Searches for SUSY in leptonic final states with the CMS experiment

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Lepton Photon 2021

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Leptonic SUSY in CMS

- So far, no signs of SUSY at LHC in most straightforward scenarios
  - Impressive constraints on strong SUSY sector, since early Run II!!
- However, EWK SUSY at weak scale remains among most promising solutions to the Higgs mass hierarchy problem.
- Considering large Run II dataset, and the time to analyze it: now is the moment for EWKino searches to shine!

Recent CMS searches covered today:

Inclusive searches with broad reach

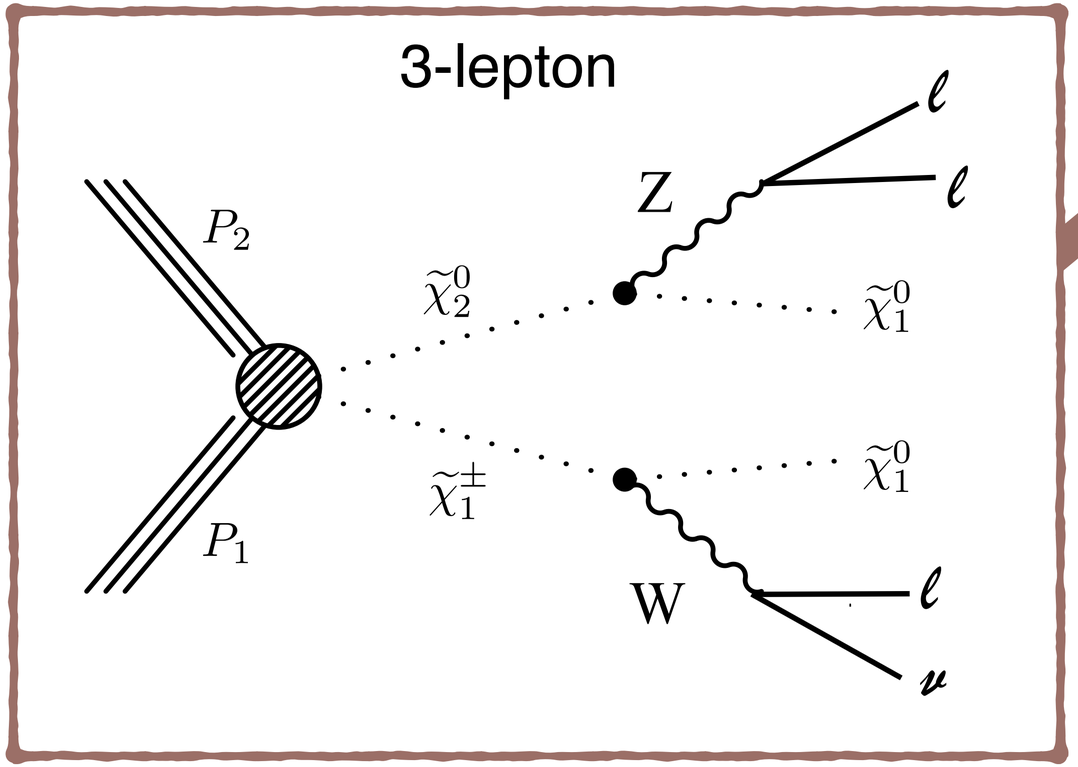
- Multilepton (2106.14246)
- WH (1-lep) (2107.12553)

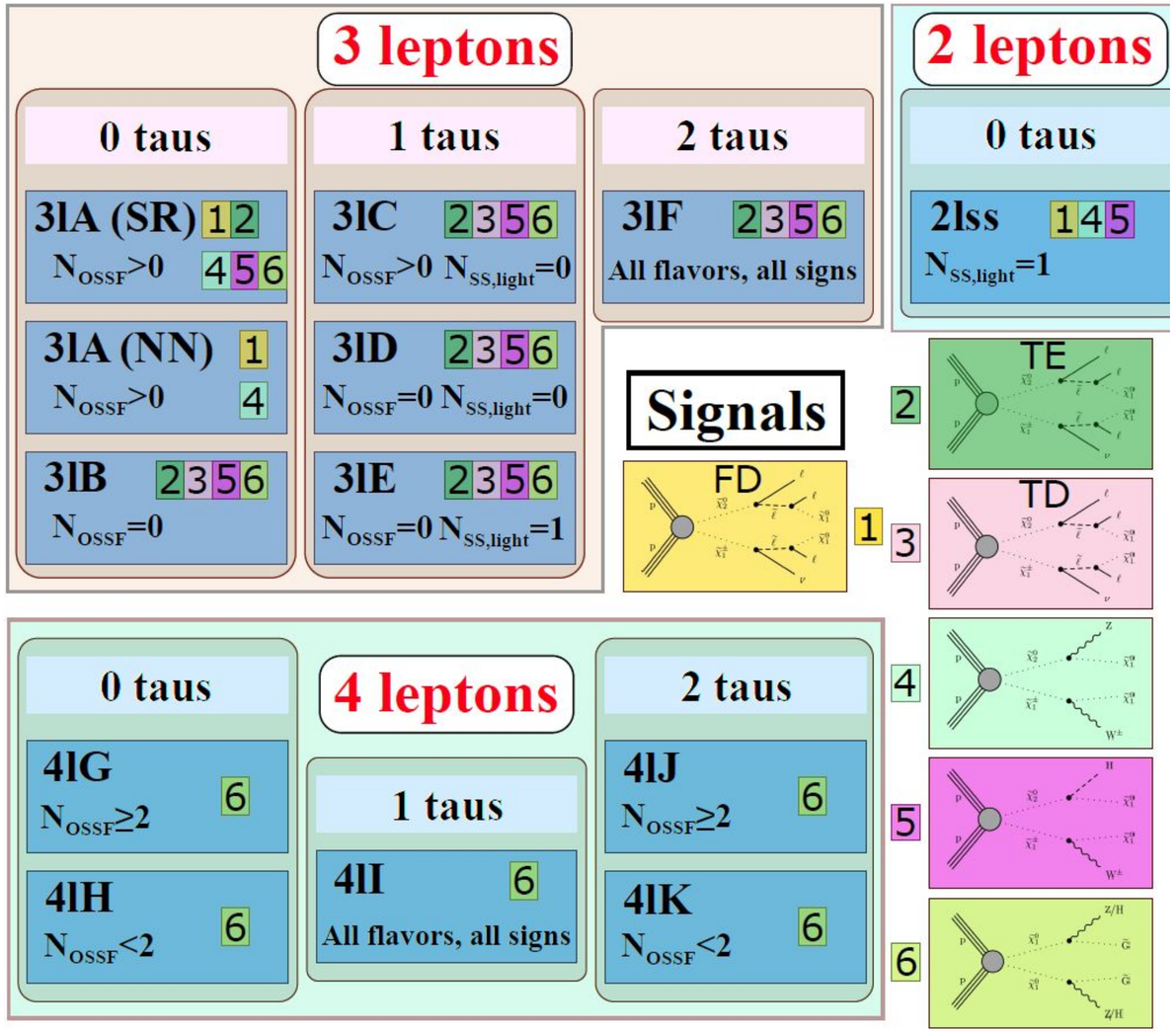
Targetted searches for challenging signatures

- Soft leptons (2111.06296)
- Stealth stop corridor (2107.10892)

Multilepton EWKino search

- Numerous final states possible depending on SUSY spectrum





Fermilab

Multilepton EWKino search

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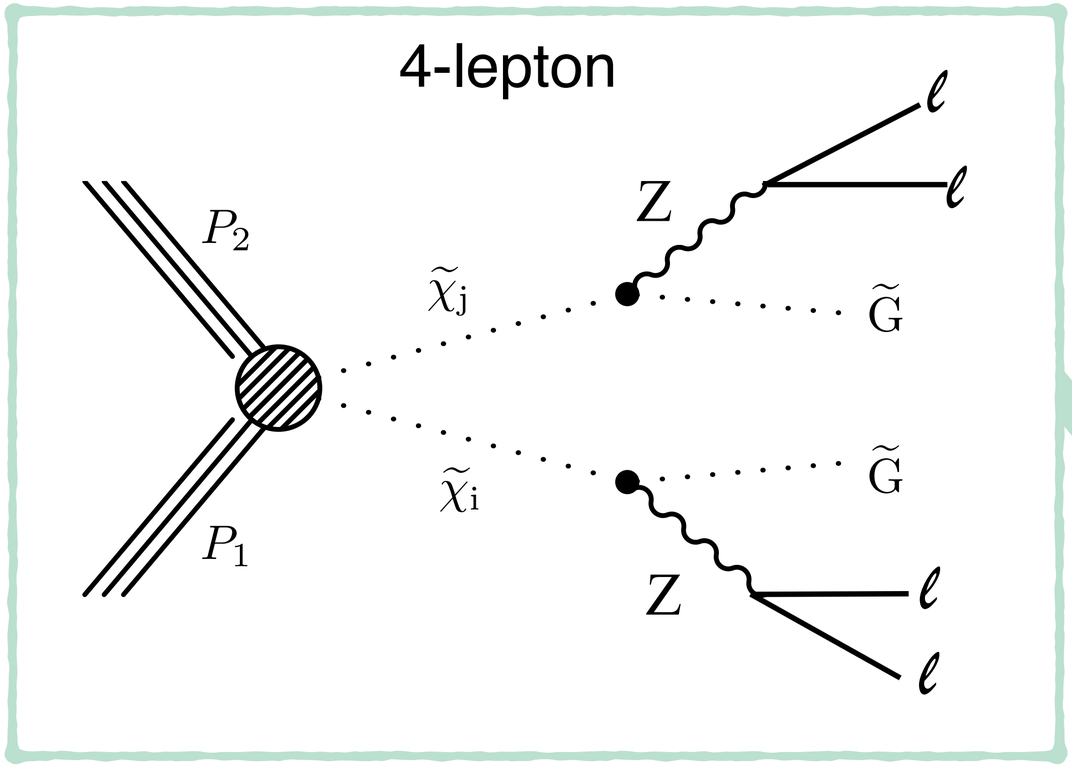

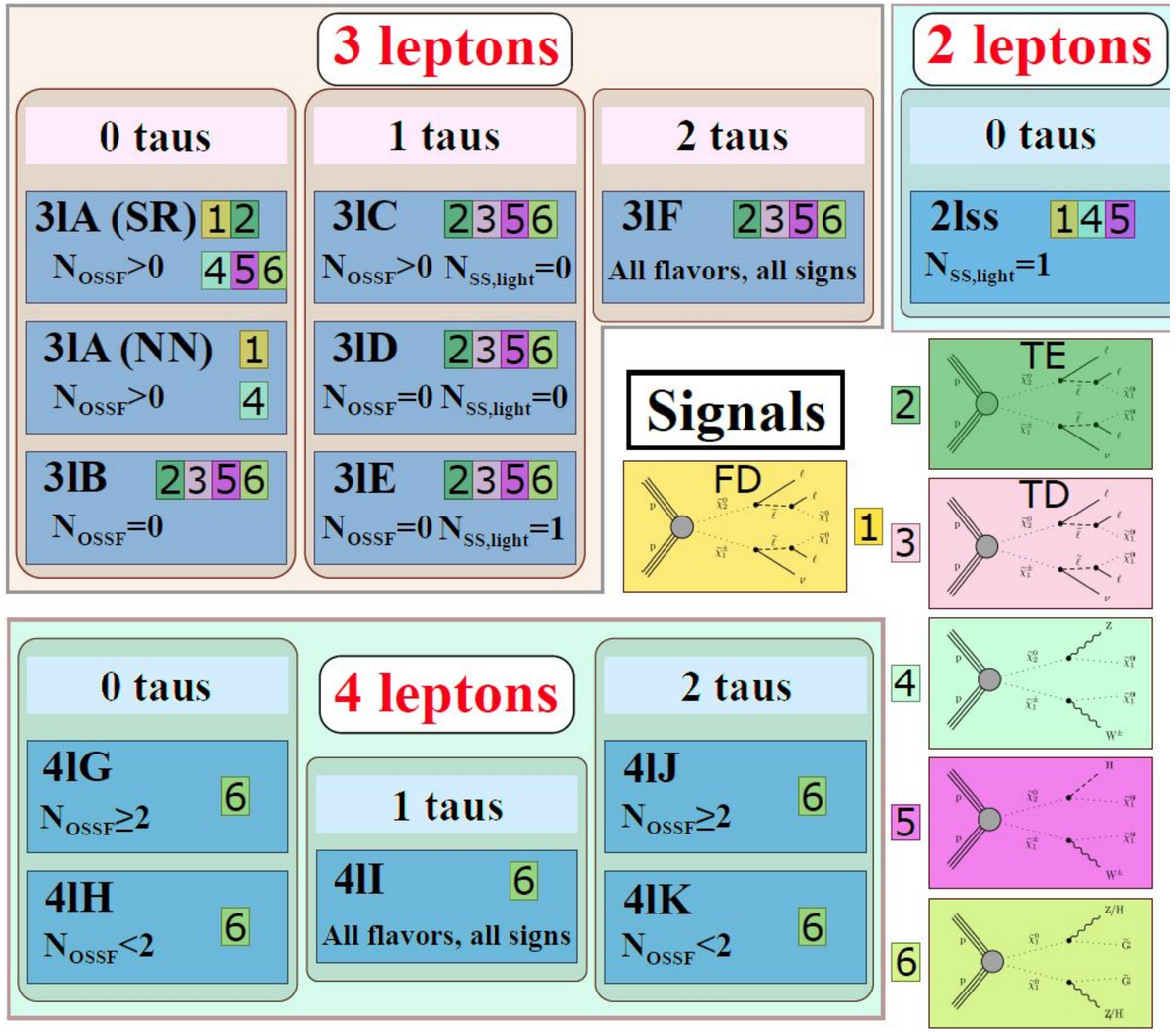

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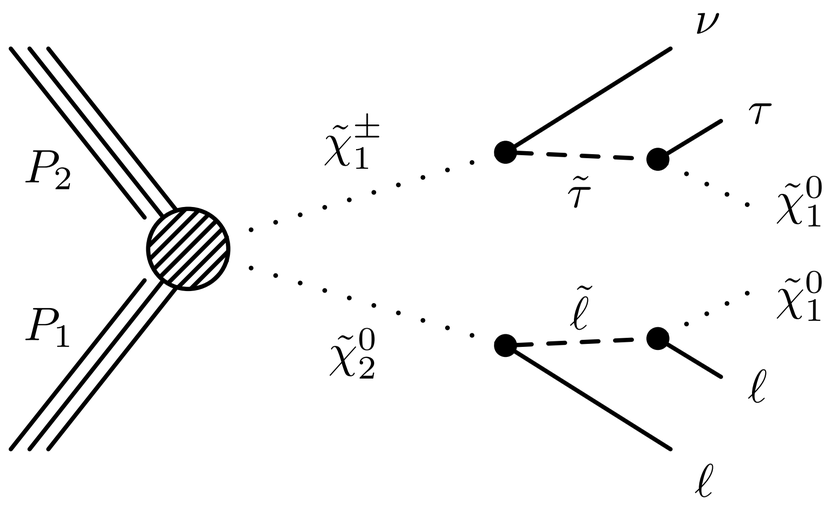
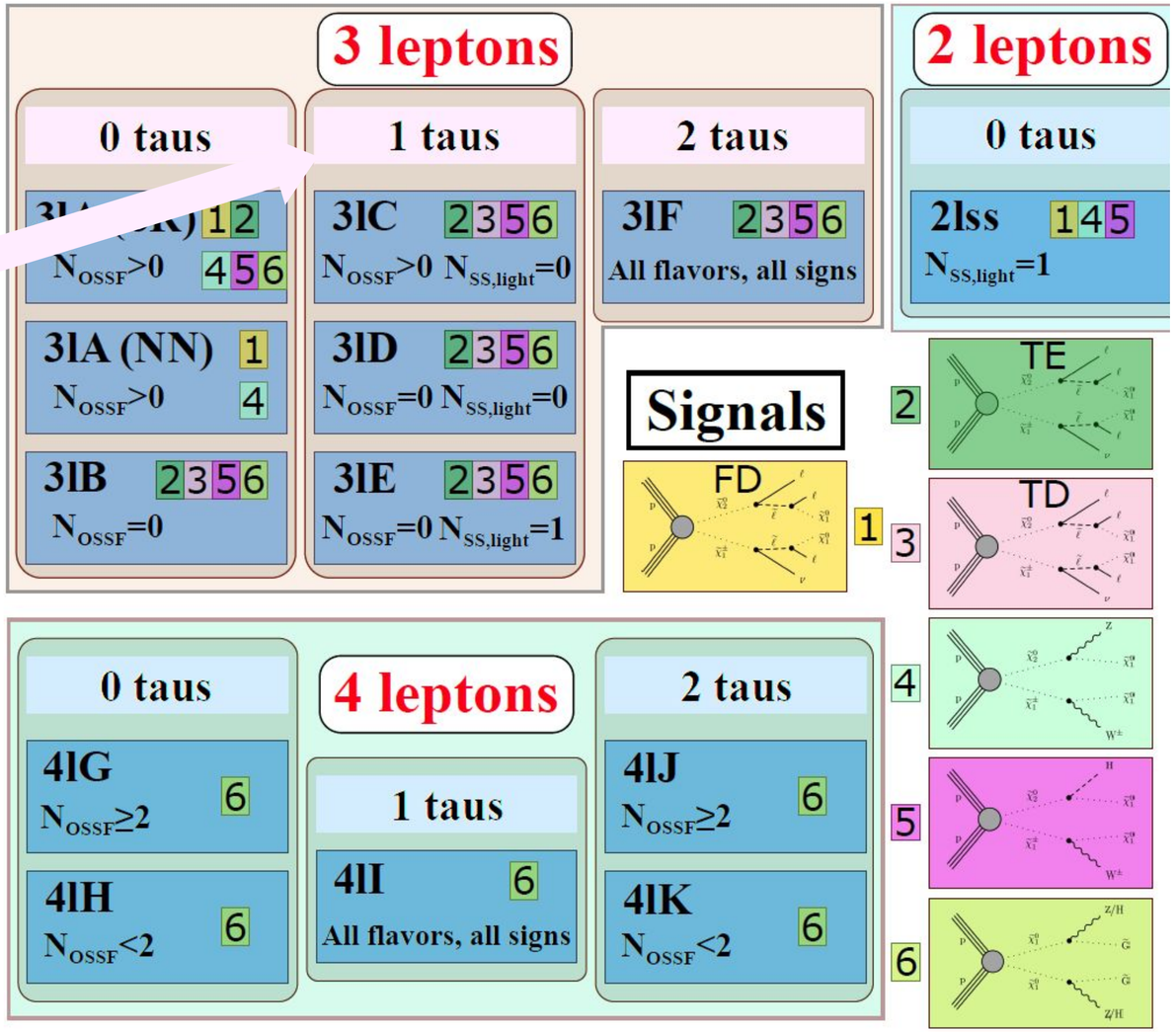
Multilepton EWKino search

- Numerous final states possible depending on SUSY spectrum

Tau-enriched (slepton-mediated)





Need to cast wide net to catch SUSY!

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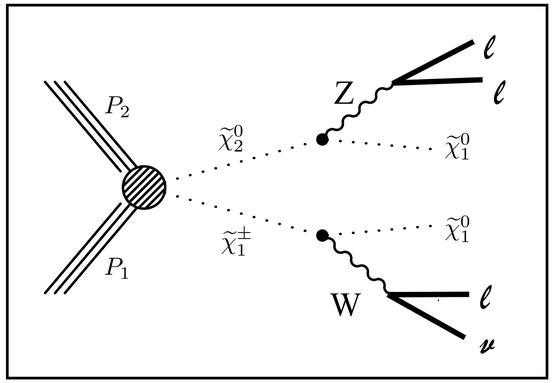
3x light-lepton final state

- Sensitive to important models, but large BG (SM WZ)
- Many good variables to enhance signal:
  - M_{ll}, M_T^W, M_T^{3l}, L_T, H_T, MET
- However, across topologies & mass plane, huge variation in kinematics!

Traditional approach: exhaustive set of bins to cover phase space.

WZ-mediated



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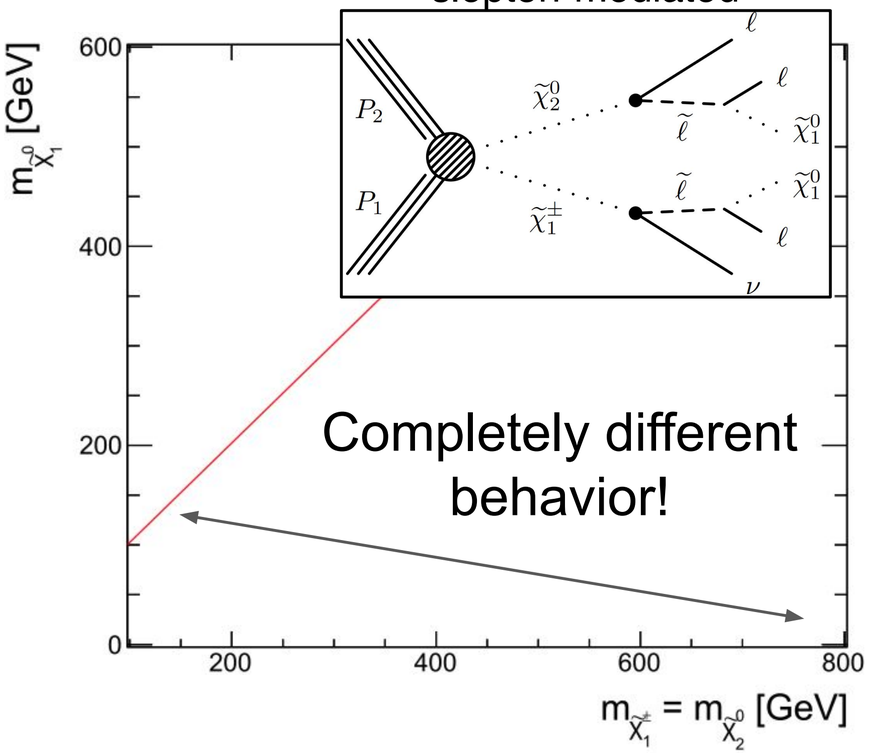

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3x light-lepton final state

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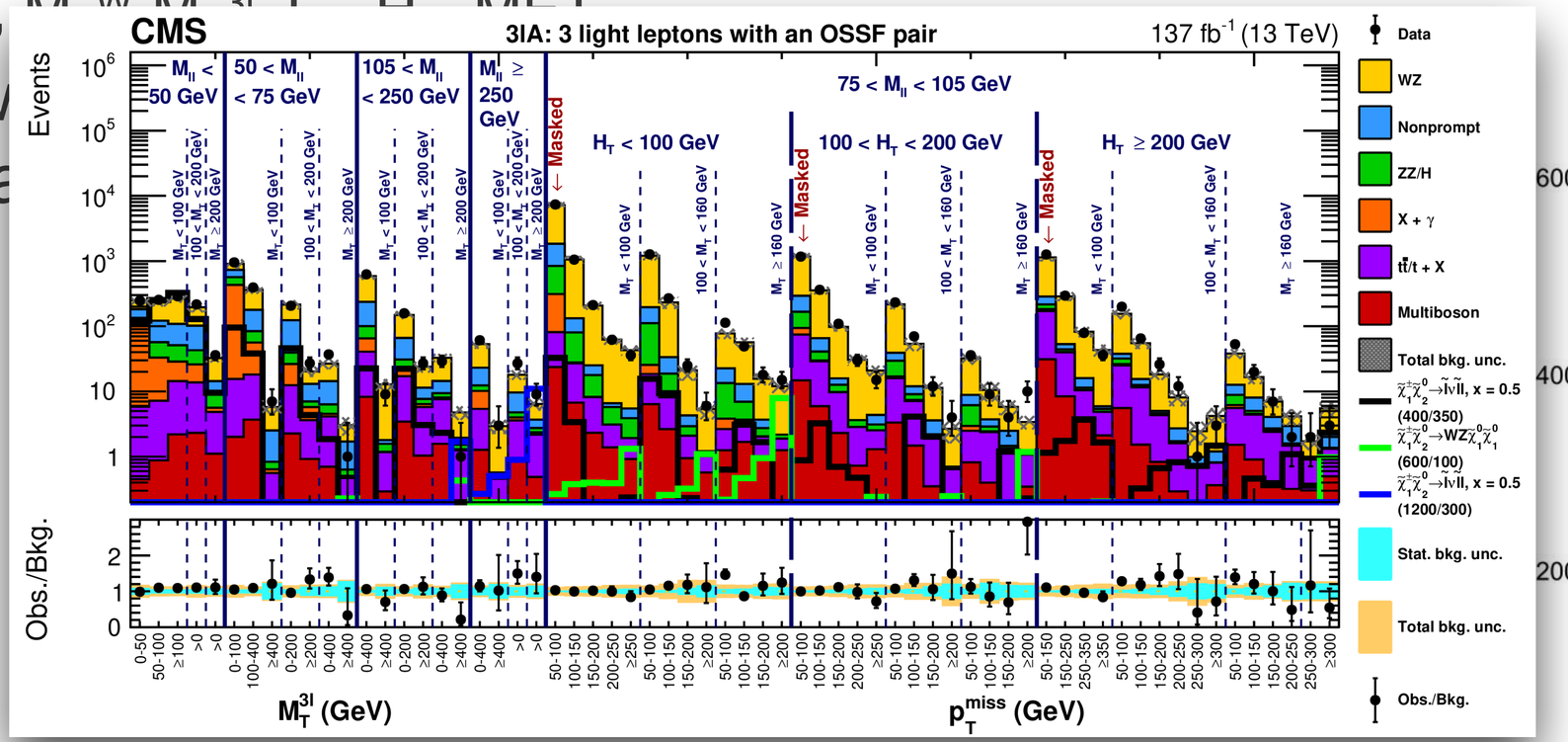

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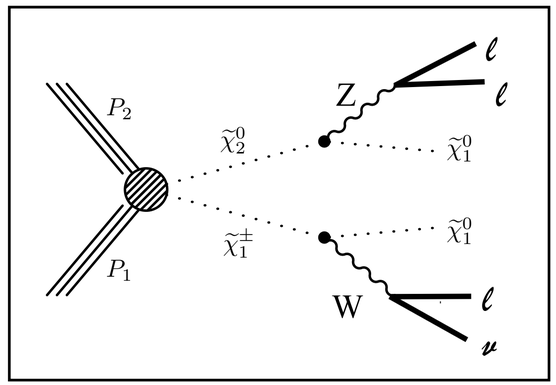

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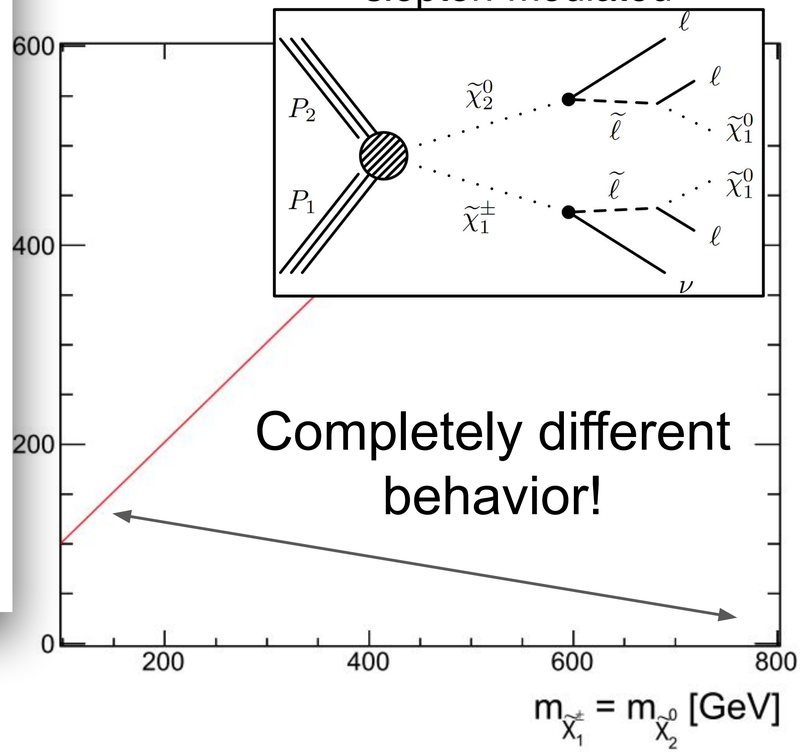

Effective, but complex and non-optimal.
Can we simplify?

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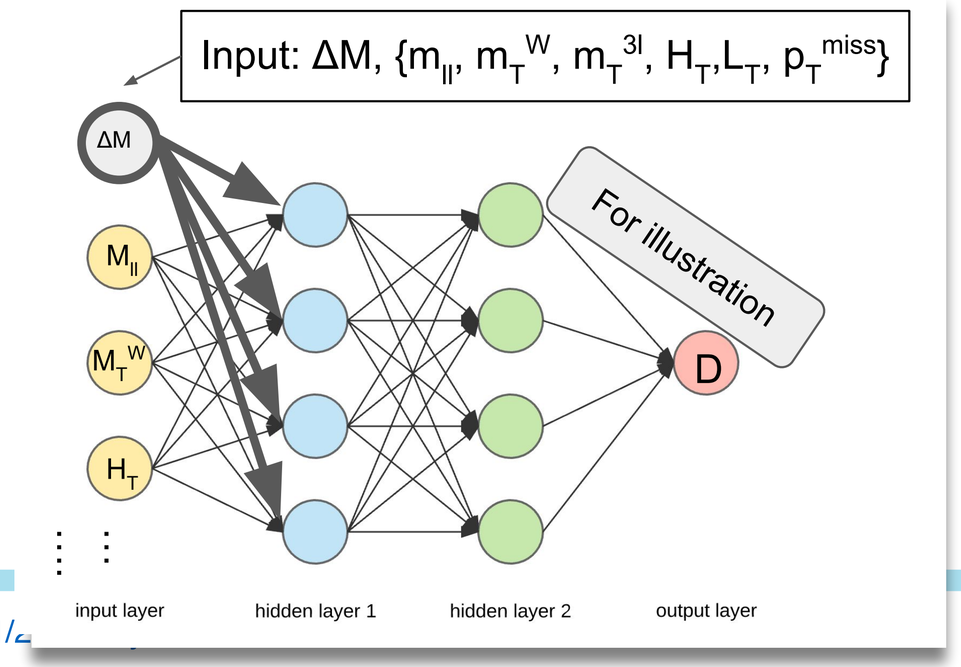
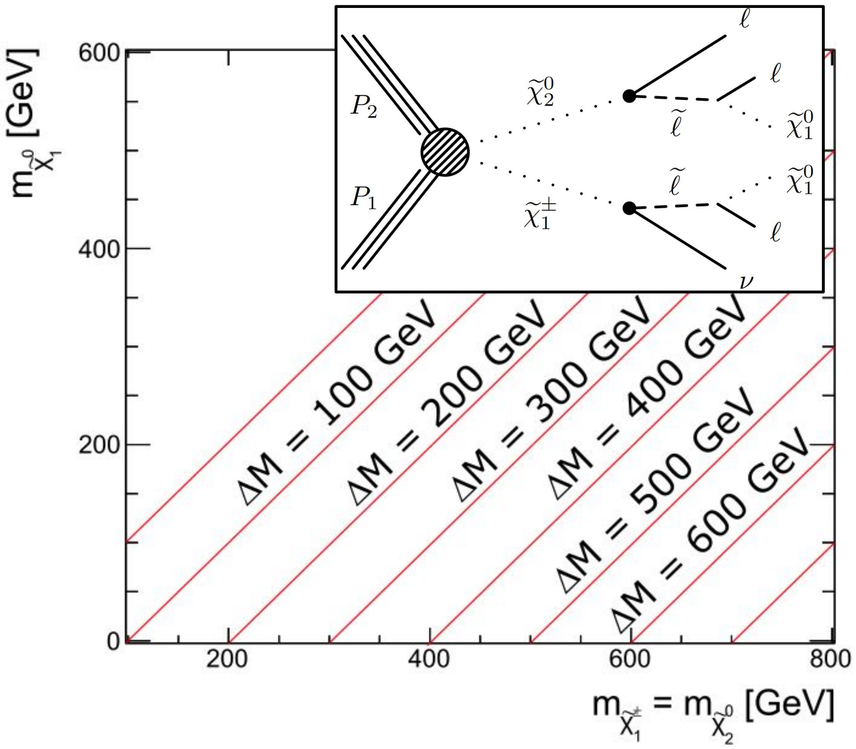
Parametric deep learning

- Ideal sensitivity: train neural net for every model.
  - Simply not feasible—not enough MC statistics, nor computing resources.
- Key innovation: Parametric Neural Net (PNN)
  - Most signal variation driven by ΔM
  - Train with ΔM as input, over all mass points simultaneously
  - PNN learns correlation of ΔM with other variables.
  - Evaluate PNN at specific ΔM signal hypotheses.





Kinematics are quite similar

at fixed ΔM = m_{N2} - m_{N1}

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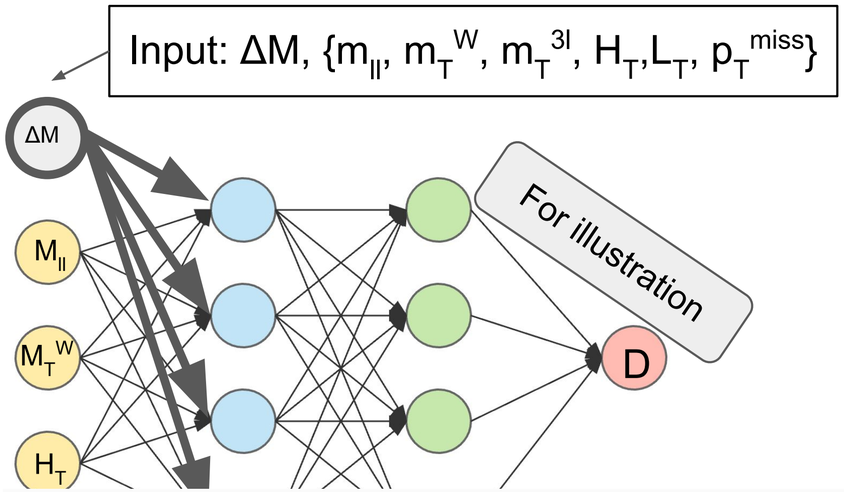

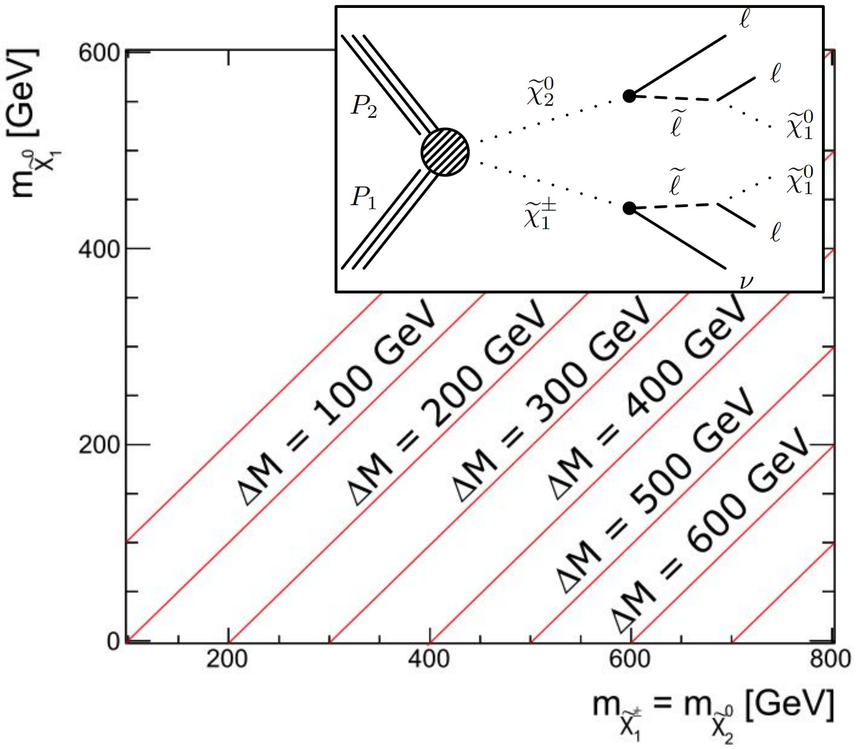

Kinematics are quite similar

at fixed ΔM = $m_{N2} - m_{N1}$

Bottom line:
Single PNN covers entire mass plane, and exploits full MC statistics.

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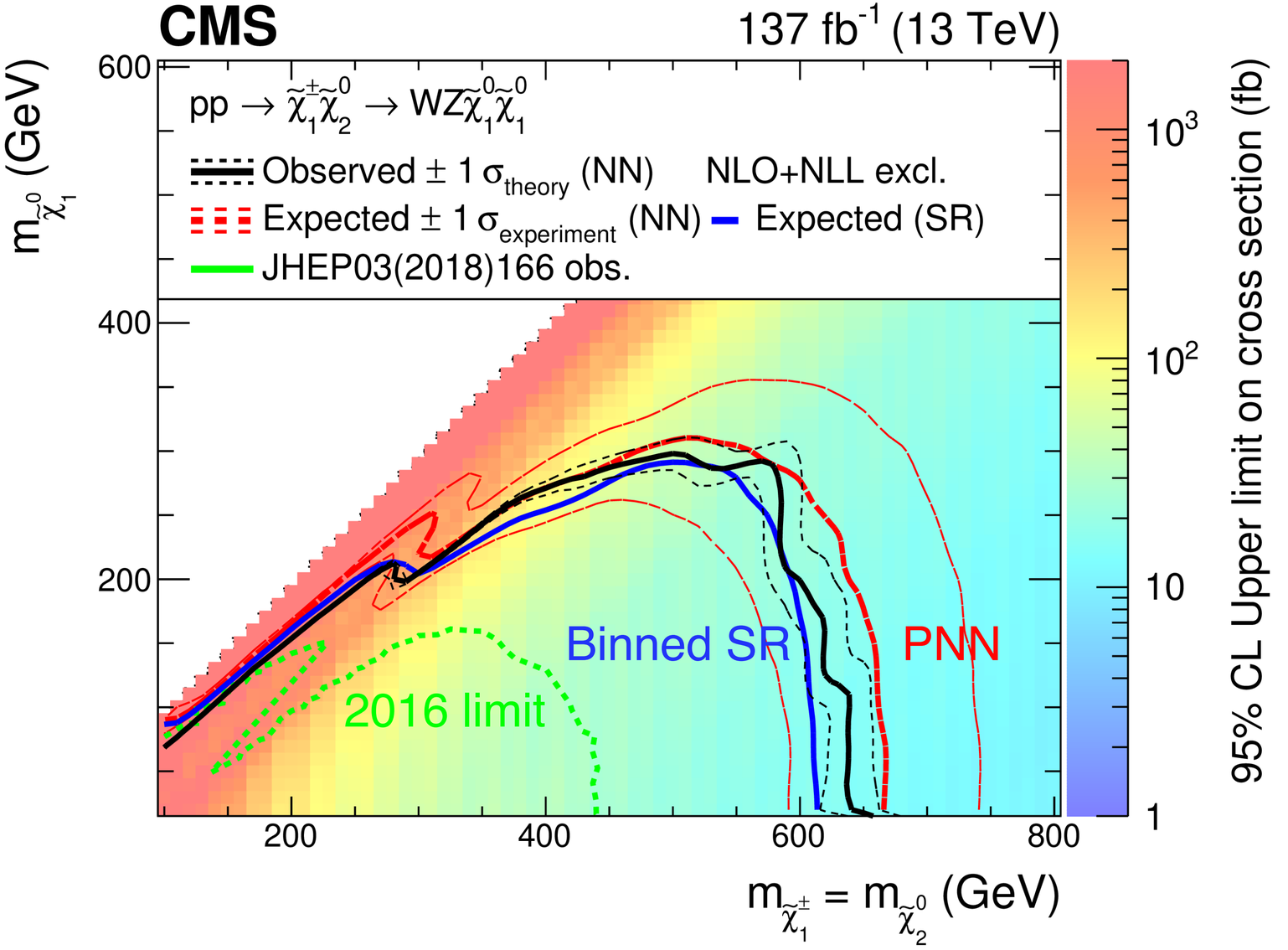
WZ-mediated interpretation

- Sensitivity above 650 GeV for high ΔM!



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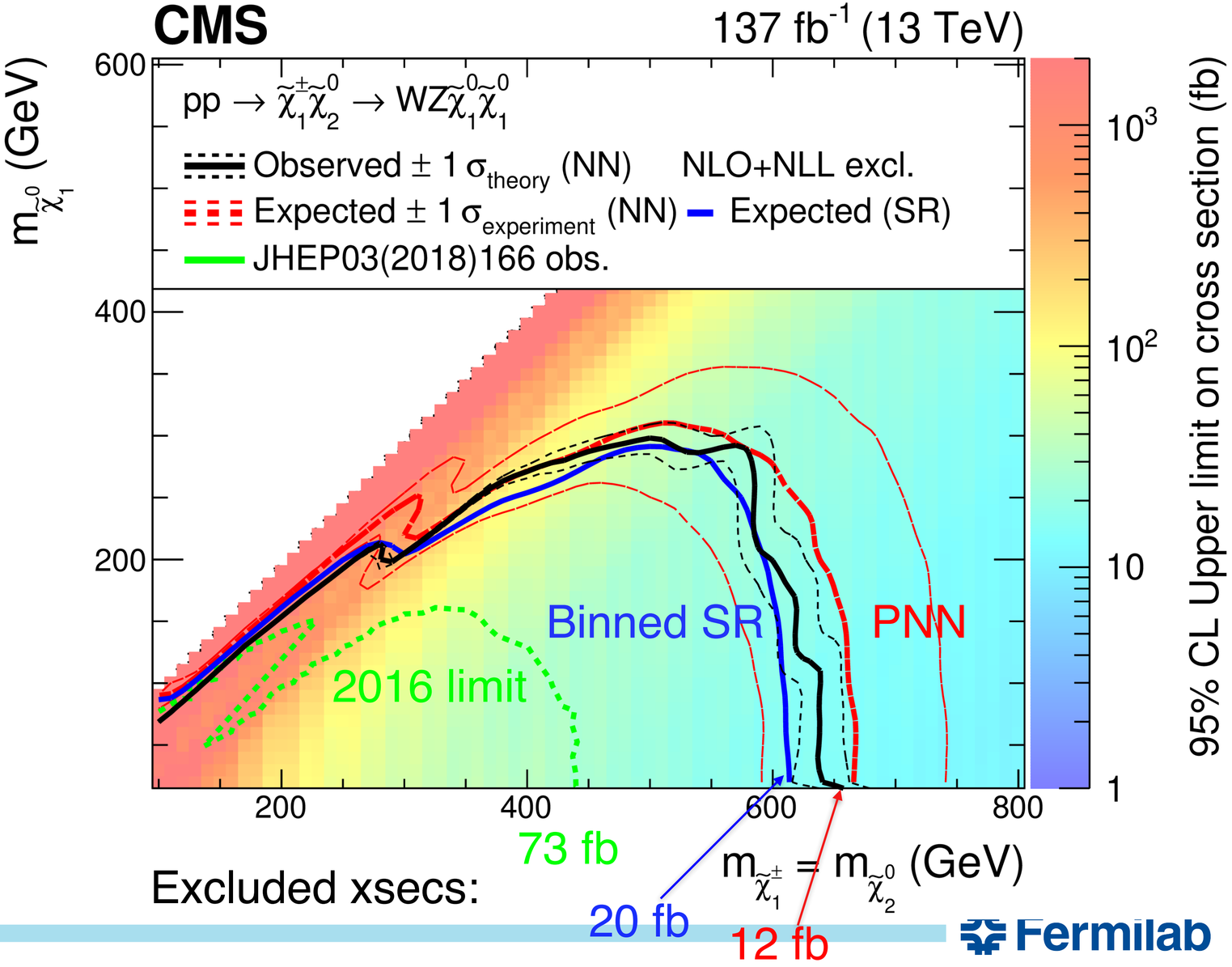
WZ-mediated interpretation

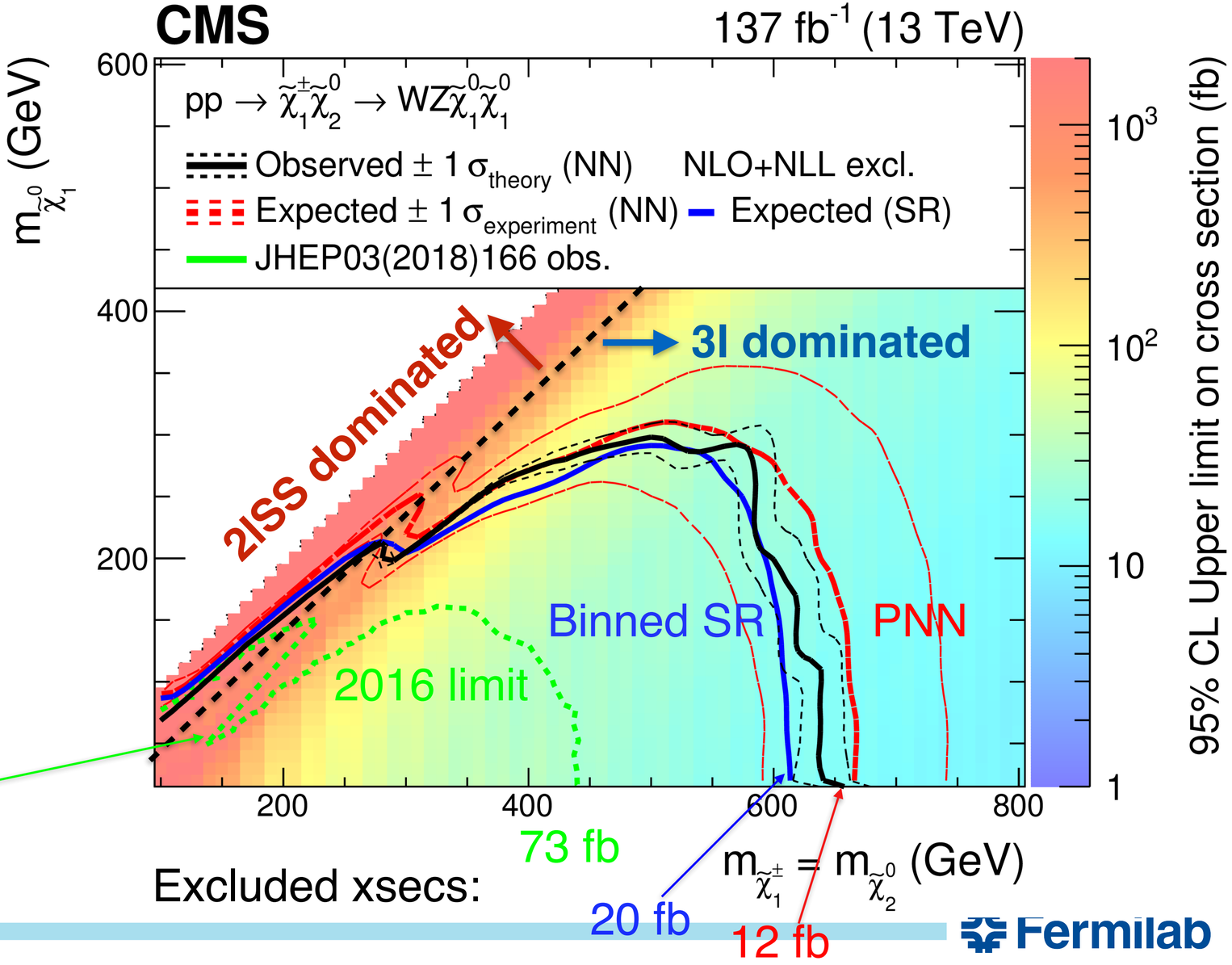
- Sensitivity above 650 GeV for high ΔM!
- Binned analysis: limit scales with luminosity from 2016 to 2016-2018
- PNN improves xsec limit by additional ~40%!



Fermilab

WZ-mediated interpretation

- Sensitivity above 650 GeV for high ΔM!
- Binned analysis: limit scales with luminosity from 2016 to 2016-2018
- PNN improves xsec limit by additional ~40%!
- 2016 gap closed, thanks to 2l same-sign channel!



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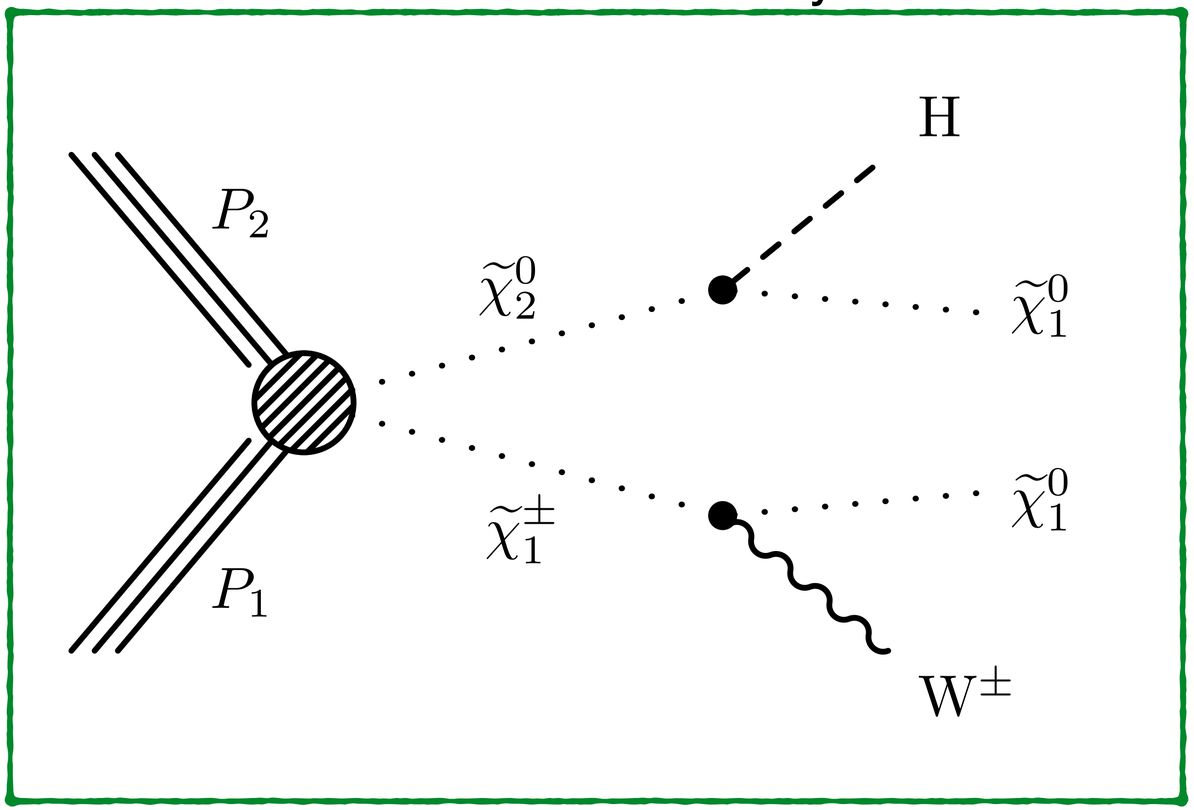
WH + MET search

WH-mediated decays



- For WH-mediated decays, multilepton BR is very small.
- Instead, target final state with $W \rightarrow l\nu$ and $H \rightarrow bb$

  - **single lepton**
  - **2 b-tags, $90 < m_{bb} < 150$ GeV**
  - **0 or 1 additional jets**
  - **bin in MET [125, 200, 300, 400+ GeV]**

- Huge BGs in single lepton state:
  - top pairs, W + heavy flavor

- BG rejection: m_{bb}, m_T, m_{CT}, boosted Higgs tag

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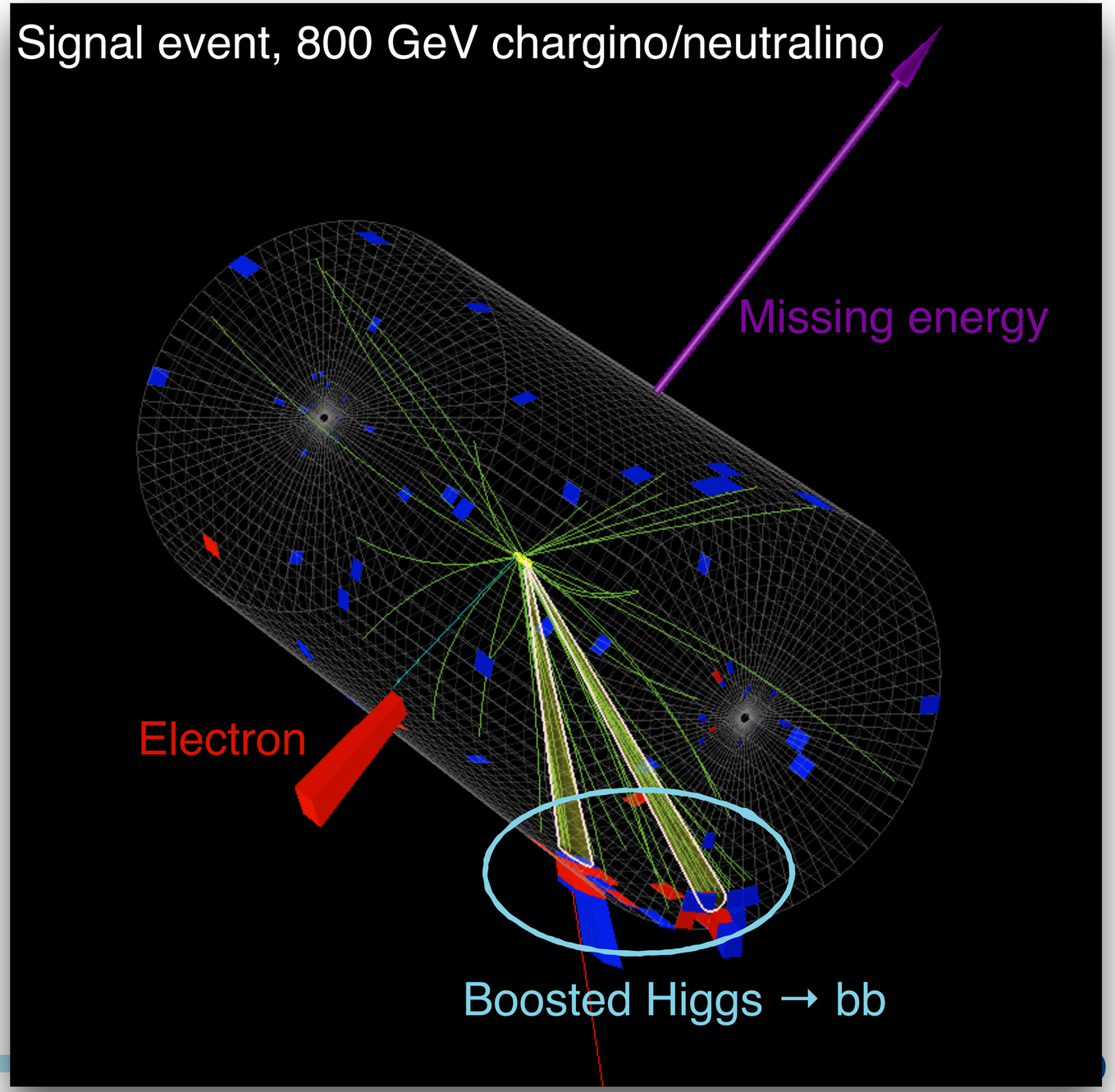
Boosted H tagging

- At high momentum, H → bb collimated into single large jet.

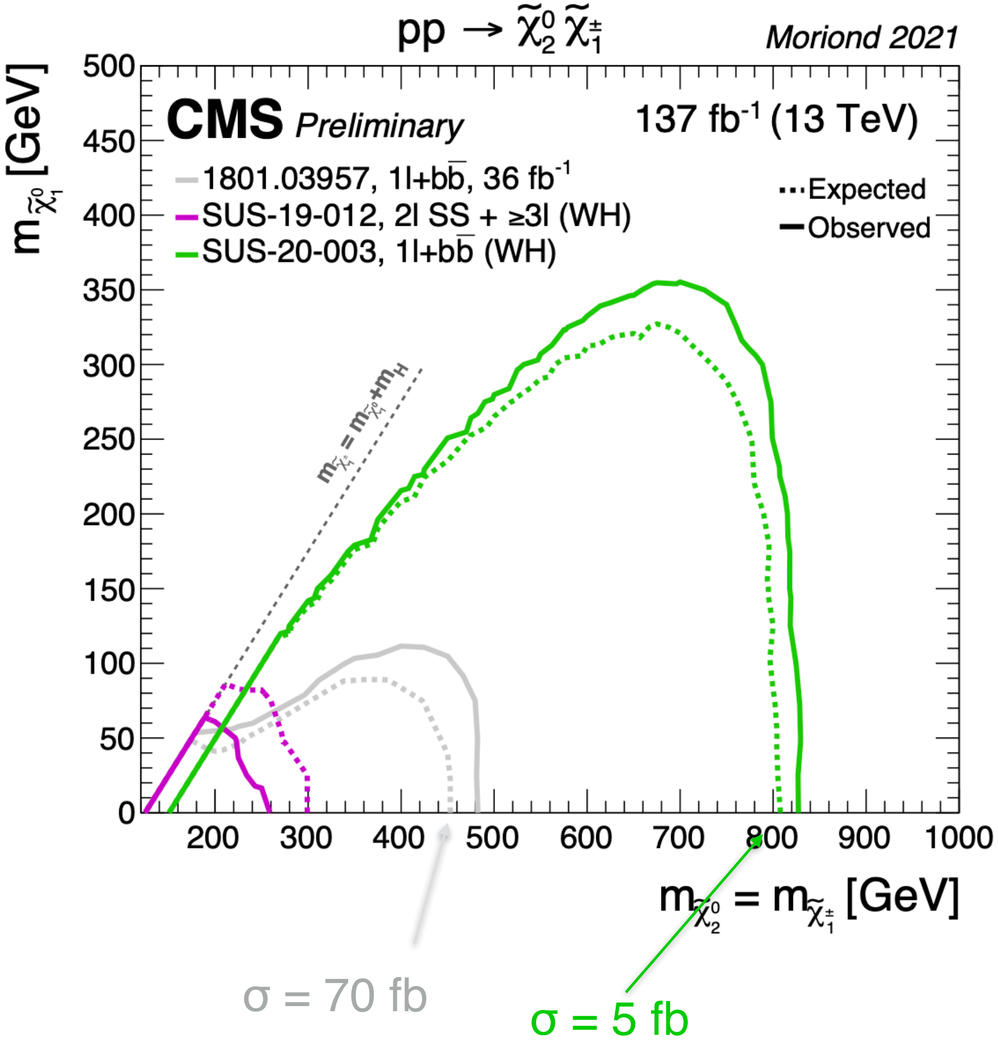
- Tag with deep neural net (DeepAK8)
  - Powerful BG suppression
  - Ultra-boosted: gain signal efficiency when individual b-jets not resolved!



WH (1-lep) (2107.12553)

WH-mediated interpretation

- Exclude neutralino/chargino production up to $M_{\chi 2/\chi +} = 800$ GeV!
- Major progress since 2016 result.
  - 4x more data, but
  - 14x better cross section limit!
- Why? Hadronic signature.
  - At low mass: just not very distinctive.
  - Higher mass: all discriminating variables become much more powerful.
- After critical luminosity, sensitivity can ‘snowball’ to much higher mass.
  - Run III has a ton of potential for growth!!



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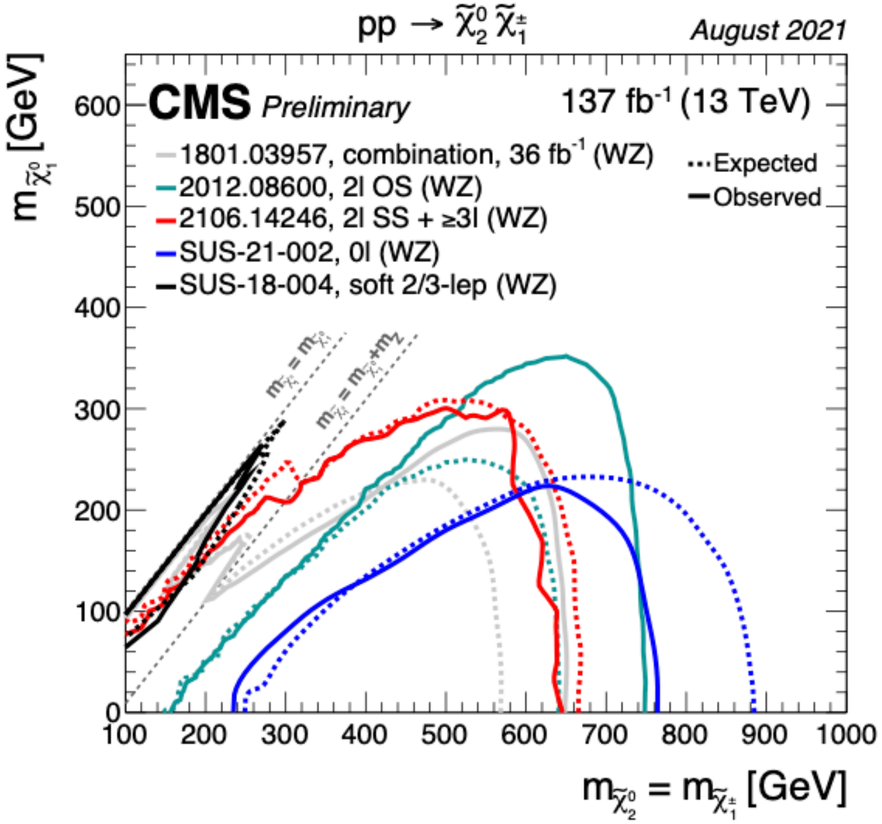
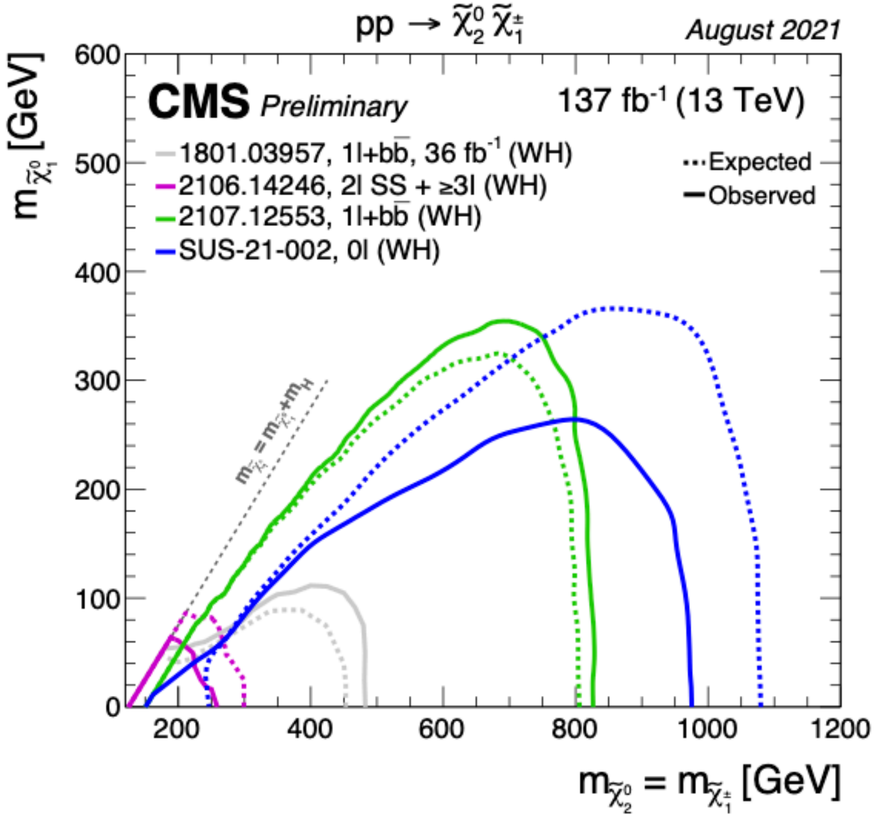
Summary of inclusive EWKino limits

- Leptonic limits reach $M_{\chi 2/\chi +}$ = 750-800 GeV for both WZ and WH modes.
- Fully hadronic analysis approach ~1 TeV
  - See earlier talk by J. Wilson





- Complementarity: hadronic searches probe high ΔM; leptonic can access difficult, compressed scenarios.

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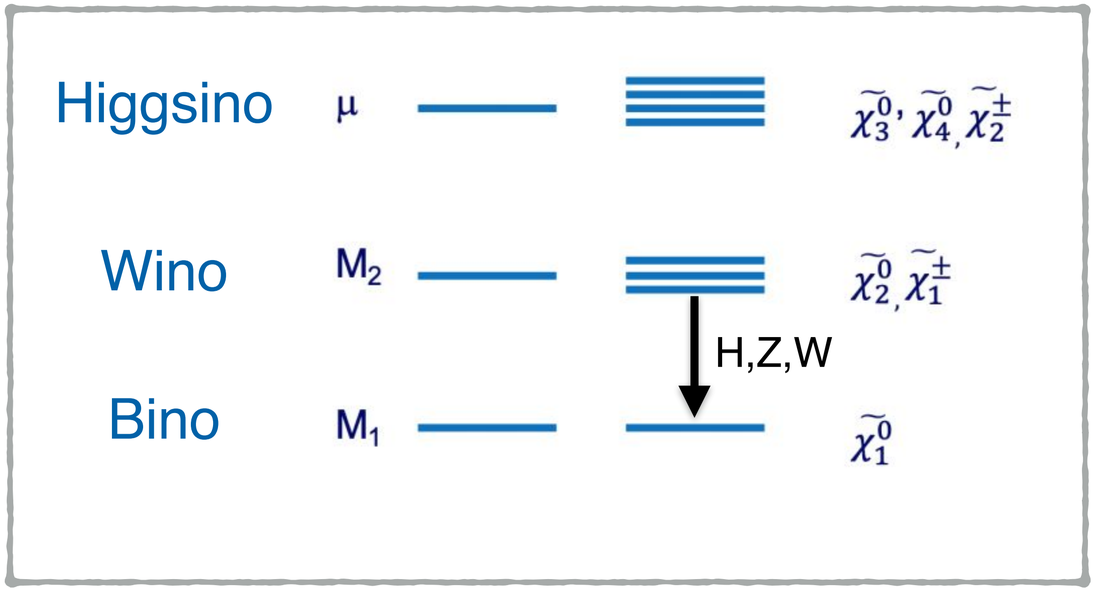
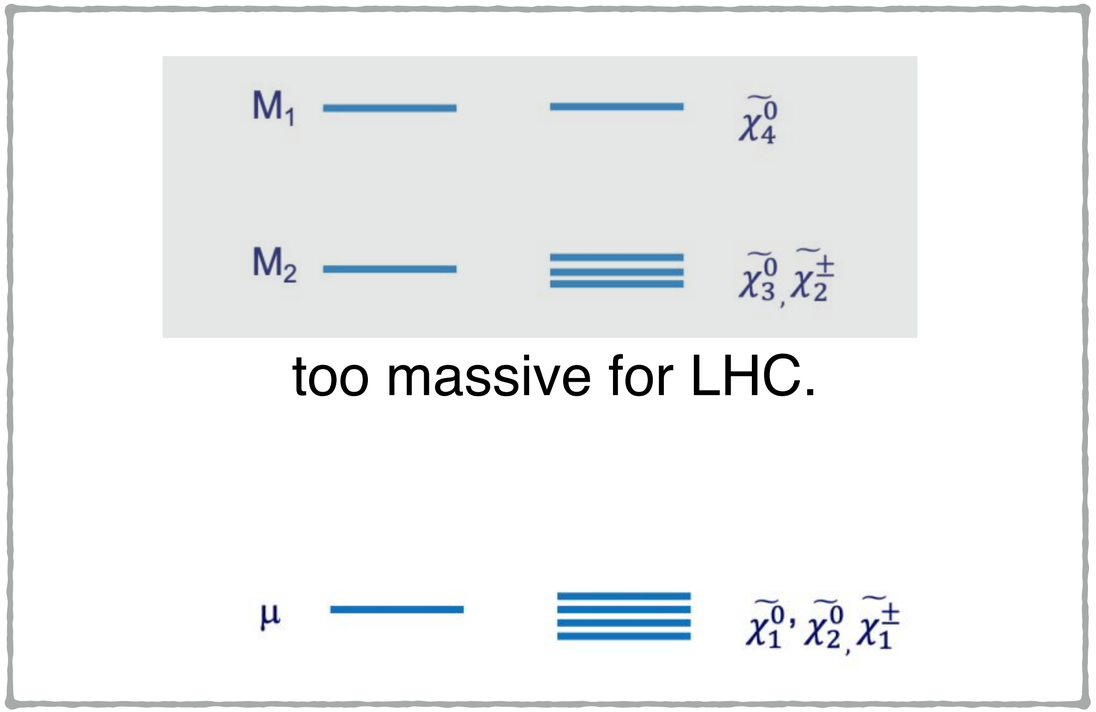
Compressed electroweakino spectra

- So far, we have been considering scenario with Bino/Wino as LSP
- However, Higgsino LSP is possible—

Bino-Wino LSP



Higgsino LSP



Challenging scenario— Bino/Wino decoupled

And it meets the minimum naturalness requirements…

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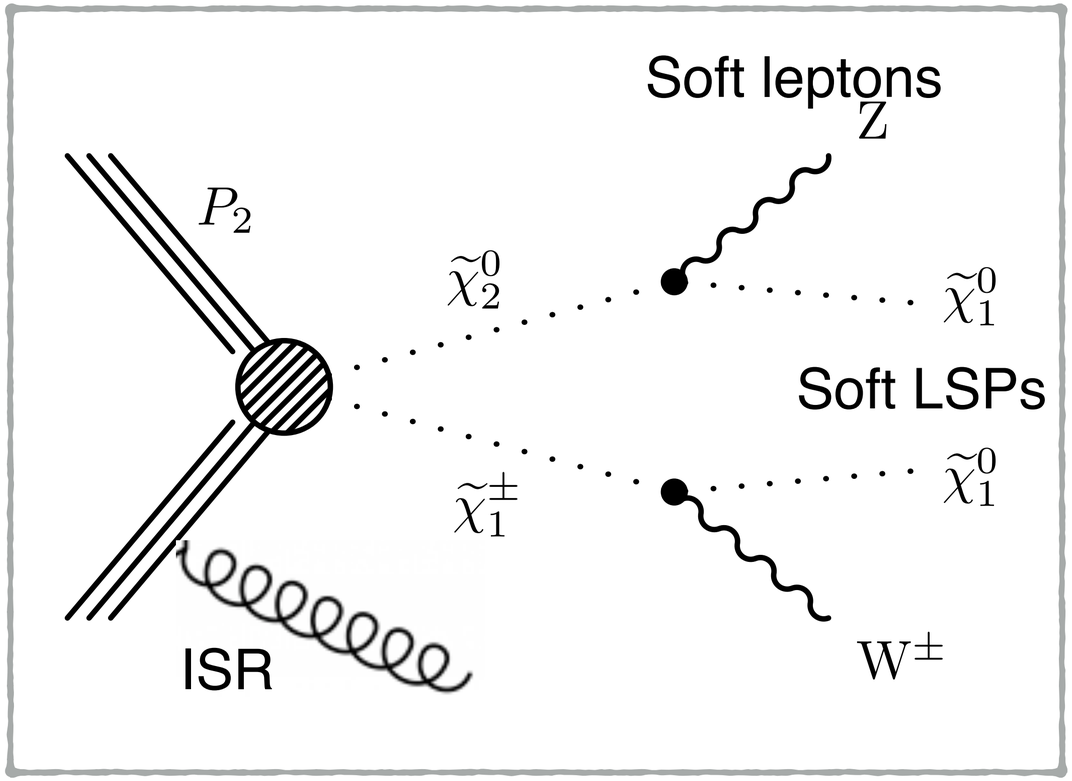
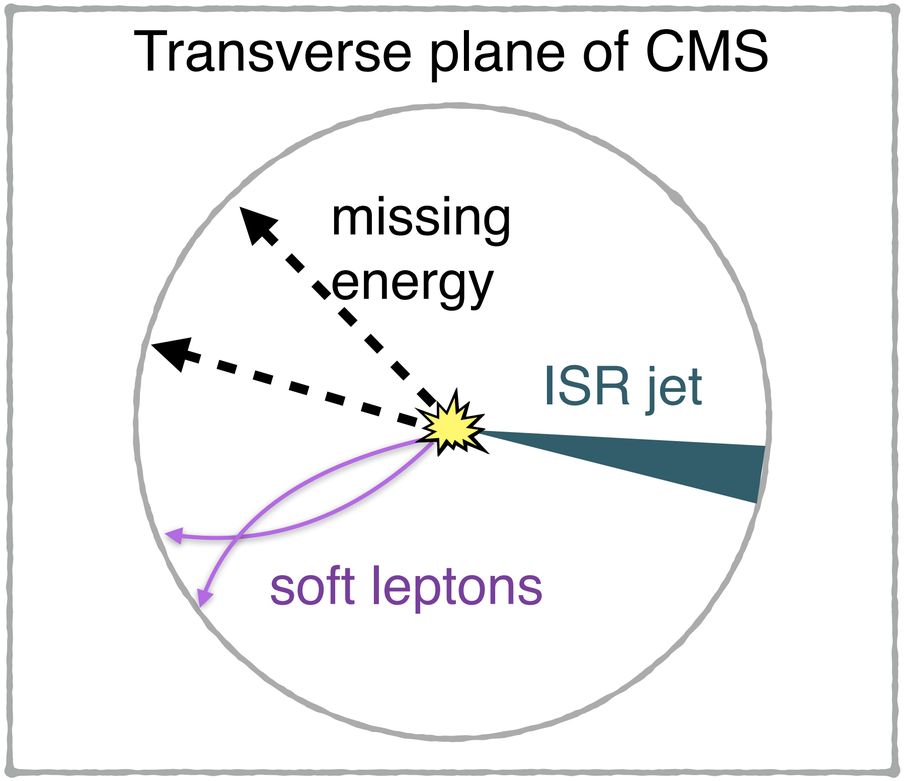
Compressed searches

- In compressed scenario, decay products are extremely soft.
- Rely on ISR jet to provide boost.





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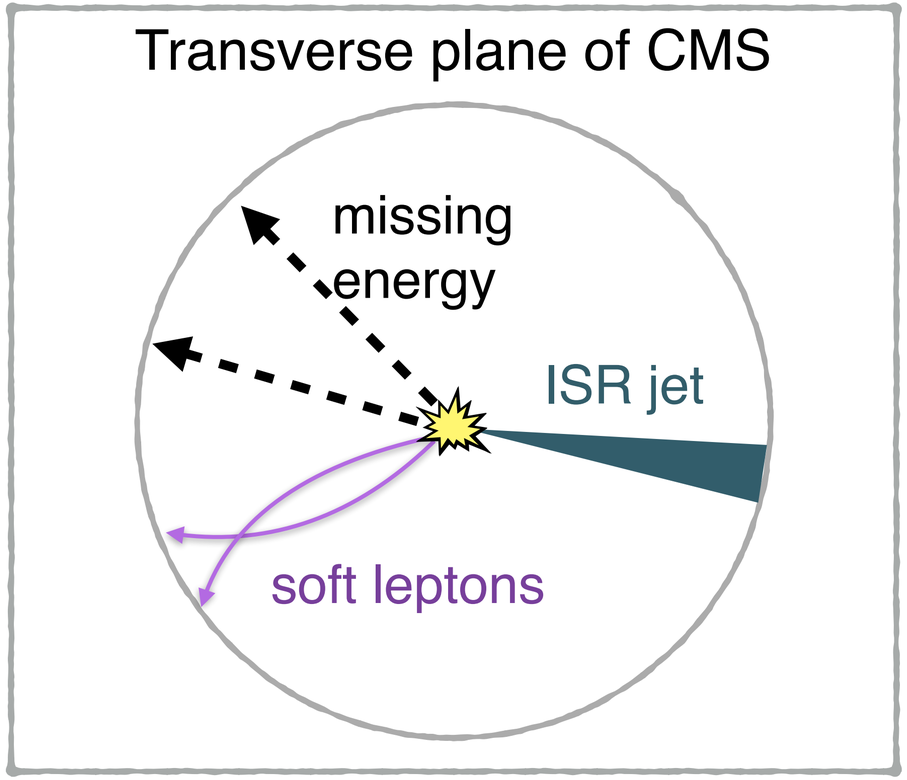
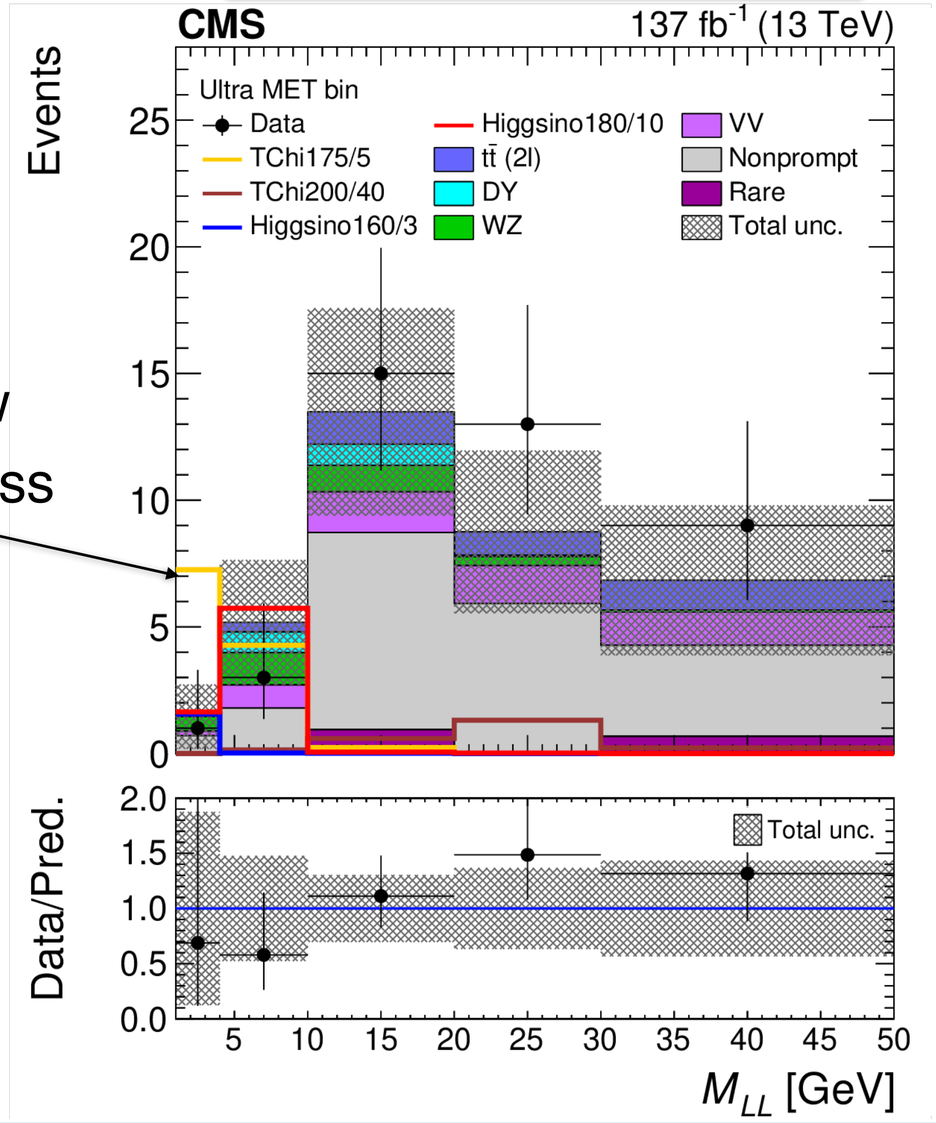
Experimental challenges

- How to trigger?
  - Use MET, when possible: MET > 200 GeV
  - Dedicated soft dimuon + MET trigger
    - muon p_T > 3 GeV and MET > 125 GeV
- How to safely identify soft leptons?
  - p_T > 3.5 GeV (muon) or 5 GeV (electron)
  - Extremely tight impact parameter: 100 microns
  - Tailored isolation cuts
  - Efficiencies:
    - electrons: 30—70% for 5–30 GeV
    - muons: 70—85% for 3.5—30 GeV



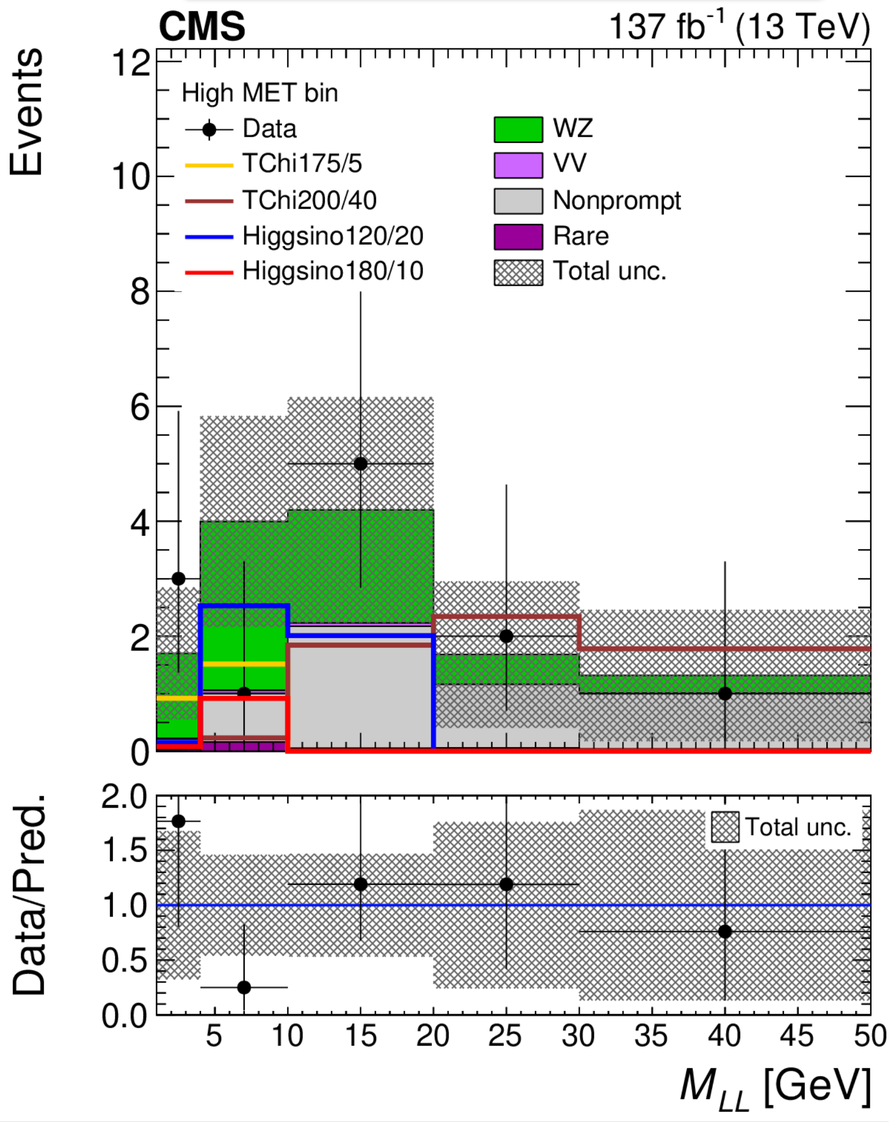
Results

2-lep, MET > 290 GeV



Signal at low invariant mass

3-lep, MET > 200 GeV



3-lepton: add sensitivity for higher dM

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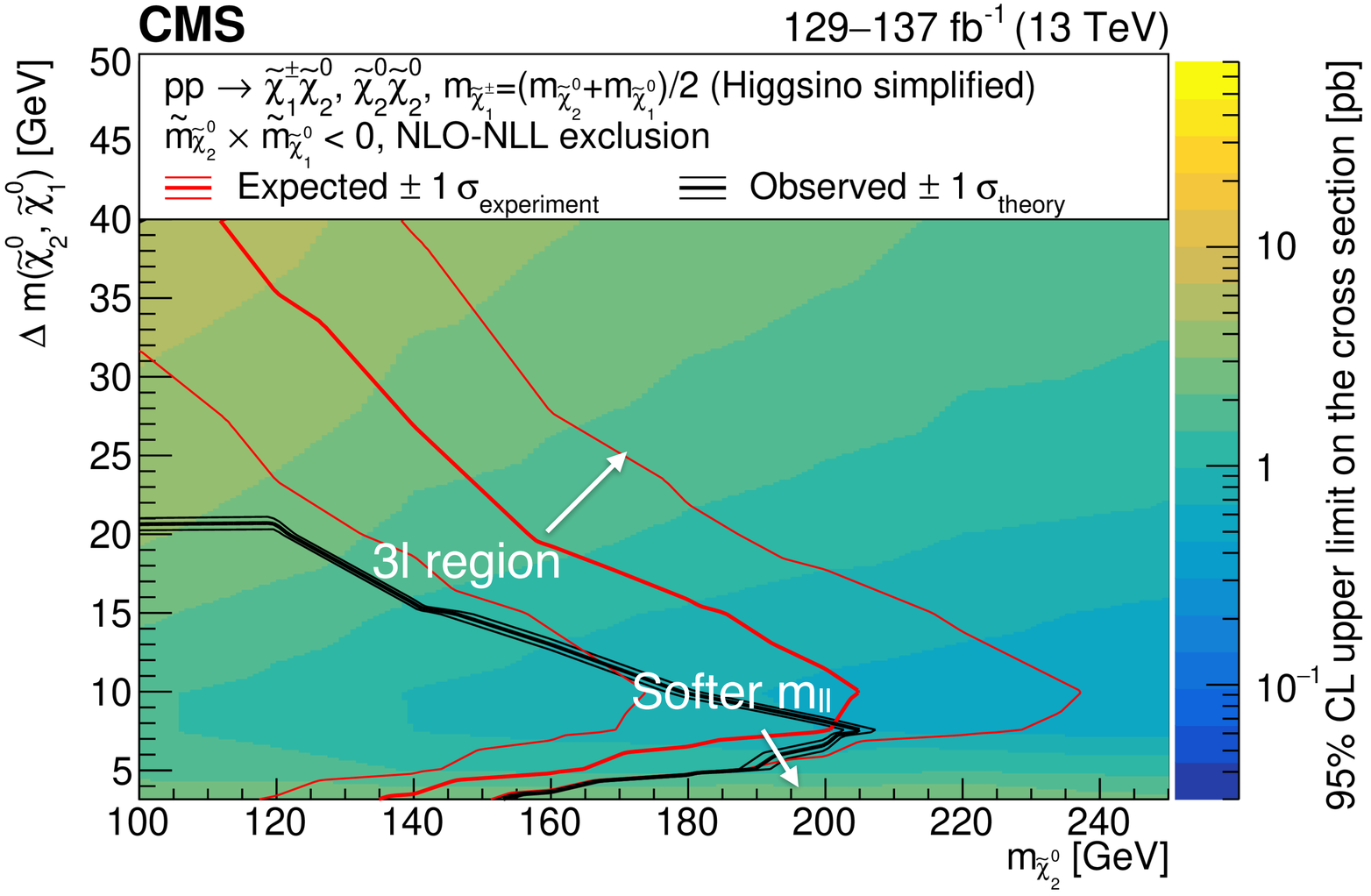
Higgsino intepretation

- Higgsinos excluded up to 210 GeV for ΔM = 7 GeV
- Sensitivity down to ΔM ~ 3 GeV!

Really astounding progress in difficult search!!



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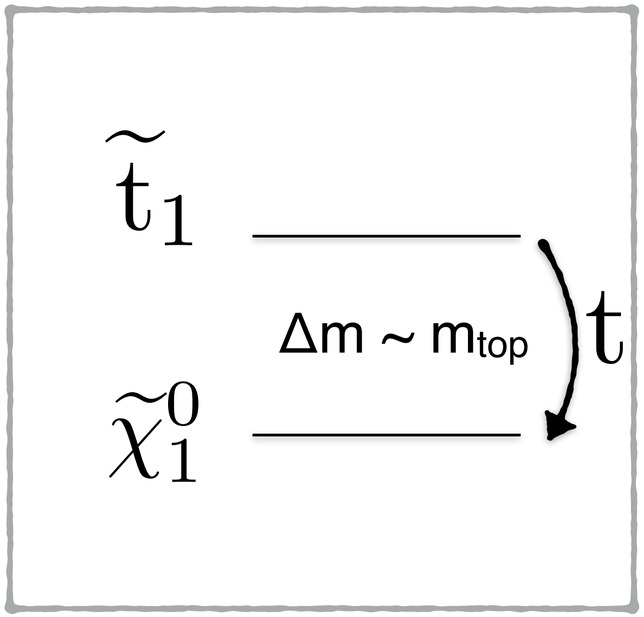
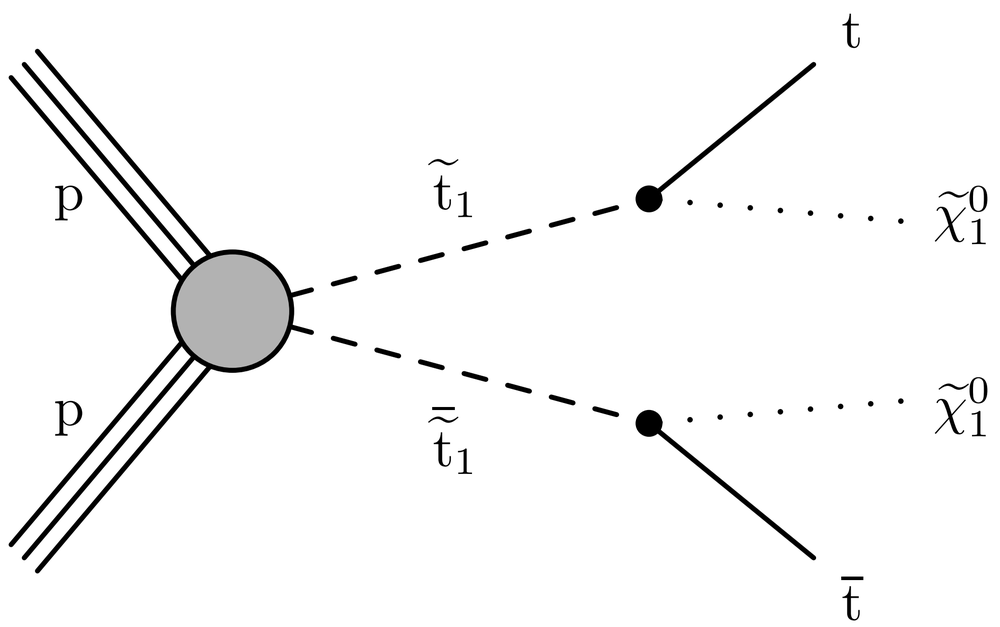
Stealth stop corridor

- Another famous challenge: stealth stops

Stealth stop spectrum



No boost from stop decay!



Soft LSPs

- $m_{stop} \sim m_{top}$, $m_{LSP} \sim 1$ GeV: nearly identical to ttbar production!
- “Stop corridor” needs dedicated search.

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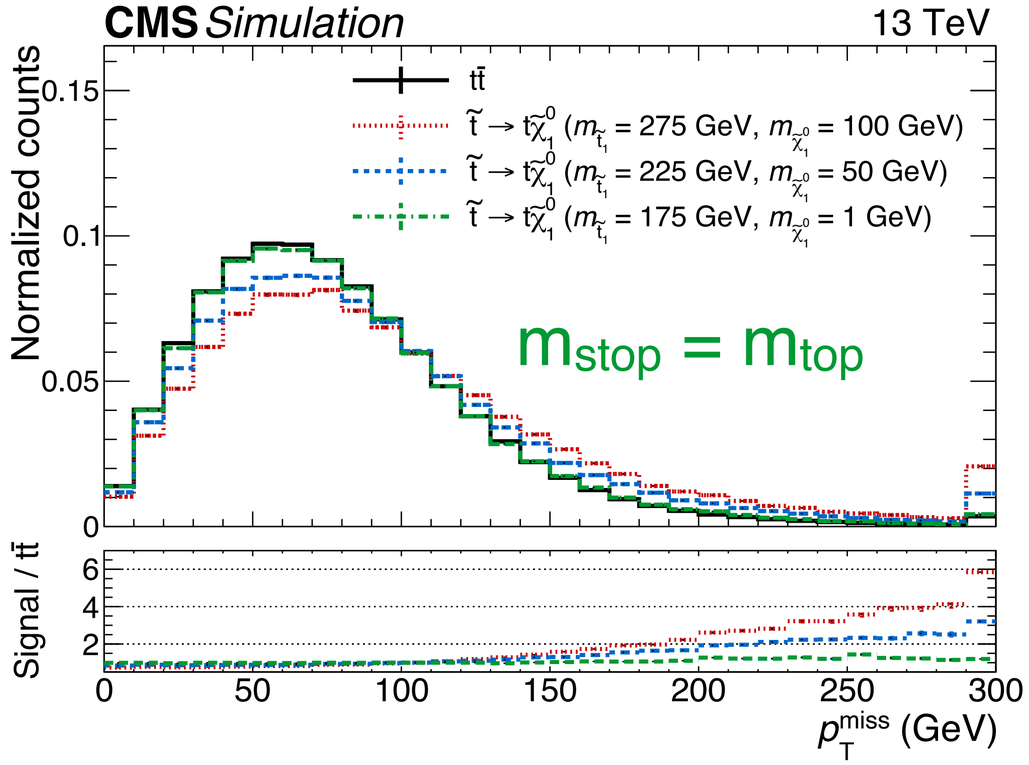
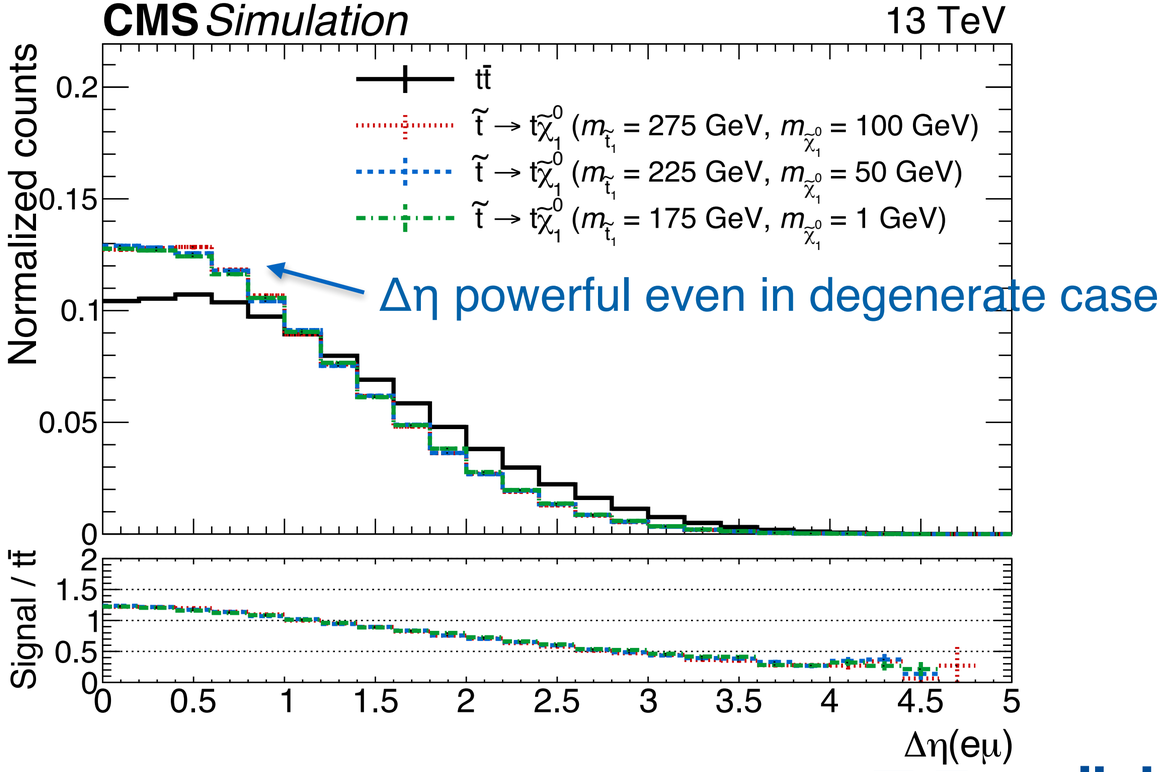
Stop corridor kinematics

- Pure degenerate case ($m_{stop} = m_{top}$) → lose all extra MET!
- Only remaining handles:
  - Angular correlations (scalar vs fermionic production)
  - Small modification to ttbar cross section.





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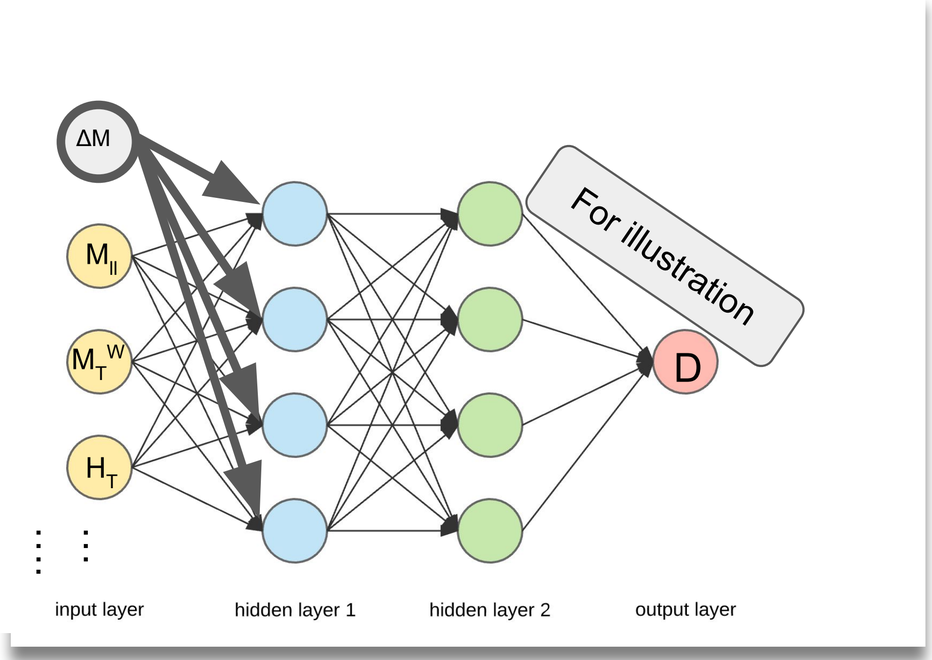
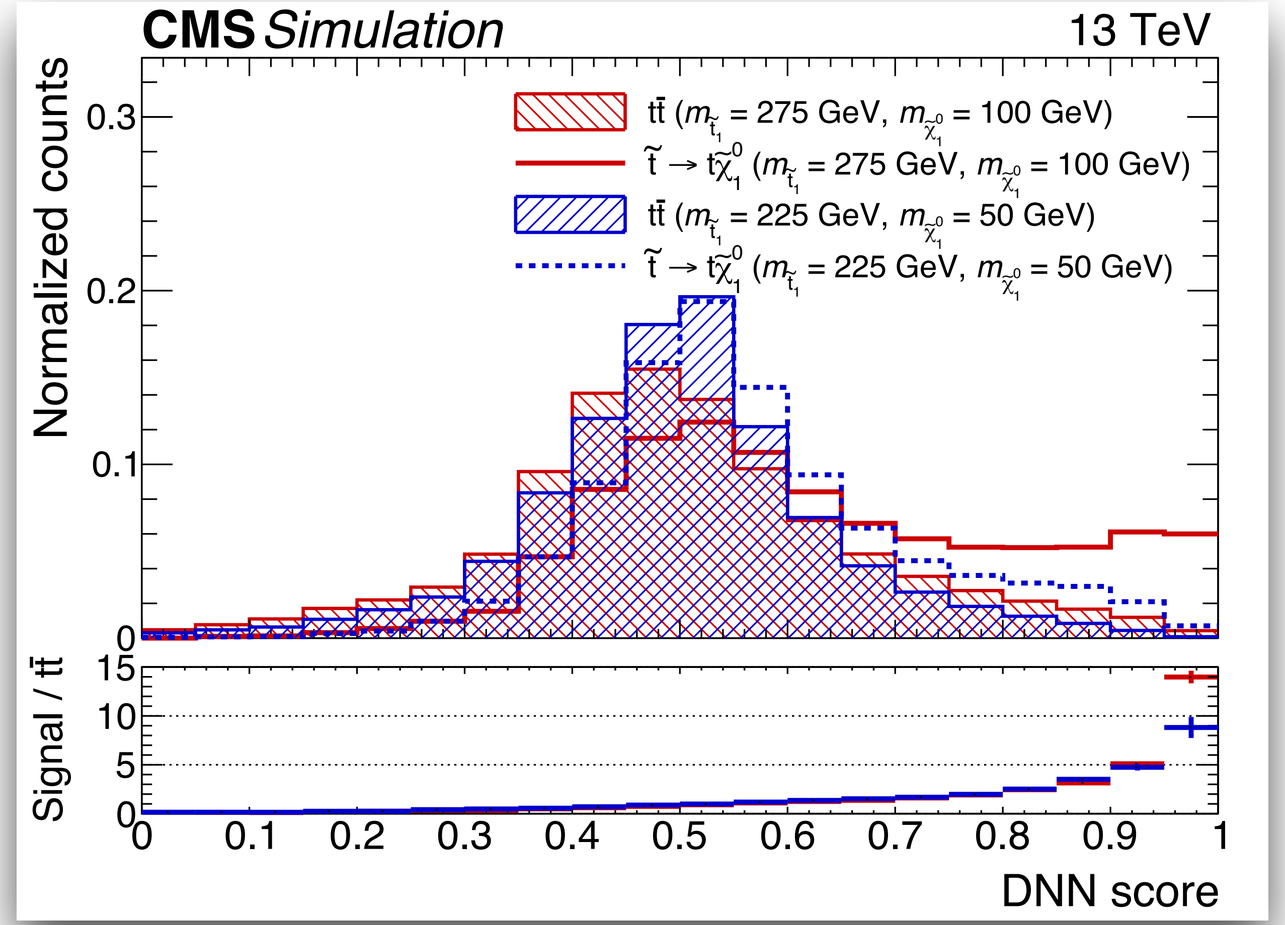
Search strategy

- Use similar parametric technique as Multilepton search, with 11 inputs
  - m_{T2}, m_{ll}, p_T^{miss}, H_T
  - $p_T(e\mu)$, $\Delta\eta(e\mu)$, $\Delta\phi(e\mu)$
  - $p_T(\ell_i)$, $\eta(\ell_i)$, $i = 1,2$
- Parametrize based on m_{stop}, m_{lsp}



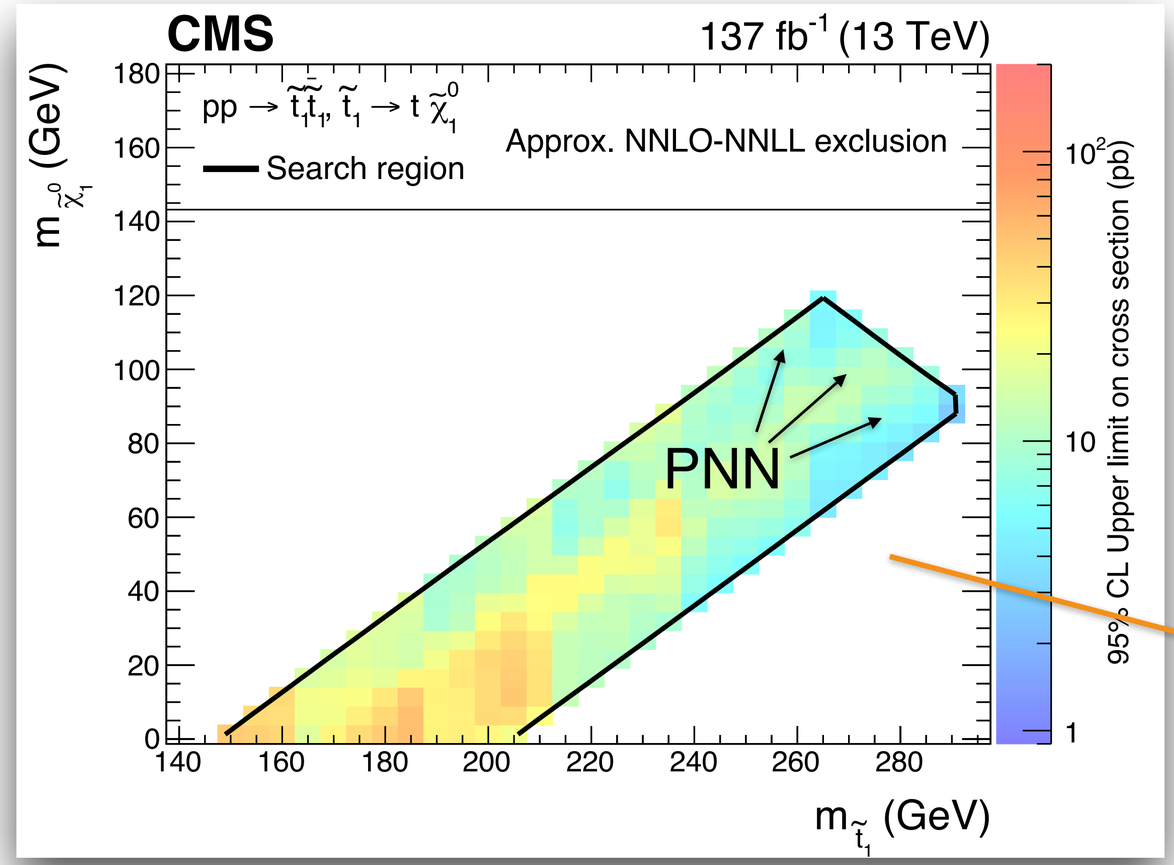


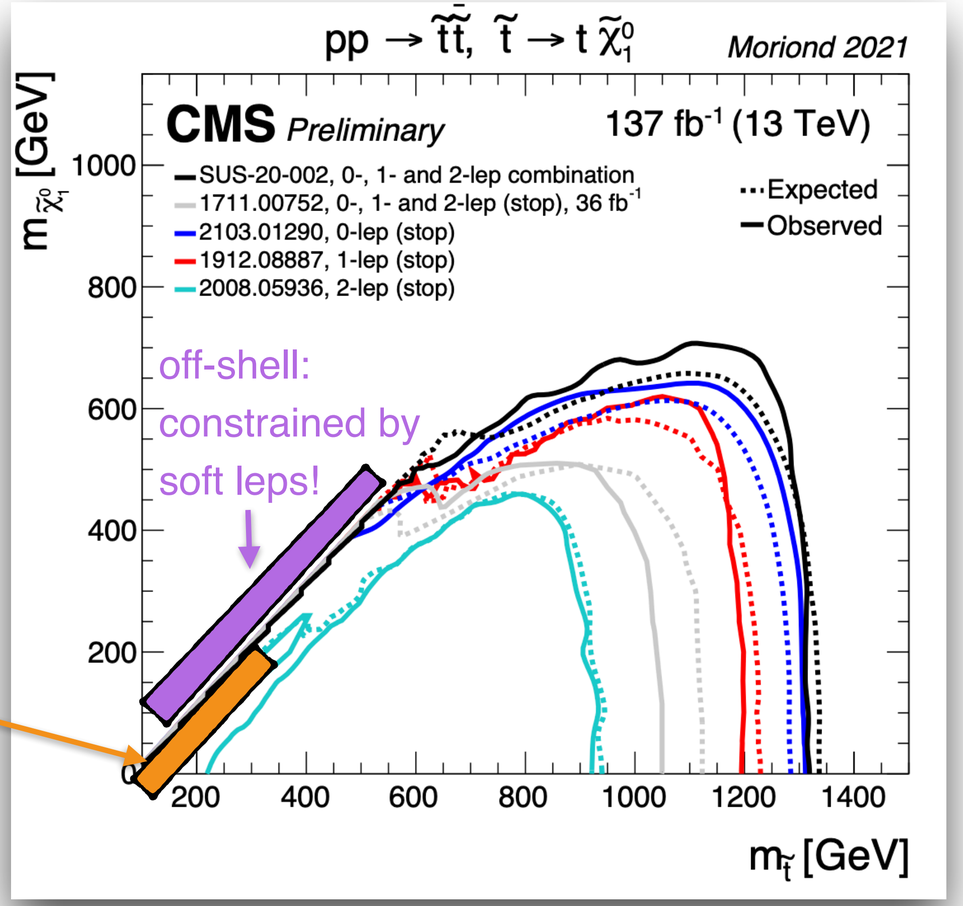
PNN gives strong discrimination across mass plane & leverages all MC stats.

Stealth stop corridor (2107.10892)

Stop corridor results

- Exclude entire stop corridor region for first time in CMS, thanks to PNN!





Advanced techniques close gaps in stop sensitivity, complementary to inclusive searches!

Summary of leptonic SUSY results

- CMS has made extensive progress searching for leptonic SUSY signatures!
  - Inclusive leptonic EWKino searches exclude chargino-neutralino production to 800 GeV !!
  - Targetted searches close gaps in well-motivated & extremely difficult compressed spectra.

- EWK SUSY in “vanilla” case now under stress in interesting regime.
  - But, Higgsino searches just scratching the surface
  - Many ways for signal to hide: R-parity violation, Long-lived sparticles, unfavorable BRs…

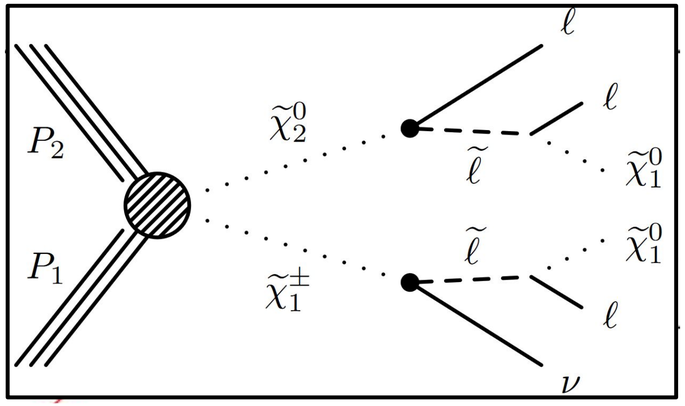
- Most difficult searches: most to gain from Run III and HL-LHC!
  - Larger dataset can give surprisingly dramatic improvement beyond sqrt(L)
  - Develop more advanced methods for object tagging and signal extraction
  - Radically improved Phase II detector for most challenging signatures!!

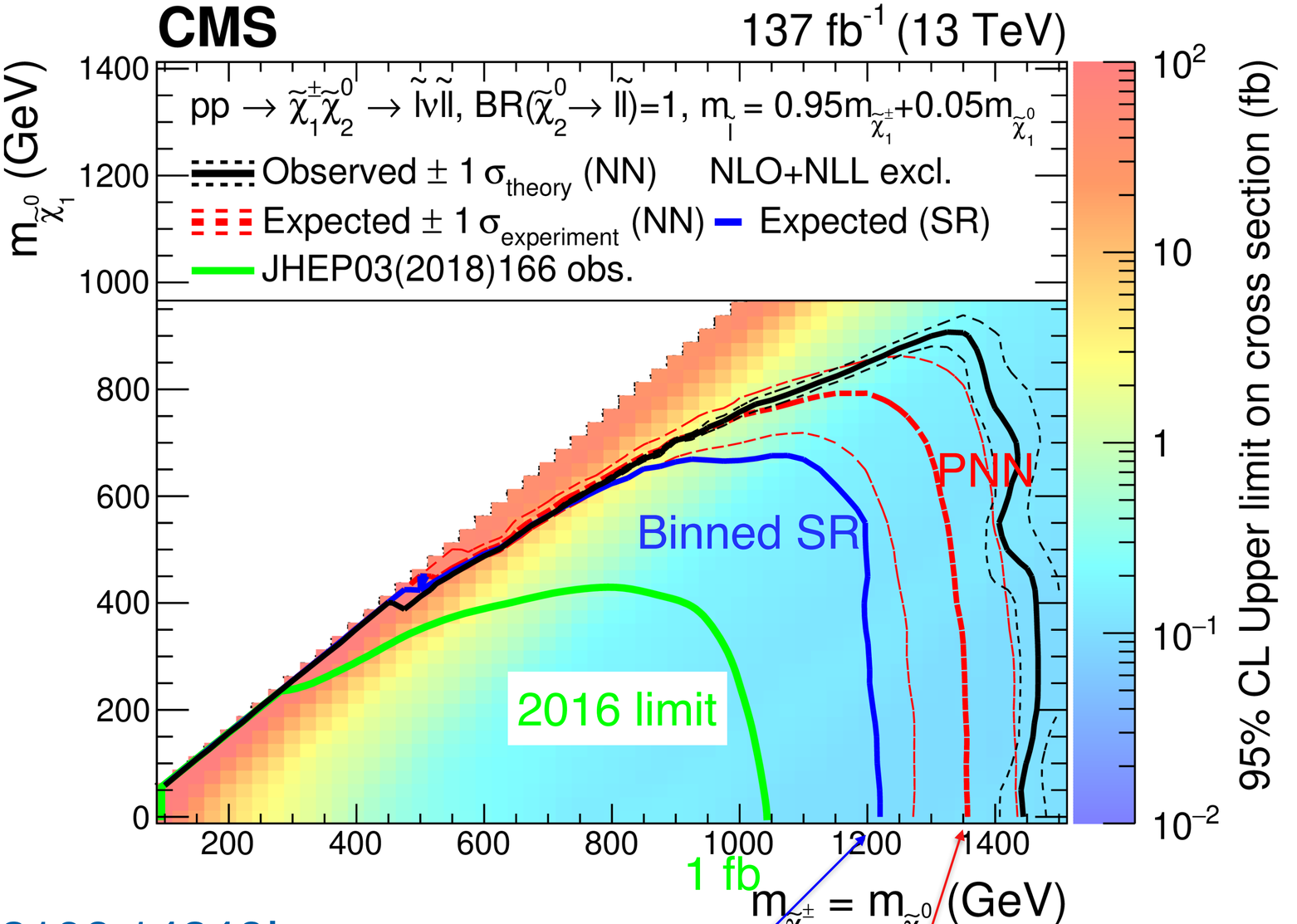
Look forward to new creative CMS results in next years!

Slepton-mediated interpretation

- Slepton mode much easier:
  - Guaranteed lepton BR
  - Much less BG: off-Z mass!

- PNN improves xsec limit by factor of 2!





Many, many more interpretations in 2106.14246!