Searches for supersymmetry in tau final states with the CMS detector

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Motivation

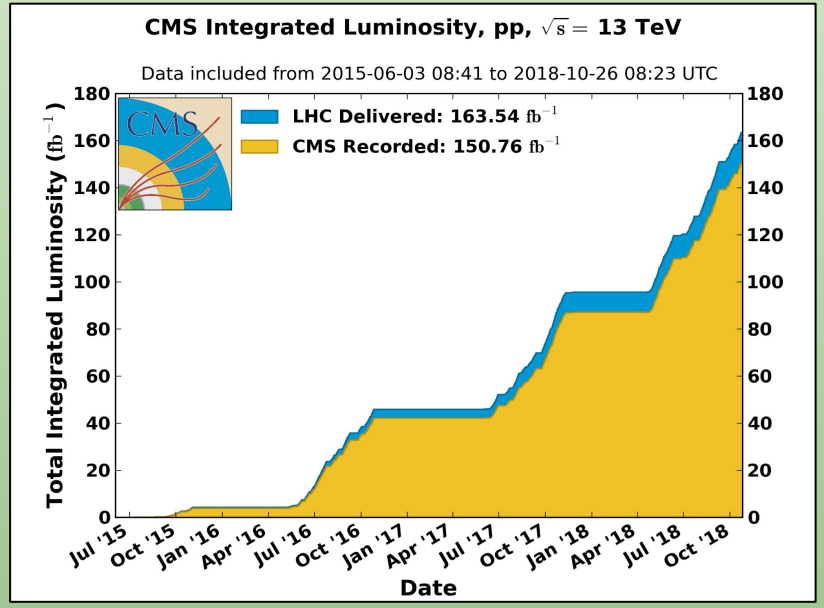
SUSY search with τ lepton rich final state is theoretically well motivated. For example:

- ➔ Stau-neutralino coannihilation scenario
- ➔ Chargino- neutralino production in higgsino like scenario
- ➔ Top squark production in higgsino like and high tanβ scenario

The talk is based on three SUSY search results in CMS:

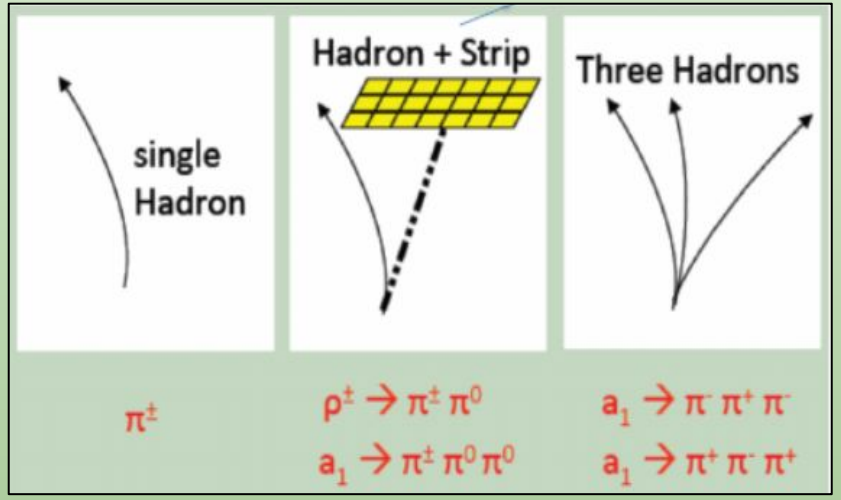
- ➢ Tau slepton search in all-hadronic τ final state (https://cds.cern.ch/record/2777046)
- ➢ Search for electroweak production of charginos and neutralinos (arXiv:2106.14246)
- ➢ Top squark search in di-τ (all-hadronic) final state (arXiv:1910.12932, 10.1007/JHEP02(2020)015)

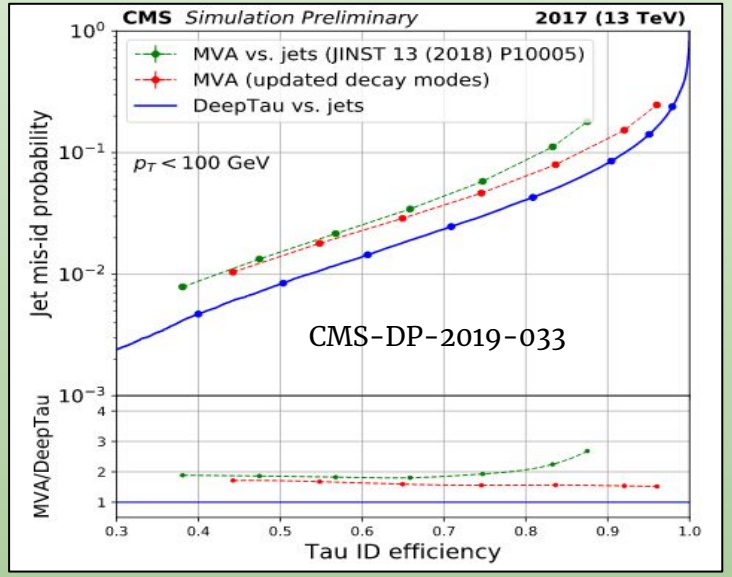
CMS Run 2 luminosity



- ➔ Total Run 2 integrated luminosity 137 fb^{-1}
- ➔ Large enough dataset to look for rare processes

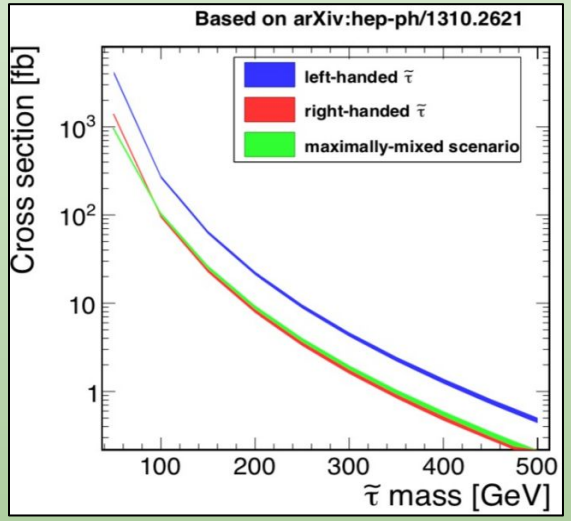
τ-lepton reconstruction in CMS





- Hadron Plus Strip (HPS) algorithm is used to reconstruct hadronically decaying τ lepton (τ_h)
- Reconstruct only one and three prong hadronic decay of τ
- Use of Deep Neural Network (DNN) based τ_h identification technique provides better identification efficiency and much improved mis-identification rate

Tau Slepton Search in all-hadronic final state[1]

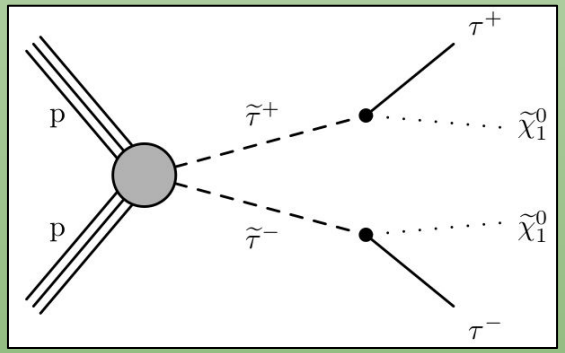


Motivation:

- ❏ Early universe stau-neutralino coannihilation provides mechanism explaining DM relic density when $\Delta m = m_{stau} - m_{Neutralino} \sim$ 10-15 GeV
- ❏ Motivates existence of stau as NLSP, leading to enhanced production of stau with τ lepton final state

Signal Models:

- ❏ Direct stau pair production with simplified model is used
- ➔ Prompt stau: Left handed (LH), Right handed (RH) and Degenerate (LH+RH) scenarios are considered
- ➔ Long-lived (displaced) staus: Sensitive to GMSB SUSY scenario



Signal events are characterized by two hadronically decaying τ lepton and large amount of missing energy due to the neutralinos

https://cds.cern.ch/record/2777046

Tau Slepton Search in all-hadronic final state [2]

Event Selection

Prompt tau category:

- Exactly two τ_h of opposite charge passing the DNN based working point having 40% tagging efficiency and 0.06% misidentification rates
- Veto events with any extra lepton or τ_h
- Veto events any b-tagged jet to reduce the $t\bar{t}$ background
- $|\Delta\phi(\tau_h(1),\tau_h(2)| > 1.5$ to reduce the $Z/\gamma^* \rightarrow \tau\tau$ contribution
- $p_T^{miss} > 50$ GeV to reduce QCD contribution

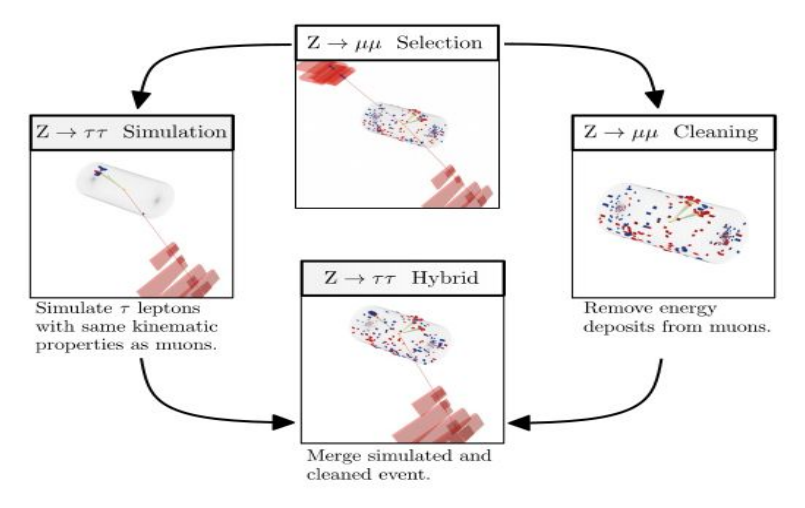
Displaced tau category:

Along with the above selection conditions, two extra conditions are applied:

- the significance of the τ_h impact parameter relative to the PV in the transverse plane > 5
- the absolute value of its three-dimensional impact parameter (IP3D) > 100 μm
- $|\Delta\phi(\tau_h(1),\tau_h(2)| > 1.75$

Tau Slepton Search in all-hadronic final state [3]

Background estimation



Embedding procedure:

- ➔ Select di-muon events from data
- ➔ remove tracks and energy deposits of the selected muons from the reconstructed event record
- ➔ simulate two τ leptons with the same kinematic properties as the removed muons in an otherwise empty detector
- ➔ combine the energy deposits of the simulated tau lepton decays with the original reconstructed event record

arXiv:1903.01216

Background from genuine τ_h:

- ❑ Background from genuine τ_h arises from DY+jets, $t\bar{t}$
- ❑ Tau ID based on Deep Neural Network is used
- ❑ Embedded samples used for modelling genuine di-τ_h background, leading to more precise estimation and no need for corrections and uncertainties on: jet energy scale, pile-up, b-tagging efficiency etc

Fake background:

- ❑ Fake background arises from QCD jets misidentified as τ_h
- ❑ Data-driven technique used for fake background estimation

Tau Slepton Search in all-hadronic final state [4]

Signal region optimization

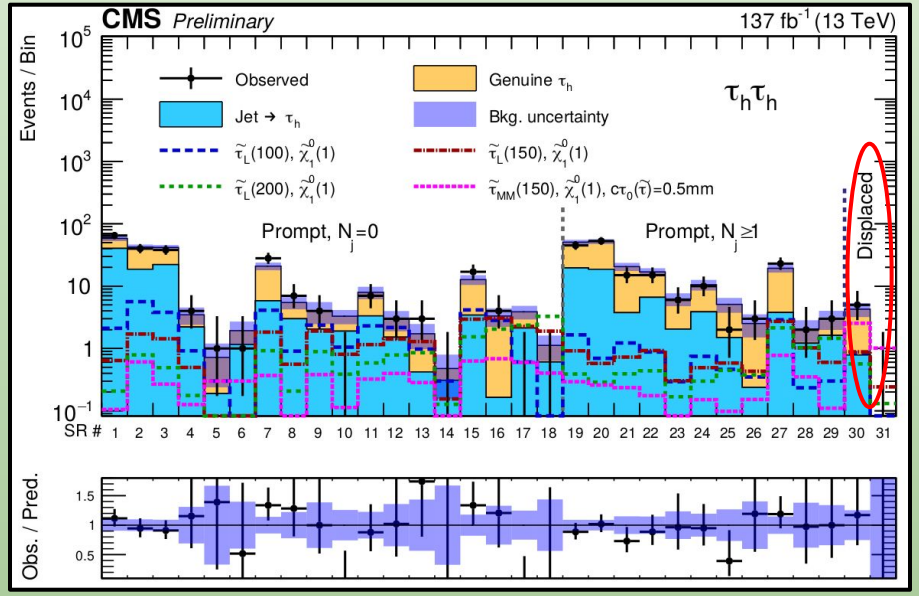
Signal region optimization is performed using the following set of variables:

- Number of reconstructed jets (N_j)
- The leading τ_h p_T
- The sum of the transverse masses (m_T) calculated for each tauh and p_T^{miss}

$$\boxed{\sum m_T = m_T(\tau_h(1), \vec{p}_T^{miss}) + m_T(\tau_h(2), \vec{p}_T^{miss})}$$

- The stransverse mass:

$$m_{T2} = \min_{\vec{p}_T^{X(1)} + \vec{p}_T^{X(2)} = \vec{p}_T^{miss}} \left[\max \left(m_T^{(1)}, m_T^{(2)} \right) \right]$$



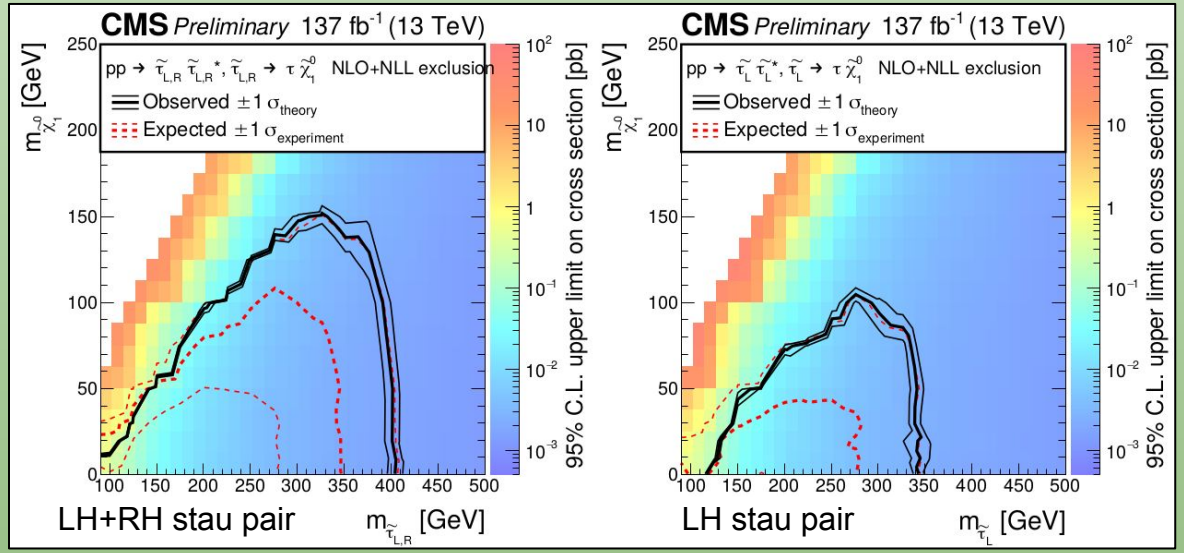
- Overall 31 search bins are fitted to extract the upper limits

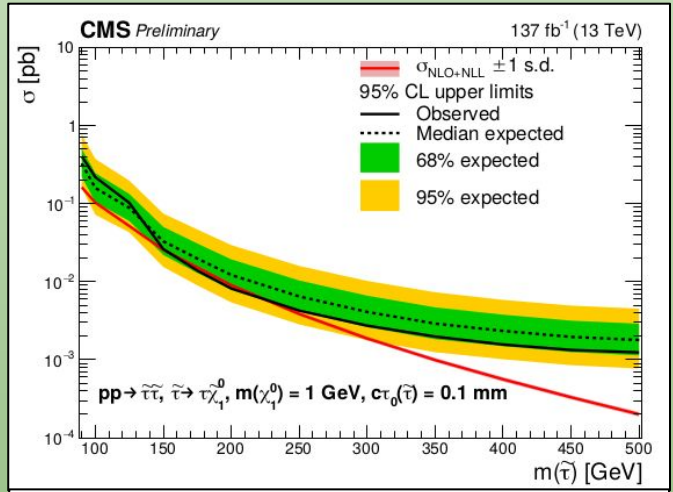
Major systematics are coming from τ_h misidentification rate and τ_h id efficiency

Tau Slepton Search in all-hadronic final state [5]

Interpretation

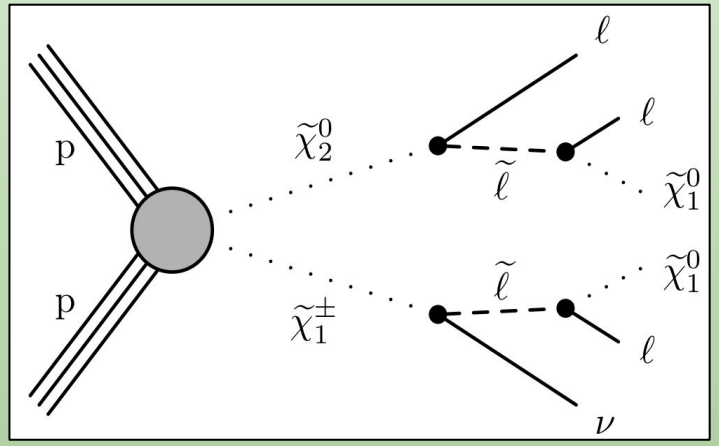
- Excluded stau production upto 400 GeV for degenerate scenario
- Excluded stau production upto 350 GeV for LH scenario
- The search also targets long lived staus, which can occur in GMSB models





Long lived stau pair for maximally mixing scenario

Search for electroweak production of charginos and neutralinos[1]



Motivation:

Following two scenarios give rise to the tau lepton enriched final state:

- If only the chargino is higgsino like, it couples to the right handed sleptons, giving rise to τ enriched final state
- If chargino and neutralino both are higgsino like, decays mediated by τ sleptons is favoured, giving rise to τ dominated final state

Signal models:

- Simplified model with 100% branching fractions to the leptons is assumed
- $m_{Chargino} = m_{Neutralino}$
- The slepton mass parametrization:
  $m_{slepton} = x.m_{Neutralino} + (1-x).m_{Chargino}$, x = [0.05,0.5,.0.95]

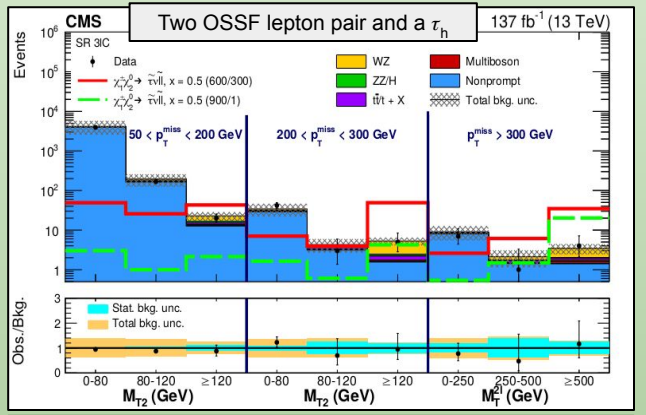
Search for electroweak production of charginos and neutralinos[2]

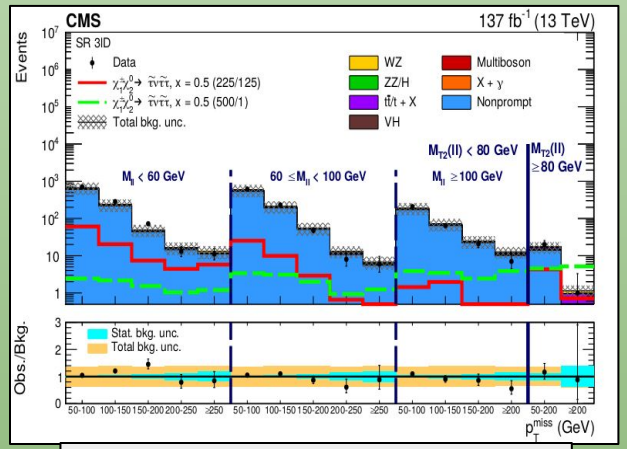
Search strategies

arXiv:2106.14246

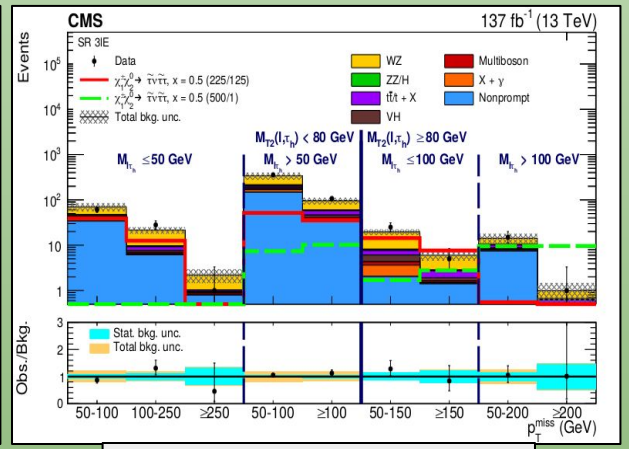
Overall four categories involving τ_h

- A pair of light leptons forming an Opposite sign Same flavor pair and a τ_h
- A pair of light leptons of different flavor and opposite charge and a τ_h
- A pair of light leptons of same charge and a τ_h
- A light lepton and two τ_h
- τ_h identification is done with MVA based technique

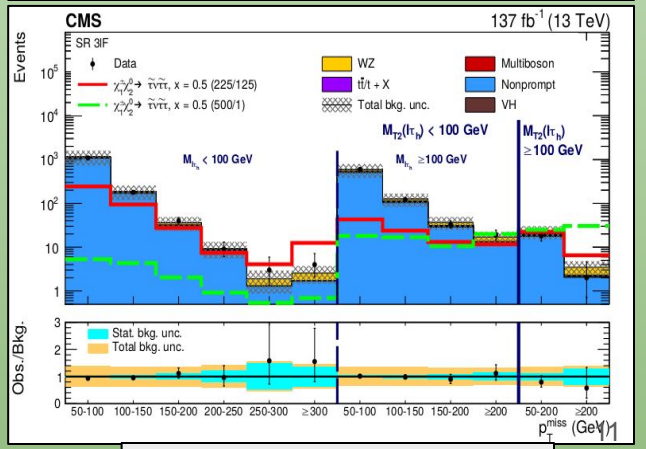




OS lepton pair of different flavor and a τ_h



SS lepton pair and a τ_h

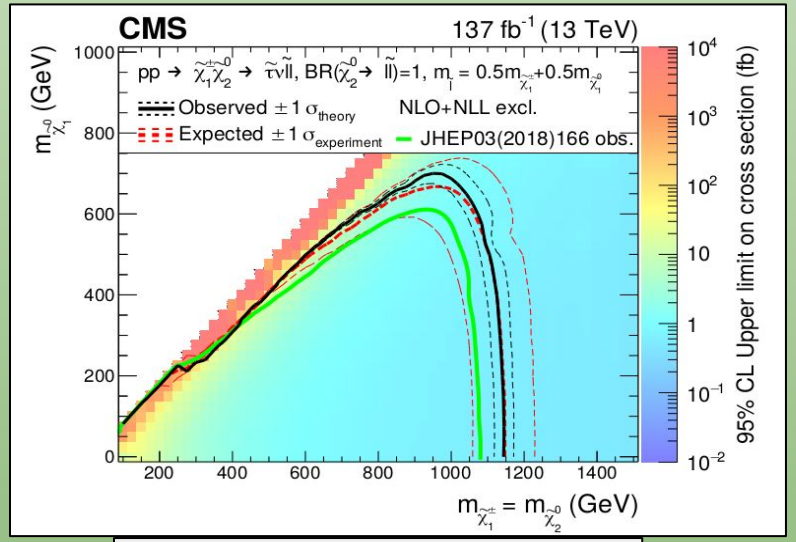


A light lepton and two τ_h

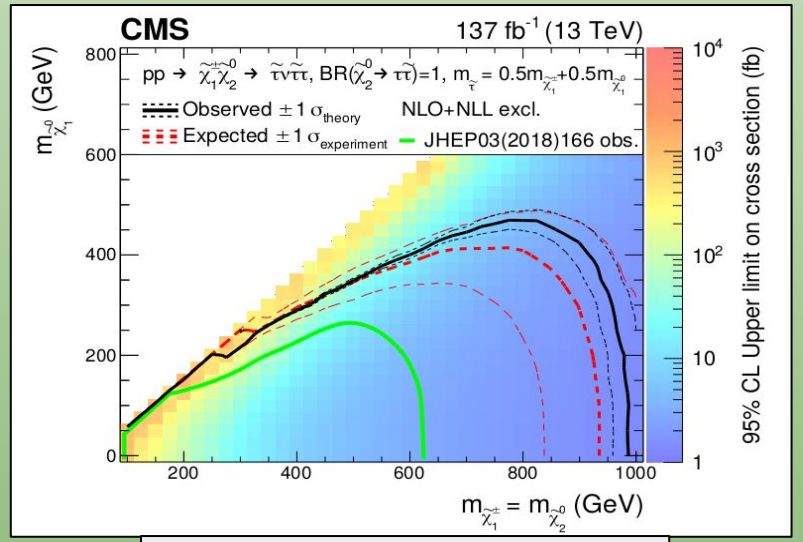
Search for electroweak production of charginos and neutralinos[3]

Interpretation

- For τ enriched final state, where chargino is higgsino and couples only to RH slepton, chargino masses up to 1150 GeV are excluded
- For τ dominated final state, where chargino and neutralino both are higgsino like and decays mediated by τ sleptons, chargino masses up to 1000 GeV are excluded

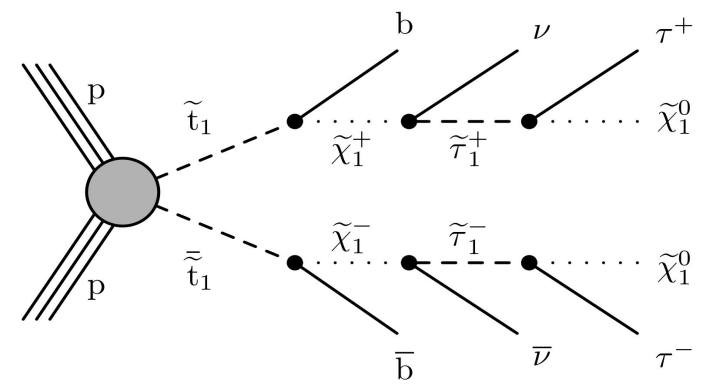


τ enriched final state



τ dominated final state

Top squark search in di-τ final state[1]



Motivation:

- The higgsino component of chargino/neutralino couples to sleptons with a strength $\propto(m_l/\cos\beta)$
- In high $\tan\beta$ region and higgsino like scenario, the chargino most often decays to $\boldsymbol{\tau}$ lepton as $m_{\tau} >> m_e, m_{\mu}$

Search variables:

Three search variables are used to construct the signal region:

- ➔ Missing transverse energy
- ➔ H_T (scalar p_T sum of all final state objects)
- ➔ M_{T2}(two τ_h and missing energy)

Signal models:

- ➔ Simplified model with 100% branching fraction of the SUSY particles considered
- ➔ Mass relations:
  - $m_{Chargino} - m_{Neutralino} = 0.5(m_{Stop} - m_{Neutralino})$
  - $m_{Stau} - m_{Neutralino} = x.(m_{Chargino} - m_{Neutralino})$
  - x= [0.25, 0.5, 0.75]

Dominant backgrounds comes from the mis-identification of jets as τ_h, $t\bar{t}$, and Drell-Yan+jets

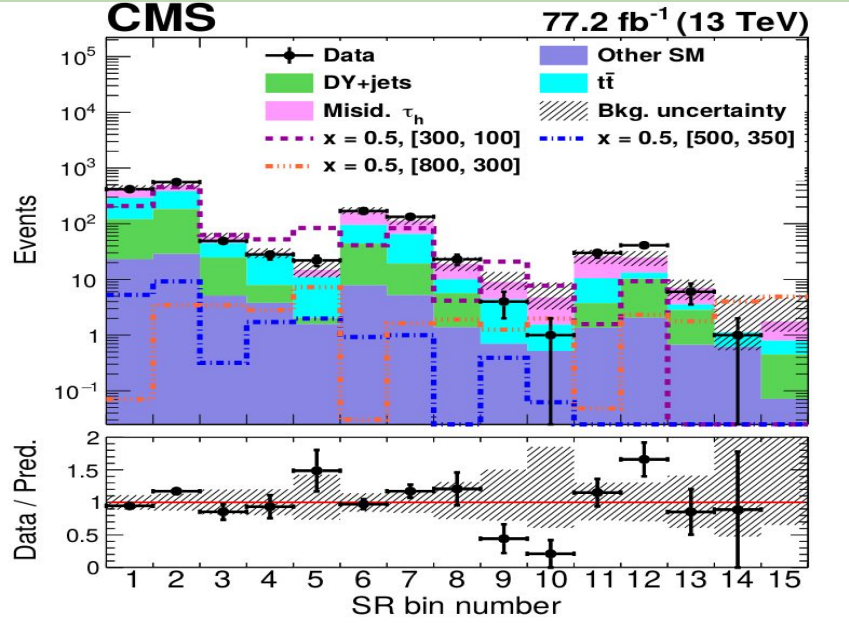
arXiv:1910.12932, 10.1007/JHEP02(2020)015

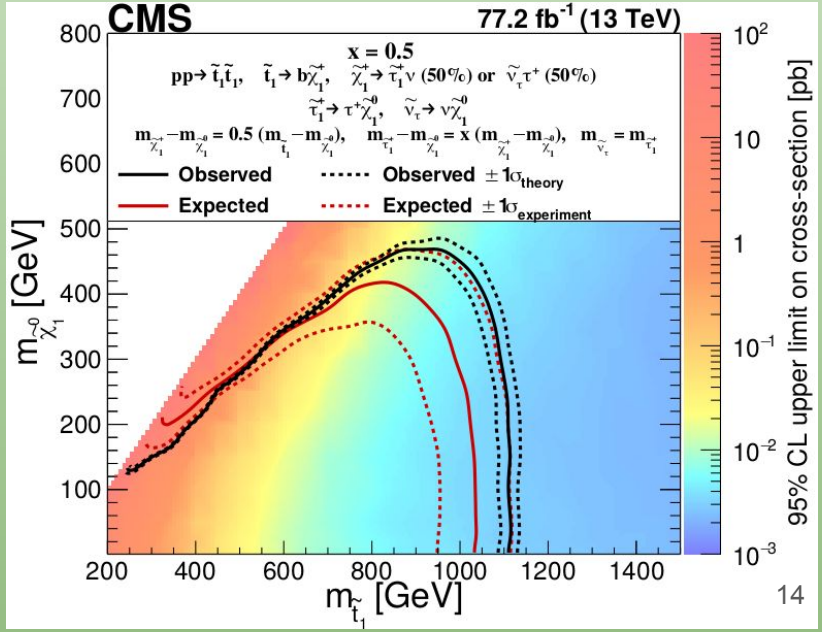
Top squark search in di-τ final state[2]

Result and interpretation

Major sources of systematics are coming from τ_h identification and parton flavour dependence of τ_h- mis-id rate

Top squark mass upto 1.1 TeV is excluded





Conclusion

- SUSY search with τ lepton rich final state is theoretically well motivated
- Three SUSY search results from CMS experiment are presented here
- No significant excess is observed and results are consistent with the SM predictions

Thank You

Back Up