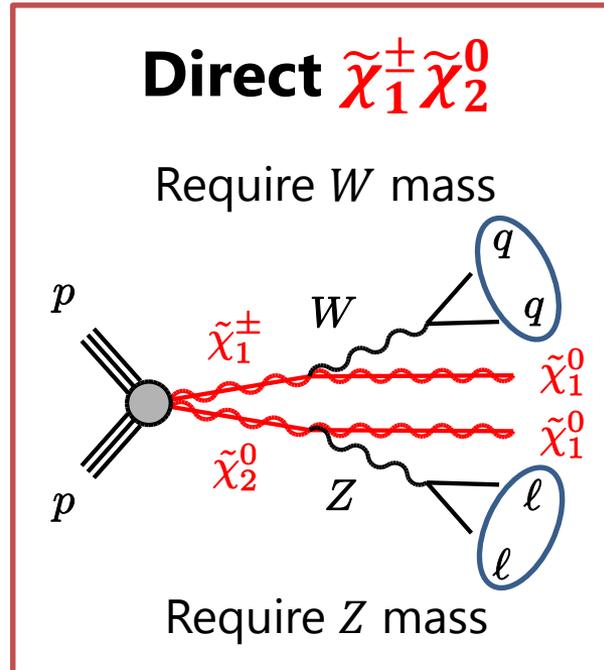
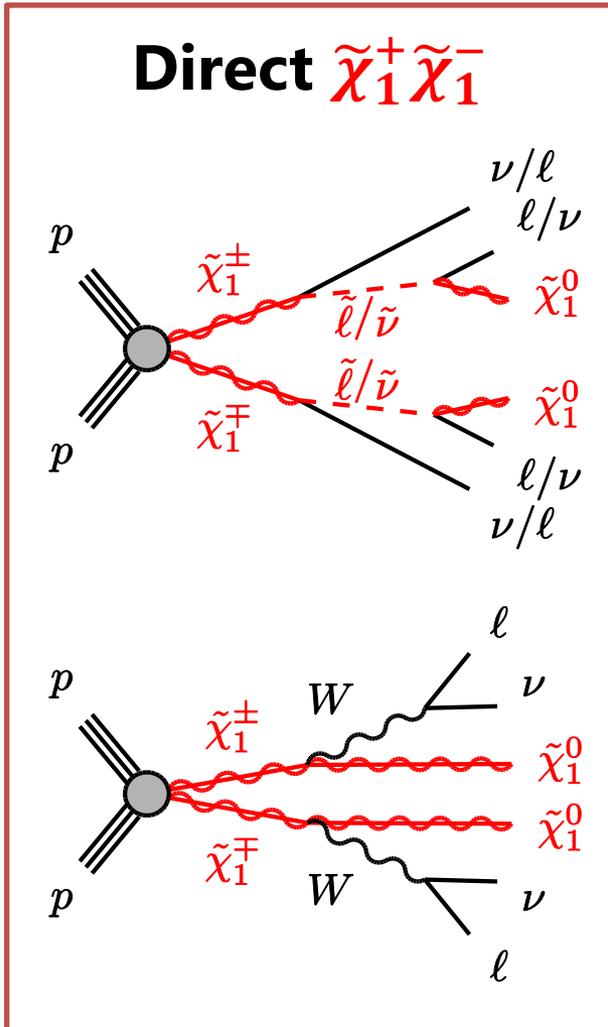
New!

References : arXiv:1403.5294 (2 leptons (e, μ) + MET)

ATLAS-CONF-2013-028 (2 taus + MET)



- Can consider many modes for 2-lepton search



- **Separated signal regions** for no taus
 - Choose SR with the best exclusion
- **2 taus (no e, μ) + MET search**
 - good sensitivity for scenarios including **staus**

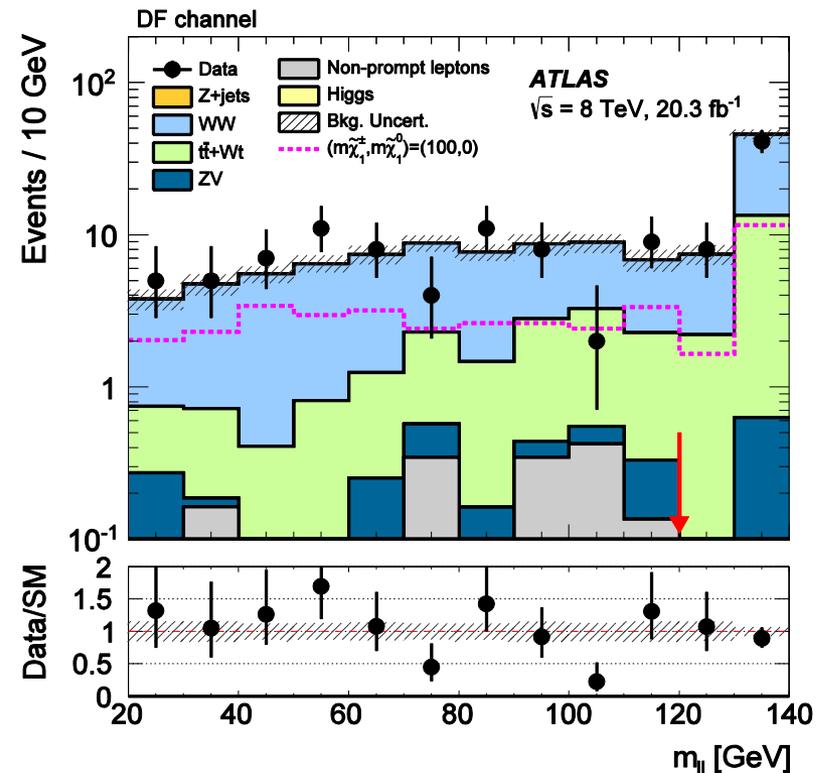
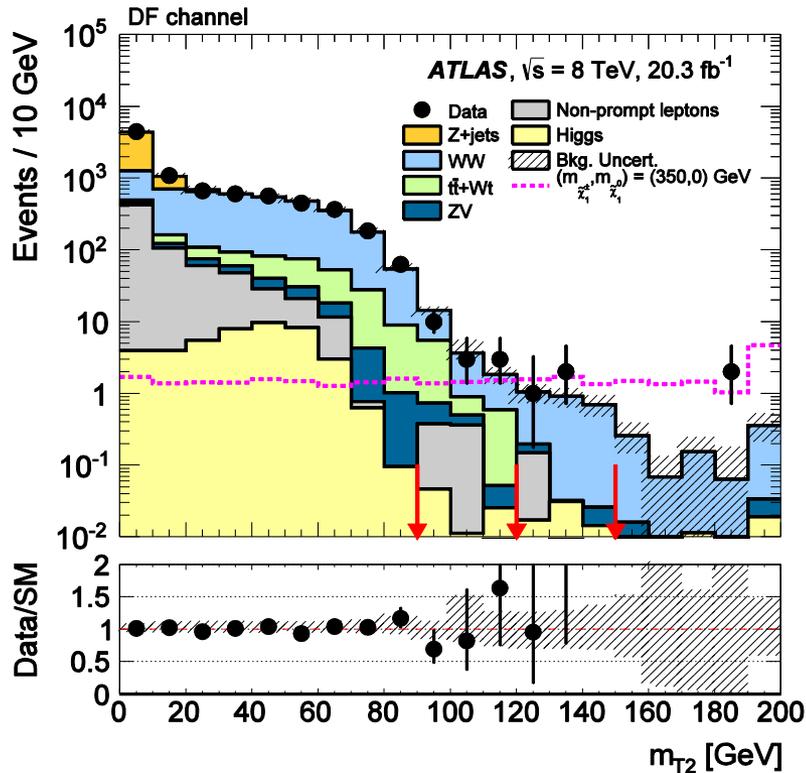
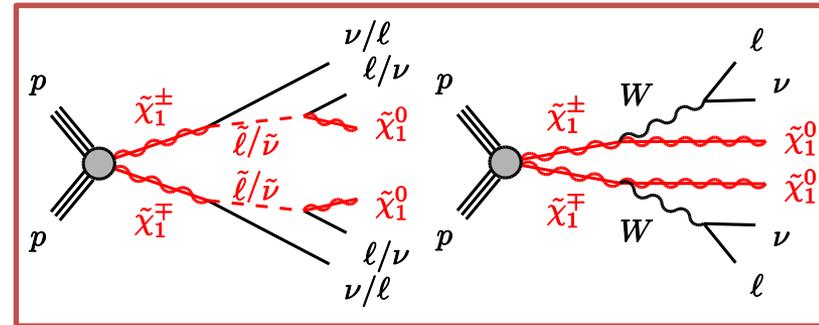
2 leptons (e, μ) + MET

New!

arXiv:1403.5294

- ▶ Divided by flavours
- ▶ Opposite-sign lepton pair
- ▶ kinds of $E_T^{\text{miss,rel}}$, m_{T2} , $m_{\ell\ell}$ cut

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



No significant excess was observed

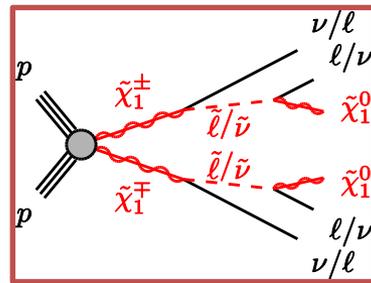
2 leptons (e, μ) + MET New!

arXiv:1403.5294

► SR with *the best expected exclusion limit* is chosen

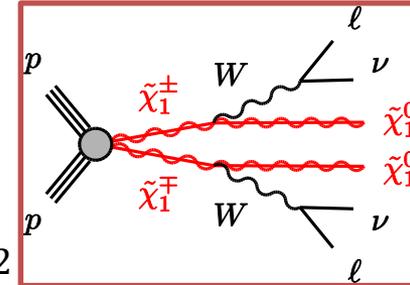
$\tilde{\ell}/\tilde{\nu}$ -mediated

→ SR divided by m_{T2} is used

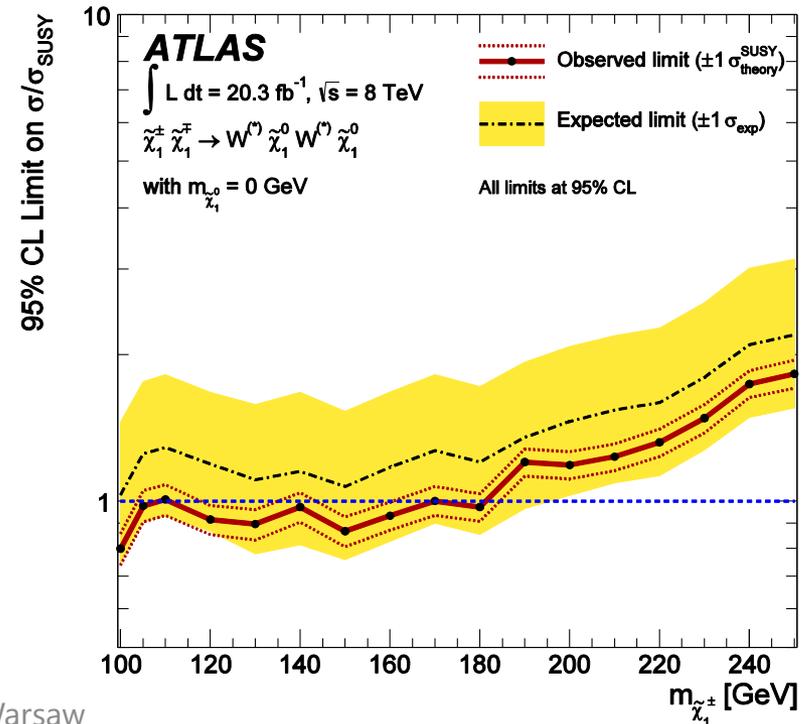
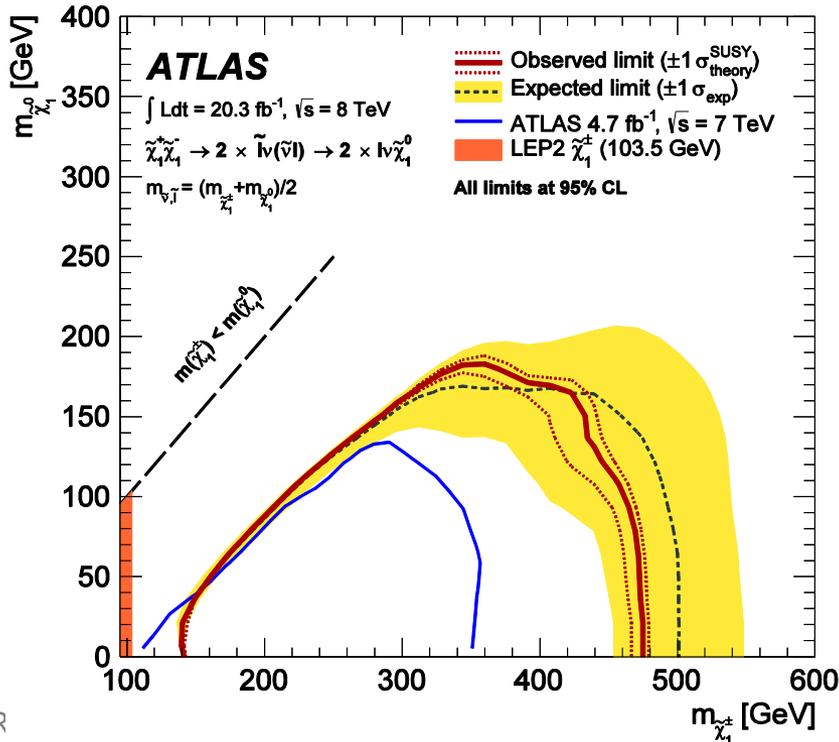


WW-mediated

→ SR divided by m_{T2} & $E_T^{\text{miss,rel}}$ is used



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

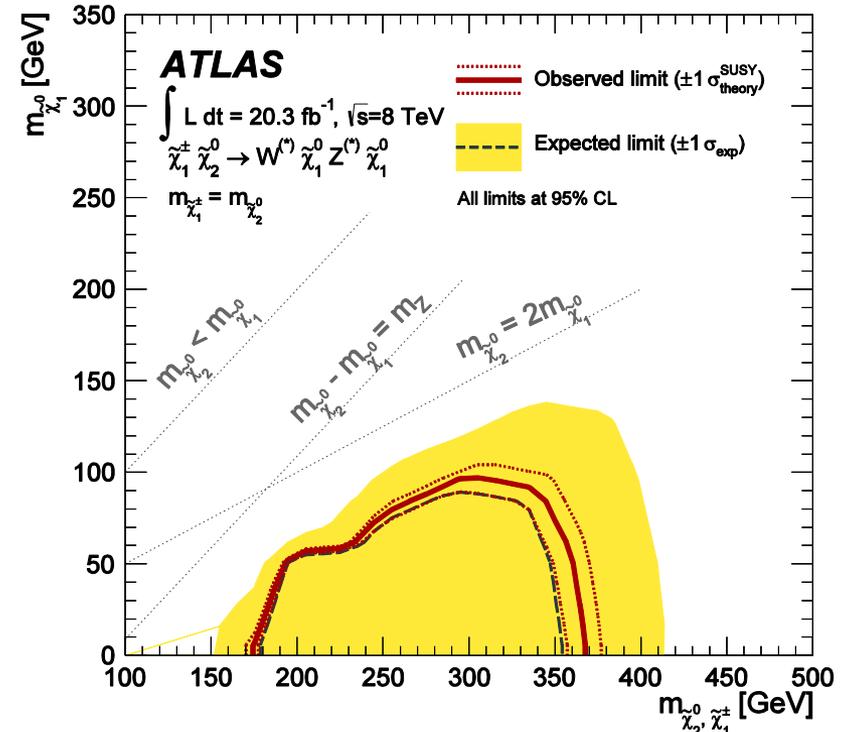
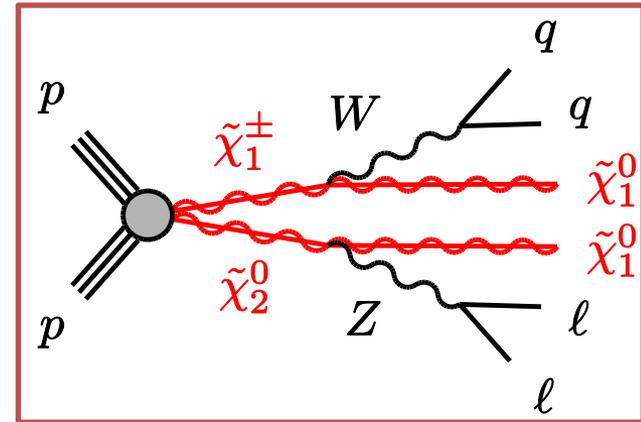
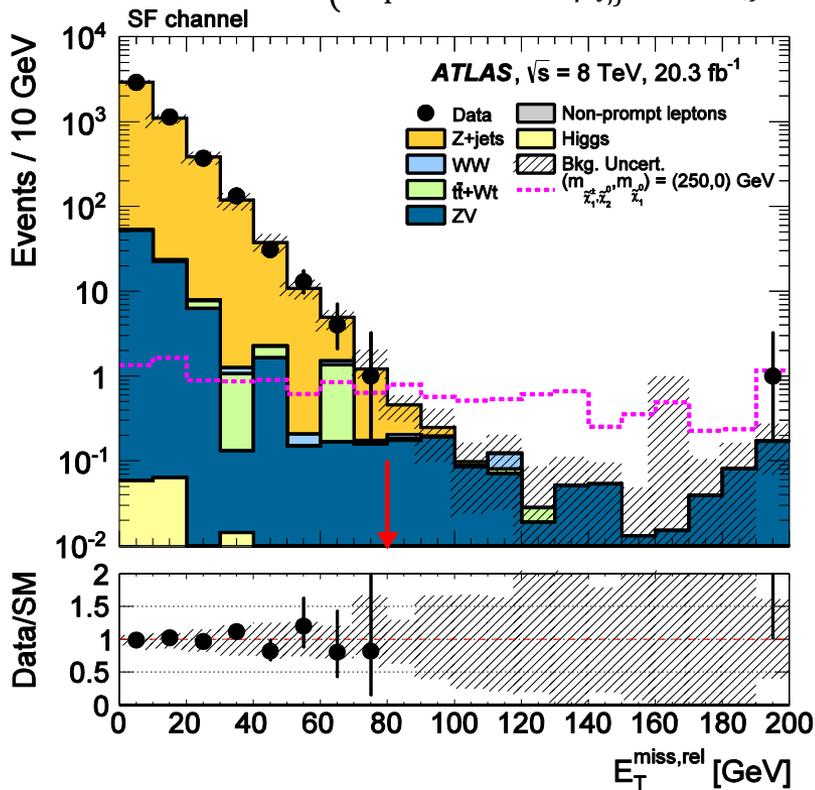


2 leptons (e, μ) + MET New!

arXiv:1403.5294

- ▶ **Z-selection** (m_{SFOS} within Z mass window)
- ▶ **W-selection** (m_{jj} within W mass window)
- can separate QCD Z+jets background

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



No significant excess was observed

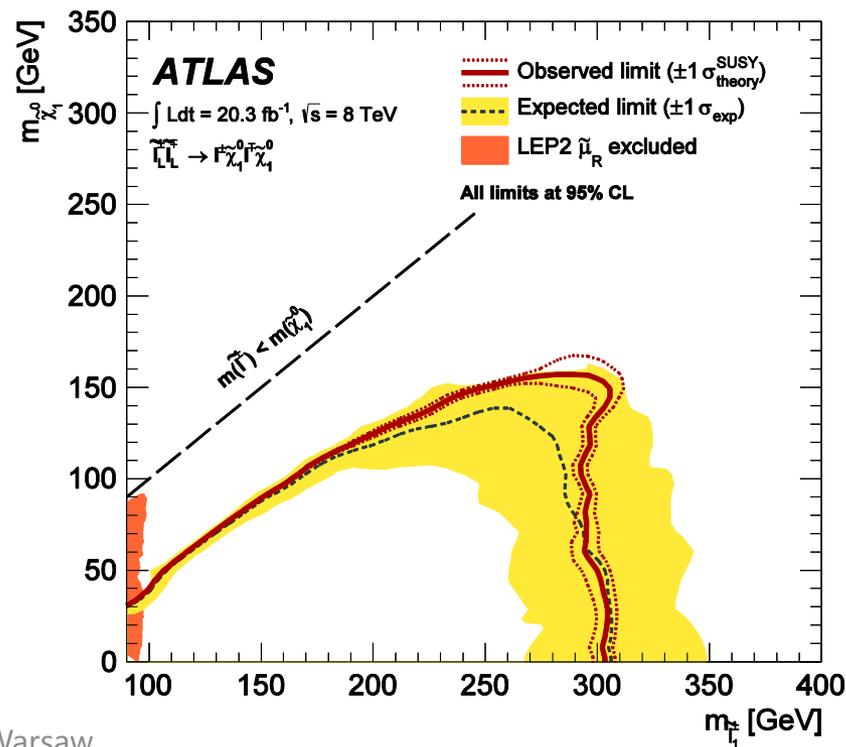
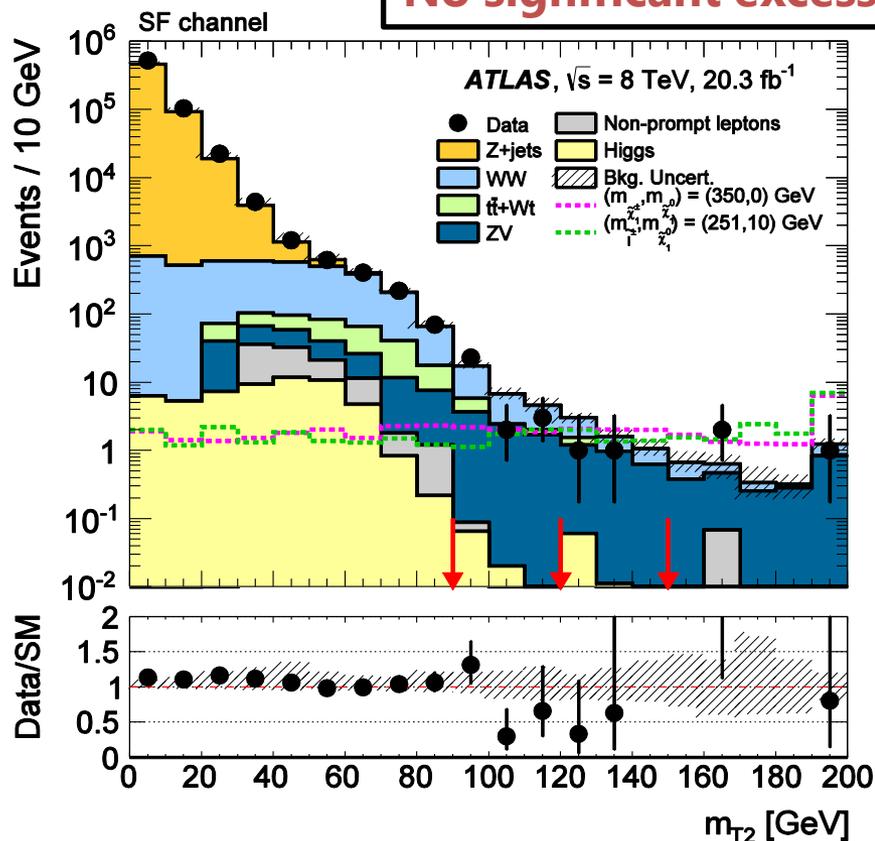
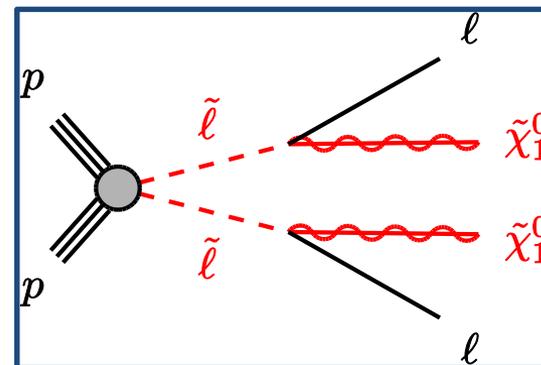
2 leptons (e, μ) + MET New!

arXiv:1403.5294

► Direct sleptons pair production

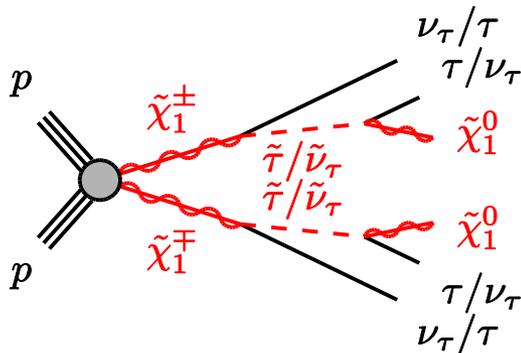
- Opposite-sign SR divided by m_{T2} is used
- SR with *the best expected exclusion limit* is chosen

No significant excess was observed



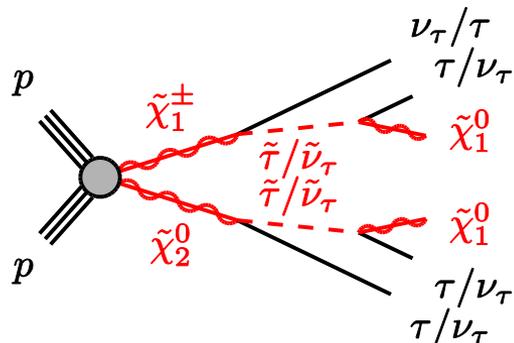
► Considered scenarios :

$\tilde{\chi}_1^+ \tilde{\chi}_1^-$ via $\tilde{\tau}/\tilde{\nu}_\tau$ -mediated



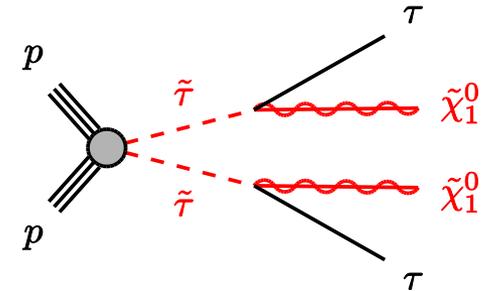
- ≥ 1 tau pair : opposite-sign
- Events containing e/μ vetoed

$\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via $\tilde{\tau}$ -mediated



- For $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production, there are $3\tau_h$ but assume 1 τ is missing

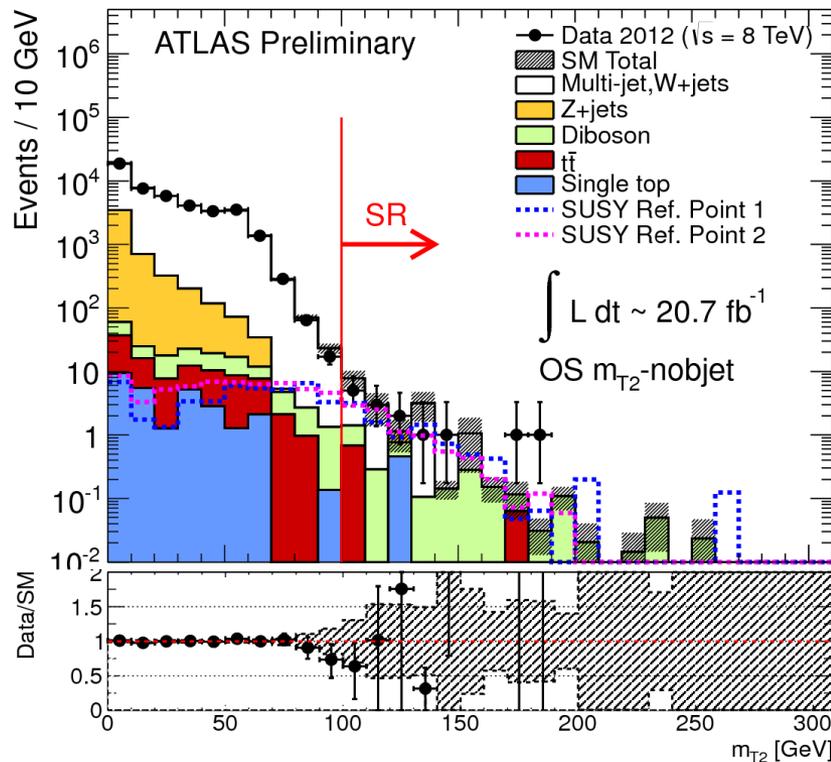
Direct $\tilde{\tau}\tilde{\tau}$ production



- Low cross-section and low sensitivity for this scenario
- Best point : mass of stau & $\tilde{\chi}_1^0 \rightarrow 140, 10$ GeV
- Excluded cross-section ~ 0.17 pb

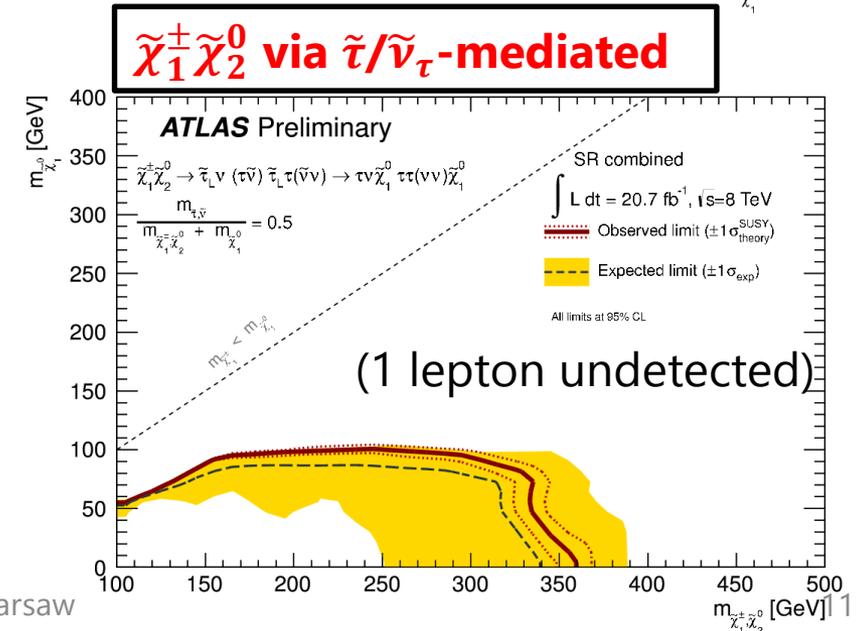
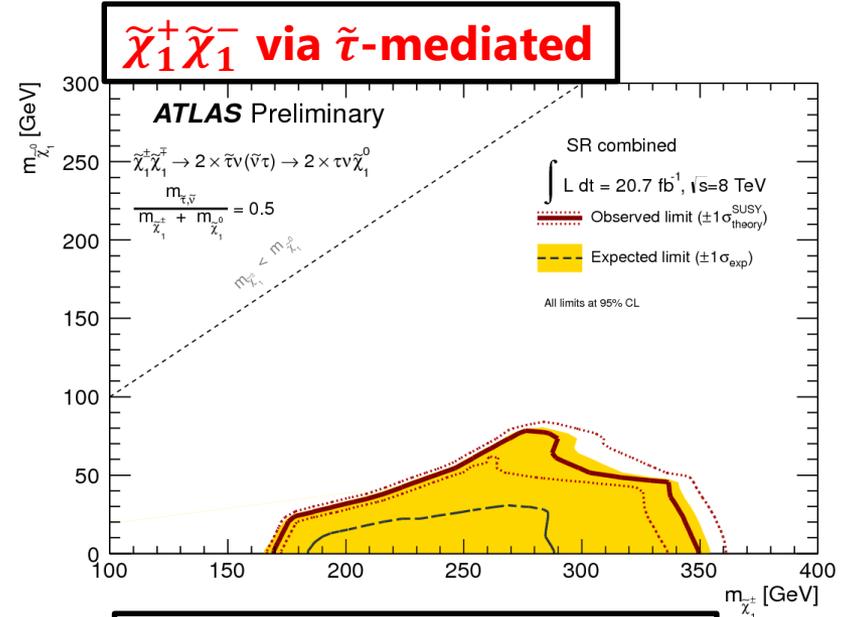
2 leptons (τ) + MET

- ▶ **2 hadronic tau selection**
→ other lepton vetoed
- ▶ **Large contribution of mis-ID taus**
→ estimated with "ABCD method"



No significant excess was observed

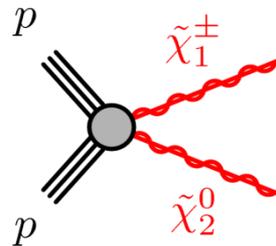
- SUSY Ref. Point 1 : $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production, $m(\tilde{\chi}_1^\pm) = 250, m(\tilde{\chi}_1^0) = 100 \text{ GeV}$
- R SUSY Ref. Point 2 : $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production, $m(\tilde{\chi}_1^\pm) = 250, m(\tilde{\chi}_1^0) = 50 \text{ GeV}$



New!

➤ 3 LEPTONS + MET SEARCH

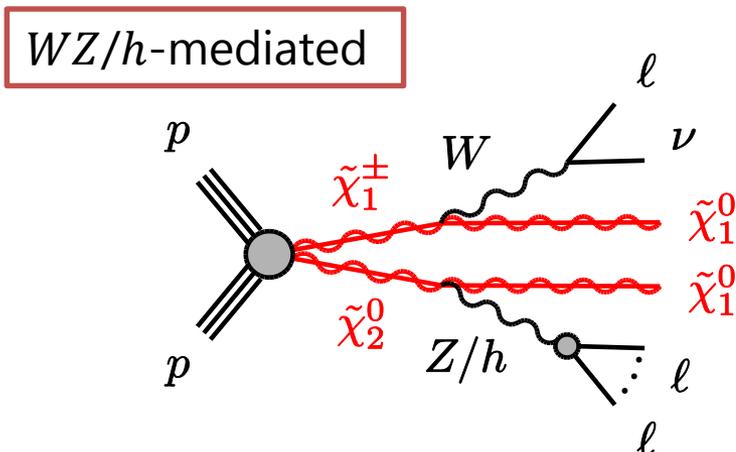
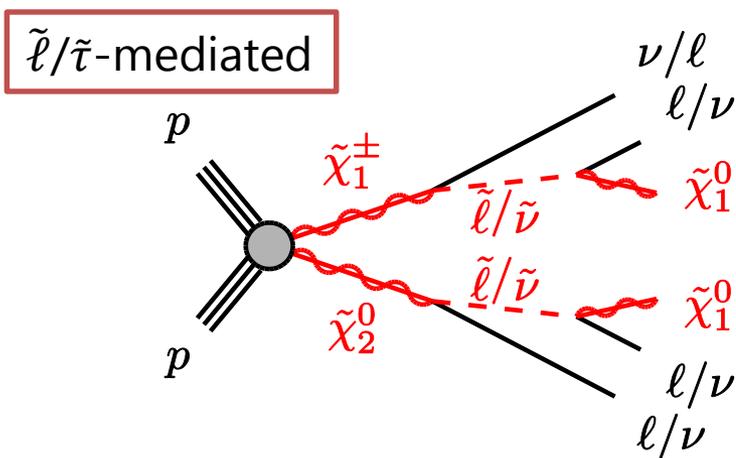
Reference : arXiv:1402.7029



3 leptons (e, μ, τ) + MET New!

arXiv:1402.7029

- ▶ Target : $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production \rightarrow large cross-sections



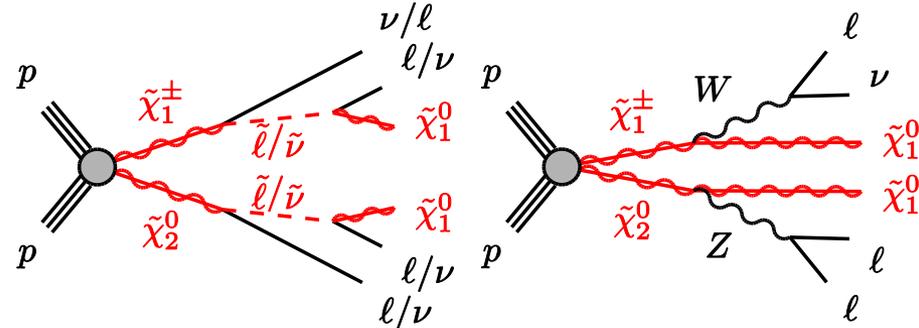
- ▶ If sleptons ($\tilde{e}, \tilde{\mu}$) are light, $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ decay via sleptons
- ▶ NEW! Decay via *staus only*
 $\rightarrow \geq 1 \tau_h + \text{leptons}$
- ▶ If all sleptons are heavy,
 - $\tilde{\chi}_1^\pm$ decays via W boson
 - $\tilde{\chi}_2^0$ decays via Z/h boson
- ▶ NEW! Decay via higgs ($\rightarrow \tau\tau$)
 $\rightarrow \geq 1 \tau_h + \text{leptons}$

3 leptons (e, μ, τ) + MET

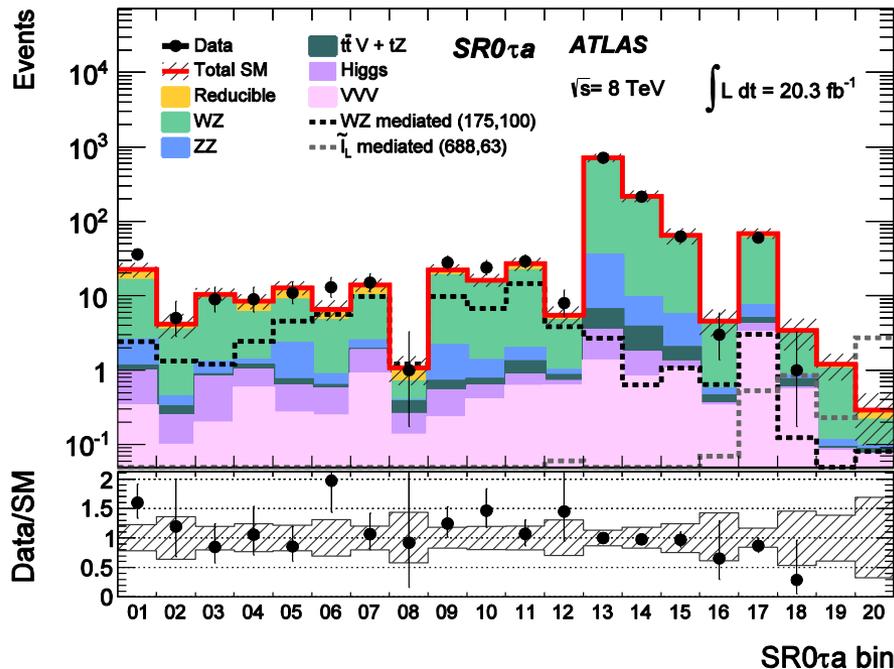
New!

arXiv:1402.7029

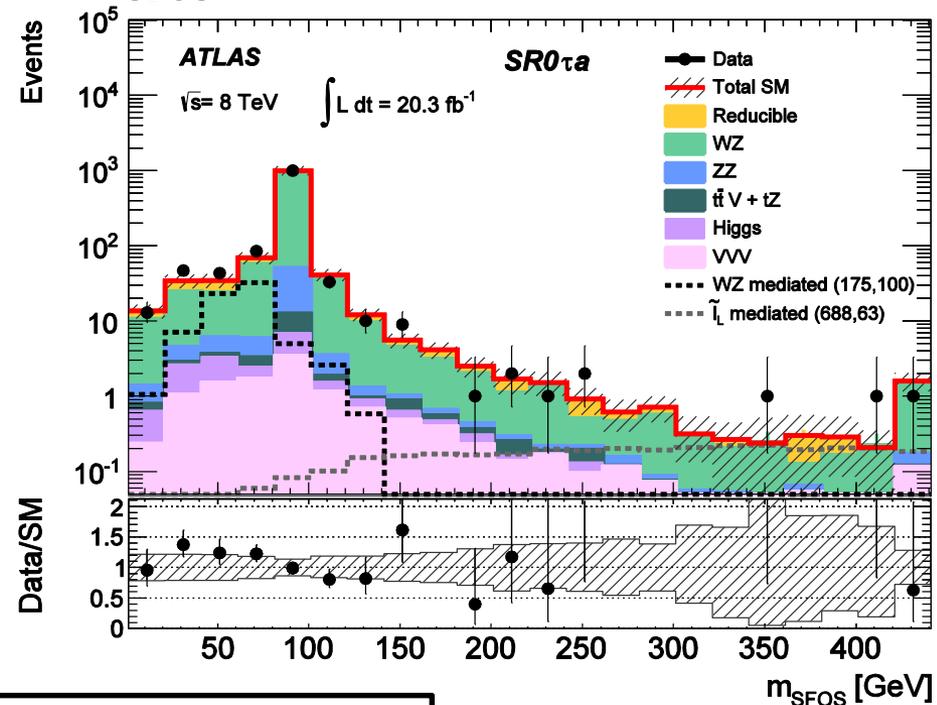
- ▶ Target scenarios :
 - $\tilde{\ell}$ -mediated & WZ -mediated
- ▶ No taus region
 - 20 bins in E_T^{miss} , m_T and m_{SFOS}



Binned signal region yield



m_{SFOS} distribution, combined 20 bins



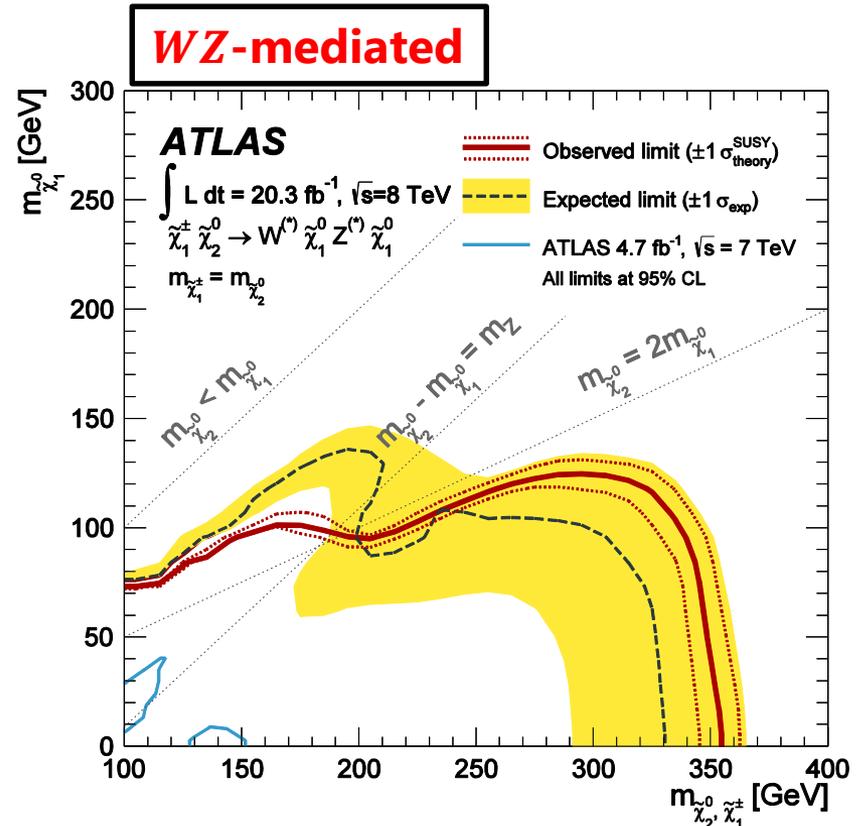
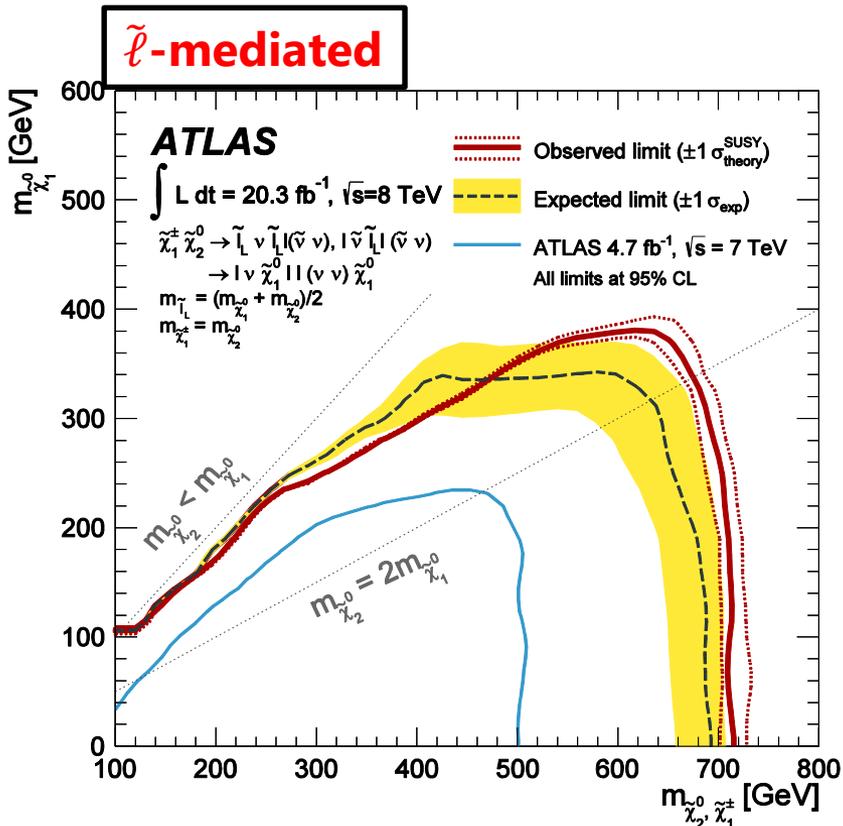
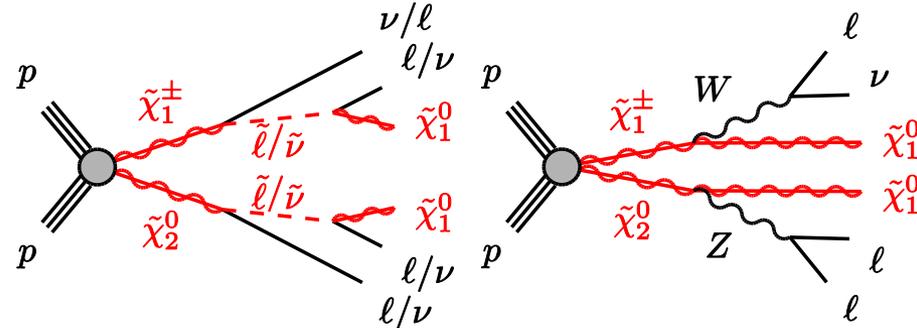
No significant excess was observed

3 leptons (e, μ, τ) + MET

New!

arXiv:1402.7029

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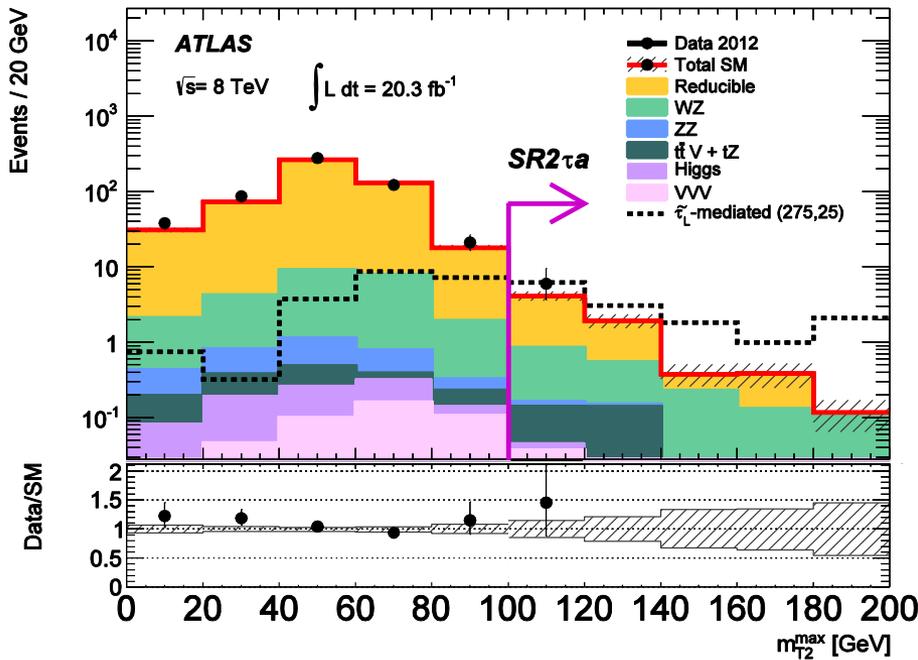
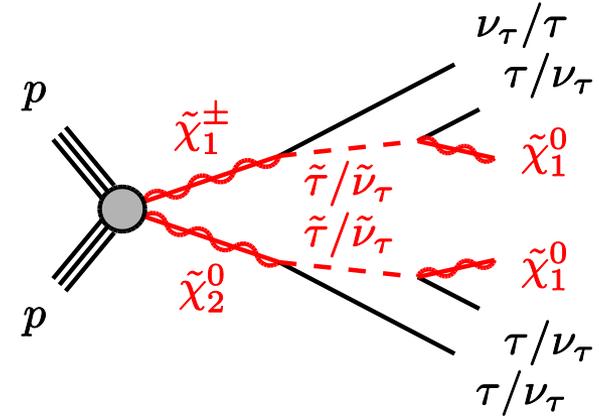


3 leptons (e, μ, τ) + MET

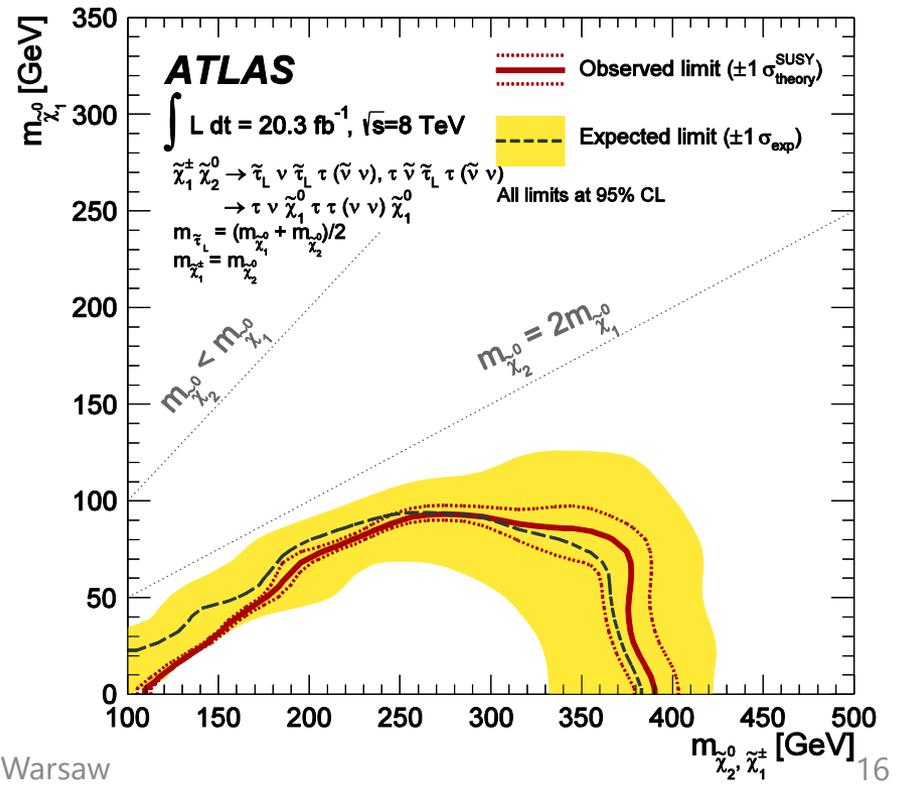
New!

arXiv:1402.7029

- ▶ Target : **via stau-mediated** scenario
 - Require $\geq 1 \tau_h$,
at least 1 lepton for trigger
- ▶ **Large** contribution of **mis-ID taus**
 - estimated **from data**



No significant excess was observed

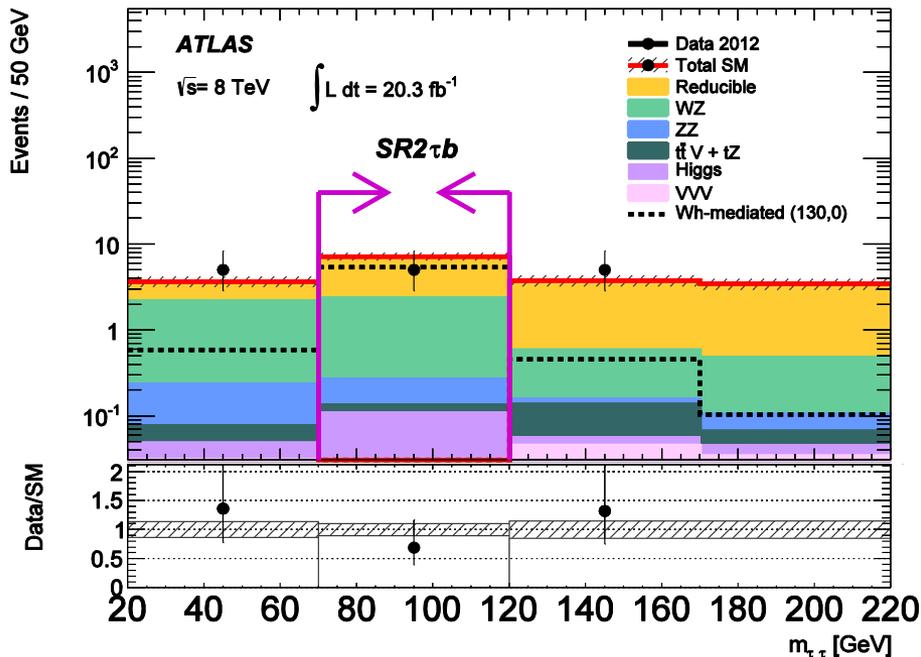
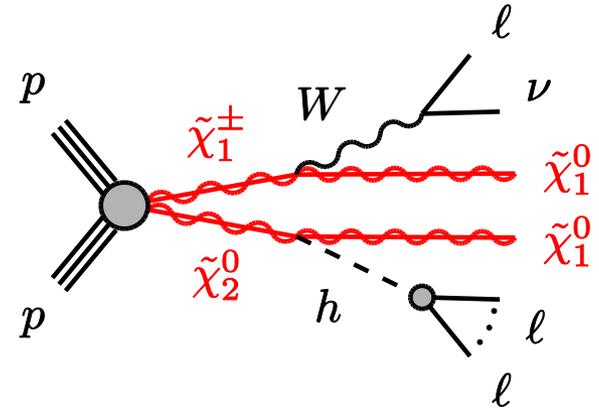


3 leptons (e, μ, τ) + MET

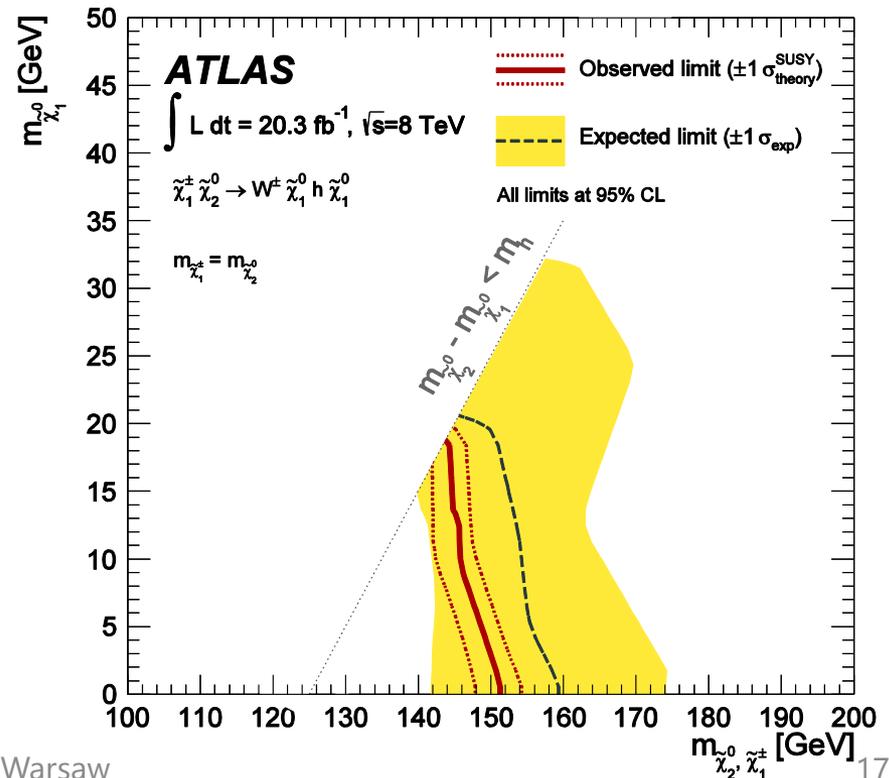
New!

arXiv:1402.7029

- ▶ Target : **via Wh -mediated** scenario
- A) Require $\geq 1 \tau_h$ (target : $h \rightarrow \tau\tau$)
 → higgs mass (~ 125 GeV)
- B) Require $\Delta\phi_{\ell\ell}^{\min} < 1$ rad (target : $h \rightarrow WW$)
- ▶ **Large** contribution of **mis-ID taus**
 → estimated **from data**



No significant excess was observed

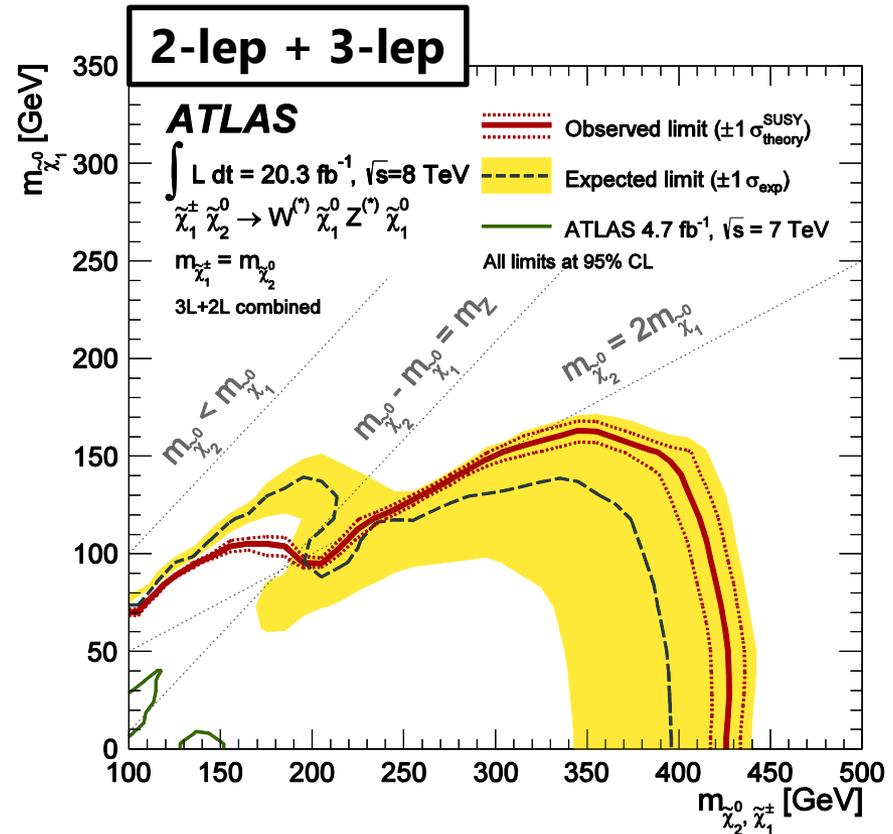
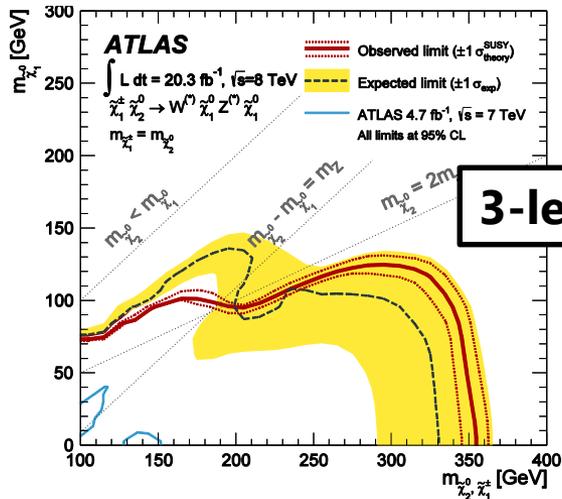
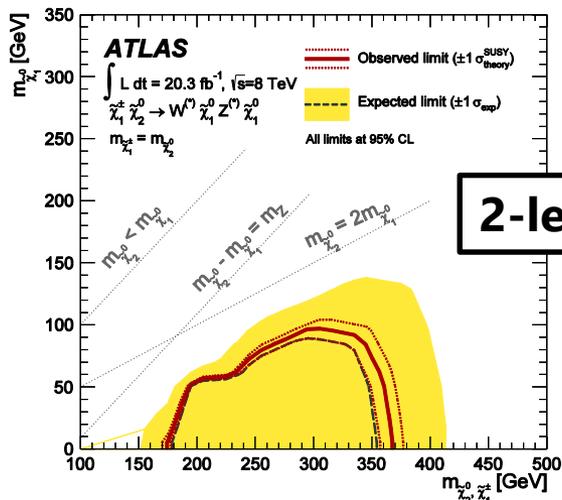


Combination of 2-lep & 3-lep

New!

arXiv:1403.5294

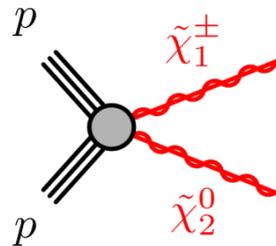
► $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ decay via **WZ-mediated** scenario



Degenerate $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ mass < 415 GeV are excluded at 95% CL

➤ 1 LEPTON + 2 B-JETS + MET SEARCH

Reference : ATLAS-CONF-2013-093

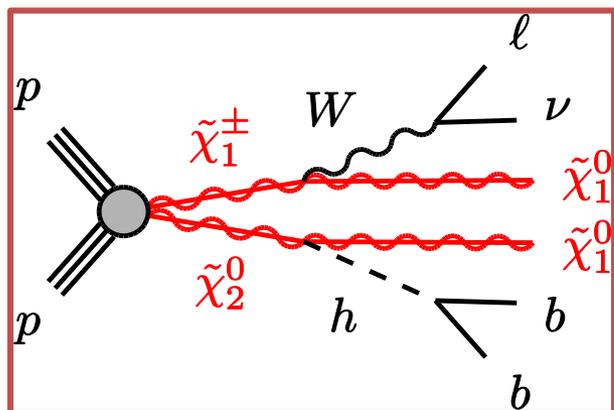
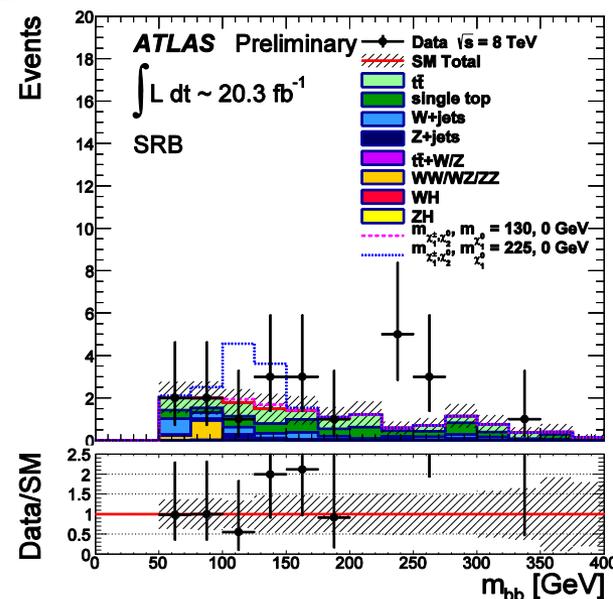
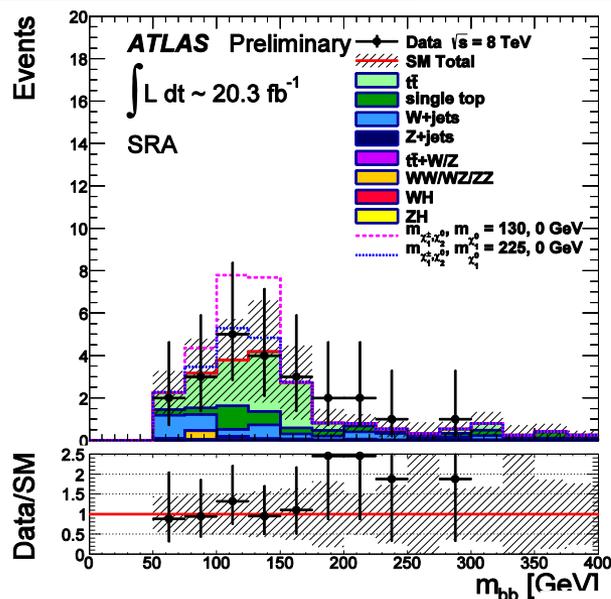


1 lepton (e, μ) + 2 b -jets + MET

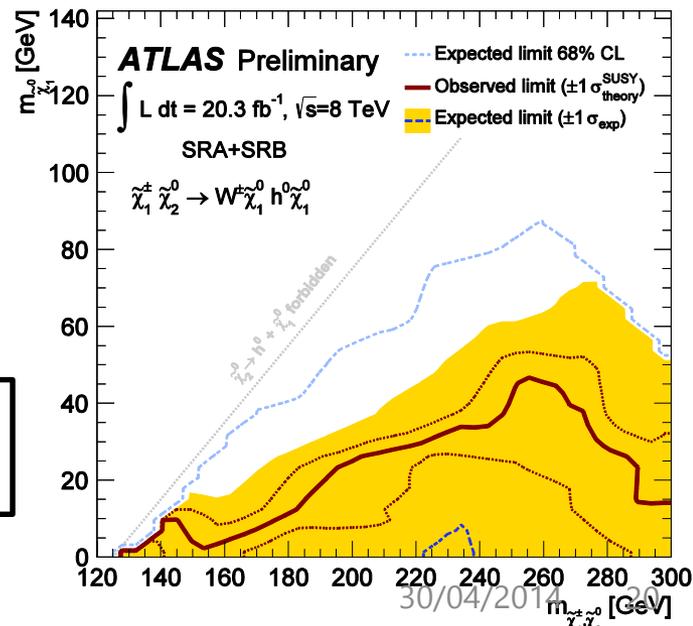
ATLAS-CONF-2013-093

- Set m_{bb} bins of
 - 50-75 GeV
 - 75-105 GeV
 - **105-135 GeV**
 - 135-165 GeV
 - > 165 GeV

- Simultaneous background fit using m_{bb} bins



No significant excess was observed



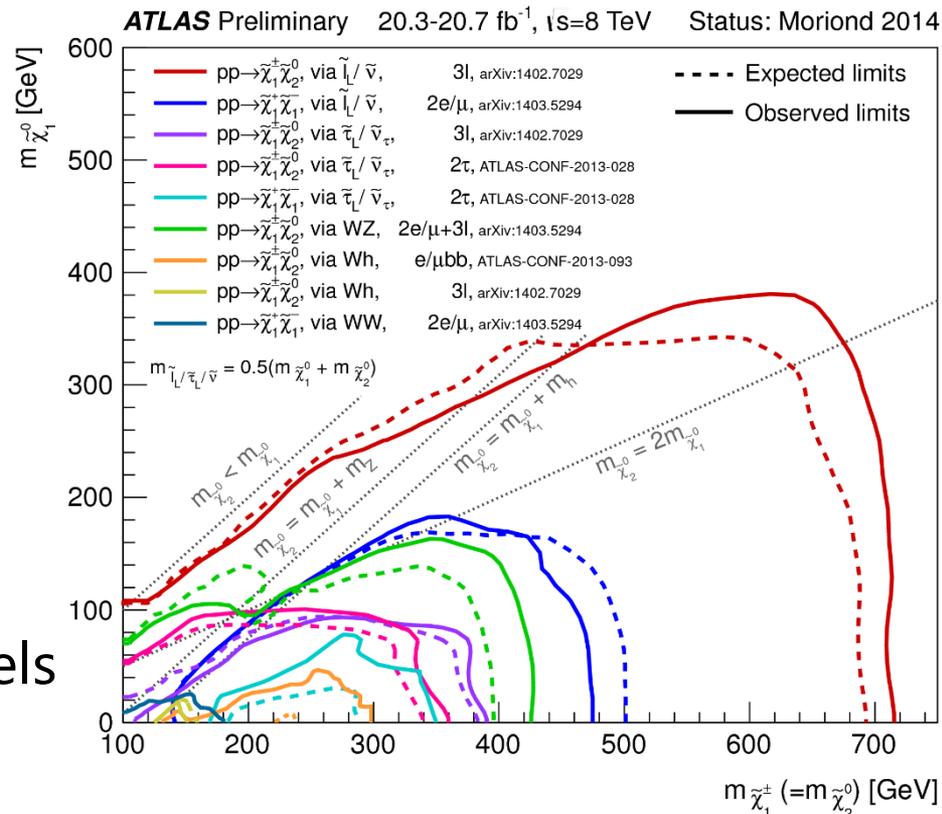
Conclusion

- ▶ Consideration for EW production of SUSY particles is now very important because...
 - dark matter candidate can be lightest neutralino
 - light mass region for strong production SUSY is already excluded

- ▶ We have many modes of EW SUSY production:
 - Direct **charginos/neutralinos**
 - boson ($W/Z/h$)-mediated
 - slepton ($\tilde{\ell}/\tilde{\tau}$)-mediated
 - Direct **sleptons** production

- ▶ **No significant deviation** from SM expectation

- ▶ Limits are set in Simplified Models for the EW SUSY modes



BACKUP

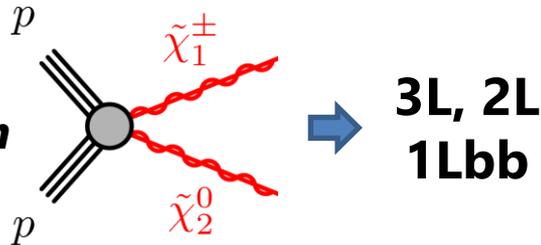
Target SUSY scenarios

- ▶ Direct production of charginos/neutralinos/sleptons

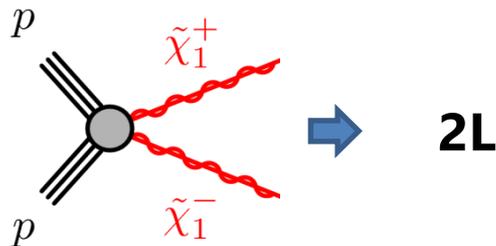
Direct **charginos/neutralinos** production

- $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$

Largest cross-section

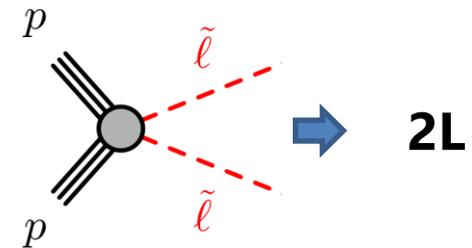


- $\tilde{\chi}_1^+ \tilde{\chi}_1^-$



Direct **sleptons** production

- $\tilde{\ell}^+ \tilde{\ell}^-$



- ▶ We have many search modes for electroweak SUSY!
- ▶ **Multi-leptons** (+MET) can contribute to reduce QCD backgrounds!

Background estimation method

- ▶ Backgrounds can be divided by the number of *real leptons*

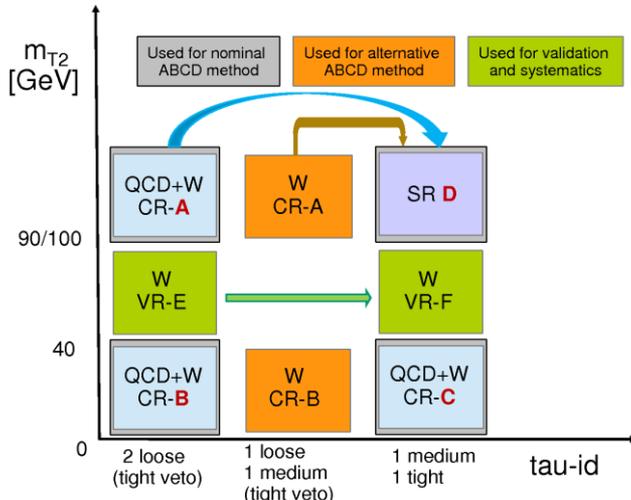
Irreducible background : **#Real leptons** \geq **Signature**

- *Example* : Standard Model $WZ^{(*)}$ production for 3-lepton mode
- Estimated from **MC**

Reducible background : ≥ 1 **mis-identified leptons**

“ABCD method”

- Control Regions A, B & C
→ assume $A/B = D/C$



“matrix method”

- Loose(L)/tight(T) leptons were defined
- count the numbers of events passed loose/tight selection (N_L, N_T) **from data**
- Apply following eq. (for 1 fake)

$$\begin{pmatrix} N_T \\ N_L \end{pmatrix} = \begin{pmatrix} \epsilon & f \\ 1 - \epsilon & 1 - f \end{pmatrix} \begin{pmatrix} N_R \\ N_F \end{pmatrix}$$

- ϵ : probability of loose \rightarrow tight for **real** leptons
- f : probability of loose \rightarrow tight for **fake** leptons

1 lepton (e, μ) + 2 b -jets + MET ATLAS-CONF-2013-093

- ▶ Focus on $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via **Wh -mediated** scenario
 - $\text{Br}(h \rightarrow b\bar{b}) \sim 60\%$: *highest branching ratio!*
 - Higgs mass reconstruction is POWERFUL
 - For the single lepton trigger, the lepton from W requires e/μ
 - Background only fit is performed in “side bands” of CRs

