Compressed SUSY at CMS

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On behalf of the CMS collaboration
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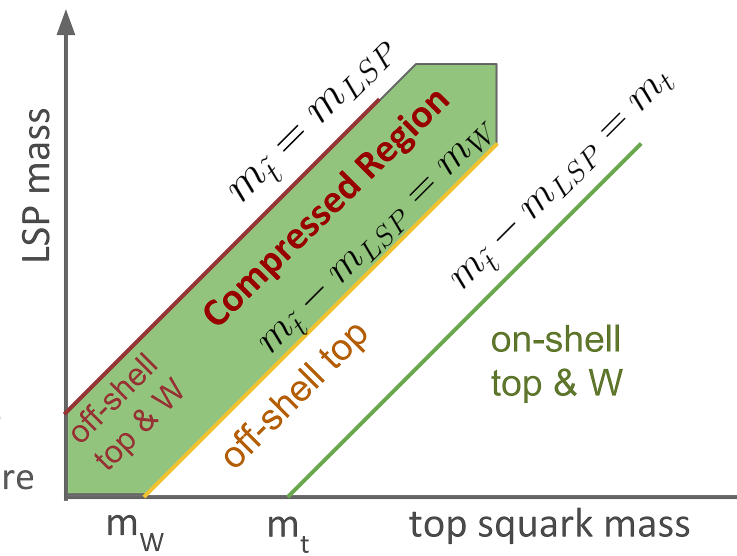
Compressed Mass Spectra

- Compressed SUSY:
  - Small mass difference (Δm) between the produced SUSY particles, and the lightest SUSY particle (LSP)
  - Δm determines the allowed decays and the kinematics of the final state particles
  - In this talk: Δm < m_W (ex. W and t are off-shell)
- Challenges:
  - Due to small mass splitting, final state particles are soft (low transverse momenta)
    - Often too soft to pass the detector thresholds
    - Unless: an initial state radiation (ISR) is present!
      - The SUSY particles become boosted and therefore can enter acceptance

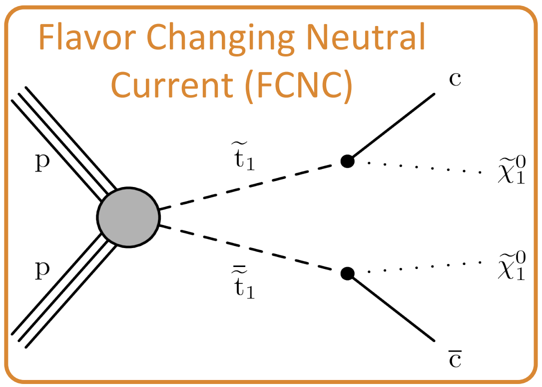


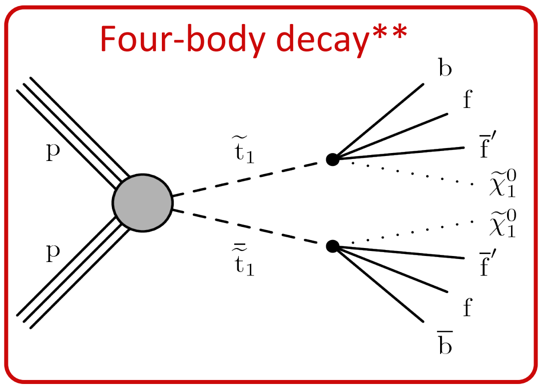
- Challenging region, but highly motivated!
  - relatively light stops/sbottom still allowed in this region!
  - Coannihilation between the stop and the LSP can help produce the correct dark matter relic densities

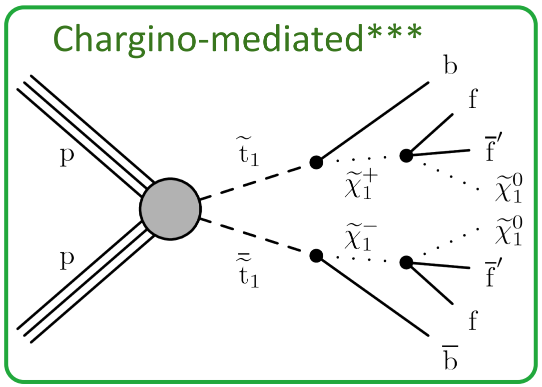
Compressed Simplified Models

- Soft-Opposite-Sign (soft 2ℓ):
  - CMS-PAS-SUS-16-048
- Soft Single-Lepton (soft 1ℓ):
  - CMS-PAS-SUS-16-052
- All-Hadronic search (stop 0ℓ):
  - CMS-SUS-16-049
  - arXiv:1707.03316
- Sbottom/stop search:
  - CMS-SUS-16-032
  - arXiv:1707.07274
- MT2 (Inclusive 0ℓ):
  - CMS-SUS-16-036
  - arXiv:1705.04650

Simplified Model*







Analysis

FCNC	Four-body decay	Chargino-mediated
Stop 0ℓ **sbottom/stop** **MT2**	**Stop 0ℓ** **Soft 1ℓ**	**Stop 0ℓ** **Soft 1ℓ** **Soft 2ℓ**

* Branching fractions assumed to be 100%

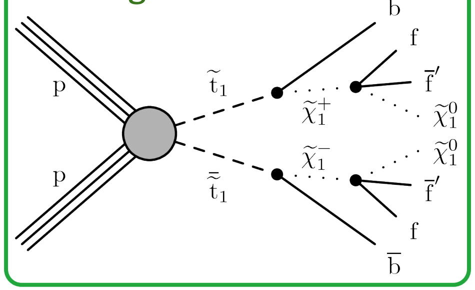
** life times are not taken into account for the four-body decay

*** chargino mass is set half between stop and LSP

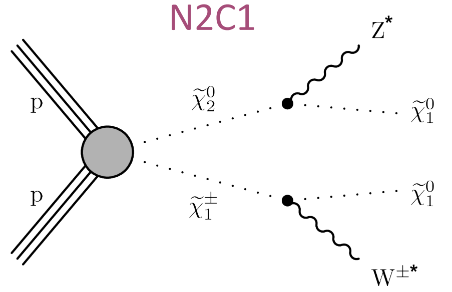
Soft Opposite-Sign leptons (soft 2ℓ)

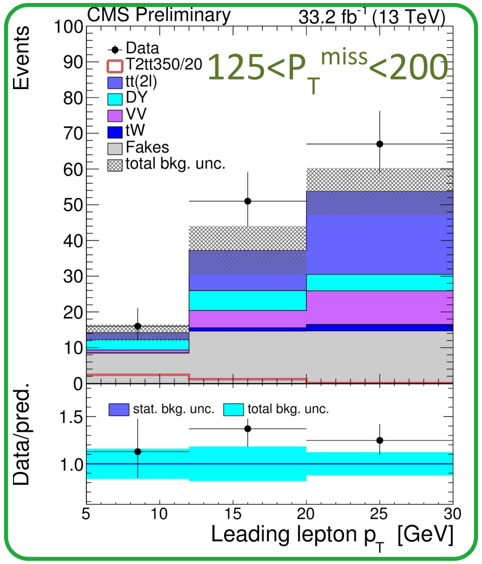
- **Selection:**
  - Two soft leptons with opposite signs
    - **3.5 GeV < p_T (μ) < 30 GeV**
    - 5 GeV < p_T (e) < 30 GeV
    - **Dedicated dimuon trigger ⟶ lower p_T^{miss} thresh.**
  - $N_b = 0$ reduce ttbar
  - M($\tau\tau$) reduce DY⟶ $\tau\tau$
- **Backgrounds:**
  - DY ⟶ $\tau\tau$, ttbar
    - Dedicated CRs for each process in bins of p_T^{miss}
  - Diboson: From simulation, validation with data
  - Nonprompt leptons: “Fake-rate” method
- **Two sets of signal regions:**
  - Stop Search:
    - Includes all flavor combinations
    - Binned in p_T(ℓ) , p_T^{miss}
  - “Ewkino” Search:
    - Motivated by higgsinos
    - Only same flavor leptons
    - Binned in M(ℓℓ), p_T^{miss}

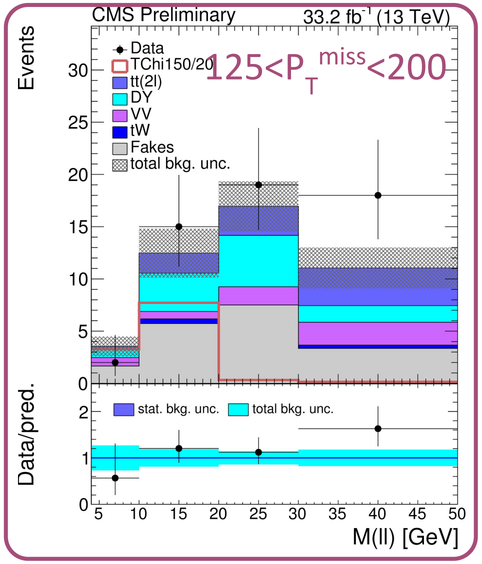
Chargino-mediated



N2C1

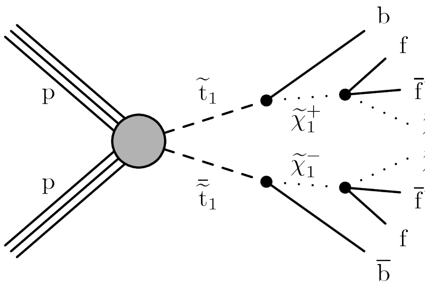




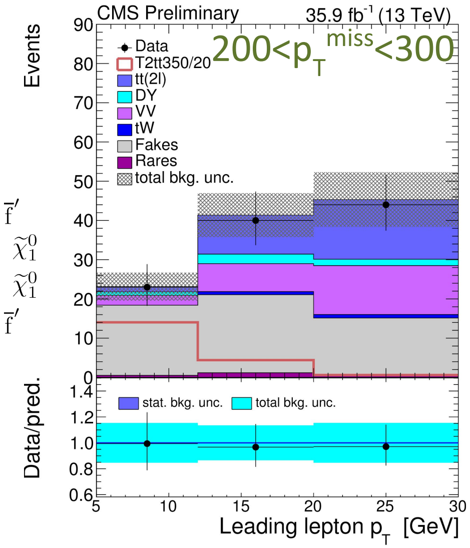


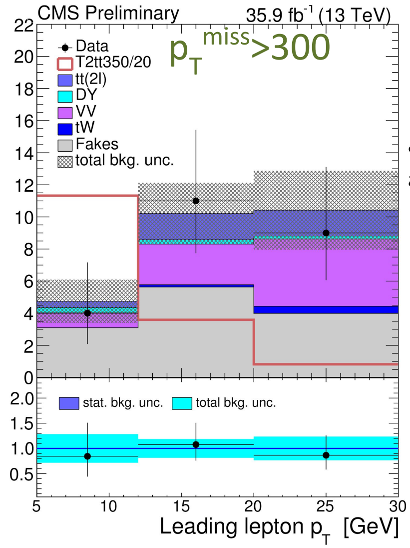
Soft 2ℓ: Results and Interpretations

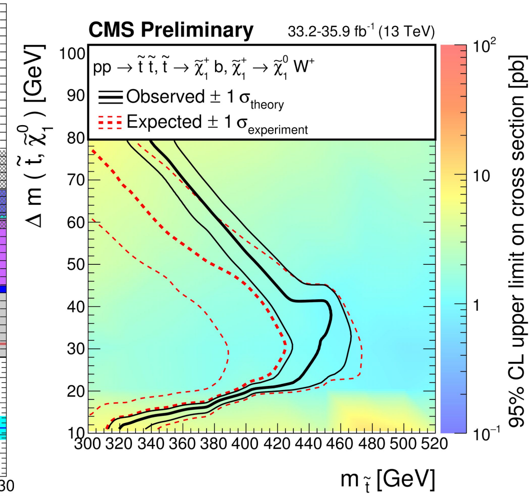
Stop search



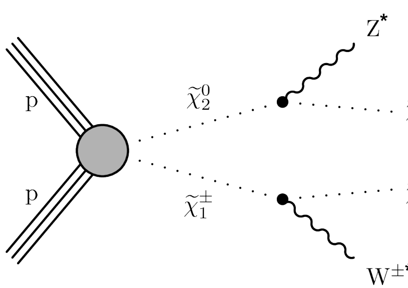
Chargino-mediated

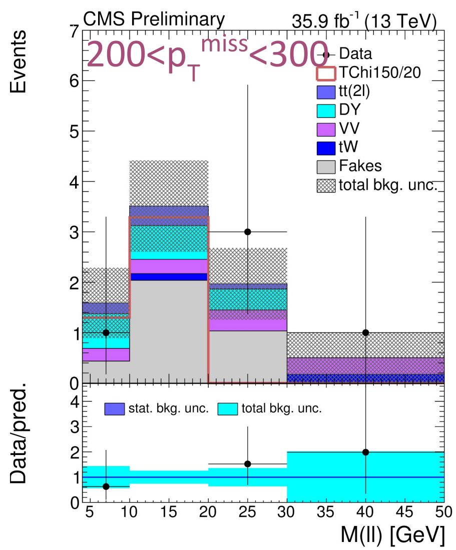


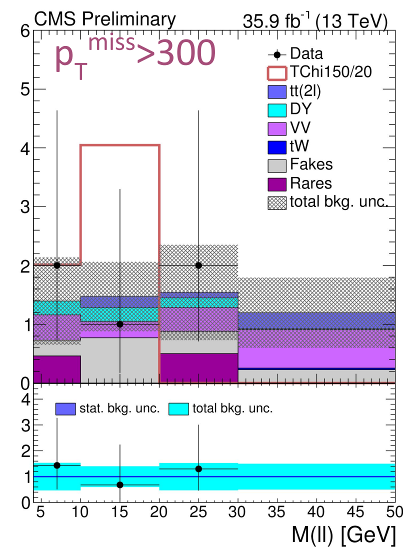


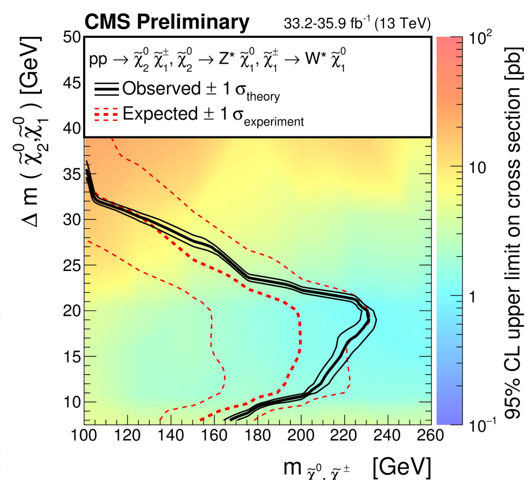


Electroweak search





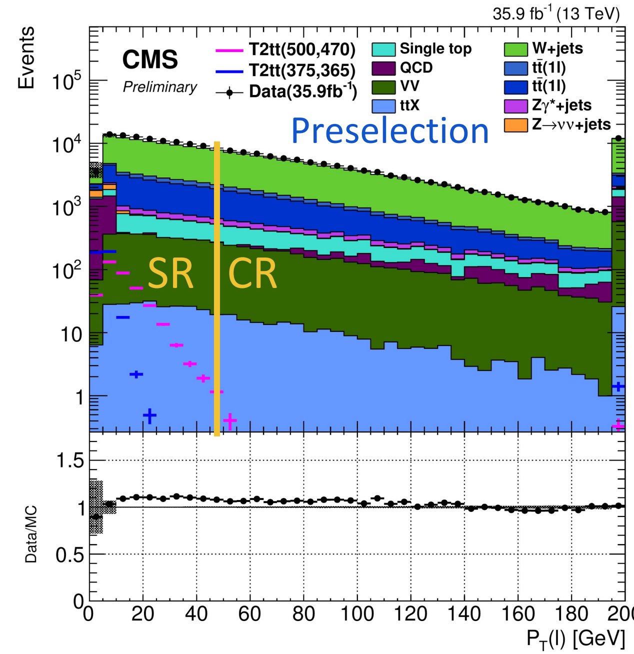


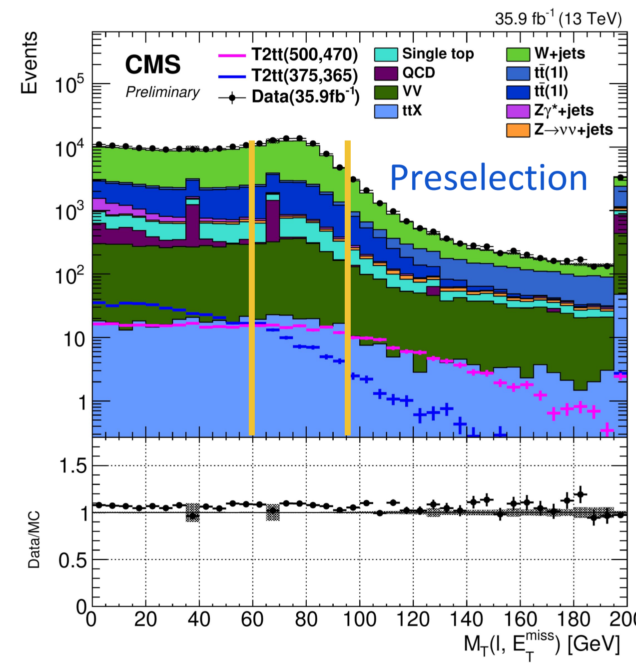


For more on Higgsinos see Henning's talk

Soft Single Lepton Search (soft 1ℓ)

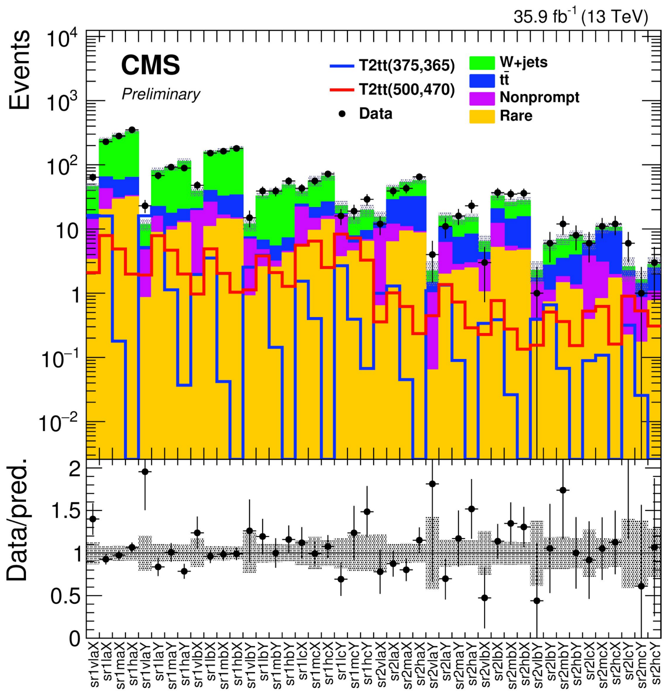
- **Selection:**
  - Soft single lepton (2nd hard lepton veto)
    - **3.5 GeV < p_T (μ) < 30 GeV**
    - 5 GeV < p_T (e) < 30 GeV
  - Require a high-p_T jet as ISR
- **Two sets of Signal Regions (SRs):**
  - SR1 (targeted to very low Δm)
    - $N_b = 0$, moderate p_T^{ISR}
    - Binned in combined variable $C_{T1}(p_T^{miss}, H_T)$
  - SR2 (targeted to larger Δm)
    - One soft b-jet (but no hard ones)
    - Larger p_T^{ISR}
    - Binned in combined variable $C_{T2}(p_T^{miss}, p_T^{ISR})$
  - SR1 and SR2 binned in p_T(l) , m_T (44 SRs)
- **Backgrounds:**
  - Prompt: W+jets and ttbar
    - Normalization from p_T(l) >30 GeV, shape from MC
  - Nonprompt estimated with “fake-rate” method
  - Rare-backgrounds from MC



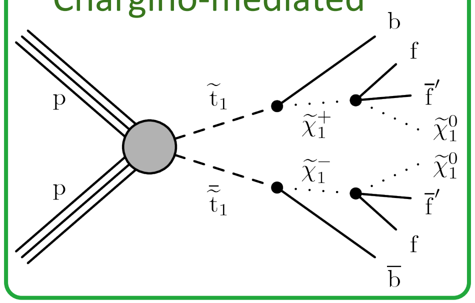


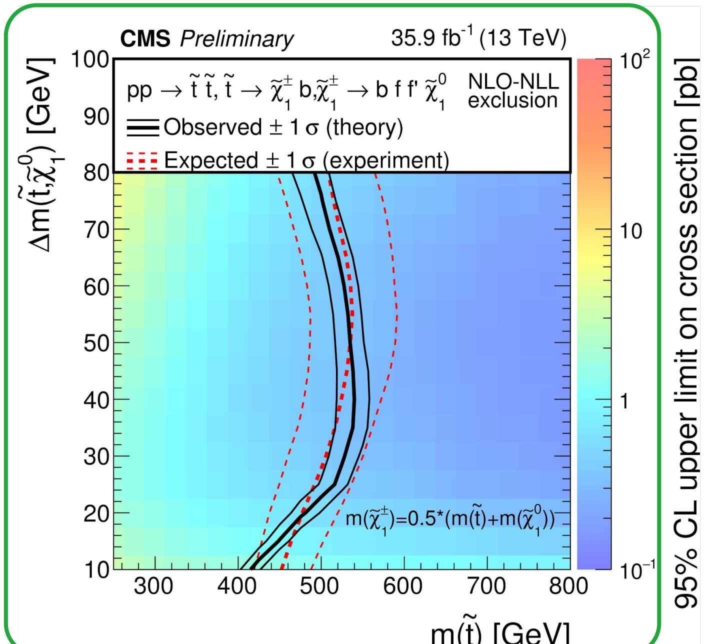
Soft 1ℓ: Results and Interpretations

No significant deviation from SM is observed



Chargino-mediated

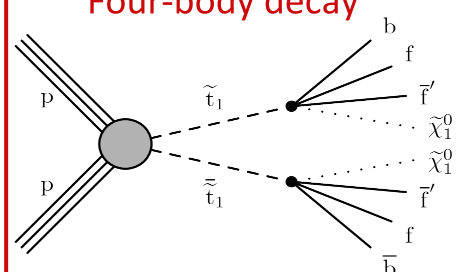


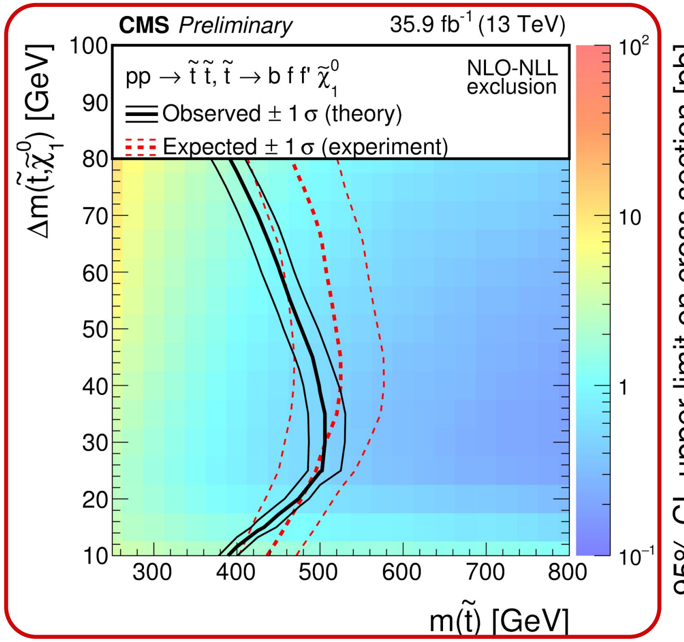


Interpretations :

- Chargino-mediated:
  - Masses of up to ~540 GeV
- Four-body decay exclusion:
  - Masses of up to ~500 GeV

Four-body decay



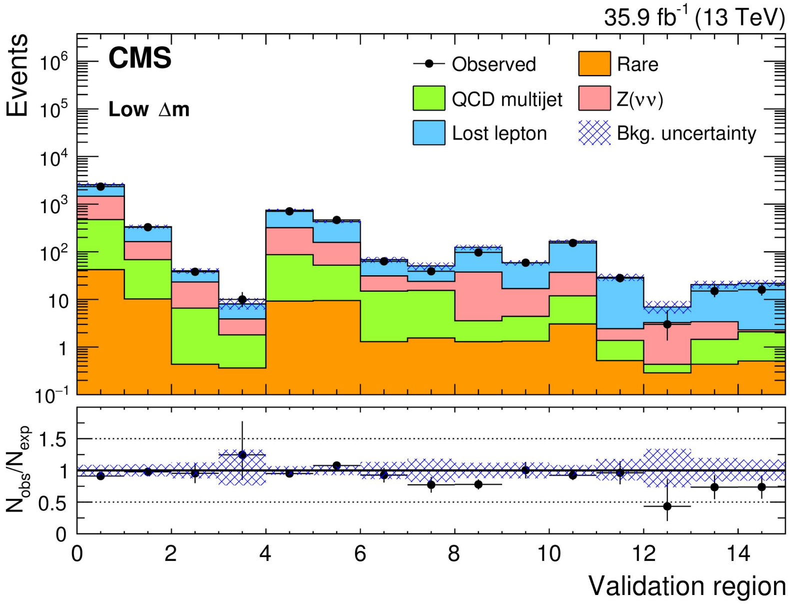


All-Hadroic Search (stop 0ℓ)

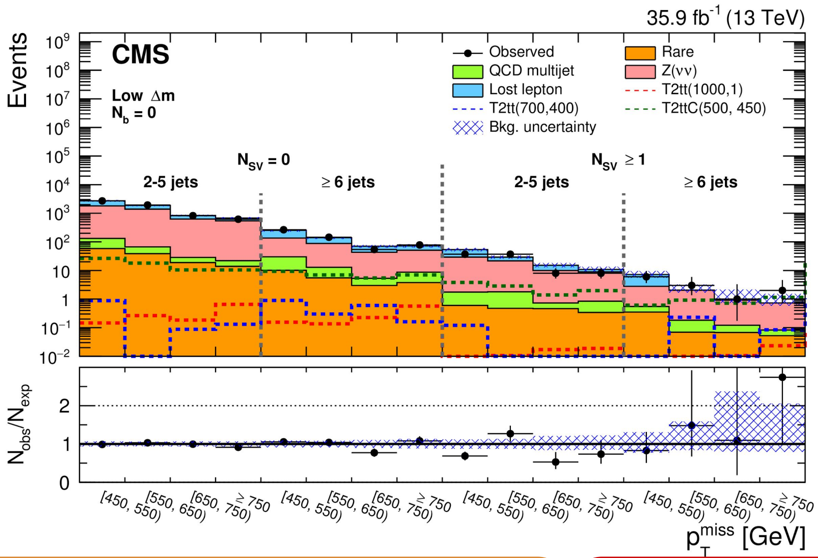
Inclusive stop search covering the full range of stop-lsp plane!

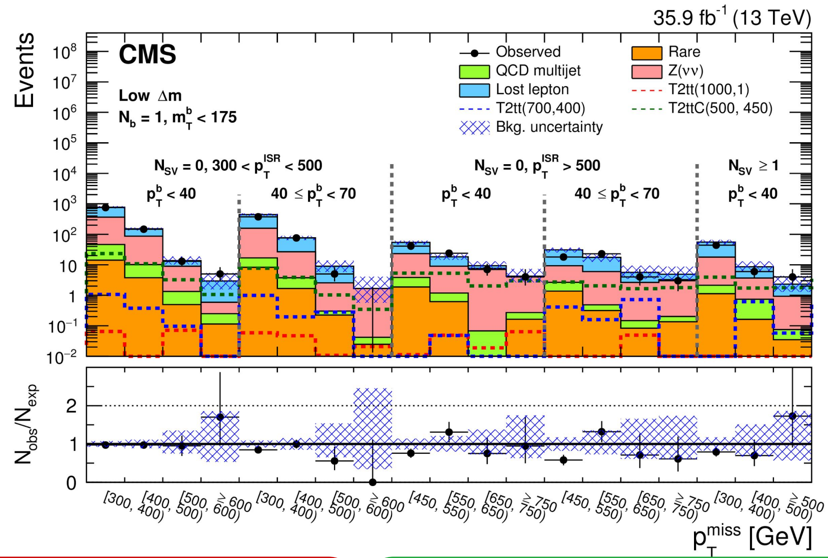
Here I focus on Δm< m(W) (For Δm>m(W) refer to Tom's talk)

- Novelties:
  - **Soft-btagging:**
    - Soft b from the stop decay, difficult to reconstruct
    - Identify secondary-vertex (SV) not associated to jets
    - 20% efficiency with <1% mistag rate (**10 <p_T(b)< 20 GeV**)
  - ISR tag: Use "fat" jets to capture ISR from gluons
- Selection:
  - Require at least 2 jets with moderate p_T^{miss}
  - Veto t or W candidates
  - Binned in N_b, N_{SV}, p_T^{ISR}, p_T^{miss}
  - 53 signal regions (optimized for small Δm)
- Backgrounds
  - Lost-Lepton background (W, ttbar)
  - Z→ νν (estimated from Z→ ll and γ+jets)
  - QCD Multijet events

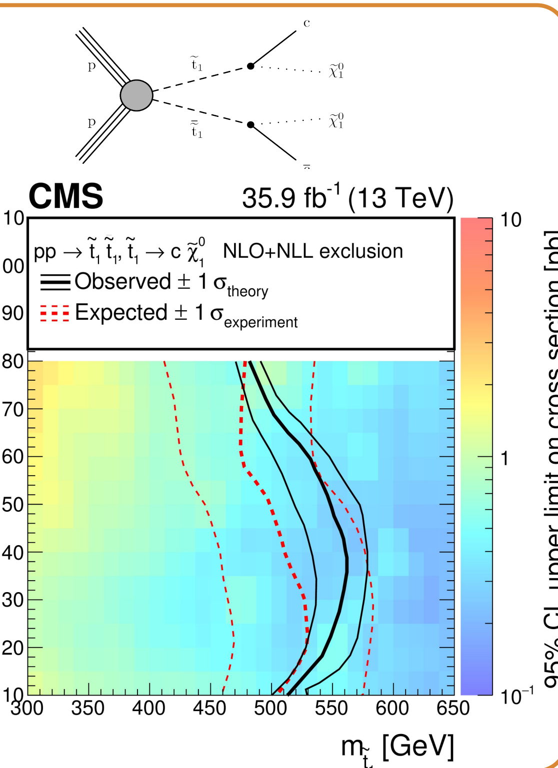


Stop 0ℓ: Results and Interpretations

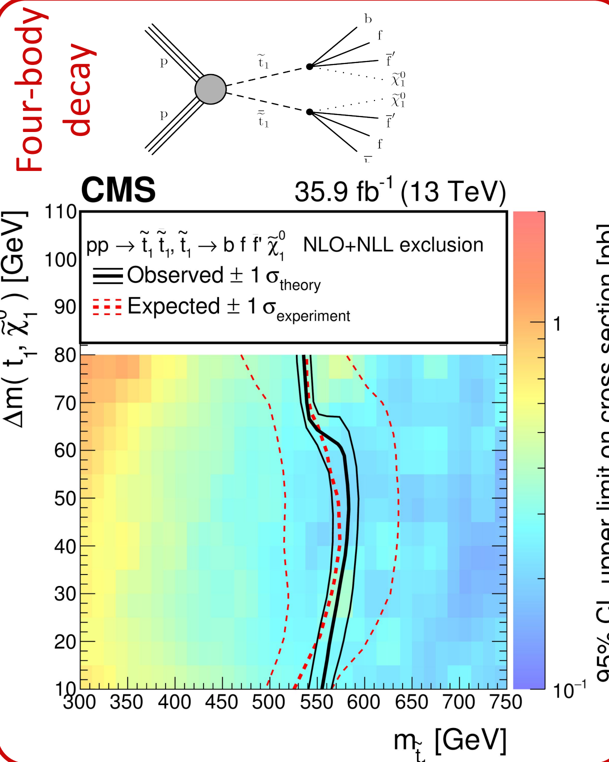




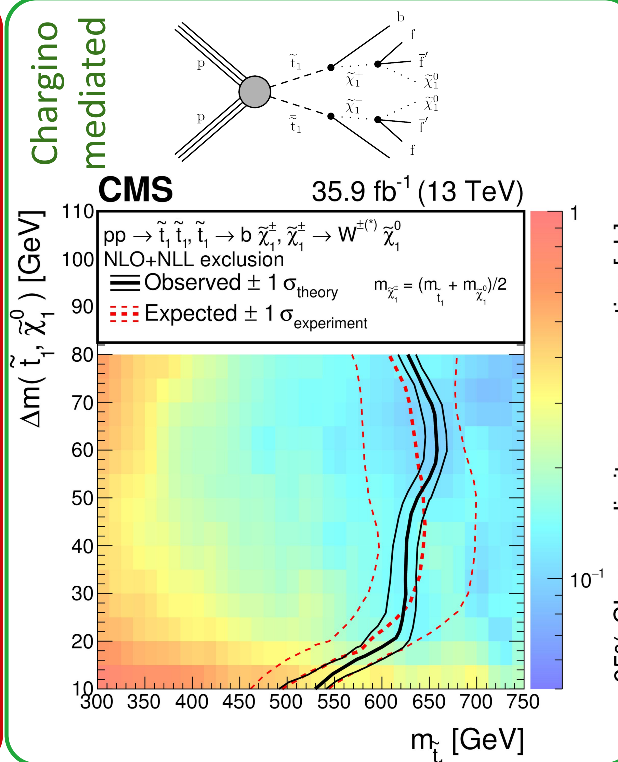
FCNC



Four-body decay



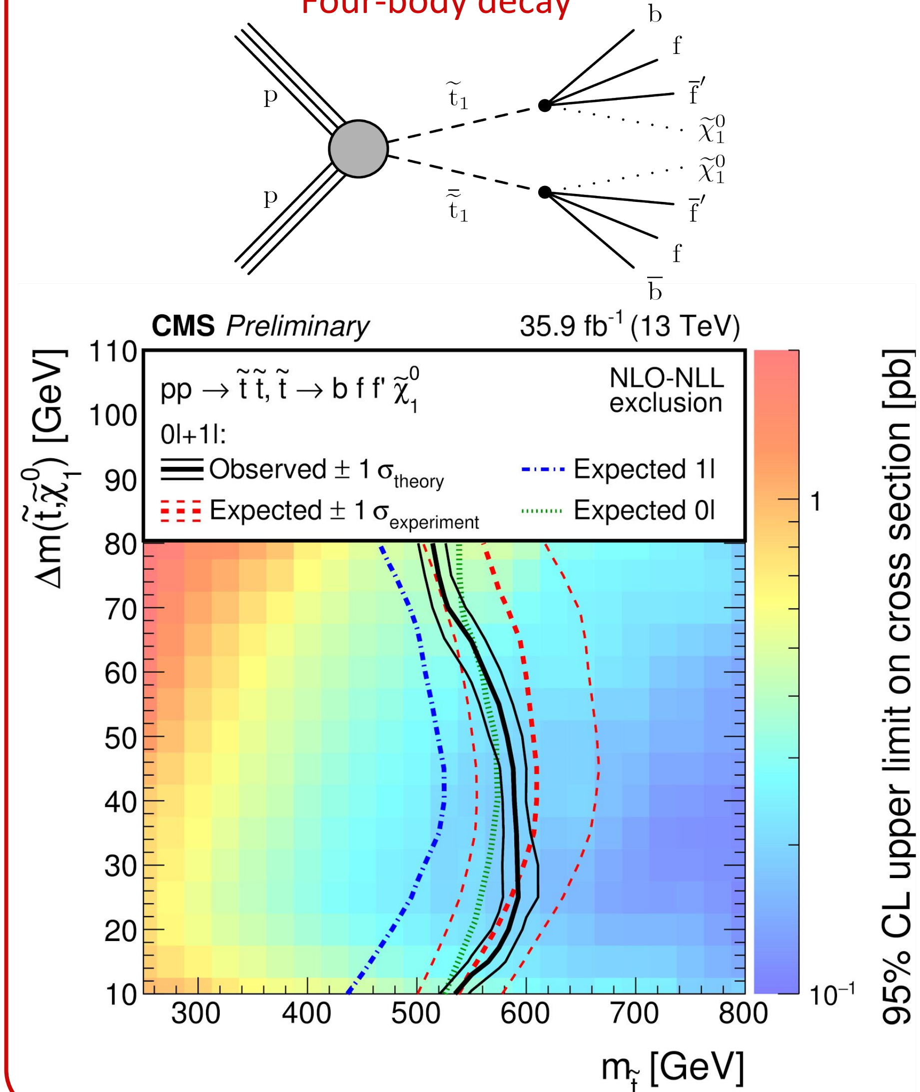
Chargino mediated



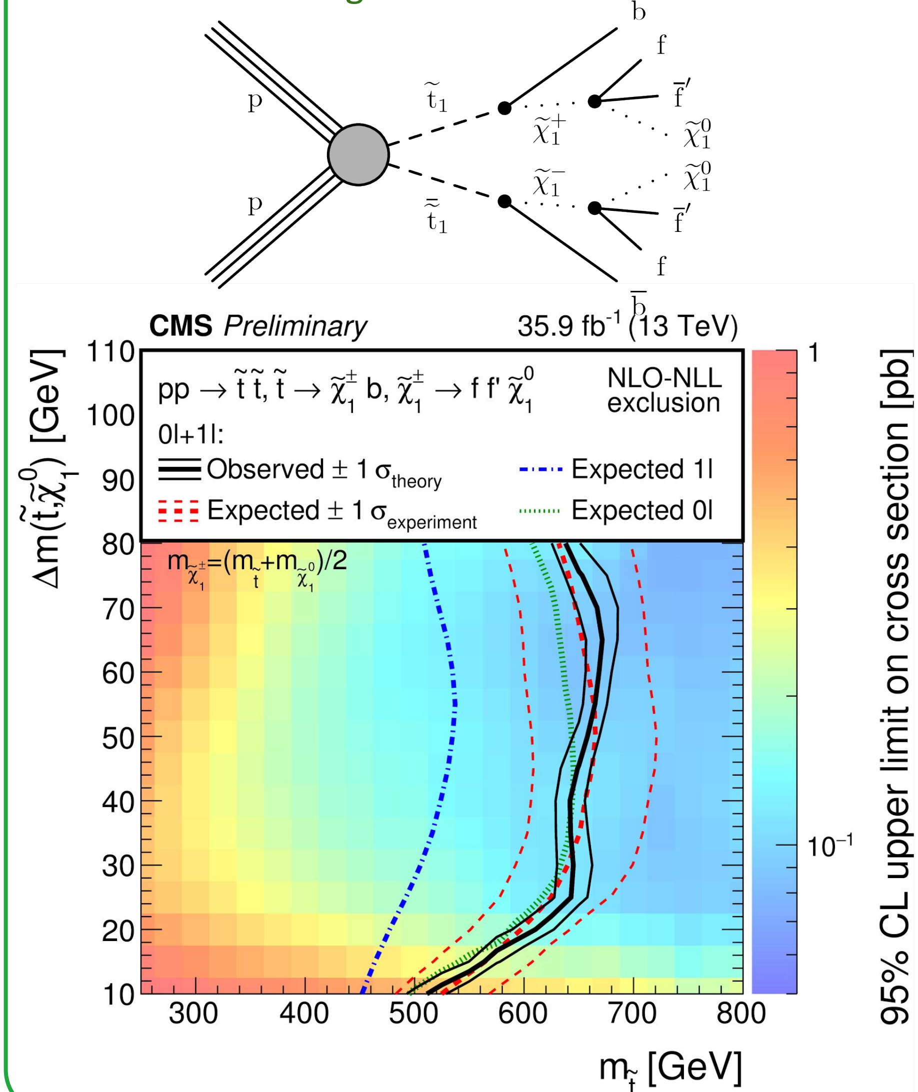
0ℓ-1ℓ Combination

Statistical combination of 0ℓ amd 1ℓ searches:

Four-body decay

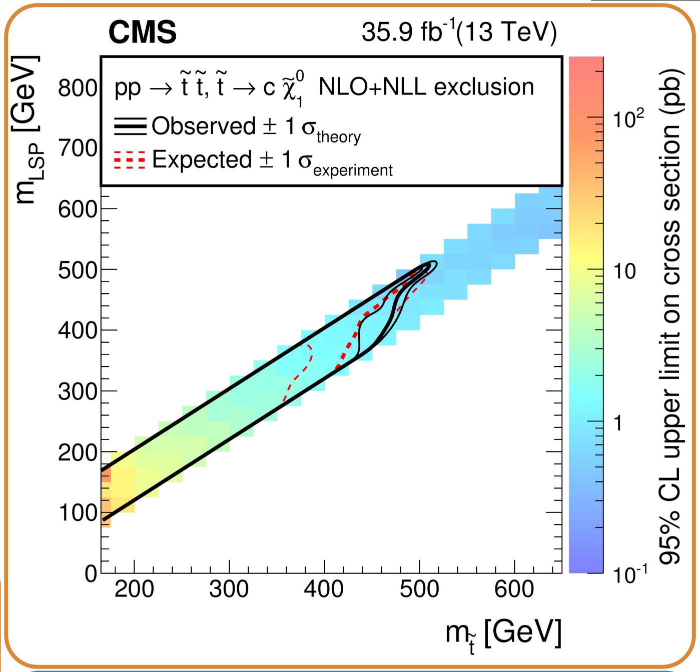


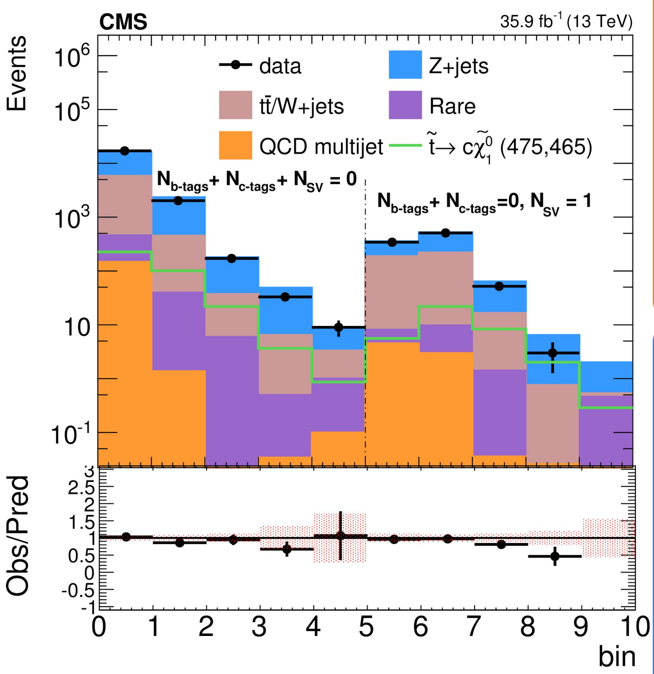
Chargino-mediated



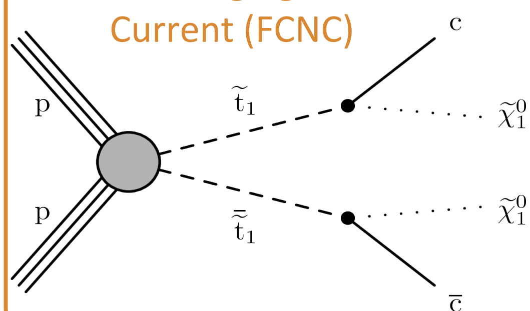
Bottom and top squark production

- Search for sbottom/stop productions
  - Looking for two b/c jets
- Selection:
  - 2-4 jets
  - **Use SV to id b/c quarks**
  - Bin in N_{SV}, N_b, N_c, H_T , p_T^{miss}
- Backgrounds
  - Z→ νν, ttbar , W+jets, QCD

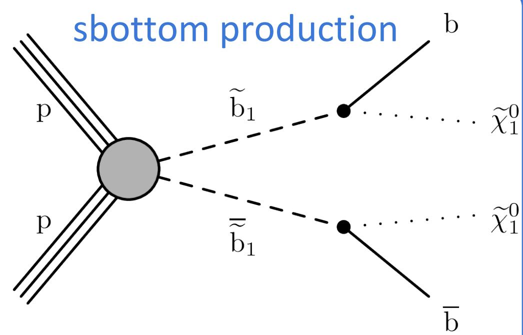


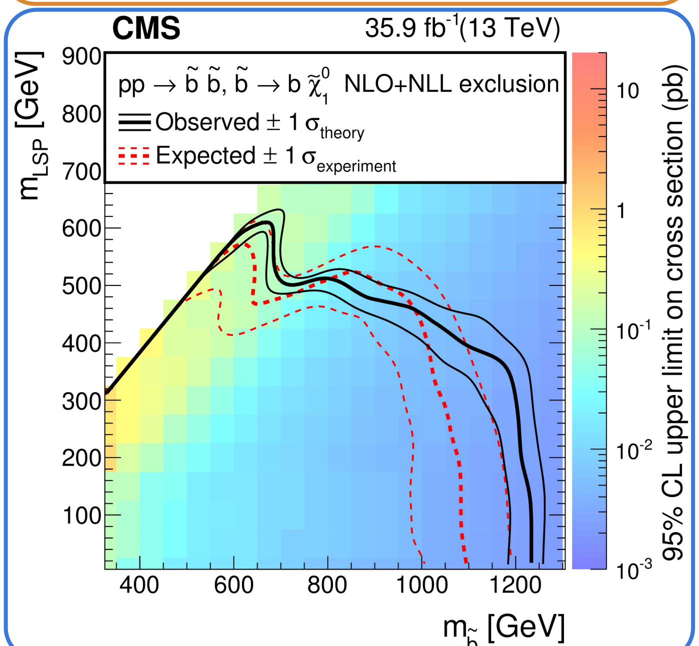


Flavor Changing Neutral Current (FCNC)



sbottom production



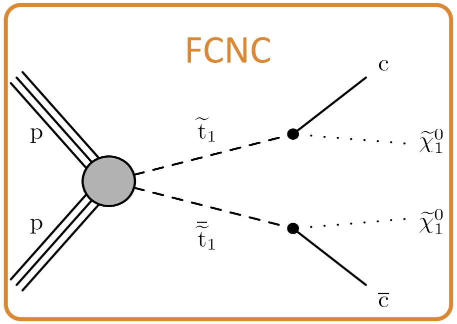


MT2 Analysis (Inclusive 0ℓ)

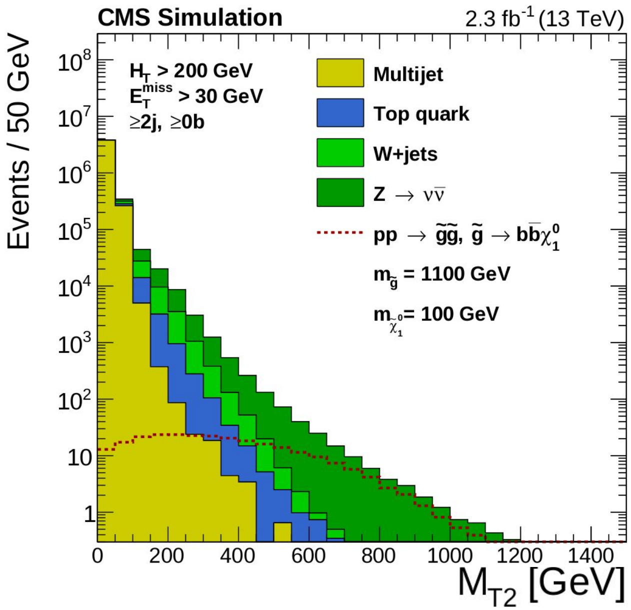
- Selection :
  - Events with one jet:
    - p_T(jet)>250 GeV, binned in N_b, p_T(jet)
  - Events with least two jets:
    - Categorized in topological regions by:
      - N_{jets}, N_b, H_T
      - Further binned in M_{T2}

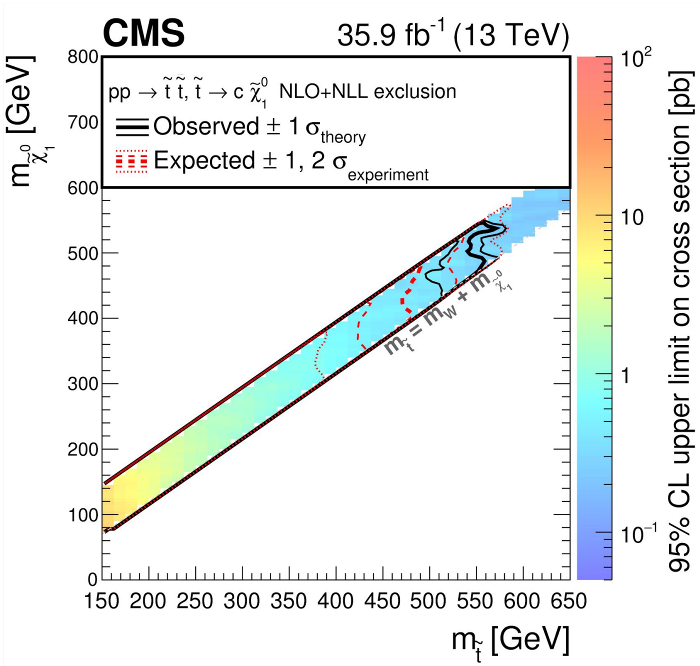
$$M_{T2} = \min_{\vec{p}_T^{\,\text{miss}X(1)} + \vec{p}_T^{\,\text{miss}X(2)} = \vec{p}_T^{\,\text{miss}}} \left[\max \left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

- Backgrounds:
  - Z⟶ νν
  - Lost lepton from W+jets, tt-production
  - Multijet events



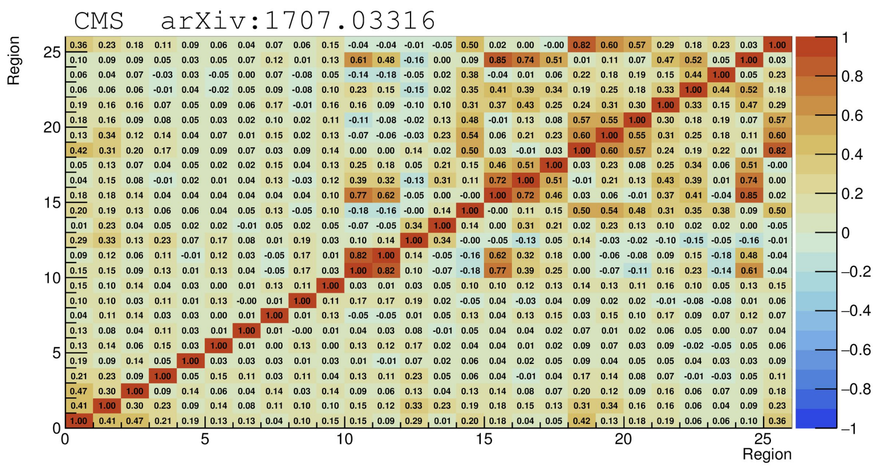
- More interpretations in Scarlet's talk

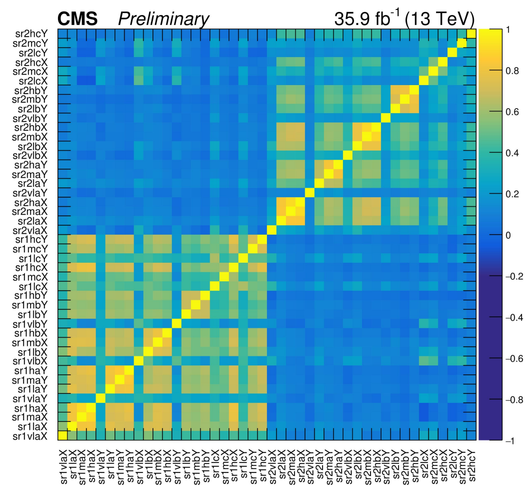


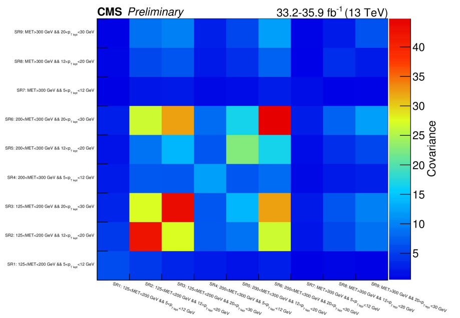


Summary

- Thanks to the great performance of LHC in 2016, CMS was able to probe new regions in the SUSY parameter space, particularly the compressed region.
- Many new search and analysis tools developed to probe these difficult regions: tagging soft b quarks, muons as low as 3.5 GeV
- But still no hint of SUSY even in the compressed region!
- Results provided for reinterpretation for the analysis:
  - Covariance matrix, efficiency maps, etc (links provided on slide 3)
- Need to think of new interpretations, new topologies, new signatures!







BACK UP

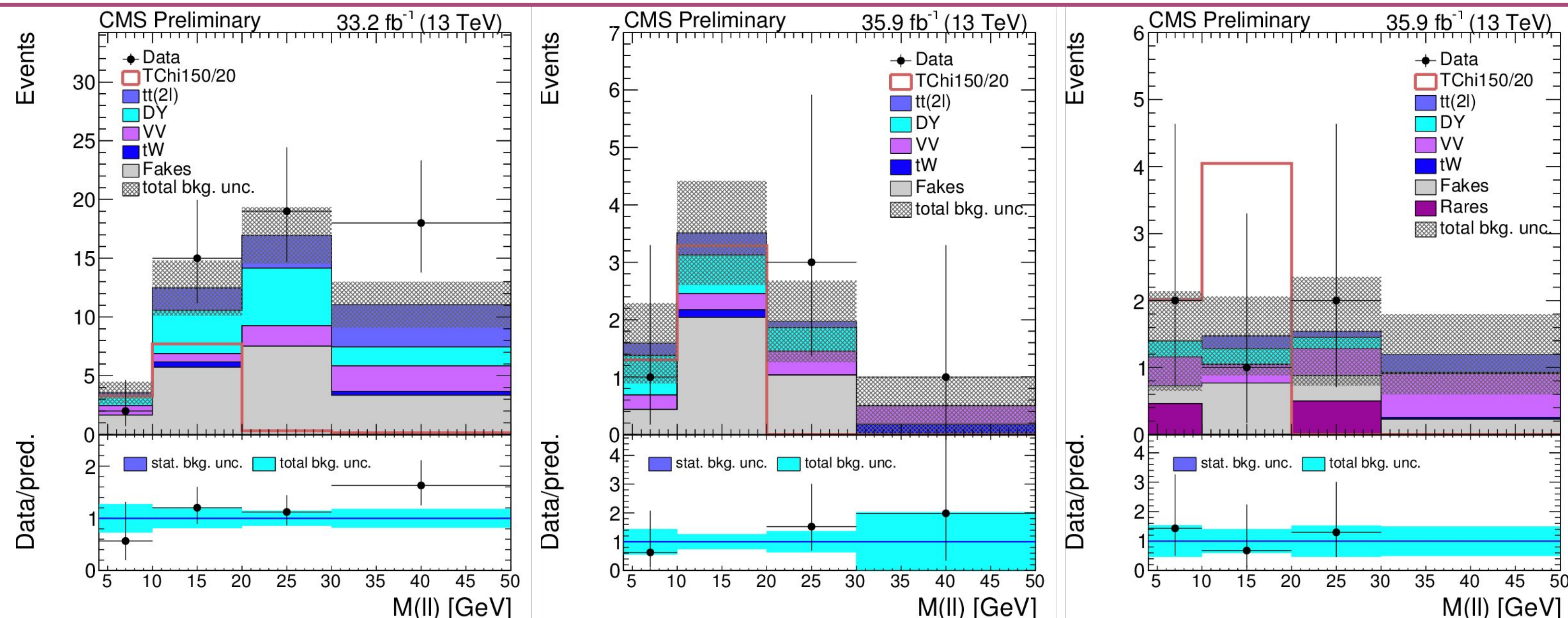
1ℓ: Region Definitions

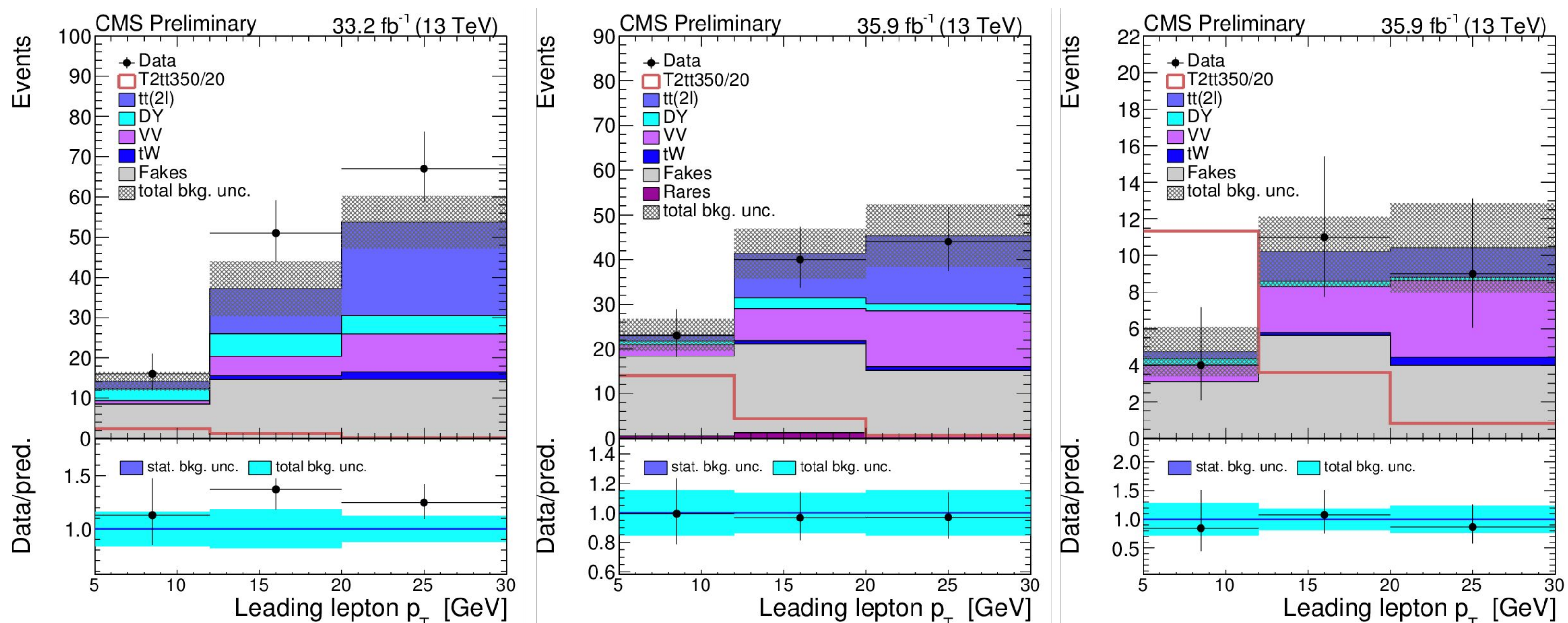
Variable	common to all SRs					
Number of hard jets	≤ 2					
$\Delta\phi$(hard jets) (rad)	< 2.5					
$p_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	> 300					
Lepton rejection	no τ, or additional ℓ with $p_{\mathrm{T}} > 20\,\mathrm{GeV}$					
	SR1			SR2		
H_{T} (GeV)	> 400			> 300		
p_{T}(ISR jet) (GeV)	> 100			> 325		
Number of b jets	0			$\geq$1 soft, 0 hard		
$\lvert\eta(\ell)\rvert$	< 1.5			< 2.4		
	SR1a	SR1b	SR1c	SR2a	SR2b	SR2c
m_{T} (GeV)	< 60	60–95	> 95	< 60	60–95	> 95
$Q(\ell)$	-1	-1	any	any	any	any
$p_{\mathrm{T}}(\mu)$ (GeV)	3.5–5 (VL)	3.5–5 (VL)	-	3.5–5 (VL)	3.5–5 (VL)	-
$p_{\mathrm{T}}(\mathrm{e},\mu)$ (GeV)	5–12 (L) 12–20 (M) 20–30 (H) > 30 (CR)	5–12 (L) 12–20 (M) 20–30 (H) > 30 (CR)	5–12 (L) 12–20 (M) 20–30 (H) > 30 (CR)	5–12 (L) 12–20 (M) 20–30 (H) > 30 (CR)	5–12 (L) 12–20 (M) 20–30 (H) > 30 (CR)	5–12 (L) 12–20 (M) 20–30 (H) > 30 (CR)
C_{T} (GeV)	$300 < C_{\mathrm{T1}} < 400$ (X) $C_{\mathrm{T1}} > 400$ (Y)			$300 < C_{\mathrm{T2}} < 400$ (X) $C_{\mathrm{T2}} > 400$ (Y)		

2ℓ: Region Definitions

Variable	SR selection criteria
N_ℓ	$= 2$ $(ee, \mu\mu, e\mu)$
$\mathrm{Q}(\ell_1)\mathrm{Q}(\ell_2)$	-1
$p_\mathrm{T}(\ell_1)$, $p_\mathrm{T}(\ell_2)$	$[5, 30]$ GeV
$p_\mathrm{T}(\mu_2)$ for high $E_\mathrm{T}^\mathrm{miss}$ $\widetilde{\mathrm{t}}$-like SR	$[3.5, 30]$ GeV
$\lvert\eta_\mu\rvert$	< 2.4
$\lvert\eta_\mathrm{e}\rvert$	< 2.5
IP_{3D}	< 0.01 cm
SIP_{3D}	< 2
$Iso_\mathrm{rel}(\ell_{1,2})$& $Iso_\mathrm{abs}(\ell_{1,2})$	< 0.5 && < 5 GeV
$p_\mathrm{T}(jet1)$	> 25 GeV
$\lvert\eta\rvert(jet1)$	< 2.4
N_b (>25 GeV, CSVv2L)	$= 0$
$M(\ell\ell)$	< 50 GeV
$p_\mathrm{T}(\ell\ell)$	> 3 GeV
$E_\mathrm{T}^\mathrm{miss}$	> 125 GeV
$E_\mathrm{T}^\mathrm{miss}$ (muon subtracted)	> 125 GeV
$E_\mathrm{T}^\mathrm{miss} / H_\mathrm{T}$	$[0.6, 1.4]$
H_T	> 100 GeV
$M(\ell\ell)$	> 4 GeV
$M(\ell\ell)$	veto$[9, 10.5]$ GeV
$M_{\tau\tau}$	veto$[0, 160]$ GeV
$M_\mathrm{T}(\ell_x, E_\mathrm{T}^\mathrm{miss}), x = 1, 2$	< 70 GeV (for electroweakino selection only)

Soft 2ℓ: Results



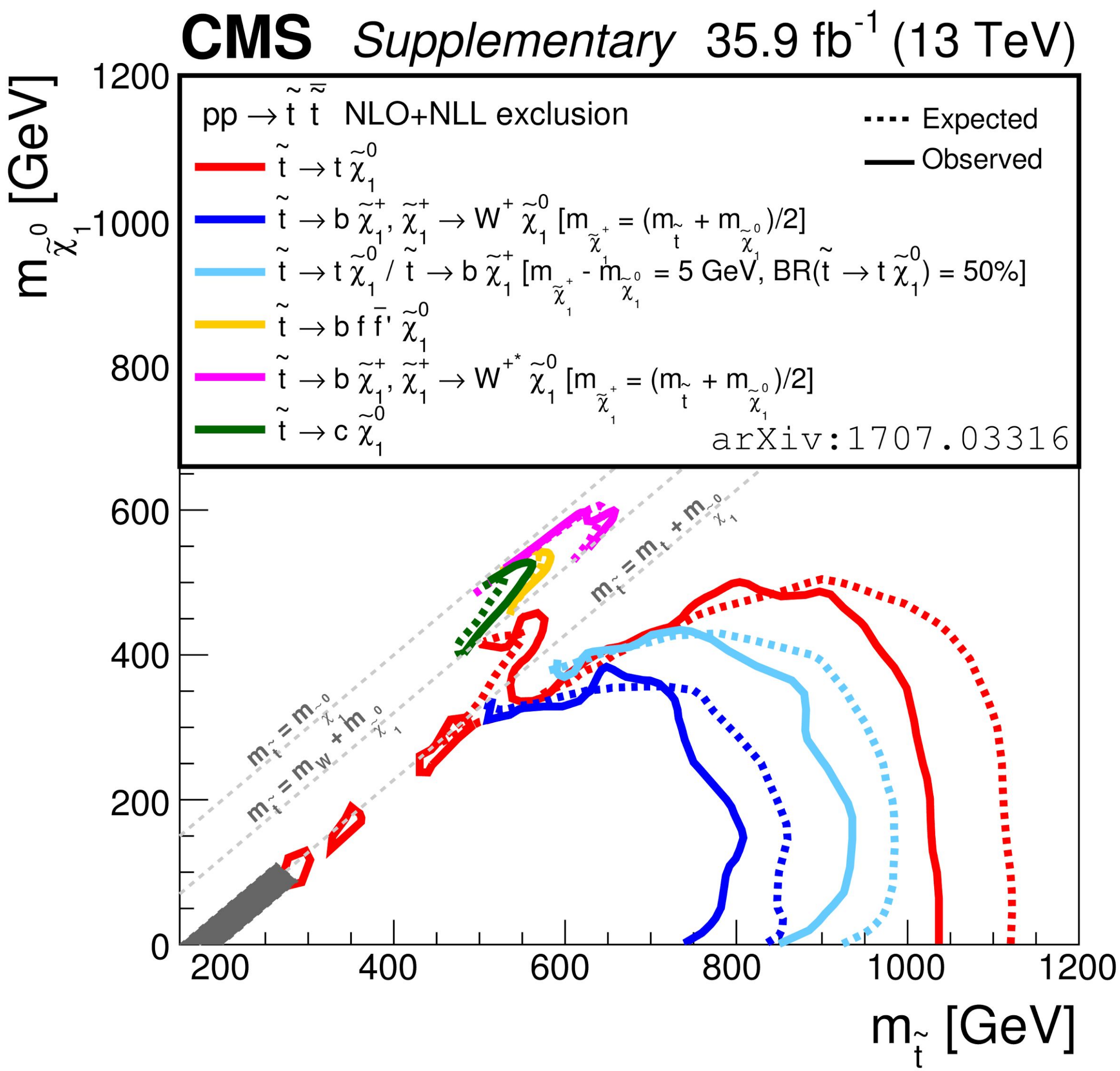


Stop 0ℓ: Low DeltaM Regions

Table 2: Summary of the 53 non-overlapping search regions that mainly target low Δm signal. The low Δm baseline selection is $N_{\mathrm{j}} \geq 2$, $p_{\mathrm{T}}^{\mathrm{miss}} \geq 250\,\mathrm{GeV}$, no leptons, $N_{\mathrm{t}} = N_{\mathrm{W}} = N_{\mathrm{res}} = 0$, $m_{\mathrm{T}}^{\mathrm{b}} < 175\,\mathrm{GeV}$ (when applicable), $|\Delta\phi(\mathrm{j}_1, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})| \geq 0.5$, $|\Delta\phi(\mathrm{j}_{2,3}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})| \geq 0.15$, and an ISR jet with $p_{\mathrm{T}}^{\mathrm{ISR}} \geq 300\,\mathrm{GeV}$, $|\eta| \leq 2.4$, $|\Delta\phi(j_{\mathrm{ISR}}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})| \geq 2$, and $S_{E_{\mathrm{T}}^{\mathrm{miss}}} \geq 10\,\sqrt{\mathrm{GeV}}$.

N_{j}	N_{b}	N_{SV}	$p_{\mathrm{T}}^{\mathrm{ISR}}$ [GeV]	$p_{\mathrm{T}}^{\mathrm{b}}$ [GeV]	$p_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]
2–5	0	0	≥500	—	450–550, 550–650, 650–750, ≥750
≥6		0			450–550, 550–650, 650–750, ≥750
2–5		≥1			450–550, 550–650, 650–750, ≥750
≥6		≥1			450–550, 550–650, 650–750, ≥750
≥2	1	0	300–500	20–40	300–400, 400–500, 500–600, ≥600
		0	300–500	40–70	300–400, 400–500, 500–600, ≥600
		0	≥500	20–40	450–550, 550–650, 650–750, ≥750
		0	≥500	40–70	450–550, 550–650, 650–750, ≥750
		≥1	≥300	20–40	300–400, 400–500, ≥500
≥2	≥2	≥0	300–500	40–80	300–400, 400–500, ≥500
≥2			300–500	80–140	300–400, 400–500, ≥500
≥7			300–500	≥140	300–400, 400–500, ≥500
≥2			≥500	40–80	450–550, 550–650, ≥650
≥2			≥500	80–140	450–550, 550–650, ≥650
≥7			≥300	≥140	450–550, 550–650, ≥650

0ℓ: Limits Summary



MT2 Analysis: Back up

Trigger	$p_T^{miss} > 120\,\text{GeV}$ and $H_T^{miss} > 120\,\text{GeV}$ or $H_T > 300\,\text{GeV}$ and $p_T^{miss} > 110\,\text{GeV}$ or $H_T > 900\,\text{GeV}$ or jet $p_T > 450\,\text{GeV}$
Jet selection	$R = 0.4$, $p_T > 30\,\text{GeV}$, $\lvert\eta\rvert < 2.4$
b tag selection	$p_T > 20\,\text{GeV}$, $\lvert\eta\rvert < 2.4$
p_T^{miss}	$p_T^{miss} > 250\,\text{GeV}$ for $H_T < 1000\,\text{GeV}$, else $p_T^{miss} > 30\,\text{GeV}$ $\Delta\phi_{min} = \Delta\phi\left(p_T^{miss}, j_{1,2,3,4}\right) > 0.3$ $\lvert\vec{p}_T^{miss} - \vec{H}_T^{miss}\rvert / p_T^{miss} < 0.5$
M_{T2}	$M_{T2} > 200\,\text{GeV}$ for $H_T < 1500\,\text{GeV}$, else $M_{T2} > 400\,\text{GeV}$
Veto muon	$p_T > 10\,\text{GeV}$, $\lvert\eta\rvert < 2.4$, $p_T^{sum} < 0.2\,p_T^{lep}$ or $p_T > 5\,\text{GeV}$, $\lvert\eta\rvert < 2.4$, $M_T < 100\,\text{GeV}$, $p_T^{sum} < 0.2\,p_T^{lep}$
Veto electron	$p_T > 10\,\text{GeV}$, $\lvert\eta\rvert < 2.4$, $p_T^{sum} < 0.1\,p_T^{lep}$ or $p_T > 5\,\text{GeV}$, $\lvert\eta\rvert < 2.4$, $M_T < 100\,\text{GeV}$, $p_T^{sum} < 0.2\,p_T^{lep}$
Veto track	$p_T > 10\,\text{GeV}$, $\lvert\eta\rvert < 2.4$, $M_T < 100\,\text{GeV}$, $p_T^{sum} < 0.1\,p_T^{track}$
p_T^{sum} cone	Veto e or μ: $\Delta R = \min(0.2, \max(10\,\text{GeV}/p_T^{lep}, 0.05))$ Veto track: $\Delta R = 0.3$

MT2: Limit Summary