Supersymmetry searches at CMS

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for the CMS collaboration

SUSY
Mumbai, TIFR, December 2017

SUSY at the LHC

- As Paris told us on Monday, SUSY discovery was easy
  - Prescription: look for high p_T particles and large missing energy and you can't miss it

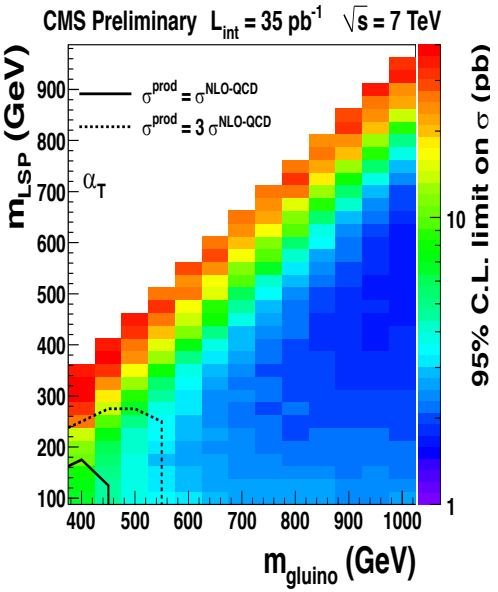
The prevailing wisdom from the good old days:

- SUSY discovery (should be) easy and fast
  - Expect very large yield of events in clean signatures (dilepton, diphoton).
    - Establishing mass scale is also easy (M_{eff})
- Squarks and gluinos can be discovered over very large range in SUGRA space (M_0,$M_{1/2}$)~(2,1)TeV
  - Discovery of charginos/neutralinos depends on model
  - Sleptons difficult if mass > 300 GeV

- So what happened?

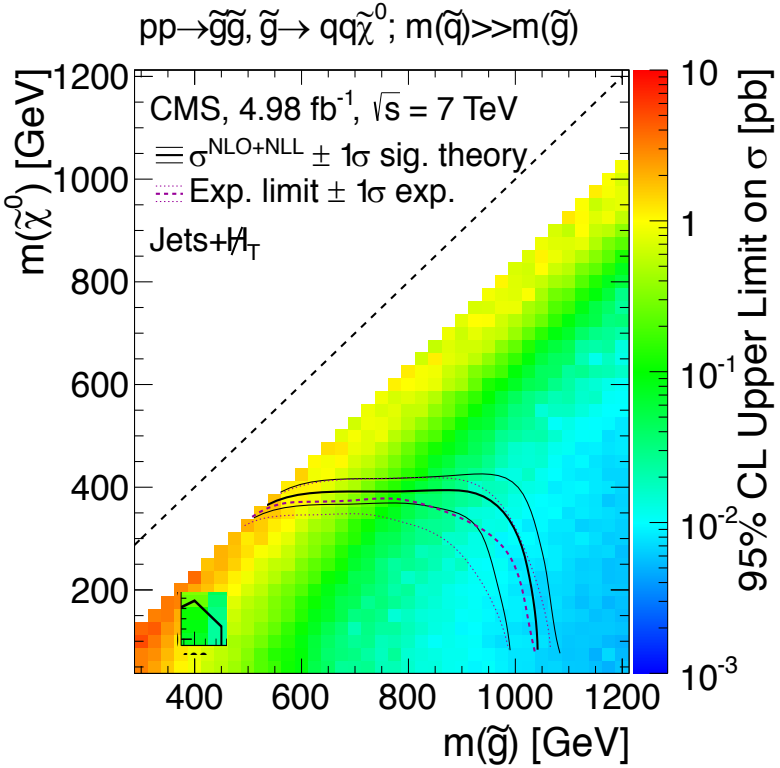
Gluino Mass Reach

2010:



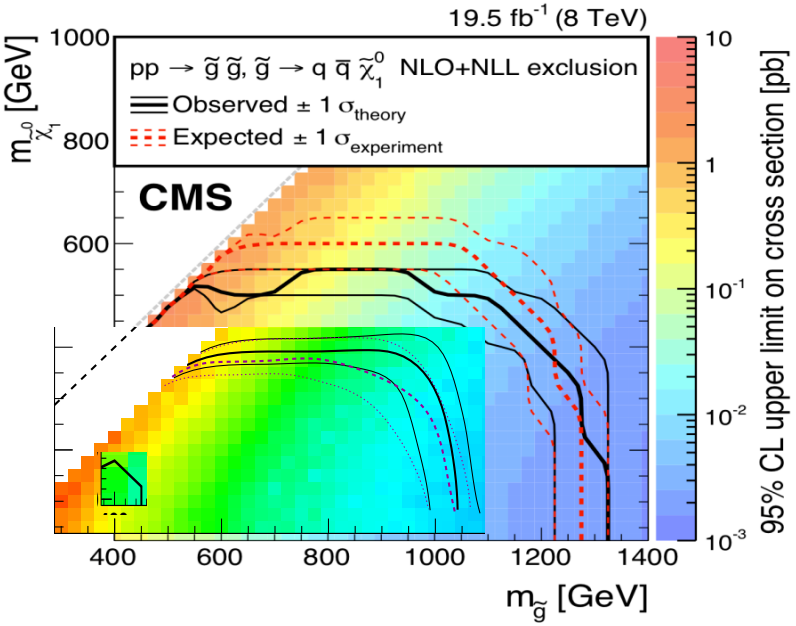
Gluino Mass Reach

2011:

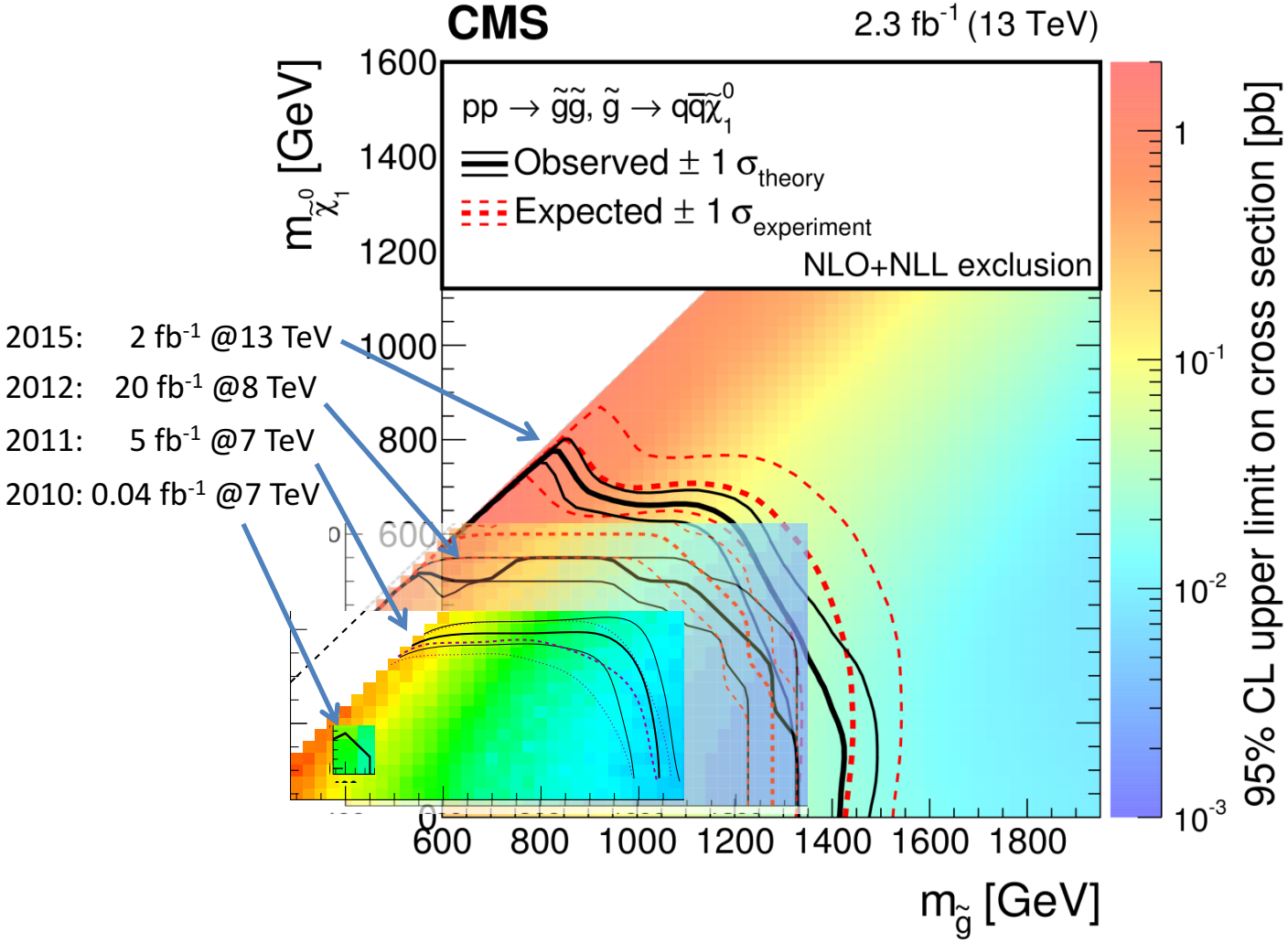


Gluino Mass Reach

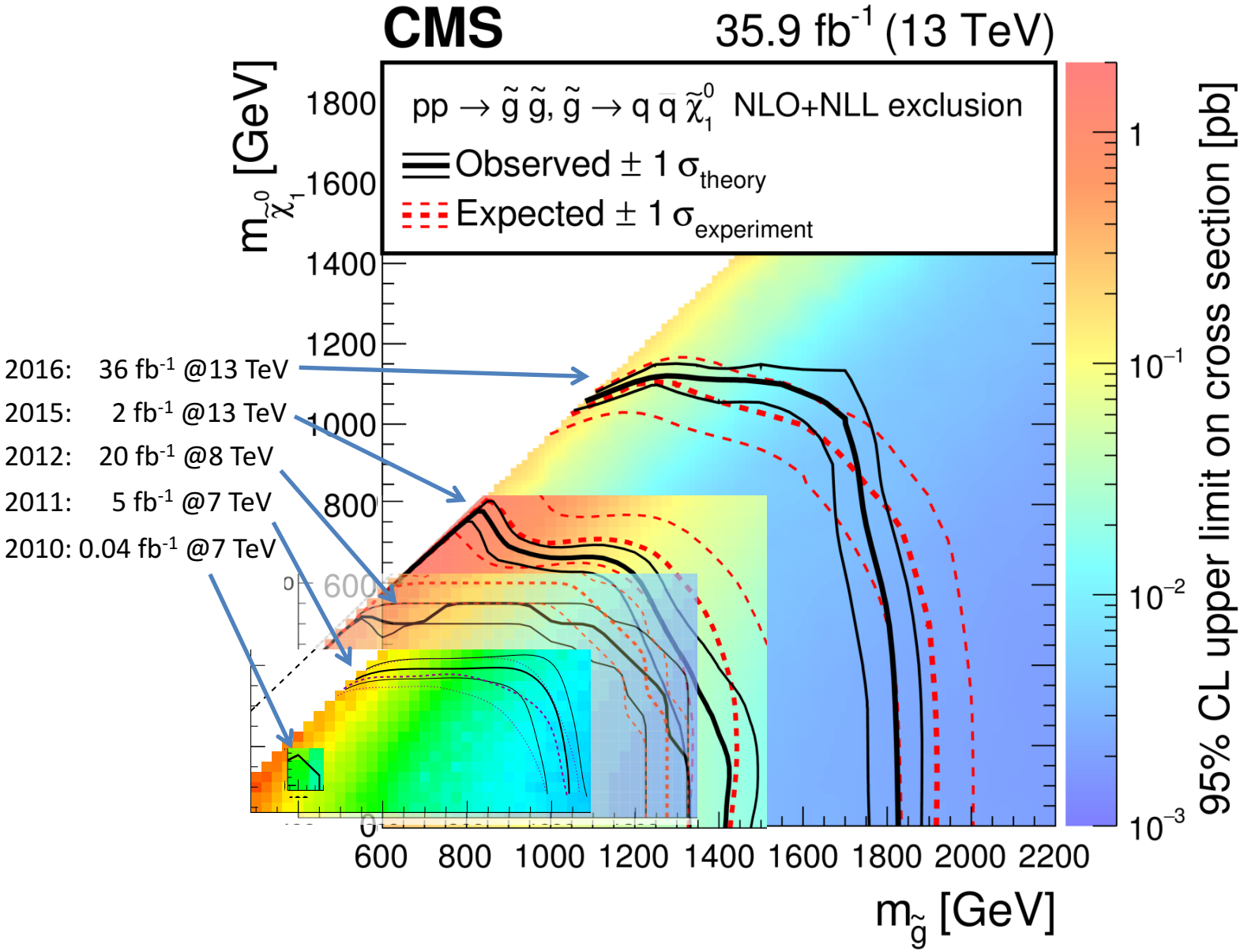
2012:



Gluino Mass Reach

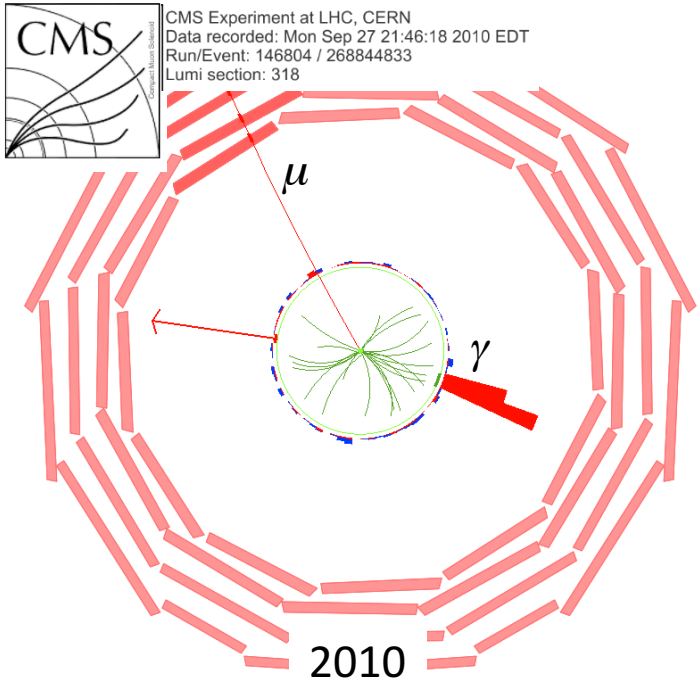


Gluino Mass Reach

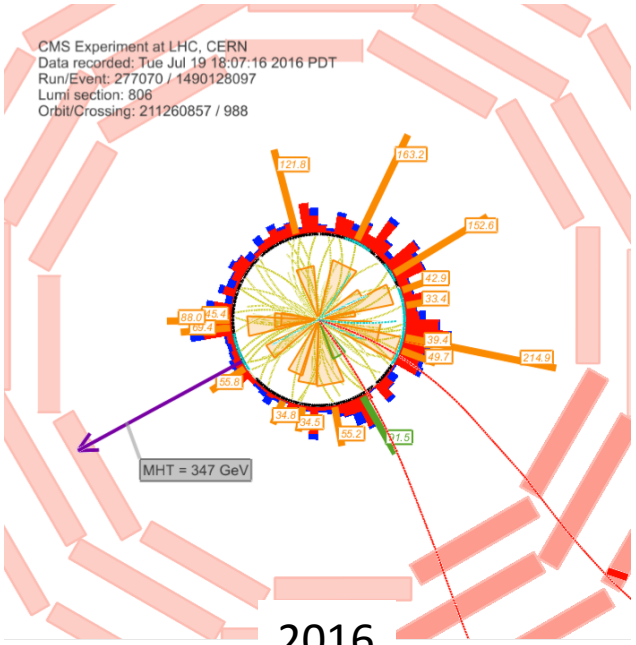


SUSY at the LHC

- Despite lack of observation, have made huge of progress in SUSY searches
  - Generally very inclusive searches with broad reach
  - Sophisticated analysis techniques, robust background predictions, comprehensive interpretation techniques, searching further in kinematic tails, …



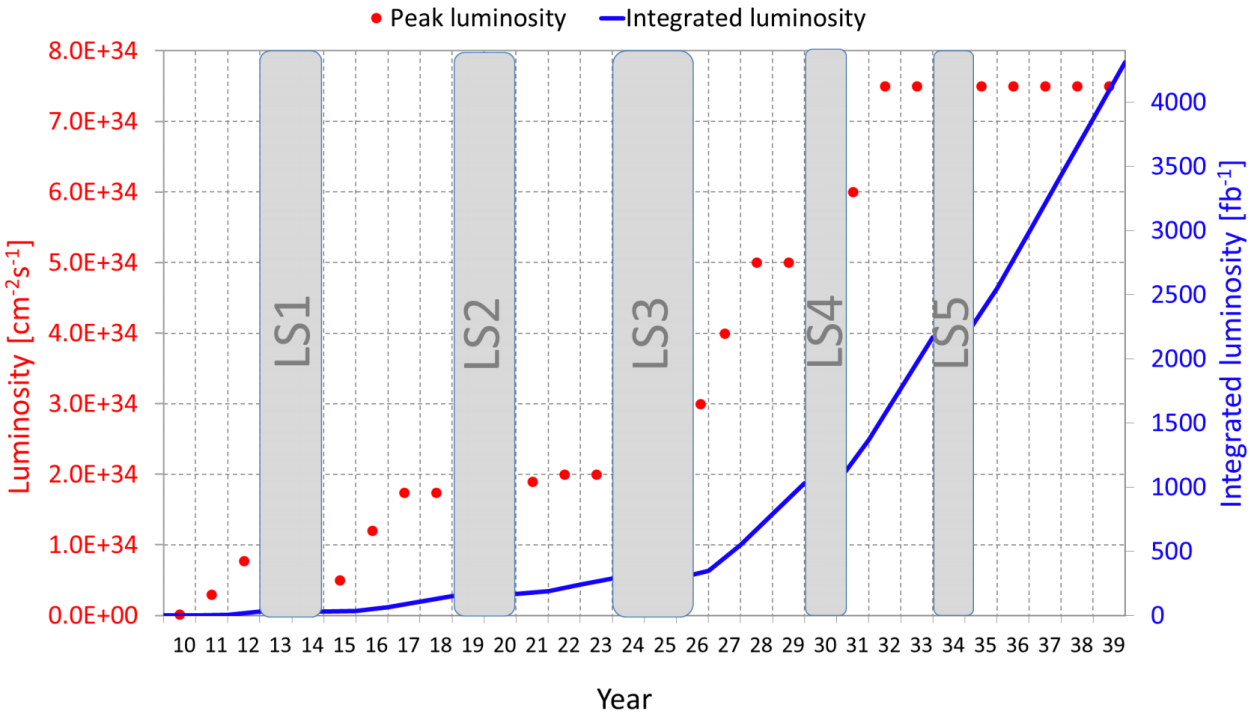
2010



2016

See Parallel Talks:
Tom Cornelis, Vinay Hegde, Scarlet Norberg, Daniel Spitzbart, Leonora Vesterbacka

Some paths forward

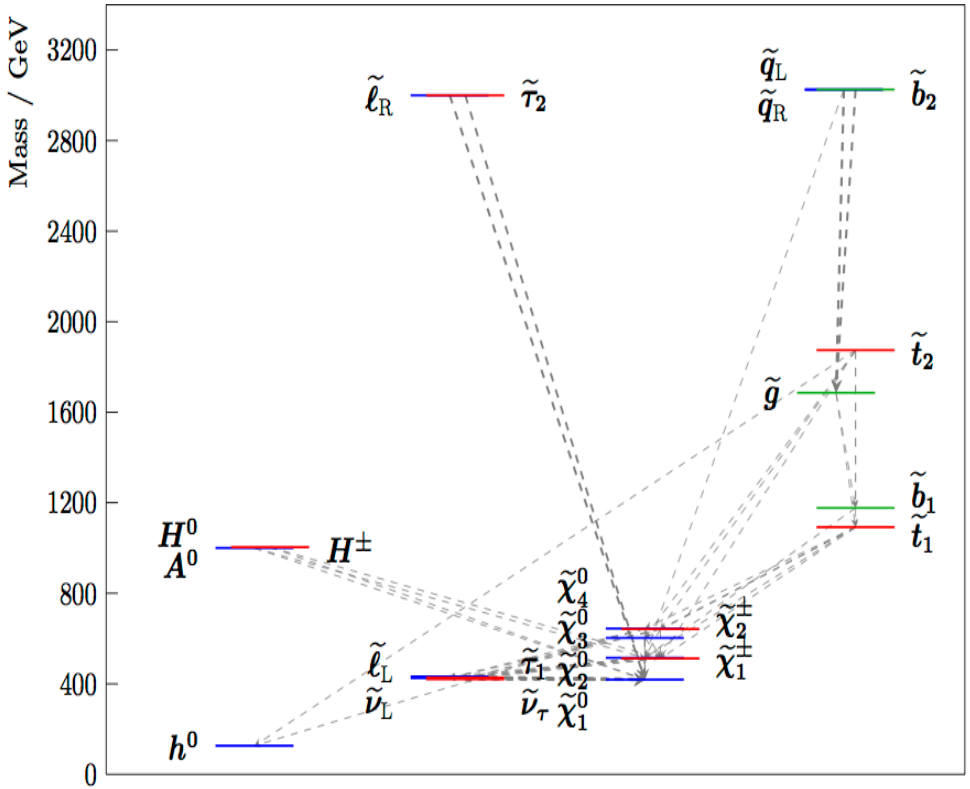


- The era of large jumps in energy or luminosity is over (for awhile!)

- This talk: My view of ways to push beyond the inclusive SUSY searches
  - Digging deeper: Boosted and long-lived signatures
  - More targeted corners: Compressed spectra, RPV
  - Lower cross sections: Electroweak production

Digging Under Background

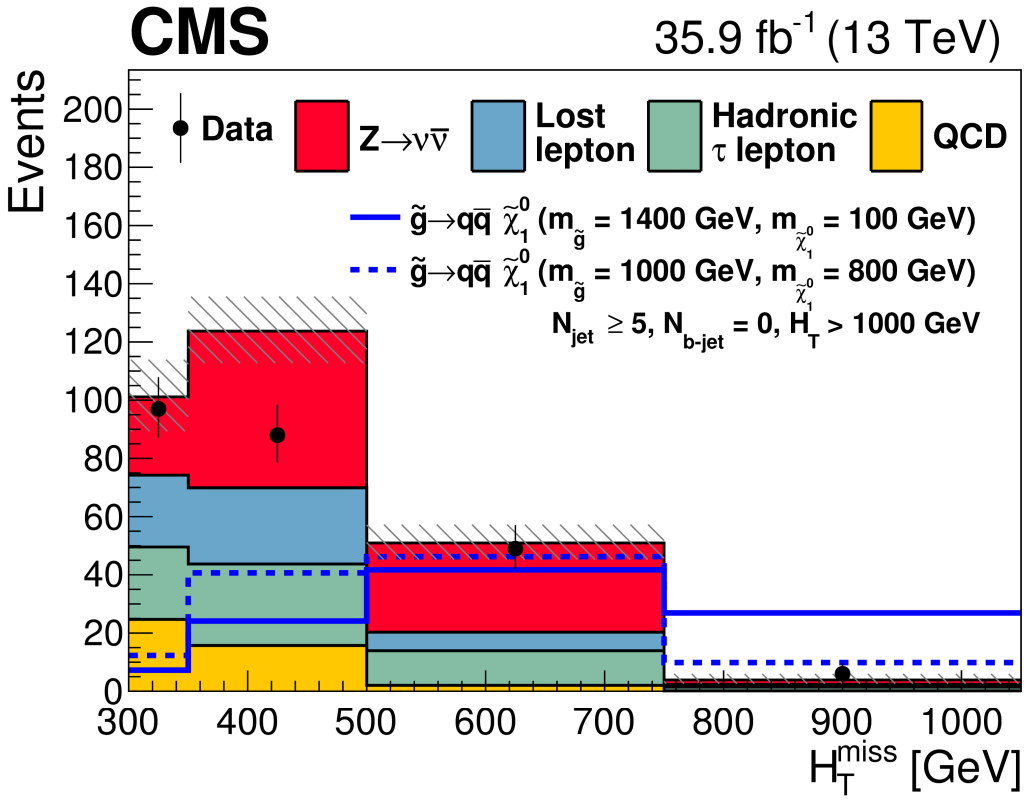
- SUSY can give a remarkably wide range of potential signatures
  - Essentially anything from the SM + missing energy
  - Have recent and ongoing searches in just about every combination imaginable
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS



An example SUSY spectrum

Digging Under Background

- Traditional approach is to look in extreme tails of kinematic distributions

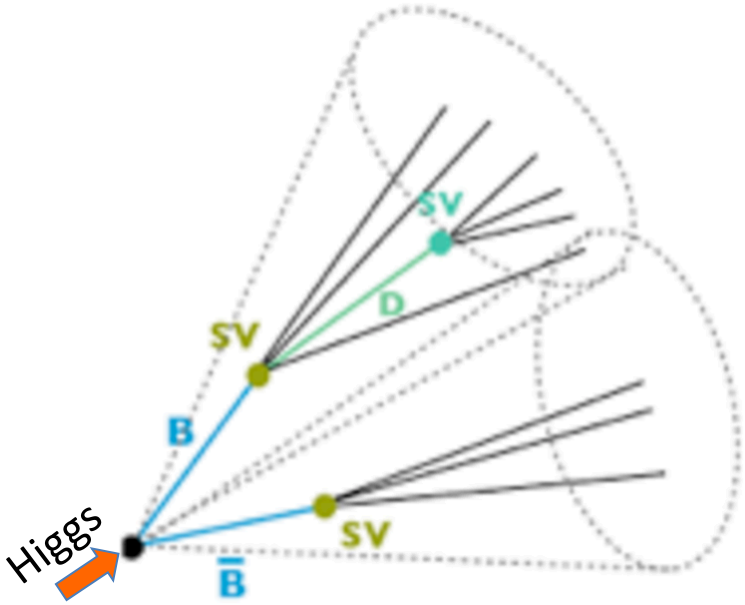


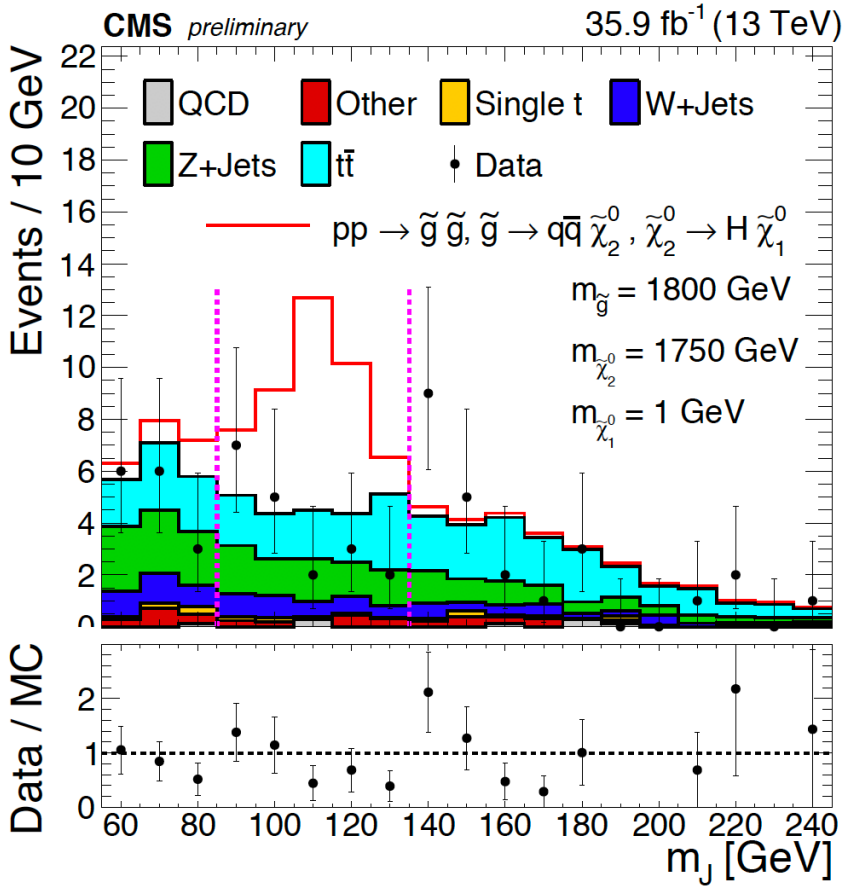
- But signals could be hiding in the bulk with lower rates
- Another option is to use new unique signatures to beat down backgrounds in these cases
- Will give two examples from canonical multi-jet signals

Boosted Object Tagging

- High p_T H→bb decay with small opening angle
- Use large angle jets to capture full Higgs decay
- Identify Higgs tags by presence of two displaced subjets
- Jet mass shows clear peaking structure

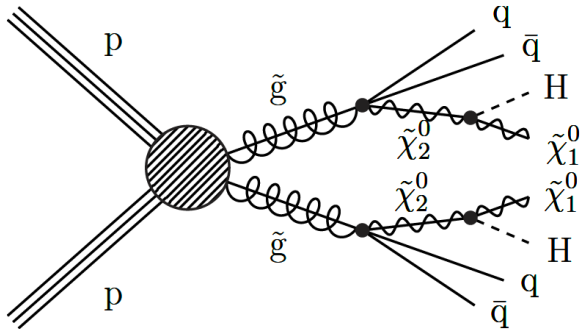
CMS-SUS-17-006

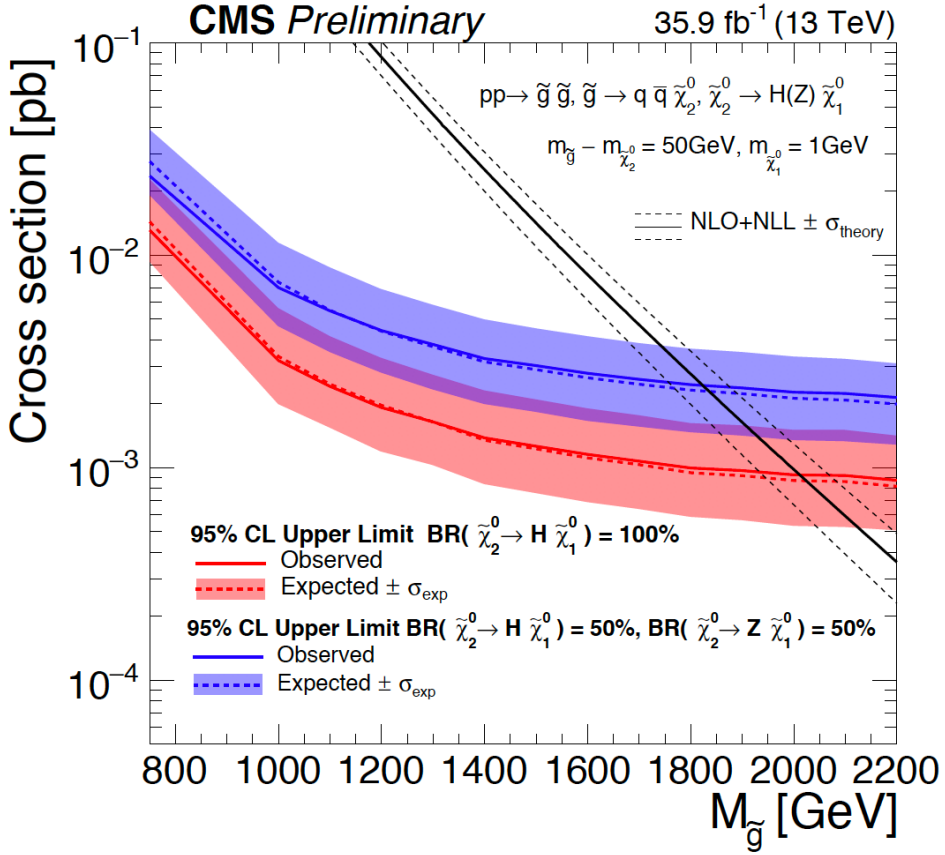




Boosted Higgs Search

- Select events with 1 or 2 Higgs tags and large missing energy
  - 2 AK8 jets with p_T > 300 GeV
  - MET > 300 GeV
- Backgrounds predicted from mass and bb-tag sidebands in data
- Interpret in gluino decay model with mass splittings that give high p_T Higgs bosons



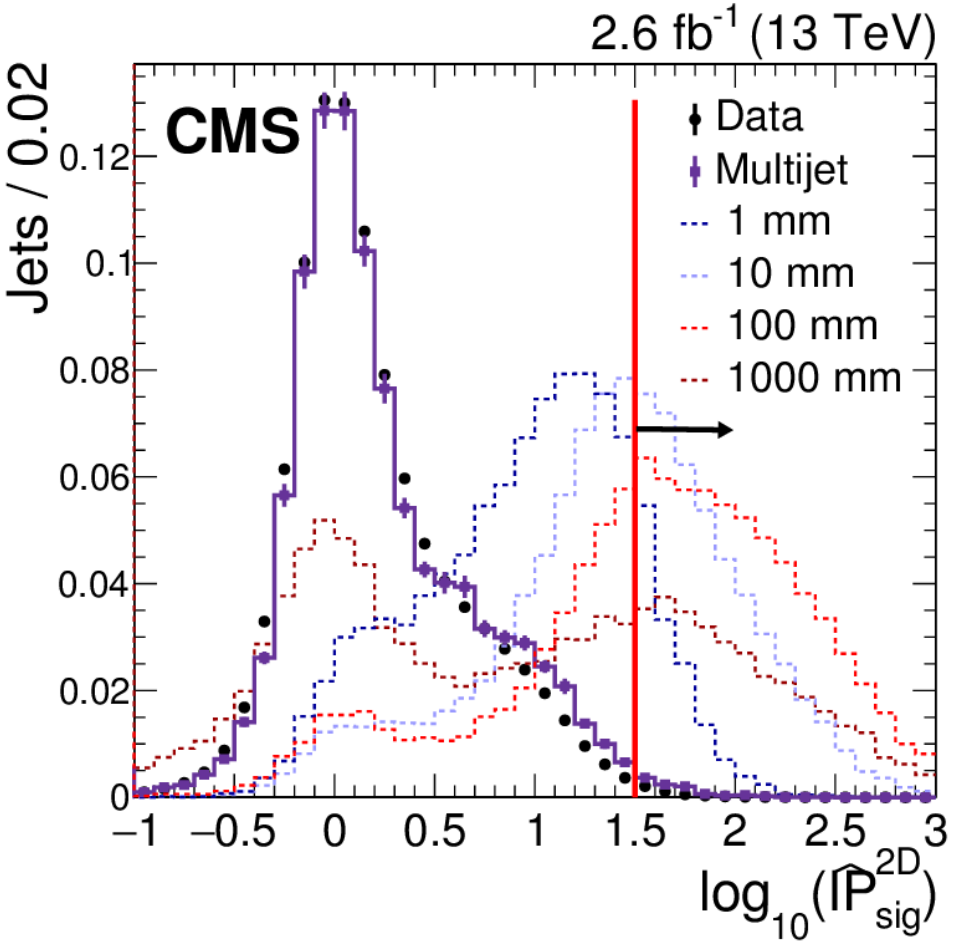


See Parallel Talks: Simon Kurz

Long-lived SUSY decays

CMS-EXO-16-003
arXiv: 1711.09120

- Search for events with jets displaced from the beamline
- Jets reconstructed from calorimeters only
- Use tracks within $\Delta R < 0.4$ to tag jets as displaced
  - Ex. Impact parameter significance of the tracks
  - Jet tagging eff. ~60% for $c\tau$ = 3 cm
  - Mis-id rate ~0.05%
- Search for events with 2 or ≥3 tagged displaced jets

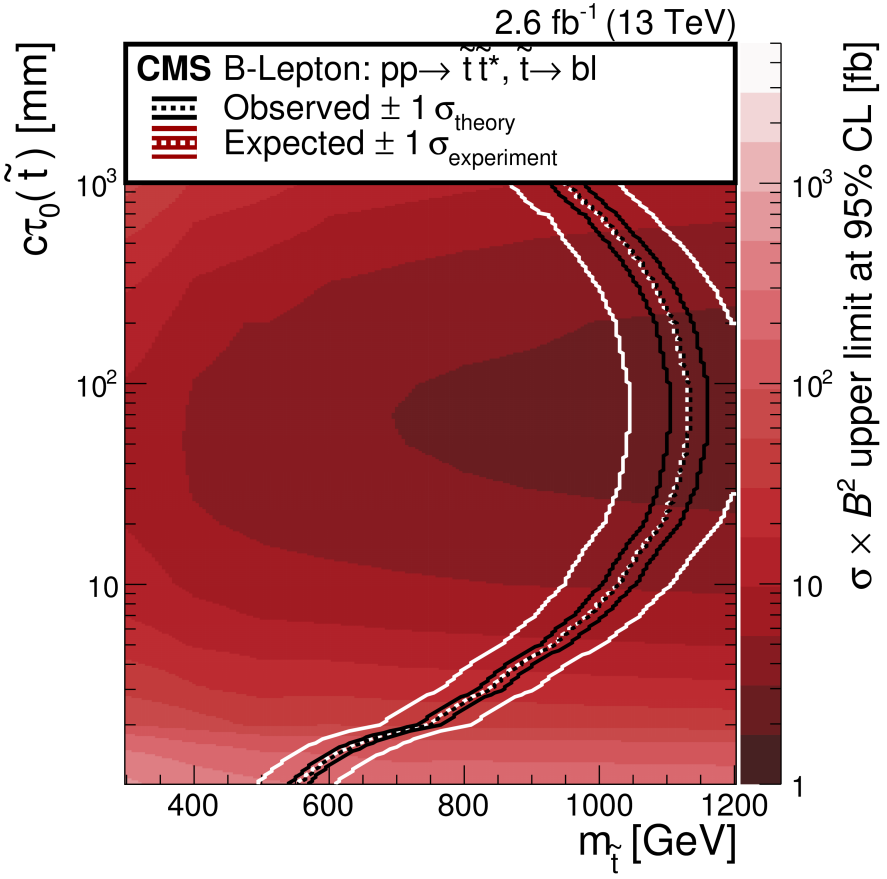


Results from displaced jets

- Very low backgrounds from good displaced jet ID

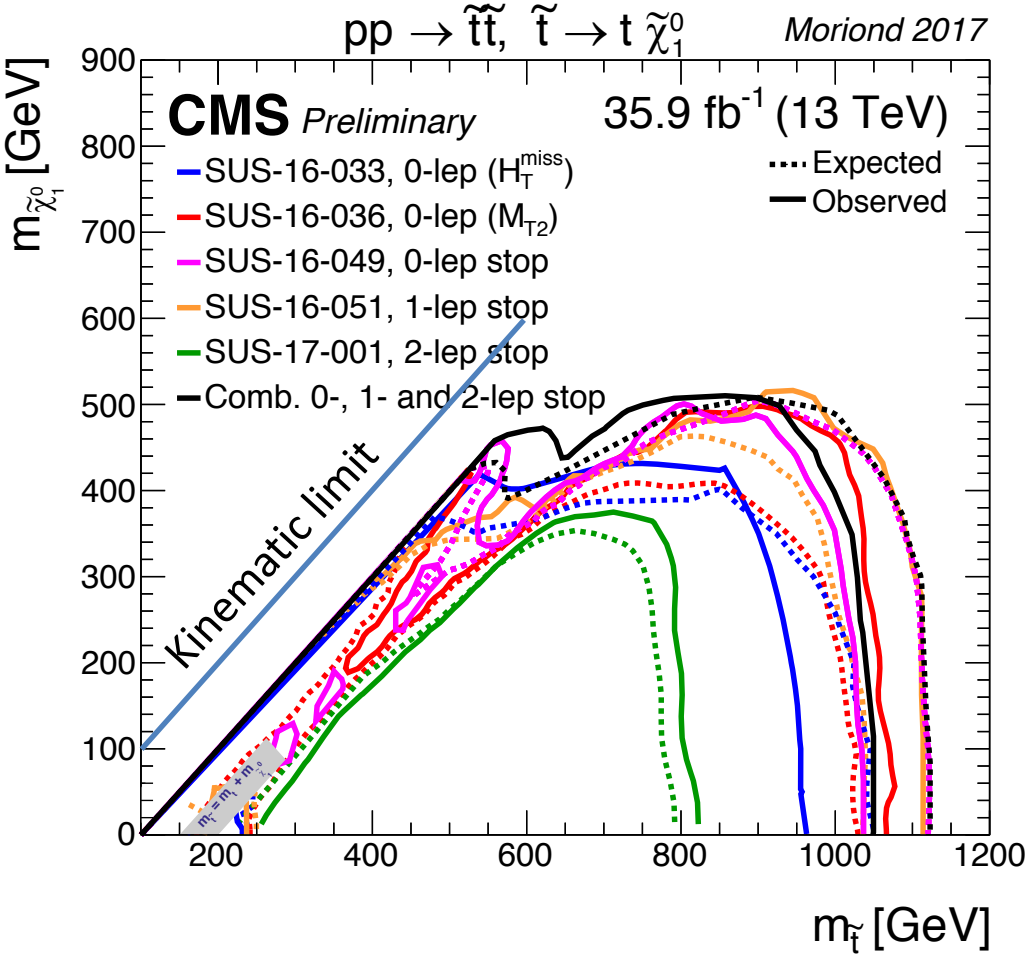
N_{tags}	Expected	Observed
2	1.09 ± 0.16	1
≥ 3	$(4.9 \pm 1.0) \times 10^{-4}$	0

- Interpret in a long-lived stop scenario decaying to a b-jet and a lepton



See Parallel Talks: Luca Pernie

Targeting Corners

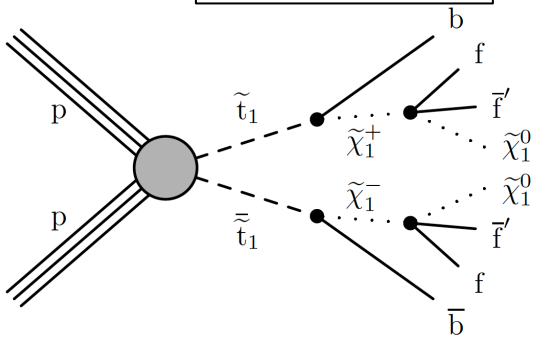


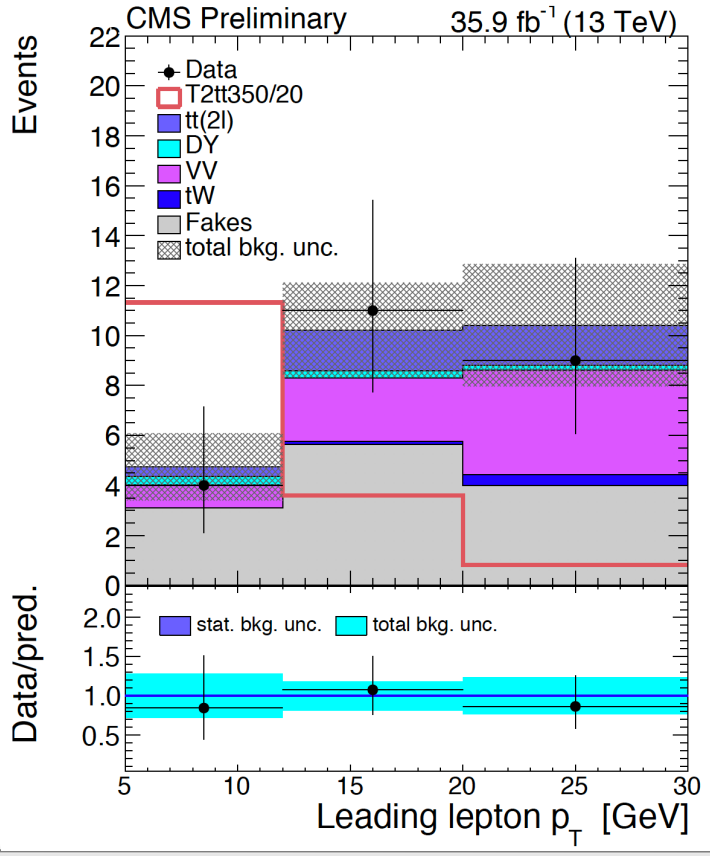
- Broad inclusive searches can leave gaps in sensitivity in challenging regions
  - Dedicated searches extend and complete the coverage

Compressed Stop

CMS-SUS-16-048
CMS-SUS-16-049
CMS-SUS-16-052

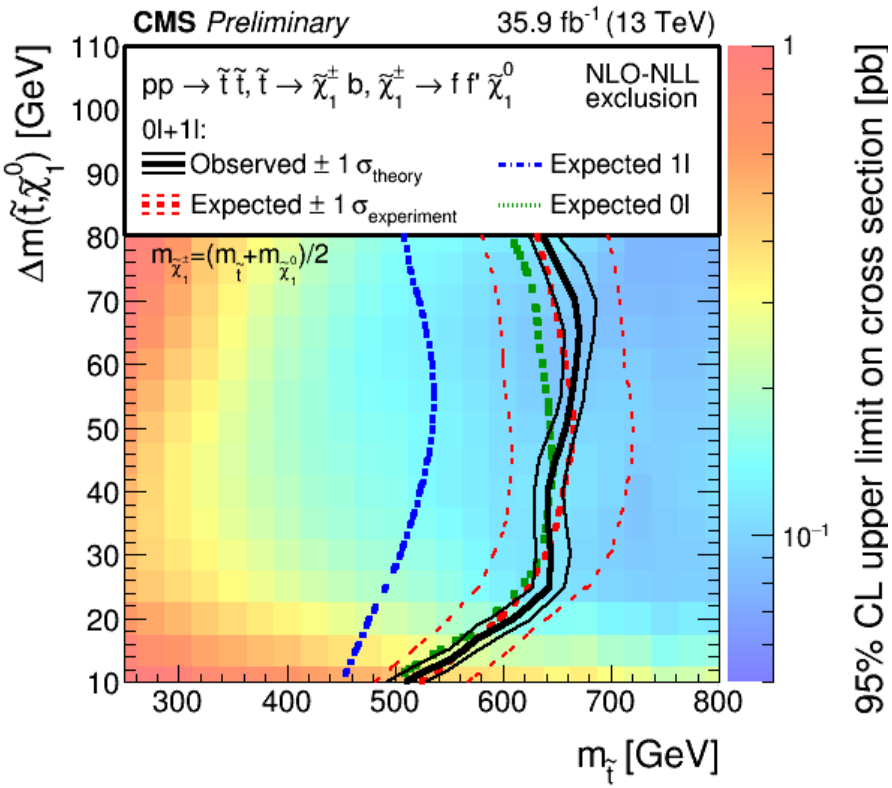
- Compressed scenario with small Δm(stop,LSP) proceeds through off-shell W
  - Results in low p_T decay products
  - Target this signature with soft leptons
- Rely on events with large ISR boost for sizeable MET
- Search in both 1L and 2L channels
  - $p_T(\mu^-)$: 3.5 – 30 GeV
  - $p_T(e^-)$: 5 – 30 GeV
- Backgrounds: W+jets, 1L/2L tt, Z->tau,tau
  - From MC normalized to data in control regions



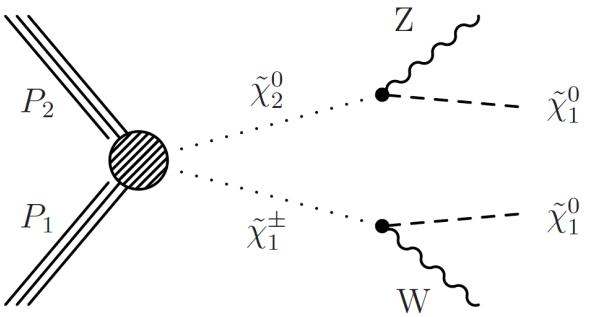


Compressed Stop

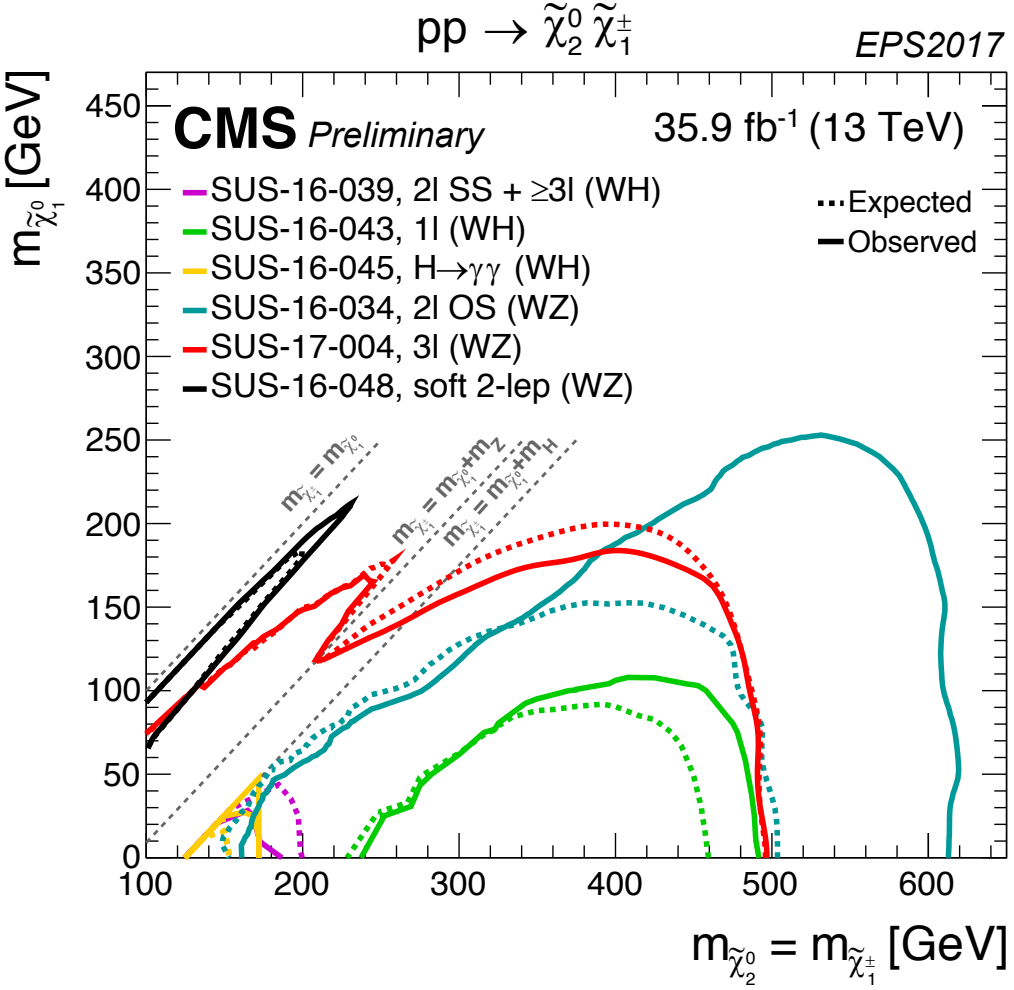
- Variety of signal regions binned in lepton p_T, MET, m_T(l,MET), m(ll) to capture large and small mass splittings
- Stop masses excluded up to ~600 GeV for Δm(stop,LSP) < m(W)
  - Results shown for combination of 0L and 1L searches



Compressed Higgsino



- Soft dilepton search also sensitive to Higgsino production
- Difficult scenario with light Higgsino multiplet and other SUSY decoupled
- First new limits since LEP

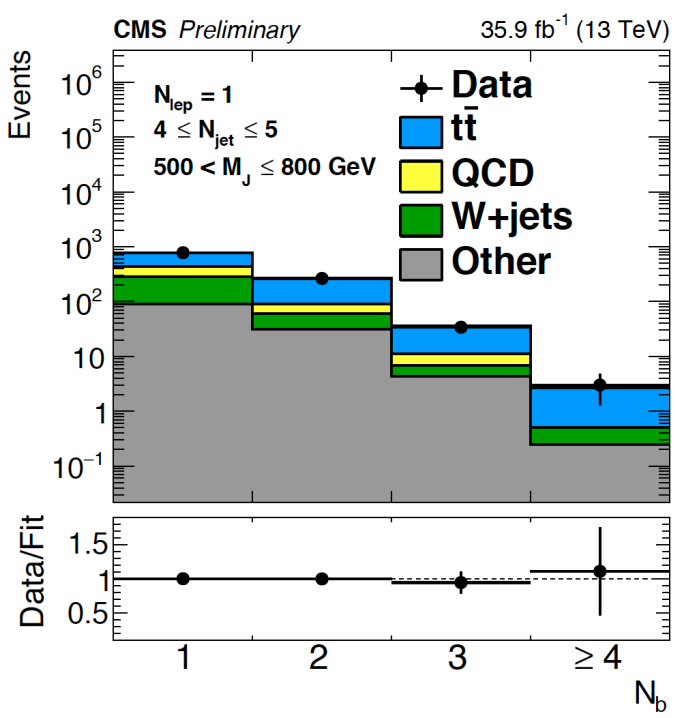


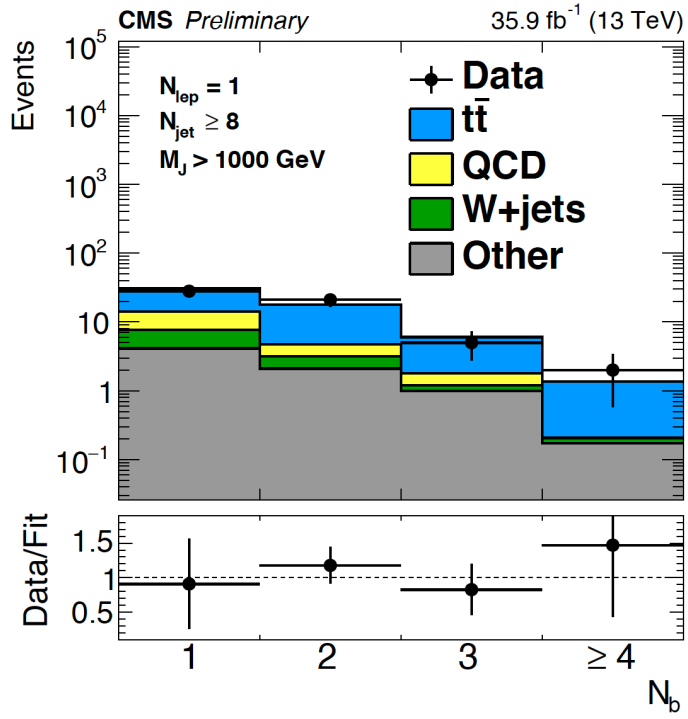
See Parallel Talks: Henning Kirschenmann, Navid Rad

R-parity violation

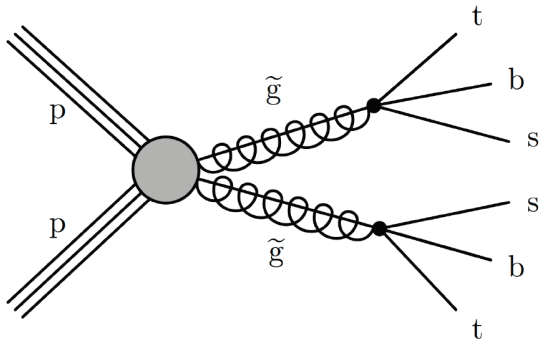
CMS-SUS-16-040

- Missing energy is the hallmark of a “SUSY” search
  - Has served us well, but can potentially blind us to other possibilities
- RPV multi-b analysis searching in tails of high nJet and high nB multiplicity
  - Trigger on single jet or HT (no MET requirement)
  - HT > 1200 GeV, nJet ≥ 4, nB ≥ 1, MJ > 500 GeV
  - One isolated e^- or μ^-
- Fit the nB distribution in categories of nJet and MJ

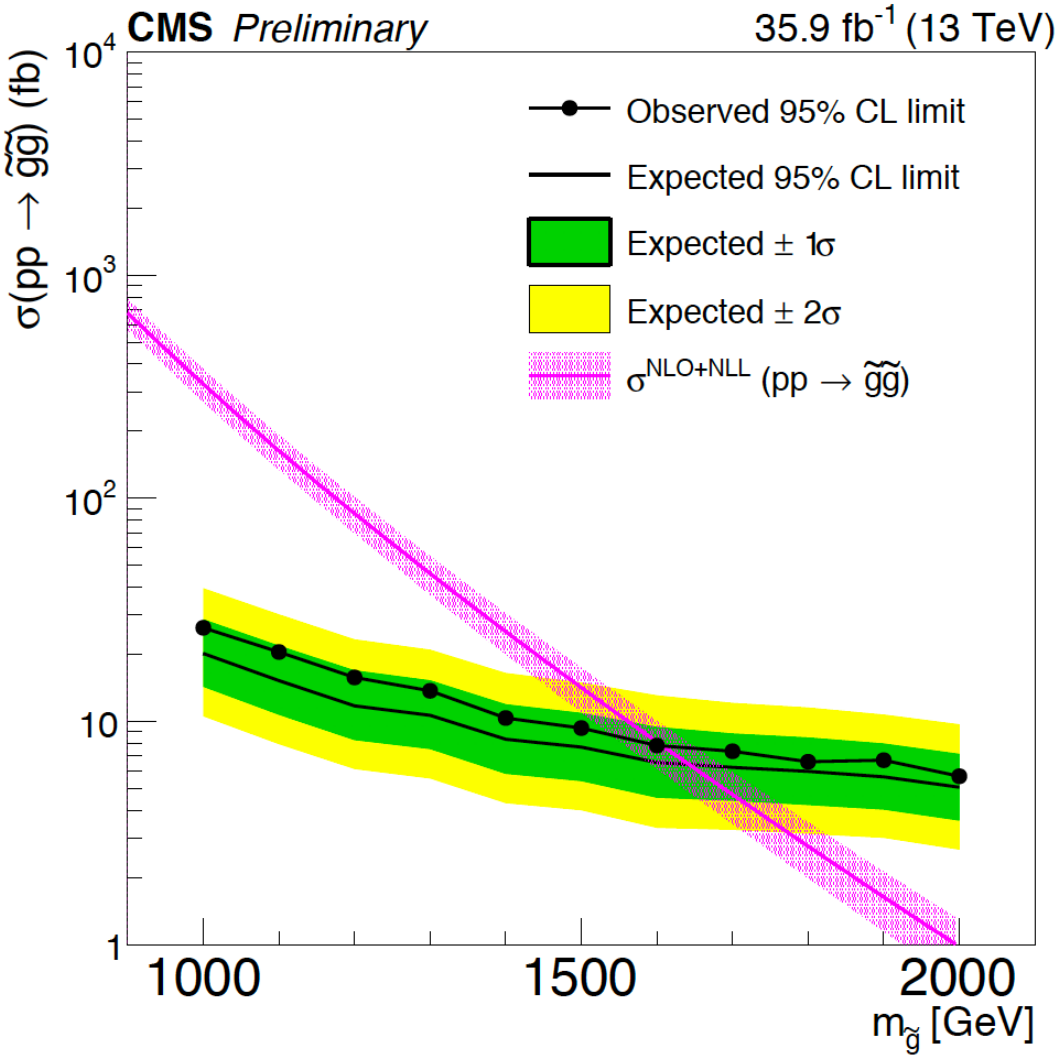




R-Parity violation

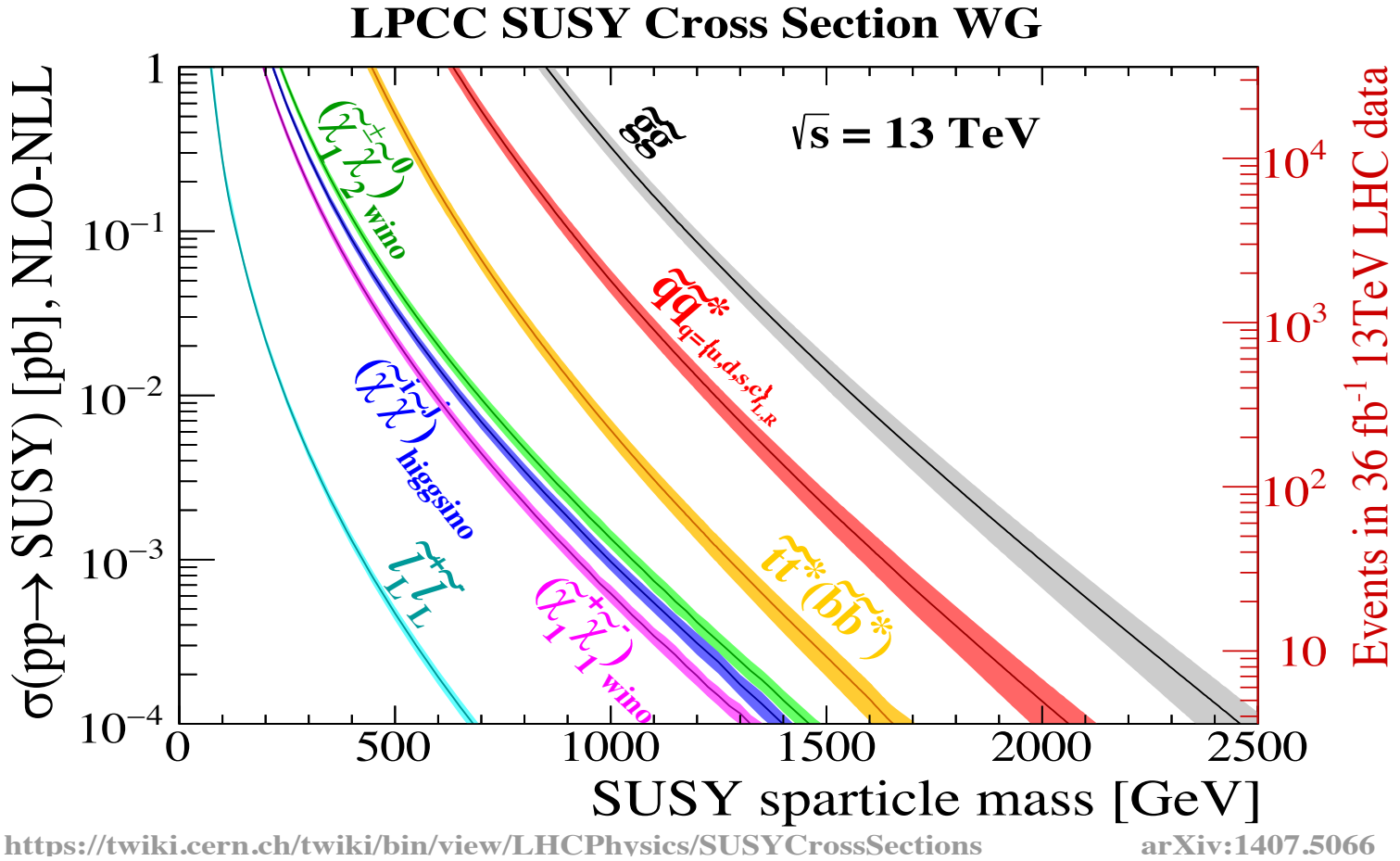


- Background predictions anchored at low nB, searching for signal with ≥3 b-tags
- Interpret in RPV gluino decay to 3rd generation particles



See Parallel Talks: Jae Yoo

Getting to lower cross sections

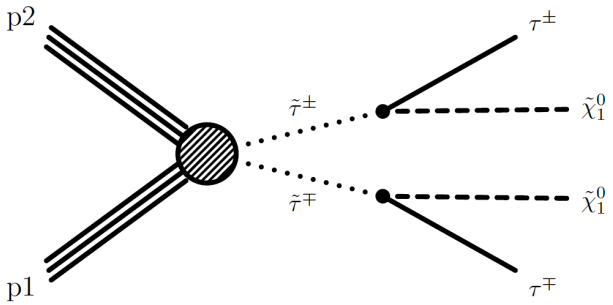


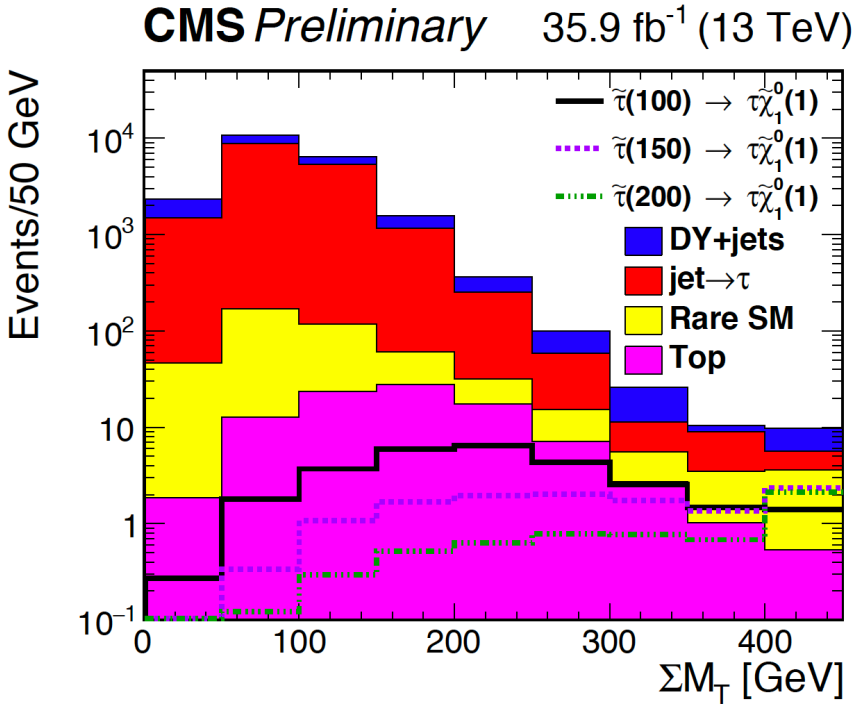
- Abundance of LHC data now allows targeting electroweak SUSY production

Stau Production

CMS-SUS-17-003

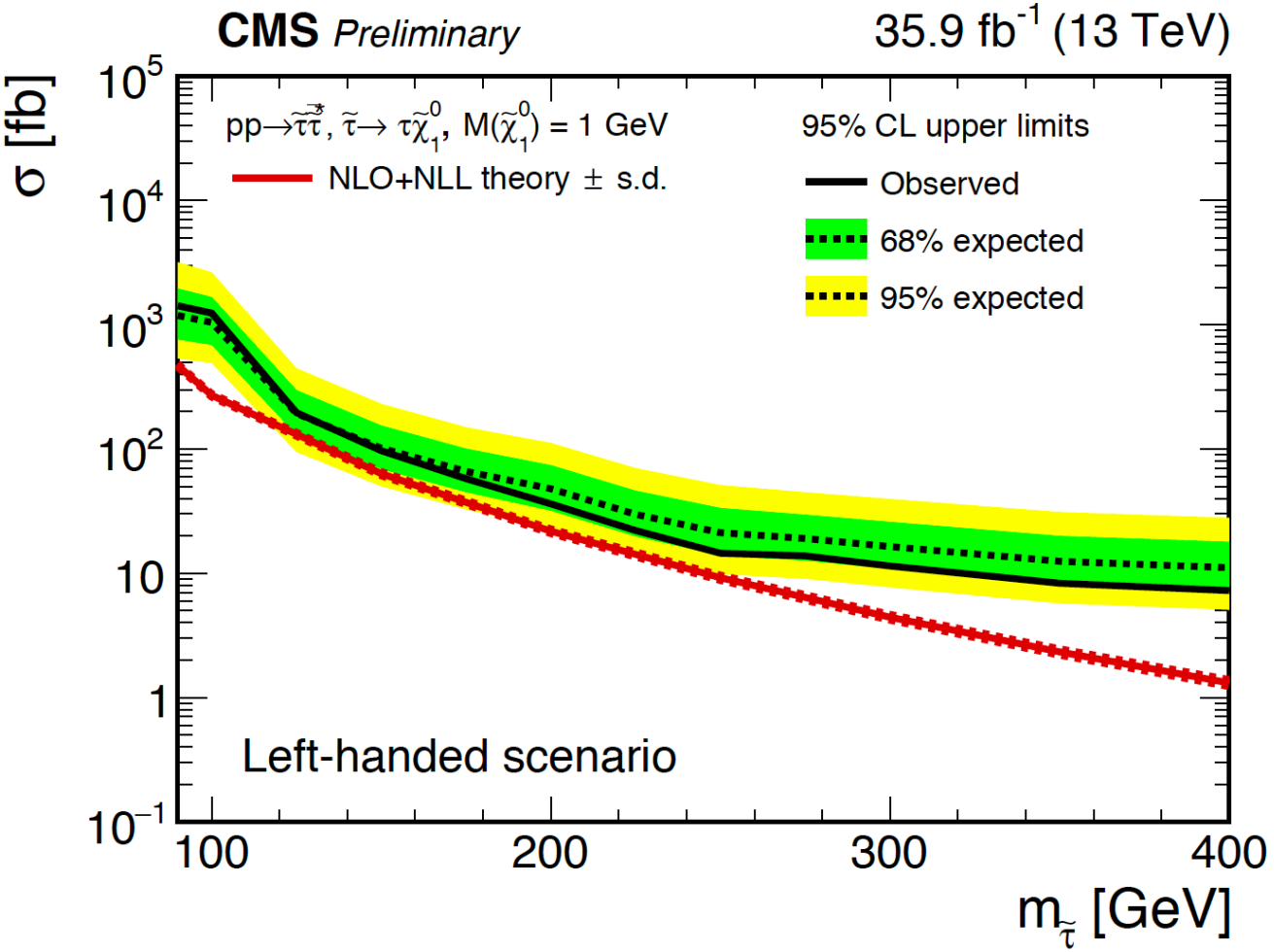
- Target direct stau pair production in 2τ + MET final state
  - 2 isolated hadronically decaying taus with $p_T > 40$ GeV
  - Main discriminating variable: Sum of transverse mass from tau candidates
  - Veto events with e^-/μ^-
    - Other tau decay channels will be complementary
- Main backgrounds from QCD multi-jet and W+jets
  - Fake had tau background measured in data from loose isolation sideband





Stau Production Limits

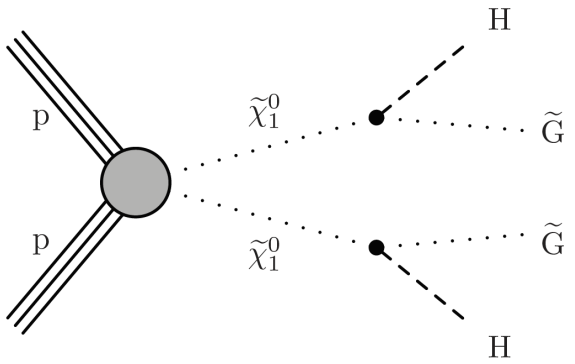
- No excess observed in 3 signal regions
- Set 95% CL upper limits on di-stau cross section
- Limits not quite to expected cross section (1.5x SM)
- Significant dependence on stau polarization

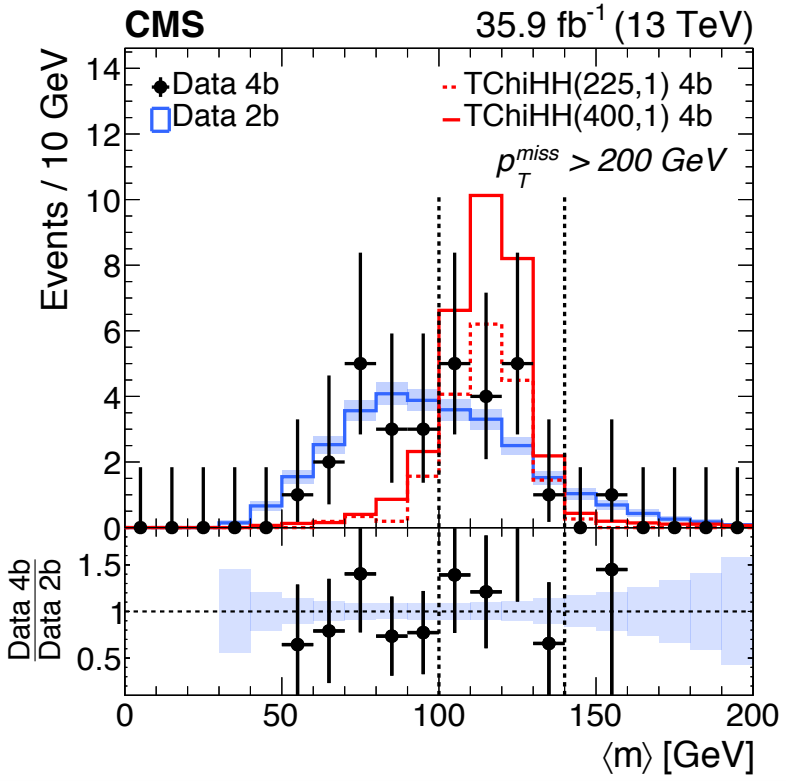


Higgsino Search

CMS-SUS-16-044
arXiv: 1709.04896

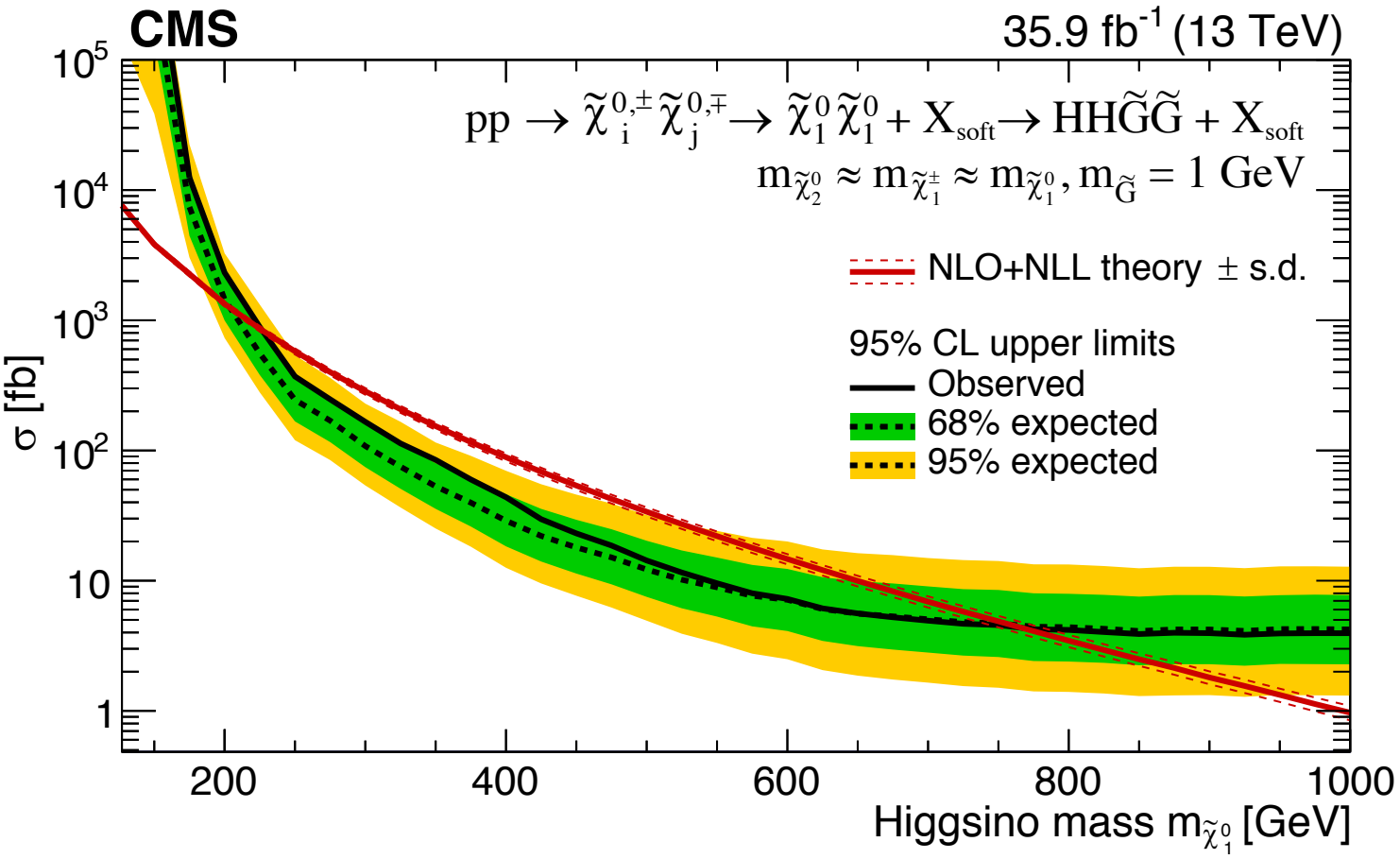
- Search for direct production of EW-inos in decays to Higgs bosons
- Utilize largest Higgs branching fraction to bb
- Select candidates with 2 pairs of b-jets with mass consistent with the Higgs
- Search regions binned in MET starting with >150 GeV
- Background measured in data from 2b and Higgs mass sidebands
  - Mostly from tt





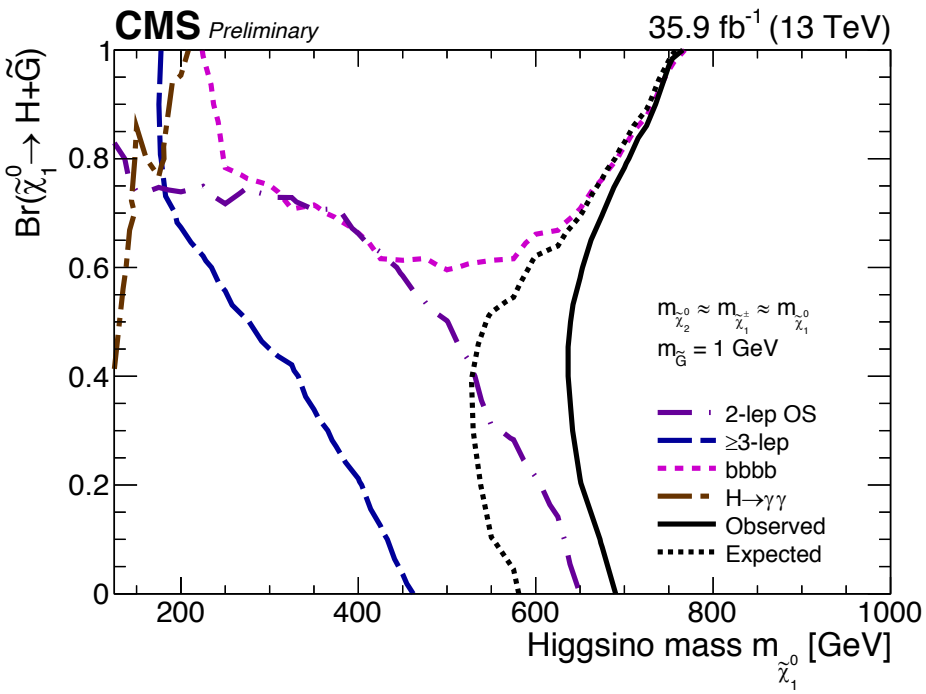
Higgsino Search

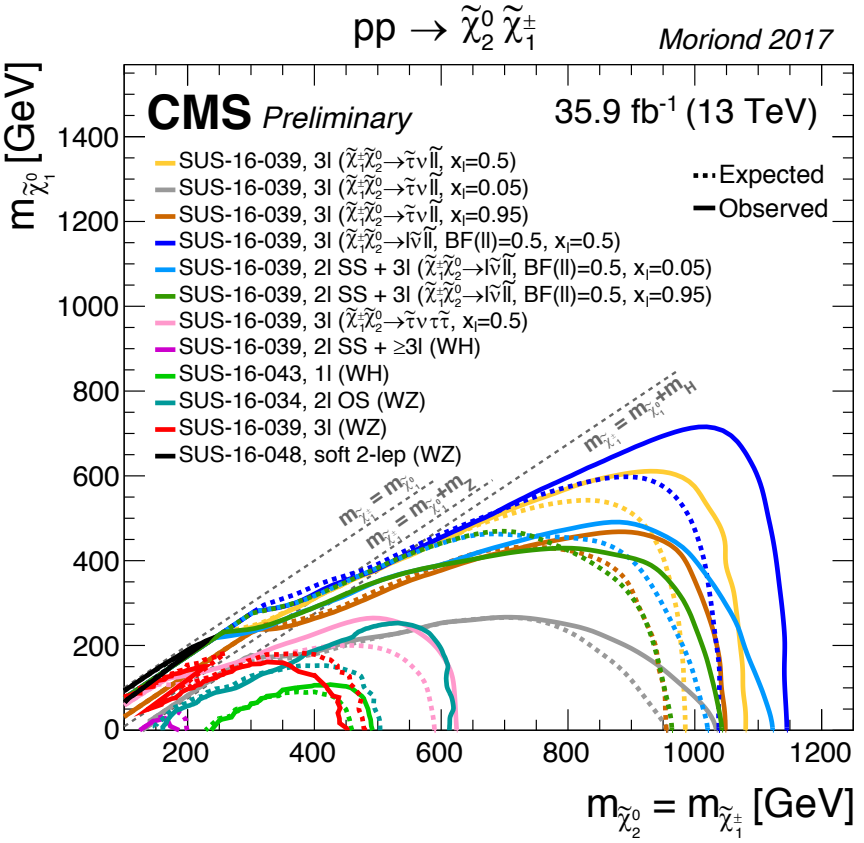
- Observation consistent with SM expectation
- Set limits on Higgsino mass from 230 – 770 GeV in a gauge mediated scenario with 100% BF to Higgs



Electroweak Summary

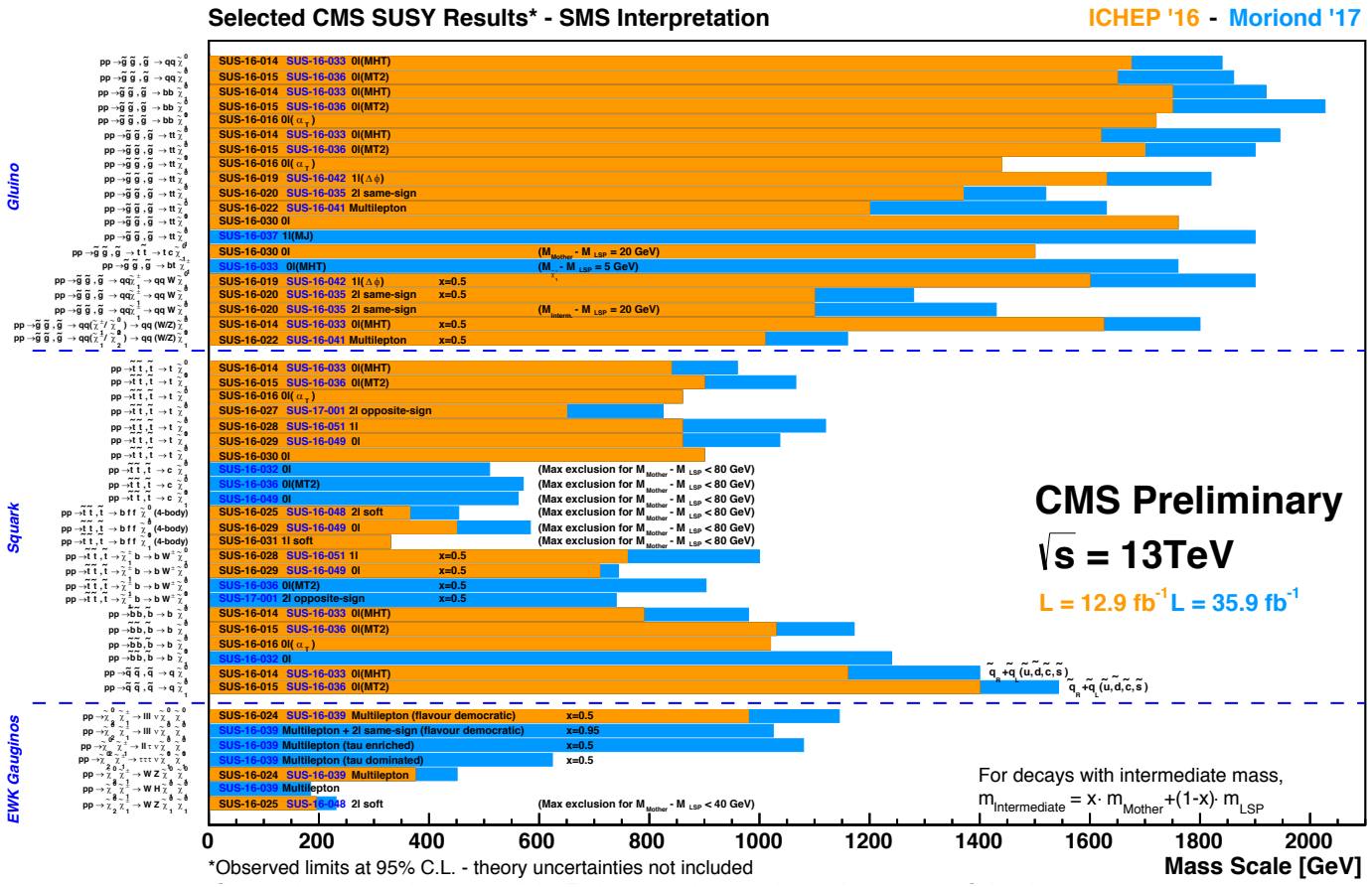
- Wide range of EW-ino production and decays possible
- Search sensitivity generally at lower masses than strong production





See Parallel Talks: Illia Babounikau , Henning Kirschenmann, Laurent Thomas

CMS SUSY Summary

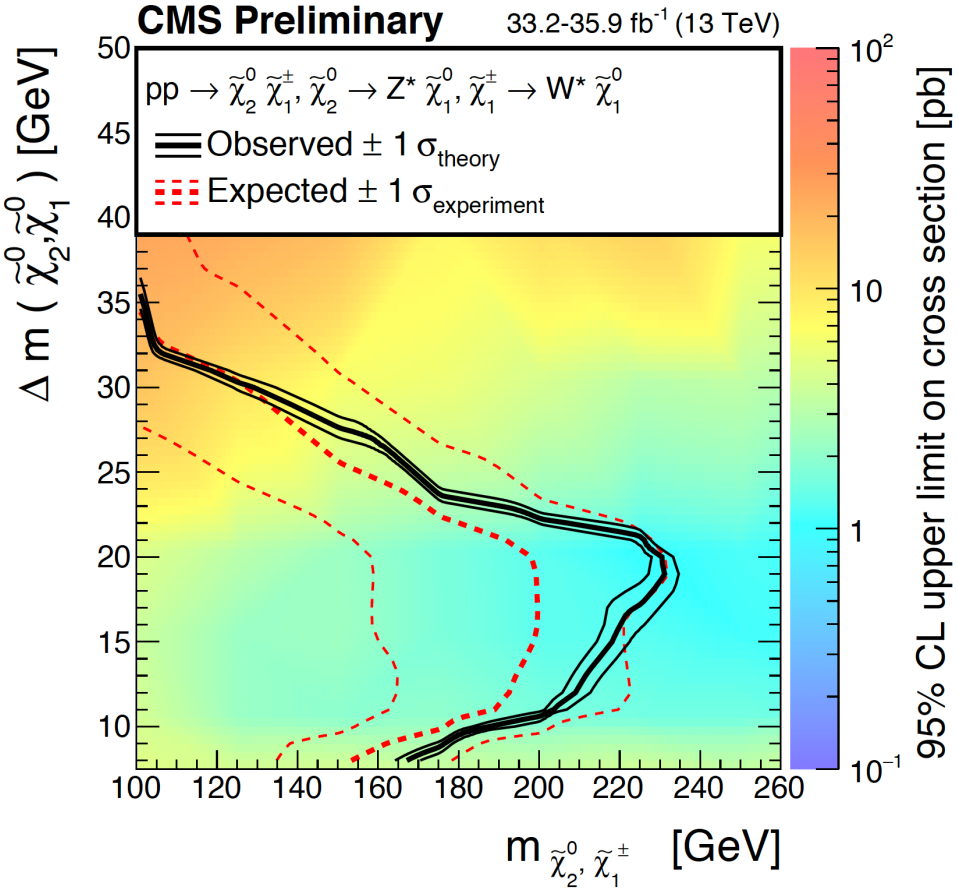


- Wide array of complementary searches to cover possible signature space
- Increasingly probing more dedicated corners and specialized signatures to complement broad inclusive searches
- Searches are adding creativity on top of well established techniques, but alas no signs of new physics yet

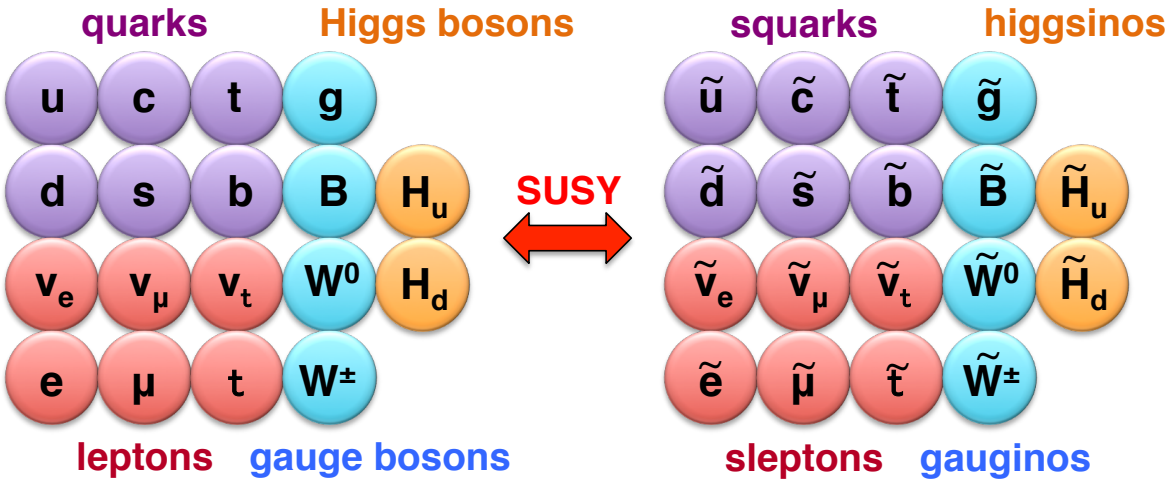
Extra Slides

SOS Higgsino limits

- Limits from SUS-16-048
  - Wino production cross section



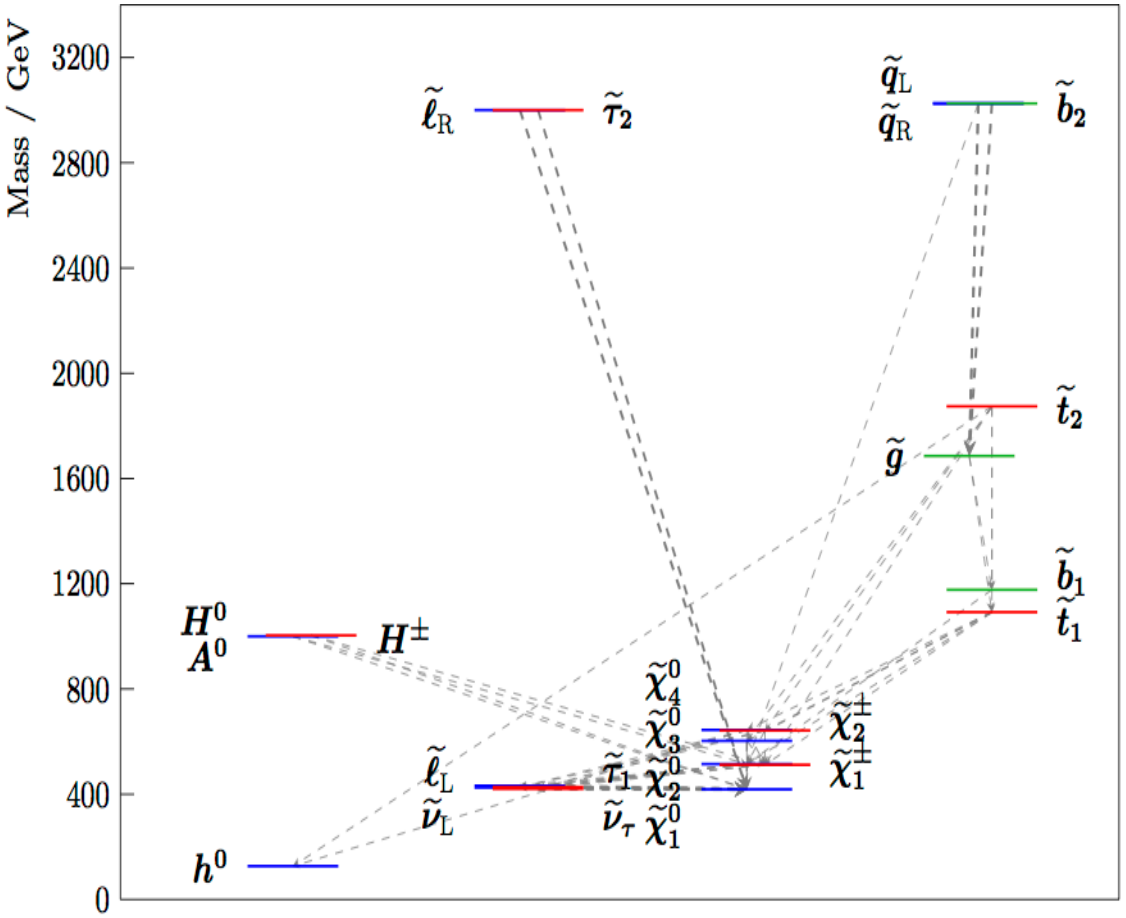
Supersymmetry

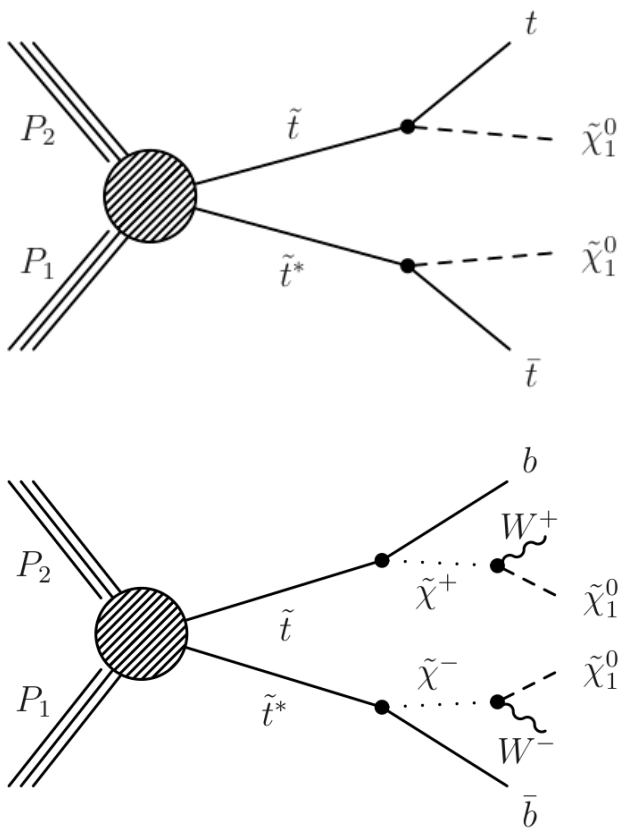


- SUSY offers eloquent solutions to many pressing issues in the SM
  - Natural cancelation of Higgs mass divergences
  - DM candidate with stable lightest SUSY particle (LSP)
  - Potential gauge coupling strength unification

- The experimentalist's note:
  - "SUSY" used as a proxy for a broader class of new physics models
  - Ex. Search for production of any new particles decaying to stable DM
    - Alternatively, see Henning Flacher for pure DM production

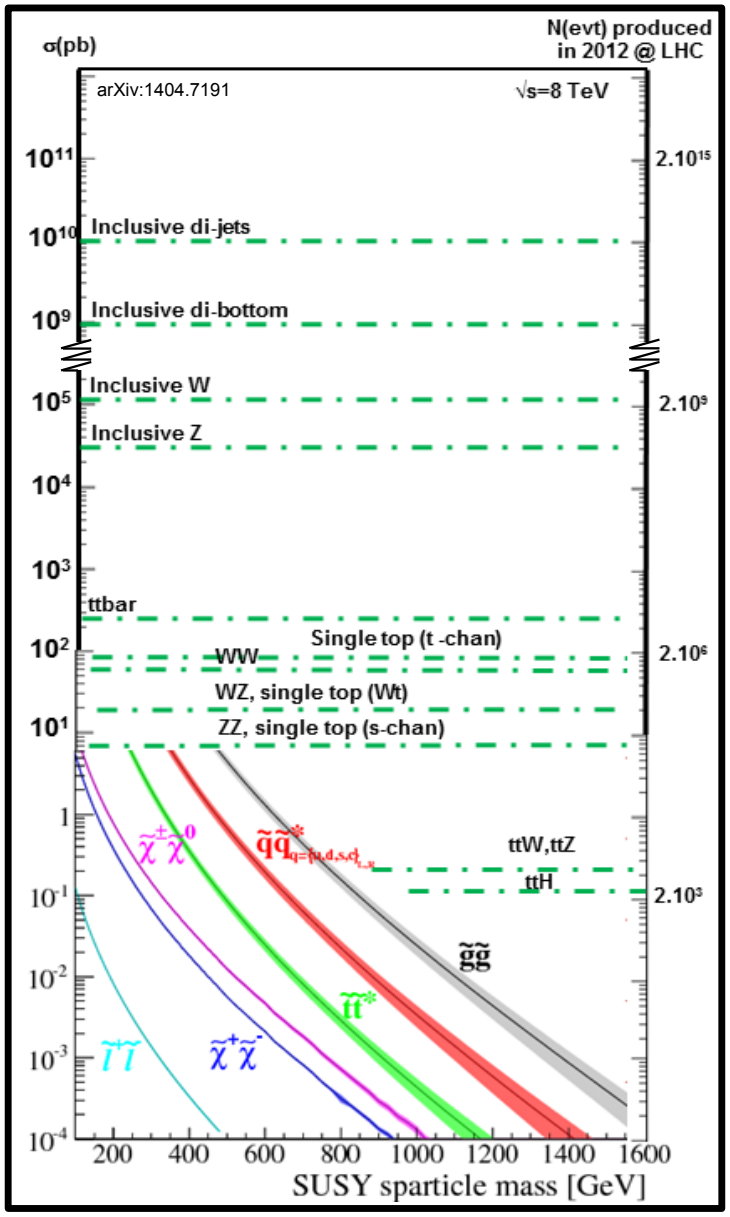
An Experimentalist's Playground





- Rich spectrum can be broken down into individual signatures

The Experimentalist's Challenge



- SUSY production buried under mountain of SM background
- Goal to accurately measure SM contributions in regions where new physics may have significant contributions
- This talk:
  - Give flavor of where we search and how we measure SM backgrounds
  - Can't possibly cover all results…

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

SUSY at the LHC