Searches for GMSB in ATLAS with higgsino next-to-lightest SUSY particles

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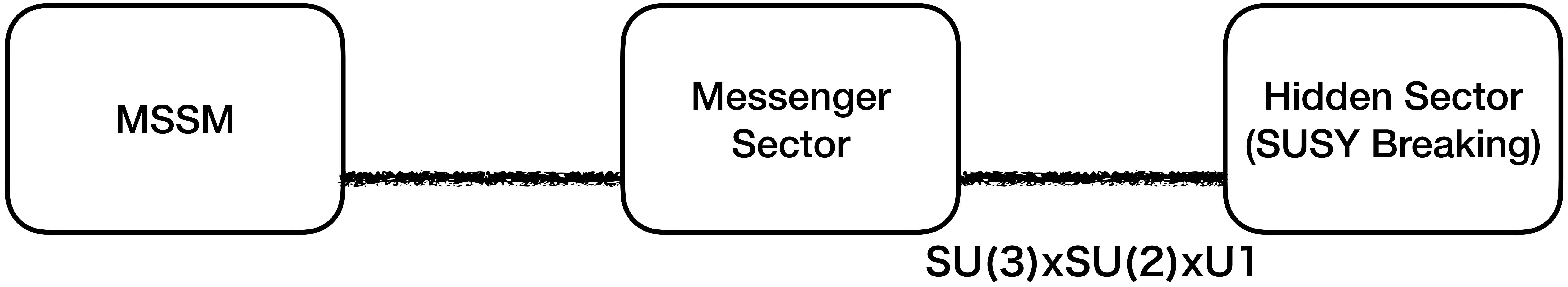
On behalf of the ATLAS collaboration

21 July 2023

SUSY 2023 @ University of Southampton Highfield Campus

Gauge Mediated SUSY Breaking

- SUSY breaking mediated from hidden to visible sector by gauge interactions



MSSM

Messenger Sector

Hidden Sector (SUSY Breaking)

SU(3)xSU(2)xU1

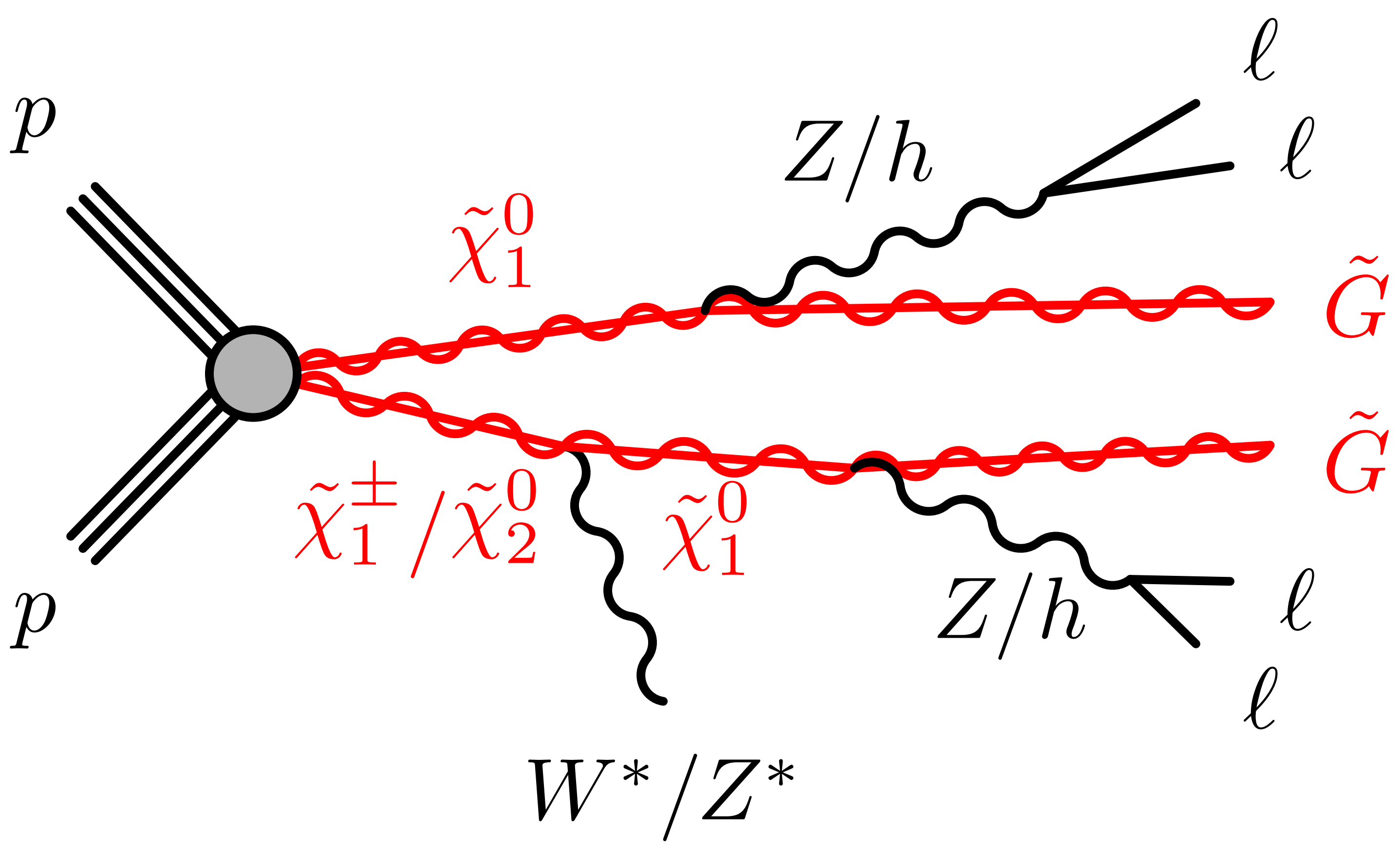
- Lightest SUSY particle (LSP) : **gravitino,** $\tilde{G}$
  - Weakly interacting, neutral
  - Taken to be nearly massless : O(eV - keV)
- Assuming R-parity conserved→SUSY particles produced in pairs
  - Decay to a stable gravitino LSP
  - Experimental signature : missing transverse momentum
- Next-to-lightest SUSY particle (NLSP)
  - **Neutralino**, $\tilde{\chi}_1^0$
    - From naive naturalness arguments, focus on relatively light **higgsino,** $\tilde{H}$
      - Decays to $\underline{h/Z + \tilde{G}}$ (Coupling to photons suppressed)
      - Measurement with scanning the branching fraction: $\underline{B(\tilde{H} \to Z\tilde{G}) = 1 - B(\tilde{H} \to h\tilde{G})}$

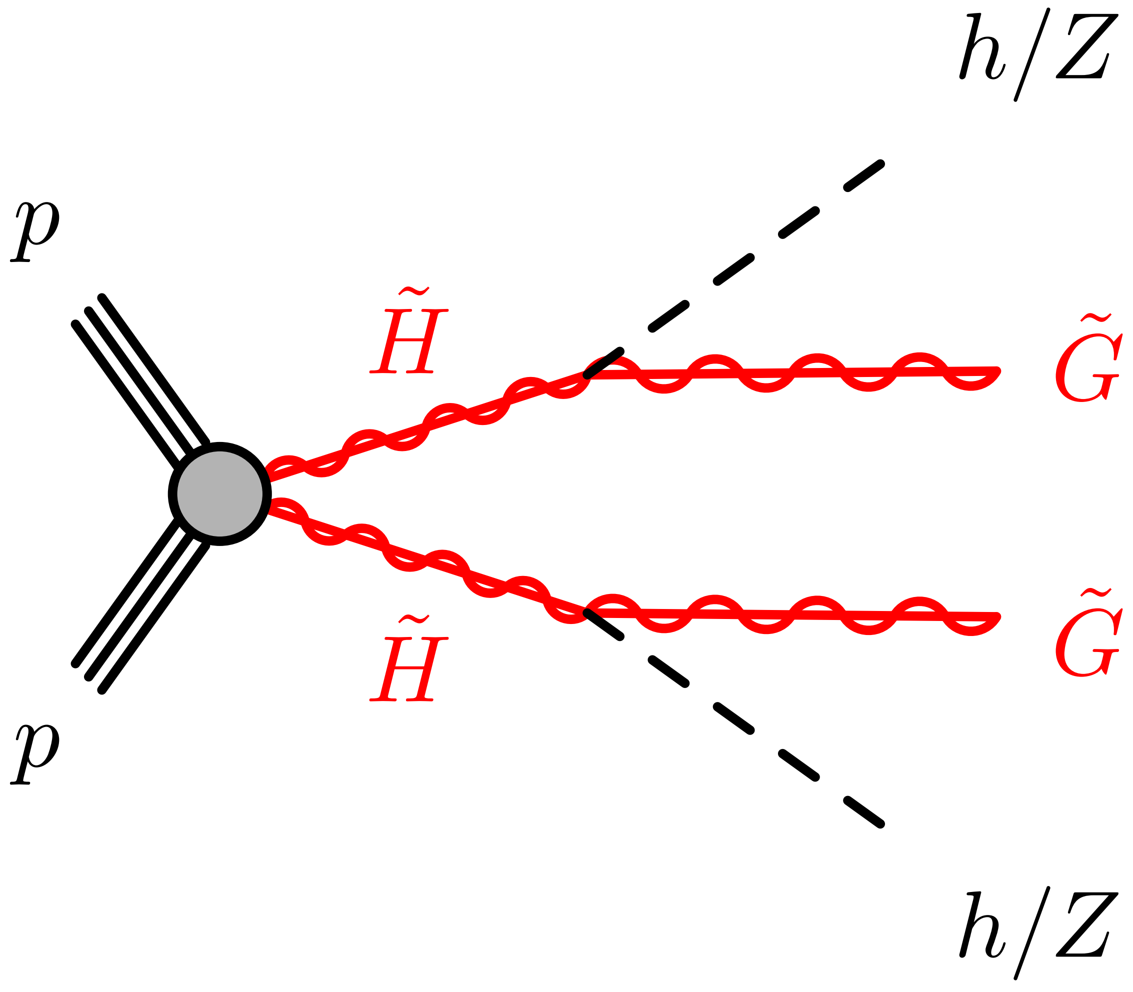
Higgsino production and decays

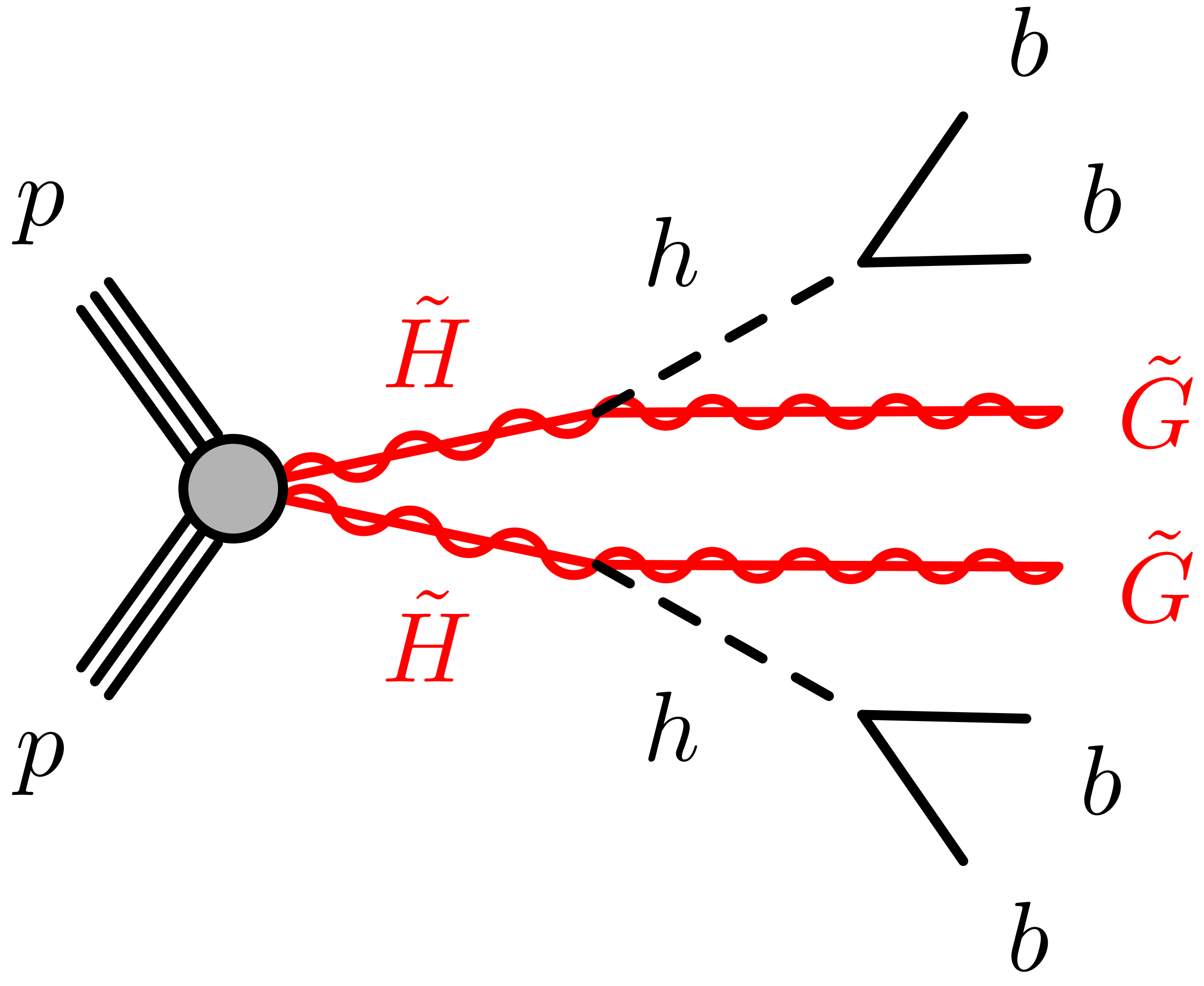
- Production modes
  - Cascade with small mass difference
    - Considered in multi leptons analysis
  - Mass degenerate scenarios
    - Direct productions of higgsino NLSPs

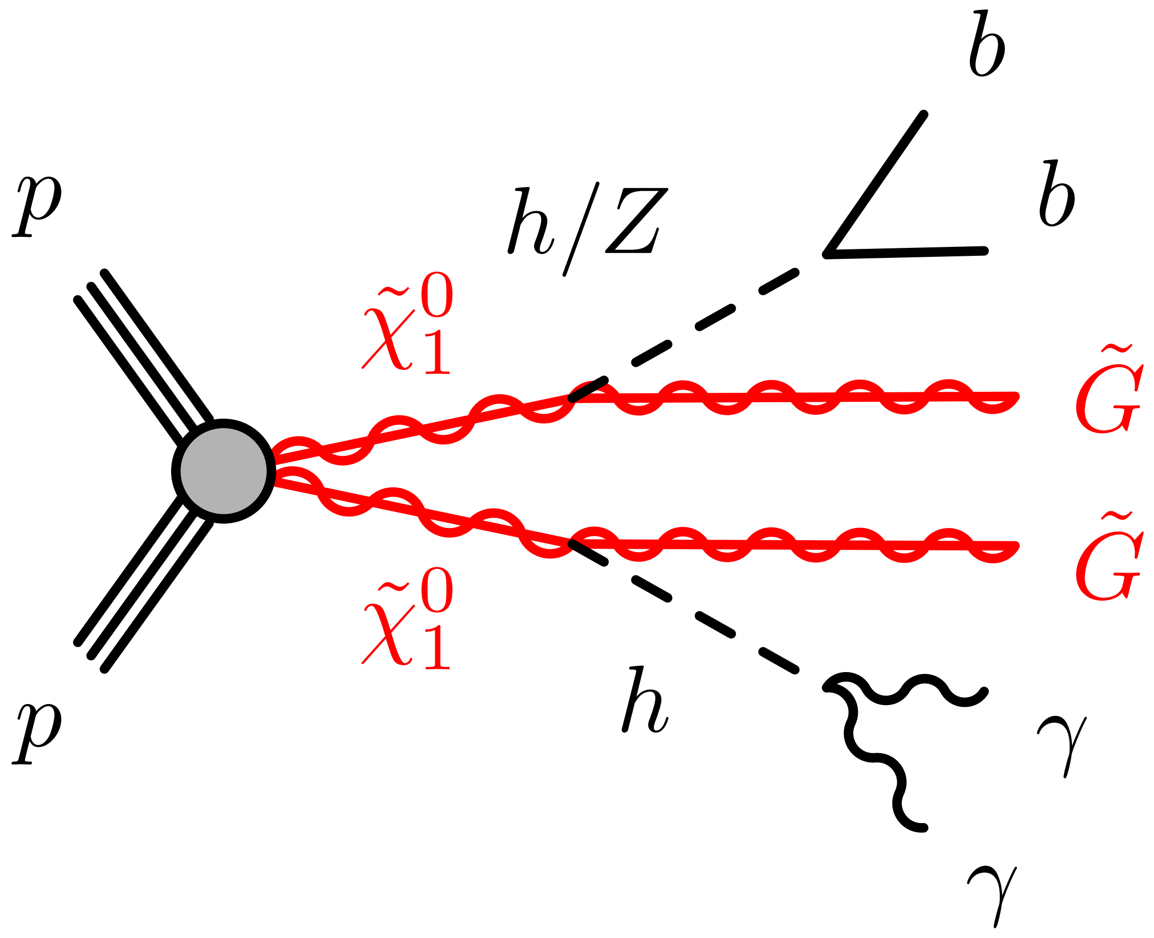
- Categorization
  - Z boson decay
    - $Z \to \ell\ell, bb, qq(\text{light flavor})$
  - Higgs decay
    - $h \to bb, \gamma\gamma$

- Analyses covered in this talk (by ATLAS)
  - **4 or more leptons** arXiv:2103.11684
  - **2 leptons + jets** arXiv:2204.13072
  - **0 lepton**
    - 4b arXiv:1806.04030
    - 2b + 2q, 4q arXiv:2108.07586
    - 2b + 2γ ATLAS-CONF-2023-009







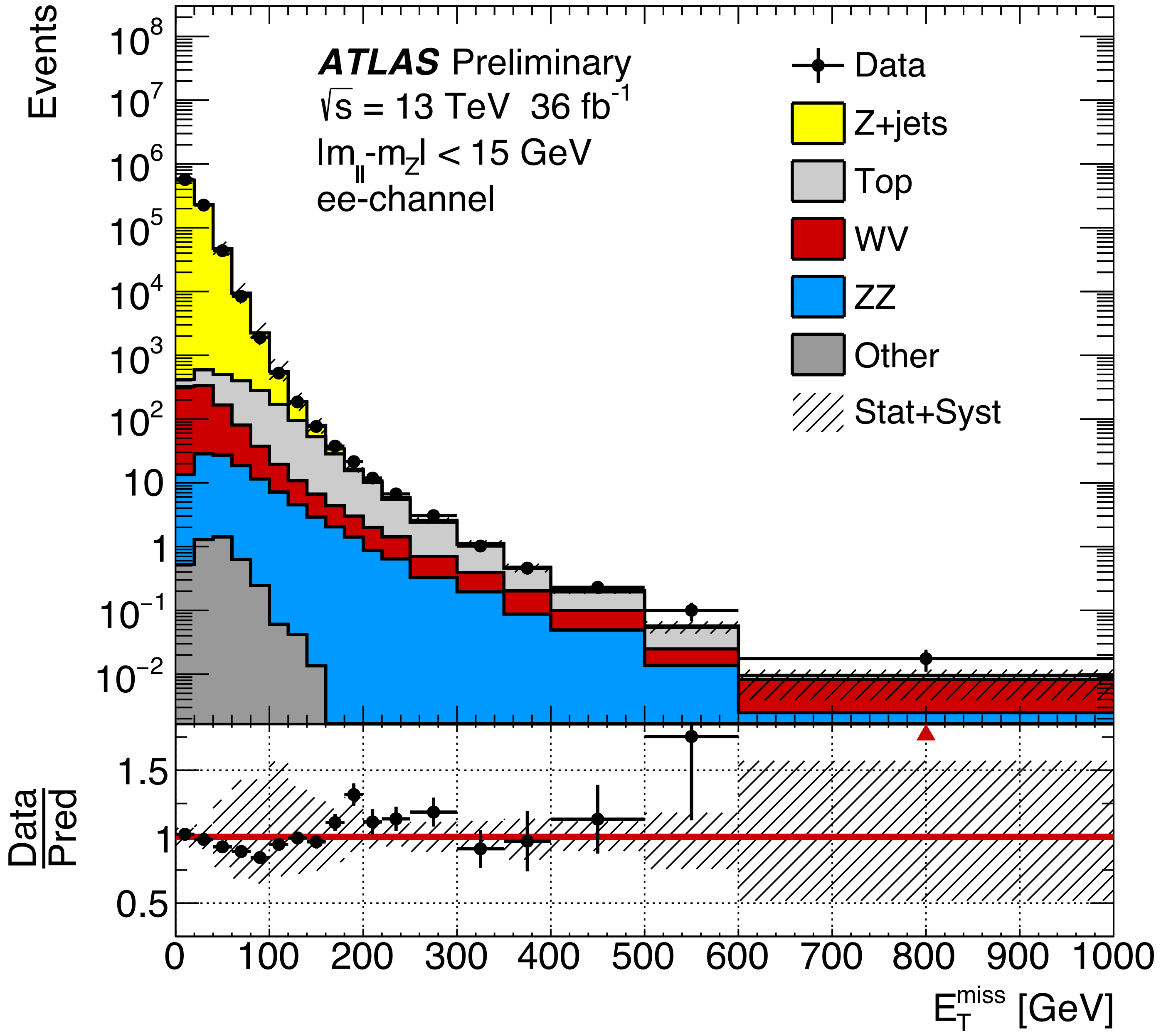


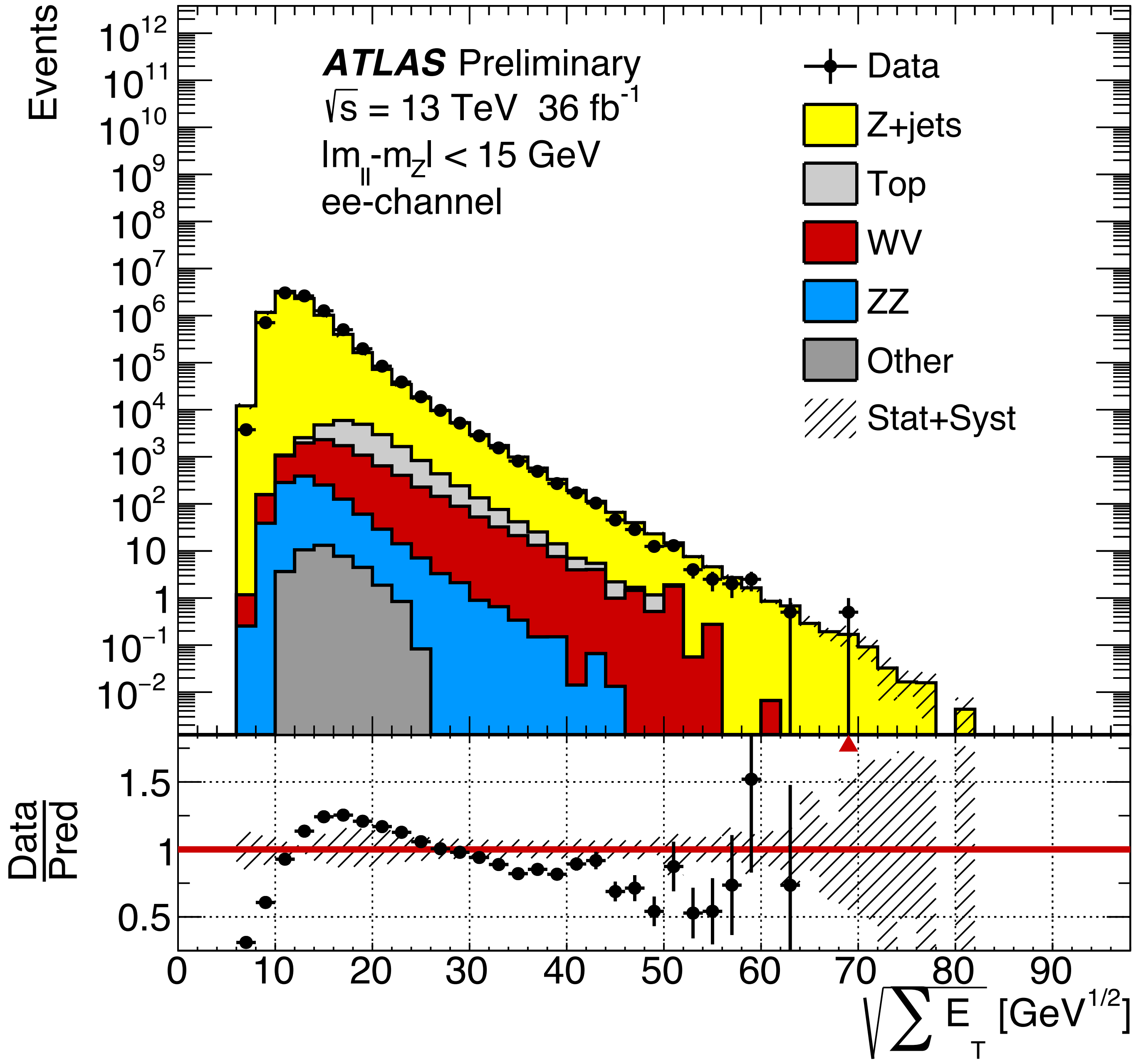
✓ Higgsino can be long-lived due to small coupling while focusing on prompt decays in this talk
cf.) displaced decay vertex arXiv:2304.12885

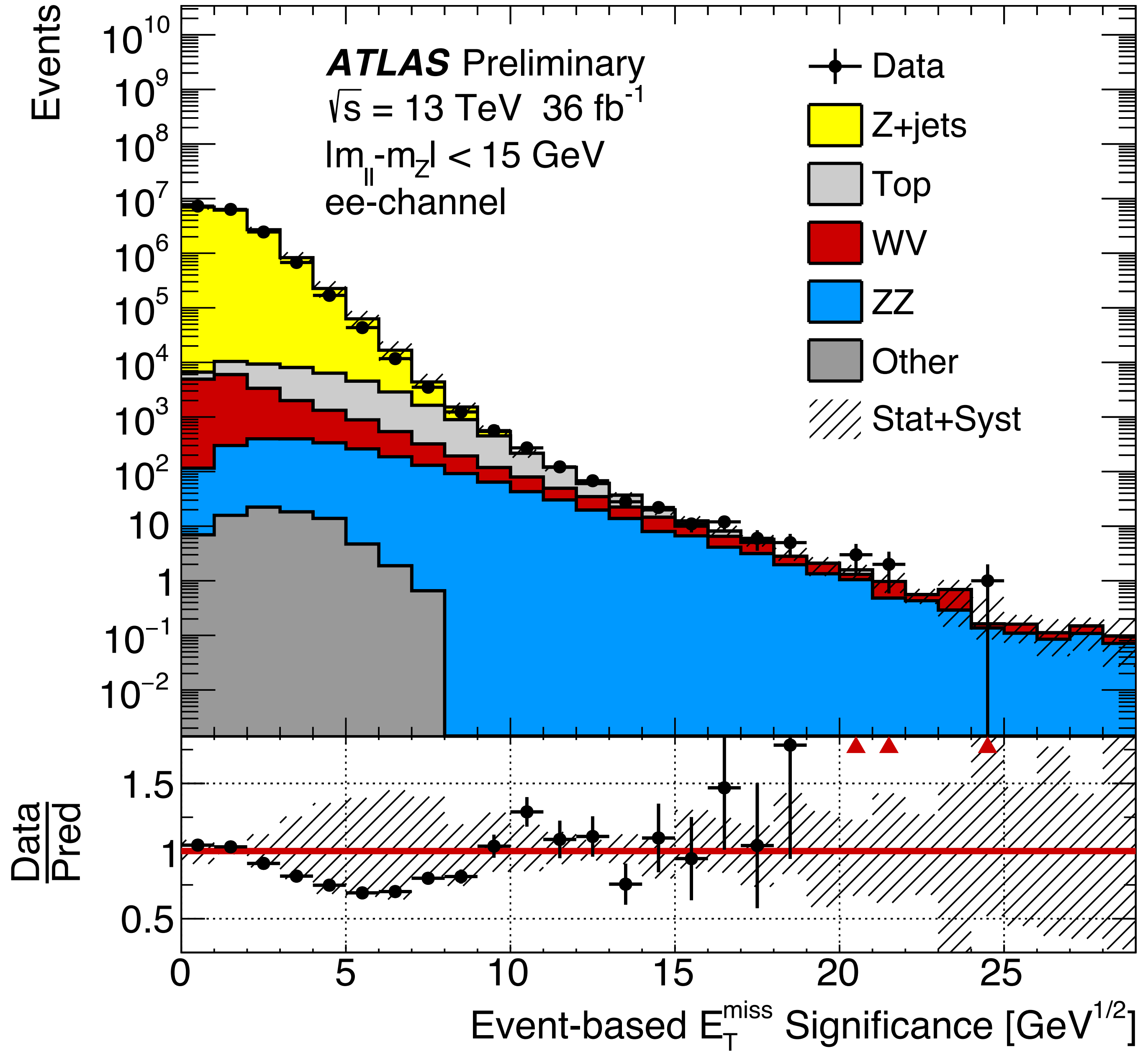
Variables

ATLAS-CONF-2018-038

- Missing Transverse Energy (Missing E_T, MET)
  - $E_T^{\text{miss}} = |-\Sigma_i \vec{p}_T(i)|,\ i = \text{all objects}$
    - Important to identify LSP
- MET significance
  - $S(E_T^{\text{miss}}) = E_T^{\text{miss}}/\sqrt{H_T}$
    - $H_T = \Sigma p_T$ (scalar sum of momentum)
- Transverse mass
  - $M_T^2 = 2E_{T1}E_{T2}(1-\cos\theta)$
- Effective mass
  - $m_{\text{eff}} = E_T^{\text{miss}} + H_T$







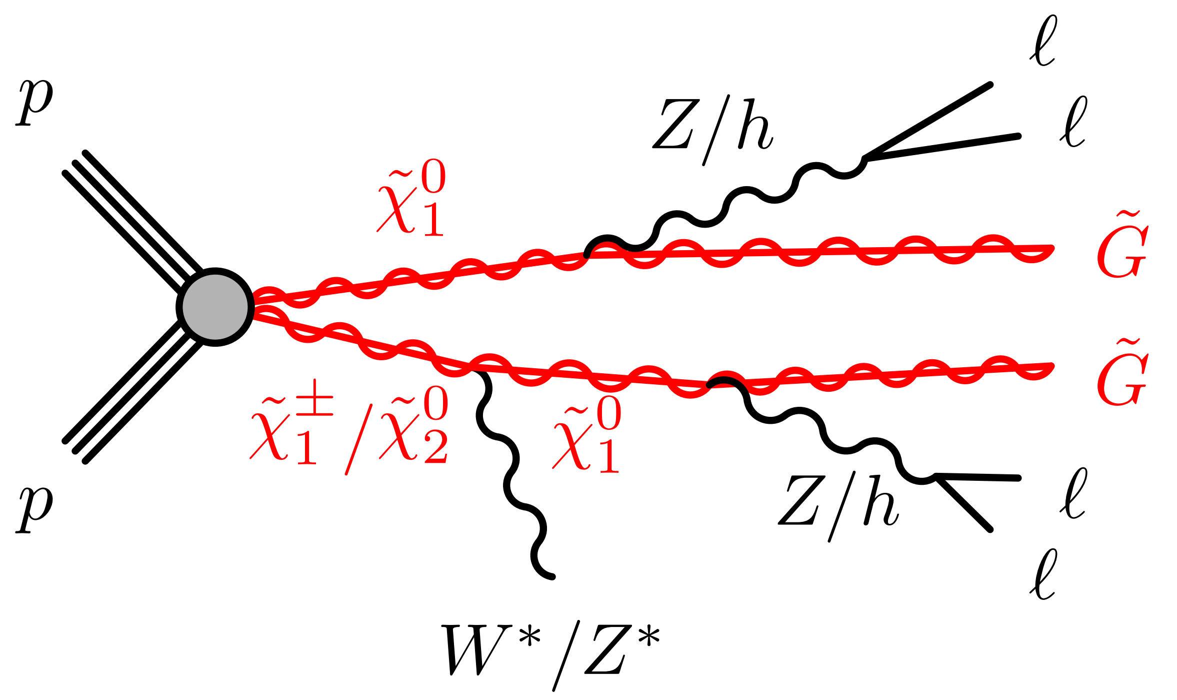
Four leptons analysis

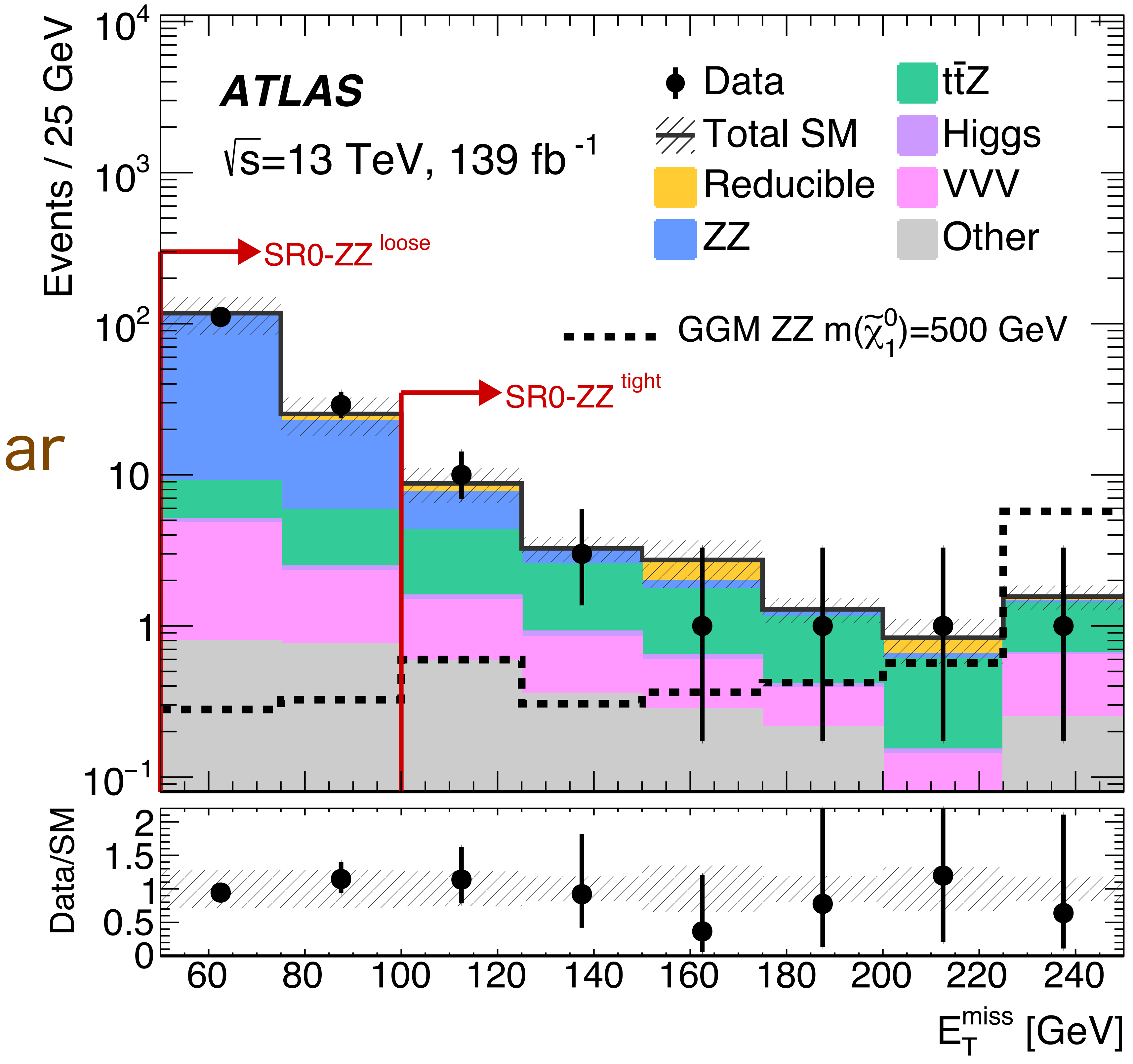
arXiv:2103.11684

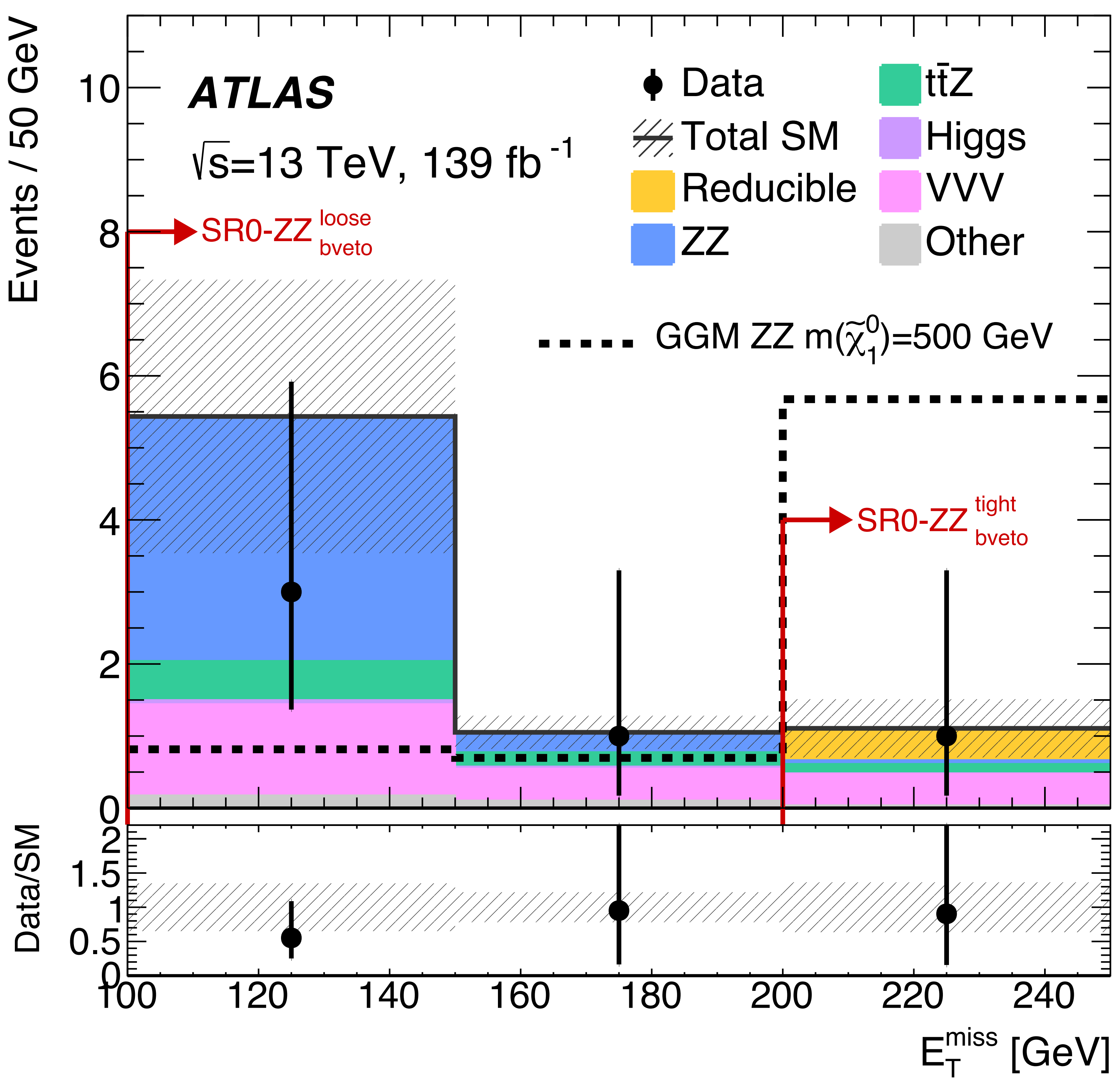
- Signal
  - Higgsino pair production (including cascade)

    $\rightarrow Z(\ell\ell)Z(\ell\ell) + E_T^{\text{miss}}$
- Signal regions
  - >= 4 leptons
  - $m_{\ell\ell}$ close to Z mass for both lepton pairs

    (for GMSB analysis)
  - b-jet veto
  - $E_T^{\text{miss}} > 100 \text{ or } 200 \text{ GeV}$
- Backgrounds
  - "Reducible" : ZZ, ttZ
  - "Irreducible" : Z+jets, ttbar



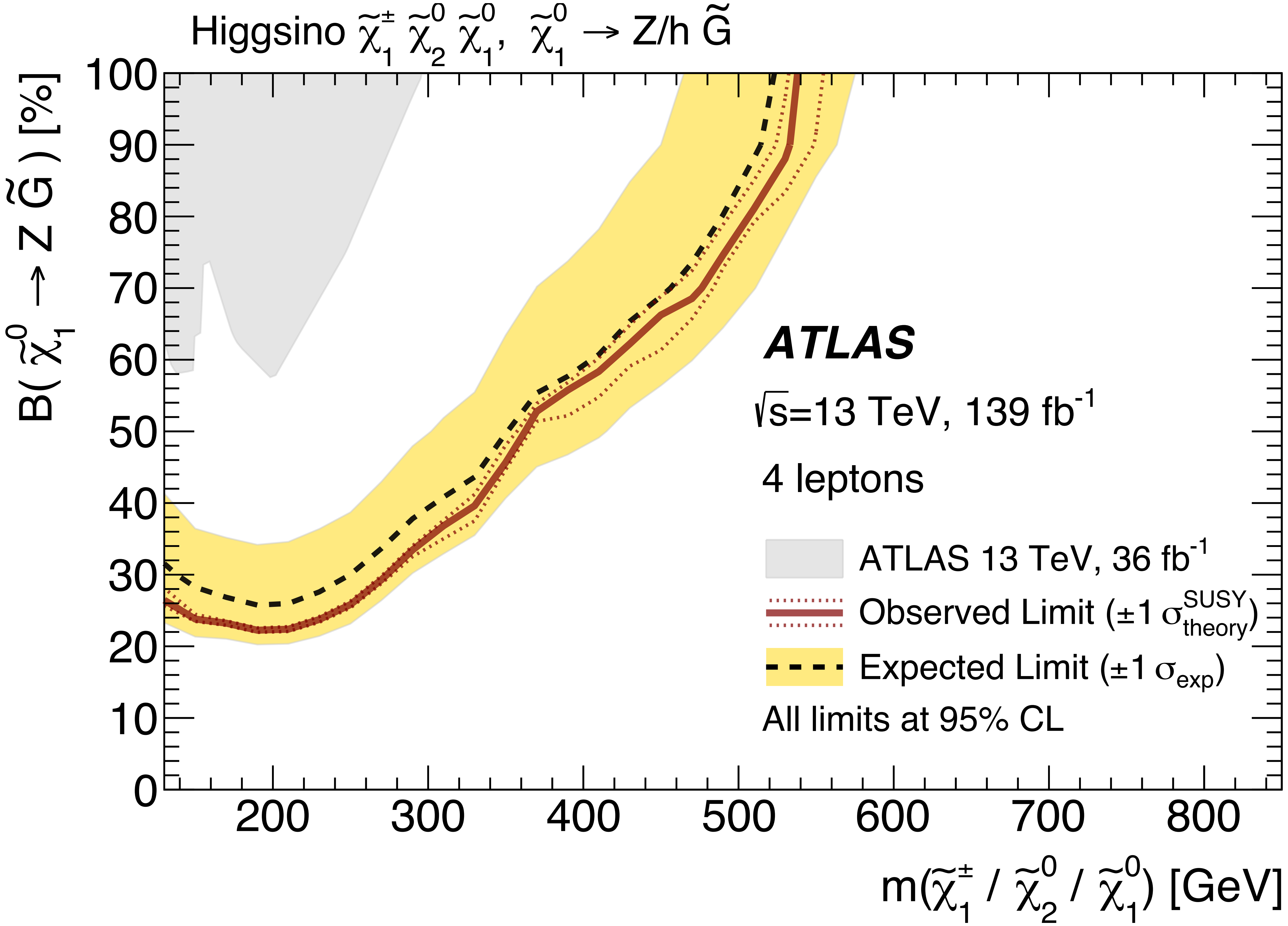




Four leptons analysis

arXiv:2103.11684

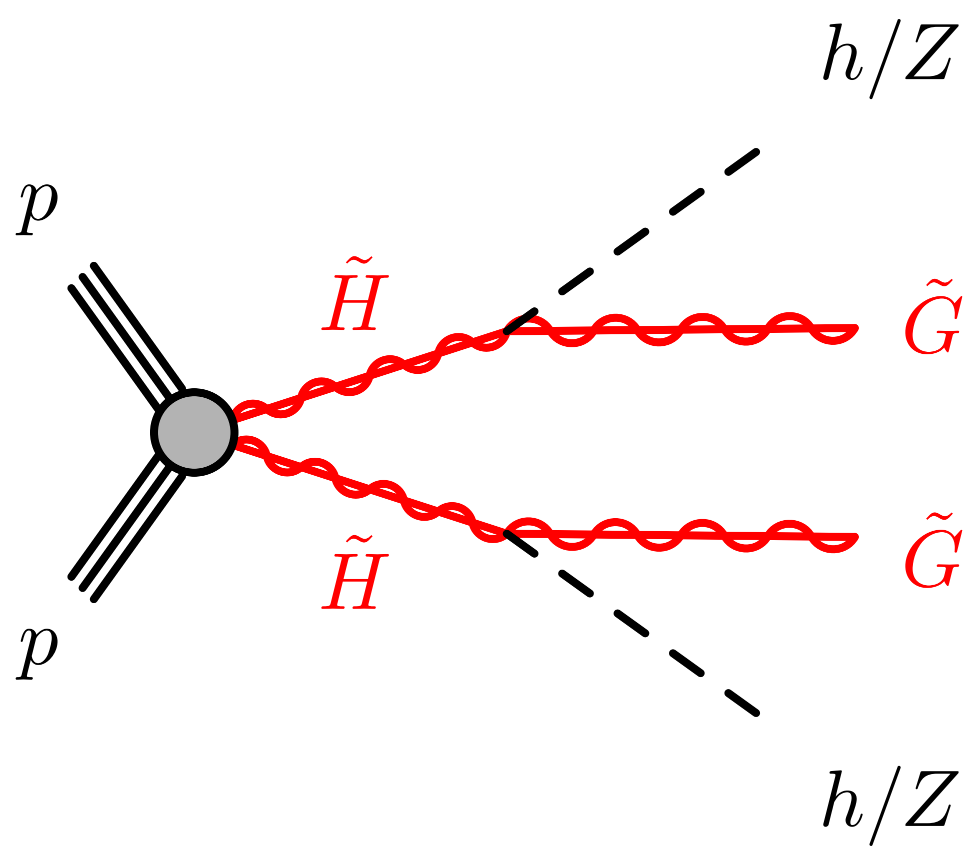
- Result
  - Better sensitivity due to low backgrounds for $Z \to \ell\ell$
  - Excluded up to ~ 550 GeV with $\tilde{\chi}_1^0 \to Z\tilde{G}$



Two leptons + jets analysis

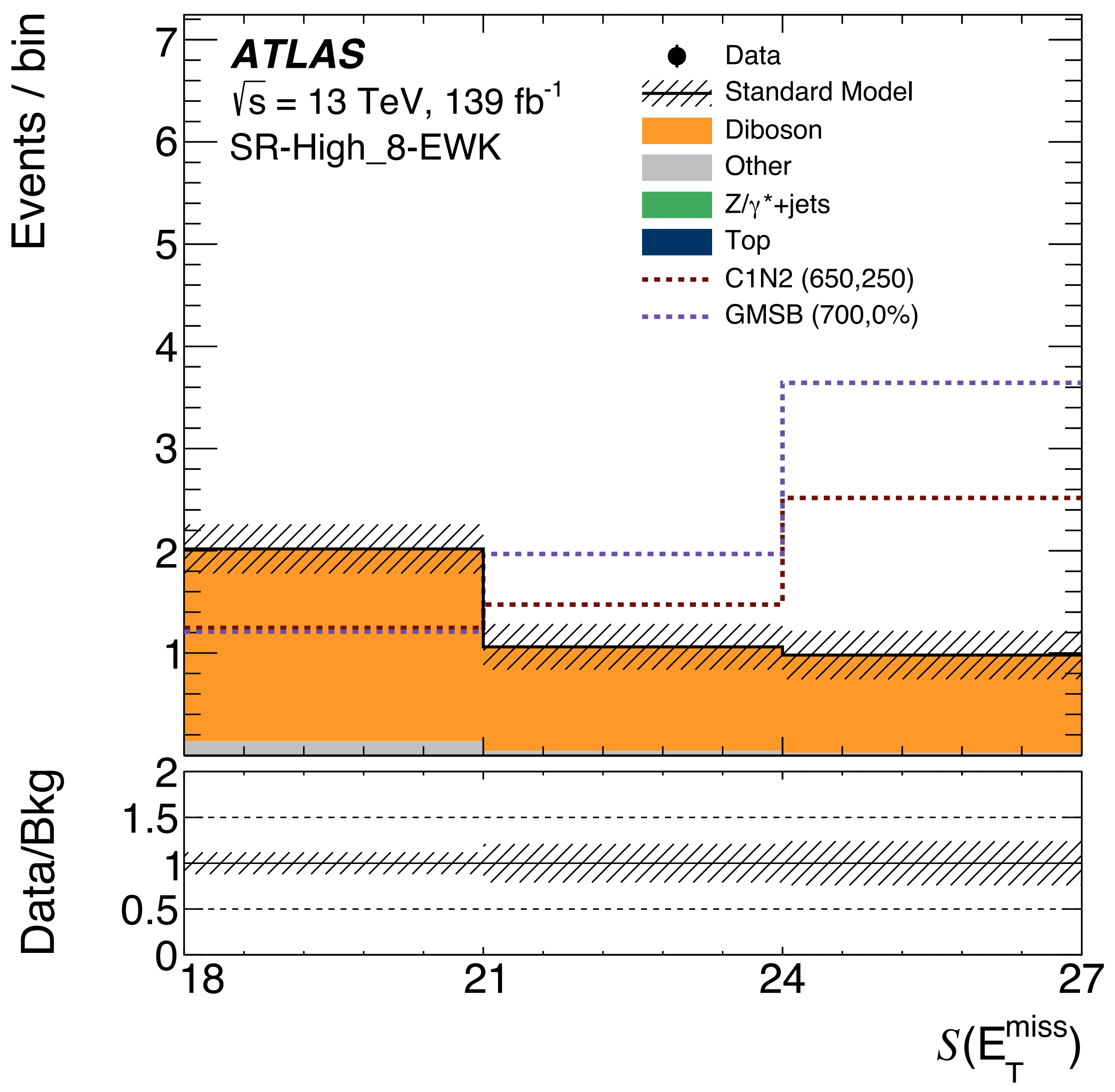
arXiv:2204.13072

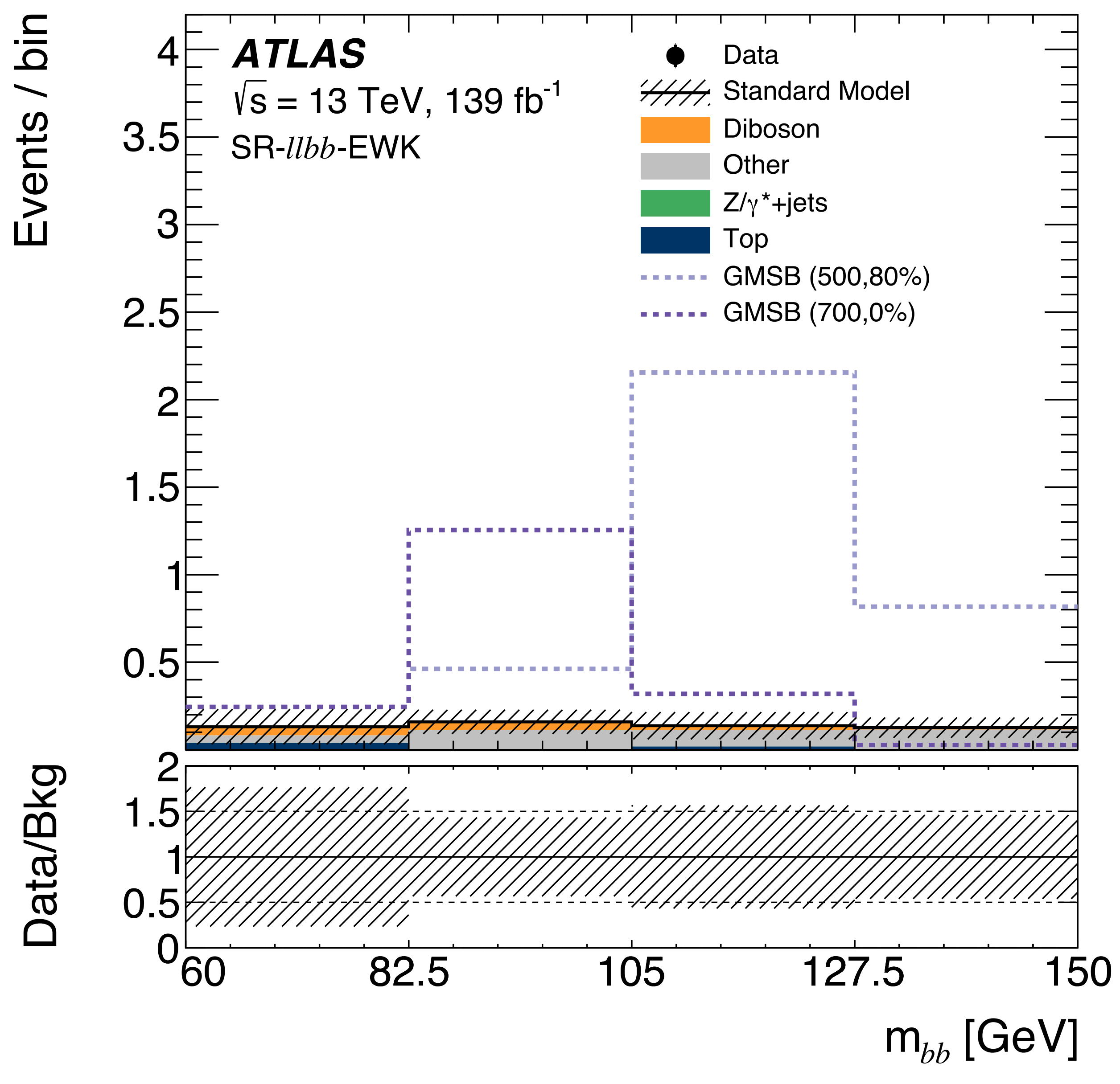
- Signal
  - Higgsino pair production
    $\rightarrow Z(\ell\ell)\ h/Z(bb/qq) + E_T^{\text{miss}}$



- Event selection
  - 2 leptons with opposite-sign electric charge(OS), at least 2 jets and E_T^{miss}

- Backgrounds
  - Diboson (VV), Top (tt, Wt), Z/γ^* +jets:
    - MC normalization factors extract from CRs
    - Fake or non-prompt lepton data-driven (Matrix method)
    - Other rare SM processes from MC

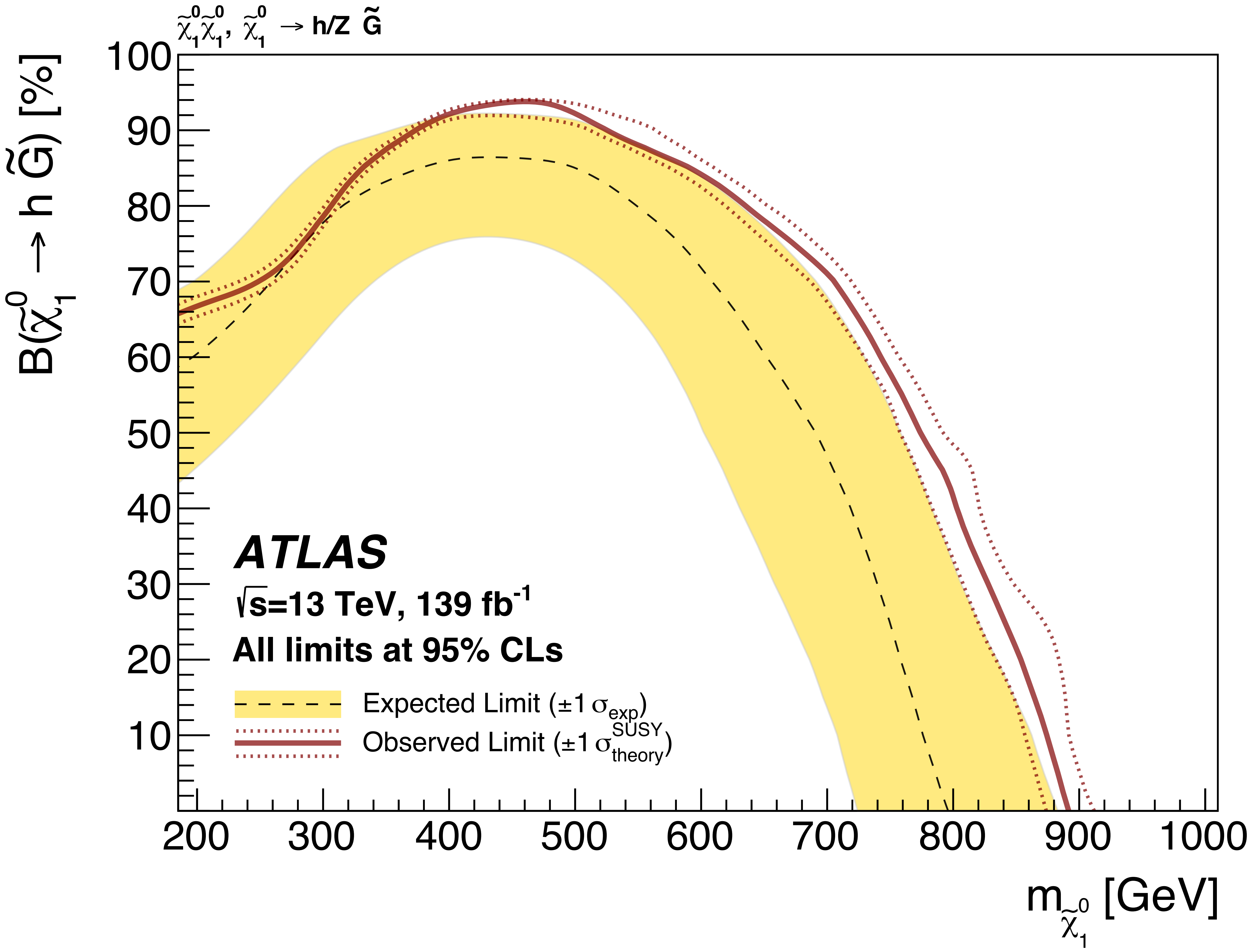




Two leptons + jets analysis

arXiv:2204.13072

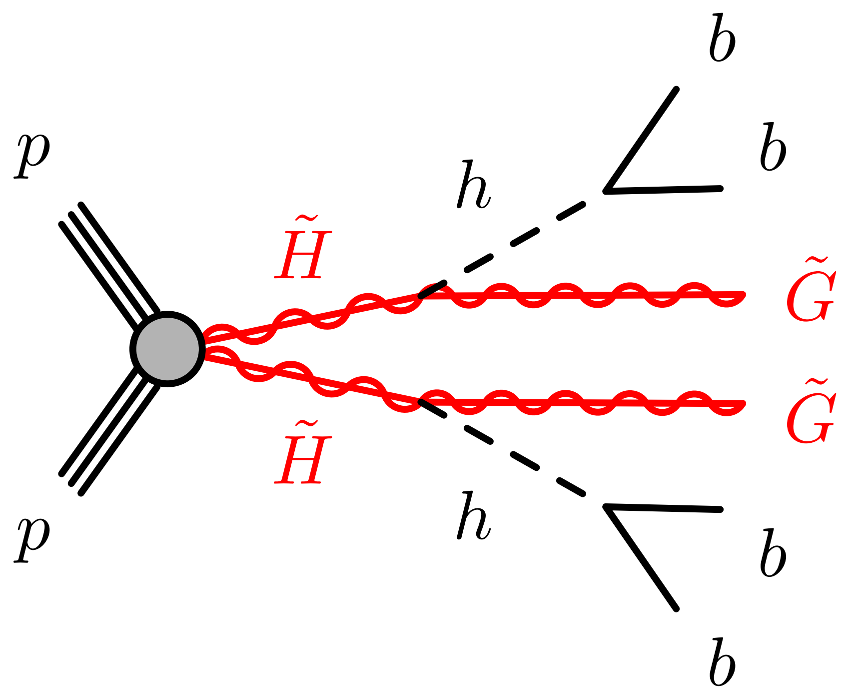
- Results
  - Observed data in agreement with SM prediction
  - Exclude higgsino Next-to-LSP mass up to 900 GeV

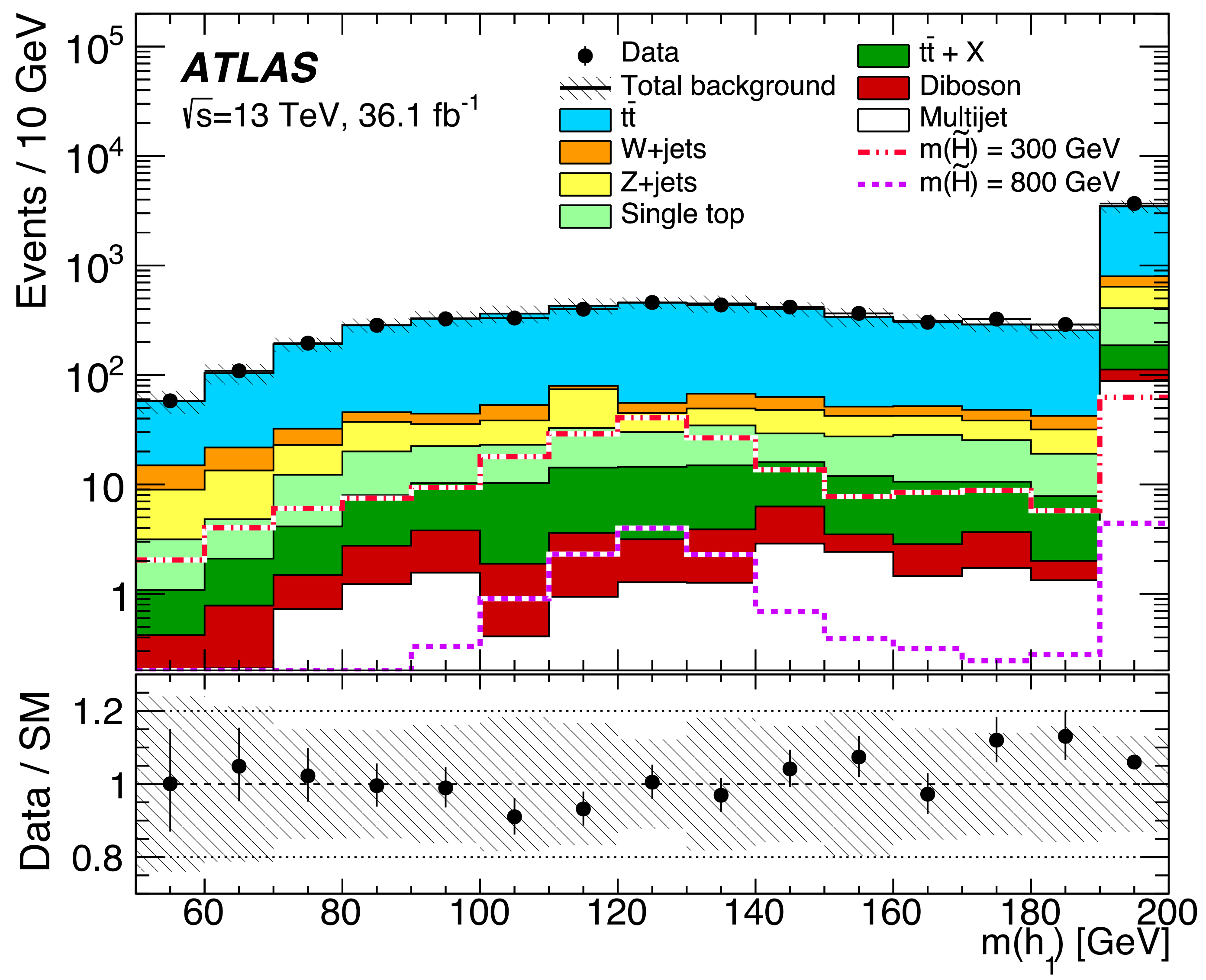


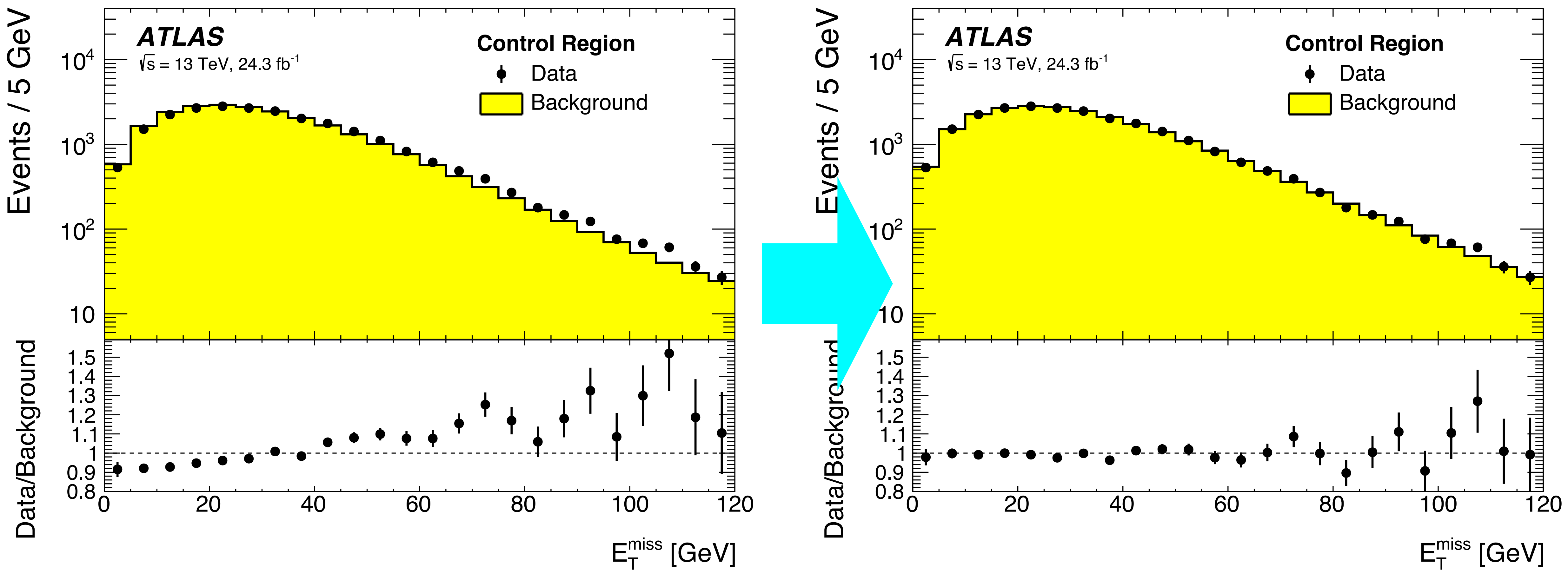
Four b-jets analysis

arXiv:1806.04030

- Signal
  - $h(bb)\ h(bb) + E_T^{\mathrm{miss}}$
    - Requiring Higgs mass
- High-mass search : $m_{\tilde{H}} > 300\ \mathrm{GeV}$
  - $E_T^{\mathrm{miss}} > 200\ \mathrm{GeV}$: trigger
  - >= 4 jets (>= 3 b-tagged)
    - Paired based on ΔR_{jj} (captures both h/Z)
  - Separated jets and large m_{eff}
  - $t\bar{t}$ normalized to data
    - Other backgrounds from Monte-Carlo
- Low-mass search : $m_{\tilde{H}} < 300\ \mathrm{GeV}$
  - b-jet trigger
    - Allows probing low-MET
  - >= 4b-jets
    - Use 4 w/ highest b-tag score paired based on ΔR_{jj} and m_{jj}
  - Multi-bins in MET and m_{eff}
    - Extract 2-tag→4-tag normalization and shape corrections in dedicated regions using purely data-driven BDT





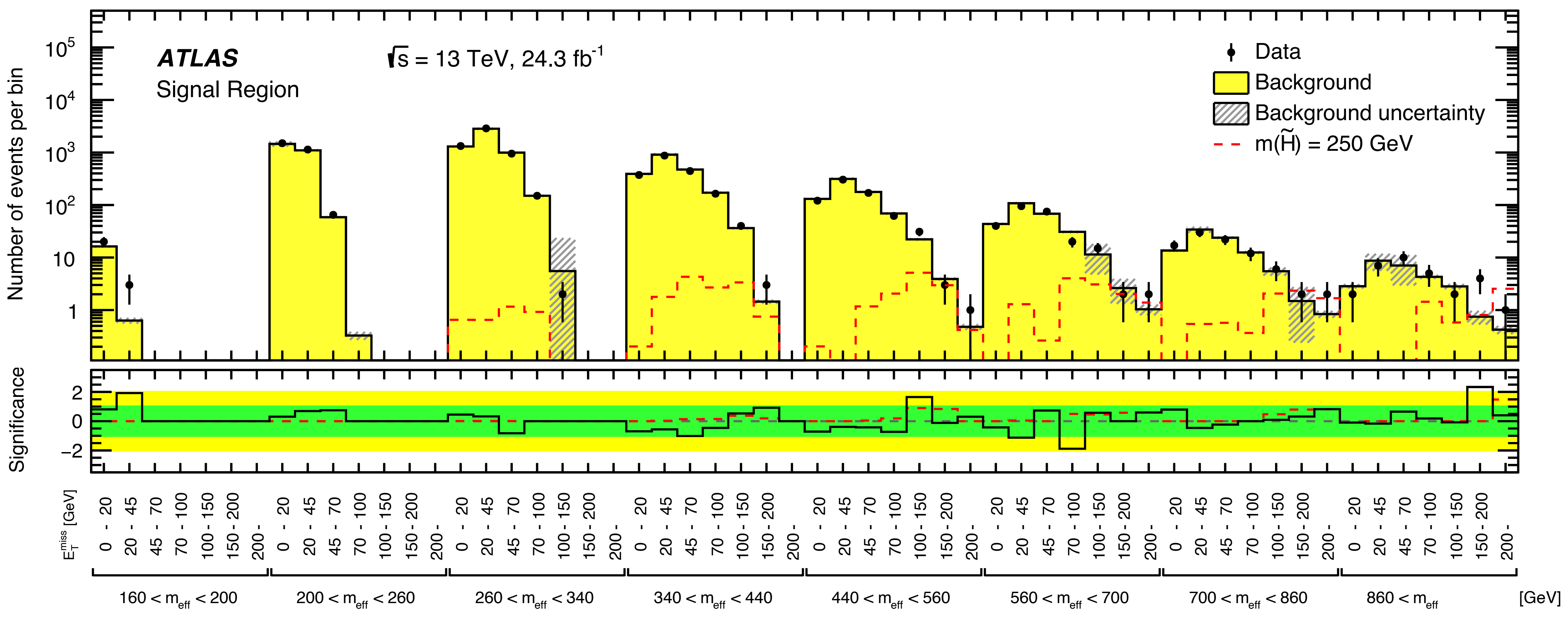


BDT reweighting

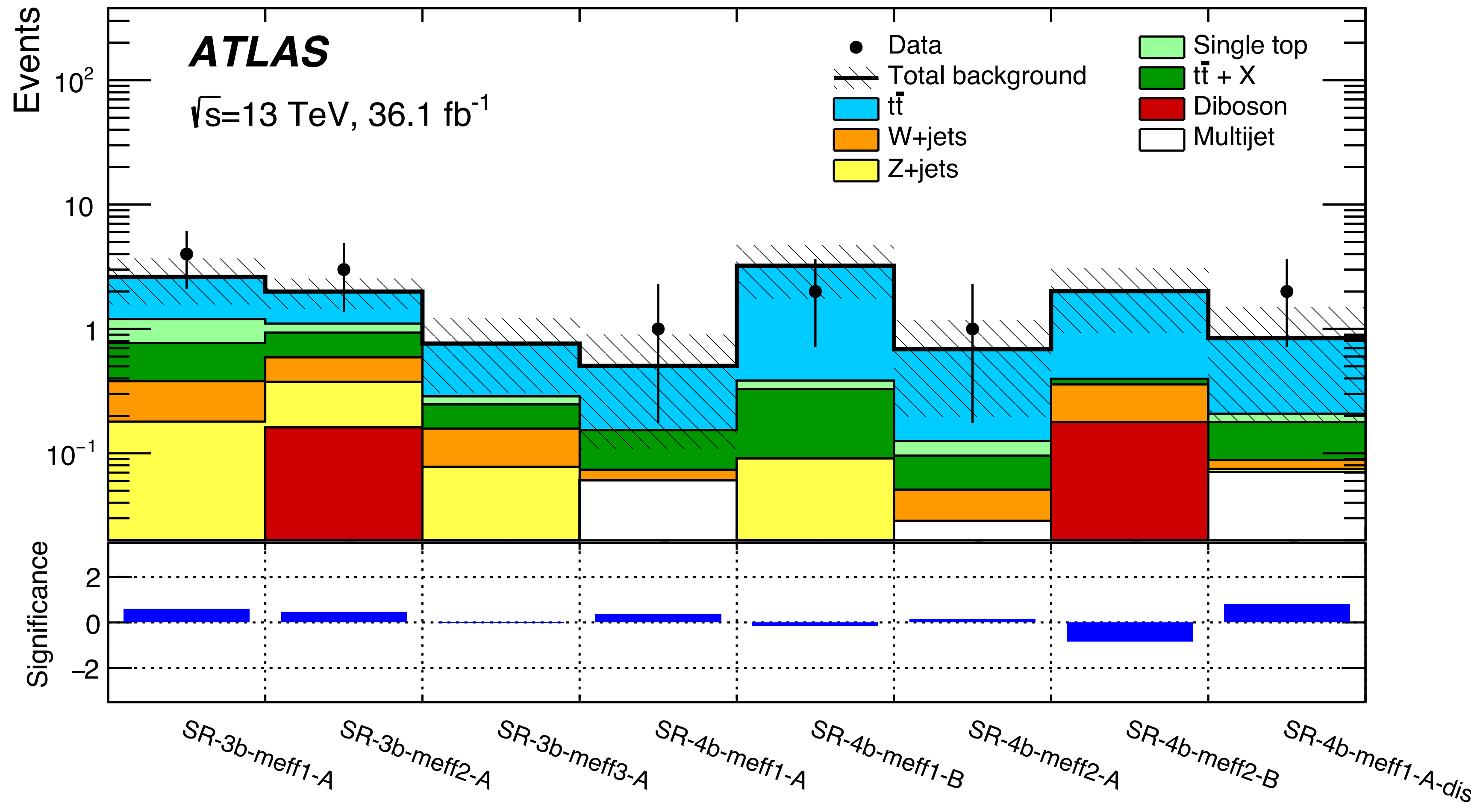
Four b-jets analysis

arXiv:1806.04030

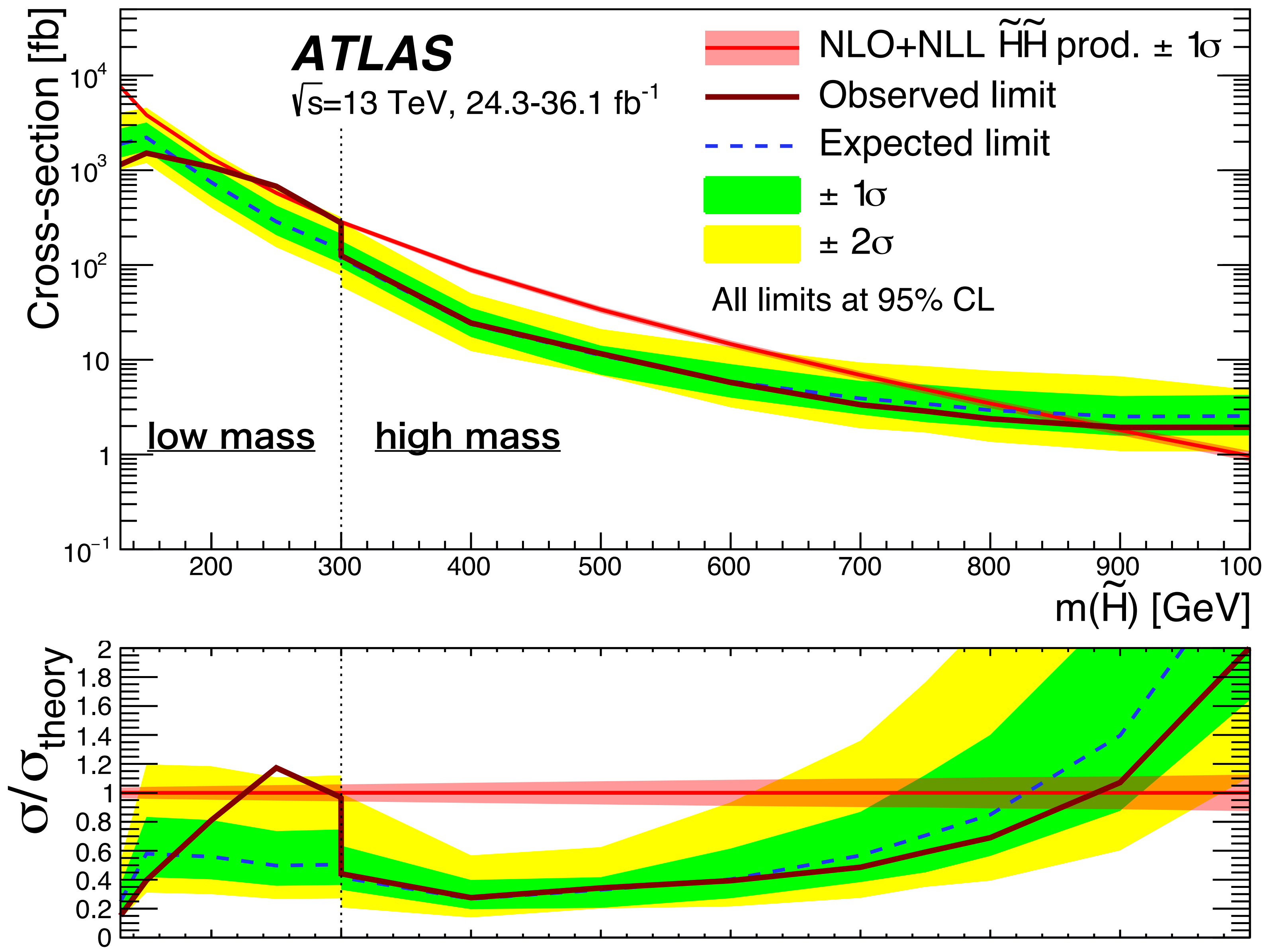
low mass

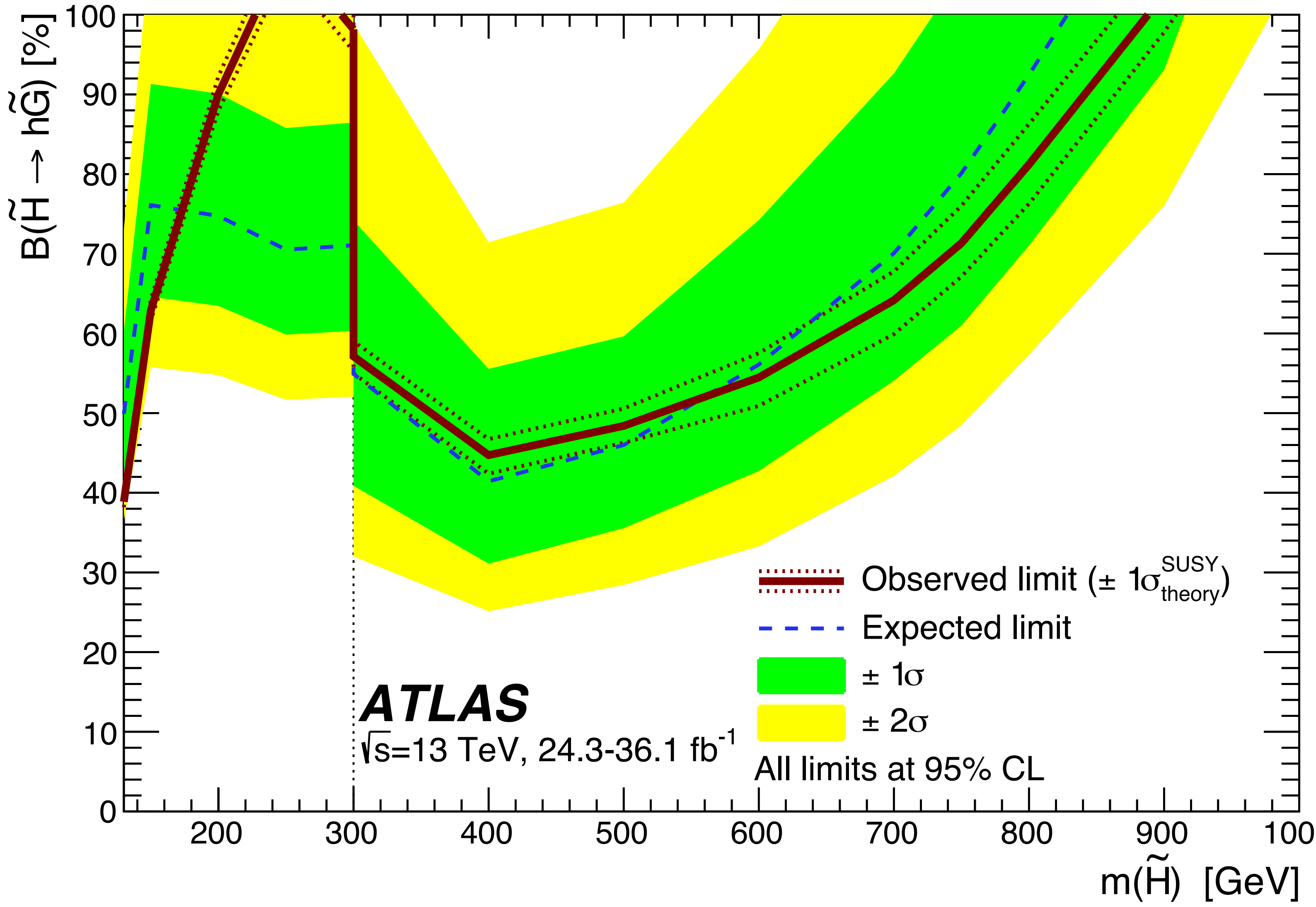


high mass



- Signal regions
  - 56 complementary bins in low-mass selection
  - 8 complementary bins in high-mass selection
- Results
  - Largest excess is ~2σ
    - 4 data vs 1.0±0.2 background @ 200 -300 GeV
  - Excluded up to 900 GeV w/ $B(\tilde{H} \to h\tilde{G}) = 100\,\%$

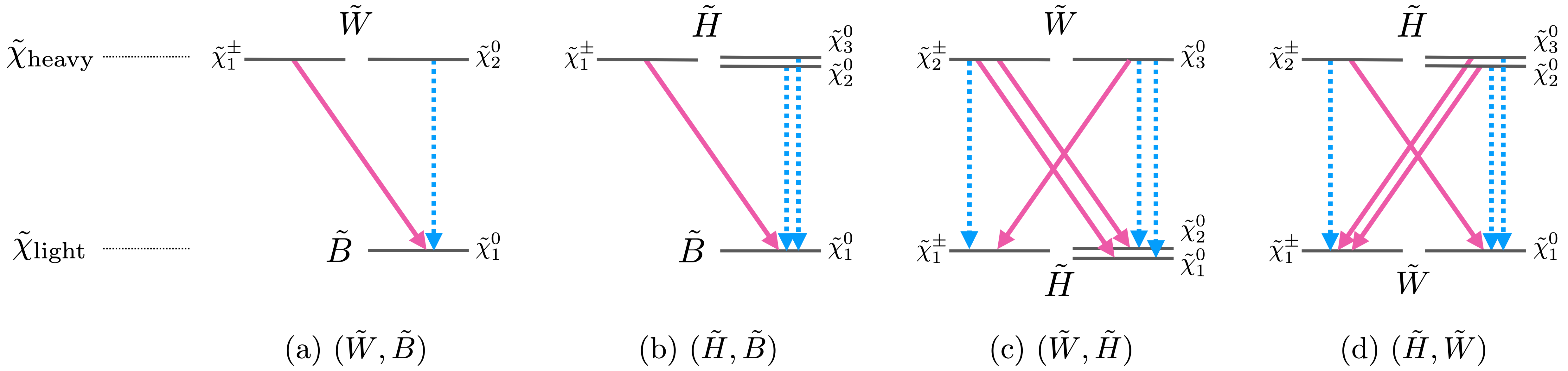




All-hadronic analysis

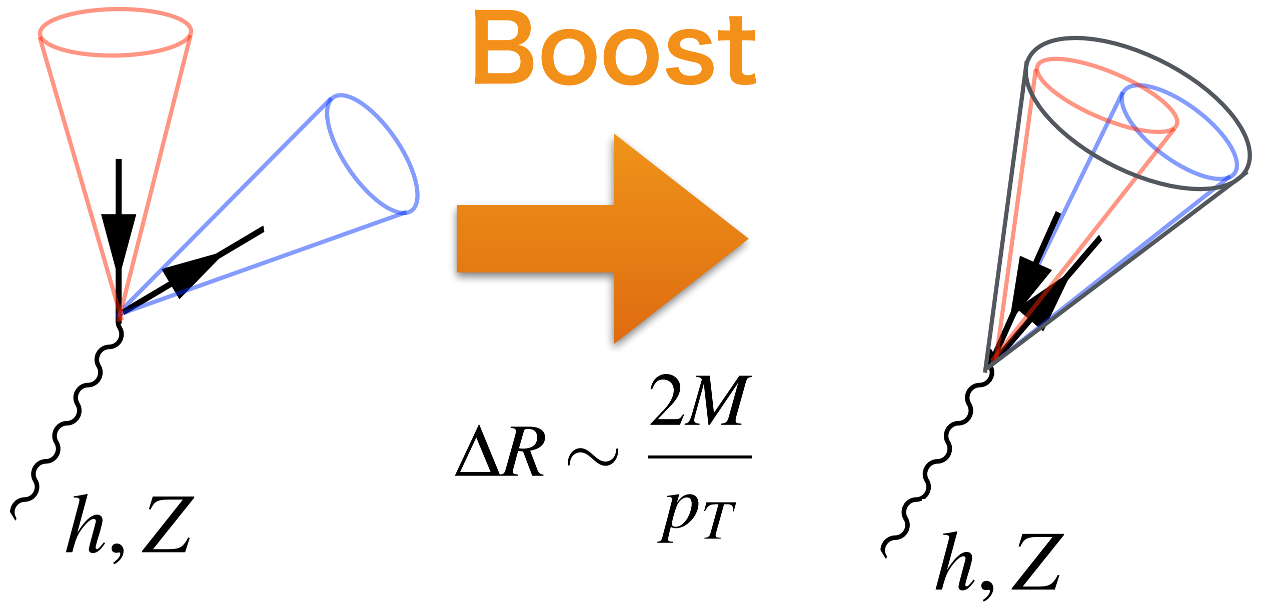
arXiv:2108.07586

- Signal
  - $h/Z(qq)\ h/Z(bb/qq) + E_T^{\text{miss}}$
    - Two "boson-tagged" jets with large radii
      - up to two b-jets

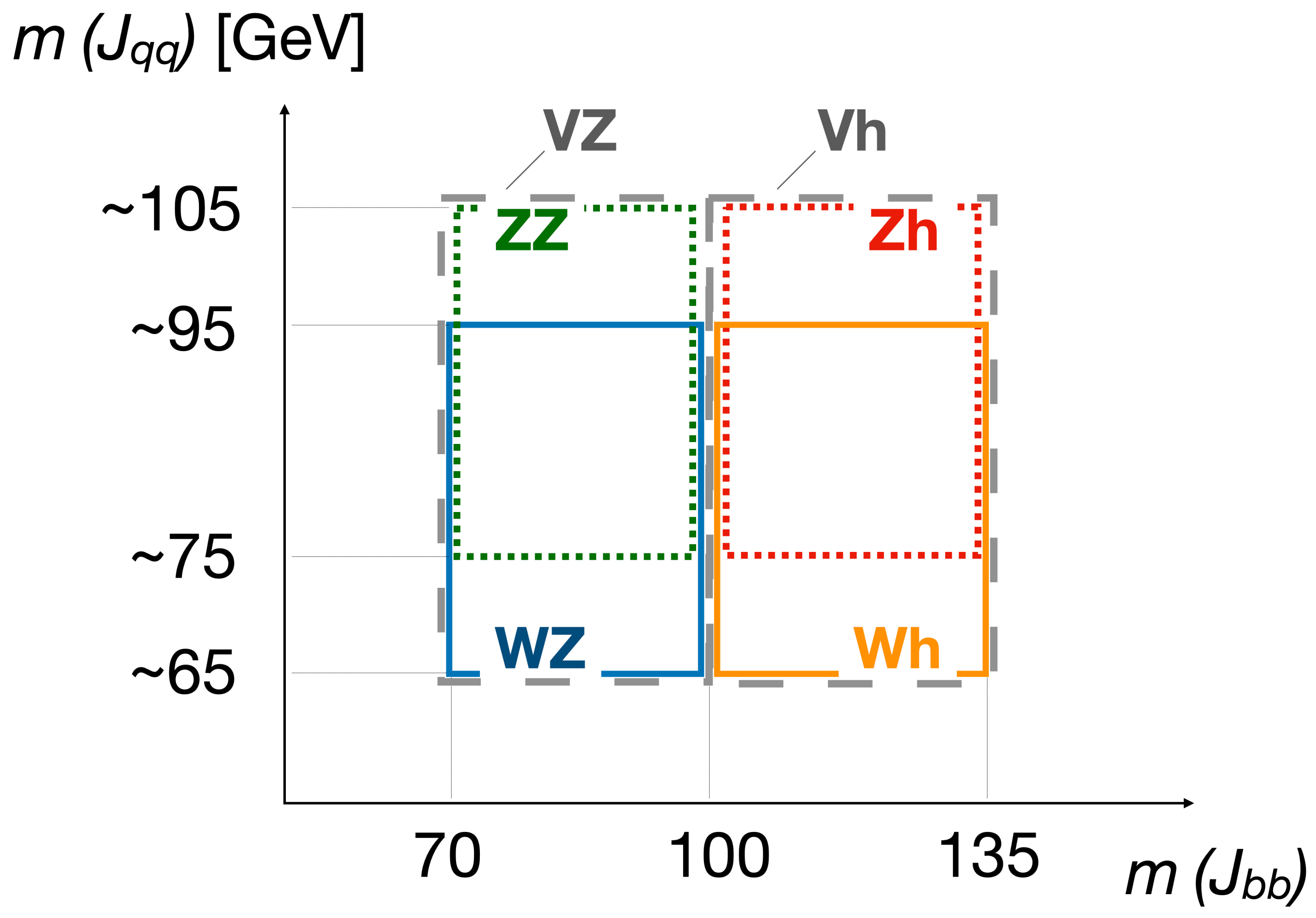


(a) $(\tilde{W}, \tilde{B})$ (b) $(\tilde{H}, \tilde{B})$ (c) $(\tilde{W}, \tilde{H})$ (d) $(\tilde{H}, \tilde{W})$

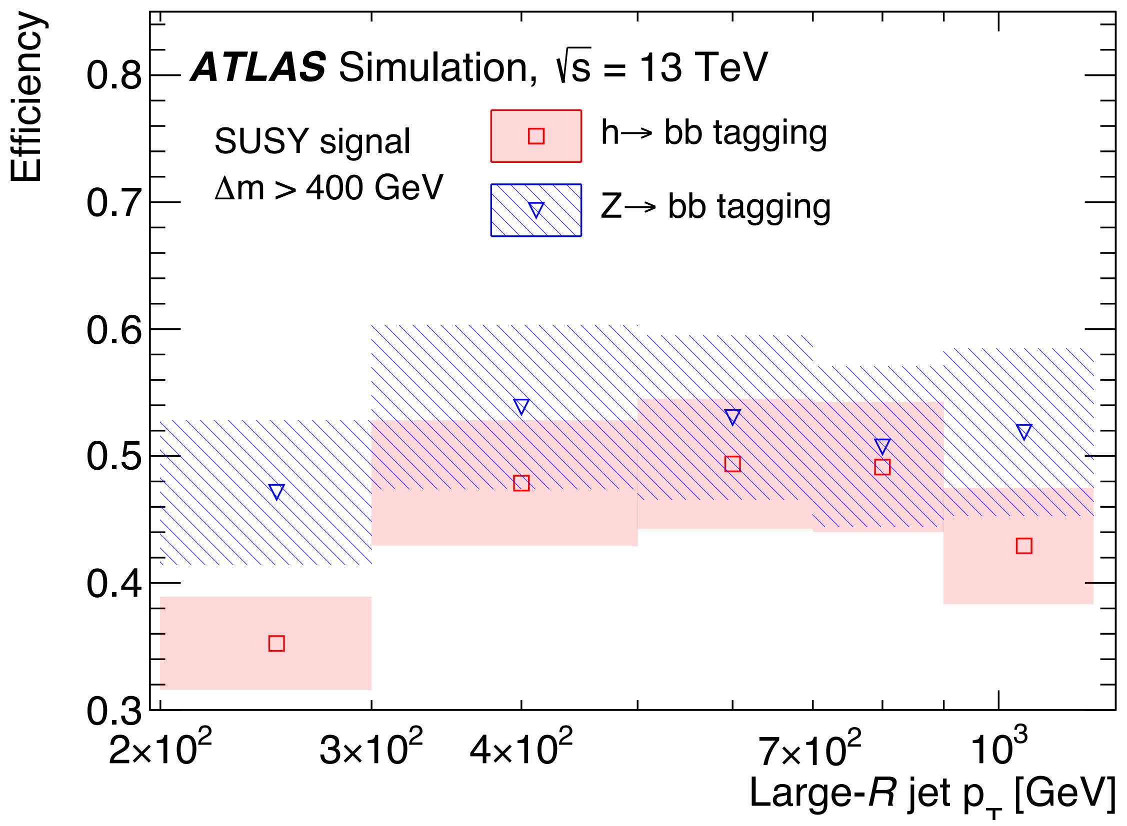
- Simultaneous interpretation for the large mass difference region between LSP and NLSP
  - Methods applicable for inclusive searches for models with Bino/Wino/Higgsino LSP

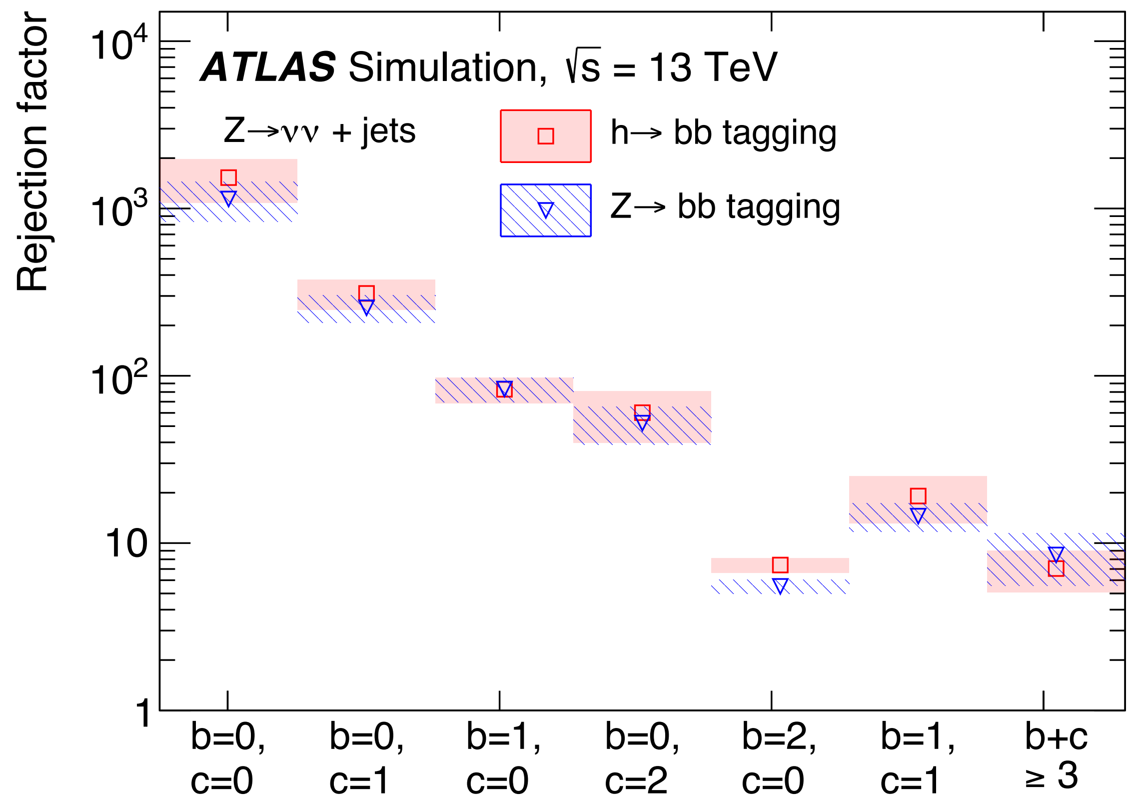


$$\Delta R \sim \frac{2M}{p_T}$$



- Boosted Boson Tagging
  - For highly boosted h/Z→qq/bb
    - Combinations with jet mass and jet-substructure variables for "2-pronginess"
  - Performance
    - e.g. ~ 50% efficiency in h→bb tagging with rejection factor of >1000 for light quark jets
      - Now the all-hadronic analysis possible against huge $Z \to \nu\nu$ + jets background

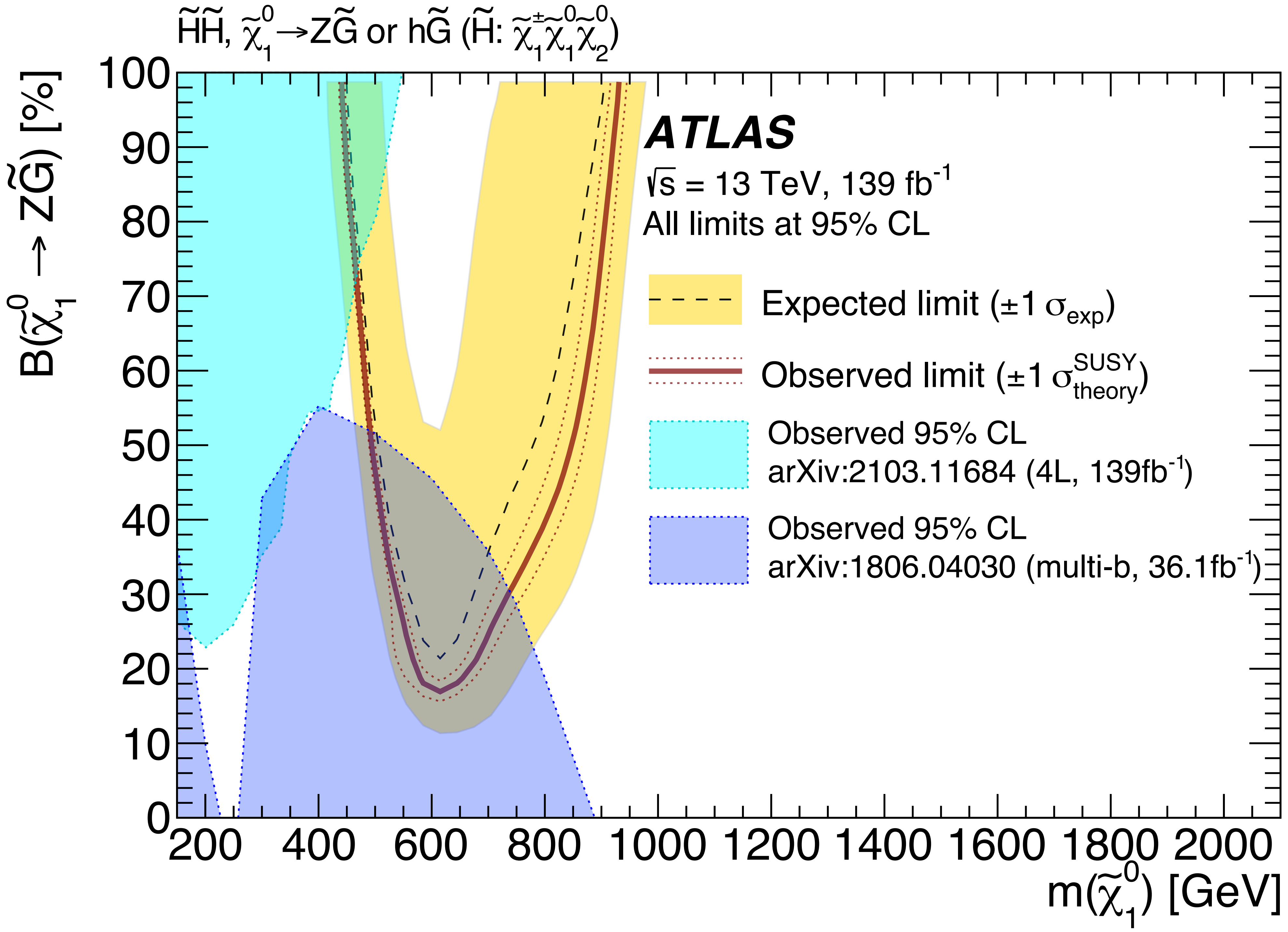


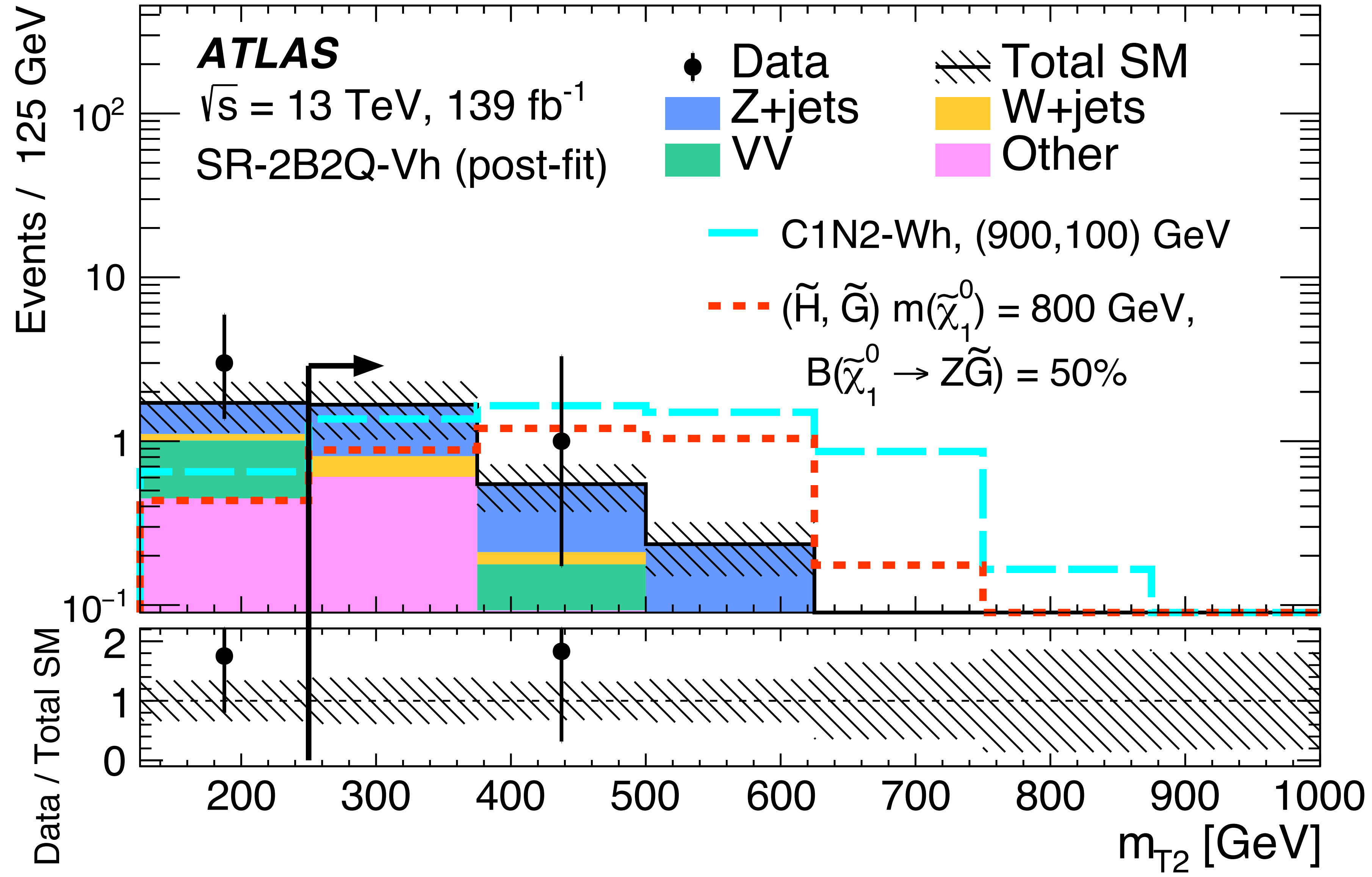


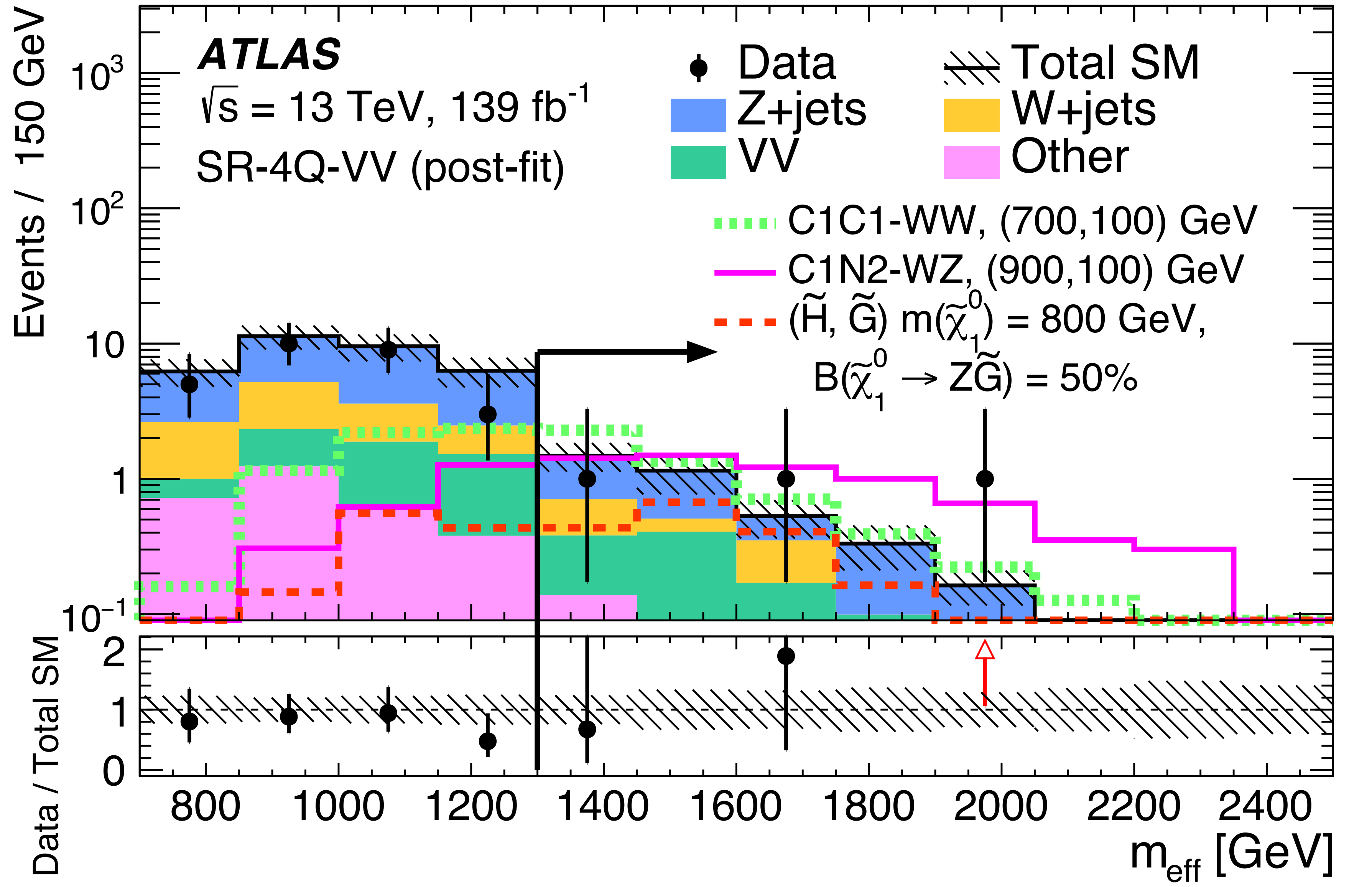
All-hadronic analysis

arXiv:2108.07586

- Backgrounds
  - Z+jets
  - diboson
- Results
  - No signal excess
    - ▸ Extended sensitivity to higher mass regions
      - < 900 GeV excluded



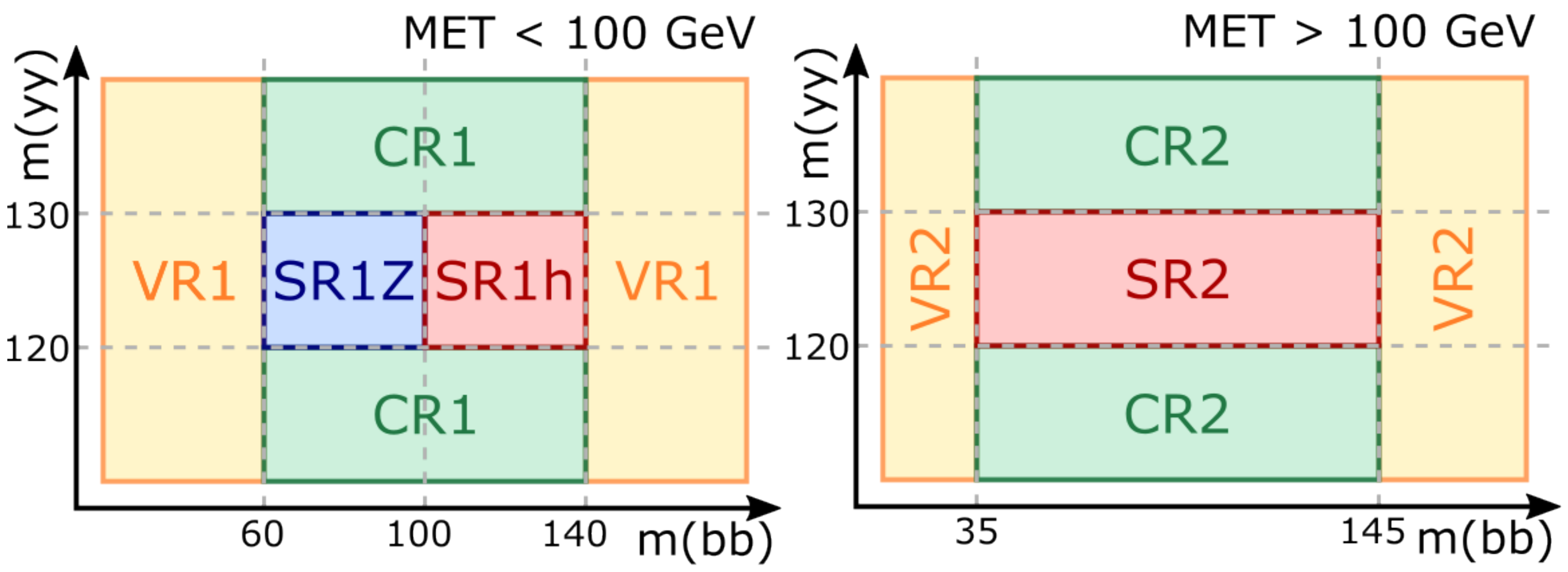


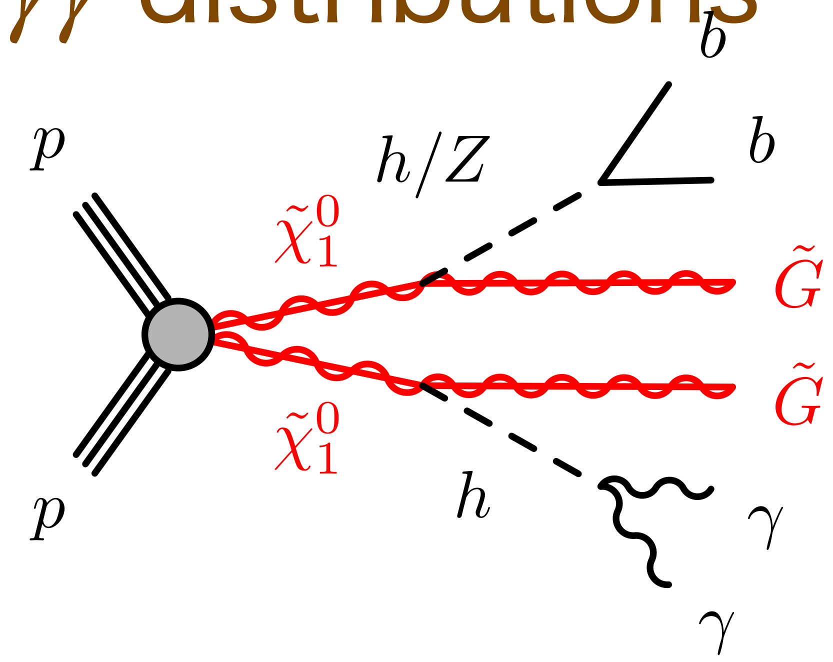


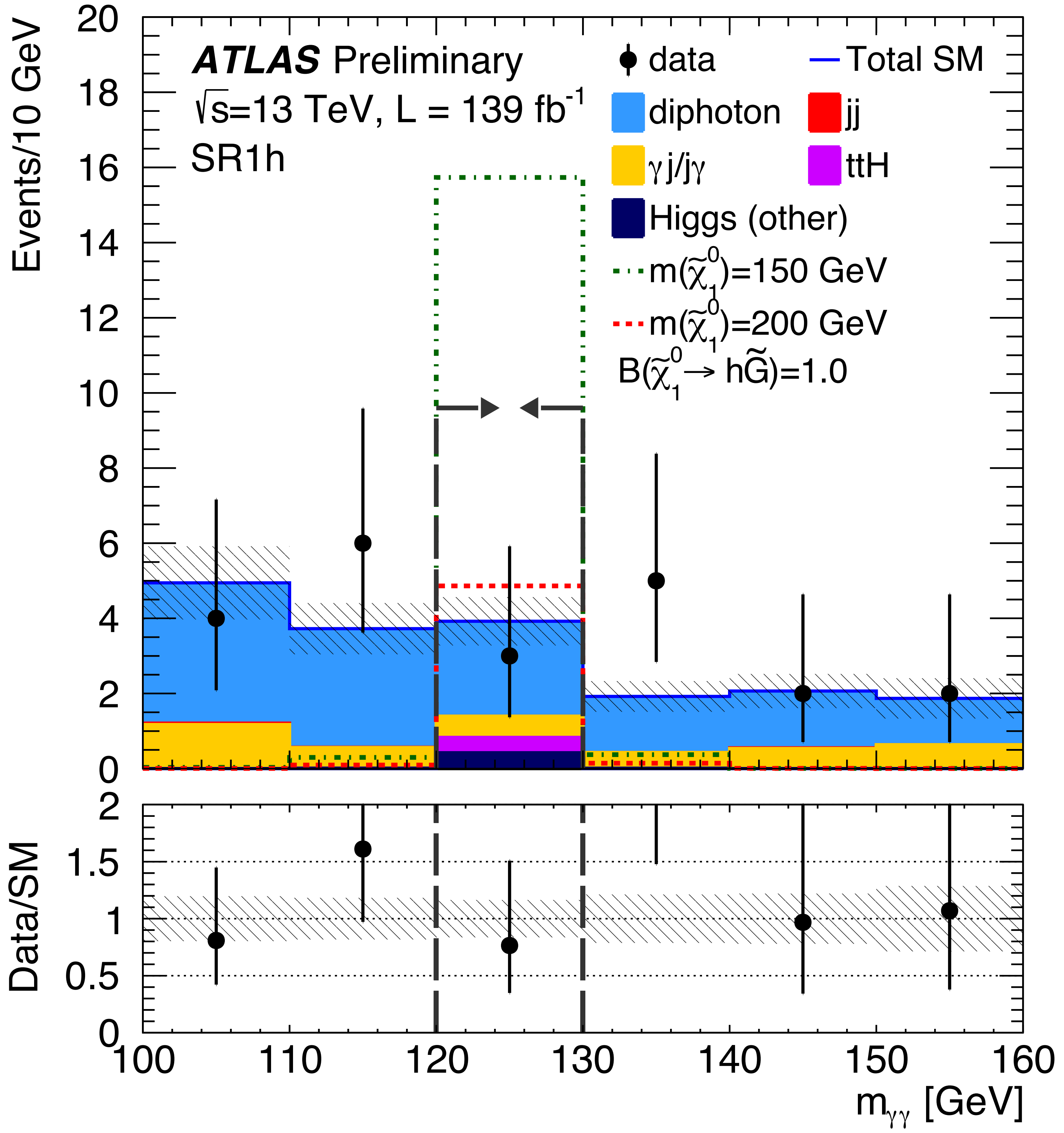
γγ + bb analysis

ATLAS-CONF-2023-009

- Signal
  - $h(\gamma\gamma)\ h/Z(bb) + E_T^{\text{miss}}$
- Methods
  - Three orthogonal SR to gain sensitivity to different Higgsino mass hypothesis and decay modes
- Backgrounds
  - Resonant background from H → $\gamma\gamma$ (subdominant) determined from MC
  - Non-resonant background (dominant) estimated using data in the sidebands of $m\gamma\gamma$ distributions



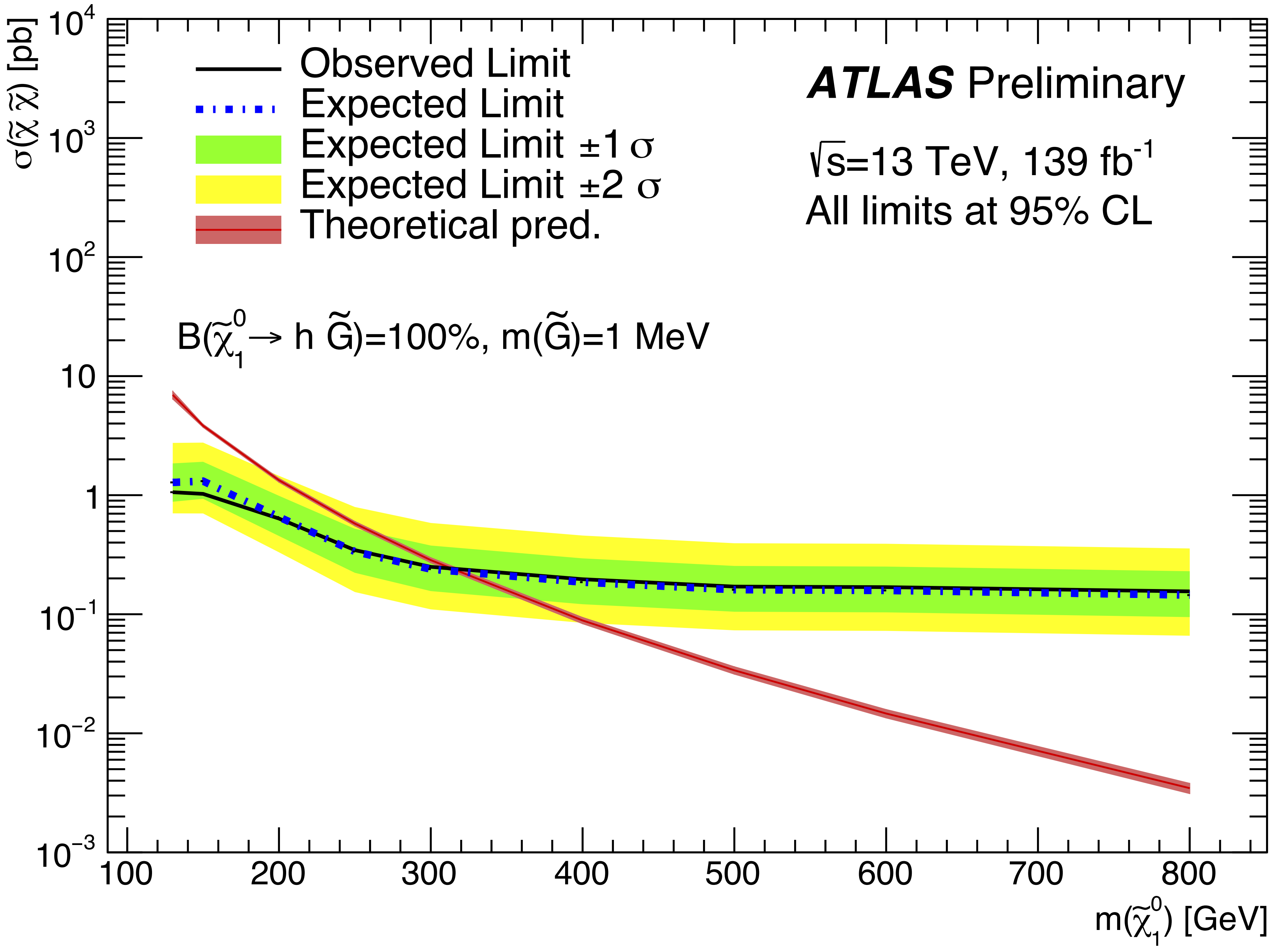


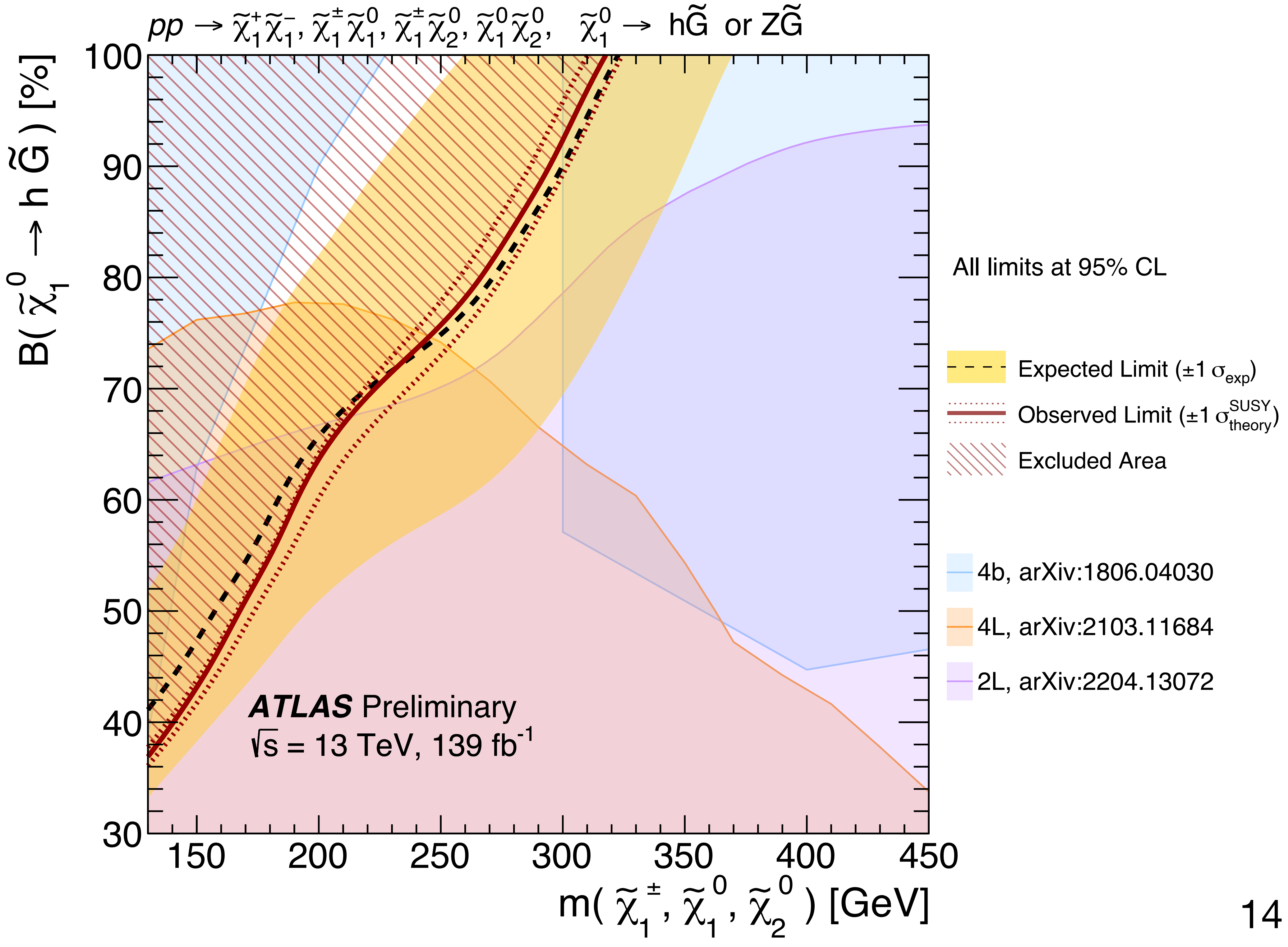


γγ + bb analysis

ATLAS-CONF-2023-009

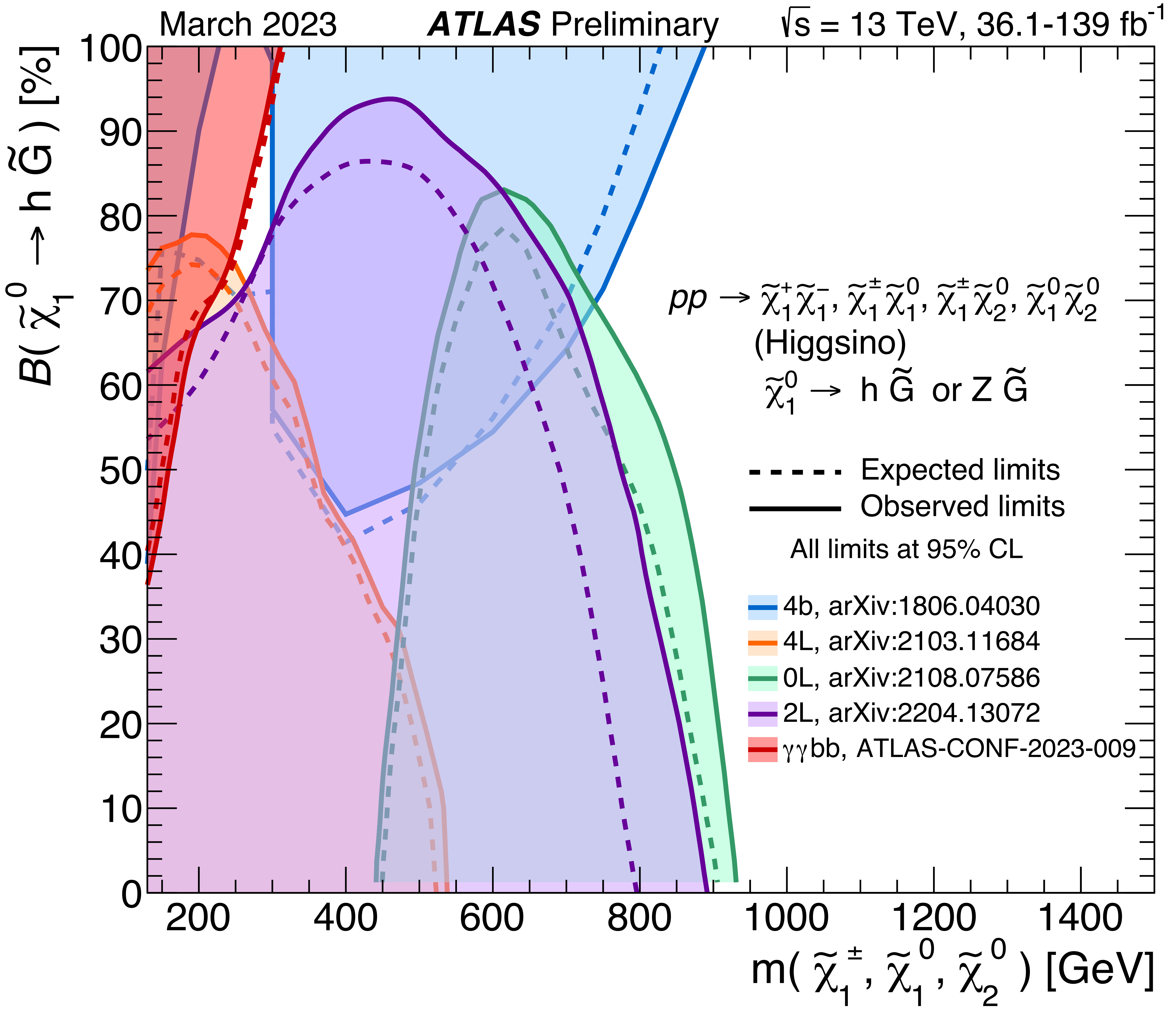
- Results
  - Excluded $m(\tilde{\chi}^0) \lesssim 200\,\mathrm{GeV}$ in Higgsino pair production
  - Sensitivity extended at the lower mass region





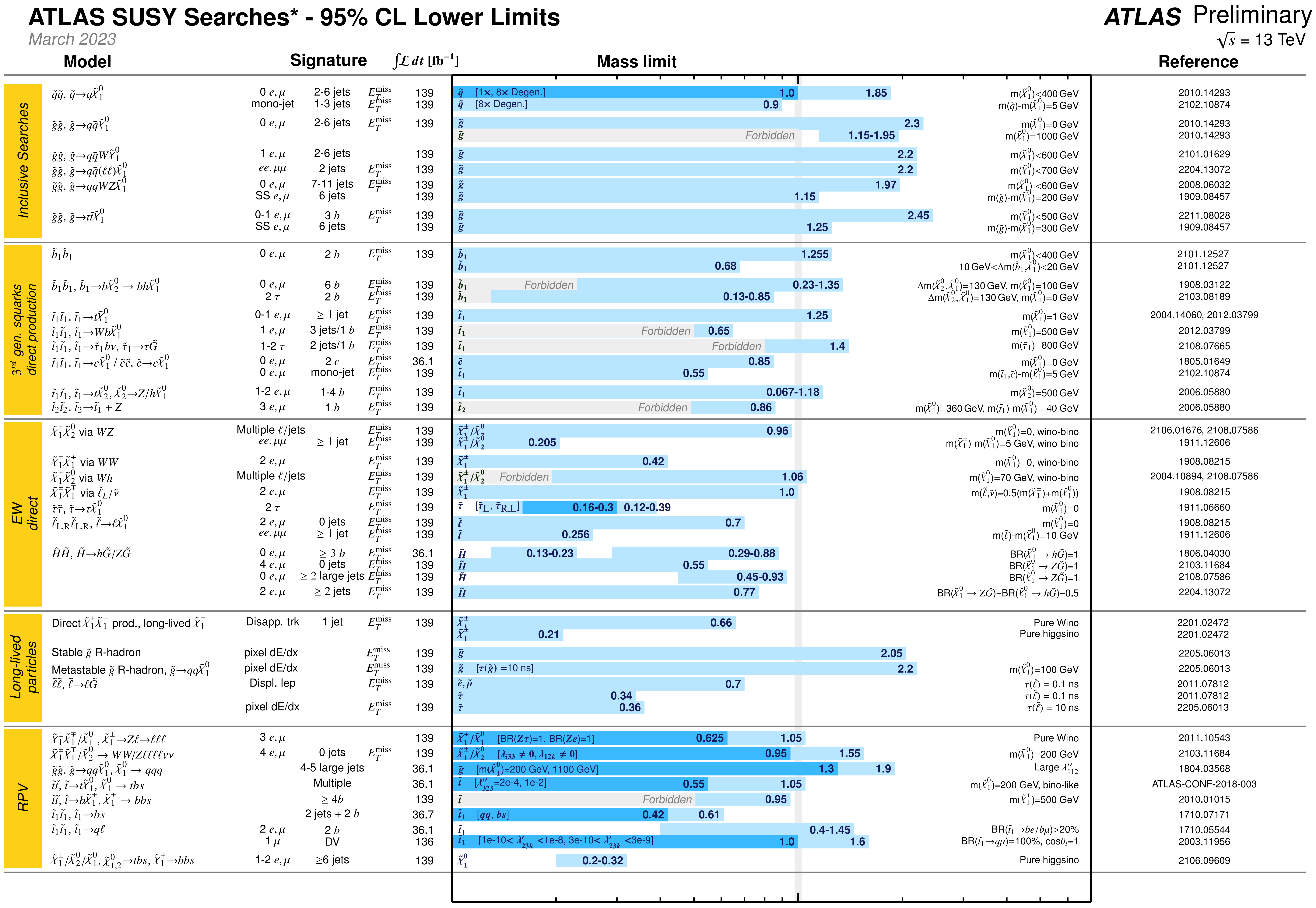
Summary

- Several searches by ATLAS targeting GMSB scenario performed
  - Assuming prompt higgsino NLSP decays to $h/Z + \tilde{G}$
- Results
  - No signal seen
  - Constraining simplified models motivated by General Gauge Mediation
- Future
  - Much more data (140 → 400 /fb) coming in Run3 to explore wider regions
    - Stay tuned !!



Backup

Summary of ATLAS SUSY Searches



ATLAS SUSY Searches* - 95% CL Lower Limits

March 2023

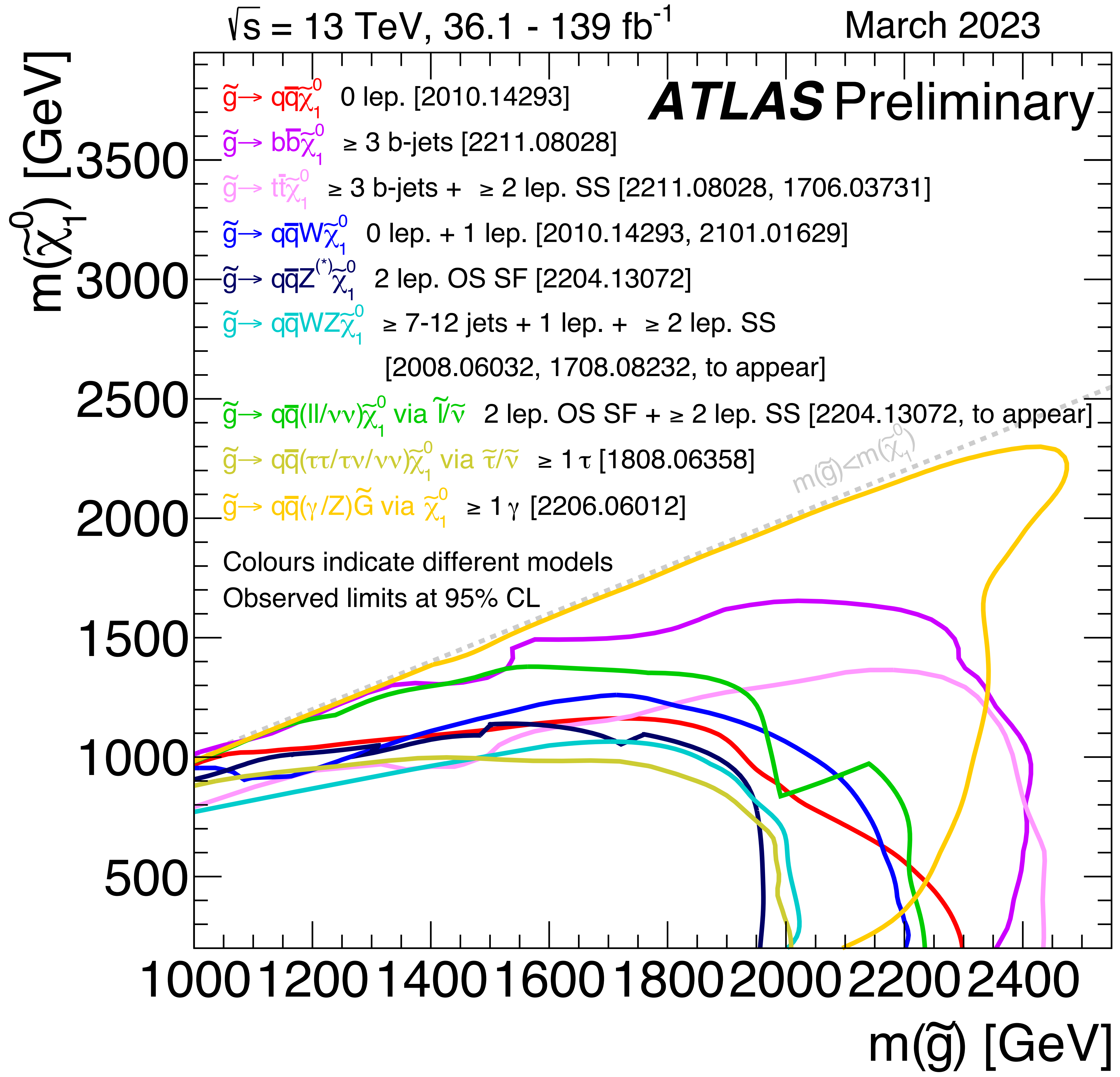
ATLAS Preliminary

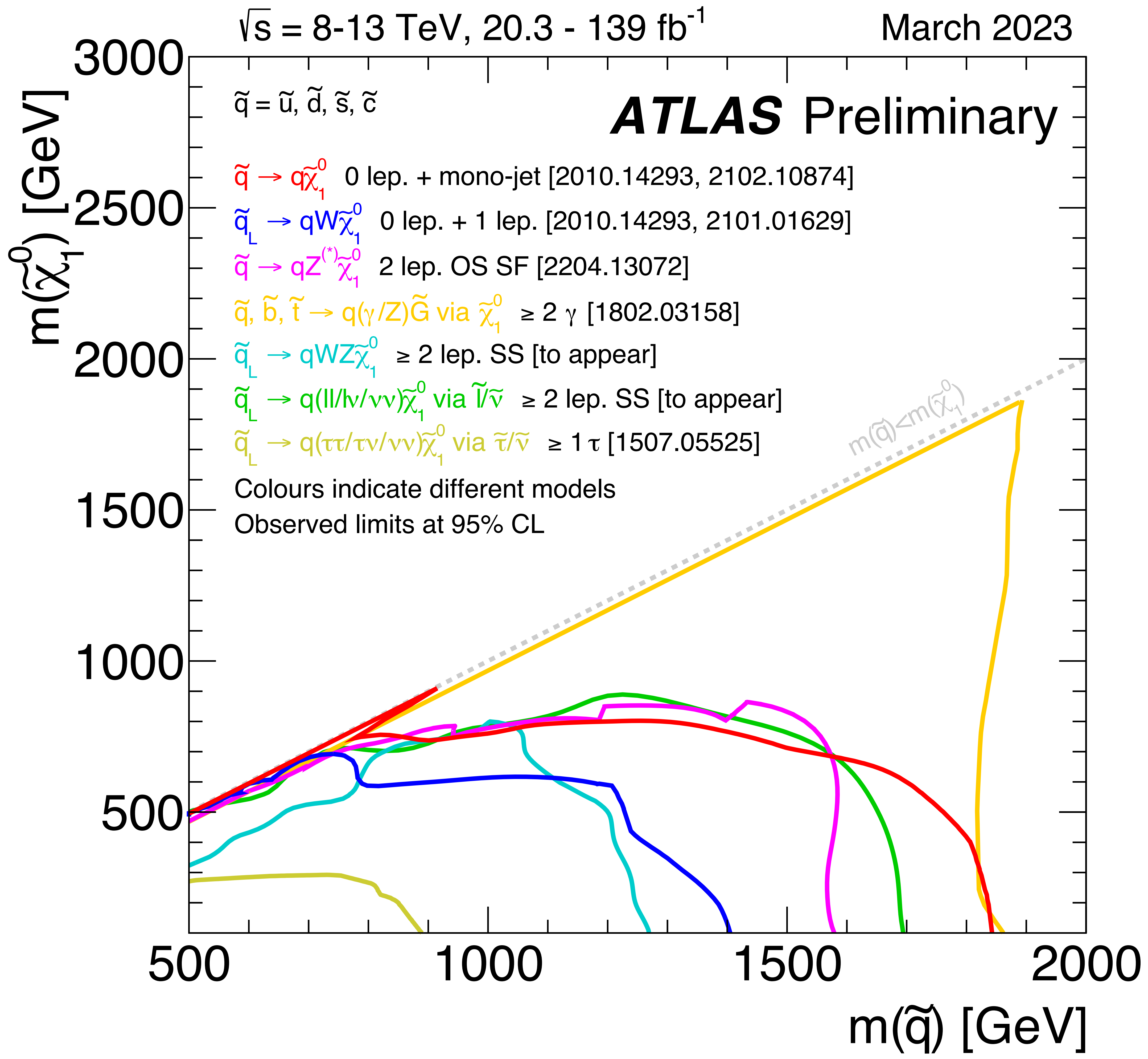
$\sqrt{s}$ = 13 TeV

	Model	Signature			$\int\mathcal{L}\,dt$ [fb^{-1}]	Mass limit			Reference
Inclusive Searches	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}^0_1$	0 e,μ	2-6 jets	E_T^{miss}	139	$\tilde{q}$ [1×, 8× Degen.]	1.0 1.85	m($\tilde{\chi}^0_1$)<400 GeV	2010.14293
		mono-jet	1-3 jets	E_T^{miss}	139	$\tilde{q}$ [8× Degen.]	0.9	m($\tilde{q}$)-m($\tilde{\chi}^0_1$)=5 GeV	2102.10874
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0 e,μ	2-6 jets	E_T^{miss}	139	$\tilde{g}$	2.3	m($\tilde{\chi}^0_1$)=0 GeV	2010.14293
						$\tilde{g}$ Forbidden	1.15-1.95	m($\tilde{\chi}^0_1$)=1000 GeV	2010.14293
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}W\tilde{\chi}^0_1$	1 e,μ	2-6 jets		139	$\tilde{g}$	2.2	m($\tilde{\chi}^0_1$)<600 GeV	2101.01629
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}^0_1$	$ee,\mu\mu$	2 jets	E_T^{miss}	139	$\tilde{g}$	2.2	m($\tilde{\chi}^0_1$)<700 GeV	2204.13072
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}^0_1$	0 e,μ	7-11 jets	E_T^{miss}	139	$\tilde{g}$	1.97	m($\tilde{\chi}^0_1$) <600 GeV	2008.06032
		SS e,μ	6 jets		139	$\tilde{g}$	1.15	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=200 GeV	1909.08457
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	E_T^{miss}	139	$\tilde{g}$	2.45	m($\tilde{\chi}^0_1$)<500 GeV	2211.08028
		SS e,μ	6 jets		139	$\tilde{g}$	1.25	m($\tilde{g}$)-m($\tilde{\chi}^0_1$)=300 GeV	1909.08457
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$	0 e,μ	2 b	E_T^{miss}	139	$\tilde{b}_1$	1.255	m($\tilde{\chi}^0_1$)<400 GeV	2101.12527
						$\tilde{b}_1$	0.68	10 GeV<Δm($\tilde{b}_1$,$\tilde{\chi}^0_1$)<20 GeV	2101.12527
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_2\to bh\tilde{\chi}^0_1$	0 e,μ	6 b	E_T^{miss}	139	$\tilde{b}_1$ Forbidden	0.23-1.35	Δm($\tilde{\chi}^0_2$,$\tilde{\chi}^0_1$)=130 GeV, m($\tilde{\chi}^0_1$)=100 GeV	1908.03122
		2 τ	2 b	E_T^{miss}	139	$\tilde{b}_1$	0.13-0.85	Δm($\tilde{\chi}^0_2$,$\tilde{\chi}^0_1$)=130 GeV, m($\tilde{\chi}^0_1$)=0 GeV	2103.08189
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to t\tilde{\chi}^0_1$	0-1 e,μ	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{t}_1$	1.25	m($\tilde{\chi}^0_1$)=1 GeV	2004.14060, 2012.03799
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}^0_1$	1 e,μ	3 jets/1 b	E_T^{miss}	139	$\tilde{t}_1$ Forbidden	0.65	m($\tilde{\chi}^0_1$)=500 GeV	2012.03799
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to\tilde{\tau}_1 b\nu$, $\tilde{\tau}_1\to\tau\tilde{G}$	1-2 τ	2 jets/1 b	E_T^{miss}	139	$\tilde{t}_1$ Forbidden	1.4	m($\tilde{\tau}_1$)=800 GeV	2108.07665
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$ / $\tilde{c}\tilde{c}$, $\tilde{c}\to c\tilde{\chi}^0_1$	0 e,μ	2 c	E_T^{miss}	36.1	$\tilde{c}$	0.85	m($\tilde{\chi}^0_1$)=0 GeV	1805.01649
		0 e,μ	mono-jet	E_T^{miss}	139	$\tilde{t}_1$	0.55	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}^0_1$)=5 GeV	2102.10874
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to t\tilde{\chi}^0_2$, $\tilde{\chi}^0_2\to Z/h\tilde{\chi}^0_1$	1-2 e,μ	1-4 b	E_T^{miss}	139	$\tilde{t}_1$	0.067-1.18	m($\tilde{\chi}^0_2$)=500 GeV	2006.05880
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ	1 b	E_T^{miss}	139	$\tilde{t}_2$ Forbidden	0.86	m($\tilde{\chi}^0_1$)=360 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}^0_1$)= 40 GeV	2006.05880
EW direct	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via WZ	Multiple ℓ/jets		E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	0.96	m($\tilde{\chi}^0_1$)=0, wino-bino	2106.01676, 2108.07586
		$ee,\mu\mu$	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$	0.205	m($\tilde{\chi}^\pm_1$)-m($\tilde{\chi}^0_1$)=5 GeV, wino-bino	1911.12606
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via WW	2 e,μ		E_T^{miss}	139	$\tilde{\chi}^\pm_1$	0.42	m($\tilde{\chi}^0_1$)=0, wino-bino	1908.08215
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via Wh	Multiple ℓ/jets		E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ Forbidden	1.06	m($\tilde{\chi}^0_1$)=70 GeV, wino-bino	2004.10894, 2108.07586
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e,μ		E_T^{miss}	139	$\tilde{\chi}^\pm_1$	1.0	m($\tilde{\ell}$,$\tilde{\nu}$)=0.5(m($\tilde{\chi}^\pm_1$)+m($\tilde{\chi}^0_1$))	1908.08215
	$\tilde{\tau}\tilde{\tau}$, $\tilde{\tau}\to\tau\tilde{\chi}^0_1$	2 τ		E_T^{miss}	139	$\tilde{\tau}$ [$\tilde{\tau}_{\text{L}}$, $\tilde{\tau}_{\text{R,L}}$]	0.16-0.3 0.12-0.39	m($\tilde{\chi}^0_1$)=0	1911.06660
	$\tilde{\ell}_{\text{L,R}}\tilde{\ell}_{\text{L,R}}$, $\tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0 jets	E_T^{miss}	139	$\tilde{\ell}$	0.7	m($\tilde{\chi}^0_1$)=0	1908.08215
		$ee,\mu\mu$	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{\ell}$	0.256	m($\tilde{\ell}$)-m($\tilde{\chi}^0_1$)=10 GeV	1911.12606
	$\tilde{H}\tilde{H}$, $\tilde{H}\to h\tilde{G}/Z\tilde{G}$	0 e,μ	$\geq$ 3 b	E_T^{miss}	36.1	$\tilde{H}$	0.13-0.23 0.29-0.88	BR($\tilde{\chi}^0_1\to h\tilde{G}$)=1	1806.04030
		4 e,μ	0 jets	E_T^{miss}	139	$\tilde{H}$	0.55	BR($\tilde{\chi}^0_1\to Z\tilde{G}$)=1	2103.11684
		0 e,μ	$\geq$ 2 large jets	E_T^{miss}	139	$\tilde{H}$	0.45-0.93	BR($\tilde{\chi}^0_1\to Z\tilde{G}$)=1	2108.07586
		2 e,μ	$\geq$ 2 jets	E_T^{miss}	139	$\tilde{H}$	0.77	BR($\tilde{\chi}^0_1\to Z\tilde{G}$)=BR($\tilde{\chi}^0_1\to h\tilde{G}$)=0.5	2204.13072
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	E_T^{miss}	139	$\tilde{\chi}^\pm_1$	0.66	Pure Wino	2201.02472
						$\tilde{\chi}^\pm_1$	0.21	Pure higgsino	2201.02472
	Stable $\tilde{g}$ R-hadron	pixel dE/dx		E_T^{miss}	139	$\tilde{g}$	2.05		2205.06013
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}^0_1$	pixel dE/dx		E_T^{miss}	139	$\tilde{g}$ [$\tau(\tilde{g})$ =10 ns]	2.2	m($\tilde{\chi}^0_1$)=100 GeV	2205.06013
	$\tilde{\ell}\tilde{\ell}$, $\tilde{\ell}\to\ell\tilde{G}$	Displ. lep		E_T^{miss}	139	$\tilde{e}$,$\tilde{\mu}$	0.7	$\tau(\tilde{\ell})$ = 0.1 ns	2011.07812
						$\tilde{\tau}$	0.34	$\tau(\tilde{\ell})$ = 0.1 ns	2011.07812
		pixel dE/dx		E_T^{miss}	139	$\tilde{\tau}$	0.36	$\tau(\tilde{\ell})$ = 10 ns	2205.06013
RPV	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_1$, $\tilde{\chi}^\pm_1\to Z\ell\to\ell\ell\ell$	3 e,μ			139	$\tilde{\chi}^\mp_1/\tilde{\chi}^0_1$ [BR($Z\tau$)=1, BR(Ze)=1]	0.625 1.05	Pure Wino	2011.10543
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_2\to WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0 jets	E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ [$\lambda_{i33}\neq 0$, $\lambda_{12k}\neq 0$]	0.95 1.55	m($\tilde{\chi}^0_1$)=200 GeV	2103.11684
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to qqq$		4-5 large jets		36.1	$\tilde{g}$ [m($\tilde{\chi}^0_1$)=200 GeV, 1100 GeV]	1.3 1.9	Large λ''_{112}	1804.03568
	$\tilde{t}\tilde{t}$, $\tilde{t}\to t\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to tbs$		Multiple		36.1	$\tilde{t}$ [λ''_{323}=2e-4, 1e-2]	0.55 1.05	m($\tilde{\chi}^0_1$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}$, $\tilde{t}\to b\tilde{\chi}^\pm_1$, $\tilde{\chi}^\pm_1\to bbs$		$\geq 4b$		139	$\tilde{t}$ Forbidden	0.95	m($\tilde{\chi}^\pm_1$)=500 GeV	2010.01015
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$		2 jets + 2 b		36.7	$\tilde{t}_1$ [qq, bs]	0.42 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to q\ell$	2 e,μ	2 b		36.1	$\tilde{t}_1$	0.4-1.45	BR($\tilde{t}_1\to be/b\mu$)>20%	1710.05544
		1 μ	DV		136	$\tilde{t}_1$ [1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e-9]	1.0 1.6	BR($\tilde{t}_1\to q\mu$)=100%, cosθ_t=1	2003.11956
	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2/\tilde{\chi}^0_1$, $\tilde{\chi}^0_{1,2}\to tbs$, $\tilde{\chi}^+_1\to bbs$	1-2 e,μ	$\geq$6 jets		139	$\tilde{\chi}^0_1$	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.

Strong productions





The ATLAS detector

CERN-GE-0803012