ETH Institute for
Particle Physics

Search for electroweak SUSY production at CMS

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on behalf of the CMS collaboration

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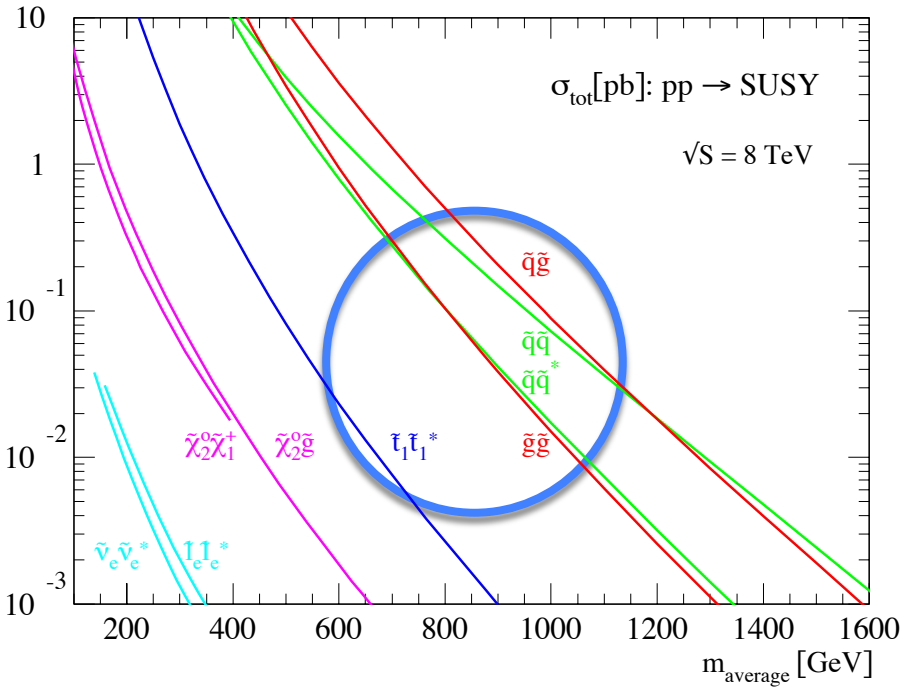
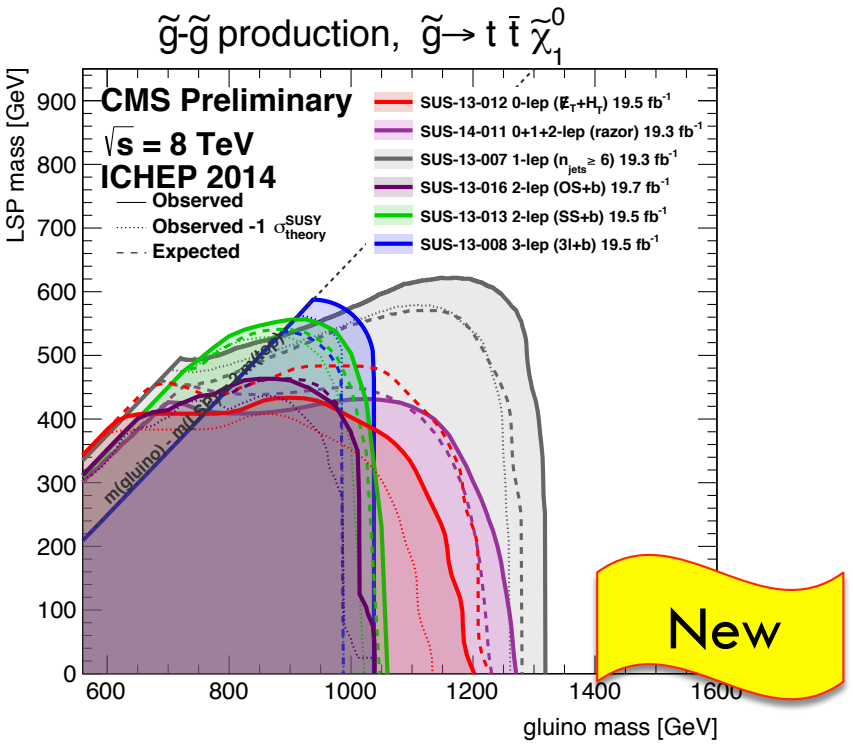
Particles And Nuclei International Conference

Why electroweak SUSY?

- Most of SUSY searches look for **strong** SUSY production
  - ✓ **Larger cross section**
  - ➢ **No** evidence of signal
  - ➢ Set exclusions up to **m(gluino)** ≲ **1.3 TeV**



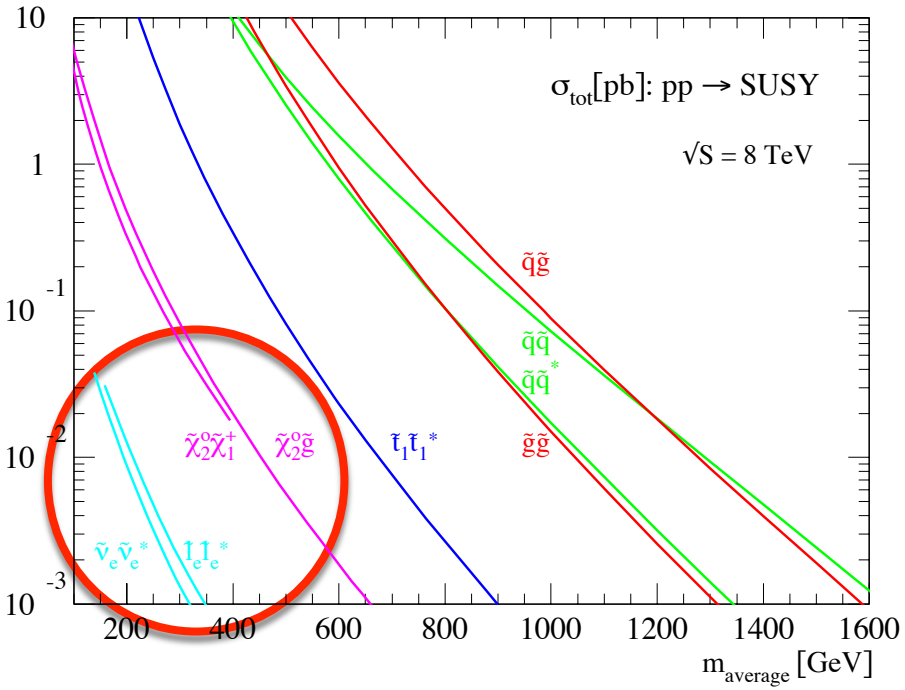


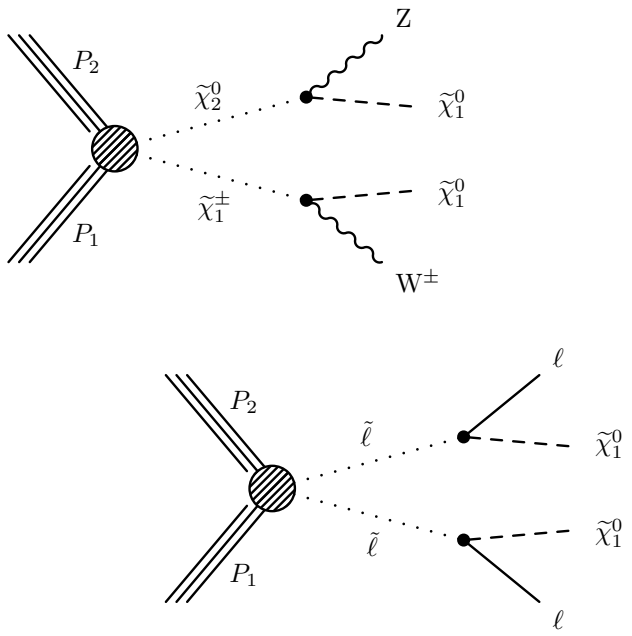
Why electroweak SUSY?

- If there, **squarks** and **gluinos** must be heavy

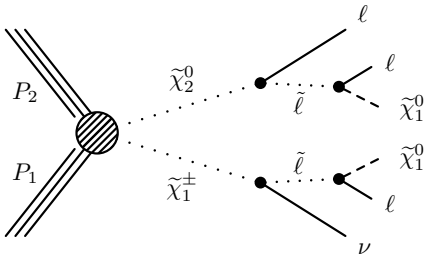
➢ **EWK** SUSY models may be favoured

- ✓ **Direct** production of **charginos, neutralinos** and **sleptons**
- ✓ **Charginos** and **neutralinos** decay to **sleptons,** or **W/Z/h⁰** bosons
- ✓ Low hadronic activity





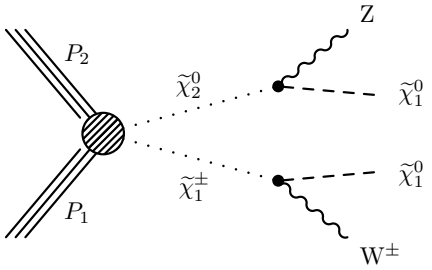
Electroweak SUSY searches @ CMS



✓ Light sleptons / sneutrinos

➢ **3-lepton search**

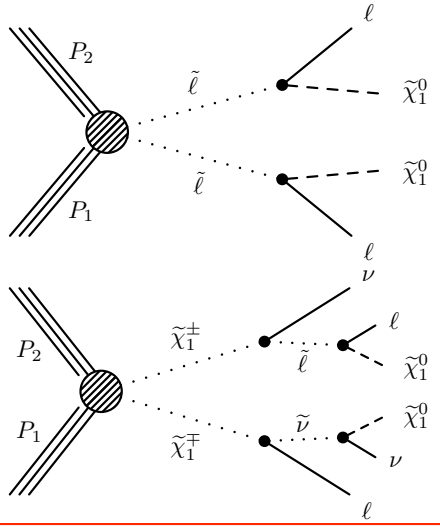
➢ **Same-sign di-lepton**



✓ Heavier sleptons

➢ **Multi-lepton search**

➢ **Di-lepton + di-jet + E_T^{miss}**

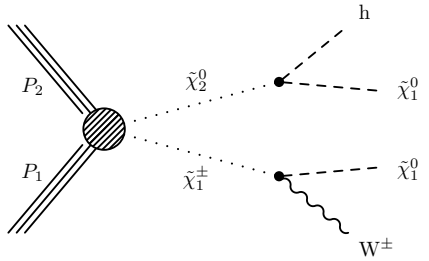


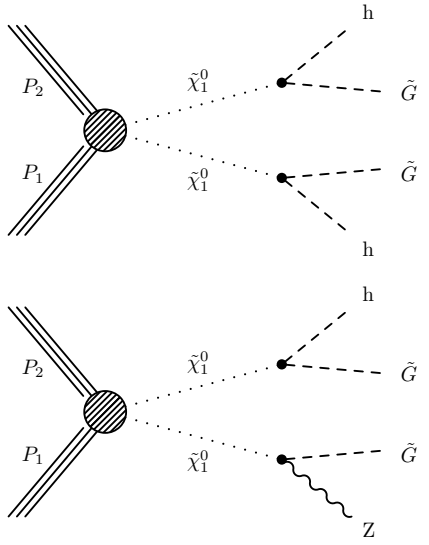
✓ Pair production of sleptons

✓ And charginos

➢ **Opposite-sign di-lepton**

After **Higgs** discovery…

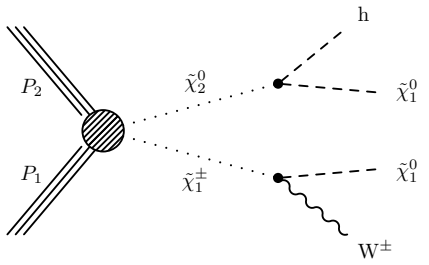




GMSB models with **N**LSP higgsino

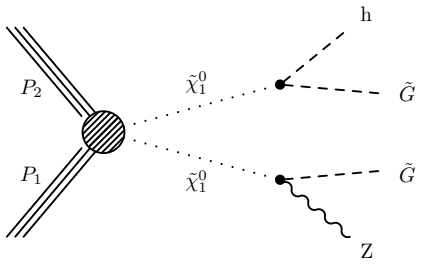
Electroweak SUSY with h^0 boson

$hW + E_T^{miss}$



Neutralino = LSP

$hh, hZ, ZZ + E_T^{miss}$



Higgsino = NLSP
Gravitino = LSP

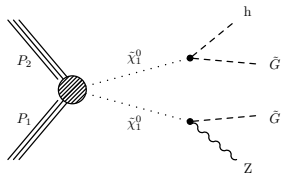
Diverse final states are explored, depending on the h^0 decay:

➢ **h^0** → bb, WW, ZZ, γγ, ττ

- **Single lepton + 2 b's**
- **Same-sign di-lepton**
- **Multi-lepton**

- **Di-leptons + di-jet**
- **γγ + di-jet**
- **γγ + lepton(s)**
- **4 b's**

hZ to (bb) + (ll)



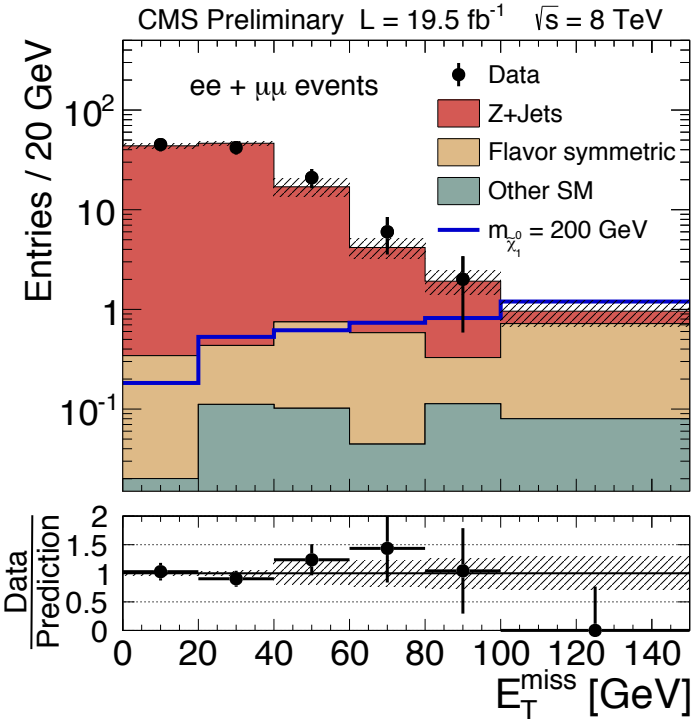
New

CMS PAS SUS-14-002

- Higgs reconstruction
  - ➢ Two **most b-like** jets
  - ✓ with 100 < M_{bb} < 150 GeV
- Z boson reconstruction
  - ➢ **Exactly one** e^+e^- or $\mu^+\mu^-$ pair
  - ✓ with 81 < M_{ll} < 101 GeV
- **Background** estimation
  - ✓ **Z+jets**
  - ➢ E^T_{miss} **template** from γ+jets sample, normalized to data w/ E^T_{miss} < 50 GeV
  - ✓ **Flavour symmetric** (tt, WW, tW, ττ)
  - ➢ Normalization to **eμ** sample
  - ✓ Other SM from MC

- Use E^T_{miss} as discovery variable
  - ➢ **Bins** to maximize sensitivity

➢ **Agreement** with **SM** prediction

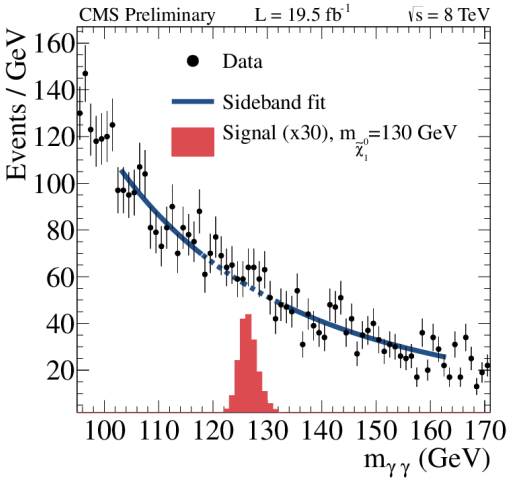


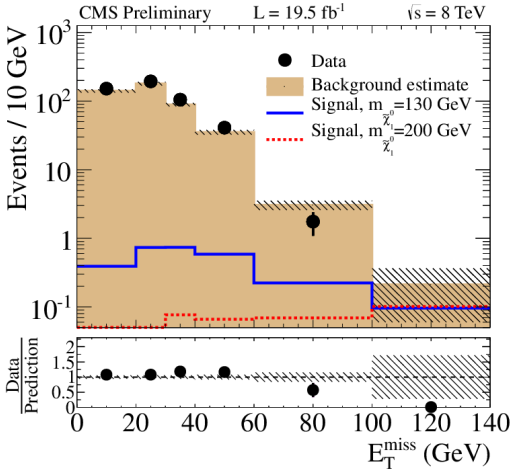
hZ, hW to γγ + 2 jets

New

CMS PAS SUS-14-002

- Select events with **no isolated leptons**
- **No** events with **2 b-jets** & 95 < M_{bb} < 155 GeV
- **Z/W boson** reconstruction
  - ➢ 70 < M_{ij} < 110 GeV
- Use E_T^{miss} as discovery variable
  - ➢ **Bins** to maximize sensitivity
- Estimate **SM background** from $M_{\gamma\gamma}$ sidebands
  - ➢ E_T^{miss} **template** from $M_{\gamma\gamma}$ sidebands
  - ➢ Normalized by fit of $M_{\gamma\gamma}$ sidebands
- ➢ Observation **consistent** with **SM** background





hh, hZ and hW to γγ + lepton(s)

New

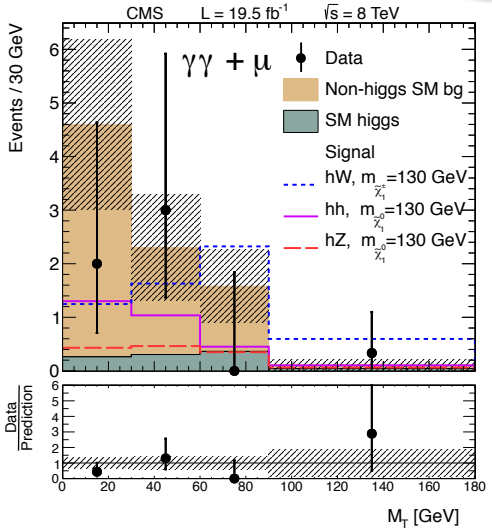
CMS PAS SUS-14-002

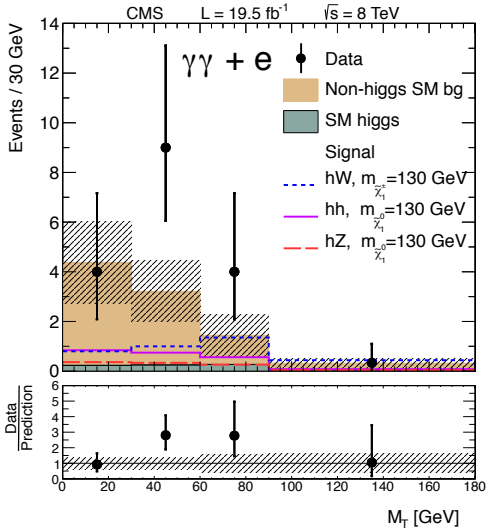
- Include **hh,** with **one** h → WW, ZZ, or ττ
- Select events with **≤1 b-jet** to avoid overlap
- Require **at least one lepton** per event
  - ➢ ≥ 1 μ's
  - ➢ NO μ && ≥ 1 e
  - ✓ 93% of events have only 1 e **or** 1 μ
- Use M_T as discovery variable
  - ✓ Transverse mass of leading lepton + E_t^{miss}
- Estimate **SM background** by fit of $M_{\gamma\gamma}$ sidebands

➢ **μ**-channel in agreement with SM prediction

➢ **e**-channel shows an excess of **2.1σ**

- ✓ **Consistent with background fluctuation**





hh and hZ: GMSB intepretation

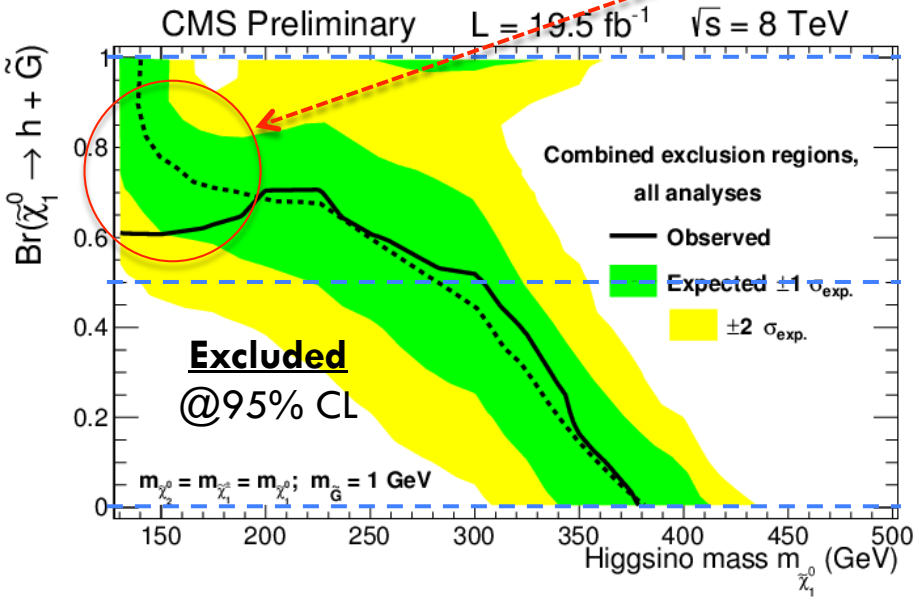
New

CMS PAS SUS-14-002

- **GMSB** scenario where neutralinos and charginos are **higgsinos** nearly degenerate

✓ Lightest neutralino is NLSP

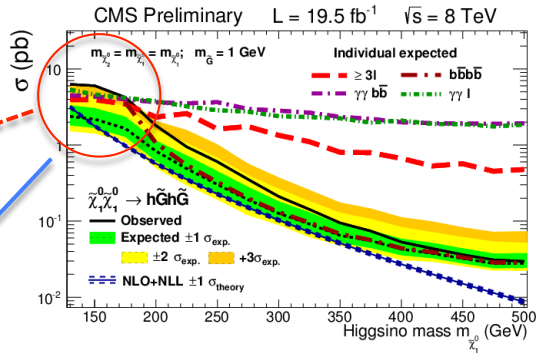
✓ Gravitino (nearly mass-less) is LSP

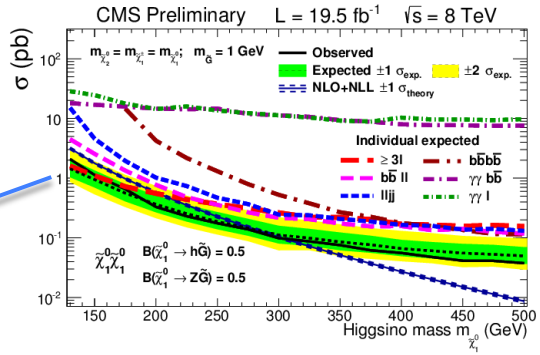


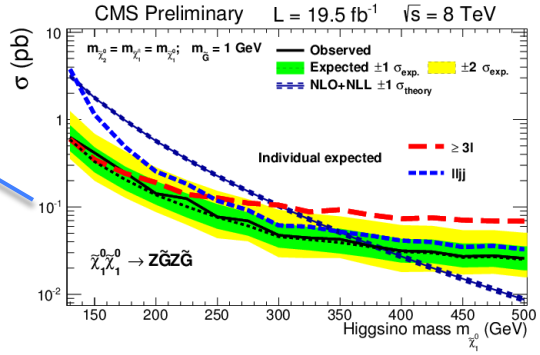
100% **hh**

25% **hh**
50% **hz**
25% **ZZ**

100% **ZZ**

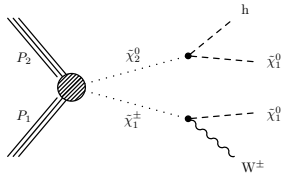






- Cross section *vs* higgsino mass (right)
- BR($\chi_1^0 \to h\tilde{G}$) *vs* higgsino mass (left)

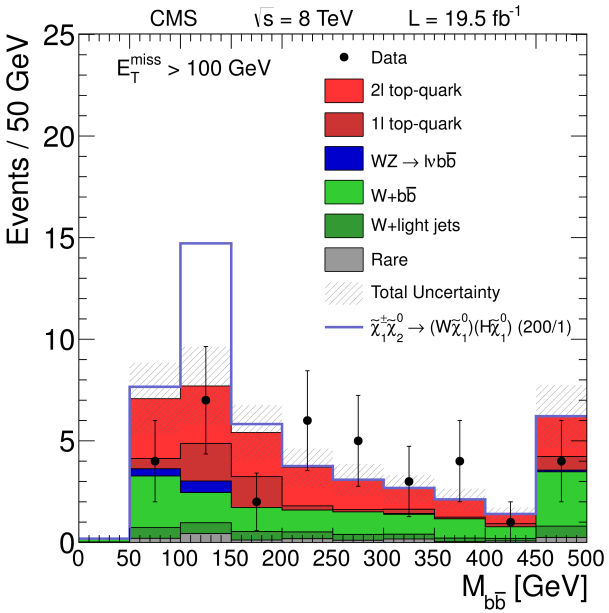
hW + E_T^{miss}

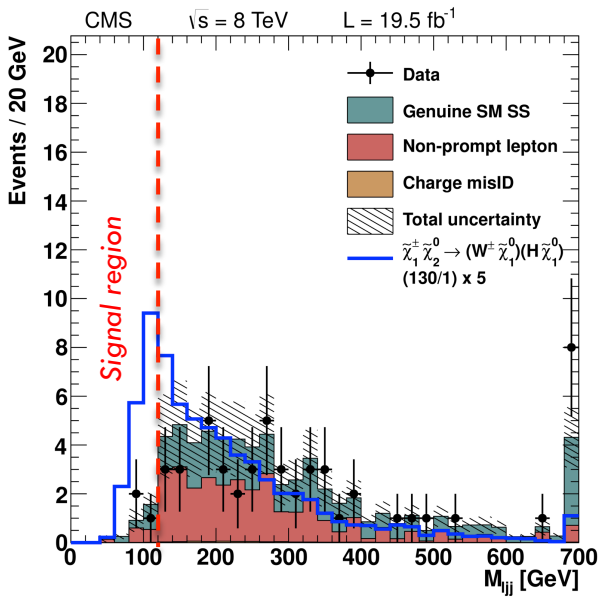


CMS PAS SUS-13-006, arXiv:1405.7570

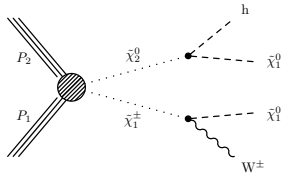
- **Single lepton** final state
  - **h(bb)** W(lν)
  - ✓ Events with 1 lepton + 2 b-jets
  - ✓ Large E_T^{miss} (**bins**)
  - ✓ Background from MC
    - Scale factors from data
  - ✓ Use M_{bb} as discovery variable

- **Same-sign di-lepton** final state
  - **h(WW)** W(lν)
  - ✓ Events with SS lepton pair, no b-jets & exactly 2 or 3 jets
  - ✓ Large E_T^{miss}, M_T and M_{T2}
  - ✓ Data-driven/MC background
  - ✓ Use M_{ljj} as discovery variable





hW + E_T^{miss}



CMS PAS SUS-13-006, arXiv:1405.7570

- **Single lepton** final state
  - ➢ **h(bb)** W(lν)
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  - ✓ Large $\mathbf{E_T^{miss}}$ (**bins**)
  - ✓ Background from MC
    - Scale factors from data
  - ✓ Use $\mathbf{M_{bb}}$ as discovery variable

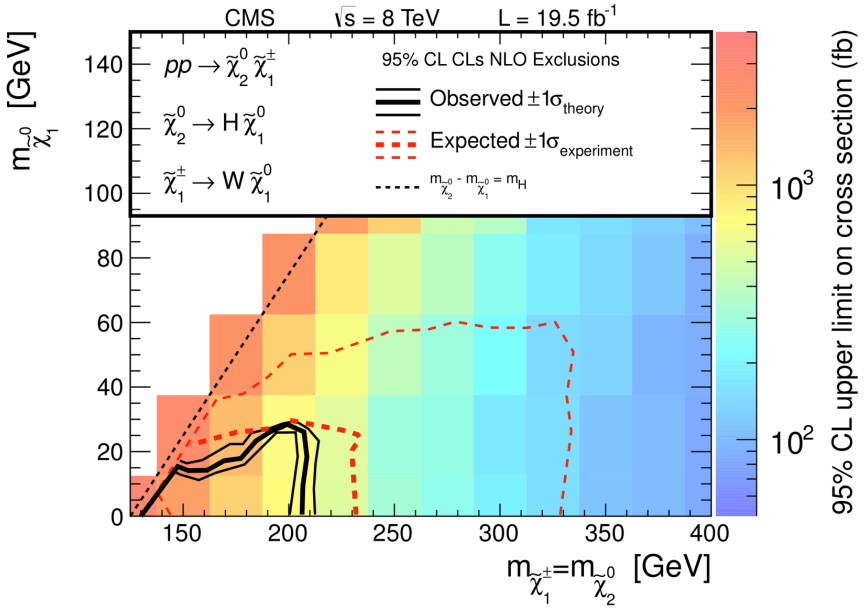
- **Same-sign di-lepton** final state
  - ➢ **h(WW)** W(lν)
  - ✓ Events with SS lepton pair, no b-jets & exactly 2 or 3 jets
  - ✓ Large $\mathbf{E_T^{miss}}$, $\mathbf{M_T}$ and $\mathbf{M_{T2}}$
  - ✓ Data-driven/MC background
  - ✓ Use $\mathbf{M_{ljj}}$ as discovery variable

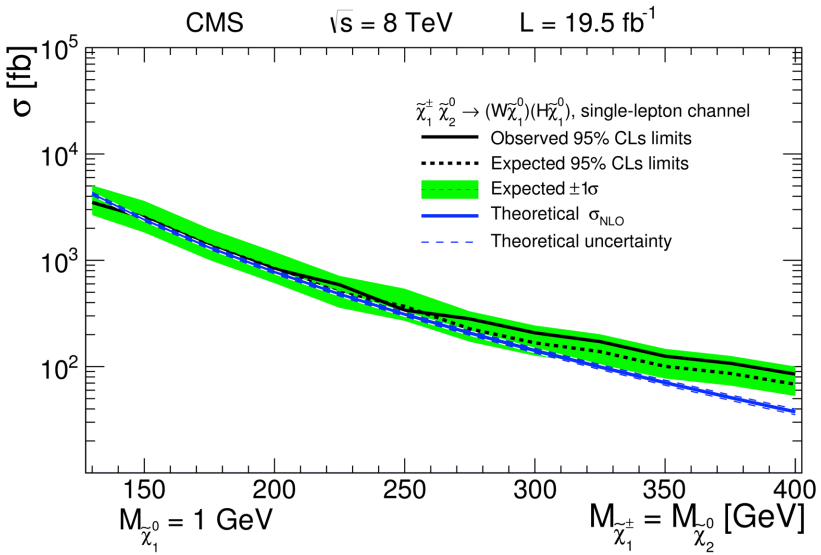
- **Multi-lepton** final state
  - Re-interpretation of **arXiv:1404.5801**
  - ➢ **h(WW, ZZ, ττ)** W(lν)
  - ✓ Events with ≥ 3 leptons
    - Including e, μ and τ_h
  - ✓ Data-driven/MC background
  - ✓ **Bins** in lepton and b-jet multiplicity, E_T^{miss} and H_T

$\chi_1^{\pm}\,\chi_2^{0}$ production to hW

CMS PAS SUS-13-006, arXiv:1405.7570

- Exclusion limits on production cross-section
  - ✓ Combination of all the channels
    - Single lepton final state
    - Same-sign di-lepton
    - Multi-lepton final state



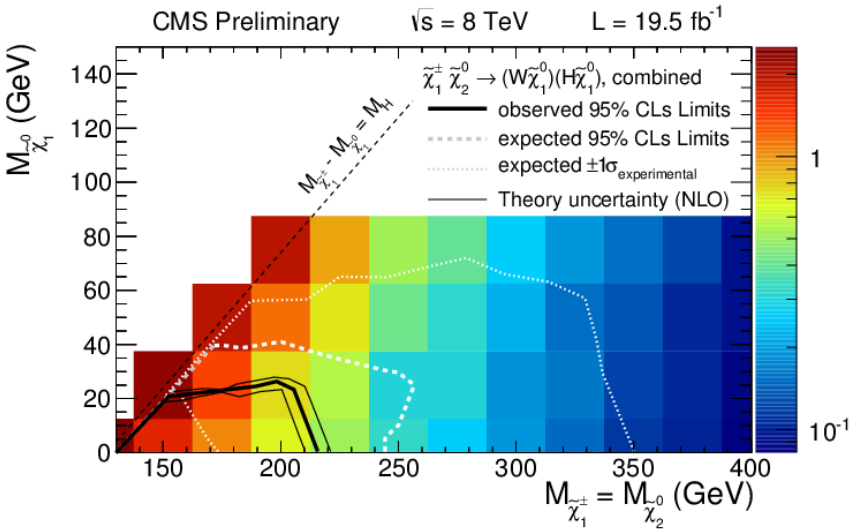


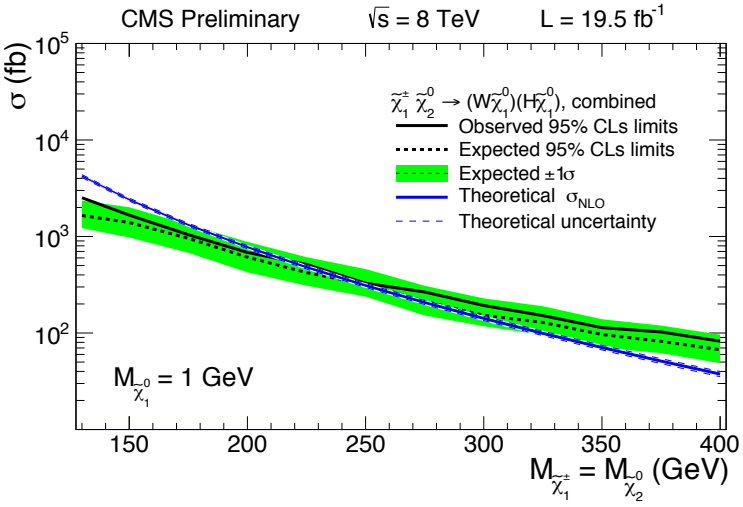
$\chi_1^{\pm}\,\chi_2^{0}$ production to hW

CMS PAS SUS-13-006, arXiv:1405.7570 + **CMS PAS SUS-14-002**

New

- Exclusion limits on production cross-section
  - ✓ Combination of all the channels
    - Single lepton final state
    - Same-sign di-lepton
    - Multi-lepton final state
  - ✓ Addition of **h(γγ)** final states from CMS PAS **SUS-14-002**

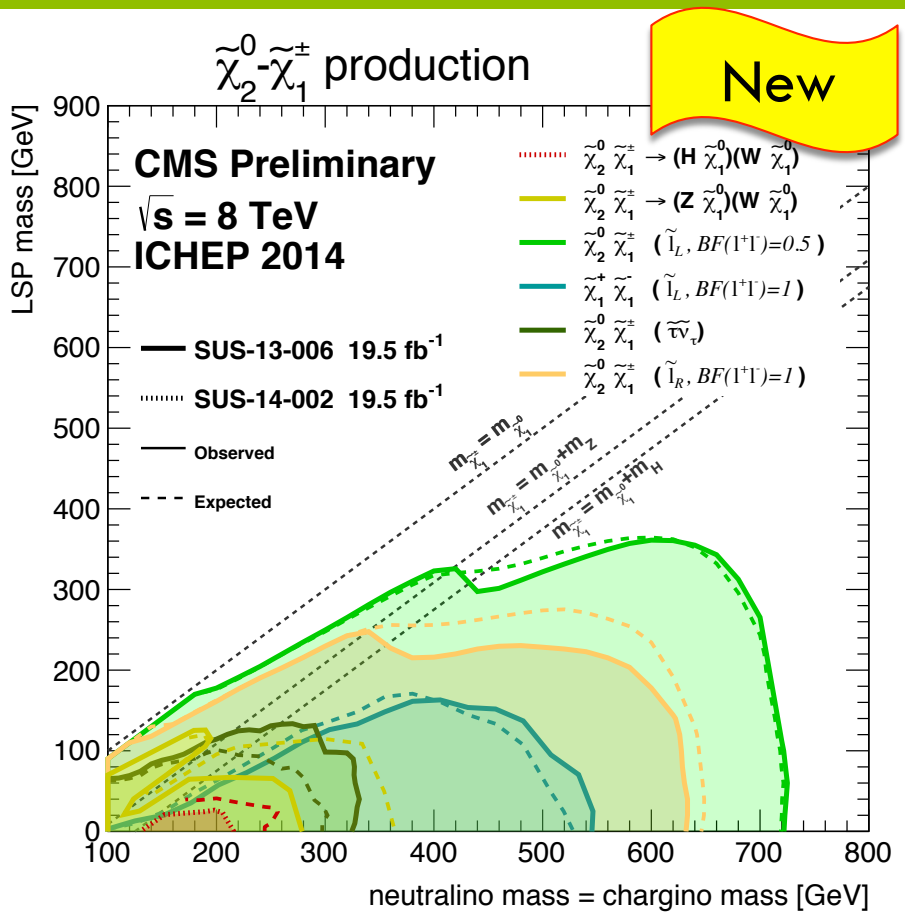




Summary

- Wide spectrum of analyses searching for electroweak SUSY production
  - ✓ Only a selection presented today!
- Many new searches with Higgs tagging
  - ✓ Complementary to previous results
- Neutralino & chargino mass probed up to 700 GeV
- **No evidence for SUSY**, yet

➢ Looking forward to 2015!



THANK YOU!

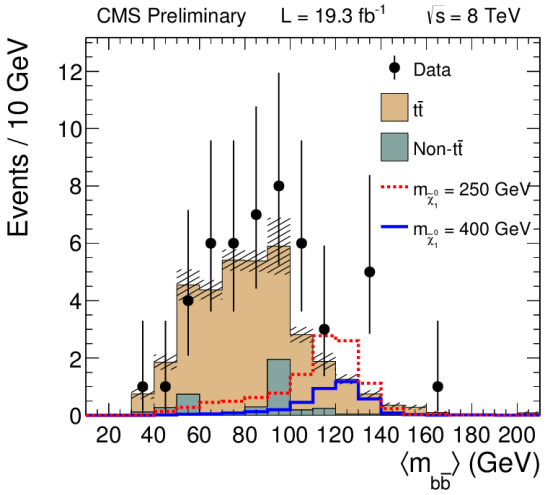
Backup

hh to 4 b's

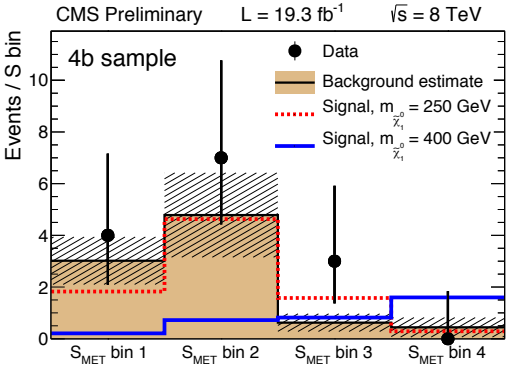
CMS PAS SUS-14-002

- Exploit largest branching ratio for Higgs boson decay
  - ✓ BR(h → bb) ≈ 56%
- Select events with
  - ✓ Exactly 4 or 5 jets
  - ✓ ≥ 2 b-jets (tight ID)
- Double Higgs reconstruction
  - ✓ b-pairs with minimum ΔM_{bb}
  - ✓ $|\Delta M_{bb}| < 20$ GeV
  - ✓ $100 < \langle M_{bb} \rangle < 140$ GeV
- Bins in E_T^{miss} significance, **S_{MET}**
- Data-driven **background**

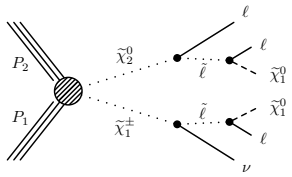
➢ **Agreement** with **SM**



$\mathcal{S}_{MET}$ bin	$\mathcal{S}_{MET}$ range
1	30 – 50
2	50 – 100
3	100 – 150
4	> 150



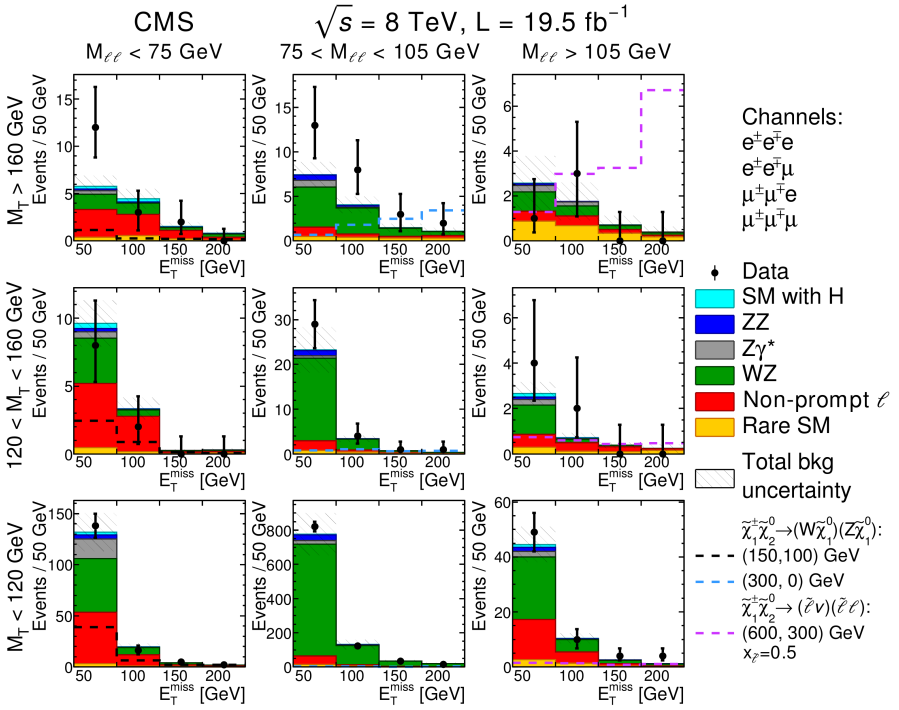
Three-lepton search



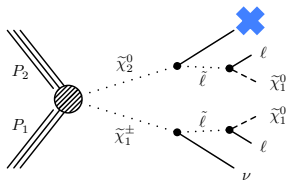
CMS PAS SUS-13-006, arXiv:1405.7570

- Select events with **exactly 3 leptons**
  - ✓ Including e, μ and (≤ 1) τ_h
- **NO** events with b-jets
  - ✓ Reject **tt** background
- Large E_T^{miss} (> 50 GeV)
- Bins (3D) in E_T^{miss}, M_T, M_{ll}
- Exploit multiple final states
  - 3 e/μ with(out) OSSF pair
  - SS pair + τ_h
  - OS eμ + τ_h
- **Background** data-driven estimation

➢ Observation **consistent** with **SM** prediction in the full phase-space



Same-sign di-lepton

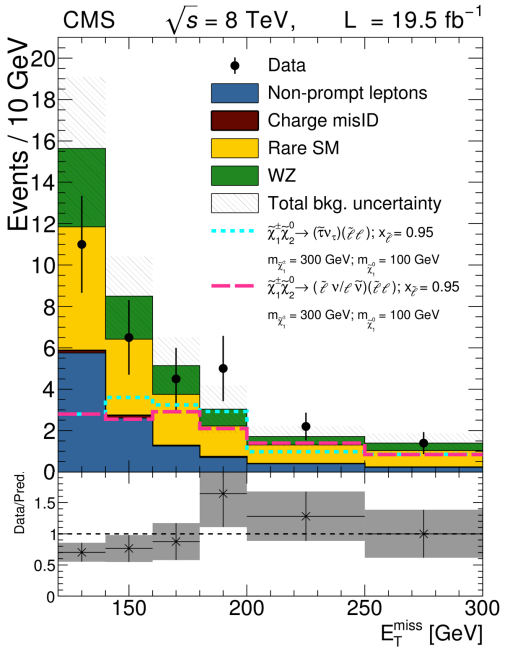


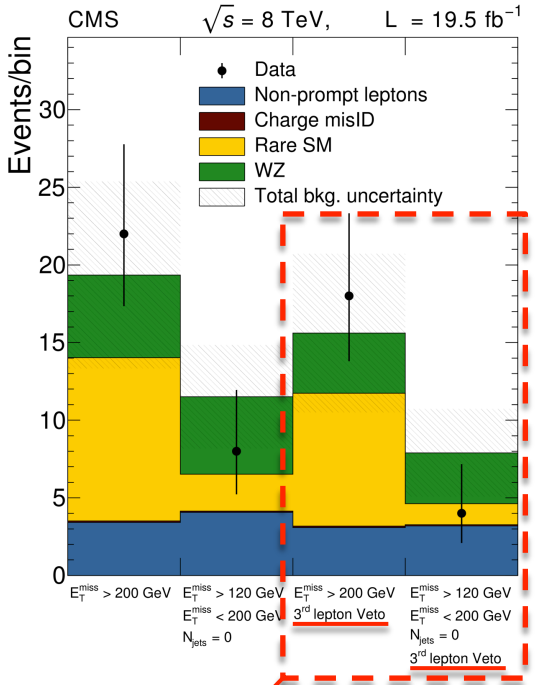
CMS PAS SUS-13-006, arXiv:1405.7570

- Three-lepton final states **not** sensitive to cases with one *lost* lepton
  - ➢ **Not** sensitive to **small mass splitting**, because of soft leptons
  - ➢ **Recover** events with **same-sign di-lepton** search

- Select events with exactly 1 SS lepton pair (**ee, eμ, μμ**)
- **NO** events with OSSF pair within 15 GeV from Z boson mass
- Large $\mathbf{E_T^{miss}}$ (> 120 GeV)
- **Bins** in $\mathbf{E_T^{miss}}$ (plus hadronic veto)
- MC/data-driven **background**

➢ **Agreement** with **SM** prediction





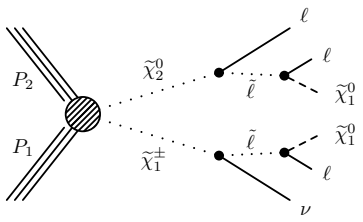
For **combination** with three-lepton search

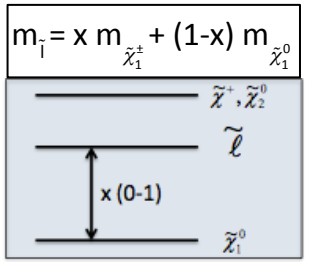
$\chi_1^{\pm}\ \chi_2^{0}$ production

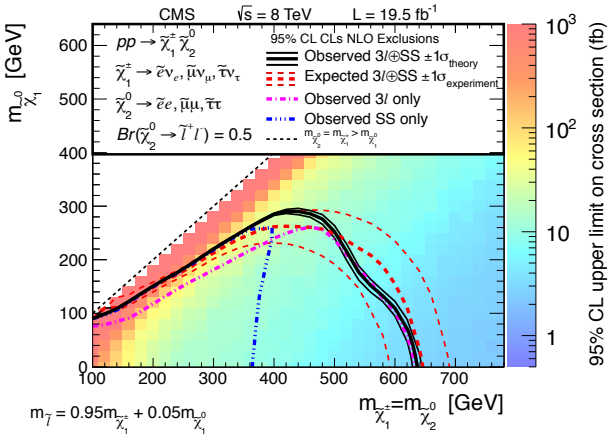
CMS PAS SUS-13-006, arXiv:1405.7570

- Results are interpreted in diverse scenarios
- And with different mass splitting

➢ Only a selection is presented today!

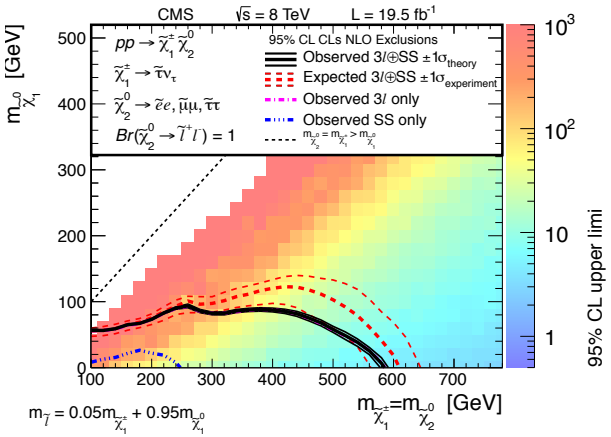


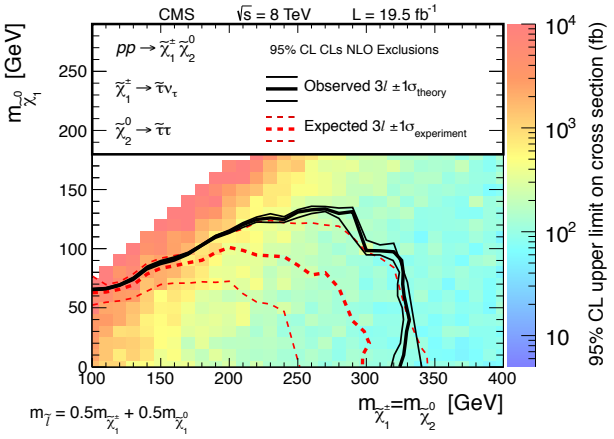




✓ Flavour democratic
✓ x = 0.95

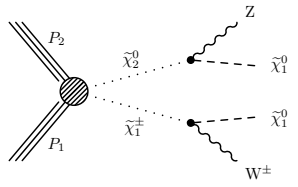
✓ τ enriched
✓ x = 0.05





✓ τ dominated
✓ x = 0.5

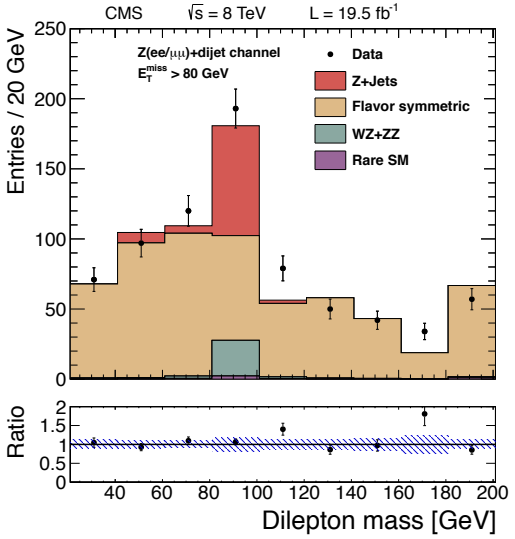
Z(ll) + di-jet

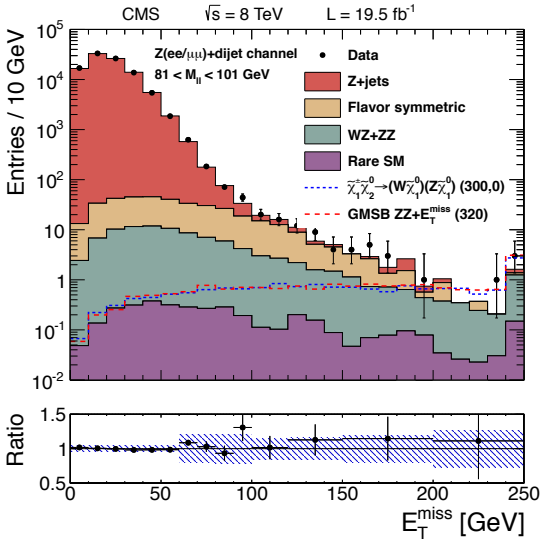


CMS PAS SUS-13-006, arXiv:1405.7570

- Select events with a Z candidate
  - ✓ Exactly 2 leptons, with Z → ll
- And ≥ 2 jets, consistent with a W/Z
  - ✓ 70 < M_{ll} < 110 GeV
  - ✓ Reject **Z+jets** background
- **NO** events with b-jets
  - ✓ Reject **tt** background
- Large E_T^{miss} (> 80 GeV)
- Bins in E_T^{miss}, M_T, M_{ll}
- **Background** data-driven estimation

➢ **Observation** is consistent with **SM**

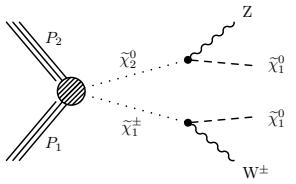


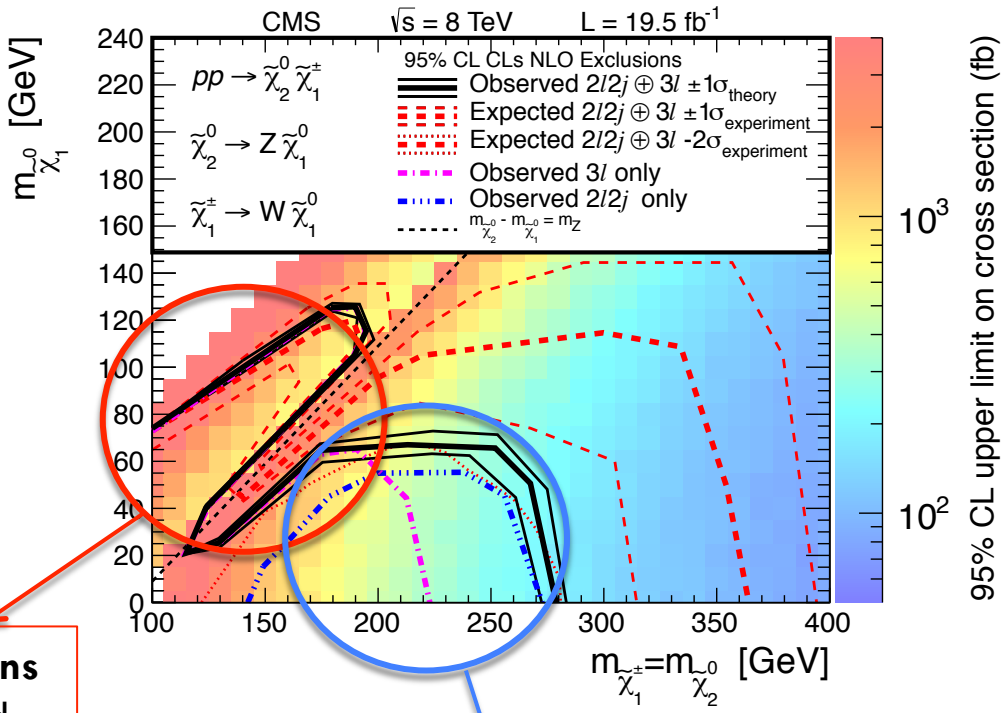


$\chi_1^{\pm}\,\chi_2^{0}$ production to ZW

CMS PAS SUS-13-006, arXiv:1405.7570

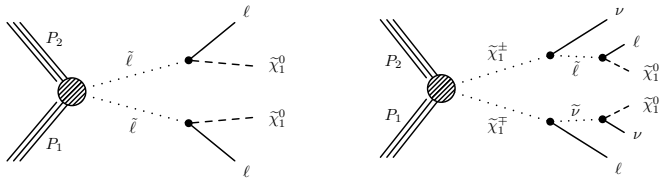
- From the combination of Z + di-jet and three-leptons searches





ETH Institute for Particle Physics

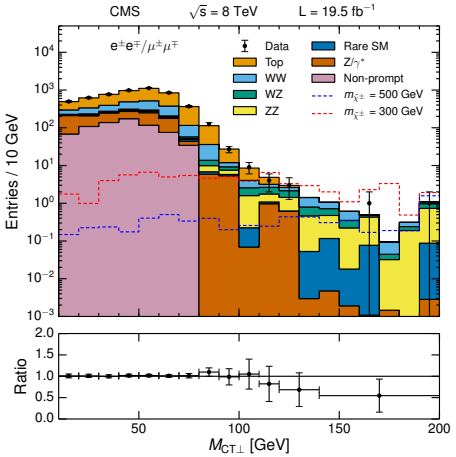
OS di-lepton

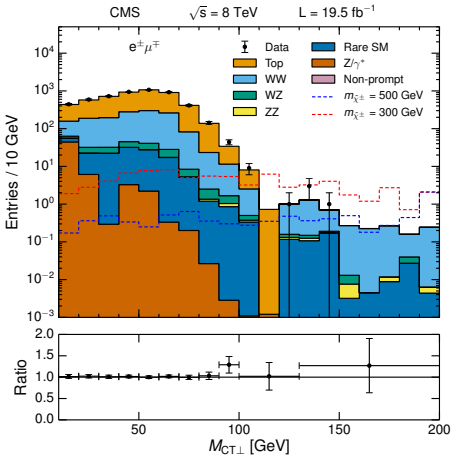


CMS PAS SUS-13-006, arXiv:1405.7570

- Select events with exactly 2 OS lepton pair (**ee, eμ, μμ**)
- **NO** events with OSSF pair within 15 GeV from Z boson mass
- **NO** events with b-jets
  - ✓ Reject **tt** background
- Large $\mathbf{E_T^{miss}}$ (> 60 GeV)
- Use $\mathbf{M_{CT\perp}}$ as discovery variable
  - ✓ Binned max likelihood fit (bakcground only hypothesis)
- Data-driven **background**

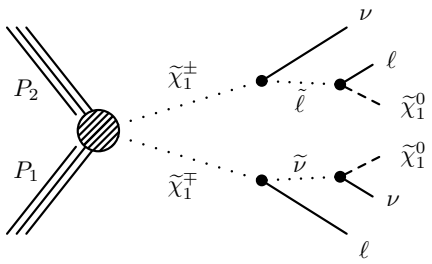
➢ **Agreement** with **SM** prediction

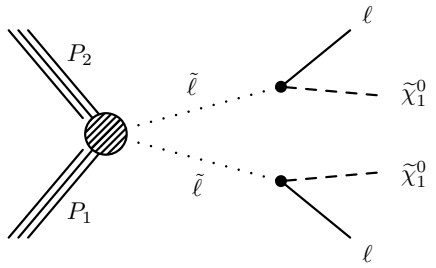


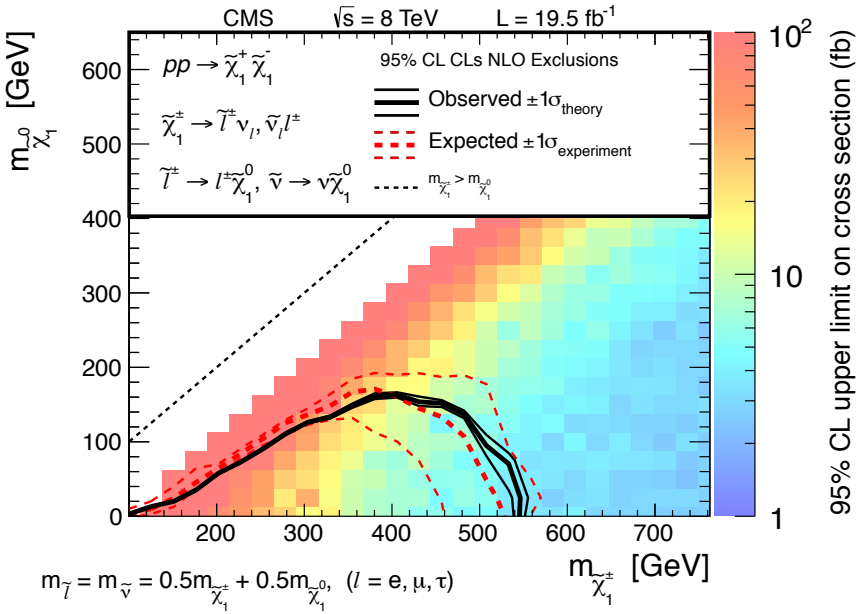


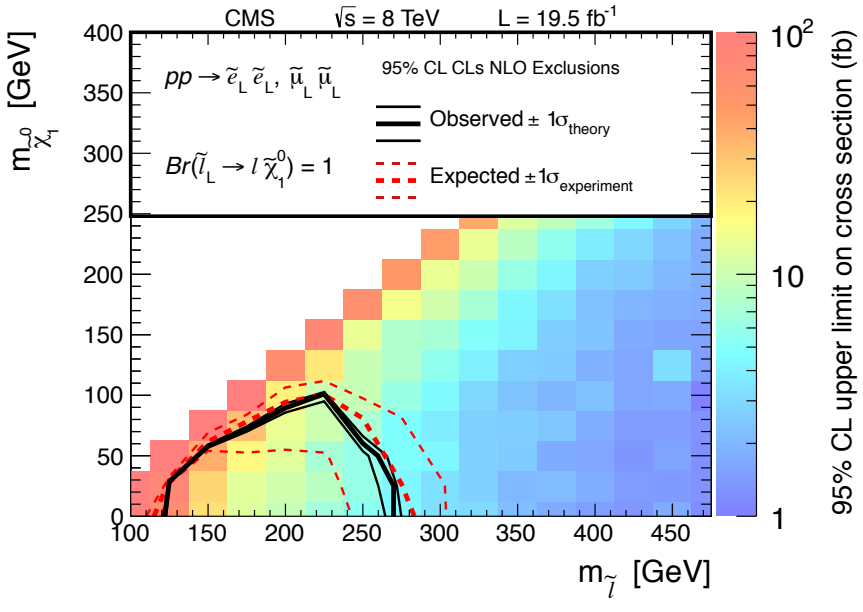
Chargino/slepton pair production

CMS PAS SUS-13-006, arXiv:1405.7570







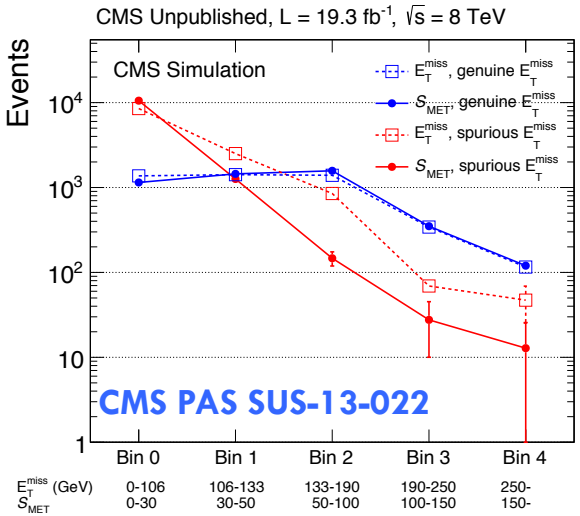


E_T^{miss} significance – S_{MET}

- χ^2 of **observed** E_T^{miss} wrt. null hypothesis (i.e., $E_T^{miss} = 0$)

$$S_{MET} = (E_T^{miss}) C^{-1} (E_T^{miss})^T$$

✓ **C** - covariance matrix → Resolution of all the objects in the event



➢ Better **fake**-E_T^{miss} rejection than plain E_T^{miss}

* Bibliography: arXiv:1106.5048

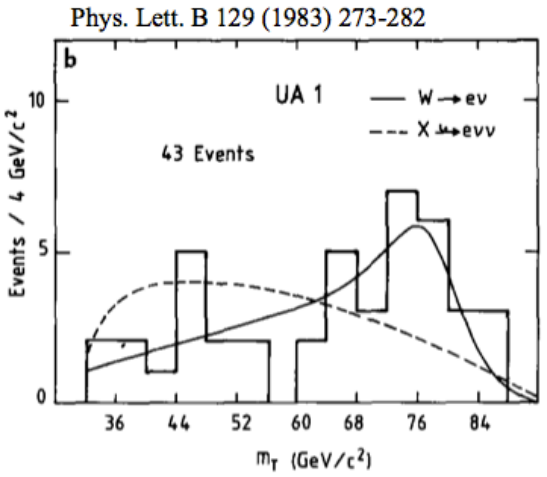
Transverse mass – M_T

- Projection of the mass M on the transverse plan

$$M_T^2=(E_{T,1}+E_{T,2})^2-(\vec{p}_{T,1}+\vec{p}_{T,2})^2$$

➢ $M_T \leq M$

⇒ **End-point** at parent mass



Discovery of W boson at UA1 (1983)

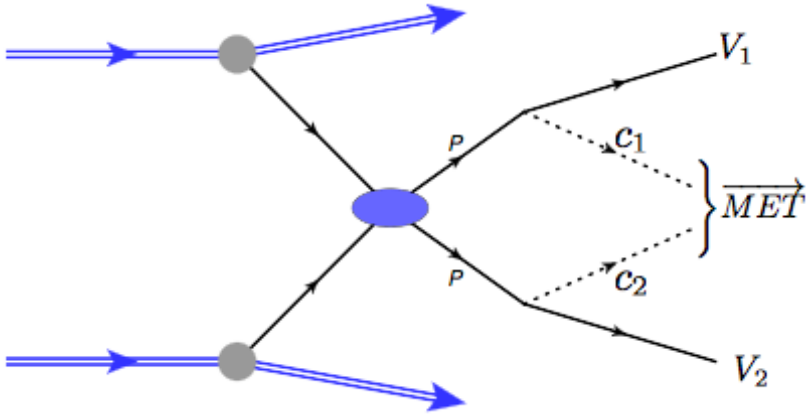
S-transverse mass – M_{T2}

- **Generalization** of transverse mass $\mathbf{M_T}$ to case of **two** decay chains with an **un**observed particle each

$$M_{T2}(m_c) = \min_{\vec{p}_T^{\,c(1)} + \vec{p}_T^{\,c(2)} = \vec{p}_T^{\,miss}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

  - ✓ If all masses are known, M_{T2} will have an **endpoint** at the parent mass

- **Division** of events into **two massless pseudo-jets**



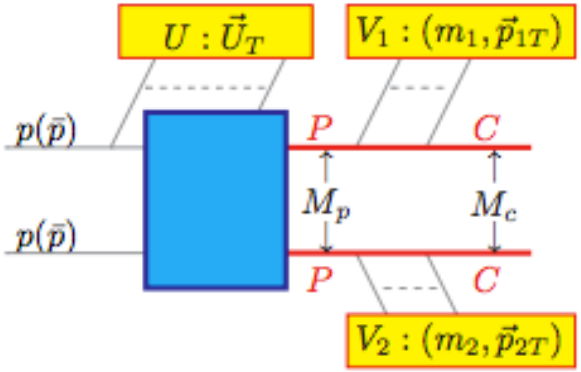
* Bibliography: arXiv:hep-ph/9906349, arxiv:hep-ph/0907.2713

Contranverse mass – M_{CT}

- New variable derived from the transverse mass M_T

➢ Parity transformation: $\mathbf{p}_2 \rightarrow P(\mathbf{p}_2)$ ⇒ $M_{CT}^2 = (E_{T,1}^2 + E_{T,2}^2) - (\vec{p}_{T,1}^2 - \vec{p}_{T,2}^2)$

- **Division** of events into **three systems**
  - ➢ $\mathbf{U_T}$ – All upstream objects
  - ➢ $\mathbf{V_i}$ (i = 1,2) – Composite visible particles



- **Projection** of $\mathbf{M_{CT}}$ on the direction of $\mathbf{U_T}$
  - ➢ $\mathbf{M_{CT//}}$
  - ➢ $\mathbf{M_{CT\perp}}$

➢ $\mathbf{M_{CT\perp}}$ is **in**sensitive of the upstream momentum

➢ And has **end-point** at the parent mass

* Bibliography: arXiv:0910.1584