Stealth/RPV SUSY Searches with CMS

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Overview

- **Presenting searches involving RPV and/or low p_T^{miss}**

  SUS-19-001

  Search for stealth SUSY with diphotons, jets and low MET

  SUS-23-001

  Search for Stealth/RPV stops using Double DisCo neural network method

  SUS-23-015

  Search for RPV SUSY in trilepton + jets final states

Introduction

- Searching for SUSY is well motivated
  - ➢ Can solve the hierarchy problem and offers potential DM candidates
- Typical SUSY signatures involve high p_T^{miss} from a massive invisible particle
  - ➢ No significant evidence has been observed
- Alternative SUSY signatures can involve low p_T^{miss}

Stealth scenario

- Light hidden sector with single scalar boson S and nearly mass degenerate $\tilde{S}$
- $\tilde{S} \to \tilde{G} S$ where $\tilde{G}$ is ~massless and stable (LSP)
- Small $\Delta(m_{\tilde{S}}, m_S)$ suppresses final state p_T^{miss}

RPV scenario

- p_T^{miss} source in R-parity conserved models, $\tilde{\chi}_1^0$ undergoes decay to 3 light quarks

Search for stealth SUSY with diphotons, jets and low MET

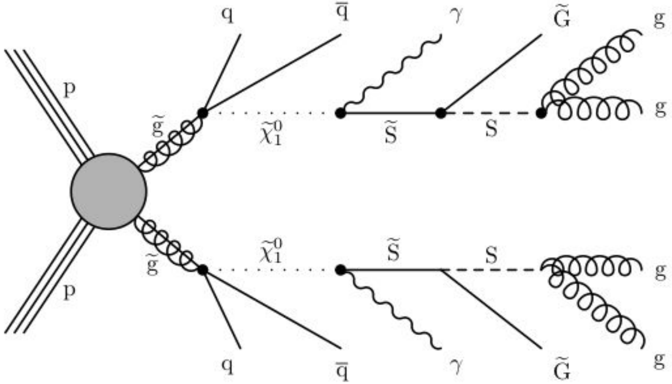
- Strong production of $\tilde{q}\bar{\tilde{q}}, \tilde{g}\tilde{g}$ to $\tilde{\chi}_1^0$ with subsequent decay through stealth sector

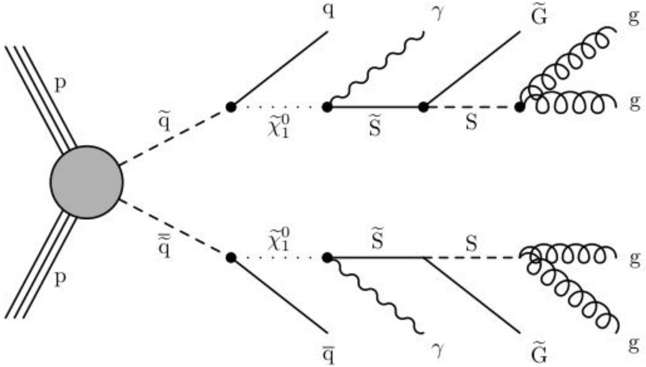
$$\tilde{g} \rightarrow qq\tilde{\chi}_1^0\,;\ \tilde{q} \rightarrow q\tilde{\chi}_1^0$$
$$\tilde{\chi}_1^0 \rightarrow \gamma\tilde{S}$$
$$\tilde{S} \rightarrow \tilde{G}S$$
$$S \rightarrow gg$$

Final state consists of: Jets + γ pair + low p_T^{miss}

Benchmark Model Parameters

$$m_{\tilde{S}} = 100\,\text{GeV},\ m_S = 90\,\text{GeV},\ \Delta(m_{\tilde{S}}, m_S) = 10\,\text{GeV}$$
$$1250 < m_{\tilde{g}} < 2350\,\text{GeV}$$
$$1100 < m_{\tilde{q}} < 2000\,\text{GeV}$$
$$150\,\text{GeV} < m_{\tilde{\chi}_1^0} < m_{\tilde{g}/\tilde{q}} - 100\,\text{GeV}$$

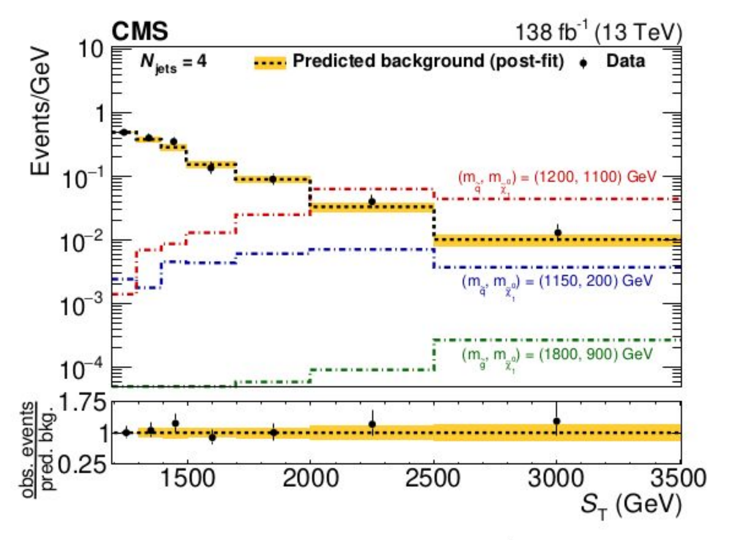




Search for stealth SUSY with diphotons, jets and low MET

Based on observable $S_T = p_T^{miss} + \sum p_T^{\gamma} + \sum p_T^{\text{jets}}$

$$\text{Preselection :}$$
$$N_\gamma = 2;\ m_{\gamma\gamma} > 90\,\text{GeV}$$
$$N_{\text{jets}} \geq 2;\ S_T > 1200\,\text{GeV}$$



Control Regions:

$N_{\text{jets}} = 2$: data-driven S_T shape sideband for high N_{jets}

$1200 < S_T < 1300$: data-driven normalization sideband per N_{jets}

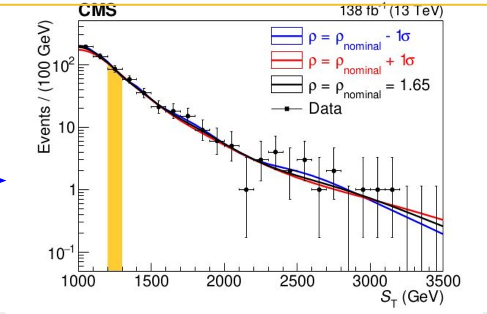
Signal Regions:

$N_{\text{jets}} = 4, 5, \geq 6$ in bins of $S_T > [1300, 1400, .., \geq 2500]$

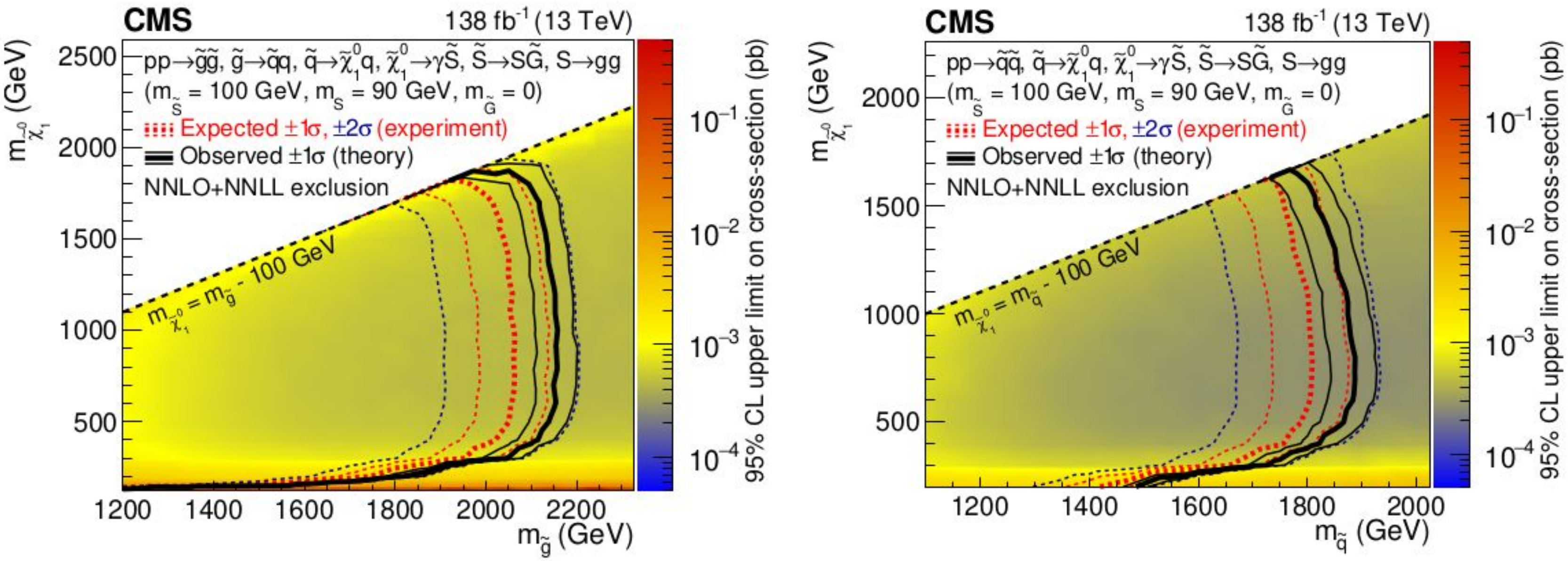
Background Prediction:

$$b(N_{\text{jets}}, S_{\text{T}}\,\text{bin}\,i) = N^{\text{evts}}(N_{\text{jets}}, 1200 < S_{\text{T}} < 1300\,\text{GeV}) \times f^{\text{AGK}}(S_{\text{T}}\,\text{bin}\,i) \times r(N_{\text{jets}}, S_{\text{T}}\,\text{bin}\,i),$$

MC based shape template correction

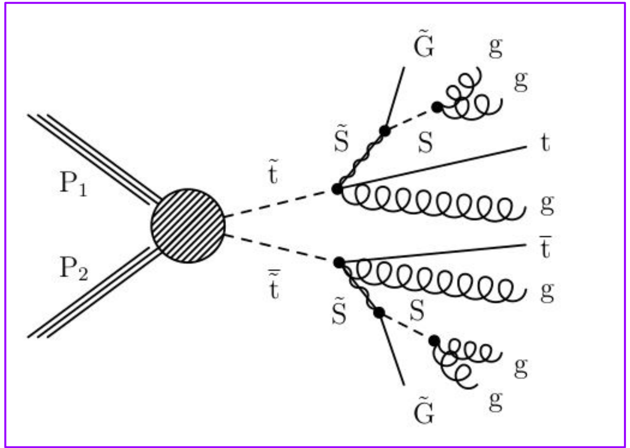


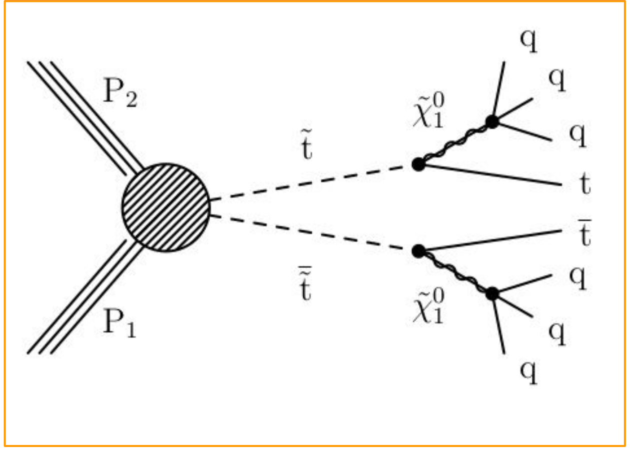
Search for stealth SUSY with diphotons, jets and low MET



- 95% CL U.L. on the gluino and squark production cross sections in stealth scenarios
- Excludes gluino (squark) up to 2150 (1850) GeV

Search for Stealth/RPV stops using Double DisCo neural network





- Top squark production with decay through stealth sector
- Top squark pair production with $\tilde{\chi}_1^0$ cascade decay

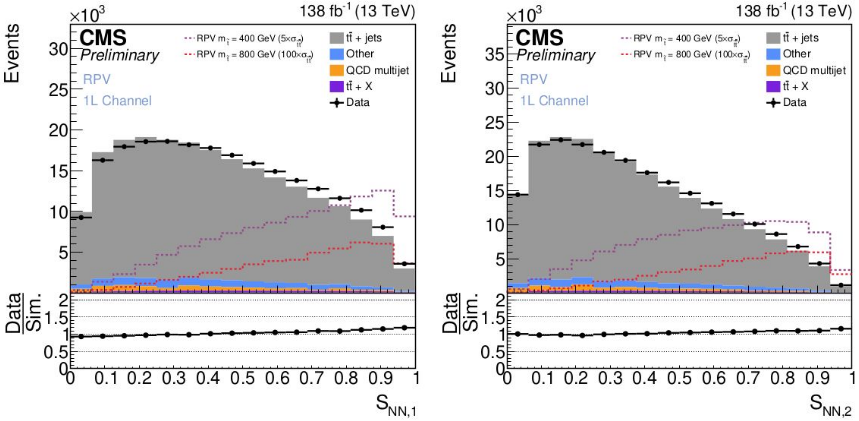
- Looking for both an R-parity violating (RPV) and a Stealth SUSY signature (SYY)
- The final state of both signal models is tt+ jets with little to no p_T^{miss}
- The analysis is split into three channels: zero lepton (0L), one lepton (1L), and two lepton (2L).

Search for Stealth/RPV stops using Double DisCo neural network

The primary challenge of this analysis is minimizing and estimating the tt+jets background event yield in the search regions.

The analysis strategy is as follows:

- Estimate tt+jets from data with simultaneous fit for signal + tt+jets using ABCDisCoTEC method
- Extract the prediction for the QCD multijet background from a dedicated control region
- Predict tt + X, Other, and Signal from simulation
- Combine the three analysis channels in a simultaneous multi-bin fit separated by jet multiplicity



NN automates ABCD background estimation

➢ Produces two independent discriminating quantities for tt+jets vs stealth (RPV) signals

Search for Stealth/RPV stops using Double DisCo neural network

- Signal and tt + jets estimated separately in each Njets bin with simultaneous fit to data in four 'ABCD' bins of $S_{NN,1}$ vs. $S_{NN,2}$ plane
- $S_{NN,1}$ and $S_{NN,2}$ are independent variables that discriminate signal from tt+ jets generated using ABCDisCoTEC neural network
- Floating parameters of fit are tt+ jets event yields in each ABCD bin (N_A, N_B , N_C , N_D) and signal strength
- Fit relies on key 'ABCD' constraint that $N_A = \kappa (N_B N_C / N_D)$, which is appropriate given independence of $S_{NN,1}$ and $S_{NN,2}$
  - ➢ κ is correction factor obtained from simulation

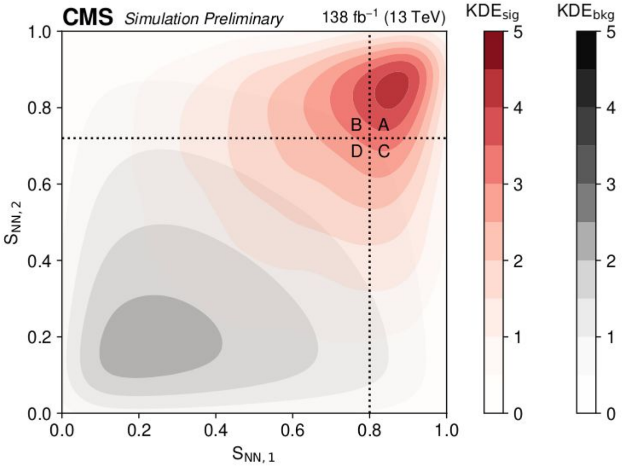
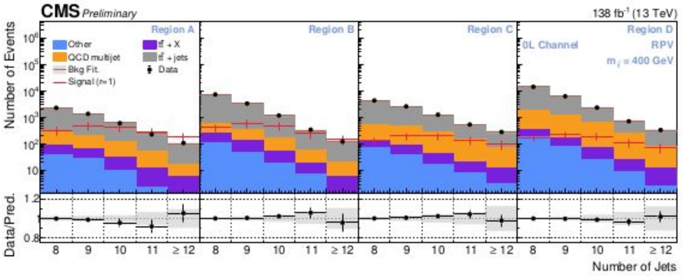


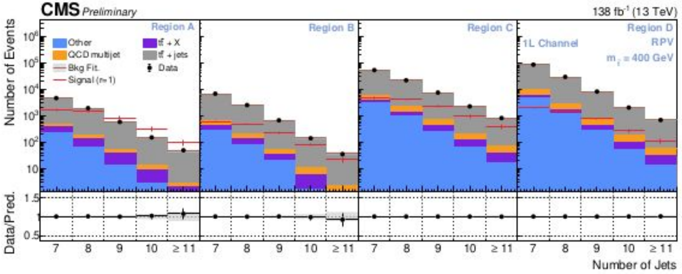
Figure: ABCDisCoTEC neural network generates two independent signal vs. background discriminators which are the basis variables for the ABCD background estimation

Search for Stealth/RPV stops using Double DisCo neural network

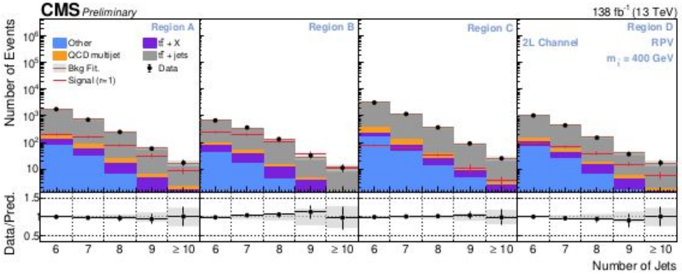
0L



1L

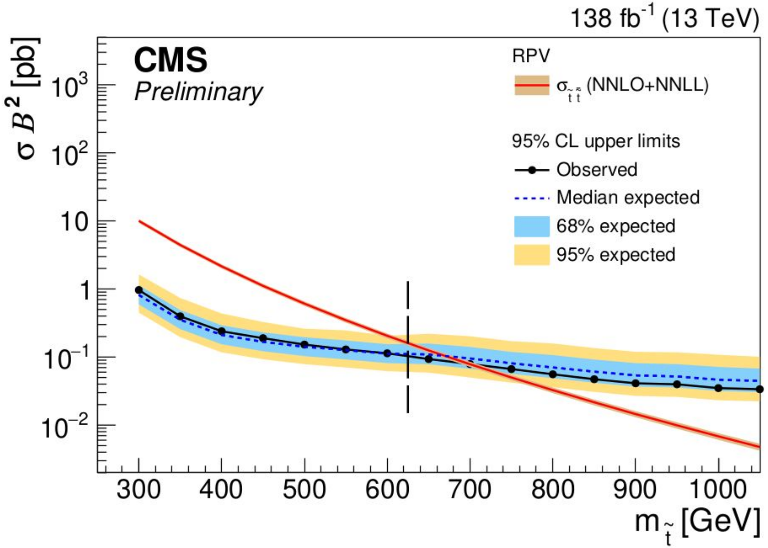


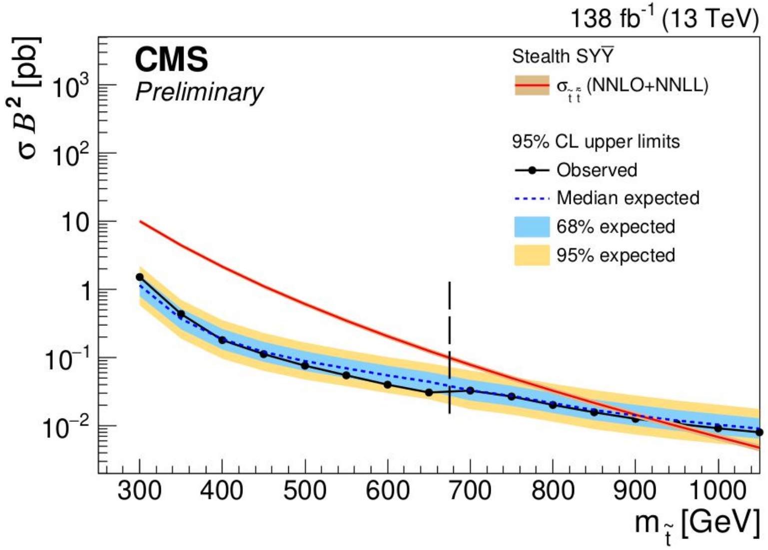
2L



- Background-only post-fit plots shown for the three channels
- Good agreement seen for all optimizations and signal models between background only fits and data

Search for Stealth/RPV stops using Double DisCo neural network





- Three channel combination limit plots shown for the RPV (left) and SYY (right) signal models
- No significance excess of events observed above the expected background for either model
- Mass exclusion limits set at 700 GeV for the RPV model and 930 GeV for the Stealth SYY model

Search for RPV SUSY in trilepton + jets final states

- Degenerate wino-like Neutralino/Chargino production with unstable light Neutralino

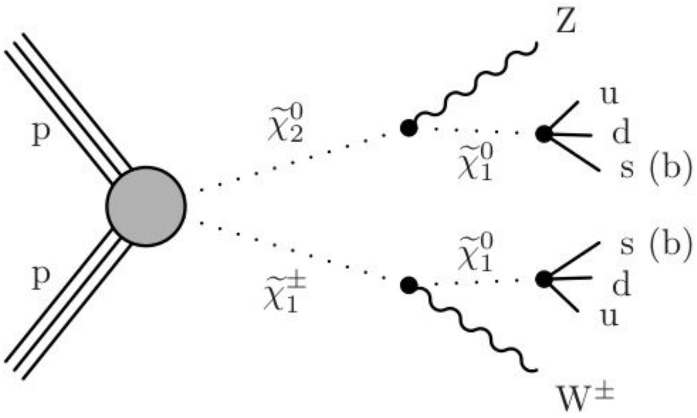
$$\tilde{\chi}_2^0 \rightarrow Z\tilde{\chi}_1^0\,;\;\; \tilde{\chi}_1^\pm \rightarrow W^\pm\tilde{\chi}_1^0$$

$$\tilde{\chi}_1^0 \rightarrow \mathrm{uds}$$

$$\tilde{\chi}_1^0 \rightarrow \mathrm{udb}$$

- Target final states consist of three-leptons and up to six jets
- One, two, and four lepton events to calibrate and probe for supersymmetric production of events with three leptons

$$S_T = p_T^{\mathrm{miss}} + \sum p_T^\ell + \sum p_T^{\mathrm{jets}}$$



Preselection

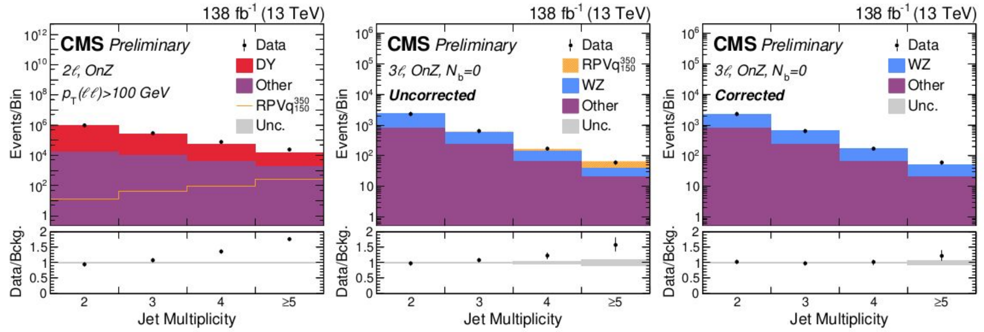
$$N_\ell = 1, 2, 3, 4\,;\;\; N_{\mathrm{jets}} > 2$$

$$N_{\text{b-jets}} \geq 1\ (\mathrm{RPVb})\,;\;\; N_{\text{b-jets}} = 0\ \ (\mathrm{RPVq})$$

$$\text{Bins in: } S_T,\ M_T,\ N_\ell,\ N_{\mathrm{jets}},\ N_{\text{b-jets}}$$

Search for RPV SUSY in trilepton + jets final states

- Many dedicated control regions to constrain background in corresponding N_ℓ, N_{jets}, $N_{\text{b-jets}}$ bins
- Poor Modeling in MC with high jet multiplicity
    - Corrections to SR high jet multiplicities are propagated from CR



SR

Bin No.	N_ℓ	M_{OSSF}	N_j	N_b	Additional selection criteria
1	4	2OnZ	-	-	-
2	4	OnZ	-	0	-
3	4	OnZ	-	>0	$S_T > 350$ GeV
4	3	BelowZ	-	-	$76 < M(3\ell) < 106$ GeV
5	3	-	-	-	no OSSF lepton pairs
6	3	AboveZ	0	-	-
7	3	AboveZ	>0	-	-
8-10	3	OnZ	0	-	3 M_T bins (GeV): 0, 30, 90, 150
11-13	3	OnZ	1	-	3 M_T bins (GeV): 0, 30, 90, 150
14-30	3	OnZ	2	0	17 S_T bins (GeV): 150-1650 (15×100 GeV), 1850, 2050
31-47	3	OnZ	3	0	17 S_T bins (GeV): 250-1750 (15×100 GeV), 1950, 2150
48-61	3	OnZ	4	0	14 S_T bins (GeV): 300-1500 (12×100 GeV), 1800, 2100
62-68	3	OnZ	>4	0	7 S_T bins (GeV): 400-1800 (7×200 GeV)
69-82	3	OnZ	2	>0	14 S_T bins (GeV): 150-1350 (12×100 GeV), 1550, 1750
83-97	3	OnZ	3	>0	15 S_T bins (GeV): 200-1500 (13×100 GeV), 1700, 1900
98-110	3	OnZ	4	>0	13 S_T bins (GeV): 350-1350 (10×100 GeV), 1550, 1750 1960
111-119	3	OnZ	>4	>0	9 S_T bins (GeV): 400-2200 (9×200 GeV)

Table 4: A summary of 1L, 2L, 3L and 4L control regions as defined in this analysis.

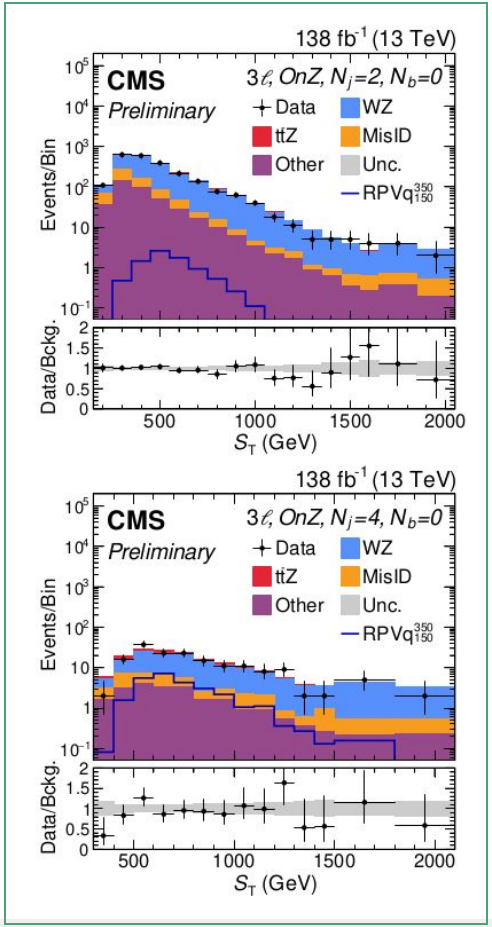
CR

CR name	OSSFn	M_{OSSF}	N_j	N_b	Other selections
1L W	–	–	–	0	$70 < M_T < 110$ GeV
1L $t\bar{t}$	–	–	>1	>0	$70 < M_T < 110$ GeV
2L DY	OSSF1	OnZ	–	–	–
2L $t\bar{t}$	OSSF0	–	–	–	$S_T > 300$ GeV, $e\mu$ opposite-sign
3L $Z\gamma$	OSSF1	BelowZ	–	0	$76 < M_{3\ell} < 106$ GeV
3L OnZ	OSSF1	OnZ	<2	–	–
3L MisID	OSSF1	OnZ	<2	–	$M_T < 50$ GeV
3L MisID	OSSF1	AboveZ	–	–	–
3L MisID	OSSF0	–	–	–	M_{SSSF} OnZ veto
3L WZ	OSSF1	OnZ	<2	0	$M_T > 50$ GeV
4L $t\bar{t}Z$	OSSF1	OnZ	–	>0	$S_T > 350$ GeV
4L ZZ	OSSF2	2OnZ	–	-	–
4L ZZ	OSSF2	1OnZ	–	0	–

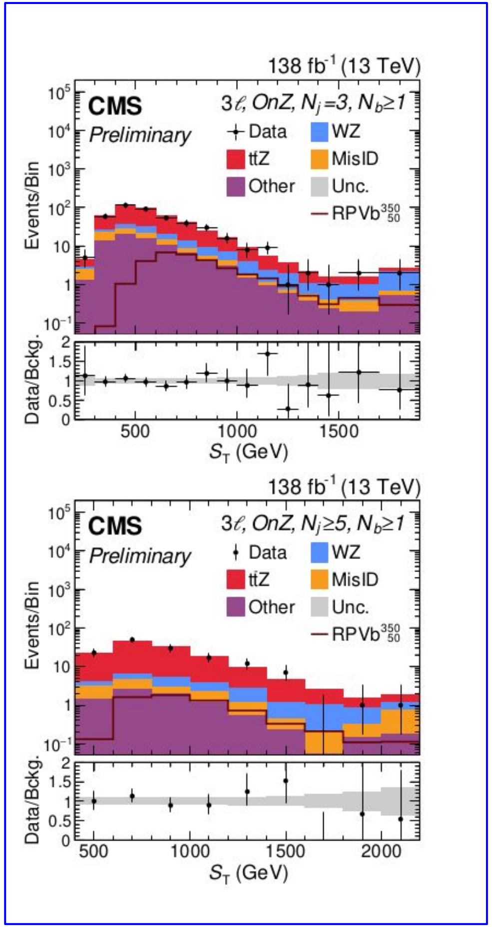
Search for RPV SUSY in trilepton + jets final states

- All SR bins are fit simultaneously in a binned maximum likelihood fit

- Data and post-fit model are in agreement across all SR categories

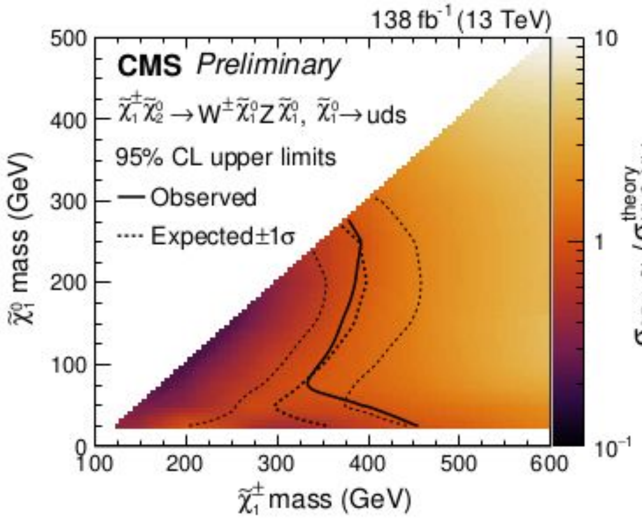


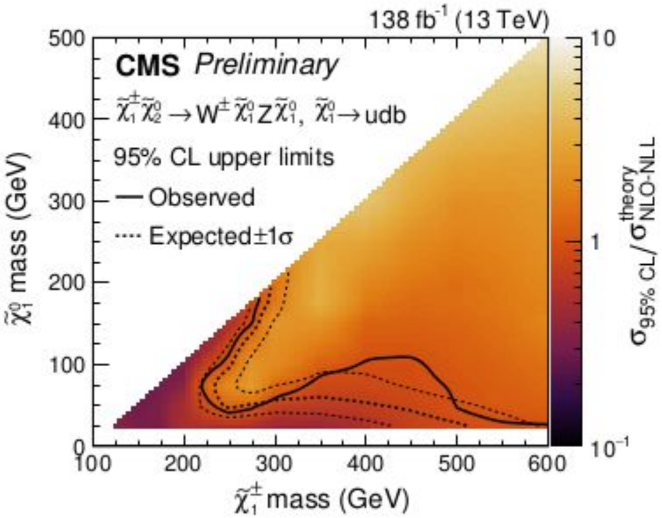
RPVq



RPVb

Search for RPV SUSY in trilepton + jets final states





RPVq **RPVb**

- 95% CL U.L. for the RPVq and RPVb models
- RPVq exclusion of neutralino with masses up to 275 GeV
- RPVb exclusion of neutralino with masses up to 180 GeV

Summary

- **Presented searches involving RPV/Stealth SUSY**
  - Search for stealth SUSY with diphotons, jets and low MET
    - compared to previously published results, achieved a ≈70% improvement
  - Search for Stealth/RPV stops using Double DisCo neural network method
    - previous search for these signatures observed a deviation with local significance of 2.8 standard deviations for a top squark mass of 400 GeV for the RPV model, which has not been confirmed by a new analysis
  - Search for RPV SUSY in trilepton + jets final states
    - the first direct bounds on this new class of supersymmetric extension of the SM
- No significant excesses found for RPV/Stealth SUSY so exclusion limits have been set
- Searches continue into Run 3