Searches for Supersymmetry with compressed scenarios

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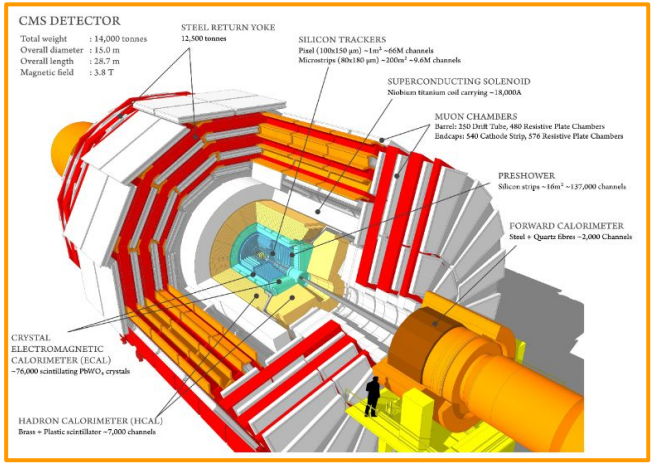
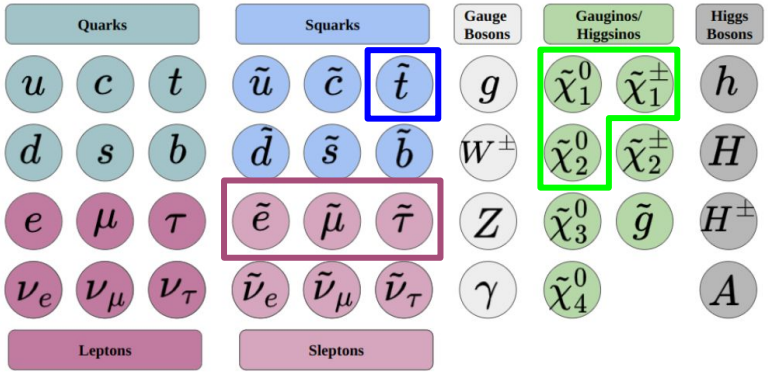
Introduction

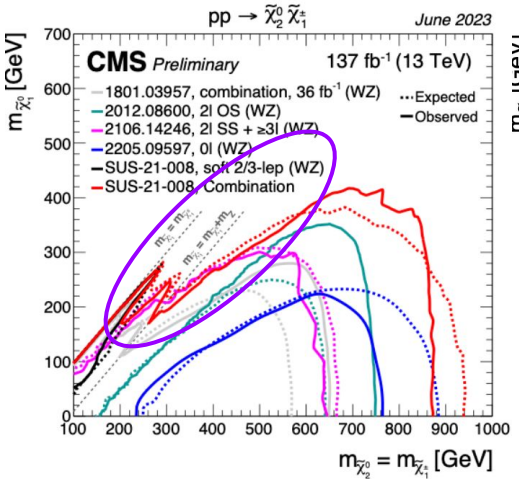
- Searching for new super symmetric particles produced in p-p collisions with CMS at the LHC
- The presented searches will use the full Run 2 dataset corresponding to 138 fb^{-1} at 13 TeV
- Targeting final states in compressed scenarios that include:
  - Top squarks
  - Electroweak-inos
  - Sleptons
- Ewk-inos are a mixture of gauge eigenstates – Wino/Bino/Higgsino

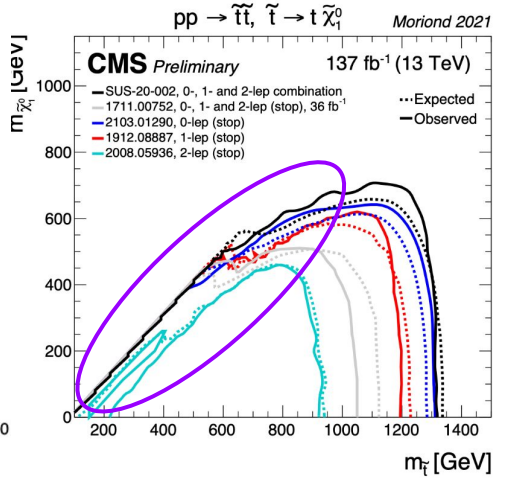


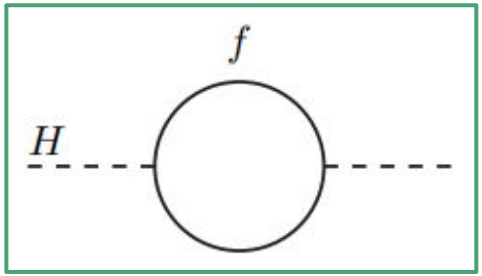


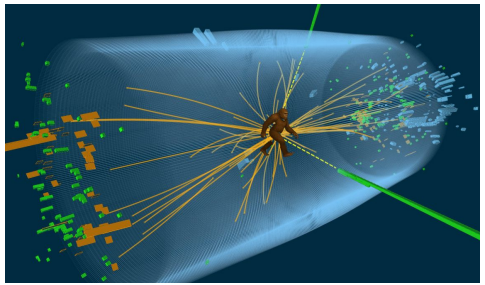
Why Compressed SUSY?

- SUSY is generally well motivated by providing dark matter candidate
  - For these analyses it will be the $\tilde{\chi}_1^0$ which is massive, stable, and invisible
- SUSY also solves the hierarchy problem – superpartners create cancellations to stabilize the Higgs mass
- Many non compressed SUSY SMS limits up to a 1-2 TeV
- SUSY is valid up to several TeV, compressed limits << TeV





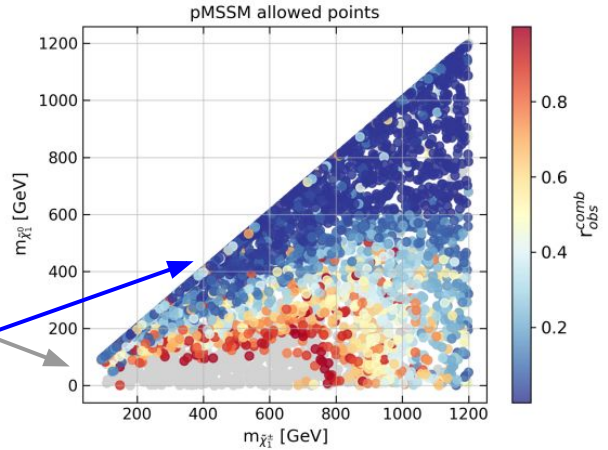


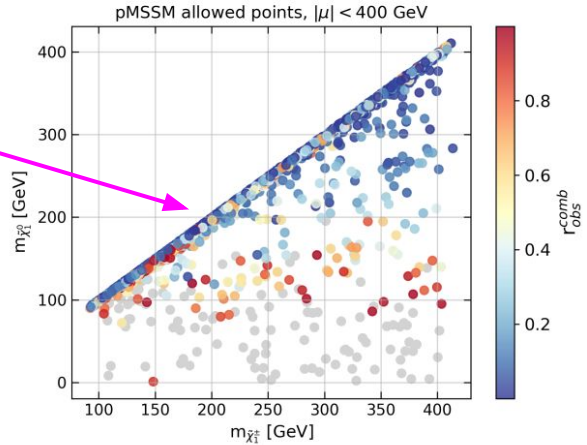


Why Compressed SUSY?

2505.11251

- Here are pMSSM scans with the chargino and N1
- **r < 1 chargino ruled out** by experiment
- **High density of compressed models** along the diagonal
- Avoid fine-tuning and enforce naturalness to get **compressed higgsinos**
- Wino/Bino are optimistic couplings/cross-sections and higgsinos are pessimistic (factor of 4 less x-sec)



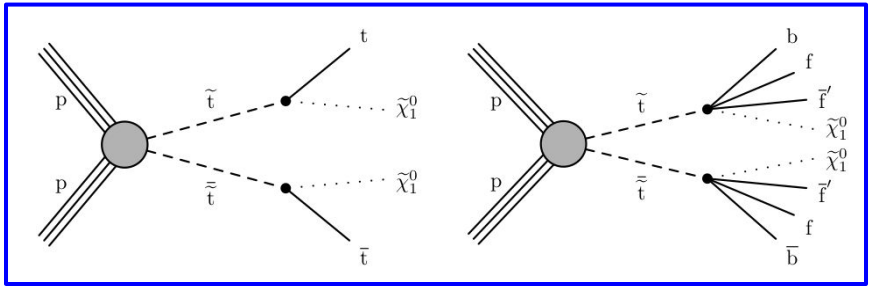


What Is Compressed?

Compressed can mean different things in different final states

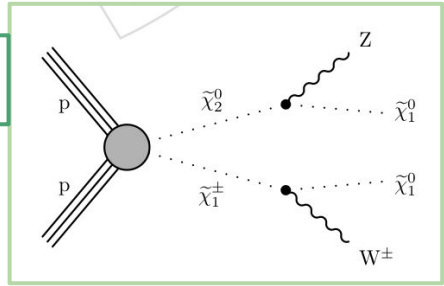
- Top squark

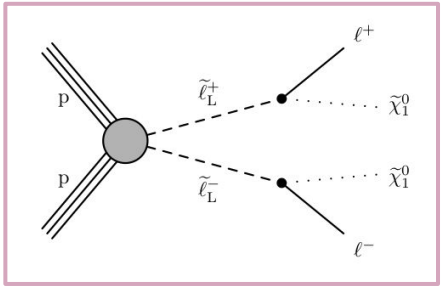
$\Delta m(\tilde{t}, \tilde{\chi}_1^0) < m_t$ $\Delta m(\tilde{t}, \tilde{\chi}_1^0) < m_W$



- Electroweak-inos

$\Delta m(\tilde{\chi}_1^\pm, \tilde{\chi}_1^0) < m_W$ $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0) < m_Z$



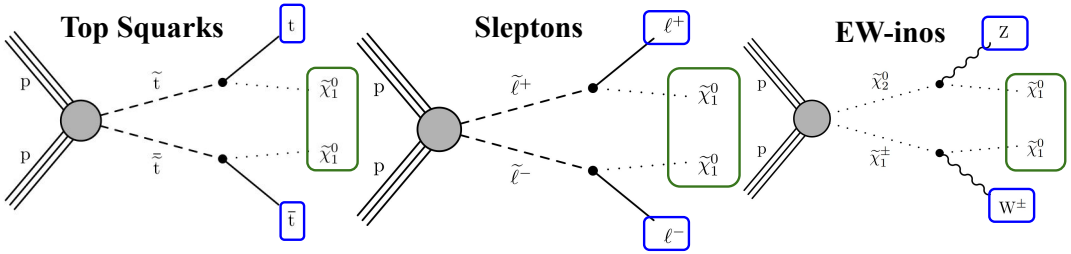


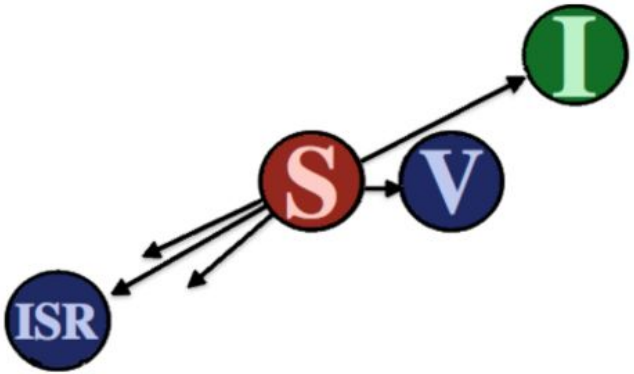
- Sleptons

$\Delta m(\tilde{\ell}, \tilde{\chi}_1^0) \sim$ soft

The Compressed Search Strategy

- Soft SUSY searches are hard due to the soft visible components and overwhelming backgrounds
- We use an ISR-assisted strategy and look for **large missing energy recoiling against ISR**
- **Jets + MET + Soft Objs.** will be the common theme of what is presented here





Searches Overview

- Presenting results from the CMS experiment a for supersymmetry searches targeting compressed spectra – small mass splittings between the different supersymmetric partners.

More compressed

SUS-23-003

A general search for supersymmetric particles in scenarios with compressed mass spectra using proton-proton collisions at $\sqrt{s} = 13$ TeV

EXO-23-017

Search for new physics with compressed mass spectra in final states with soft leptons and missing transverse energy in proton-proton collisions at $\sqrt{s} = 13$ TeV

SUS-24-003

Search for Higgsinos in final states with low-momentum lepton-track pairs at 13 TeV

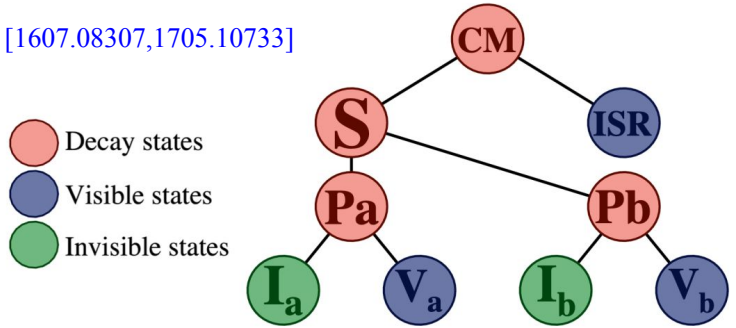
SUS-24-012

Search for compressed electroweakinos with low-momentum isolated tracks

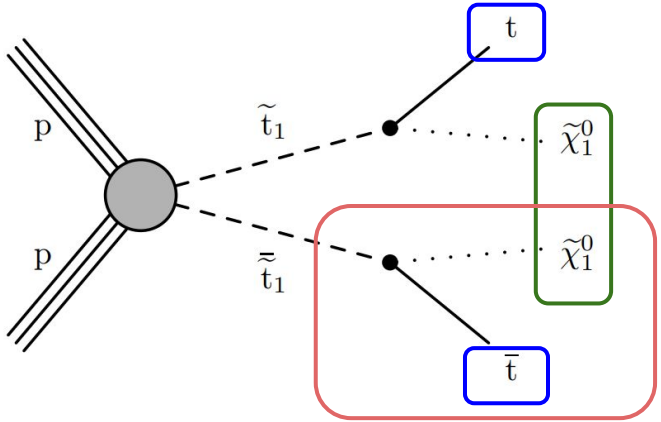
RJR General Search for Compressed SUSY

To conduct a general search we employ Recursive Jigsaw Reconstruction (RJR)

[1607.08307,1705.10733]



1. Impose a decay tree to interpret the event
   - Expect R-parity conserving sparticle pair production ⇒ Pa, Pb
2. Use RJR rules (e.g. minimize mass) to do assign objects to the decay tree and partition **ptmiss**
3. Approximate decay tree rest frames to construct mass-sensitive observables

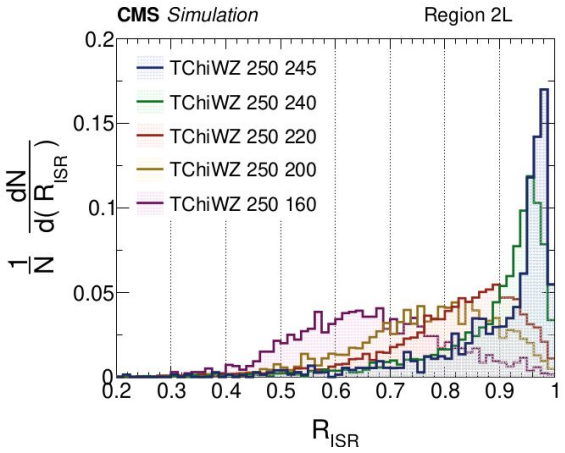


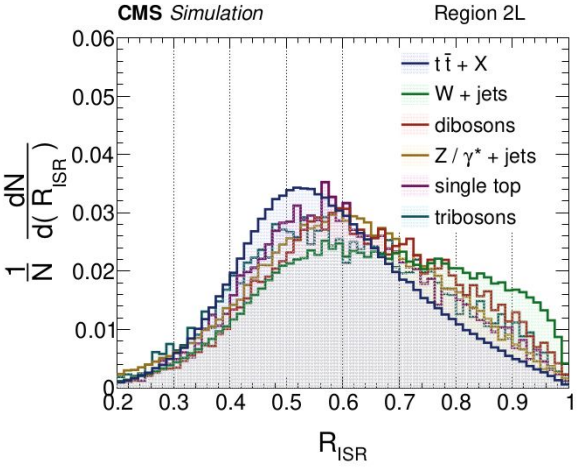
RJR General Search for Compressed SUSY

- For a general search we define the most important kinematic observable: RISR

$$R_{\mathrm{ISR}} \equiv \frac{\vec{p}_{\mathrm{I}}^{\,\mathrm{CM}} \cdot \hat{p}_{\mathrm{ISR}}^{\,\mathrm{CM}}}{p_{\mathrm{ISR}}^{\mathrm{CM}}} \sim \frac{m_{\tilde{\chi}}}{m_{\tilde{P}}}$$

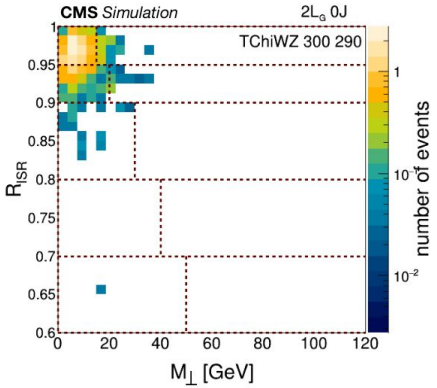
- Peaks at the ratio of mother to LSP mass
- Signal final state/ process independent and very sensitive to mass splitting

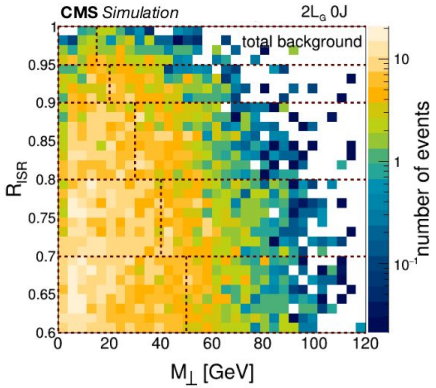


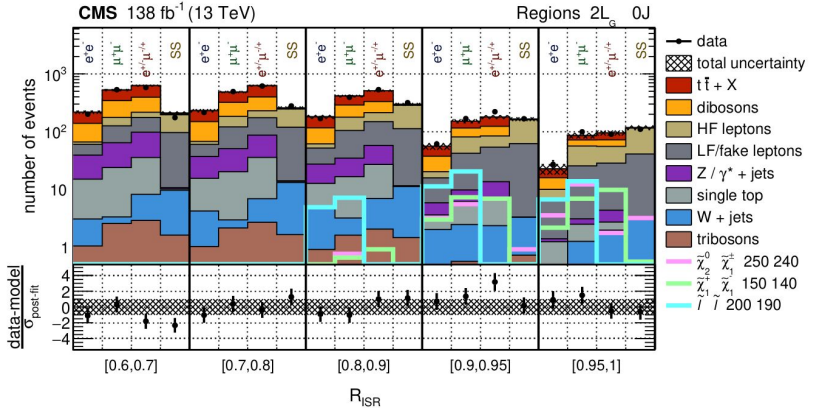


RJR General Search for Compressed SUSY

- Perform a 2D bump hunt over RISR and Mperp (an RJR mass symmetry observable)
- Spans 0L,1L,2L,3L final states
- Categories in Nlep+Njets with finer breakdown in object counting and other complementary kinematic observables
- Simultaneous SR+CR data-driven fit to all ~390 categories and ~2000 bins

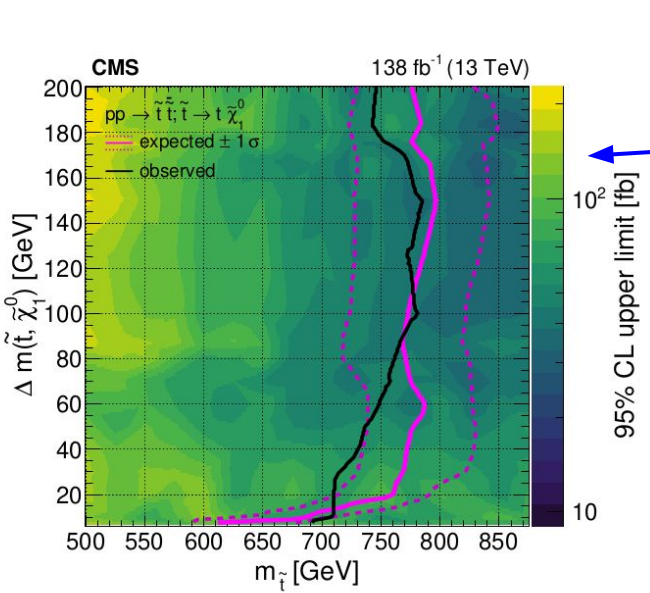


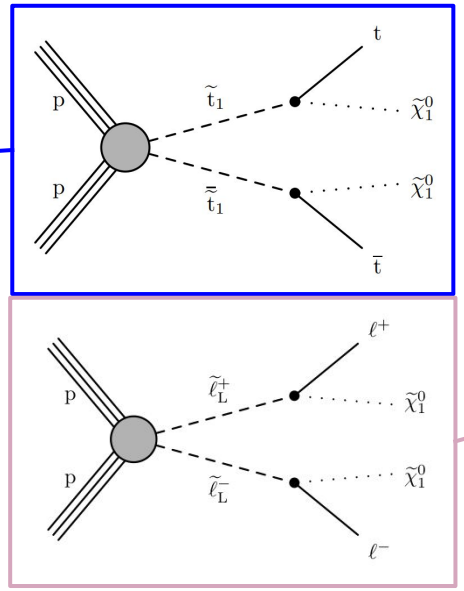


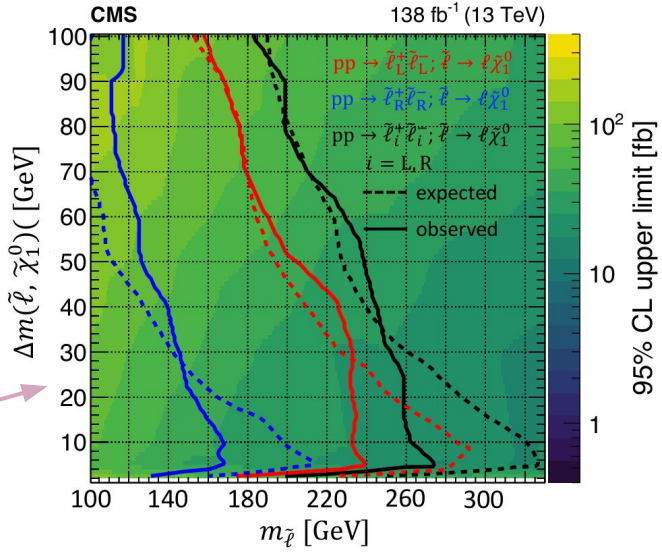


RJR General Search for Compressed SUSY

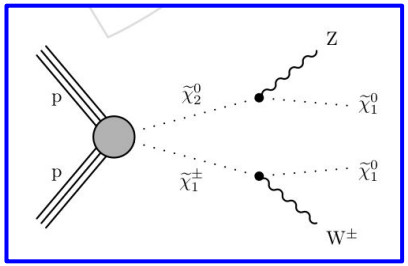
- Exclusion of top squarks up to 700-750 GeV and down to dM=6
- Slepton limits up to 260 GeV and down to dM=5
- Only CMS/ATLAS result to include interpretations for L,R,smu, and selectron independent results



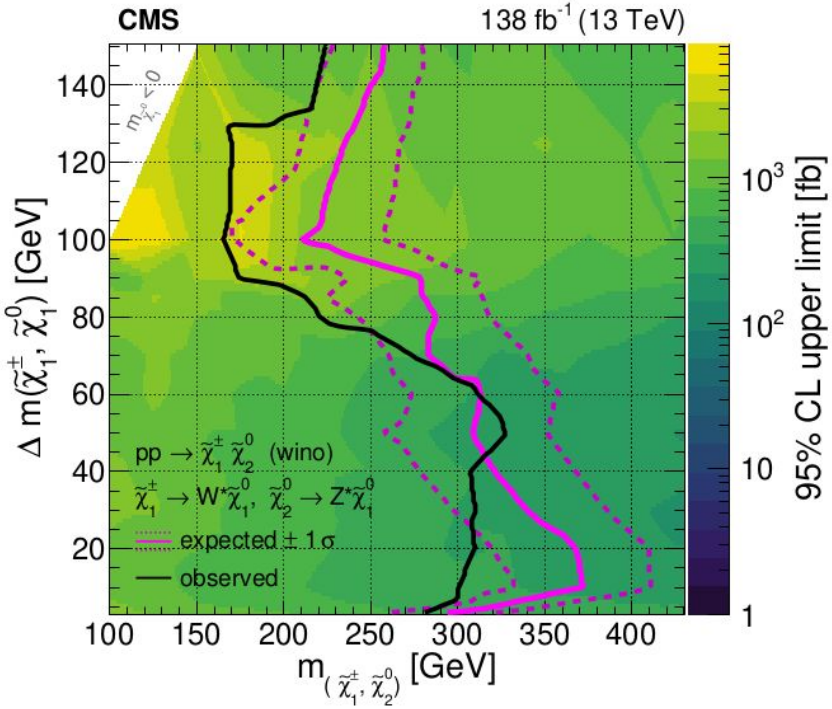




RJR General Search for Compressed SUSY

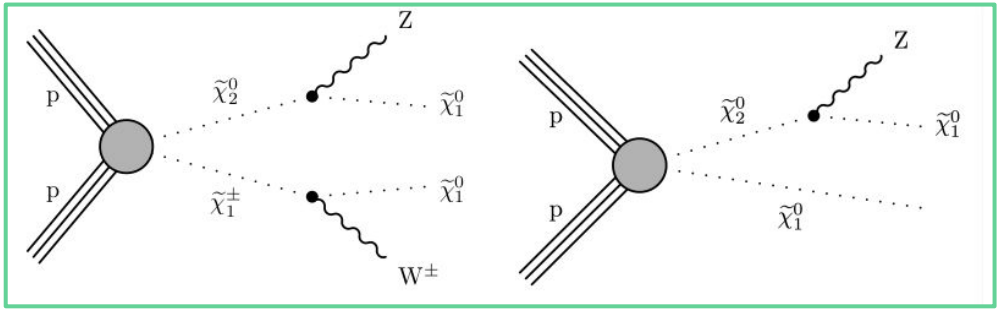


- Limits TChiWZ with the optimistic Wino cross-section
- SMS assumes N2,C1 are mass degenerate
- Observed limit excludes compressed N2,C1 ~300 GeV down to ~275 at dM=3 GeV
- Many more models (including higgsino interpretations) are available in the **paper**



Search for Compressed SUSY with soft leptons and MET

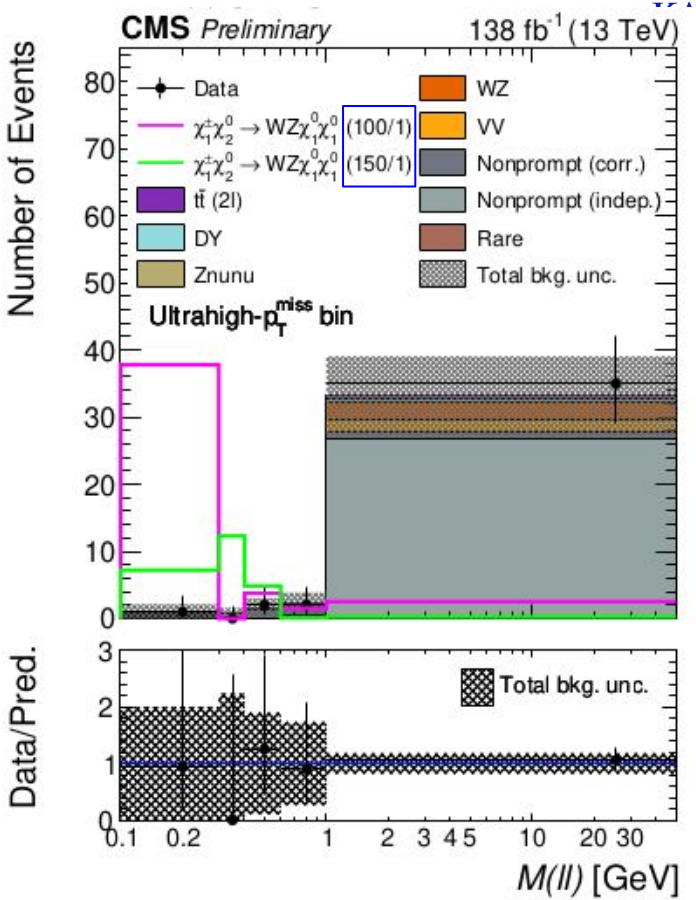
- Zooming in into dM<10 we have a search for **soft leptons** and **ptmiss**
- Cut and count approach considering both **2L** and **3L**
- SRs consists of bins of **di-lepton mass** and **ptmiss**
- Both the SR and CR are simultaneously fit



Variable	Prompt $\mu\mu$ Low-p_T^{miss}	Prompt $\mu\mu$/ee Higher-p_T^{miss}	Prompt 3ℓ Low-p_T^{miss}	Prompt 3ℓ Higher-p_T^{miss}
N_{lep}	2	2	3	3
$p_T(\ell_{1,2})$[GeV] for e (μ)	(5,30)	(1(3.5),30)	(5,30)	(1(3.5),30)
$p_T(\ell_3)$[GeV] for e (μ)	—	—	(5,30)	(1(3.5),30)
1 OS pair			✓	
1 OSSF pair			✓	
$\Delta R(\ell_i\ell_j)$ ($i,j=1,2,3, i\neq j$)	—	> 0.05	—	> 0.05
$m_{SFOS}(\ell\ell)$ ($m^{min}_{SFOS}(\ell\ell)$ in 3ℓ) [GeV]	(4,50)	(0.1,50)	(4,50)	(0.1,50)
$m^{max}_{SFAS}(\ell\ell)$ (AS=any sign) [GeV]	—	—	<60	—
$m_{SFOS}(\ell\ell)$ ($m^{min}_{SFOS}(\ell\ell)$ in 3ℓ) [GeV]		veto (3,3.2) and (9,10.5)		
$p_T(\ell\ell)$[GeV]		>3		—
Leading jet "tight lepton veto"		✓		—
$m_T(\ell_i, p_T^{miss})$[GeV] ($i=1,2$)		<70		—
H_T[GeV]			> 100	
p_T^{miss}/H_T		(2/3,1.4)		—
$N_b(p_T > 25\,GeV)$			=0	
$m_{\tau\tau}$[GeV]		veto (0,160)		—
$p_T(\ell_i)/m(\ell\ell)$		$p_T(\ell_2) > 0.6 + 0.25 m_{SFOS}(\ell\ell)$		$p_T(\ell_3) > 0.6 + 0.25 m^{min}_{SFOS}(\ell\ell)$
$\max(\Delta\phi(\ell_i, p_T^{miss}))$ ($i=1,2$)		< 1.5		—

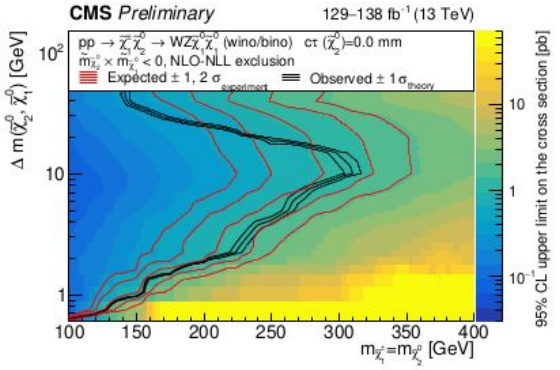
Search for Compressed SUSY with soft leptons and MET

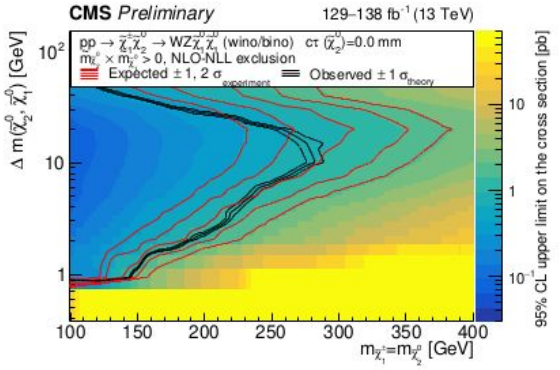
- Careful attention is made to the model theoretical underpinnings
  - The di-lepton mass lineshape depends on the sign of the mass eigenstates
- Utilizes a new collection of electrons with pt from 1-3 GeV
  - Uses a dedicated low-pt algorithm to supplements the standard reconstruction
- New collection now makes dM=1 possible

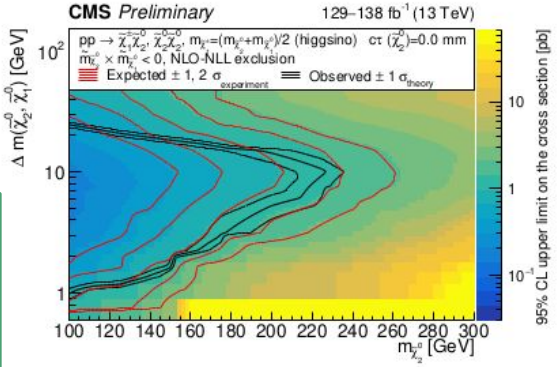


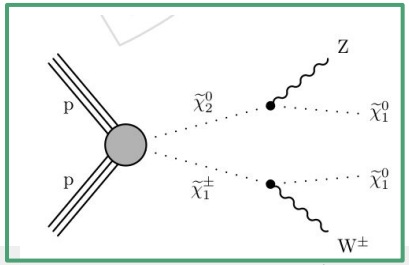
Search for Compressed SUSY with soft leptons and MET

- Results now extend limits for TChiWZ Wino/Bino mass splittings of 1 GeV
- Includes interpretations for (+) or (-) eigenstates
- Exclude Wino-like charginos up to 150 GeV @ dM=1 GeV
- Also includes the natural higgsino interpretation with the "sandwich model"
  - Chargino mass halfway between neutralinos



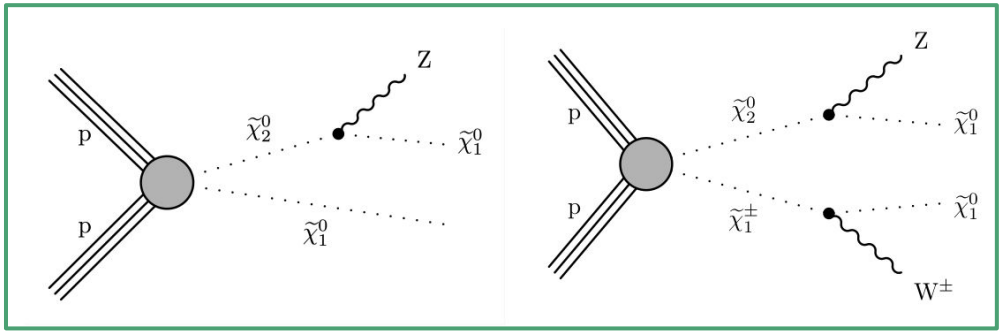






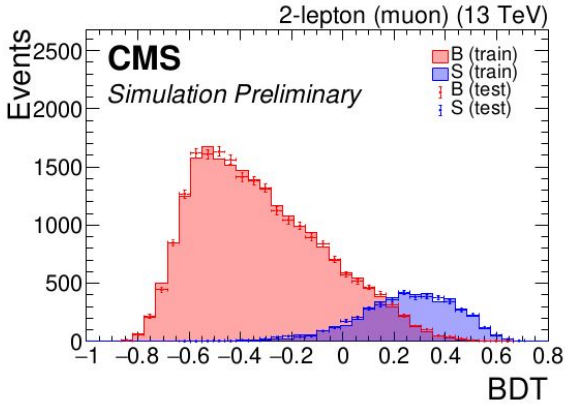
Search for Higgsinos with lepton-track pairs

- Here we have a smaller scope analysis in the same dM<10 regime
- Analysis employs BDTs to identify events with N2 leptonic decays
- SRs consist of **dimuon** or **muon + isolated track**, alongside high **PTmiss**
- Exclusive track BDTs pick best track



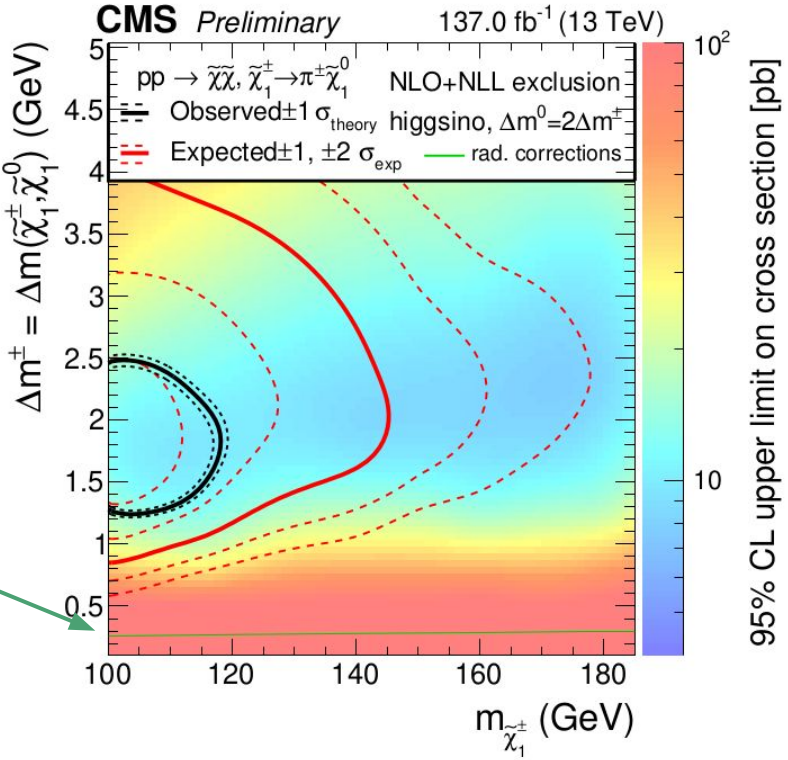
BDT inputs

Rank	Variable
1	$\Delta R\,(t,\ell)$
2	$\lvert\Delta\eta\,(t,\ell)\rvert$
3	$p_{\mathrm{T}}(\ell)$
4	$\lvert\Delta\phi\,(t,\text{hard}\,\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})\rvert$
5	$\lvert\Delta\eta\,(t,j_1)\rvert$
6	$\lvert\Delta\phi\,(t,\ell)\rvert$
7	$\lvert\eta\,(t)\rvert$
8	$\lvert\eta\,(\ell)\rvert$
9	$\Delta R\,(\ell,j_1)$
10	$m_{t\ell}$



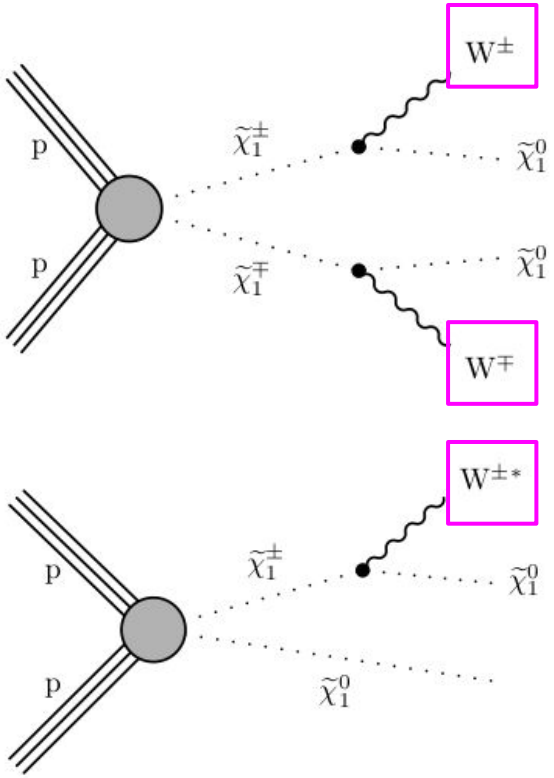
Search for Higgsinos with lepton-track pairs

- Results are the among the first to interpret the natural sandwich model
- Event selection is orthogonal with soft lepton + MET thus the results can be combined
- Starting to approach the compression limit ~250 MeV



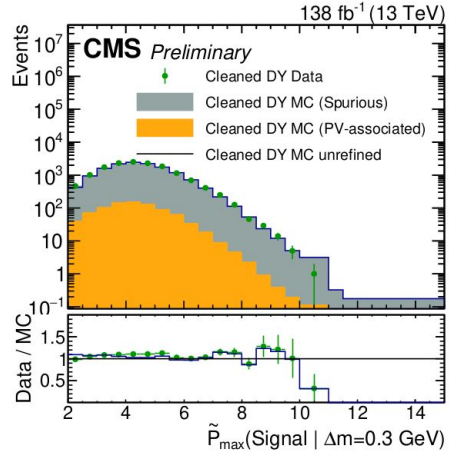
Search for compressed electroweakinos soft isolated tracks

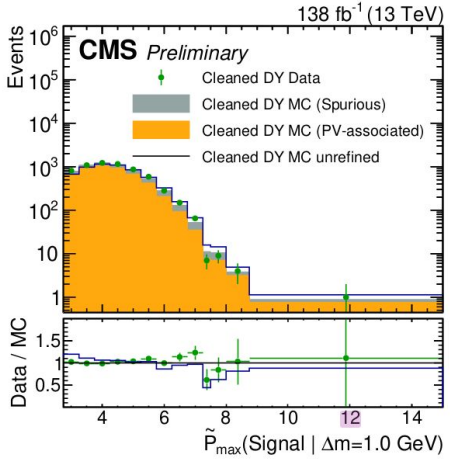
- Our last analysis zooms into the ultra compressed regime dM<1 GeV
- The focus here shifts from **Z**s to **W**s
- We expect the chargino decays to charged pion→the soft isolated track
- The pion is also expected to be mildly displaced (< 2 cm)
- Targets events with a **isolated tracks**, **large PTmiss**, **large HT**, **no leptons or photons**

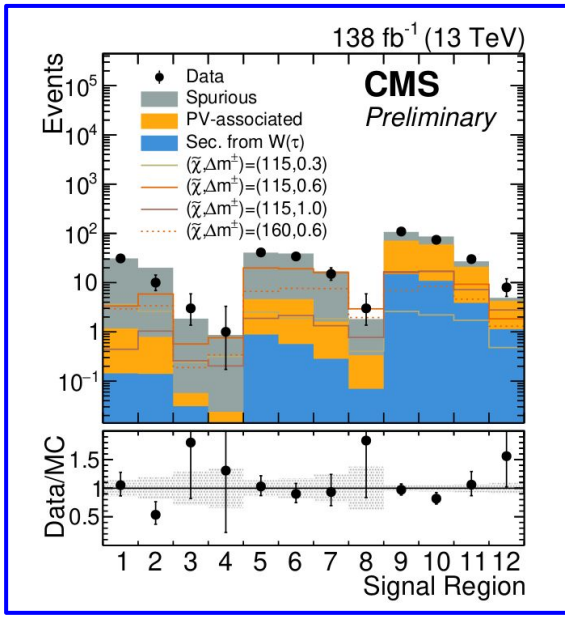


Search for compressed electroweakinos soft isolated tracks

- Analysis employs a dM parameterized NN that uses a similar approach as the BDT Higgsino analysis
- Classifies events into 5 categories: signal, prompt bkg, non-prompt bkg, spurious track, or tau
- NN inputs are: track + model dM, + event variables (MET, dR, pT, …)
- Each track is given each model dM (0.3,0.6,1.0) and the max P(Signal | dM) is chosen – sorting tracks into different signal regions
- We end up with 12 SR bins – 3 dMs with 4 bins of Pmax each

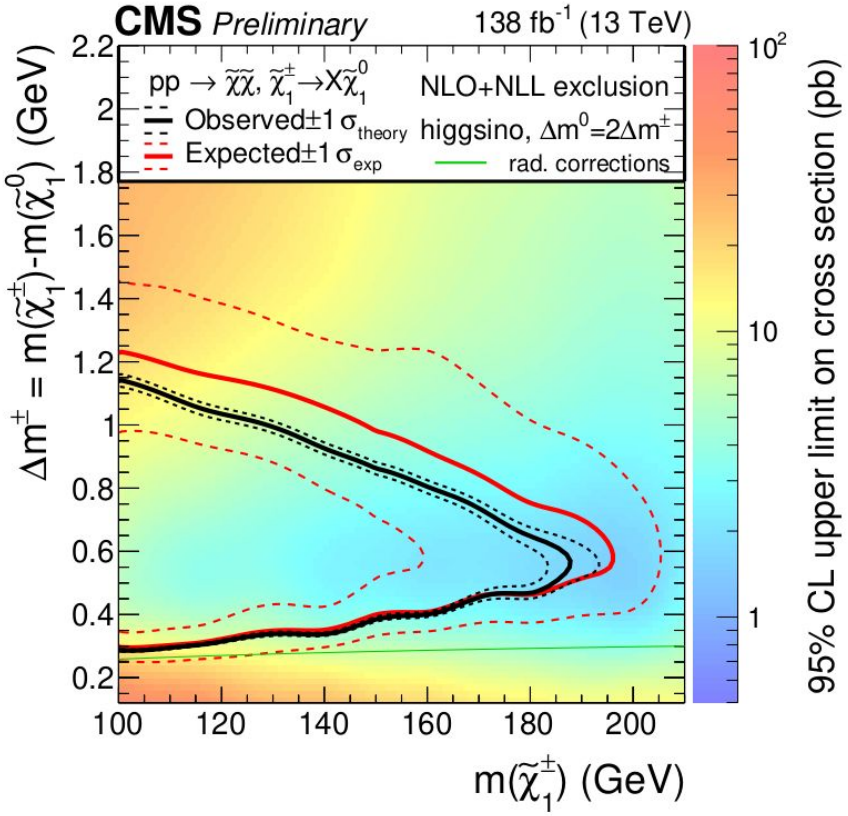






Search for compressed electroweakinos soft isolated tracks

- Ultra compressed limits reach all the way down dM 250 MeV
- Results also focus on the natural sandwich model
- Exclusion of chargino up to mass of 180 GeV and dM of 0.6 GeV

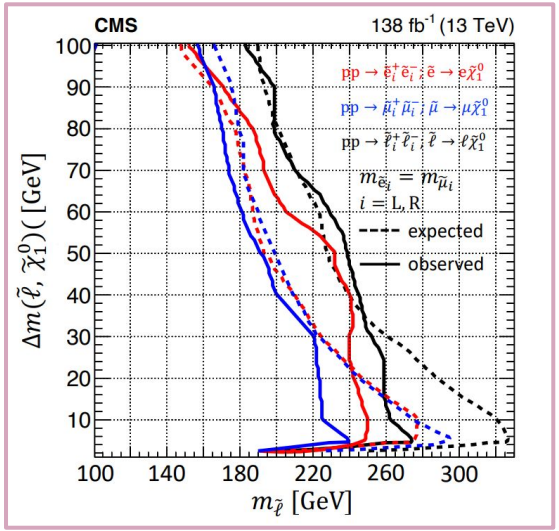


Summary

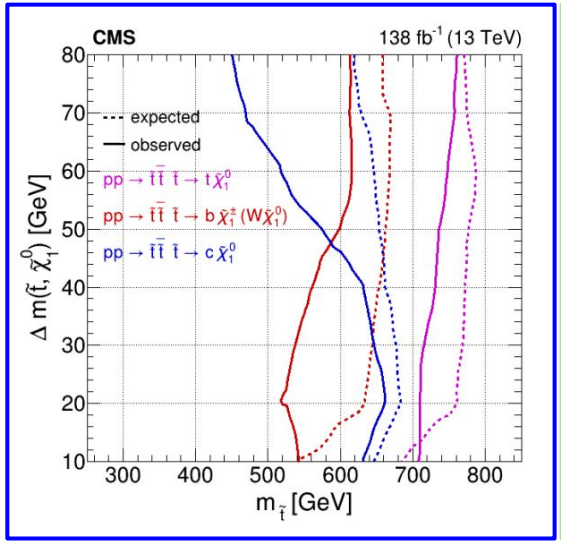
- **Presented Run 2 search results for compressed SUSY with CMS**
- Comprehensive results for a variety of models and final states among 4 searches
  - **SUS-23-003, EXO-23-017, SUS-24-003, SUS-24-012**
- No significant excesses found for compressed SUSY so exclusion limits have been set
- Searches continue into Run 3

Compressed SUSY Limit Summaries

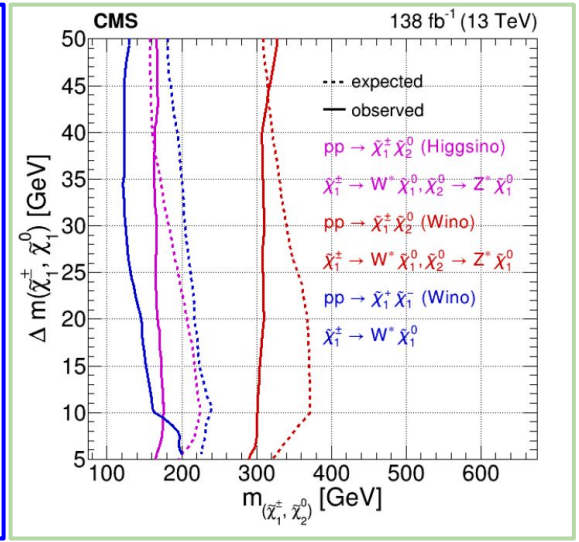
Sleptons



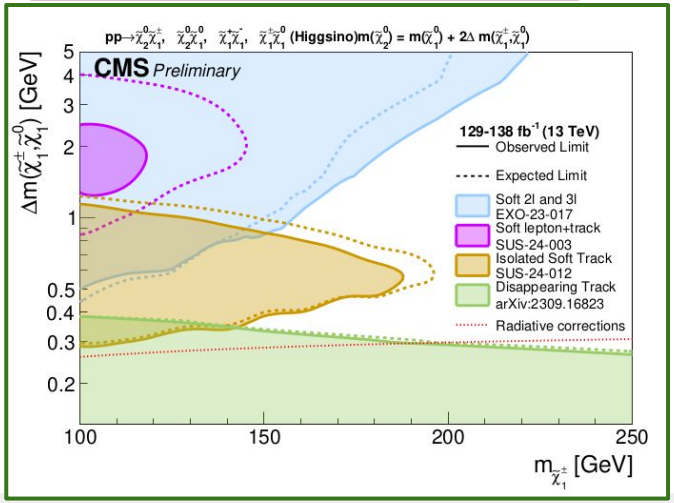
Top squarks



Electroweak-inos



Electroweak-inos
(sandwich model)



Thanks!