



Searches for Supersymmetry with electroweakino production and same-sign or three lepton signature using Run2 ATLAS data

SUSY EWK SS/3L

[ATLAS-CONF-2022-057](#)

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On behalf of the ATLAS Collaboration
11 May 2023, LHC Red Madrid



EXCELENCIA
SEVERO
OCHOA

SUSY EWK SS/3L

- Presenting results of the Supersymmetry search
- [ATLAS-CONF-2022-057](#)
- Last steps towards publication in JHEP



ATLAS CONF Note

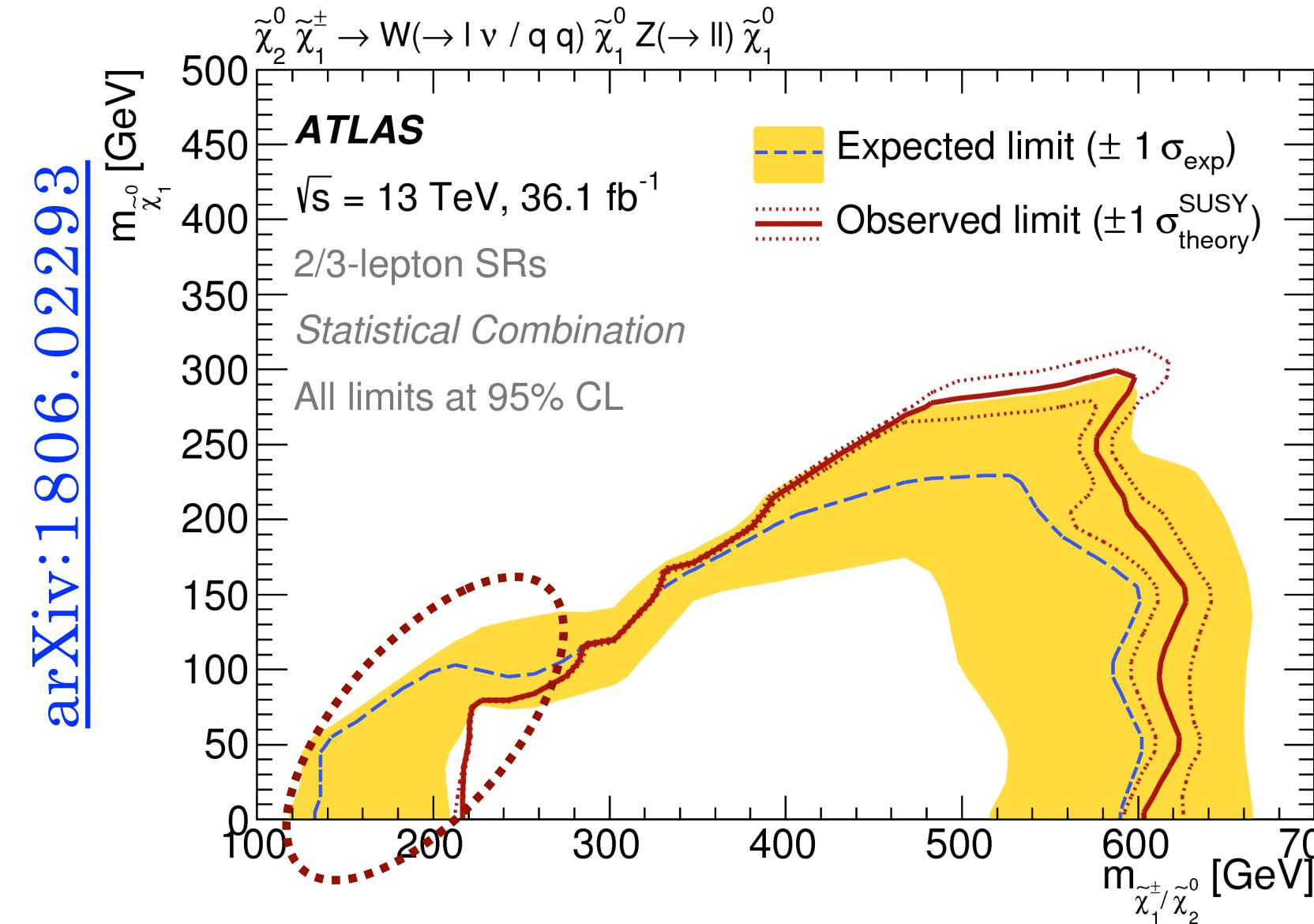
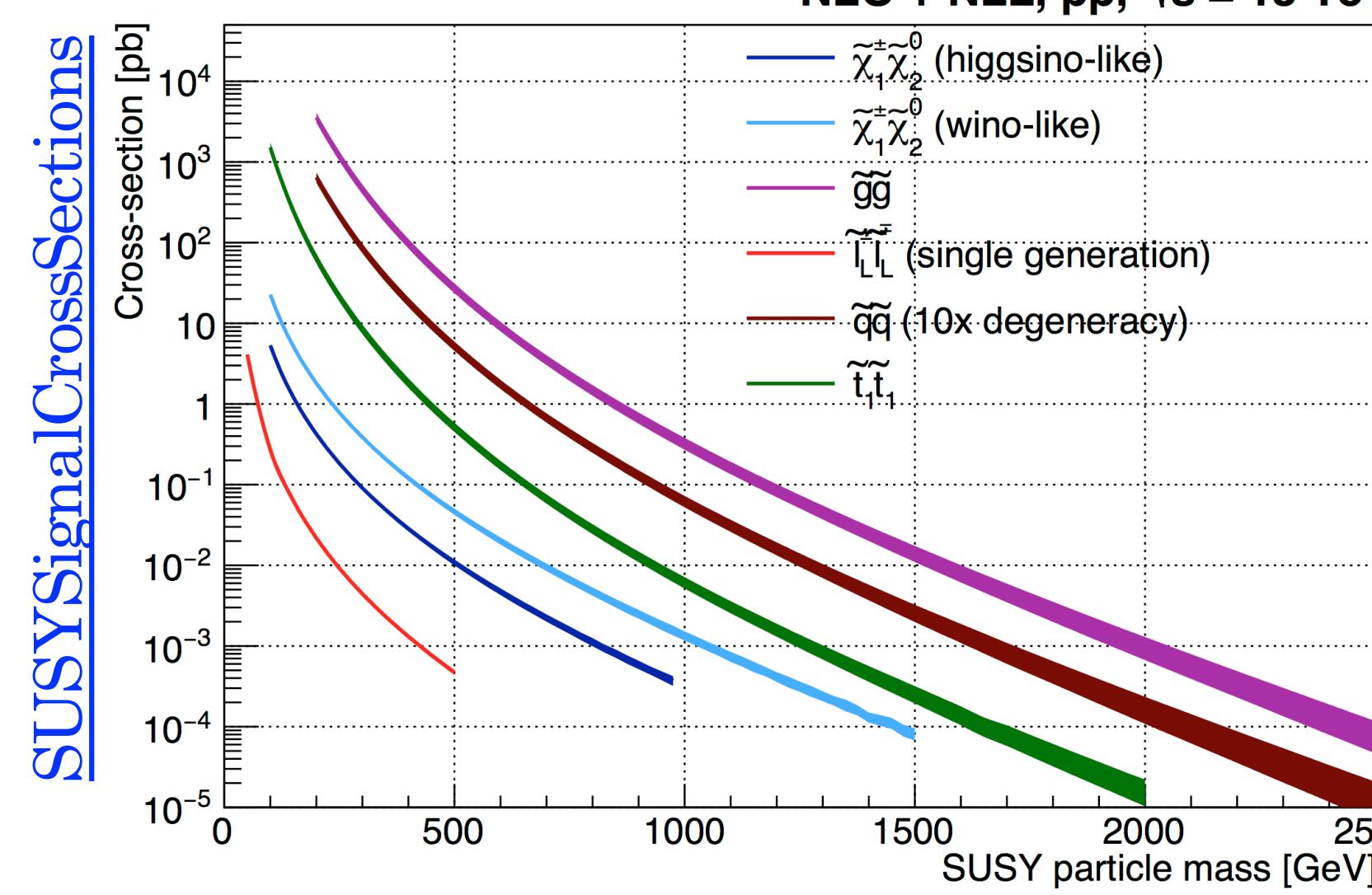
ATLAS-CONF-2022-057

9th September 2022

**Search for direct production of winos and higgsinos
in events with two same-sign or three leptons in $p p$
collision data at $\sqrt{s} = 13$ TeV with the ATLAS
detector**



Motivation

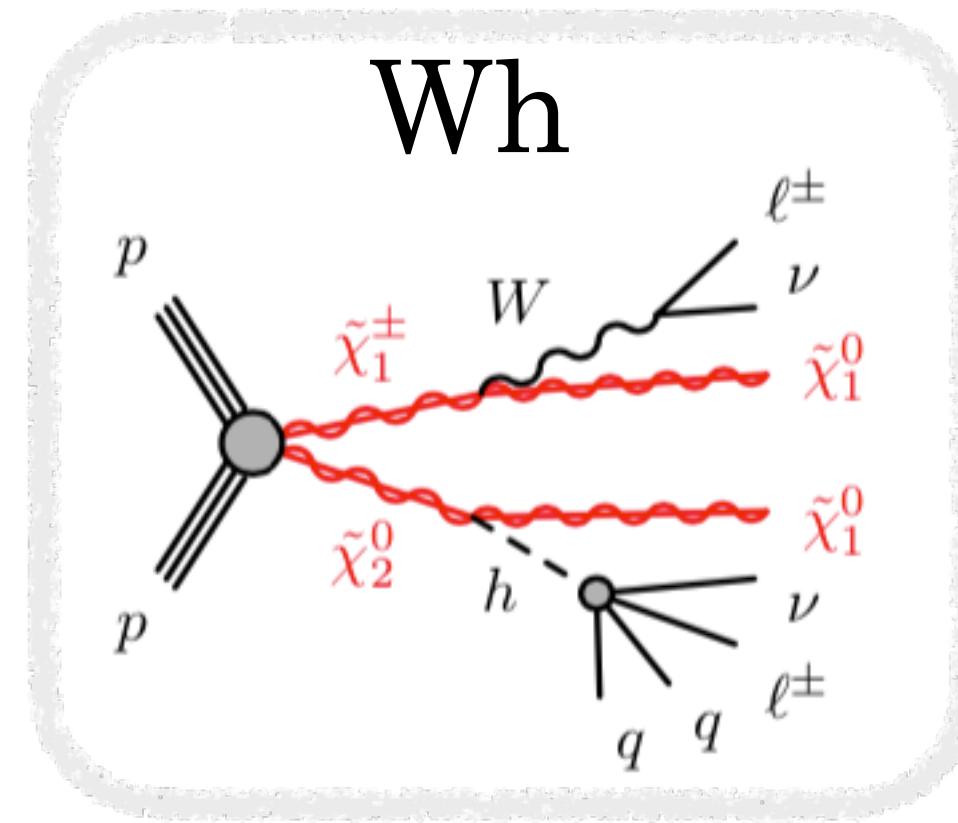


- Supersymmetry (SUSY) is a well motivated extension of the Standard Model, introduces a new set of particles at the high mass scale.
- Extensive searches for SUSY have been conducted at the LHC.
- With high integrated luminosity in Run2 **electroweak** searches viable.
- With high exclusion of RPC models more interest in **RPV** models.
- Previous searches for **wino** production have seen **small excesses** (3.02σ in the ISR region using 2015+2016 data). However, with more data this excess was disproven using opposite-sign search.
- **RPV** models using **higgsino** production were less studied at ATLAS.
- **Same-sign** (SS) signature offers a good background separation from Standard Model, it is orthogonal to the existing opposite-sign (OS) searches, important to have dedicated searches for these models using SS signature.

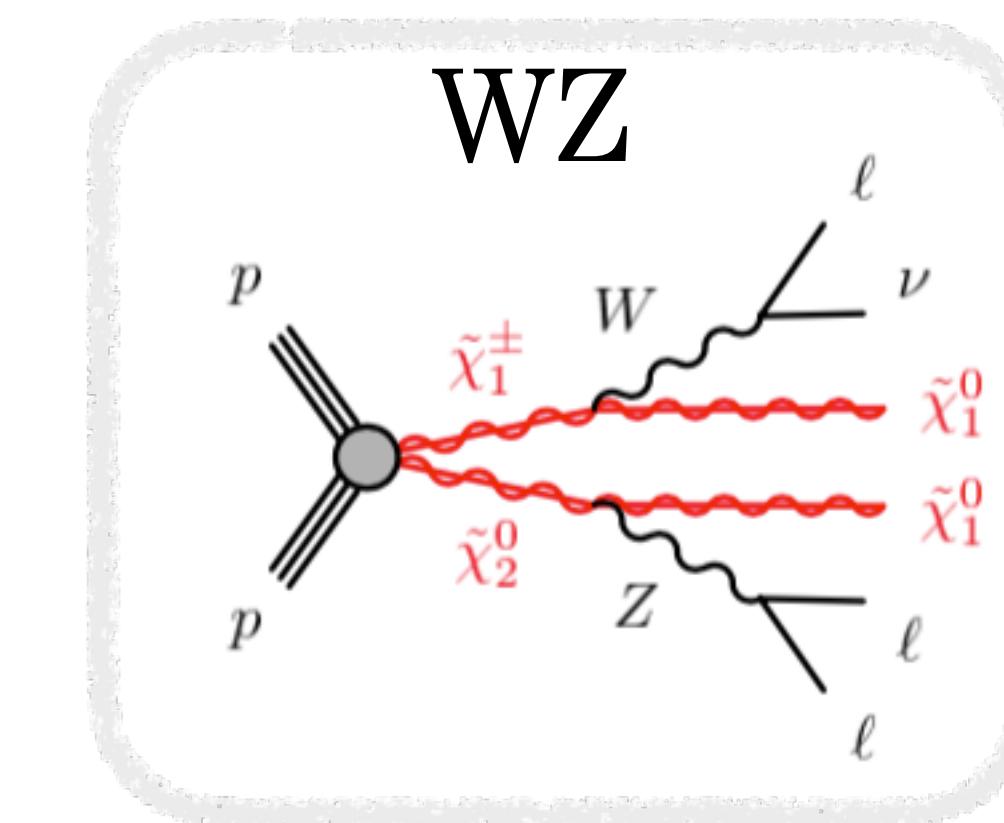
Models

- Analysis considers a variety of models motivated by the SS/3L signature
 - Consider wino (low cross-section) and higgsino (very low cross-section) production
 - Cover R-parity conserving (RPC) and R-parity violating (RPV) scenarios

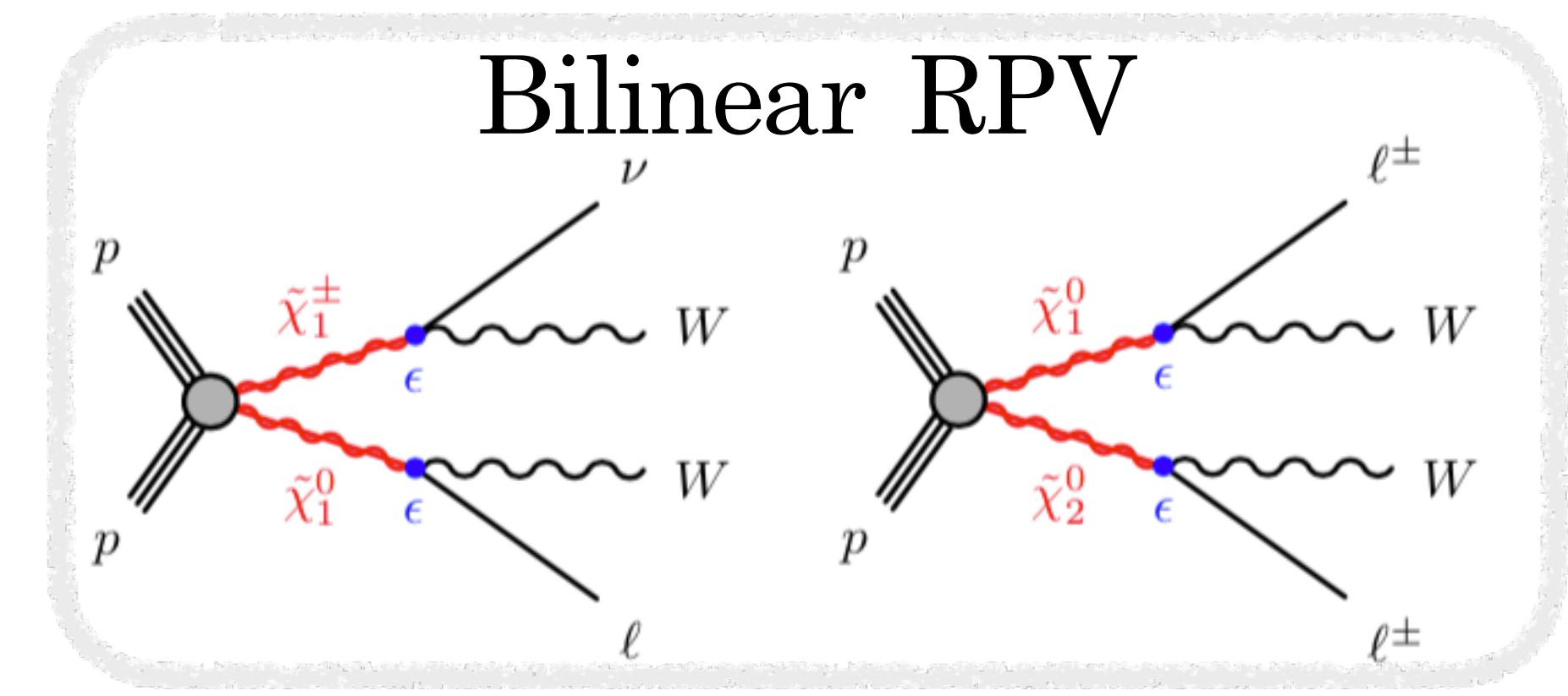
wino-like $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$



WZ



higgsino-like $\tilde{\chi}_1^\pm \tilde{\chi}_{1,2}^0, \tilde{\chi}_1^0 \tilde{\chi}_2^0$



Improves significantly compared to previous SS searches for this model.

Motivated by previous small excesses, complementary to OS searches, no dedicated search for this model using SS signature.

$$W_{R_P} = \frac{1}{2} \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \epsilon_i L_i H_2 + \frac{1}{2} \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

Bilinear terms related to neutrino oscillations, bRPV couplings determined as a fit to neutrino oscillation data. First search for this model using higgsino production.

Analysis strategy

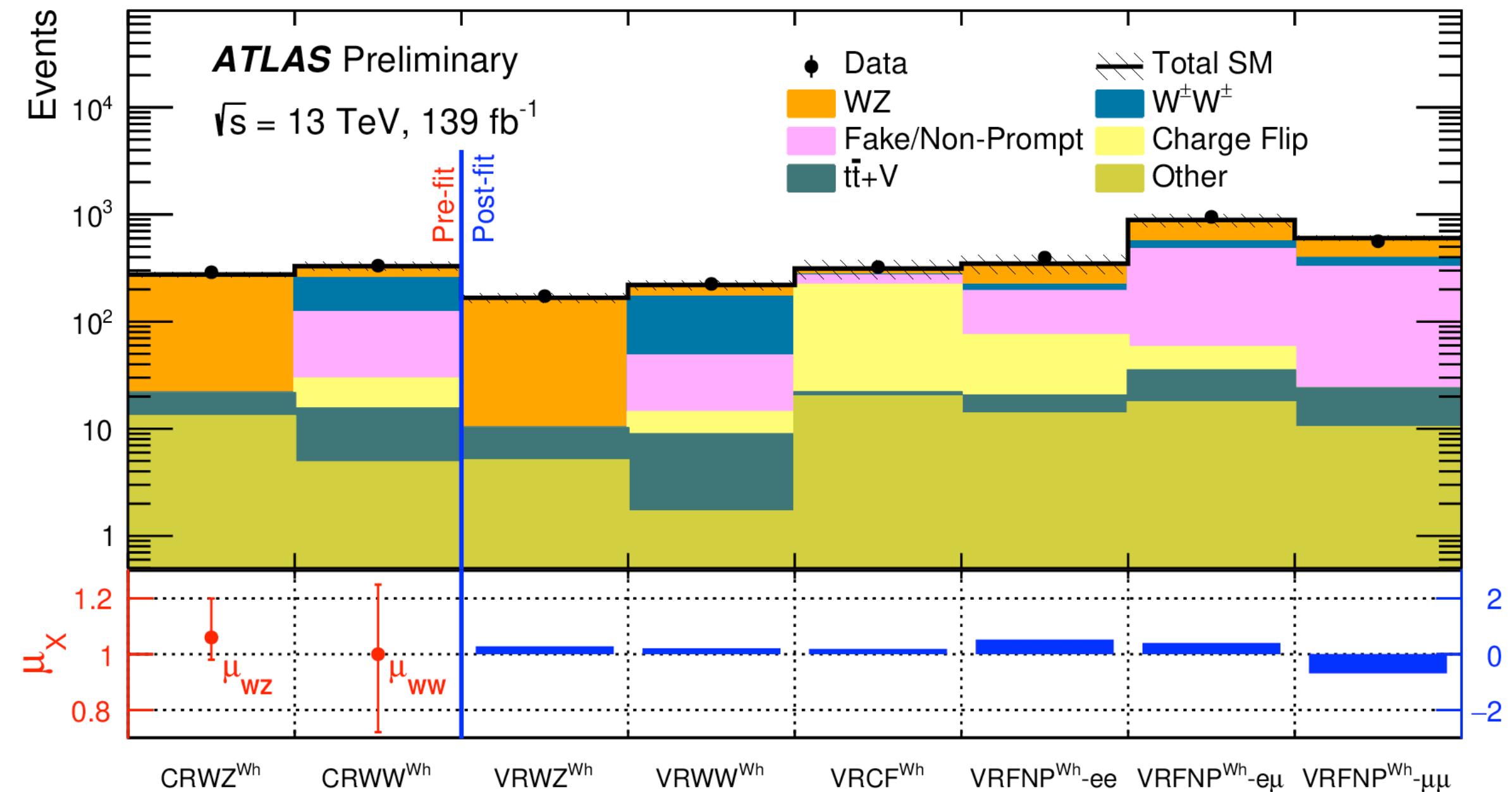
- Signal regions to maximise sensitivity for a model
 - WZ, Wh, bRPV use ==2LSS
 - bRPV also uses ==3L
 - In 2LSS selections using b-jet veto to remove the $t\bar{t}$ background, results in dominant WZ and $W^\pm W^\pm$ backgrounds
 - 3L (SR_{3l}^{bRPV}) is b-jet agnostic, dominant background is $t\bar{t}V$
 - Selection on kinematic variables (lepton pT, jet multiplicity and pT, E_T^{miss} , m_{T2} , $S(E_T^{\text{miss}})$) and geometric variables (angular difference between 2 leptons or lepton and jet, azimuthal difference between 2 leptons and missing pT) to maximize sensitivity
 - Wh analysis further categorized in flavor bins ($e^\pm e^\pm$, $e^\pm \mu^\pm$, $\mu^\pm \mu^\pm$)
 - Profile log-likelihood fit
 - Statistical combination of sub-regions
-
- The diagram illustrates the signal regions (SR) for the 2LSS analysis as a function of the invariant mass of the two jets (m_{T2}). The vertical axis represents the signal regions, and the horizontal axis represents m_{T2} . The regions are color-coded orange. There are three main regions:
 - $SR_{high_m_{T2}}^{WZ/Wh} - 3$: The topmost region, corresponding to the highest m_{T2} values.
 - $SR_{high_m_{T2}}^{WZ/Wh} - 2$: The middle region.
 - $SR_{high_m_{T2}}^{WZ/Wh} - 1$: The bottommost region, corresponding to the lowest m_{T2} values.A legend on the right indicates that the orange color corresponds to "For Wh: E_T^{miss} " and "For WZ: $S(E_T^{\text{miss}})$ ". An arrow points upwards from the regions towards the text "For Wh: E_T^{miss} ".

Background determination

- Analysis uses common background determination strategy, and dedicated background estimates for WZ , $W^\pm W^\pm$, charge-flip and fake, non-prompt leptons.
- Orthogonality to SR obtained using b-jet and lepton multiplicity, inverted cut on E_{miss}^T and veto on SRs

		WZ and bRPV	Wh
Irreducible	Monte Carlo	All smaller backgrounds	
Prompt leptons, highest contributions from diboson, multiboson, $t\bar{t}V$, other rare top processes	CR/VR	CR/VR for WZ background VR designed for $t\bar{t}V$	CR/VR for WZ and $W^\pm W^\pm$
Reducible	Charge-flip	Data Driven estimate	
Charge-flip and fake, non-prompt leptons, highest contributions from V+jets, $t\bar{t}$, single-top, $t\bar{t}+HF$	Fake, non-prompt leptons	Matrix Method	Fake Factor Method

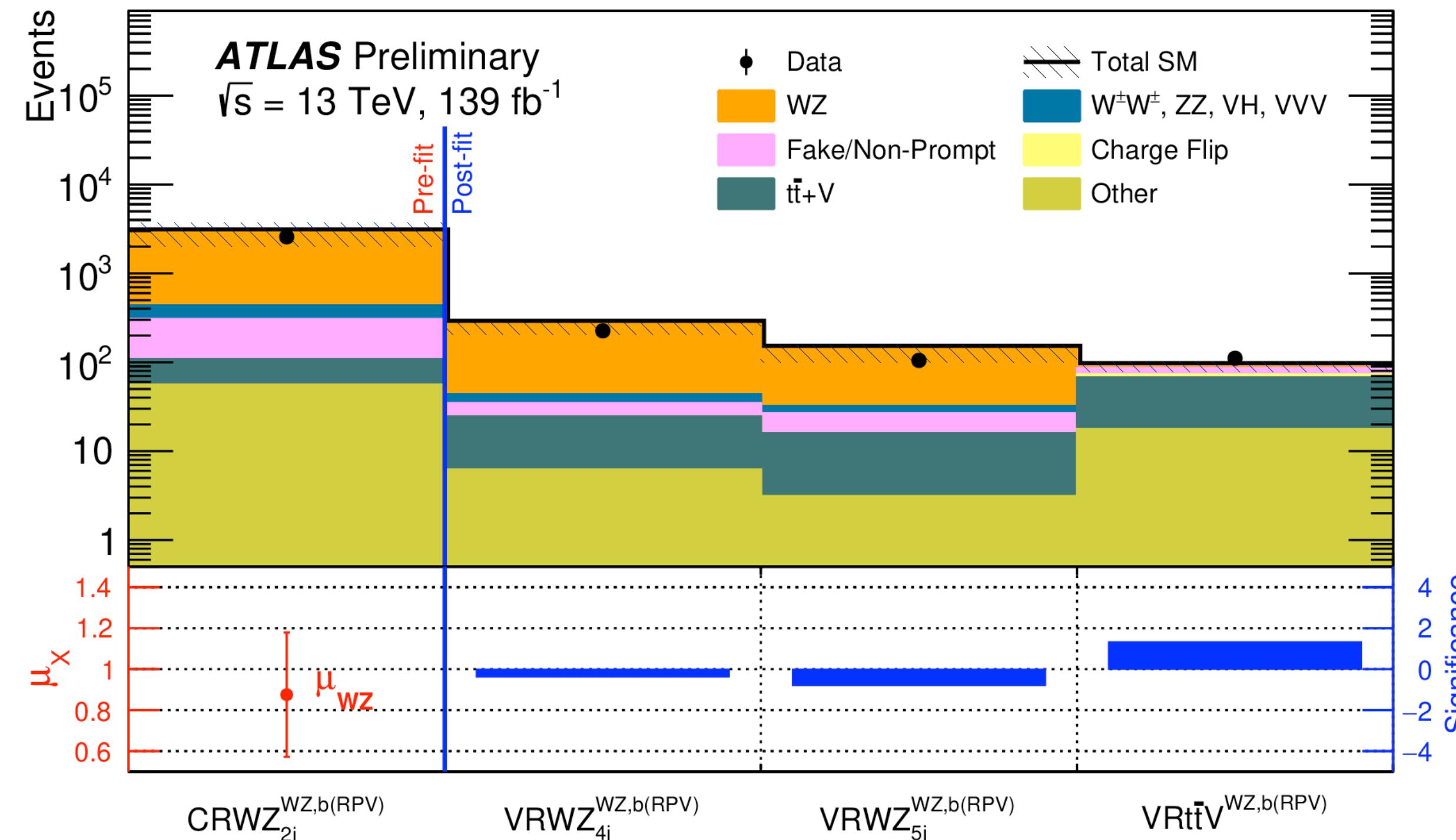
Validation – Wh



Good agreement in all VRs

- Irreducible, designed to be very close to SR, simultaneous fit in CRs
- WZ (purity CR 90%, VR 90%), orthogonality by inverted E_{miss}^T cut, ==3L
- $W^\pm W^\pm$ (purity CR 45%, VR 55%), orthogonality by inverted E_{miss}^T cut, ==2L
- Reducible, determined separately
 - Charge-flip using standard ATLAS determination tools and validated in VRCF
 - Fake, non-prompt using Fake Factor method and validated in VR for flavor bins

Validation – WZ and bRPV

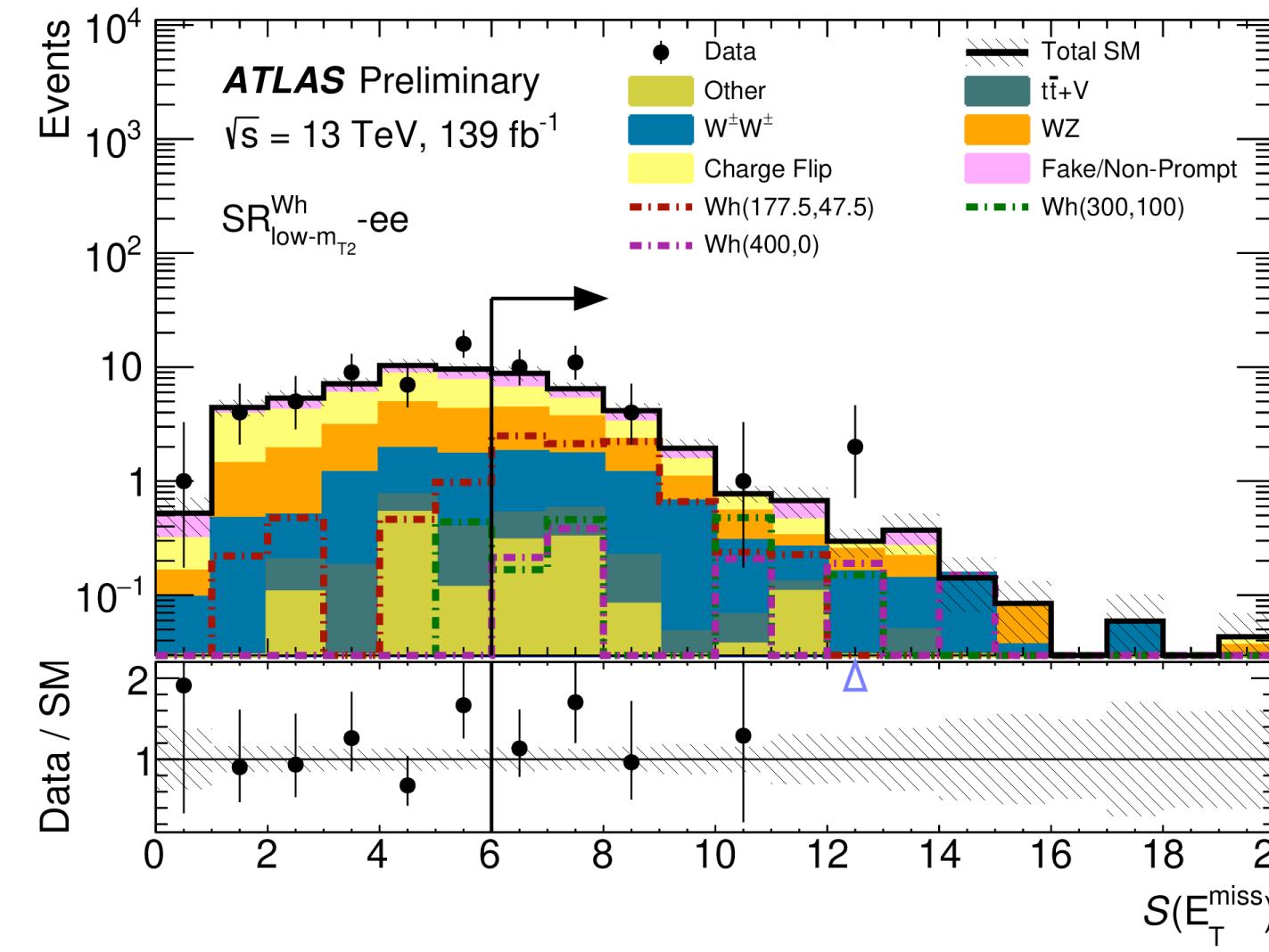


Good agreement in all VRs

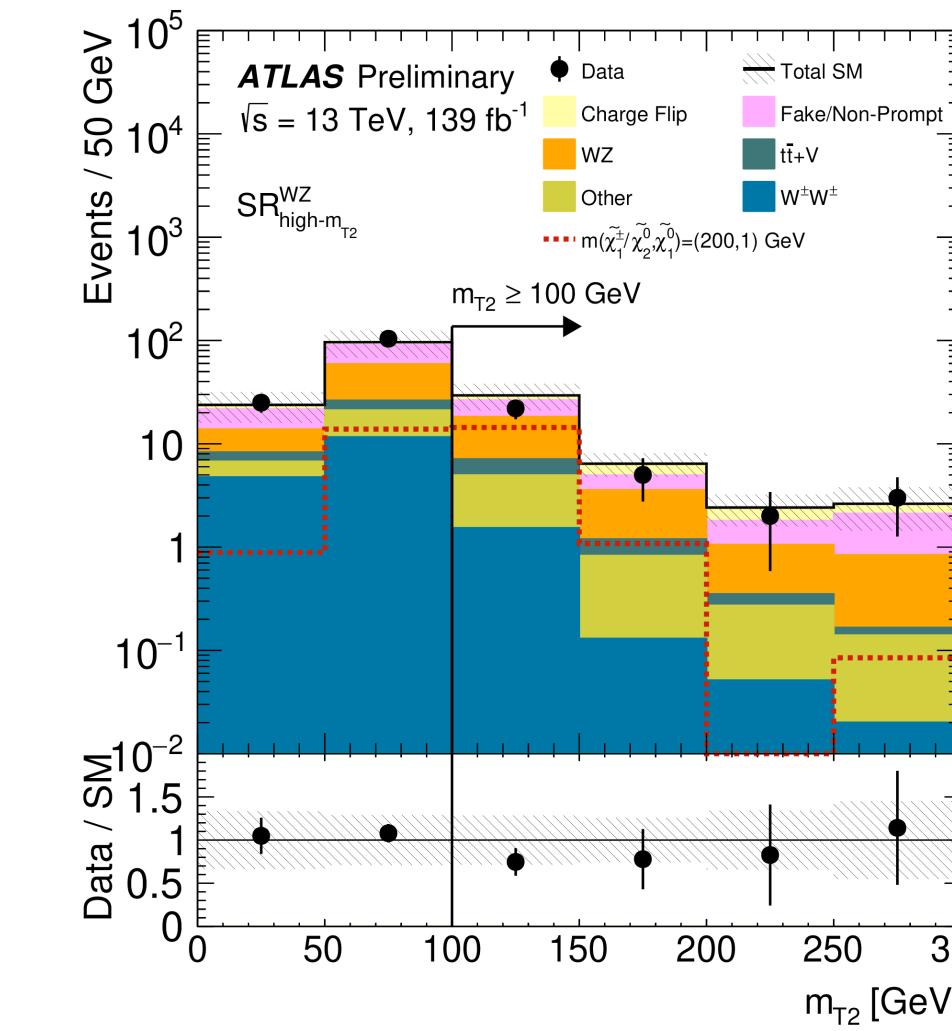
- Irreducible, designed to be close to SR
 - WZ (purity CR(2j) 85%, VR 62-84 %), orthogonality using ==3L and veto on WZ and bRPV SRs
 - t
- Reducible, determined separately
 - Charge-flip using standard ATLAS determination tools
 - Fake, non-prompt using matrix method

Results

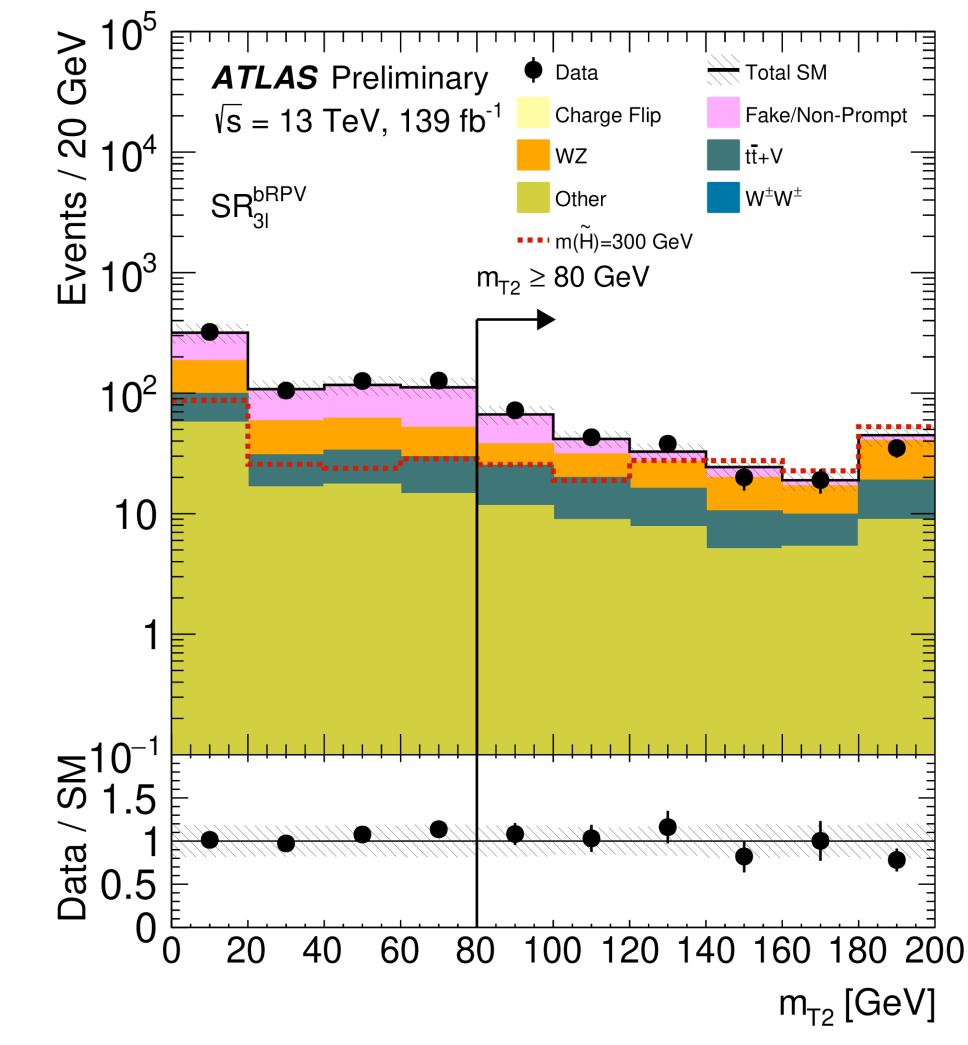
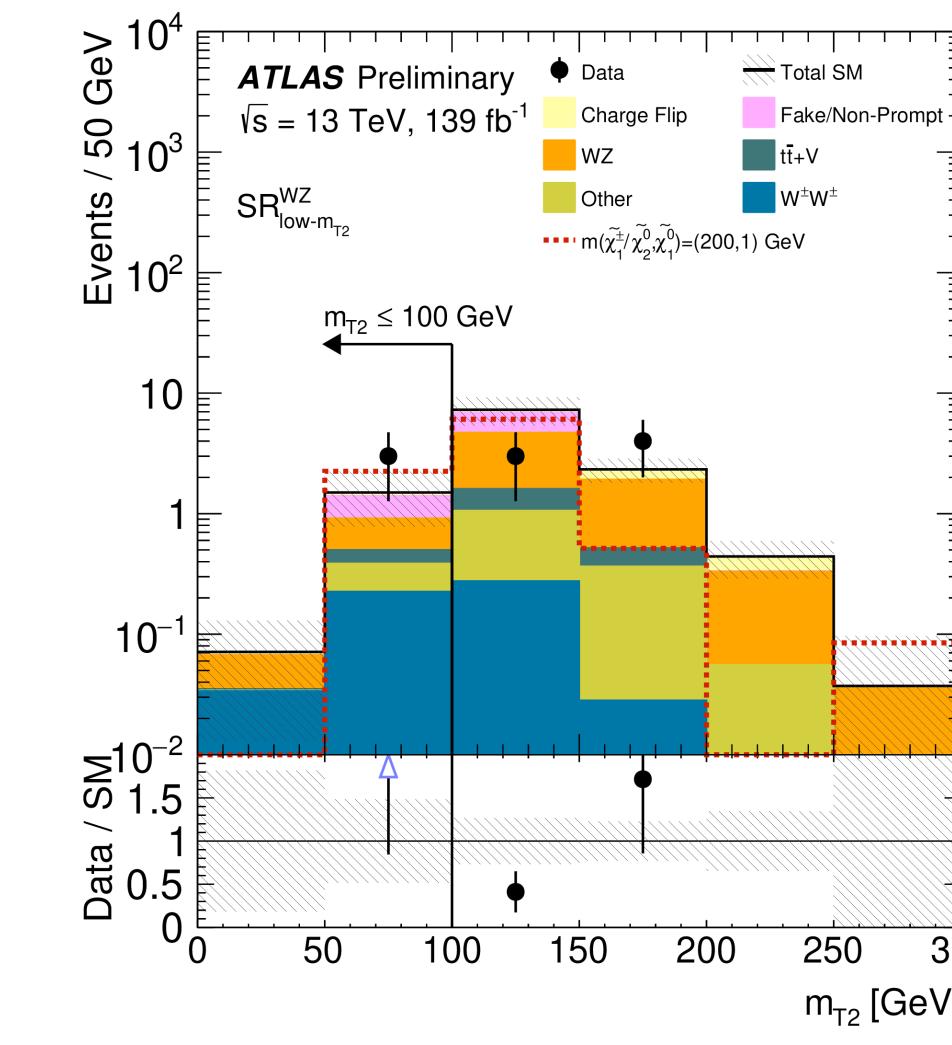
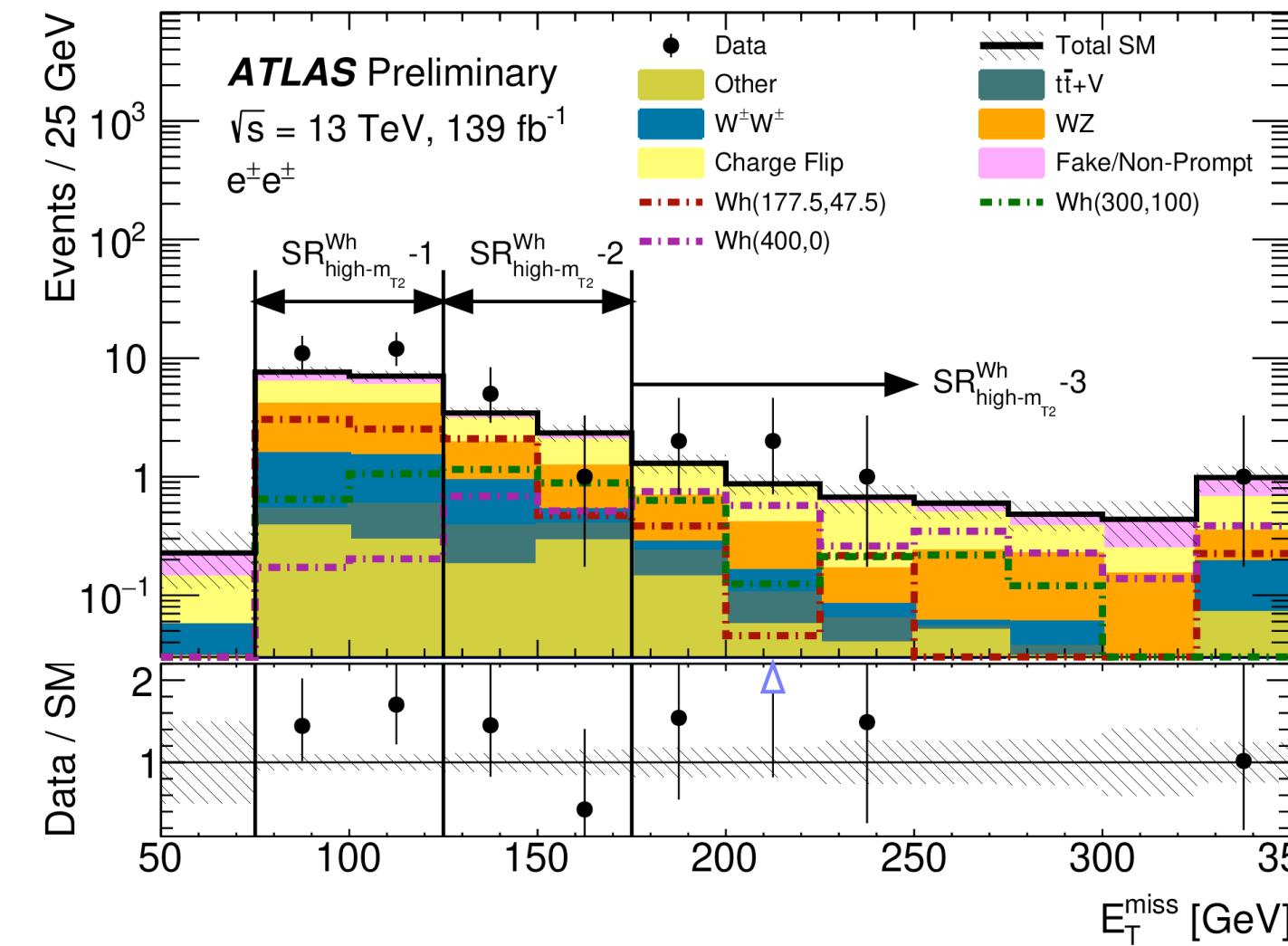
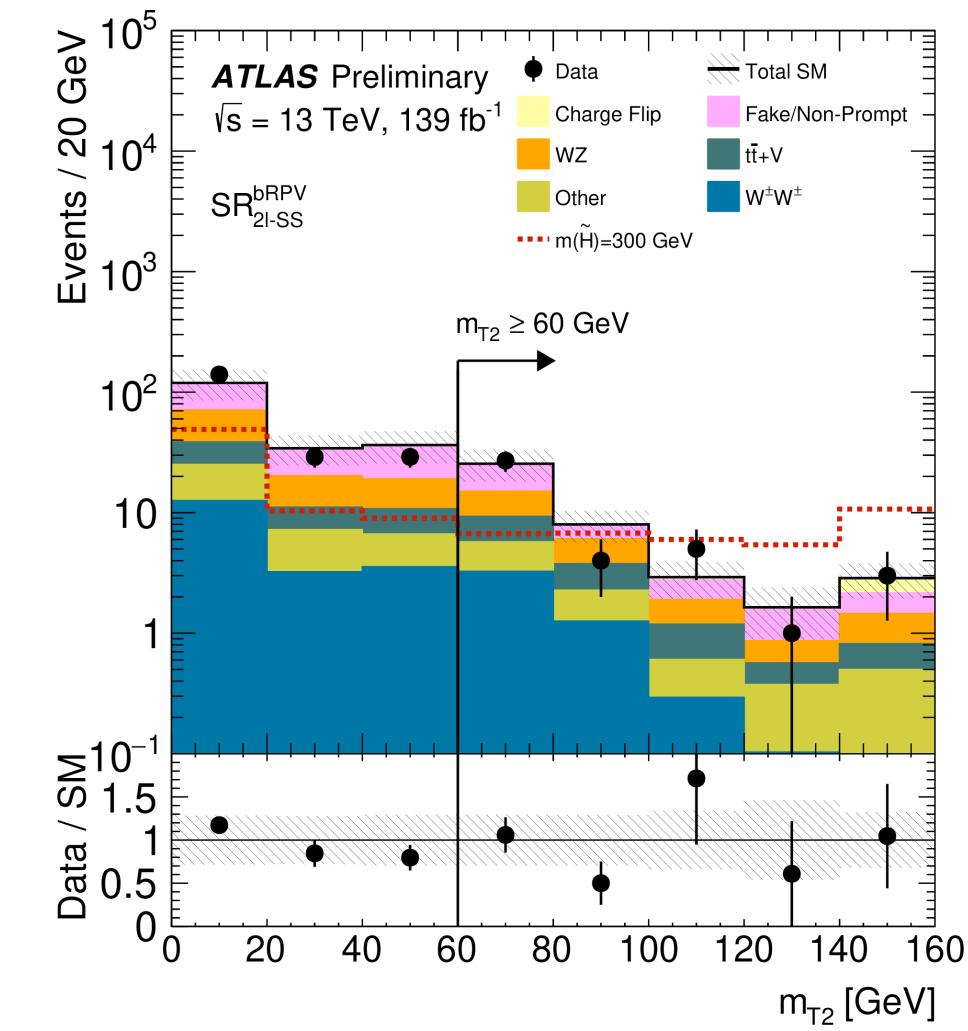
Wino Wh



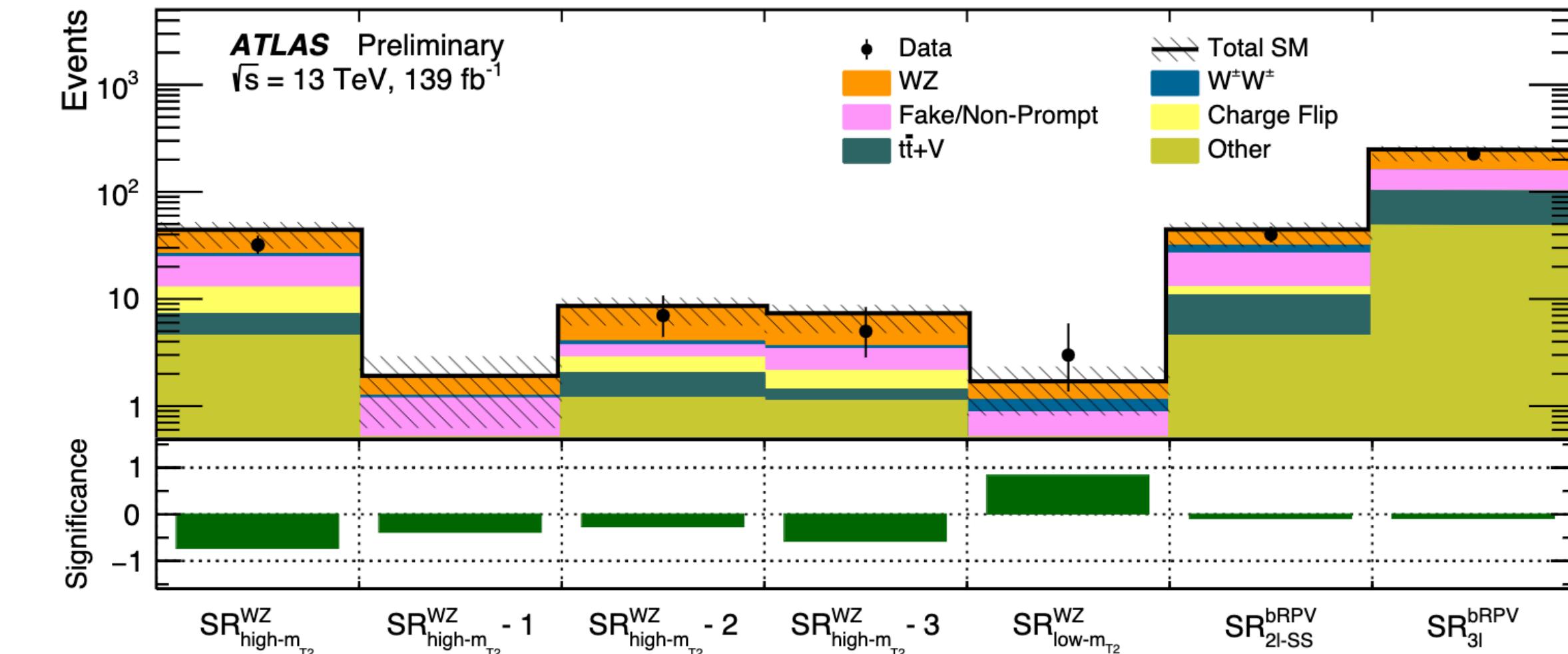
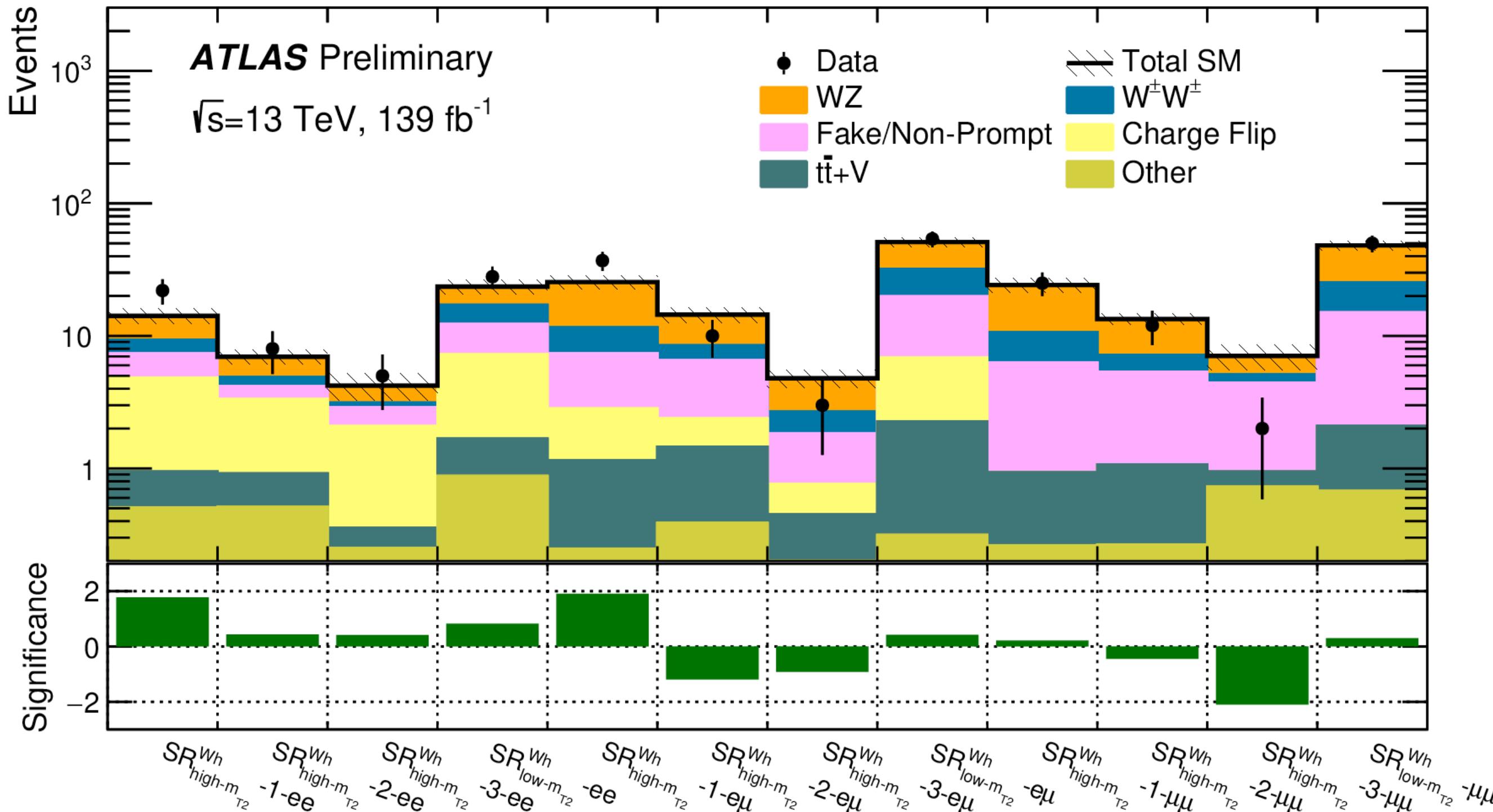
Wino WZ



Higgsino bRPV



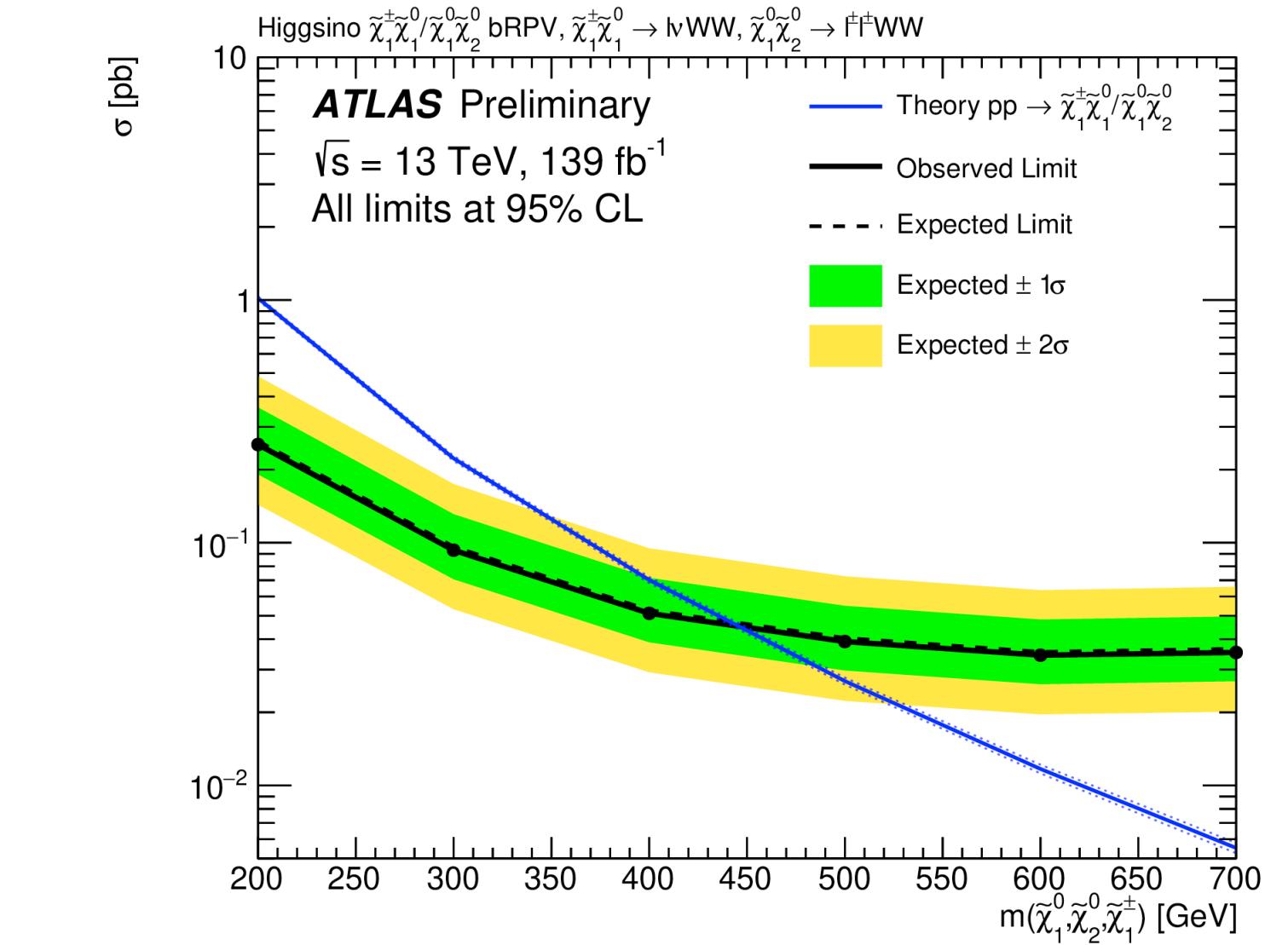
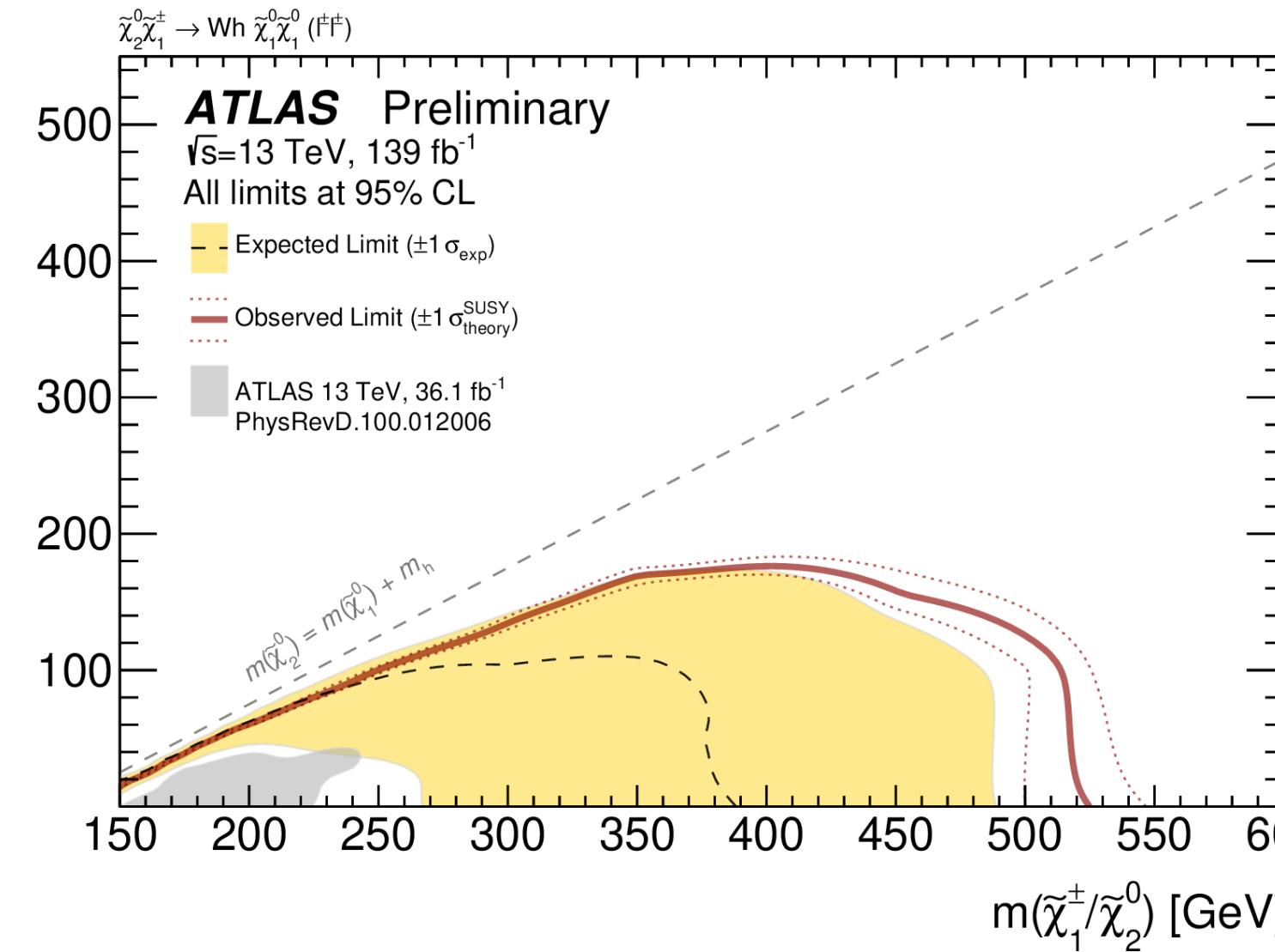
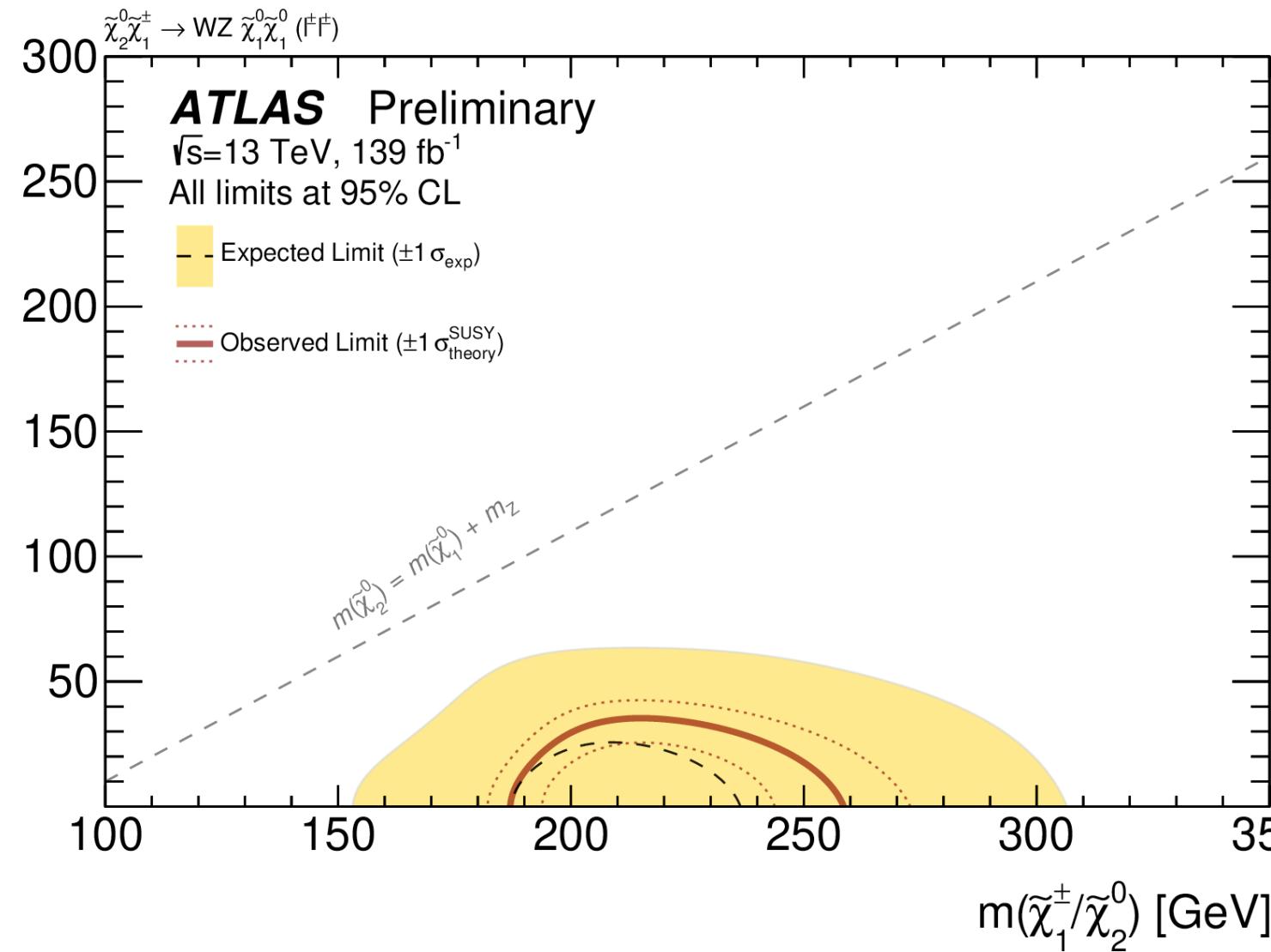
Results



- 18 orthogonal SRs: 12 for Wh, 4 for WZ model, 2 for bRPV
- No significant excess seen compared to the Standard Model prediction
- Two below $\sim 2 \sigma$ excesses cancel out with the few deficits for $SR^{Wh}_{high-m_{T2}}$
- 2.02σ deficit due to statistical fluctuation in $SR^{Wh}_{high-m_{T2}} - 3\mu\mu$ SR

Signal channel	$p_0 (Z)$
$SR^{Wh}_{high-m_{T2}}$	0.34 (0.41)
$SR^{Wh}_{low-m_{T2}}$	0.33 (0.43)
$SR^{WZ}_{high-m_{T2}}$	0.50 (0.00)
$SR^{WZ}_{low-m_{T2}}$	0.22 (0.76)
$SR^{bRPV}_{2\ell-SS}$	0.50 (0.00)
$SR^{bRPV}_{3\ell}$	0.50 (0.00)

Interpretation



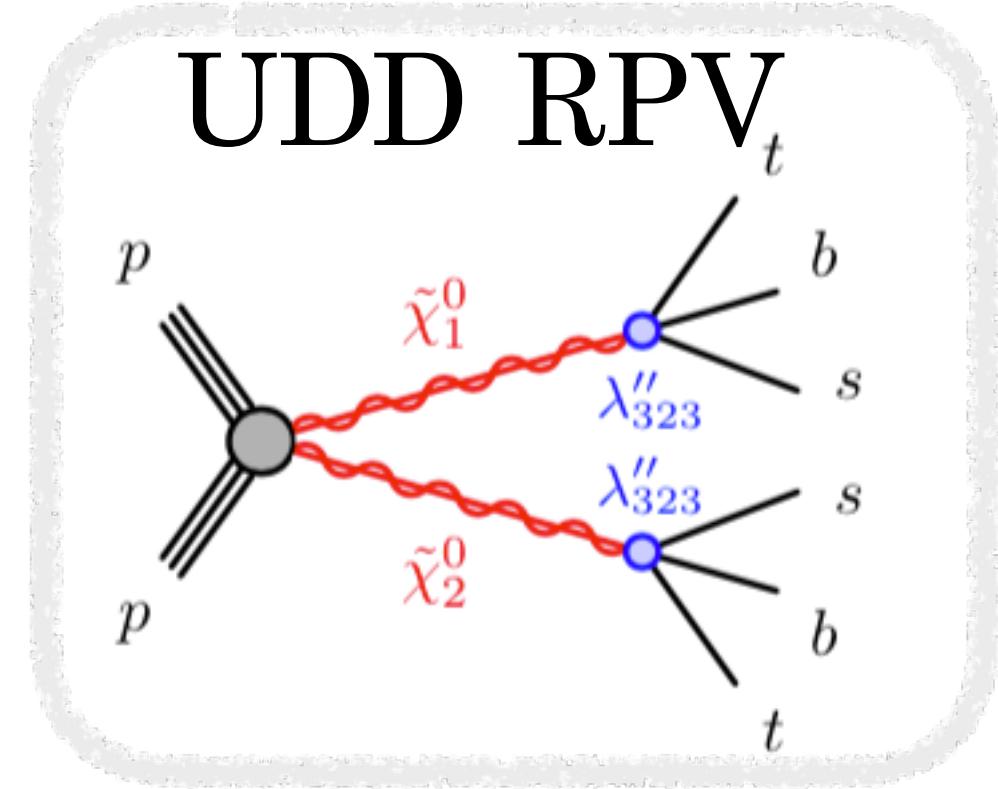
- Wino-WZ: Upper limits have been set on the visible cross-section
- Wino-Wh: Significantly extends sensitivity for the model compared to previous search, up to 525 GeV for the massless LSP
- Higgsino-bRPV: First interpretation of this model using higgsino production, up to 440 GeV

Thank you for your attention!

Backup

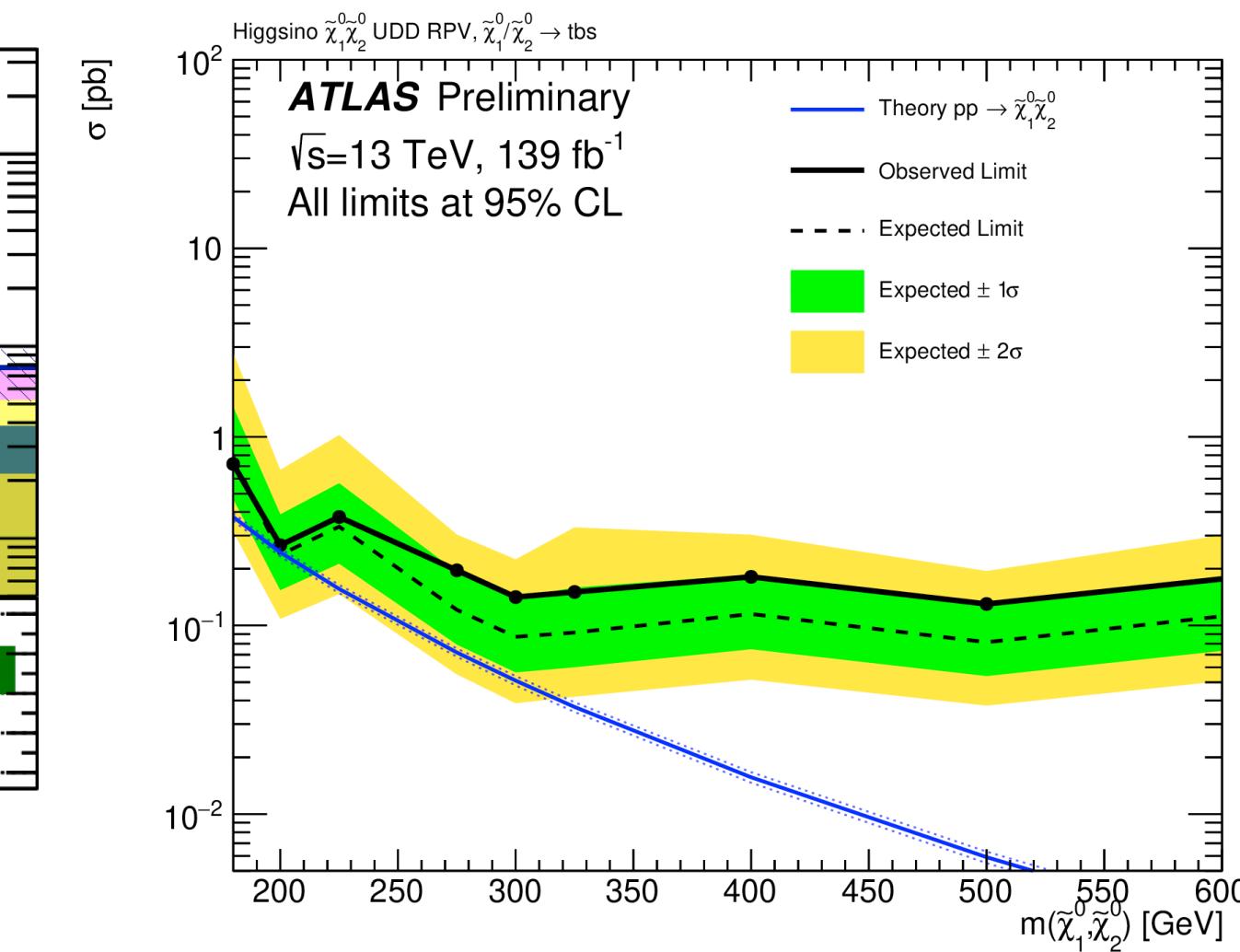
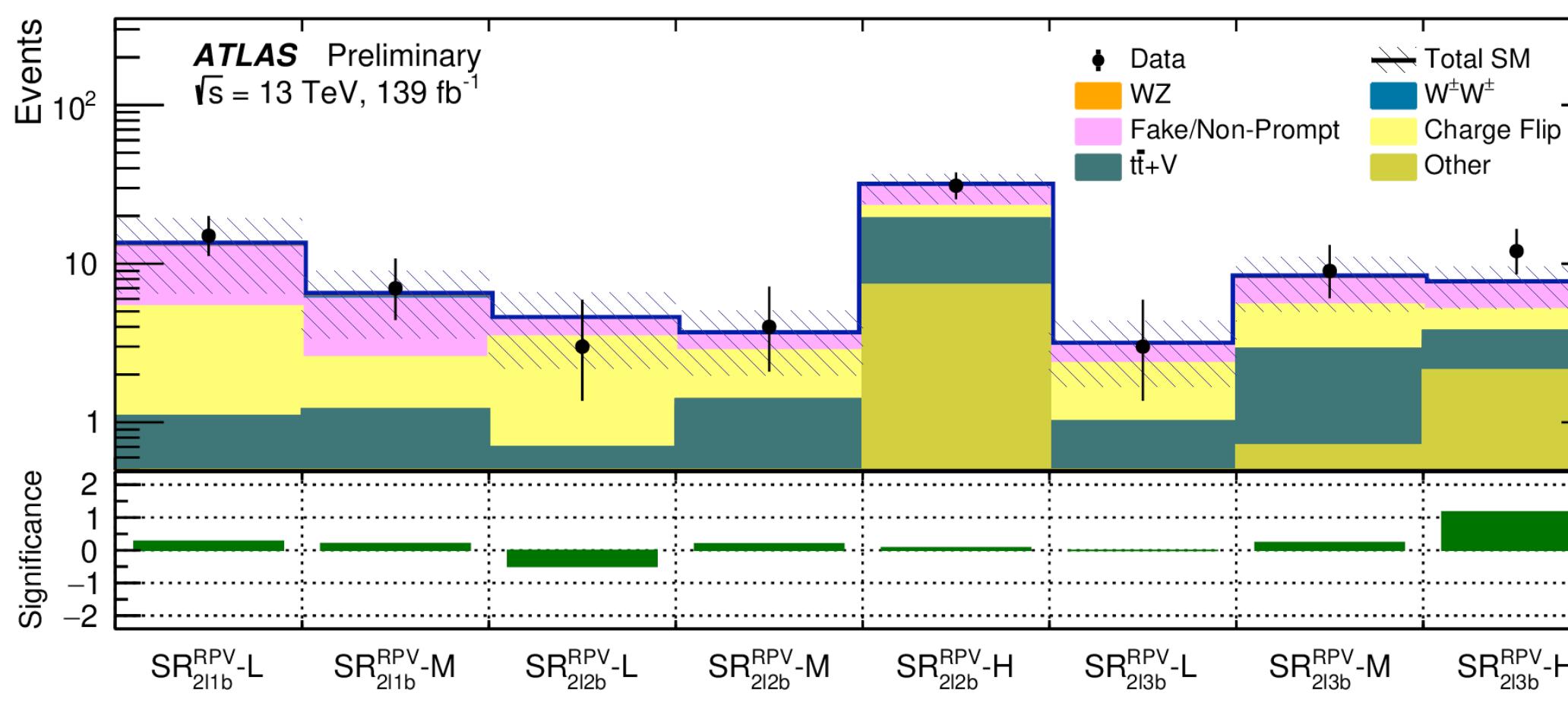
UDD RPV

$$W_{R_p} = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \epsilon_iL_iH_2 + \frac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k$$

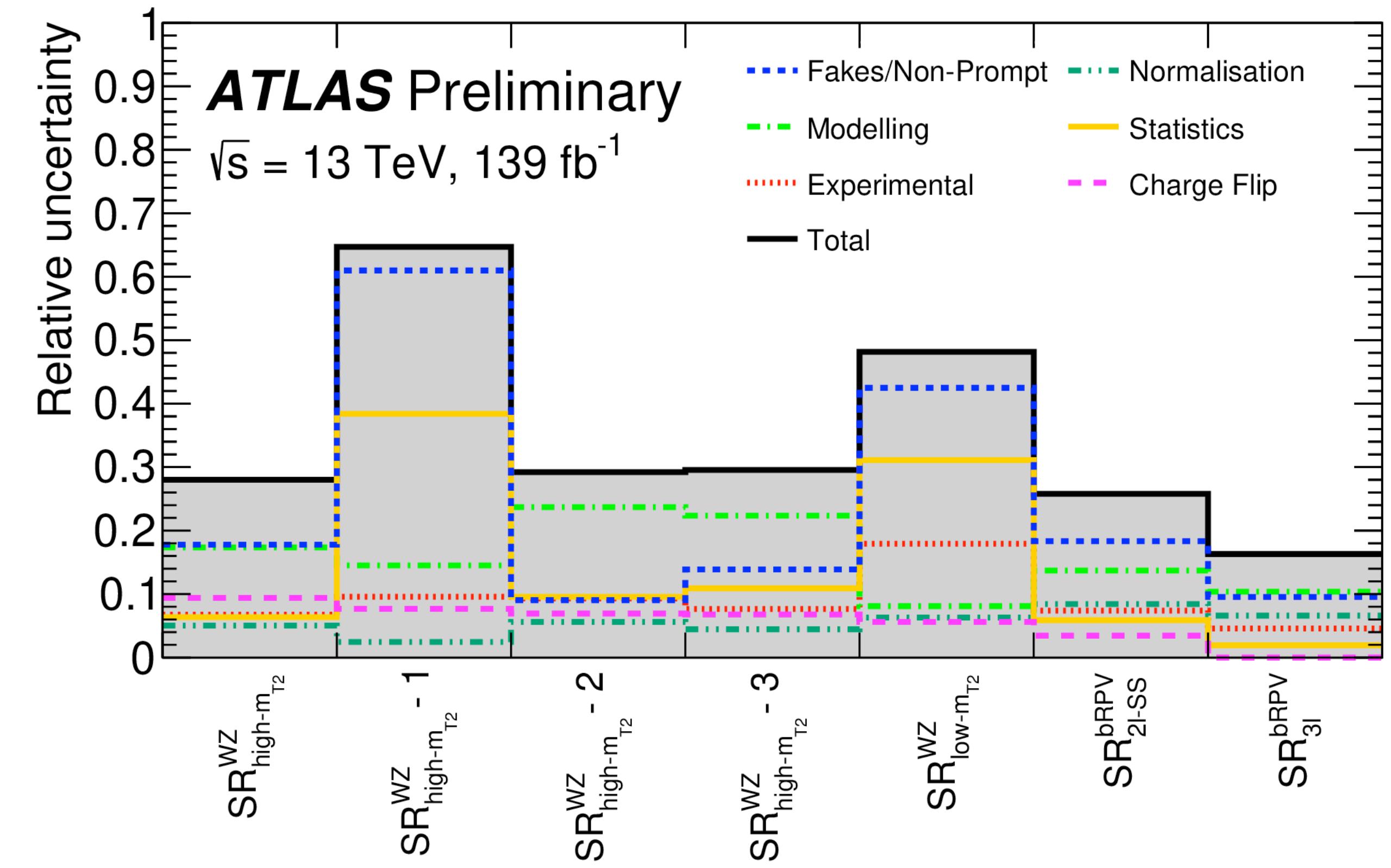
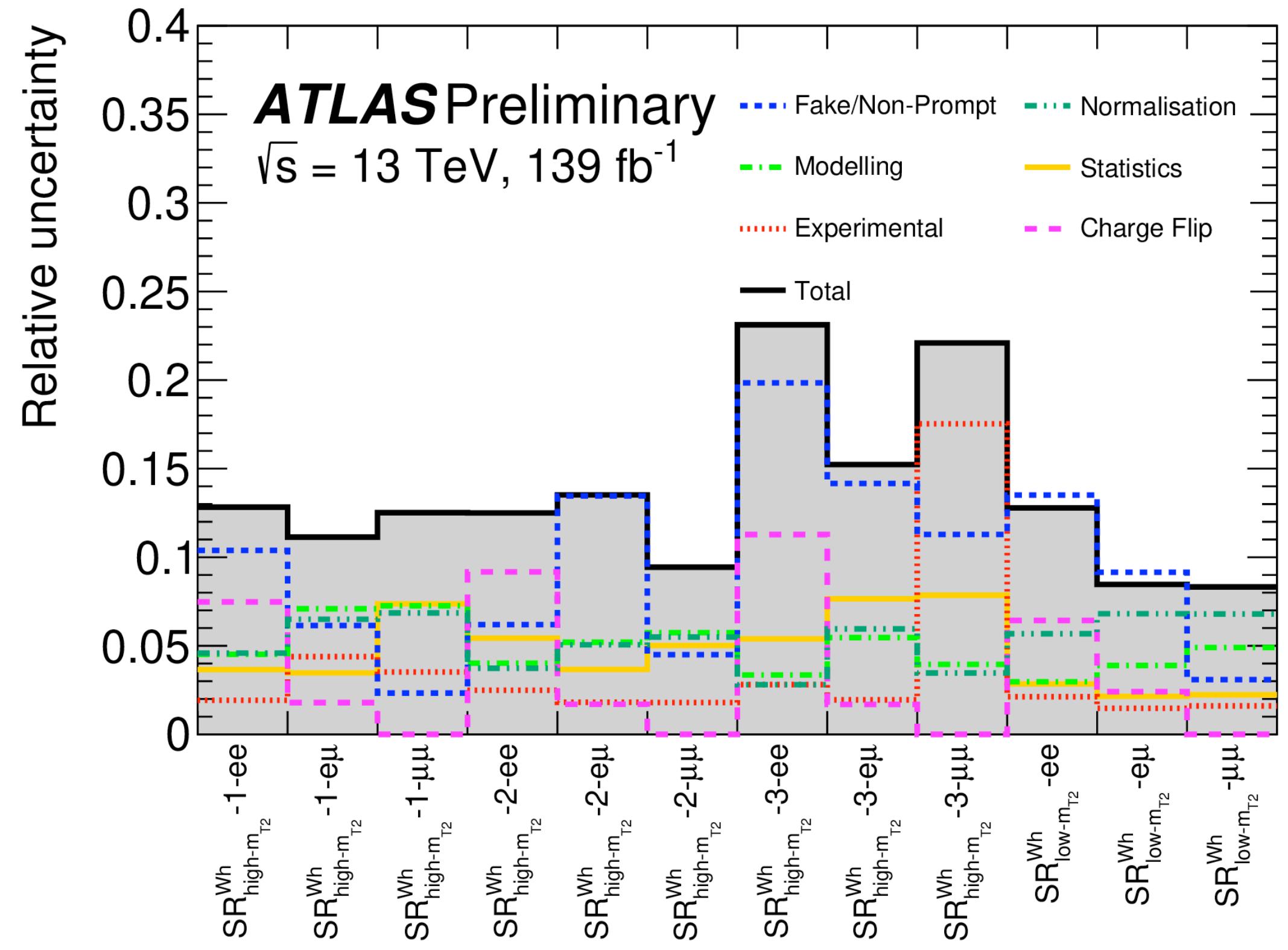


λ''_{323} is predicted to be dominant under minimal flavour hypothesis, and sufficiently strong to have prompt decays. Aims to improve on previous searches.

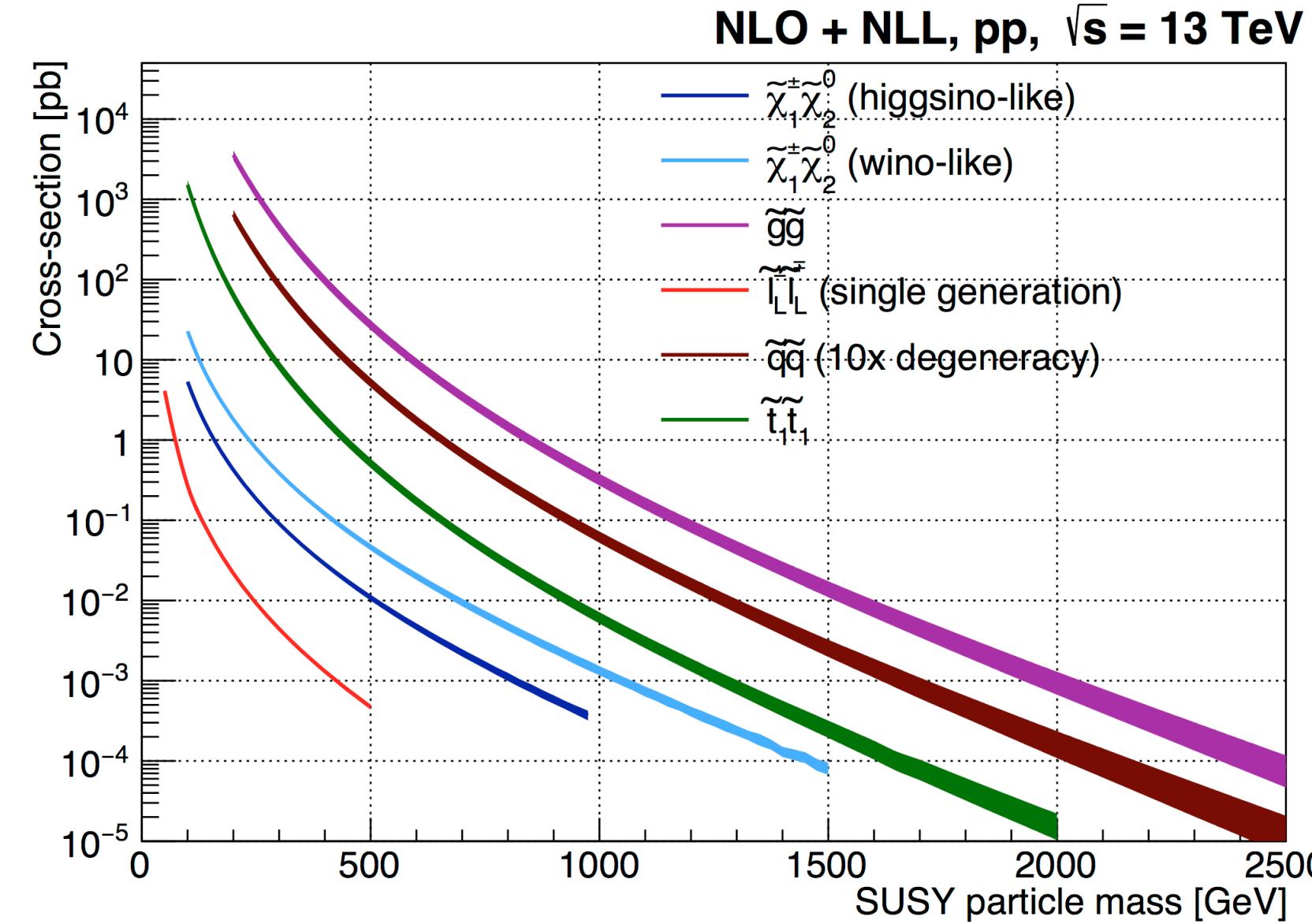
	SR _{2l1b} L M		SR _{2l2b} L M		SR _{2l3b} L M H	
$N_{BL}(\ell)$			= 2			
$N_{Sig}(\ell)$			= 2			
Charge(ℓ)			same-sign			
$p_T(\ell)$			> 25 GeV			
$n_{jets} (p_T > 25 \text{ GeV})$			≥ 1			
$n_{b\text{-jets}}$						
$\sum p_T(\ell)$	$= 1$	$\geq 100 \text{ GeV}$	$= 2$	$\geq 80 \text{ GeV}$	$= 3$	$\geq 20 \text{ GeV}$
E_T^{miss}	$\geq 100 \text{ GeV}$	$\geq 50 \text{ GeV}$	$-$	$\geq 80 \text{ GeV}$	$-$	$\geq 20 \text{ GeV}$
$n_{jets} (p_T > 25 \text{ GeV})$	≤ 2	$= 2 \text{ or } = 3$	≤ 3	$= 3 \text{ or } = 4$	$\geq 5 \text{ and } \leq 6$	≤ 3
$\sum p_T^{b\text{-jet}} / \sum p_T^{\text{jet}}$	≥ 0.7	≥ 0.45	≥ 0.9	≥ 0.75	$-$	≥ 0.8
$\sum p_T^{\text{jet}}$	$\geq 120 \text{ GeV}$	$\geq 400 \text{ GeV}$	$\geq 300 \text{ GeV}$	$\geq 420 \text{ GeV}$	$\geq 420 \text{ GeV}$	≥ 0.8
$\Delta R(\ell_1, \text{jet})_{\min}$	≤ 1.2	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.5
$\Delta R(\ell^\pm, \ell^\pm)$	≥ 2.0	≥ 2.5	≥ 2.5	≥ 2.5	≥ 2.0	≥ 2.0



Systematics



Naturalness



SUSY Analyses grouped around production channel cross-sections (RPC):

- Strong production
 - Third generation
 - Electroweak
- Study in addition:
- * RPV
 - * Long Lived

- First analyses with high cross-section (strong, third generation).
- With high integrated luminosity more interesting become electroweak searches, compressed, difficult regions.
- With high exclusion of RPC models more interest in RPV models, and uncovered signatures.
- With improvements in reconstruction techniques and clever solutions for specific signatures, searches for Long-Lived particles interesting.

Naturalness a useful (but not required) criterion on motivation for a given SUSY model.

$$-\frac{m_Z^2}{2} = |\mu|^2 + m_H^2$$

$$m_H^2 = (m_H^2)_{bare} + \delta m_H^2$$

$$\delta m_H^2 \sim -y_t^2 m_{\tilde{t}_1}^2 \log\left(\frac{\Lambda}{\text{TeV}}\right)$$

- Stops in the TeV range.
- Maximal mixing.

Search for light stop.

$$\delta m_H^2 \sim -y_t^2 |M_3|^2 \log^2\left(\frac{\Lambda}{\text{TeV}}\right)$$

- Light gluinos (few TeV).

Search for light gluino.

- Minimisation condition for Higgs scalar potential.
- Contributions must be tuned to achieve EWSB at the observed energy level, favour low fine tuning.

$$|\mu|^2$$

- Address naturalness independently of the Higgs boson mass.

Search for low higgsino parameter.