Search for SUSY with CMS

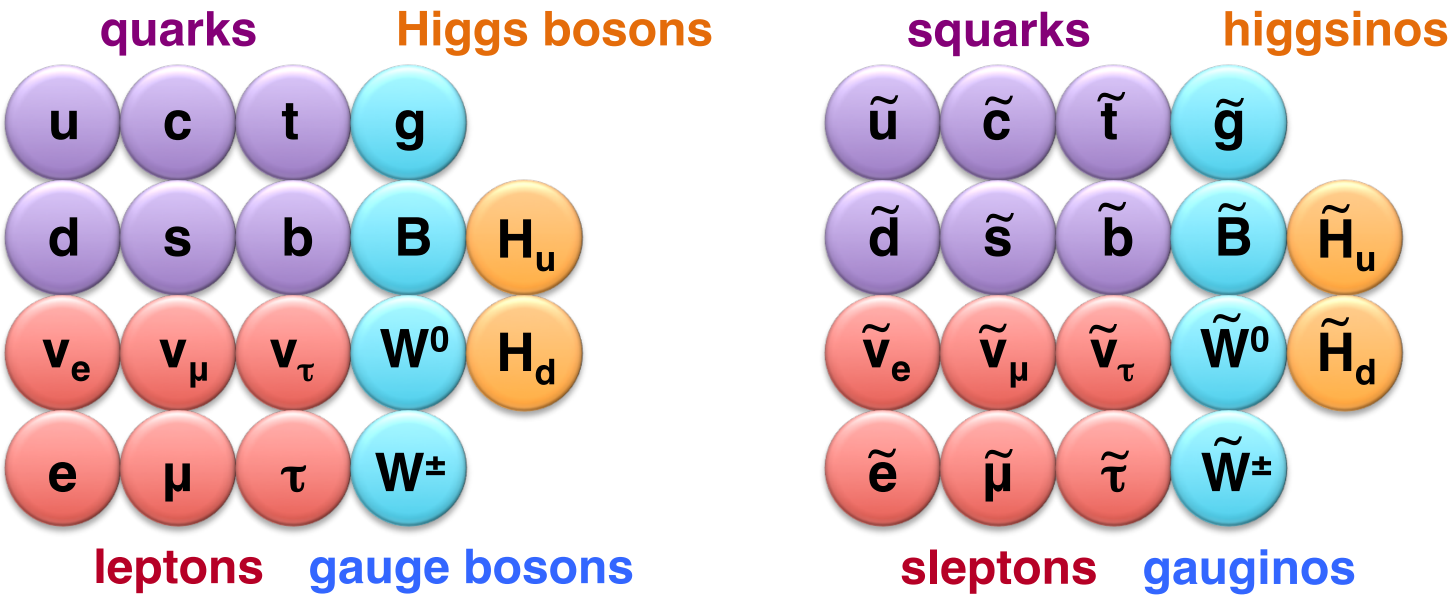
A select set of topics from 8TeV search program

Frank Würthwein
UCSD

Overview

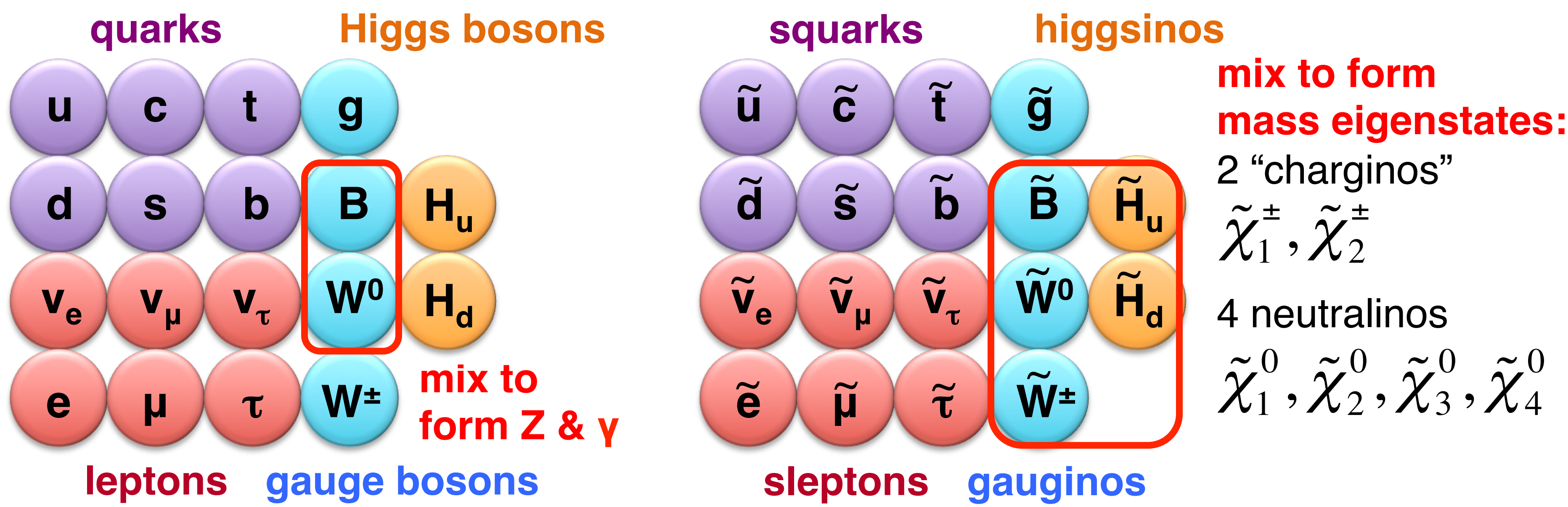
- Introduction of "target spectrum"
- Searches for weakly interacting SUSY
- Searches for stop and sbottom
- Searches for gluino
- Natural SUSY without a Dark Matter candidate

SUperSYmmetry Overview



- SUSY introduces partners to SM with $\Delta_{spin} = ½$
- Wide variety of signatures due to rich phenomenology

SUperSYmmetry Overview



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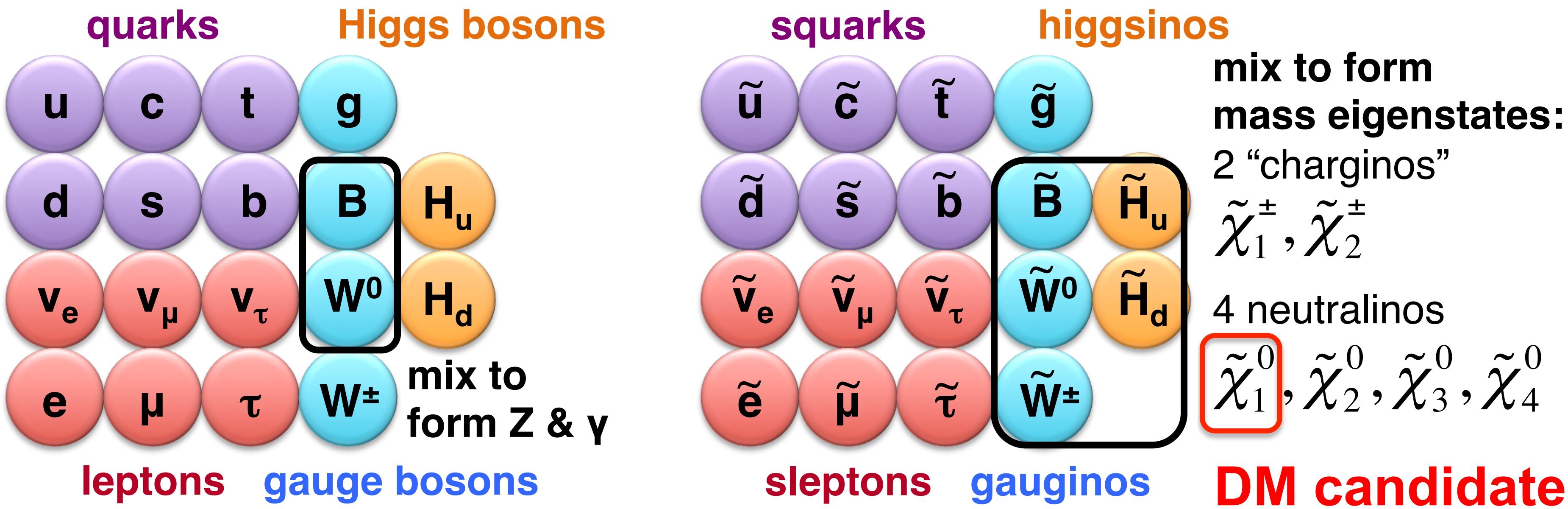
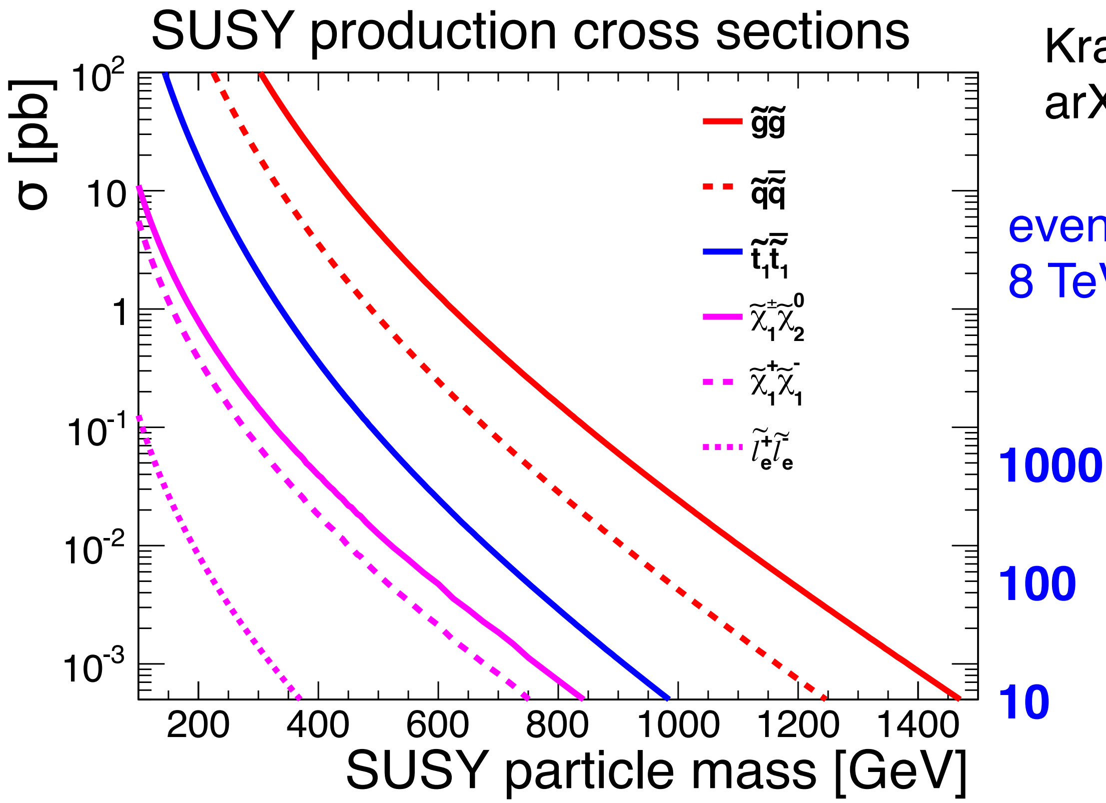
- Wide variety of signatures due to rich phenomenology
- Mixing produces 2 charginos & 4 neutralinos

SUperSYmmetry Overview



- SUSY introduces partners to SM with $\Delta_{spin} = ½$
- Wide variety of signatures due to rich phenomenology
- Mixing produces 2 charginos & 4 neutralinos
- Lightest SUSY particle (LSP) provides WIMP dark matter candidate -> **MET signature in detector**.

SUSY Production Xsection

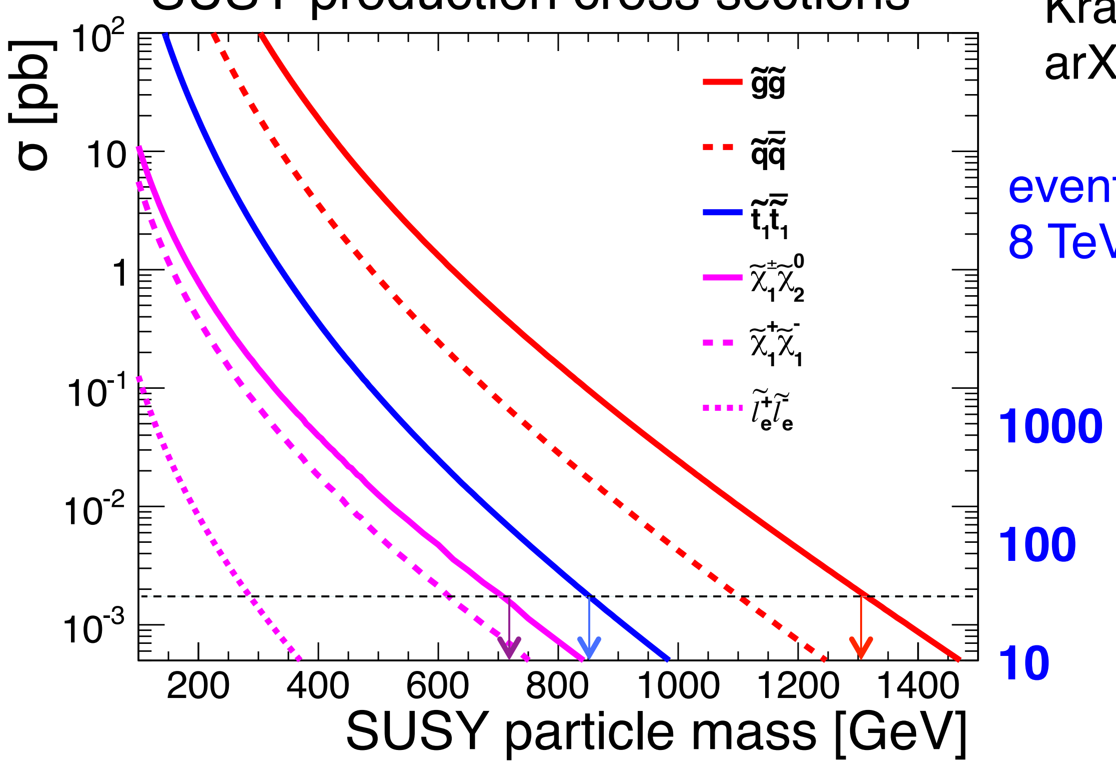


Kramer et. al.
arXiv:1206.2892

events in 20 fb^{-1}
8 TeV data sample

- SUSY production fully specified by:
  - Parton distribution functions
  - Gauge Couplings -> same as SM
  - SUSY particle masses

To set the scale

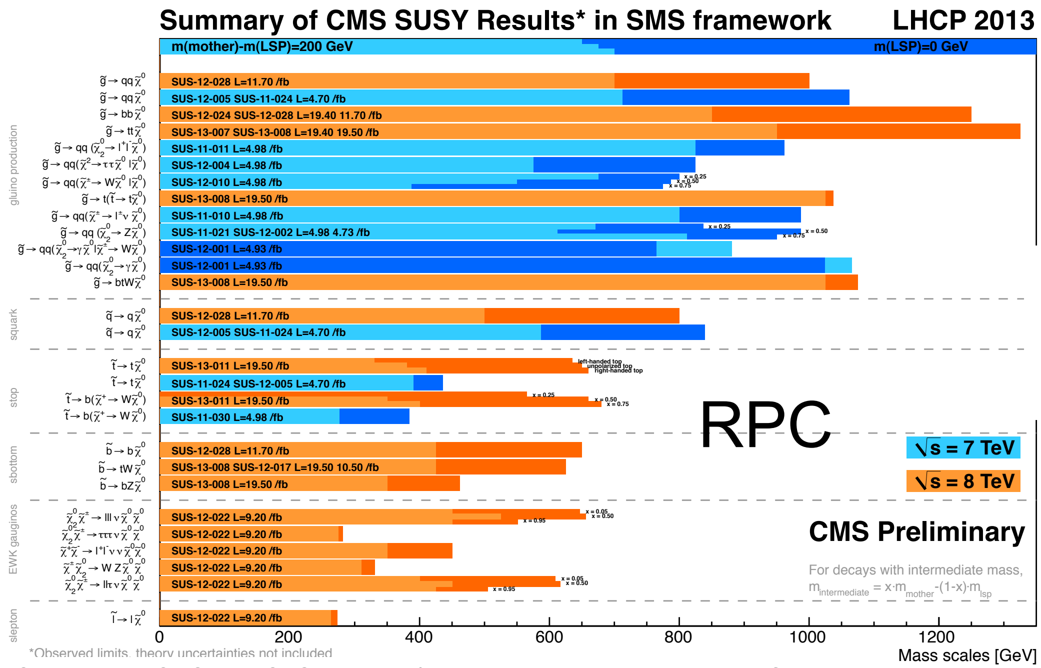


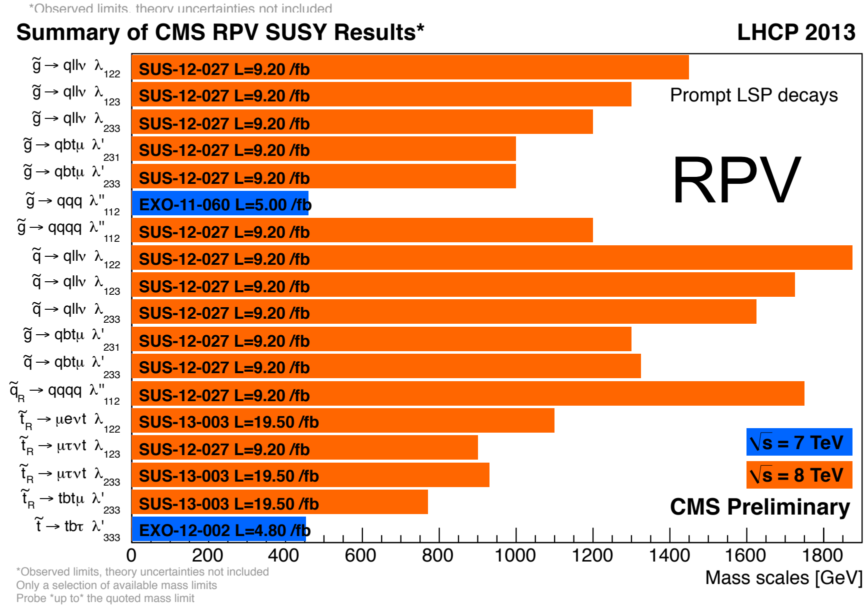
Kramer et. al.
arXiv:1206.2892

events in 20 fb^{-1}
8 TeV data sample

- "threshold" for producing ~ 40 events
  - Gluinos @ ~ 1300 GeV
  - Stop/sbottom @ ~ 850 GeV
  - Chargino/neutralino @ ~ 700GeV

The Grand Summary





Large variety of searches probing wide range of models

No SUSY found anywhere!

For this talk: Decided to pick a theme, and focus on a subset of only 8TeV searches.

Theme for this talk

- Is SUSY relevant to Electroweak Symmetry Breaking ?

$\Rightarrow$“Natural SUSY”

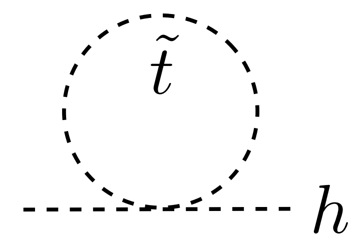
- To what extent have we probed “Natural SUSY” ?

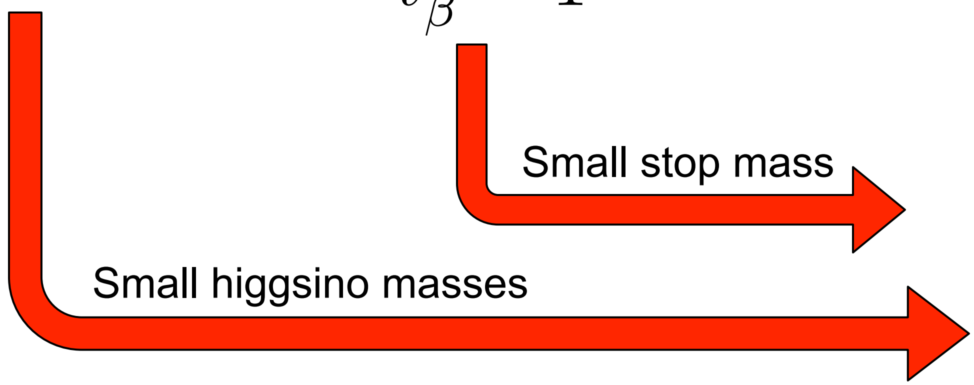
Naturalness for Experimentalists

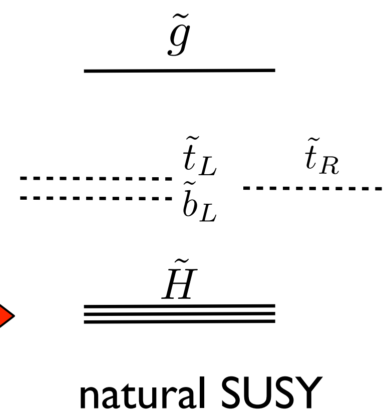
"Large" cancellations are "unnatural"

$$M_Z^2 = -2\mu^2 + 2\,\frac{m_{H_d}^2 - t_\beta^2\, m_{H_u}^2}{t_\beta^2 - 1}\,,$$

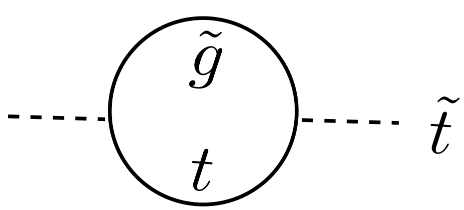
Eq. from
arXiv:1206.5800





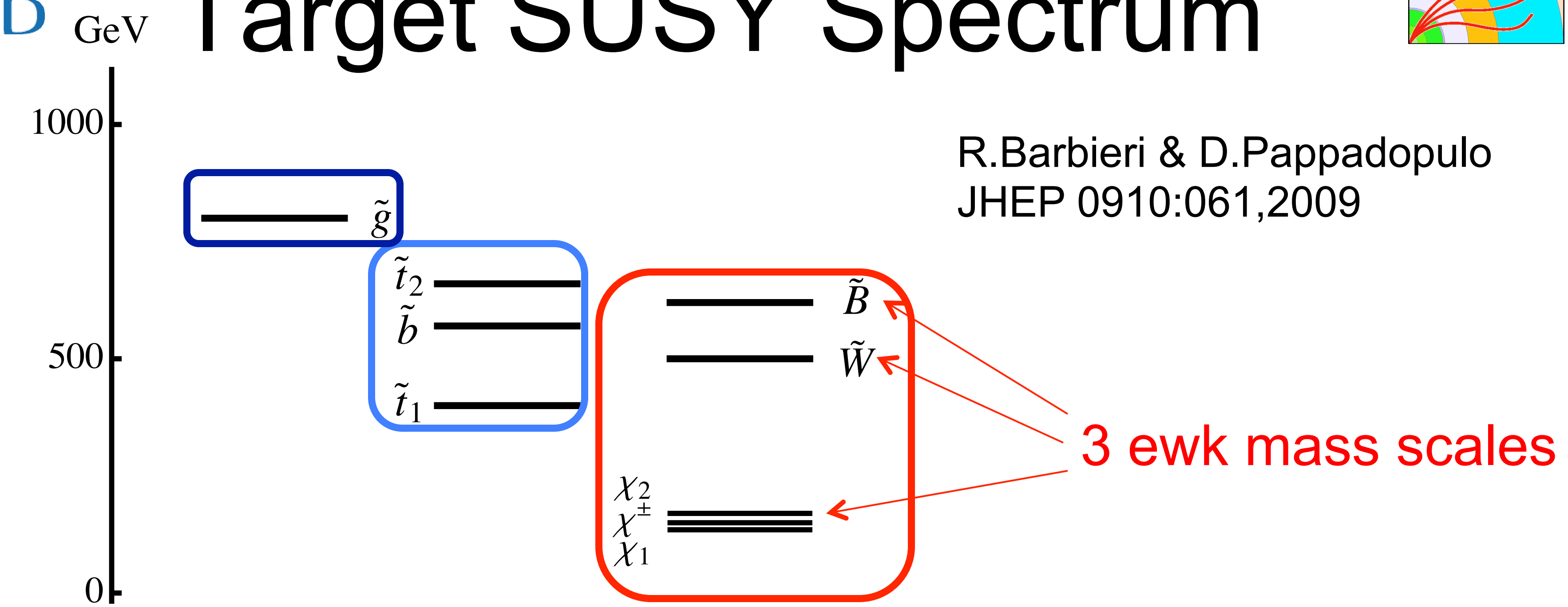


Cartoon from
arXiv:1110.6926



2nd order loop contributions to second term also require the gluino not to be too large in mass.

Target SUSY Spectrum

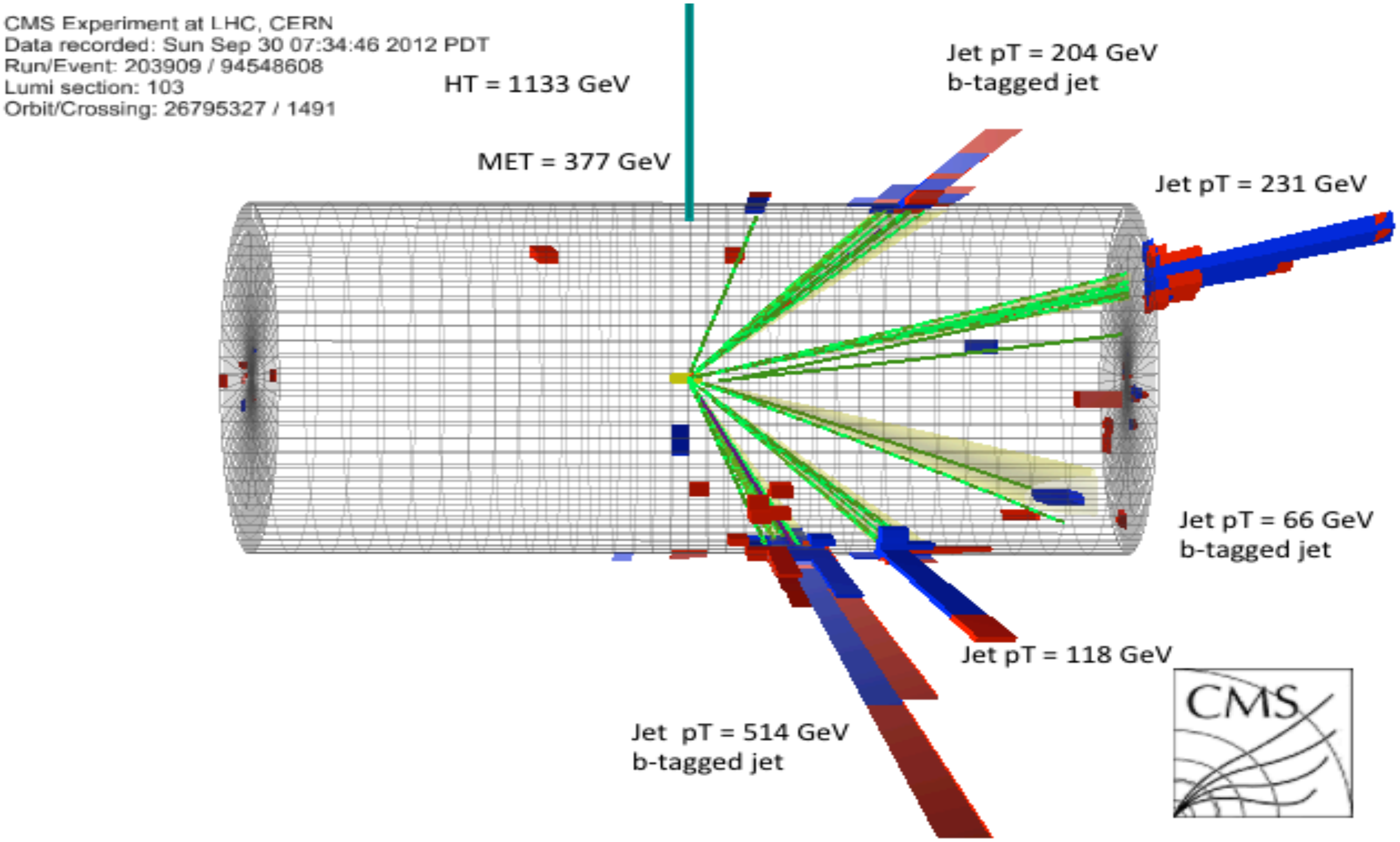


R.Barbieri & D.Pappadopulo
JHEP 0910:061,2009

Discuss 3 types of searches:

Pair production of
weakly interacting SUSY particles,
stop and sbottom,
gluinos.

SUSY Signatures in Detector



- Jets: # of jets, H_T = sum of jet pT, # of b-tagged jets
- Leptons: electrons, muons, tau
- MET: transfer momentum imbalance

Pair Production of weakly interacting s-particles

Mass Scales

"Bino": $B \rightarrow \chi_1^0$

"Wino": $W_3, W^{\pm} \rightarrow \chi_2^0, \chi_1^{\pm}$

"Higgsino": $H_u, H_d \rightarrow \chi_3^0, \chi_4^0, \chi_2^{\pm}$

3 independent mass scales

Sparticle masses (almost) degenerate at each scale, unless scales are "close" to each other.

Search for decay products in cascades between scales plus MET from LSP.

For details on mass splittings see: Gunion,Haber PRD 37, 2515 (1988)

Search Strategies

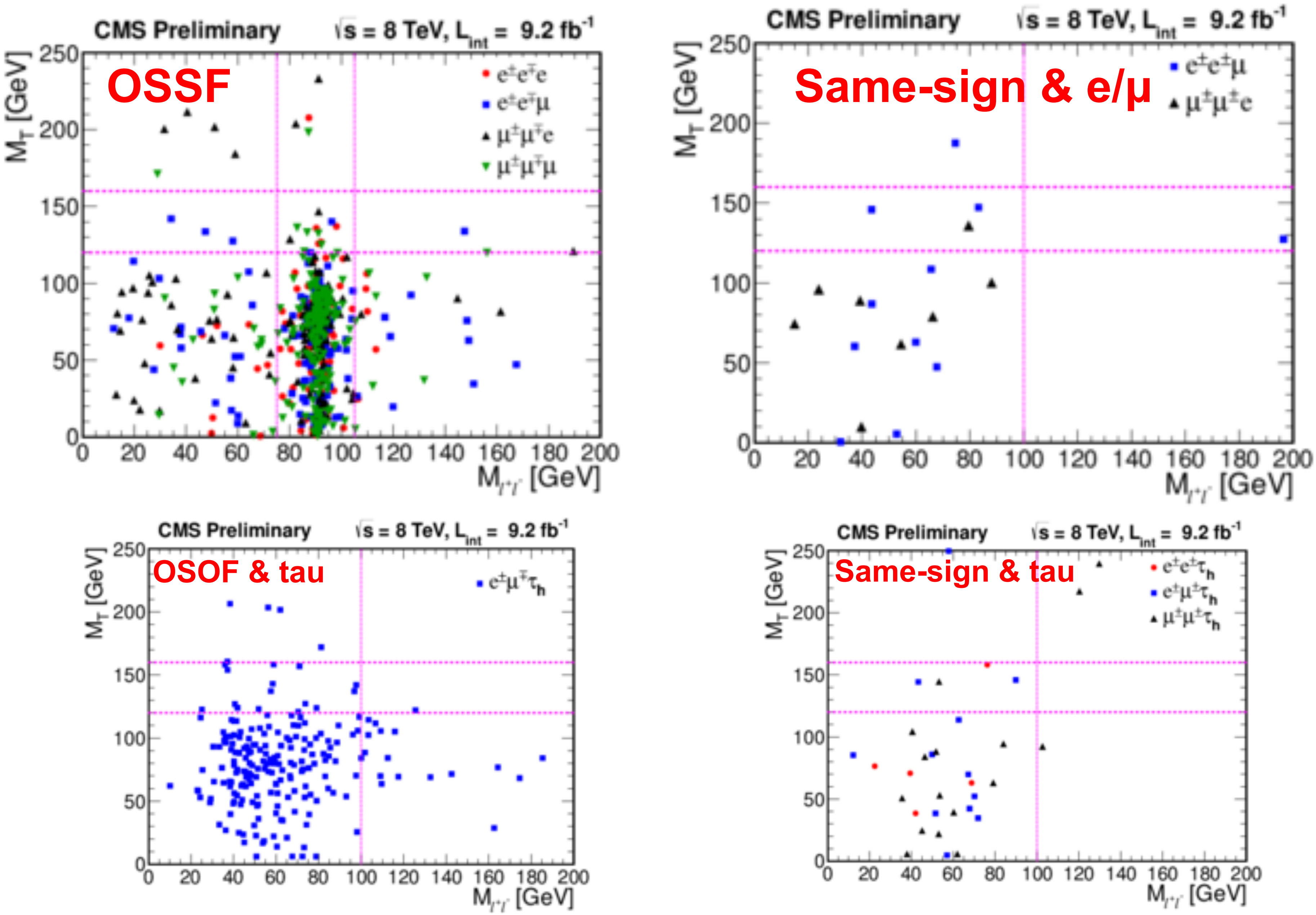
SUS-12-022

- Search with 2,3,4 lepton in 9.2/fb @ 8TeV
  - Dilepton 20/10 pT trigger ee, eμ, μμ
    - Extra e,μ (tau) w. pT > 10(20)GeV
  - Same-sign and Opposite sign dileptons with e,μ
  - 3,4 leptons with at most one hadronic tau
  - Distinguish with/without OSSF candidate
    - OSSF = opposite sign same flavor e, μ

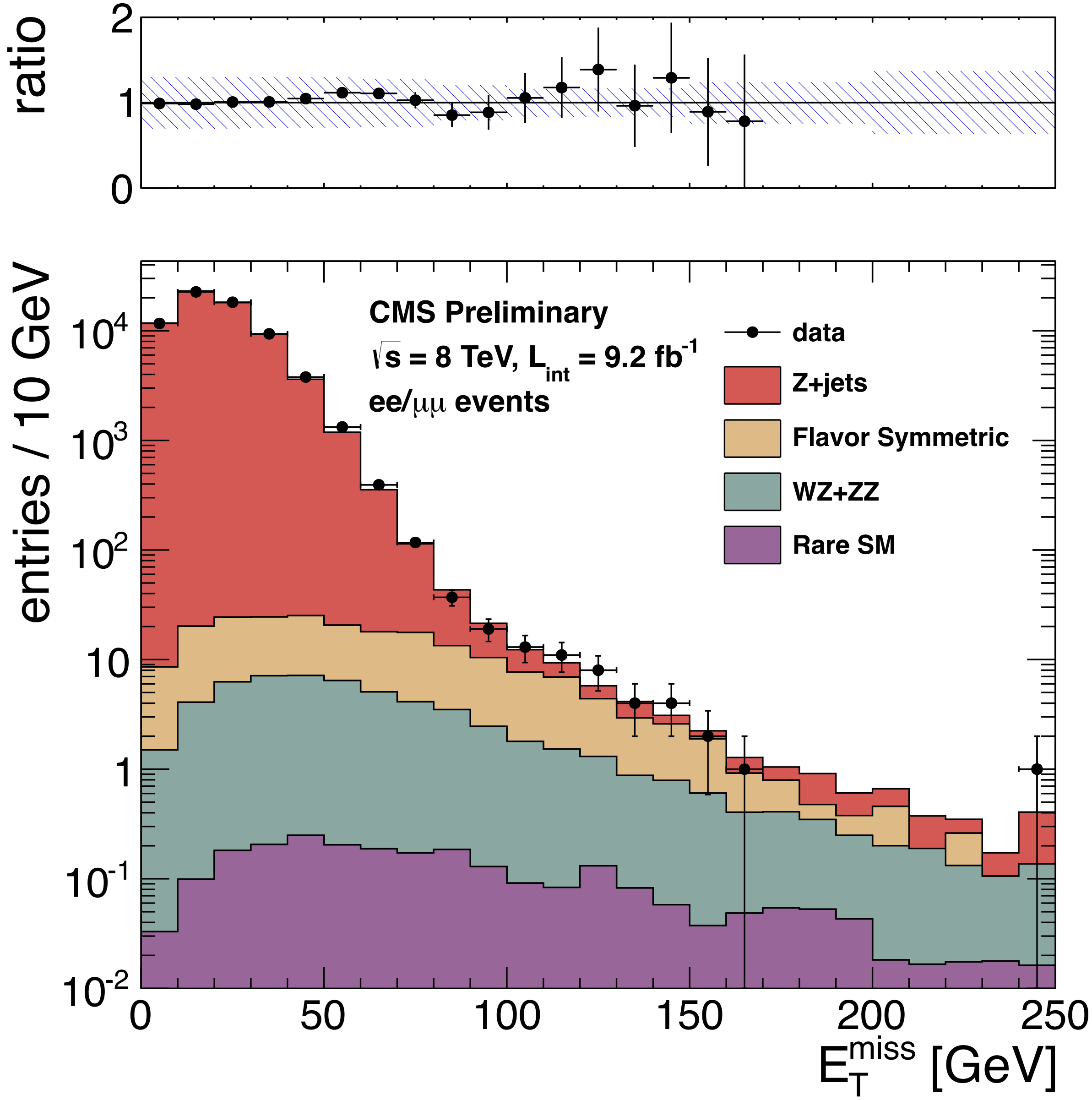
In the following only a subset of the results are shown.

More details at: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS12022

Tri-leptons & MET > 50GeV



Z + MET + dijets

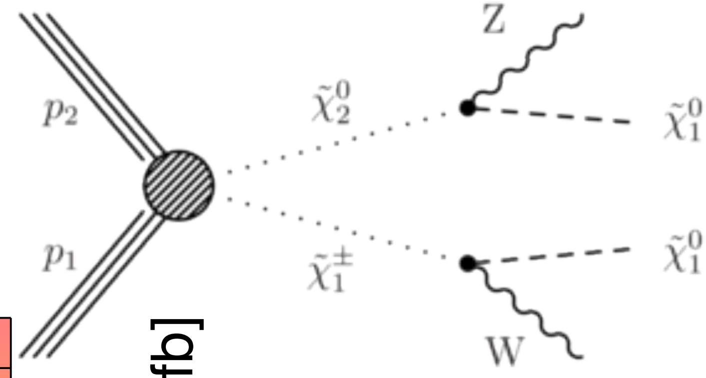


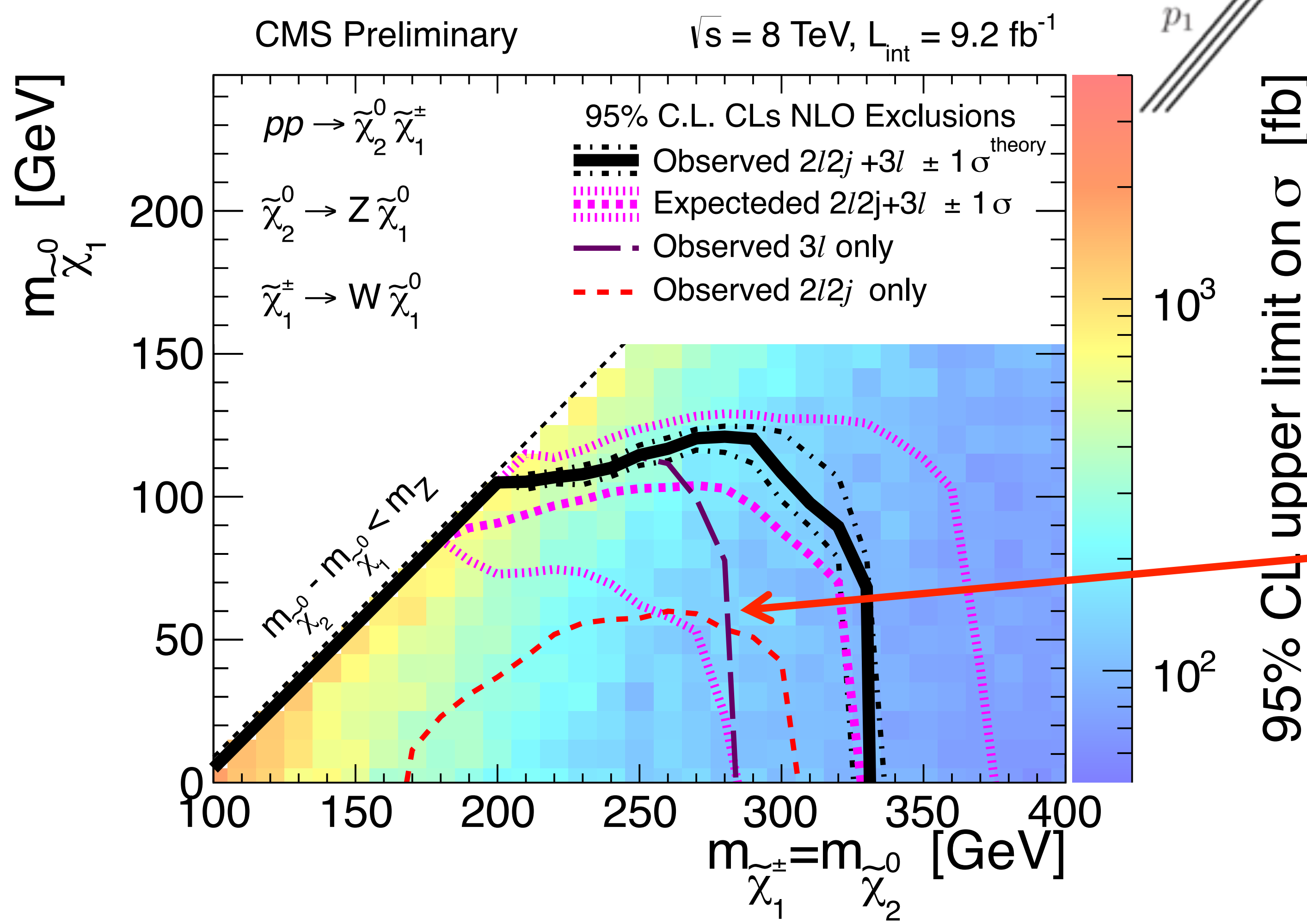
b-veto & dijet mass consistent w. W/Z to suppress top bkg

Z+jets and flavor symmetric bkg estimated from data.

Interpretation as WZ+MET

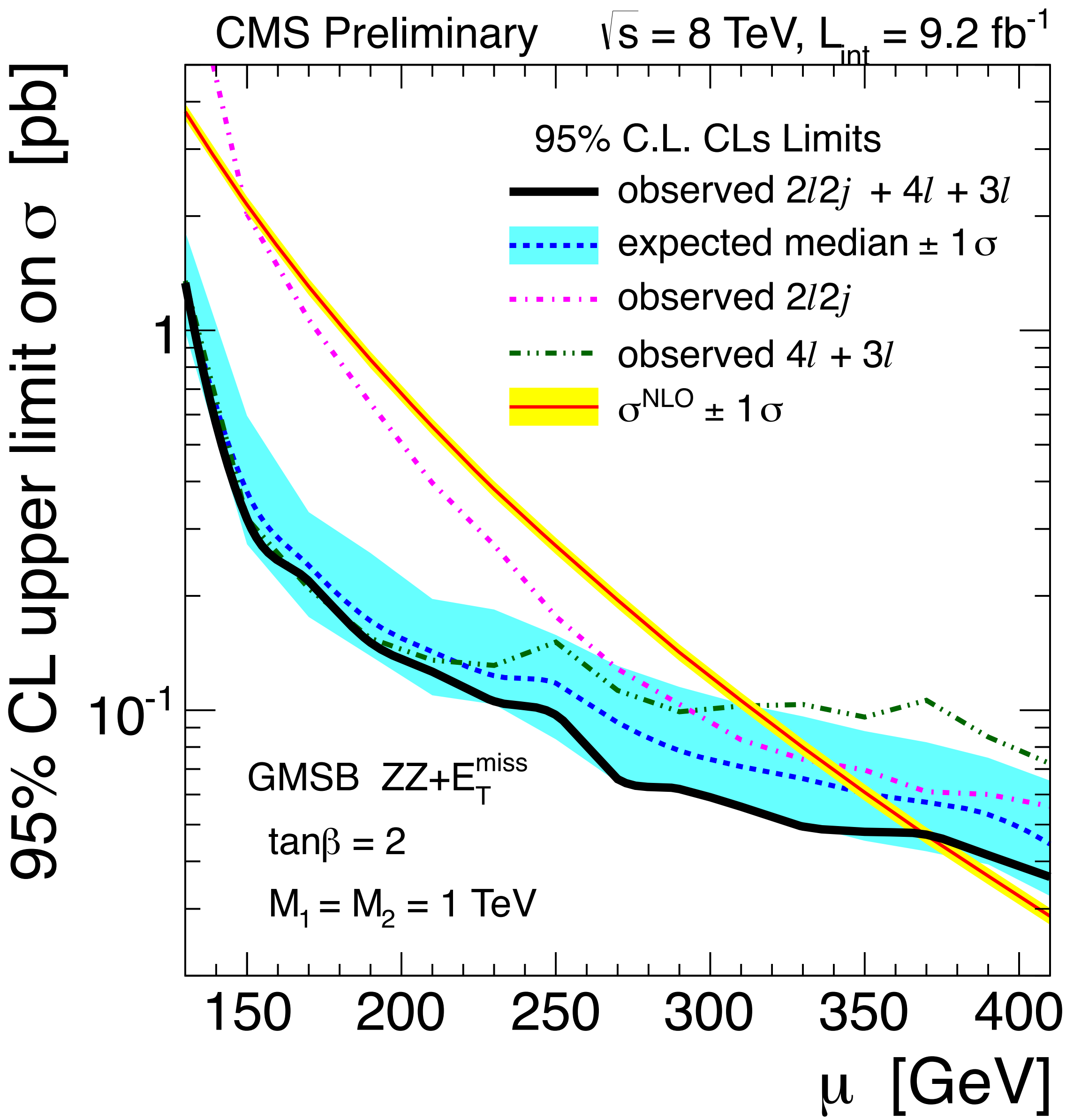
Wino-Bino scale combo up to 300/100GeV ruled out.





3l & 2l2j complement each other

Interpretation in Higgsino GMSB model



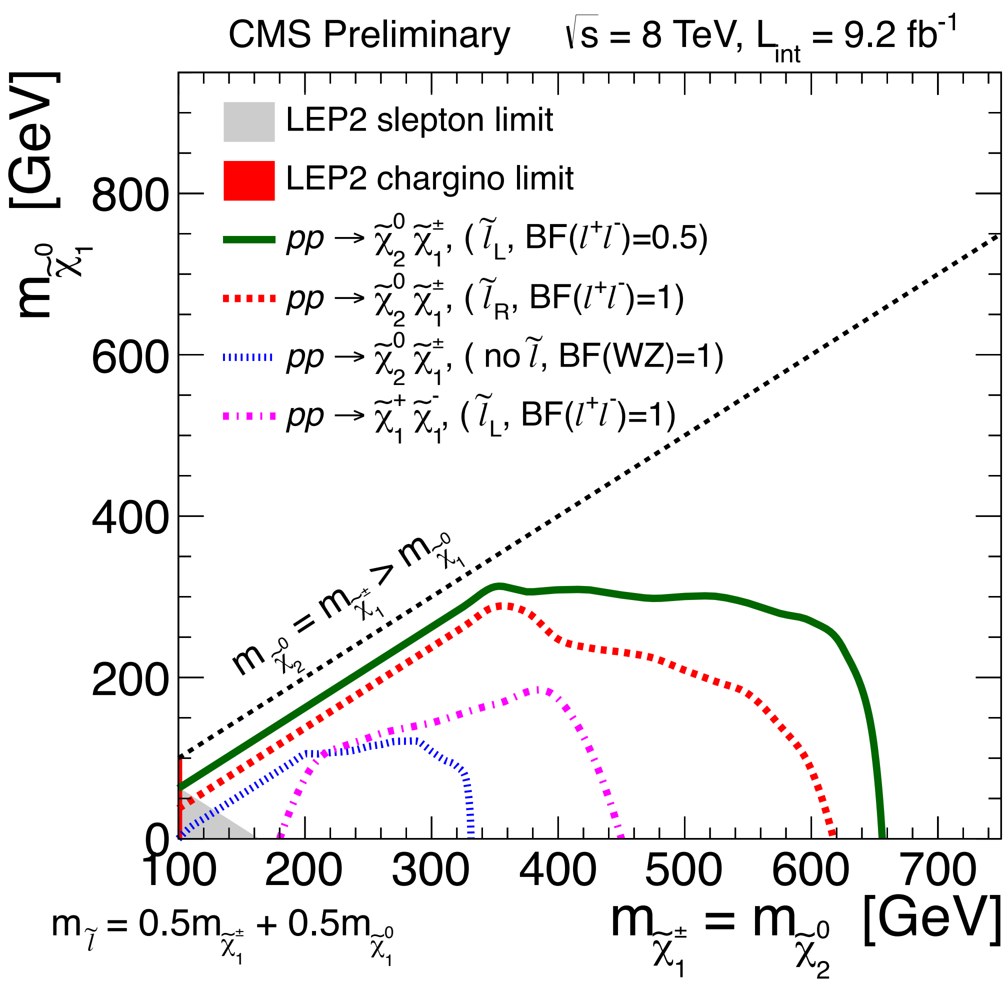
Z-enriched Higgsino model
Ruderman & Shih
JHEP08(2012)159

3 higgsinos are ~ degenerate, and X_1^0 decays to Z gravitino.

BR(X_1^0 -> Z gravitino) ~ 85% - 100% depending on μ.

μ < 370GeV ruled out in this model.

Summary Ewkinos

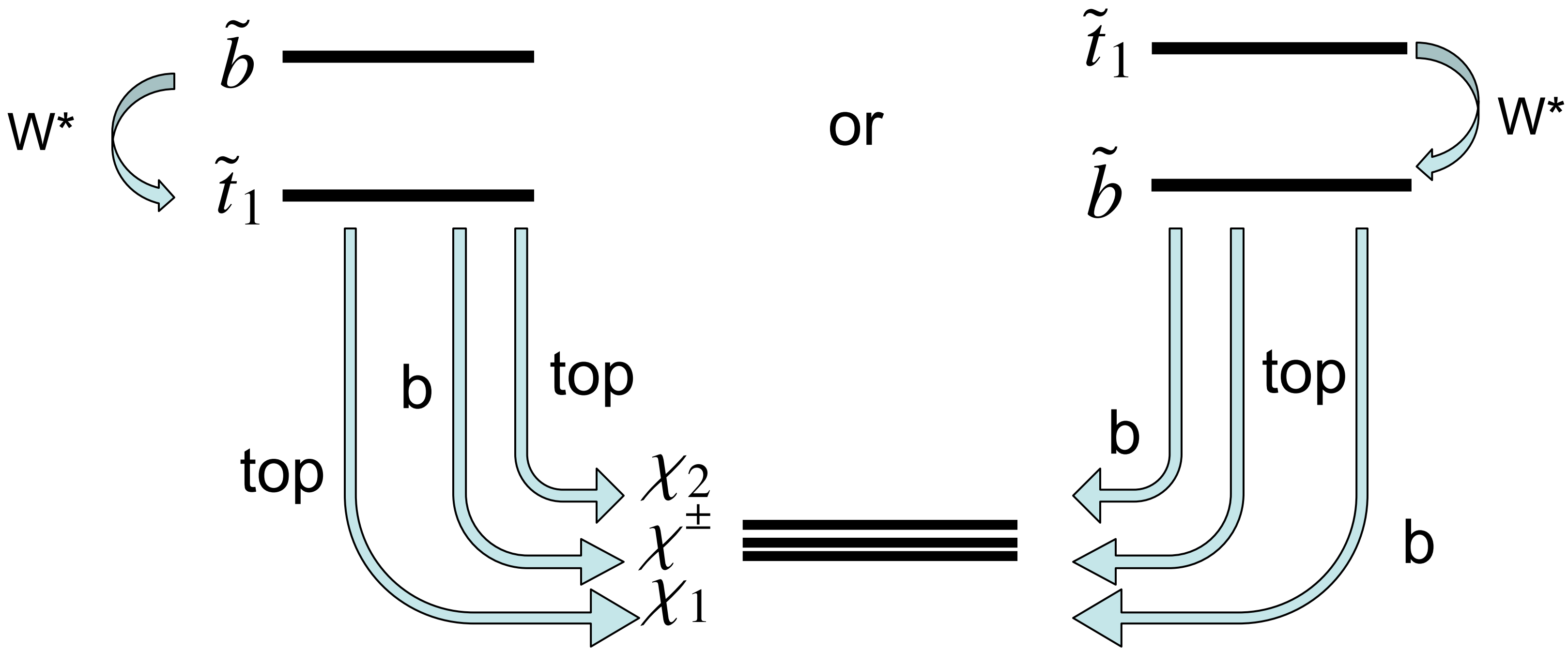


Reach of up to 650/250GeV Wino/Bino scale combo iff BR into leptons ~ 100%

Reach of up to 300/100GeV Wino/Bino scale combo for BR to leptons typical of W/Z decays.

No applicable limits outside GMSB if Higgsinos are the only low mass ewkinos.

Pair production of sbottom and stop



Typical final states:

2 b & MET
2 top & MET
1 top 1 b & MET

Search Strategies

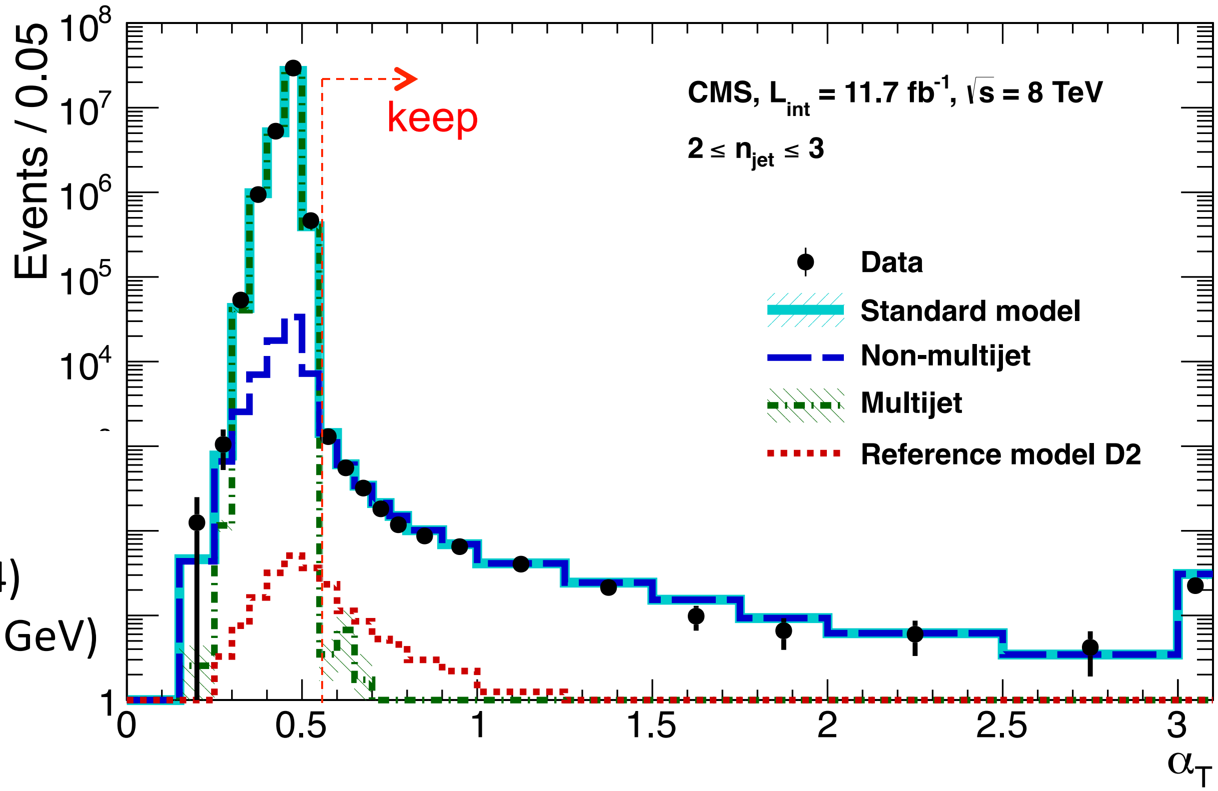
- 2 b + MET
  - Fully hadronic search using alphaT and binned in b-tags, # of jet and H_T.
    - SUS-12-028 “alphaT” (11.7/fb @ 8TeV)
- 2 top + MET
  - 1-lepton & 4 jets & 1 b-tag analysis optimized for stop to top X^0 decay.
    - SUS-13-011 (19.5/fb @ 8TeV)

Fully Hadronic alphaT

$$\alpha_T = \frac{E_T^{jet2}}{\underbrace{M_T}_{\text{di-jet}}}$$

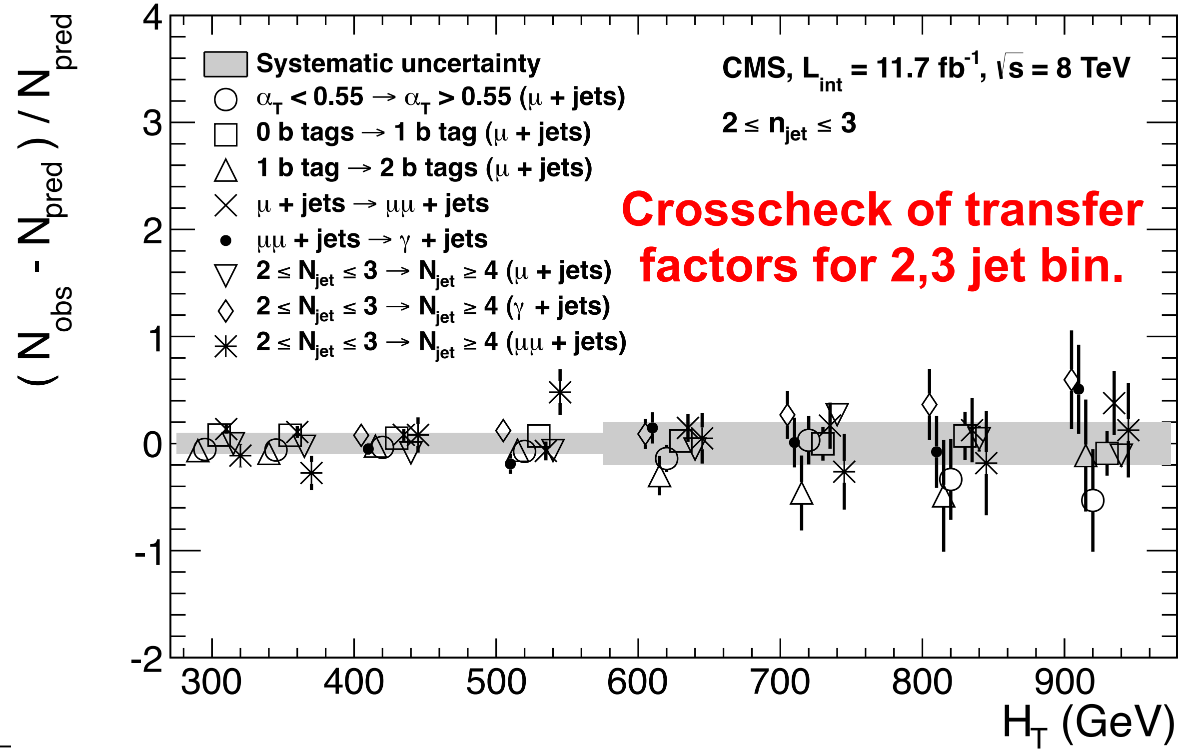
Binned in (67 signal regions)

- Number of jets (2-3, >=4)
- Number of b-jets (0,1,2,3,>=4)
- H_T (8 bins from 275 to >=875 GeV)

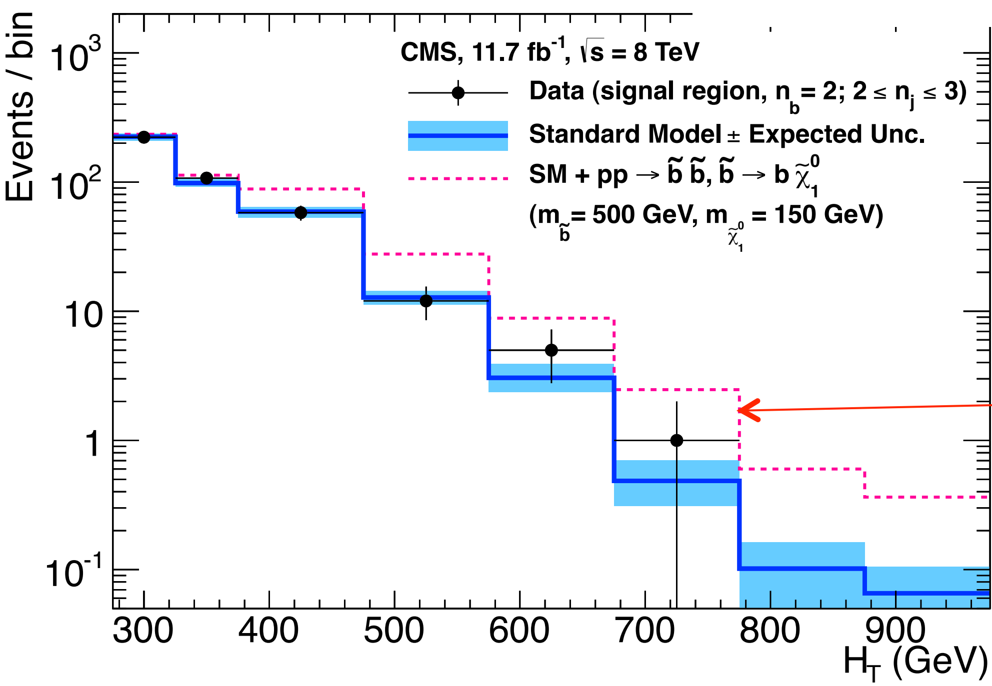


Remaining bkg estimated from data control regions with transfer factors from MC for each of the 67 signal regions. Transfer factors checked by extrapolating yields between appropriately chosen control regions.

For details see: arxXiv:1303.2985



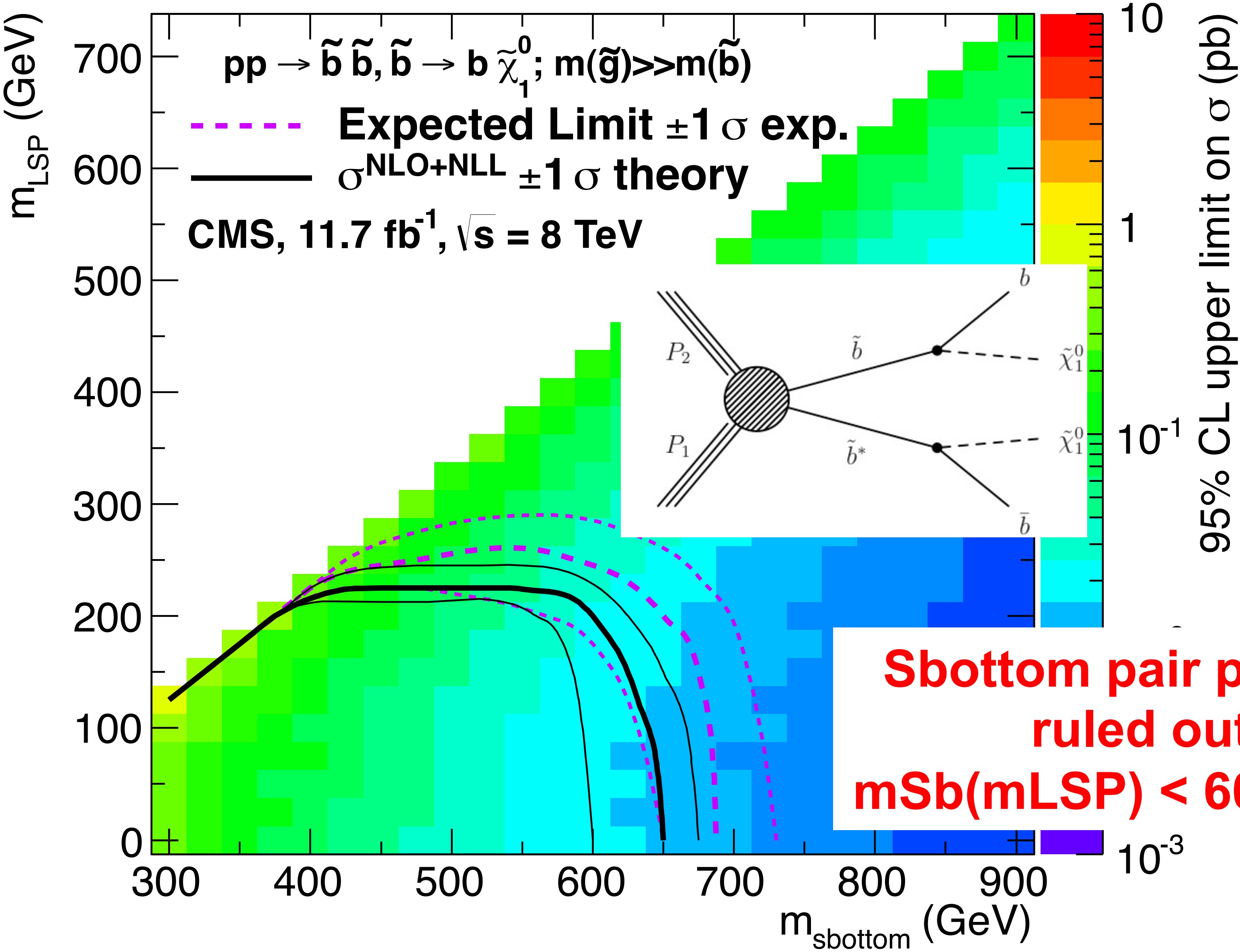
Crosscheck of transfer factors for 2,3 jet bin.



H_T prediction and observed for 2 b + MET search region.

Example signal overlayed

Interpretation



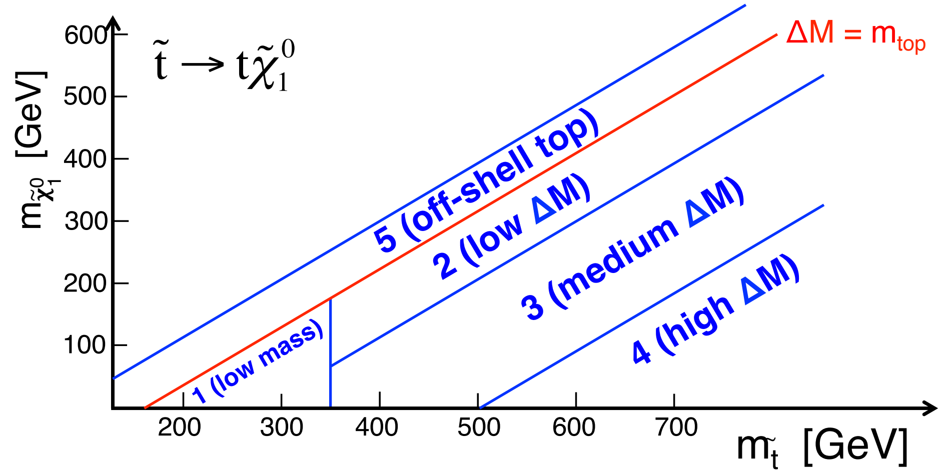
Sbottom pair production ruled out for mSb(mLSP) < 600(200)GeV

2 top + MET final state

- 1 high pT>25 (30) isolated μ(e)
- Additional isolated track or hadronic tau veto to suppress bkg from top pair to dileptons
- ≥4 jets, ≥1 b-tag to suppress W+jets
- MET > 100GeV
- M_T > 120GeV to suppress lepton+jets from both W and top.

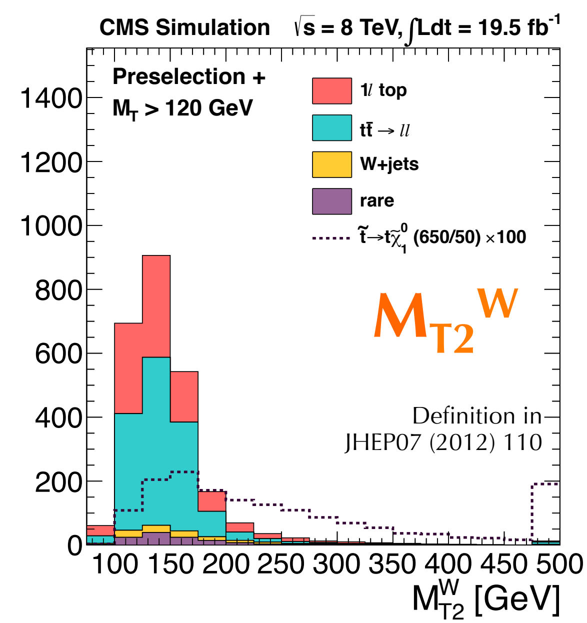
Signal region definitions

BDT optimized for different kinematic regions.



Cut based analysis as cross-check.

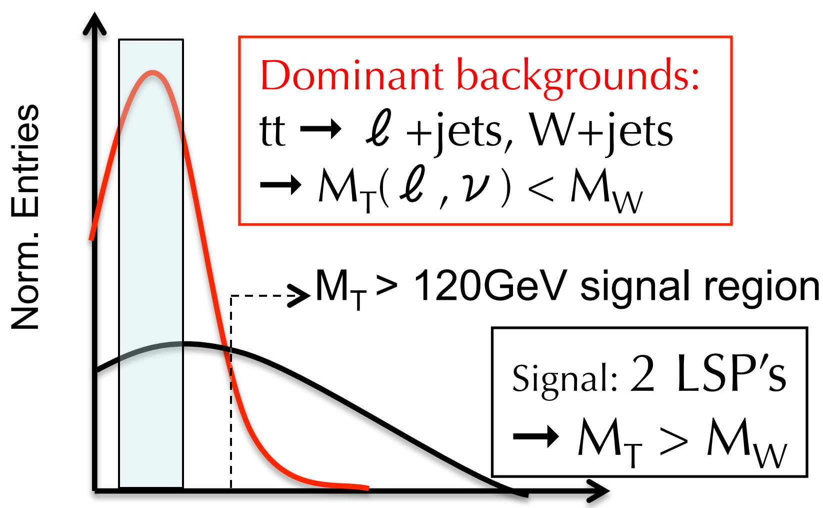
Selection	$\tilde{t} \rightarrow t\tilde{\chi}_1^0$ cut-based Low ΔM	High ΔM	$\tilde{t} \rightarrow t\tilde{\chi}_1^0$ BDT
E_T^{miss}(GeV)	$>$ 150,200, 250,300	$>$ 150,200, 250,300	yes
M_{T2}^W (GeV)		$>$ 200	yes
min $\Delta\phi$	$>$ 0.8	$>$ 0.8	yes
H_T^{ratio}			yes
χ^2	<5	<5	yes
leading b-jet p_T (GeV)			(off-shell top)
$\Delta R(\ell$,leading b-jet)			



Bkg Estimation Strategy

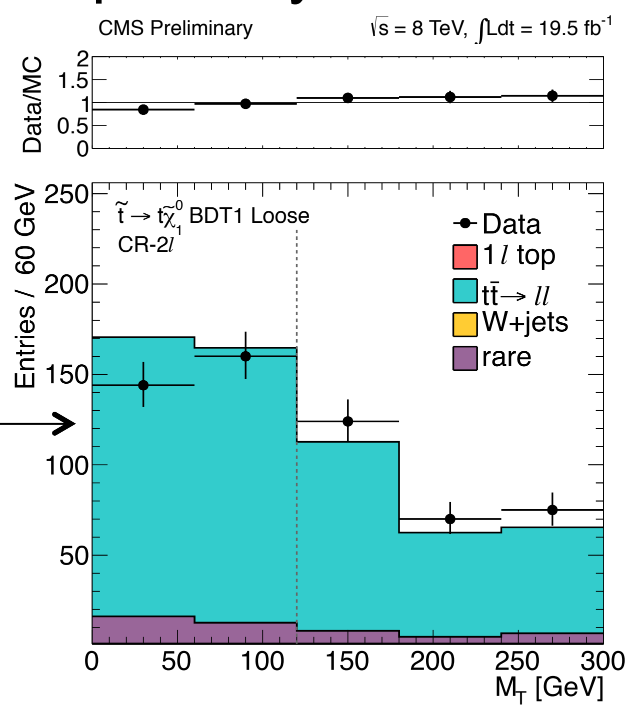
1) Normalize data to MC in M_T peak region

2) Extrapolate to tail via MC tail/peak ratio



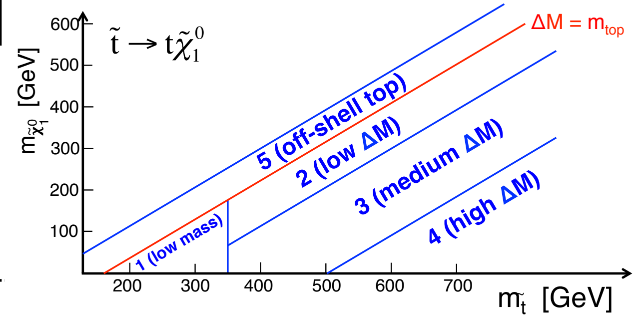
3)Extract corrections and uncert. on extrapolation from data control regions for 1 and 2 lepton bkg separately.

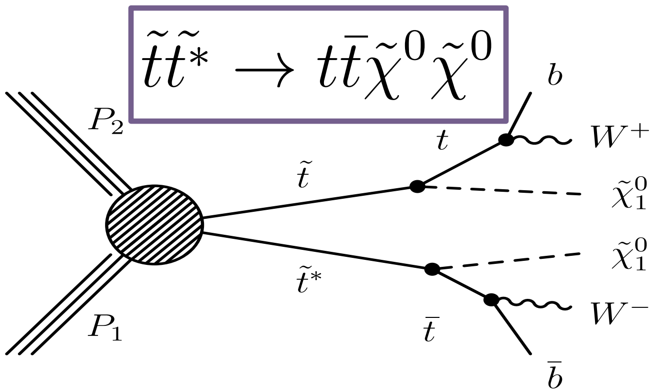
Example dilepton control region. Every signal region has it's own corresponding control regions.



Yields & Interpretation

Sample	BDT1 Loose	BDT1 Tight	BDT2	BDT3	BDT4	BDT5
$t\bar{t} \rightarrow \ell\ell$	438 ± 37	68 ± 11	46 ± 10	5 ± 2	0.3 ± 0.3	48 ± 13
1 ℓ Top	251 ± 93	37 ± 17	22 ± 12	4 ± 3	0.8 ± 0.9	30 ± 12
W+jets	27 ± 7	7 ± 2	6 ± 2	2 ± 1	0.8 ± 0.3	5 ± 2
rare	47 ± 23	11 ± 6	10 ± 5	3 ± 1	1.0 ± 0.5	4 ± 2
Total	**763 ± 102**	**124 ± 21**	**85 ± 16**	**13 ± 4**	**2.9 ± 1.1**	**87 ± 18**
Data	**728**	**104**	**56**	**8**	**2**	**76**

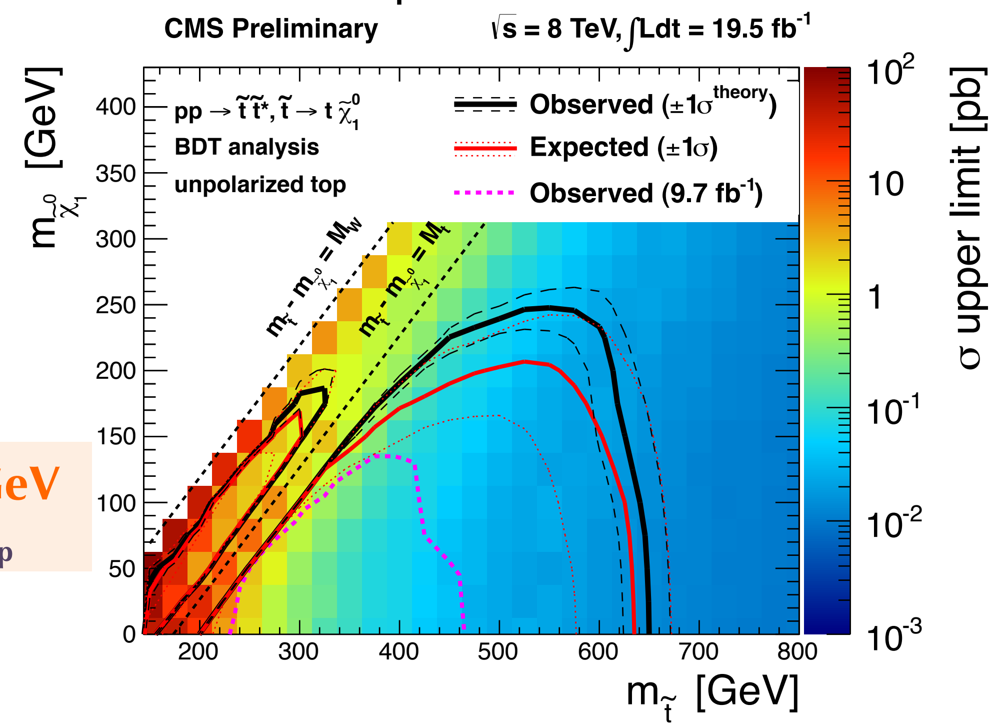




Probe $m(\tilde{t}) \lesssim 650$ GeV for $m(\tilde{\chi}^0) \lesssim 250$ GeV

Sensitivity also to $\Delta M < m_{top}$ and $m_{stop} < m_{top}$

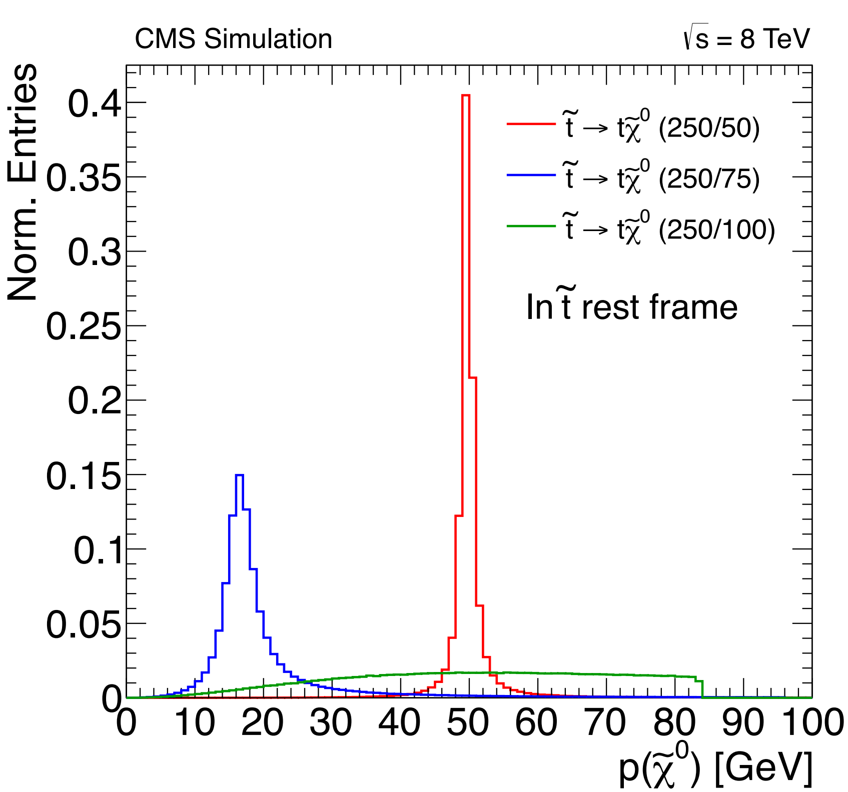
For each point in 2D plane, the region with best expected limit is chosen.

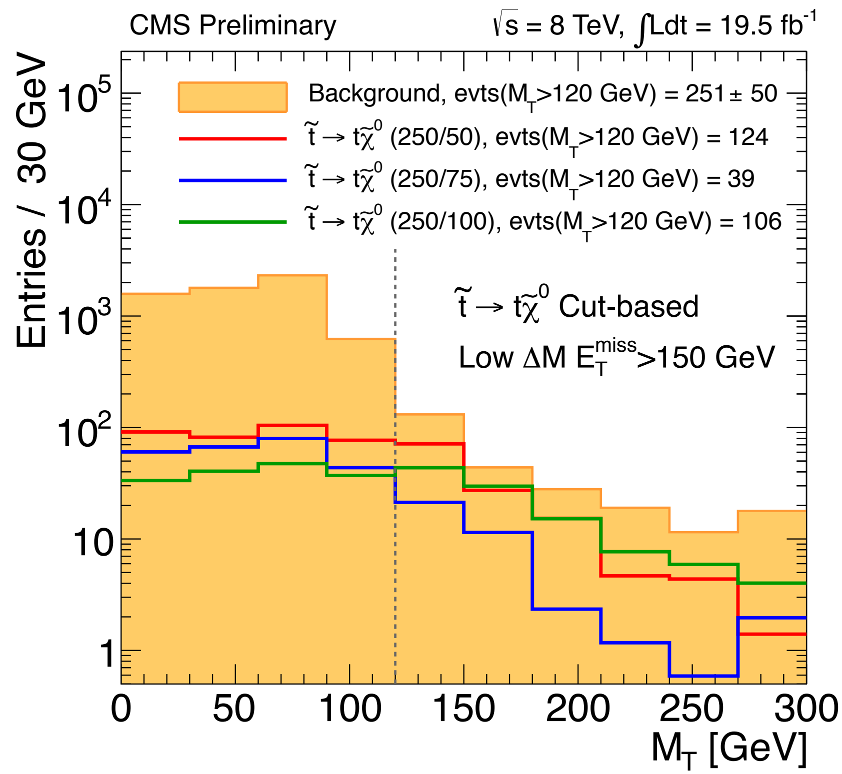


5/17/13

Sensitivity around m_{top}

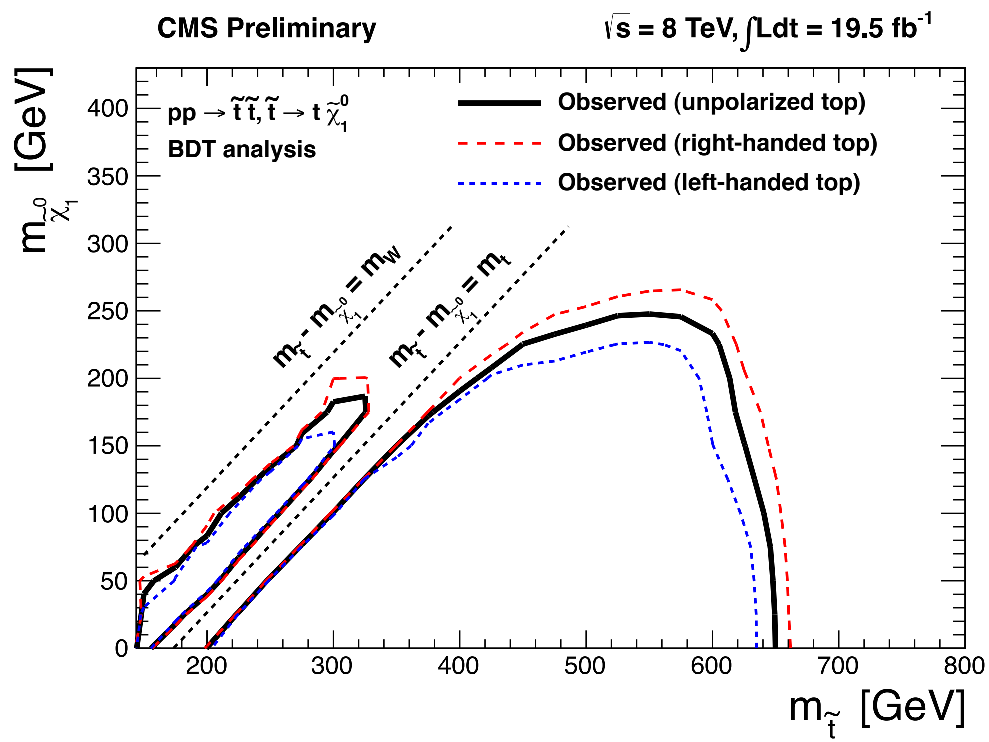
- Reduced sensitivity in region $\Delta m = m_t - m_{\chi^0} \sim m_{top}$
  - Momentum of the χ^0 is reduced in the 'compressed' region → reduced source of ME_T which is the main discriminator from background
  - Results in a reduced M_T acceptance





Top Polarization

Top polarization in stop decay depends on both stop mixing and neutralino mixing => very model dependent.



Provide limit for two extremes. And choose unpolarized for our nominal result.

Impact of polarization on limit ~ +- 20 GeV

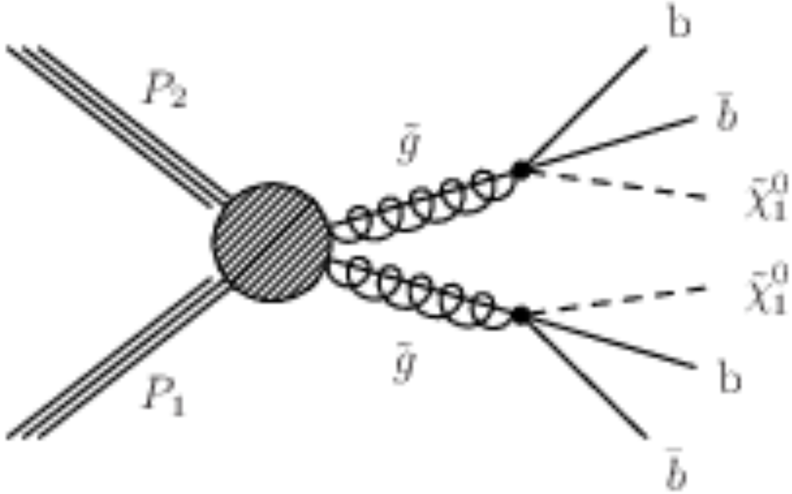
Summary of stop and sbottom pair production

- 2 b + MET final state, limits up to 600/200 GeV for squark/LSP combos.
- 2 top + MET final state, limits up to 650/250 GeV for squark/LSP combos.
  - Problematic region near $\Delta m \sim m_{top}$
  - Reduced sensitivity in $m_W < \Delta m < m_{top}$

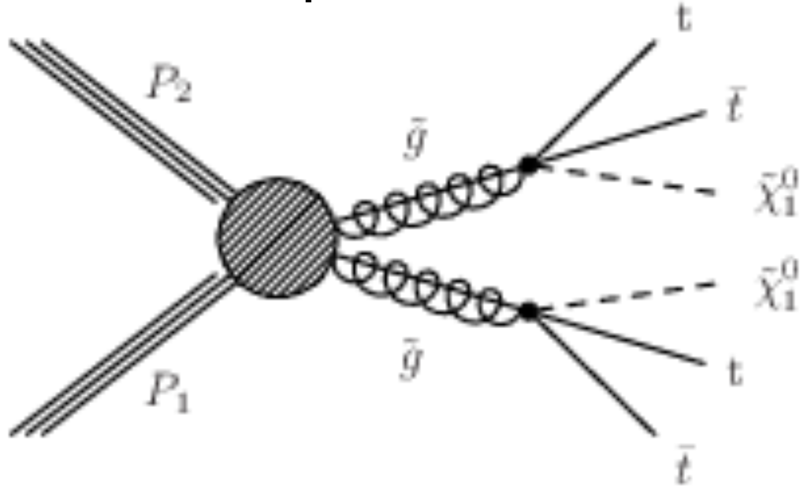
No sensitivity for m_{LSP} > 250GeV for any stop/sbottom mass

Pair production of gluinos

4 b & MET



4 top & MET



For this talk, we focus on these two signatures.

Four Final States

- 0-lepton: binned 3d fit in H_T, MET, # of b-tags **arXiv:1305.2390**
- 1-lepton: ≥ 6 jets out of which ≥ 2 are b-tagged, H_T > 500GeV, 2 methods to define signal region & estimate bkg. **SUS-13-007**
- 2-leptons: same-sign e/μ, ≥ 2 b-tags

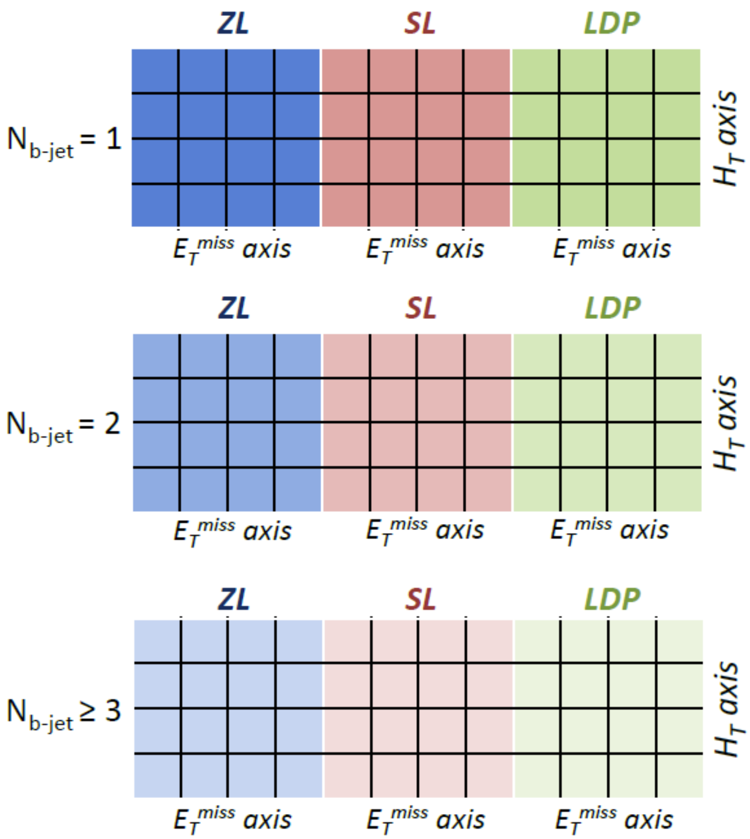
  JHEP03 (2013) 037
- ≥ 3-leptons: e/μ, # of jets ≥ 2, ≥ 1 b-tags, MET > 50GeV **SUS-13-008**

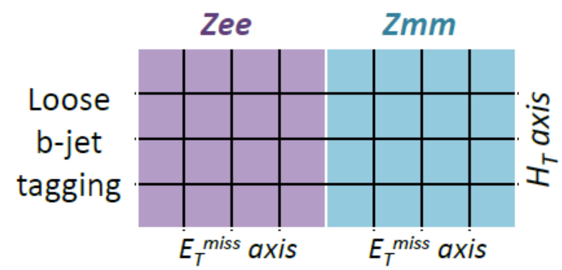
H_T vs MET vs b-tag fit

0-lepton

Event sample legend

ZL = Zero Lepton; signal sample	*SL* = Single Lepton; top & W+jets control sample	*LDP* = low $\Delta\hat{\phi}_{min}$; QCD control sample	*Zee* = Z → e^+e^-; Z to $\nu\bar{\nu}$ control sample	*Zmm* = Z → $\mu^+\mu^-$; Z to $\nu\bar{\nu}$ control sample

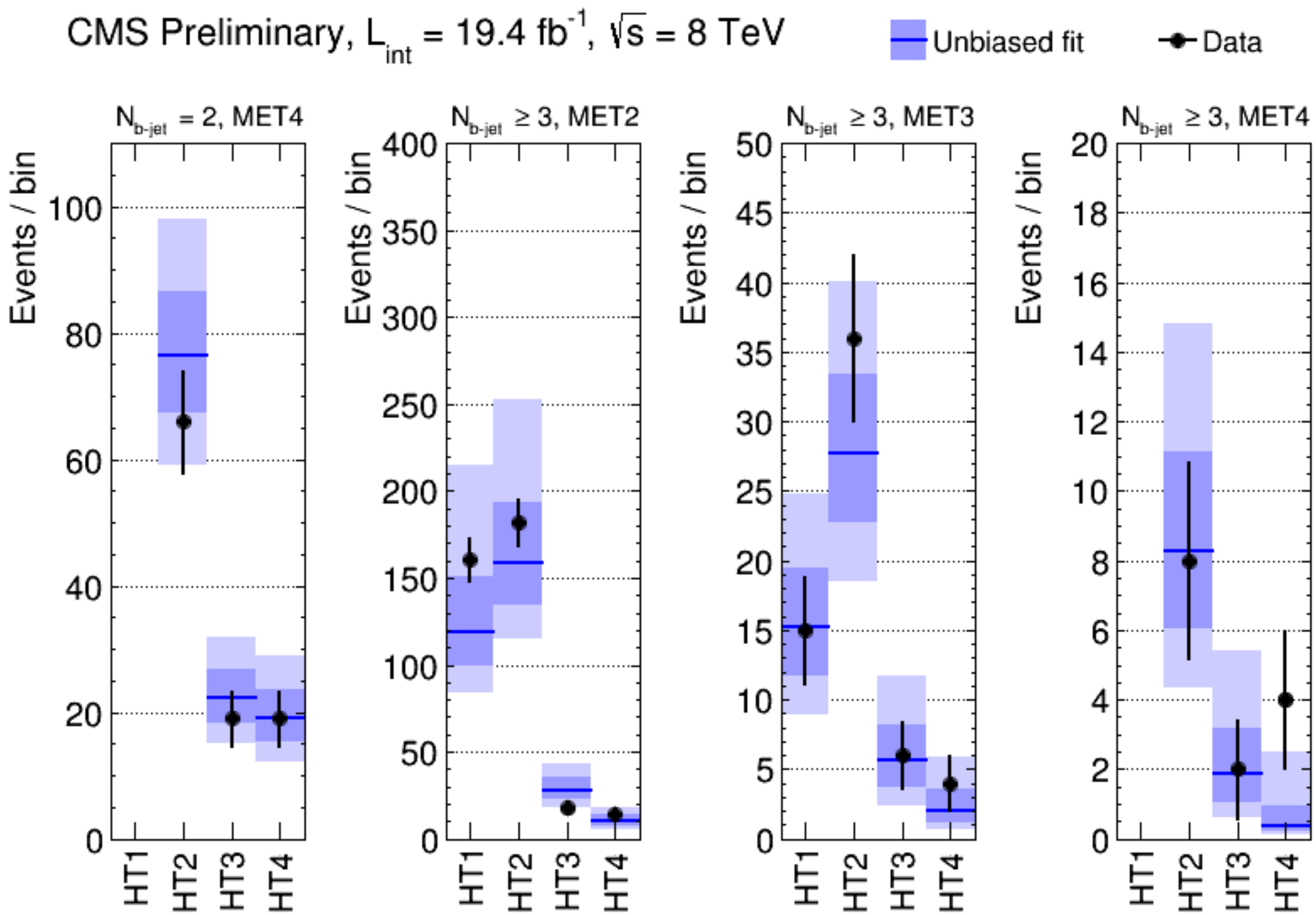




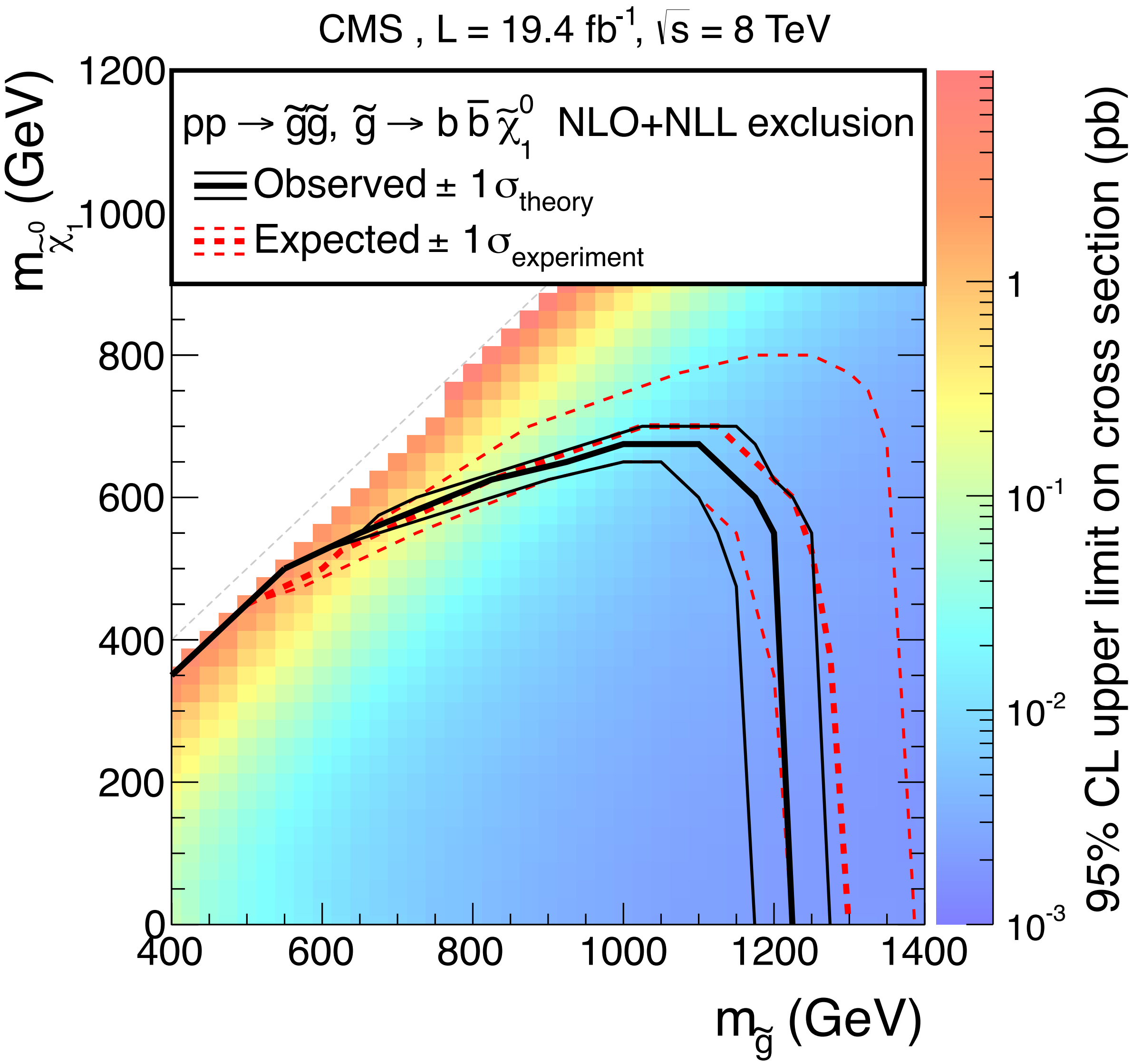
Bin	H_T (GeV)	E_T^{miss} (GeV)
1	400 – 500 (HT1)	125 – 150 (MET1)
2	500 – 800 (HT2)	150 – 250 (MET2)
3	800 – 1000 (HT3)	250 – 350 (MET3)
4	> 1000 (HT4)	> 350 (MET4)

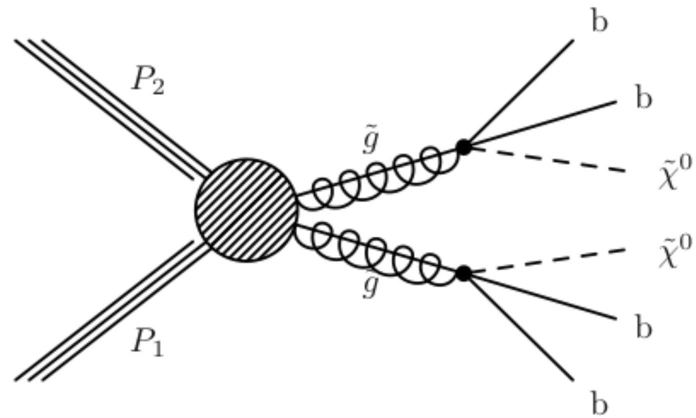
For details, see: arXiv:1305.2390

H_T vs MET vs b-tag fit



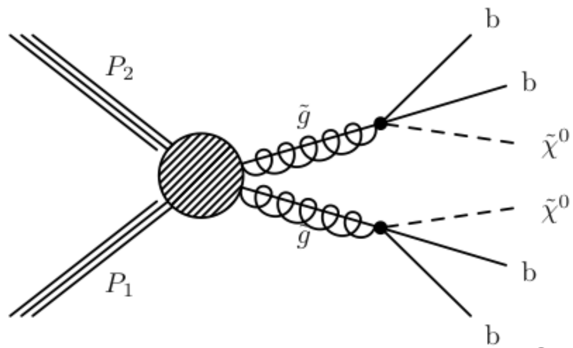
H_T vs MET vs b-tag Interpretation



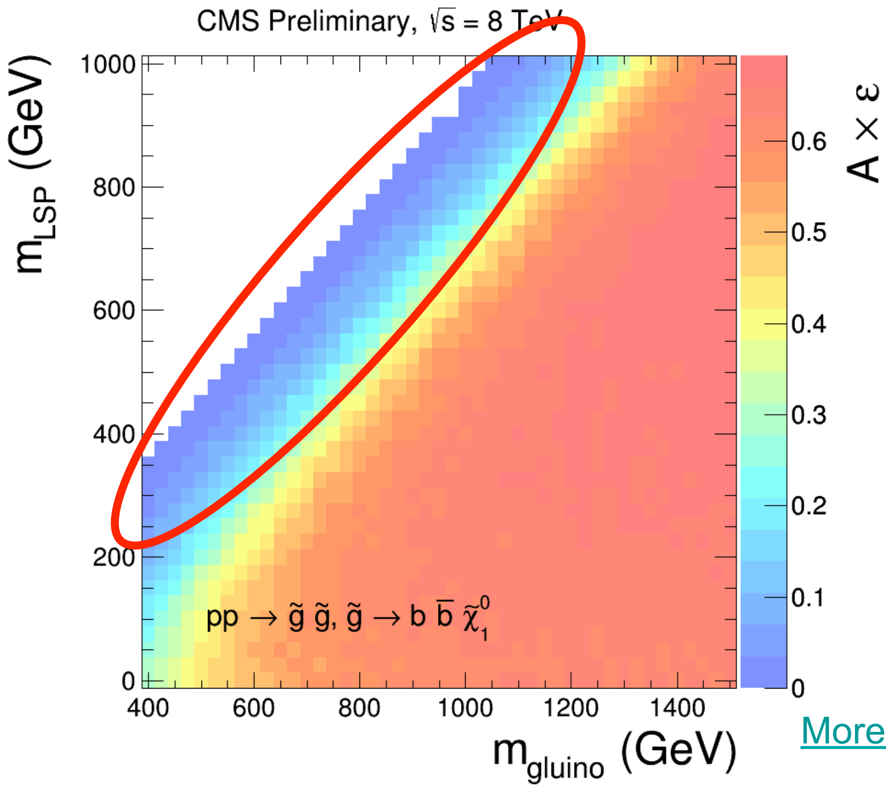


arXiv:1305.2390

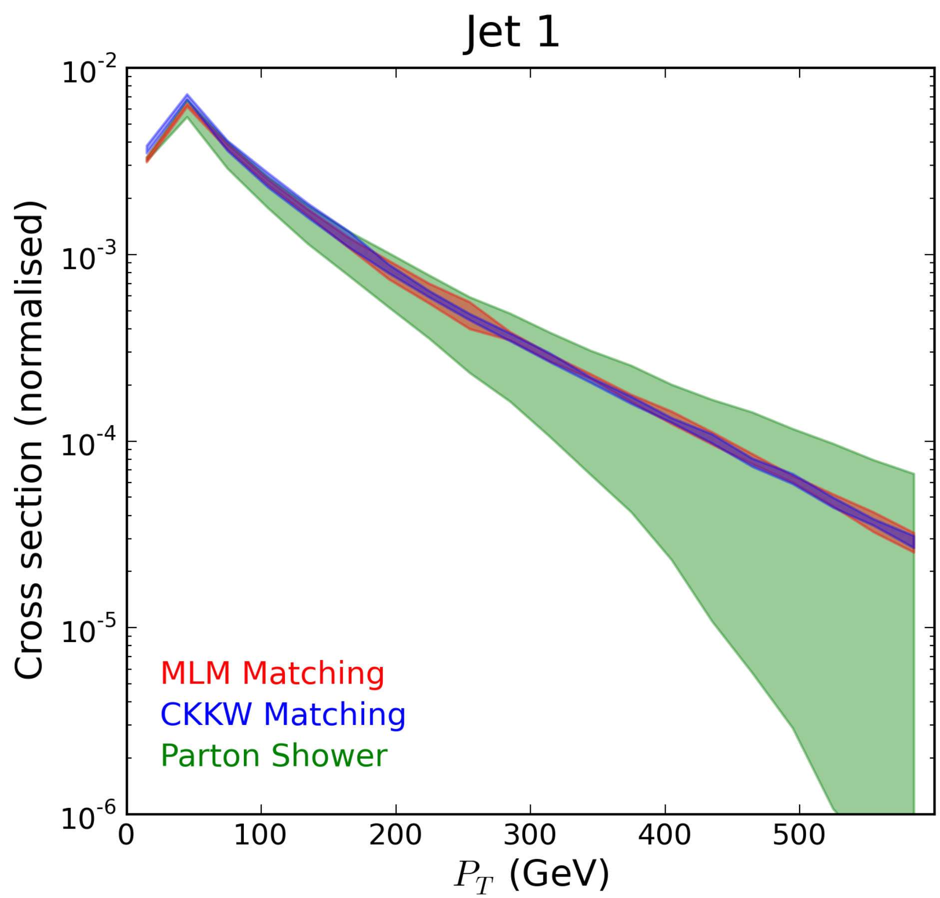
Aside on “Compressed Spectra”



Close to diagonal we trigger & select because of ISR jet production.



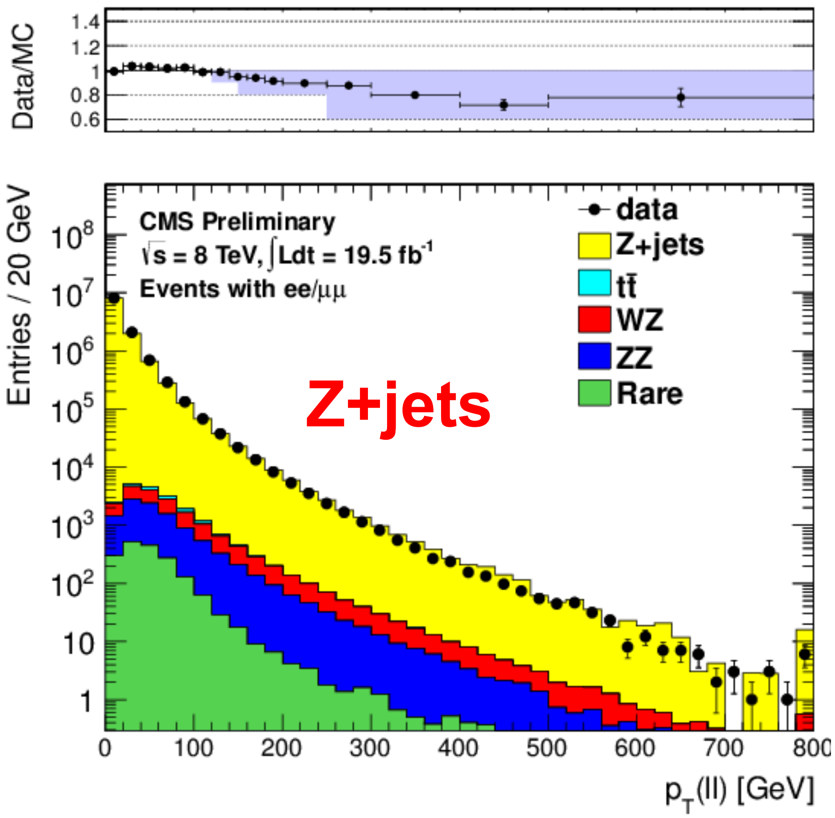
http://arxiv.orrg/pdf/1207.1613.pdf

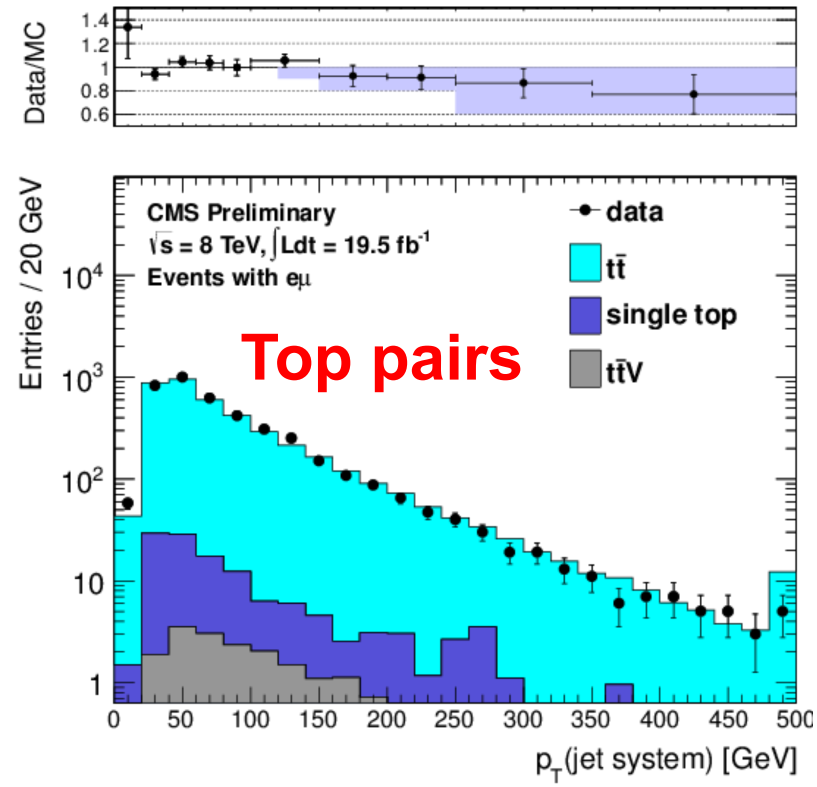


ME+PS reduces uncertainties, but needs validation in data.

More details on signal MC see M.Pierini at DESY workshop.

Compare Recoil pT in data & MC





Select dilepton & 2 b-tags
Rest of event is recoil.

Derive recoil pT dependent correction from data/mc shape.
Apply to signal MC & take full correction as systematic error.

For details see SUS-13-011

Large H_T,MET, jets, 1-lepton

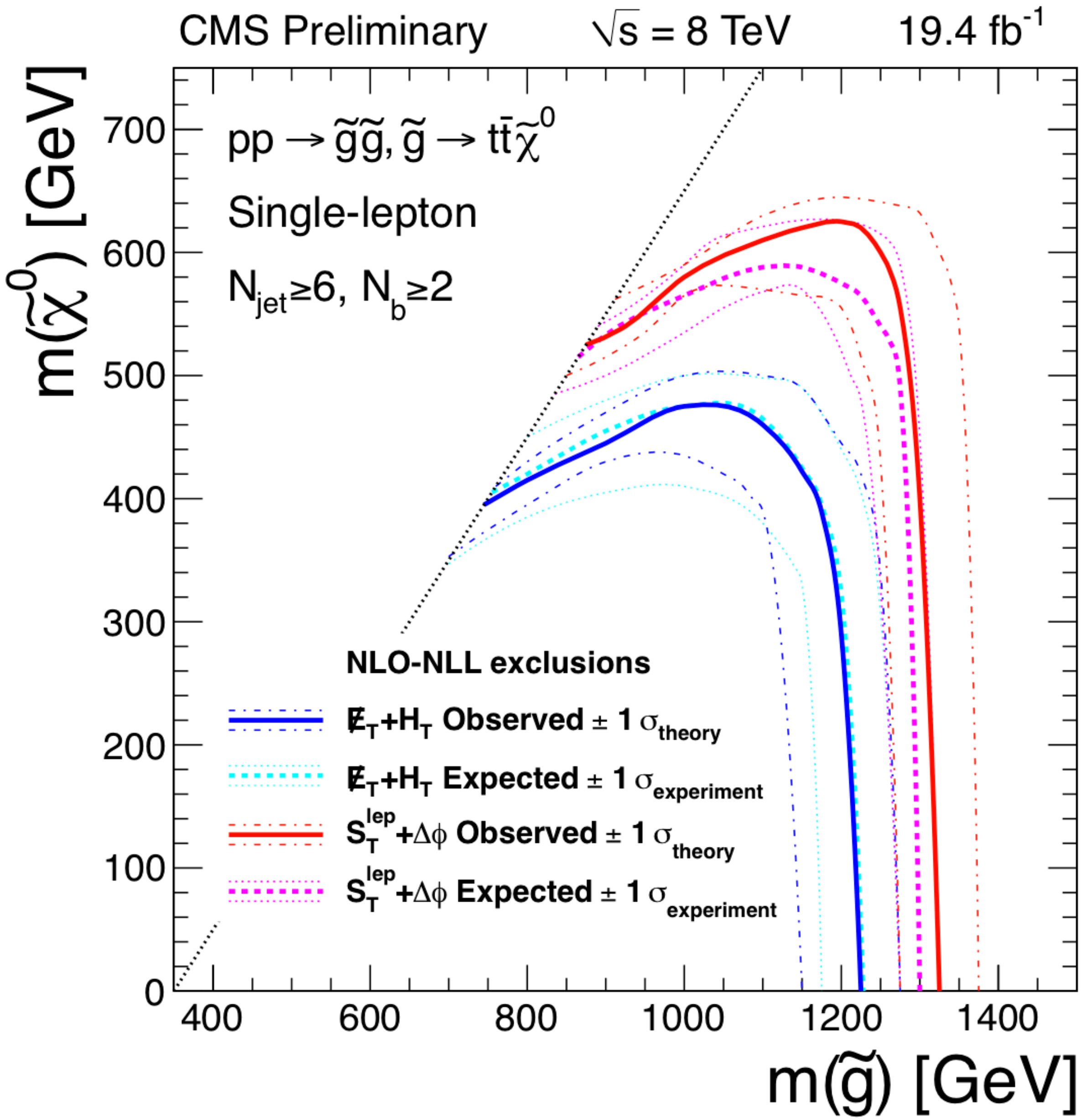
- ≥ 6 jets out of which ≥ 2 are b-tagged
  - pT > 40GeV, H_T > 500GeV
- 1 isolated e or μ w. p_T > 20GeV
- Two Analyses:
  - "Lepton Spectrum" Method:
    - MET > 250GeV
    - Use lepton spectrum to predict bkg MET spectrum
  - "S_T^{lep} vs Δϕ(W,lep)" Method:
    - Bin in $S_T^{lep} = pT_{lep}$ + MET for Δϕ(W,lep) > 1
    - Use Δϕ(W,lep) < 1 to predict bkg

Results for "S_T^{lep}" Method

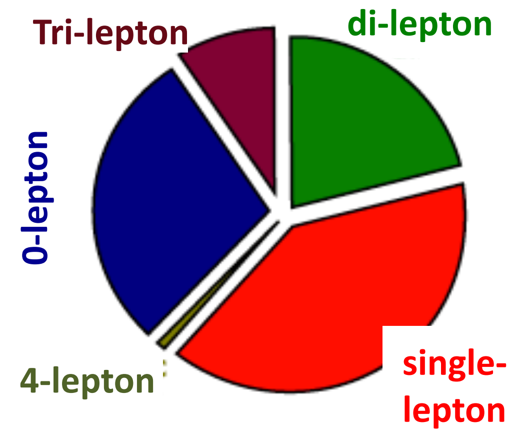
		S_T^{lep} [GeV]	control reg. data	prediction	observation
N_{btag}=2	Muons	[250,350]	141	$6.00 \pm 2.23 \pm 2.40$	9
		[350,450]	24	$1.37 \pm 1.12 \pm 1.19$	2
		>450	9	$0.0 \pm 0.66 \pm 0.66$	0
	Electr.	[250,350]	112	$3.83 \pm 1.75 \pm 1.84$	9
		[350,450]	28	$2.74 \pm 1.86 \pm 2.02$	2
		>450	9	$0.0 \pm 0.42 \pm 0.42$	0
$N_{btag} \geq 3$	Muons	[250,350]	28	$1.92 \pm 0.84 \pm 0.95$	0
		[350,450]	13	$0.57 \pm 0.52 \pm 0.58$	0
		>450	2	$0.0 \pm 0.22 \pm 0.22$	0
	Electr.	[250,350]	45	$1.89 \pm 0.94 \pm 1.03$	4
		[350,450]	7	$0.85 \pm 0.70 \pm 0.80$	0
		>450	0	$0.0 \pm 0.08 \pm 0.08$	0

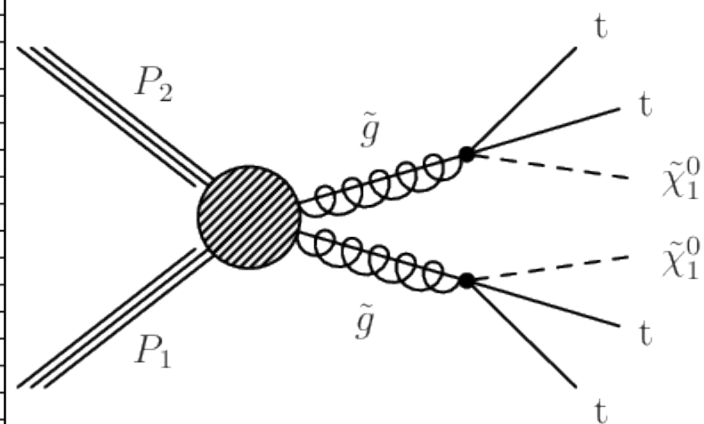
No excess => setting limits !!!

Interpretation



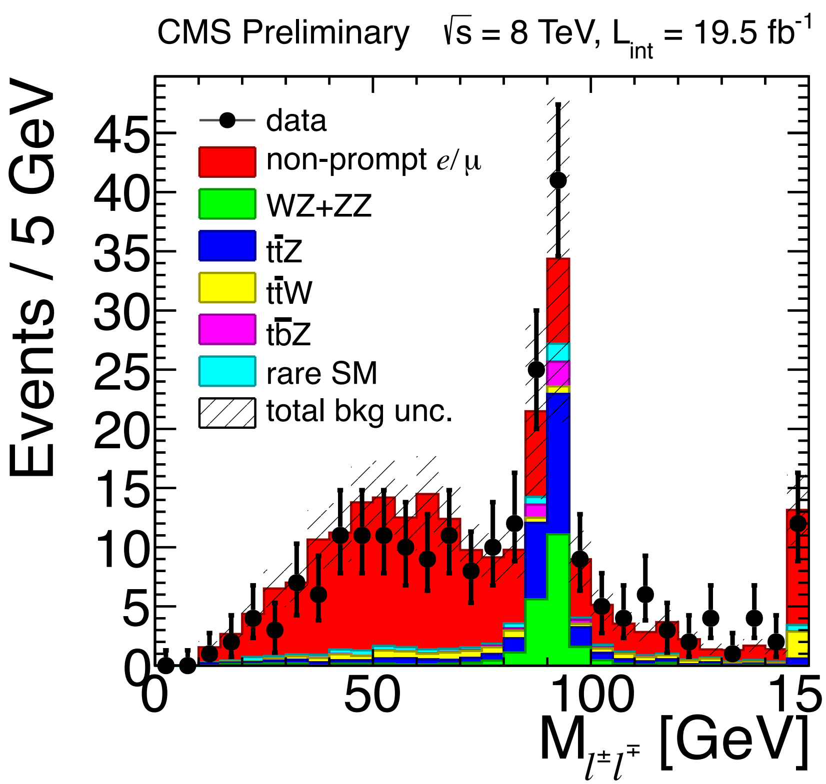
4-W branching fraction



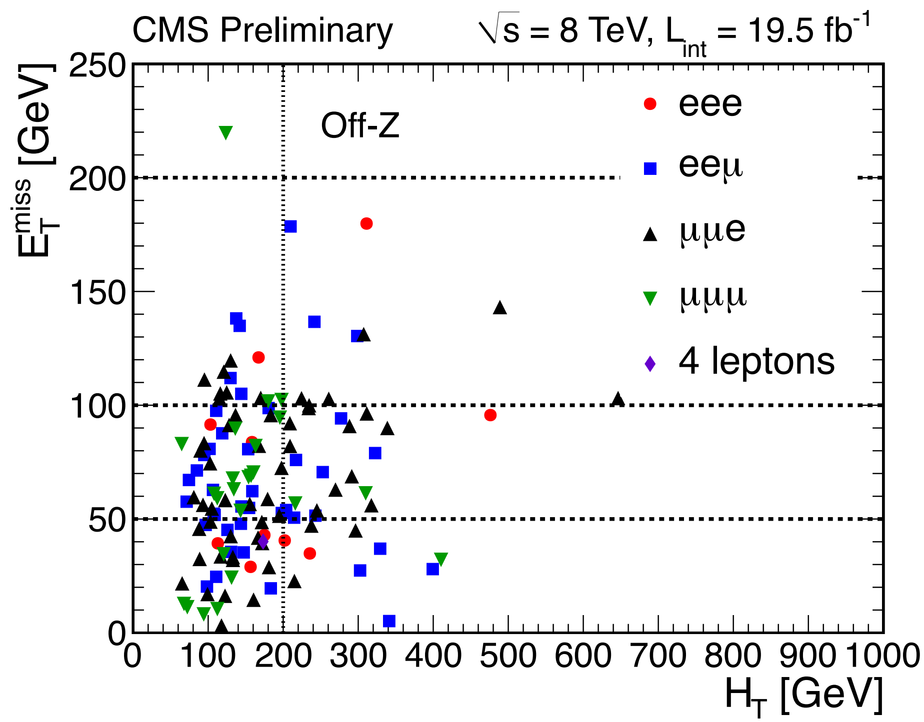


≥ 3-lepton & b-tags Search Strategy

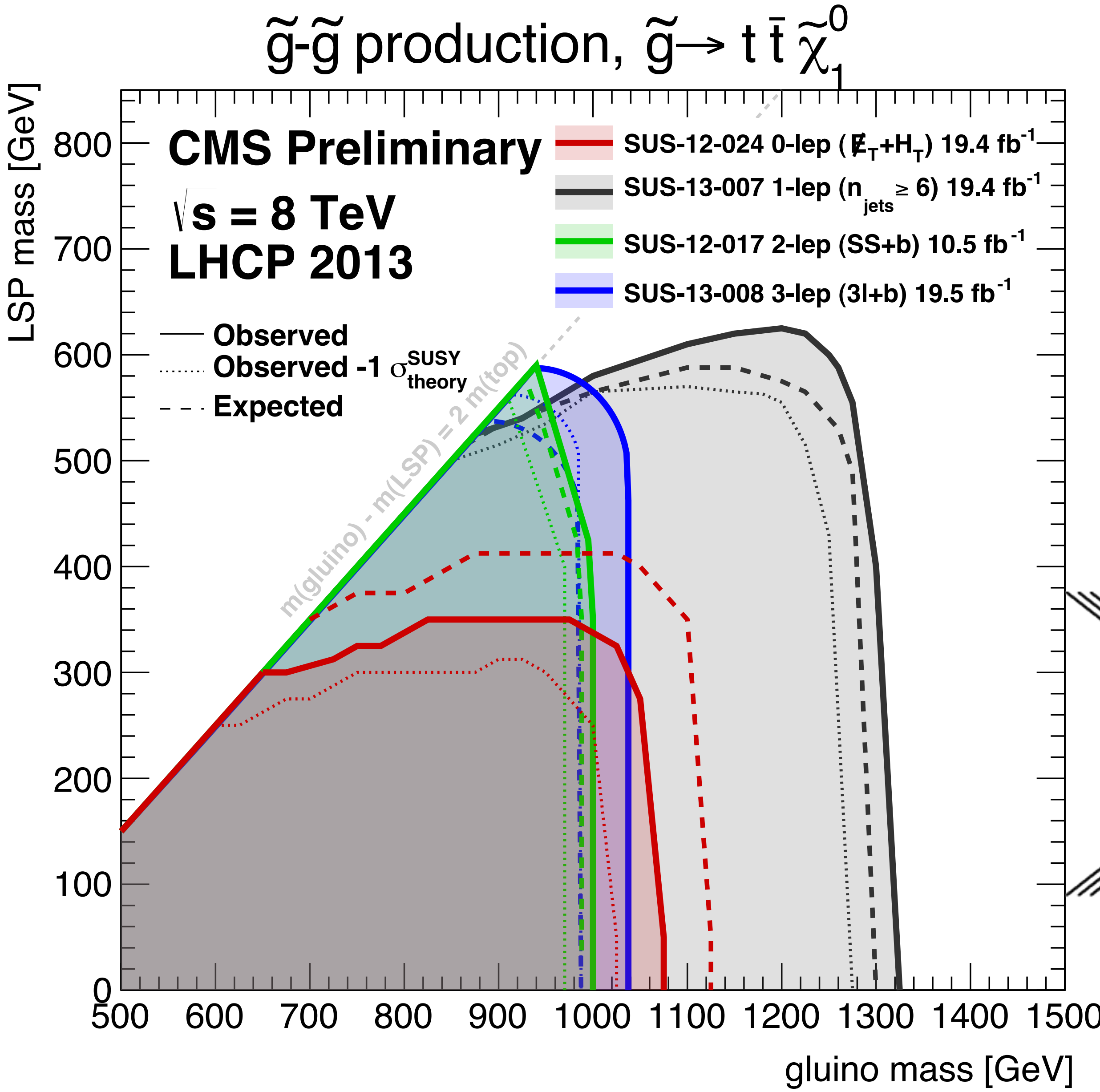
- ≥ 3 isolated > 20/10/10 GeV leptons (e/μ)
- # of jets ≥ 2, ≥ 1 b-tags, MET > 50GeV
- Exclusive search regions in H_T, MET, # of jets, # of b-tags, with/without Z candidate
- Multi-bin fit to extract limits



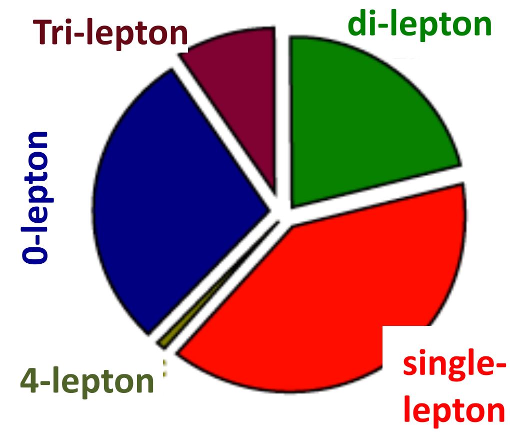
Selected events with no Z candidate

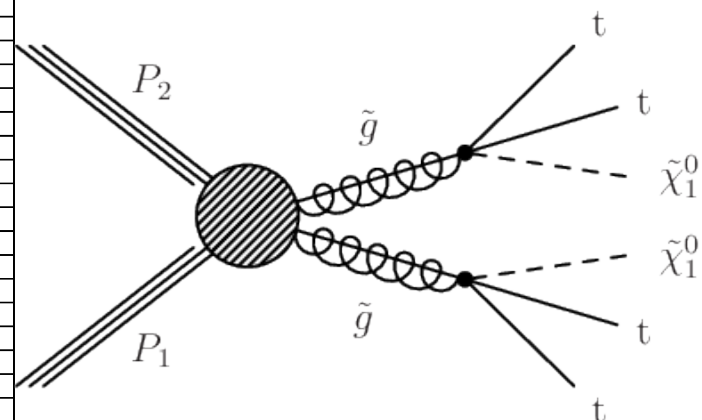


Comparison of final states



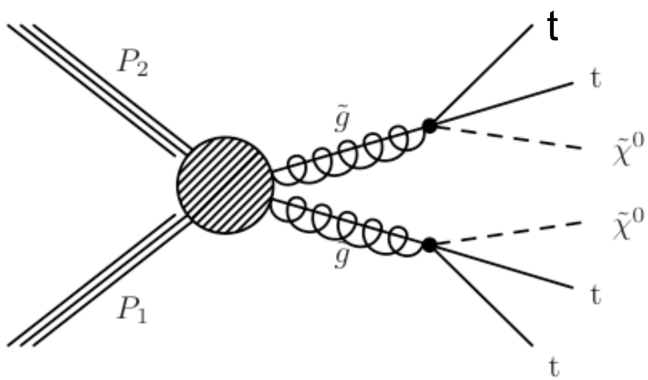
4-W branching fraction

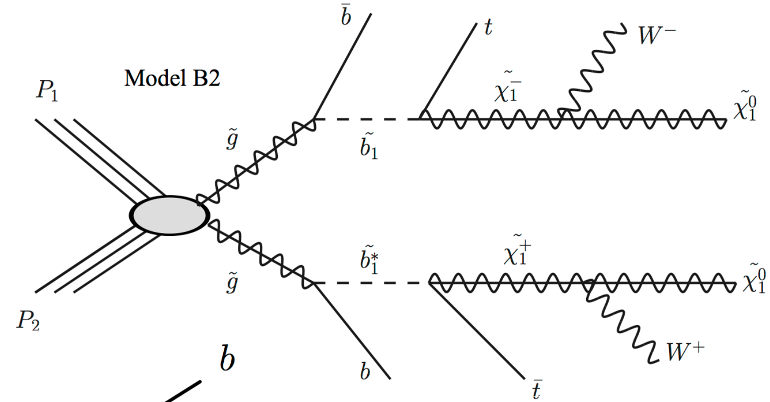




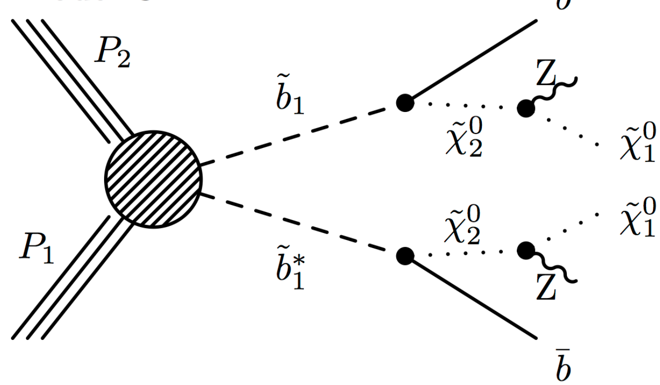
Lot’s more interpretations

See SUS-13-008,011 and JHEP03 (2013) 037 for details.

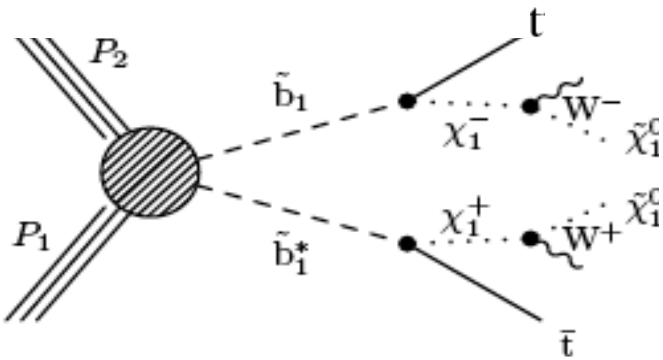




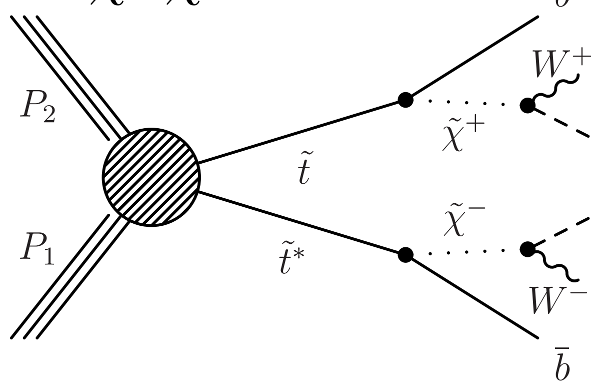
Model C1



$$pp \to \tilde b_1 \tilde b_1^* \to t\bar t WW \tilde\chi_1^0 \tilde\chi_1^0$$



$$\tilde t \tilde t^* \to b\bar b \tilde\chi^+ \tilde\chi^- \to b\bar b W^+ W_b^- \tilde\chi^0 \tilde\chi^0$$



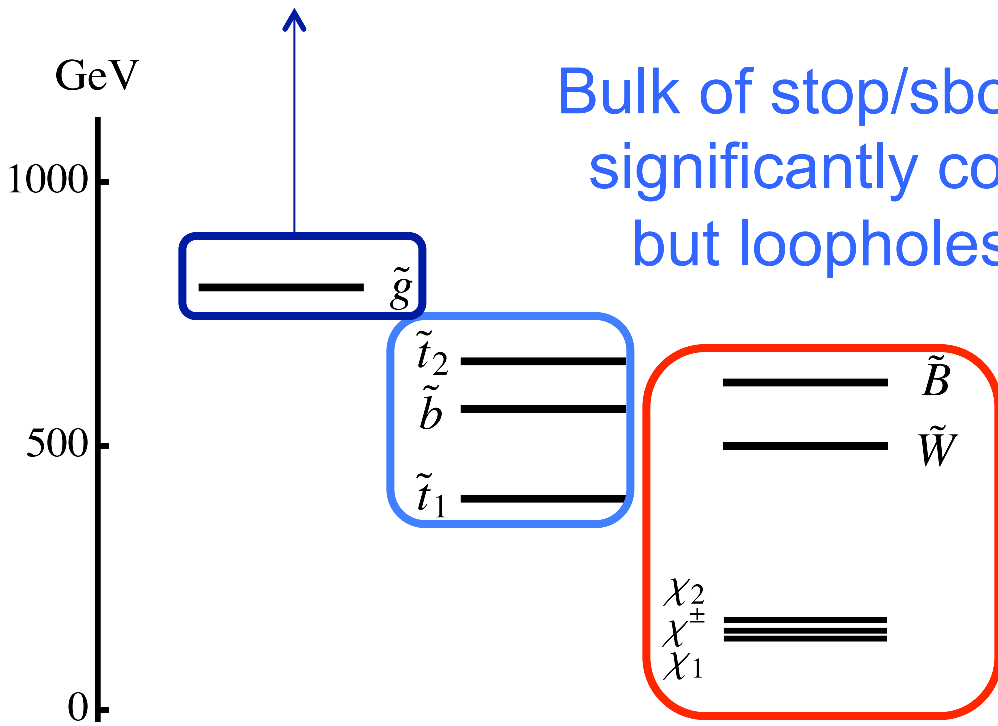
Summary 4b & MET, 4top & MET

- Gluino masses up to 1.2 or 1.3 TeV are ruled out for LSP masses of up to 600GeV.
- Details of resonance structure matter little.
- While we have not yet shown the sensitivity for 2 top 2b & MET, it seems unlikely to be very different once all final states are combined.

Fairly general "natural gluino" limit of ~1.2TeV for up to 600GeV LSP mass.

Natural SUSY Summary

gluino mass below 1.2TeV ruled out



Bulk of stop/sbottom range significantly constrained, but loopholes remain.

Most significant constraints on ewkino sector within context of GMSB.

Natural SUSY without a Dark Matter Candidate

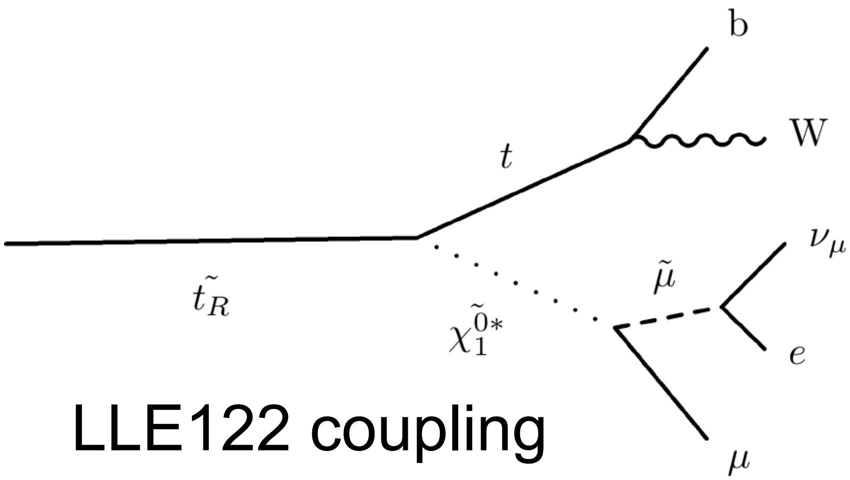
RPV Intro

$$W_{\not{R}_p} = \mu_i H_u L_i + \frac{1}{2}\lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \frac{1}{2}\lambda''_{ijk} U^c_i D^c_k D^c_k$$

Leptonic RPV | LQD RPV | Hadronic RPV

- Three trilinear Yukawa couplings.
- Can result in a near infinitely diverse set of experimental observables.
- We pick illustrative examples rather than attempting completeness.

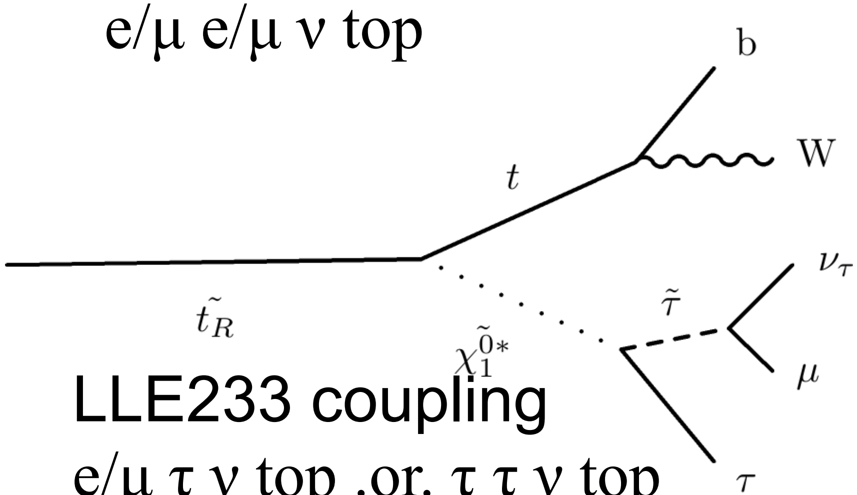
RPV Stop Decays



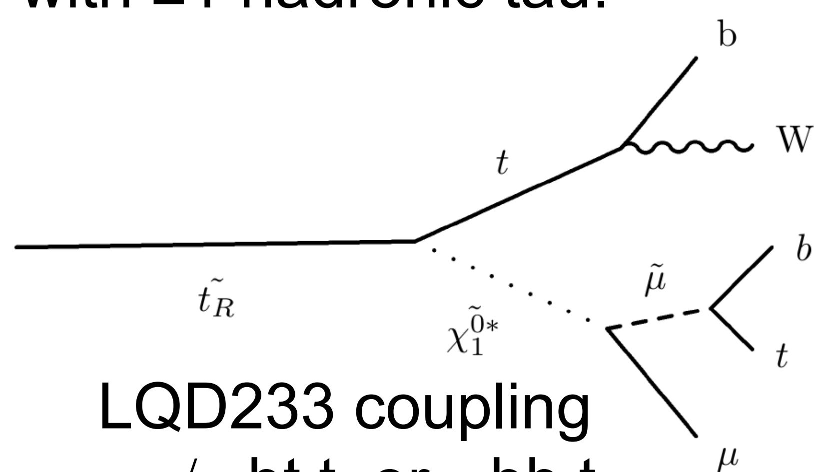
"Standard" stop to top X^0, followed by RPV X^0 decay

LLE122 coupling
e/μ e/μ ν top

Searched for in ≥3 leptons with ≤1 hadronic tau.



LLE233 coupling
e/μ τ ν top .or. τ τ ν top

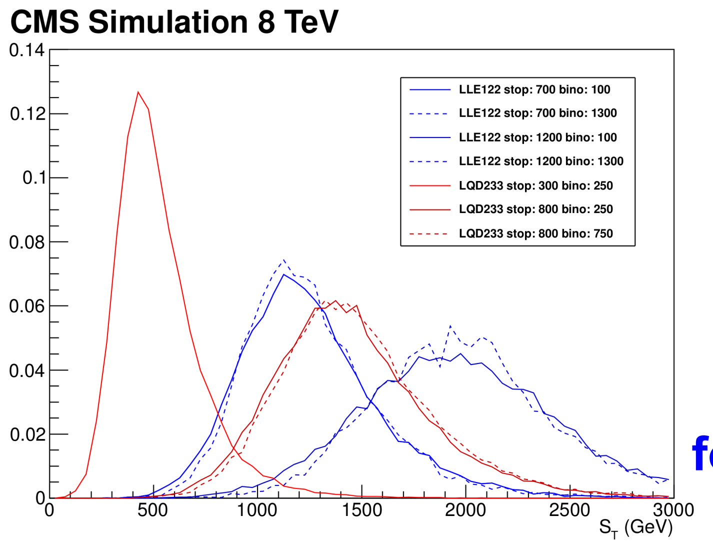


LQD233 coupling
e/μ bt t .or. νbb t

≥3 leptons Analysis

- 20/10 pT ee/eμ/μμ dilepton trigger
- Additional e/μ (tau) with pT>10 (20)GeV
- At most one hadronic tau out of 3(4) leptons
- All leptons are prompt and isolated
- Distinguish 3 (4) leptons with/without tau
- Bin in S_T = MET + H_T + p_T of leptons
- Distinguish Z to dilepton events
- Distinguish ≥ 1 b-tag events

≥3 leptons Results



Choose S_T binning to measures mass of stop irrespective of decay details.

X^0 masses 100 vs 1300GeV for blue dashed vs solid for stop mass 700 vs 1200GeV

N_ℓ	N_τ	$0 < S_T < 300$		$300 < S_T < 600$		$600 < S_T < 1000$		$1000 < S_T < 1500$		$S_T > 1500$	
		obs	exp	obs	exp	obs	exp	obs	exp	obs	exp
4	0	0	0.186 ± 0.074	1	0.43 ± 0.22	0	0.19 ± 0.12	0	0.037 ± 0.039	0	0.000 ± 0.021
4	1	1	0.89 ± 0.42	0	1.31 ± 0.48	0	0.39 ± 0.19	0	0.019 ± 0.026	0	0.000 ± 0.021
3	0	116	123 ± 50	130	127 ± 54	13	18.9 ± 6.7	1	1.43 ± 0.51	0	0.208 ± 0.096
3	1	710	698 ± 287	746	837 ± 423	83	97 ± 48	3	6.9 ± 3.9	0	0.73 ± 0.49

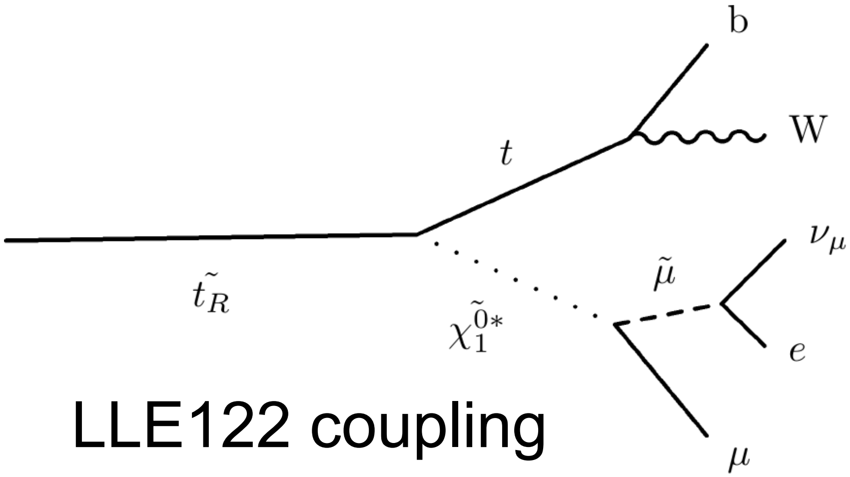
↑ Z veto && b-tag

N_ℓ	N_τ	$600 < S_T < 1000$		$1000 < S_T < 1500$		$S_T > 1500$	
		obs	exp	obs	exp	obs	exp
4	0	5	8.2 ± 2.6	2	0.96 ± 0.37	0	0.113 ± 0.056
4	1	2	3.8 ± 1.3	0	0.34 ± 0.16	0	0.040 ± 0.033
3	0	165	174 ± 53	16	21.4 ± 8.4	5	2.18 ± 0.99
3	1	276	249 ± 80	17	19.9 ± 6.8	0	1.84 ± 0.83

← !(Z veto && b-tag)

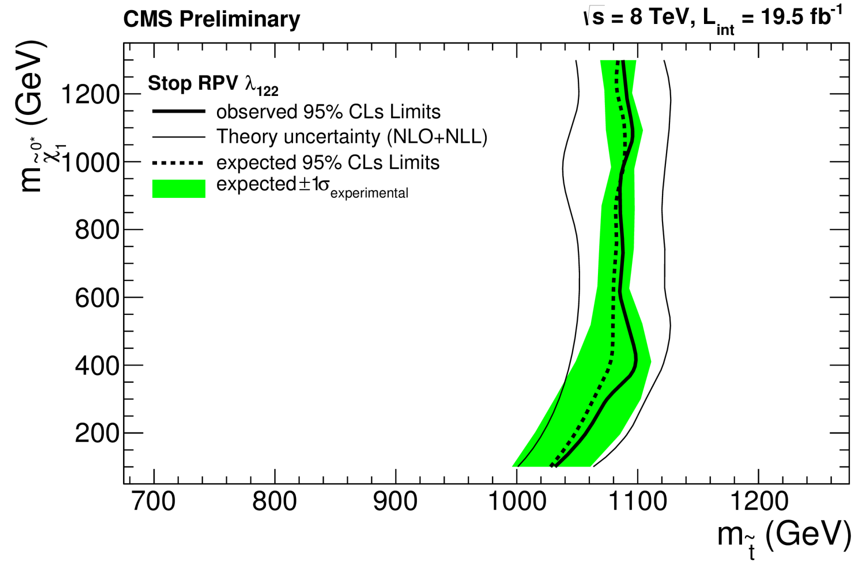
No Excess anywhere => Setting limits

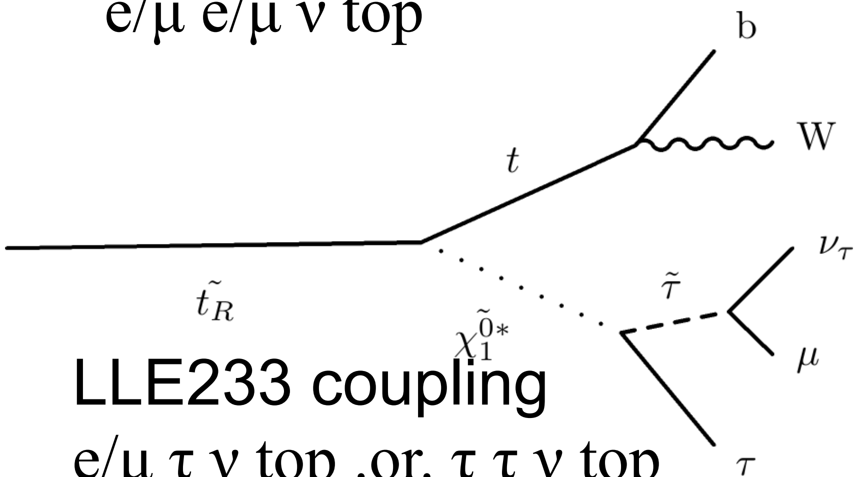
≥3 leptons Results



LLE122 coupling

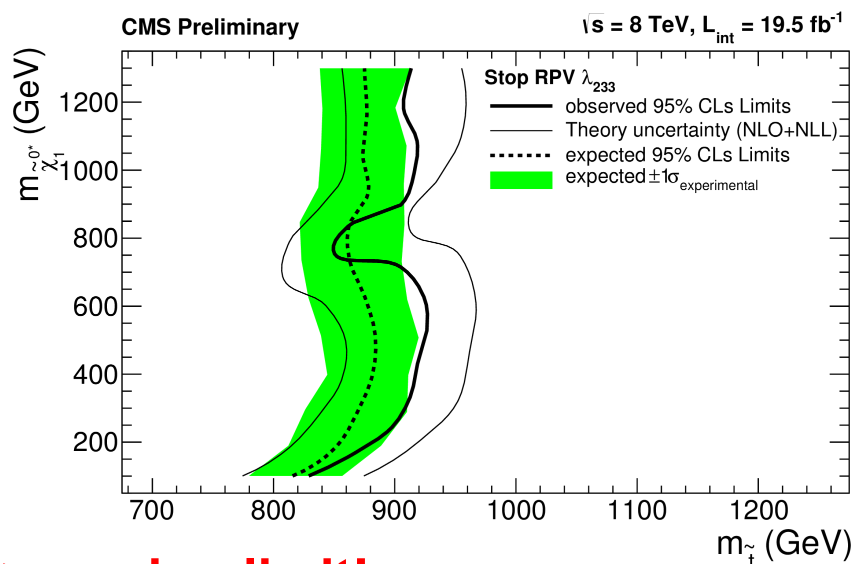
e/μ e/μ ν top





LLE233 coupling

e/μ τ ν top .or. τ τ ν top

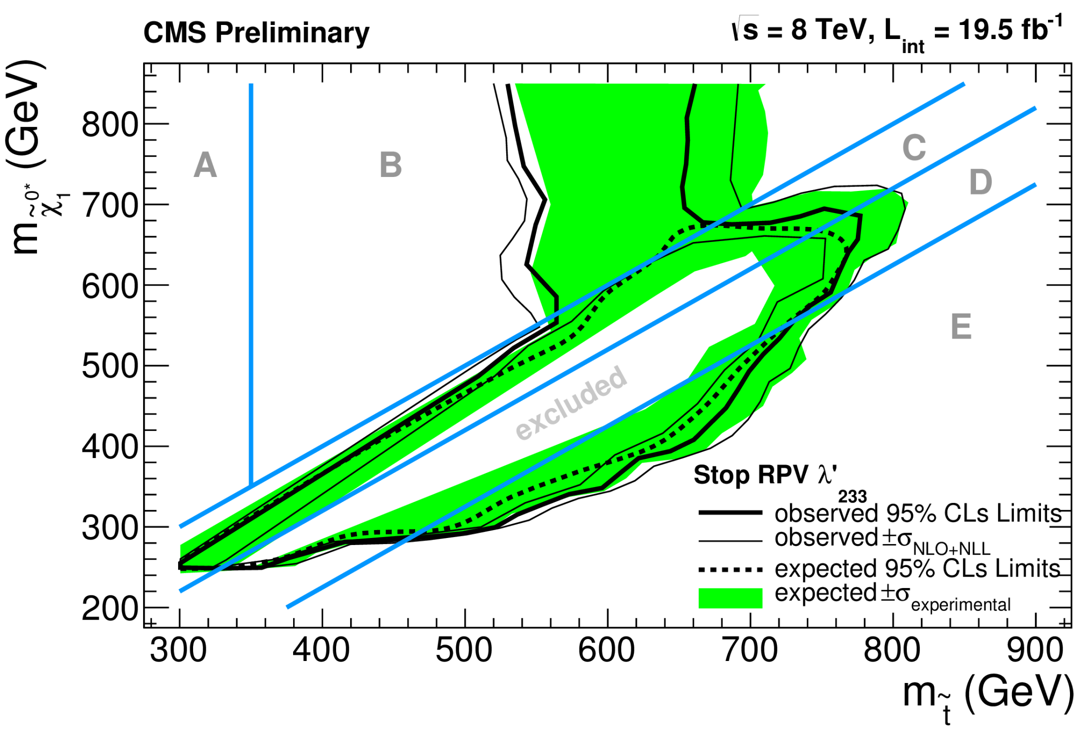


Smaller eff. for tau => weaker limit!

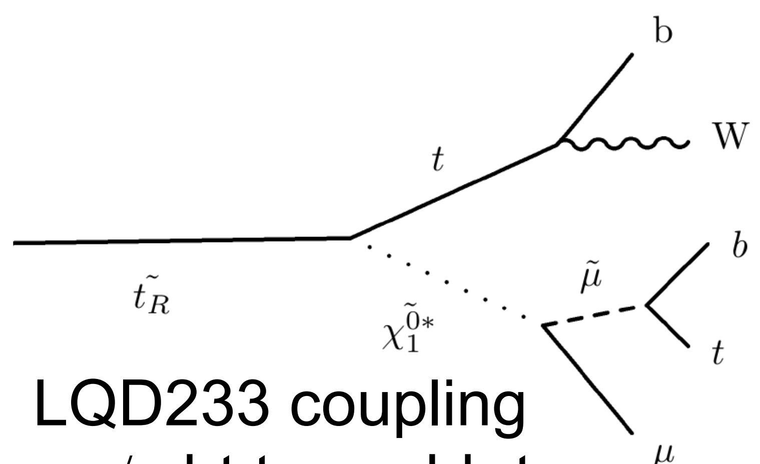
≥3 leptons Results

Complicated BR x eff.
=> Complicated exclusion

region label	kinematic region	stop decay mode(s)
A	$m_t < m_{\tilde{t}} < 2m_t, m_{\tilde{\chi}_1^0}$	$\tilde{t} \to t\nu b\bar{b}$
B	$2m_t < m_{\tilde{t}} < m_{\tilde{\chi}_1^0}$	$\tilde{t} \to t\mu t\bar{b} + t\nu b\bar{b}$
C	$m_{\tilde{\chi}_1^0} < m_{\tilde{t}} < m_W + m_{\tilde{\chi}_1^0}$	$\tilde{t} \to \ell\nu b\tilde{\chi}_1^0 + jjb\tilde{\chi}_1^0$
D	$m_W + m_{\tilde{\chi}_1^0} < m_{\tilde{t}} < m_t + m_{\tilde{\chi}_1^0}$	$\tilde{t} \to Wb\tilde{\chi}_1^0$
E	$m_t + m_{\tilde{\chi}_1^0} < m_{\tilde{t}}$	$\tilde{t} \to t\tilde{\chi}_1^0$



νbb dominates over e/μ bt in A,B and parts of E.



LQD233 coupling
e/μ bt t .or. νbb t

From 1209.0764

RPV stop decay final states that we (at the time) did not cover well in either ATLAS or CMS.

Final state	b-jets	Scenario(s)
$(\tau^+ j)(\tau^- j)$	0	LQD332
$(jj)(jj)$	$0, 2$	UDD312/323
$8j$	$4, 6$	UDD312/323 with $\tilde{H}$ decaying via $\tilde{t}$; UDD213 with $\tilde{H}^{\pm} \to \tilde{H}^0$
$\ell^+\ell^- + 6j$	$2, 4, 6$	LQD232/233 with $\tilde{H}/\tilde{W}$ (unless decays via $\tilde{b}_L$ or $\tilde{b}_R$) LQD221/123 with $\tilde{W}$
$\tau^+\tau^- + 6j$	$2, 4, 6$	LQD332/333 with $\tilde{H}/\tilde{W}$ (unless decays via $\tilde{b}_L$ or $\tilde{b}_R$) LQD321/323 with $\tilde{H}$-$\tilde{\nu}_\tau/\tilde{\tau}_L$ or $\tilde{W}$ (with or without $\tilde{\chi}^{\pm} \to \tilde{\chi}^0$)
$\tau^{\pm}\tau^{\pm} + 6j$	$2, 4$	LQD321/323 with $\tilde{H}$-$\tilde{\nu}_\tau/\tilde{\tau}_L$ or $\tilde{W}$, with $\tilde{\chi}^{\pm} \to \tilde{\chi}^0$
$t\bar{t} + 6j$	$2, 4$	UDD212/213 with $\tilde{g}/\tilde{B}$; UDD213 with $\tilde{H}$
$t\bar{t} + 4j + \mathrm{MET}$	$2, 4, 6$	LQD321/323 with $\tilde{g}/\tilde{B}$ LQD323/233/333 with $\tilde{H}$ decaying via $\tilde{b}_R$ LQD232/233/332/333 with $\tilde{H}/\tilde{W}$ decaying via $\tilde{b}_L$ LQD232/233/332/333 with $\tilde{B}$ (unless decays via $\tilde{t}$)
$(tt$ or $t\bar{t}) + 6j$	$4, 6$	UDD312/323 with $\tilde{H}^{\pm} \to \tilde{H}^0$
$t\bar{t} + 2\tau + 4j$ $t\bar{t} + \tau + 4j + \mathrm{MET}$	2, 4	LQD321/323 with $\tilde{g}/\tilde{B}$; LQD323 with $\tilde{H}$-$\tilde{b}_R$
$\tau^+\tau^- W^+W^- + 2j$ $\tau + W^+W^- + 2j + \mathrm{MET}$ $W^+W^- + 2j + \mathrm{MET}$	0	LQD323 with $\tilde{b}_R$
4 tops $+ 4j$	$4, 6$	UDD312/323 with $\tilde{B}$
$6j + \mathrm{MET}$	$2, 4$	LQD221/123/321/323 with $\tilde{W}$ LQD321/323 with $\tilde{W}^{\pm} \to \tilde{W}^0$ LQD232/332 with $\tilde{W}^{\pm} \to \tilde{W}^0$ (unless decays via $\tilde{t}$) LQD323 with $\tilde{H}^{\pm} \to \tilde{H}^0 \to \tilde{b}_R$
$\ell + 6j + \mathrm{MET}$	$2, 4$	LQD221/123 with $\tilde{W}$
$\tau + 6j + \mathrm{MET}$	$2, 4$	LQD321/323 with $\tilde{W}$ (with or without $\tilde{W}^{\pm} \to \tilde{W}^0$) LQD323 with $\tilde{H}^{\pm} \to \tilde{H}^0 \to \tilde{b}_R$
$\tau^+\tau^- + 2b + \mathrm{MET}$	2	LLE123/233 with heavy $\tilde{W}$
$W^+W^- + 4j$	0	UDD213 with $\tilde{b}_R$

Natural RPV Summary

- We started …
- … but RPV has such a rich phenomenology that we are still far from done.
- 1-lepton, many jets, modest or no MET final state would go a long way to complement what we already have.

Summary & Conclusions

- A very diverse program of SUSY searches with the 7TeV and 8TeV datasets has been completed.
- Starting to place significant constraints on "Natural SUSY"
- Program at 8TeV is far from over, many more analyses to come this summer.

Backup

Yields for Ewkino Searches

3ℓ: OSSF pair, no τ_h

M_T (GeV)	E_T^{miss} (GeV)	$M_{\ell\ell} < 75$ GeV total bkg	$M_{\ell\ell} < 75$ GeV observed	$75 \text{ GeV} < M_{\ell\ell} < 105$ GeV total bkg	$75 \text{ GeV} < M_{\ell\ell} < 105$ GeV observed	$M_{\ell\ell} > 105$ GeV total bkg	$M_{\ell\ell} > 105$ GeV 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 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±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

Trileptons

3ℓ: OSOF pair and a 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	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

3ℓ: SS leptons and a 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	1.8±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

Yield Tables for Z+MET+djets

	E_T^{miss} 0–30 GeV	E_T^{miss} 30–60 GeV	E_T^{miss} 60–80 GeV	E_T^{miss} 80–100 GeV
Z + jets bkg	52823 ± 15847	14015 ± 4205	433 ± 130	40.9 ± 12.4
FS bkg	41.3 ± 7.2	49.5 ± 8.6	26.4 ± 4.7	17.9 ± 3.3
WZ bkg	9.5 ± 6.6	15.9 ± 11.2	6.6 ± 4.7	3.9 ± 2.7
ZZ bkg	2.1 ± 1.0	4.1 ± 2.1	2.2 ± 1.1	1.8 ± 0.9
rare SM bkg	0.3 ± 0.2	0.7 ± 0.3	0.4 ± 0.2	0.3 ± 0.2
total bkg	52876 ± 15847	14085 ± 4205	468 ± 130	64.7 ± 13.2
data	52485	14476	510	56

	E_T^{miss} 100–120 GeV	E_T^{miss} 120–150 GeV	E_T^{miss} 150–200 GeV	E_T^{miss} > 200 GeV
Z + jets bkg	7.0 ± 2.2	3.1 ± 0.9	1.6 ± 0.5	0.8 ± 0.3
FS bkg	11.3 ± 2.2	6.9 ± 1.5	2.4 ± 1.1	0.4 ± 0.3
WZ bkg	2.1 ± 1.5	1.6 ± 1.1	1.0 ± 0.7	0.5 ± 0.5
ZZ bkg	1.0 ± 0.5	1.1 ± 0.6	0.8 ± 0.4	0.7 ± 0.7
rare SM bkg	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.2 ± 0.2
total bkg	21.7 ± 3.5	13.0 ± 2.2	6.1 ± 1.5	2.5 ± 0.9
data	24	16	3	1