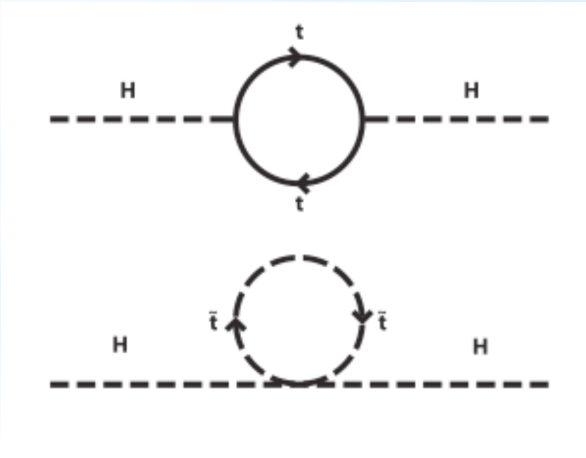
* recent SUSY results from CMS

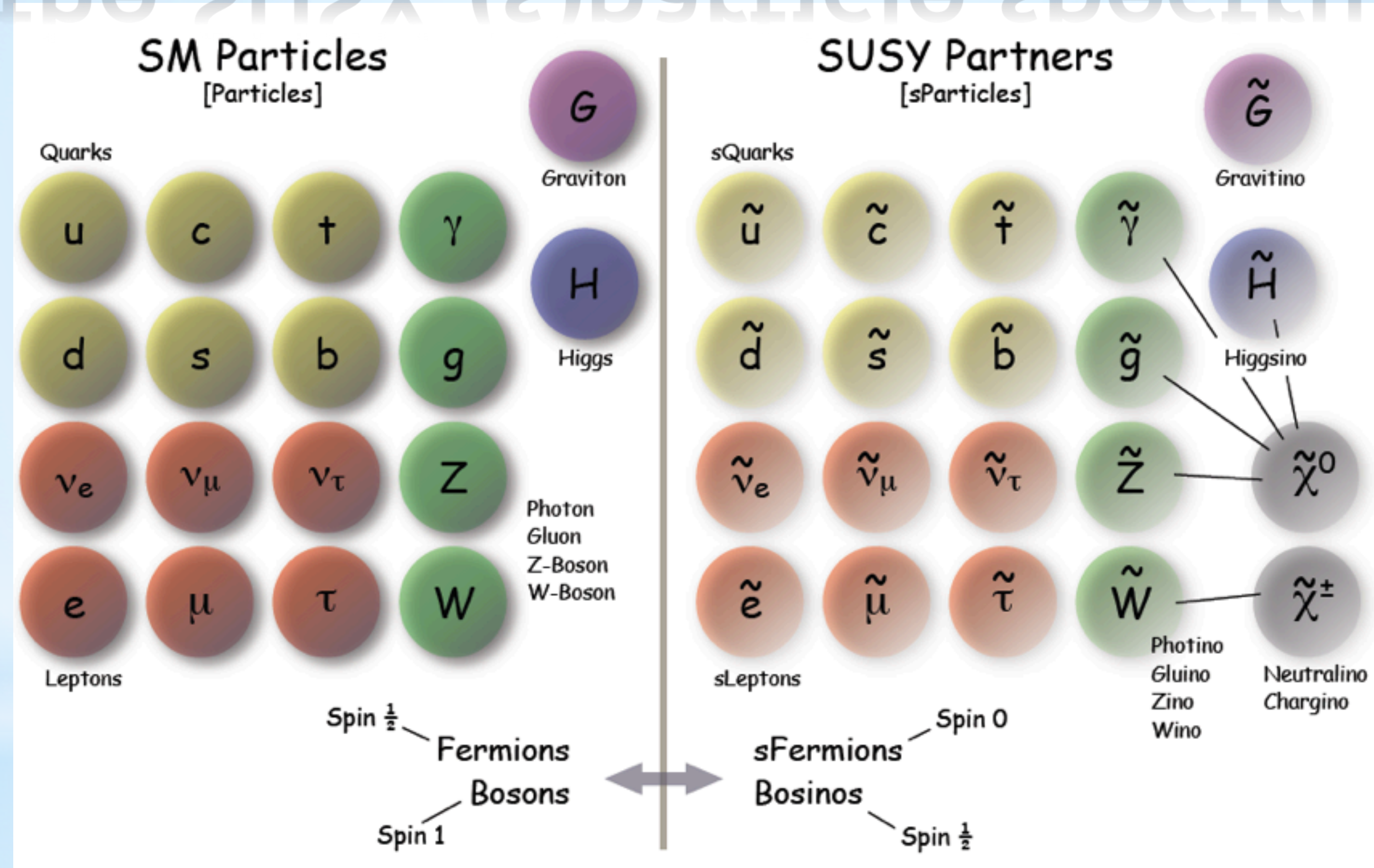
Henning Flaecher
University of Bristol
for the CMS Collaboration

*motivation for supersymmetry

- Supersymmetry is a global symmetry of spin
  - each fermion has a bosonic partner, and vice versa
  - all other properties identical
- Supersymmetry is theoretically well motivated
  - it provides a solution to the hierarchy problem
  - unification of gauge couplings
  - can provide a candidate for Dark Matter
- Higher order corrections to Higgs mass
  - fermion and boson loops have opposite sign
  - hence the quadratic divergences cancel
- Next step in understanding of fundamental science, after Higgs-like boson discovery



the SUSY (s)particle spectrum



* Search for ~all of these, produced either directly or in cascades

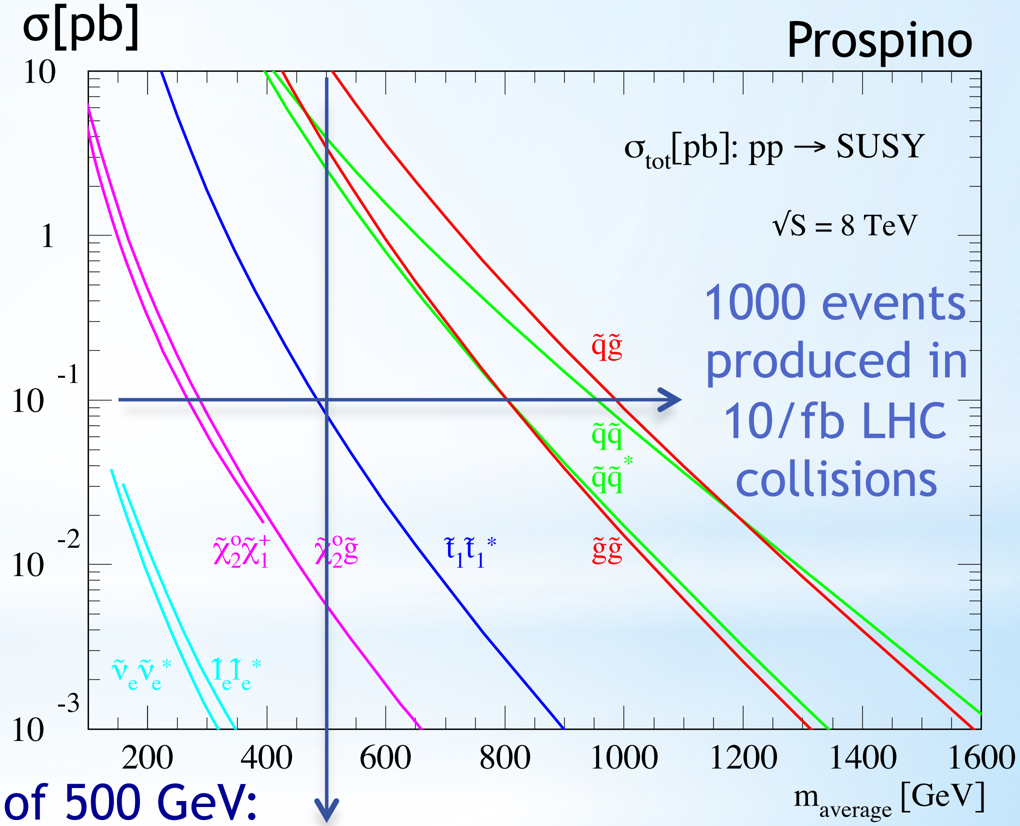
*production of SUSY particles at the LHC

* Highest cross section for production of 1st & 2nd generation squarks and gluinos

* Direct production of electroweakinos and stops/sbottoms are in reach with current integrated luminosity

* Searches include those for:
  * neutralinos/charginos
  * stops and sbottoms
  * but also staus
  * either produced directly or in gluino decays

* Experimental signatures involve:
  * multiple leptons
  * tops
  * multiple b-jets
  * taus
  * missing energy

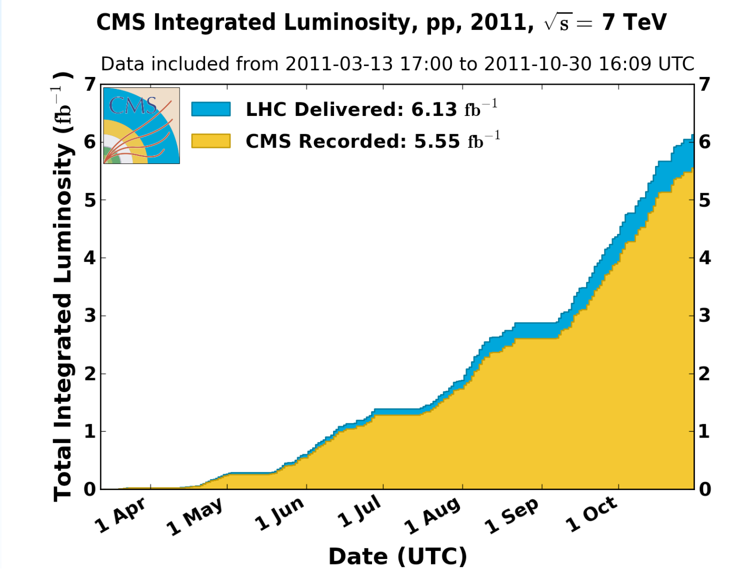


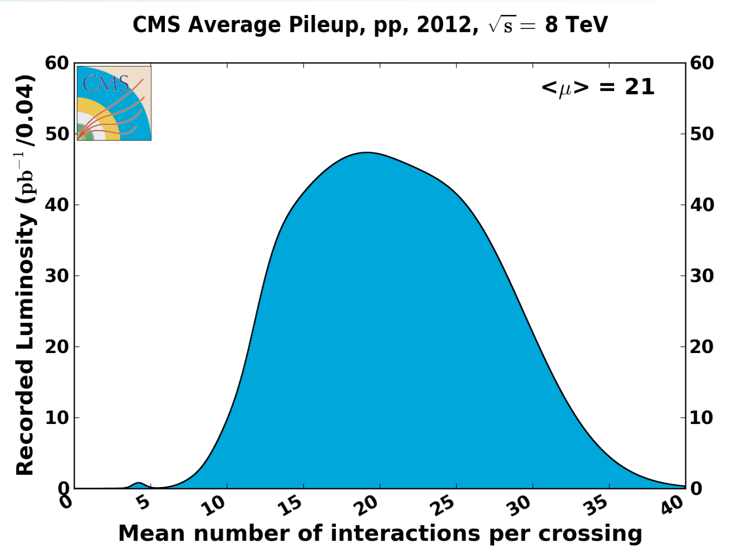
At mass of 500 GeV:

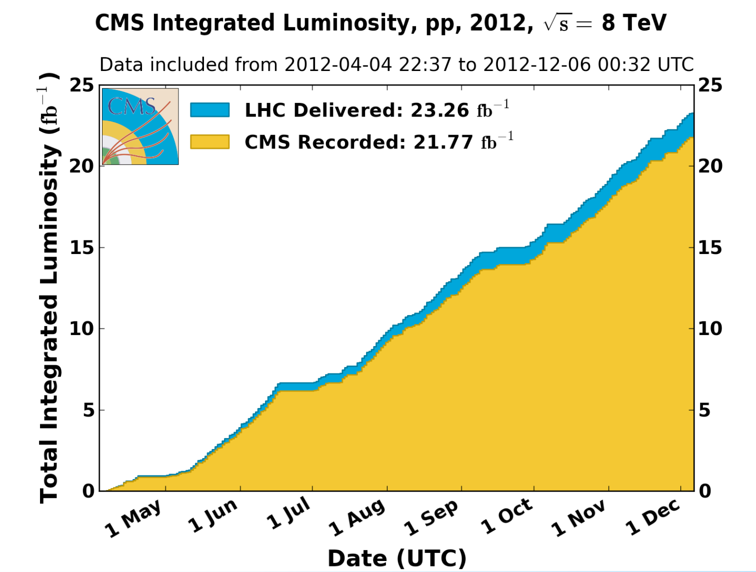
40k gluino pairs, 1000 stops, 50 chargino/neutralino pairs in 10/fb

* data recorded by CMS

* 2011 / 7 TeV analyses:
  * used 4.98/fb of certified data
* 2012 / 8 TeV analyses:
  * used between 9.2/fb and 11.7/fb of certified data
* Very different pile-up scenario in 2012







* CMS search overview

* Recent results:

* Direct production of charginos, neutralinos & sleptons
    * Multilepton searches – SUS-12-022, SUS-12-026, SUS-12-027
    * di-tau searches with the razor variables – SUS-11-029

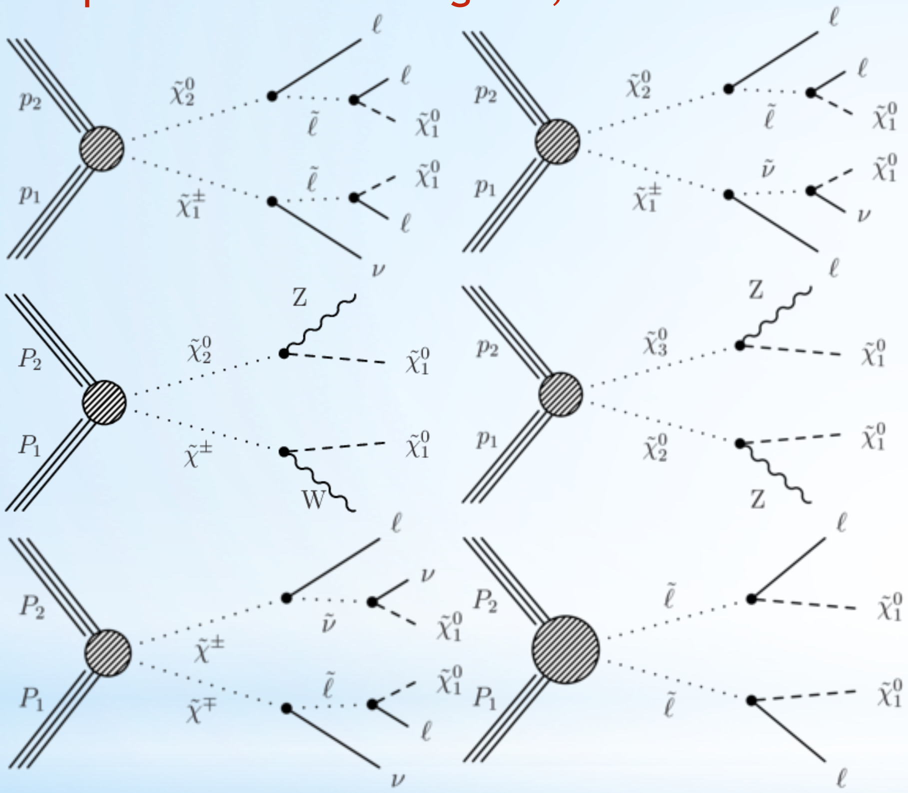
* Searches for direct stop pair production
    * Hadronic decays SUS-11-030 and semileptonic decays – SUS-12-023

* Inclusive searches with (multiple) b-tags
    * direct and gluino mediated production of sbottoms and stops
    * Hadronic HT and α_T – SUS-12-028
    * Same-sign di-leptons + multiple b-tags – SUS-12-029

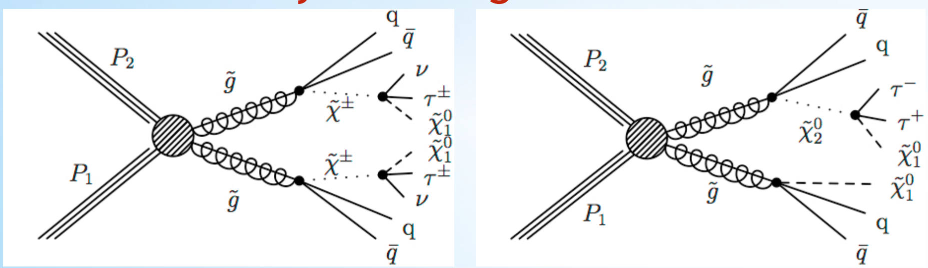
SUSY signatures

Interpretation in Simplified Models

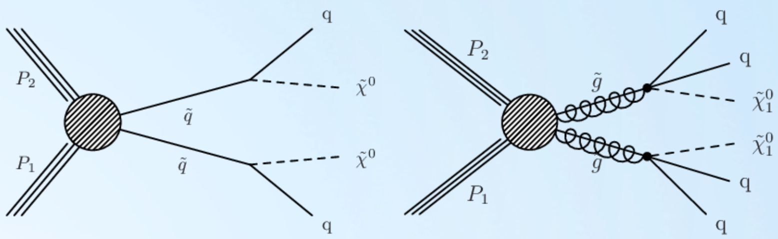
Direct production of charginos, neutralinos & sleptons



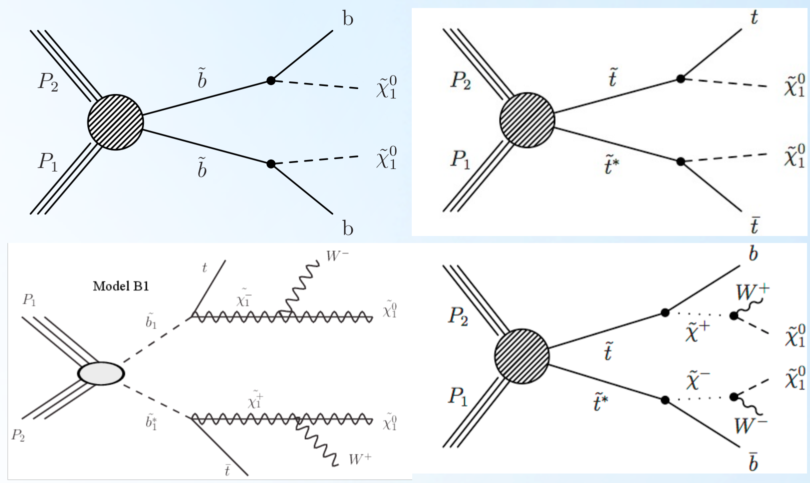
Taus in decays of charginos and neutralinos



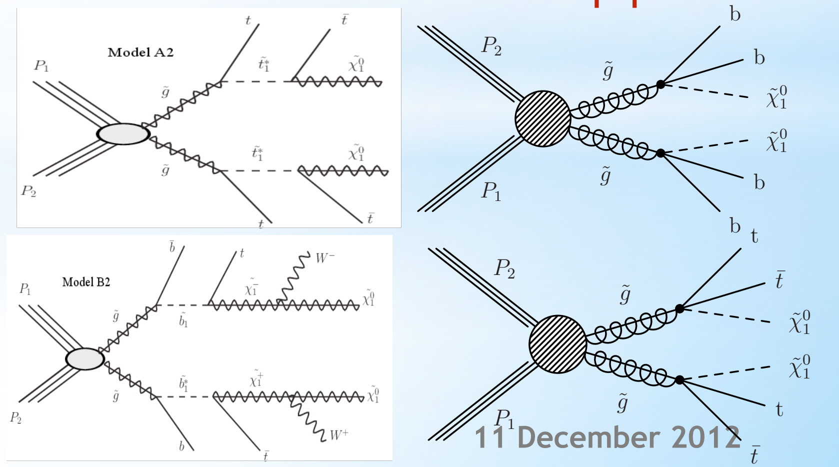
Squark and gluino production



Direct sbottom and stop production



Gluino mediated sbottom and stop production



*multilepton searches

* mostly searching for direct chargino, neutralino and slepton production

* multilepton search   SUS-12-022

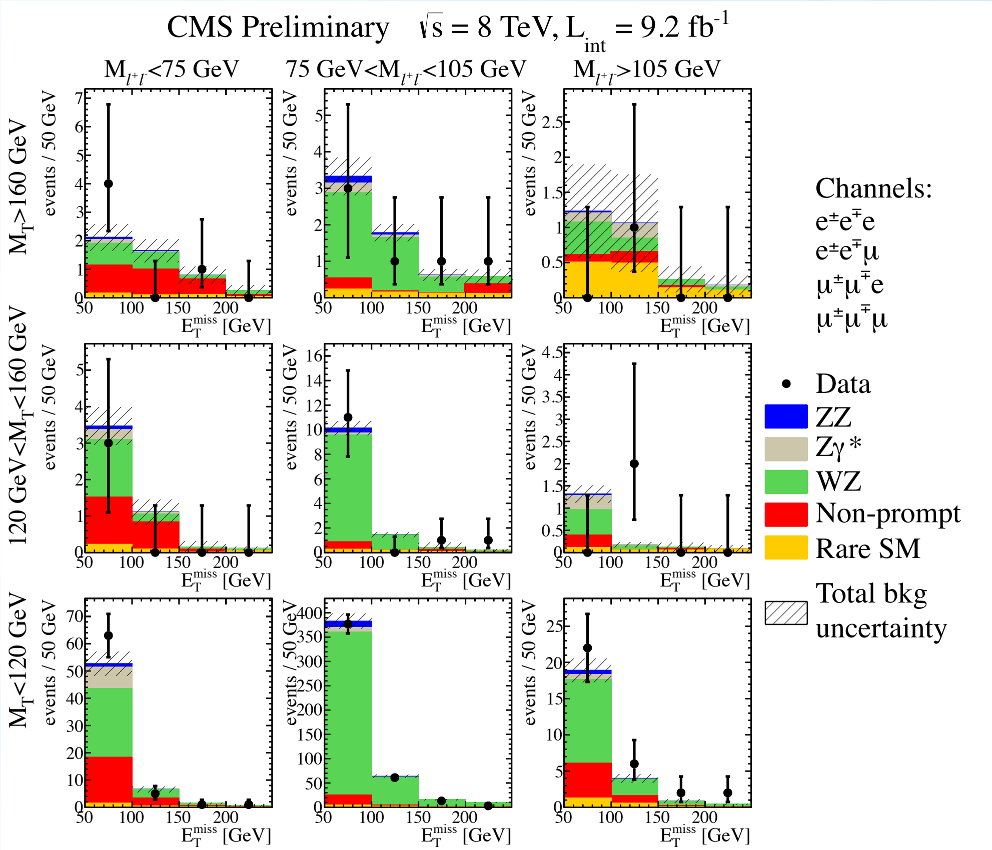
* Decays of charginos, neutralinos and sleptons can result in **large lepton multiplicities**
  * rare in the SM, mainly di-boson production: WZ, ZZ
  * categorization into:
    * 3 lepton
    * 4 lepton
    * same-sign (SS) di-lepton
    * opposite-sign-same-flavour (OSSF) di-leptons (Z) + 2 jets
    * non-resonant OS dilepton final states (Z veto)

SUS-12-022

multilepton search - 3 leptons

- 3 leptons
  - leading lepton p_T > 20 GeV
  - trailing leptons p_T > 10 GeV
- Search in bins of M_{ll}, MET and MT
  - veto b-jets to suppress top BG
- Distinguish
  - OSSF pair, no tau
  - no OSSF pair, no tau
  - SS pair and tau
  - OSOF pair and tau

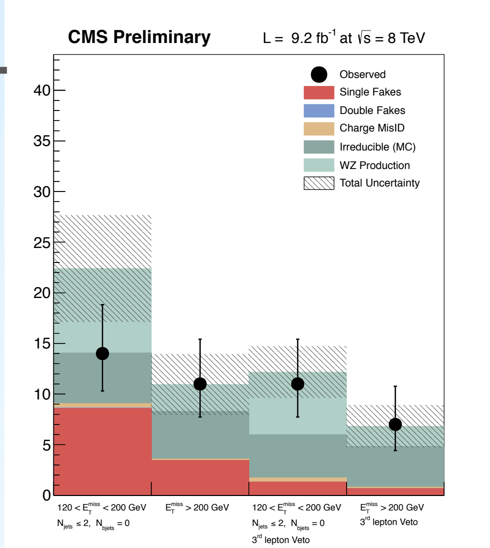
OSSF dilepton pairs (no tau)



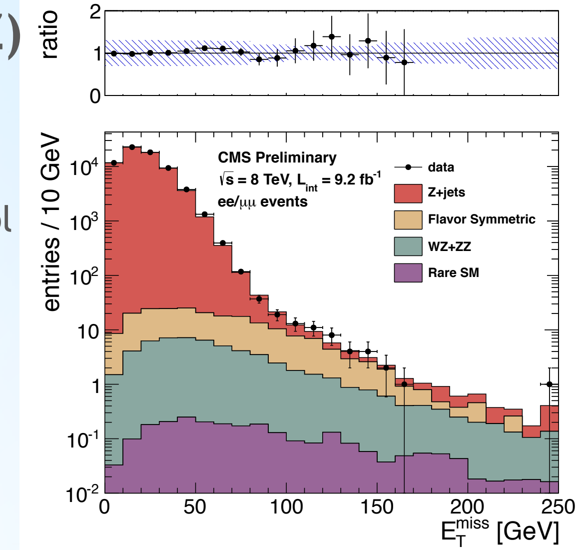
* di-lepton channels

SUS-12-022

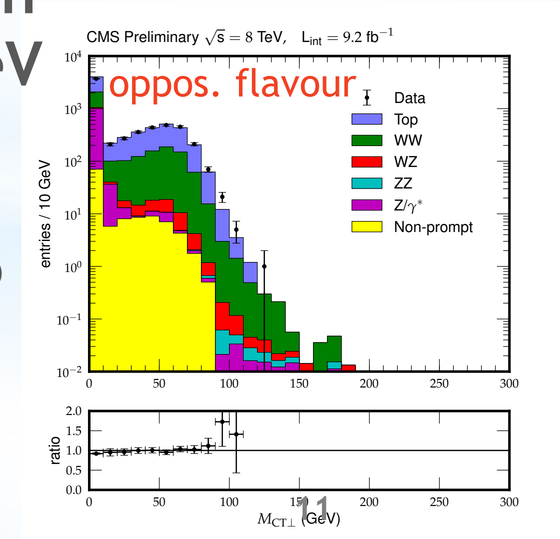
* SS di-leptons as fctn of MET
  * WZ BG from Z enriched control sample
  * non-prompt leptons from tight/loose ratios

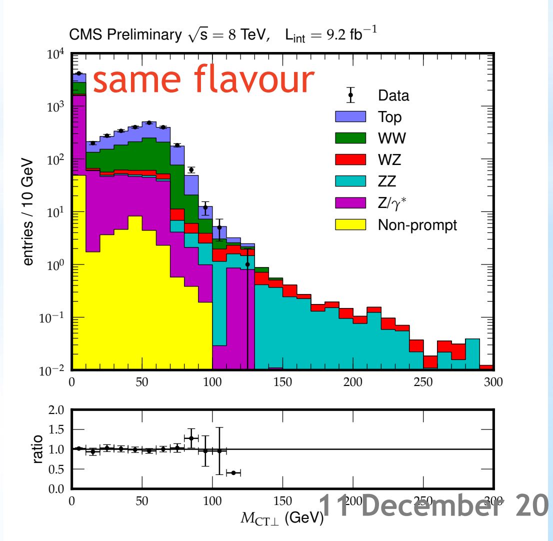


* OS di-leptons (Z) + 2 jets as fctn of MET
  * Z+jet BG from gamma+jet control sample
  * flavour symmetric BG from emu events
  * rare BG (ttZ, ZZZ, ZZW, ZWW) from MC



* non-res OS di-lepton using $M_{CT\perp}$ > 100 GeV
  * background obtained with templates from control regions, fit to low M_{CT} region

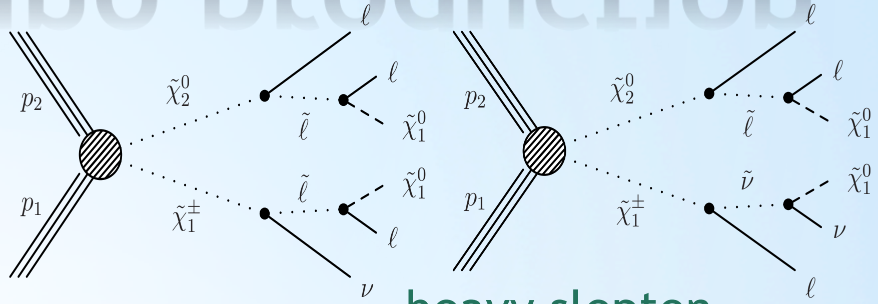


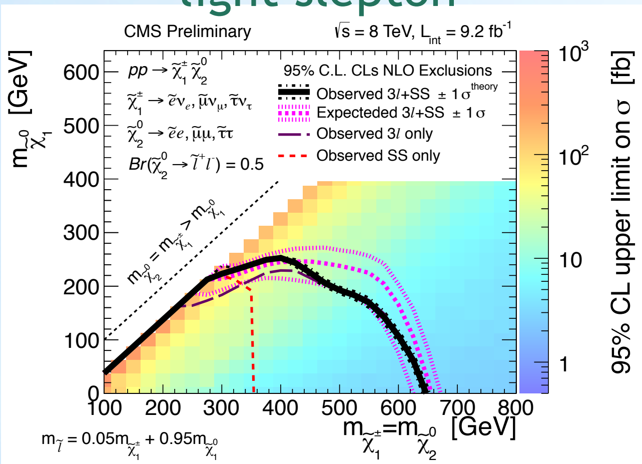


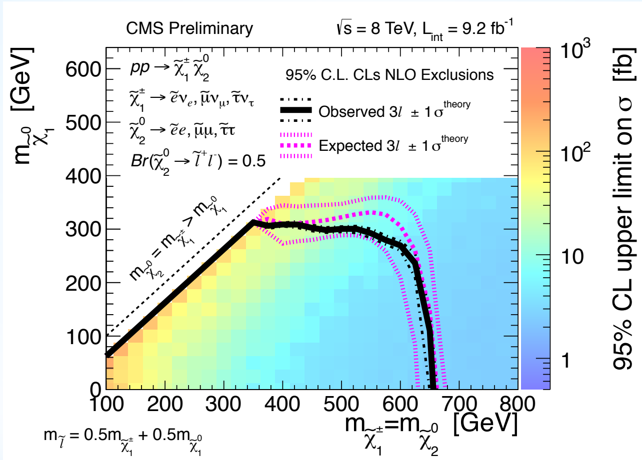
SUS-12-022

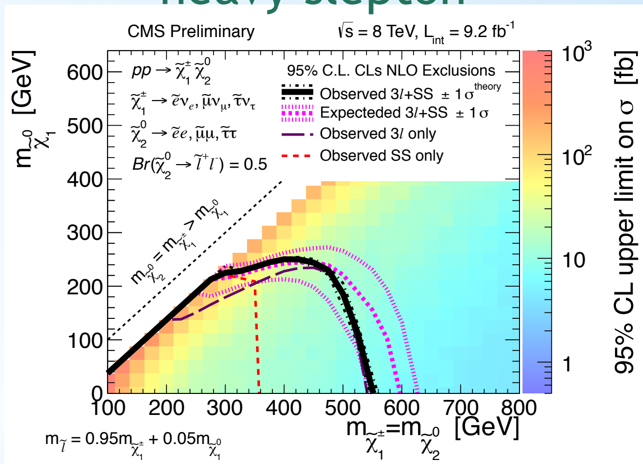
*neutralino-chargino production

* 3 lepton search
  * includes SS dilepton (missed soft lepton)

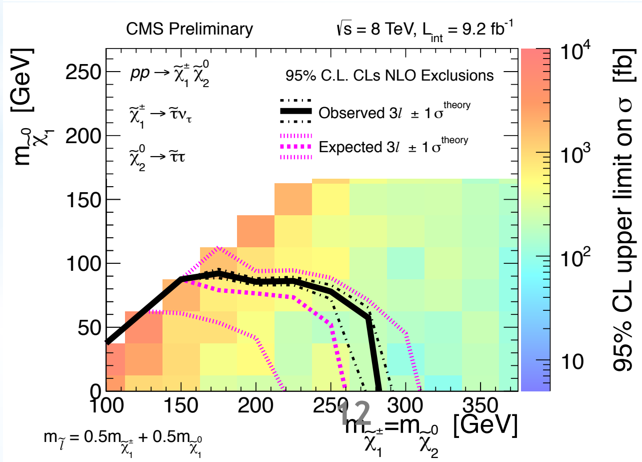






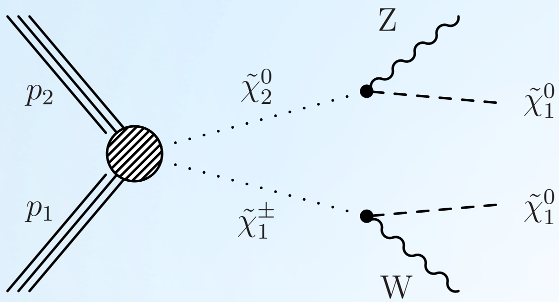


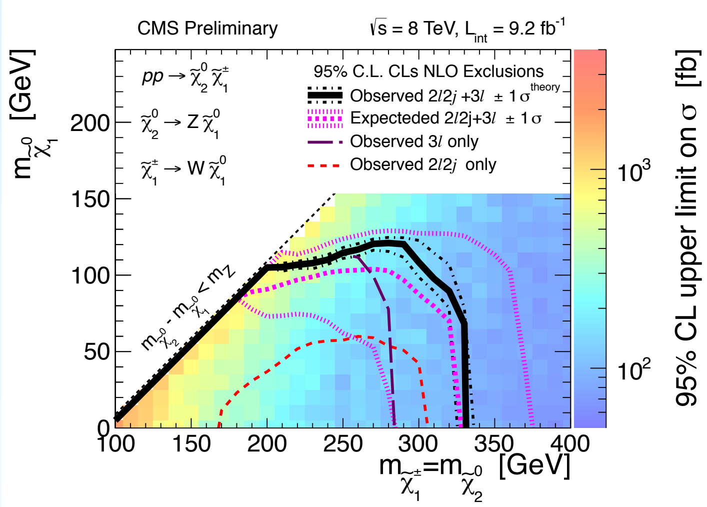
* tau dominated scenario, i.e. chargino and neutralino decay to stau



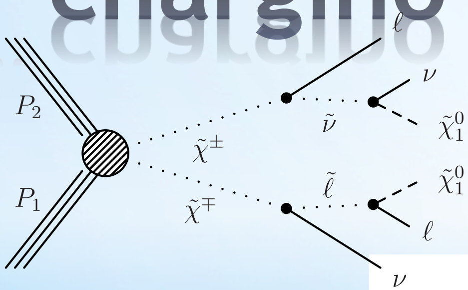
* neutralino/chargino decays to Z/W+LSP

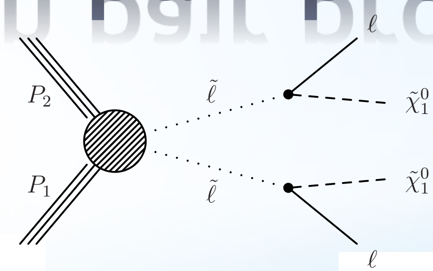
* combine WZ+MET analysis with 3lepton





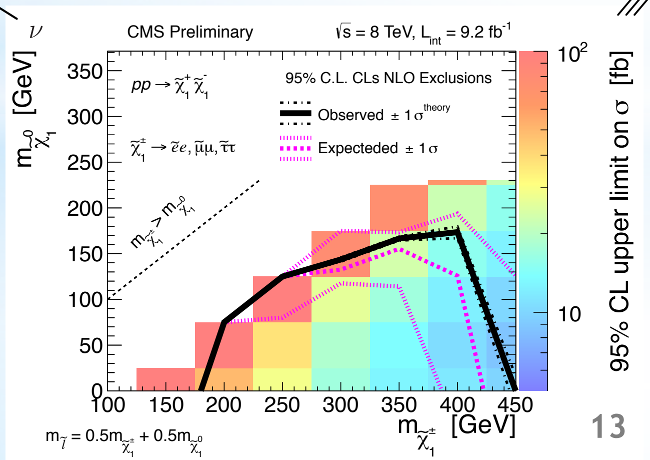
* chargino and slepton pair production



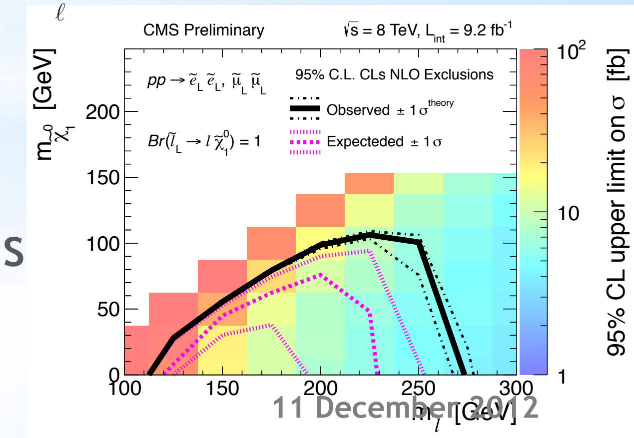


SUS-12-022

* Opposite and same flavour dileptons



* Same flavour dileptons



* multileptons (>=3) with jets SUS-12-026

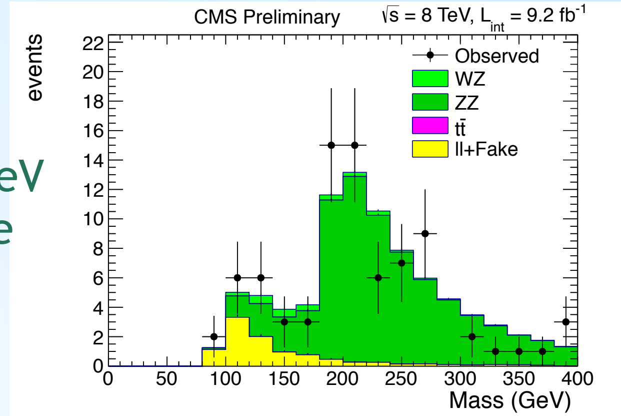
* Classify events by:

- * number of leptons (3 or 4)
- * no of OSSF pairs, on/off Z peak
- * presence of taus
- * presence of b-jets
- * HT, MET, ST = HT+MET+Σp_T^{lep}

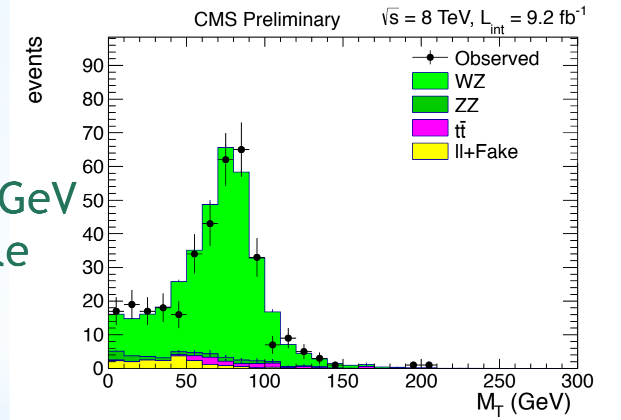
* Background from:

- * fake leptons from low MET, low HT control samples using conversion factor from isolated track -> identified lepton
- * irreducible WZ background by correcting lepton efficiency and MET resolution in simulation
- * ttbar from simulation after validation in 1 & 2 lepton control regions

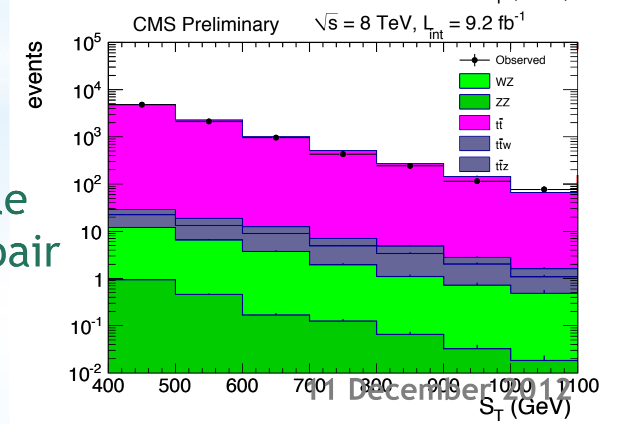
ZZ 4 lepton
low MET < 50 GeV
control sample



WZ 3 lepton
50 < MET < 100 GeV
control sample

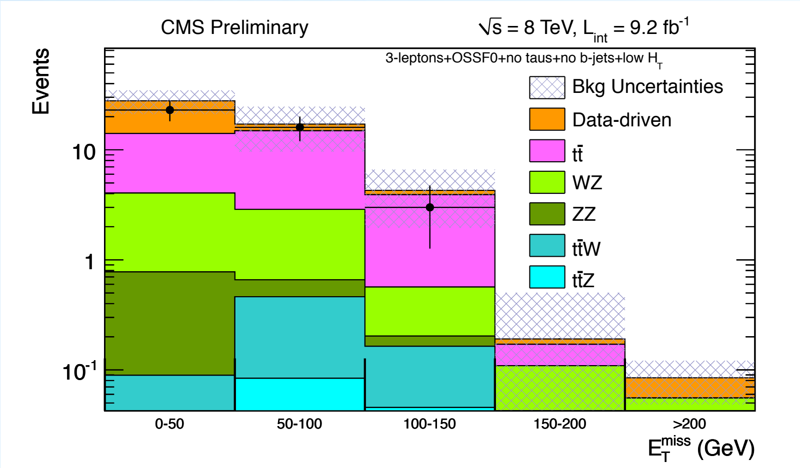


ST in ttbar
control sample
with OS e-mu pair

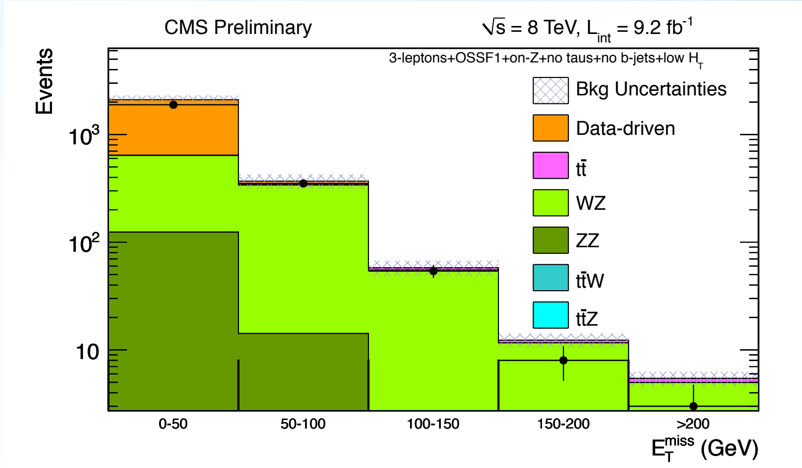


* examples of MET distributions

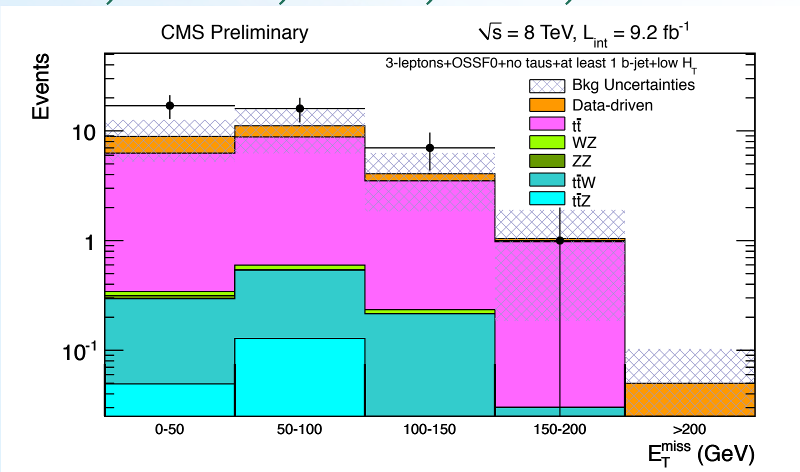
3l, 0 OSSF, 0 tau, 0b, HT< 200



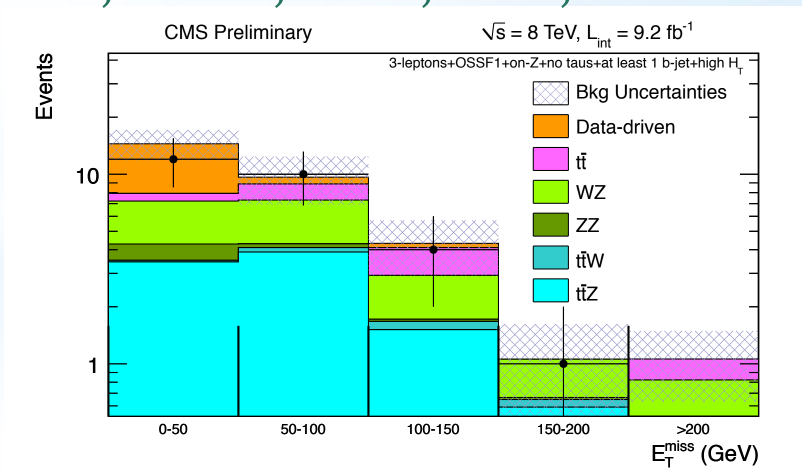
3l, 1 OSSF, 0 tau, 0b, HT< 200



3l, 0 OSSF, 0 tau, >=1b, HT< 200



3l, 1 OSSF, 0 tau, >=1b, HT> 200

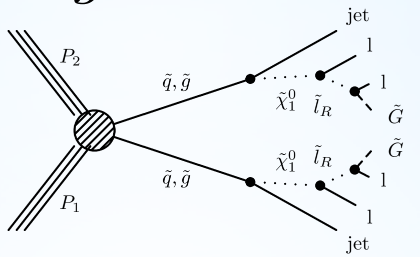


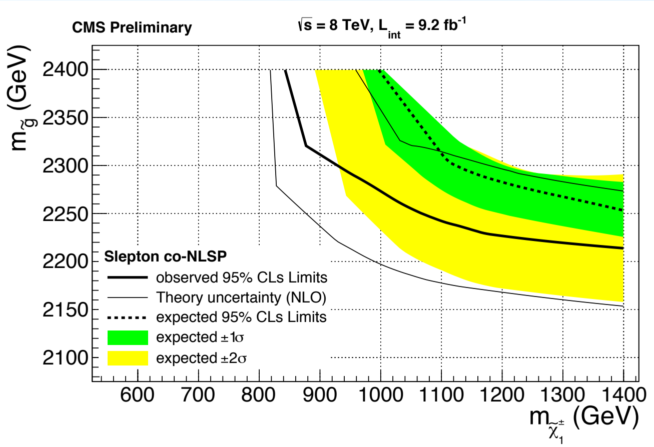
SUS-12-026

interpretation - R parity conserving

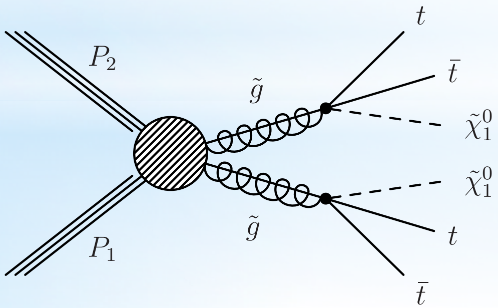
- Slepton coNLSP model (GMSM) - gravitino LSP
  - all decay chains go to $\chi_1^0 \to \tilde{\ell}_R + \ell,\ \tilde{\ell}_R \to \tilde{G} + \ell$
  - parameterized by $\tilde{\chi}^{\pm}$ *and* $\tilde{g}$

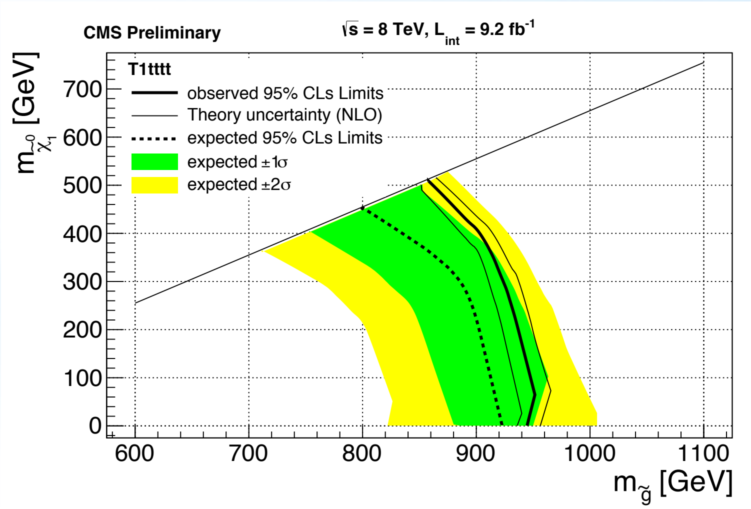
    with $m_{\tilde{\ell}_R} = 0.3\, m_{\chi_1^\pm},\ m_{\chi_1^0} = 0.5\, m_{\chi_1^\pm},$ $m_{\tilde{\ell}_L} = 0.8\, m_{\chi_1^\pm}$, and $m_{\tilde{q}} = 0.8\, m_{\tilde{g}}$
  - each event has 4 leptons





- Gluino mediated stop production
  - three body decay of gluino





SUS-12-027

* RPV multilepton search

- very similar to SUS-12-026
- events classified by
  - number of leptons (3 or 4)
  - OSSF pairs, on/off Z peak
  - presence of taus
  - presence of b's
  - 6 bins in ST = HT+MET+Σp_T^{lep}

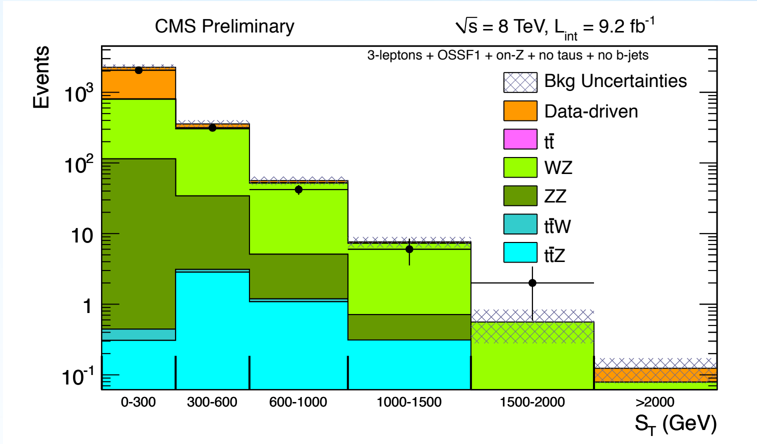
- **Superpotential with 3 trilinear RPV terms with Yukawa couplings λ_{ijk}**

$$W_{\not R_p} = \mu_i H_u L_i + \frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k,$$

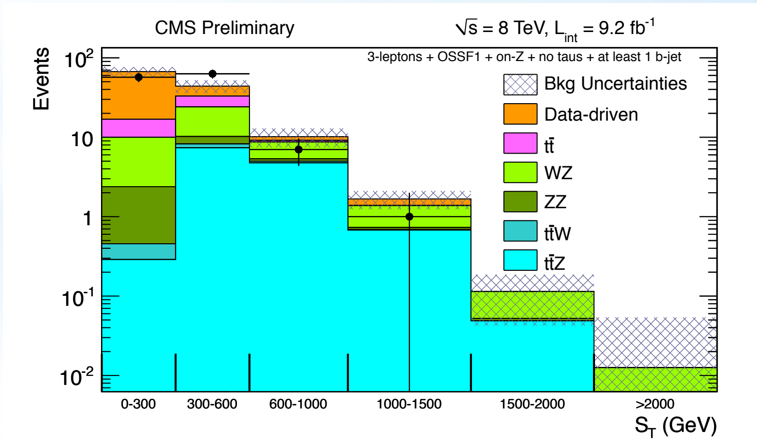
Leptonic RPV	LQD RPV	Hadronic RPV
4 leptons 0-2 OSSF pairs	2-6 leptons 0-3 OSSF pairs	4 leptons 2 OSSF pairs

Examples of ST distributions

3l, 1 OSSF, 1Z, 0 tau, 0b



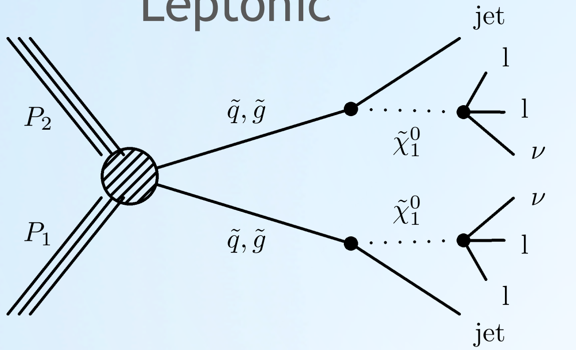
3l, 1 OSSF, 1Z, 0 tau, >=1b



* leptonic & hadronic RPV interpretation

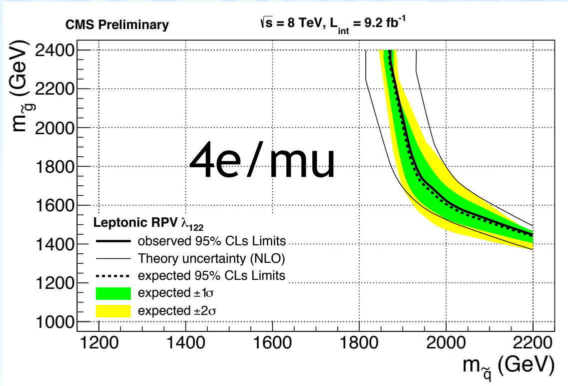
squark/gluino production

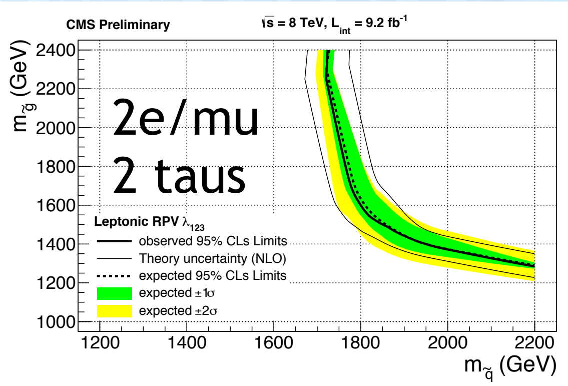
Leptonic



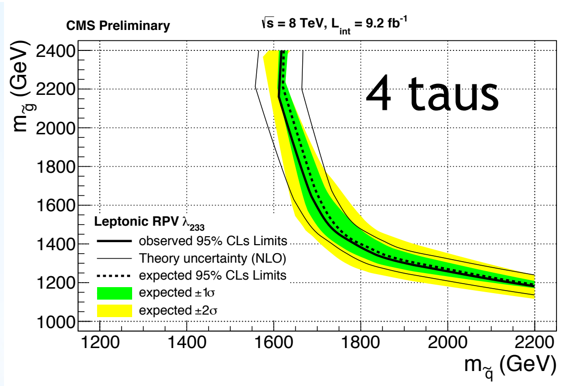
$\tilde{g} \to \chi_1^0 + \text{jets}$ $\tilde{q} \to \chi_1^0 + \text{jets}$

$\chi_1^0 \to \ell_i + \nu_j + \ell_k$ and $\nu_i + \ell_j + \ell_k$

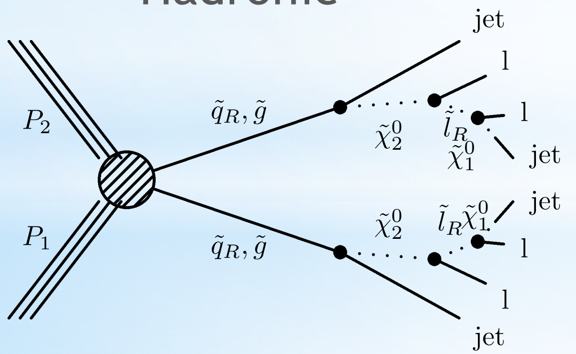




m_{χ^0} fixed to 300 GeV, other superpartners decoupled



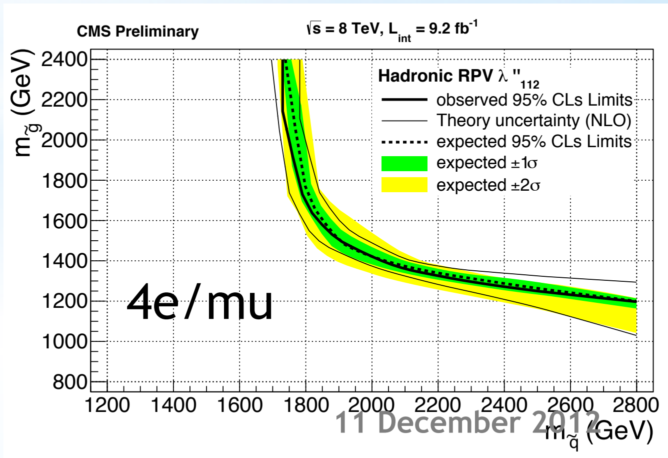
Hadronic



$\tilde{g} \to \chi_2^0 + \text{jets}$ $\tilde{q}_R \to \chi_2^0 + \text{jets}$

$\chi_2^0 \to \tilde{\ell}_R + \ell$ $\tilde{\ell}_R \to \chi_1^0 + \ell$ $\chi_1^0 \to \text{jets}$

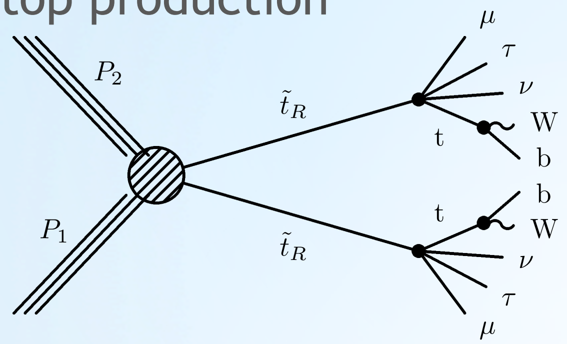
$$m_{\chi_1^0} = m_{\chi_1^\pm} = 150GeV$$
$$m_{\tilde{l}_R} = 300GeV$$
$$m_{\chi_2^0} = 500GeV$$



SUS-12-027

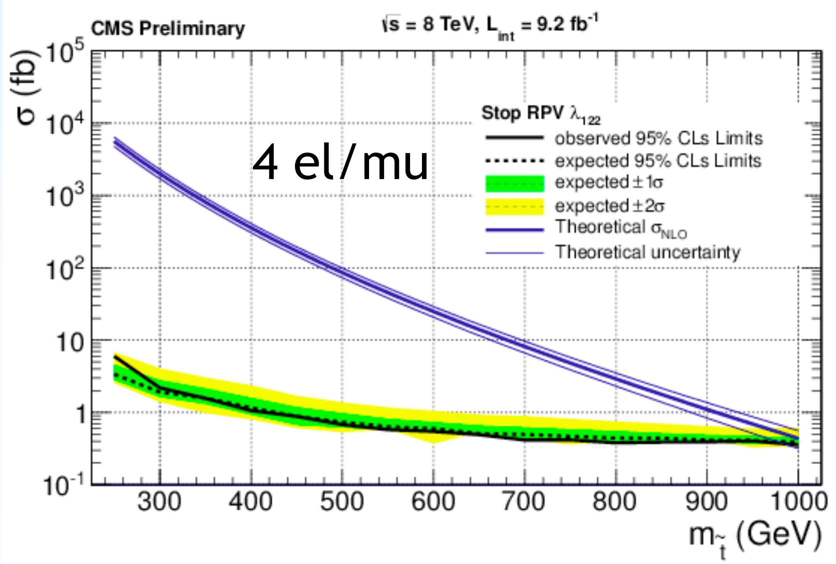
*stop RPV interpretation

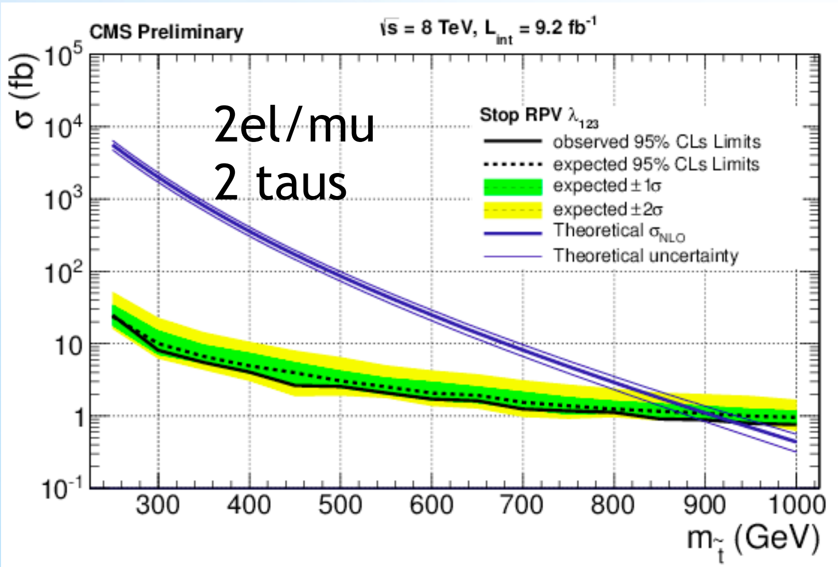
direct stop production

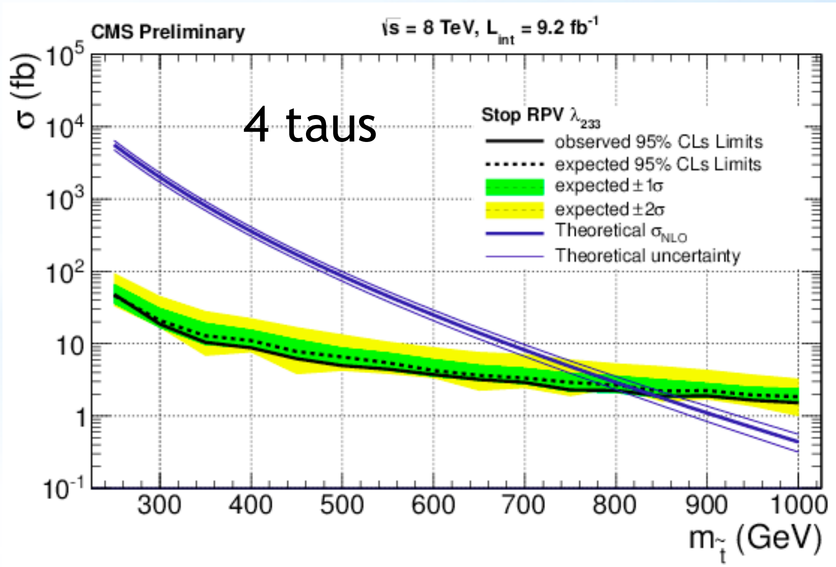


$\tilde{t}_R \to t + \ell_i + \nu_j + \ell_k$ and $t + \nu_i + \ell_j + \ell_k$

off-shell particles 100 GeV above stop







* Search for SUSY in events with taus with the razor variables

SUS-11-029
7 TeV

* Razor assumes pair production of new particles
* Reconstruct pseudo di-jet topology with hemispheres
* 2D search in "razor plane" M_R vs R^2
  * new physics mass scale M_R

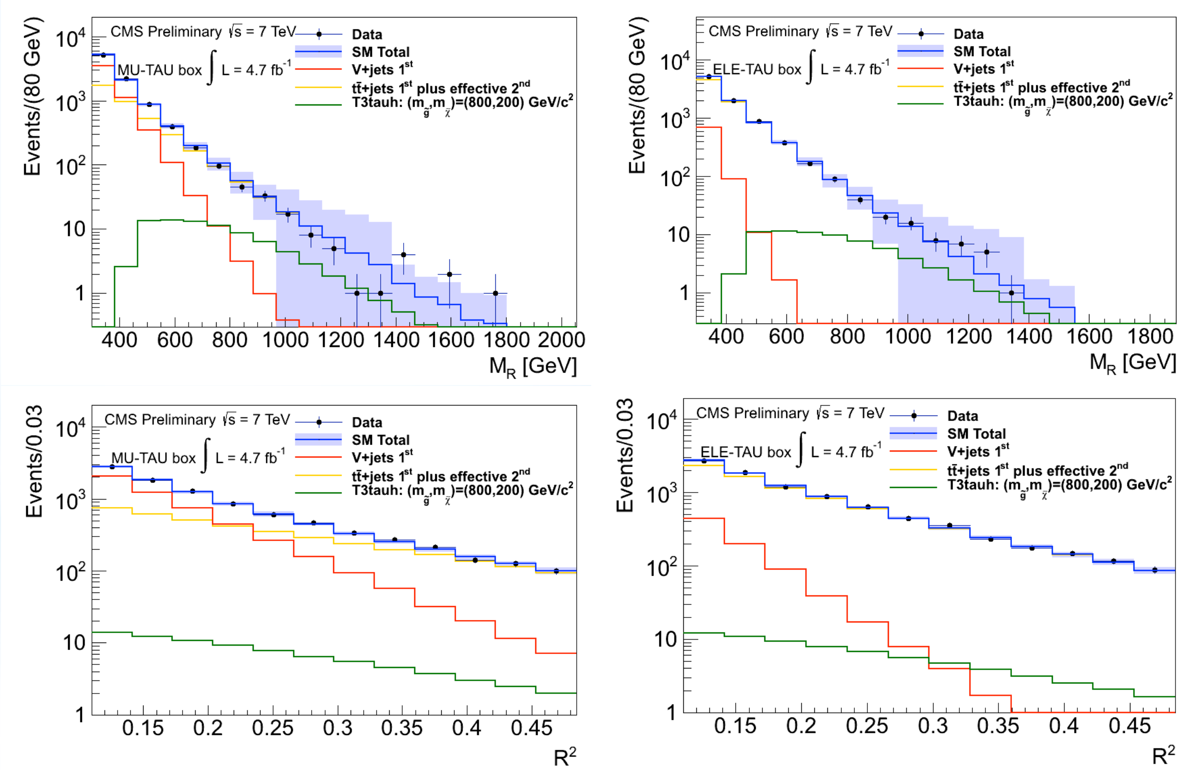
$$M_R \equiv \sqrt{(p_{j_1} + p_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{j1} + \vec{p}_T^{j2})}{2}}$$

$$R \equiv \frac{M_T^R}{M_R}.$$

* Define 4 "boxes":
  * Mu-Tau
  * Mu
  * El-Tau
  * El
* Fit double exponential to control region in low (M_R,R^2) space and extrapolate to large (M_R,R^2) signal region

MU-TAU and ELE-Tau boxes as examples

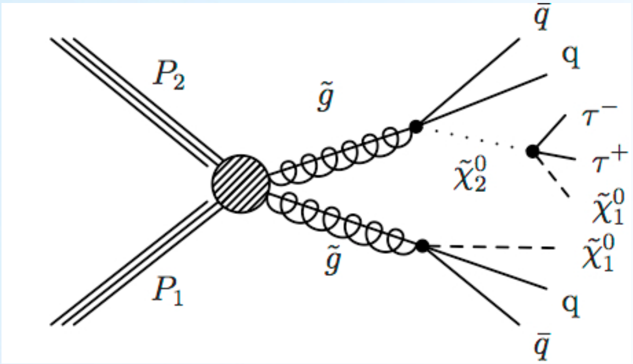


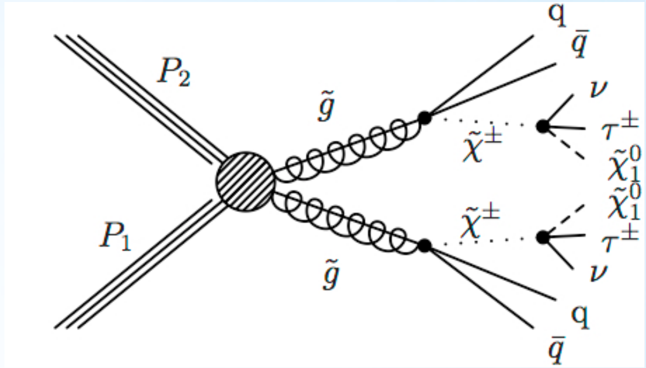
*SMS interpretation

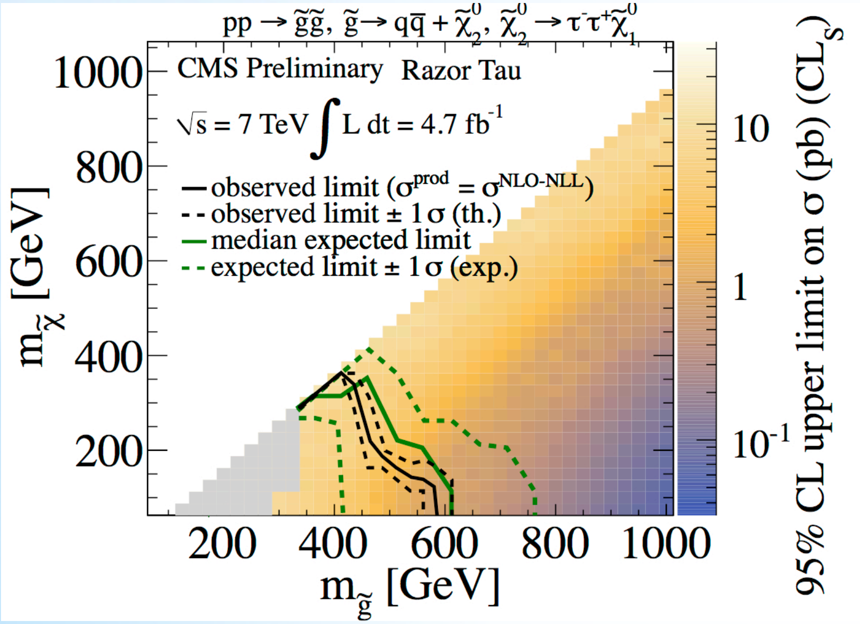
SUS-11-029

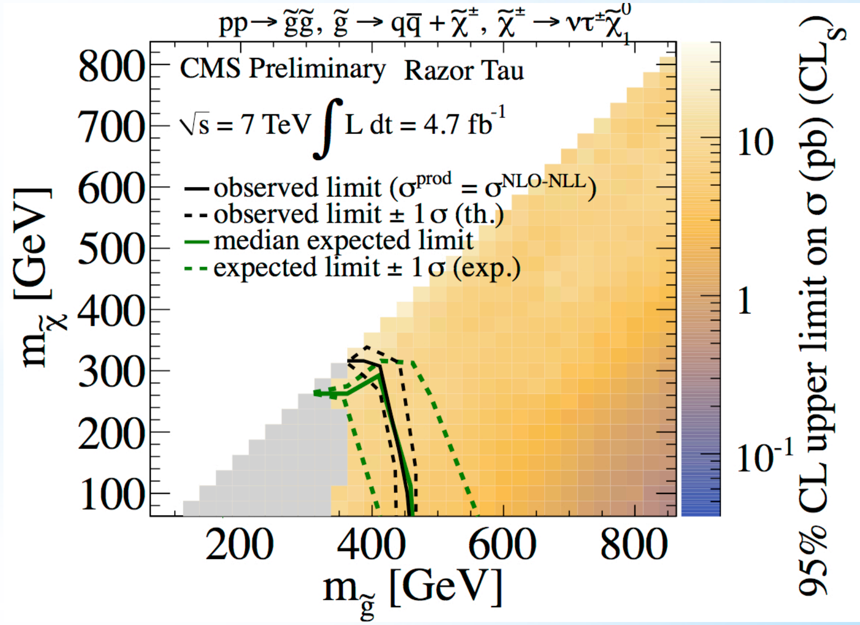
7 TeV

* Chargino and neutralinos decays to taus produced in cascade from gluinos

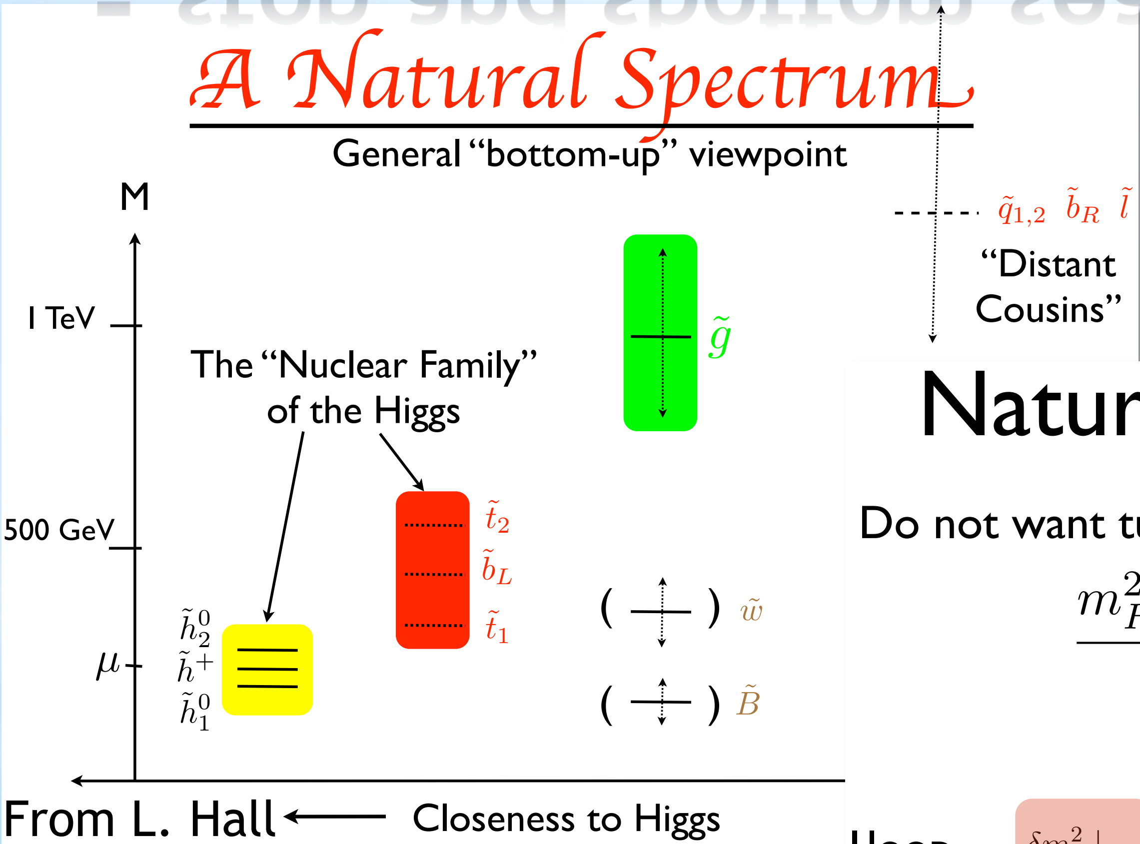








*search for 3rd generation SUSY - stop and sbottom searches



Mass hierarchies that avoid finetuning

Natural EWSB & SUSY *

* valid beyond MSSM

Do not want tuning in (Higgs mass)^2

$$\frac{m^2_{Higgs}}{2} = -|\mu|^2 + \ldots + \delta m_H^2$$

Higgsinos

1loop $$\delta m_H^2|_{stop} = -\frac{3}{8\pi^2} y_t^2 \left(m_{U_3}^2 + m_{Q_3}^2 + |A_t|^2\right) \log\left(\frac{\Lambda}{\text{TeV}}\right)$$

stops, sbottom$_L$

2loop $$\delta m_H^2|_{gluino} = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi}\right) |M_3|^2 \log^2\left(\frac{\Lambda}{\text{TeV}}\right)$$

gluino

From A. Weiler

*exclusive searches

*searches for direct production of stops and sbottoms

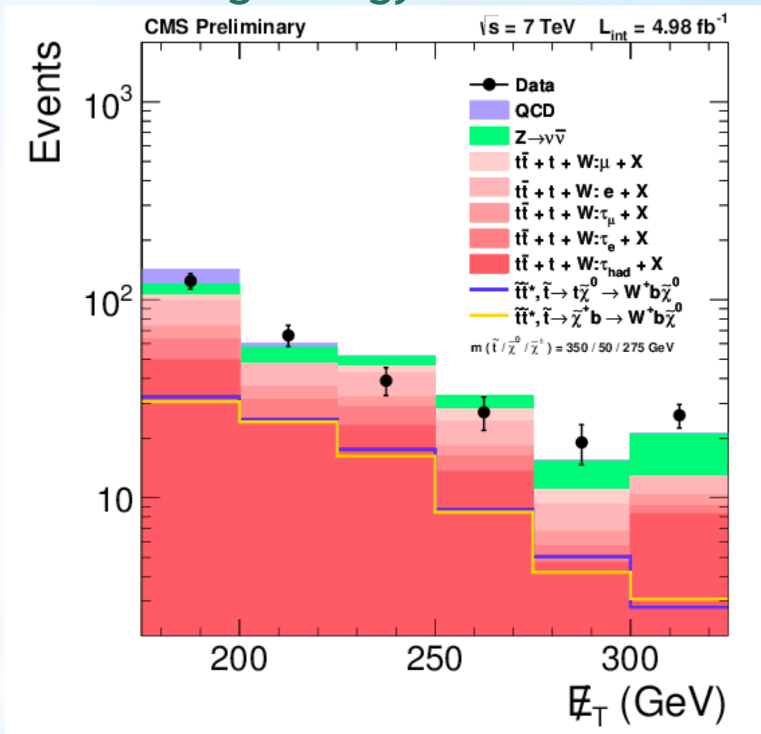
SUS-11-030

* search for hadronic stop decays

7 TeV

* **Final state with 2 W's, 2 b's and missing energy from neutrinos and neutralinos**
* Baseline selection:
  * 5 jets with p_T > 30 GeV,
  * leading 3 jets with p_T > 50 GeV
  * 1 tight b-tag
  * MET > 175 GeV
  * $\Delta\phi(\vec{\not\!\!E}_T, \mathrm{jet}) > 0.5, 0.5, \text{and } 0.3$
  * veto e, μ and τs

Missing energy for baseline



* Tighter search regions:

Loose:	$\min\lvert\Delta\phi(\vec{\not\!\!E}_T, \vec{p}_{T,b})\rvert \geq 1.0$ and $(\not\!\!E_T \geq 175 \wedge n_j \geq 7) \vee (\not\!\!E_T \geq 200 \wedge n_j \geq 5)$
Medium:	$\min\lvert\Delta\phi(\vec{\not\!\!E}_T, \vec{p}_{T,b})\rvert \geq 1.0$ and $(\not\!\!E_T \geq 175 \wedge n_j \geq 7) \vee (\not\!\!E_T \geq 200 \wedge n_j \geq 6)$ $\vee (\not\!\!E_T \geq 250 \wedge n_j \geq 5)$
Tight:	$\min\lvert\Delta\phi(\vec{\not\!\!E}_T, \vec{p}_{T,b})\rvert \geq 1.0$ and $(\not\!\!E_T \geq 175 \wedge n_j \geq 7) \vee (\not\!\!E_T \geq 200 \wedge n_j \geq 6)$

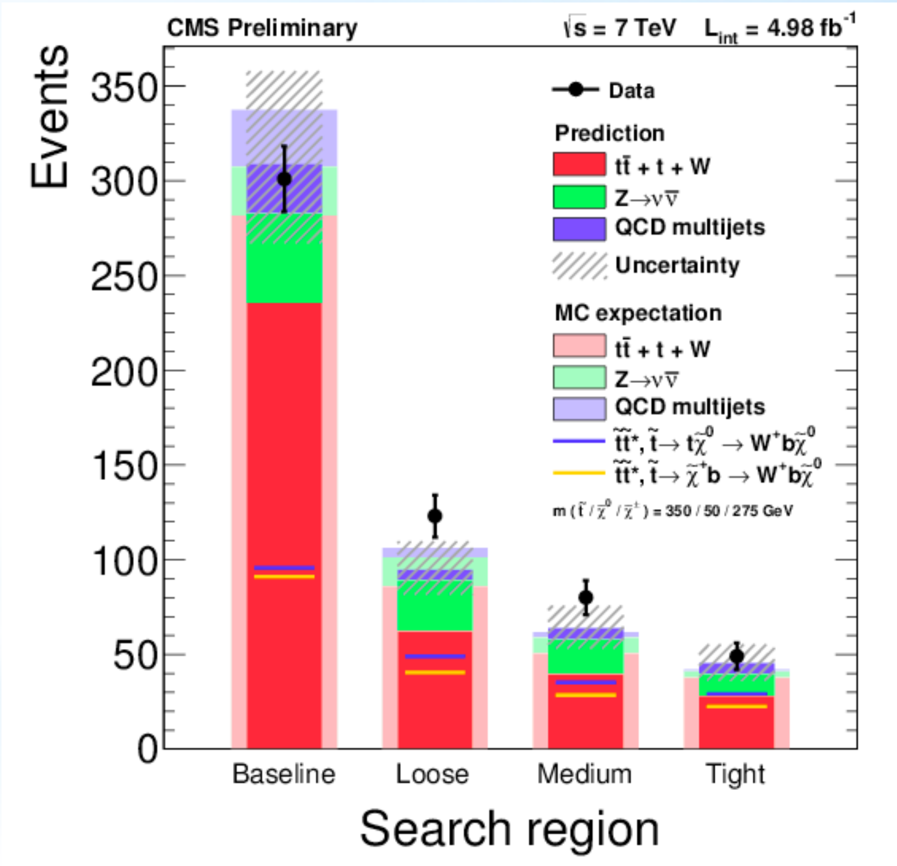
SUS-11-030

search for hadronic stop decays

7 TeV

* Selection based on missing energy, number of jets and ΔΦ(MET,b-jet)

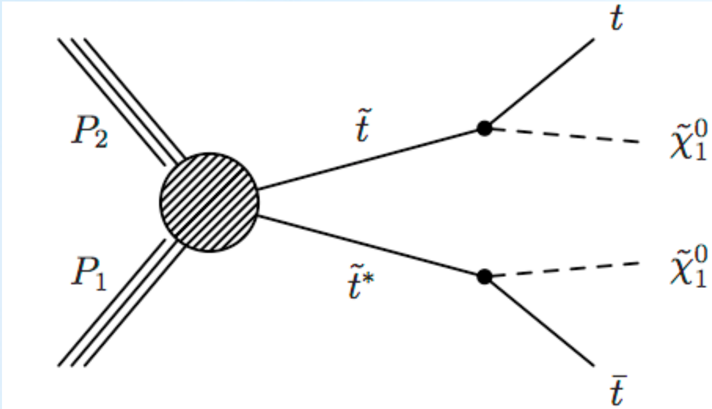
* **Data-driven background estimations**
* taus and lost leptons from Ws and tops via lepton embedding in real muon data events
* Z-> νν prediction from Z->μμ rescaled to b-tag fraction from higher statistics photon + jets control sample
* QCD from reweighted MC

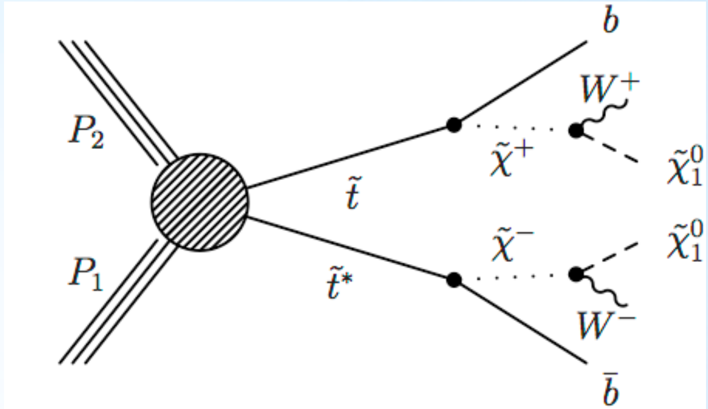


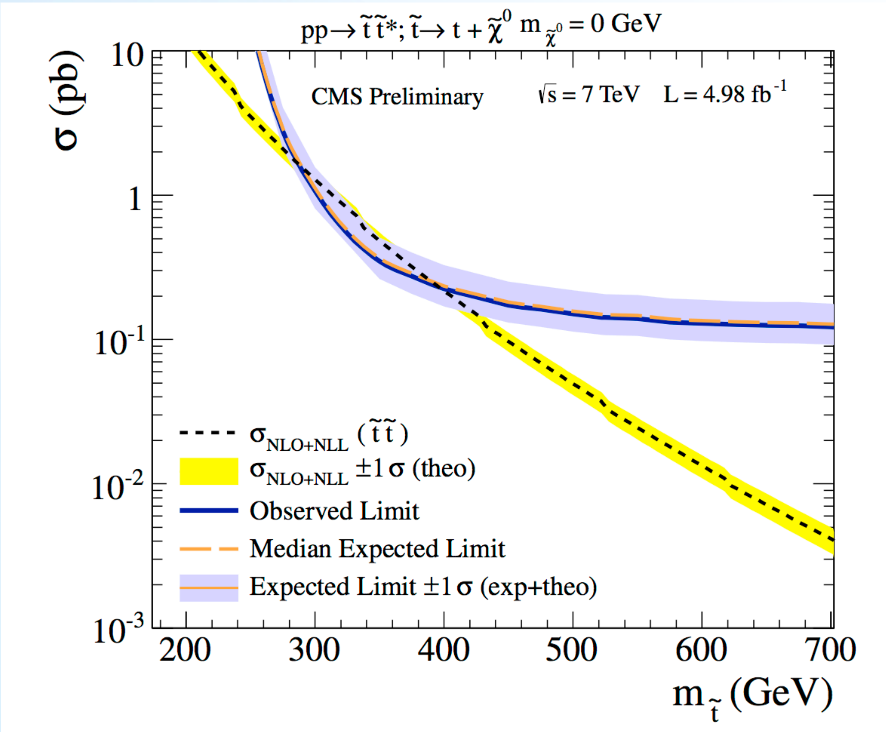
SUS-11-030

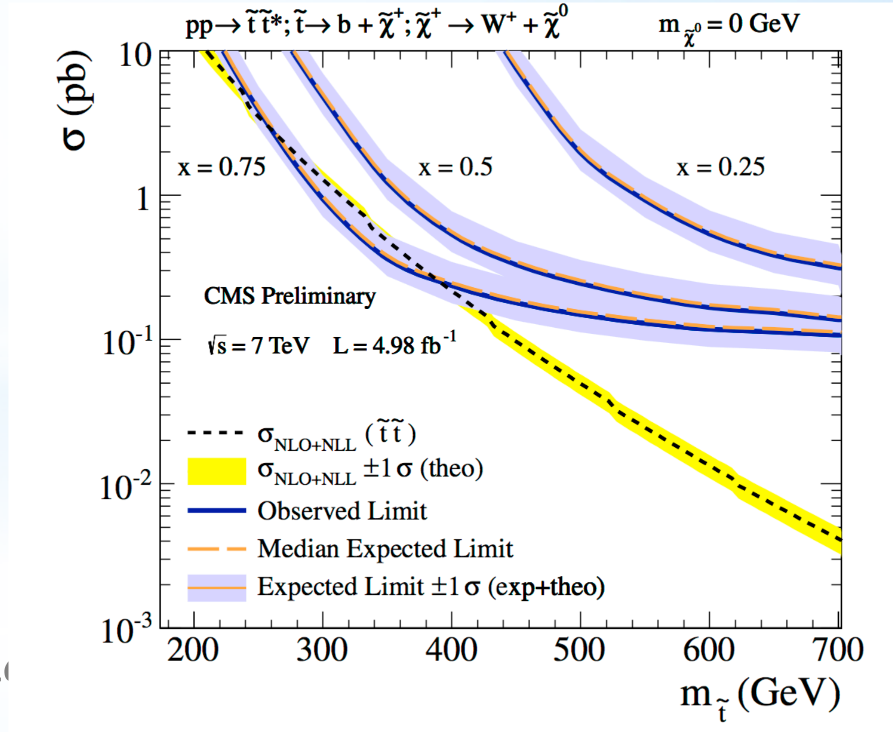
*search for hadronic stop decays

7 TeV









SUS-12-023

* search for semileptonic stop decays

* Search in the tail of the MET and MT distributions

* Event selection
  * 1 isolated lepton (e or μ) with p_T > 30 GeV
  * >= 4 jets with p_T > 30 GeV, |η| < 2.5 and ΔR(jet,lepton) > 0.4
  * 1 medium b-tag (70% eff, 1% mis-tag prob)
  * MET > 50 GeV
  * veto on isolated track against dileptonic ttbar background

Signal Region	Minimum M_T [GeV]	Minimum E_T^{miss} [GeV]
SRA	150	100
SRB	120	150
SRC	120	200
SRD	120	250
SRE	120	300
SRF	120	350
SRG	120	400

* Main backgrounds:

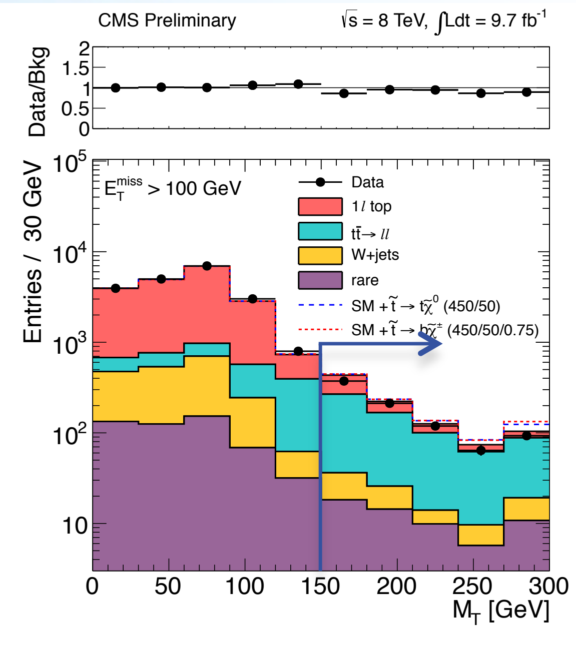
  * dileptonic ttbar decays with 1 lepton unidentified (60-70%)
  * semileptonic ttbar events suriviing event selection (15-30%)
  * rare processes, e.g. ttZ, ttW, di- and tri-boson production (5-20%)
  * W+jets production (3-7%)

* search for semileptonic stop decays

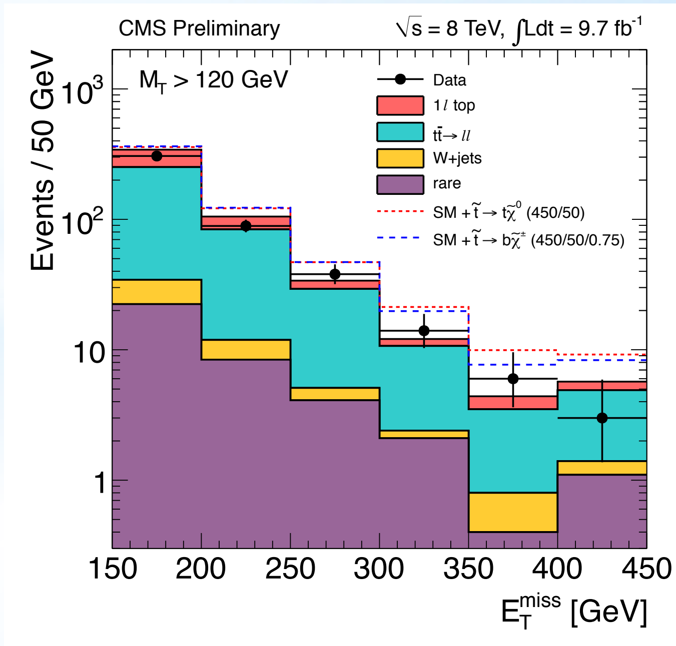
* Control regions to validate MC and derive correction factors

Selection Criteria	exactly 1 lepton	exactly 2 leptons	1 lepton + isolated track
0 b-tags	CR1) W+Jets dominated: Validate W+Jets M_T tail	CR2) apply Z-mass constraint $\rightarrow$ Z+Jets dominated: Validate $t\bar{t} \rightarrow \ell +$ jets M_T tail comparing data vs. MC "pseudo-M_T"	CR3) not used
≥ 1 b-tags	SIGNAL REGION	CR4) Apply Z-mass veto $\rightarrow t\bar{t} \rightarrow \ell\ell$ dominated: Validate "physics" modeling of $t\bar{t} \rightarrow \ell\ell$	CR5) $t\bar{t} \rightarrow \ell\ell$, $t\bar{t} \rightarrow \ell\tau$ and $t\bar{t} \rightarrow \ell$fake dominated: Validate τ and fake lepton modeling/ detector effects in $t\bar{t} \rightarrow \ell\ell$

Signal region A

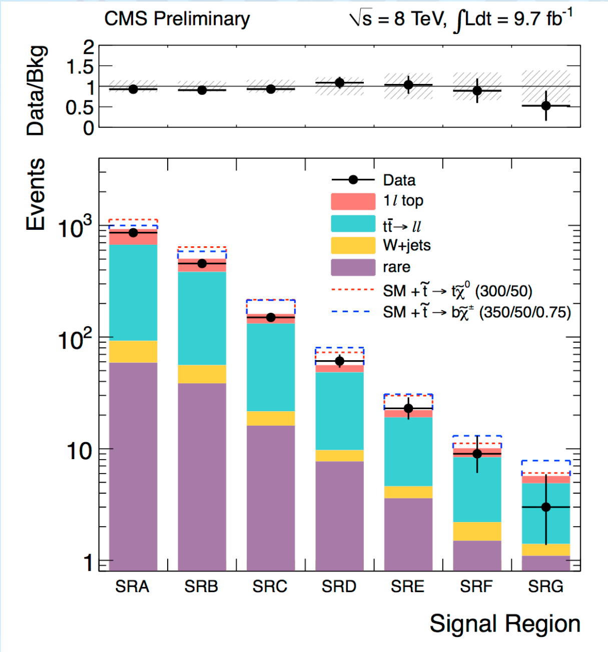


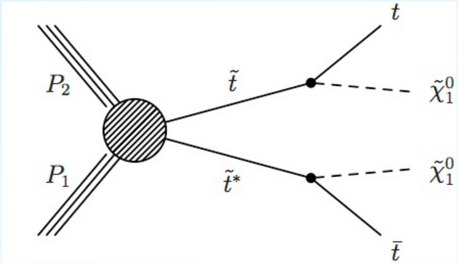
Signal regions B-G

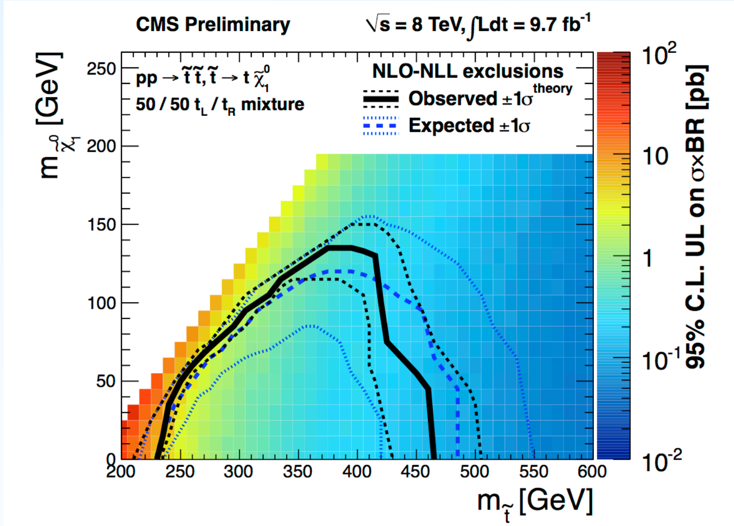


SUS-12-023

* search for semileptonic stop decays

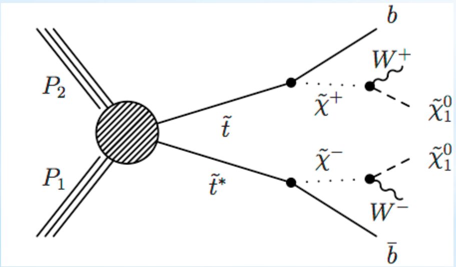


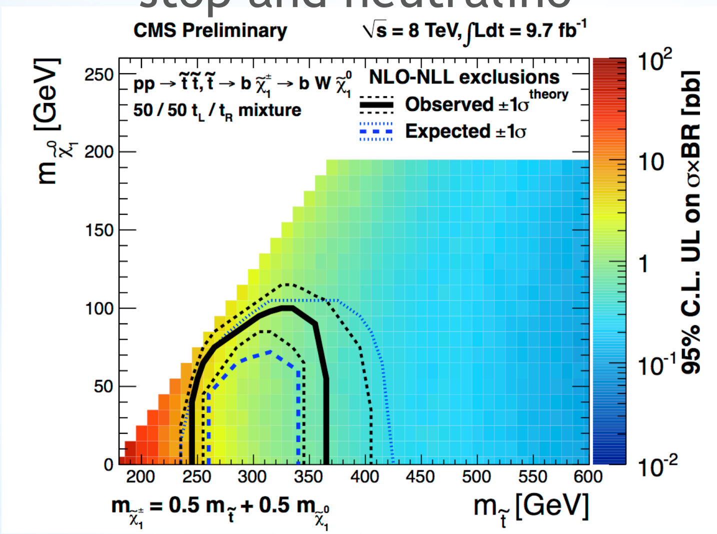


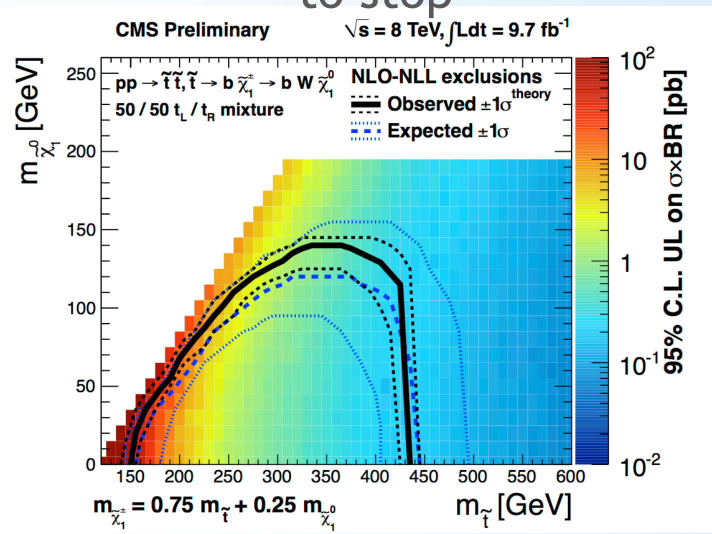


chargino between stop and neutralino

chargino closer to stop







*inclusive searches

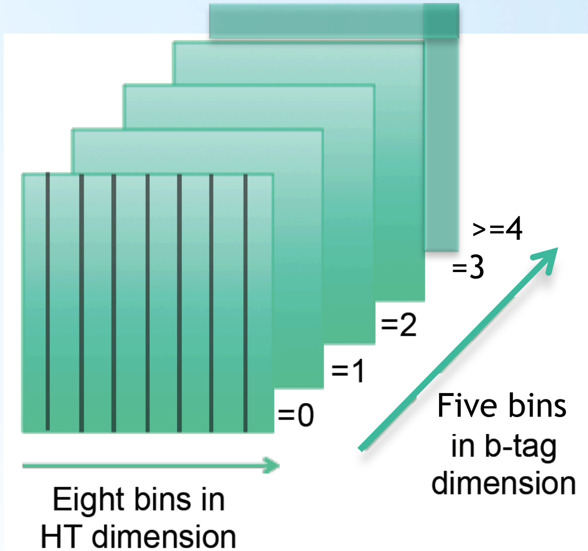
* gluino mediated or direct production of stops and sbottoms

SUS-12-028

α_T with 0,1,2,>=3 b-tags

8 TeV
11.7/fb

- SUS-12-028 – publication in preparation
- All-hadronic search with missing energy
- Improved sensitivity to 3rd generation models through exclusive b-tag binning!
- Search in low and high jet multiplicity regions
  - <=3 jets and >=4 jets
- 2D analysis in 8 bins of HT from 275 GeV to > 875 GeV and 5 exclusive b-tag bins
  - require >=2 jets with p_T > 50 GeV, $|\eta|<3.0$
  - muon, electron and photon veto



- Use α_T to suppress QCD multi-jet events
- Di-jet events: $\alpha_T = \frac{E_T^{j_2}}{M_T}$ Multi-jet evts: (pseudo-di-jet) $\alpha_T = \frac{1}{2} \cdot \frac{H_T - \Delta H_T}{\sqrt{{H_T}^2 - {\not{H}_T}^2}}$
-
- Balanced QCD events give α_T=0.5
- Events with real missing energy can have α_T>>0.55

SUS-12-028

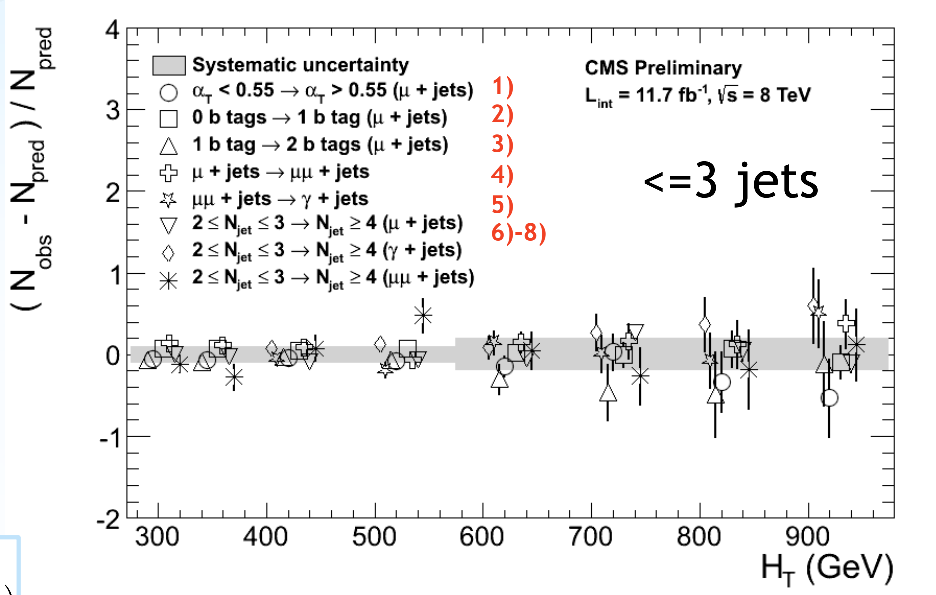
* α_T - background estimation

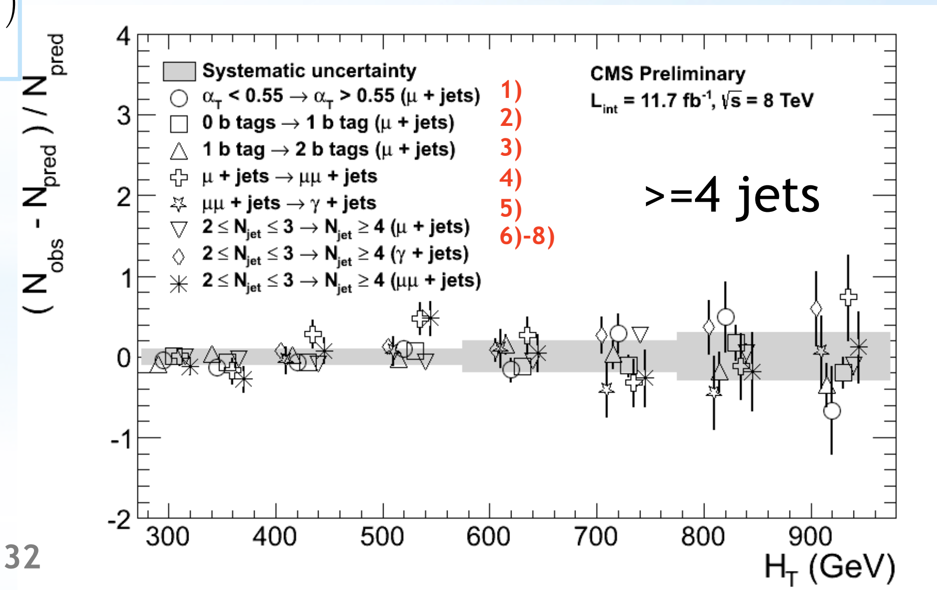
- Data-driven background estimation from
  - single muon, di-muon and photon control samples
- Related to hadronic signal region by MC translation factors
  - as fcn of HT and b-tag multiplicity

$$N^{\rm signal}_{\rm pred}(H_{\rm T}, n^{\rm reco}_{\rm b}) = N^{\rm control}_{\rm obs}(H_{\rm T}, n^{\rm reco}_{\rm b}) \times \frac{N^{\rm signal}_{\rm MC}}{N^{\rm control}_{\rm MC}}(H_{\rm T}, n^{\rm reco}_{\rm b})$$

- Validated through multiple "closure" test
  - HT dependent systematic uncertainties

1) α_T distribution in generic MET events
2) relative composition of ttbar and W+jets
3) b-jet reconstruction
4) relative contribution of Z+jets to W/ttbar
5) consistency between μμ+jets and γ+jets
6)-8) jet multiplicity closure between control samples

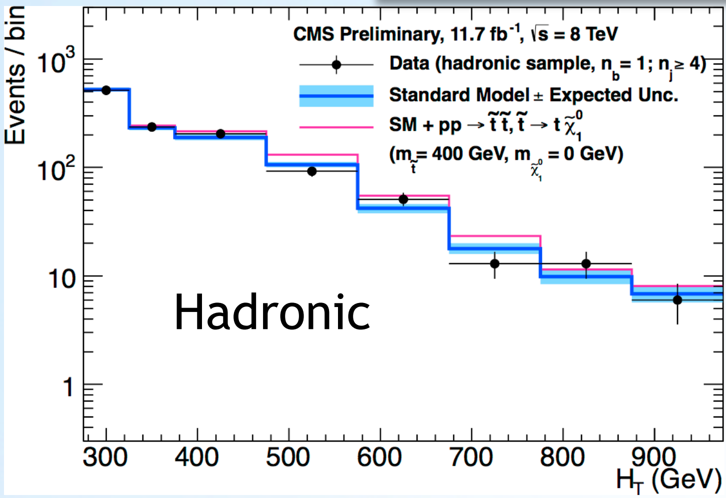


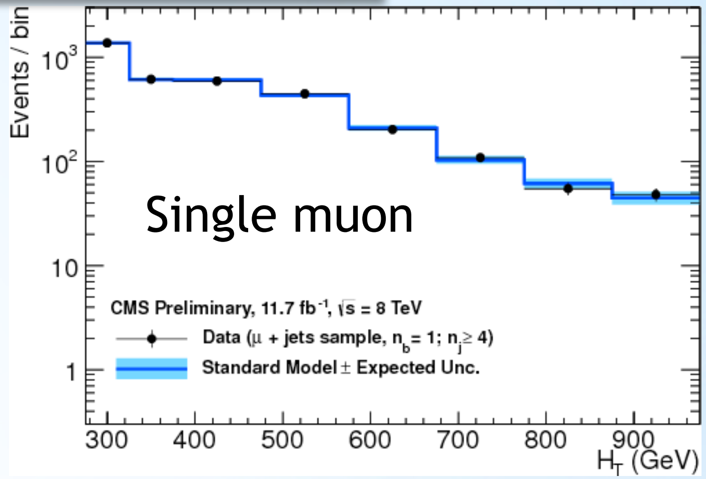


*α_T - likelihood fit to control and signal samples

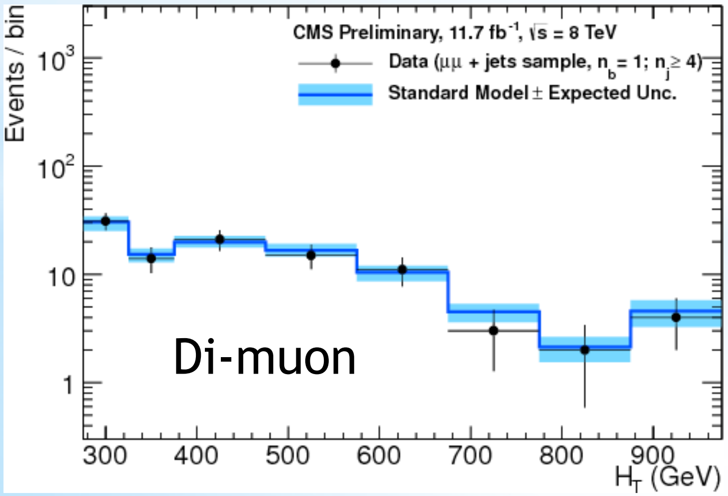
SUS-12-028

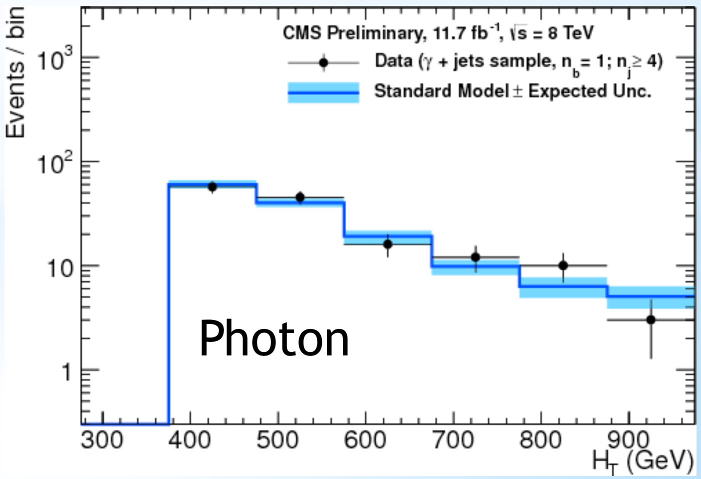
$$L_{\text{total}} = L_{\text{hadronic}} \times L_{\mu+\text{jets}} \times L_{\mu\mu+\text{jets}} \times L_{\gamma+\text{jets}} \quad n_{\text{b}}^{\text{reco}} \leq 1$$
$$L_{\text{total}} = L_{\text{hadronic}} \times L_{\mu+\text{jets}} \quad n_{\text{b}}^{\text{reco}} \geq 2$$





1 b-tags, >=4 jets as example

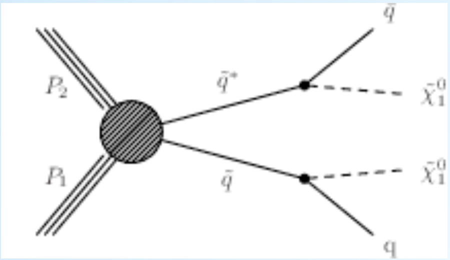


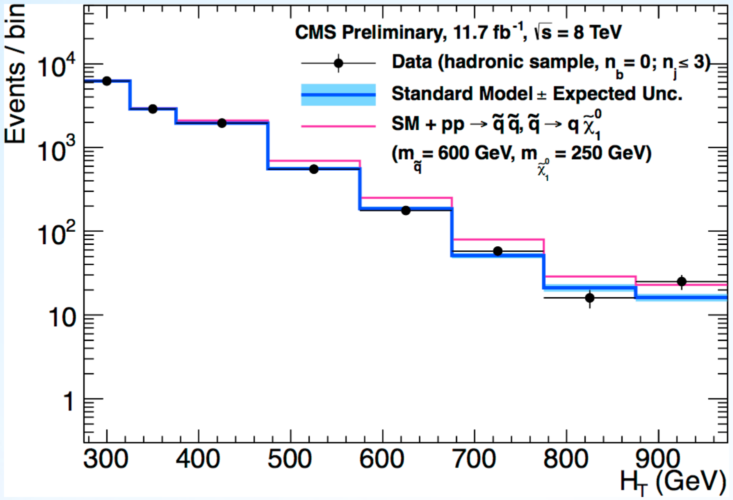


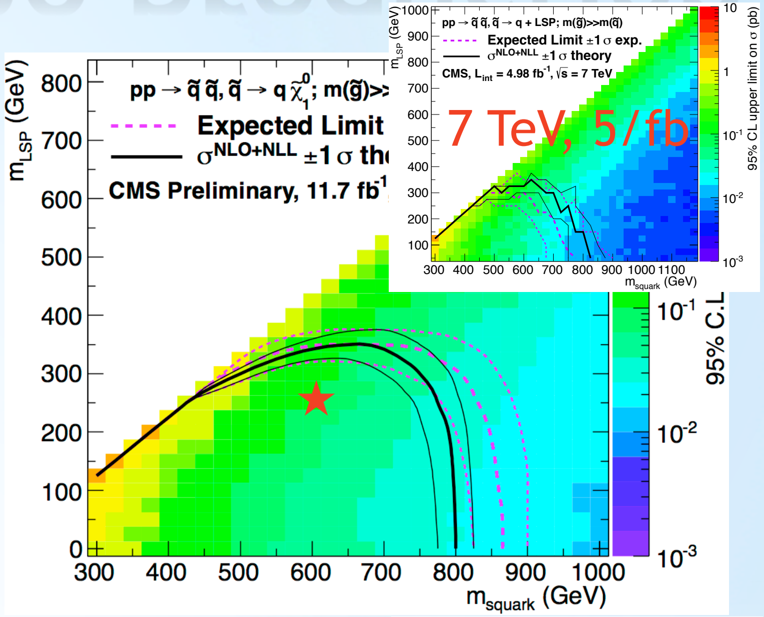
SUS-12-028

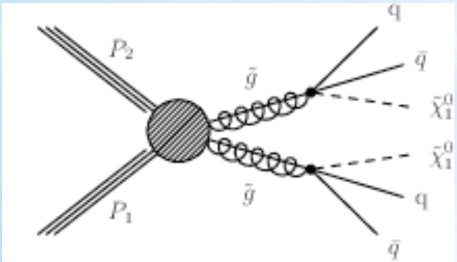
* α_T: Squark and Gluino production

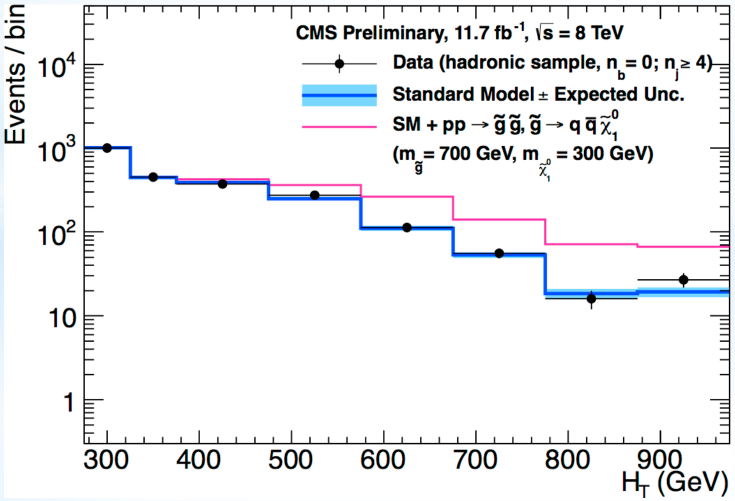
* 1^{st} and 2^{nd} generation

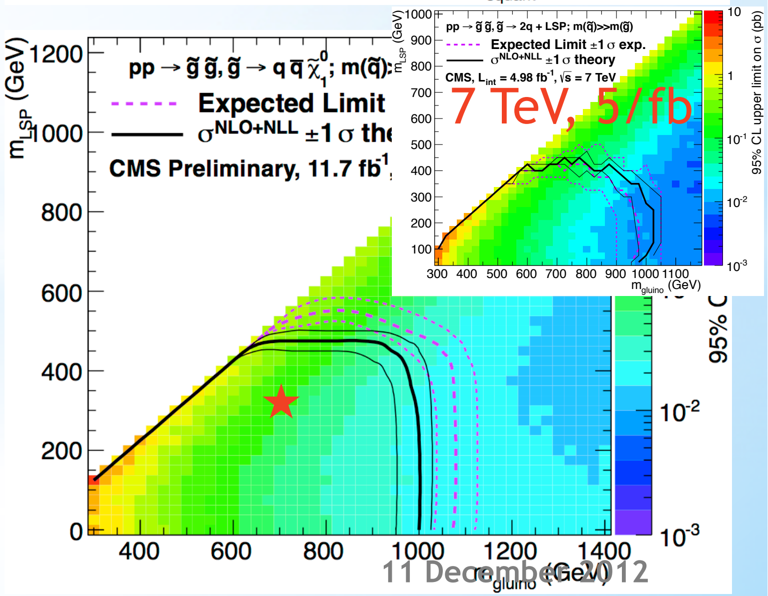






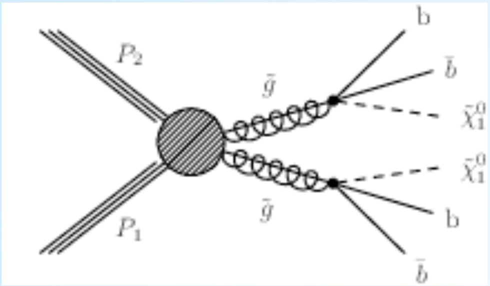


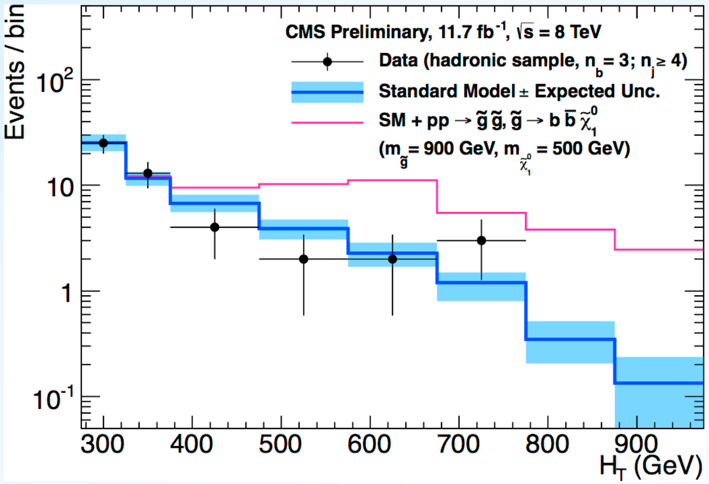


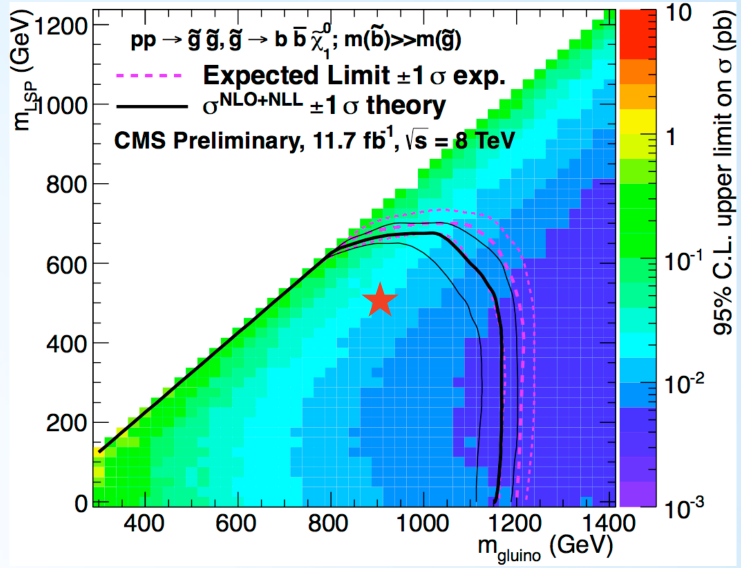


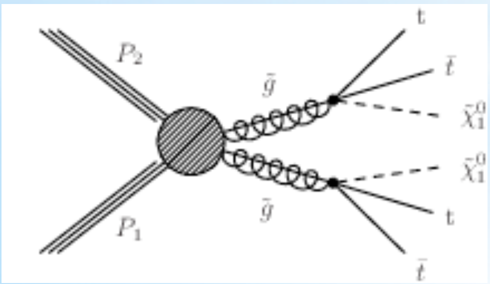
SUS-12-028

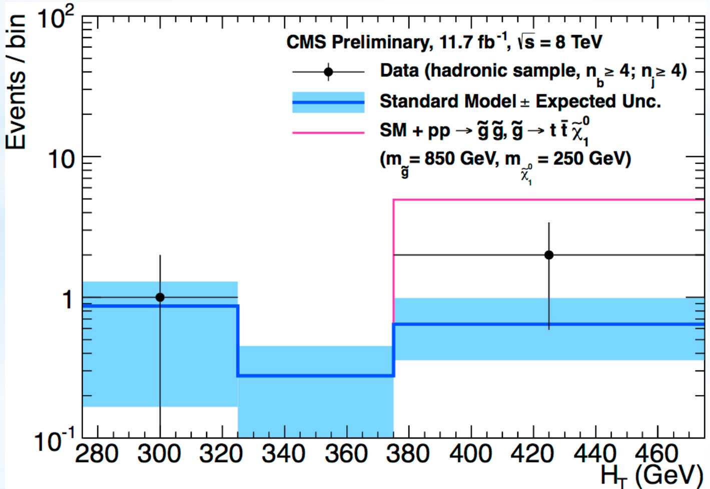
*α_T: Gluino mediated sbottom and stop production

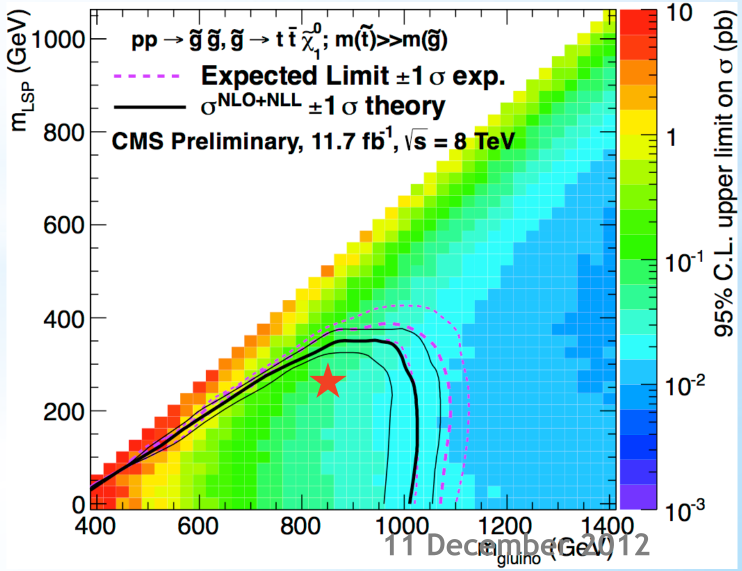






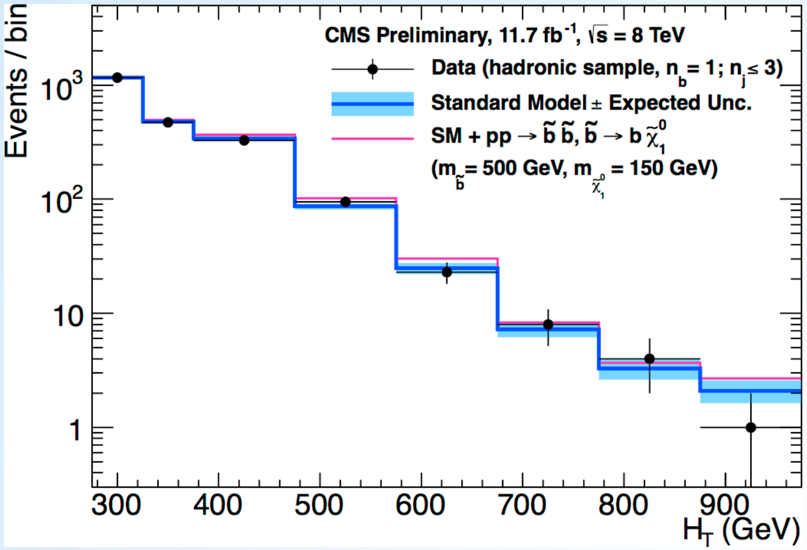


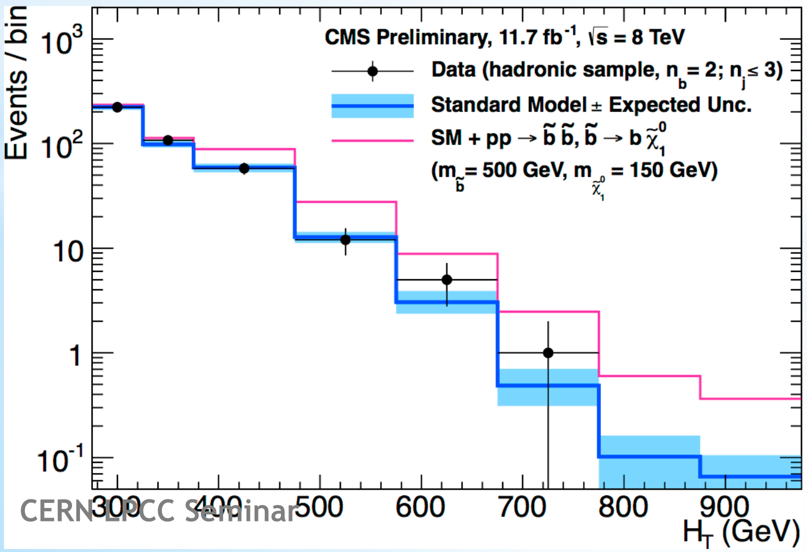


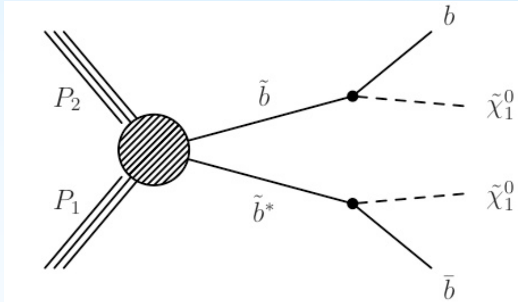


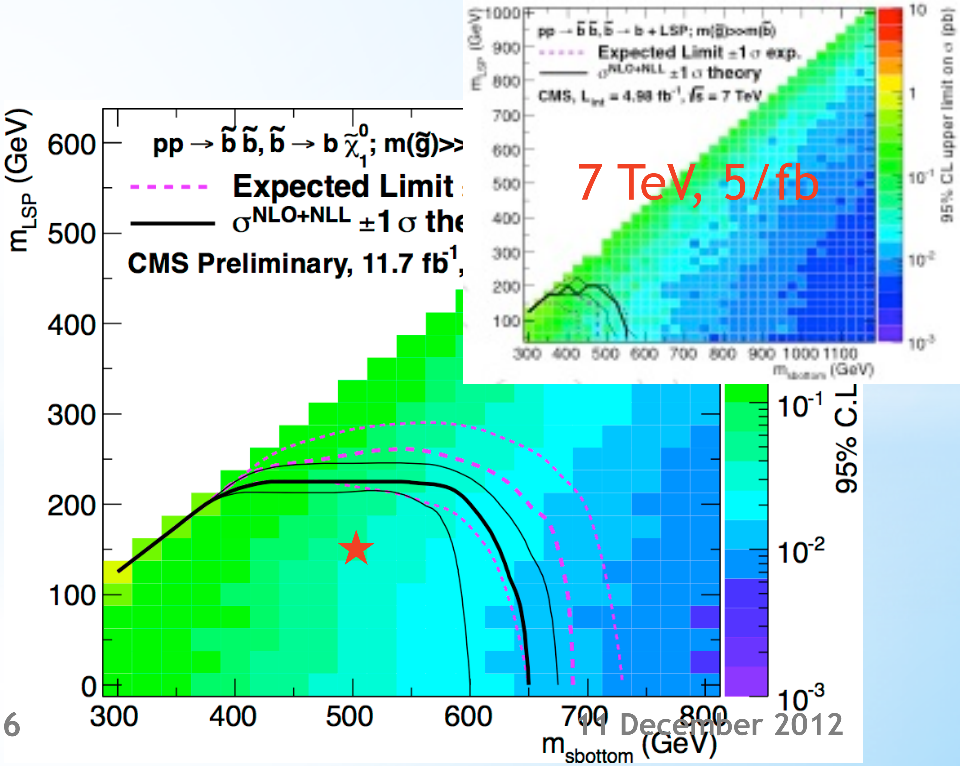
SUS-12-028

*α_T: direct sbottom production





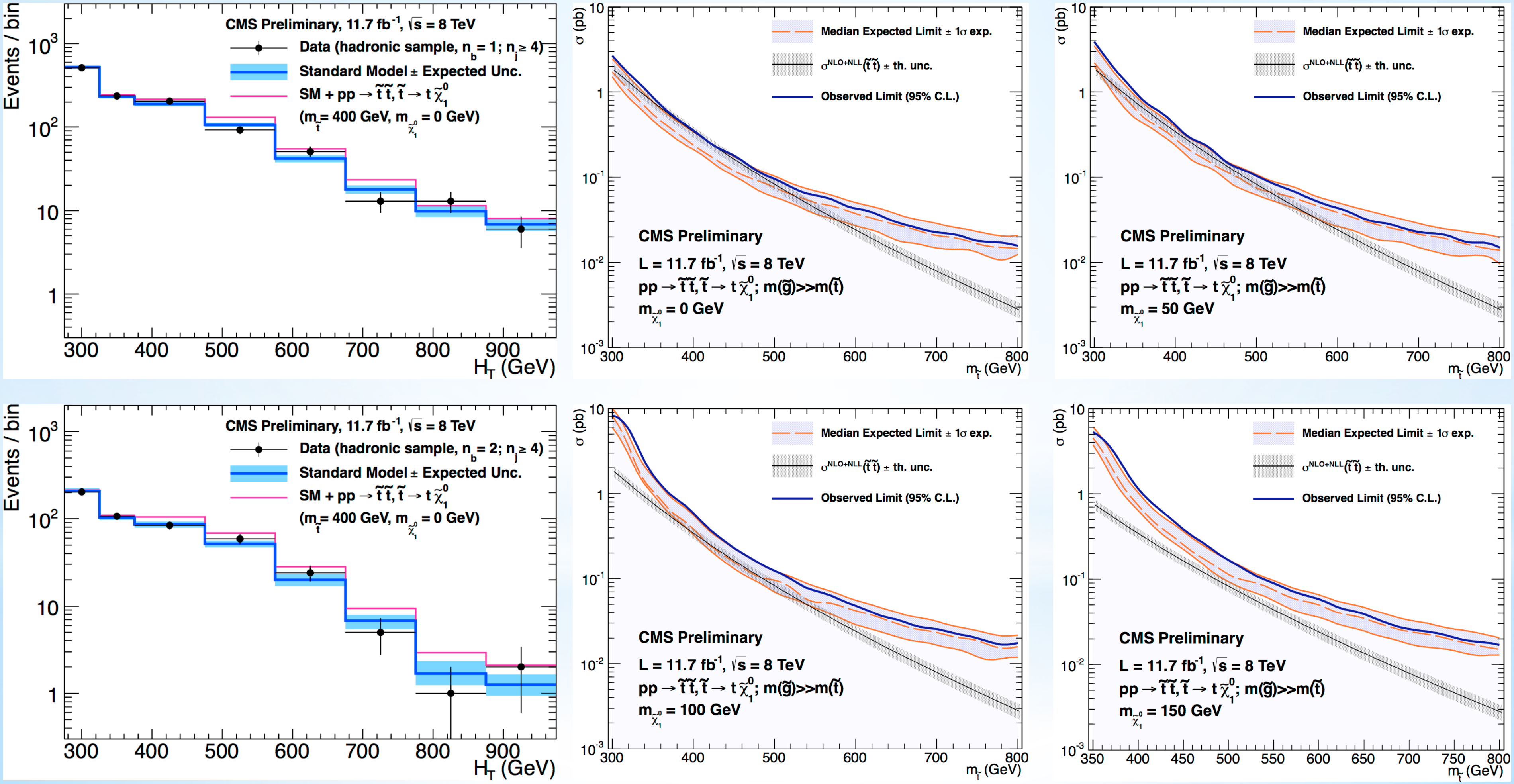




SUS-12-028

α_T: direct stop pair production

$$pp \to \tilde{t}\tilde{t}, \tilde{t} \to t\chi^0$$



SUS-12-029

*same-sign dileptons + b-tags

* SUS-12-029
* select same-sign electrons and muons
* define several signal regions based on jet multiplicity, no of b-tags, MET and HT

10.5/fb
8 TeV data!

	P_T	η
electrons	$P_T > 20$ GeV	$\lvert\eta\rvert < 1.442$ or $1.566 < \lvert\eta\rvert < 2.4$
muons	$P_T > 20$ GeV	$\lvert\eta\rvert < 2.4$
jets	$P_T > 40$ GeV	$\lvert\eta\rvert < 2.4$
b-tagged jets	$P_T > 40$ GeV	$\lvert\eta\rvert < 2.4$

* Main backgrounds:
  * fake leptons from heavy flavour, mis-identified hadrons, muons from meson decays, electrons from unidentified conversions
    * measured from tight-to-loose ratio of lepton isolation
    * measured as fct of lepton type, p_T and η
  * charge misreconstruction, e.g. in case of severe bremsstrahlung
    * for electrons, determined from Z's, around 10^{-3}
    * negligible for muons, around 10^{-4}-10^{-5}
  * rare SM processes

SUS-12-029

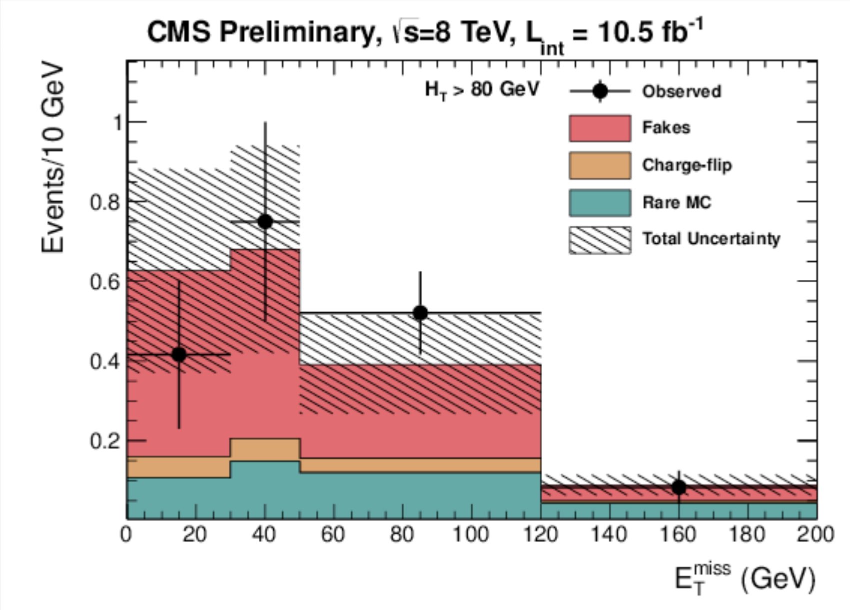
same-sign dileptons + b-tags

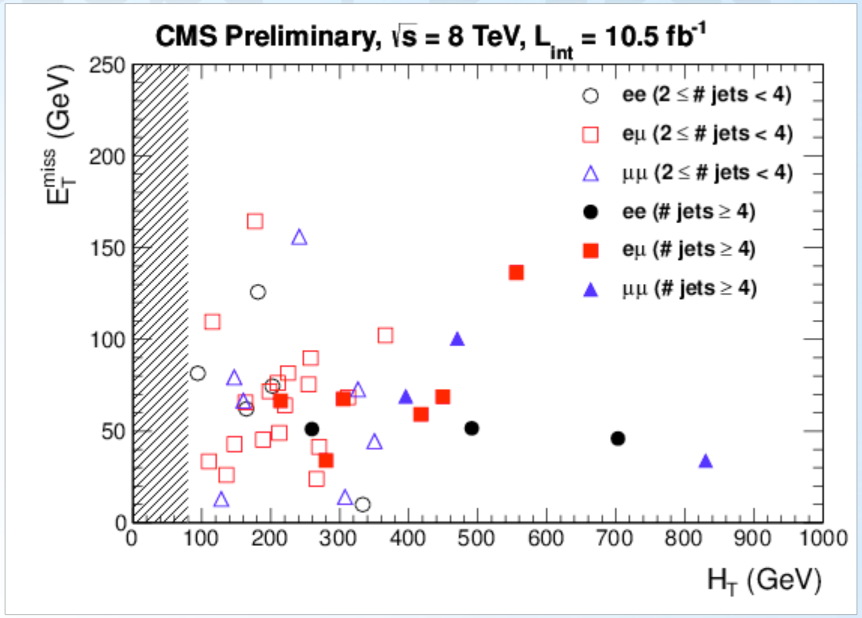
- SUS-12-029
- Select same-sign electrons and muons
- Signal regions based on jet multiplicity, of b-tags, MET and HT

No. of jets	≥ 2	≥ 2	≥ 2	≥ 4	≥ 4	≥ 4	≥ 4	≥ 3	≥ 4
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
Lepton charges	$++/--$	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
E_T^{miss}	> 0 GeV	> 30 GeV	> 30 GeV	> 120 GeV	> 50 GeV	> 50 GeV	> 120 GeV	> 50 GeV	> 0 GeV
H_T	> 80 GeV	> 80 GeV	> 80 GeV	> 200 GeV	> 200 GeV	> 320 GeV	> 320 GeV	> 200 GeV	> 320 GeV
Fake BG	24.8 ± 12.6	19.2 ± 9.8	9.6 ± 5.0	0.99 ± 0.69	4.5 ± 2.9	2.9 ± 1.7	0.7 ± 0.5	0.71 ± 0.47	4.4 ± 2.6
Charge-flip BG	3.4 ± 0.7	2.7 ± 0.5	1.4 ± 0.3	0.04 ± 0.01	0.21 ± 0.05	0.14 ± 0.03	0.04 ± 0.01	0.03 ± 0.01	0.21 ± 0.05
Rare SM BG	11.8 ± 5.9	10.5 ± 5.3	6.7 ± 3.4	1.2 ± 0.7	3.4 ± 1.8	2.7 ± 1.5	1.0 ± 0.6	0.44 ± 0.39	3.5 ± 1.9
Total BG	39.9 ± 13.9	32.3 ± 11.2	17.7 ± 6.1	2.2 ± 1.0	8.1 ± 3.4	5.7 ± 2.4	1.7 ± 0.7	1.2 ± 0.6	8.1 ± 3.3
Event yield	43	38	14	1	10	7	1	1	9
N_{UL} (13% unc.)	27.2	26.0	9.9	3.6	10.8	8.6	3.6	3.7	9.6
N_{UL} (20% unc.)	28.2	27.2	10.2	3.6	11.2	8.9	3.7	3.8	9.9
N_{UL} (30% unc.)	30.4	29.6	10.7	3.8	12.0	9.6	3.9	4.0	10.5

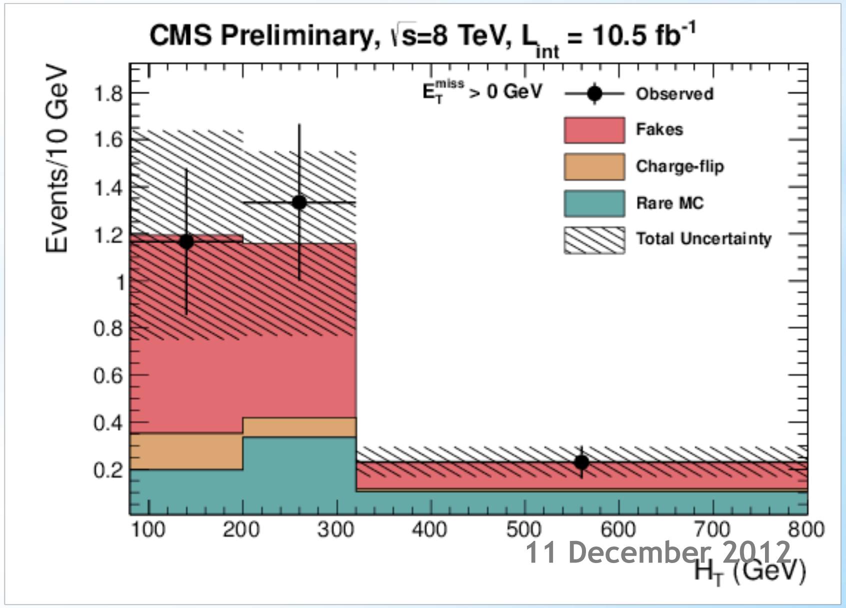
- Good agreement with SM expectation in all signal regions

same-sign dileptons + b-tags



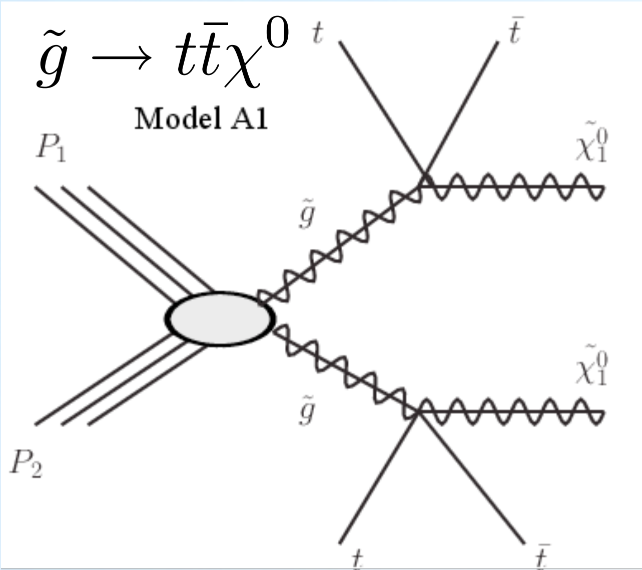


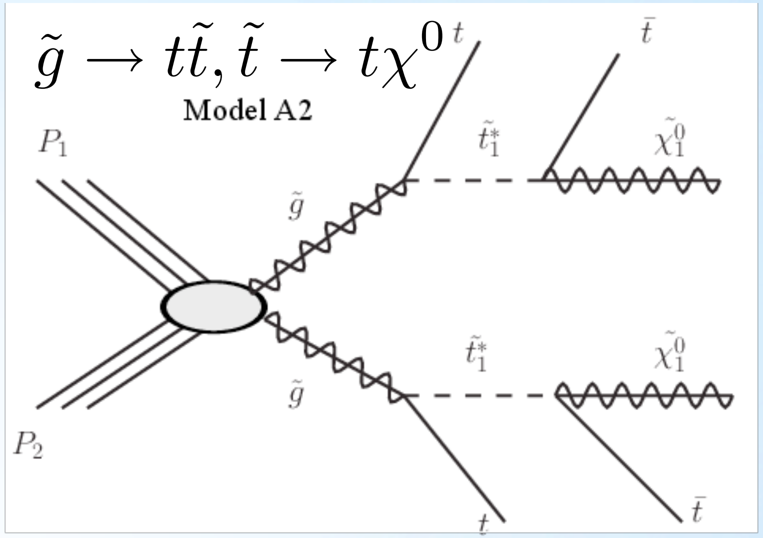
- 43 events in SR0:
  - >=2 jets
  - >=2 b-tags
  - HT > 80 GeV
  - MET > 0 GeV

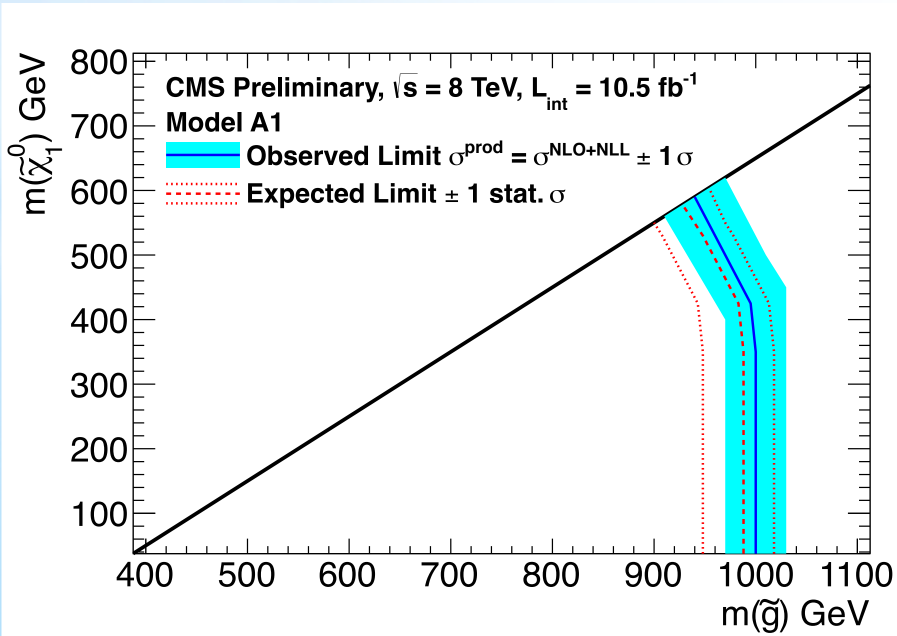


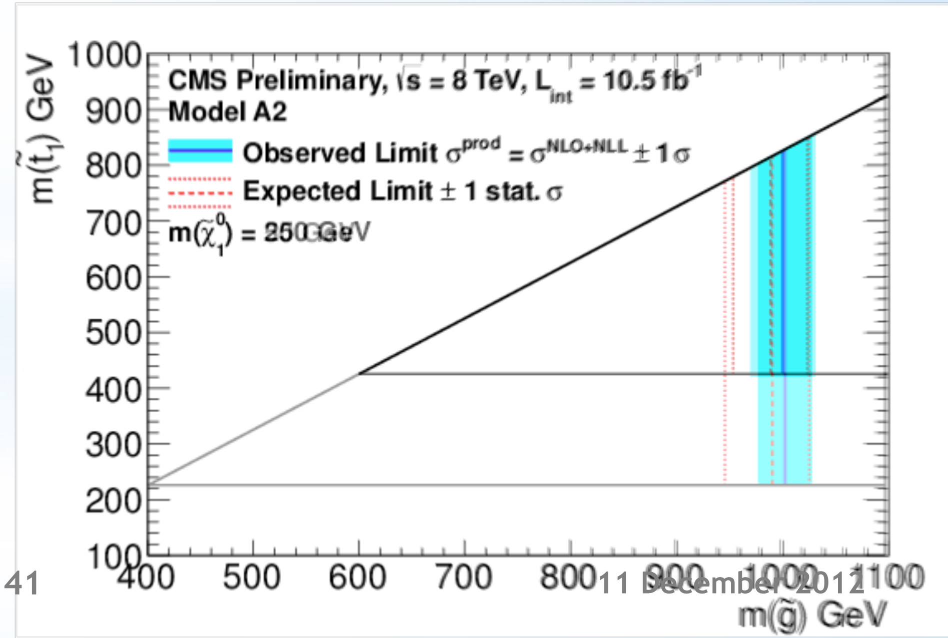
* SS+b: Gluino mediated stop production

SUS-12-029





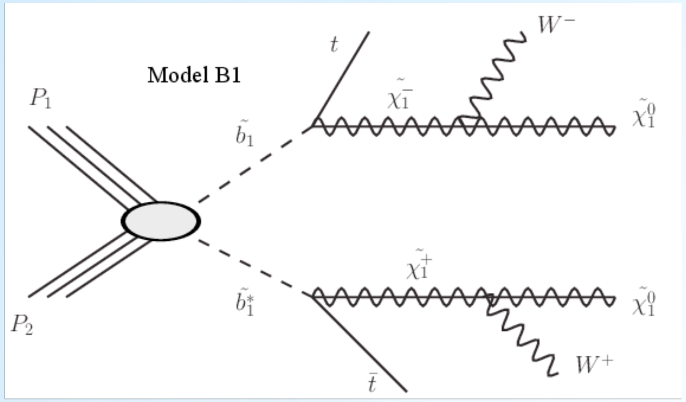




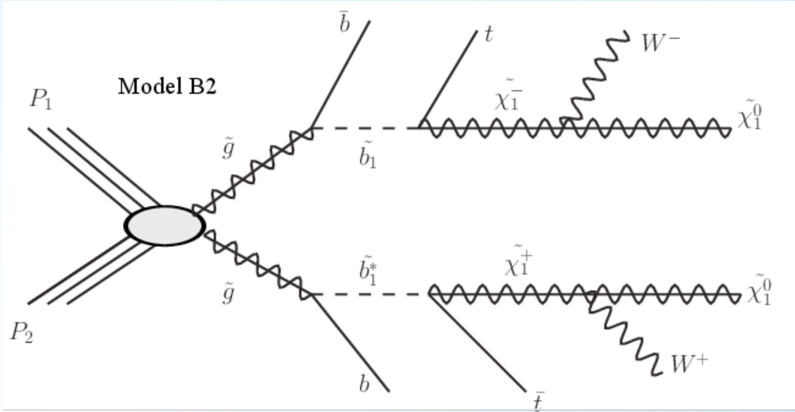
SUS-12-029

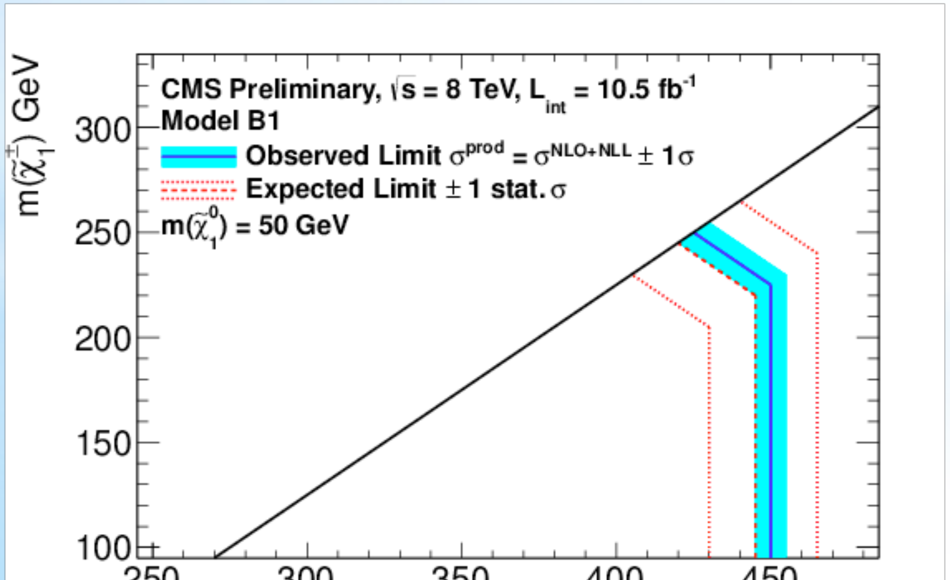
* SS+b:(Gluino mediated) sbottom production

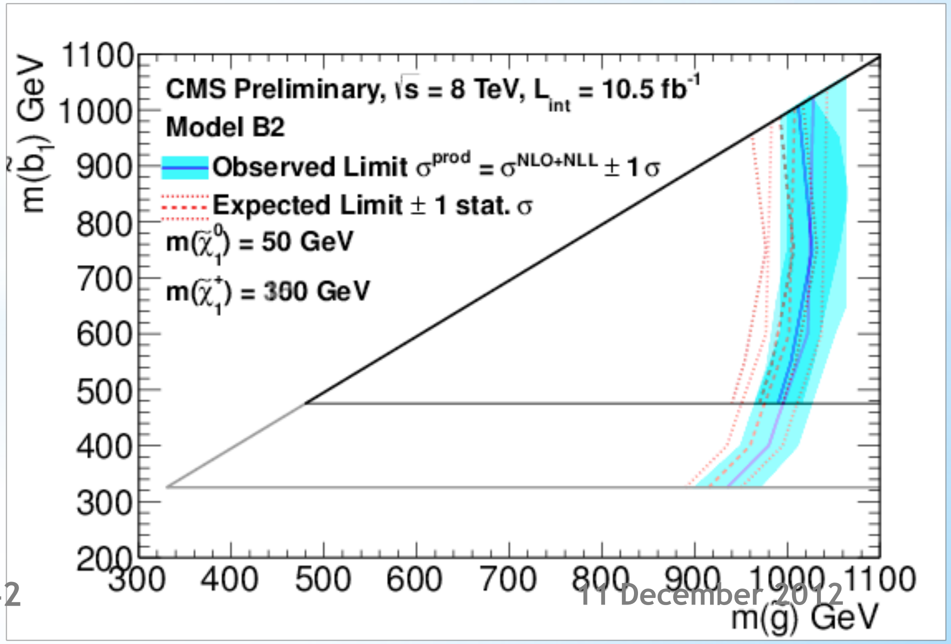
$\tilde{b} \rightarrow t\chi^{-}, \chi^{-} \rightarrow W^{-}\chi^{0}$



$\tilde{g} \rightarrow b\tilde{b}, \tilde{b} \rightarrow t\chi^{-}, \chi^{-} \rightarrow W^{-}\chi^{0}$







future challenges

* In several cases we have analyzed ~50% of the 8 TeV 2012 data
* Increased mass reach for many supersymmetric particles, e.g.,

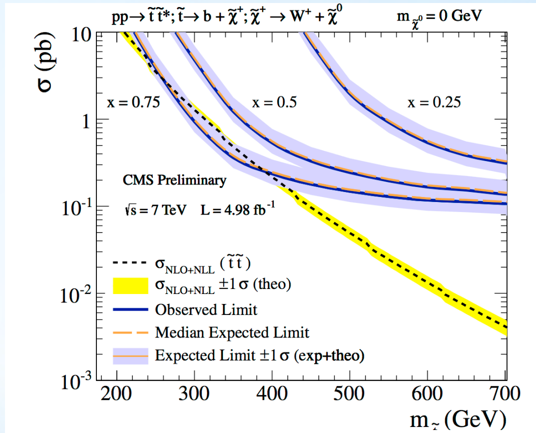
Model	T2 qqχχ	T2bb bbχχ	T2tt ttχχ	T2bW (x=0.5) bbWWχχ	T1 qqqqχχ	T1bbbb bbbbχχ	T1tttt ttttχχ
m_{max}^{parent} obs [GeV] (exp)	775 (850)	600 (650)	430 (520)	345 (340)	950 (1050)	1125 (1200)	950 (1075)
m_{max}^{LSP} obs [GeV] (exp)	325 (350)	200 (250)	135 (120)	85 (70)	450 (550)	650 (700)	560 (580)

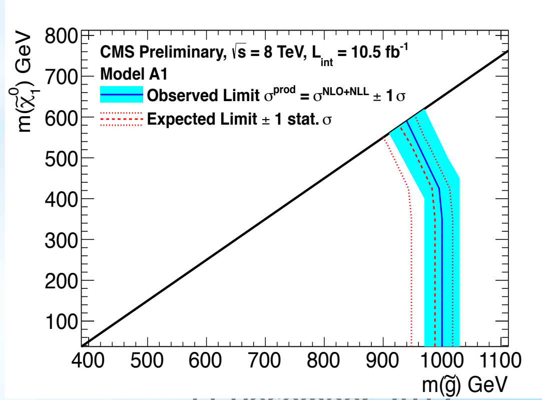
for guidance only - treat with caution (e.g. BF=1, assumed masses for other sparticles)

  * but limit on LSP much weaker than on produced parent

* **Future challenges are compressed spectra with small mass gaps between produced sparticle and LSP**
  * Analysis of "parked data" with lower trigger thresholds

* Very compressed scenarios, e.g. $m_{stop} - m_{\chi 0} < m_W$
  * stop -> charm χ0





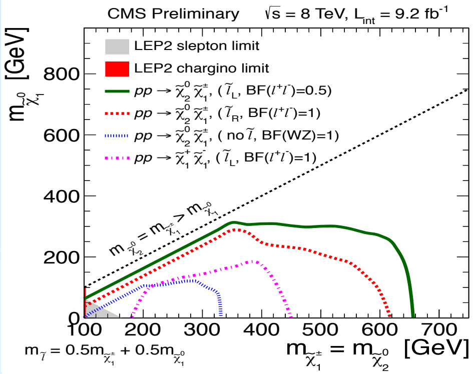
* summary & outlook

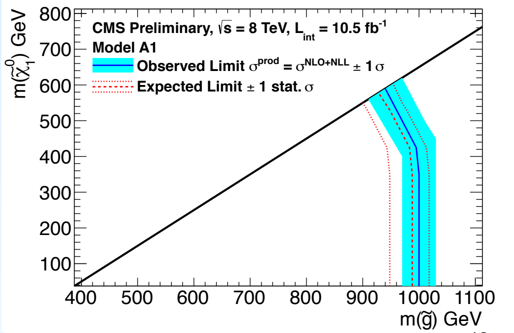
* No striking sign of supersymmetry so far!

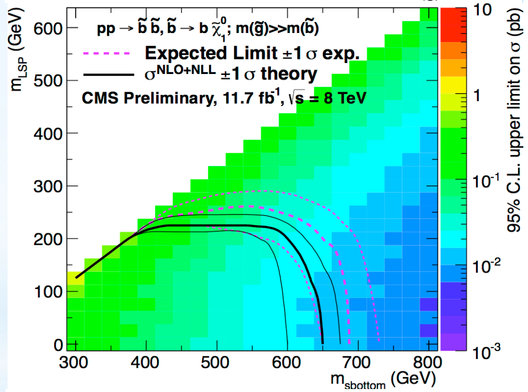
* Large variety of SUSY searches underway at CMS
* Wide spectrum of results from 8 TeV analyses available
    * strong limits on light squark and gluino masses
    * first results on direct production of charginos, neutralinos and sleptons
    * starting to constrain stop and sbottom masses

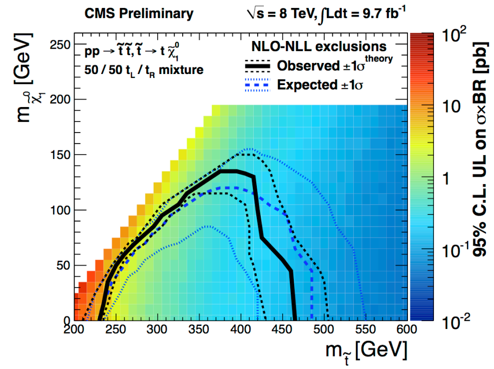
* However, there's still room for Supersymmetry
    * next challenge are small mass splittings/compressed spectra
    * parked data will help to increase CMS sensitivity
    * eventually, higher centre-of-mass energy after LS1 will further increase mass reach

* For latest results, see:
    * https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS



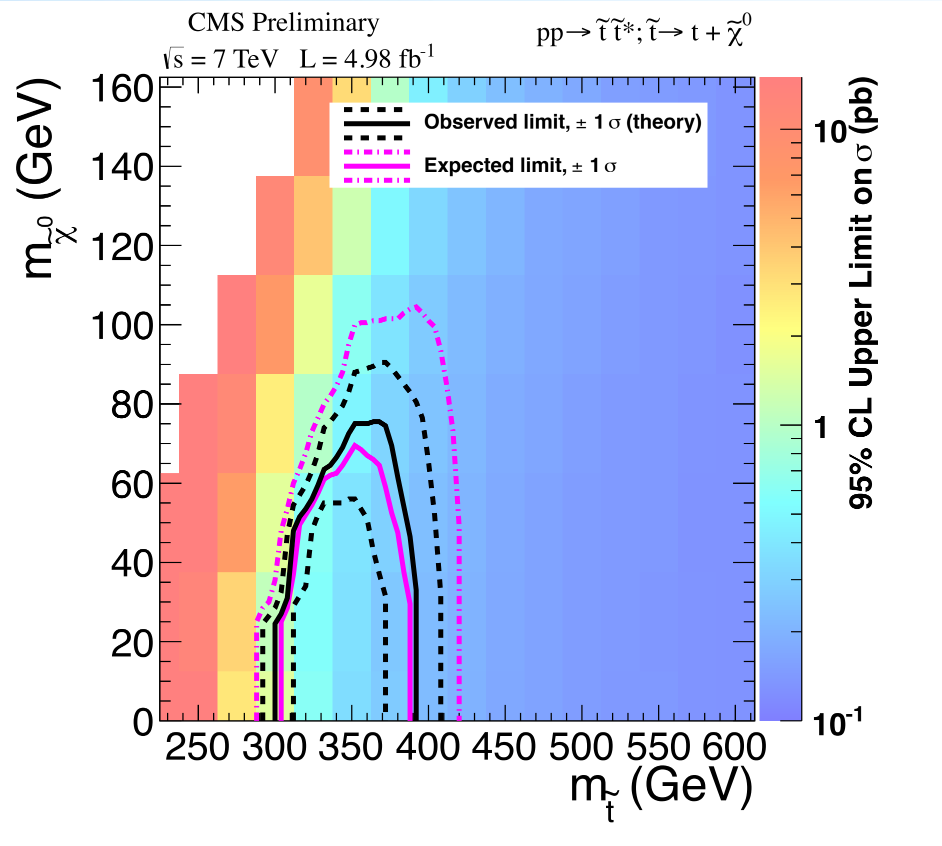


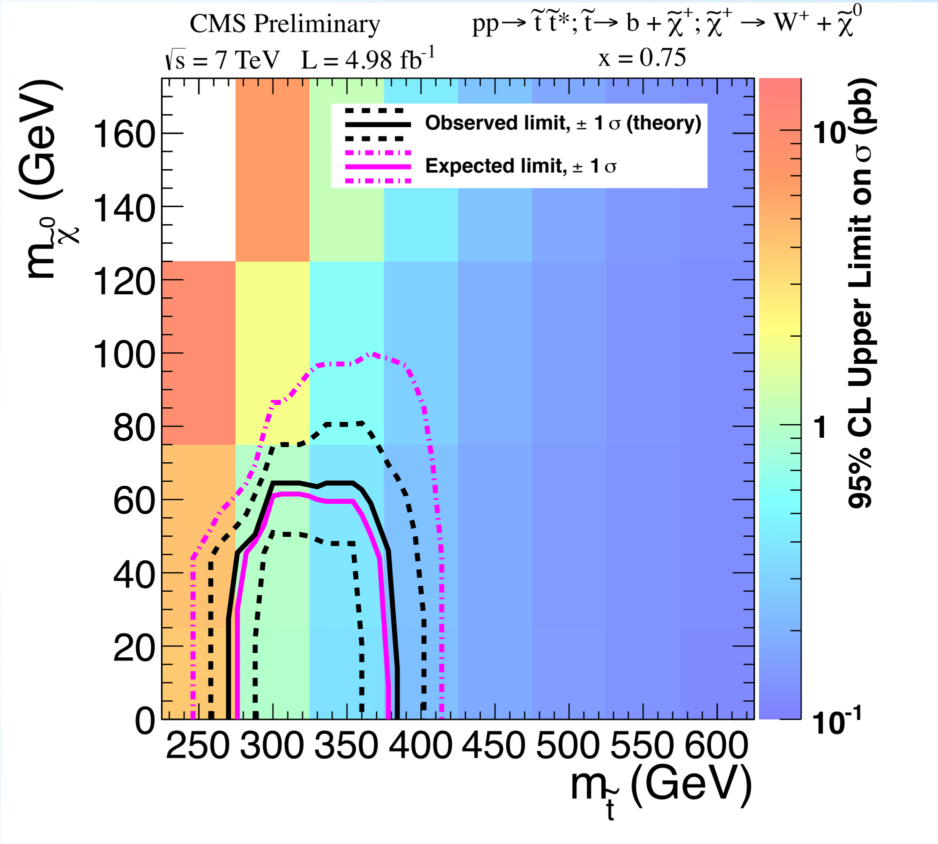




*backup

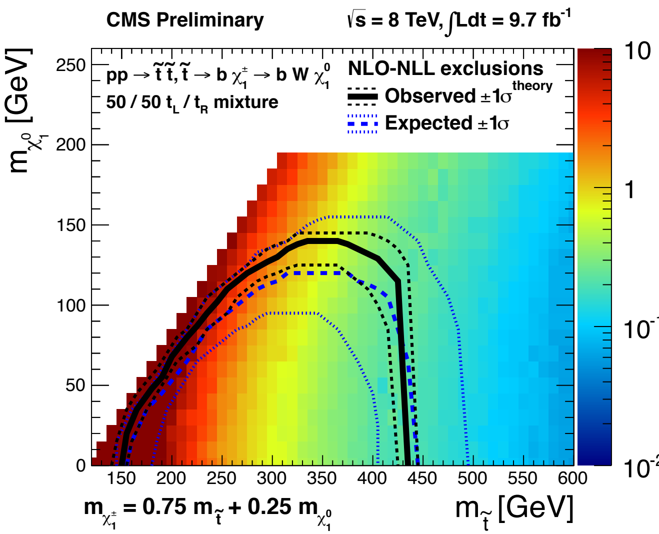
*Hardonic stop search



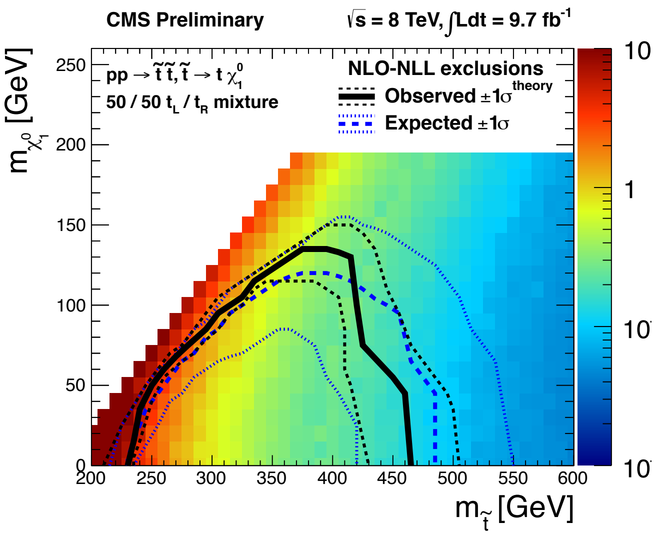


CMS vs. ATLAS comparison

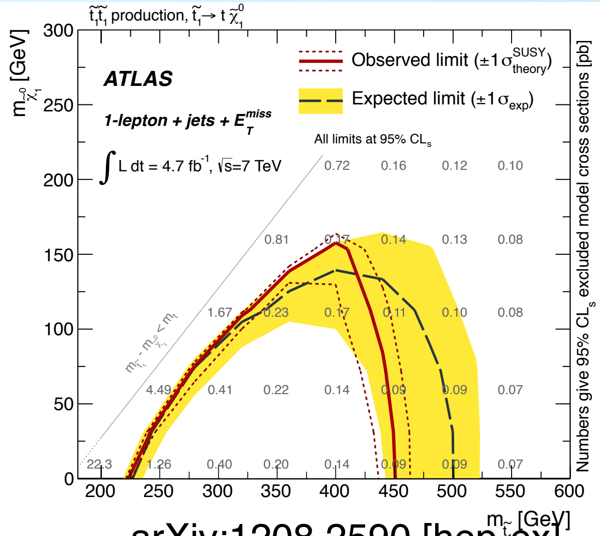
$\tilde{t} \to b\chi^{\pm}$ x = 0.75



$\tilde{t} \to t\chi^{0}$



$\tilde{t} \to t\chi^{0}$



arXiv:1208.2590 [hep-ex]

- When correcting for luminosity and √s, the ATLAS limit covers more of the $\tilde{t} \to t\, x^0$ space for 2 reasons:
  - 1) Different signal model: CMS signal model has **unpolarized tops** from $\tilde{t} \to t\, x^0$. ATLAS signal model has **top quarks which are mostly right-handed**. This choice increases the large lepton p_T and M_T(ℓ,MET) acceptance because it causes the lepton to be emitted preferentially parallel to the top boost. **We estimate the size of this effect to be ~25%**.
  - 2) Tuned kinematical requirements: The most important one appears to be the **hadronic top reconstruction**. This is not currently implemented in the CMS analysis in order to **maintain sensitivity to both the $\tilde{t} \to t\, x^0$ and $\tilde{t} \to b\, x^{\pm}$ decay modes**.

*Multilepton search categories

3ℓ: OSSF pair, no τ_h

M_T (GeV)	E_T^{miss} (GeV)	$M_{\ell\ell} < 75$ GeV		75 GeV $< M_{\ell\ell} <$ 105 GeV		$M_{\ell\ell} > 105$ GeV	
		total bkg	observed	total bkg	observed	total bkg	observed
> 160	50 – 100	2.1±0.46	4	3.3±0.51	3	1.2±0.66	0
	100 – 150	1.7±0.4	0	1.8±0.23	1	1.1±0.69	1
	150 – 200	0.79±0.3	1	0.63±0.16	1	0.26±0.18	0
	> 200	0.25±0.2	0	0.58±0.19	1	0.18±0.14	0
120 – 160	50 – 100	3.5±0.51	3	10±0.58	11	1.3±0.19	0
	100 – 150	1.1±0.34	0	1.5±0.21	0	0.17±0.053	2
	150 – 200	0.15±0.16	0	0.4±0.42	1	0.12±0.1	0
	> 200	0.11±0.047	0	0.17±0.097	1	0.079±0.086	0
0 – 120	50 – 100	53±4.5	63	382±15.3	377	19±1.7	22
	100 – 150	6.6±1	5	63±3.1	61	4±0.56	6
	150 – 200	1.4±0.25	1	16±0.86	13	0.87±0.25	2
	> 200	0.54±0.17	1	9.5±0.58	3	0.43±0.076	2

3ℓ: no OSSF pair, no τ_h

M_T (GeV)	E_T^{miss} (GeV)	$M_{\ell\ell} < 100$ GeV		$M_{\ell\ell} > 100$ GeV	
		total bkg	observed	total bkg	observed
> 160	50 – 100	1±0.33	1	0.49±0.76	0
	100 – 150	0.59±0.27	0	0.16±0.14	0
	150 – 200	0.16±0.17	0	0.027±0.067	0
	> 200	0.083±0.049	0	0.073±0.059	0
120 – 160	50 – 100	2±0.56	1	0.11±0.026	1
	100 – 150	0.52±0.63	1	0.064±0.069	0
	150 – 200	0.077±0.066	1	0.00021±0.00019	0
	> 200	0.013±0.0075	0	0.004±0.0046	0
0 – 120	50 – 100	12±2.4	12	0.61±0.16	0
	100 – 150	2.5±0.63	2	0.065±0.02	0
	150 – 200	0.16±0.055	0	0.086±0.083	0
	> 200	0.24±0.22	0	0.00021±0.00017	0

Multilepton search categories

3ℓ: SS leptons and a τ_h

M_T (GeV)	E_T^{miss} (GeV)	$M_{\ell\ell} < 100$ GeV total bkg	$M_{\ell\ell} < 100$ GeV observed	$M_{\ell\ell} > 100$ GeV total bkg	$M_{\ell\ell} > 100$ GeV observed
> 160	50 – 100	1.8±0.54	1	0.22±0.13	1
	100 – 150	0.77±0.31	0	0.21±0.15	1
	150 – 200	0.3±0.17	0	0.065±0.043	0
	> 200	0.22±0.12	2	0.012±0.0086	0
120 – 160	50 – 100	3.1±0.84	3	0.056±0.033	0
	100 – 150	0.54±0.21	1	0.013±0.01	0
	150 – 200	0.031±0.02	0	0±0	0
	> 200	0.032±0.024	0	0.0065±0.0064	0
0 – 120	50 – 100	33±6.1	25	1.3±0.42	1
	100 – 150	3.9±1	0	0.29±0.11	0
	150 – 200	0.82±0.29	0	0.042±0.027	0
	> 200	0.31±0.14	0	0.027±0.024	0

3ℓ: OSOF pair and a τ_h

M_T (GeV)	E_T^{miss} (GeV)	$M_{\ell\ell} < 100$ GeV total bkg	$M_{\ell\ell} < 100$ GeV observed	$M_{\ell\ell} > 100$ GeV total bkg	$M_{\ell\ell} > 100$ GeV observed
> 160	50 – 100	6.7±3.2	9	1.9±0.9	0
	100 – 150	5.2±3.2	8	1.2±0.91	1
	150 – 200	0.42±0.3	1	0.33±0.39	1
	> 200	0.42±0.31	1	0.055±0.019	0
120 – 160	50 – 100	18±7	21	3.4±1.5	1
	100 – 150	6.7±3.6	6	0.54±0.41	1
	150 – 200	0.34±0.25	1	6.6e-05±7.5e-05	0
	> 200	0.025±0.012	1	0.23±0.24	0
0 – 120	50 – 100	114±36.5	124	12±4.9	12
	100 – 150	22±9.1	28	2.4±0.96	3
	150 – 200	4.3±2.1	3	1.1±0.77	0
	> 200	0.25±0.1	1	0.095±0.073	0

* RPV Multilepton search categories

N_{OSSF}	onZ	S_T(GeV)	0-τ, 0-b		1-τ, 0-b		0-τ, 1+b		1-τ, 1+b	
			obs	expect	obs	expect	obs	expect	obs	expect
3 Lepton Results										
0	-	$S_T > 2000$ GeV	0	0 ± 0.009	0	0 ± 0.2	0	0 ± 0.01	0	0 ± 0.2
0	-	$1500 < S_T < 2000$ GeV	0	0.01 ± 0.01	0	0.003 ± 0.2	0	0 ± 0.01	0	0.5 ± 0.48
0	-	$1000 < S_T < 1500$ GeV	0	0.07 ± 0.03	0	0.4 ± 0.22	0	0.6 ± 0.5	2	1.3 ± 0.9
0	-	$600 < S_T < 1000$ GeV	2	2.1 ± 1.2	17	9 ± 3.5	1	3.3 ± 1.6	23	20 ± 10
0	-	$300 < S_T < 600$ GeV	14	13 ± 5.7	129	134 ± 53	20	16 ± 6.5	206	186 ± 98
0	-	$0 < S_T < 300$ GeV	30	37 ± 10	555	581 ± 130	22	13 ± 5.9	150	150 ± 72
1	$m_{\ell^+\ell^-} > 105$ GeV	$S_T > 2000$ GeV	0	0.0005 ± 0.01	0	0 ± 0.2	0	0 ± 0.03	0	0 ± 0.2
1	$m_{\ell^+\ell^-} < 75$ GeV	$S_T > 2000$ GeV	0	0.002 ± 0.01	0	0 ± 0.2	0	0 ± 0.03	0	0 ± 0.2
1	onZ	$S_T > 2000$ GeV	0	0.12 ± 0.04	0	0.005 ± 0.2	0	0.01 ± 0.04	0	0 ± 0.2
1	$m_{\ell^+\ell^-} > 105$ GeV	$1500 < S_T < 2000$ GeV	0	0.08 ± 0.04	0	0.2 ± 0.2	0	0.06 ± 0.04	0	0.05 ± 0.05
1	$m_{\ell^+\ell^-} < 75$ GeV	$1500 < S_T < 2000$ GeV	1	0.02 ± 0.03	0	0 ± 0.2	0	0.06 ± 0.04	0	0 ± 0.2
1	onZ	$1500 < S_T < 2000$ GeV	2	0.5 ± 0.28	0	0.12 ± 0.08	0	0.11 ± 0.07	0	0.07 ± 0.05
1	$m_{\ell^+\ell^-} > 105$ GeV	$1000 < S_T < 1500$ GeV	0	0.46 ± 0.11	0	0.6 ± 0.28	0	0.15 ± 0.07	1	0.9 ± 0.6
1	$m_{\ell^+\ell^-} < 75$ GeV	$1000 < S_T < 1500$ GeV	0	0.41 ± 0.08	0	0.2 ± 0.12	0	0.16 ± 0.08	0	0.6 ± 0.6
1	onZ	$1000 < S_T < 1500$ GeV	6	7.6 ± 1.3	3	2.4 ± 0.5	1	1.6 ± 0.43	1	0.8 ± 0.6
1	$m_{\ell^+\ell^-} > 105$ GeV	$600 < S_T < 1000$ GeV	6	5.2 ± 1.2	12	8.5 ± 2.6	3	3.9 ± 1.5	13	9.8 ± 5.4
1	$m_{\ell^+\ell^-} < 75$ GeV	$600 < S_T < 1000$ GeV	2	4.7 ± 0.9	11	6.8 ± 2.5	0	3.3 ± 1.1	5	5.1 ± 2.8
1	onZ	$600 < S_T < 1000$ GeV	42	56 ± 7.6	48	35 ± 7.2	7	10 ± 2.7	10	6.5 ± 1.9
1	$m_{\ell^+\ell^-} > 105$ GeV	$300 < S_T < 600$ GeV	34	31 ± 5.3	149	170 ± 39	12	17 ± 6.1	80	73 ± 35
1	$m_{\ell^+\ell^-} < 75$ GeV	$300 < S_T < 600$ GeV	34	38 ± 6	139	128 ± 29	26	23 ± 9	87	81 ± 35
1	onZ	$300 < S_T < 600$ GeV	314	356 ± 45	1023	1219 ± 290	63	44 ± 8.1	131	132 ± 31
1	$m_{\ell^+\ell^-} > 105$ GeV	$0 < S_T < 300$ GeV	81	97 ± 9.5	799	761 ± 182	11	11 ± 4.6	50	41 ± 17
1	$m_{\ell^+\ell^-} < 75$ GeV	$0 < S_T < 300$ GeV	308	325 ± 36	4933	4208 ± 1033	31	35 ± 13	146	129 ± 38
1	onZ	$0 < S_T < 300$ GeV	2054	2260 ± 213	24078	22191 ± 5517	57	67 ± 9.3	391	369 ± 87
Total3	All	All	2930	3239 ± 308	31896	29460 ± 7204	254	252 ± 59	1296	1211 ± 351

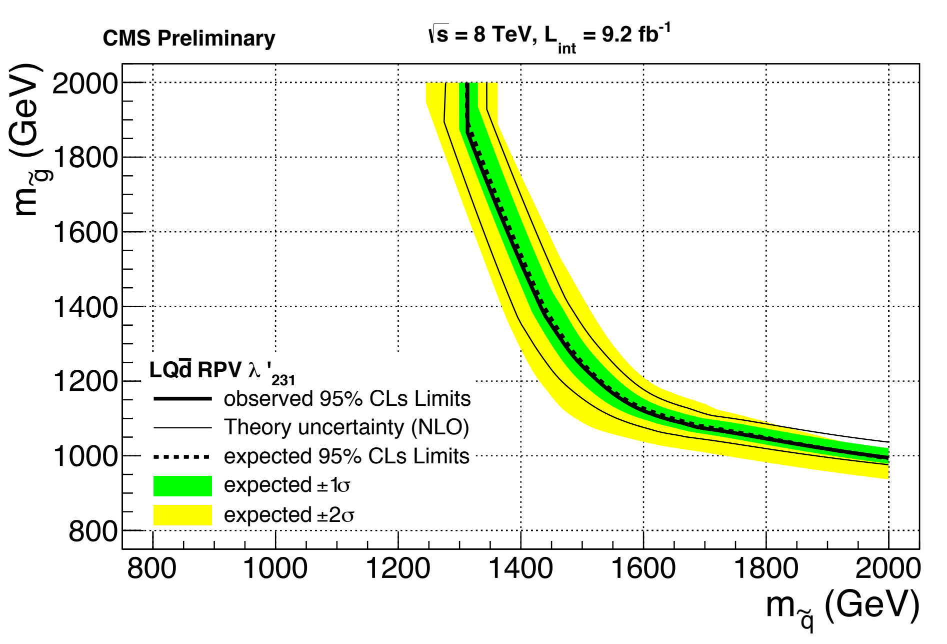
Table 1: 3 Lepton Results

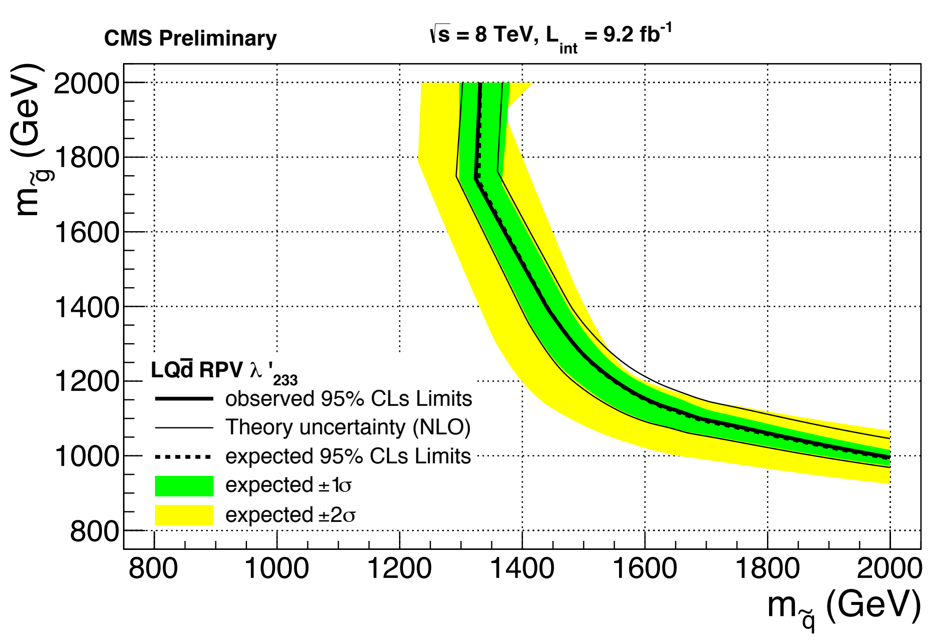
*RPV Multilepton search categories

N_{OSSF}	onZ	S_T(GeV)	0-τ, 0-b obs	0-τ, 0-b expect	1-τ, 0-b obs	1-τ, 0-b expect	0-τ, 1+b obs	0-τ, 1+b expect	1-τ, 1+b obs	1-τ, 1+b expect
4 Lepton Results										
0	-	$S_T > 2000$ GeV	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009
0	-	$1500 < S_T < 2000$ GeV	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009
0	-	$1000 < S_T < 1500$ GeV	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009
0	-	$600 < S_T < 1000$ GeV	0	0 ± 0.009	0	0.01 ± 0.01	0	0.01 ± 0.02	0	0 ± 0.009
0	-	$300 < S_T < 600$ GeV	0	0.009 ± 0.01	0	0.6 ± 0.5	0	0.0007 ± 0.009	0	0.11 ± 0.07
0	-	$0 < S_T < 300$ GeV	0	0.004 ± 0.009	2	0.16 ± 0.08	0	0.0002 ± 0.009	0	0.14 ± 0.09
1	offZ	$S_T > 2000$ GeV	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009
1	onZ	$S_T > 2000$ GeV	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009	0	0 ± 0.009
1	offZ	$1500 < S_T < 2000$ GeV	0	0 ± 0.009	0	0.007 ± 0.01	0	0 ± 0.009	0	0 ± 0.009
1	onZ	$1500 < S_T < 2000$ GeV	0	0 ± 0.009	0	0.01 ± 0.01	0	0.009 ± 0.01	0	0 ± 0.009
1	offZ	$1000 < S_T < 1500$ GeV	0	0.001 ± 0.009	0	0.06 ± 0.03	0	0.01 ± 0.01	0	0.001 ± 0.009
1	onZ	$1000 < S_T < 1500$ GeV	0	0.03 ± 0.02	0	0.05 ± 0.03	0	0.06 ± 0.04	0	0.02 ± 0.02
1	offZ	$600 < S_T < 1000$ GeV	0	0.02 ± 0.02	2	0.15 ± 0.05	0	0.03 ± 0.02	0	0.09 ± 0.05
1	onZ	$600 < S_T < 1000$ GeV	0	0.18 ± 0.06	0	0.7 ± 0.13	0	0.22 ± 0.13	0	0.32 ± 0.14
1	offZ	$300 < S_T < 600$ GeV	0	0.07 ± 0.02	1	0.7 ± 0.15	0	0.1 ± 0.06	0	0.47 ± 0.21
1	onZ	$300 < S_T < 600$ GeV	2	0.6 ± 0.17	5	4.7 ± 0.7	0	0.47 ± 0.25	1	0.7 ± 0.23
1	offZ	$0 < S_T < 300$ GeV	1	0.17 ± 0.05	9	4 ± 1.2	0	0.009 ± 0.01	0	0.19 ± 0.11
1	onZ	$0 < S_T < 300$ GeV	0	1.2 ± 0.38	18	18 ± 5.2	2	0.02 ± 0.02	2	0.37 ± 0.17
2	offZ	$S_T > 2000$ GeV	0	0 ± 0.009	0	0 ± 0	0	0 ± 0.009	0	0 ± 0
2	onZ	$S_T > 2000$ GeV	0	0.001 ± 0.009	0	0 ± 0	0	0.01 ± 0.01	0	0 ± 0
2	offZ	$1500 < S_T < 2000$ GeV	0	0 ± 0.009	0	0 ± 0	0	0 ± 0.009	0	0 ± 0
2	onZ	$1500 < S_T < 2000$ GeV	0	0.02 ± 0.01	0	0 ± 0	0	0.002 ± 0.009	0	0 ± 0
2	offZ	$1000 < S_T < 1500$ GeV	0	0.004 ± 0.01	0	0 ± 0	0	0 ± 0.009	0	0 ± 0
2	onZ	$1000 < S_T < 1500$ GeV	0	0.27 ± 0.06	0	0 ± 0	0	0.04 ± 0.02	0	0 ± 0
2	offZ	$600 < S_T < 1000$ GeV	0	0.04 ± 0.01	0	0 ± 0	0	0.04 ± 0.02	0	0 ± 0
2	onZ	$600 < S_T < 1000$ GeV	1	2.6 ± 0.5	0	0 ± 0	1	0.45 ± 0.14	0	0 ± 0
2	offZ	$300 < S_T < 600$ GeV	1	0.46 ± 0.1	0	0 ± 0	1	0.1 ± 0.06	0	0 ± 0
2	onZ	$300 < S_T < 600$ GeV	10	19 ± 3.8	0	0 ± 0	2	1.4 ± 0.39	0	0 ± 0
2	offZ	$0 < S_T < 300$ GeV	4	3.4 ± 0.9	0	0 ± 0	0	0.07 ± 0.03	0	0 ± 0
2	onZ	$0 < S_T < 300$ GeV	68	56 ± 13	0	0 ± 0	1	0.44 ± 0.12	0	0 ± 0
Total4	All	All	87	84 ± 19	37	29 ± 6.9	7	3.6 ± 1.1	3	2.5 ± 0.7

Table 1: 4 Lepton Results

* Multilepton - semileptonic RPV





*Razor with taus