

# Status of SUSY searches in ATLAS



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# Introduction

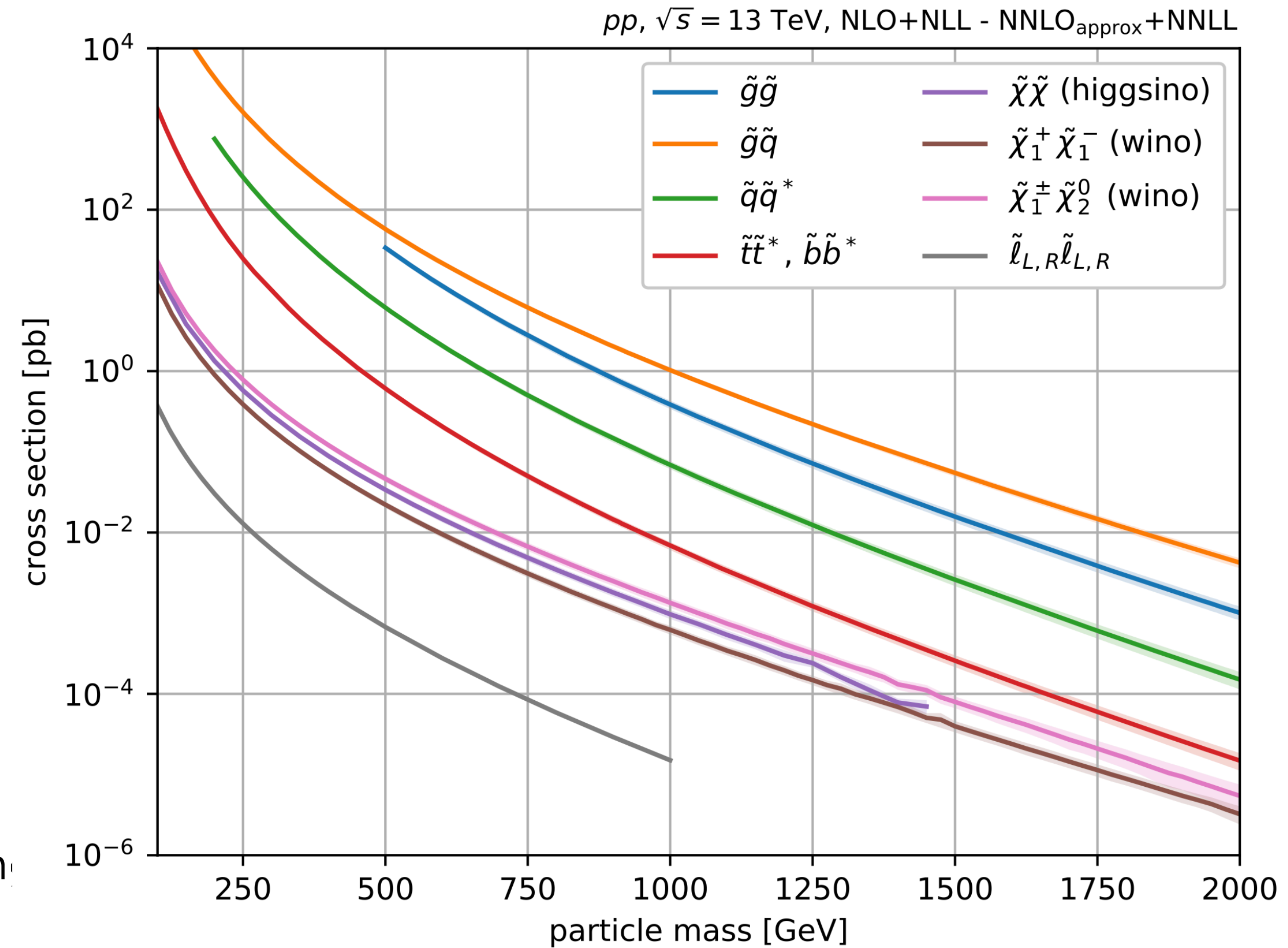
- Supersymmetry (SUSY): promising extension of the SM
  - Additional symmetry relating fermions and bosons
  - Provides natural solution to hierarchy problem
  - Dark matter candidate (if R-parity is conserved)
- SUSY parameter space is huge (SM +105 new parameters)
- Many new particles predicted, some of them can be in the LHC reachable energy
- We reduce the number of parameters to a more manageable number by focusing on very simplified models with well motivated assumptions
  - For example:
    - RPC → particles produced in pairs and LSP is stable (MET)
  - Limits on simplified models, not on SUSY

|          |                 |                   |                    |                  |                           |
|----------|-----------------|-------------------|--------------------|------------------|---------------------------|
| quarks   | $u$             | $c$               | $t$                | $g$              | gauge bosons              |
|          | $d$             | $s$               | $b$                | $\gamma$         |                           |
| leptons  | $\nu_e$         | $\nu_\mu$         | $\nu_\tau$         | $Z$              | Higgs                     |
|          | $e$             | $\mu$             | $\tau$             | $W$              |                           |
| squarks  | $\tilde{u}$     | $\tilde{c}$       | $\tilde{t}$        | $\tilde{g}$      | gluino                    |
|          | $\tilde{d}$     | $\tilde{s}$       | $\tilde{b}$        | $\tilde{\gamma}$ |                           |
| sleptons | $\tilde{\nu}_e$ | $\tilde{\nu}_\mu$ | $\tilde{\nu}_\tau$ | $\tilde{Z}$      | neutralinos/<br>charginos |
|          | $\tilde{e}$     | $\tilde{\mu}$     | $\tilde{\tau}$     | $\tilde{W}$      |                           |

# SUSY searches in ATLAS

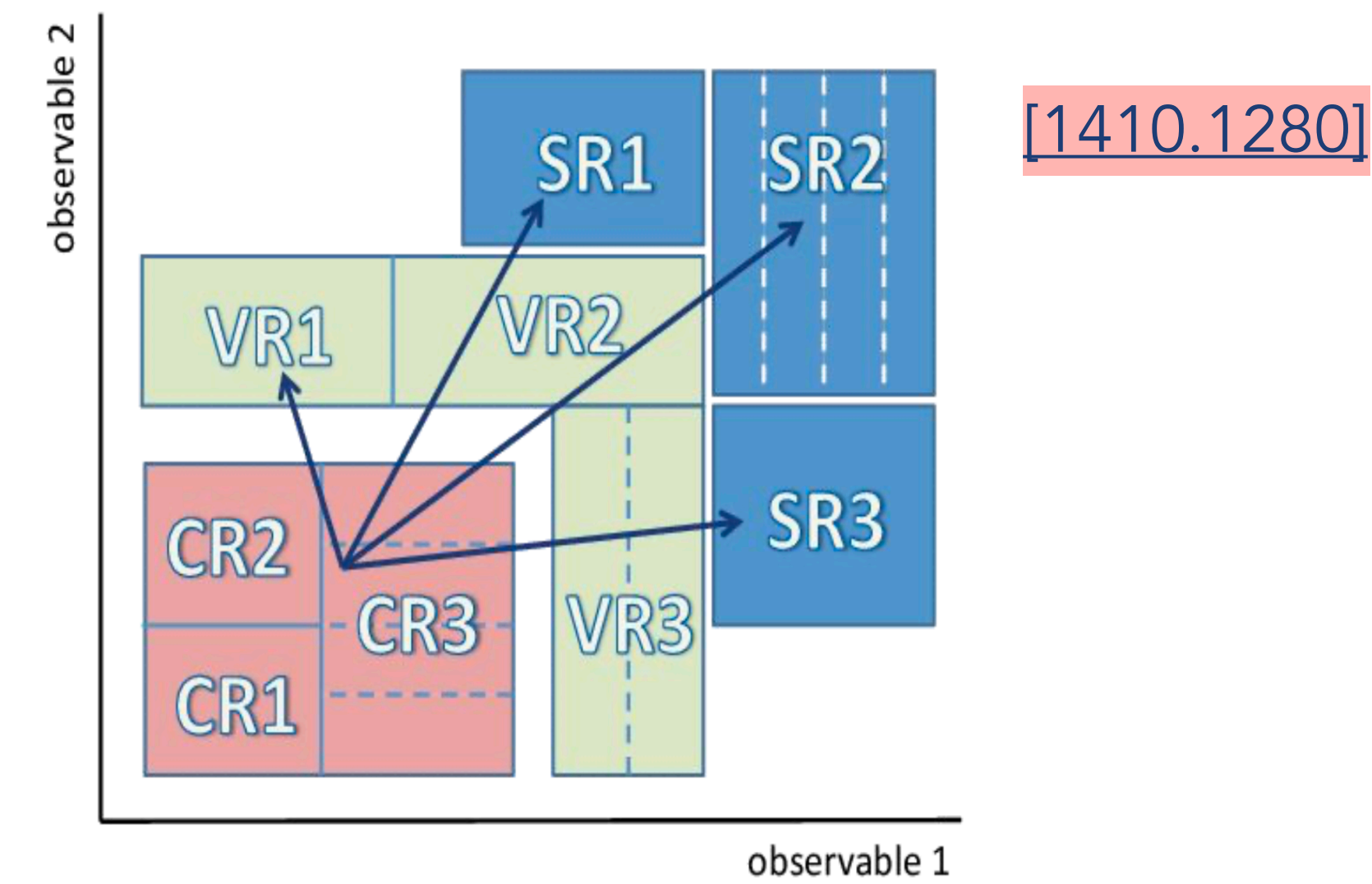
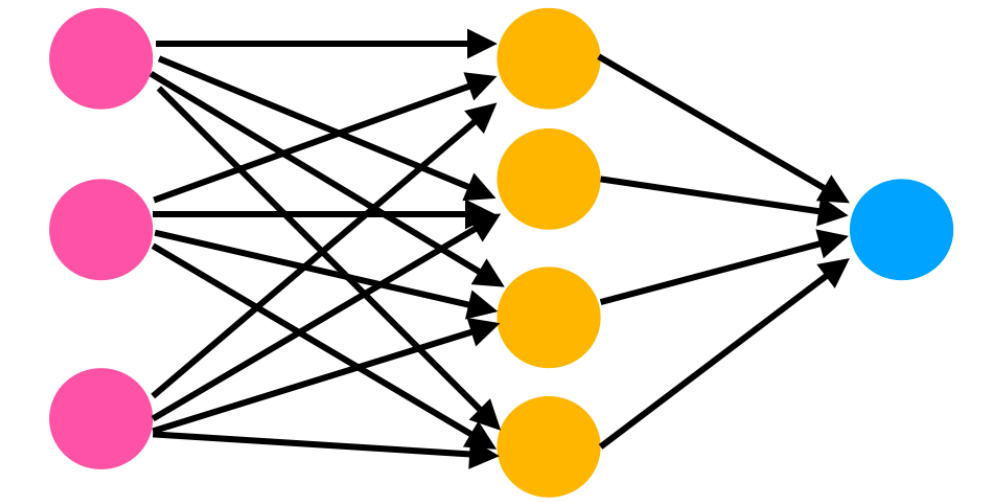
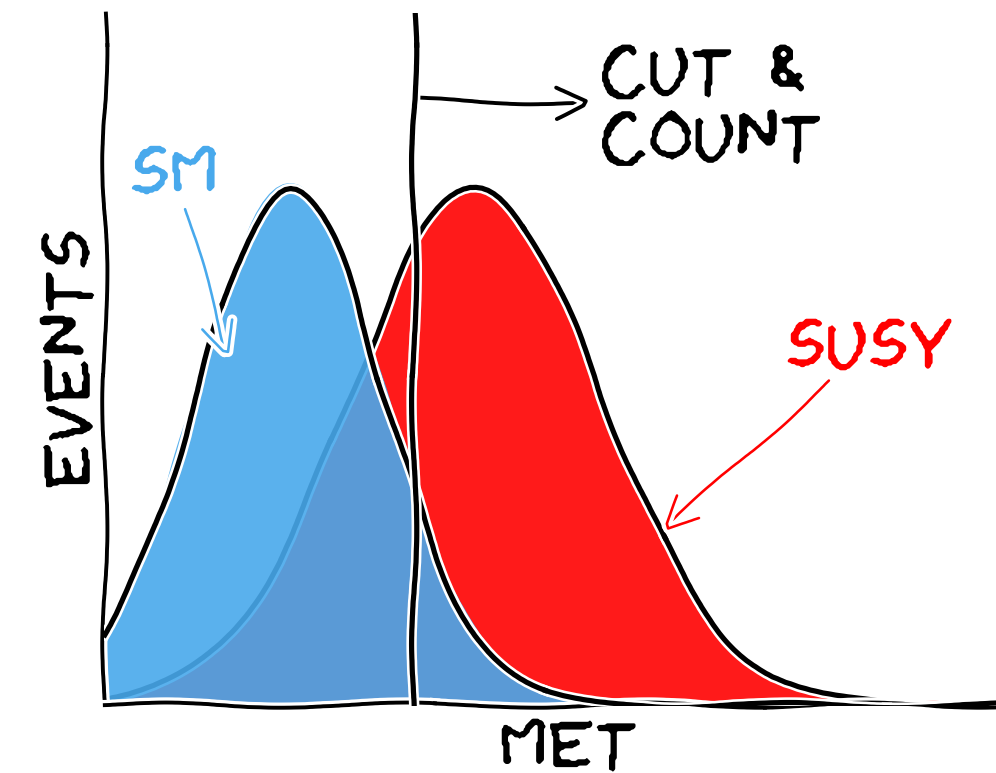
- Comprehensive search programme
- Searches are final state oriented, driven by cross-section and event topology:
  - gluinos/squarks
  - stop/sbottom
  - electroweakinos and sleptons
- Conventional searches with RPC and prompt decays
- Unconventional searches including RPV and long-lived particles
- Combinations and phase space scans
- This talk will cover some of the most recent searches using the full Run-2 data

→  $\sqrt{s} = 13 \text{ TeV}$ ,  $\sim 139 \text{ fb}^{-1}$



# General analysis strategy

- Signal regions (SR) motivated by SUSY model and enriched optimized to have a good signal/background significance
- SM background estimation/modeling
  - Data-driven estimation for fake backgrounds
  - Monte Carlo simulation normalized in dedicated Control Regions (CR)
  - Validation regions (VR) to cross-check estimation in between CR/SR
- Statistical interpretation using simultaneous likelihood fit
  - Discovery significance
  - Exclusion limits at 95% CL using CR+SR combined fit for specific SUSY signal model as function of masses and or BR
  - Model independent limits on visible cross section



| Model  | Signature   | $\int \mathcal{L} dt$ [fb <sup>-1</sup> ]            | Mass limit   | Reference  |  |   |   |  |
|--|---|--|--|--|--|---|---|--|
| Inclusive Searches   | $\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$   | 0 $e, \mu$<br>mono-jet                               | 2-6 jets<br>1-3 jets   | $E_T^{\text{miss}}$<br>$E_T^{\text{miss}}$   | 140<br>140   | $\tilde{q}$ [1x, 8x Degen.] 1.0<br>$\tilde{q}$ [8x Degen.] 0.9  | $m(\tilde{\chi}_1^0) < 400$ GeV<br>$m(\tilde{q}) - m(\tilde{\chi}_1^0) = 5$ GeV   | 2101.14293<br>2102.10874   |
|  | $\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$  | 0 $e, \mu$   | 2-6 jets   | $E_T^{\text{miss}}$  | 140  | $\tilde{g}$ 2.3<br>$\tilde{g}$ Forbidden 1.15-1.95  | $m(\tilde{\chi}_1^0) = 0$ GeV<br>$m(\tilde{\chi}_1^0) = 1000$ GeV   | 2101.14293<br>2010.14293   |
|  | $\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}W\tilde{\chi}_1^0$   | 1 $e, \mu$   | 2-6 jets   | $E_T^{\text{miss}}$  | 140  | $\tilde{g}$ 2.2   | $m(\tilde{\chi}_1^0) < 600$ GeV   | 2101.01629   |
|  | $\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}(\ell\ell)\tilde{\chi}_1^0$  | $ee, \mu\mu$   | 2 jets   | $E_T^{\text{miss}}$  | 140  | $\tilde{g}$ 2.2   | $m(\tilde{\chi}_1^0) < 700$ GeV   | 2204.13072   |
|  | $\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}WZ\tilde{\chi}_1^0$  | 0 $e, \mu$<br>SS $e, \mu$                            | 7-11 jets<br>6 jets  | $E_T^{\text{miss}}$<br>$E_T^{\text{miss}}$   | 140<br>140   | $\tilde{g}$ 1.97<br>$\tilde{g}$ 1.15  | $m(\tilde{\chi}_1^0) < 600$ GeV<br>$m(\tilde{g}) - m(\tilde{\chi}_1^0) = 200$ GeV   | 2008.06032<br>2307.01094   |
|  | $\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$  | 0-1 $e, \mu$<br>SS $e, \mu$                          | 3 $b$<br>6 jets  | $E_T^{\text{miss}}$<br>$E_T^{\text{miss}}$   | 140<br>140   | $\tilde{g}$ 2.45<br>$\tilde{g}$ 1.25  | $m(\tilde{\chi}_1^0) < 500$ GeV<br>$m(\tilde{g}) - m(\tilde{\chi}_1^0) = 300$ GeV   | 2211.08028<br>1909.08457   |
|  | 3 <sup>rd</sup> gen. squarks direct production  | $\tilde{b}_1\tilde{b}_1$                             | 0 $e, \mu$   | 2 $b$  | $E_T^{\text{miss}}$  | 140   | $\tilde{b}_1$ 1.255<br>$\tilde{b}_1$ 0.68   | $m(\tilde{\chi}_1^0) < 400$ GeV<br>10 GeV < $\Delta m(\tilde{b}_1, \tilde{\chi}_1^0) < 20$ GeV |
| $\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_1^0 \rightarrow bh\tilde{\chi}_1^0$                                   |   | 0 $e, \mu$<br>2 $\tau$                               | 6 $b$<br>2 $b$   | $E_T^{\text{miss}}$<br>$E_T^{\text{miss}}$   | 140<br>140   | $\tilde{b}_1$ Forbidden 0.23-1.35<br>$\tilde{b}_1$ 0.13-0.85  | $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130$ GeV, $m(\tilde{\chi}_1^0) = 100$ GeV<br>$\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) = 130$ GeV, $m(\tilde{\chi}_1^0) = 0$ GeV  | 1908.03122<br>2103.08189   |
| $\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$  |   | 0-1 $e, \mu$   | $\geq 1$ jet   | $E_T^{\text{miss}}$  | 140  | $\tilde{t}_1$ 1.25  | $m(\tilde{\chi}_1^0) = 1$ GeV   | 2004.14060, 2012.03799   |
| $\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$   |   | 1 $e, \mu$   | 3 jets/1 $b$   | $E_T^{\text{miss}}$  | 140  | $\tilde{t}_1$ Forbidden 1.05  | $m(\tilde{\chi}_1^0) = 500$ GeV   | 2012.03799, ATLAS-CONF-2023-043  |
| $\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{\tau}_1 b\nu, \tilde{\tau}_1 \rightarrow \tau\tilde{G}$                      |   | 1-2 $\tau$   | 2 jets/1 $b$   | $E_T^{\text{miss}}$  | 140  | $\tilde{t}_1$ Forbidden 1.4   | $m(\tilde{\tau}_1) = 800$ GeV   | 2108.07665   |
| $\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 / \tilde{c}\tilde{c}, \tilde{c} \rightarrow c\tilde{\chi}_1^0$    |   | 0 $e, \mu$<br>0 $e, \mu$                             | 2 $c$<br>mono-jet  | $E_T^{\text{miss}}$<br>$E_T^{\text{miss}}$   | 36.1<br>140  | $\tilde{c}$ 0.85<br>$\tilde{t}_1$ 0.55  | $m(\tilde{\chi}_1^0) = 0$ GeV<br>$m(\tilde{t}_1, \tilde{c}) - m(\tilde{\chi}_1^0) = 5$ GeV  | 1805.01649<br>2102.10874   |
| $\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$                |   | 1-2 $e, \mu$   | 1-4 $b$  | $E_T^{\text{miss}}$  | 140  | $\tilde{t}_1$ 0.067-1.18  | $m(\tilde{\chi}_2^0) = 500$ GeV   | 2006.05880   |
| $\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$  | 3 $e, \mu$  | 1 $b$  | $E_T^{\text{miss}}$  | 140  | $\tilde{t}_2$ Forbidden 0.86   | $m(\tilde{\chi}_1^0) = 360$ GeV, $m(\tilde{t}_1) - m(\tilde{\chi}_1^0) = 40$ GeV  | 2006.05880  |  |
| EW direct  | $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via WZ  | Multiple $\ell$ /jets<br>$ee, \mu\mu$                | $\geq 1$ jet   | $E_T^{\text{miss}}$<br>$E_T^{\text{miss}}$   | 140<br>140   | $\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ 0.96<br>$\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ 0.205   | $m(\tilde{\chi}_1^0) = 0$ , wino-bino<br>$m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_1^0) = 5$ GeV, wino-bino   | 2106.01676, 2108.07586<br>1911.12606   |
|  | $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$ via WW  | 2 $e, \mu$   |  | $E_T^{\text{miss}}$  | 140  | $\tilde{\chi}_1^\pm$ 0.42   | $m(\tilde{\chi}_1^0) = 0$ , wino-bino   | 1908.08215   |
|  | $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via Wh  | Multiple $\ell$ /jets                                |  | $E_T^{\text{miss}}$  | 140  | $\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ Forbidden 1.06  | $m(\tilde{\chi}_1^0) = 70$ GeV, wino-bino   | 2004.10894, 2108.07586   |
|  | $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$ via $\tilde{\ell}_L/\tilde{\nu}$  | 2 $e, \mu$   |  | $E_T^{\text{miss}}$  | 140  | $\tilde{\chi}_1^\pm$ 1.0  | $m(\tilde{\ell}, \tilde{\nu}) = 0.5(m(\tilde{\chi}_1^\pm) + m(\tilde{\chi}_1^0))$   | 1908.08215   |
|  | $\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau\tilde{\chi}_1^0$   | 2 $\tau$   |  | $E_T^{\text{miss}}$  | 140  | $\tilde{\tau}$ [ $\tilde{\tau}_R, \tilde{\tau}_{R,L}$ ] 0.34 0.48   | $m(\tilde{\chi}_1^0) = 0$   | ATLAS-CONF-2023-029  |
|  | $\tilde{\ell}_{L,R} \tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \ell\tilde{\chi}_1^0$                                    | 2 $e, \mu$<br>$ee, \mu\mu$                           | 0 jets<br>$\geq 1$ jet   | $E_T^{\text{miss}}$<br>$E_T^{\text{miss}}$   | 140<br>140   | $\tilde{\ell}$ 0.7<br>$\tilde{\ell}$ 0.26   | $m(\tilde{\chi}_1^0) = 0$<br>$m(\tilde{\ell}) - m(\tilde{\chi}_1^0) = 10$ GeV   | 1908.08215<br>1911.12606   |
|  | $\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$   | 0 $e, \mu$<br>4 $e, \mu$<br>0 $e, \mu$<br>2 $e, \mu$ | $\geq 3$ $b$<br>0 jets<br>$\geq 2$ large jets<br>$\geq 2$ jets | $E_T^{\text{miss}}$<br>$E_T^{\text{miss}}$<br>$E_T^{\text{miss}}$<br>$E_T^{\text{miss}}$ | 140<br>140<br>140<br>140   | $\tilde{H}$ 0.94<br>$\tilde{H}$ 0.55<br>$\tilde{H}$ 0.45-0.93<br>$\tilde{H}$ 0.77   | $\text{BR}(\tilde{\chi}_1^0 \rightarrow h\tilde{G}) = 1$<br>$\text{BR}(\tilde{\chi}_1^0 \rightarrow Z\tilde{G}) = 1$<br>$\text{BR}(\tilde{\chi}_1^0 \rightarrow Z\tilde{G}) = 1$<br>$\text{BR}(\tilde{\chi}_1^0 \rightarrow Z\tilde{G}) = \text{BR}(\tilde{\chi}_1^0 \rightarrow h\tilde{G}) = 0.5$ | To appear<br>2103.11684<br>2108.07586<br>2204.13072  |
| Long-lived particles   | Direct $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$ prod., long-lived $\tilde{\chi}_1^\pm$                                     | Disapp. trk  | 1 jet  | $E_T^{\text{miss}}$  | 140  | $\tilde{\chi}_1^\pm$ 0.66<br>$\tilde{\chi}_1^\pm$ 0.21  | Pure Wino<br>Pure higgsino  | 2201.02472<br>2201.02472   |
|  | Stable $\tilde{g}$ R-hadron   | pixel dE/dx  |  | $E_T^{\text{miss}}$  | 140  | $\tilde{g}$ 2.05  |   | 2205.06013   |
|  | Metastable $\tilde{g}$ R-hadron, $\tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$                                       | pixel dE/dx  |  | $E_T^{\text{miss}}$  | 140  | $\tilde{g}$ [ $\tau(\tilde{g}) = 10$ ns] 2.2  | $m(\tilde{\chi}_1^0) = 100$ GeV   | 2205.06013   |
|  | $\tilde{\ell}\tilde{\ell}, \tilde{\ell} \rightarrow \ell\tilde{G}$  | Displ. lep   |  | $E_T^{\text{miss}}$  | 140  | $\tilde{\ell}, \tilde{\mu}$ 0.7<br>$\tilde{\tau}$ 0.34<br>$\tilde{\tau}$ 0.36   | $\tau(\tilde{\ell}) = 0.1$ ns<br>$\tau(\tilde{\ell}) = 0.1$ ns<br>$\tau(\tilde{\ell}) = 10$ ns  | 2011.07812<br>2011.07812<br>2205.06013   |
| RPV  | $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp / \tilde{\chi}_1^0, \tilde{\chi}_1^\pm \rightarrow Z\ell \rightarrow \ell\ell\ell$ | 3 $e, \mu$   |  | $E_T^{\text{miss}}$  | 140  | $\tilde{\chi}_1^\pm / \tilde{\chi}_1^0$ [BR(Z $\tau$ )=1, BR(Z $e$ )=1] 1.05<br>$\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ [BR(Z $\tau$ )=1, BR(Z $e$ )=1] 0.625                 | Pure Wino   | 2011.10543   |
|  | $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp / \tilde{\chi}_2^0 \rightarrow WW/Z\ell\ell\ell\nu\nu$                             | 4 $e, \mu$   | 0 jets   | $E_T^{\text{miss}}$  | 140  | $\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ [ $\lambda_{133} \neq 0, \lambda_{12k} \neq 0$ ] 1.55<br>$\tilde{\chi}_1^\pm / \tilde{\chi}_2^0$ [BR(Z $\tau$ )=1, BR(Z $e$ )=1] 0.95 | $m(\tilde{\chi}_1^0) = 200$ GeV   | 2103.11684   |
|  | $\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow qq$                   |  | $\geq 8$ jets  | $E_T^{\text{miss}}$  | 140  | $\tilde{g}$ [ $m(\tilde{\chi}_1^0) = 50$ GeV, 1250 GeV] 2.25<br>$\tilde{g}$ [ $\lambda'_{323} = 2e-4, 1e-2$ ] 1.6   | Large $\lambda'_{12}$   | To appear  |
|  | $\tilde{u}, \tilde{t} \rightarrow \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow tbs$                                     |  | Multiple   | $E_T^{\text{miss}}$  | 36.1   | $\tilde{t}$ 1.05  | $m(\tilde{\chi}_1^0) = 200$ GeV, bino-like  | ATLAS-CONF-2018-003  |
|  | $\tilde{u}, \tilde{t} \rightarrow b\tilde{\chi}_1^\pm, \tilde{\chi}_1^\pm \rightarrow bbs$                                |  | $\geq 4b$  | $E_T^{\text{miss}}$  | 140  | $\tilde{t}$ Forbidden 0.95  | $m(\tilde{\chi}_1^0) = 500$ GeV   | 2010.01015   |
|  | $\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow bs$  |  | 2 jets + 2 $b$   | $E_T^{\text{miss}}$  | 36.7   | $\tilde{t}_1$ [ $qq, bs$ ] 0.61<br>$\tilde{t}_1$ 0.42   |   | 1710.07171   |
| $\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow q\ell$  | 2 $e, \mu$<br>1 $\mu$   | 2 $b$<br>DV  | $E_T^{\text{miss}}$<br>$E_T^{\text{miss}}$                     | 36.1<br>136  | $\tilde{t}_1$ 1.6<br>$\tilde{t}_1$ [1e-10 < $\lambda'_{23k} < 1e-8, 3e-10 < \lambda'_{23k} < 3e-9$ ] 1.0 | $\text{BR}(\tilde{t}_1 \rightarrow b\ell/b\mu) > 20\%$<br>$\text{BR}(\tilde{t}_1 \rightarrow q\mu) = 100\%, \cos\theta = 1$   | 1710.05544<br>2003.11956  |  |
| $\tilde{\chi}_1^\pm / \tilde{\chi}_2^0 / \tilde{\chi}_1^0, \tilde{\chi}_{1,2}^0 \rightarrow tbs, \tilde{\chi}_1^\pm \rightarrow bbs$ | 1-2 $e, \mu$  | $\geq 6$ jets  | $E_T^{\text{miss}}$  | 140  | $\tilde{\chi}_1^0$ 0.2-0.32  | Pure higgsino   | 2106.09609  |  |

\*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

10<sup>-1</sup>

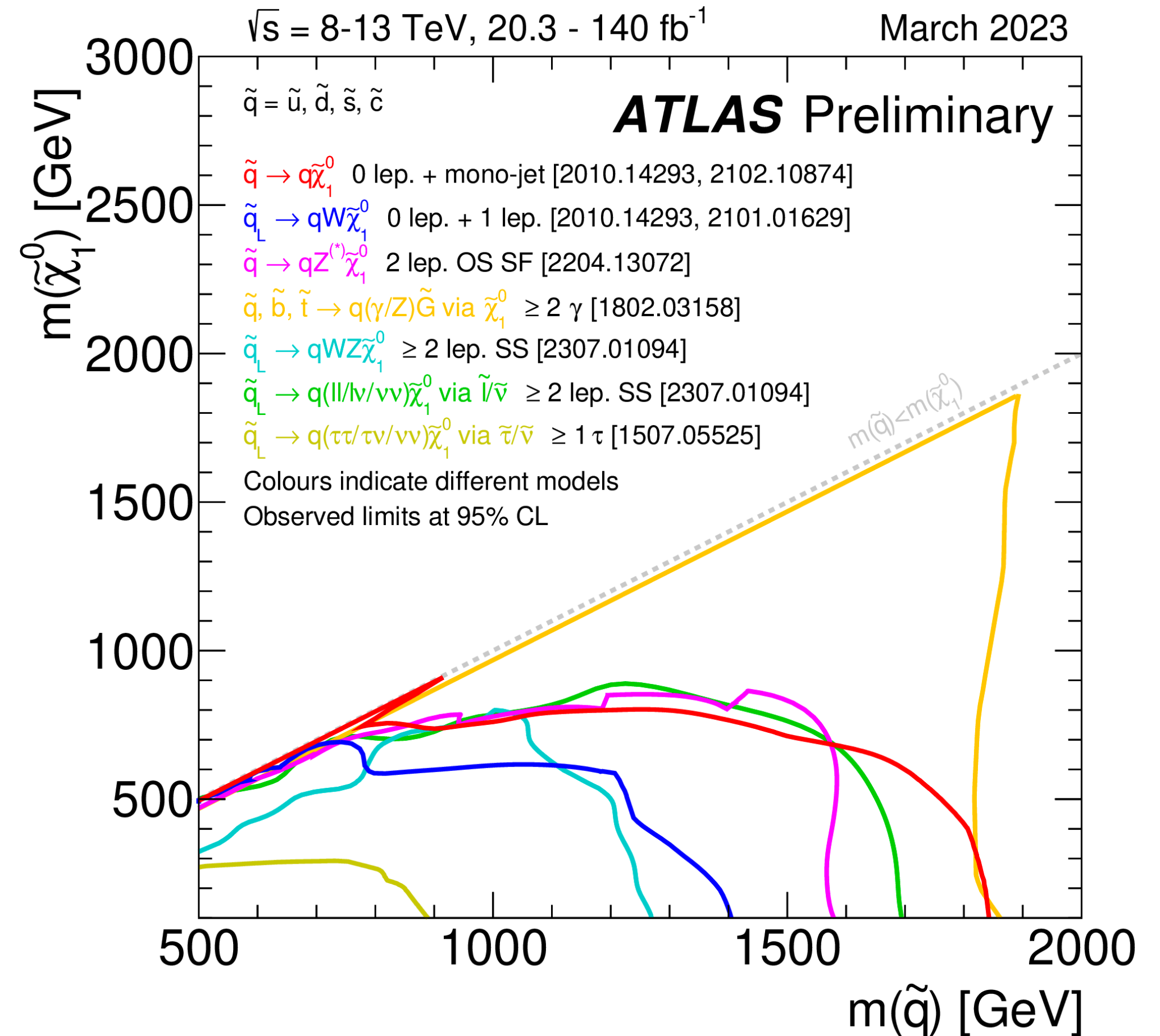
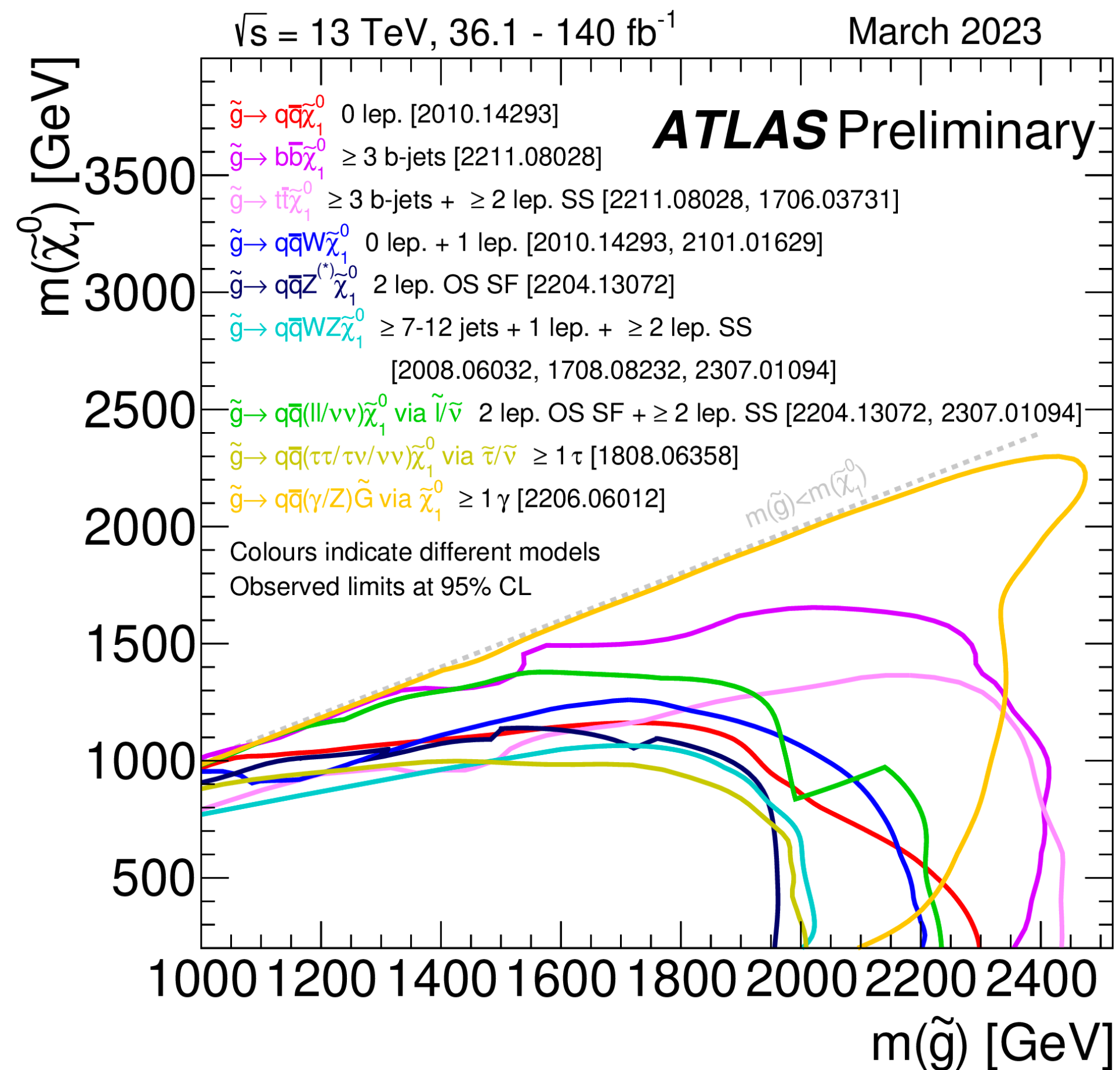
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Mass scale [TeV]

Wide range of searches in ATLAS covering vast regions of SUSY phase space

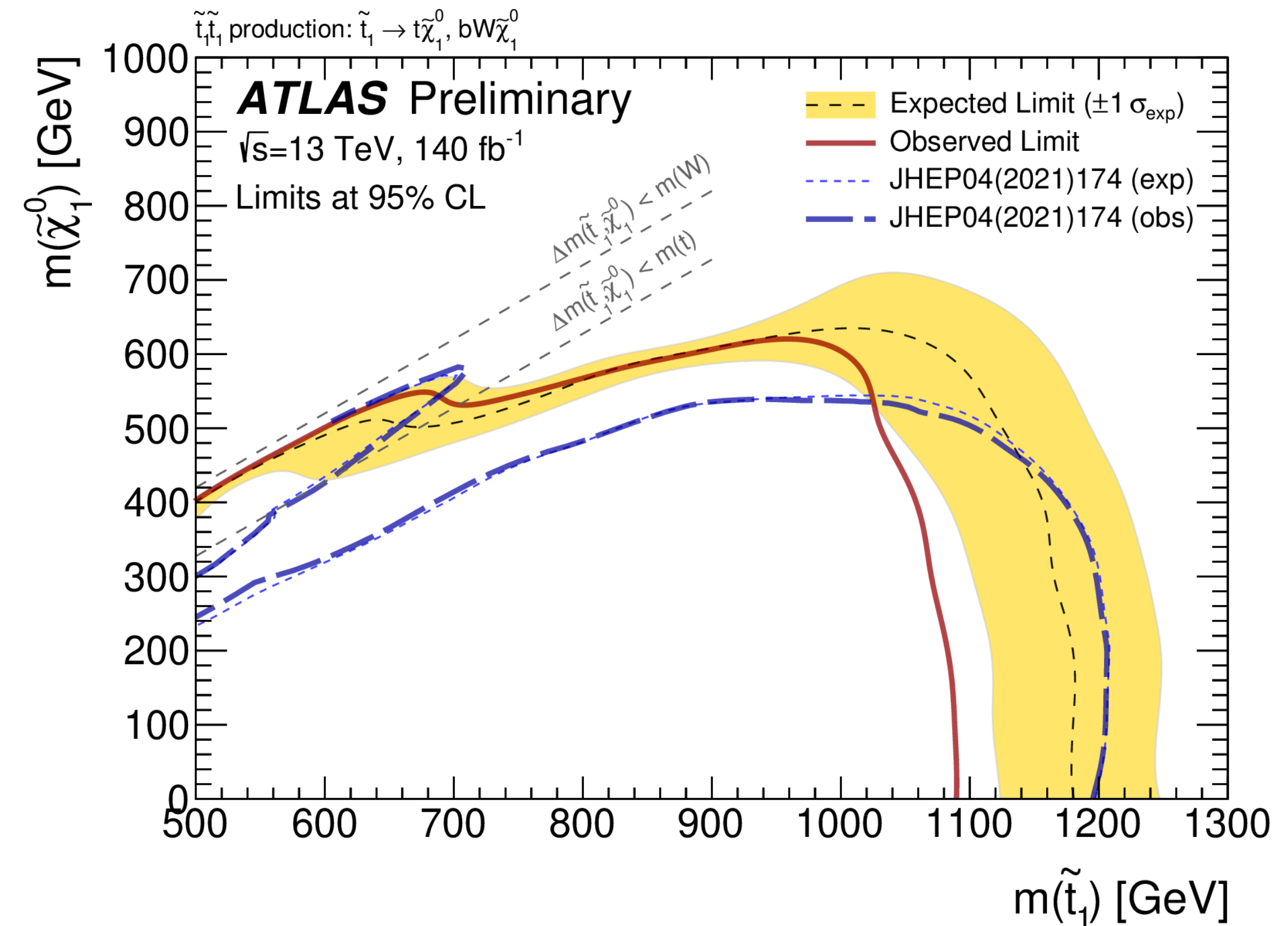
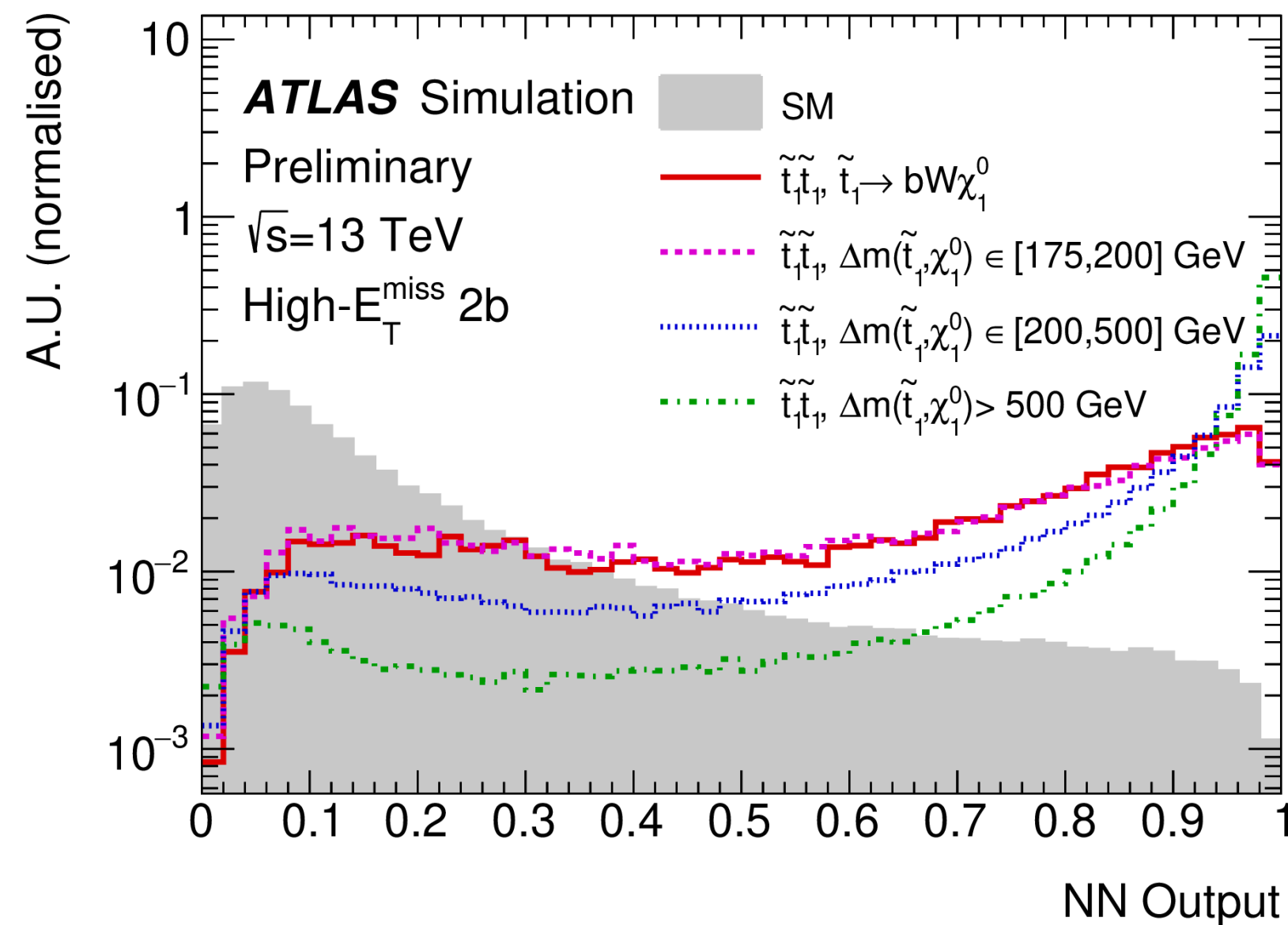
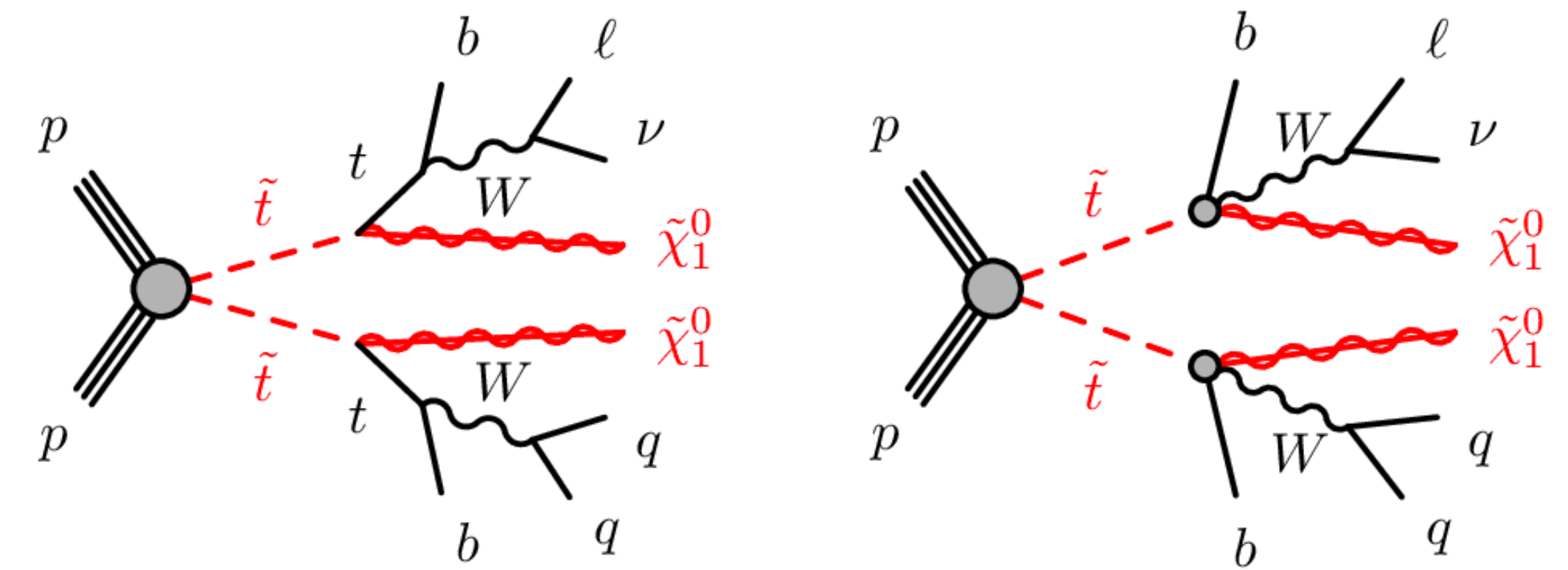
# Squarks and gluinos searches

- Analyses covering each corner of the phase space for different gluino/squark decay modes
- Masses excluded up to 1-2 TeV depending the model considered
- Weaker limits in the compressed region for neutralino LSP  $\rightarrow$  work ongoing to improve this with ML



# Stop search: $t\bar{t} + \text{MET}$

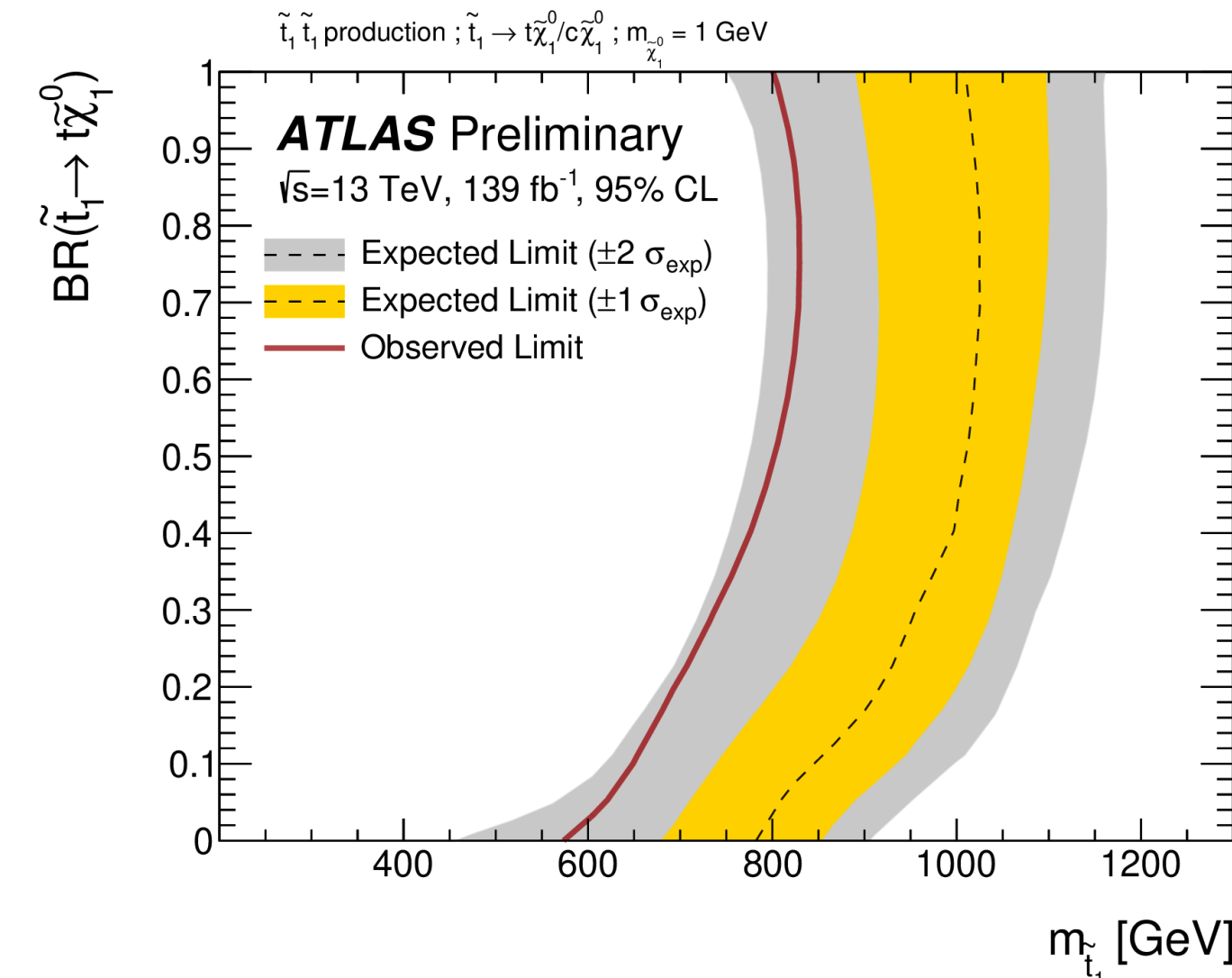
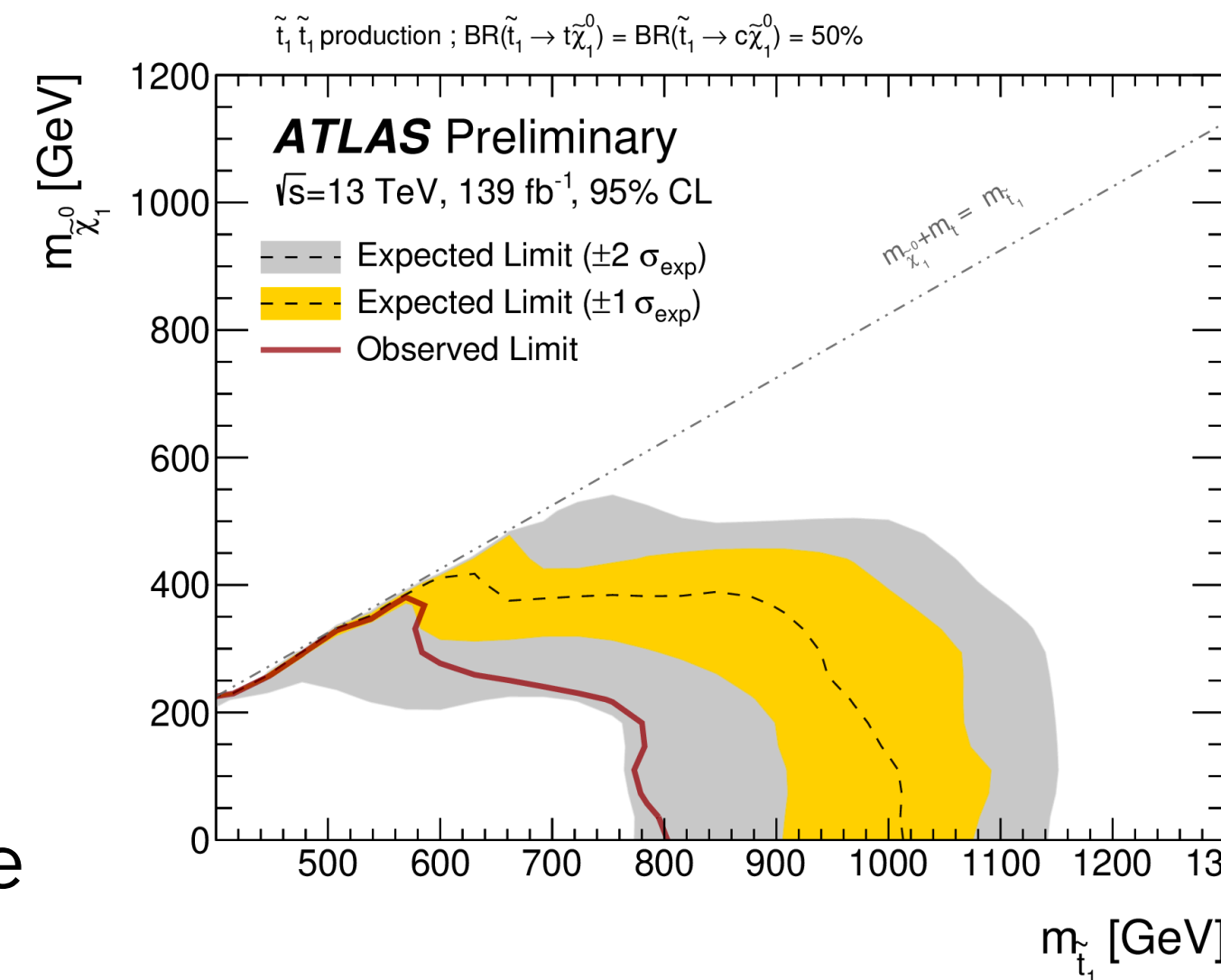
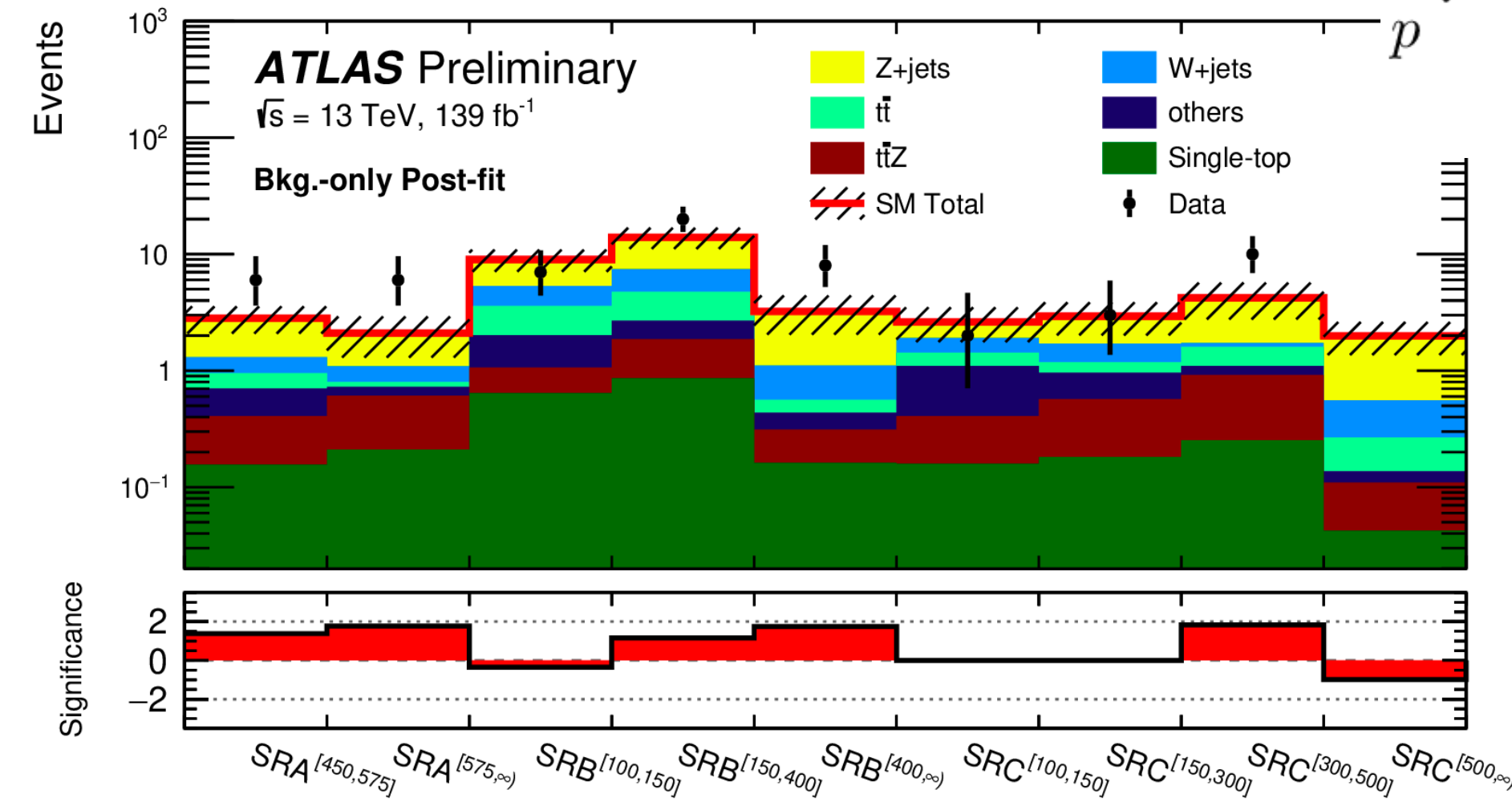
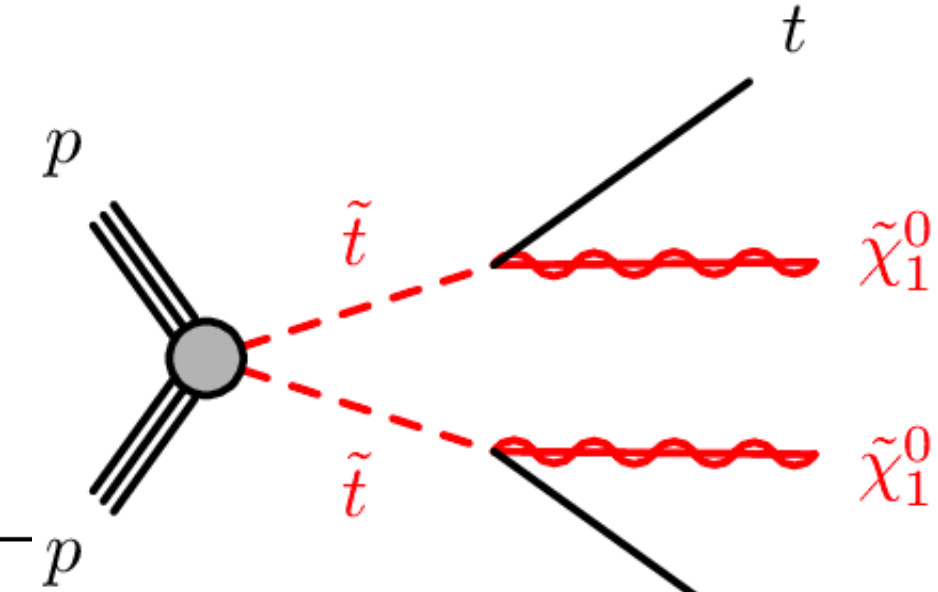
- Search for direct stop pair production with one lepton (from on-shell  $W$ ), jets and high MET
- Orthogonal and inclusive event categories depending on number of  $b$ -jets and jets from top quarks
- Neural network to discriminate signal/background for each SR
- Exclusion limits
  - Neutralino up to 600 GeV from direct stop decays
  - Stop masses up to 1.1 TeV for low neutralino mass



# Stop search: $t\tilde{c} + \text{MET}$

- Dropping assumption of minimal flavor violation allow stop and scharm mixing
  - mixed decays with one hadronic top, one charm jet and MET
  - Scan of  $\text{BR}(\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 / t\tilde{\chi}_1^0)$
- Dedicated charm tagger with 20% c-tag efficiency
- DNN top tagger to identify large-R jets from top decays
- Final state kinematics very dependent on mass splitting
  - 4 orthogonal SRs
  - ISR jet used for compressed region
- Top squark masses excluded up to 800 GeV for light neutralinos and 600 GeV for degenerate case

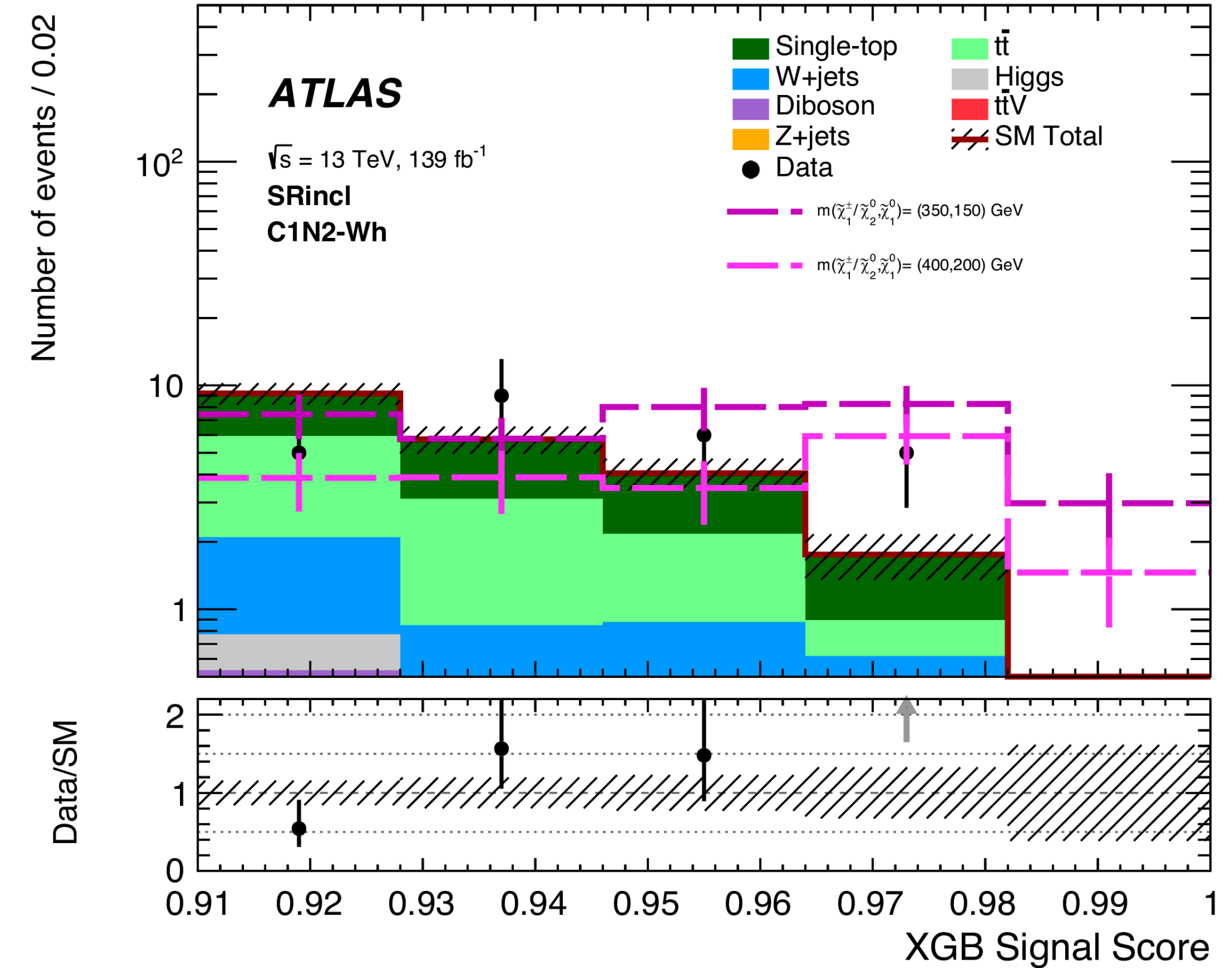
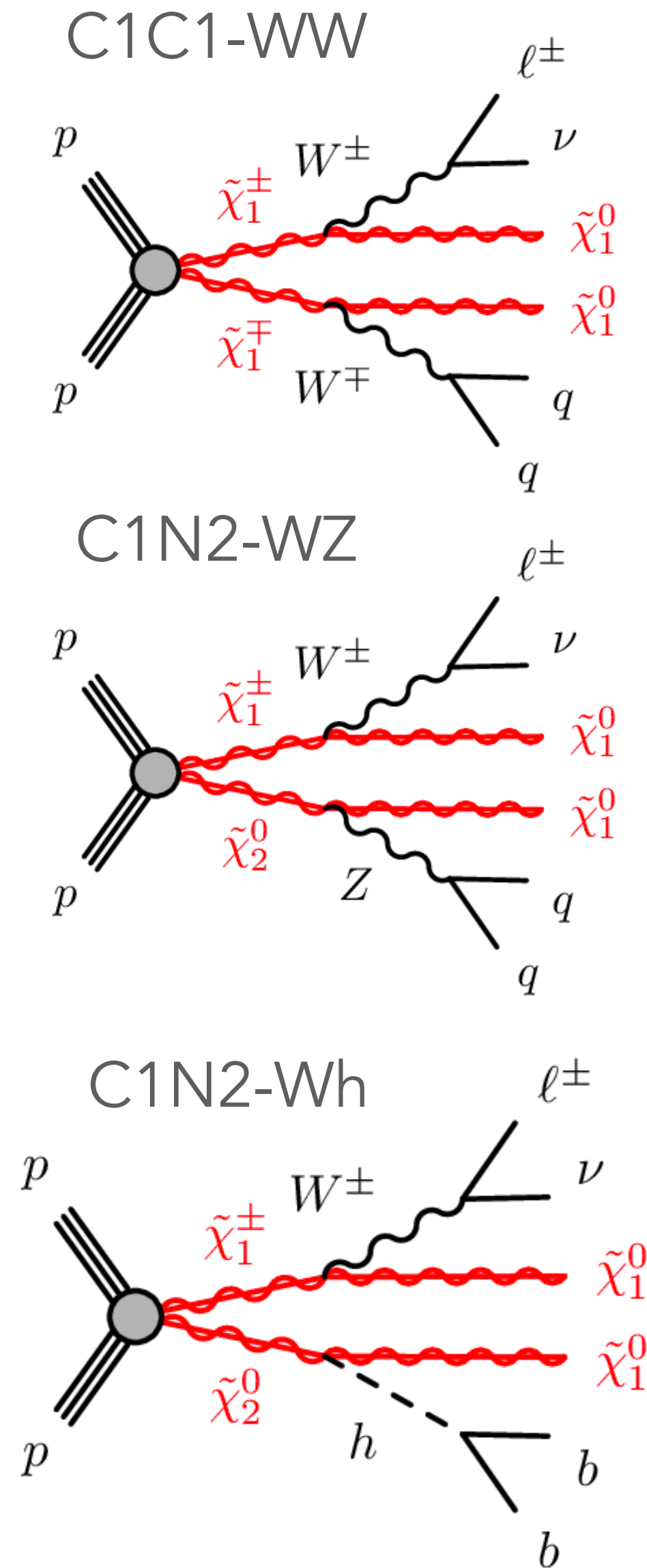
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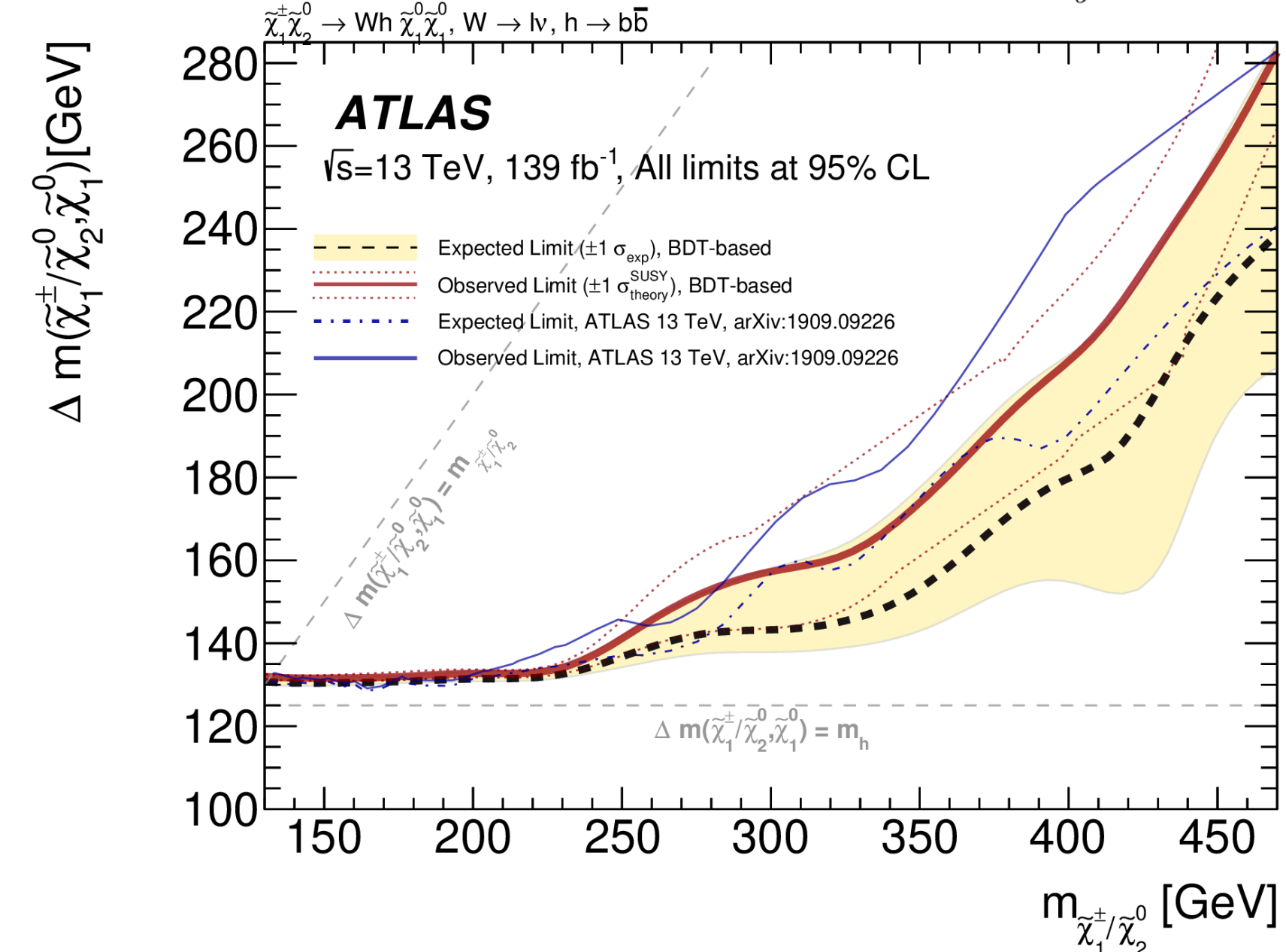
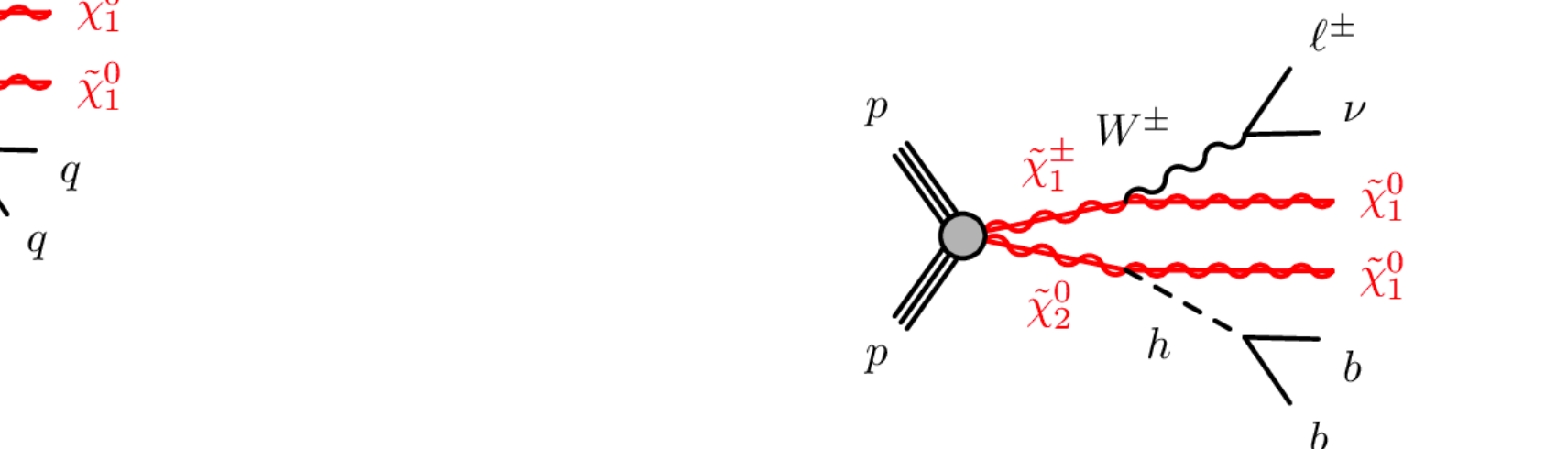
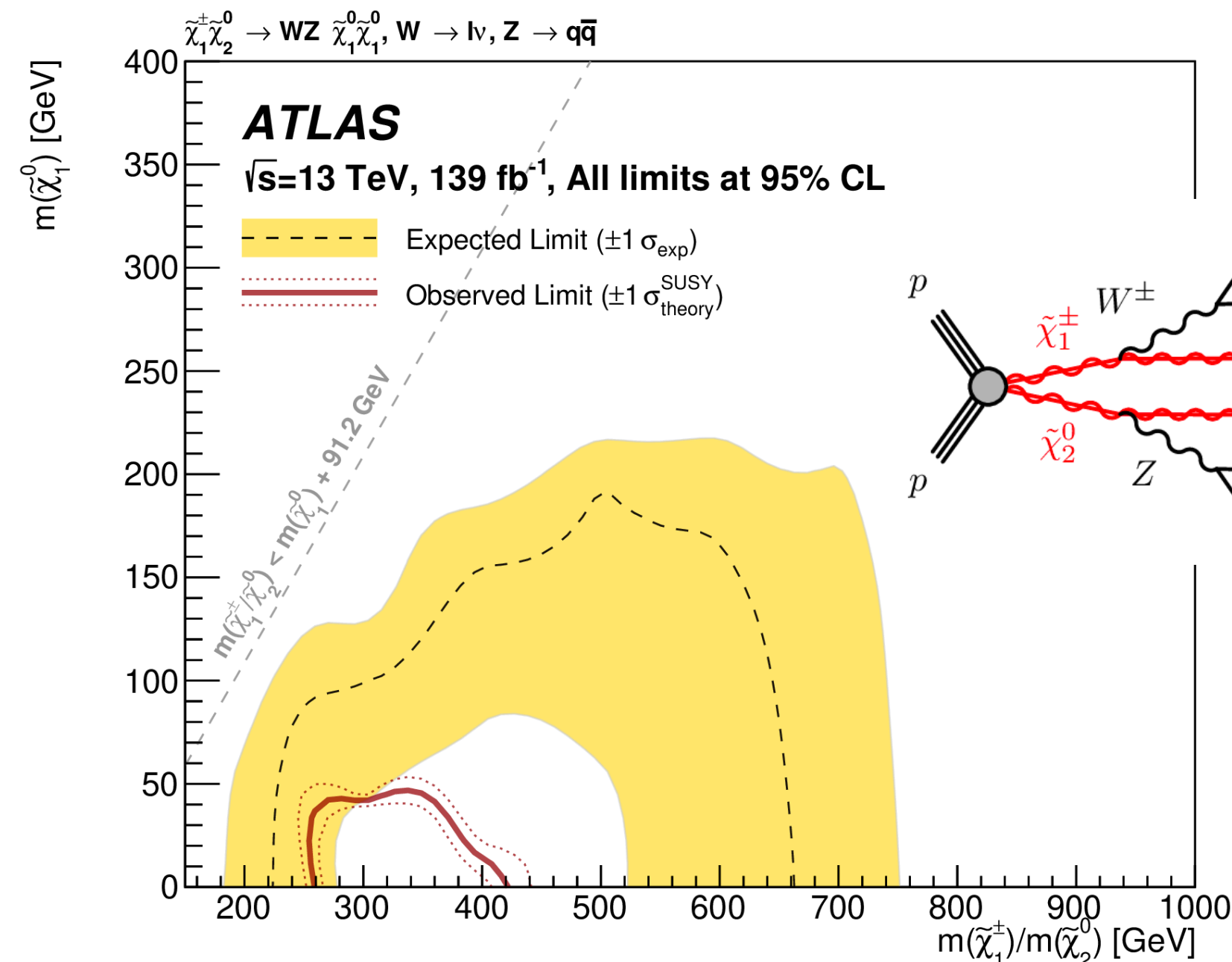
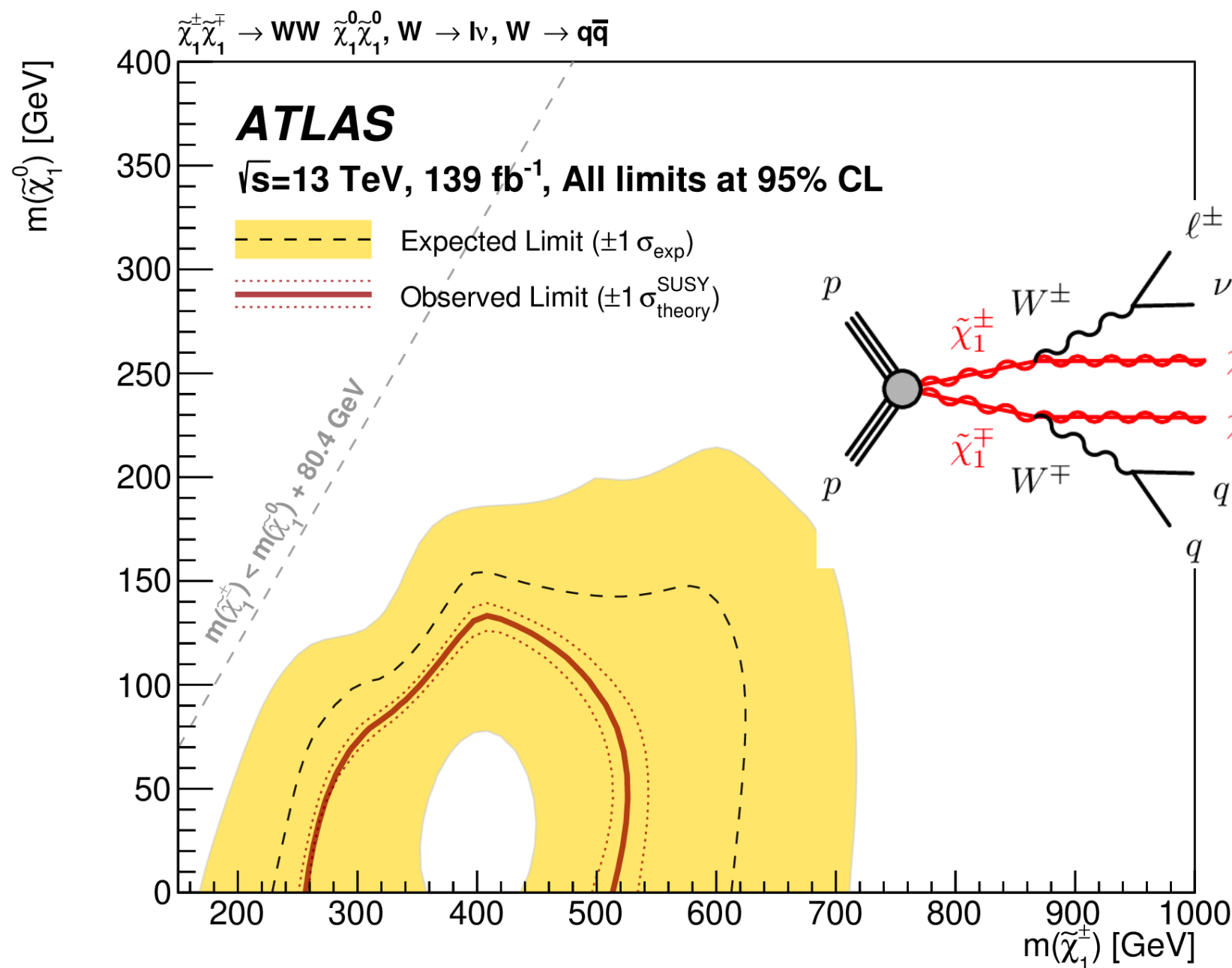


# Electroweak searches with one lepton

- $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$  and  $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$  production
- Single isolated lepton ( $e/\mu$ ), jets and MET
- Three sets of SRs targeting the 3 production/decay models
- WW/WZ channels:
  - One lepton and 3 jets
  - W and Z tagging
- Wh channel:
  - 2 b-jets to identify Higgs boson
  - BDT as final discriminant
- Backgrounds from MC with CRs



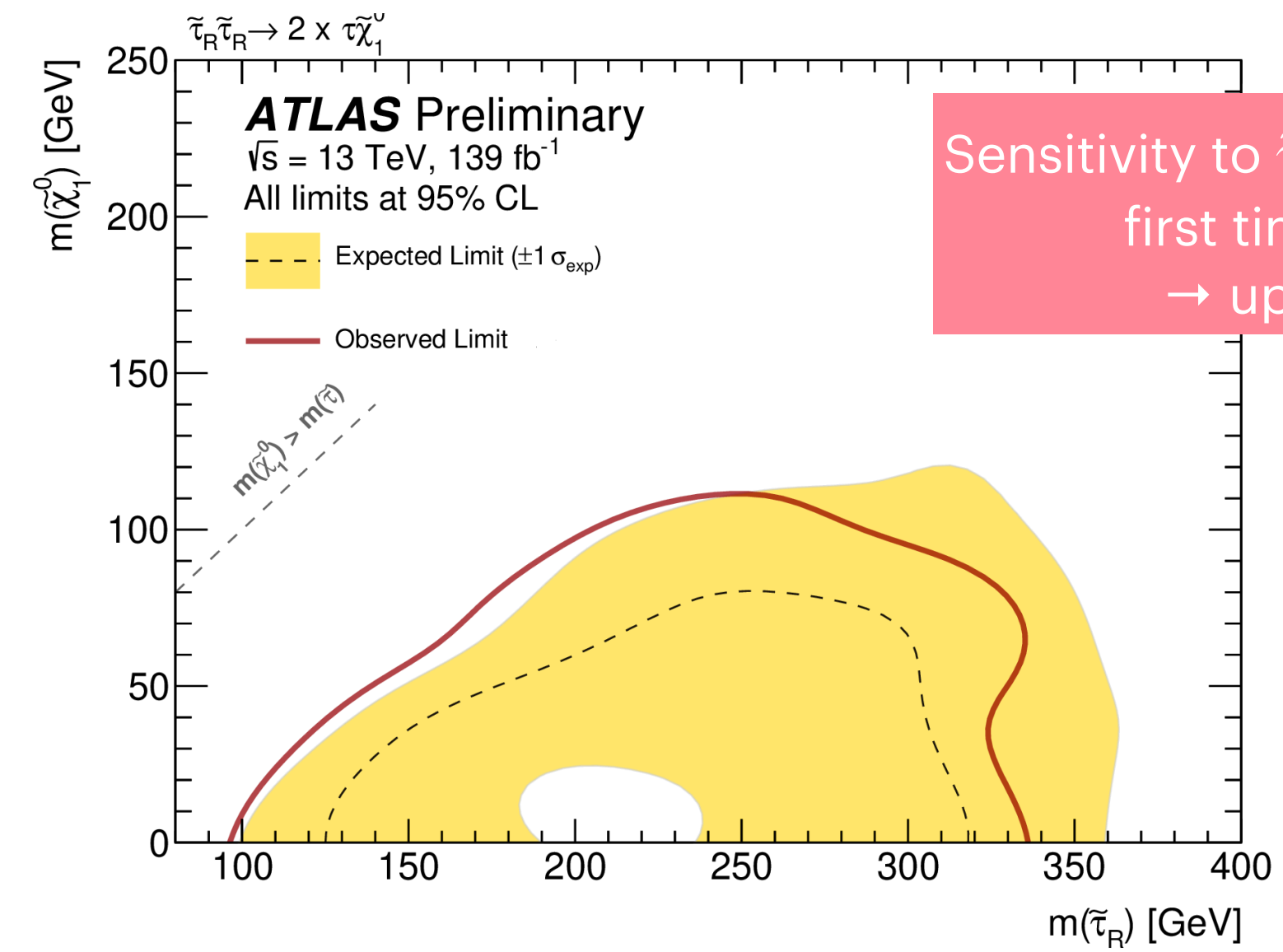
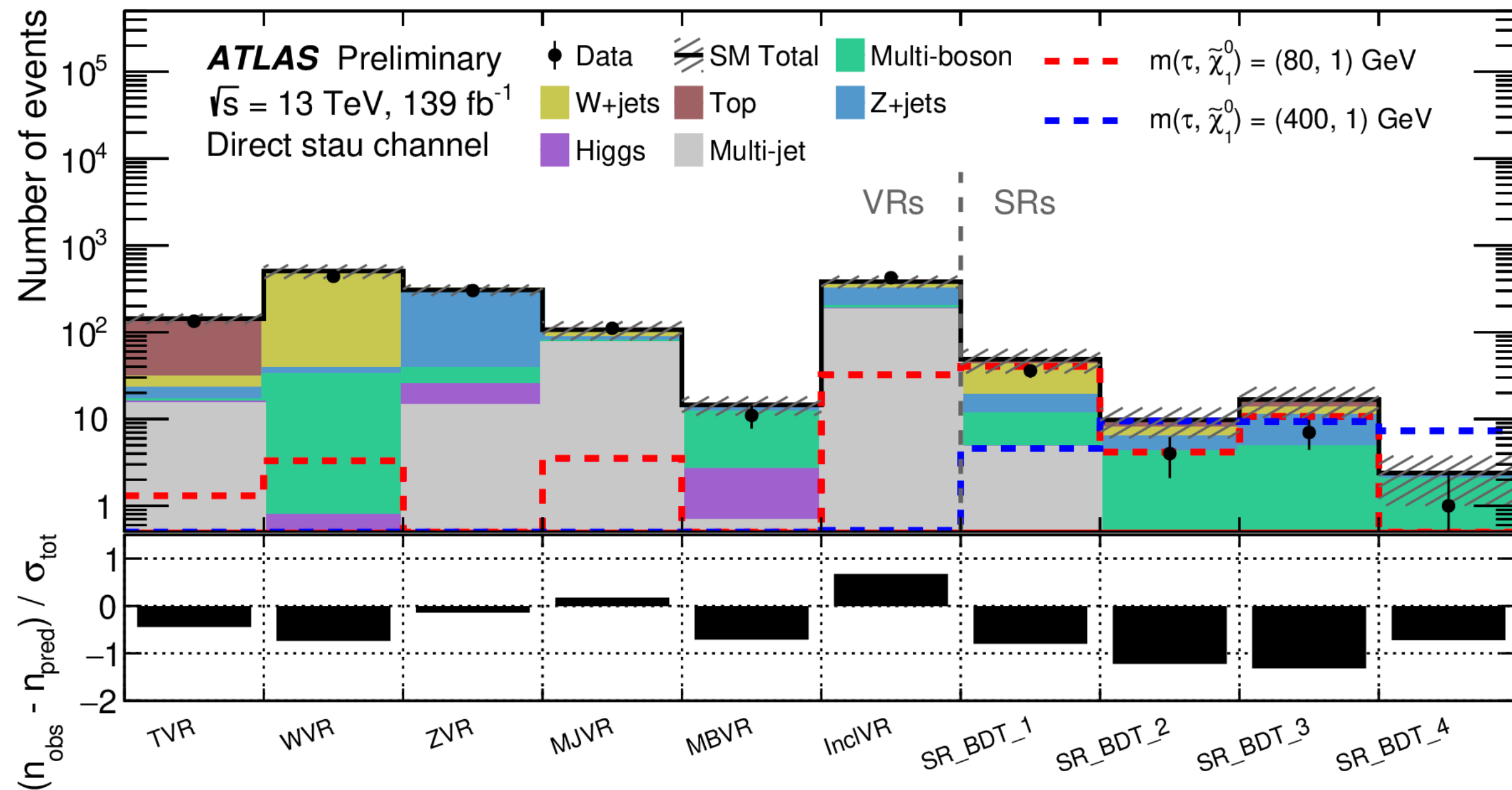
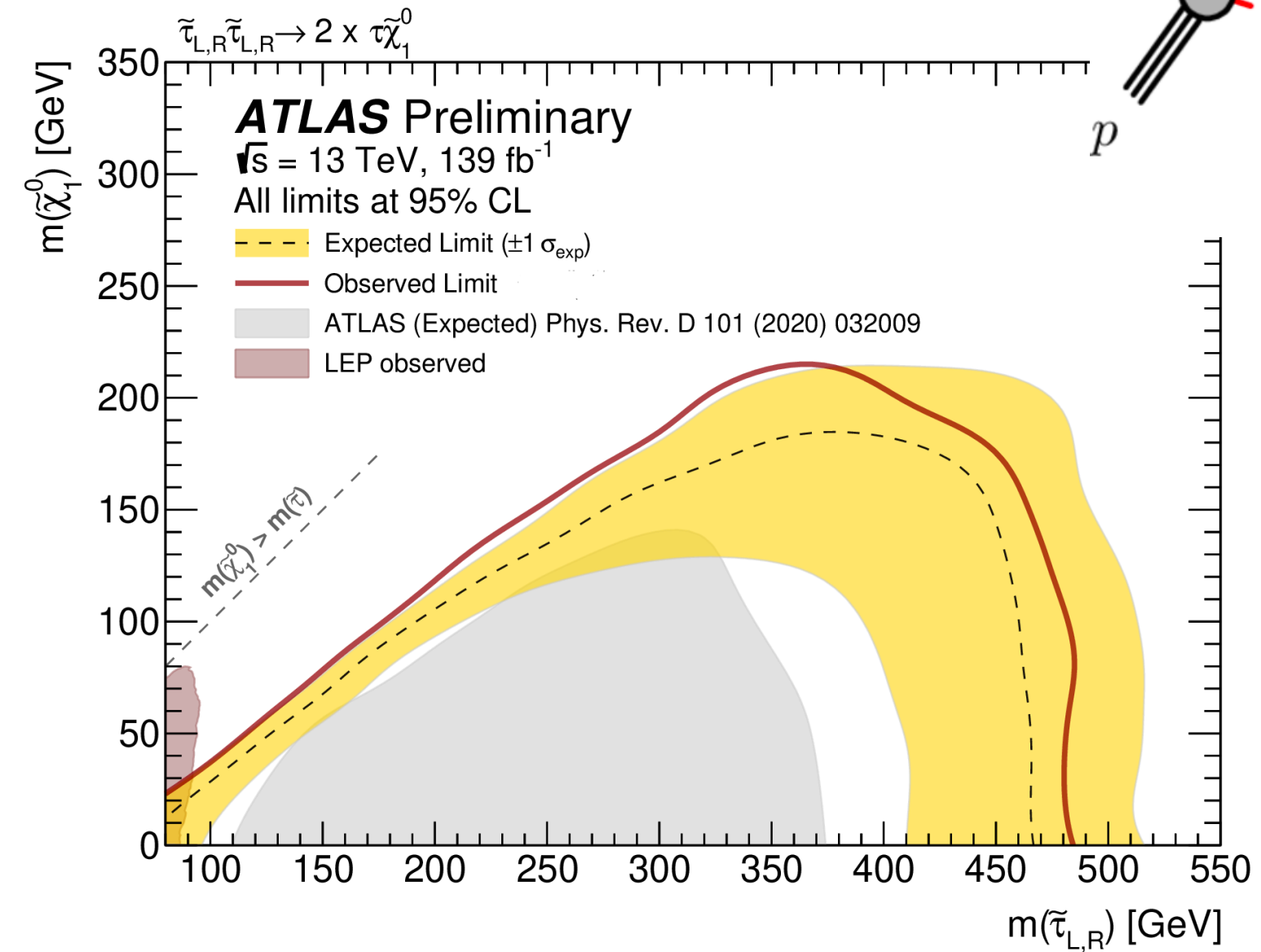
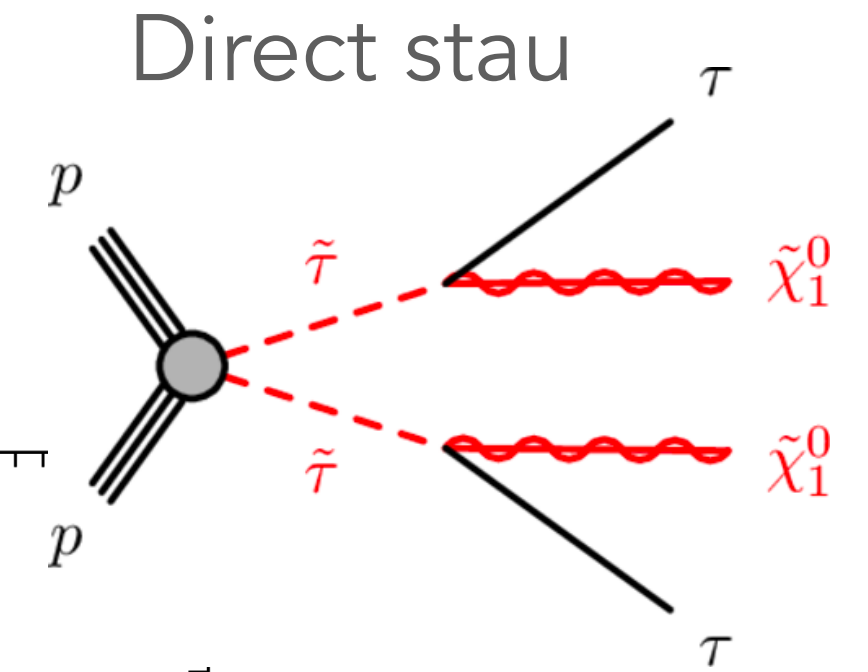
# Electroweak searches with one lepton



- No deviations from SM
- Exclusion limits on the three simplified models:
  - 260 to 520 GeV  $\tilde{\chi}_1^\pm$  for massless  $\tilde{\chi}_1^0$
  - 260 to 420 GeV  $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$  for massless  $\tilde{\chi}_1^0$  for  $\tilde{\chi}_2^0 \rightarrow Z\tilde{\chi}_1^0$
  - Improved limits by up to 40 GeV in the Wh model

# Electroweak with taus: direct $\tilde{\tau}$

- Search for direct left and/or right handed stau production decaying to tau and LSP 100% of the time
- Mass degenerate or non-degenerate  $\tilde{\tau}_{L,R}$
- 4 BDT models trained for different mass spaces
  - QCD multijets background data-driven
  - W/Z+jets and top backgrounds normalized in CRs
- Extended sensitivity to 480 GeV for  $\tilde{\tau}_{L,R}$



Sensitivity to  $\tilde{\tau}_R$  production for the first time in the LHC  
 → up to 330 GeV

# Electroweak higgsinos with multi b-jets

- Production of higgsinos decaying to  $h(bb)h(bb) + \text{MET}$  in GMSB models
- New method for pairing  $b$ -jets into Higgs boson candidates, improved jet reconstruction and  $b$ -tagging, MVA techniques

- Two complementary analyses:

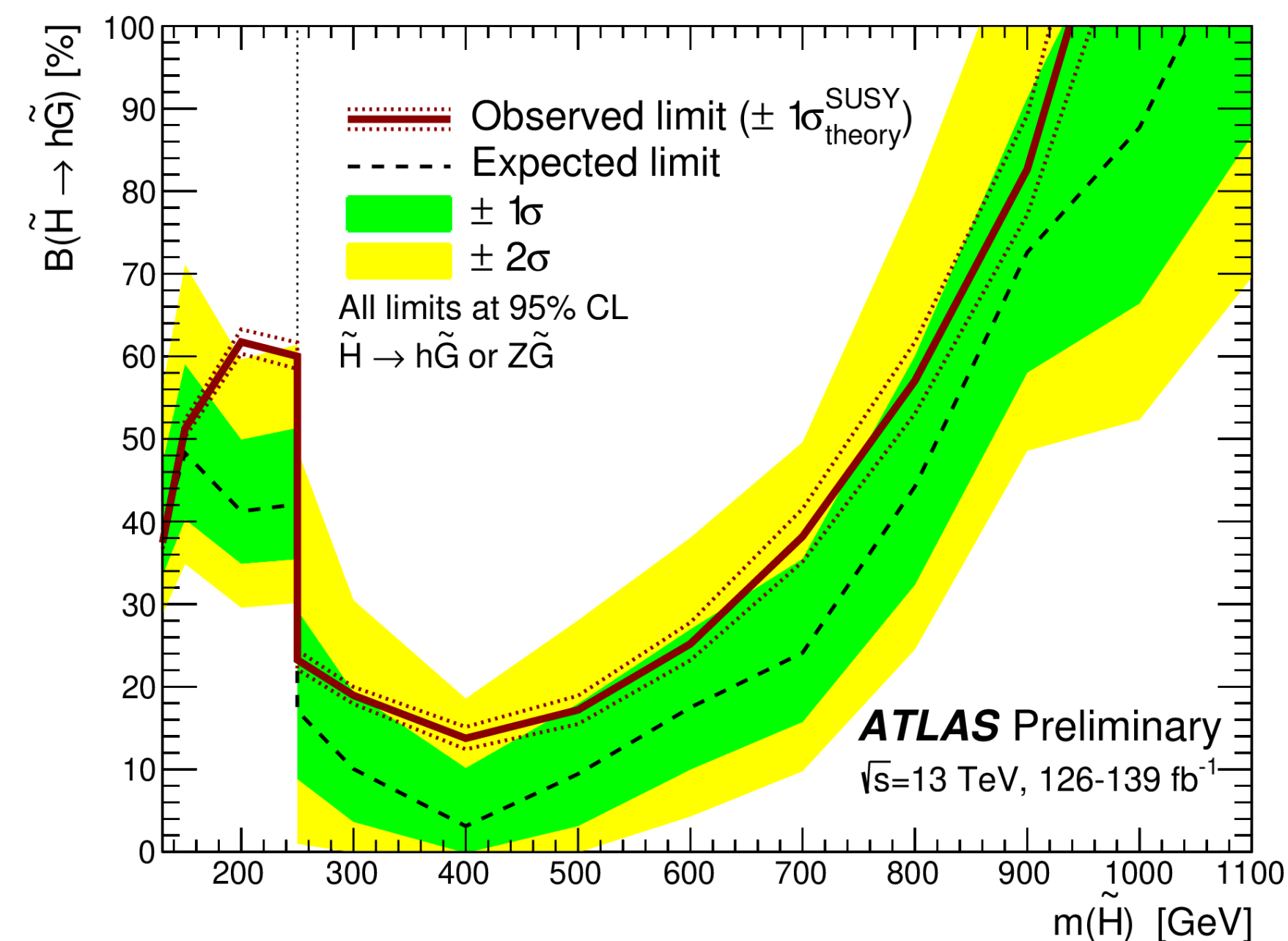
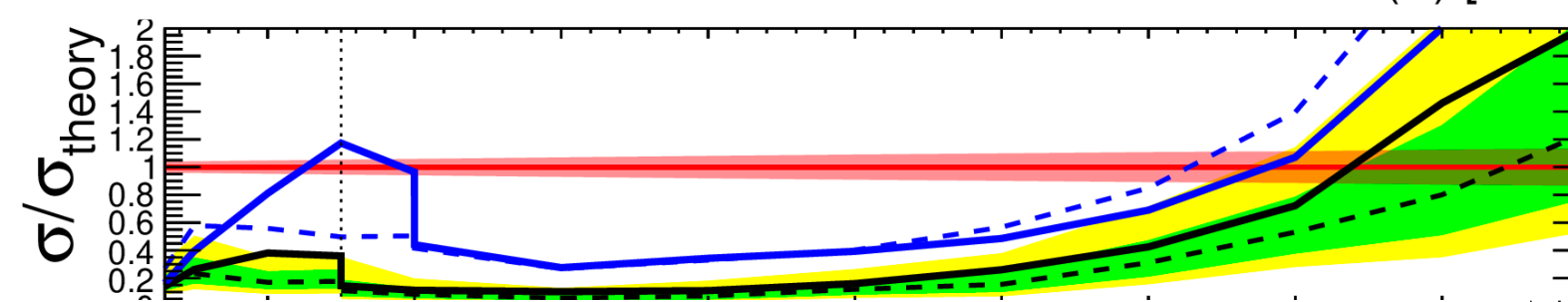
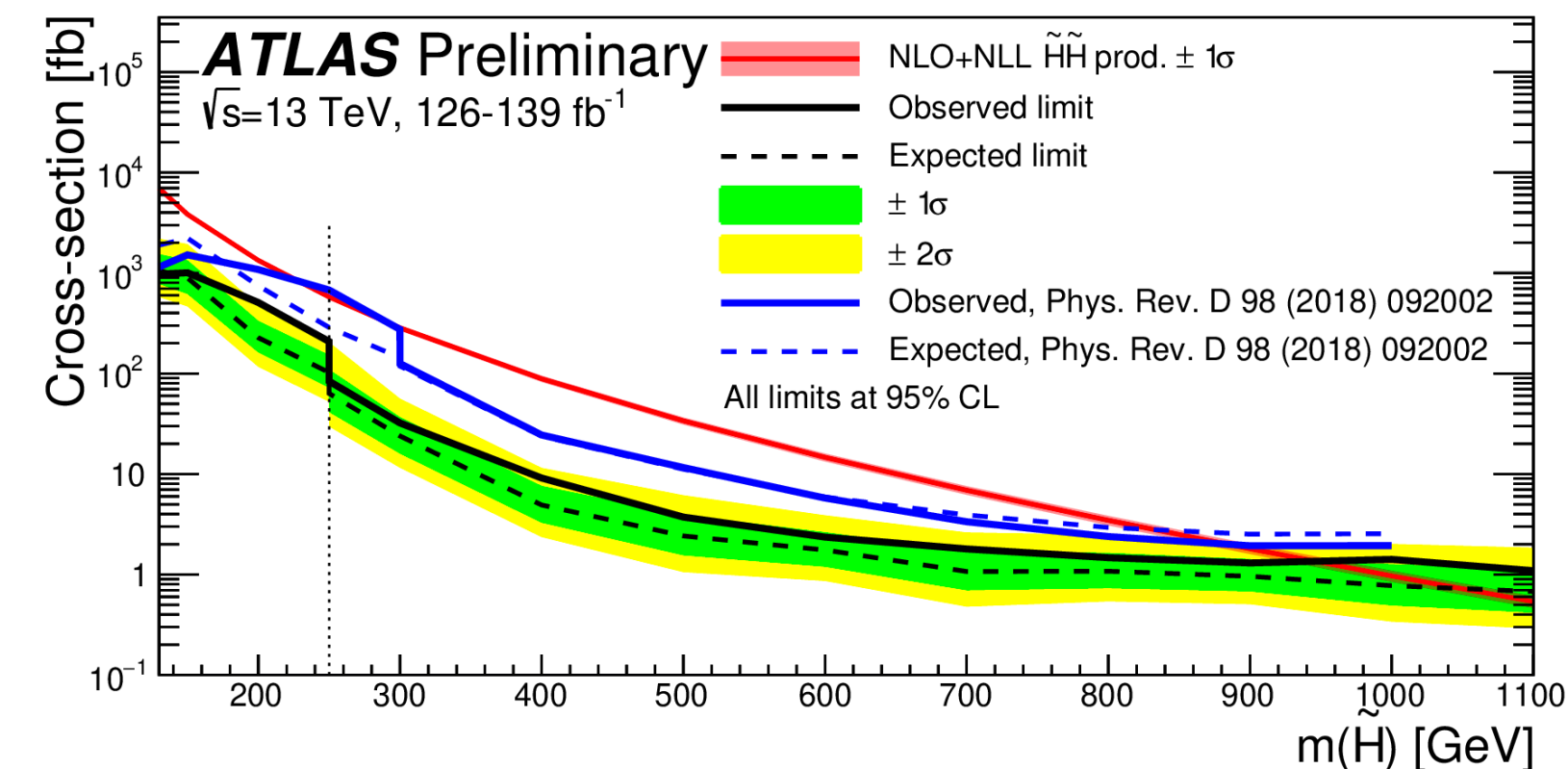
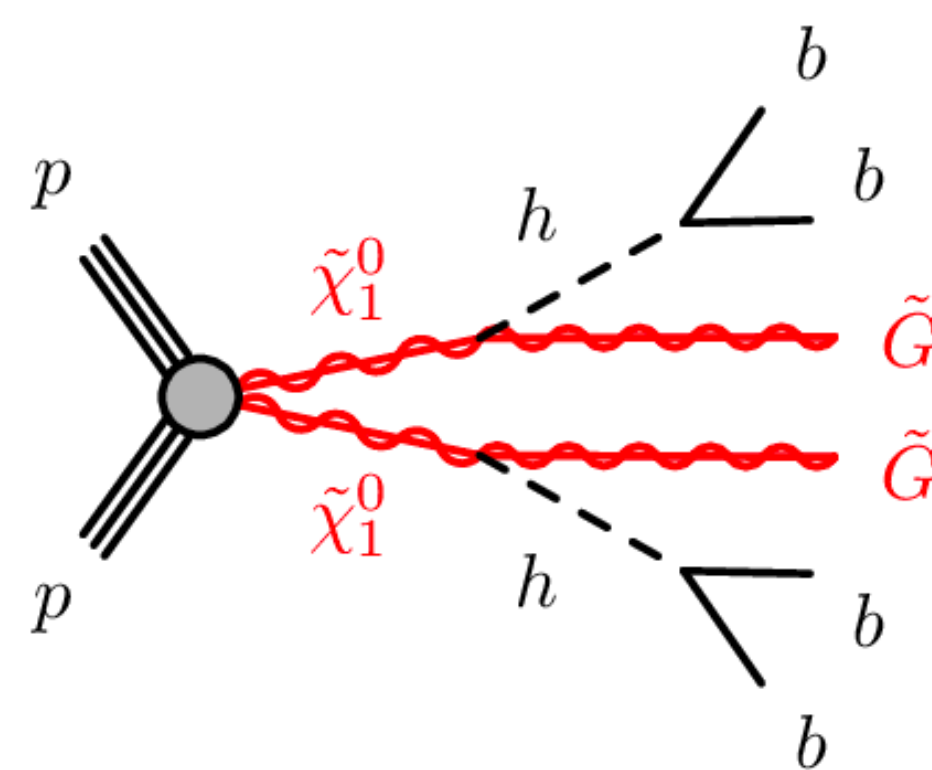
## Low higgsino mass (<250 GeV)

- Low MET ( $b$ -jet triggers)
- Four or more  $b$ -jets to reconstruct Higgs bosons
- QCD multijet and  $t\bar{t}$  estimated using ABCD method

## High higgsino mass (>250 GeV)

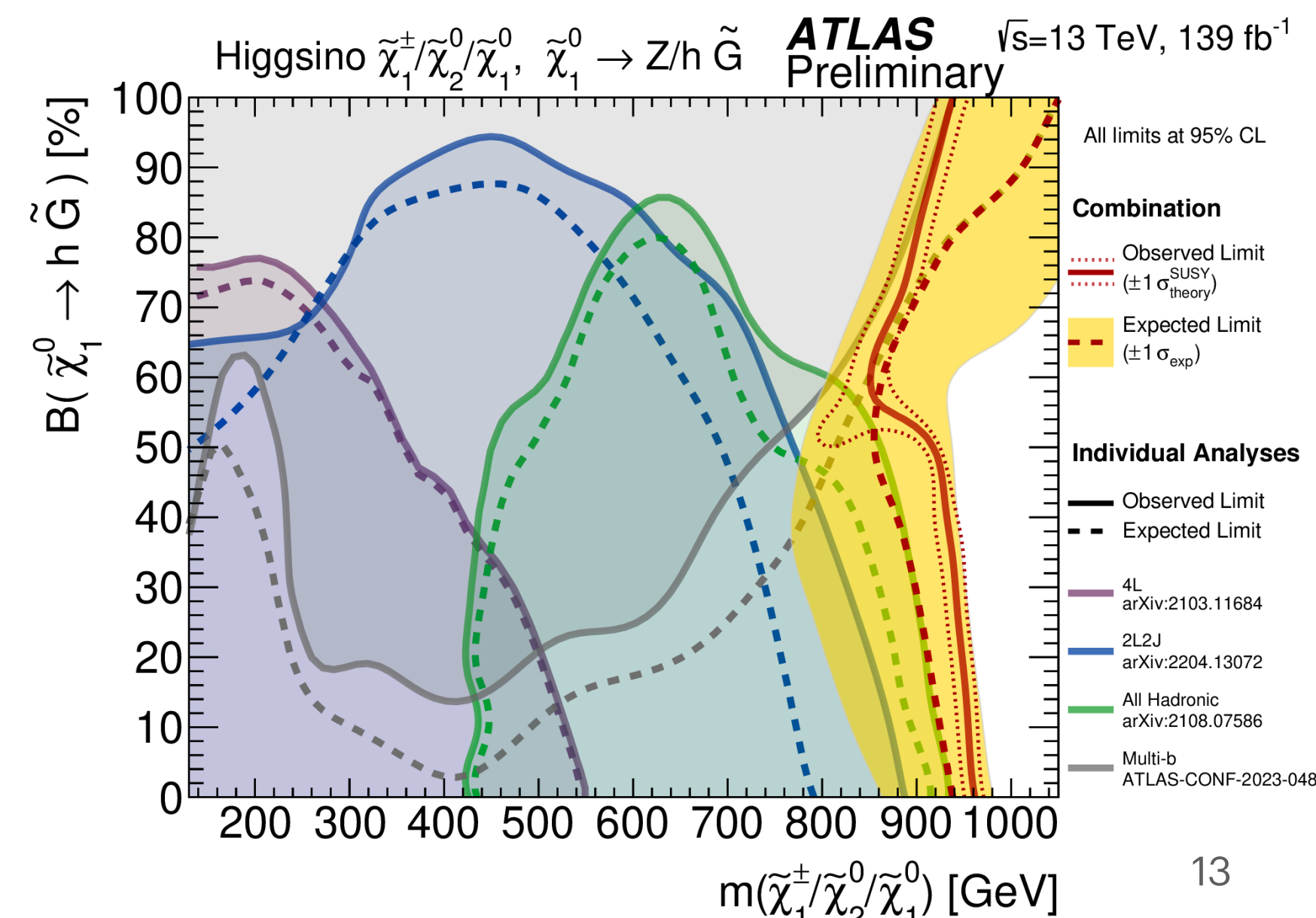
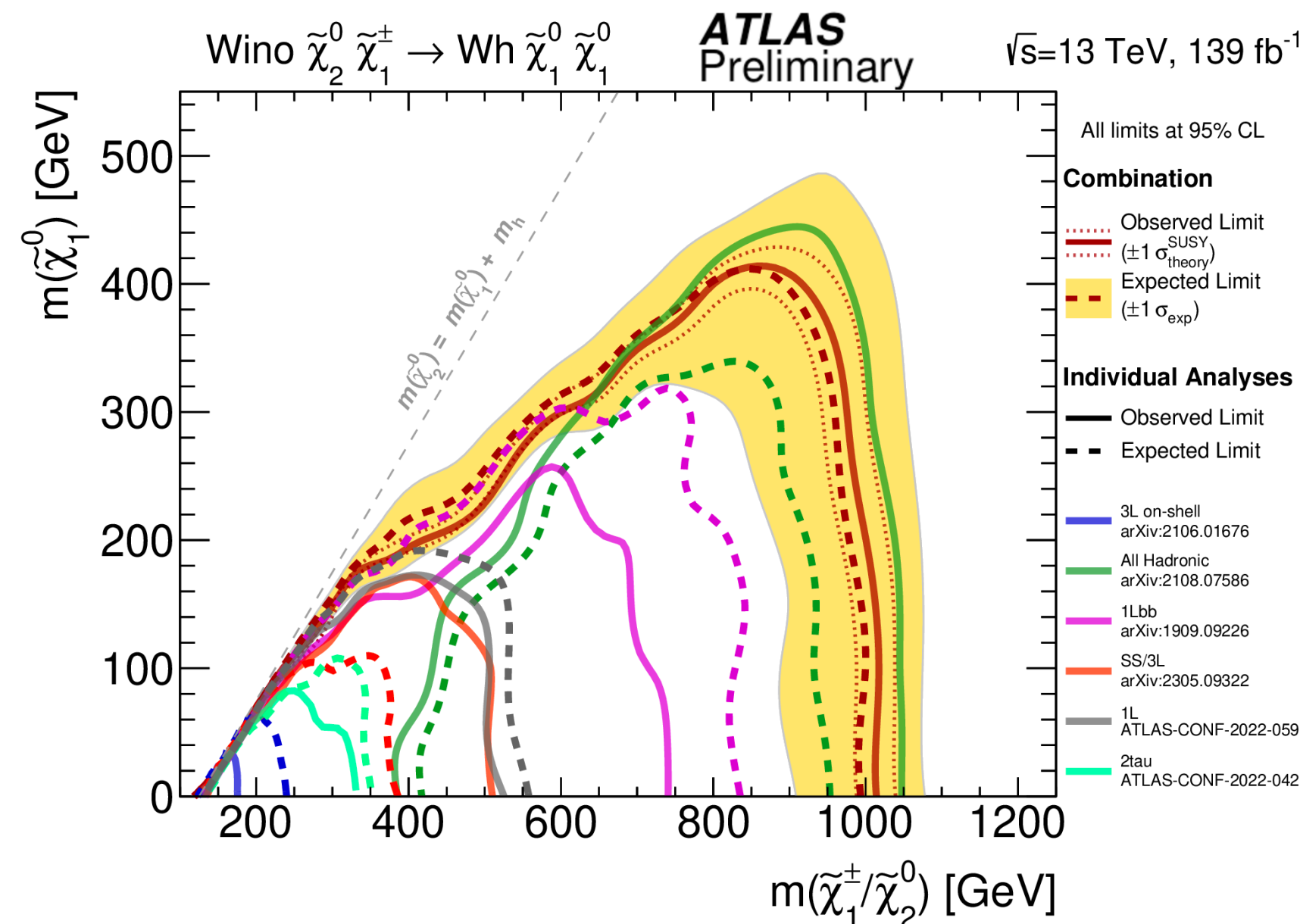
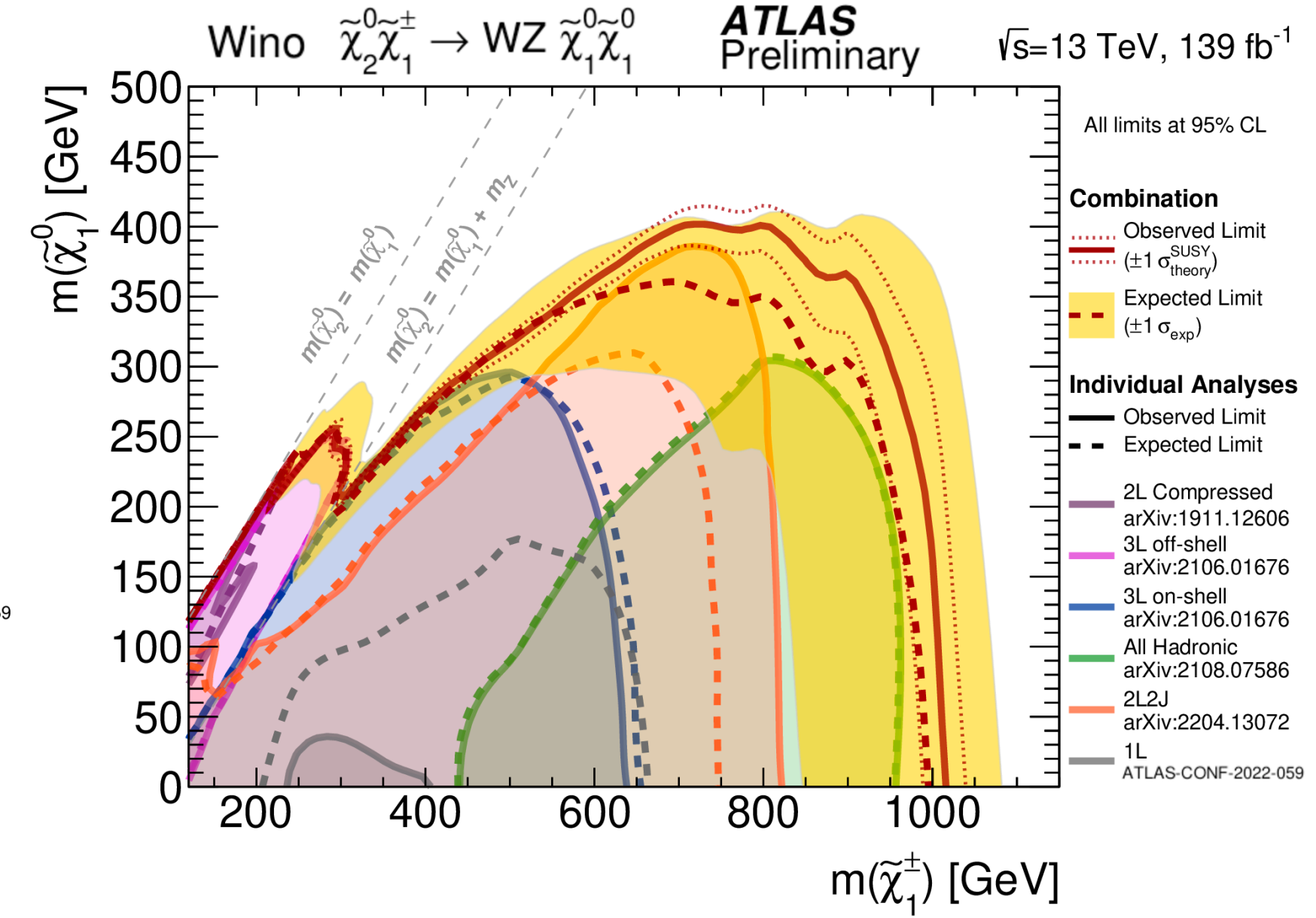
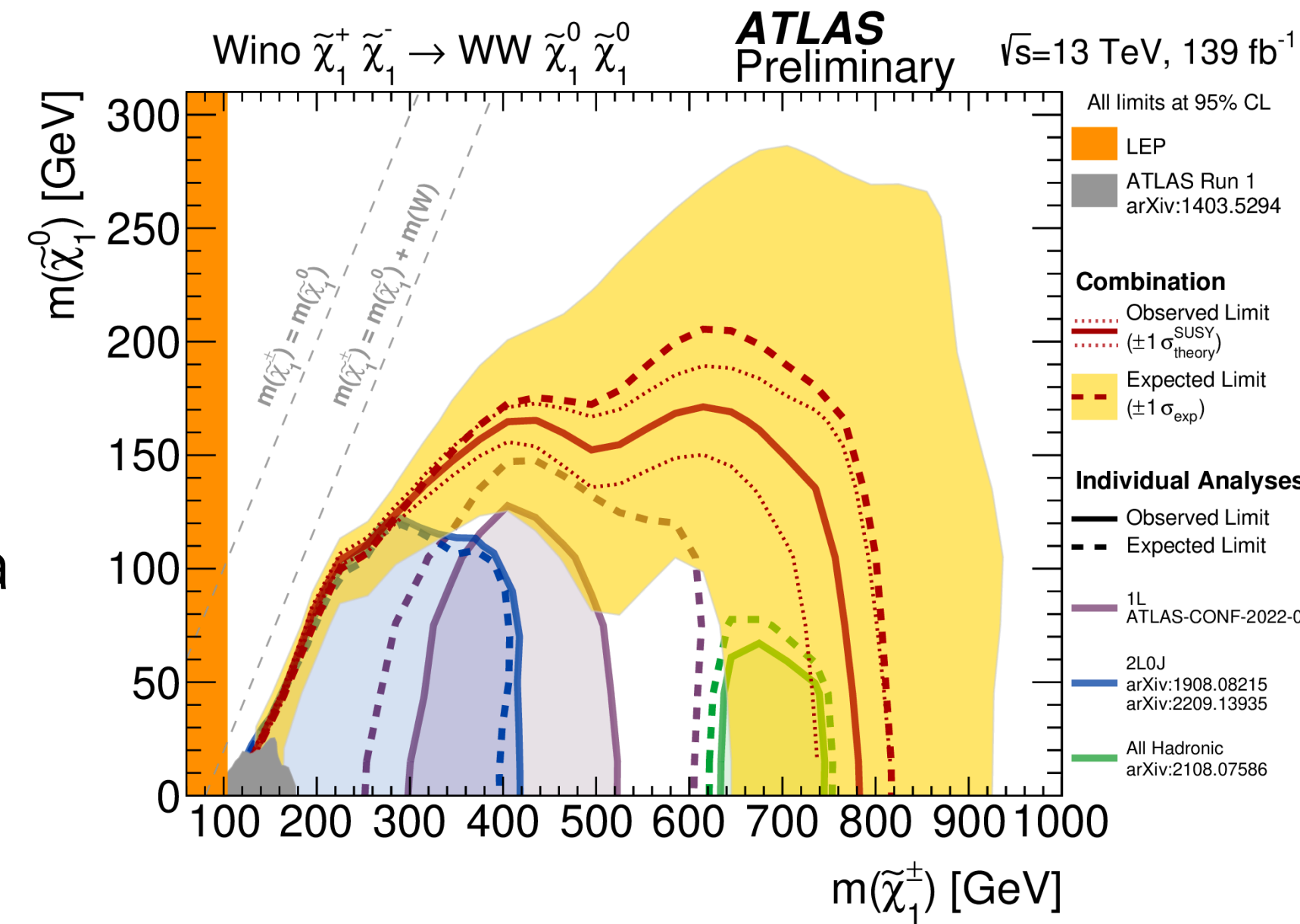
- High MET (MET based triggers)
- At least 3  $b$ -jets
- Z+jets and  $t\bar{t}$  CR and QCD multijet data-driven
- BDT signal/background discrimination

- Higgsino masses excluded up to 940 GeV for 100%  $BR(\tilde{H} \rightarrow h\tilde{G})$



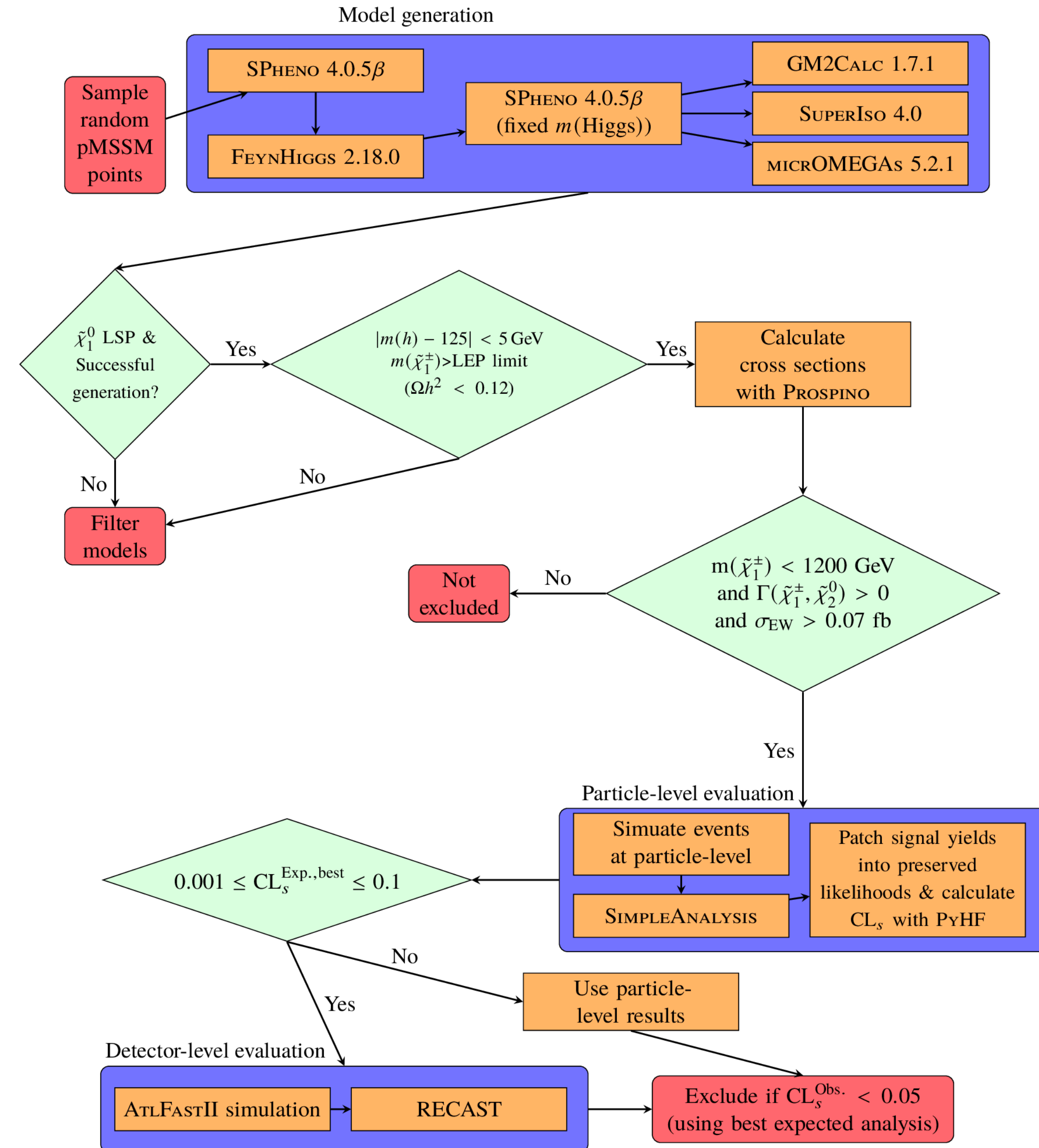
# Electroweak combination

- Statistical combination of wino/higgsino searches using various decay channels via  $W$ ,  $Z$  and  $h$
- Analyses harmonized to allow the statistical combination
  - Different lepton multiplicity
- Mass reach extended 30-100 GeV
- Cross section limit improved by up to 40%



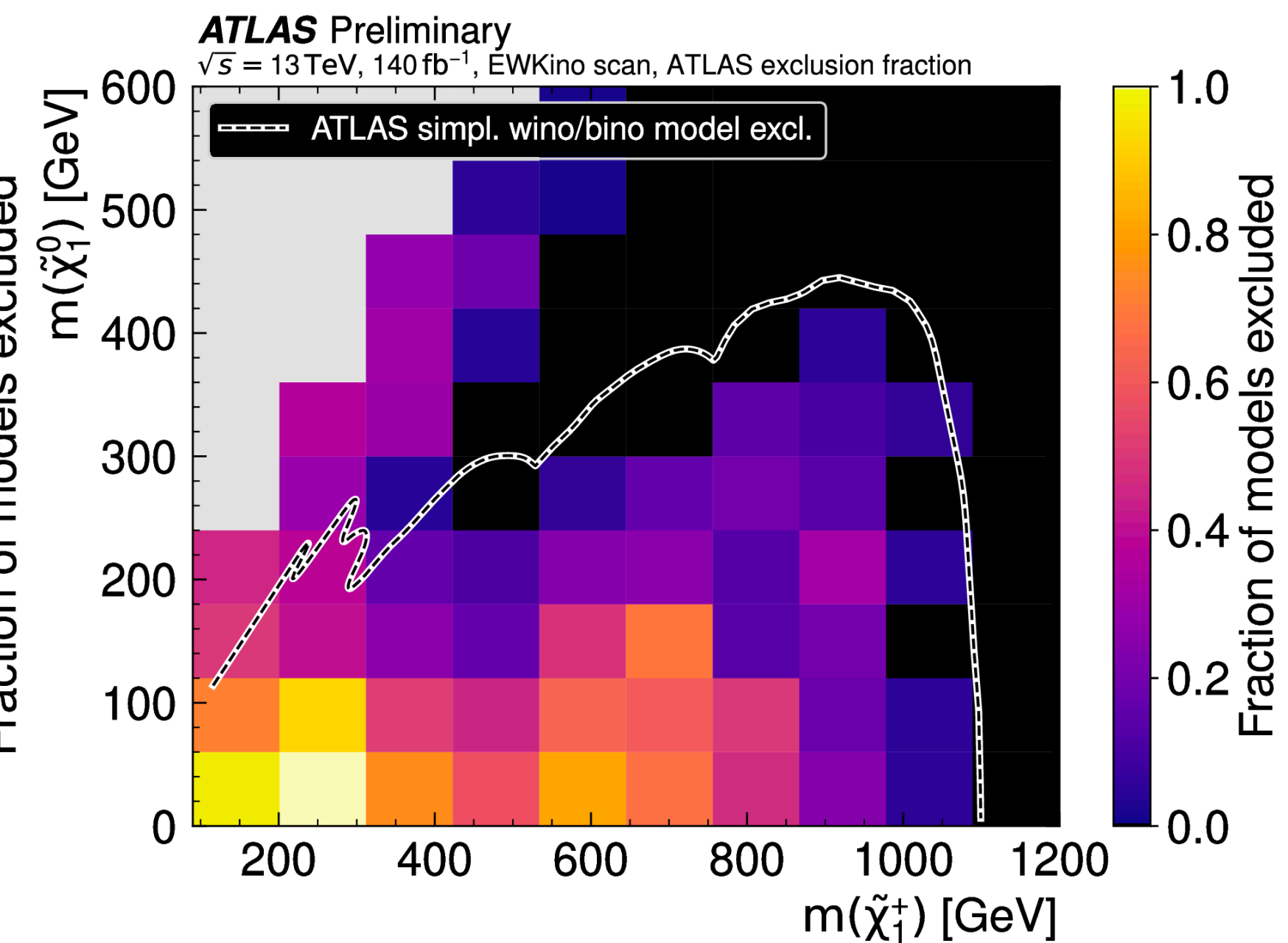
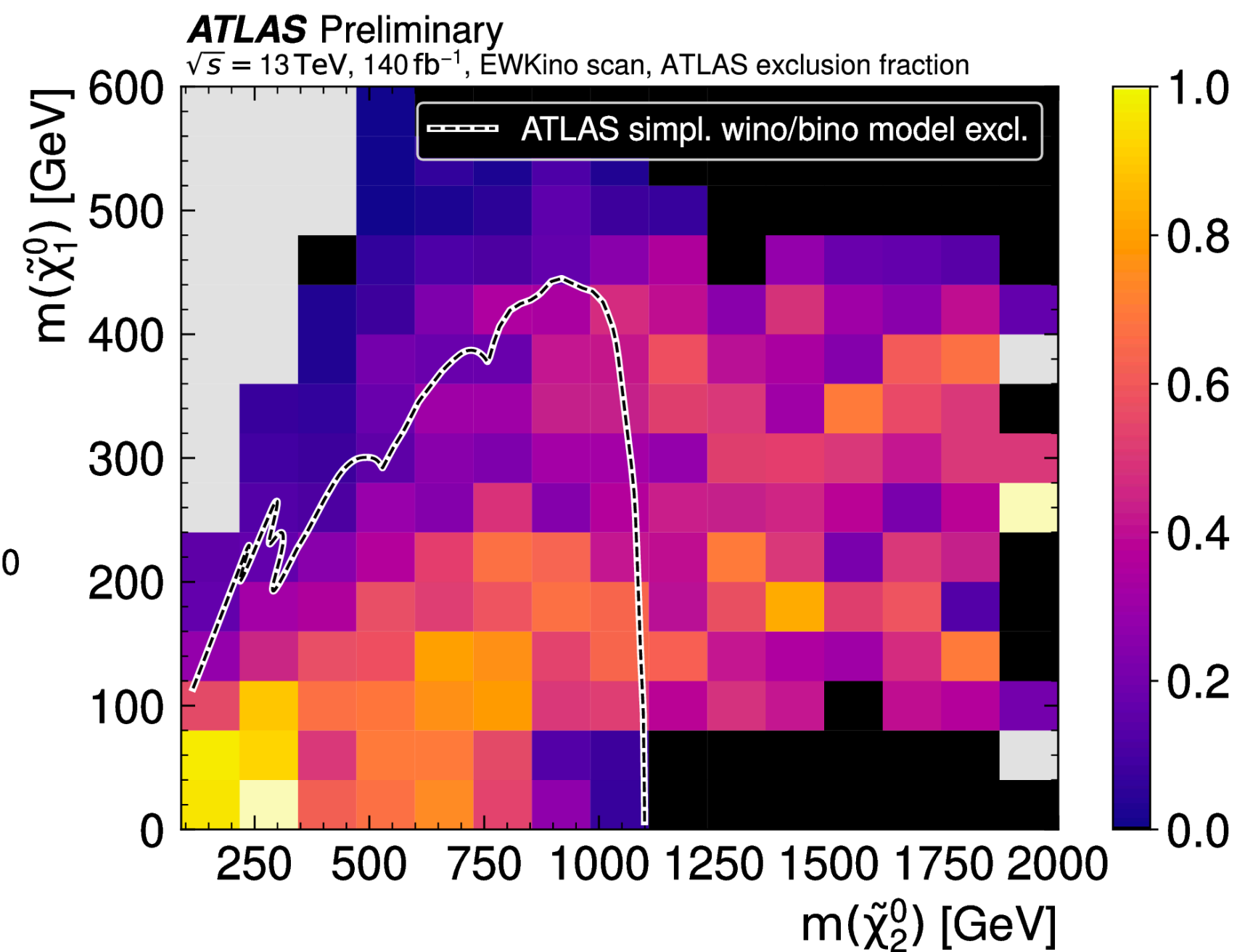
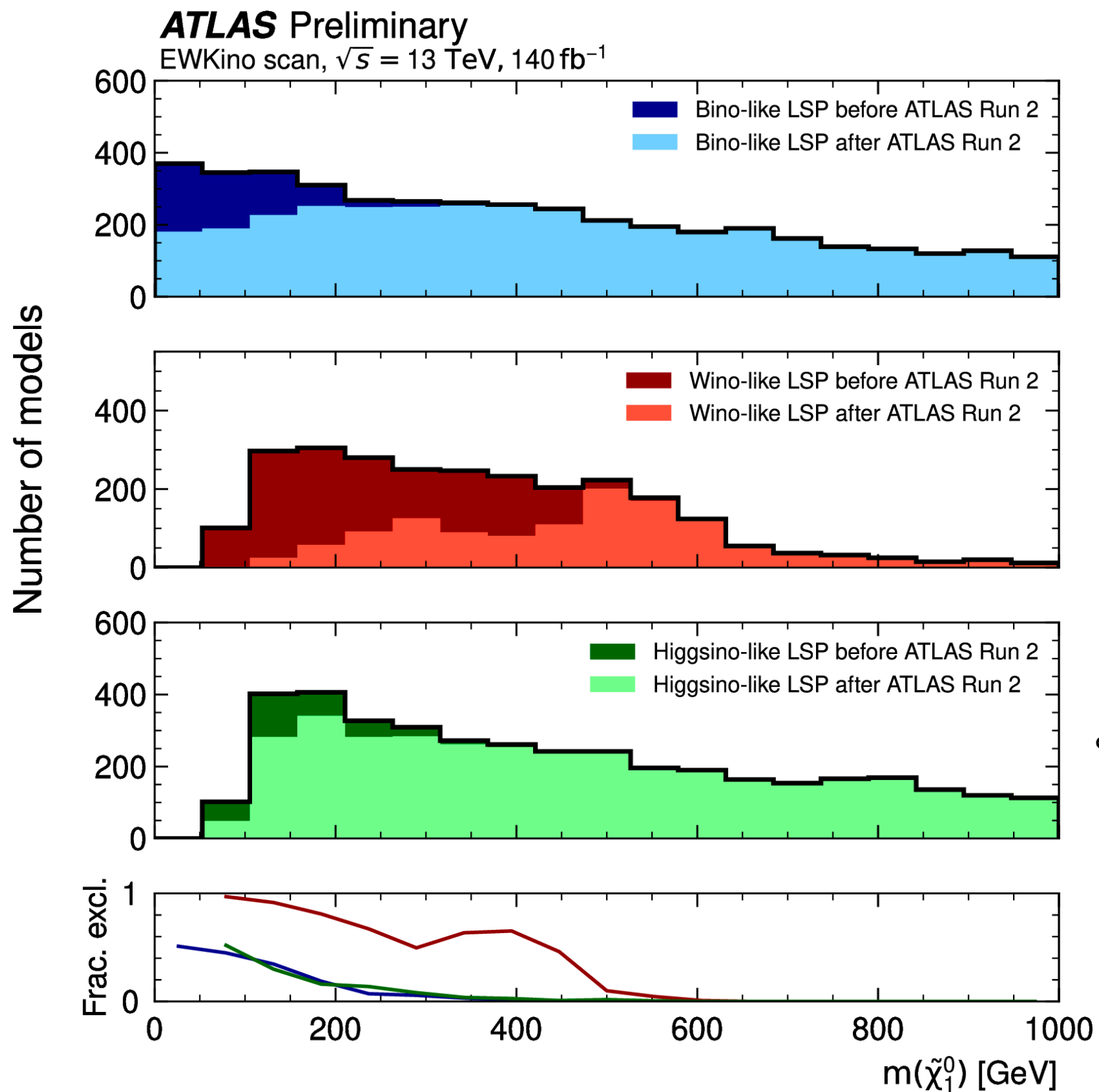
# Electroweak pMSSM Scan

- LHC exclusion limits on “simplified models”
  - not exhaustive exploration of MSSM
- Phenomenological MSSM:
  - CP-conserved, R-parity conservation, minimal flavour violation
  - SUSY parameter space reduced to 19 parameters
- pMSSM electroweak parameter space randomly scanned
  - General EWKino scan
  - Bino-DM scan
- Using eight Run-2 electroweak ATLAS analyses
  - +  $\text{BR}(h \rightarrow \text{inv}) < 0.107, m(A) > 480 \text{ GeV}$
- Constraints from previous EWK, flavour and DM related measurements are considered



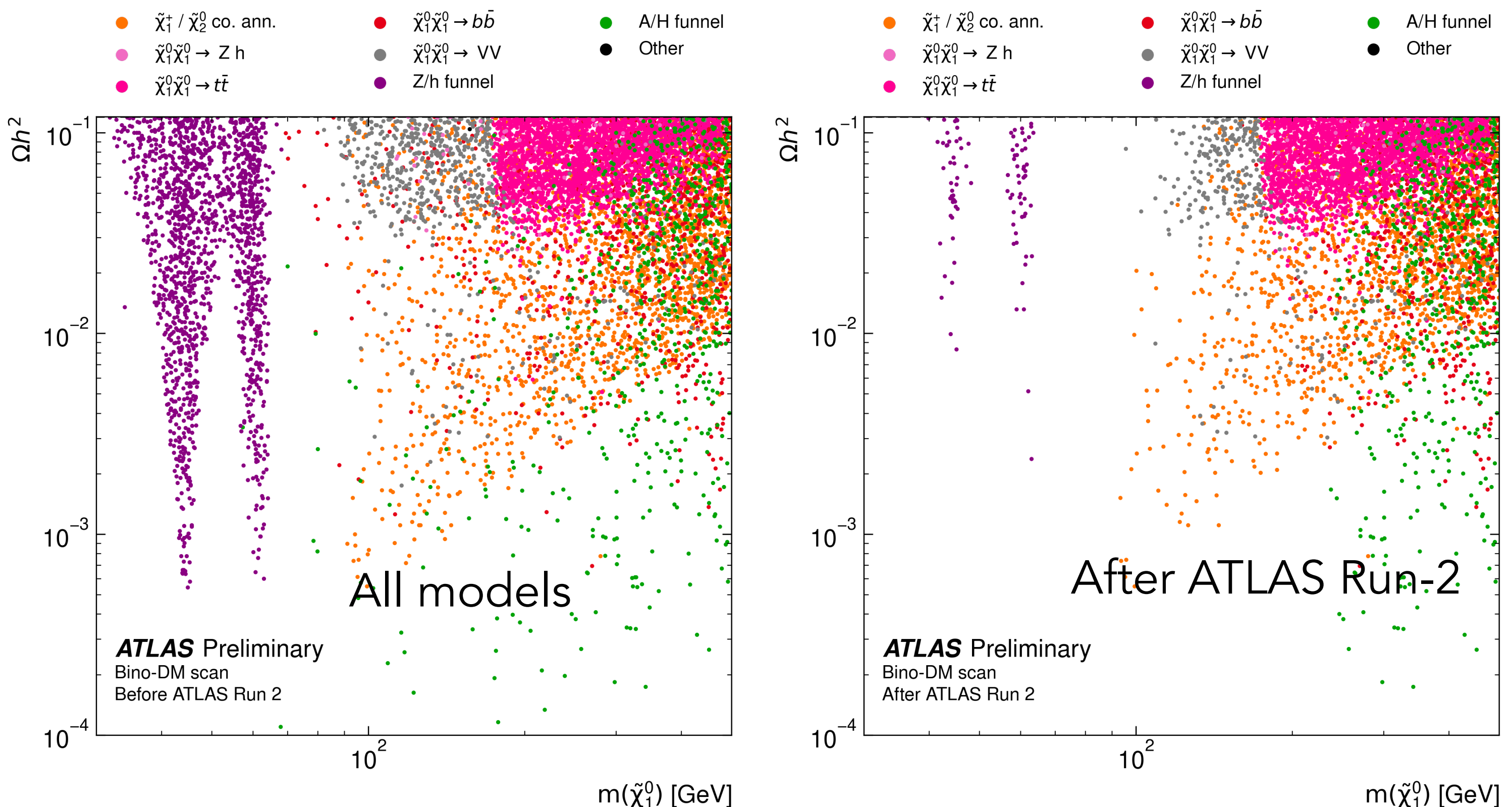
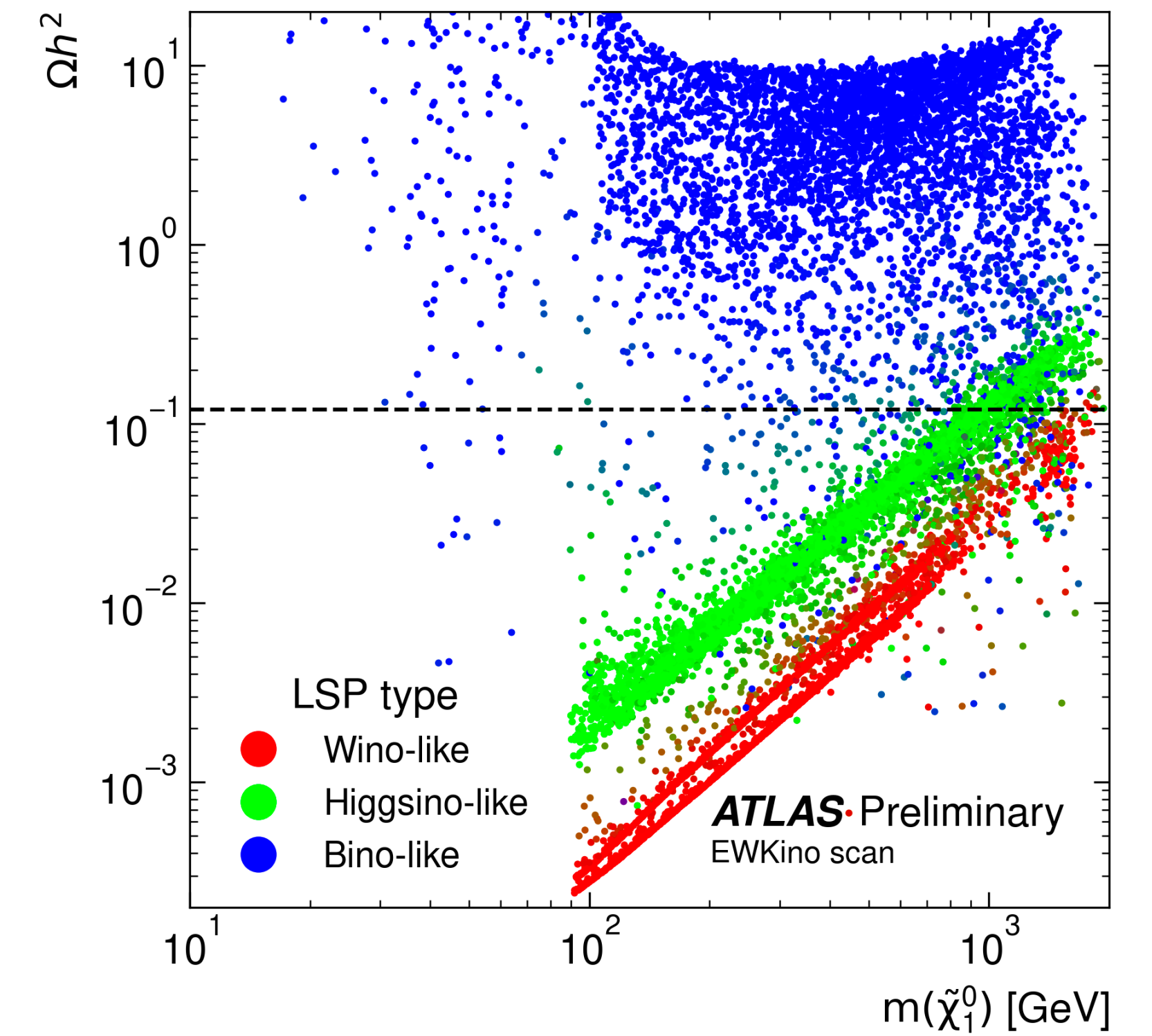
# Electroweak pMSSM General Scan

- Fraction of models excluded by ATLAS Run-2 searches
- Exclude at least 50% of models up to chargino mass of 400 GeV (even outside simplified model contour)
- Almost all models excluded for low mass LSP



# Electroweak pMSSM Bino-DM Scan

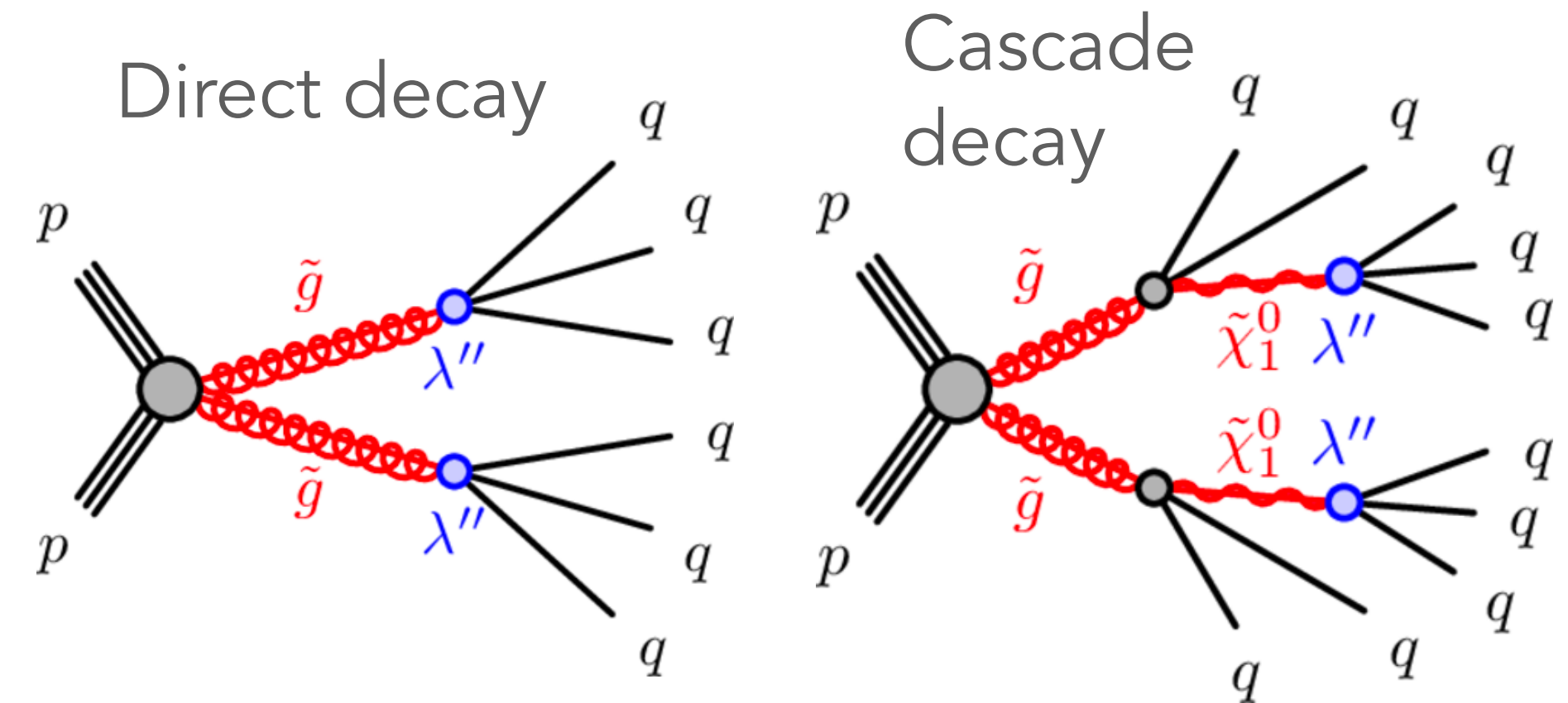
- Bino-like LSP models typically overestimate the relic dark matter density
- Additional annihilation mechanisms are required:
  - compress mass splitting between LSP and  $\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$
  - Z/h funnel regions where LSP mass is half of the Z/H mass
- Special scan with  $|M_1| < 500$  GeV to focus on low-mass bino models
- Z/h funnel region almost completely excluded by ATLAS Run-2 data





# RPV Multijet search

- Dropping R-parity conservation assumptions, UDD RPV coupling leads to decays to quarks → pure multijet final state
- Main challenge: massive QCD multi jet background

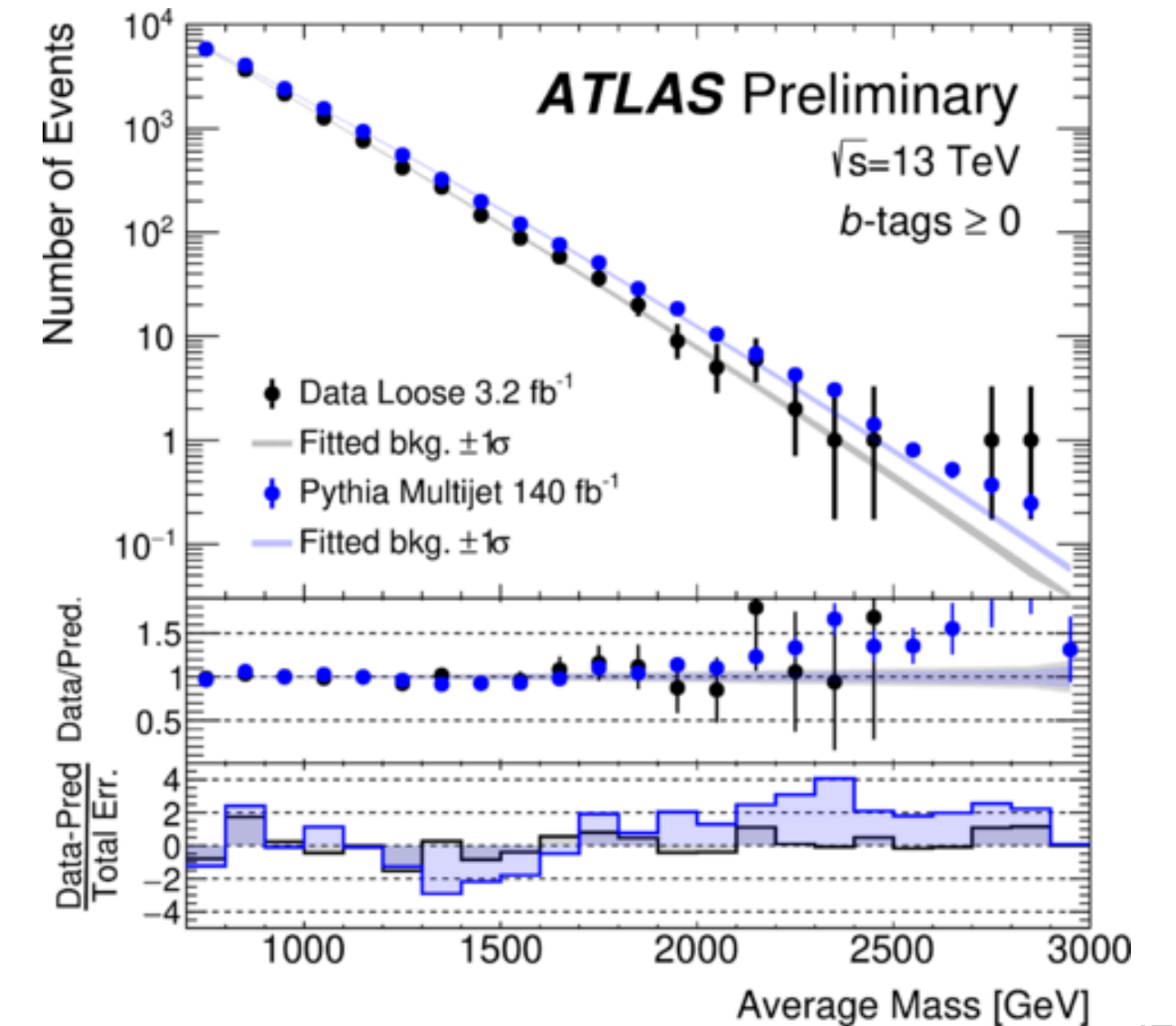
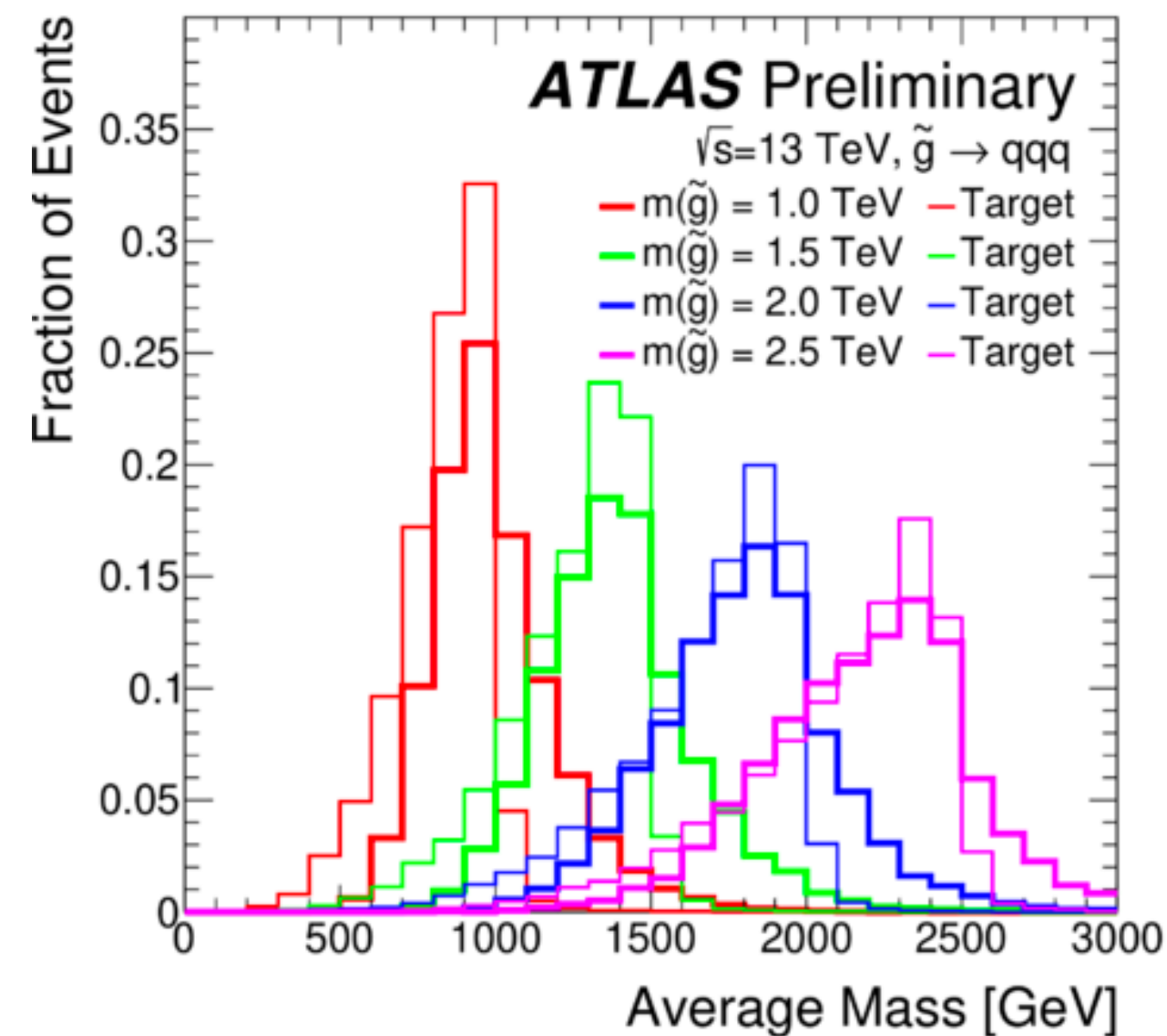
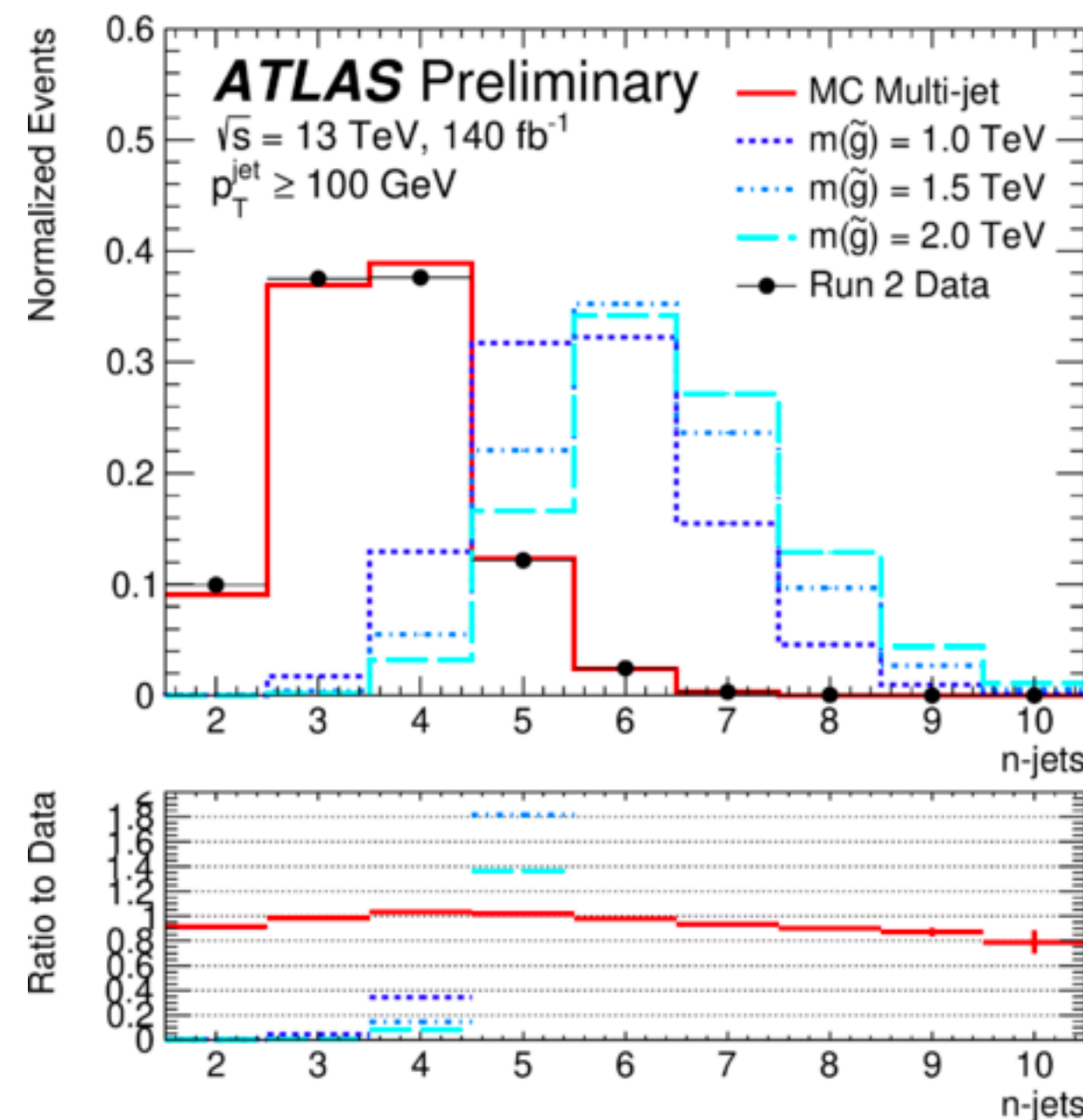


## Jet counting analysis

- SRs depending on number of jets, energy isotropy and number of b-tags

## Mass resonance analysis

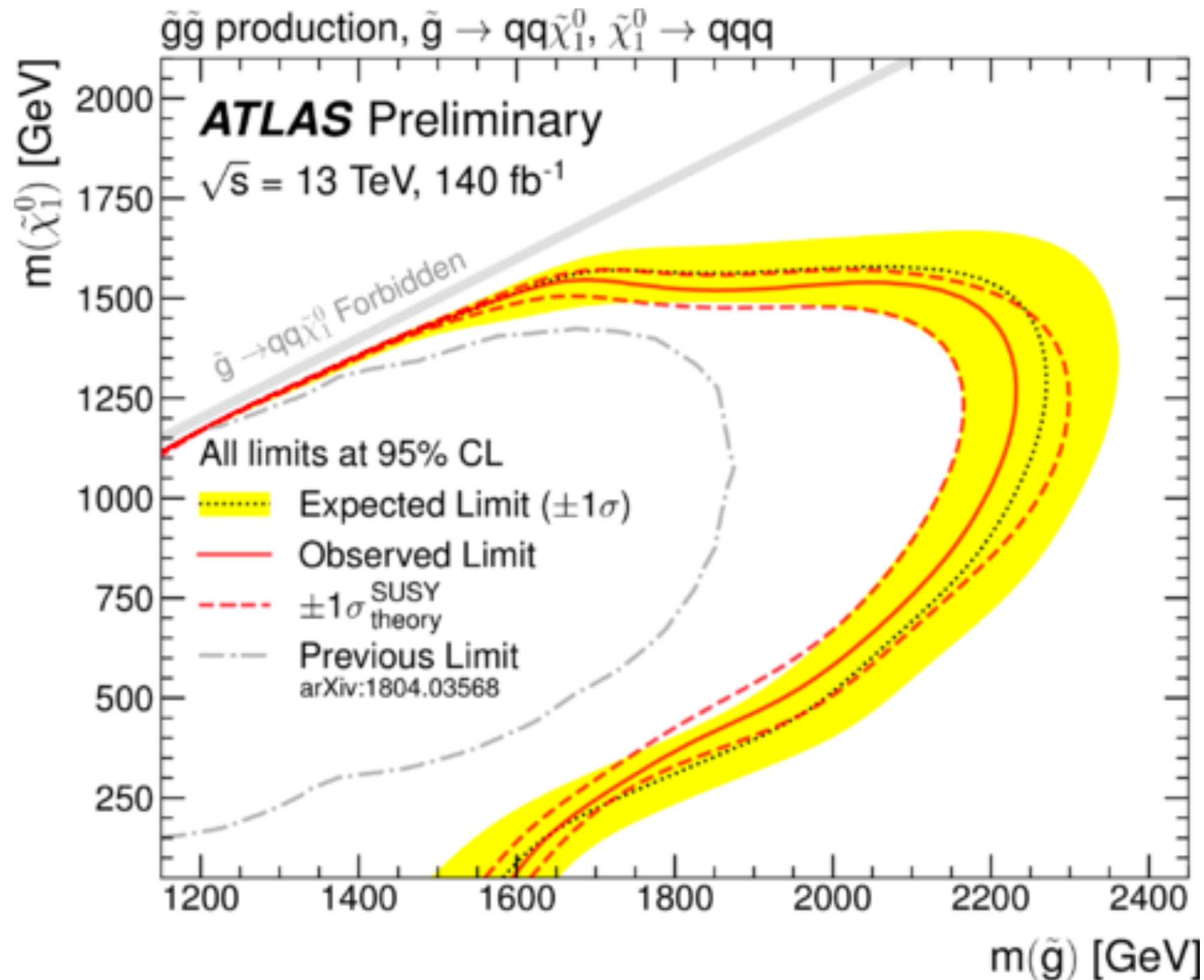
- NN model to reconstruct gluino mass and bump hunt



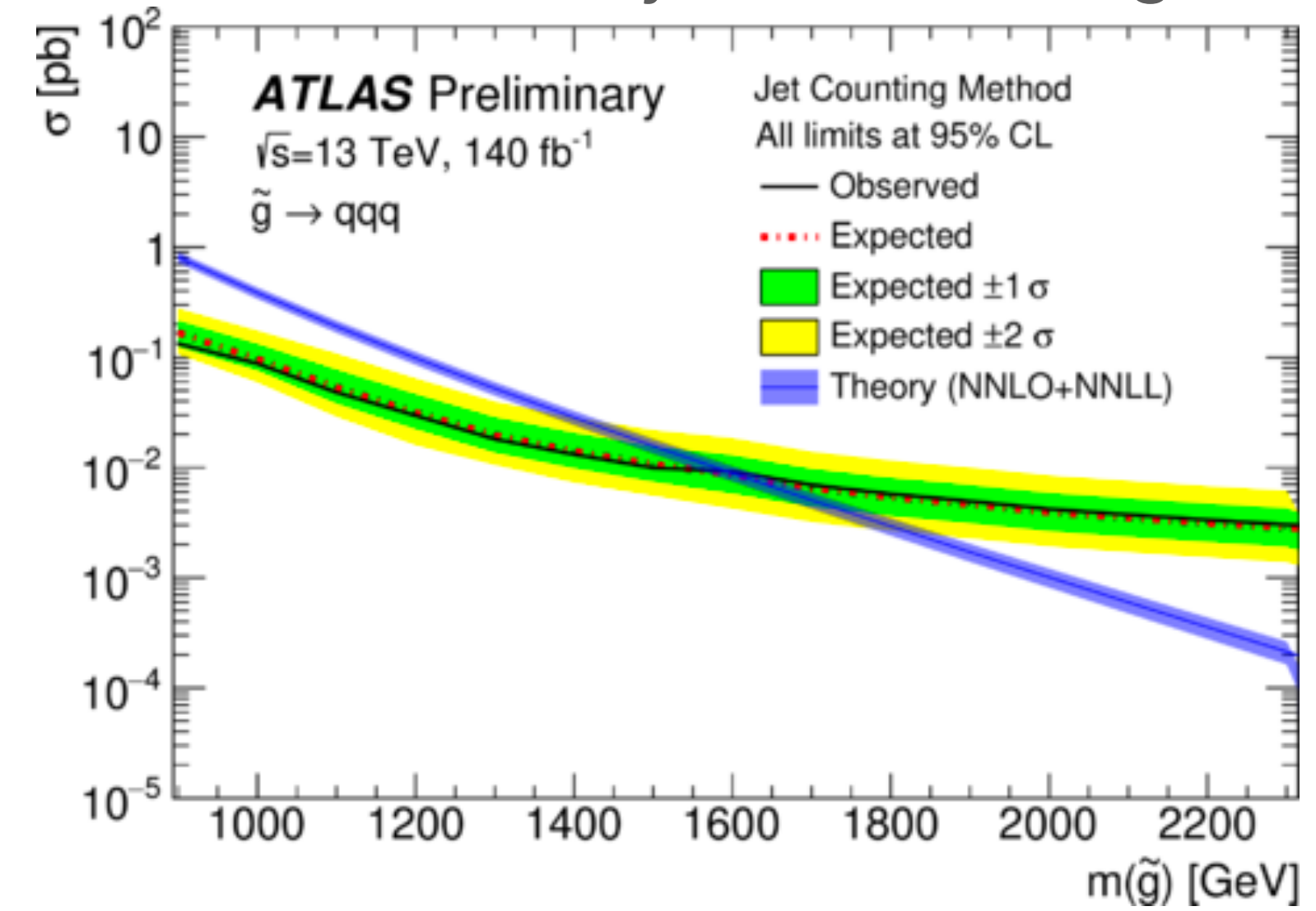
# RPV Multijet results

- Data consistent with background expectation in all the SRs
- Improved limits thanks to the new analysis techniques

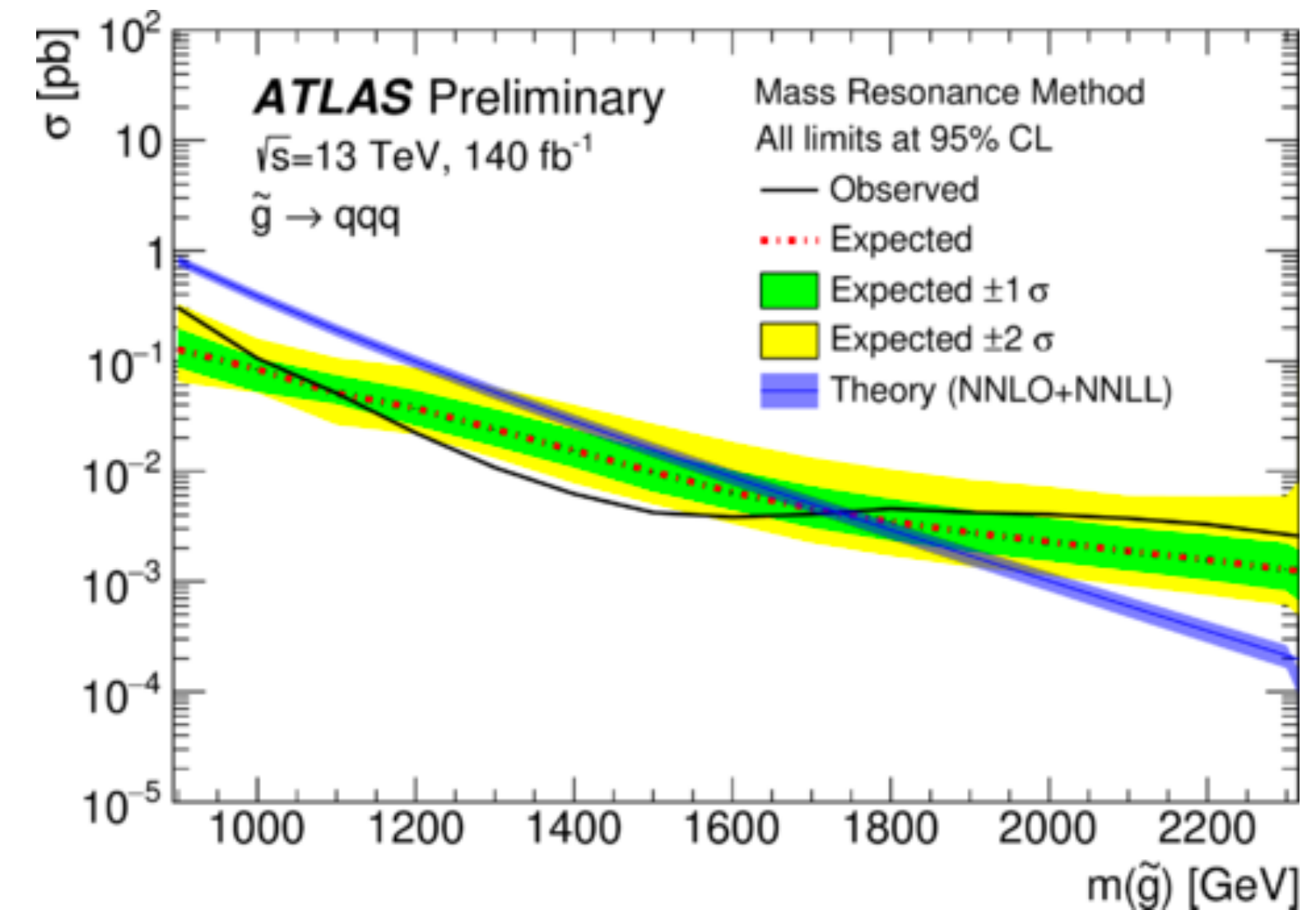
Cascade decay - Jet counting



Direct decay - Jet counting

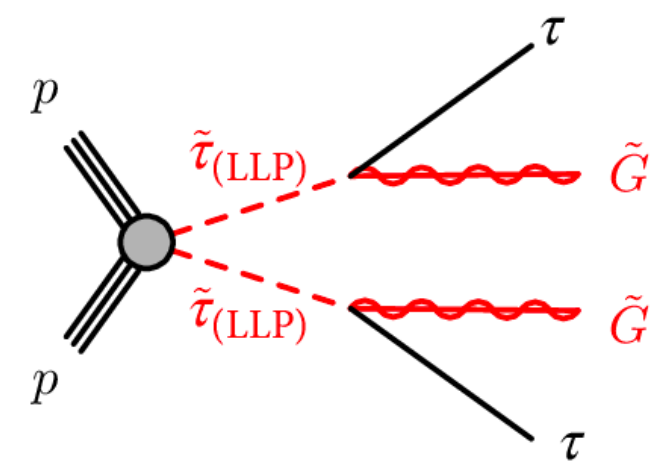
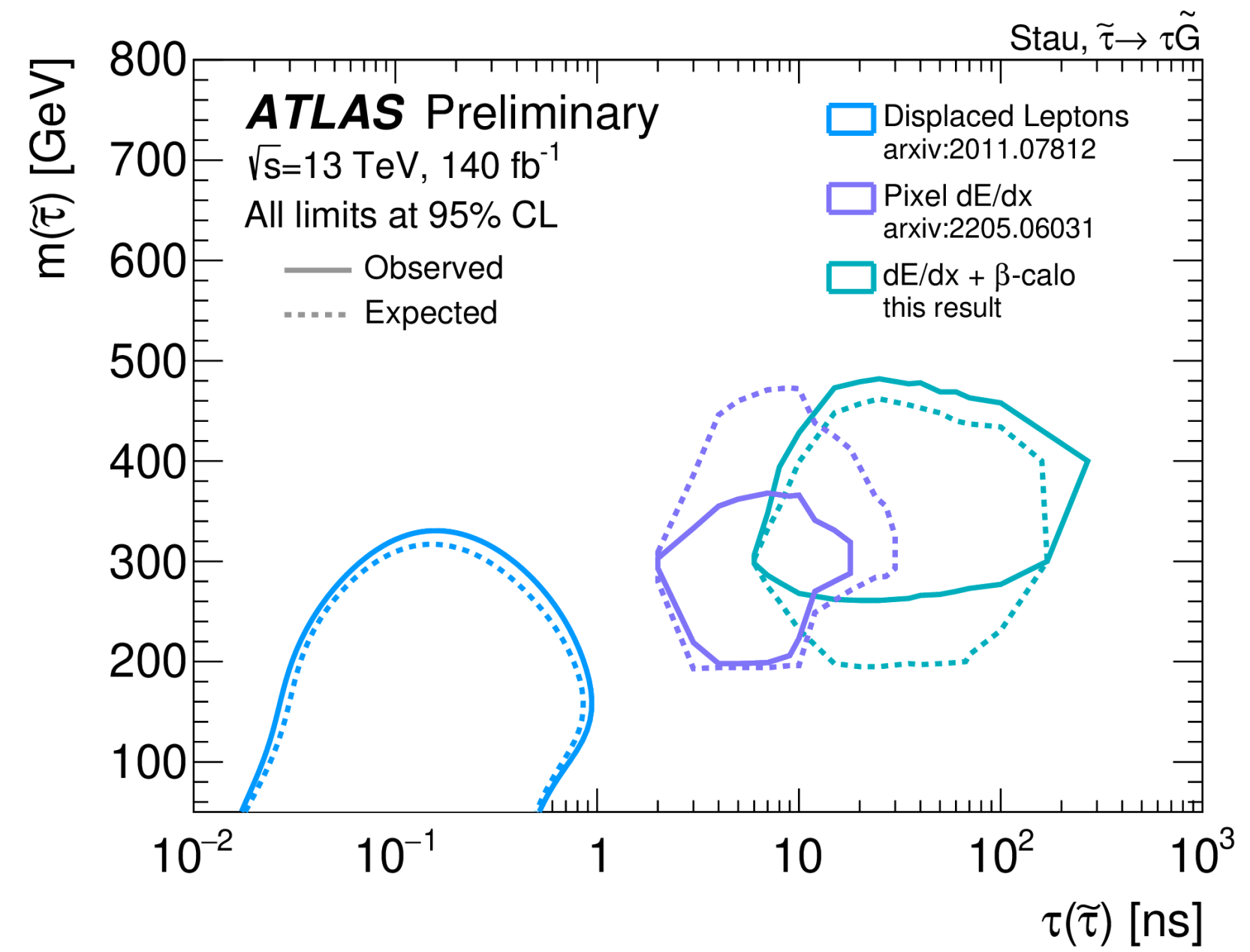
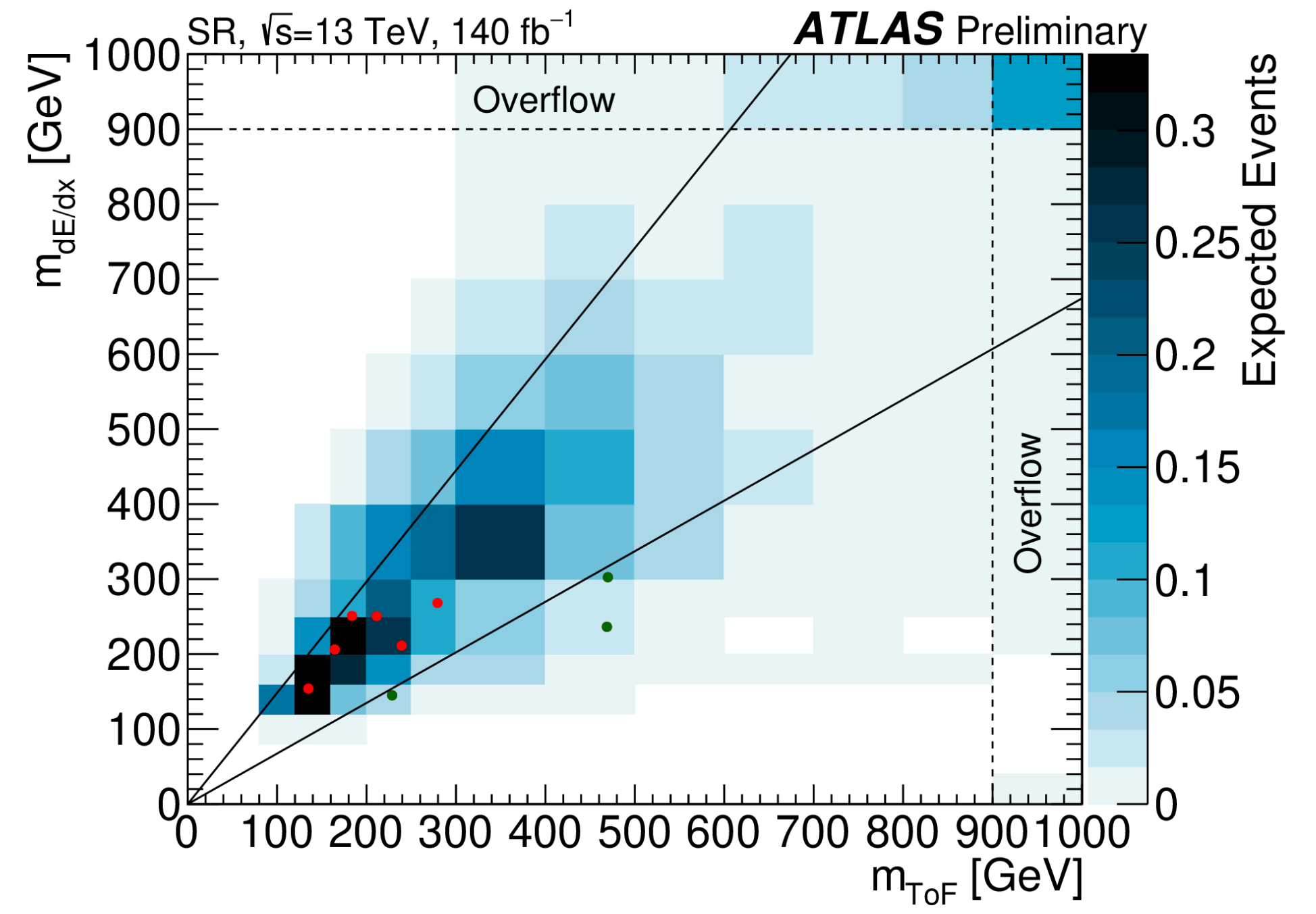


Direct decay - Mass resonance



# Long-lived heavy particles

- Hypothetical massive charge long-lived particles move significantly slower than  $c$  and can be identified as:
  - Isolated high momentum track with large ionisation energy loss ( $dE/dx$ ) measured in the pixel detector
  - Significantly slower as measured by the calorimeter time-of-flight
- Main observable is the mass of the particle associated to the track  $m \equiv p/\beta\gamma$
- Constraints on SUSY pair production of long-lived  $R$ -hadrons and staus
- Agreement with background expectation
  - 6 observed,  $3.7 \pm 0.4$  expected
- Most stringent limits to date for detector unstable LLPs in the LHC for lifetime range above 10 ns

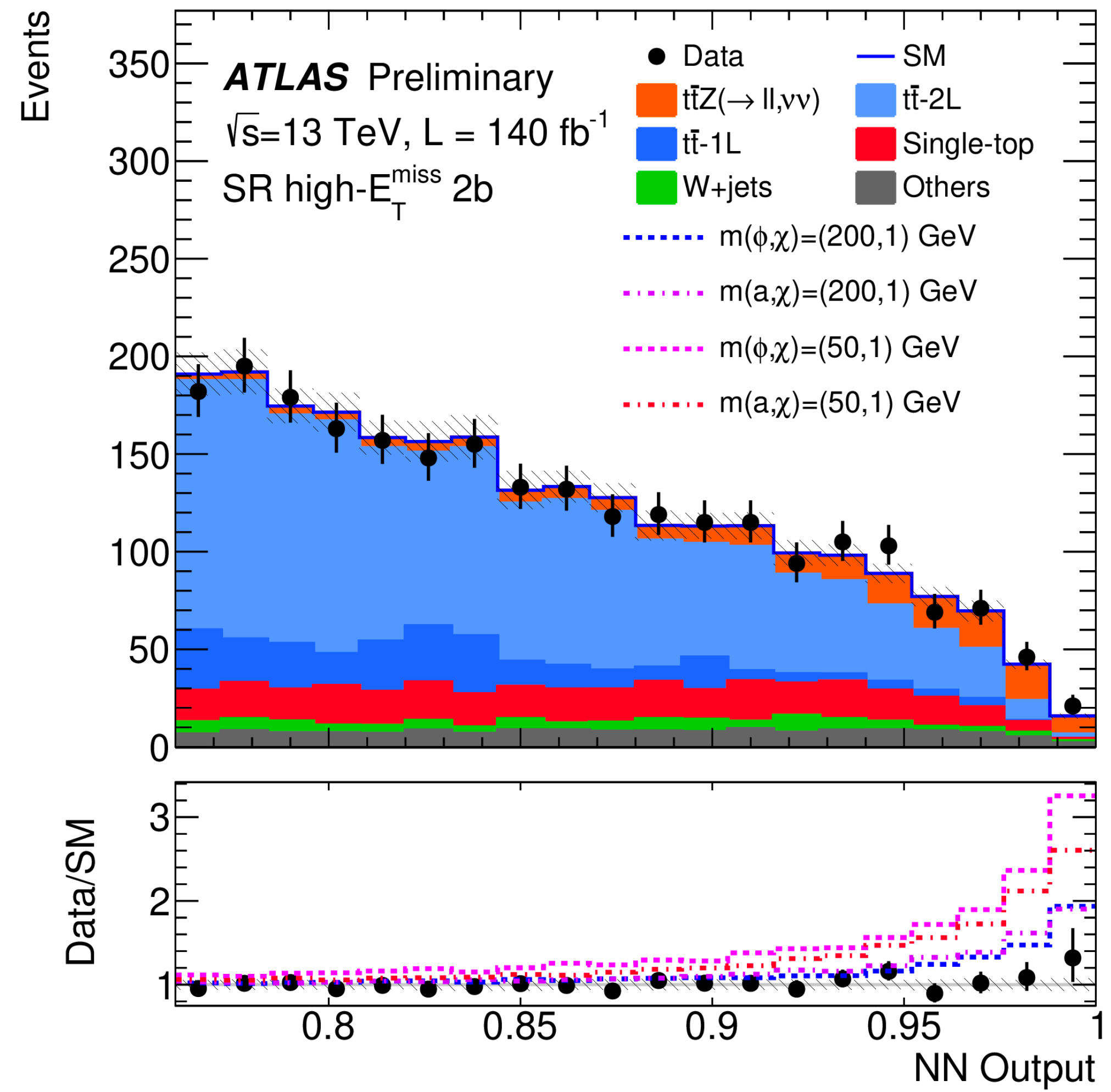
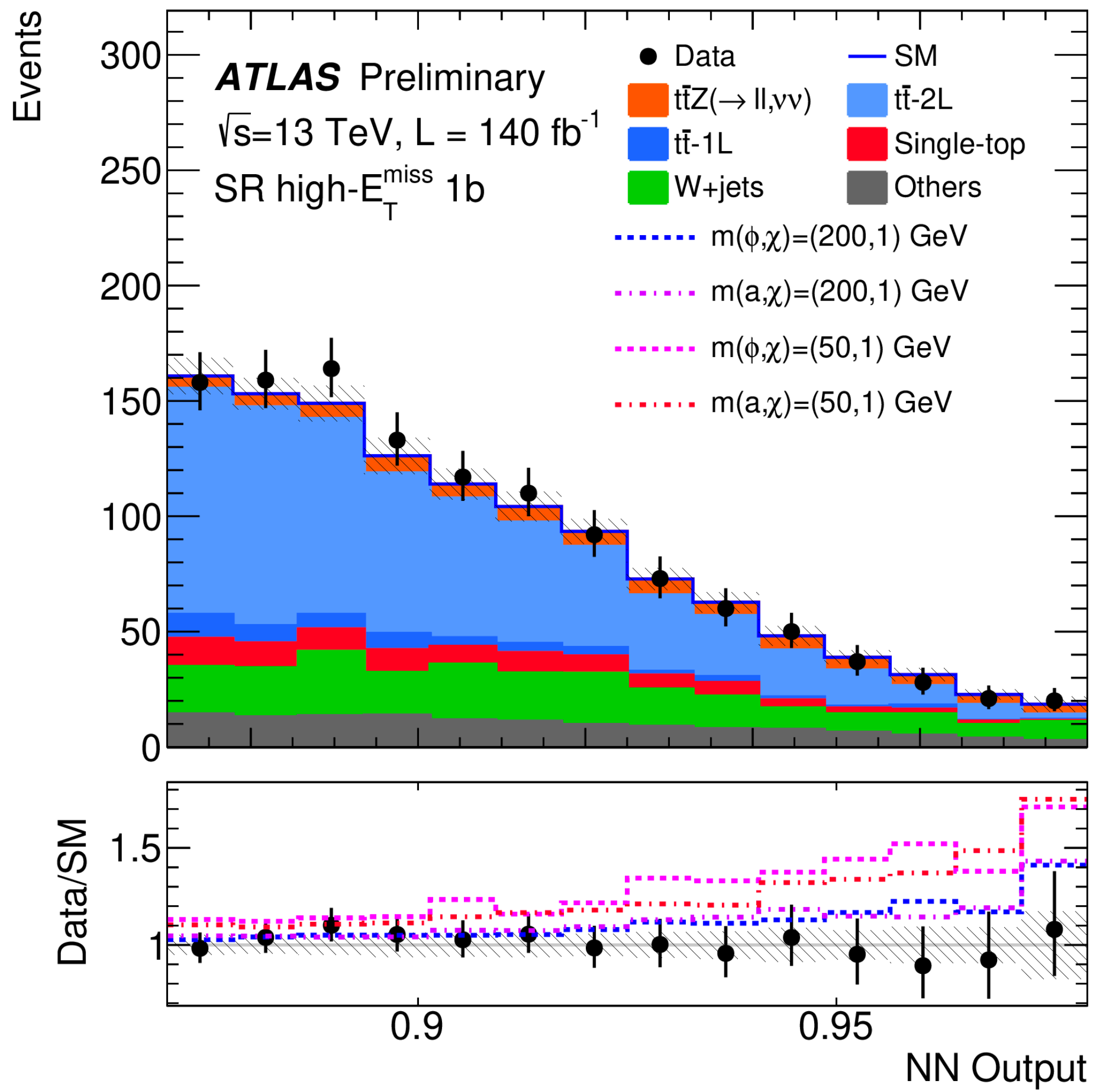


# Summary

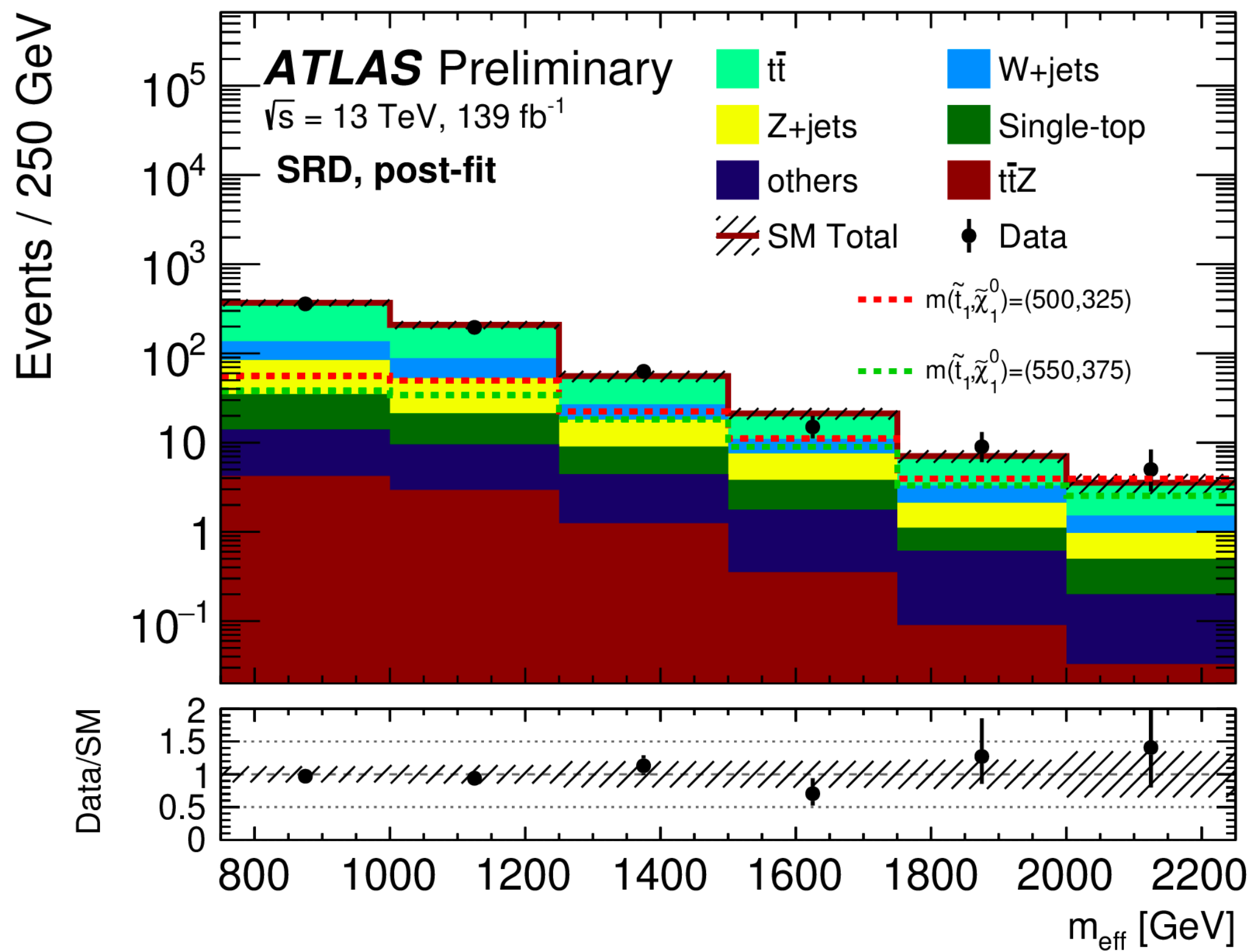
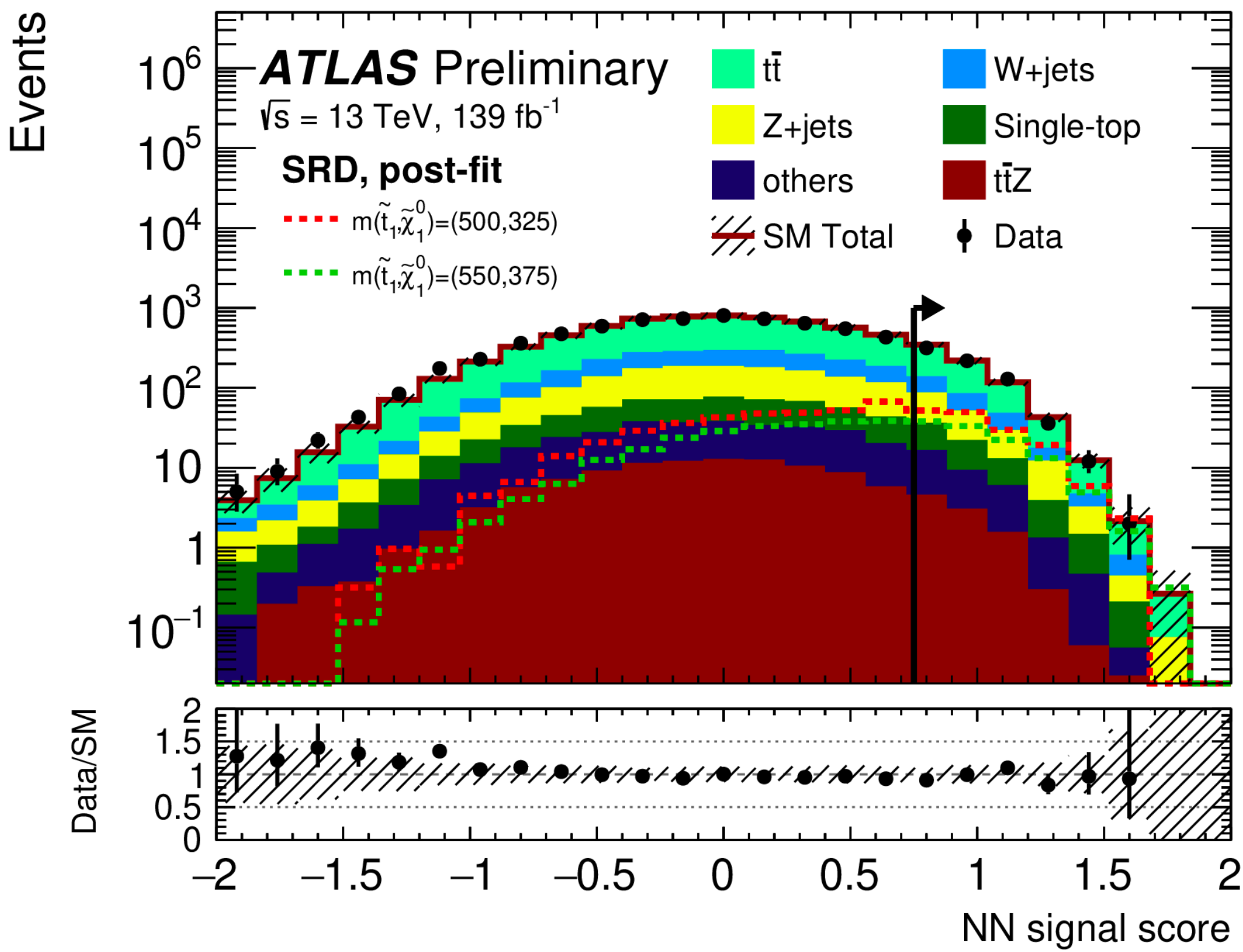
- Comprehensive ATLAS SUSY search programme using the full Run-2 data from LHC
  - Probing large part of the SUSY phase space including very difficult final state signatures with compressed scenarios and unconventional signatures
  - Find all the ATLAS SUSY results [here](#)
- For the moment good agreement between observed data and SM expectation in all final states
  - Stringent limits on several simplified models
  - Chargino/neutralino mass excluded up to  $\sim 1$  TeV
  - First limits set on  $m(\tilde{\tau}_R)$  at the LHC
- Results with LHC Run-3 data are coming not only including more data:
  - More sophisticated ML techniques improving object reconstruction/identification and also signal and background discrimination
  - More combinations and SUSY parameter scans
  - More public data for re-interpretation: model independent limits, code snippets, likelihoods (<https://www.hepdata.net>)

**Backup slides**

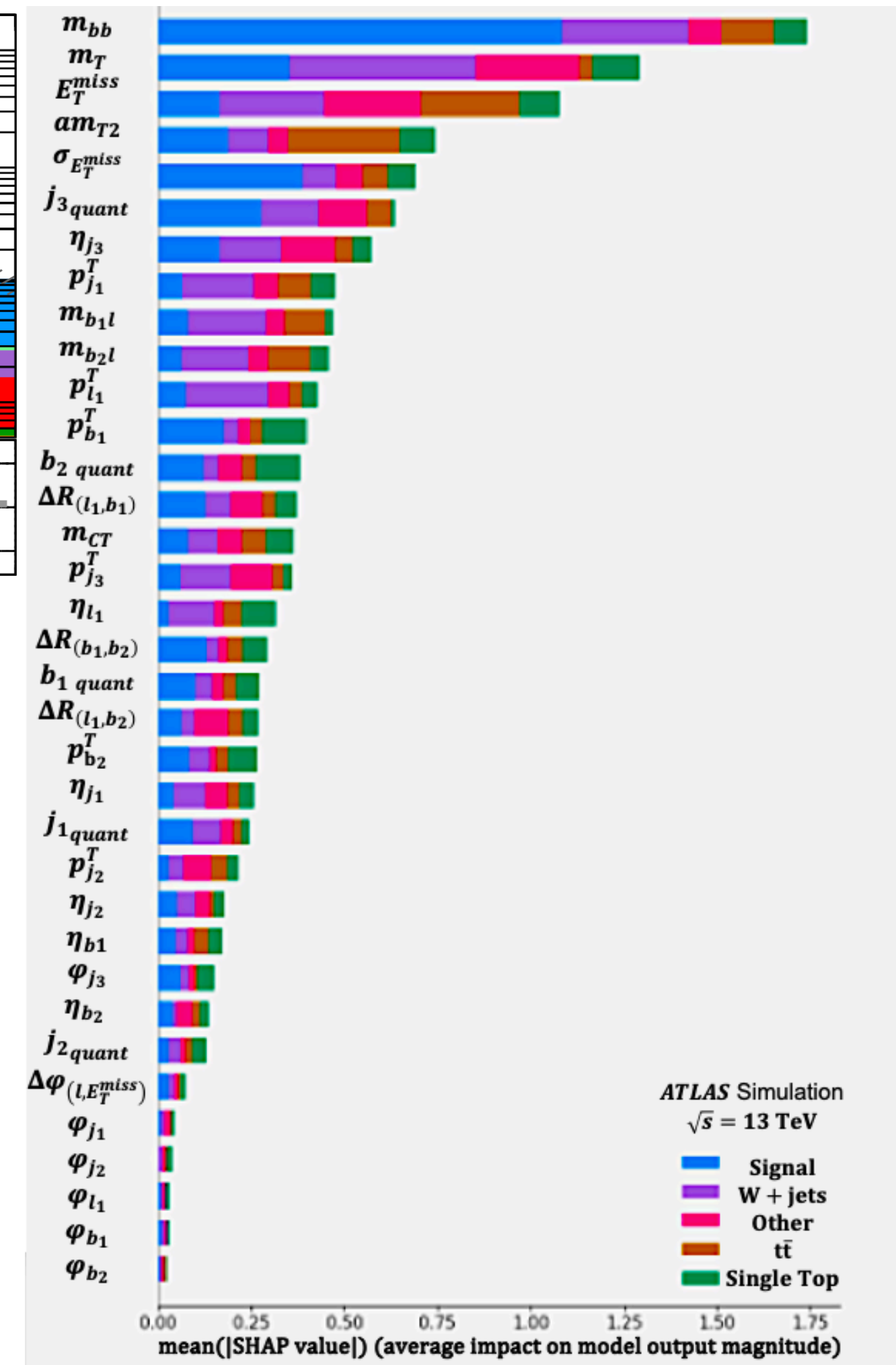
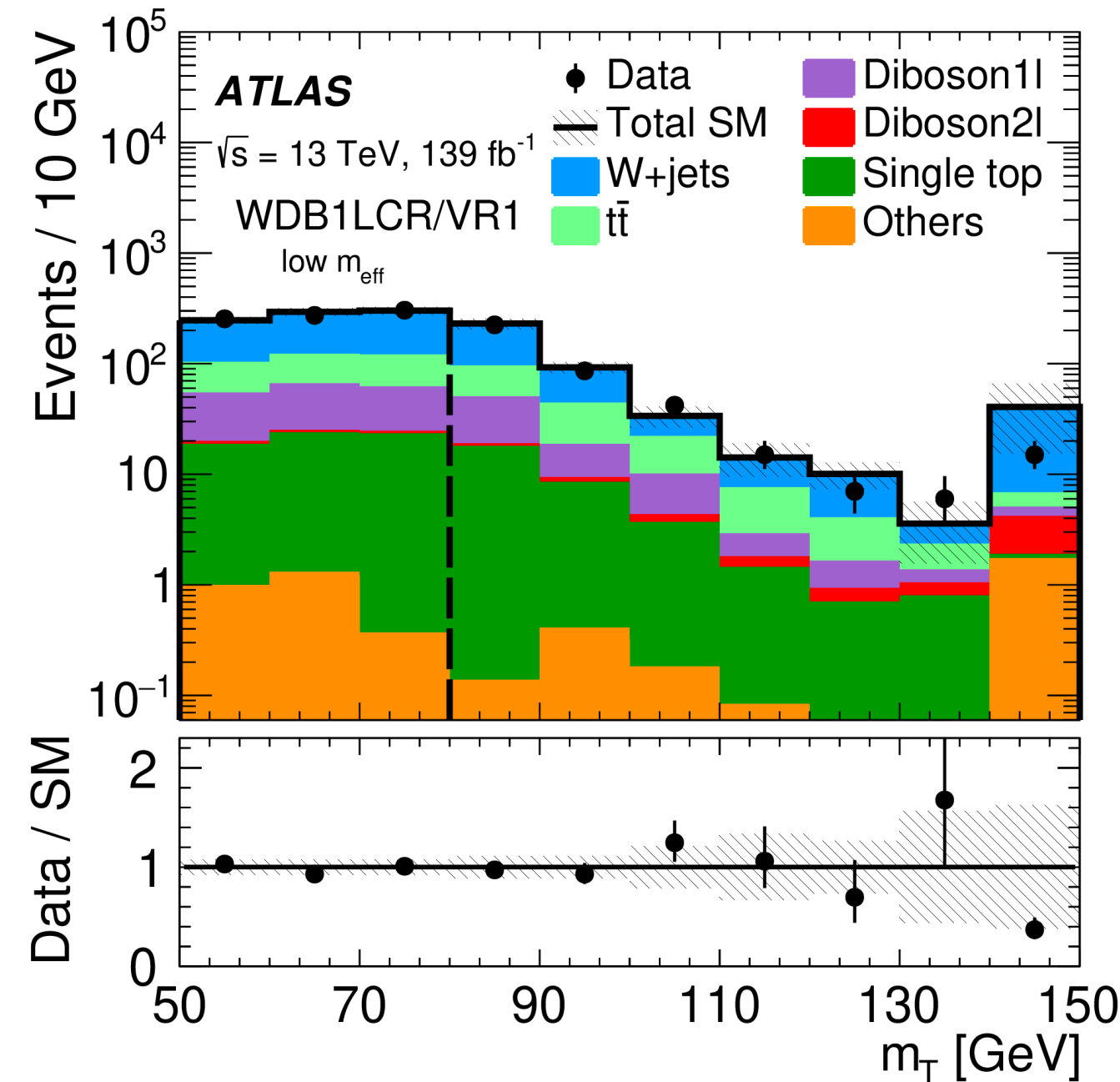
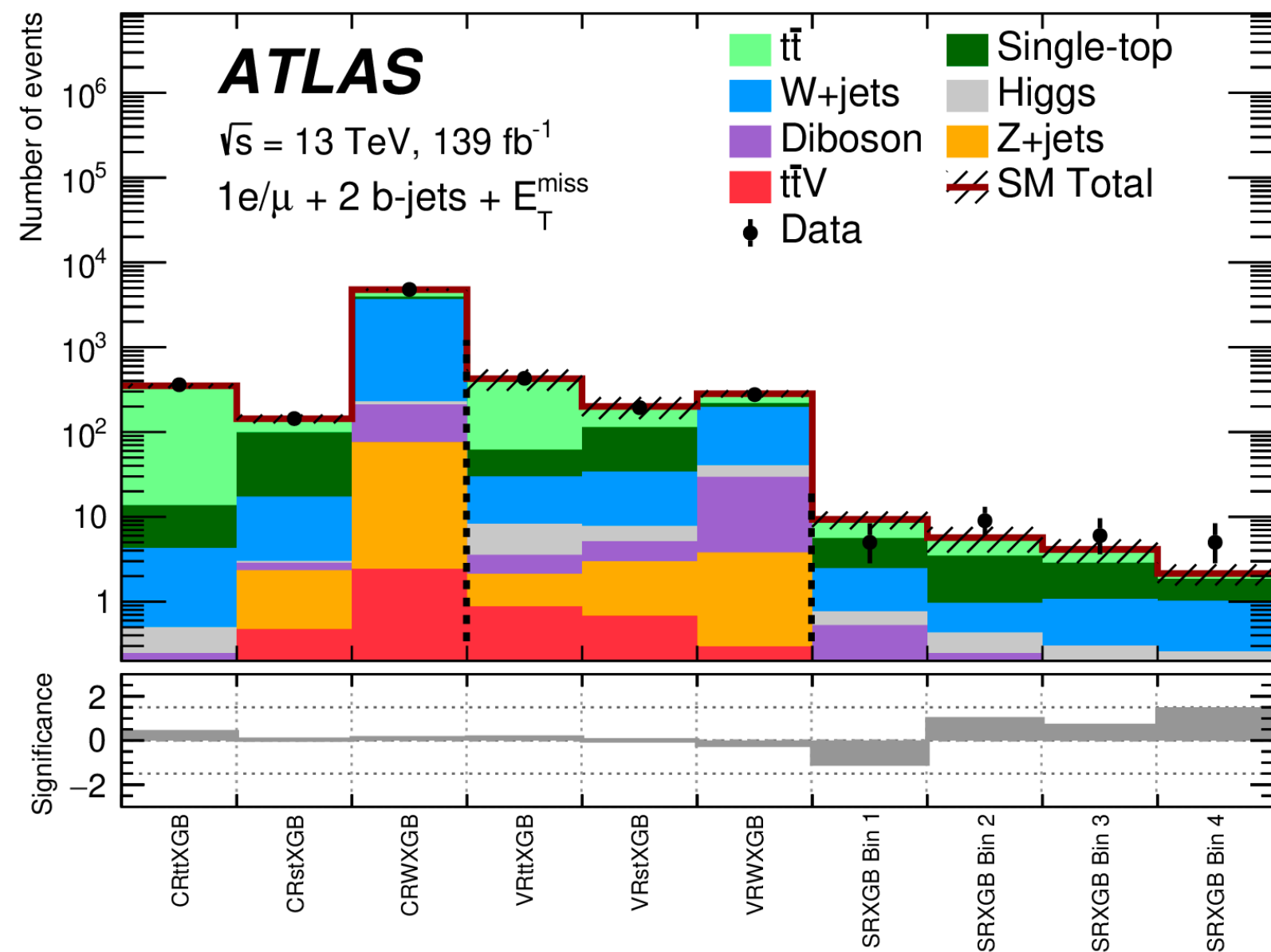
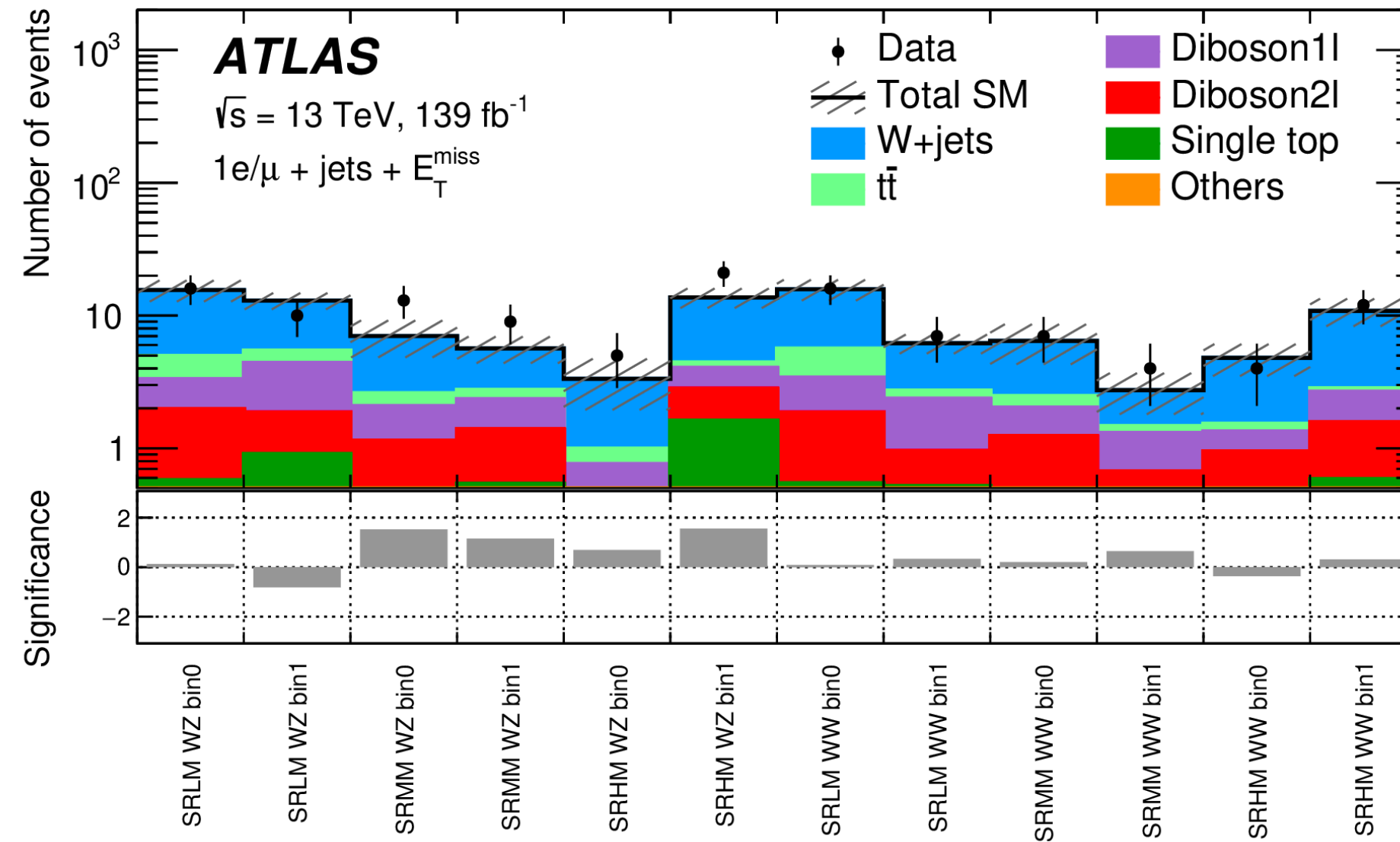
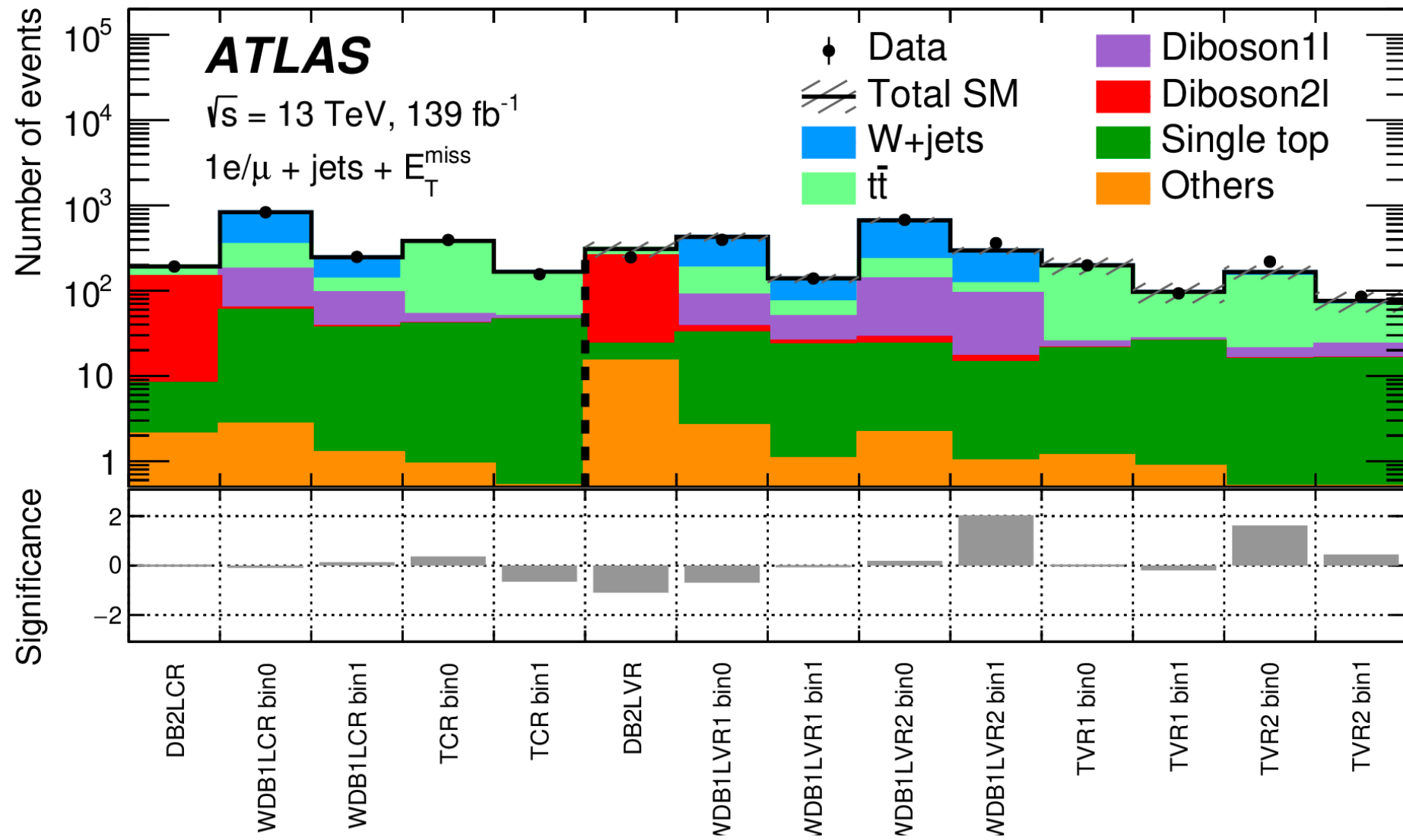
# Stop search: $t\bar{t}$ +MET



# Stop search: tc+MET

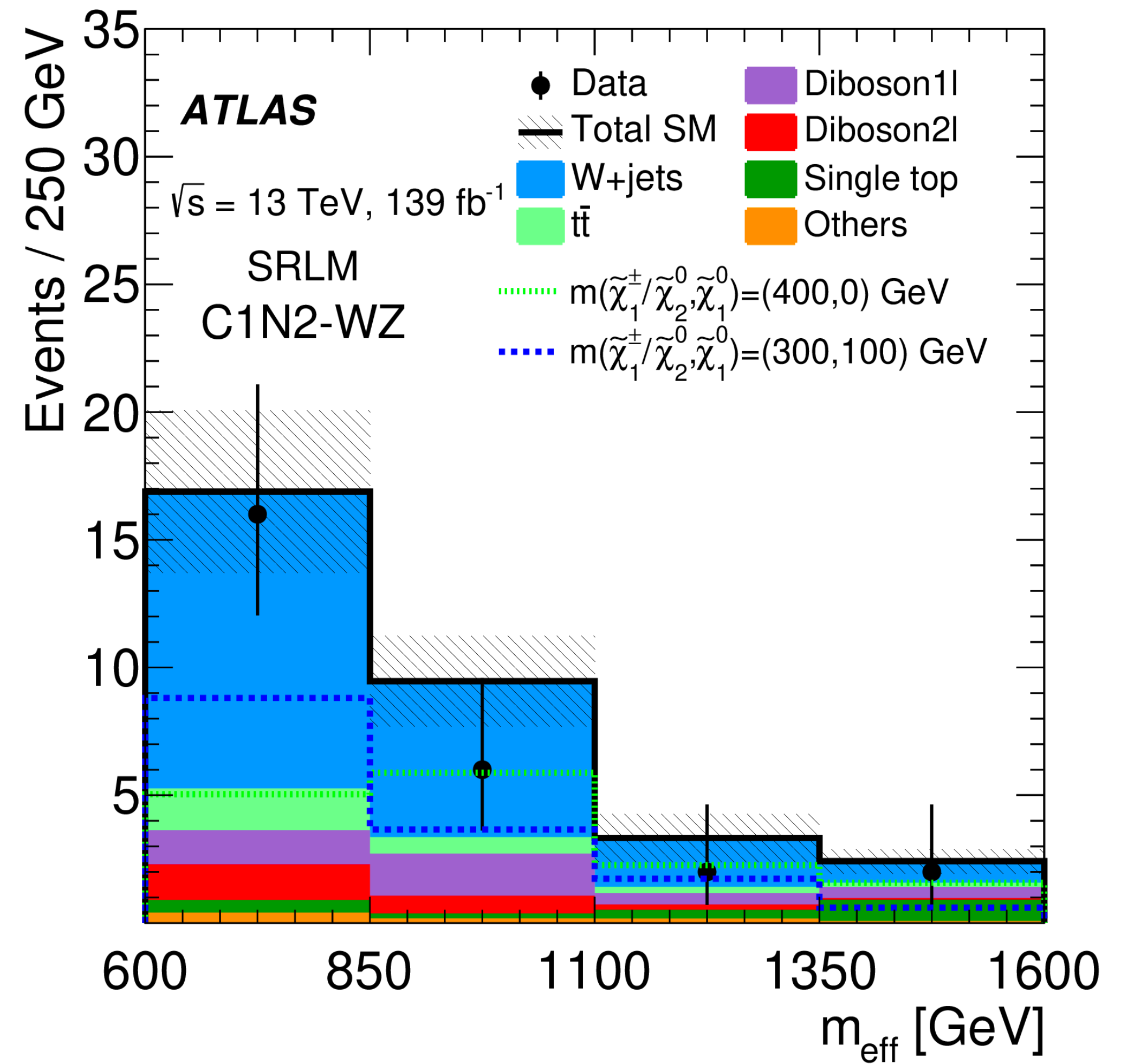
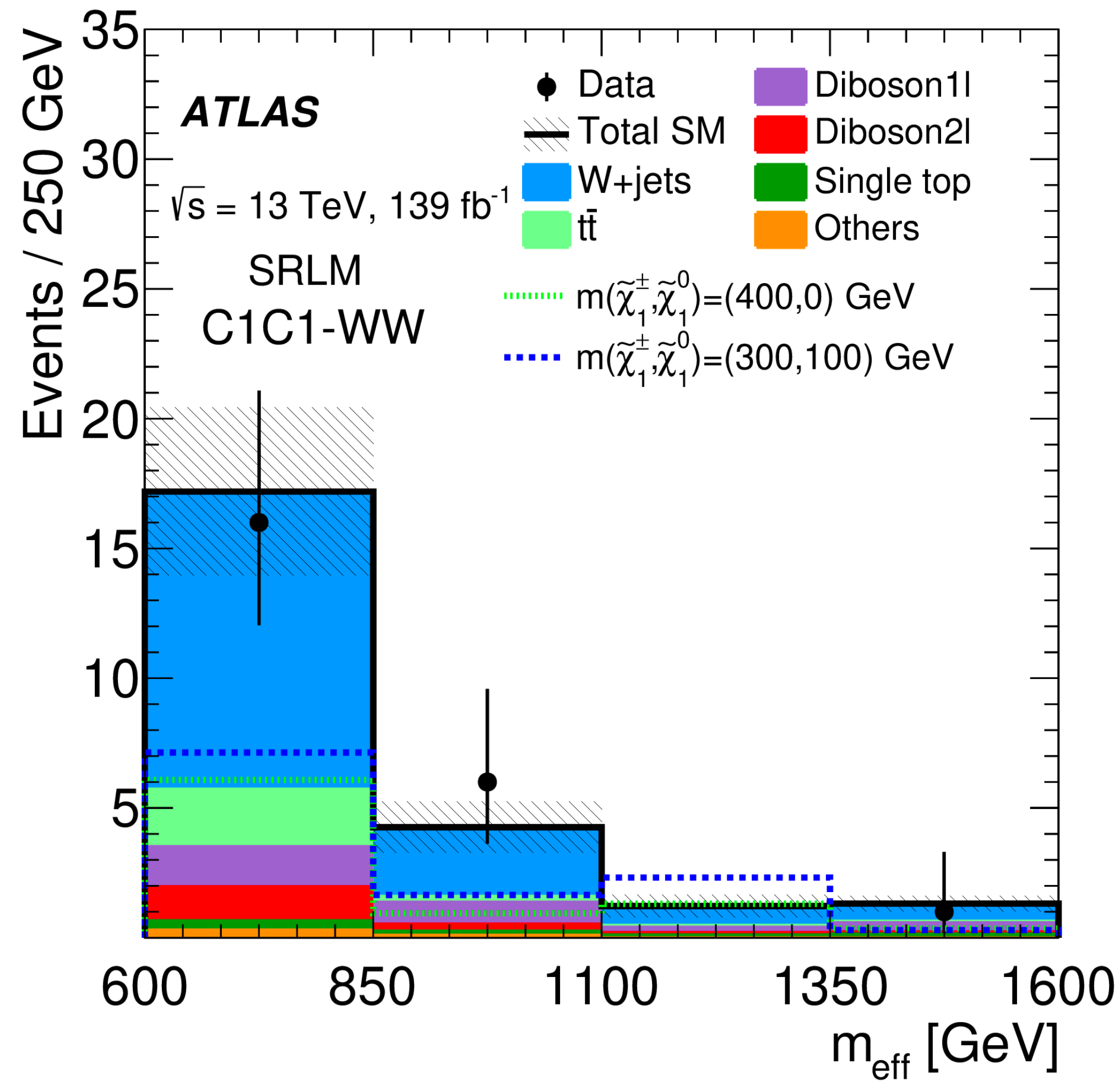


# Electroweak with one lepton

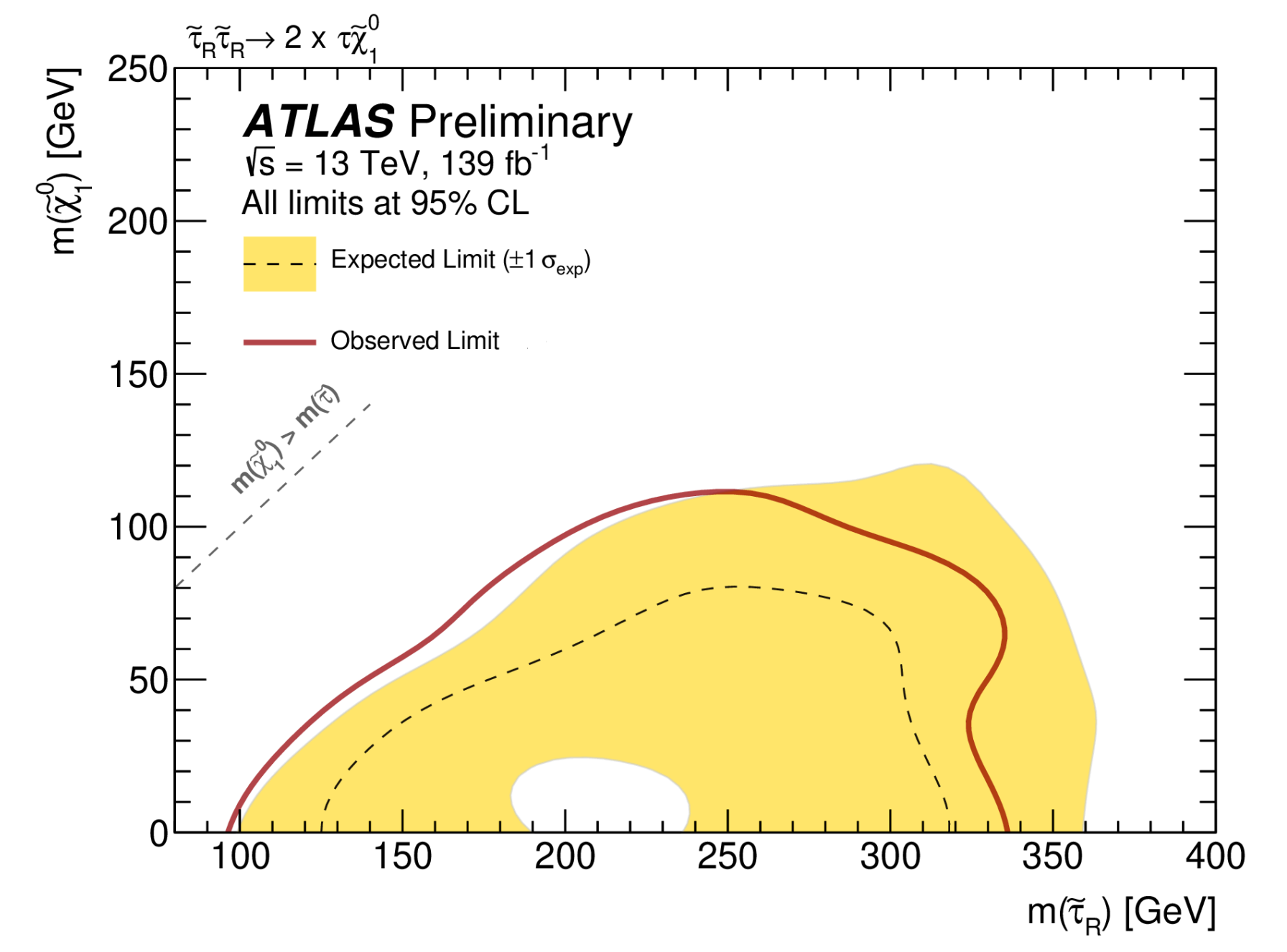
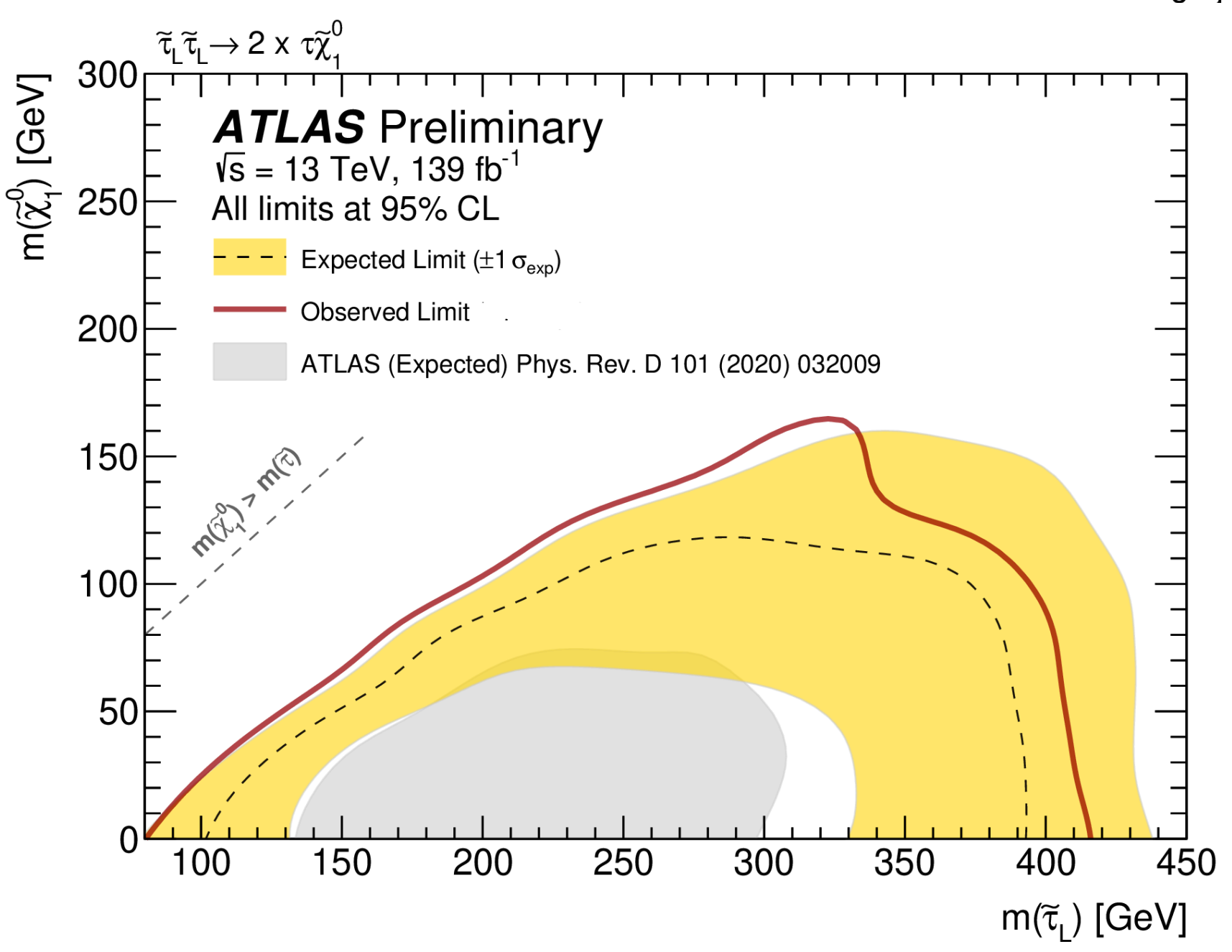
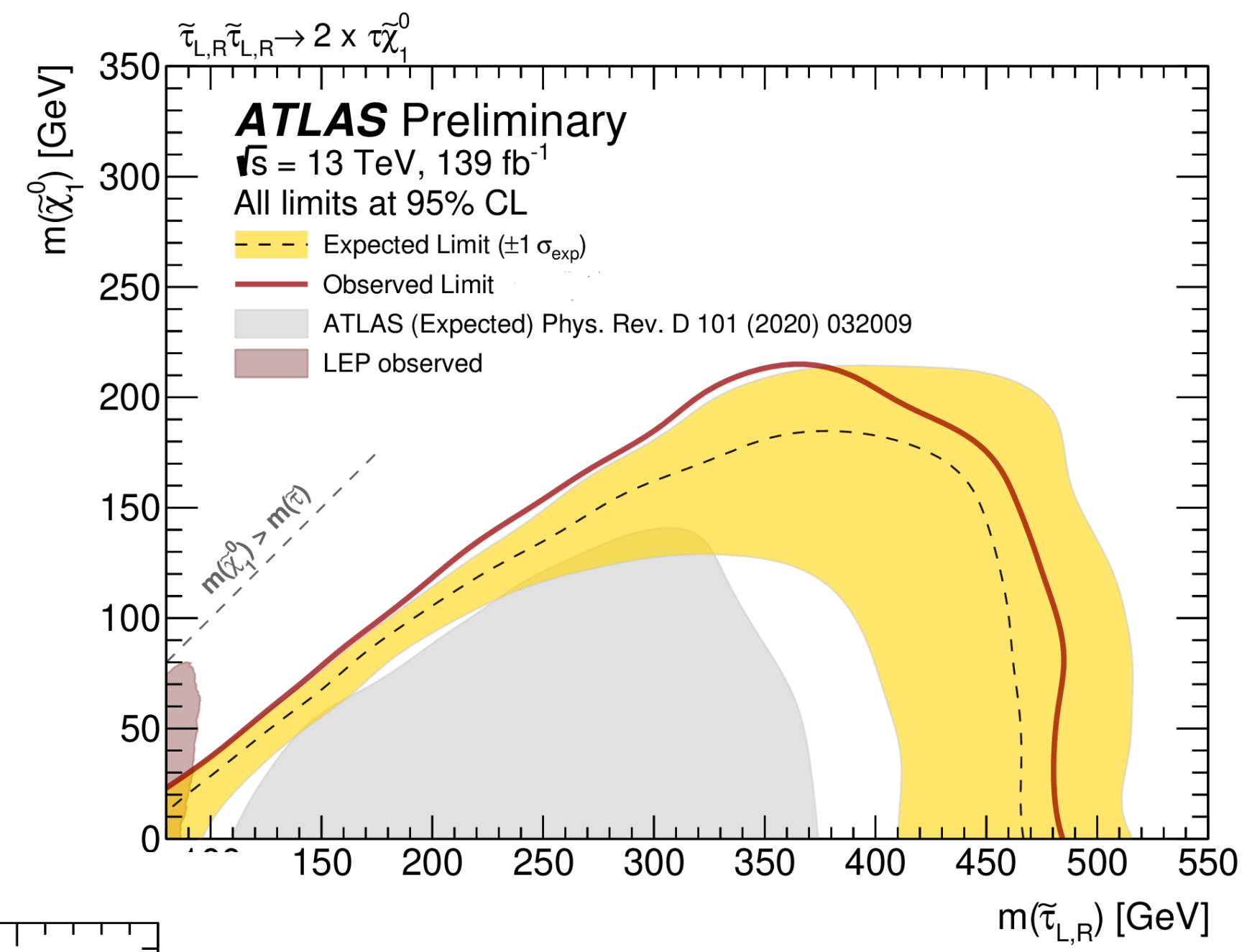




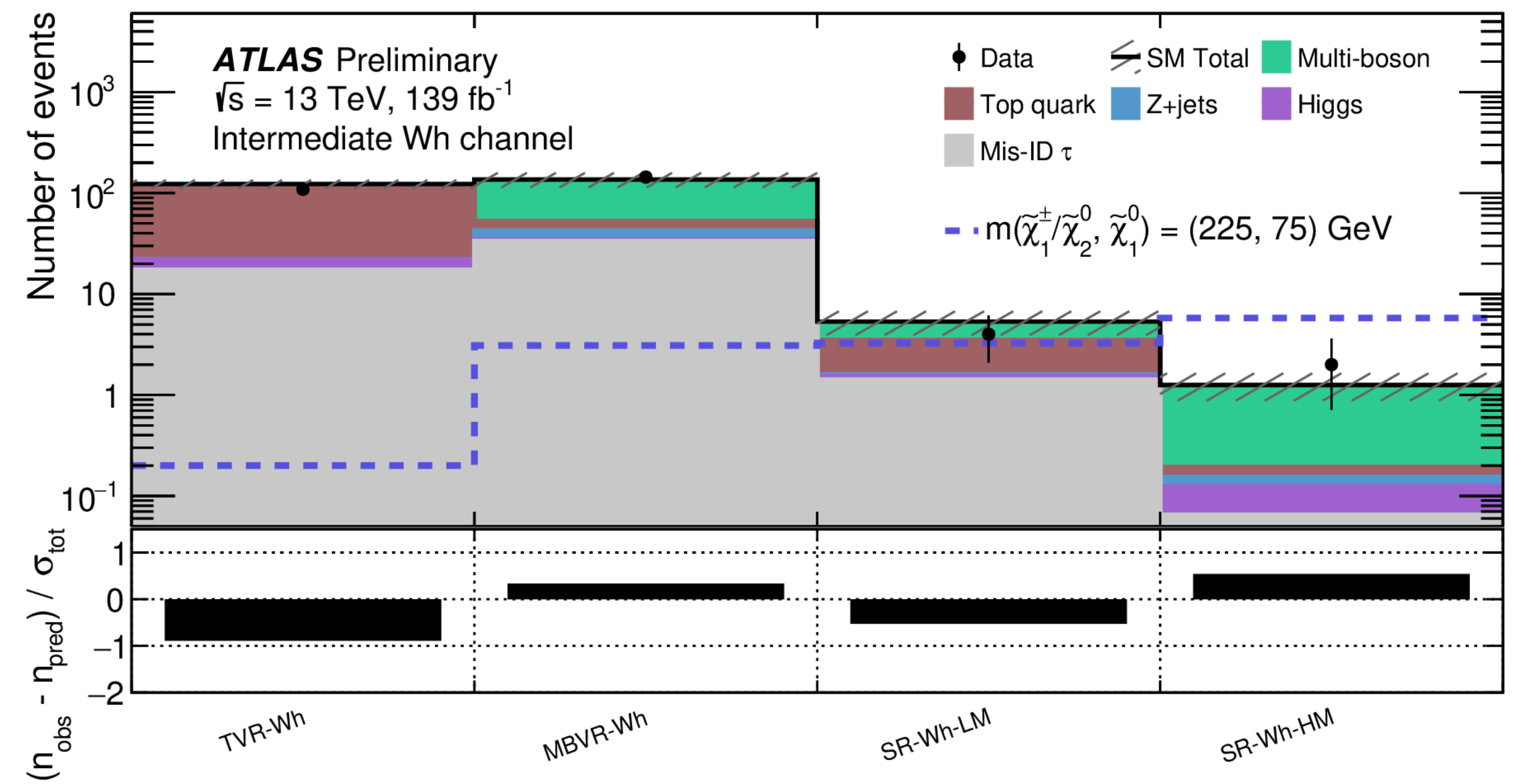
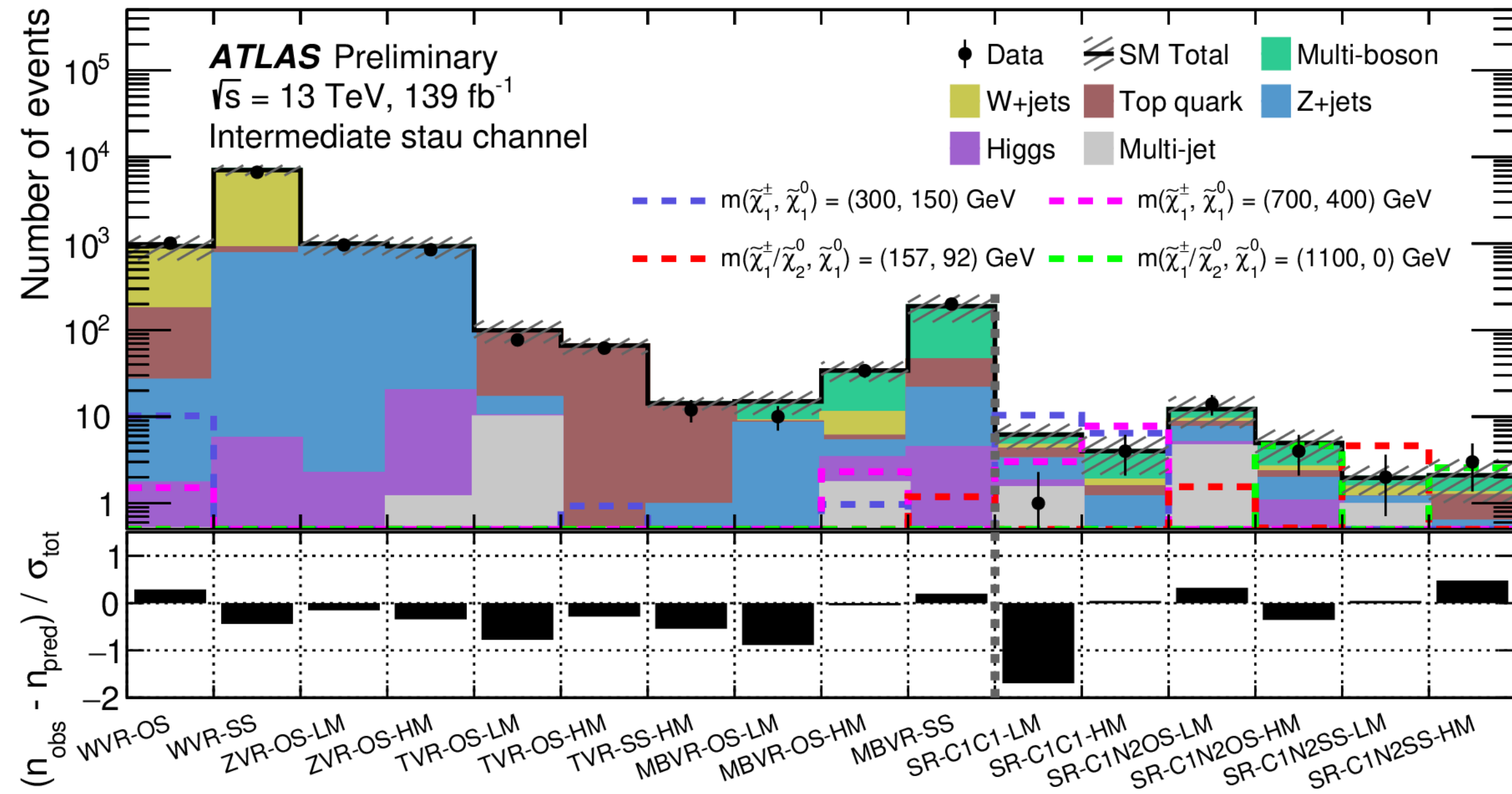
# Electroweak with one lepton



# Electroweak with taus: direct $\tilde{\tau}$



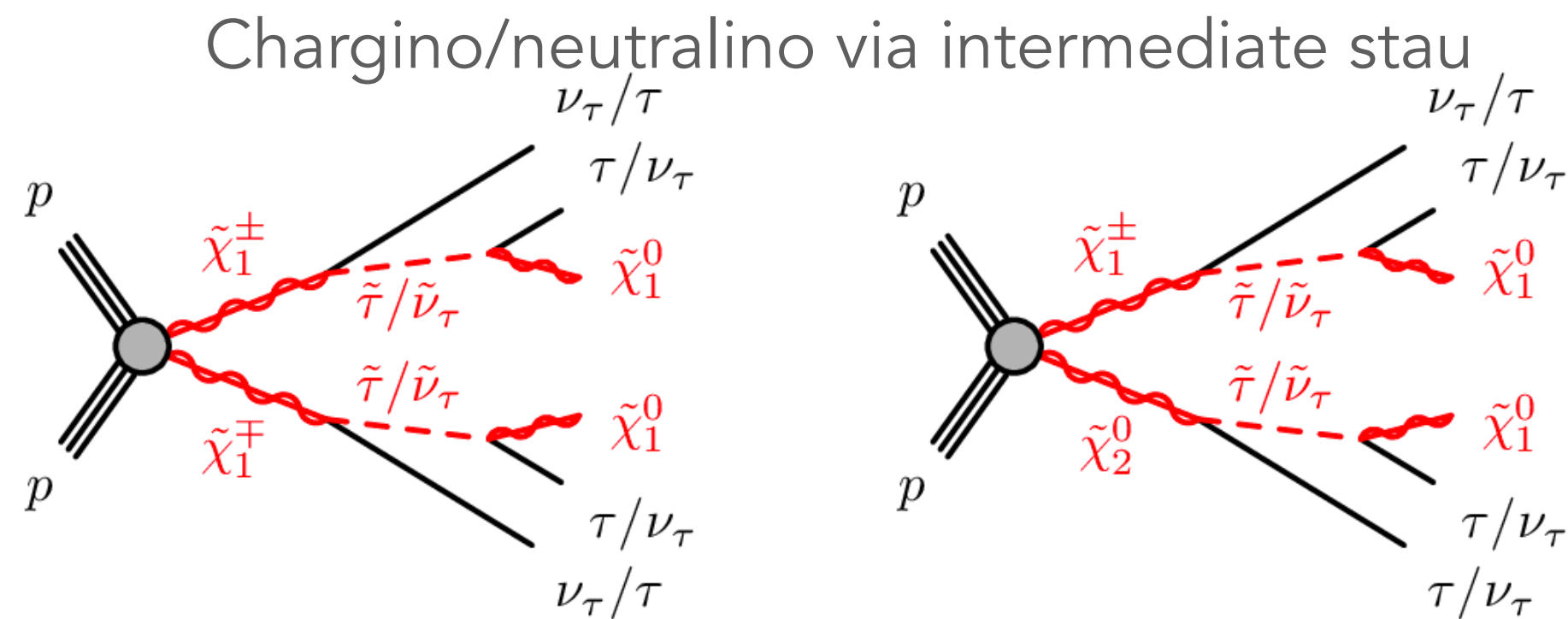
# Electroweak with taus: intermediate stau/Wh



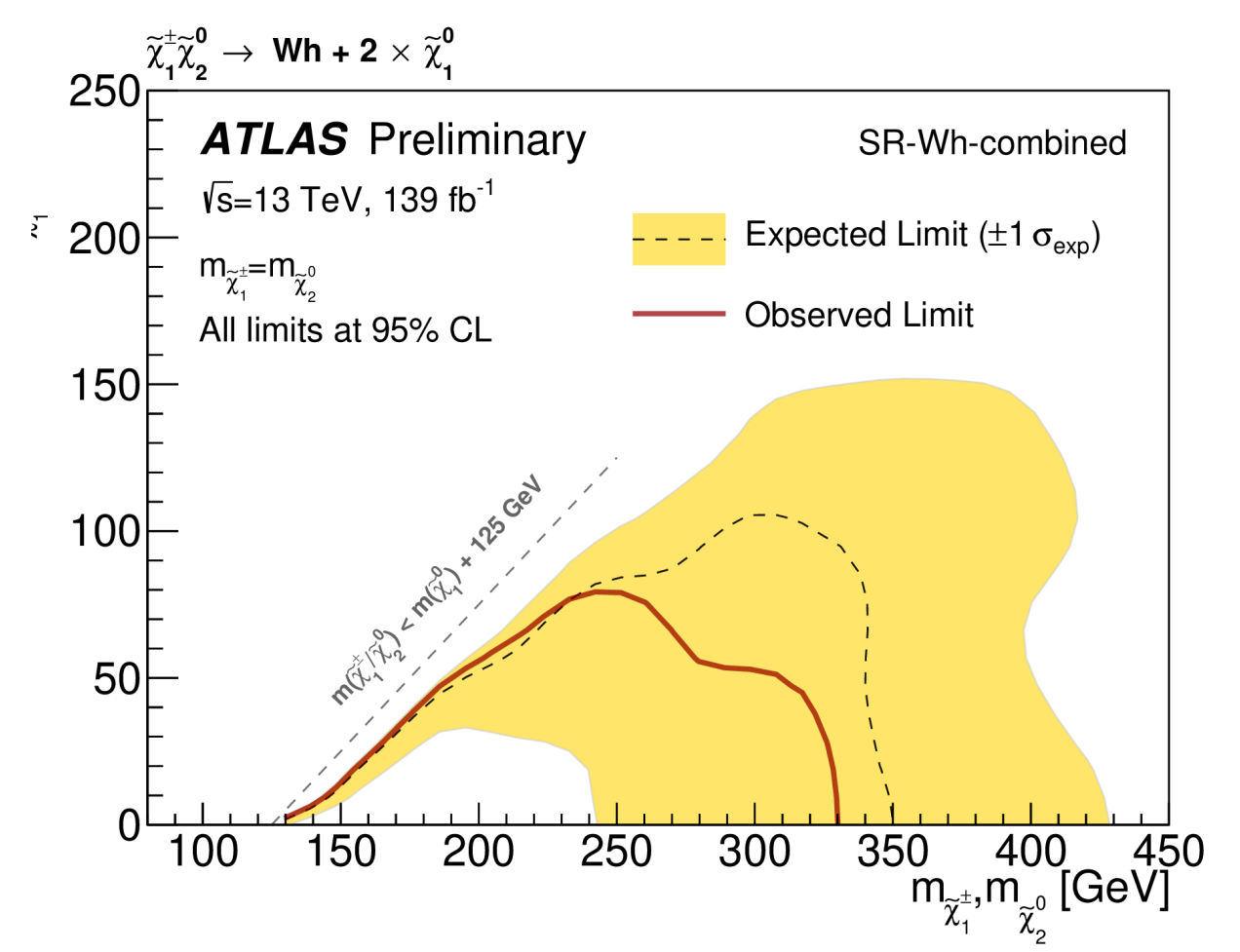
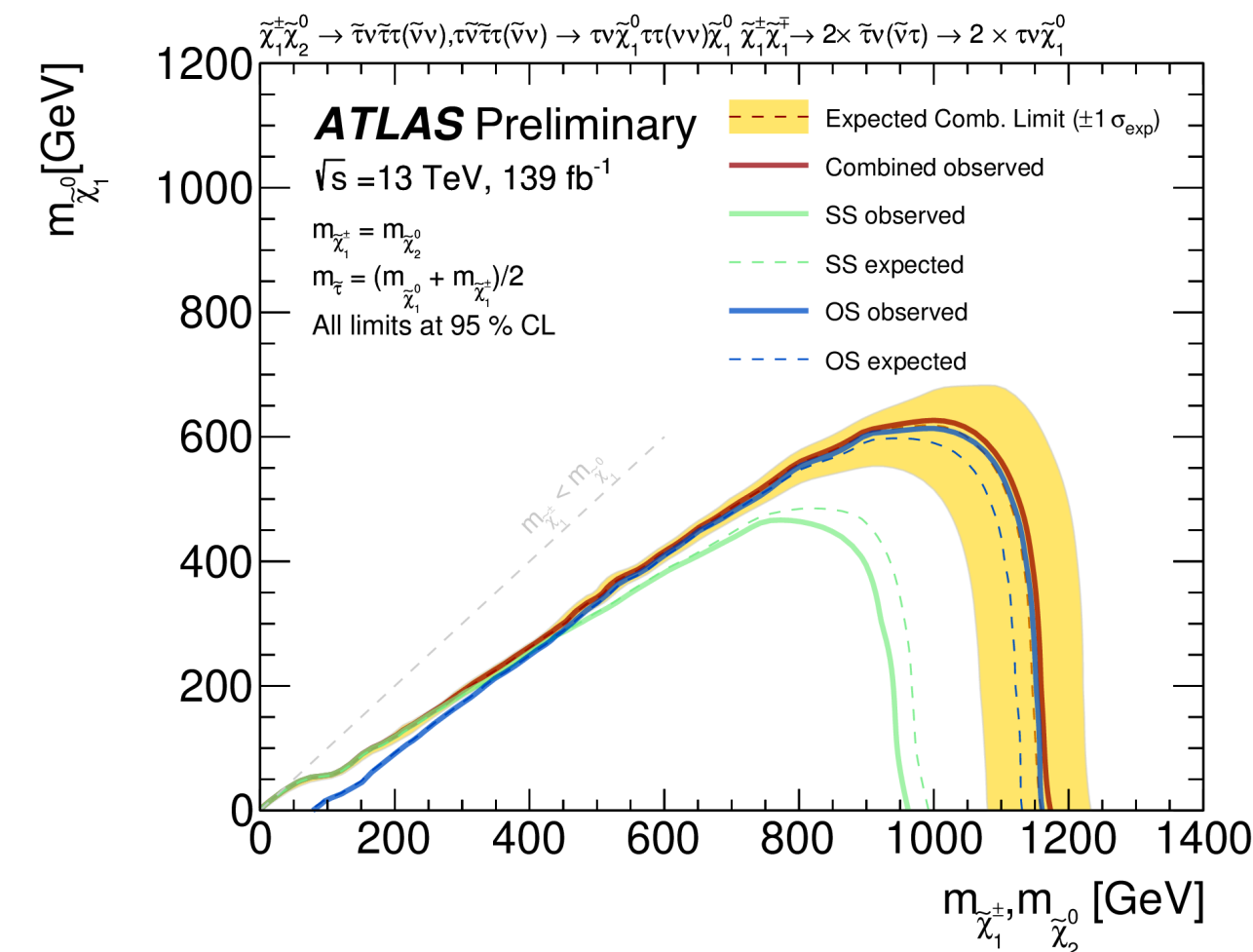
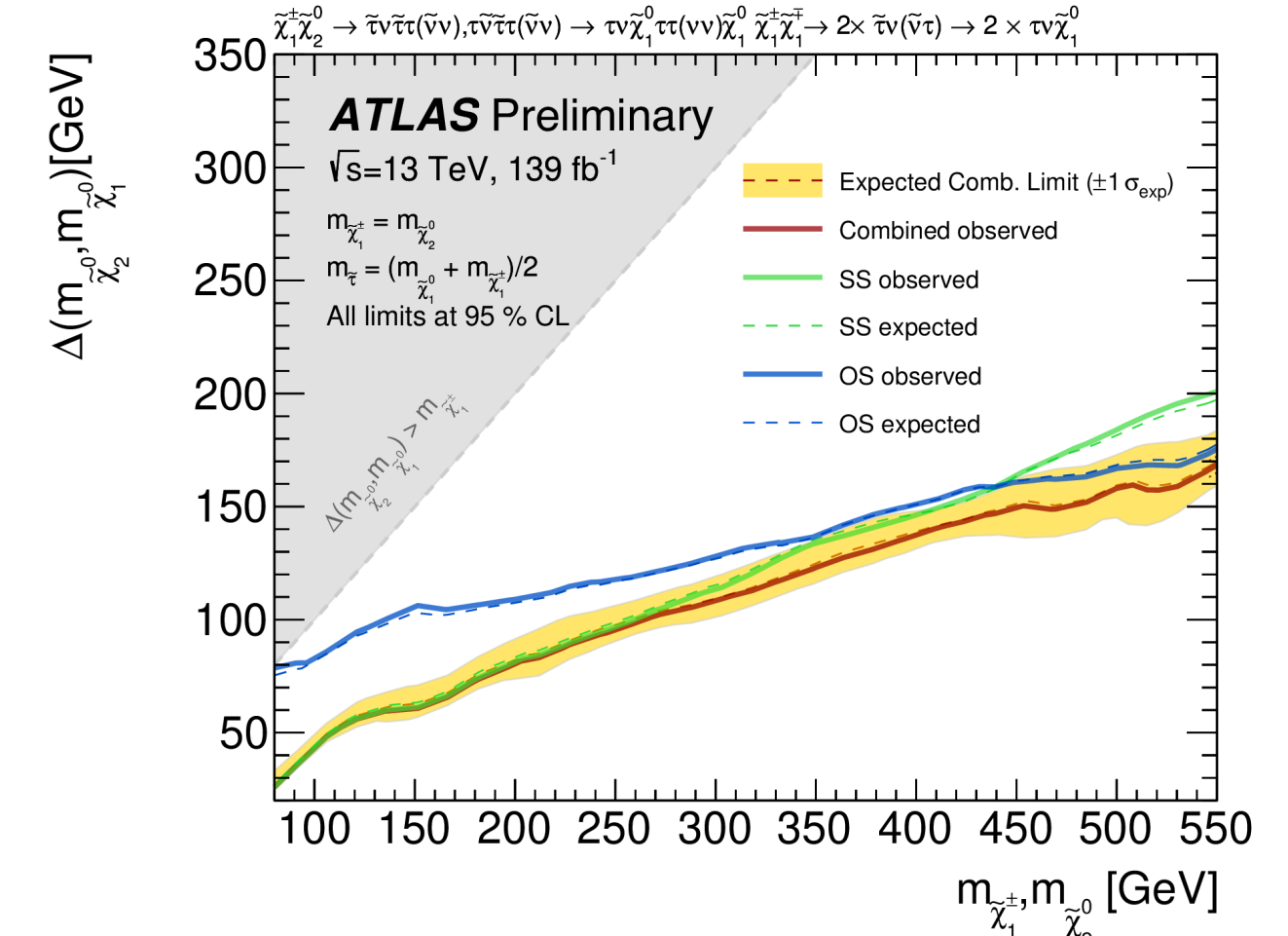
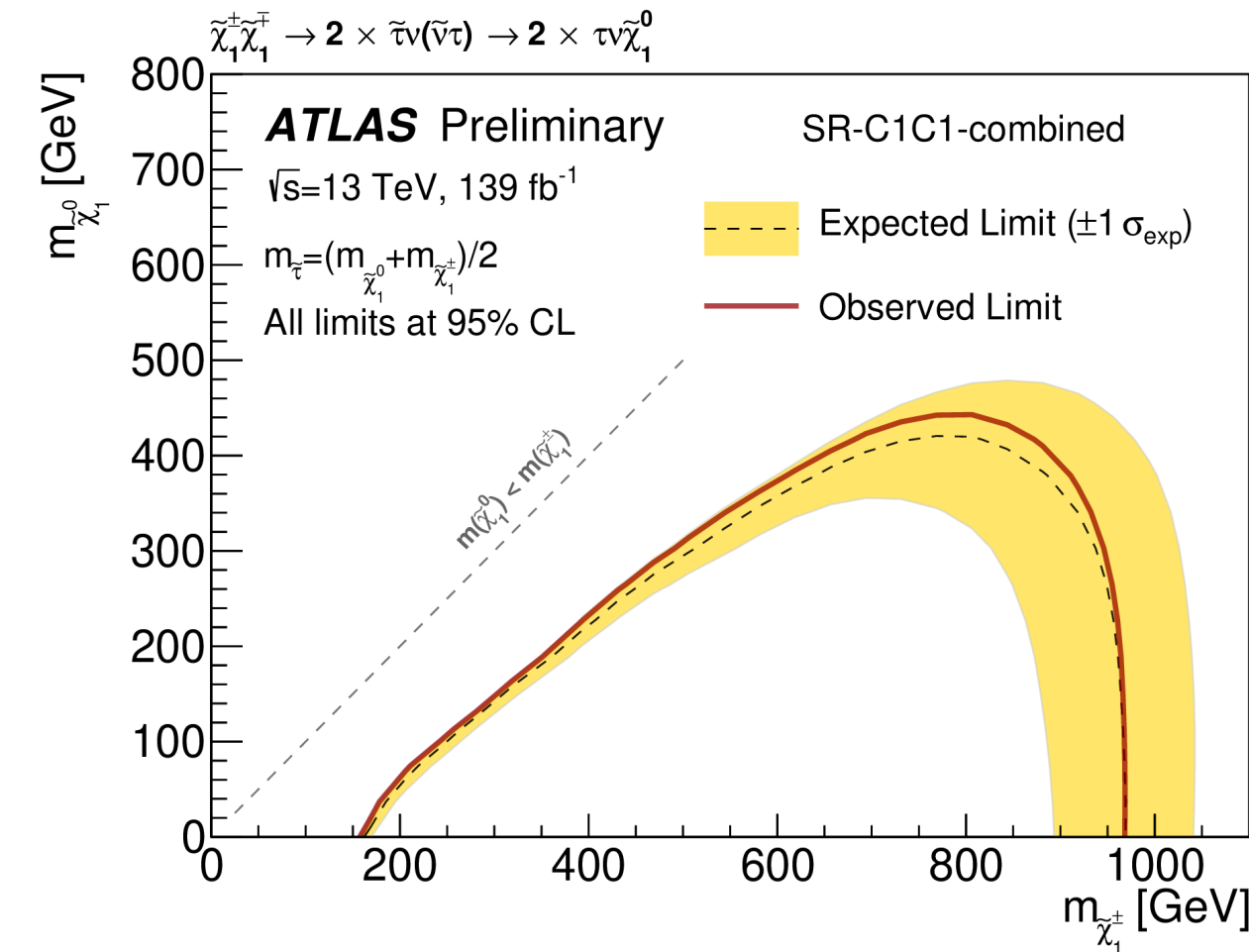
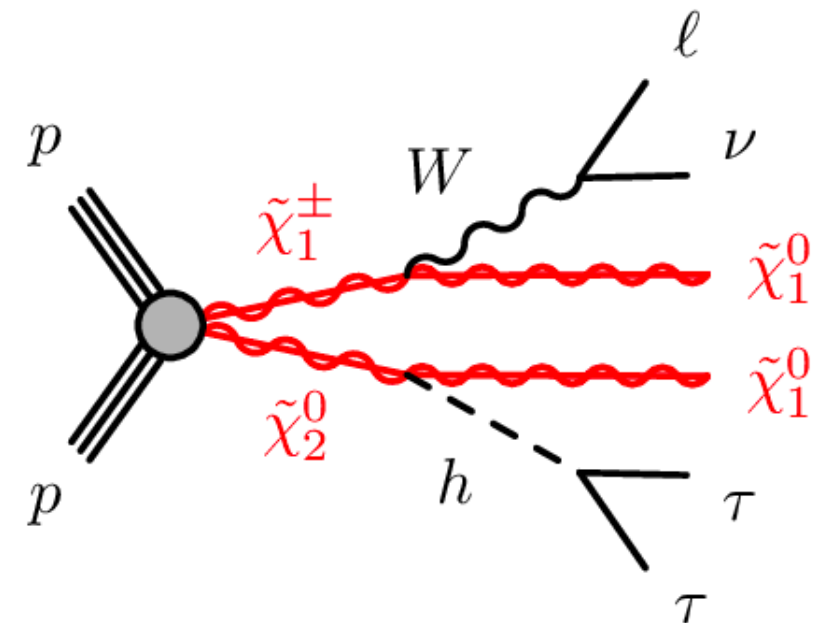
# Electroweak with taus: intermediate $\tilde{\tau}/Wh$

ATLAS-CONF-2023-029

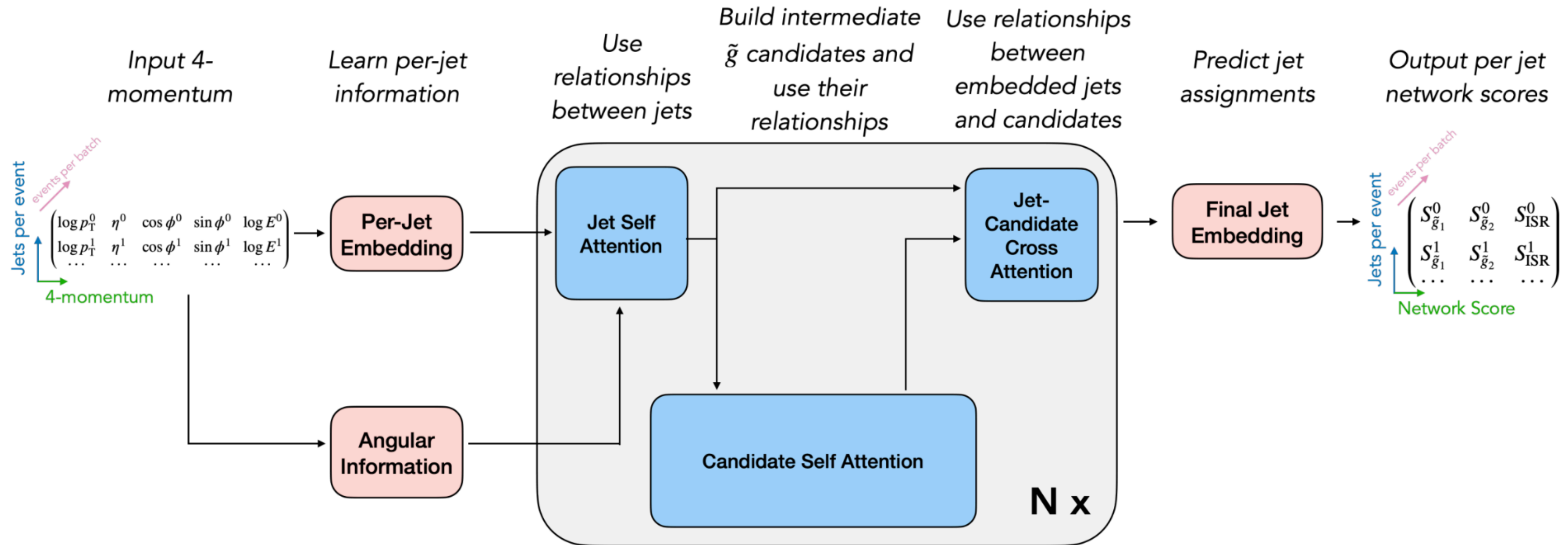
- Two hadronically decaying taus, low jet activity and large MET (from neutralinos and neutrinos)
- Neutralino/chargino production
  - decaying to LSP through intermediate staus or tau sneutrinos with same BR
  - decaying through W and Higgs boson



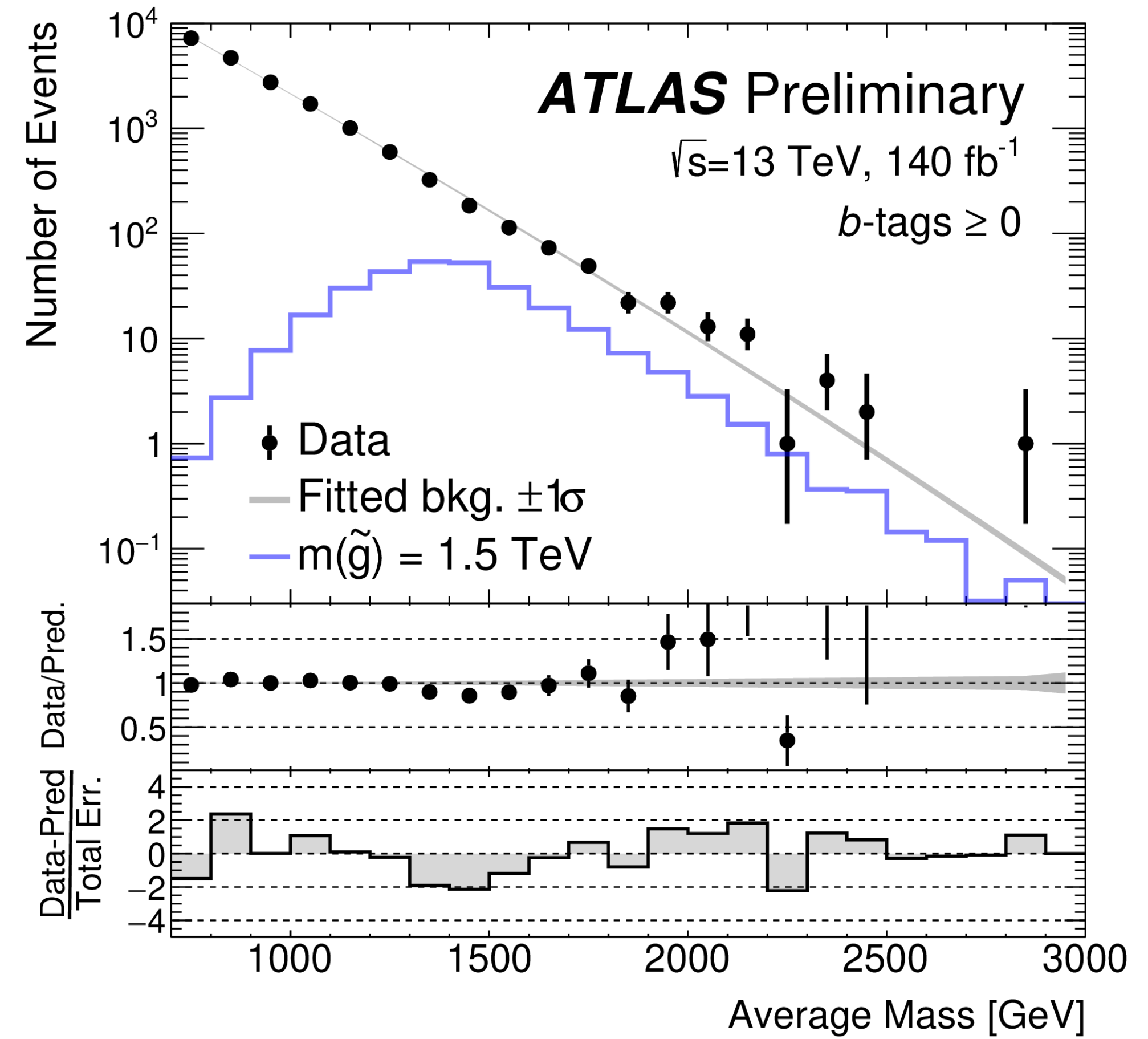
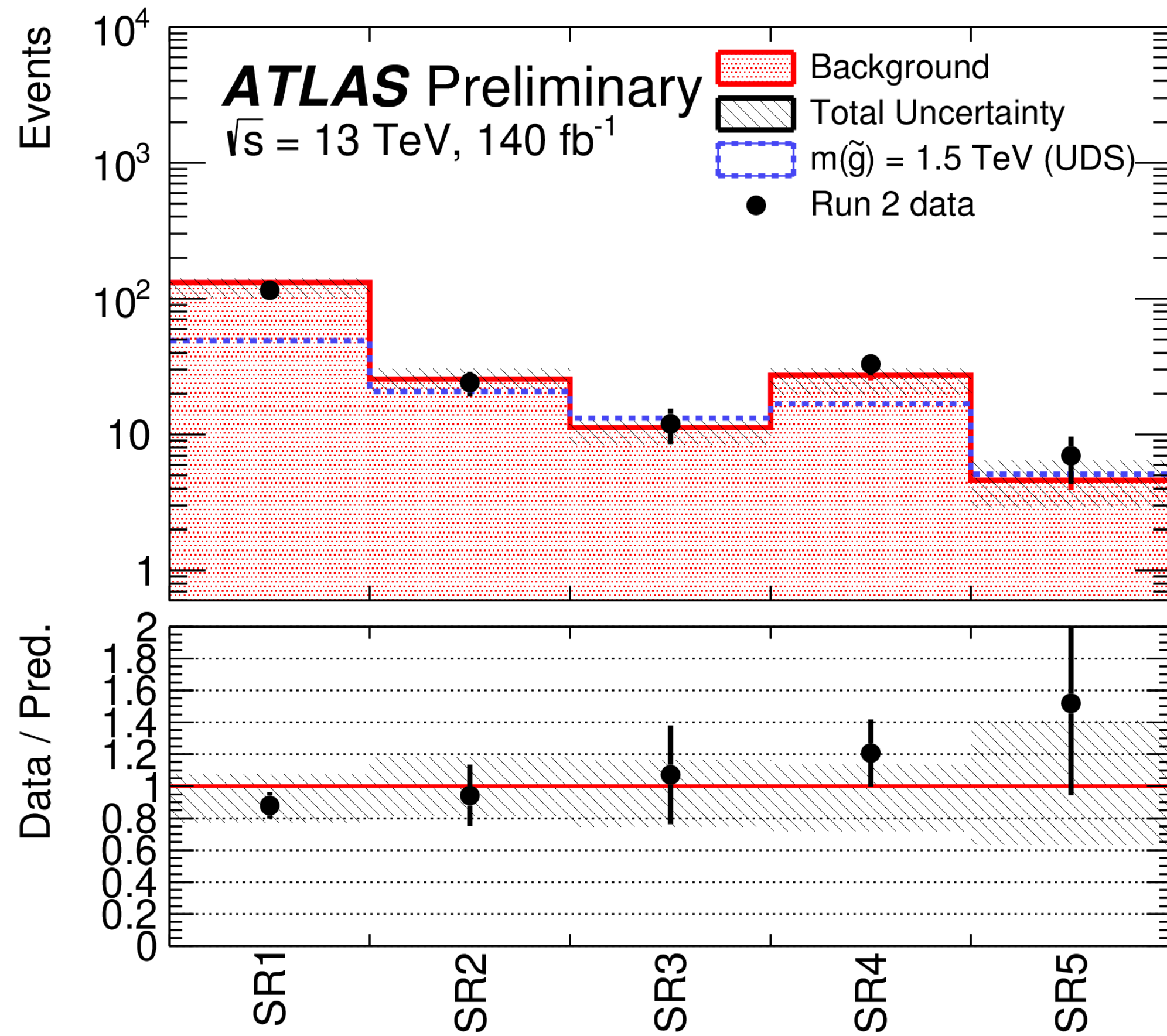
Intermediate Wh channel



# RPV Multijet neural network



# RPV Multijet: Results in SR



# pMSSM Interpretation: external constraints

| Category      | Constraint  | Lower bound           | Upper bound           | Notes   |
|---------------|---|-----------------------|-----------------------|---|
| Flavour       | $\text{BR}(b \rightarrow s\gamma)$                  | $3.11 \times 10^{-4}$ | $3.87 \times 10^{-4}$ | 2022 PDG average [58]   |
|               | $\text{BR}(B_s \rightarrow \mu\mu)$                 | $1.87 \times 10^{-9}$ | $4.31 \times 10^{-9}$ | Most recent LHCb result [59]  |
|               | $\text{BR}(B^+ \rightarrow \tau\nu)$                | $6.10 \times 10^{-5}$ | $1.57 \times 10^{-4}$ | 2022 PDG average [58]   |
| Precision EWK | $\Delta\rho$  | -0.0004               | 0.0018                | Updated global electroweak fit by GFitter group [60] (not including CDF $W$ -mass measurement [61])   |
|               | $\Gamma_{\text{inv}}(Z)$                            | --                    | 2 MeV                 | Precision electroweak measurements on the $Z$ -resonance from experiments at the SLC and LEP colliders [62].  |
|               | $m(W)$  | 80.347 GeV            | 80.407 GeV            | 2022 PDG result (excluding CDF $W$ -mass measurement [61]) [58] but with the $2\sigma$ window expanded by 6 MeV to allow for uncertainty due to the top-quark mass in the MSSM Higgs calculation [63] |
| Dark matter   | Relic density                                       | --                    | 0.12                  | Latest bound from Planck [64]   |
|               | Direct detection $\sigma_{\text{Spin-independent}}$ |                       |                       | Exclusion contour on direct-detection of DM from the LZ collaboration [65]  |
|               | Direct detection $\sigma_{\text{Spin-dependent}}$   |                       |                       | Exclusion contour on direct-detection of DM from PICO-60 [66]   |

# pMSSM Interpretation: Analyses

Table 5: EWK analyses considered in this work.

| Analysis                | Simplified models targeted   |
|-------------------------|--|
| FullHad [24]            | Wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via $WZ$ , Wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via $Wh$ , Wino $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ via $WW$ , Higgsino GGM               |
| 1Lbb [15]               | Wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via $Wh$  |
| 2L0J [19]               | Wino $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ via $WW$ , slepton pairs  |
| 2L2J [25]               | Wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via $WZ$ , Higgsino GGM   |
| 3L [23]                 | Wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via $WZ$ , Wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via $Wh$ , Higgsino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \tilde{\chi}_1^0$ , Higgsino GGM |
| 4L [22]                 | Higgsino GGM   |
| Compressed [20]         | Wino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ via $WZ$ , Higgsino $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \tilde{\chi}_1^0$  |
| Disappearing-track [27] | Wino $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ and $\tilde{\chi}_1^\pm \tilde{\chi}_1^0$   |



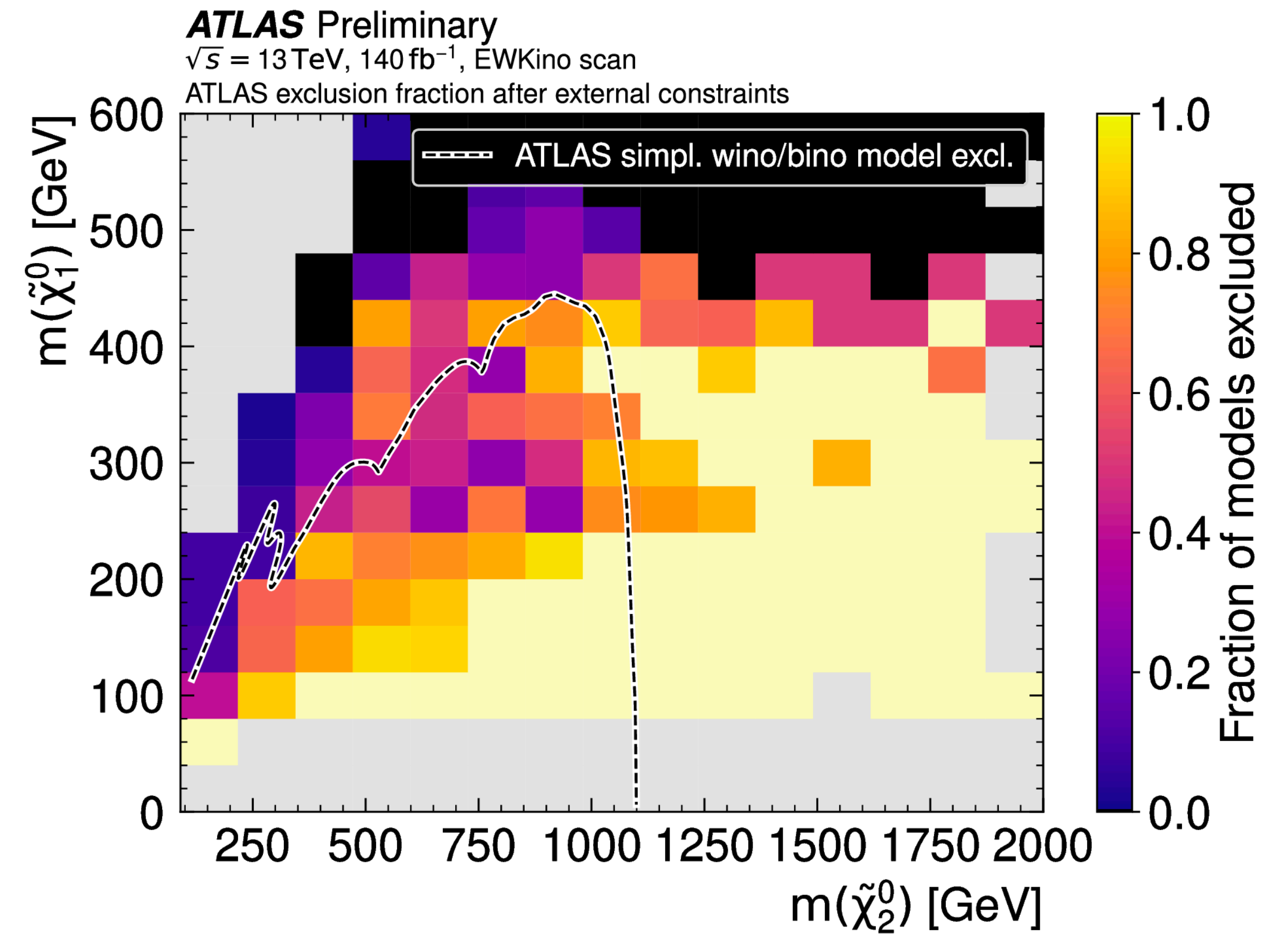
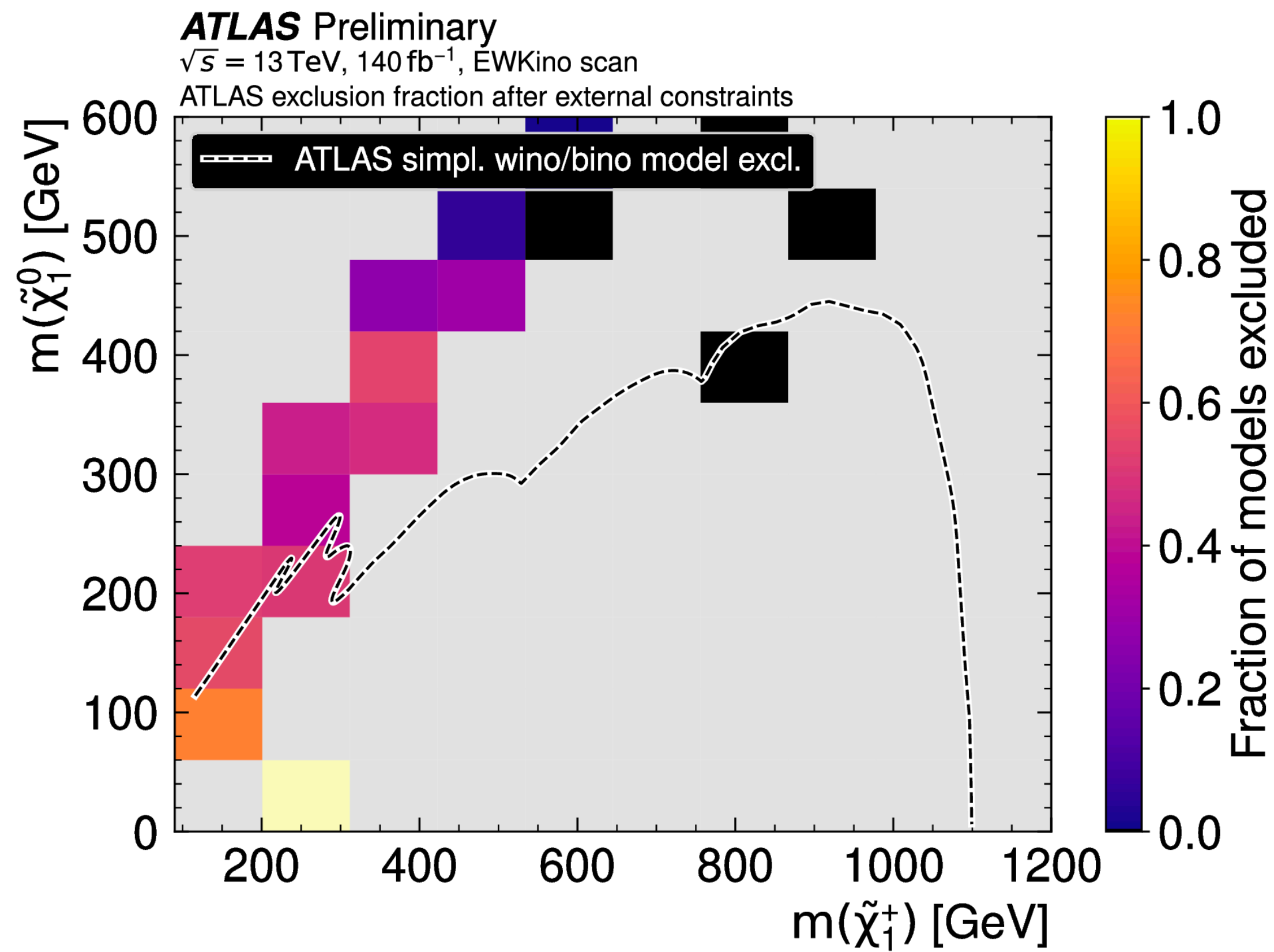
# pMSSM Interpretation: Scan

| Parameter                            | min    | max    | Note   |
|--------------------------------------|--------|--------|--|
| $M_{\tilde{L}_1} (=M_{\tilde{L}_2})$ | 10 TeV | 10 TeV | Left-handed slepton (first two gens.) mass           |
| $M_{\tilde{e}_1} (=M_{\tilde{e}_2})$ | 10 TeV | 10 TeV | Right-handed slepton (first two gens.) mass          |
| $M_{\tilde{L}_3}$                    | 10 TeV | 10 TeV | Left-handed stau doublet mass                        |
| $M_{\tilde{e}_3}$                    | 10 TeV | 10 TeV | Right-handed stau mass                               |
| $M_{\tilde{Q}_1} (=M_{\tilde{Q}_2})$ | 10 TeV | 10 TeV | Left-handed squark (first two gens.) mass            |
| $M_{\tilde{u}_1} (=M_{\tilde{u}_2})$ | 10 TeV | 10 TeV | Right-handed up-type squark (first two gens.) mass   |
| $M_{\tilde{d}_1} (=M_{\tilde{d}_2})$ | 10 TeV | 10 TeV | Right-handed down-type squark (first two gens.) mass |
| $M_{\tilde{Q}_3}$                    | 2 TeV  | 5 TeV  | Left-handed squark (third gen.) mass                 |
| $M_{\tilde{u}_3}$                    | 2 TeV  | 5 TeV  | Right-handed top squark mass                         |
| $M_{\tilde{d}_3}$                    | 2 TeV  | 5 TeV  | Right-handed bottom squark mass                      |
| $M_1$                                | -2 TeV | 2 TeV  | Bino mass parameter                                  |
| $M_2$                                | -2 TeV | 2 TeV  | Wino mass parameter                                  |
| $\mu$                                | -2 TeV | 2 TeV  | Bilinear Higgs mass parameter                        |
| $M_3$                                | 1 TeV  | 5 TeV  | Gluino mass parameter                                |
| $A_t$                                | -8 TeV | 8 TeV  | Trilinear top coupling                               |
| $A_b$                                | -2 TeV | 2 TeV  | Trilinear bottom coupling                            |
| $A_\tau$                             | -2 TeV | 2 TeV  | Trilinear $\tau$ lepton coupling                     |
| $M_A$                                | 0 TeV  | 5 TeV  | Pseudoscalar Higgs boson mass                        |
| $\tan\beta$                          | 1      | 60     | Ratio of the Higgs vacuum expectation values         |

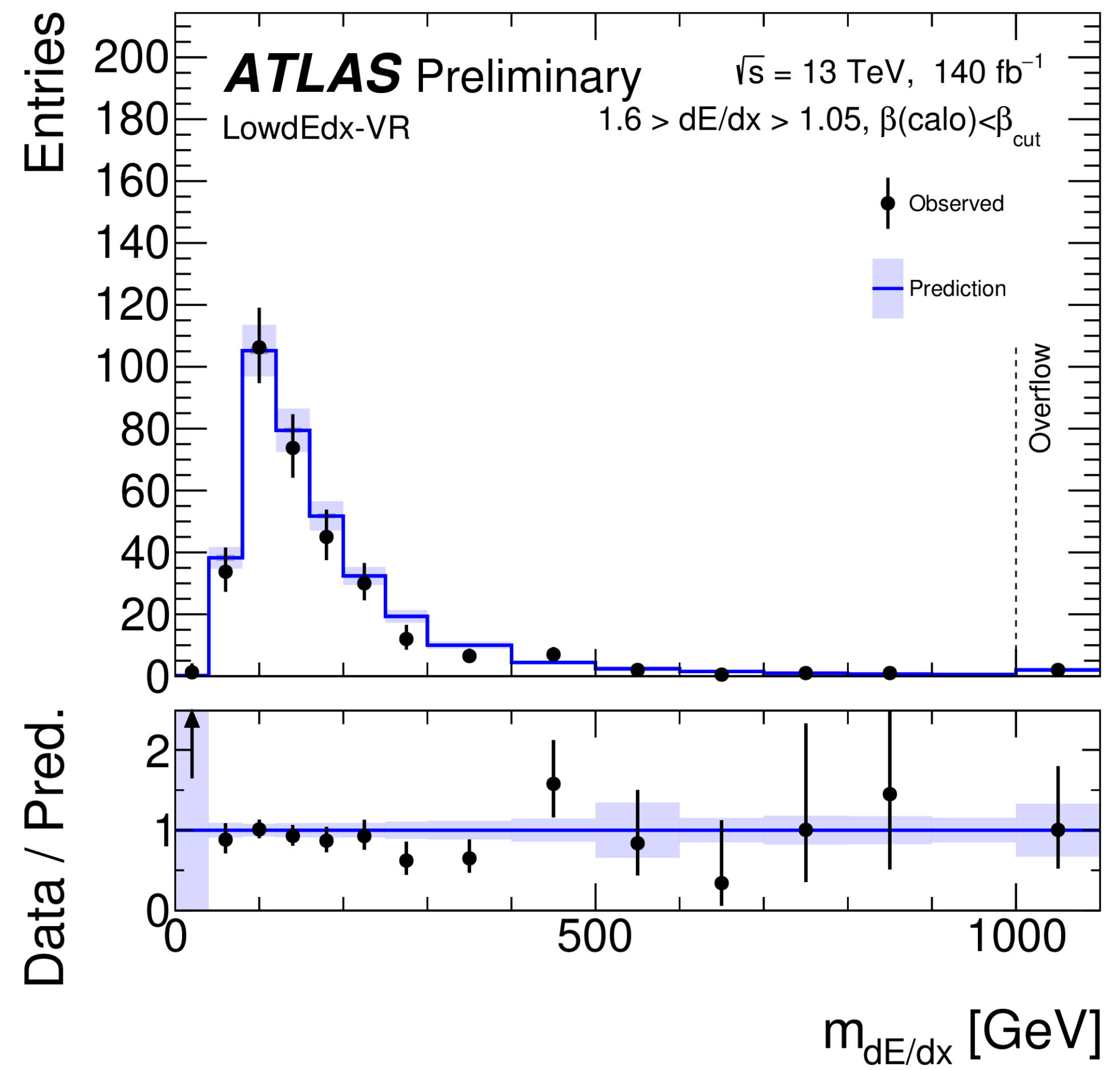
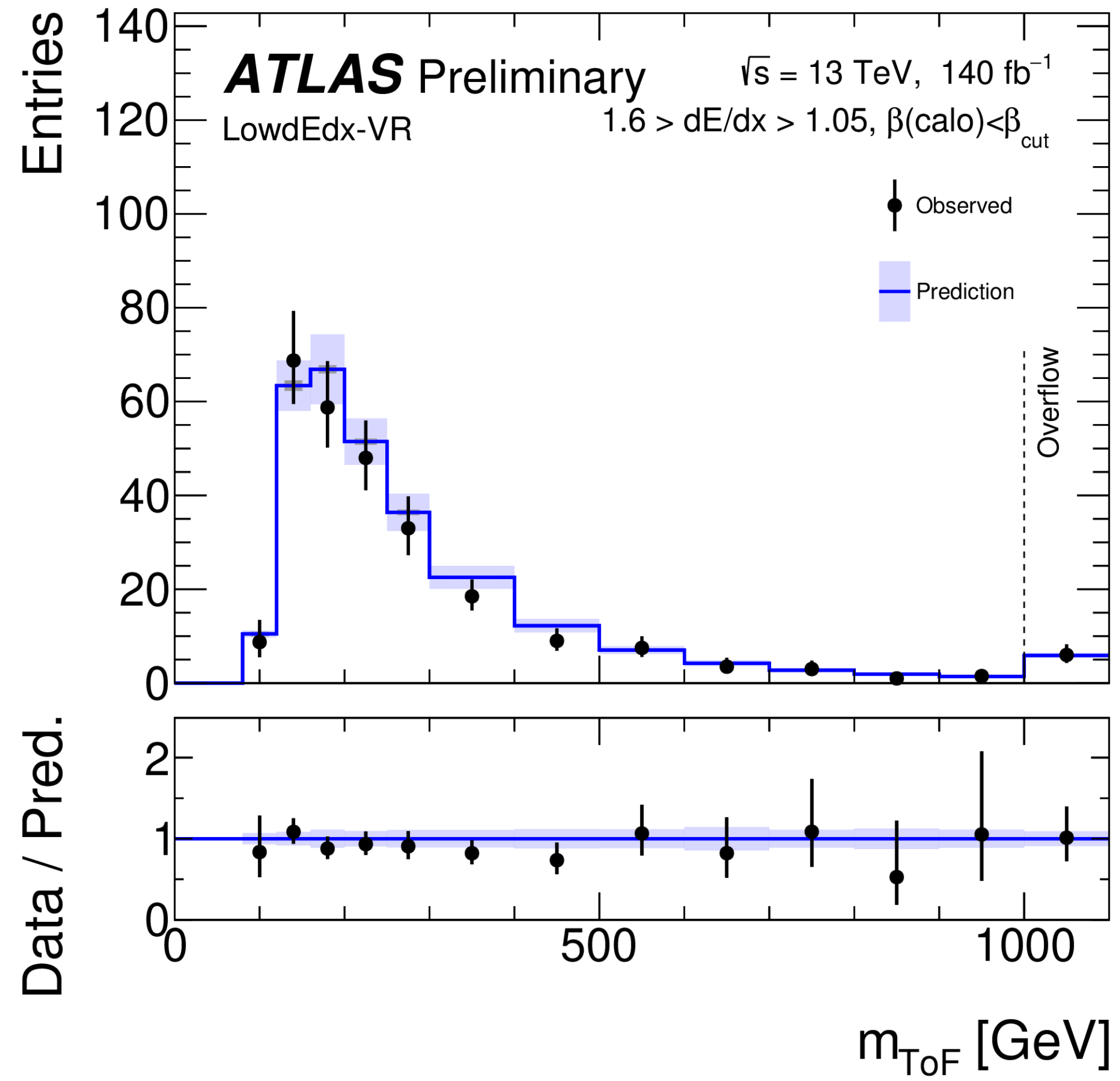
| Scan name   | EWKino     | Bino-DM              |
|---|------------|----------------------|
| $ M_1 $ range   | 0 – 2 TeV  | 0 – 500 GeV          |
| LSP type  | Neutralino | Bino-like neutralino |
| <b>Number of models generated:</b>                      |            |                      |
| Sampled   | 20,000     | 437,500              |
| Successful generation                                   | 16,667     | 370,017              |
| Correct LSP type  | 15,321     | 286,267              |
| Pass DM relic density constraint $\Omega h^2 \leq 0.12$ | N/A        | 11,122               |
| Pass LEP chargino mass constraint                       | 13,969     | 10,174               |
| 120 GeV < m(h) < 130 GeV                                | 12,280     | 8,897                |

# pMSSM Interpretation

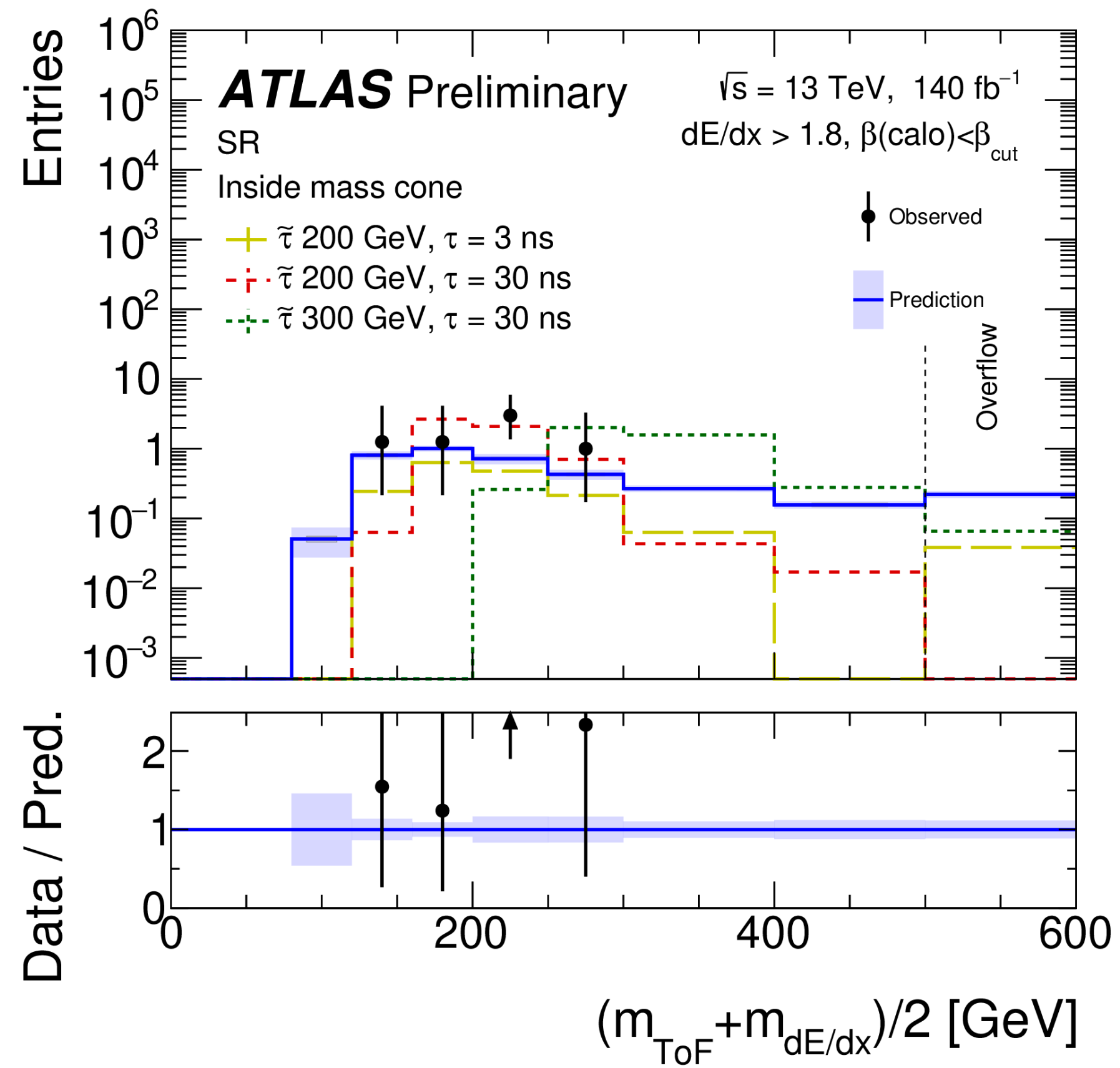
- Only models passing all external constraints



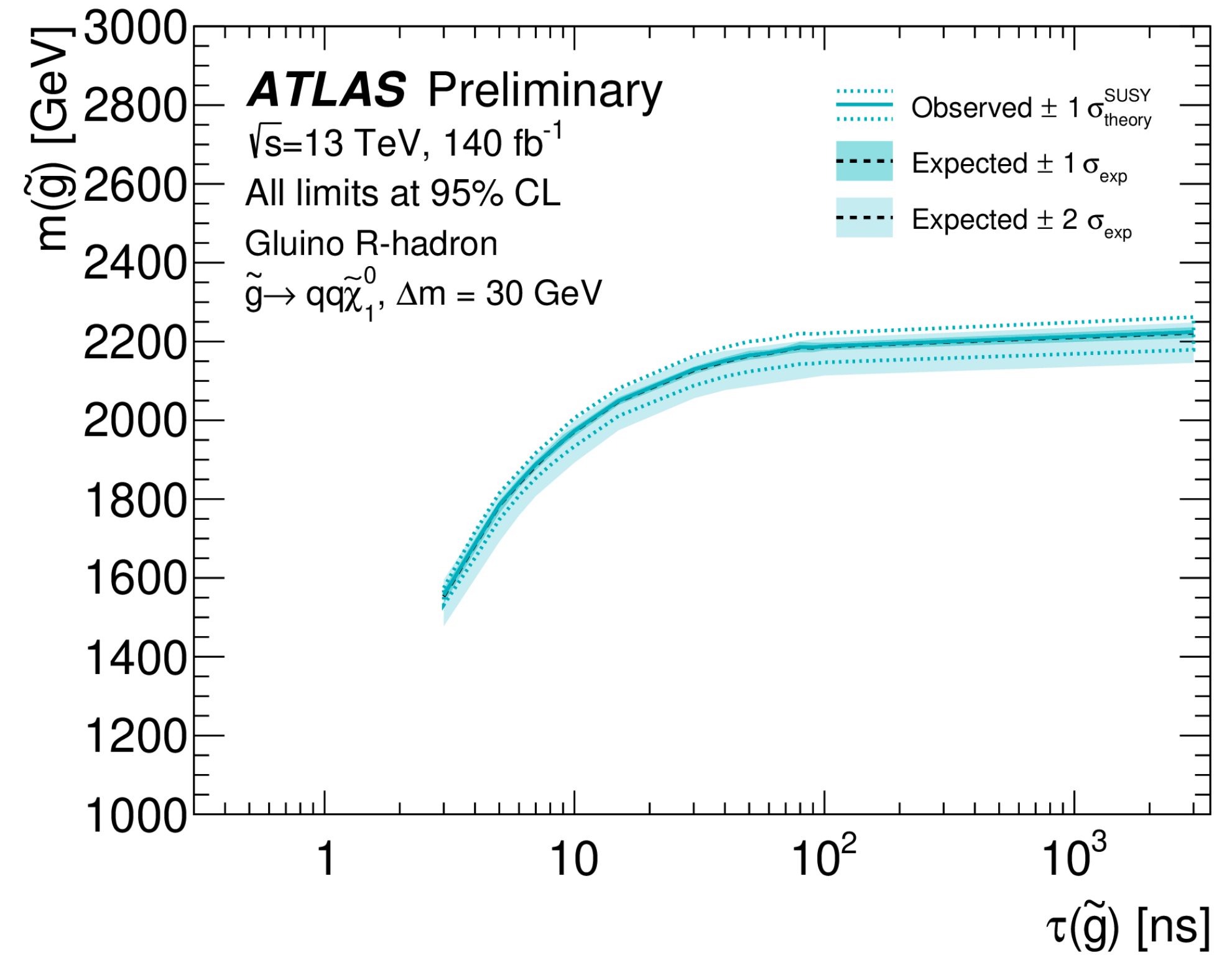
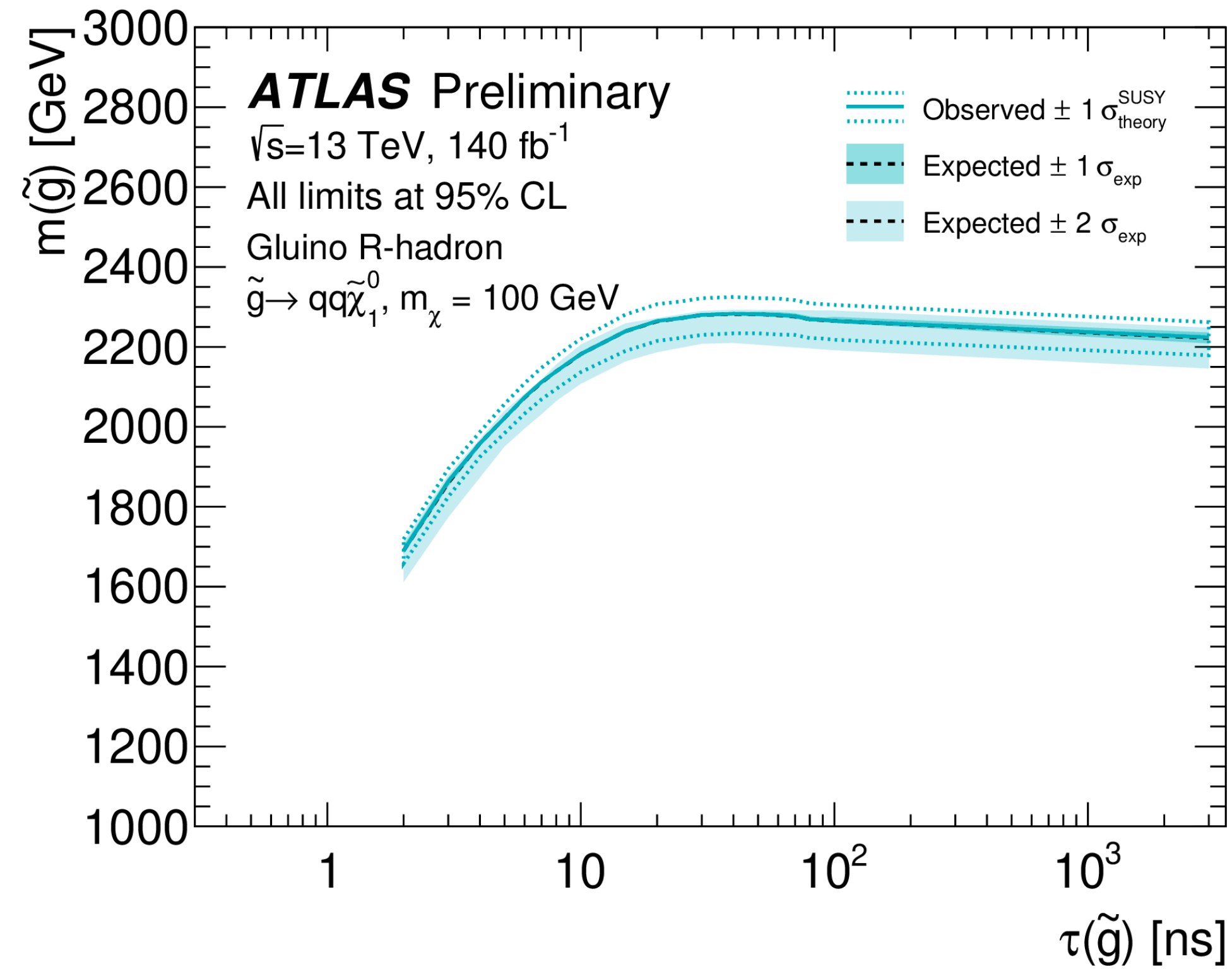
# Long-lived particles search



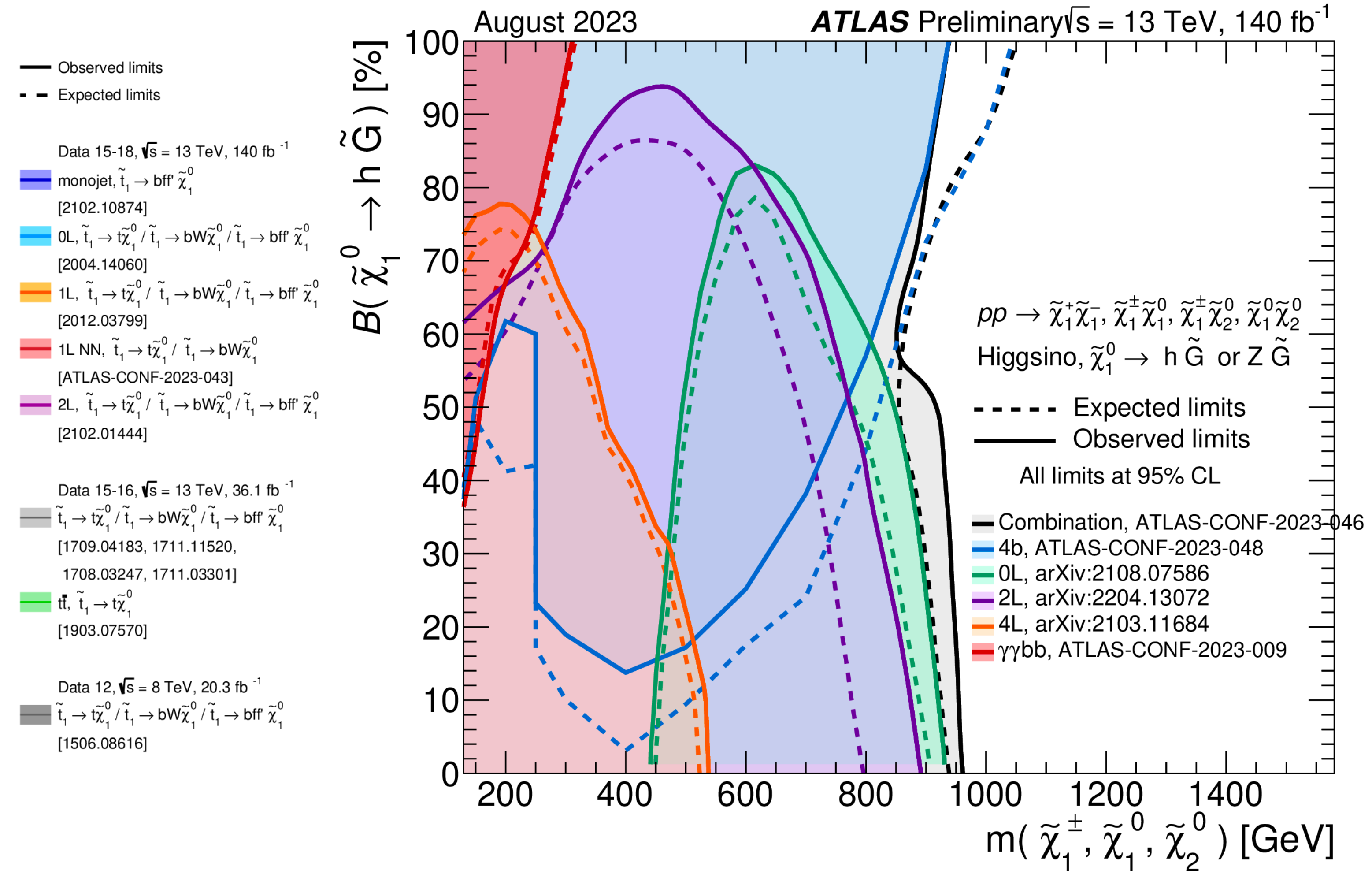
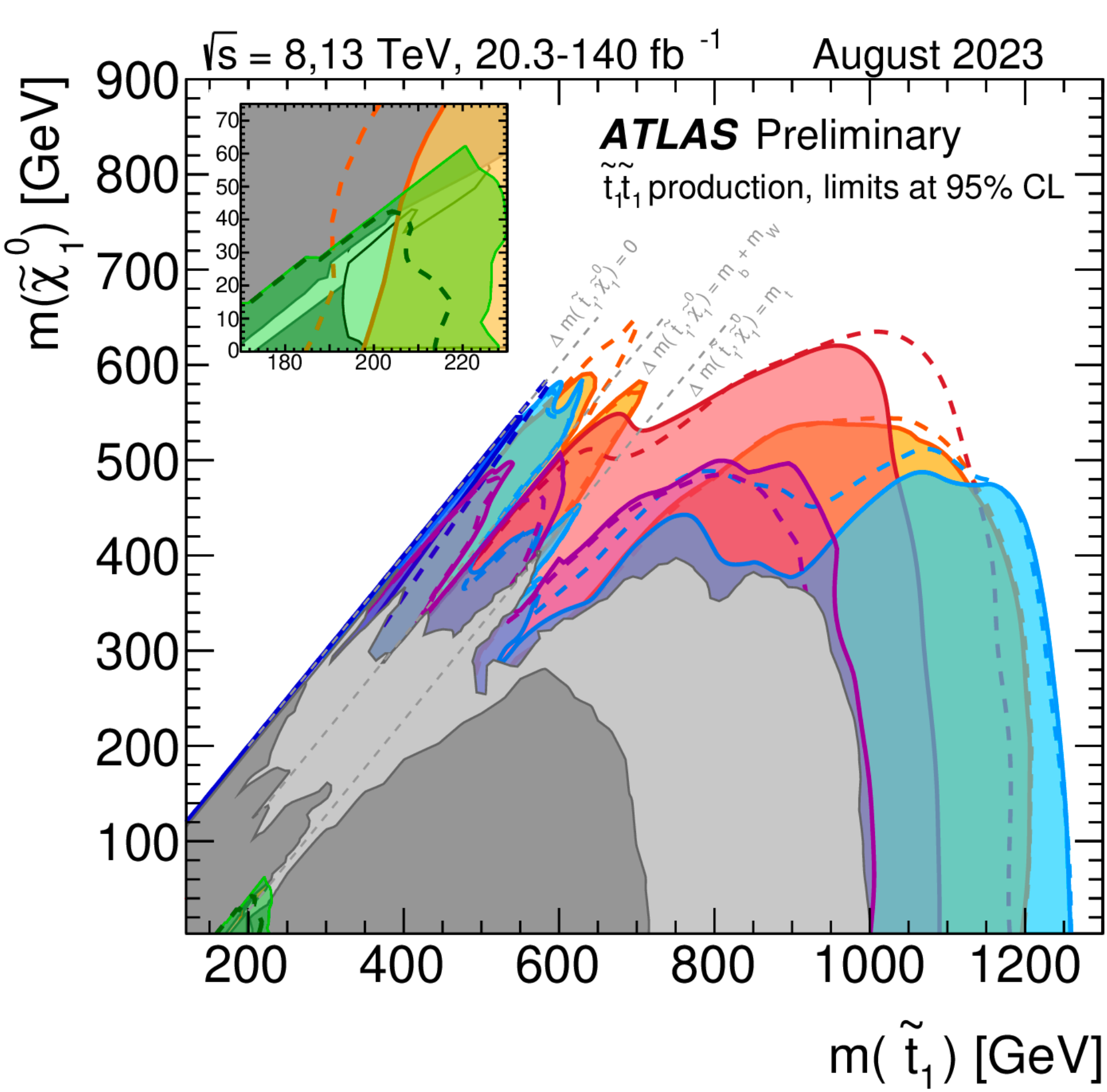
# Long-lived particles search



# Long-lived particles search



# Summary plots



# Summary plots

