SEARCH FOR STOP QUARK PAIR PRODUCTION AT THE CMS EXPERIMENT

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(On behalf of the CMS Collaboration)

- Red LHC Workshop -

4-6 November 2020

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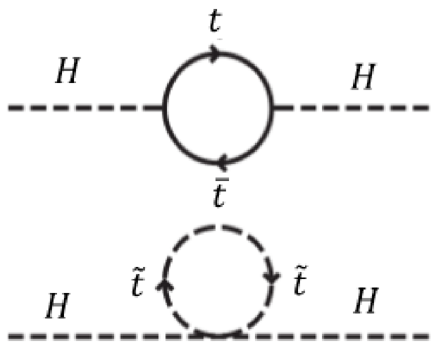
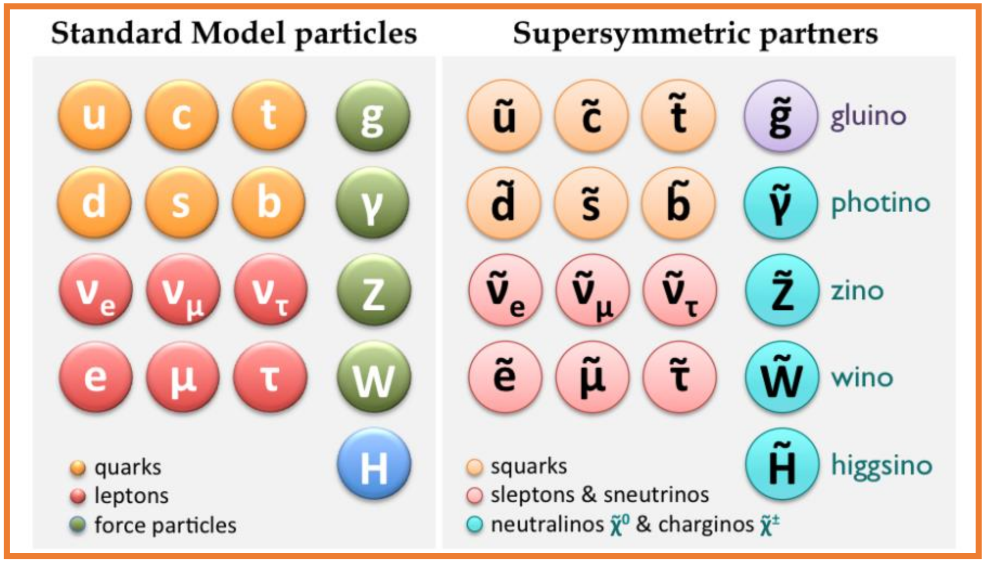
INTRODUCTION

- **Supersymmetry** is an extension of the SM that assigns a new particle (**superpartner**) to every SM particle differing only in ½ of spin.

- This model can solve several shortcomings of the SM:
    - **Unification.**
    - If R-parity is conserved, the lightest supersymmetric particle (**LSP**) is stable and potentially massive, providing a good candidate for **Dark Matter**.
    - The **hierarchy problem** of the quantum loop corrections to the Higgs mass, due mainly to the top quark, can be compensated by the effect of the top quark superpartner.

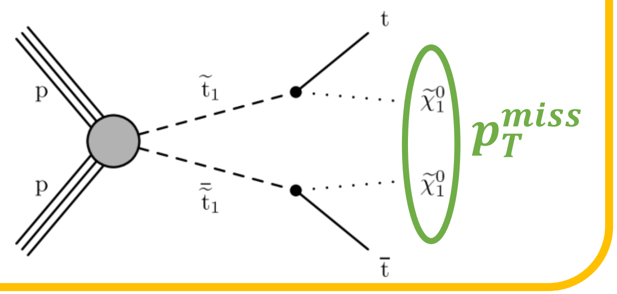


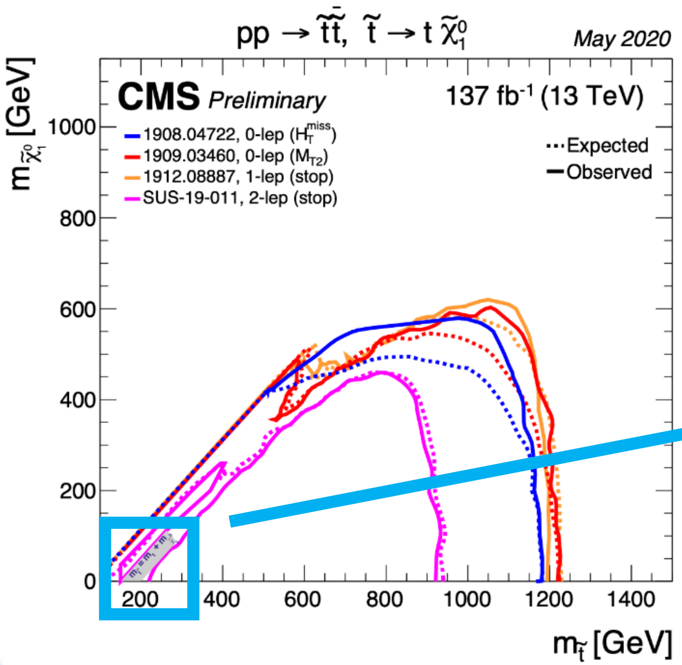


STOP QUARK SEARCHES

- The stop quark plays an essential role in understanding the SUSY models.
- Several searches with the full **Run 2 dataset** have been performed by the CMS Collaboration excluding stop masses up to 1.2 TeV, but most of these searches are not sensitive in the so-called "top corridor".
- Final states include **0, 1** and **2** leptons**:**
  - All jets: *Eur. Phys. J. C 80 (2020) 3*, *JHEP 10 (2019) 244*
  - Lepton + jets: *JHEP 05 (2020) 032*
  - Dileptons: arXiv:2008.05936, JHEP 03 (2019) 101 *(top corridor)

Simplified Model Spectra "T2tt"





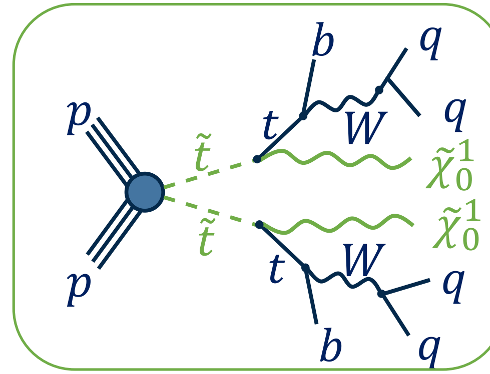
TOP CORRIDOR

- The mass difference between stop and neutralino is close to the **top mass**.
- Signal and $t\bar{t}$ background have **similar kinematics**, especially at low neutralino masses.
- Signal events can only be detected as an **excess on the $t\bar{t}$ cross section**.
- The **accurate estimation of $t\bar{t}$** process is very important to have sensitivity.

JHEP 03 (2019) 101

STOP 0 LEPTON SEARCH

Eur. Phys. J. C 80 (2020) 3



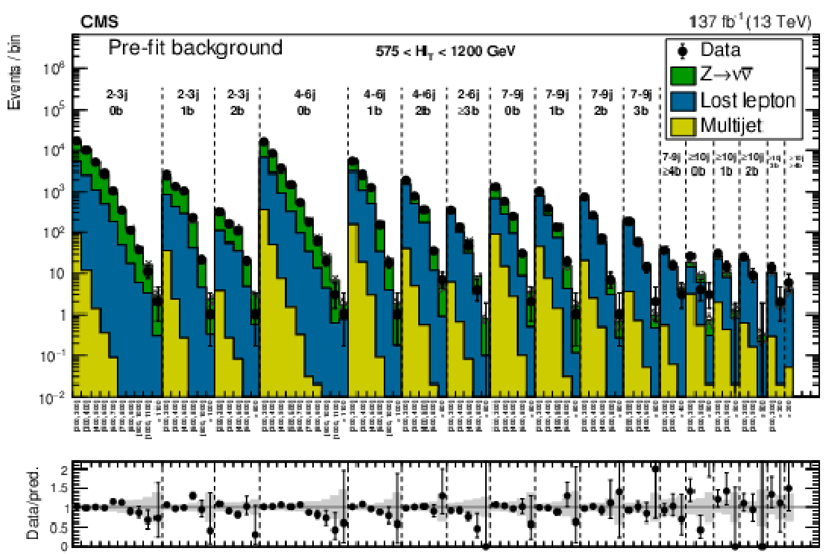
➢ Event selection and strategy

- **All-hadronic** search: veto on leptons and isolated tracks.
- Events classified by $\boldsymbol{H_T}$, $\boldsymbol{N_j}$, $\boldsymbol{N_b}$ **and** $\boldsymbol{M_{T2}}$.
- Monojet regions binned in N_b and jet p_T.

➢ Backgrounds estimated from data in control regions

- **Lost lepton**: genuine p_T^{miss} from semi-leptonic W decay (W+jets, tt+jets).
- **Irreducible background**: Z+jets events where the Z boson decays to neutrinos.
- **QCD multijet**: fake p_T^{miss} from mis-measured jets.

M_{T2} bins for medium H_T



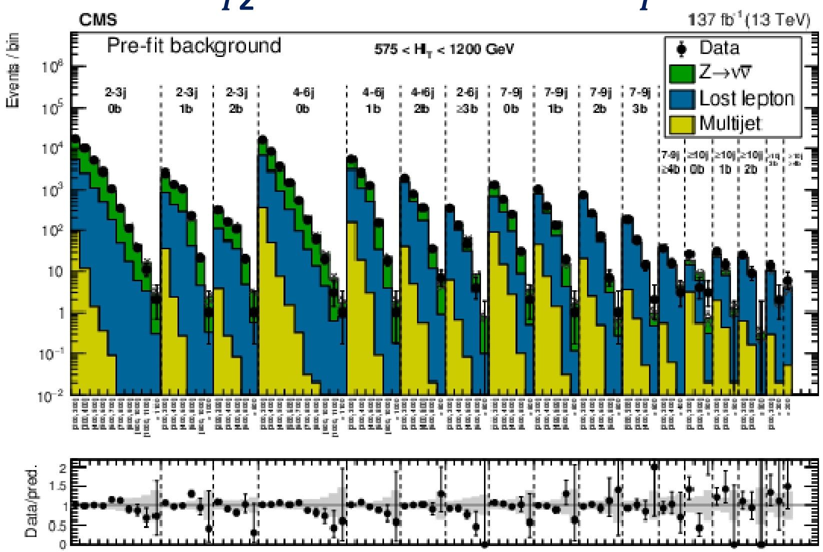
This is an inclusive analysis that has sensitivity also to other models.

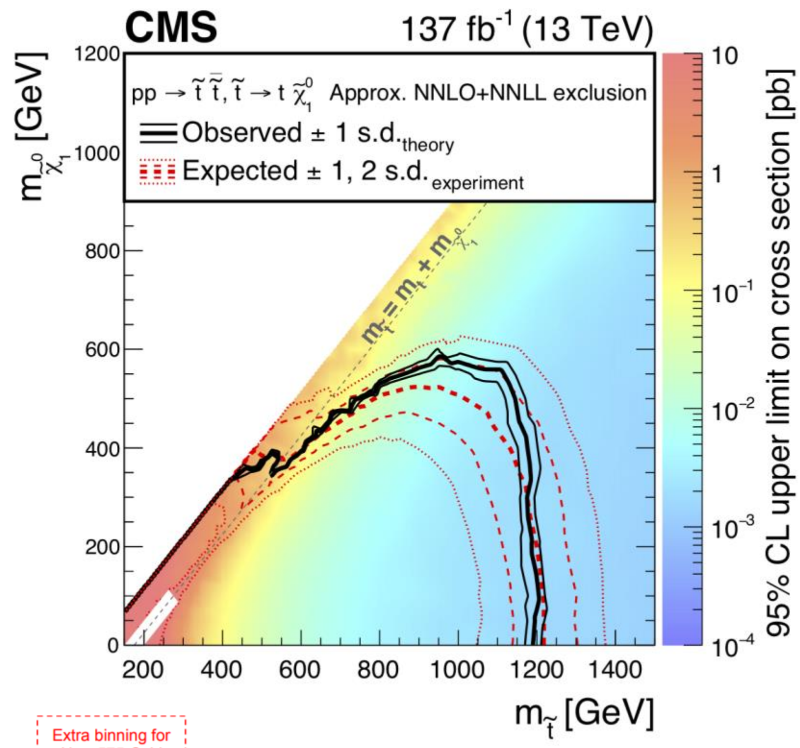
STOP 0 LEPTON SEARCH

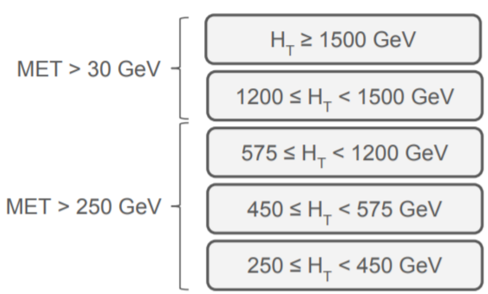
[Eur. Phys. J. C 80 (2020) 3]

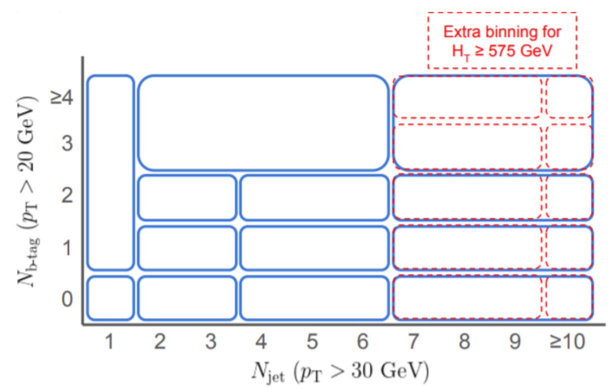
- Interpret **results** in terms of **exclusion limits** on simplified models of SUSY.

M_{T2} bins for medium H_T





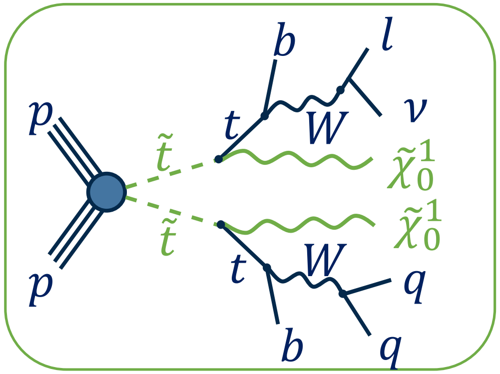




Stop masses excluded up to 1.2 TeV

STOP 1 LEPTON SEARCH

[JHEP 05 (2020) 032]

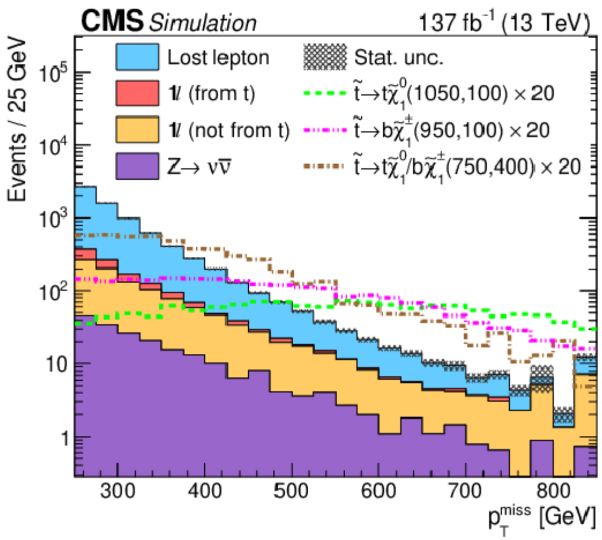


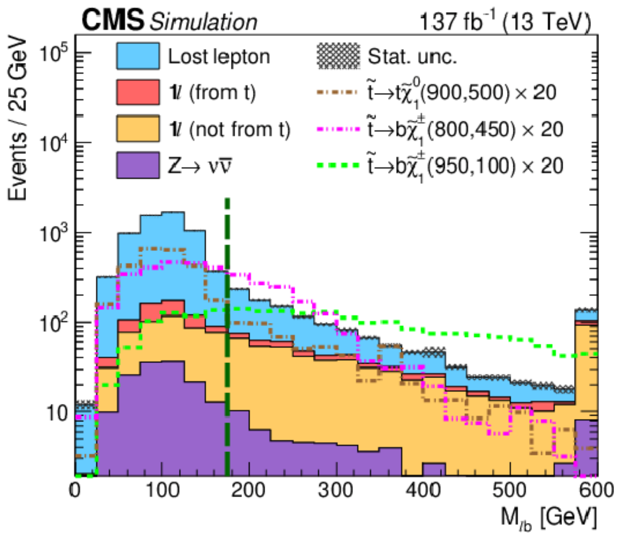
➢ Event selection and strategy

- Exactly **one** isolated **electron or muon**, $N_j \geq 2$, $N_b \geq 1$ and $p_T^{miss} > 250\ GeV$.
- Events classified by $\boldsymbol{N_j}$, $\boldsymbol{p_T^{miss}}$, $\boldsymbol{M_{lb}}$, $\boldsymbol{t_{mod}}$ and 3 top quark tagging categories (**untagged, merged and resolved**).
- **2 additional regions**: $\Delta m(\tilde{t}, \tilde{\chi}_0^1) \sim m_W$ and $\Delta m(\tilde{t}, \tilde{\chi}_0^1) \sim m_t$.

➢ Backgrounds estimated using control samples and simulation

- **Lost lepton**: one bad lepton from a W boson decaying leptonically ($t\bar{t}$, single top).
- **Z → νν** : events where the Z boson decays to neutrinos.
- **One lepton**: single W boson decaying leptonically without any additional genuine p_T^{miss}.

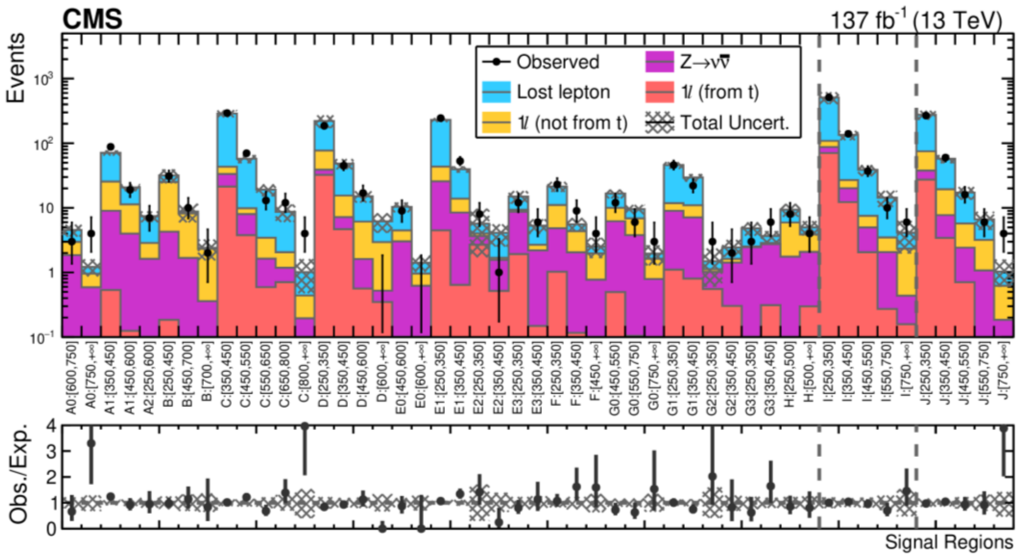




STOP 1 LEPTON SEARCH

JHEP 05 (2020) 032

➢ Interpret **results** in terms of **exclusion limits** on simplified models of SUSY.



Stop masses excluded up to 1.2 TeV

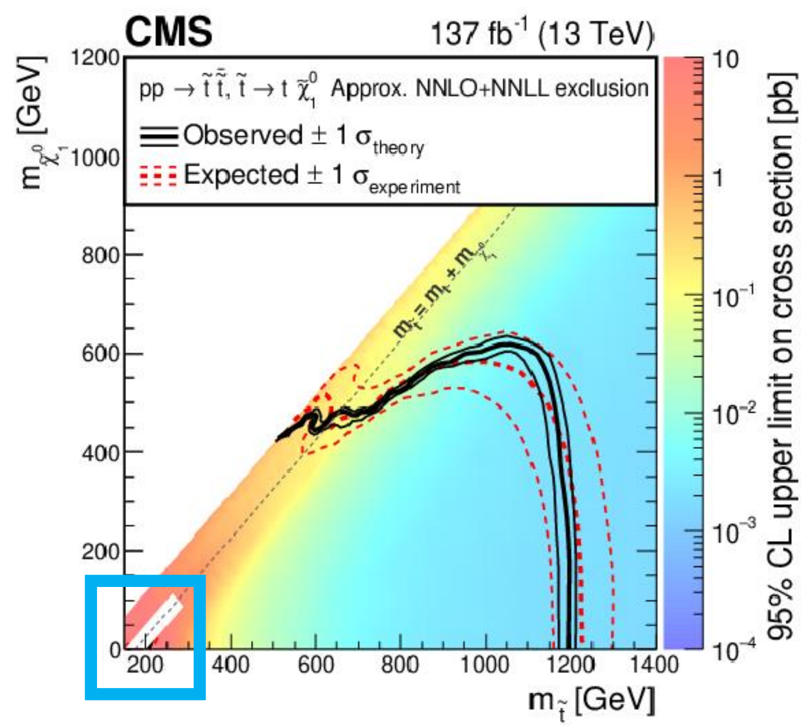
	N_J	t_{mod}	$M_{\ell b}$ [GeV]
A	2–3	> 10	≤ 175
B	2–3	> 10	> 175
C	≥ 4	≤ 0	≤ 175
D	≥ 4	≤ 0	> 175
E	≥ 4	0–10	≤ 175
F	≥ 4	0–10	> 175
G	≥ 4	> 10	≤ 175
H	≥ 4	> 10	> 175

X0: Inclusive
X1: Untagged
X2: Merged t quark tag
X3: Resolved t quark tag

Standard search

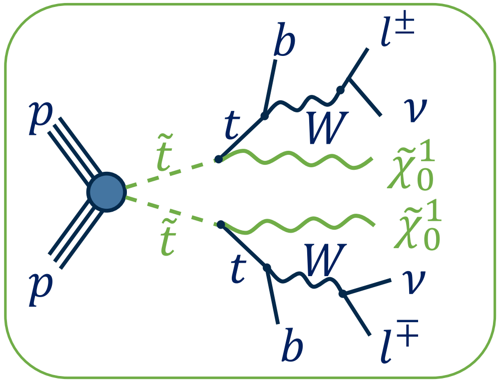
I: $N_J \geq 5$, $N_{b,med} \geq 1$ → **Top corridor search**

J: $N_J \geq 3$, $N_{b,soft} \geq 1$ → **W corridor search**



STOP 2 LEPTONS SEARCH

arXiv:2008.05936

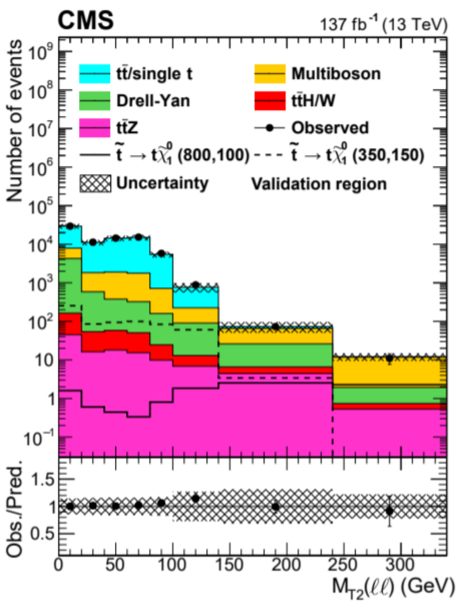


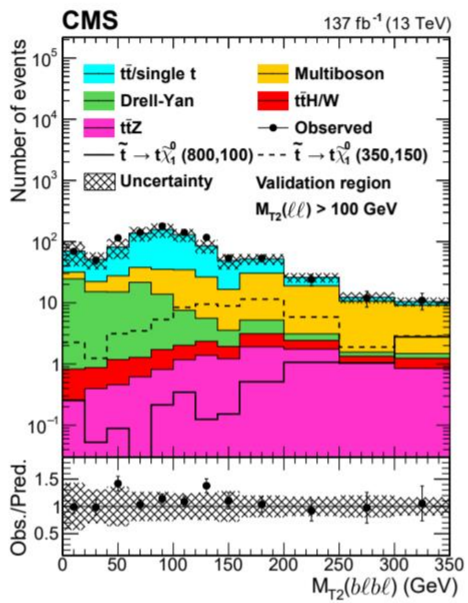
Event selection and strategy

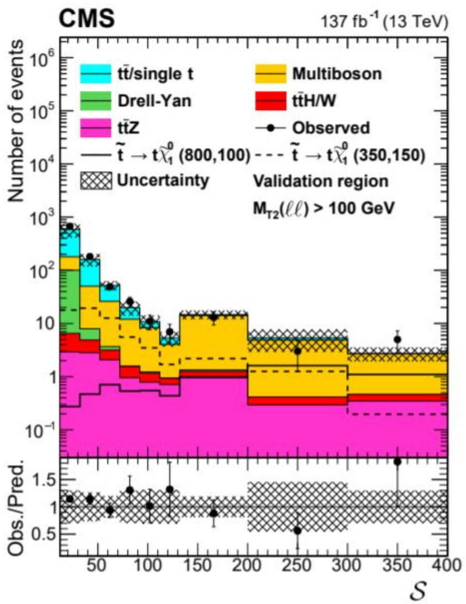
- OS lepton pair, $N_j \geq 2$, $N_b \geq 1$, $M(ll) \geq 20\ GeV$, $p_T^{miss} significance > 12$ and $M_{T2}(ll) > 100\ GeV$.
- Events classified by $\boldsymbol{p_T^{miss}\ significance}$, $\boldsymbol{M_{T2}(ll)}$ and $\boldsymbol{M_{T2}(blbl)}$.

Backgrounds, evaluated in control regions

- **Irreducible background**: Z+jets events where the Z boson decays to neutrinos.
- **Reducible DY and multiboson:** supressed with $p_T^{miss} significance$.
- $\boldsymbol{t\bar{t}}$ **+ jets at high** $\boldsymbol{M_{T2}(ll)}$**:** $t\bar{t}$ with additional p_T^{miss} from jets mismeasurements.





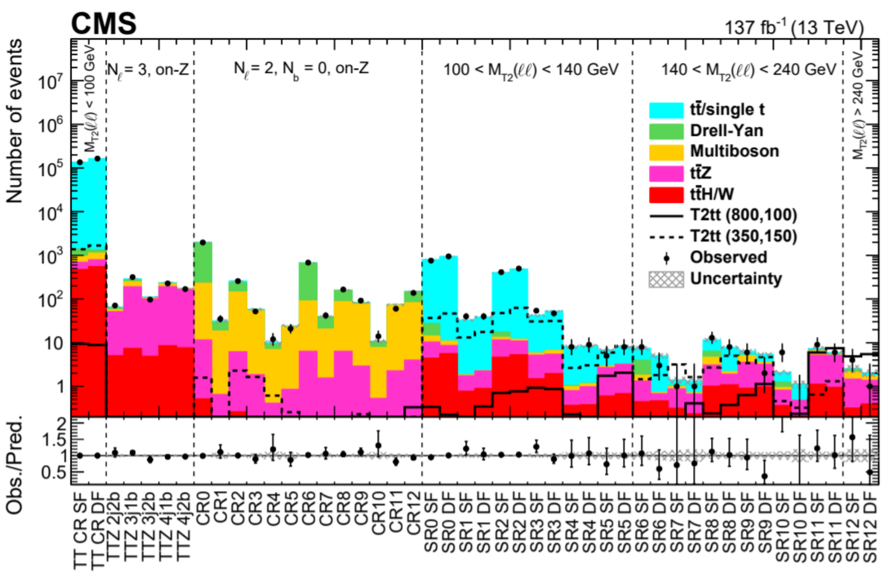


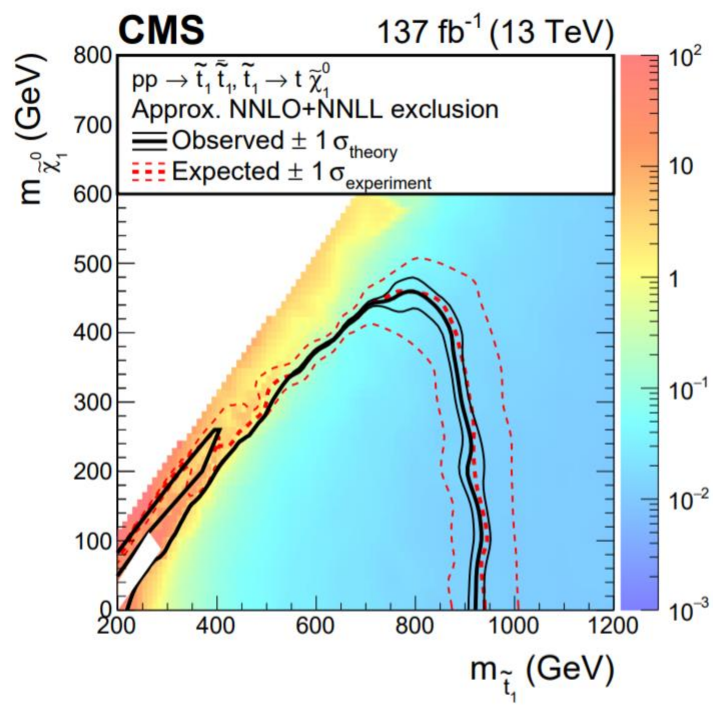
STOP 2 LEPTONS SEARCH

arXiv:2008.05936

➢ Interpret **results** in terms of **exclusion limits** on simplified models of SUSY.

$M_{T2}(b\ell b\ell)$ (GeV)	$\mathcal{S}$	$100 < M_{T2}(\ell\ell) < 140\,\text{GeV}$	$140 < M_{T2}(\ell\ell) < 240\,\text{GeV}$	$M_{T2}(\ell\ell) > 240\,\text{GeV}$
0–100	12–50	SR0	SR6	SR12
	>50	SR1	SR7	
100–200	12–50	SR2	SR8	
	>50	SR3	SR9	
>200	12–50	SR4	SR10	
	>50	SR5	SR11	





Stop masses excluded up to 925 GeV

STOP 2 LEPTONS SEARCH: TOP CORRIDOR

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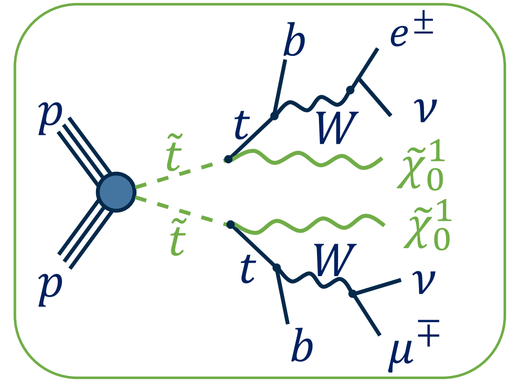


Event selection and strategy

- **2016 dataset** used, 36 fb^{-1}.
- OS eμ pair, $N_j \geq 2$ and $N_b \geq 1$.
- Search for degenerate stop pair production in 3 diagonals:

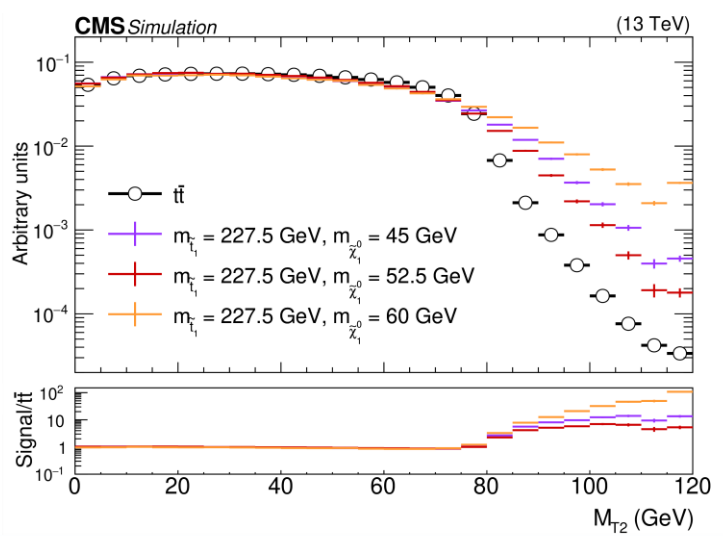
$$\Delta m(\tilde{t}, \tilde{\chi}_0^1) = m_t, m_t \pm 7.5\ GeV$$

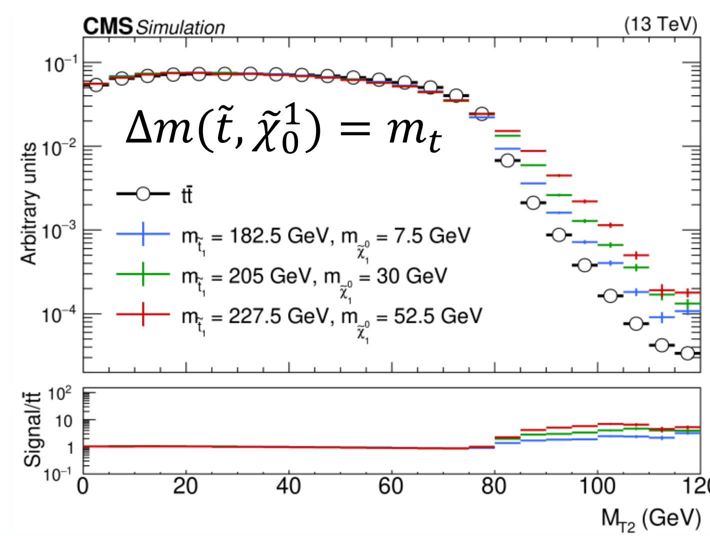
- Main discriminating variable: $\boldsymbol{M_{T2}(e\mu)}$

$$M_{T2}(e\mu) = \min_{\vec{p}_{T,1}^{miss} + \vec{p}_{T,2}^{miss} = \vec{p}_T^{miss}} \left(\max[m_T(\vec{p}_T^{l1}, \vec{p}_{T,1}^{miss}), m_T(\vec{p}_T^{l2}, \vec{p}_{T,1}^{miss})] \right)$$

Backgrounds

- The main background is $\boldsymbol{t\bar{t}}$ due to the similar kinematics with the signal process in this region. It is estimated from MC with an accurate knowledge.





STOP 2 LEPTONS SEARCH: TOP CORRIDOR

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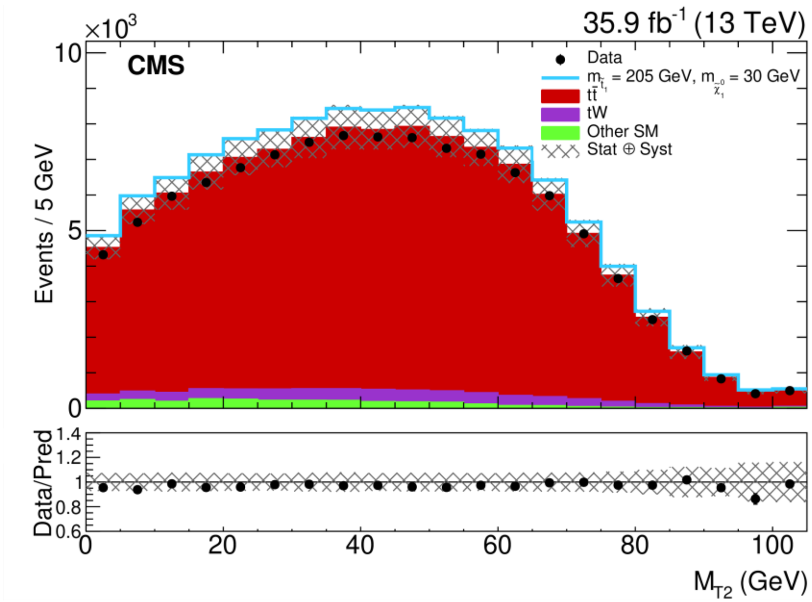
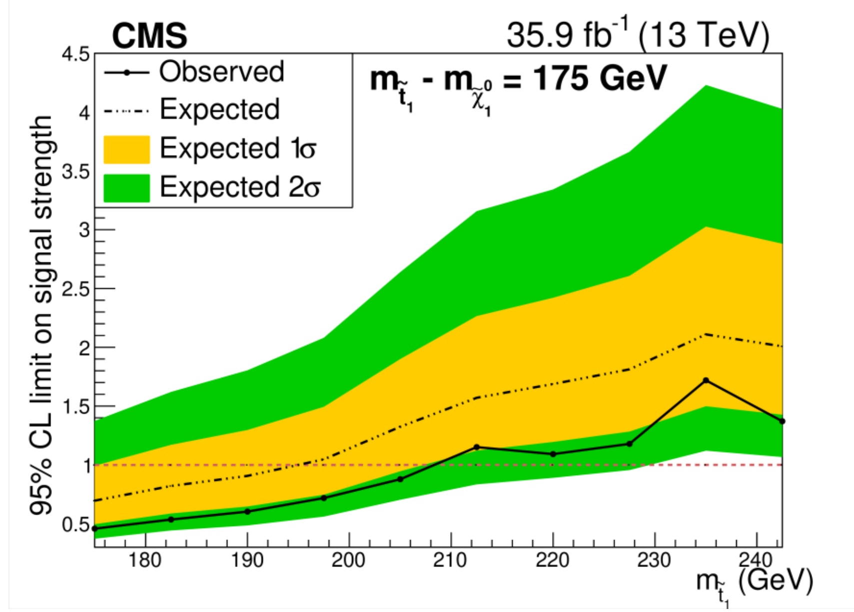
- **No excess** was observed and for the signal extraction the $\mathbf{M_{T2}}$ **distribution** is used.
- Results are presented in terms of **exclusion limits** on simplified models of SUSY.





Stop masses excluded up to:
208 GeV in $\Delta m(\tilde{t}, \tilde{\chi}_0^1) = m_t$
235 GeV in $\Delta m(\tilde{t}, \tilde{\chi}_0^1) = m_t$-7.5 GeV
242 GeV in $\Delta m(\tilde{t}, \tilde{\chi}_0^1) = m_t$+7.5 GeV

This result significantly extends the exclusion limits of stop quark searches at the LHC to higher stop masses in this region, that was previously unexplored.

· Currently analyzing the full Run 2 Dataset with the goal of exclude the full blank region.

STOP 2 LEPTONS SEARCH: TOP CORRIDOR

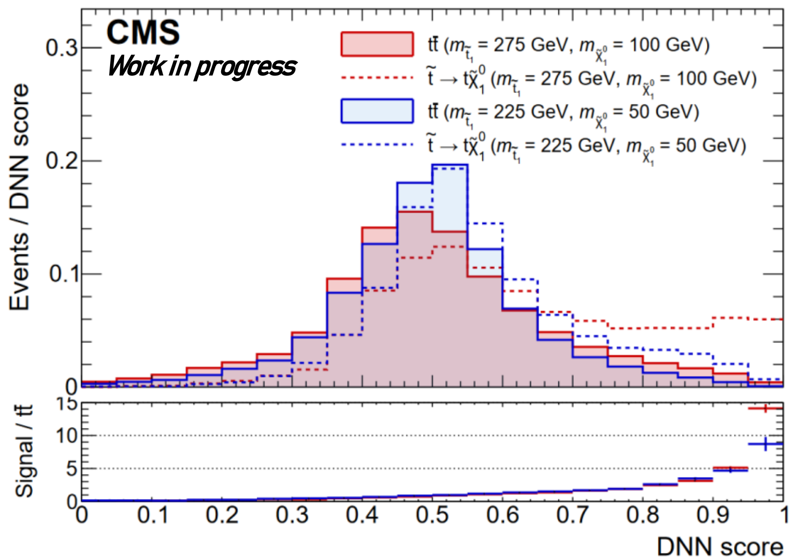
New direction being explored

- **Parametric Deep Neural Network**

With one DNN we have an specific model for each mass point! It is achieved by introducing stop and neutralino masses in the training.

- Only $t\bar{t}$ **samples** are taken as background.
- **13 training variables**:

$$m_{stop}, m_{LSP}, p_T^{e\mu}, \Delta\phi, \Delta\eta, p_T(l_0), \eta(l_0), p_T(l_1), \eta(l_1), p_T^{miss}, m_{e\mu}, m_{T2}(e\mu), H_T$$



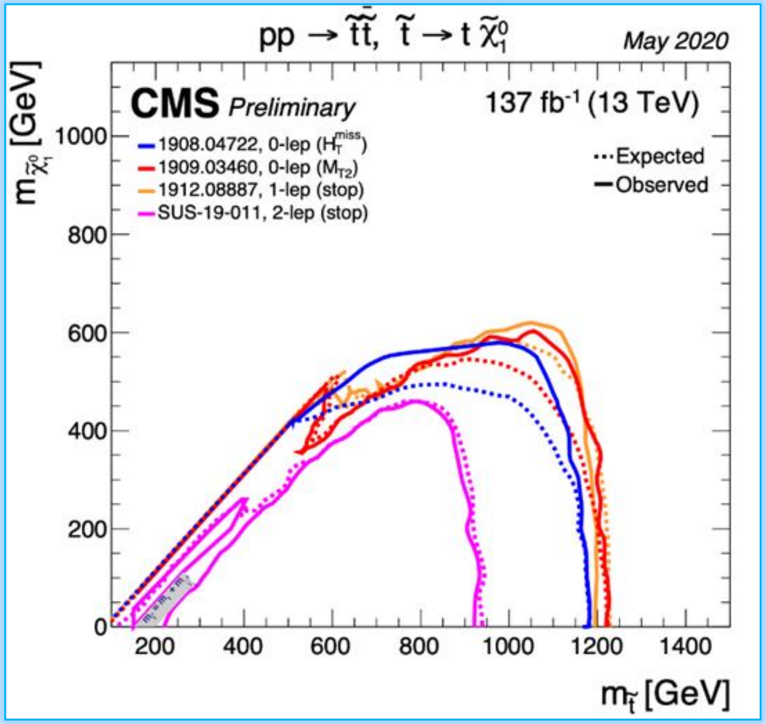
The DNN score is different in each point because of the parametric training. **We have one background distribution for each mass point**.

SUMMARY

- First analyses with **full Run 2 in CMS** achieve excellent exclusion limits, excluding stop quarks with masses up to **1.2 TeV.**

- **The Run 2 combination is on the way!**

All Hadronic analysis: SUS-19-010
+
Single lepton analysis: SUS-19-009
+
Dilepton analysis: SUS-19-011
+
Corridor analysis: SUS-20-002



STAY TUNED!

CMS Public SUSY Results:
http://cms-results.web.cern.ch/cms-results/public-results/publications/SUS/STOP.html

BACK UP

M_{T2} variable

- Stop 0 leptons:

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

$\vec{p}_T^{\,missX(i)}$ $(i = 1,2)$ are trial vectors obtained by decomposing $\vec{p}_T^{\,miss}$, and $M_T^{(i)}$ are the transverse masses obtained by pairing either of the trial vectors with one of the two pseudojets.

- Stop 2 leptons:

$$M_{\mathrm{T2}} = \min_{\vec{p}_{\mathrm{T},1}^{\,\mathrm{miss}} + \vec{p}_{\mathrm{T},2}^{\,\mathrm{miss}} = \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}} \left(\max\left[m_{\mathrm{T}}(\vec{p}_{\mathrm{T}}^{\,\ell 1}, \vec{p}_{\mathrm{T},1}^{\,\mathrm{miss}}), m_{\mathrm{T}}(\vec{p}_{\mathrm{T}}^{\,\ell 2}, \vec{p}_{\mathrm{T},2}^{\,\mathrm{miss}}) \right] \right)$$