Searches for compressed SUSY scenarios with the CMS experiment

SUSY2023, Southampton, UK

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Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Why is SUSY “likely” compressed

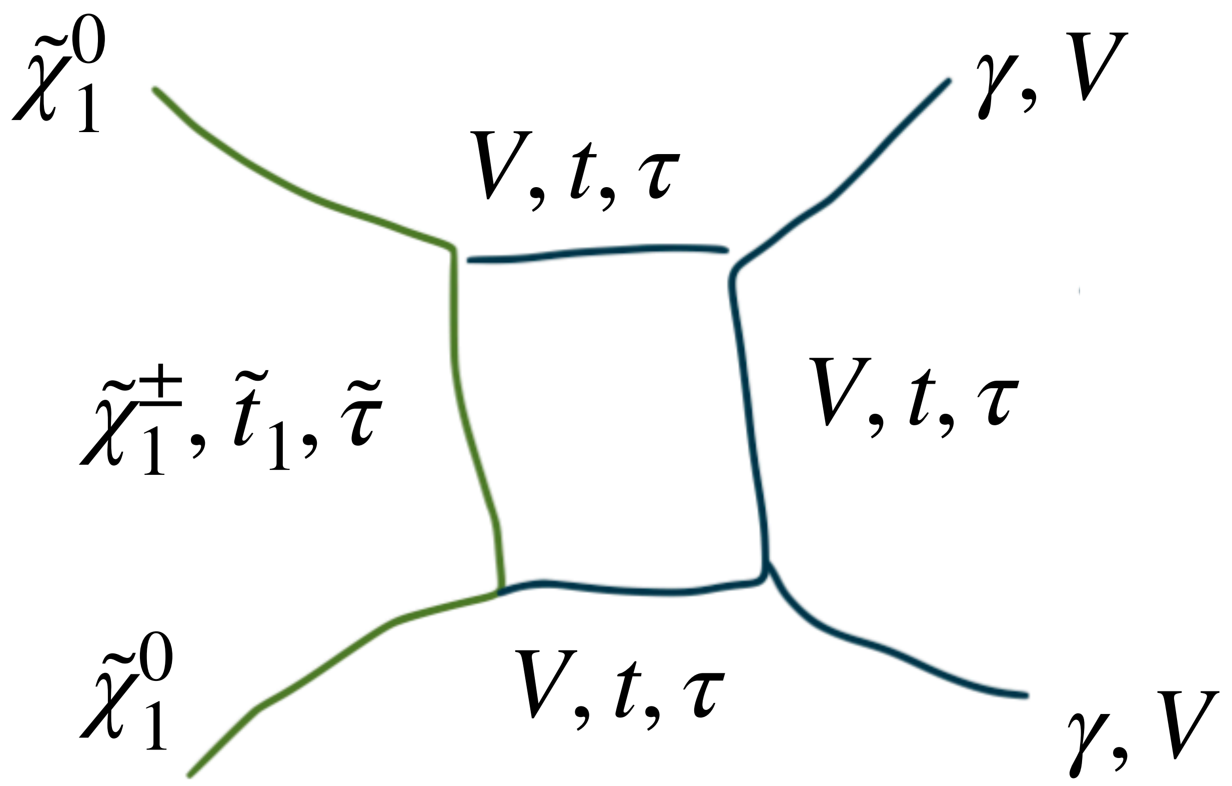
(if it exists)

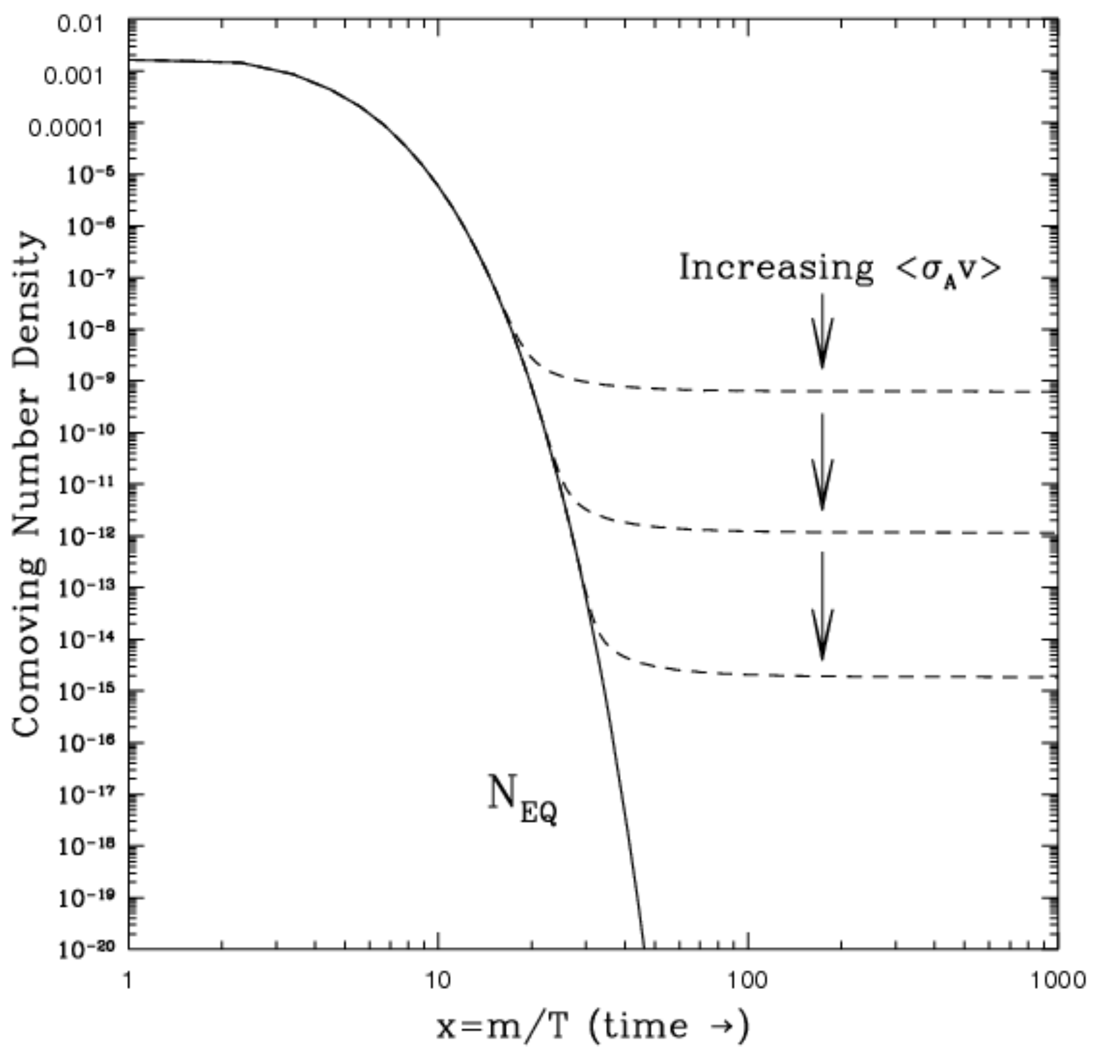
Original motivations

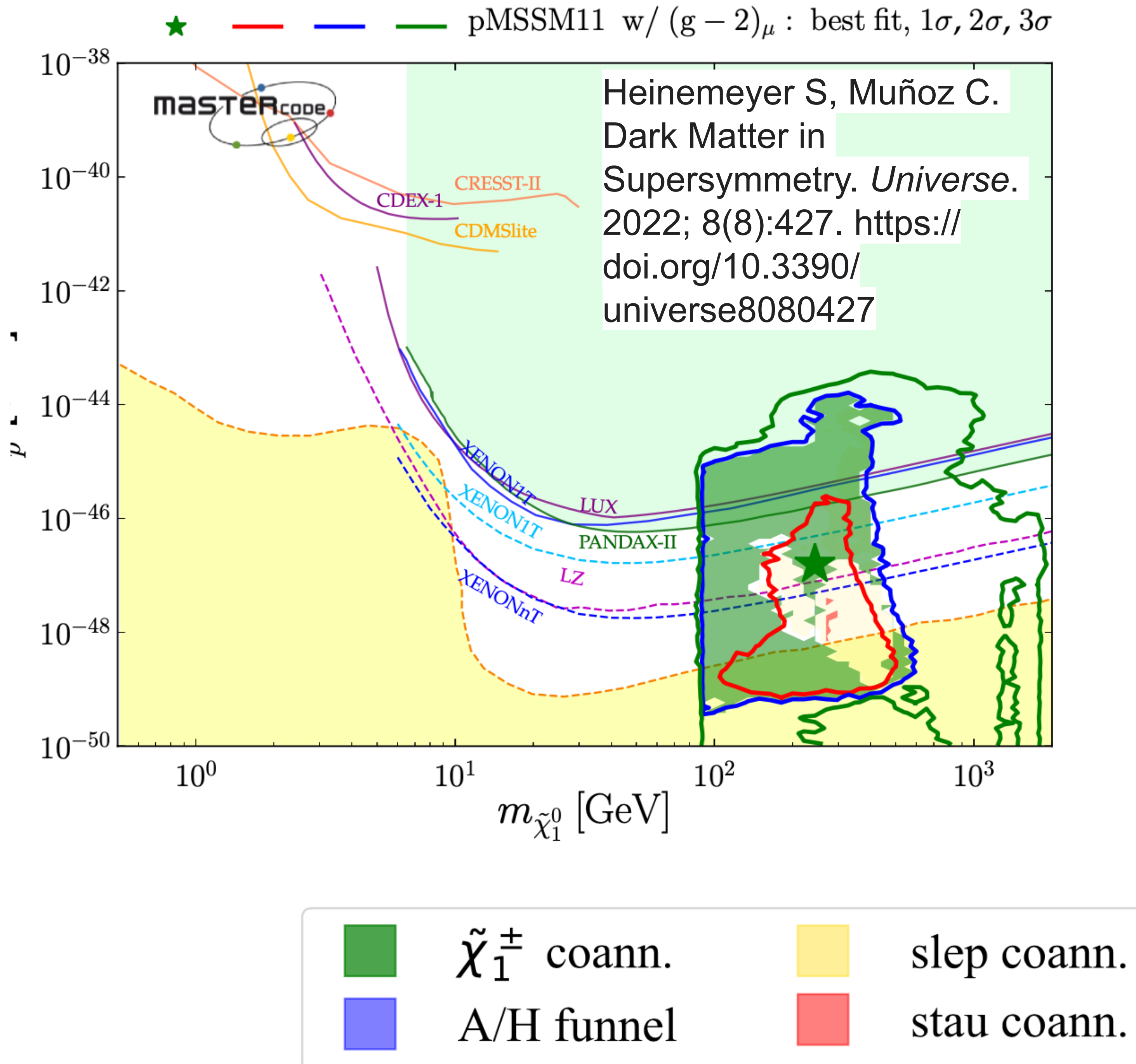
- SUSY can account for DM if
  - R-parity is conserved (assume this today)
  - Neutralino is the LSP (assume this today)
  - If enough LSPs can annihilate before freeze-out - requires small Δm or funnel
- Fine tuning
  - Large hierarchy problem fully solved
  - Little hierarchy problem could arise- SUSY should be light - but light surviving scenarios are hard to see - low acceptance?

(There’s a deeper reason)

Light co-annihilation partner





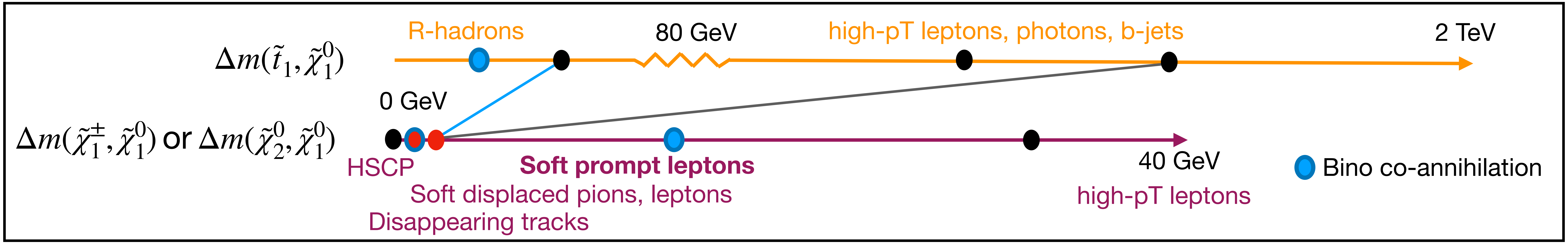


Map of compressed SUSY

- Types of compression
    1. Produced particle **and** LSP (low missing eT and low-pT final state objects)
    2. Intermediate particle **and** LSP (low-pT final state objects)
- How compressed is compressed?
    - mass differences from 0 to ~m(W)
    - standard triggers lose acceptance to final state objects
- Besides by accidental alignment of parameters, when does SUSY exhibit compression?
    - Pure or mixed wino or Higgsino LSPs are always compressed ●
    - Models consistent with DM relic density measurements (higgsino LSP 1 TeV) o ——

[Roszkowski@SUSY2023]

Map: Each dot or line represents a SUSY model

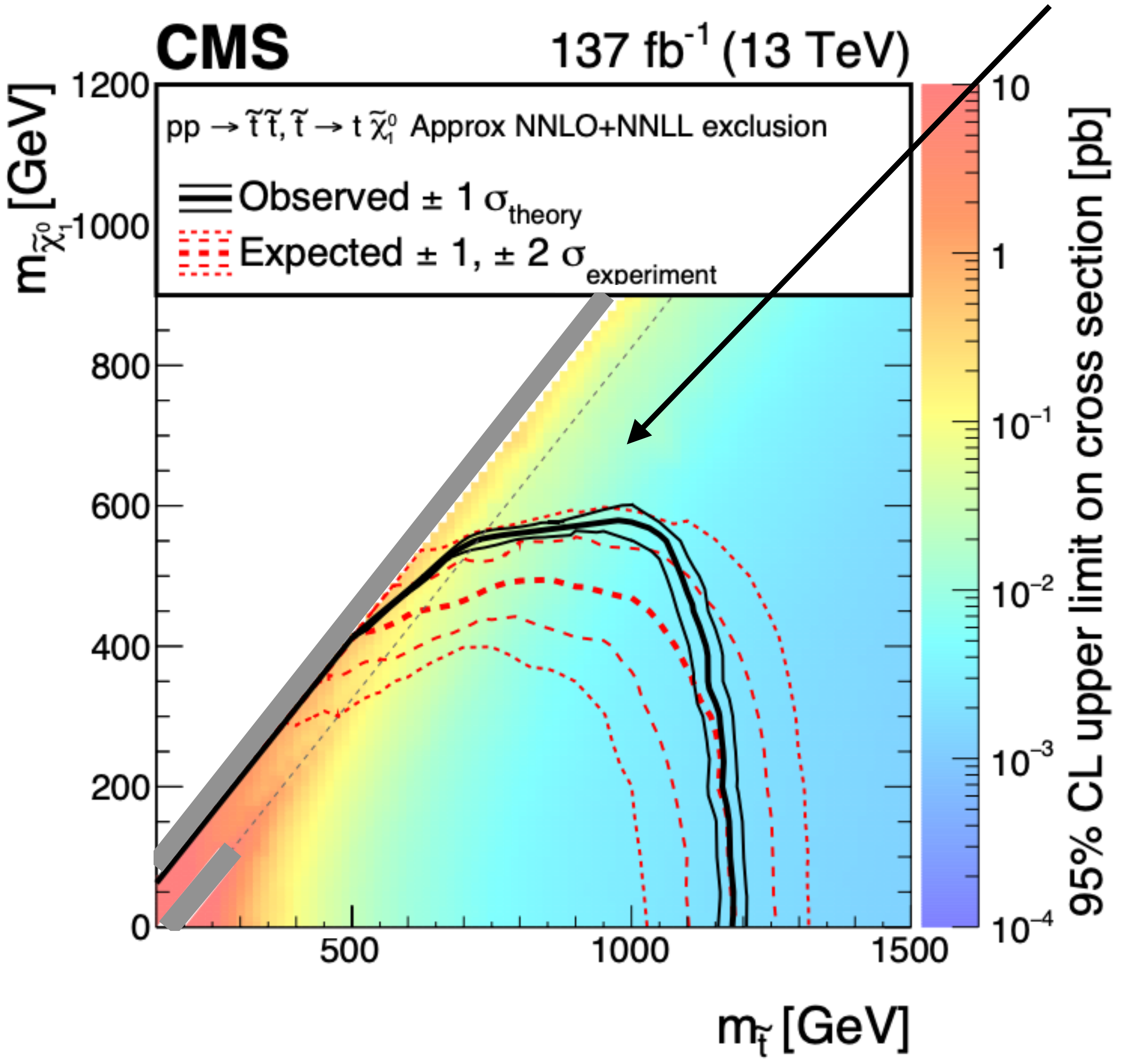


Targeting compressed SUSY

- Traditional SUSY search (jets+MET)
  - Vanishing sensitivity in compressed region

e.g., arxiv.1909.03460

e.g., arXiv:1908.04722



  - x-axis determines cross section

- Loss in sensitivity arises from
  - loss of signal acceptance
  - migration of signal from low-background search regions (SRs) to high-background SRs

$m(\tilde{t}) < m_W, m(\tilde{t}) \approx m_t + m_W$

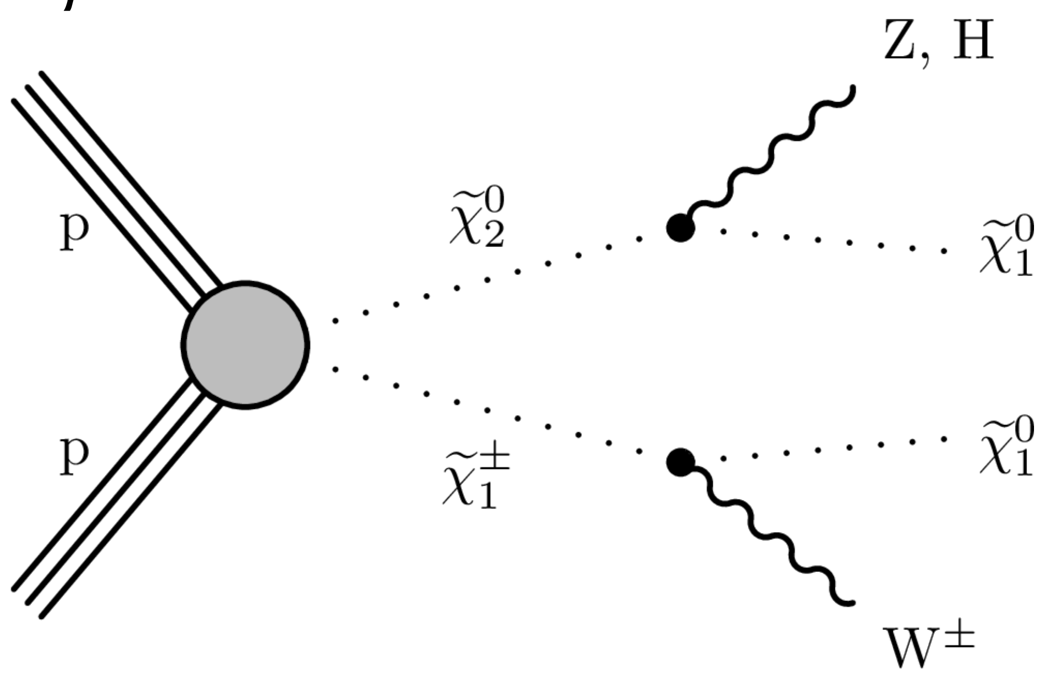
often hard to simulate, not reported

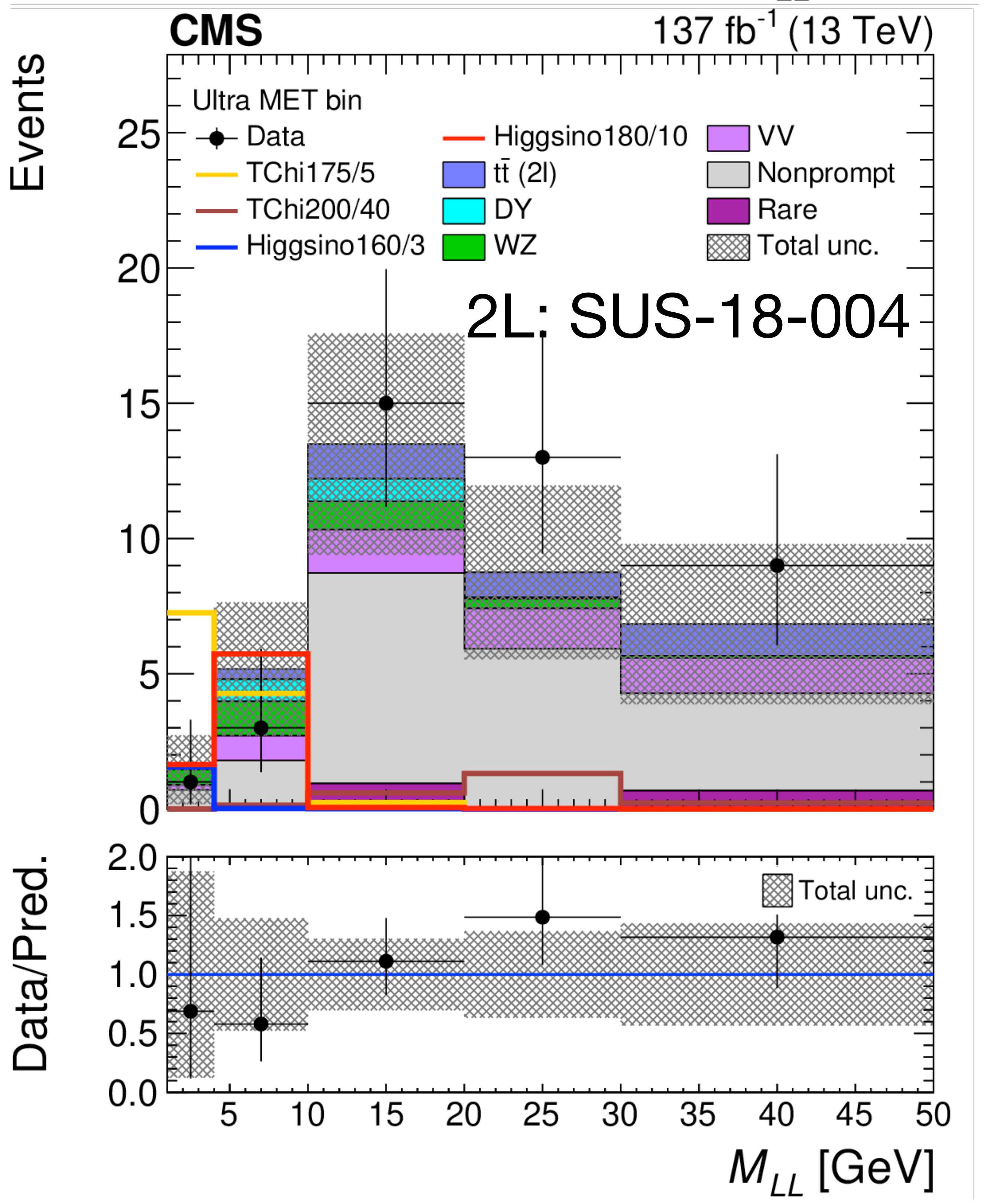
- Try to recover with
  - dedicated trigger paths
  - low-pT or exotic signatures
  - machine learning

EWK SUSY with (soft) leptons

SUS-18-004: *Search for SUSY in final states with 2 or 3 soft leptons and MET in [pp collisions at 13 TeV]*

- Triggers
  - Pure MET path….. $p_T^{\text{miss}} > 120$ GeV
  - Specialty trigger…. $p_T^{\text{miss}} > 60$ GeV with soft $n_\mu \geq 2$
- Selection
  - $n_\mu = 2;\ n_e = 2;\ n_\mu + n_e \geq 3$
  - Lepton p_T in range $(3.5,30)$ GeV or $(5,30)$ GeV
  - Leptons isolated, dilepton $\Delta R(\ell, \ell) > 0.3$
  - Tight impact parameter cuts



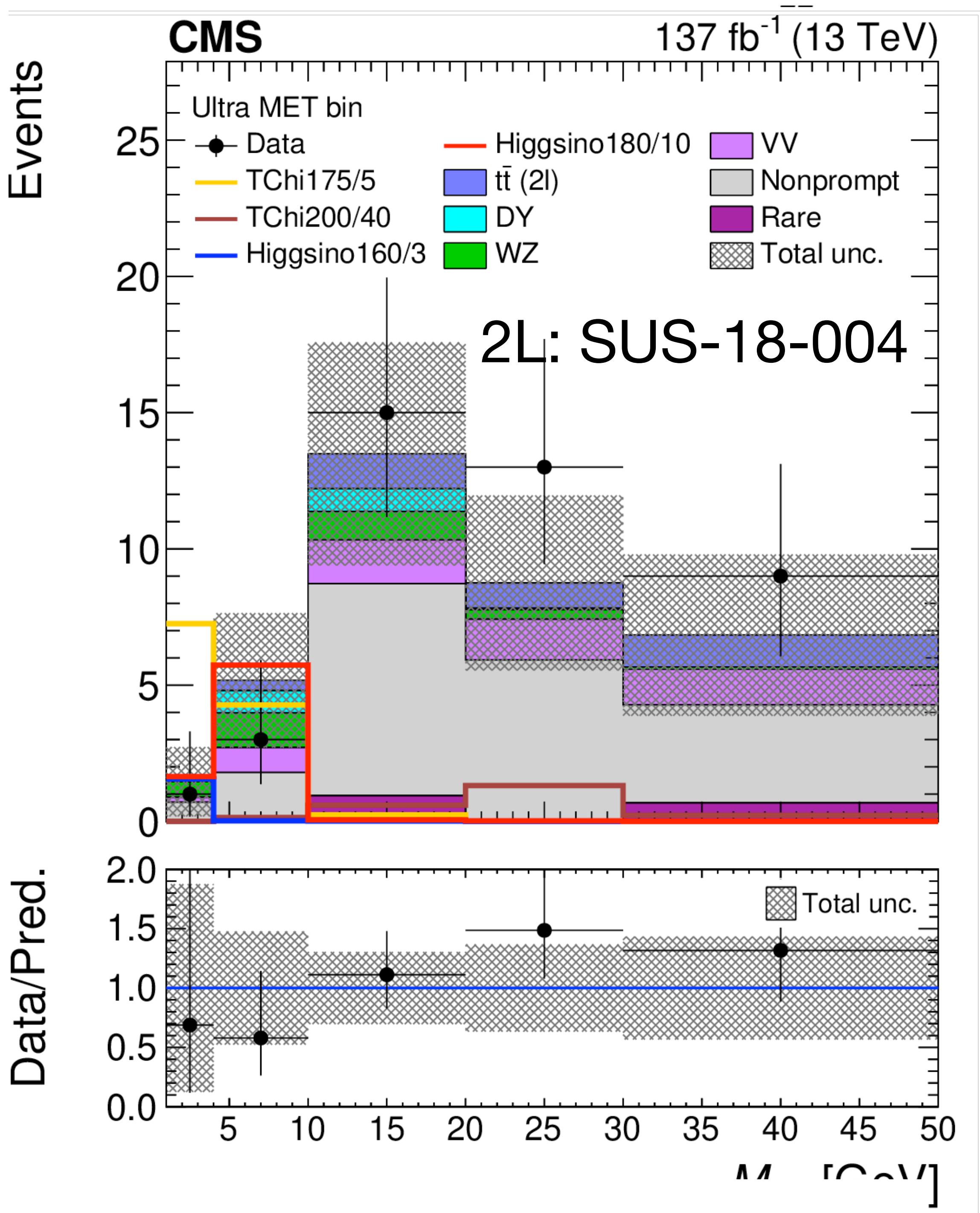


SUS-19-012: *Search for electroweak production of charginos and neutralinos* [pp collisions at 13 TeV]

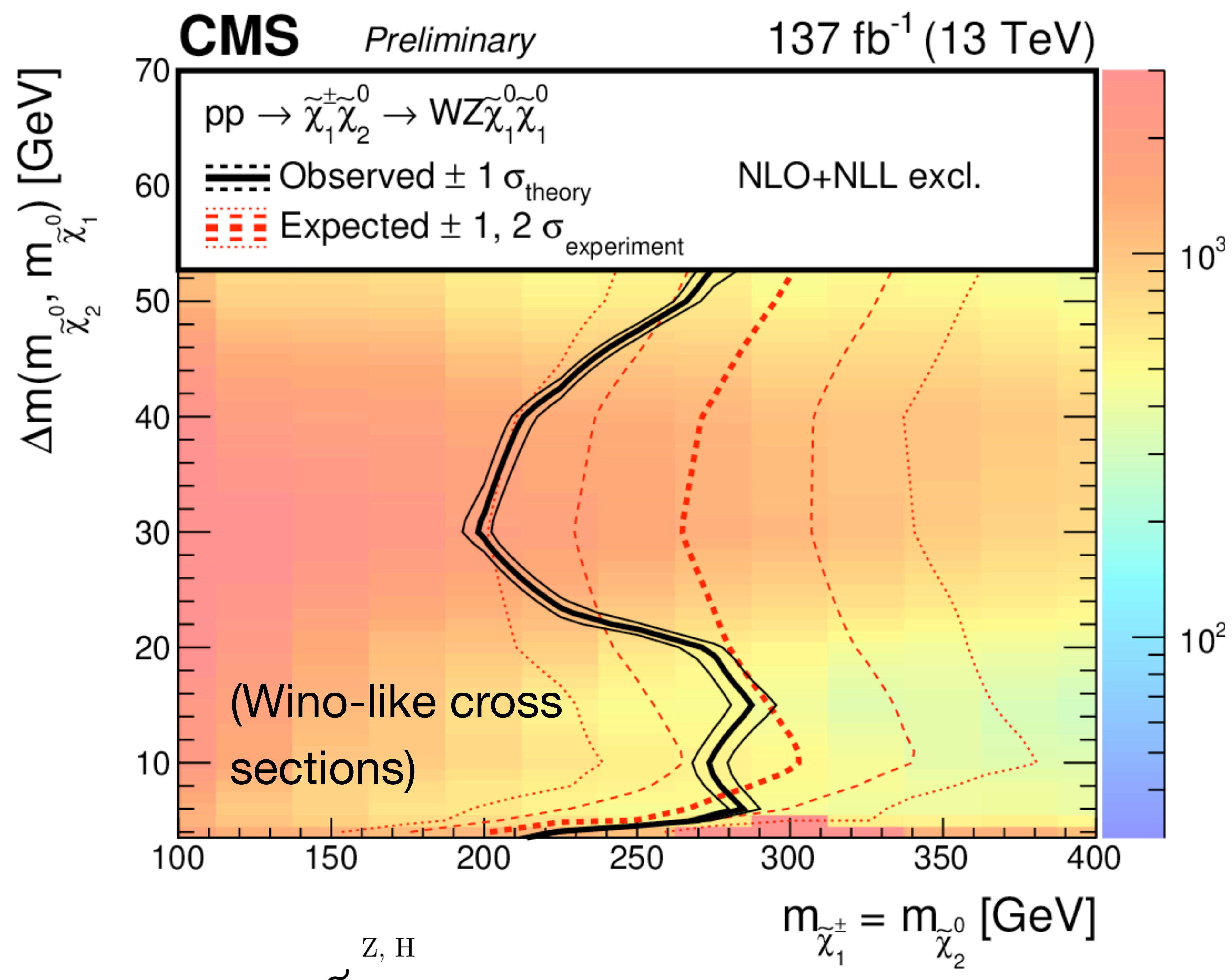
- 3 or more leptons with pT>10 GeV
- NN trained parametric in mass difference Δm

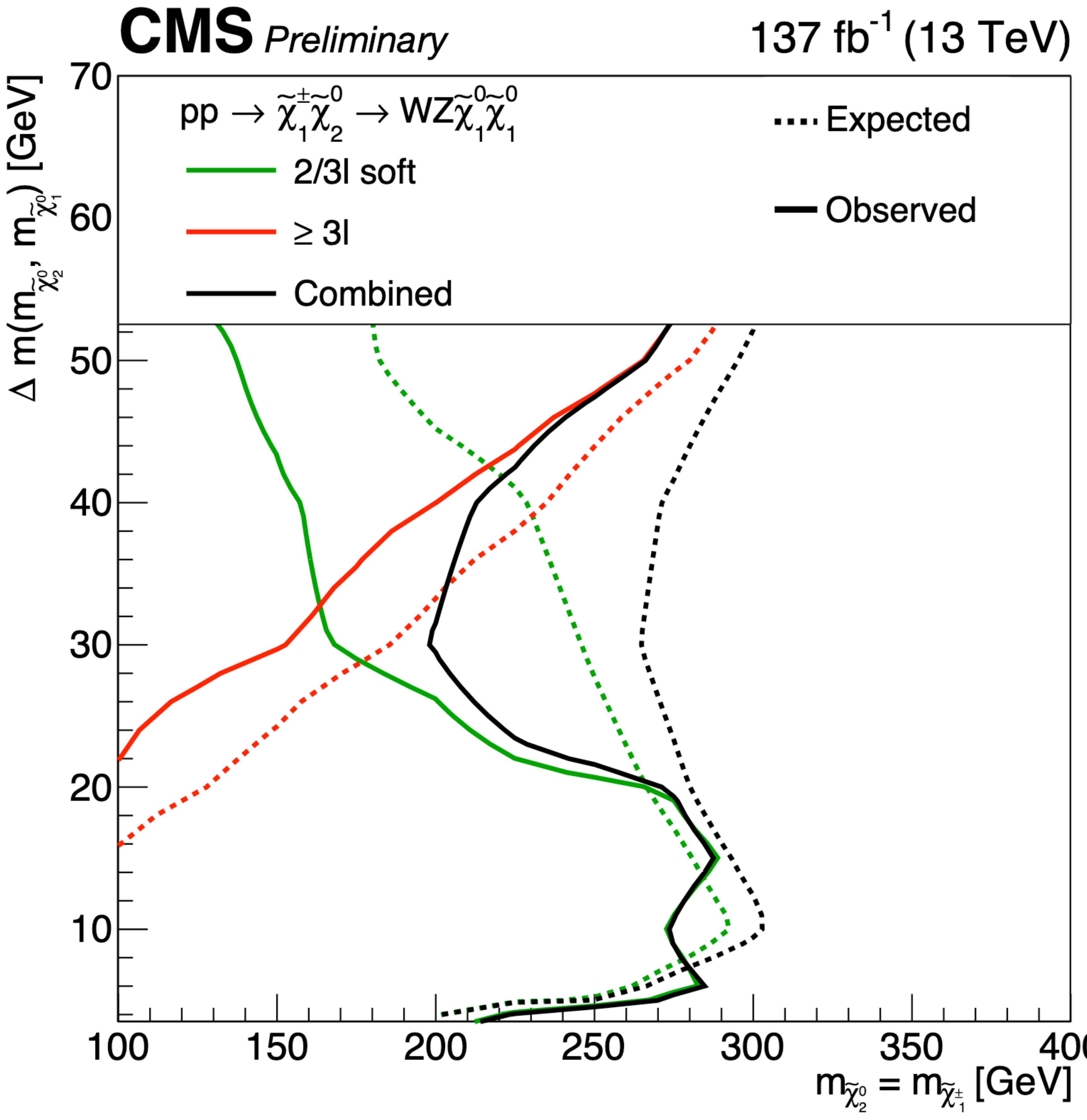
Combination discussed in SUSY2023 talk from Pablo Matorras-Cuevas

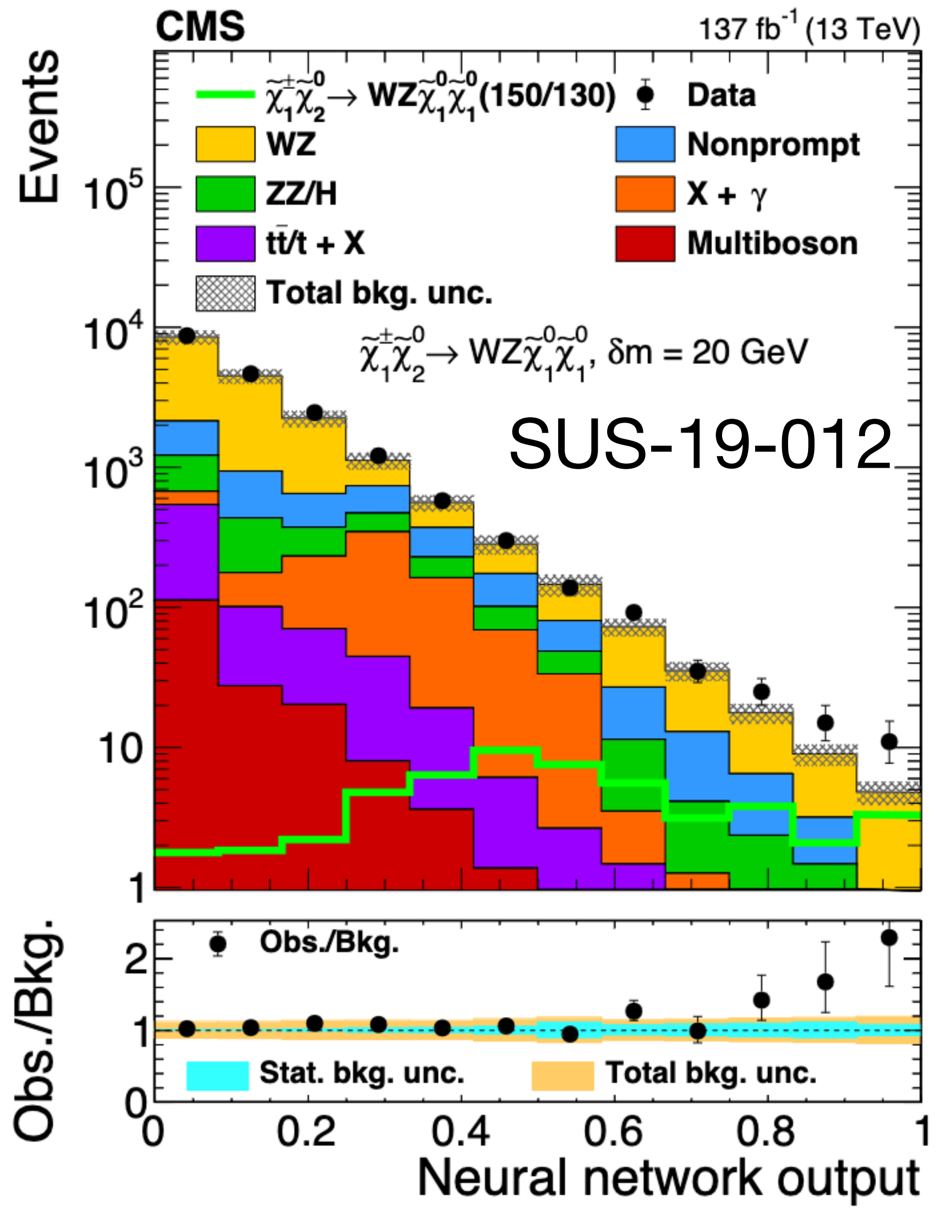
EWK SUSY with (soft) leptons

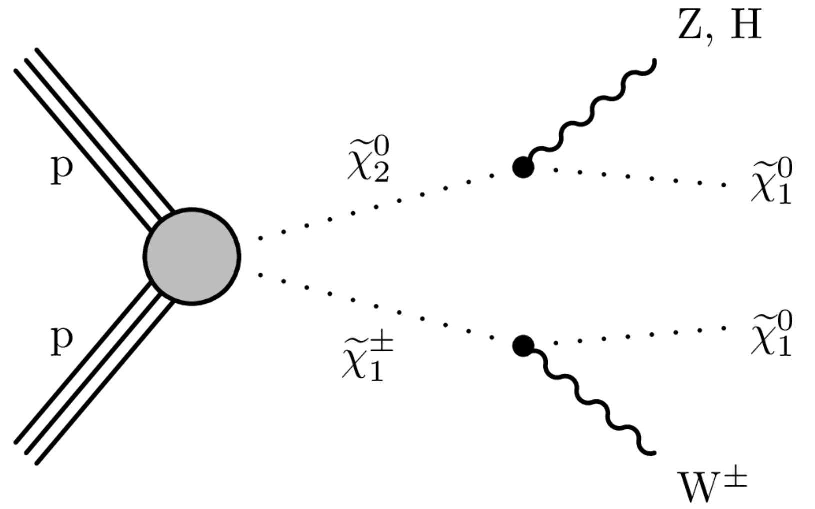


SUS-21-008 combination



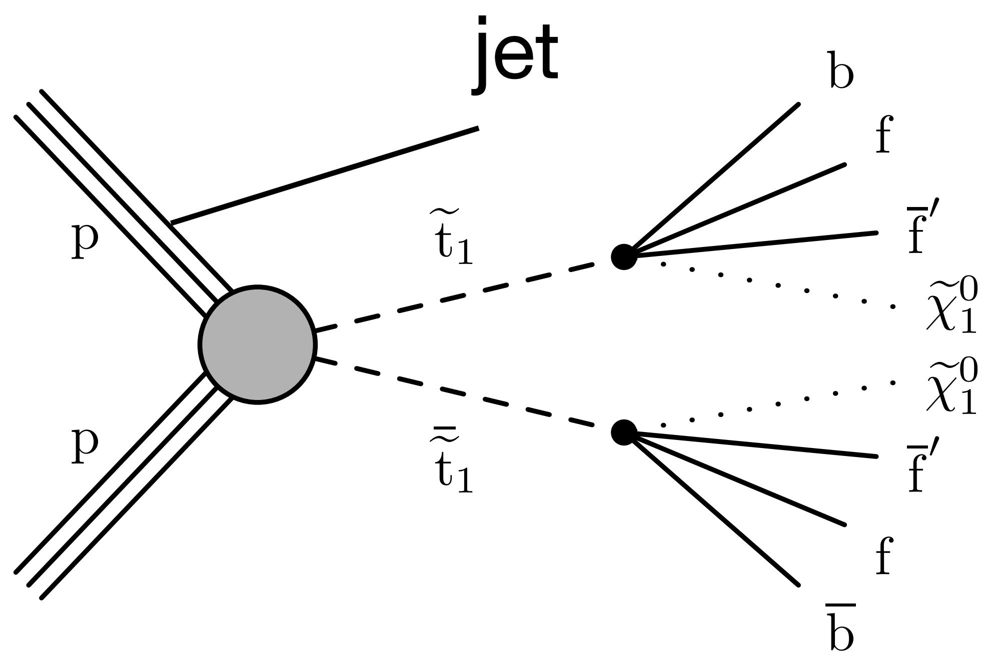






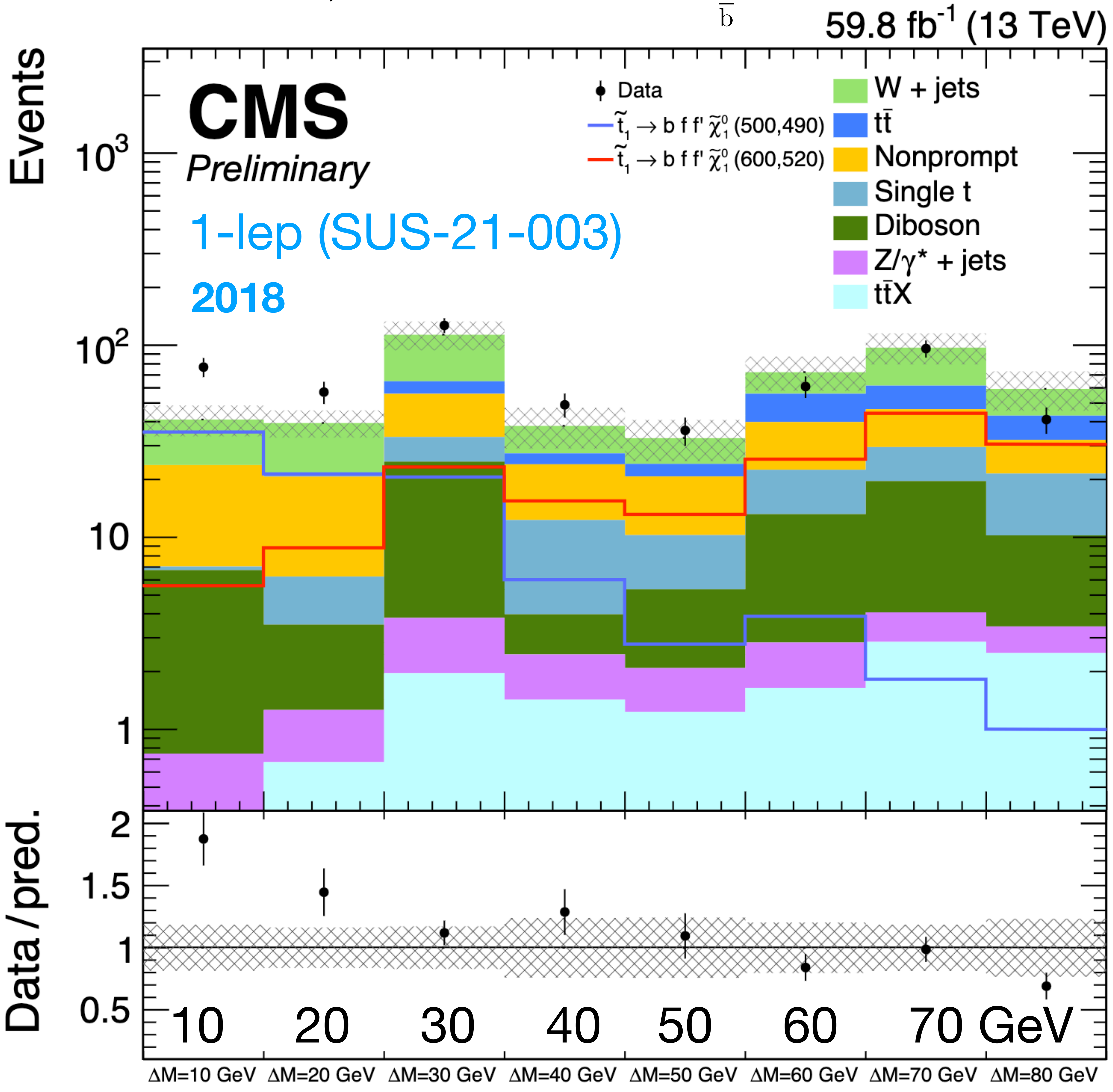
Weakened observed limit in the range Δm ~ 30 GeV falls in region of maximum complementarity between the $2\ell/3\ell$(soft) and $n_\ell \geq 3$ analyses

Top squark searches



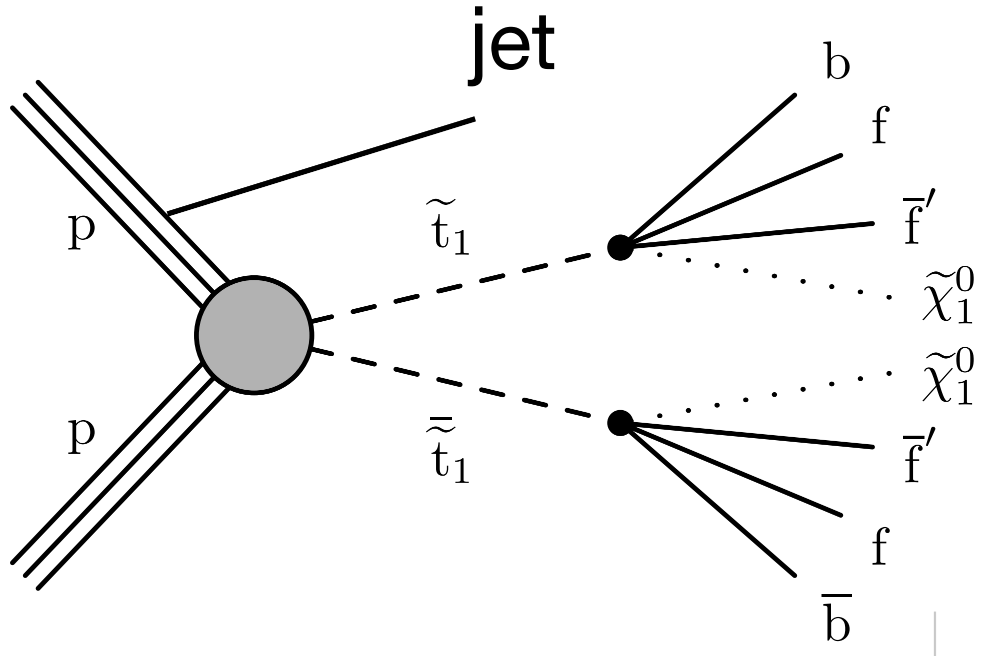
Analyses targeting compressed region $m(\tilde{t}) - \tilde{\chi}_1^0 < m_W$

- Stop decays to 4 fermions
- **0-lep**, (SUS-19-010)**:** *Search for top squark production in fully-hadronic final states [at 13 TeV]*
  - Dedicated soft b-tagging (p_T>20 GeV), also count number of displaced vertices
  - Leading jet with p_T >100 GeV non b-tagged - selects ISR jet
- **1-lep,** e or μ (SUS-21-003): *Search for top squarks in the four-body decay mode with single lepton final states [at 13 TeV]*
  - Loose pre-selection: drop b-tagging cuts
  - Employ **8 BDT event classifiers**, 1 for each $\Delta m(\tilde{t}, \tilde{\chi}_1^0)$
    - Input: b-tagging (scores) as well as event kinematics
    - Optimize for signal mass points Δm = [10,20,30,…80] GeV

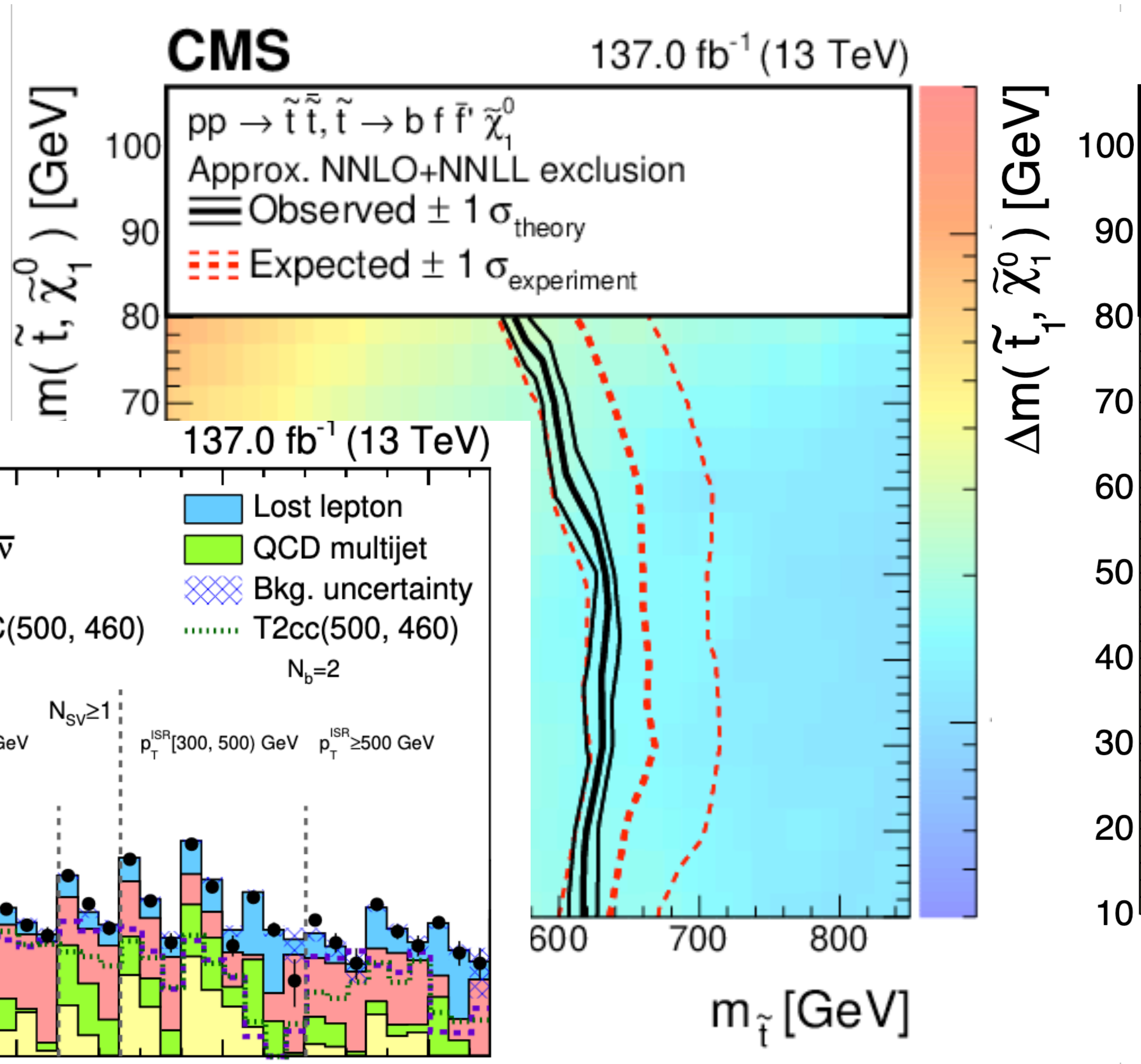


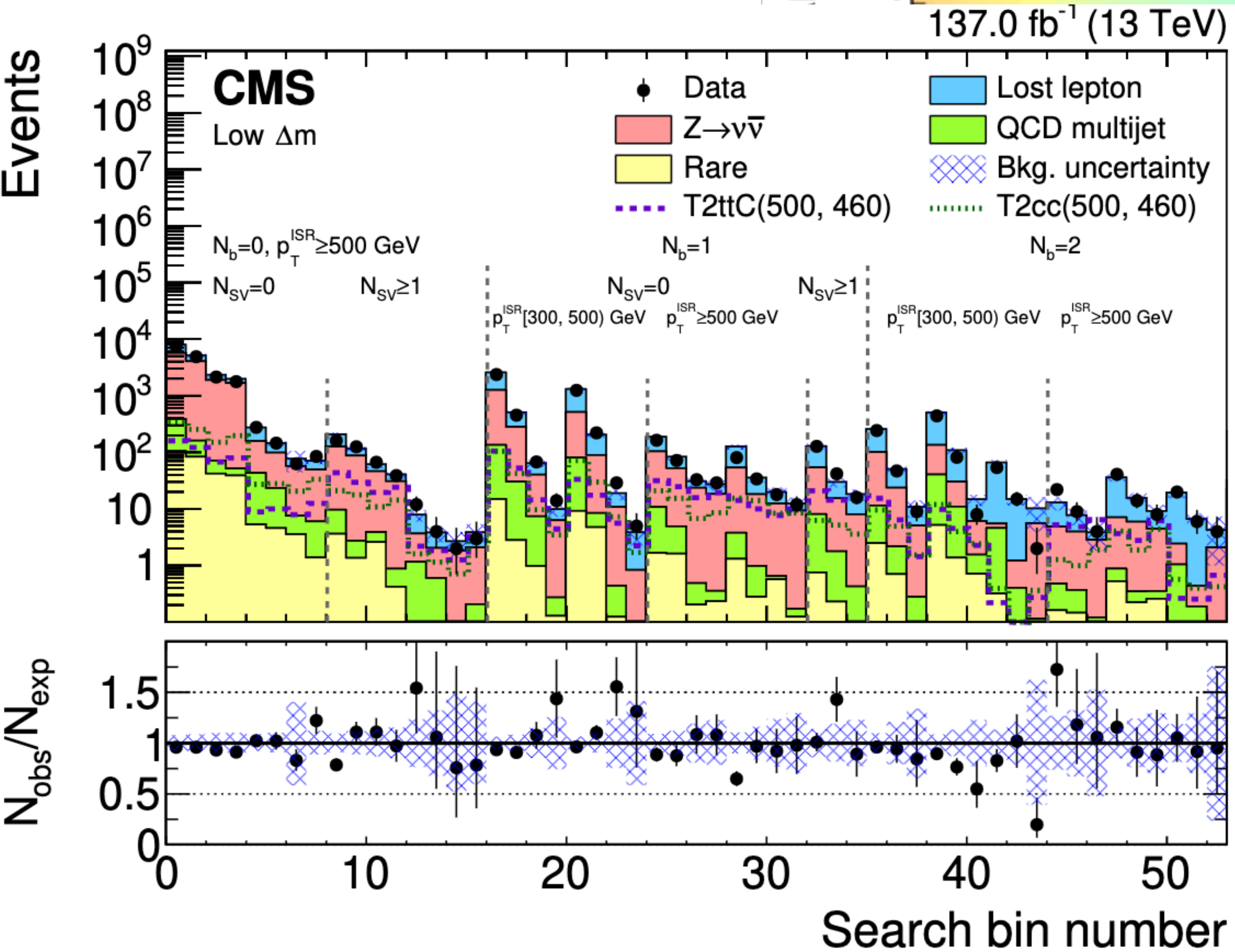
Backgrounds estimated with data-
driven and hybrid data/MC hybrid

Compressed stop limits

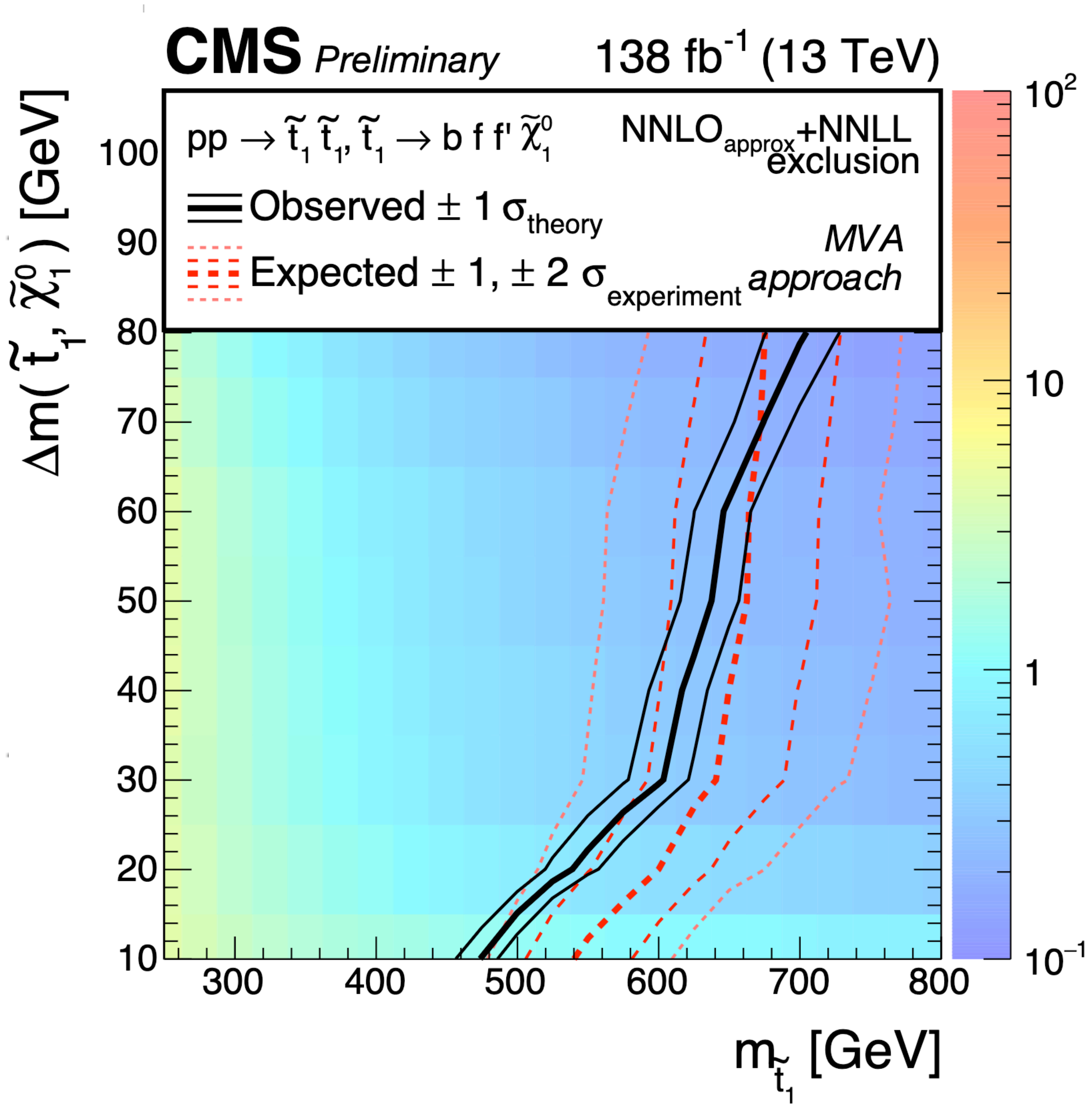


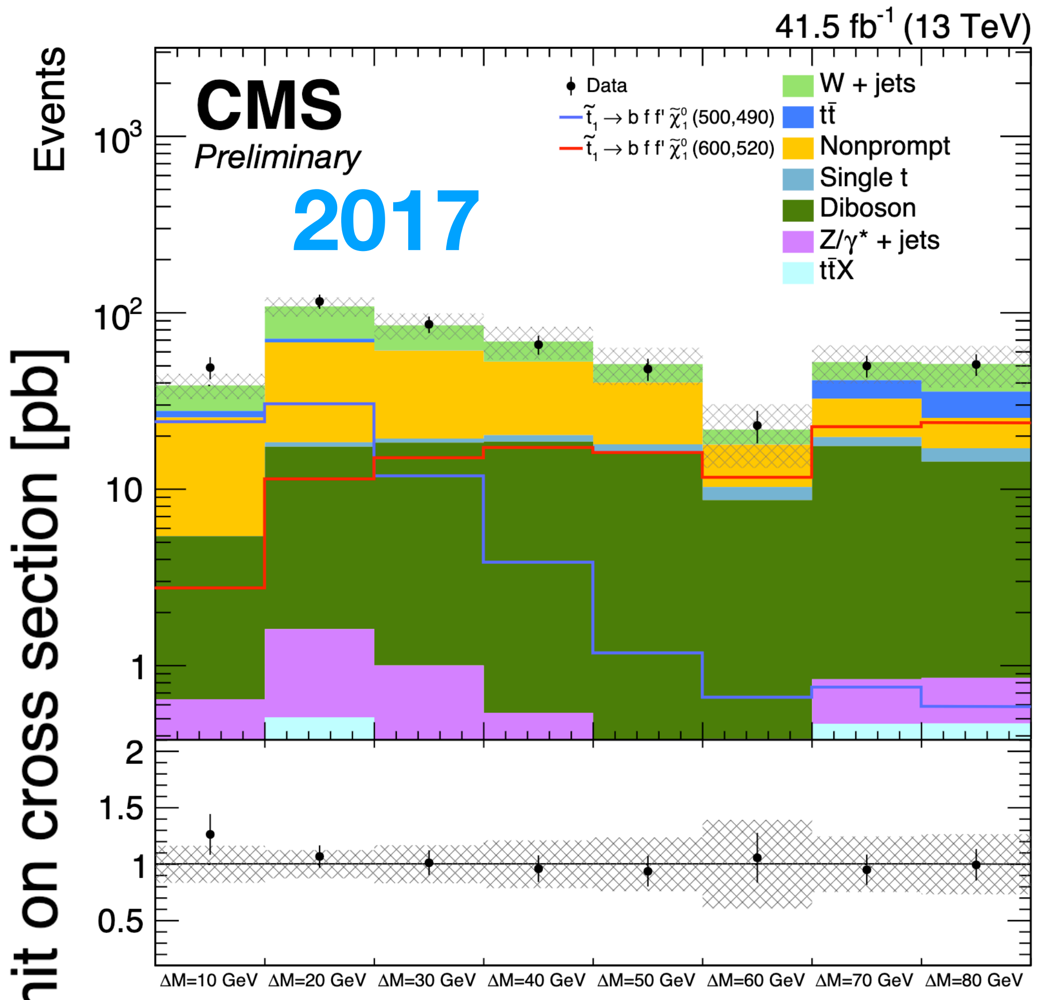
0-lep (SUS-19-010)

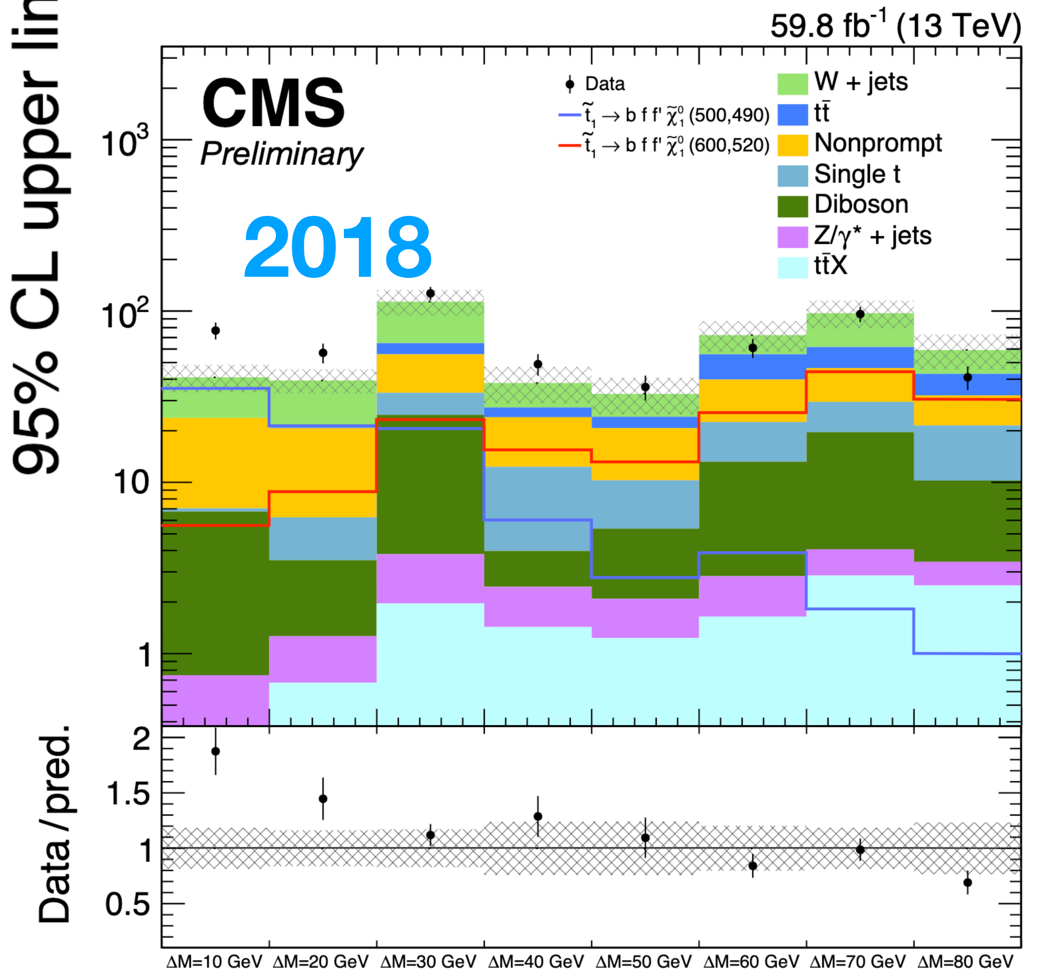




1-lep (SUS-21-003)





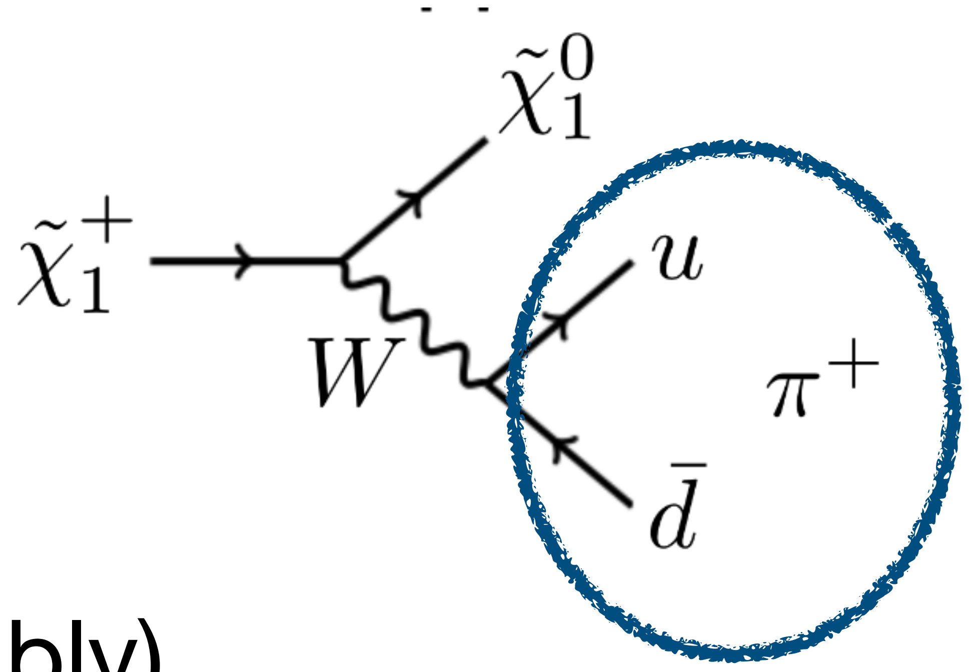


No evidence of new physics reported

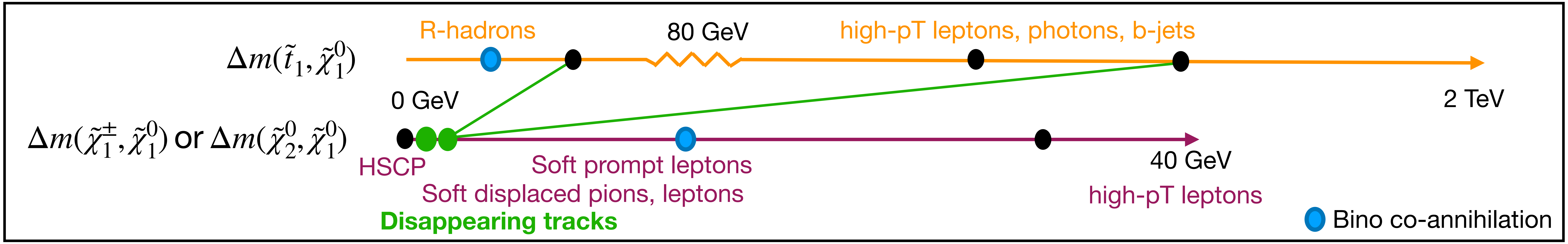
2016: 0.7σ; 2017: 1.1σ; 2018: 2.9σ

Ultra compressed SUSY

- For pure wino or higgsino LSPs, EWKino mass difference fall in the range of a few hundred MeV
- This gives rise to long-lived $\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$(for higgsinos) or $\tilde{\tau}_1$
- For $\tilde{\chi}_1^{\pm}$, the dominant decay is to an LSP and soft $\pi^{\pm}$
- How long? Up to 10 cm in the MSSM ($\tilde{\chi}_1^{\pm}$ leaves track and decays invisibly)

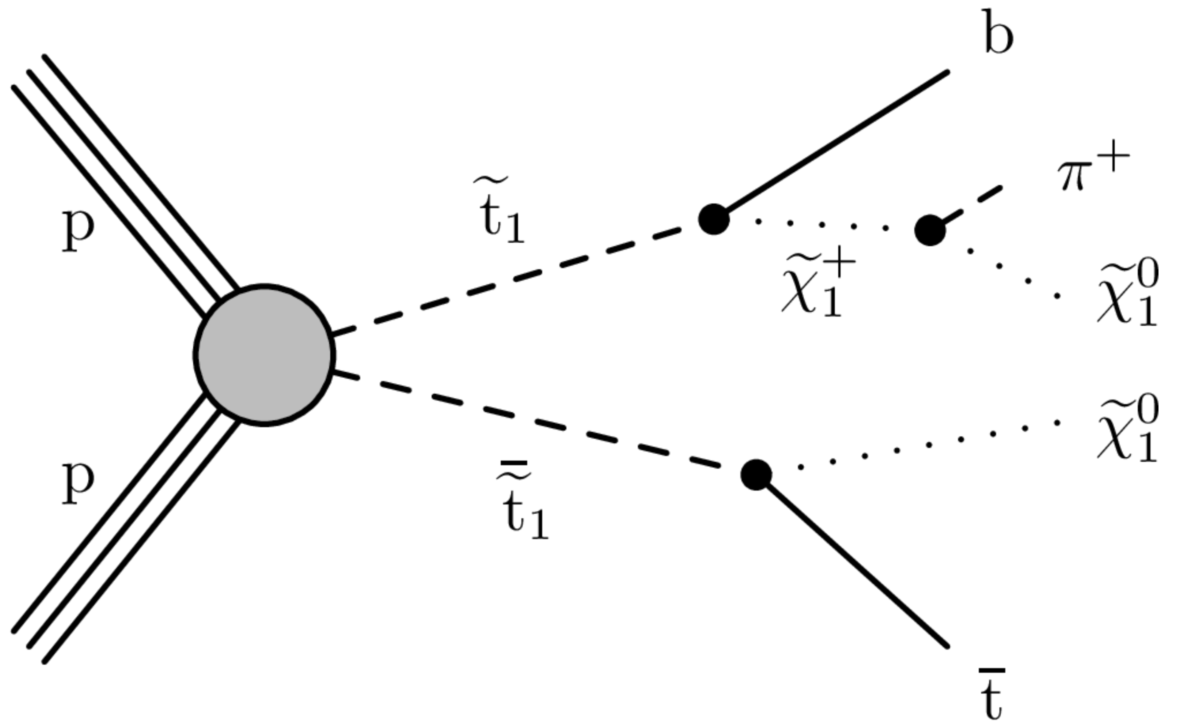


Soft! And (practically) invisible

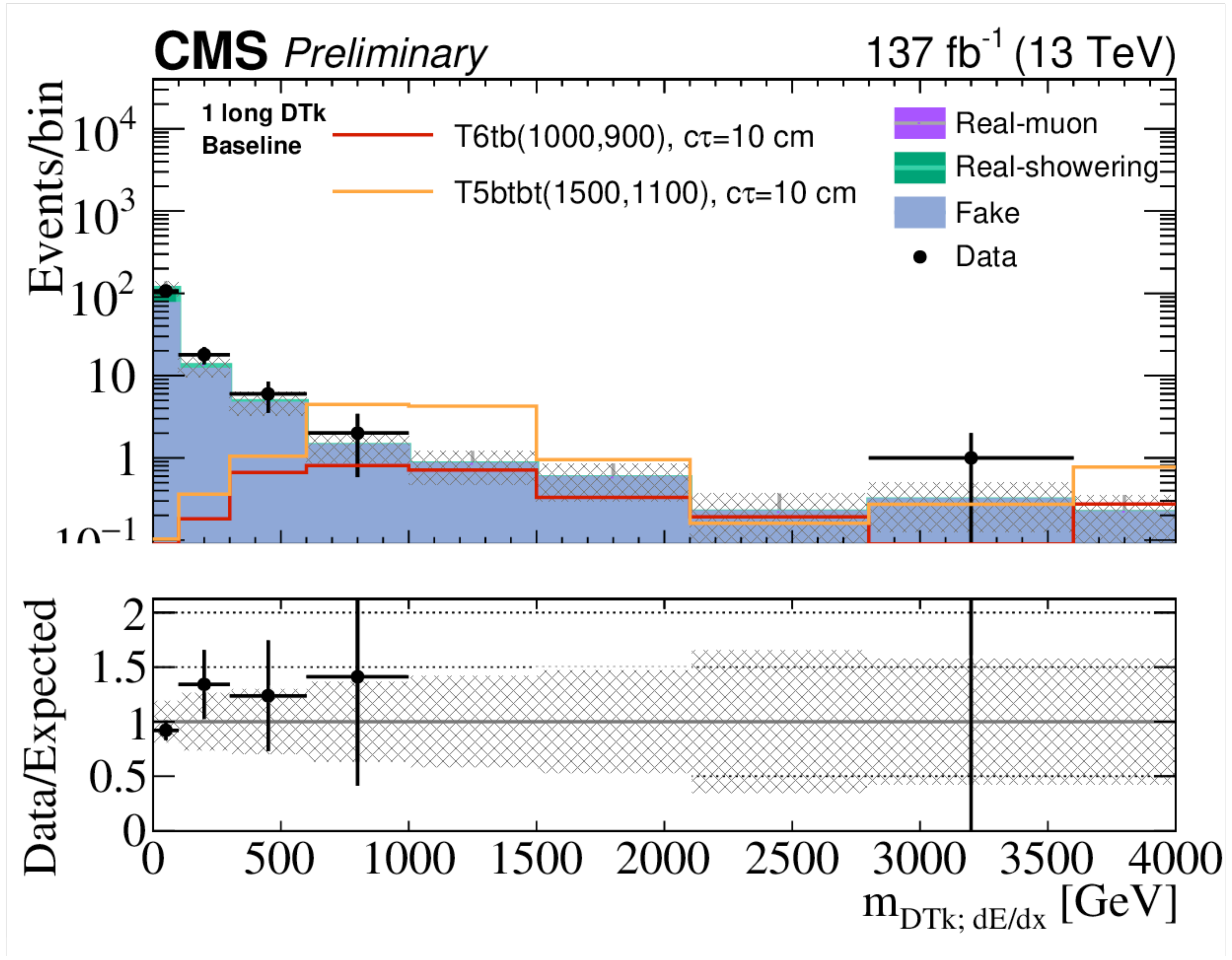


- Previously Run 2 searches
- 0-lepton
  - **arXiv:2004.05153** inclusive search for tracks with at least 2 missing outer hits; **arXiv:2103.01290:** search based on MT2 variable in final

Disappearing tracks

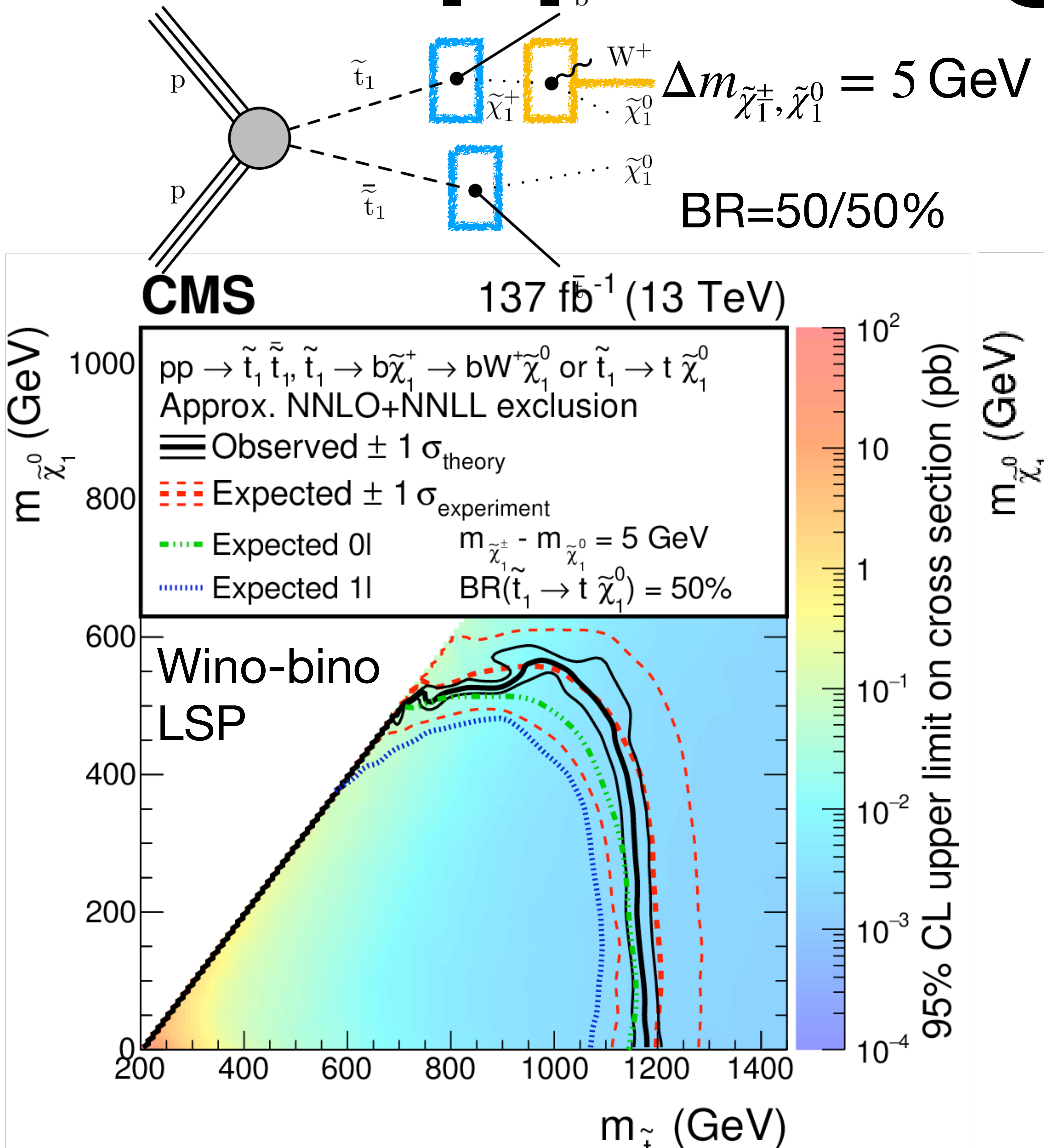


- 0-lepton, 1-lepton (e or μ)
  - **SUS-21-006:** *Search for supersymmetry in final states with disappearing tracks in proton-proton collisions at 13 TeV* (PAS, 24 May 2023)
  - Muons, electrons with $p_T > 40$ GeV
  - Machine learning-based disappearing chargino tagger reject fake tracks and mis-reconstructed particles
  - Binning in
    - $n_\mu + n_e = 0, \geq 1$
    - jet multiplicity [1-2, ≥3]
    - B-tagged jet multiplicity [0, ≥1]
    - dE/dx energy loss of particles, derived mass
    - Categories
      - short track (~8 cm), long track (~200 cm), ≥2 tracks

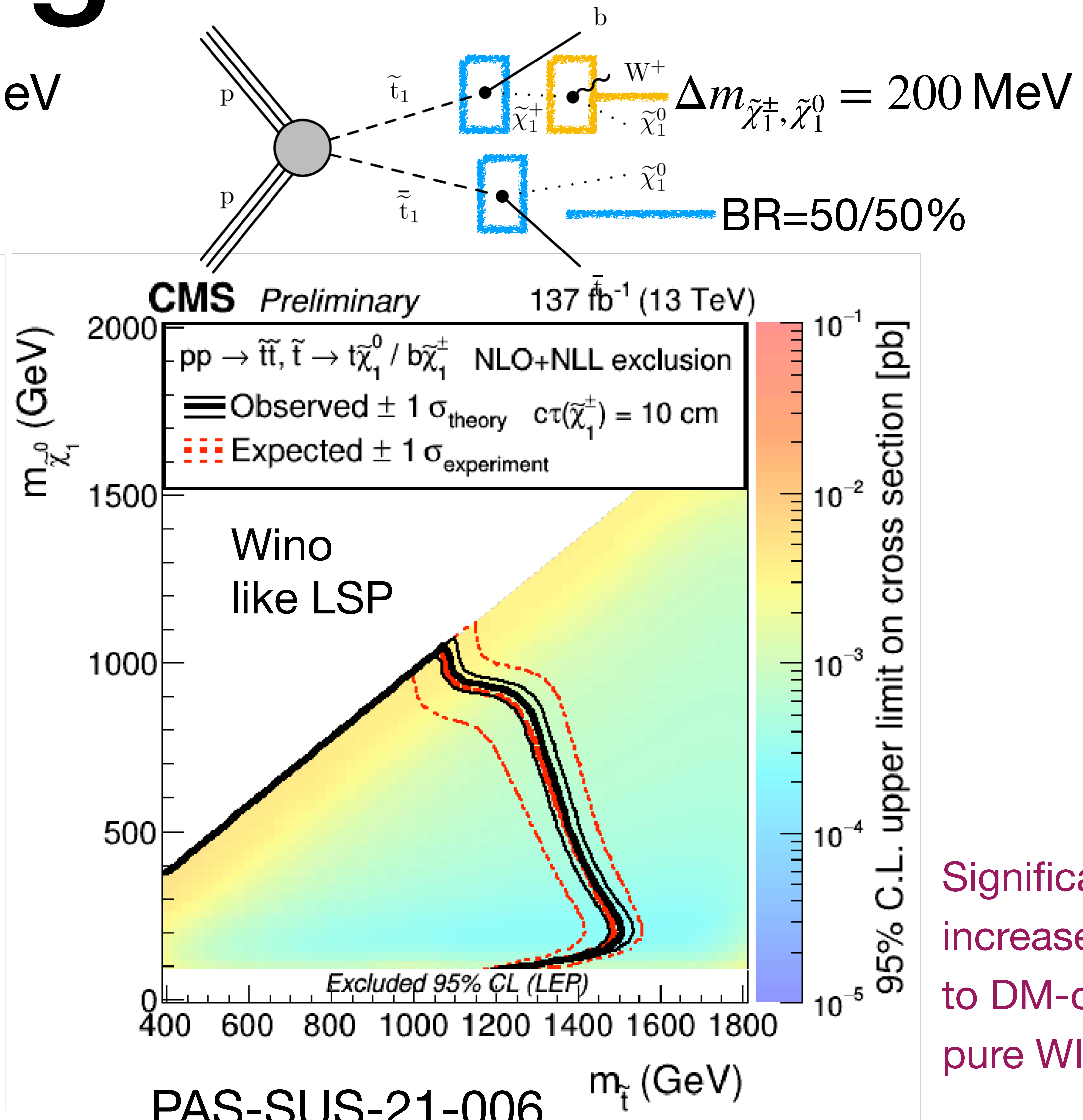


Background estimation based on all data-driven methods

Disappearing track Limits



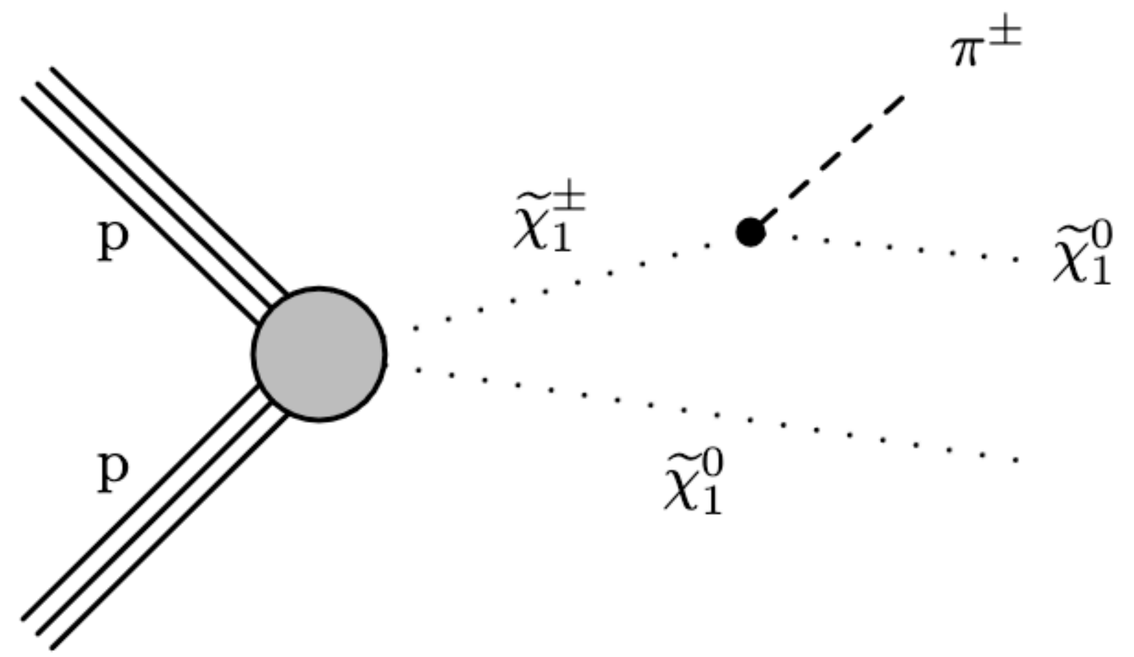
<u>SUS-21-003</u> stop combination



<u>PAS-SUS-21-006</u>

Significant increases in reach to DM-consistent pure WIMP states

Summary



- CMS searches continue to probe challenging compressed spectrum
- Parameter space meaningfully constrained, numerous blind spots covered, few tantalising hints?
- SUSY models continue to guide the development of new powerful objects and selection criteria
- Reason for excitement for Runs 3 and 4 - compressed searches will benefit from new techniques and luminosity
- Let's leave no stone unturned!