SUSY Electroweak Production in 2-Tau Final State & RPV Reinterpretation

Shiyi Liang, Jiarong Yuan

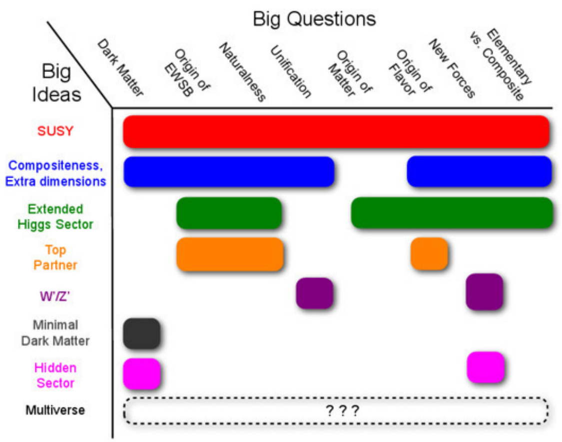
CLHCP 2024

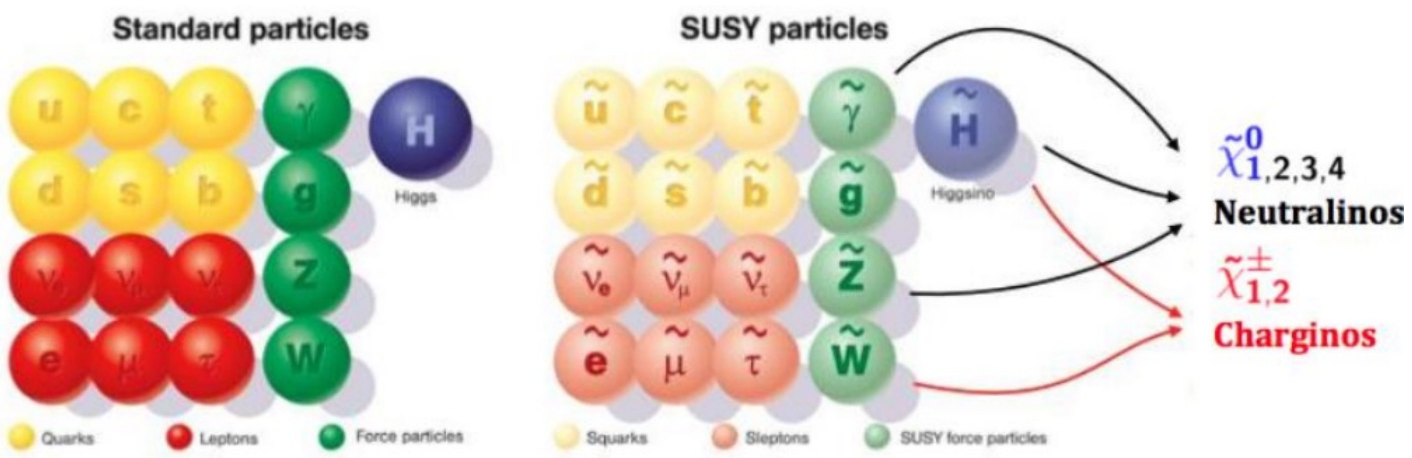
16th November 2024

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

SUSY

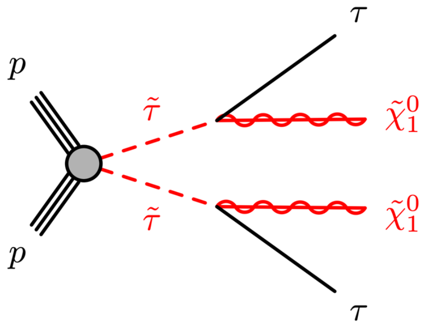
- Standard Model (SM) of particle physics
  - Precisely described the fundamental particles and the interactions between them
- Some problems are still unsolved: dark matter, hierarchy problem, the GUT, muon g-2, etc.
- Supersymmetry (SUSY) is one of the most appealing BSM theories.

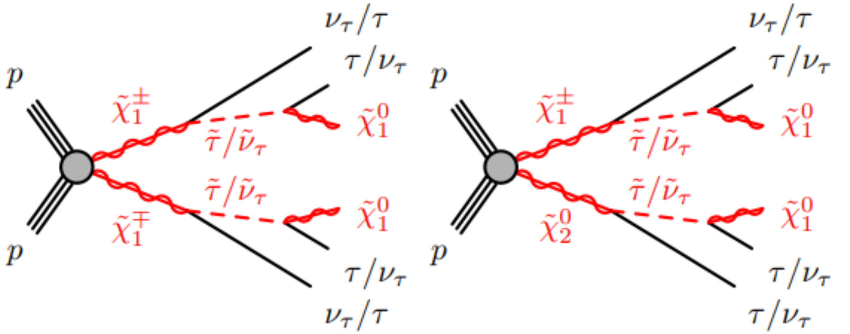


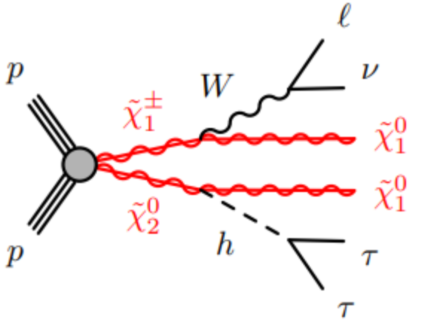


Introduction

- SUSY searches on di-tau or di-tau+1-lepton final states
- Direct stau production with $2\tau + E_T^{miss}$
  - Light sleptons could play a role in the co-annihilation of neutralinos in the early universe.
  - Models with light stau decaying to light neutralinos are consistent with dark matter searches.
  - Independent studies of all three lepton flavours are necessary.
- Gaugino production ($\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}, \tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$) via stau with $\geq 2\tau + E_T^{miss}$
  - Gaugino production has higher cross-section.
- Gaugino production ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$) via Wh with $2\tau + 1\ell + E_T^{miss}$
  - One lepton requirements could suppress the SM backgrounds

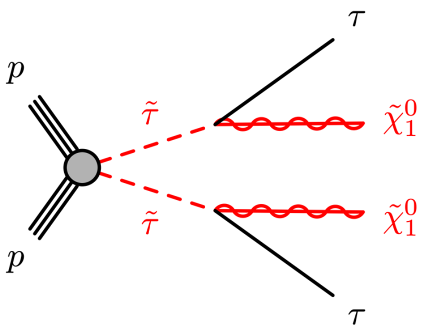




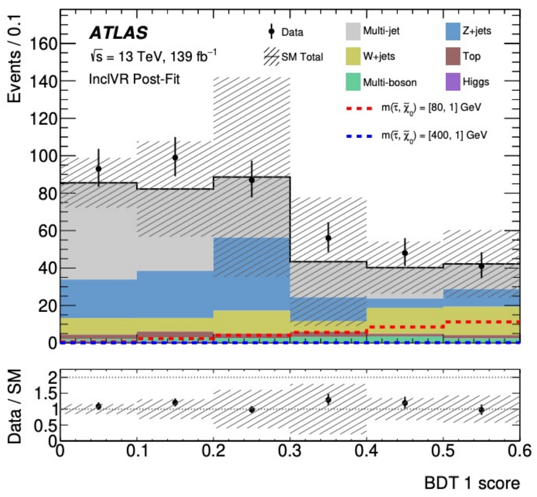


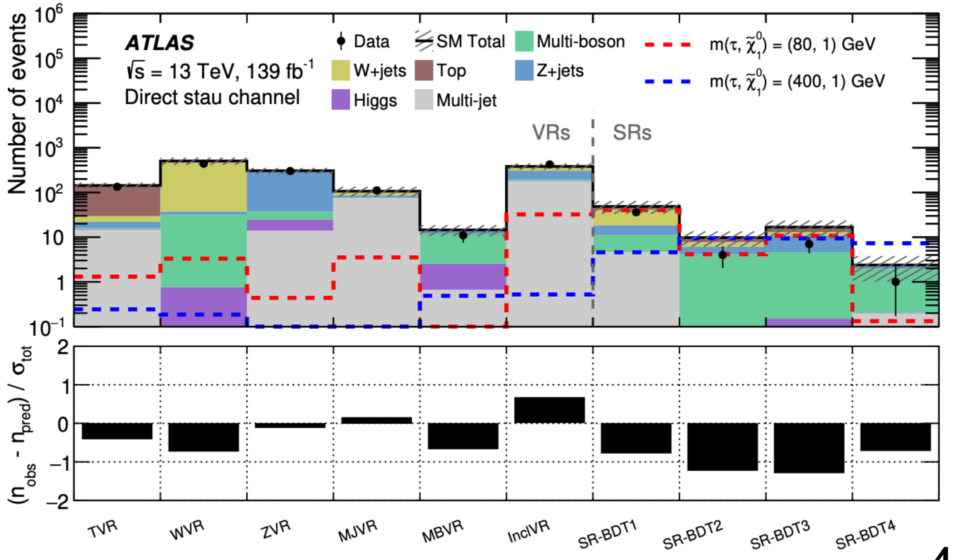
Direct stau production

- Signal models
  - Direct production of stau pair, then decay to taus and LSP
  - Signature: $2\tau + E_T^{miss}$
- Analysis Strategy
  - Four BDTs are trained using the LightGBM on four groups of signal scenarios chosen for $m(\tilde{\tau}), \Delta m(\tilde{\tau}, \tilde{\chi}_1^0)$
    - BDT inputs: $E_T^{miss}, p_T(\tau_1), m_T(\tau_1), p_T(\tau_2), m_T(\tau_2), \Delta\phi(\tau_1, \vec{p}_T^{miss}), \Delta\phi(\tau_2, \vec{p}_T^{miss}), \Delta\eta(\tau_1, \tau_2), m(\tau_1, \tau_2), m_{eff}, m_{Tsum}$
  - Multi-jet background is estimated by ABCD method.
  - Dominant backgrounds (Z+jets, W+jets, top) are normalized in dedicated control regions.
  - Other minor backgrounds are estimated by MC and validated in validation regions.



	BDT Training Preselection						
N medium τ	≥ 2						
Charge combination	OS						
Trigger	asymm. di-τ						
N e/μ	$= 0$						
N b-jets	$= 0$						
E_T^{miss} [GeV]	> 20						
m_{T2} [GeV]	> 30						
$m(\tau_1, \tau_2)$ [GeV]	> 120						
$\Delta R(\tau_1, \tau_2)$	< 4						
	SR-BDT1		SR-BDT2		SR-BDT3		SR-BDT4
	Bin 1	Bin 2	Bin 1	Bin 2	Bin 1	Bin 2	
Target scenario	Low $m(\tilde{\tau})$ Small $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0)$		Mid $m(\tilde{\tau})$ Large $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0)$		Mid $m(\tilde{\tau})$ Small $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0)$		High $m(\tilde{\tau})$
N medium τ	$= 2$						
BDT1 score	$\in (0.73, 0.78)$	> 0.78	—	—	—	—	—
BDT2 score	—	—	$\in (0.78, 0.82)$	> 0.82	—	—	—
BDT3 score	—	—	—	—	$\in (0.79, 0.86)$	> 0.86	—
BDT4 score	—	—	—	—	—	—	> 0.64

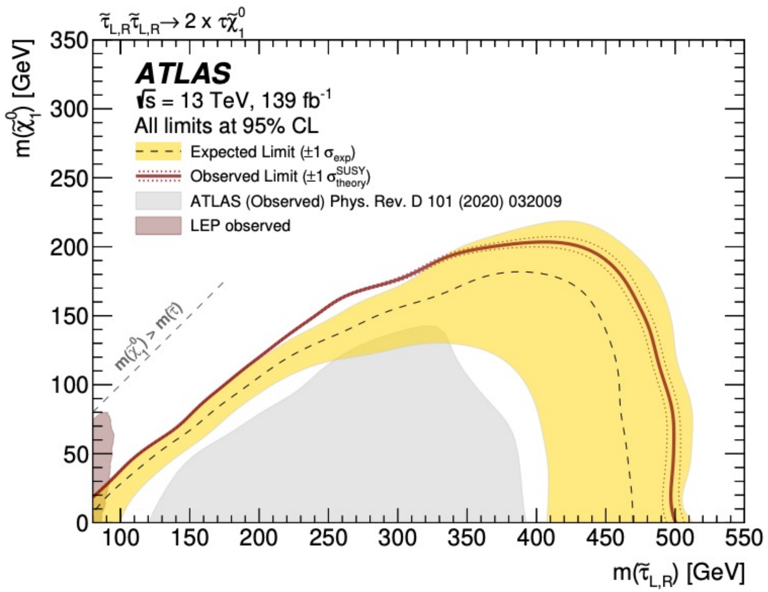




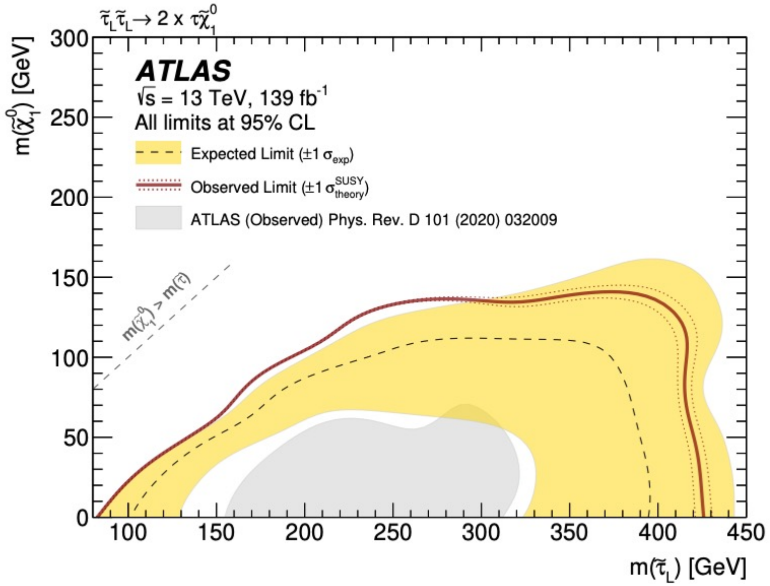
Direct stau production

- No significant excess over the SM background is observed
- For the combined $\tilde{\tau}_L$ and $\tilde{\tau}_R$ production, the stau masses up to 500 GeV are excluded for a massless LSP
- For the $\tilde{\tau}_L$ production, the stau masses up to 425 GeV are excluded
- Sensitivity to $\tilde{\tau}_R$ is obtained for the first time.

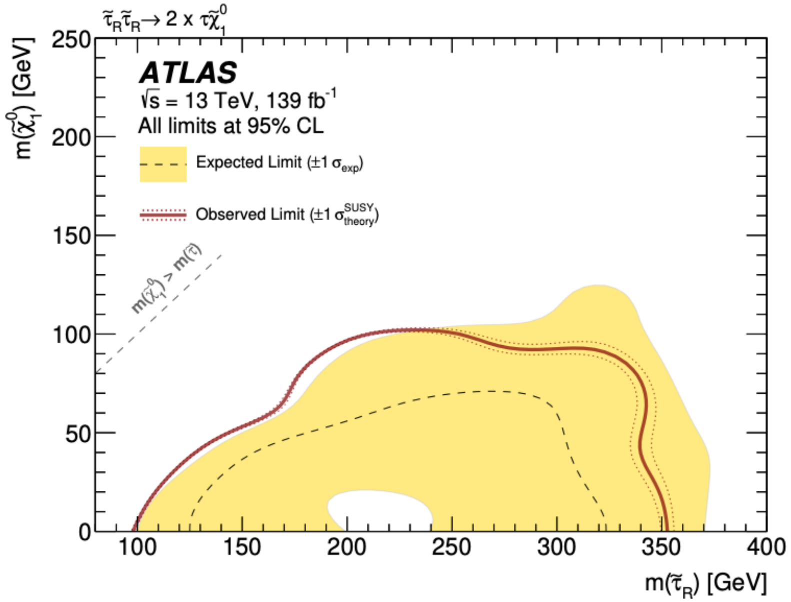
Combined $\tilde{\tau}_L$ and $\tilde{\tau}_R$



Only $\tilde{\tau}_L$

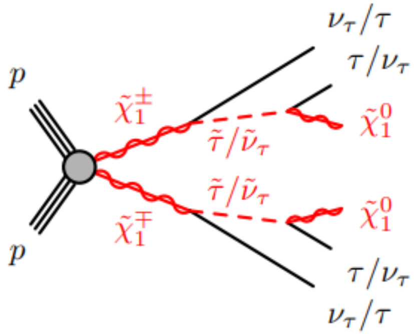


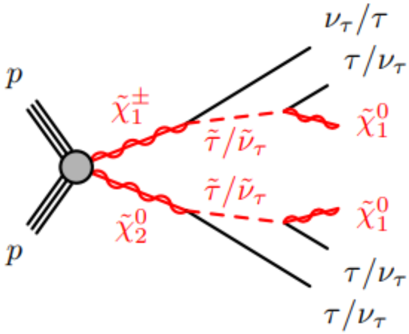
Only $\tilde{\tau}_R$



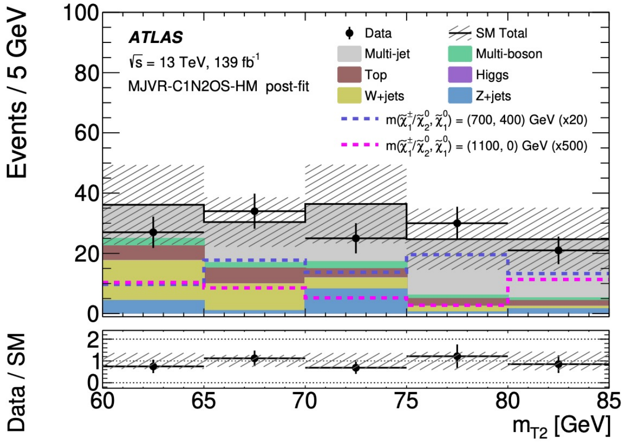
Gaugino production ($\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}, \tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$) via stau

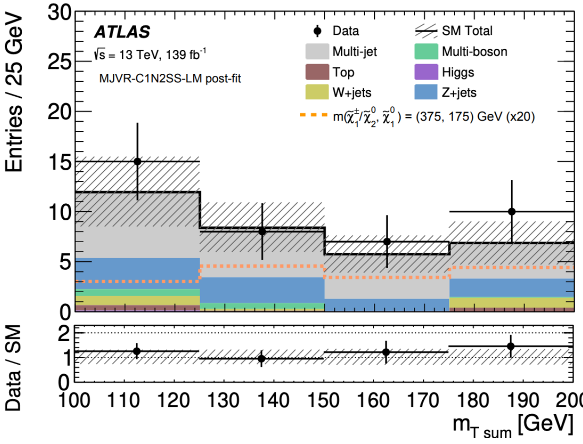
- Signal models
  - Gaugino pair production
  - Signature: $\geq 2\tau + E_T^{miss}$
- Analysis Strategy
  - Six signal regions aiming for OS/SS channels and different $\Delta(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^{0}, \tilde{\chi}_1^{0})$
  - Multi-jet background is estimated by ABCD method.
  - W+jets, Top(SS) backgrounds are normalized in dedicated control regions.
  - Other backgrounds are estimated by MC and validated in validation regions.





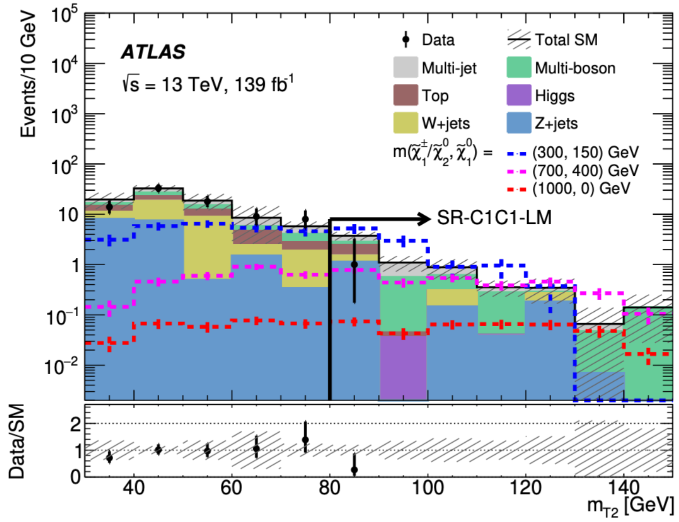
SR-	C1C1-LM	C1N2OS-LM	C1N2SS-LM	C1C1-HM	C1N2OS-HM	C1N2SS-HM
Trigger	asymm. di-τ			di-τ + E_T^{miss}		
E_T^{miss} [GeV]	< 150			> 150		
N medium τ	$= 2$	≥ 2	≥ 2	$= 2$	≥ 2	≥ 2
N tight τ	≥ 1	≥ 1	—	—	—	—
Charge combination	OS	OS	SS	OS	OS	SS
N b-jets	$= 0$	$= 0$	$= 0$	$= 0$	$= 0$	$= 0$
N jets	—	< 3	< 3	—	—	—
$\lvert\Delta\phi(\tau_1, \tau_2)\rvert$	> 1.6	—	> 1.5	—	—	—
$m(\tau_1, \tau_2)$ [GeV]	> 120	> 120	—	> 120	> 120	—
E_T^{miss} [GeV]	> 60	> 60	—	—	—	—
$m_{T\mathrm{sum}}$ [GeV]	—	—	> 200	> 400	> 400	> 450
m_{T2} [GeV]	> 80	> 70	> 80	> 85	> 85	> 80

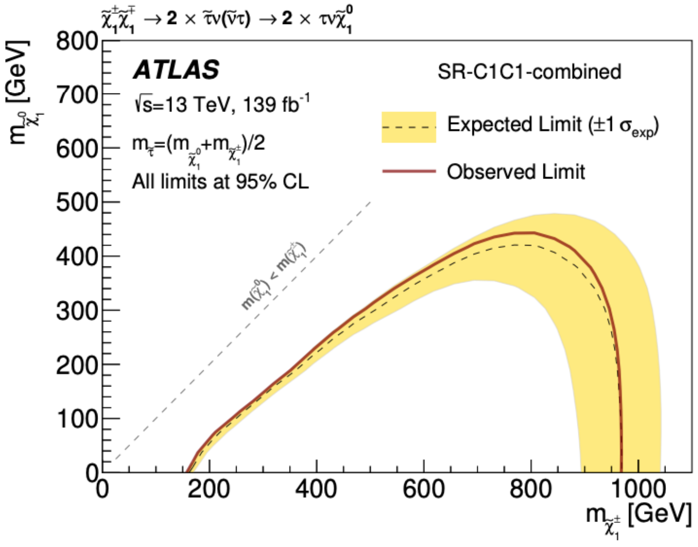


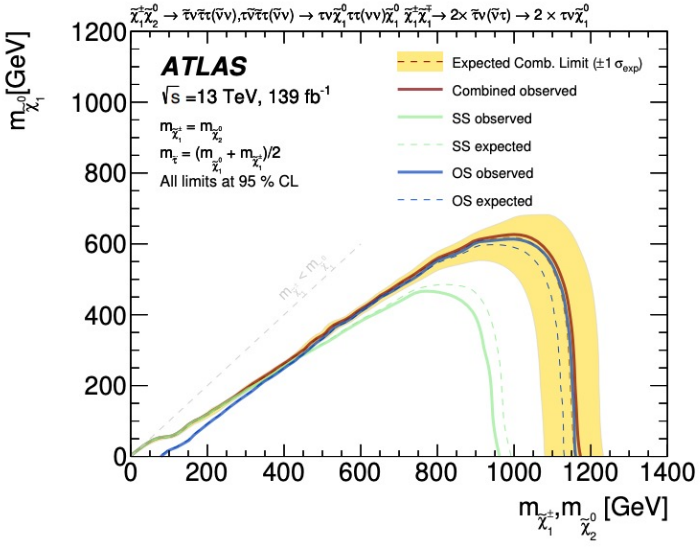


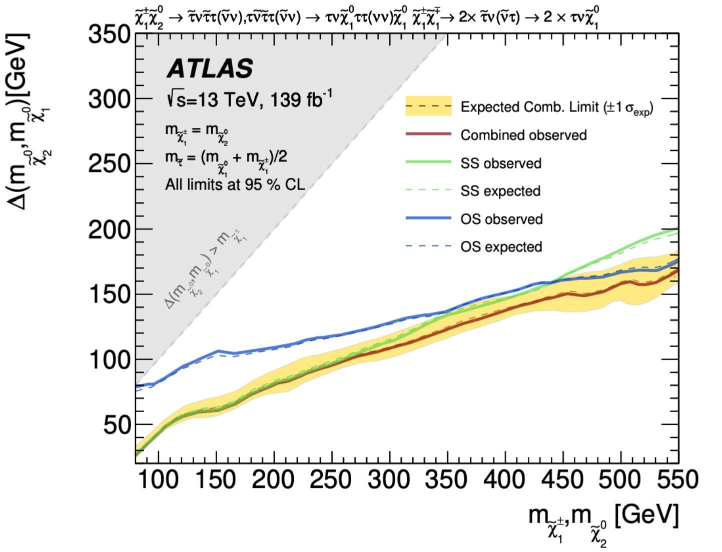
Gaugino production ($\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}, \tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$) via stau

- No significant excess over the SM background is observed
- For $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$, chargino masses up to 970 GeV are excluded for a massless LSP
- For $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ and $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$, chargino masses up to 1160 GeV are excluded for a massless LSP



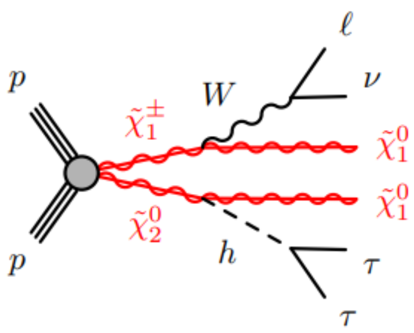




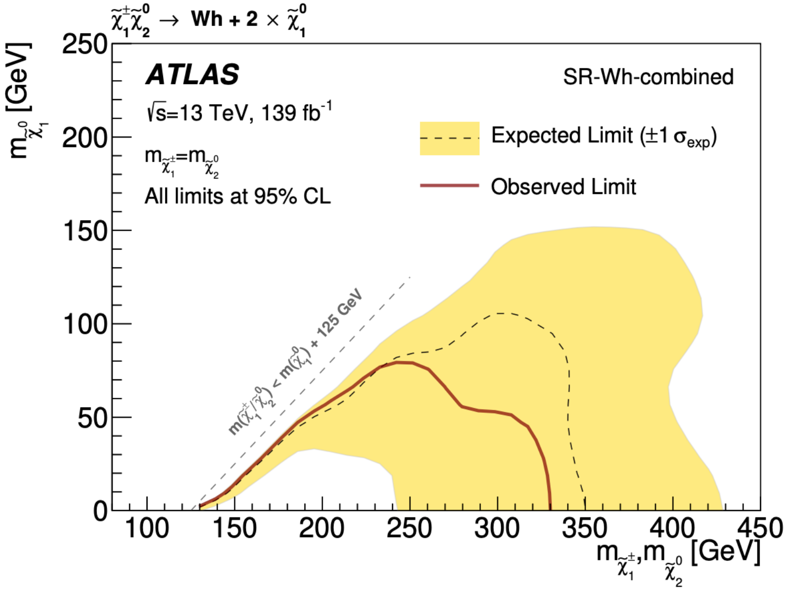


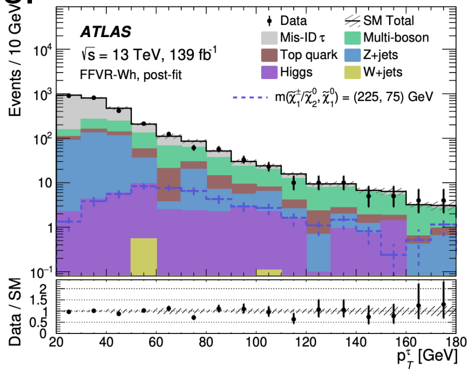
Gaugino production ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$) via Wh

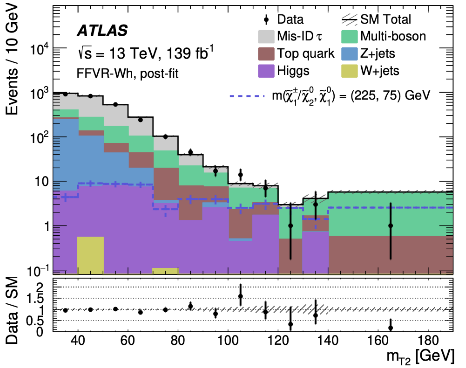
- Signal models
  - Gaugino pair production
  - Signature: $2\tau + 1\ell + E_T^{miss}$
- Analysis Strategy
  - Two signal regions aiming for different $\Delta(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0, \tilde{\chi}_1^0)$
  - Fake backgrounds are estimated using data-driven method
  - Other backgrounds are estimated by MC and validated in validation regions.
- No significant excess over the SM background is observed
- Chargino masses up to 330 GeV are excluded for a massless LSP

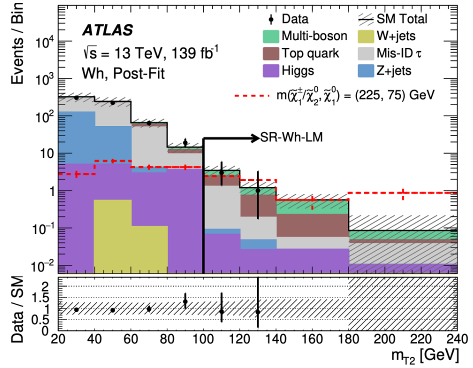


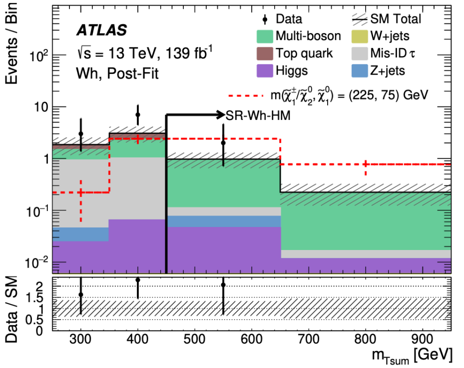
	SR-Wh-LM	SR-Wh-HM
Trigger	Single e or μ	
N medium τ	≥ 2	
N e/μ	$= 1$	
Charge combination	OS	
N b-jets	$= 0$	
$\lvert\Delta\phi(\tau_1,\tau_2)\rvert$	< 3	
$\Delta R(\tau_1,\tau_2)$	—	< 2.2
$m(\tau_1,\tau_2)$ [GeV]	$\in [90, 130]$	$\in [80, 160]$
m_{T2} [GeV]	> 100	> 80
$m_{T,\ell}$ [GeV]	—	> 80
m_{Tsum} [GeV]	—	> 450









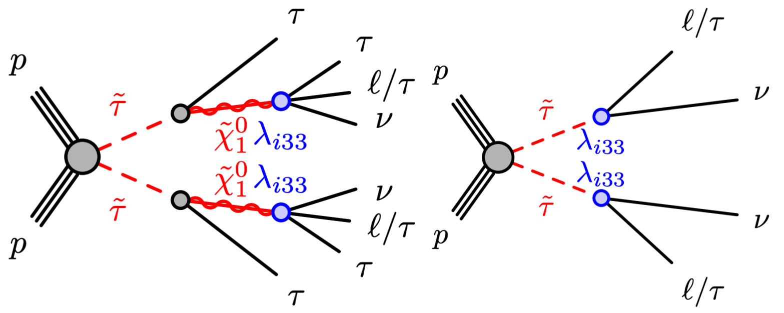


RPV Reinterpretation

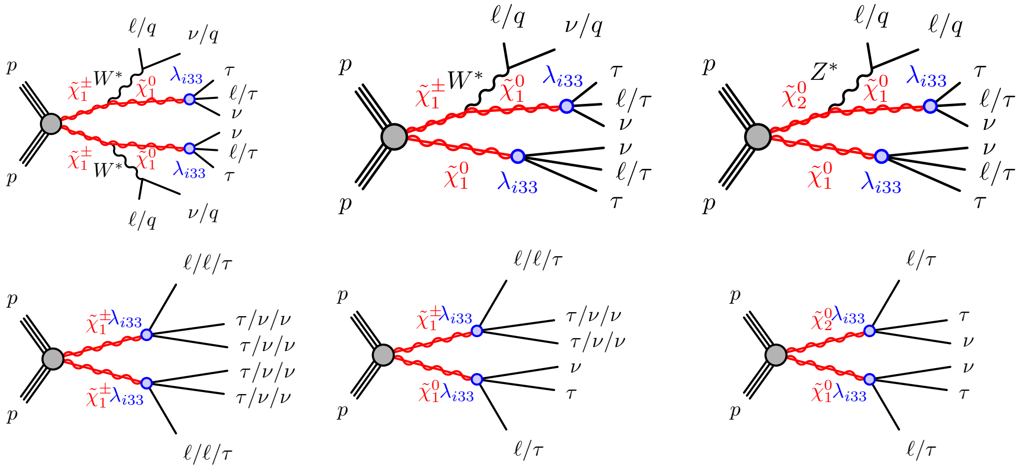
- Reinterpretation in RPV models with variable RPV coupling strength
- The most general superpotential introduces terms allowing for baryon- and lepton-number violation.
  - The LNV RPV $\lambda_{133}, \lambda_{233}$ are assumed non-zero, which makes the LSP unstable and decay to SM particles.
  - LSP lifetime depends on the RPV coupling strength and slepton mass.
- The di-τ [JHEP 05, 150 (2024)] and four-lepton[JHEP 2021, 167 (2021)] analyses have been reinterpreted.

$$W_{\mathrm{RPV}} = \frac{\lambda_{ijk}}{2} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{\lambda''_{ijk}}{2} \bar{U}_i \bar{D}_j \bar{D}_k + k_i L_i H_u$$

Stau-Model

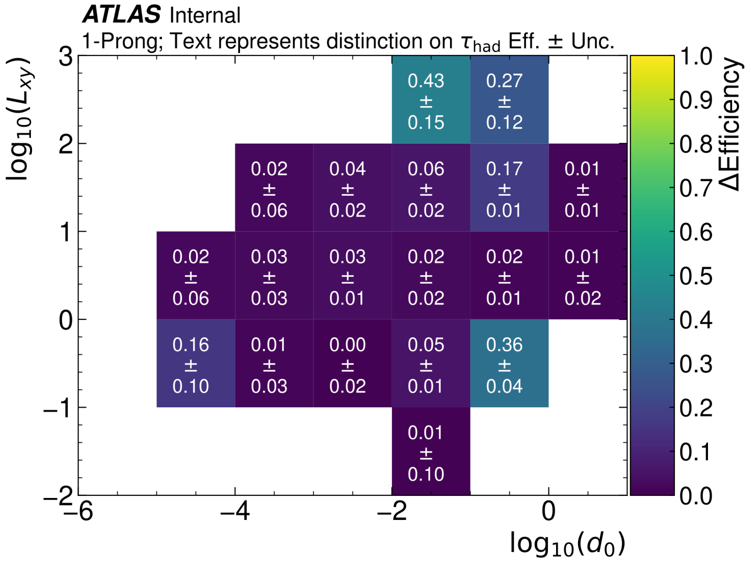


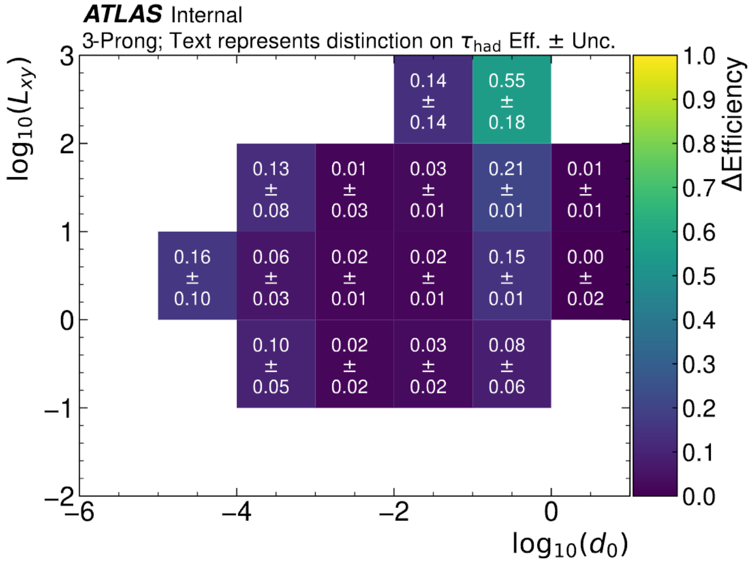
Higgsino-Model



Displaced Tau Systematics

- The di-τ analysis includes two additional uncertainties to account for deviations from the conventional systematics resulting from displaced τ_{had}.
  - Tau reconstruction and identification uncertainty for displaced τ_{had}
    - The uncertainty ranges from 1% to 6%(1% to 20%) for 1(3)-prong τ in bins of τ d_0 and L_{xy}.
  - Di-τ trigger uncertainty for displaced τ_{had}
    - The trigger efficiency uncertainty is within 6% (12%) for asymmetric di-τ (di-τ+E_T^{miss}) trigger.

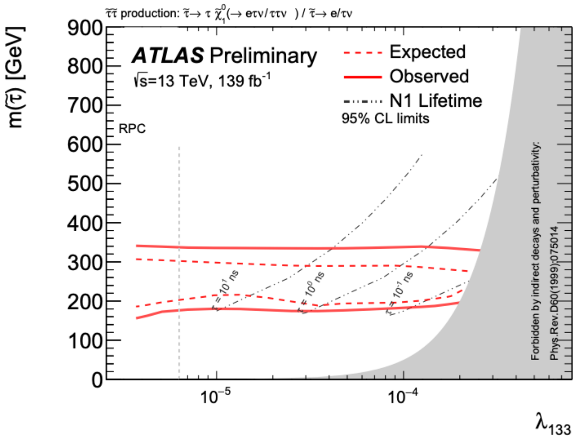


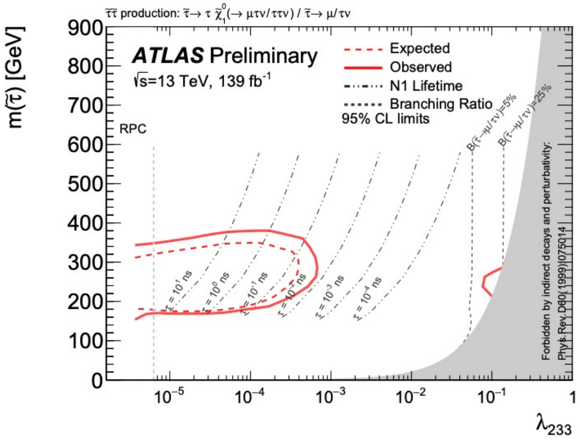


Model-dependent Limits

- 95% CL exclusion limits are set for stau and higgsino scenarios.

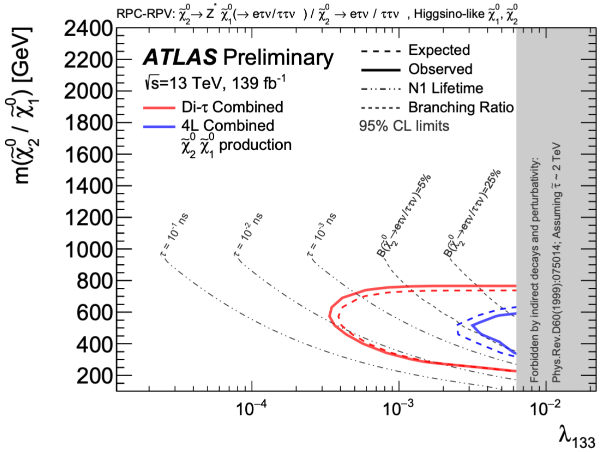
Stau-Model

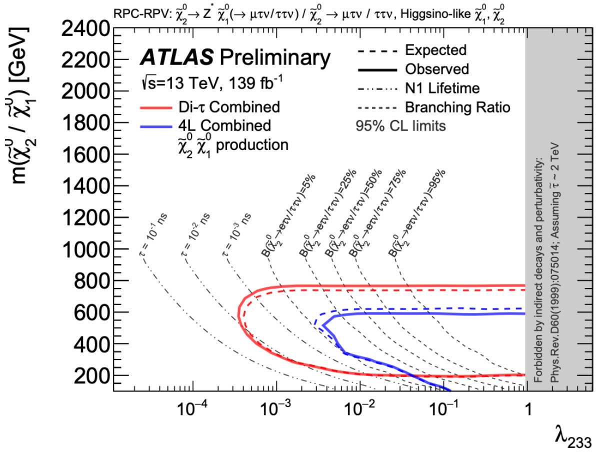




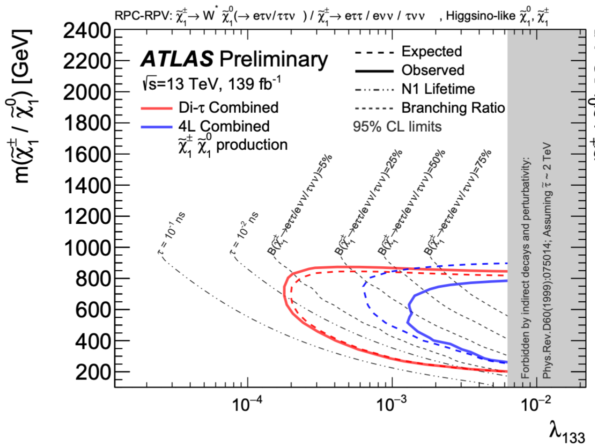
Higgsino-Model

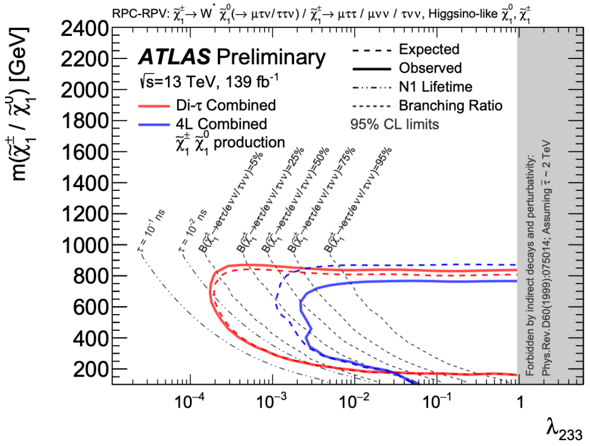
$\tilde{\chi}_1^0\tilde{\chi}_2^0$ Production



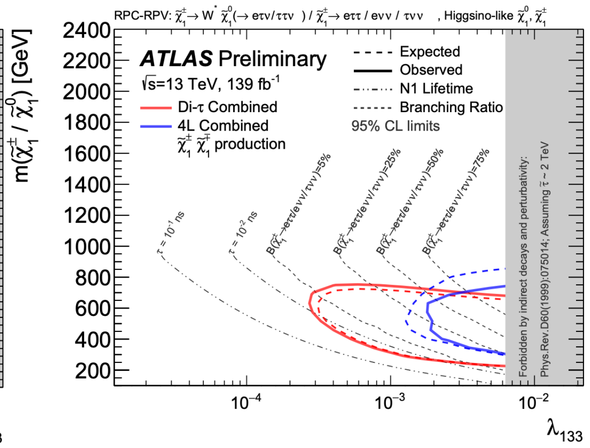


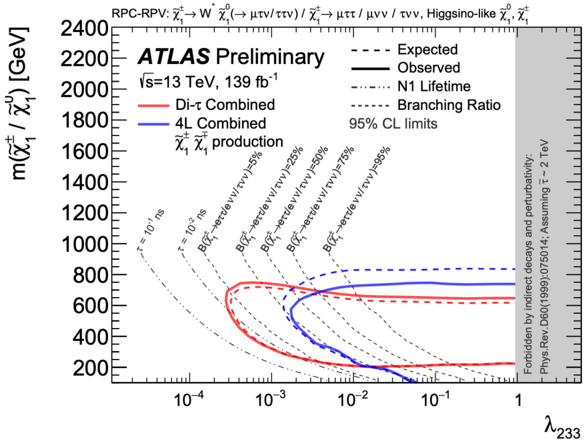
$\tilde{\chi}_1^\pm\tilde{\chi}_1^0$ Production





$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$ Production





Summary

- An overview of the SUSY searches on di-tau or di-tau+1-lepton final states and the RPV reinterpretation with final states containing taus
- The current results have improved a lot compared to previous results
- Run3 analysis focusing on scenarios in the compressed region