ATLAS + CMS Searches for EWK SUSY in hadronic and semi-leptonic final states

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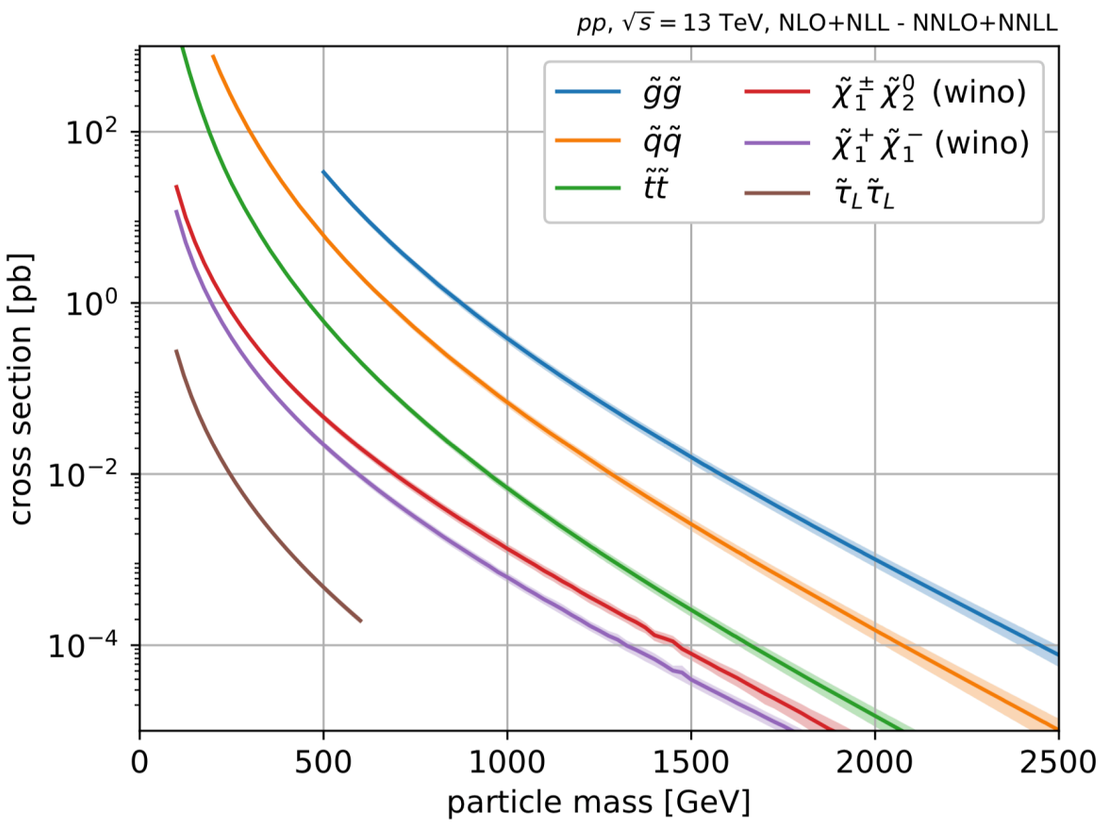
On behalf of the ATLAS + CMS Collaborations

LHCP 2021

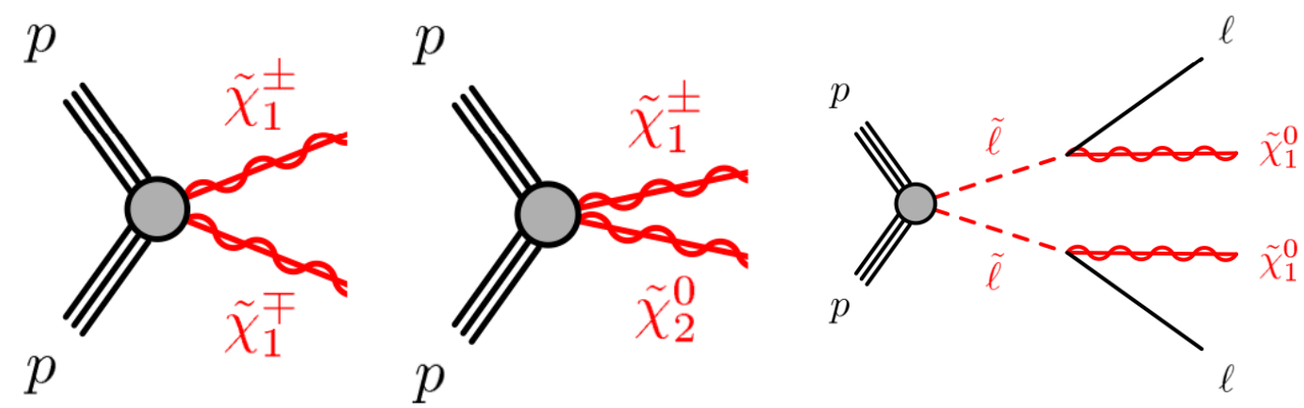
June 8th, 2021

Electroweak SUSY at the LHC

- **SM processes being measured with exceptional precision**
  - Including new measurements of rare SM processes
- **Stringent limits on strong-production of SUSY particles**
  - Lower mass limits: **gluinos** (2 TeV) and **stops** (1 TeV)

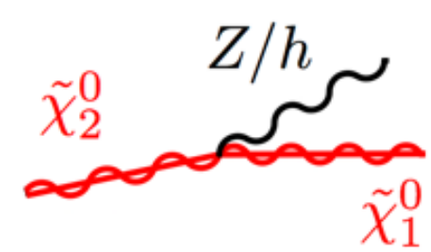


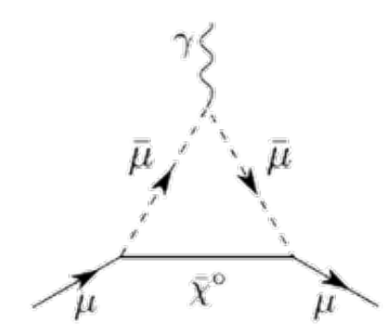
- **With the full Run-2 dataset:**
  - Can probe direct electroweak production of charginos/neutralinos and sleptons



- **Naturalness favours light higgsinos, *begin probing with full Run-2 dataset***

- Access to rare processes which require a lot of data for discovery potential
- **Using the now well established Higgs boson as a portal to new physics**
- *Connections to recent anomalies*





Fully hadronic boosted

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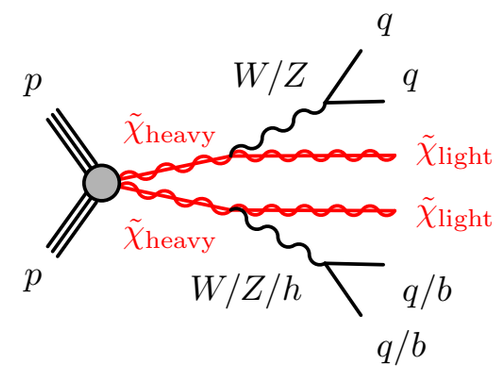
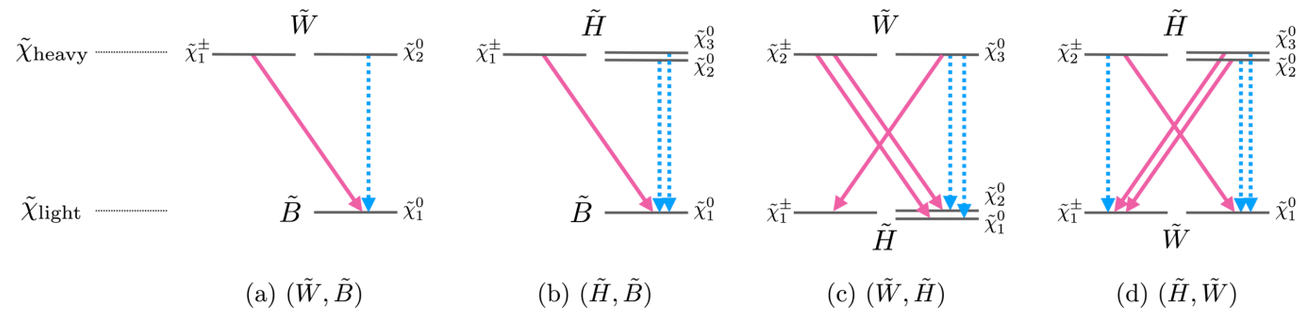
NEW

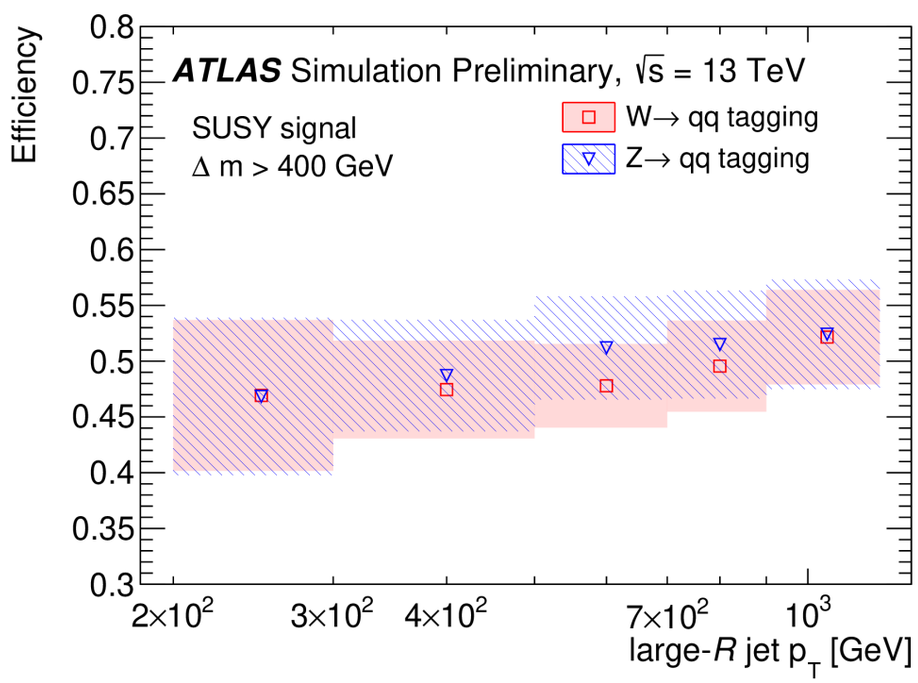


- **Interpretations based on various models:**
  - Baseline MSSM scenario with bino, wino and higgsino
  - Light higgsinos and gravitino LSP
  - Light higgsinos and axino LSP assuming the SM extension with a QCD axion

- **Mass heirarchy in the bino/wino/higgsino LSP scenario**



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

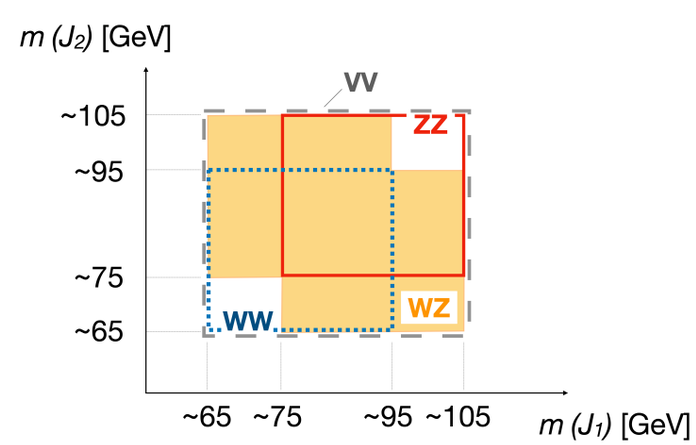


- **Boosted boson identification**
  - **Large-R jet tagging (R = 1.0)**
- **Events contain two large-R jets:** Boson tagging

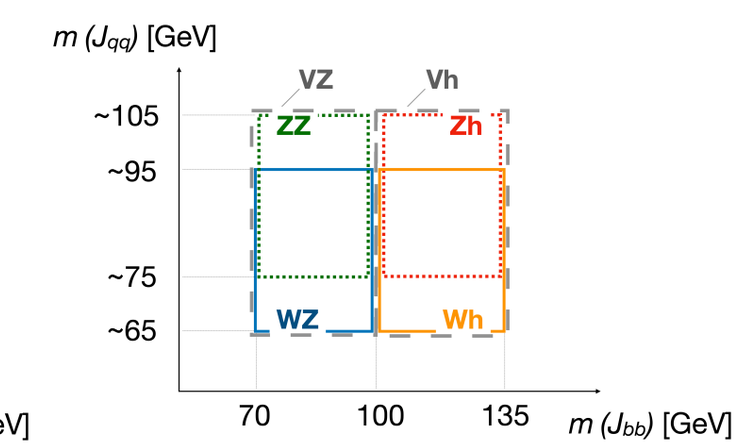
- SRs categorized based on: 2B2Q or 4Q
- Variable radius track jets for b-jet ID inside jet

- **Backgrounds:**
- Irreducible: VVV, tt+X, estimated from MC
- Reducible: Z+jets, W+jets, tt estimated from CR

Both W or Z tagging

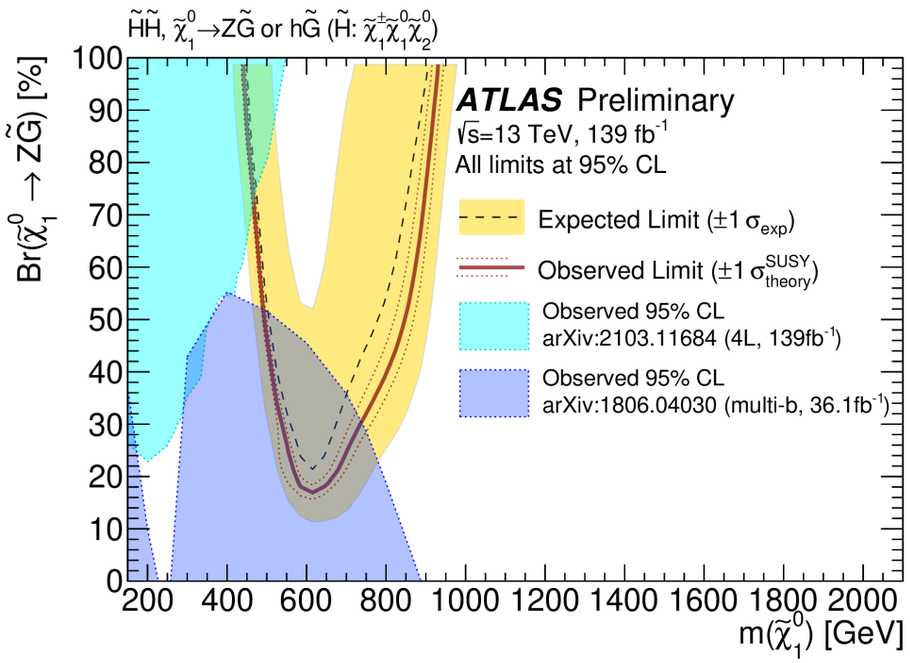


Exactly two b-tagged VR track jets



Fully hadronic boosted

- **No significant excess above SM prediction**
- Higgsino production decaying into a massless gravitino LSP: **940 GeV (100 % Br)**



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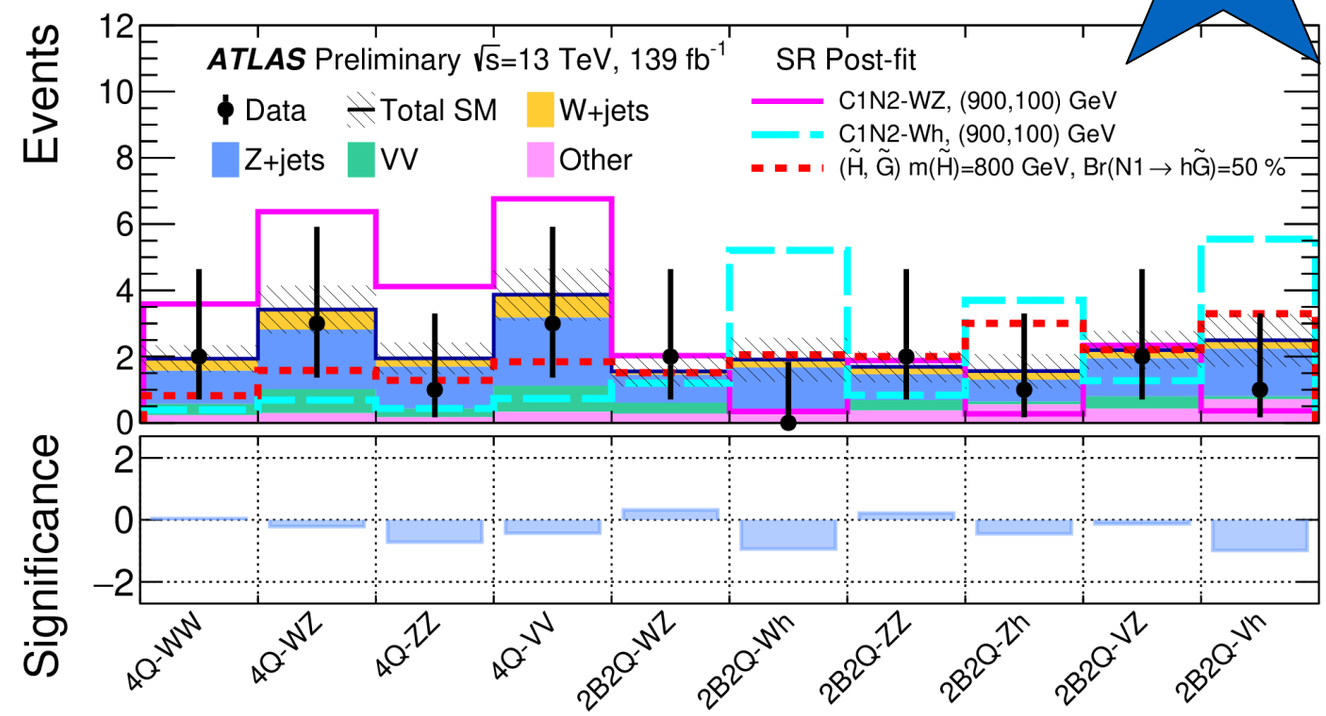
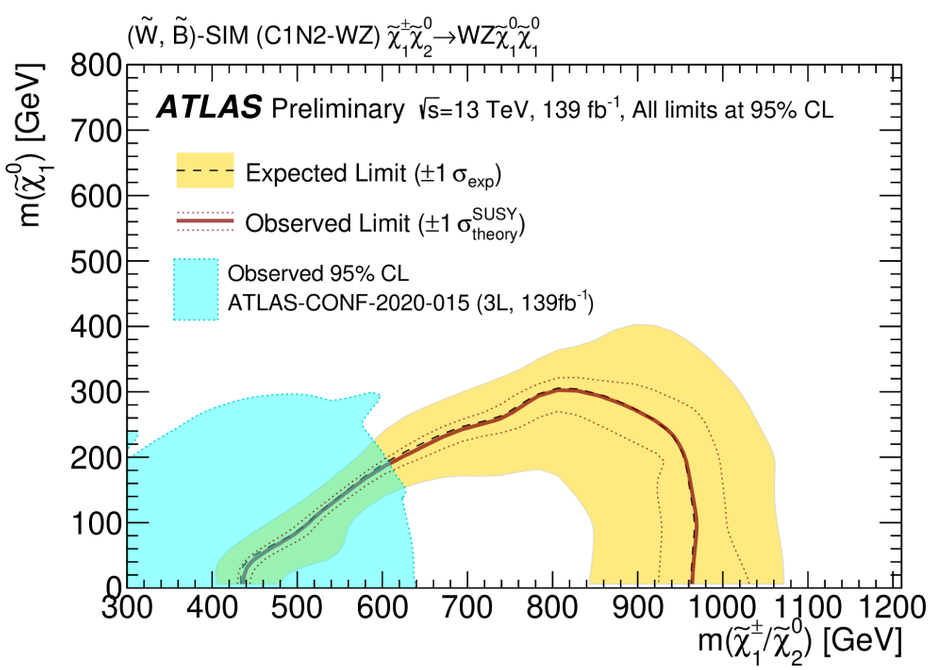
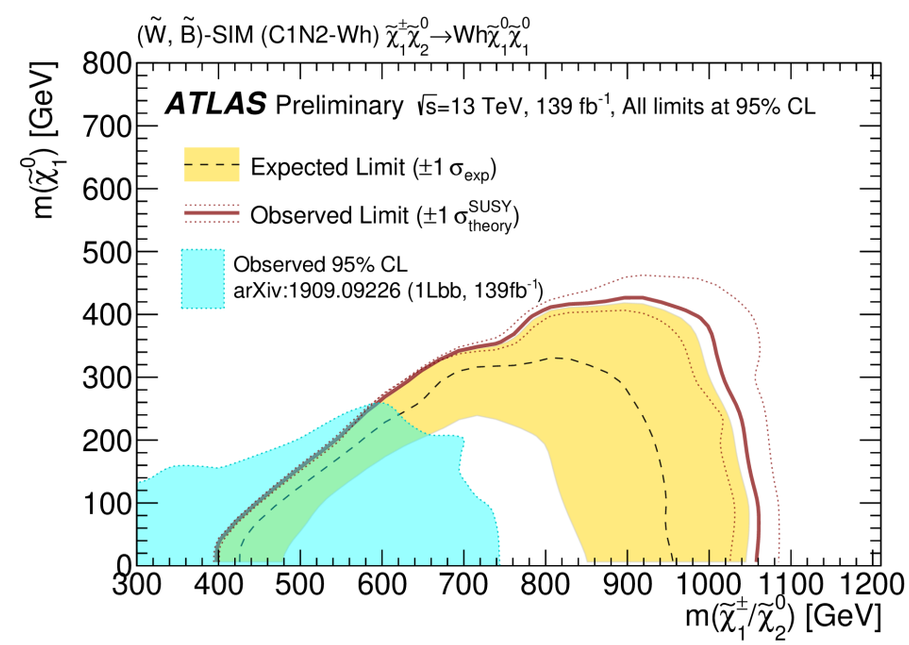


- **Exclusion limits on simplified wino/bino models**
- Chargino-neutralino pair production limits:
  - 960 GeV in WZ and 1060 GeV in Wh



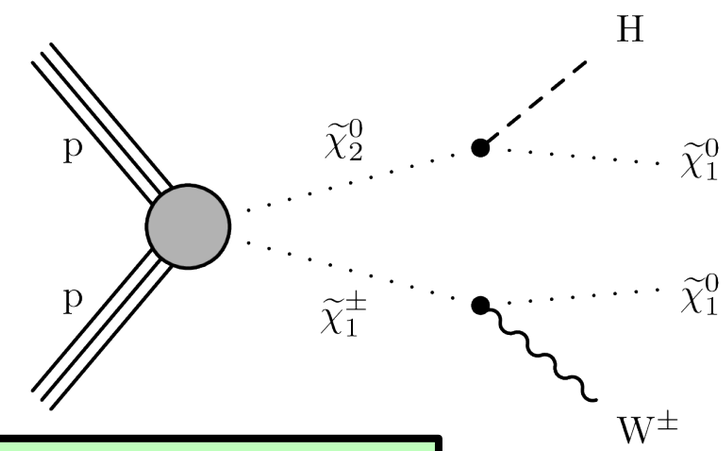


Chargino/Neutralino: Wh, h->bb

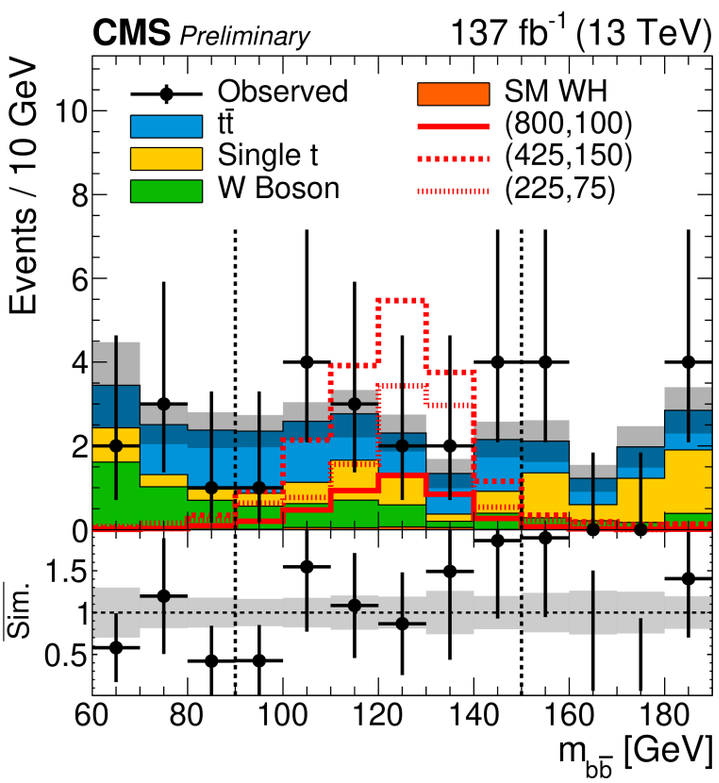
CMS PAS SUS-20-003

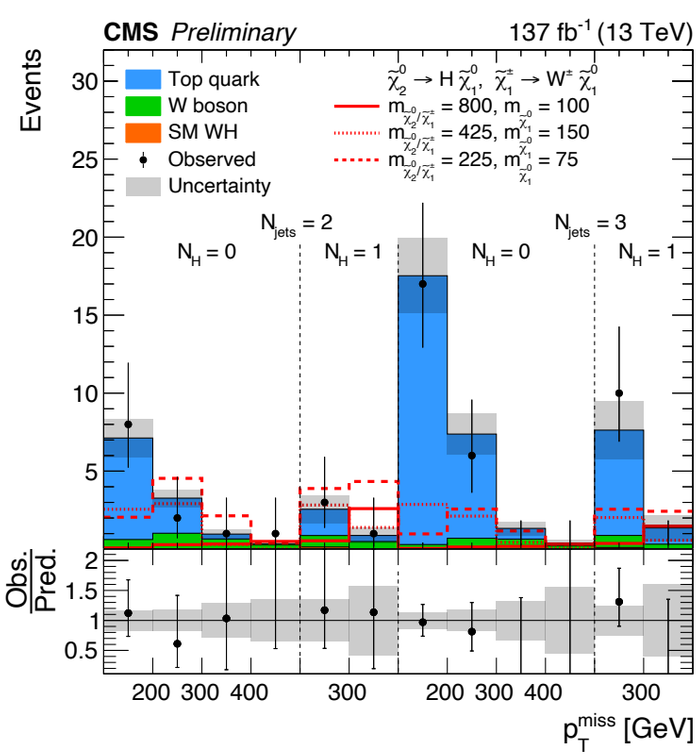
- **Single lepton + bb + p_T^{miss} final state**

- Both small-R (ΔR = 0.4) and large-R (ΔR = 0.8) jet collections
  - Large-R jets pT > 250 GeV

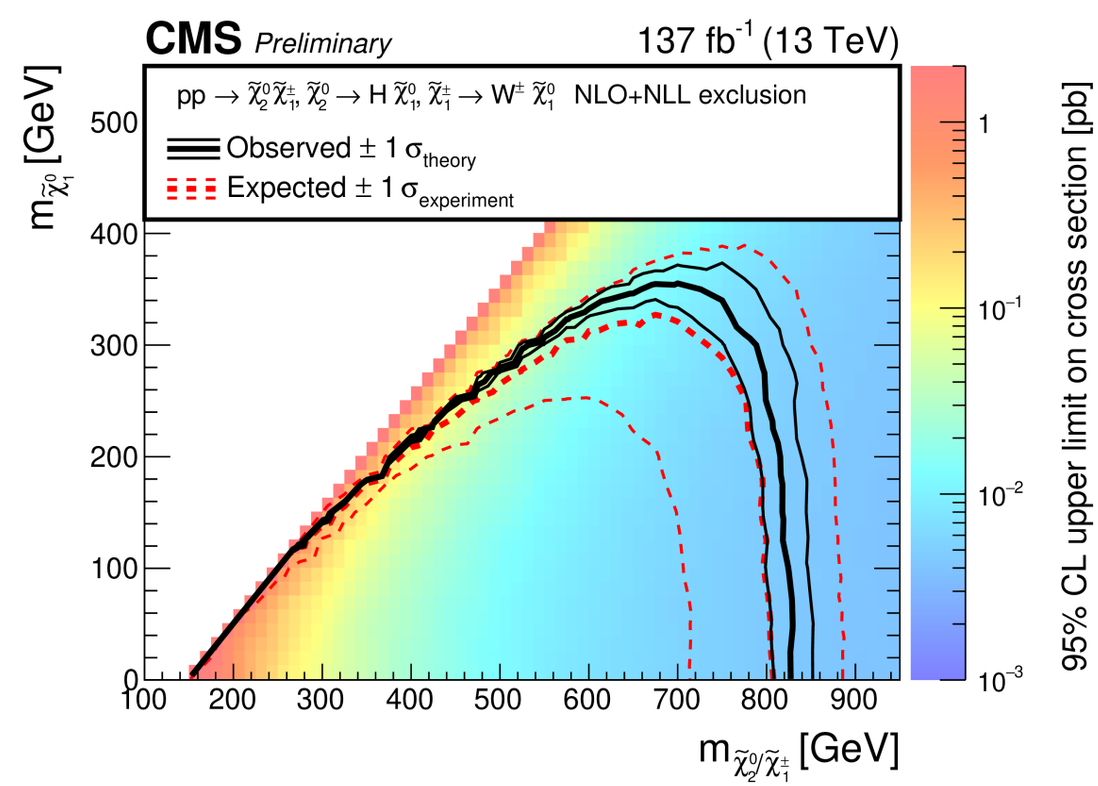


Wino-like model NLSP





- **Higgs tagger discriminator:** deep neural network algorithm
- Kinematic variables: m_{CT}, bb inv. mass, mT, p_T^{miss}



- Charginos / neutralinos excluded with masses up to 820 GeV
- LSPs with mass up to 350 GeV are excluded when the mass of the chargino / neutralino is ~ 700 GeV

Chargino/Neutralino: Wh, h->bb

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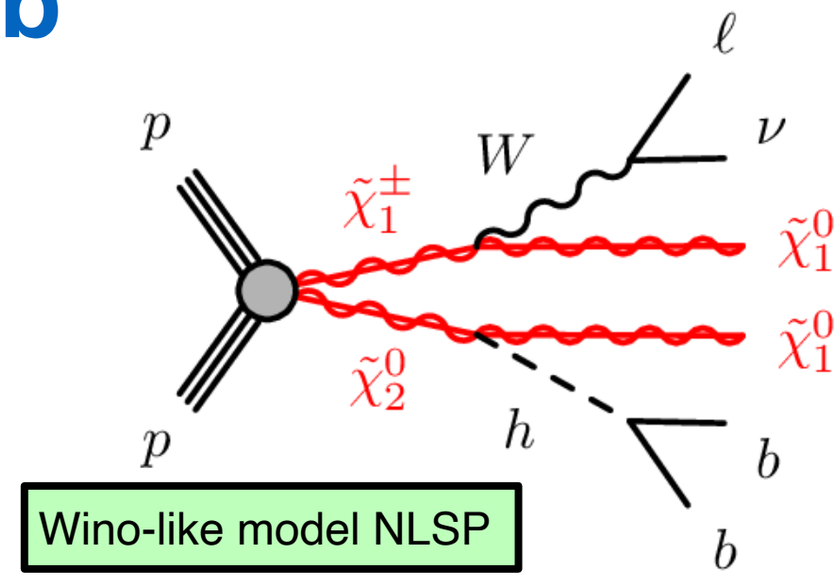
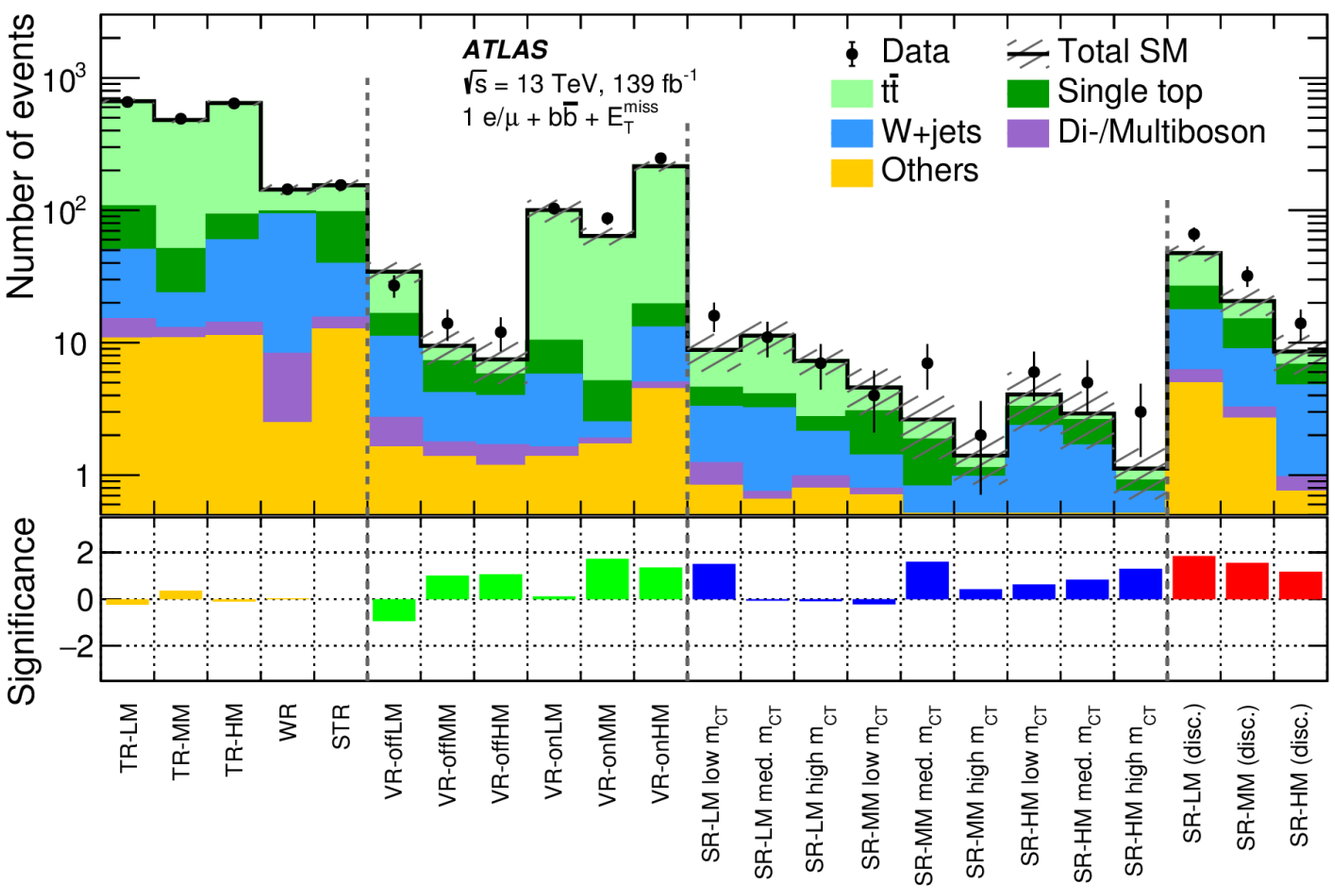
- **Search for charginos and neutralinos decaying to Higgs boson and W boson**
  - W boson —> leptonic decays (single lepton)
  - Higgs decays to bb

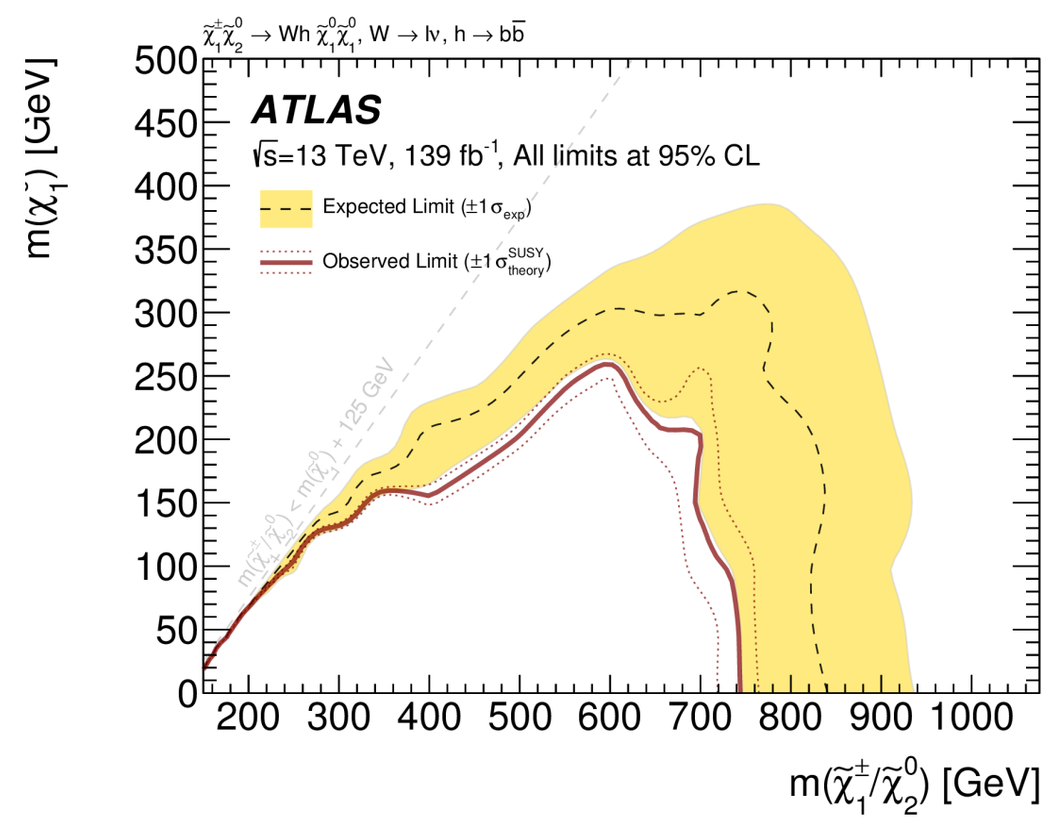


- Large MET, tagging of h and W decays



- 2D signal regions based on m_T and m_{CT}

$$m_{CT} = \sqrt{2 p_T^{b_1} p_T^{b_2} (1 + \cos \Delta\phi_{bb})}$$

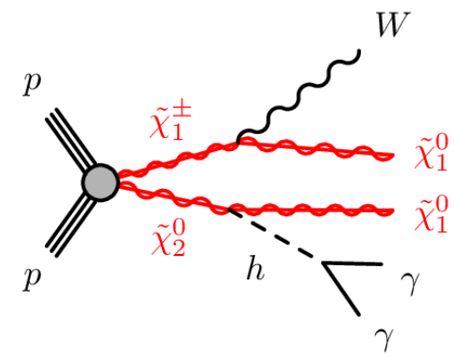


- No significant excess found < 2 sigma local
- **Exclusion limits: up to 740 GeV**

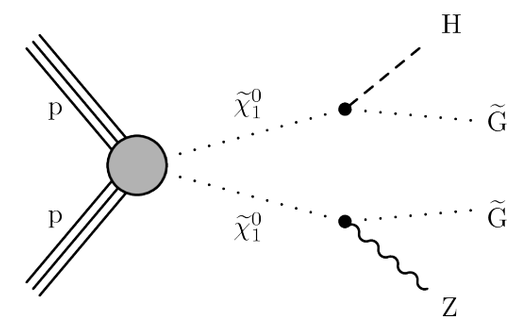
Chargino/Neutralino: h->γγ

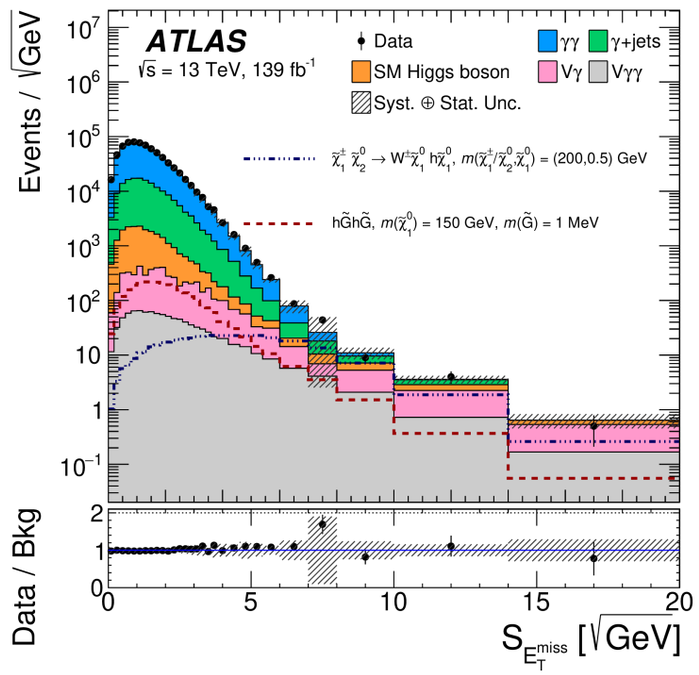
- **Higgs boson decay to diphotons (narrow peak in γγ)**
- Main backgrounds from γγ and γ+jets
- Parametrised likelihood fits in each category-based SRs
  - W-boson decay, MET significance, N (b-)jets, razor

Wino-like model NLSP



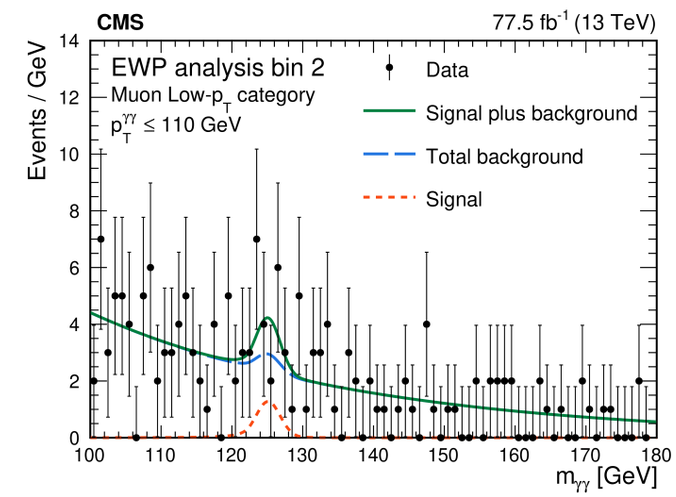
Higgsino-like neutralino PP

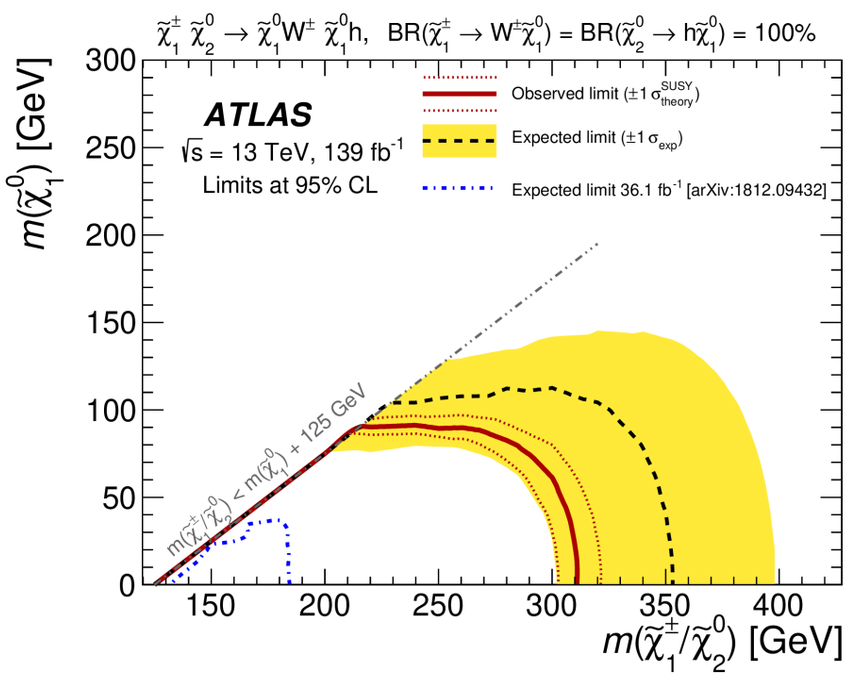


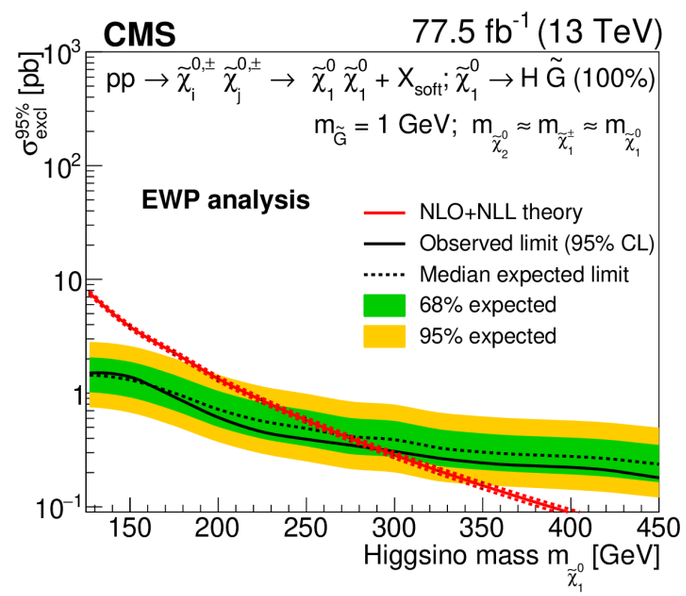


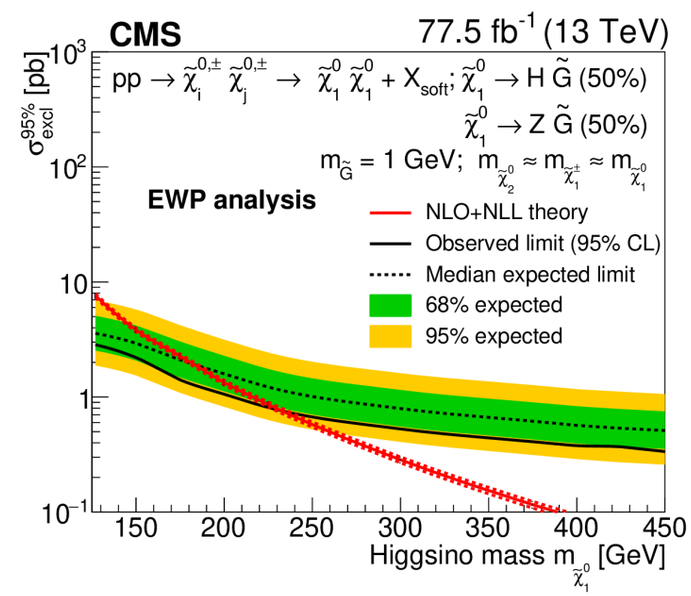
- **ATLAS**: Limits up to 310 GeV for electroweakino production (Wh decays)

- **CMS Higgsino-like:** Excluded neutralino decays exclusively to a h and a gravitino for neutralino masses below 290 GeV





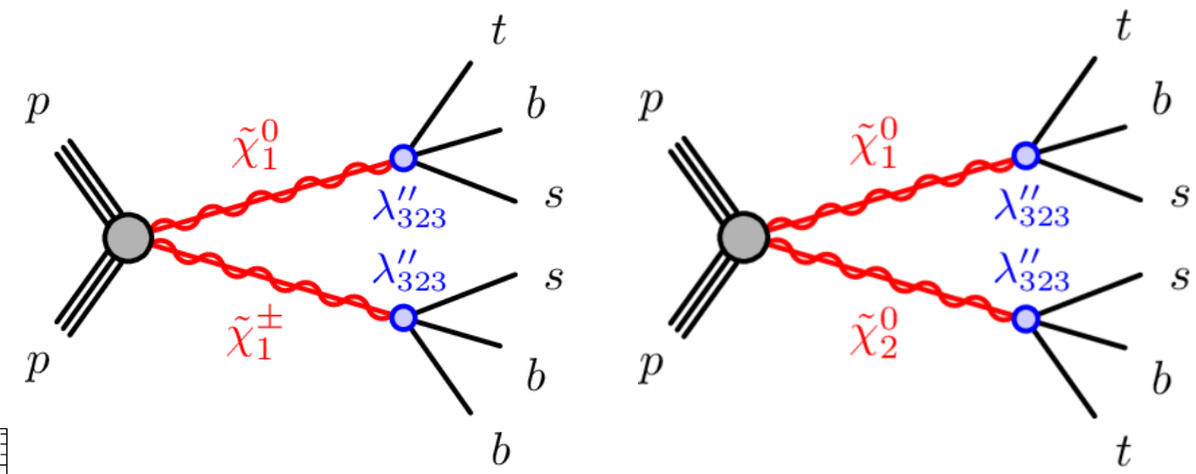


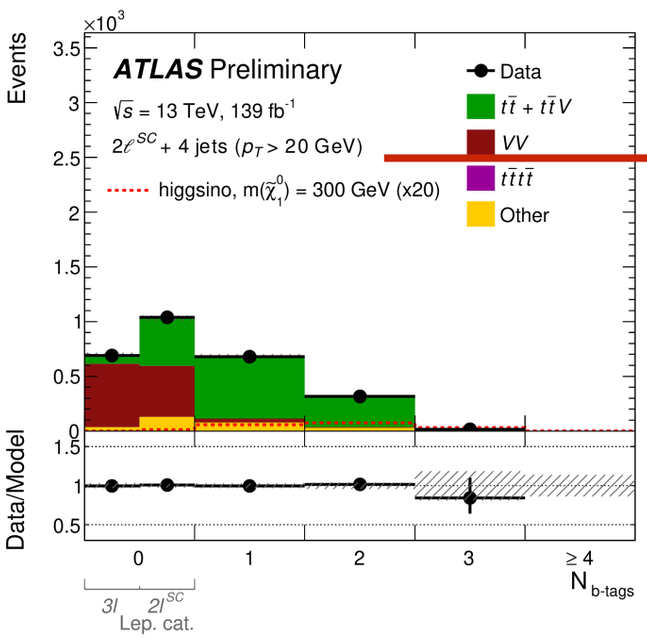


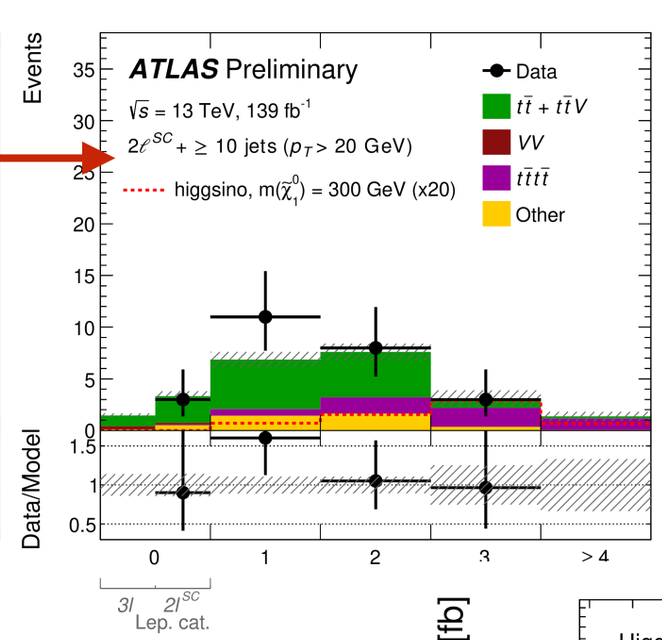
RPV SUSY

ATLAS-CONF-2021-007

- **EWKino production, higgsino LSP type**
- RPV: LSP unstable and decays in SM particles
- ≥ 1l/2lSS, and **many (b-)jets final states**





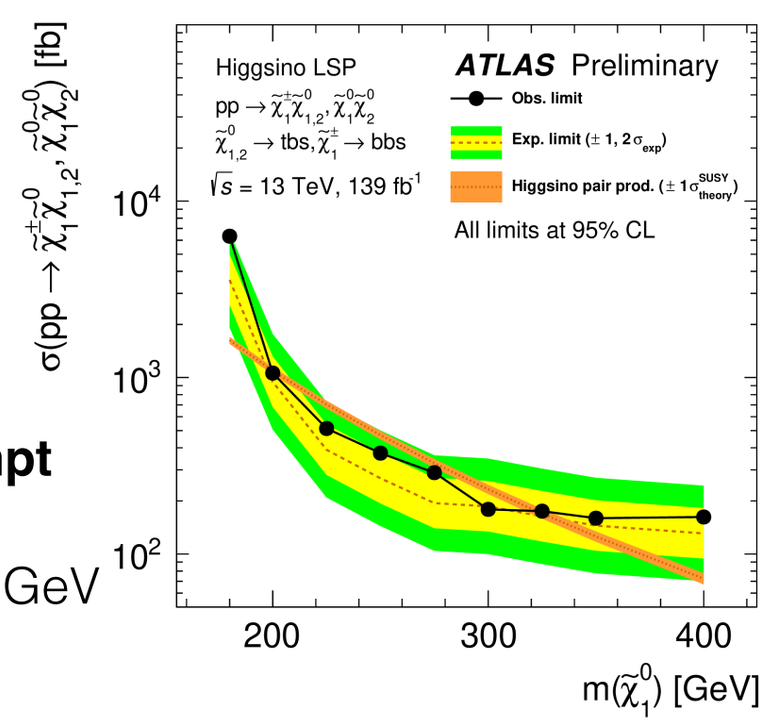


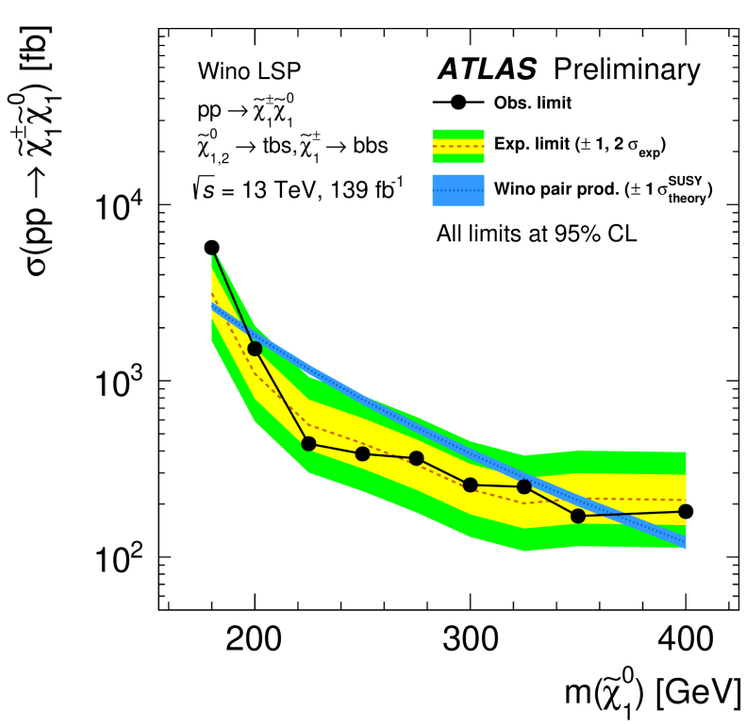
- Jet multiplicity predicted by parametrization of the jet scaling up to 10 or more jets

- b-jet multiplicity extracted at low number of jets
- NN discriminant to reach sensitivity to Higgsino production
  - *Background invariance under N b-jets*

- SRs up to 15 (10) jets for the ≥1l (2SSl) with 0, 1, 2, 3 and ≥ 4 b-jets
- Data driven approach to estimate backgrounds in each N jet slice

- **First limits on EWK production with prompt RPV decay to quarks since LEP**
- Higgsino (wino) masses between 200 (197) GeV and 320 (365) GeV excluded





Stau pair production

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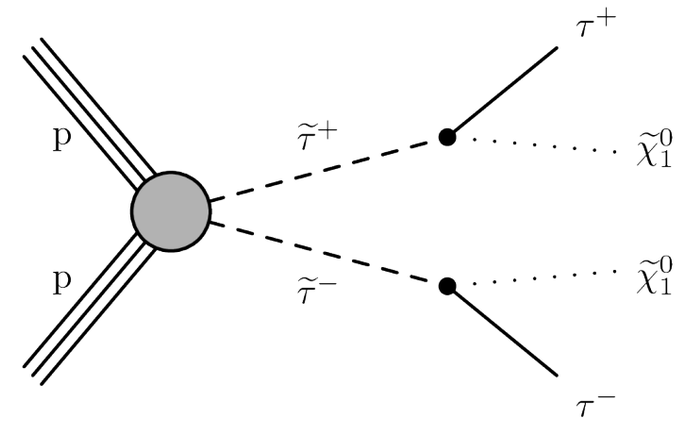
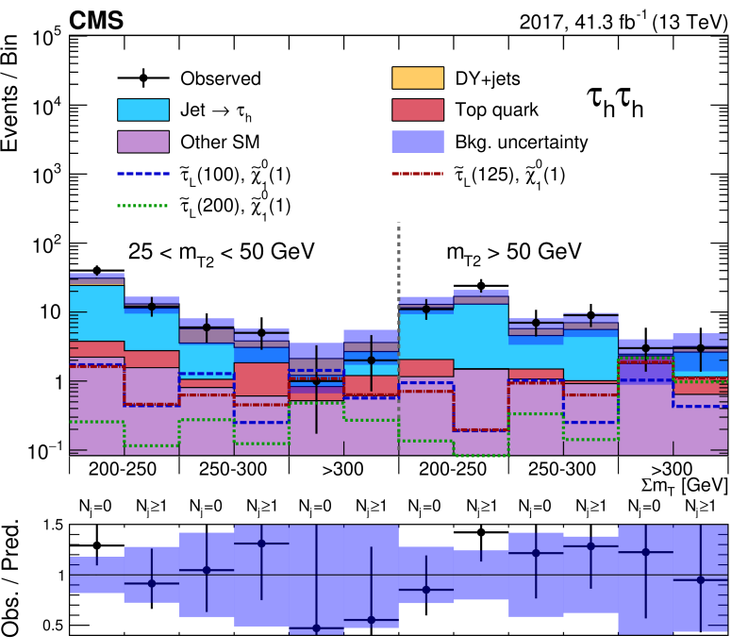
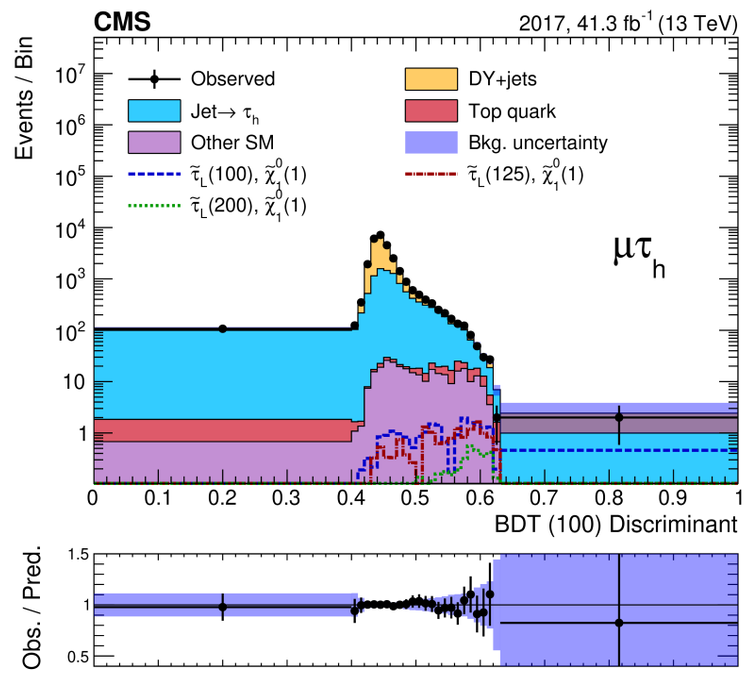
- **Two hadronic tau and light lepton + hadronic tau final states** (77.2 fb^{-1}) = 2016+2017
- Backgrounds from fake tau estimates —> transfer factor







- **Hadronic:** m_{T2} (stransverse mass), Sum m_T and N_j

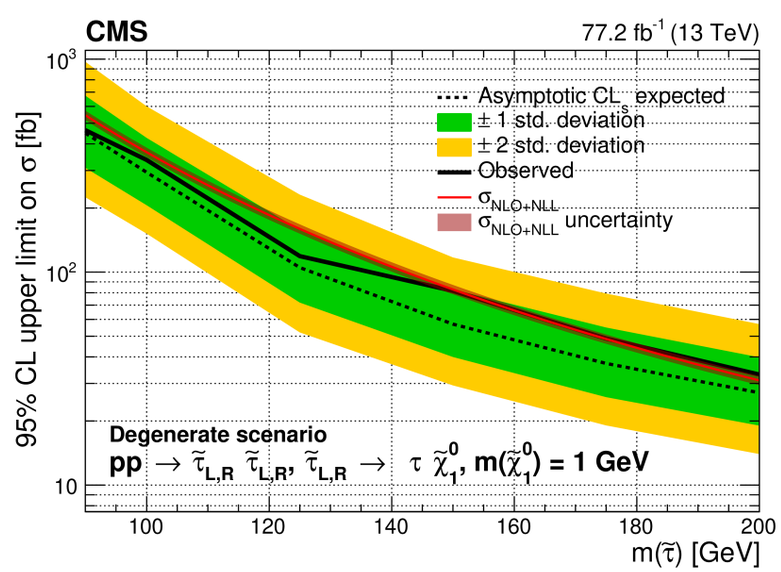
$$m_{\mathrm{T2}} = \min_{\vec{p}_{\mathrm{T}}^{\mathrm{X}(1)}+\vec{p}_{\mathrm{T}}^{\mathrm{X}(2)}=\vec{p}_{\mathrm{T}}^{\mathrm{miss}}} \left[\max\left(m_{\mathrm{T}}^{(1)}, m_{\mathrm{T}}^{(2)}\right)\right]$$

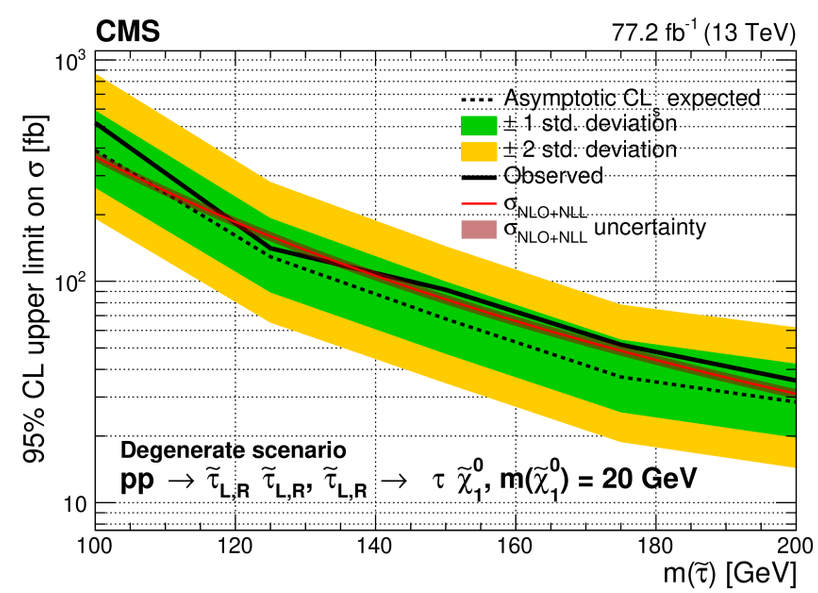
- **Semi-leptonic:** BDT of kinematic variables (e.g. contransverse mass)

$$m_{\mathrm{CT}} \equiv \sqrt{2p_{\mathrm{T}}^{\ell}p_{\mathrm{T}}^{\tau_{\mathrm{h}}}[1+\cos\Delta\phi(\ell,\tau_{\mathrm{h}})]}$$

- **No significant excess found**

- Limits set between 90 and 200 GeV and neutralino masses of 1, 10, and 20 GeV
- Combination of both channels





Stau pair production

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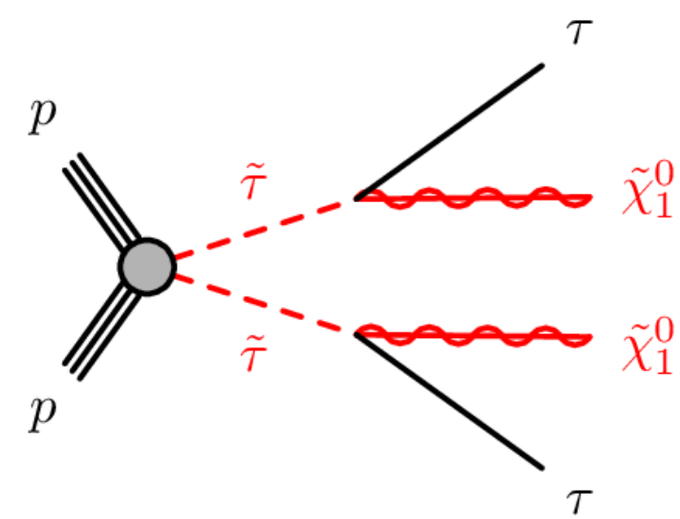
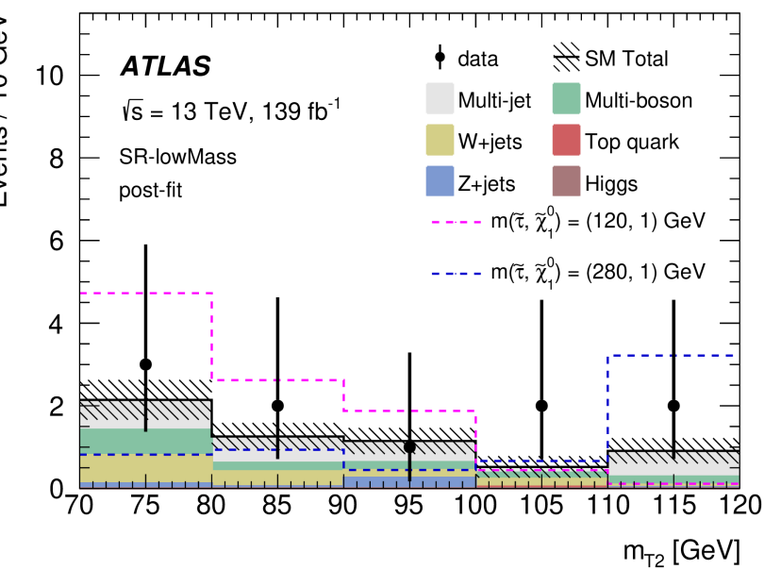
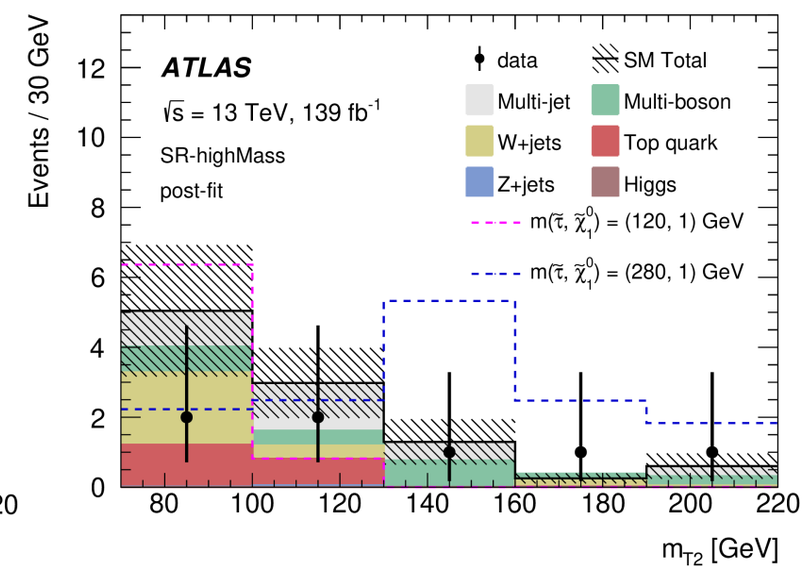


- **Two hadronic tau** final state
- Final state divided into **low and high E_T^{miss} regions**
- **Two SRs: highMass and lowMass SR**
  - Trigger dependent
  - E_T^{miss} cut to split SRs (150 GeV)
  - mT2 > 70 GeV

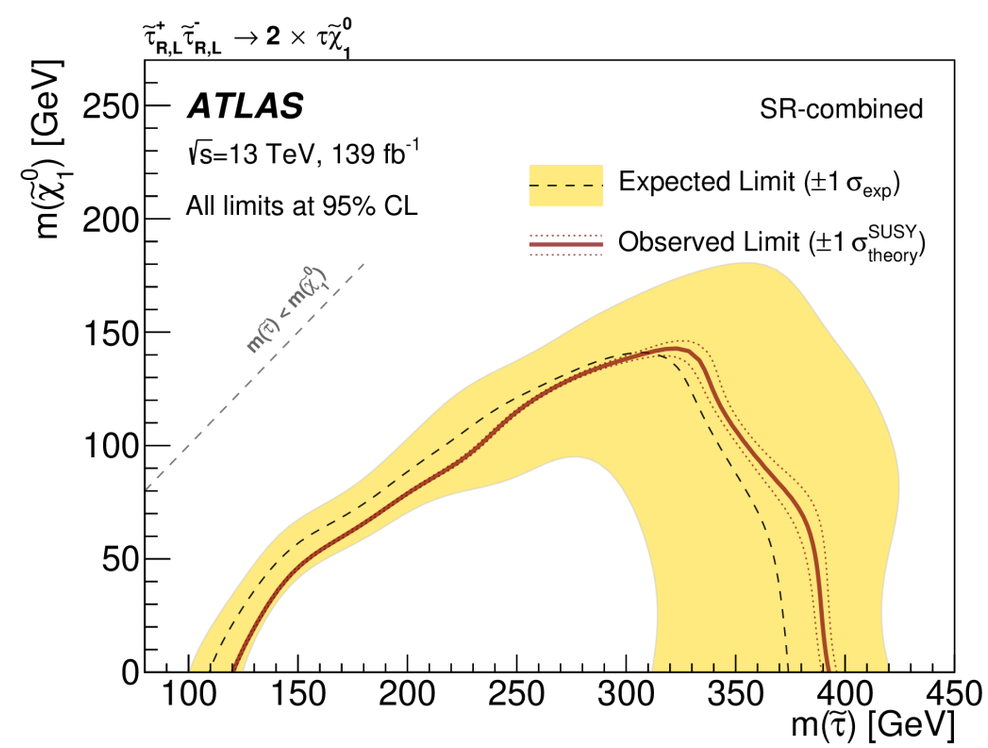
- **Both SRs are shown binned in m_{T2}**





- Large contribution from W+jets and multi-jet events (1 or 2 fake taus)

- **ABCD Method to model multi-jet**



- **No excess is found in either of the signal regions**
  - **Exclude 120 GeV < m(stau) < 390 GeV**
- 2-SR single bin combined fit only

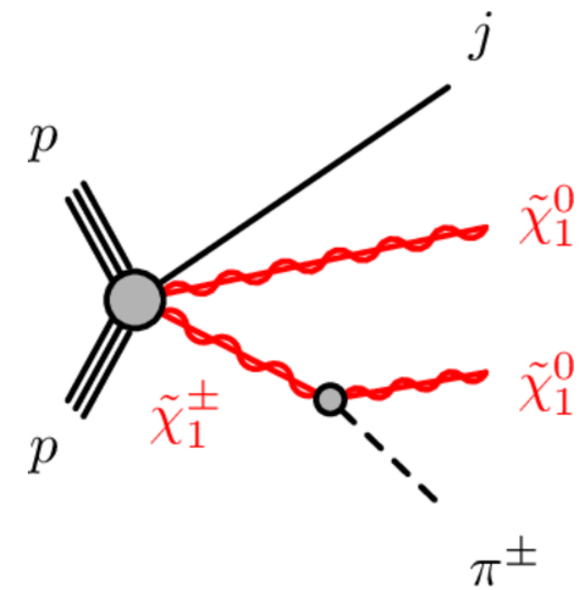
Long Lived Charginos

- *Details in talk by: E. Sian Kuwertz*

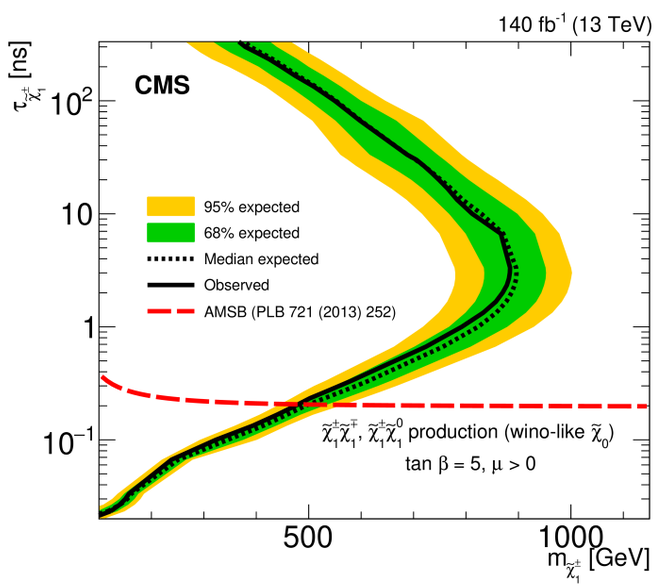
Phys. Lett. B 806 (2020) 135502

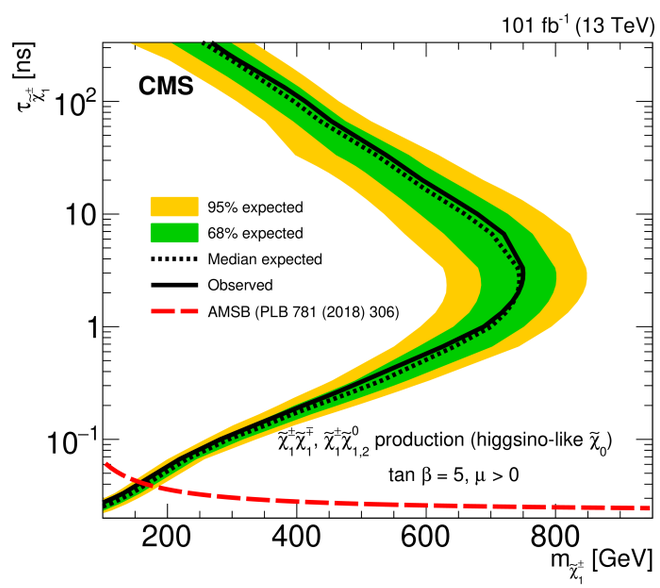
ATLAS-CONF-2021-015

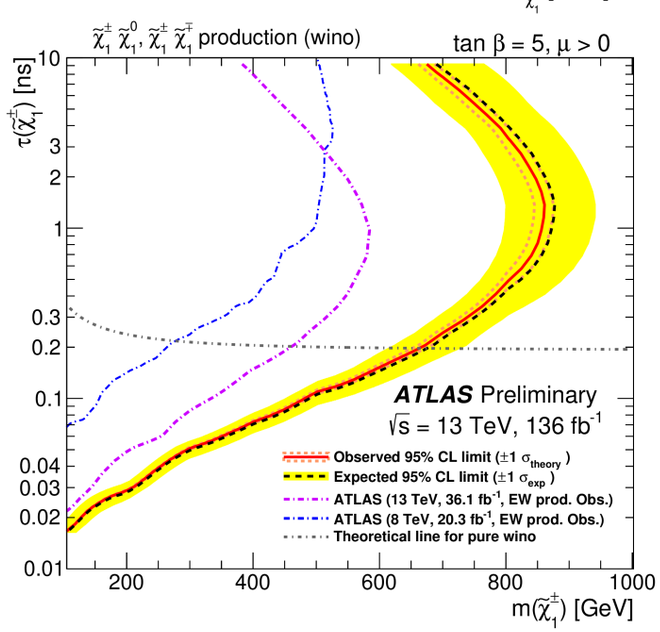
- **Search for long-lived chargino production**
  - Using disappearing track signature in ID
  - Tracks which have hits in the inner-most pixels

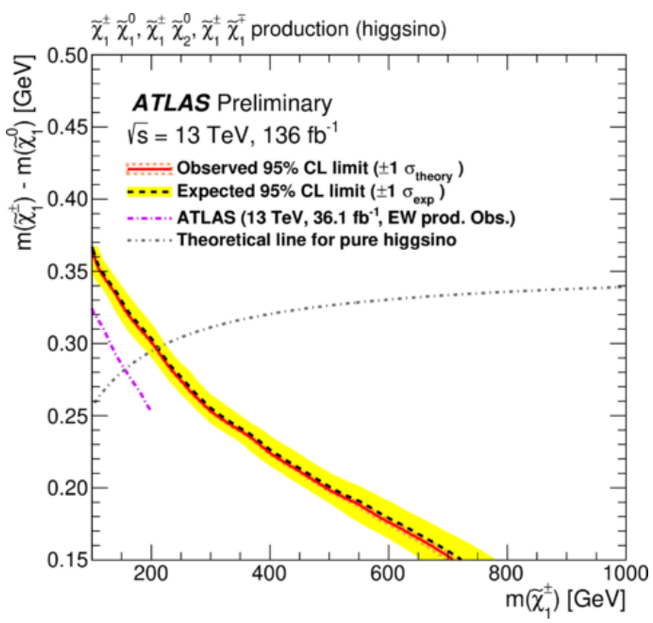


- **Charginos that are pure wino or higgsino**





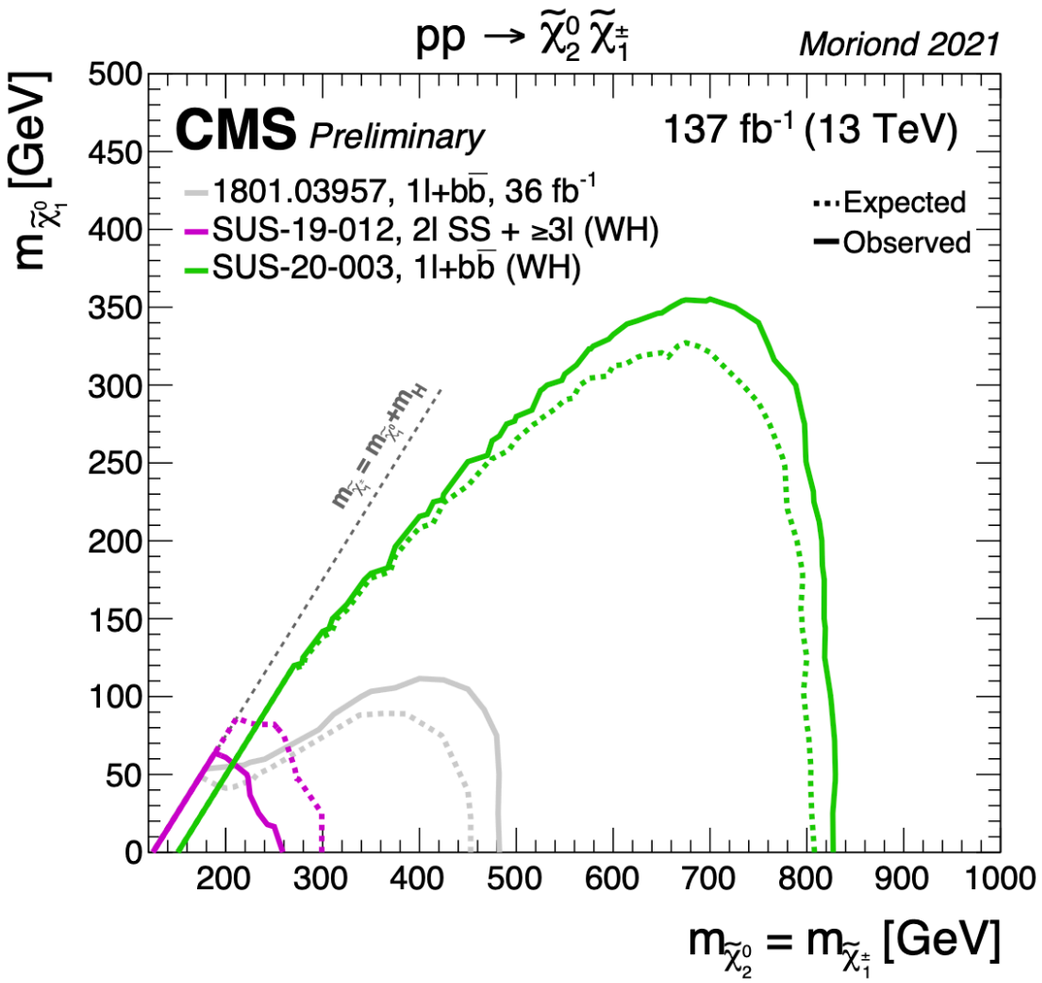


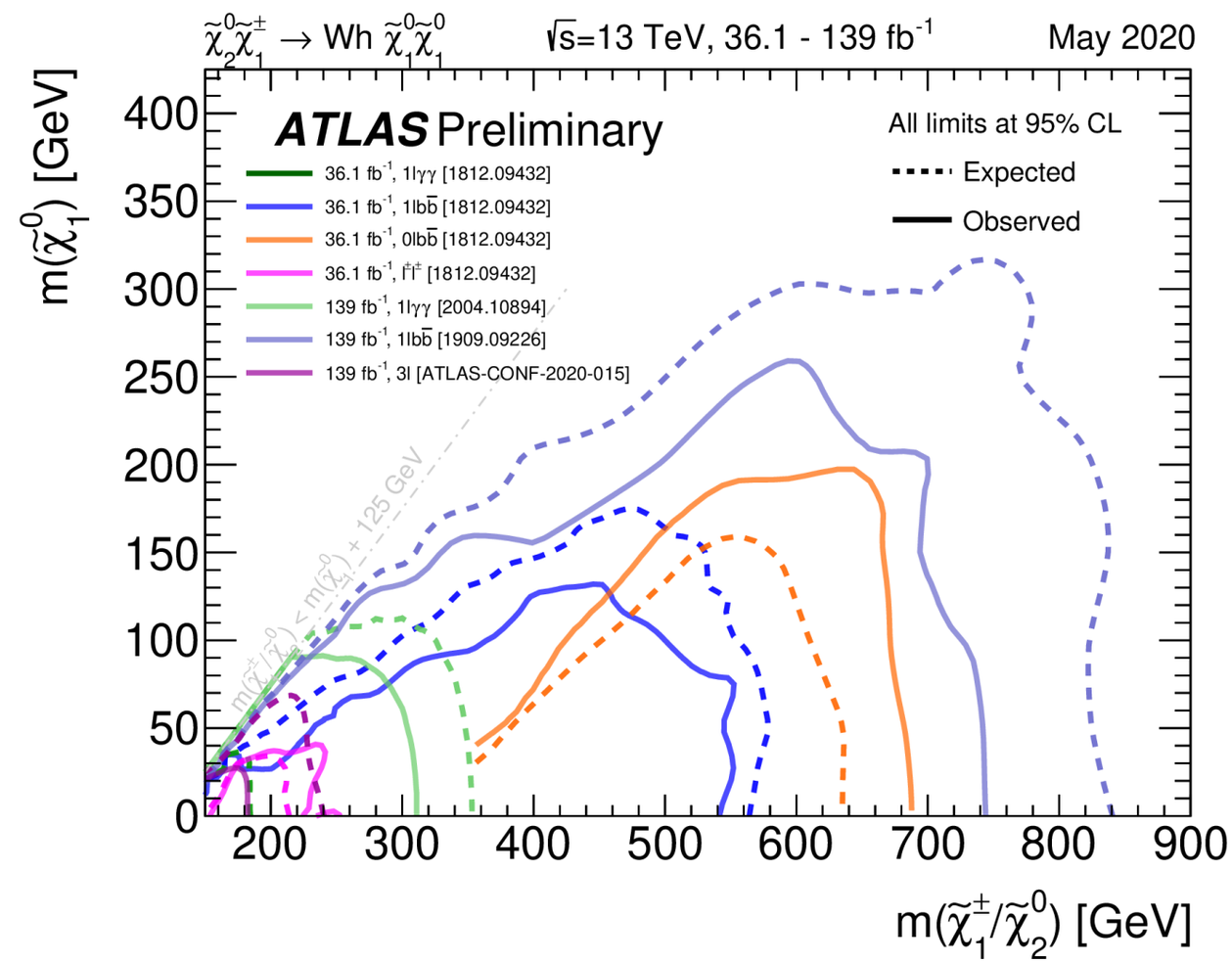


- Lifetime dependent limits
- Chargino masses up to 474 (175) GeV are excluded in scenarios where the chargino is a pure wino (higgsino)
- Chargino masses up to 660 (210) GeV are excluded in scenarios where the chargino is a pure wino (higgsino)

Summary Figures

- Still no indication for SUSY yet in the LHC
- Summary figures of chargino/neutralino exclusion limits (CMS and ATLAS)





- Not all of the production and decay modes are fully analysed using the full Run-2 dataset
  - Small production modes, difficult multi-object final states

- More results to come from the full Run-2 dataset

Summary and Outlook

- **New searches for electroweak SUSY at CMS and ATLAS**
  - Using the large, high-quality Run 2 dataset
  - *Thanks to the excellent performance of the LHC and experiments!*

- **Exploring new signals**
  - First sensitivity to direct stau searches, additional final states with Higgs
  - Probing very difficult final state signatures in compressed scenarios

- **For now the data remains compatible with SM predictions**
  - Though we know the SM cannot explain everything we observe in the Universe

- **New searches for SUSY are still to come with the full Run-2 dataset**
  - **Preparing optimal searches for the upcoming larger Run-3 dataset in order to explore new regions of phase space**

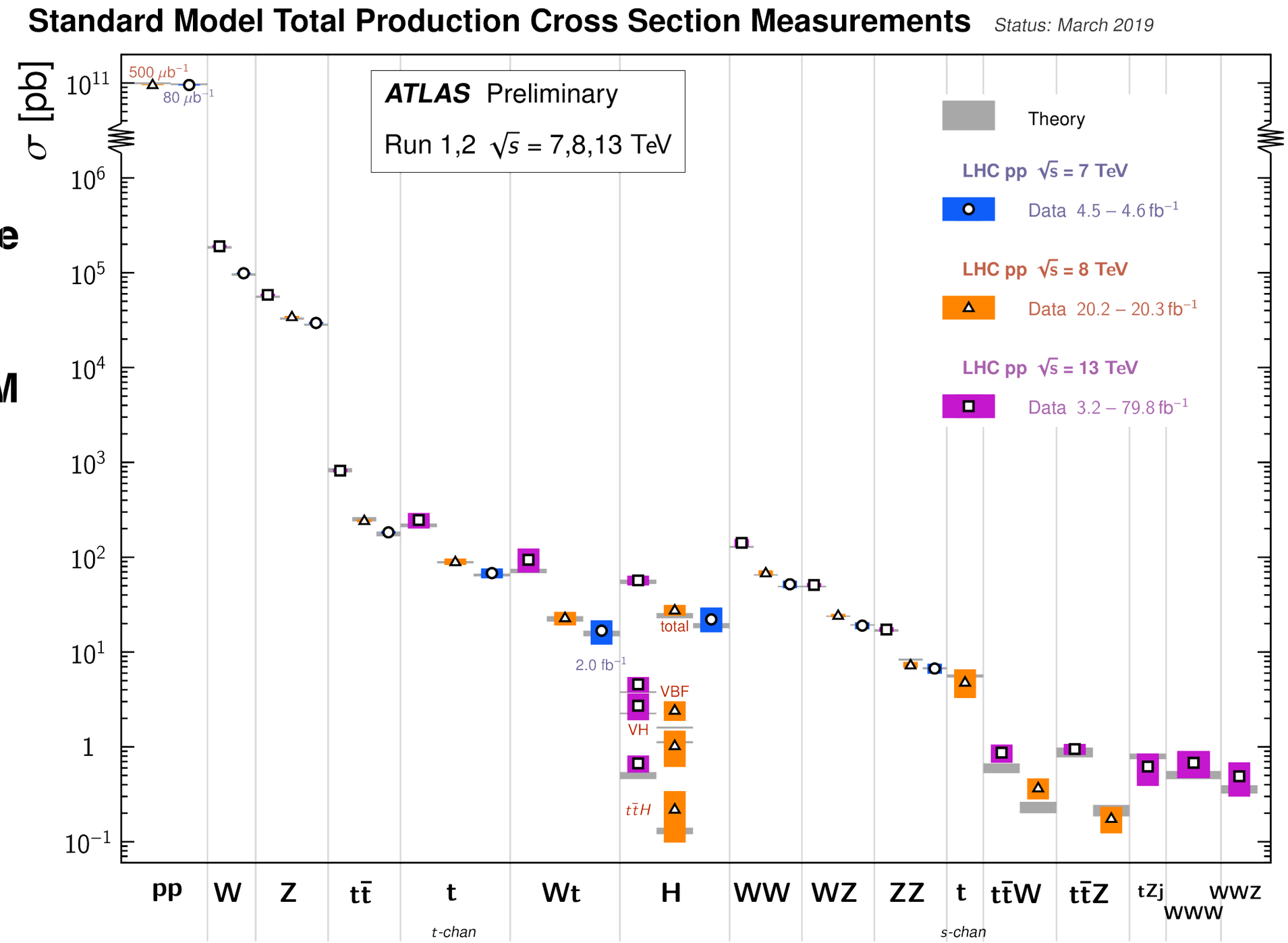
- **Still only a fraction of data-taking at the full lifetime of LHC and HL-LHC**

Additional Slides

Status of the Standard Model

- **LHC has given us the opportunity to test fundamental parameters of the SM**

- **Impressive agreement of SM theory predictions to ATLAS data**



Supersymmetry

- **A new symmetry to protect masses of particles at the Planck scale**
- Symmetry between fermions and bosons
  - *Includes an extended Higgs sector*

- **Can offer a DM candidate $\longrightarrow$ also a WIMP**
- **Solves the fine-tuning problem of the Higgs mass**

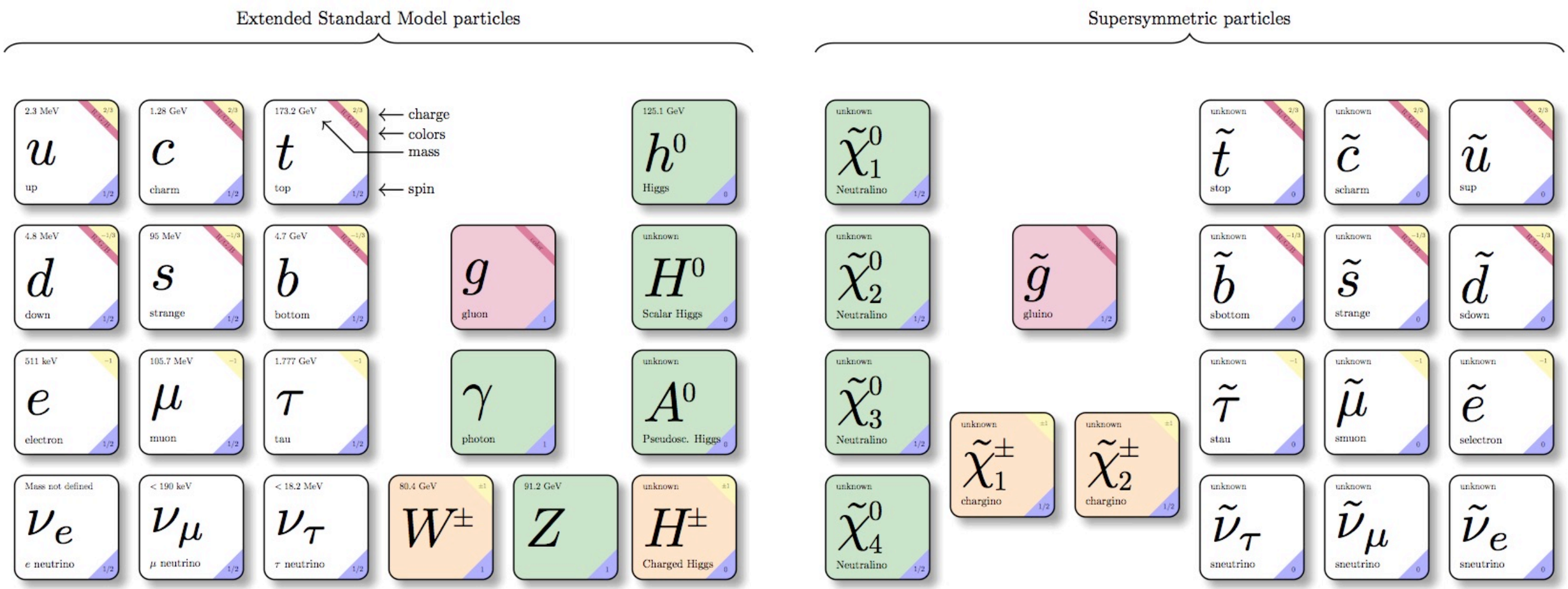


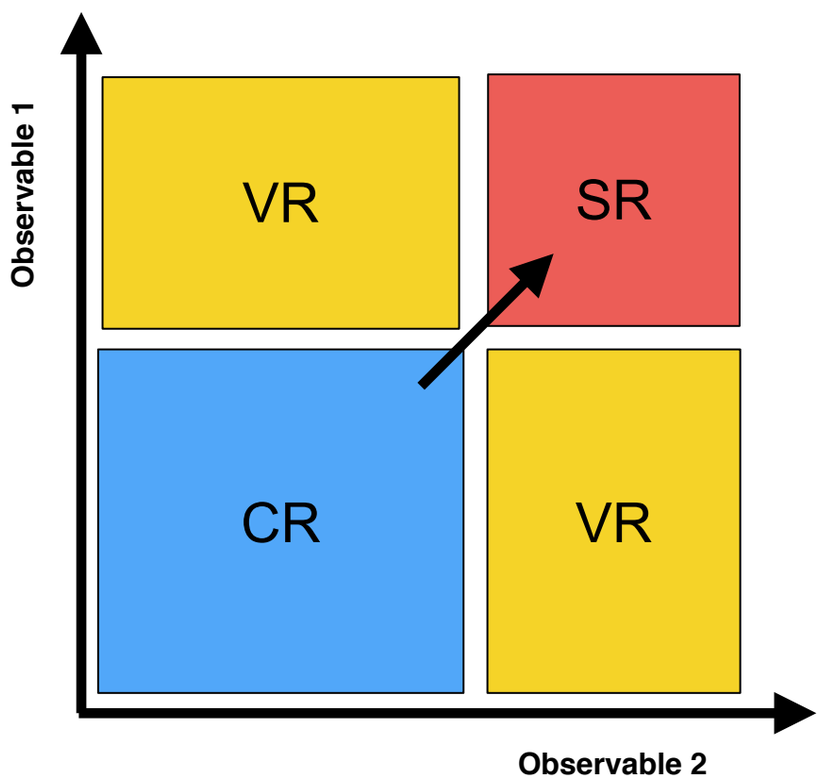
Image credit: M. Rimoldi

- ***Broken symmetry: mass (SUSY) $\neq$ mass (SM)***

Analysis Strategy

- Build **signal regions (SRs)** based on requirements on signal / background discriminating variables to target specific SUSY event topologies
  - Optimised for discovery & exclusion

- Determine Standard Model background in **control regions (CRs)** and test background estimates in the **validation regions (VRs)**



- **Fit in CR:**
  - Simultaneous fit of all components in CR

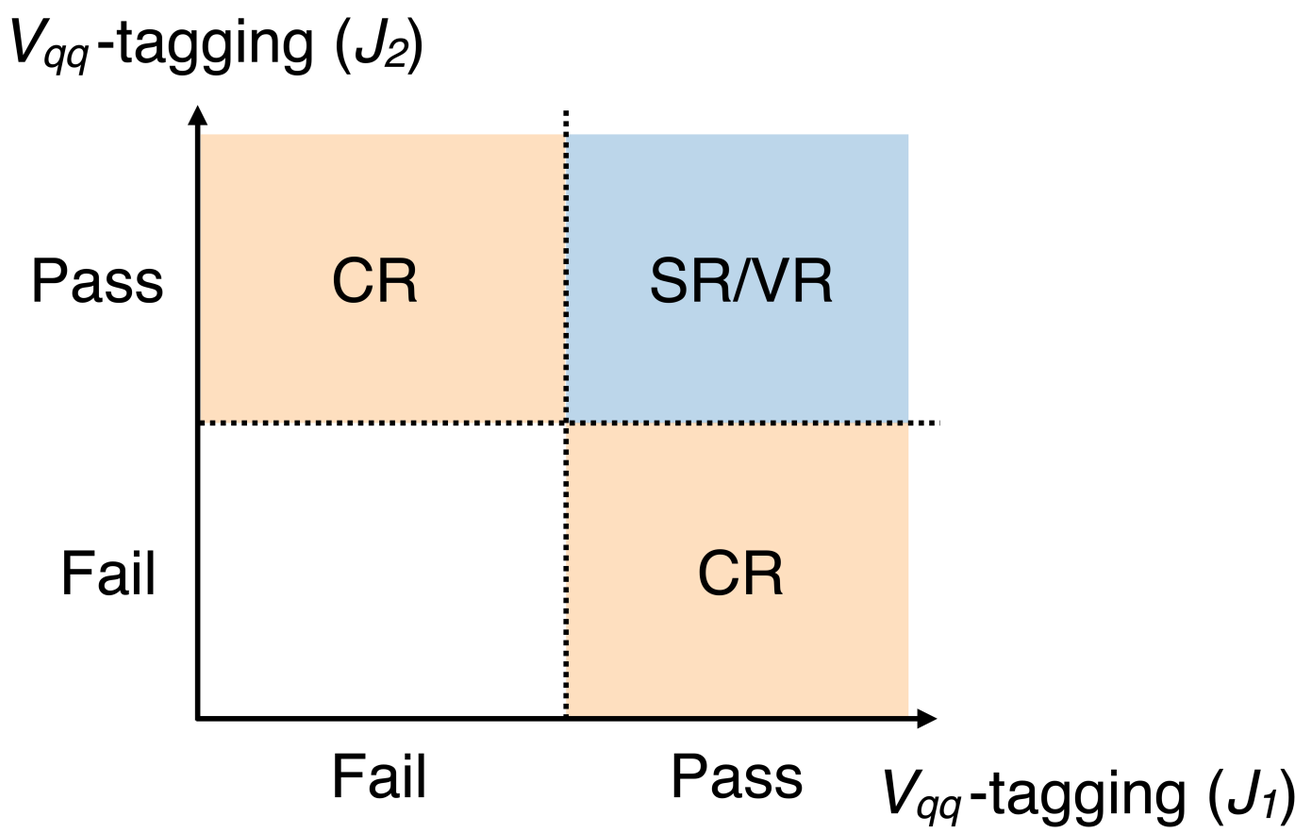
- **Check modelling in VR (post-fit):**
  - SM backgrounds (with MC)
  - Fake objects (MC and/or data-driven)

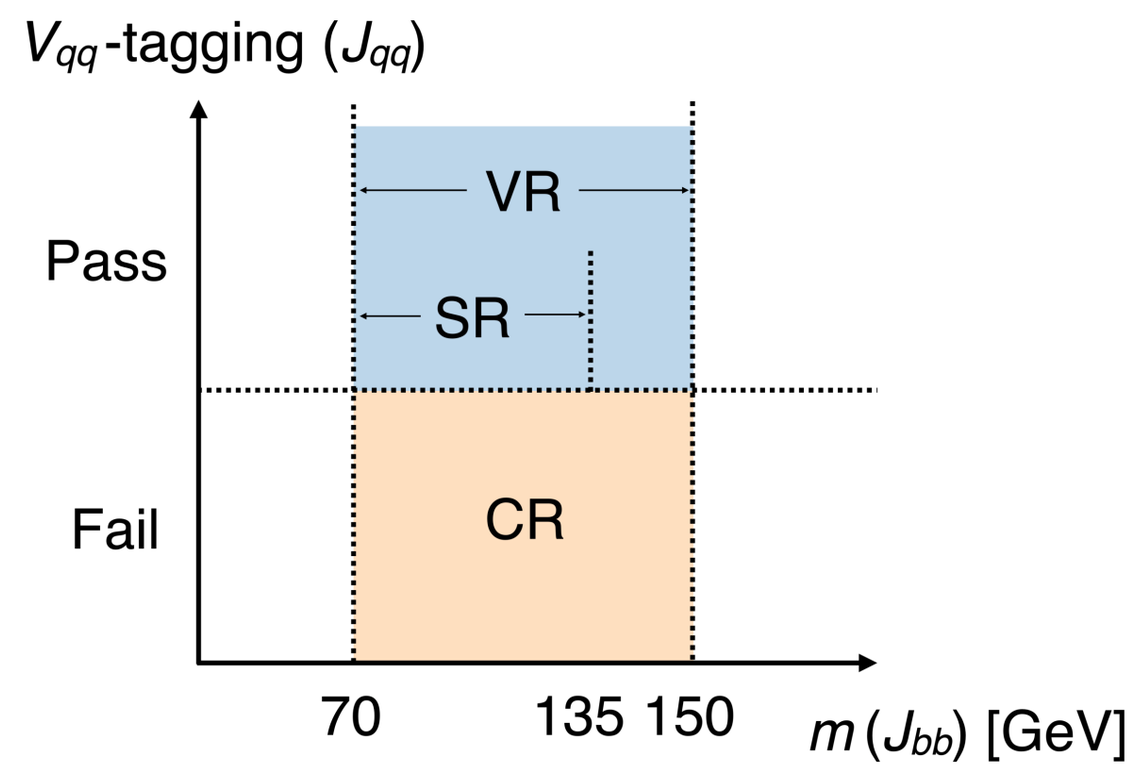
- **Combined fit of CR and SR:**
  - Fit for discovery or exclusion

Fully hadronic production modes

Model	Production	Final states	SRs simultaneously fitted	Branching ratio
$(\widetilde{W},\widetilde{B})$	$\widetilde{\chi}_1^\pm\widetilde{\chi}_1^\mp, \widetilde{\chi}_1^\pm\widetilde{\chi}_2^0$	WW, WZ, Wh	4Q-VV, 2B2Q-WZ, 2B2Q-Wh	$\mathcal{B}(\widetilde{\chi}_1^\pm \to W\widetilde{\chi}_1^0) = 1$, $\mathcal{B}(\widetilde{\chi}_2^0 \to Z\widetilde{\chi}_1^0)$ scanned.
$(\widetilde{H},\widetilde{B})$	$\widetilde{\chi}_1^\pm\widetilde{\chi}_1^\mp, \widetilde{\chi}_1^\pm\widetilde{\chi}_2^0, \widetilde{\chi}_1^\pm\widetilde{\chi}_3^0, \widetilde{\chi}_2^0\widetilde{\chi}_3^0$	WW, WZ, Wh, ZZ, Zh, hh	4Q-VV, 2B2Q-VZ, 2B2Q-Vh	$\mathcal{B}(\widetilde{\chi}_1^\pm \to W\widetilde{\chi}_1^0) = 1$, $\mathcal{B}(\widetilde{\chi}_2^0 \to Z\widetilde{\chi}_1^0)$ scanned, $\mathcal{B}(\widetilde{\chi}_3^0 \to h\widetilde{\chi}_1^0) = 1 - \mathcal{B}(\widetilde{\chi}_2^0 \to Z\widetilde{\chi}_1^0)$
$(\widetilde{W},\widetilde{H})$	$\widetilde{\chi}_2^\pm\widetilde{\chi}_2^\mp, \widetilde{\chi}_2^\pm\widetilde{\chi}_3^0$	WW, WZ, Wh, ZZ, Zh, hh	4Q-VV, 2B2Q-VZ, 2B2Q-Vh	Determined from $(M_2, \mu, \tan\beta)$.
$(\widetilde{H},\widetilde{W})$	$\widetilde{\chi}_2^\pm\widetilde{\chi}_2^\mp, \widetilde{\chi}_2^\pm\widetilde{\chi}_2^0, \widetilde{\chi}_2^\pm\widetilde{\chi}_3^0, \widetilde{\chi}_2^0\widetilde{\chi}_3^0$	WW, WZ, Wh, ZZ, Zh, hh	4Q-VV, 2B2Q-VZ, 2B2Q-Vh	Determined from $(M_2, \mu, \tan\beta)$.
$(\widetilde{H},\widetilde{G})$	$\widetilde{\chi}_1^\pm\widetilde{\chi}_1^\mp, \widetilde{\chi}_1^\pm\widetilde{\chi}_1^0, \widetilde{\chi}_1^\pm\widetilde{\chi}_2^0, \widetilde{\chi}_1^0\widetilde{\chi}_2^0$	ZZ, Zh, hh	4Q-ZZ, 2B2Q-ZZ, 2B2Q-Zh	$\mathcal{B}(\widetilde{\chi}_1^0 \to h\widetilde{G})$ scanned.
$(\widetilde{H},\tilde{a})$	$\widetilde{\chi}_1^\pm\widetilde{\chi}_1^\mp, \widetilde{\chi}_1^\pm\widetilde{\chi}_1^0, \widetilde{\chi}_1^\pm\widetilde{\chi}_2^0, \widetilde{\chi}_1^0\widetilde{\chi}_2^0$	ZZ, Zh, hh	4Q-ZZ, 2B2Q-ZZ, 2B2Q-Zh	$\mathcal{B}(\widetilde{\chi}_1^0 \to h\tilde{a})$ scanned.
$(\widetilde{W},\widetilde{B})$ simplified models: $(\widetilde{W},\widetilde{B})$-SIM				
C1C1-WW	$\widetilde{\chi}_1^\pm\widetilde{\chi}_1^\mp$	WW	4Q-WW	$\mathcal{B}(\widetilde{\chi}_1^\pm \to W\widetilde{\chi}_1^0) = 1$.
C1N2-WZ	$\widetilde{\chi}_1^\pm\widetilde{\chi}_2^0$	WZ	4Q-WZ, 2B2Q-WZ	$\mathcal{B}(\widetilde{\chi}_1^\pm \to W\widetilde{\chi}_1^0) = \mathcal{B}(\widetilde{\chi}_2^0 \to Z\widetilde{\chi}_1^0) = 1$.
C1N2-Wh	$\widetilde{\chi}_1^\pm\widetilde{\chi}_2^0$	Wh	2B2Q-Wh	$\mathcal{B}(\widetilde{\chi}_1^\pm \to W\widetilde{\chi}_1^0) = \mathcal{B}(\widetilde{\chi}_2^0 \to h\widetilde{\chi}_1^0) = 1$.

Fully hadronic SR definitions





Fully hadronic boosted regions

	SR(CR0L)		VR(CR)1L		VR(CR)1Y		VRTTX
	4Q	2B2Q	4Q	2B2Q	4Q	2B2Q	
$n_{\text{Large}-R\text{ jets}}$	≥ 2		≥ 2		≥ 2		$= 1$
n_{lepton}	$= 0$		$= 1$		$= 0$		$= 3$
$p_{\text{T}}(\ell_1)$ [GeV]	-		> 30		-		> 30
n_{photon}	-		-		$= 1$		-
$n(V_{qq})$	$= 2\ (= 1)$	$= 1\ (= 0)$	$= 2\ (= 1)$	$= 1\ (= 0)$	$= 2\ (= 1)$	$= 1\ (= 0)$	-
$n(!V_{qq})$	$= 0\ (= 1)$	$= 0\ (= 1)$	$= 0\ (= 1)$	$= 0\ (= 1)$	$= 0\ (= 1)$	$= 0\ (= 1)$	-
$n(J_{bb})$	$= 0$	$= 1$	$= 0$	$= 1$	$= 0$	$= 1$	$= 1$
$m(J_{bb})$ [GeV]	-	$\in [70, 135\ (150)]$	-	$\in [70, 150]$	-	$\in [70, 150]$	-
$n_{b-\text{jet}}^{\text{unmatched}}$	$= 0$		$= 0$		$= 0$		-
$n_{b-\text{jet}}$	≤ 1	-	$= 0$	-	≤ 1	-	-
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 300	> 200	> 50		< 200		-
$p_{\text{T}}(W)$ [GeV]	-		> 200		-		-
$p_{\text{T}}(\gamma)$ [GeV]	-		-		> 200		-
m_{eff} [GeV]	> 1300	$> 1000\ (> 900)$	> 1000	> 900	> 1000	> 900	-
$\min \Delta\phi(V, j)$	> 1.0		> 1.0		> 1.0		-
m_{T2} [GeV]	-	> 250	-	> 250	-	> 250	-

EWP yy analysis categories

Bin number	Category	$p_T^{\gamma\gamma}$ (GeV)	M_R (GeV)	R^2
EWP 0	Two-Lepton	No req.	No req.	No req.
EWP 1	Muon High-p_T	≥110	≥150	≥0.0
EWP 2	Muon Low-p_T	0–110	≥150	≥0.0
EWP 3	Electron High-p_T	≥110	≥150	≥0.0
EWP 4	Electron Low-p_T	0–110	≥150	0.000–0.055
EWP 5	Electron Low-p_T	0–110	≥150	0.055–0.125
EWP 6	Electron Low-p_T	0–110	≥150	≥0.125
EWP 7	$Hb\bar{b}$ High-p_T	≥110	≥150	0.000–0.080
EWP 8	$Hb\bar{b}$ High-p_T	≥110	≥150	≥0.080
EWP 9	$Hb\bar{b}$ Low-p_T	0–110	≥150	0.000–0.080
EWP 10	$Hb\bar{b}$ Low-p_T	0–110	≥150	≥0.080
EWP 11	$Zb\bar{b}$ High-p_T	≥110	≥150	0.000–0.035
EWP 12	$Zb\bar{b}$ High-p_T	≥110	≥150	0.035–0.090
EWP 13	$Zb\bar{b}$ High-p_T	≥110	≥150	≥0.090
EWP 14	$Zb\bar{b}$ Low-p_T	0–110	≥150	0.000–0.035
EWP 15	$Zb\bar{b}$ Low-p_T	0–110	≥150	0.035–0.090
EWP 16	$Zb\bar{b}$ Low-p_T	0–110	≥150	≥0.090
EWP 17	High-p_T	≥110	≥150	≥0.260
EWP 18	High-p_T	≥110	150–250	0.170–0.260
EWP 19	High-p_T	≥110	≥250	0.170–0.260
EWP 20	High-p_T	≥110	≥150	0.000–0.110
EWP 21	High-p_T	≥110	150–350	0.110–0.170
EWP 22	High-p_T	≥110	≥350	0.110–0.170
EWP 23	High-Res	0–110	≥150	≥0.325
EWP 24	High-Res	0–110	≥150	0.285–0.325
EWP 25	High-Res	0–110	≥150	0.225–0.285
EWP 26	High-Res	0–110	≥150	0.000–0.185
EWP 27	High-Res	0–110	150–200	0.185–0.225
EWP 28	High-Res	0–110	≥200	0.185–0.225
EWP 29	Low-Res	0–110	≥150	≥0.325
EWP 30	Low-Res	0–110	≥150	0.285–0.325
EWP 31	Low-Res	0–110	≥150	0.225–0.285
EWP 32	Low-Res	0–110	≥150	0.000–0.185
EWP 33	Low-Res	0–110	150–200	0.185–0.225
EWP 34	Low-Res	0–110	≥200	0.185–0.225

Chargino/Neutralino: Wh, h->γγ

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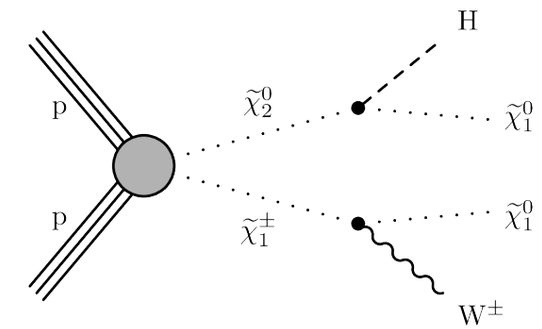
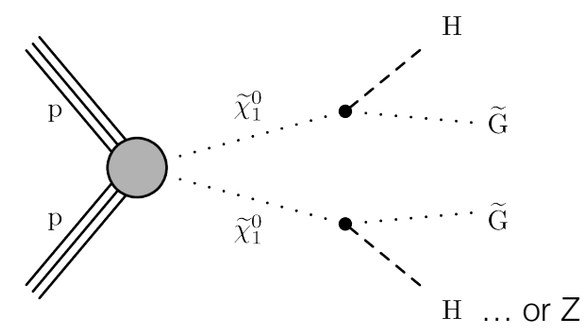
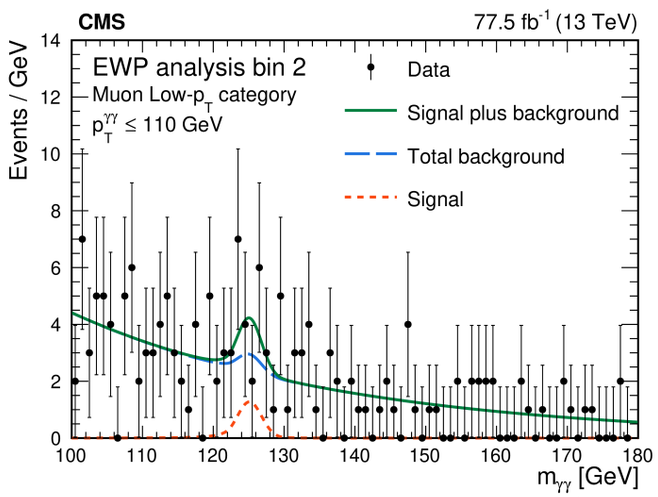
- **Higgs boson decay to diphotons**
- Categories based on pT of the diphoton h, and additional Z, W, or H → bb candidates
- SR bins: N (b-)jets and razor variables



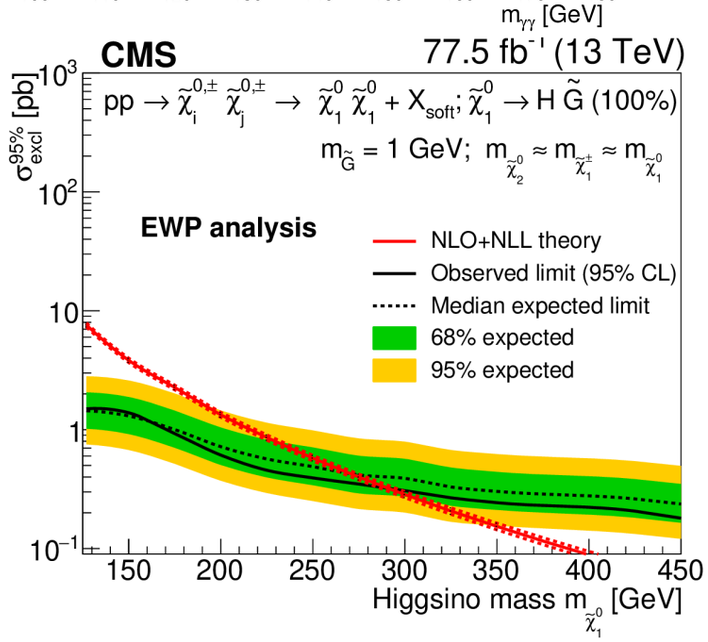
Wino-like model NLSP

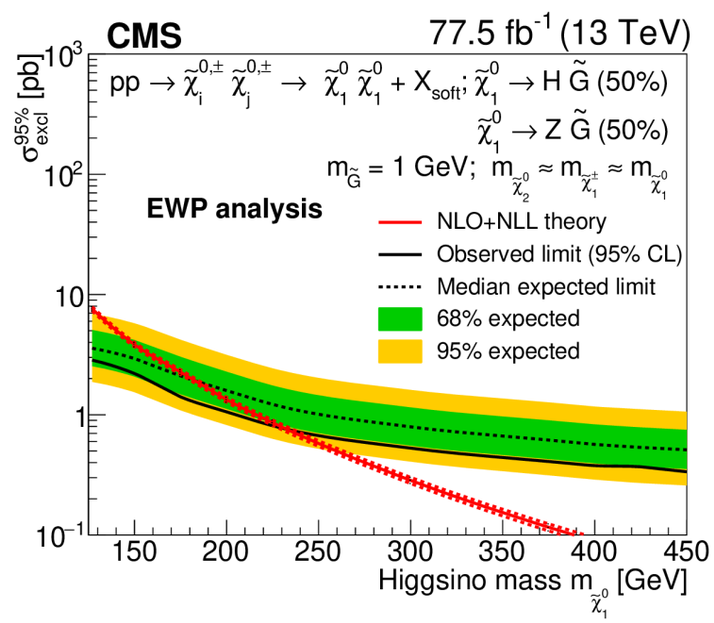


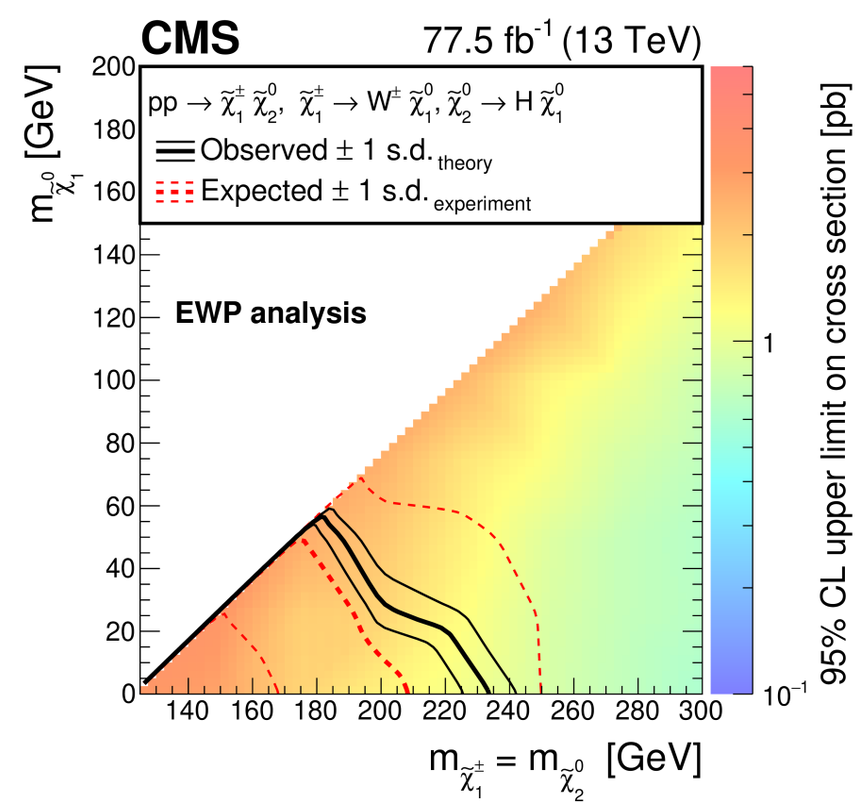
Higgsino-like neutralino PP



- Parametrised likelihood fits in each SR
- **Wino-like:** Excluded chargino and neutralino masses below 235 GeV with a gravitino mass of 1 GeV





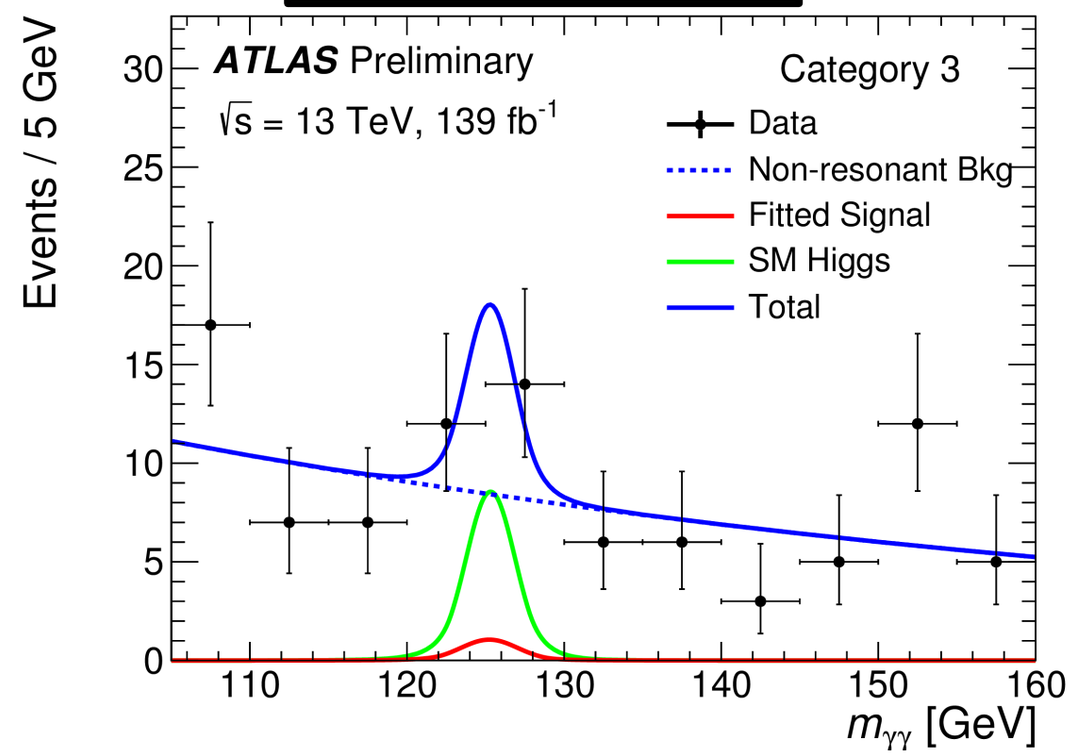


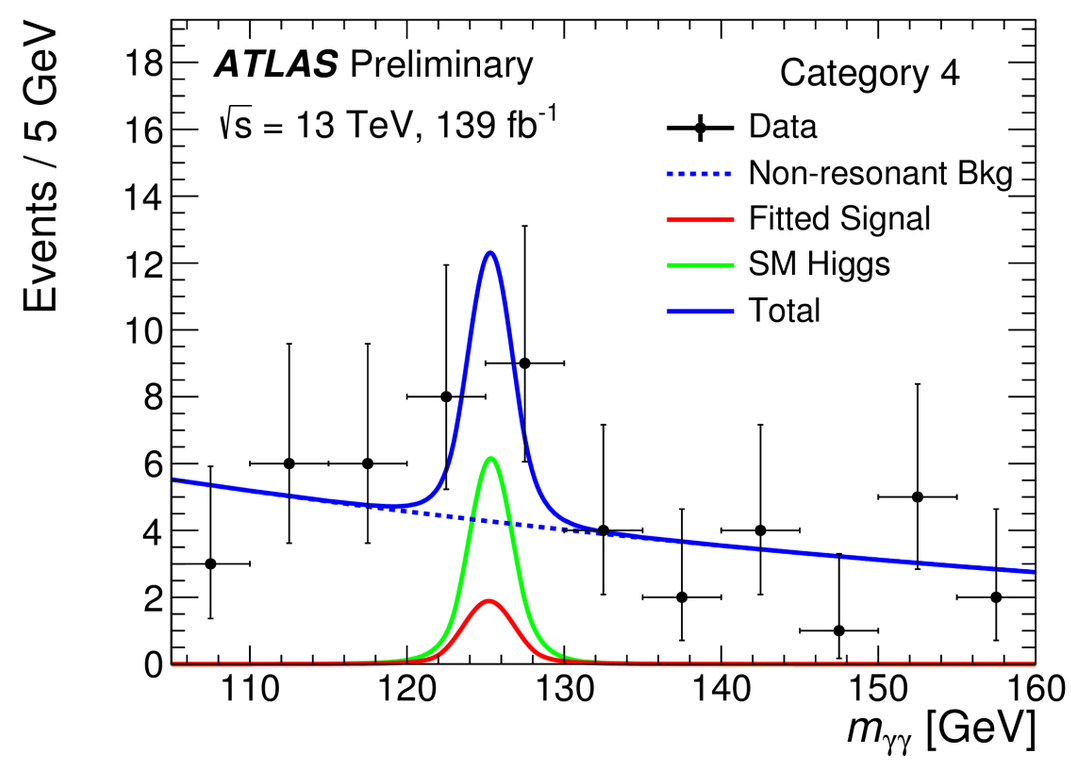
- **Higgsino-like:** Excluded neutralino decays exclusively to a h and a gravitino for neutralino masses below 290 GeV

Modelling the Higgs as background

- **Dominant backgrounds:**
  - Resonant Higgs
  - Non-resonant γγ, γ+jet
- Higgs modelled as double-sided crystal ball functions
- Non-resonant background fitted in sideband regions
  - *Different analytic functions per region*
- SM Higgs predictions across categories
- **Excess fitted as signal**
- Combined un-binned likelihood fit

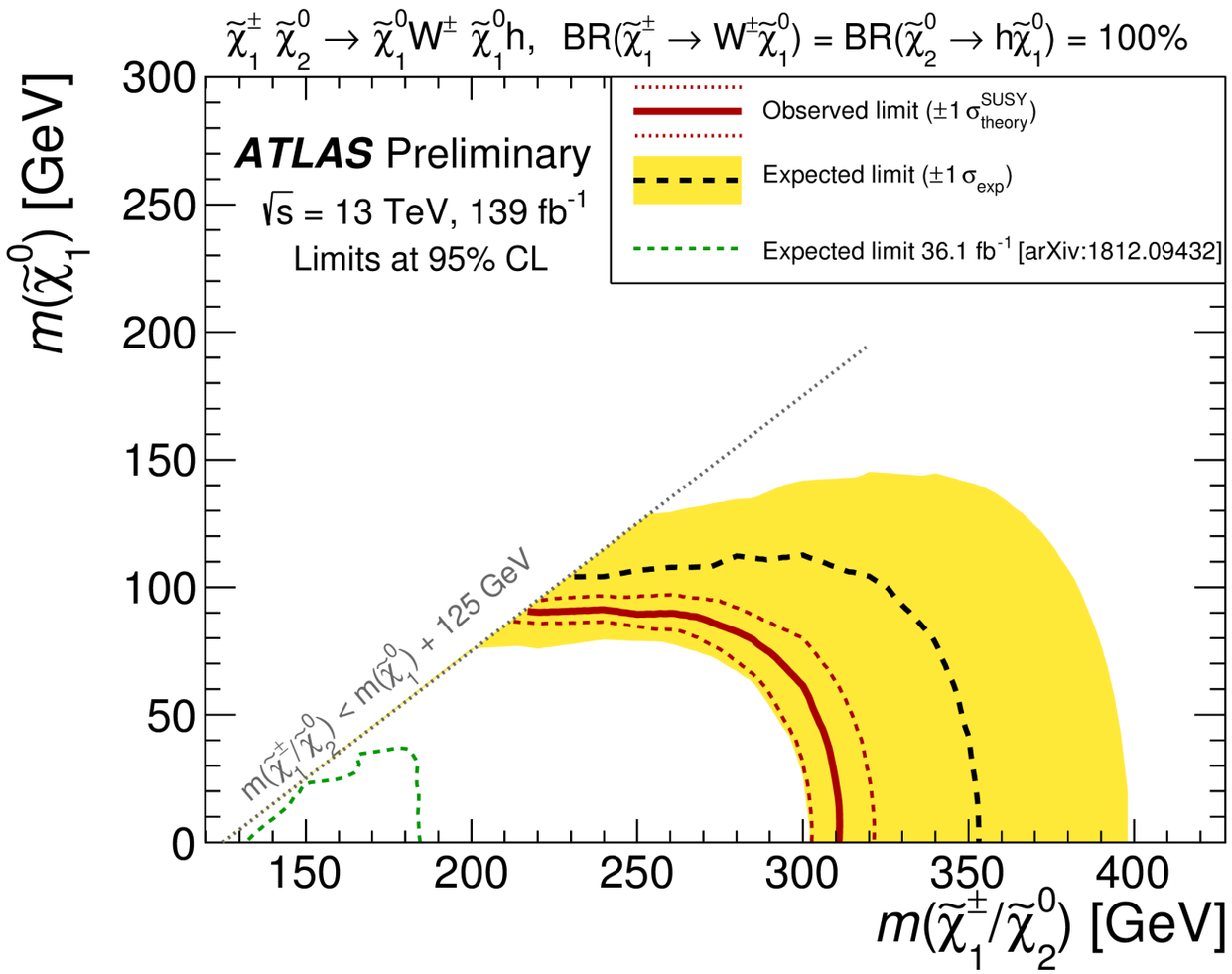
2 Leptonic categories



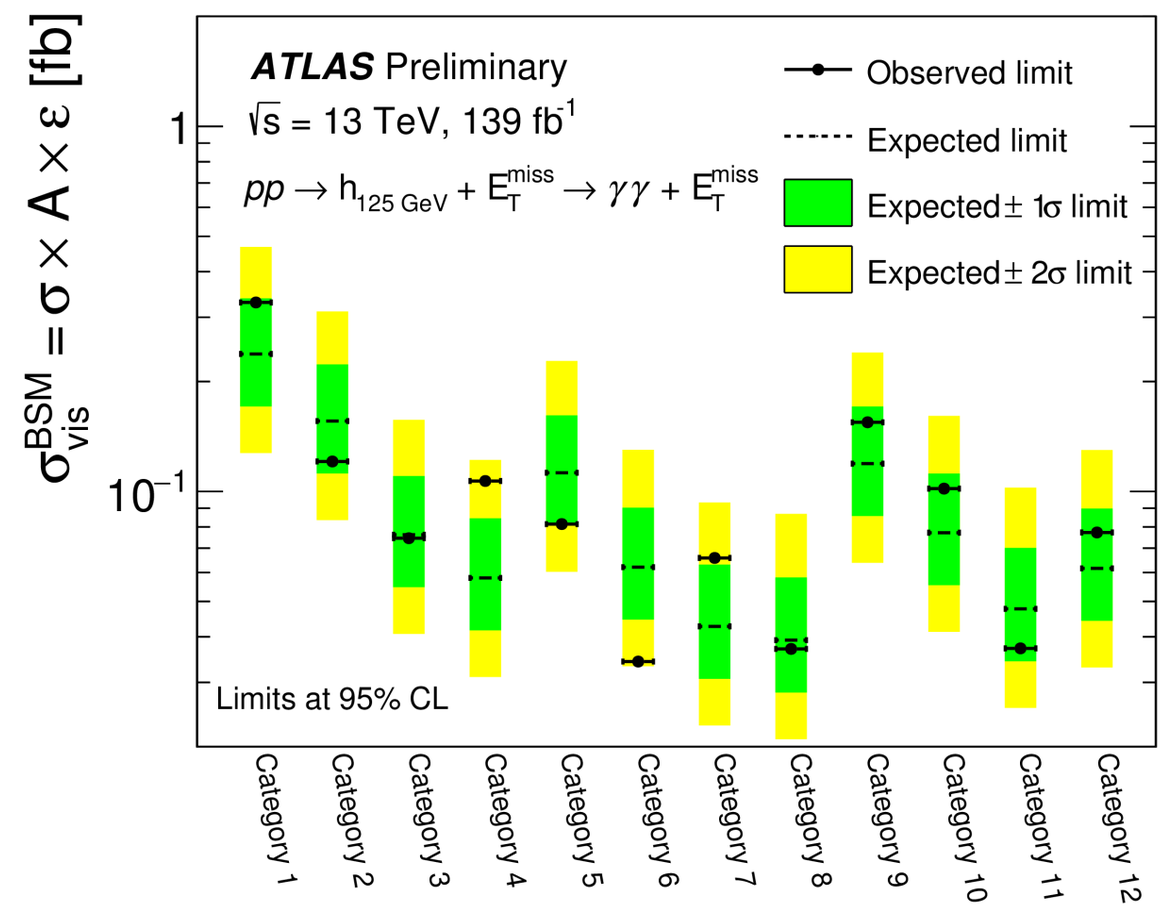


General Limits

- No significant excess was found in any individual category
- **No significant excess observed in combined fit to data**



Model-independent upper limits on the visible cross section



- **First observed sensitivity to Wh(γγ) at ATLAS**
- Large gain when compared to 36 fb^{-1}
  - *Use of all W boson decay channels*

WH(γγ) Categories

Channels	Names	Selection
Leptonic	Category 1	$0 < S_{E_{\mathrm{T}}^{\mathrm{miss}}} \leq 2,\ N_\ell \geq 1$
	Category 2	$2 < S_{E_{\mathrm{T}}^{\mathrm{miss}}} \leq 4,\ N_\ell \geq 1$
	Category 3	$4 < S_{E_{\mathrm{T}}^{\mathrm{miss}}} \leq 6,\ N_\ell \geq 1$
	Category 4	$S_{E_{\mathrm{T}}^{\mathrm{miss}}} > 6,\ N_\ell \geq 1$
Hadronic	Category 5	$5 < S_{E_{\mathrm{T}}^{\mathrm{miss}}} \leq 6,\ N_\ell = 0,\ N_j \geq 2,\ M_{jj} \in [40, 120]\ GeV$
	Category 6	$6 < S_{E_{\mathrm{T}}^{\mathrm{miss}}} \leq 7,\ N_\ell = 0,\ N_j \geq 2,\ M_{jj} \in [40, 120]\ GeV$
	Category 7	$7 < S_{E_{\mathrm{T}}^{\mathrm{miss}}} \leq 8,\ N_\ell = 0,\ N_j \geq 2,\ M_{jj} \in [40, 120]\ GeV$
	Category 8	$S_{E_{\mathrm{T}}^{\mathrm{miss}}} > 8,\ N_\ell = 0,\ N_j \geq 2,\ M_{jj} \in [40, 120]\ GeV$
Rest	Category 9	$6 < S_{E_{\mathrm{T}}^{\mathrm{miss}}} \leq 7,\ N_\ell = 0,\ N_j < 2$ or $(\ N_j \geq 2,\ M_{jj} \notin [40, 120]\ GeV)$
	Category 10	$7 < S_{E_{\mathrm{T}}^{\mathrm{miss}}} \leq 8,\ N_\ell = 0,\ N_j < 2$ or $(\ N_j \geq 2,\ M_{jj} \notin [40, 120]\ GeV)$
	Category 11	$8 < S_{E_{\mathrm{T}}^{\mathrm{miss}}} \leq 9,\ N_\ell = 0,\ N_j < 2$ or $(\ N_j \geq 2,\ M_{jj} \notin [40, 120]\ GeV)$
	Category 12	$S_{E_{\mathrm{T}}^{\mathrm{miss}}} > 9,\ N_\ell = 0,\ N_j < 2$ or $(\ N_j \geq 2,\ M_{jj} \notin [40, 120]\ GeV)$

WH(γγ): Analytic function

Category	Function	$\Delta N_{\text{bkg}}^{\text{non-res}}$	$\Delta N_{\text{bkg}}^{\text{non-res}} / N_{\text{bkg}}^{\text{non-res.}}$ [%]
1	$(1 - x^{1/3})^b \cdot x^a$	5.5	2.4
2	$\sum_{j=0}^{3} C_3^j x^j (1-x)^{3-j} b_{j,3}$	1.8	2.4
3	$\exp(a \cdot x)$	0.6	3.6
4	$\exp(a \cdot x)$	0.3	3.7
5	$\exp(a \cdot x)$	1.6	2.8
6	$\exp(a \cdot x)$	0.5	3.3
7	$\exp(a \cdot x)$	0.3	5.1
8	$\exp(a \cdot x)$	0.2	4.6
9	$\exp(a \cdot x)$	1.5	2.3
10	$\exp(a \cdot x)$	0.6	2.5
11	$\exp(a \cdot x)$	0.4	5.6
12	$\exp(a \cdot x)$	0.4	3.0

WH(γγ): Systematic uncertainties

Source	Signals [%]	Backgrounds [%]	
		SM Higgs boson	Non-resonant background
Experimental			
Luminosity		1.7	–
Jets (Scale, Resolution, JVT)	0.2–3.3	0.9–30.7	–
Electron/Photon (Scale, Resolution)	0.3–1.5	0.6–2.7	–
Photon (identification, isolation, trigger)	2.2–2.6	2.8–4.3	–
Electron (identification isolation)	0.0–0.5	0.0–0.6	–
Muon (identification, isolation, Scale, Resolution)	< 0.6	< 0.3	–
$E_{\mathrm{T}}^{\mathrm{miss}}$ reconstruction (jets, soft term)	< 0.7	0.4–13.9	–
Pileup reweighting	0.3–1.8	1.3–15	–
Non-resonant background modelling		–	2–6
Theoretical			
Factorization and renormalization scale	< 1	3.7–5.9	–
PDF+α_{S}	< 6.6	2.1–2.9	–
Multiple parton-parton interactions		< 1	–
BR($H \to \gamma\gamma$)		1.73	–

Chargino/Neutralino: Wh, h->γγ

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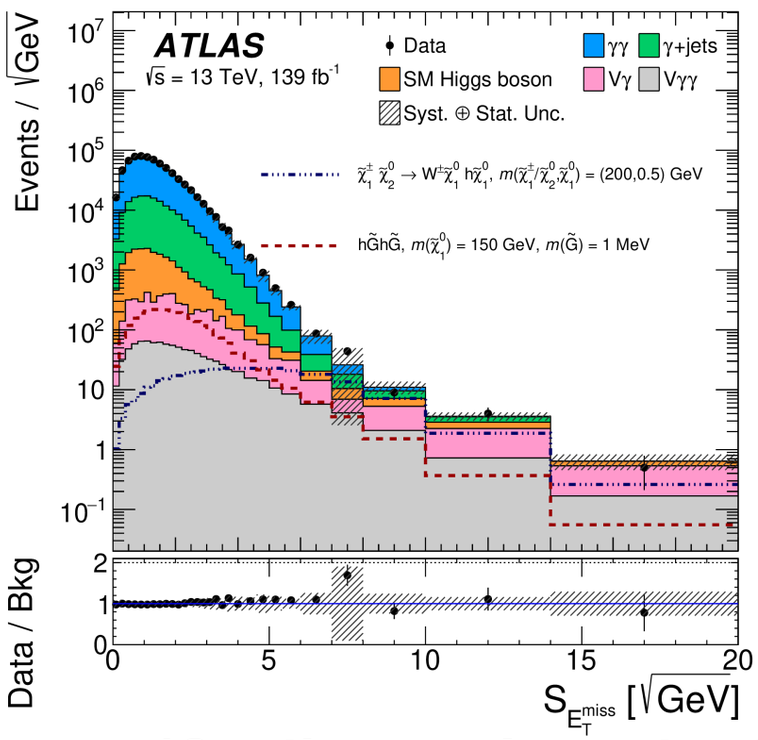
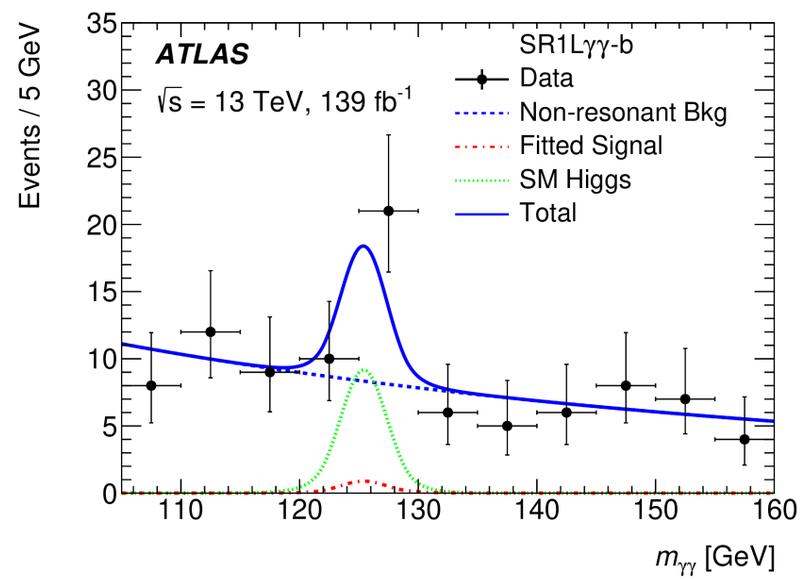
- Higgs boson decay to diphotons
  - Higgs Mass window: m(h)[105,160]GeV

- Main backgrounds from γγ and γ+jets
- Parametrised likelihood fits in each SR

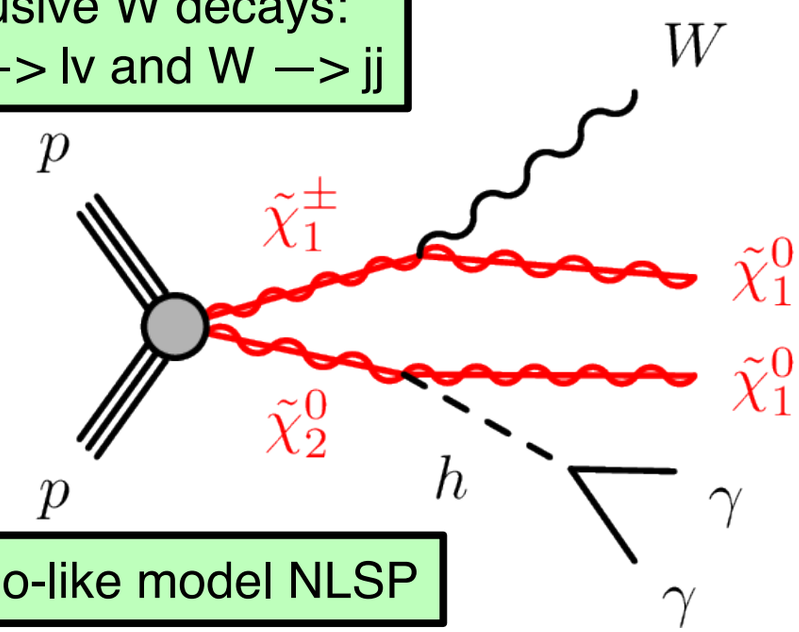




- **12 orthogonal event categories:**
  - Lepton / jet number
  - $S_{E_T^{miss}} = E_T^{miss} / \sqrt{E_T}$
  - Dijet invariant mass in 2jet categories

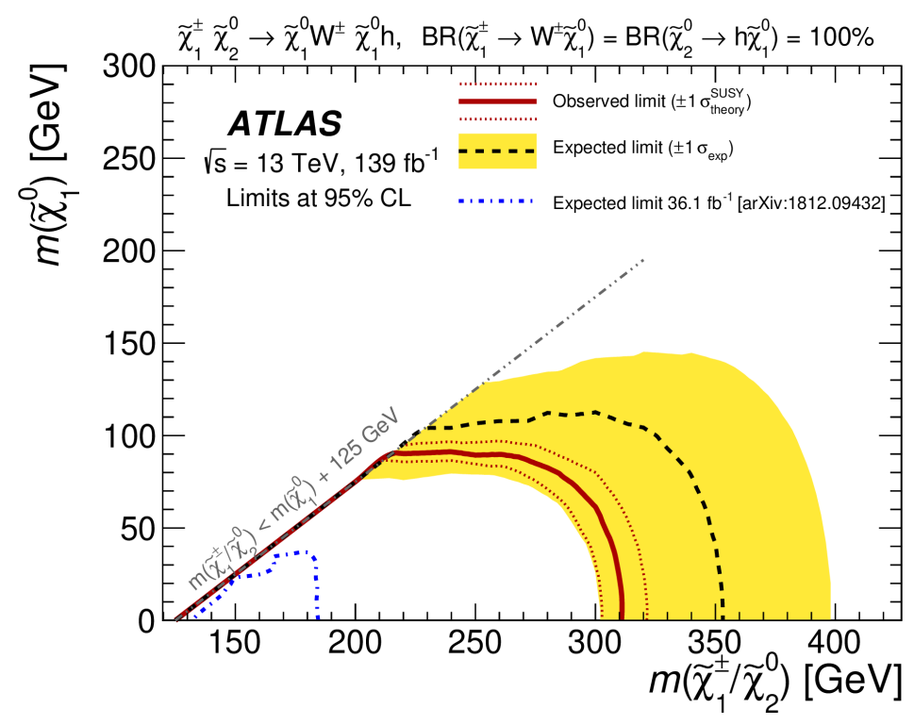
- **First observed sensitivity to Wh(γγ) at ATLAS**
- Limits up to 310 GeV for electroweakino production

Inclusive W decays:
W —> lν and W —> jj



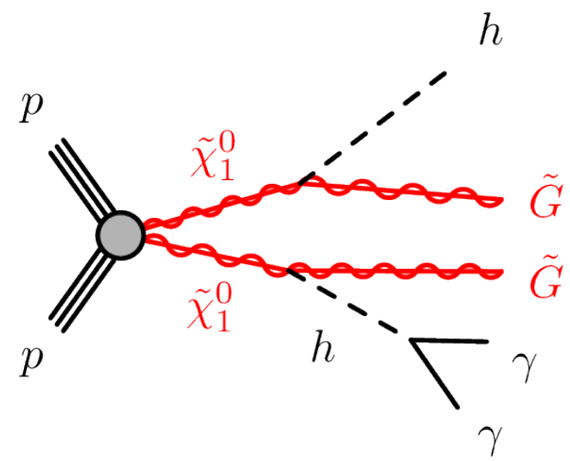
Wino-like model NLSP

- Non-resonant background fitted in sideband regions

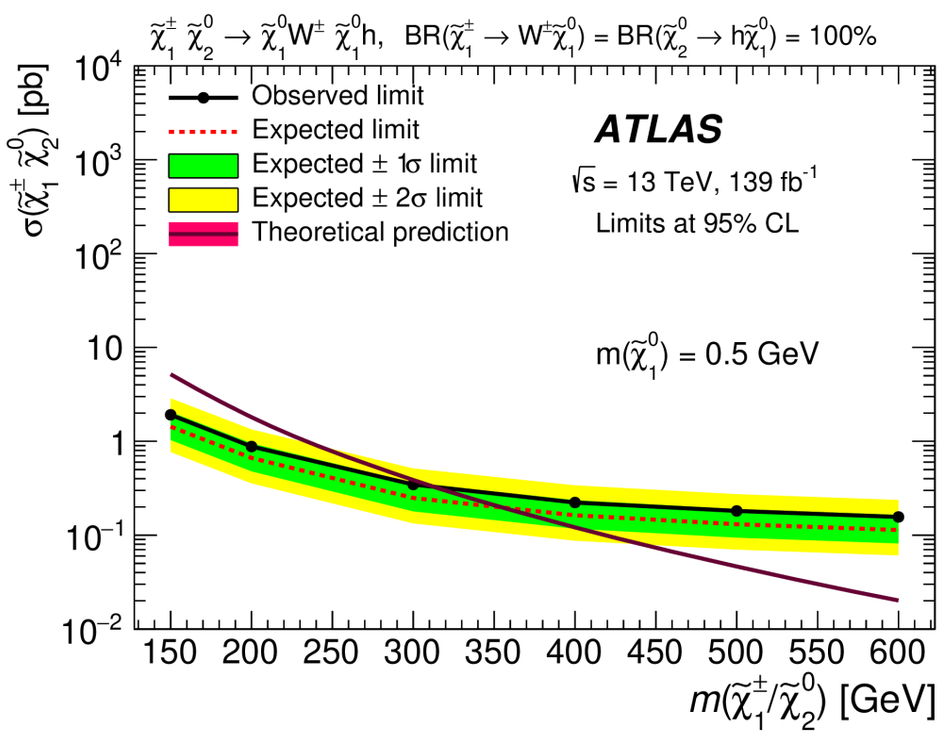


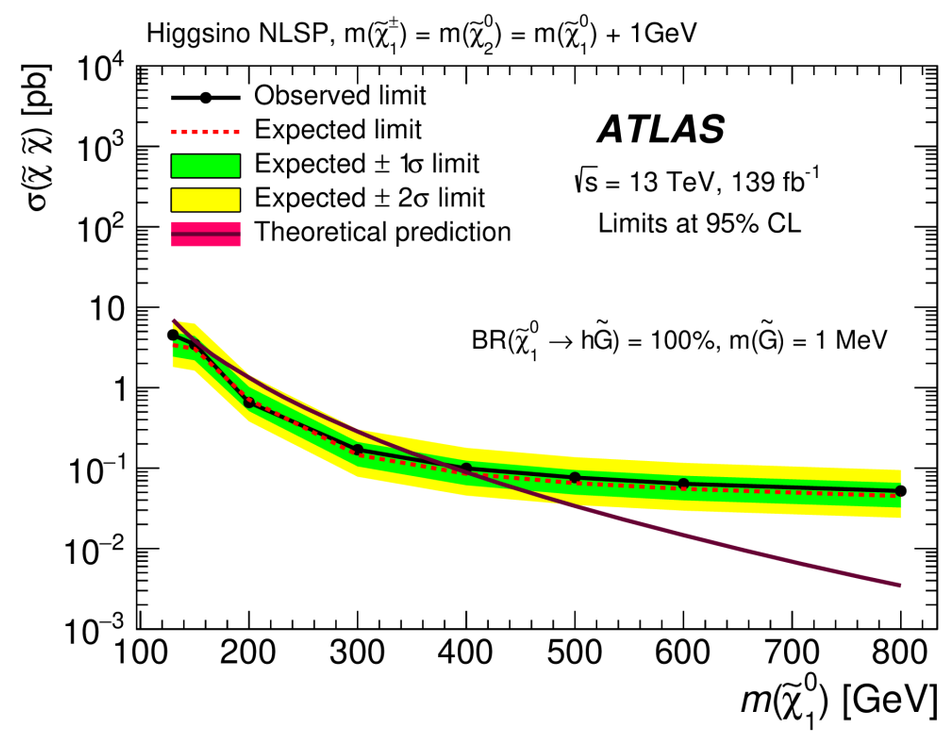
WH(γγ): Limits on GMSB model

- **GMSB model where two lightest neutralinos and the lightest chargino are Higgsinos**
- **LSP is the gravitino**



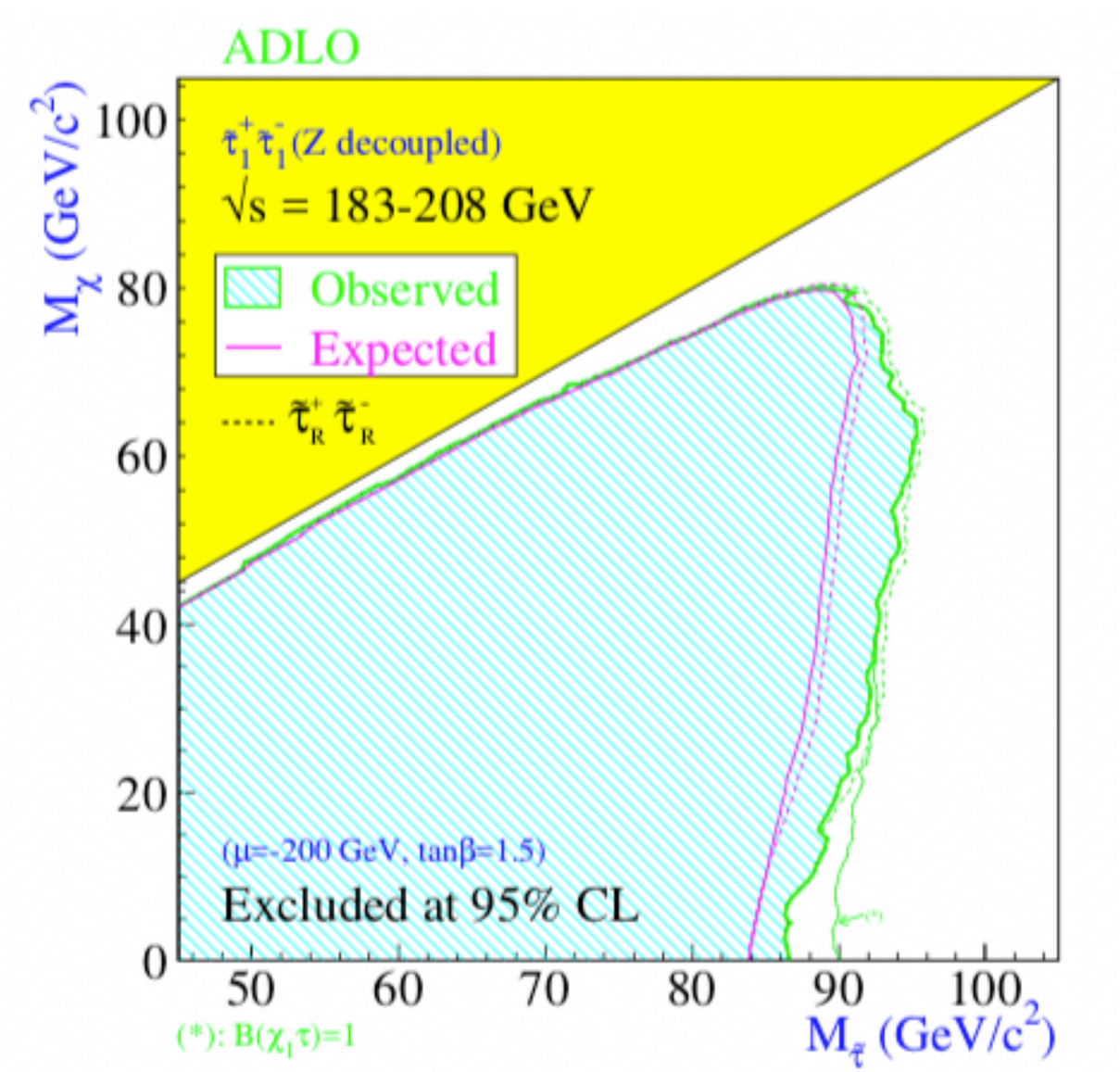
BR(hG) = 100 %

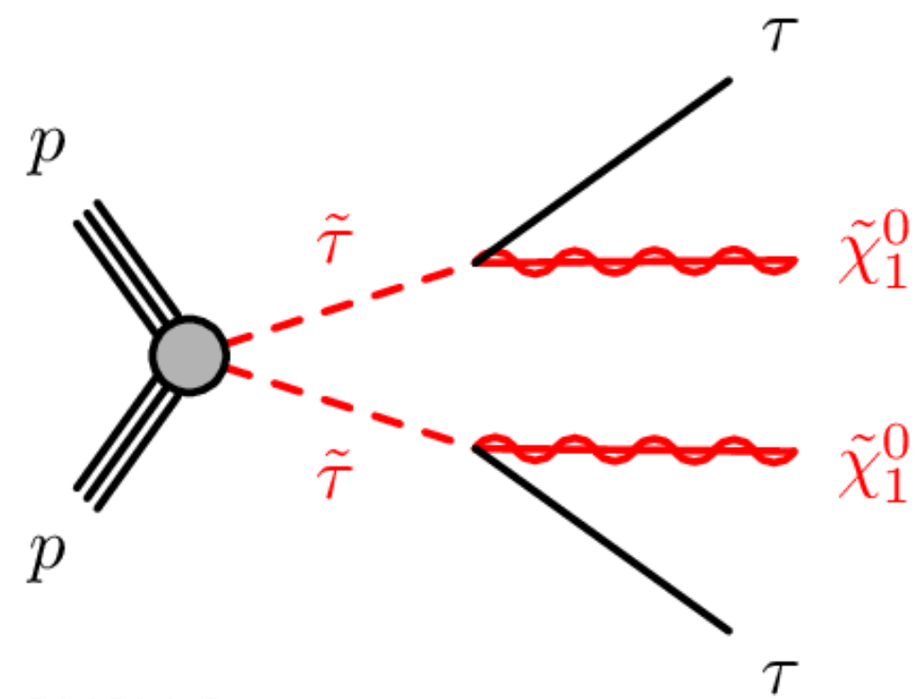




Direct stau production

- **Search for direct stau production using full Run-2**
  - Simplified model assuming two mass-degenerate staus
  - Decay to neutralino (LSP) and tau leptons





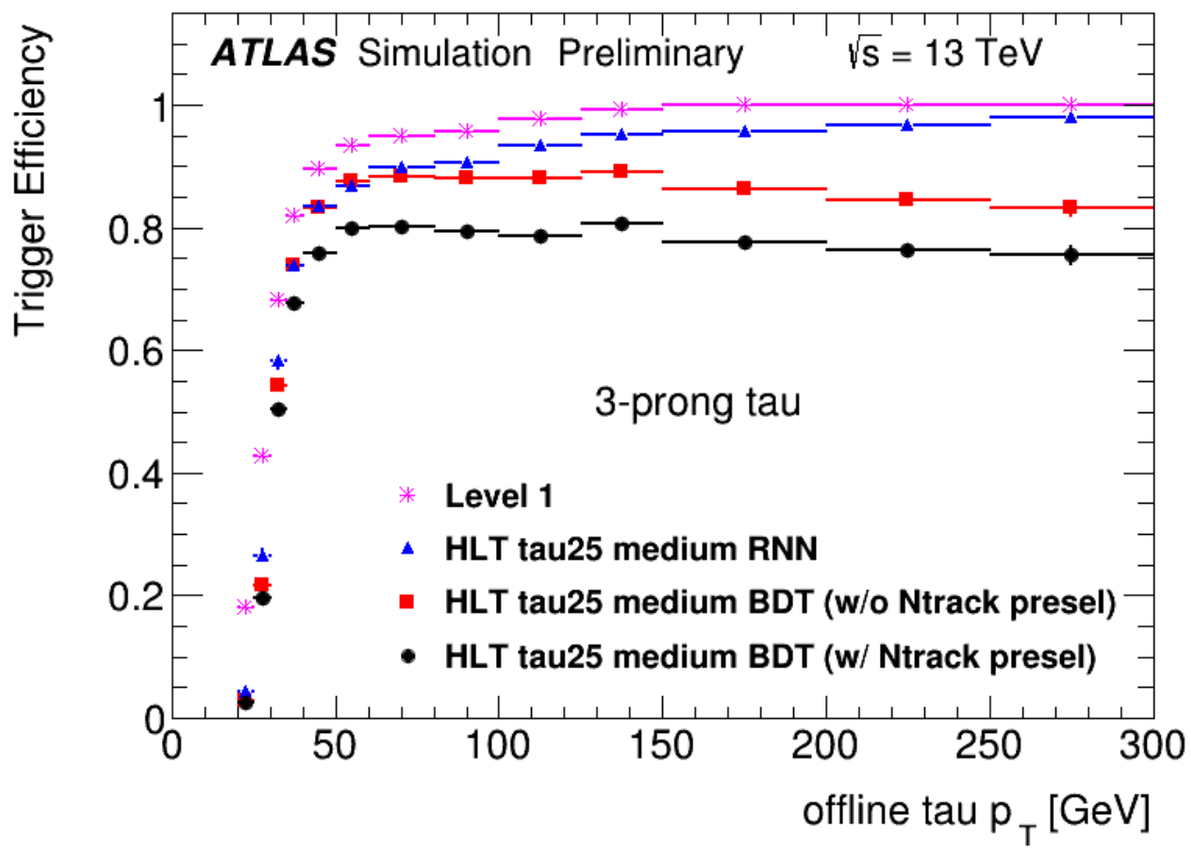
- *LEP SUSY Summary*
- Lower limits ~ 90 GeV for all neutralino masses *(set in 2004)*
- Combined LEP limit has prevailed to LHC Run-2

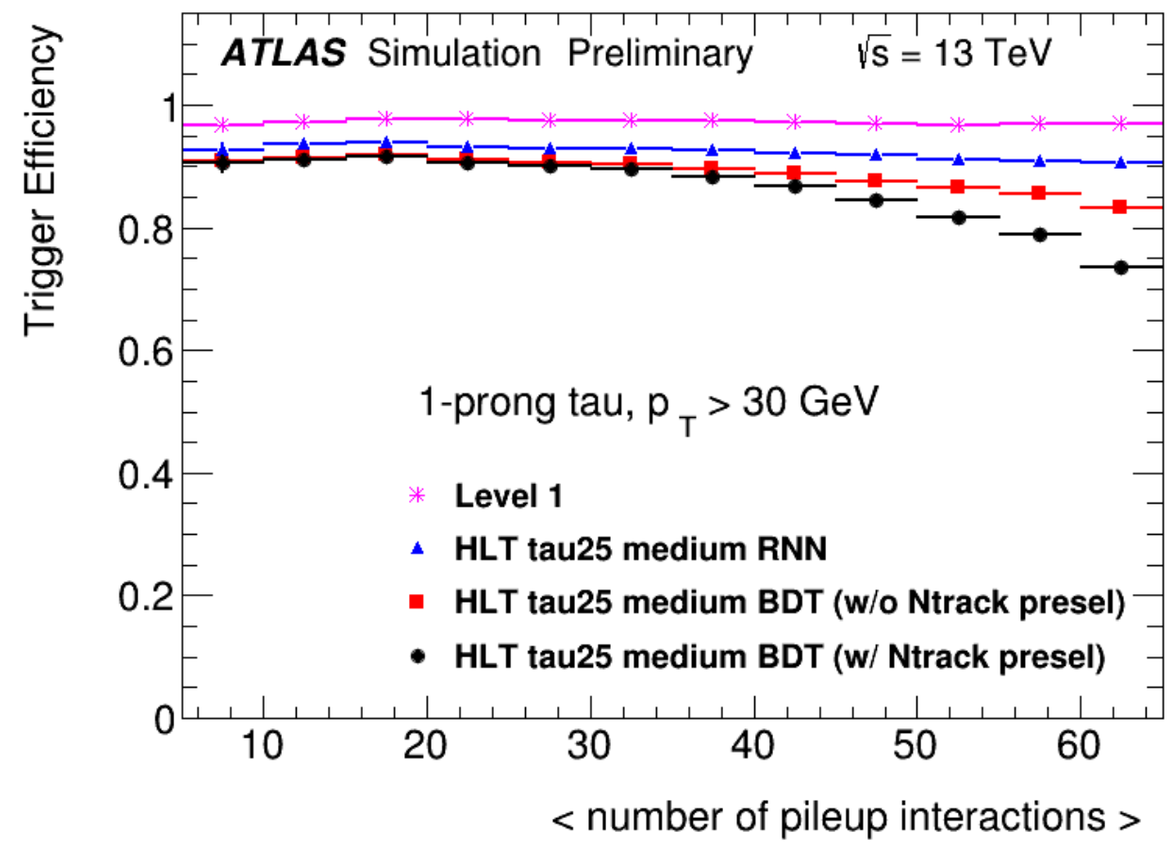
Identifying taus - Triggers

- **Improvements in tau triggers in 2018 data-taking**

- For full 2018 - included precision tracking instead of fast tracking pre-selection
  - *Reduction in fake track contamination —> increase in 3-prong tau efficiency*

- Post TS1 - included possibility to use RNN ID for taus

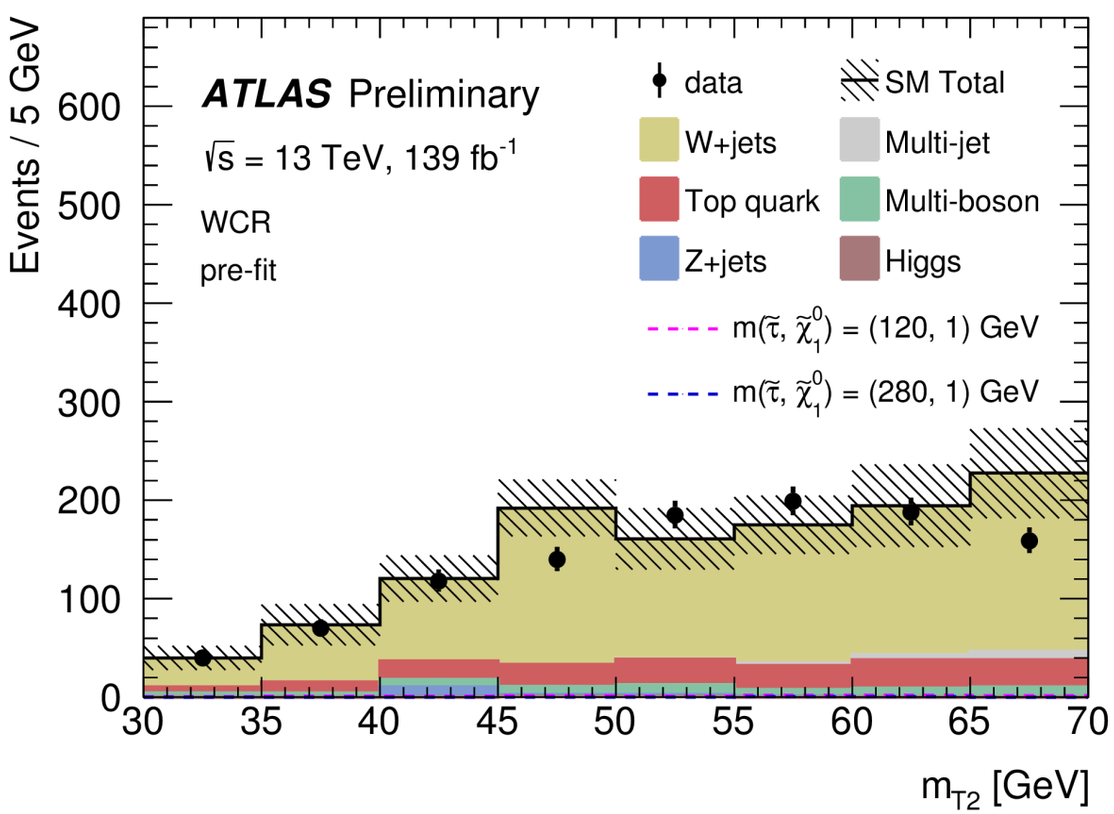


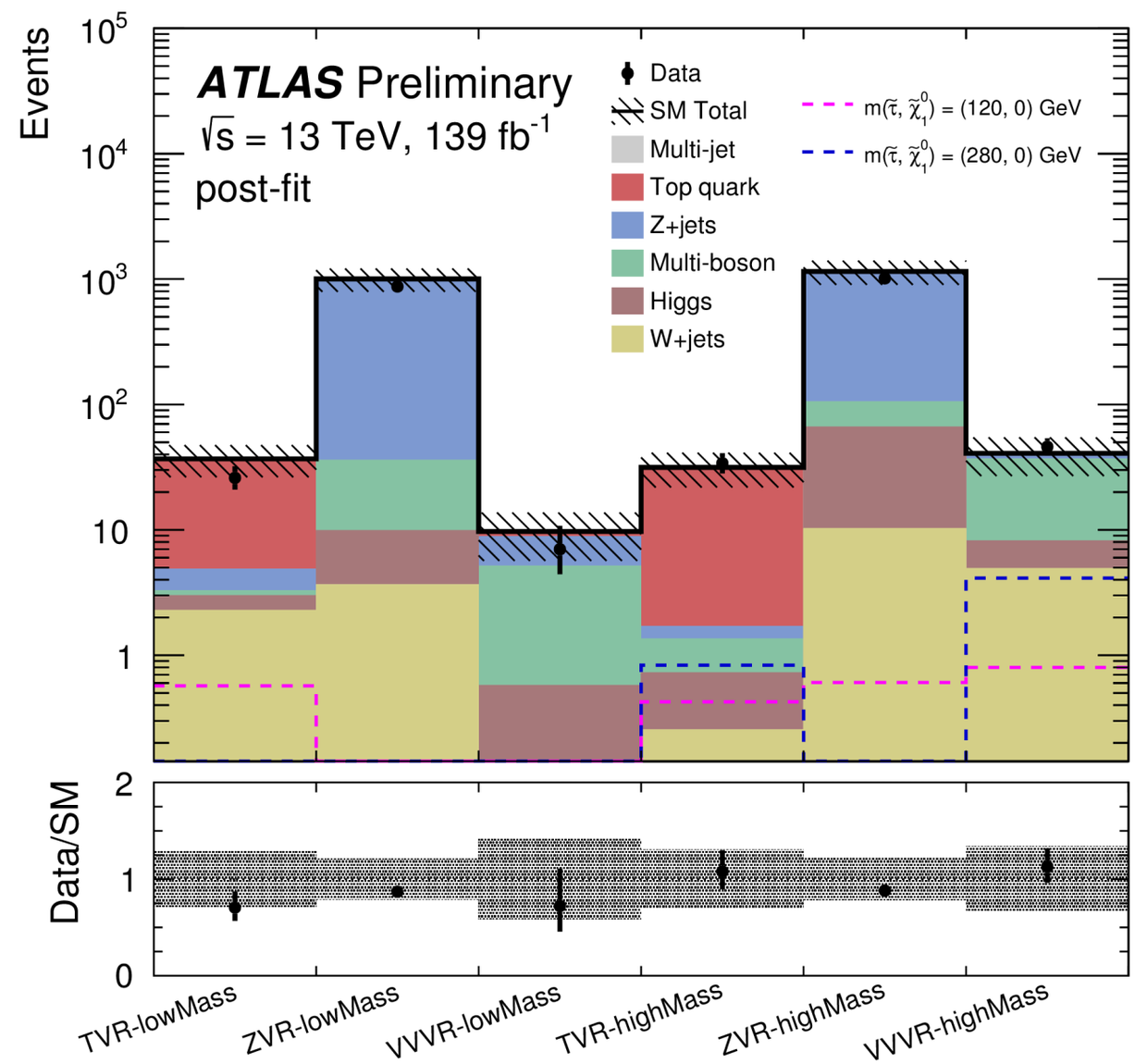


SRs and VRs

- **Two SRs: highMass and lowMass SR**
  - Trigger dependent
  - E_T^{miss} cut to split SRs (150 GeV)
  - mT2 > 70 GeV

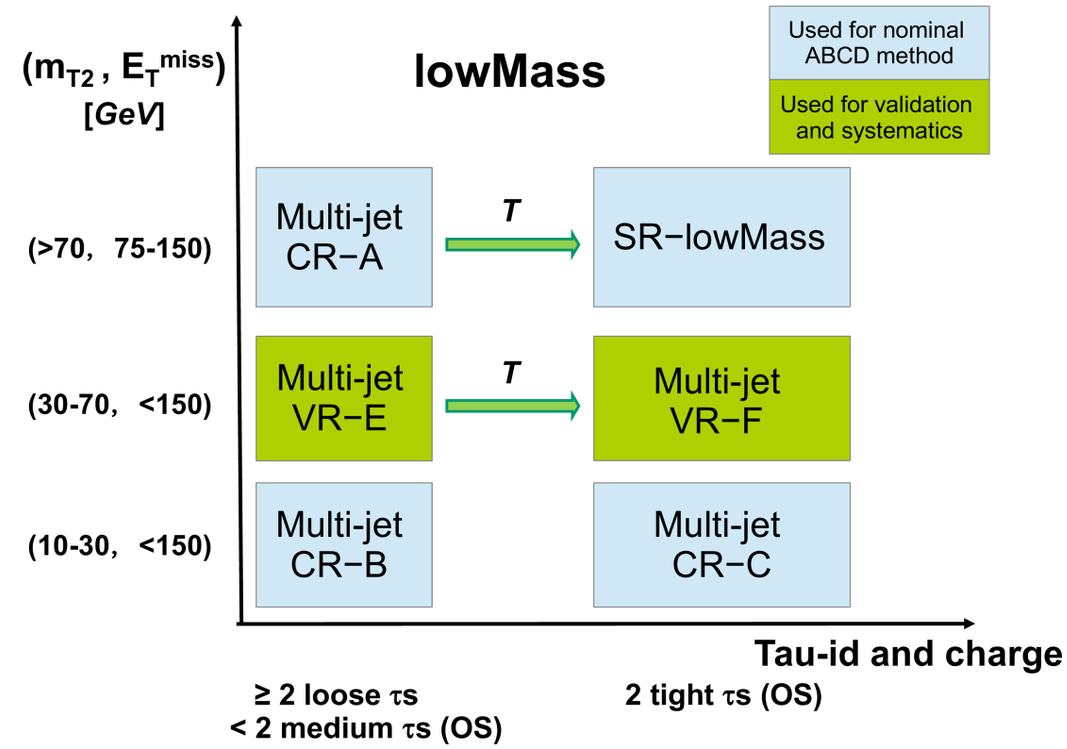
- Validation regions confirm good modelling of SM backgrounds (using MC)

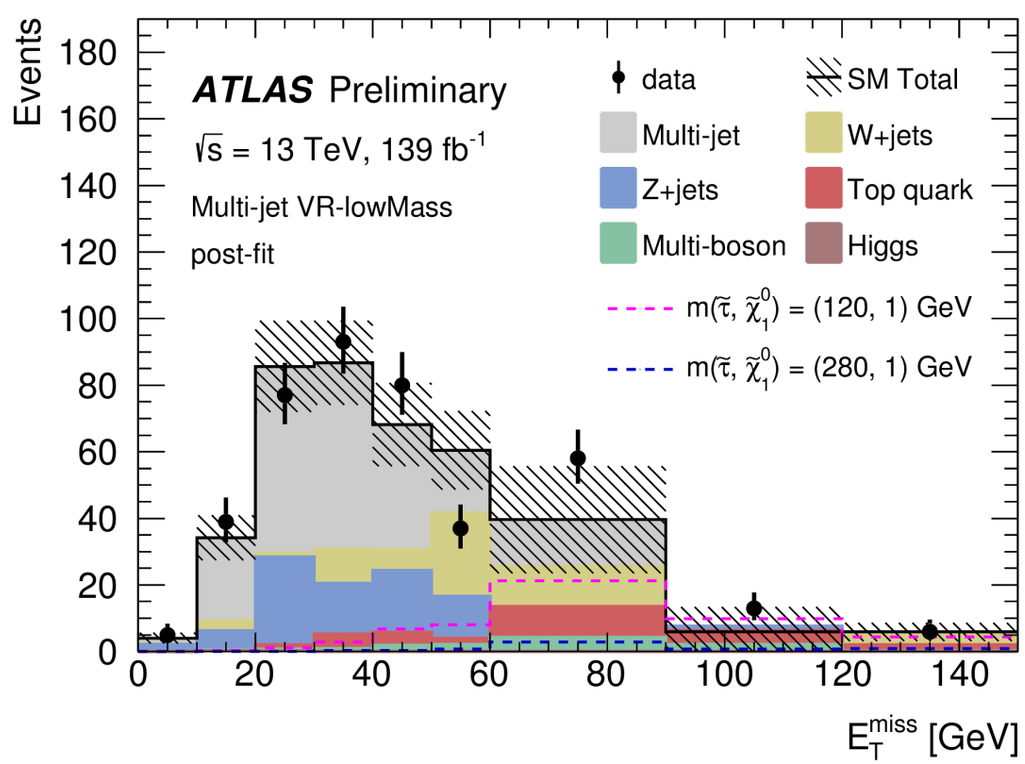


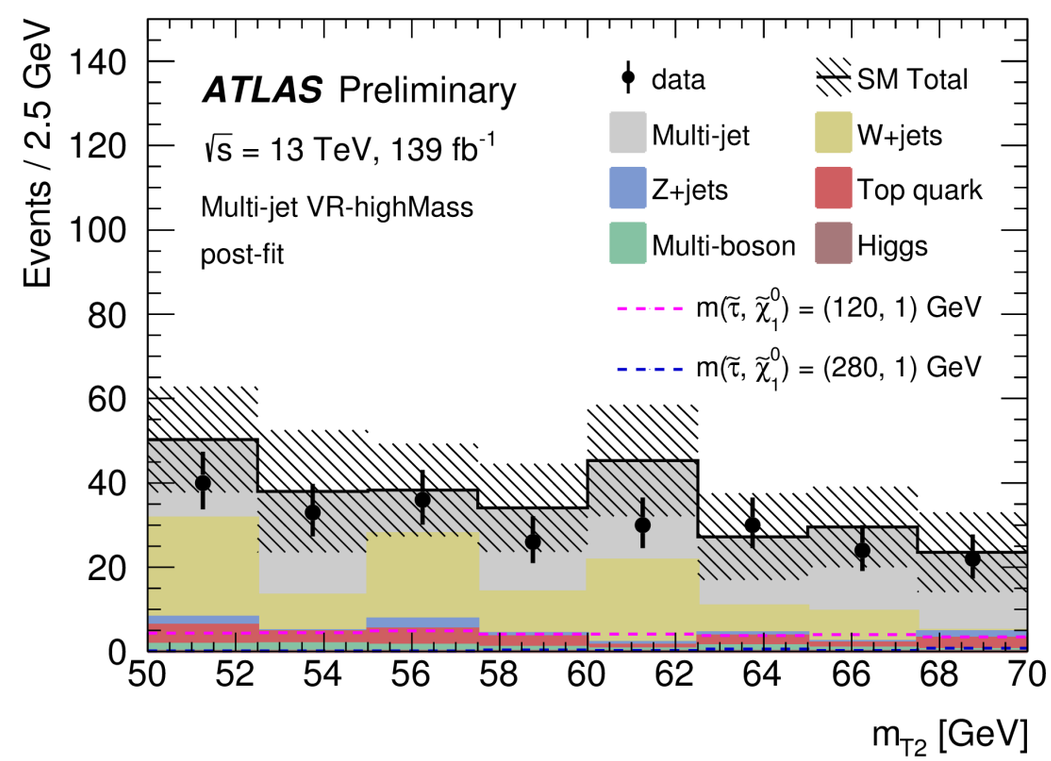


Fake tau Modelling

- **ABCD Method to model multi-jet**
  - 2 fake taus in the event
- **Separate lowMass and highMass regions**
  - Multi-jet contributions larger in lowMass regions (75 GeV < E_T^{miss} < 150 GeV)
- **Good agreement observed in VRs**



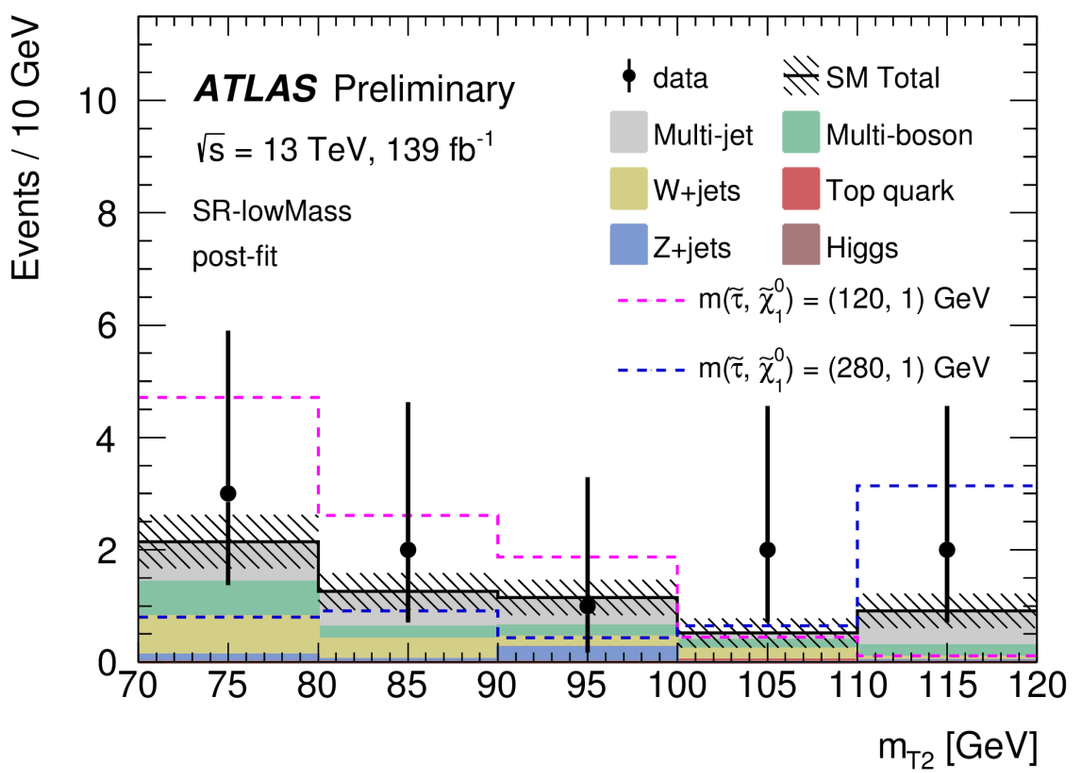


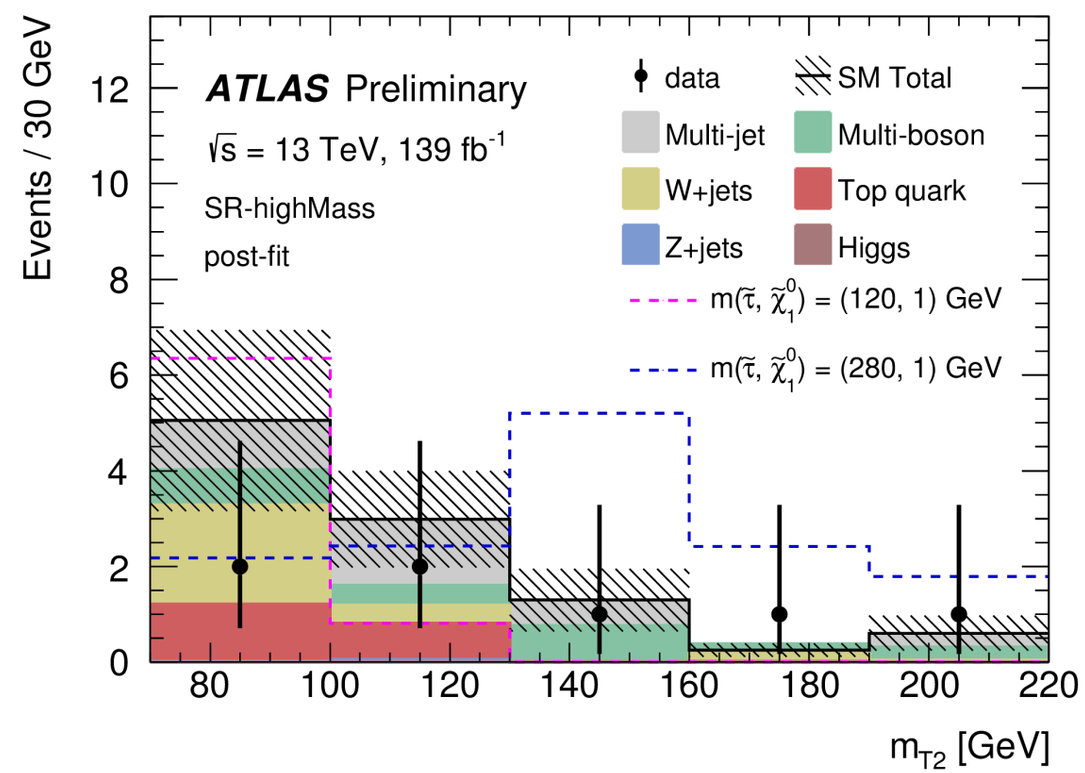


Signal Regions

- **No excess is found in either of the signal regions**
- 2-SR single bin combined fit only
- Both SRs are shown binned in m_{T2}

SM process	SR -lowMass	SR -highMass
Diboson	1.4 ± 0.8	2.6 ± 1.2
W+jets	1.5 ± 0.7	2.5 ± 1.9
Top quark	$0.04^{+0.80}_{-0.04}$	2.0 ± 0.5
Z+jets	$0.4^{+0.5}_{-0.4}$	$0.04^{+0.13}_{-0.04}$
Higgs	$0.01^{+0.02}_{-0.01}$	–
Multi-jet	2.6 ± 0.7	3.1 ± 1.5
SM total	6.0 ± 1.7	10.2 ± 3.3
Observed	10	7



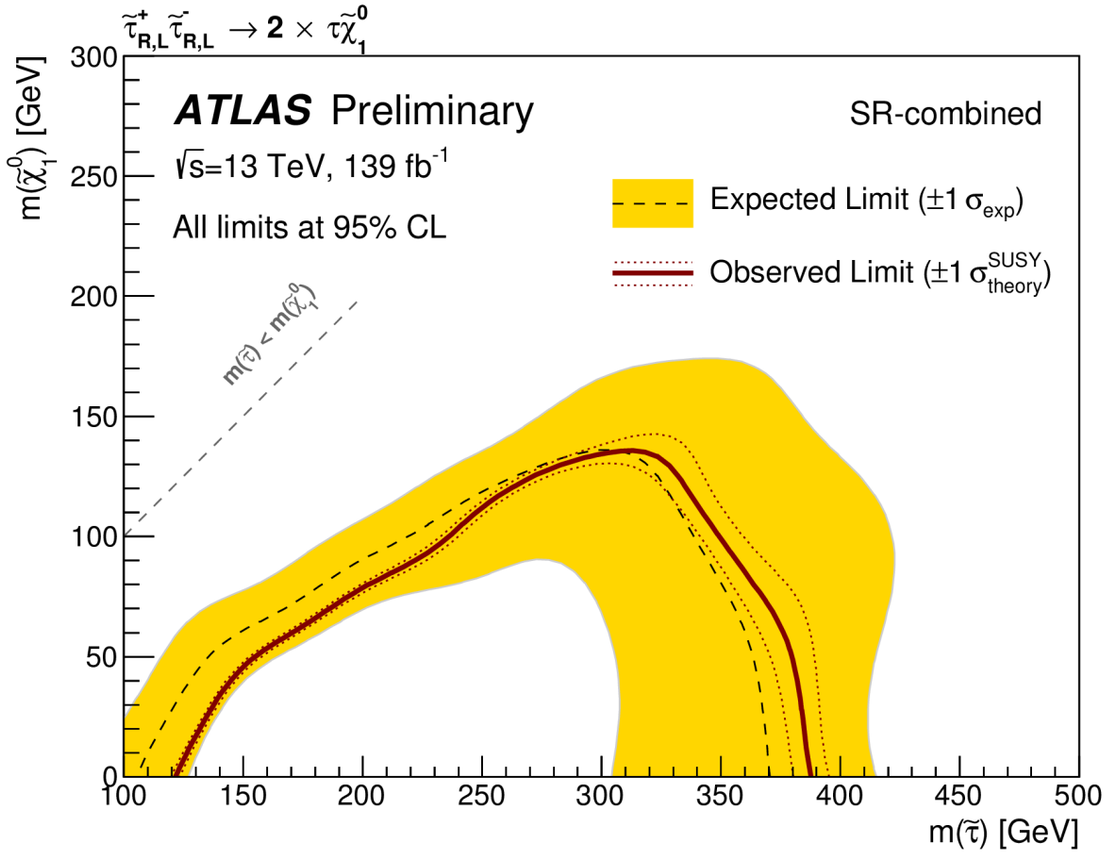


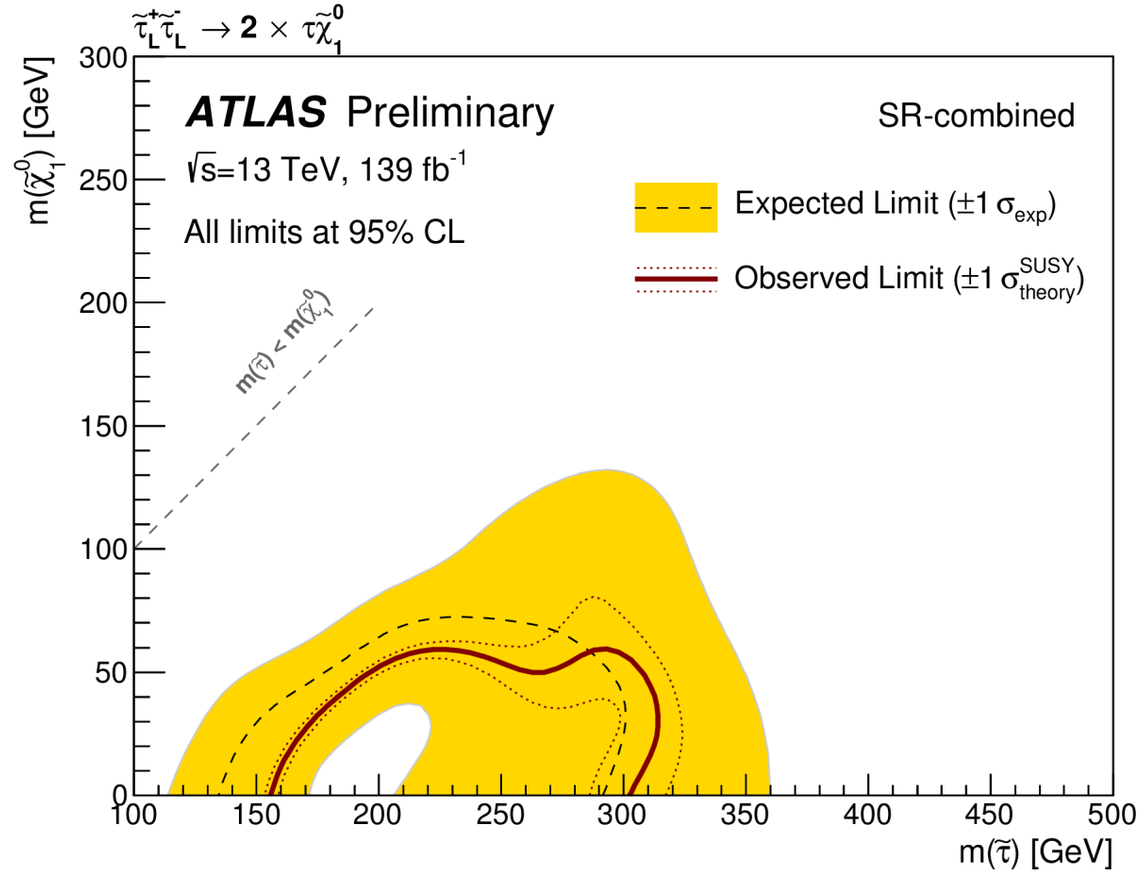
Model-dependent exclusions

- **Limits on mass-degenerate staus (left and right-handed)**

- **First direct stau limits from ATLAS:**
  - 95 % CL excluded" **120 GeV < m(stau) < 390 GeV** for massless neutralino
  - 95 % CL excluded" **160 GeV < m(stau) < 300 GeV** for left-handed staus only and a massless neutralino

- No observed sensitivity to right-handed staus

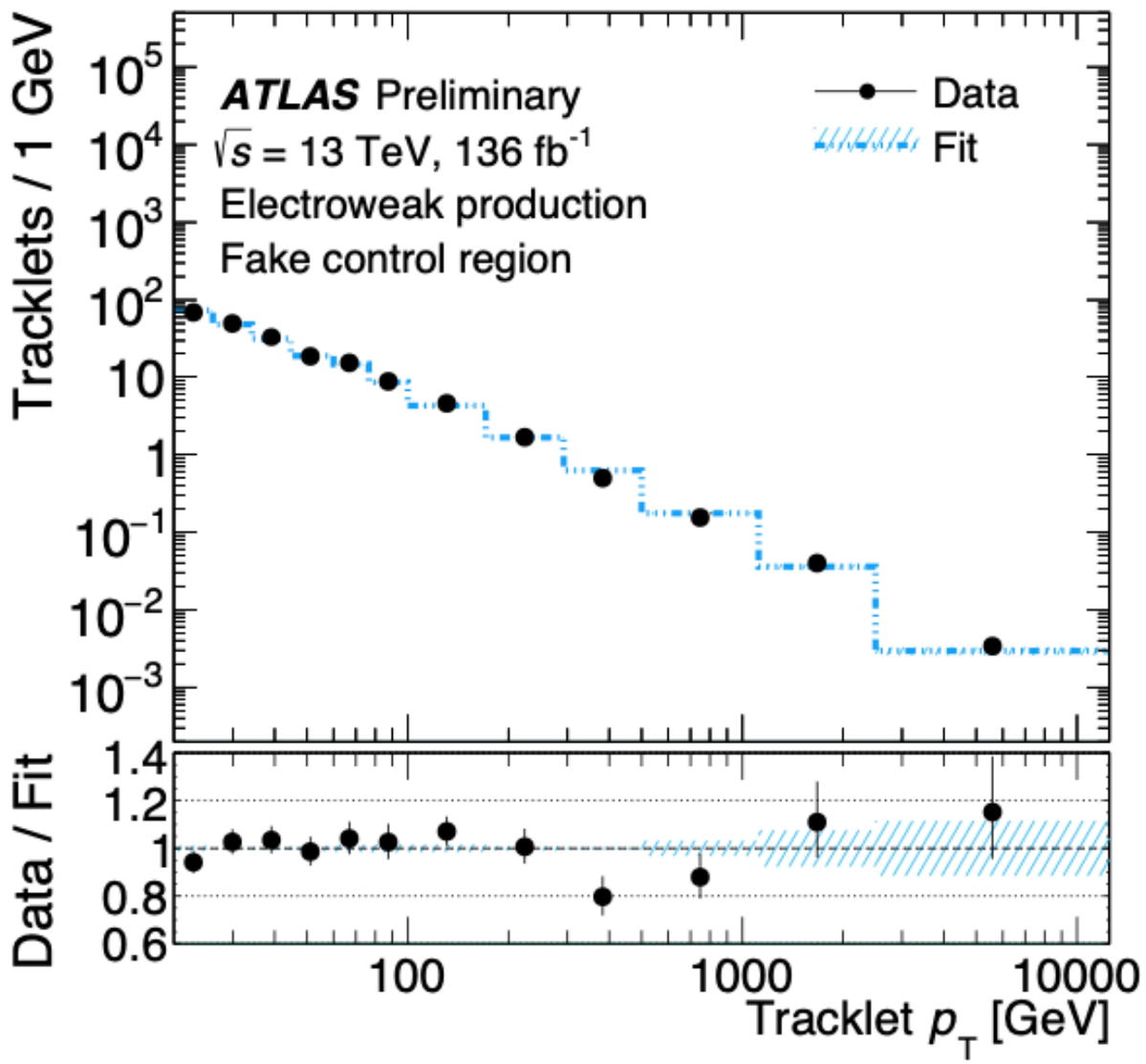


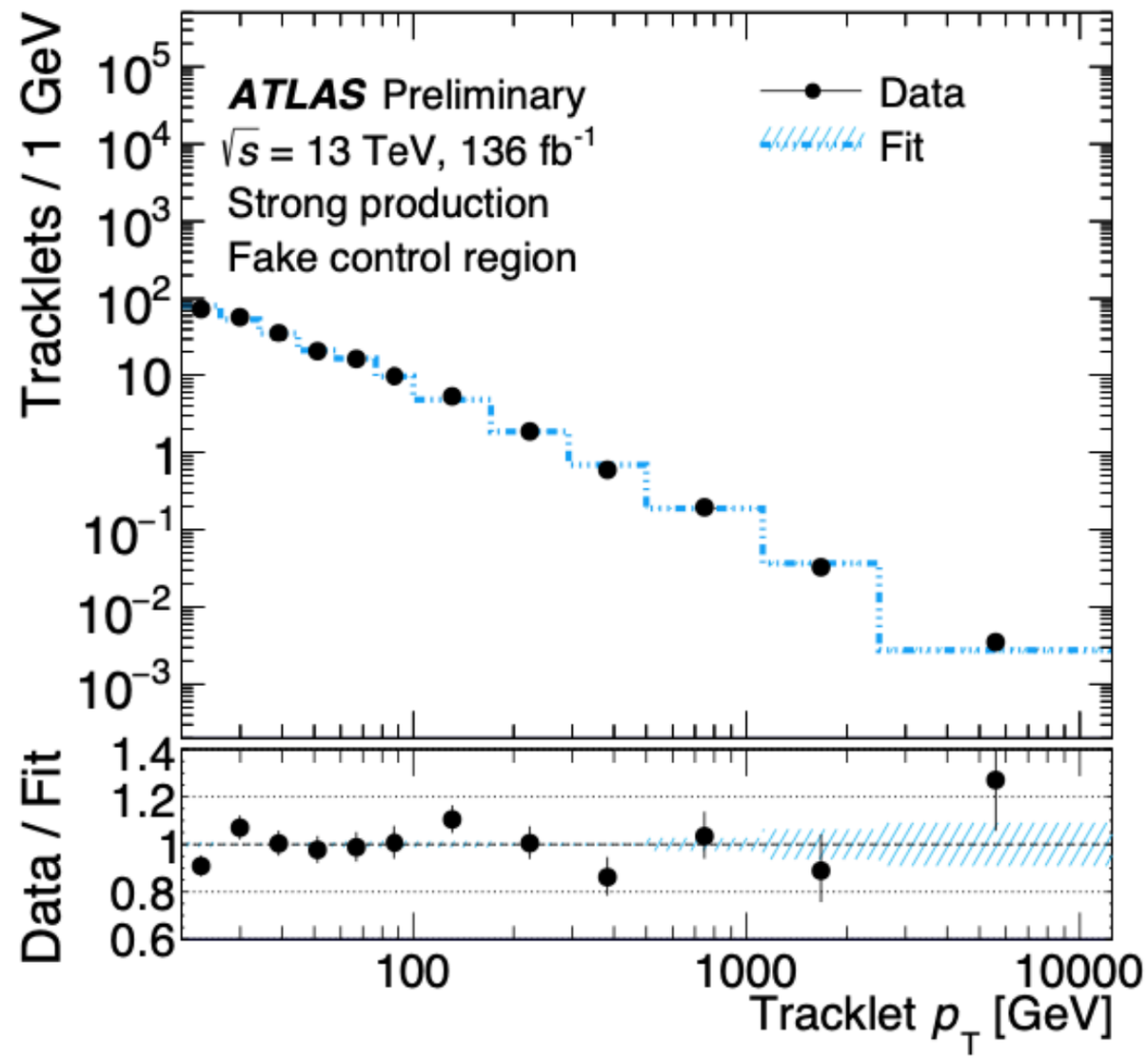


Long-lived Chargino SR

Signal region	Electroweak production	Strong production
Number of electrons and muons	0	
Number of pixel tracklets	≥ 1	
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 200	> 250
Number of jets ($p_{\mathrm{T}} >$ 20 GeV)	≥ 1	≥ 3
Leading jet p_{T} [GeV]	> 100	> 100
Second and third jet p_{T} [GeV]	–	> 20
$\Delta\phi_{min}^{\mathrm{jet}-E_{\mathrm{T}}^{\mathrm{miss}}}$	> 1.0	> 0.4

Fit to the fake tracklet CR





Long Lived Charginos

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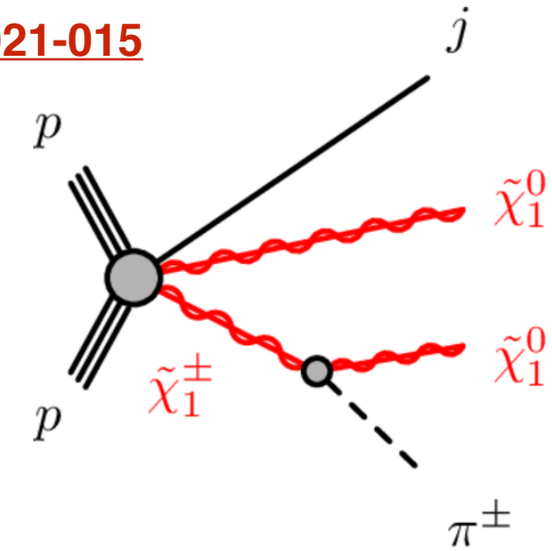
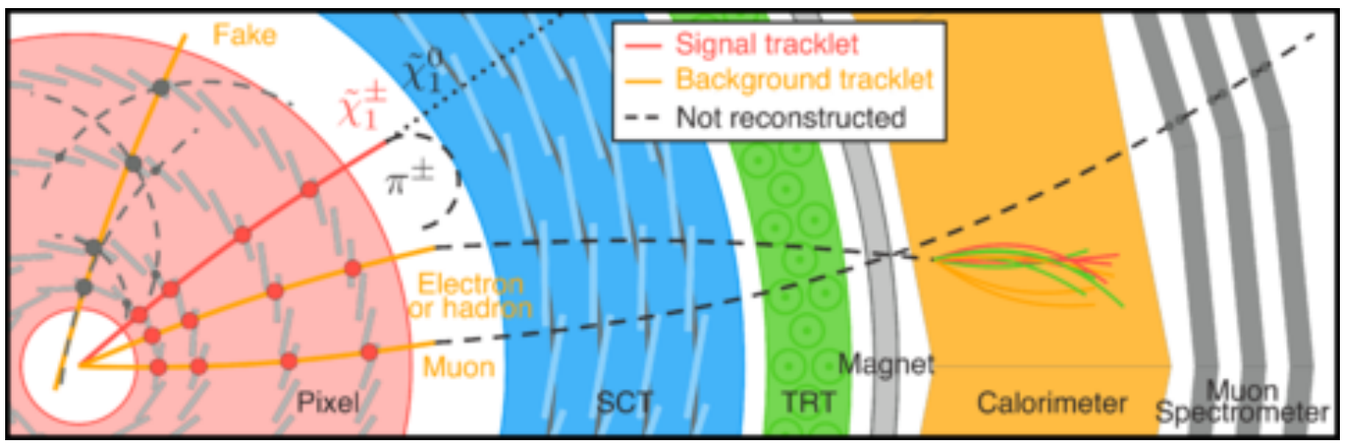
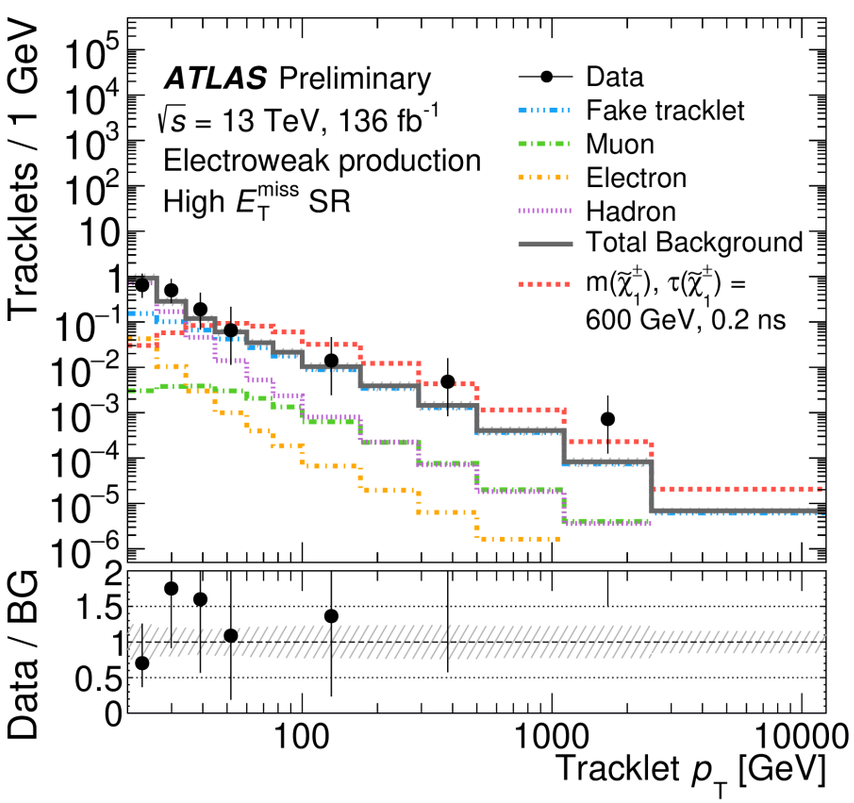


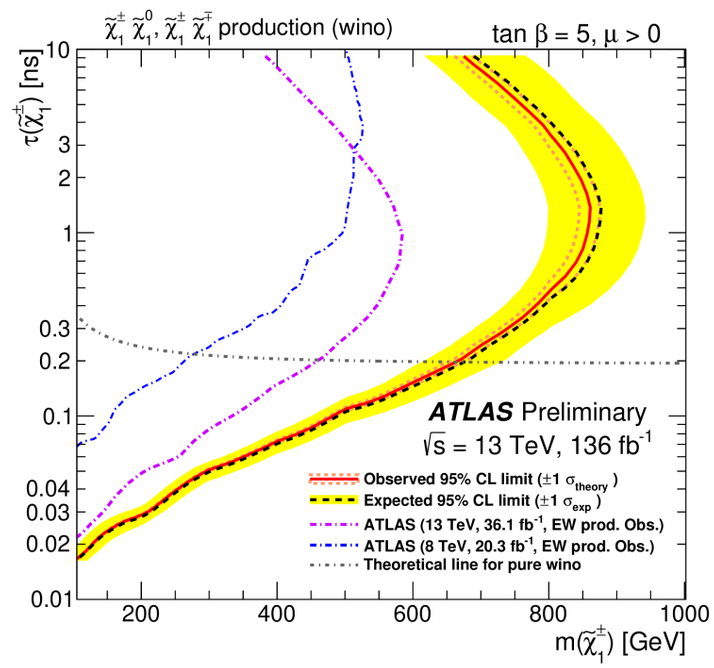
- **Search for long-lived chargino production**
  - Using disappearing track signature in ID
- At least 4 hits in Pixel, no hits in SCT or further energy deposits

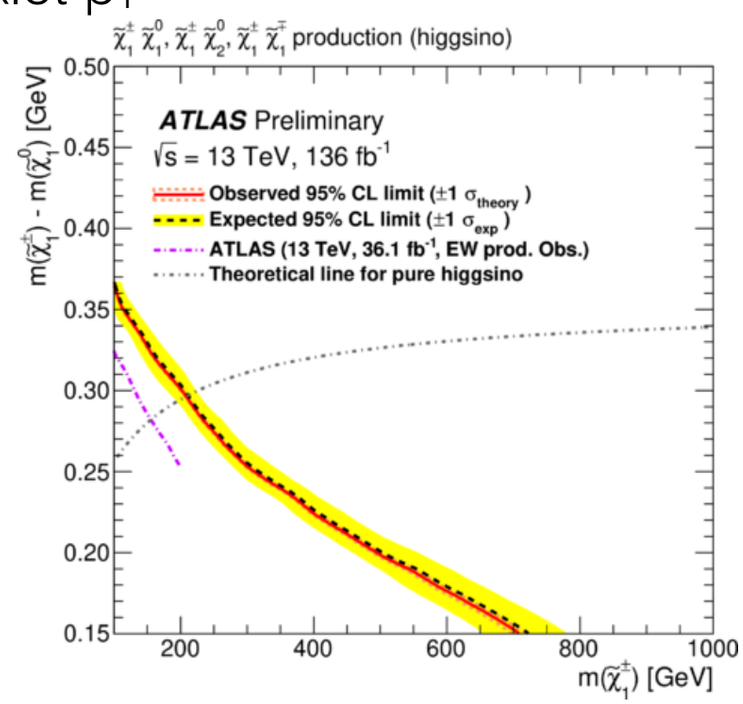


- One additional high pT jet (> 100 GeV) and large missing transverse energy (> 200 GeV)
- Fully data-driven unbinned likelihood in tracklet p_T

- Tracklet pT in hight E_T^{miss} SR







- Chargino masses up to 660 (210) GeV are excluded in scenarios where the chargino is a pure wino (higgsino)