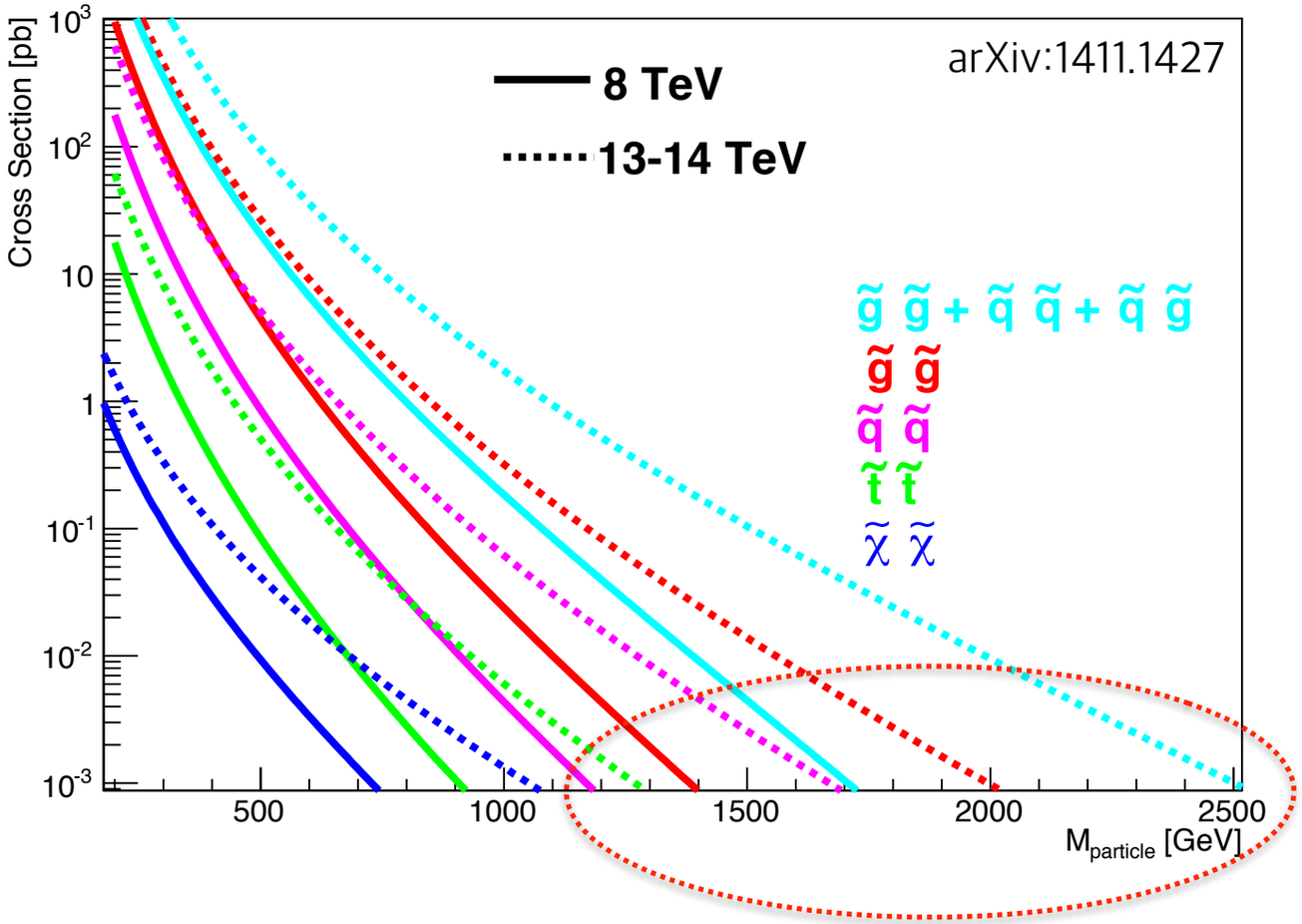
Searches for electroweak production of SUSY with CMS

Minsuk Kim (Kyungpook National University)
On behalf of the CMS Collaboration

Pheno17, May 8-10, University of Pittsburgh

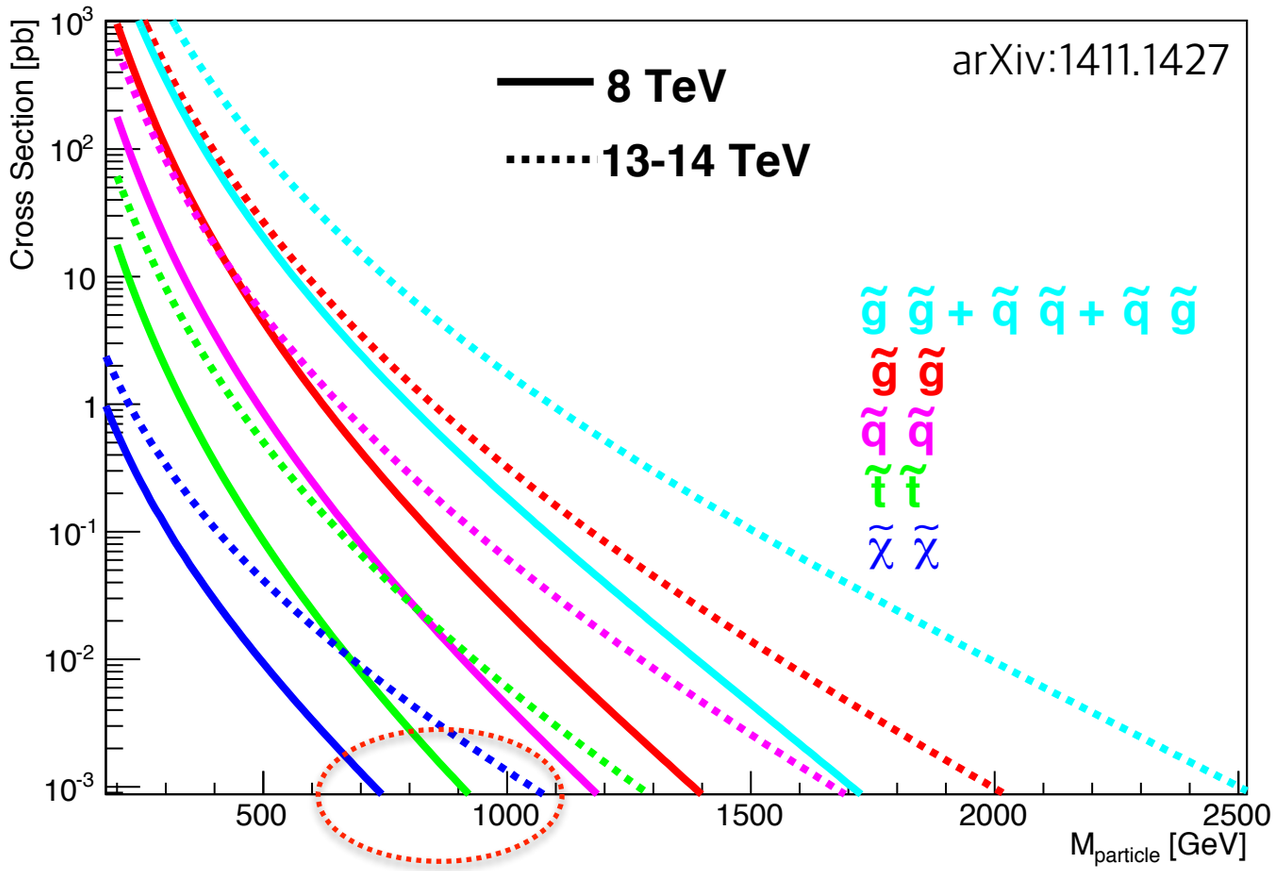
Motivation



- Strongly produced SUSY
  - Largest cross section
  - Large hadronic activity
  - TeV-scale mass limits
  - No evidence yet

- SUSY search strategy was driven by the cross section and luminosity
- Most of the LHC searches focus on strong production, with largest cross section and large hadronic activity
  - Analyses dominated by inclusive searches for gluino/squark production
- Current searches at 13 TeV prob gluinos and squarks up to about 2 TeV

Electroweak SUSY



- Strongly produced SUSY
  - Largest cross section
  - Large hadronic activity
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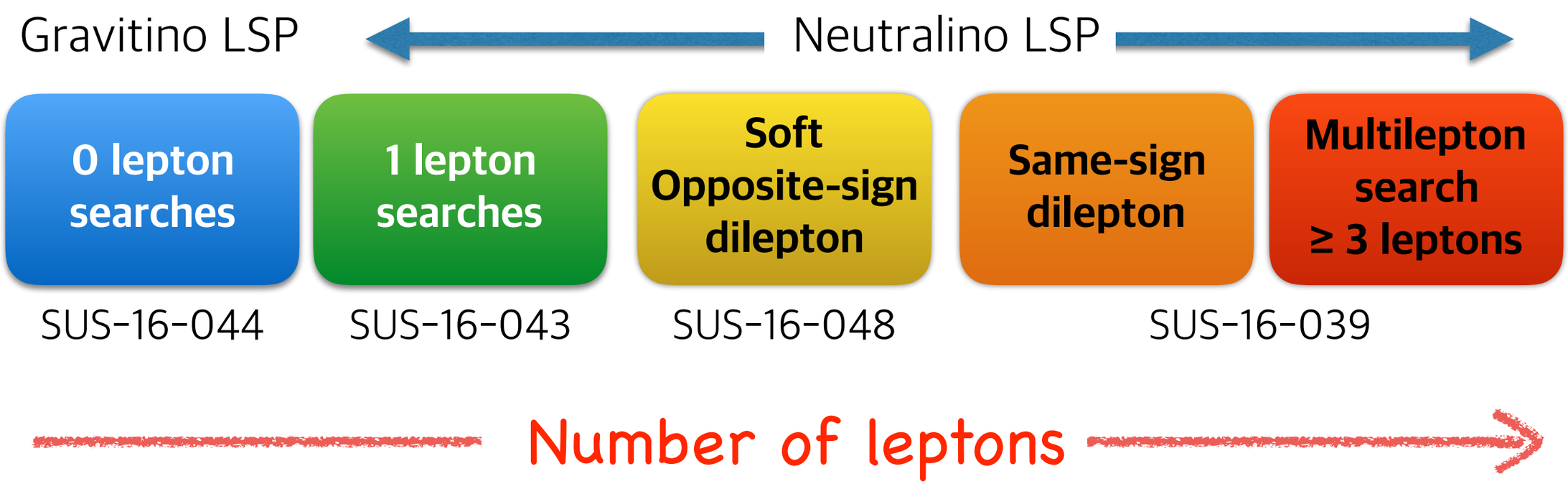
- If gluinos and squarks are too heavy to be produced at LHC energies, then Electroweak SUSY can be the dominant SUSY production
- Direct production of EWKinos, with low hadronic activity and significant MET, may be the key to new physics (charginos/neutralinos will decay then to sleptons or W, Z, h bosons)
- High discovery potential, but challenging due to small cross section
- Need multiple final states to enhance sensitivity → Comprehensive search
- Searches for compressed EWK SUSY → Intensive searches at the LHC

↪ Challenging detector signatures: low MET and soft decay products

EWK SUSY searches at CMS

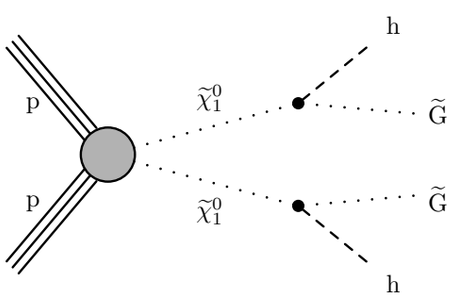


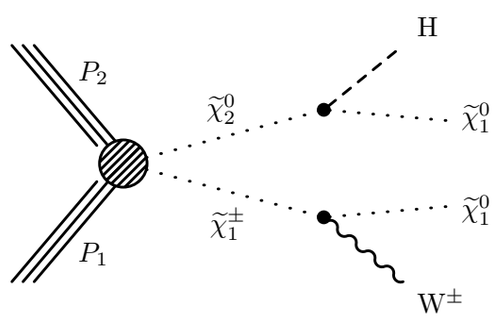
- Interpretation: simplified SUSY models
  - Described by a minimal set of parameters: sparticle masses, production cross sections and decay modes
  - Assuming a 100% branching ratio of sparticles
- Several models considered for a given analysis
- Results can be interpreted, independent of the model

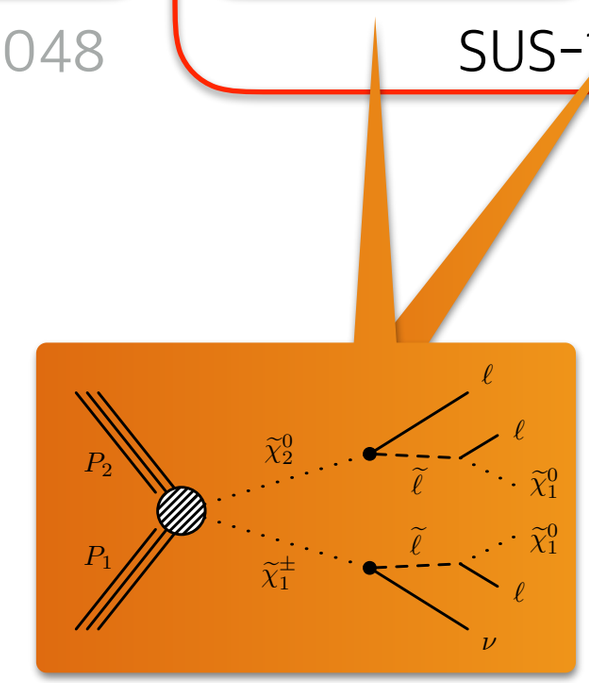
EWK SUSY searches at CMS

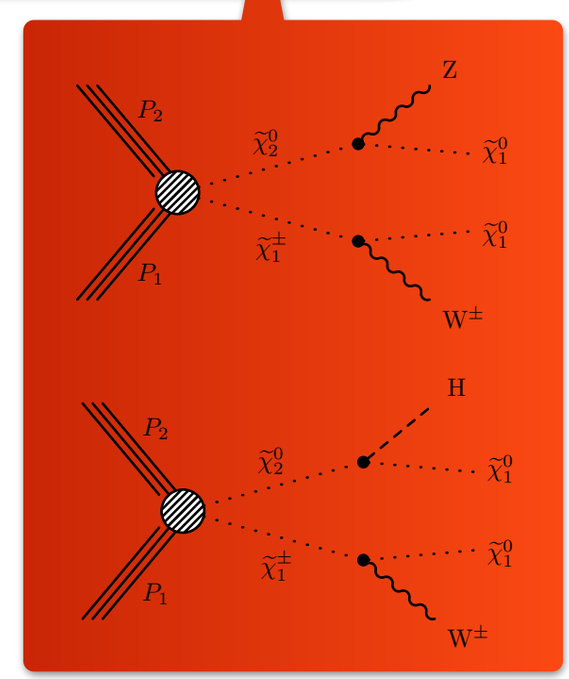
Gravitino LSP ← Neutralino LSP →

0 lepton searches	1 lepton searches	Soft Opposite-sign dilepton	Same-sign dilepton	Multilepton search ≥ 3 leptons
SUS-16-044	SUS-16-043	SUS-16-048	SUS-16-039	









- **Main goals:**
  - 2L SS/3/3+: Inclusive multilepton search to improve sensitivity for various models in uncharged territory (H→WW, ZZ or $\tau\tau$)
  - Soft OS 2L: Targeting compressed spectra of natural SUSY
  - 1L: Other signature to extend the search (H→bb)
  - 0L: Targeted search with Higgs tagging (H→bb)

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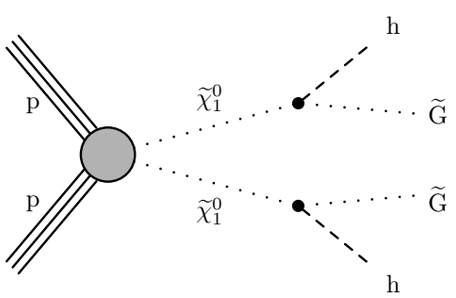

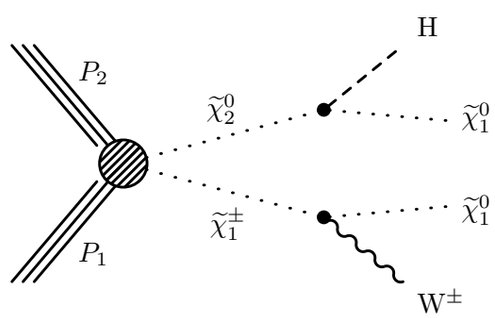

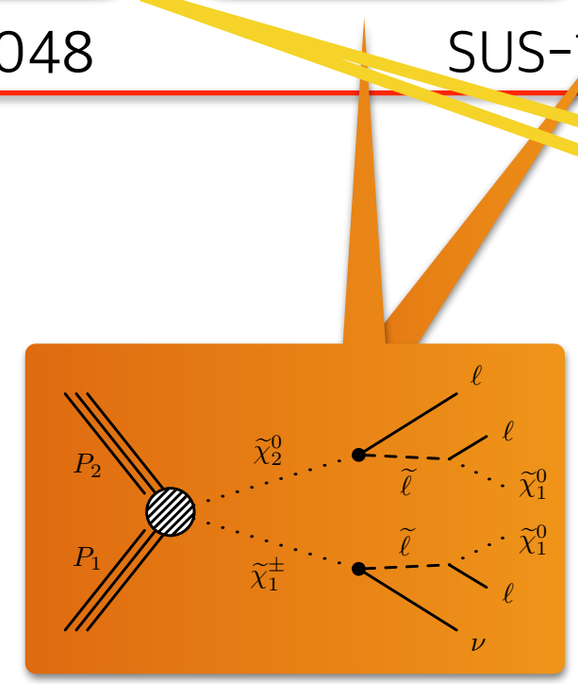

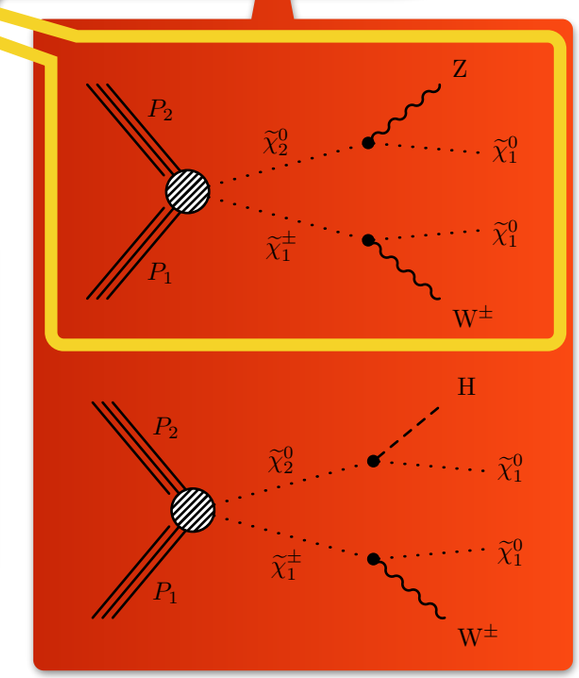

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EWK SUSY searches at CMS

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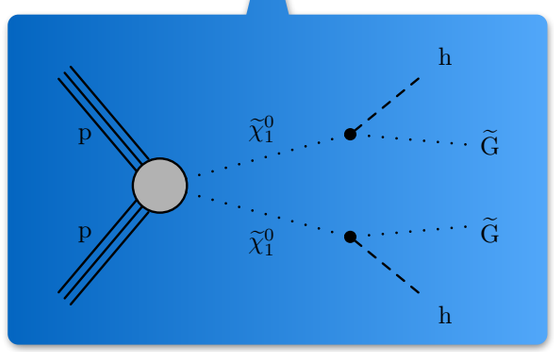
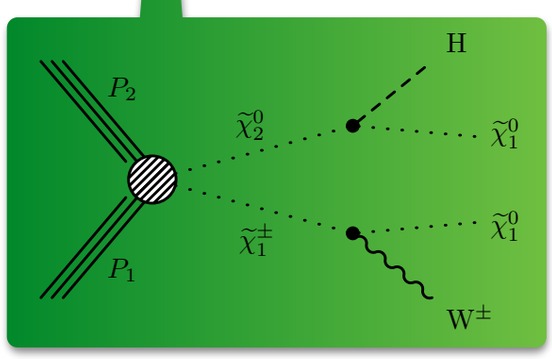
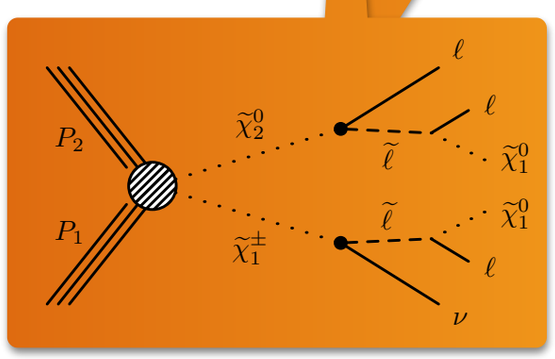
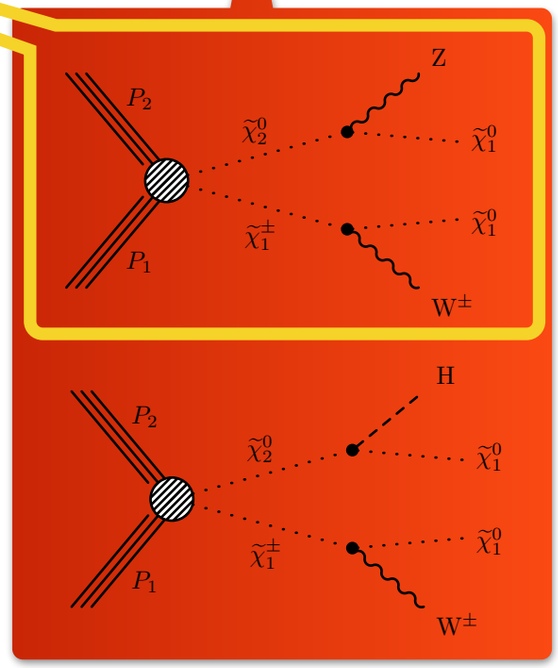


$m_{\tilde{\chi}_2^0} \approx m_{\tilde{\chi}_1^\pm} \approx m_{\tilde{\chi}_1^0}$, $m_{\tilde{G}} = 1$ GeV
(degenerate Higgsinos in GMSB)







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  - Soft OS 2L: Targeting compressed spectra of natural SUSY
  - 1L: Other signature to extend the search (H→bb) H2bb has a BF of 60%
  - 0L: Targeted search with Higgs tagging (H→bb) → Need high b-tagging efficiency

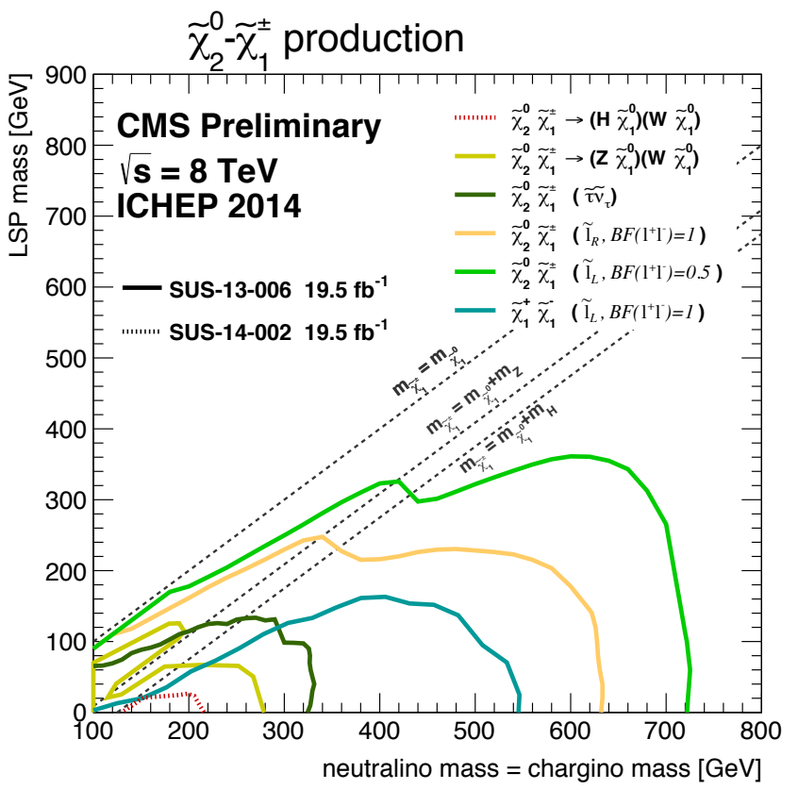
Improvement in Sensitivity

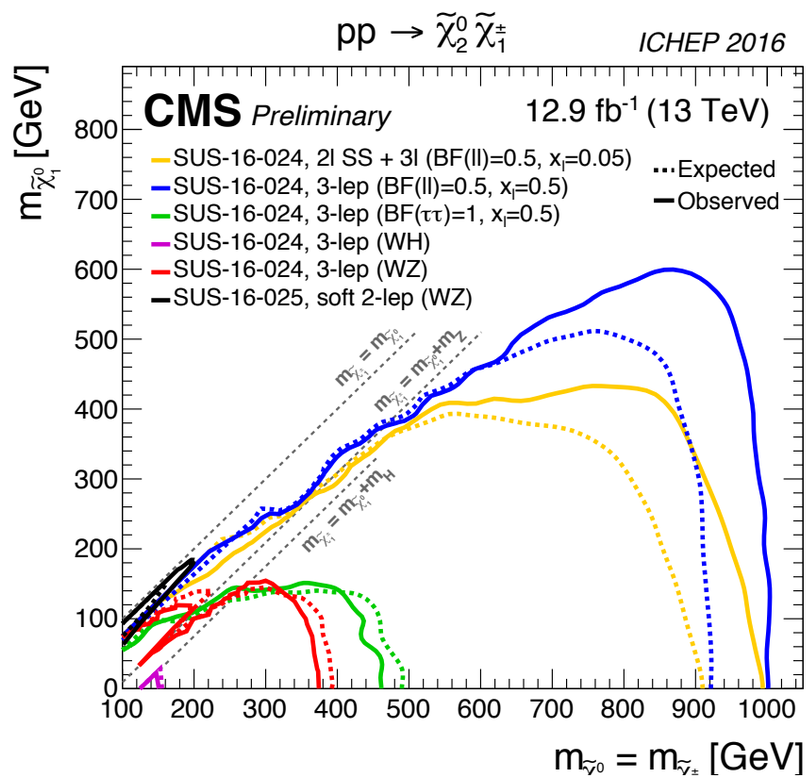
- With full 2016 dataset of 35.9 fb^{-1}, got finally access to new territories, even to light-degenerate-Higgsinos (GMSB higgsino NLSP scenario)
- Exclusion of charginos and neutralinos pushed up to more than 1.1 TeV
- Limits increased in 3L channel (C1N2 with light sleptons and sneutrinos)

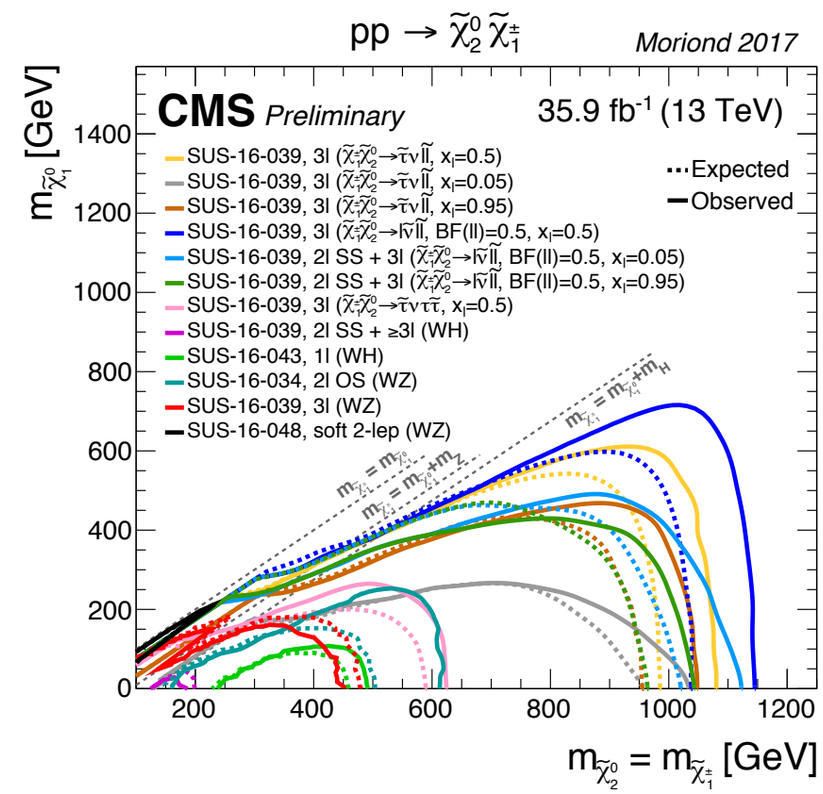
8 TeV → (+ 300 GeV) → early 13 TeV → (+ 100 GeV) → 13 TeV

Summer16, reproduced Run 1 EWKino

Thanks to more lumi and new idea

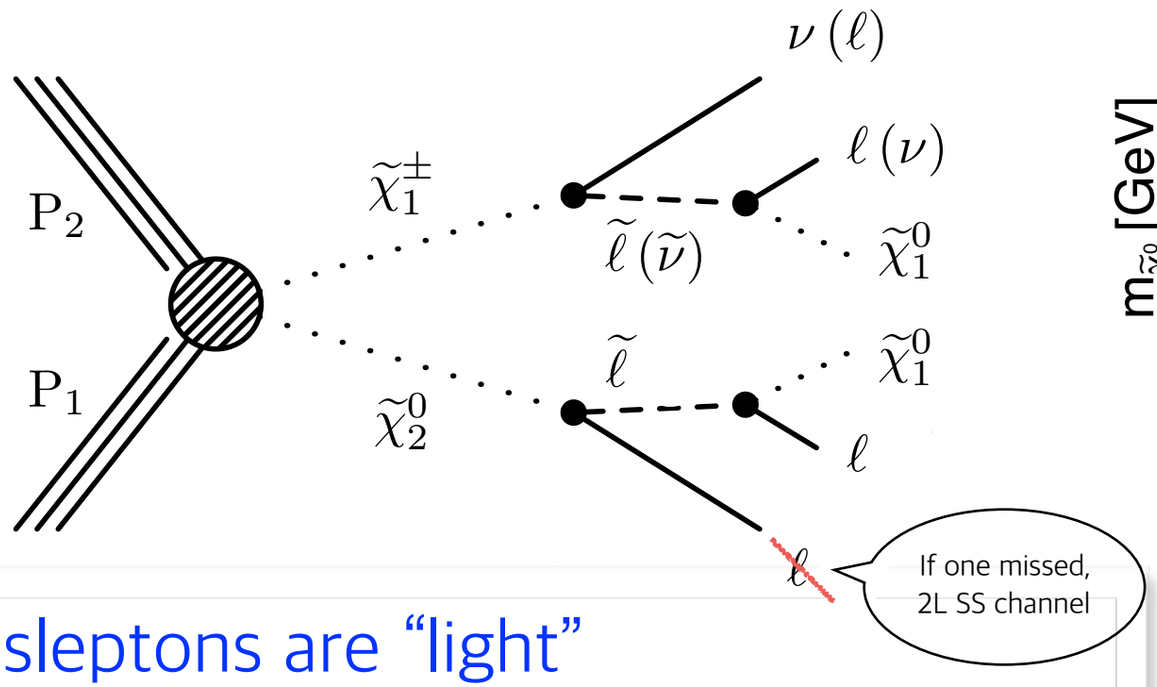


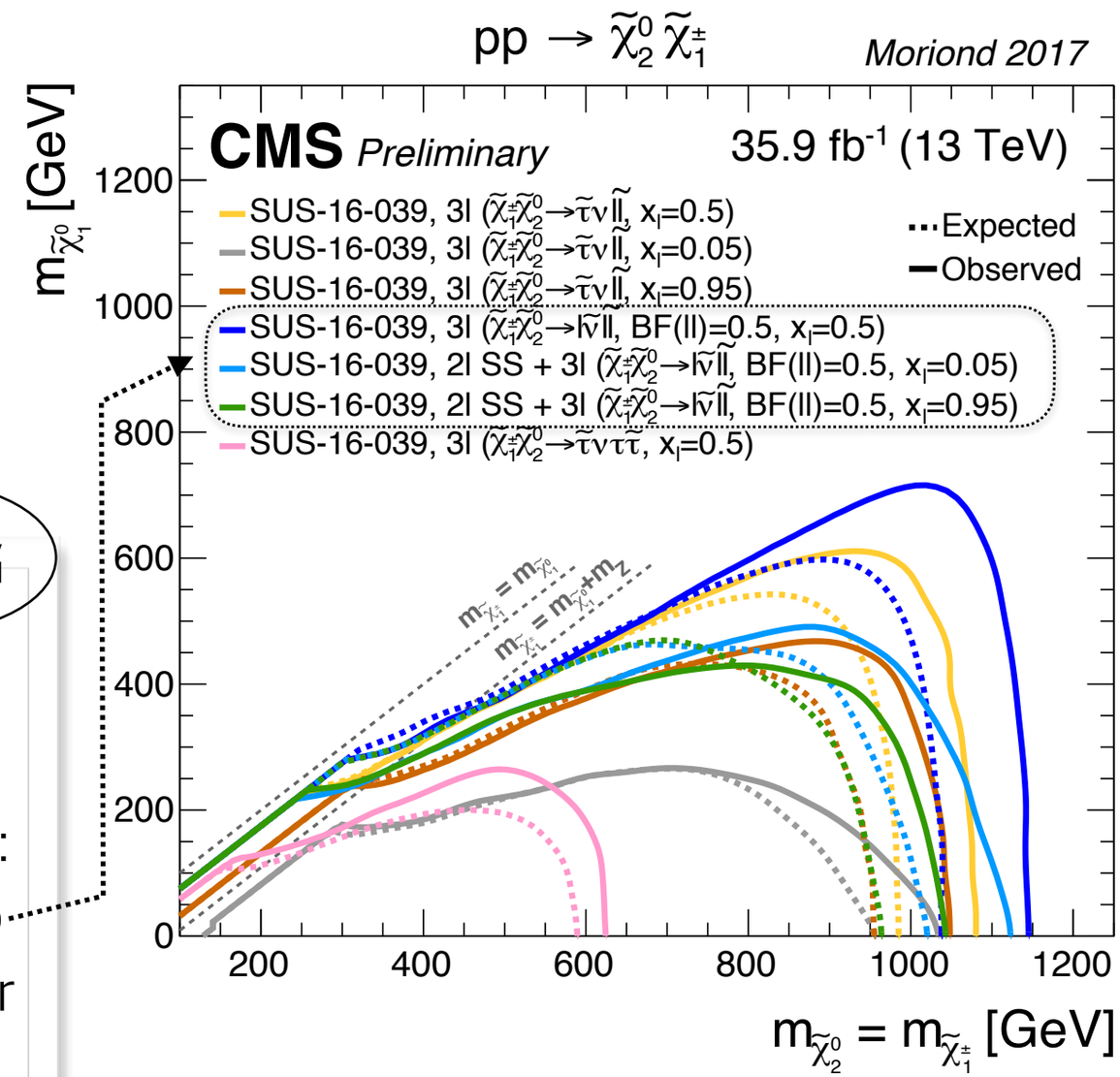




From 8 to 13 TeV

EWKino Slepton Results





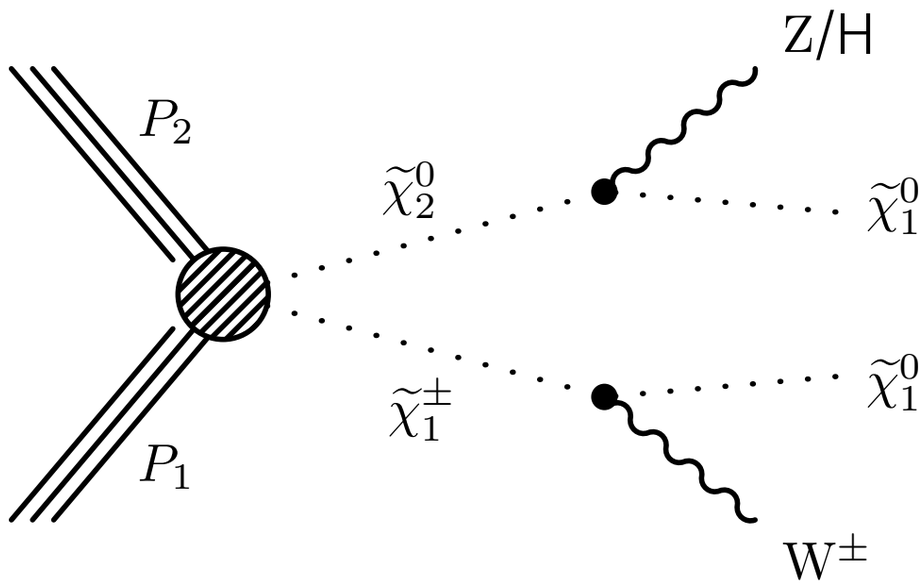
If sleptons are "light"

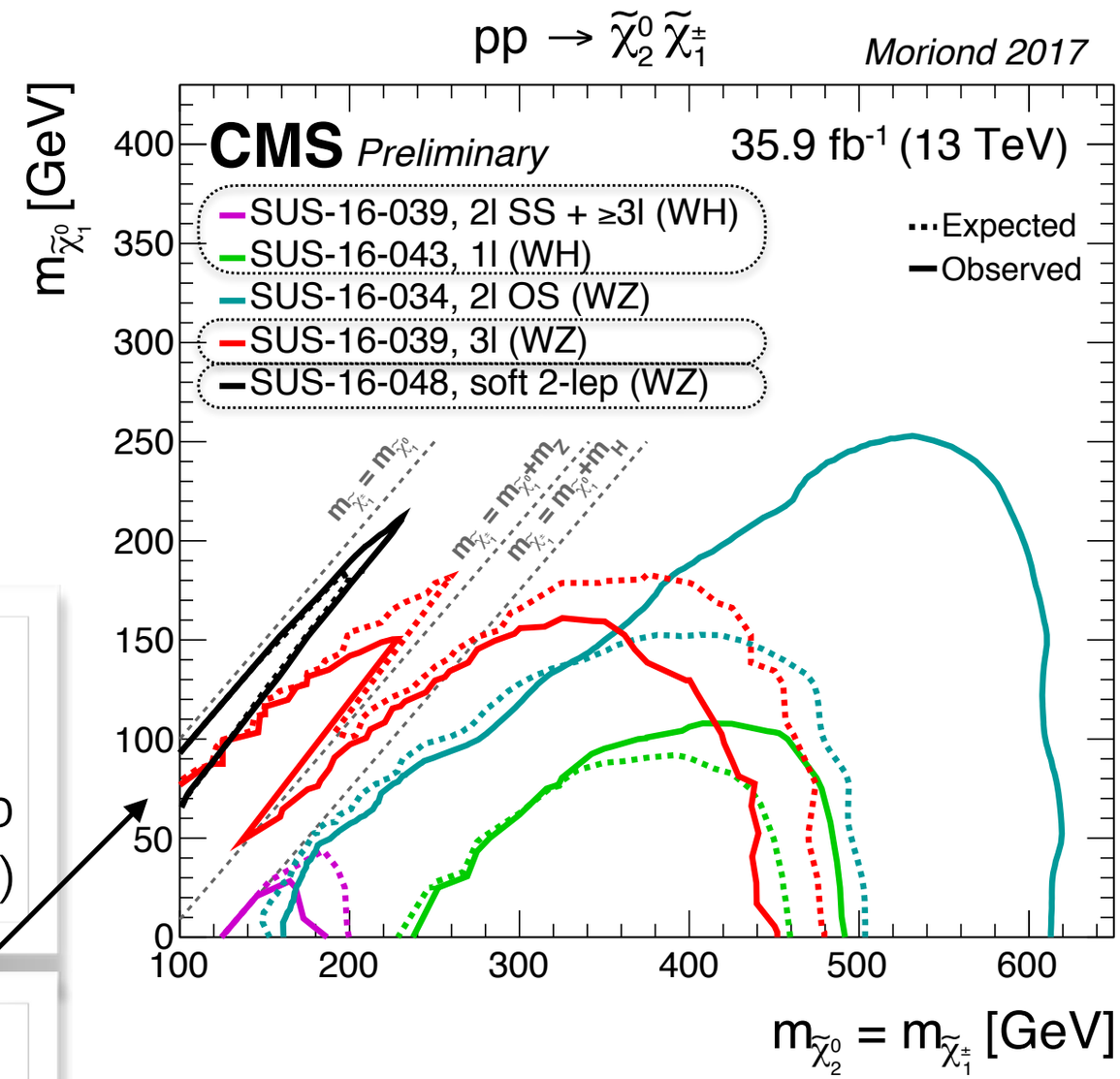
- Only leptonic final states
  - $m_{\tilde{\ell}} = m_{\tilde{\nu}} = m_{\tilde{\chi}_1^0} + x \cdot (m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0})$
- Simplified models with various assumptions:
  - different mass splittings (x=0.95, 0.5, 0.05)
  - same probability of decay via sleptons or sneutrinos → 50% of decays lead to 3L
  - flavour democratic or tau-enriched (C1 decays only to a tau) or dominated
- Categorisation based on number of leptons
  - 2L Same-Sign (x=0.95, 0.05)
  - 3L including up to $2\tau_h$ (x=0.95, 0.5, 0.05)

Signatures covered in this talk:

- 2L SS or 3L + MET (CMS-PAS-SUS-16-039)

EWKino Results





If sleptons are too heavy to participate

- Direct decay to LSP via W and Z/H emission
  - Leptonic decay: 3 or 4L, and WH 1L + bb
  - Higgs tagging: 0L + 4b (GMSB higgsinos)

If sleptons are too heavy and LSP is part of the Higgsino sector

- Soft 2L (targeting compressed spectra)
  - Need ISR to boost the sparticle pair system

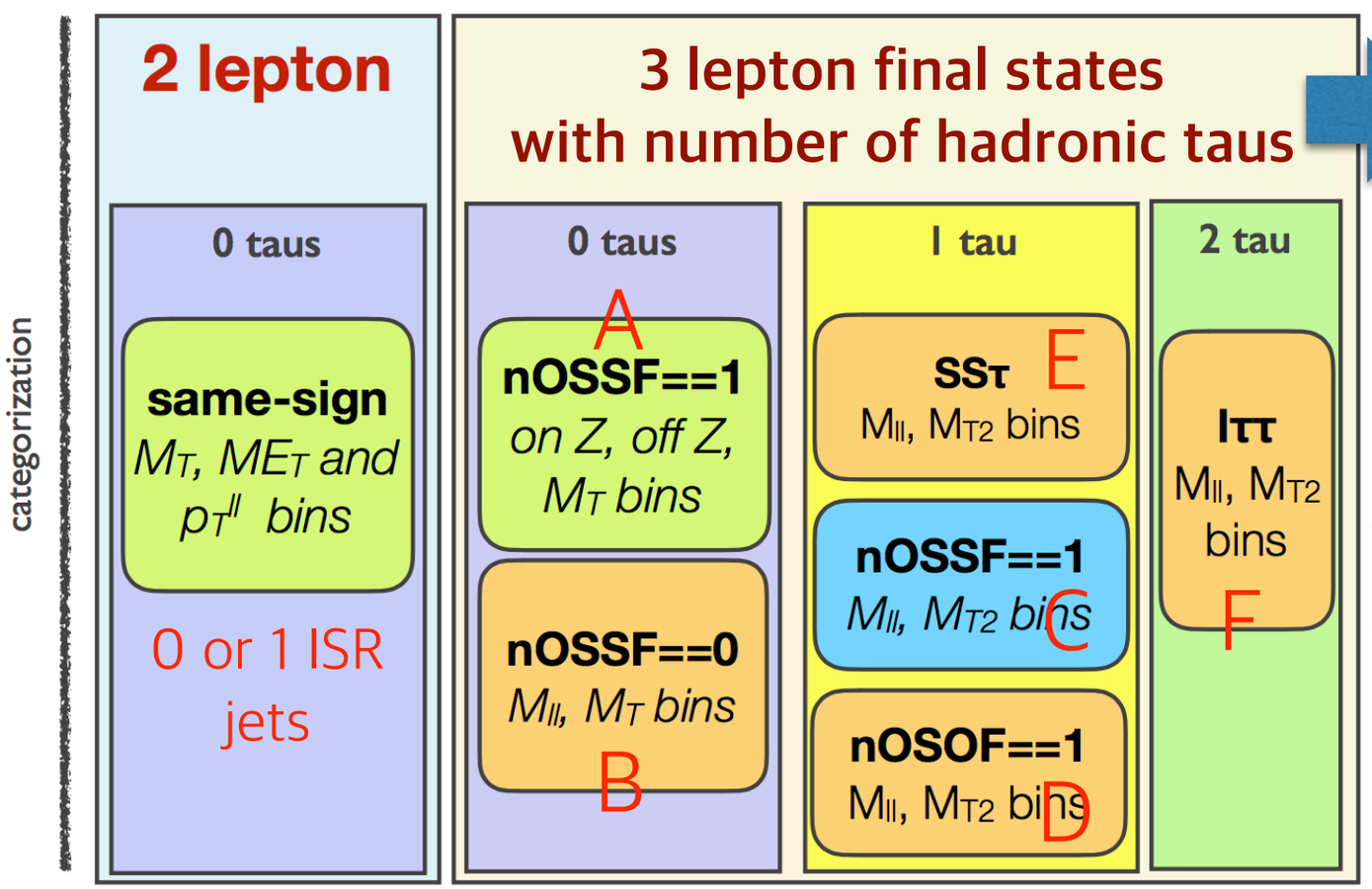
- Ongoing: Soft 3L, 1L + Hgg, VBF C1N2 and Sleptons, direct or C1C1

Signatures covered in this talk:	
• 3 or 4L + MET	SUS-16-039
• $Z^* \to ll$ + jets + MET	SUS-16-048
• h → bb + 1L + MET	SUS-16-043
• hh → bbbb + MET	SUS-16-044

CMS-SUS-16-039

Multilepton Search

- To face the small cross section the analysis is subdivided into several **categories defined by the number of leptons, their flavour and charge** (uses dilepton triggers, and single lepton triggers for $2\tau_h$ channels):
  - Events with 2 SS (e,μ) or 3/3+ (up to $2\tau_h$) leptons with e (μ) p_T > 25 (20), 15 (10), 10 (10) GeV
- Signal Regions further subdivided into bins defined by kinematic variables: ME_T, $M_T(\ell,ME_T)$, $p_T(\ell\ell)$, $M_{T2}(\ell,\ell)$
  - To discriminate from SM bkg contributions and increase sensitivity to possible mass hierarchies
- b-jet veto to suppress ttbar, ME_T>60/50 GeV to suppress Z+jets, veto on m(3ℓ) to suppress conversions
- Main residual bkg: WZ, non-prompt leptons (W+j/ttbar/DY+j), rare SM processes, charge mis-ID, conversions
- Data-driven background estimation: Non-prompt leptons
- WZ(γ^*) shape from MC, normalisation and shape uncertainties driven by 3L CR in data with low ME_T and M_T



3+ lepton with 5 categories (G-K) by ME_T, ntaus and nOSSF in p.13

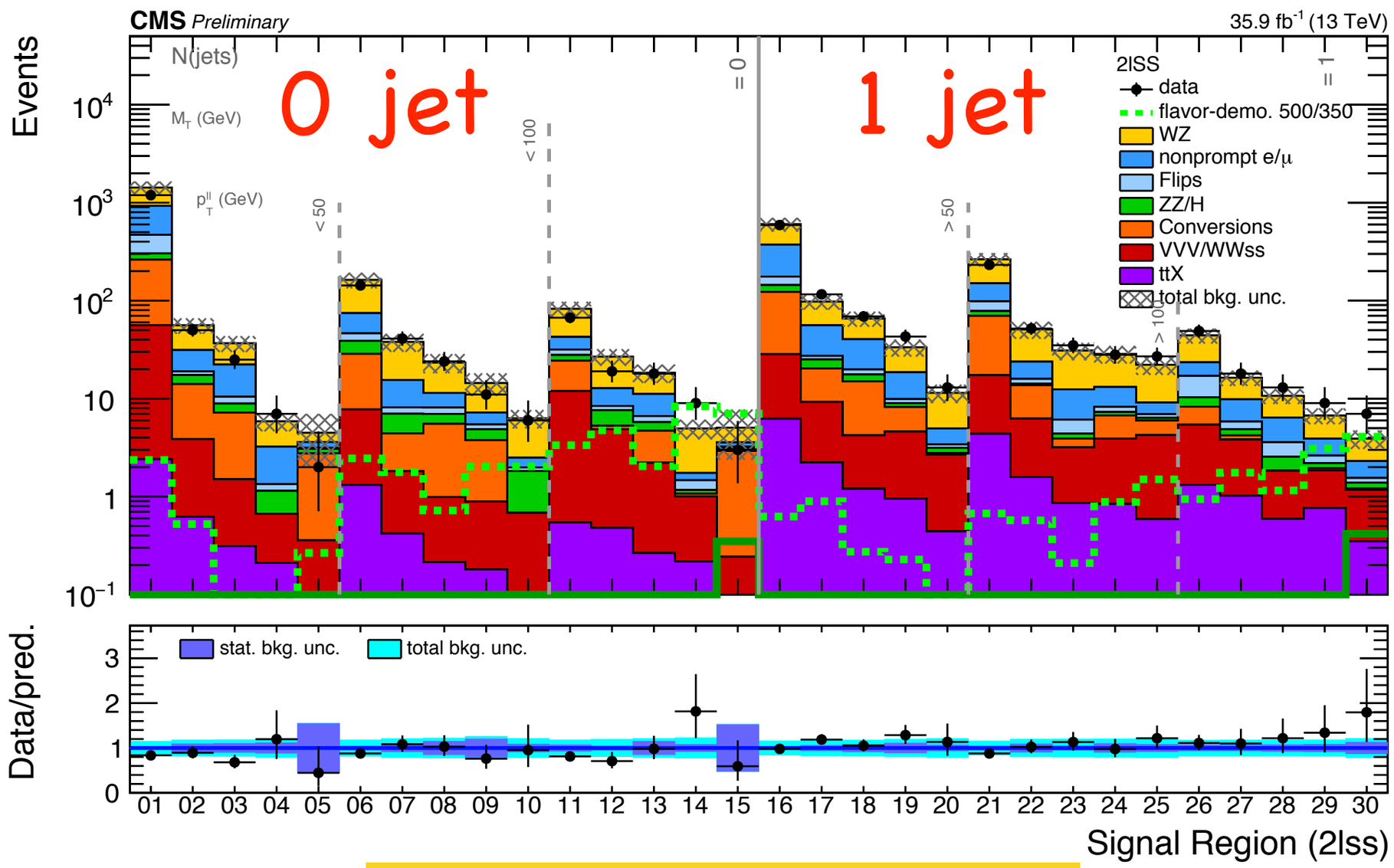
$$M_T = \sqrt{2E_T^{miss} p_T^{\ell} (1 - \cos(\Delta\phi))}$$

$$M_{T2}^2 = \min_{\vec{p}_{T1}^{miss} + \vec{p}_{T2}^{miss} = \vec{p}_T^{miss}} \left[\max\{ M_T^2(\vec{p}_T^{\ell_1}, \vec{p}_{T1}^{miss}), M_T^2(\vec{p}_T^{\ell_2}, \vec{p}_{T2}^{miss}) \} \right]$$

2 Same-Sign Leptons: Results

CMS-SUS-16-039

- Events are further categorised in number of jets: 0 or 1 ISR jet (p_T>40 GeV), min(M_T), $p_T(\ell\ell)$ and ME_T to improve sensitivity for compressed scenario
- Data in good agreement in the SM prediction



↪ No significant excess observed

3L without taus: Results

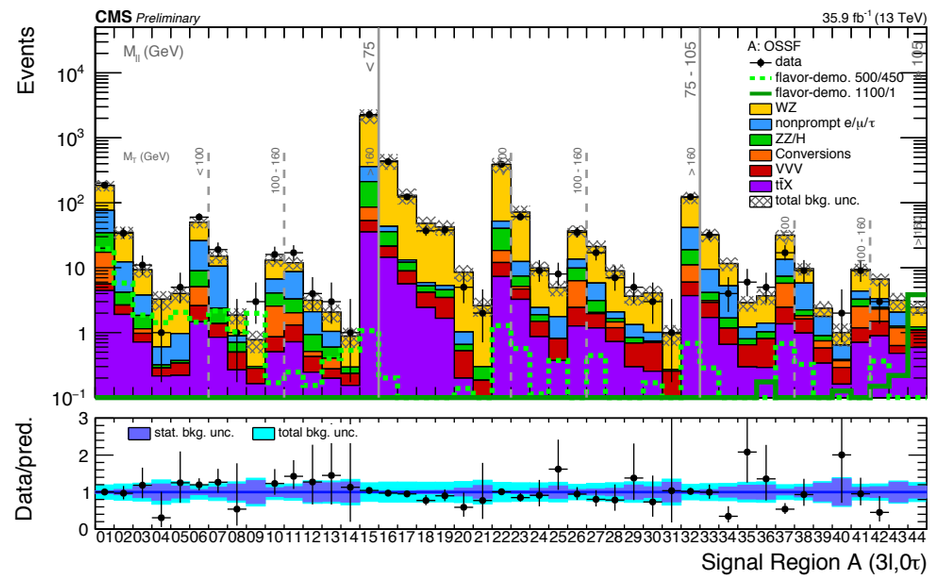
CMS-SUS-16-039

2 of 3 light-flavour leptons (e or μ)

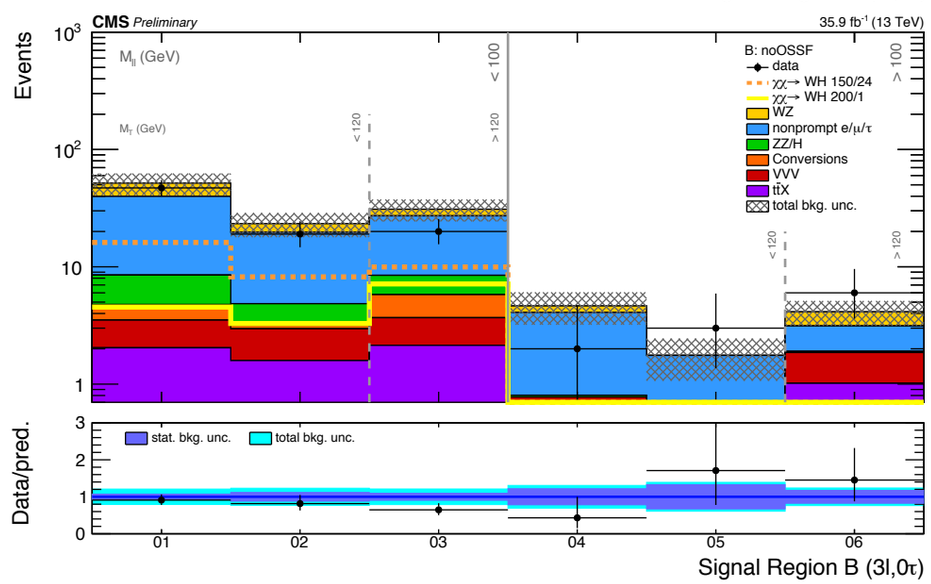
- Form an OSSF pair in most of the cases (top)
- No OSSF: a leptonic decay of Z → $\tau\tau$ (bottom)

➜ both cases further subdivided into ME_T bins

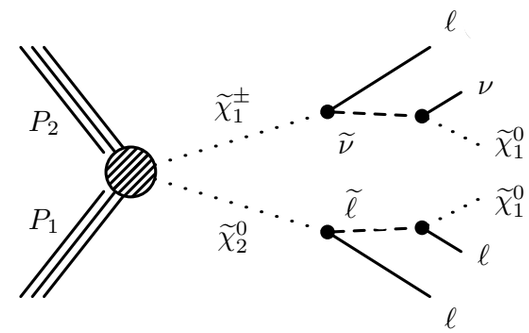
nOSSF==1

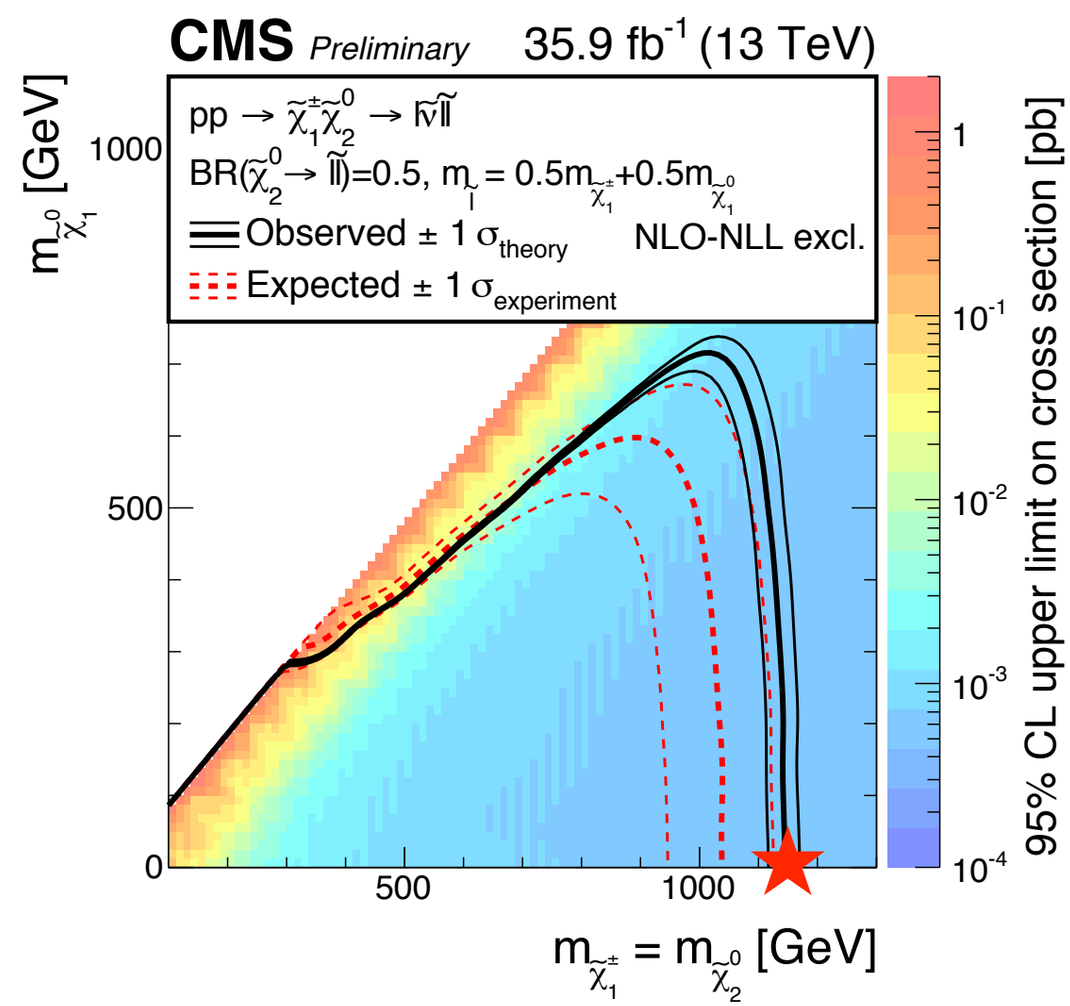


nOSSF==0



The strongest limit on C1N2 production by 3L





Chargino masses excluded up to 1150 GeV

Search with soft leptons

CMS-SUS-16-048 targeting compressed spectra

Baseline selection and background

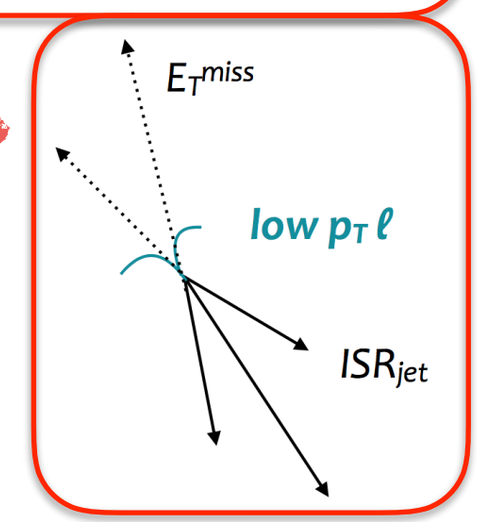
Focus on the presence of $Z \to \ell\ell$

- 2 opposite sign μ(e) p_T 3.5(5)-30 GeV with tight ID to reject non-prompt leptons
  - efficiency for μ(e) 80-90% (50-60%)
- ISR jet, ME_T > 125 GeV for high trigger eff
- HT > 100 GeV, to suppress bkg with low hadronic activity in the event
- 0.6 < ME_T/HT < 1.4, to reject QCD events
- $m(\ell\ell)$ < 50 GeV with ME_T bins (125-200-250-∞)
- $m(\tau\tau)$ veto [0,160] GeV, to reduce boosted DY→$\tau\tau$ bkg (also reduced by tight lepton cuts
- b-jet veto, to reduce ttbar dileptonic bkg
- $M_T(\ell,ME_T)$ < 70 GeV, for the signal the leading lepton is aligned with the boost direction of MET ($\Delta\phi(\ell,ME_T)$~0)

Main residual backgrounds

- DY→$\tau\tau$, non-prompt leptons (mainly W+jets), ttbar dilepton, VV (mainly WW)

- Relatively low visible energy and ME_T
- Topologies missed by standard search
- Need ISR to boost the sparticle pair system



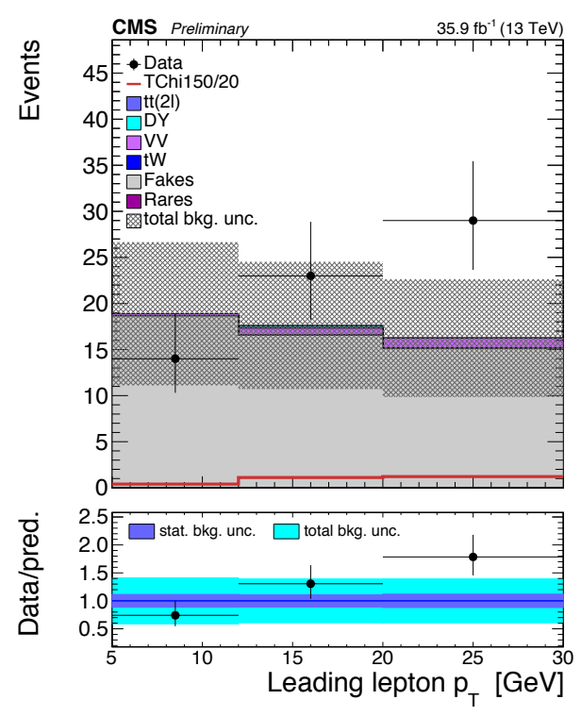
Non-prompt leptons bkg

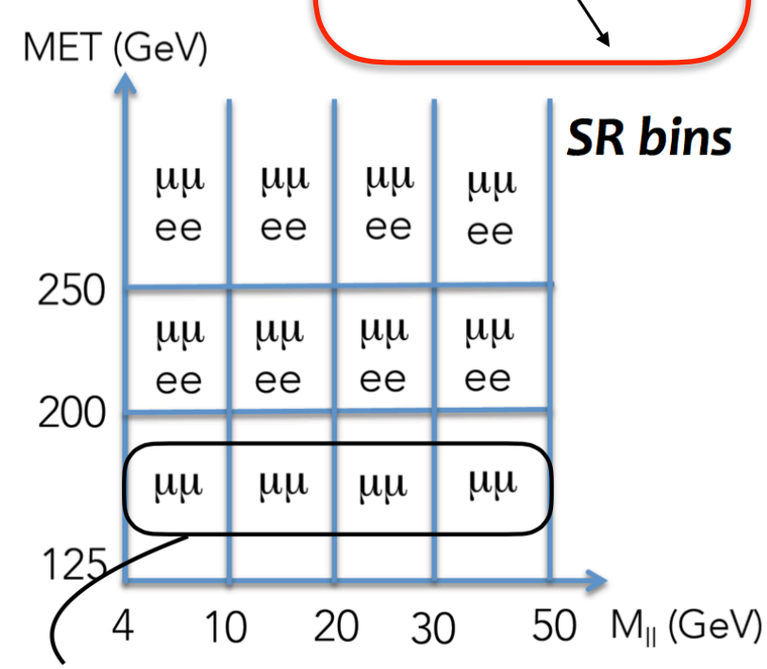
Source: real lepton in jets, jet-misID (e)

Processes: W+jets and ttbar

Data driven estimation: fake rate method

CR: same-sign leptons in high ME_T

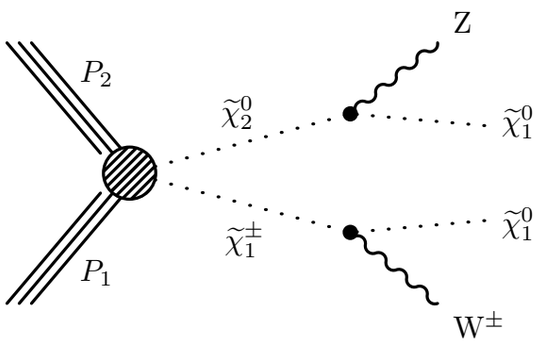




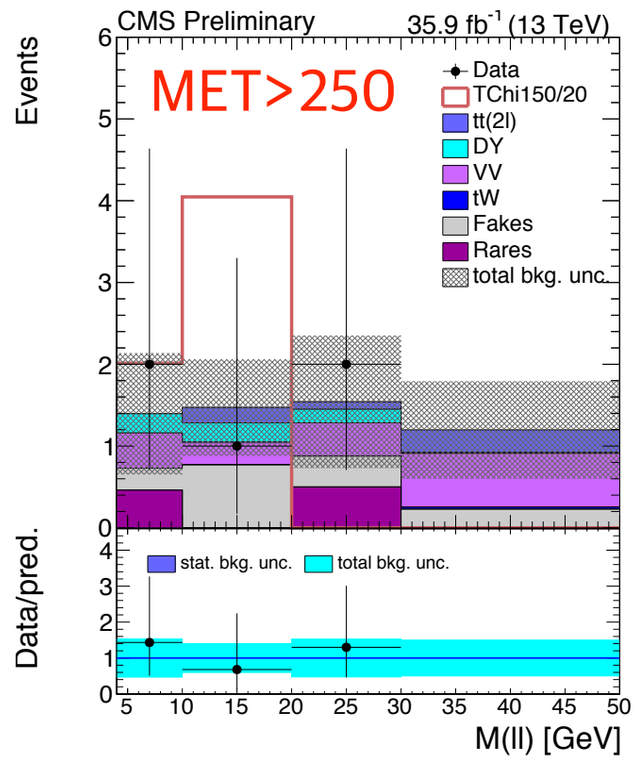
Extending reach down to 125 GeV with dimu+ME_T special trigger

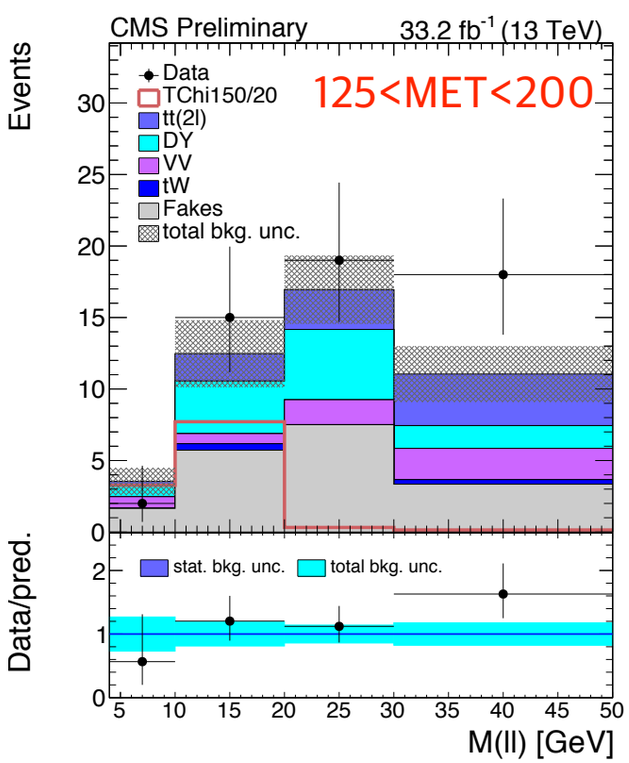
Soft 2L OS: Results

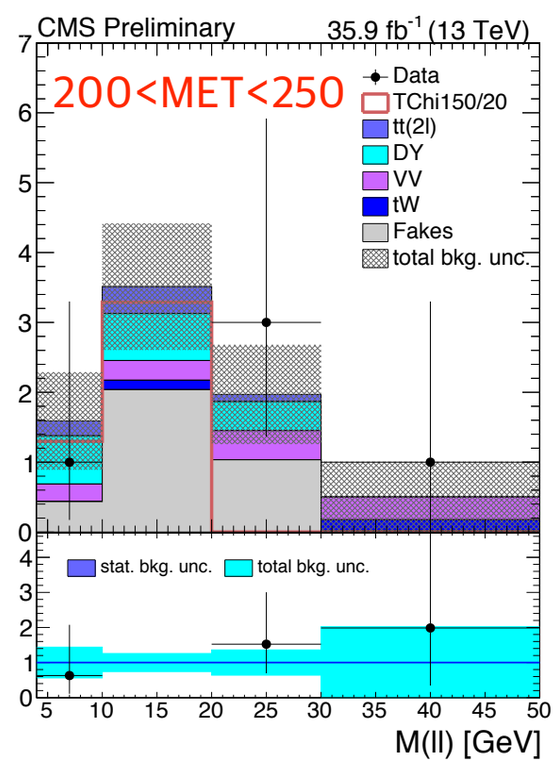
CMS-SUS-16-048

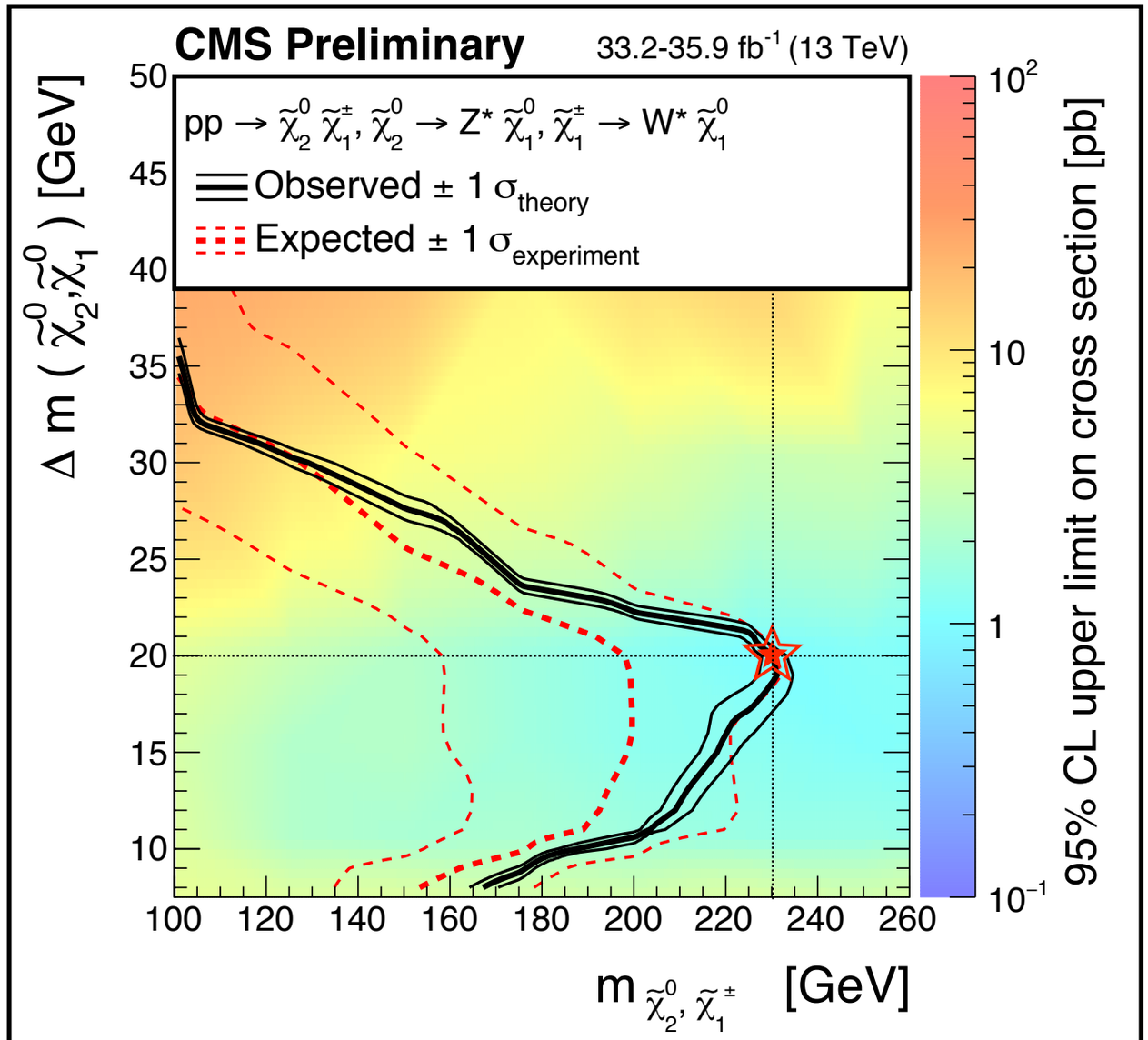


- Dominant bkg predicted with data
- No significant excess observed









First coverage of Δm = 7.5~30 GeV

Chargino/neutralino masses excluded up to 230 GeV for Δm = 20 GeV

Note that results based on a simplified model with a pure Wino production cross section

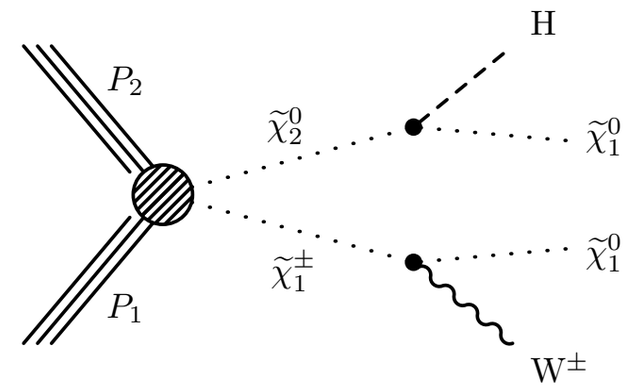
(Higgsino interpretation in preparation)

WH 1L + bb + MET

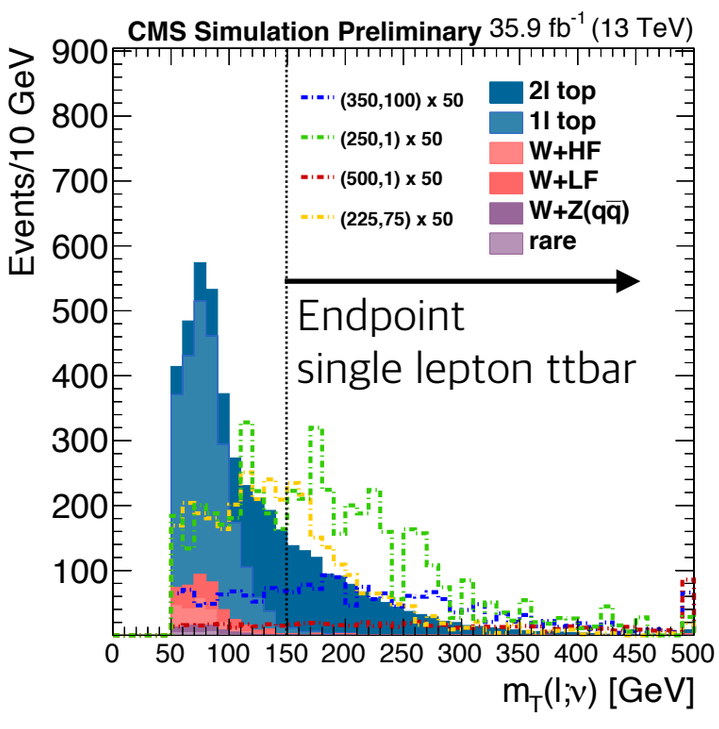
CMS-SUS-16-043

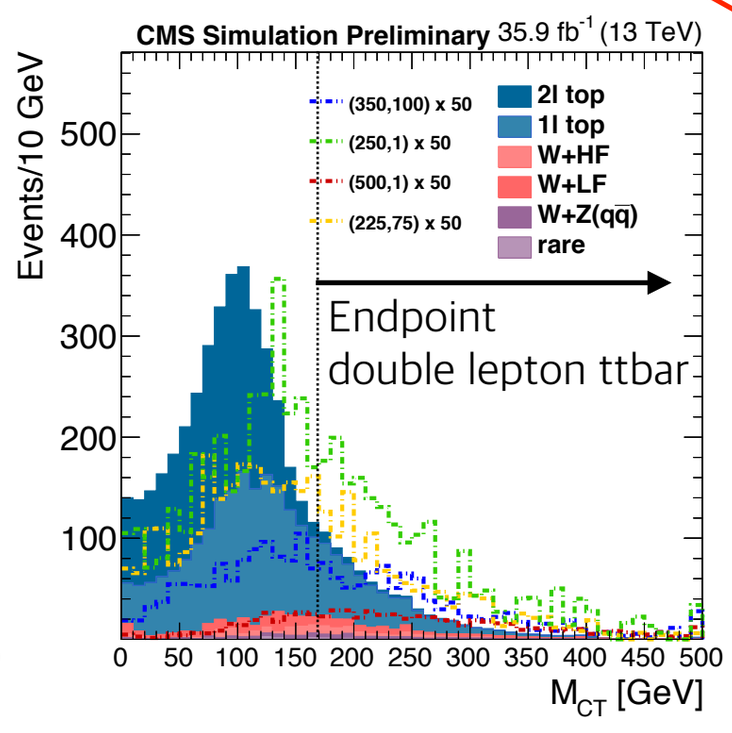
- Use single lepton trigger: offline e(μ) p_T > 30 (25) GeV, 2 b-jets p_T > 30 GeV, ME_T > 125 GeV
  - Veto additional leptons, isolated tracks, τ_h candidates to reduce main bkg: dilepton ttbar
  - Require 90 < m(bb) < 150 GeV
  - M_T > 150 GeV to reduce single lepton ttbar
  - M_{CT} > 170 GeV (endpoint at top mass for dilepton ttbar)

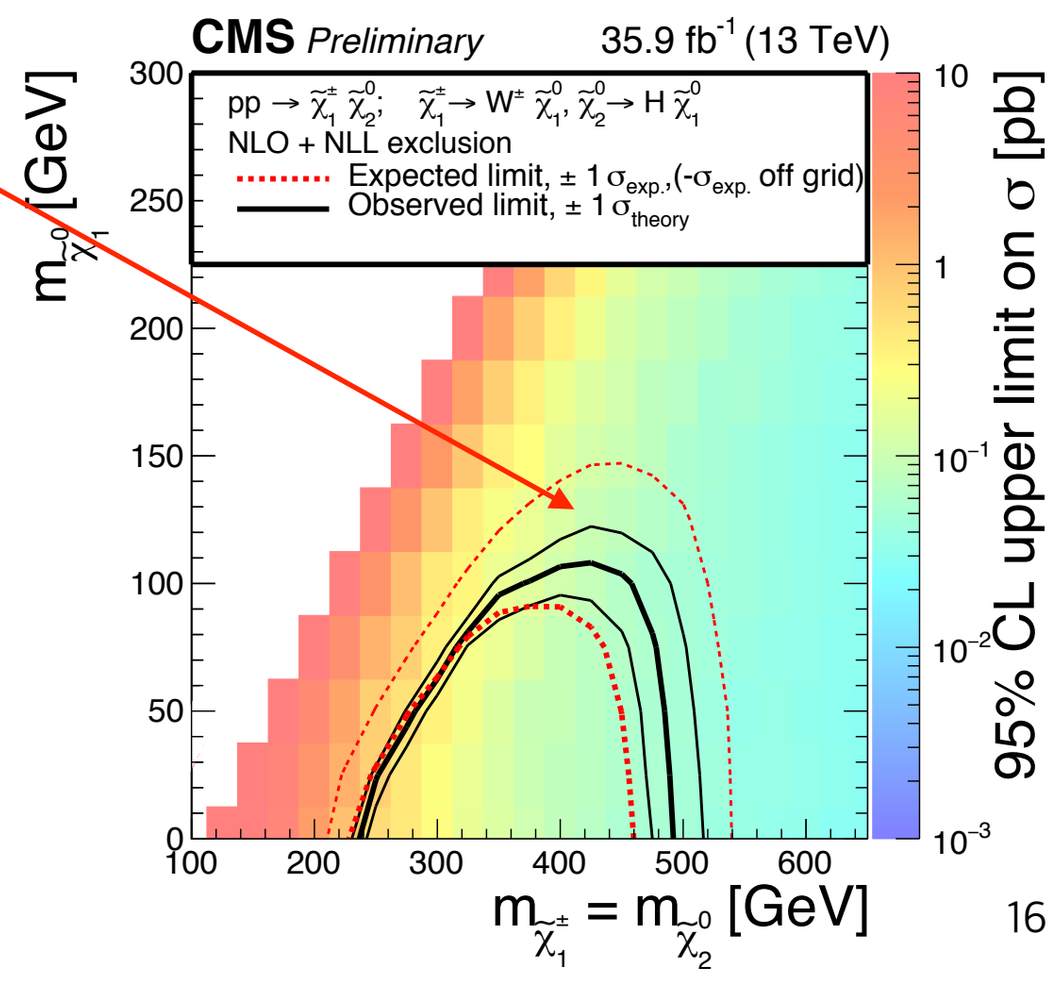
$$M_{CT}^2 = 2p_T^{b1}p_T^{b2}(1+\cos(\Delta\phi_{bb}))$$



- Probe chargino mass between 250 and 500 GeV
- Probe LSP mass up to 120 GeV at $m_{C1} \sim 450$ GeV







0L: GMSB Higgsinos in 4b

CMS-SUS-16-044

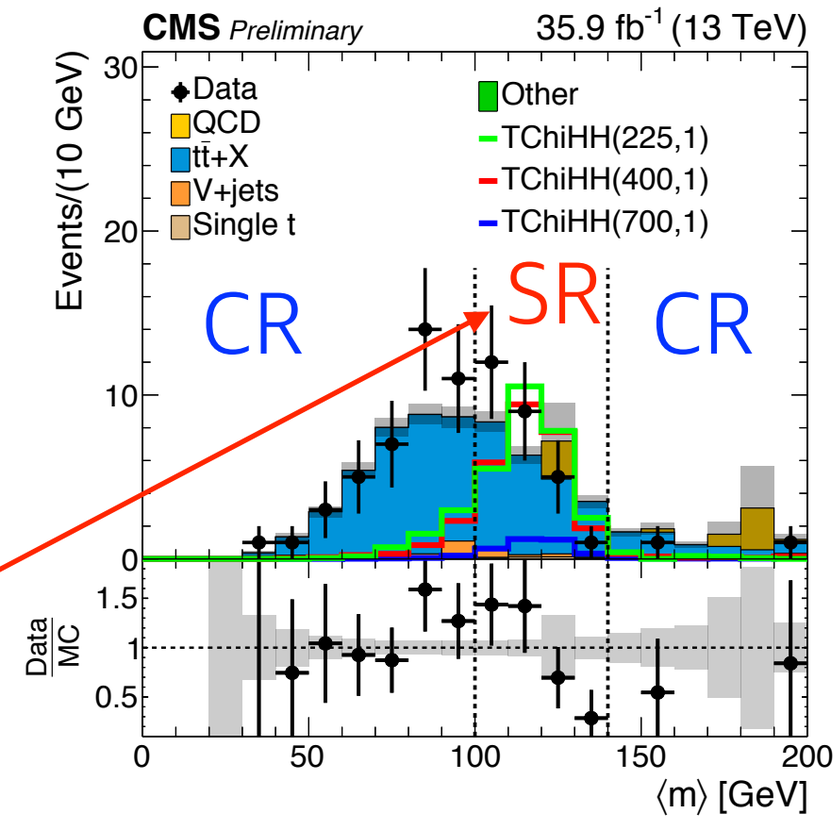
General strategy for 2 higgs bosons

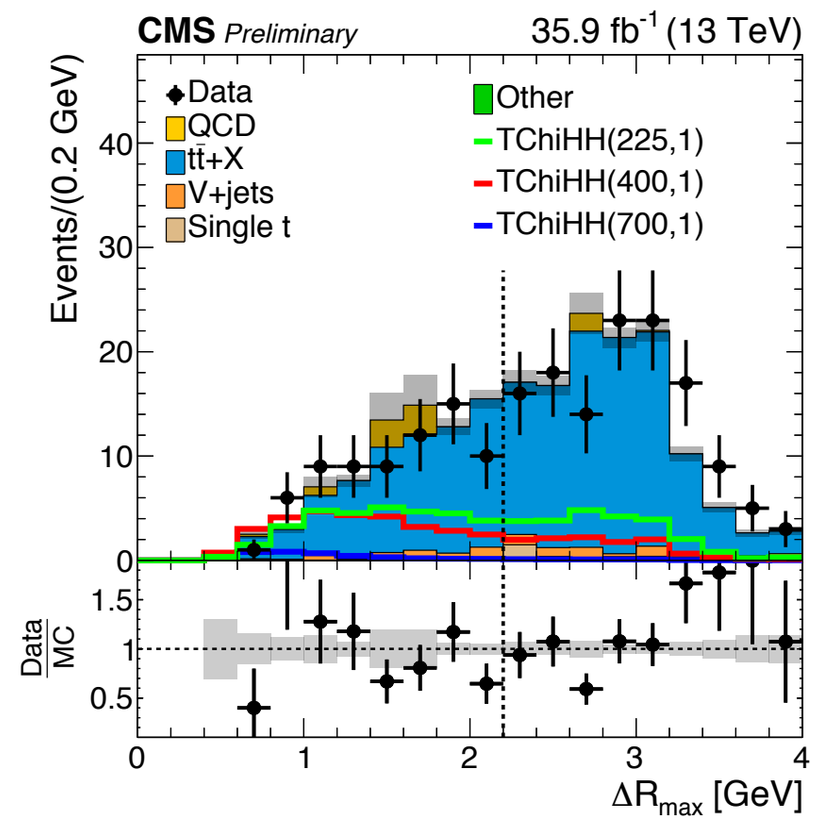
- ME_T > 150 GeV
- 4 or 5 jets with p_T > 25 GeV
- No leptons to reduce main bkg, single lepton (τ_h) ttbar
- Reconstruct two h→bb candidates:
  - Three different h_1h_2 pairings from 4 highest b-tagging discriminator jets (deep learning b-tagging)
  - Select pair that minimise $\Delta m_h \equiv m_{h1}-m_{h2}$ < 40 GeV
  - Use <m> [100,140] GeV for signal extraction
  - $\Delta R(b,b)_{max} \equiv \max(\Delta R_{h1}, \Delta R_{h2})$<2.2 against ttbar
- Categories:
  - 2b, 3b and 4b
  - 4 ME_T: 150-200-300-450-∞

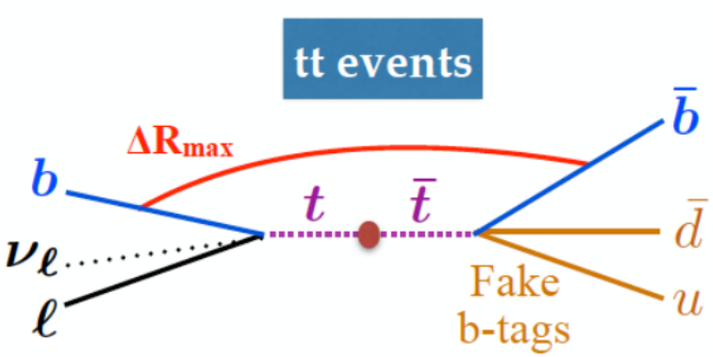
$$\langle m \rangle \equiv \frac{m_{H_1} + m_{H_2}}{2}$$

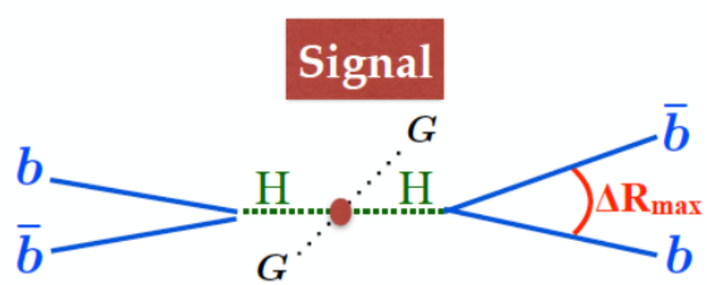
Main residual backgrounds

- Single lepton (τ_h) ttbar 85% and Z→$\nu\nu$ + jets (10%)









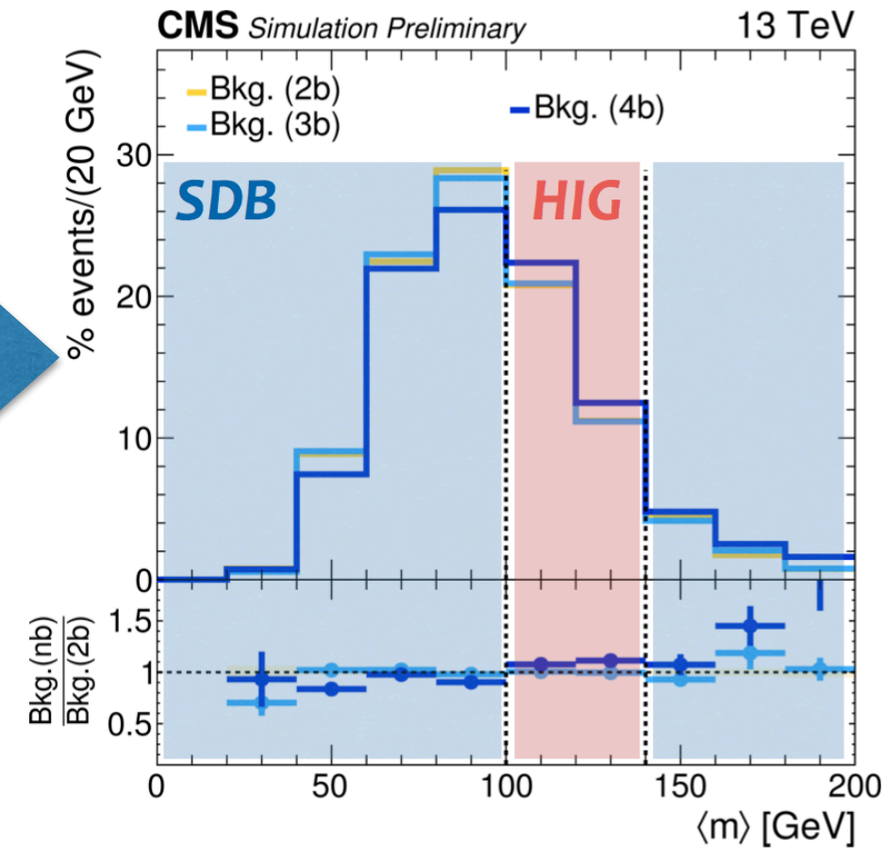
Data Driven Bkg Estimation

CMS-SUS-16-044

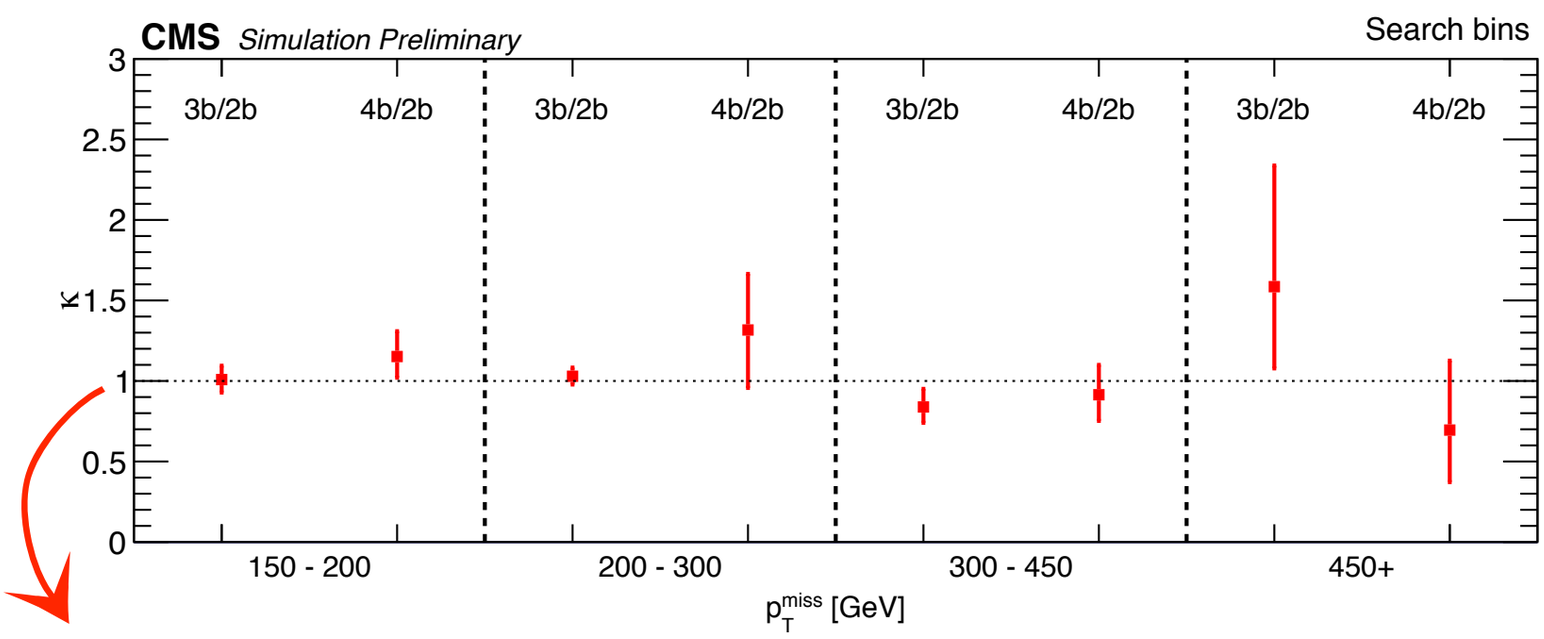
- Background in all three b-tag categories by events containing only 2 real b, with the additional b-tagged jets in 3b, 4b categories from mis-tagged light/gluon jets
- Construct an ABCD method for bkg estimation
  - based on observation that <m> is approximately uncorrelated with $N_{b\text{-tags}}$
  - using <m> shape in 2 b-tagged jets CR to predict shape in 3b, 4b
  - define HIG region with <m> between 100-140 GeV, and SBD region as sum of all events outside the window up to <m> < 200 GeV

$$N_{3b}^{HIG} = N_{3b}^{SBD} \times \frac{N_{2b}^{HIG}}{N_{2b}^{SBD}} \qquad N_{4b}^{HIG} = N_{4b}^{SBD} \times \frac{N_{2b}^{HIG}}{N_{2b}^{SBD}}$$

  - perform the closure test in simulation for systematics



↳ <m> shapes for 3 event categories agree within statistics



In the simulation, the k factors are close to 1 because <m> and N_b distributions are independent for each bkg category

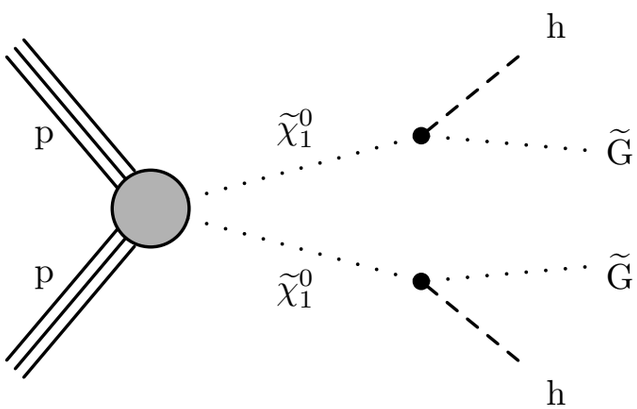
- closure, is the ability to predict the bkg rates in the signal regions, is quantified with double ratio k

$$\kappa_{nb} = \left(\frac{\mu_{HIG}^{bkg}}{\mu_{SBD}^{bkg}}\right)_{nb} / \left(\frac{\mu_{HIG}^{bkg}}{\mu_{SBD}^{bkg}}\right)_{2b}$$

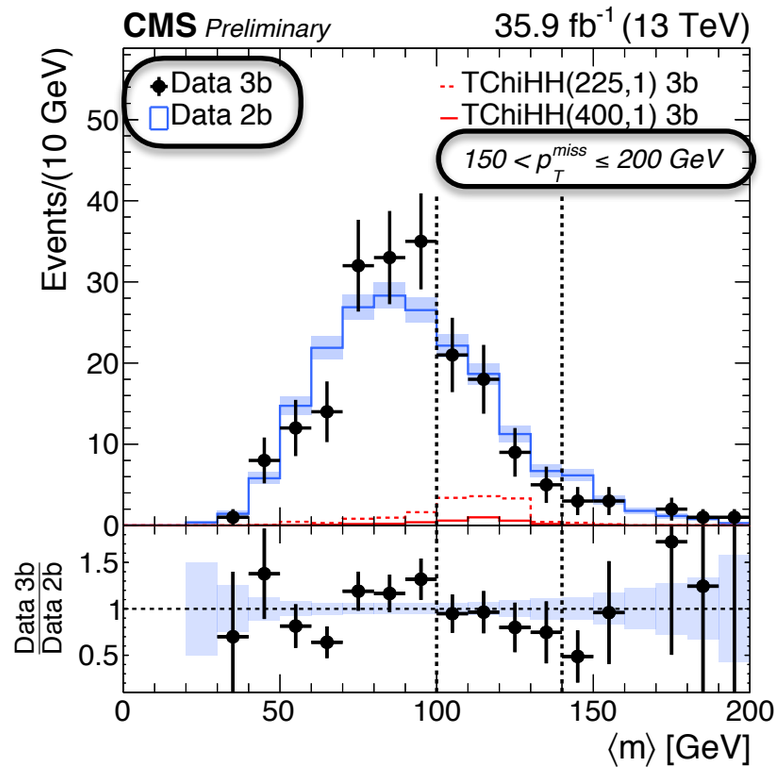
- k factors measure impact of any residual correlation between b-tag cat. and <m>
- k factors in simulation are consistent with unity for both 3b & 4b regions

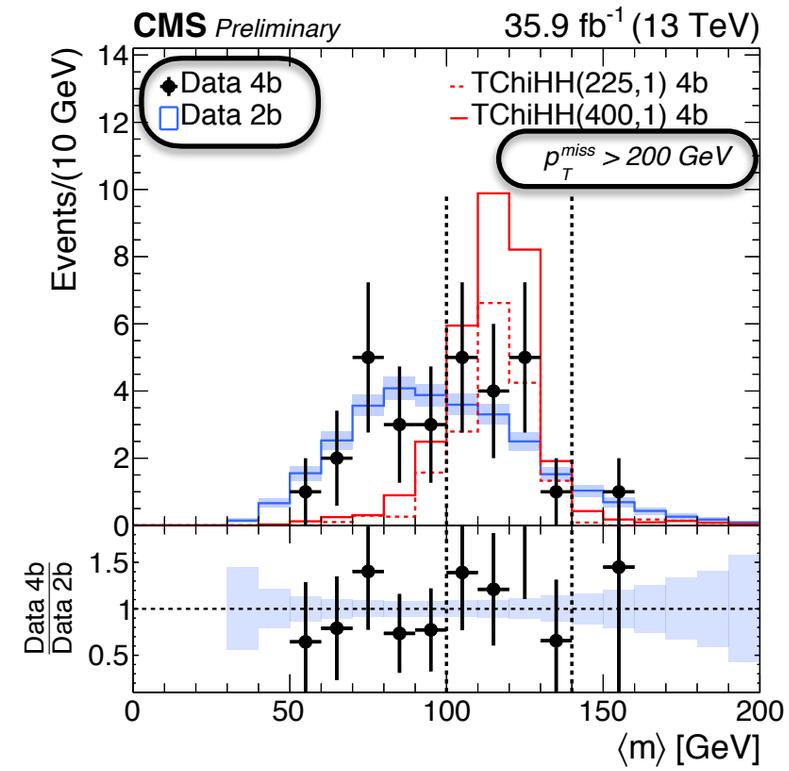
GMSB Higgsinos: Results

CMS-SUS-16-044

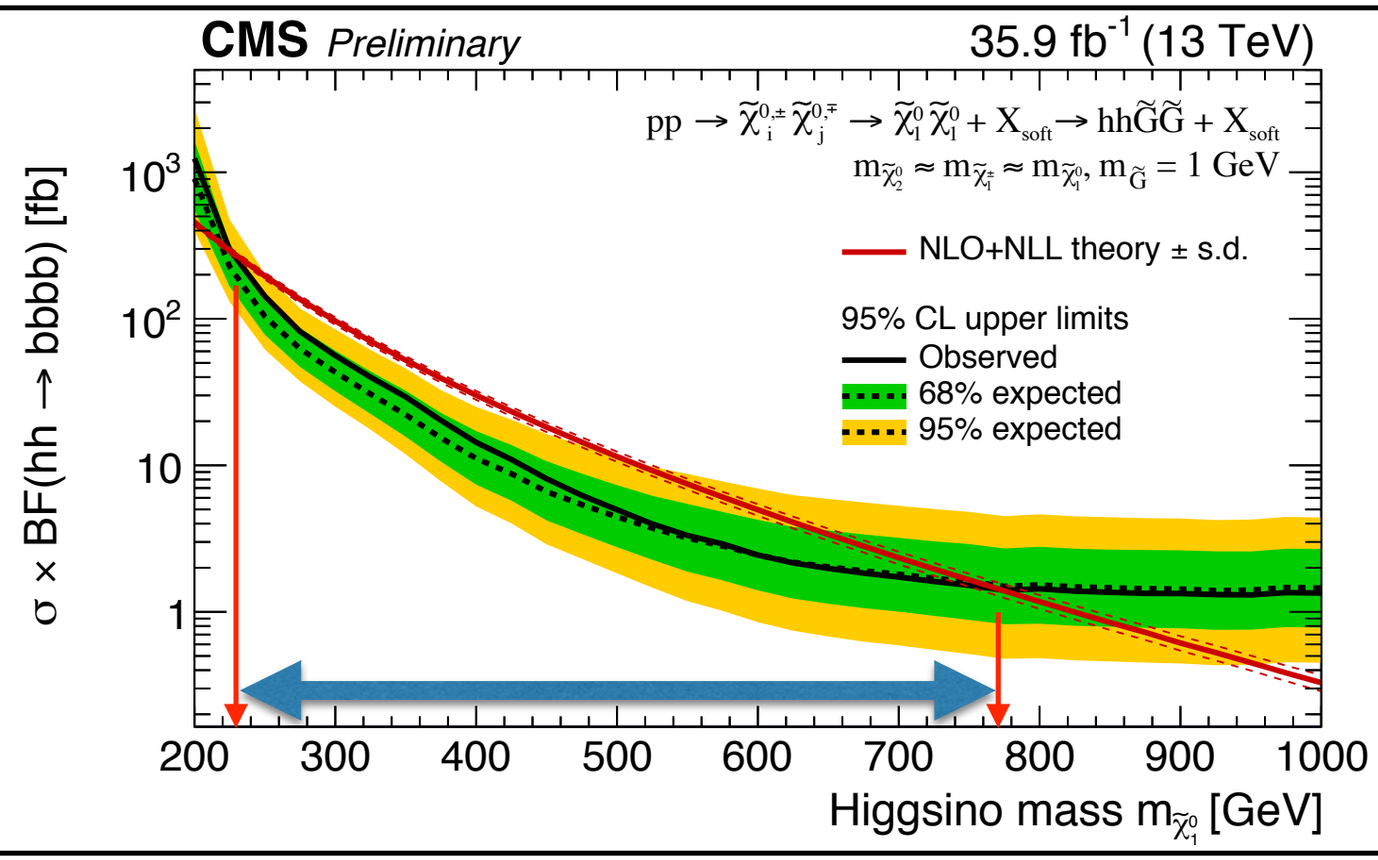


For the smallest Δm (< 40 GeV), observed data are in agreement with the SM expectation





Higgsino masses excluded from 225 to 770 GeV at 95% C.L. (using a simplified model framework for the production and decay of approximately degenerate Higgsinos in the context of GMSB)



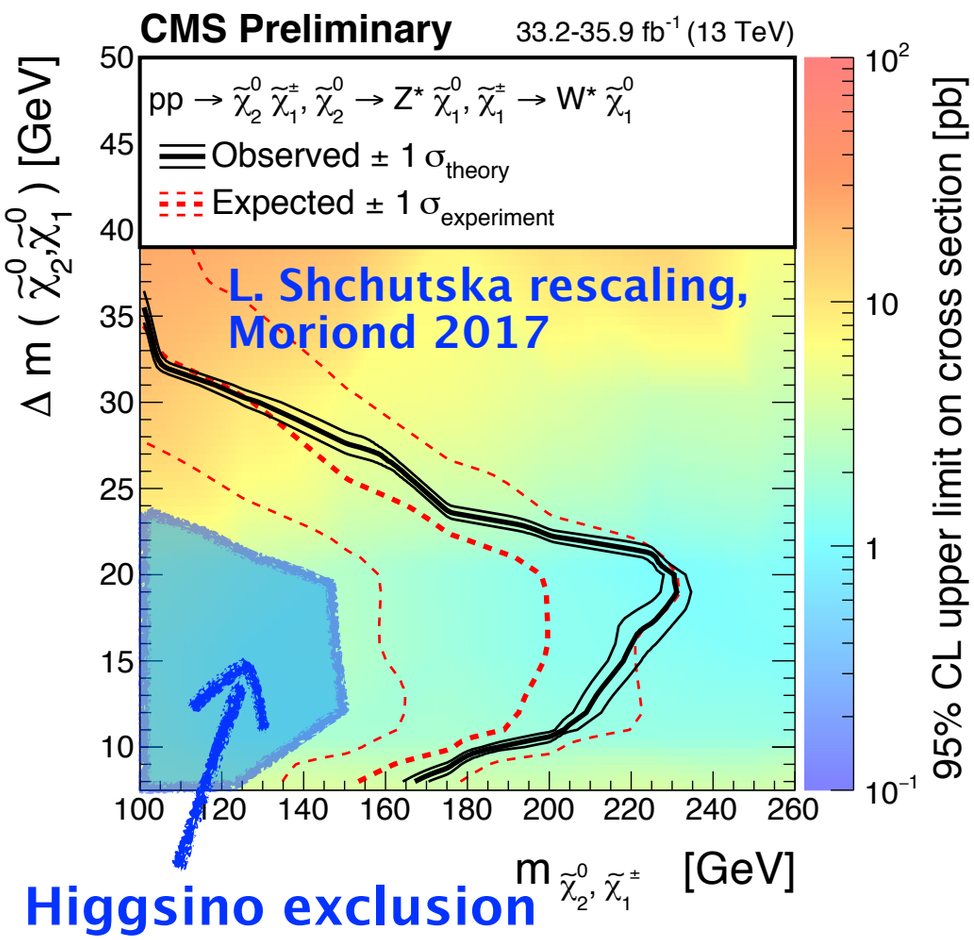
Summary

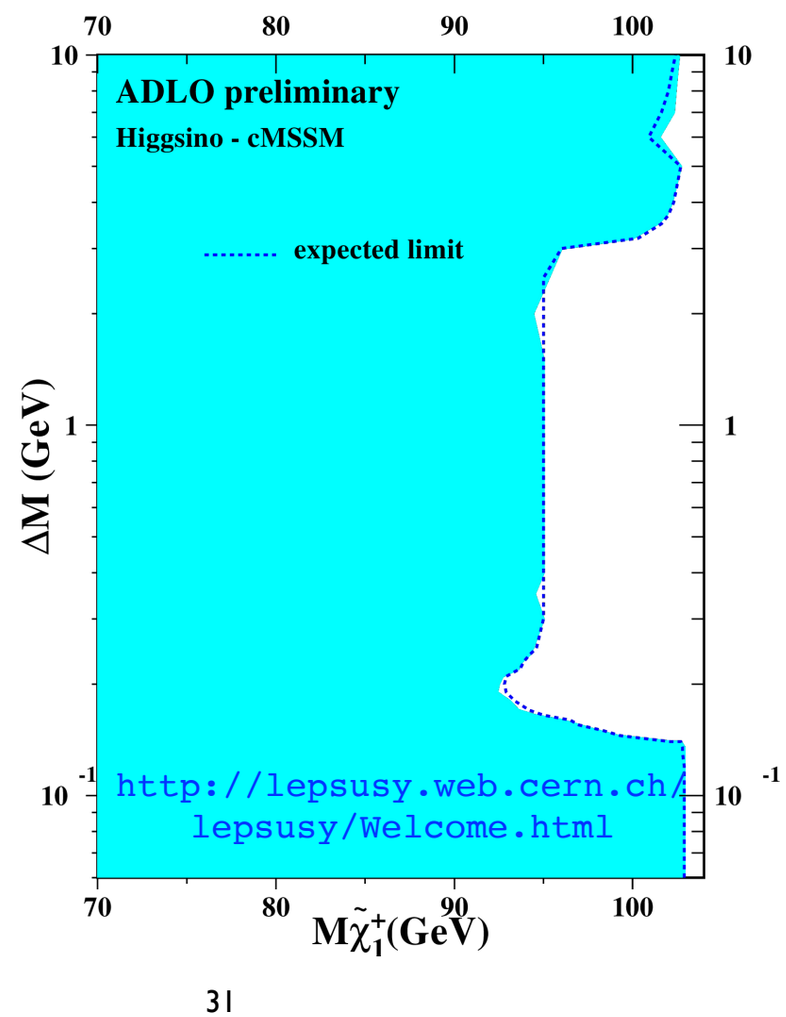
- The EWK SUSY production happens with very low rates
  - low cross section
  - need leptonic final states or Higgs boson tagging
- The 2016 full dataset gave us the possibility to explore new territories in the EWKino sector
- Results are interpreted in the context of simplified models of chargino-neutralino
- With an extensive search program covering diverse topologies, CMS extended the Run 1 searches with the increased luminosity and center of mass energy
- No significant excess indicating presence of physics beyond the Standard Model
- Developing new ideas and final states to cover all the possible corners of the phase space, especially in the Higgsino sector

Additional material

Slide from Jim Hirschauer's talk

Higgsino sensitivity





At Δm=10 GeV:

- LEP limit is 100 GeV.
- CMS wino limit rescaled to higgsino xsec is 130 GeV.

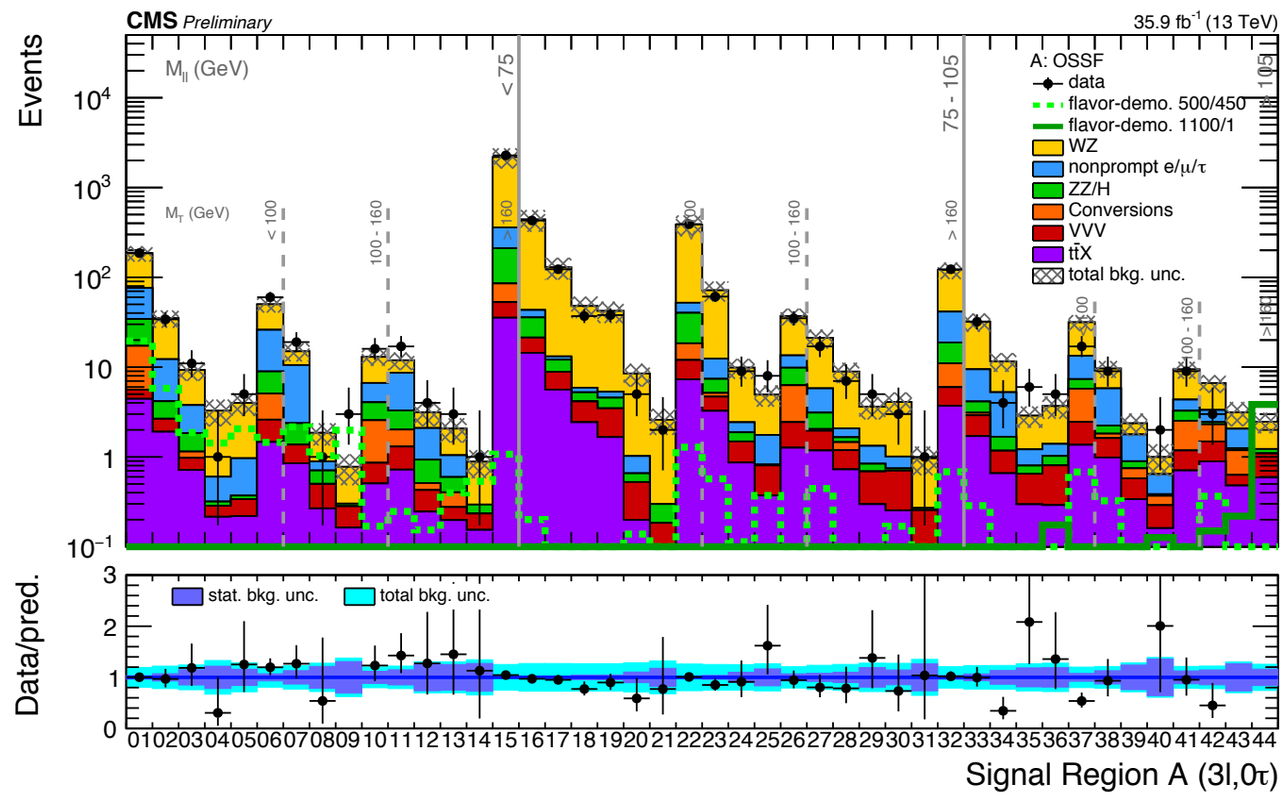
LHC only now pushing beyond LEP limits!

- Soft OS dilepton:
  - milestone for Higgino LSP searches at LHC
- Just projection! real results coming:
  - limit at ~120 (~150) GeV for dM = 7.5 (20) GeV

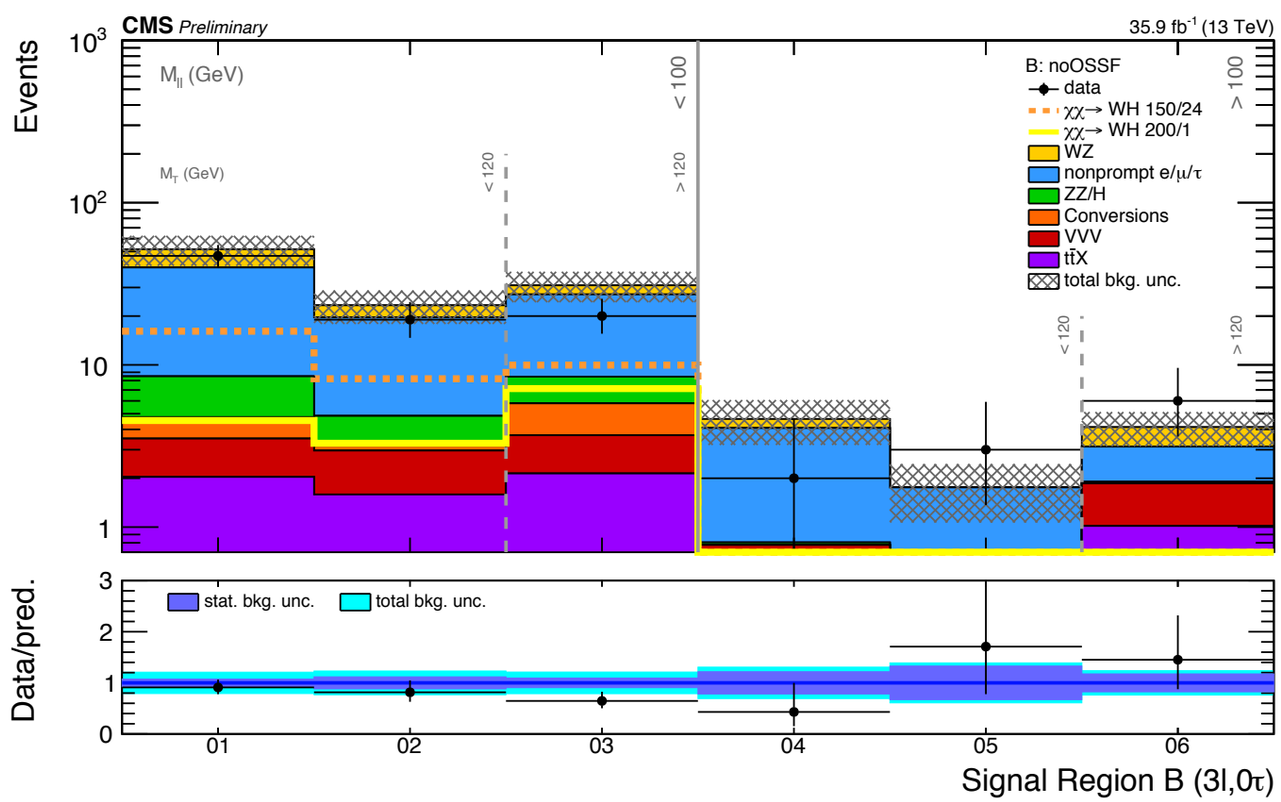
CMS-SUS-16-039

3L without τ_h: Results

Category A
events with OSSF pair



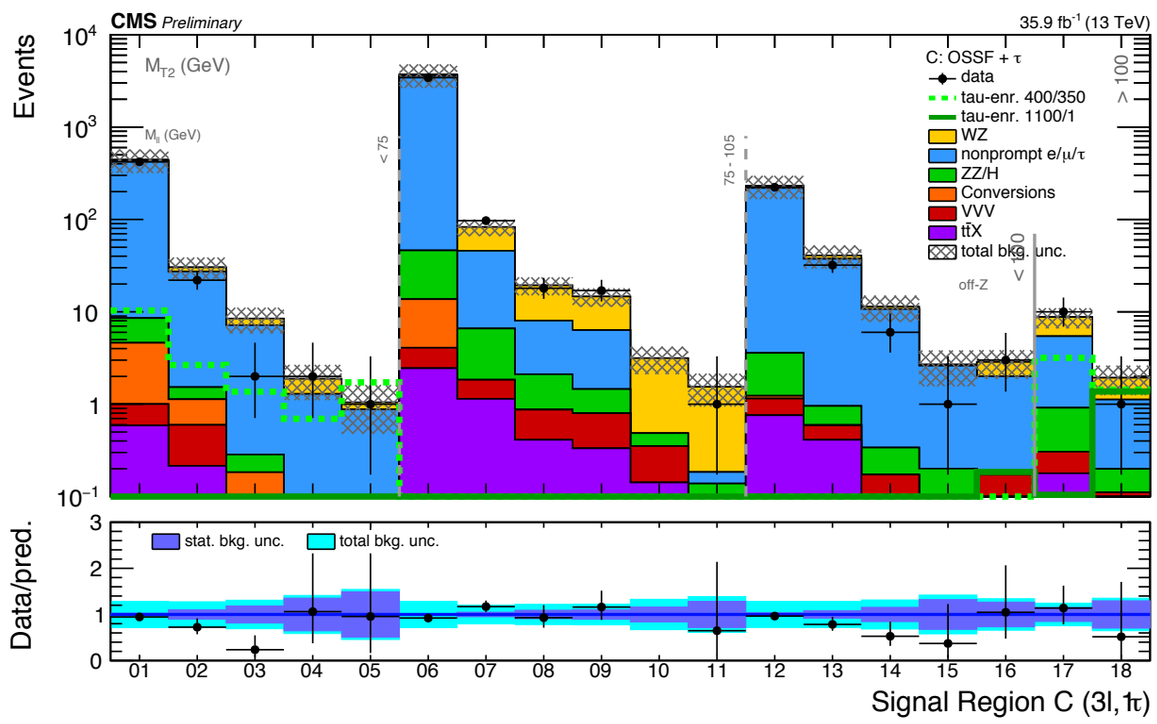
Category B
events without OSSF pair



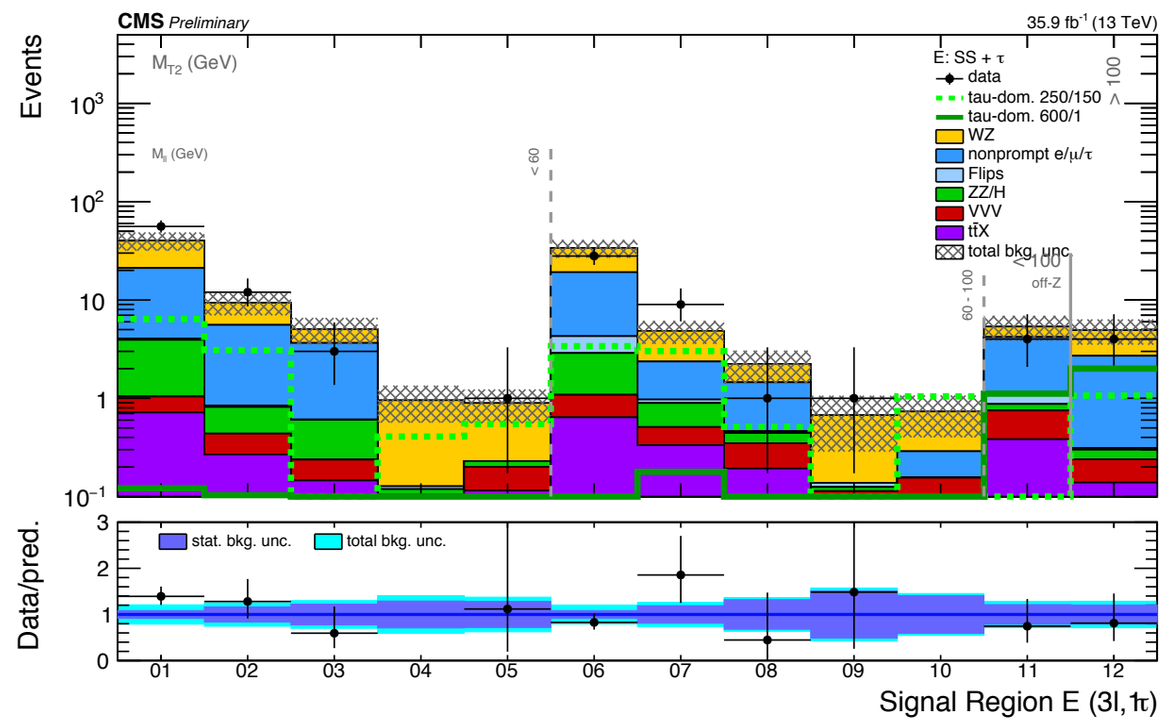
CMS-SUS-16-039

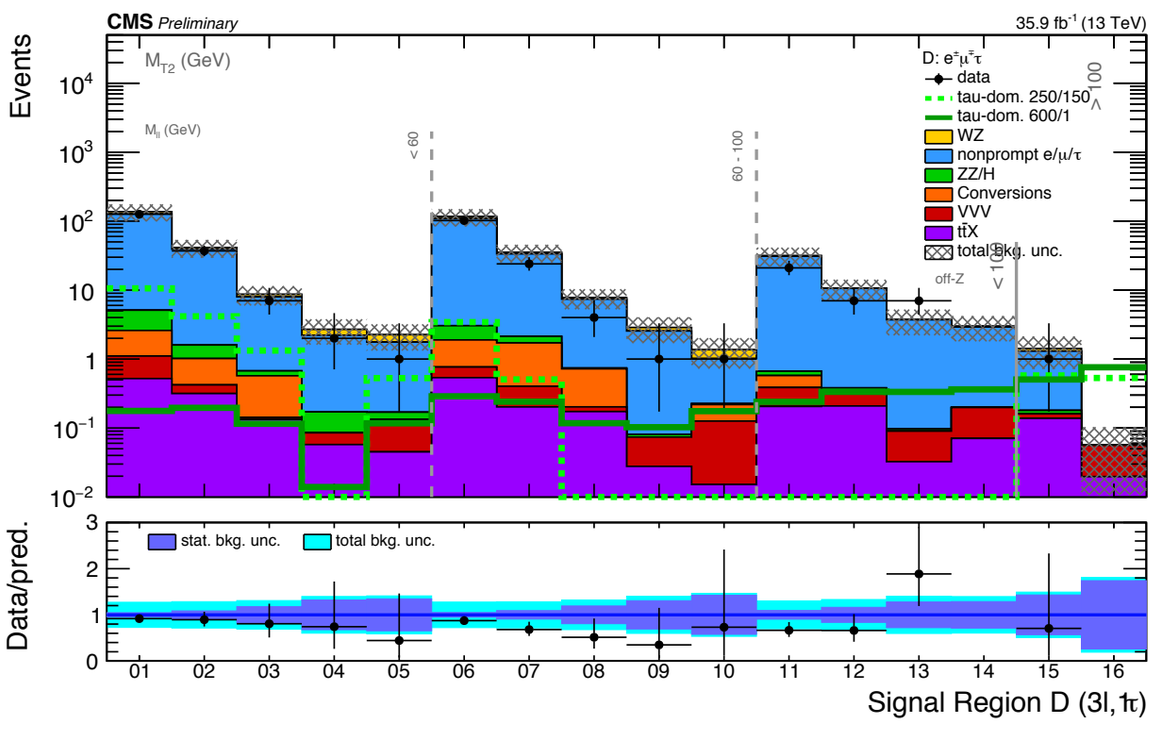
3L + 1 or 2 τ_h: Results

Category C with OSSF pair ($e^{\pm}e^{\mp}\tau_h$, $\mu^{\pm}\mu^{\mp}\tau_h$)

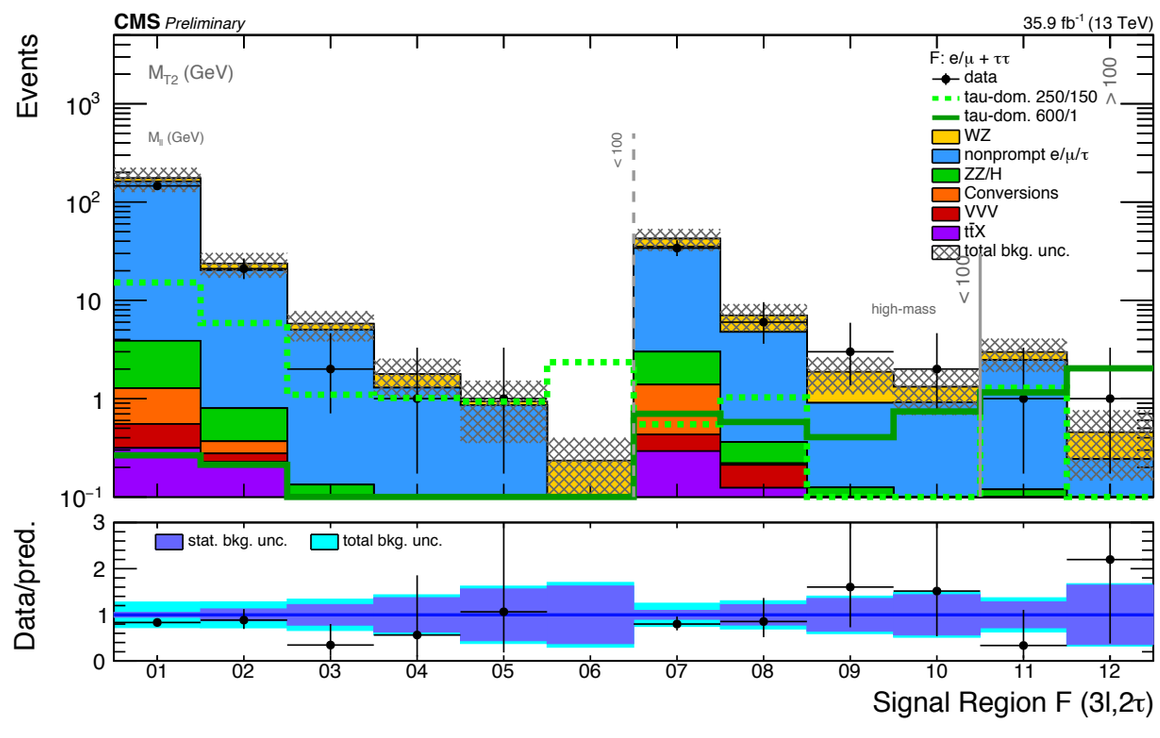


Category E with SS pair (ee/$\mu\mu$/eμ + τ_h)





Category D with OSOF pair ($e^{\pm}\mu^{\mp}\tau_h$)



Category F: e/μ with two τ_h

CMS-SUS-16-039

At least four leptons

- Electrons (muons) with p_T > 25 (20), 15 (10), 10 (10) GeV
- Benefit from much lower SM bkg compared to 3L, but much lower signal rate: fewer SR binning
- Signal Regions G to K with further binning in:
  - ME_T to more efficient discriminate between signal and bkg
  - Number of τ_h's and nOSSF pairs to separate a Z or H boson in the decay chain

E_T^{miss} (GeV)	$0\tau_h$		$1\tau_h$	$2\tau_h$	
	nOSSF ≥ 2	nOSSF < 2	nOSSF ≥ 0	nOSSF ≥ 2	nOSSF < 2
$0-50$					
$50-100$					
$100-150$					
$150-200$					
≥ 200