# Inclusive SUSY searches at CMS


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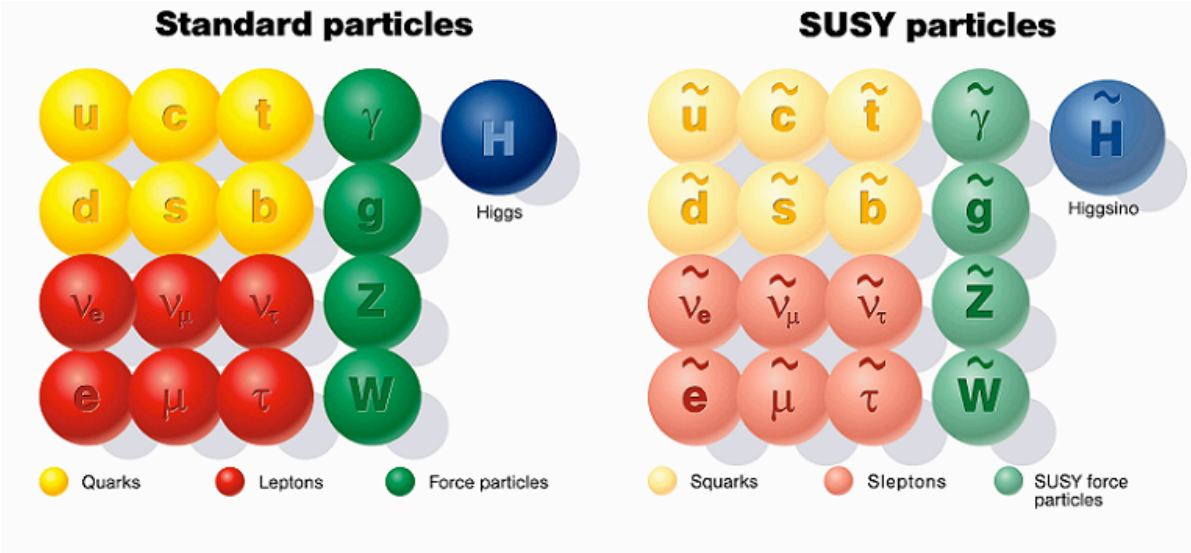
# Outline

- Introduction to SUSY
- Motivation for inclusive searches
- Physics analyses
  - Inclusive multijet searches
  - Opposite sign dilepton search
  - Same-sign dilepton search
  - Chargino/neutralino production
- Summary

# Introduction

- SUSY has strong motivations as a BSM theory which seeks to explain the shortcomings in the SM
- It is able to provide an explanation for fine tuning, dark matter through the LSP, unification of gauge coupling
- Thus searching for it is a major objective of the LHC experiments

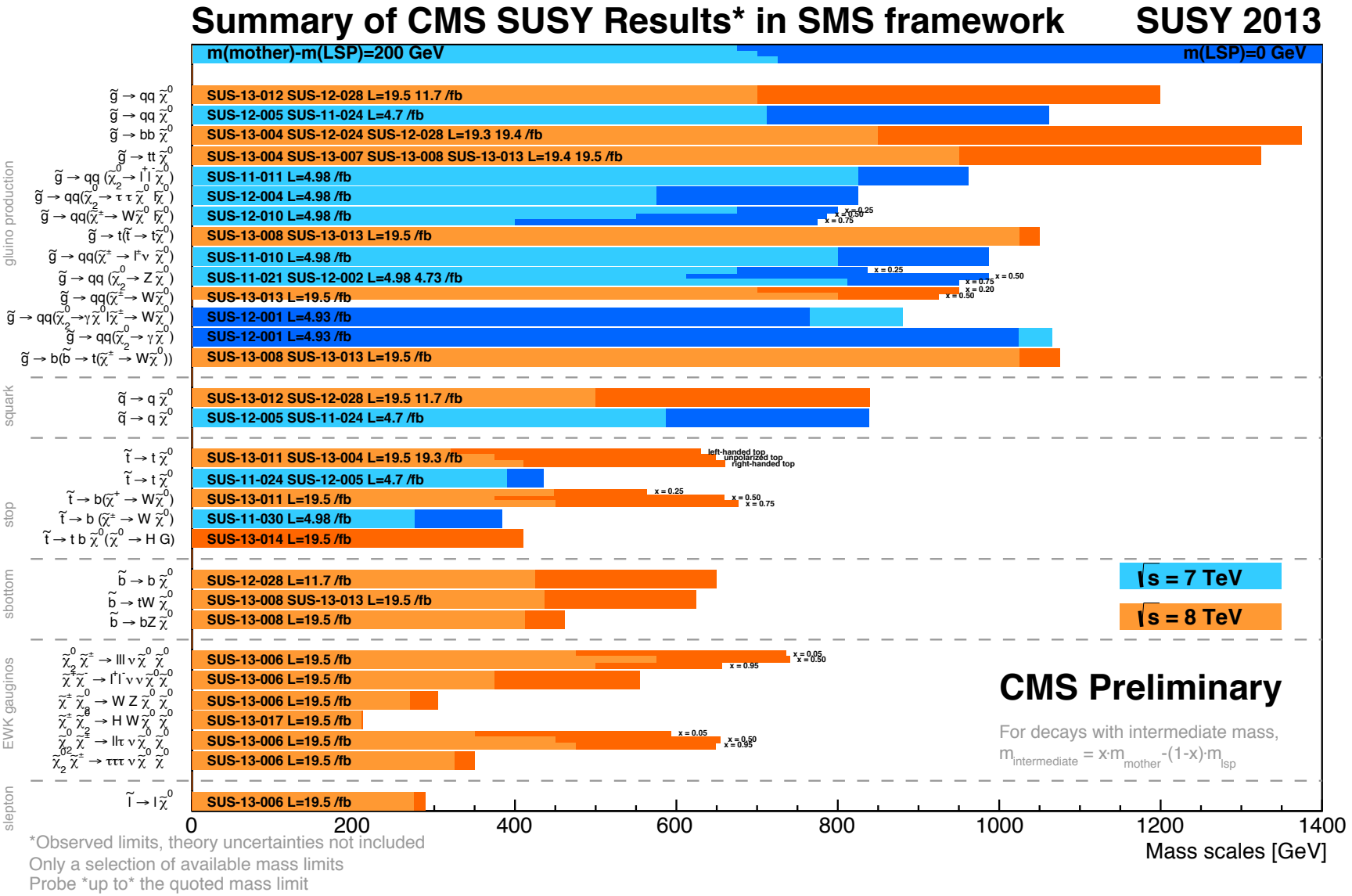



- Superpartner for every SM particle
- Spin differs by one half
- SUSY particles produced/ annihilated in pairs
- LSP is stable in R parity conserving models

# CMS searches

- Important to keep a wide range of searches on-going – you never know where you will find the first signs for New Physics!
- Go after direct stop/sbottom but also go after high jet multiplicities, chargino/neutralinos/sleptons etc
- I will present 4 analyses across the latter areas, all are with the full 2012 8 Tev LHC dataset
- Interpretation with Simplified Model Spectra – masses of primary particles and LSP are free parameters

# CMS searches

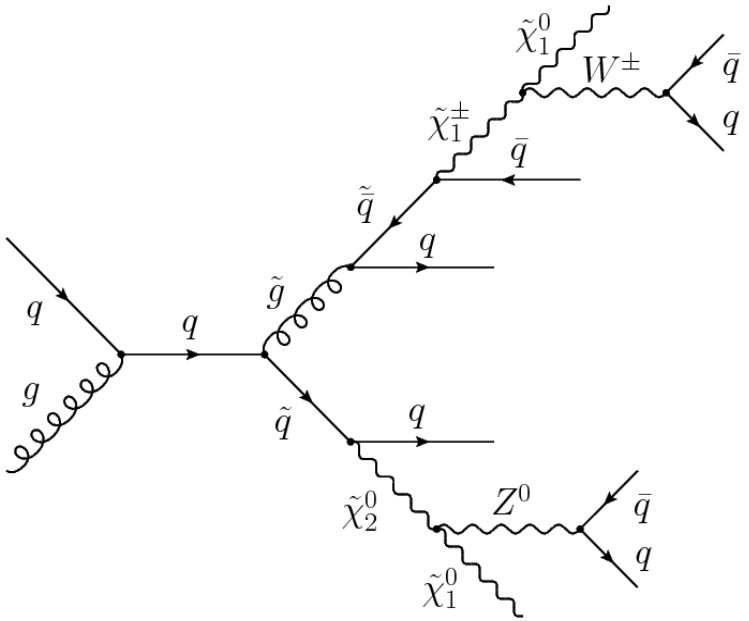


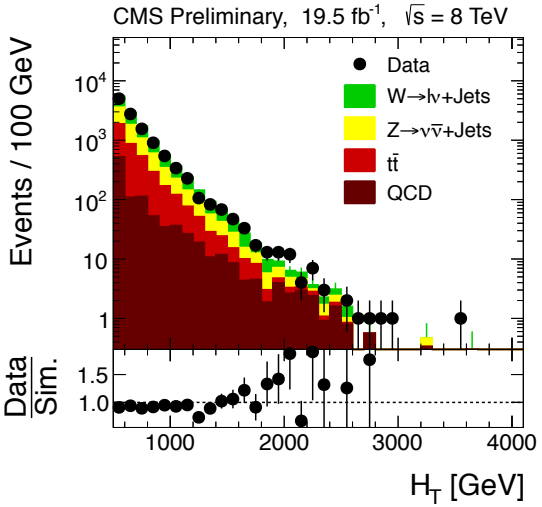

*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

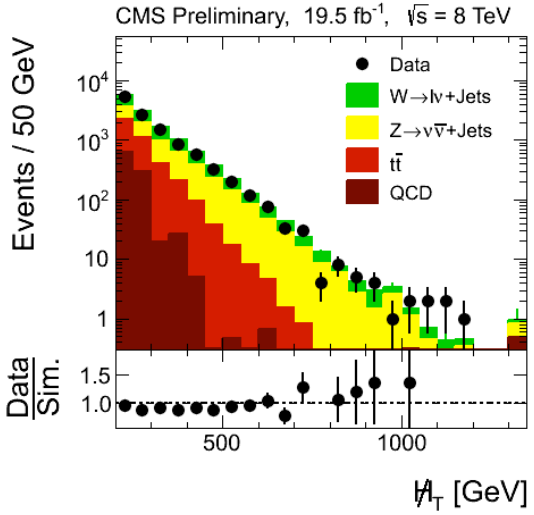
# Multi-jets + MHT (SUS-13-012)

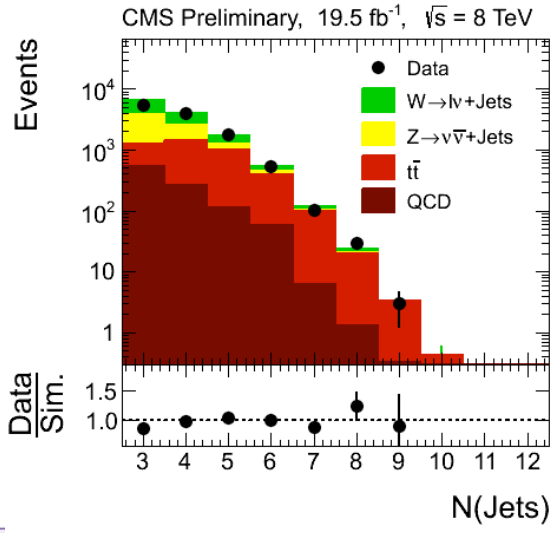
- As inclusive as possible by placing no requirements on b-jets or leptons
- 36 exclusive signal regions, divided using Njets, MHT, and HT –independent – combine for statistical power

$$H_T = \sum_{i}^{jets} \left| \vec{p}_{T,i} \right| \qquad \not{H}_T = \left| -\sum_{i}^{jets} \vec{p}_{T,i} \right|$$



# Multi-jets + MHT (SUS-13-012)

- Backgrounds are estimated using data-driven techniques

## $t\bar{t}/W + jets(e/\mu + \nu)$

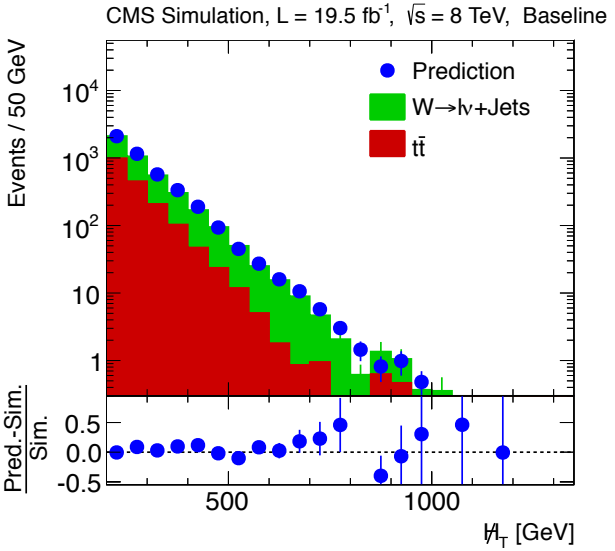
- Occurs when the e/μ are out of acceptance, not isolated, not reconstructed
- Control sample consisting of a single isolated muon is weighted according to e/μ reconstruction and isolation efficiencies to predict the background in search regions.

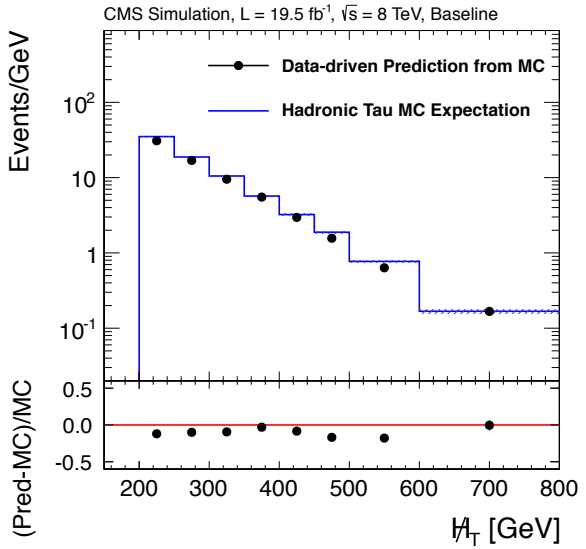
## $t\bar{t}/W + jets(\tau_{had} + \nu)$

- Similar control sample selection as e/μ method – but muon is replaced by an expected τ jet response

Dominant Systematics:

- Statistics of control sample
- Efficiency difference between data and MC



# Multi-jets + $M\not{H}T$ (SUS-13-012)

- Backgrounds are estimated using data-driven techniques

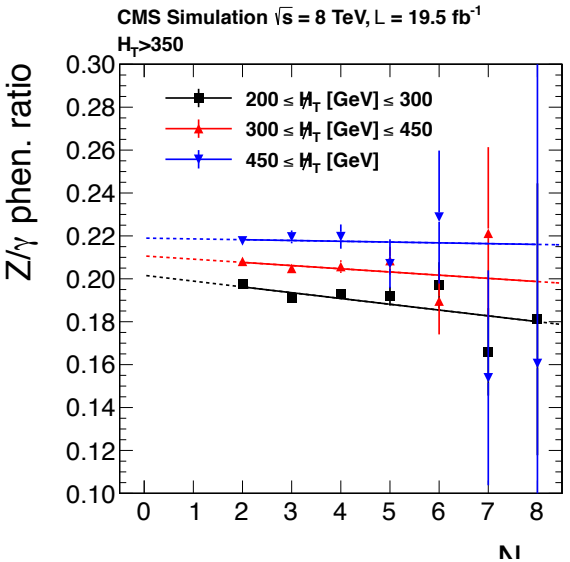
## $Z \rightarrow \nu\bar{\nu}$

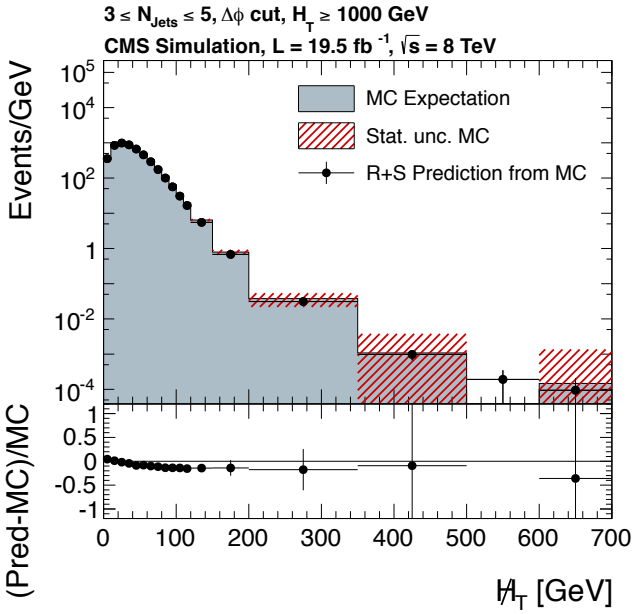
- Irreducible background that results in real Missing Energy
- Use Photon + Jets controls sample to extract cross-section ratio in MC, then apply to data.
- Accuracy of MC ratio is verified with Z-dilepton data and MC

- Systematic: Theoretical error on cross-section ratio

## QCD multijet

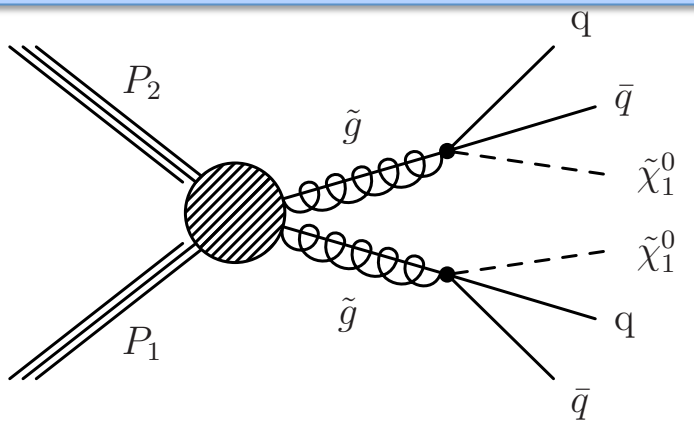
- From leptonic decays of heavy-flavour hadrons, jet energy mis-measurement
- Events in data are re-balanced such that they have no missing transverse momentum – then they are smeared with jet – response functions



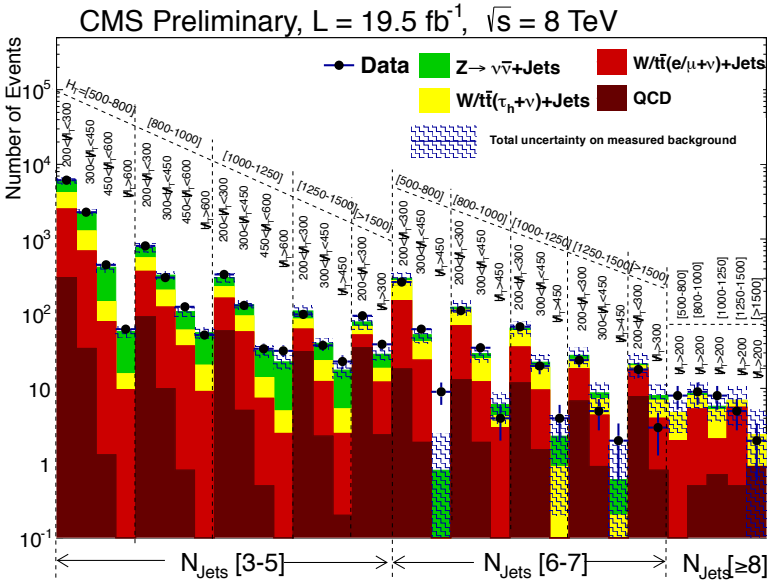



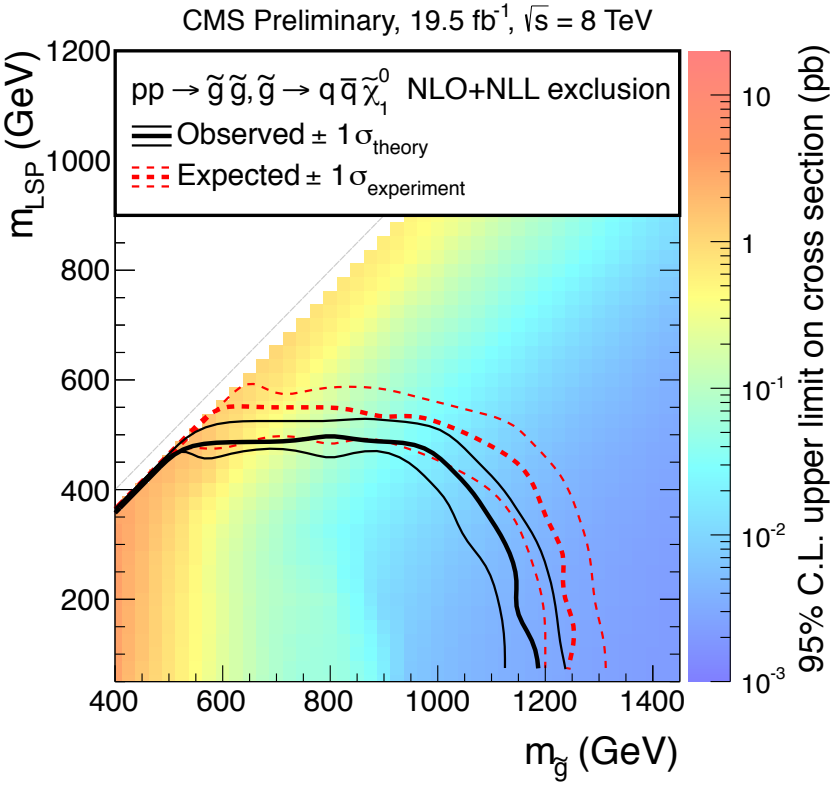
# Multi-jets + MHT (SUS-13-012)

- INTERPRETATION




No significant excess



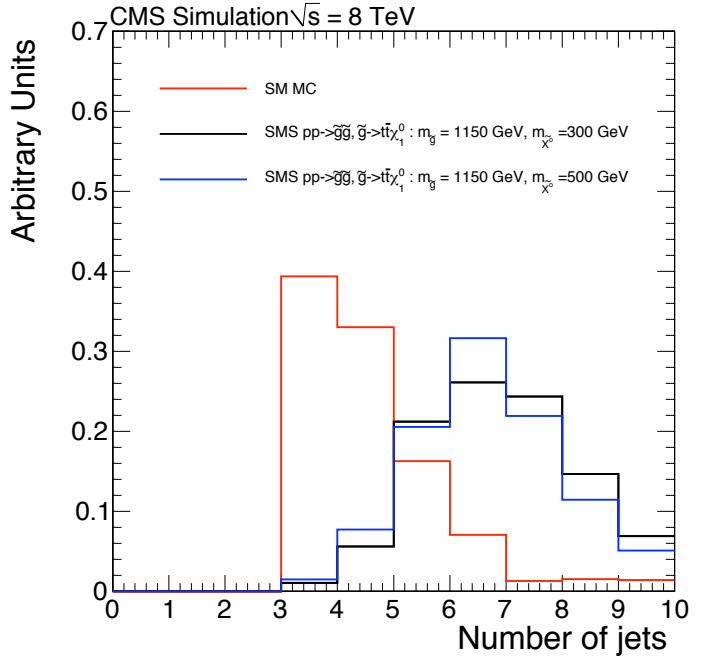



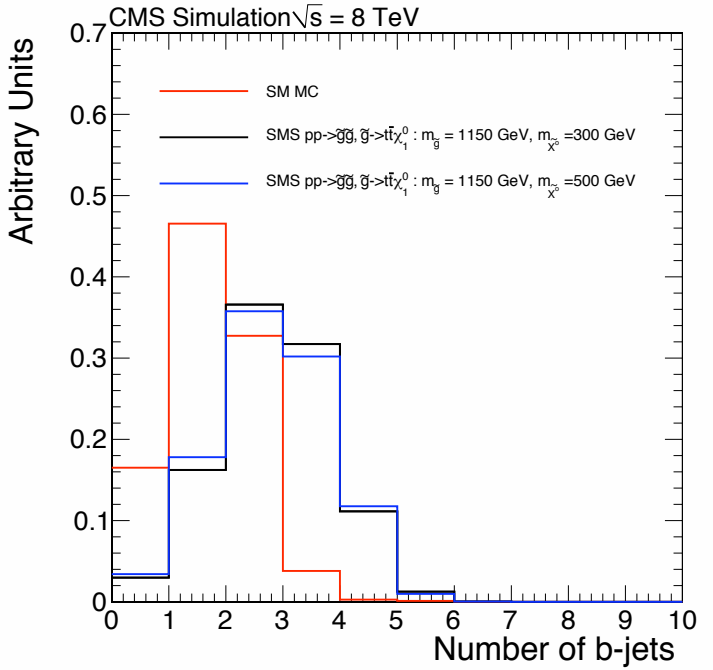
# Opposite-sign dilepton search (SUS-13-016)

- 2 opposite sign dileptons (muon, electrons) with b-tagged jets
- Uses combination of discriminating variables to assess sensitivity to T1tttt.

Table 1: Selection criteria for the definition of signal region

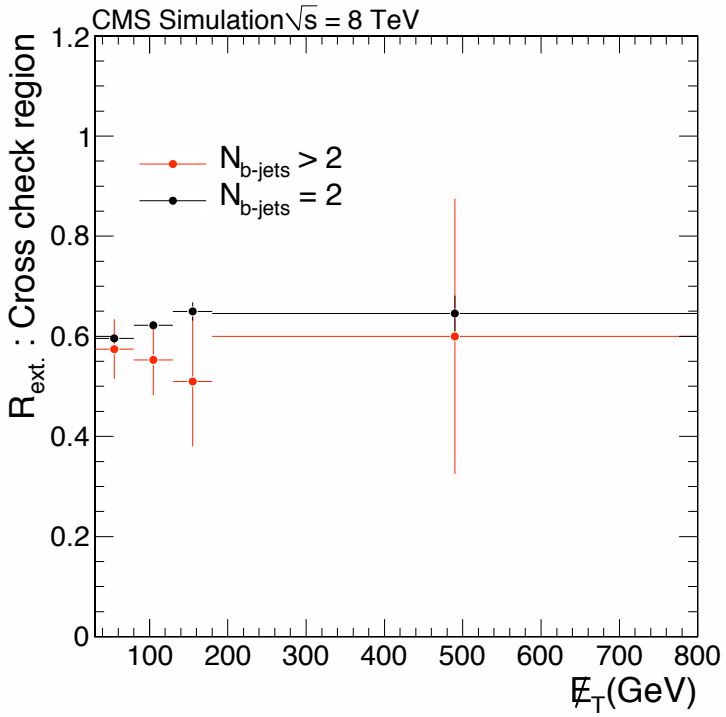
| Variable | Description | Criterion |
|---|---|---|
| $\not\!\!E_T$ | Missing transverse energy | $> 180$ GeV |
| $N_{\text{jets}}$ | Number of jets | $> 4$ |
| $N_{\text{b-jets}}$ | Number of b-tagged jets | $> 2$ |
| Jet1 $\lvert\eta\rvert$ | Leading jet $\eta$ | $< 1$ |
| Jet2 $\lvert\eta\rvert$ | Sub-leading jet $\eta$ | $< 1$ |

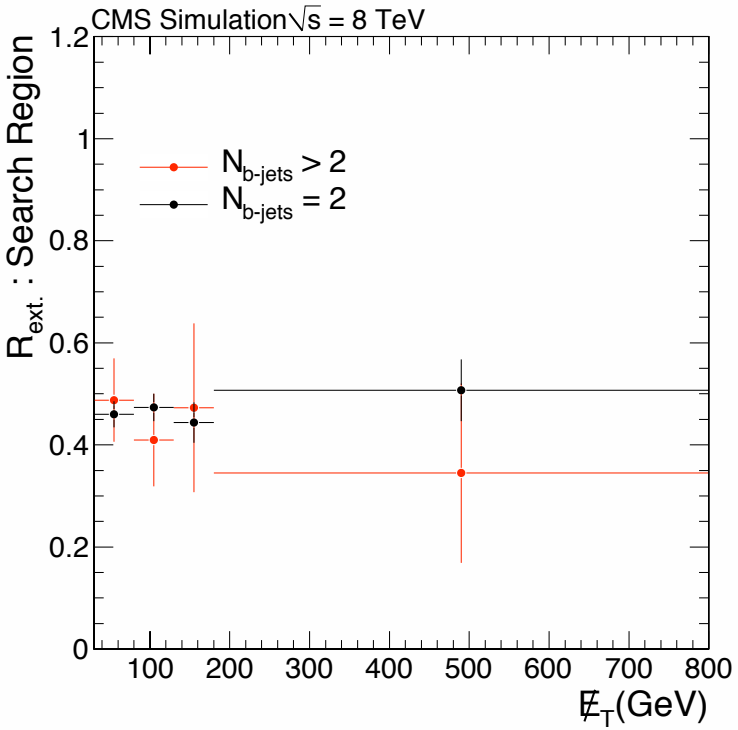


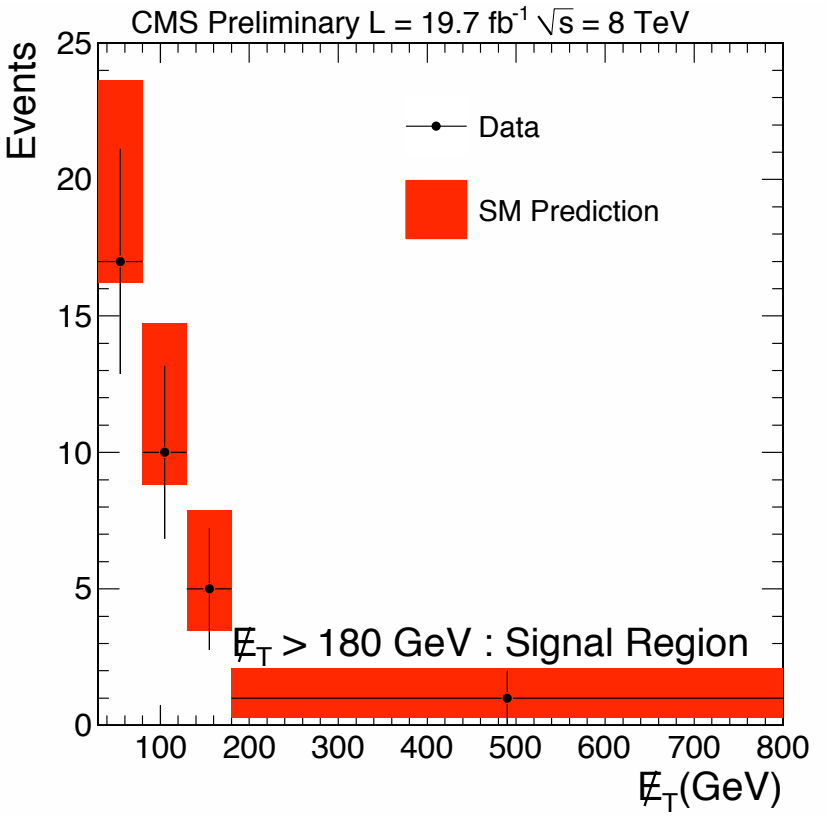
# Opposite-sign dilepton search (SUS-13-016)

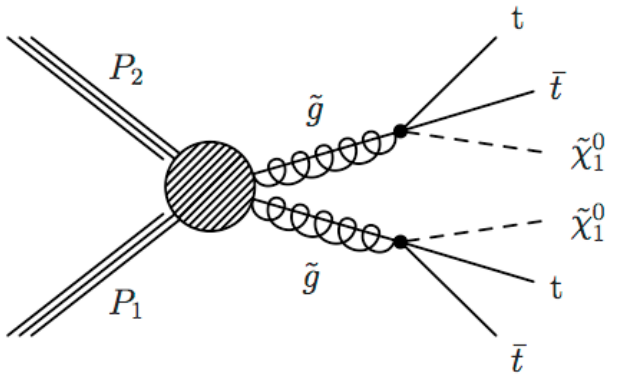
- Signal Region, SR, defined on previous page, Control Region, CR, defined by inverting one of the two leading jet eta cuts
- CR is dominated by SM processes
- Extrapolation factor in bins of MET, for a given b jet multiplicity $R_{ext.} = \frac{N_{nb,SR}}{N_{nb,CR}}$,

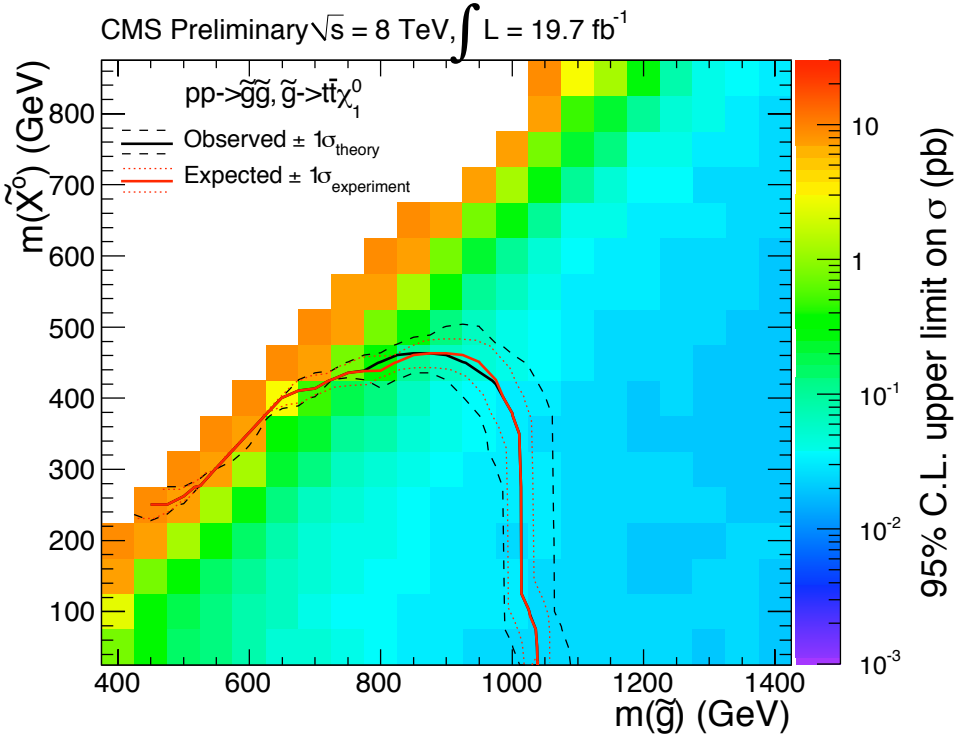


# Opposite-sign dilepton search (SUS-13-016)



# Same-Sign Dilepton search (SUS-13-013)

- This analysis benefits from a very clear SUSY signature, and small SM backgrounds, (ttbar + V, VV)
- 54 bins in HT, MET, #*b*-tags, and $N_{jets}$ to be sensitive to a range of scenarios
- Only electrons and muons, not taus are selected
- Third lepton rejected if pair falls into the Z mass window

| $N_{b-jets}$ | $E_T^{miss}$ (GeV) | $N_{jets}$ | $H_T \in [200, 400]$ (GeV) | $H_T > 400$ (GeV) |
|---|---|---|---|---|
| $= 0$ | 50-120 | 2-3 | SR01 | SR02 |
| | | $\geq 4$ | SR03 | SR04 |
| | $> 120$ | 2-3 | SR05 | SR06 |
| | | $\geq 4$ | SR07 | SR08 |
| $= 1$ | 50-120 | 2-3 | SR11 | SR12 |
| | | $\geq 4$ | SR13 | SR14 |
| | $> 120$ | 2-3 | SR15 | SR16 |
| | | $\geq 4$ | SR17 | SR18 |
| $\geq 2$ | 50-120 | 2-3 | SR21 | SR22 |
| | | $\geq 4$ | SR23 | SR24 |
| | $> 120$ | 2-3 | SR25 | SR26 |
| | | $\geq 4$ | SR27 | SR28 |

# Same-Sign Dilepton - background (SUS-13-013)

- Non-prompt leptons

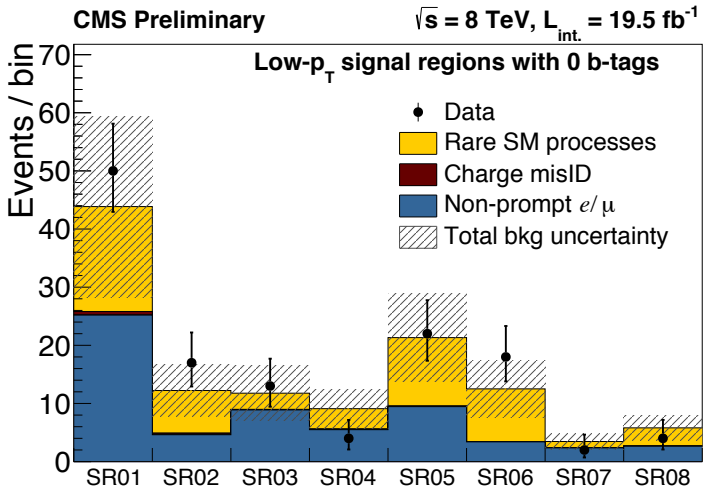
  - From heavy flavour decay, electrons from photon conversion etc
  - Estimated from DATA using a sample that passes a loose selection, but fails tight selection – then use ratio tight-to-loose

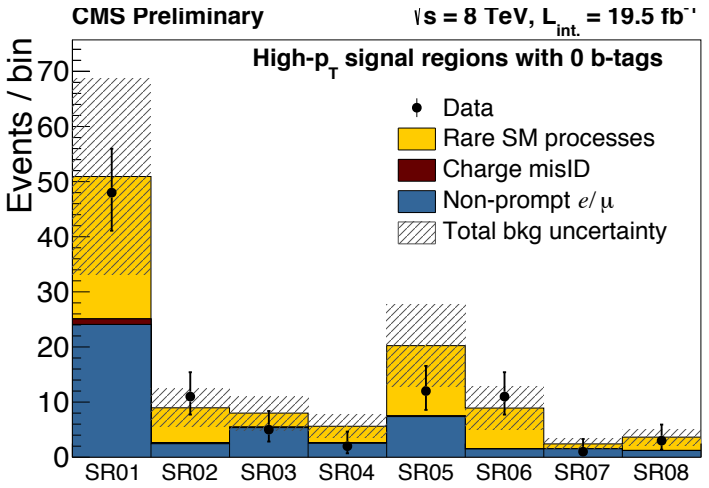
- Rare SM processes

  - ttW, ttZ, WW, ZZ
  - Estimated using MC, but corrected for data/MC differences found in object selection efficiencies

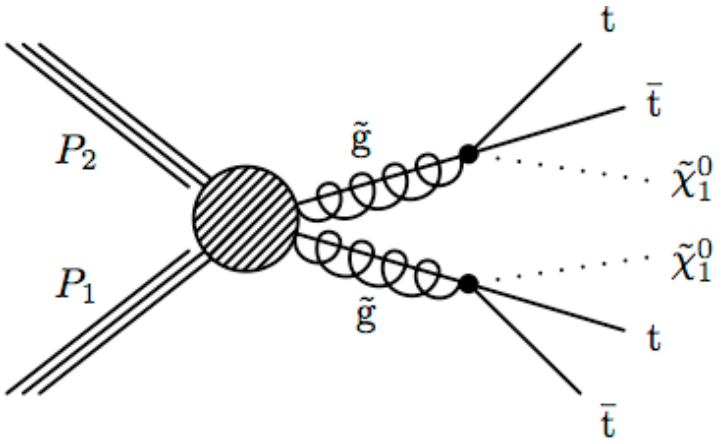
- Charge Mis-ID

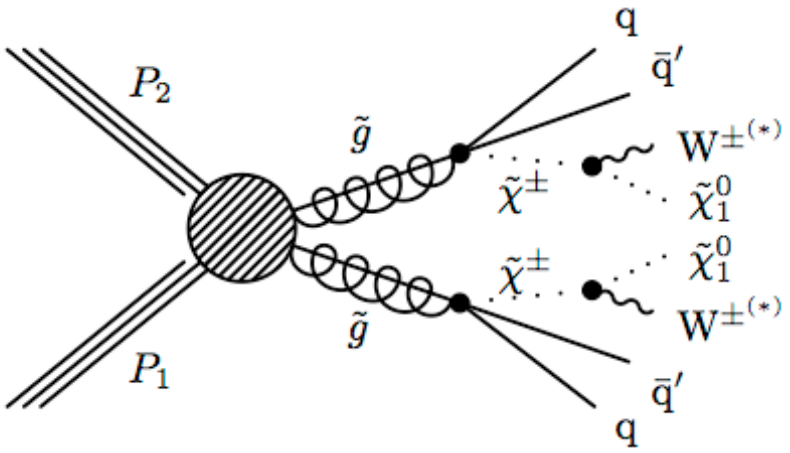
  - Events with opposite-sign leptons with the charge mis-reconstructed
  - Estimated by selecting opposite ee or e –mu events passing full kinematic selection – then weighted by probability of electron charge mis-assignment

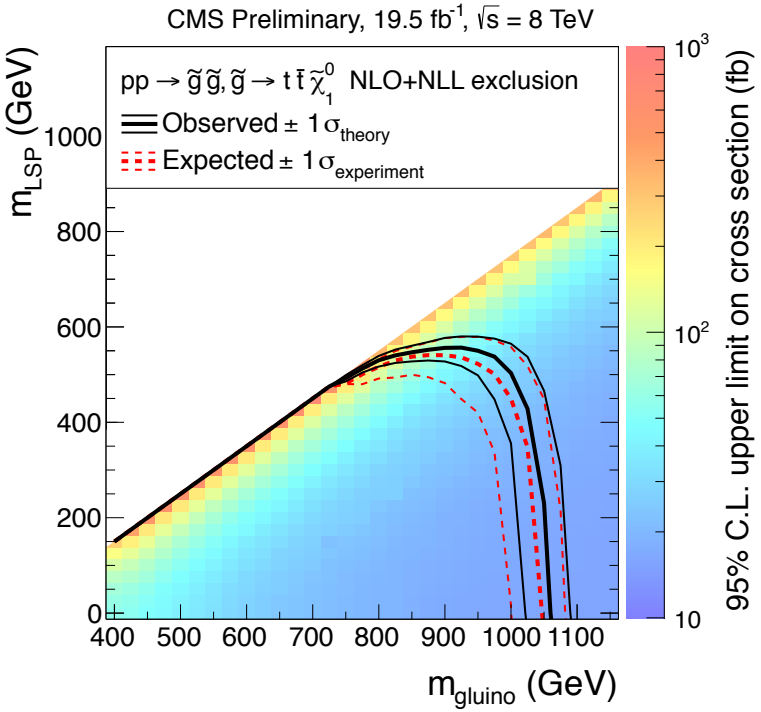


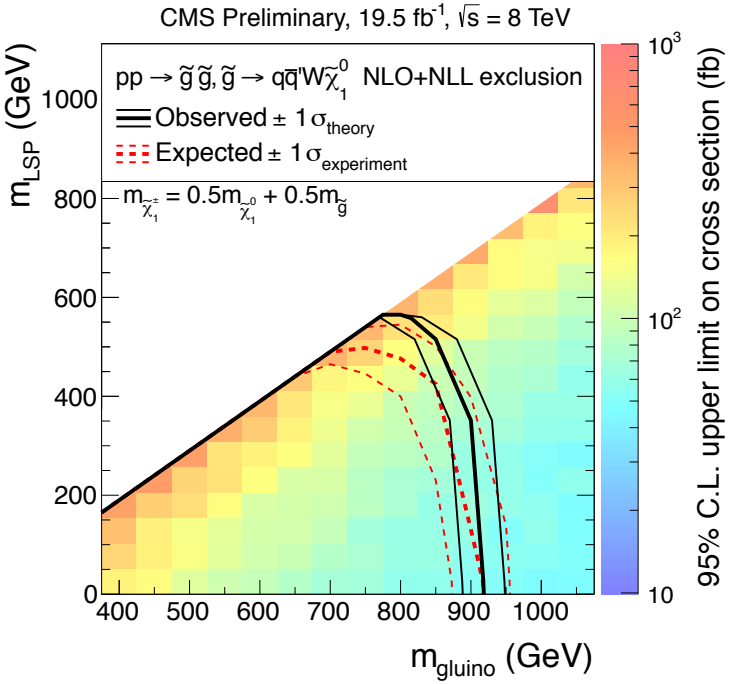



# Same-Sign Dilepton - Interpretation (SUS-13-013)

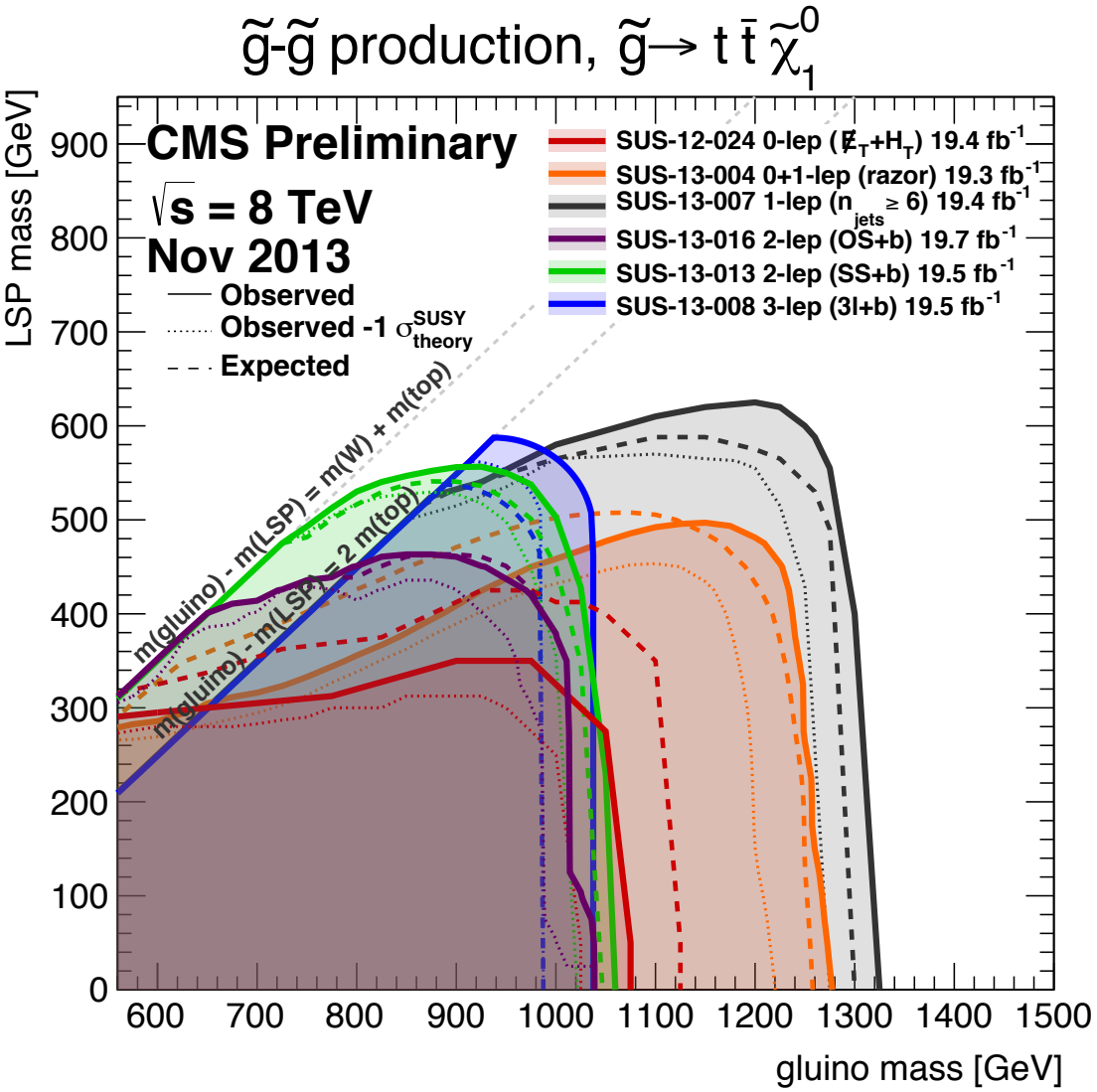


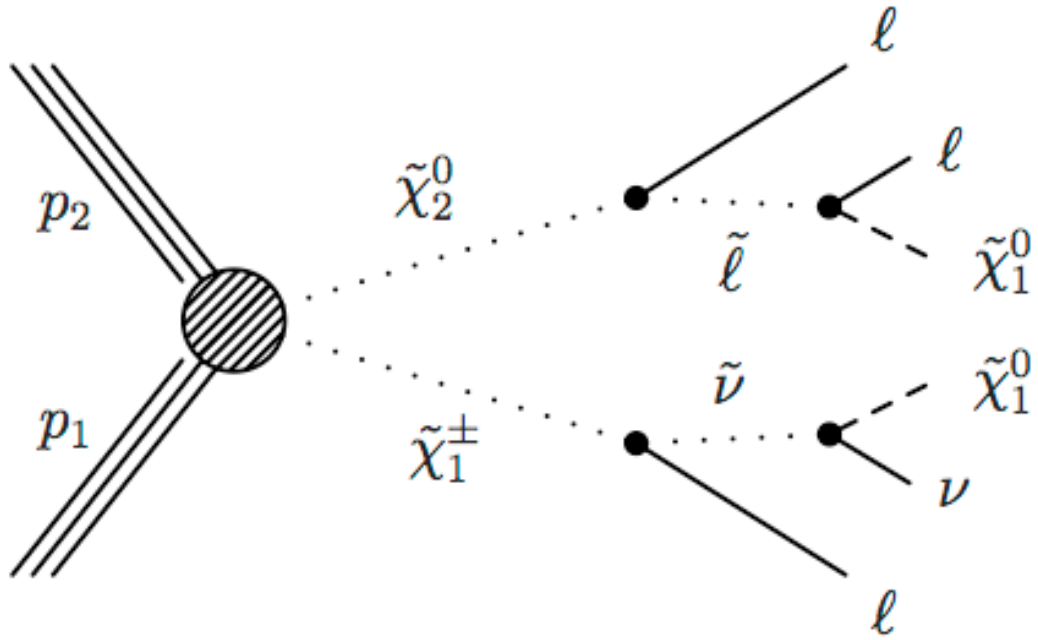



# Tttt summary plot



# Search for Charginos, Neutralinos (SUS-13-006)

- What are we looking for?




- Three lepton search

- Select electrons, muons and hadronically –decaying taus (one tau at most)
- Principal backgrounds from WZ production, tt with a misidentified "non-prompt" lepton
- Events are split into signal regions according to $M_{ll}$, MET and MT

# Search for Charginos, Neutralinos (SUS-13-006)

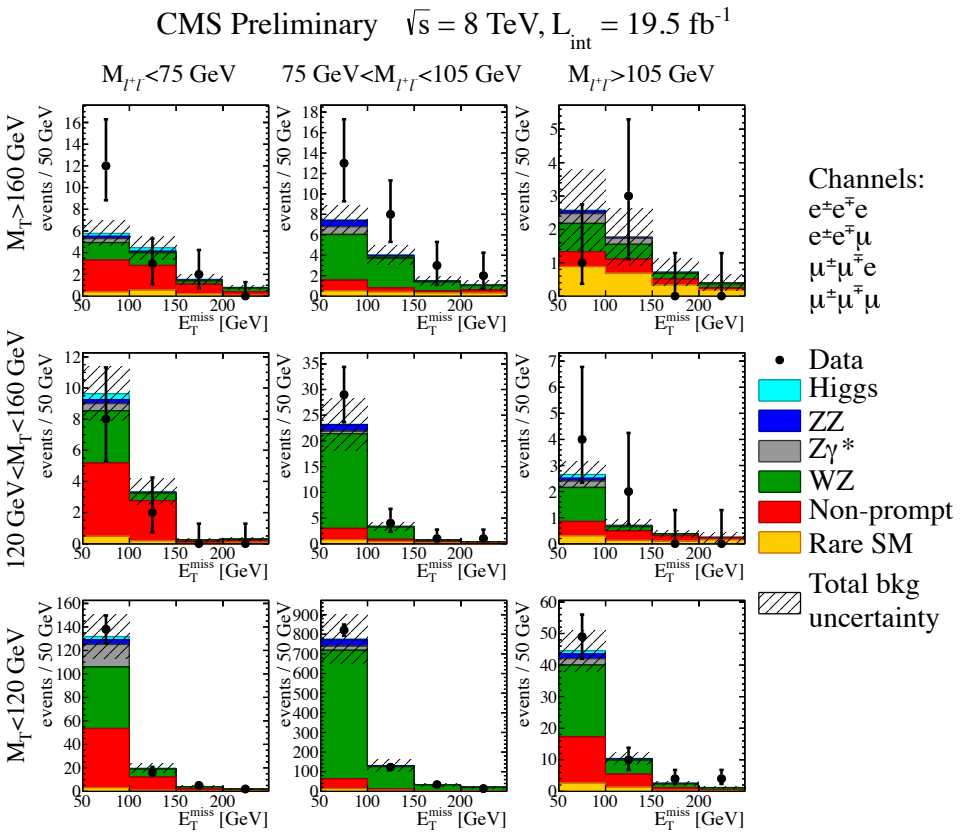
- Backgrounds: WZ production

  - MC MET distribution is corrected by the data
    - MET distribution split into regions of HT and Number of reconstructed vertices, as both of these degrade the MET resolution
    - Magnitude of the correction varies from a few per cent to 30%.

- Fake and non-prompt leptons

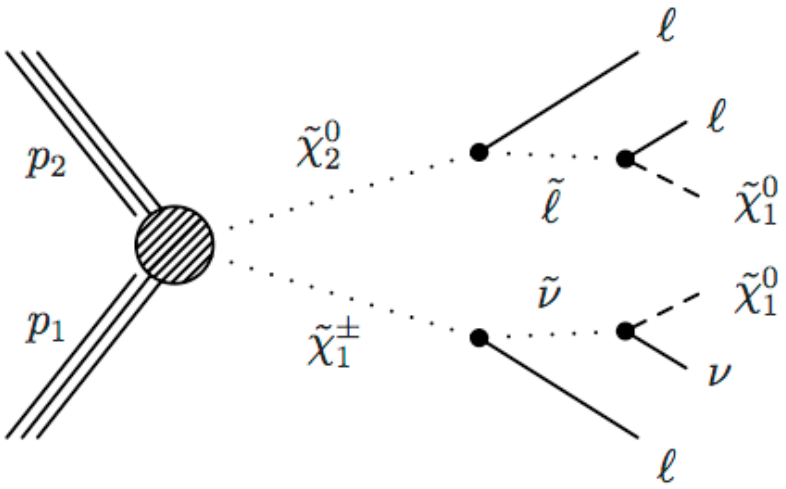
  - Probability for a non-prompt lepton to satisfy isolation requirement is measured in QCD-enriched data sample
  - This is then applied to a three-lepton sample with one of the leptons' isolation requirement inverted

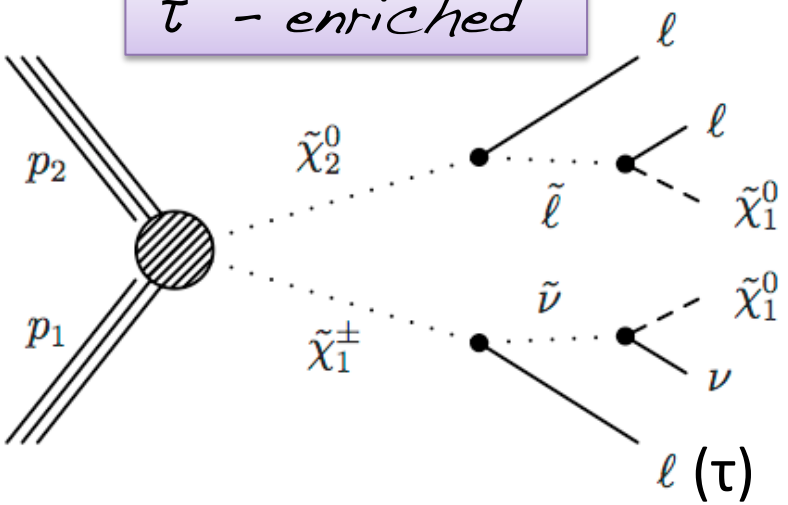
Backgrounds are consistent with observations

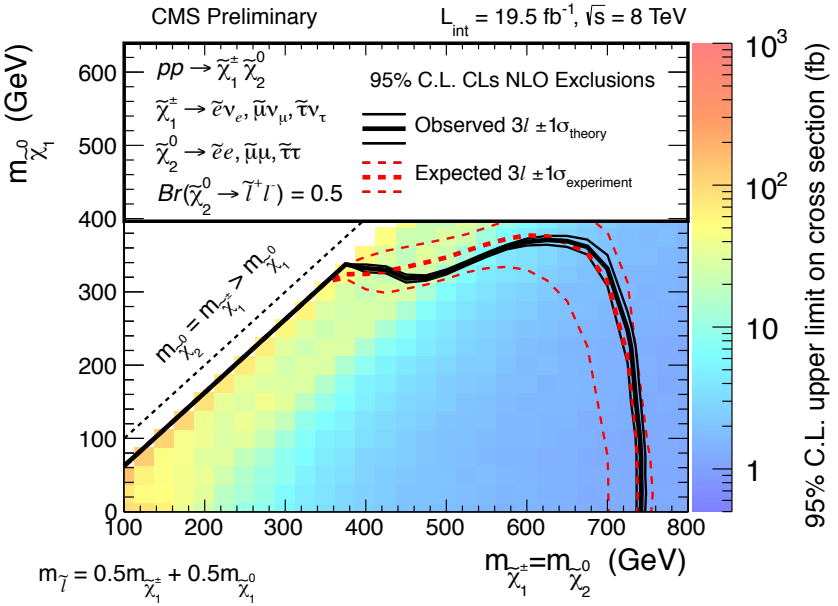


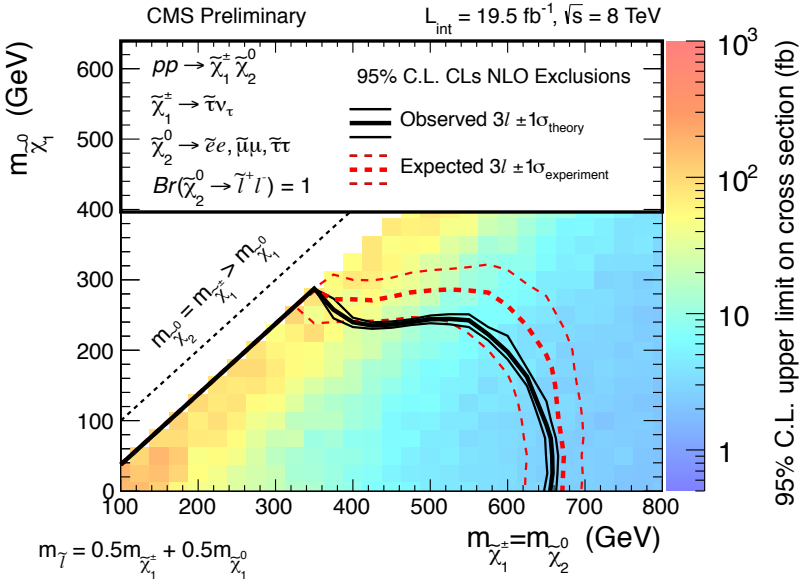
# Search for Charginos, Neutralinos (SUS-13-006)

τ - enriched

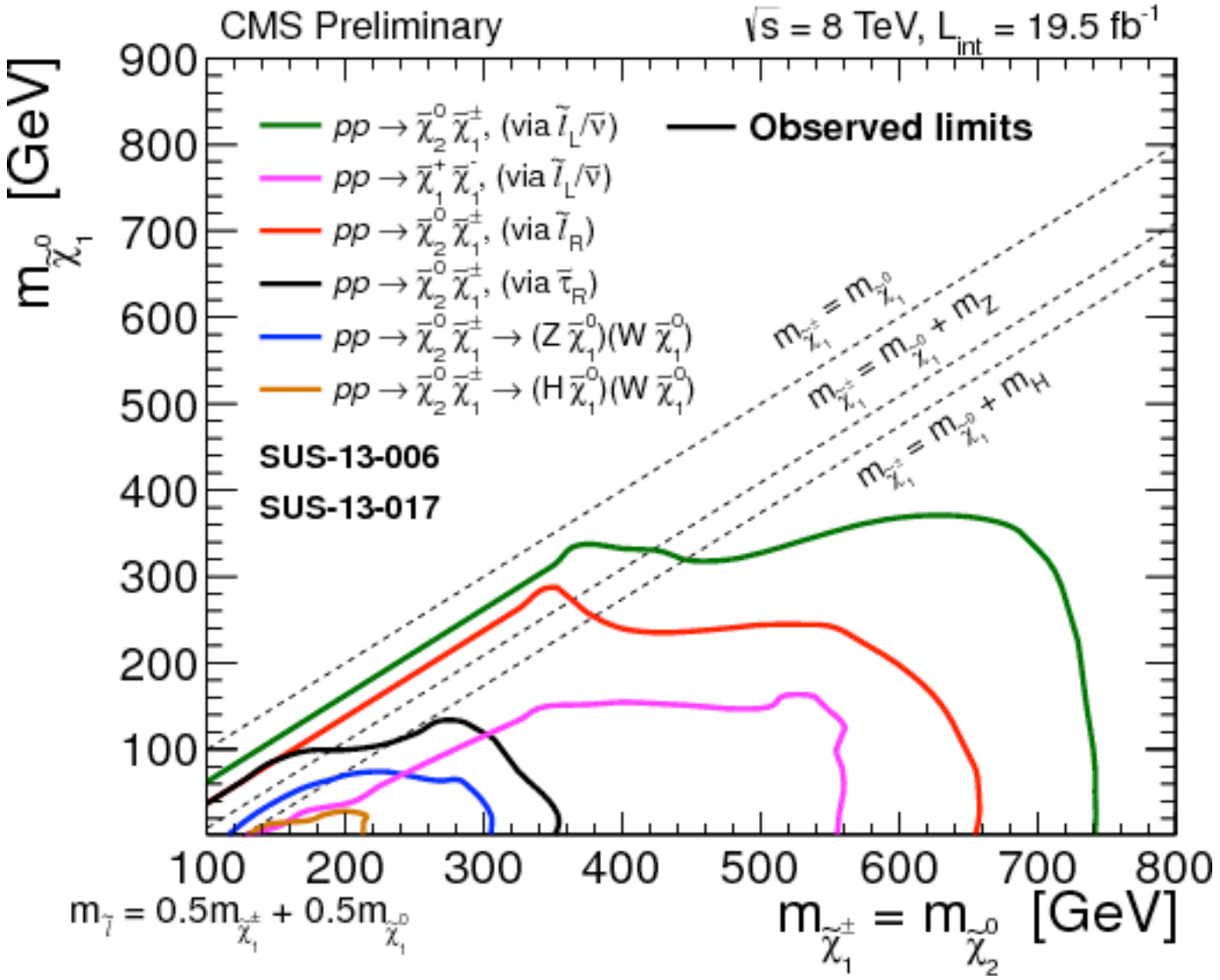


# Summary of multi-lepton



# Summary

- The search for New Physics remains a key motivation of the LHC experiments
- CMS has a broad array of searches, probing vast areas of parameter space
- No significant SUSY signal has been observed…
- A small fraction of the analyses has been presented, please see
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
- See also Daryl Hare's talk here for CMS results on third generation SUSY searches

# Back-Up

# CMS Detector