Universität Hamburg
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Latest Results on Searches for Supersymmetry from CMS

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on behalf of the CMS Collaboration

LPCC Seminar– 3rd September 2013 – CERN

Outline

- **Introduction**
- **Searches for gluinos and 1st+2nd generation squarks**
  - Multijet + MHT (SUS-13-012)
- **Searches for gluinos and 3rd generation squarks**
  - Razor (SUS-13-004)
  - Same sign di-leptons (SUS-13-013)
  - Search for stops and higgsinos using di-photon Higgs decay (SUS-13-014)
  - Anomalous multi-lepton production (SUS-13-002) … also interpreted as search for light sleptons
- **Search for electroweak SUSY partners and sleptons**
  - Electroweak production of charginos/neutralinos/sleptons (SUS-13-006)
  - Chargino/Neutralino production with Higgs in final state (SUS-13-017)
- **Conclusion**

All results in this talk:
8 TeV, 19.5 fb^{-1}, EPS13 or newer

Supersymmetry

Last possible extension of Poincare group: Fermions ↔ Bosons

Conserved *R* parity (originally introduced for stability of proton):

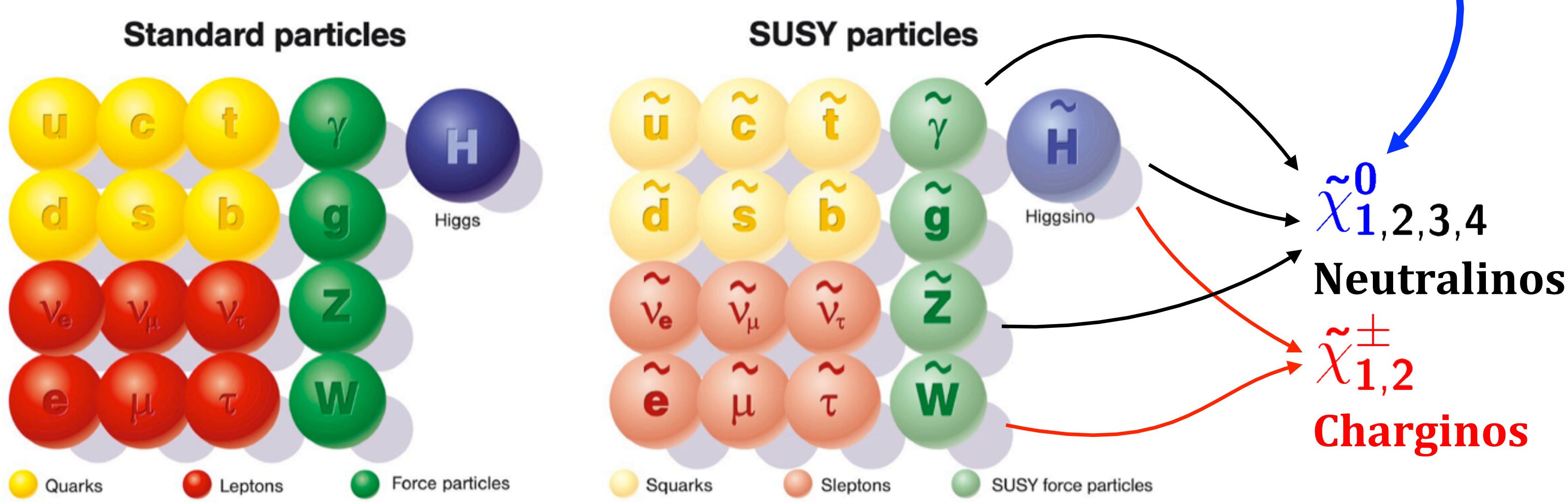
$$R = (-1)^{3(B-L)+2S}$$

→ SUSY particles produced/annihilated in pairs

→ Lightest SUSY particle (LSP) stable

→ **Typical signature: jets/leptons/photons + MET**

Remark: SUSY needs at least two Higgs doublets → 5 Higgses (h,H,A,$H^{\pm}$)

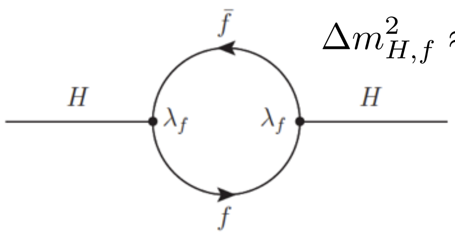


SUSY Propaganda

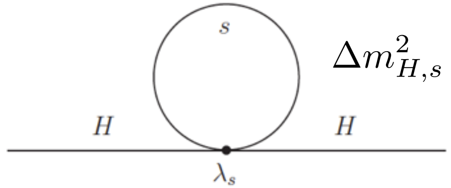
Nice features of Supersymmetry:

- **Solving hierarchy problem without "fine tuning":**

→ SUSY contributions to Higgs mass cancel SM contributions



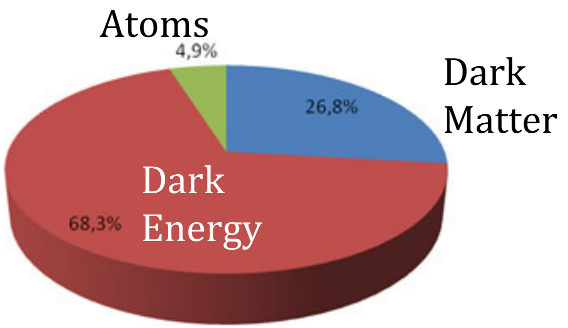
$$\Delta m_{H,f}^2 \approx -\frac{\lambda_f^2}{8\pi^2}\Lambda_{\mathrm{UV}}^2$$



$$\Delta m_{H,s}^2 \approx \frac{\lambda_s}{16\pi^2}\Lambda_{\mathrm{UV}}^2$$

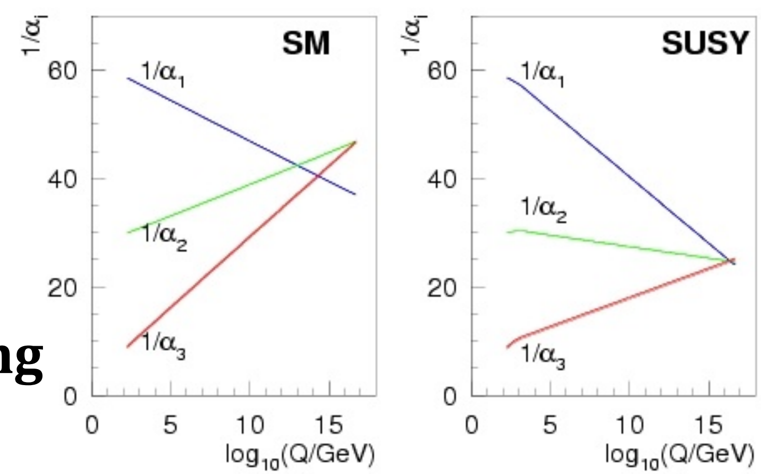
- **Provides Dark Matter candidate**

→ Lightest SUSY particle (LSP) can be stable and only weakly interacting



- **Unification of gauge couplings**

→ New particle content changes running of couplings



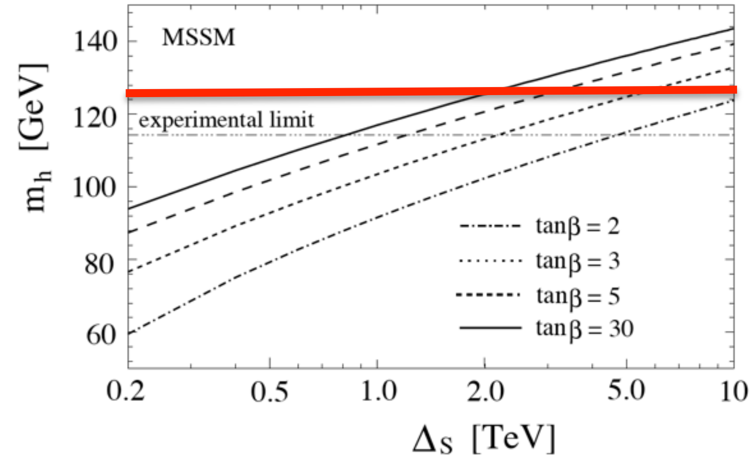
- **Connection of gravity and gauge symmetries**

Some of the arguments are most convincing for SUSY particles at the ~TeV scale

Supersymmetry-Higgs Interplay

Tobe, Wells
PRD 66 (2002) 013010

Implications of 125 GeV MSSM-Higgs:



$$M_h^2 \approx M_Z^2 \cos^2 2\beta + \underbrace{\eta}_{\mathcal{O}(1)} \frac{3G_F m_t^4}{\sqrt{2}\pi^2} \log \frac{\Delta_S^2}{m_t^2} \quad \text{with} \quad \Delta_S^2 = m_{\tilde{t}_1} m_{\tilde{t}_2}$$

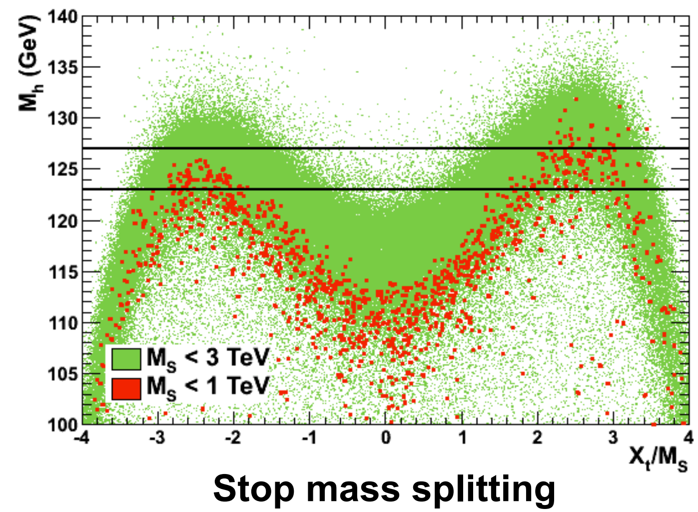
- Either stops are heavy (≫1 TeV) → Tension to "naturalness" (→ some amount of fine tuning)

$$\frac{M_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d) - (m_{H_u}^2 + \Sigma_u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2$$

Radiative EWSB

- or large stop mass splitting ("Maximal mixing")

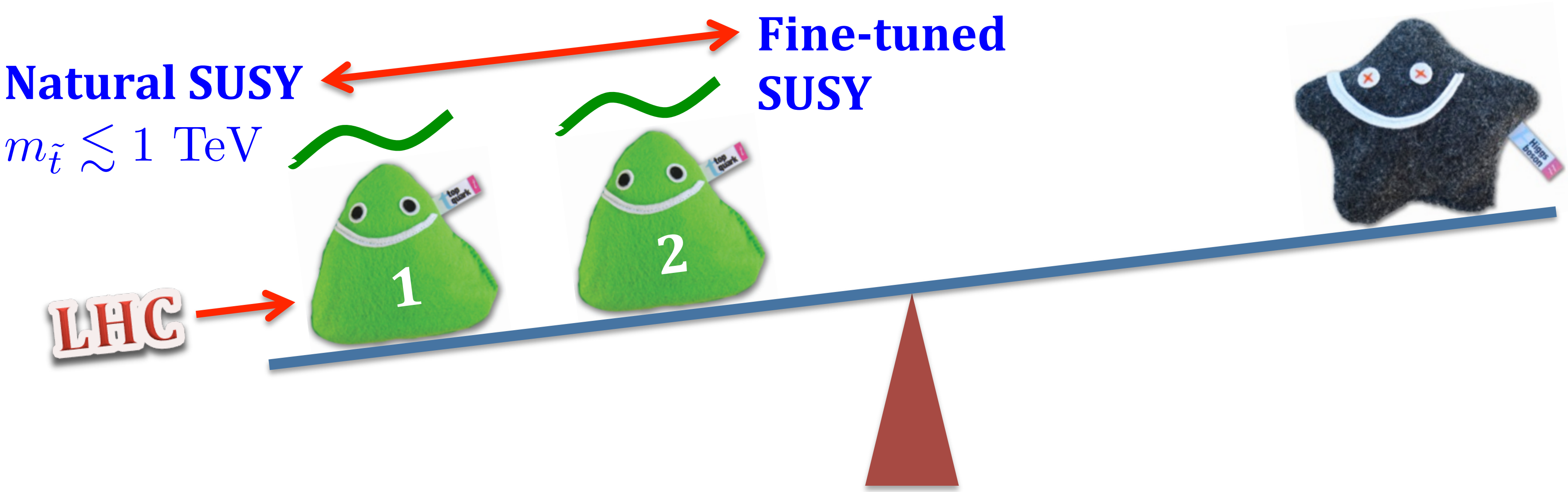
$$\mathcal{M}_{\tilde{t}} = \begin{pmatrix} \tilde{m}_{t_L}^2 & \overbrace{m_t(A_t - \mu\cot\beta)}^{X_t} \\ m_t(A_t - \mu\cot\beta) & \tilde{m}_{t_R}^2 \end{pmatrix}$$



Arbey, Battaglia, Djouadi, Mahmoudi, Quevillon
arXiv:1112.3028

A Simplified Picture

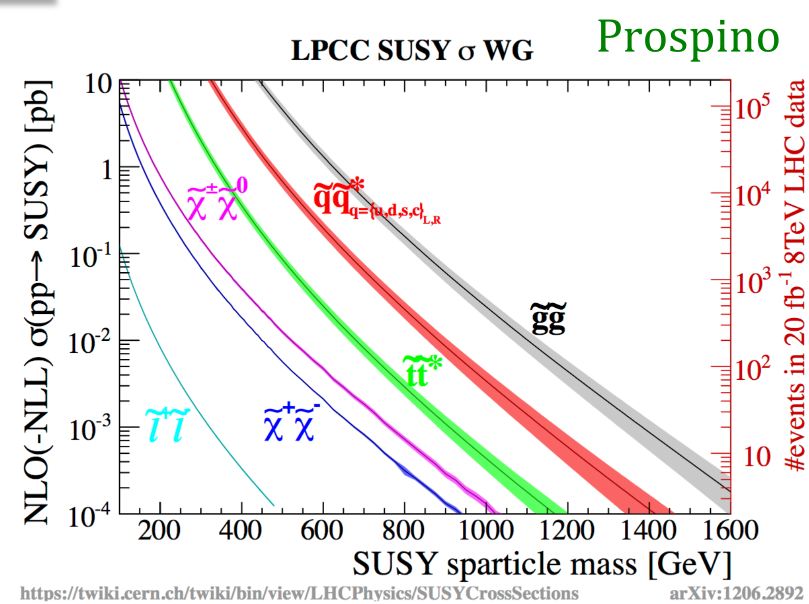
$m_H \sim 125$ GeV



Stop production cross section significantly smaller (compared to light squark production)

→ LHC limits on squark masses only apply for 1st and 2nd generation

→ Stop quarks can be lighter than 1st and 2nd generation squarks!

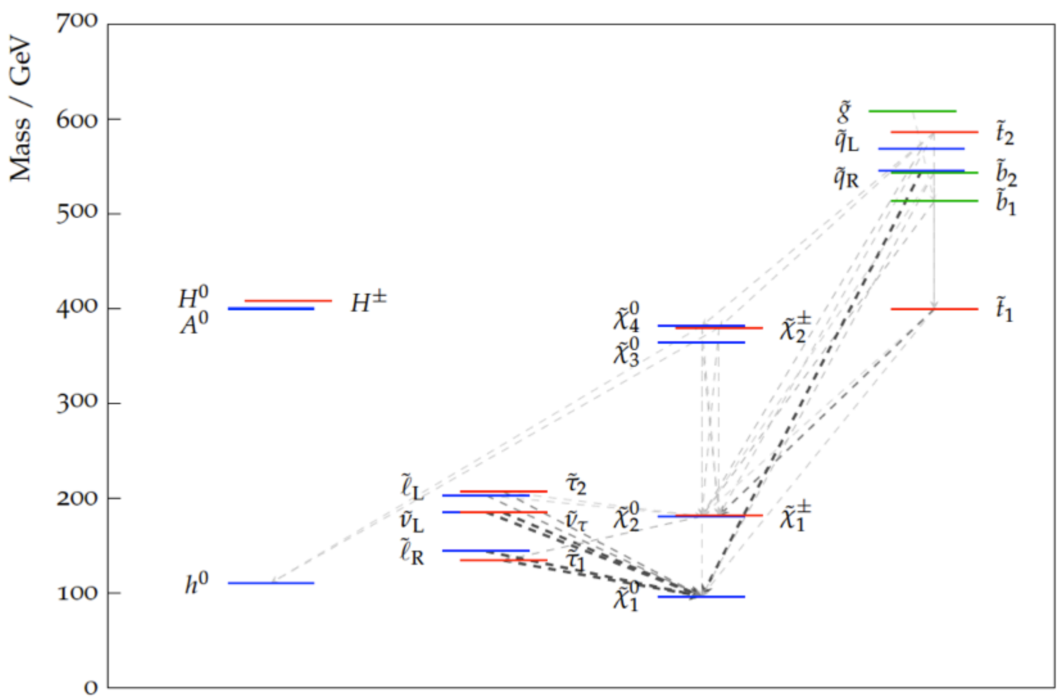


Interpretation of Results

Full models (e. g. cMSSM) have many possible decay chains, but

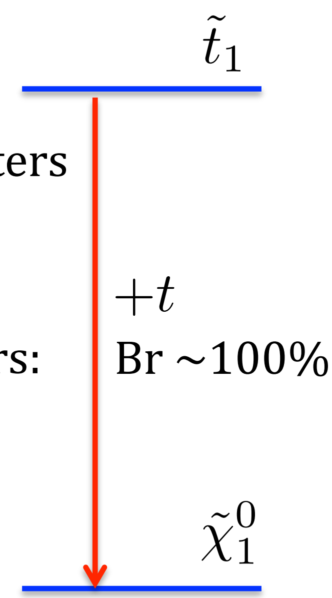
- One cascade might be dominant
- Analysis might be sensitive to only one specific cascade
- Limits on model parameters are not applicable for other models

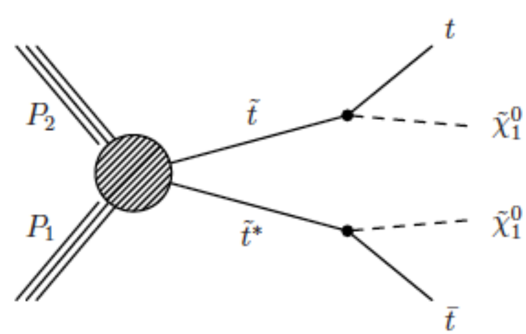
→ Interpret results in simplified models (SMS) with min. # of free parameters



SPS1a, visualized by slhaplot

Example SMS
free parameters:
$m(\tilde{t}),\ m(\tilde{\chi}_1^0)$





Standard Model Backgrounds

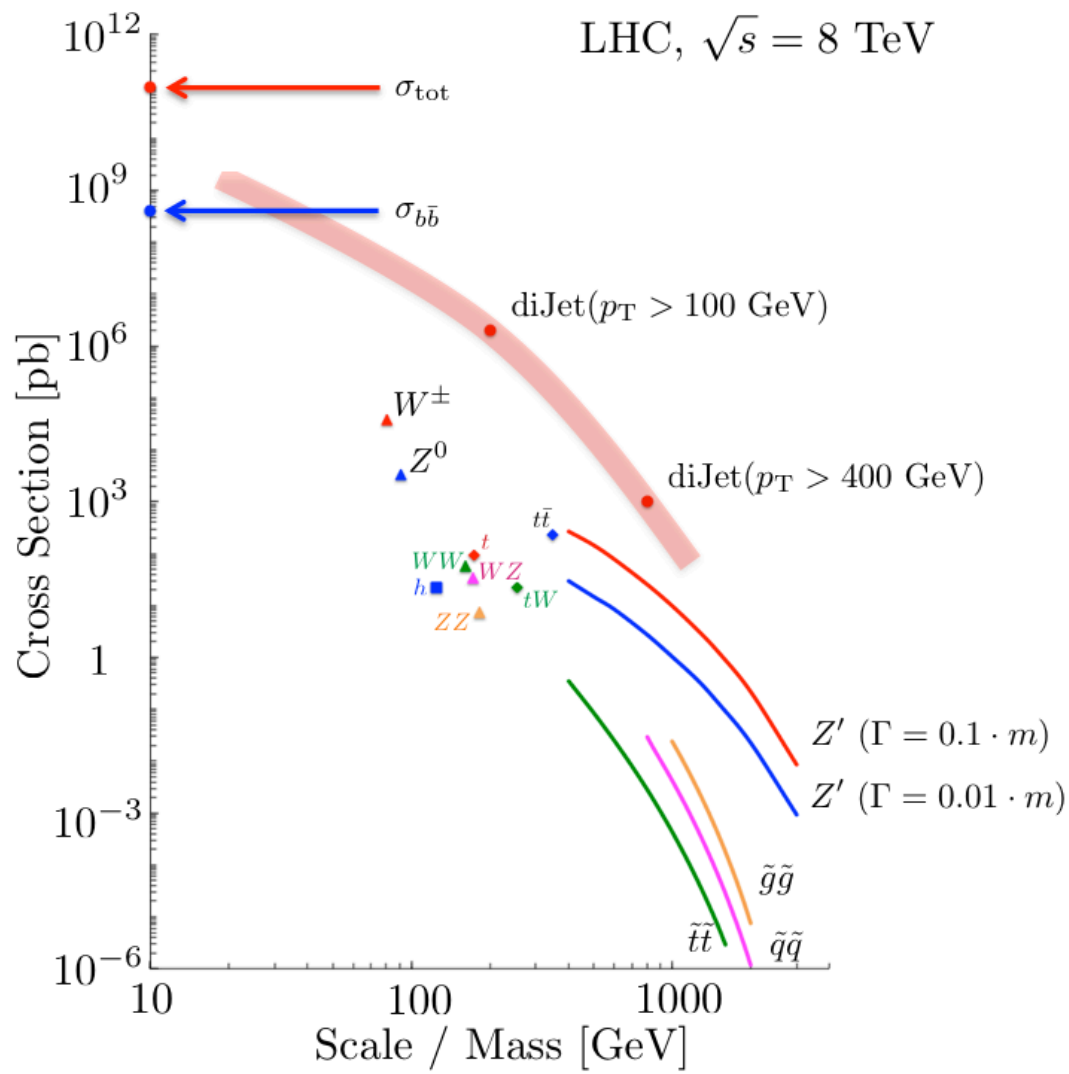
SM backgrounds have orders of magnitude larger cross sections than signal

Search in tails of distributions requires precise knowledge of:

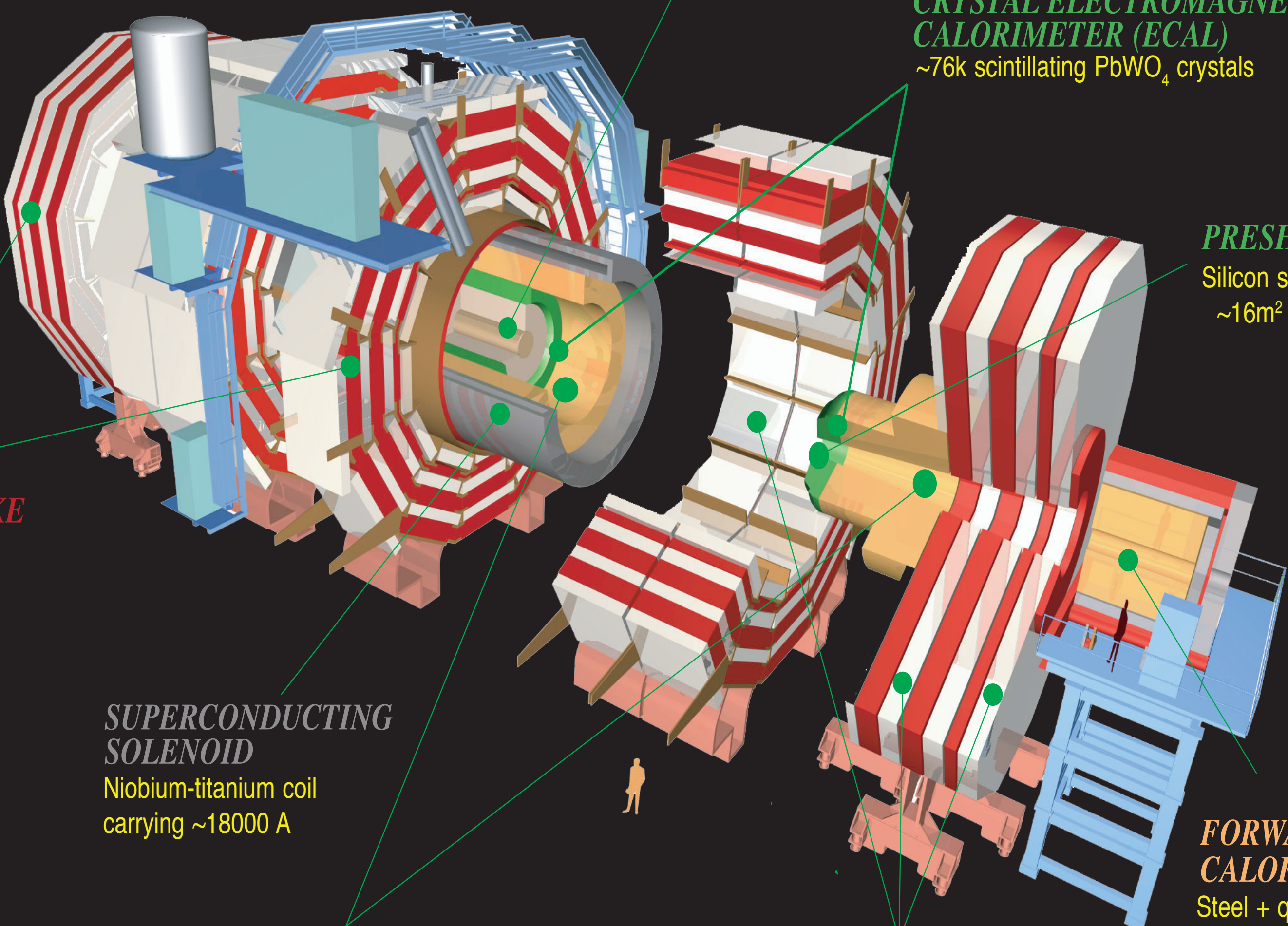
- SM processes
- Detector effects

→ **Use data as much as possible to estimate and validate background predictions**

→ **Extensive use of MC simulation to validate methods and predict rare backgrounds**



CMS Detector



Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

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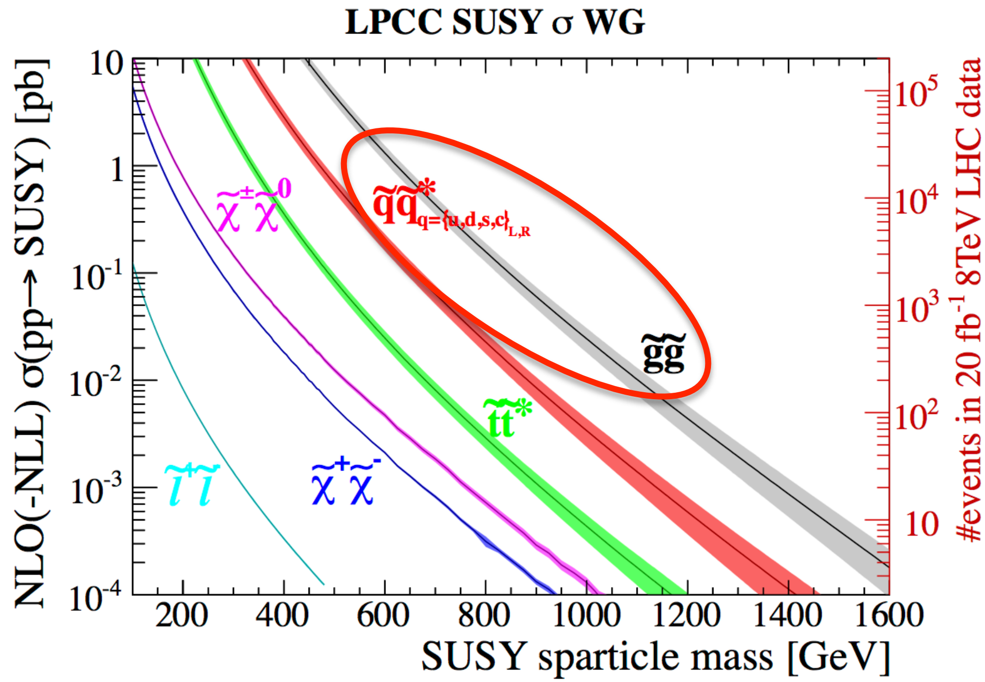
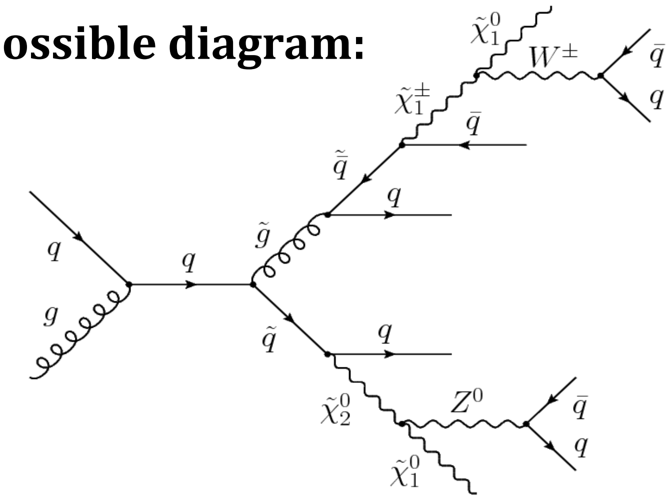


https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections arXiv:1206.2892

Multi-Jets + MHT

SUS-13-012

Possible diagram:

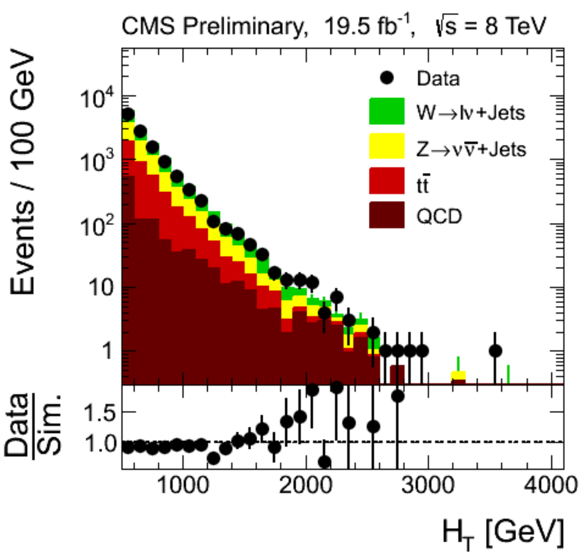


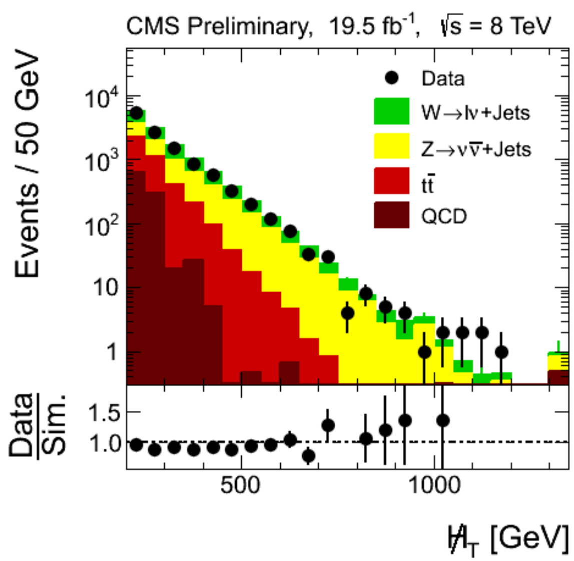
Baseline selection:

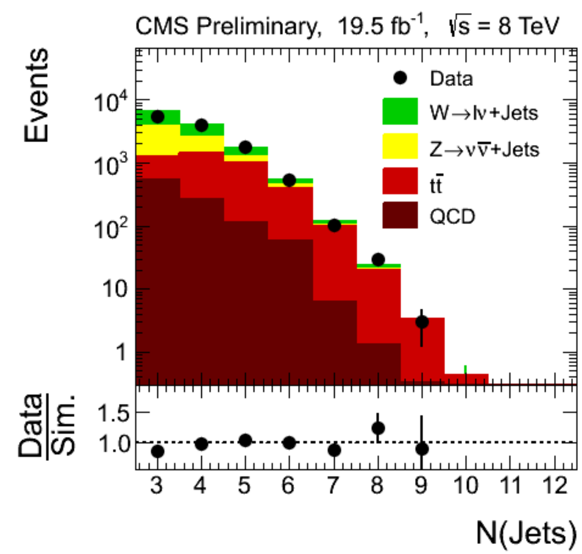
- $N_{jet} \geq 3$ ($p_T > 50$ GeV, $|\eta| < 2.5$)
- $H_T > 500$ GeV (jet $|p_T|$ sum: $p_T > 50$ GeV, $|\eta| < 2.5$)
- MHT > 200 GeV (jet p_T vector sum: $p_T > 30$ GeV, $|\eta| < 5$)
- $\Delta\Phi$(MHT, $jet_{1,2,3}$)>(0.5,0.5,0.3)
- Veto of isolated leptons (e/μ) with $p_T > 10$ GeV

Analysis performed in 36 excl. bins in (N_{jet}, H_T and MHT)

Pure data-MC comparison: reasonable agreement







Multi-Jets + MHT – Backgrounds

Estimate bgs as much as possible from data:

- $t\bar{t}, W + \text{jets}\ (e/\mu + \nu)$: e/μ not reconstructed, not isolated, or out of acceptance ("Lost Lepton")

→ From evts with one e/μ (weighted according to acceptance and detector inefficiencies)

Dominant uncertainties:

- Statistics of control sample
- Iso/reco eff. differences between data and simulation
- MC statistics for validation of method

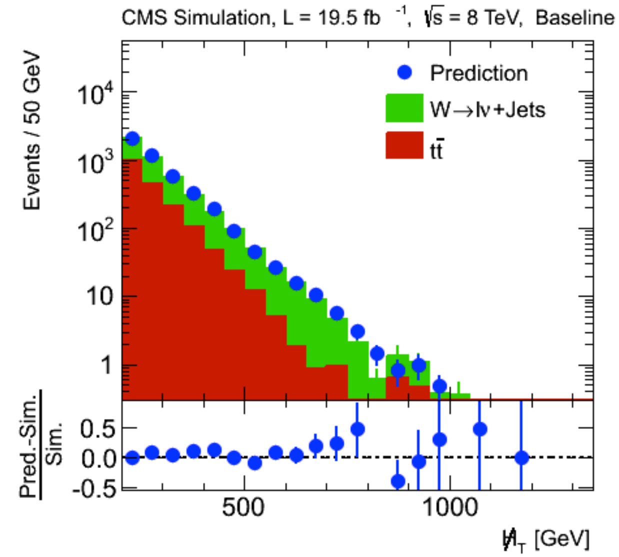
- $t\bar{t}, W + \text{jets}\ (\tau_{\text{had}} + \nu)$: Lepton is τ (faking a jet)

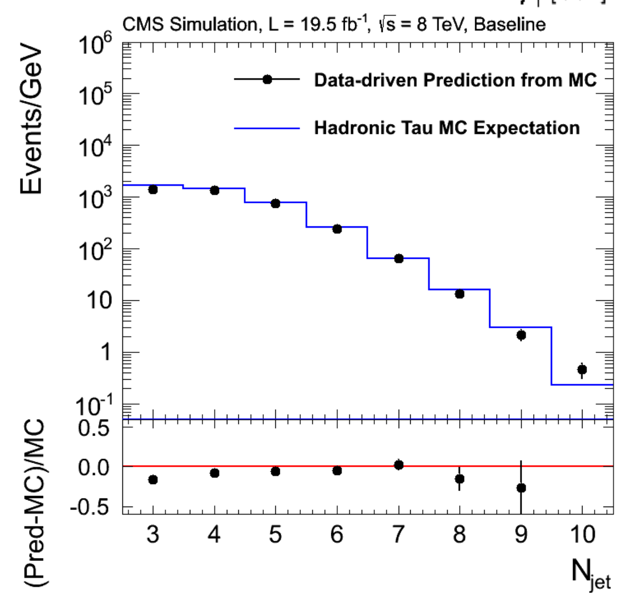
→ From evts with one e/μ; lepton is replaced by "τ-jet" with smeared p_T (according to expected response)

Dominant uncertainties:

- Similar as for Lost Lepton
- τ_{had} "jet" response

Validation on simulated evts:





SUS-13-012

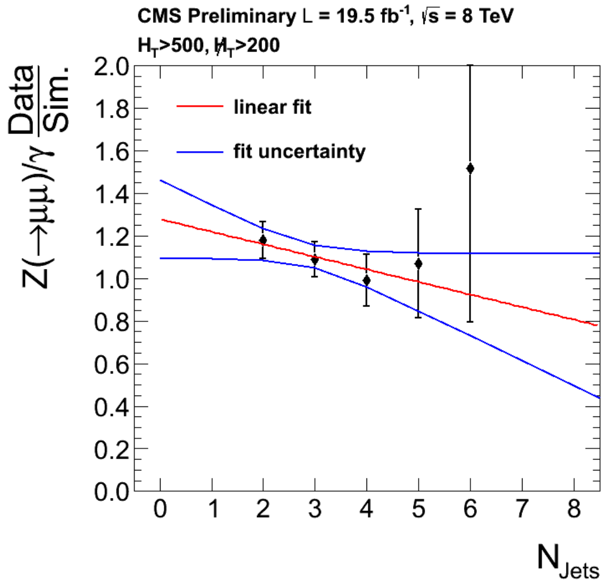
Multi-Jets + MHT – Backgrounds

Estimate bgs as much as possible from data:

- $Z(\to \nu\nu) + \text{jets}$: irreducible background

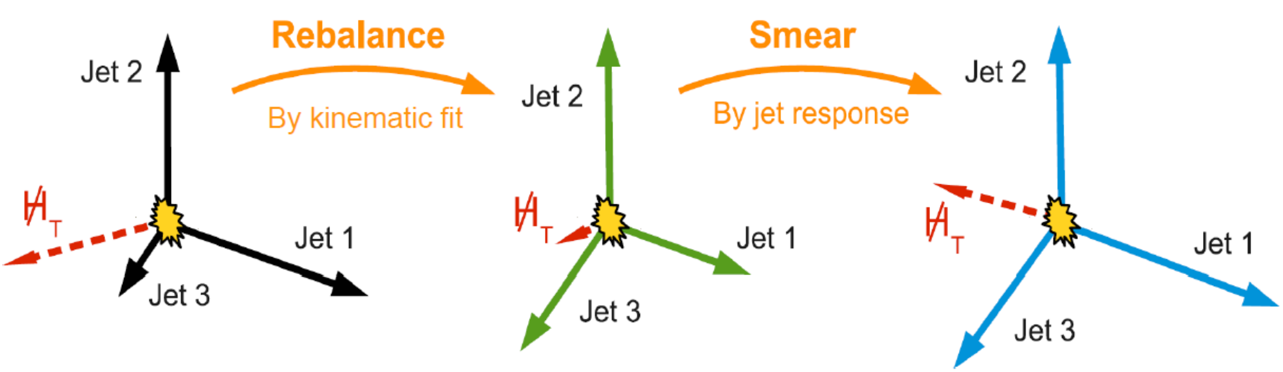
→ From γ+jets evts (similar kinematics at high boson p_T)

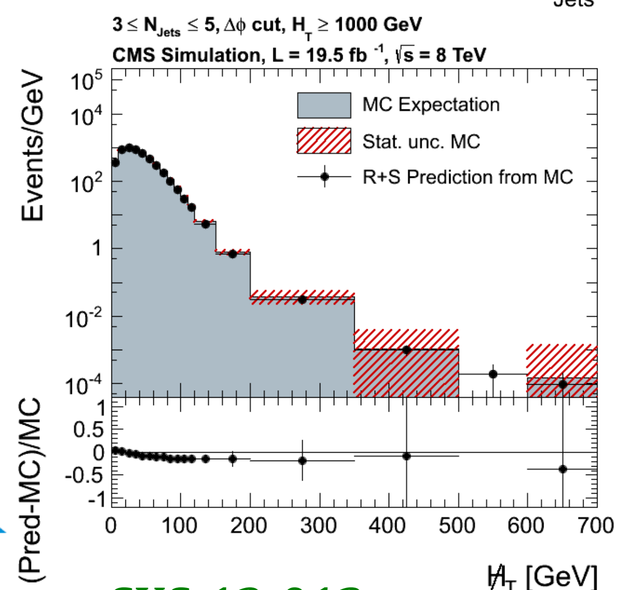
  - "Translation" factor (e.g. cross section, acceptance) from simulation
  - Estimation of theoretical uncertainty by comparing ratio from data and simulation: $\frac{(Z \to \mu^+\mu^-) + \text{jets}}{\gamma + \text{jets}}$



- QCD multi-jet: Large jet p_T mismeasurement

→ From rebalancing and smearing (R+S) of evts with measured jet response (incl. non-Gaussian tails)



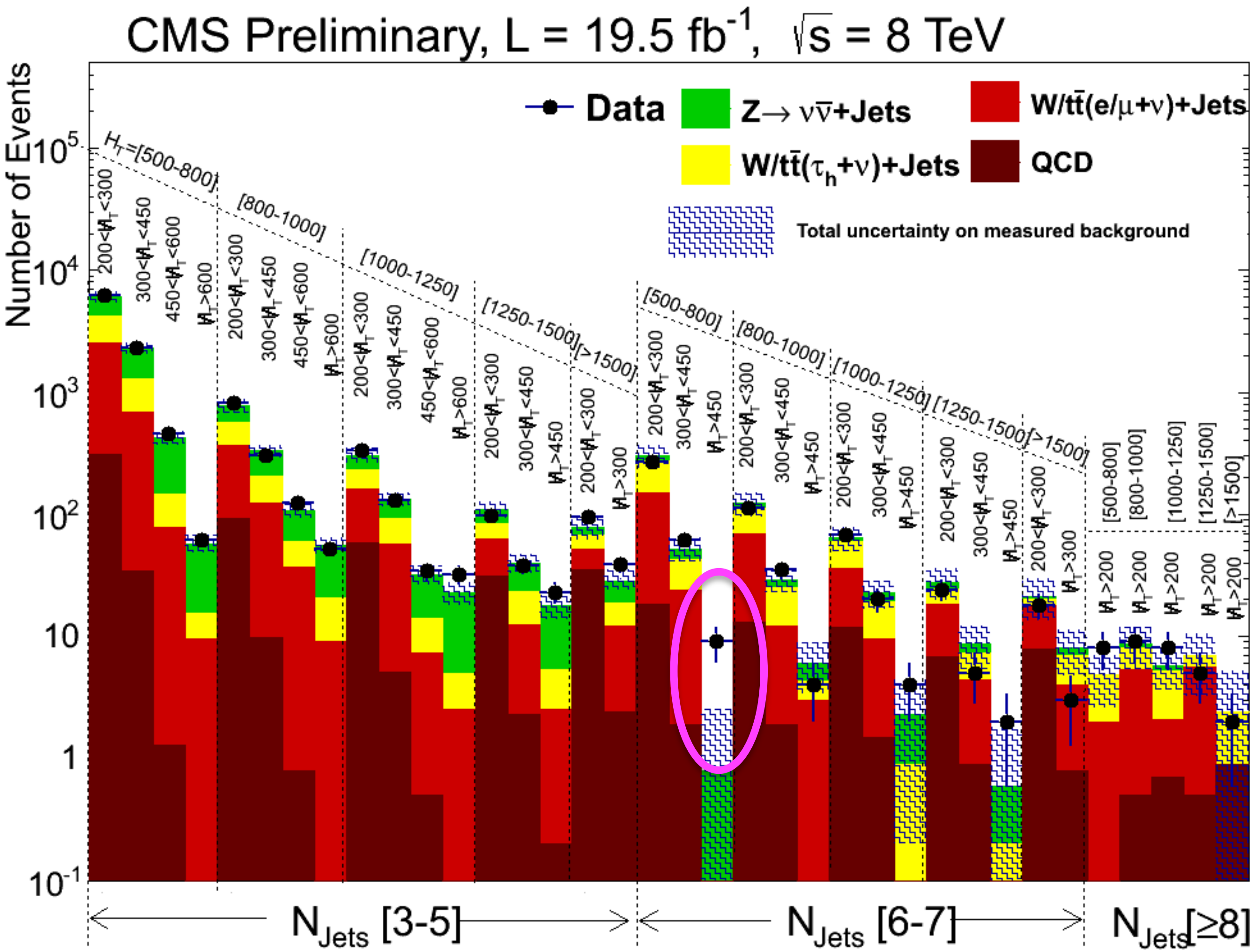


SUS-13-012

Multi-Jets + MHT – Result

SUS-13-012

No significant deviation of data from data-driven SM prediction!



One bin shows an excess! Do we have to get exited?

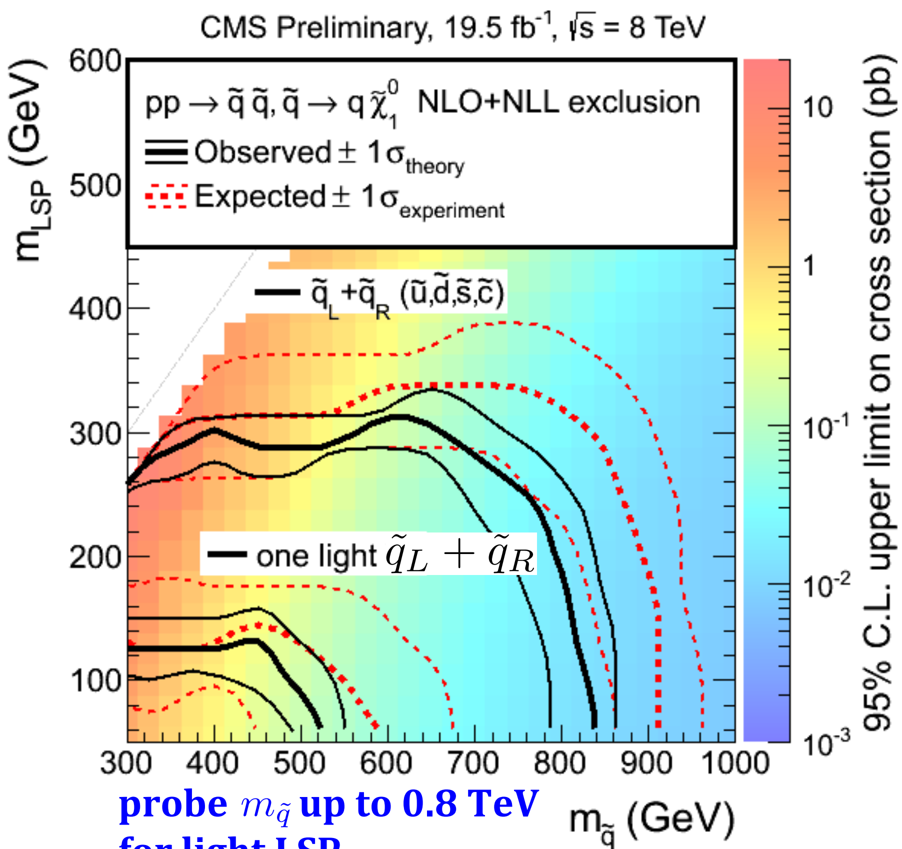
N_{bg} = 0.7”±”1.8
N_{data} = 9

p (≥9|0.7”±”1.8) ~ 0.004
→ ~2.7 σ

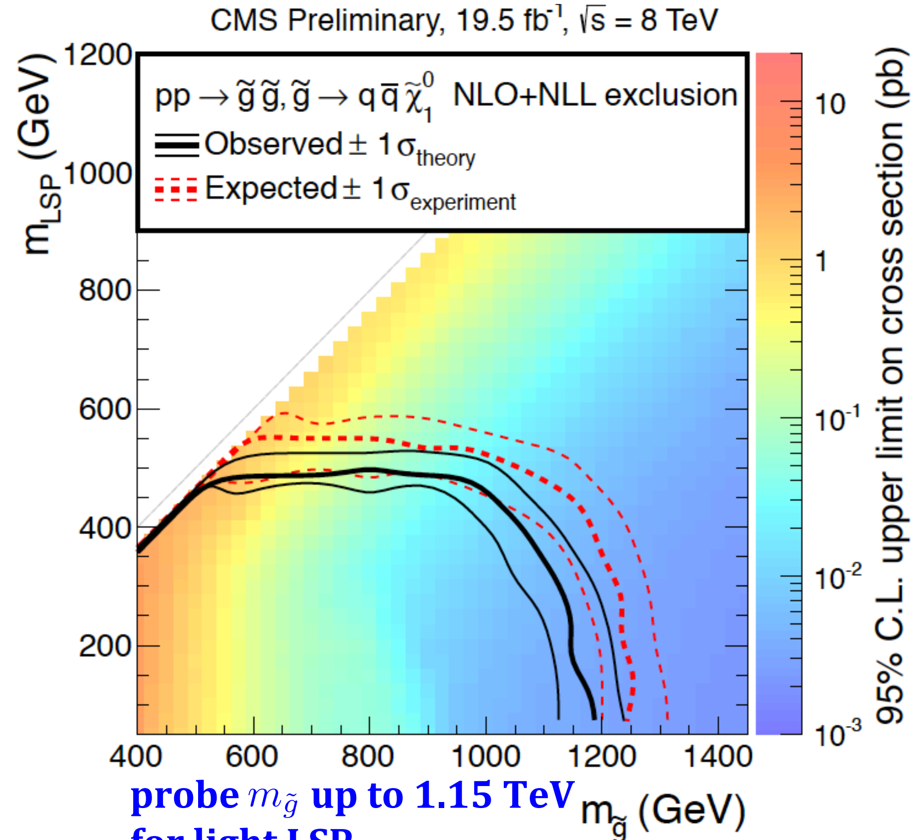
To observe such (or a larger) fluctuation in any of the 36 bins:

p ~ 0.11 → ~1.2 σ

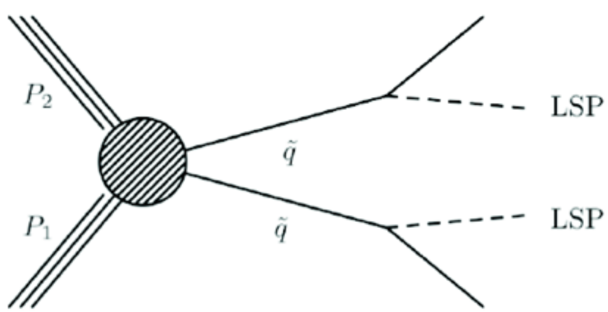
Multi-Jets + MHT – Interpretation

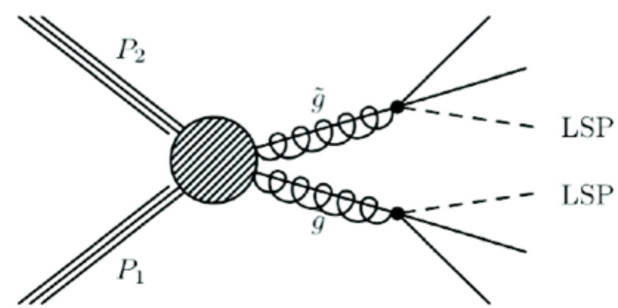


probe $m_{\tilde{q}}$ up to 0.8 TeV for light LSP



probe $m_{\tilde{g}}$ up to 1.15 TeV for light LSP





SUS-13-012

Multi-Jets + MHT – Interpretation

Constrained MSSM:

- Only 5 free parameters → strongly correlated masses
- LHC@7/8 TeV → largest part of interesting parameter space excluded

Simplified Models:

- Not really a model (Br~100%, most masses fixed at high scales)
- Important tool for interpretation

Phenomenological MSSM:

- 19 free parameters:
  - M_1, M_2, and M_3
  - tan β, μ, and m_A
  - 10 sfermion mass parameters
  - A_t, A_b, and A_τ
- *Constraints: No RPV; no new sources of CP violation; mass degeneracy of 1st and 2nd generation; no FCNC*

pMSSM captures "most" of phenomenologic features of R-parity conserving MSSM

Comprehensive and computationally realistic approximation of the MSSM with neutralino LSP

more details: SUS-12-030

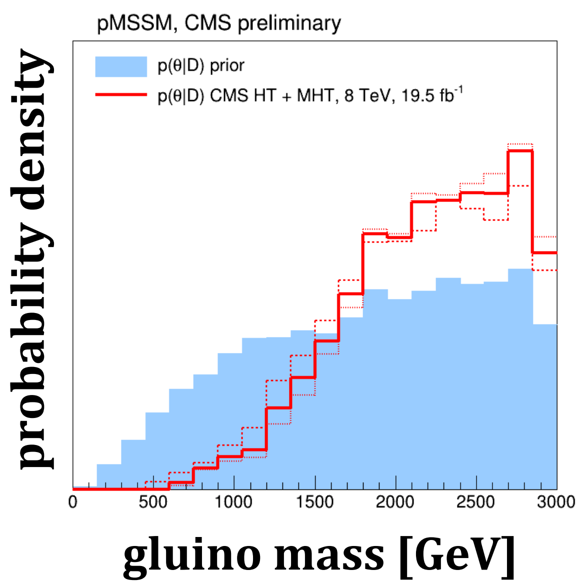
pMSSM Interpretation

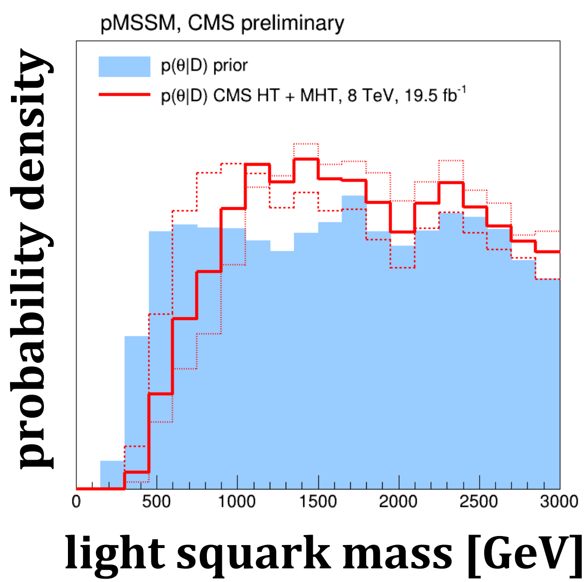
- Generate pMSSM models according to preLHC data (MCMC)
- Randomly select 7300 models and simulate 10k events each
- Construct likelihood, that observed data originates from model θ

$$L(\text{data}|\theta) = \prod_{i=1}^{N_{\text{bins}}} \int p(d_i|s_i(\theta) + b_i) p(b_i|b_i^{\text{SM}}, \Delta b_i^{\text{SM}}) db_i$$

and weight all models with it to get posterior probability

$$L(\theta|\text{data}) \propto L(\text{data}|\theta) \cdot p(\theta)$$





As expected: probability density of mass of coloured particles shifted to larger masses

But: a few light mass models remain (e. g. compressed SUSY)

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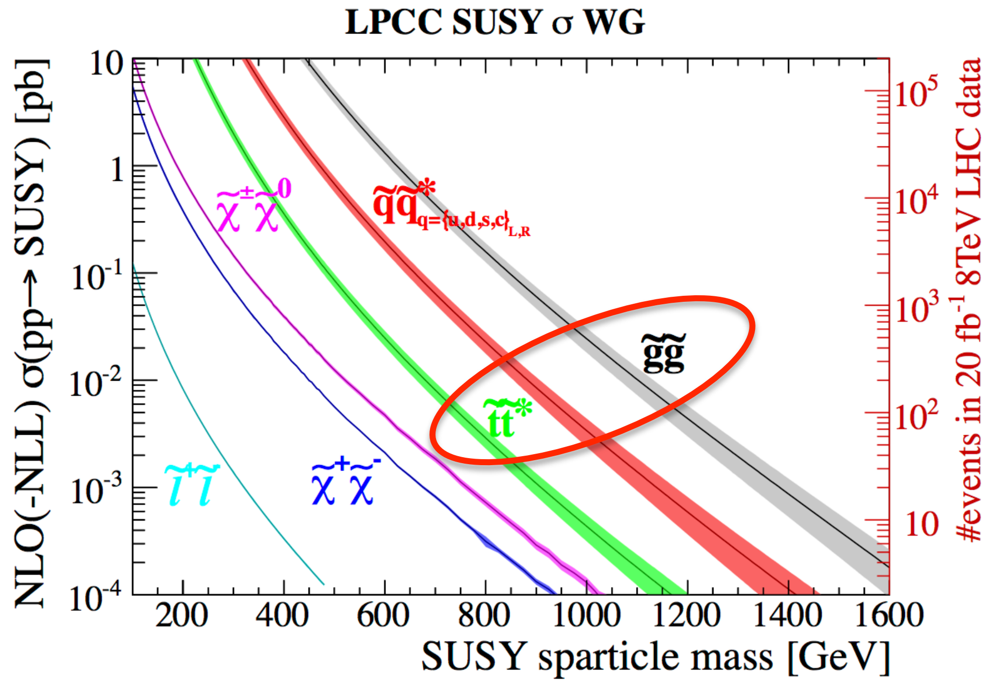
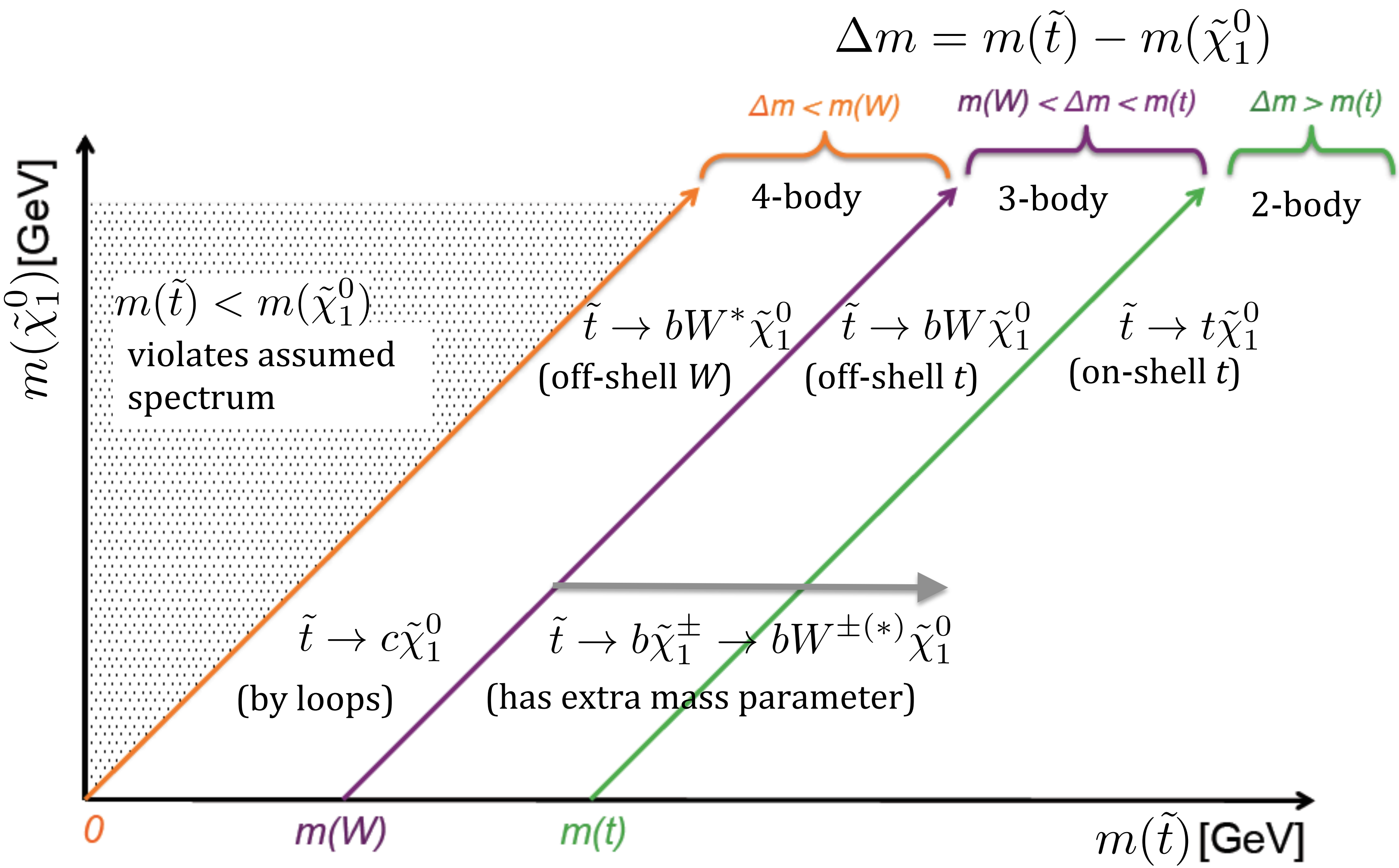


https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections arXiv:1206.2892

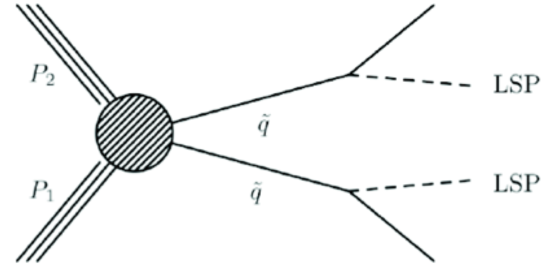
Searches for Light Stop-Quarks



C. Rogan, arXiv:1006.2727

Razor – Definition

Example: direct squark production with $\tilde{q} \rightarrow \tilde{\chi}_1^0 + q$



Define

$$M_R = \sqrt{(|\vec{p}_{q1}| + |\vec{p}_{q2}|)^2 - (p_{z,q1} + p_{z,q2})^2}$$

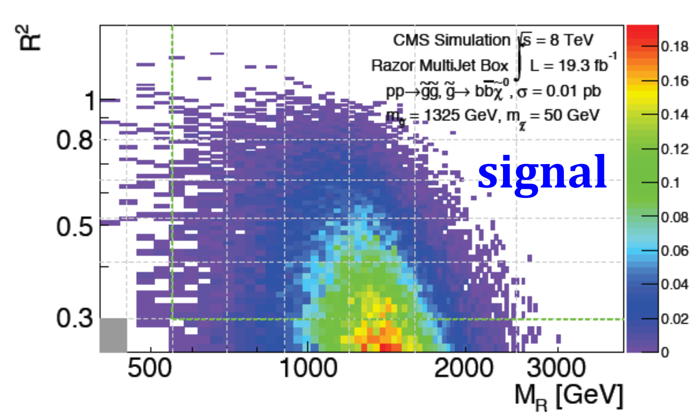
and

$$M_T^R = \sqrt{\frac{E_{\mathrm{T}}^{\mathrm{miss}}(p_{\mathrm{T}}^{q1} + p_{\mathrm{T}}^{q2}) - \vec{E}_{\mathrm{T}}^{\mathrm{miss}}(\vec{p}_{\mathrm{t}}^{\,q1} + \vec{p}_T^{\,q2})}{2}}$$

Cluster more than two jets to two "Mega-Jets"

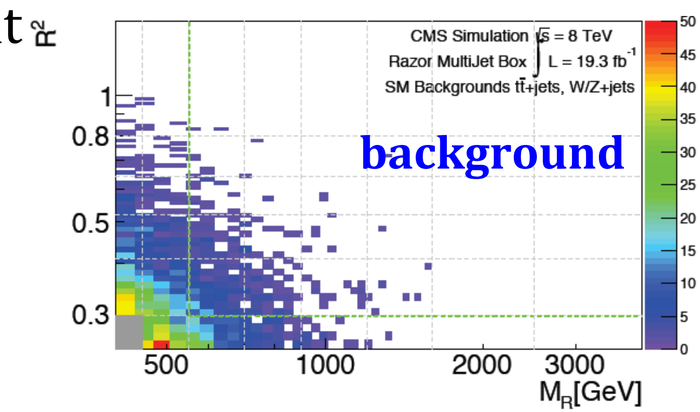
Define **the "Razor"**:

$$R = \frac{M_T^R}{M_R}$$



- For signal: M_R has peak and $M_T{}^R$ has endpoint at

$$M_\Delta = \frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}_1^0}^2}{M_{\tilde{q}}}$$



- For bg: exponentially falling at relevant scales

Razor – Boxes

SUS-13-004

Very inclusive approach: signatures with and without leptons

Assign each event unambiguously to a "box"

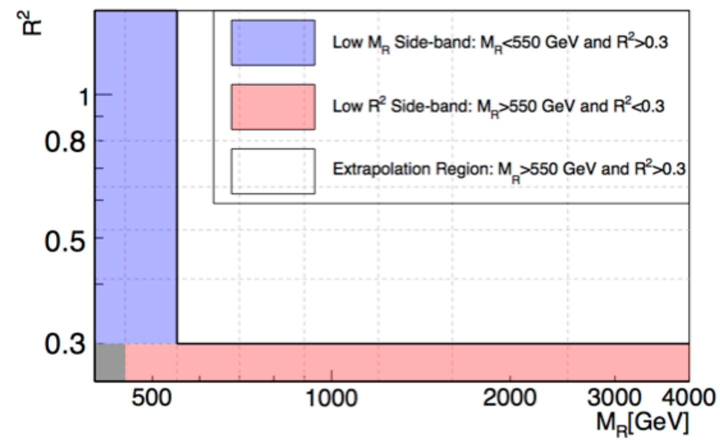
Requirements				
Box	lepton	b-tag	kinematic	jet
Dilepton Boxes				
MuEle	$\geq$ 1 tight electron and $\geq$ 1 loose muon	$\geq$ 1 b-tag	($M_R >$ 300 GeV and $R^2 >$ 0.15) and ($M_R >$ 450 GeV or $R^2 >$ 0.2)	$\geq$ 2 jets
MuMu	$\geq$ 1 tight muon and $\geq$ 1 loose muon	$\geq$ 1 b-tag	($M_R >$ 300 GeV and $R^2 >$ 0.15) and ($M_R >$ 450 GeV or $R^2 >$ 0.2)	$\geq$ 2 jets
EleEle	$\geq$ 1 tight electron and $\geq$ 1 loose electron	$\geq$ 1 b-tag	($M_R >$ 300 GeV and $R^2 >$ 0.15) and ($M_R >$ 450 GeV or $R^2 >$ 0.2)	$\geq$ 2 jets
Single Lepton Boxes				
MuMultiJet	$\geq$ 1 tight muon	$\geq$ 1 b-tag	($M_R >$ 300 GeV and $R^2 >$ 0.15) and ($M_R >$ 450 GeV or $R^2 >$ 0.2)	$\geq$ 4 jets
MuJet	$\geq$ 1 tight muon	$\geq$ 1 b-tag	($M_R >$ 300 GeV and $R^2 >$ 0.15) and ($M_R >$ 450 GeV or $R^2 >$ 0.2)	2 or 3 jets
EleMultiJet	$\geq$ 1 tight electron	$\geq$ 1 b-tag	($M_R >$ 300 GeV and $R^2 >$ 0.15) and ($M_R >$ 450 GeV or $R^2 >$ 0.2)	$\geq$ 4 jets
EleJet	$\geq$ 1 tight electron	$\geq$ 1 b-tag	($M_R >$ 300 GeV and $R^2 >$ 0.15) and ($M_R >$ 450 GeV or $R^2 >$ 0.2)	2 or 3 jets
Hadronic Boxes				
MultiJet	none	$\geq$ 1 b-tag	($M_R >$ 400 GeV and $R^2 >$ 0.25) and ($M_R >$ 550 GeV or $R^2 >$ 0.3)	$\geq$ 4 jets
2b-Jet	none	$\geq$ 2 b-tag	($M_R >$ 400 GeV and $R^2 >$ 0.25) and ($M_R >$ 550 GeV or $R^2 >$ 0.3)	2 or 3 jets

Single lepton and hadronic boxes further binned in *b*-jet multiplicity: #*b*-tags = 1,2,≥3

Razor – Extrapolation

SUS-13-004

- Extrapolate from bg dominated side bands at low M_R and R^2 to "search region"



Background model: 2D function of M_R and R^2

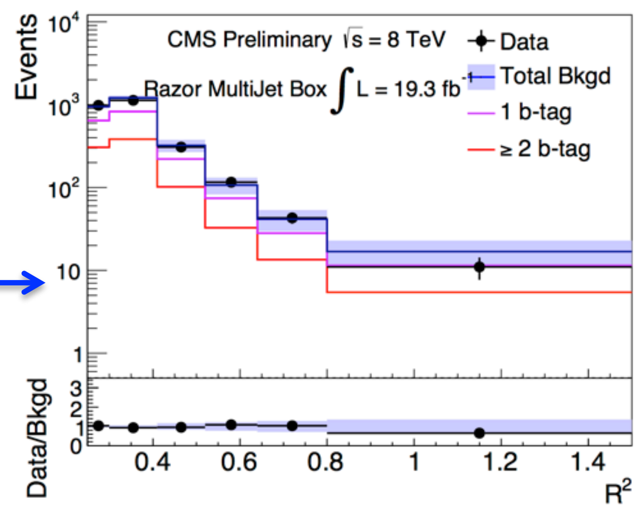
- Model is fitted in each box independently but simultaneously for each b-tag multiplicity
- Shape parameters (n, $M_R{}^0$ and $R^2{}_0$) to describe potential differences between shape in data and simulation

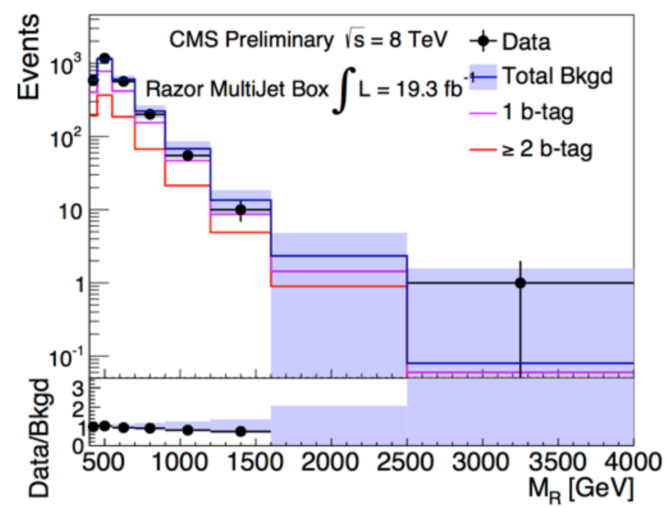
$$f_{SM}(M_R, R^2) = [b(M_R - M_R^0)^{1/n}(R^2 - R_0^2)^{1/n} - 1]e^{-bn(M_R - M_R^0)^{1/n}(R^2 - R_0^2)^{1/n}}$$

Analysis uses unbinned likelihood

Projection of 2D plane on M_R and R^2 axis →

No deviation in in any box!



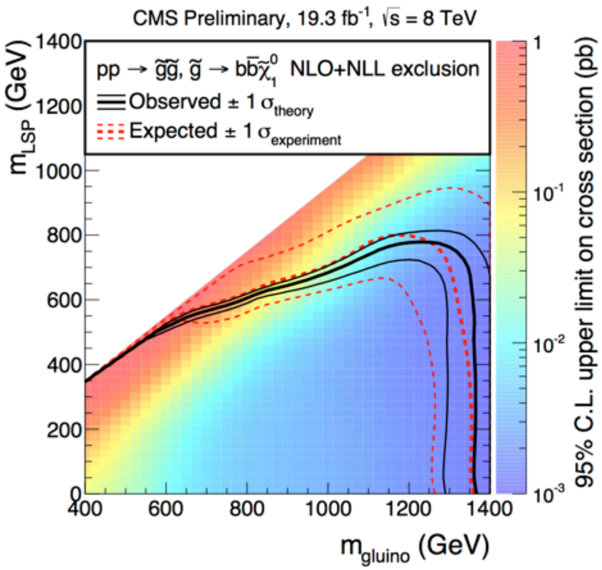


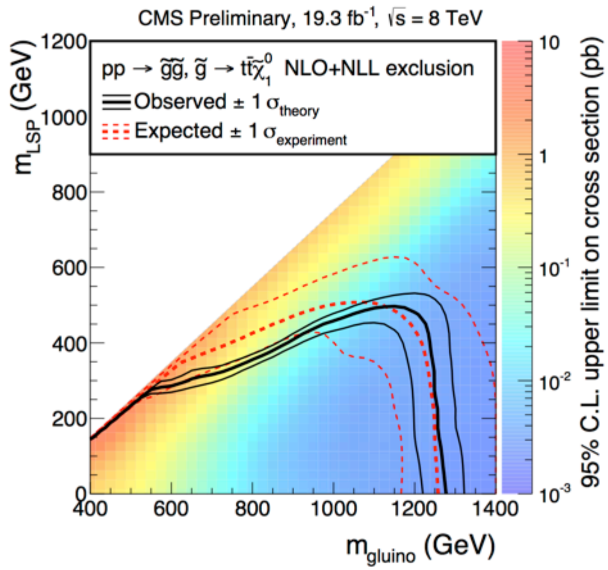
Razor – Interpretation

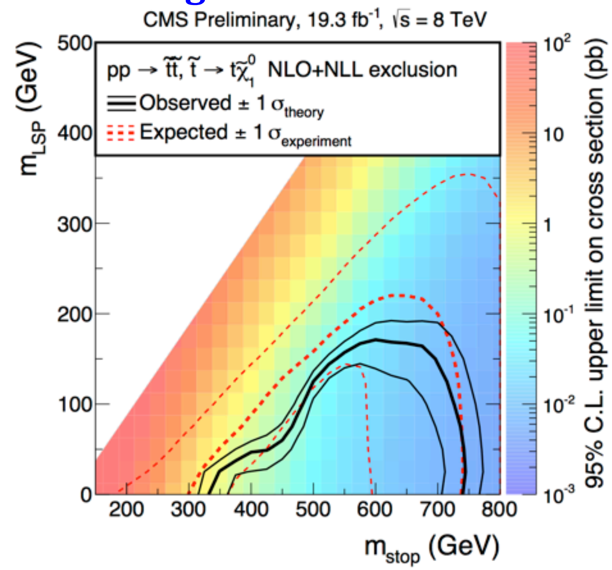
SUS-13-004

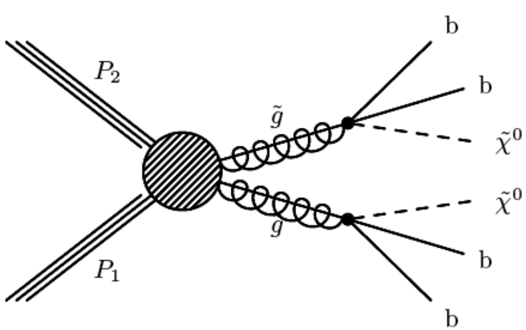
- Sensitive limits in various Simplified Models of scenarios which involve third generation squarks

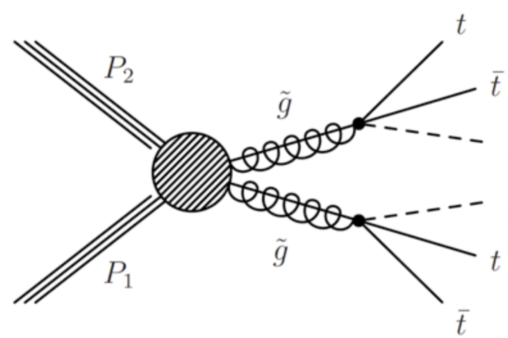
probe $m_{\tilde{t}}$ up to 0.7 TeV for light LSP

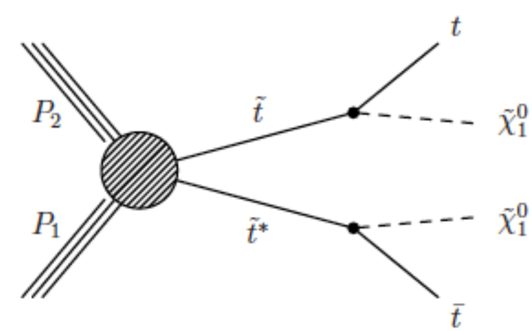






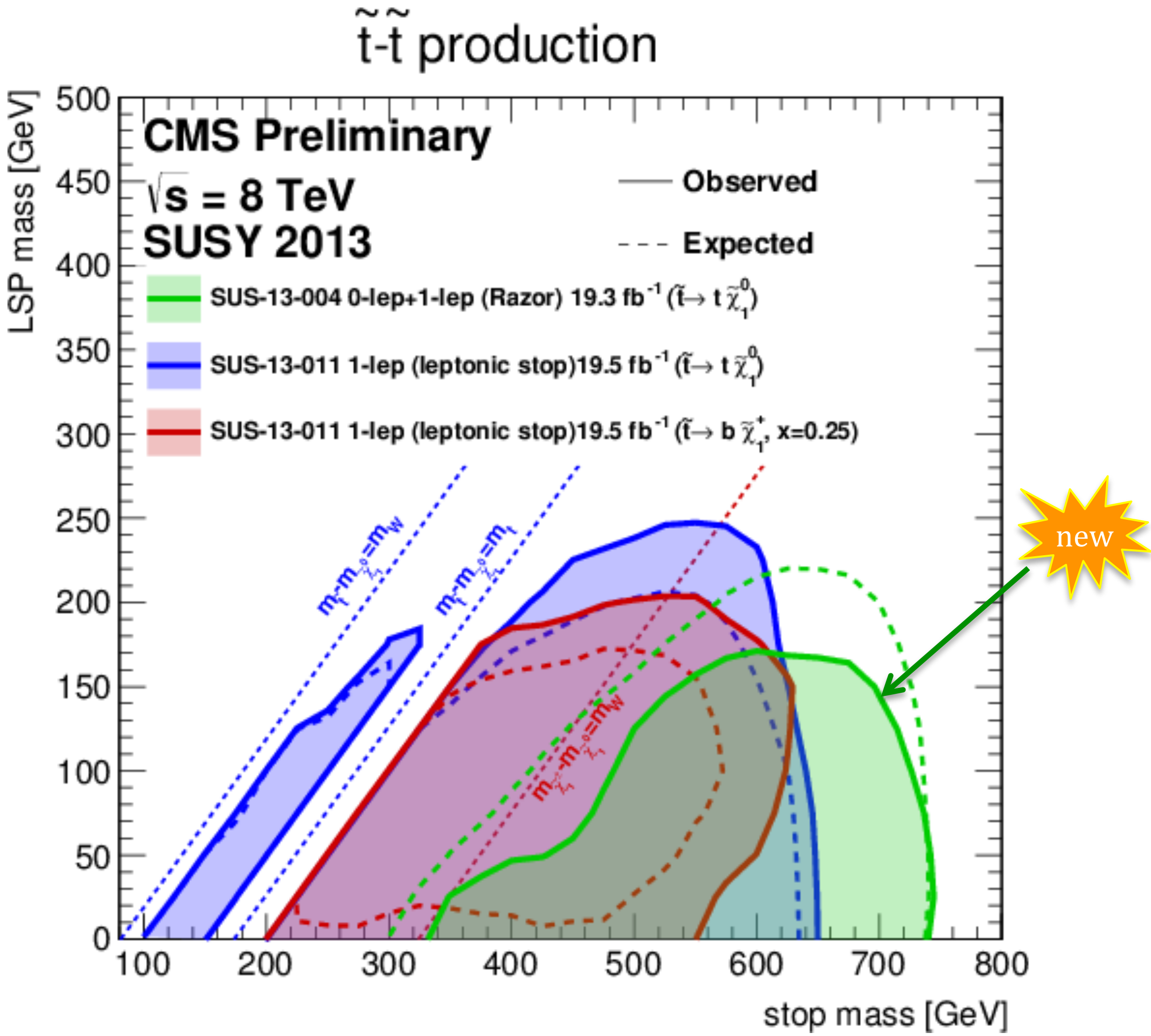




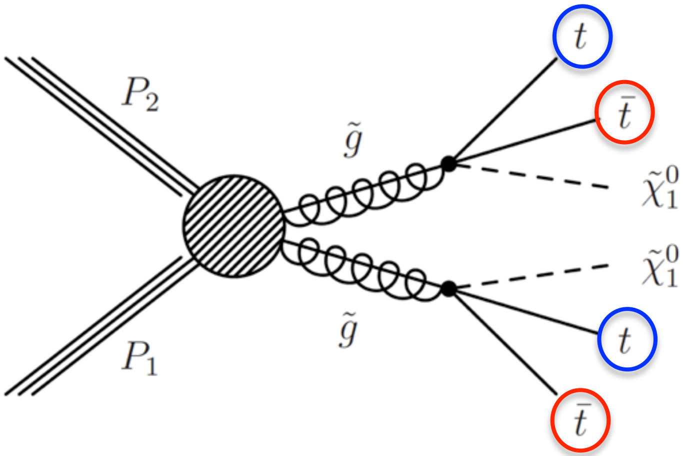


Searches for Light $\tilde{t}$ – Summary

Summary on CMS results on direct Stop searches:



Same Sign Di-Leptons



Very clear SUSY signature

Small SM backgrounds: rare SM ($t\bar{t}+V,\ VV$), "fakes"/non-prompt, or charge mis-ID

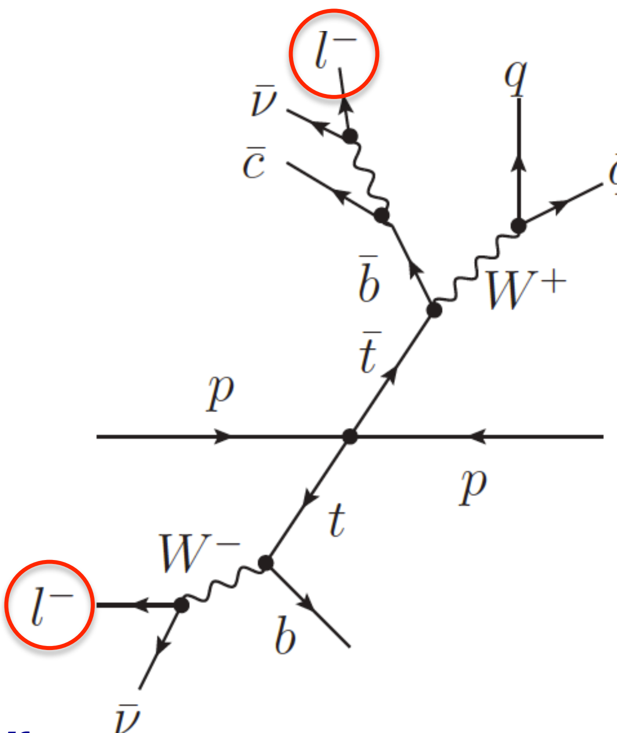
Selection:

- 2 SS leptons (e/μ) with p_T>10/20 GeV (low/high p_T)
- N_{jets} > 2 (p_T > 40 GeV, $|\eta|$ < 2.4)
- HT>200/250 GeV (high/low p_T)
- MET>50 GeV (and >0 for RPV searches)

→ 54 bins in HT, MET, #b-tags, and N_{jets}

Backgrounds:

- Rare SM bgs from simulation corrected for data/MC differences
- Non-prompt from data: events with loosely isolated lepton are weighted by tight/loose ratio
- Charge mis-ID from data: e^+e^- events weighted with charge mis-ID probability from simulation

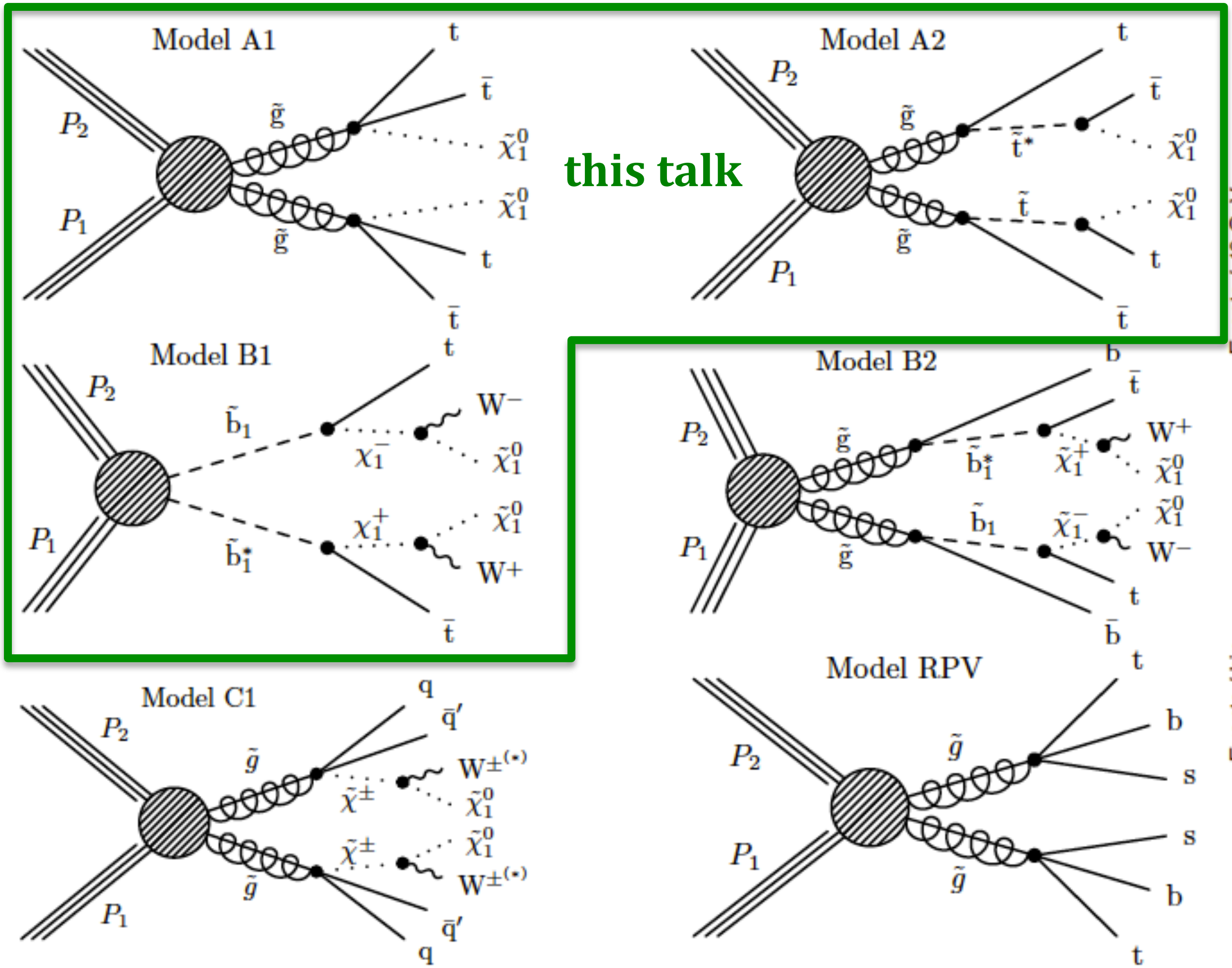


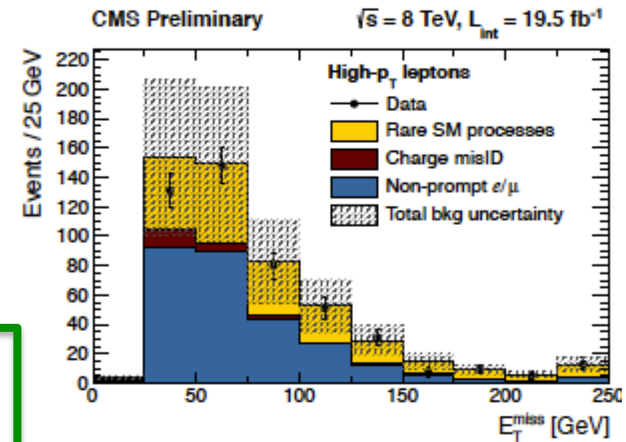
SS Di-Leptons

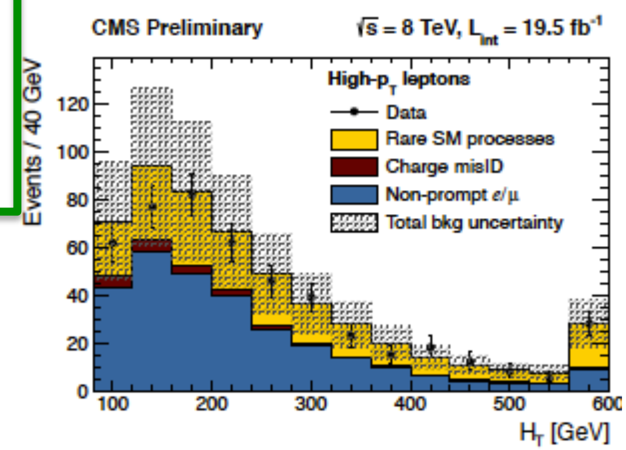
SUS-13-013

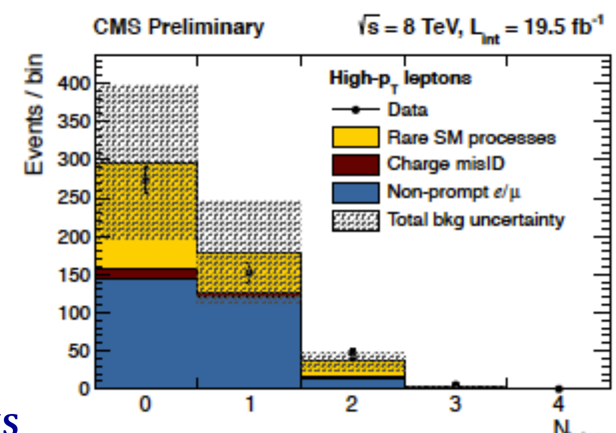
SM expectation in good agreement with data!

Limits in various models:

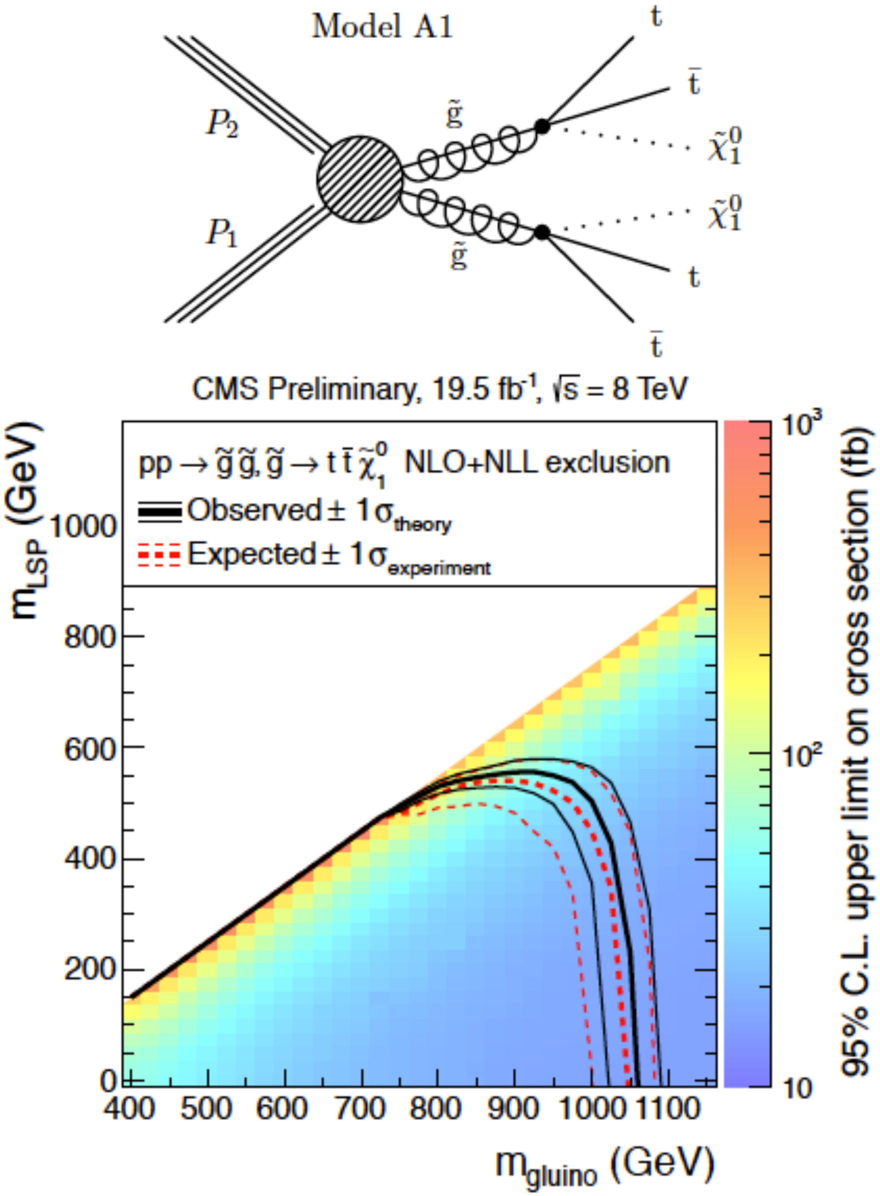


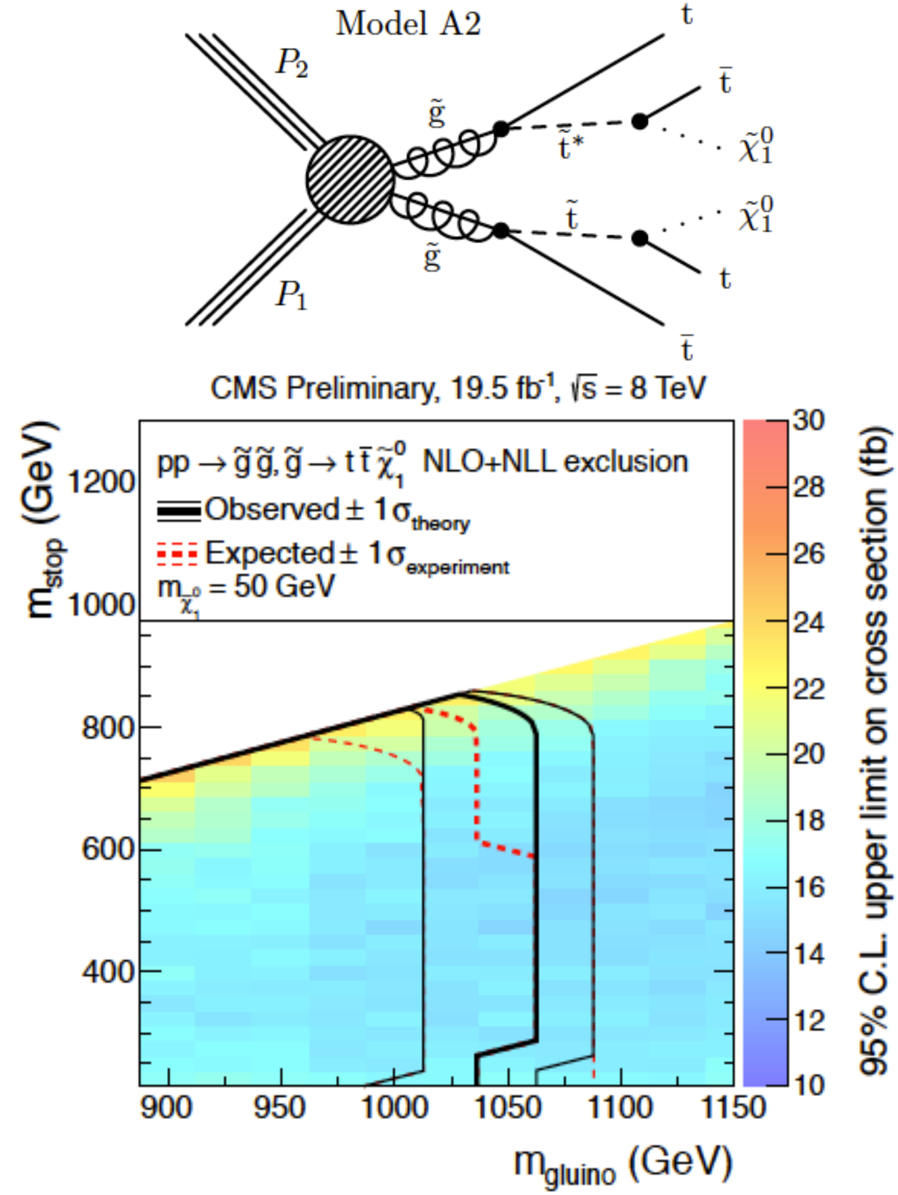




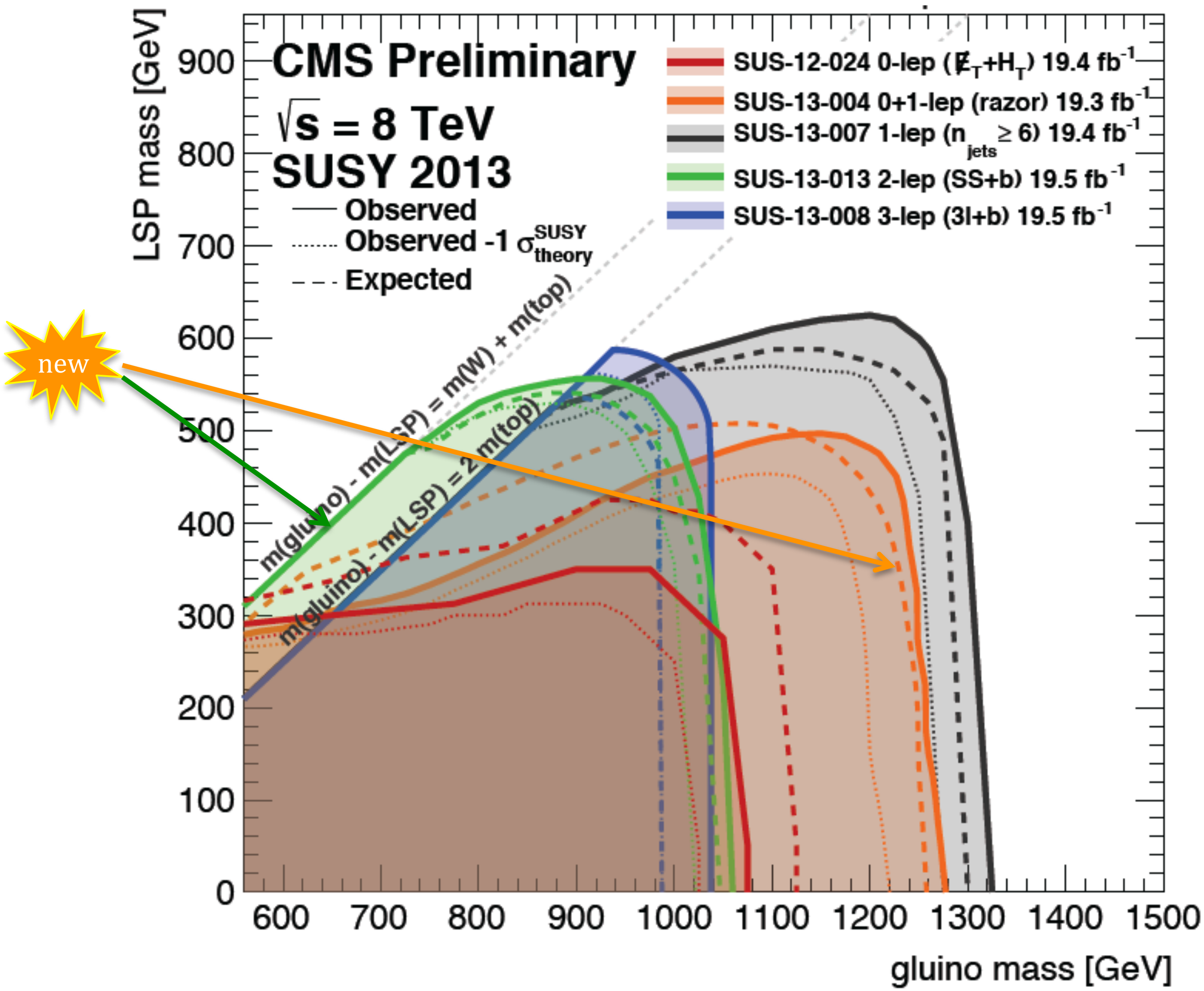


SS Di-Leptons – Interpretation





Summary for $\tilde{g}\tilde{g} \to t\bar{t}t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0$



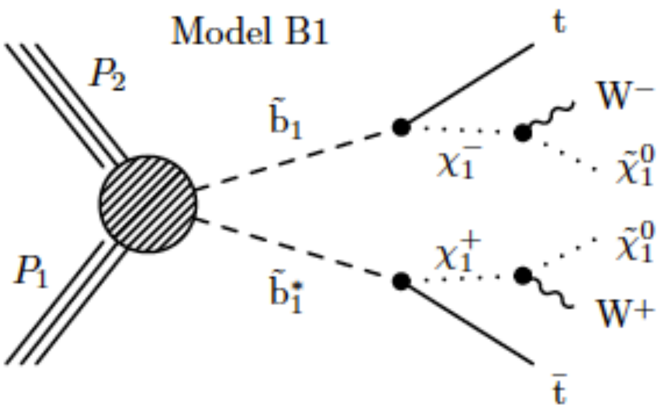
SS Di-Lepton - Interpretation

SUS-13-013

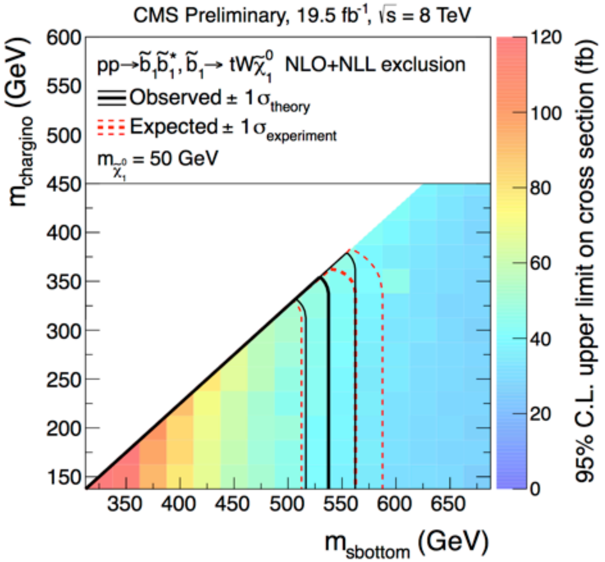
Example: $\tilde{b}_1 \rightarrow t\tilde{\chi}_1^{\pm} \rightarrow tW^{\pm}\tilde{\chi}_1^0$

Three masses involved: $m(\tilde{b}_1)$, $m(\tilde{\chi}_1^{\pm})$, $m(\tilde{\chi}_1^0)$

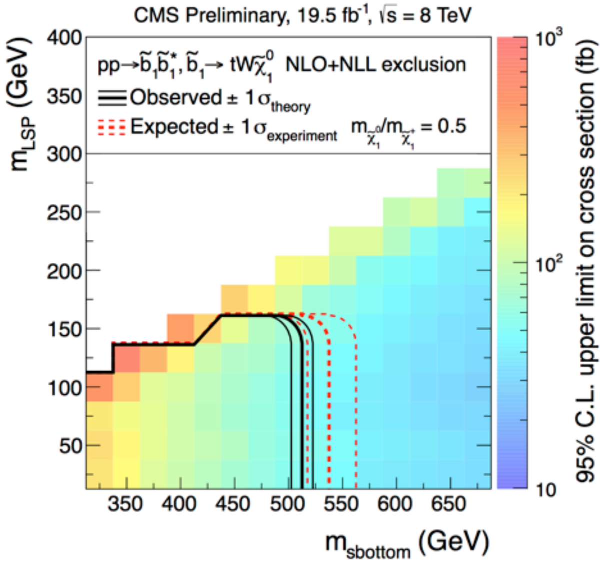
Exclusion limits depend on details of mass spectrum:



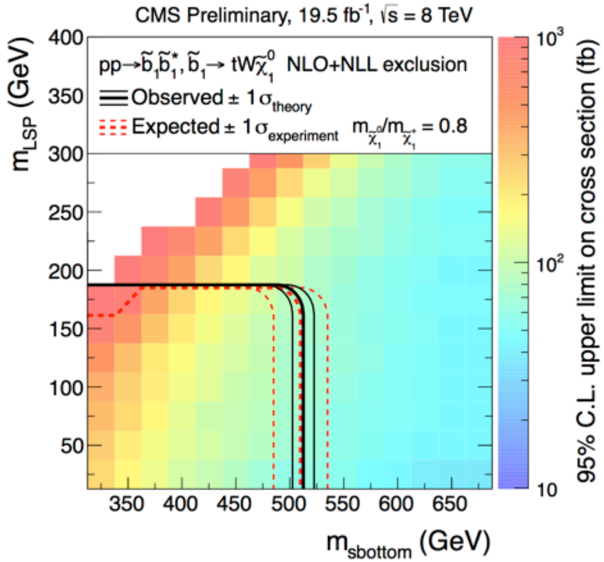
$m(\tilde{b}_1)$ vs. $m(\tilde{\chi}_1^{\pm})$
$m(\tilde{\chi}_1^0) = 50\,\mathrm{GeV}$



$m(\tilde{b}_1)$ vs. $m(\tilde{\chi}_1^0)$
$m(\tilde{\chi}_1^0)/m(\tilde{\chi}_1^{\pm}) = 0.5$



$m(\tilde{b}_1)$ vs. $m(\tilde{\chi}_1^0)$
$m(\tilde{\chi}_1^0)/m(\tilde{\chi}_1^{\pm}) = 0.8$



$\tilde{t}$ and $\tilde{\chi}_1^0$ Search with $H \to \gamma\gamma$

If SUSY is broken by Gauge Mediation

→ Gravitino is LSP

Decay chain depends on nature of NLSP:

- Large higgsino component: $\tilde{\chi}_1^0 \to H\tilde{G}$

Previous CMS searches:

Final states with jets + MET + 1 or more photon

→ Now targeting also natural SUSY (light stops)

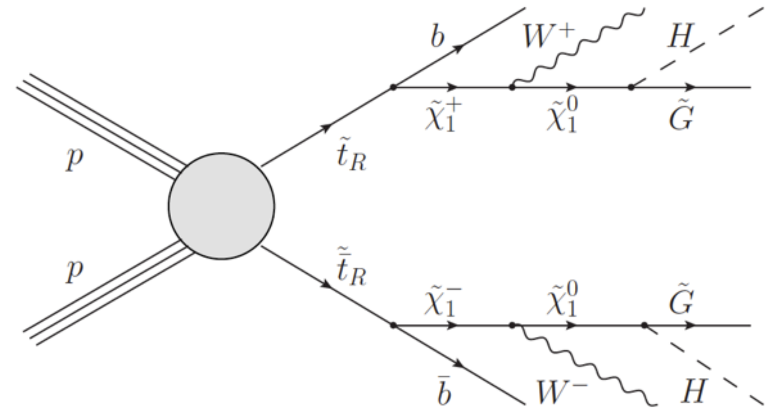
Signature:

- ≥2 photons (p_T > 40, 25 GeV)
- ≥2 b-tags (p_T > 30 GeV)

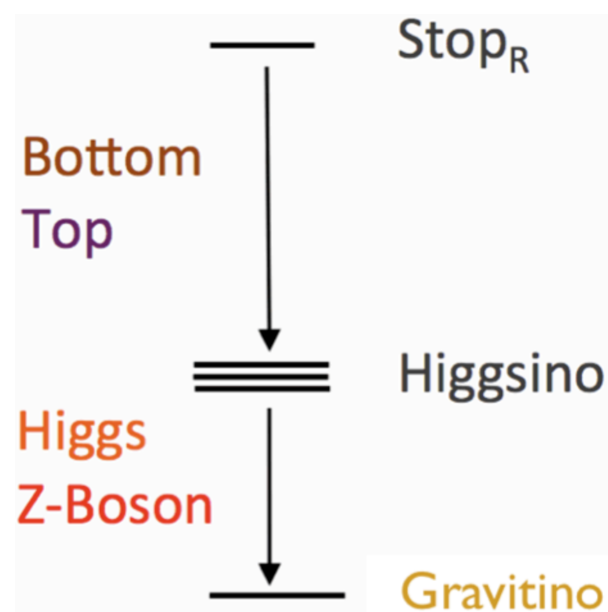
Backgrounds:

- QCD: $\gamma\gamma b\bar{b}$ + $\gamma b\bar{b} + \text{jet}$ (with γ-fakes from jets)
- Small bg from electrons (faking a photon)

SUS-13-014



One Higgs decays to photons, the other to b-quarks



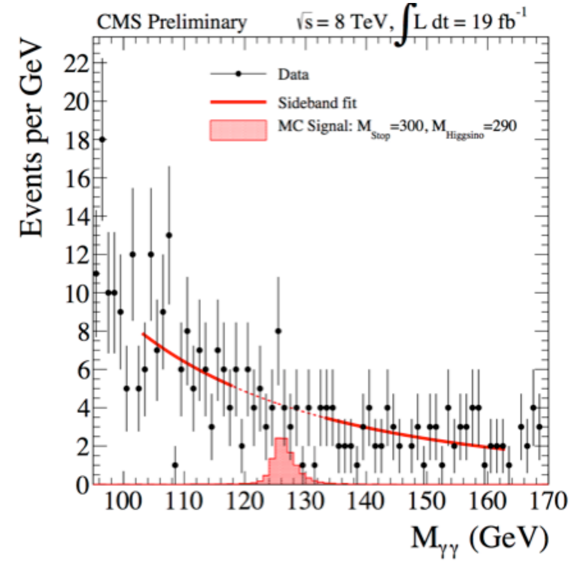
$\tilde{t}$ to $\tilde{G}$ Search with $H \to \gamma\gamma$

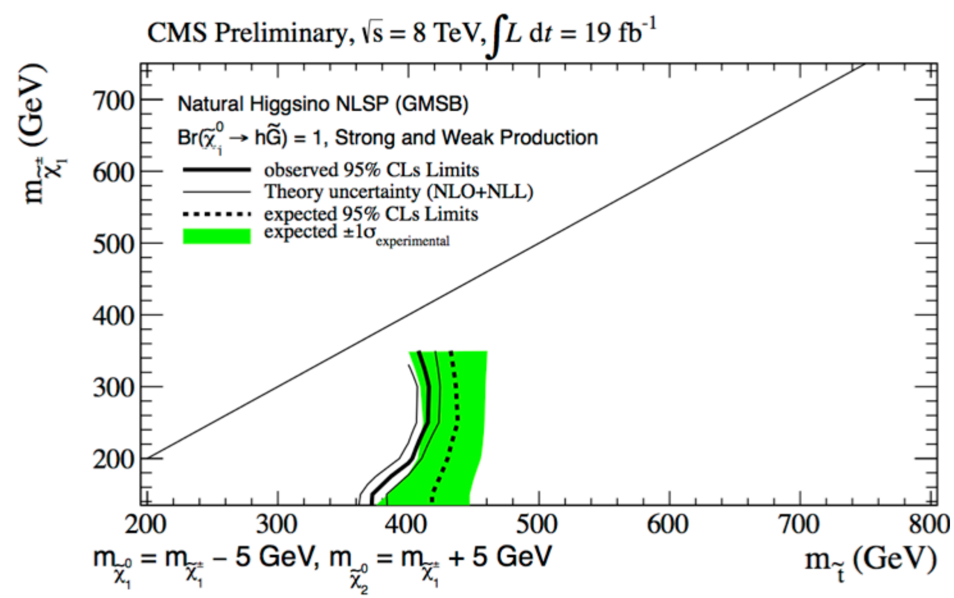
Background estimation: fit to $m_{\gamma\gamma}$ in side bands and interpolate to search region (118-133 GeV)

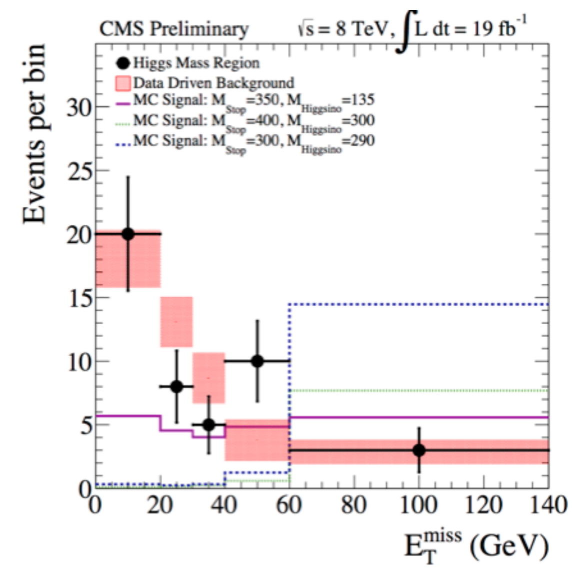
Take MET shape from sidebands (syst. uncertainty: 50% from difference of upper and lower side band)

Do prediction in three categories ($m_{b\bar{b}}$ compatible / not compatible with Higgs mass, $N_{\text{b-tags}} \geq 3$)

Limits on stop mass: 360-410 GeV (depending on NLSP mass)







SUS-13-014

SUS-13-002

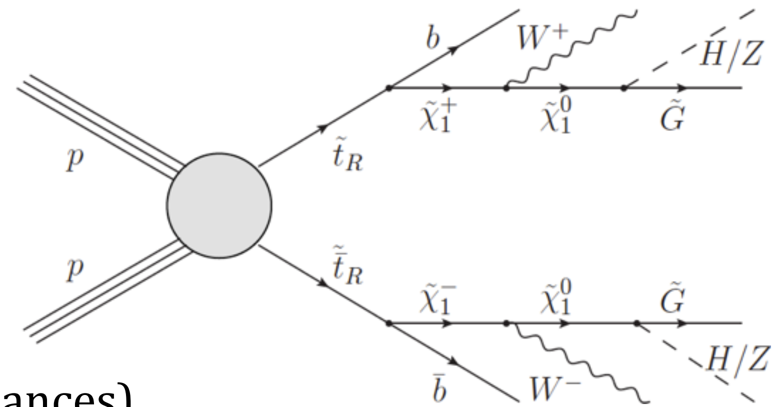
Anomalous Multi-Leptons

Generic search for multi-leptons and interpretation in various models

Selection:

- 3 or 4 leptons (leading e/μ p_T > 20 GeV, further e/μ p_T > 10 GeV)
- Possibly one τ_{had} among leptons with p_T > 20 GeV
- 0 or ≥1 b-tag
- HT < 200 GeV or > 200 GeV
- 0, 1 or 2 OSSF pairs
- If OSSF: $m_{\ell\ell}$ below-/on-/above Z-mass
- Reject events with $m_{l^+l^-} < 12$ GeV (low m resonances)
- Reject events with both $|m_{l^+l^-} - m_Z| > 15$ GeV and $|m_{l^+l^-l'} - m_Z| < 15$ GeV (photon conversion from FSR)

→ **MET distributions for 64 categories**



Also sensitive to stop to gravitino decays in GMSB models

Backgrounds:

- Rare SM; non-prompt leptons; fake taus → Estimated from data
- Small bg from asymmetric internal photon conversion → Estimated from data

$\tilde{t}$ to $\tilde{G}$ Search with H

SUS-13-002

Natural SUSY model in GMSB-models:

Light stops + light Higgsino + Gravitino LSP

Higgsino decay is $\tilde{\chi}_1^0 \rightarrow Z + \tilde{G}$ or $\tilde{\chi}_1^0 \rightarrow H + \tilde{G}$

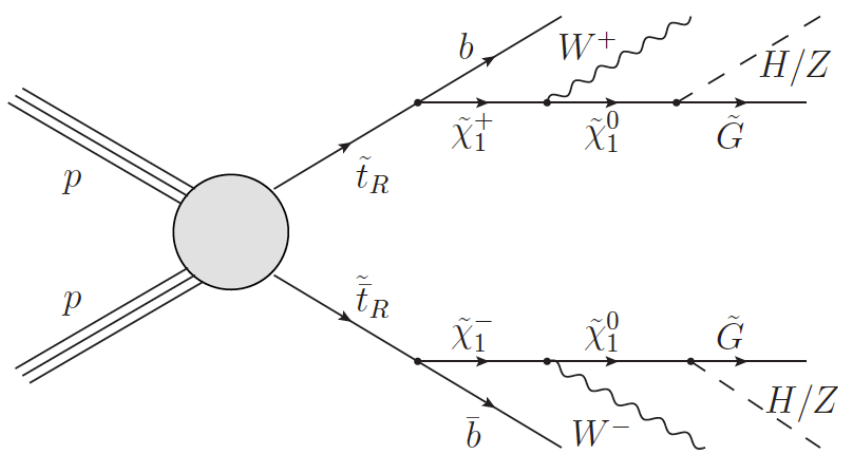
Consider Higgs decay modes:

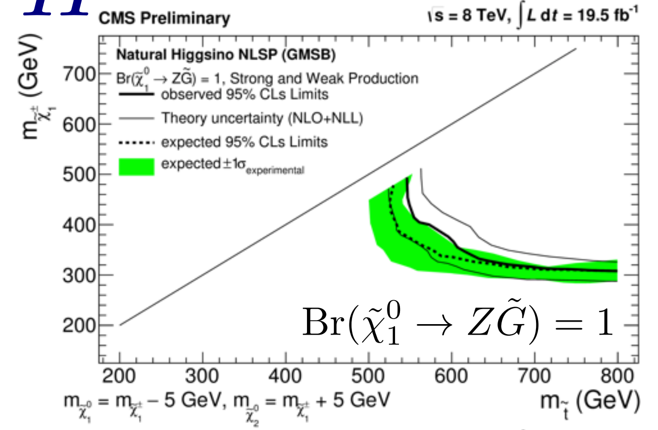
$$HH \rightarrow \tau^+\tau^-\tau^+\tau^-, WW^*WW^*, ZZ^*, ZZ^*$$

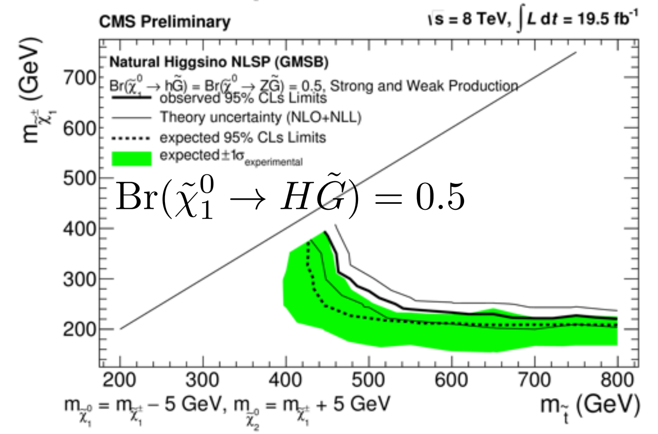
$$HH \rightarrow WW^*ZZ^*, WW^*\tau^+\tau^-, ZZ^*\tau^+\tau^-, ZZ^*b\bar{b}$$

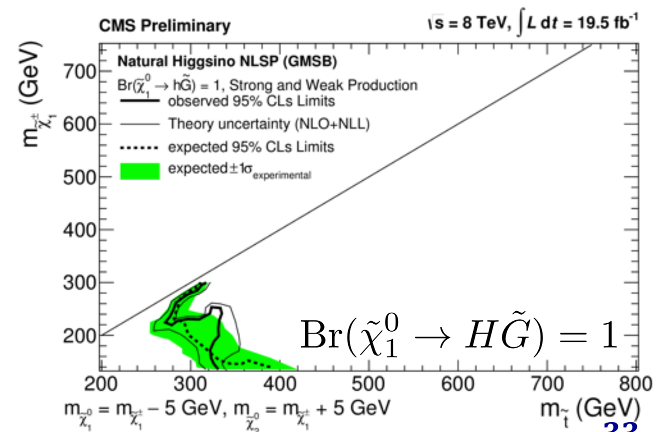
→ Possibly large lepton multiplicity

Limits depend on Higgsino branching ratios!





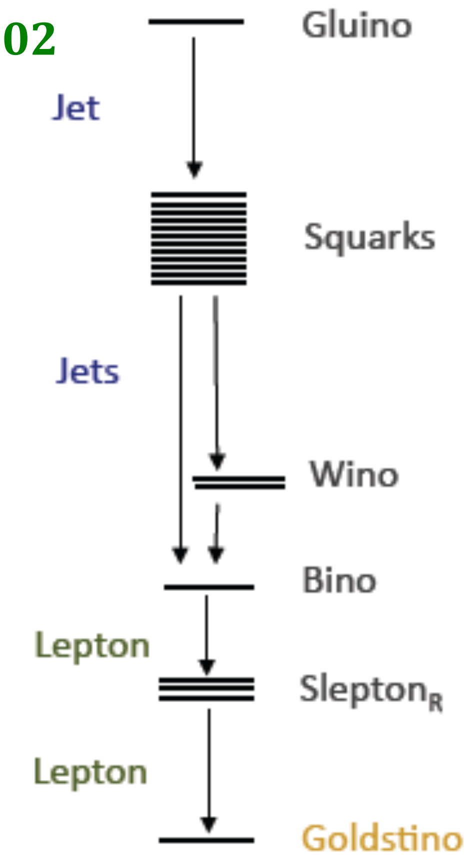


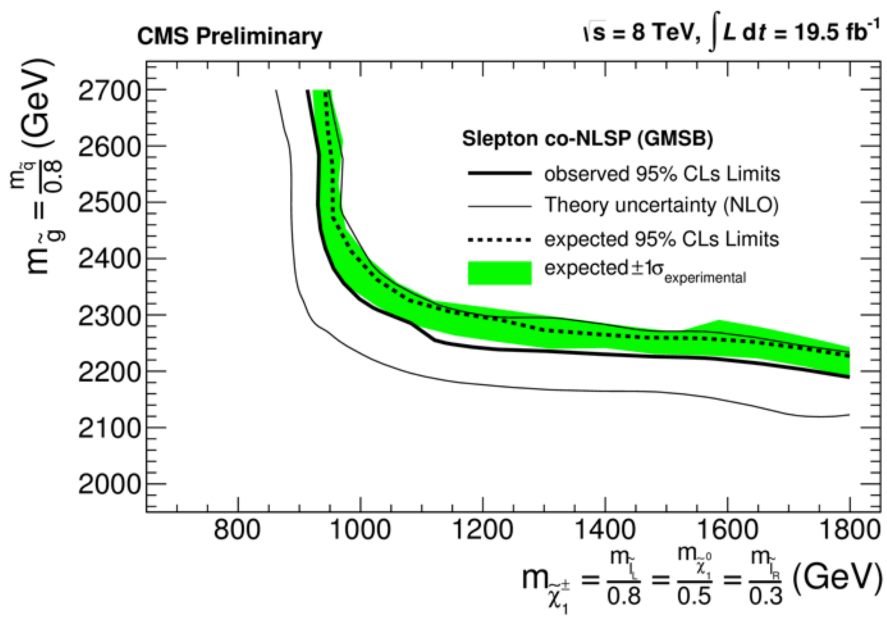


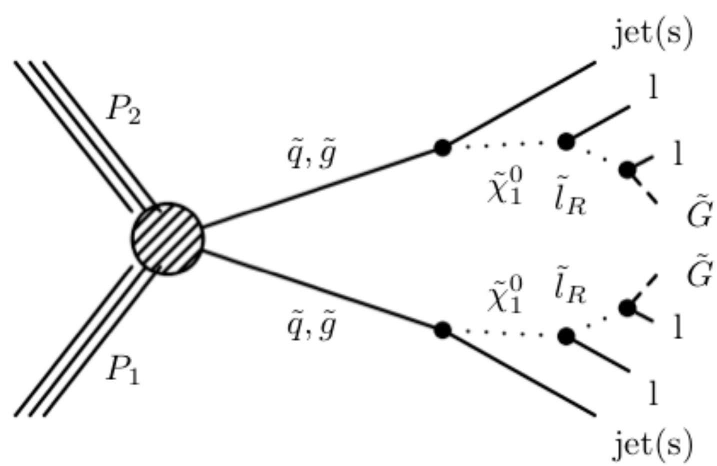
Slepton co-NLSP

SUS-13-002

- (Strong) production of light sleptons in GMSB models
- GMSB: Gravitino (Goldstino) is LSP
- $\tilde{l}_R$ are flavour degenerate at low masses (NLSP)
- → Large lepton multiplicities in final state
- Interpretation in $m_{\tilde{\chi}_1^\pm} - m_{\tilde{g}}$ plane (other masses fixed) → composition of production processes strongly dependent on details of mass spectrum

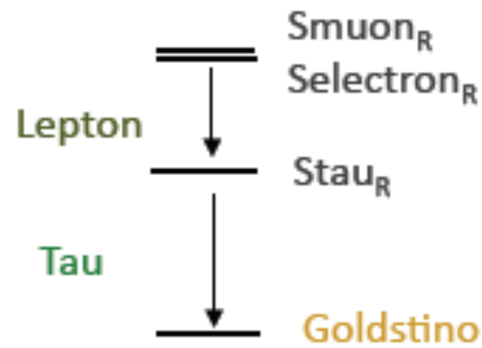


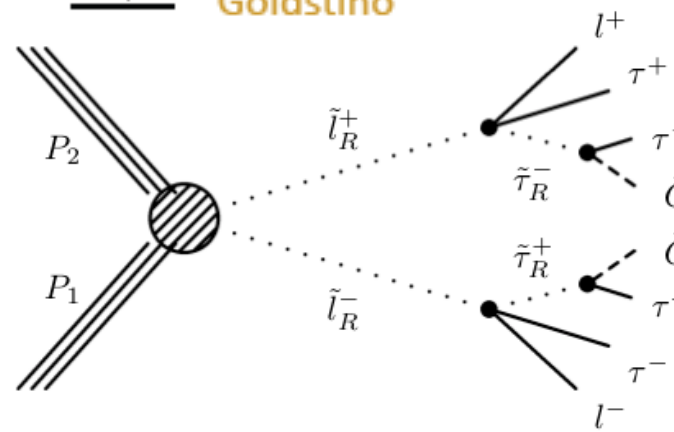




Stau (N)NLSP

SUS-13-002



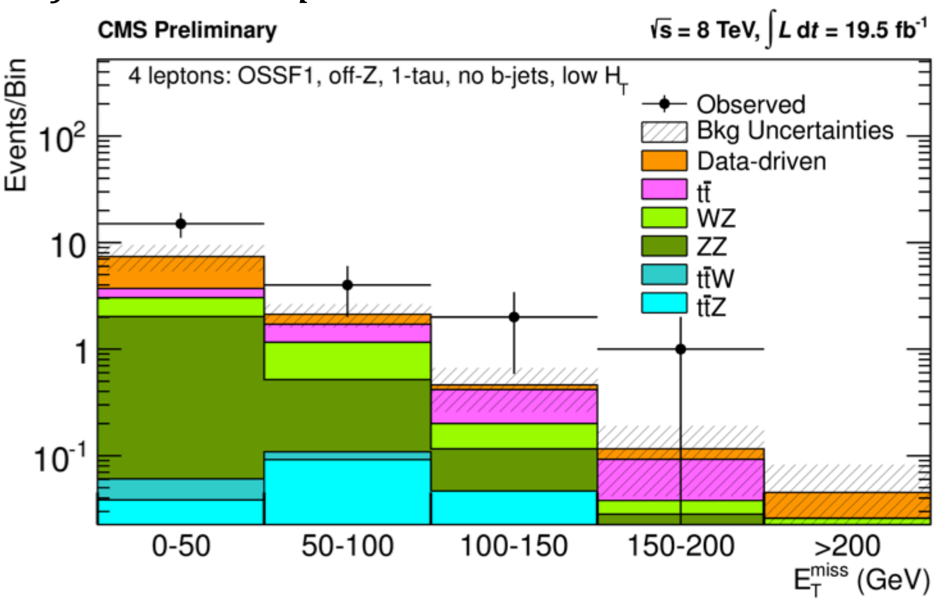


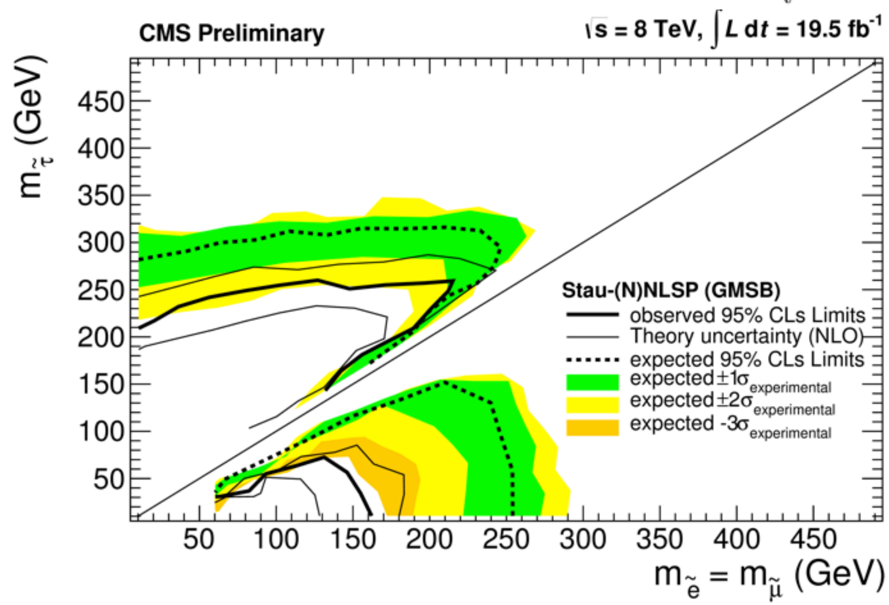
4ℓ ($1\ \tau_{\mathrm{had}}$), 1 OSSF (off-Z), no *b*, low HT has high sensitivity for such models

Slight excess → lower limits

Probability that

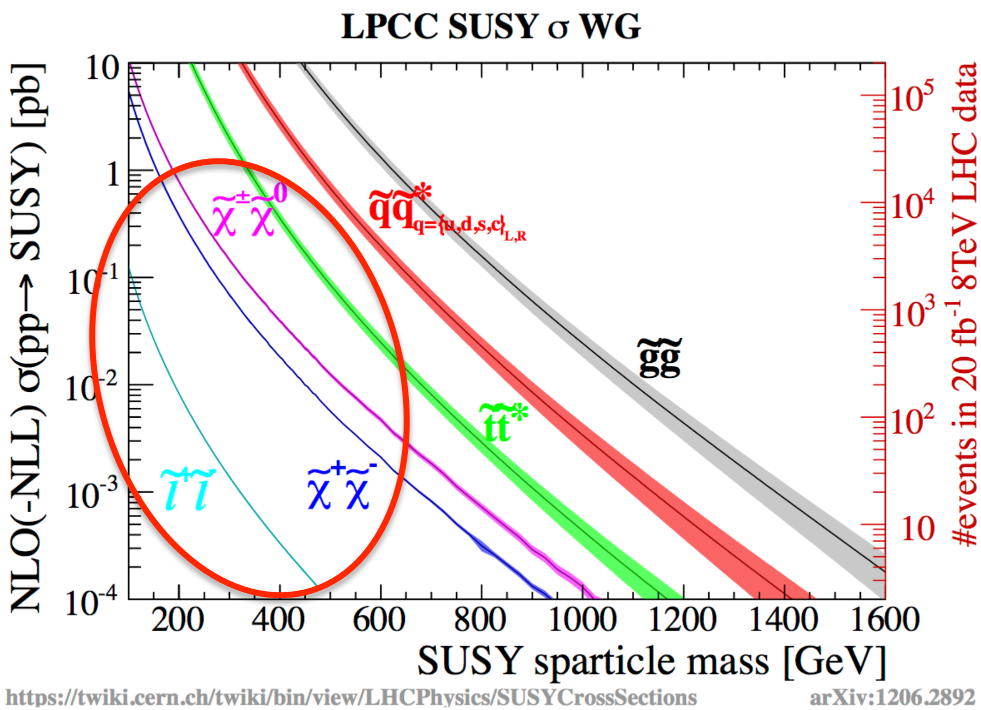
- *Sum of all bins in 1 of 64 categories shows such a deviation: p~0.5*
- *All bins in 1 of 64 category show such a fluctuation: p~0.05*





Outline

- Introduction
- Searches for gluinos and $1^{st}+2^{nd}$ generation squarks
  - Multijet + MHT (SUS-13-012)
- Searches for gluinos and 3^{rd} generation squarks
  - Razor (SUS-13-004)
  - Same sign di-leptons (SUS-13-013)
  - Search for stops and higgsinos using di-photon Higgs decay (SUS-13-014)
  - Anomalous multi-lepton production (SUS-13-002) … also interpreted as search for light sleptons
- **Search for electroweak SUSY partners and sleptons**
  - Electroweak production of charginos/neutralinos/sleptons (SUS-13-006)
  - Chargino/neutralino production with Higgs in final state (SUS-13-017)
- Conclusion



Electroweak Production

SUS-13-006

If coloured sparticles much heavier than EW partners

→ **Direct chargino/neutralino/slepton prod.**

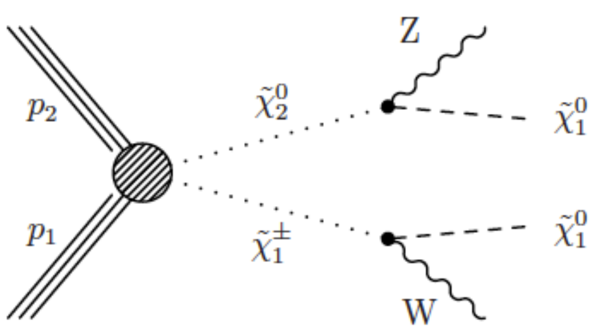
Leptonic decay modes provide clean signature:

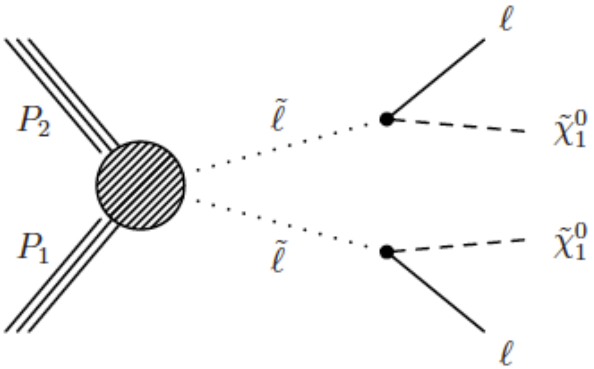
- Many leptons (up to 4) + MET
- Possibly taus
- Possibly SS of OSSF lepton pairs with $m_{\ell\ell} = m_Z$
- Low jet activity
- In case of *WZ*+MET final state:

$$M_T = \sqrt{2E_T^{miss} p_T^l (1 - \cos\Delta\phi_{l,E_T^{miss}})}$$

is discriminating (typically $M_T < M_W$ for bg)

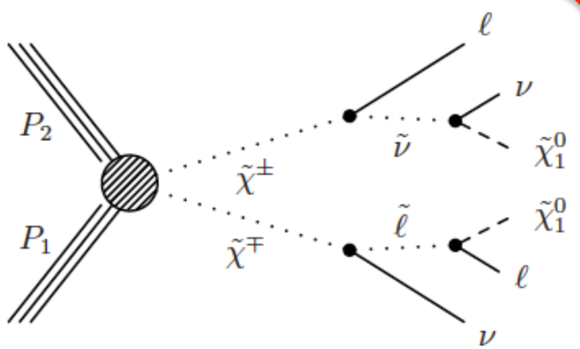
Example processes:

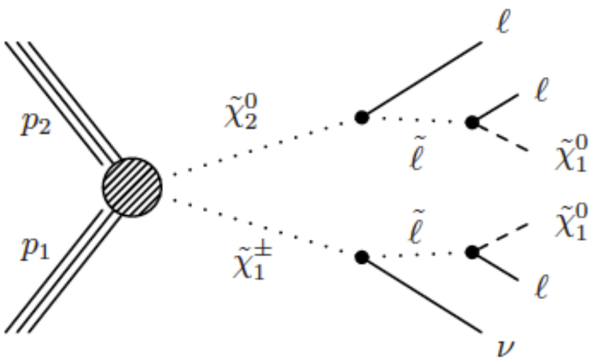


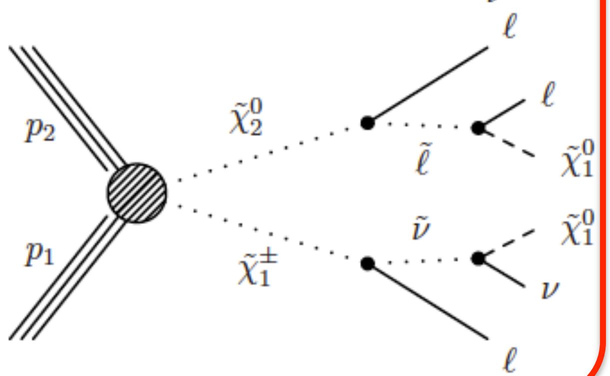


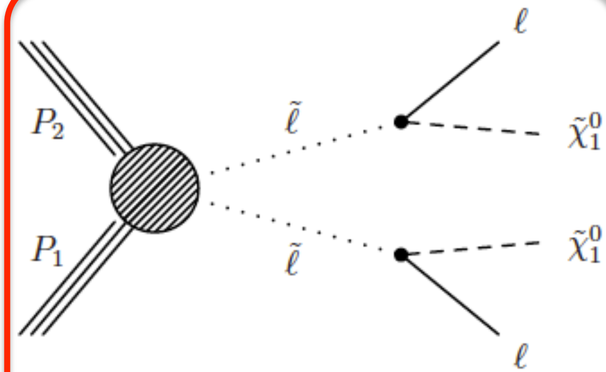
$\tilde{\chi}^0,\ \tilde{\chi}^{\pm}$ and $\tilde{l}$ Production

$\tilde{\chi}^0,\ \tilde{\chi}^{\pm}$:
decay via sleptons

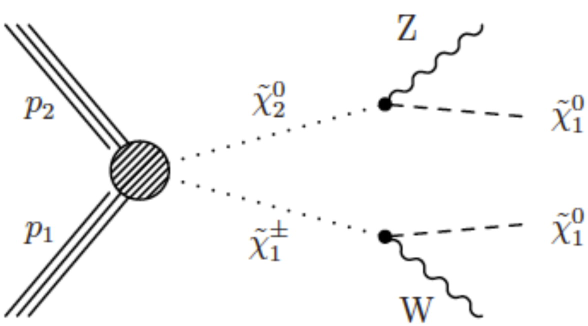






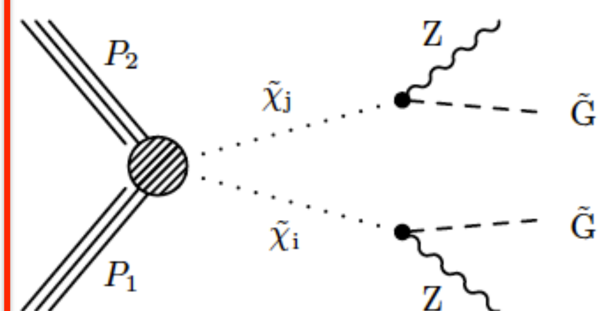


Direct slepton production



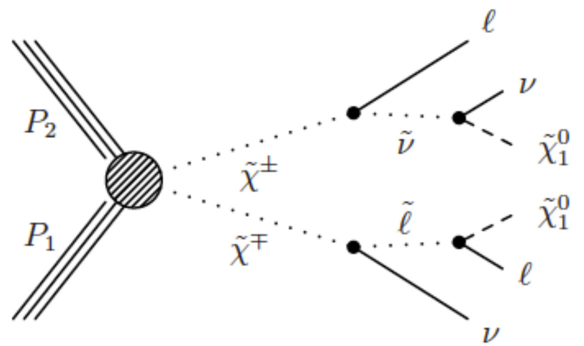
$\tilde{\chi}^0,\ \tilde{\chi}^{\pm}$:
direct decay
$\Delta m(\tilde{\chi}^0,\ \tilde{\chi}^{\pm}) > m_{Z,W}$

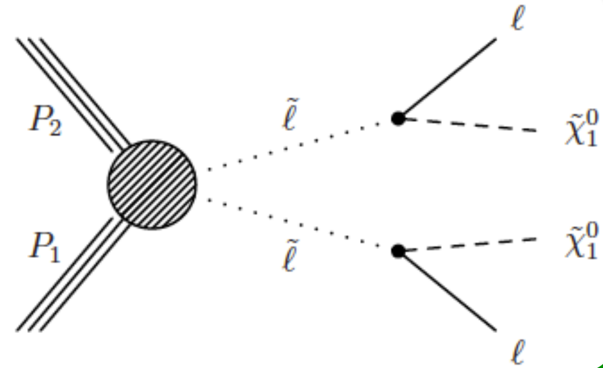
ZZ enriched models:
e. g. in GMSB

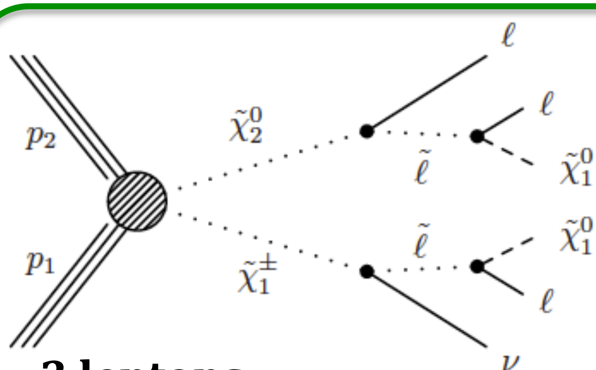


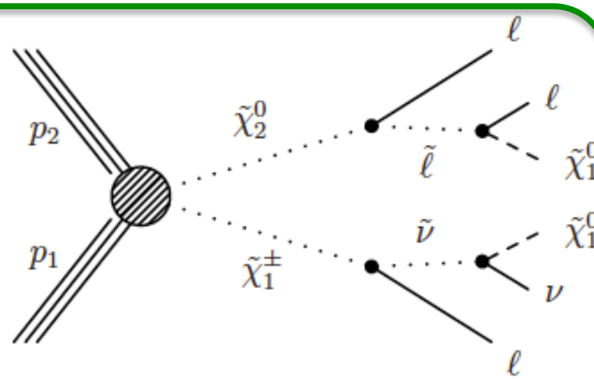
$\tilde{\chi}^0$, $\tilde{\chi}^\pm$ and $\tilde{l}$ Signatures

Mostly **2 leptons:**
- possibly 1 OSSF pair







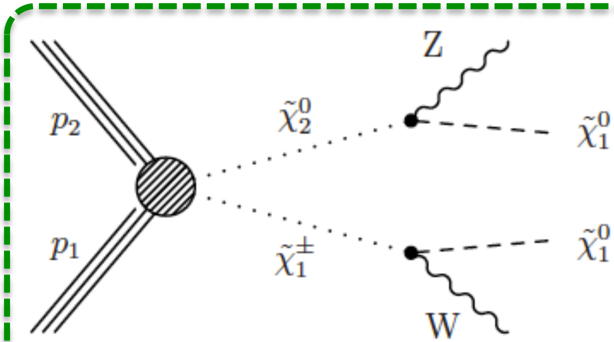


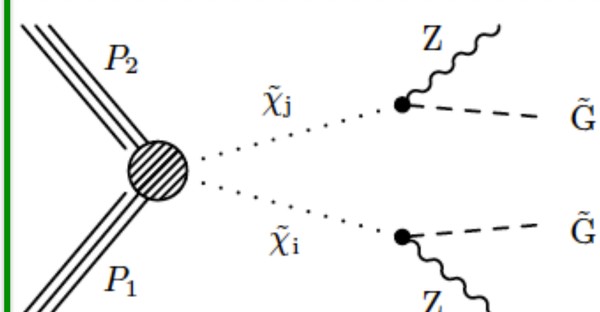
3 leptons:
- possibly 1 OSSF pair
- possibly $m_{ll} \sim m_Z$
- possibly SS leptons (if one lepton is "lost")

also: **2 leptons + 2 jets**

Up to **four leptons**
- up to 2 OSSF

also: **2 leptons + 2 jets**

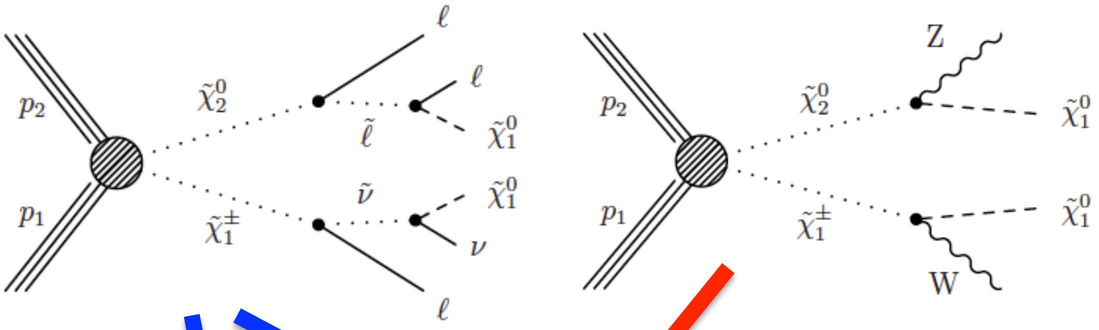


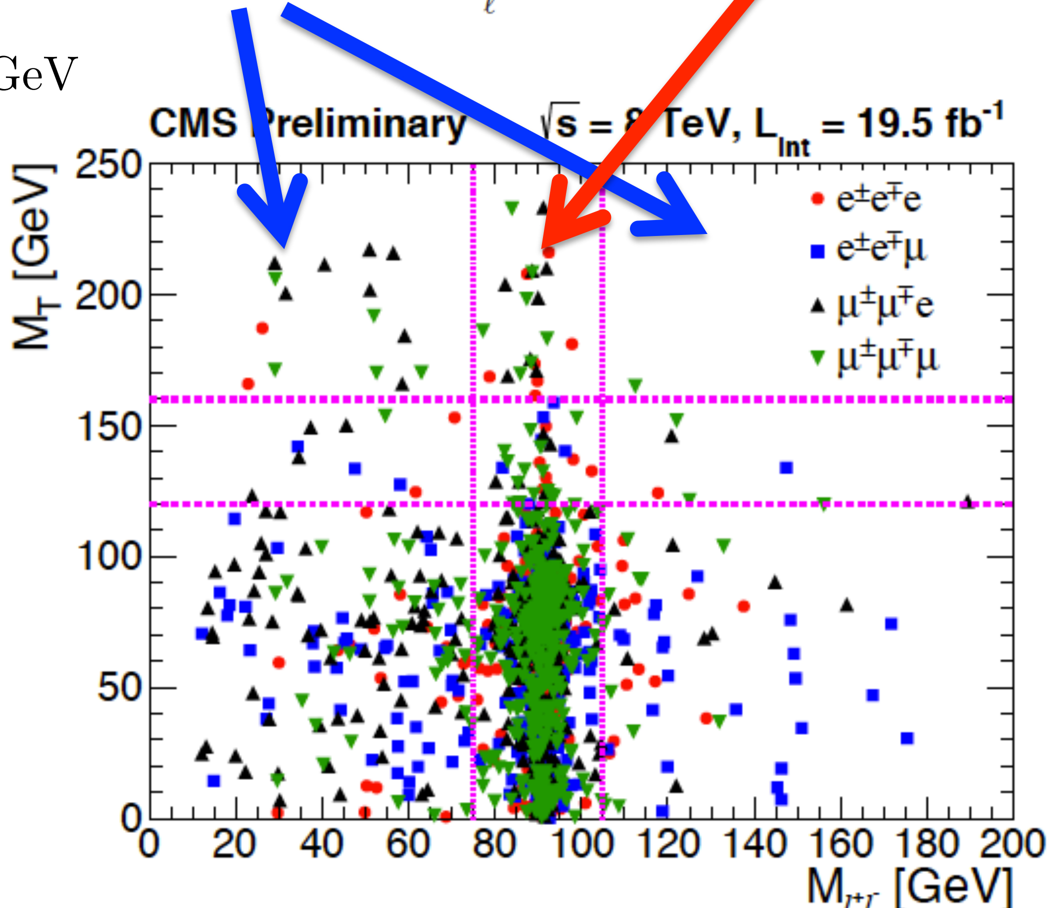


Three-Lepton Channel

Event selection:

- $N_{\text{leptons}} = 3$
- $N_{b\text{-tag}} = 0$ (suppress $t\bar{t}$)
- MET > 50 GeV (suppress Z+jets)
- Reject events with $m_{l^+l^-} < 12$ GeV
- Search binned in
  - Lepton flavours
  - MET
  - M_T
  - $m_{\ell\ell}$ below/on/above Z mass



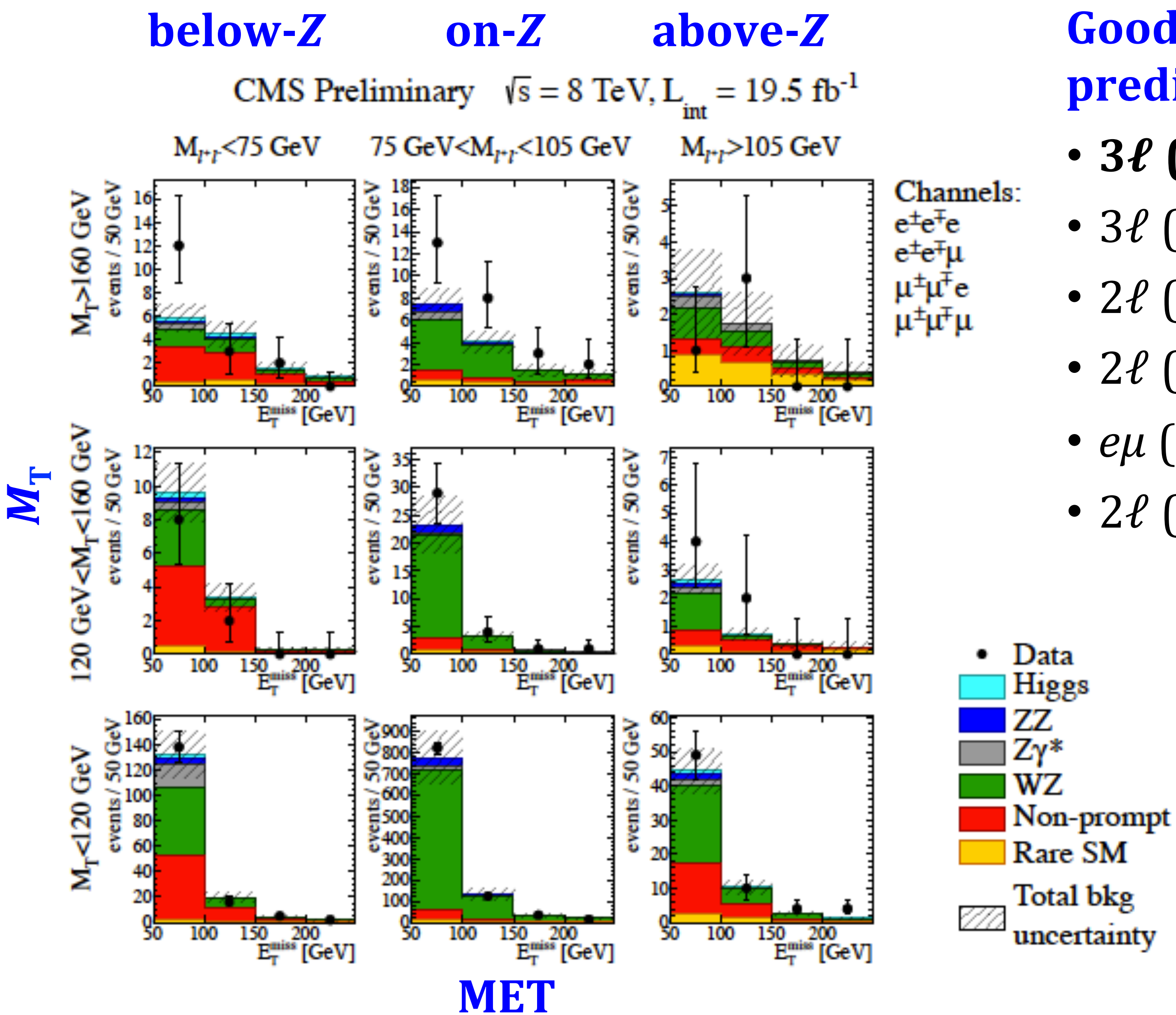


Backgrounds:

- WZ : MC simulation + data driven MET correction
- $t\bar{t}$: data driven "fake" rate methods

Three Lepton Channel

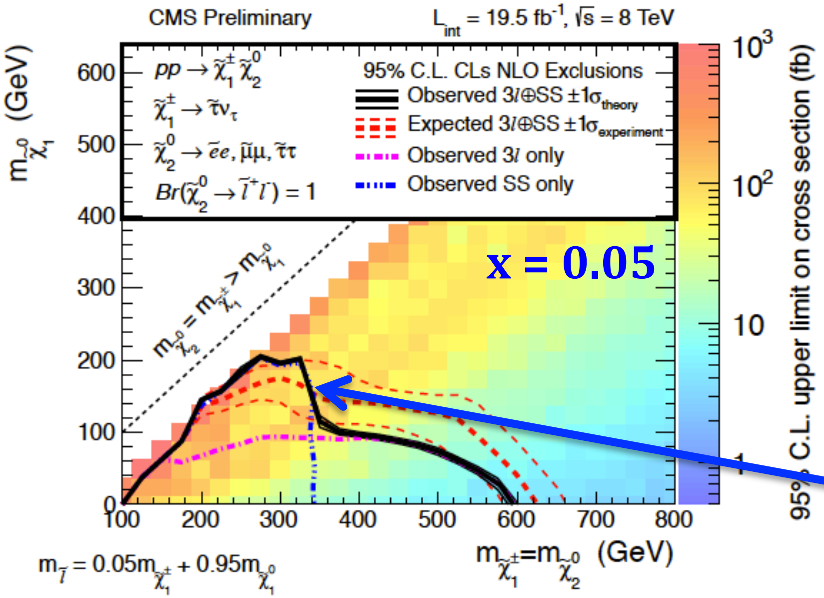
SUS-13-006



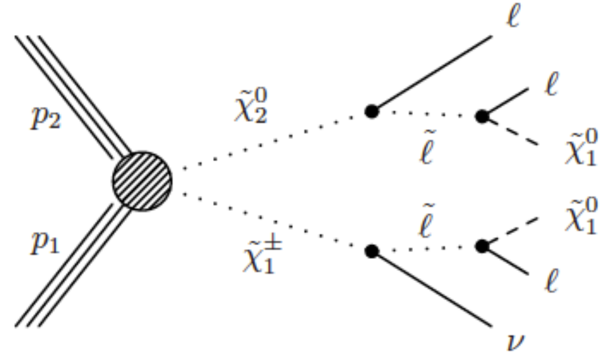
Good agreement of bg prediction with data:

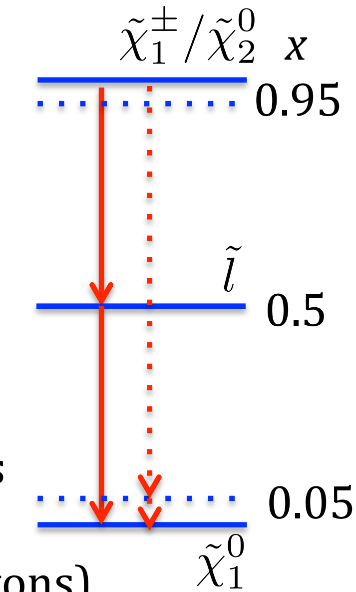
- **3ℓ (+OSSF) (shown)**
- 3ℓ (+SSSF)
- 2ℓ (SS)
- 2ℓ (SS) + 1τ
- *eμ* (OS) + 1τ
- 2ℓ (OSSF) + 2 jets

Multilepton – Interpretation

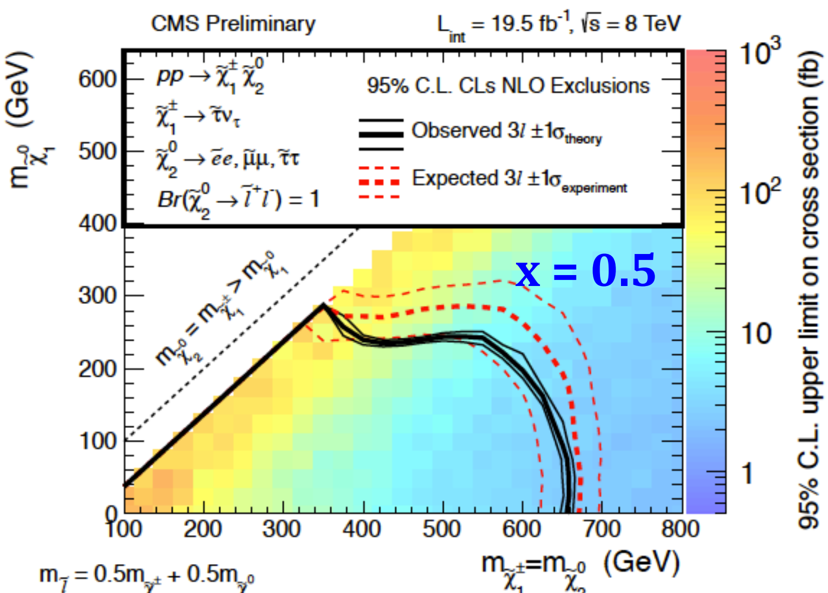


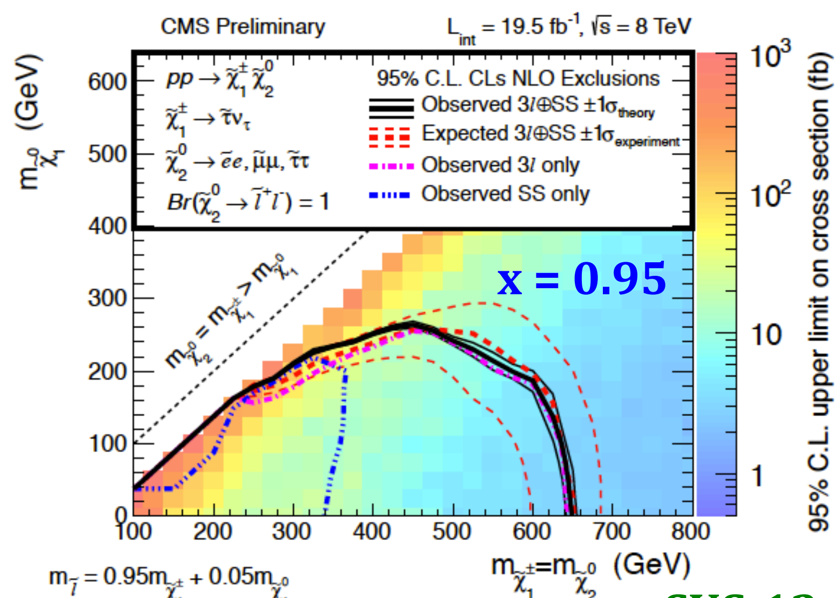
$$m_{\tilde{\ell}} = m_{\tilde{\chi}_1^0} + x_{\tilde{\ell}}\left(m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0}\right)$$





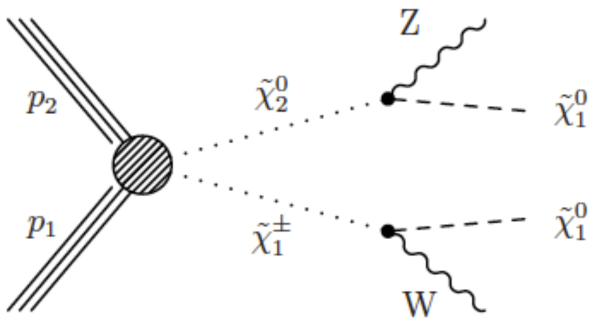
Complementary search channels
e. g. SS recovery for x=0.05
(compressed spectra → soft leptons)

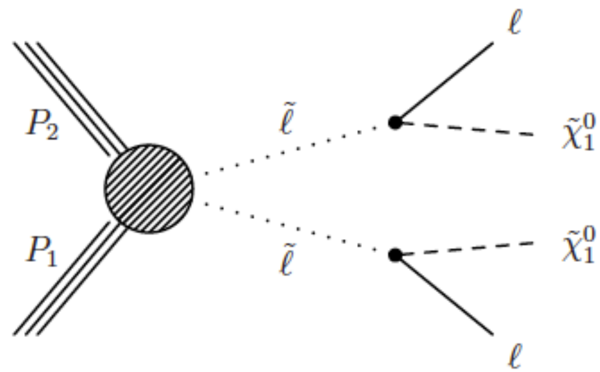


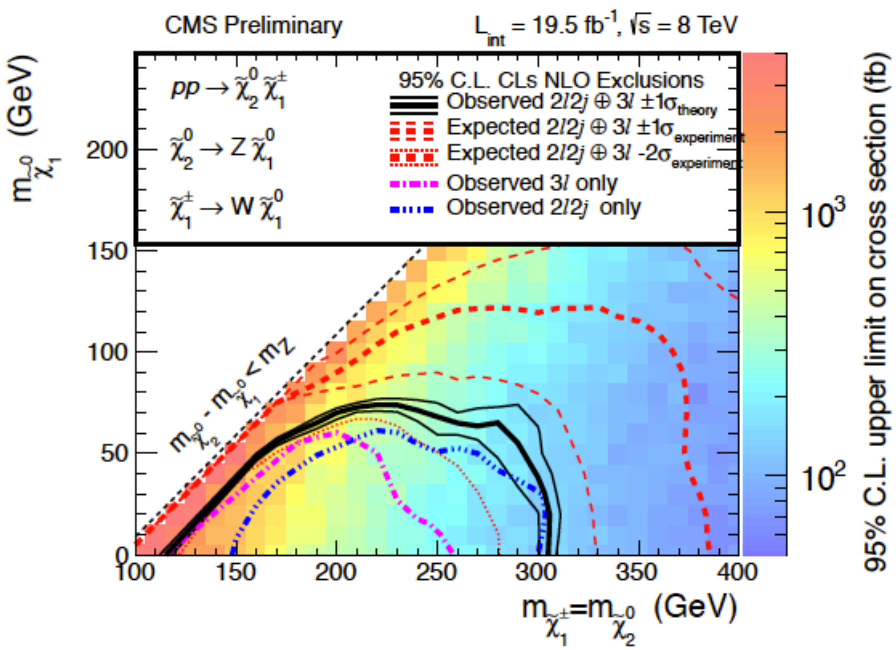


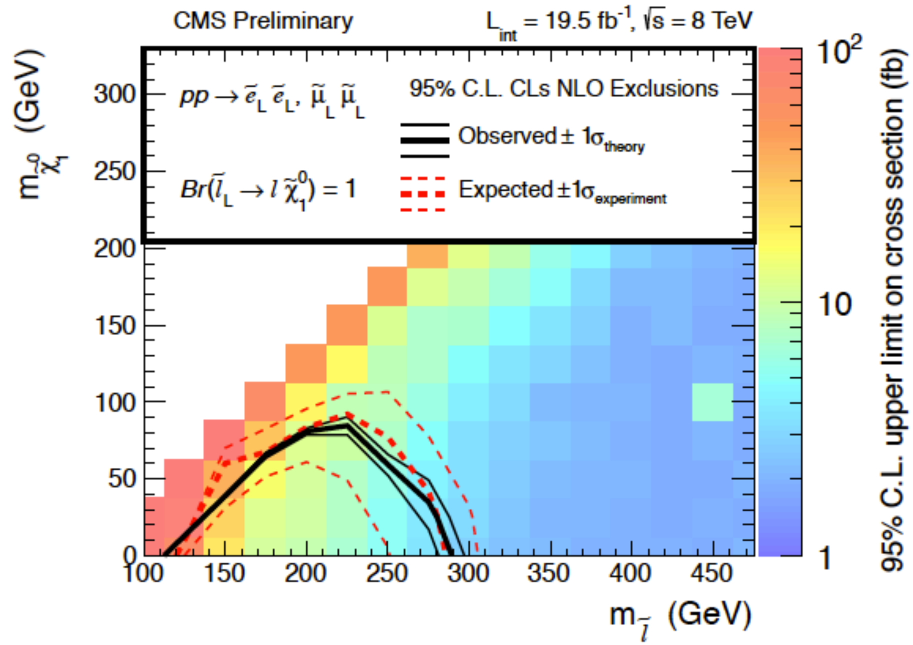
SUS-13-006

Multilepton – Interpretation









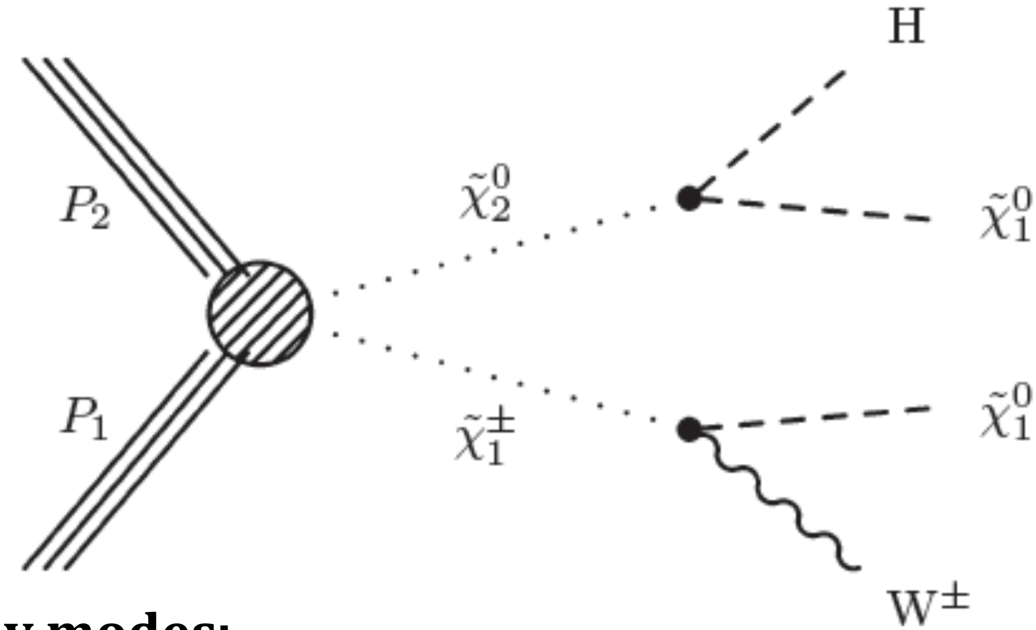
$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to W^\pm Z \tilde{\chi}_1^0 \tilde{\chi}_1^0$ **:**
probed up to 300 GeV

light sleptons:
probed up to 280 GeV

SUS-13-006

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow W^{\pm}H + E_{\mathrm{T}}^{\mathrm{miss}}$

SUS-13-017



Realized if

$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} > m_H$

***H* decay modes:**

- $H \rightarrow b\bar{b}$: **1ℓ + 2 b-tags**
- $H \rightarrow W(\rightarrow l\nu)W(\rightarrow q\bar{q})$: **2ℓ (SS)**
- $H \rightarrow W^+W^-/\tau^+\tau^-/ZZ$: **3ℓ (reinterpretation of SUS-13-002)**

→ **Novel approaches: "Higgs tagging" in SUSY searches**

1ℓ + 2 b-tags + MET

Event selection:

- Exactly 1 high p_T e/μ
- Exactly 2 jets, both b-tagged
- Moderate MET

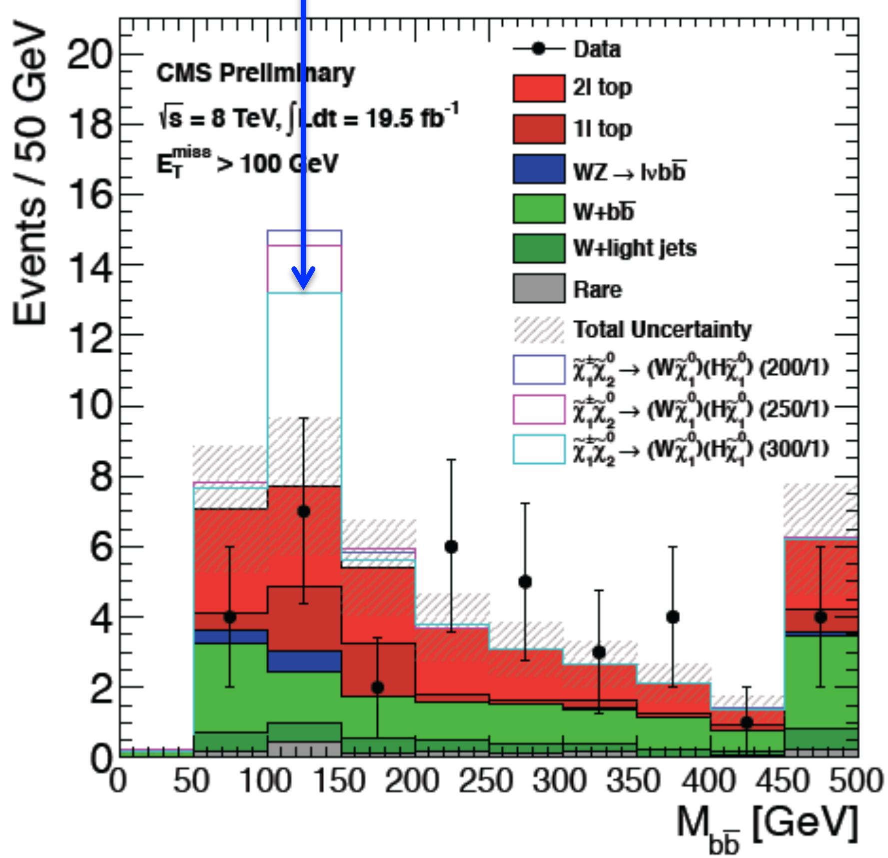
Strategy:

- Suppress SM backgrounds with MET and related quantities
- Background from MC, corrections & uncertainties from data
- Search for peak in M_{bb}

Results:

- No evidence for a peak in M_{bb}
- Data agrees with bkg in signal bin

signal bin



SS di-Leptons + MET

SUS-13-017

Event selection:

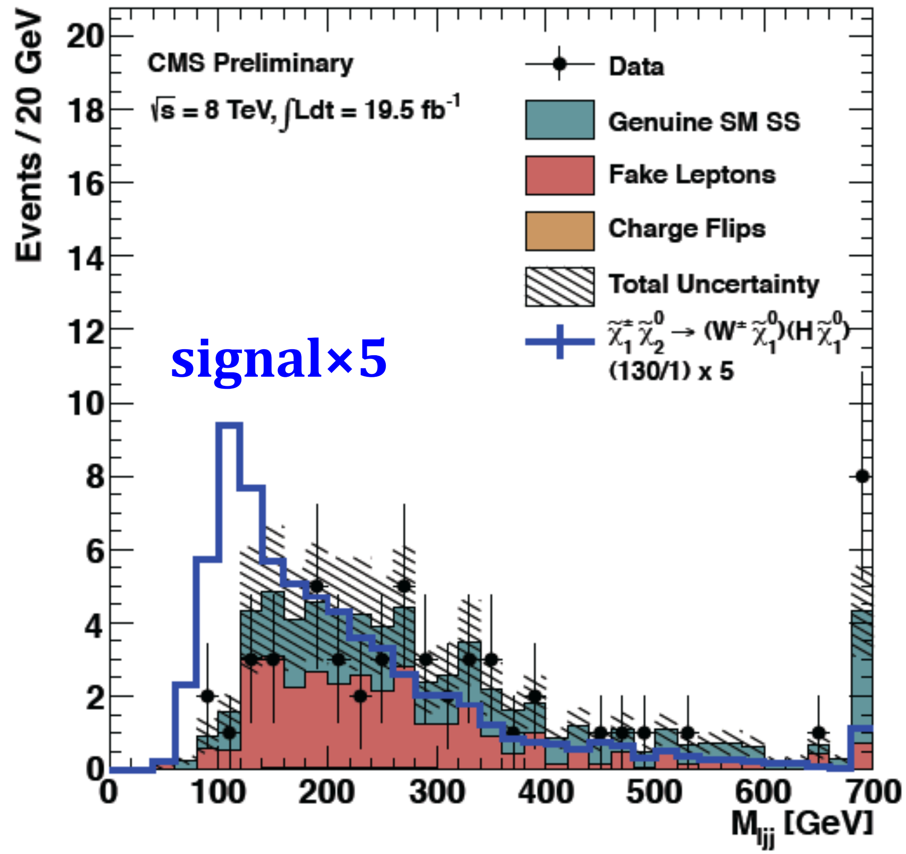
- Exactly 2 SS e/μ leptons
- 2 or 3 jets, b-veto
- Moderate MET

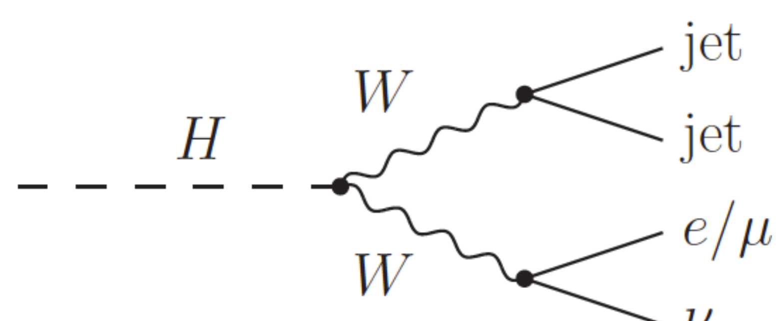
Strategy:

- Suppress SM backgrounds with MET and related quantities
- Data-driven fake lepton estimate
- Prompt SS 2ℓ bkg from MC
- Search for bump in $M(\ell jj) \sim M_H$ (with ℓ closest to jj)

Results:

- No evidence for a bump in $M(\ell jj)$
- Good agreement in signal region



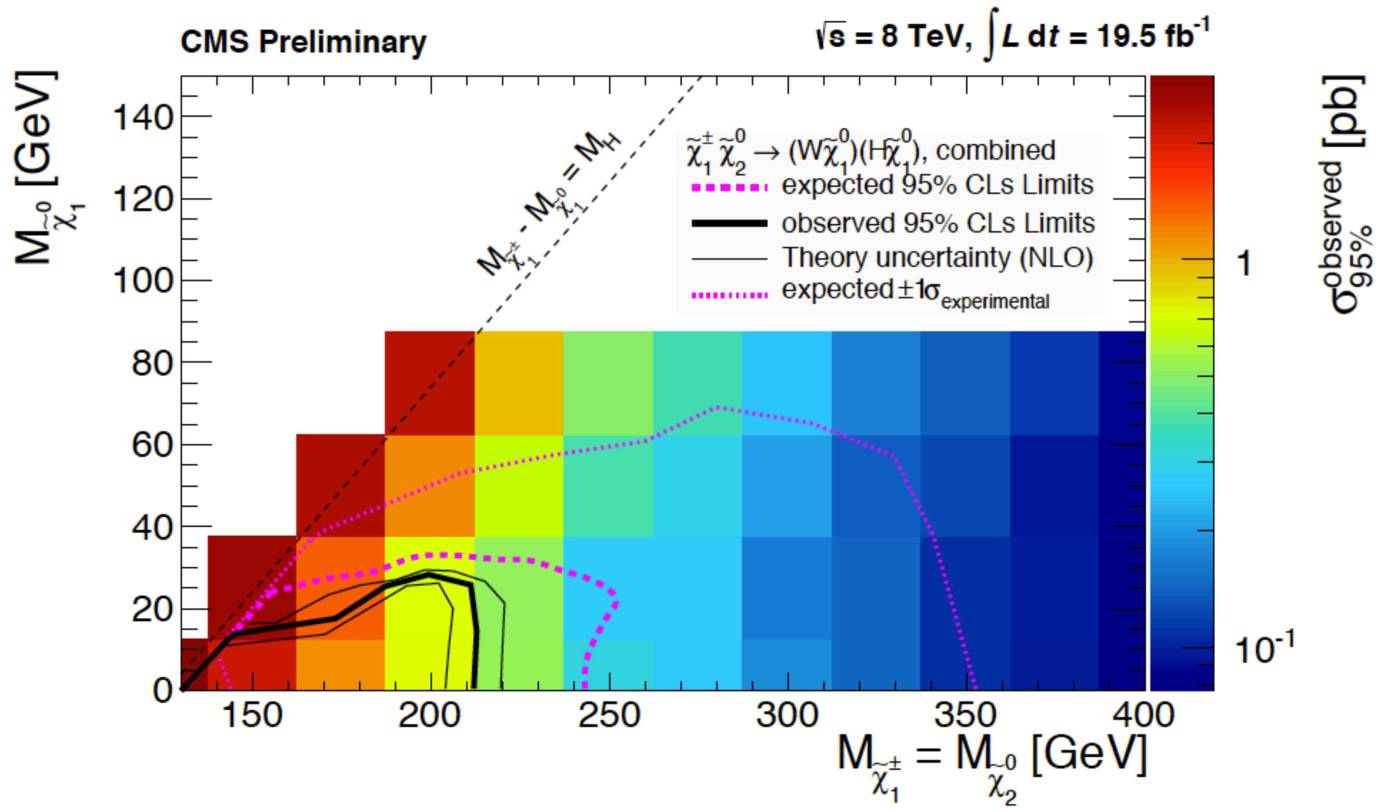


WH – Interpretation

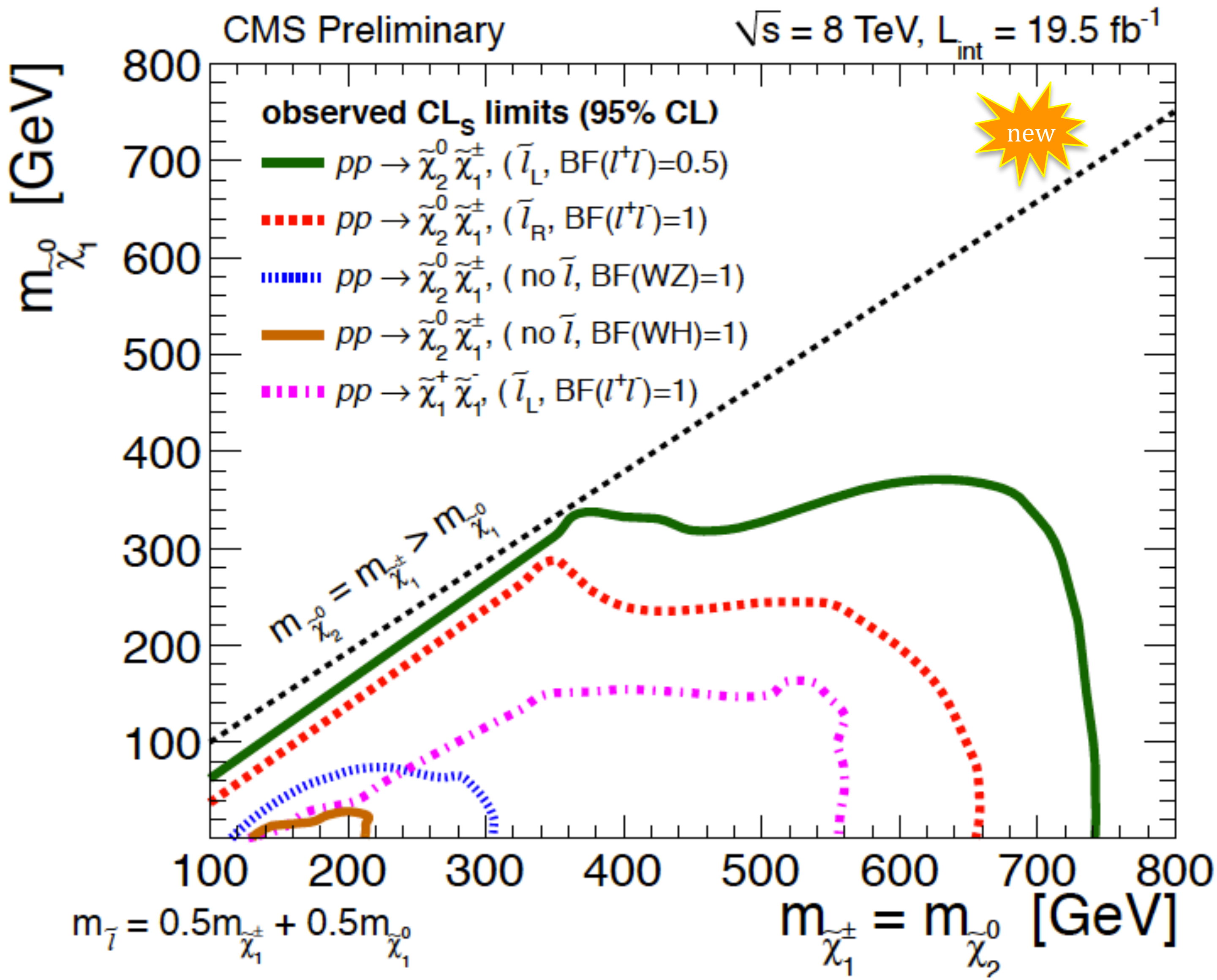
Combination of 1ℓ + 2 b-tags, 2ℓ (SS) and 3ℓ

→ Search is getting sensitive to this process (probing neutralino/chargino masses up to 210 GeV)

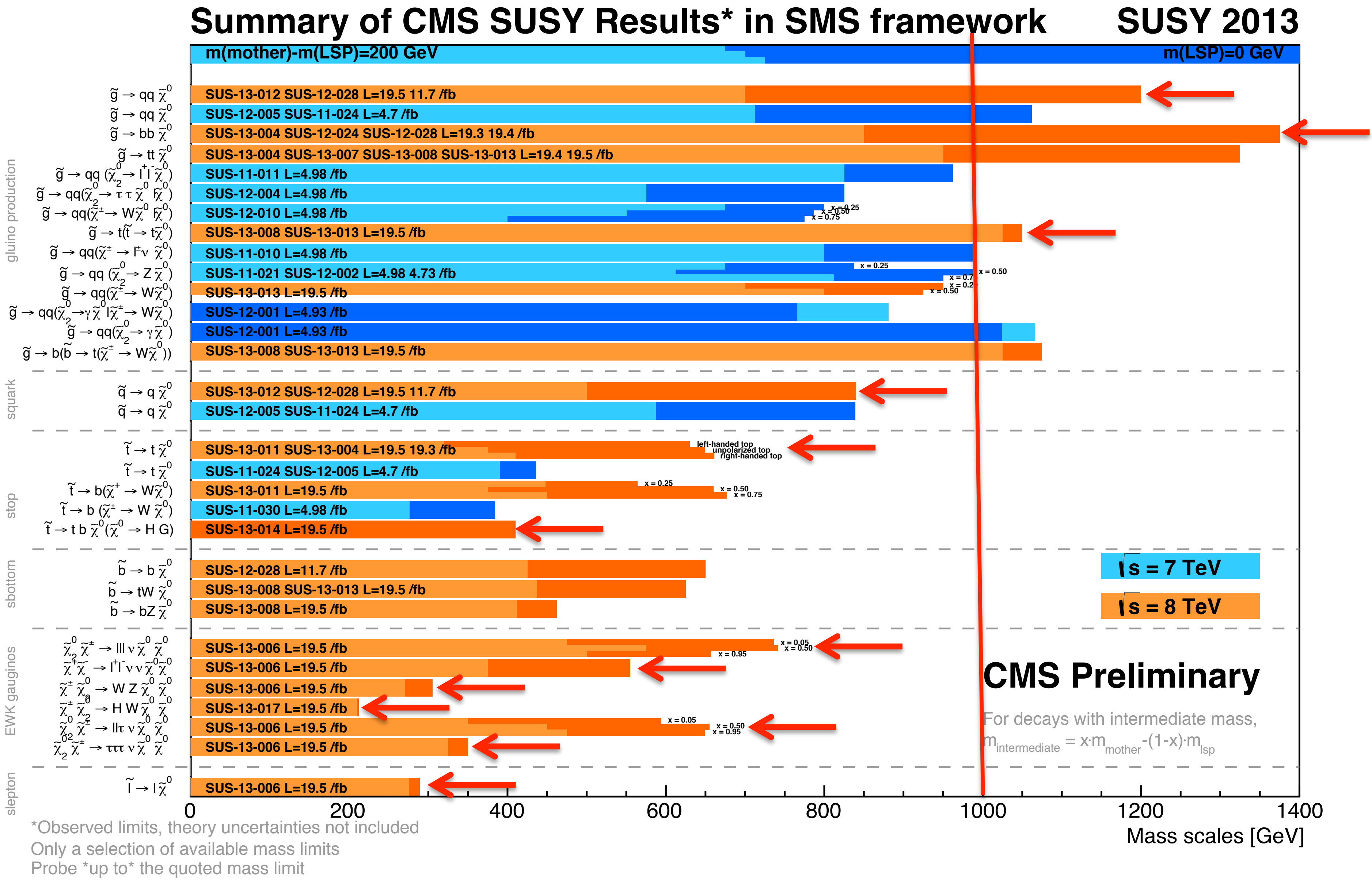
→ Very promising for 13/14 TeV



Multilepton – Summary



Overview of RPC Results ← this talk



Conclusion

- Search for physics beyond the Standard Model is one of the main motivations for the LHC experiments
- So far, no significant deviation from SM observed → Stringent limits on almost all SUSY scenarios
- Many more CMS results available and more to come from Run 1 dataset

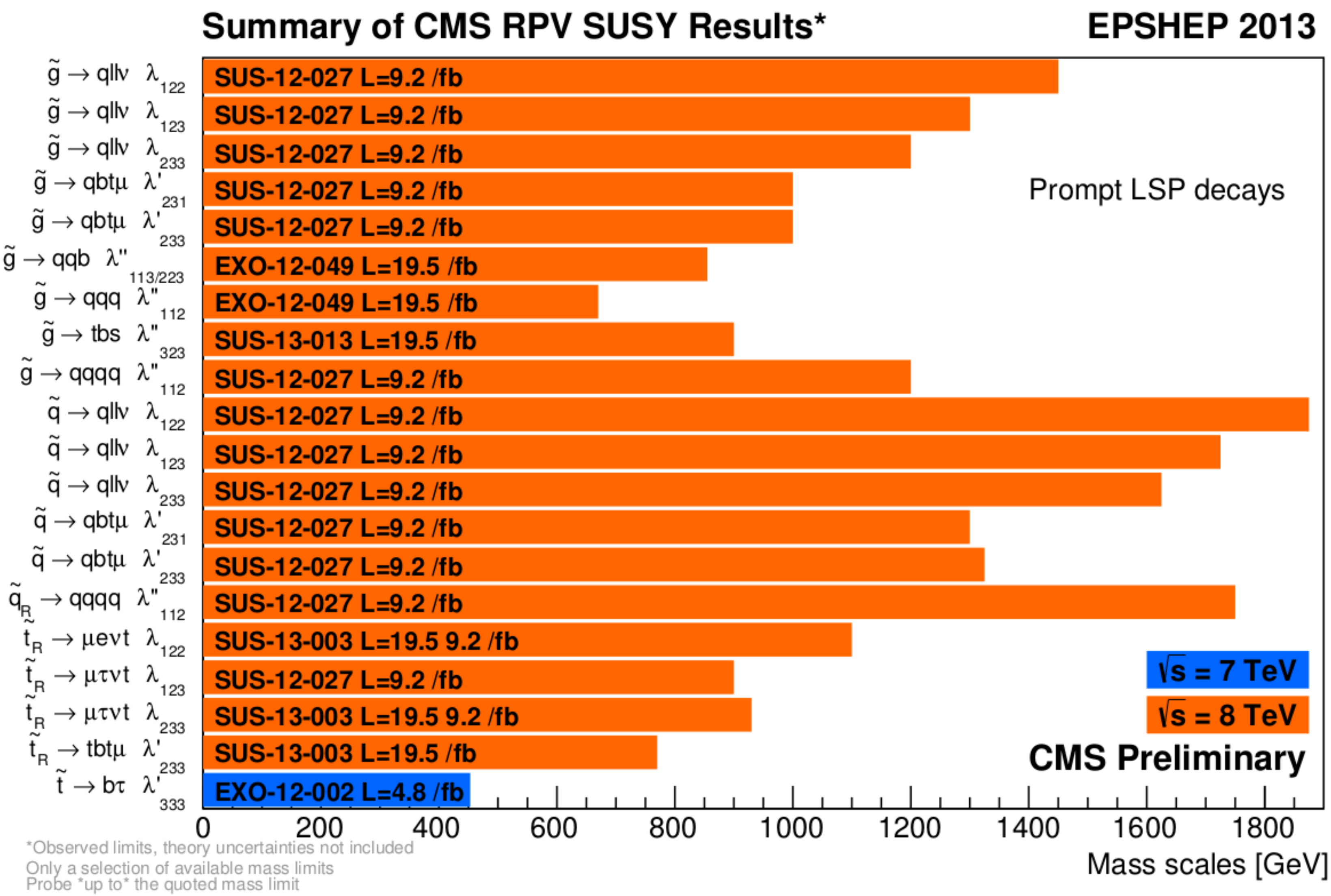
→ Watch the public result pages:

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

... to be continued at 13/14 TeV

Backup

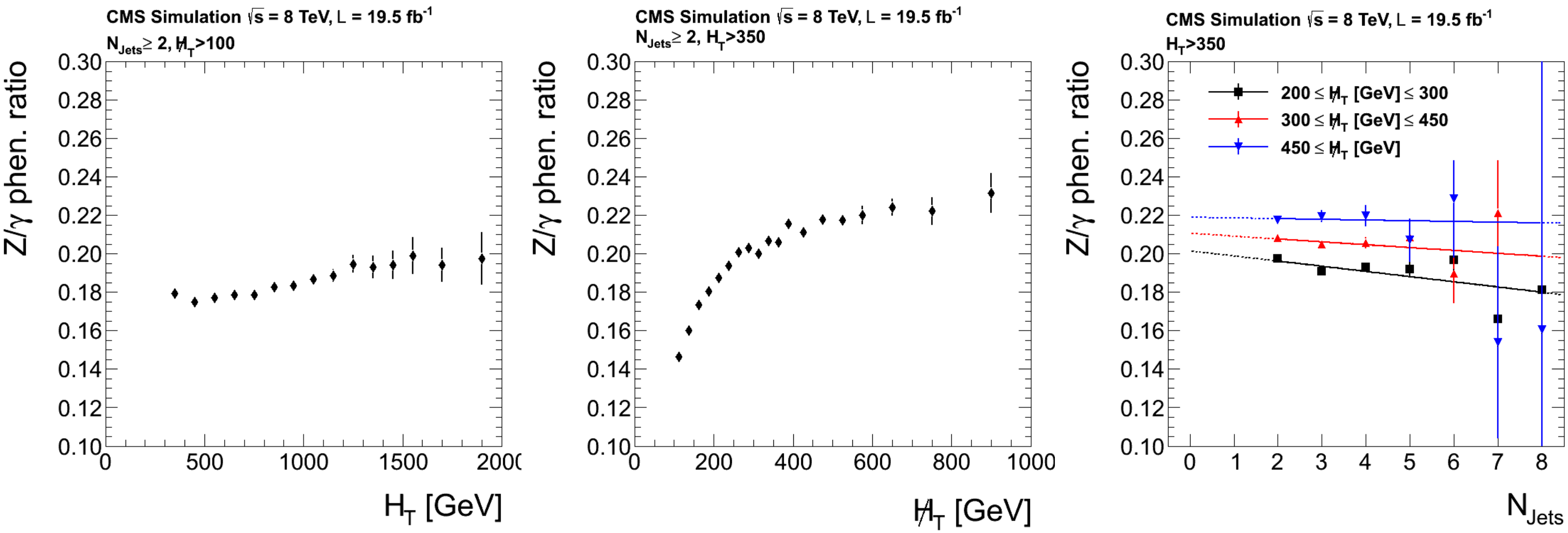
Overview of RPV Results



Multi-Jets + MET – Results

N_{jets}	Selection H_T	$\not{H}_T$	$Z\to\nu\bar{\nu}$ from γ+jets	$t\bar{t}/W \to e,\mu$+X	$t\bar{t}/W \to \tau_h$+X	QCD	Total background	Obs. data
3-5	500-800	200-300	1821.3±326.5	2210.7±447.8	1683.7±171.4	307.4±219.4	6023.1±620.2	6159
3-5	500-800	300-450	993.6±177.9	660.1±133.3	591.9± 62.5	34.5± 23.8	2280.0±232.1	2305
3-5	500-800	450-600	273.2± 51.1	77.3± 17.9	67.6± 9.5	1.3± 1.5	419.5± 55.0	454
3-5	500-800	> 600	42.0± 8.7	9.5± 4.0	6.0± 1.9	0.1± 0.3	57.6± 9.7	62
3-5	800-1000	200-300	215.8± 40.0	277.5± 62.4	191.6± 23.2	91.7± 65.5	776.7±101.6	808
3-5	800-1000	300-450	124.1± 23.7	112.8± 26.9	83.3± 11.2	9.9± 7.4	330.1± 38.3	305
3-5	800-1000	450-600	46.9± 9.8	36.1± 9.9	23.6± 3.9	0.8± 1.3	107.5± 14.5	124
3-5	800-1000	> 600	35.3± 7.5	9.0± 3.7	11.4± 3.2	0.1± 0.4	55.8± 9.0	52
3-5	1000-1250	200-300	76.3± 14.8	103.5± 25.9	66.8± 10.0	59.0± 24.7	305.6± 40.1	335
3-5	1000-1250	300-450	39.3± 8.2	52.4± 13.6	35.7± 6.2	5.1± 2.7	132.6± 17.3	129
3-5	1000-1250	450-600	18.1± 4.4	6.9± 3.2	6.6± 2.1	0.5± 0.7	32.1± 5.9	34
3-5	1000-1250	> 600	17.8± 4.3	2.4± 1.8	2.5± 1.0	0.1± 0.3	22.8± 4.7	32
3-5	1250-1500	200-300	25.3± 5.5	31.0± 9.5	22.2± 3.9	31.2± 13.1	109.7± 17.5	98
3-5	1250-1500	300-450	16.7± 4.0	10.1± 4.4	11.1± 3.6	2.3± 1.6	40.2± 7.1	38
3-5	1250-1500	> 450	12.3± 3.2	2.3± 1.7	2.8± 1.5	0.2± 0.5	17.6± 4.0	23
3-5	>1500	200-300	10.5± 2.8	16.7± 6.2	15.2± 3.4	35.1± 14.1	77.6± 16.1	94
3-5	>1500	> 300	10.9± 2.9	9.7± 4.3	6.5± 2.0	2.4± 2.0	29.6± 5.8	39
6-7	500-800	200-300	22.7± 6.1	132.5± 58.6	127.1± 21.5	18.2± 9.2	300.5± 63.4	266
6-7	500-800	300-450	9.9± 3.1	22.0± 10.8	18.6± 4.3	1.9± 1.7	52.3± 12.1	62
6-7	500-800	> 450	0.7± 0.6	0.0± 1.6	0.1± 0.3	0.0± 0.1	0.8± 1.7	9
6-7	800-1000	200-300	9.1± 2.8	55.8± 25.4	44.6± 8.2	13.1± 6.6	122.6± 27.7	111
6-7	800-1000	300-450	4.2± 1.6	10.4± 5.5	12.8± 3.1	1.9± 1.4	29.3± 6.6	35
6-7	800-1000	> 450	1.8± 1.0	2.9± 2.5	1.3± 0.5	0.1± 0.4	6.1± 2.7	4
6-7	1000-1250	200-300	4.4± 1.6	24.1± 12.0	24.0± 5.5	11.9± 6.0	64.4± 14.6	67
6-7	1000-1250	300-450	3.5± 1.4	8.0± 4.7	9.6± 2.5	1.5± 1.5	22.6± 5.7	20
6-7	1000-1250	> 450	1.4± 0.8	0.0± 1.8	0.8± 0.5	0.1± 0.3	2.3± 2.1	4
6-7	1250-1500	200-300	3.3± 1.3	11.5± 6.5	6.1± 2.5	6.8± 3.9	27.7± 8.1	24
6-7	1250-1500	300-450	1.4± 0.8	3.5± 2.6	2.9± 1.5	0.9± 1.3	8.8± 3.4	5
6-7	1250-1500	> 450	0.4± 0.4	0.0± 1.2	0.1± 0.2	0.1± 0.3	0.5± 1.3	2
6-7	>1500	200-300	1.3± 0.8	10.0± 6.9	2.3± 1.3	7.8± 4.0	21.5± 8.1	18
6-7	>1500	> 300	1.1± 0.7	3.2± 2.8	2.9± 1.2	0.8± 1.1	8.0± 3.3	3
≥8	500-800	> 200	0.0± 0.6	1.9± 1.5	2.8± 1.3	0.1± 0.4	4.8± 2.1	8
≥8	800-1000	> 200	0.6± 0.5	4.8± 2.9	2.7± 1.1	0.5± 0.9	8.7± 3.3	9
≥8	1000-1250	> 200	0.6± 0.5	1.4± 1.5	3.1± 1.2	0.7± 0.9	5.8± 2.2	8
≥8	1250-1500	> 200	0.0± 0.7	5.1± 3.5	1.3± 0.8	0.5± 0.9	6.9± 3.7	5
≥8	1500-	> 200	0.0± 0.6	0.0± 2.1	1.5± 1.0	0.9± 1.3	2.4± 2.8	2

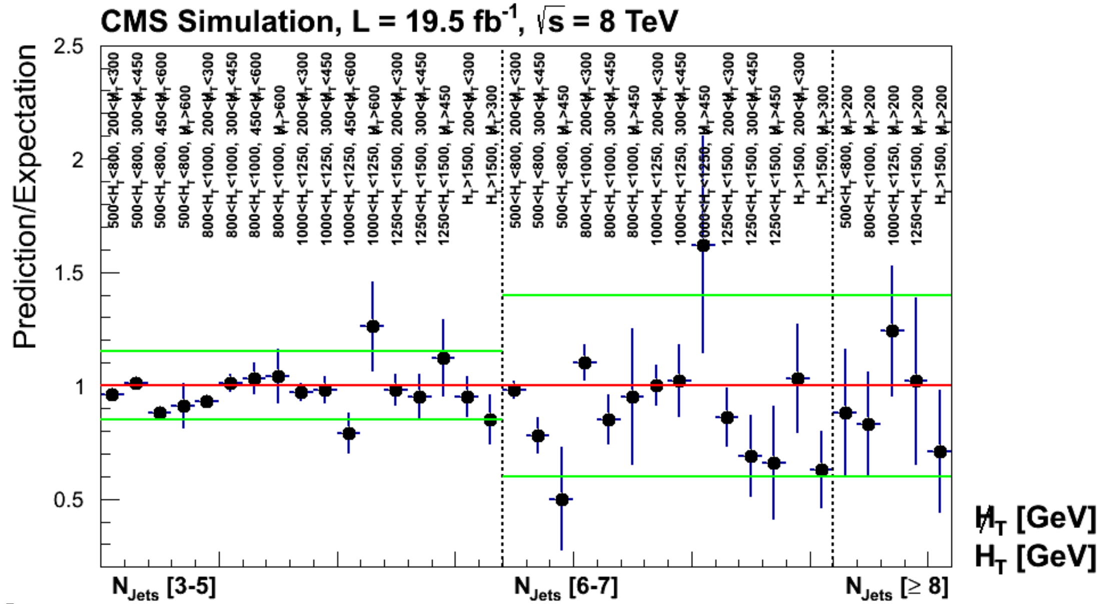
Multi-Jet + MET – *Z* + jets



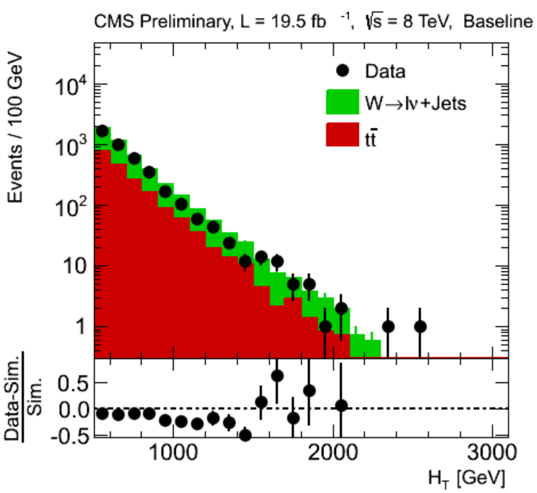
Z/gamma ratio vs. HT (left), MHT (middle), and Njets (right)

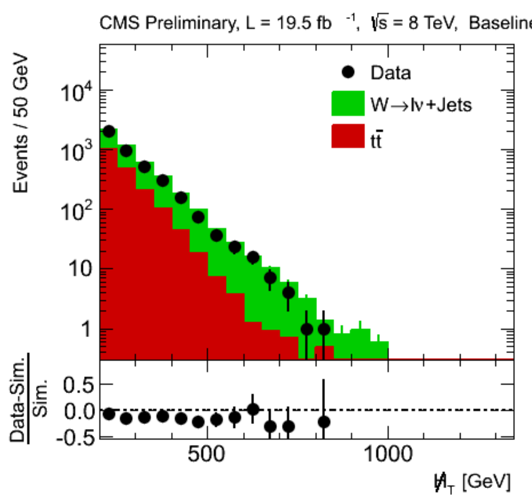
Multi-Jet + MET – Lost Lepton

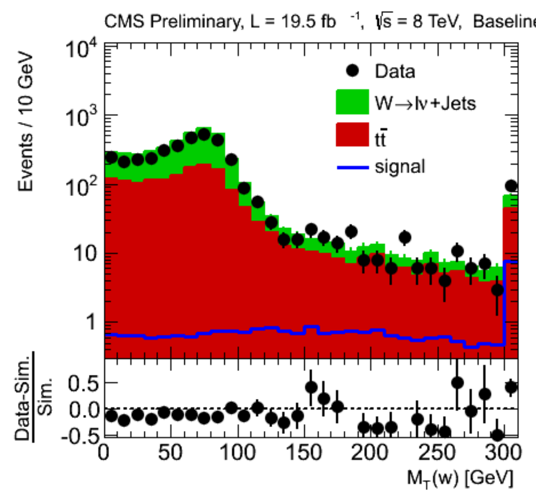
Closure tests on MC simulation:



Data-MC comparison for muon control sample:

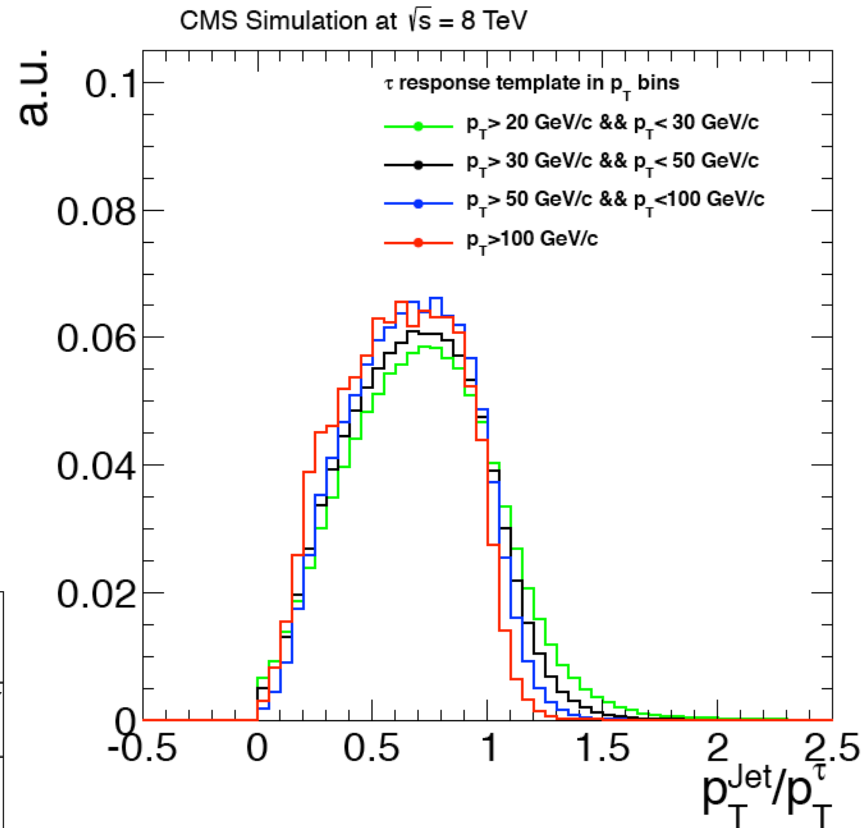




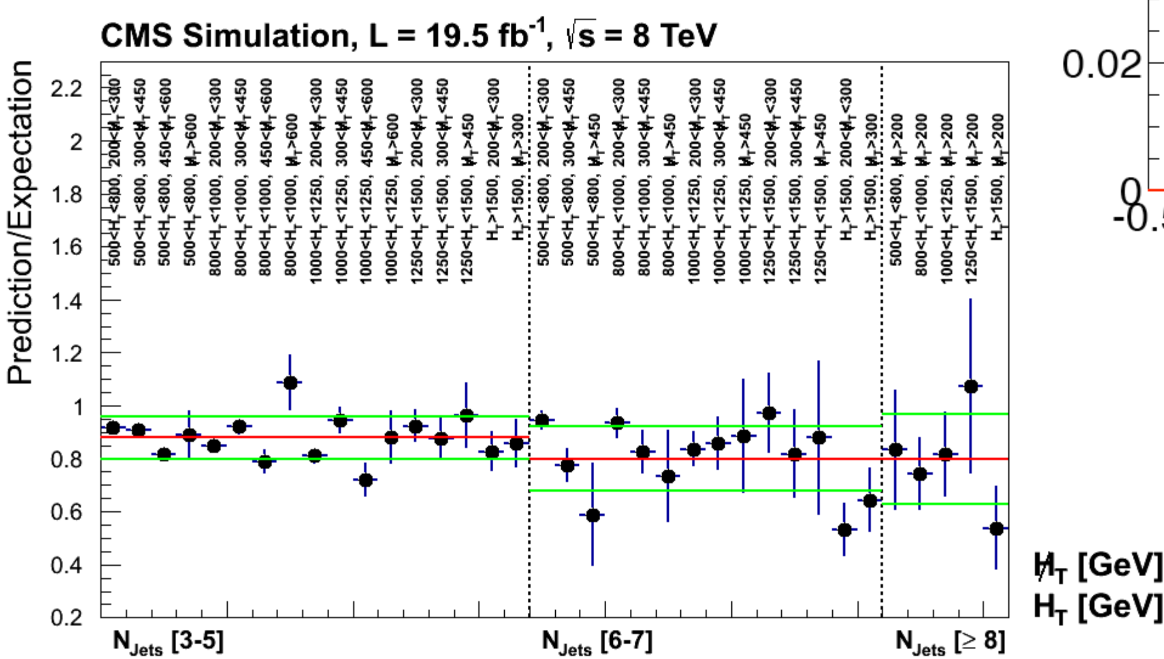


Multi-Jet + MET – Hadronic Tau

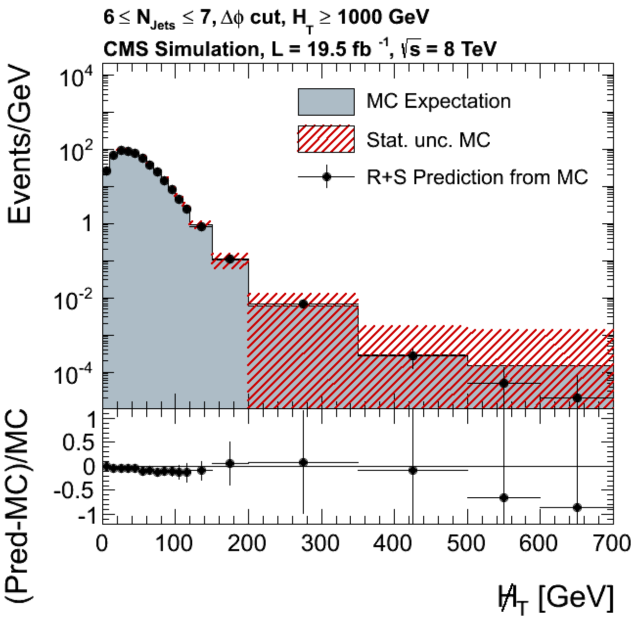
Tau response templates:

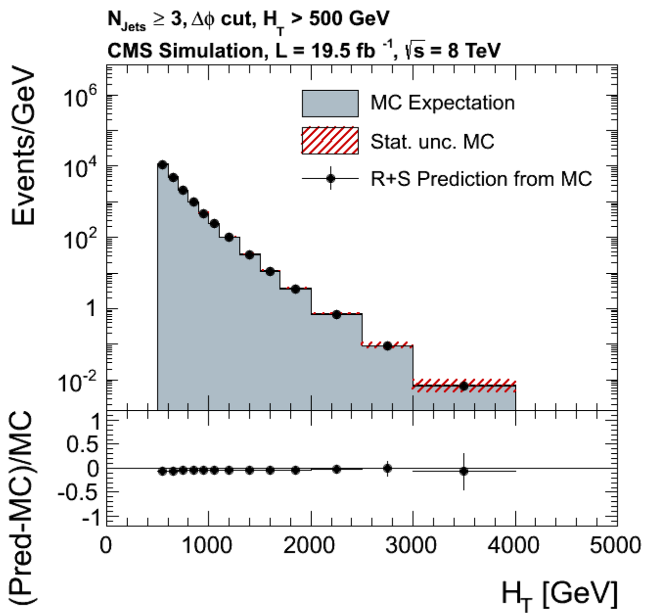


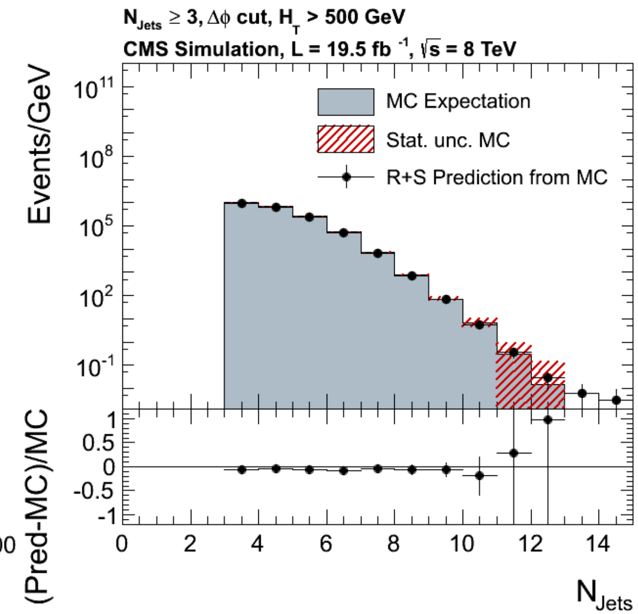
Closure tests on MC simulation:



Multi-Jet + MET – R+S / QCD

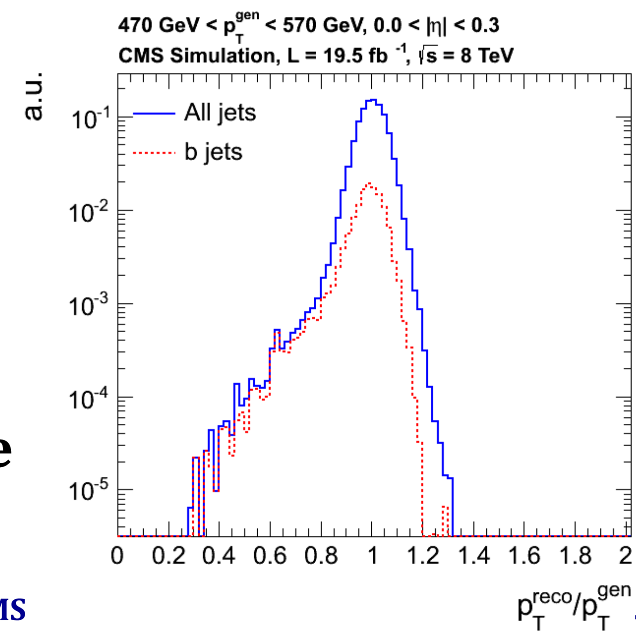




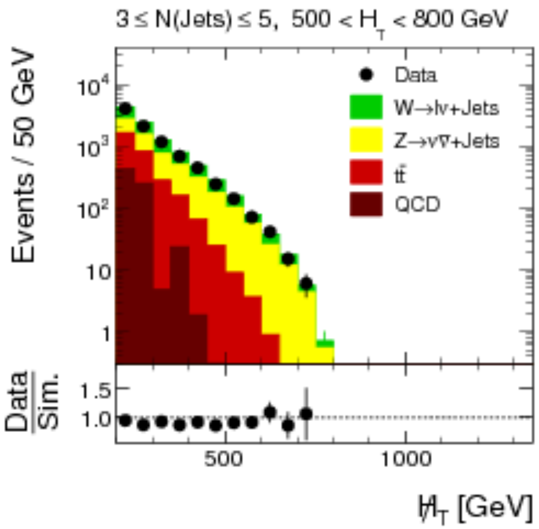


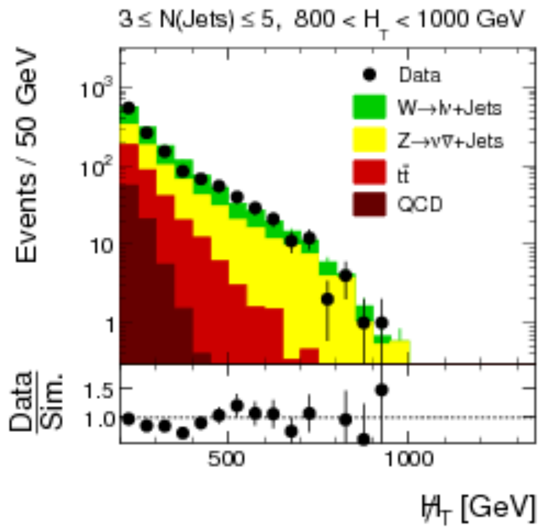
Closure tests on MC simulation:

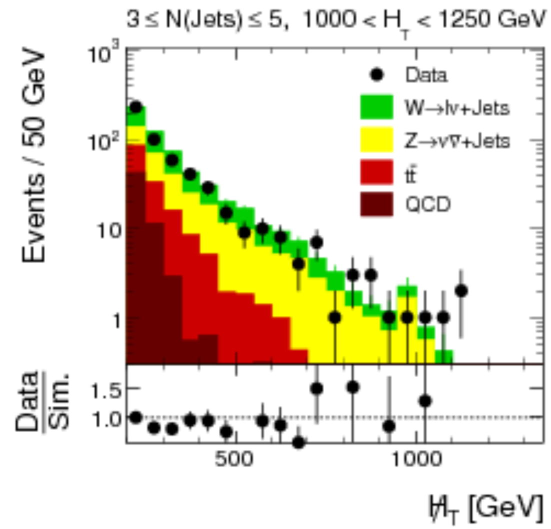
Typical jet response template:

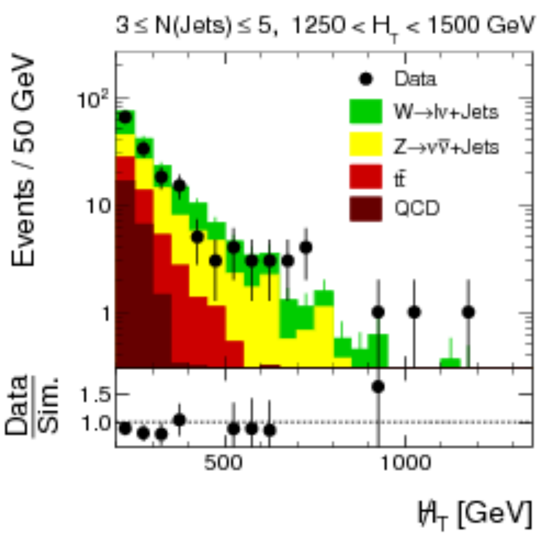


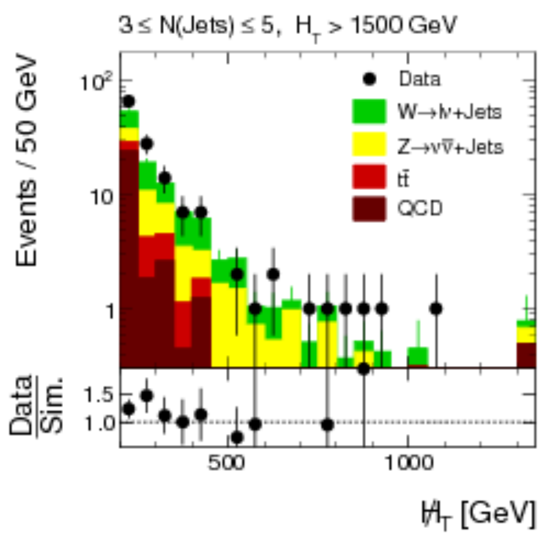
Multi-Jet + MET – Data vs. MC





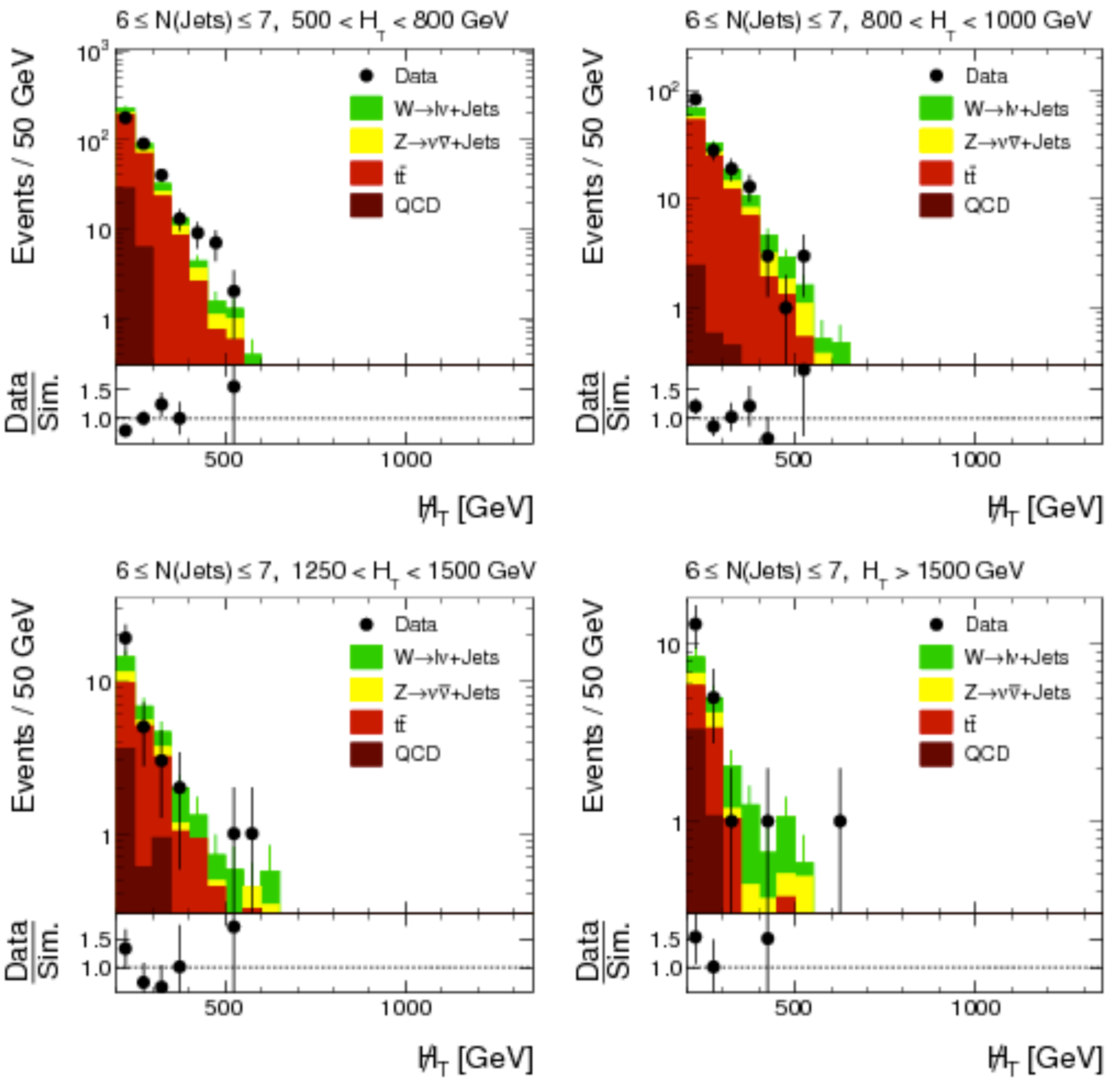






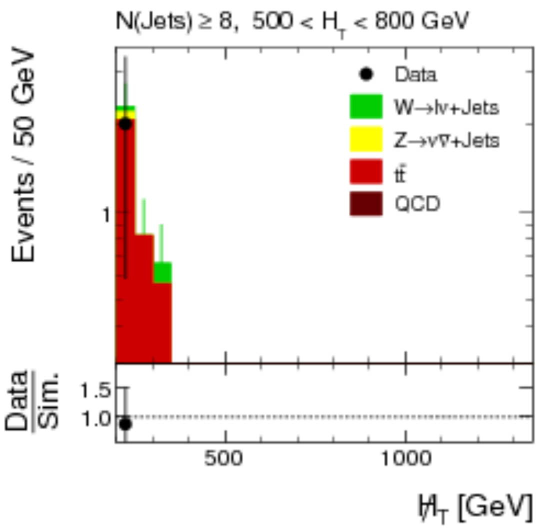
MHT distributions for various HT bins: N_{jets} = 3-5

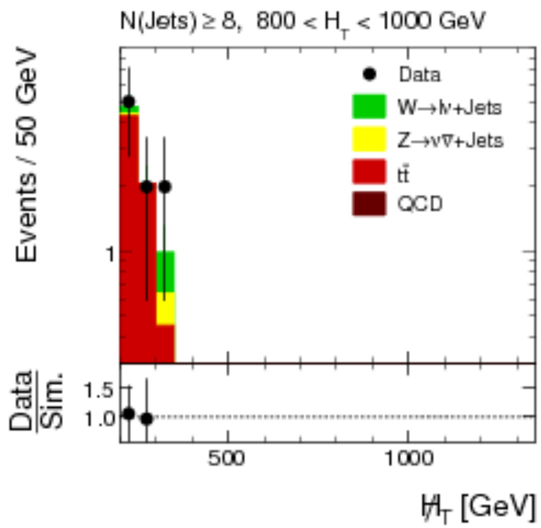
Multi-Jet + MET – Data vs. MC

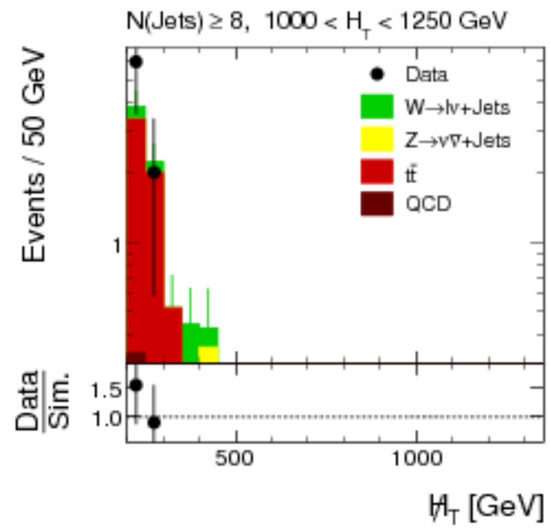


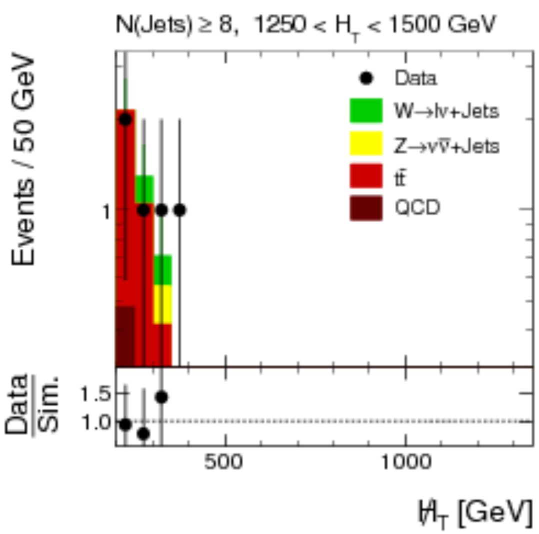
MHT distributions for various HT bins:
N_{jets} = 6-7

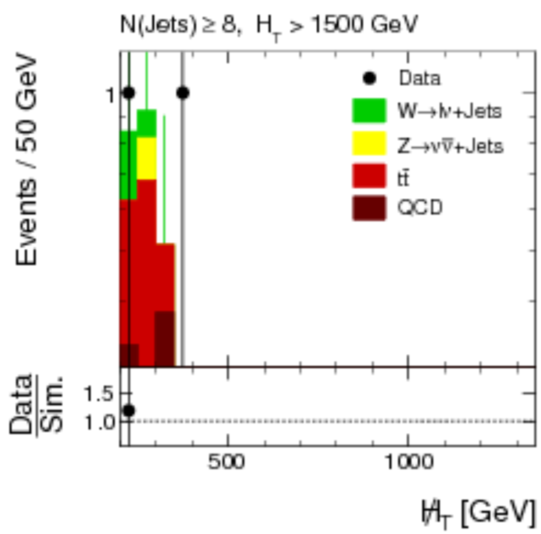
Multi-Jet + MET – Data vs. MC





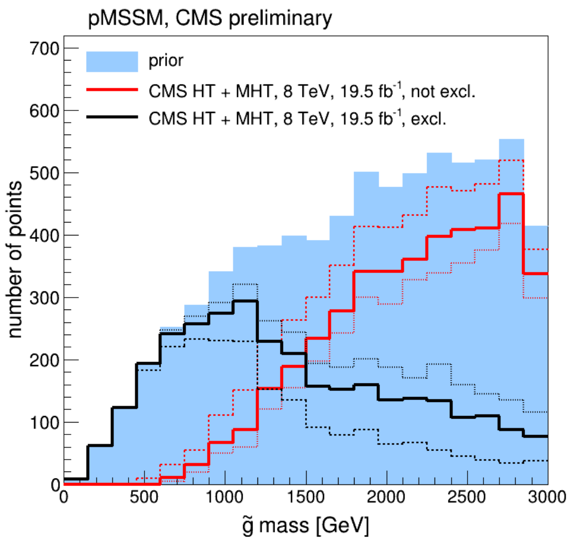


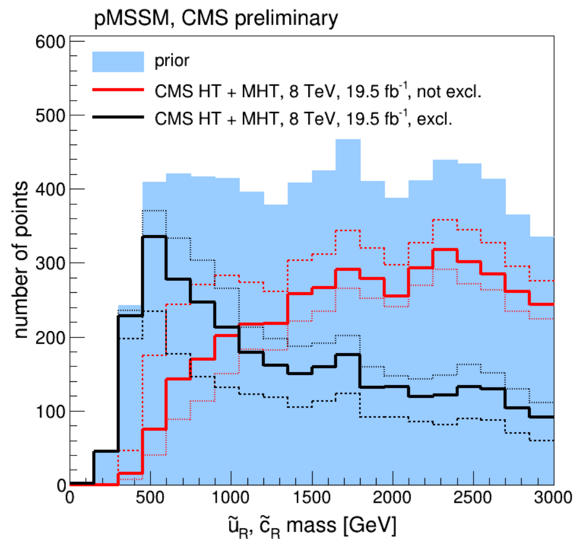


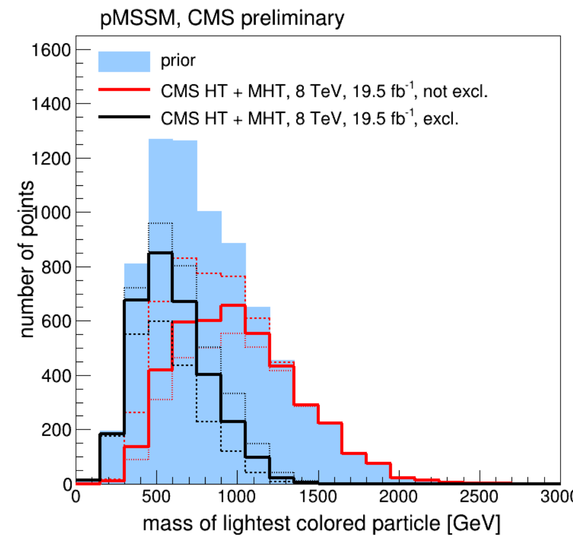


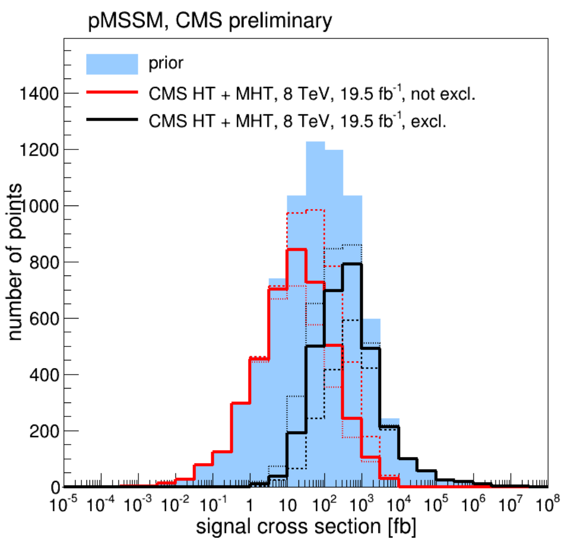
MHT distributions for various HT bins: $N_{\text{jets}} \geq 8$

Multi-Jets + MHT – pMSSM







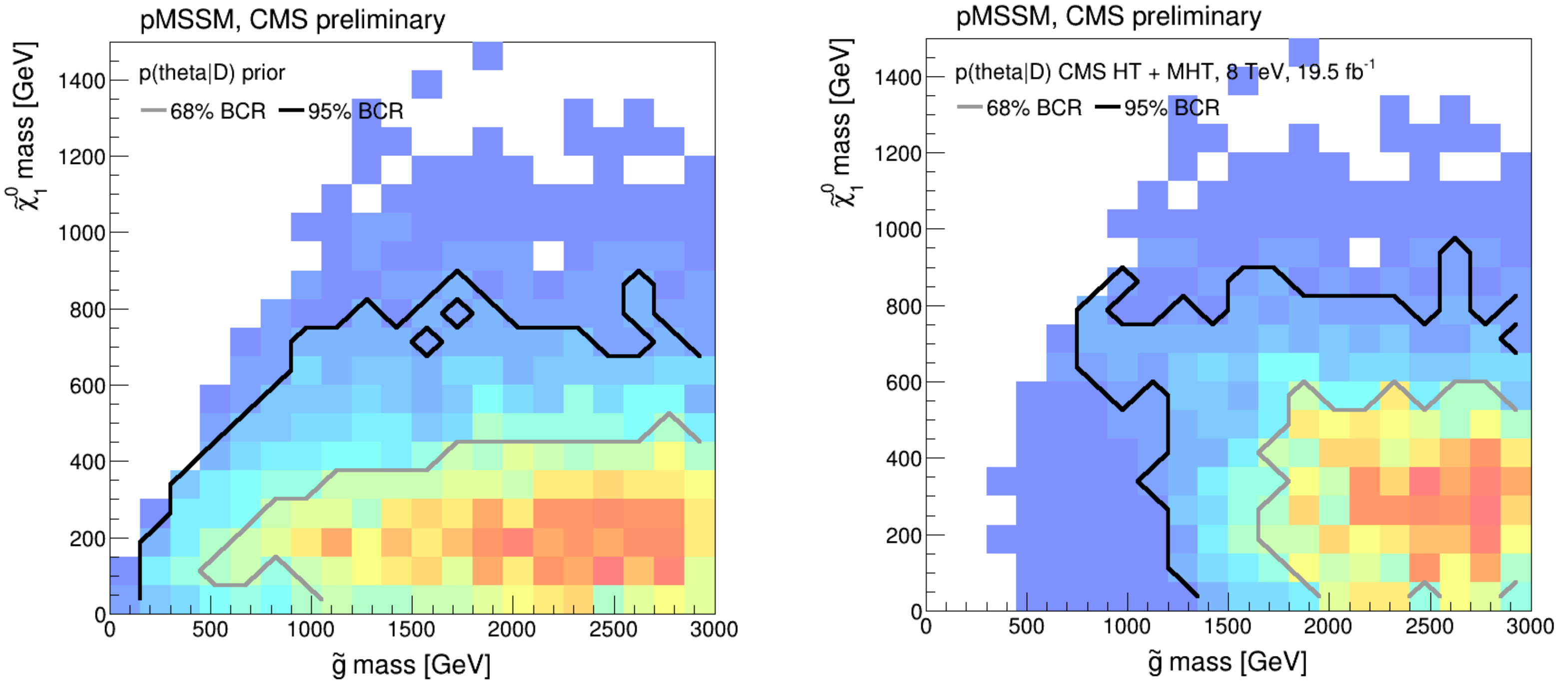


Distributions of excluded and not-excluded pMSSM models:

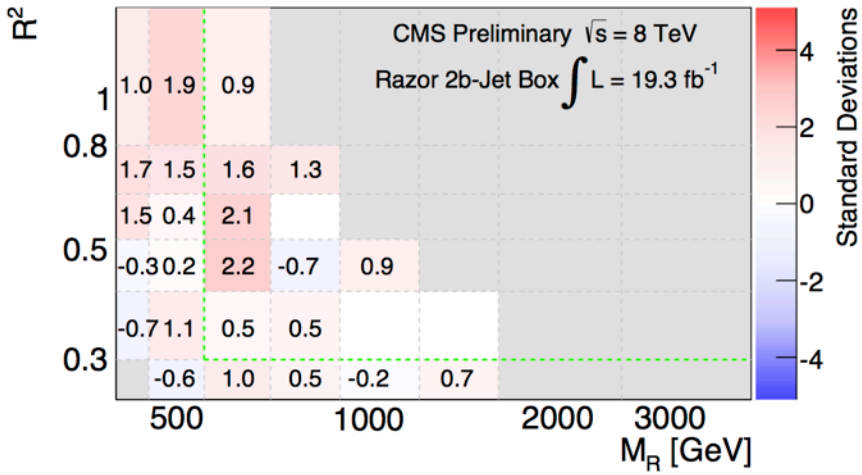
Multi-Jets + MHT – pMSSM

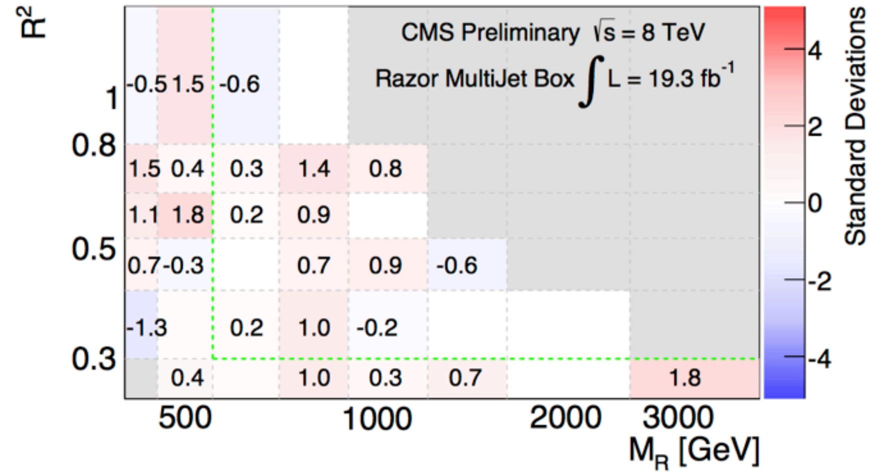
Different representation:

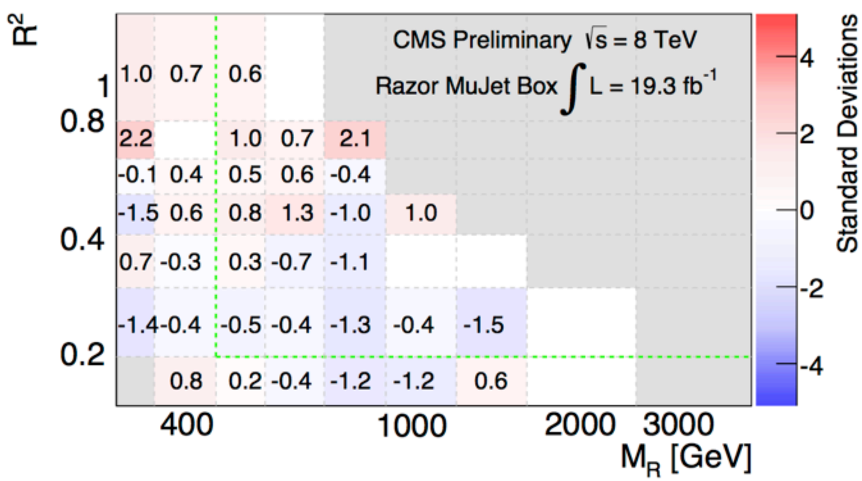
Marginalized posterior probability distribution for gluino mass versus LSP mass before and after including the Multi-Jet + MHT analysis.

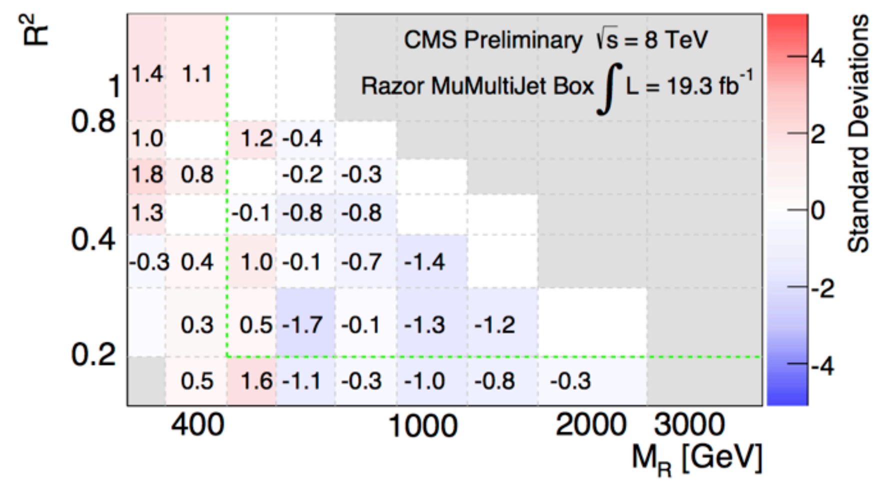


Razor – Binned Data-Bg Comparisons



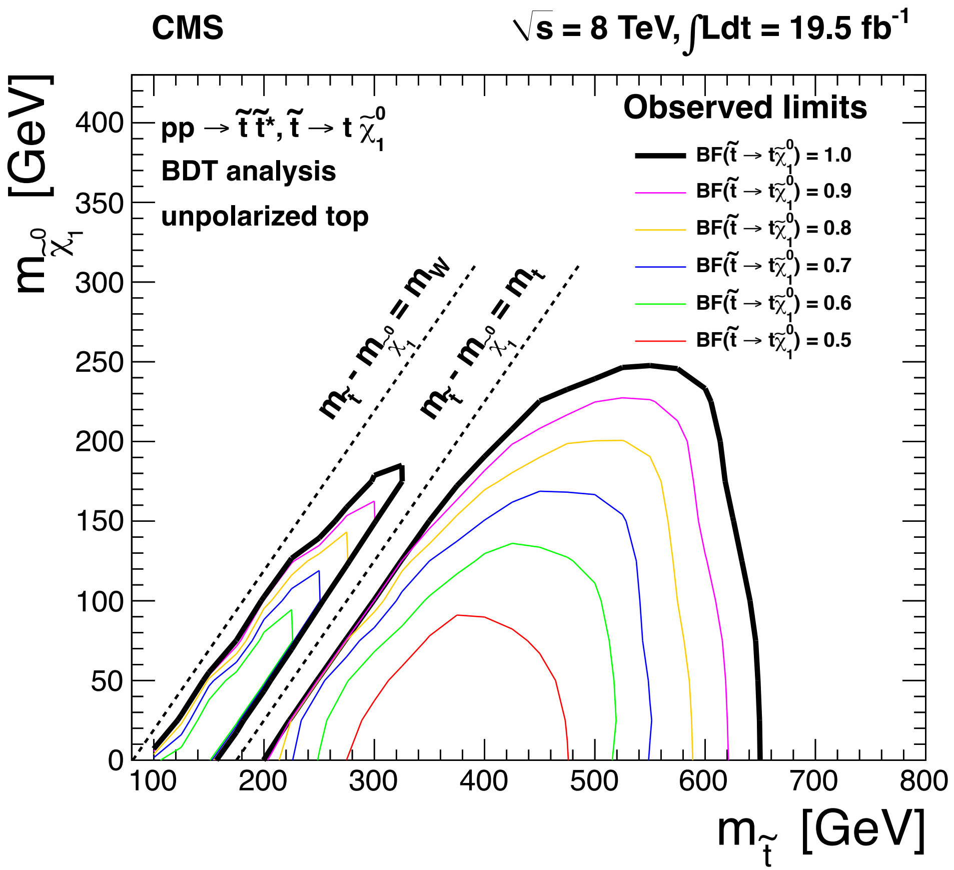






Direct Stop Searches

- Exclusion limits depend on branching ratios
- BUT: $\mathrm{Br}(\tilde{t} \to t\tilde{\chi}_1^0) < 1$ means that other decay channels my open up, for which this (or another analysis) also has some sensitivity



Same Sign Di-Leptons

Lepton acceptance:

	p_T (GeV)	$\|\eta\|$
electrons	$> 10(20)$	< 2.4 and $\notin [1.442, 1.566]$
muons	$> 10(20)$	< 2.4
jets	> 40	< 2.4
b-tagged jets	> 40	< 2.4

Trigger efficiencies:

channel	low-p_T	high-p_T
$\mu\mu$ $\|\eta\| < 1$	0.94 ± 0.06	0.90 ± 0.05
$\mu\mu$ $\|\eta\| > 1$	0.90 ± 0.05	0.81 ± 0.05
$e\mu$	0.93 ± 0.06	0.93 ± 0.06
ee $p_T < 30$ GeV	0.93 ± 0.06	0.92 ± 0.05
ee $p_T > 30$ GeV	0.93 ± 0.06	0.96 ± 0.06

Systematic uncertainties:

Source	%
Luminosity	4.4
Modeling of lepton selection (ID and isolation)	10
Jet energy scale	1–10
Jet energy resolution	0–3
b-jet identification	2–10
Trigger scaling	6
ISR modeling	3–15
Pileup modeling	5
Total	14–23

Search strategy:

H_T (GeV)	E_T^{miss} (GeV)	N_{jets}	$N_{b\text{-jets}}$	SR
> 250 (80)	> 30 if $H_T < 500$ else > 0	≥ 2	$= 0$	BSR0
> 250 (80)	> 30 if $H_T < 500$ else > 0	≥ 2	$= 1$	BSR1
> 250 (80)	> 30 if $H_T < 500$ else > 0	≥ 2	≥ 2	BSR2

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

N_{jets}	$N_{b\text{-jets}}$	E_T^{miss} (GeV)	H_T (GeV)	charge	SR
≥ 2	≥ 0	> 0	> 500	$++/--$	RPV0
≥ 2	≥ 2	> 0	> 500	$++/--$	RPV2
≥ 2	$= 1$	> 30	> 80	$++/--$	SStop1
≥ 2	$= 1$	> 30	> 80	$++$ only	SStop1++
≥ 2	≥ 2	> 30	> 80	$++/--$	SStop2
≥ 2	≥ 2	> 30	> 80	$++$ only	SStop2++

Same Sign Di-Leptons – Results

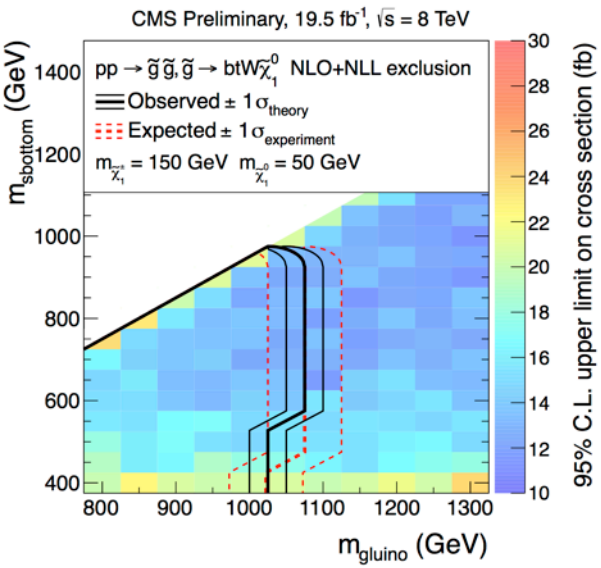
SR	low-p_T Expected			low-p_T Observed	high-p_T Expected			high-p_T Observed
1	44	±	16	50	51	±	18	48
2	12	±	4	17	9.0	±	3.5	11
3	12	±	5	13	8.0	±	3.1	5
4	9.1	±	3.4	4	5.6	±	2.1	2
5	21	±	8	22	20	±	7	12
6	13	±	5	18	9	±	4	11
7	3.5	±	1.4	2	2.4	±	1.0	1
8	5.8	±	2.1	4	3.6	±	1.5	3
11	32	±	13	40	36	±	14	29
12	6.0	±	2.2	5	3.8	±	1.4	5
13	17	±	7	15	10	±	4	6
14	10	±	4	6	5.9	±	2.2	2
15	13	±	5	9	11	±	4	11
16	5.5	±	2.0	5	3.9	±	1.5	2
17	4.2	±	1.6	3	2.8	±	1.1	3
18	6.8	±	2.5	11	4.0	±	1.5	7
21	7.6	±	2.8	10	7.1	±	2.5	12
22	1.5	±	0.7	1	1.0	±	0.5	1
23	7.1	±	2.7	6	3.8	±	1.4	3
24	4.4	±	1.7	11	2.8	±	1.2	7
25	2.8	±	1.1	1	2.9	±	1.1	4
26	1.3	±	0.6	2	0.8	±	0.5	1
27	1.8	±	0.8	0	1.2	±	0.6	0
28	3.4	±	1.3	3	2.2	±	1.0	2

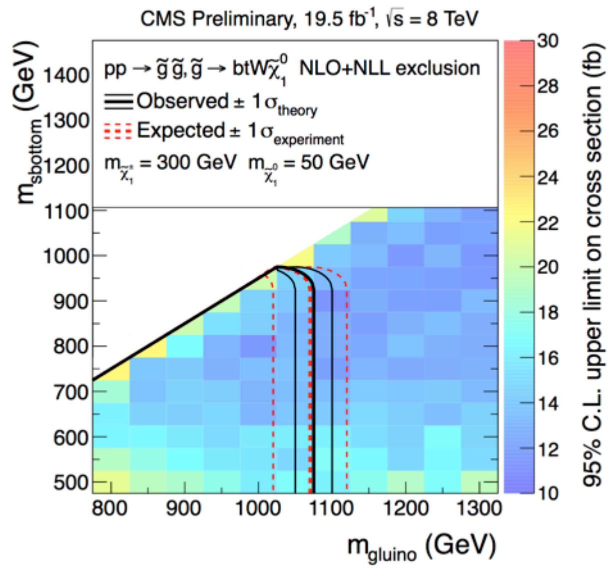
SR	Expected			Observed
RPV0	38	±	14	35
RPV2	5.3	±	2.1	5
SStop1	160	±	59	152
SStop1++	90	±	32	92
SStop2	40	±	13	52
SStop2++	22	±	8	25

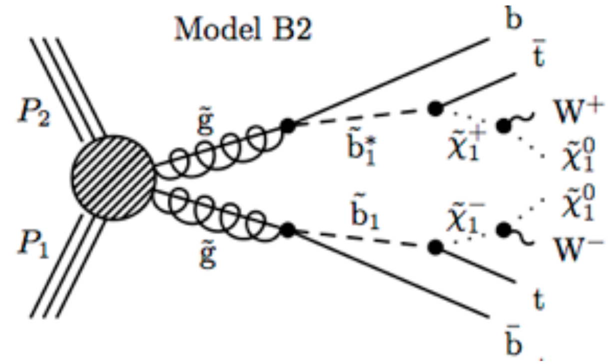
Most sensitive search bins for each tested model:

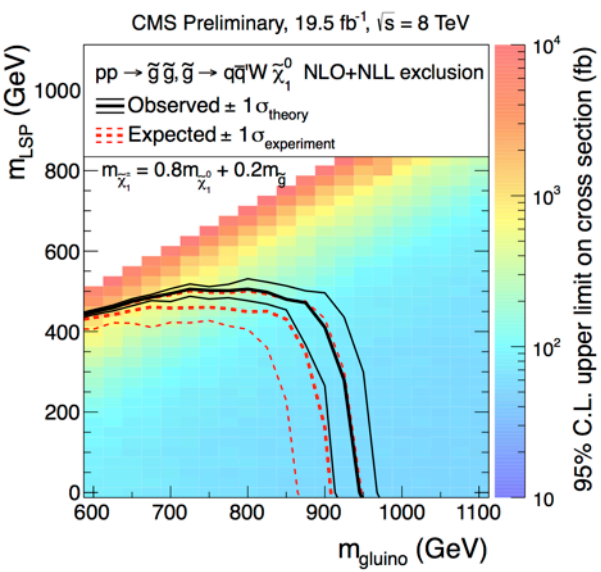
Model	Model parameter	Analysis	Signal Regions used
A1		high-p_T	21–28
A2	$m_{\chi_1^0} = 50$ GeV	high-p_T	21–28
B1	$m_{\chi_1^0} = 50$ GeV	high-p_T	11–18, 21–28
B1	$x = m_{\chi_1^0}/m_{\chi_1^\pm} = 0.5$	high-p_T	11–18, 21–28
B1	$x = m_{\chi_1^0}/m_{\chi_1^\pm} = 0.8$	low-p_T	11–18, 21–28
B2	$m_{\chi_1^0} = 50$ GeV, $m_{\chi_1^\pm} = 150$ GeV	high-p_T	21–28
B2	$m_{\chi_1^0} = 50$ GeV, $m_{\chi_1^\pm} = 300$ GeV	high-p_T	21–28
C1	$x = 0.5$	high-p_T	01–08
C1	$x = 0.8$	low-p_T	01–08
RPV		high-p_T	RPV2
$pp \to tt + \bar{t}\bar{t}$		high-p_T	SStop1, SStop2
$pp \to tt$		high-p_T	SStop1++, SStop2++
$pp \to tt\bar{t}\bar{t}$		high-p_T	21–28

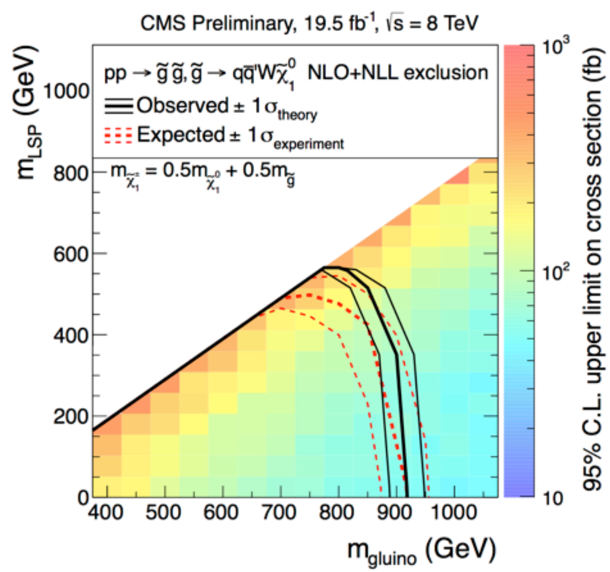
SS Di-Leptons – Interpretations

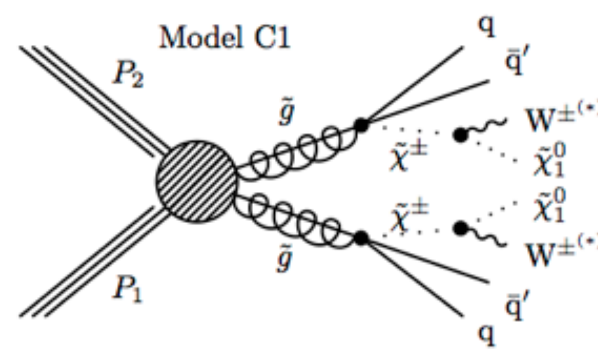




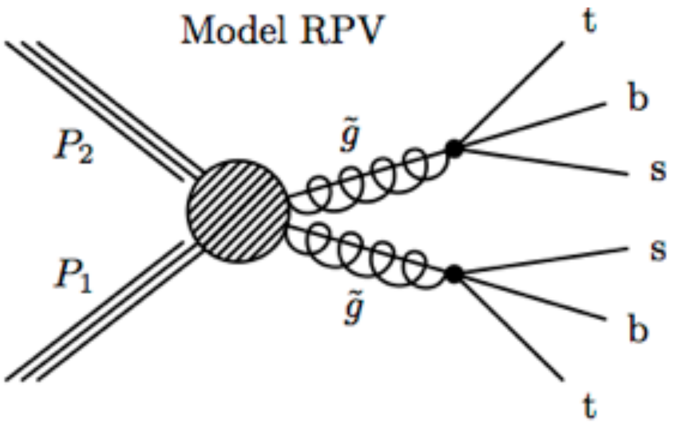


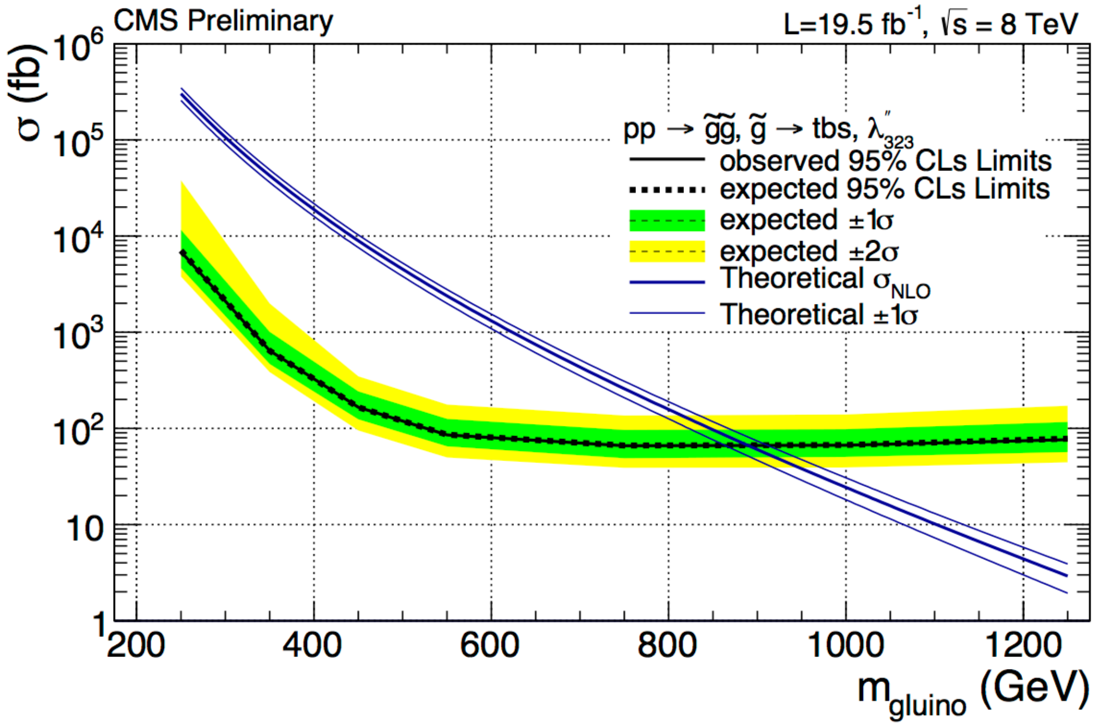






SS Di-Leptons – Interpretations





Electroweak Production

SUS-13-006

If coloured sparticles much heavier than EW partners

→ **Direct chargino/neutralino/slepton prod.**

Leptonic decay modes provide clean signature:

- Many leptons (up to 4) + MET
- Possibly SS of OSSF lepton pairs with $m_{\ell\ell} = m_Z$
- Low jet activity
- In case of WZ+MET final state:

$$M_{\mathrm{T}} = \sqrt{2E_{\mathrm{T}}^{\mathrm{miss}} p_{\mathrm{T}}^{l} (1 - \cos\Delta\phi_{l,E_{\mathrm{T}}^{\mathrm{miss}}})}$$

is discriminating (typically $M_T < M_W$ for bg)

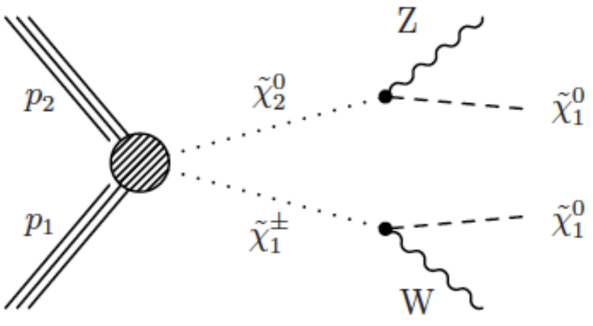
- In case of $\tilde{l}\tilde{l} \to l^+ l^- \tilde{\chi}_1^0 \tilde{\chi}_1^0$ M_{CT} is separating

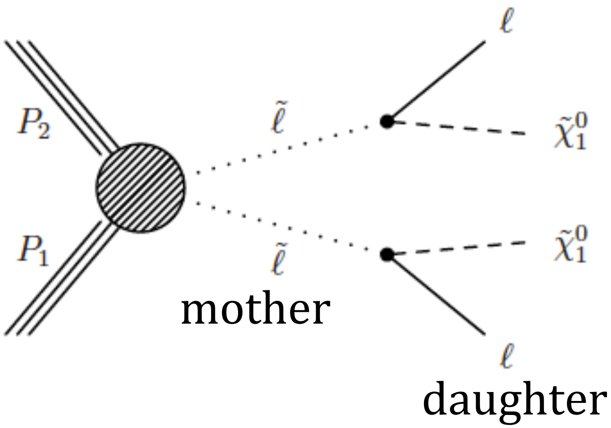
$$M_{\mathrm{CT}} = \sqrt{2m_l^2 + 2(E_{\mathrm{T}}^{l+} E_{\mathrm{T}}^{l-} + p_{\mathrm{T}}^{l+} \cdot p_{\mathrm{T}}^{l-})}$$

with

$$M_{\mathrm{CT}} < \frac{m_{\mathrm{mother}}^2 - m_{\mathrm{daughter}}^2}{m_{\mathrm{parent}}} \approx m_W \quad \text{for } WW \text{ bg}$$

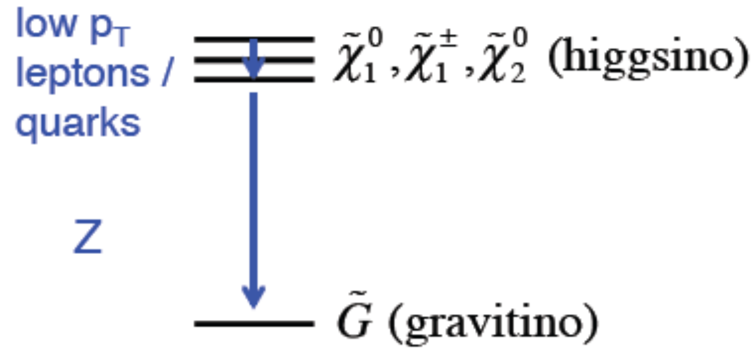
Example processes:

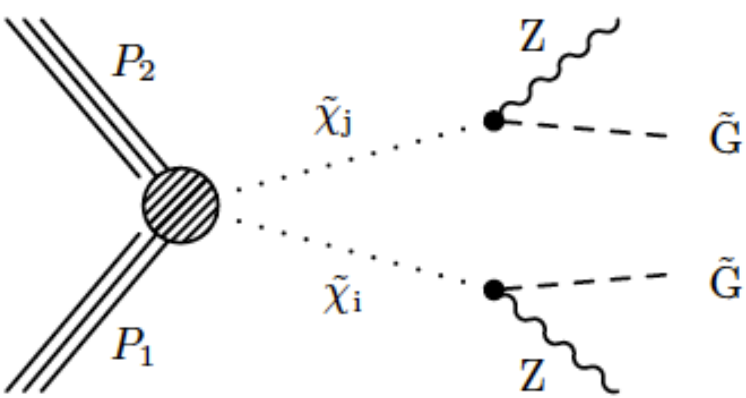


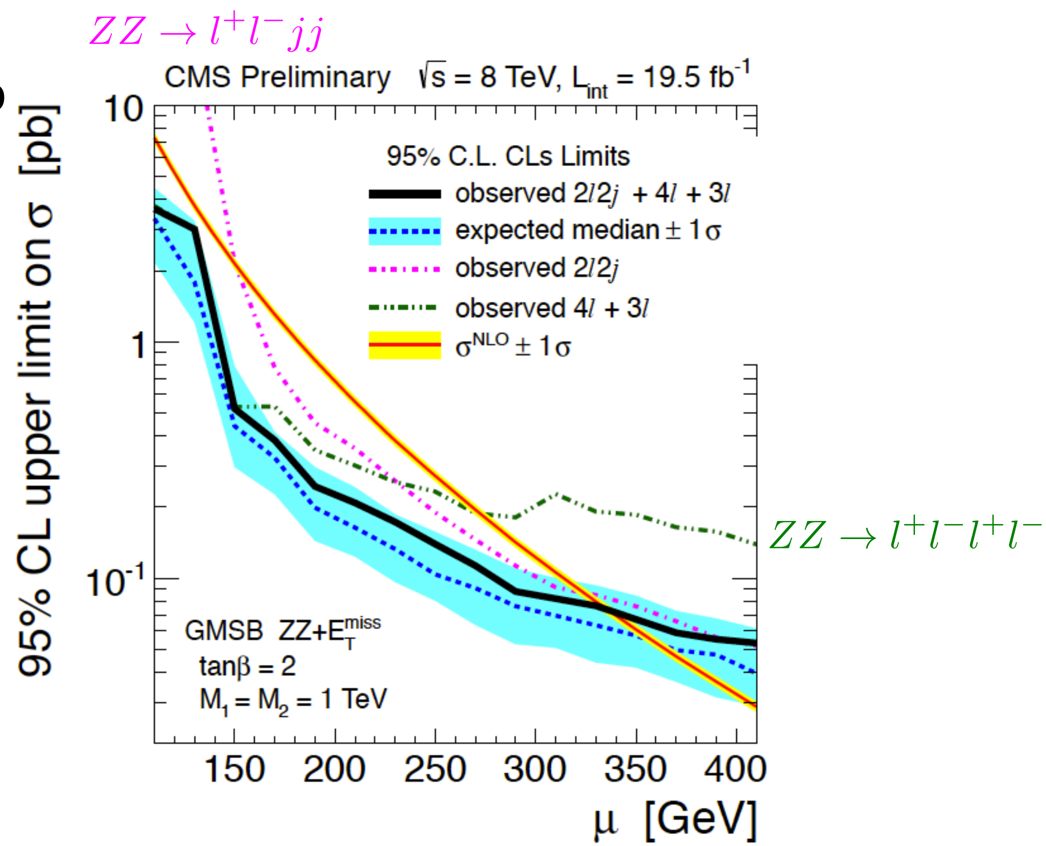


Multi-Lepton – Interpretation

- Light higgsino (μ ≤ few hundred GeV) preferred by naturalness
- Direct constraint in combined $4\ell/3\ell/2\ell+jj$ search on μ in GMSB models
- μ in range from from 110 GeV to 330 GeV excluded







Anomalous Multi-Leptons – Backgrounds

SUS-13-002

Bg from non-prompt leptons or tau candidates

- Data driven method to estimate using "tight-to-loose" ratios

Irreducible background from *WZ* / *ZZ* production

- From MC simulations + data driven MET correction

Bg from $t\bar{t}$

- From MC simulations + data driven MET and lepton efficiency corrections; N_{jet} reweighting validation in data control regions
- Apply correction factor for isolation efficiency of leptons from jets

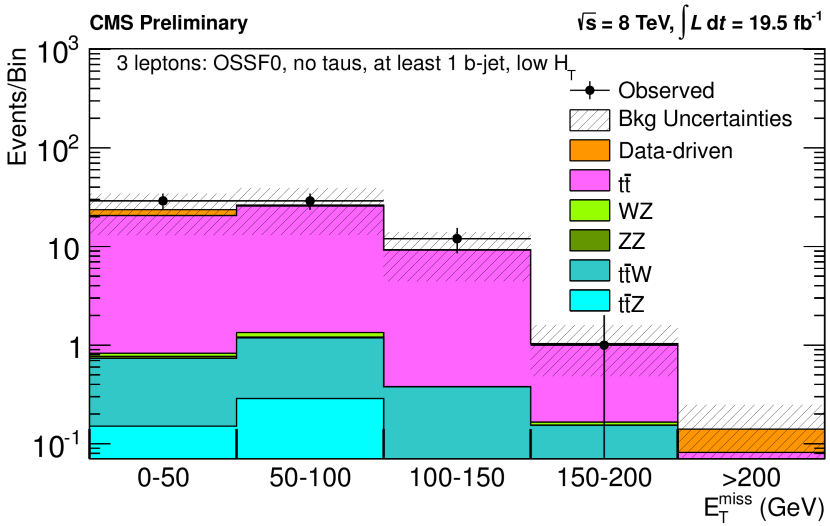
Small bg from asymmetric internal photon conversion

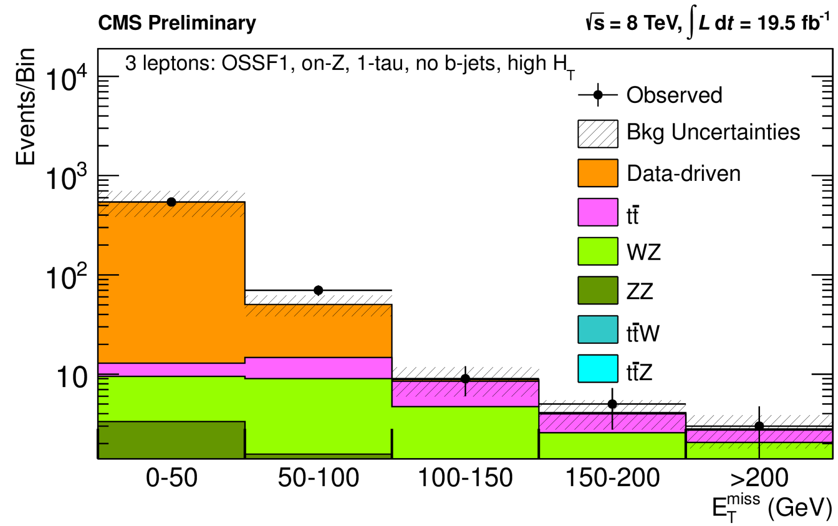
- *External conversion:* an on-shell γ converts to e^+e^- in detector material
- *Internal conversion:* virtual γ produces lepton pair; one can be soft and below p_T thresholds → Estimated from data by applying conversion probability to Z+γ events

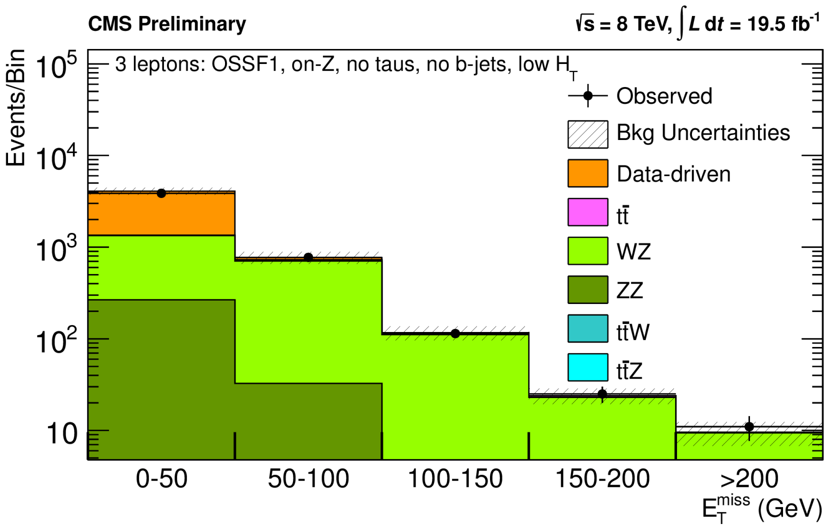
$$p_{\text{int. conversion}} \approx \frac{\#\text{ of evts. with } |m(l^+l^-l') - m_Z| < 15\text{ GeV}}{\#\text{ of evts. with } |m(l^+l^-\gamma) - m_Z| < 15\text{ GeV}}$$

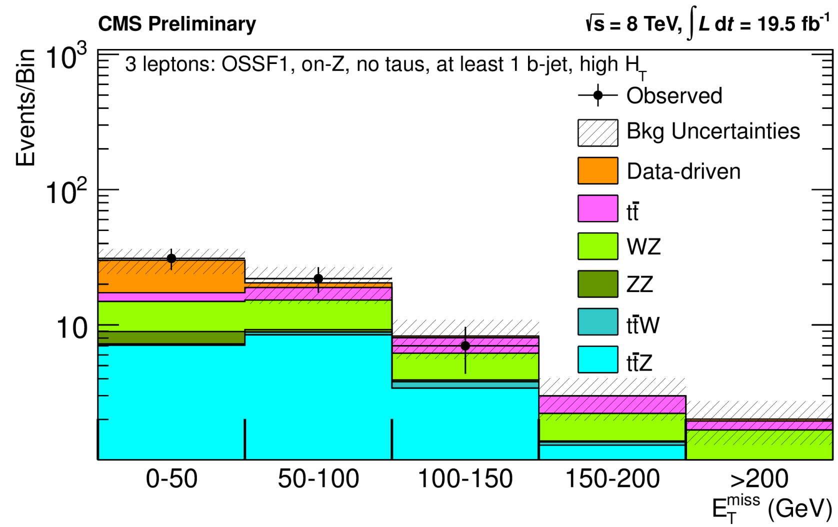
Anomalous Multi-Leptons – 3ℓ

MET distribution for four out of 64 categories, each with a completely different bg composition









Anomalous Multi-Leptons – 4ℓ

Selection 4 Lepton Results		E_T^{miss}	$N(\tau_h)=0, N_{b-jets}=0$ obs	exp	$N(\tau_h)=1, N_{b-jets}=0$ obs	exp	$N(\tau_h)=0, N_{b-jets}\geq 1$ obs	exp	$N(\tau_h)=1, N_{b-jets}\geq 1$ obs	exp
OSSF0 $H_T > 200$	NA	$(100,\infty)$	0	0.01 ± 0.03	0	0.01 ± 0.06	0	0.02 ± 0.04	0	0.11 ± 0.08
OSSF0 $H_T > 200$	NA	(50,100)	0	0 ± 0.02	0	0.01 ± 0.06	0	0 ± 0.03	0	0.12 ± 0.07
OSSF0 $H_T > 200$	NA	(0,50)	0	1e-05 $\pm$ 0.02	0	0.07 ± 0.1	0	0 ± 0.02	0	0.02 ± 0.02
OSSF1 $H_T > 200$	off-Z	$(100,\infty)$	0	0.005 ± 0.02	1	0.25 ± 0.11	0	0.13 ± 0.08	0	0.12 ± 0.12
OSSF1 $H_T > 200$	on-Z	$(100,\infty)$	1	0.1 ± 0.06	0	0.5 ± 0.27	0	0.42 ± 0.22	0	0.42 ± 0.19
OSSF1 $H_T > 200$	off-Z	(50,100)	0	0.07 ± 0.06	1	0.29 ± 0.13	0	0.04 ± 0.04	0	0.23 ± 0.13
OSSF1 $H_T > 200$	on-Z	(50,100)	0	0.23 ± 0.11	1	0.7 ± 0.31	0	0.23 ± 0.13	1	0.34 ± 0.16
OSSF1 $H_T > 200$	off-Z	(0,50)	0	0.02 ± 0.03	0	0.27 ± 0.12	0	0.03 ± 0.04	0	0.31 ± 0.15
OSSF1 $H_T > 200$	on-Z	(0,50)	0	0.2 ± 0.08	0	1.3 ± 0.47	0	0.06 ± 0.04	1	0.49 ± 0.19
OSSF2 $H_T > 200$	off-Z	$(100,\infty)$	0	0.01 ± 0.02	-	-	0	0.01 ± 0.06	-	-
OSSF2 $H_T > 200$	on-Z	$(100,\infty)$	1	0.15 ± 0.16	-	-	0	0.34 ± 0.18	-	-
OSSF2 $H_T > 200$	off-Z	(50,100)	0	0.03 ± 0.02	-	-	0	0.13 ± 0.09	-	-
OSSF2 $H_T > 200$	on-Z	(50,100)	0	0.8 ± 0.4	-	-	0	0.36 ± 0.19	-	-
OSSF2 $H_T > 200$	off-Z	(0,50)	1	0.27 ± 0.13	-	-	0	0.08 ± 0.05	-	-
OSSF2 $H_T > 200$	on-Z	(0,50)	5	7.4 ± 3.5	-	-	2	0.8 ± 0.4	-	-

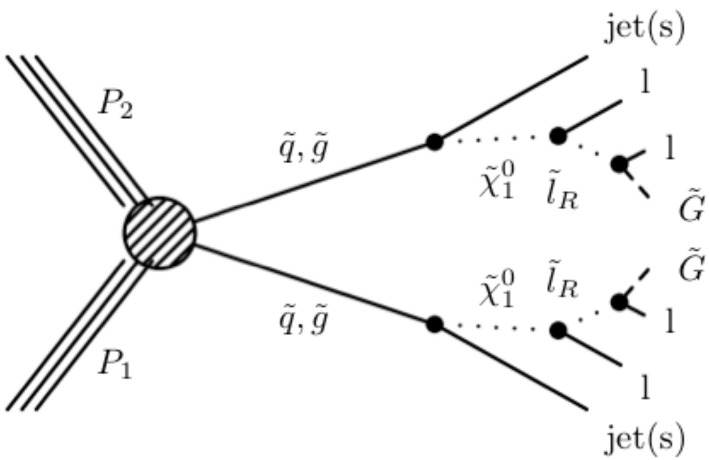
Selection 4 Lepton Results		E_T^{miss}	$N(\tau_h)=0, N_{b-jets}=0$ obs	exp	$N(\tau_h)=1, N_{b-jets}=0$ obs	exp	$N(\tau_h)=0, N_{b-jets}\geq 1$ obs	exp	$N(\tau_h)=1, N_{b-jets}\geq 1$ obs	exp
OSSF0 $H_T < 200$	NA	$(100,\infty)$	0	0.11 ± 0.08	0	0.17 ± 0.1	0	0.03 ± 0.04	0	0.04 ± 0.04
OSSF0 $H_T < 200$	NA	(50,100)	0	0.01 ± 0.03	2	0.7 ± 0.33	0	0 ± 0.02	0	0.28 ± 0.16
OSSF0 $H_T < 200$	NA	(0,50)	0	0.01 ± 0.02	1	0.7 ± 0.3	0	0.001 ± 0.02	0	0.13 ± 0.08
OSSF1 $H_T < 200$	off-Z	$(100,\infty)$	0	0.06 ± 0.04	3	0.6 ± 0.24	0	0.02 ± 0.04	0	0.32 ± 0.2
OSSF1 $H_T < 200$	on-Z	$(100,\infty)$	1	0.5 ± 0.18	2	2.5 ± 0.5	1	0.38 ± 0.2	0	0.21 ± 0.1
OSSF1 $H_T < 200$	off-Z	(50,100)	0	0.18 ± 0.06	4	2.1 ± 0.5	0	0.16 ± 0.08	1	0.45 ± 0.24
OSSF1 $H_T < 200$	on-Z	(50,100)	2	1.2 ± 0.34	9	9.6 ± 1.6	2	0.42 ± 0.23	0	0.5 ± 0.16
OSSF1 $H_T < 200$	off-Z	(0,50)	2	0.46 ± 0.18	15	7.5 ± 2	0	0.09 ± 0.06	0	0.7 ± 0.31
OSSF1 $H_T < 200$	on-Z	(0,50)	4	3 ± 0.8	41	40 ± 10	1	0.31 ± 0.15	2	1.5 ± 0.47
OSSF2 $H_T < 200$	off-Z	$(100,\infty)$	0	0.04 ± 0.03	-	-	0	0.05 ± 0.04	-	-
OSSF2 $H_T < 200$	on-Z	$(100,\infty)$	0	0.34 ± 0.15	-	-	0	0.46 ± 0.25	-	-
OSSF2 $H_T < 200$	off-Z	(50,100)	2	0.18 ± 0.13	-	-	0	0.02 ± 0.03	-	-
OSSF2 $H_T < 200$	on-Z	(50,100)	4	3.9 ± 2.5	-	-	0	0.5 ± 0.21	-	-
OSSF2 $H_T < 200$	off-Z	(0,50)	7	8.9 ± 2.4	-	-	1	0.23 ± 0.09	-	-
OSSF2 $H_T < 200$	on-Z	(0,50)	*156	159 ± 34	-	-	4	2.9 ± 0.8	-	-

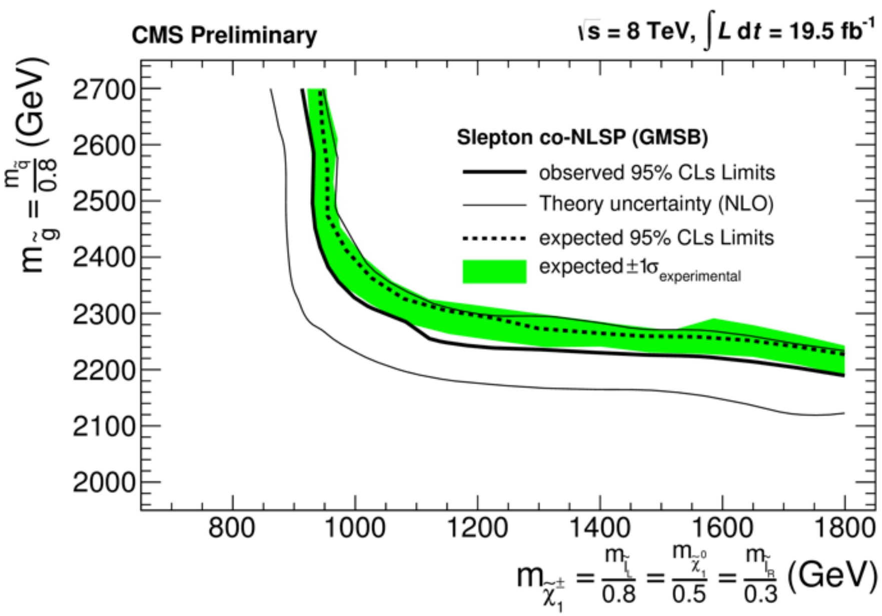
Anomalous Multi-Leptons – 3ℓ

Selection 3 Lepton Results		E_T^{miss}	$N(\tau_h)=0$, $N_{b-jets}=0$ obs	exp	$N(\tau_h)=1$, $N_{b-jets}=0$ obs	exp	$N(\tau_h)=0$, $N_{b-jets}\geq 1$ obs	exp	$N(\tau_h)=1$, $N_{b-jets}\geq 1$ obs	exp
OSSF0 $H_T > 200$	NA	(100,∞)	5	3.7 ± 1.6	35	33 ± 14	1	5.5 ± 2.2	47	61 ± 30
OSSF0 $H_T > 200$	NA	(50,100)	3	3.5 ± 1.4	34	36 ± 16	8	7.7 ± 2.7	82	91 ± 46
OSSF0 $H_T > 200$	NA	(0,50)	4	2.1 ± 0.8	25	25 ± 9.7	1	3.6 ± 1.5	52	59 ± 29
OSSF1 $H_T > 200$	above-Z	(100,∞)	5	3.6 ± 1.2	2	10 ± 4.8	3	4.7 ± 1.6	19	22 ± 11
OSSF1 $H_T > 200$	below-Z	(100,∞)	7	9.7 ± 3.3	18	14 ± 6.4	8	9.1 ± 3.4	21	23 ± 11
OSSF1 $H_T > 200$	on-Z	(100,∞)	39	61 ± 23	17	15 ± 4.9	9	14 ± 4.4	10	12 ± 5.8
OSSF1 $H_T > 200$	above-Z	(50,100)	4	5 ± 1.6	14	11 ± 5.2	6	6.8 ± 2.4	32	30 ± 15
OSSF1 $H_T > 200$	below-Z	(50,100)	10	11 ± 3.8	24	19 ± 6.4	10	9.9 ± 3.7	25	32 ± 16
OSSF1 $H_T > 200$	on-Z	(50,100)	78	80 ± 32	70	50 ± 11	22	22 ± 6.3	36	24 ± 9.8
OSSF1 $H_T > 200$	above-Z	(0,50)	3	7.3 ± 2	41	33 ± 8.7	4	5.3 ± 1.5	15	23 ± 11
OSSF1 $H_T > 200$	below-Z	(0,50)	26	25 ± 6.8	110	86 ± 23	5	10 ± 2.5	24	26 ± 11
OSSF1 $H_T > 200$	on-Z	(0,50)	*135	127 ± 41	542	543 ± 159	31	32 ± 6.5	86	75 ± 19

Selection 3 Lepton Results		E_T^{miss}	$N(\tau_h)=0$, $N_{b-jets}=0$ obs	exp	$N(\tau_h)=1$, $N_{b-jets}=0$ obs	exp	$N(\tau_h)=0$, $N_{b-jets}\geq 1$ obs	exp	$N(\tau_h)=1$, $N_{b-jets}\geq 1$ obs	exp
OSSF0 $H_T < 200$	NA	(100,∞)	7	11 ± 4.9	101	111 ± 54	13	10 ± 5.3	87	119 ± 61
OSSF0 $H_T < 200$	NA	(50,100)	35	38 ± 15	406	402 ± 152	29	26 ± 13	269	298 ± 151
OSSF0 $H_T < 200$	NA	(0,50)	53	51 ± 11	910	1035 ± 255	29	23 ± 10	237	240 ± 113
OSSF1 $H_T < 200$	above-Z	(100,∞)	18	13 ± 3.5	25	38 ± 18	10	6.5 ± 2.9	24	35 ± 18
OSSF1 $H_T < 200$	below-Z	(100,∞)	21	24 ± 9	41	50 ± 25	14	20 ± 10	42	54 ± 28
OSSF1 $H_T < 200$	on-Z	(100,∞)l	150	152 ± 26	39	48 ± 13	15	14 ± 4.8	19	23 ± 11
OSSF1 $H_T < 200$	above-Z	(50,100)	50	46 ± 9.7	169	139 ± 48	20	18 ± 8	85	93 ± 47
OSSF1 $H_T < 200$	below-Z	(50,100)	142	125 ± 27	353	355 ± 92	48	48 ± 23	140	133 ± 68
OSSF1 $H_T < 200$	on-Z	(50,100)	*773	777 ± 116	1276	1154 ± 306	56	47 ± 13	81	75 ± 32
OSSF1 $H_T < 200$	above-Z	(0,50)	178	196 ± 35	1676	1882 ± 540	17	18 ± 6.7	115	94 ± 42
OSSF1 $H_T < 200$	below-Z	(0,50)	510	547 ± 87	9939	8980 ± 2660	34	42 ± 11	226	228 ± 63
OSSF1 $H_T < 200$	on-Z	(0,50)	*3869	4105 ± 666	*50188	50162 ± 14984	*148	156 ± 24	906	925 ± 263

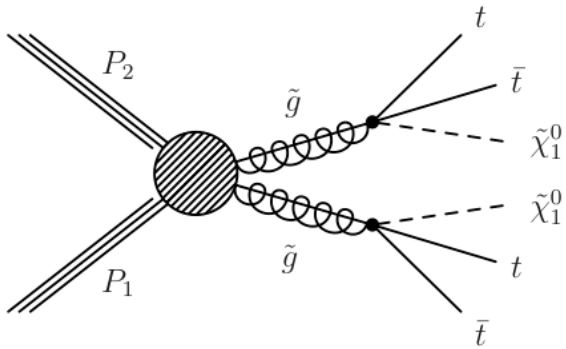
Slepton co-NLSP

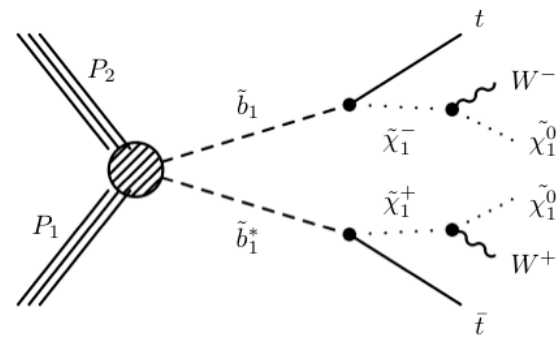


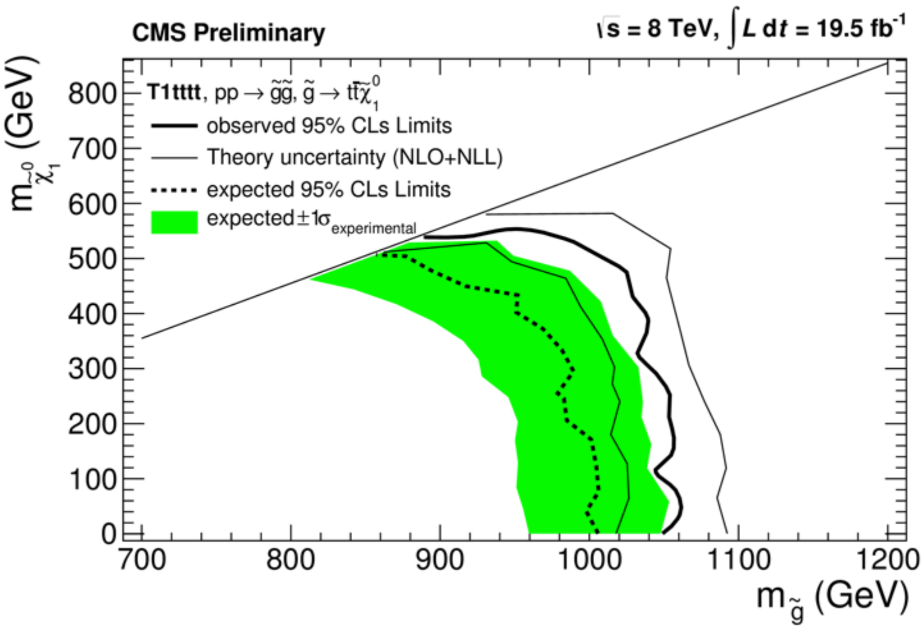


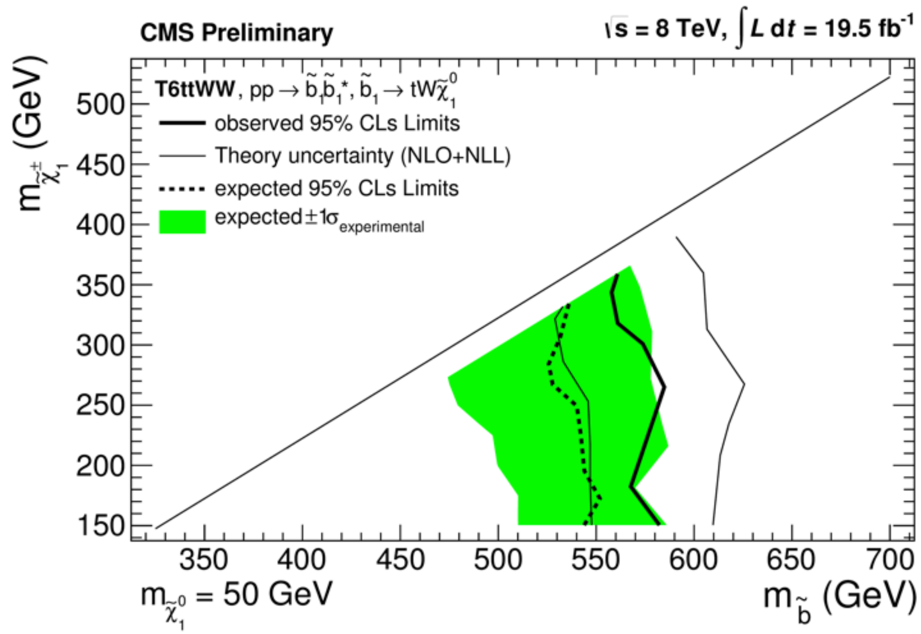
	Production mode	σ_{NLO} (fb)
	left end point	
$m_{\tilde{\chi}_1^\pm} = 900$ GeV $m_{\tilde{g}} = 2700$ GeV $\sigma_{NLO}^{total} = 3.3$ fb $\epsilon \times A = 8.9\,\%$	$\tilde{\tau}_1\bar{\tilde{\tau}}_1$	0.96
	$\tilde{e}_R\bar{\tilde{e}}_R$	0.91
	$\tilde{\mu}_R\bar{\tilde{\mu}}_R$	0.91
	$\tilde{\chi}_2^0\tilde{\chi}_1^\pm$	0.16
	$\tilde{\ell}_L\bar{\tilde{\nu}}_\ell$	0.083
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$	0.077
	$\tilde{\tau}_2\bar{\tilde{\nu}}_\tau$	0.039
	$\tilde{\nu}_\ell\bar{\tilde{\nu}}_\ell$	0.019
	$\tilde{\mu}_L\bar{\tilde{\mu}}_L$	0.014
	$\tilde{\nu}_\tau\bar{\tilde{\nu}}_\tau$	0.014
	$\tilde{e}_L\bar{\tilde{e}}_L$	0.011
	right end point	
$m_{\tilde{\chi}_1^\pm} = 1800$ GeV $m_{\tilde{g}} = 2200$ GeV $\sigma_{NLO}^{total} = 0.53$ fb $\epsilon \times A = 46\,\%$	$\tilde{q}_R^i\tilde{q}_R^j$	0.15
	$\tilde{q}_L^i\tilde{q}_L^j$	0.15
	$\tilde{q}_L^i\tilde{q}_R^j$	0.036
	$\tilde{e}_R\bar{\tilde{e}}_R$	0.036
	$\tilde{\tau}_1\bar{\tilde{\tau}}_1$	0.035
	$\tilde{\mu}_R\bar{\tilde{\mu}}_R$	0.033
	$\tilde{q}_L^i\bar{\tilde{q}}_R^j$	0.025
	$\tilde{q}_R^j\tilde{g}$	0.024
	$\tilde{q}_L^j\tilde{g}$	0.022
	$\tilde{q}_R^j\tilde{\chi}_1^0$	0.006

Anomalous Multi-Leptons









Natural SUSY under Pressure