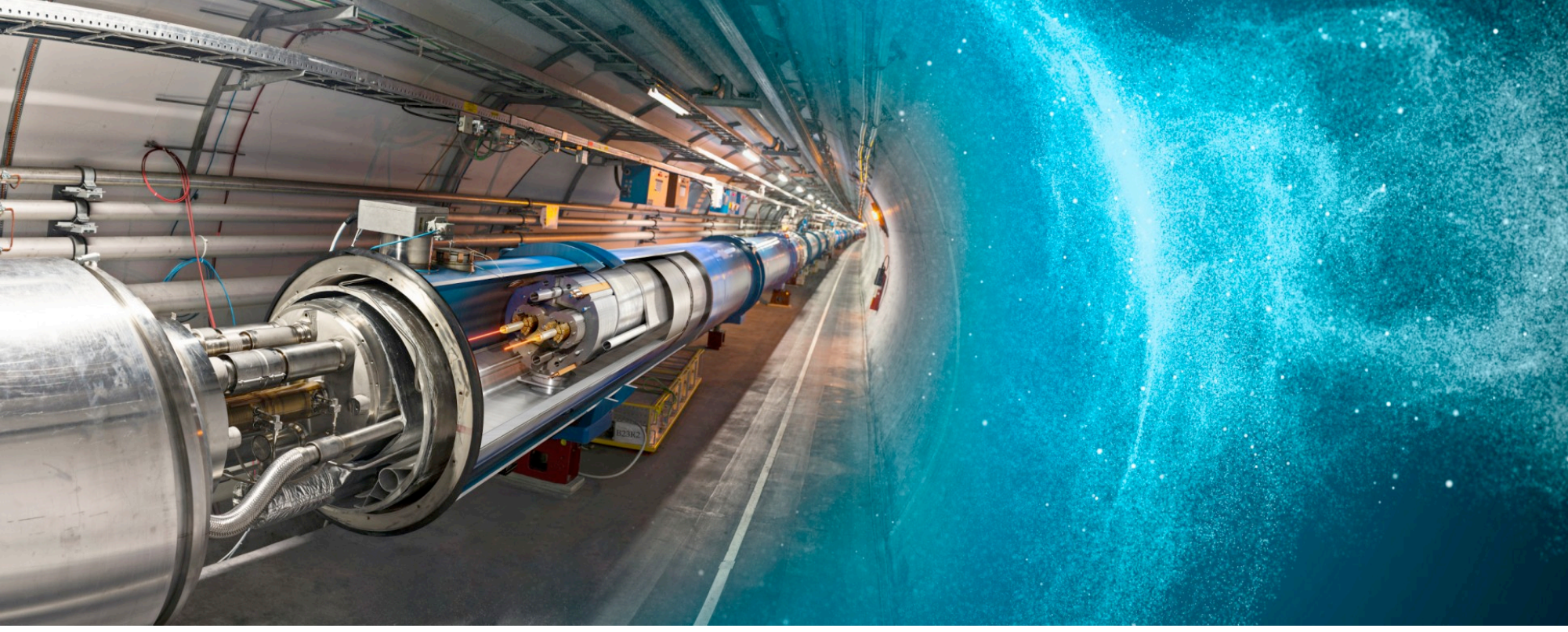


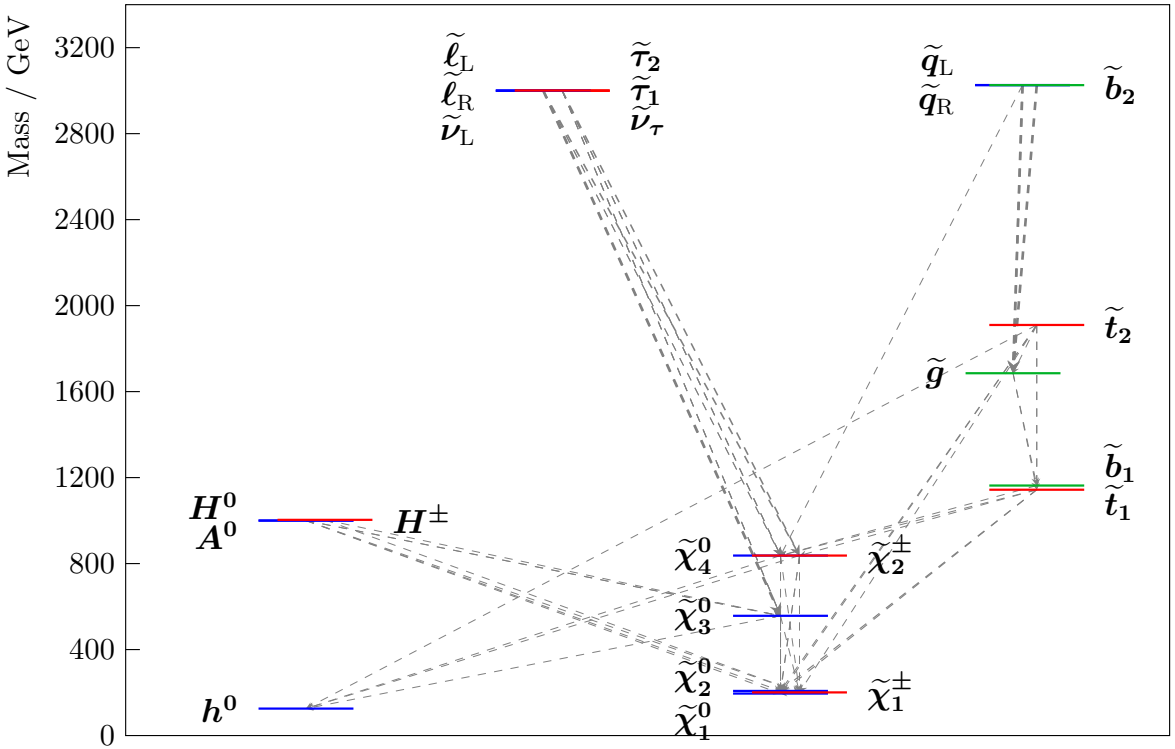
SUSY searches with leptons

Lesya Shchutska
ETH Zürich

May 19, 2017

SUSY signatures

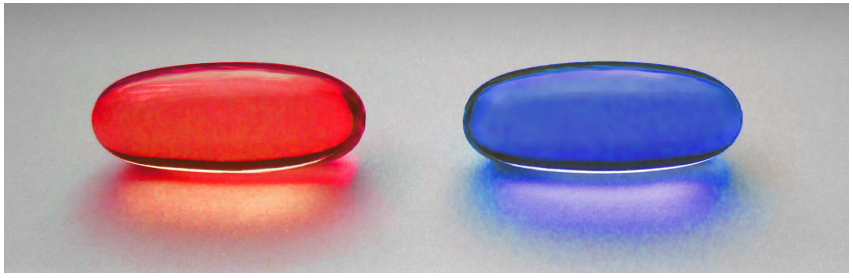
One (of many) possible SUSY spectra:



- dominating decay channels vary with sparticles masses/properties
- strongly produces sparticles: decay to jetty final states
- EWKly produced particles: decays can be dominated by leptons
- often plenty of W, Z, H bosons in the transitions

To be open to any possibility - cannot stay too specific in new physics searches

Choose which price to pay: sensitivity vs. generality



SUSY searches strategy choice

Signatures are complementary: a different angle on the same SUSY scenario

signature	all-hadronic	1 lepton	2 leptons opposite-sign	2 leptons same-sign	≥ 3 leptons
backgrounds	QCD $t\bar{t}$, W+jets $Z \to \nu\nu$ $(10^3 - 10^9$ pb)	$t\bar{t}$, W+jets $(10^3 - 10^4$ pb)	$t\bar{t}$ $Z \to \ell\ell$ $(10^2 - 10^3$ pb)	WZ, $t\bar{t}V$ $t\bar{t}$, W+jets ("fake" leptons) ~ 0.1 pb	WZ, $t\bar{t}V$ $t\bar{t}$, $Z \to \ell\ell$ ("fake" leptons) < 0.1 pb

decreasing background →

← increasing signal acceptance

Background rate is relevant both in an offline analysis and in a trigger: high signal acceptance case might be never recorded if coming with high rate SM processes

SUSY searches strategy choice

Signatures could be unique: each one has its own "corner of dominance"

scenario \ signature	all-hadronic	1 lepton	2 leptons opposite-sign	2 leptons same-sign	≥ 3 leptons
anything with high $E_{\mathrm{T}}^{\mathrm{miss}}$	low multiplicity ($\tilde{\bar{\mathrm{t}}}\tilde{\mathrm{t}}$) lower $E_{\mathrm{T}}^{\mathrm{miss}}$	$\tilde{\bar{\mathrm{t}}}\tilde{\mathrm{t}}$; $\tilde{\chi}_i^0 \rightarrow \tilde{\chi}_j^0$; sleptons	$\tilde{\mathrm{g}}\tilde{\mathrm{g}}$; cascades with low $E_{\mathrm{T}}^{\mathrm{miss}}$	cascades with low $E_{\mathrm{T}}^{\mathrm{miss}}$; gauginos

Many analyses are designed to be generic enough to be sensitive to **any new physics** in given channels

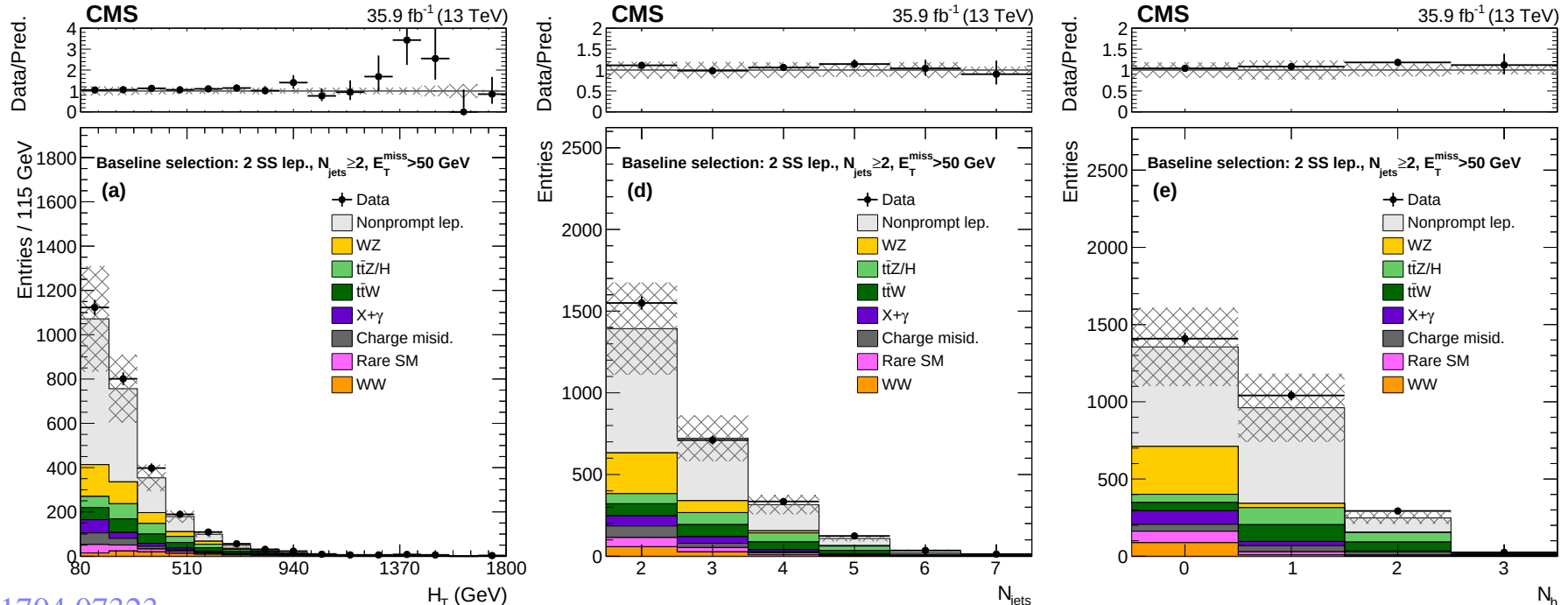
For difficult cases could become more targeted

Same-sign dilepton search

- at least 2 leptons with same charge (2ℓSS e or μ)
  - $10 < p_{\mathrm{T}}^{\ell} < 25$ GeV: low-p_{T} leptons (L)
  - $p_{\mathrm{T}}^{\ell} > 25$ GeV: high-p_{T} leptons (H)
  - categories: HL (fakes), HH, LL (no fakes)
- slice in $N_{\text{b-jets}}$, N_{jets}, H_{T}, $E_{\mathrm{T}}^{\text{miss}} > 50$ GeV, $M_{\mathrm{T}}^{\text{min}}$
- slice in $++$, $--$ where W+jets or $\mathrm{t\bar{t}W}$ matter
- $\Longrightarrow$ 100 search regions in total

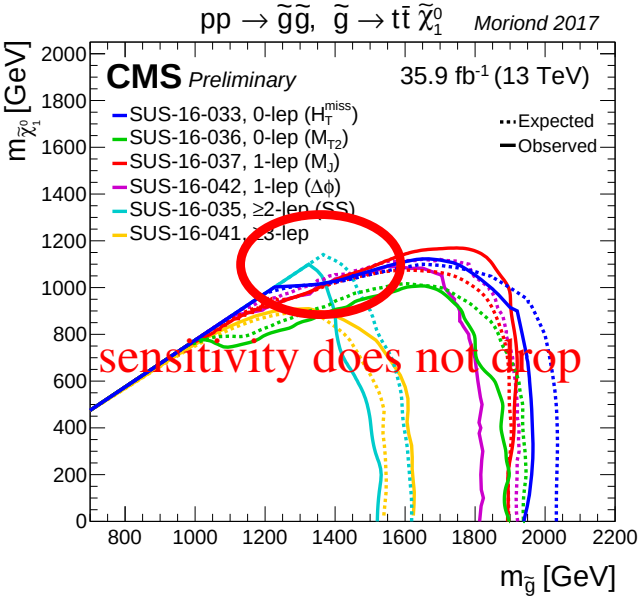
Backgrounds:

- fake (nonprompt) leptons: data-driven
- WZ and $\mathrm{t\bar{t}Z}$: MC, normalized in CR
- other rare SM processes: MC
  - $\mathrm{t\bar{t}Z}$ and $\mathrm{t\bar{t}W}$ become important!
  - a lot of dependence on theory
- charge-flip: data-driven

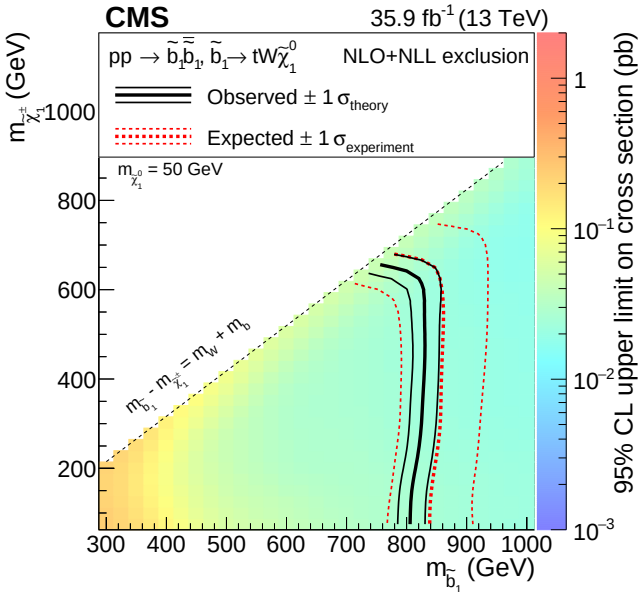


Same-sign dilepton search: interpretations

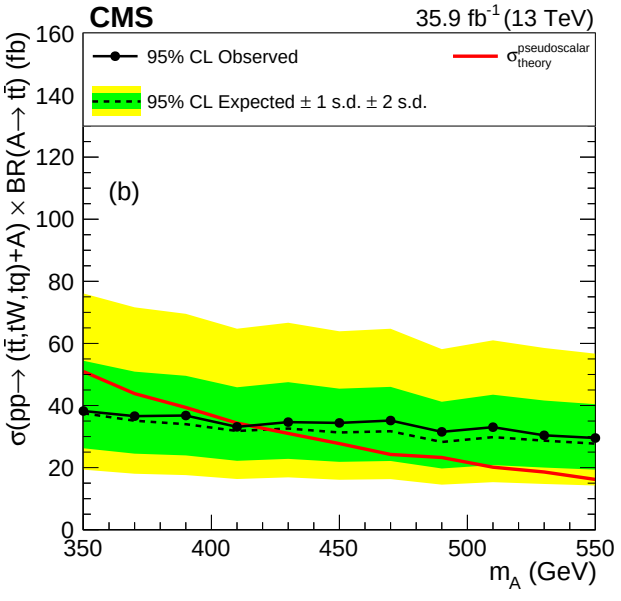
gluinos with low E_T^{miss}

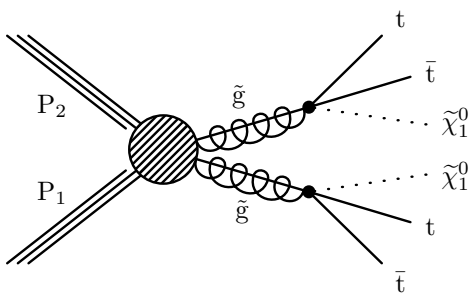


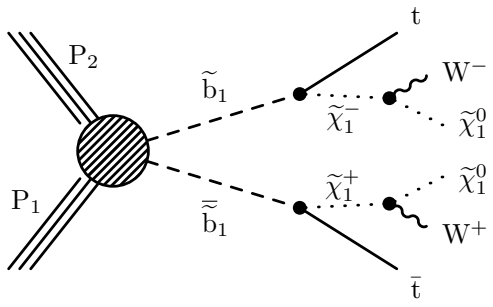
cascades

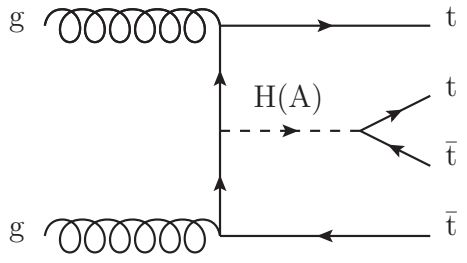


mutlitple top quarks (heavy (pseudo)scalar)



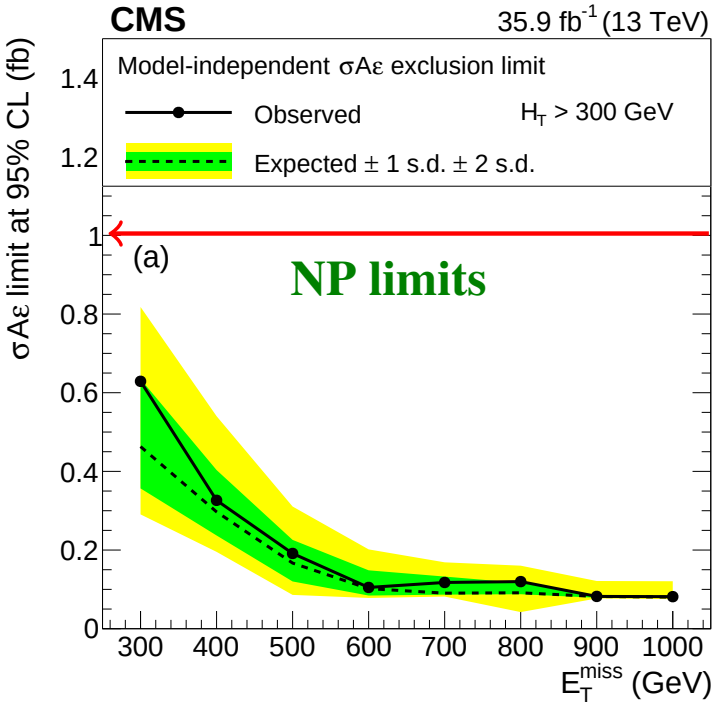


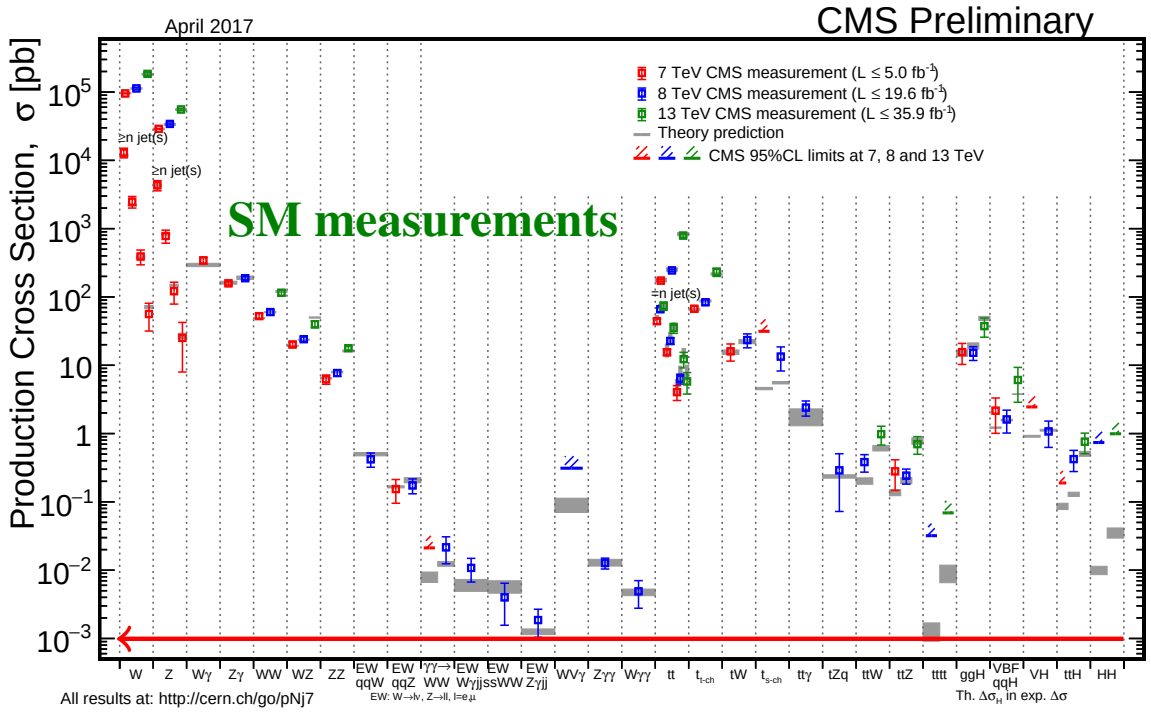




arXiv:1704.07323

Level of cross sections probed





- model-independent limits on new physics at the level of the rarest SM processes
- caveat: MI limit is on $\sigma \times \mathcal{A} \times \varepsilon$
- fair comparison (corrected by efficiencies):
  - obs (exp) $\sigma(\mathrm{t\bar{t}t\bar{t}}) < 42\ (27^{+13}_{-8})$ fb at 95% CL
  - SM value $9.2^{+2.9}_{-2.4}$ fb

arXiv:1704.07323

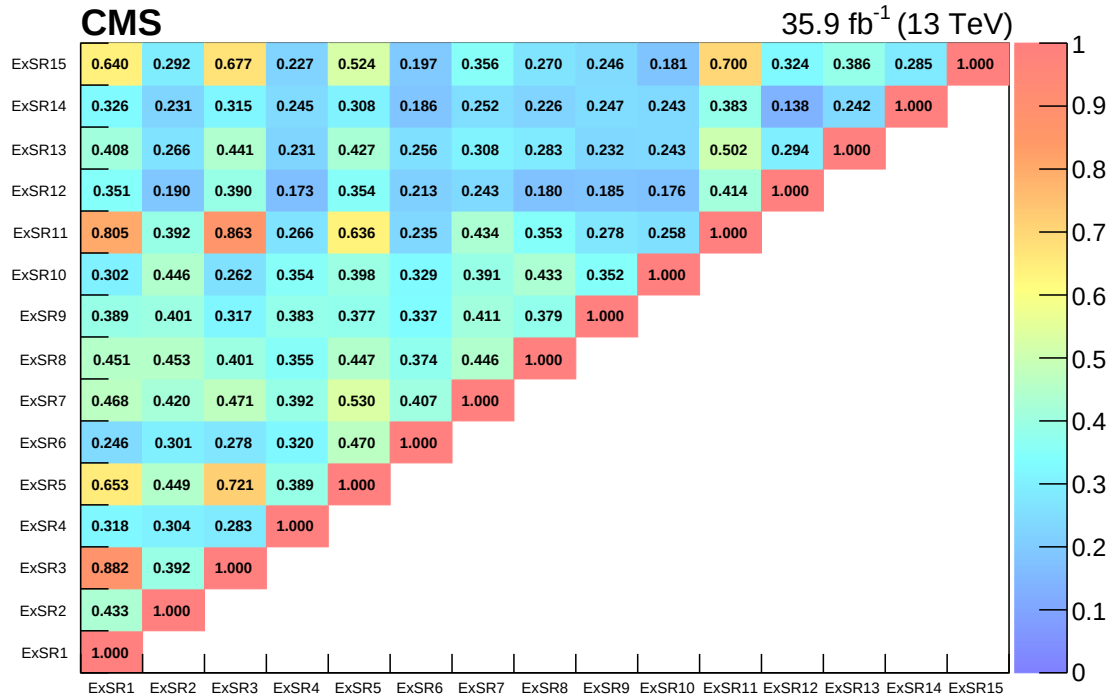
Making a reinterpretation accessible

For the outside reinterpretation, go down from 100 exclusive SR to:

- **15 inclusive SR**: to be used one at a time, e.g.:

SR	Leptons	N_{jets}	$N_{\text{b-jets}}$	H_{T} (GeV)	$E_{\text{T}}^{\text{miss}}$ (GeV)	$M_{\text{T}}^{\text{min}}$ (GeV)	SM expected	Observed	$N_{\text{obs,UL}}^{95\%\text{CL}}$
InSR1	HH	$\geq$2	0	$\geq$1200	$\geq$50	—	4.00 ± 0.79	10	12.35
InSR2		$\geq$2	$\geq$2	$\geq$1100	$\geq$50	—	3.63 ± 0.71	4	5.64
InSR3		$\geq$2	0	—	$\geq$450	—	3.72 ± 0.83	4	5.62

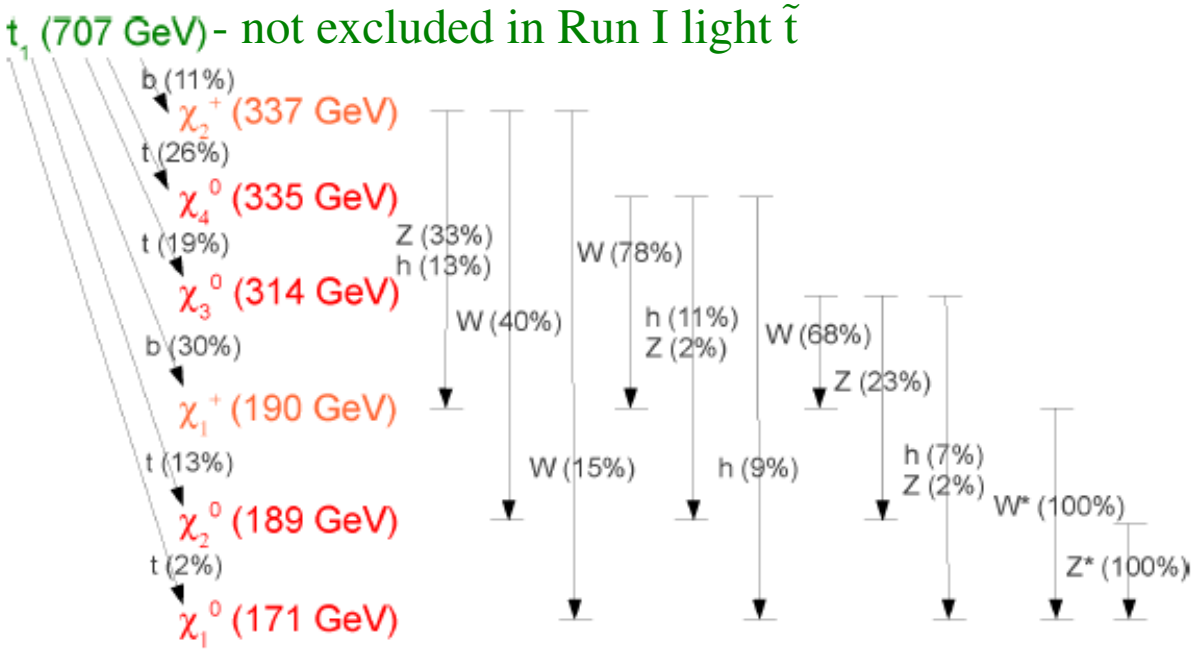
- **15 exclusive SR**: to be used together with a supplied correlation matrix:



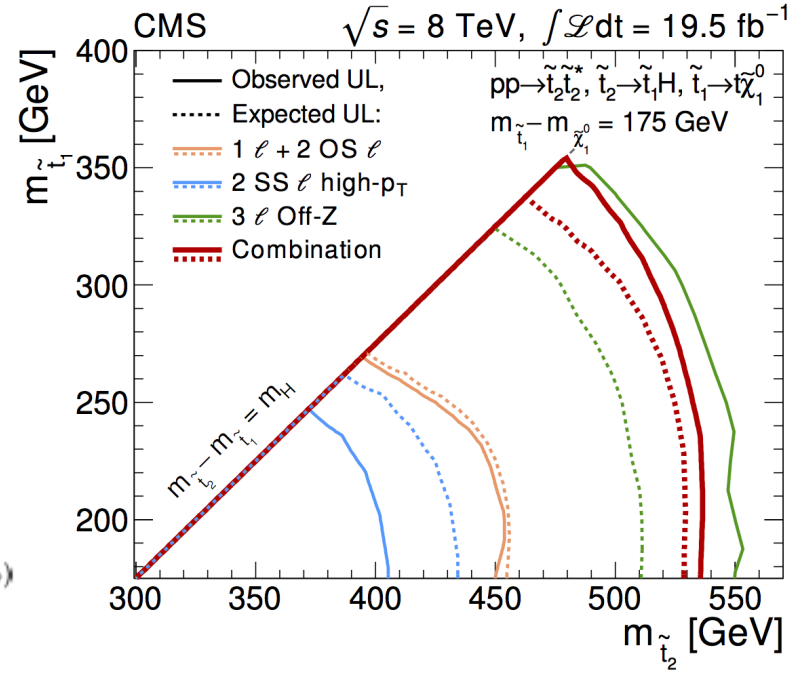
arXiv:1704.07323 public web-page with electronic material

Multileptons in cascades: strong production

2-particle simplified models are missing smth:



$t\bar{t}HH$ topology

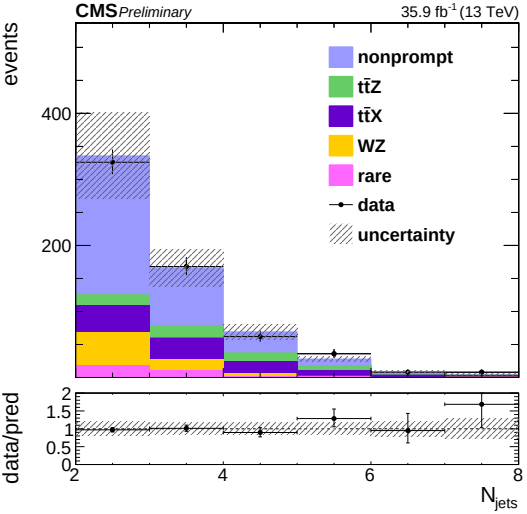


In cascade decays multilepton searches surpass other channels

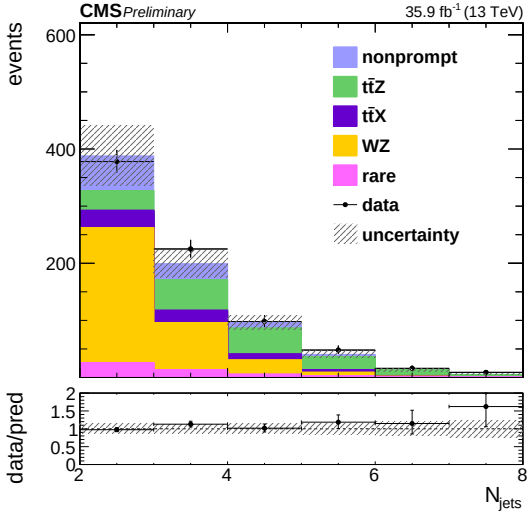
arXiv:1405.3886

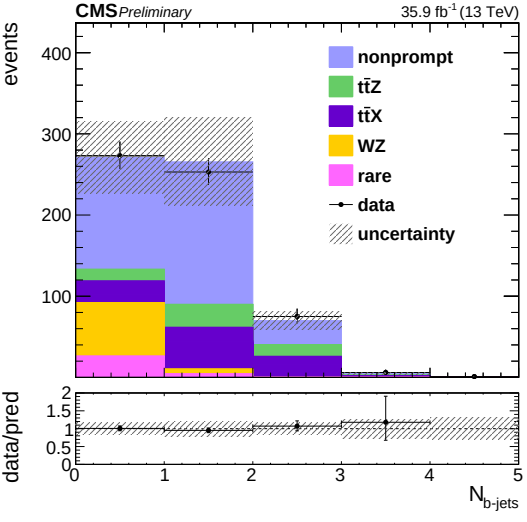
Multileptons in strong production

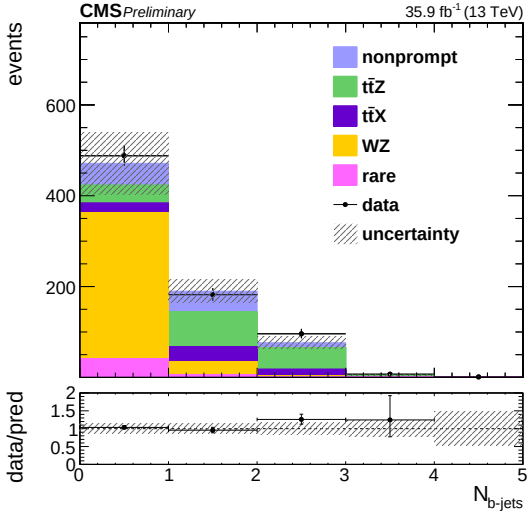
Without a Z-candidate:



With a Z-candidate:



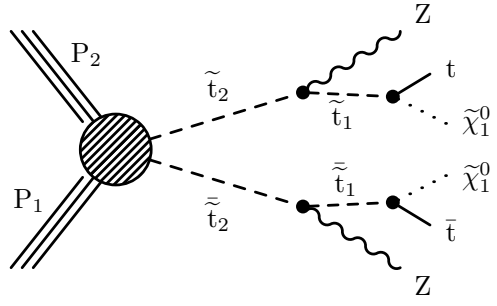


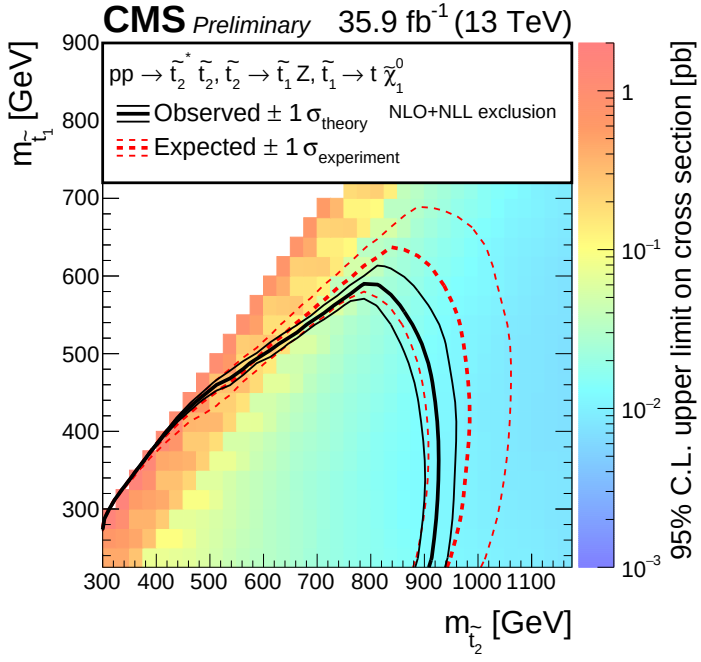


- tt̄W and tt̄H in tails
- overlap with 2ℓSS search
- high $N_{\text{b jets}}$ bins pure in tt̄Z
- orthogonal to 2ℓSS search

Methods and backgrounds similar to 2ℓSS:

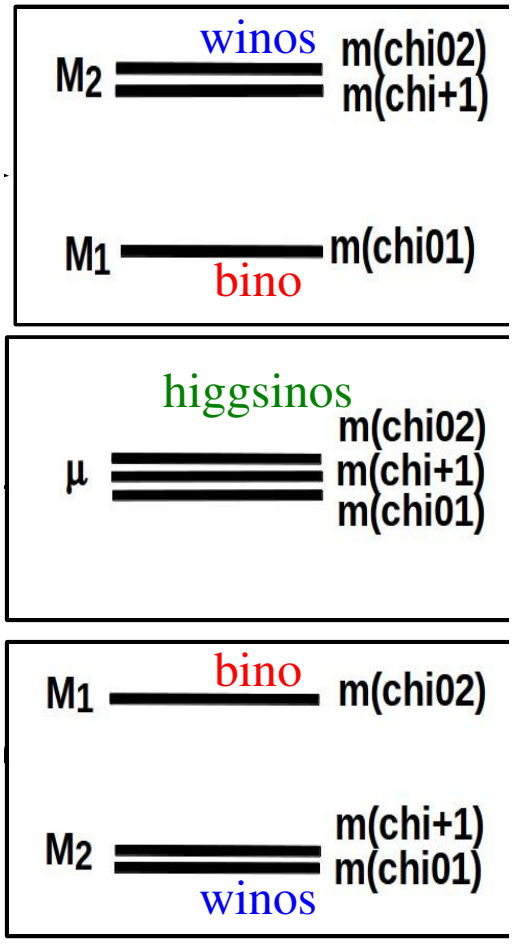
- ≥ 3 e (μ) $p_{\text{T}} > 25(20)/15(10)/10$ GeV
- slice in $N_{\text{b jets}}$, H_{T}, $E_{\text{T}}^{\text{miss}}$, M_{T}
- 46 exclusive search regions
- and 4 exclusive super-SR: for reinterpretation





SUS-16-041

EWKino searches



Multilepton searches (SUS-16-039, ATLAS-CONF-2017-039)

Mass-degenerate $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0$ decay via W, Z, H bosons or leptons to $\widetilde{\chi}_1^0$

- search for events with multiple leptons, $E_{\mathrm{T}}^{\mathrm{miss}}$, b jet veto

Compressed searches (SUS-16-048)

Close in mass higgsinos decay via deeply off-shell W and Z bosons to a higgsino LSP

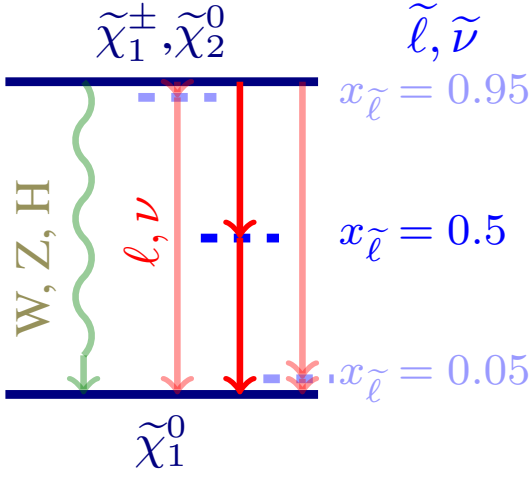
- multiple soft leptons, low $E_{\mathrm{T}}^{\mathrm{miss}} \implies$ not visible!
- need to boost the system in the transverse plane $\implies$ use events with ISR jets

Long-lived searches (EXO-12-034, ATLAS-CONF-2017-017)

Wino $\widetilde{\chi}_1^{\pm}$ flies in the detector before a decay to $\widetilde{\chi}_1^0$: $\widetilde{\chi}_1^{\pm} \to \pi^{\pm}\widetilde{\chi}_1^0$

- search for disappearing tracks in the detector
- complementary approach from EXO side

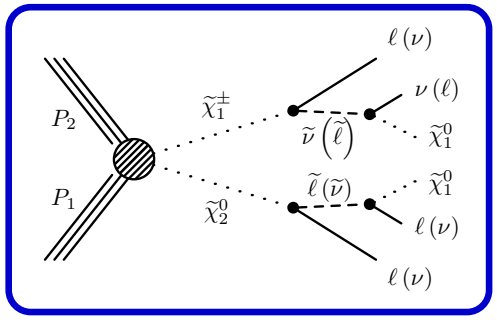
Considered scenarios in multilepton searches

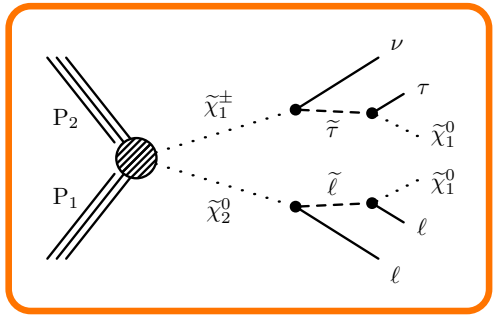


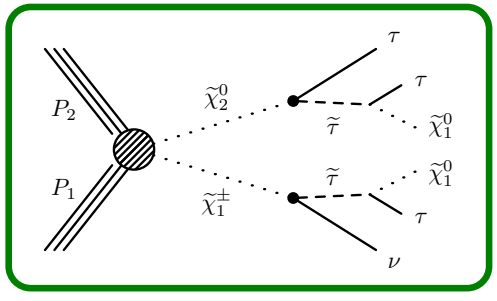
flavor-democratic

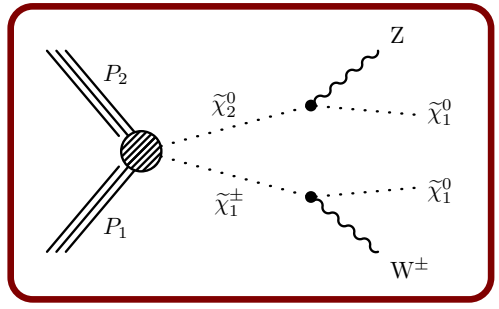
τ-enriched?

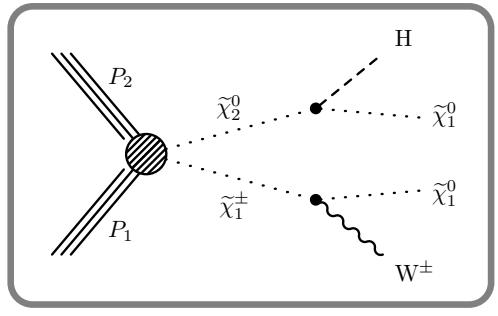
τ-dominated?







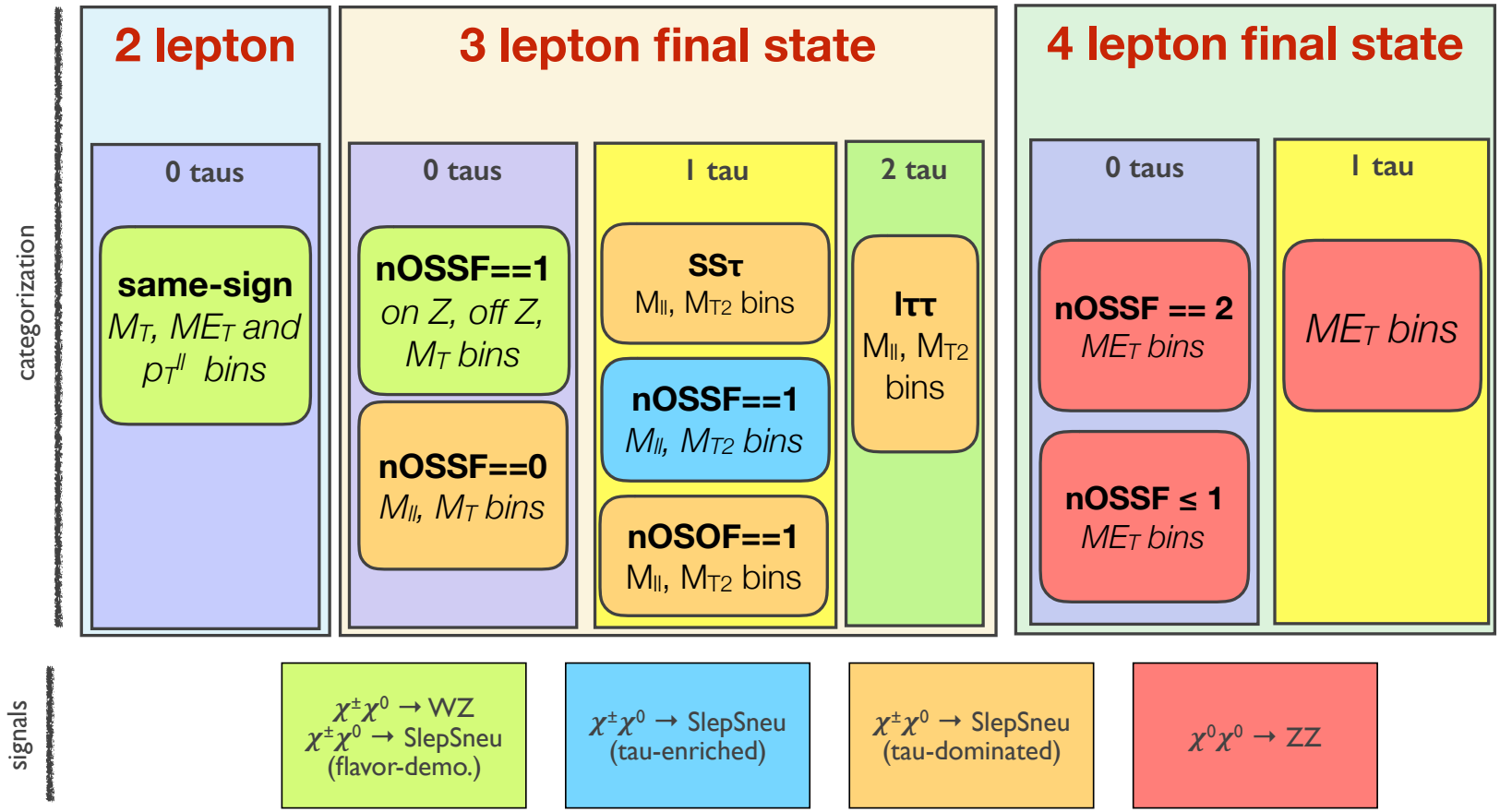




- slepton-mediated decays differ in kinematics and do not take a hit on BF to leptons
- in some cases decays via $\widetilde{\tau}$ preferred: optimize searches to cover this

Multileptons EWKino: event categorization

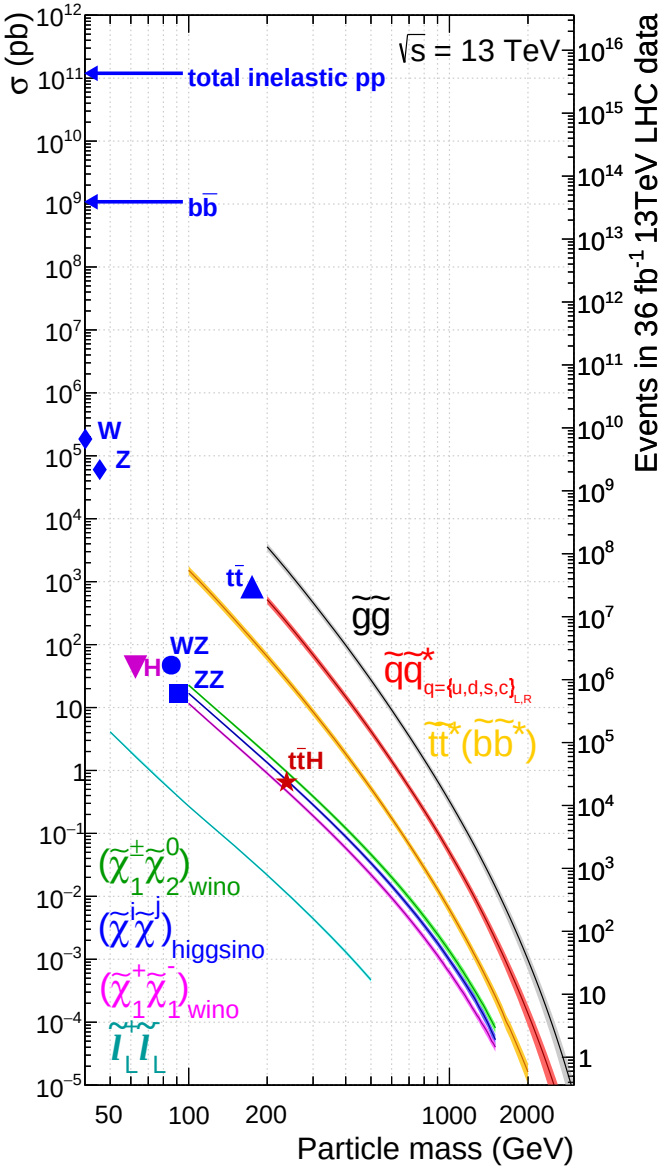
- split by lepton multiplicity (2, 3, 4), flavor (e, μ, τ_h), charge (same-sign or not), kinematic properties ($M_{\ell\ell}$, M_T, M_{T2})
- b-veto to suppress $t\bar{t}$; $E_T^{miss} > 50$ GeV for $\geq 3\ell$ and > 60 GeV for 2ℓSS
- main backgrounds: WZ$\rightarrow 3\ell$, non-prompt leptons ($t\bar{t}$, DY), conversions, rare SM



nOSSF = number of OSSF pairs (ee, μμ, ττ)
nOSOF = number of OS different flavour pairs (ee, μμ, eμ)

Cross section hierarchy

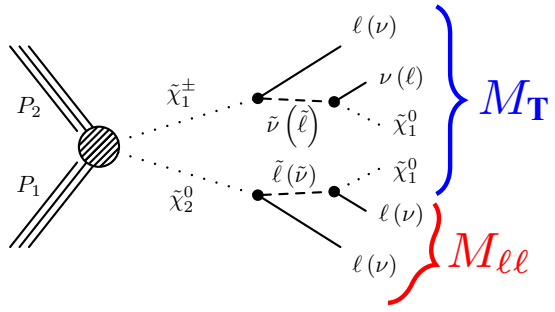
- low cross sections compared to SM WZ(3ℓ): need to be creative in event selection



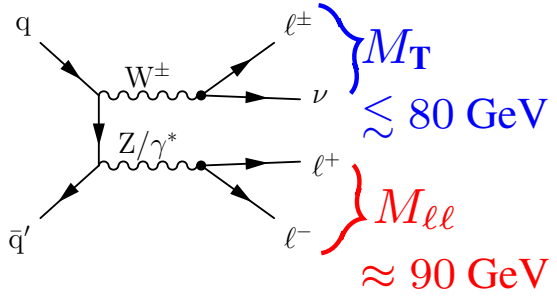
Example for 3 light lepton final state:

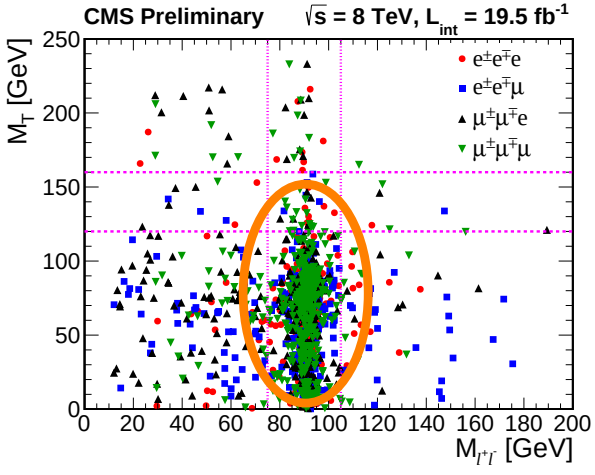
- pick a most Z-like pair of leptons and compute $M_{\ell\ell}$
- use the third lepton to get M_{T}

SUSY in 3ℓ



SM in 3ℓ

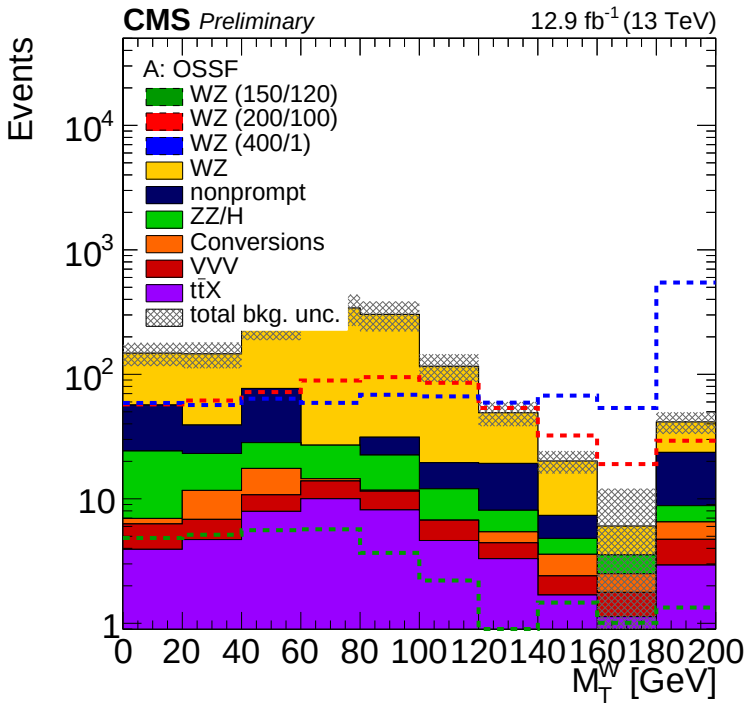




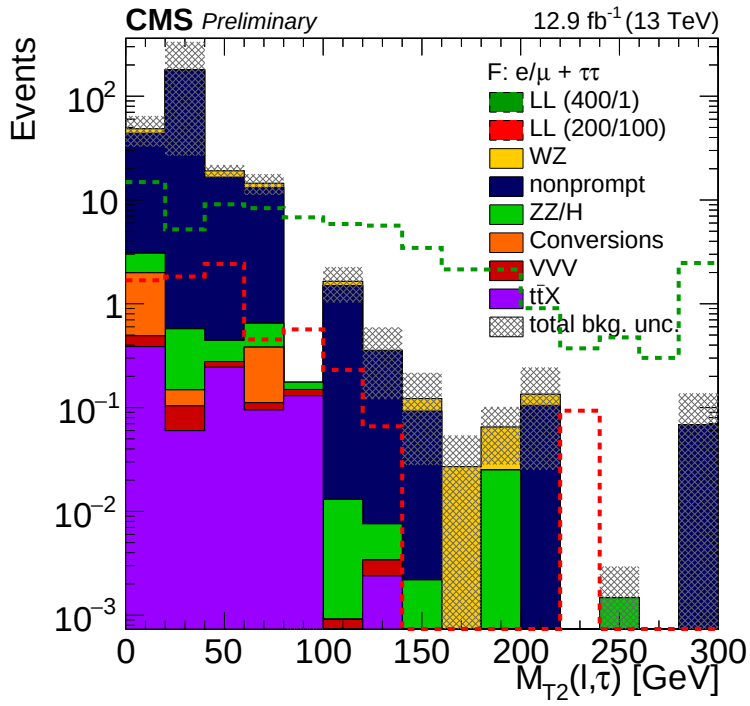
- contain all the SM WZ background in few bins of phase-space
- search for new physics in the tails

Picking the right variables

3 light leptons: M_{T}



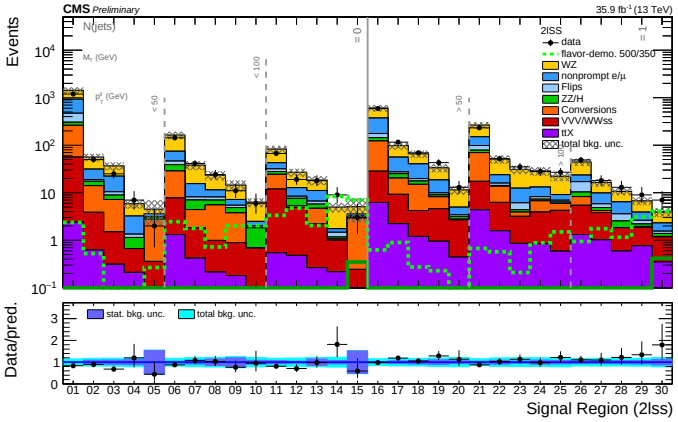
e/μ+2τ_{had}: M_{T2}

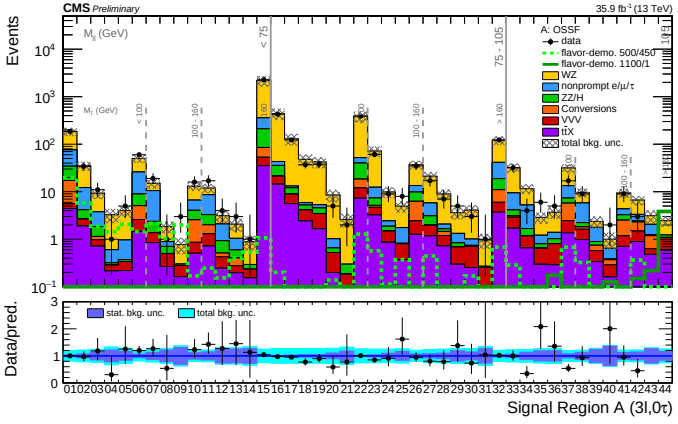


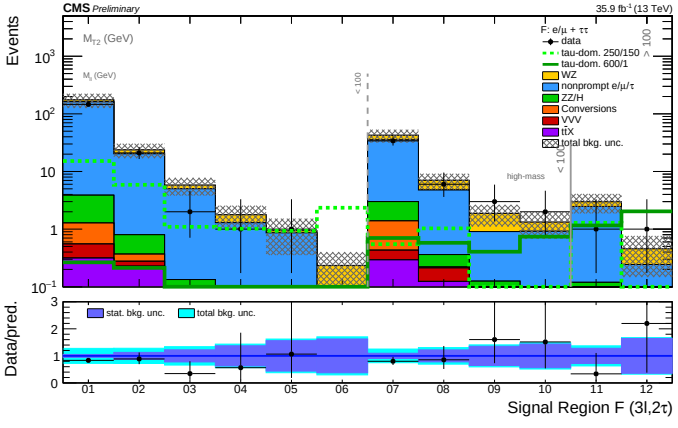
- tailor kinematic variables to contain dominating SM processes in each channel:
  - 3 light leptons: WZ(3ℓ) $\implies$ M_{T} of 3$^{\mathrm{rd}}$ lepton cuts-off at W mass
  - e/μ+2τ_{had}: $\mathrm{t\bar{t}} \to \ell\tau_{\mathrm{h}}$ + a fake τ_{h} $\implies$ M_{T2} with leading ℓ, τ_{h} cuts-off at W mass

Results

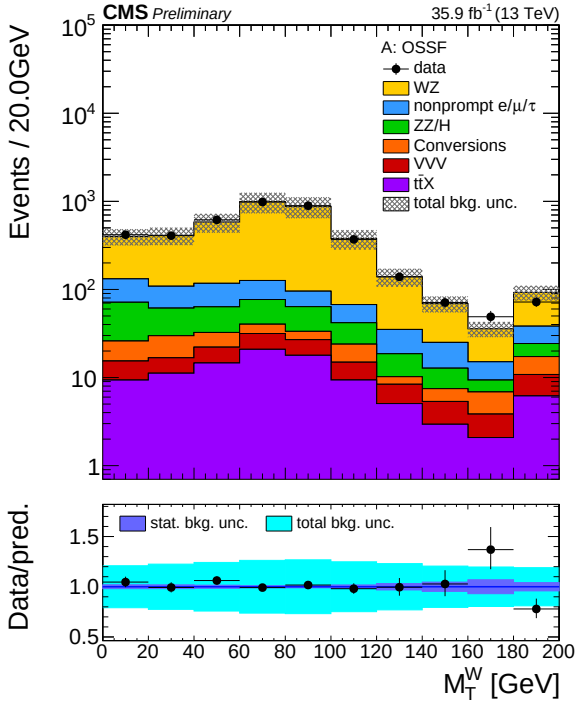
Selected SR (out of 158):



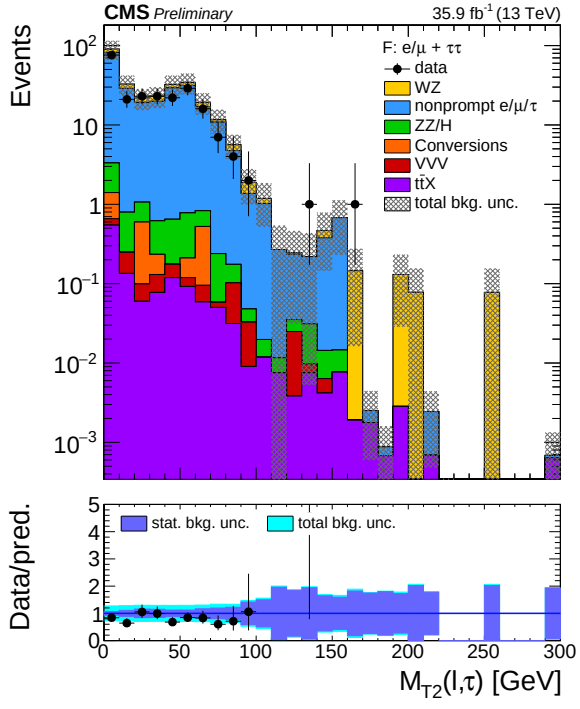




3 light leptons: M_T



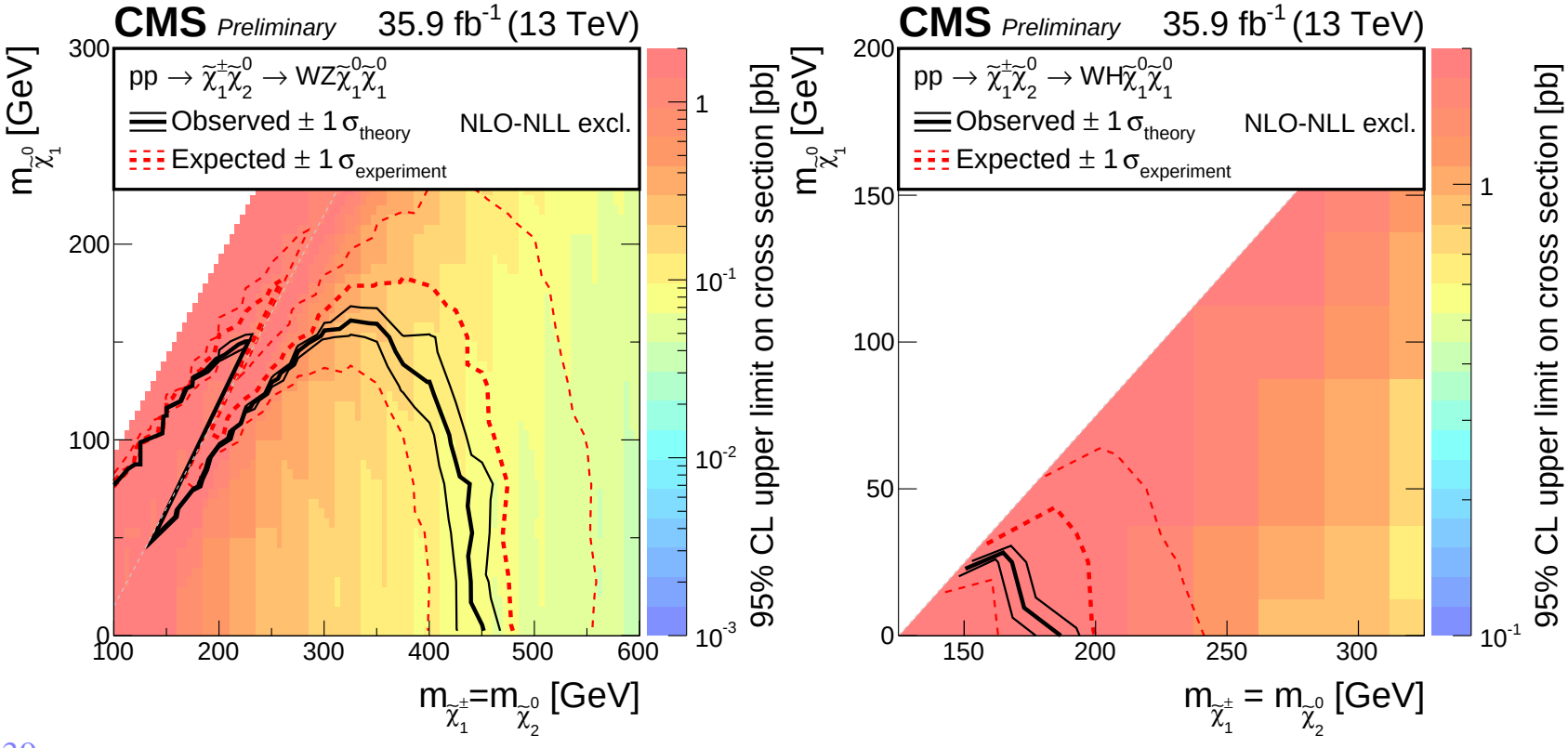
e/μ+2τ_{had}: M_{T2}



- no significant excess in any of the categories
- 8 super-SR regions are available for the reinterpretation

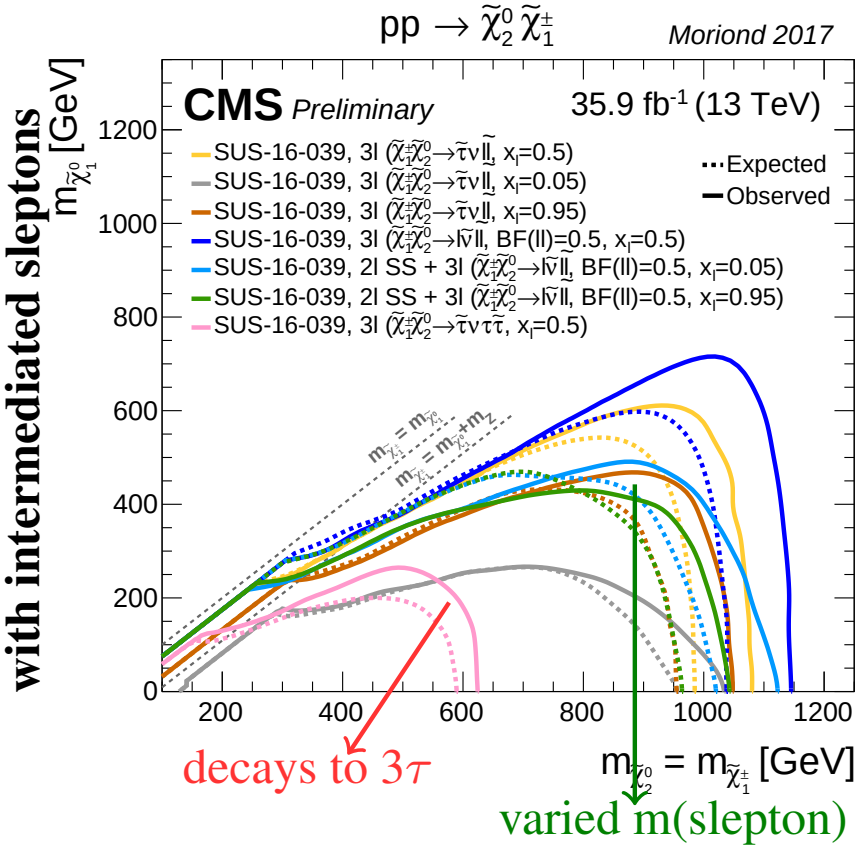
Interpretations

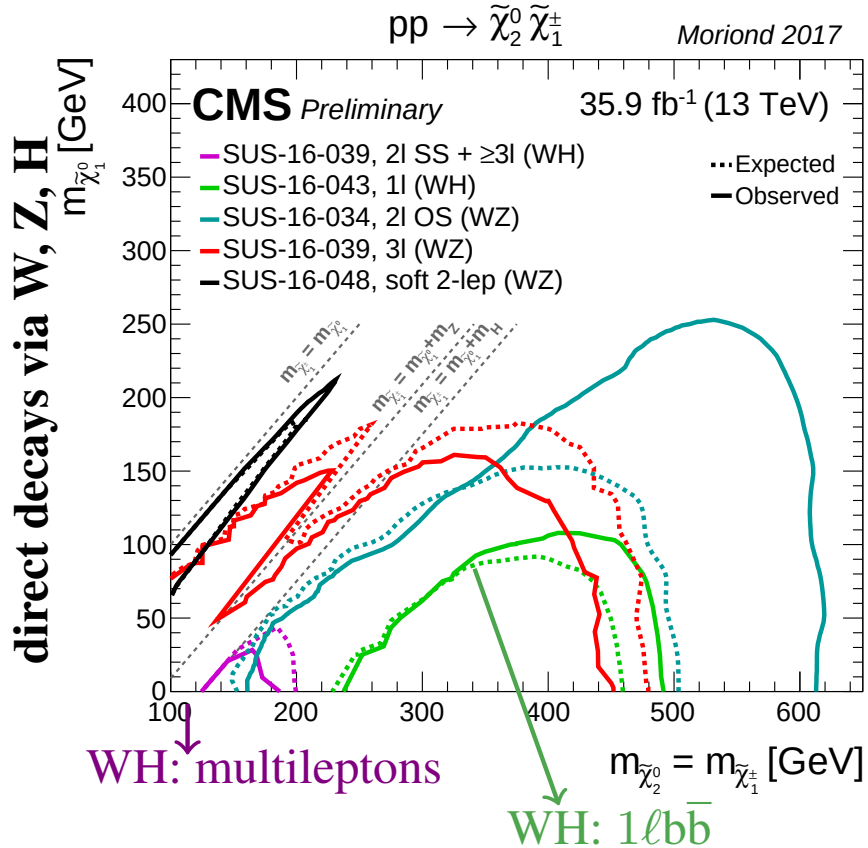
- no intermediate sleptons: $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0 \to \mathrm{WZ}\widetilde{\chi}_1^0\widetilde{\chi}_1^0$ and $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0 \to \mathrm{WH}\widetilde{\chi}_1^0\widetilde{\chi}_1^0$
- gap in sensitivity for $m_{\widetilde{\chi}_2^0} - m_{\widetilde{\chi}_1^0} \approx m_{\mathrm{Z}}$:
  - LSP is produced with low momentum - no extra $E_{\mathrm{T}}^{\mathrm{miss}}$
  - very SM WZ-like final state
  - exploring additional handles there at the moment



SUS-16-039

Interpretations summary





- sensitivity pushes 1 TeV in case of slepton-mediated decays
- in less reach spectra: between 200 and 500 GeV for $\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ masses:
  - more realistic scenario has combination of $\tilde{\chi}_2^0 \to$H/Z$\tilde{\chi}_1^0$
  - new result combining all the channels for H decays is in preparation

An aftermath

No SUSY discovery in the picture yet, but we are still on the road:

Analysis	Luminosity (fb^{-1})	Model NM1	NM2	NM3	STC	STOC
all-hadronic (H_T-H_T^{miss}) search	300					
	3000					
all-hadronic (M_{T2}) search	300					
	3000					
all-hadronic $\widetilde{b}_1$ search	300					
	3000					
1-lepton $\widetilde{t}_1$ search	300					
	3000					
monojet $\widetilde{t}_1$ search	300					
	3000					
$m_{\ell^+\ell^-}$ kinematic edge	300					
	3000					
multilepton + b-tag search	300					
	3000					
multilepton search	300					
	3000					
ewkino WH search	300					
	3000					

$< 3\sigma$ | $3 - 5\sigma$ | $> 5\sigma$

- just pushing the luminosity we can touch gauginos at 300-1000 GeV across all mass splittings
  - *innovativeness is harder to project*
- and this is with only a couple of analyses
  - *we have many more*
- if there is SUSY: it will be visible across multitude of signatures
- **2-3σ evidence** in multiple places could be as good as **5σ discovery** in one channel
- this makes 95%CL reach as important as 5σ one

Could seem tight for the discovery at the (HL-)LHC
but there is plenty of phase-space for strong hints!

CMS-PAS-SUS-14-012