Search for EWK SUSY production in multilepton final states with the CMS experiment (CMS-PAS-SUS-19-012)

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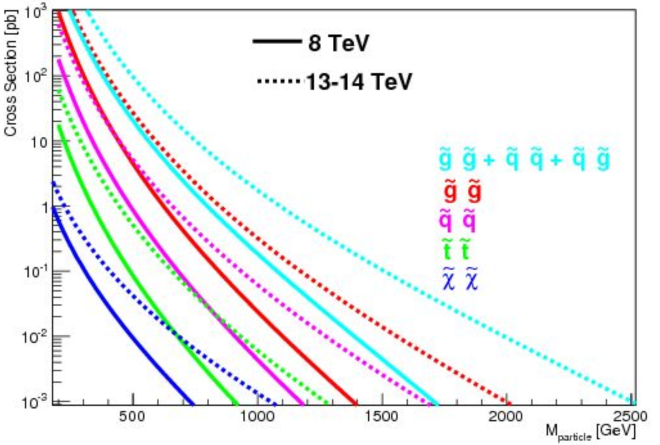
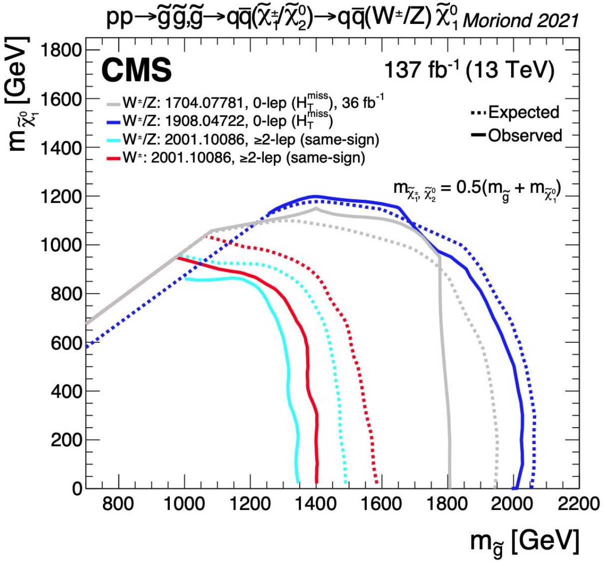
Motivation and challenges



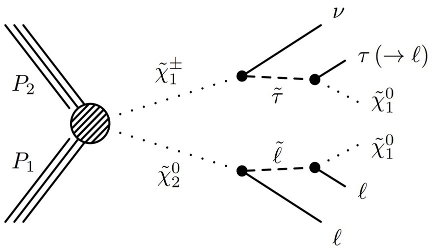
⇢ Still no direct hints of BSM physics in the LHC… but we are not done yet! SUSY is still a strong framework to search for new physics at the LHC.

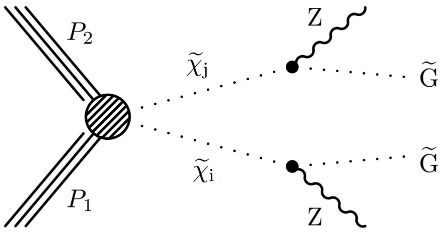
⇢ Strongly charged SUSY partners are preferred at the similar energy scale, but limits have been pushed way above the TeV scale (more in Xuan's/Pablo's talks!)



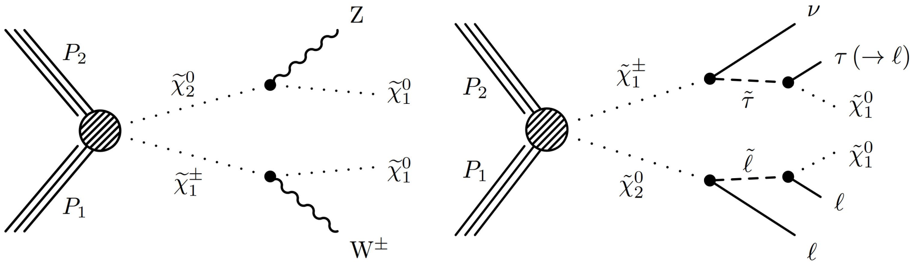
⇢ Non coloured superpartners might be the only particles accessible at the ~TeV scale, making EWK SUSY preferred experimentally.

⇢ Moreover, N1 will always be a strong WIMP DM candidate. An even stronger reason to look for EWK SUSY.





Overall strategy

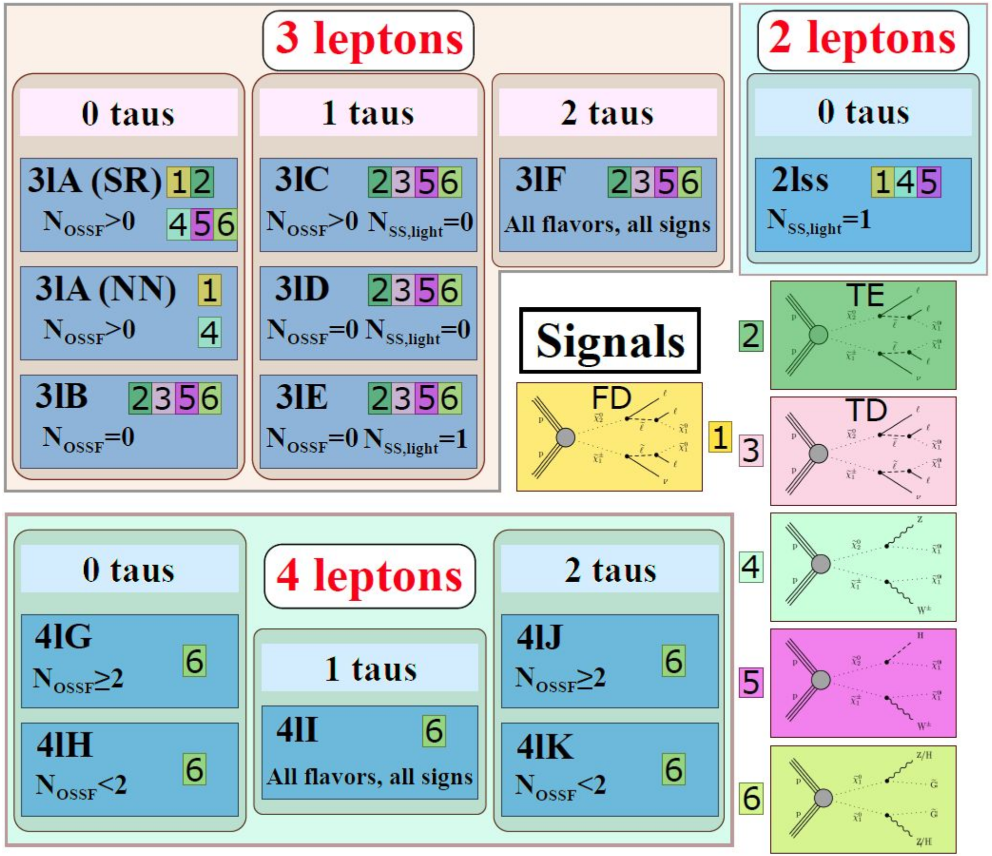


⇢ We look for gaugino pair production producing multiple leptons from resonant or non-resonant decays. **12 SMS models used as templates to look for possible SUSY configurations**.

⇢Key problem: the unknown nature of “True SUSY” means it could be anywhere.

⇢ Our answer is to **search exhaustively: look at up to 13 different leptonic final states**!

⇢ This introduces the challenge of obtaining a clear understanding of the SM in very different final states.



CMS-PAS-SUS-19-012 at a glance
(Will highlight ⅓ of the results, much more in backup)

Three lepton final states - Maximizing reach with a PNN

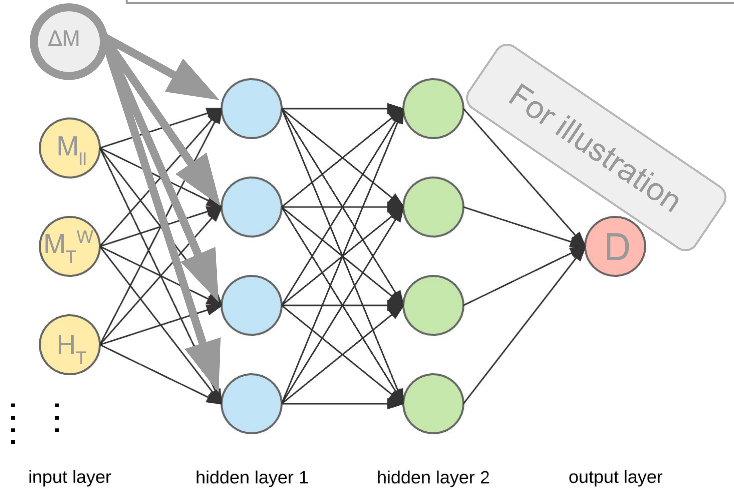
⇢ The “three light leptons” final state is sensitive to many different models with wildly varying kinematics.

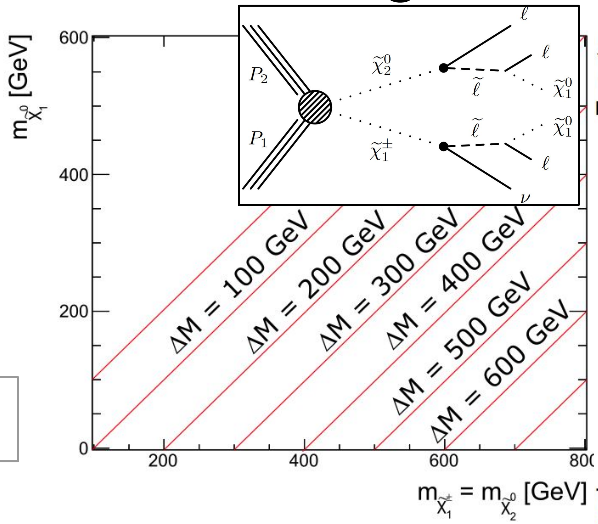
⇢ Our approach is to **use a parametric NN**:

⇢ **NN**: to obtain maximal S/B separation

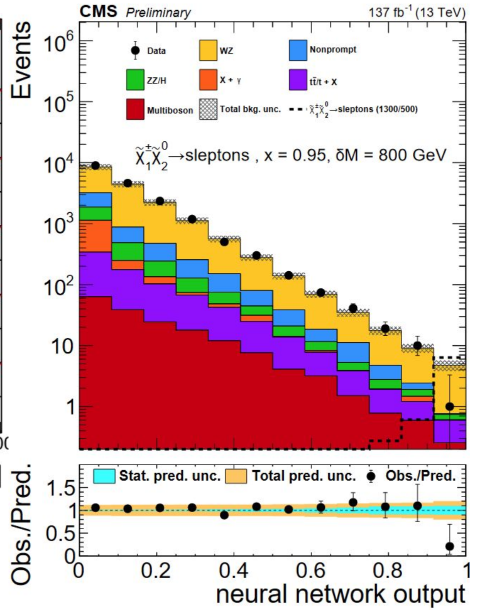
⇢ **Parametric**: learn peculiarities of the signal kinematics depending on SUSY parameters.

Input: ΔM, $\{m_{ll}, m_T^W, m_T^{3l}, H_T, L_T, p_T^{miss}\}$





Kinematics are quite similar at fixed $\Delta M = m_{NLSP} - m_{LSP}$



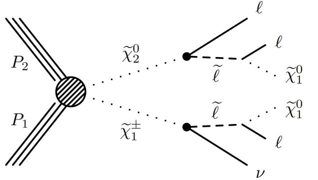
⇢ The parameter is introduced as a training variable so we incorporate the **correlations of ΔM with other quantities.**

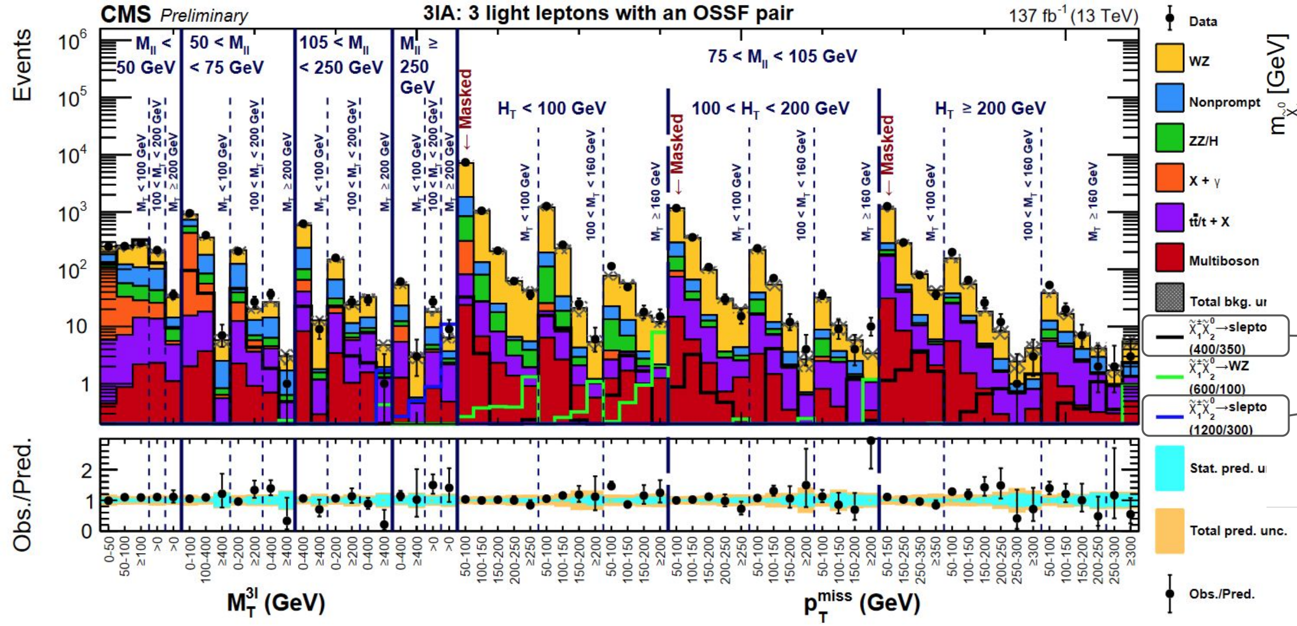
⇢ And then evaluate them to **aim for optimal performance for each specific signal hypothesis**.

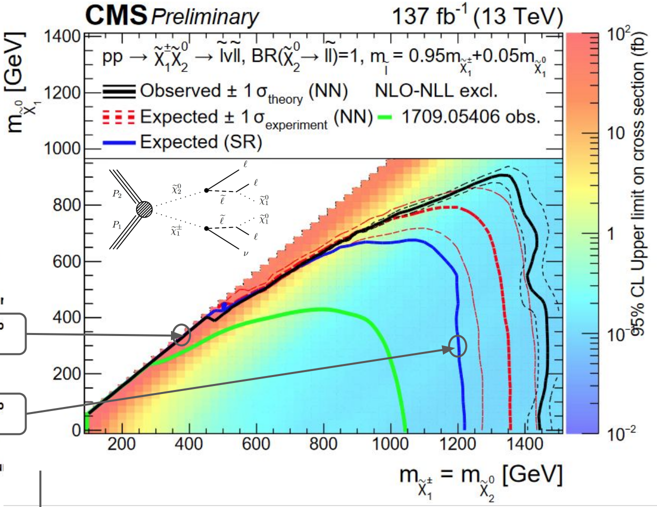
⇢ Separate trainings for different SMS models.

⇢ Talk by Andrea on the technique on last month’s comp workshop.

SR baseline + SMS Interpretation





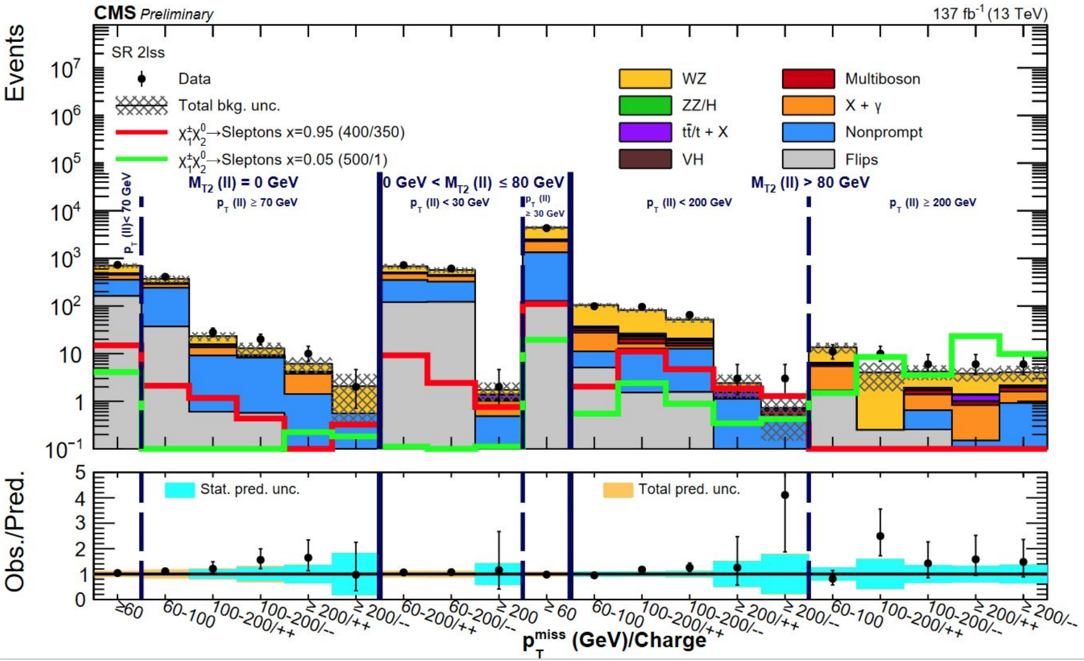


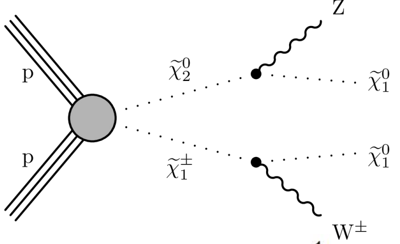
- ⇢ Cut-based SR approach as a **<u>baseline easier to reinterpret than a p-NN</u>**.
- ⇢ Still quite challenging as, again, SUSY could high anywhere, **<u>need diverse SRs</u>**:
  - ⇢ WZ-like -> hide “on-Z” dilepton mass
  - ⇢ Very boosted final states -> high H_T, high M_T
  - ⇢ Very compressed mass spectra -> low m_{ll}, low m_T

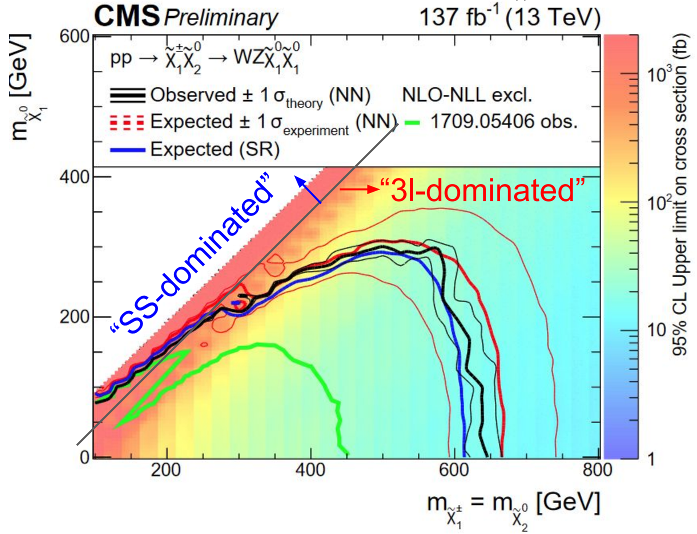
- ⇢ SMS - slepton mediated decays:
  - ⇢ N2/C1 are “wino-like”: Equal decays to all ℓ flavours.

- ⇢ Current <u>best exclusions in gaugino masses up to date</u> (of course, in reality branching ratios play a role)

Results - Same Sign final state







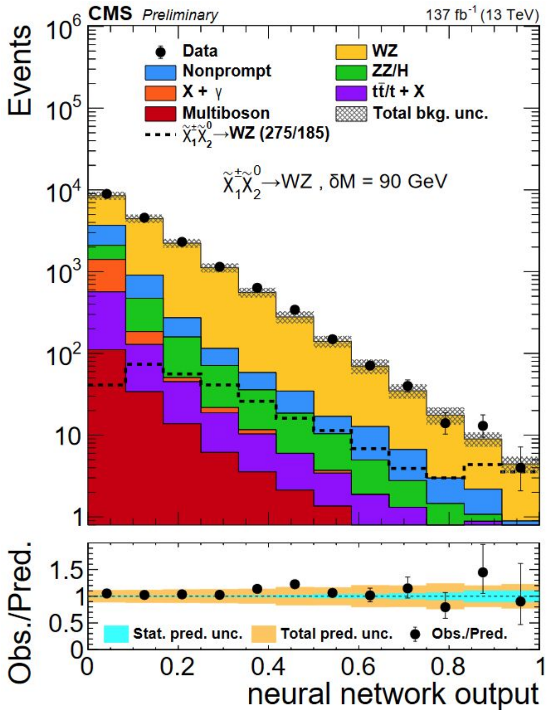
⇢ Final states with a same-sign lepton pair are quite clean SM-wise, and can be home to more compressed SUSY.

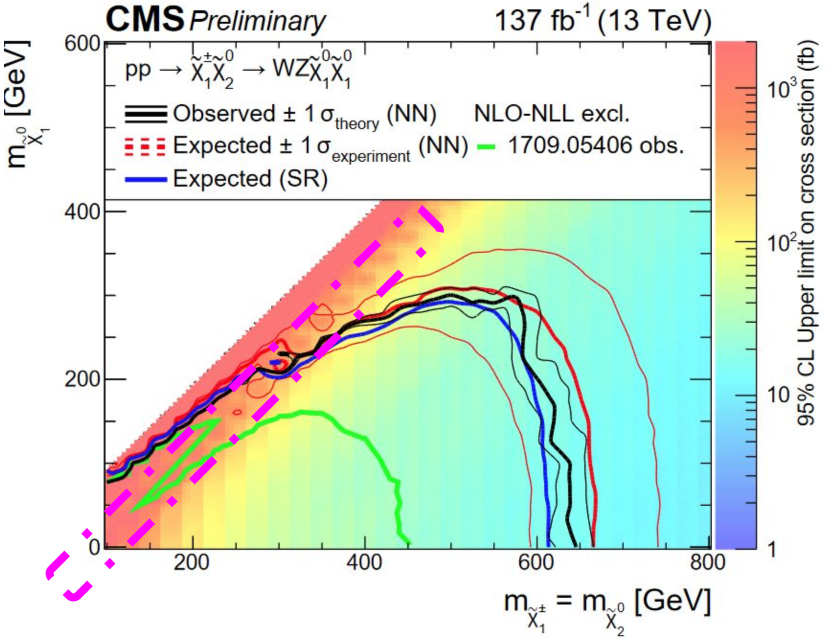
⇢ The problem is dealing with "non-prompt" leptons: use a dedicated and precise data-driven estimation.

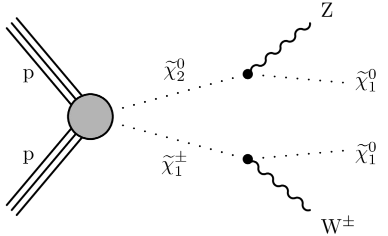
⇢ Results are combined with three lepton final states (previous slides) to probe the **challenging WZ-mediated C1N2 scenario**:

- ⇢ Some tension from past results showing small excesses in this region with 2016 data, but nothing from Run II sadly...
- ⇢ New strategies and increased precision in the WZ estimation allows us to **"close the gap in the WZ corridor"**.

The WZ-like "gap”







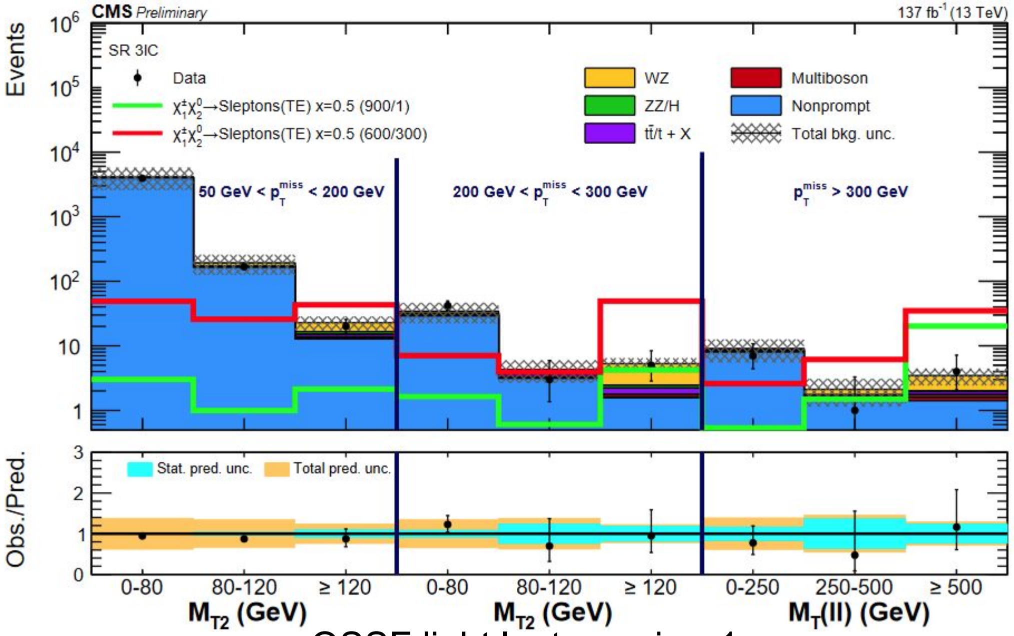
⇢ m_{N2}- m_{N1}~m_Z leads to one of the most challenging regions to probe experimentally: kinematics are near identical to SM WZ. Not closed with 2016 data.

⇢ Also, some reinterpretations of ATLAS+CMS results pointed to some global tensions around electroweak mass splittings (arxiv:1809.02097).

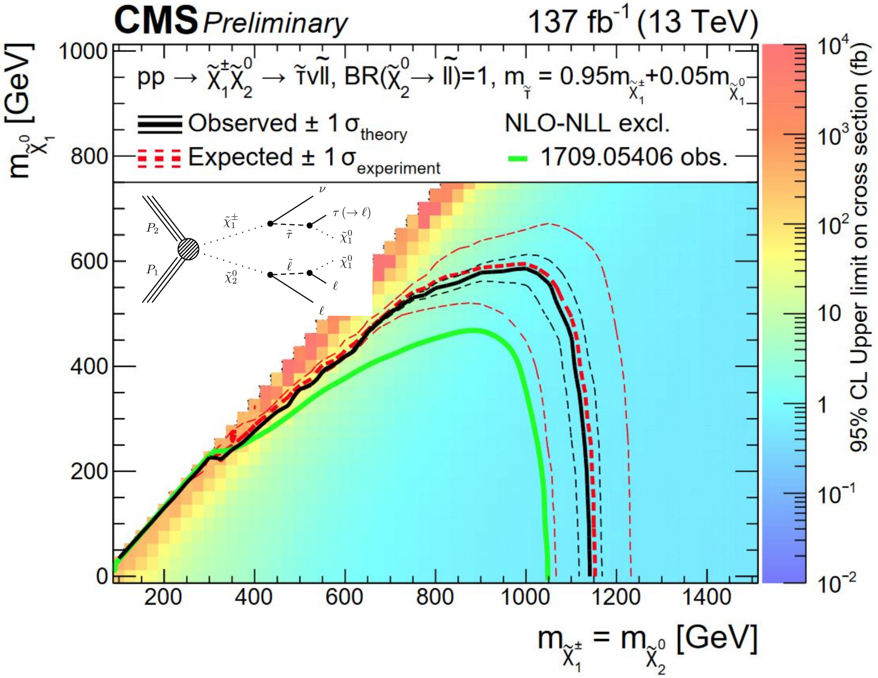
⇢ New improvements bring more power to the table on top of extra statistics:

- ⇢ Precise WZ background estimation techniques.
- ⇢ Improved signal extraction procedure (both SR+NN).

Categories with τ_h - highlight 1



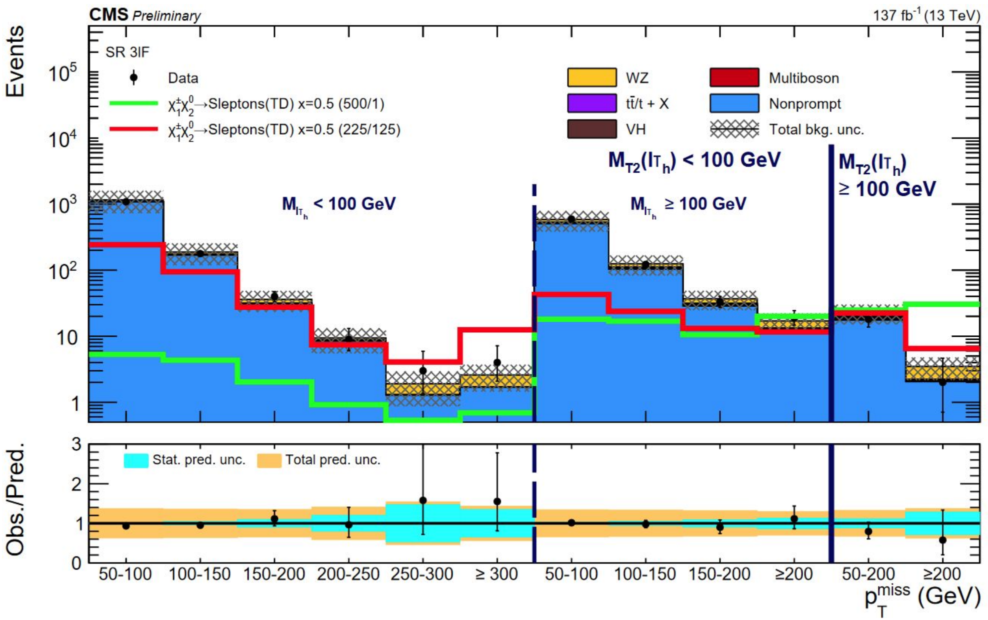
OSSF light lepton pair + 1 τ_h



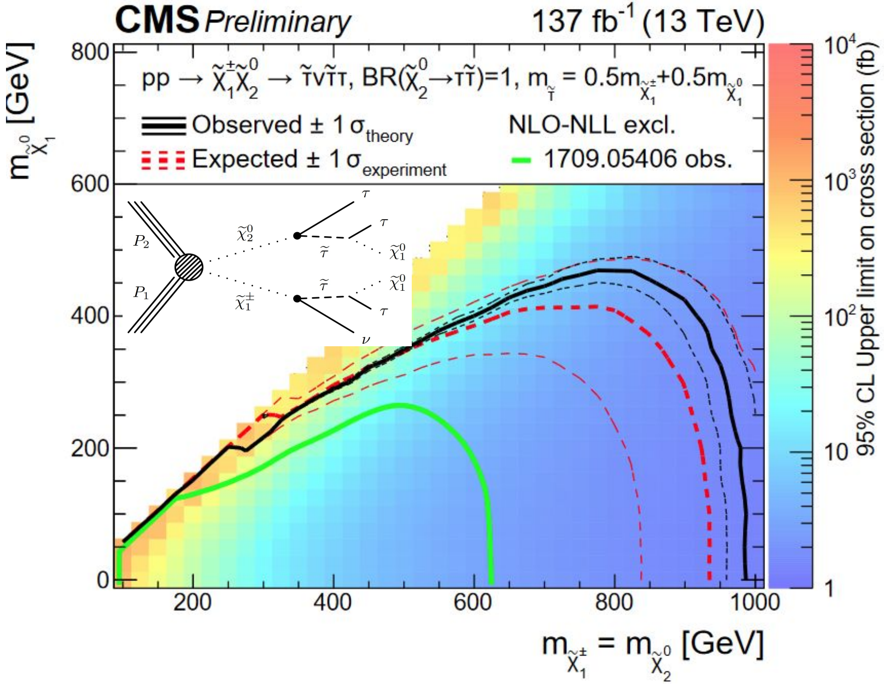
- Experimental challenge: the presence of overwhelming non prompt τ_h
- The key is to do robust data-driven estimations of such background:
  - Measurements done “in place” at low p_T^{miss} control region
  - Different measurements for DY-enriched and tt-enriched are combined

- Key in interpretations that are enriched in taus, for example, this SMS:
  - -C1 is higgsino-like
  - -N2 is wino-like

Categories with τ_h - highlight 2



Two τ_h plus a light lepton



⇢ Quite similar challenges as in the previous slide, magnified by the requirement of two hadronic taus instead of one.

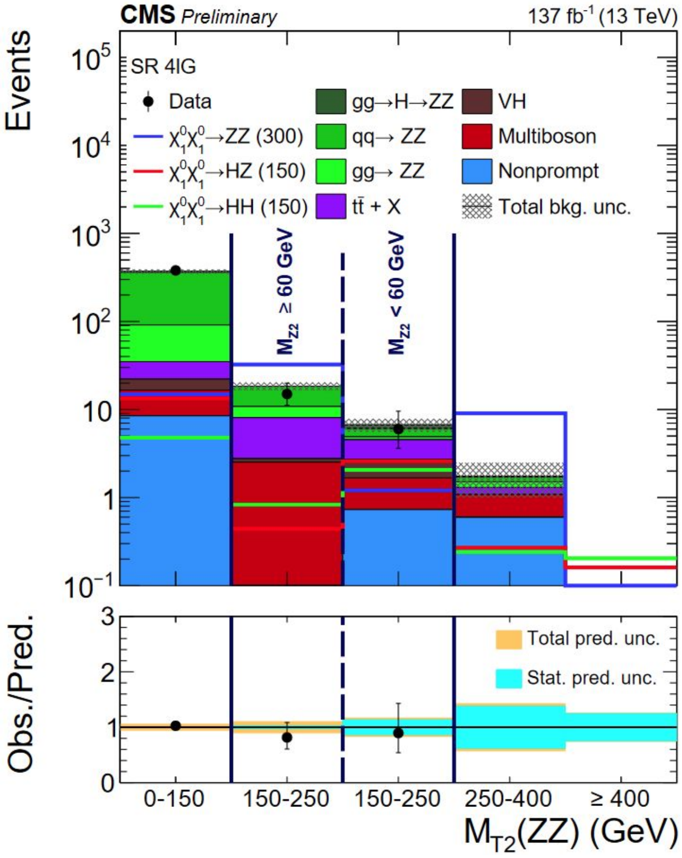
⇢ Signal extraction strategy has been heavily optimized to improve drastically the previous analysis sensitivity.

⇢ Key in interpretations that are completely dominated by taus, for example, this SMS:

-C1 is higgsino-like

-N2 is higgsino-like

Four light leptons final states - highlight

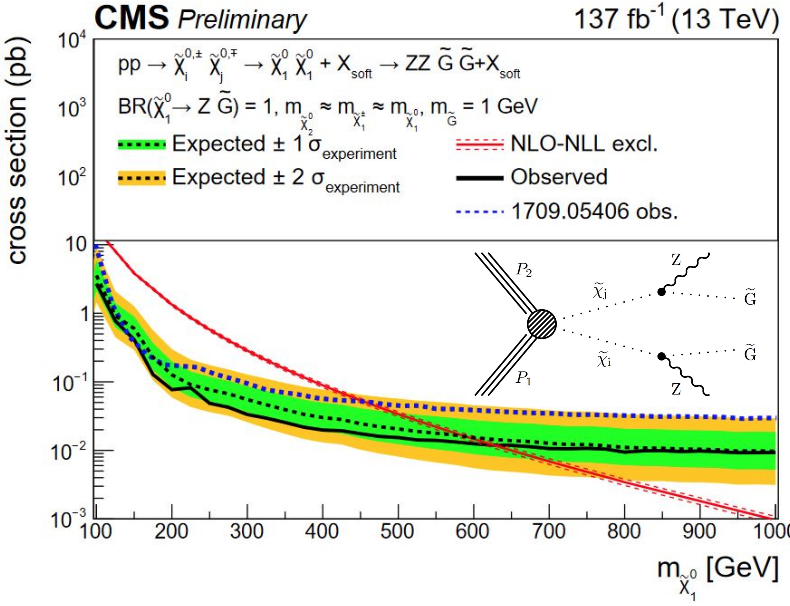


⇢ Four light leptons forming two OSSF pairs.

⇢ Discrimination is achieved by building an M_{T2}-like variable using the reconstructed Z bosons (from OSSF pairs). For resonant models like the one below, kinematical endpoint appears at $\sim m_{NLSP}$

SMS interpretation:
- GMSB model
- Near degenerate higgsino-like N1/N2/C1
- LSP is a near massless gravitino

Pushing cross section limits to the ~.01 pb region for this kind of signatures.



A view to the future

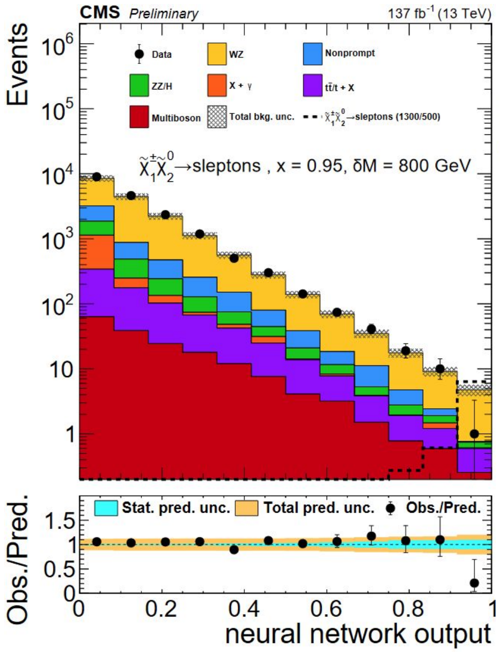
⇢ Showed highlights of CMS-PAS-SUS-19-012. New ML tools and a deep improvement of the previous ones leading to new sensitivity highs.

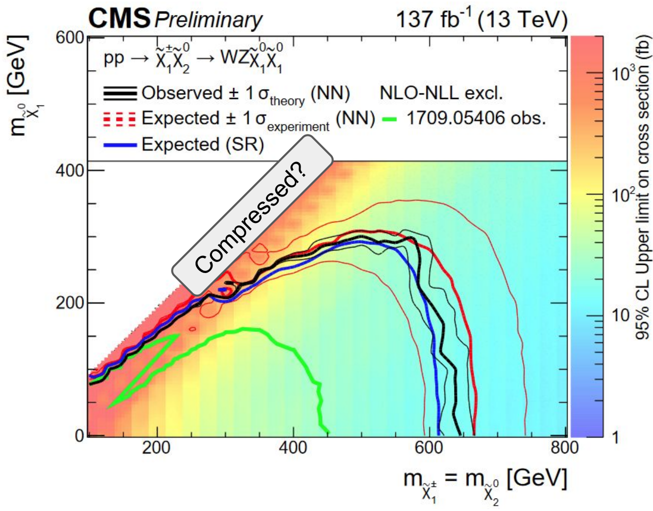
⇢ The story doesn't end here for our **newly implemented techniques**.

⇢ **Profit from them to dive into the more unexplored regions**:

- ⇢ Compressed mass scenarios?
- ⇢ Long-lived?
- ⇢ RPV?

⇢ Only time and everybody's hard work will tell where SUSY could be hiding!





Backup

Same Sign category

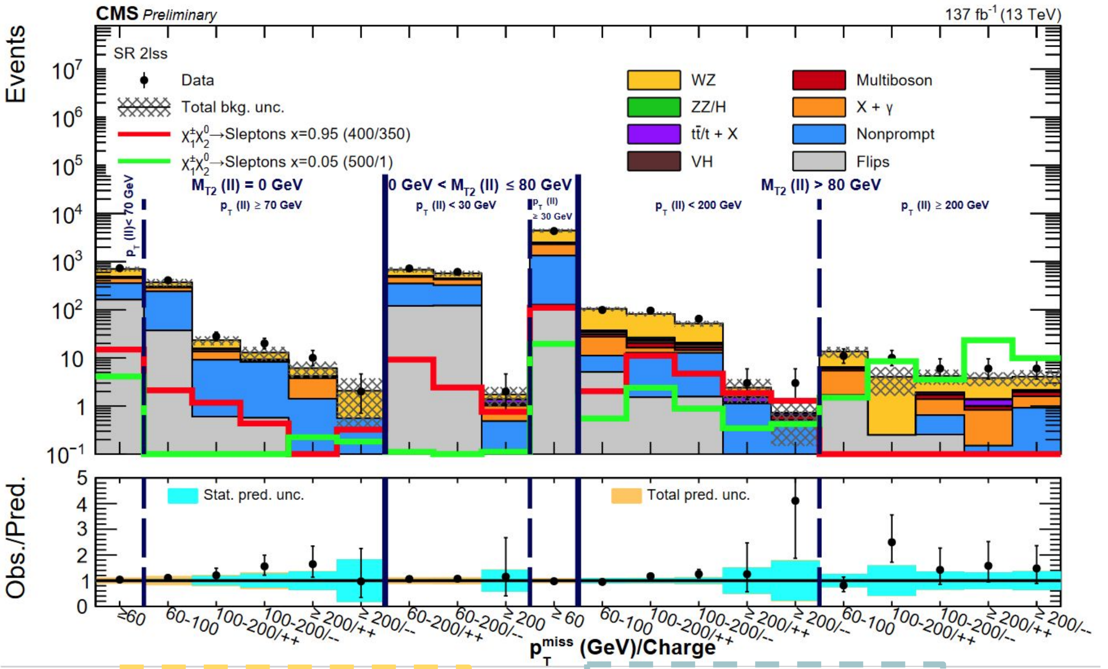
⇢ A same sign light lepton pair plus:

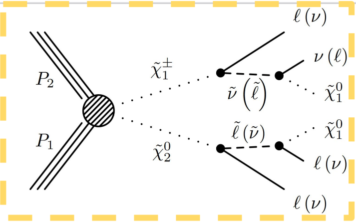
p_T^{miss} > 60 GeV (reduce non-prompt)

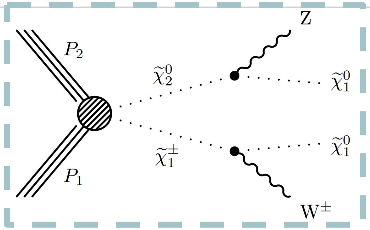
N_{jet} < 2 (reduce semileptonic tt)

⇢ The main challenge of the category is to discriminate against the overwhelming non-prompt background:

- ⇢ Very tight high p_T, high M_{T2} regions do the trick but are statistically limited.
- ⇢ In the bulk sensitivity is driven by non-prompt related uncertainties







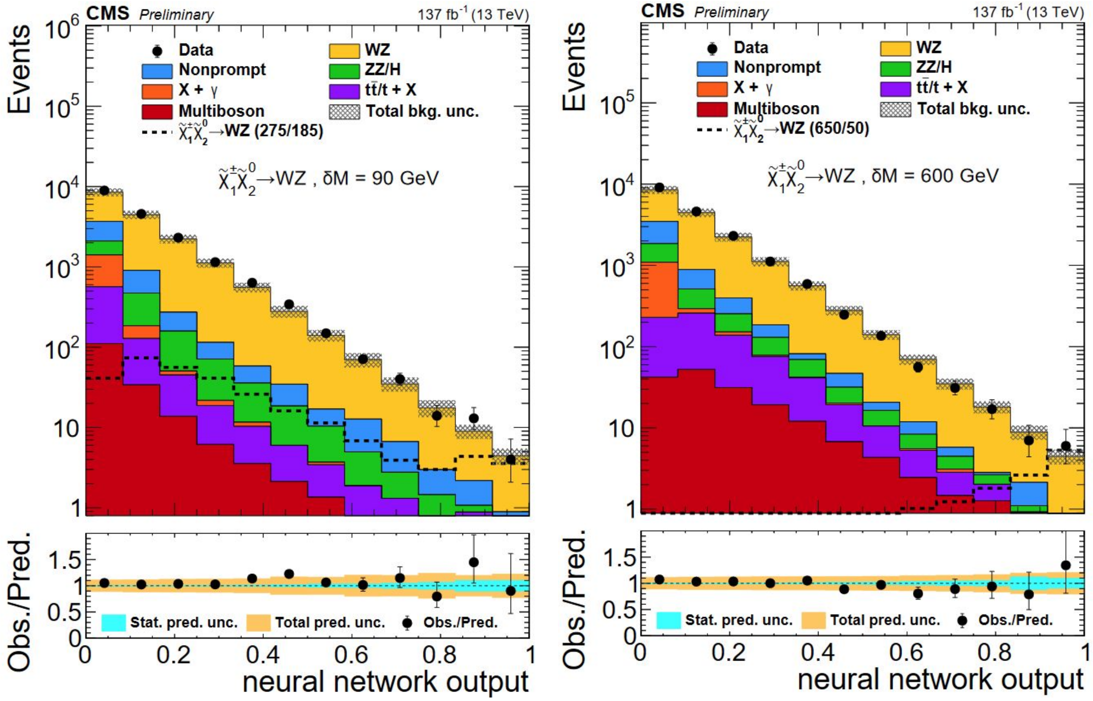
⇢ Usually sensitive to more compressed slepton mediated or WZ mediated scenarios.

3lA category

⇢ Three light leptons with an OSSF pair: p_T^{miss} > 50 GeV (enrich in signal)

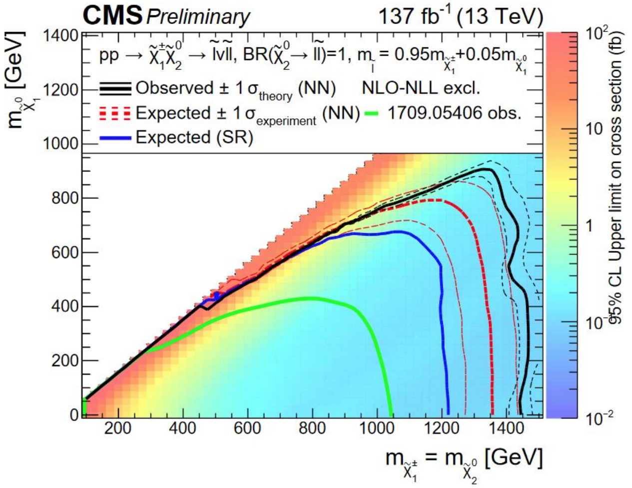
⇢ The main challenge of the category is to be simultaneously sensitive to basically all models considered in the analysis: we need exhaustive SR binning to cover all of our bases (or the PNN approach).

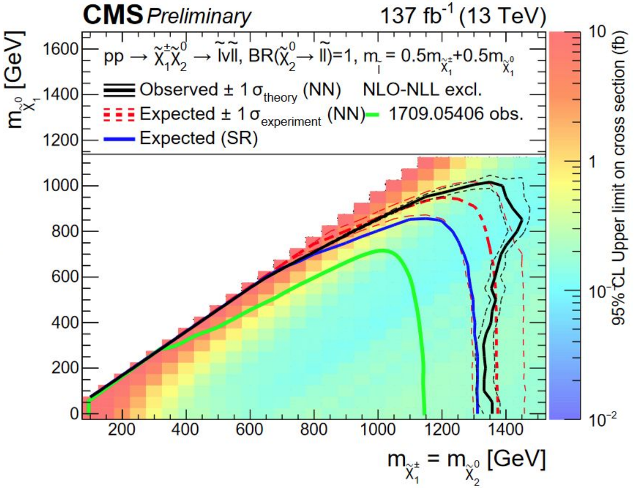
⇢ Exclusion usually comes from both tails (statistically dominated) or bulk (dominated by WZ uncertainties).

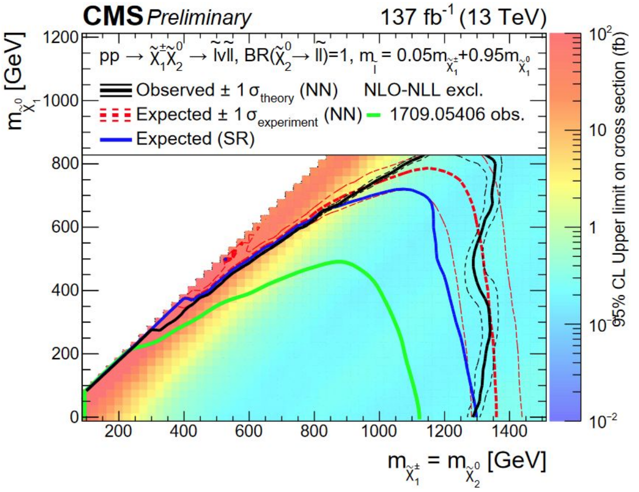


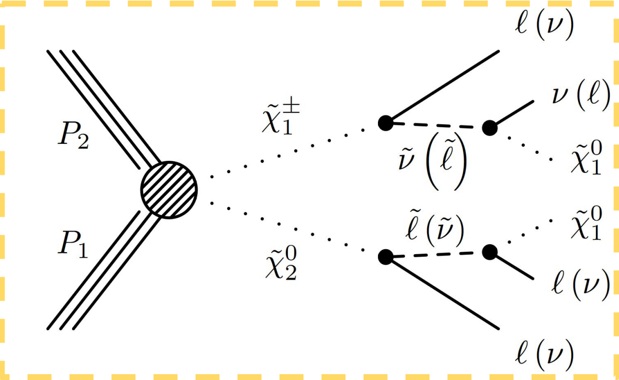
⇢ Our dedicated estimation of WZ behavior inside an specifically designed CR pays off to constrain its effects.

SMS interpretation - Slepton mediated C1N2







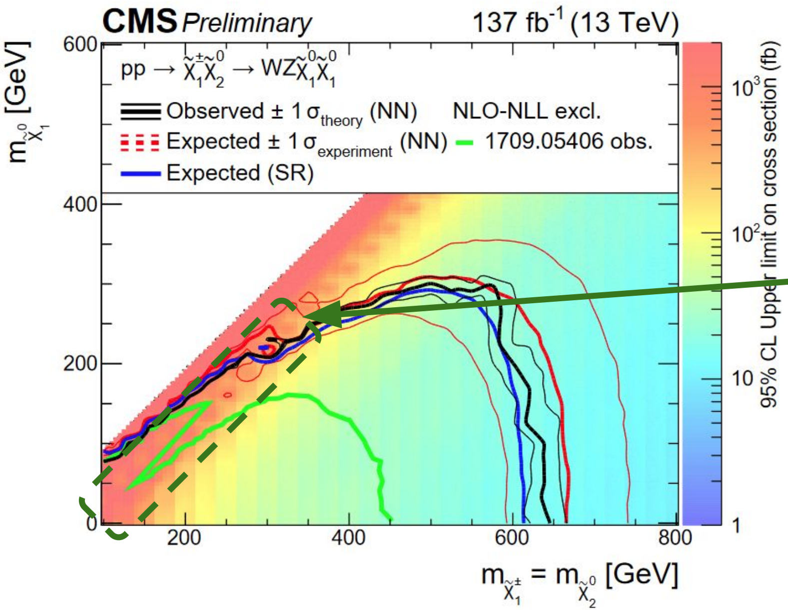


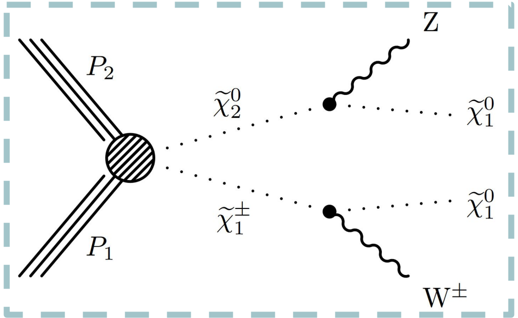
⇢ Both the SS and 3l categories contribute to the exclusion of slepton mediated C1N2 decays exclusion. SS dominates the more “compressed” regions while the 3l category provides sensitivity to uncompressed ones (thus the gain of the NN).

⇢The model assumes <u>**equal branching fraction to all lepton flavors**</u>.

⇢Three different assumptions for mass splitting between slepton and C1

SMS interpretation - WZ mediated C1N2





⇢ Quite challenging final model, as the behavior can mimic very strongly SM WZ production.

⇢ For the "WZ corridor region" even a greater challenge, as the kinematics are nearly identical due to near to no extra boost in the SM bosons.

⇢We are finally able to "close the gap" that appeared in the 2016 analysis thanks to:

- ⇢More precise estimation of WZ background.
- ⇢Increased sensitivity from both NN and SR approach.

⇢Interpretation includes SS and 3 light leptons regions.

3lB category

⇢ Three light leptons with no OSSF pair:

p_T^{miss} > 50 GeV (enrich in signal)

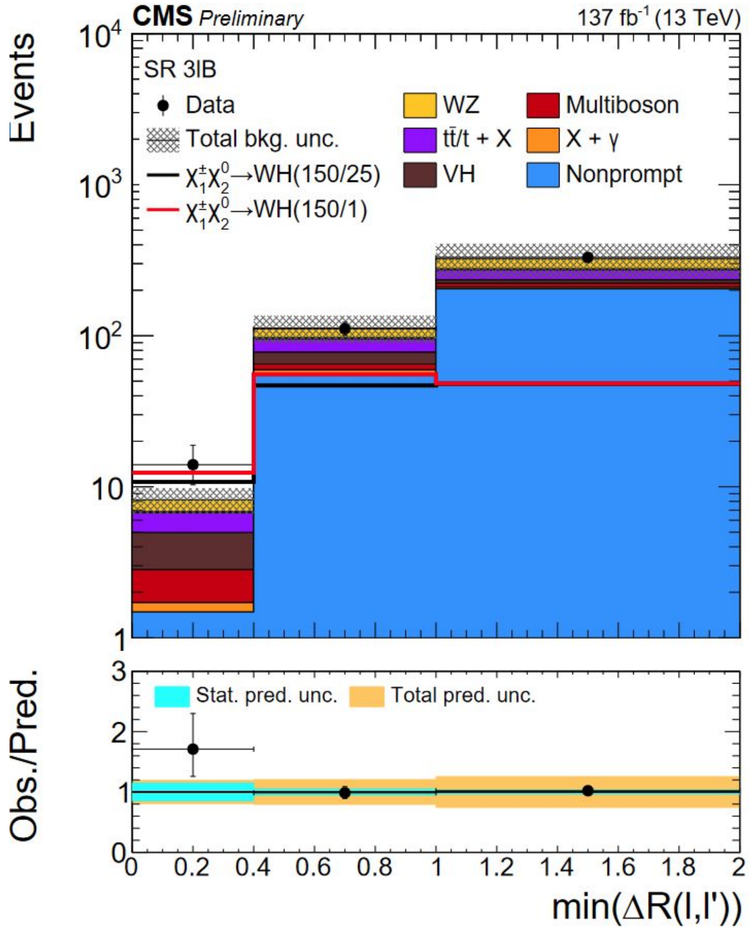
⇢ The picture changes completely once we don't require a lepton pair compatible with the Z:

⇢ Much more depleted from SM processes

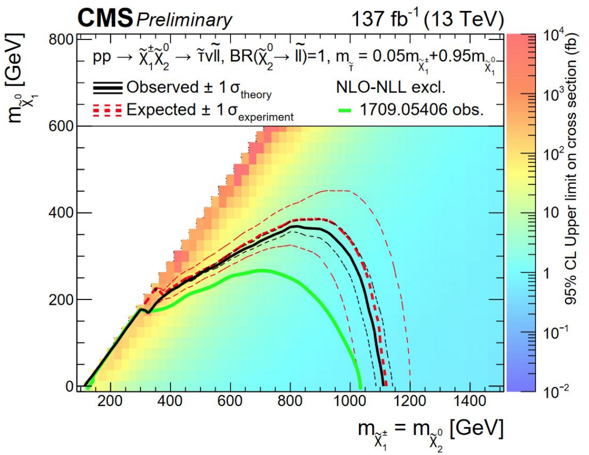
⇢ Quite dominated by non prompt contributions.

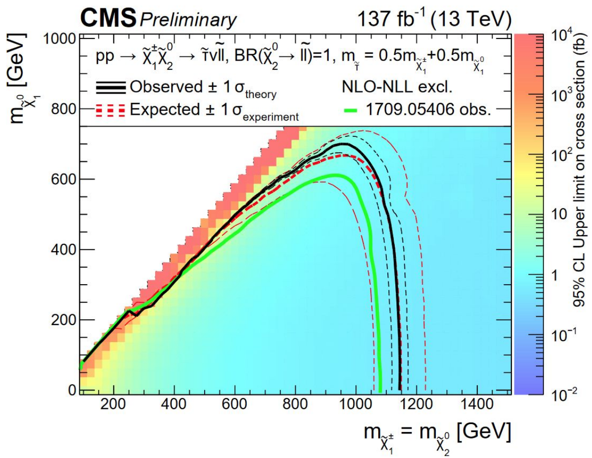
⇢ Offers unique sensitivities to signals that produce a H->WW signature, thus we go for an approach sensitive to Higgs presence.

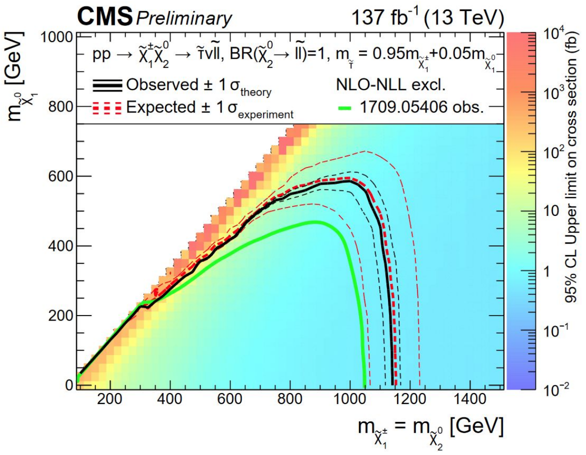
All plots include a p_T^{miss} > 50 GeV requirement

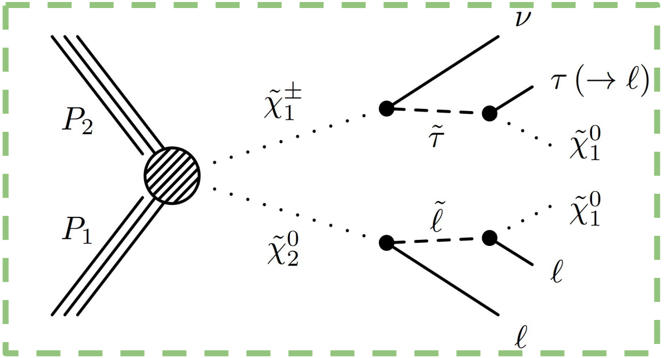


SMS interpretation - Tau enhanced slepton mediated C1N2 decays







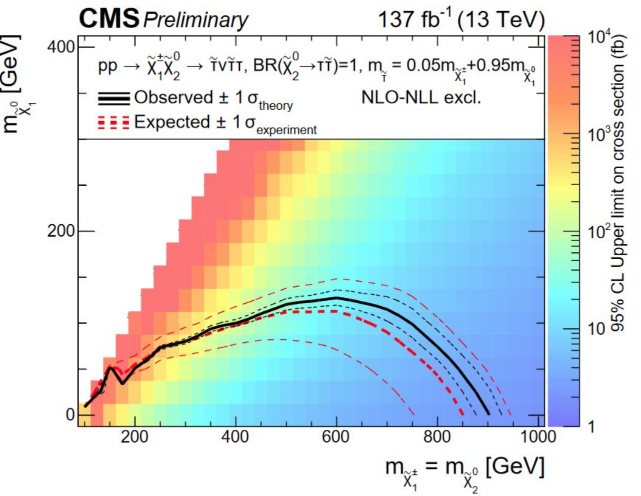


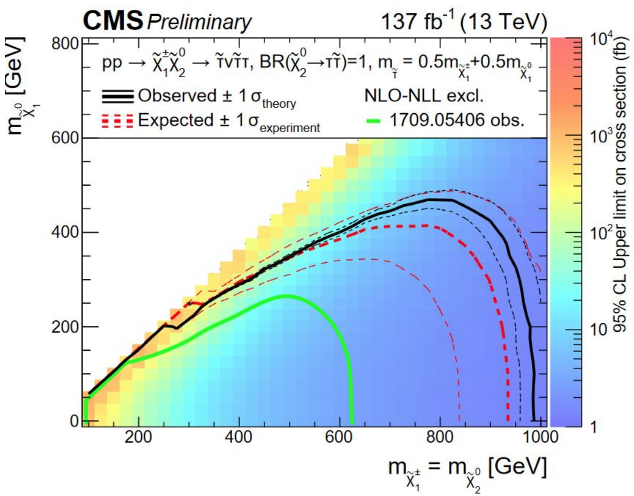
⇢ All three lepton categories are all included to try an increase our sensitivity to these kind of scenarios.

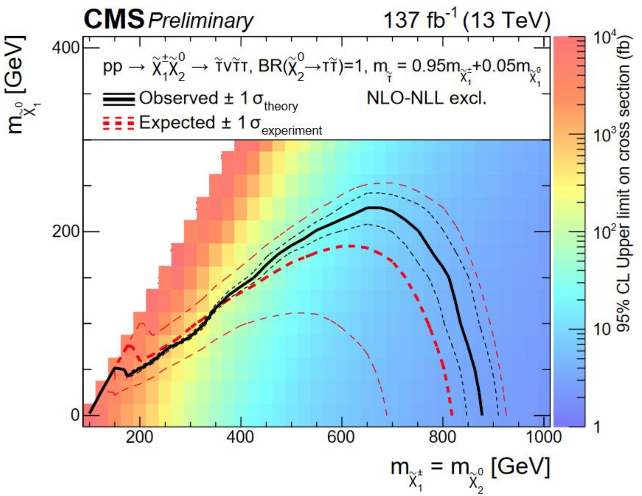
⇢The model assumes **preference towards staus in C1 decays** (can happen if it is quite higgsino-like).

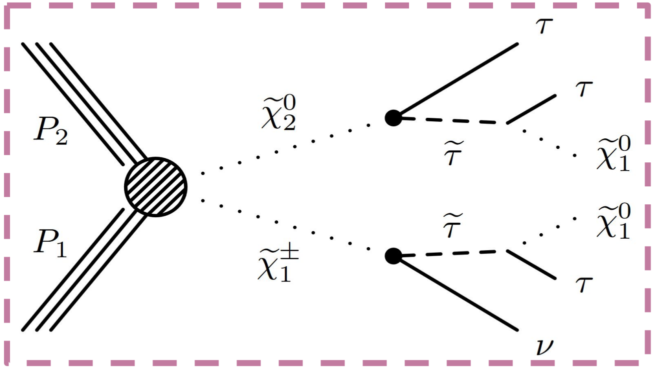
⇢Three different assumptions for mass splitting between slepton and C1, similar to other slepton decaying scenarios.

SMS interpretation - Tau dominated slepton mediated C1N2 decays







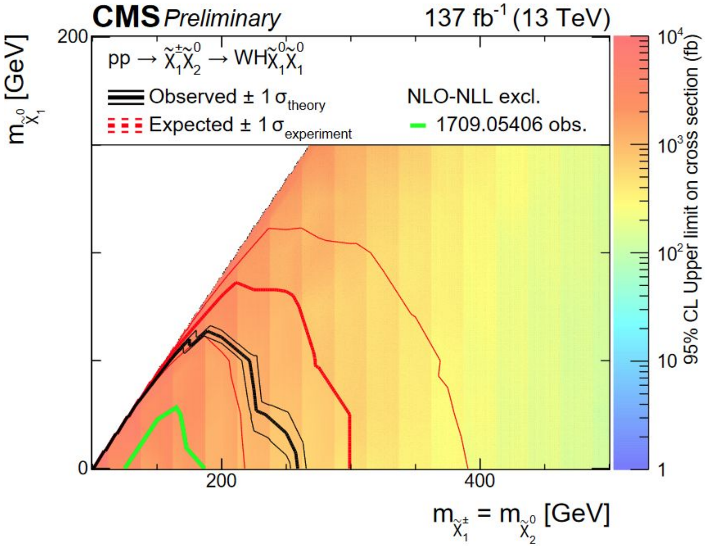


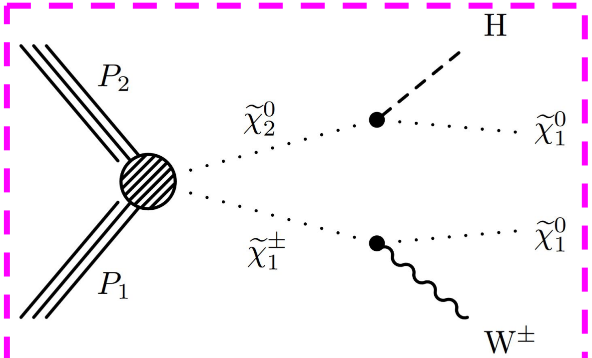
⇢ Categories 3lB to 3lF are all included to try an increase our sensitivity to these kind of scenarios. But result is near completely dominated by 3lF.

⇢The model assumes **<u>preference towards staus in C1 and N2 decays</u>** (can happen if both are quite higgsino-like).

⇢Three different assumptions for mass splitting between slepton and C1, similar to other slepton decaying scenarios.

SMS interpretation - WH mediated C1N2





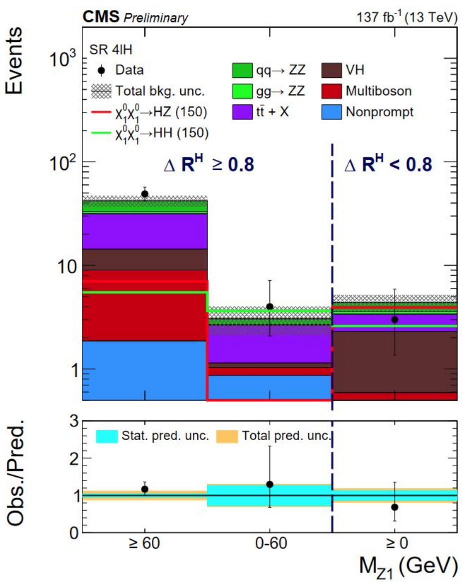
⇢Interpretation includes all two lepton and three lepton categories, but it is quite dominated by the 3lB which is dedicated to Higgs-mediated models.

⇢ More challenging than WZ mediated in multileptonic final states due to the reduced branching fractions of the Higgs leading to extra leptons.

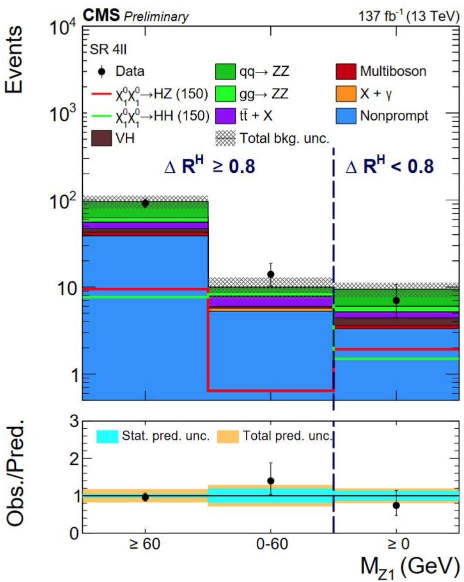
⇢ Still the gains are quite significant when compared when the previous iterations of the analysis.

Other four lepton final states

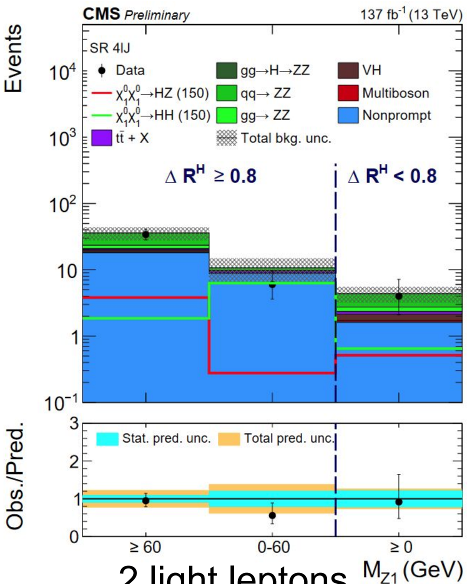
All plots include a $p_T^{miss} > 50$ GeV requirement



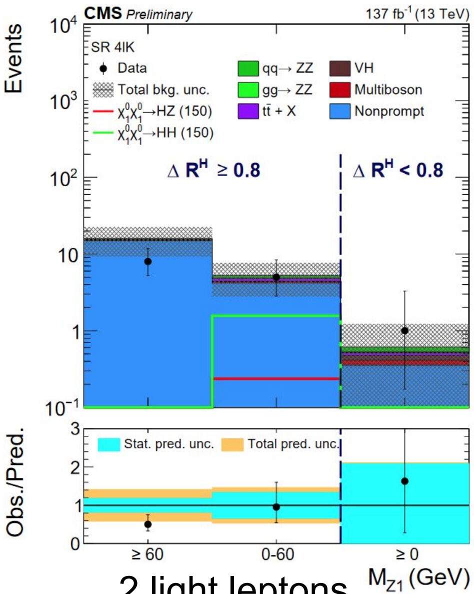
4 light leptons, <2 OSSF



3 light leptons, $1\tau_h$



2 light leptons, $2\tau_h$ (both OSSF)

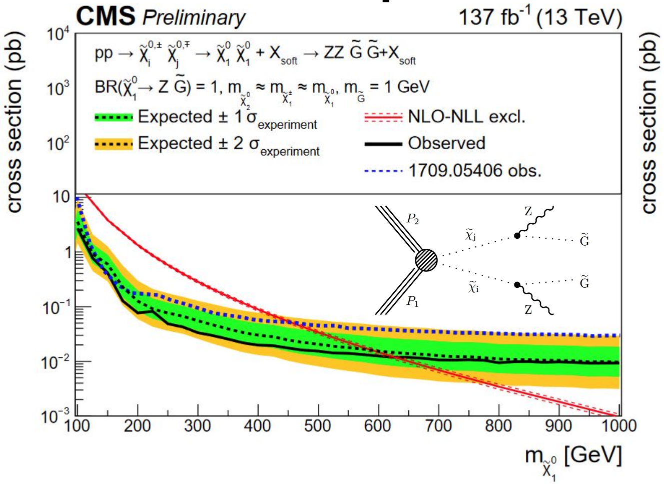


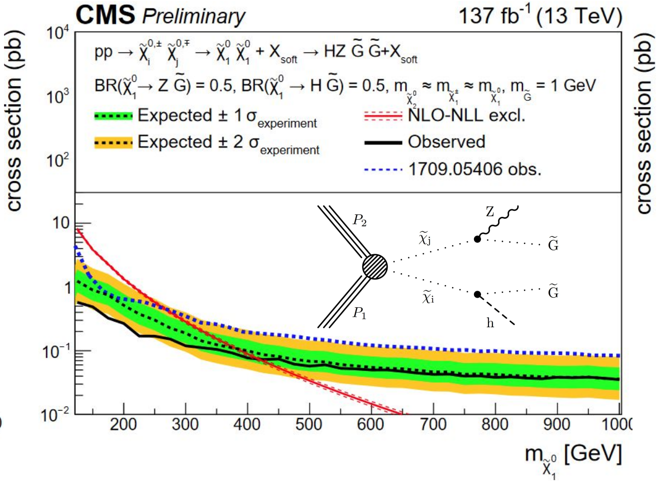
2 light leptons, $2\tau_h$ (not both OSSF)

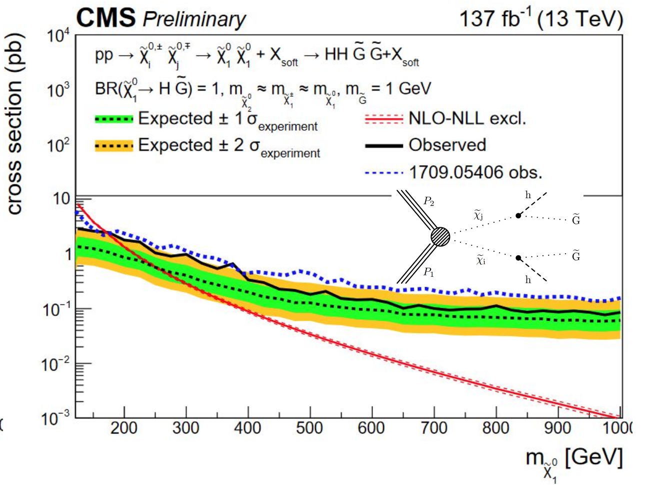
⇢ All other possible flavor and charge distributions totalling to four leptons are similarly sensitive to the same signal models but with very different background presence.

⇢ We opt to use a very similar "tagging" strategy in each category to reconstruct the Z and H bosons and then use associated discriminant quantities to bin the SR.

SMS interpretation - GMSB models







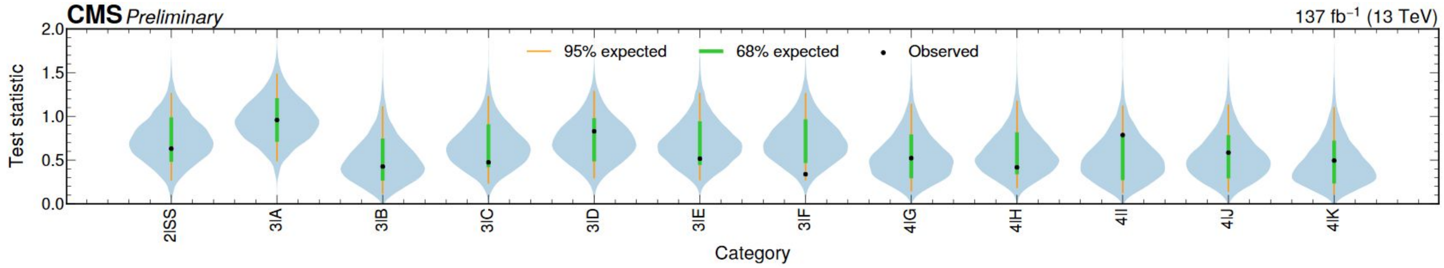
⇢ All interpretations are different variations of a GMSB scenario in which near mass-degenerate Higgsinos decay into massless gravitinos. Difference arise in the Higgsino decay branching fractions.

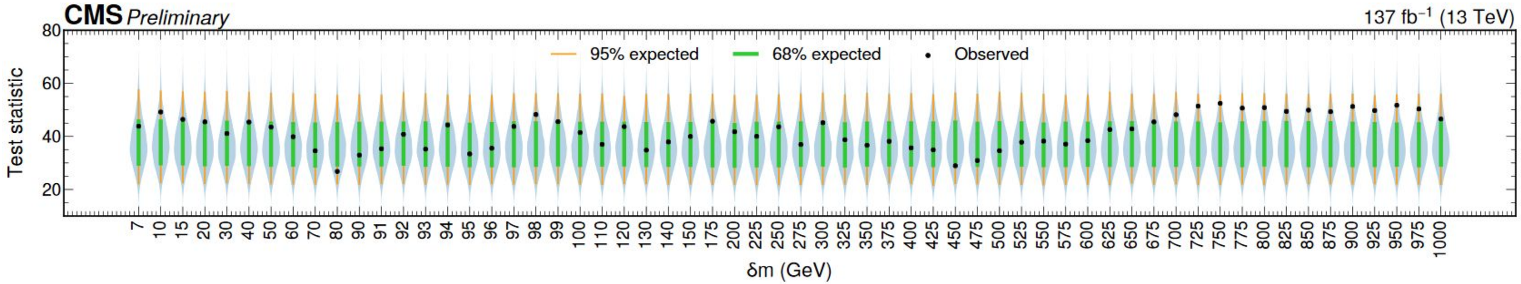
⇢ All analysis categories included into this fits, but most sensitivity coming from the four lepton ones.

⇢Increasingly difficult to reach the cases that are more enriched in Higgs bosons due to the lower possibility of obtaining prompt leptons from the Higgs decays.

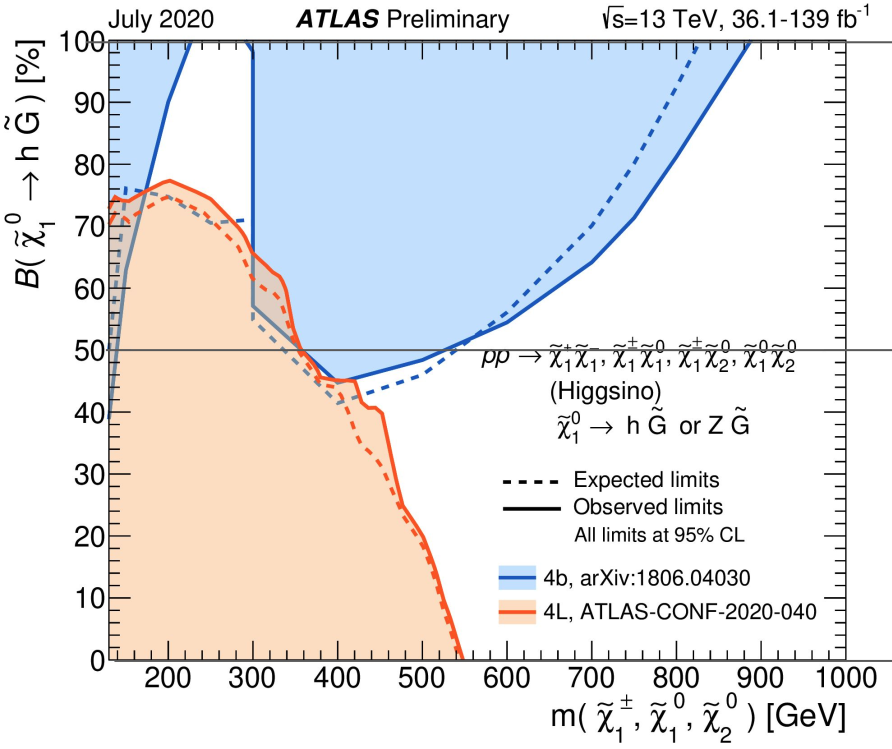
Summary NN plots

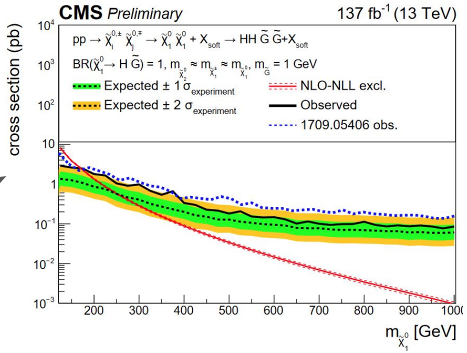
⇢ As a way of summarizing overall agreement of the NN (and SR) discriminants, compare a chi-square like test statistic (fit to a saturated model) between our observed data and b-only toys:

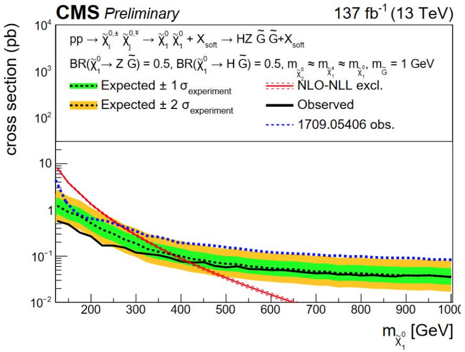


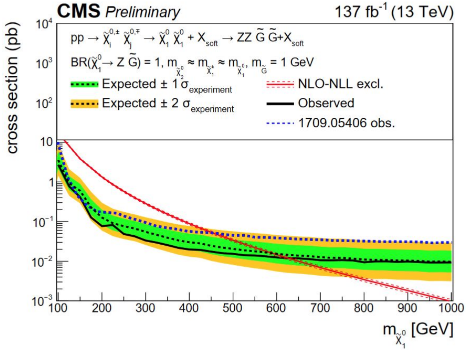


Summary ATLAS/CMS plots (GMSB)



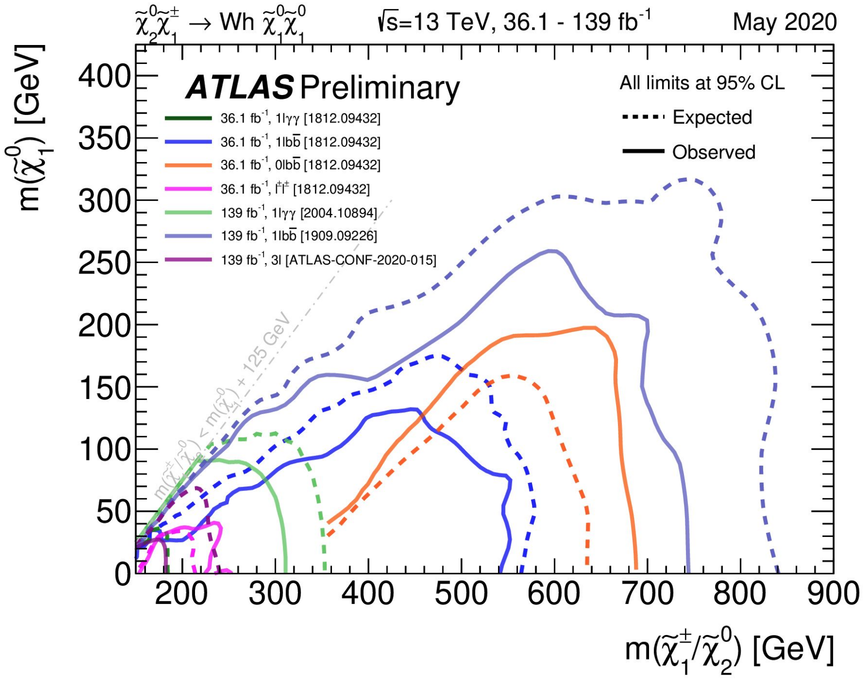


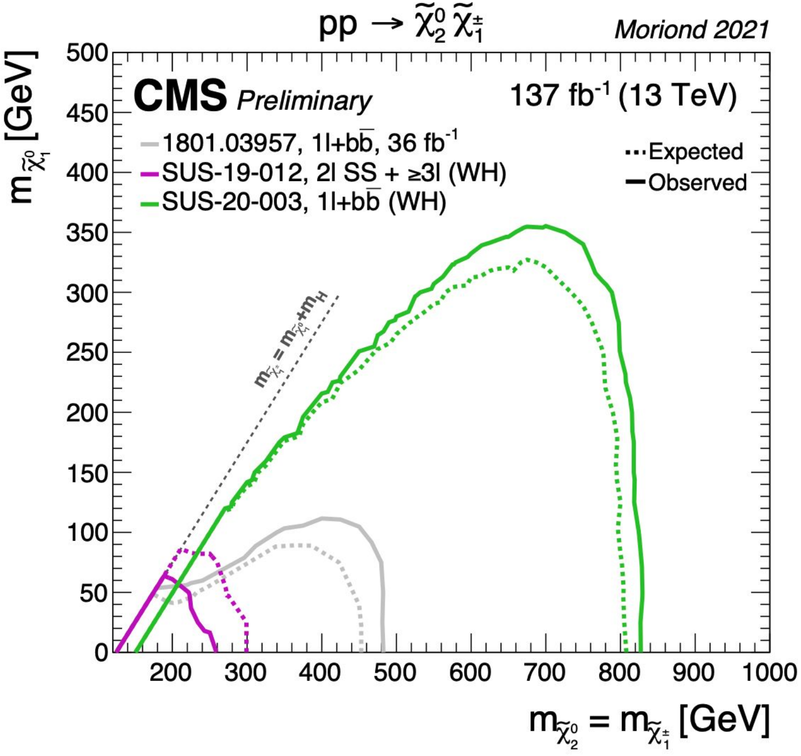




(No summary from CMS yet, but also check Pablo’s talk)

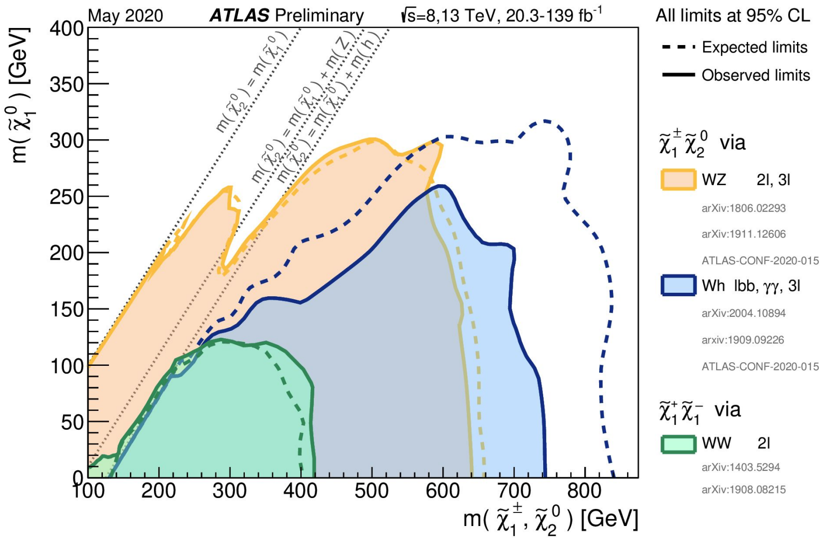
Summary ATLAS/CMS plots (WH)

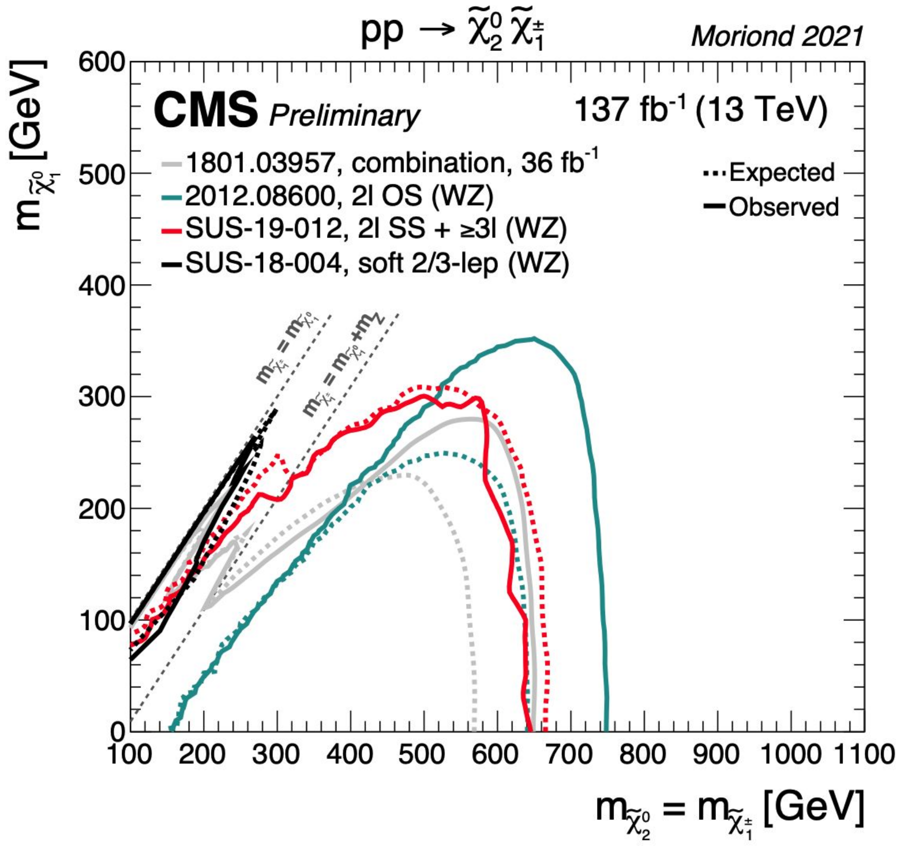




Summary ATLAS/CMS plots (WZ/WW)

(Not trying to make ATLAS dirty, just getting the same Y axis sizes for comparison…)





Summary ATLAS/CMS plots (Slepton mediated)

(Not trying to make ATLAS dirty, just getting the same Y axis sizes for comparison…)