Searches for electroweak production of supersymmetric particles with the ATLAS detector

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on behalf of ATLAS experiment

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ATLAS EXPERIMENT

中国科学院高能物理研究所
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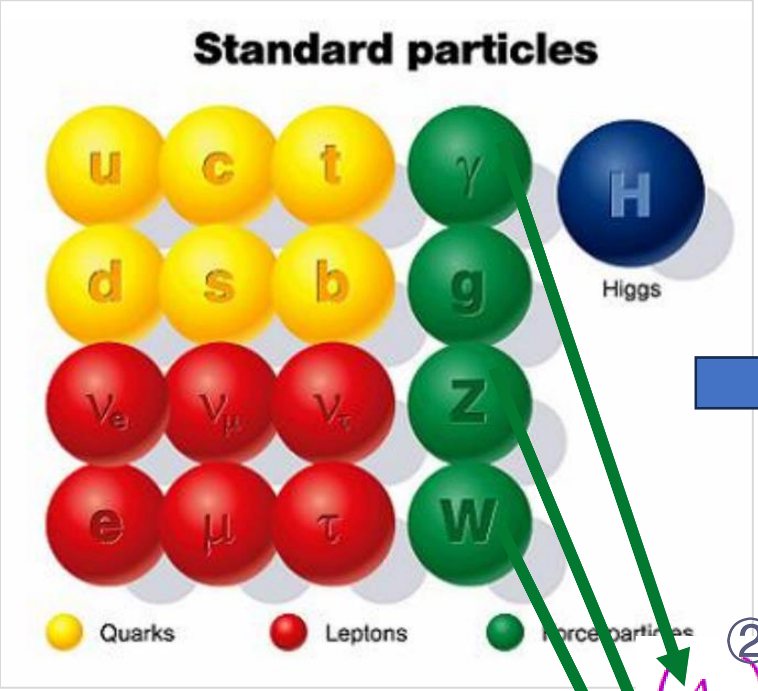
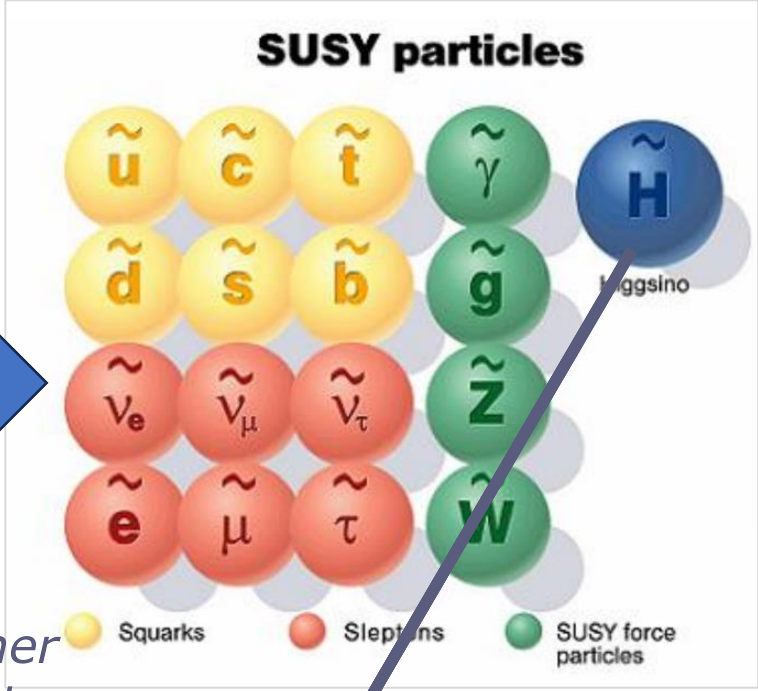
UNIVERSITY OF SUSSEX

A supersymmetric extension of the Standard Model



① *New fermionic/bosonic superpartners to each of the SM bosons/fermions.*



② *Weinberg angle*

$$\begin{pmatrix} A_\mu \\ Z_\mu \end{pmatrix} = \begin{pmatrix} c_W & s_W \\ -s_W & c_W \end{pmatrix} \begin{pmatrix} B_\mu \\ W_\mu^3 \end{pmatrix}$$

$$(W_\mu^1 \pm iW_\mu^2/\sqrt{2})$$

③ *superpartner of gauge fields*

$$(\tilde{B}, \widetilde{W})$$

(Bino, Wino, Higgsino)

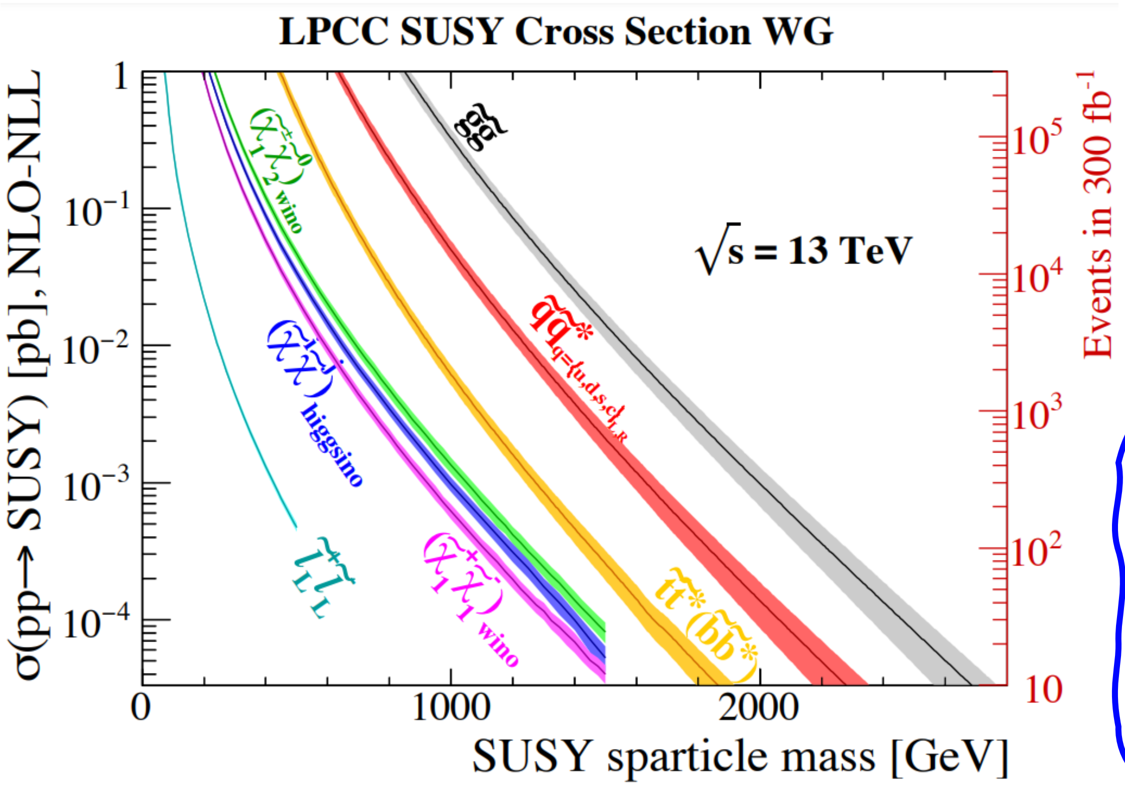
④ *Mix to form mass eigenstates*

$$(\tilde{\chi}_i^0, \tilde{\chi}_j^\pm)$$

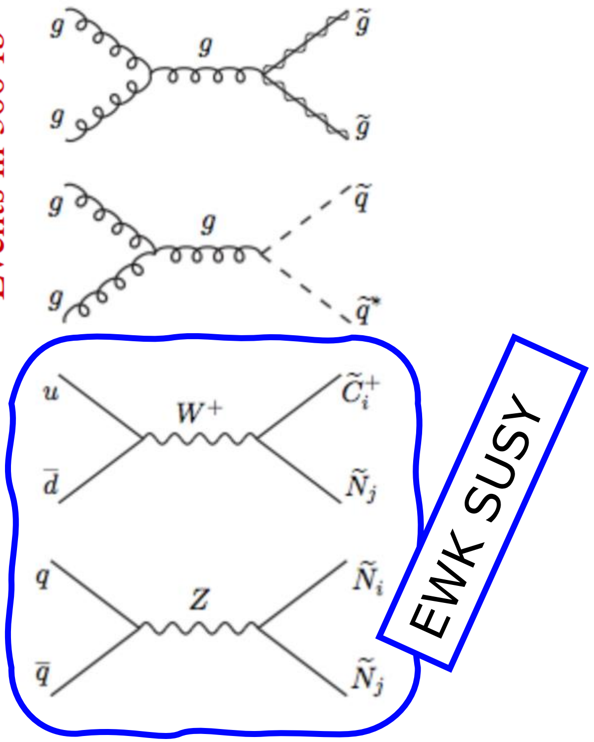
⑤ *Neutralino and Chargino*

- In MSSM, terms which violate baryon number or lepton number could exist: R-Parityis introduced to eliminate this possibility:
  - LSP (lightest supersymmetric particle) is stable; Sparticle will eventually decay to odd number of LSP.
  - Sparticles are produced in even numbers on LHC
- In ATLAS, a simplified SUSY model is applied.

Electroweak SUSY



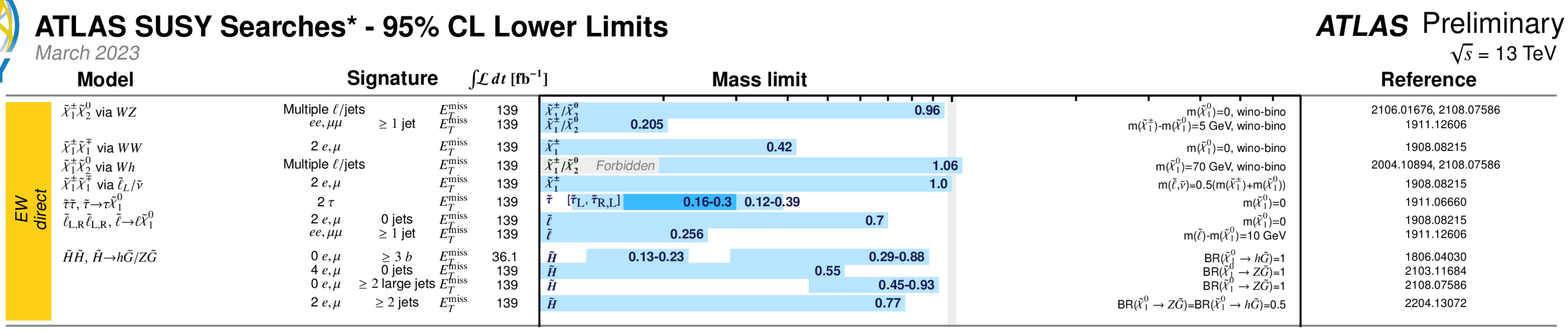
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections arXiv:1407.5066



Motivations:

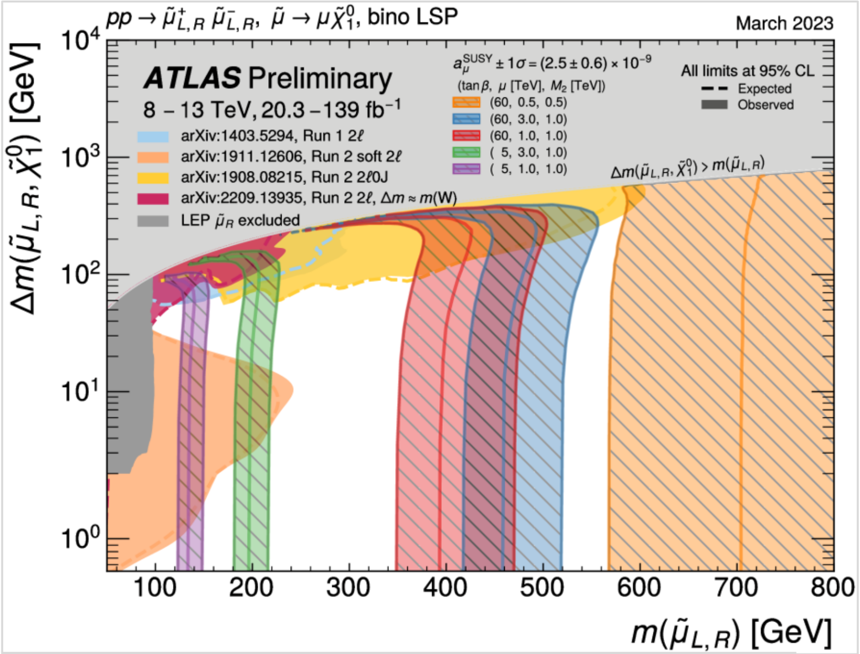
- Smaller cross-section on LHC, fewer constraints by direct searches.
- If R-Parity is conserved, SUSY is still favoured by DM-nucleus SI cross-section and relic density, and even $(g-2)_\mu$ result, especially in Bino Compressed scenario.
- If R-Parity is violated, weaker constraints on SUSY.

ATLAS searches for electroweak SUSY - this talk



- This talk includes 4 analyses
  - 2L0J: 2209.13935 ; 1L: ATLAS-CONF-2022-059 ;
    2tau: ATLAS-CONF-2023-029 ; SS/3L: 2305.09322

  cover the search for compressed region, $\tilde{\tau}$, and RPV scenario.
- For more relative talks in ICNFP2023:
  - SUSY Strong Production [*Egor Antipov*]: Brief intro on SUSY + General strategy.
  - Result Reinterpretation on DM [*Tae Min Hong*]: SUSY-DM.
- For more results not presented in this talk, please find them here.



Mass regions favoured by (g-2)

Search for the Compressed Region

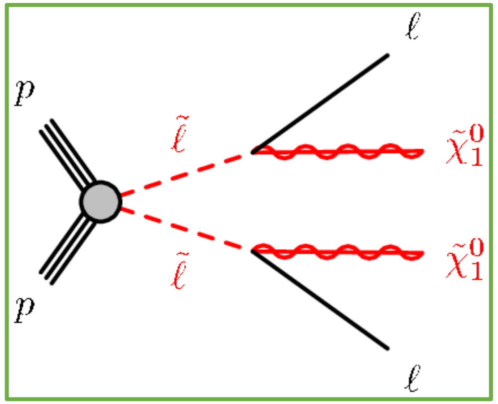
2LOJ: 2209.13935

Search for compressed region

The analysis targeting "moderately compressed" phrase space.

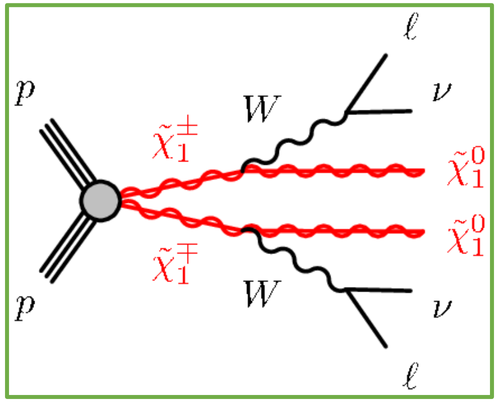
- Two channels with two leptons final state targeting @ $\Delta M \sim m_W$

1, Slepton ($\tilde{e}, \tilde{\mu}$) pair production



- Light slepton and light stable LSP can is compatible with $(g-2)_\mu$ anomaly.
- Different assumptions about the masses of $\tilde{e}_L$, $\tilde{e}_R$, $\tilde{\mu}_L$, $\tilde{\mu}_R$ are considered.
- Same-Flavour lepton Signature, further classified into 0-Jet and 1-Jet sets.

2, Chargino $\tilde{\chi}_1^\pm$ pair production



- Pure Wino $\tilde{\chi}_1^\pm$ decays to Bino $\tilde{\chi}_1^0$ and on-shell W boson, focus on 2 leptons.
- Small gap Bino-Wino model can explain all the contribution of DM relic density.
- Same-Flavour lepton and Different-Flavour lepton categories.

Search for compressed region

Slepton pair production

- Multi-bin method binned in m_{T2}^{100}.

Chargino $\tilde{\chi}_1^{\pm}$ pair production

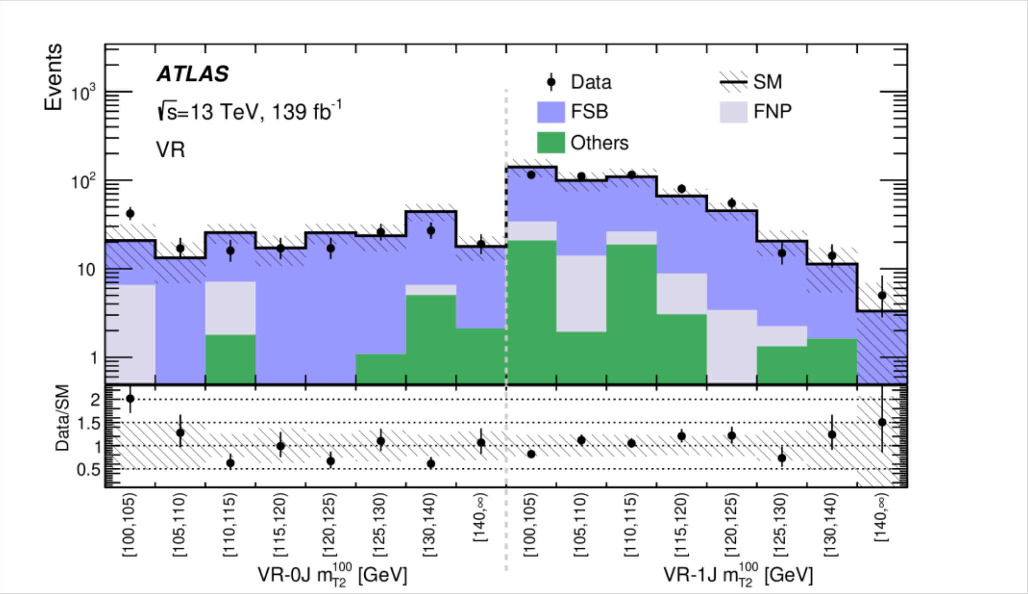
- BDT method is applied.

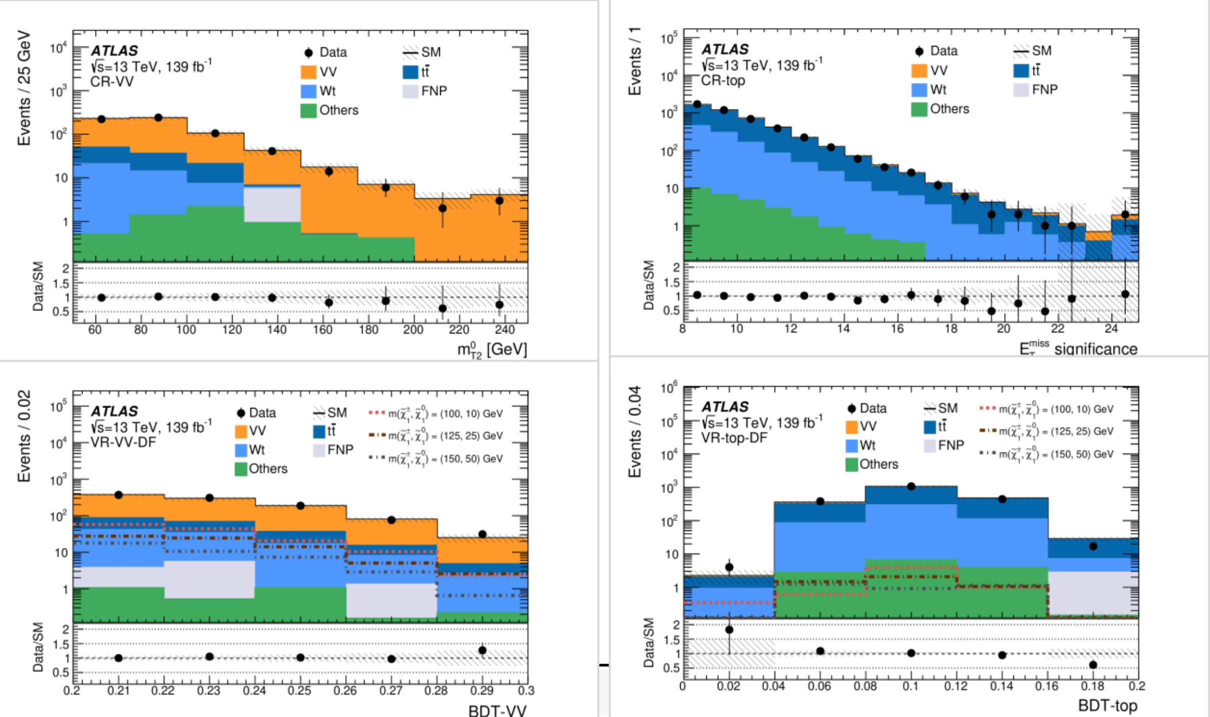
Irreducible Background: *Top-quark processes, Dibosons*

- *Flavour-symmetric backgrounds (FSB)*
- *CR-Top, CR-VV, VRs For VV/Top, SF/DF*

Reducible Background: *Fake/non-prompt lepton: Matrix Method (MM)*

- **Dominant Syst Unc.** are from FSB statistical uncertainty and estimation.
- VV theoretical uncertainty normalization of BKGs, Jet energy scale, and E_T^{miss} modelling.

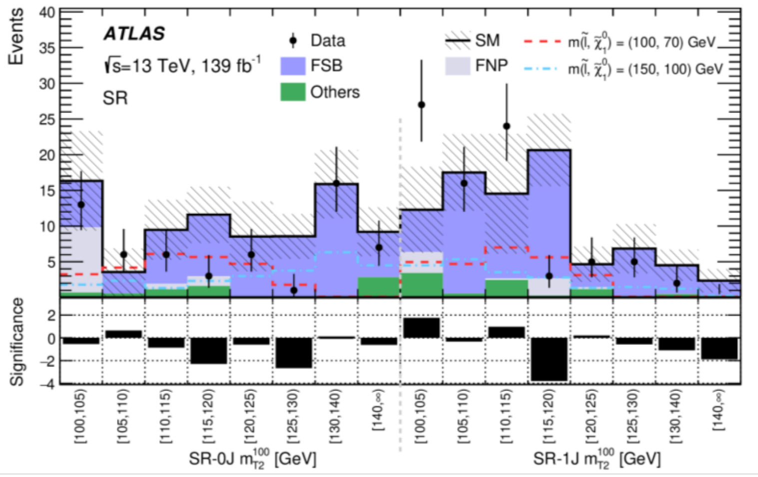




Search for compressed region

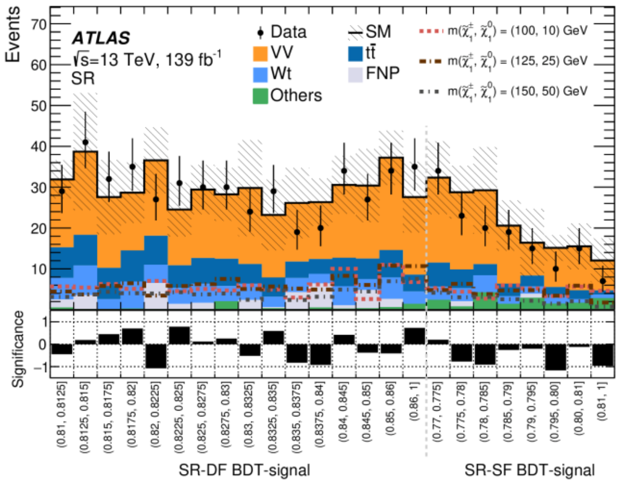
Slepton pair production

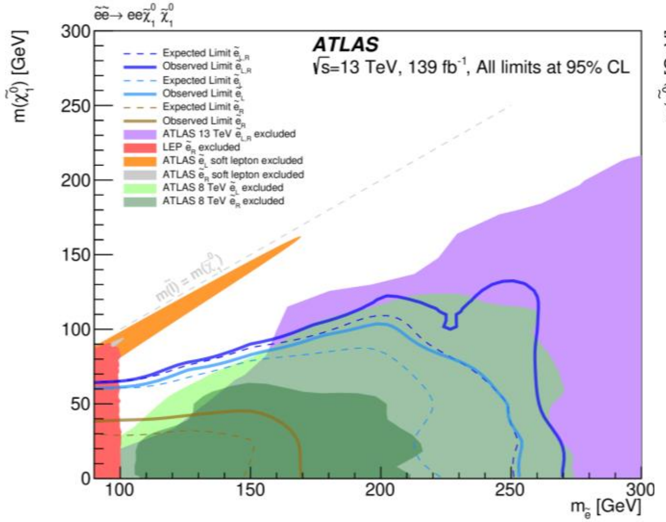
- 1.5σ excess and 3.5σ local data deficit.
- Strictly Correlated to stat-fluctuation.
- Bridge the gap between the previous ATLAS searches and LEP.

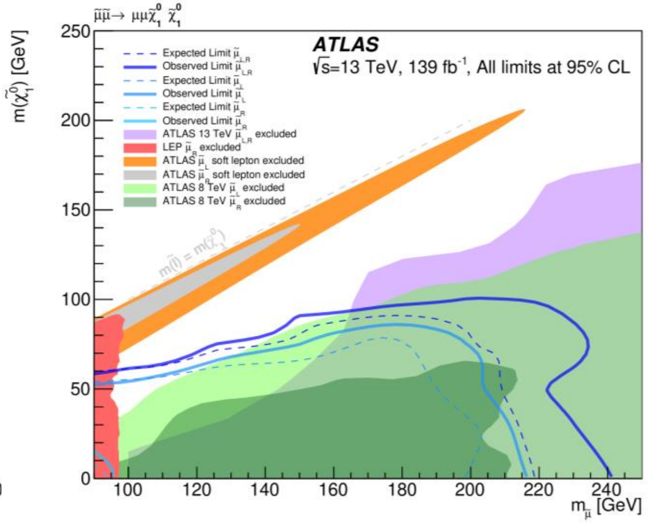


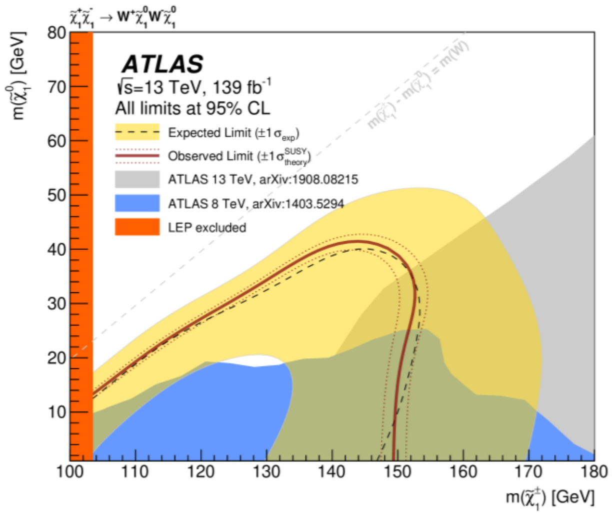
Chargino pair production

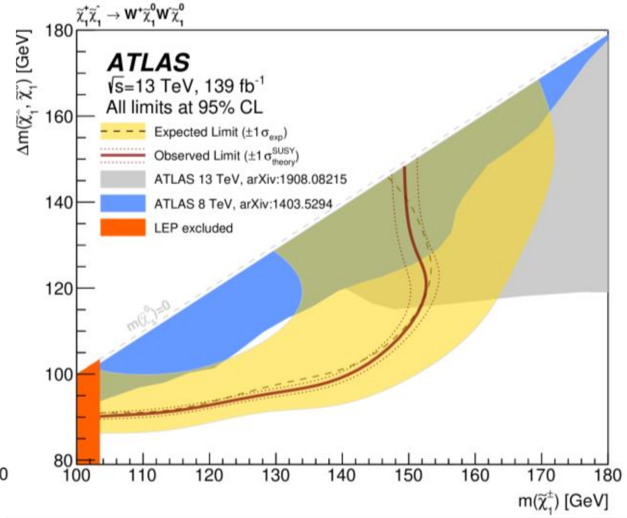
- Within 1 σ
- Extends beyond the previous limits











1 lepton + 2 jets final state

1L: ATLAS-CONF-2022-059

1 lepton + 2 jets final state

1, Chargino $\tilde{\chi}_1^{\pm}$ pair production

2, Chargino-Neutrilino $\tilde{\chi}_1^{\pm}$ $\tilde{\chi}_2^0$ pair production

- Pure Wino $\tilde{\chi}_1^{\pm}$ or $\tilde{\chi}_2^0$ pair decays to Bino $\tilde{\chi}_1^0$ + W or Z boson, focus on 1 lepton + 2 jets final state.

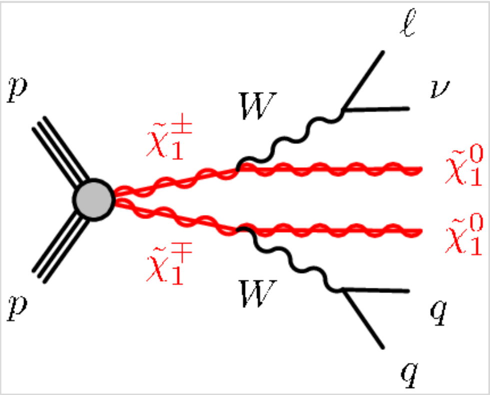
SR optimization

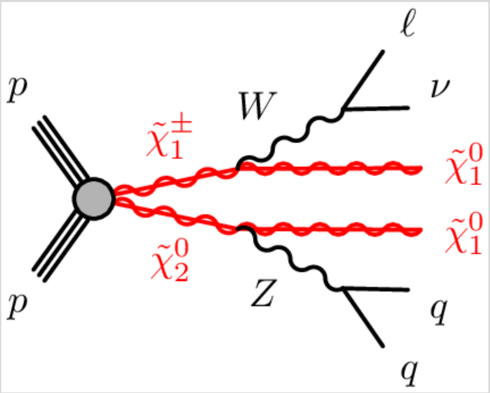
- $m_{T;lep}$ is used to define low (LM), Medium(MM), and High(HM) Mass differences regions.
- m_{eff} is used in each Mass differences region for Wino Masses.

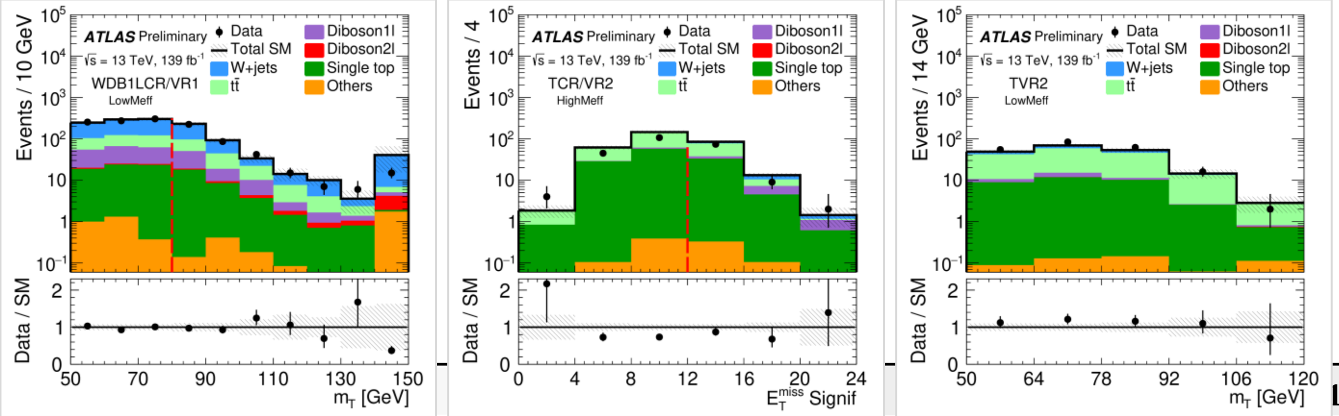
BKG estimation strategy

- Dominant BKGs are W+jets, Dibosons, and $t\bar{t}$.
- A set of dedicated CRs are designed for Normalisation factors, which are validated in VRs.

The main systematic uncertainties are theoretical uncertainty, Jet energy resolution and scale, and normalisation factors of dominant BKGs.







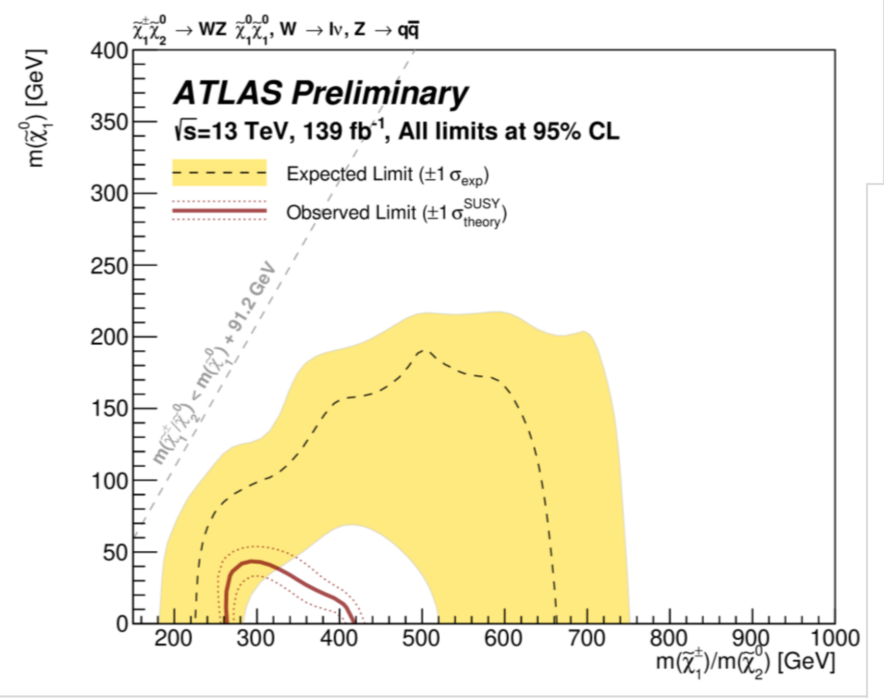
1 lepton + 2 jets final state

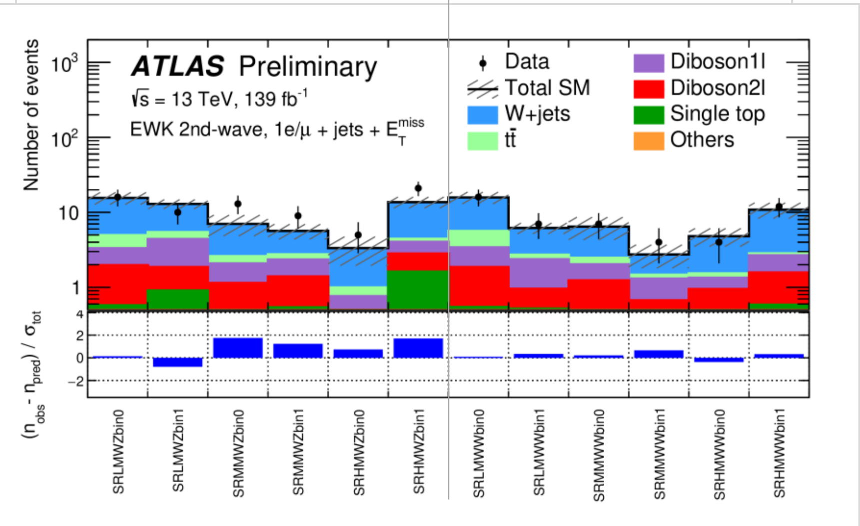
$\tilde{\chi}_1^{\pm}\,\tilde{\chi}_2^0$ pair production

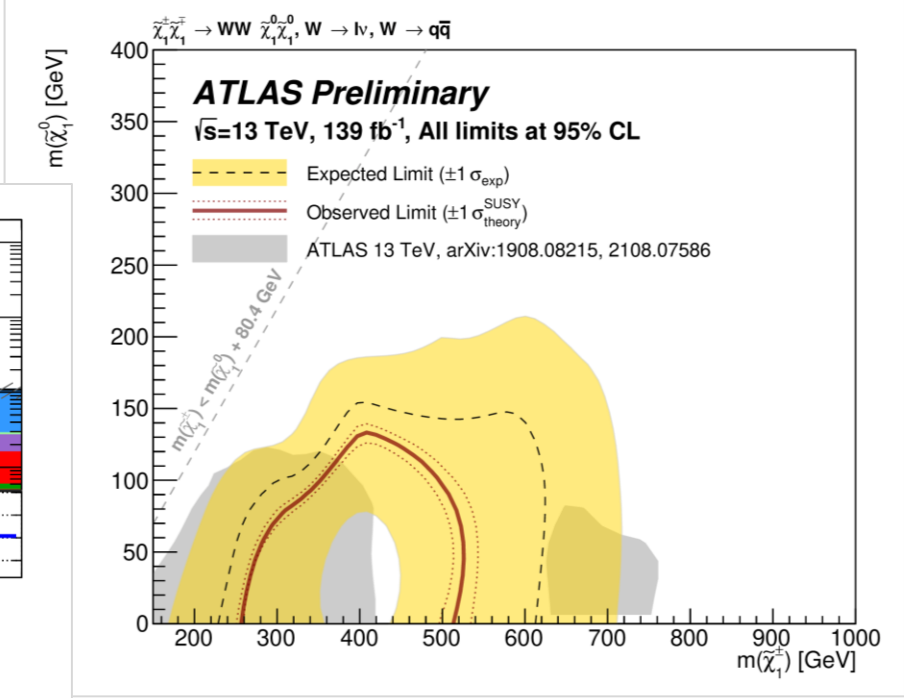
- Mild excesses are seen.
- Combining the bins of SRMMWZ leads to 2.1 σ.
- Leads to an exclusion limit ranging from 260-420 GeV for a massless LSP.

$\tilde{\chi}_1^{\pm}$ pair production

- Within the uncertainties.
- Covers the intermediate region between 0L analysis and 2L analysis.







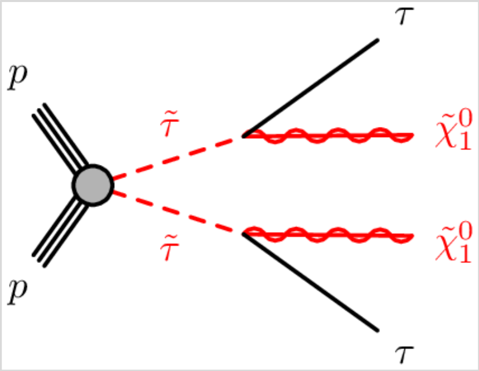
2 tau final state

2tau: ATLAS-CONF-2023-029

2 tau final state

1, Stau ($\tilde{\tau}$) pair production

- Left-handed stau and right-handed stau are interpreted separately.



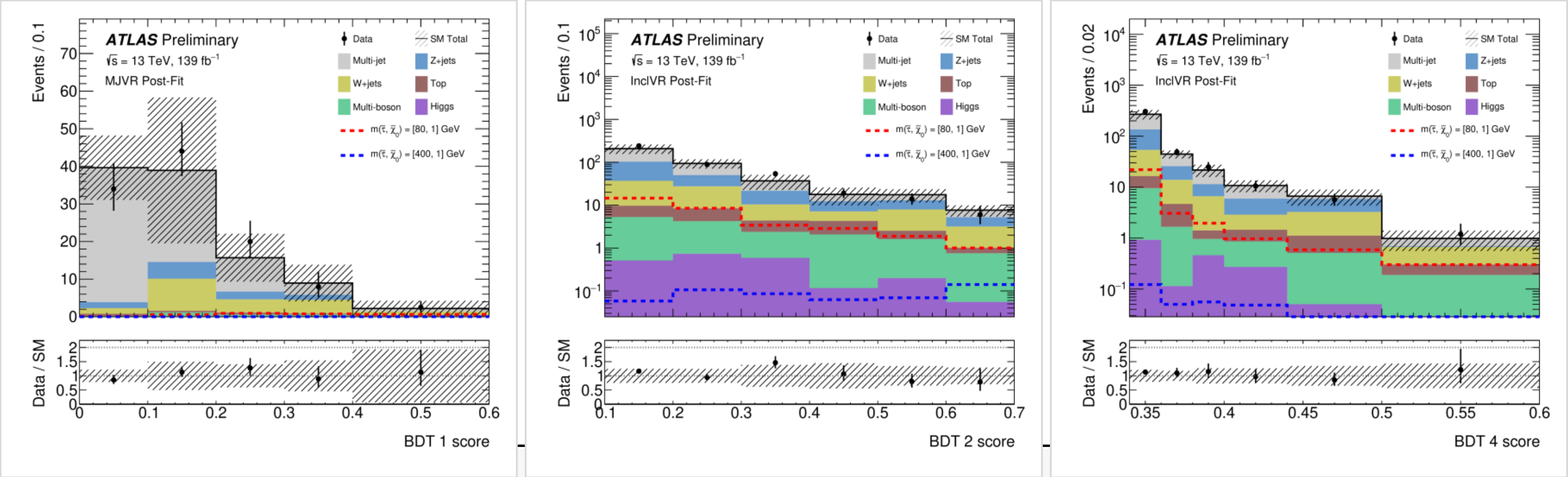
SR optimization

- 4 BDT models are trained for different mass phrase spaces.
- 3 of them have two bins.

Background Estimation:

- Multi-jet background: ABCD-method
- W+jets, Z+jets, Top processes are normalized in CRs separately.

The main systematic uncertainties are statistics of the MC samples, jet energy scale and resolution, dibosons theoretical uncertainty.



2 tau final state

2, Chargino/Neutrilino pair production with 2 hadronically decaying τ

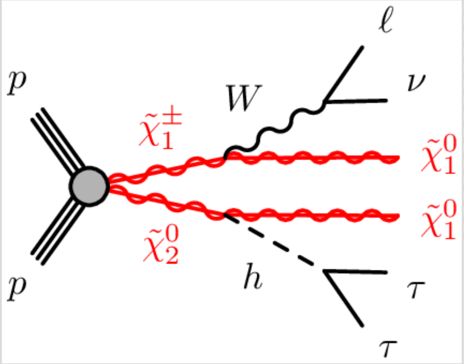
- Decay *via $\tilde{\tau}$* and decay *via Wh* to two tau final state.

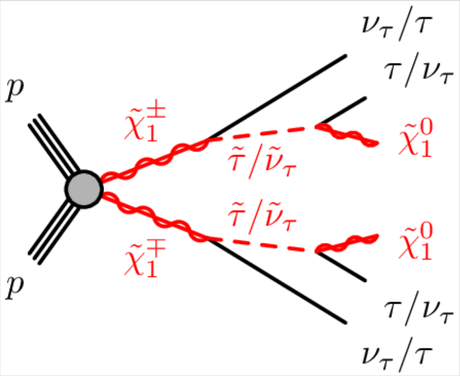
SR optimization

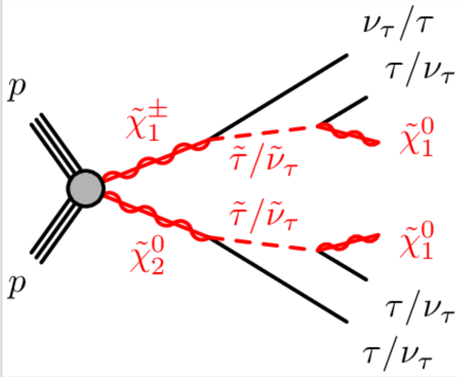
- Via $\tilde{\tau}$ decay has two tau opposite sign (OS) or same sign (SS) charge SRs.
- All channels have LM and HM SR.

Background estimation:

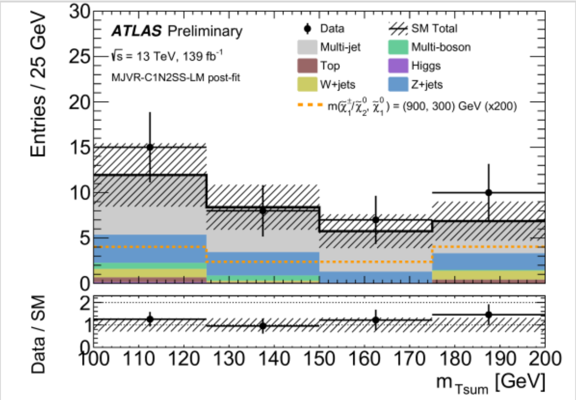
- *Via stau*: Multi-boson is the dominant background, estimated by MC simulated and checked in VRs; Top processes: dedicated CRs; Fake Tau Contribution(Multijets) are estimated by ABCD method.
- *Via Wh:* Top processes are the dominant *1 Fake tau contribution*, estimated by dedicated CRs. The *2 Fake tau contribution* is estimated by fake factor method.

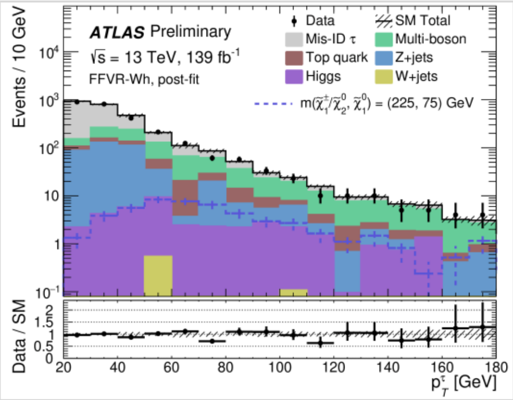






The main systematic uncertainties are statistics of the MC samples, jet energy scale and resolution, dibosons theoretical uncertainty.

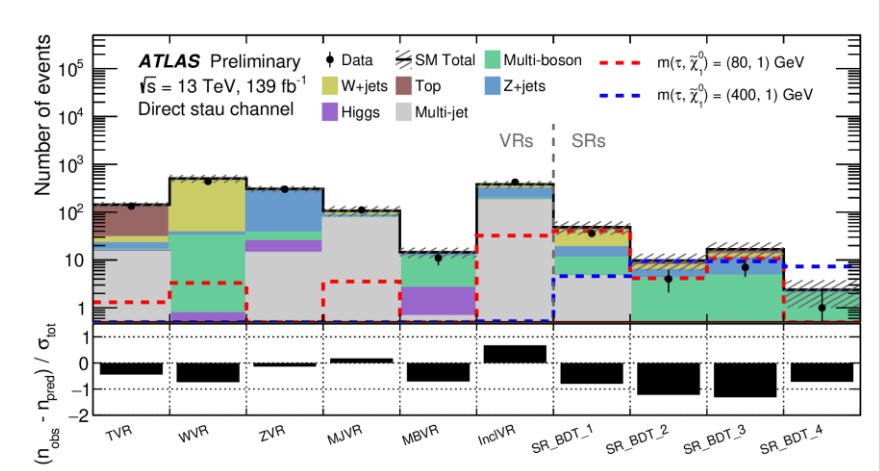


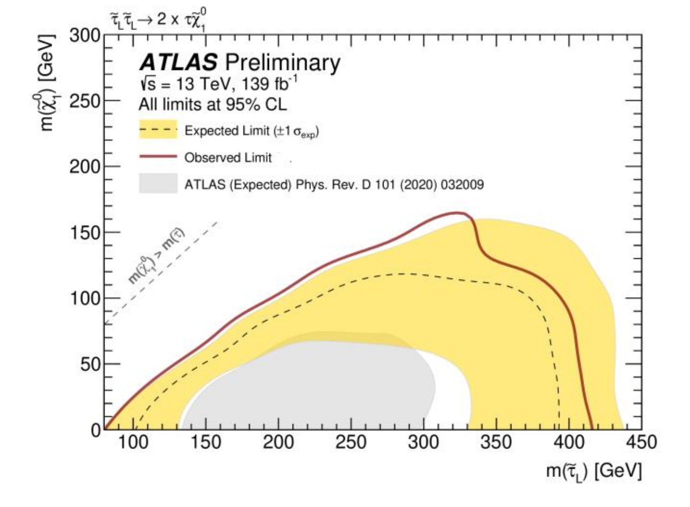


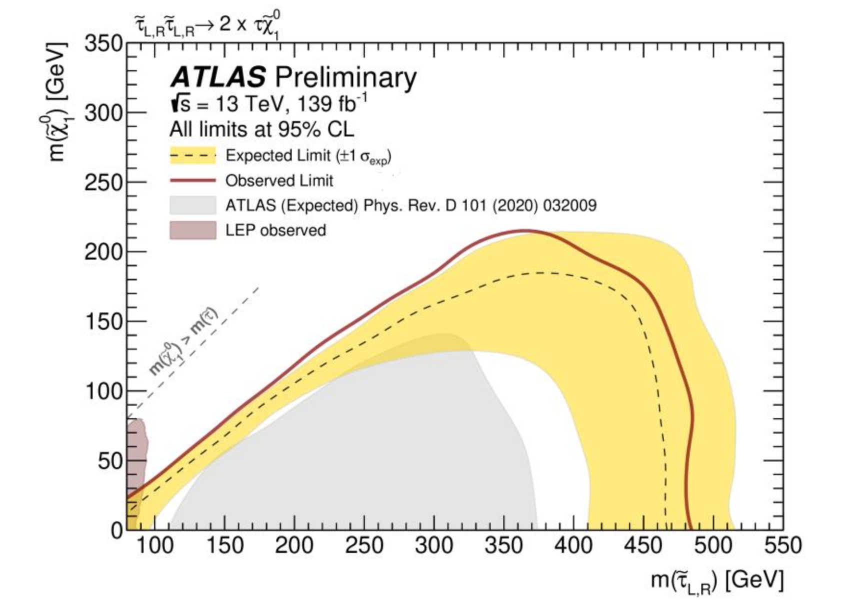
2 tau final state

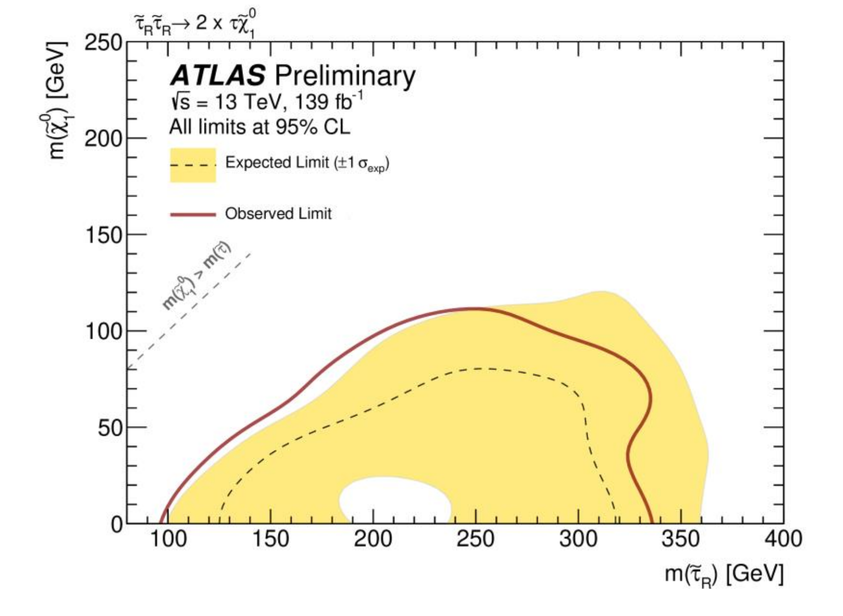
1, Stau ($\tilde{\tau}$) pair production

- Common deficit of significance 0.7 – 1.3 σ, caused by the overlap between SRs.
- For mass-degenerate $\tilde{\tau}_L$, $\tilde{\tau}_R$ production, stau masses up to 480 GeV are excluded.
- The bump in the observed limit around stau masses of 350 GeV is due to a transition from one SR-BDT to another.
- Sensitivity to $\tilde{\tau}_R$ production is obtained for the first time at the LHC, with masses excluded up to 330 GeV.





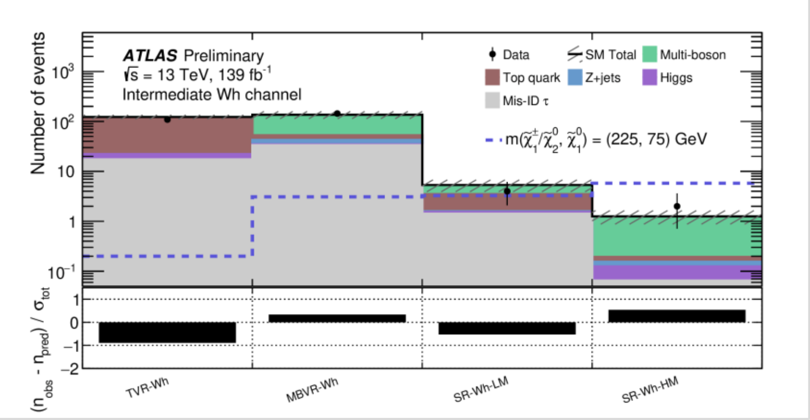


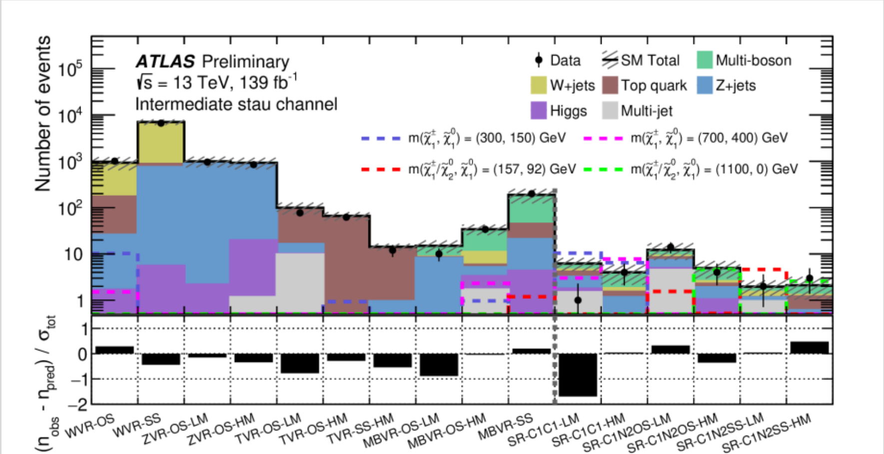


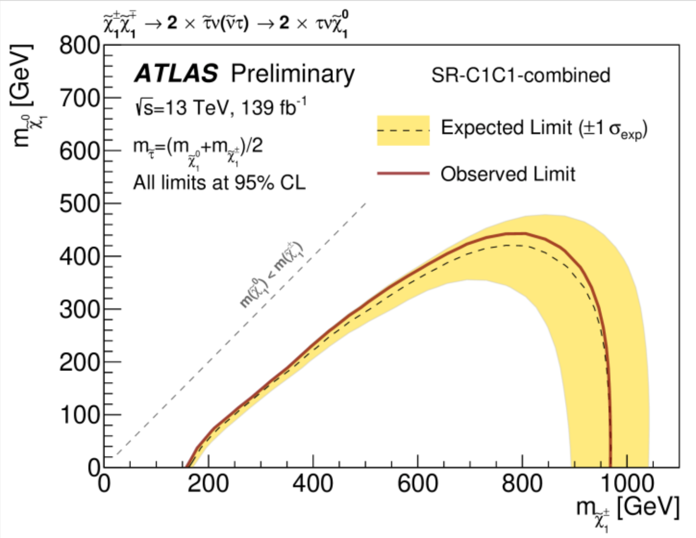
2 tau final state

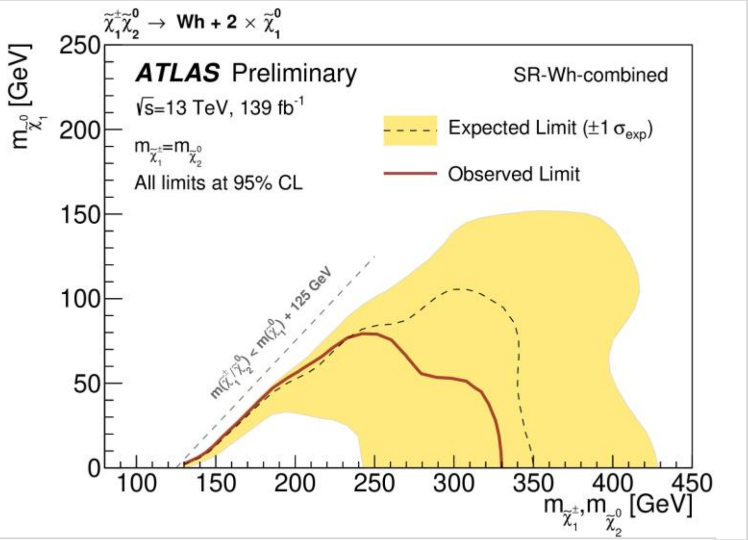
2, Chargino/Neutrilino pair production with 2 hadronically decaying τ

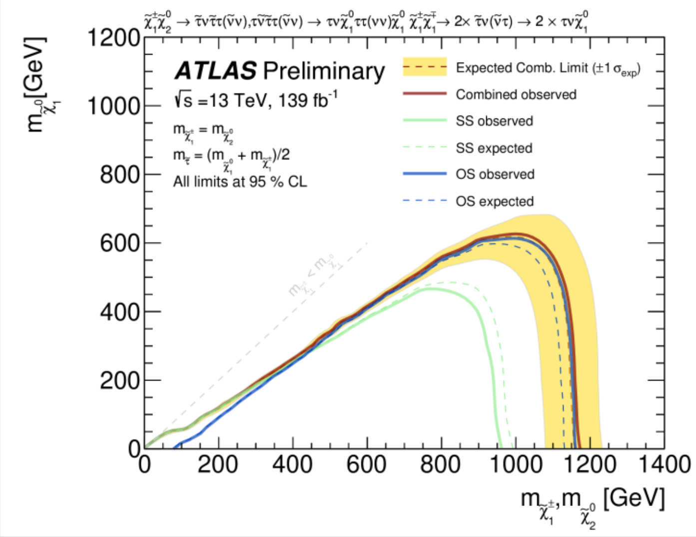
- chargino masses up to 970 GeV and Gaugino masses up to 1.16 TeV are excluded for a massless LSP.
- SS improves sensitive @compressed and low mass region.

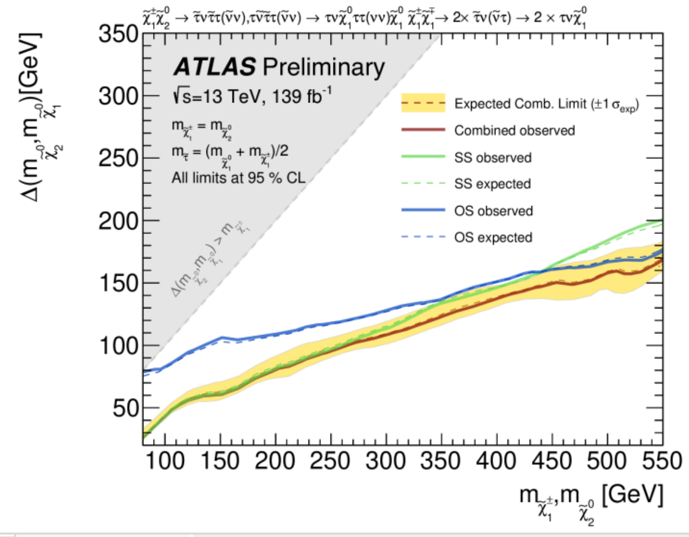












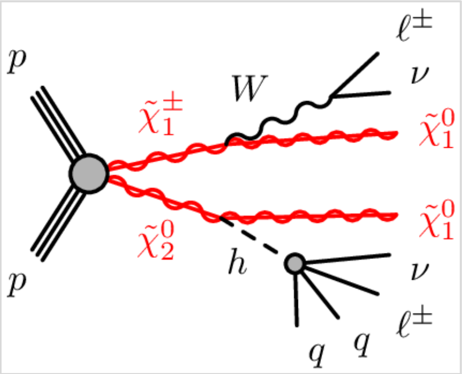
Multi-lep final state and Prompt RPV Search

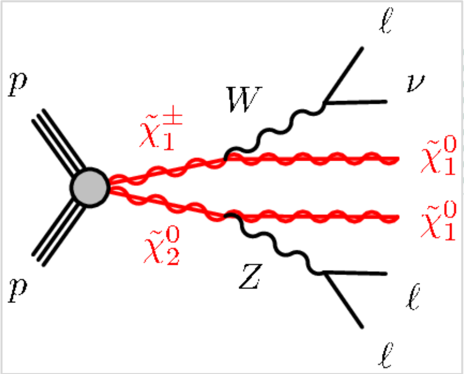
SS/3L: [2305.09322]

Multi-lep final state and Prompt RPV Search

$\tilde{\chi}_1^{\pm}\,\tilde{\chi}_2^{0}$ pair production

- Wino-like NLSP decays via on-shell WZ or Wh boson pair and bino-like LSP.
- In Wh channel, all possible decays of higgs that result in 1L are considered.



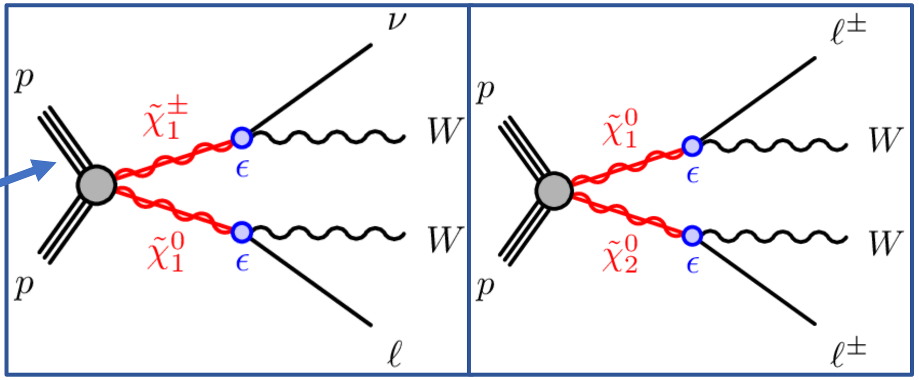


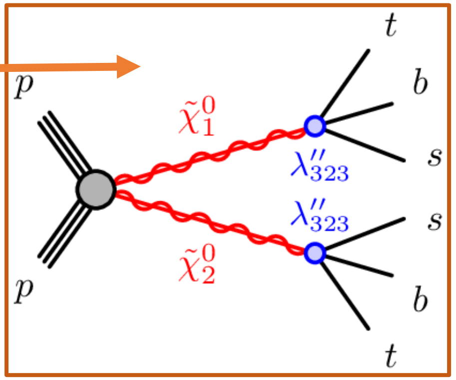
Higgsino pair production

- $\tilde{\chi}_1^{\pm}\,\tilde{\chi}_1^{\mp}$, $\tilde{\chi}_1^{\pm}\,\tilde{\chi}_2^{0}$, $\tilde{\chi}_1^{\pm}\,\tilde{\chi}_1^{0}$, $\tilde{\chi}_1^{0}\,\tilde{\chi}_2^{0}$
- RPV susy can't provide DM candidate.
- RPV superpotential:
  - $W_{RPV\{L\}} \supset \frac{1}{2}\lambda_{ijk}\,\hat{L}_i\,\hat{L}_j\,\hat{E}_k + \lambda'_{ijk}\hat{L}_i\,\hat{Q}_j\,\hat{D}_k - \epsilon_i\,\hat{L}_i\,\hat{H}_u$
  - $W_{RPV\{B\}} \supset \frac{1}{2}\lambda''_{ijk}\,\hat{U}_i\,\hat{D}_j\,\hat{D}_k$

bilinear RPV term

trilinear RPV term





- **bRPV term** could give neutrino mass.
- **Baryon-number violation term** is featured in grand unified theories and models with black holes. And can describe the observed baryon asymmetry.

Multi-lep final state and Prompt RPV Search

$\tilde{\chi}_1^{\pm}\,\tilde{\chi}_2^0$ pair production

- m_{T2} is used to define two sets of SRs for Wh and WZ separately (Wh/WZ-LM/HM).
- Multi-bin strategy is applied in HM SRs.

Higgsino pair production

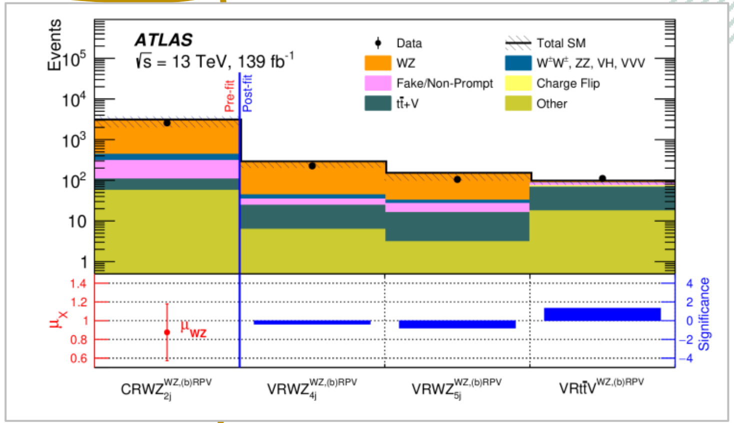
- Since the existence of the neutrino, E_T^{miss} is still useful.
- Two jets and three jets signal region.

Irreducible Background: *Dibosons, top processes*

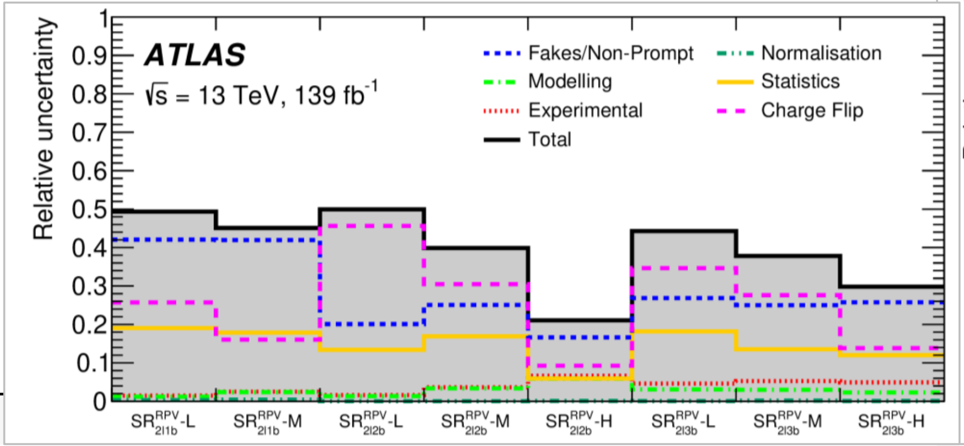
CRs are defined

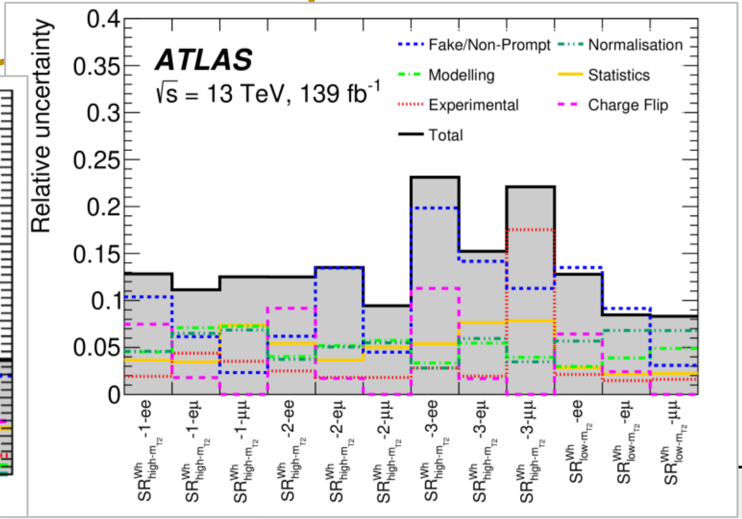
Reducible Background: *lepton charge flip, Fake/non-prompt lepton*

- *lepton charge flip: reweighted data events with two OS leptons*
- *Fake/non-prompt lepton: fake-factor method for Wh,*
  matrix method for WZ and RPV channels,
  template method for validation.



- **Dominant Syst Unc** is from FNP for all channels

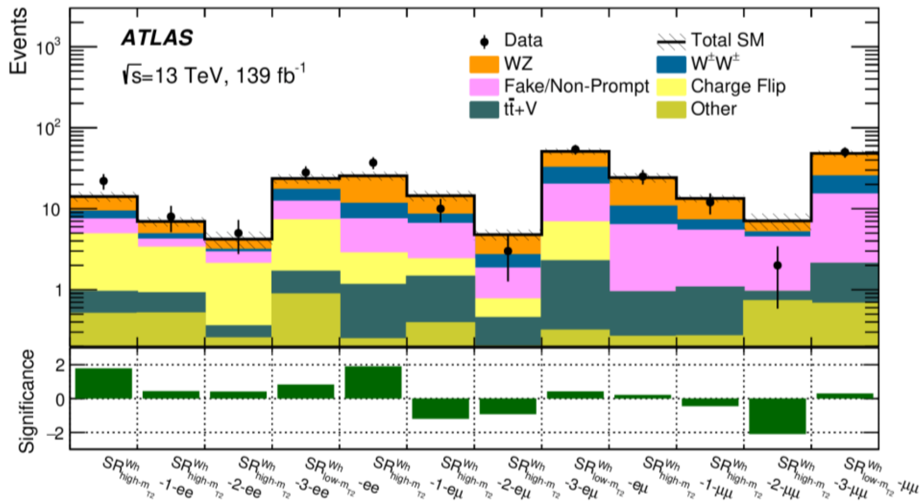


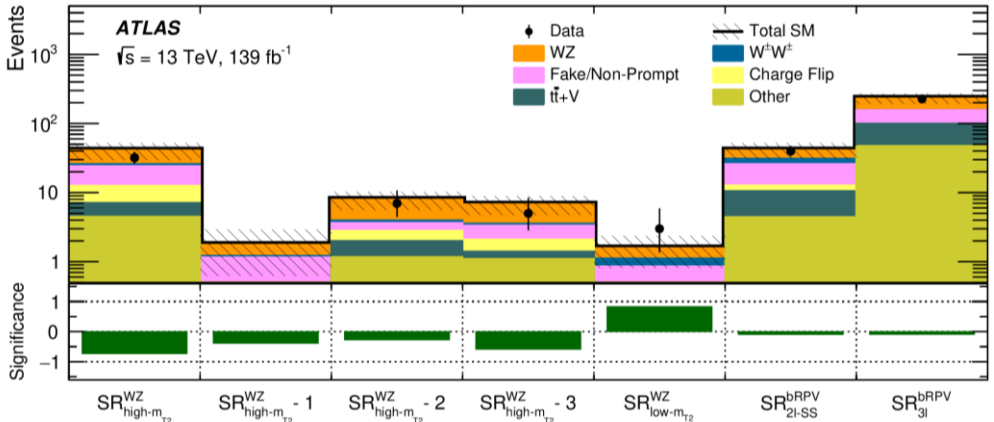


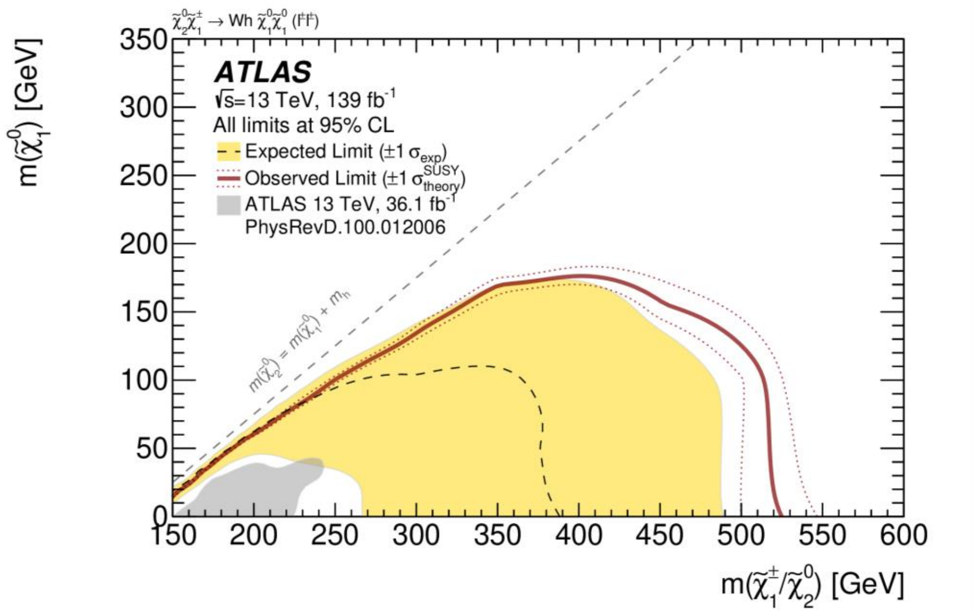
Multi-lep final state and Prompt RPV Search

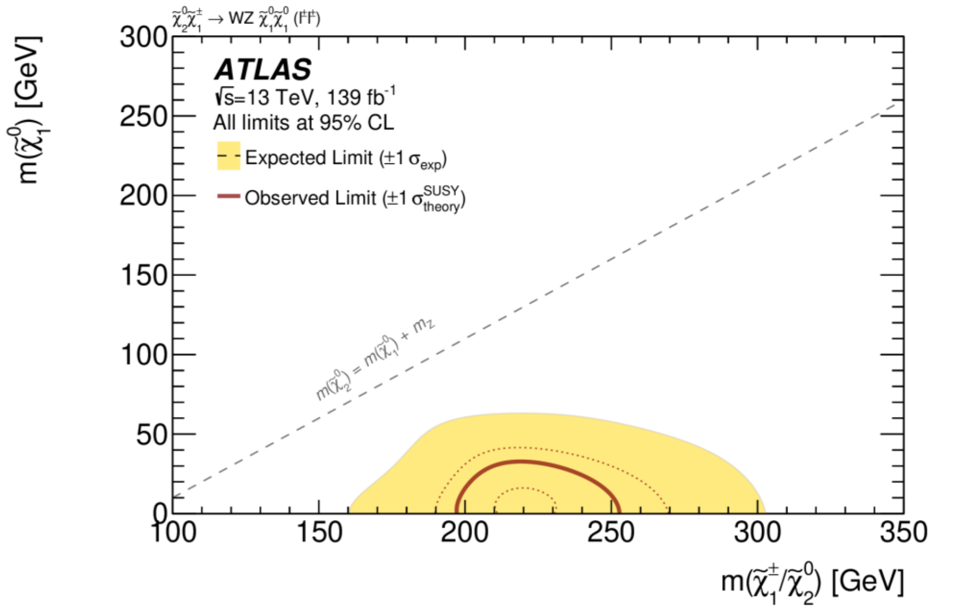
$\tilde{\chi}_1^{\pm}\ \tilde{\chi}_2^{0}$ pair production

- The deficit in data is due to statistical fluctuation.
- In Wh channel, Next-to-LSP masses of up to 525 GeV have been excluded for a massless LSP.





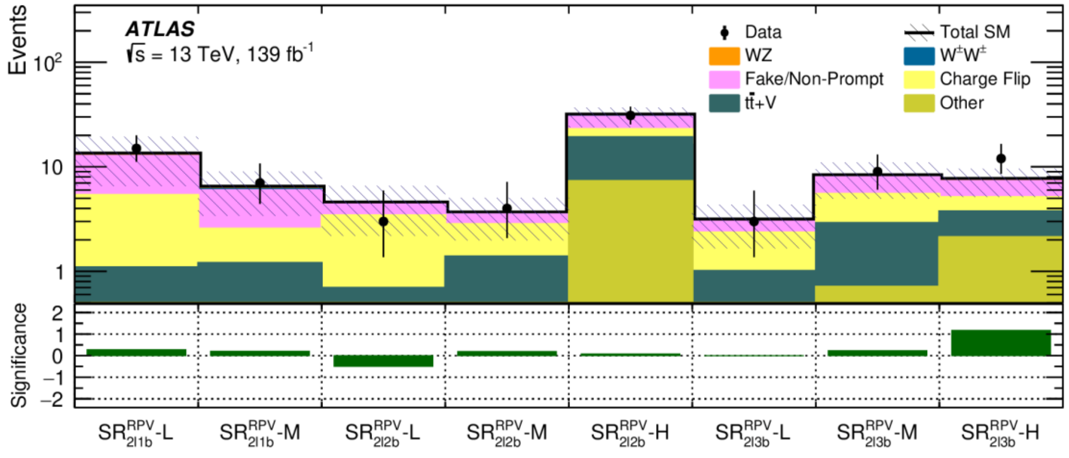




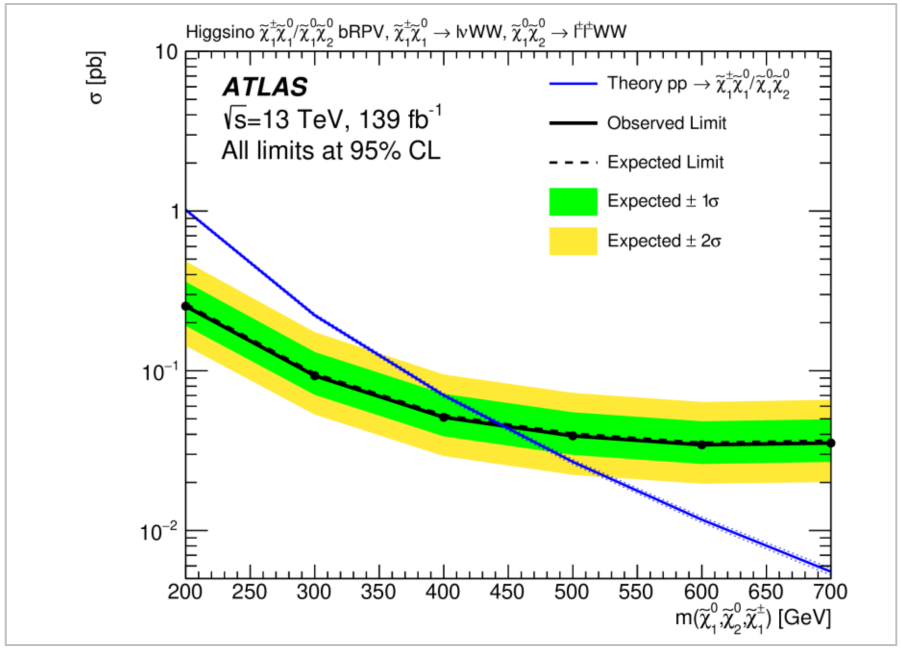
Multi-lep final state and Prompt RPV Search

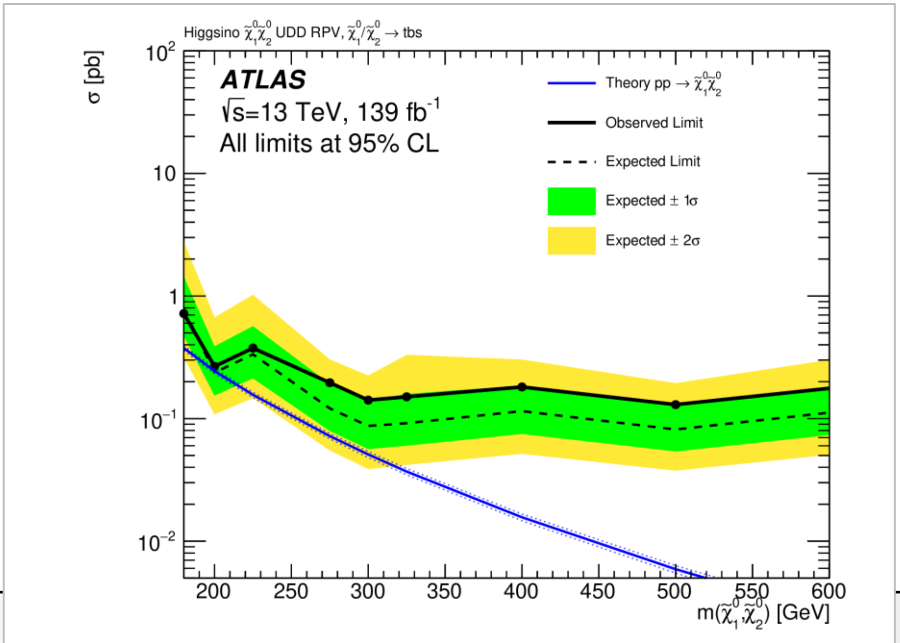
Higgsino pair production

- Observed data are compatible with SM prediction in RPV SRs



- Assuming inclusive higgsino pair production and all predicted RPV decay modes, the exclusion limits is around 440 GeV.





Summary

The searches for EWK production SUSY…

- Push forward to close difficult SUSY phase space gaps
- Extend to higher SUSY masses
- Extend coverage to more models

No significant excess was observed on top of the SM predictions, and exclusion limits have been placed on the parameters space for Slepton and Gauginos

- Exclusion on chargino/neutralino mass reaches to O(1) TeV

Run-3 has started.

Looking forward to more exciting results with Run 3 data.

Thank you!

B A C K U P S

a supersymmetry primer

- https://arxiv.org/pdf/hep-ph/9709356.pdf

It is often useful to recast matter parity in terms of R-parity, defined for each particle as

$$P_R = (-1)^{3(B-L)+2s} \qquad (6.2.5)$$

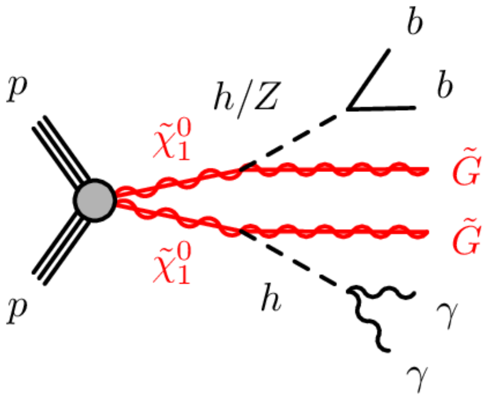
where s is the spin of the particle. Now, matter parity conservation and R-parity conservation are precisely equivalent, since the product of $(-1)^{2s}$ for the particles involved in any interaction vertex in a theory that conserves angular momentum is always equal to +1. However, particles within the same supermultiplet do not have the same R-parity. In general, symmetries with the property that fields within the same supermultiplet have different transformations are called R symmetries; they do not commute with supersymmetry. Continuous $U(1)$ R symmetries were described in section 4.11, and are

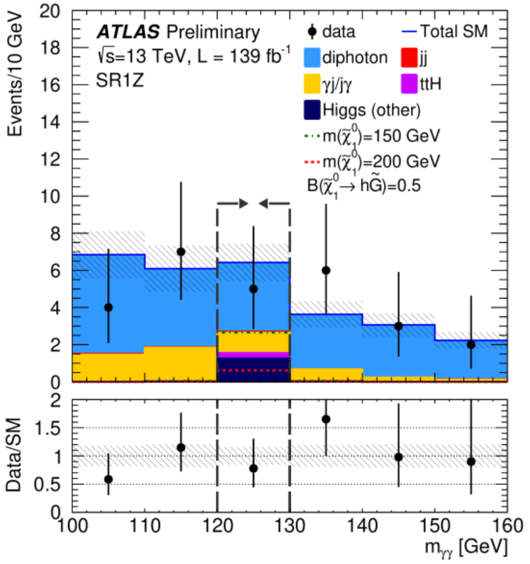
Names		spin 0	spin 1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks	Q	$(\widetilde{u}_L \ \widetilde{d}_L)$	$(u_L \ d_L)$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})$
(×3 families)	$\overline{u}$	$\widetilde{u}^*_R$	$u^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})$
	$\overline{d}$	$\widetilde{d}^*_R$	$d^\dagger_R$	$(\overline{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$
sleptons, leptons	L	$(\widetilde{\nu} \ \widetilde{e}_L)$	$(\nu \ e_L)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$
(×3 families)	$\overline{e}$	$\widetilde{e}^*_R$	$e^\dagger_R$	$(\mathbf{1}, \mathbf{1}, 1)$
Higgs, higgsinos	H_u	$(H_u^+ \ H_u^0)$	$(\widetilde{H}_u^+ \ \widetilde{H}_u^0)$	$(\mathbf{1}, \mathbf{2}, +\frac{1}{2})$
	H_d	$(H_d^0 \ H_d^-)$	$(\widetilde{H}_d^0 \ \widetilde{H}_d^-)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$

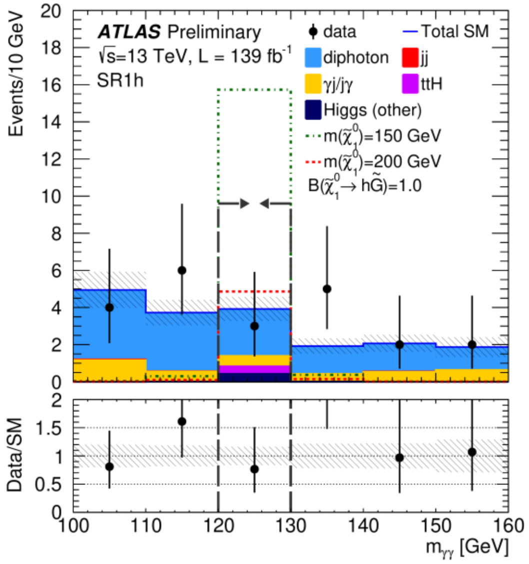
Names	spin 1/2	spin 1	$SU(3)_C, SU(2)_L, U(1)_Y$
gluino, gluon	$\widetilde{g}$	g	$(\mathbf{8}, \mathbf{1}, 0)$
winos, W bosons	$\widetilde{W}^\pm \ \widetilde{W}^0$	$W^\pm \ W^0$	$(\mathbf{1}, \mathbf{3}, 0)$
bino, B boson	$\widetilde{B}^0$	B^0	$(\mathbf{1}, \mathbf{1}, 0)$

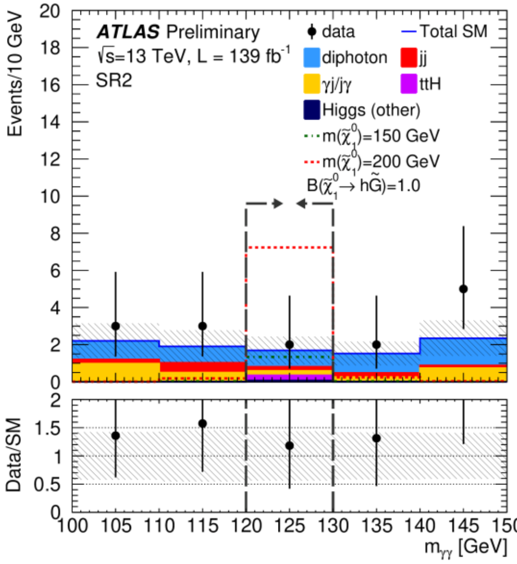
EWK GMSB

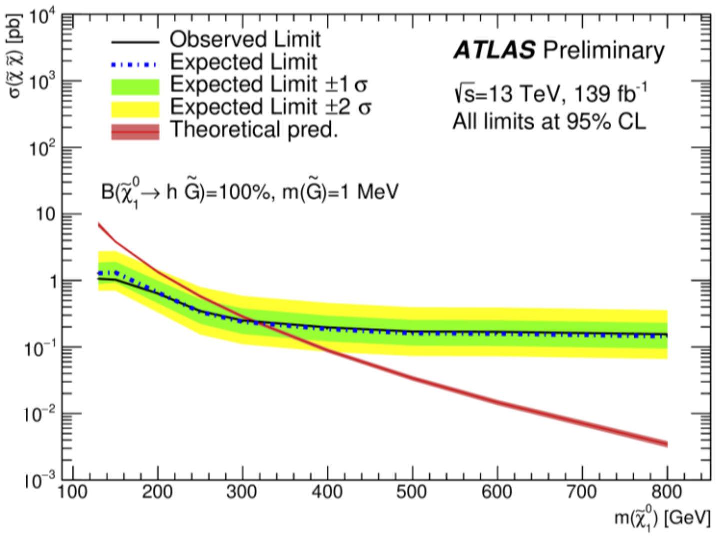
- https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2023-009/
- gauge-mediated supersymmetry models, $\tilde{\chi}^1_0$ decays to a light gravitino $\tilde{G}$

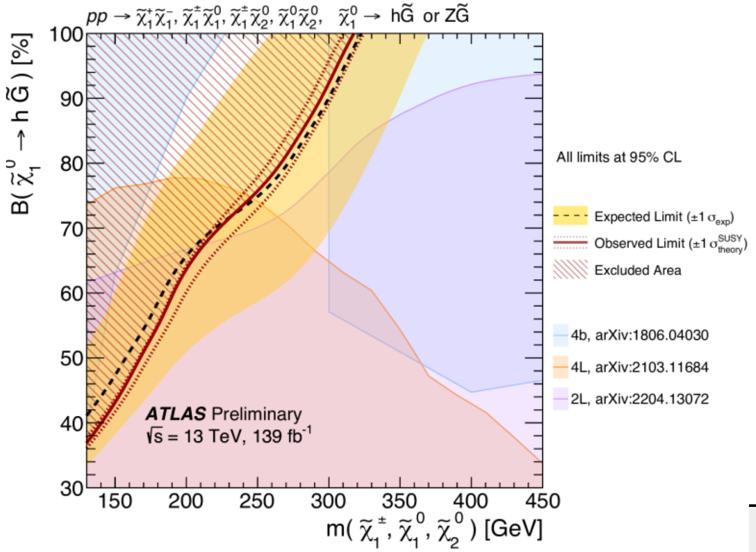












2L region definitions

Table 2: The definitions of the binned and inclusive signal regions for the slepton model. Relevant kinematic variables are defined in the text. The '0J' and '1J' labels refer to the multiplicity of non-b-tagged jets.

Signal region (SR)	SR-0J	SR-1J
$n_{b\text{-tagged jets}}$	$= 0$	
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	>7	
$n_{\text{non-}b\text{-tagged jets}}$	$= 0$	$= 1$
$p_{\mathrm{T}}^{\ell_1}$ [GeV]	> 140	> 100
$p_{\mathrm{T}}^{\ell_2}$ [GeV]	> 20	> 50
$m_{\ell\ell}$ [GeV]	> 11	> 60
$p_{\mathrm{T,boost}}^{\ell\ell}$ [GeV]	< 5	-
$\lvert\cos\theta^{*}_{\ell\ell}\rvert$	< 0.2	< 0.1
$\Delta\phi_{\ell,\ell}$	> 2.2	> 2.8
$\Delta\phi_{p_{\mathrm{T}}^{\mathrm{miss}},\ell_1}$	> 2.2	-
Binned SRs		
m_{T2}^{100} [GeV]	$\in[100,105)$	
	$\in[105,110)$	
	$\in[110,115)$	
	$\in[115,120)$	
	$\in[120,125)$	
	$\in[125,130)$	
	$\in[130,140)$	
	$\in[140,\infty)$	
Inclusive SRs		
m_{T2}^{100} [GeV]	$\in[100,\infty)$	
	$\in[110,\infty)$	
	$\in[120,\infty)$	
	$\in[130,\infty)$	
	$\in[140,\infty)$	

Table 3: The definitions of the binned and inclusive signal regions for the chargino model. Relevant variables are defined in the text. The signal regions are separated for DF and SF, except for the first inclusive SR (subsequently indicated with $\mathrm{SR}^{\text{-DF BDT-signal}\in(0.81,1]}_{\text{-SF BDT-signal}\in(0.77,1]}$), which contains DF events with BDT-signal $\in(0.81,1]$ and SF events with BDT-signal $\in(0.77,1]$.

Signal region (SR)	SR-DF	SR-SF
$n_{b\text{-tagged jets}}$	$= 0$	
$n_{\text{non-}b\text{-tagged jets}}$	$= 0$	
$E_{\mathrm{T}}^{\mathrm{miss}}$ significance	>8	
m_{T2} [GeV]	>50	
BDT-other		< 0.01
Binned SRs		
BDT-signal	$\in(0.81,0.8125]$	$\in(0.77,0.775]$
	$\in(0.8125,0.815]$	$\in(0.775,0.78]$
	$\in(0.815,0.8175]$	$\in(0.78,0.785]$
	$\in(0.8175,0.82]$	$\in(0.785,0.79]$
	$\in(0.82,0.8225]$	$\in(0.79,0.795]$
	$\in(0.8225,0.825]$	$\in(0.795,0.80]$
	$\in(0.825,0.8275]$	$\in(0.80,0.81]$
	$\in(0.8275,0.83]$	$\in(0.81,1]$
	$\in(0.83,0.8325]$	
	$\in(0.8325,0.835]$	
	$\in(0.835,0.8375]$	
	$\in(0.8375,0.84]$	
	$\in(0.84,0.845]$	
	$\in(0.845,0.85]$	
	$\in(0.85,0.86]$	
	$\in(0.86,1]$	
Inclusive SRs		
BDT-signal	$\in(0.81,1]$	$\in(0.77,1]$
	$\in(0.81,1]$	
	$\in(0.82,1]$	
	$\in(0.83,1]$	
	$\in(0.84,1]$	
	$\in(0.85,1]$	
		$\in(0.77,1]$
		$\in(0.78,1]$
		$\in(0.79,1]$
		$\in(0.80,1]$

FSB method

- Method
  - DF -> SF by:

$$N_{ee}^{\text{expected}} = 0.5 \times \frac{1}{\kappa} \times \alpha \times N_{\text{DF}}$$

$$N_{\mu\mu}^{\text{expected}} = 0.5 \times \kappa \times \alpha \times N_{\text{DF}}$$

$$N_{\text{SF}}^{\text{expected}} = 0.5 \times \left(\kappa + \frac{1}{\kappa}\right) \times \alpha \times N_{\text{DF}}$$

$$\kappa = \sqrt{\frac{N_{\mu^+\mu^-}}{N_{e^+e^-}}}$$

$$\alpha = \frac{\sqrt{\epsilon_{\mu\mu}^{\text{trig}} \epsilon_{ee}^{\text{trig}}}}{\epsilon_{e\mu}^{\text{trig}}}$$

  - k is extracted from a CR close to SR, parameterized as a function of leading lep pT and computed in different eta region

$$\kappa = a + b/p_{\text{T}}^{\ell_1}$$

  - Different sample efficiencies are studied.

  - α is extracted in another SR

$$\epsilon^{trig} = \frac{N^{pass\ cuts\ and\ singlepTrig}}{N^{pass\ cuts}}$$

  - Data-MC comparison shows a good agreement

- Uncertainty:
  - α: Data-MC comparison
  - k: the difference between global k and the one in η bin.
  - Subleading lepton pT as the reweighting method.
  - Uncertainty on the fit of $\kappa = a + b/p_{\text{T}}^{\ell_1}$
  - 10% overall uncertainty.

Matrix method (MM)

- Method
  - T: leptons passing the tight identification criteria
  - L: leptons that at least pass the loose criteria (inclusive loose).
  - l: Leptons passing loose but not tight are called exclusive loose.
  - The real efficiency, r, is the probability that a real prompt lepton passes the loose & tight id.
  - The fake rate, f, is the probability for an FNP lepton that passes loose & tight.

$$\begin{bmatrix} N_{TT} \\ N_{Tl} \\ N_{lT} \\ N_{ll} \end{bmatrix} = \begin{bmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1)r_2 & (1-r_1)f_2 & (1-f_1)r_2 & (1-f_1)f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{bmatrix} \begin{bmatrix} N_{LL}^{RR} \\ N_{LL}^{RF} \\ N_{LL}^{FR} \\ N_{LL}^{FF} \end{bmatrix}$$

$$\begin{aligned} N_{LL}^{RR} &= (1-f_1)(1-f_2)N_{TT} - [f_2(1-f_1)]\, N_{Tl} - [f_1(1-f_2)]\, N_{lT} + f_1 f_2 N_{ll} \\ N_{LL}^{RF} &= -(1-f_1)(1-r_2)N_{TT} + [r_2(1-f_1)]\, N_{Tl} + [f_1(1-r_2)]\, N_{lT} + f_1 r_2 N_{ll} \\ N_{LL}^{RF} &= -(1-f_2)(1-r_1)N_{TT} + [f_2(1-r_1)]\, N_{Tl} + [r_1(1-f_2)]\, N_{lT} + f_2 r_1 N_{ll} \\ N_{LL}^{FF} &= (1-r_1)(1-r_2)N_{TT} - [r_2(1-r_1)]\, N_{Tl} - [r_1(1-r_2)]\, N_{lT} + r_1 r_2 N_{ll}. \end{aligned}$$

$$\begin{aligned} N_{TT}^{RR} &= r_1 r_2 N_{LL}^{RR} \\ N_{TT}^{RF} &= r_1 f_2 N_{LL}^{RF} \\ N_{TT}^{FR} &= f_1 r_2 N_{LL}^{FR} \\ N_{TT}^{FF} &= f_1 f_2 N_{LL}^{FF}. \end{aligned}$$

  - p_T: $f_{total}(p_T) = \Sigma\, f_i(p_T)\, w_i(p_T)$
  - A series CR to extract r and f for different FNP sources.
  - Trigger influence is considered.
  - if there are 3 leps, apply on sub-leading and subsub-leading.
- Uncertainty
  - relative changes from Reco, ID, Isolation, Trigger.
  - subtraction of real lepton MC in HF fake rate estimation.
  - Fake component relative fraction
  - Reweight difference for the event which enters multiple CRs and has multiple weights.
  - Statistical uncertainty.

Signal region [GeV]	Observed	Expected	σ^{obs} [fb]	$S^{0.95}_{\text{obs}}$	$S^{0.95}_{\text{exp}}$	p_0
SR-0J $m_{T2}^{100} \in [100, \infty)$	58	76 ± 13	0.13	18.3	26^{+10}_{-7}	0.50
SR-0J $m_{T2}^{100} \in [110, \infty)$	39	58 ± 11	0.09	13.2	21^{+8}_{-6}	0.50
SR-0J $m_{T2}^{100} \in [120, \infty)$	30	40 ± 8	0.10	13.5	18^{+7}_{-5}	0.50
SR-0J $m_{T2}^{100} \in [130, \infty)$	23	24 ± 6	0.10	14.2	15^{+6}_{-4}	0.50
SR-0J $m_{T2}^{100} \in [140, \infty)$	7	9.2 ± 3.4	0.05	7.5	$8.6^{+4}_{-2.5}$	0.50
SR-1J $m_{T2}^{100} \in [100, \infty)$	82	78 ± 13	0.24	33.5	31^{+11}_{-8}	0.41
SR-1J $m_{T2}^{100} \in [110, \infty)$	39	50 ± 17	0.17	24.0	28^{+9}_{-7}	0.50
SR-1J $m_{T2}^{100} \in [120, \infty)$	12	16 ± 5	0.07	9.5	12^{+5}_{-3}	0.50
SR-1J $m_{T2}^{100} \in [130, \infty)$	2	6.9 ± 2.8	0.03	3.9	$6.1^{+3.0}_{-1.9}$	0.50
SR-1J $m_{T2}^{100} \in [140, \infty)$	0	2.4 ± 1.6	0.02	2.4	$3.4^{+2.2}_{-1.2}$	0.50

Signal region	Observed	Expected	σ^{obs} [fb]	$S^{0.95}_{\text{obs}}$	$S^{0.95}_{\text{exp}}$	p_0
SR -DF BDT-signal∈(0.81,1] -SF BDT-signal∈(0.77,1]	620	630 ± 70	1.20	166.2	$175.1^{+44.9}_{-49.2}$	0.50
SR-DF BDT-signal∈(0.81,1]	477	470 ± 50	0.80	111.0	$108.9^{+43.1}_{-31.1}$	0.47
SR-DF BDT-signal∈(0.82,1]	340	350 ± 40	0.55	76.0	$81.5^{+32.7}_{-22.9}$	0.50
SR-DF BDT-signal∈(0.83,1]	222	231 ± 26	0.38	52.3	$57.8^{+22.9}_{-16.1}$	0.50
SR-DF BDT-signal∈(0.84,1]	130	126 ± 15	0.29	40.0	$37.5^{+15.0}_{-10.5}$	0.41
SR-DF BDT-signal∈(0.85,1]	69	65 ± 10	0.22	30.9	$28.0^{+12.0}_{-8.3}$	0.38
SR-SF BDT-signal∈(0.77,1]	143	167 ± 32	0.47	65.5	$80.6^{+19.4}_{-23.0}$	0.50
SR-SF BDT-signal∈(0.78,1]	86	108 ± 23	0.31	42.8	$53.9^{+18.9}_{-13.6}$	0.50
SR-SF BDT-signal∈(0.79,1]	47	58 ± 15	0.21	28.9	$34.1^{+10.8}_{-7.8}$	0.50
SR-SF BDT-signal∈(0.80,1]	22	28 ± 8	0.10	14.3	$16.8^{+5.9}_{-4.5}$	0.50

1L SR,CR definitions

Variable	C1C1-WW model			C1N2-WZ model		
	SRLM	**SRMM**	**SRHM**	**SRLM**	**SRMM**	**SRHM**
N_{lep} ($p_{\mathrm{T}} > 25$ GeV)	1					
N_{jet} ($p_{\mathrm{T}} > 30$ GeV)	1 – 3					
$N_{\mathrm{large-Rjet}}$ ($p_{\mathrm{T}} > 250$ GeV)	≥ 1					
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 200					
$\Delta\phi(\ell, \mathrm{E}_{\mathrm{T}}^{\mathrm{miss}})$	< 2.6					
large-R jet type	W-tagged			Z-tagged		
m_{T} [GeV]	120–200	200–300	> 300	120–200	200–300	> 300
	Exclusion SR					
m_{eff} [GeV] (excl.)	[600–850, > 850]			[600–850, > 850]		
m_{jj}[GeV] (excl.)	[70–90, -]			[80–100, -]		
$\sigma_{E_{\mathrm{T}}^{\mathrm{miss}}}$ (excl.)	[> 12, > 15]			[> 12, > 12]		
	Discovery SR					
m_{eff} [GeV] (disc.)	> 600	> 600	> 850	> 600	> 850	> 850
m_{jj}[GeV] (disc.)	-	-	-	80–100	-	-
$\sigma_{E_{\mathrm{T}}^{\mathrm{miss}}}$ (disc.)	> 15	> 15	> 15	> 12	> 12	> 12

- The missing transverse energy significance, $\sigma_{E_{\mathrm{T}}^{\mathrm{miss}}}$ [99], is defined as the log-likelihood ratio of measuring the total observed transverse momentum to the likelihood of the null hypothesis,

$$\sigma_{E_{\mathrm{T}}^{\mathrm{miss}}} = \sqrt{2\ln\left[\frac{\max_{\boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}}\neq 0}\mathcal{L}\left(E_{\mathrm{T}}^{\mathrm{miss}}|\boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}}\right)}{\max_{\boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}}=0}\mathcal{L}\left(E_{\mathrm{T}}^{\mathrm{miss}}|\boldsymbol{p}_{\mathrm{T}}^{\mathrm{inv}}\right)}\right]}. \tag{2}$$

  A high value indicates that the measured $E_{\mathrm{T}}^{\mathrm{miss}}$ value is not compatible with resolution effects only and suggests that the event is more likely to contain objects escaping detection, which happens more in the signal events than the background events.

The discovery SRs are constructed for model-independent limits and null-hypothesis tests ('disc.' for discovery). The various m_{eff} bins are merged for each of the three SRs and selections on m_{jj} and $\sigma_{E_{\mathrm{T}}^{\mathrm{miss}}}$ are optimized for the best signal sensitivity on a benchmark point for each m_{eff} bin. The signal and background

Signal channel	Observed events	Total SM background	$\langle\epsilon\sigma\rangle^{95}_{\rm obs}$[fb]	$S^{95}_{\rm obs}$	$S^{95}_{\rm exp}$	$\mathrm{CL_B}$	p_0	Z
C1C1-WW model								
SRLM (disc.)	16	11.6 ± 1.6	0.09	13.0	$8.8^{+4.3}_{-1.5}$	0.84	0.14	1.09
SRMM (disc.)	9	9.8 ± 2.0	0.06	7.9	$9.0^{+5.4}_{-1.4}$	0.42	0.50	0.00
SRHM (disc.)	12	10.8 ± 2.5	0.07	10.4	$9.4^{+4.1}_{-3.0}$	0.60	0.39	0.29
C1N2-WZ model								
SRLM (disc.)	17	18.4 ± 2.9	0.08	11.5	$13.7^{+4.0}_{-4.5}$	0.40	0.50	0.00
SRMM (disc.)	9	5.7 ± 1.3	0.07	10.2	$6.8^{+3.1}_{-0.9}$	0.87	0.13	1.11
SRHM (disc.)	21	13.7 ± 2.3	0.13	17.5	$10.5^{+4.4}_{-2.4}$	0.92	0.06	1.54

DiTau

Table 1: Summary of the selection requirements for the stau pair production SRs.

<table>
<tr><td></td><td colspan="4">BDT Training Preselection</td></tr>
<tr><td></td><td colspan="4">≥ 2 “medium” τ (OS)
asymmetric di-tau Trigger
e, μ, b-jet veto
$E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV
$m_{\mathrm{T2}} > 30$ GeV
$m(\tau_1, \tau_2) > 120$ GeV
$\Delta R(\tau_1, \tau_2) < 4$</td></tr>
<tr><td></td><td>SR-BDT1</td><td>SR-BDT2</td><td>SR-BDT3</td><td>SR-BDT4</td></tr>
<tr><td>Target
scenario</td><td>Low $m_{\tilde{\tau}}$
Small $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0)$</td><td>Mid $m_{\tilde{\tau}}$
Large $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0)$</td><td>Mid $m_{\tilde{\tau}}$
Small $\Delta m(\tilde{\tau}, \tilde{\chi}_1^0)$</td><td>High $m_{\tilde{\tau}}$</td></tr>
<tr><td></td><td colspan="4">= 2 “medium” τ</td></tr>
<tr><td>Bin 1
Bin 2</td><td>BDT1 score $\in (0.73, 0.78)$
BDT1 score > 0.78</td><td>BDT2 score $\in (0.78, 0.82)$
BDT2 score > 0.82</td><td>BDT3 score $\in (0.79, 0.86)$
BDT3 score > 0.86</td><td>BDT4 score > 0.64
–</td></tr>
</table>

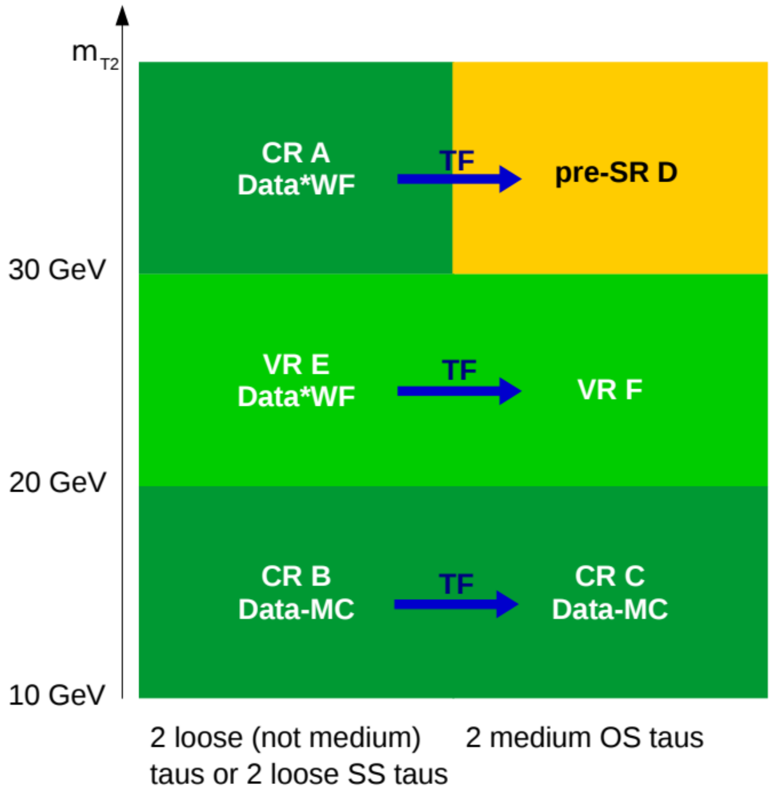
Table 3: Summary of the selection requirements for the gaugino pair production SRs for channels that decay via an intermediate stau.

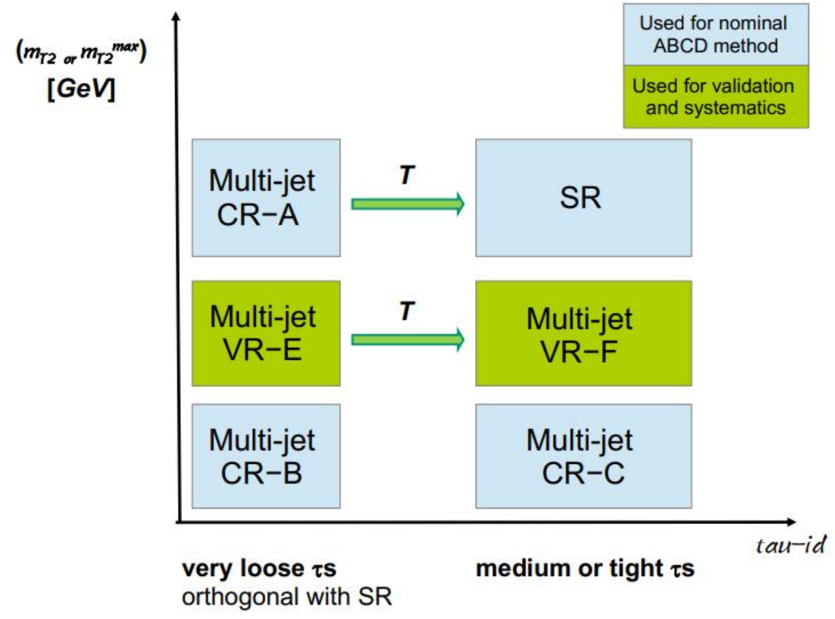
<table>
<tr><td>SR-C1C1-LM</td><td>SR-C1N2OS-LM</td><td>SR-C1N2SS-LM</td></tr>
<tr><td>= 2 “medium” τ (OS)</td><td>≥ 2 “medium” τ (OS)</td><td>≥ 2 “medium” τ (SS)</td></tr>
<tr><td colspan="2">≥ 1 “tight” τ</td><td>-</td></tr>
<tr><td colspan="3">asymmetric di-tau trigger
$E_{\mathrm{T}}^{\mathrm{miss}} < 150$ GeV
b-jet veto</td></tr>
<tr><td>-</td><td colspan="2">$N_{\mathrm{jets}} < 3$</td></tr>
<tr><td>$|\Delta\phi(\tau_1, \tau_2)| > 1.6$</td><td>-</td><td>$|\Delta\phi(\tau_1, \tau_2)| > 1.5$</td></tr>
<tr><td colspan="2">Z/h veto ($m(\tau_1, \tau_2) > 120$ GeV)</td><td>-</td></tr>
<tr><td colspan="2">$E_{\mathrm{T}}^{\mathrm{miss}} > 60$ GeV</td><td>$m_{\mathrm{Tsum}} > 200$ GeV</td></tr>
<tr><td>$m_{\mathrm{T2}} > 80$ GeV</td><td>$m_{\mathrm{T2}} > 70$ GeV</td><td>$m_{\mathrm{T2}} > 80$ GeV</td></tr>
<tr><td>SR-C1C1-HM</td><td>SR-C1N2OS-HM</td><td>SR-C1N2SS-HM</td></tr>
<tr><td>= 2 “medium” τ (OS)</td><td>≥ 2 “medium” τ (OS)</td><td>≥ 2 “medium” τ (SS)</td></tr>
<tr><td colspan="3">di-tau + $E_{\mathrm{T}}^{\mathrm{miss}}$ trigger
$E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV
b-jet veto</td></tr>
<tr><td colspan="2">Z/h veto ($m(\tau_1, \tau_2) > 120$ GeV)
$m_{\mathrm{Tsum}} > 400$ GeV
$m_{\mathrm{T2}} > 85$ GeV</td><td>-
$m_{\mathrm{Tsum}} > 450$ GeV
$m_{\mathrm{T2}} > 80$ GeV</td></tr>
</table>

Table 6: Summary of selection requirements for the SRs of gaugino pair production decaying to an intermediate Wh for low mass and high mass regions. The two SRs are not orthogonal.

<table>
<tr><td>SR-Wh-LM</td><td>SR-Wh-HM</td></tr>
<tr><td colspan="2">= 1 light lepton
≥ 2 “medium” τ (OS)
b-jet veto
$|\Delta\phi(\tau_1, \tau_2)| < 3$</td></tr>
<tr><td>-</td><td>$\Delta R(\tau_1, \tau_2) < 2.2$</td></tr>
<tr><td>$90 < m(\tau_1, \tau_2) < 130$ GeV</td><td>$80 < m(\tau_1, \tau_2) < 160$ GeV</td></tr>
<tr><td>$m_{\mathrm{T2}} > 100$ GeV</td><td>$m_{\mathrm{T2}} > 80$ GeV</td></tr>
<tr><td>-</td><td>$m_{\mathrm{T},\ell} > 80$ GeV</td></tr>
<tr><td>-</td><td>$m_{Tsum} > 450$ GeV</td></tr>
</table>

BKG estimation





$$N^{preselect}_{fakebkg} = N^{preselect}_{AA,fakebkg} \times \mathrm{FF}^{\mathrm{CR}}_{\tau 1} \times \mathrm{FF}^{\mathrm{CR}}_{\tau 2}$$

$$\mathrm{FF}^{\mathrm{CR}}_{\tau 1} = \frac{N^{CR}_{AA,fakebkg}}{N^{CR}_{MA,fakebkg}}$$

$$\mathrm{FF}^{\mathrm{CR}}_{\tau 2} = \frac{N^{CR}_{MA,fakebkg}}{N^{CR}_{MM,fakebkg}}$$

$$N_{fakebkg} = N_{data} - N^{\geq 1 truthtau}_{MCbkg}$$

MM: >= 2 medium tau ; MA: leading tau pass medium, sub leading not medium ; AA: both two tau not medium

RPV SUSY through bilinear terms is strongly motivated by its inherent connection with neutrino physics [89–91]. Sneutrino vacuum expectation values (VEVs) introduce a mixing between neutrinos and neutralinos, leading to a see-saw mechanism that gives mass to one neutrino at tree level, with the other two neutrino masses being induced by loop effects [92, 93]. The same VEVs are also involved in the decay of the LSP, which is thus constrained by experimental neutrino measurements.

Table 1: Signal region definitions designed for the Wh model. The variables are defined in the text.

	$SR^{Wh}_{\text{high-}m_{T2}}$	$SR^{Wh}_{\text{low-}m_{T2}}$
	$e^\pm e^\pm$ | $e^\pm\mu^\pm$ | $\mu^\pm\mu^\pm$	$e^\pm e^\pm$ | $e^\pm\mu^\pm$ | $\mu^\pm\mu^\pm$
$N_{BL}(\ell)$	$= 2$	
$N_{Sig}(\ell)$	$= 2$	
Charge(ℓ)	same-sign	
$p_T(\ell)$	≥ 25 GeV	
n_{jets} ($p_T > 25$ GeV)	≥ 1	
$n_{b\text{-jets}}$	$= 0$	
m_{jj}	< 350 GeV	
m_{T2}	≥ 80 GeV	< 80 GeV
m_T^{min}	–	≥ 100 GeV
$S(E_T^{miss})$	≥ 7	≥ 6
E_T^{miss}	≥ 75 GeV	≥ 50 GeV
E_T^{miss} binning [GeV][a]	$SR^{Wh}_{\text{high-}m_{T2}}$-1: $\in [75, 125)$ $SR^{Wh}_{\text{high-}m_{T2}}$-2: $\in [125, 175)$ $SR^{Wh}_{\text{high-}m_{T2}}$-3: $\in [175, +\infty)$	–

[a] The E_T^{miss} binning applies separately to each flavour channel of $SR^{Wh}_{\text{high-}m_{T2}}$.

Table 2: Signal region definitions designed for the WZ model. The variables are defined in the text.

	$SR^{WZ}_{\text{high-}m_{T2}}$	$SR^{WZ}_{\text{low-}m_{T2}}$
$N_{BL}(\ell)$	$= 2$	
$N_{Sig}(\ell)$	$= 2$	
Charge(ℓ)	same-sign	
$p_T(\ell)$	≥ 25 GeV	
n_{jets} ($p_T > 25$ GeV)	≥ 1	
$n_{b\text{-jets}}$	$= 0$	
m_{jj}	≤ 350 GeV	
m_{T2}	≥ 100 GeV	≤ 100 GeV
m_T^{min}	≥ 100 GeV	≥ 130 GeV
E_T^{miss}	≥ 100 GeV	≥ 140 GeV
m_{eff}	–	≤ 600 GeV
$\Delta R(\ell^\pm, \ell^\pm)$	–	≤ 3
Bins	$S(E_T^{miss})$: $\in [0, 10)$, Spread(Φ) ≥ 2.2 $S(E_T^{miss})$: $\in [10, 13)$ $S(E_T^{miss})$: $\in [13, +\infty]$, $\Delta R(\ell^\pm, \ell^\pm) \geq 1$	–

Table 3: Signal region definitions designed for the bRPV model. The variables are defined in the text.

	$SR^{bRPV}_{2\ell\text{-SS}}$	$SR^{bRPV}_{3\ell}$
$N_{BL}(\ell)$	–	
p_T (ℓ)	≥ 20 GeV for (sub)leading leptons	
n_{jets} ($p_T > 25$ GeV)	≥ 1	
$N_{Sig}(\ell)$	$= 2$	$= 3$
Charge(ℓ)	same-sign	–
m_{T2}	≥ 60 GeV	≥ 80 GeV
E_T^{miss}	≥ 100 GeV	≥ 120 GeV
m_{eff}	–	≥ 350 GeV
$n_{b\text{-jets}}$	$= 0$	–
n_{jets} ($p_T > 40$ GeV)	≥ 4	–
$m_{e^\pm e^\mp}$, $m_{\mu^\pm\mu^\mp}$	–	$\notin [81, 101]$ GeV

	$SR^{RPV}_{2\ell 1b}$ L	$SR^{RPV}_{2\ell 1b}$ M	$SR^{RPV}_{2\ell 2b}$ L	$SR^{RPV}_{2\ell 2b}$ M	$SR^{RPV}_{2\ell 2b}$ H	$SR^{RPV}_{2\ell 3b}$ L	$SR^{RPV}_{2\ell 3b}$ M	$SR^{RPV}_{2\ell 3b}$ H
$N_{BL}(\ell)$	$= 2$							
$N_{Sig}(\ell)$	$= 2$							
Charge(ℓ)	same-sign							
$p_T(\ell)$	> 25 GeV							
n_{jets} ($p_T > 25$ GeV)	≥ 1							
$n_{b\text{-jets}}$	$= 1$		$= 2$			≥ 3		
$\sum p_T(\ell)$	≥ 100 GeV		–			–		
E_T^{miss}	≥ 100 GeV	≥ 50 GeV	≥ 80 GeV			≥ 20 GeV		
n_{jets} ($p_T > 25$ GeV)	≤ 2	$= 2$ or $= 3$	≤ 3	$=3$ or $= 4$	≥ 5 and ≤ 6	≤ 3	≤ 3	≤ 6
$\sum p_T^{b\text{-jet}} / \sum p_T^{jet}$	≥ 0.7	≥ 0.45	≥ 0.9	≥ 0.75	–	≥ 0.8	≥ 0.8	≥ 0.5
$\sum p_T^{jet}$	≥ 120 GeV	≥ 400 GeV	≥ 300 GeV	≥ 420 GeV	≥ 420 GeV	–	–	≥ 350 GeV
$\Delta R(\ell_1, \text{jet})_{min}$	≤ 1.2	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.5	–	≤ 1.0
$\Delta R(\ell^\pm, \ell^\pm)$	≥ 2.0	≥ 2.5	≥ 2.5	≥ 2.5	≥ 2.0	≥ 2.0	–	≥ 2.0

Lepton charge flip

$$w_{\text{flip}} = \xi_1(1-\xi_2) + (1-\xi_1)\xi_2$$

- Assuming electron charge flip rates: $X(p_T, \eta)$ where $\xi_{(i)} = 0$ for muons.
- the true charge flip rates are multiplied by the charge flip scale factors released by the Egamma T&P sub-group to obtain the charge flip rates in data. $\xi_{\text{Data}} = \xi_{\text{True}} \times SF; \quad (SF = \frac{\xi_{\text{Data}}}{\xi_{\text{MC}}})$
- True is measured in MC $\xi_{\text{True}} = \frac{N_{\text{GoodEleWrongQ}}}{N_{\text{GoodEle}}}$

- Traditional method: sources of events with two true/prompt electrons in the final state, comparing the yields of opposite-sign and same-sign pairs $\xi = \frac{N_{SS}}{N_{SS} + 2N_{OS}}$
- But it is not applicable when OS and SS have different kinematics. So two methods are considered.
  - If $p_T < 40\ GeV$ and $|\eta| < 1.37$, $\xi = \frac{N_{SS}}{N_{SS} + 2N_{OS}}$
  - If one electron $|\eta| < 0.08$ the other is from end-cap. Tag barrel, probe end-cap.
- The measured rates (ϵ) are used to obtain the charge-flip background estimate in a same-sign event selection,by re-weighting opposite-sign events in data by the factor:

$$w_{CF}(i,j) = \frac{\epsilon_1(i)\cdot[1-\epsilon_2(j)] + [1-\epsilon_1(i)]\cdot\epsilon_2(j)}{[1-\epsilon_1(i)]\cdot[1-\epsilon_2(j)] + \epsilon_1(i)\cdot\epsilon_2(j)}$$

- Uncertainty
  - MCstat:
  - SFstat
  - SFsys

Fake-factor method

- the signal lepton definition used in the analysis (called Tight or ID)
- and ii) a complementary selection (called Loose-Not-Tight or anti-ID
- In di-leptonic same-sign and same-flavour eventsCR:

$$FF_e(i) = \frac{N^{\text{Data}}_{\text{ID, CR\_FakeEl}}(i) - N^{\text{prompt MC}}_{\text{ID, CR\_FakeEl}}(i) - N^{\text{CF-est}}_{\text{ID, CR\_FakeEl}}(i)}{N^{\text{Data}}_{\text{anti-ID, CR\_FakeEl}}(i) - N^{\text{prompt MC}}_{\text{anti-ID, CR\_FakeEl}}(i) - N^{\text{CF-est}}_{\text{anti-ID, CR\_FakeEl}}(i)}$$

$$FF_\mu(i) = \frac{N^{\text{Data}}_{\text{ID, CR\_FakeMu}}(i) - N^{\text{prompt MC}}_{\text{ID, CR\_FakeMu}}(i)}{N^{\text{Data}}_{\text{anti-ID, CR\_FakeMu}}(i) - N^{\text{prompt MC}}_{\text{anti-ID, CR\_FakeMu}}(i)}$$

- The estimate of the total FNP lepton background in same-sign any region of interest and in each flavour channel

$$N^{FNP}_{e_1e_2} = FF_{e_1} \times \left(N^{\text{Data}}_{\not{e}_1 e_2} - N^{\text{prompt MC}}_{\not{e}_1 e_2} - N^{\text{CF-est}}_{\not{e}_1 e_2}\right) + FF_{e_2} \times \left(N^{\text{Data}}_{e_1\not{e}_2} - N^{\text{prompt MC}}_{e_1\not{e}_2} - N^{\text{CF-est}}_{e_1\not{e}_2}\right) - FF_{e_1} \times FF_{e_2} \times \left(N^{\text{Data}}_{\not{e}_1\not{e}_2} - N^{\text{prompt MC}}_{\not{e}_1\not{e}_2} - N^{\text{CF-est}}_{\not{e}_1\not{e}_2}\right)$$

$$N^{FNP}_{e\mu} = FF_e \times \left(N^{\text{Data}}_{\not{e}\mu} - N^{\text{prompt MC}}_{\not{e}\mu} - N^{\text{CF-est}}_{\not{e}\mu}\right) + FF_\mu \times \left(N^{\text{Data}}_{e\not{\mu}} - N^{\text{prompt MC}}_{e\not{\mu}} - N^{\text{CF-est}}_{e\not{\mu}}\right) - FF_e \times FF_\mu \times \left(N^{\text{Data}}_{\not{e}\not{\mu}} - N^{\text{prompt MC}}_{\not{e}\not{\mu}} - N^{\text{CF-est}}_{\not{e}\not{\mu}}\right)$$

$$N^{FNP}_{\mu_1\mu_2} = FF_{\mu_1} \times \left(N^{\text{Data}}_{\not{\mu}_1\mu_2} - N^{\text{prompt MC}}_{\not{\mu}_1\mu_2}\right) + FF_{\mu_2} \times \left(N^{\text{Data}}_{\mu_1\not{\mu}_2} - N^{\text{prompt MC}}_{\mu_1\not{\mu}_2}\right) - FF_{\mu_1} \times FF_{\mu_2} \times \left(N^{\text{Data}}_{\not{\mu}_1\not{\mu}_2} - N^{\text{prompt MC}}_{\not{\mu}_1\not{\mu}_2}\right)$$

- Uncertainties:
  - Fake-factors statistics
  - CR→SR extrapolation: CR->a SR-like region
  - Fake tag contamination
  - Prompt subtraction
  - Charge-flip subtraction

Matrix method & Template method

- ε: prompt leptons pass tight
- ζ: fake/non-prompt leptons pass tight

$$f_{\text{tight}}(i) = \varepsilon f_{\text{prompt}}(i) + \zeta\left(1 - f_{\text{prompt}}(i)\right)$$

$$n_{\text{fakes}}^{\text{tight}} = \zeta\left(1 - f_{\text{prompt}}(i)\right) n = \frac{\zeta}{\varepsilon - \zeta}\left(\varepsilon n - n_{\text{tight}}\right)$$

- semi-data driven: MC simulations extrapolate from CRs to SR
  - CR: electrons with charge flip
  - CR: electrons from light flavor sources
  - CR: electrons from heavy flavor sources
  - CR: fake muon
  - CR: $t\bar{t}W$
  - CR: WZ
  - …

Signal region	$\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$ [fb]	S^{95}_{obs}	S^{95}_{exp}	CL_b	p_0 (Z)
$\text{SR}^{Wh}_{\text{high-}m_{\text{T2}}}$	0.28	39.3	$33.9^{+14.3}_{-10.0}$	0.66	0.34 (0.41)
$\text{SR}^{Wh}_{\text{high-}m_{\text{T2}}}$-1-$ee$	0.13	17.4	$9.9^{+4.4}_{-2.8}$	0.94	0.04 (1.72)
$\text{SR}^{Wh}_{\text{high-}m_{\text{T2}}}$-1-$e\mu$	0.17	23.6	$12.9^{+5.6}_{-3.6}$	0.96	0.03 (1.85)
$\text{SR}^{Wh}_{\text{high-}m_{\text{T2}}}$-1-$\mu\mu$	0.09	13.0	$12.6^{+5.4}_{-3.6}$	0.55	0.45 (0.14)
$\text{SR}^{Wh}_{\text{high-}m_{\text{T2}}}$-2-$ee$	0.06	7.8	$7.2^{+3.1}_{-2.2}$	0.63	0.36 (0.36)
$\text{SR}^{Wh}_{\text{high-}m_{\text{T2}}}$-2-$e\mu$	0.05	6.8	$9.5^{+4.0}_{-2.7}$	0.16	0.50 (0.00)
$\text{SR}^{Wh}_{\text{high-}m_{\text{T2}}}$-2-$\mu\mu$	0.07	9.6	$7.7^{+0.6}_{-0.2}$	0.64	0.50 (0.00)
$\text{SR}^{Wh}_{\text{high-}m_{\text{T2}}}$-3-$ee$	0.05	6.9	$6.1^{+3.0}_{-1.6}$	0.61	0.37 (0.33)
$\text{SR}^{Wh}_{\text{high-}m_{\text{T2}}}$-3-$e\mu$	0.03	4.8	$6.1^{+3.0}_{-1.6}$	0.24	0.50 (0.00)
$\text{SR}^{Wh}_{\text{high-}m_{\text{T2}}}$-3-$\mu\mu$	0.03	4.3	$6.9^{+3.0}_{-2.0}$	0.06	0.50 (0.00)
$\text{SR}^{Wh}_{\text{low-}m_{\text{T2}}}$	0.24	33.0	$29.5^{+11.7}_{-8.8}$	0.63	0.33 (0.43)
$\text{SR}^{Wh}_{\text{low-}m_{\text{T2}}}$-$ee$	0.12	16.2	$12.6^{+5.4}_{-3.6}$	0.76	0.23 (0.76)
$\text{SR}^{Wh}_{\text{low-}m_{\text{T2}}}$-$e\mu$	0.14	19.9	$17.6^{+7.4}_{-5.1}$	0.63	0.36 (0.35)
$\text{SR}^{Wh}_{\text{low-}m_{\text{T2}}}$-$\mu\mu$	0.13	18.2	$17.0^{+7.0}_{-4.9}$	0.59	0.41 (0.22)
$\text{SR}^{WZ}_{\text{high-}m_{\text{T2}}}$	0.13	18.7	$24.4^{+6.8}_{-5.0}$	0.12	0.50 (0.00)
$\text{SR}^{WZ}_{\text{high-}m_{\text{T2}}}$-1	0.01	1.7	$3.6^{+1.3}_{-0.6}$	0.02	0.45 (0.12)
$\text{SR}^{WZ}_{\text{high-}m_{\text{T2}}}$-2	0.05	7.4	$8.3^{+3.2}_{-2.2}$	0.34	0.50 (0.00)
$\text{SR}^{WZ}_{\text{high-}m_{\text{T2}}}$-3	0.04	5.2	$7.3^{+2.7}_{-1.8}$	0.11	0.50 (0.00)
$\text{SR}^{WZ}_{\text{low-}m_{\text{T2}}}$	0.04	5.9	$4.4^{+1.8}_{-0.8}$	0.81	0.22 (0.76)
$\text{SR}^{\text{bRPV}}_{2\ell\text{-SS}}$	0.16	22.6	$25.8^{+7.9}_{-5.8}$	0.29	0.50 (0.00)
$\text{SR}^{\text{bRPV}}_{3\ell}$	0.44	61.4	$93.0^{+56.0}_{-20.3}$	0.02	0.50 (0.00)

Signal channel	$\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$ [fb]	S^{95}_{obs}	S^{95}_{exp}	CL_b	p_0 (Z)
$\text{SR}^{\text{RPV}}_{2\ell 1b}$-L	0.13	17.5	$15.1^{+4.8}_{-3.7}$	0.69	0.38 (0.32)
$\text{SR}^{\text{RPV}}_{2\ell 1b}$-M	0.07	10.1	$8.9^{+3.1}_{-1.7}$	0.66	0.46 (0.11)
$\text{SR}^{\text{RPV}}_{2\ell 2b}$-L	0.04	6.1	$6.2^{+2.4}_{-1.1}$	0.48	0.50 (0.00)
$\text{SR}^{\text{RPV}}_{2\ell 2b}$-M	0.05	6.8	$6.0^{+2.3}_{-1.2}$	0.65	0.38 (0.30)
$\text{SR}^{\text{RPV}}_{2\ell 2b}$-H	0.15	20.7	$18.6^{+6.0}_{-4.3}$	0.64	0.41 (0.22)
$\text{SR}^{\text{RPV}}_{2\ell 3b}$-L	0.04	6.1	$5.7^{+1.9}_{-1.0}$	0.61	0.50 (0.00)
$\text{SR}^{\text{RPV}}_{2\ell 3b}$-M	0.08	11.5	$9.7^{+3.2}_{-1.8}$	0.70	0.35 (0.37)
$\text{SR}^{\text{RPV}}_{2\ell 3b}$-H	0.10	13.5	$8.6^{+3.2}_{-2.5}$	0.92	0.10 (1.31)