Recent Electroweak SUSY searches at CMS

Hunting SUSY @ HL-LHC
ICTS - Bengaluru

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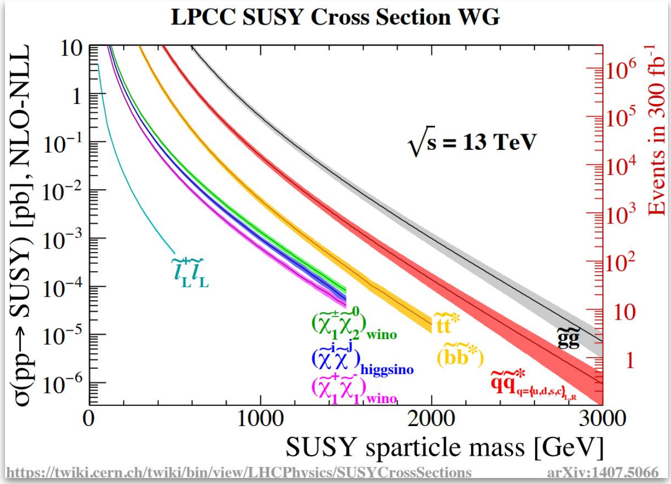
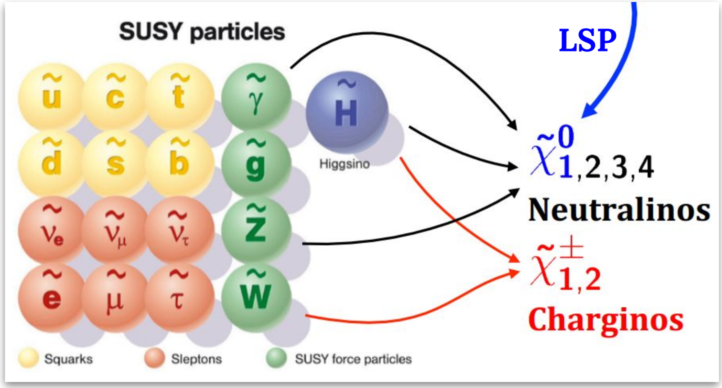
Vinay Hegde
Texas Tech University

Introduction

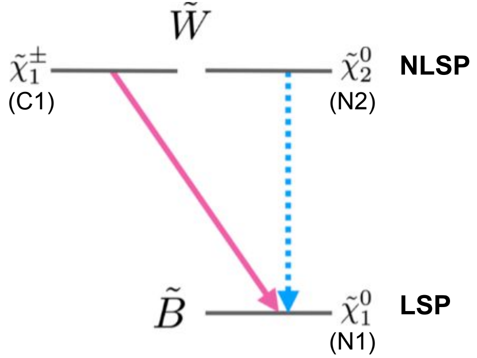
- Strong SUSY production
  - Explored extensively since the start of LHC.
  - No hints for SUSY so far and limits are quite <u>*strong*</u>.
- Search for electroweak production is challenging since the cross sections are low.
- Naturalness → higgsinos mass near the EW scale.
- Probing small cross section EWKino:
  - leptonic signatures
  - advanced analysis techniques
  - large LHC dataset



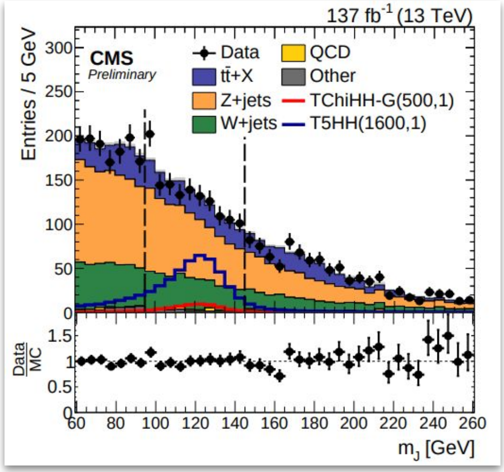


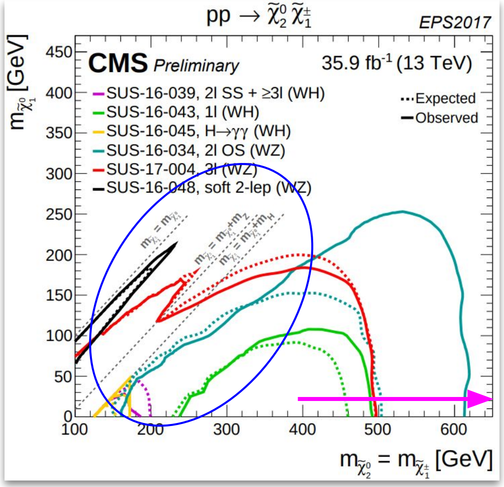
Mass spectra and analysis techniques

- If the mass difference between LSP (χ^0_1) and NLSP ($\chi^\pm_1 / \chi^0_2$) is small & m_{NLSP} is low
  - $\chi^0_1 \rightarrow$ low/moderate momentum $\rightarrow$ low/moderate p_T^{miss}.
  - Low/moderate boson p_T bosons from NLSP decay.
  - Good sensitivity from leptonic searches.
- For large mass difference and high m_{NLSP},
  - $\chi^0_1 \rightarrow$ high momentum $\rightarrow$ high p_T^{miss}.
  - Bosons from NLSP decay $\rightarrow$ high momentum.



- High p_T bosons: Take advantage of higher BR for hadronic decays, large radius jet with mass near the boson mass and sub-jet properties.



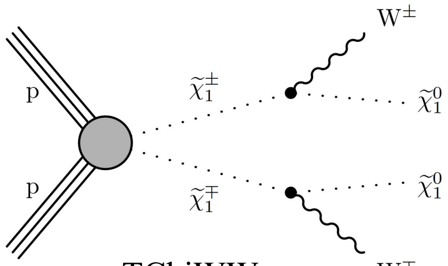


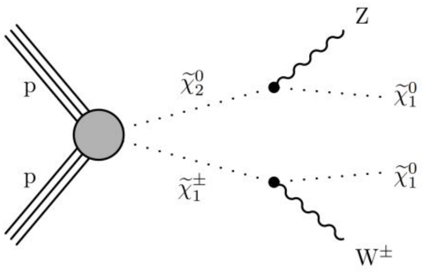
Searches covered today….

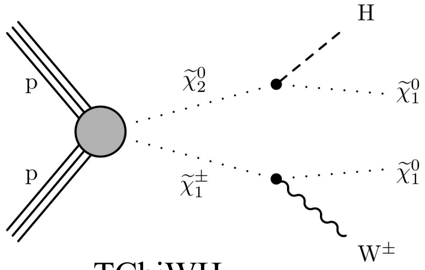
- **All hadronic final state searches**
  - **WX + p_T^{miss}** (SUS-21-002)
  - **HH + p_T^{miss}** (SUS-20-004)
- Leptonic searches
  - WH-1l search (arXiv:2107.12553)
  - Generic multilepton (arXiv:2106.14246)
  - Soft lepton search (SUS-18-004)
  - Stau lepton search (SUS-21-001)

Main focus

WX + p_T^{miss} final state search







- 2 bosons decay hadronically, giving 2 AK8 jets.
- Search regions are designed based on the number of b-jet tags.

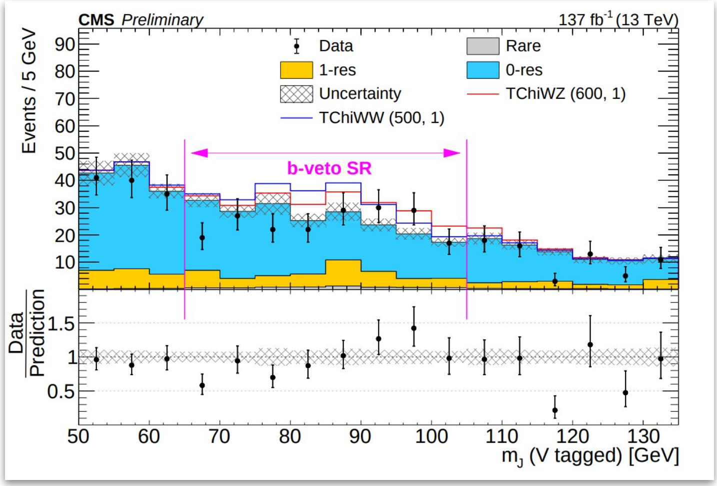
- **0 b-**tags

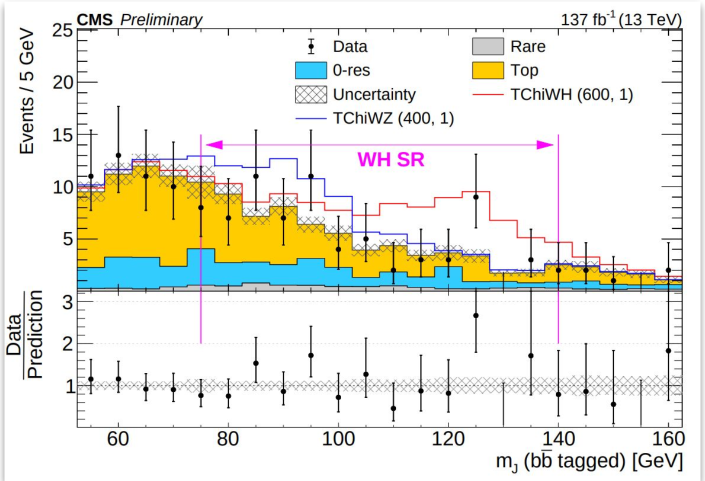
- **0 b-tags** when Z → qq
- **⩾1 b-tags** when Z→ bb

- **⩾1 b-tags** from H→ bb

Search strategy

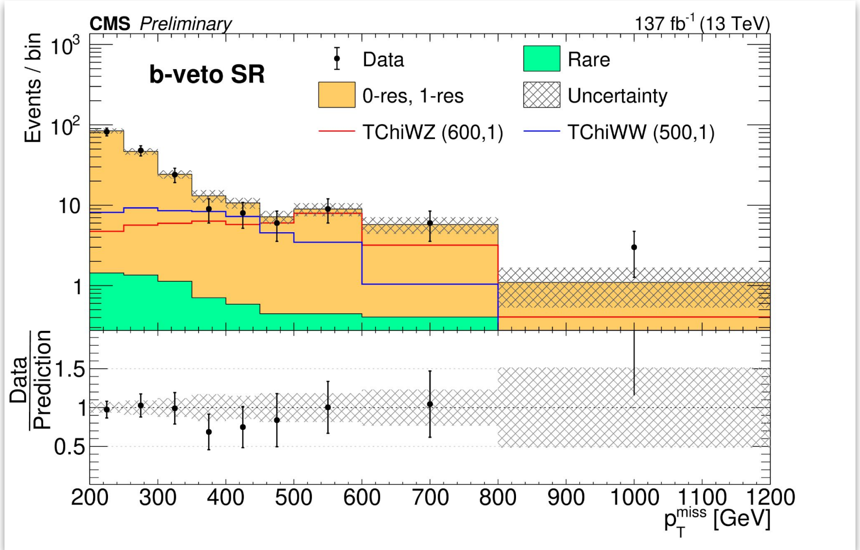
- The search is designed for high p_T^{miss} events arising from high mass NLSP decaying to low mass LSP.
- Uses AK8 jet properties to reduce background
  - soft-drop mass
  - DeepAK8 taggers - W(qq) vs QCD, W/Z (qq) vs QCD, H/Z (bb) vs QCD.

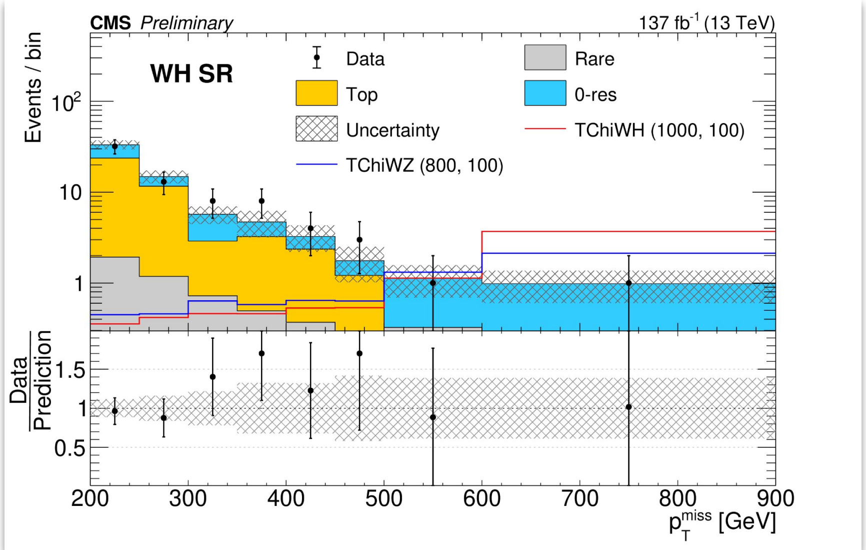




Background estimation and results

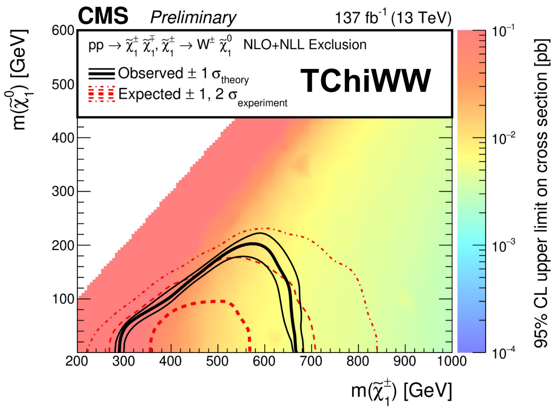
- Z(*νν*), W(*lν*) and tt are the dominant SM backgrounds.
- Background estimation uses control regions defined by inverting the deepAK8 discriminator cuts and single & dilepton regions.
- No significant deviations from SM predictions.

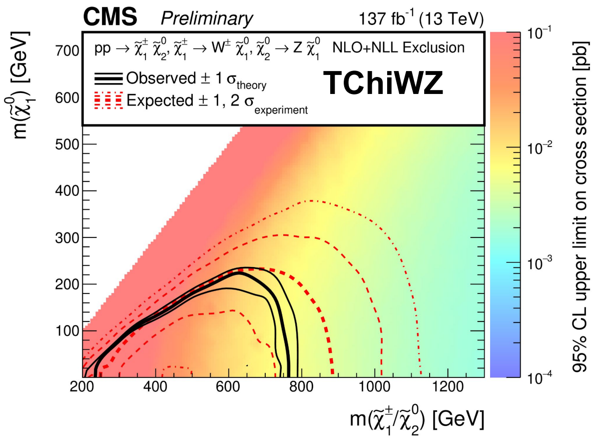


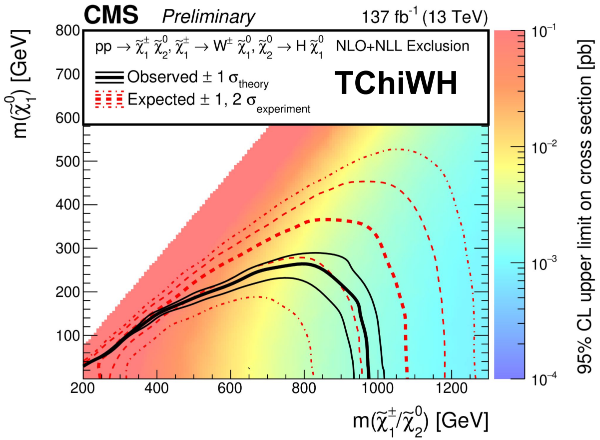


Simplified model interpretations

- For wino cross section scenarios with m_{LSP} ~ 0, the search places some of the most stringent limits.
- Mass exclusions
  - TChiWW: 290 - 670 GeV
  - TChiWZ: 230 - 760 GeV
  - TChiWH: 200 - 970 GeV

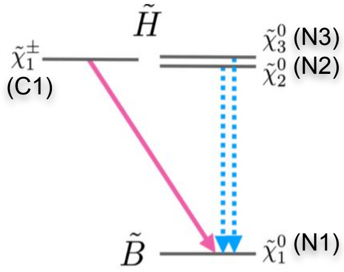


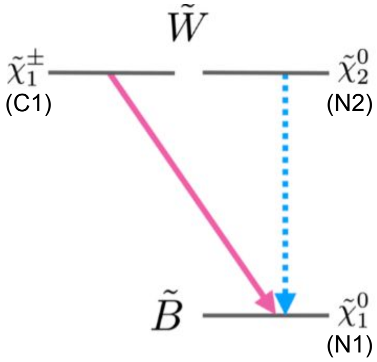




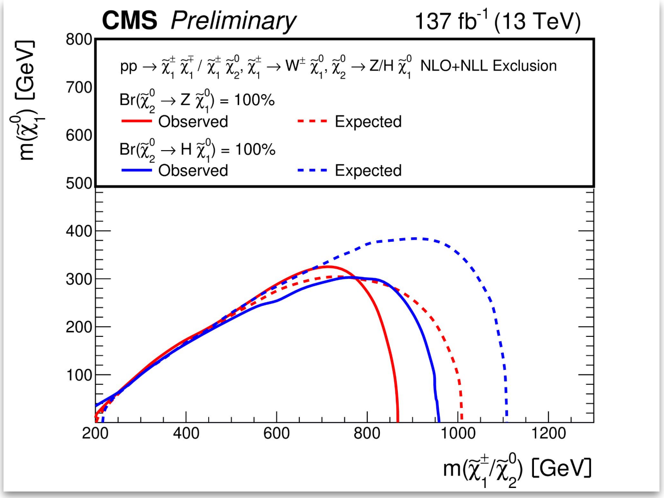
Interpretations - beyond simplified models

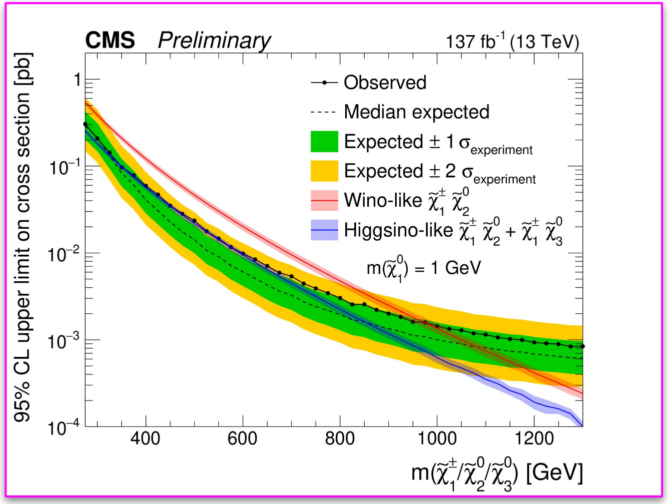
- Realistic wino scenarios involve $\chi^{\pm}{}_1\chi^{\pm}{}_1$ and $\chi^{\pm}{}_1\chi^{0}{}_2$ production. Two cases $\chi^0{}_2 \rightarrow Z + \chi^0{}_1$ with 100% BR 'or' $\chi^0{}_2 \rightarrow H + \chi^0{}_1$ with 100% BR are considered.
- Search is also sensitive to TChiWH model having $\chi^{\pm}{}_1\chi^{0}{}_2 + \chi^{\pm}{}_1\chi^{0}{}_3$ production with higgsino cross sections.





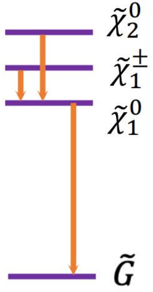
Wino scenario



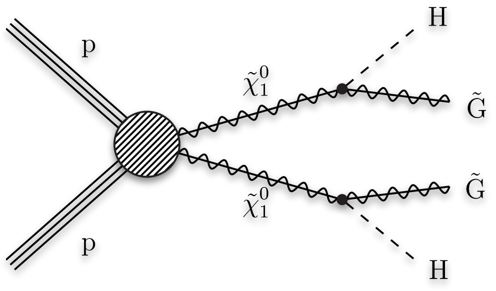


HH+p_T^{miss} search - models targeted

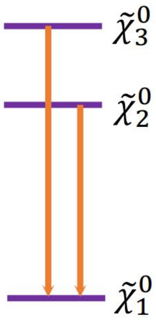
- Search for pair produced neutralinos with H(bb)H(bb) and p_T^{miss} final state.
- GMSB scenario:
  - Higher $\chi^0_1\chi^0_1$ production since $\chi^\pm_1$, χ^0_1 and χ^0_2 are mass degenerate with $\chi^\pm_1 / \chi^0_2 \rightarrow \chi^0_1$ + soft particles.
  - χ^0_1 is NLSP and goldstino, G~ is LSP.
- N2N3 scenario:
  - Only $\chi^0_2\chi^0_3$ production, $\chi^\pm_1$ is not accessible; χ^0_2 & χ^0_3 are mass degenerate.
  - χ^0_2 / χ^0_3 are co-NLSP and χ^0_1 is LSP.
- 100% BR for NLSP → H + LSP.



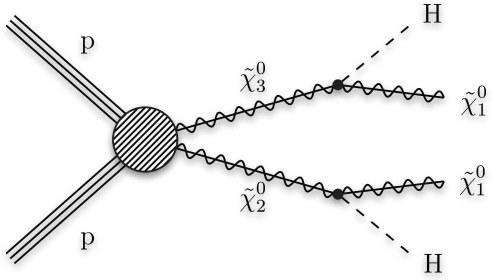
GMSB



TChiHH-G



N2N3



TChiHH

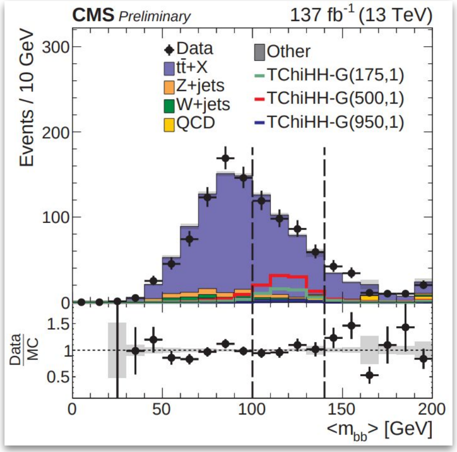
Analysis strategy

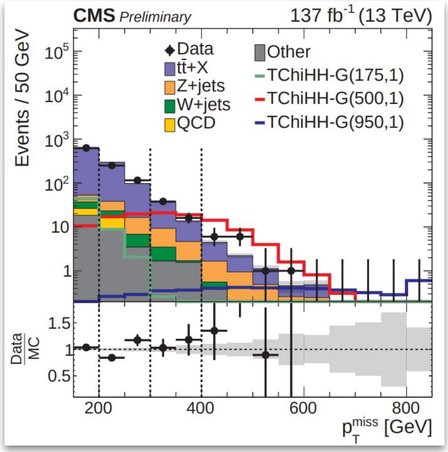
Resolved category

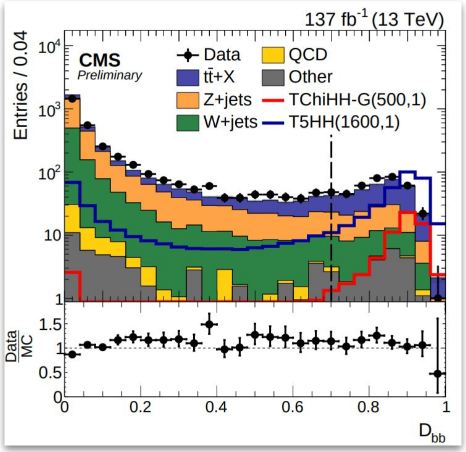
- Expect 4 AK4 jets from 2 low p_T H decays.
- Sensitive to low p_T^{miss} and $m_{NLSP} \sim m_{LSP}$ cases.
- Uses pairs of b-tagged jets to identify H candidates.

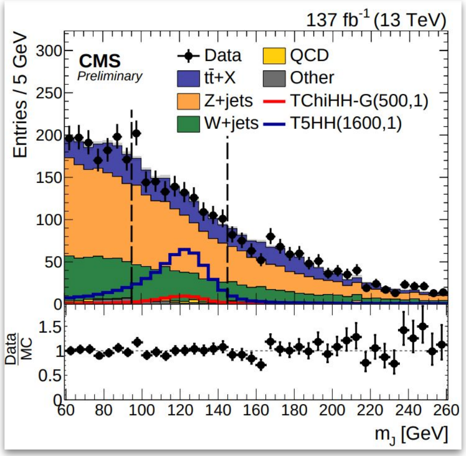
Boosted category

- Expect 2 AK8 jets from boosted H decays.
- Sensitive to high p_T^{miss}, high m_{NLSP} and $m_{NLSP} >> m_{LSP}$ cases.
- DeepAK8 bb-tagger to discriminate H candidates from background.



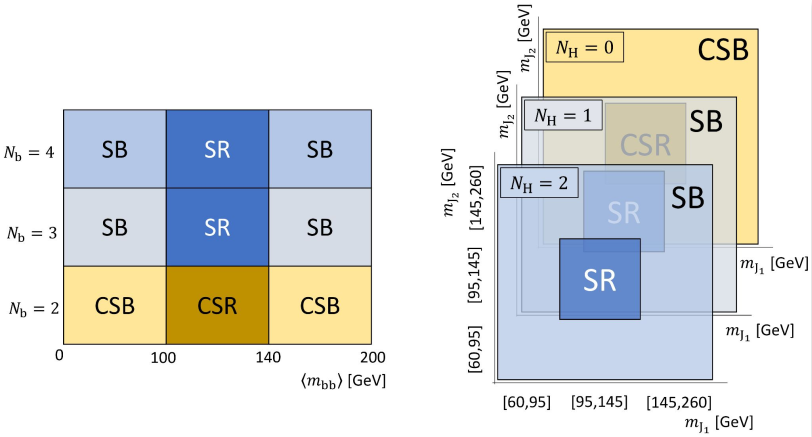


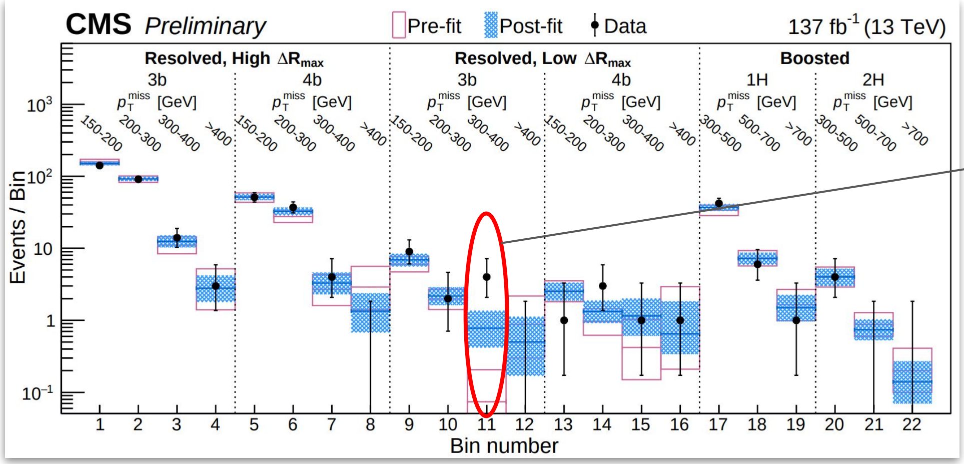




Background estimation and results

- tt and Z(νν) are the dominant backgrounds.
- Background estimation uses *ABCD* method using mass sidebands and tagging.

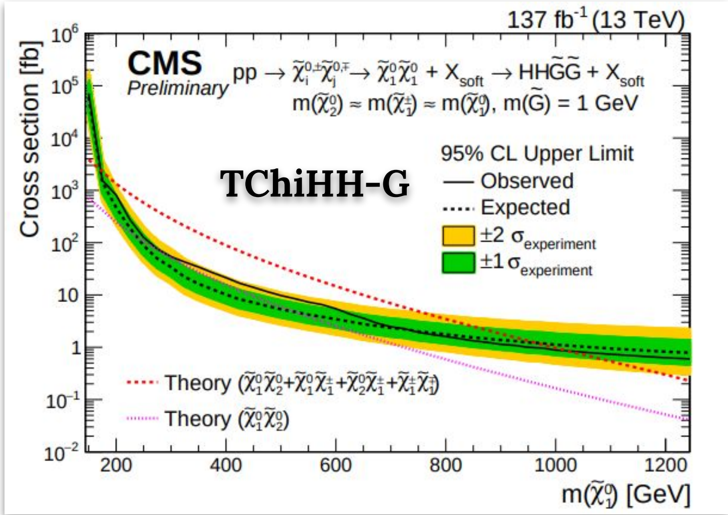


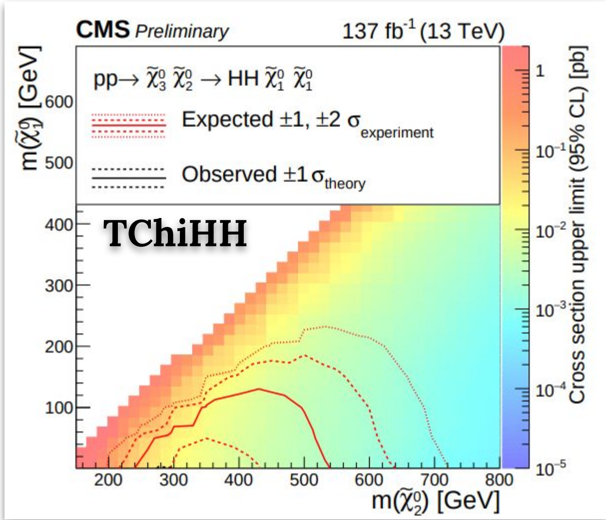


- ~3.2 σ local significance in one resolved category bin.
- A typical SUSY signal would populate several search bins - very unlikely to be a signal.

Interpretations

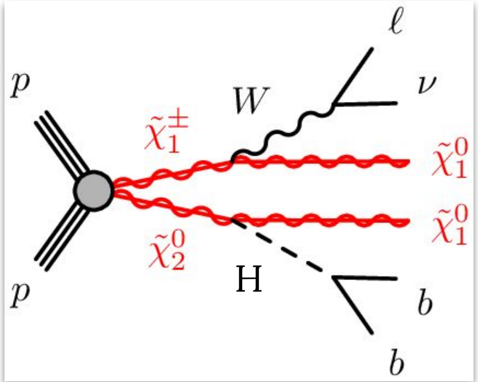
- GMSB scenario, TChiHH-G: mass exclusion 175 - 1025 GeV.
- N2N3 scenario, TChiHH: Starting to be sensitive to a large region of higgsino masses, even if there is no observed exclusion.

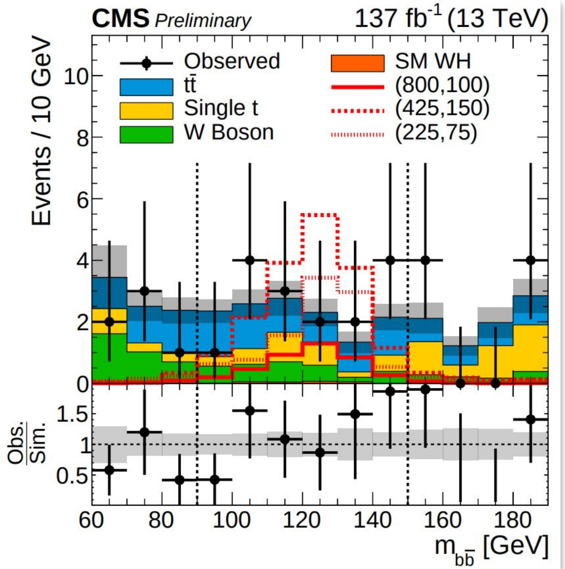


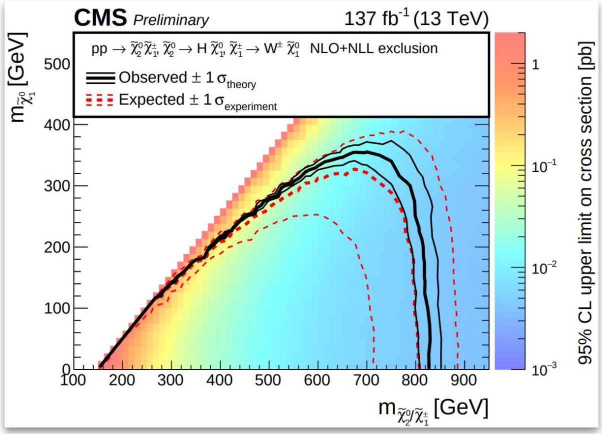


WH 1l final state

- Targets W→ $l\nu$ and H → bb decays. For **H→ bb**, m_{bb}: 90-150 GeV.
- Uses **AK8** jets with p_T > 250 GeV & DNN to identify boosted H candidates.
- With respect to previous 2016 (36 fb^{-1}) results, mass exclusion improves by ~350 GeV - half of this improvement coming from improved analysis technique & the other half from ~4x higher data.

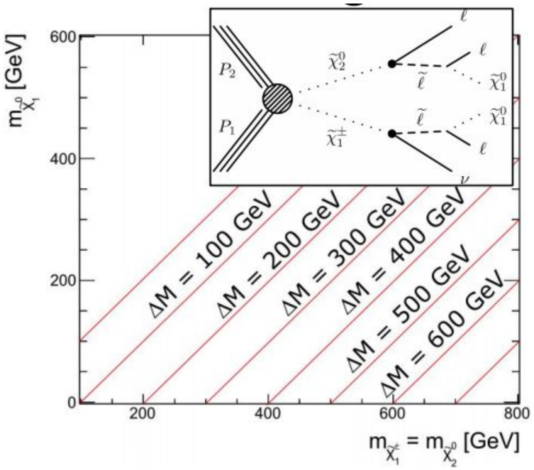




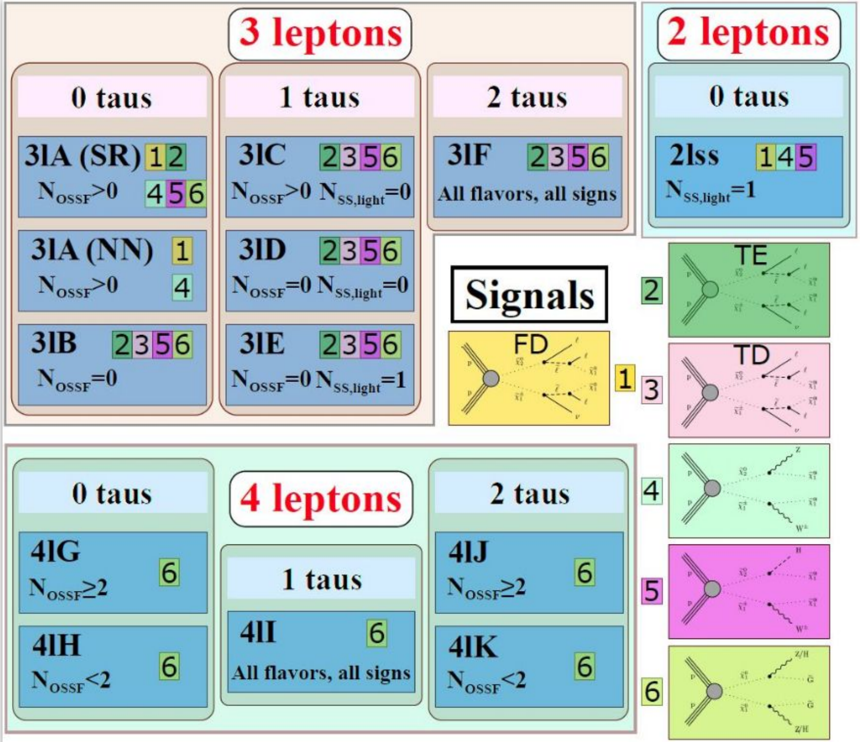


≥ 2 lepton search

- Targets wide variety of models with 13 different leptonic decay combinations - **workhorse of EWKino** searches.



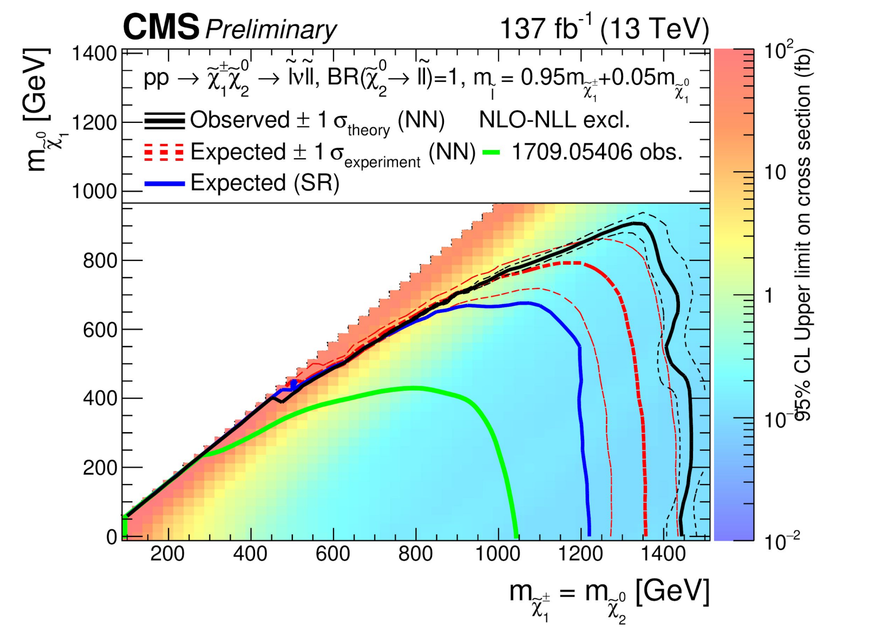
Signal kinematics vary with masses involved, very similar for a given ΔM.

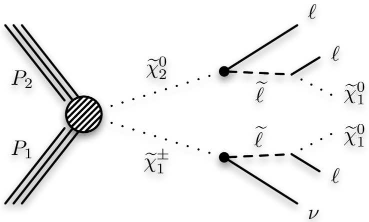


- **Parametric neural network (PNN):**
  - Maximize signal/background.
  - Learns the peculiarities of signal models using ΔM & other SUSY parameters.

Results & interpretations

- No significant deviation from SM predictions in any of the SRs.
- For slepton mediated SMS scenarios, PNN based mass limits are ~ 150 GeV better than cut based approach.



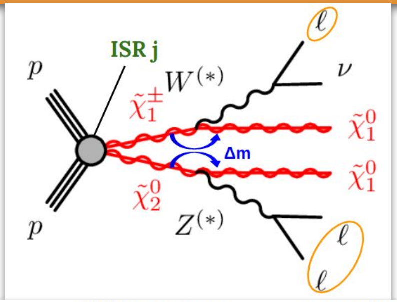


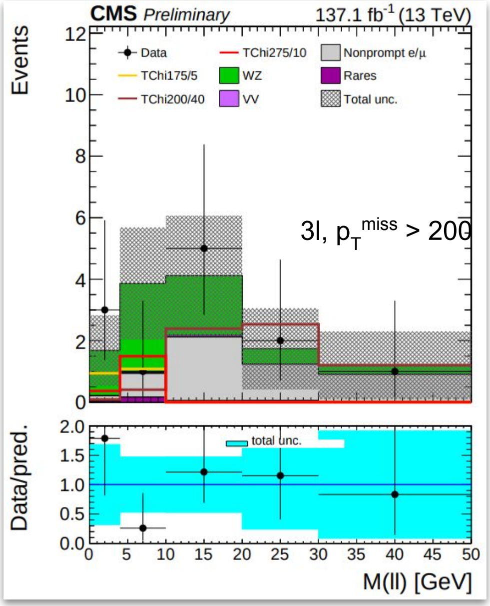
Has several SRs and interpretations!

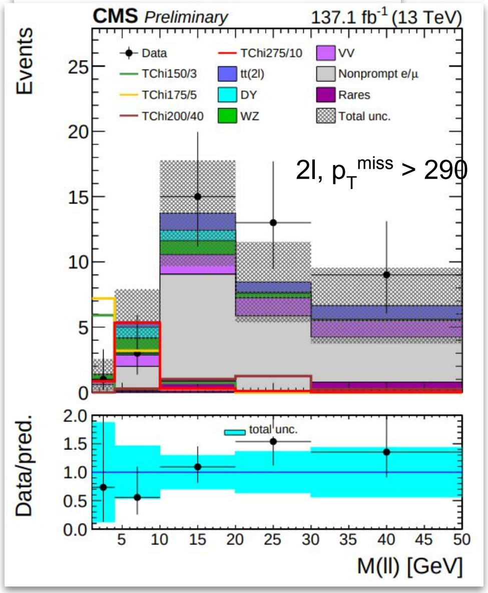
Soft opposite-sign dilepton and trilepton search

- Designed to target **compressed mass** regions (Δm ~ 0) using 2l and 3l events.
- Challenges: low p_T^{miss} and low visible energy events with huge QCD & $Z \to \nu\nu$ + jets backgrounds.
- Strategy: soft leptons with p_T down to 3.5 (5) GeV μ(e) + ISR : $(2/3) < (p_T^{miss}/HT) < 1.4$.
- No significant deviations from SM predictions.

$$\Delta m = m(\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0)$$



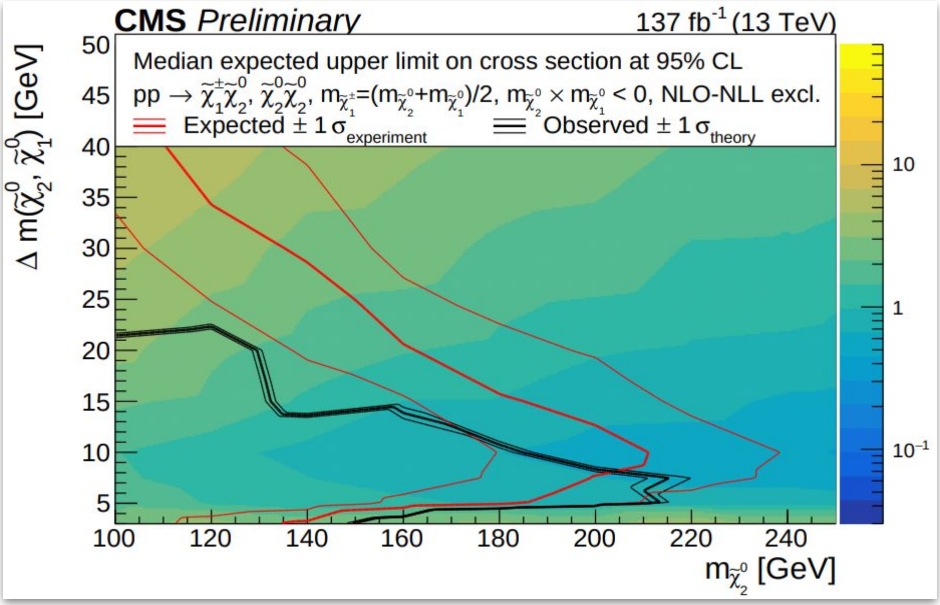




Results & interpretations

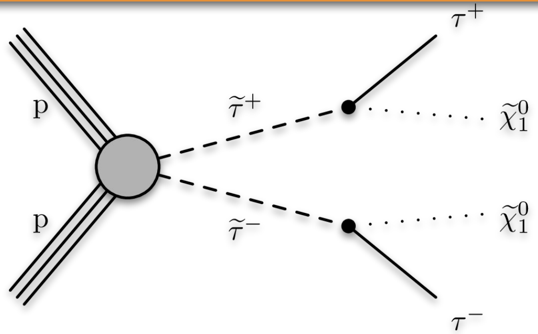
- Interpret the results in terms of wino & higgsino models.
- This search is able to probe highly compressed mass - $\Delta m \sim 3$ GeV for higgsino cross sections.

- Extended sensitivity:
  - at high Δm due to adding 3l channel
  - at low Δm by lowering p_T thresholds and Δm requirement

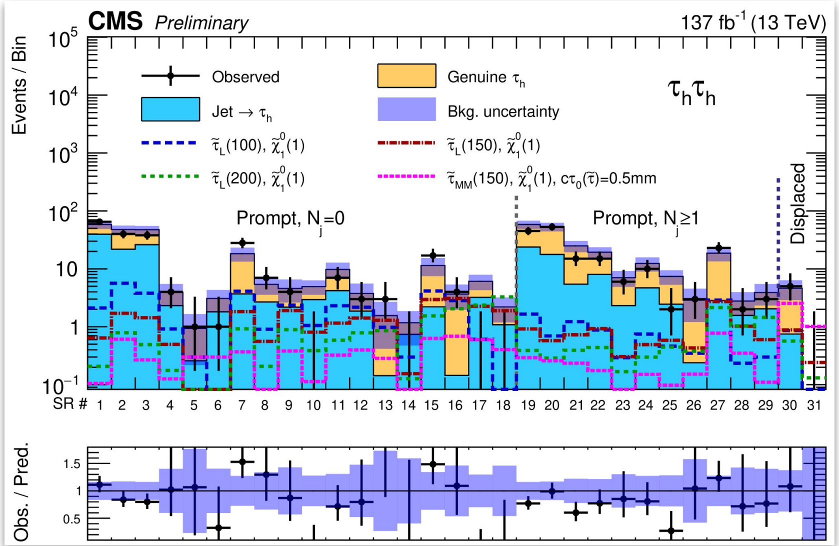


Stau pair search

- Direct pair production of status (NSLP) with hadronic ditau final state.
- Promptly decaying and long lived stau are considered.

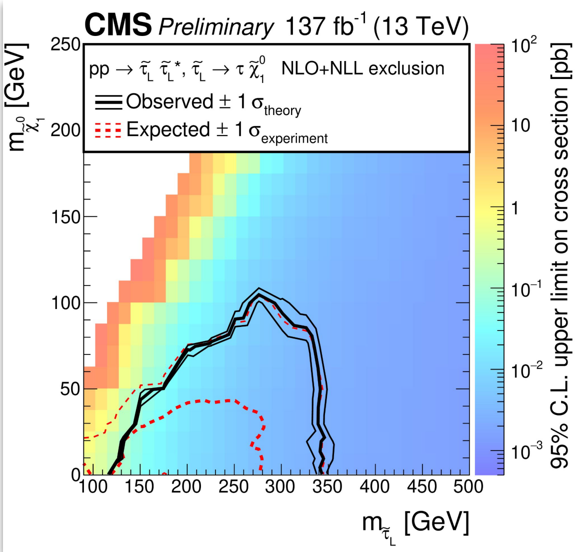


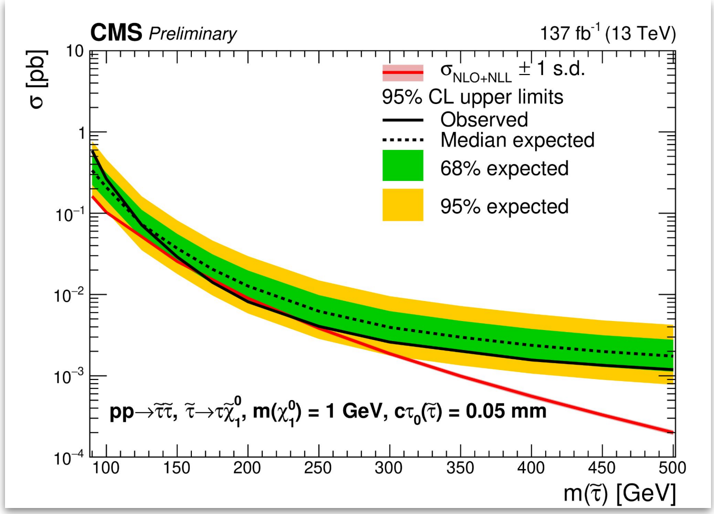
- Main background processes: DY→ $\tau\tau$, W($l\nu$), tt & QCD. DeepTau tagger is used to enhance signal to background discrimination.
- Observations are consistent with predictions from SM.



Interpretations

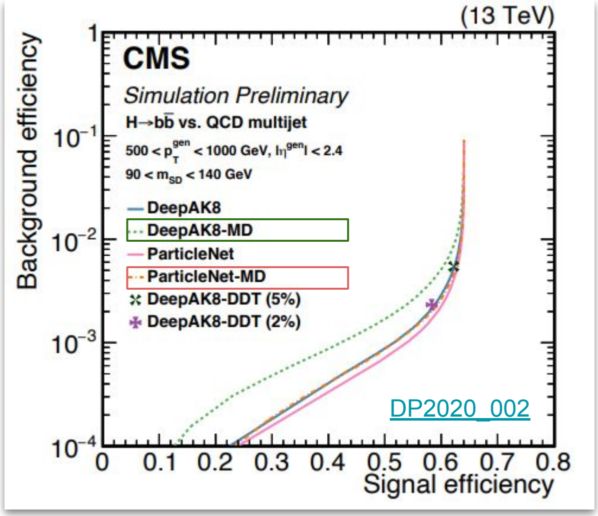
- Results are interpreted using τ_L, and degenerate scenarios.
  - Improvement from barely excluded τ_L results (using 77 fb^{-1}) to exclusion up to 350 GeV.
- Starting to exclude long lived stau scenarios as well.

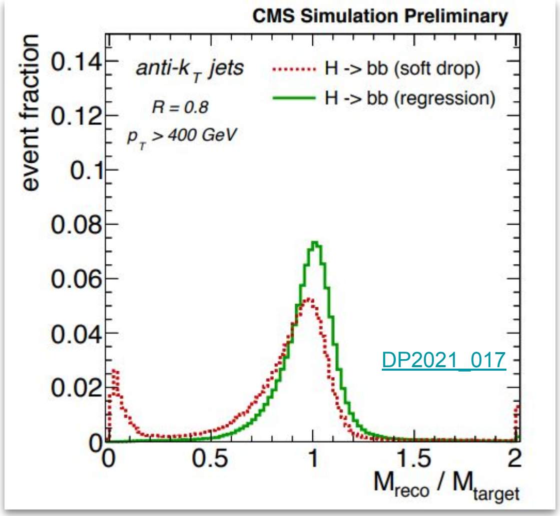


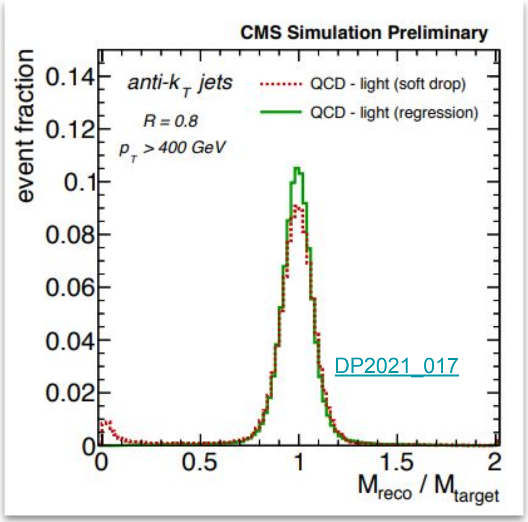


What can we expect from HL-LHC?

- Run 2 → DeepAK8 taggers which clearly an improvement over previous tagging techniques. Run 3→ ParticleNet algorithms (something else?) have shown improvements over DeepAK8.
- ParticleNet regression techniques → improvement over soft-drop mass.
- As usual, we are going to have more data and better techniques! 😊



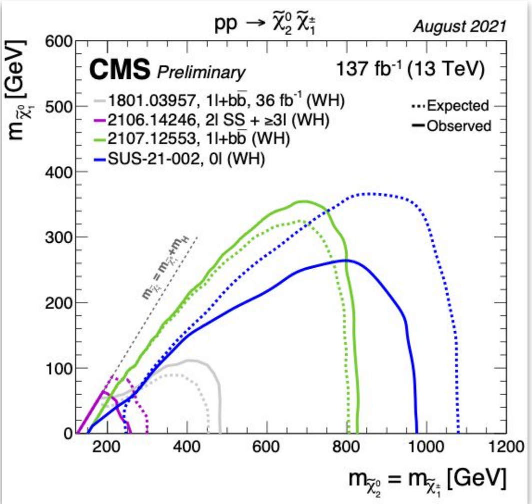


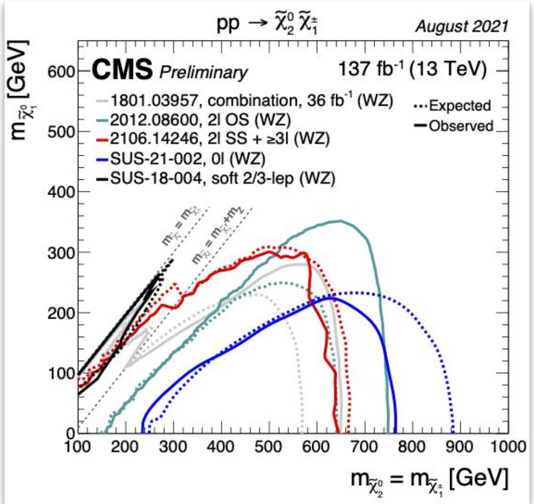


Summary & outlook

- With the help of new jet tagging techniques, hadronic searches are trying to cover higher m_{NLSP} scenarios; leptonic searches are complementary to hadronic searches.
- The EWKino mass exclusions reach ~ 1 TeV for low m_{LSP}.

- We are starting to explore low cross section higgsino scenarios.
- Several new techniques have been developed in Run 2 and we'll improve them and *hope we discover SUSY in Run 3!*

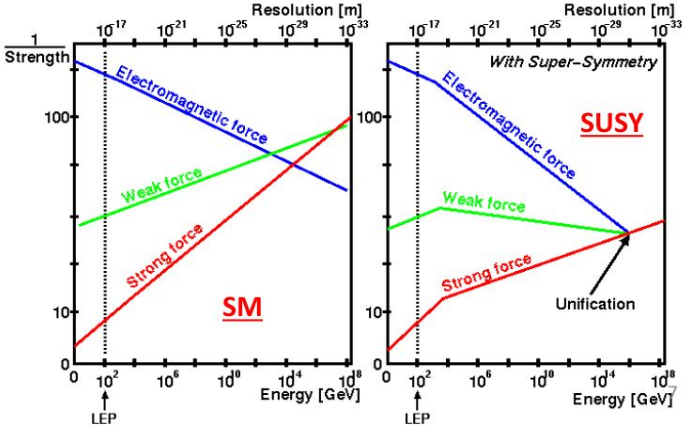


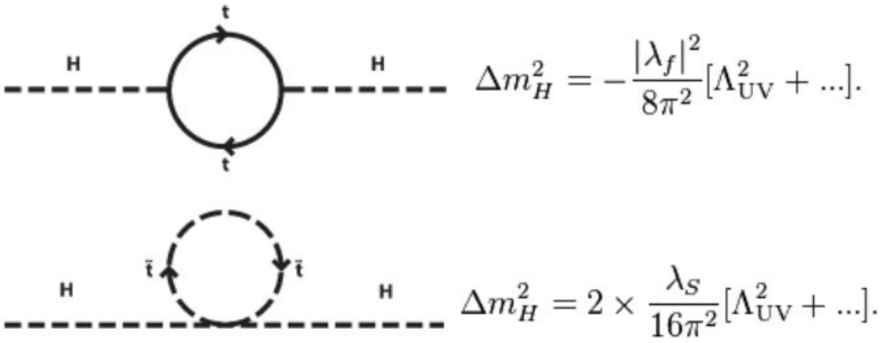


Additional information

SUSY

- R-parity, $P_R = (-1)^{3(B-L)+2S}$, where B = baryon no., L = lepton no., S = spin. It is a multiplicative quantum number. SM particles have P_R = +1, SUSY particles have P_R = -1.
- RPC consequences = SUSY particles are pair produced and their decay must result in SUSY particles and SUSY particles cannot decay to SM particles only. Lightest SUSY particles (LSP) is stable.





SUSY - mass splitting

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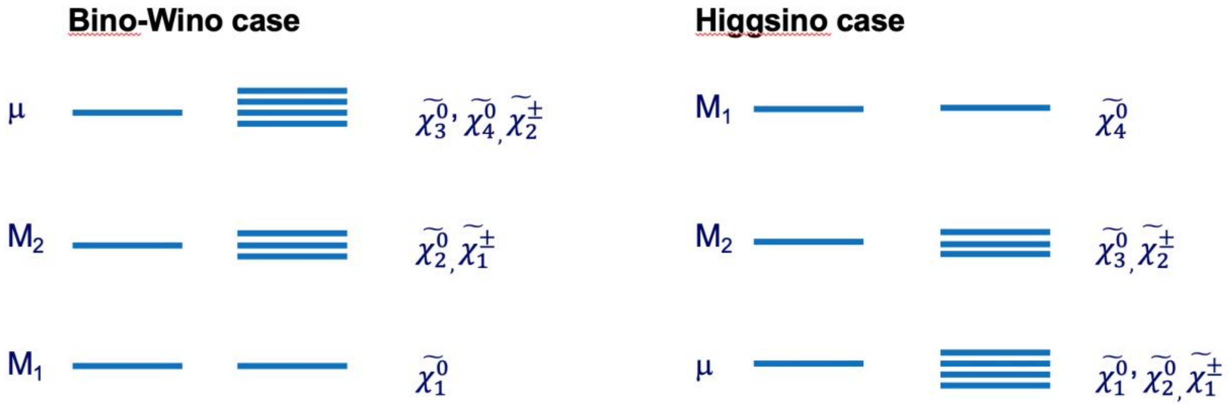
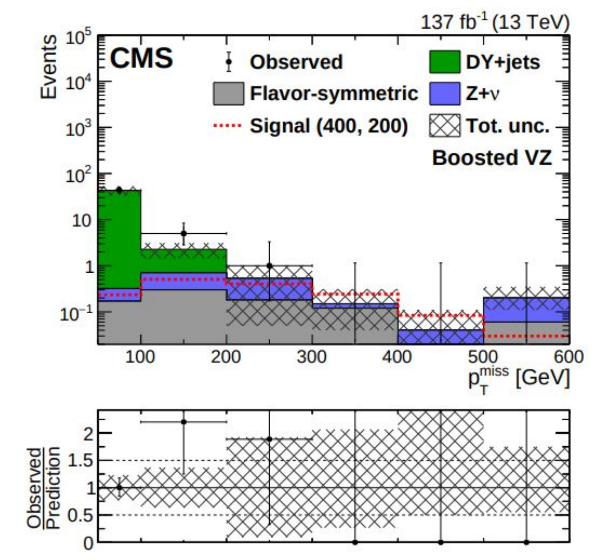
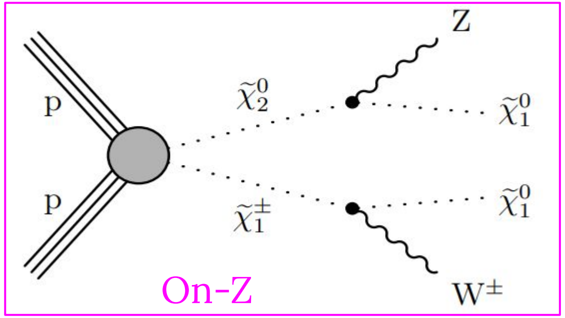
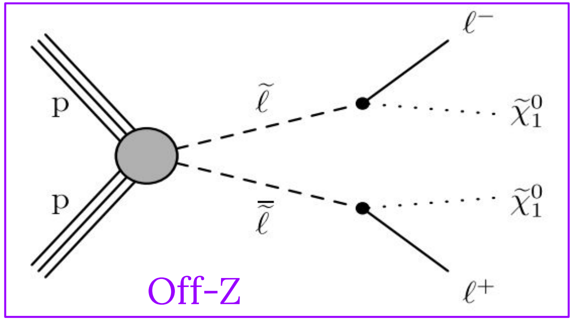


2l OSSF on-Z and off-Z

- EWKino & slepton pair production with opposite s
leptons in final state.
- SRs: on-Z and off-Z using m_{ll}.
- Key variables: p_T^{miss}, N_{jets}, merged or resolved W de
radius" jet vs 2 "small radius" jets).
- No significant excess over SM predictions.







Improved background estimation methods and re-optimized for higher 137 fb^{-1} of data.

Interpretations

- Chargino/neutralino masses up to 750 GeV are excluded (Improves previous CMS mass exclusions by 100-150 GeV).
- Slepton mass exclusions reach up to 700 GeV (~200 GeV improvement).