

Search for electroweak SUSY production at CMS

Hamed BAKHSHIANSOHI (CP3)
on behalf of the CMS collaboration

CP3 lunch-seminars
06 April 2016

Why we search for SUSY ?

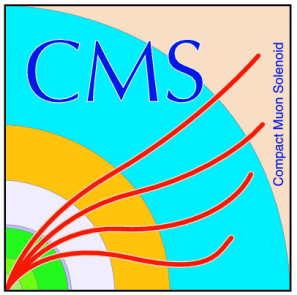
Standard model of particles :
excellent description of the fundamental particles and their interactions

Why we search for SUSY ?

Standard model of particles :
excellent description of the fundamental particles and their interactions

It has some shortcomings :

- Hierarchy problem
- Lack of dark matter candidate
- Gravity …..



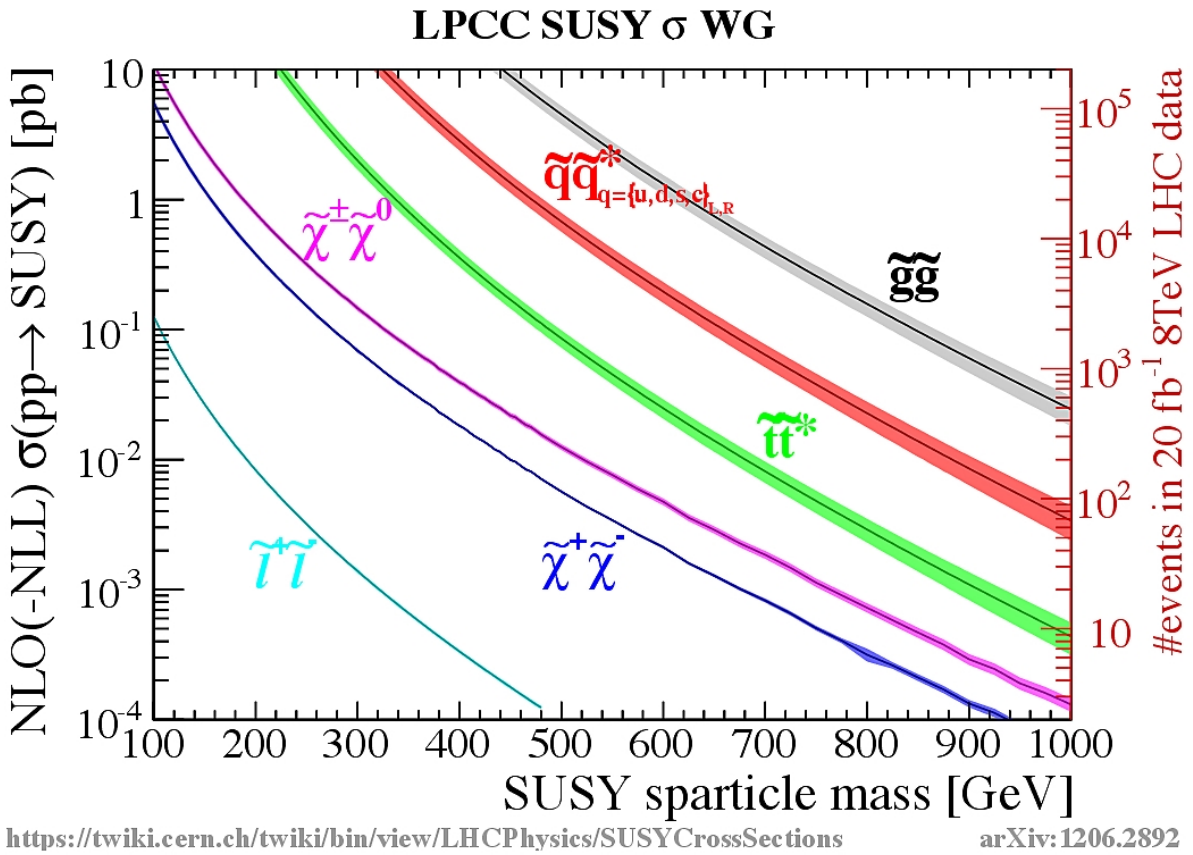
Why we search for SUSY ?

Standard model of particles :
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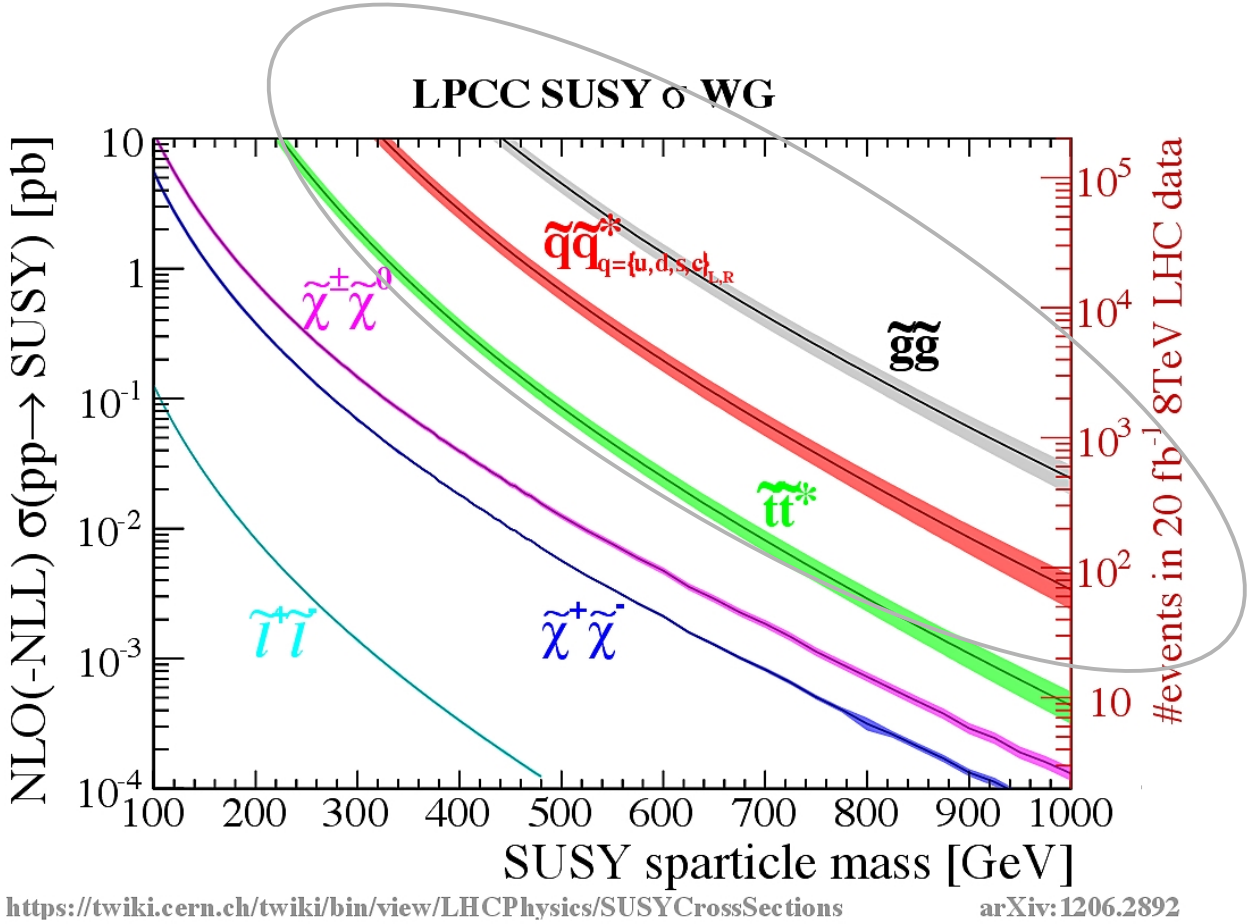
Super Symmetry tries to solve many of the problems by introducing a new (super)partner to each particle :

- Many new particles
- Many new parameters

What is this talk about

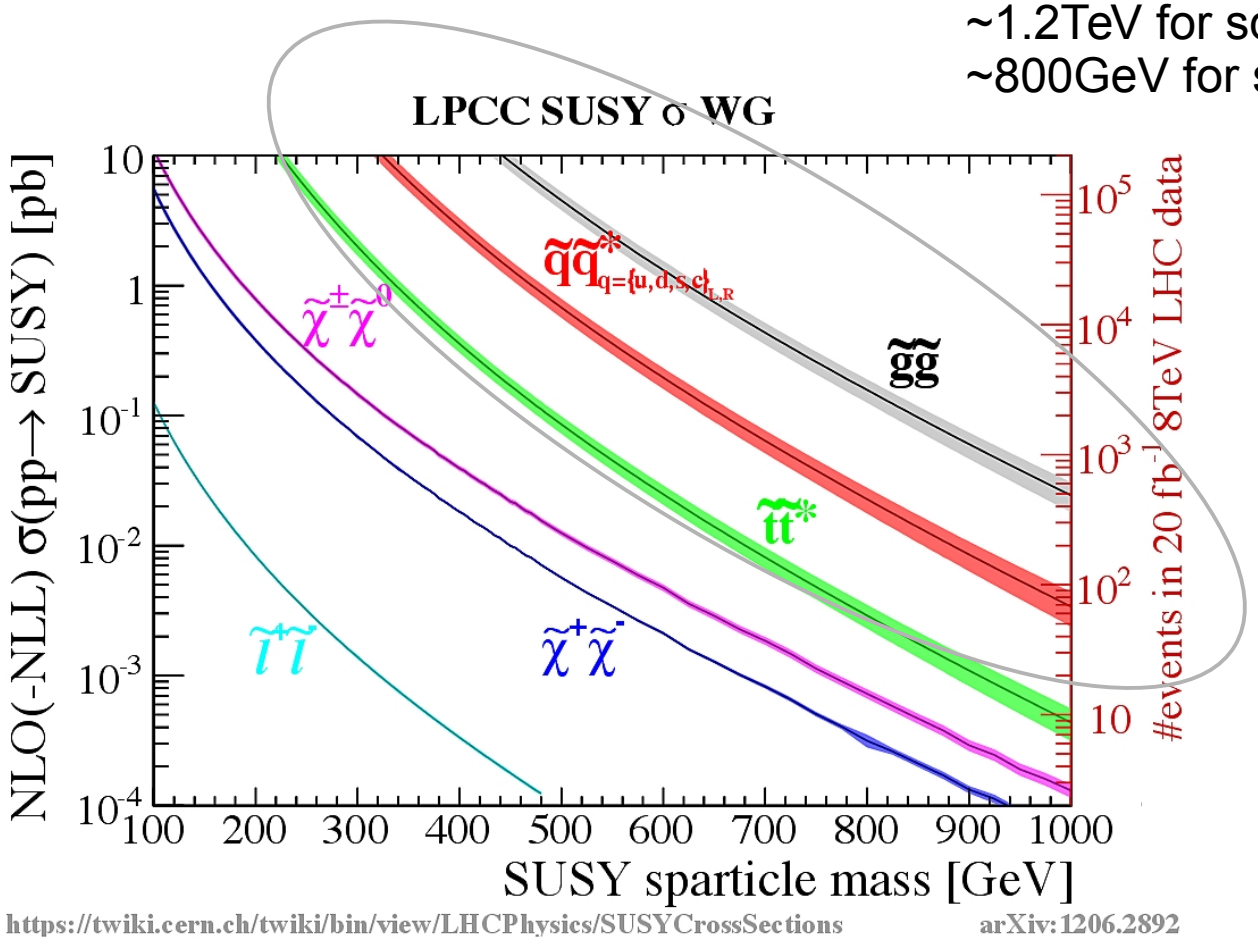


What is this talk about



What is this talk about

Nothing observed up to
- ~1.7 TeV masses for gluino
- ~1.2TeV for squarks
- ~800GeV for stop and sbottom



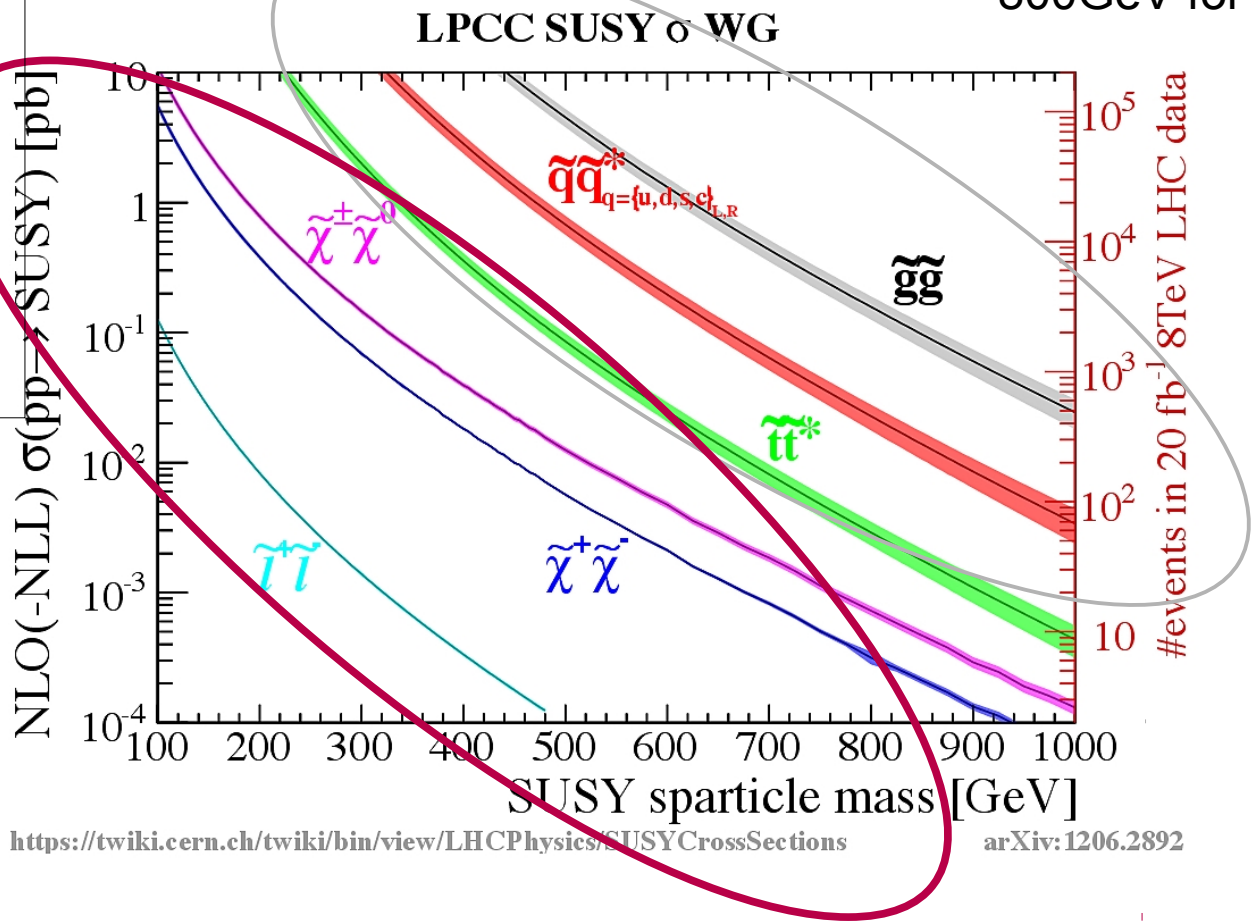
What is this talk about

Subject of this talk:

[very] Low cross sections

Clear Signatures

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~1.2TeV for squarks
~800GeV for stop and sbottom



Bibliography

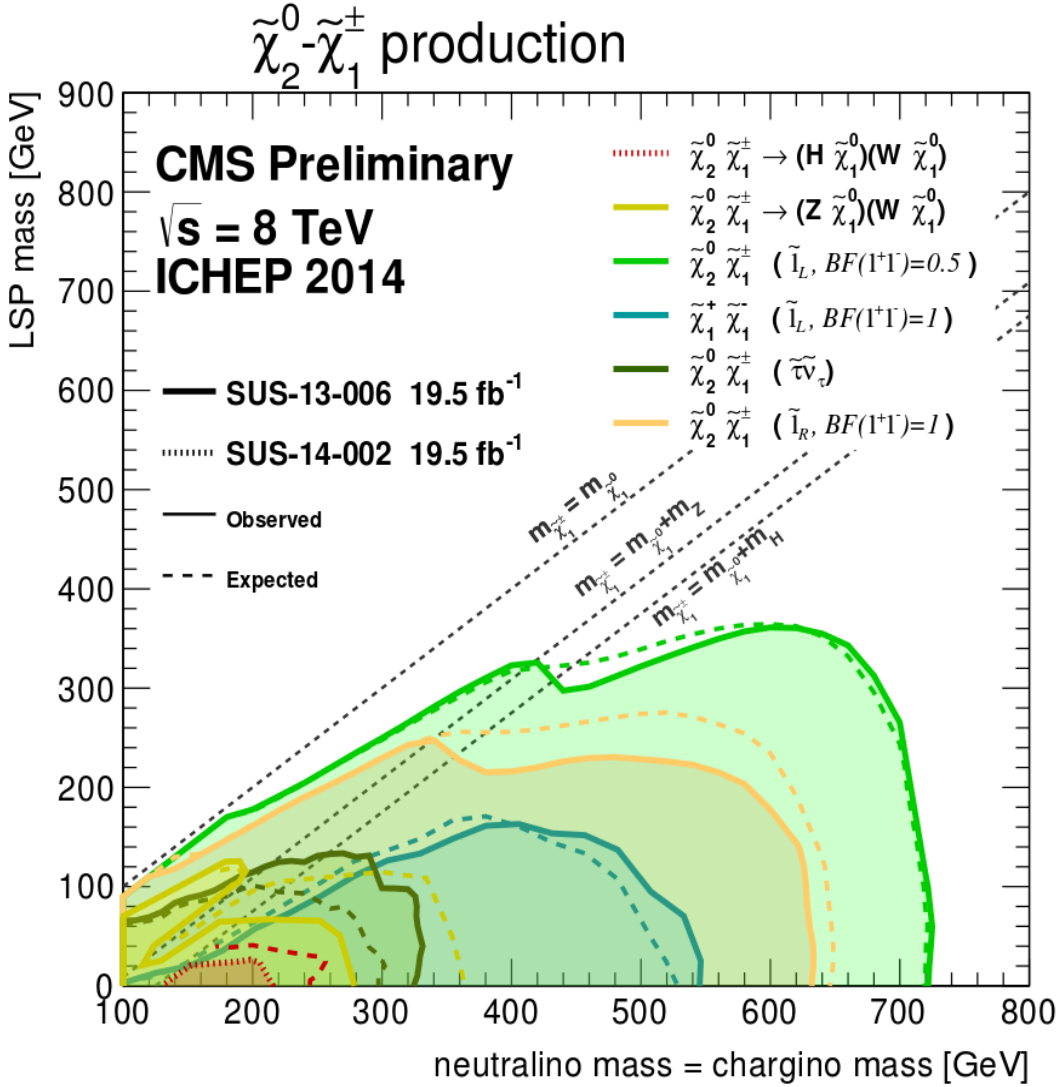
All 8 TeV, but some are fresh

- **Brief summary of**
  - *Eur. Phys. J. C 74 (2014) 3036* : charginos, neutralinos, and sleptons decaying to leptons and W, Z, and Higgs
  - *Phys. Rev. D 90 (2014) 092007* : neutralino and chargino decaying to Higgs, Z, and W
  - *JHEP (JHEP 248P 0815)* : VBF production of SUSY
  - *arxiv:1602.08772* : Photon + MET
- **Detailed Review of**
  - *SUS-14-022* **:** 2 taus in the final state

Chargino-Neutralino production

Early Summary

- **Eur. Phys. J. C 74 (2014) 3036**



Chargino-Neutralino production has the largest cross section

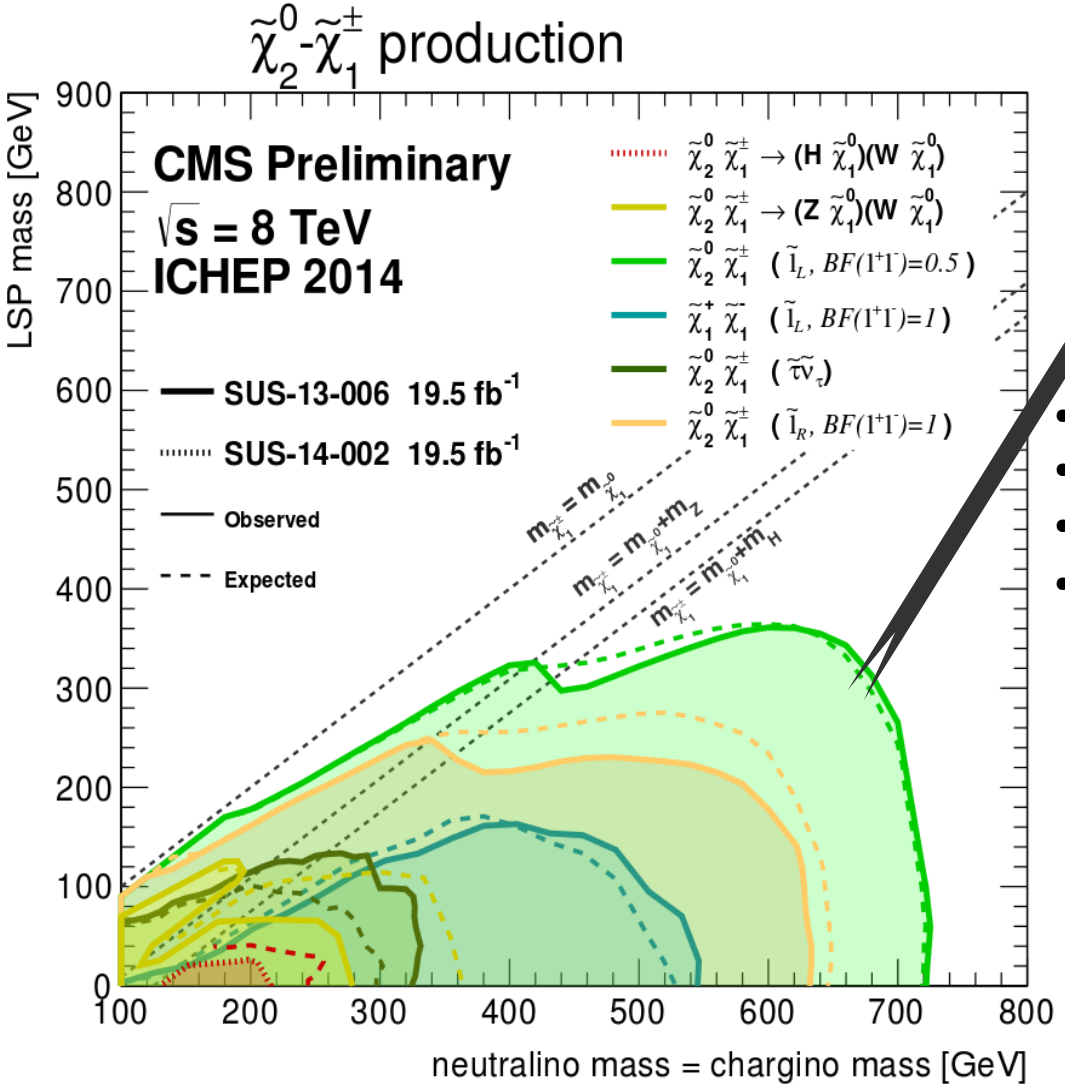
Limits on chargino mass up to ~700 GeV

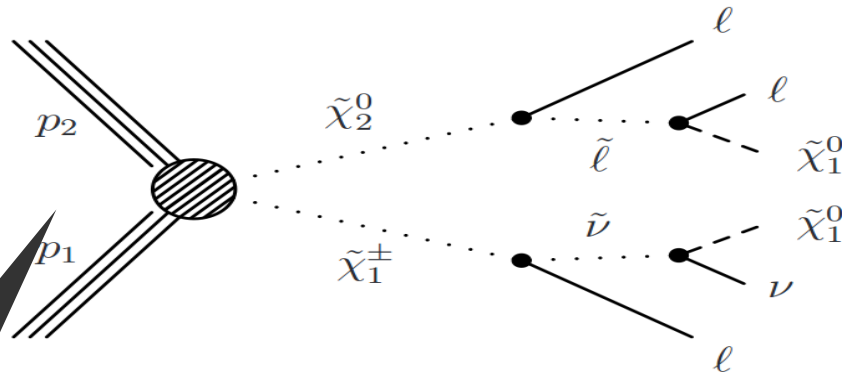
Resumino : cross sections

MadGraph 5 : for signal generation

Early Summary

- **Eur. Phys. J. C 74 (2014) 3036**

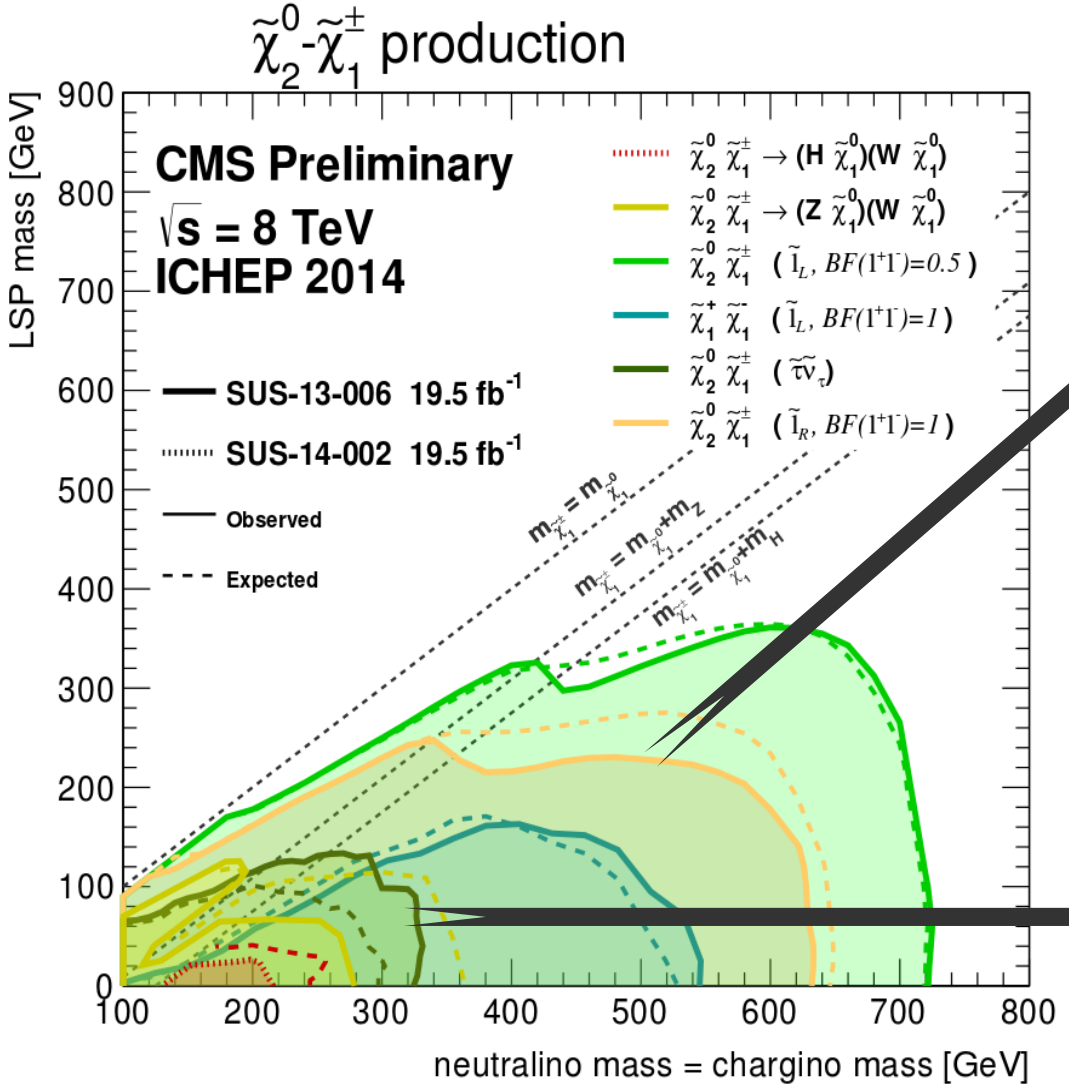




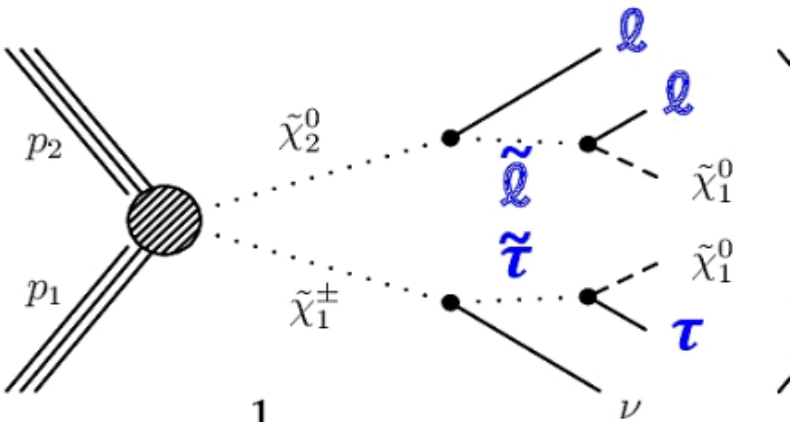
- 3leptons + MET
- Flavor democratic decay of SUSY parents
- b-veto (Suppress ttbar)
- Main Backgrounds
  - WZ : MC (with data-driven MET correction)
  - ttbar+fake : data-driven fake rate method

Early Summary

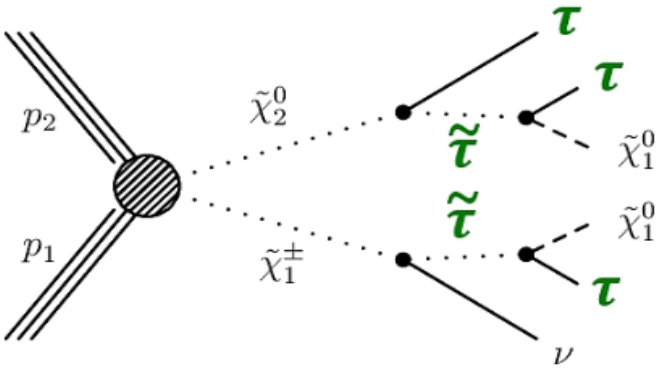
- **Eur. Phys. J. C 74 (2014) 3036**



"tau-enriched" (2ℓ+τ)
light $\tilde{\ell}_R$, small tan β

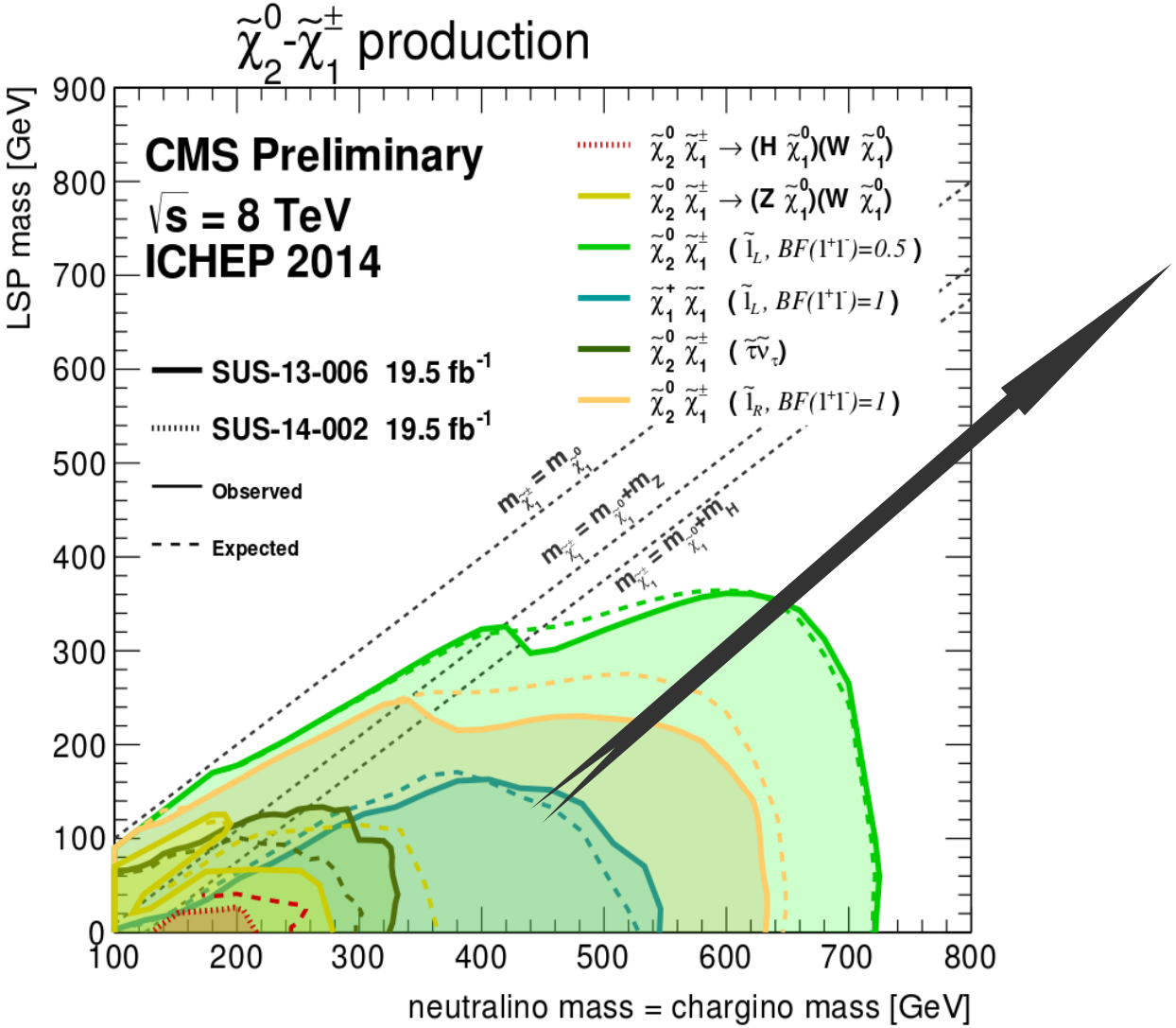


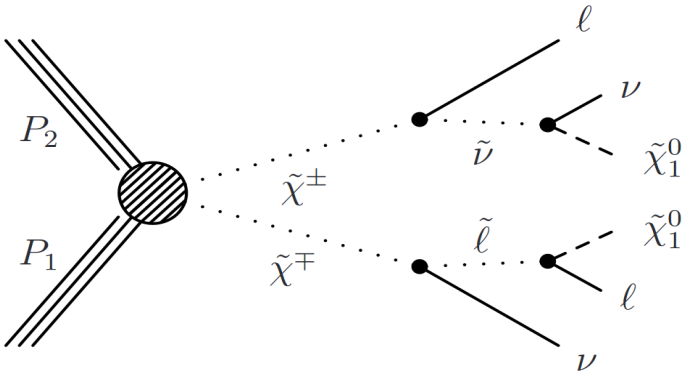
"tau-dominated" (3τ)
light $\tilde{\ell}_R$, high tan β



Early Summary

- **Eur. Phys. J. C 74 (2014) 3036**

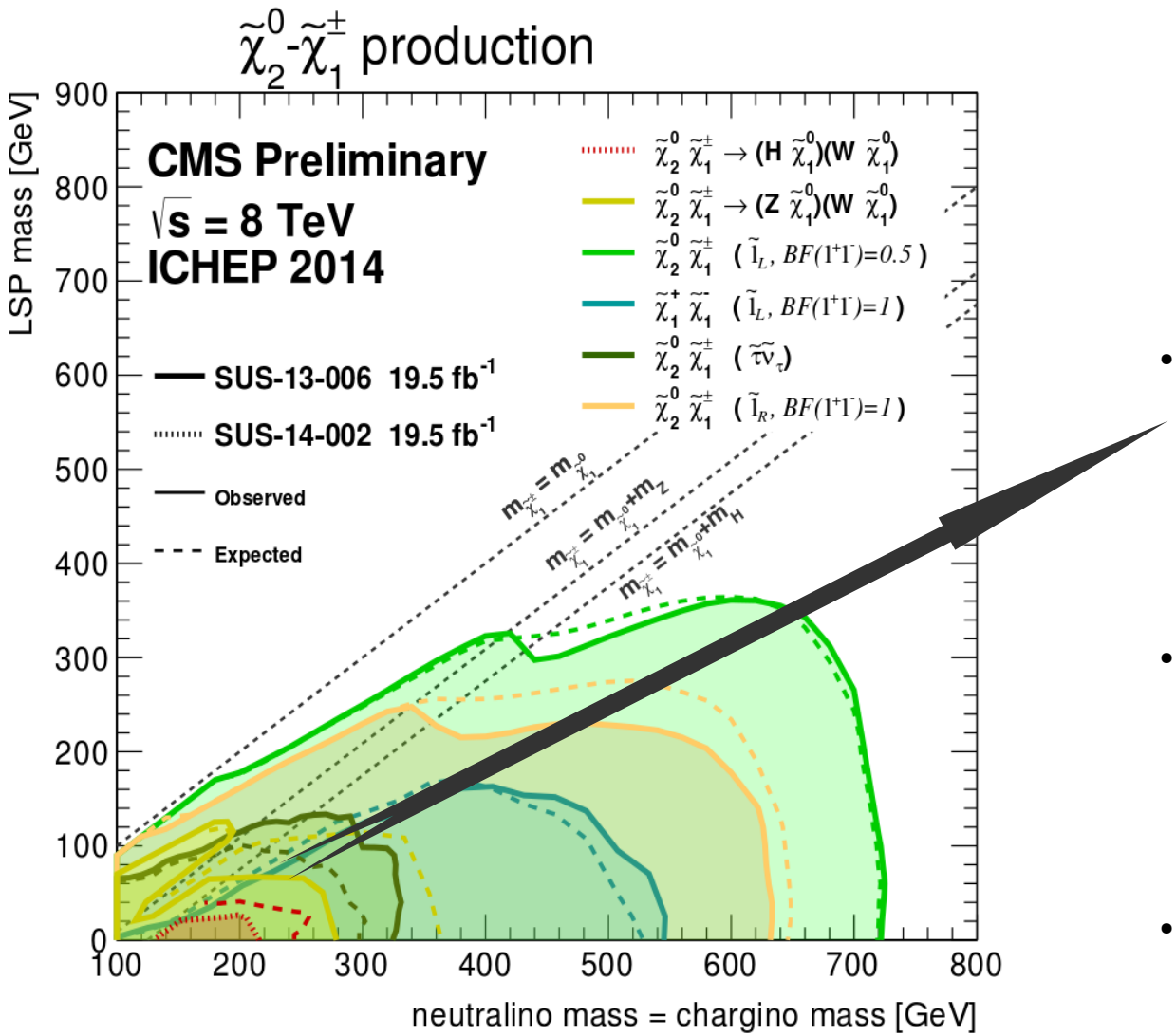


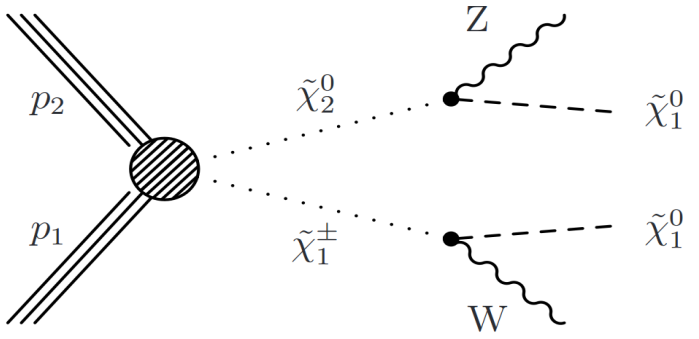


- Event Selection
  - 2 high Pt OS e/mu leptons with Z-veto
  - b-veto, moderate MET cut
- $M_{CT\perp}$:Kinematic Reconstruction
  - Separate WW backgrounds
  - Fitted using data driven templates and MC
  - Data agrees well with prediction

Early Summary

- **Eur. Phys. J. C 74 (2014) 3036**

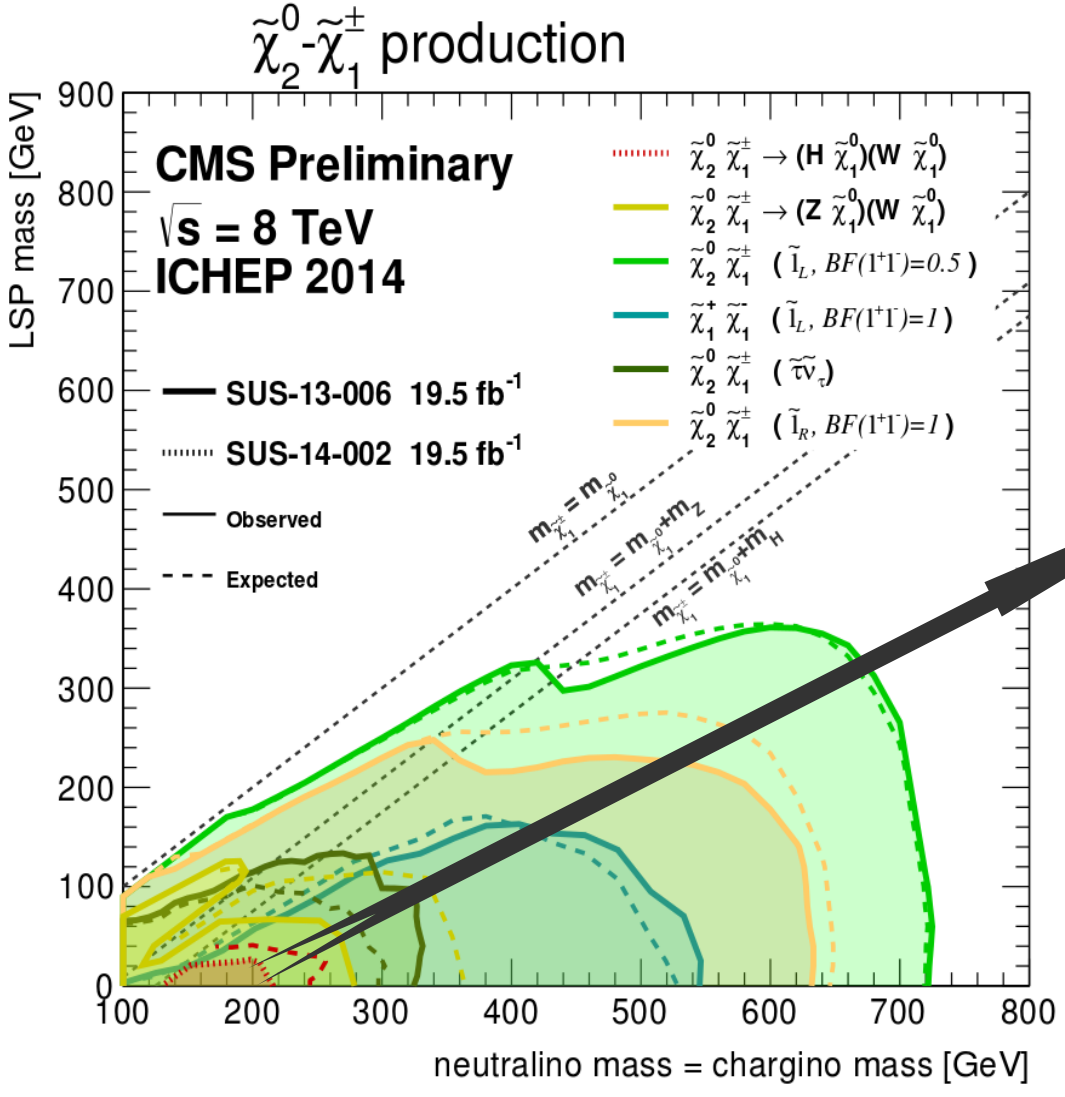


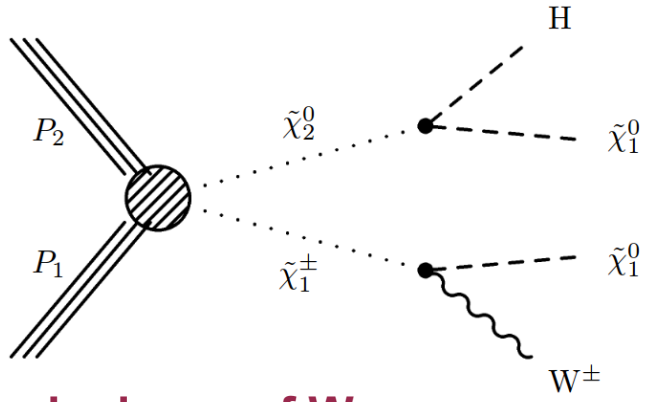


- Event Selection
  - Z → ll candidate
  - MET > 80 GeV
  - 2Jets with Mjj ~ W/Z mass
  - b-veto (to supress ttbar)
- Backgrounds
  - Z+Jets : Fake MET is modeled using photon+jets events
  - ttbar : estimated using e/mu control sample
- Categorizing events based on the ll inv.mass , MET and transverse mass

Early Summary

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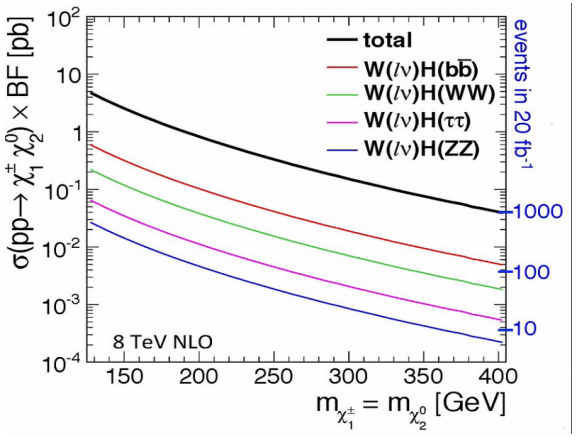


Leptonic decay of W
Higgs decay :

- **bb, W(lnu)W(jj), WW/tautau/ZZ**

Decay to Gamma is studied in (Phys. Rev. D 90 (2014) 092007)

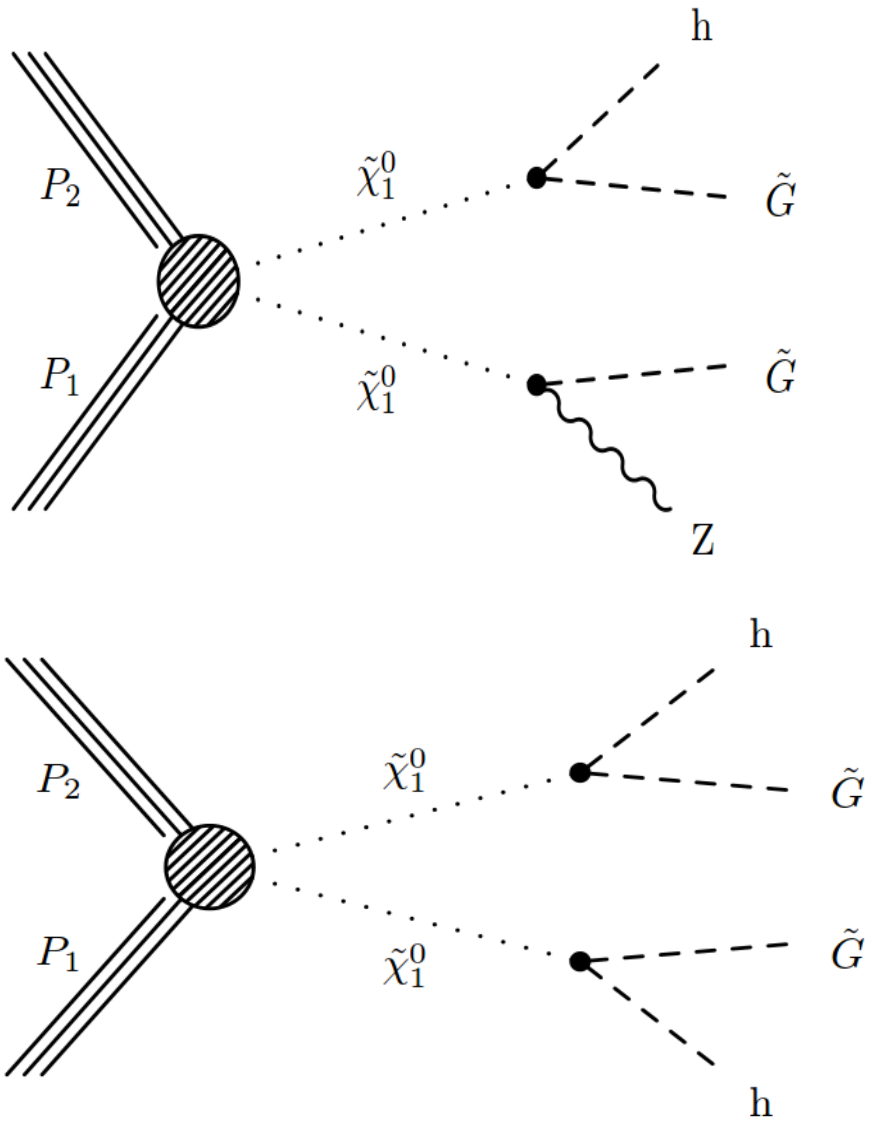
1Lepton, SS Leptons, > 2 leptons



Neutralino-Neutralino

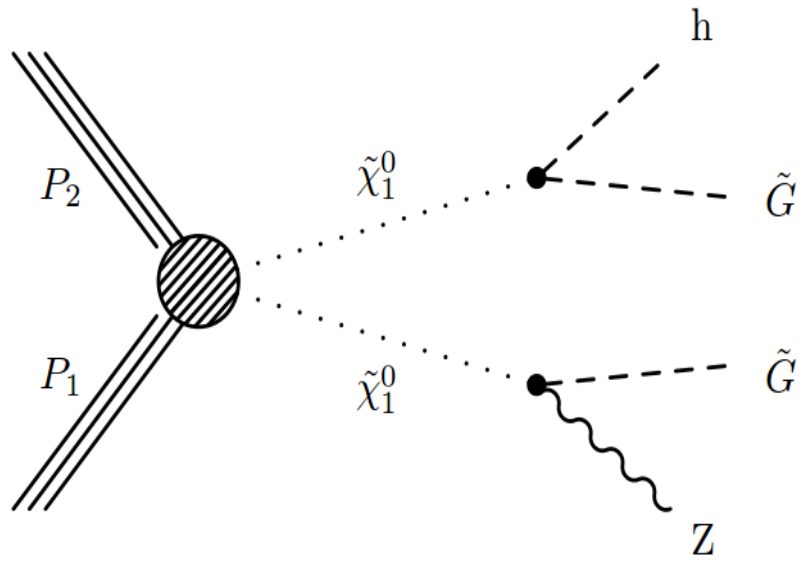
Phys. Rev. D 90 (2014) 092007

Neutralino-Neutralino decay modes

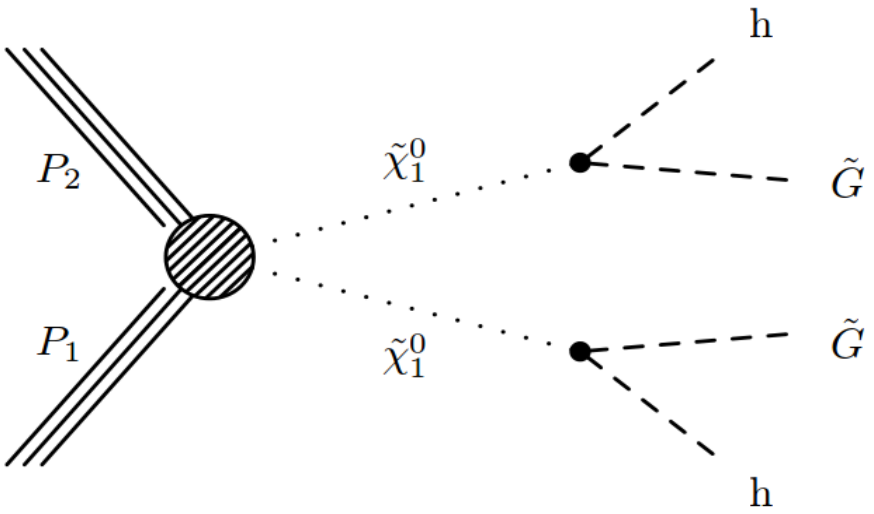


- GMSB scenario
- LSP : Gravitino (massless)
- Chargino and Neutralinos : Degenerage higsinos
- NLSP : Neutralino_1

Neutralino-Neutralino decay modes



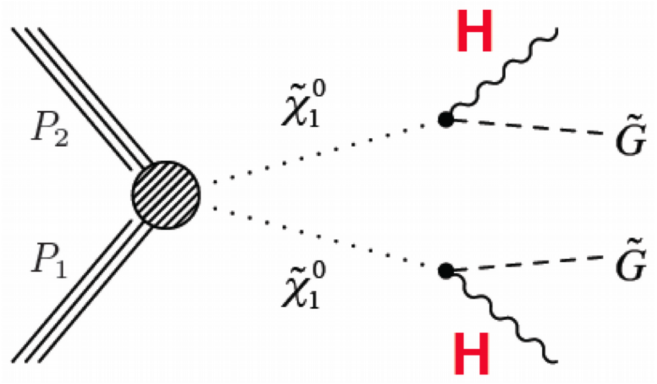
- Gamma-gamma, jj
- Gamma-gamma, ll
- b-bbar + leptons

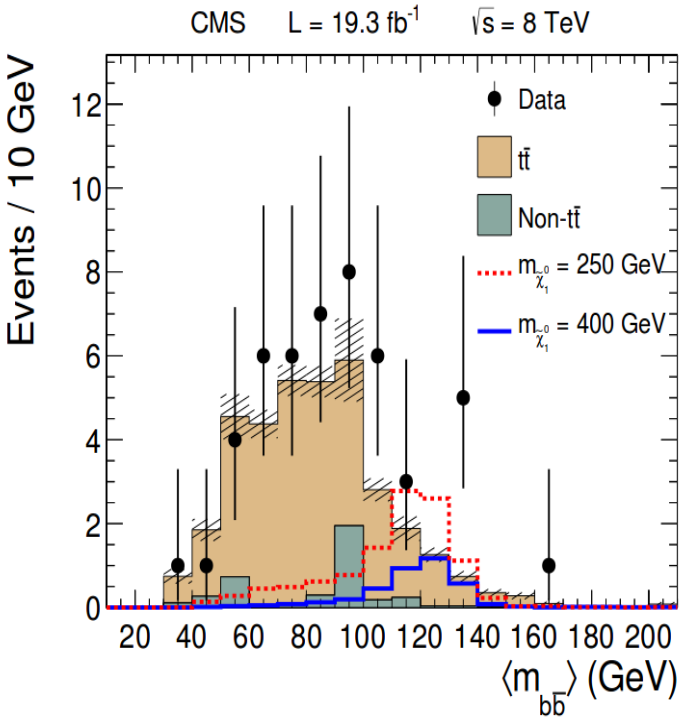


- 4 b-jets
- Gamma-gamma, bb
- Gamma-gamma + at least one lepton

Neutralino-Neutralino

H+H+MET (4b)

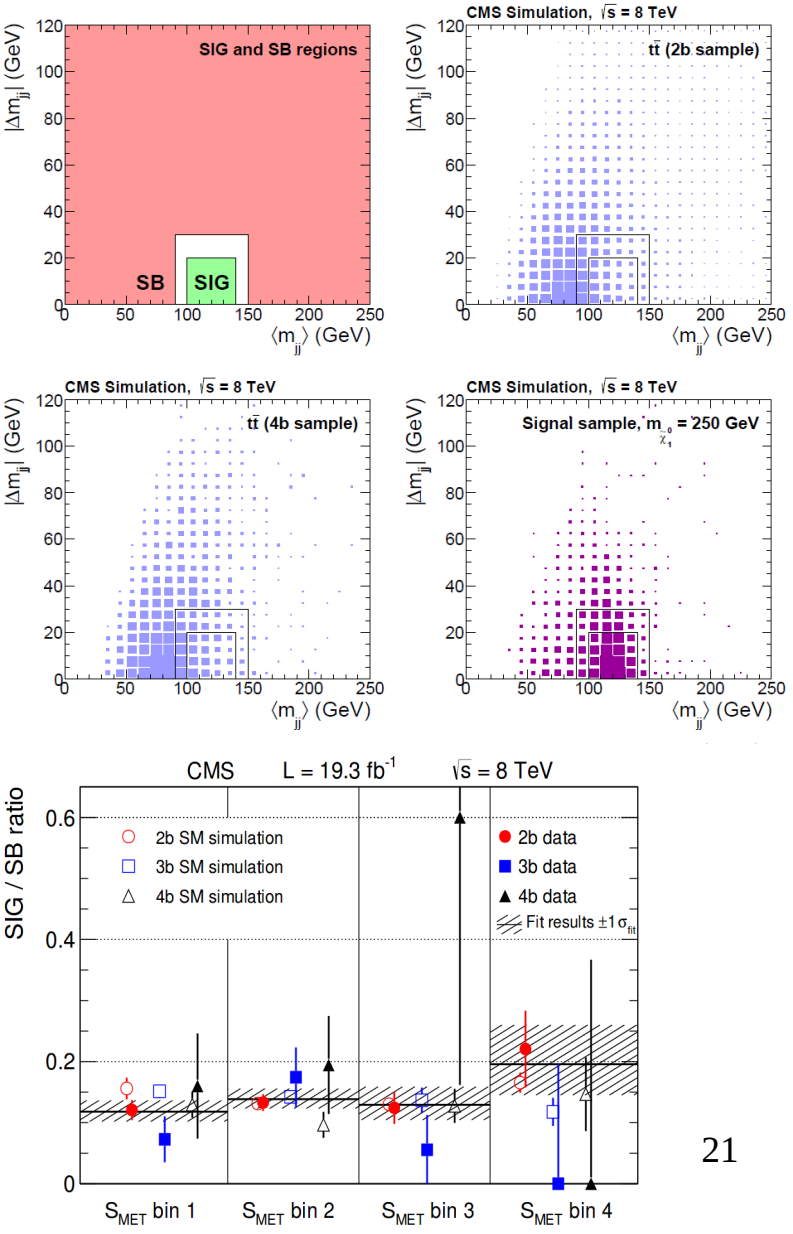




- Event Selection
  - 4/5 Jets, at least 3 b's
  - Moderate MET cut
  - Cut on Dphi of MET and Jets to eliminate QCD and ttbar
- HH Reconstruction
  - $|\Delta m_{jj}| \equiv |m_{jj,1} - m_{jj,2}|$ is minimized
  - $|\Delta m_{jj}| < 20\,\mathrm{GeV}$
  - $100 < \langle m_{jj} \rangle < 140\,\mathrm{GeV}$

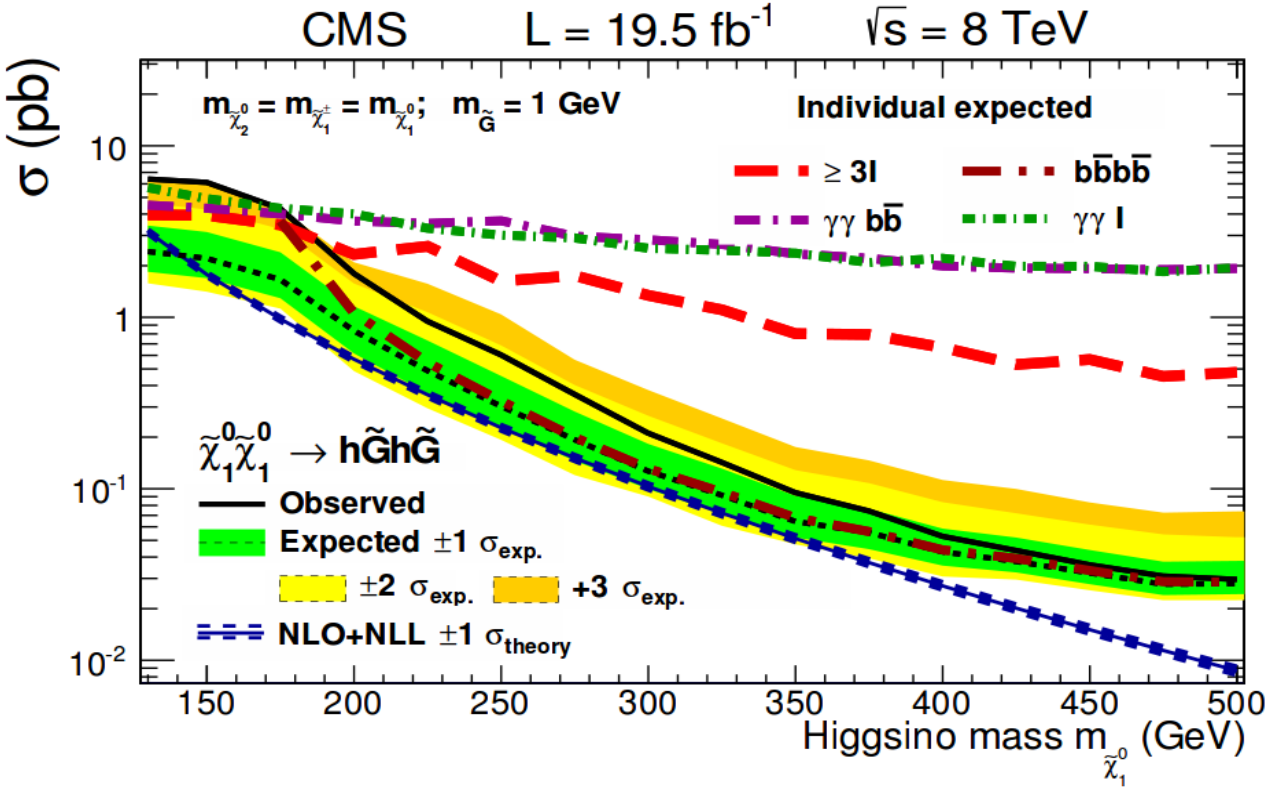
Neutralino-Neutralino H+H+MET (4b)

- Background estimation
  - $\langle m_{jj} \rangle$ and $|\Delta m_{jj}|$ are used to define signal and background regions
  - #Signal and background for different #b's are illustrated
  - #background can be estimated using an ABCD method
- Results
  - Binning vs. MET
  - No sign of new physics is observed



Neutralino-Neutralino

H+H+MET (4b)

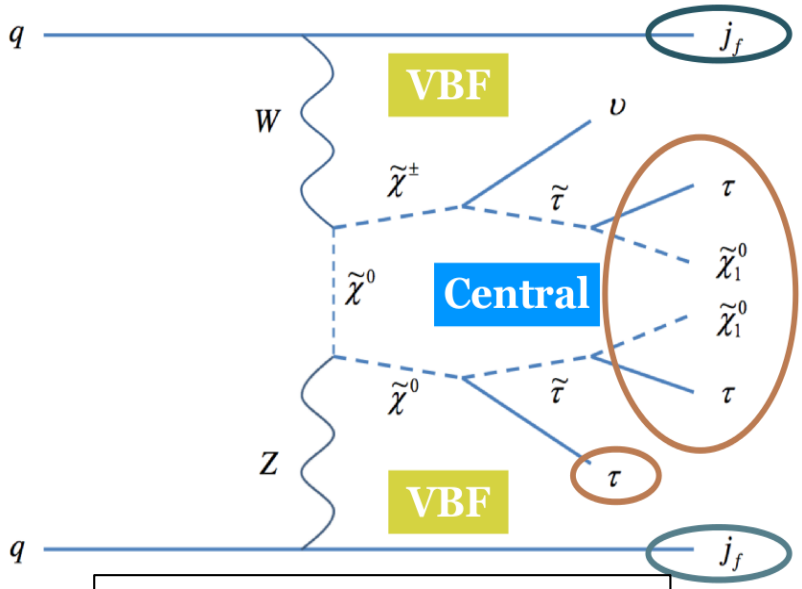


- Because of a slight excess in the observed number of events compared to the estimated background, we are unable to exclude the signal model for any value of higgsino mass.

Vector Boson Fusion production

(JHEP 248P 0815)

Searches via VBF process with ≥ 2 leptons



Madgraph : Signal generation and Cross section calculation

8 channels are studied:

eμjj, μμjj, μ$\tau_h$jj , $\tau_h\tau_h$ jj

(opposite sign and same sign leptons).

Vector Boson Fusion Selection :

- ≥ 2 jets with p T > 30 GeV “Loose” (or 50 GeV “Tight”) with |η| < 5.0
- |Δη(j,j)| > 4.2 , η1*η2 < 0
- m(jj) > 250 GeV (shape based analysis)

Helps a lot in reducing SM backgrounds (1%-0.01%)

Central Selection :

Single Muon trigger and di-tau triggers are used

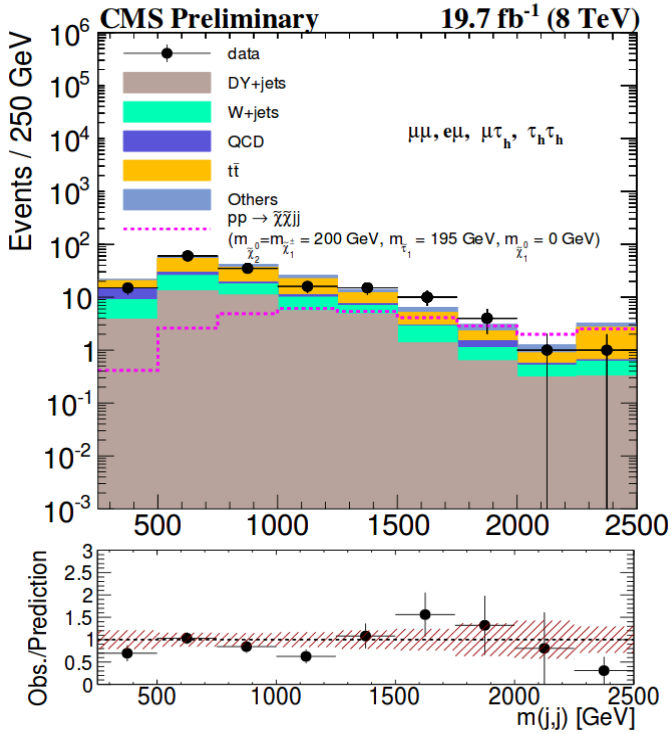
- 2 isolated leptons with |η| < 2.1, dR(l1,l2) > 0.3
- MET > 75 GeV (> 30 for di hadronic tau channel)
- No b-jets

Searches via VBF process with ≥ 2 leptons

Event yields in **OS** and **SS** selections

Process	$\mu^{\pm}\mu^{\mp}jj$	$e^{\pm}\mu^{\mp}jj$	$\mu^{\pm}\tau_h^{\mp}jj$	$\tau_h^{\pm}\tau_h^{\mp}jj$
DY + jets	4.3 ± 1.7	$3.7^{+2.1}_{-1.9}$	19.9 ± 2.9	12.3 ± 4.4
W + jets	< 0.01	$4.2^{+3.3}_{-2.5}$	17.3 ± 3.0	2.0 ± 1.7
VV	2.8 ± 0.5	3.1 ± 0.7	2.9 ± 0.5	0.5 ± 0.2
$t\bar{t}$	24.0 ± 1.7	$19.0^{+2.3}_{-2.4}$	11.7 ± 2.8	–
QCD	–	–	–	6.3 ± 1.8
Higgs	1.0 ± 0.1	1.1 ± 0.5	–	1.1 ± 0.1
VBF Z	–	–	–	0.7 ± 0.2
Total	32.2 ± 2.4	$31.1^{+4.6}_{-4.1}$	51.8 ± 5.1	22.9 ± 5.1
Observed	31	22	41	31

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DY + jets	< 0.01	$0^{+1.7}_{-0}$	0.5 ± 0.2	< 0.01
W + jets	$0.1 \pm 8.2 \times 10^{-4}$	$0^{+3.0}_{-0}$	9.3 ± 2.3	0.5 ± 0.1
VV	2.1 ± 0.3	$1.9^{+0.4}_{-0.2}$	1.1 ± 0.2	$0.1 \pm 6.5 \times 10^{-2}$
$t\bar{t}$	3.1 ± 0.1	$3.5^{+0.7}_{-0.9}$	6.7 ± 2.8	$0.1 \pm 1.2 \times 10^{-2}$
Single top	–	–	–	< 0.1
QCD	–	–	–	7.6 ± 0.9
Higgs	–	–	–	< 0.01
Total	5.4 ± 0.3	$5.4^{+3.5}_{-0.9}$	17.6 ± 3.8	8.4 ± 0.9
Observed	4	5	14	9



Searches via VBF process with ≥ 2 leptons

Event yields in **OS** and **SS** selections

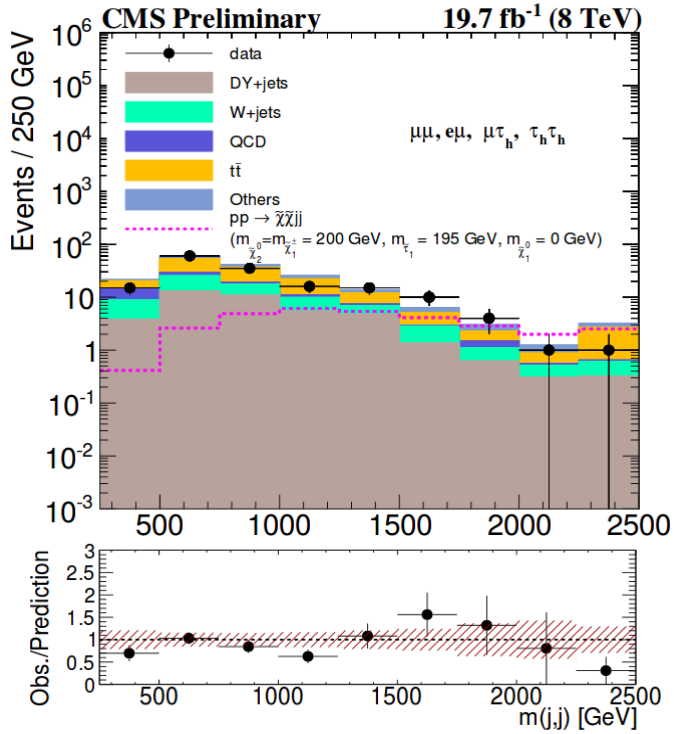
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Backgrounds are :
ttbar , V+jets, QCD multijets and VV

BG in Signal Region are estimated from data using :

$$N_{BG}^{Data} = N_{BG}^{MC}(\text{central}) \cdot SF_{\text{central}}^{CR1} \cdot \epsilon_{VBF}^{CR2}(m_{jj})$$



Searches via VBF process with ≥ 2 leptons

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BG in Signal Region are estimated from data using :

$$N_{BG}^{Data} = N_{BG}^{MC}(central) \cdot SF_{central}^{CR1} \cdot \epsilon_{VBF}^{CR2}(m_{jj})$$

N : Predicted rate in simulation without VBF selection

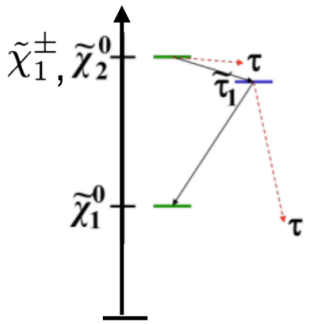
SF : data to simulation corrections

E : VBF efficiency as a function of mjj, from data

VBF Result interpretation

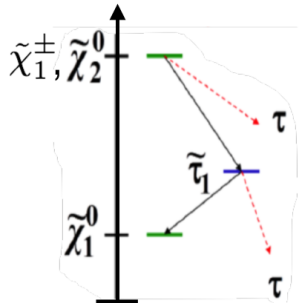
Scenario 2

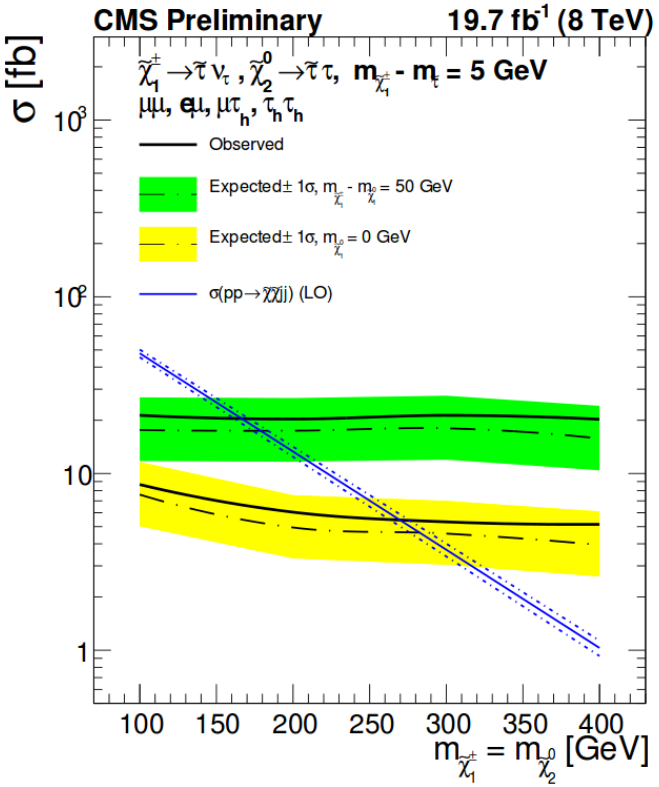
$$m(\tilde{\chi}_1^{\pm}) - m(\tilde{l}) = 5GeV$$

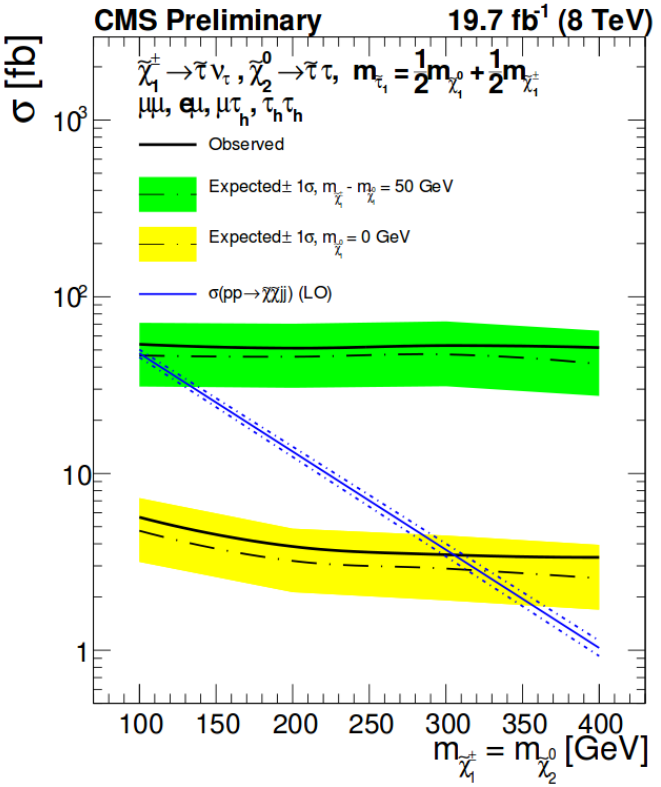


Scenario 1

$$m(\tilde{l}) = \frac{1}{2}m(\tilde{\chi}_1^0) + \frac{1}{2}m(\tilde{\chi}_1^{\pm})$$



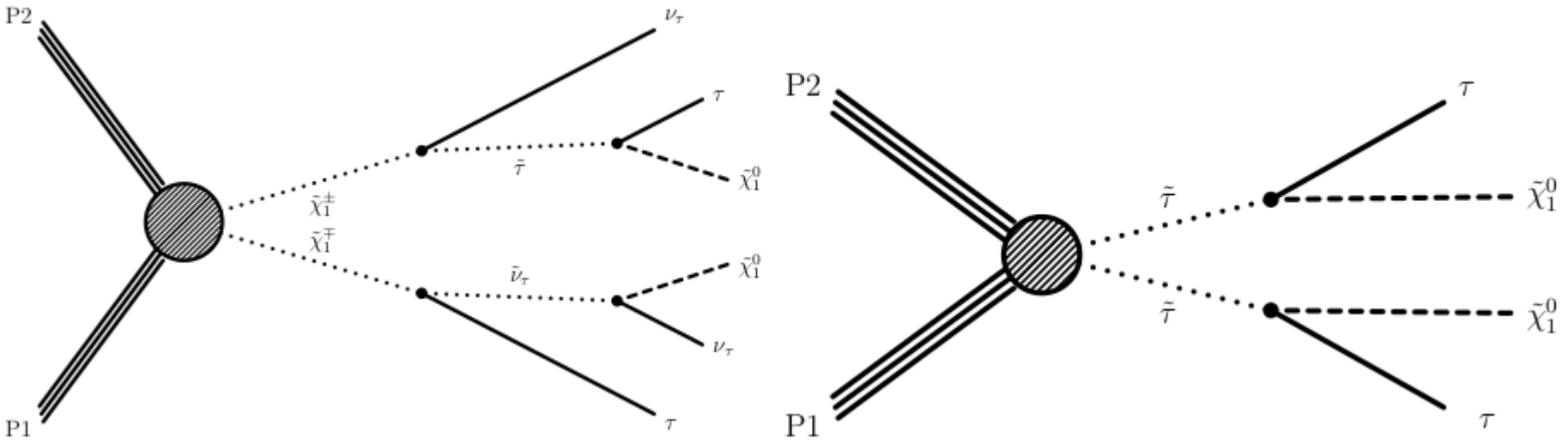




di Tau + MET Final State

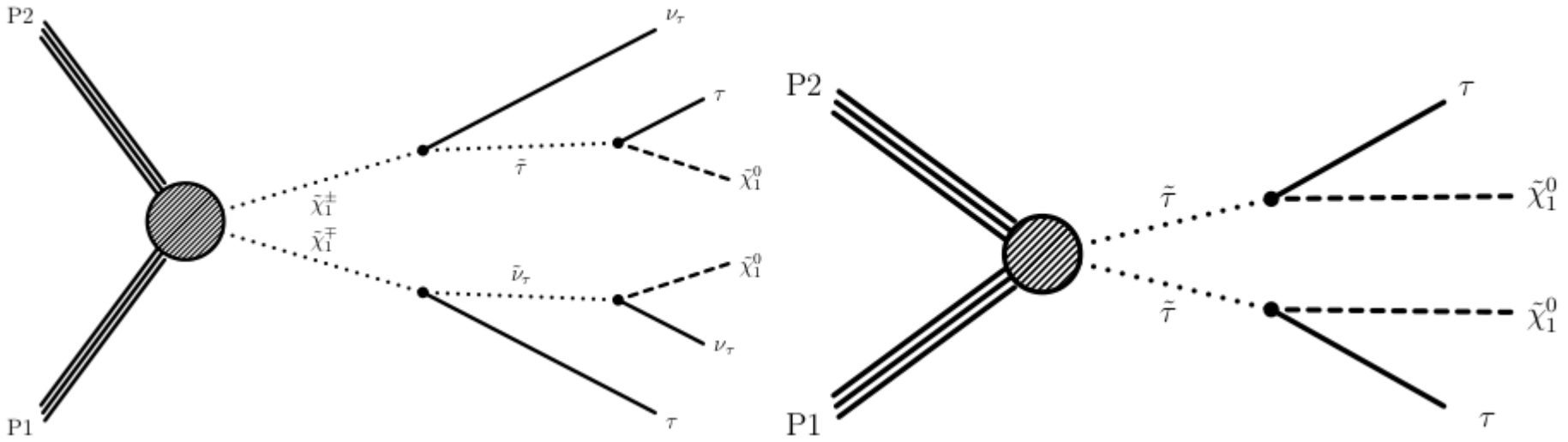
(SUS-14-022)

di tau + MET



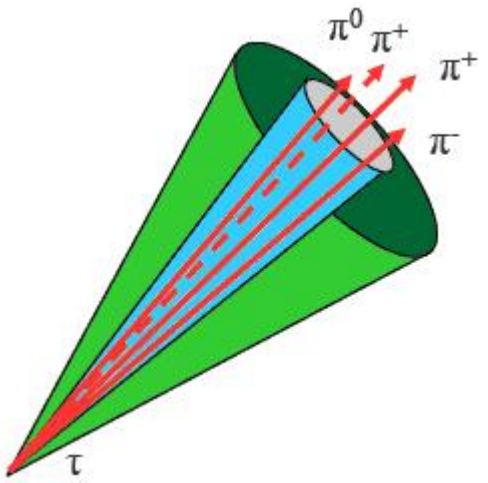
- Naturalness suggests that third generation s-particles are more interesting
- Light stau (~100GeV) is motivated in GMSB models to result consistent relic density
- Best stau limit so far > ~90GeV by LEP

di tau + MET

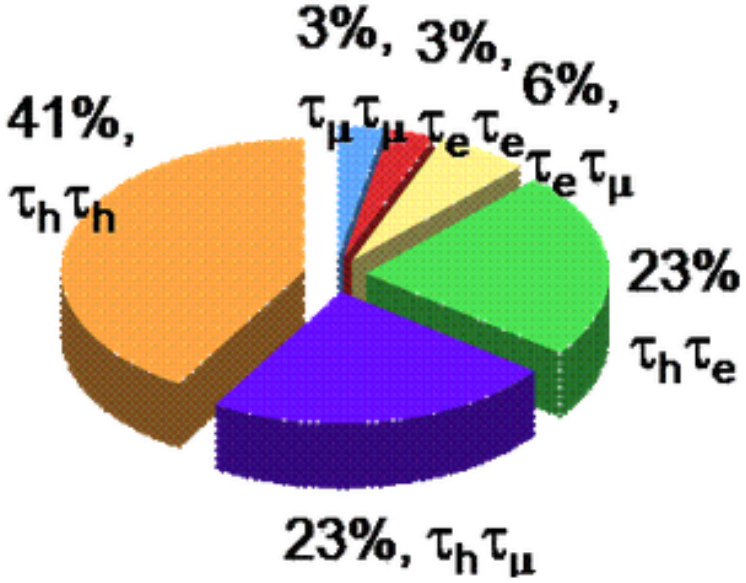


- Signal : $q\bar{q} \rightarrow (Z/\gamma)^* \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^-$
  - Resumino for the cross section
    - between 5pb to 5fb for chargino mass (100 , 500)GeV
    - Between 0.1 fb to 3 fb for stau mass (100 , 250) GeV
  - Pythia for the modeling

Tau decays and reconstruction



- Hadronic tau reconstruction:
  - Starts from jets
  - Based on the decay mode
  - 3 charged hadrons
  - One charged + up to 2 neutral pions



- Performance 50%
  - Tau-tau: 0.25 * 0.41 ~ 10%
  - Lep+ tau: 0.5 * 0.46 ~ 23%
- Higgs mass: lepton+tau the most sensitive
- Here: mu+tau / ele+tau / tau+tau combined

Leptons
Trigger and Offline selection

- For di hadronic tau :
  - 18.1 fb^{-1}
  - Trigger threshold :
    - pt > 35 GeV
    - |η| < 2.1
  - Offline cuts :
    - Pt > 45 GeV
    - Medium Isolated
    - Cleaned against electrons/muons
- For lepton + tau :
  - 19.6 fb^{-1}
  - Trigger thresholds :
    - tau pt > 20
    - electron pt > 20/22
    - Muon pt > 17/18
  - Offline cuts :

    > 25 GeV / |η| < 2.3 / Tight Iso

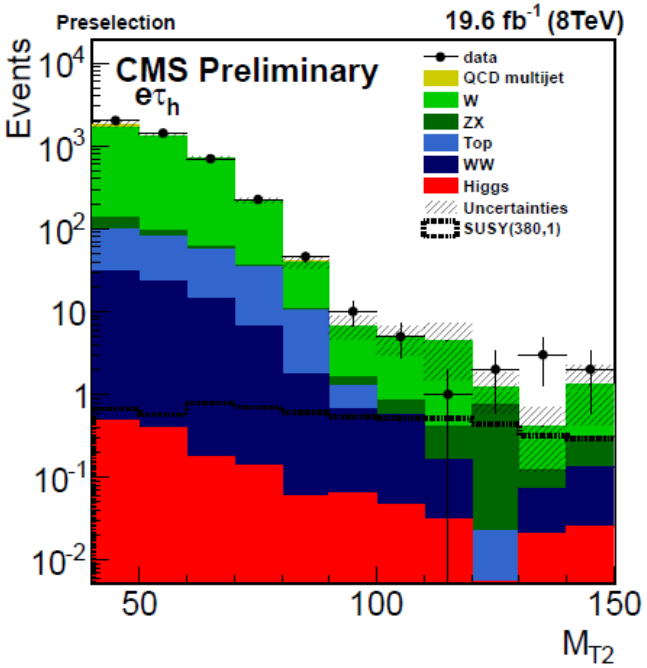
    > 25 GeV / |η| < 2.1 / Tight ID,ISO

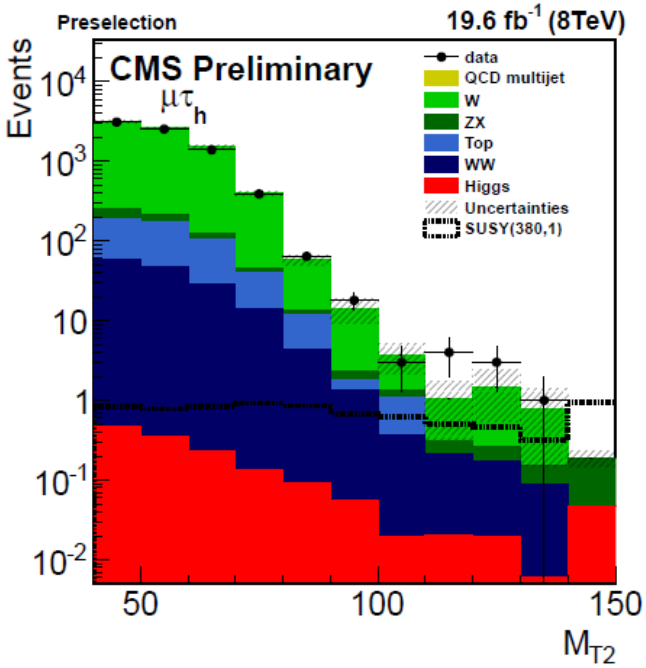
    > 20 GeV / |η| < 2.1 / Tight ID,ISO

Event Selection

- Two opposite sign leptons are requested
  - at least one hadronic decay of tau
  - Invariant mass > 15 GeV
  - Z-Veto cut on the invariant mass
- Reject events with any extra leptons
- MET > 30 GeV
- MT2 > 40 GeV
  - MT2 represents the scale of the SUSY particle
  - A function of MET and leptons
- Minimum DeltaPhi of jets and MET > 1
  - Rejects QCD and Wjets backgrounds
- b-jet veto : rejects ttbar events

Lepton + Tau





- Selection is optimized to have the best reach :
  - low MT2 region :
    - sensitive to lower SUSY masses (NLSP/LSP)
    - large background
    - not used
  - MT2>90 GeV
  - Tau MT > 200 GeV

- Backgrounds with prompt lepton and tau are estimated from simulation
- The main backgrounds are fake taus :
  - To estimate it, the tau isolation cut is loosen
  - In control regions, the probability that a fake/prompt loose tau passes the tight cuts is measured
    - For fakes : 0.54 +- 0.01
    - For prompts : 0.766 +- 0.003
    - It is independent of tau attributes and event selection cuts

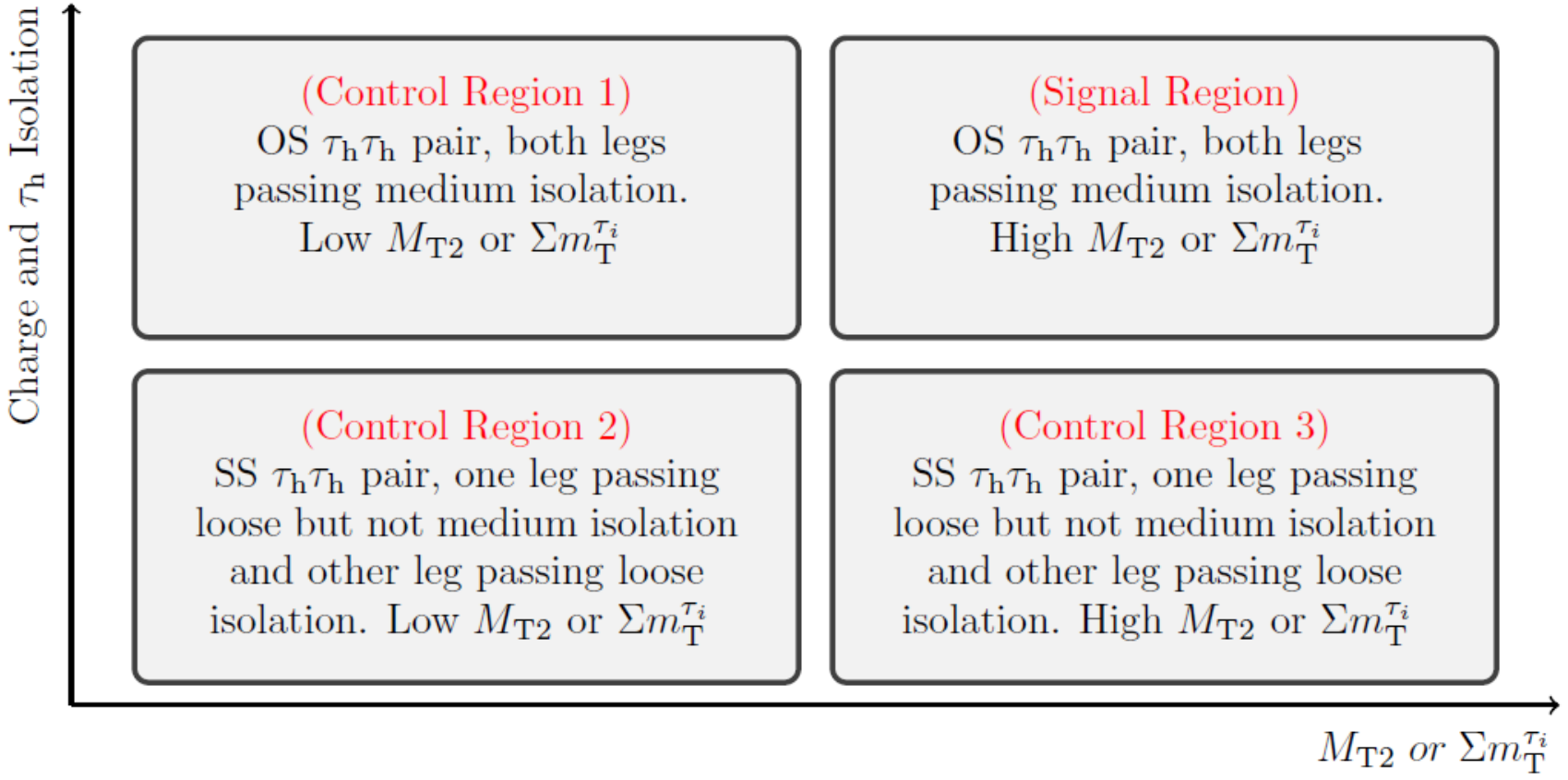
Channel	Total Fake	stat	r_{Fake} sys	r_{Real} sys	Total Unc
$\mu\tau_h$	8.15	56%	18%	5%	59%
$e\tau_h$	3.30	101%	17%	2%	102%

Tau+Tau Selection

- SR1 : High MT2 region (MT2 > 90 GeV) :
  - No extra cut is applied
  - Even the b-veto cut is relaxed (ttbar is already discarded)
- SR2 : Low MT2 region (MT2 < 90 GeV) :
  - Sum of the transverse masses of two hadronic taus is found the best variable to separate signal/bkg
  - SumMT > 200
  - Used by the ATLAS analysis

QCD backgrounds in tau-tau channels

- QCD and multi-jet backgrounds : Events with two fake taus



Signal Region	QCD Estimation
$\tau_h\tau_h$ SR1	$0.13 \pm 0.06(\text{stat}) \pm 0.18(\text{sys}) \pm 0.10(\text{fit})$
$\tau_h\tau_h$ SR2	$1.15 \pm 0.39(\text{stat}) \pm 0.70(\text{sys}) \pm 0.25(\text{fit})$

W/Z backgrounds in tau-tau channels

- MC is validated using mu+tau data events

- W+Jets
  - the efficiency of the MT2 and SumMT cuts are verified in data

Signal Region	W+jets Estimation
$\tau_h\tau_h$ SR1	0.72 ± 0.11 (stat) ± 0.11 (sys) ± 0.56 (shape)
$\tau_h\tau_h$ SR2	2.58 ± 0.35 (stat) ± 1.04 (sys) ± 0.69 (shape)

- Z events
  - Events under the z-peak are selected
  - The transverse momentum of the Z boson system, which is correlated with MT2 , is also well reproduced in simulation.

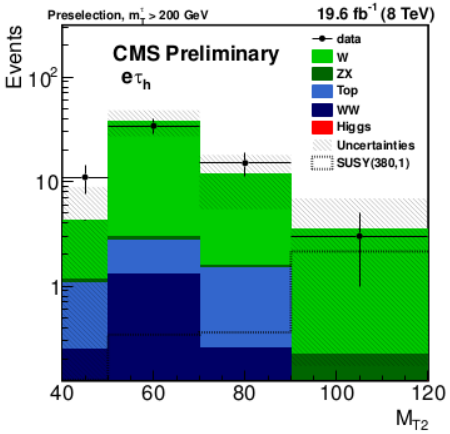
Signal Region	DY Estimation
$e\tau_h$	0.19 ± 0.04
$\mu\tau_h$	0.25 ± 0.06
$\tau_h\tau_h$ SR1	0.56 ± 0.07
$\tau_h\tau_h$ SR2	0.81 ± 0.56

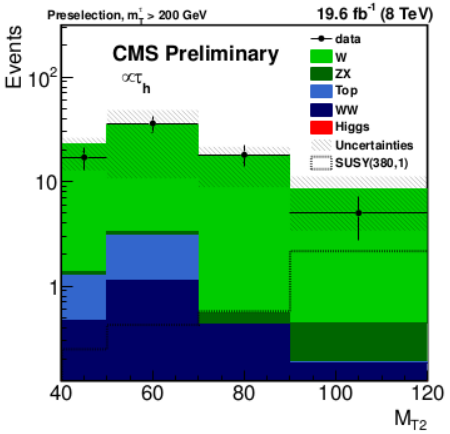
Systematic uncertainties

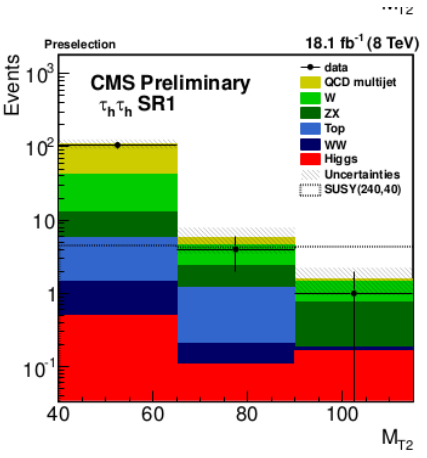
	Background			Signal		
Systematic uncertainty source	$\ell\tau_h$	$\tau_h\tau_h$ SR1	$\tau_h\tau_h$ SR2	$\ell\tau_h$	$\tau_h\tau_h$ SR1	$\tau_h\tau_h$ SR2
τ_h energy scale (*)	10%	15%		2-12%	3-15%	
τ_h id efficiency	6%	12%		6%	12%	
τ_h trigger efficiency	3%	9%		3%	9%	
Lepton trigger, id, iso efficiency	2%	-		2%	-	
p_T^{miss} (*)	5%			5%		
b-tagged jets veto	4%	-	4%	8%	-	8%
Pile-up	4%			4%		
Fast/Full τ_h id efficiency	-			5%	10%	
ISR (*)	-			3%		
$\Delta\phi_{min}$	-			6%		
PDF (*)	-			2%		
Luminosity	-			2.6%		
Total shape-altering sys.	11%	16%	16%	6-13%	7-16%	
Total non-shape-altering sys.	9%	16%	16%	14%	20%	21%
Total Systematic	14%	22%	22%	15-19%	21-25%	22-26%
Monte Carlo Statistic	22%	13%	70%	3-15%		
Total	26%	26%	73%	15-24%	21-29%	22-30%
Low rate backgrounds	50%			-		

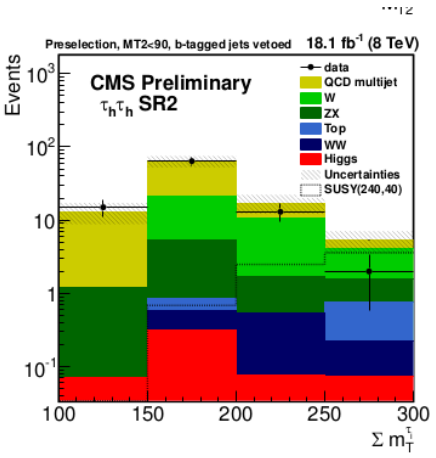
Results

	$e\tau_h$	$\mu\tau_h$	$\tau_h\tau_h$ SR1	$\tau_h\tau_h$ SR2
Z+jets	$0.19 \pm 0.04 \pm 0.03$	$0.25 \pm 0.06 \pm 0.04$	$0.56 \pm 0.07 \pm 0.12$	$0.81 \pm 0.56 \pm 0.18$
$t\bar{t}$, VV, Higgs	$0.03 \pm 0.03 \pm 0.02$	$0.19 \pm 0.09 \pm 0.09$	$0.19 \pm 0.03 \pm 0.09$	$0.75 \pm 0.35 \pm 0.38$
W+jets	$3.30 \pm 3.35 \pm 0.56$	$8.15 \pm 4.59 \pm 1.53$	$0.72 \pm 0.11 \pm 0.57$	$2.58 \pm 0.35 \pm 1.25$
QCD multijet	-	-	$0.13 \pm 0.06 \pm 0.21$	$1.15 \pm 0.39 \pm 0.74$
SM Total	$3.52 \pm 3.35 \pm 0.56$	$8.59 \pm 4.59 \pm 1.53$	$1.60 \pm 0.15 \pm 0.62$	$5.29 \pm 0.70 \pm 1.51$
Observed	3	5	1	2

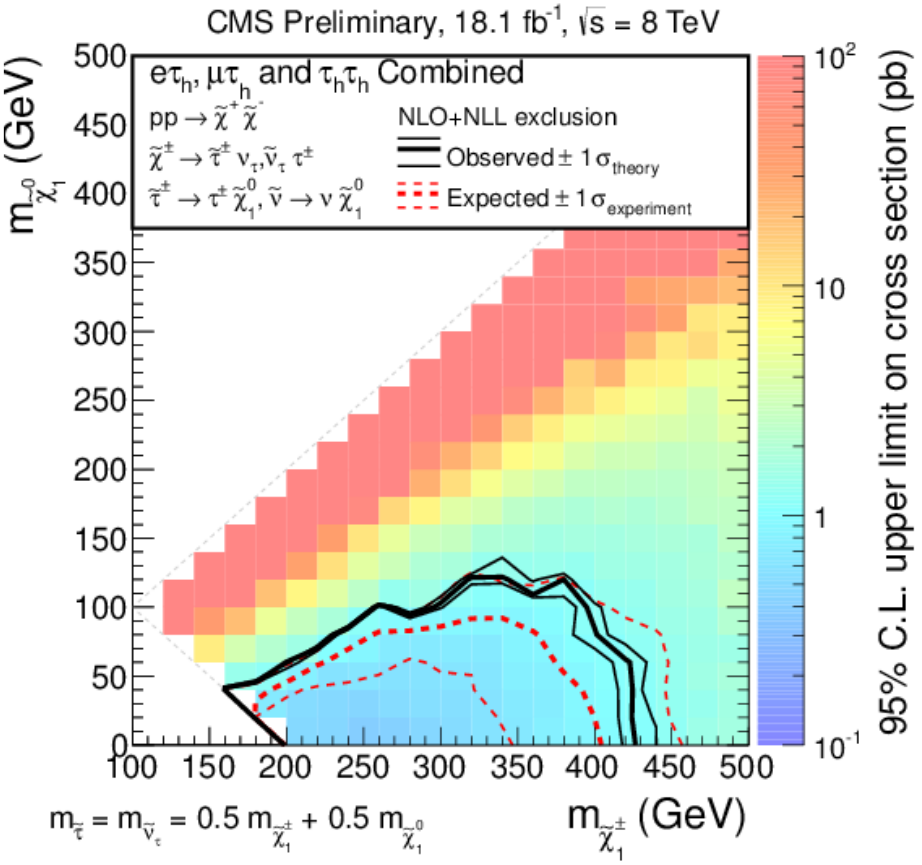


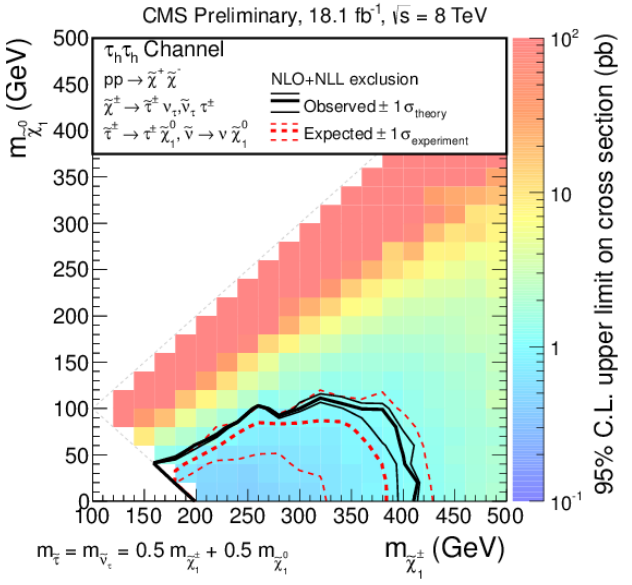


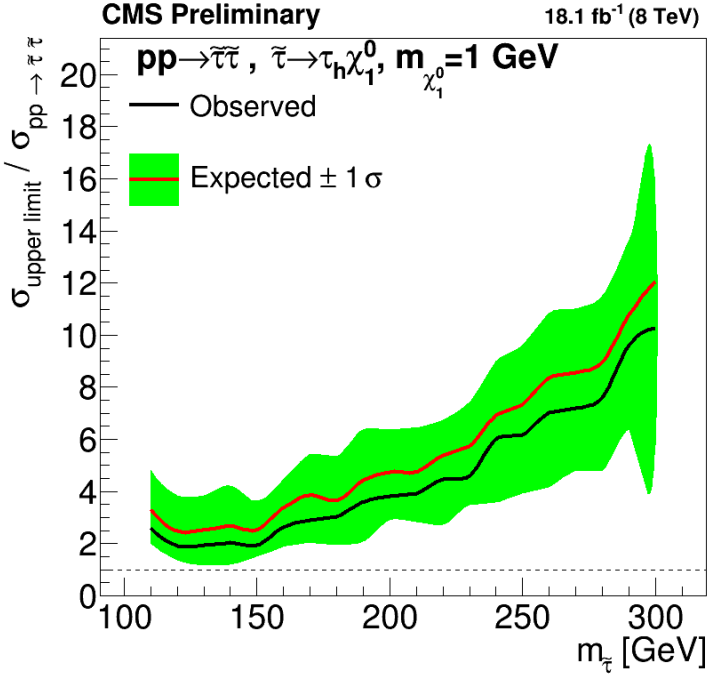




Interpretations







Summary and Conclusion

- A wide range of searches for electroweak SUSY production is performed with full 8 TeV dataset
- Different decay scenarios are considered :
  - 1,2,3,4 leptons
  - 2leptons + 2jets
  - 4b
  - VBF
  - 2taus + MET
- The results are interpreted in various simplified models spectra
- No sign of new physics is observed