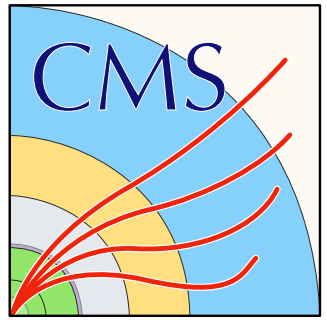
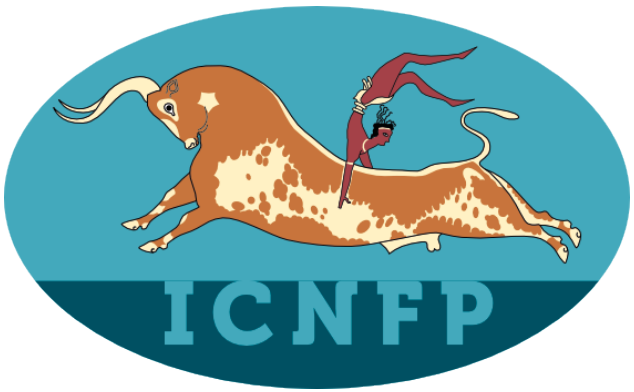
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES



Recent results of SUSY searches at CMS

Danyer Pérez Adán

On behalf of the CMS collaboration



XII International Conference
on New Frontiers in Physics
Kolymbari, Crete (Greece), 11.07.2023

- Generalization of Poincaré algebra
- Creates symmetry between fermions and bosons
- Adds new breaking scale (SUSY) tied to EWK scale

Paradigm

SUSY is a framework

Motivation

Effective extension of SM

- Naturalness & stability
- Gauge coupling unification
- Provides dark matter candidates

- No colourful supersymmetric partners observed so far
- Limits on masses easily beyond 1 TeV in simple scenarios
- No dark matter particle found up to now

Status

From searches at the LHC

Commitment

Continued large efforts in experimental collaborations

SUSY@CMS.LHC

- ~30 public results on SUSY with Run 2 data - wide spectrum
- Exploring intricate & uncovered signatures
- Using novel analysis techniques

· · · In this talk · · ·

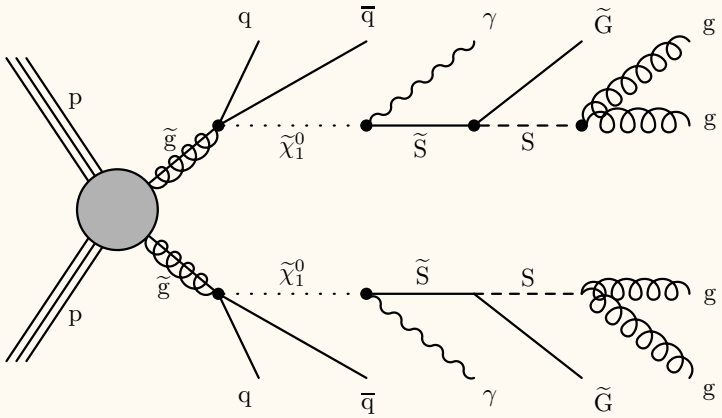
- Stealth SUSY: $2\gamma + \text{jets} + \text{small } p_T^{\text{miss}}$
- SUSY in $\gamma + \text{jets} + p_T^{\text{miss}}$ final sate
- EWKino legacy combination in Run 2
- Disappearing tracks

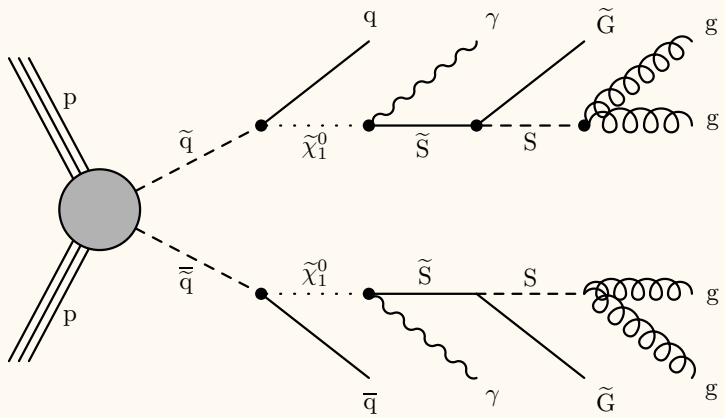
Theoretical Scenario: simplified stealth SUSY model

> Extension of MSSM with a hidden sector: **S** and $\tilde{\mathbf{S}}$

> Weakly coupled to SUSY-breaking sector ($\approx$ SUSY) $\Rightarrow$ *small* mass difference: $\Delta m(S, \tilde{S})$

> Gravitino is LSP and is produced via $\tilde{S} \to S\tilde{G}$: low momentum LSP





Experimental Signature: $2\gamma + \text{jets} + \text{small } p_T^{\text{miss}}$

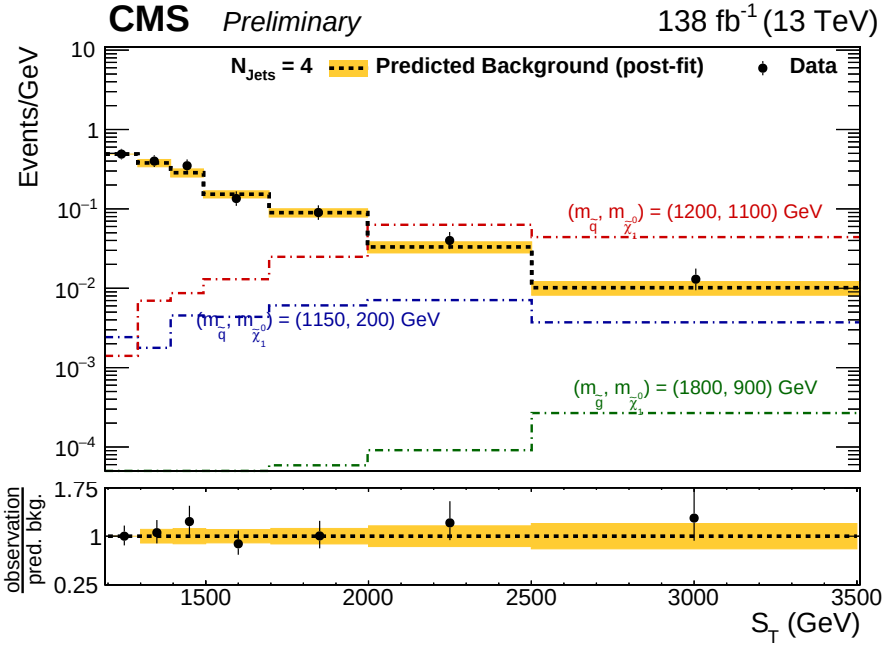
♦ Targets primary interaction through strongly-produced SUSY particles ($\tilde{g}$ or $\tilde{q}$) ♦

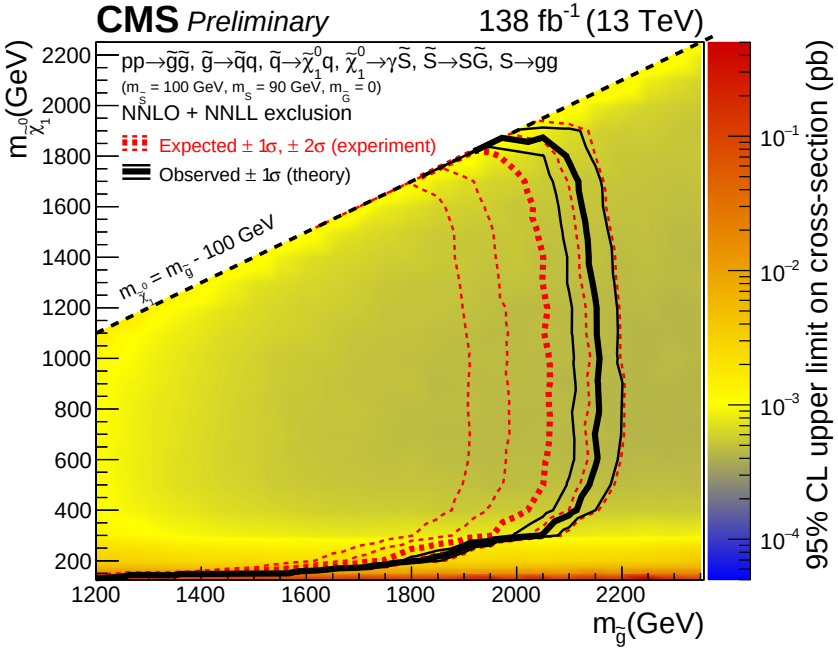
- **multiple jets** produced in decays of $\tilde{g}$ or $\tilde{q}$: $p_T > 30$ GeV & $|\eta| < 2.4$
- **two photons** arising from decays $\tilde{\chi}_1^0 \to \tilde{S}\gamma$: $p_T > 30/25$ GeV & $|\eta| < 1.442$ (triggering)
- **low $\mathbf{p_T^{miss}}$** carried by the soft and light $\tilde{G}$
- **large $\mathbf{S_T}$** $\equiv \sum_{\text{photons}} |\vec{p}_T| + \sum_{\text{jets}} |\vec{p}_T| + |\vec{p}_T^{\text{miss}}|$: $S_T > 1200$ GeV

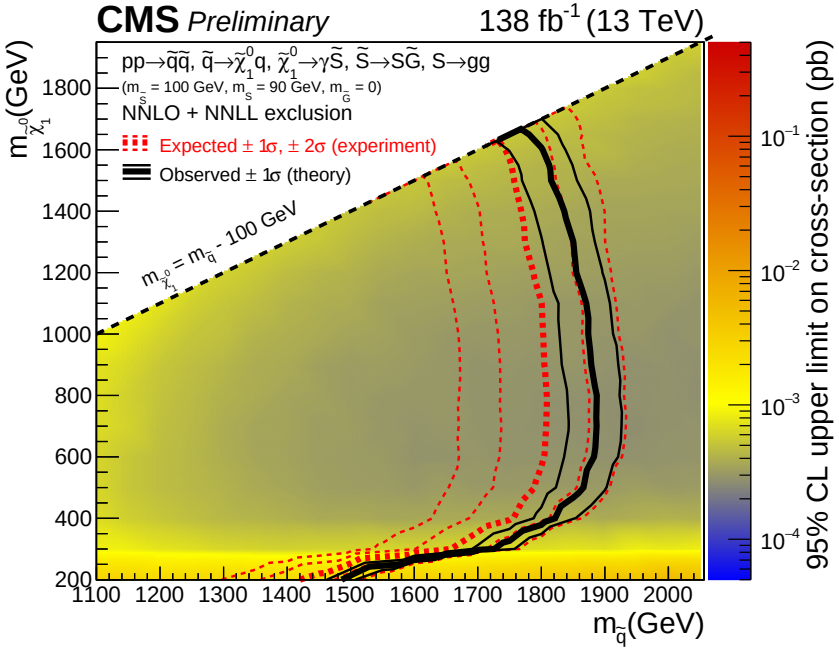
Signal Extraction

- ⋆ fit $\mathbf{S_T}$ distribution (6 bins)
- ⋆ categorization according to $\mathbf{n}_{\text{jets}}$ (3 bins): 4, 5, and > 6 jets
- ⋆ background estimation using data-driven method: $\mathbf{S_T}$ shape predicted from low $\mathbf{n}_{\text{jets}}$ region

No deviation from SM expectation ↦

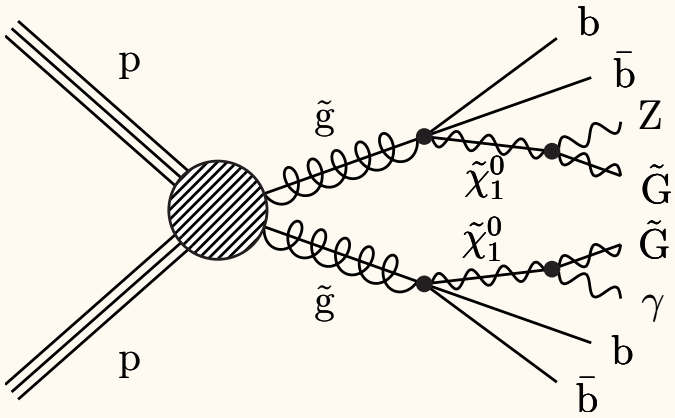


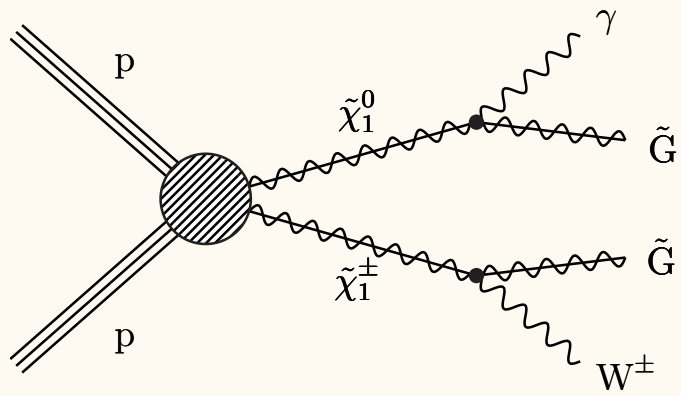




Theoretical Scenario: simplified GMSB models

- LSP is gravitino ⇒ NLSP nature primarily determines signature
  - If NLSP is $\tilde{\chi}_1^0$, decays of the form $\tilde{\chi}_1^0 \to (Z/H/\gamma)\tilde{G}$ occur
  - Similarly for $\tilde{\chi}_1^{\pm}$ co-NLSP (mass degeneracy with $\tilde{\chi}_1^0$), $\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{G}$ decay is relevant



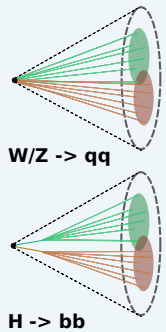


Experimental Signature: photons + jets + p_T^{miss}

♦ Optimized for strong production with dedicated search regions for electroweak modes ♦

$p_{\text{T}}^{\text{miss}}$	> 300 GeV for SRs and $\in [200, 300]$ GeV for CRs
N_{jets} ($p_{\text{T}} > 30$ GeV, $\lvert\eta\rvert < 2.4$)	≥ 2
γ ($p_{\text{T}} > 100$ GeV, $\lvert\eta\rvert < 2.4$)	≥ 1
$S_{\text{T}} = \sum_{\text{jets}} p_{\text{T}} + p_{\text{T}}^{\gamma}$	> 300 GeV
$\Delta\phi(\text{jet}\vec{p}_{\text{T}}, \vec{p}_{\text{T}}^{\text{miss}})$	> 0.3 for 2 highest p_{T} jets
Number of leptons (e, μ)	0
Number of isolated tracks	0

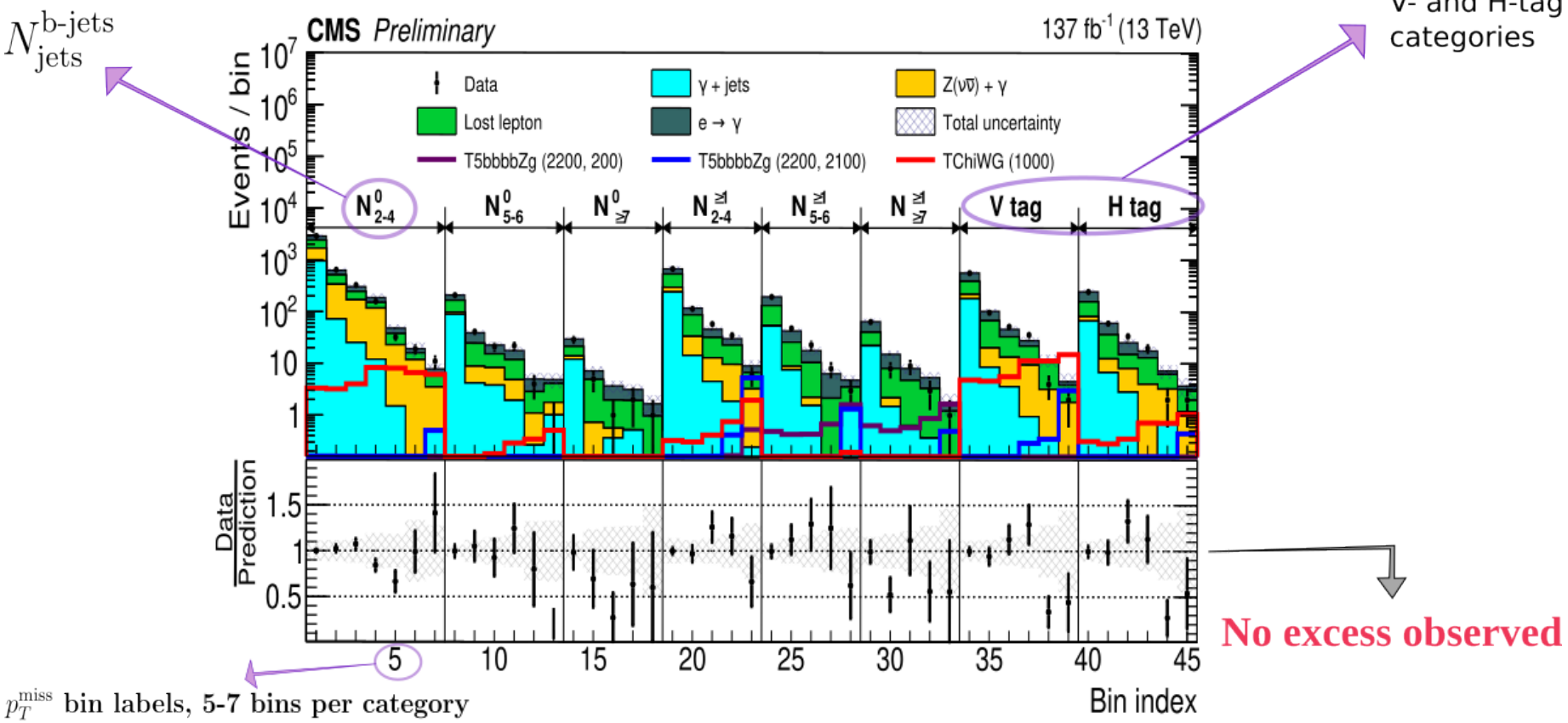
Fat-jet tagging



SM background

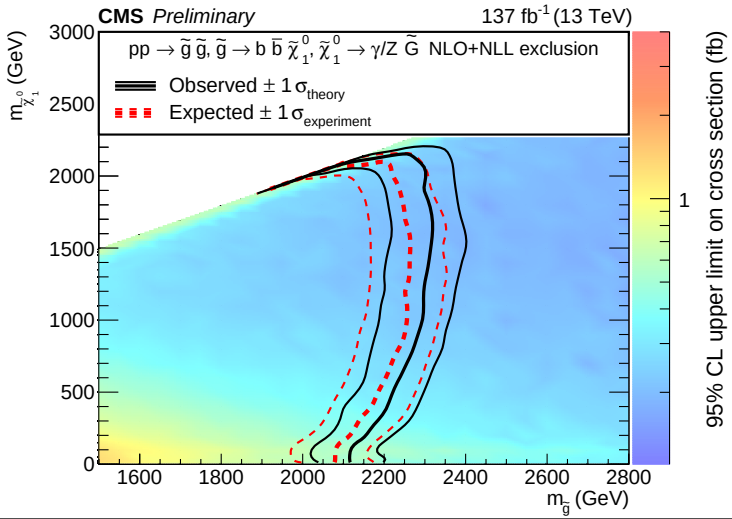
- **'lost lepton'**: $W\gamma$ + jets & $t\bar{t}\gamma$ + jets with lepton not identified
  - estimated using $1l$ control-regions (CRs) via the *transfer factor* method
- **'misidentified e $\rightarrow \gamma$'**: W + jets & $t\bar{t}$ + jets with electron misidentified as photon
  - $e \rightarrow \gamma$ *fake rates* measured in simulation and corrected from data using *tag & probe*
- **$Z(\rightarrow \nu\bar{\nu})\gamma$ + jets**: irreducible background
  - estimated from simulation with additional corrections from $2l$ CR in data
- **γ + jets** and **QCD multi-jets**: p_T^{miss} and jets mismeasurements
  - estimated using $ABCD$ method with p_T^{miss} and $\Delta\phi(\text{jet}\vec{p}_T, \vec{p}_T^{\text{miss}})$ variables

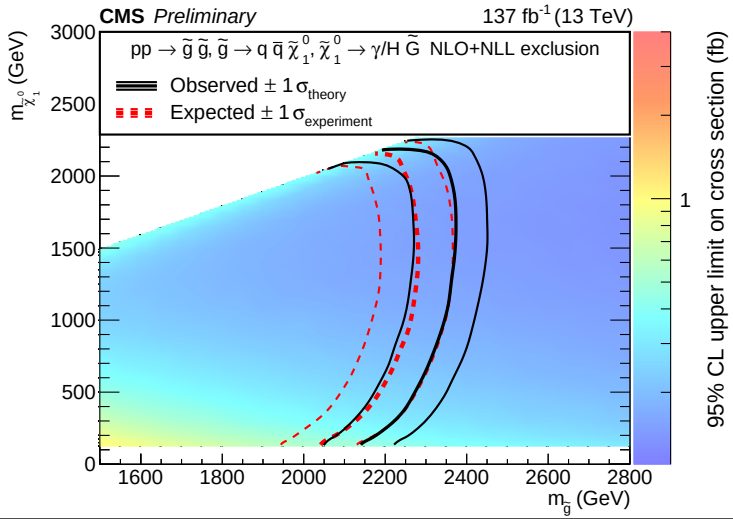
Final Discriminant



Interpretation in the context of various scenarios

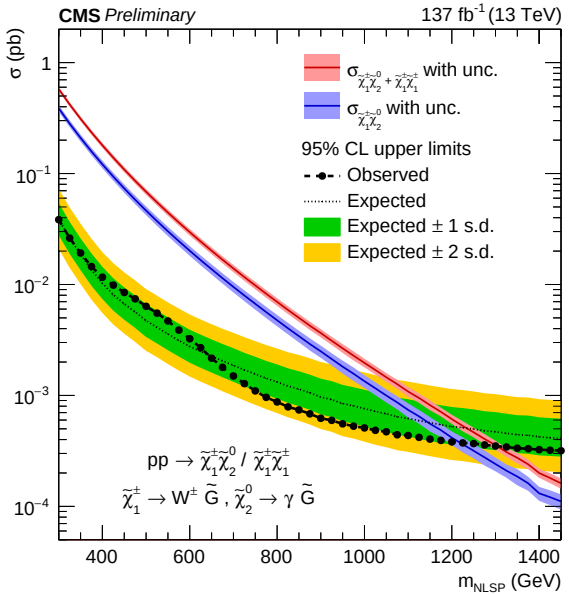
Gluino pair prodution



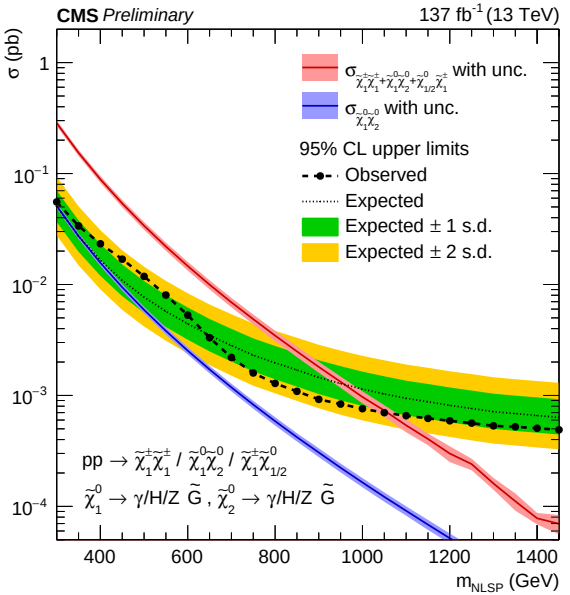


EWKino pair production

Wino-like NLSP



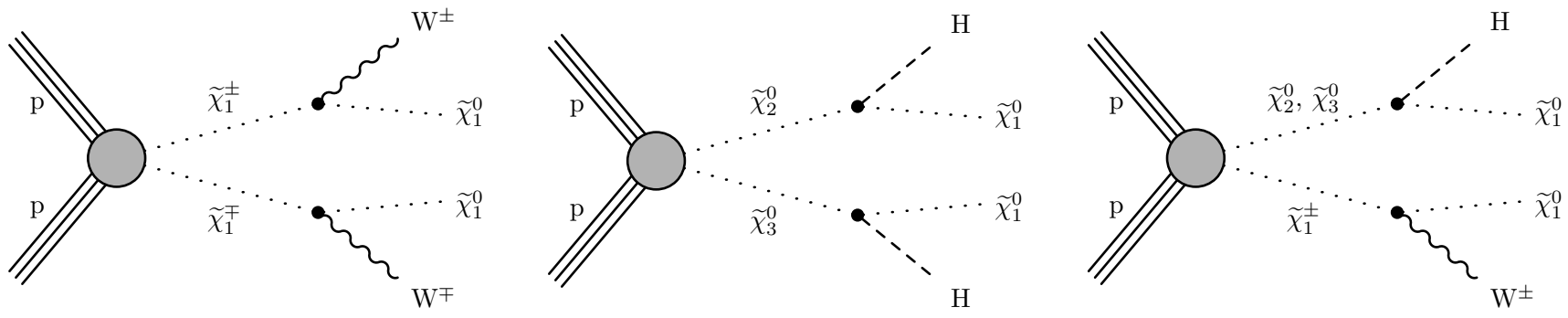
Higgsino-like NLSP



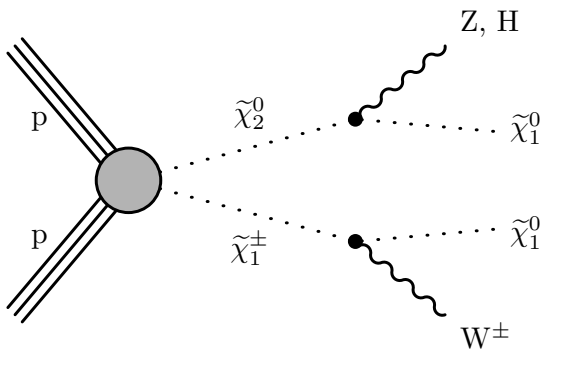
Theoretical Scenarios

- Production/decay of EWKinos, in which **NLSP → LSP X** (**X**=W,Z,H)
- Pair production of sleptons ($\tilde{l}$), in which $\tilde{\mathbf{l}} \rightarrow \mathbf{l}\tilde{\chi}_1^0$

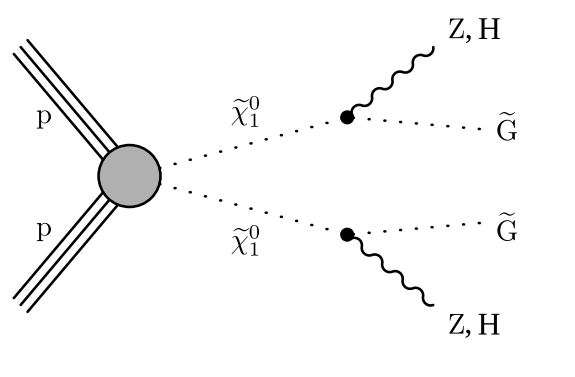
Higgsino-bino model: bino-like LSP and mass-degenerate light higgsinos



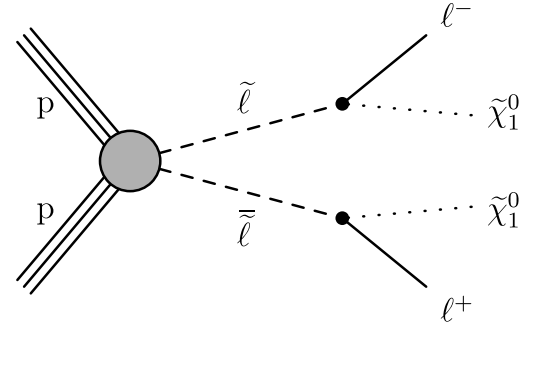
Wino-like and mass-degenerate $\tilde{\chi}_1^{\pm}$ & $\tilde{\chi}_2^0$

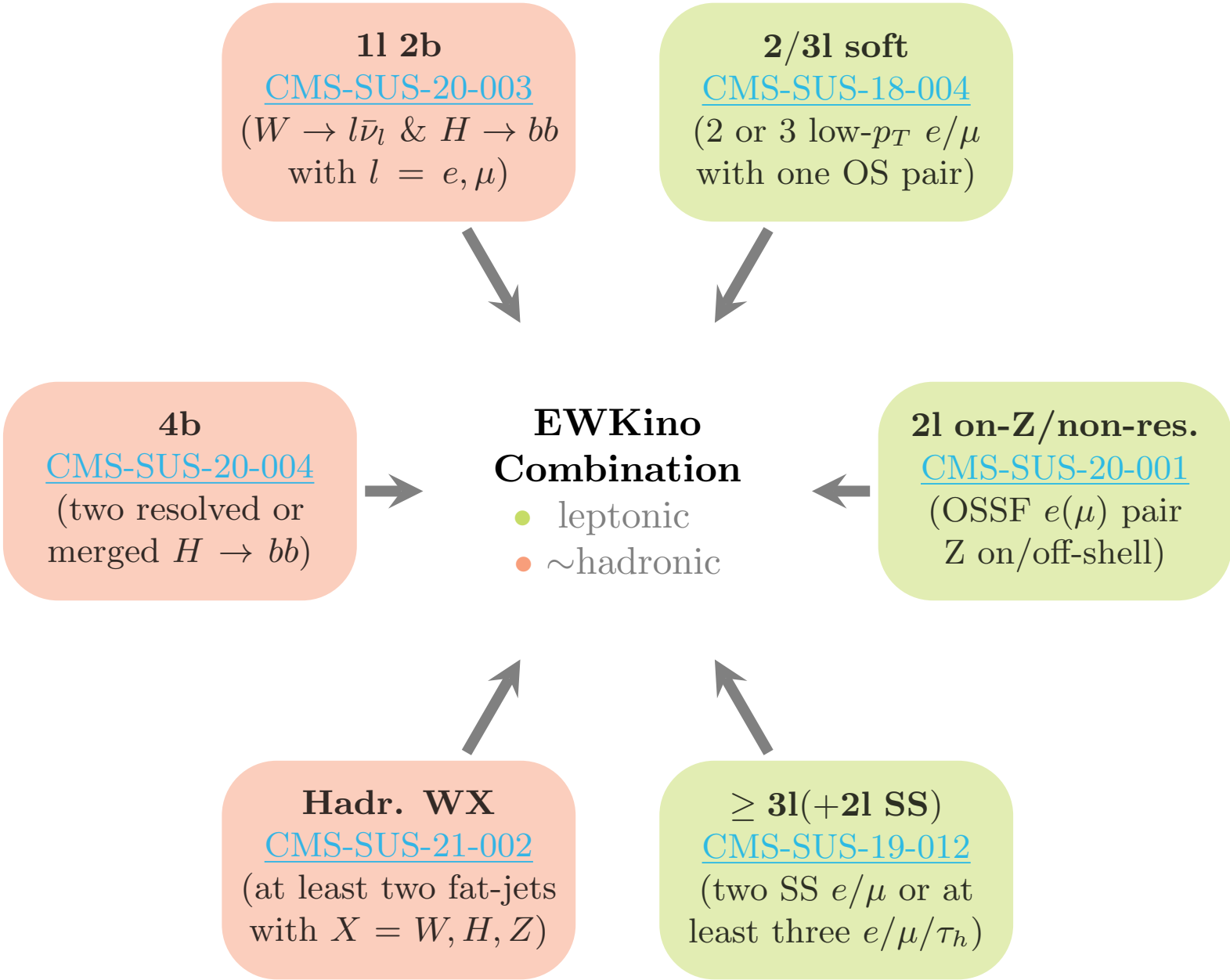


GMSB with quasi-degenerate Higgsinos



Slepton pair production (compressed scenarios)

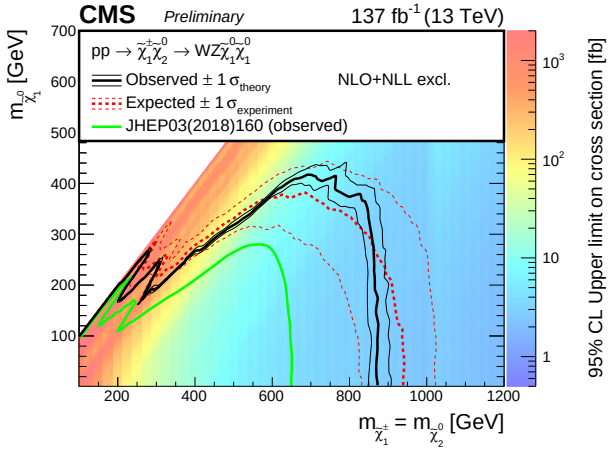


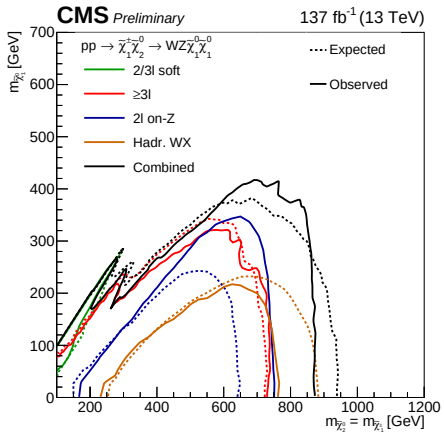

1l 2b
CMS-SUS-20-003
($W \to l\bar{\nu}_l$ & $H \to bb$ with $l = e, \mu$)
2/3l soft
CMS-SUS-18-004
(2 or 3 low-p_T e/μ with one OS pair)
4b
CMS-SUS-20-004
(two resolved or merged $H \to bb$)
EWKino Combination
leptonic
∼hadronic
2l on-Z/non-res.
CMS-SUS-20-001
(OSSF $e(\mu)$ pair Z on/off-shell)
Hadr. WX
CMS-SUS-21-002
(at least two fat-jets with $X = W, H, Z$)
≥ 3l(+2l SS)
CMS-SUS-19-012
(two SS e/μ or at least three $e/\mu/\tau_h$)

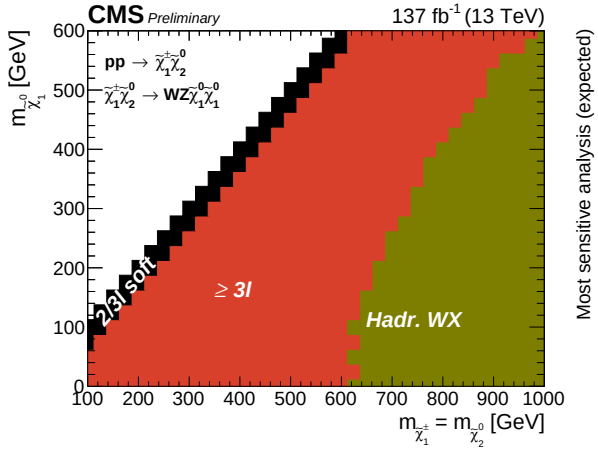
Wino-like chargino and neutralino

Search	**2/3l soft**	**2l** (on-Z)	**2l** (off-Z)	$\geq$ **3l**	**1l 2b**	**4b**	**Hadr. WX**
WZ	✓	✓		✓			✓
WH				✓	✓		✓

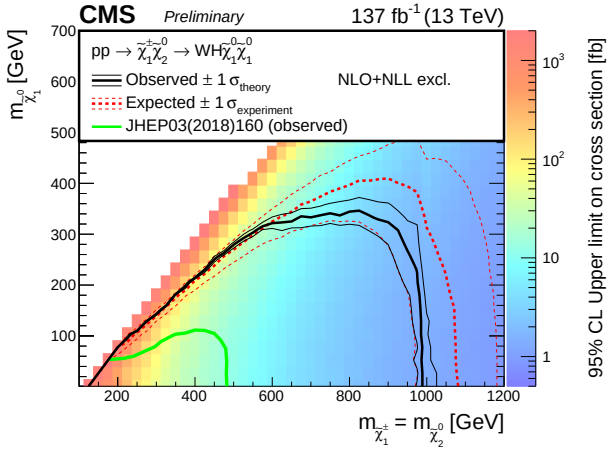
WZ

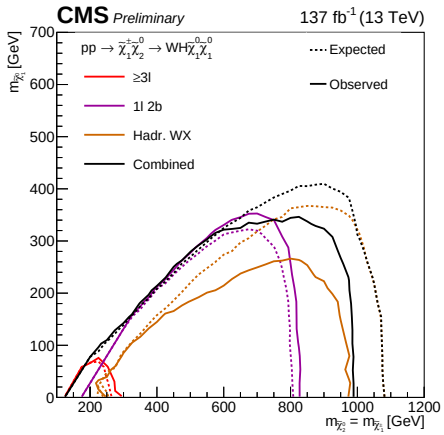


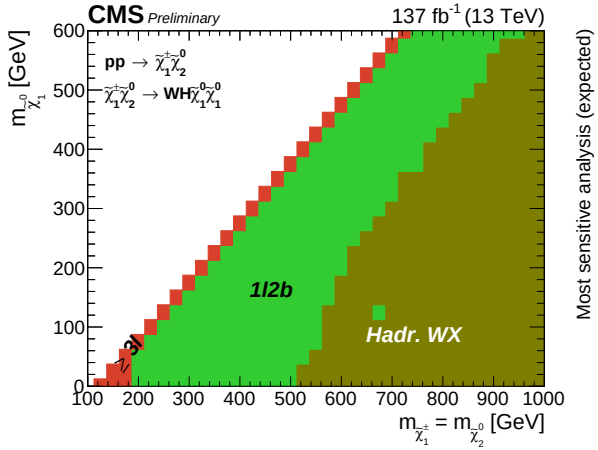




WH



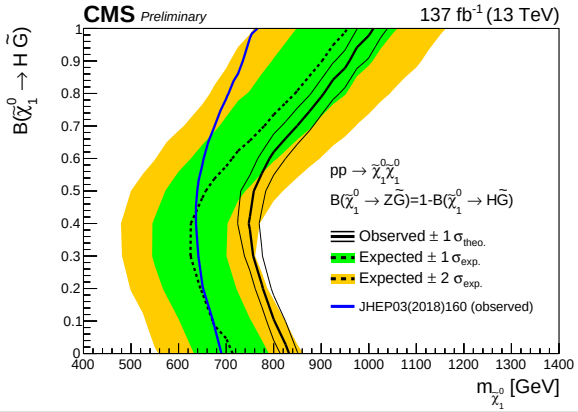


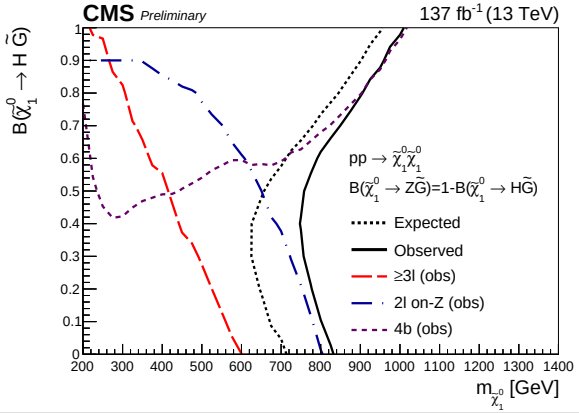


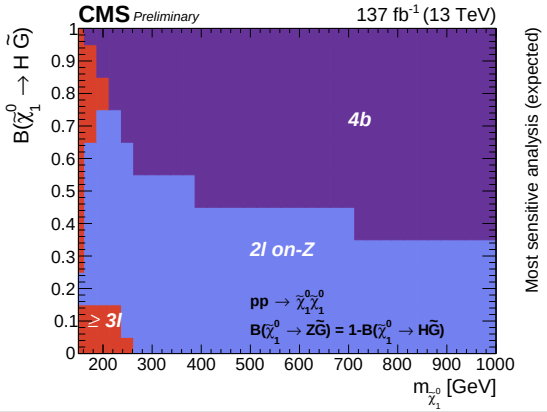
GMSB & Higgsino-bino & Sleptons

Model / Search		**2/3l soft**	**2l** (on-Z)	**2l** (off-Z)	$\geq$ **3l**	**1l 2b**	**4b**	**Hadr. WX**
GMSB	ZZ		✓		✓			
	HZ		✓		✓			
	HH				✓		✓	
Higgsino-bino	WW							✓
	HH						✓	
	WH				✓	✓		✓
Sleptons	l^+l^-	✓		✓				

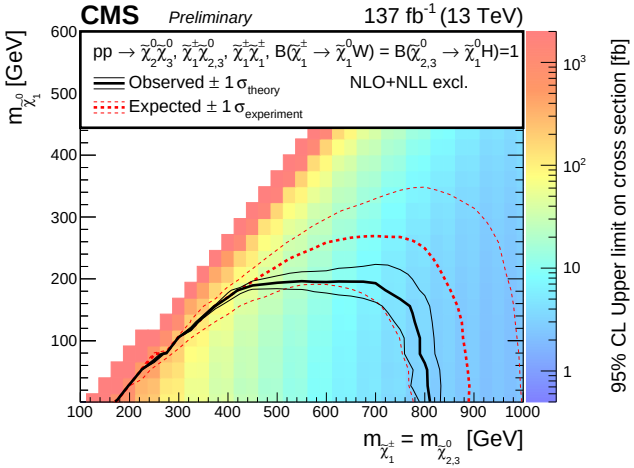
GMSB



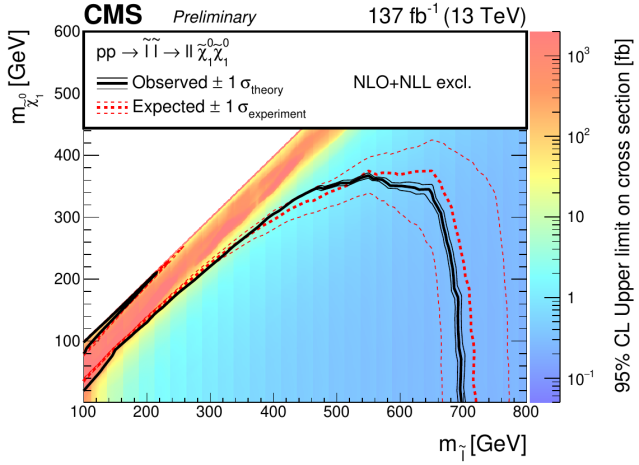




Higgsino-bino

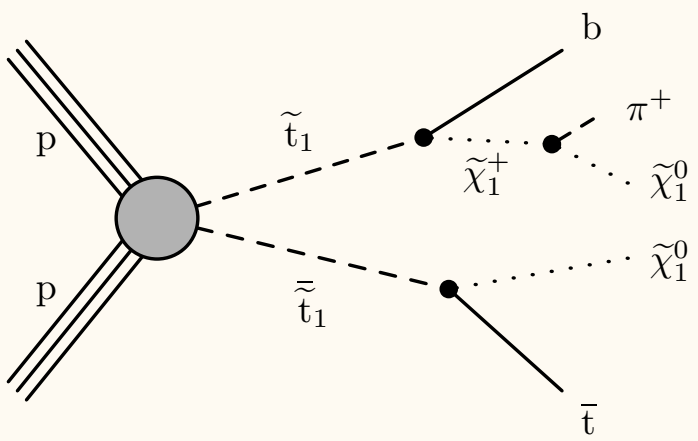


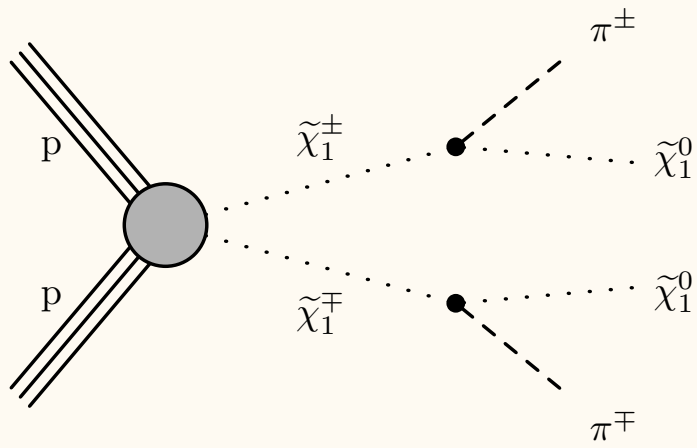
Sleptons



Theoretical Scenario: Nearly mass-degenerate chargino and LSP

- Wino-like LSP in AMSB or light LSP higgsino in generic models
- Small mass-splitting $\sim \mathcal{O}(100\text{MeV})$ between chargino and LSP $\Rightarrow$ *long-lived* chargino
- Primary decay via $\tilde{\chi}_1^{\pm} \to \tilde{\chi}_1^0 \pi^{\pm}$ with *soft* pion: initial track disappears

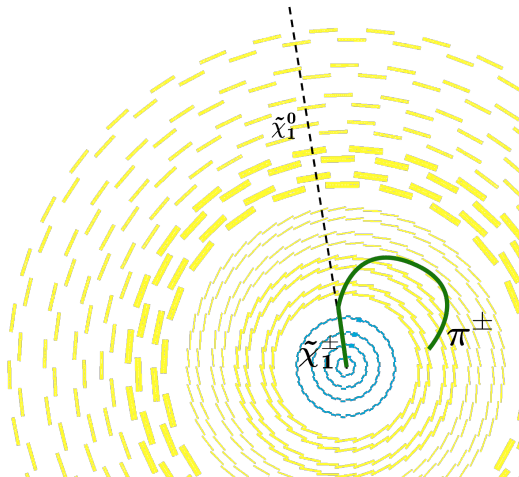




Experimental Signature: disappearing tracks (DTks)

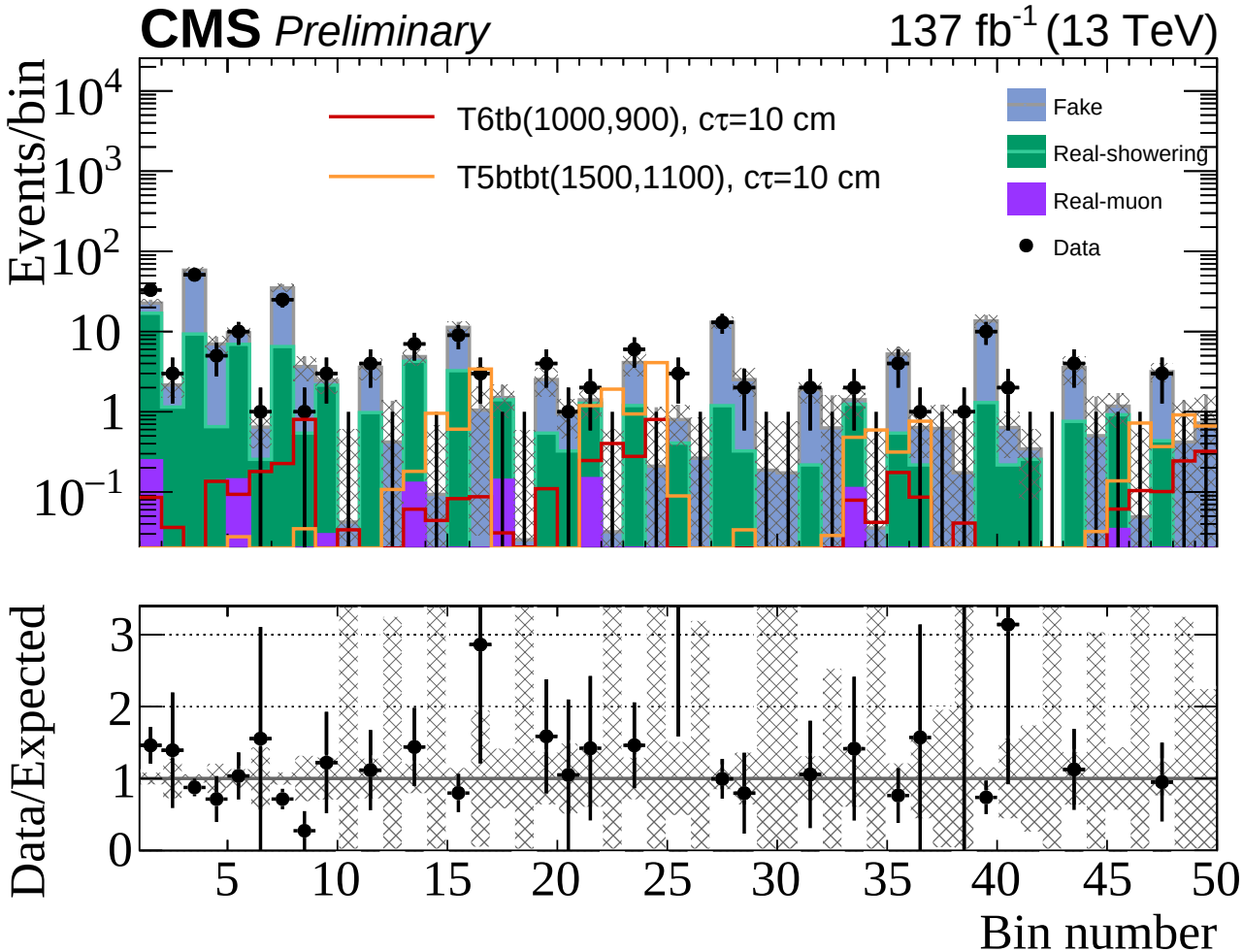
♦ Suitable for many production and decay modes ♦

- **At least one DTk**
  - two track classifications
    - short track: hits only in Pixel and $p_T > 25$ GeV
    - long track: hits in both Pixel & Strips and $p_T > 40$ GeV
  - BDT classifiers trained for both *short* and *long* tracks to improve purity of DTks
  - Small energy deposits in the calorimeters

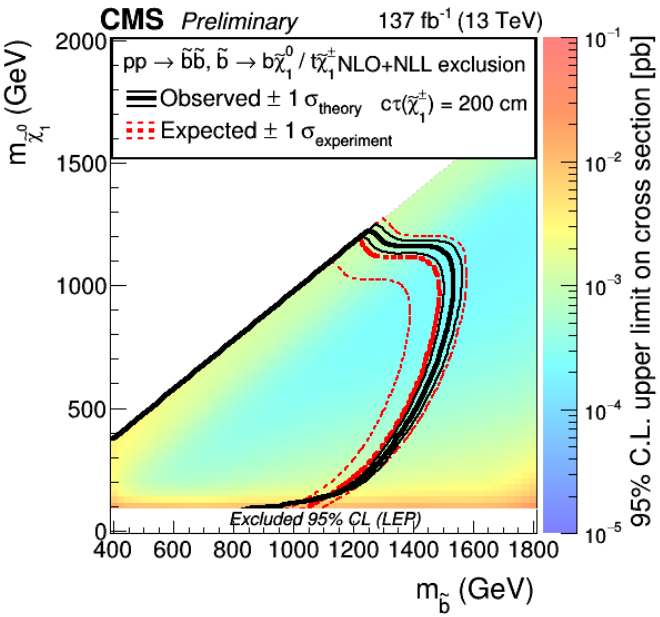


- Four search channels: **hadronic + DTk**, **e + DTk**, μ **+ DTk**, and $\geq$ **2 DTks**
- 49 SRs defined according: $\mathbf{n_{jet}}$, $\mathbf{n_{b\text{-}jet}}$, $\mathbf{n_{short}}$, $\mathbf{n_{long}}$, **hard** $\mathbf{p_T^{miss}}$, and **dE/dx**
- Background mostly originated by *instrumental* effects
  - misreconstruction of charged particles
  - coincidental alignment of hits from different tracks
  - estimated using data-driven method targeting *fake* and *prompt* track backgrounds

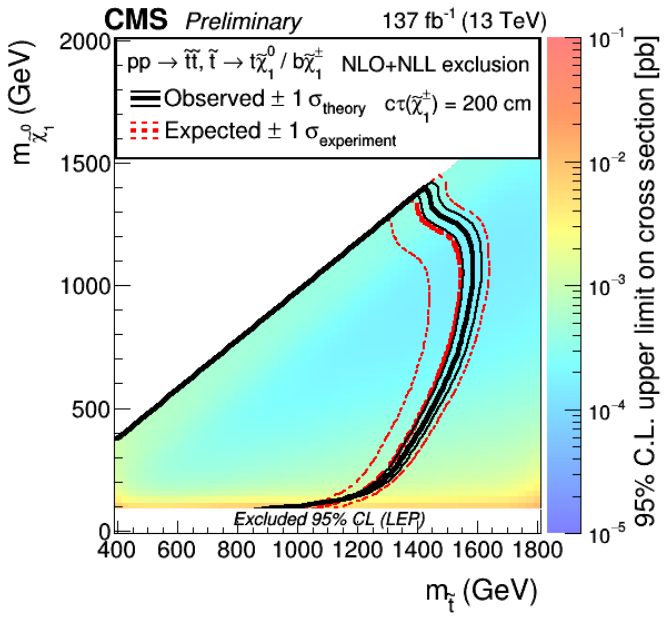
No sign of DTks observed



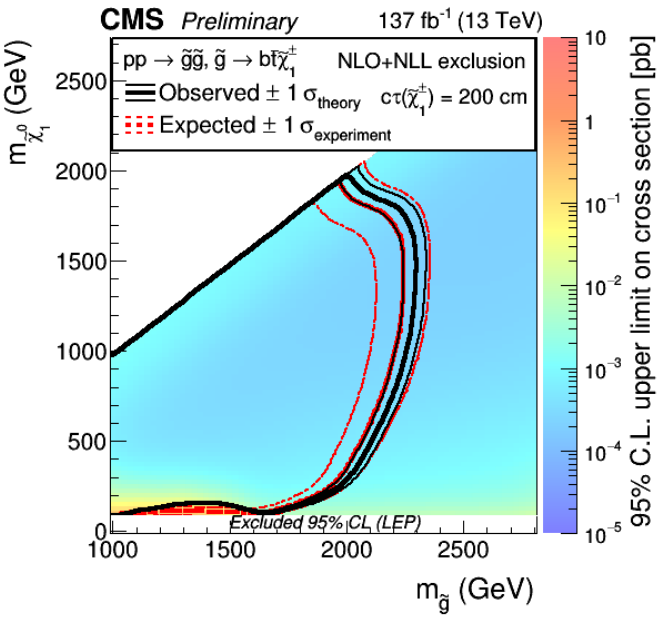
Sbottom-pair (T6tbLL)



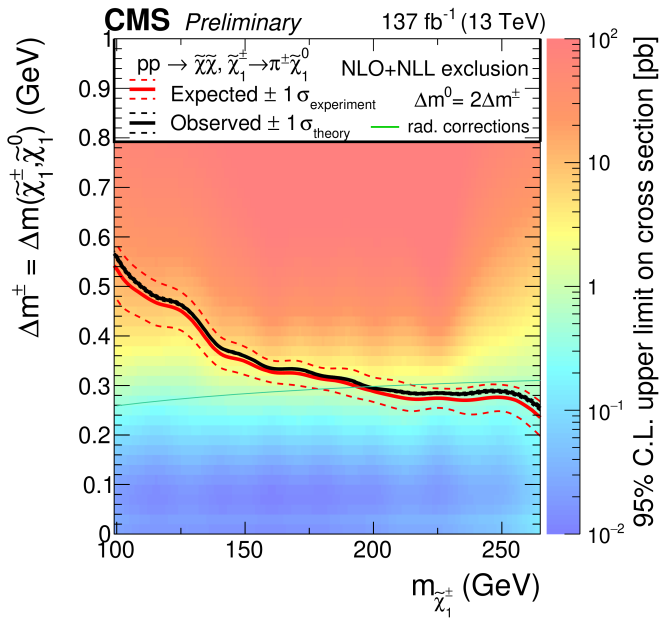
Stop-pair (T6btLL)



Gluino-pair (T5btbtLL)



Pure-higgsino DM



- Large variety of interesting and challenging SUSY signatures being covered by CMS
  - Targeting multiple final states and optimized for various production modes
  - Exploiting advanced multivariate techniques and sophisticated reconstruction algorithms
- Presented the *four* most recent SUSY results at CMS
  - Search for stealth SUSY sets *most stringent limits* on gluinos (squarks) masses for this kind of model
  - Dedicated search in $\gamma + \text{jets} + p_T^{\text{miss}}$ final state can set solid constraints on both electroweak and strong production of SUSY particles
  - *Six* searches combined in legacy EWKino combination for Run 2 $\rightarrow$ can set limits on a variety of simplified models
  - Novel search for *disappearing tracks* can probe many possibilities with long-lived particles
- **No sign of SUSY observed yet**, but exploration continues

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Thanks for your attention!