ΙΣΝ/SNF ΙΔΡΥΜΑ ΣΤΑΥΡΟΣ ΝΙΑΡΧΟΣ
STAVROS NIARCHOS FOUNDATION

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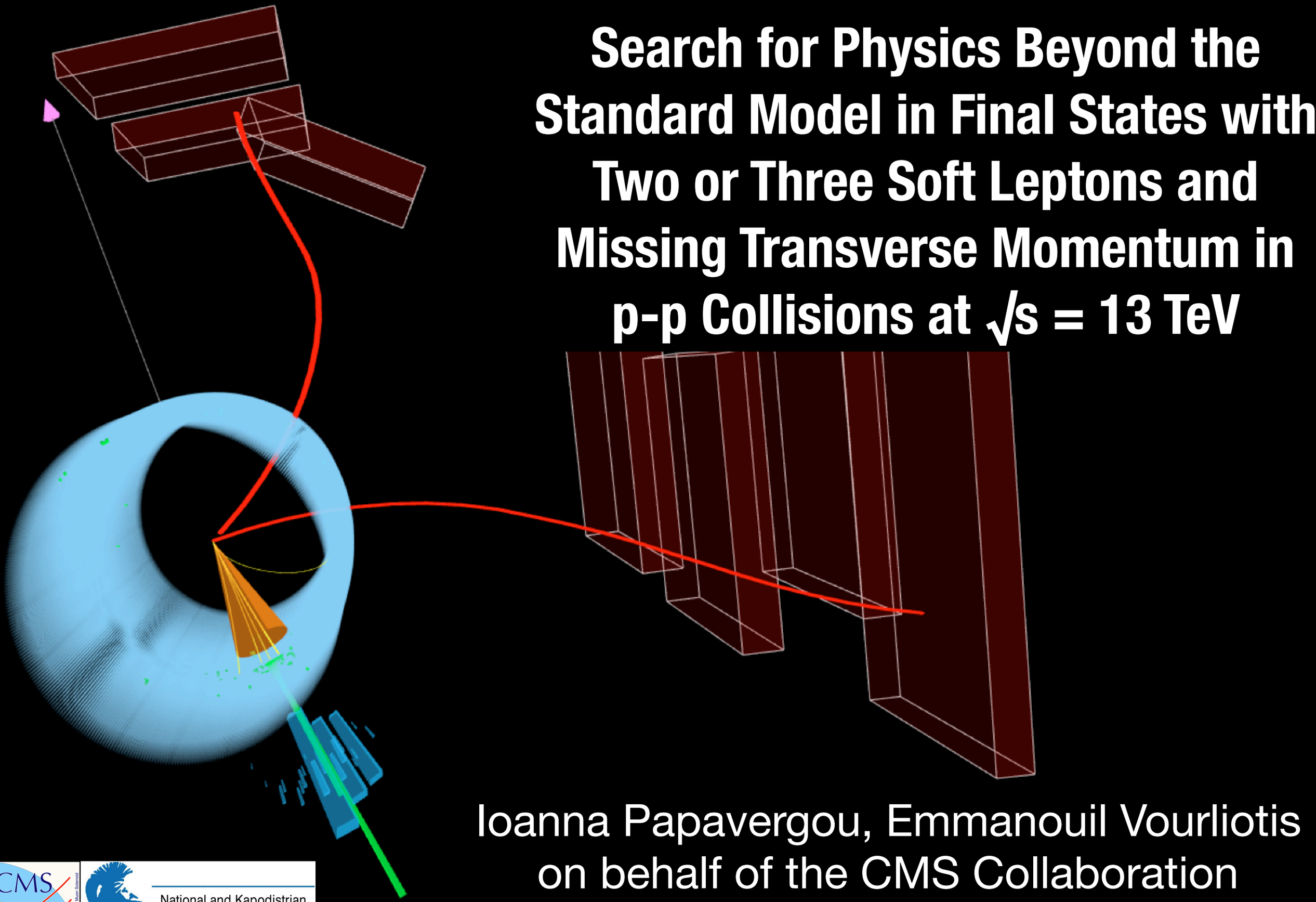
Search for Physics Beyond the Standard Model in Final States with Two or Three Soft Leptons and Missing Transverse Momentum in p-p Collisions at $\sqrt{s}$ = 13 TeV



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on behalf of the CMS Collaboration

National and Kapodistrian
UNIVERSITY OF ATHENS

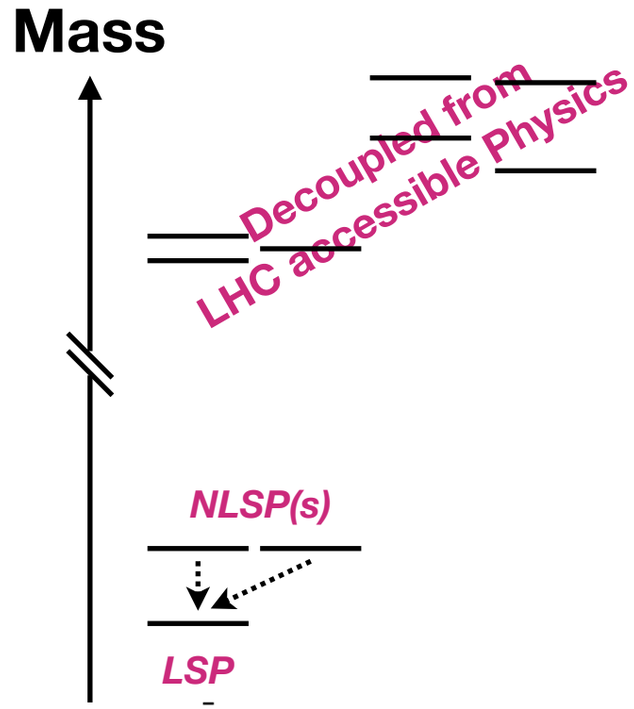
SUSY Searches in a Nutshell

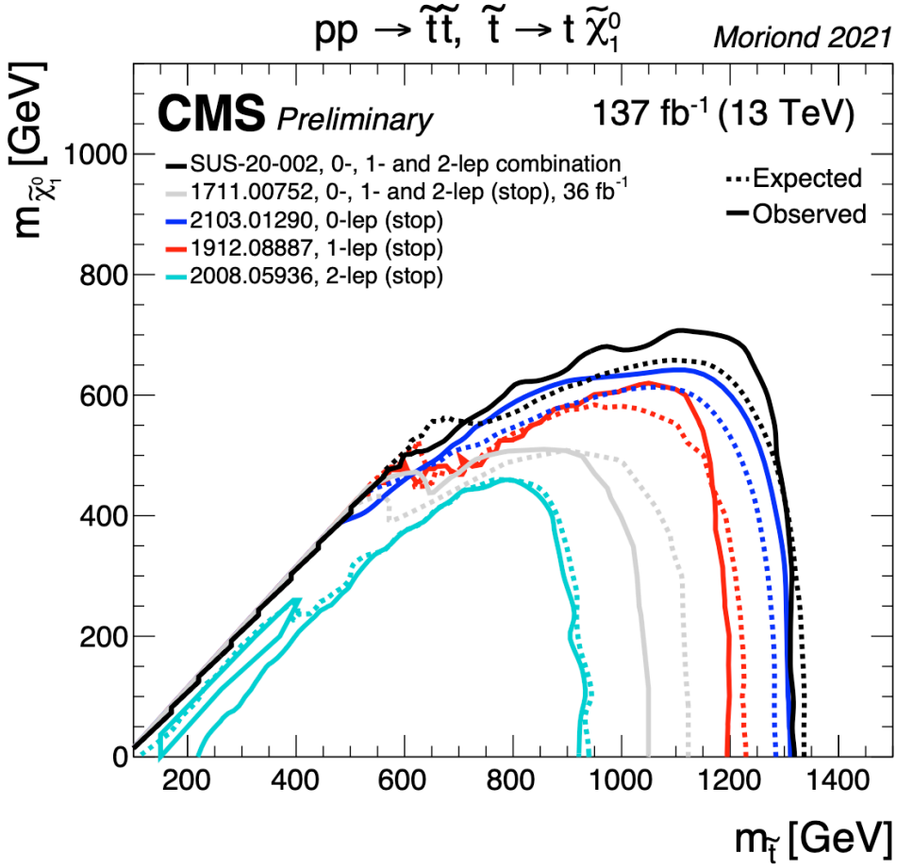
- Minimal Supersymmetric Standard Model (MSSM) → Simplified models with most particles decoupled → Phenomenology based on couple of particles @ TeV scale

- Usual signatures:
  - Large amounts of p_T^{miss}
  - Visible, high-p_T particles

⇒ No sign of SUSY particles

- Attention turns to less explored signatures:
  - Experimentally challenging
  - Highly theoretically motivated



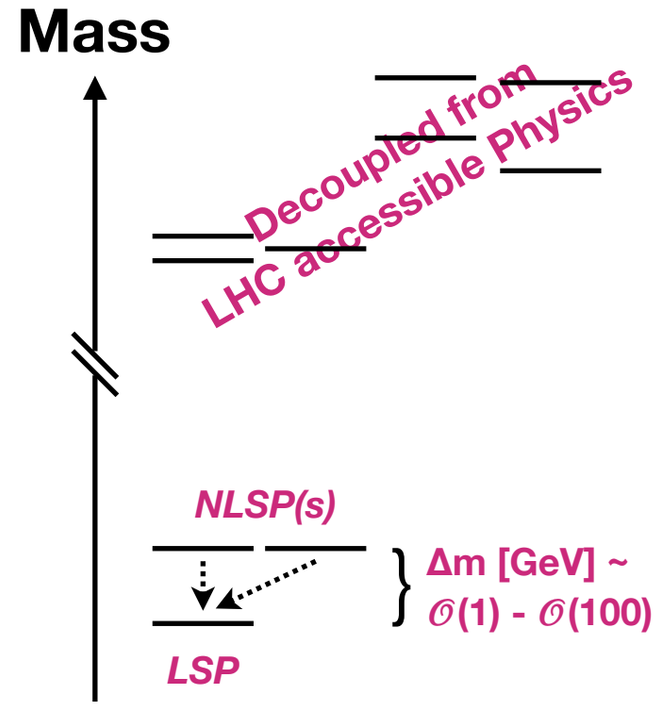


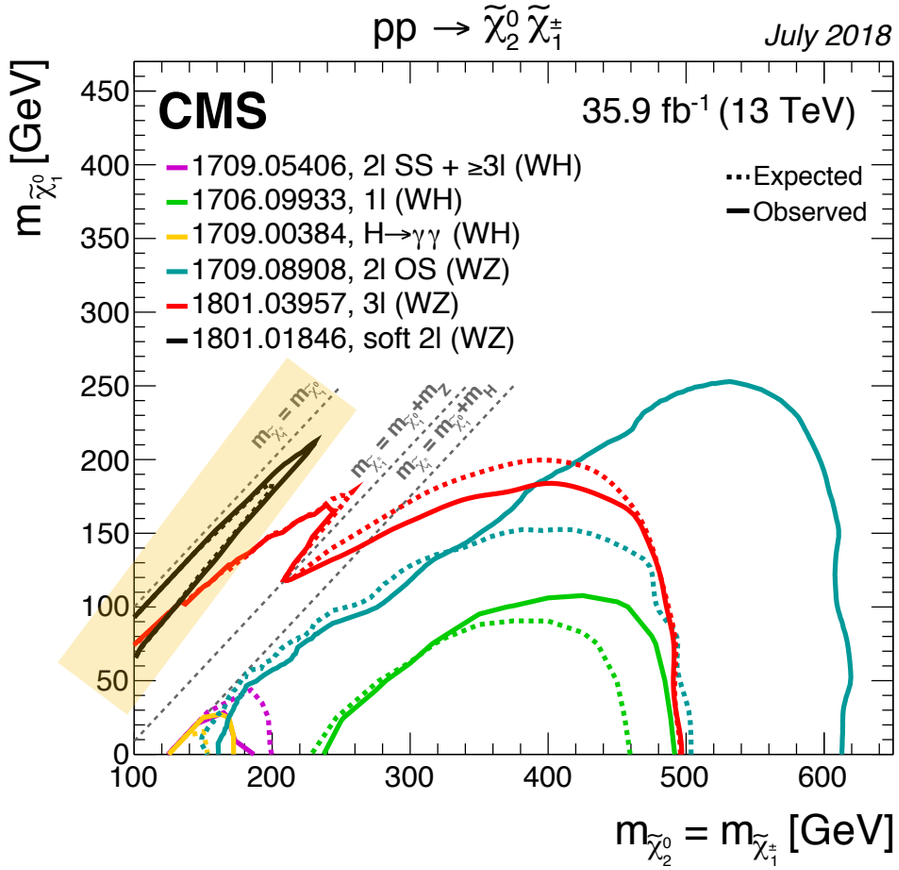
Compressed SUSY: Experiment

- SUSY with compressed mass spectrum:
  Δm(particles) $\lesssim \mathcal{O}(10\%)$ of their masses

- Final state with
  - Small to moderate amounts of p_T^{miss}
  - Visible, low-p_T particles

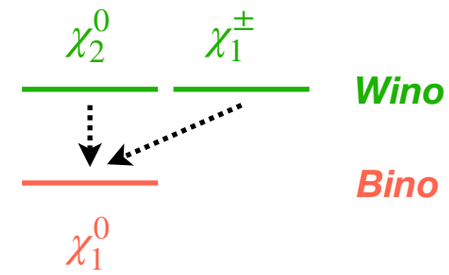
- At the limit of
  - Detection,
  - Reconstruction and
  - Identification



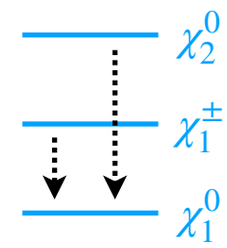


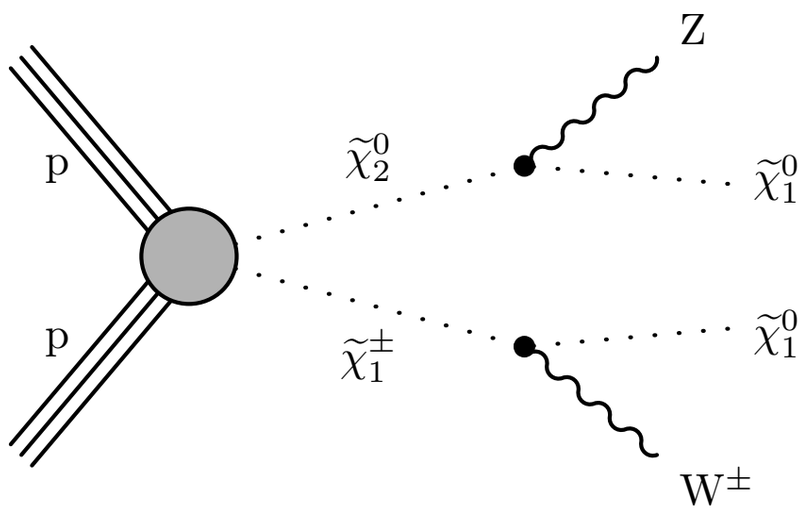
Compressed SUSY: Theory

- EWK production:
  - **Wino/bino** compressed scenario ($M_1, M_2 \ll \mu$):
    - ➤ Theoretically motivated by the observed DM density
    - ➤ Not constrained by direct DM detection experiments

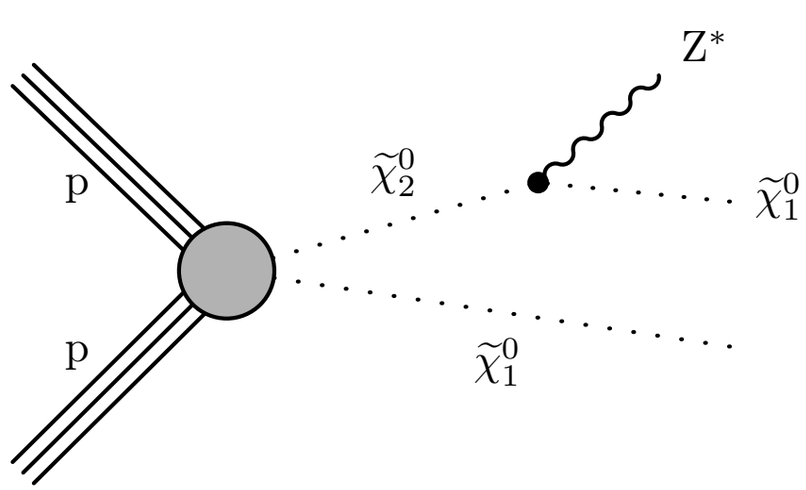


  - Direct **higgsino** production ($\mu < M_1, M_2$):
    - ➤ Naturalness arguments ⇒ Higgsino triplet with similar mass near the EW scale





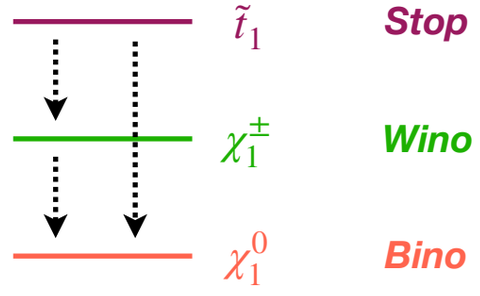
SMS C1N2

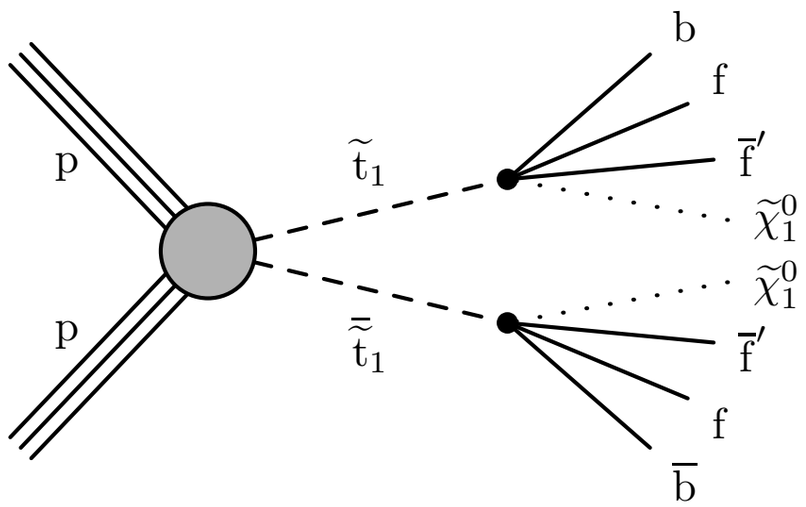


SMS N2N1

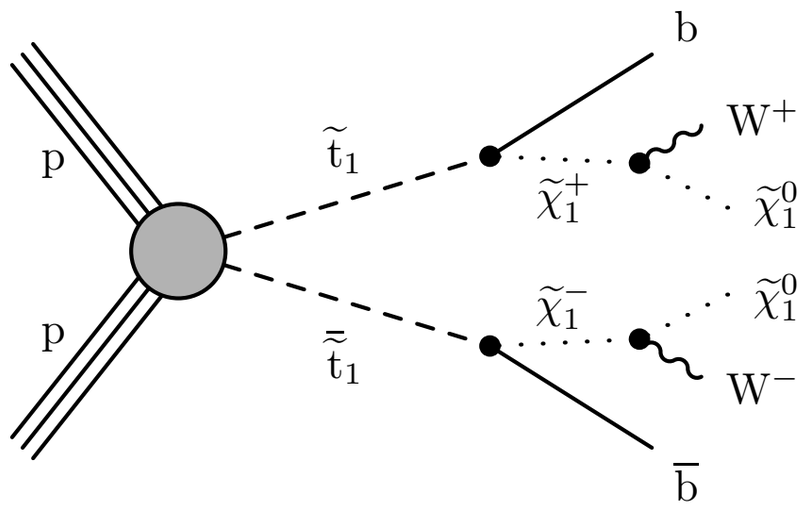
Compressed SUSY: Theory

- Top squark (**stop**) production:
  Light stop ~mass degenerate with EWK LSP
  - Large Yukawa coupling + Mixing ⇒
    Stops expected light
  - Co-annihilation region ⇒ LSP as source for DM





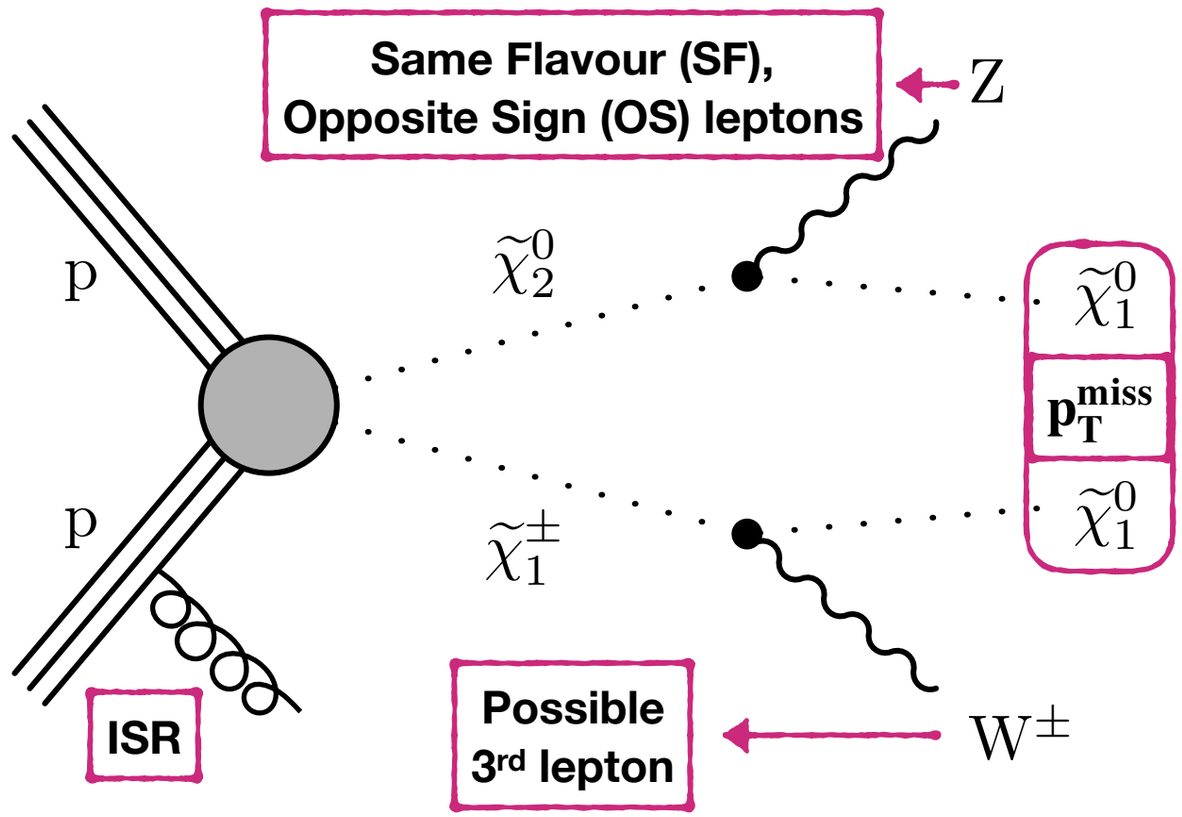
SMS T2bff



SMS T2bW

SUSY in Soft 2ℓOS & 3ℓ Final States

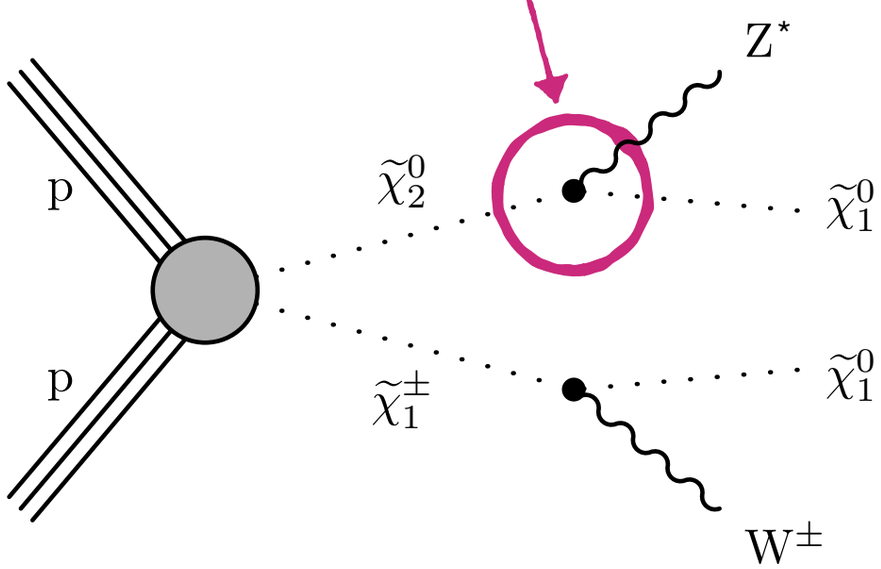
- New CMS result on compressed signatures: **CMS-SUS-PAS-18-004**
- Full Run 2 result: 137 fb^{-1} → Trigger on p_T^{miss} (+leptons)
- Electroweak production ⇒ Small cross section
- Request initial state radiation (ISR) jet to induce p_T^{miss}:
  - H_T > 100 GeV
  - p_T^{miss} > 125 GeV
- 2 SFOS (+1) leptons ($e^+e^-/\mu^+\mu^- + e^\pm/\mu^\pm$)
  - Prompt & Isolated
  - Soft: 3.5 < p_T < 30 GeV



Dilepton Mass M(ℓℓ)

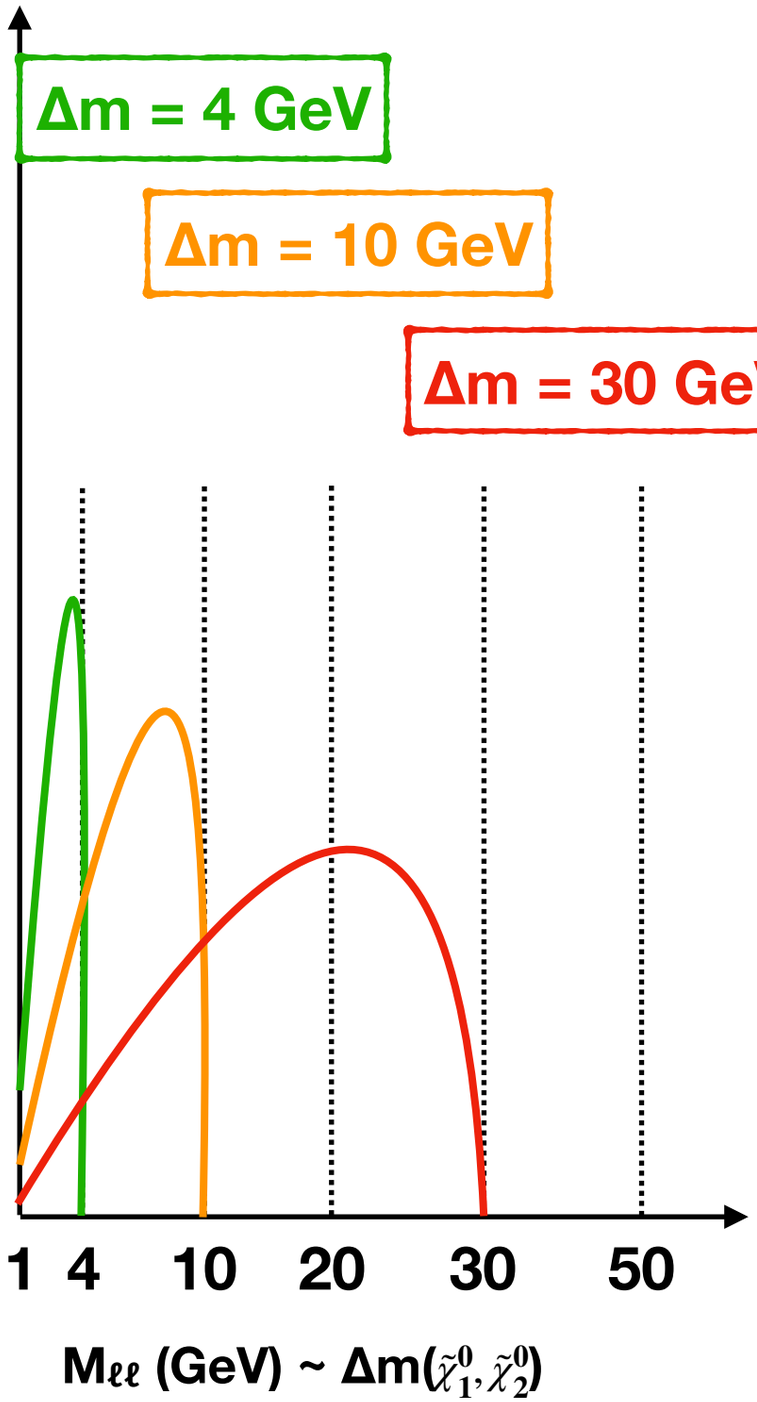
- M(ℓℓ) distribution sensitive to SUSY particles mass difference:

$$M(\ell\ell) \sim M_{Z^*} \sim \Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$$

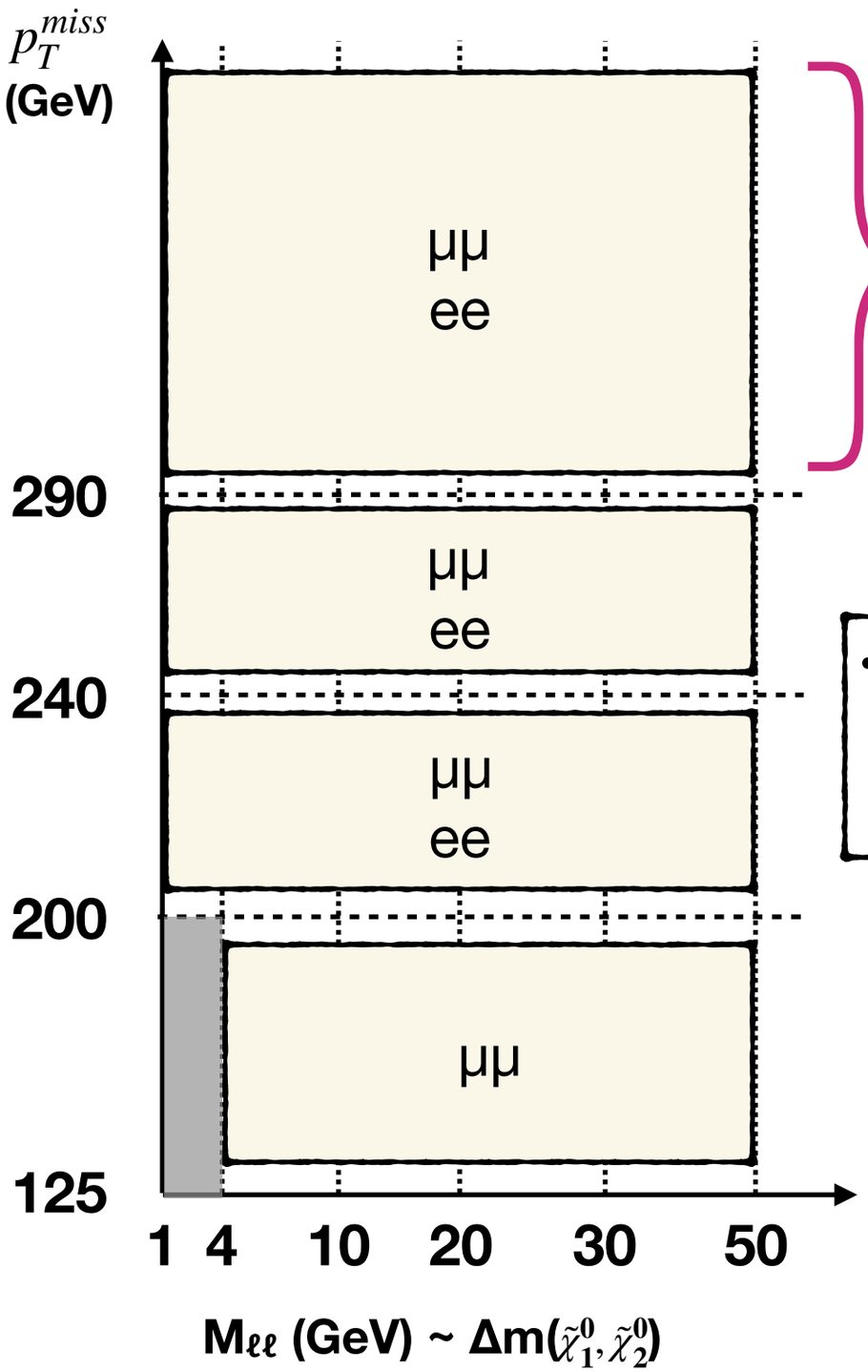


- Compressed model ⇒ 1 < M(ℓℓ) < 50 GeV

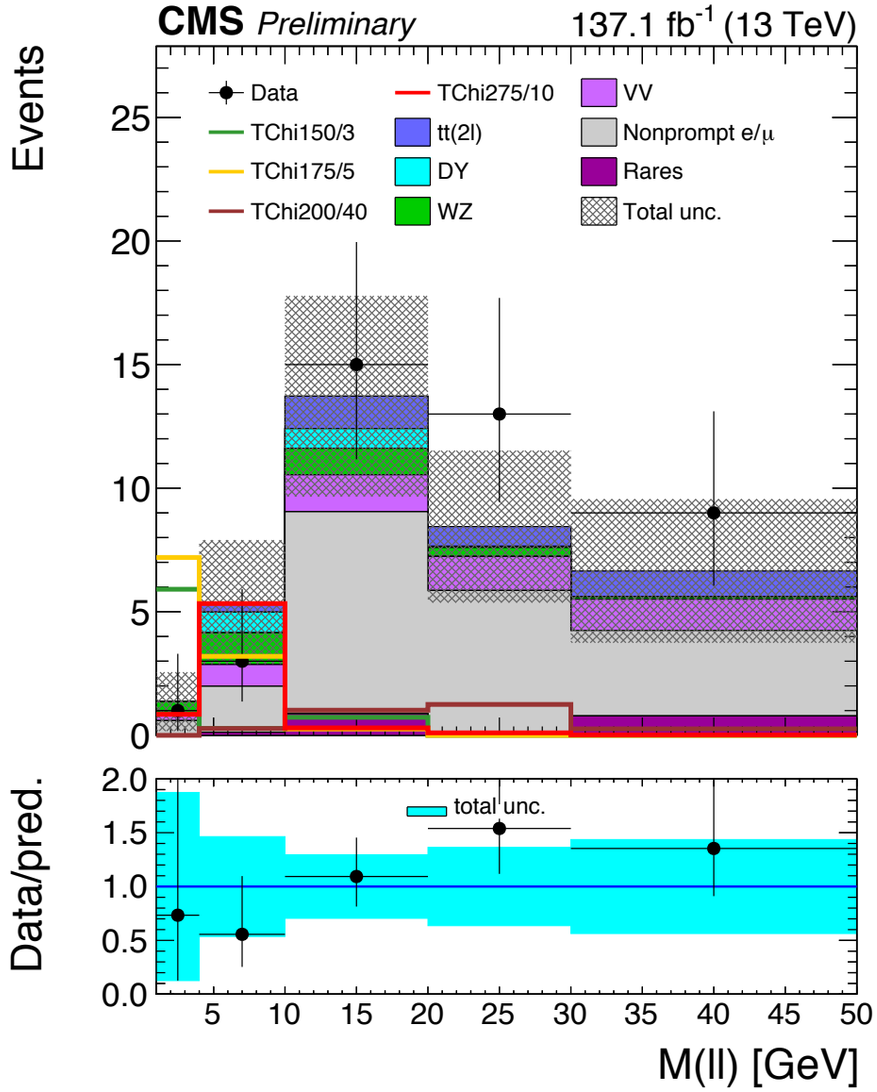
- Signal modeling refinements affect M(ℓℓ) ($\Gamma_{\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell \bar{\ell}}$, W/Z branching fraction)



2ℓOS-EWK Search Regions



- Another handle to separate signal from bkg:
  Bin in p_T^{miss}



Non-prompt bkg

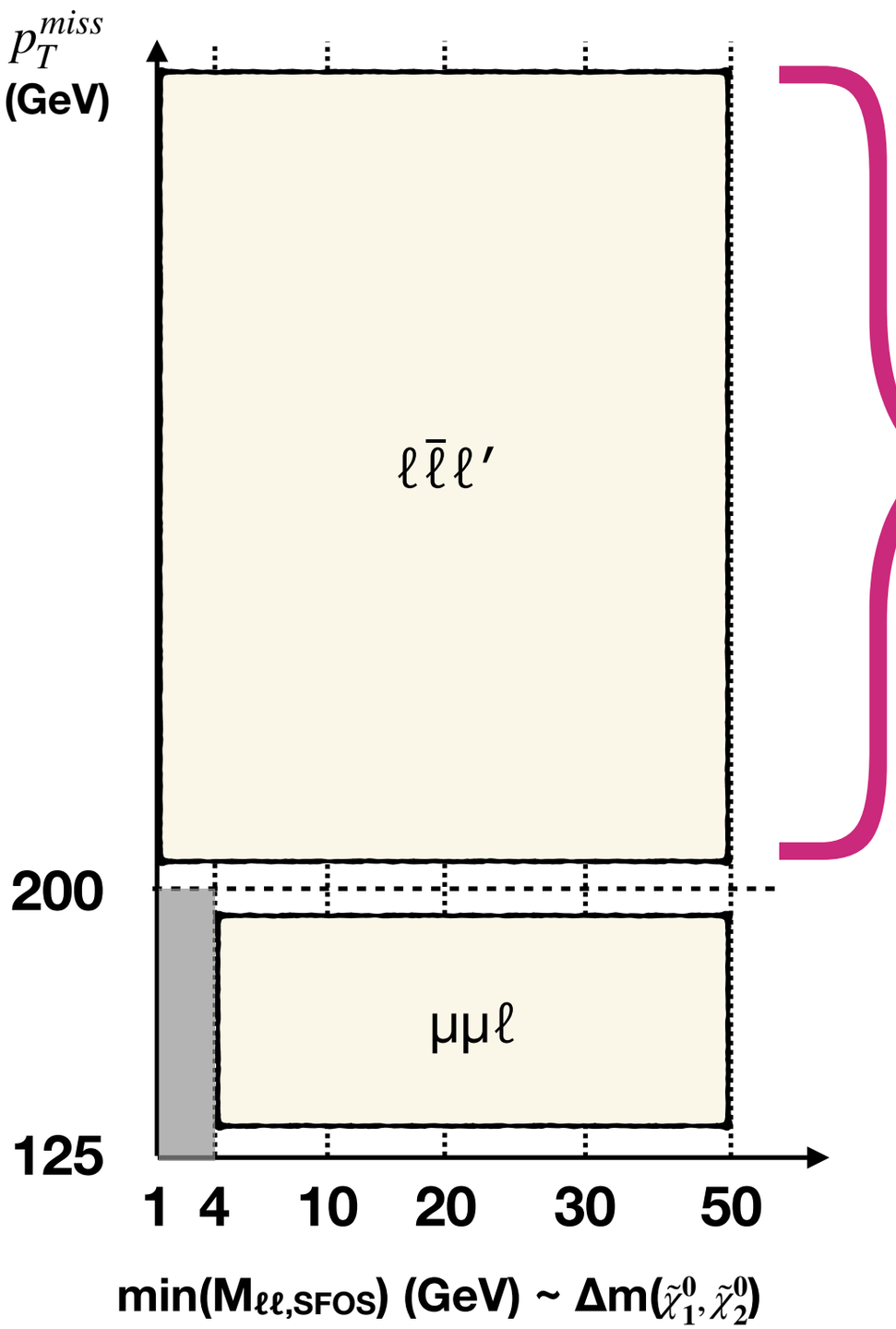
$t\bar{t}(2\ell)$

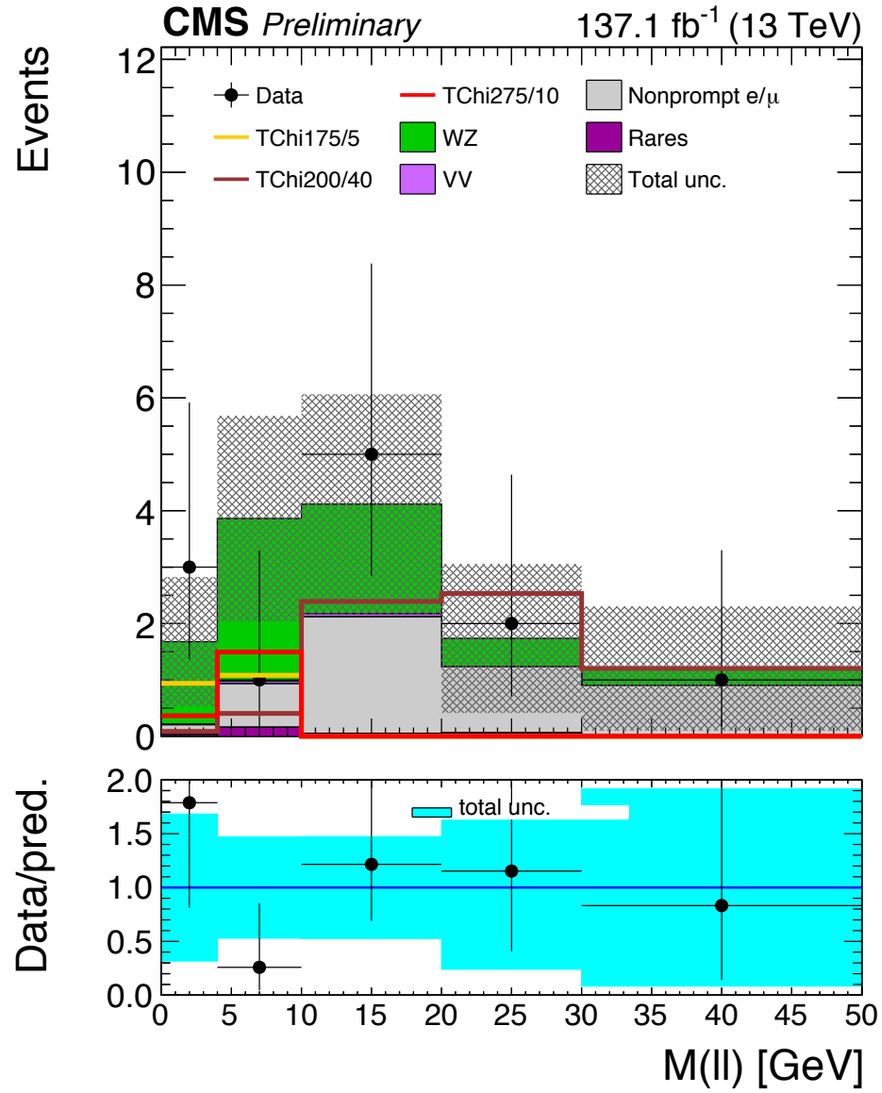
WZ

DY($\rightarrow\tau\tau$)

Diboson

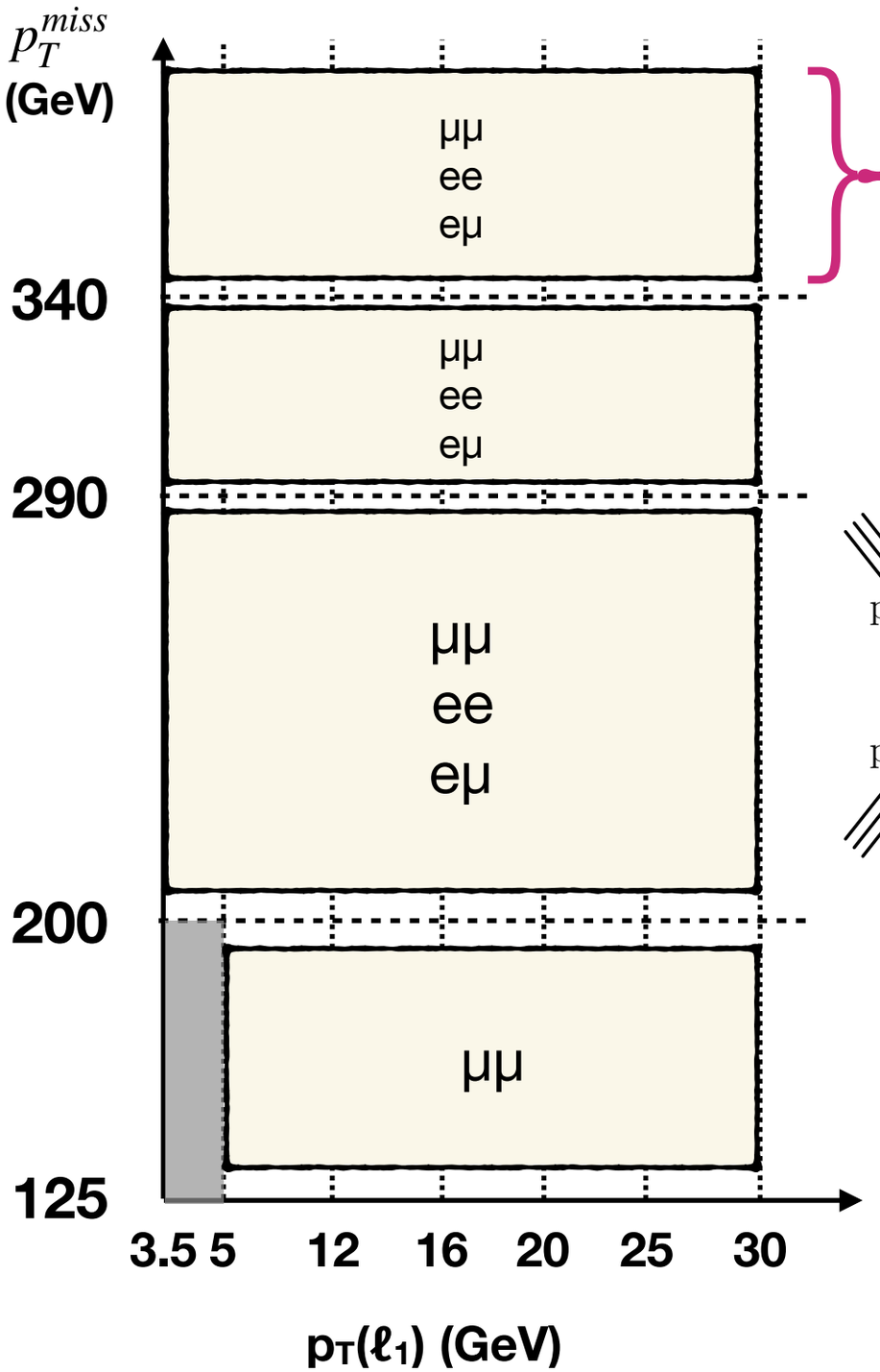
3ℓ-EWK Search Regions

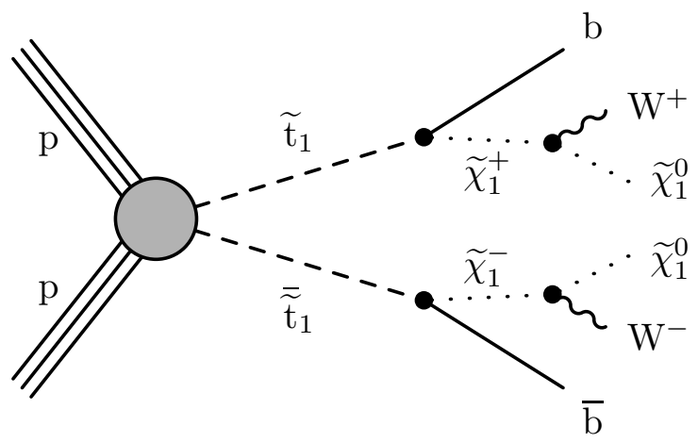


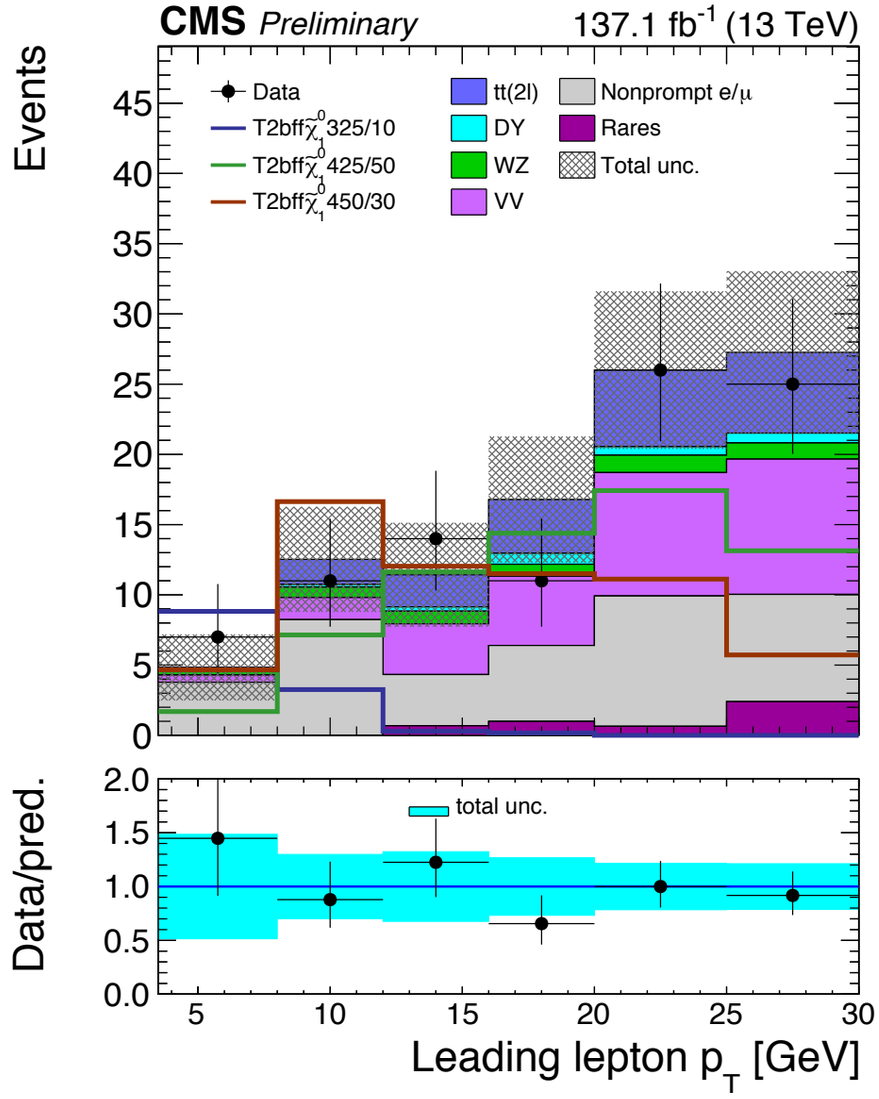


- Extra lepton ⇒ SM depleted, signal-rich
- To enhance statistics:
  - No ISR jet requirement
  - Slightly different binning

2ℓOS-Stop Signal Regions







- Include different flavour pairs
- Slightly different binning

Nonprompt ℓ

Nonprompt leptons:

- MisID'ed jets or ℓ from heavy quark decays
- Estimated with **Tight-to-Loose** method

Tight ID (tight Iso and IP_{3D} cuts)
Loose ID (non isolated and/or non prompt)

- **Measurement Region (MR)**

  Measure Fake Rate (FR) in QCD-enriched **data**

  FR: Probability of Loose ID ℓ to pass the Tight ID

$$FR(p_T, \eta) = \frac{\textbf{Tight ID } \ell}{\textbf{Loose ID } \ell}$$

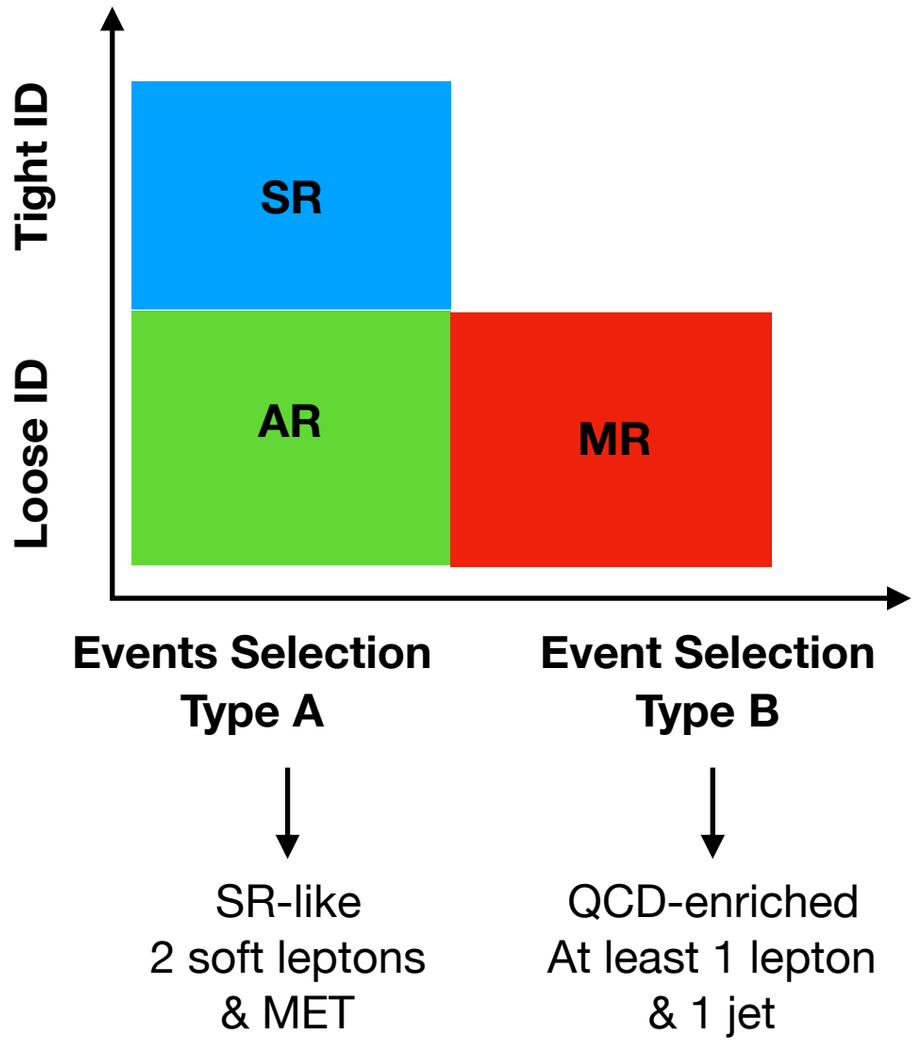
- **Application Region (AR)**

  Nonprompt enriched region with Loose ID ℓ

  passing SR-like selection → weighted by FR →

  Nonprompt estimate in **Search Region (SR)**

  ❖ Residual non-closure assigned as systematic on non prompt background (up to 40%)



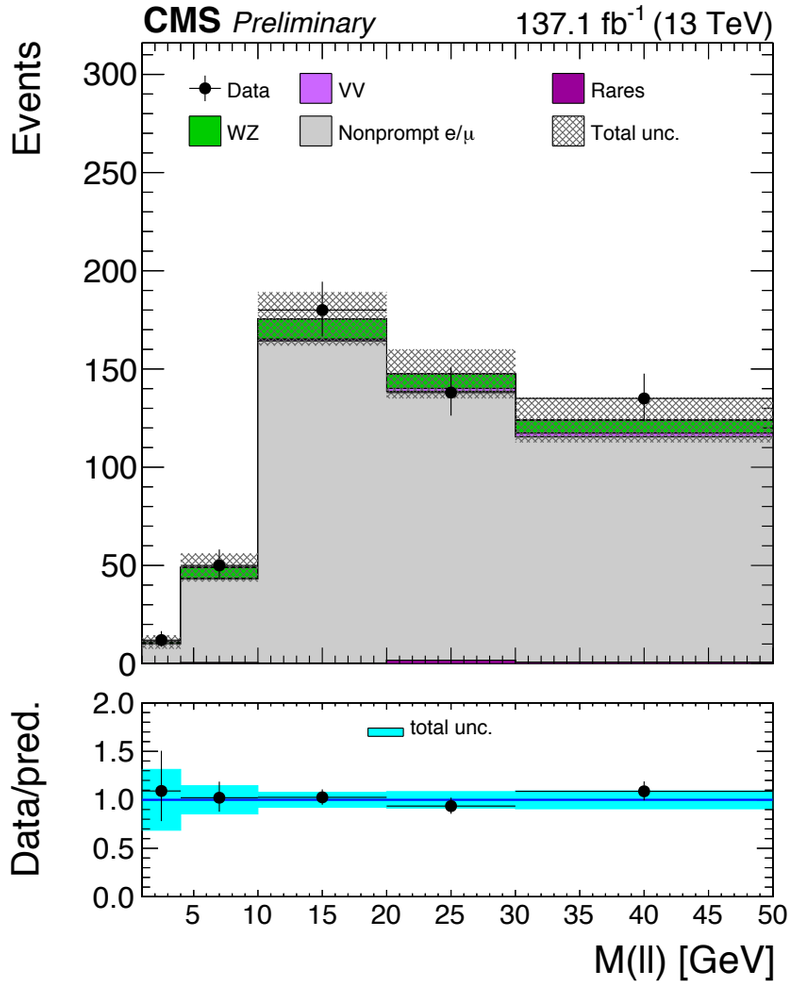
Fake Rate Application

- **Data-Driven (DD)** method: fake rate applied on AR data

- Smooth out stat. fluctuations in low yield regions:
  fake rate applied on norm-to-data AR simulation (semi-DD method)
  - Dedicated shape uncertainties

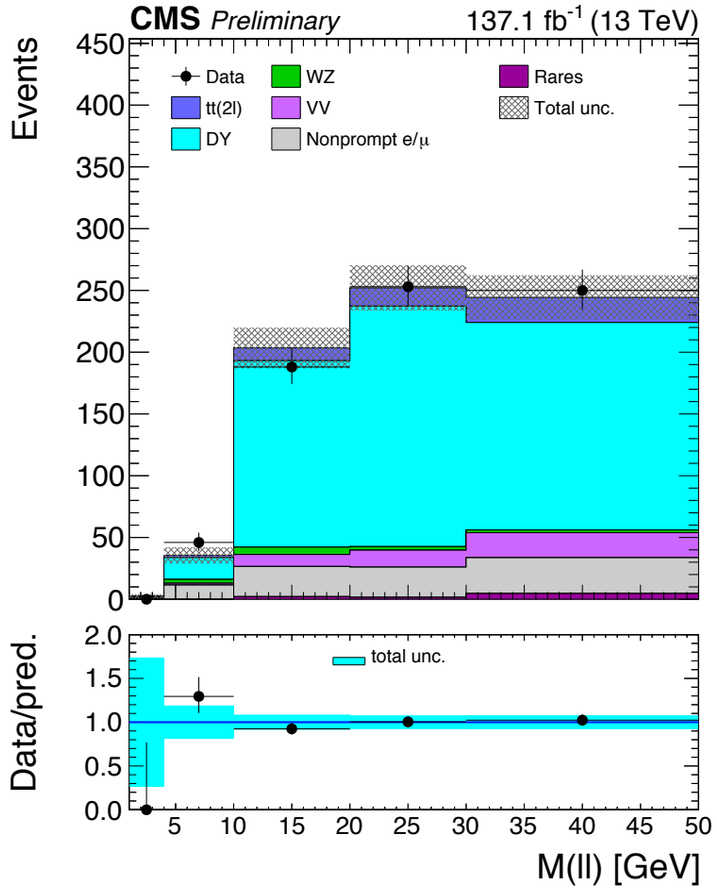
- **Same Sign (SS) CR**
  - Similar selection to SR but SS requirement
  - Used for evaluation of the nonprompt modeling
  - Strongly constrain the nonprompt bkg uncertainty

SS CR post-fit



Prompt 2ℓ Bkg

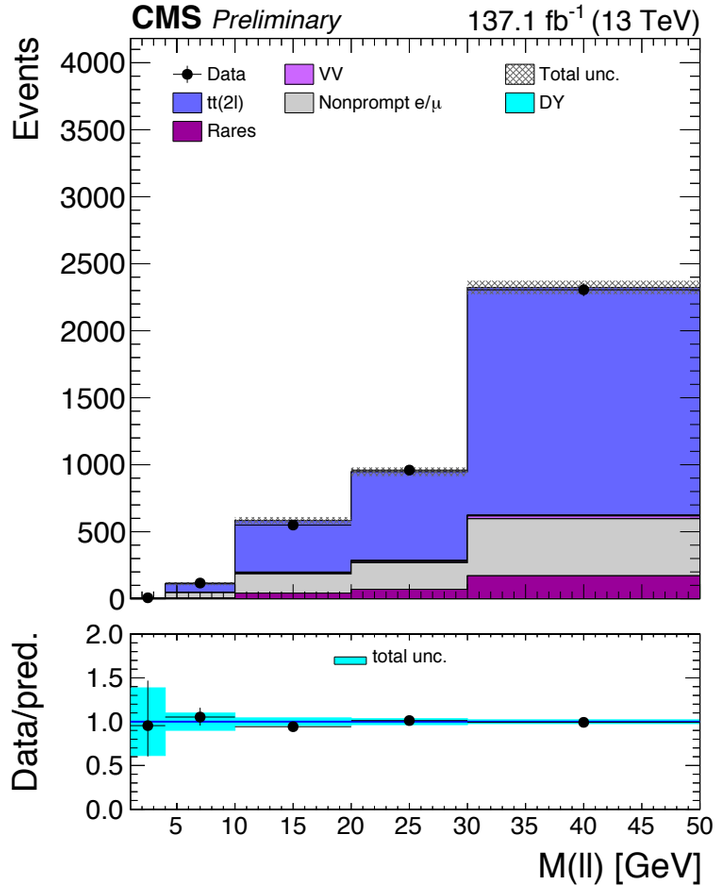
- Prompt 2ℓ bkg CR split into two MET bins:
  - **Low MET** (125-200 GeV)
  - **High MET** (>200 GeV)
- Estimated from simulation and corrected by data driven scale factor



DY(→ττ) CR

Estimate $M_{\tau\tau} \sim M_Z$ from leptons and p_T^{miss}

$0 < M_{\tau\tau} < 160$ GeV



TT CR

No $M_T(\ell, p_T^{miss})$ cut

& Invert b-tag veto

Prompt Multiboson Bkg

- Prompt multiboson bkg enriched regions split into two MET bins:
  - Low MET (125-200 GeV)
  - High MET (>200 GeV)
- Estimated from simulation and corrected by data driven scale factor

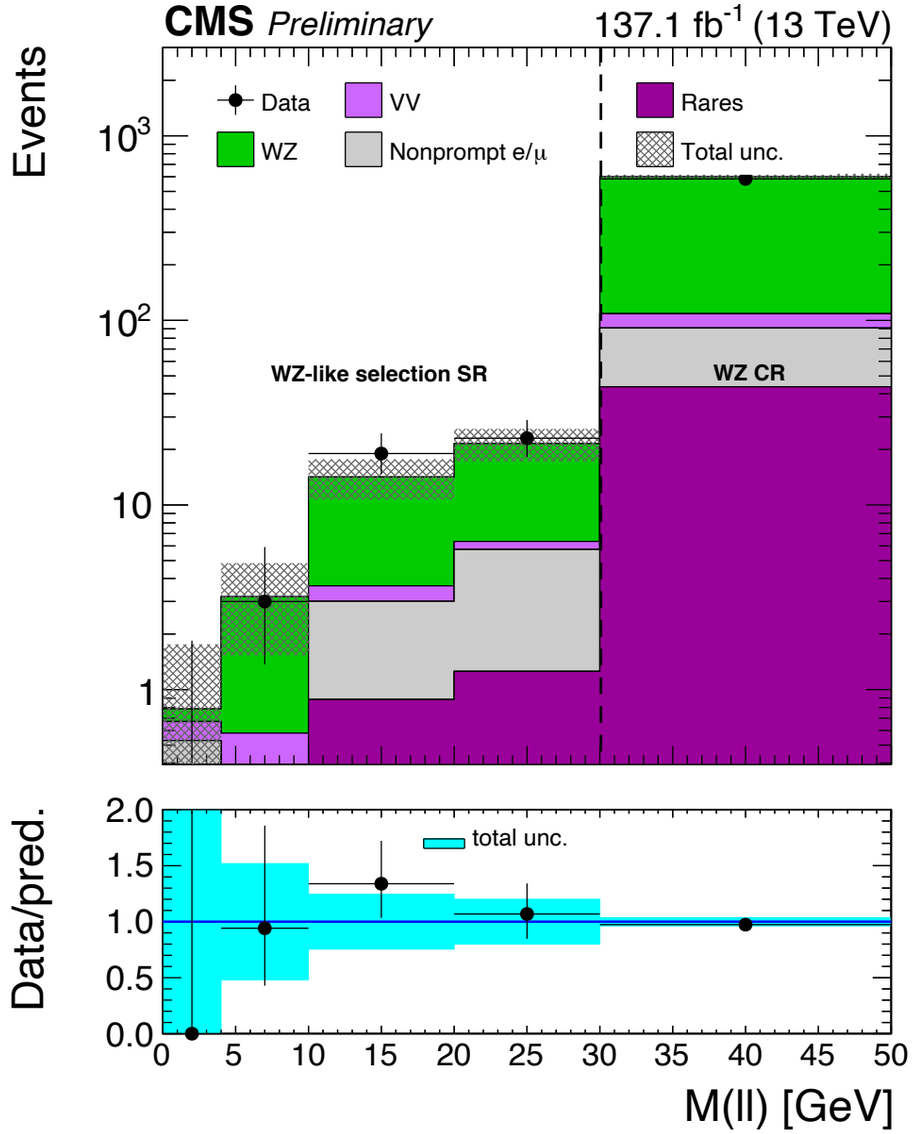
WZ enriched region

Leptonically decaying WZ most dominant prompt bkg in 3ℓ SR

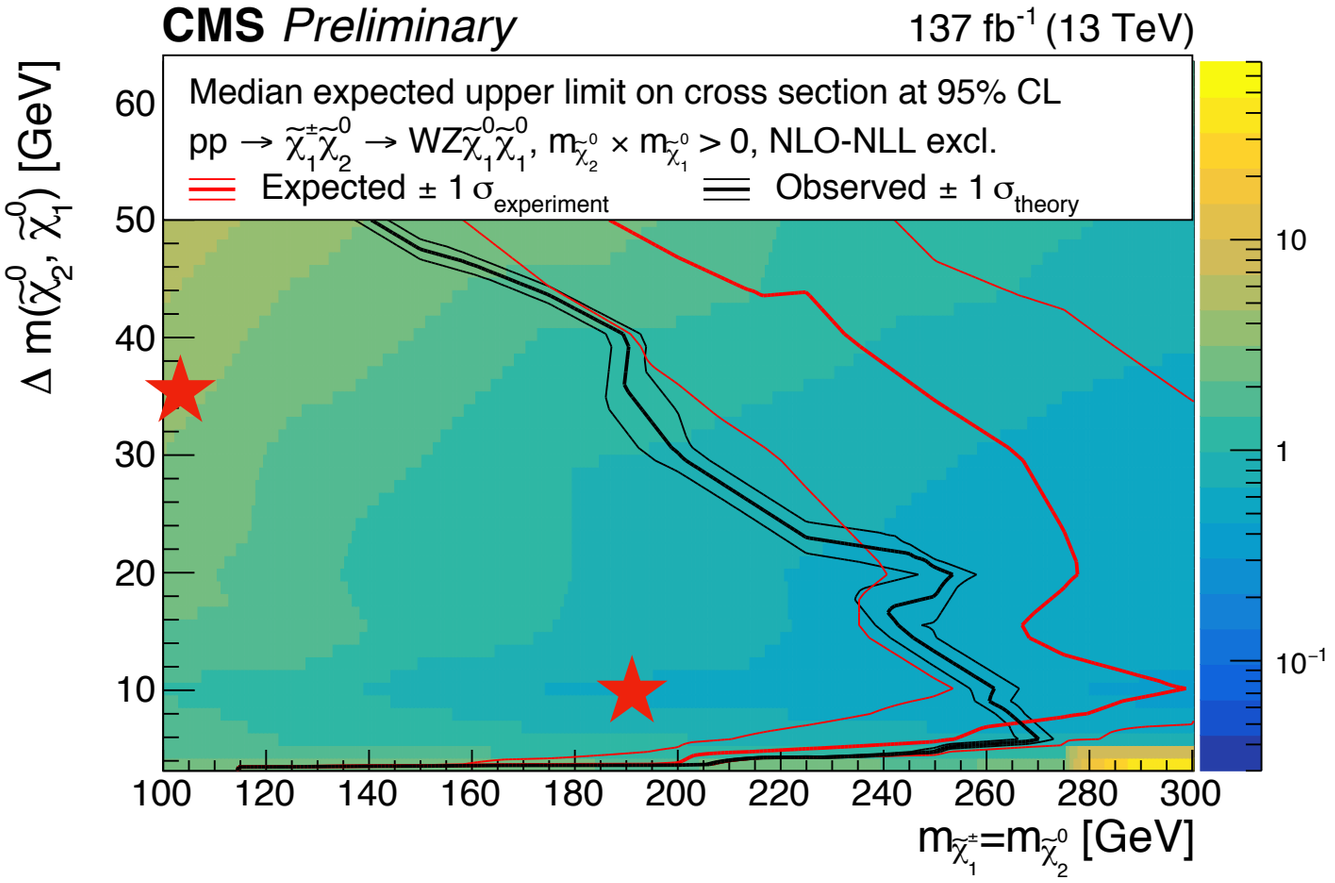
Event selection:

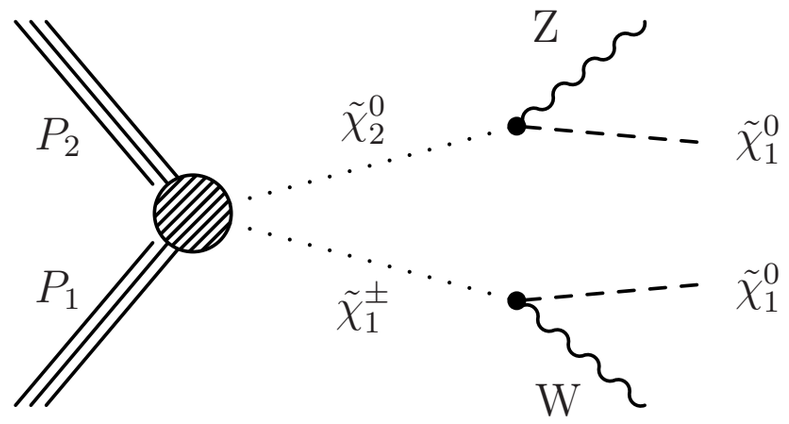
- No $m^{min}_{\ell\ell,SFOS}$ bounds
- No Z veto

- **VV (ZZ/WW)** and **Rare** bkg: estimated from simulation



Wino/Bino Interpretation





Acceptance down to low $m_{\ell\ell}$ - sensitivity down to **Δm~3 GeV**

Major improvements wrt previous analysis (★)

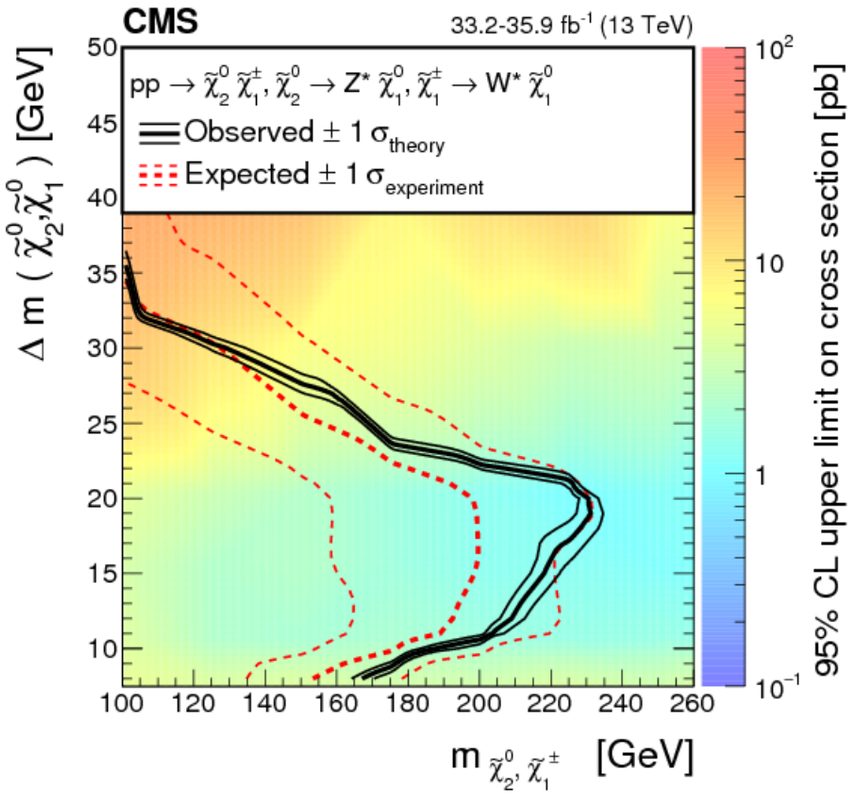
Simplified Wino/Bino model:

- Sensitivity up to $m_{\tilde{\chi}_2^0}$ **~300 GeV @ Δm ~10 GeV**

  $m_{\tilde{\chi}_2^0}$ **~250 GeV @ Δm ~35 GeV**

- Higher Δm complementarity from **3ℓ SR**

2016 result
Wino-Bino Interpretation

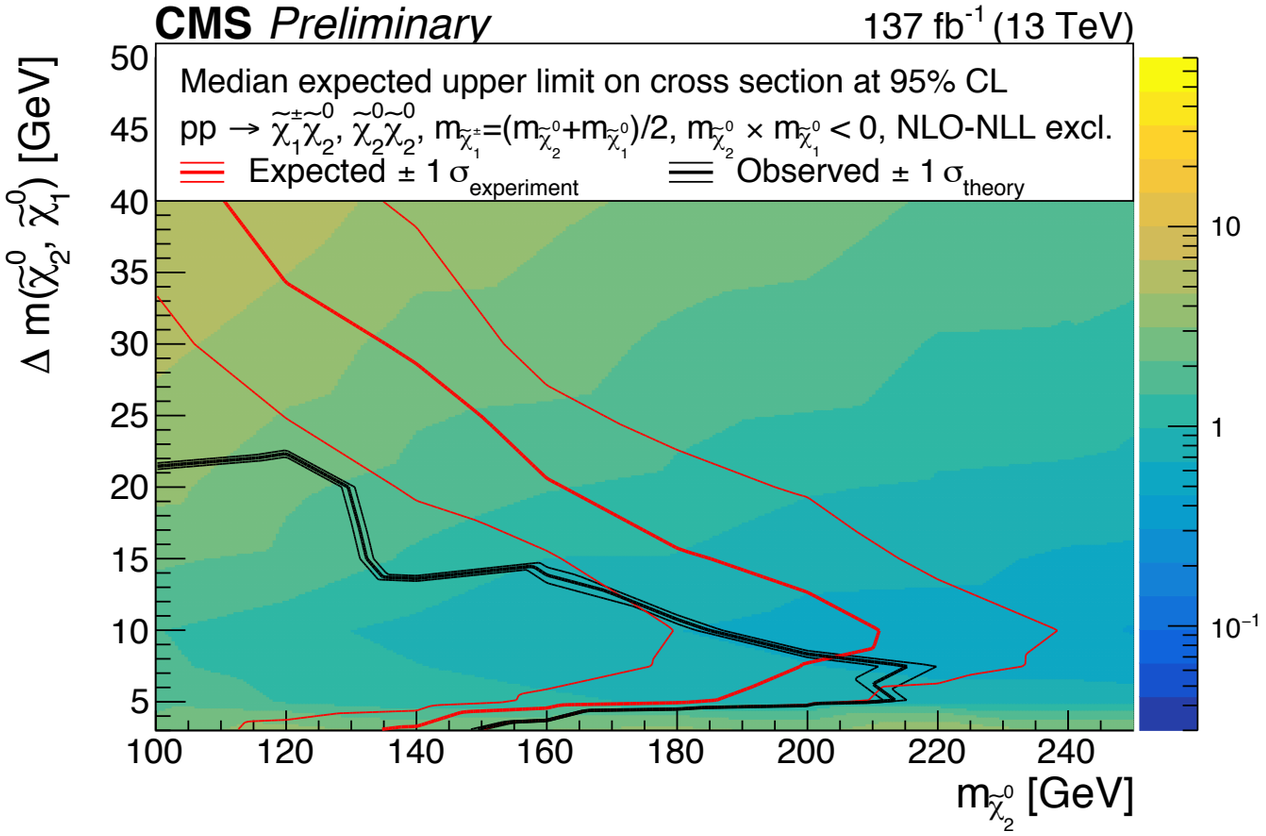


Higgsino Interpretation

$\tilde{\chi}_1^0$ $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ mostly higgsinos

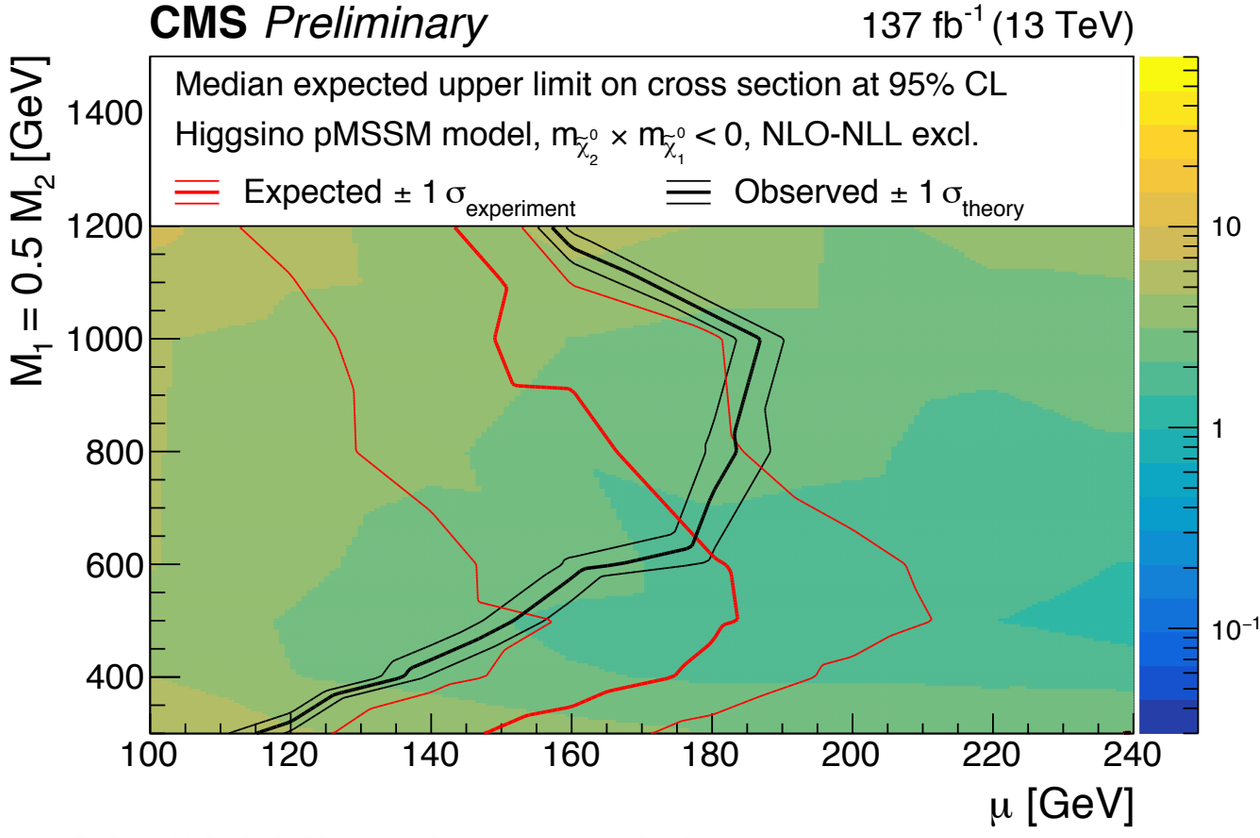
Simplified higgsino

BR=100% &
cross section pure Higgsino



pMSSM higgsino

BR & cross sections varied
according to pMSSM model



Simplified Higgsino model:

- Exclude up to $m_{\tilde{\chi}_2^0}$ **~150 GeV @ Δm ~3 GeV**

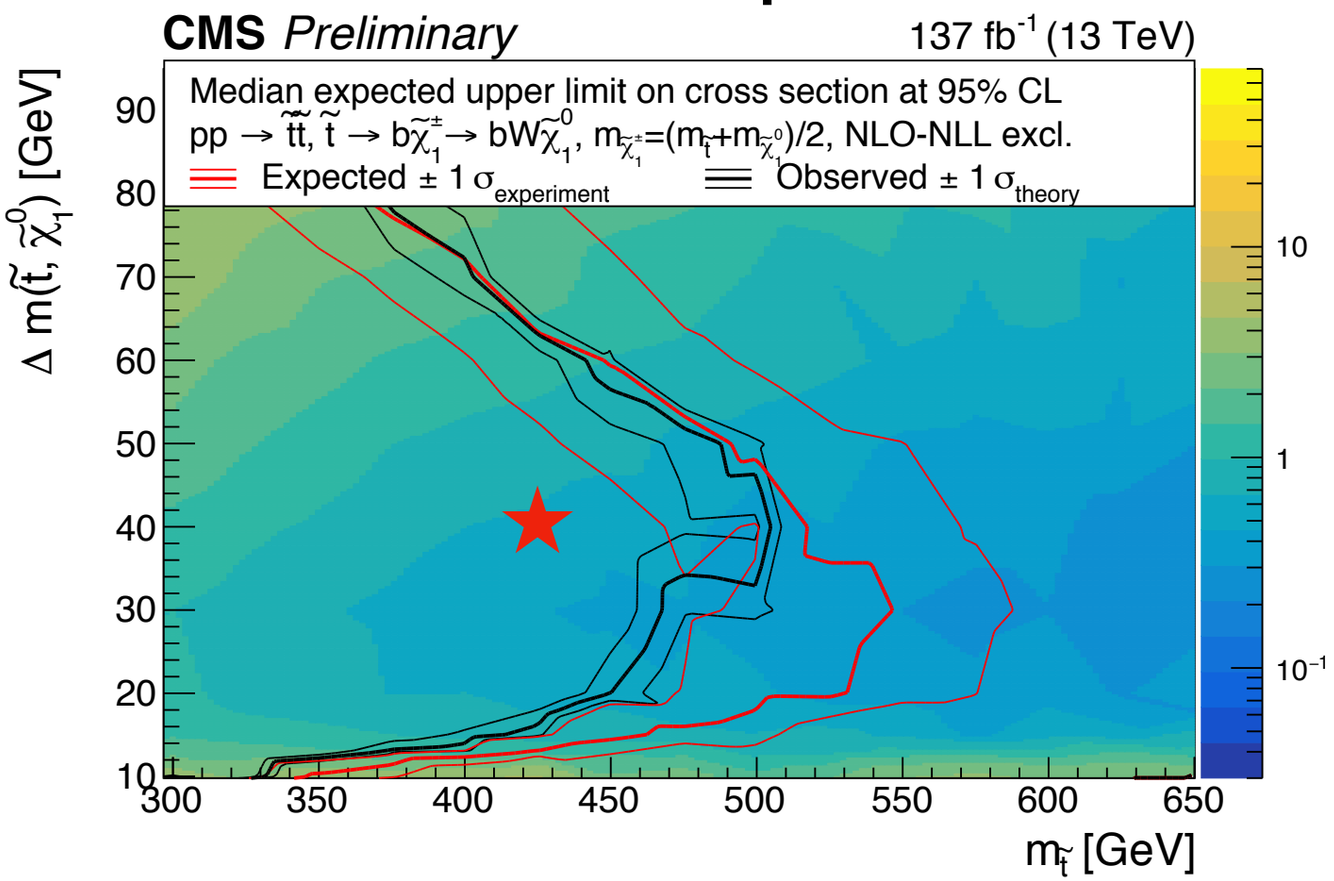
  $m_{\tilde{\chi}_2^0}$**~210 GeV @ Δm ~7 GeV**

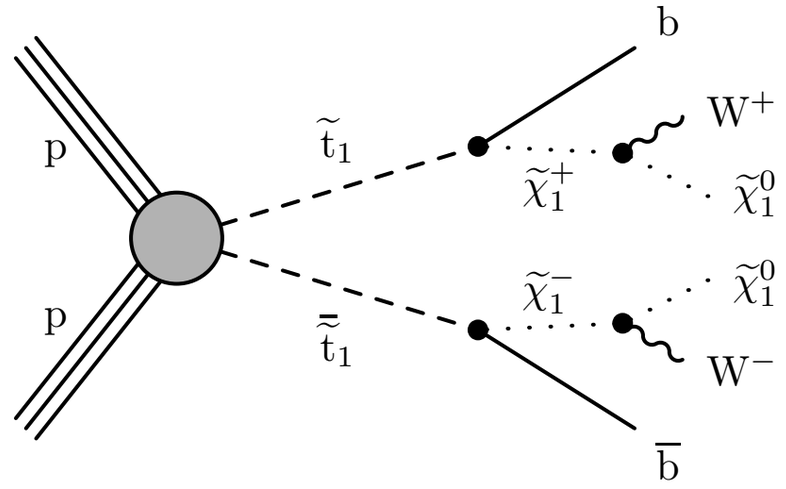
pMSSM Higgsino model:

μ-M1 parameters
Small ΔM(NLSP-LSP) mapped to large M1
Exclude up to **μ ~185 GeV @ M1~1000 GeV**

Stop Interpretations

T2bW simplified





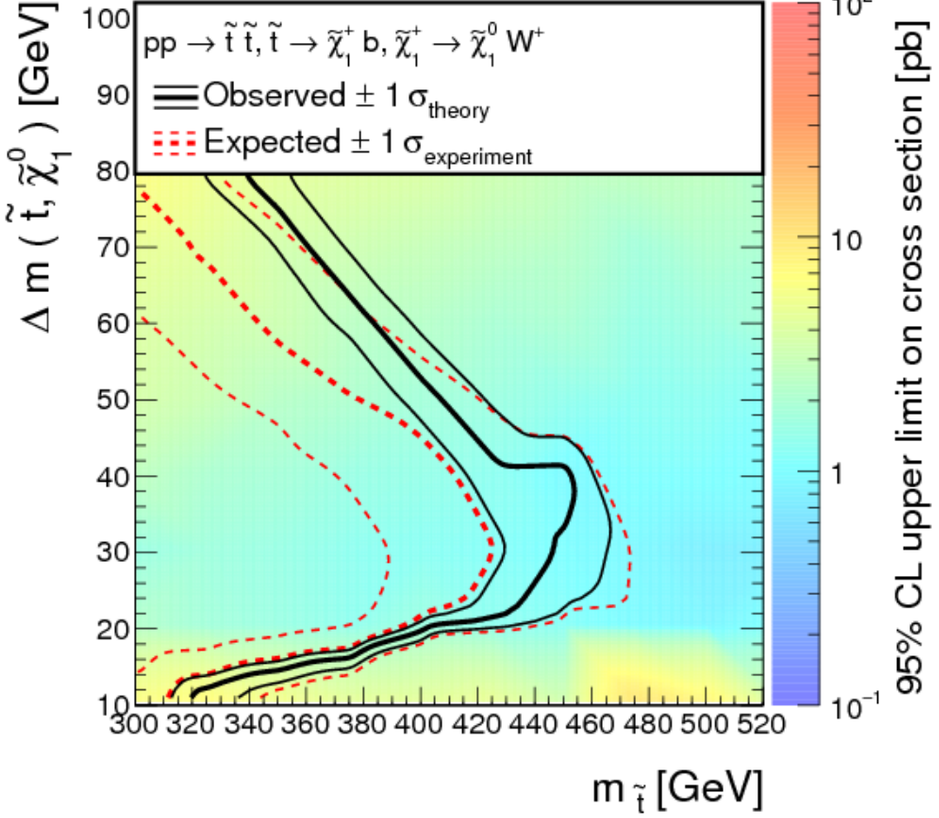
Simplified T2bW model:

- Exclude up to $m_{\tilde{t}}$ **~500 GeV @ Δm = 40 GeV**

Major improvements wrt previous analysis (★)

Similar results for T2bff model

2016 result
T2bW Interpretation



Summary

- Compressed SUSY well motivated by a number of interesting scenarios
- New CMS result on compressed SUSY searches in events with 2 or 3 soft leptons and p_T^{miss} with full Run-2 dataset
  - New approaches to overcome experimental challenges
    - ➡ Extended acceptance to low Δm
    - ➡ Good control of backgrounds
- Upper limits are set on x-sec of Wino/Bino, Higgsino and Stop models
- Great improvement compared to 2016 results
- Cover challenging corner of phase space → Complementary to other CMS searches