

ATLAS
EXPERIMENT

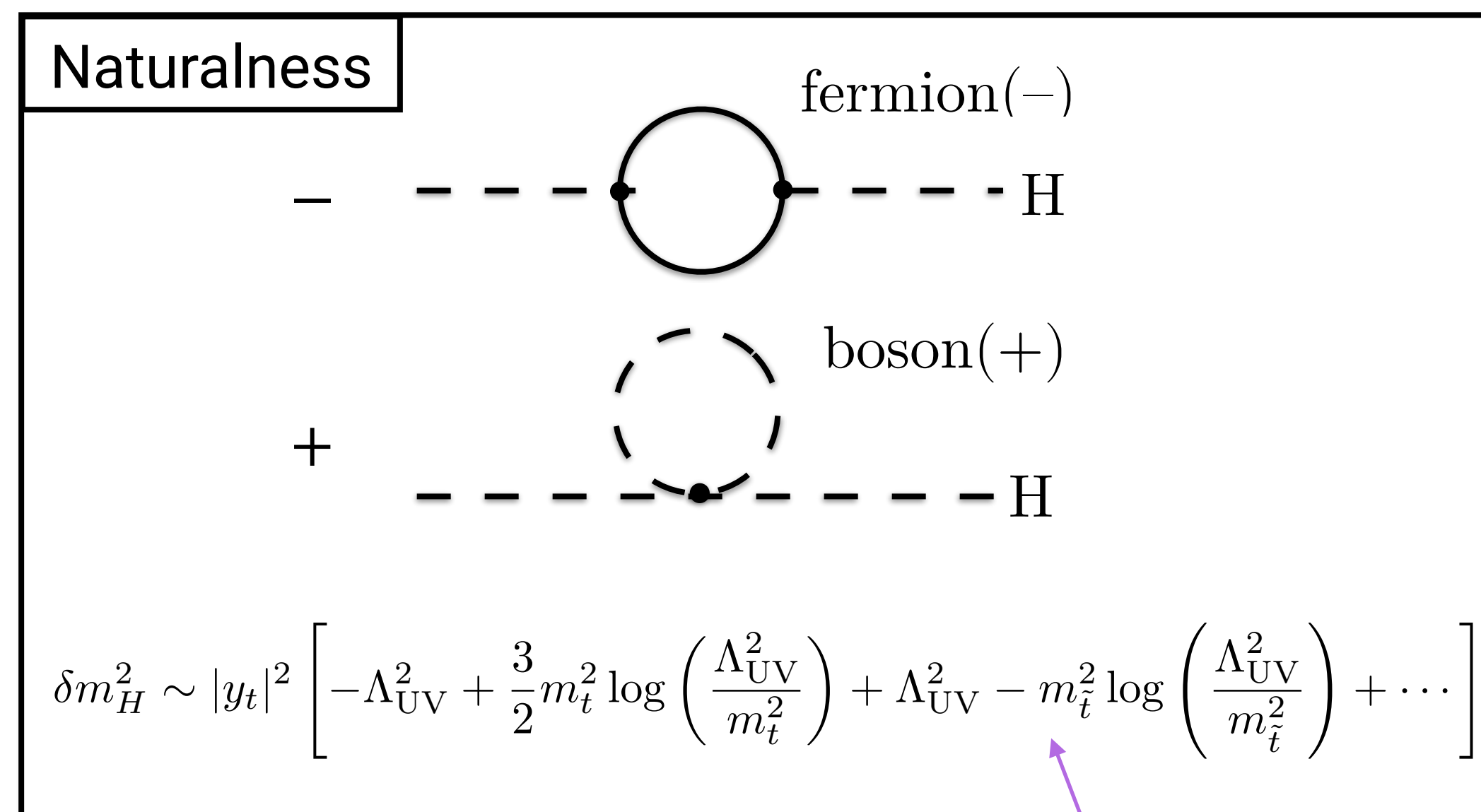


SUSY Dark Matter Searches at the LHC

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on behalf of ATLAS and CMS
4-Jun-2020, DM@LHC

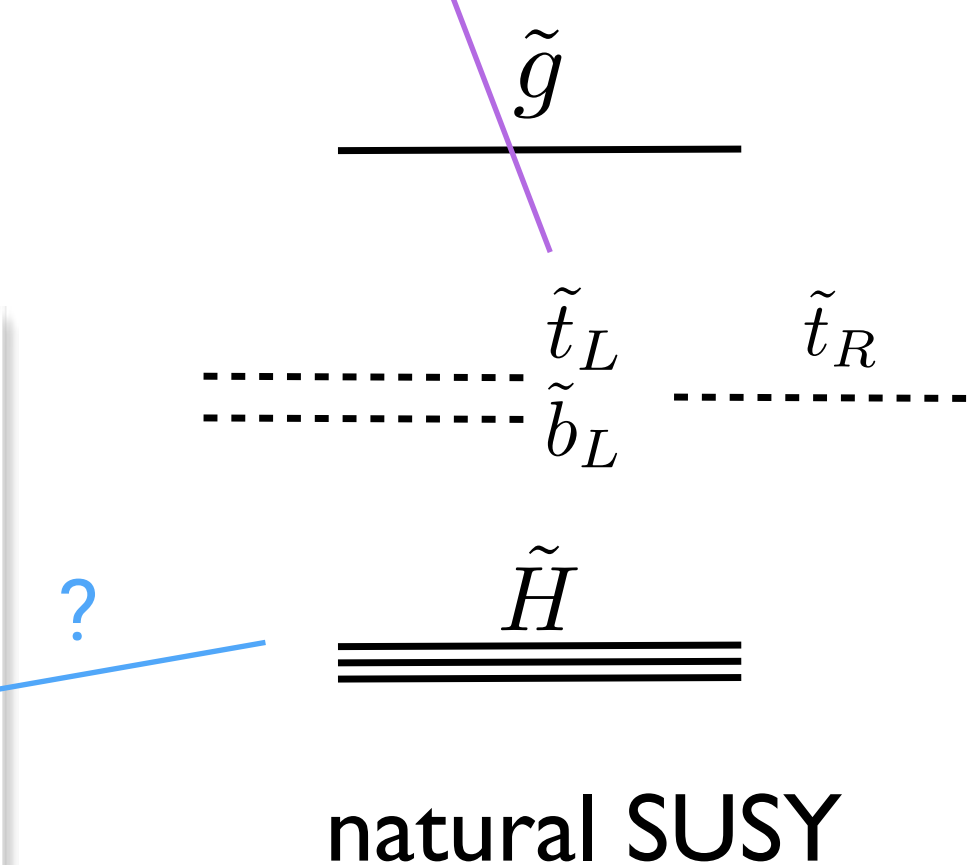
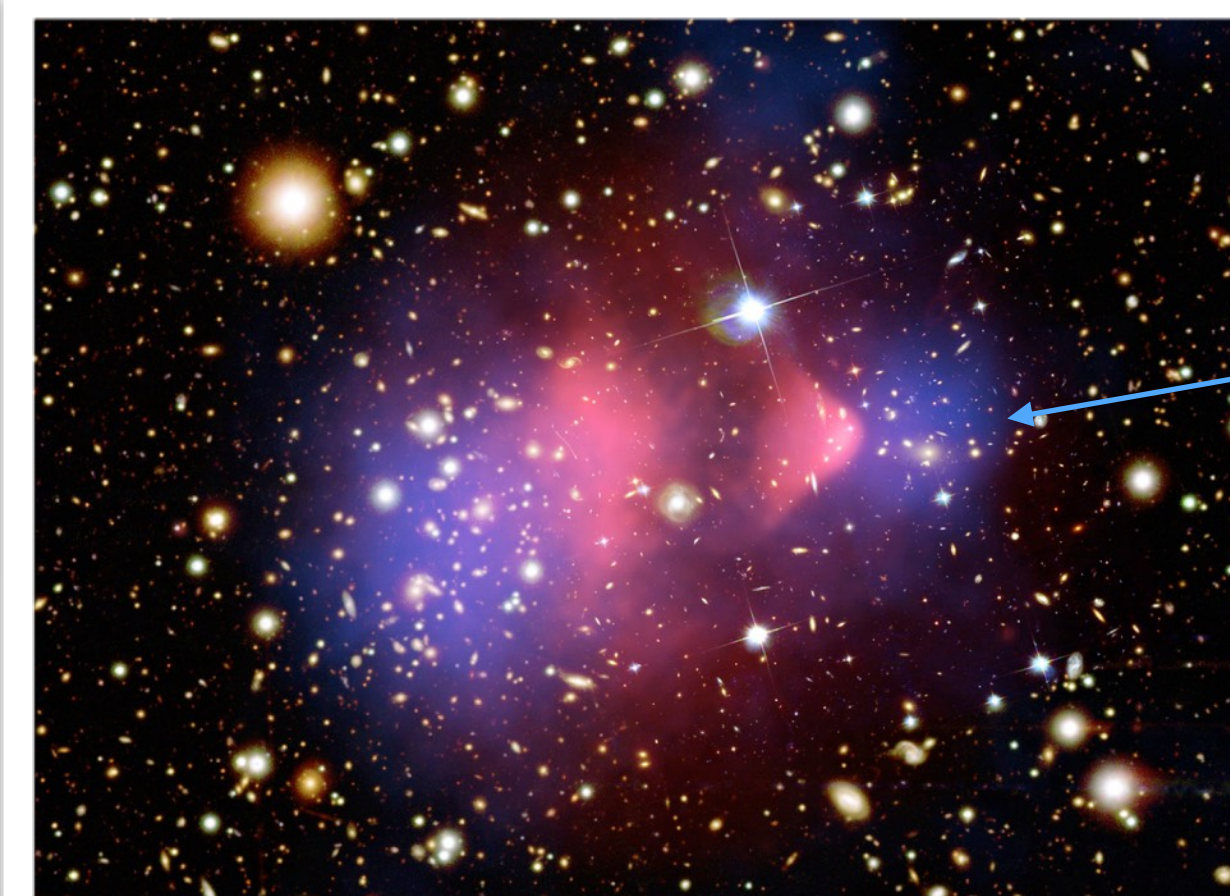


- ❖ An natural extension to the Standard Model
 - ▶ Cancels the large corrections to the scalar's mass
 - ▶ A natural solution to the naturalness problem
 - ▶ Expect interactions with the SM
 - ▶ The 3rd gen squarks expected at TeV scale



- ❖ Provide natural Dark Matter candidate
 - ▶ Assuming **R-parity is conserved**
 - Stable Lightest Supersymmetric Particle (LSP)
 - ▶ Neutralino is a great DM candidate
 - ▶ Electroweakinos are interacting weakly
 - Relic density suggest WIMP ~ Electroweak scale

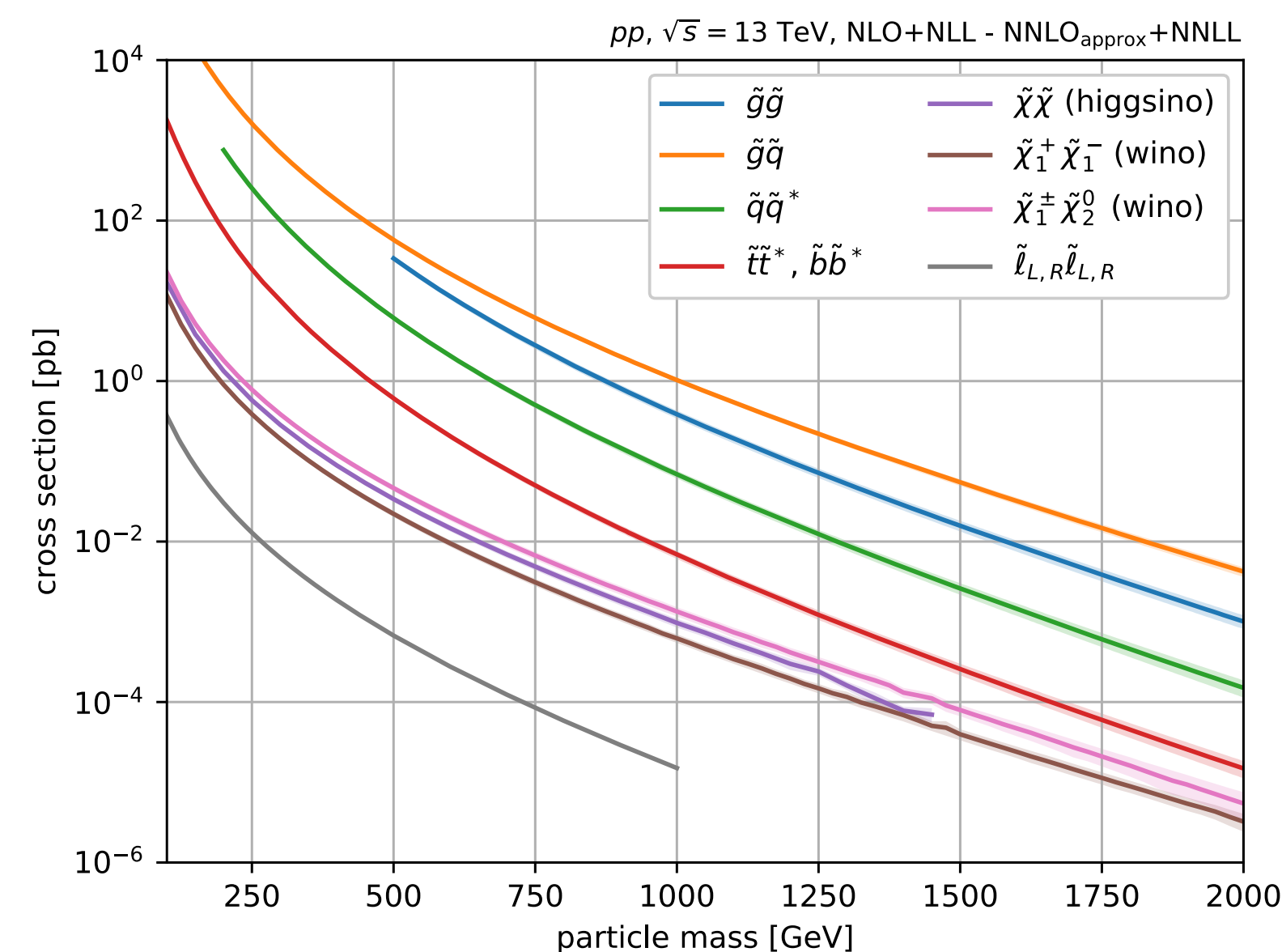
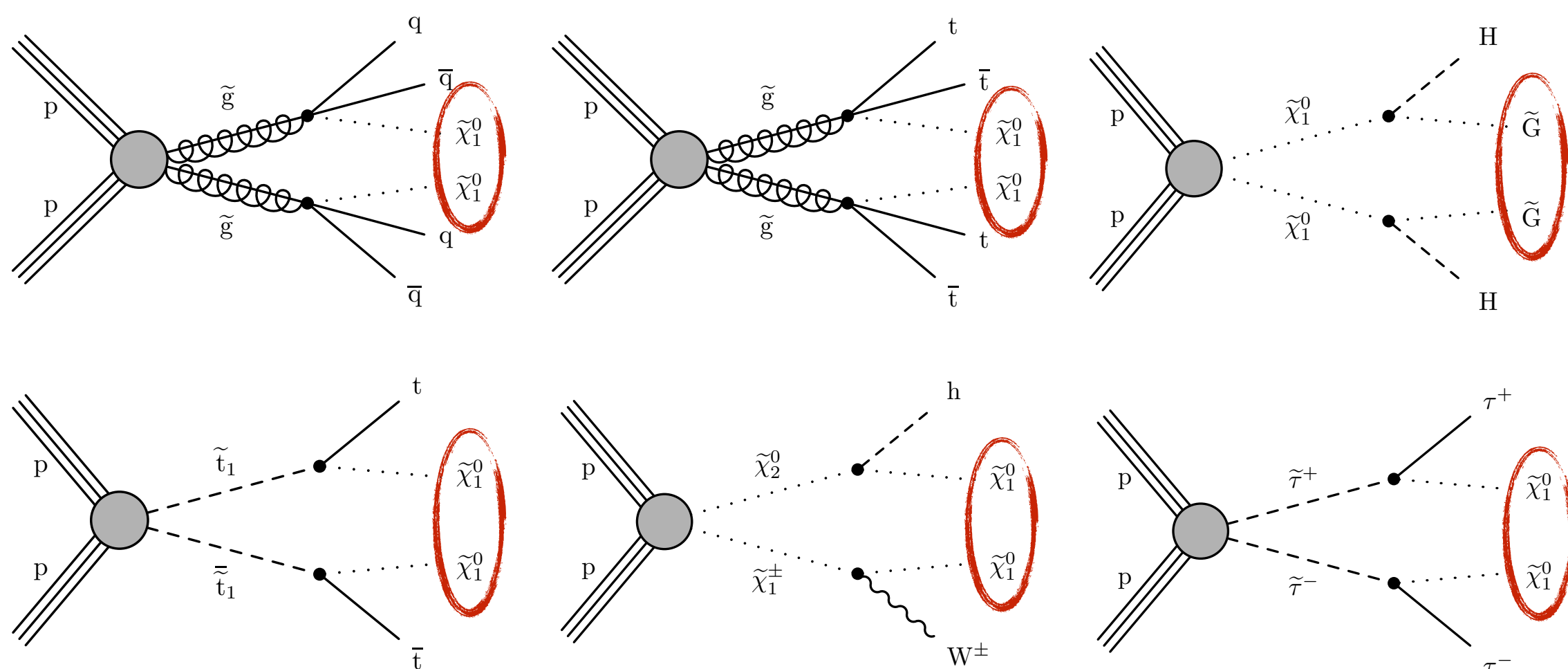
Abundant observational evidence for DM



Papucci/Ruderman/Weiler,
arxiv:1110.6926

- ❖ Comprehensive searches in CMS and ATLAS looking at a variety of production mechanisms for the DM candidate
 - ▶ Generic searches using experimental signature (e.g. #lepton, #jets)
 - ▶ Targeting the production of SUSY particles according to **simplified models**

Only looking at a few examples today!

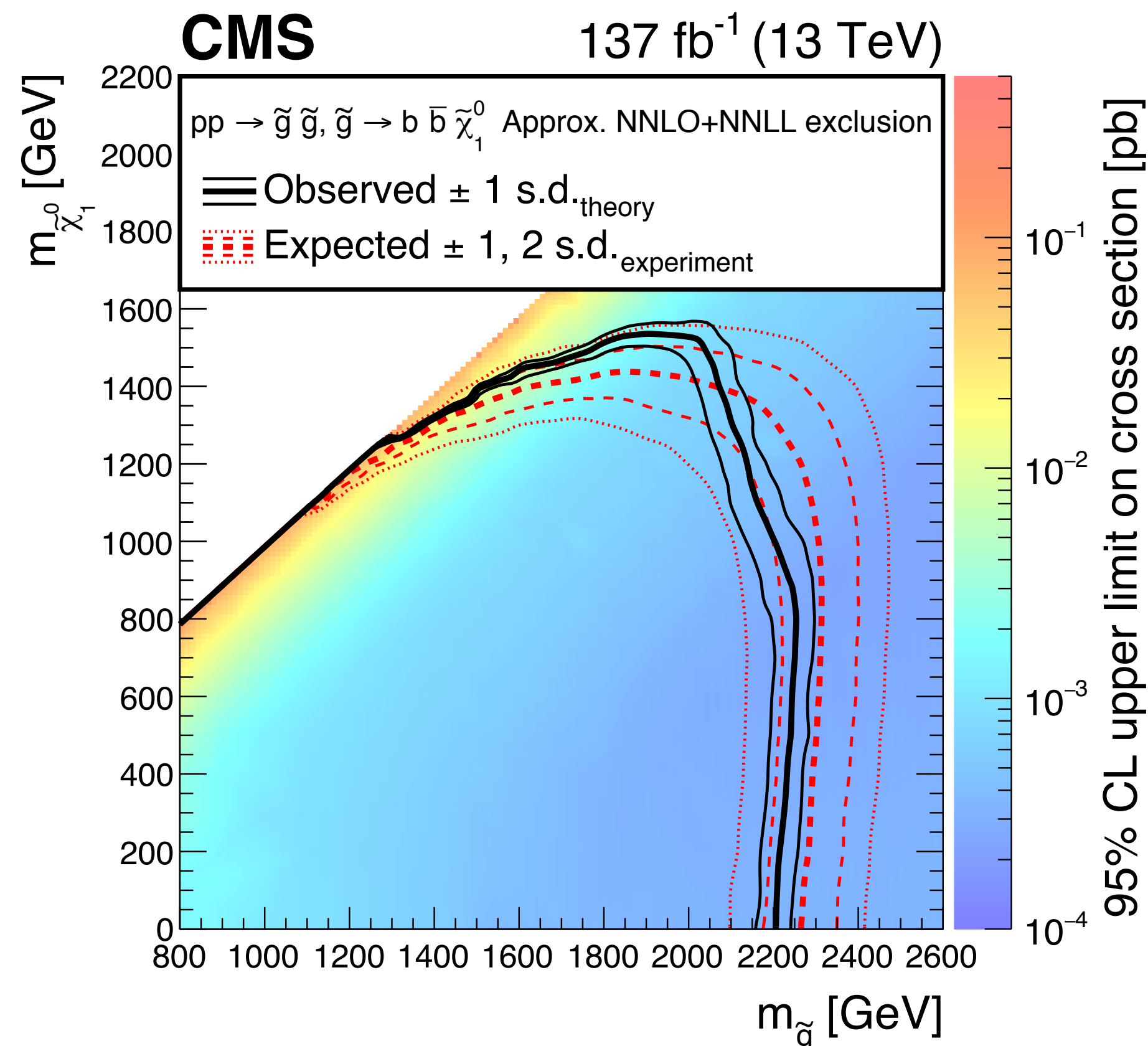


- ❖ Core strategy: **Large missing energy** from the DM candidate (LSP)
- ❖ DM limits are tied to their SUSY decay chains
 - ▶ Subject to the couplings & decay modes
- ❖ Searches are more challenging at the compressed scenarios

- ❖ Search in all hadronic final state
 - ▶ Probe the strong sector of SUSY
 - ▶ Gluino mass also constraint by naturalness

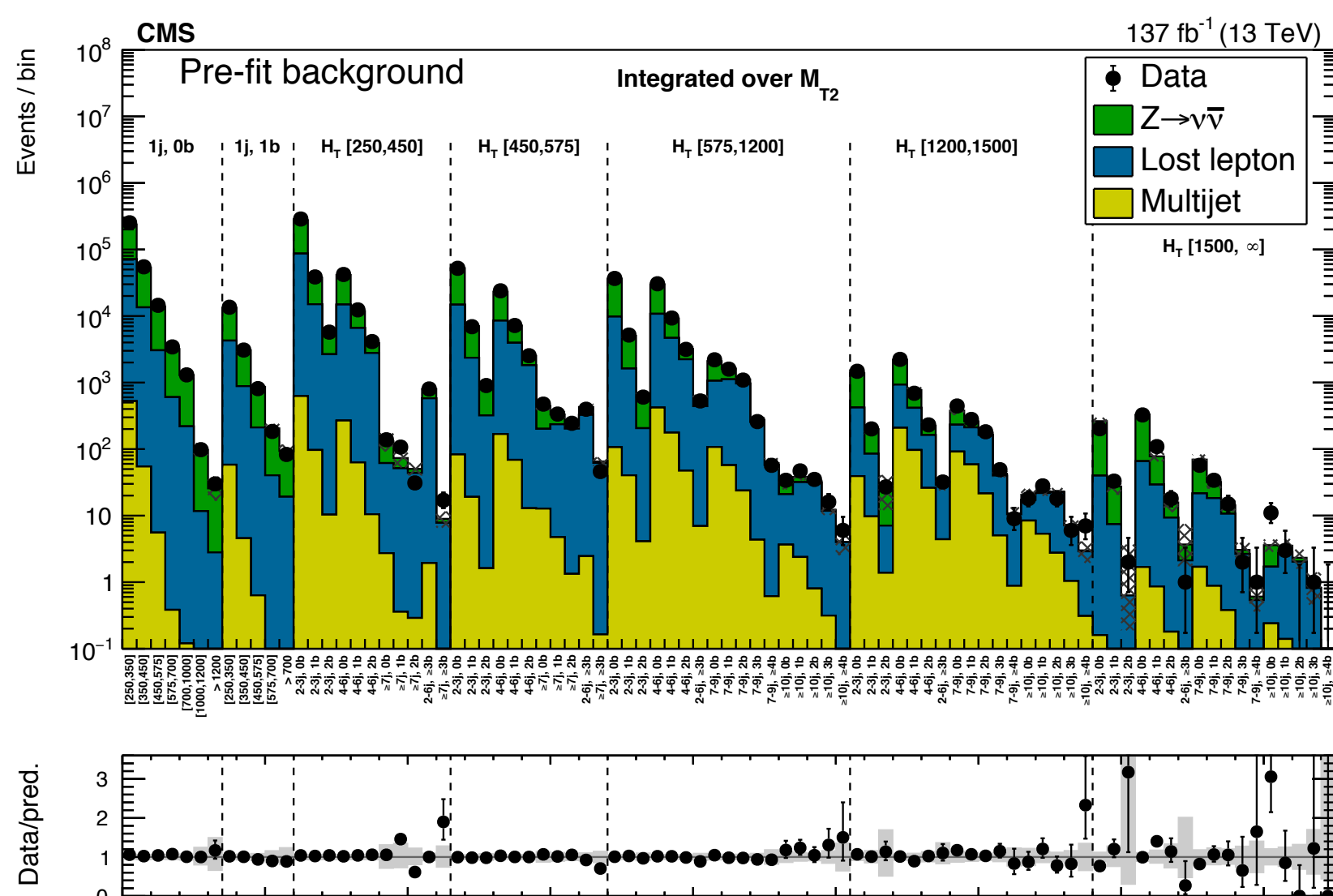
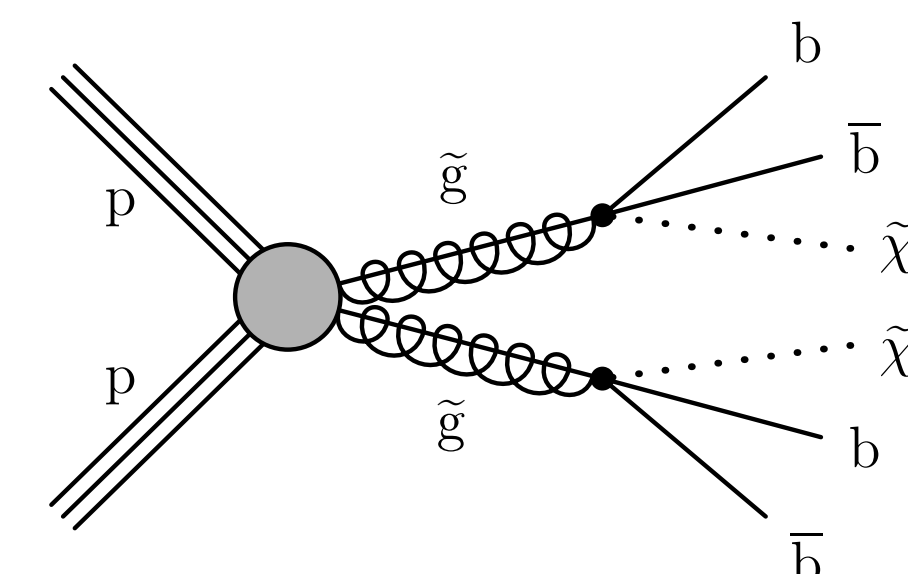
- ❖ Key strategy: constraint multi-jet with M_{T2}
 - ▶ Multi-binned cut-and-count
 - ▶ Background estimates all come from data

- ❖ Neutralino DM excluded up to 1.5 TeV



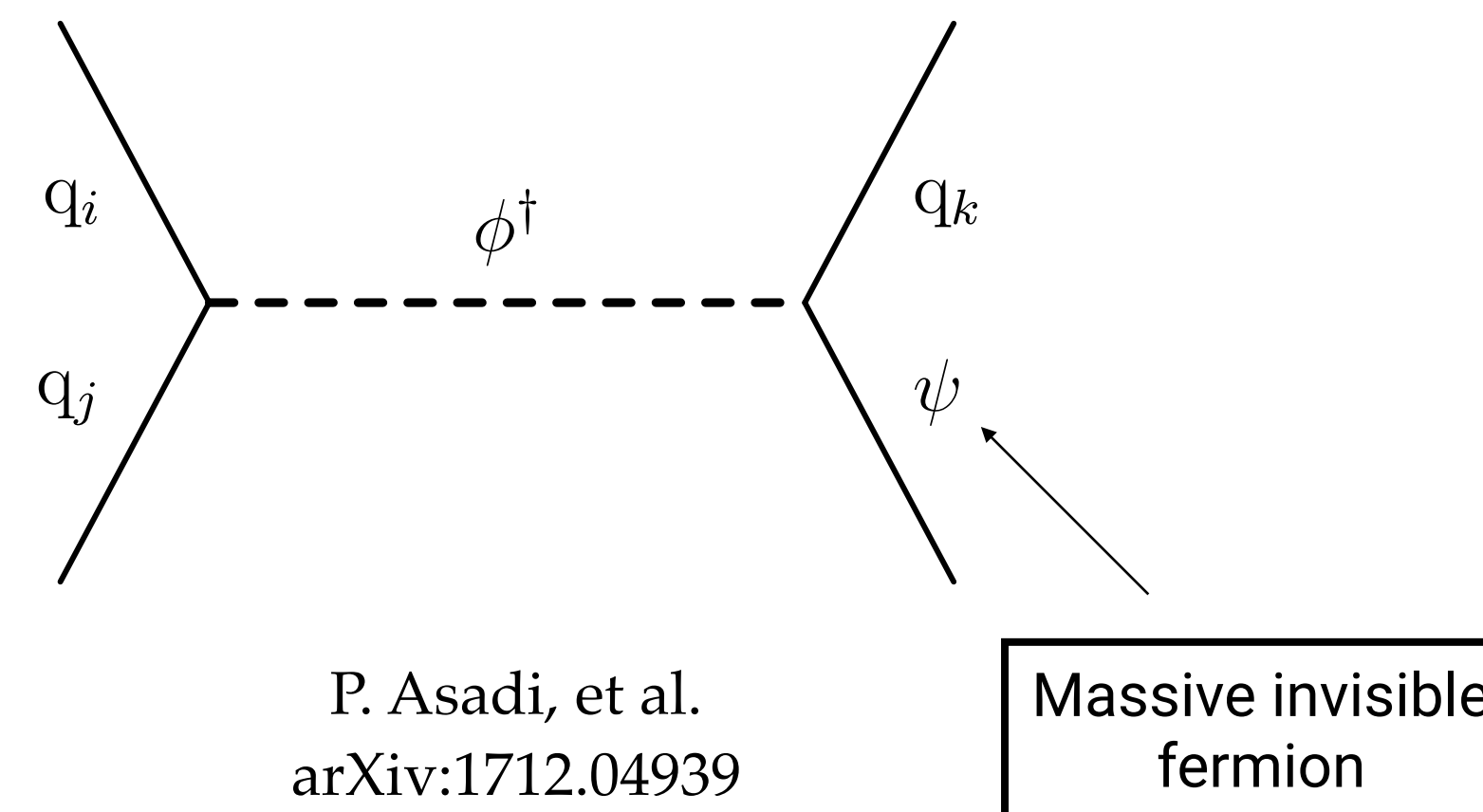
Eur. Phys. J. C 80 (2020) 3
[CMS-SUS-2019-005]

Complementary ATLAS result:
ATLAS-CONF-2020-002

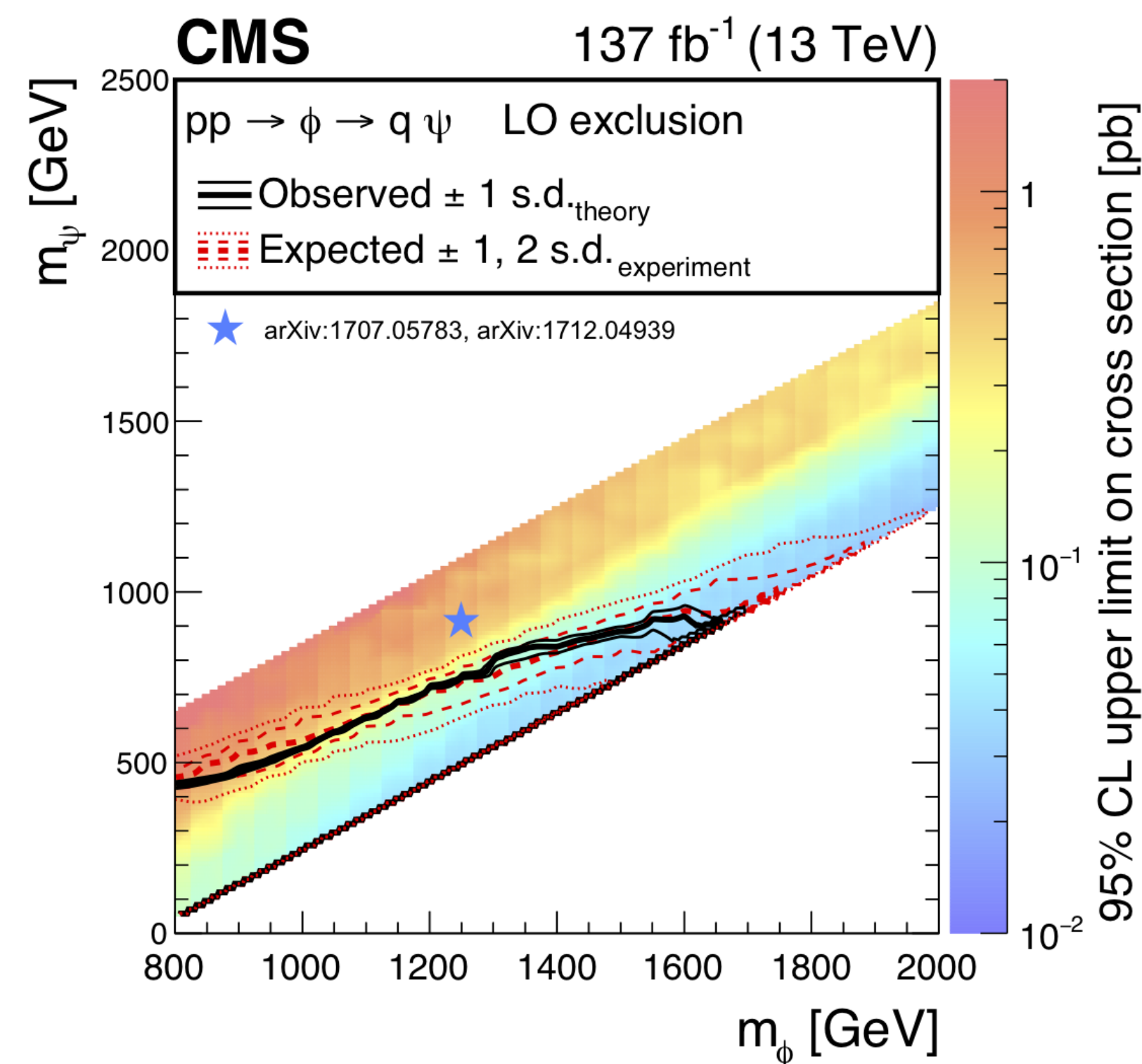


- ❖ Aggregated regions used in reinterpretation
 - ▶ Search consist of hundreds of mutual exclusive regions
 - ▶ Combining these search regions can go beyond simplified models
 - ▶ An $\sim 3\sigma$ excess was found at previous iteration by external reinterpreter [arXiv:1707.05783]
 - ▶ The new non-SUSY interpretation is included in the run2 result

- ❖ Other interpretation with LQ also included
 - ▶ LQ reinterpretation can also be found at the recent ATLAS 0ℓ search: [arXiv:2004.14060](https://arxiv.org/abs/2004.14060)



Eur. Phys. J. C 80 (2020) 3
[CMS-SUS-2019-005]



- ❖ Central piece to the naturalness problem
 - ▶ Lightest squark in natural SUSY scenarios
 - ▶ Searches with signature: $t\bar{t} + \cancel{E}_T$

- ❖ More difficult to probe in compressed spectra (low $\Delta m(\tilde{t}, \tilde{\chi}^0)$ regions)
 - ▶ Using more stats to explore low $\Delta m(\tilde{t}, \tilde{\chi}^0)$
 - Softer in object kinematics and \cancel{E}_T
 - New techniques on object tagging [recent]

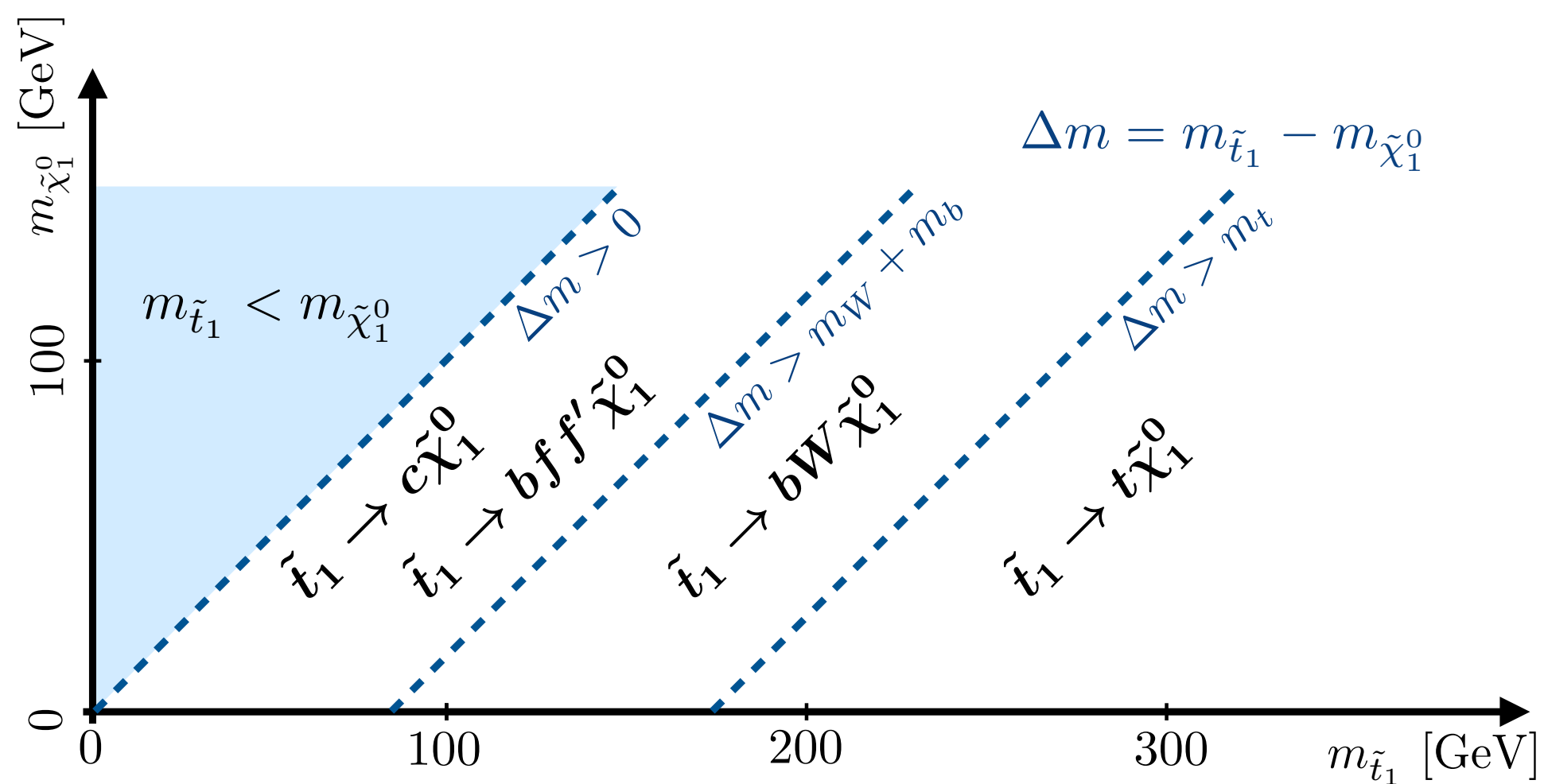
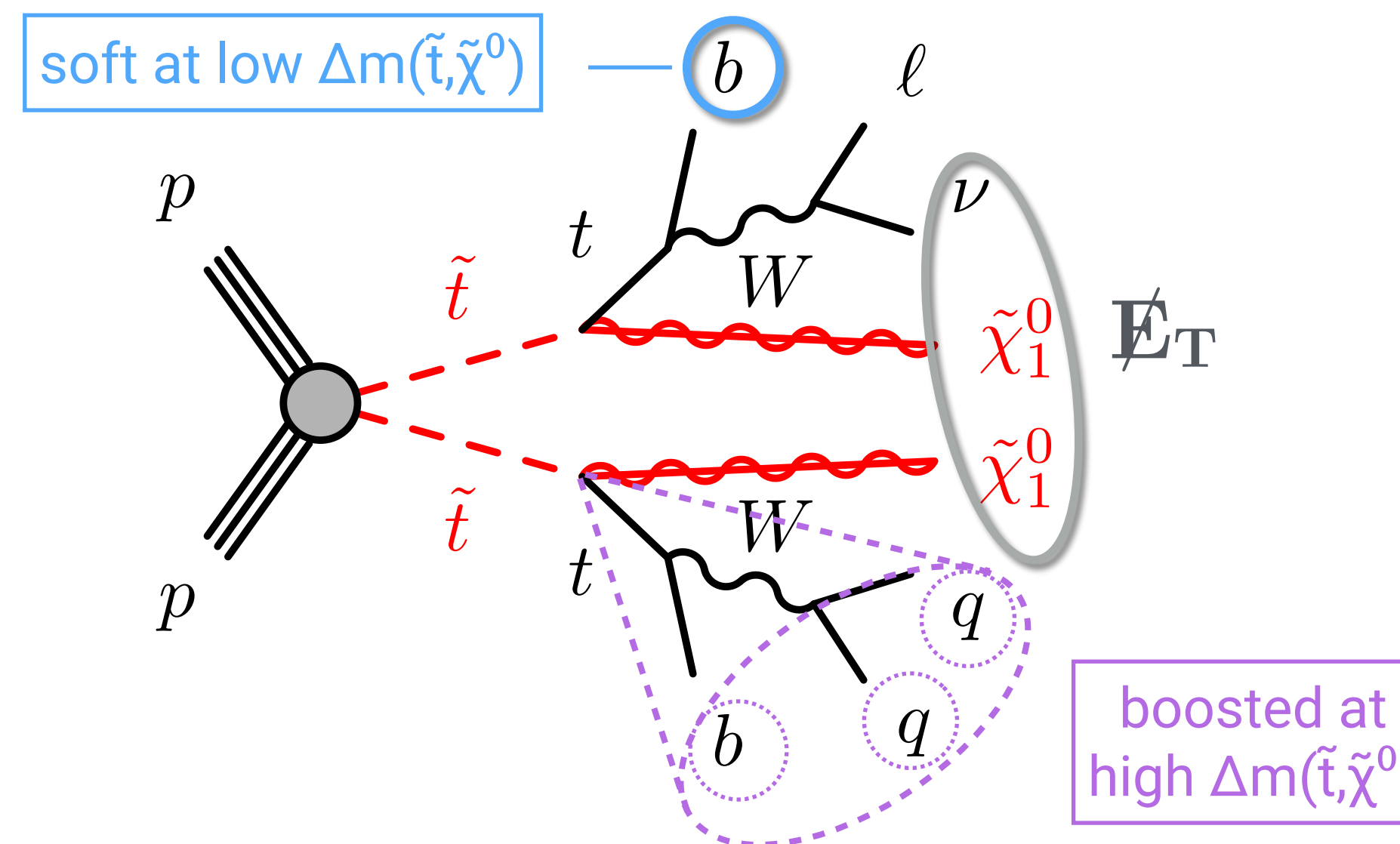
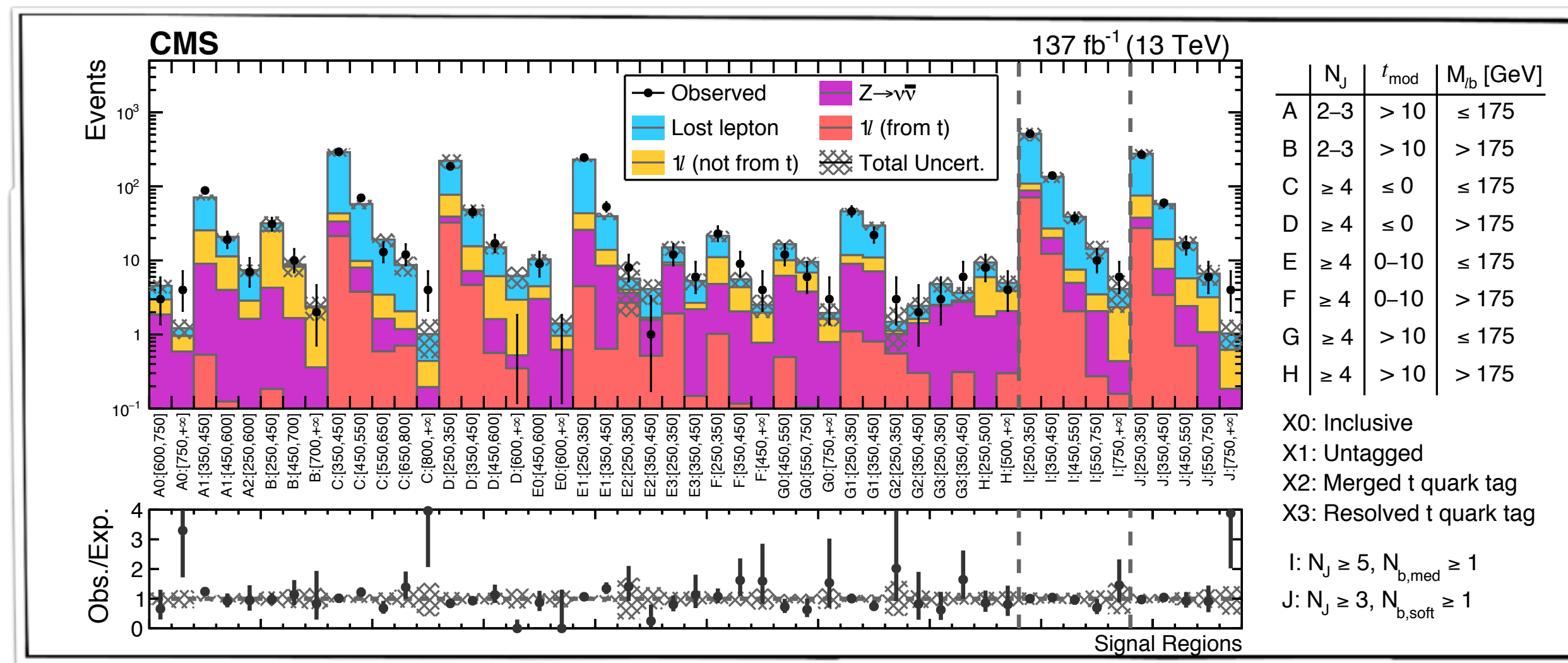
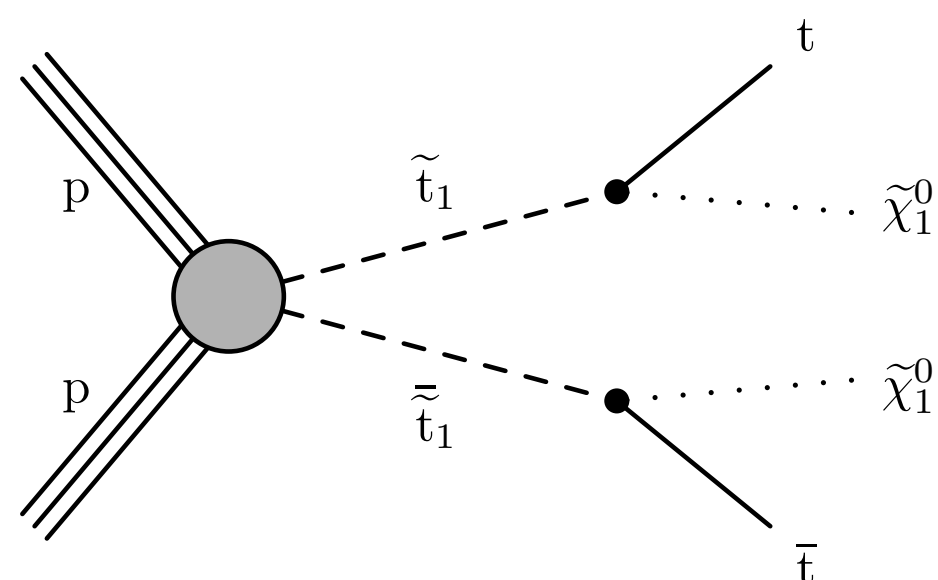


Fig. from ATLAS-CONF-2019-017

Run2 results targeting at stop pair production:
 0 ℓ : [arXiv:2004.14060](https://arxiv.org/abs/2004.14060) (ATLAS)
 1 ℓ : [ATLAS-CONF-2020-003](https://arxiv.org/abs/2002.003)
 1 ℓ : [JHEP 05 \(2020\) 032](https://arxiv.org/abs/1905.032) (CMS)
 2 ℓ : [CMS-SUS-19-011](https://arxiv.org/abs/1901.011)

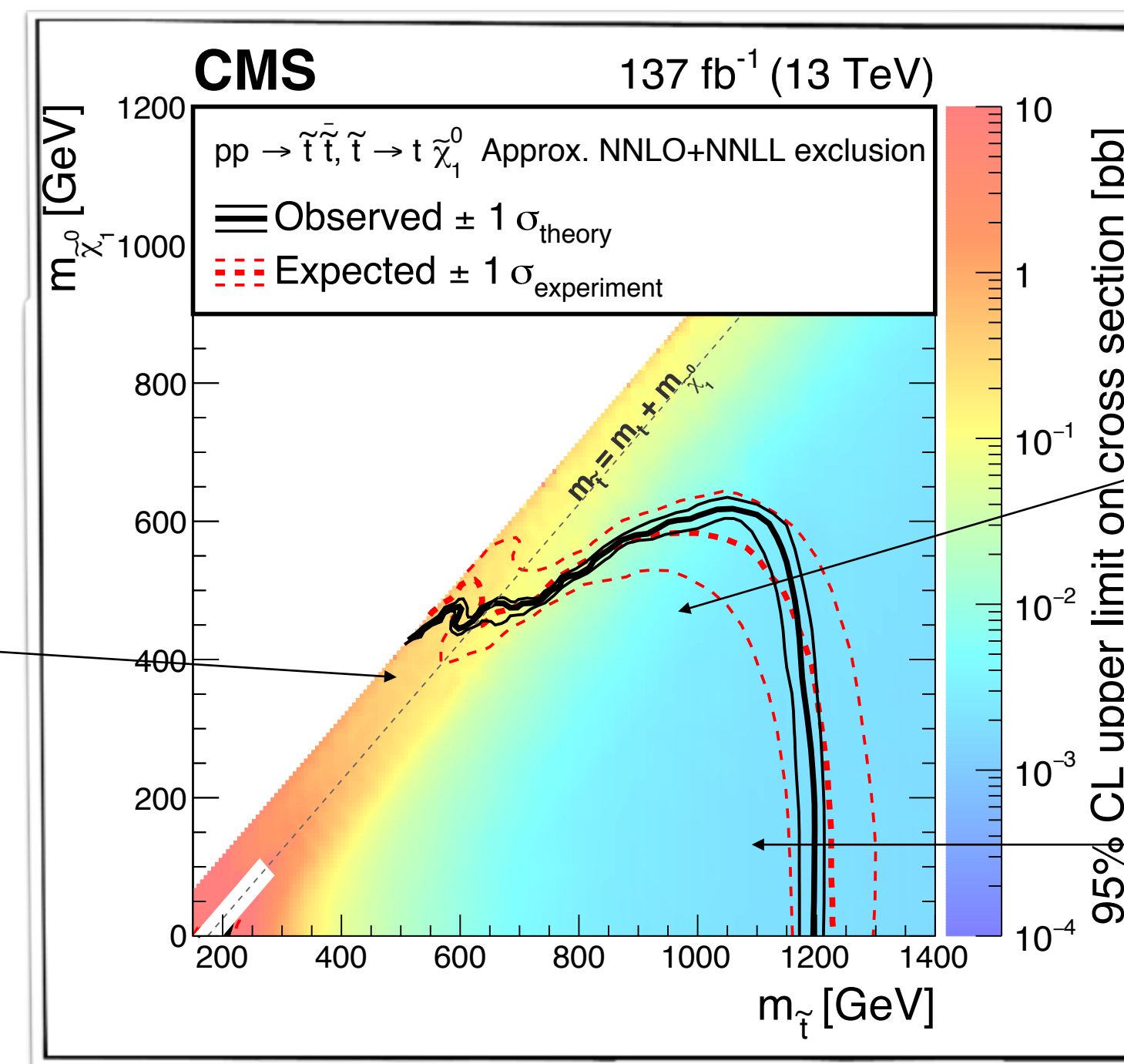
- ❖ Cut-and-count & multi-binned analysis
 - ▶ 39 search regions to cover variety of phase space and decay modes
 - ▶ Retaining ability for re-interpretations



JHEP 05 (2020) 032
[CMS-SUS-19-009]

- ❖ Optimize with heavy object identification
 - ▶ Top-tagging for large Δm
 - ▶ Soft-b tagging for $\Delta m \sim m_W$

soft-b



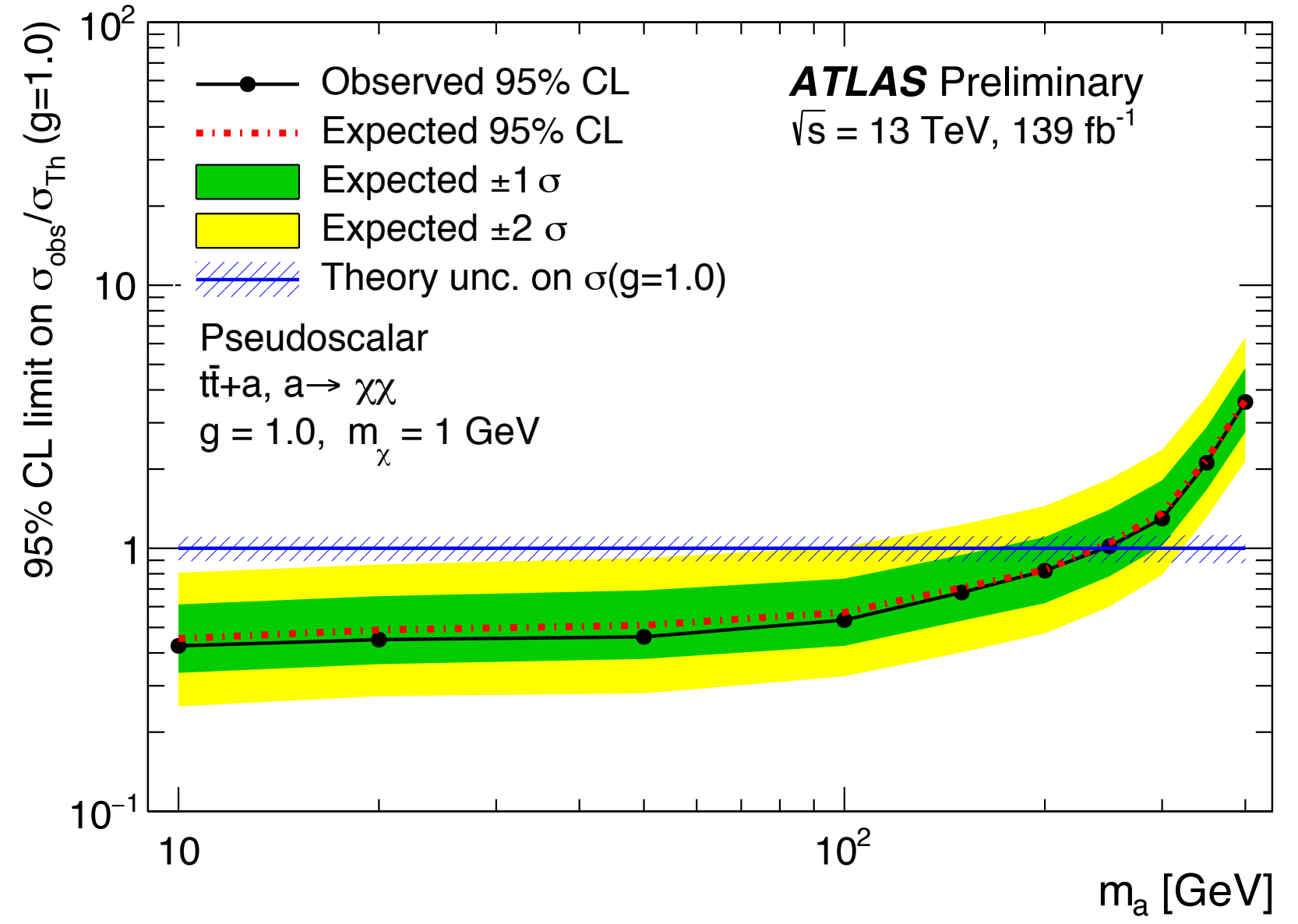
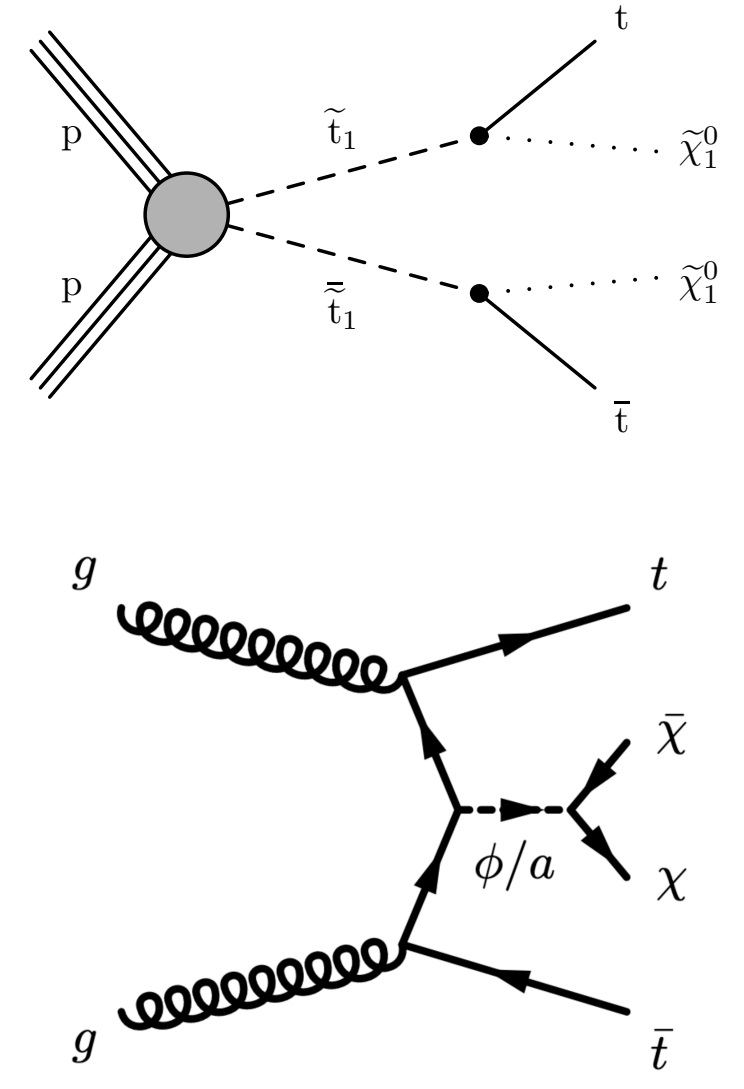
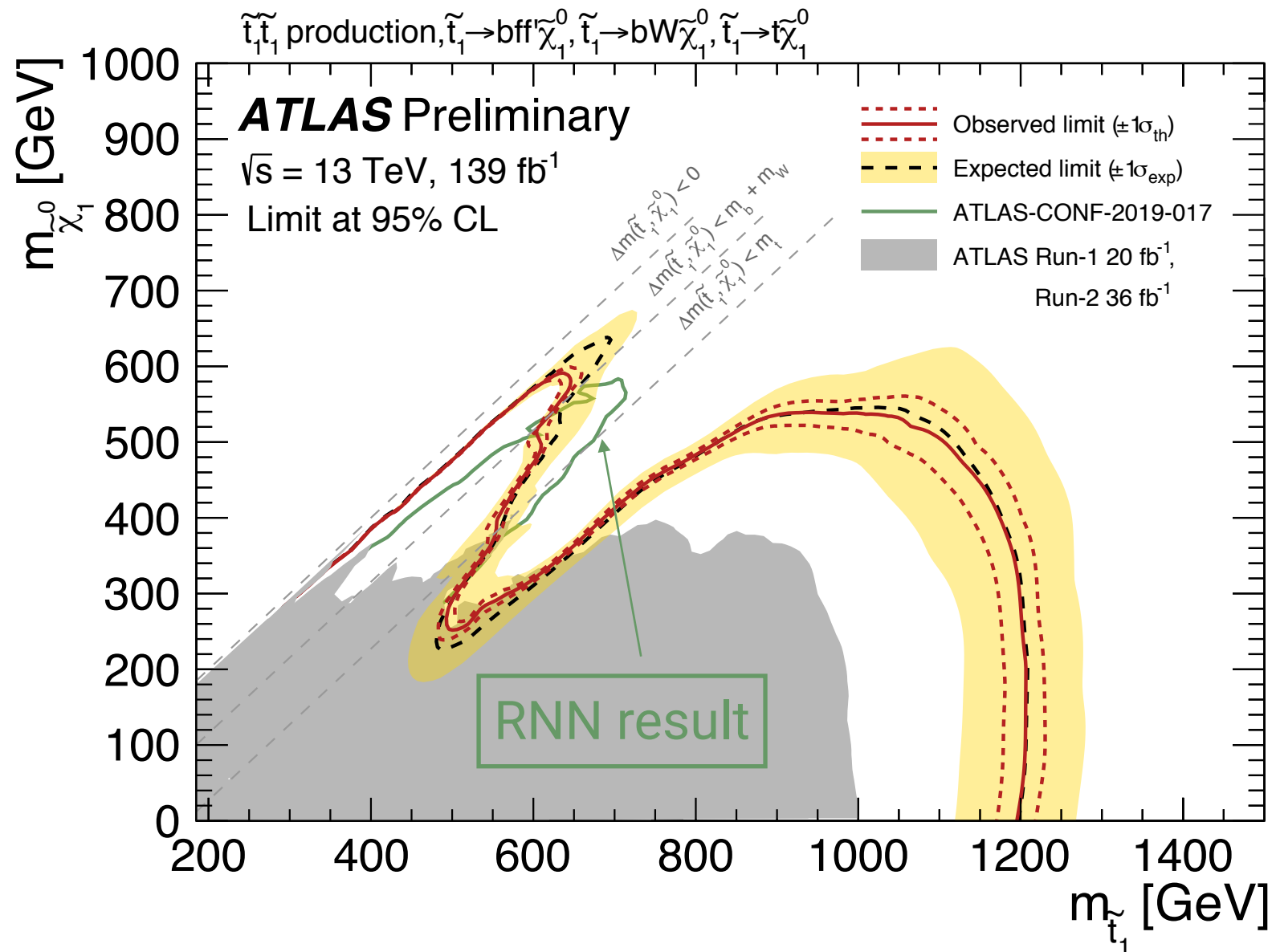
top-tagger
(resolved)

top-tagger
(merged)

- ❖ Dedicated search bins for different decay scenarios
 - Cut-and-count & shape-fit
 - Pushed limit on LSP up to 570 GeV at low Δm with soft-b tagging
 - See also [ATLAS-CONF-2019-017] for the use of Neural Network at the 3-body mode

- ❖ Interpretation in the $t\bar{t}$ +DM model
 - Important channel for models with coupling to SM $\sim y_t$
 - Exclude a scalar/pseudoscalar mediator up to 300 GeV

ATLAS-CONF-2020-003

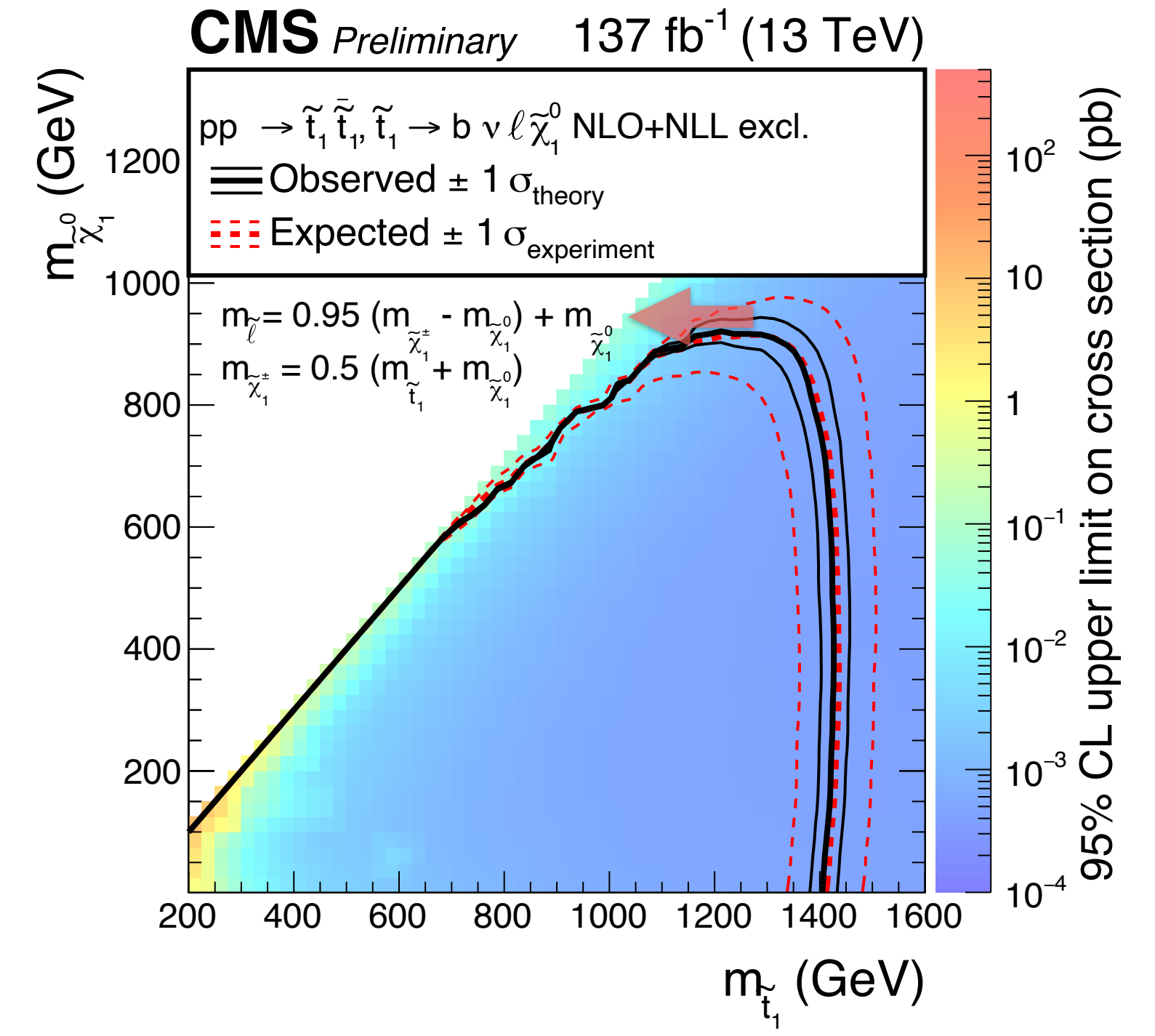
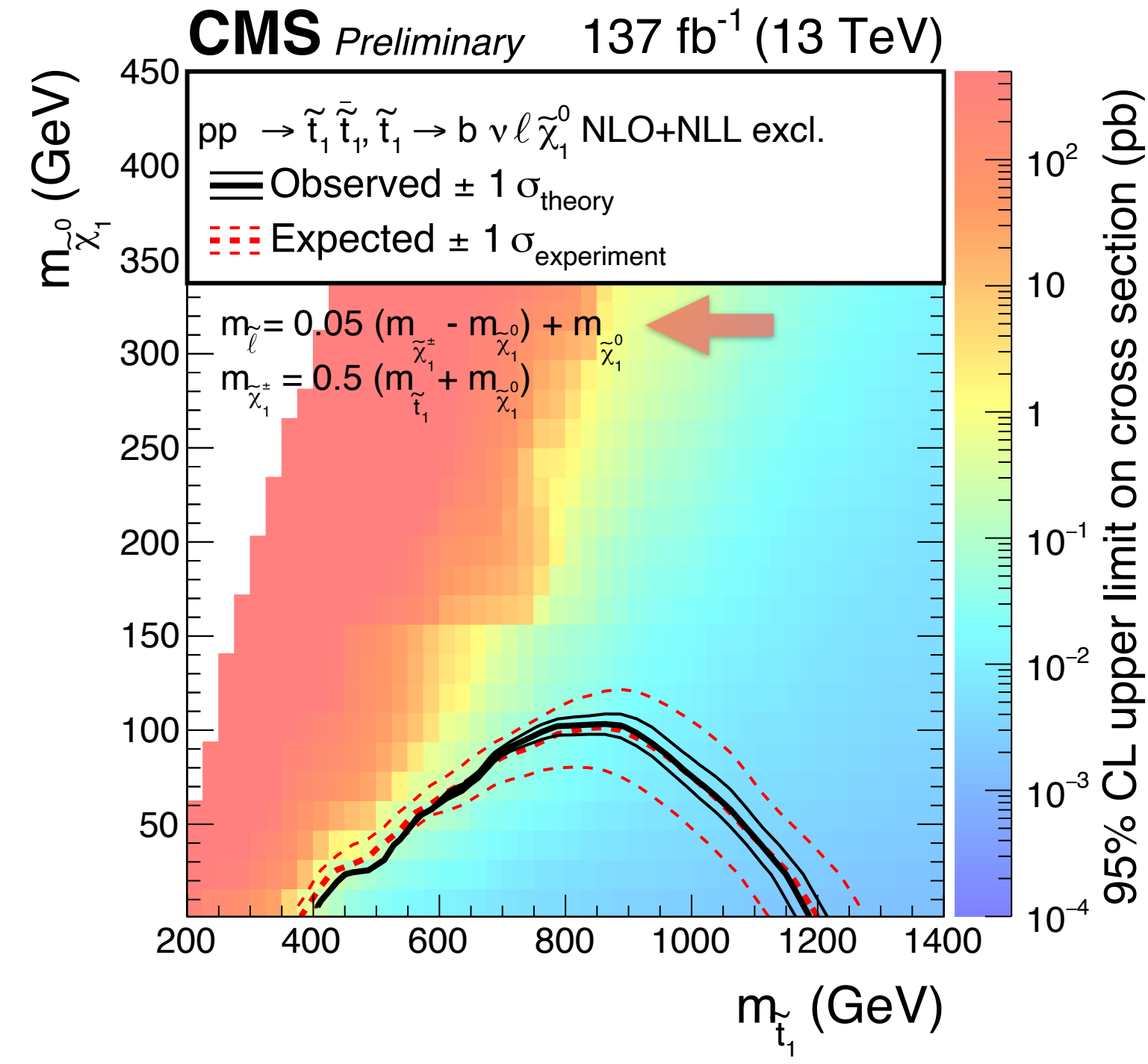
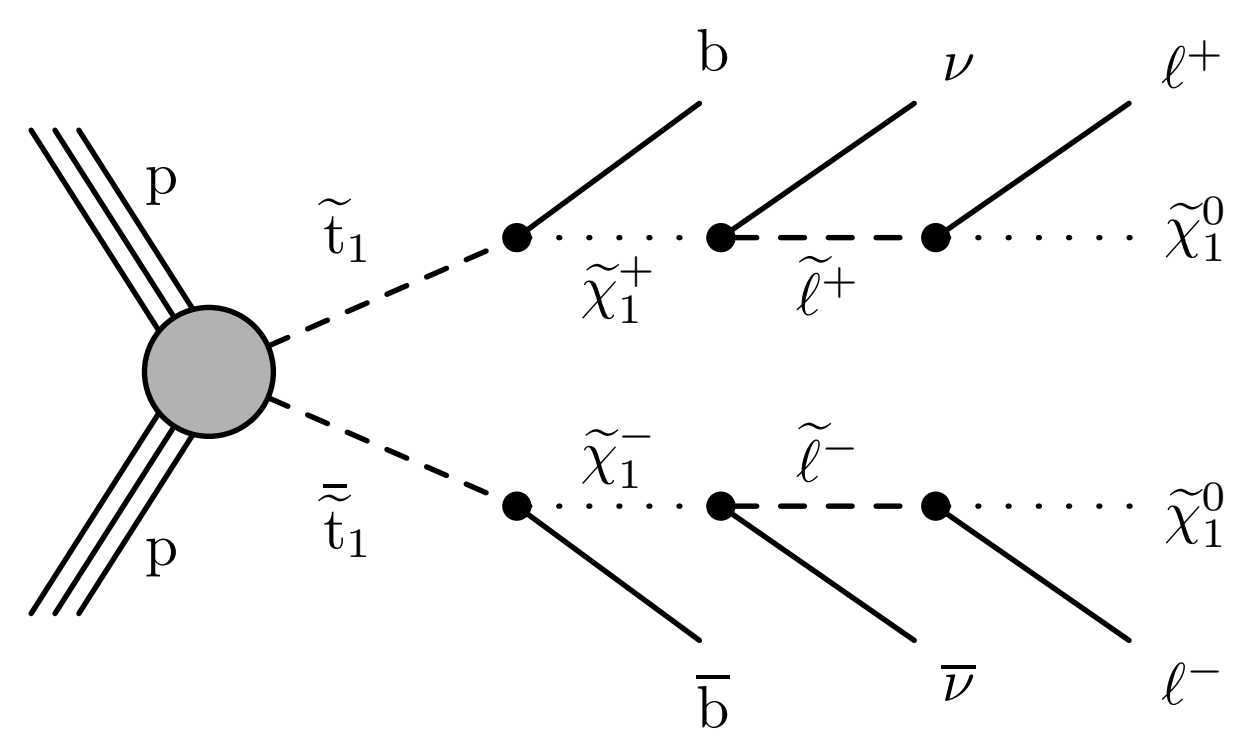
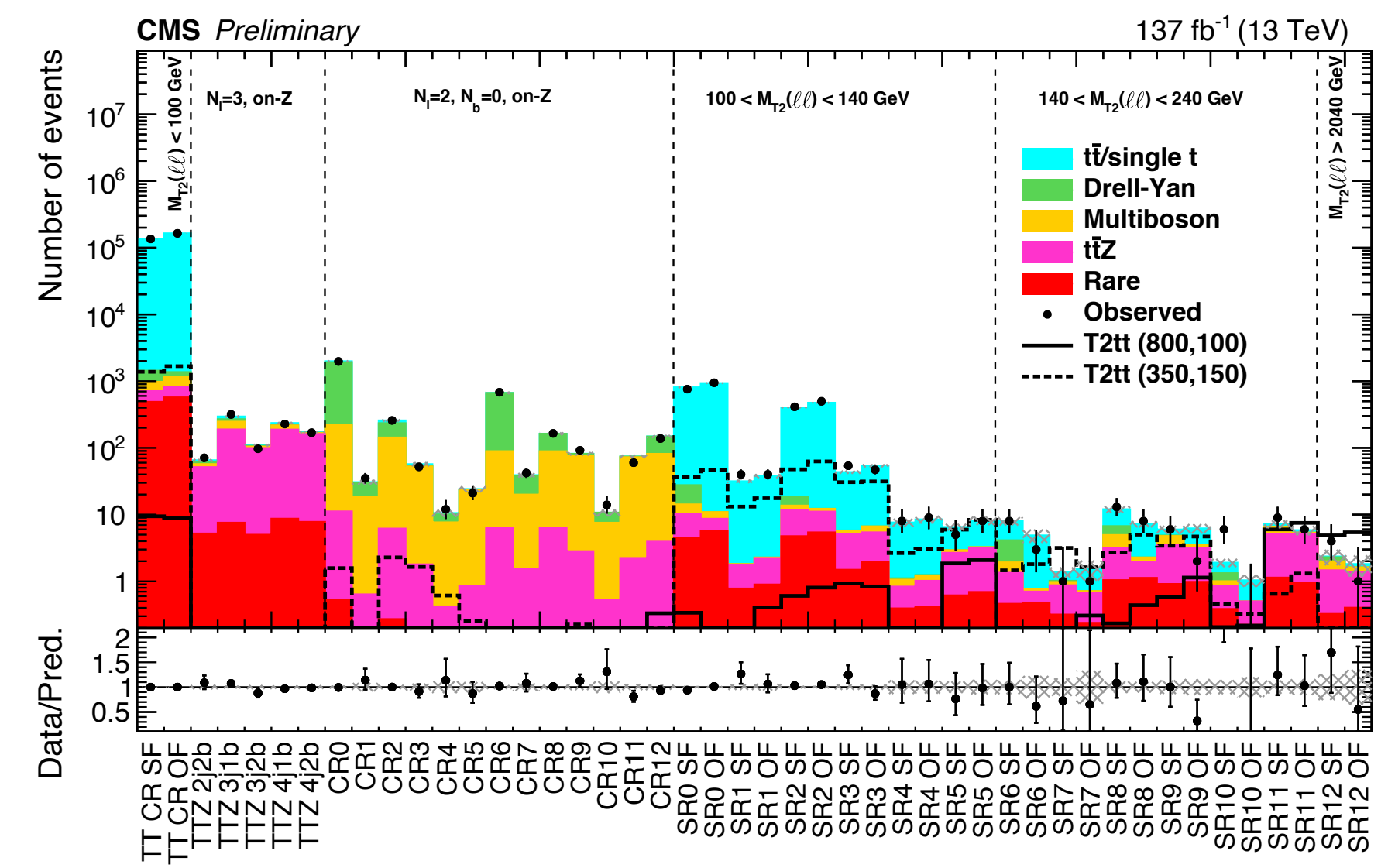


Search on Stop in 2ℓ

- ❖ No significant excess seen
 - ▶ Simultaneous fit controls the $t\bar{t}Z$ contribution
 - ▶ \cancel{E}_T significance to minimize effect from pile-up

- ❖ Also explores slepton in the decay chain
 - ▶ Exclusion limits on LSP can heavily depend on the details

CMS-SUS-19-011

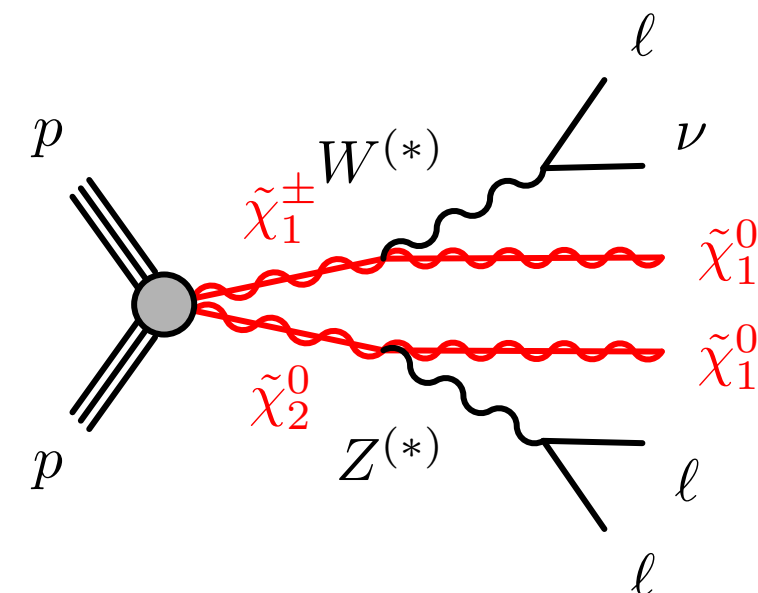


- ❖ Electroweakinos pair production
 - ▶ What if the strong sector is too heavy
 - ▶ 3ℓ : very rare in SM

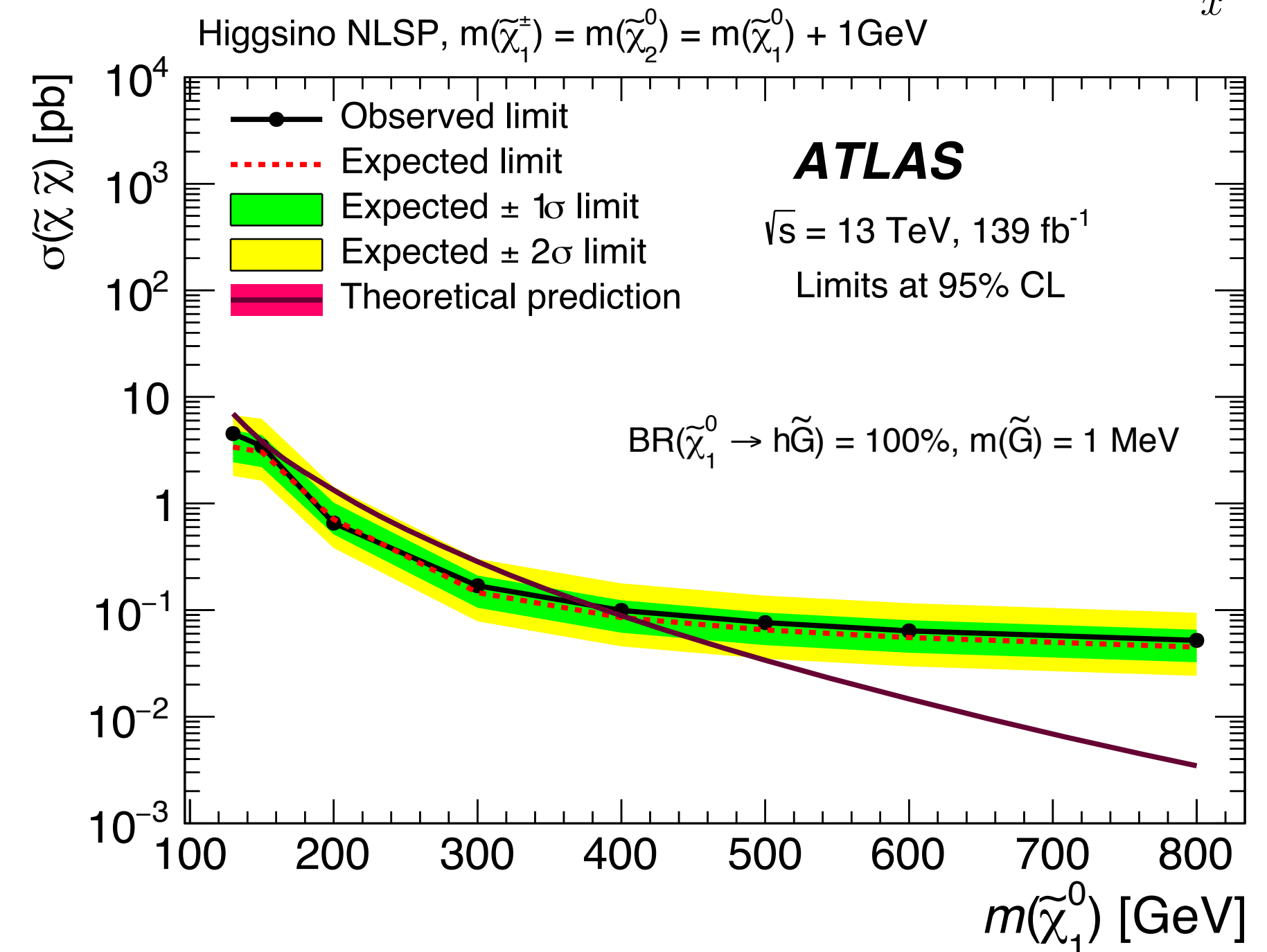
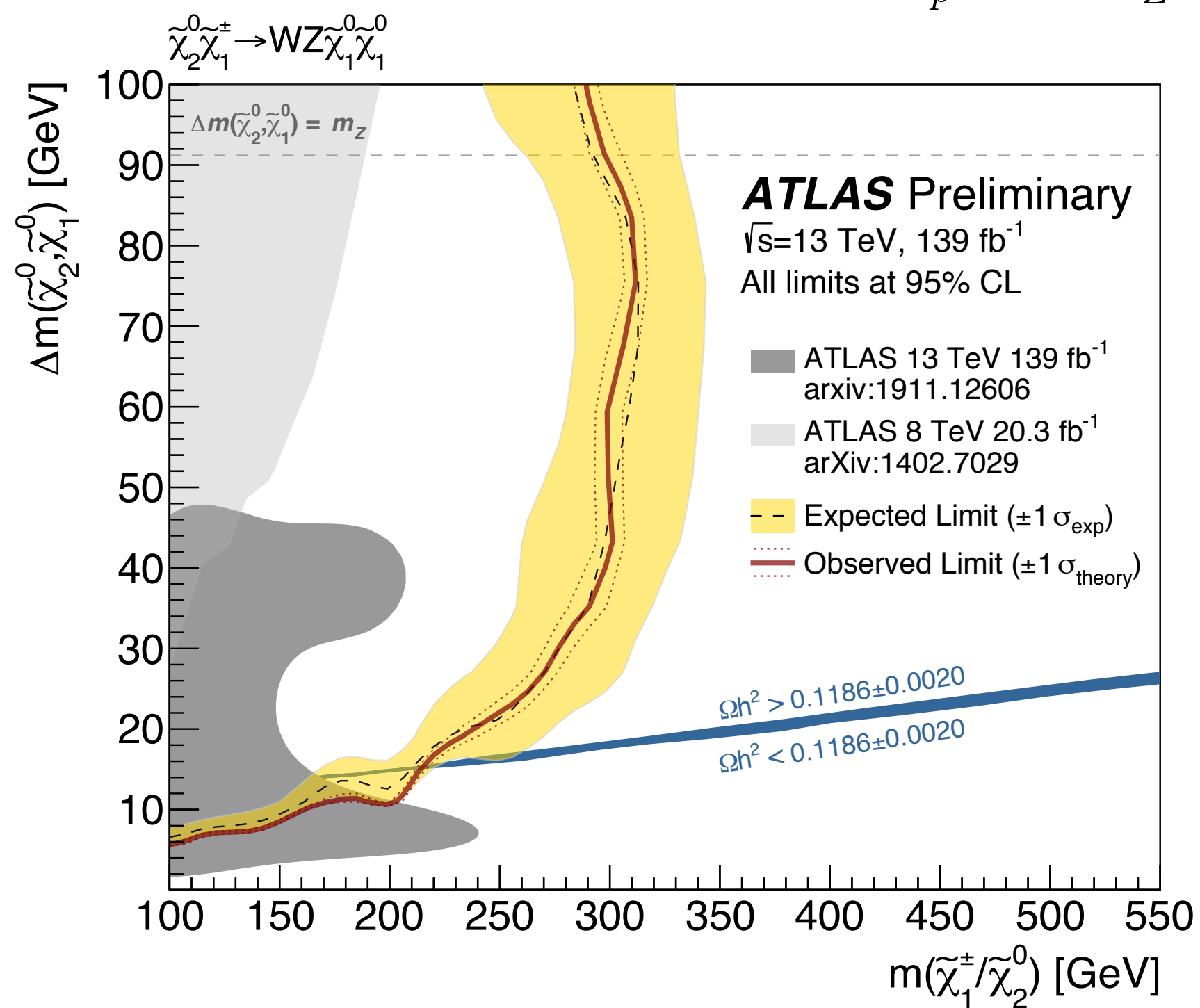
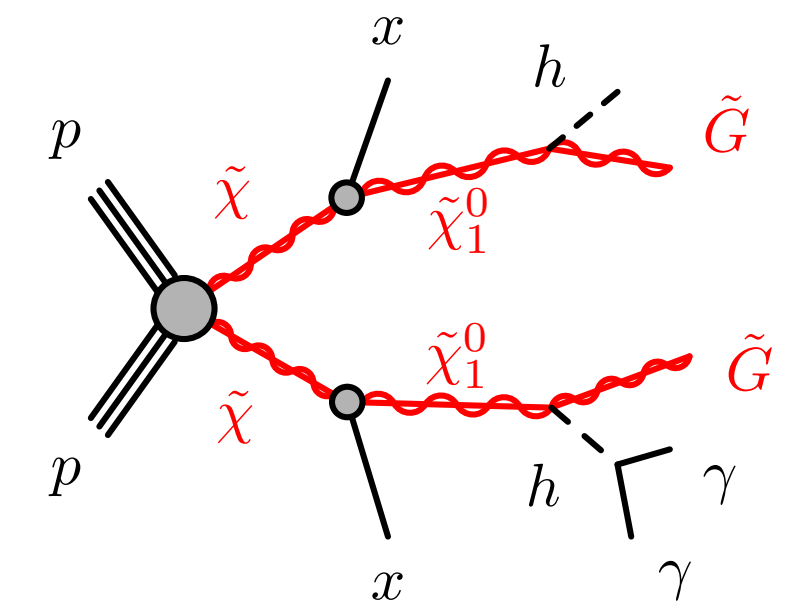
- ❖ Gravitino as the LSP
 - ▶ Neutralino as NLSP can still help in obtaining the relic density
 - ▶ Use higgs as the candle

New result

ATLAS-SUS-2020-015



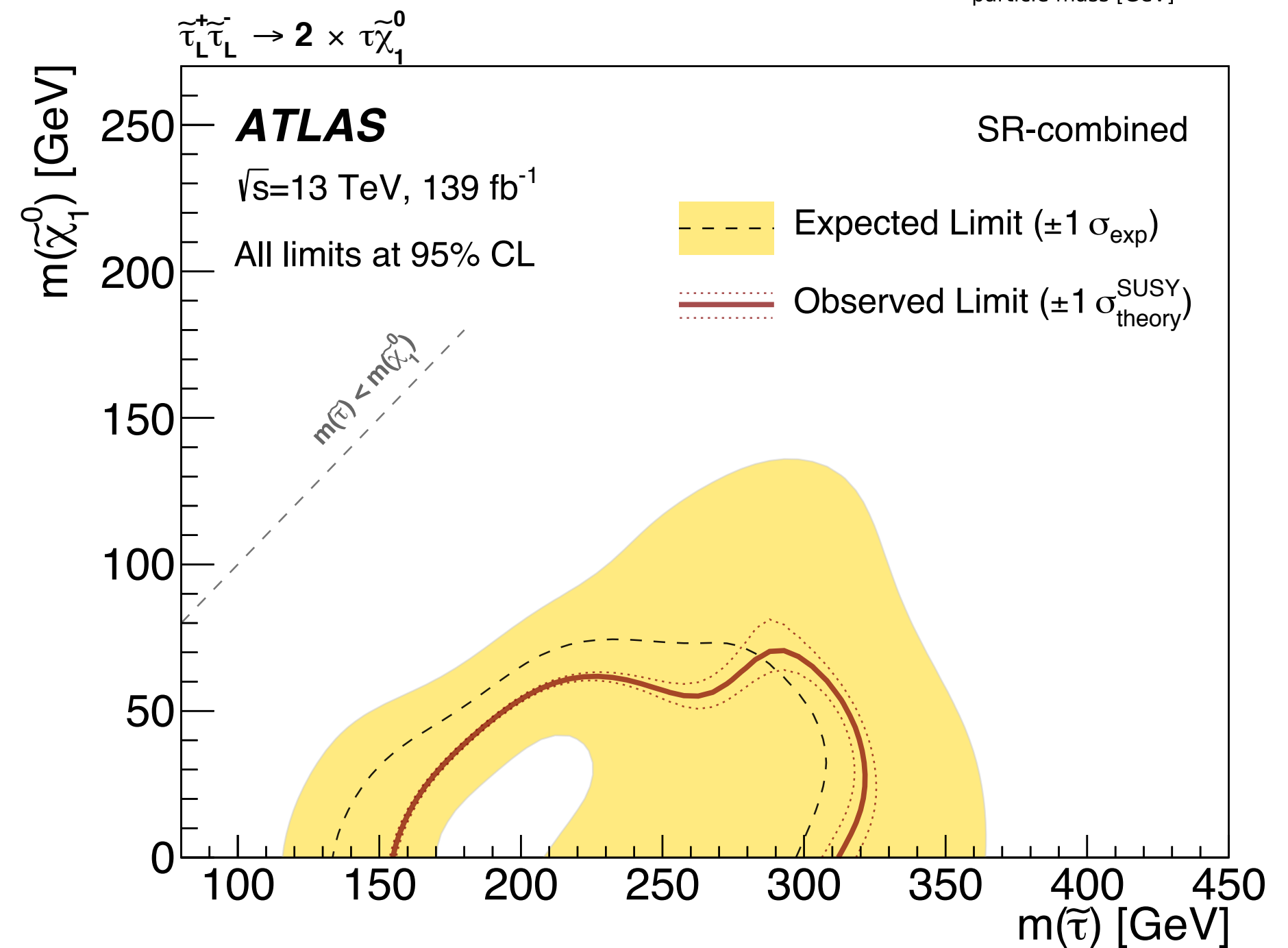
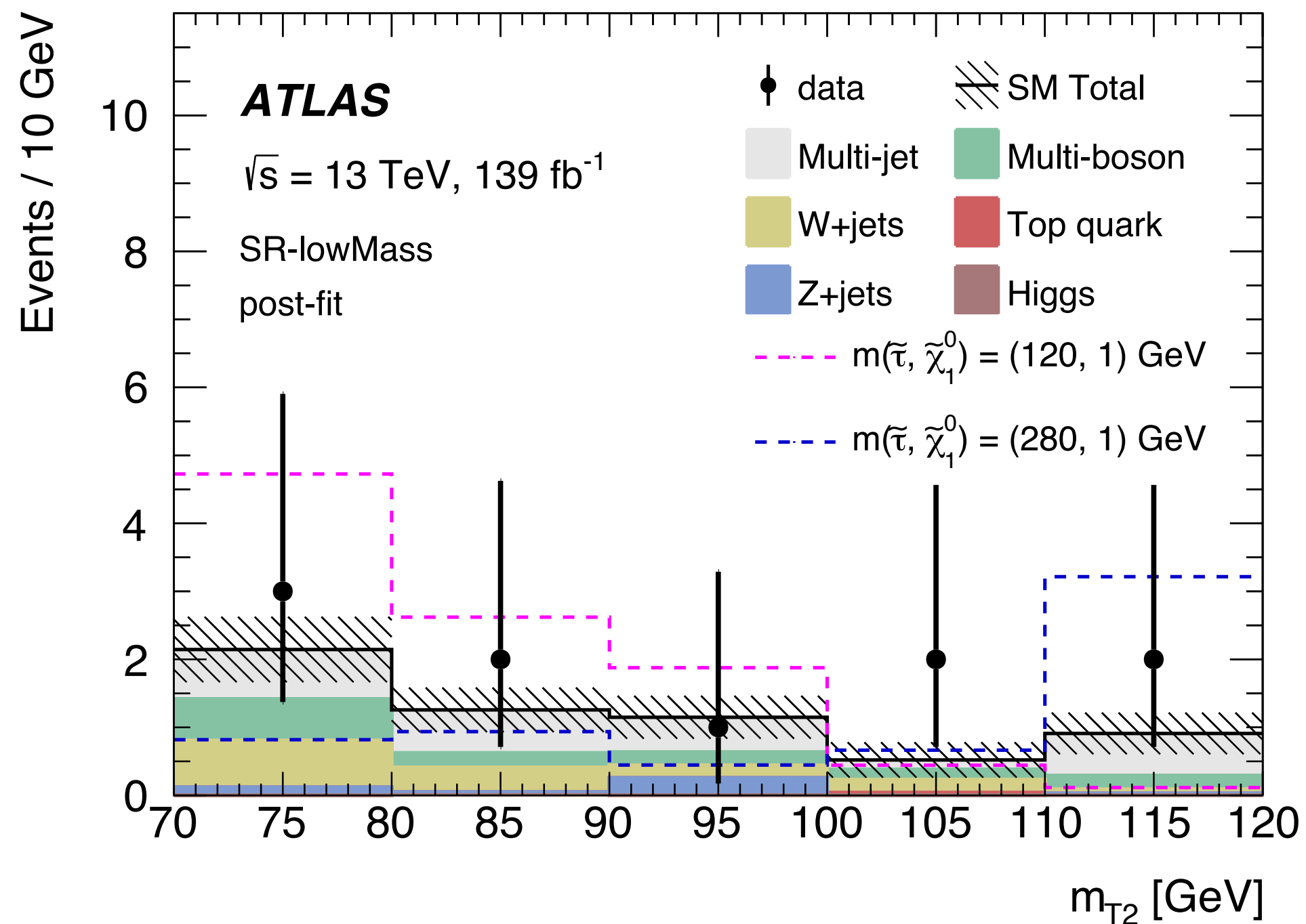
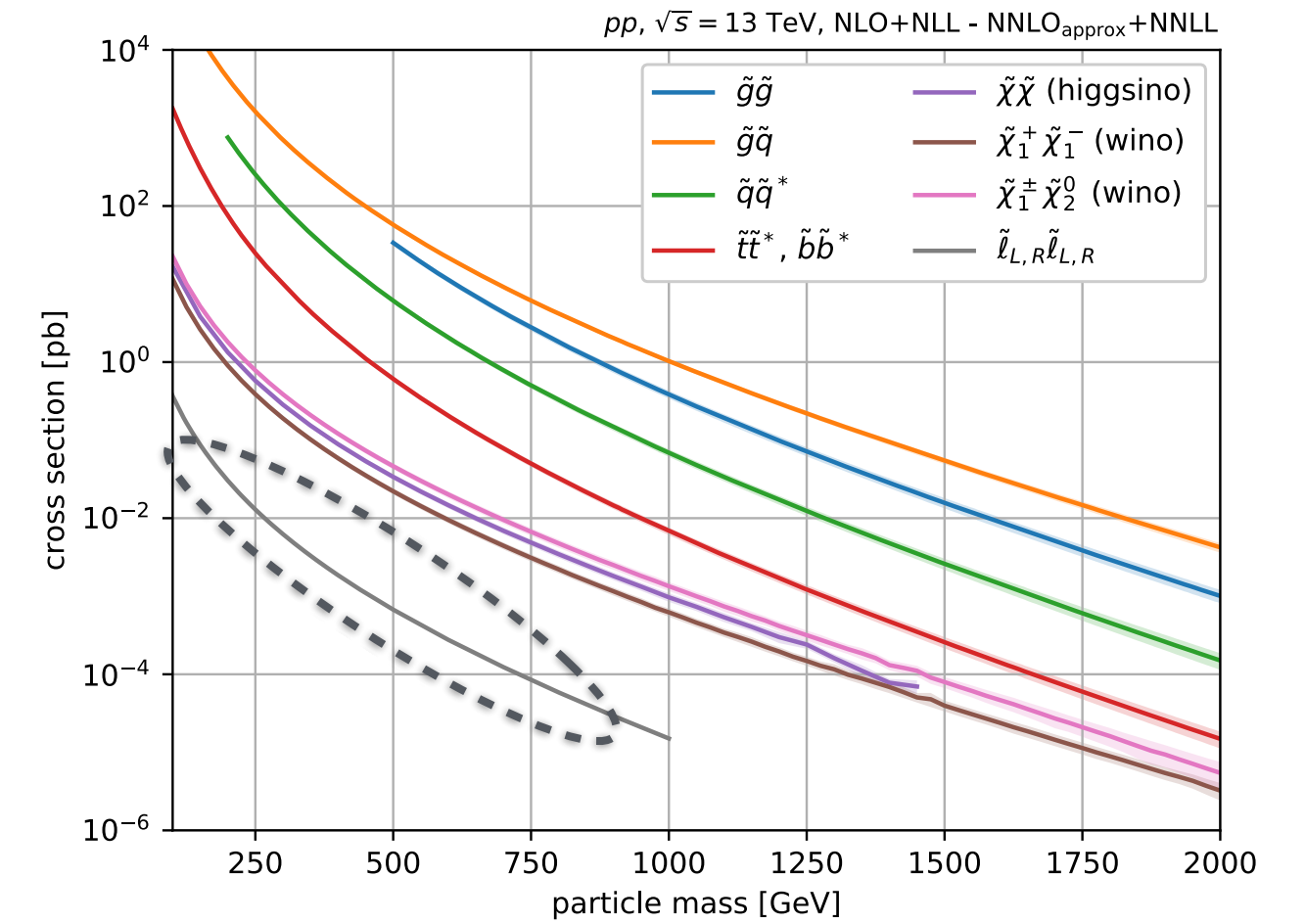
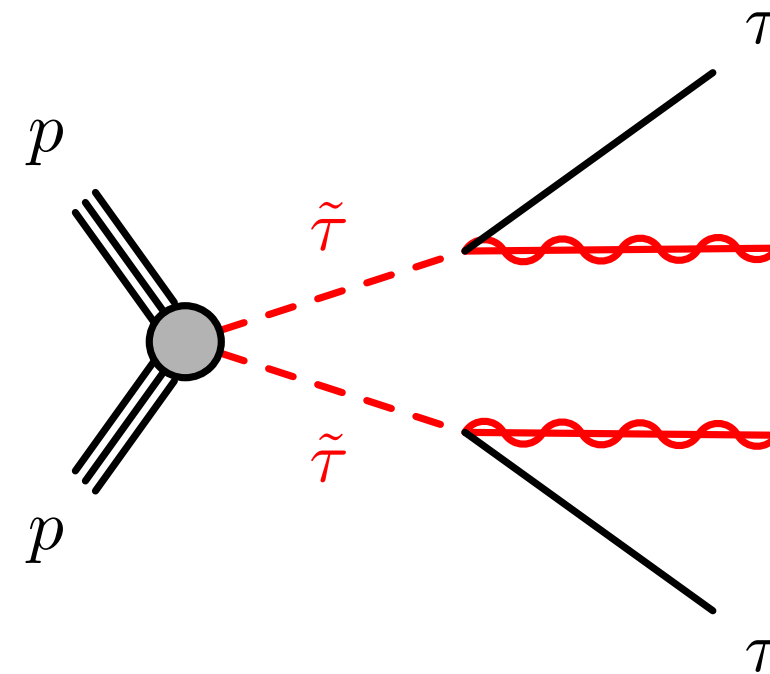
arXiv:2004.10894 (sub. to JHEP)



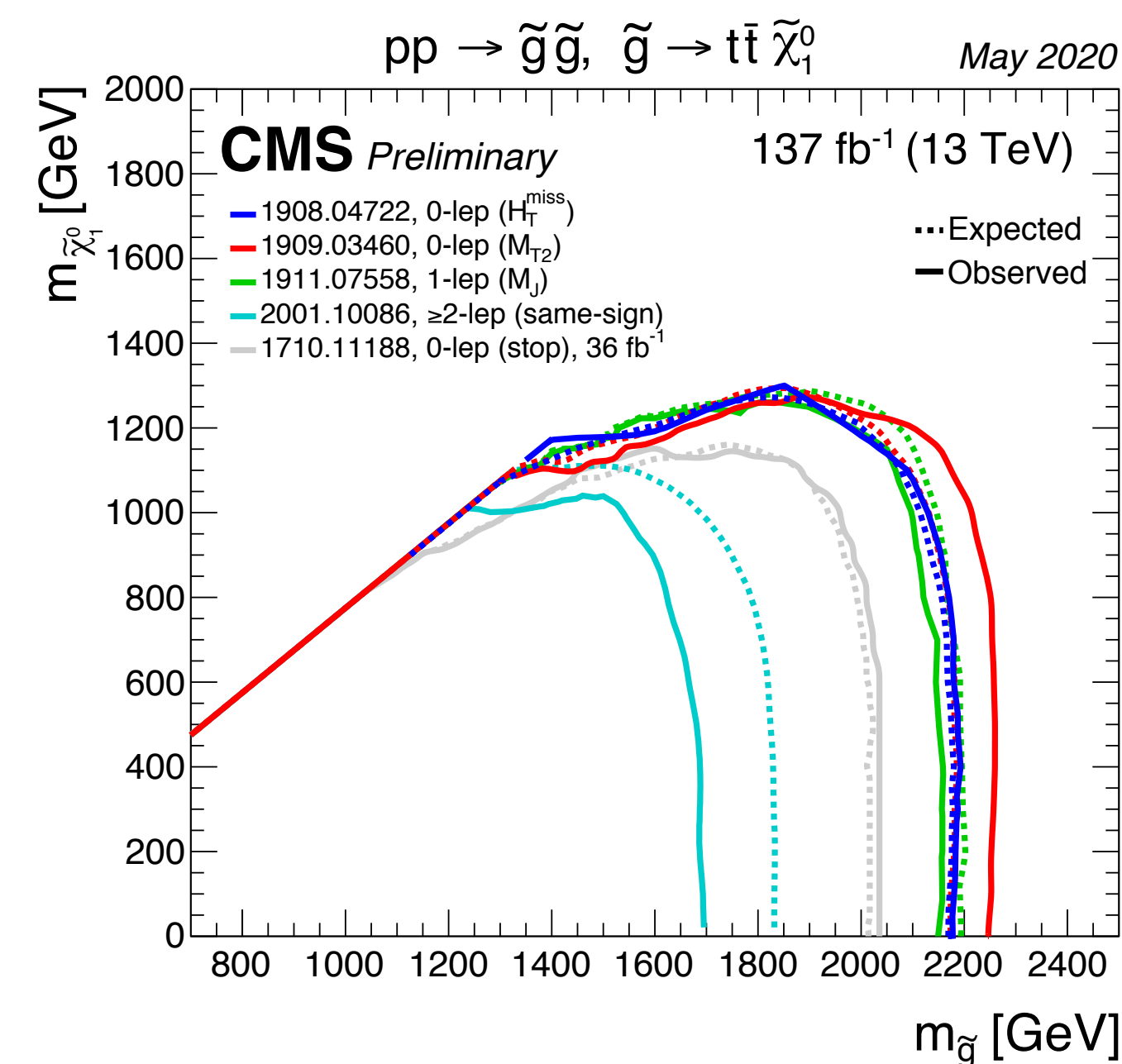
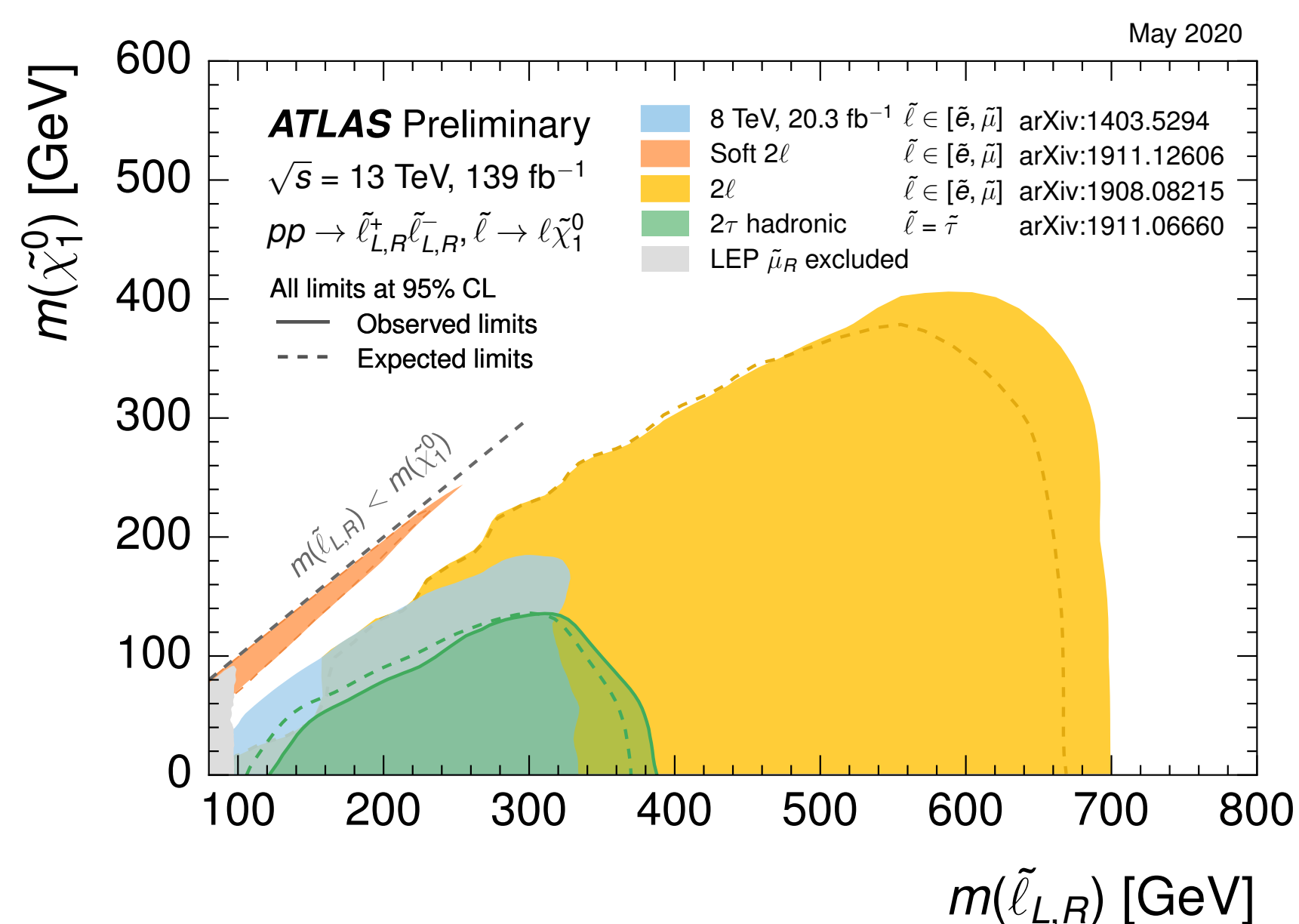
- ❖ Stau is also important in the SUSY model
 - ▶ Help in obtaining relic DM density

Phys. Rev. D 101, 032009 (2020)

- ❖ Challenging search
 - ▶ Most sensitive at $\tau_h\tau_h$ channel ← misID
 - ▶ Search in moderate \cancel{E}_T region
 - ▶ Search still limit by amount of statistics

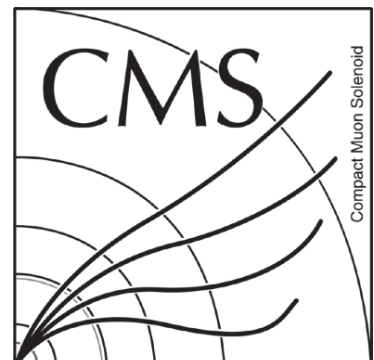


- A variety of searches for the supersymmetry is performed at LHC
 - ❖ Low scale SUSY has been studied in depth
 - ❖ So far no consistent excess that can hint SUSY mediated DM production at LHC has been observed
 - More run2 results still coming out

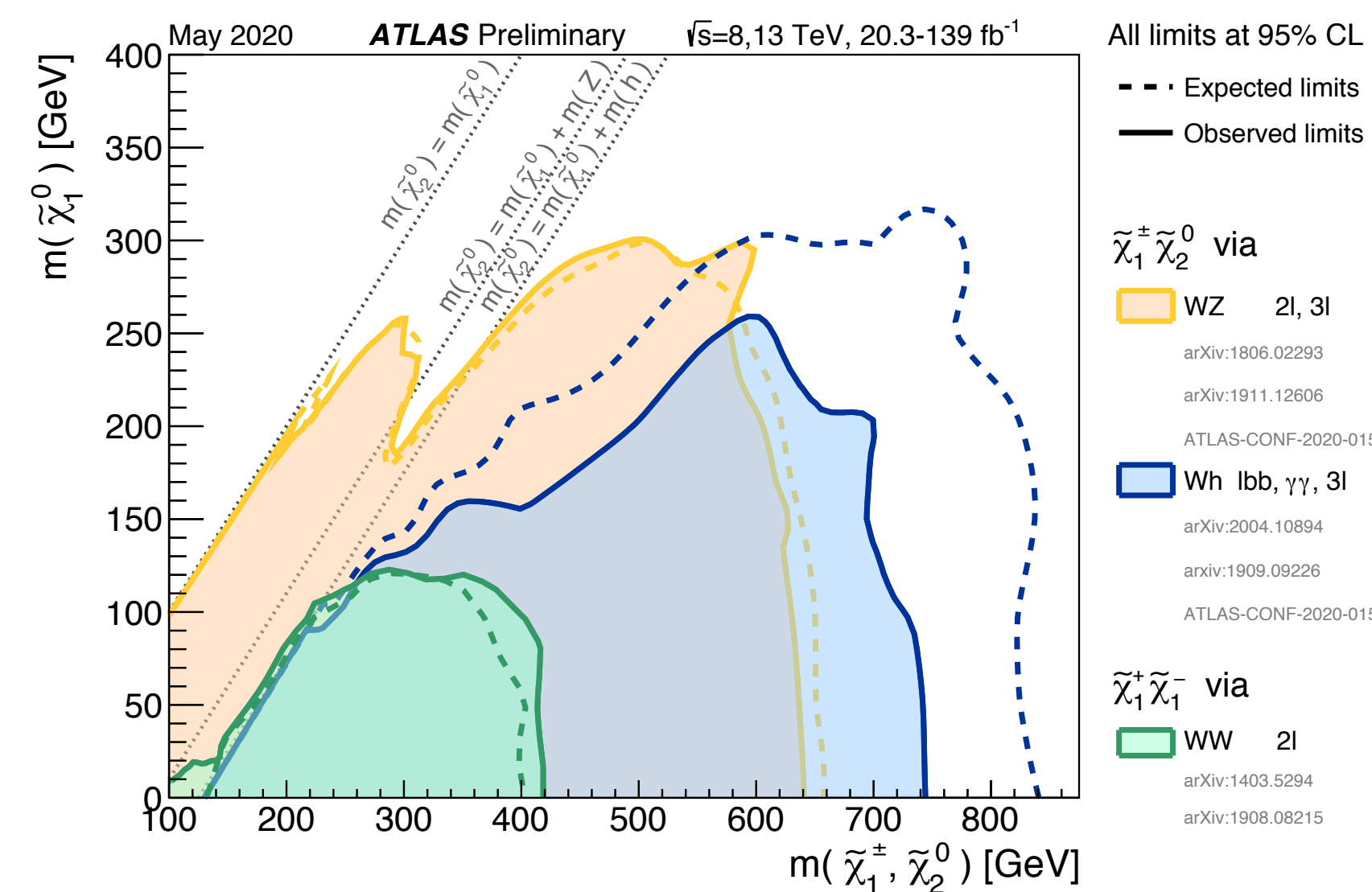
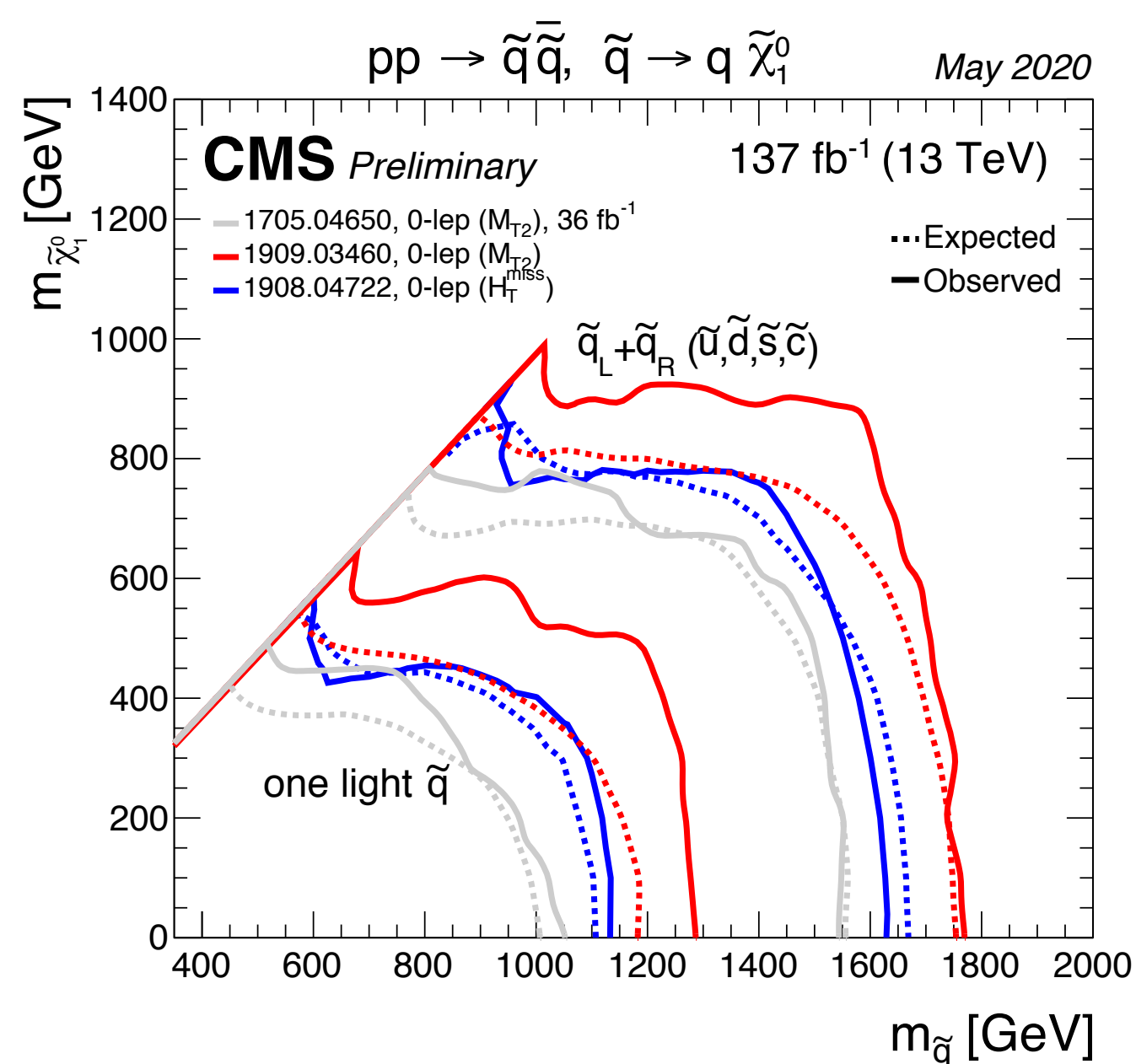
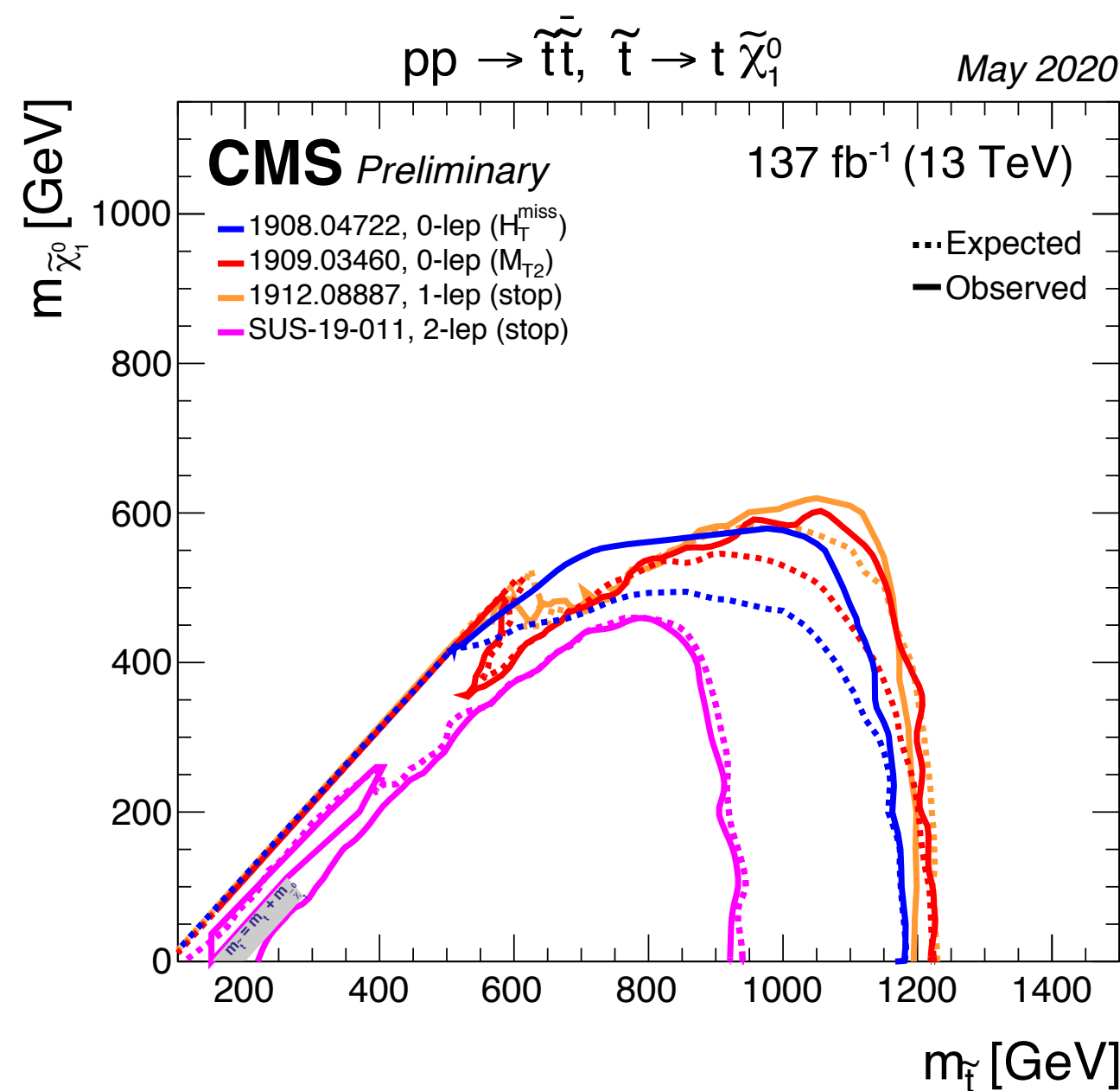
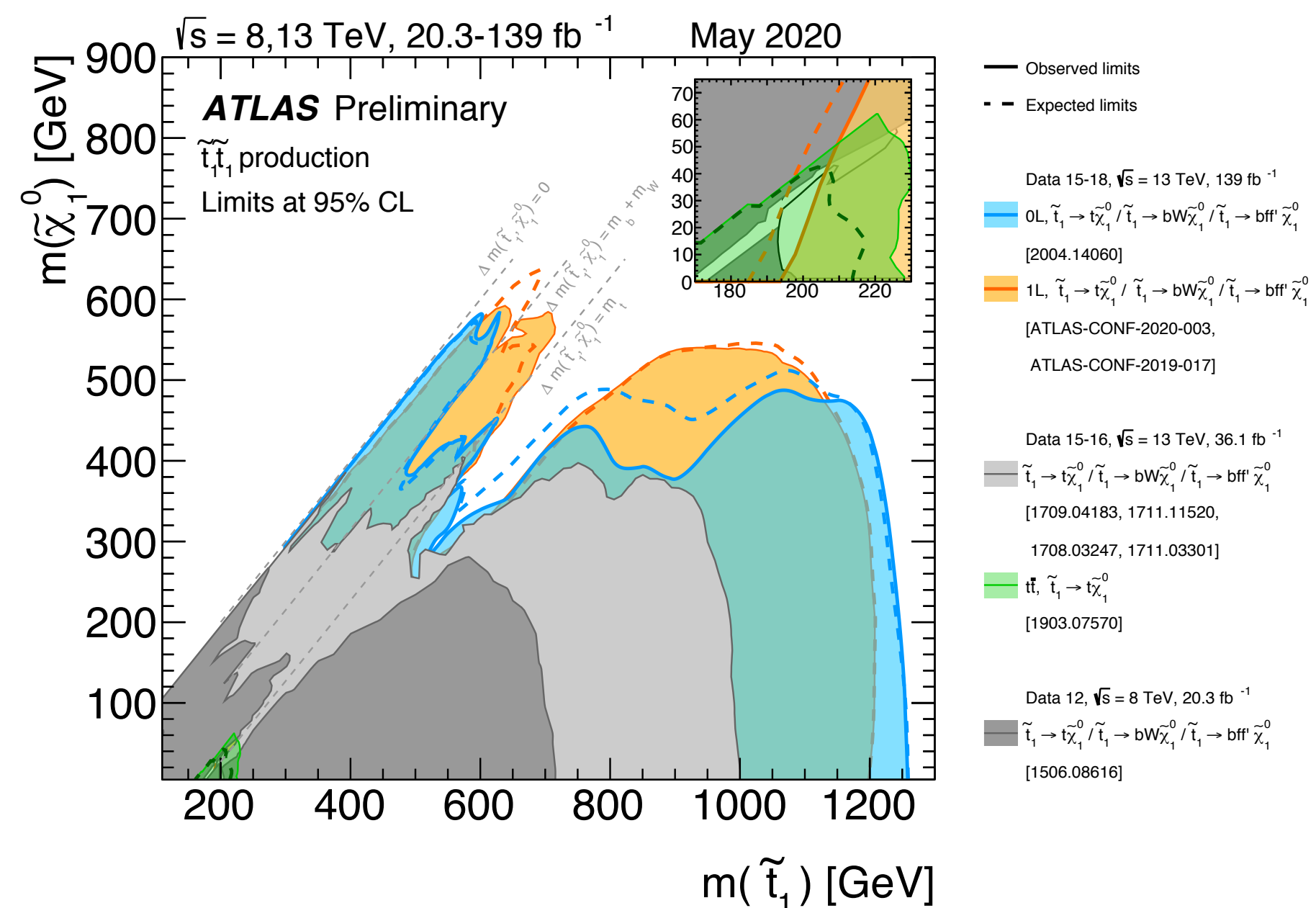
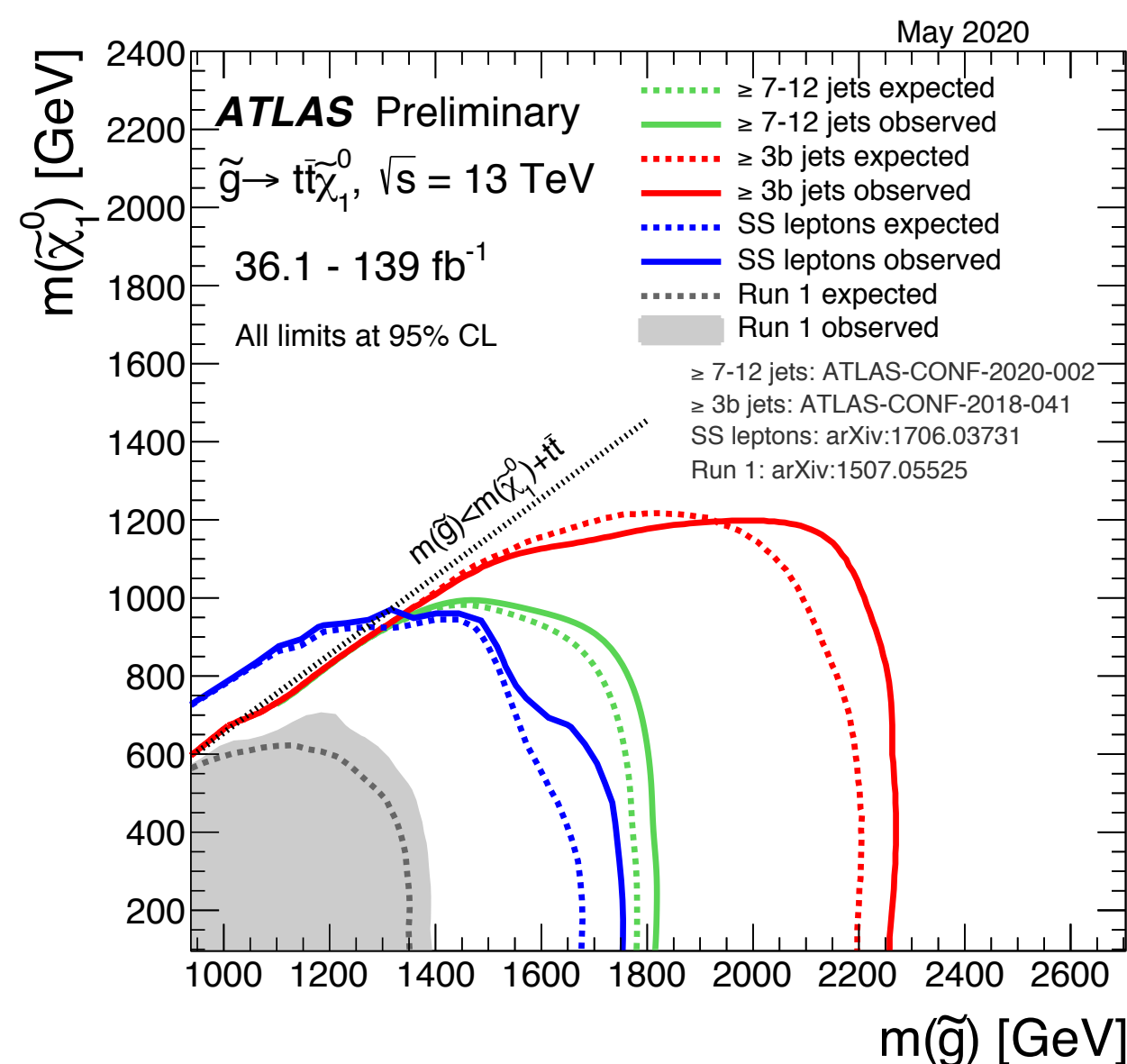
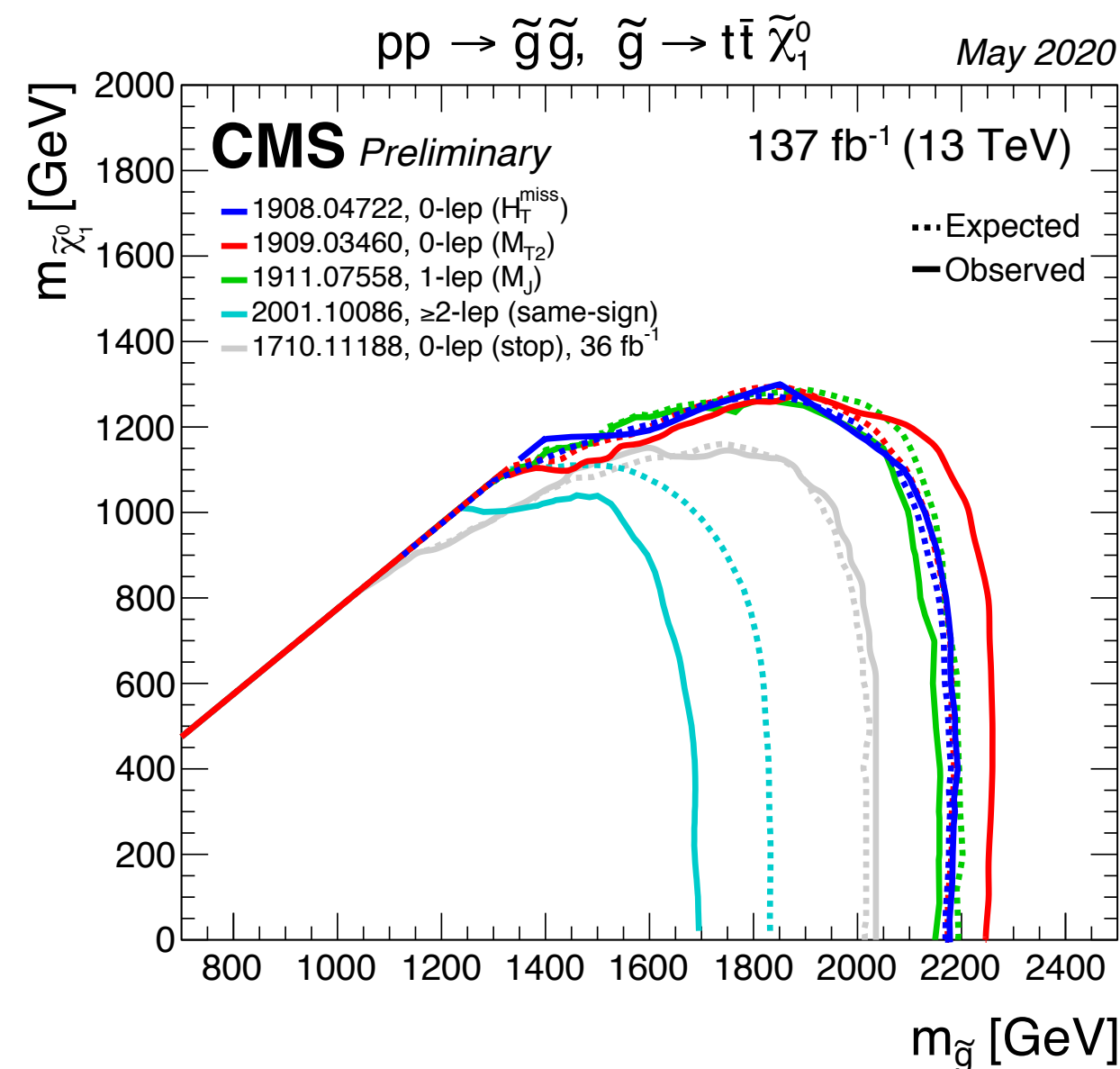


- Question for the next steps
 - ❖ How can more data help efficiently?
 - Can we revisit some of the more challenging area with our new tools?
 - ❖ Can the SUSY be hiding at space we overlooked?
 - ❖ Can we still have light neutralino DM?

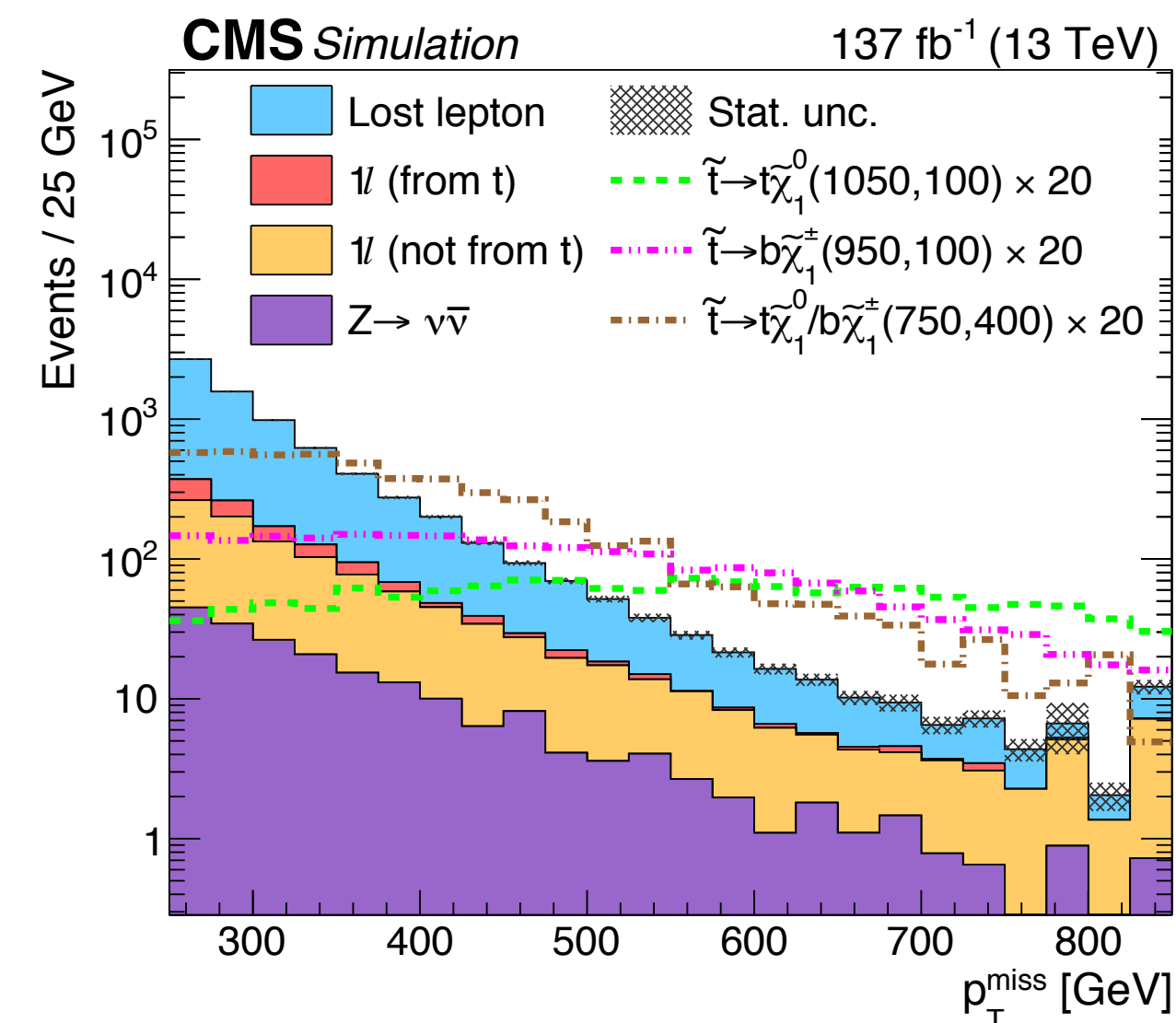
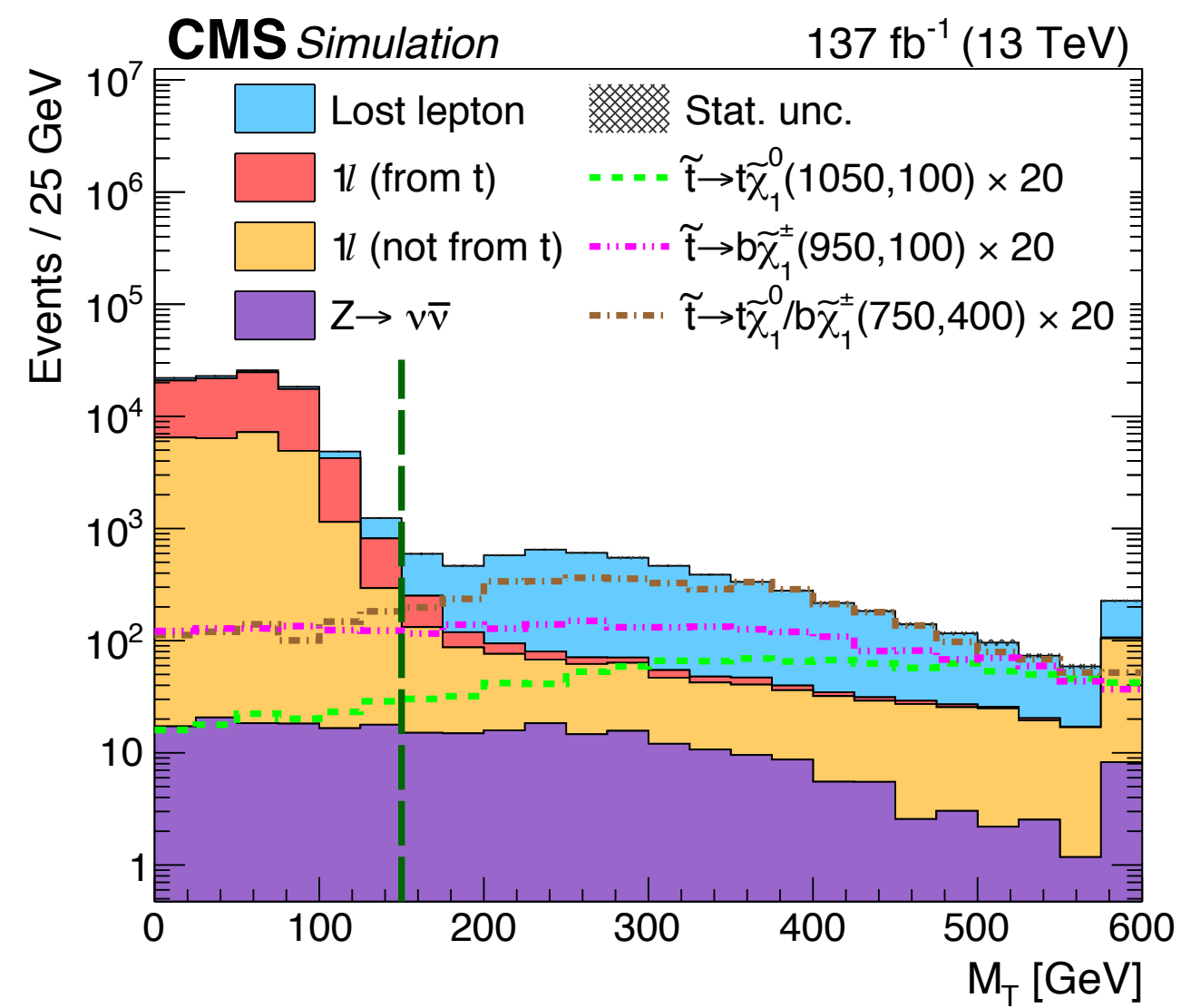
Summary plots from ATLAS
 Summary plots from CMS



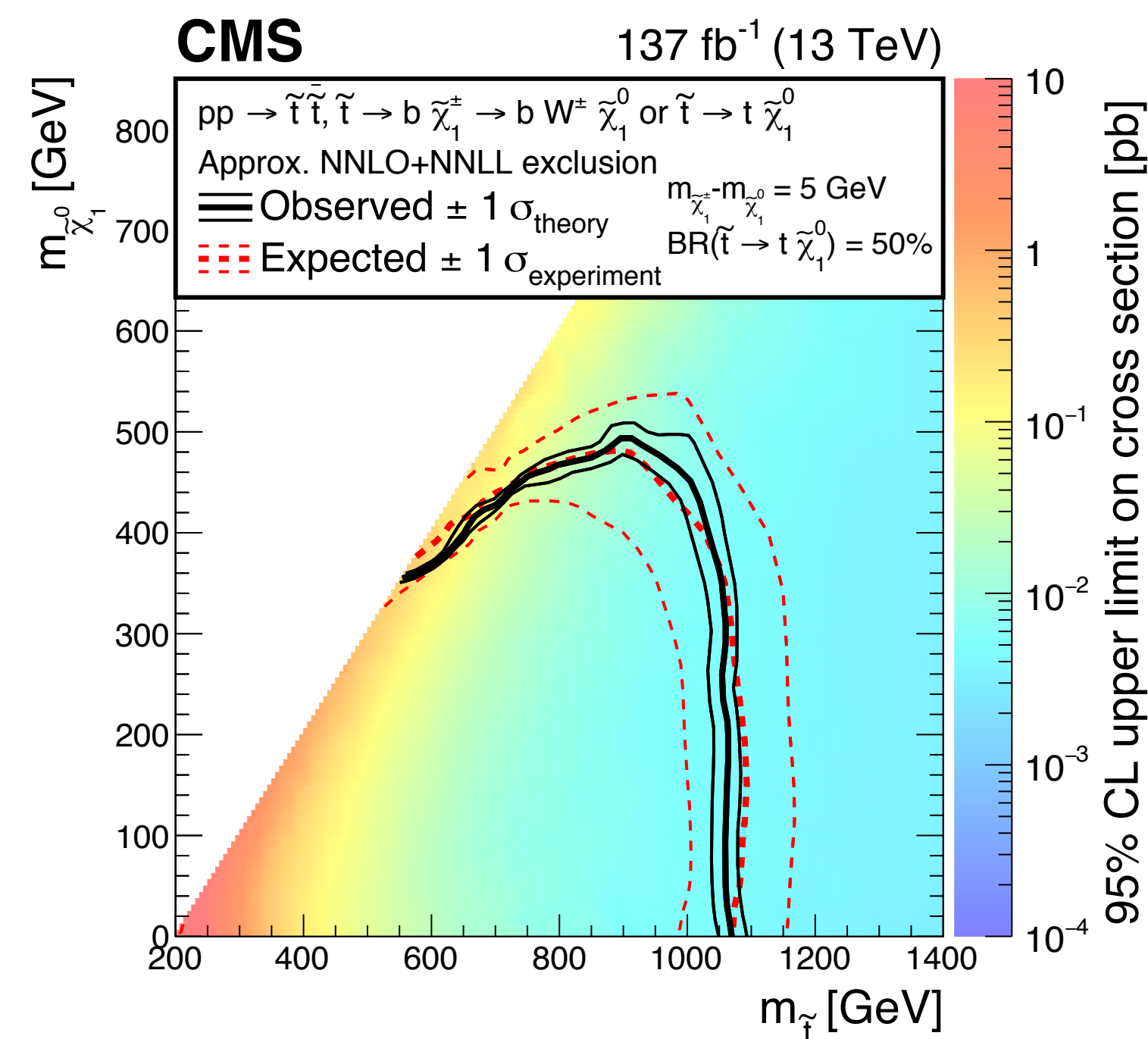
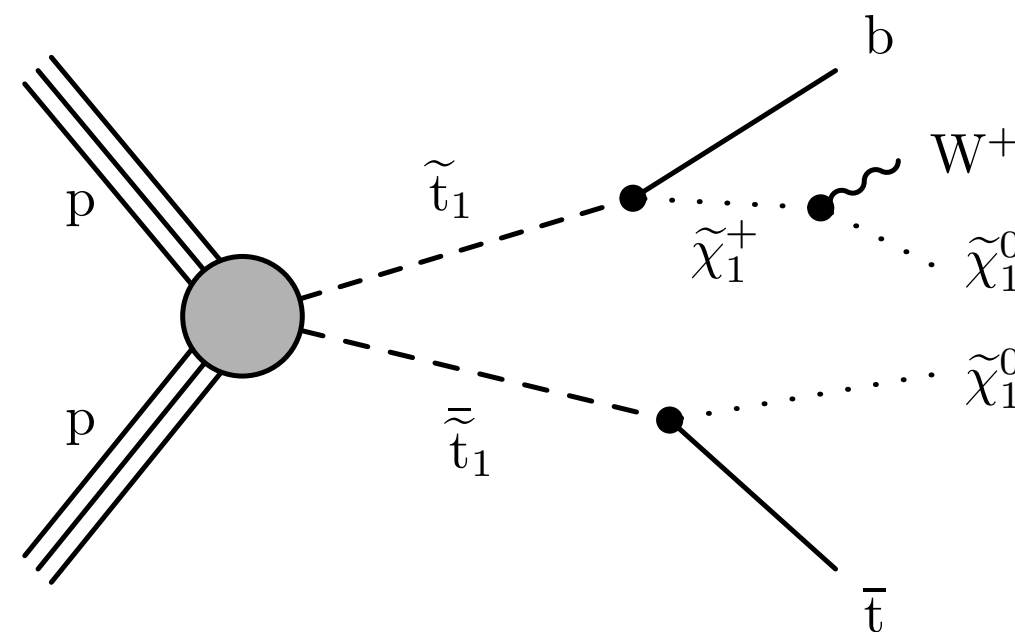
Backup



- ▶ Most important signal/background discriminator: \cancel{E}_T
- ▶ Most important background reduction method: $m_T > 150$ GeV



$$t_{\text{mod}} = \ln(\min S), \text{ with } S = \frac{(m_W^2 - (p_\nu + p_\ell)^2)^2}{a_W^4} + \frac{(m_t^2 - (p_b + p_W)^2)^2}{a_t^4},$$



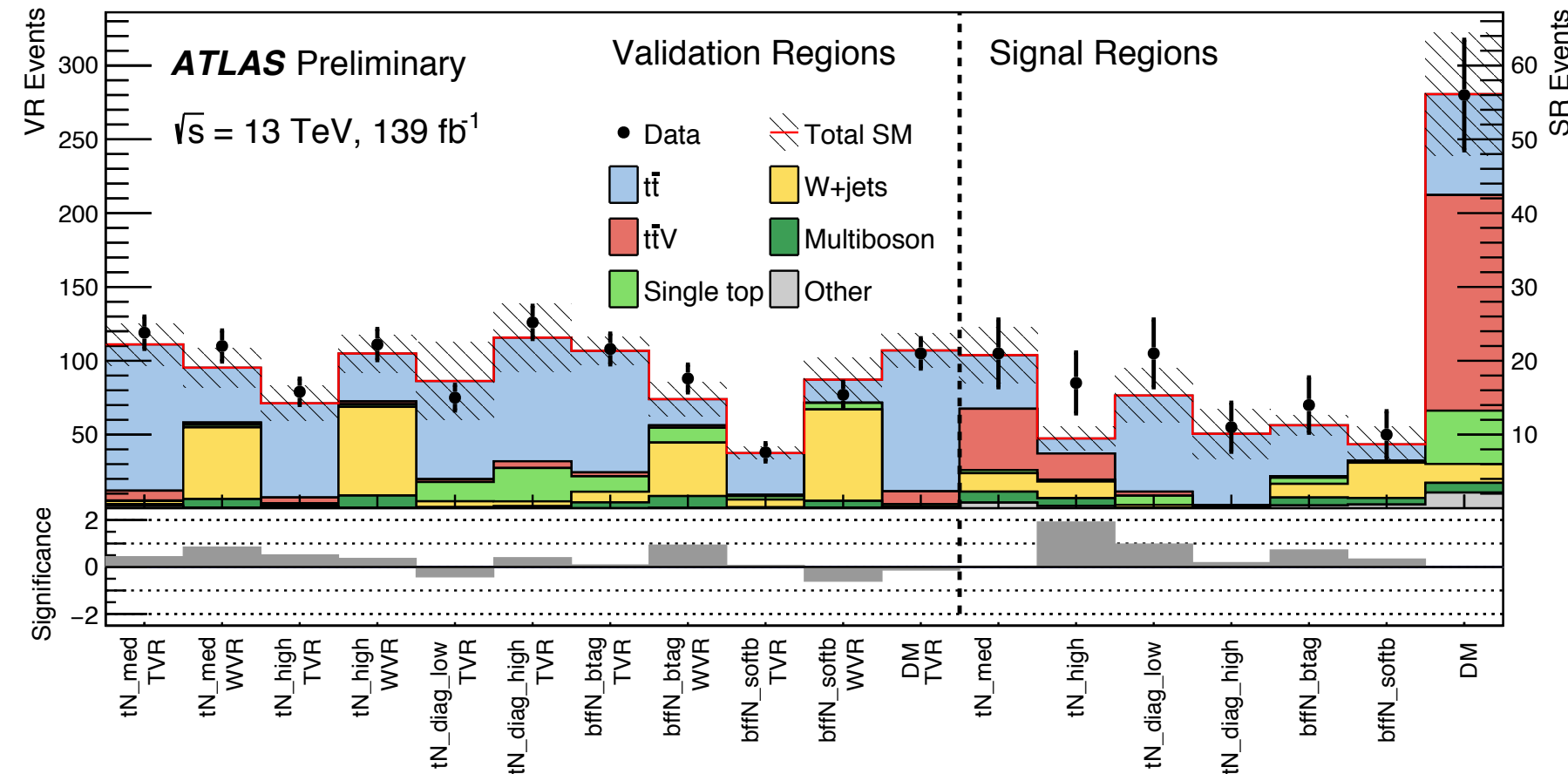


Table 7: Event selections defining the DM signal regions.

Selection	DM_scalar	DM_pseudo
Preselection	hard-lepton preselection	
$N_{\text{jet}}, N_{b\text{-jet}}$	$\geq (4, 2)$	
Jet p_T	[GeV]	$> (80, 60, 30, 25)$
b -tagged jet p_T	[GeV]	$> (80, 25)$
E_T^{miss}	[GeV]	> 230
$H_{T,\text{sig}}^{\text{miss}}$		> 15
m_T	[GeV]	> 180
topness		> 8
$m_{\text{top}}^{\text{reclustered}}$	[GeV]	> 150
$\Delta\phi(\text{jet}_i, \vec{p}_T^{\text{miss}}), i \in [1, 4]$	[rad]	> 0.9
$\Delta\phi(\vec{p}_T^{\text{miss}}, \ell)$	[rad]	> 1.1 > 1.5
Exclusion technique	Based on shape fit in $\Delta\phi(\vec{p}_T^{\text{miss}}, \ell)$	
Bin boundaries in $\Delta\phi(\vec{p}_T^{\text{miss}}, \ell)$	$\{1.1, 1.5, 2.0, 2.5, \pi\}$	

