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Search for chargino and neutralino production in final state with three leptons and missing transverse momentum, via Wh intermediate decays

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ATLAS EXPERIMENT

Outline

- Physics motivations and scenario of this search
  - *What are the motivations?*
    - Where this analysis stands among all of the so-called Beyond the Standard Model (BSM) searches
- Wh searches at Run2
  - *The state of the art*
    - First Run2 results of electroweak Wh-mediated analysis with three leptons (3L) in the final state
  - *Eye to the future*
    - Preparation of full Run2 analysis

What are the motivations?

Physics scenario

Searching for New Physics with SUSY

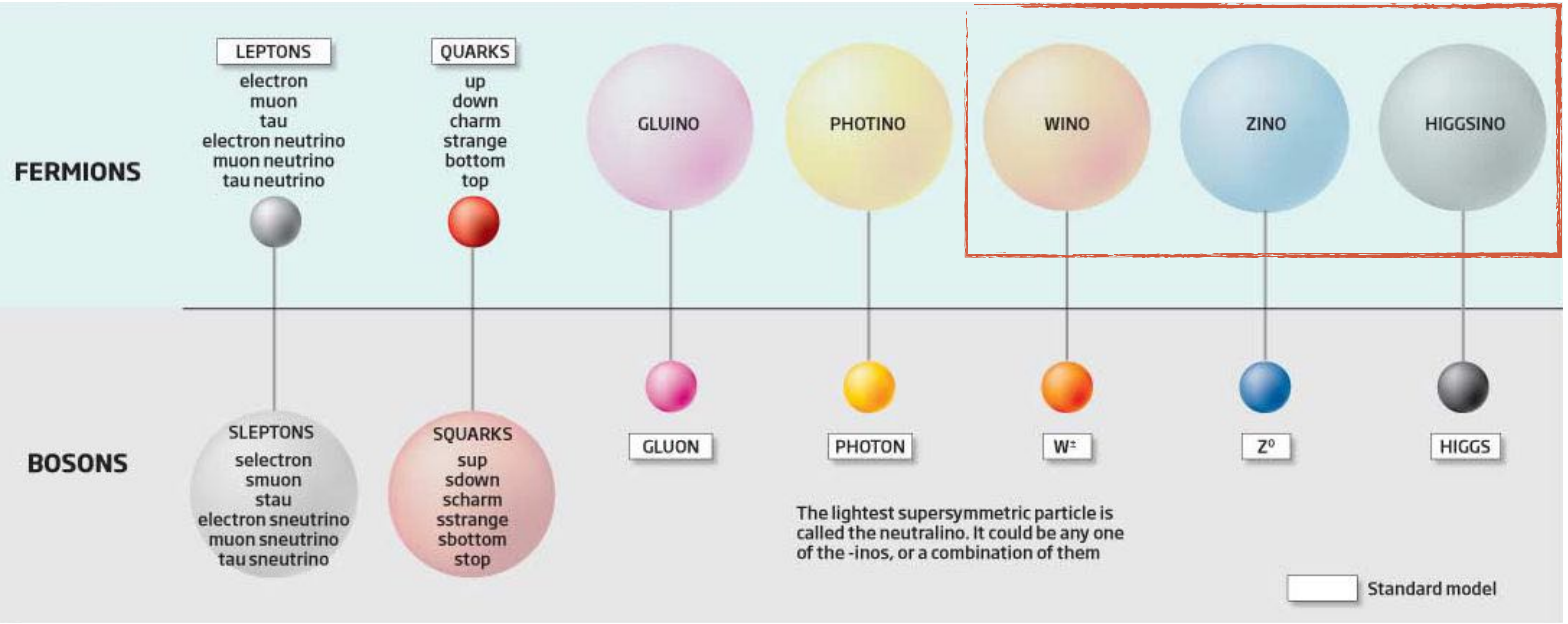
- Among all the possible BSM scenarios, SUSY is a ~~theory~~ principle which predicts a symmetry between fermions and bosons

$$^{*}R = (-1)^{3(B-L)+2s}$$

B - baryonic number
L - leptonic number
s - spin

R-parity* conservation

- SUSY particles are produced in pairs and the Lightest SUSY Particle (LSP) is stable
- The weakly interacting lightest neutralino is often the stable LSP, hence it is a good Dark Matter candidate

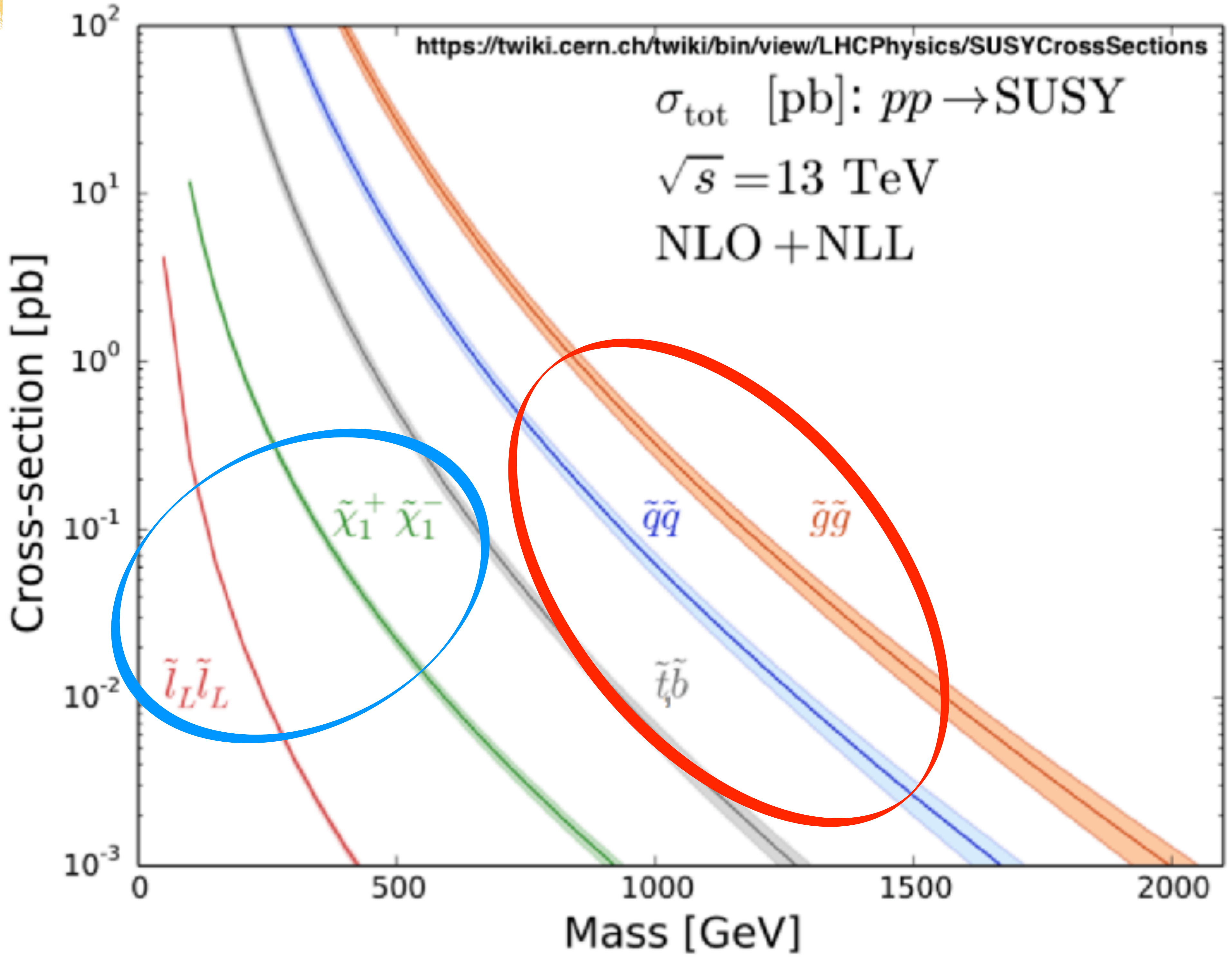


Winos, binos and higgsinos mix to form mass states charginos and neutralinos

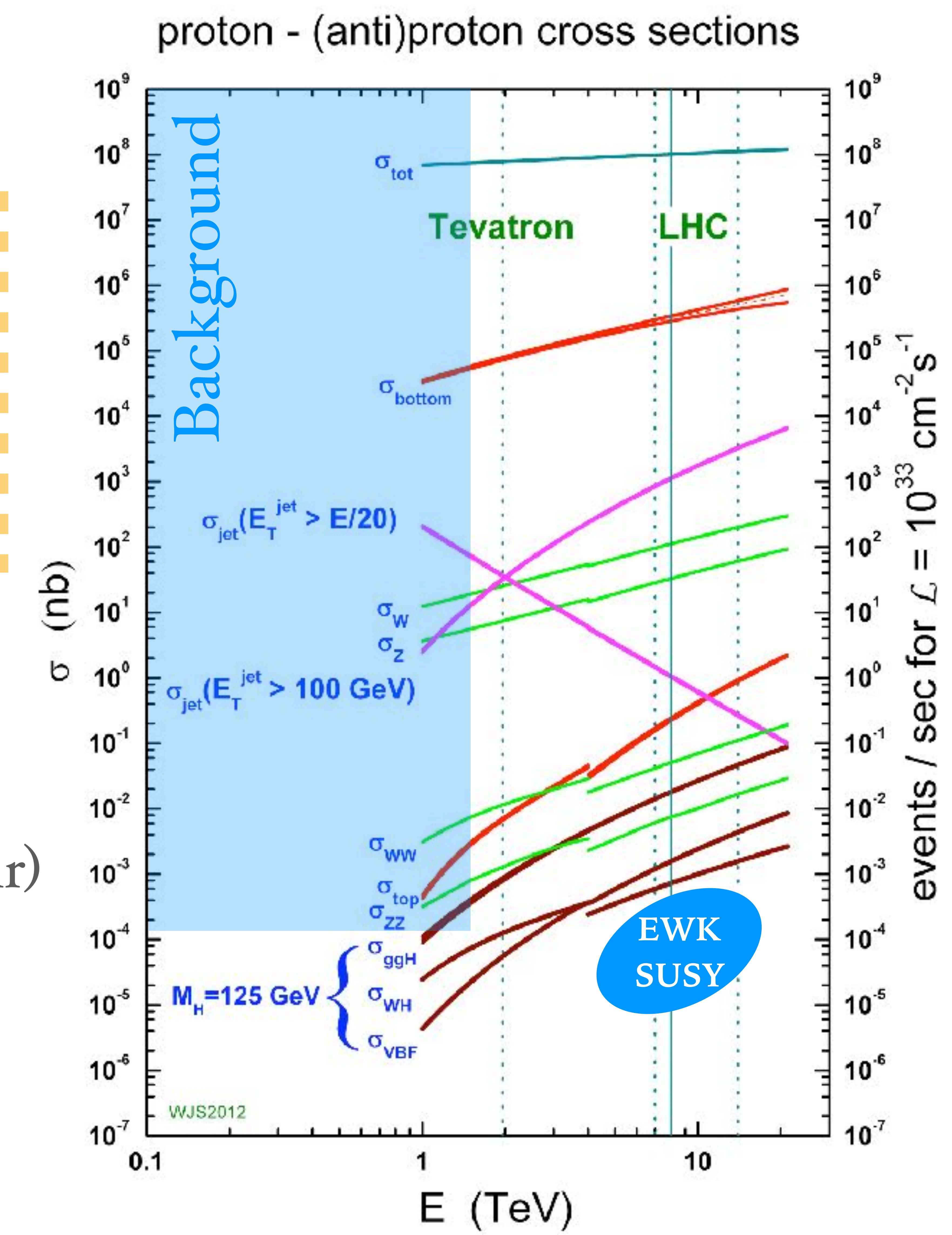
Why?

- SM hierarchy problem
- Dark matter
- Grand Unification
- It's beautiful!

Electroweak (EWK) SUSY al LHC and ATLAS



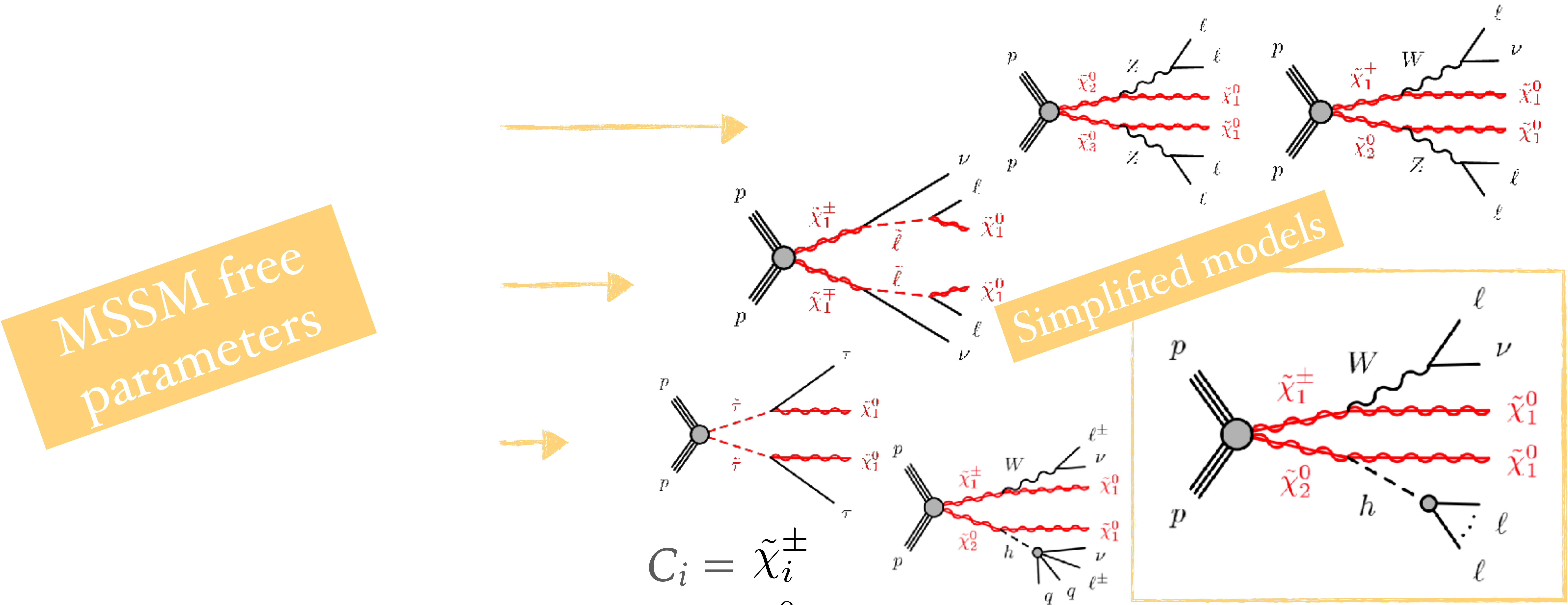
Control and suppression of Standard Model background processes is a crucial step in any SUSY analysis



- Electroweak production cross-section (e.g, chargino/neutralino pair) lower than for Strong production
- If squarks and gluinos are very heavy (as recent results suggest), EWK production becomes dominant if chargino and neutralinos masses around electroweak scale (naturalness considerations)

From MSSM to simplified models

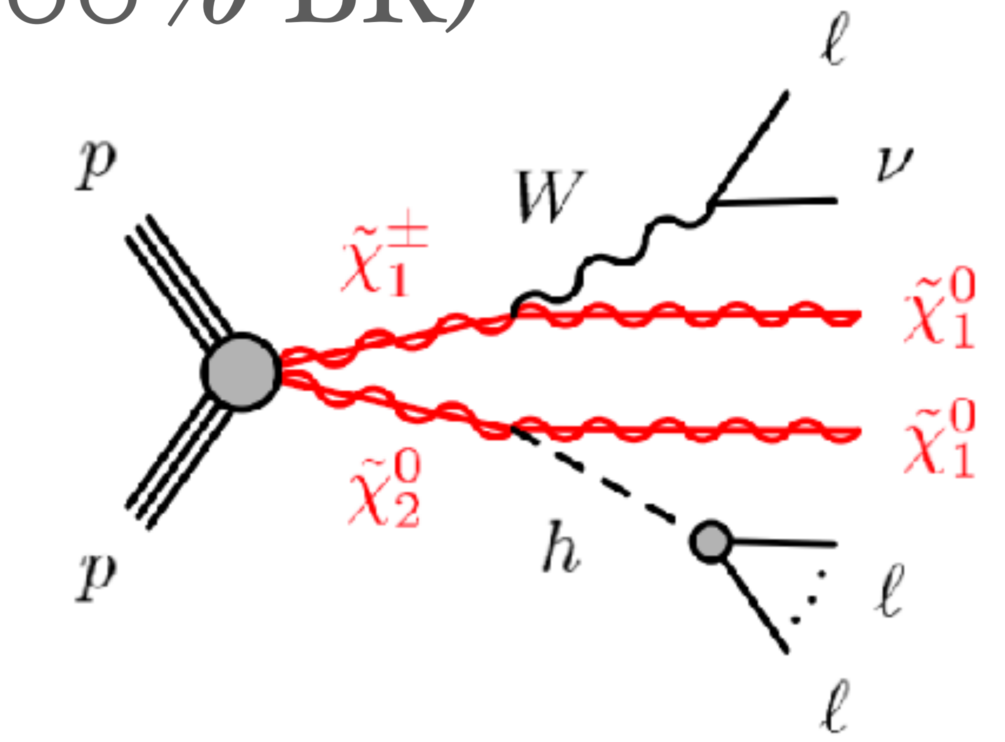
- In a simplified model, some parameters of the MSSM are fixed and others (some SUSY particle masses) are allowed to vary; individual channels are then explored one-by-one



$$C_i = \tilde{\chi}_i^{\pm}$$
$$N_i = \tilde{\chi}_i^{0}$$

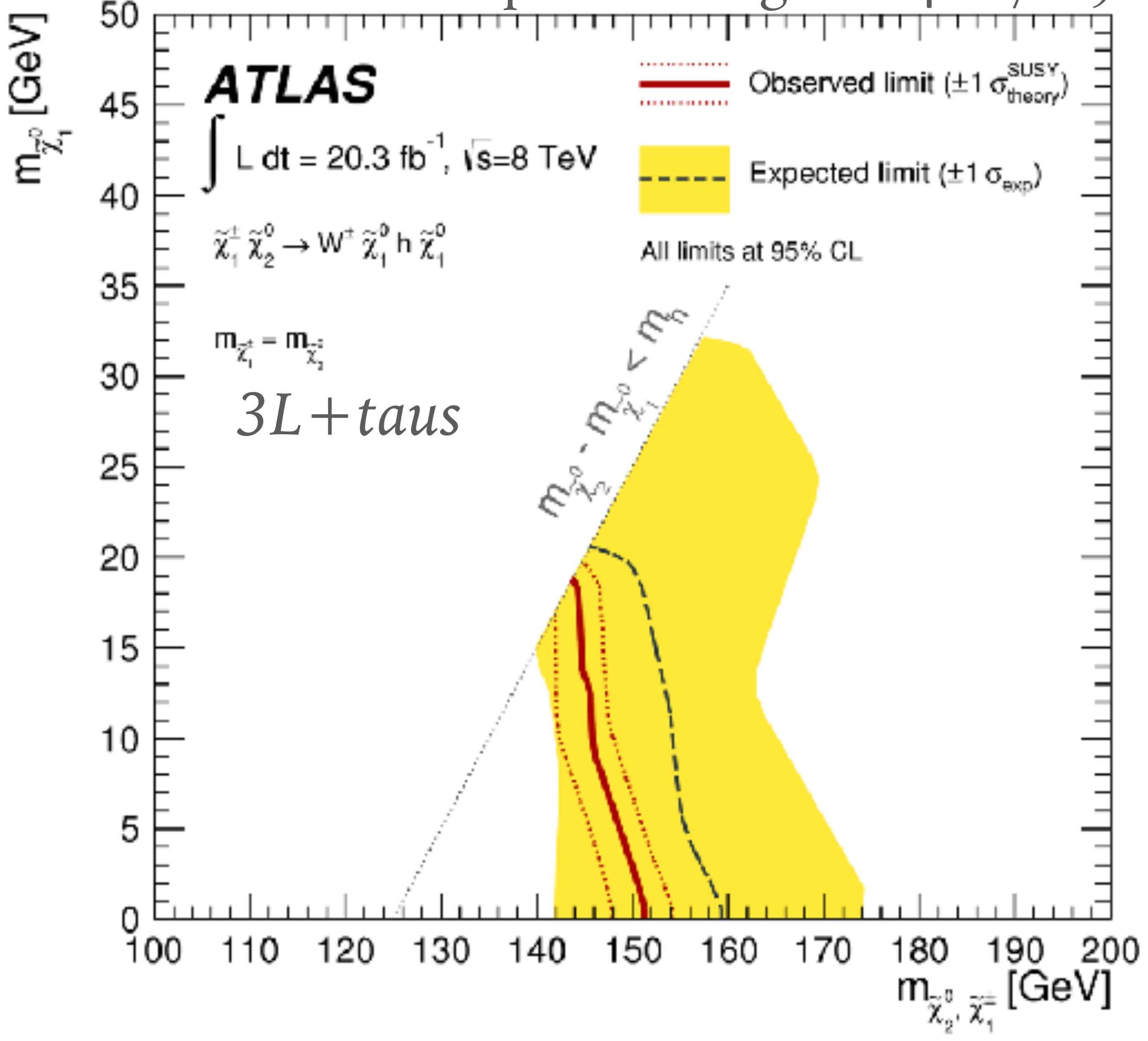
Chargino/neutralino decays via W and Higgs bosons

- RPC simplified model of pair production of mass degenerate chargino/neutralino, decaying to W and Higgs bosons and lightest neutralinos (assumed 100% BR)



- $\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$ dominant for various choices of SUSY parameters and if
  - The mass-splitting of the two lightest neutralinos is larger than the Higgs boson mass
  - Chargino/neutralino are mostly winos

https://arxiv.org/abs/1402.7029



- Possible signatures depend on the SM particles W and Higgs bosons decay into
  - e.g., multileptonic: 2LSS, 3L and 1Lbb
    - Allow the exploration of mass-splittings very close to the Higgs boson mass, started already at 8 TeV

Analysis strategy: "conventional" approach

Signal regions (SRs)

Cut-n-count **optimisation** of cuts that permit a good signal/background discrimination

Control regions (CRs)

Control of **irreducible background** in dedicated background-dominated regions

Fake/non-prompt (FNP)

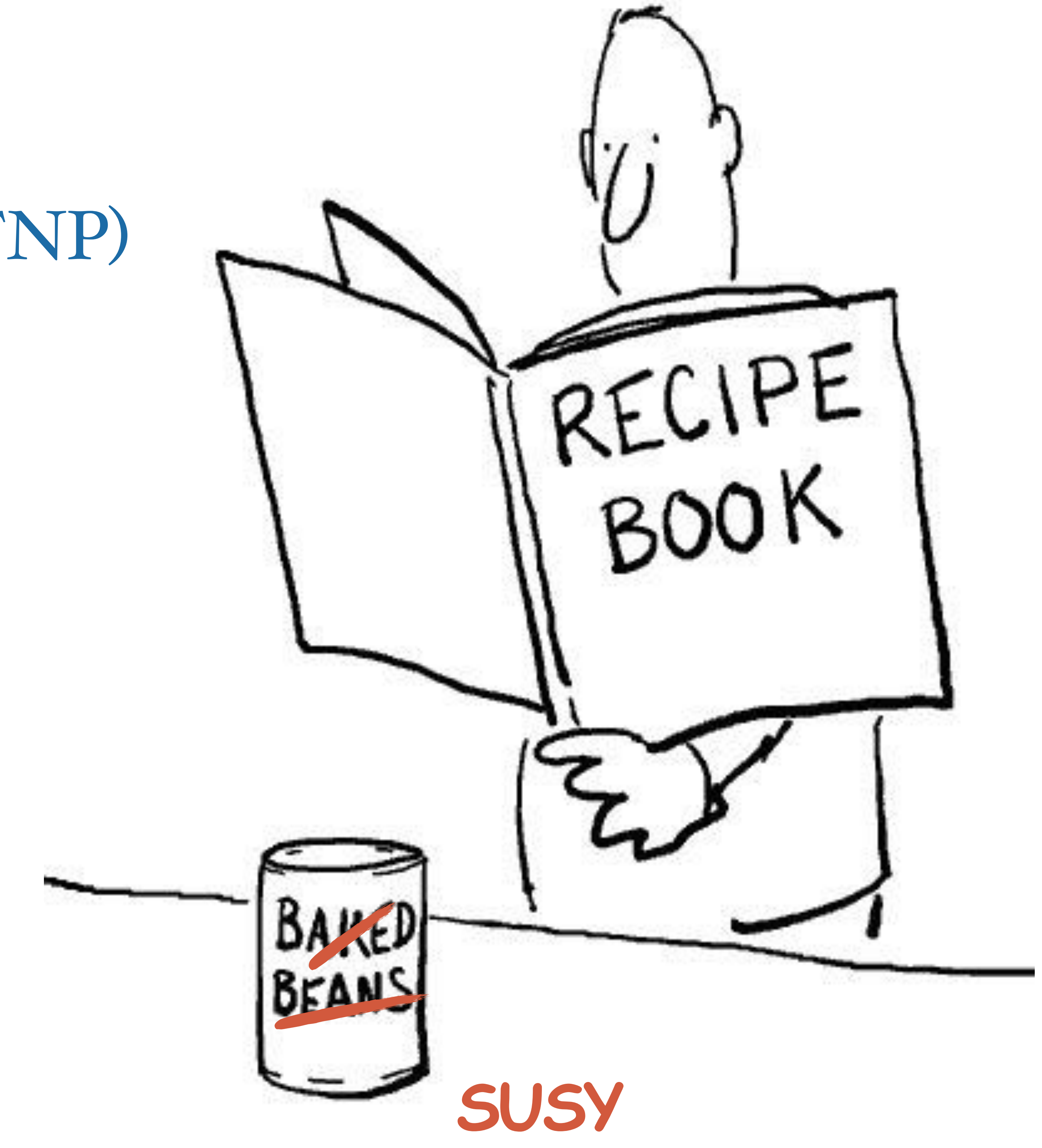
Estimation of **reducible background** with dedicated data-driven techniques

Validation regions (VRs)

Validation of background estimation

"**Unblinding**"

look for data excesses in the signal regions



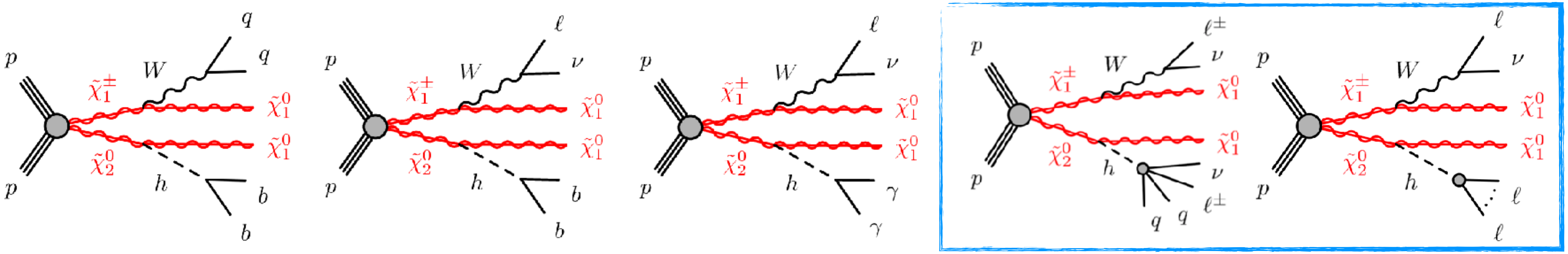
The state of the art

First Run2 Wh3L analysis results

https://arxiv.org/abs/1812.09432

Run2 Wh3L results with 36.1 fb^{-1}

- The C1/N2 Wh-mediated analysis has first Run2 results, along with four other Wh channels: full-hadronic, 1Lbb (see Matt Sullivan's talk), 1Lγγ, 2LSS



- Paper submitted to PRD and available in arXiv:1812.09432
- 3L and 2LSS presented common challenges and were harmonised in object definition and shared same method for FNP background estimation

Wh3L Event selection strategy

- Events with exactly three leptons are categorised it flavour and sign combinations
  - At least one pair of same-flavour and opposite-sign (SFOS) leptons, invariant mass outside a 20 GeV window around the Z boson mass
    - Diboson WZ (dominant) → **Irreducible**
    - Z boson + jets → **Reducible**
  - A pair of same-flavour and same-sign leptons, plus an additional lepton different-flavour and opposite sign (DFOS)
    - Pair production of top quarks → **Reducible**
    - Diboson WZ (not dominant) → **Irreducible**

Signal regions definitions

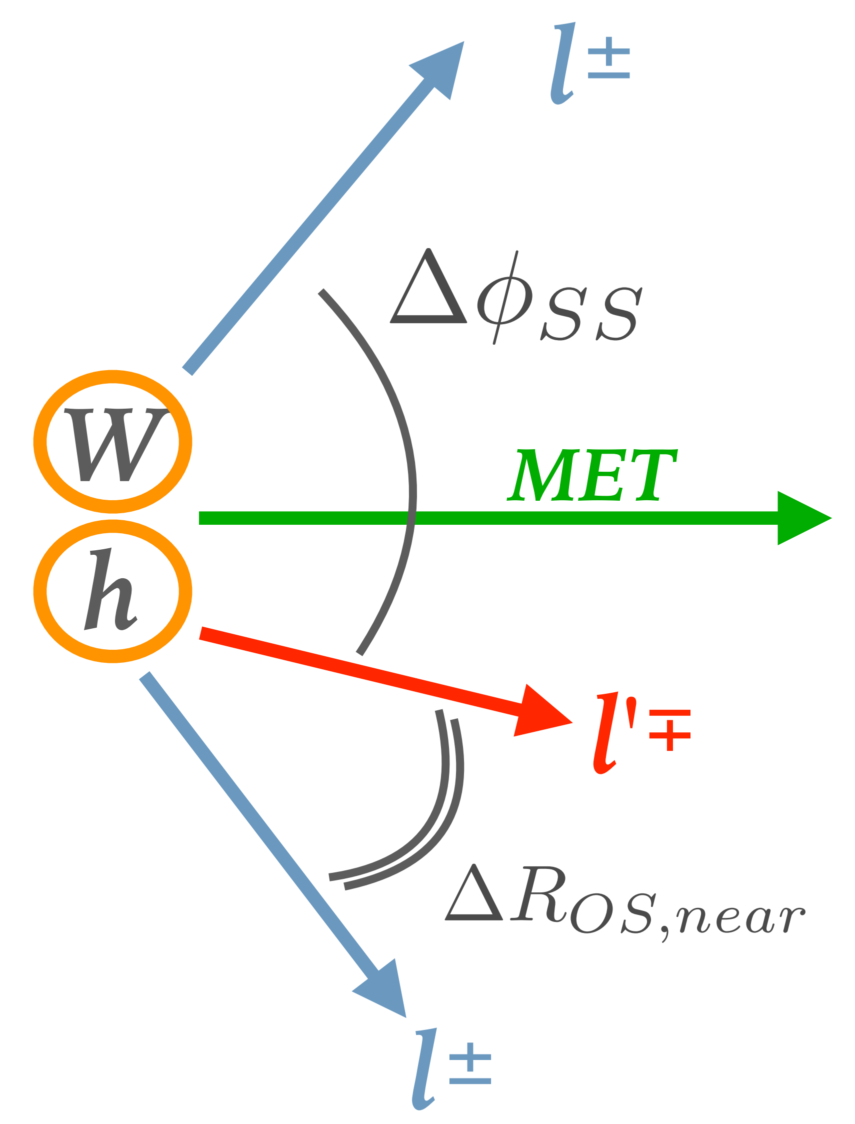
- Further binning is applied considering jet multiplicity missing transverse energy (MET)
  - For DFOS selection angular variables are used
  - For SFOS the transverse mass of the third lepton not in the SFOS pair is minimised

https://arxiv.org/abs/1812.09432

Variable	SR3L-DFOS-0J	SR3L-DFOS-1Ja	SR3L-DFOS-1Jb
N_{jet} ($p_T > 20\ GeV$)	$= 0$	> 0	> 0
$N_{b\text{-jet}}$	$= 0$	$= 0$	$= 0$
E_T^{miss} [GeV]	> 60	$\in [30, 100]$	> 100
$m_{\ell_{\text{DFOS}}+\ell_{\text{near}}}$ [GeV]	< 90	< 60	< 70
$\Delta R_{\text{OS,near}}$	-	< 1.4	< 1.4
$\Delta\phi_{\text{SS}}$	-	-	< 2.8

https://arxiv.org/abs/1812.09432

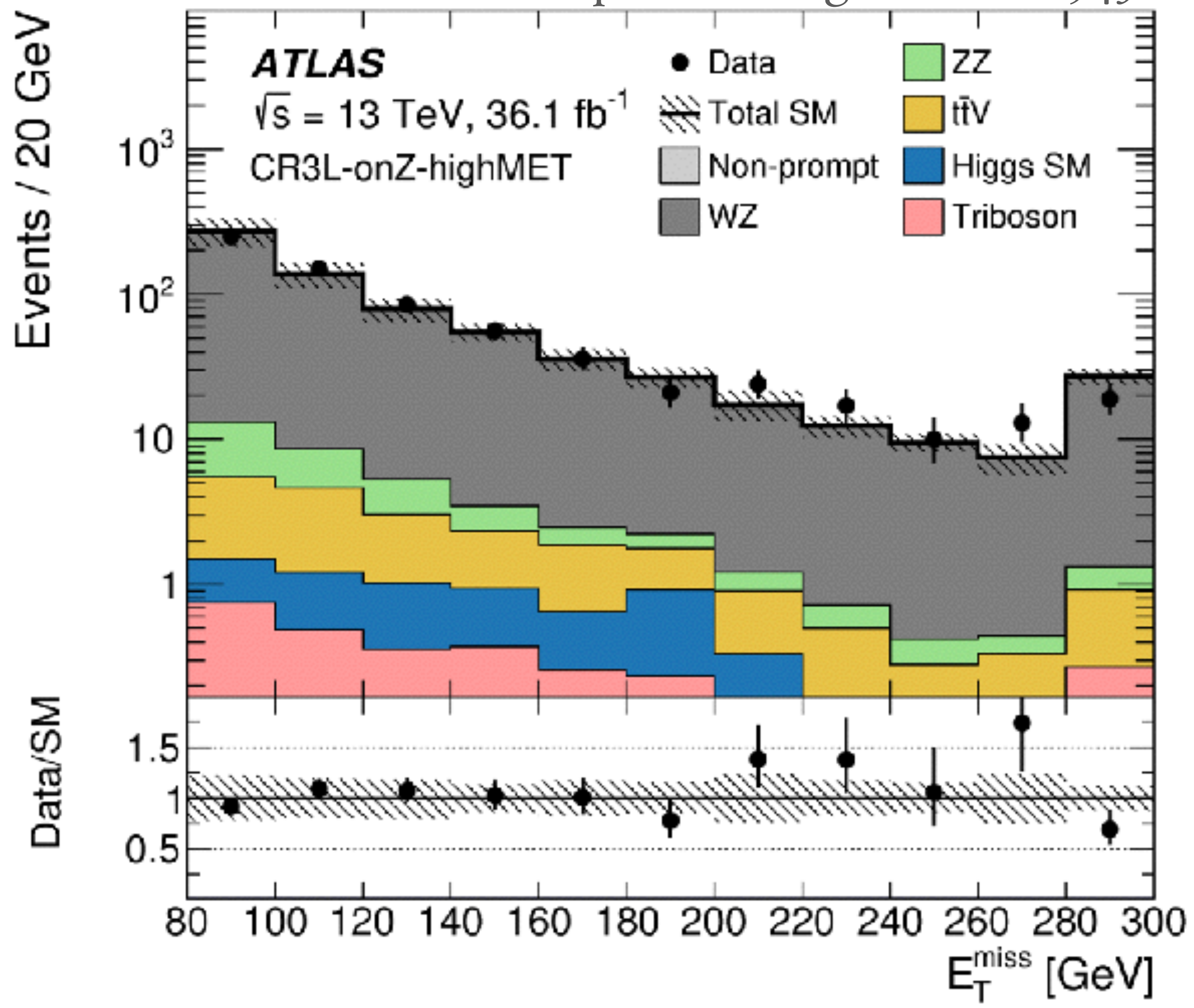
Variable	SR3L-SFOS-0Ja	SR3L-SFOS-0Jb	SR3L-SFOS-1J
N_{jet} ($p_T > 20\ GeV$)	$= 0$	$= 0$	> 0
$N_{b\text{-jet}}$	$= 0$	$= 0$	$= 0$
E_T^{miss} [GeV]	$\in [80, 120]$	> 120	> 110
m_T^{min} [GeV]	> 110	> 110	> 110
$m_{\text{SFOS}}^{\text{min}}$	$> 20\ GeV, \notin [81.2, 101.2]$	$> 20\ GeV, \notin [81.2, 101.2]$	$> 20\ GeV, \notin [81.2, 101.2]$



Background estimation

- Cross-section of irreducible background WZ is normalised in a dedicated CR
- FNP estimated with a data-driven technique (Dynamic Matrix Method), which relates the number of FNP leptons to the number of leptons which pass a specific tight or loose selection
    - Data-driven estimate is then validated in a dedicated fake enriched VR

https://arxiv.org/abs/1812.09432



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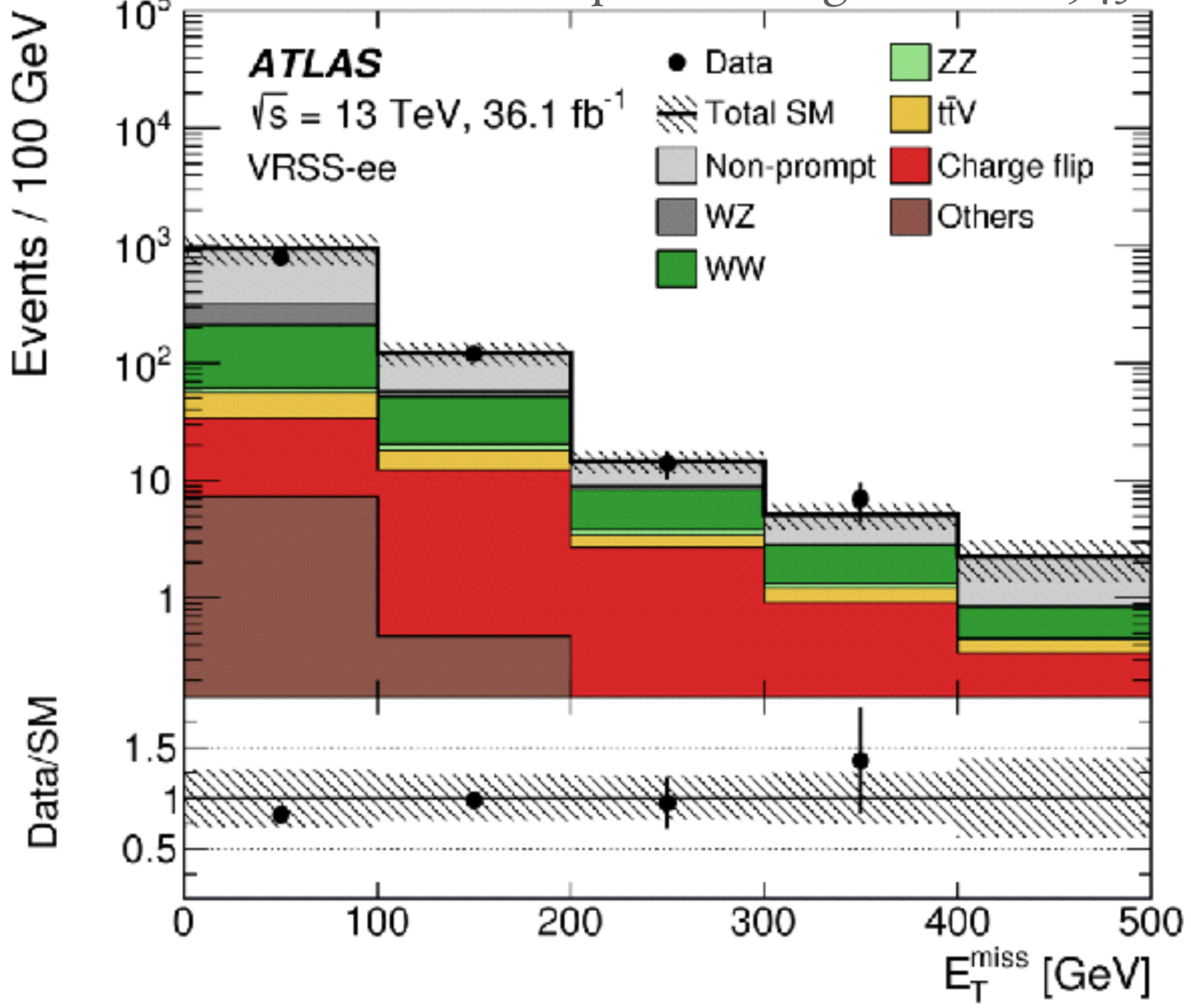

Results

- No significant deviations from SM expectation found :(

SR channels	SR3L-DFOS-1Jb	SR3L-SFOS-1J
Observed events	1	11
Fitted bkg events	1.7 ± 0.7	11.5 ± 2.6
WZ	0.54 ± 0.16	7.4 ± 2.3
ZZ	0.03 ± 0.01	0.29 ± 0.09
$t\bar{t} + V$	0.43 ± 0.16	1.9 ± 0.5
Tribosons	0.23 ± 0.08	1.4 ± 0.4
Higgs SM	0.05 ± 0.04	1.4 ± 0.4
FNP	$0.4^{+0.6}_{-0.4}$	$0.4^{+0.5}_{-0.4}$

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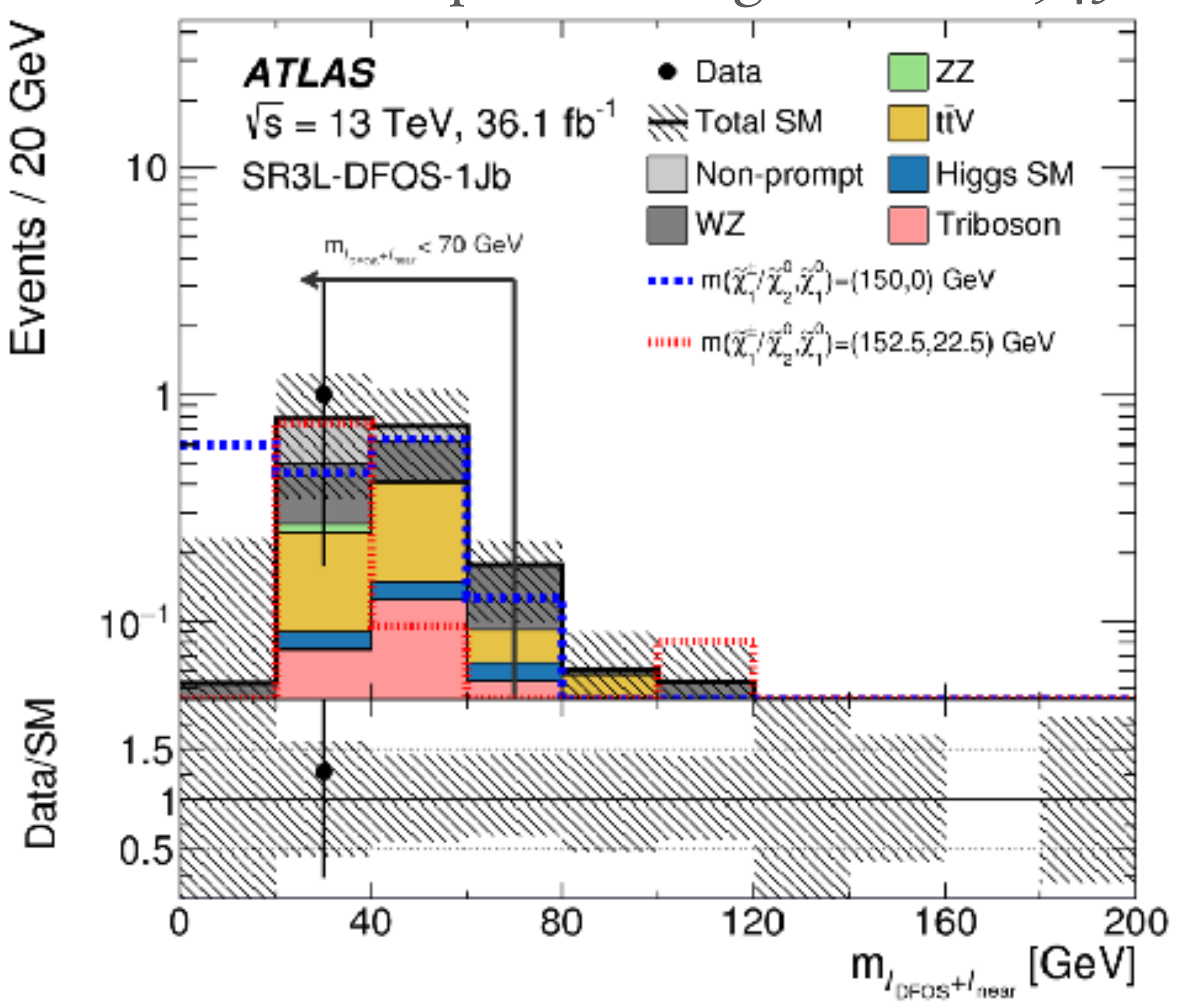

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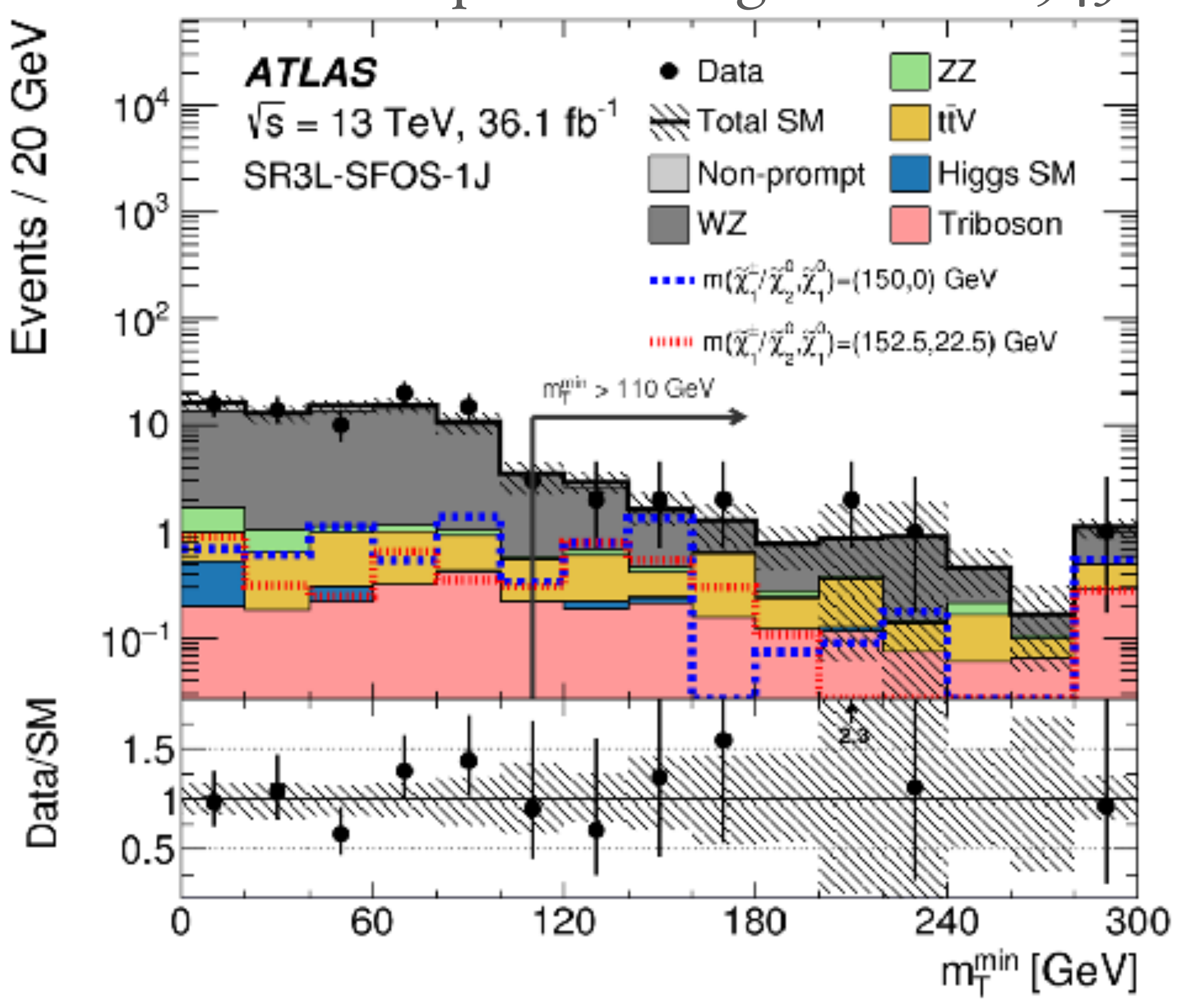
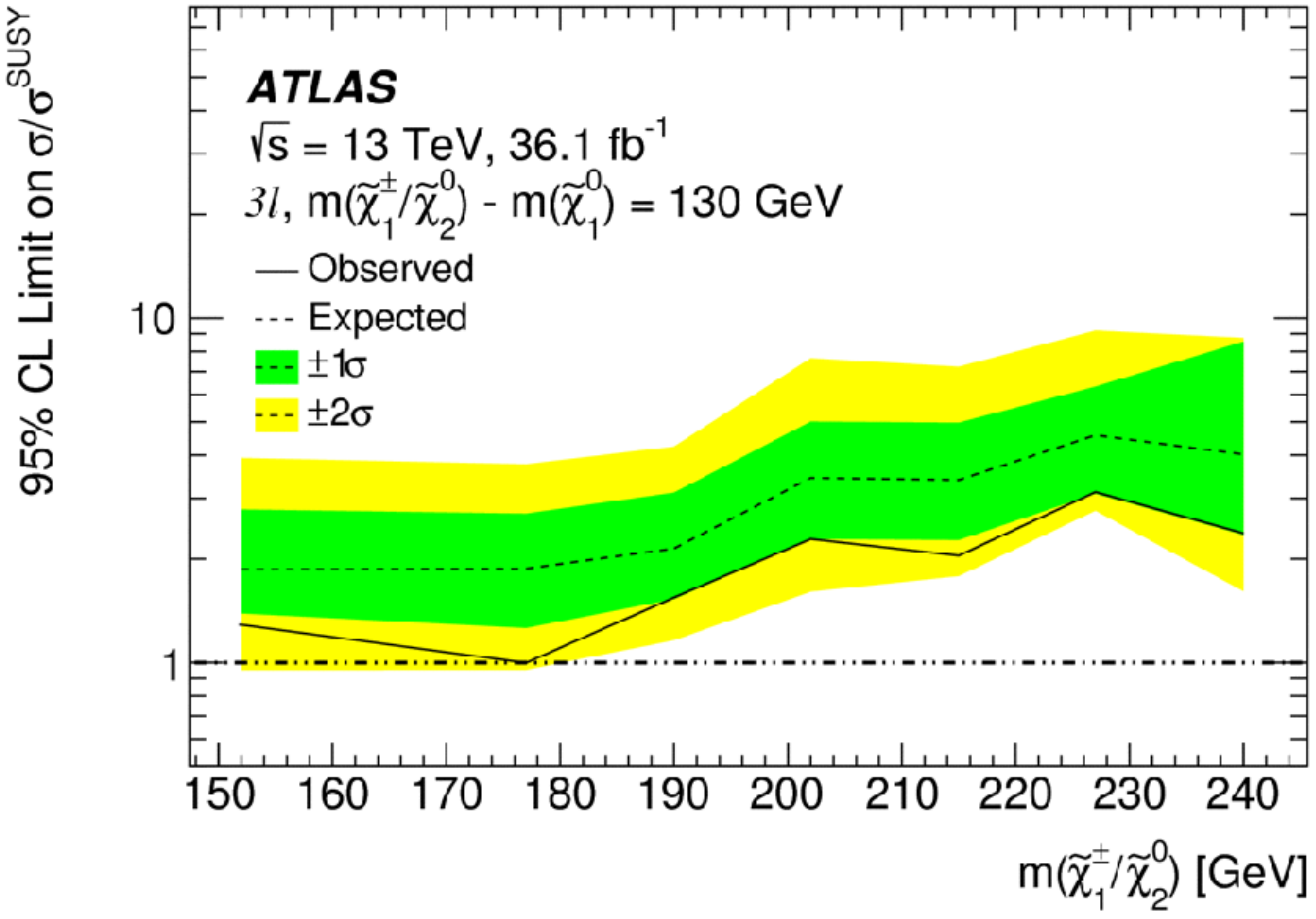


Setting limits to the models

- Wh3L shows potential search scope along the diagonal, contributing to the exploration of compressed spectra

https://arxiv.org/abs/1812.09432



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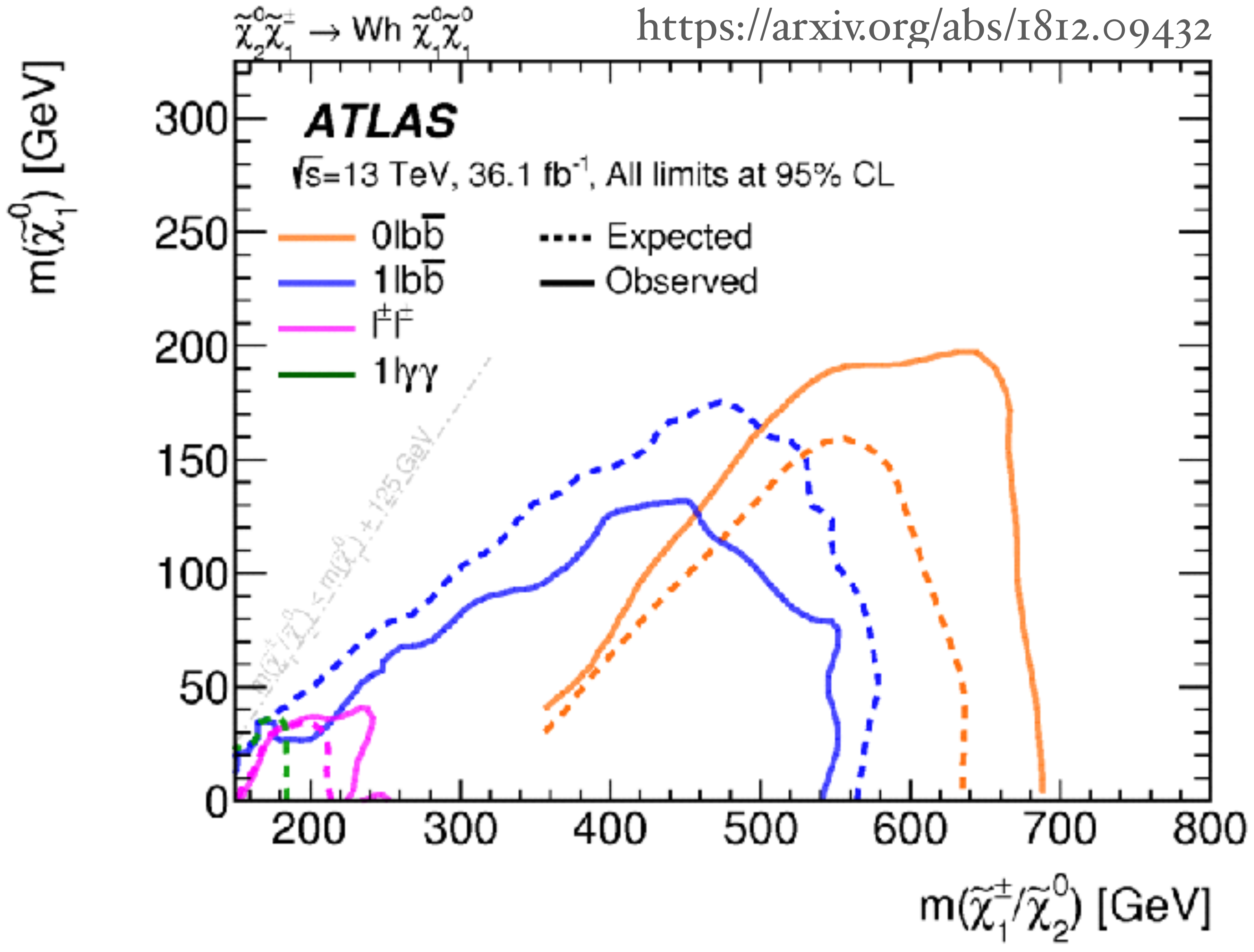
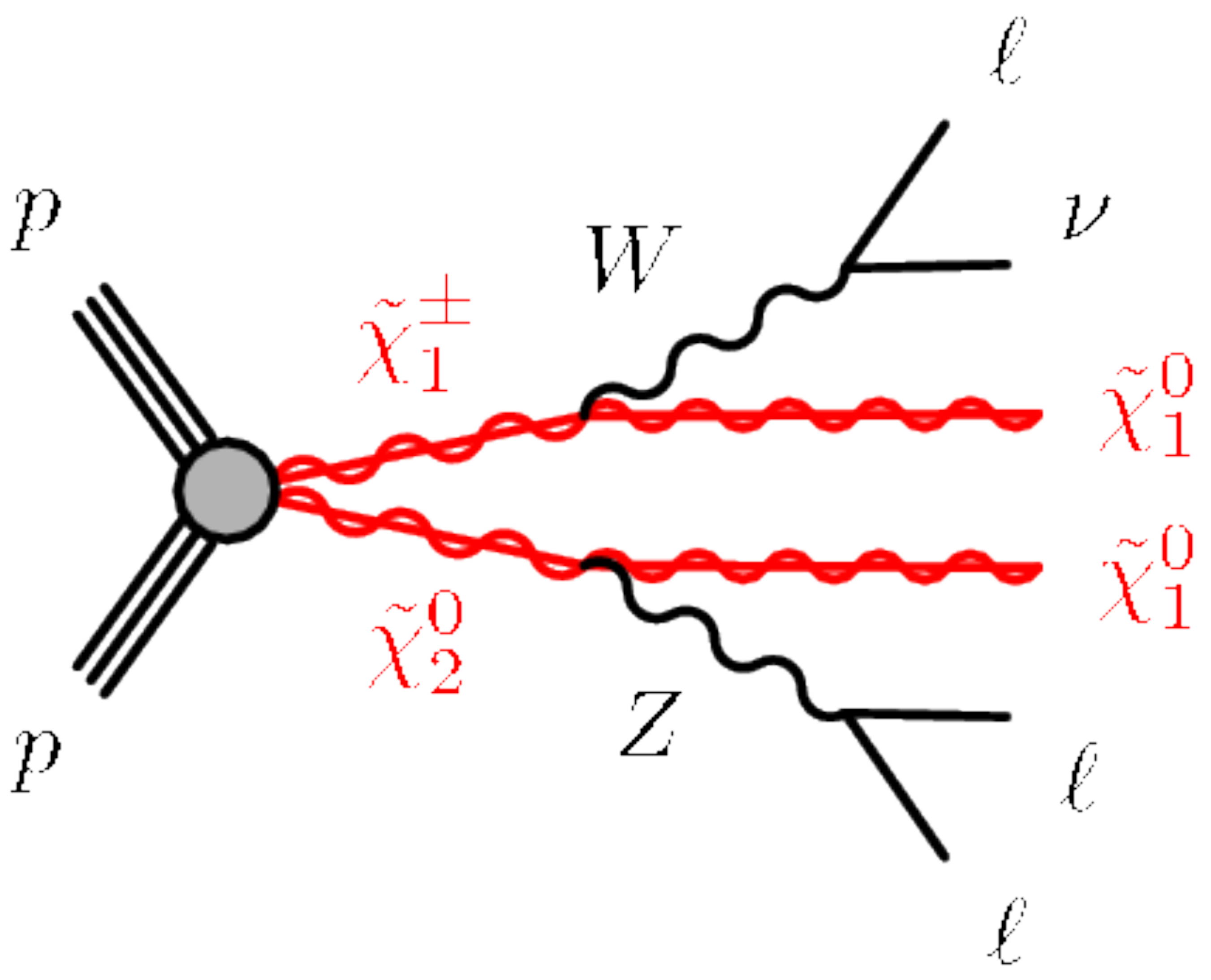


Eye to the future

Perspectives on full Run2 Wh3L analysis

Moving the Wh3L analysis to the full Run2 dataset

- Following the first round of analysis, the aim is to improve the sensitivity
- Despite the obvious gain coming from the larger data sample, other improvements are being worked on:
  - Revised optimisation
  - Revised object definitions and background estimation
  - Harmonisation to the search for WZ-mediated decays of electroweakinos
    - The two analyses are expected to present similar challenges, while targeting different physics scenarios



Conclusions and outlook

- Wh3L analysis published with 36.1 fb^{-1} Run2 dataset, in conjunction with other channels
  - https://arxiv.org/abs/1812.09432
  - Potential reach along the diagonal
- Wh3L performs best for smaller C1/LSP mass splittings
  - There is scope to improve overall sensitivity in that area of the parameter space
  - The analysis to full Run2 dataset is on-going
- For the longer term, the Wh3L analysis will be essential (in combination with other channels) to explore challenging SUSY scenarios with electroweak cross-sections

Any questions?

Thank you!

Backup

MSSM mass states

Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	$+1$	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	-1	$\widetilde{u}_L\ \widetilde{u}_R\ \widetilde{d}_L\ \widetilde{d}_R$	(same)
			$\widetilde{s}_L\ \widetilde{s}_R\ \widetilde{c}_L\ \widetilde{c}_R$	(same)
			$\widetilde{t}_L\ \widetilde{t}_R\ \widetilde{b}_L\ \widetilde{b}_R$	$\widetilde{t}_1\ \widetilde{t}_2\ \widetilde{b}_1\ \widetilde{b}_2$
sleptons	0	-1	$\widetilde{e}_L\ \widetilde{e}_R\ \widetilde{\nu}_e$	(same)
			$\widetilde{\mu}_L\ \widetilde{\mu}_R\ \widetilde{\nu}_\mu$	(same)
			$\widetilde{\tau}_L\ \widetilde{\tau}_R\ \widetilde{\nu}_\tau$	$\widetilde{\tau}_1\ \widetilde{\tau}_2\ \widetilde{\nu}_\tau$
neutralinos	1/2	-1	$\widetilde{B}^0\ \widetilde{W}^0\ \widetilde{H}_u^0\ \widetilde{H}_d^0$	$\widetilde{N}_1\ \widetilde{N}_2\ \widetilde{N}_3\ \widetilde{N}_4$
charginos	1/2	-1	$\widetilde{W}^\pm\ \widetilde{H}_u^+\ \widetilde{H}_d^-$	$\widetilde{C}_1^\pm\ \widetilde{C}_2^\pm$
gluino	1/2	-1	$\widetilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	-1	$\widetilde{G}$	(same)

CR definition

https://arxiv.org/abs/1812.09432

CR definition	
	CR3L-onZ-highMET
Baseline leptons	=3
Signal leptons	=3
Flavour/sign	SFOS
b-tagged jets	=0 ($p_{\mathrm{T}} > 20$ GeV)
$p_{\mathrm{T}}{}^{3rd\ \ell}$	$>$ 25 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	>80 GeV
$m_{\ell\ell\ell}$	$>$ 20 GeV
m_{SFOS}^{min}	$> 20, \in [81.2, 101.2]$ GeV

Results: SR pulls

https://arxiv.org/abs/1812.09432

SR channels	SR3L-DFOS-0J	SR3L-DFOS-1Ja	SR3L-DFOS-1Jb
Observed events	0	7	1
Fitted bkg events	2.1 ± 1.0	8.3 ± 3.8	1.7 ± 0.7
WZ	0.18 ± 0.13	1.01 ± 0.27	0.54 ± 0.16
ZZ	0.0017 ± 0.0012	0.06 ± 0.02	0.03 ± 0.01
$t\bar{t} + V$	0.0013 ± 0.0013	0.79 ± 0.29	0.43 ± 0.16
Tribosons	0.52 ± 0.28	0.66 ± 0.22	0.23 ± 0.08
Higgs SM	0.39 ± 0.15	$0.1^{+0.5}_{-0.1}$	0.05 ± 0.04
FNP	1.0 ± 0.9	5.6 ± 3.8	$0.4^{+0.6}_{-0.4}$

https://arxiv.org/abs/1812.09432

SR channels	SR3L-SFOS-0Ja	SR3L-SFOS-0Jb	SR3L-SFOS-1J
Observed events	0	3	11
Fitted bkg events	3.8 ± 1.7	2.4 ± 1.0	11.5 ± 2.6
WZ	2.5 ± 1.2	2.0 ± 0.9	7.4 ± 2.3
ZZ	0.10 ± 0.04	0.07 ± 0.02	0.29 ± 0.09
$t\bar{t} + V$	0.09 ± 0.03	0.02 ± 0.01	1.9 ± 0.5
Tribosons	0.57 ± 0.29	0.16 ± 0.08	1.4 ± 0.4
Higgs SM	$0.24^{+0.25}_{-0.24}$	0.07 ± 0.07	0.07 ± 0.04
FNP events	$0.27^{+0.31}_{-0.27}$	$0.11^{+0.20}_{-0.11}$	$0.4^{+0.5}_{-0.4}$

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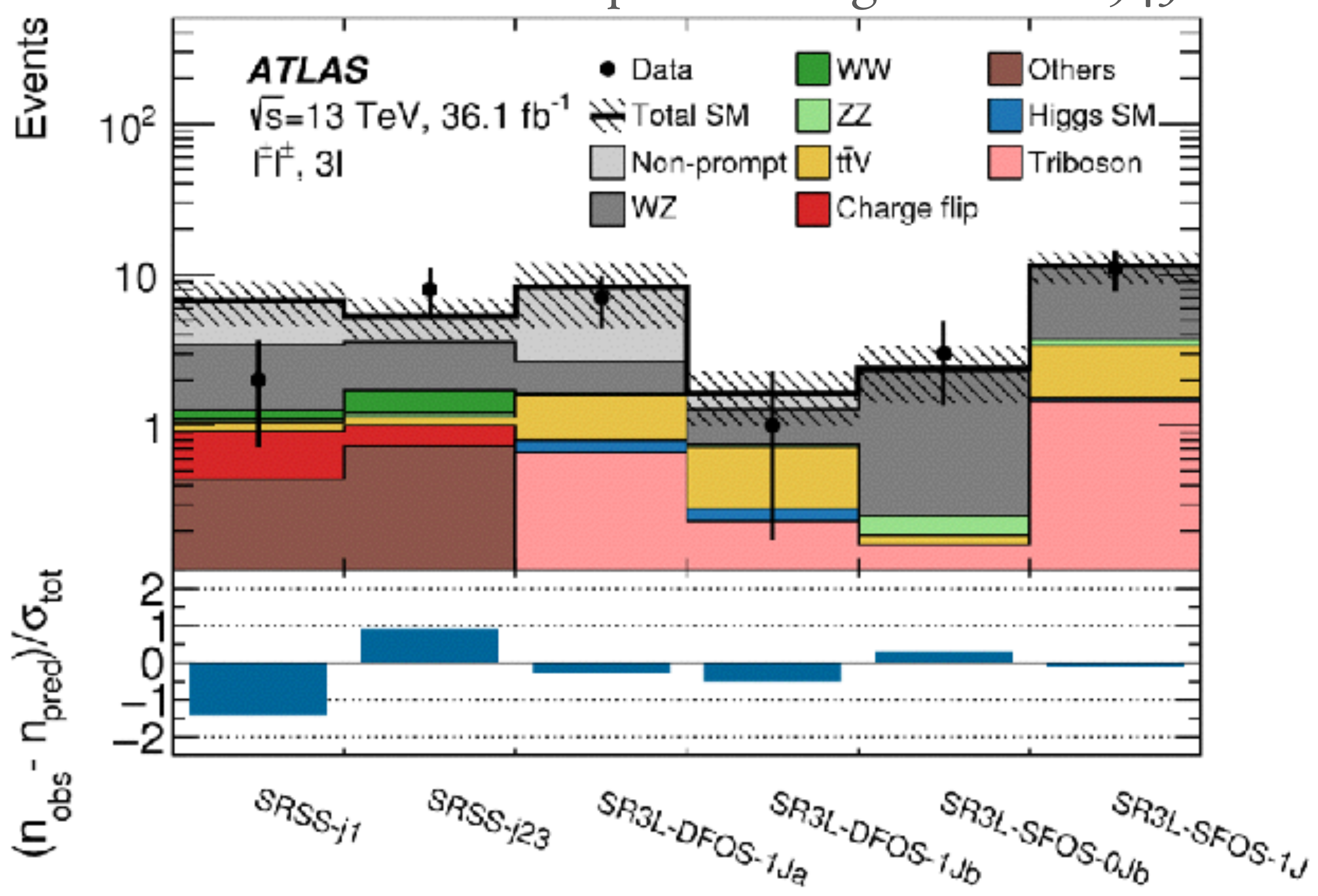

Results: limits

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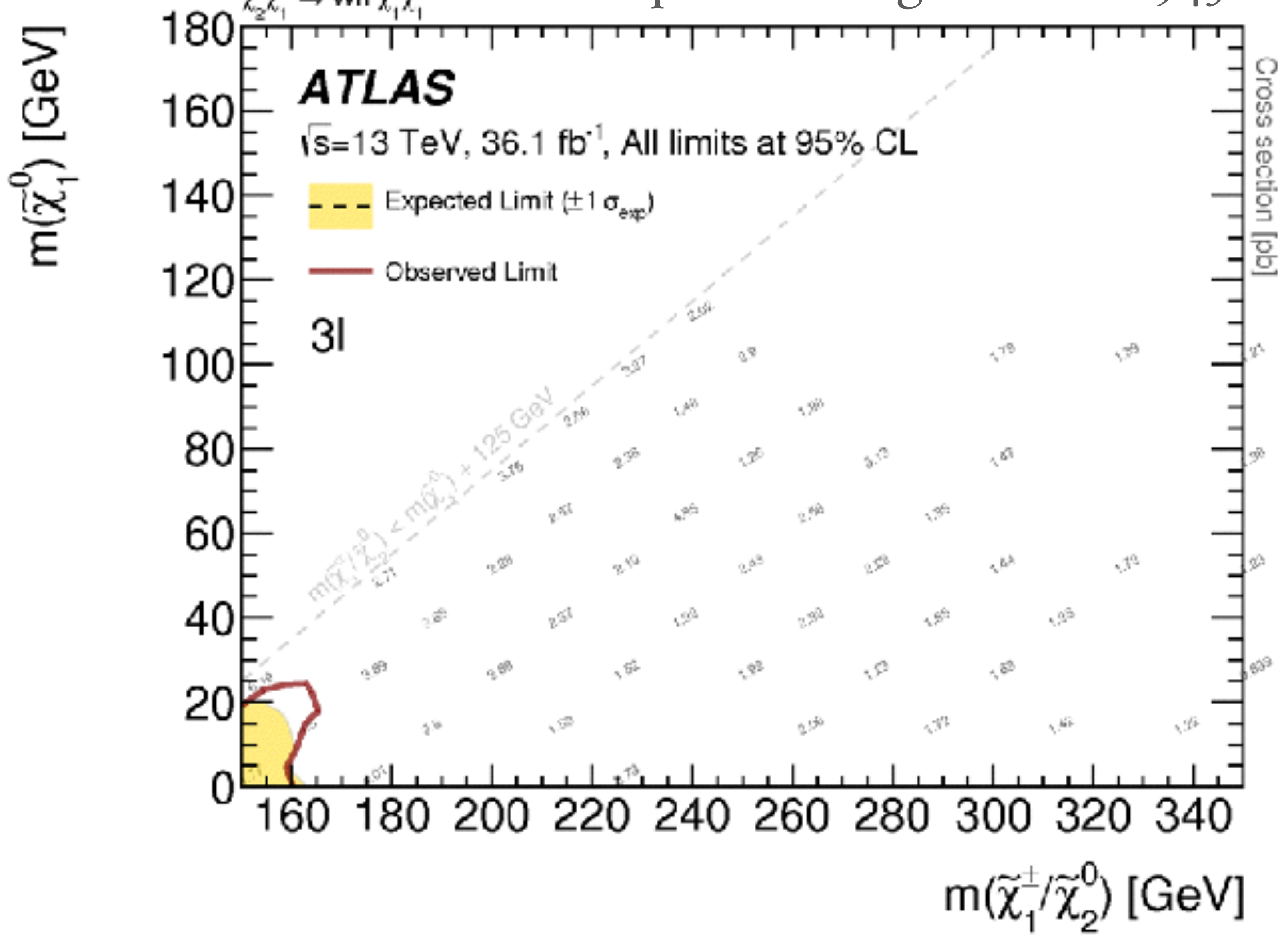

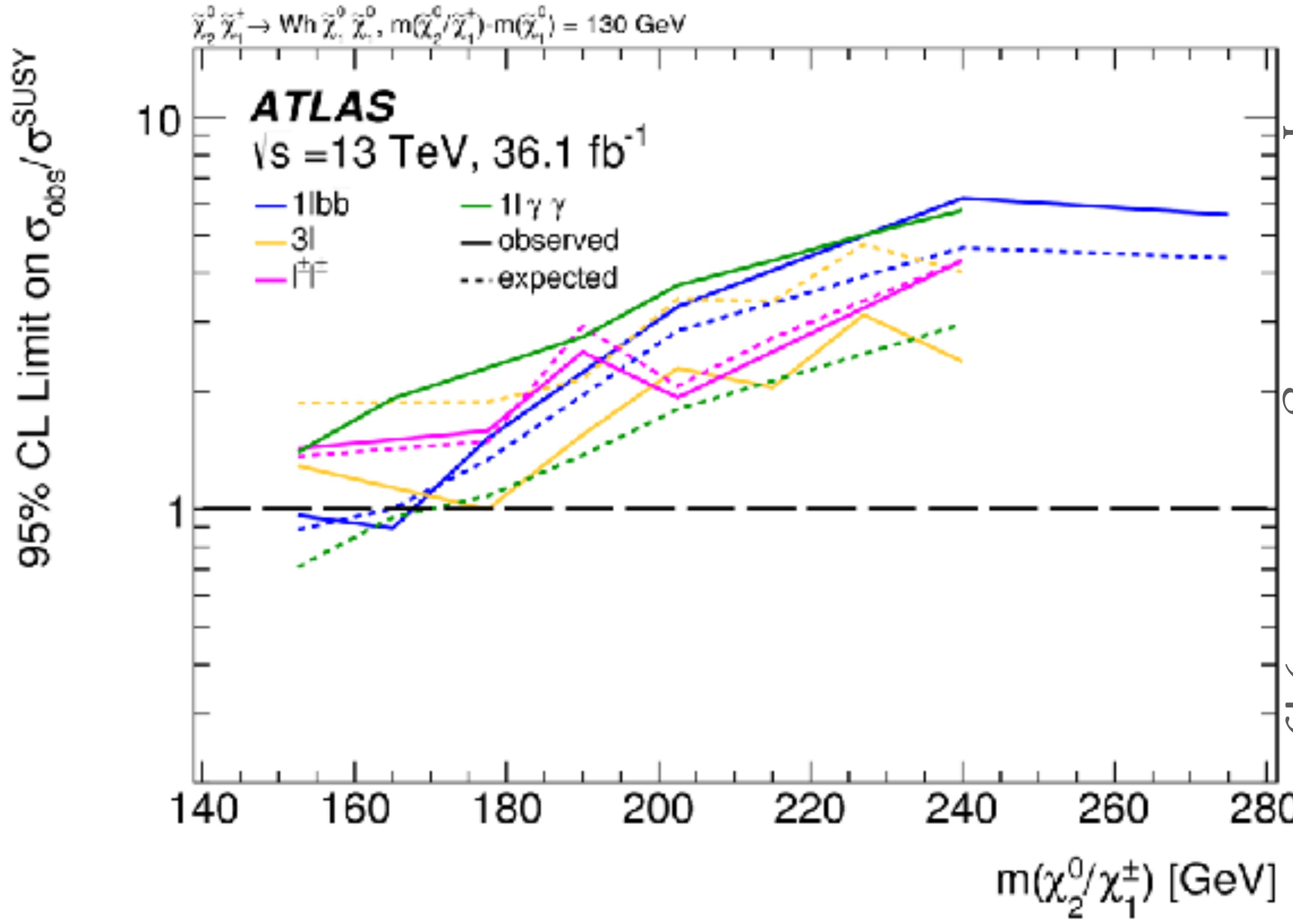

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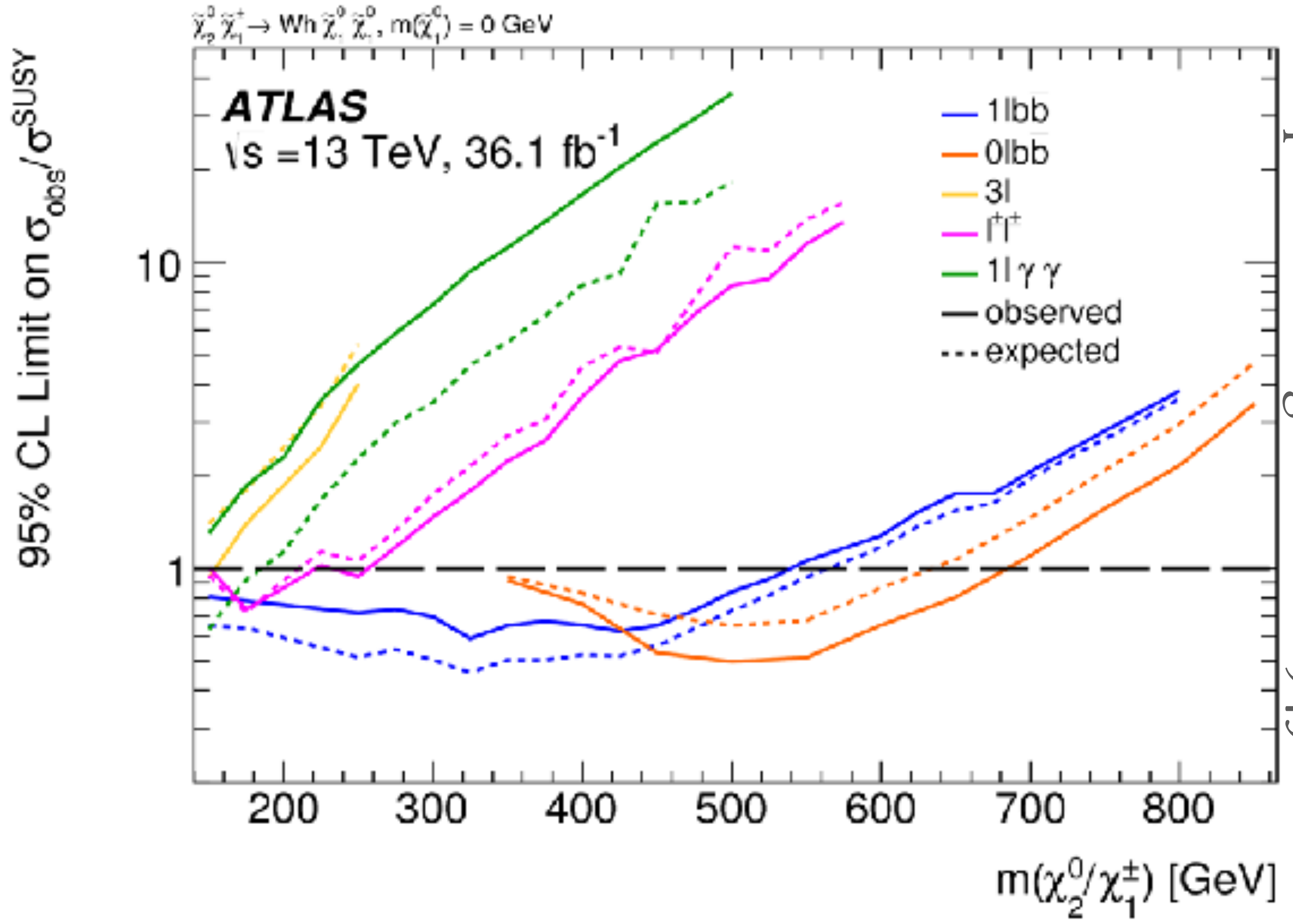

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