Search for electroweak SUSY production at CMS

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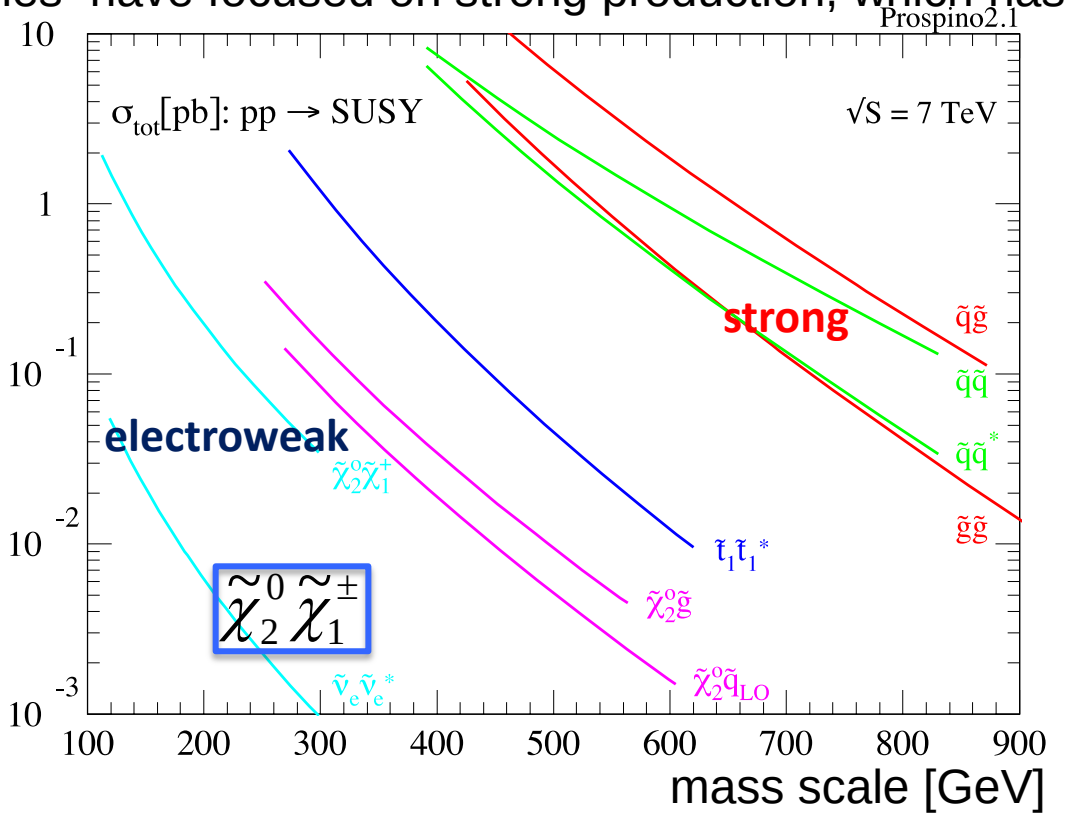
Motivation

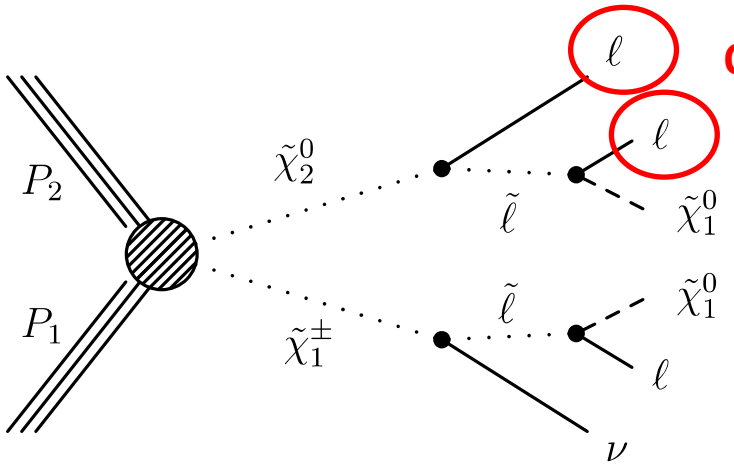
- Most SUSY searches have focused on strong production, which has the largest cross section



- Limits on these models probe masses of strongly-interacting particles up to ~1 TeV
  - Similar cross-sections to EWK gaugino's of 300-400 GeV
- Interesting when squarks and gluino's are heavy, but EWKinos are light
- Very clean multi-lepton signatures with little hadronic activity

Chargino-neutralino production

chargino-neutralino production: light sleptons and sneutrinos



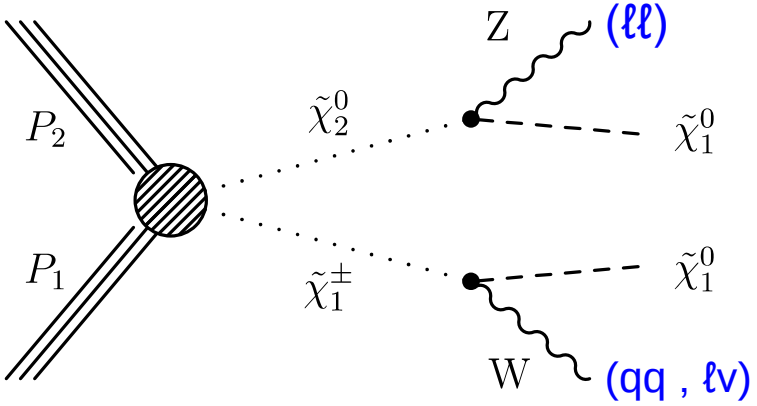
One missed:
→ SS dileptons

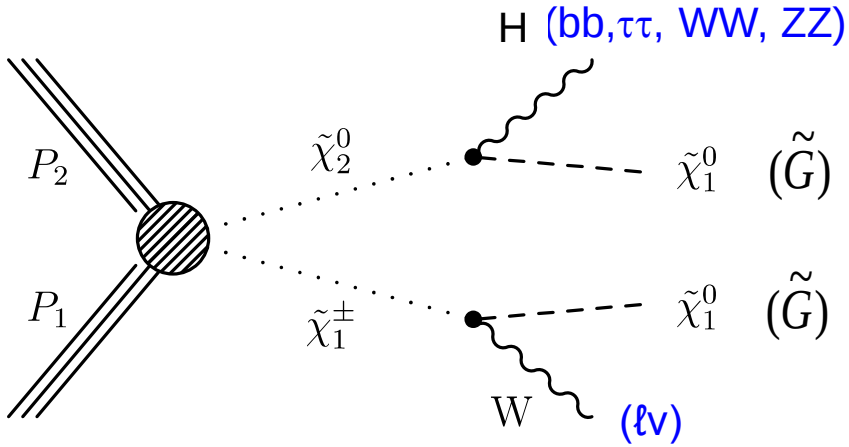
- **Model naturally gives 3ℓ (off-Z) signatures, but can give 2ℓ or 3ℓ (on-Z) signatures, depending on mass spectrum**
  - consider options where taus are preferred
    - final states with hadronic taus are considered

- Dedicated analyses:
  - 3-lepton search
  - same-sign di-lepton analysis (Veto third lepton, fully exclusive)

Chargino-neutralino production

chargino-neutralino production: direct decays to bosons (heavy sleptons)





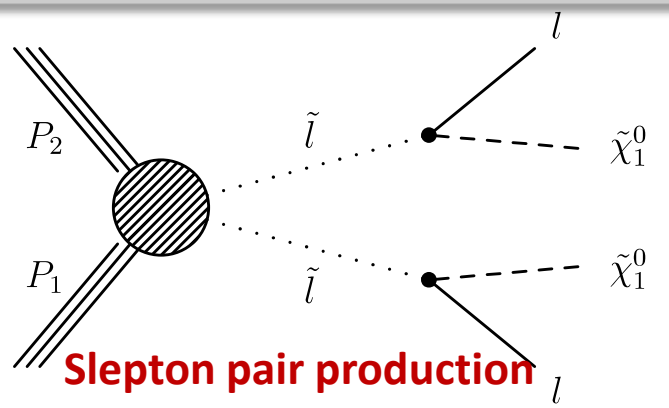
- **Model naturally gives 3ℓ and 3l (on-Z) and 2l (on-Z) + jets signatures**

- **Model naturally gives a variety of signatures following the Higgs decay modes**
  - **–Extra handle: Higgs mass**

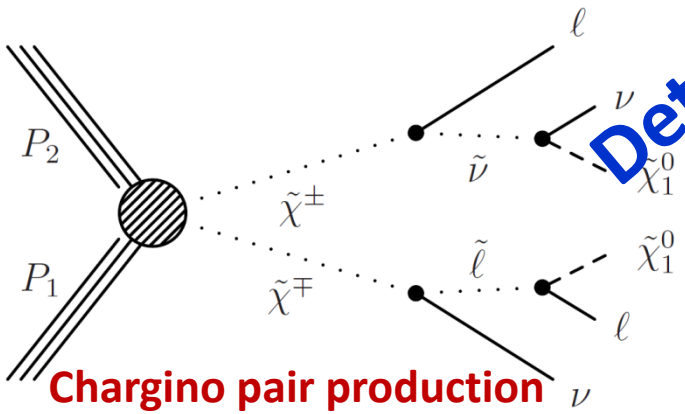
- Dedicated analyses:
  - 3-lepton + M(ll) + MT
  - 2-lepton + di-jet + MET

- Dedicated analyses:
  - 1 lepton +b's
  - SS dileptons
  - trileptons

Other models for direct EWK SUSY production



Slepton pair production

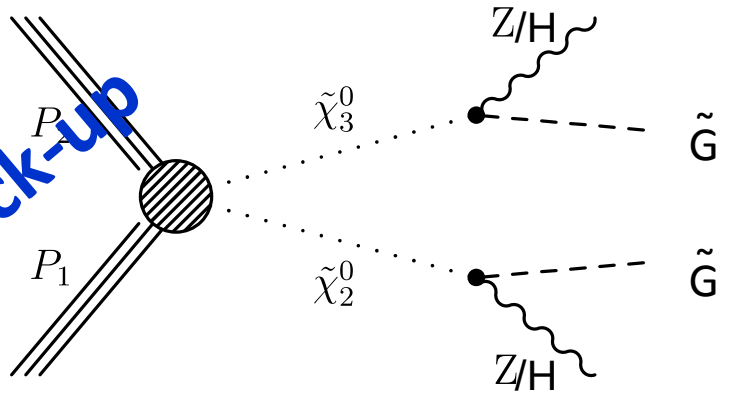


Chargino pair production

- **Models naturally give 2ℓ (off-Z) signatures**

- Dedicated analysis:
  - opposite -sign di-lepton analysis

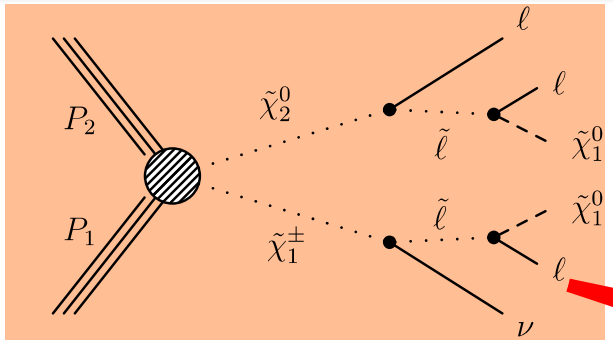
Details in back-up

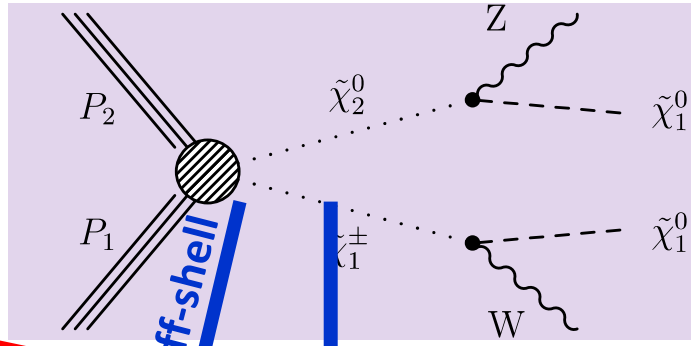


GMSB Higgsino production

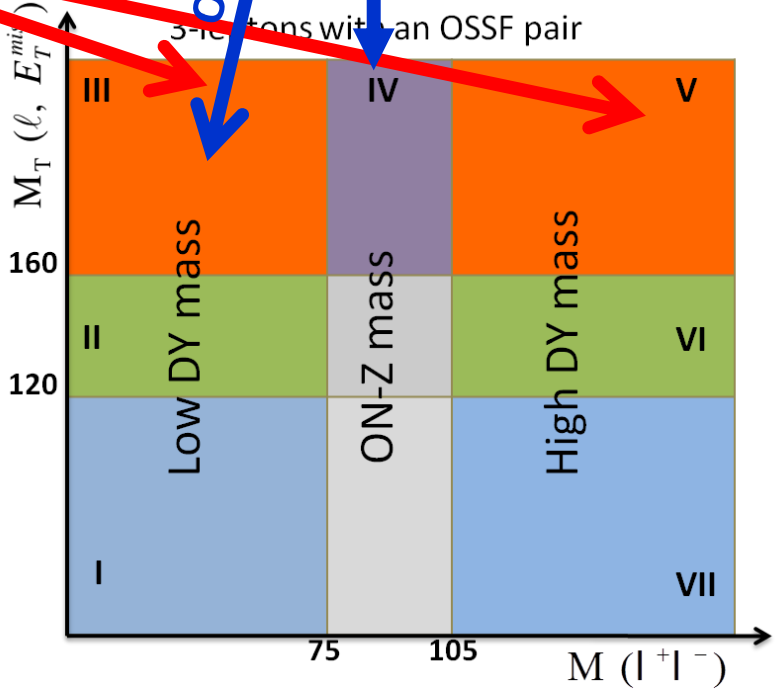
- Dedicated analysis for HH decay mode:
  - 4b analysis (SUS-13-022)
- Dedicated analysis for ZZ decay mode:
  - four leptons analysis
  - Z + dijet analysis

Three lepton analysis





- **Selection:**
  - Exactly 3 leptons, at most 1 τ_{had}
  - B-veto to reduce ttbar
  - MET>50 GeV cut to reduce Z+jets
  - MET, m_T and dilepton mass binning
    - dilepton mass bins to reduce Z backgrounds
    - mT bins to reduce W backgrounds
- **Backgrounds:**
  - Data-driven background prediction for non-prompt and misidentified leptons
  - WZ: MC with data-driven corrections to MET

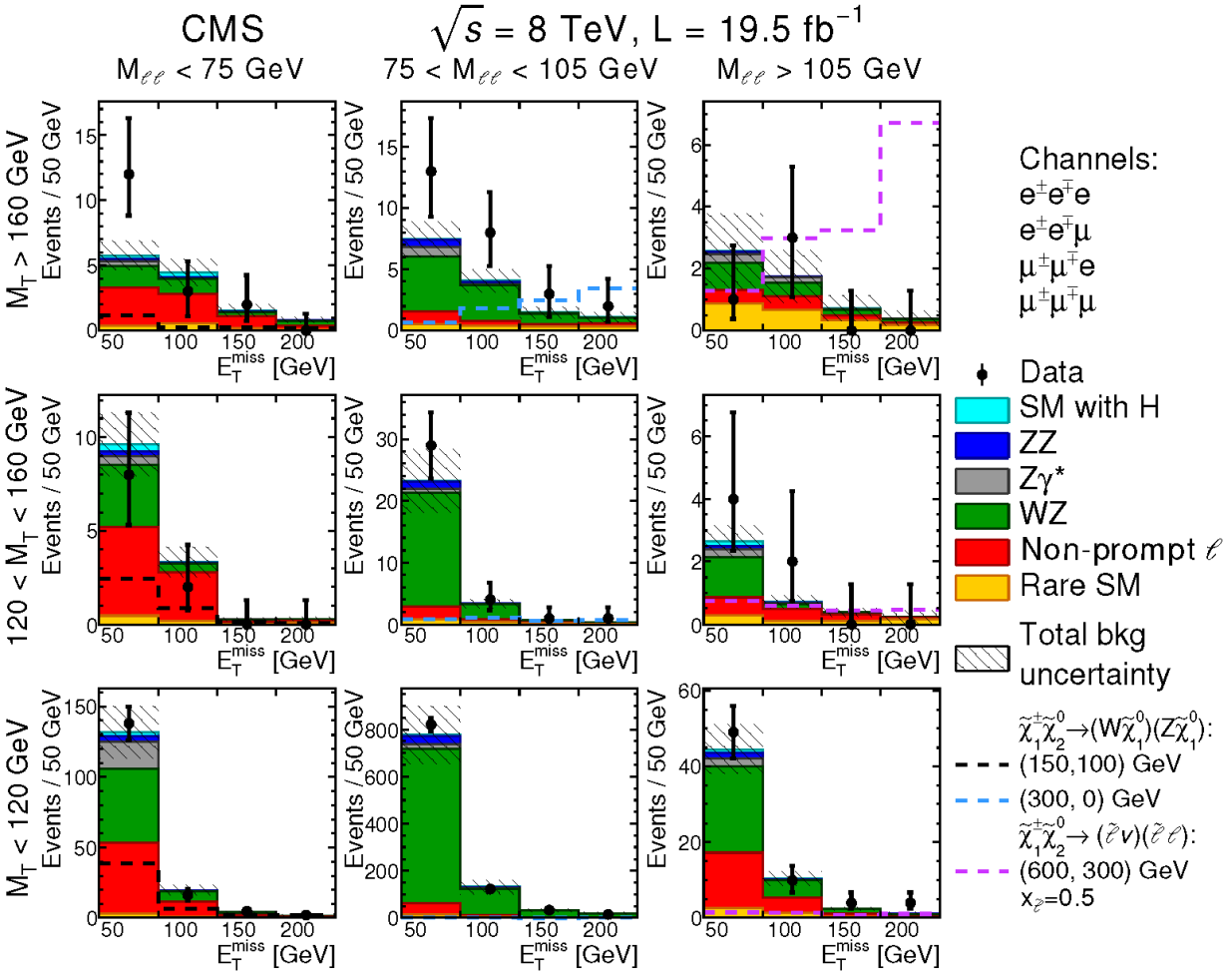


Three lepton analysis

arXiv:hep-ex/1405.7570

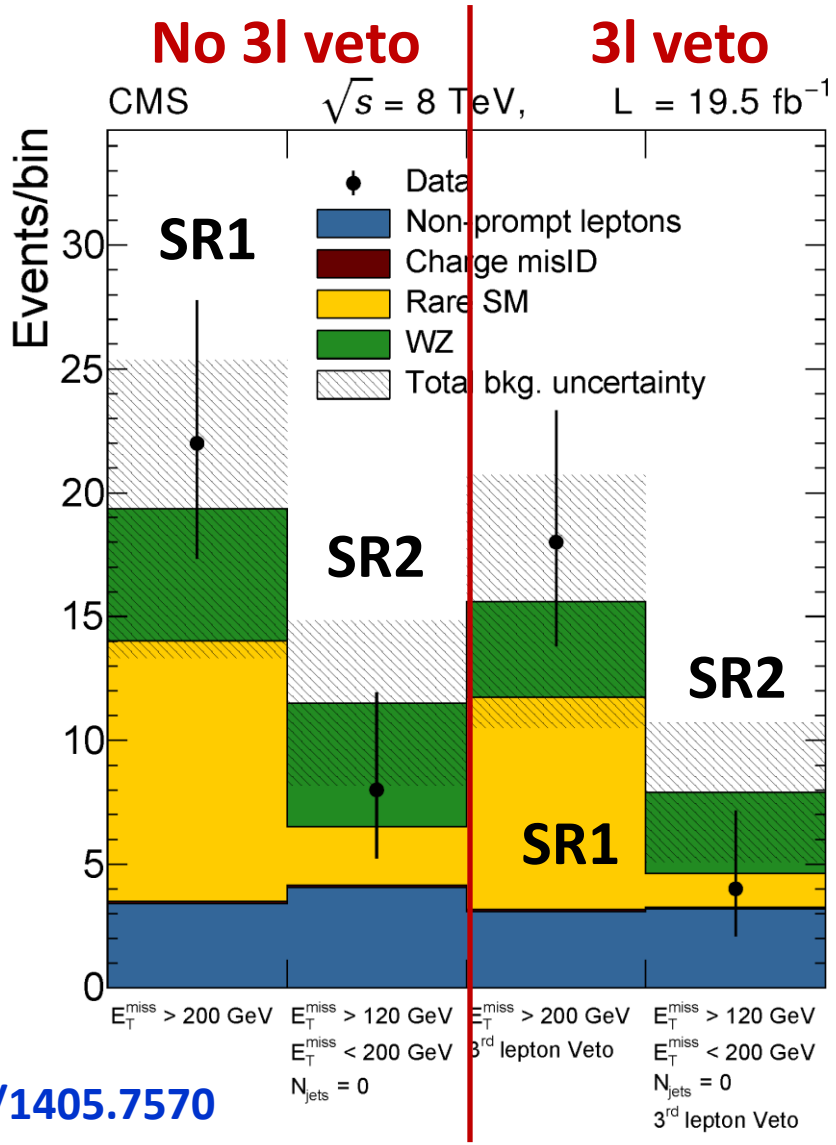
For τ-enriched models

- **Multiple final states:**
  - 3 e/μ, OSSF pair
  - 3 e/μ, no OSSF
  - SS e/μ + τ_{had}
  - OS eμ + τ_{had}
- **Results:**
  - Data consistent with prediction in the full region of phase space



Same-Sign dilepton analysis

- Small mass splittings can lead to soft leptons and missing one of the leptons
- Tighter cuts needed because of larger backgrounds
- **Selection:**
  - Exactly 2 high p_T electrons or muons
  - Z veto
  - Cut on small hadronic activity or large MET:
    - SR1: MET>200 GeV
    - SR2: jet-veto, 120 GeV<MET<200 GeV
- **Backgrounds:**
  - Data-driven background prediction for non-prompt and misidentified leptons
- **Results:**
  - Good agreement between data and prediction



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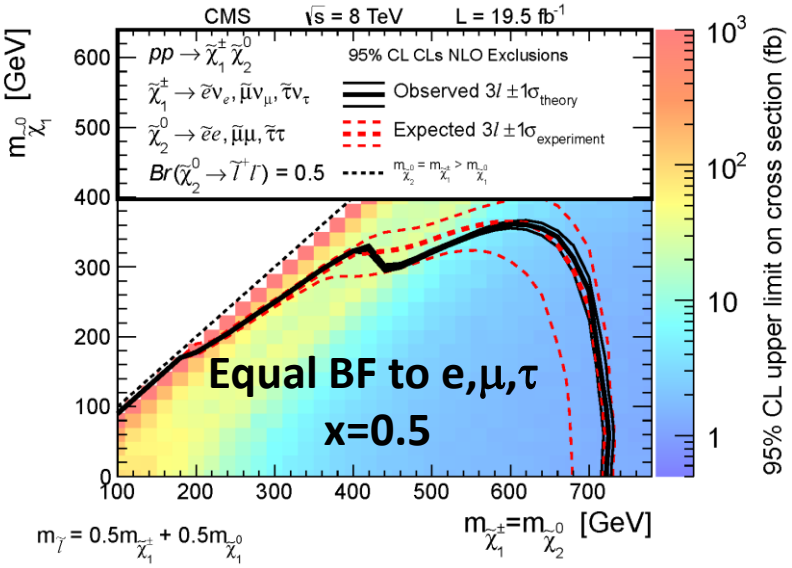
Chargino-neutralino production



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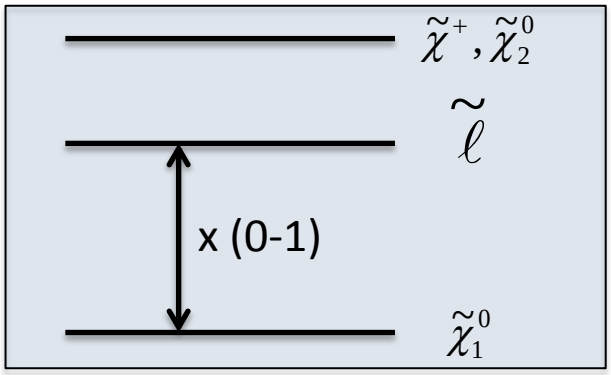
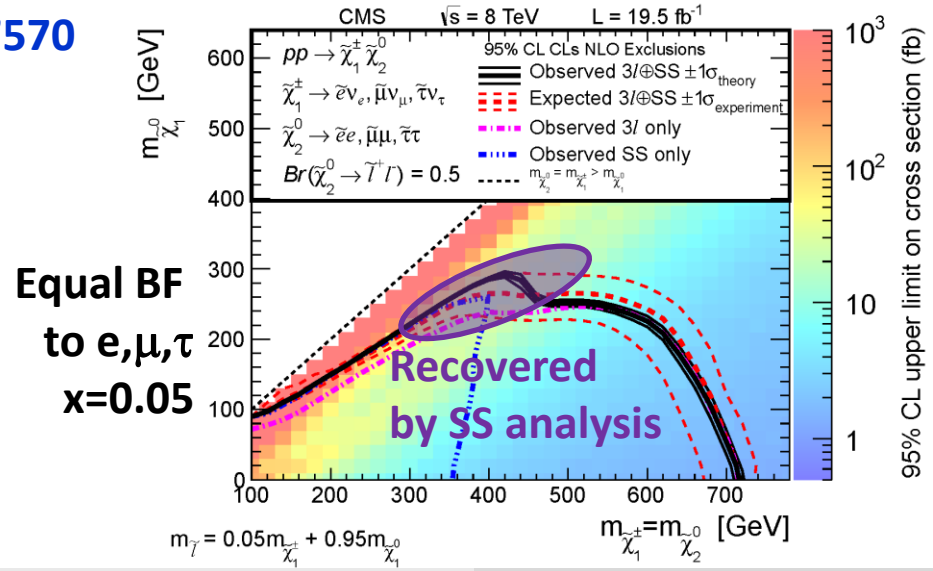
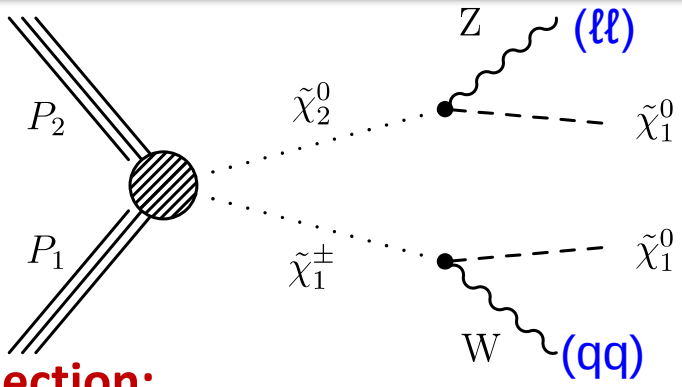


$m_{slep} = x \cdot m_{\chi^+} + (1-x) \cdot m_{LSP}$

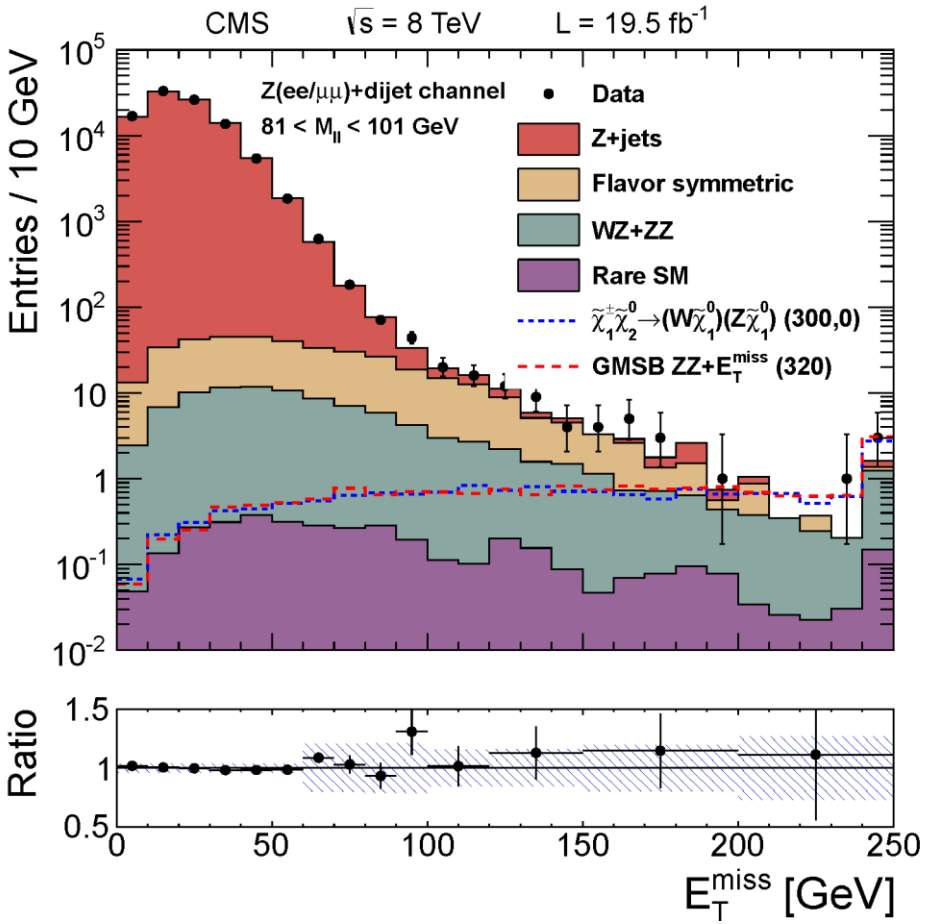


Z+dijet analysis



- **Selection:**
  - Z -> ee or μμ candidate
  - Third lepton veto
  - B veto to suppress ttbar
  - Dijet mass compatible with W boson
  - Use MET bins
- **Backgrounds:**
  - Z+jets MET modeled with γ+jets templates
  - Flavor symmetric backgrounds from eμ
- **Results:**
  - Data well described over several orders of magnitude

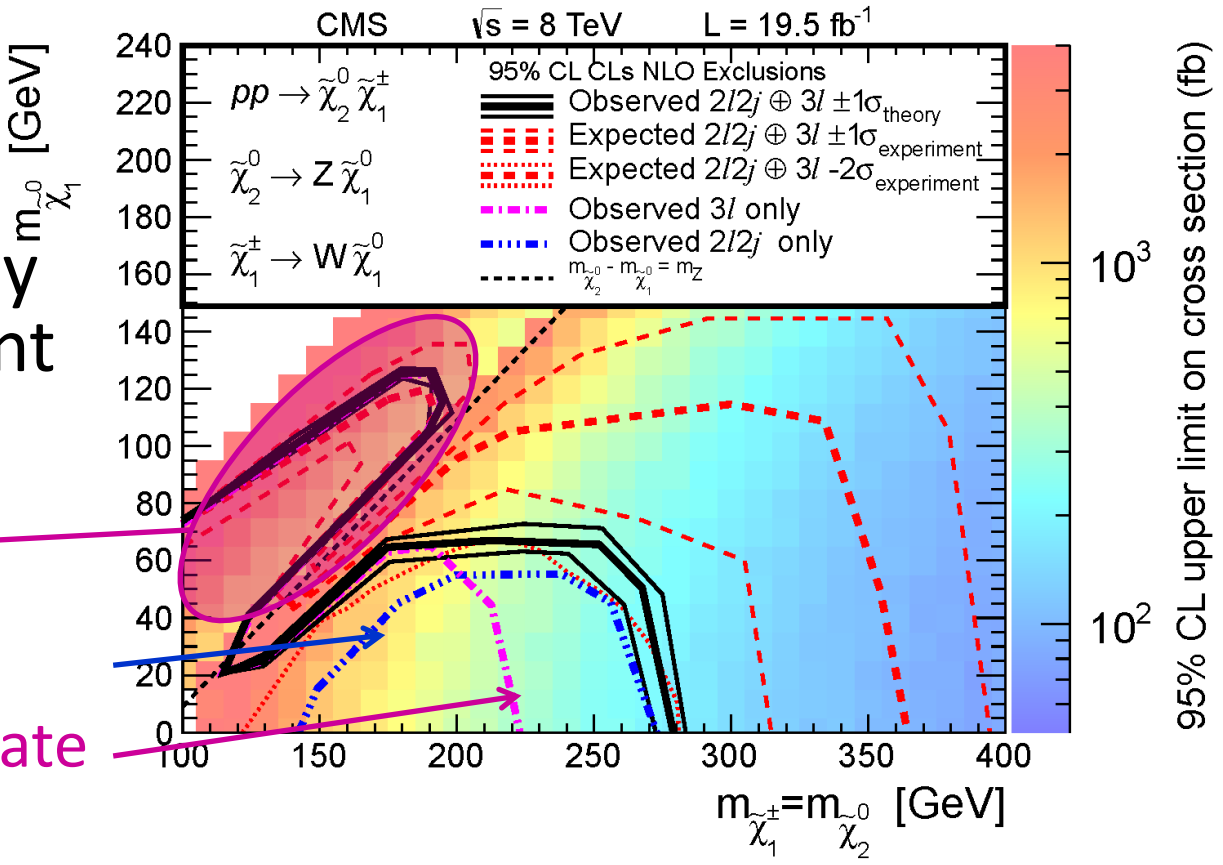
arXiv:hep-ex/1405.7570



Chargino-neutralino production to WZ

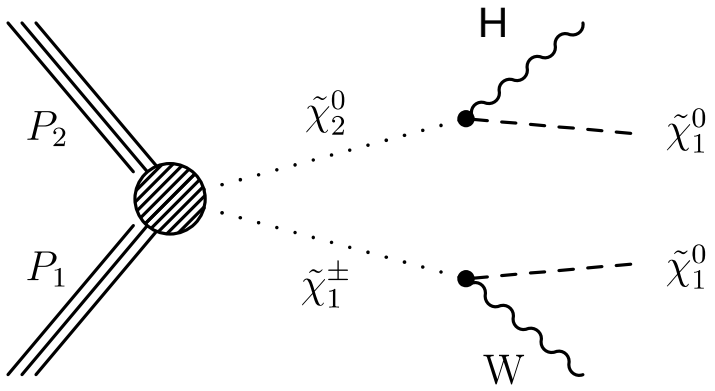
arXiv:hep-ex/1405.7570

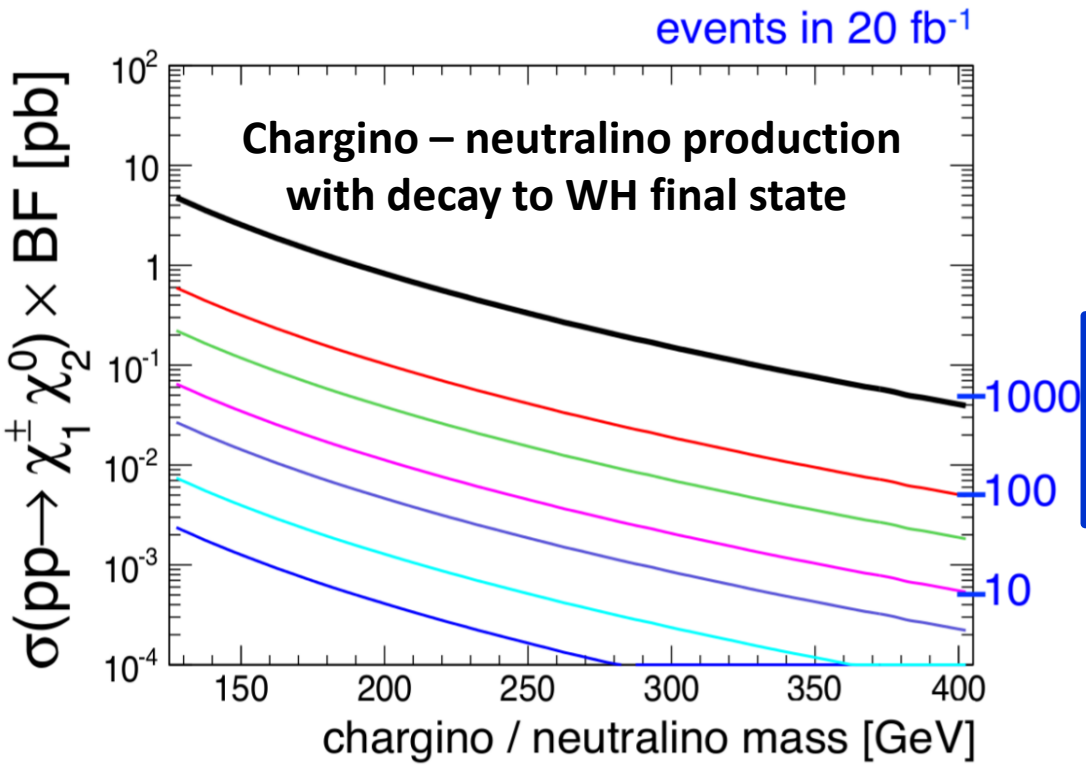
- Complementarity between different analyses:
  - 3l without Z candidate
  - Z+dijet analysis
  - 3l with Z candidate

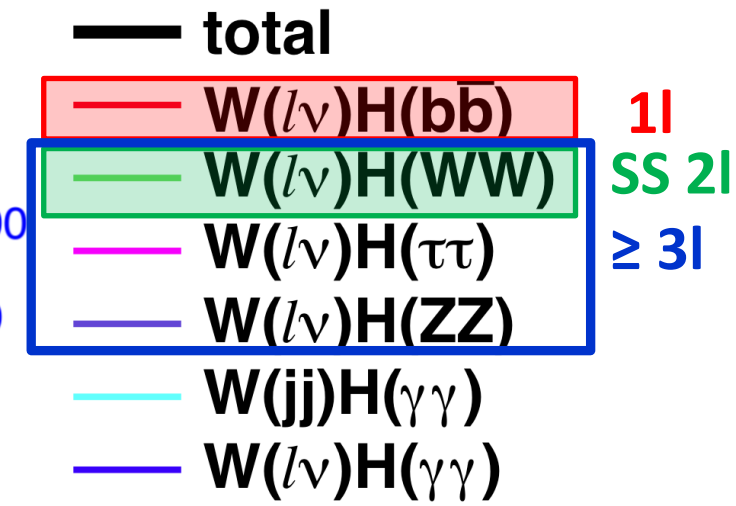


WH cross-section and final states

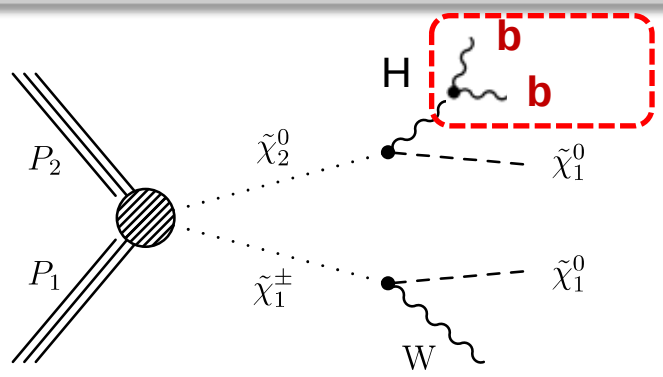
- Different Higgs decays according to SM branching fractions
  - Lead to different final state signatures







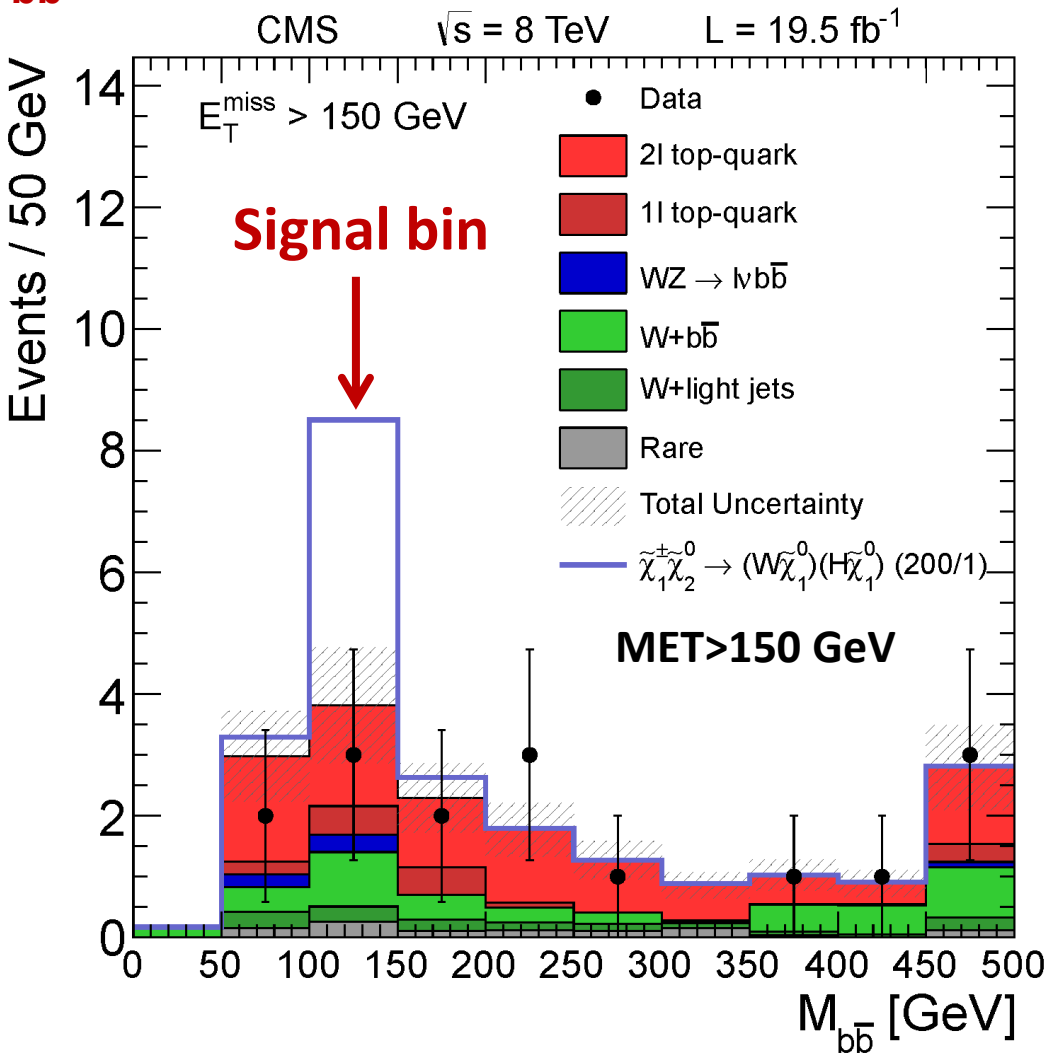
WH single-lepton



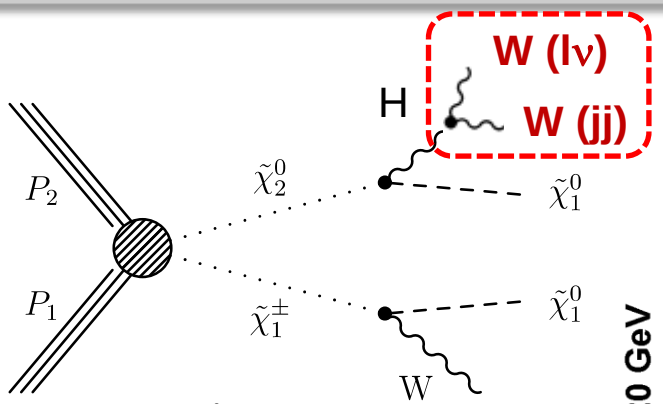
- **Selection:**
  - 1 high p_T e/μ
  - Use kinematic variables to exploit extra MET in event:
    - Cuts on m_T, m_{T2}^{bl}
    - Different MET bins
  - exactly 2 jets, both b-tagged
  - Look for resonance in M(bb)
- **Backgrounds:**
  - Mostly ttbar and W+jets
  - MC with data-driven corrections
- **Results:**
  - No peak visible in mass spectrum

M_{bb}

arXiv:hep-ex/1405.7570



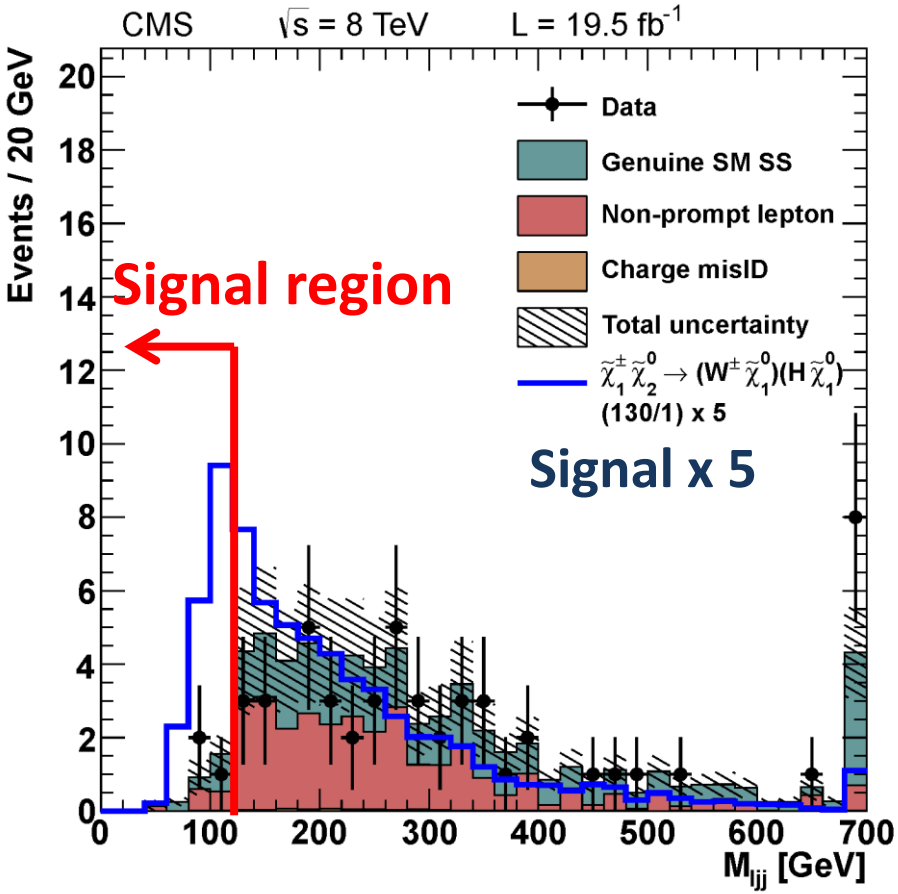
WH SS dilepton



M_{ljj}

arXiv:hep-ex/1405.7570

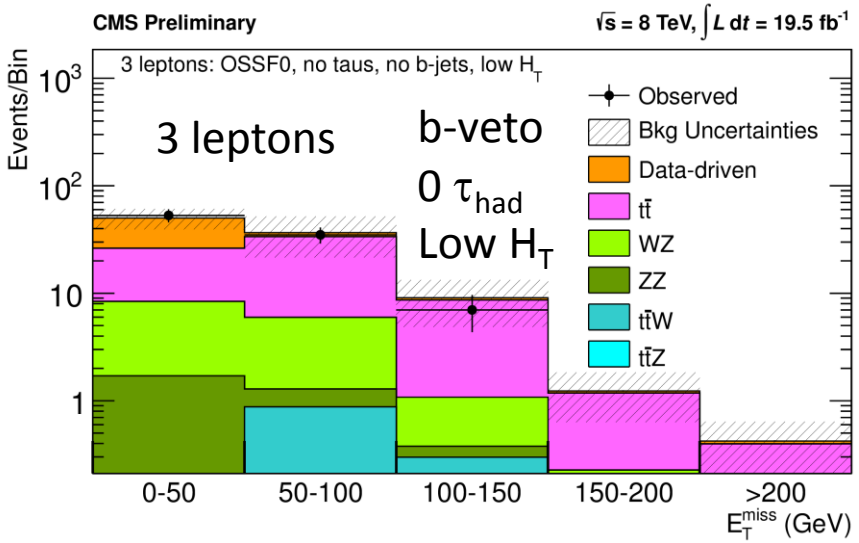
- **Selection:**
  - Exactly 2 same-sign e/μ
  - B-veto to suppress ttbar
  - 2 or 3 jets
  - Extra cuts on MET and different m_{T2} variables to reduce SM backgrounds
  - Try to reconstruct visible Higgs mass
- **Backgrounds:**
  - Data-driven estimates for non-prompt and misidentified leptons
  - Prompt SS 2l from MC
- **Results:**
  - No excess found in M_{ljj} mass spectrum

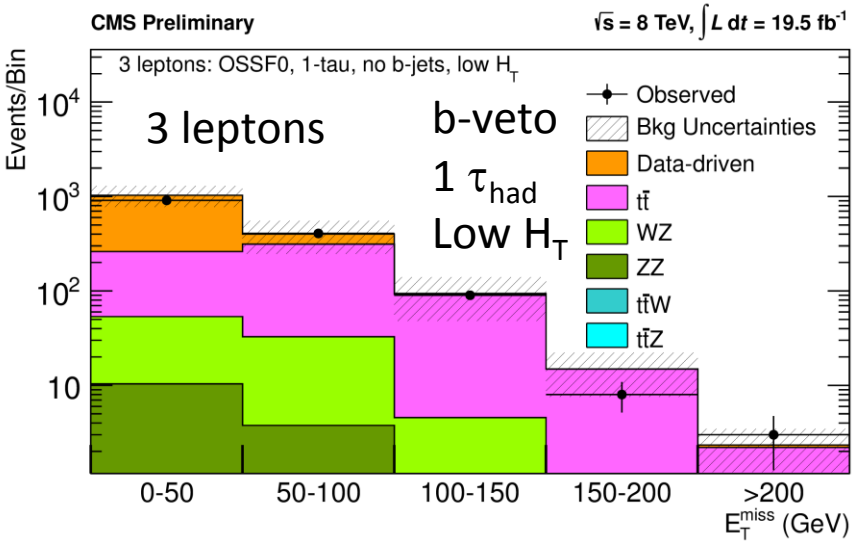


WH multi-lepton

Re-interpretation of inclusive multilepton analysis: hep-ex/1404.5801

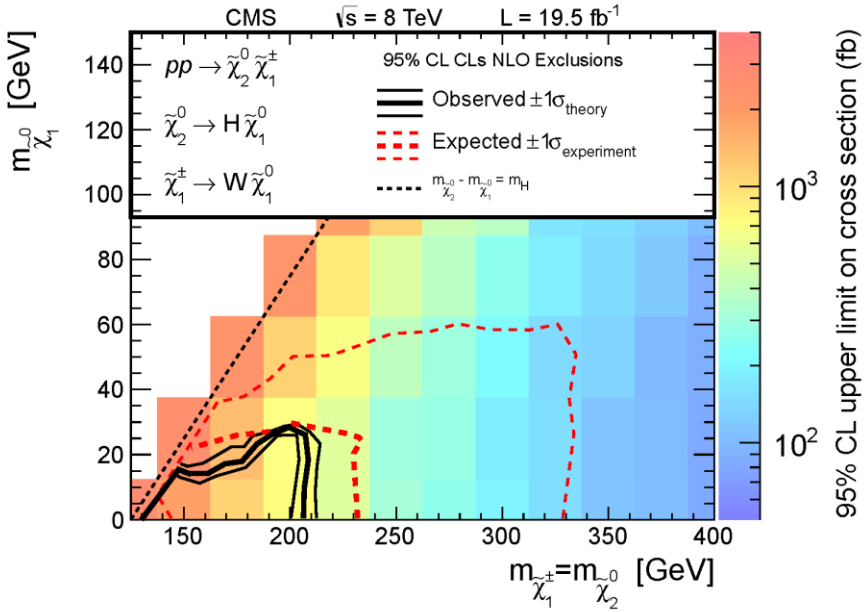
- **Selection:**
  - 3 or 4p_T leptons; max. 1 τ_{had}
  - Detailed binning:
    - Number of leptons
    - # b-jets
    - MET
    - H_T
- **Backgrounds:**
  - MC with data-driven corrections for ttbar, VV
  - Data-driven for Z+jets and Zγ*
- **Results:**
  - Focus on regions with low H_T and b-veto
  - No excess visible





Chargino-neutralino production to WH

- Sensitivity up to 200 GeV
- **1l** most powerful
  - **SS 2l** and **≥3l** contribute at low mass



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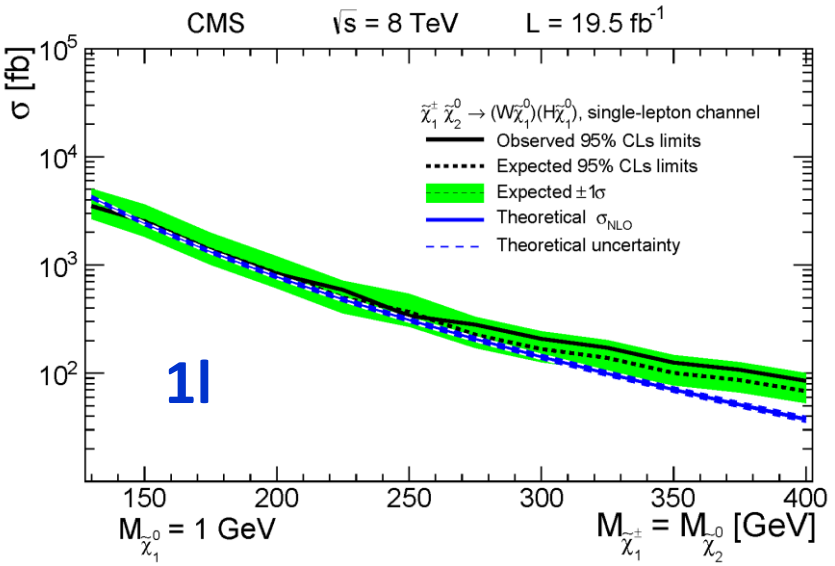
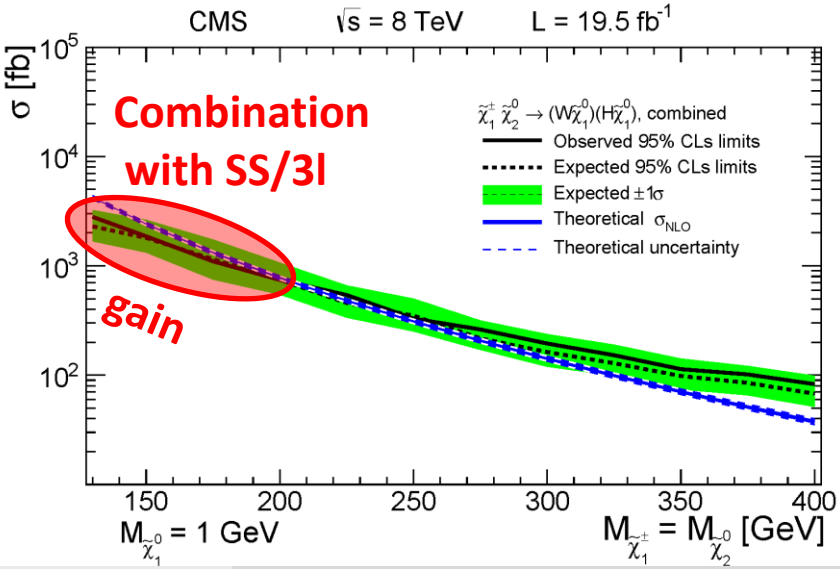
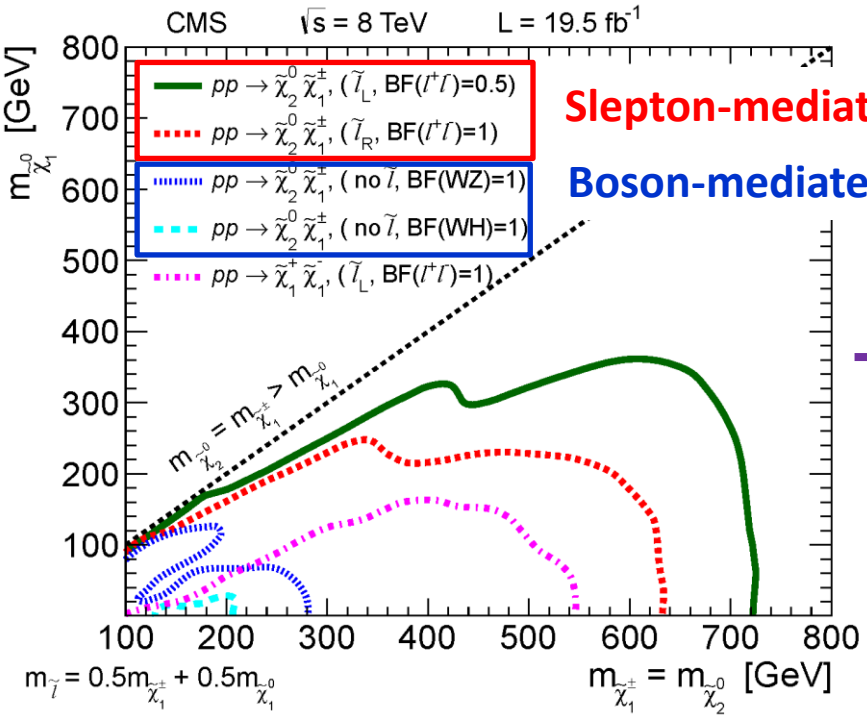




Conclusions

- Wide variety of searches for EWK SUSY
  - No SUSY found
  - Stringent constraints on masses of gauginos
- Probing chargino-neutralino masses up to 200-720 GeV, depending on decay mode

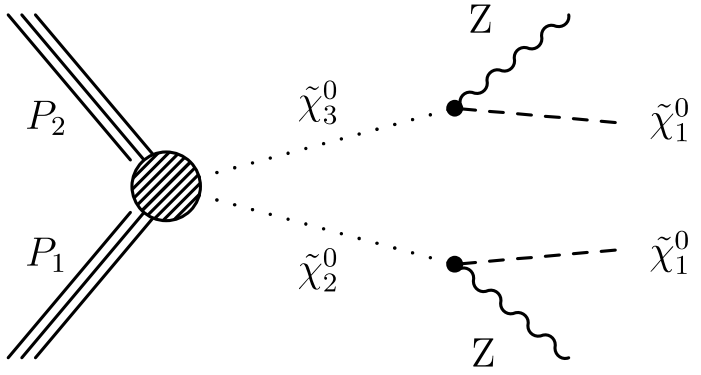
arXiv:hep-ex/1405.7570

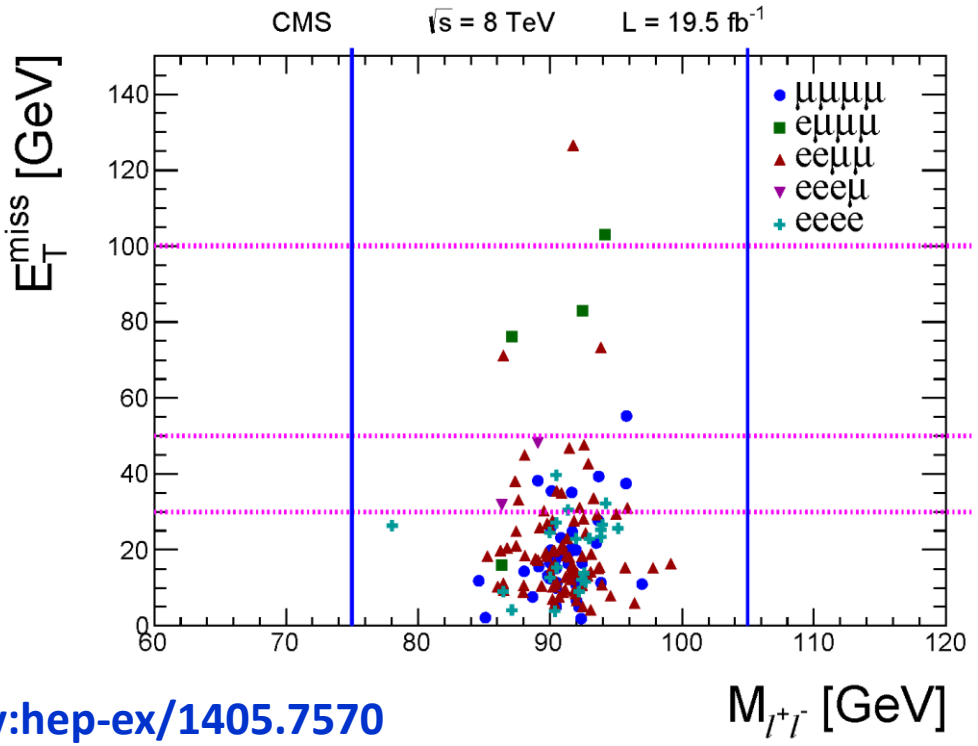


Back-up

Four lepton analysis

- **Selection:**
  - 4 e/μ or 3e/μ+τ
  - Bin in number of opposite-sign same-flavor pairs, dilepton mass and MET
  - b-jet veto to suppress ttbar
- **Backgrounds:**
  - ZZ: MC with data-driven MET corrections
  - Data-driven method for non-prompt and misidentified leptons
- **Results:**
  - No significant excess seen in data vs. prediction

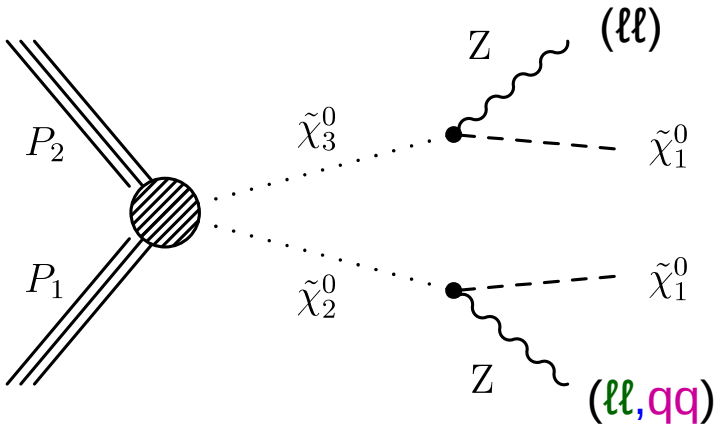


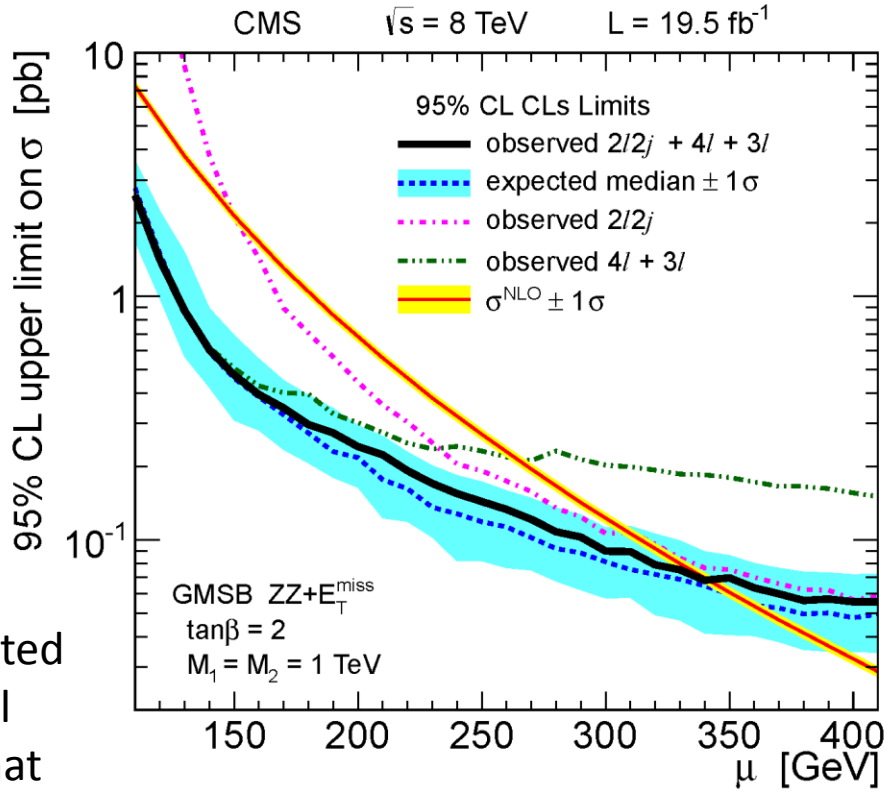


arXiv:hep-ex/1405.7570

Chargino-neutralino production to SM bosons

arXiv:hep-ex/1405.7570





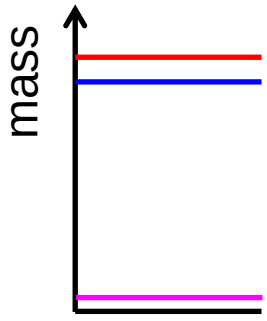
- Neutralino pair production in gauge-mediated symmetry breaking (GMSB) higgsino model
  - Exclusion in terms of parameter (μ) that controls the masses for Chargino and LSP

$$m_{\tilde{\chi}_1^\pm} \approx m_{\tilde{\chi}_1^0} \approx \mu$$

Interesting region for naturelness

GSMB model (ZZ)

- Cross section of $\chi^0\chi^0$ is suppressed w.r.t. $\chi^\pm\chi^0$ → no sensitivity to models with only $\chi^0\chi^0$ production
- Interpret results using GMSB model with large BF to ZZ+MET



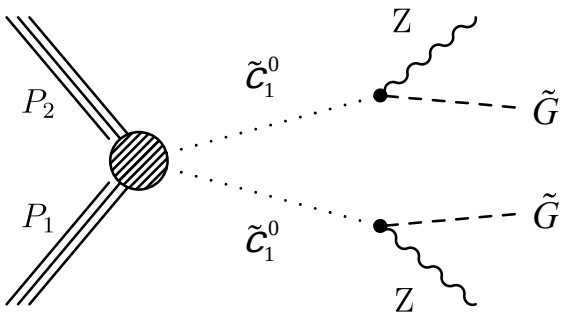
$\tilde{\chi}_1^\pm$ $\chi^\pm$ nearly mass-degenerate with NLSP: $\chi^\pm \rightarrow \chi^0$ + low p_T $\ell\nu$ / $q\bar{q}$

$\tilde{\chi}_1^0$ Z-enriched higgsino NLSP → large BF to Z + G

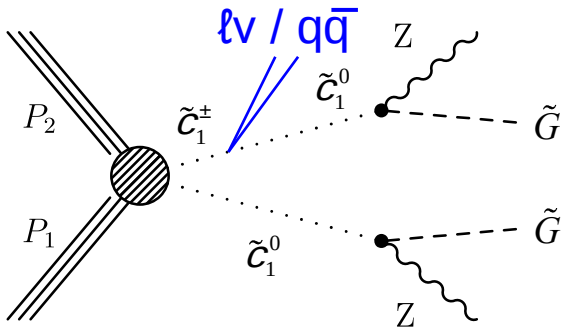
$\tilde{G}$ gravitino LSP

- **3 diagrams enhance σ × BF to ZZ+MET final state**

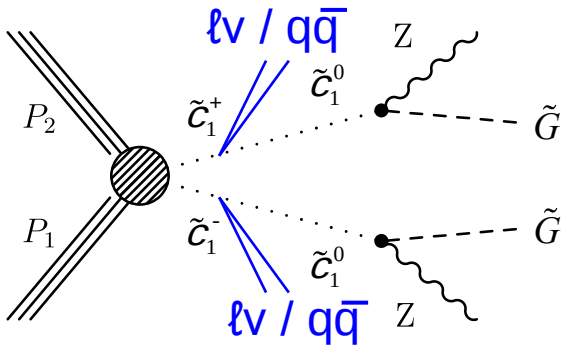
neutralino-neutralino



chargino-neutralino



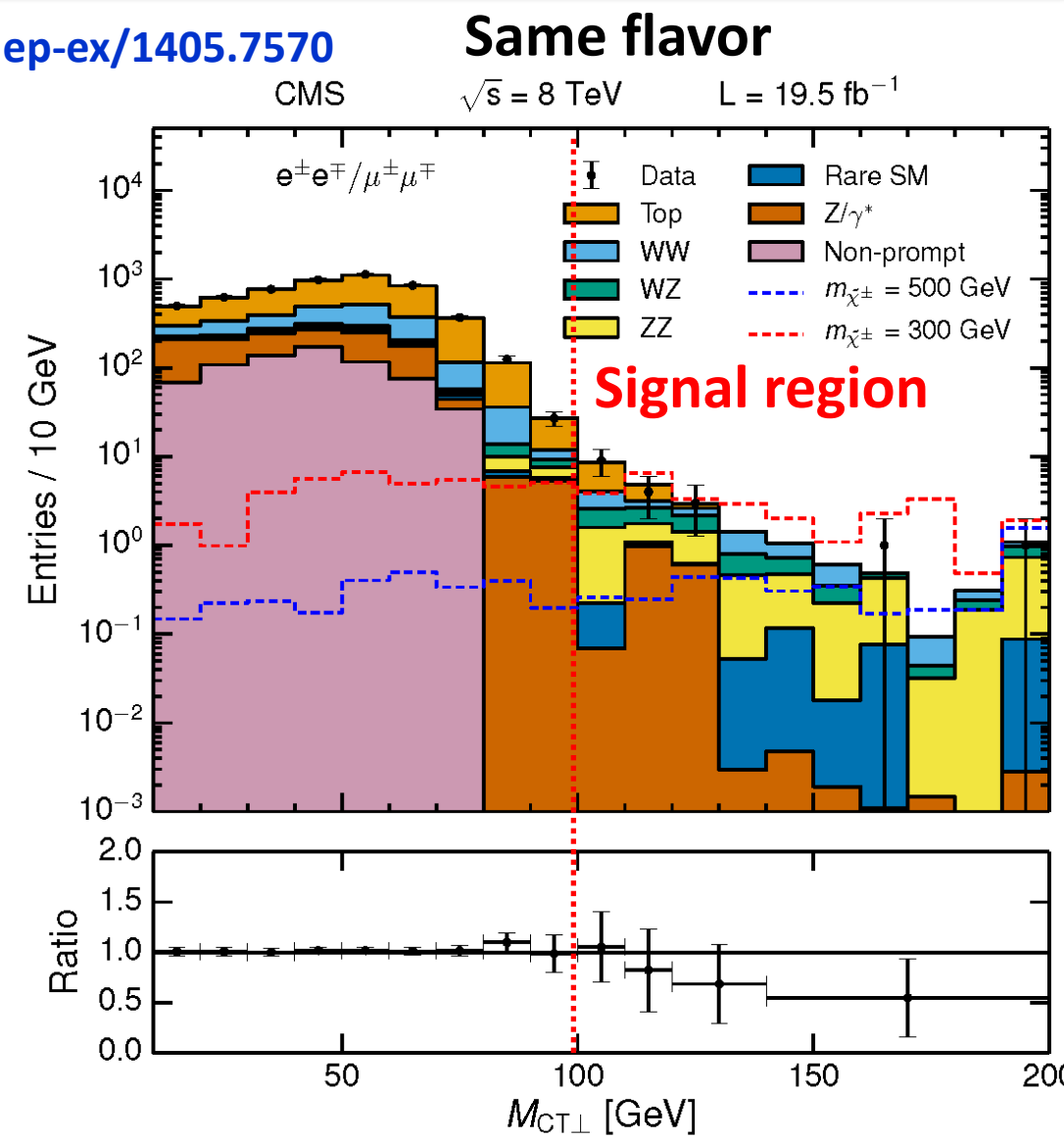
chargino-chargino



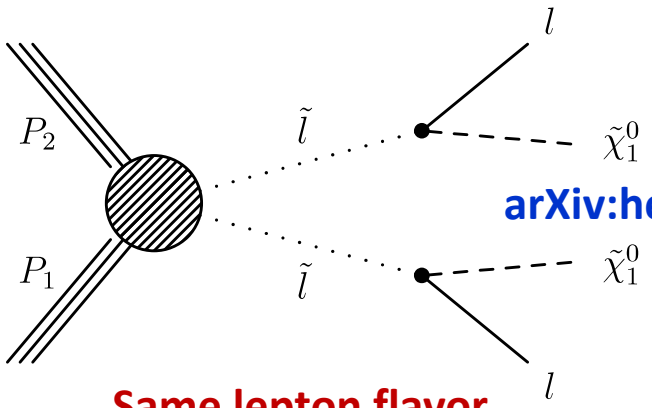
OS dilepton analysis

- **Selection:**
  - 2 OS dileptons
    - Separately eμ and ee/μμ
  - B-veto to suppress ttbar
  - MET>60 to suppress Z+jets
  - Fit $MC_{T,Perp}$-spectrum
    - Kinematic endpoint for WW, ttbar,...
- **Backgrounds:**
  - Fit templates from MC and data-driven control regions
- **Results:**
  - Observed $MC_{T,Perp}$ agrees with prediction

arXiv:hep-ex/1405.7570

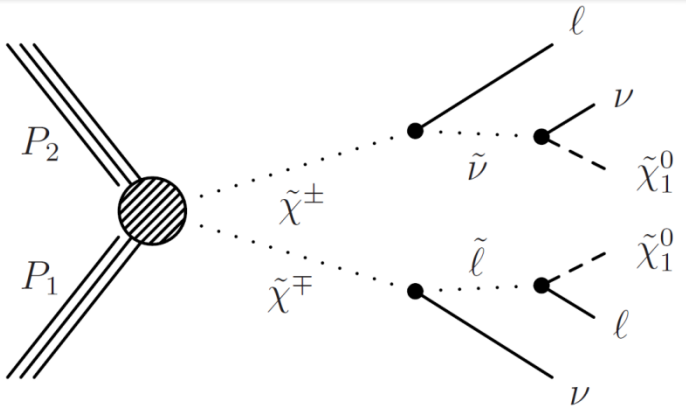


Chargino and slepton pair production

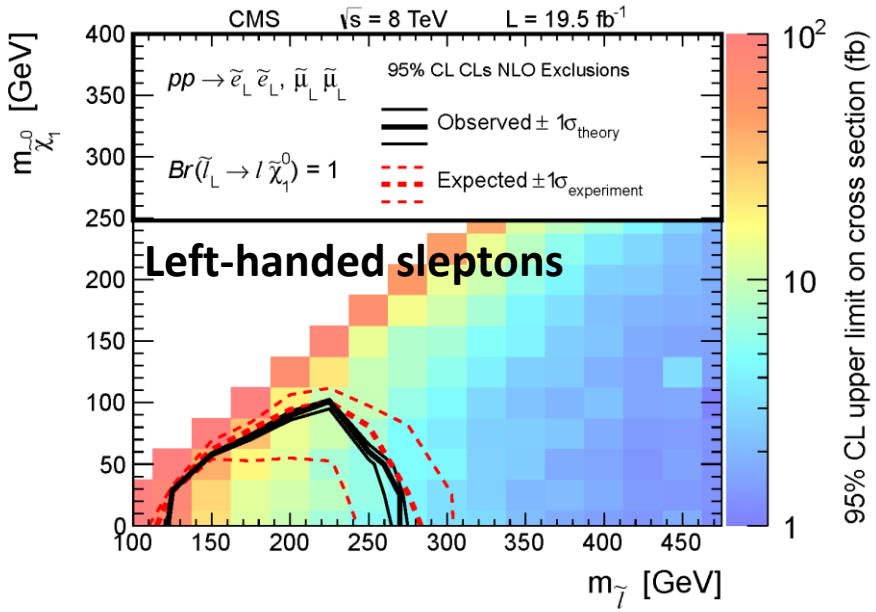


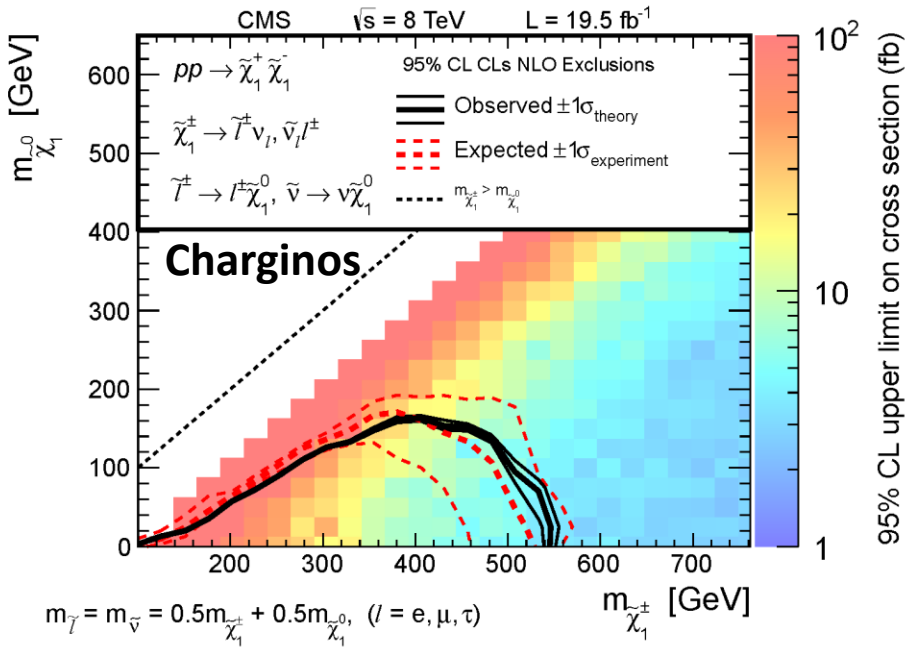
Same lepton flavor

arXiv:hep-ex/1405.7570



Independent lepton flavors

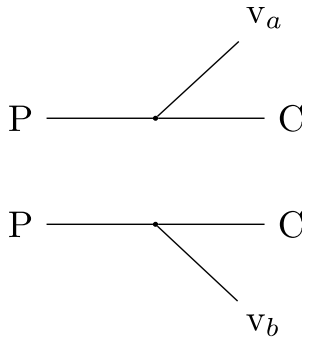




$M_{CT,Perp}$

$$M^2_{\mathrm{CT}} = m^2(\mathrm{v}_a) + m^2(\mathrm{v}_b) + 2\left[E_{\mathrm{T}}(\mathrm{v}_a)E_{\mathrm{T}}(\mathrm{v}_b) + \mathbf{p}_{\mathrm{T}}(\mathrm{v}_a)\cdot\mathbf{p}_{\mathrm{T}}(\mathrm{v}_b)\right]$$

$$M^{\max}_{\mathrm{CT}} = \frac{m^2(P) - m^2(C)}{m(P)}$$



- Endpoint only holds if PP are back-to-back (no ISR)
- Project visible momentum in direction perpendicular to ISR or other visible upstream objects **(bb)**
  - Implemented as $\vec{p}_{\mathrm{Up}} = -\left(\vec{p}_{\mathrm{T,miss}} - \vec{p}_{\mathrm{T1}} - \vec{p}_{\mathrm{T2}}\right)$

$$M^2_{\mathrm{CT}\perp} = m^2(\mathrm{v}_a) + m^2(\mathrm{v}_b) + 2\left[E_{\mathrm{T}\perp}(\mathrm{v}_a)E_{\mathrm{T}\perp}(\mathrm{v}_b) + \mathbf{p}_{\mathrm{T}\perp}(\mathrm{v}_a)\cdot\mathbf{p}_{\mathrm{T}\perp}(\mathrm{v}_b)\right]$$

arXiv:0910.1584

where

$$E_{\mathrm{T}\perp}(v) = \sqrt{m^2(v) + \mathbf{p}^2_{\mathrm{T}\perp}(v)}$$

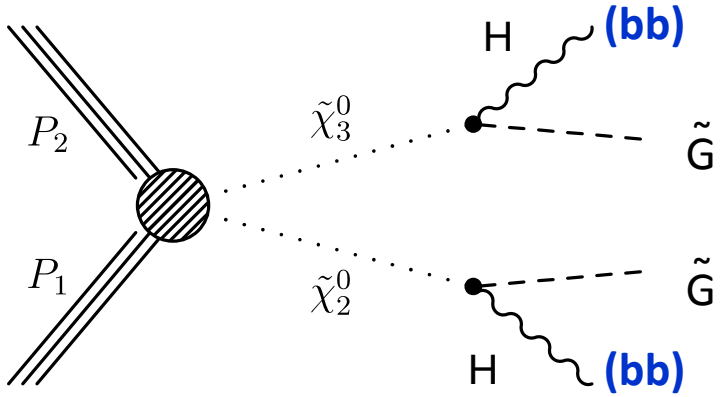
if $m(v) = 0$,

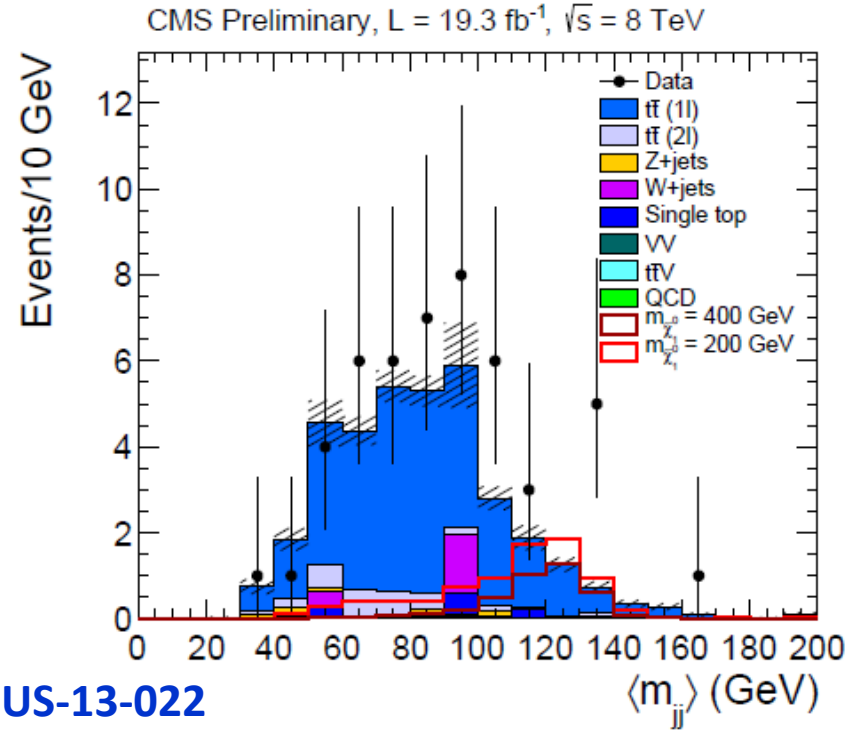
$$M^2_{\mathrm{CT}\perp} = 2p_{\mathrm{T}}(\mathrm{v}_1)p_{\mathrm{T}}(\mathrm{v}_2)\left(|\sin\phi_1||\sin\phi_2| + \sin\phi_1\sin\phi_2\right)$$

ϕ_i is the angle between $\mathbf{p}_{\mathrm{T}\perp}(v_i)$ and $\mathbf{p}_{\mathrm{Up}}$

4b + MET search

- **Selection:**
  - 4-5 jets, of which 3 or more are b-tagged
  - Pair jets into Higgs candidates
    - Minimize difference in invariant masses
  - Cut on MET significance and topological cuts ($\Delta\phi$)
  - Look at average M_{jj}
- **Backgrounds:**
  - Estimate from sidebands in mass window and # b-tags
- **Results:**
  - No significant excess seen (max. ~1.5 σ)





CMS-PAS-SUS-13-022

4b + MET search

- **Results:** CMS-PAS-SUS-13-022
  - Slight ~1.5 σ excess in 4b region
- **Interpretation:**
  - Small region expected to be excluded close Higgsino mass of 300 GeV, not excluded because of small excess