Searches for charginos and neutrinos at CMS

LHCP 2019, Puebla, Mexico

Sam Bein, on behalf of CMS

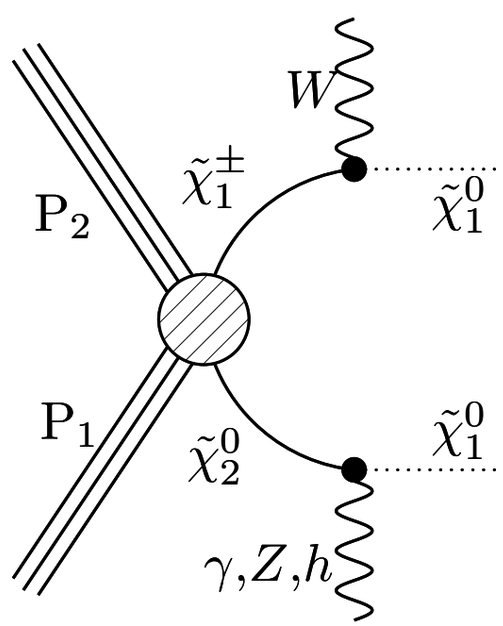
May 22, 2019

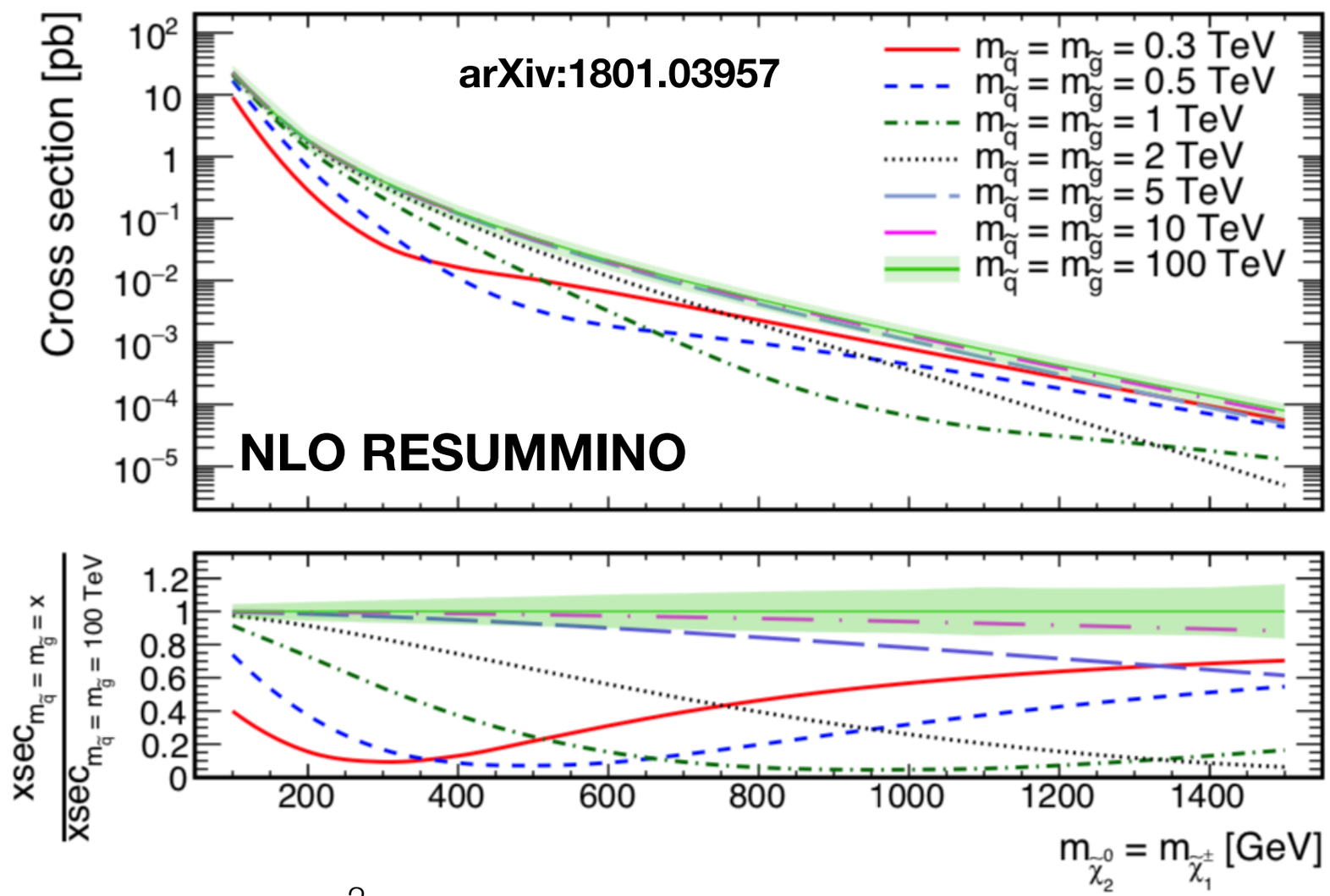
Universität Hamburg

DER FORSCHUNG | DER LEHRE | DER BILDUNG

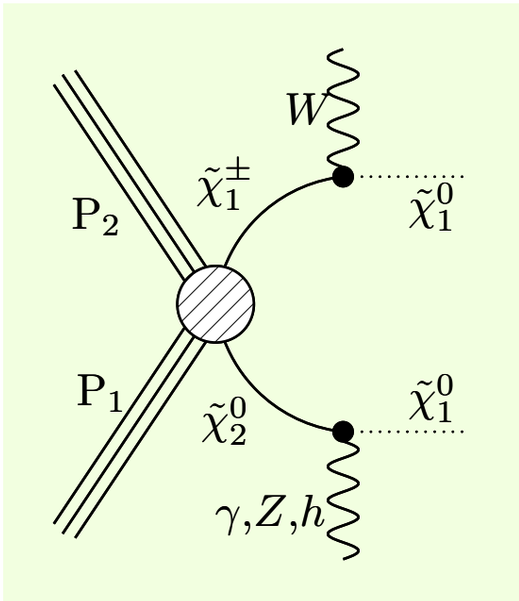
EWKino direct production

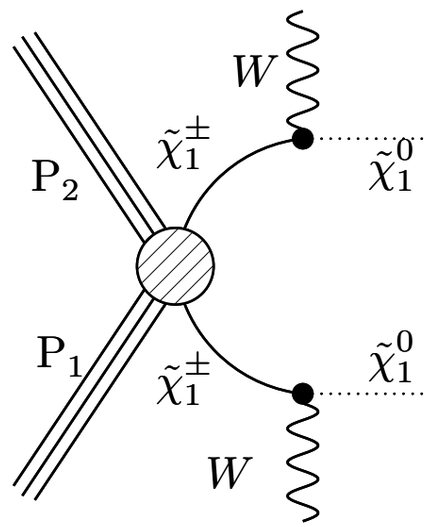
- Direct chargino and neutralino production is challenging due to small cross sections/leptonic branching fractions
  - However, more interesting as tighter bounds on strongly charged particles are established

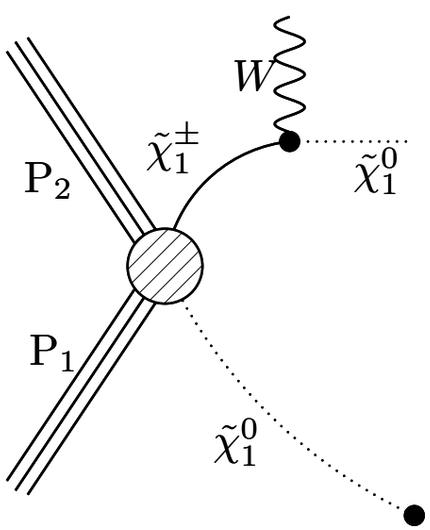


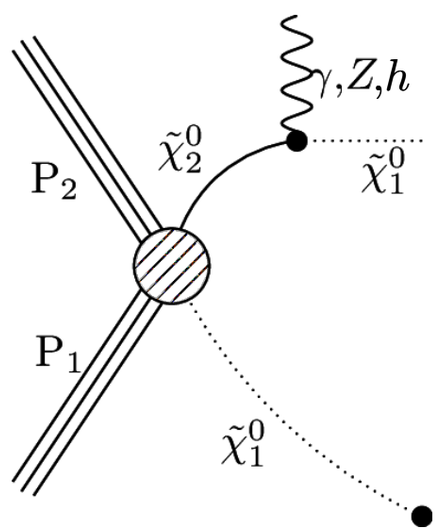


Processes









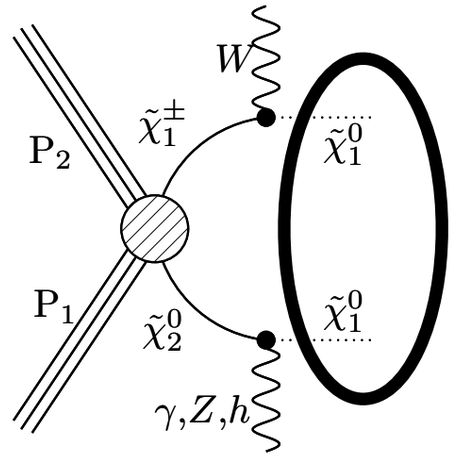
Chargino/neutralino production has the largest cross section

Outline

- Signatures
  - MET, MT, MT2, MLL, Razor
- Searches for WZ model
- WZ Combination
- Searches for WH model
- WH Combination
- New results from WH
- Summary

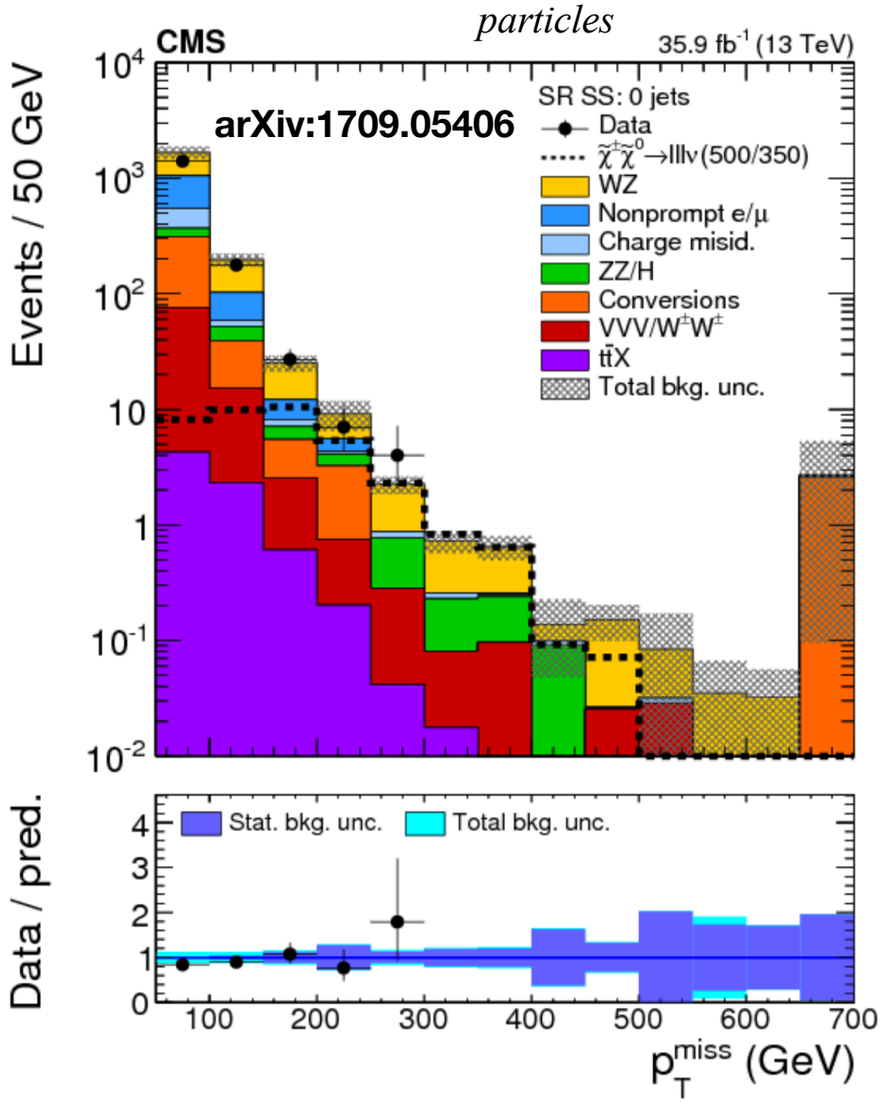
Signatures (i)

"MET"

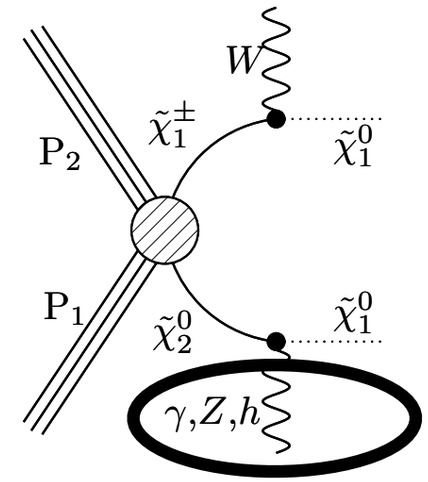


Missing transverse energy/momentum

$$E_T^{miss} = p_T^{miss} = \left| -\sum_{particles} \vec{p}_T \right|$$

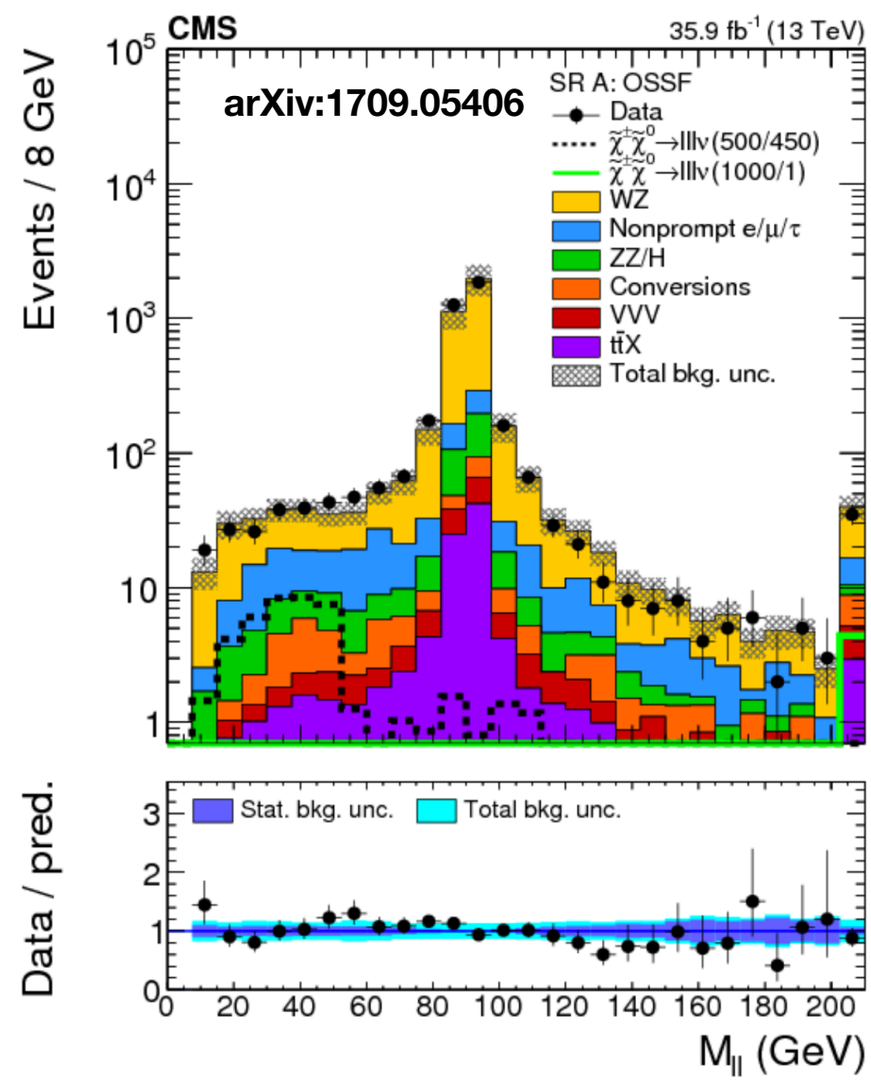


"M(LL)"



Invariant mass

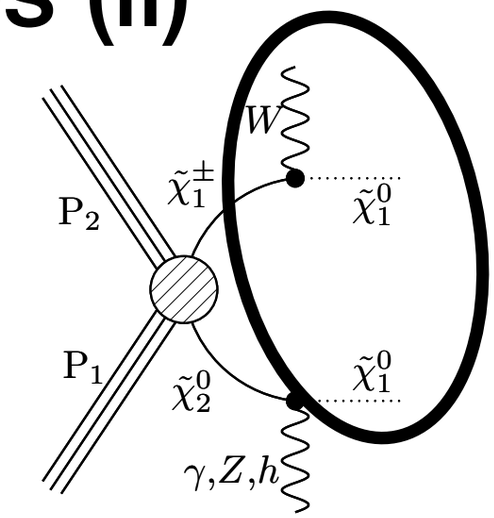
$$M_{ll} = \sqrt{(|p_{L1}| + |p_{L2}|)^2 - (|\vec{p}_{L1} + \vec{p}_{L2}|)^2)}$$



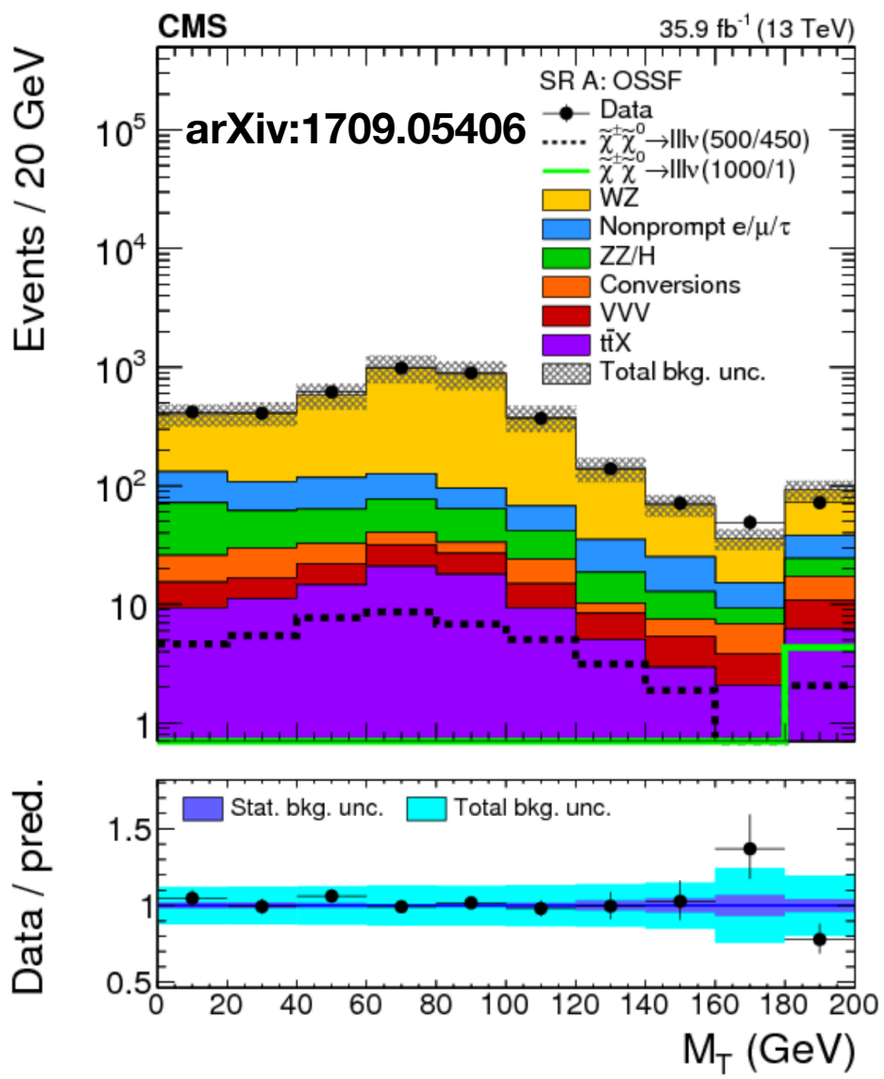
Signatures (ii)

"MT"

Transverse mass

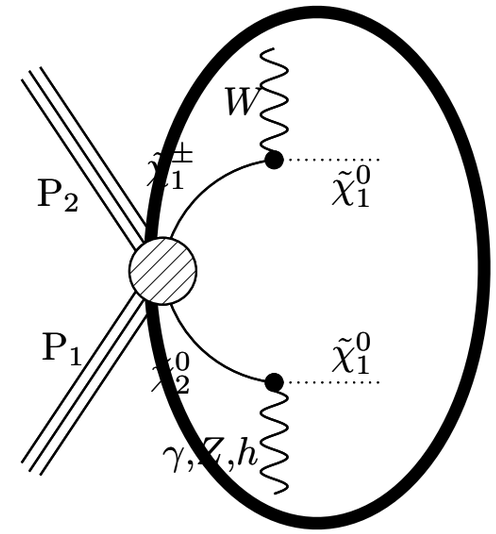


$$M_T = \sqrt{2 p_T(l) p_T^{miss} (1 - \cos[\Delta\varphi(lep, p_T^{miss})])}$$

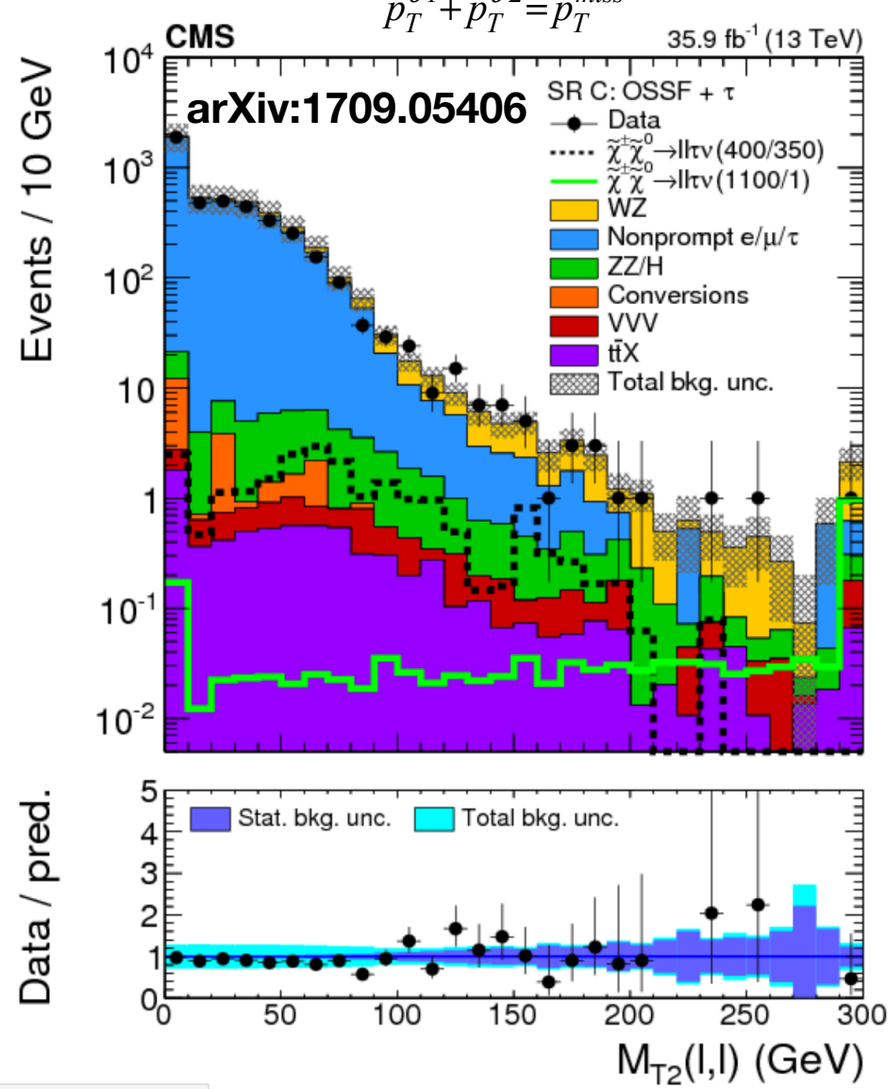


"MT2"

Stransverse mass

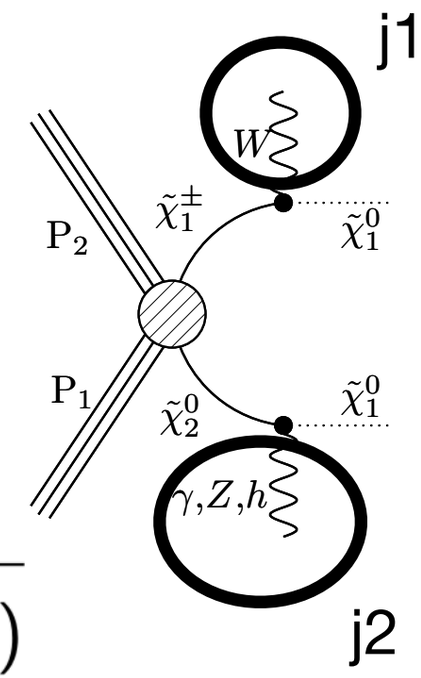


$$M_{T2}(L1, L2) = \min_{\vec{p}_T^{\,v1} + \vec{p}_T^{\,v2} = \vec{p}_T^{\,miss}} [\max(m_T^{L1} + m_T^{L2})]$$



Signatures (iii)

Razor variables

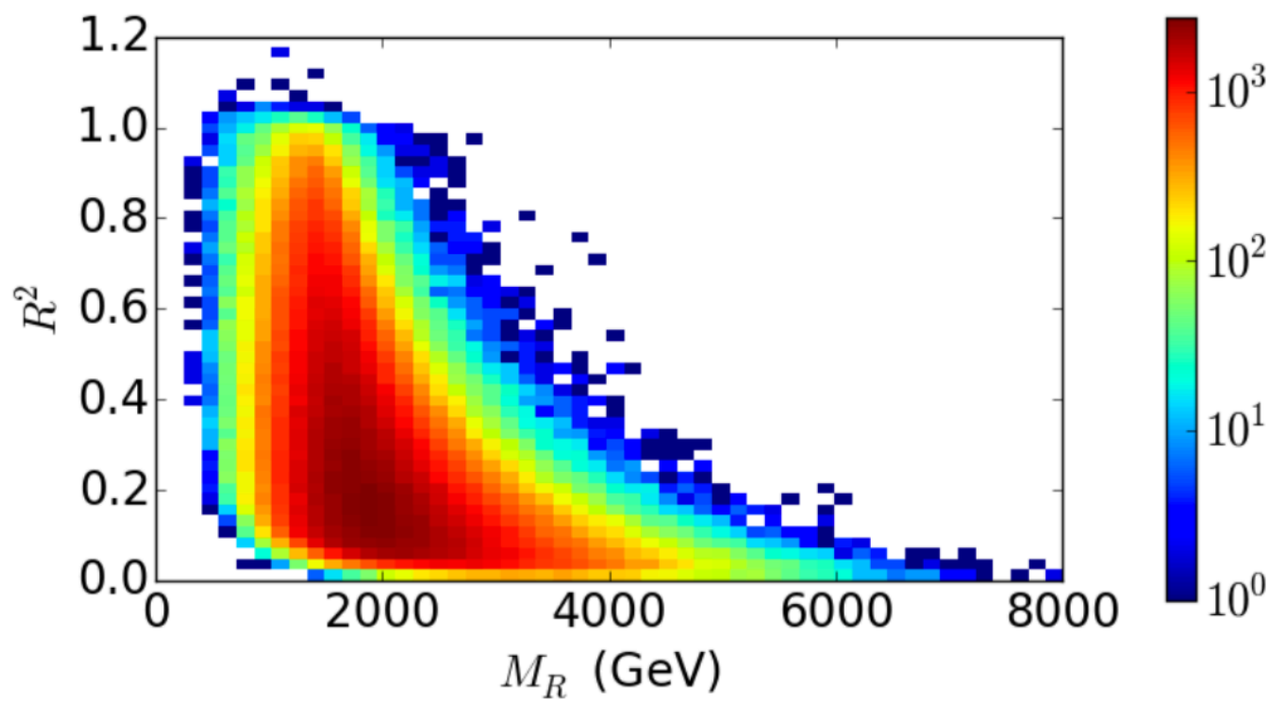


$$M_R = \sqrt{(|\vec{p}^{j1}| + |\vec{p}^{j2}|)^2 - (p_z^{j1} + p_z^{j2})}$$

$$M_T^R = (1/\sqrt{2})\sqrt{p_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{p}_T^{miss} \cdot (\vec{p}_T^{j1} + \vec{p}_T^{j2})}$$

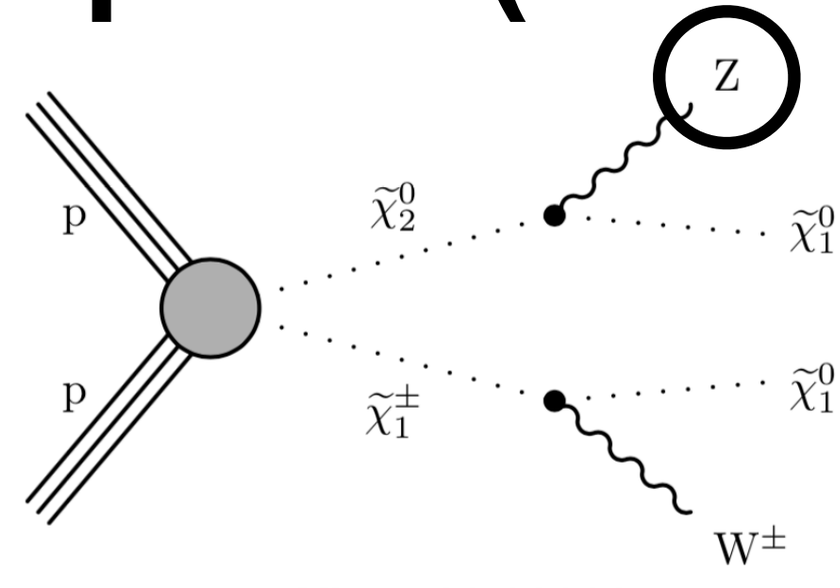
$$R = \frac{M_T^R}{M_R}$$

- Event objects clustered into “megajets”, used as j1 and j2
- MR gives mass scale
- R provides discrimination like MET



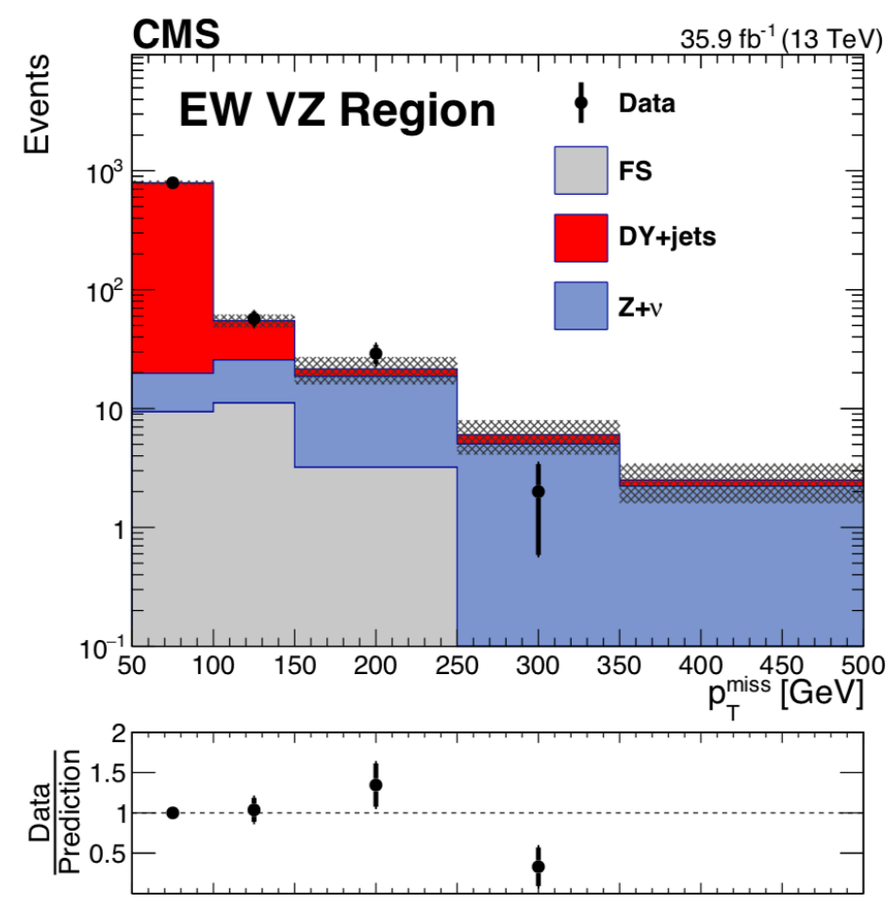
From discriminant study [Cohen et al., 2016]

Opposite-sign dilepton (on-Z)



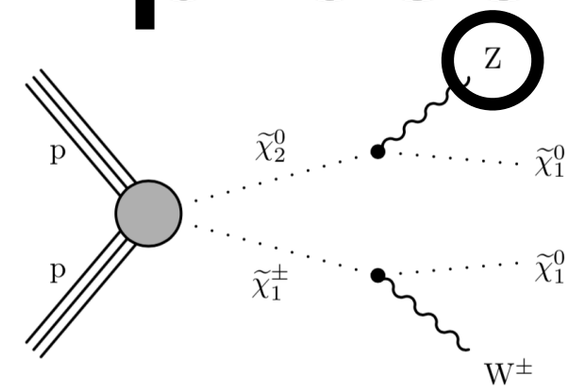
arXiv:1709.08908

- Target leptonically-decaying Z boson with hadronic decay of the W
- Events collected with di-lepton triggers, with and without isolation
- OSSF lepton pair selected with invariant mass
  - m(LL)∈[86, 96]
- Require at least 2 jets, m(JJ)<110, 0 b-tagged jets
- Require MET>100, MT2(LL)>80, MT2(LL)>80 GeV
- Categorize in MET regions: 100–150, 150–250, 250–350, and > 350 GeV

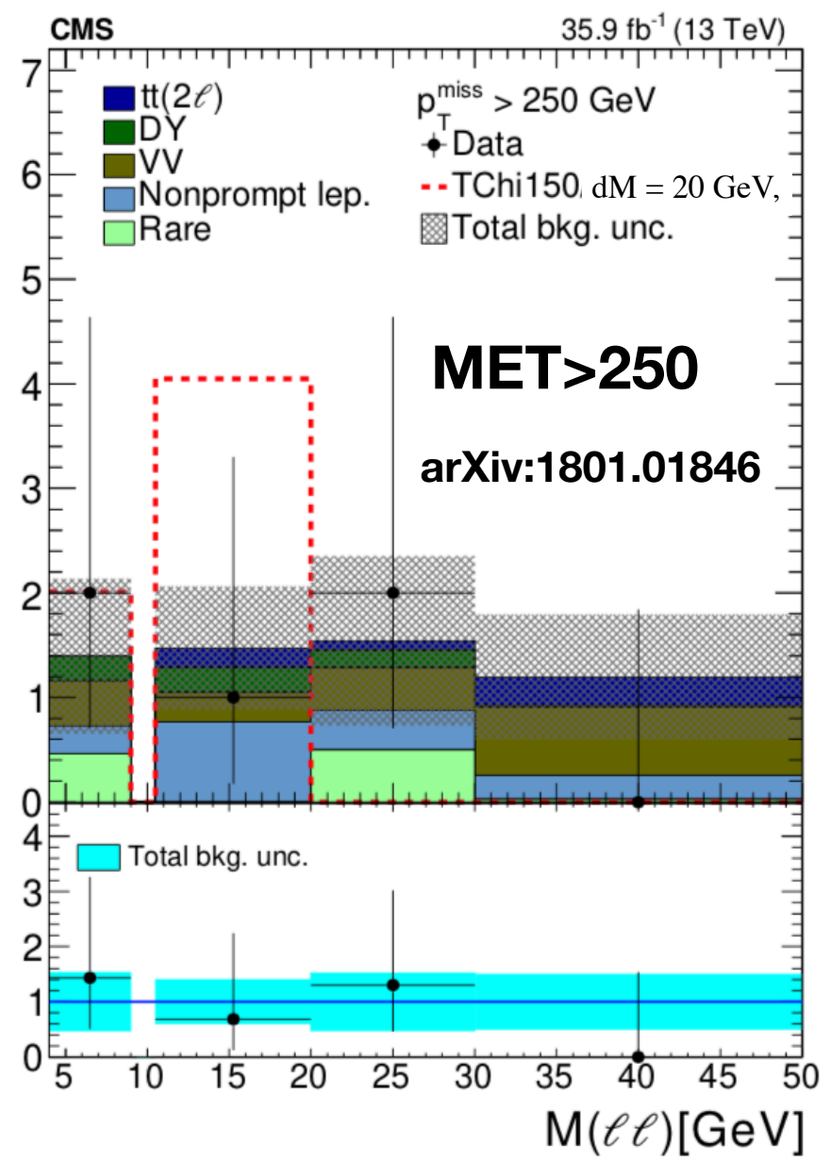


Main background in high MET tail arises from standard model WZ events, estimated with data-validated simulation

OSSF dilepton compressed

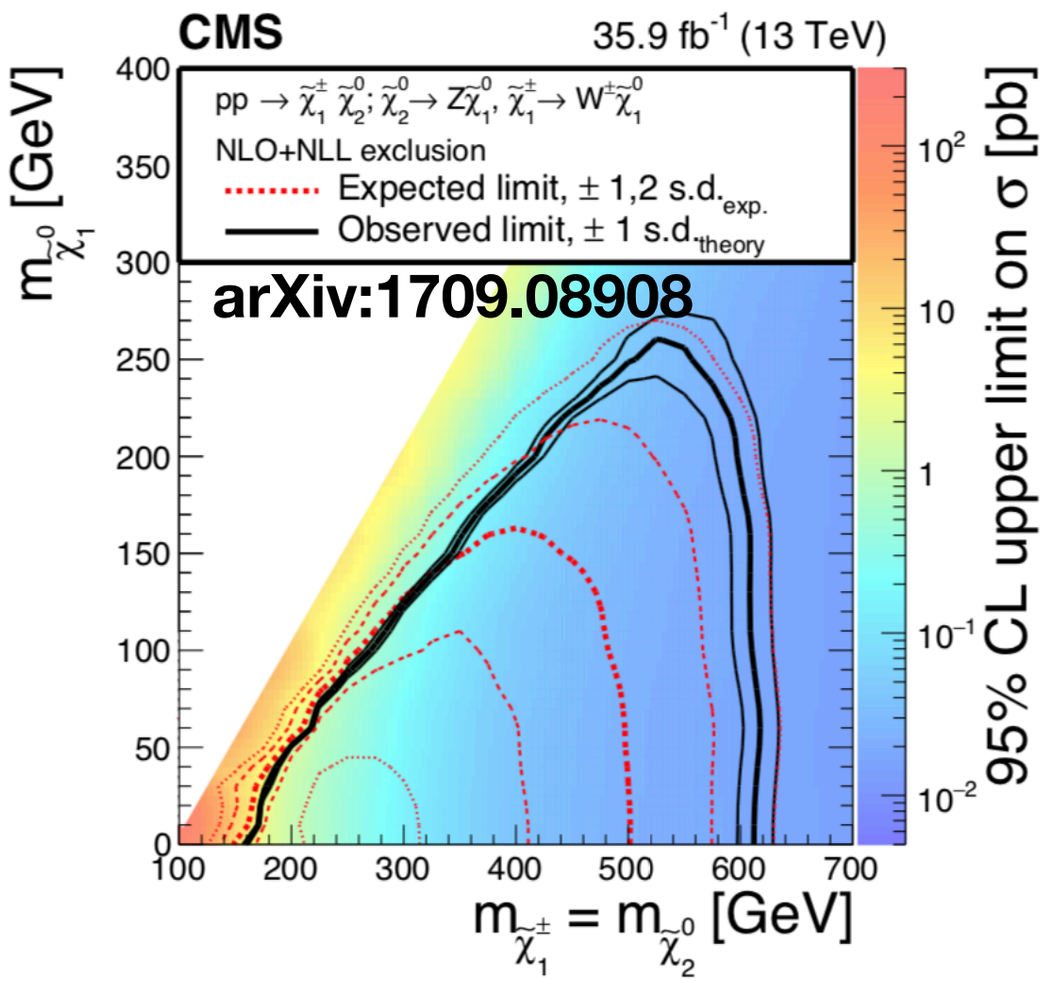


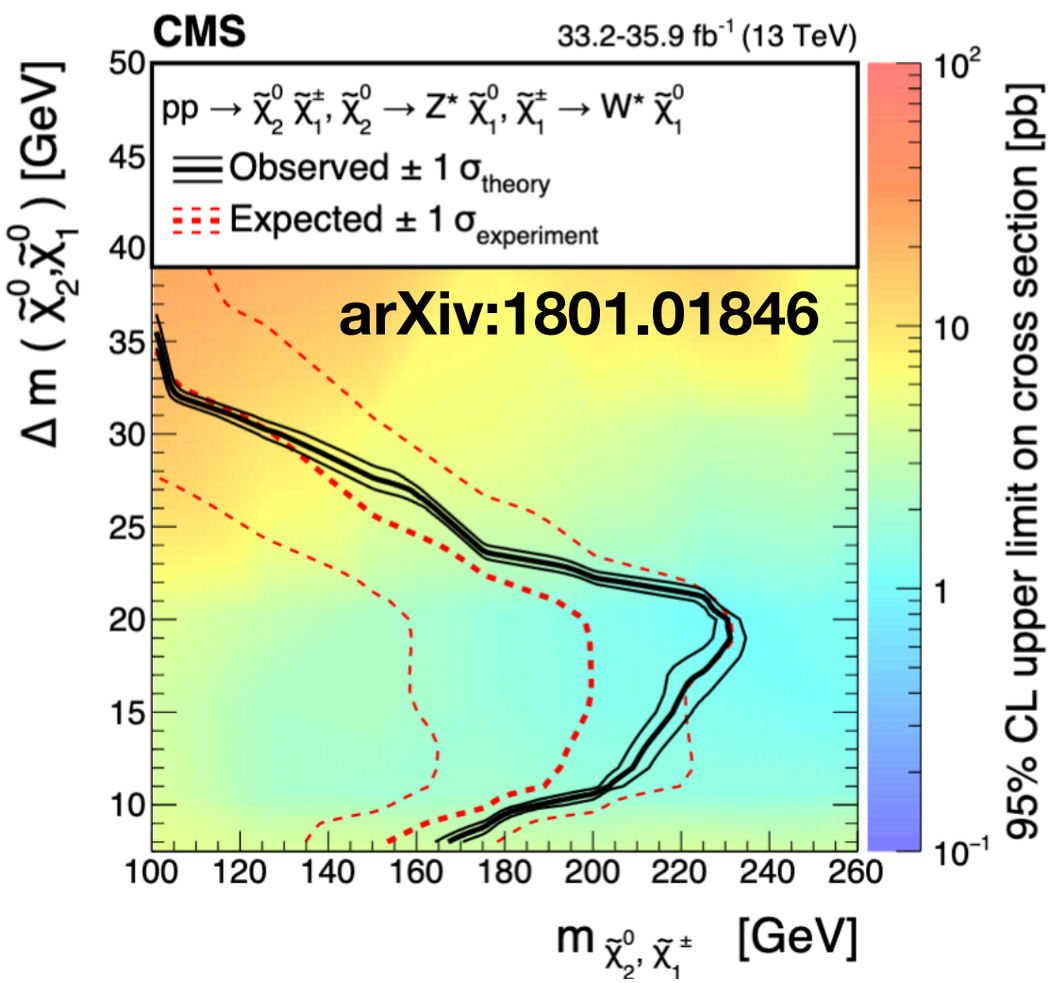
- Events triggered with MET>120 or 80 GeV
- Lepton selected with pT∈[5, 30] GeV
- OSSF loose lepton pair selected with invariant mass
  - m(LL)∈[4, 9], [10.5,50] GeV
- 0 b-tagged jets, other kinematic cuts
- Require MET>200 for ee (125 for μμ) GeV
- Categorize in MET regions: 125–200, 200–250, and > 250 GeV



Main background: events with 1 prompt+ 1fake lepton in W+jets events. A tight-to-loose ratio is applied in a loose application region

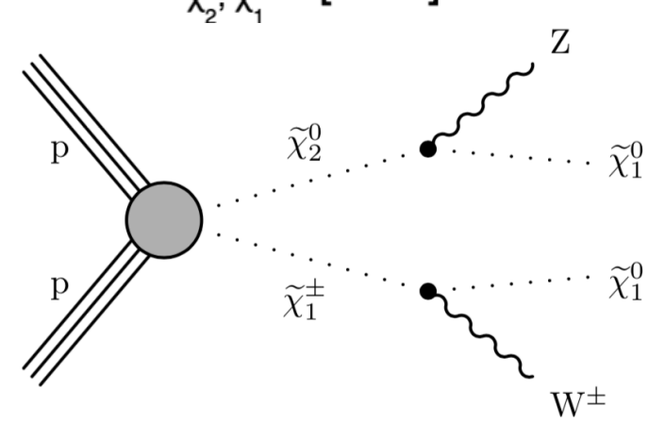
Results (OSSF lepton)





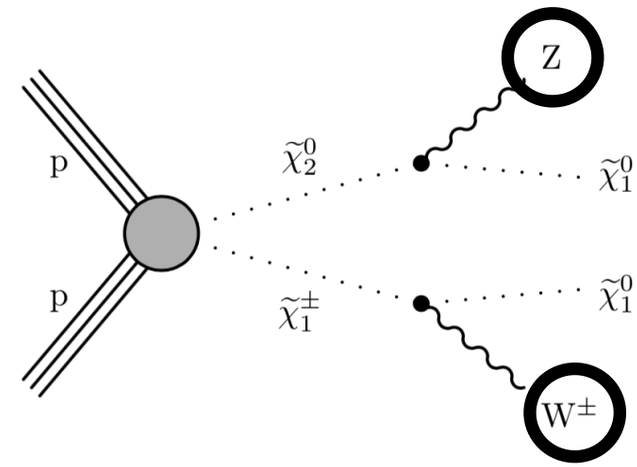
Red/black contours show 95% exclusion for wino-like cross sections

Good complementarity between search strategies



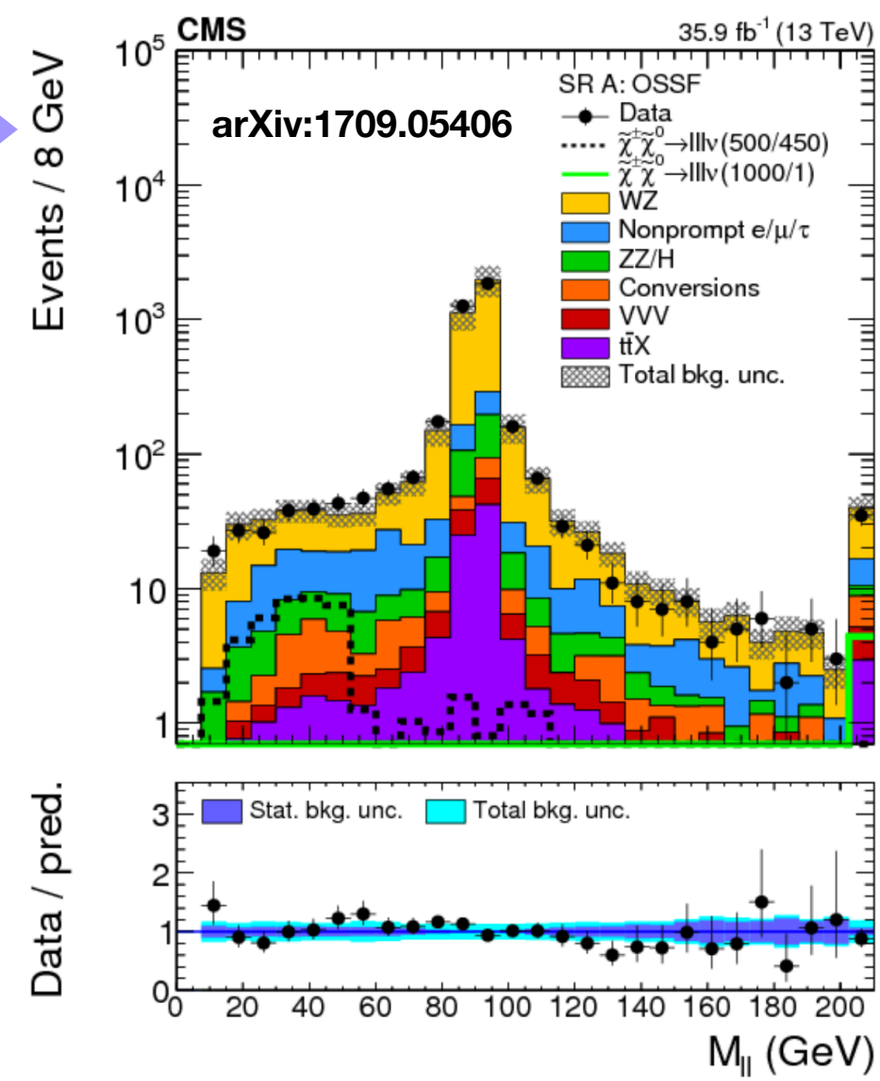
Three or more leptons

- Select event with three leptons (at most 2 *τs*)
  - pT > 25 (20) GeV for leading e (μ)
  - pT > 15 (10) GeV for sub-leading e (μ)



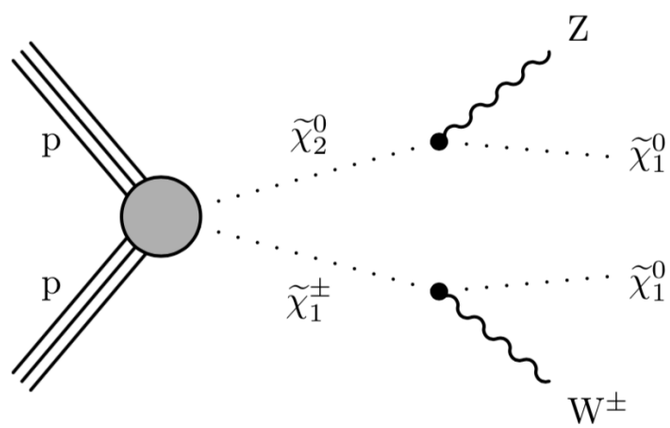
Many categories, *each* optimised:

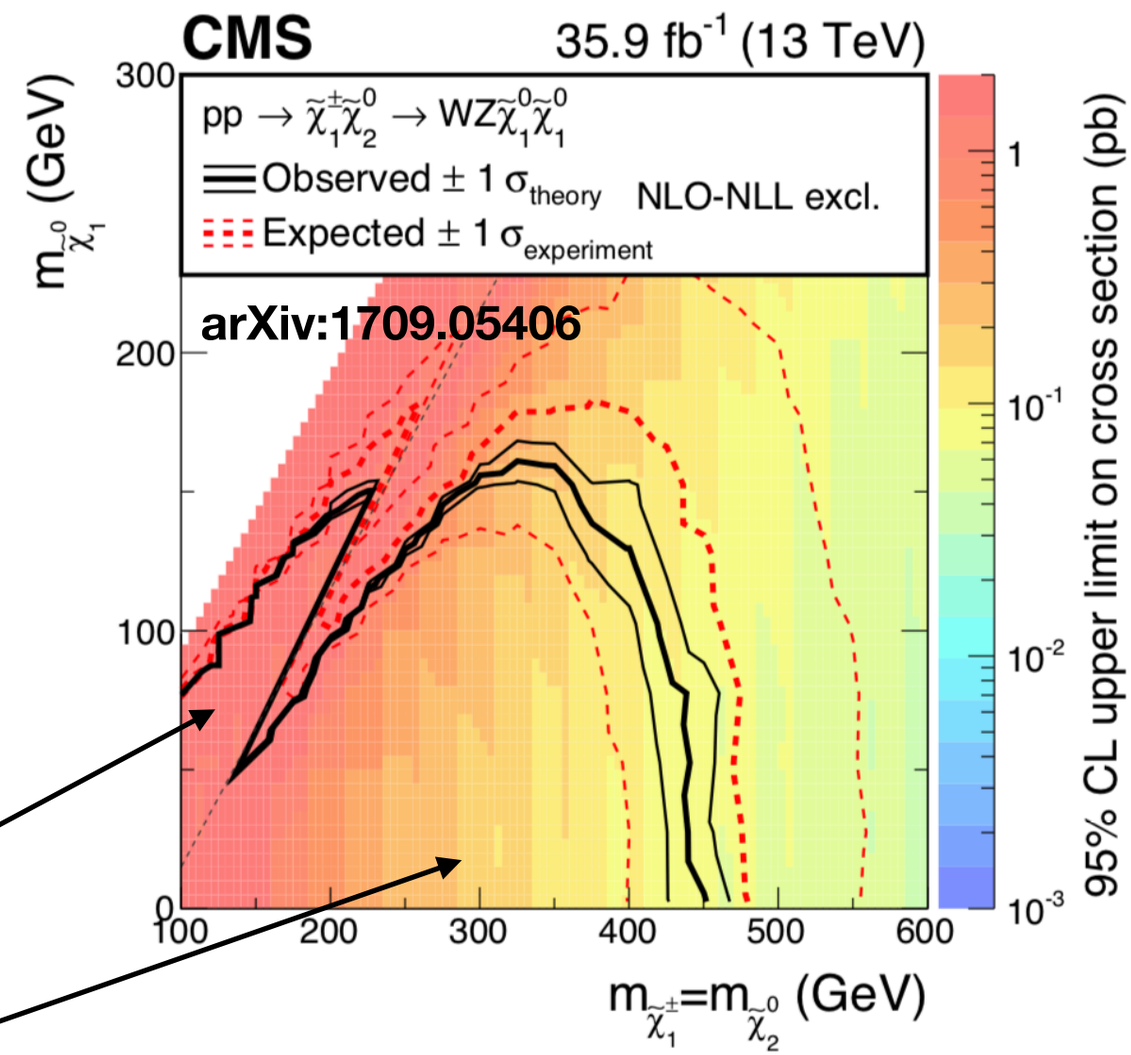
- 3 light-flavor leptons (e or μ)
- 2 light-flavor leptons and a *τ*
- 1 light-flavor lepton and 2 *τ*s
- >3 light-flavor leptons and 0 *τ*
- >2 light-flavor leptons and 1 *τ*
- >1 light-flavor leptons and 2 *τ*



Further split by presence of OSSF pair, M(LL) regions [0,75], [75, 105], [105,∞] GeV

Results multi-lepton

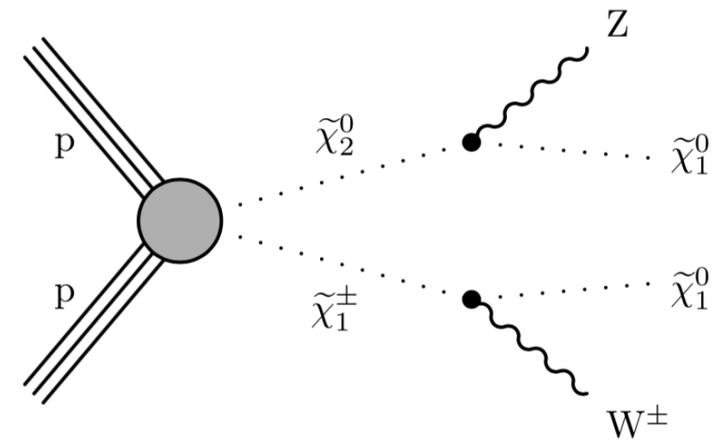


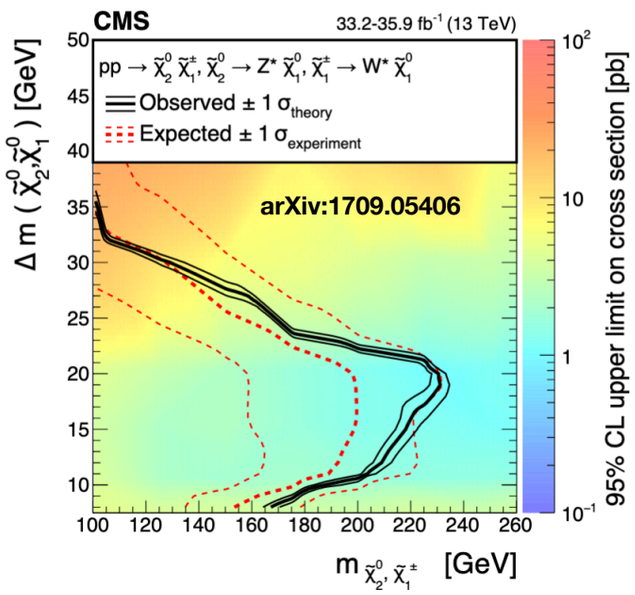


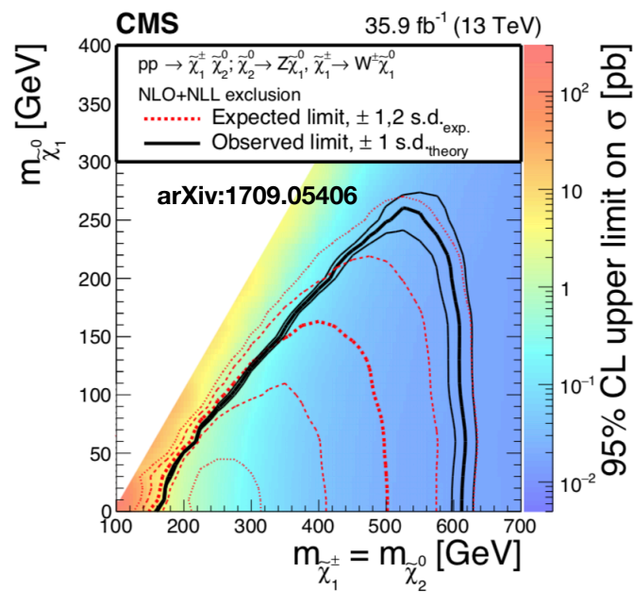
M(LL) regions [0,75], [75, 105], [105,∞]

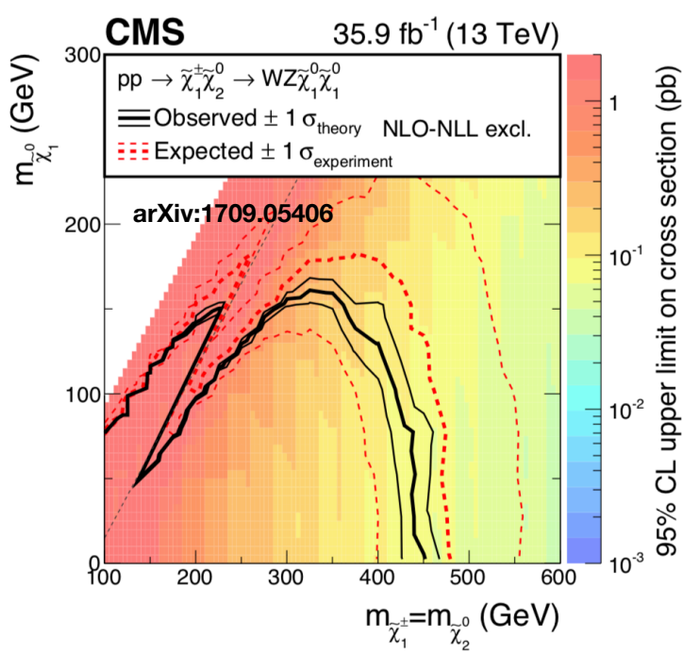
Red/black contours show 95% exclusion for wino-like cross sections

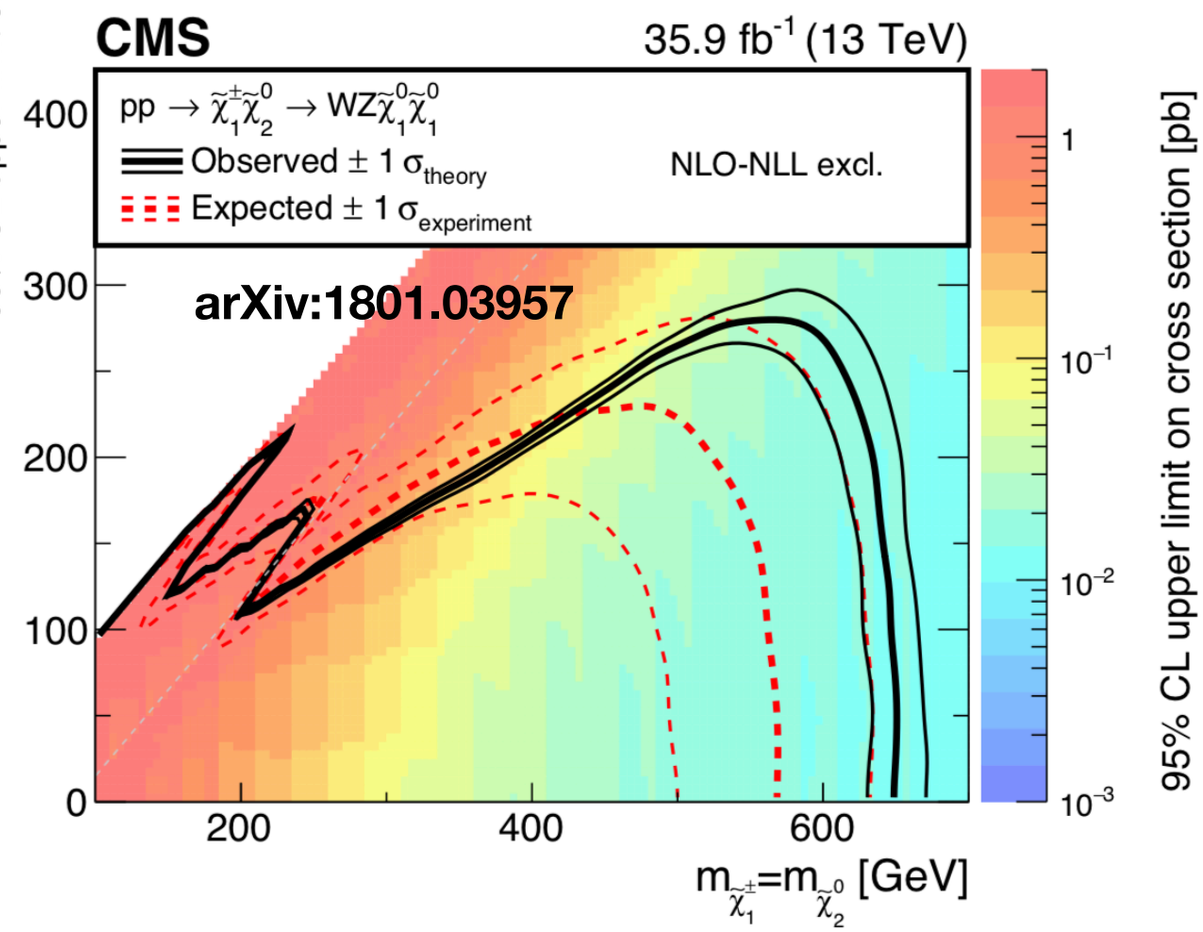
Combination of OSSF and multi-lepton searches









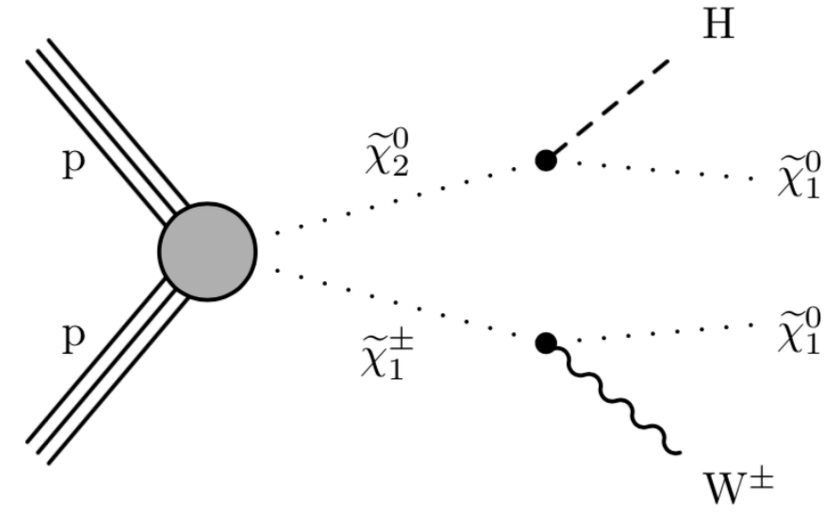


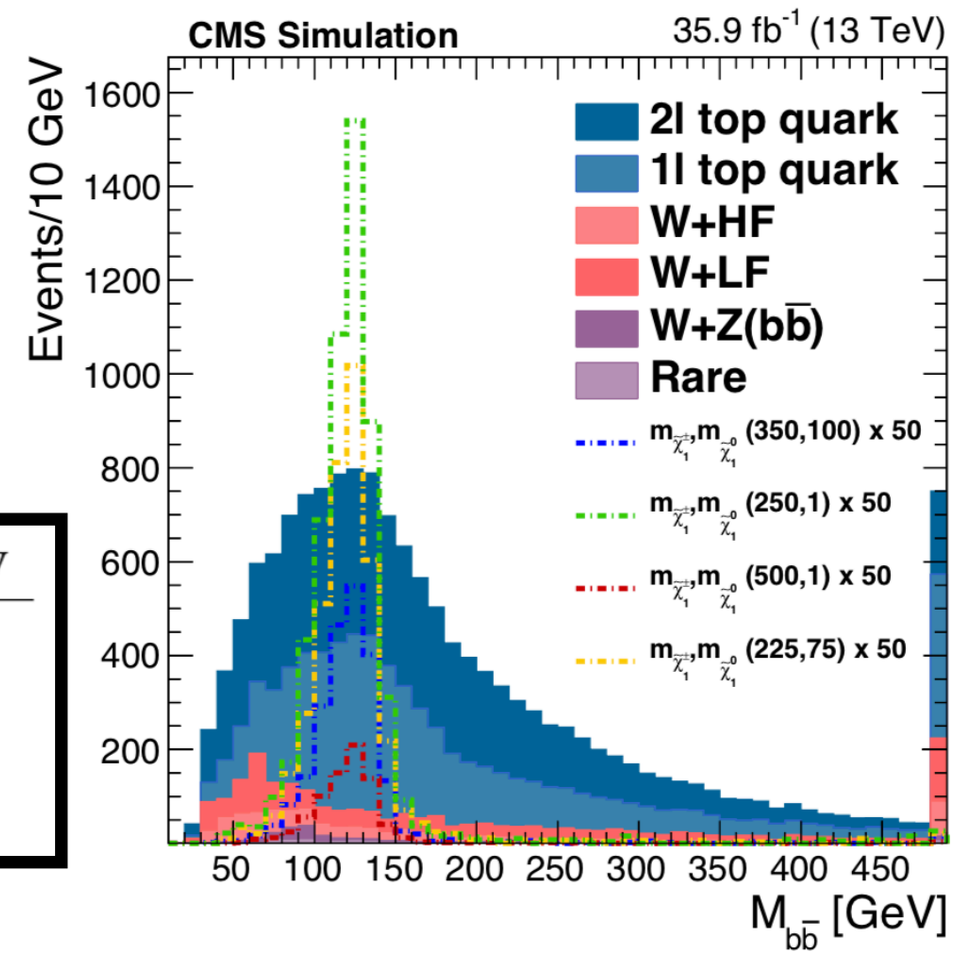
Combination arXiv:1801.03957

Red/black contours show 95% exclusion for wino-like cross sections

Higgs+MET (h->bb)

- Data samples collected with single-electron and single-muon triggers
- Require
  - exactly 1 lepton with pT > 30 (25) GeV for central e (μ)
  - exactly 2 jets with pT > 30 GeV, b-tagged
- Require
  - MET>125, MT > 50 GeV
  - MCT(bb)>170 GeV
- Require m(bb)∈[90,150] GeV
- Categorize events in MET slices

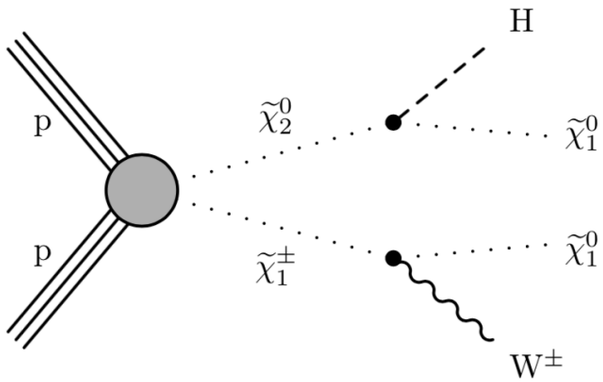




arXiv:1706.09933

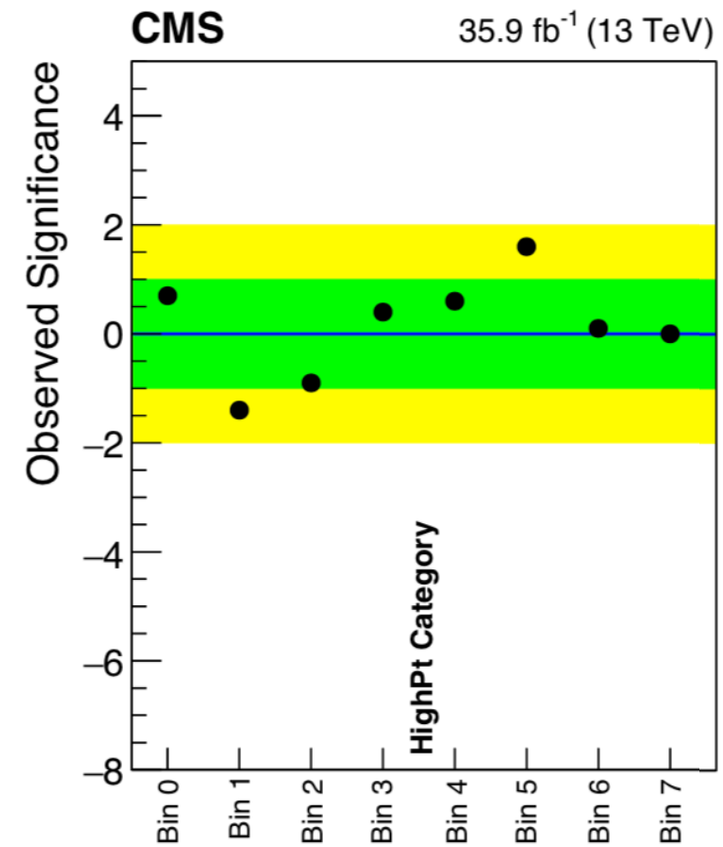
	$125 \leq E_T^{miss} < 200$ GeV	$E_T^{miss} \geq 200$ GeV
Total SM background	7.5 ± 2.5	8.7 ± 2.2
Data	11	7
$\tilde{\chi}_1^\pm \tilde{\chi}_1^0$ (225,75)	2.4 ± 0.4	2.3 ± 0.4

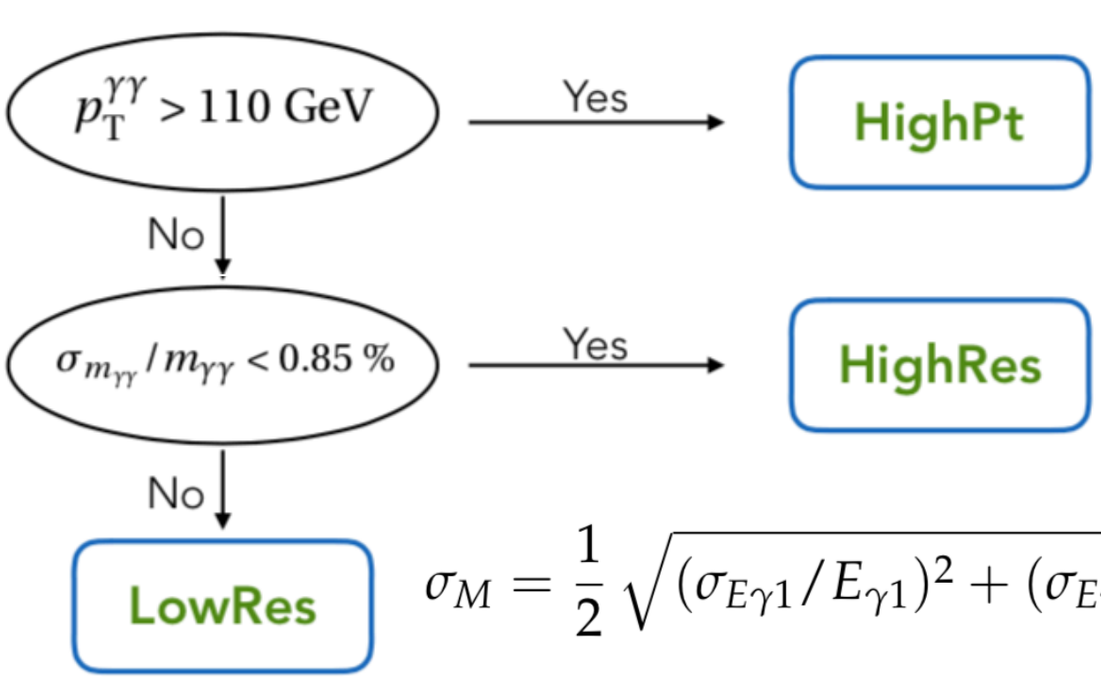
arXiv:1709.00384



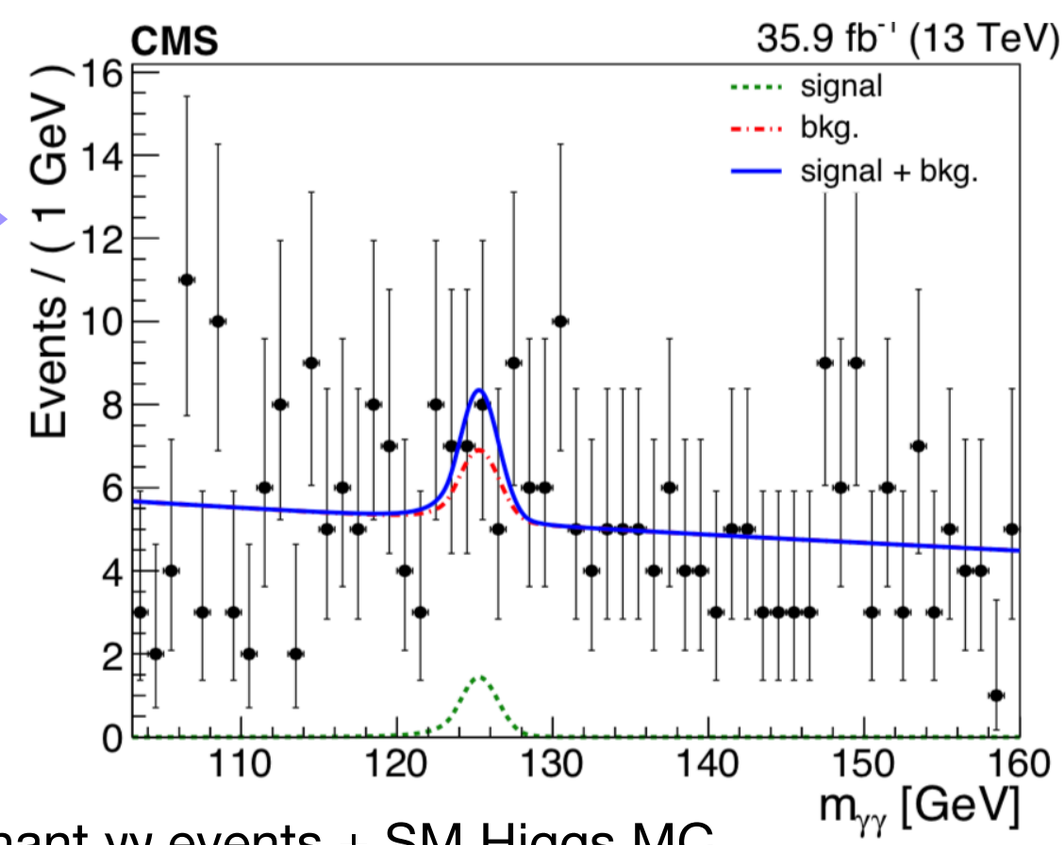
Higgs+Met
(h->γγ)

- Data samples collected with diphoton trigger
- Require exactly 2 barrel photons with pT >40 (20) GeV for leading (sub-leading), $|\eta| < 1.44$
- m(γγ)∈[103,160] GeV
- At least one additional jet with pT>30 $|\eta| < 3$
- Selection with Razor variables and binning in terms of photon resolution



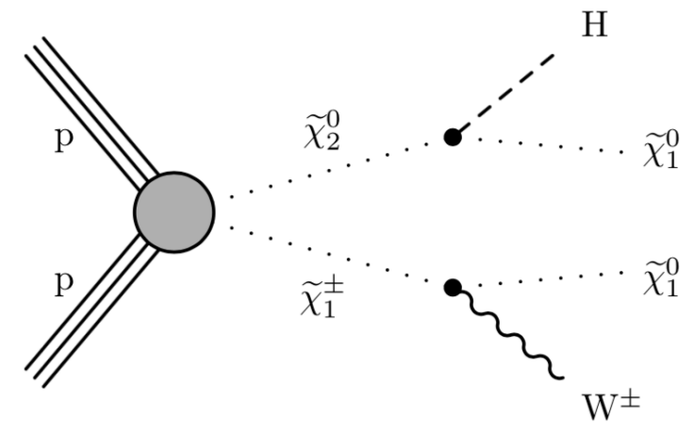


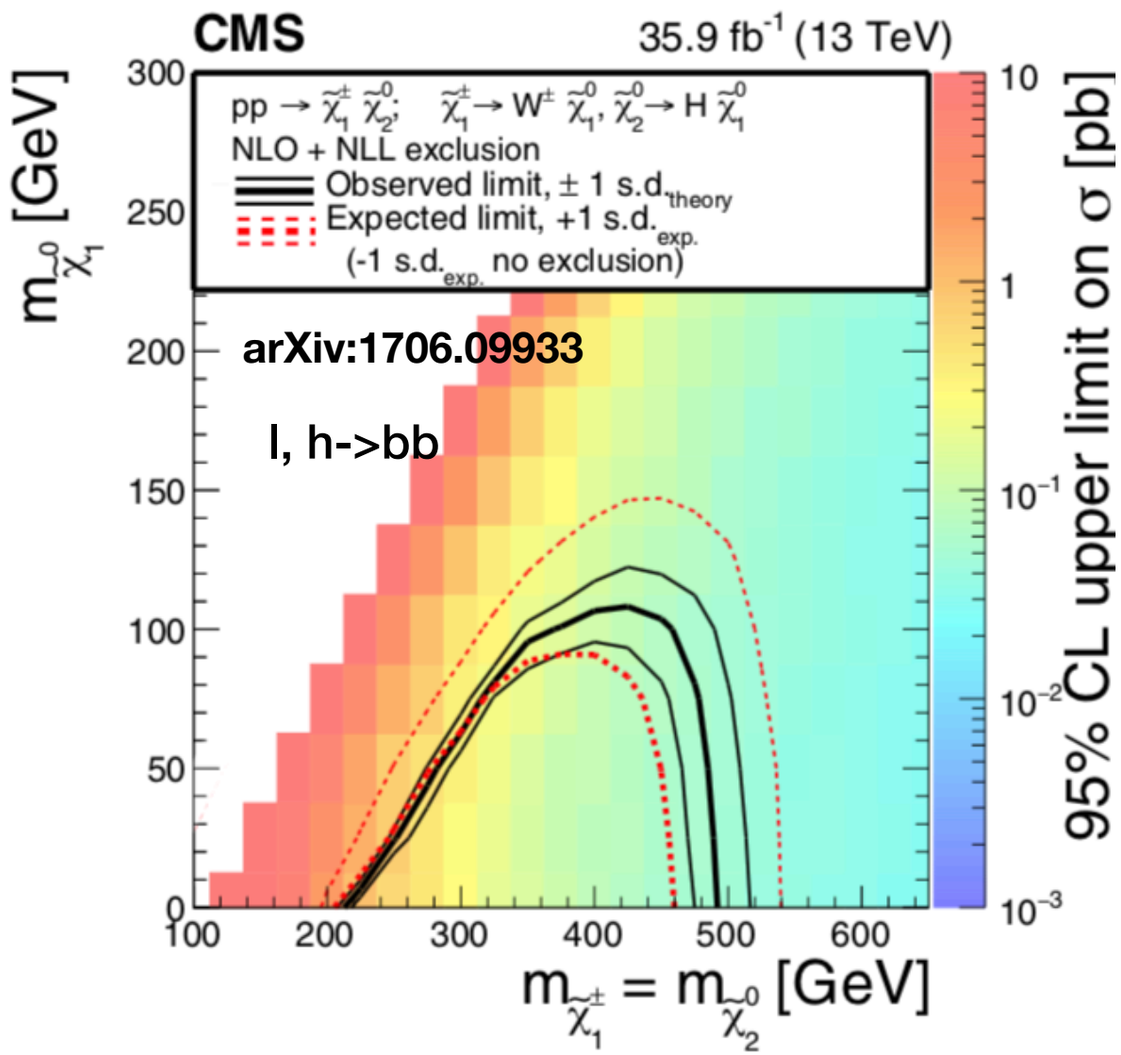
$$\sigma_M = \frac{1}{2}\sqrt{(\sigma_{E\gamma 1}/E_{\gamma 1})^2 + (\sigma_{E\gamma 2}/E_{\gamma 2})^2}$$

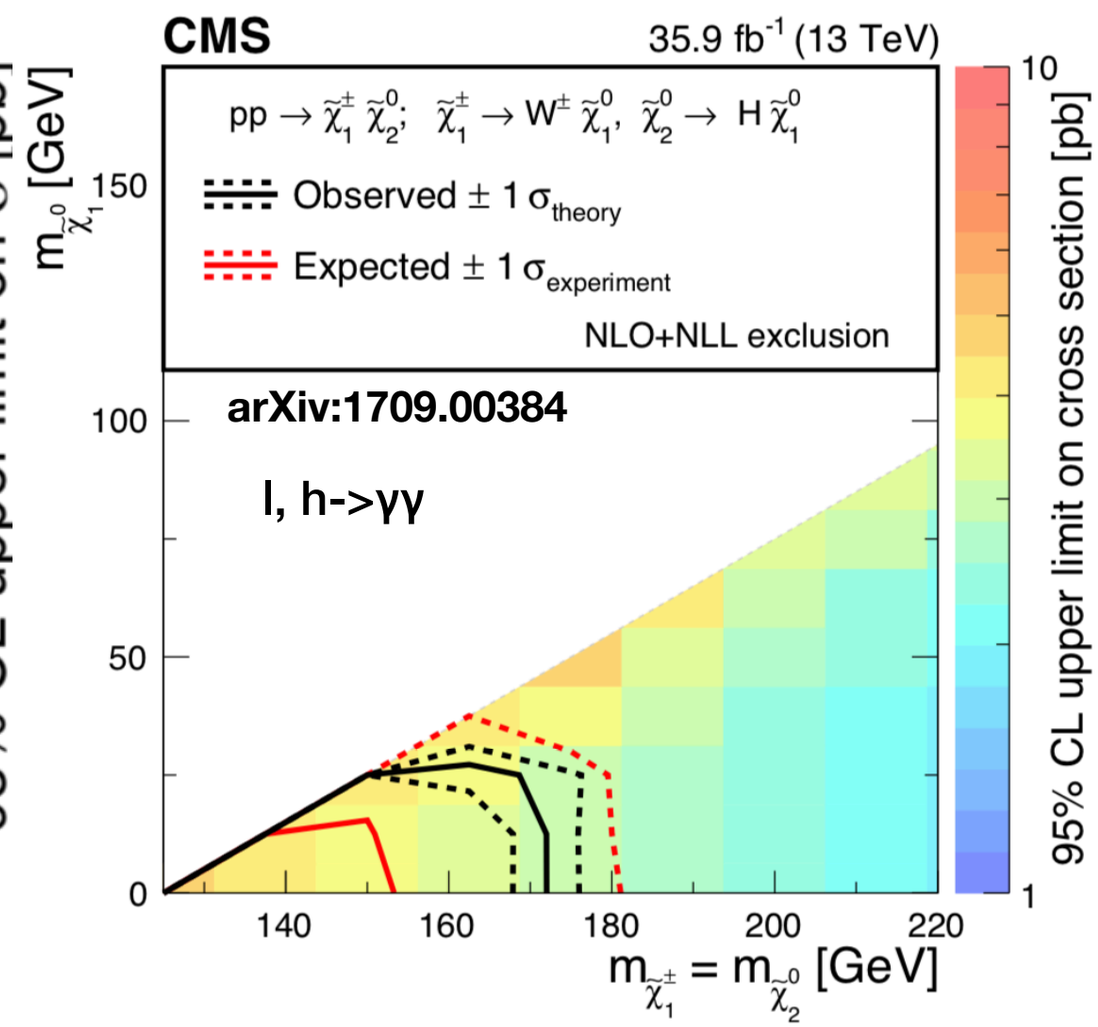


Background determined by global fit to model of non-resonant γγ events + SM Higgs MC

Results Higgs+MET (h->bb and h->γγ)

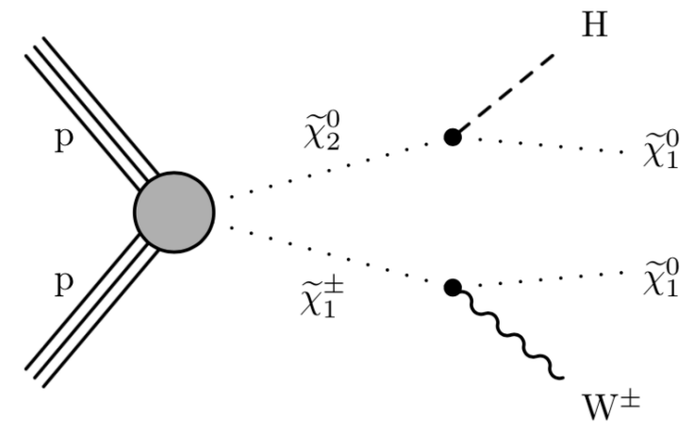


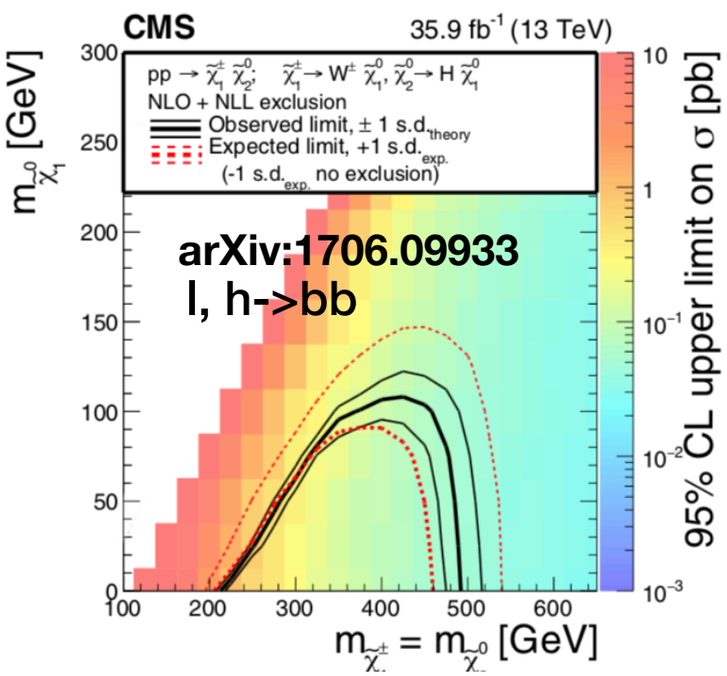


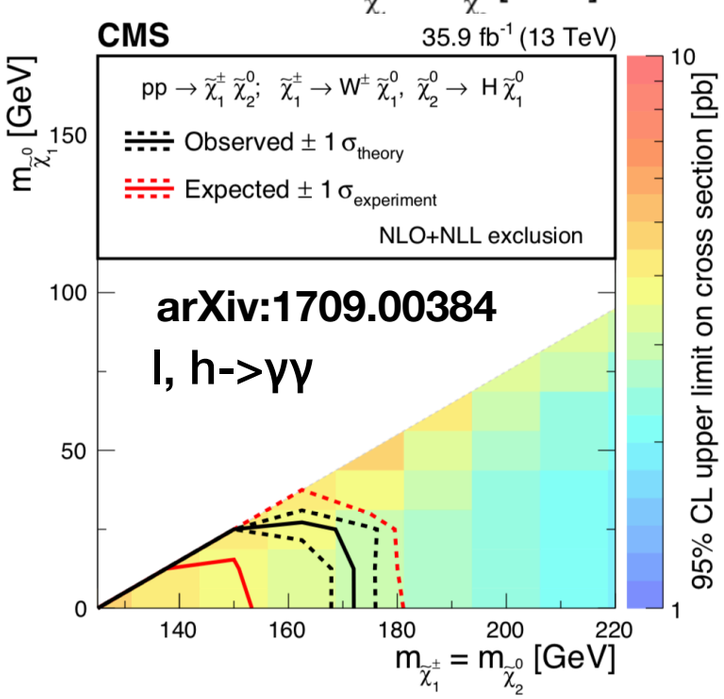


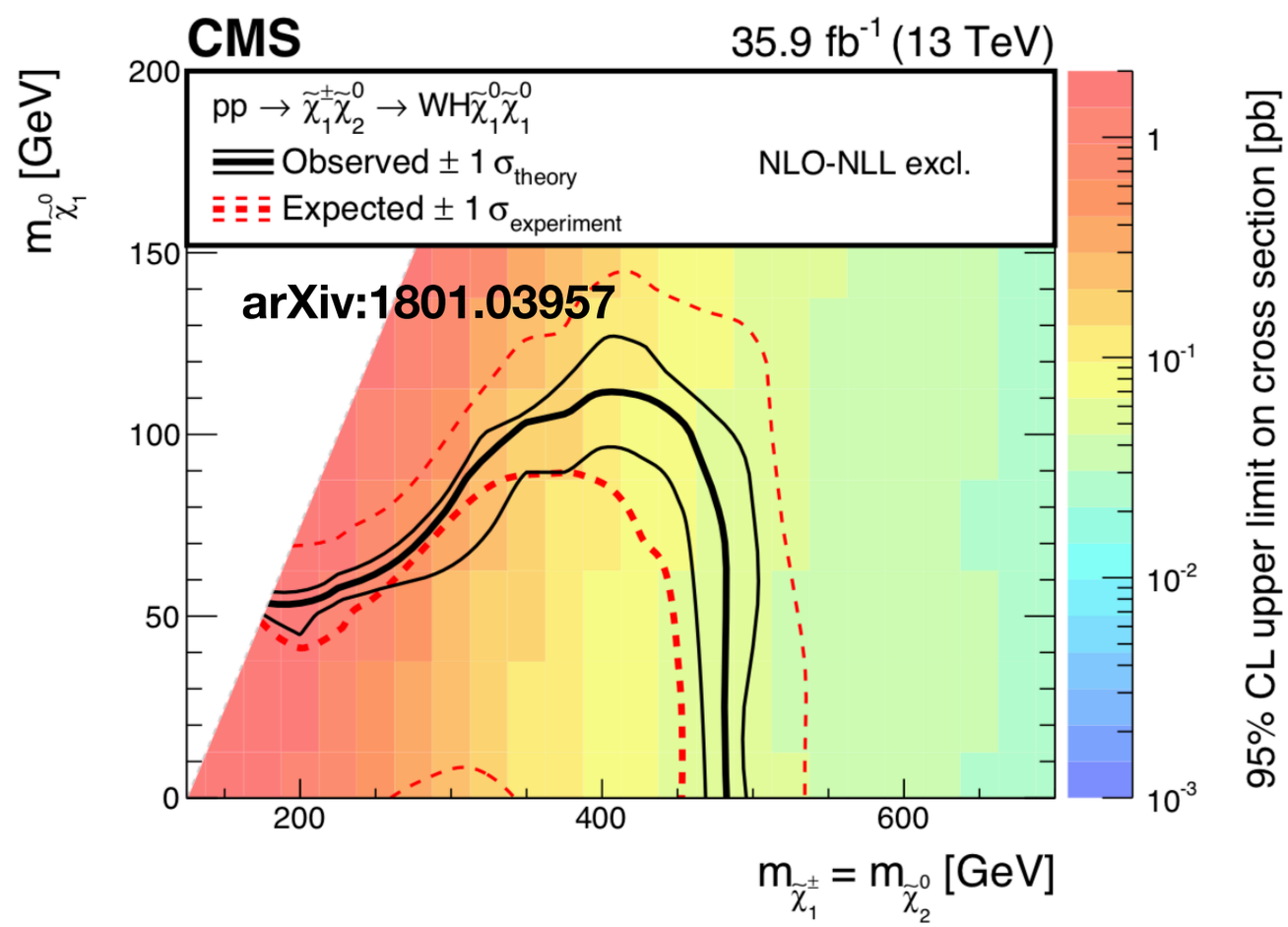
Red/black contours show 95% exclusion for wino-like cross sections

Combination Higgs+MET (h->bb and h->γγ)





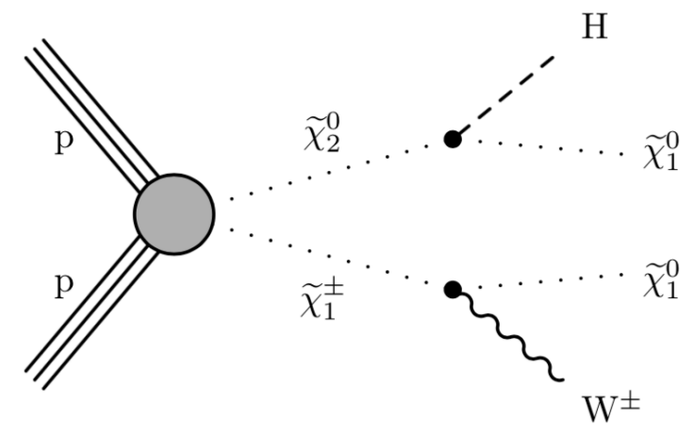




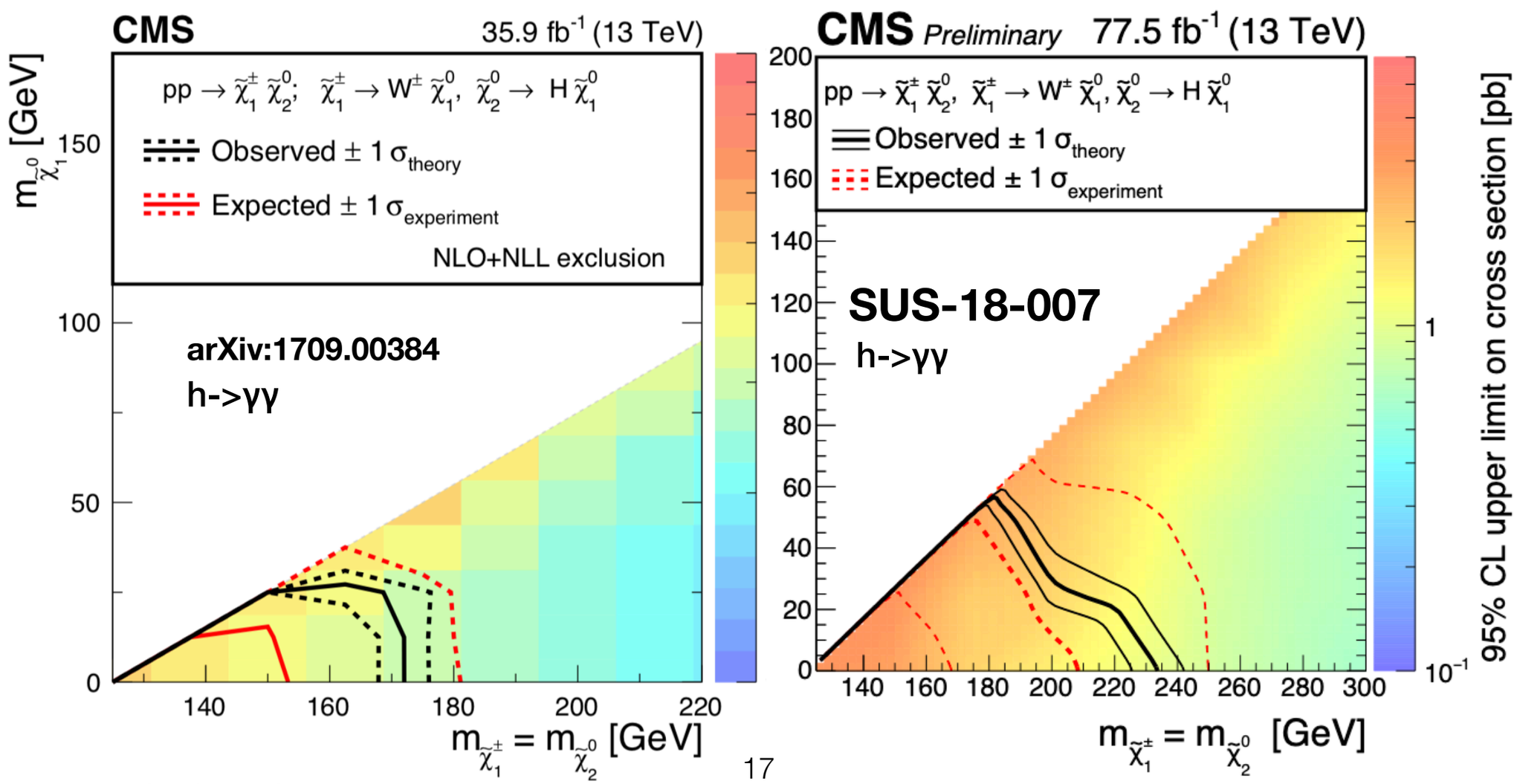
Combination arXiv:1801.03957

Red/black contours show 95% exclusion for wino-like cross sections

Updated analysis targeting h->γγ SUSY

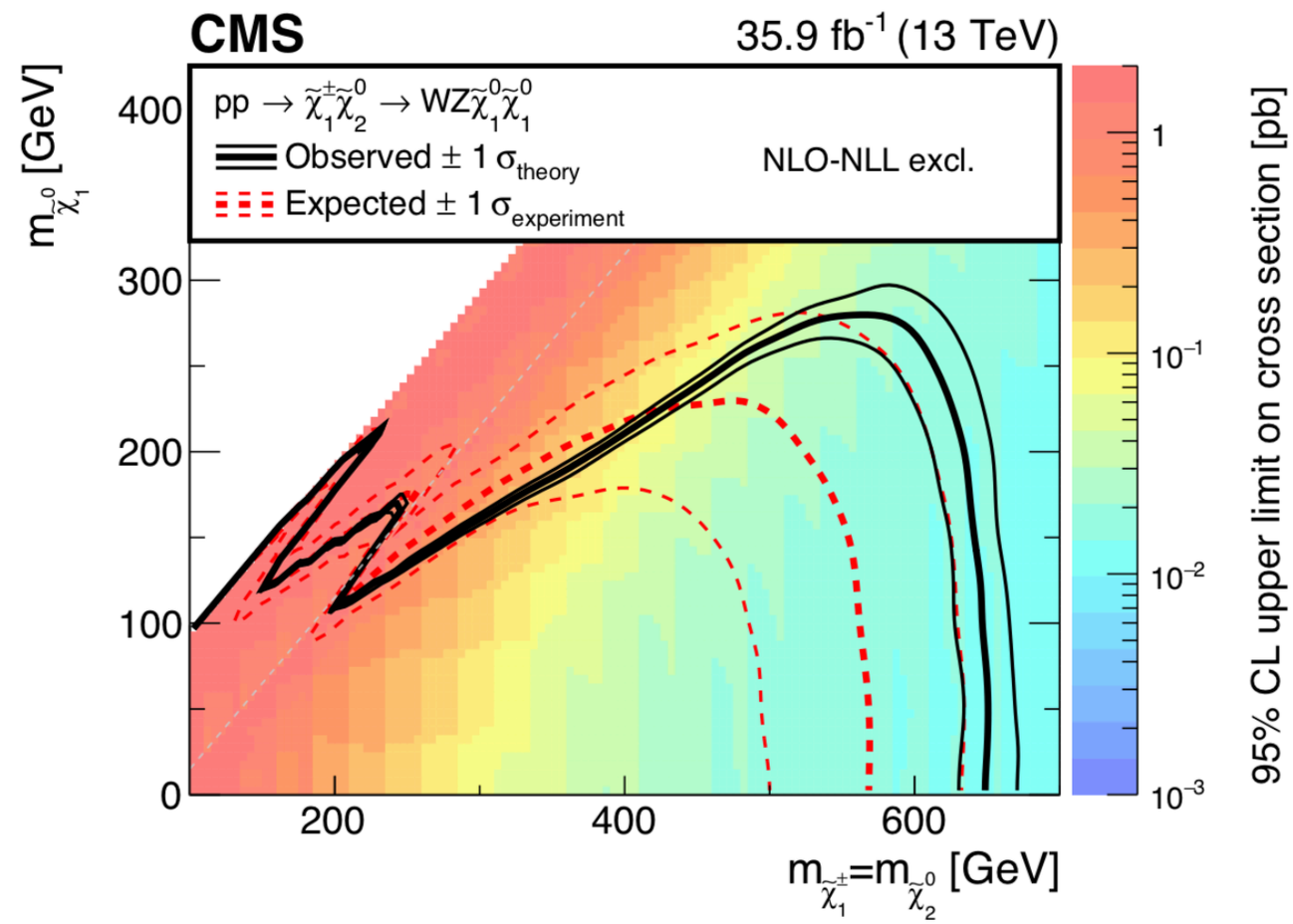


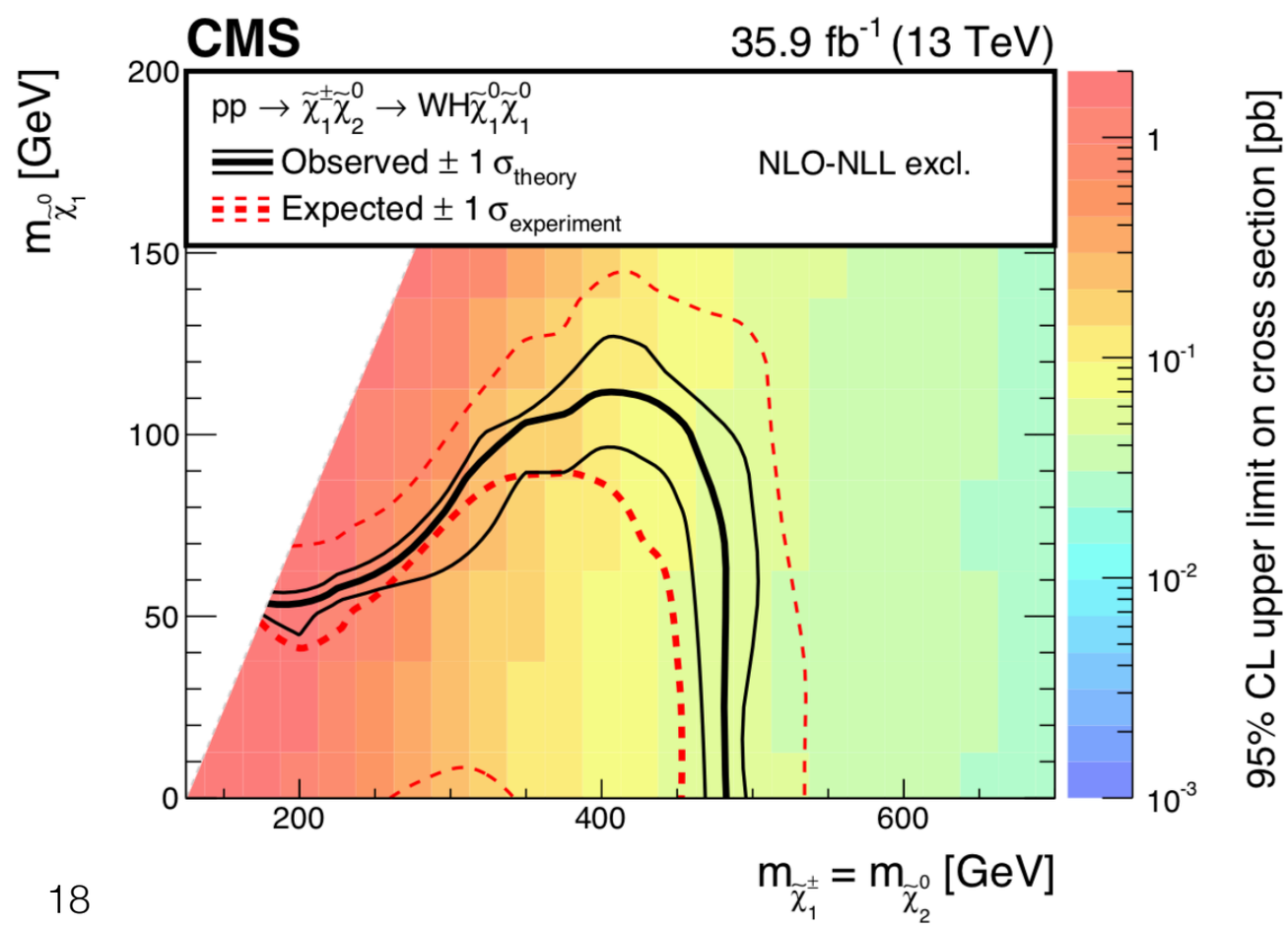
- 2016+2017 dataset used
- Additional categories based on lepton multiplicity and re-optimised selection
- Improved exclusion limit by 50 GeV on the heavier EWKinos



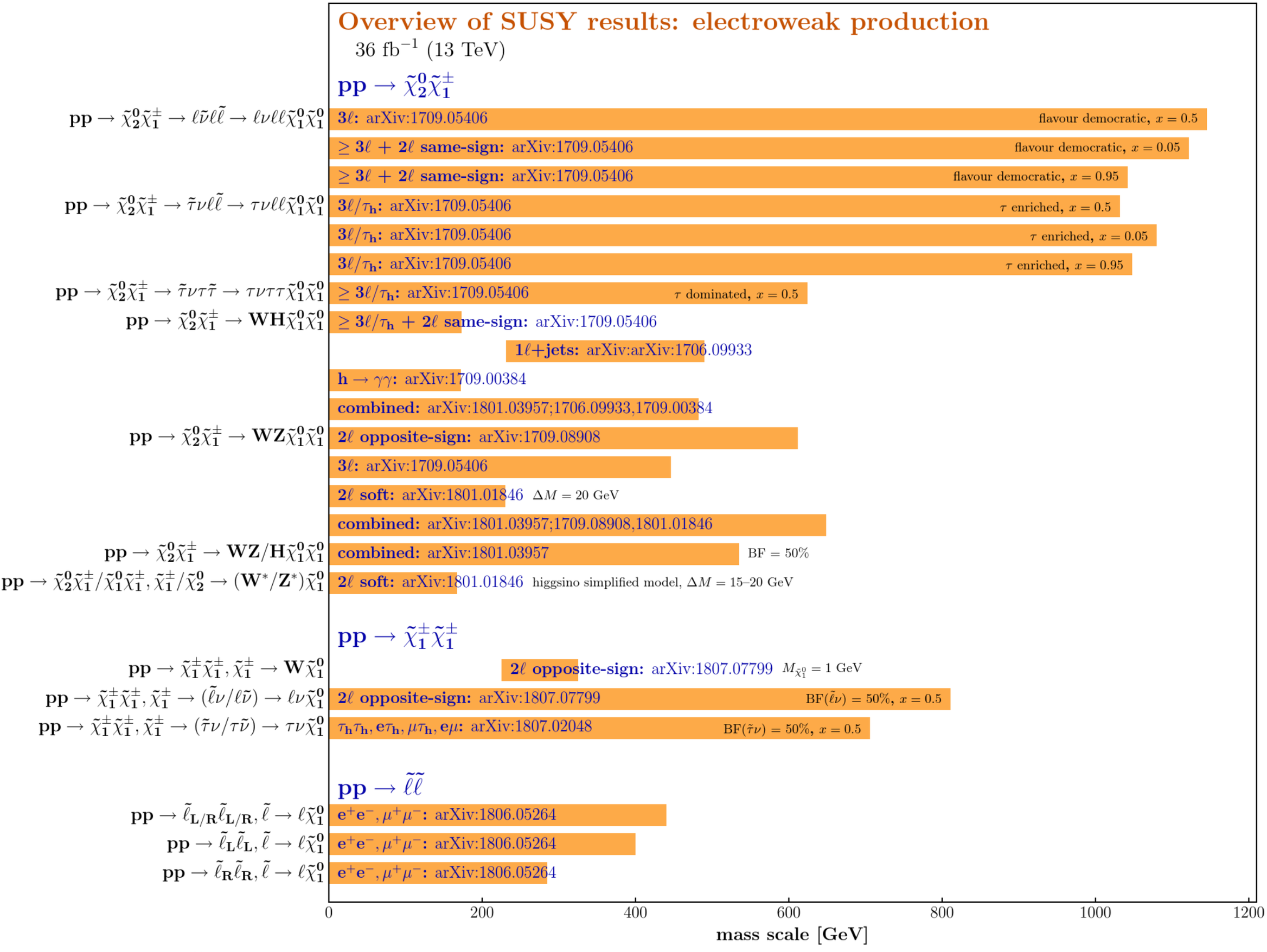
Summary

- Run 2 searches have made significant progress in constraining pure EWKinos models
- Most stringent limits on the EWKino masses for 100 GeV LSP is ~600 GeV
- Statistical combinations of final states allow for more stringent, global constraints on WZ, WH
- Naturalness is being tested, but low-mass EWKinos cannot be ruled out





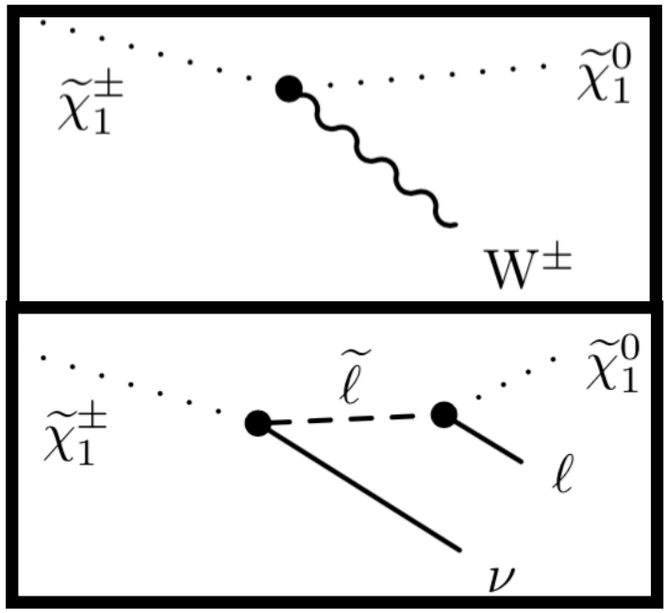
Backup



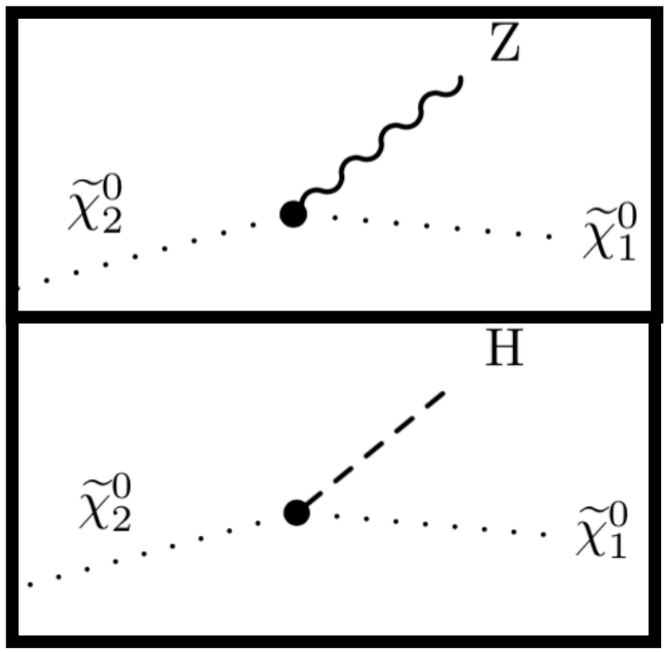
Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.

A word on decay modes

- The presence of a low-mass slepton can change the chargino branching fraction
  - Generation of slepton influences final states
    - Light staus **enhance** τ lepton final states
  - Chirality of slepton influences final state
    - Right-handed light sleptons **enhance** τ lepton final states



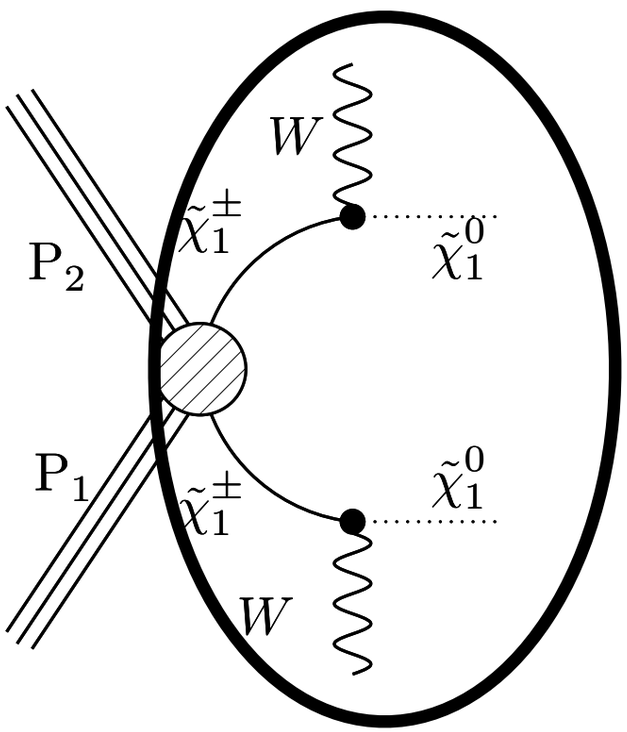
- The mixing of the EWKinos and mass differences impact the neutrino decays
  - Large mass differences can allow on-shell Higgs boson decays of the neutrinoChirality



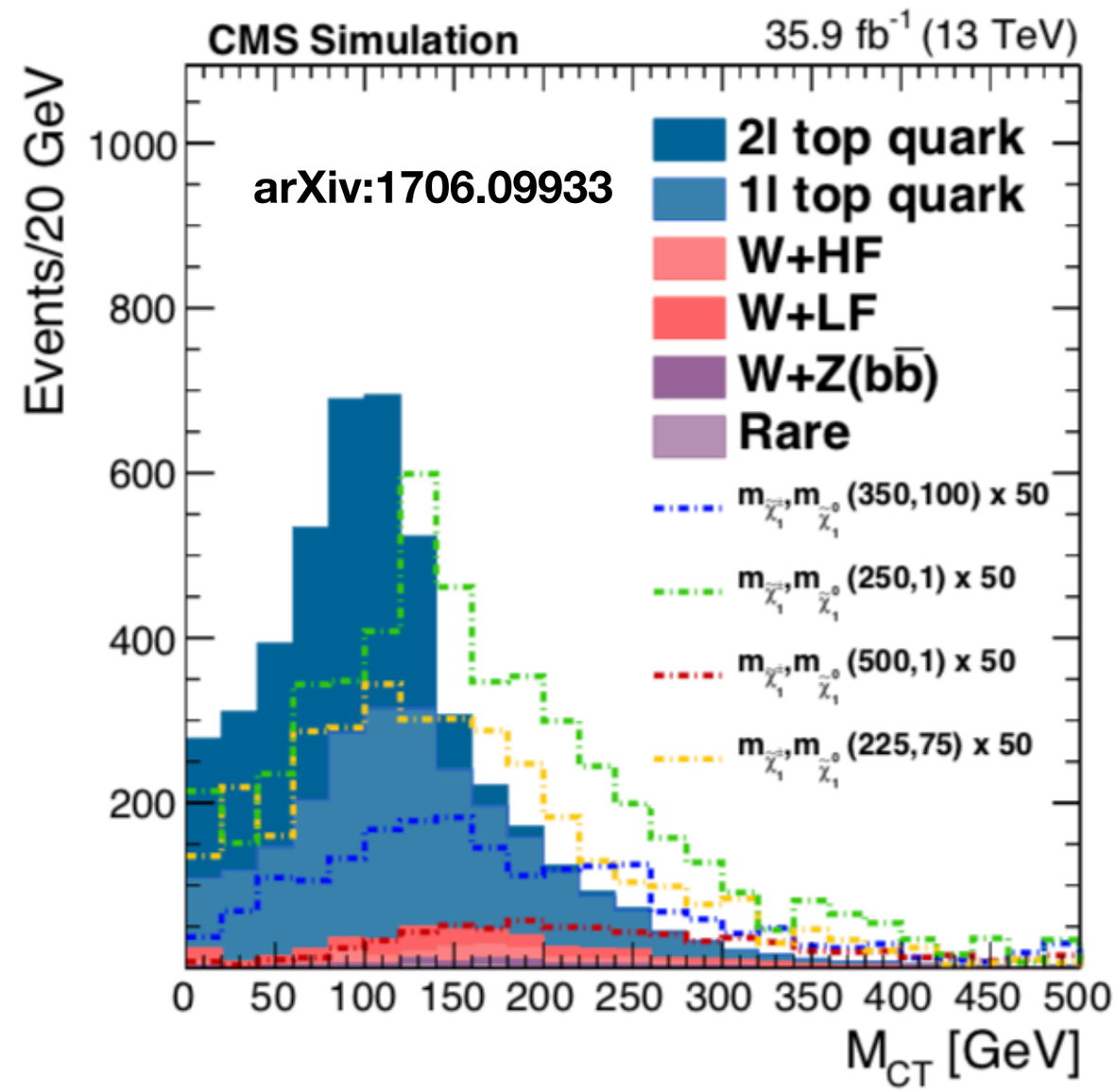
“MCT”

$$M_{CT} = \sqrt{2 p_{T1} p_{T2} (1 + \cos[\Delta\varphi(\vec{p}_1, \vec{p}_2)])}$$

Contransverse mass



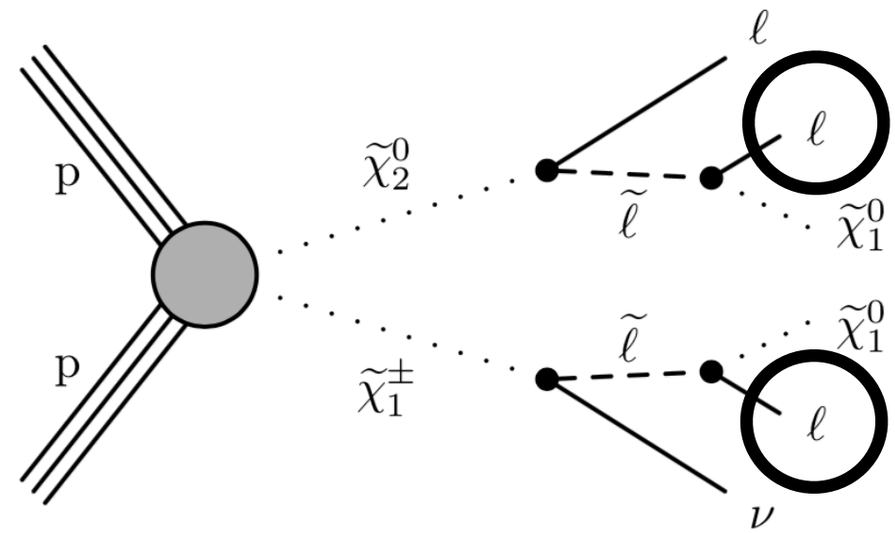
Exhibits endpoint at mass of semi-invisibly decaying pair-produced particles, without knowing about the MET



Same-sign dilepton

- Require exactly 2 tight same-charge leptons
  - pT > 25, 20 GeV (e,μ) for leading
- Veto events with OSSF pair found among all loose leptons (pT > 20, 10, 20 GeV (e,μ,τ)) with
  - abs[mLL-mZ]<15 GeV or mLL<12 GeV
- Require MET>60 GeV
- Sub-divide by n(jets)
- Further categories in di-lepton pT, MET, and MLL
- Target left-handed sleptons with masses between the EWKinos states

arXiv:1709.05406

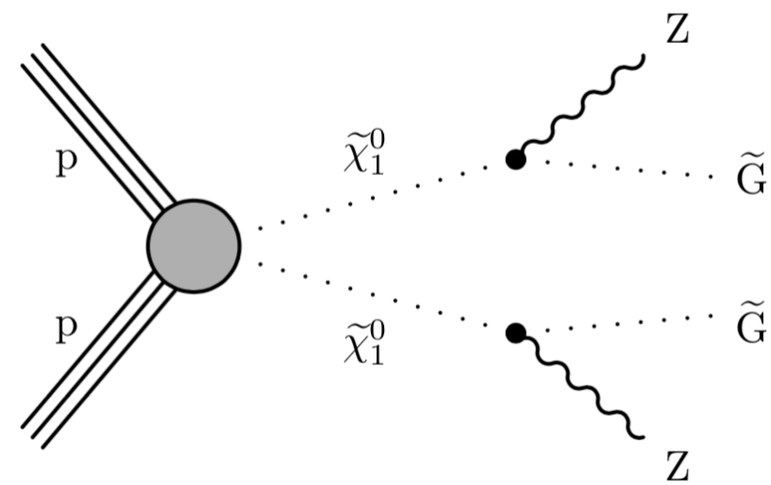


arXiv:1709.05406

N_{jets}	$100 \leq p_T^{\text{miss}} < 150\,\text{GeV}$	$150 \leq p_T^{\text{miss}} < 200\,\text{GeV}$	$p_T^{\text{miss}} \geq 200\,\text{GeV}$
0	SS02 (++) SS03 (−−)	SS04	SS05
	SS07 (++) SS08 (−−)	SS09	SS10
	SS12 (++) SS13 (−−)	SS14	SS15
1	SS17 (++) SS18 (−−)	SS19	SS20
	SS22 (++) SS23 (−−)	SS24	SS25
	SS27 (++) SS28 (−−)	SS29	SS30

Three or more light leptons

- Require exactly 2 tight same-charge leptons
  - pT > 25, 20 GeV (e,μ) for leading



Many categories, *each* optimised:

- 3 light-flavor leptons (e or μ)
- 2 light-flavor leptons and a τ
- 1 light-flavor lepton and 2 τs
- >3 light-flavor leptons and 0 τ
- >2 light-flavor leptons and 1 τ
- >1 light-flavor leptons and 2 τ

arXiv:1709.05406

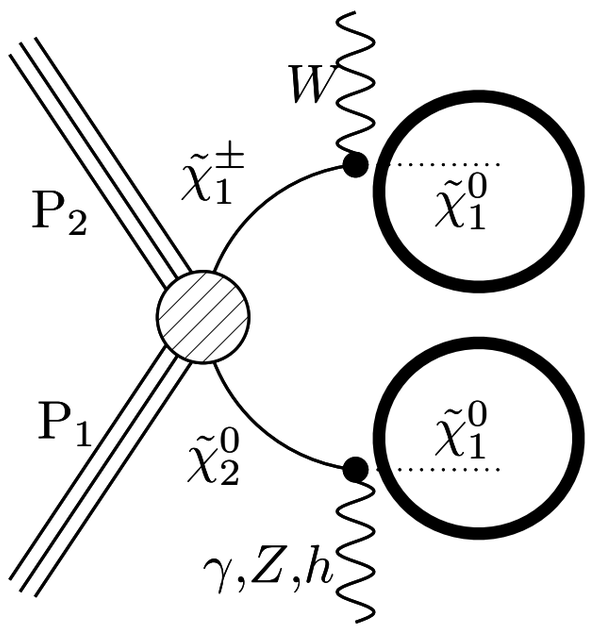
p_T^{miss} (GeV)	$0\tau_h$		$1\tau_h$
	nOSSF ≥ 2	nOSSF < 2	nOSSF ≥ 0
$0-50$	G01	H01	I01
$50-100$	G02	H02	I02
$100-150$	G03	H03	I03
$150-200$	G04	H04	I04
≥ 200	G05		

Further split by presence of OSSF pair, regions of invariant mass MLL

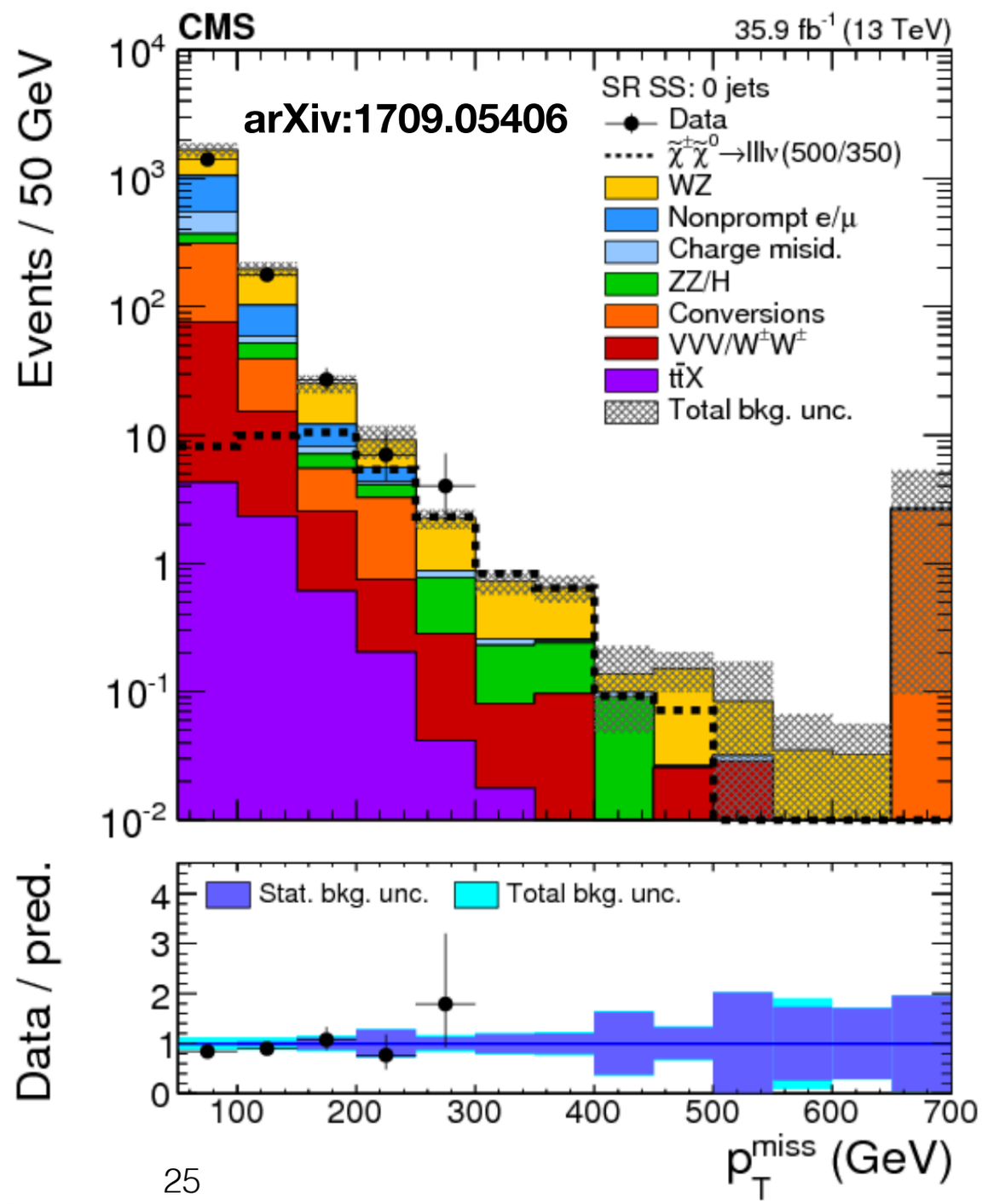
“MET”

$$E_T^{miss} = p_T^{miss} = \left| -\sum_{particles} \vec{p}_T \right|$$

Missing transverse energy/momentum



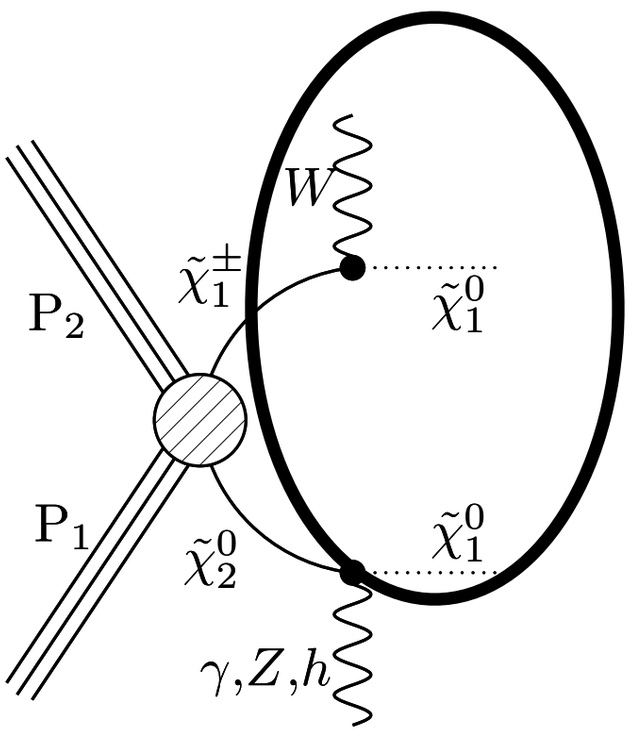
Undetected particles in the final state can carry large momentum

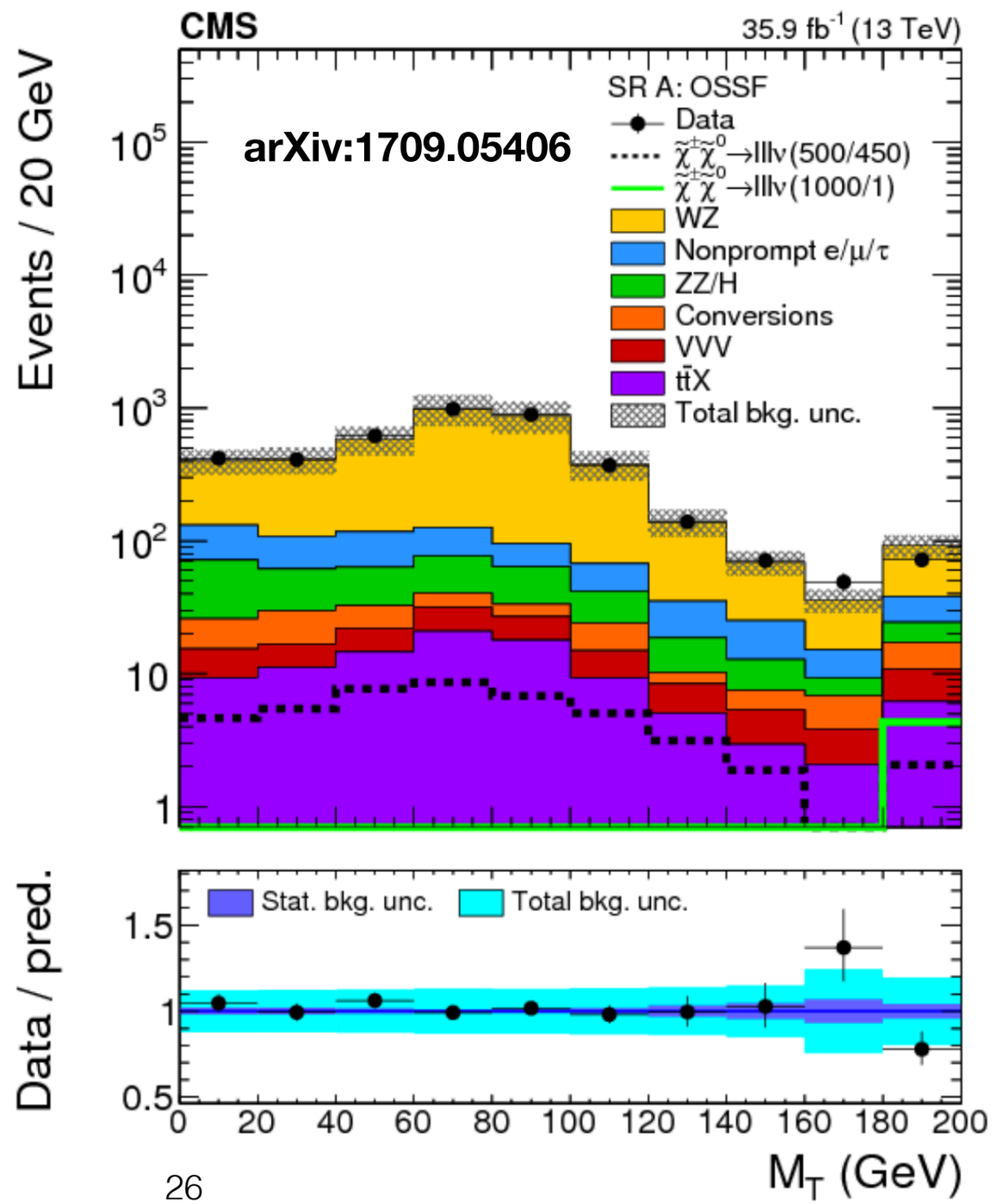


“MT”

$$M_T = \sqrt{2 p_T(l) p_T^{miss} (1 - \cos[\Delta\varphi(lep, p_T^{miss})])}$$

Transverse mass



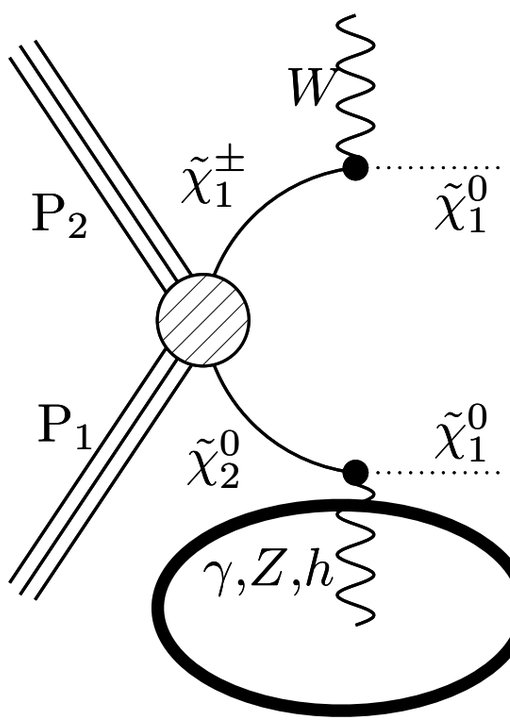


Background exhibits a smeared endpoint near the W mass

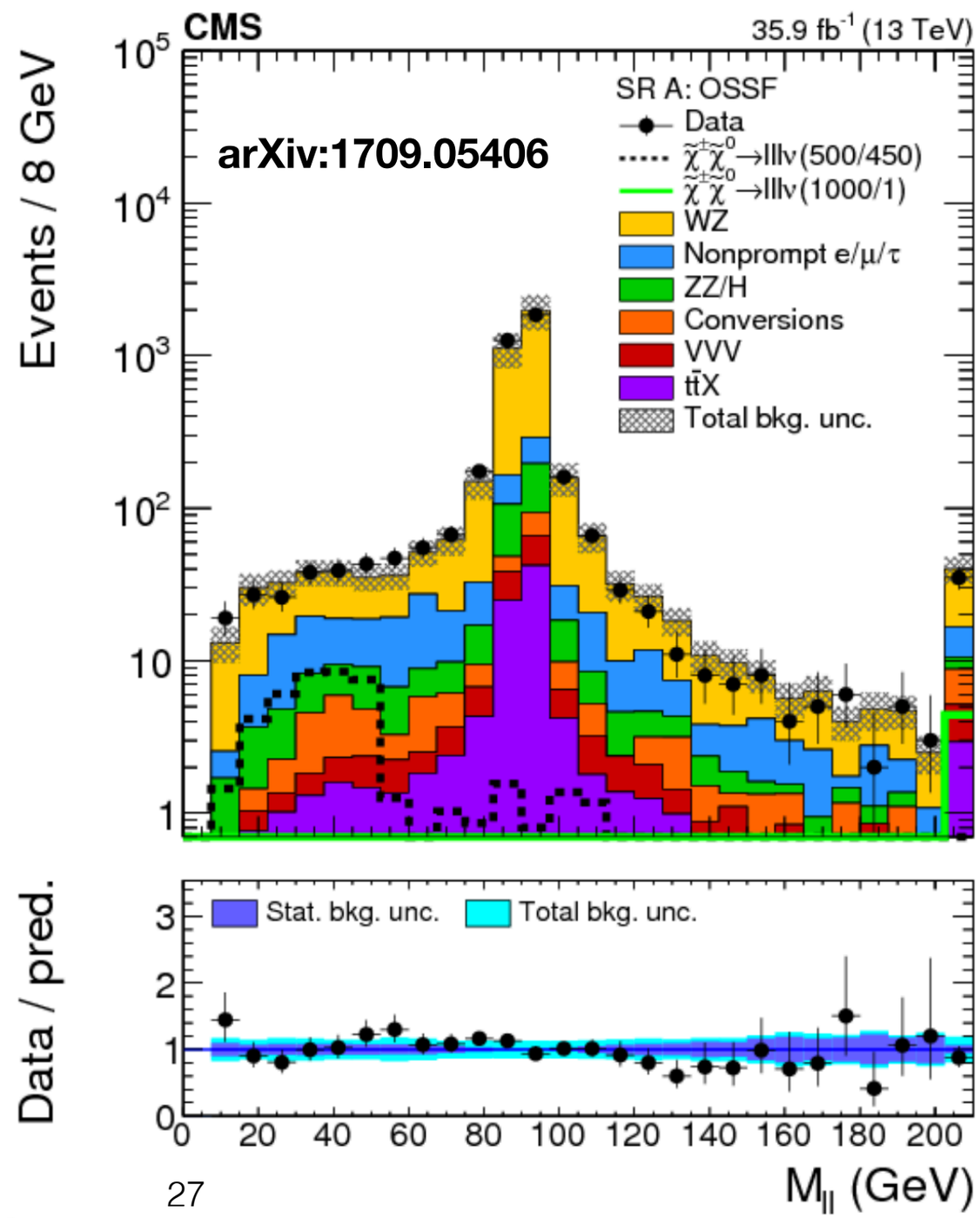
“MLL”

$$M_{ll} = \sqrt{(|p_{L1}| + |p_{L2}|)^2 - (|\vec{p}_{L1} + \vec{p}_{L2}|)^2)}$$

Invariant mass



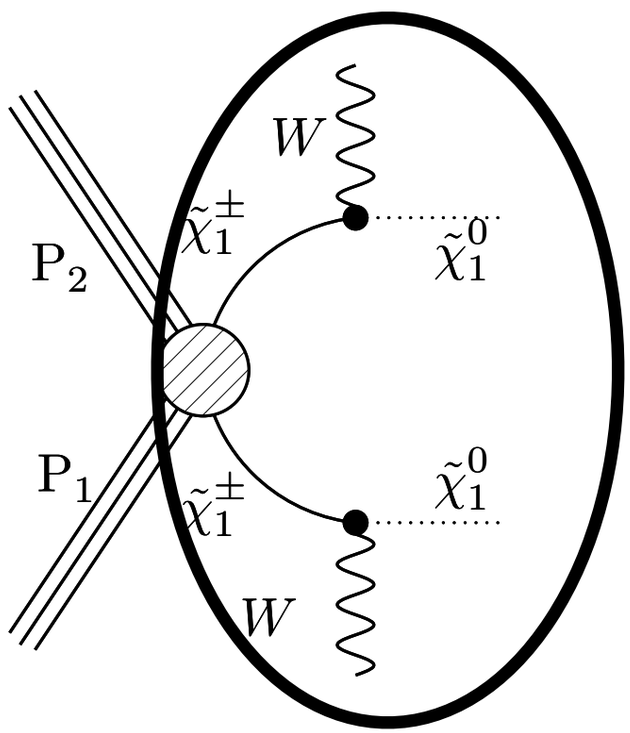
Signal exhibits endpoint structure, background has Z boson pole mass

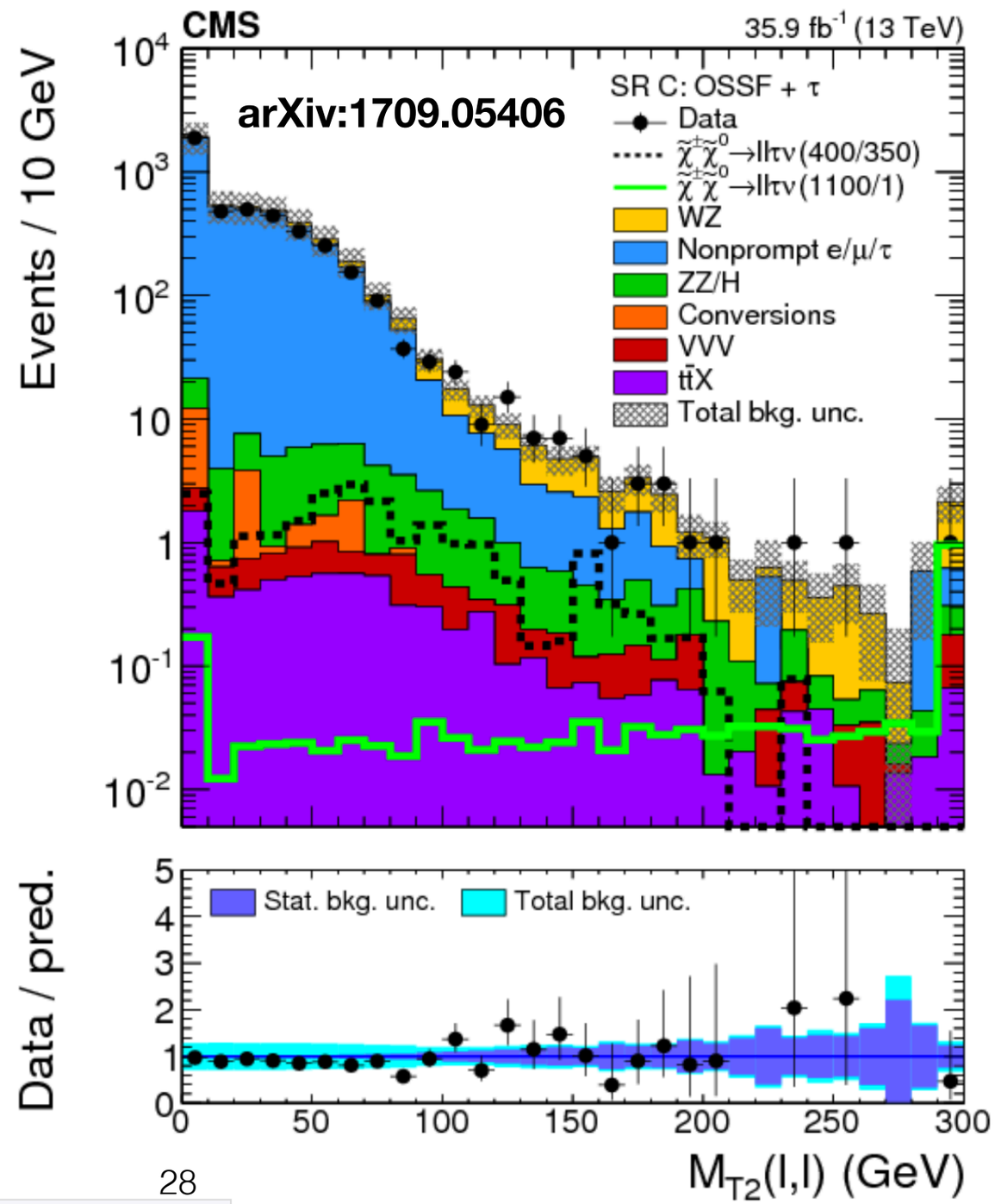


“MT2”

$$M_{T2}(L1,L2) = \min_{\vec{p}_T^{\,v1}+\vec{p}_T^{\,v2}=\vec{p}_T^{\,miss}} [\max(m_T^{L1} + m_T^{L2})]$$

Stransverse mass





Background exhibits a steep shoulder near the W mass