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Searches for third generation supersymmetric particles with the CMS experiment

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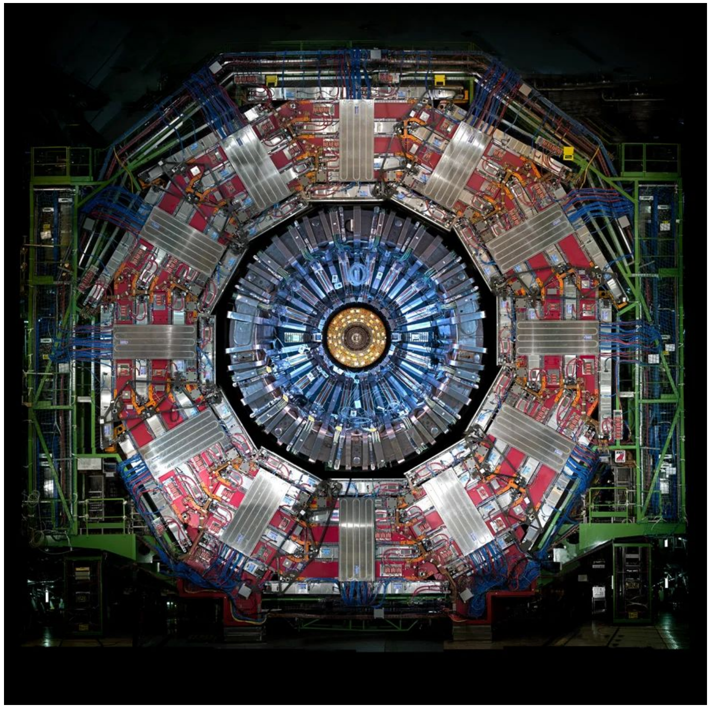
Consejo Superior de Investigaciones Científicas

EXCELENCIA MARIA DE MAEZTU

UC UNIVERSIDAD DE CANTABRIA

Outline of the talk

- Introduction to third generation Supersymmetry (SUSY).
- Selected SUSY results:
  - top squark (stop) searches:
    - → Stop in all hadronic final states: **Phys.Rev.D 104 (2021) 5, 052001**
    - → Stop hadronic & leptonic combination : **Eur.Phys.J.C 81 (2021) 11, 970**.
    - New! → Stop 4 body decays in 1l final states: **CMS-PAS-SUS-21-003**
  - Bottom squark (sbottom) searches.
  - Tau slepton (stau) searches:
    - New! → Direct stau production **CMS-PAS-SUS-21-001**
  - R-Parity Violation (RPV) and Stealth searches:
    - → Stop decays: **PhysRevD.104.032006**
  - Long lived particles (LLP) searches:
    - → 2 displaced leptons: **Eur. Phys. J. C 82, 153 (2022)**
- Summary and Outlook

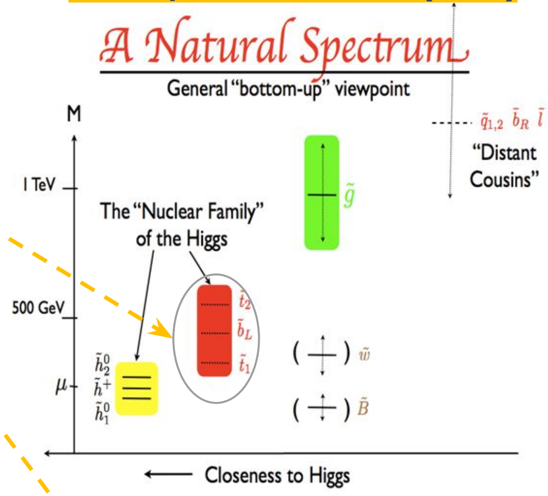


N.b. This is just a selection of analyses, the full up to date physics results are in:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

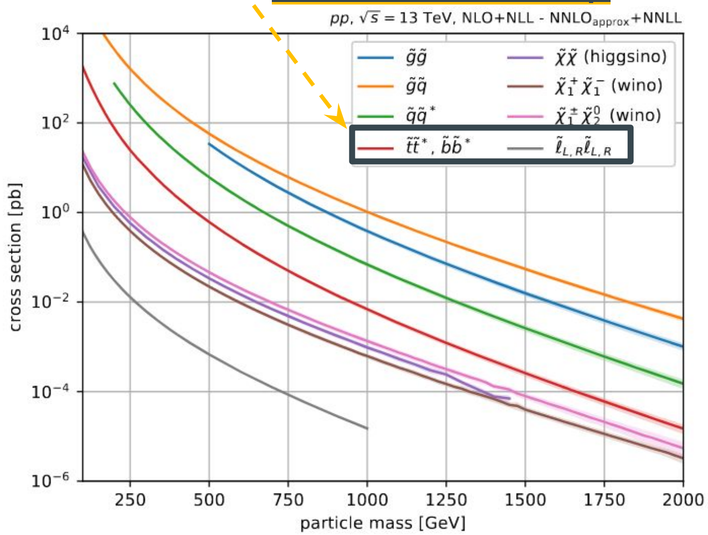
Why third generation?

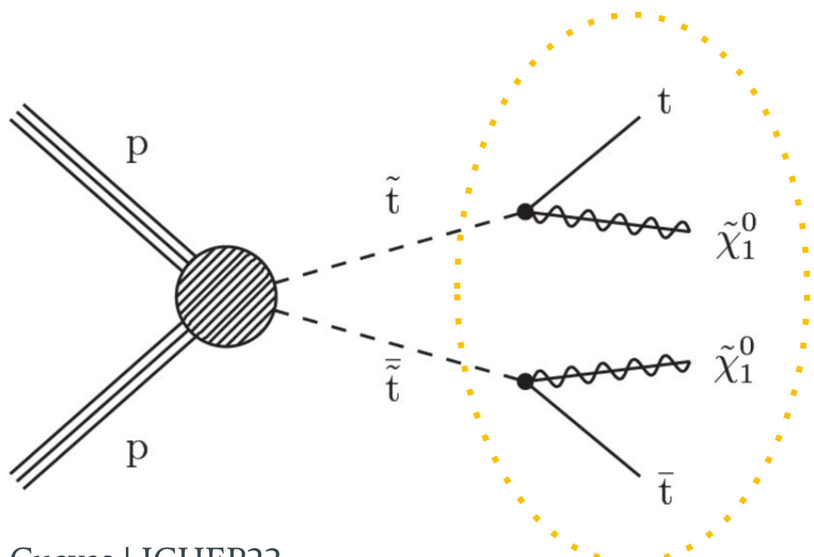
- In SUSY, Third generation sfermions are favoured by naturalness.
- Sizable cross-section at 13 TeV.
- Typically, decaying to a third generation quark/lepton.
- If R-Parity is conserved, decays involve lightest neutralino (LSP) →DM candidate.

Eur. Phys. J. C 74, 2801 (2014)



LHC SUSY XSec Group



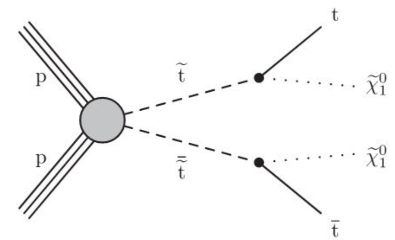


Stop searches: hadronic final states

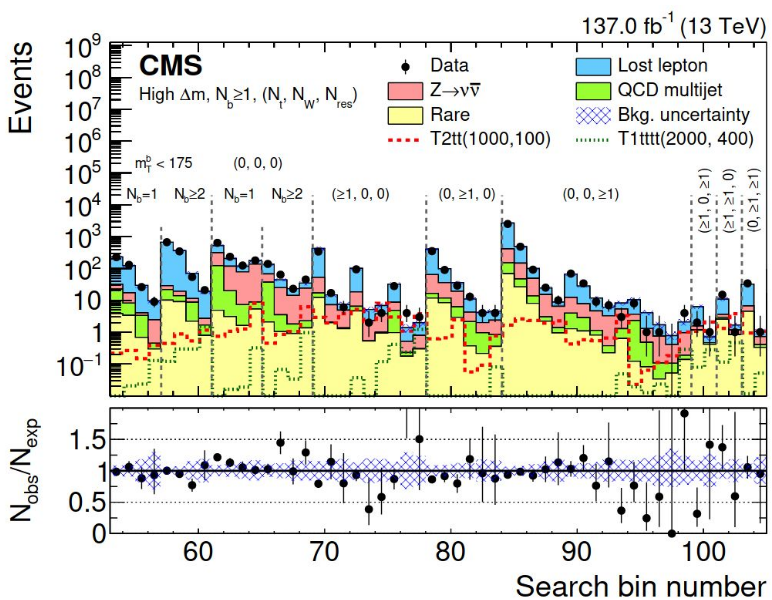
Phys.Rev.D 104 (2021) 5, 052001

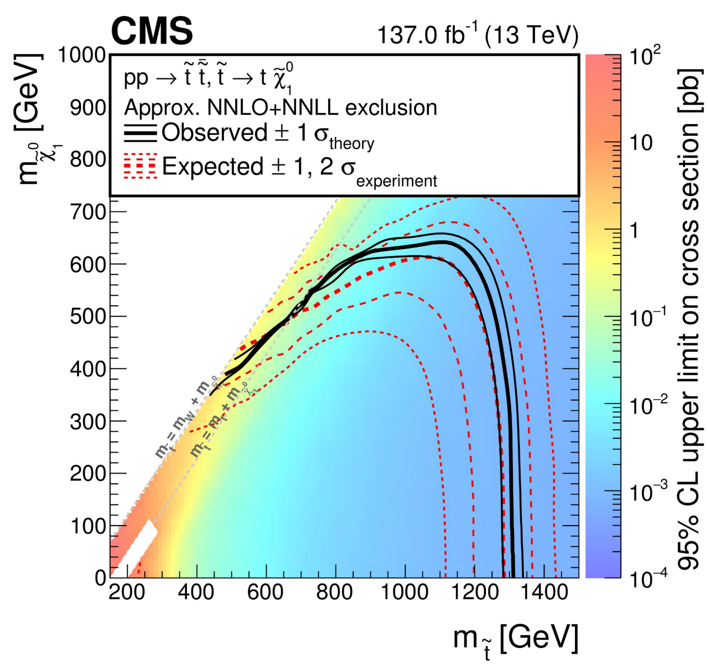
Targeting events with multiple jets, high p_T^{miss} and veto on leptons.
Dedicated object reconstructions in terms of Δm(stop, LSP):

- Low mass: soft b-tagging+initial state radiation (ISR) jets
- High mass: DNN to identify boosted top quarks or W bosons



Signal regions defined in bins of several event kinematic variables and multiplicities of dedicated objects

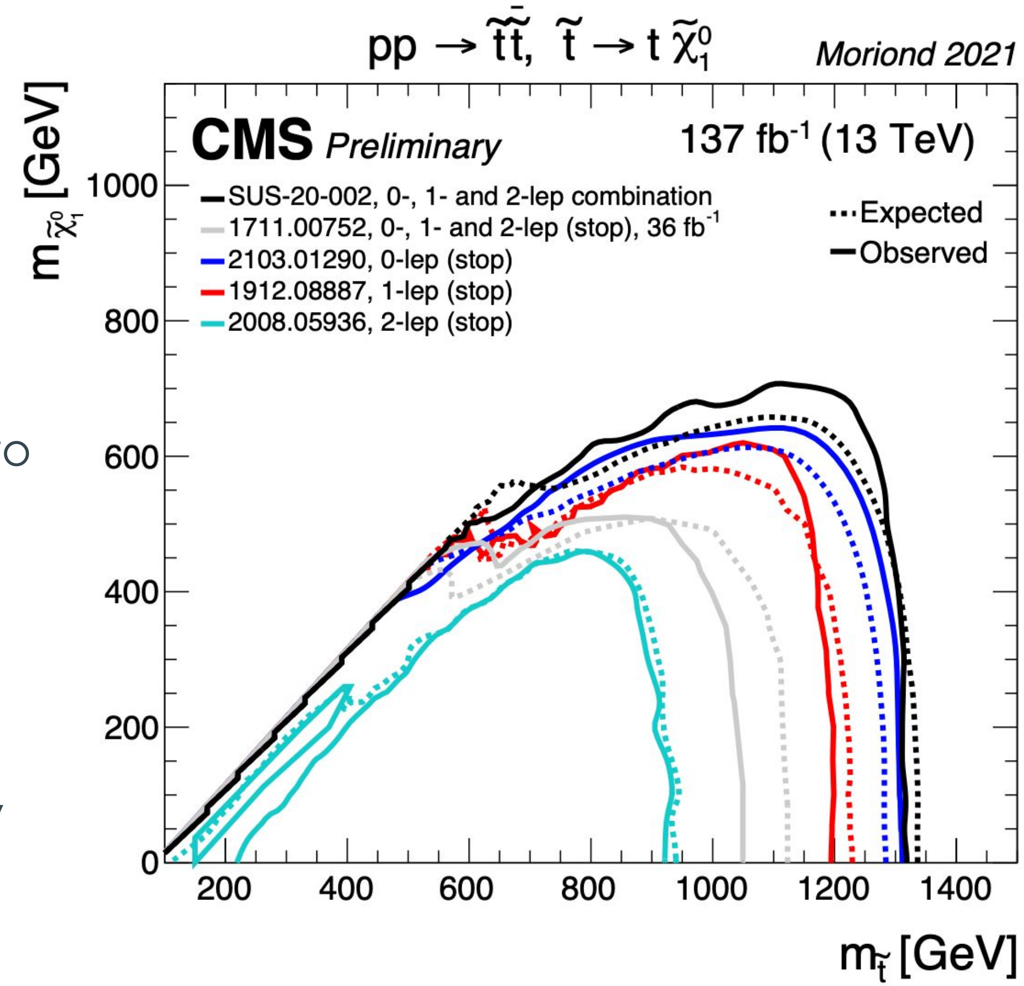




Top squark searches: summary

More details in Jaana's talk

- Several analyses have been made, searching for direct decays of stop in final states with hadrons and leptons.
- Analyses results have been combined in: **Eur.Phys.J.C 81 (2021) 11, 970**.
  - Stop masses excluded up to 1300 GeV for low LSP masses.
  - Exclusion of m_{stop} up to 1100 GeV for m_{LSP}= 700 GeV
  - $\Delta m \simeq m_{top}$ region also now excluded.

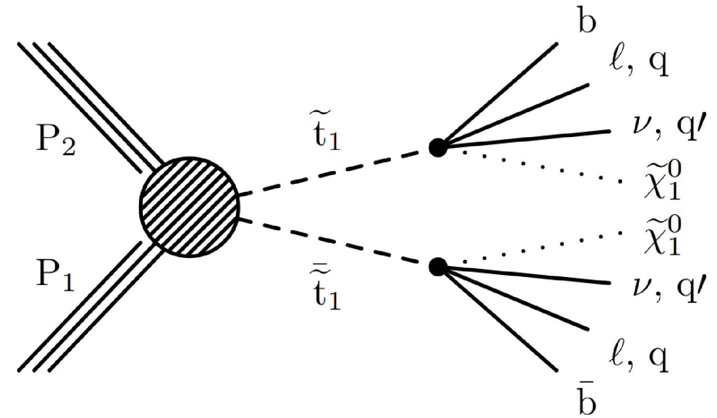


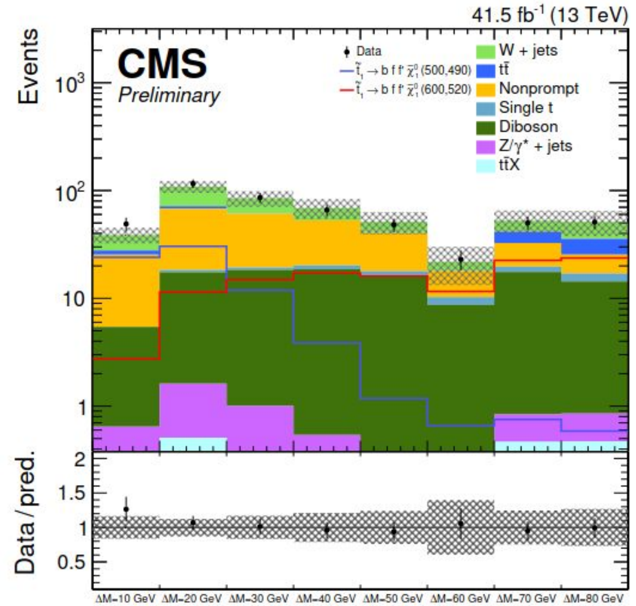
Top squark 4-body decays in 1l final states

More details in Zach's talk

CMS-PAS-SUS-21-003

- Targeting top squark four body decays, each of them involving a b-jet, two other fermions, and the LSP.
- SUSY signals are investigated so that the mass splitting (Δm) is smaller than the W boson's mass.
- Selecting events 1l plus jets, with high H_T and p_T^{miss}, and applying a using a boosted decision tree (BDT), using the p_T^{miss} together with lepton jets and b-tagged-jets variables as discriminant.
- The BDT is trained per each Δm.
- Main backgrounds: W+jets and ttbar+jets.



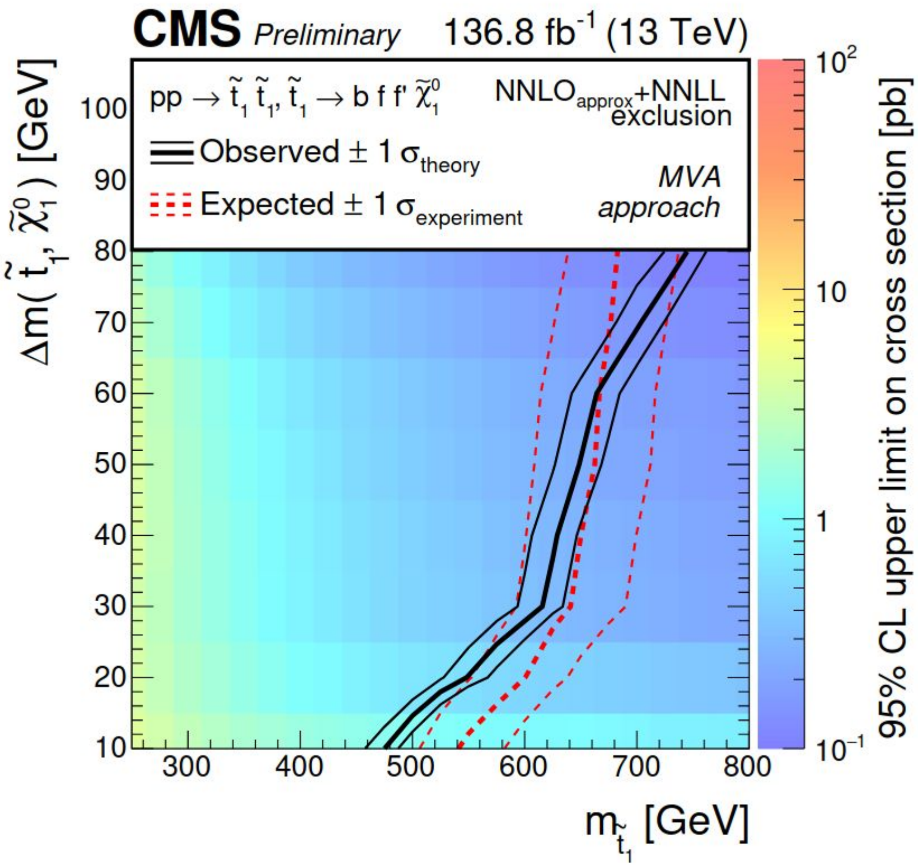


Top squark 4-body decays in 1l final states

More details in Zach's talk

CMS-PAS-SUS-21-003

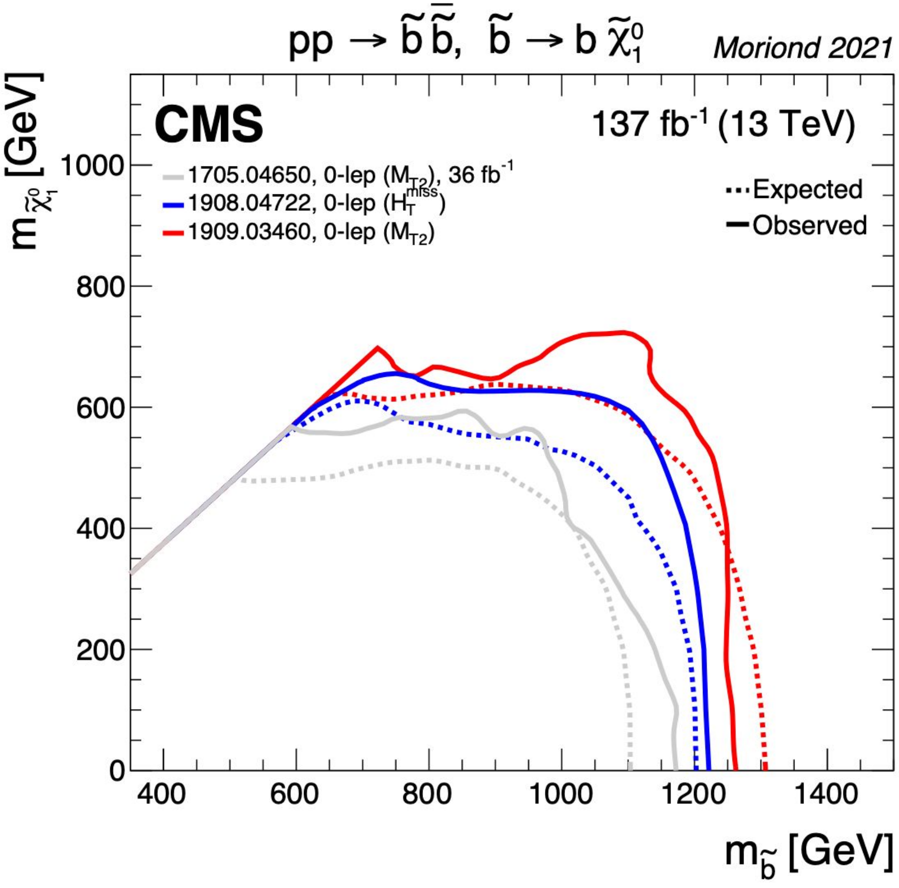
- No statistically significant deviations between data and expectations were found.
- Limits set up on the stop mass to 480 GeV for Δm=10 GeV and of 700 GeV for Δm=80 GeV
- ~100 GeV higher than CMS analysis with 2016 data (JHEP 09 (2018) 065)
- ~120 GeV more sensitive than ATLAS' equivalent analysis (JHEP 04 (2021) 174) in the low Δm area



Bottom squark searches: summary

- Several analyses have been made by CMS targeting the bottom squark, mainly in the all hadronic channel, taking advantage of the b-tagging techniques.

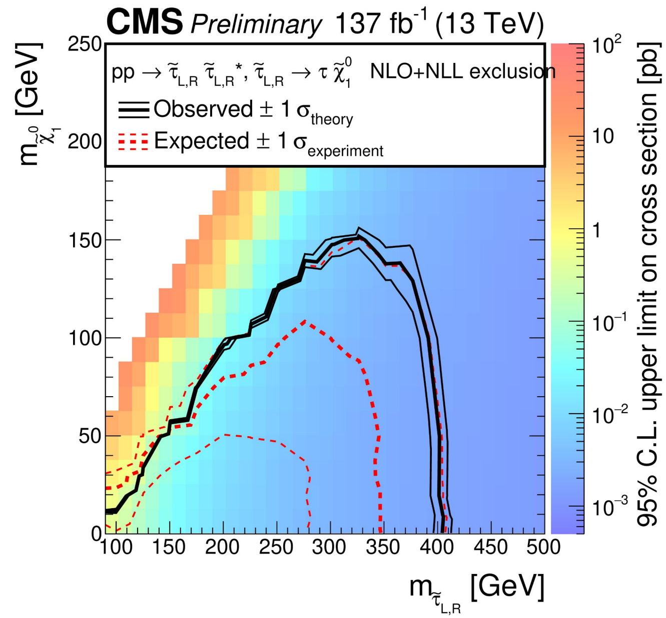
- Limits were on the sbottom mass were set up to 1200 GeV for low LSP masses, and up to 800 GeV in the compressed area.

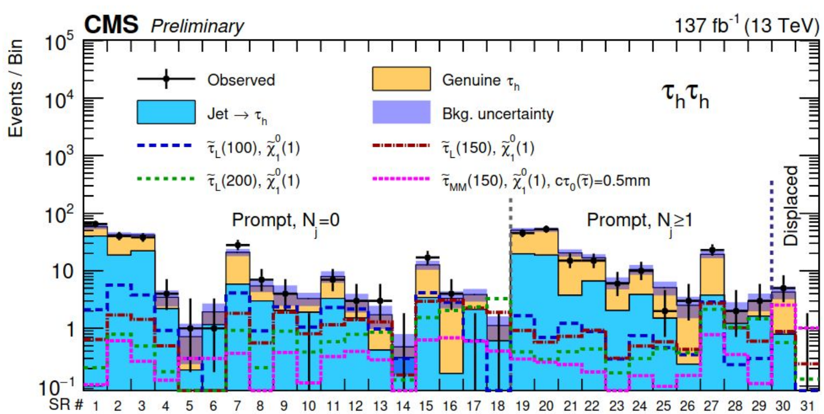


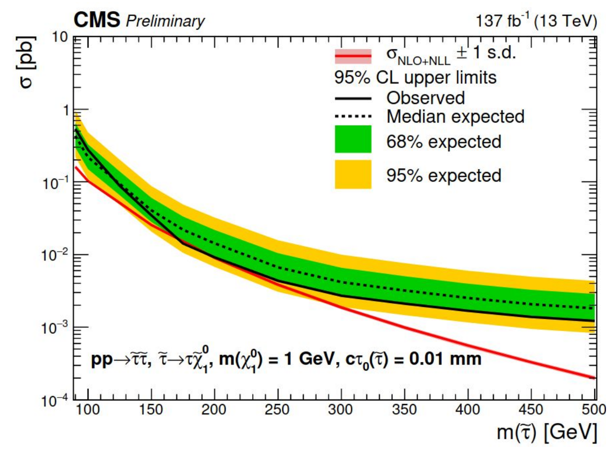
Direct tau squark pair production

CMS-PAS-SUS-21-001

- Looking for stau pair production where each stau decays to a hadronic τ (τ_h) and the LSP:
- Using the sum of each τ_h m_T (Σm_T) as discriminant variable, as well as the m_{T2}.
- Considers also displaced leptons
- stau masses up to 400 GeV excluded for the prompt case, and between 150 and 220 GeV for $c\tau_0$=0.1 mm



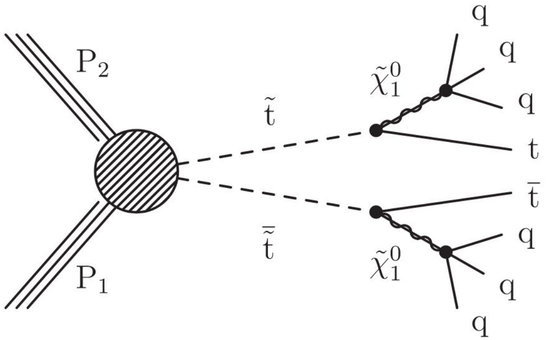


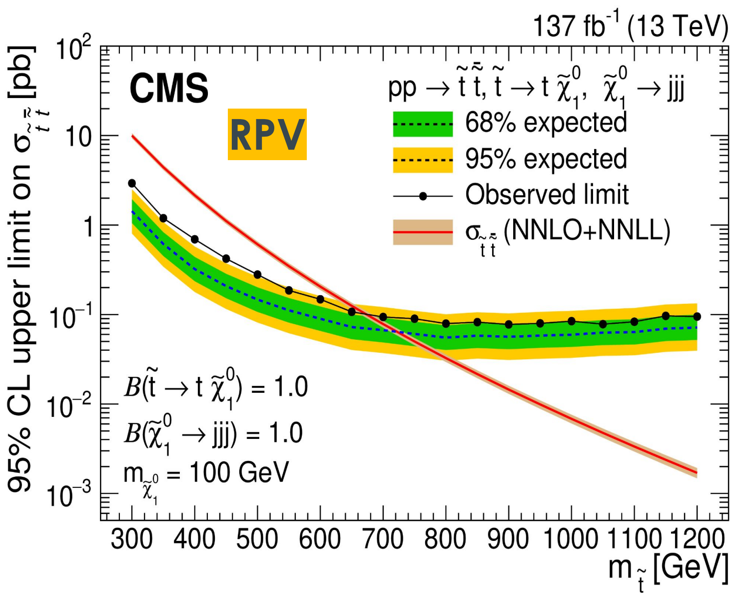


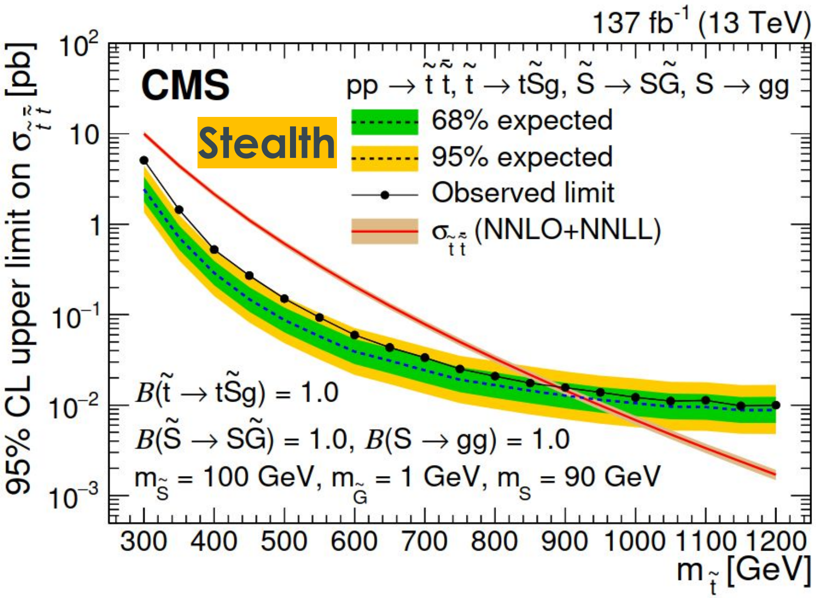
R-Parity Violation and stealth searches at CMS

PhysRevD.104.032006

- R-Parity violation scenarios also studied by CMS via stop decays in final states with no p_T^{miss} (besides neutrinos).
- Results also interpreted for a model where the stop decays through an hidden (stealth) SUSY sector
- Excluded masses up to 670 GeV for RPV and 870 GeV for Stealth SUSY





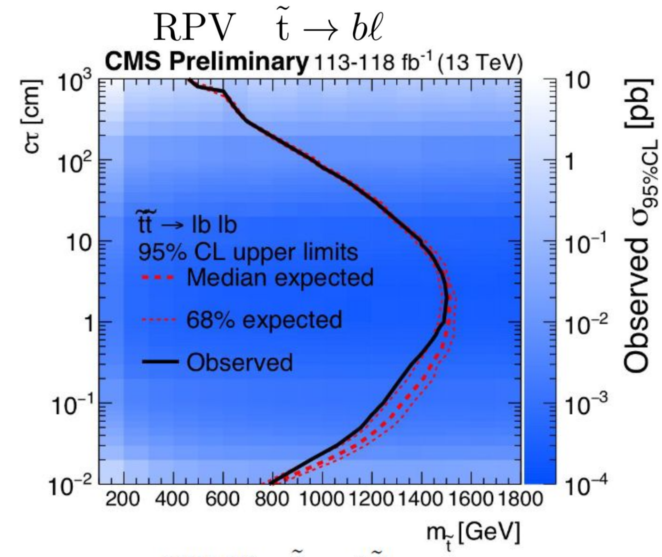


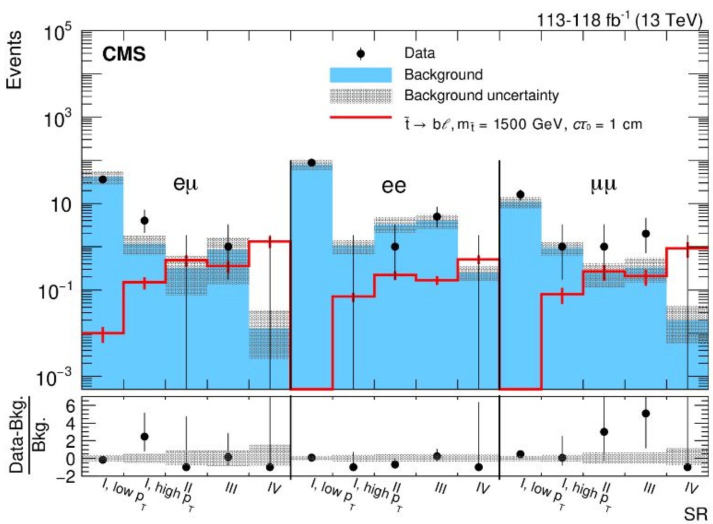
Long lived particles: Displaced leptons

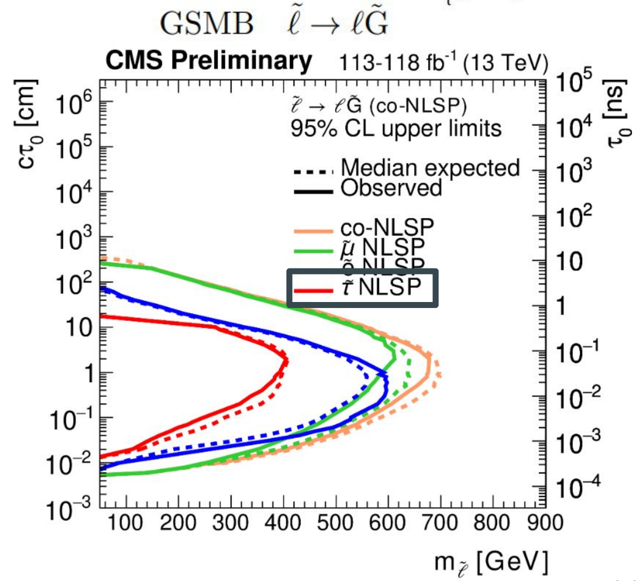
[Eur. Phys. J. C 82, 153 (2022)](#)
[More details in Celia's talk](#)

Search defined to be sensitive to any model whose signature includes 2 displaced leptons (eμ, μμ, ee).

- Uses transverse impact parameters (d_0) as the discriminant variable, with $10\mu m < |d_0| < 10cm$.
- Limits set for stop and stau production.

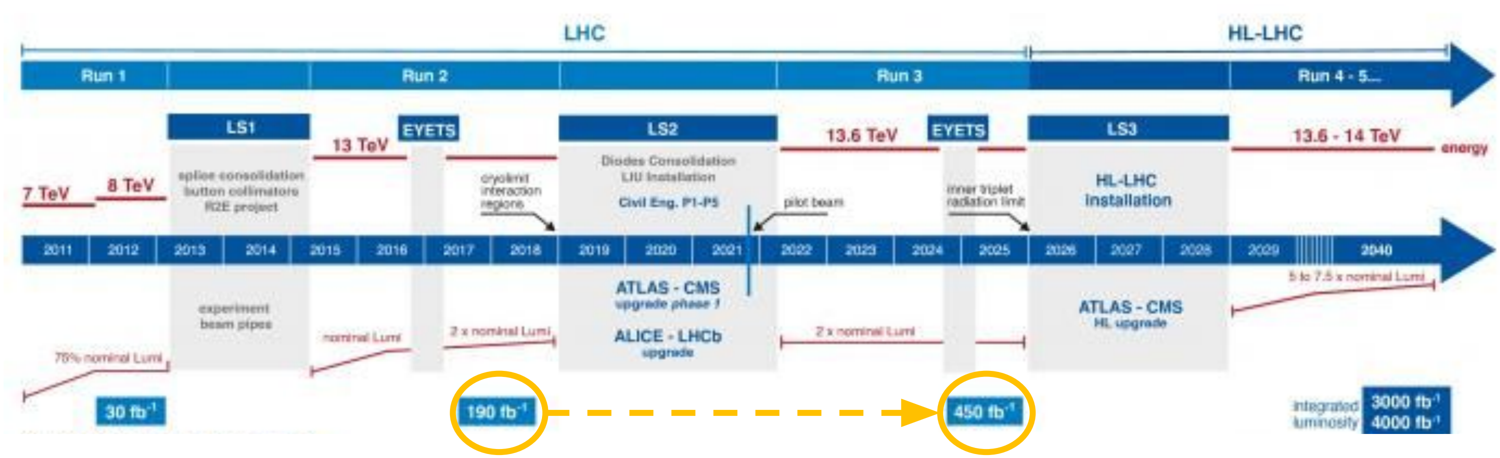






Summary and future prospects

- Plenty of analyses have been published by CMS combining Run 2 data targeting third generation SUSY particle production, also in RPV and LLP models.
- So far, many constraints on SUSY particle generations have been set, constraining the third generation squarks over 1300 GeV and the tau slepton at 400 GeV for low m_{LSP}.
- However, not all faith is lost!
  - Current exclusions come under assumptions that could be proven wrong.
  - Run-3 Is around the corner with more data, and new phase spaces will become available (compressed area, even more boosted scenarios…), and thus SUSY further probed.



Thanks for your attention

Event variables' definition

- H_T: scalar p_T sum of all jets.
- Transverse mass:

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}} p_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos \Delta\phi)}$$

- m_{T2}: Stransverse mass

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

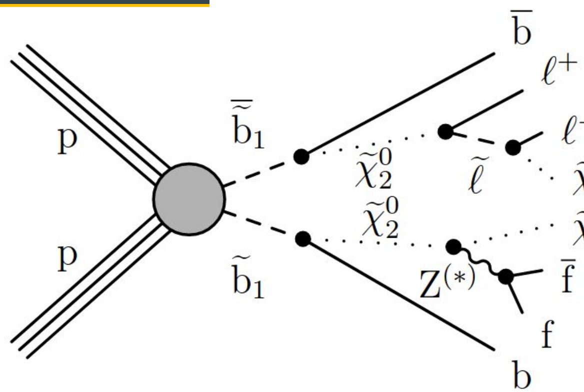
- Σm_T (**CMS-PAS-SUS-21-001**): sum of each τ_h m_T

$$\Sigma m_{\mathrm{T}} = m_{\mathrm{T}}(\tau_{\mathrm{h}}^{(1)}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}}) + m_{\mathrm{T}}(\tau_{\mathrm{h}}^{(2)}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$$

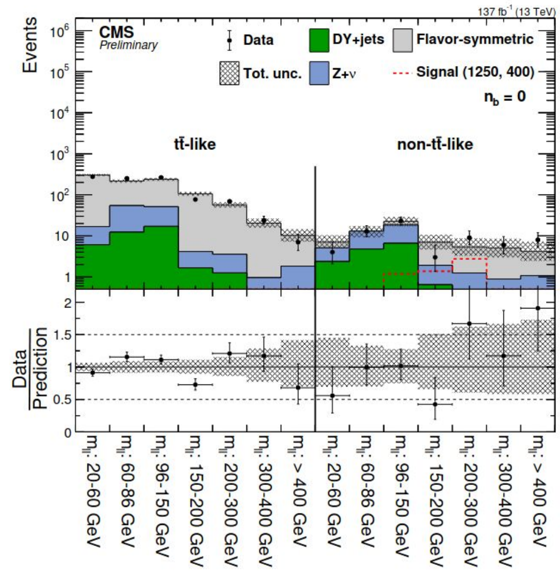
- d_0: the distance of closest approach in the transverse plane of the helical trajectory of the track with respect to the beam axis. +info here

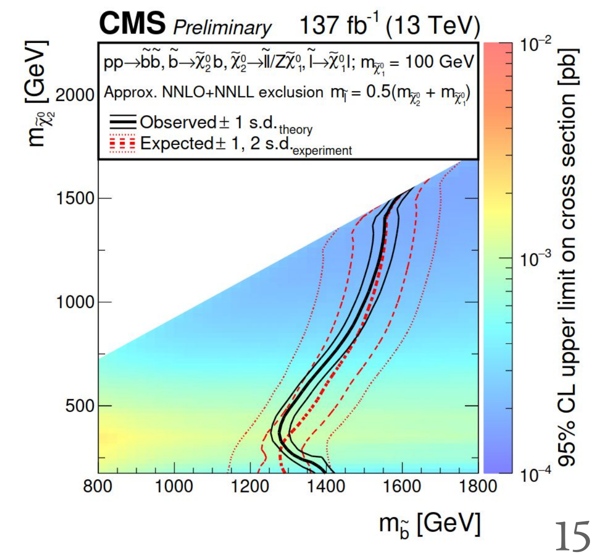
Bottom squark pair production

CMS-PAS-SUS-20-001



- Part of a more general analysis also probing dileptonic events with jets and p_T^{miss}.
- In particular, the sbottom is searched in pairs, each decaying through a decay to a b-quark and the next to LSP.
- Events with at least two jets and high m_{T2} and p_T^{miss} are required
- A Bayes discriminator is used to classify events in tt-bar like or not, giving as input variables such as p_t^{miss}, p_T^{ll}, or $\Delta\phi^{ll}$, in m_{T2} bins.
- sbottom masses up to 1600 GeV were excluded





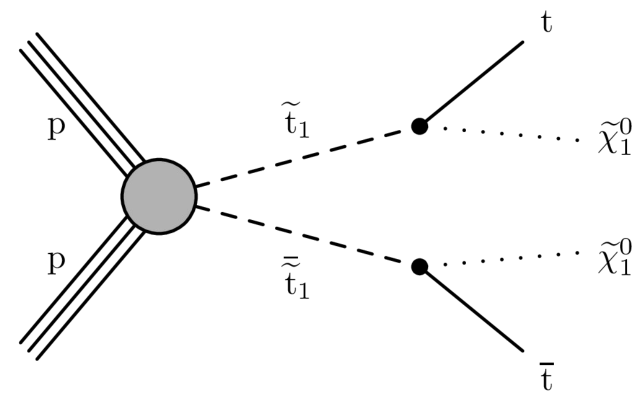
Stop searches: Δm ≃ mtop

Eur.Phys.J.C 81 (2021) 11, 970

Very challenging since the signal kinematics similar to SM ttbar events

- DNN to differentiate signal from bkg
  - At least 2 jets (at least 1 b-tagged), p_T^{miss}>50 GeV and 2 leptons.
  - Stop/neutralino masses included in the training, with optimised weights per mass point

Whole corridor excluded for the 1st time in CMS



Final state ttbar+ low mass neutralinos → Relatively low p_t^{miss}