CMS SUSY Program

Disclaimer:

Opinions expressed herein
are those of the author,
and not necessarily the CMS collaboration.

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Overview

- Status of inclusive SUSY searches
- Status of SMS motivated SUSY searches
- Planning for the future

Throughout I will try to point out issues where we need help from pheno community

Evolution of SUSY Searches

Inclusive Signatures	Searches optimized for topologies	Searches optimized for holes in sensitivity
cMSSM	SMS	Full Models

This is (roughly) the progression both experiments are on.

Status of 8TeV Results for Inclusive Searches in CMS

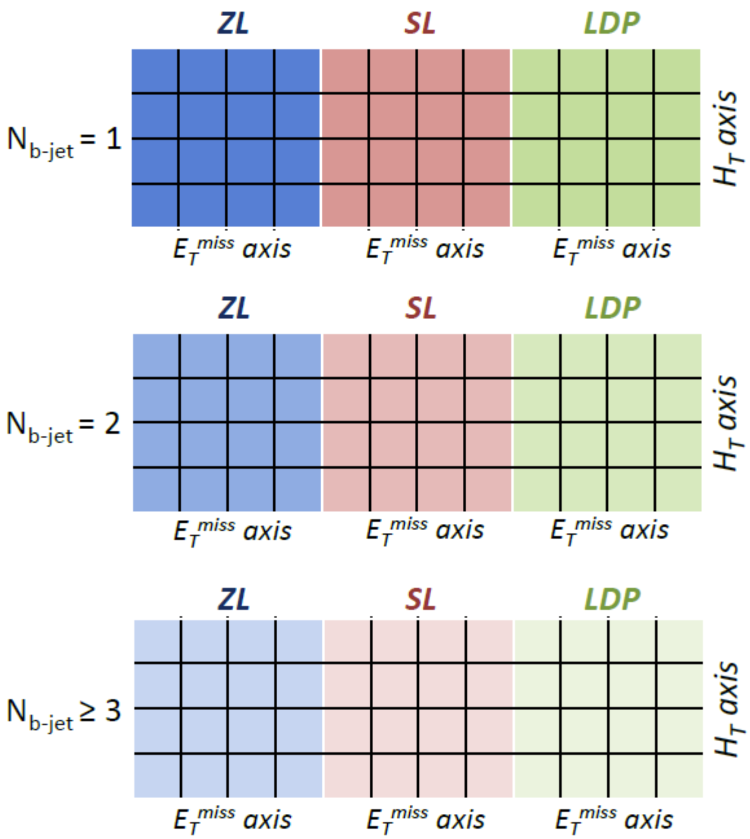
	Without b-tags	With b-tags
0-leptons		20/fb
1-lepton		20/fb
2 leptons OS		
2 leptons SS		11/fb
>= 3 leptons	9/fb	9/fb
1 photon	4/fb	
2 photons	4/fb	

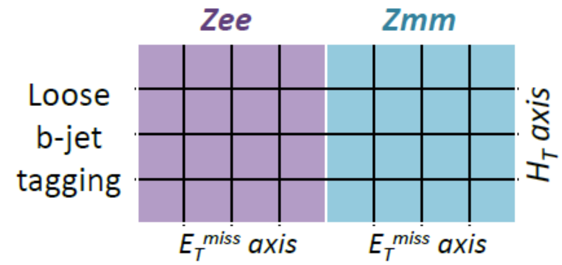
Discuss these

We are still very far away from complete coverage !!!

H_T vs MET vs b-tag fit

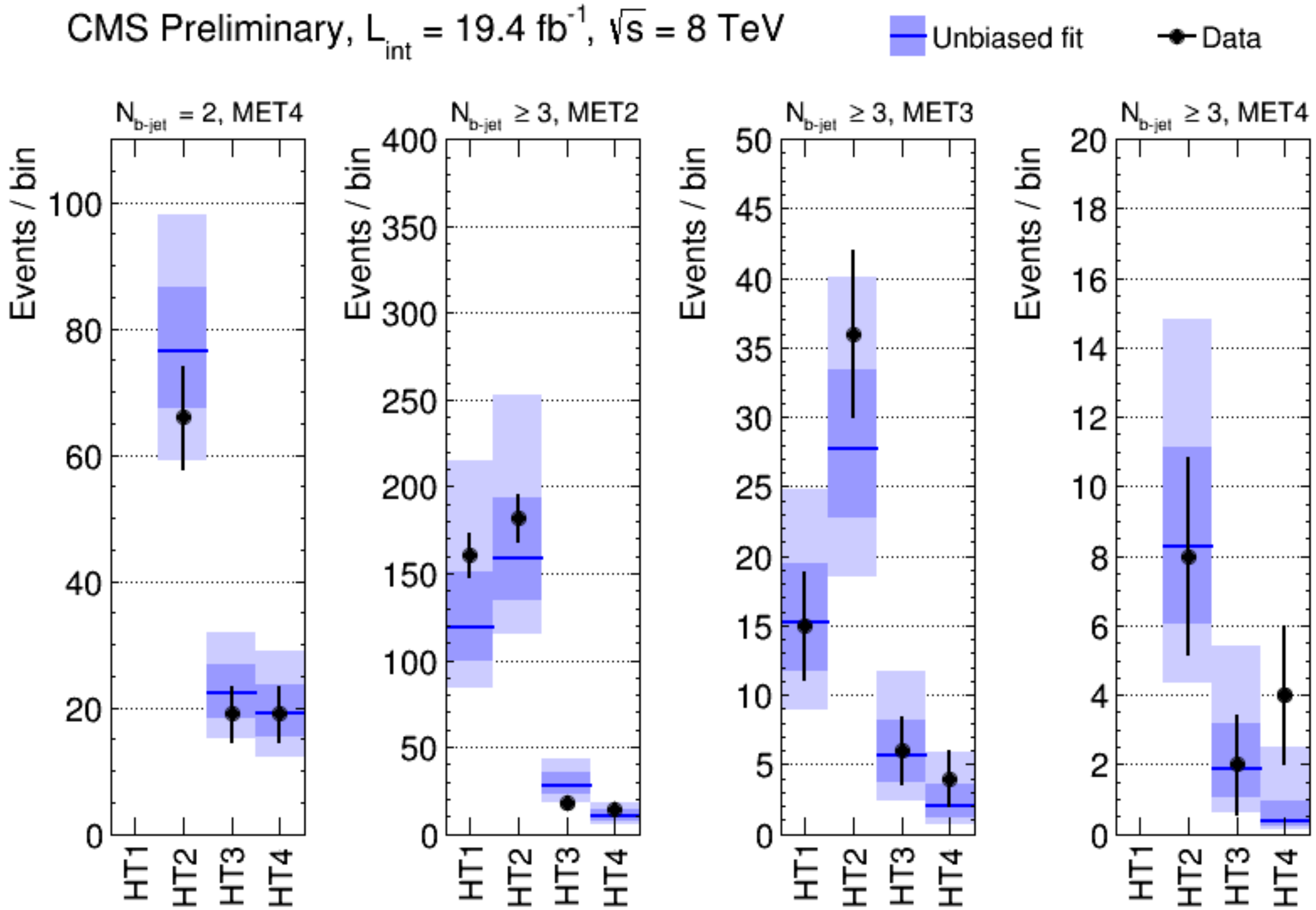
Event sample legend				
ZL = Zero Lepton; signal sample	*SL* = Single Lepton; top & W+jets control sample	*LDP* = low $\Delta\hat{\phi}_{min}$; QCD control sample	*Zee* = $Z \to e^+e^-$; Z to $\nu\bar{\nu}$ control sample	*Zmm* = $Z \to \mu^+\mu^-$; Z to $\nu\bar{\nu}$ control sample



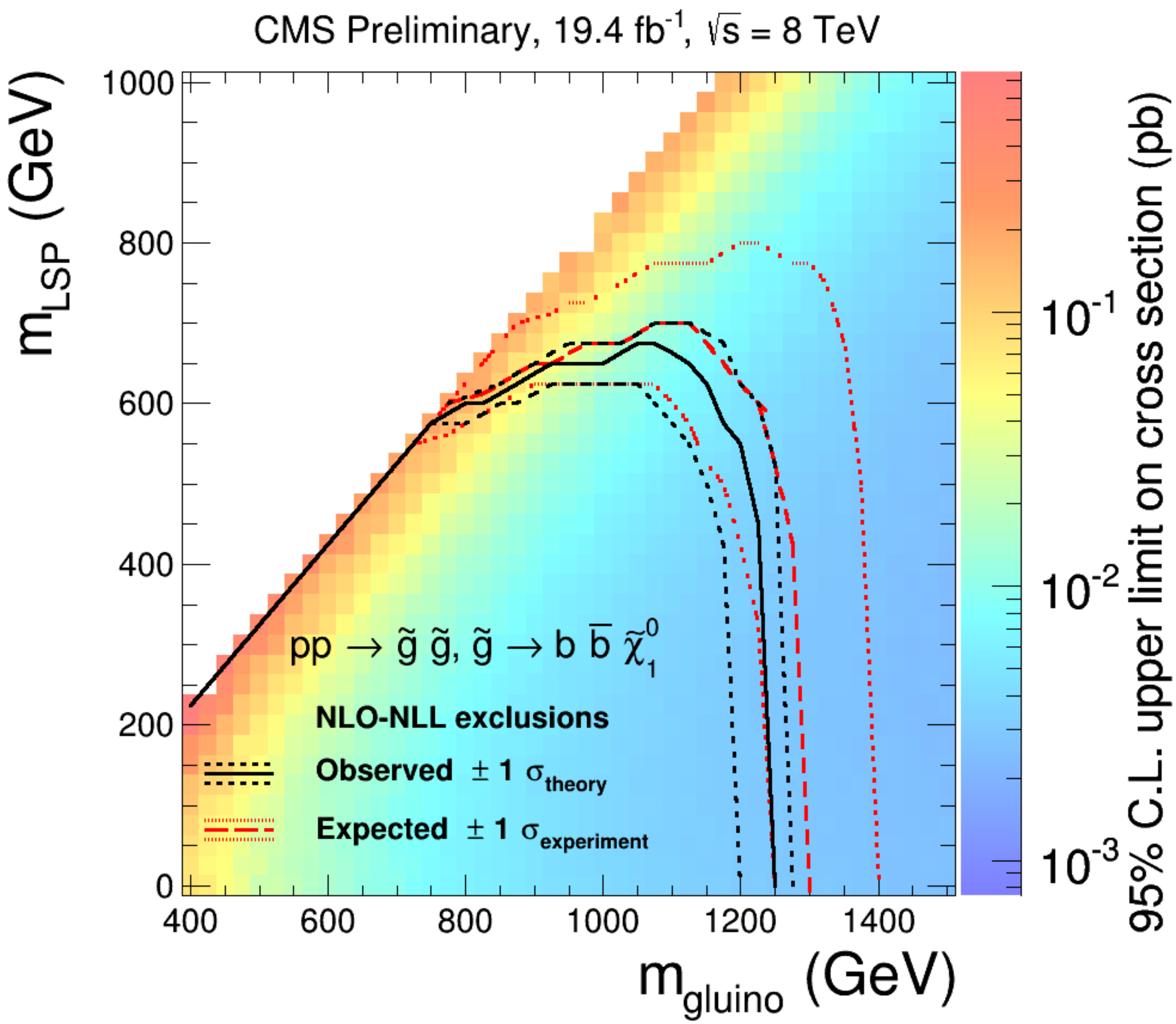


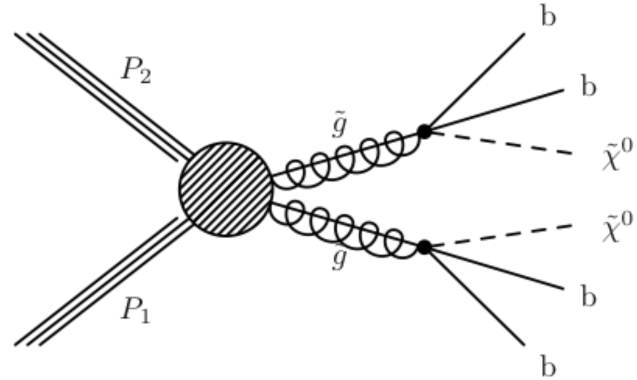
Bin	H_T (GeV)	E_T^{miss} (GeV)
1	400 – 500 (HT1)	125 – 150 (MET1)
2	500 – 800 (HT2)	150 – 250 (MET2)
3	800 – 1000 (HT3)	250 – 350 (MET3)
4	> 1000 (HT4)	> 350 (MET4)

H_T vs MET vs b-tag fit

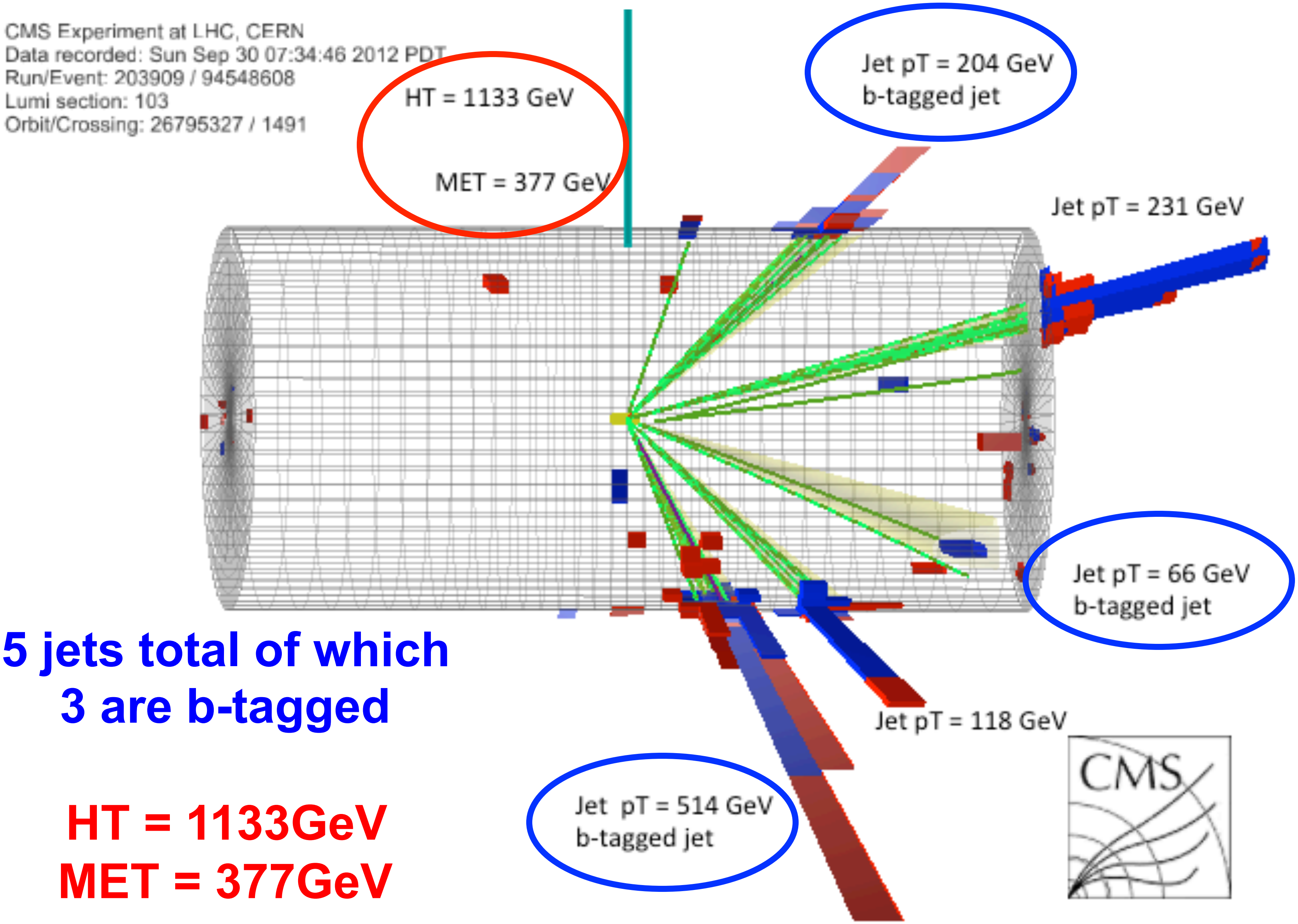


H_T vs MET vs b-tag Interpretation





Amusing Event



5 jets total of which 3 are b-tagged

HT = 1133GeV
MET = 377GeV

Large H_T,MET, jets, 1-lepton

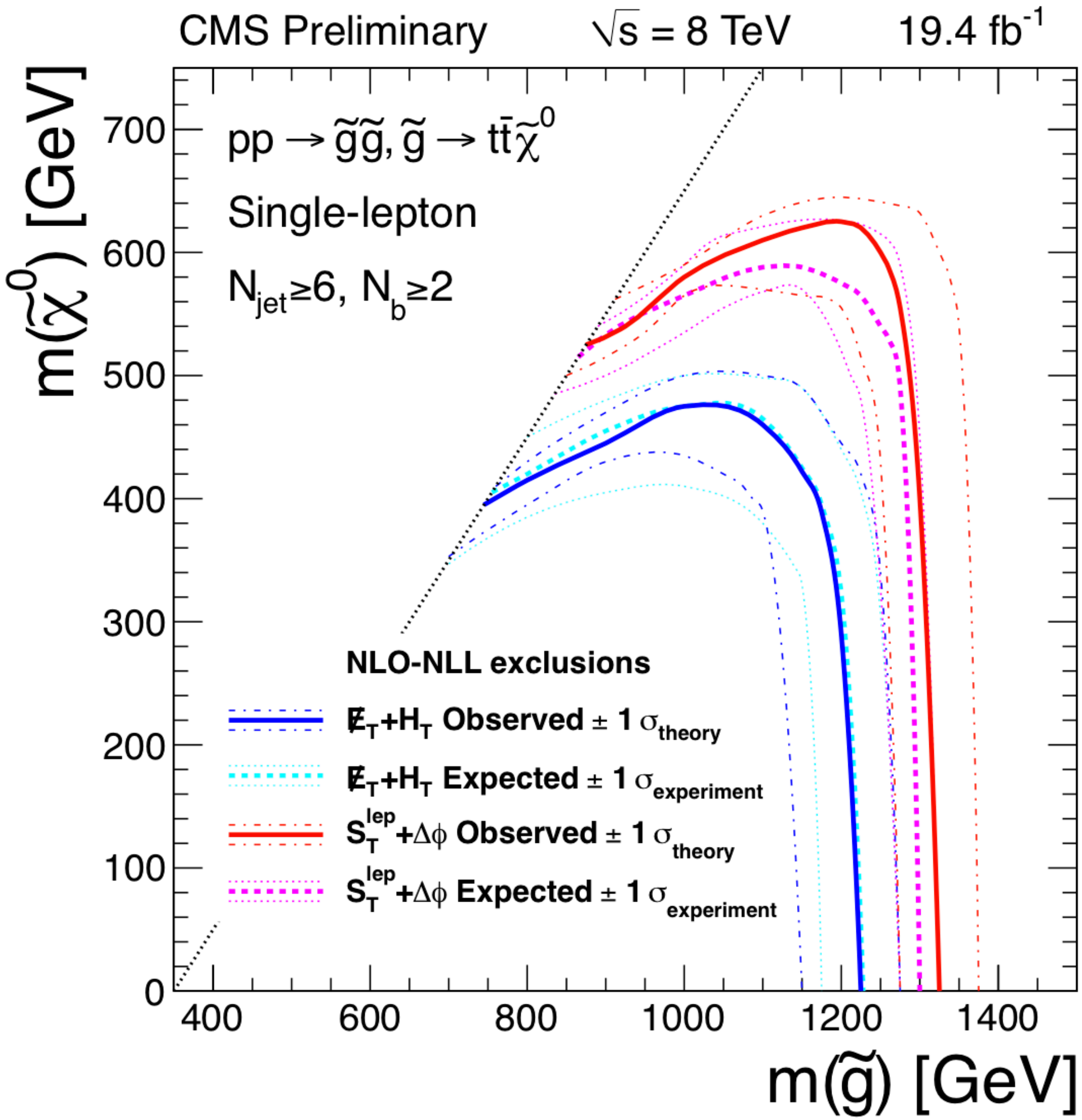
- ≥ 6 jets out of which ≥ 2 are b-tagged
  - pT > 40GeV, H_T > 500GeV
- 1 isolated e or μ w. p_T > 20GeV
- Two Analyses:
  - "Lepton Spectrum" Method:
    - MET > 250GeV
    - Use lepton spectrum to predict bkg MET spectrum
  - "S_T^{lep} vs $\Delta\phi$(W,lep)" Method:
    - Bin in $S_T^{lep} = pT_{lep}$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

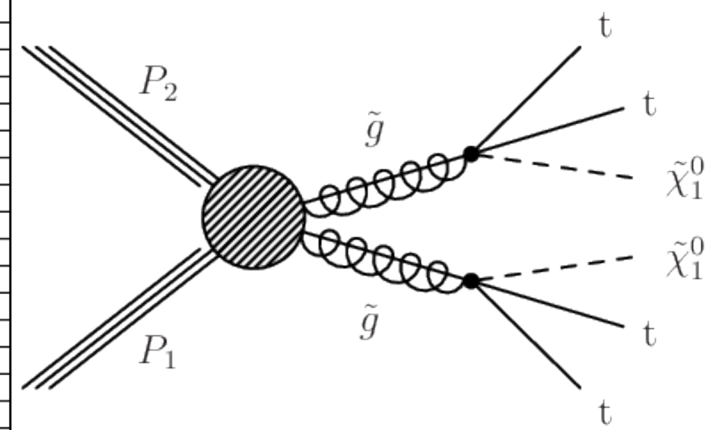
Results for "S_T^{lep}" Method

		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

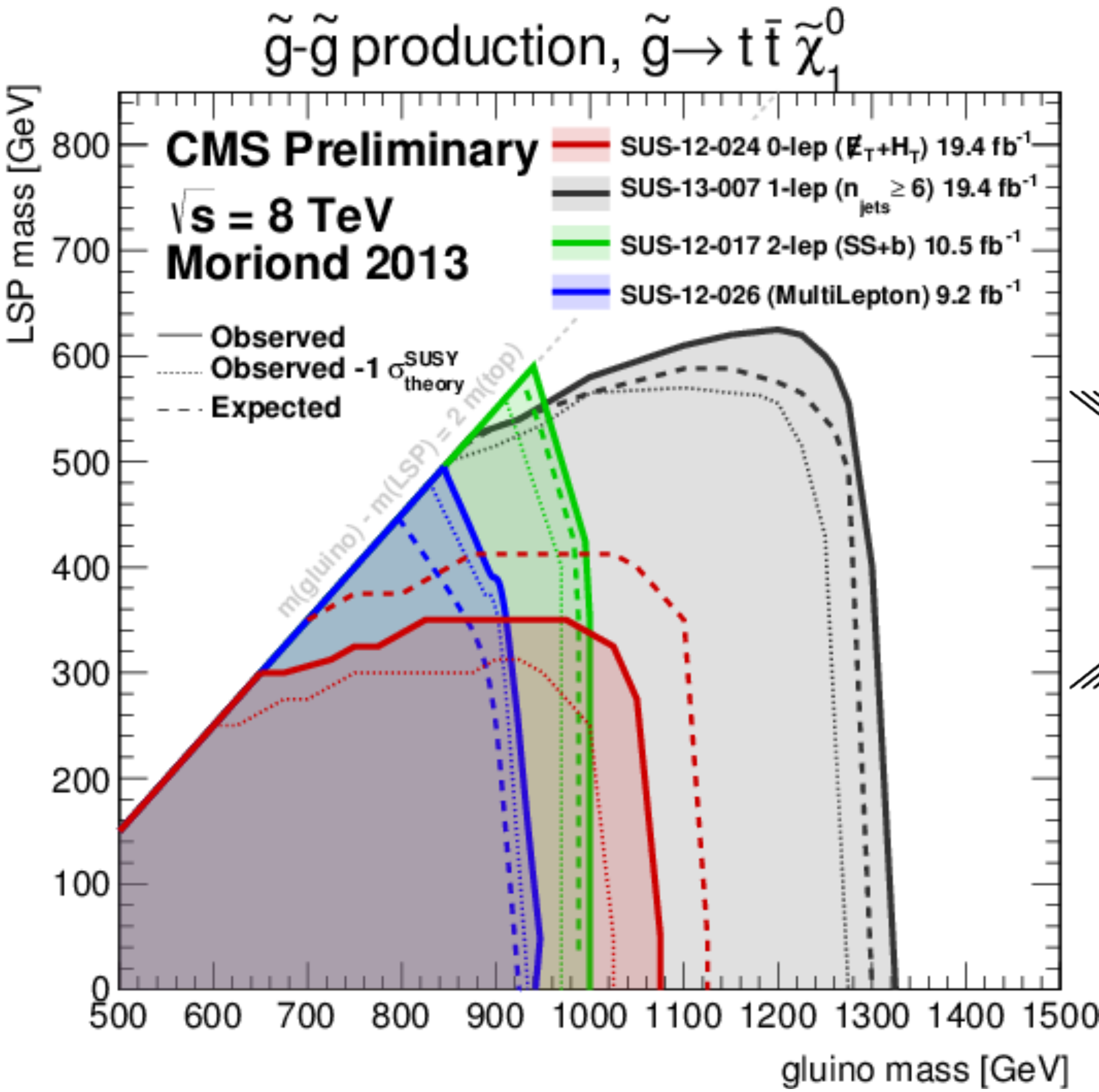
No excess => setting limits !!!

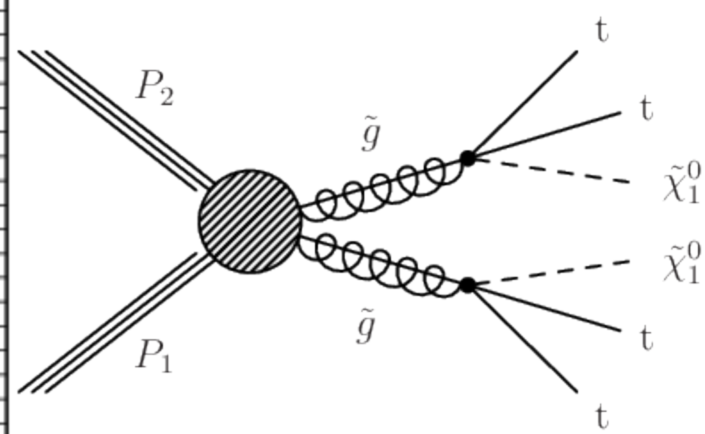
Interpretation





Comparison to other final states





Inclusive 0- & 1-lepton analyses missing

- Lower MET && larger Njet
- Fewer or no b-tags
- Lower H_T && fewer b-tags
- Lower MET && Lower H_T
- …

Basically, analyses targeting stop, RPV, compressed spectra, SUSY without b-quarks

Even where we have 20/fb results, there is lot's left to do.

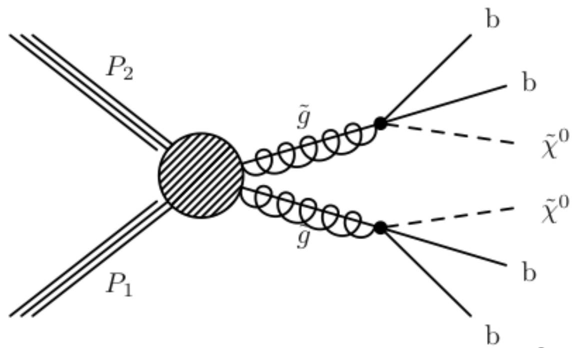
Coverage in SMS RPC topologies

Gluinos	**(almost) ok**
Squark	**Ok**
Stop	**Incomplete**
Sbottom	**Ok**
X^{+}, X^{0}	**Incomplete**
Sleptons	**Incomplete**

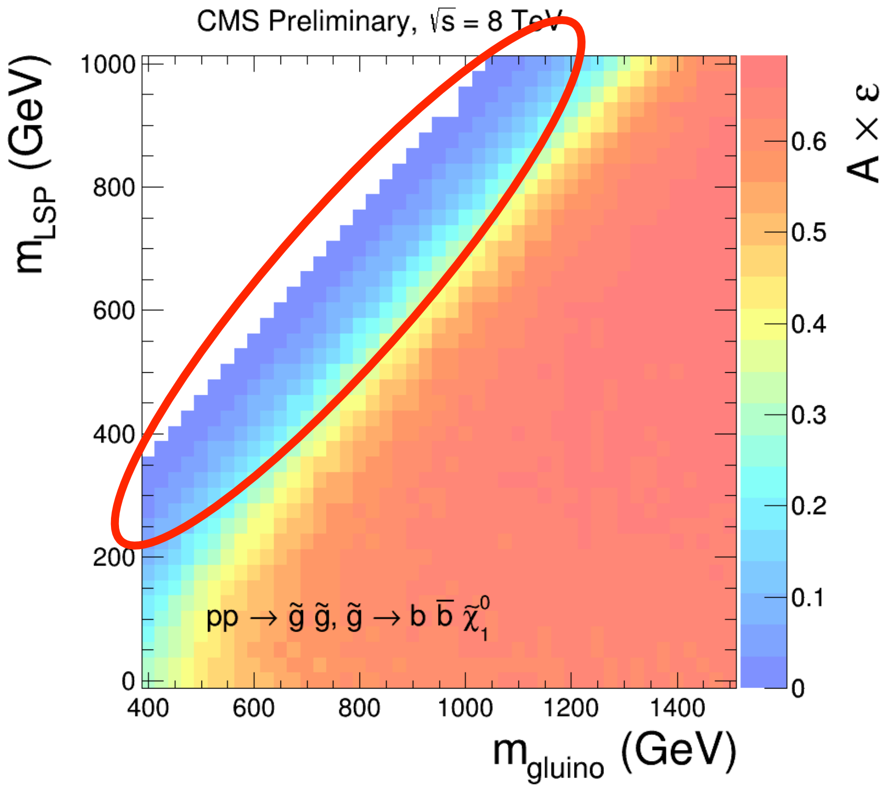
We have a good starting point, but are far from complete.

For overview of CMS@7TeV SMS results: 1301.2175

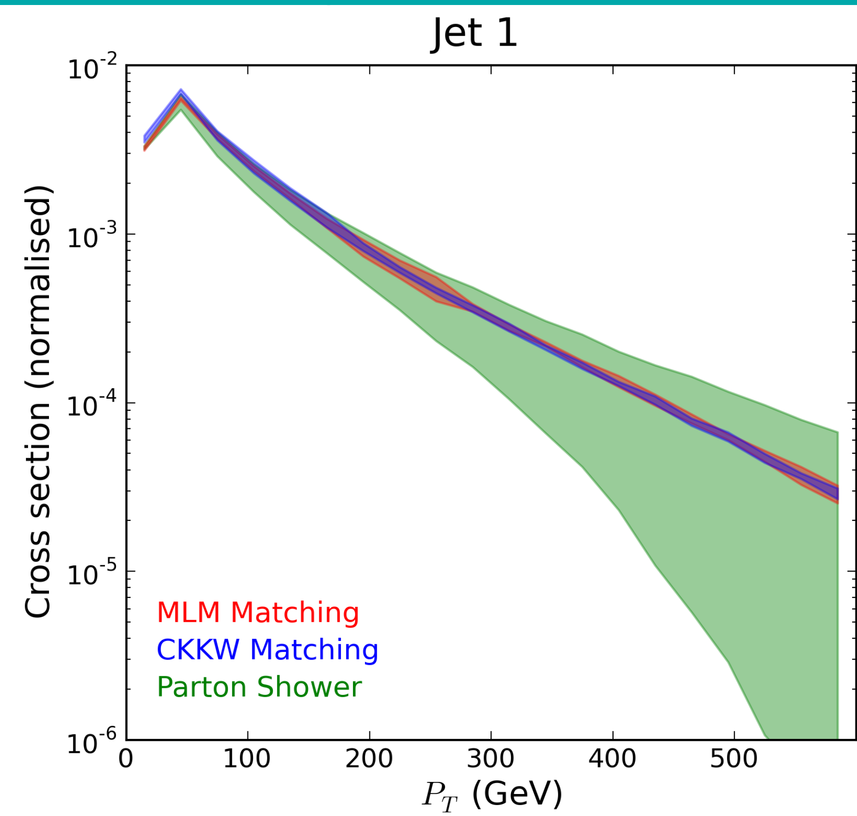
Aside on "Compressed Spectra"



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 see M.Pierini at DESY workshop.

Two Examples to explain problems with SMS strategy

- SUSY with RPV
- Direct Stop production in RPC

RPV Intro

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

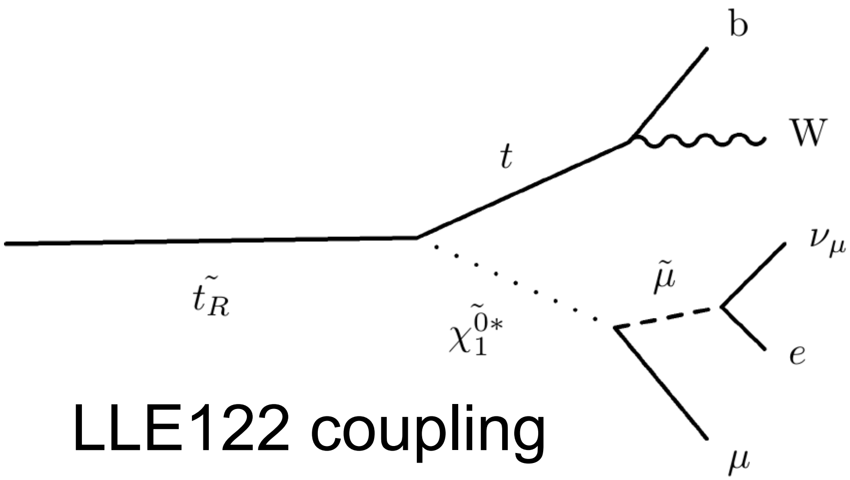
Leptonic RPV | LQD RPV | Hadronic RPV

- 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

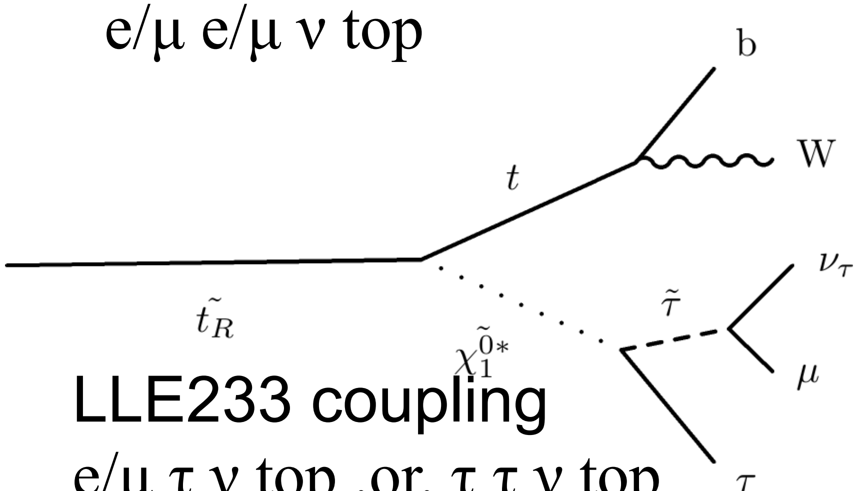
"Standard" stop to top X^0, followed by RPV X^0 decay

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



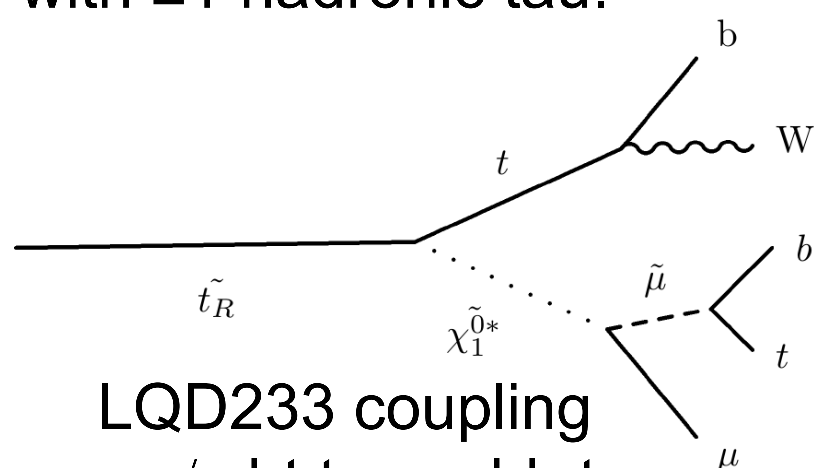
LLE122 coupling

e/μ e/μ ν top



LLE233 coupling

e/μ τ ν top .or. τ τ ν top



LQD233 coupling

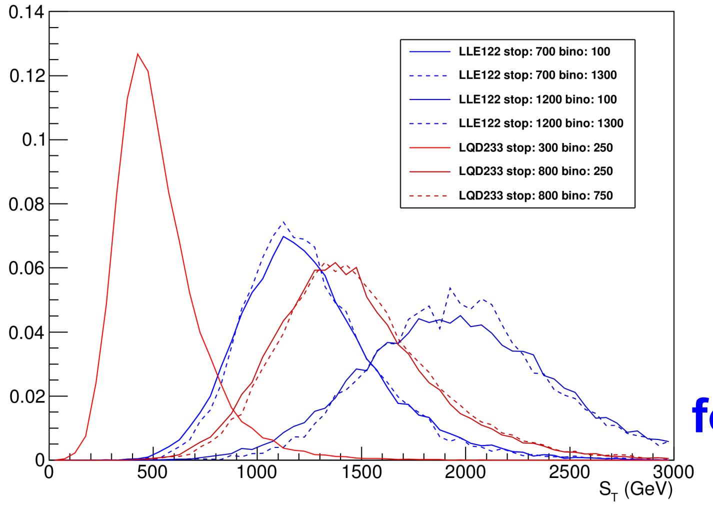
e/μ bt t .or. νbb t

≥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

CMS Simulation 8 TeV



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	$0 < S_T < 300$ obs	exp	$300 < S_T < 600$ obs	exp	$600 < S_T < 1000$ obs	exp	$1000 < S_T < 1500$ obs	exp	$S_T > 1500$ 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

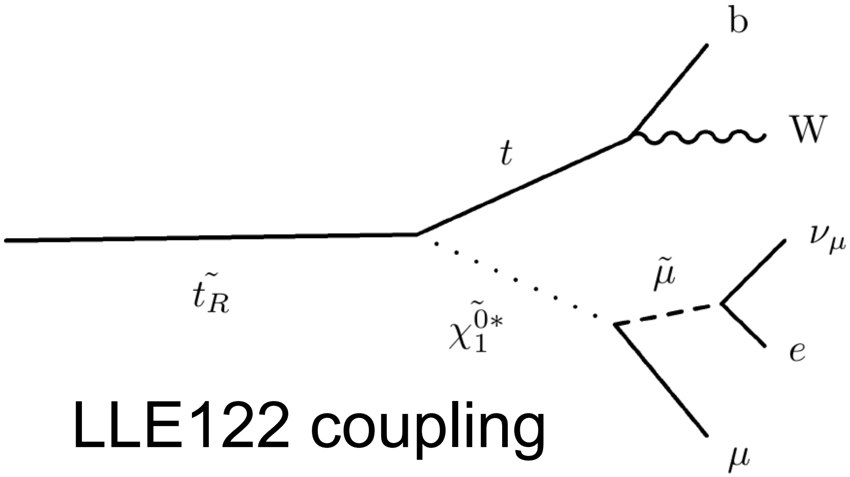
Z veto && b-tag

N_ℓ	N_τ	$600 < S_T < 1000$ obs	exp	$1000 < S_T < 1500$ obs	exp	$S_T > 1500$ 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)

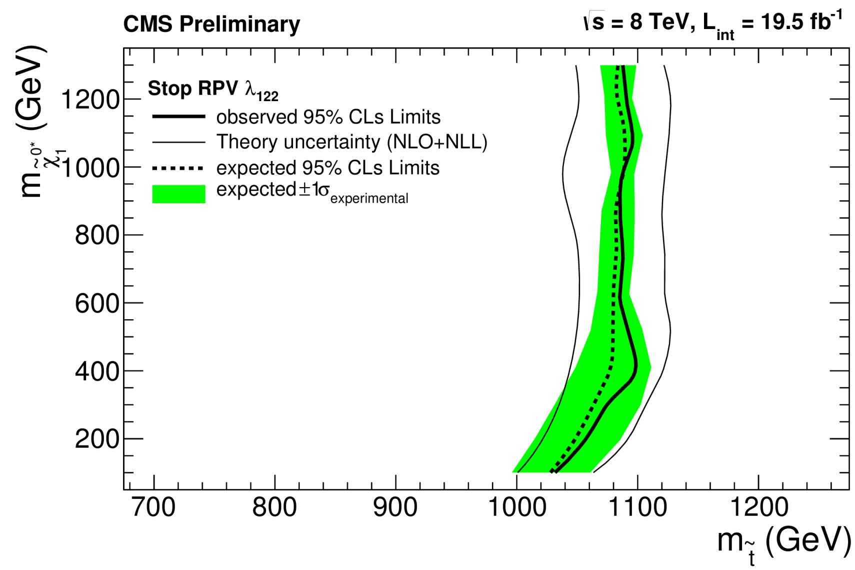
No Excess anywhere => Setting limits

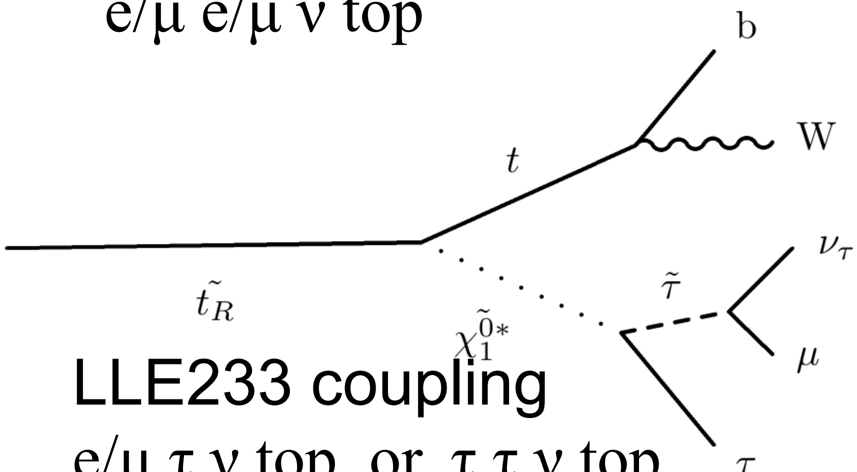
≥3 leptons Results



LLE122 coupling

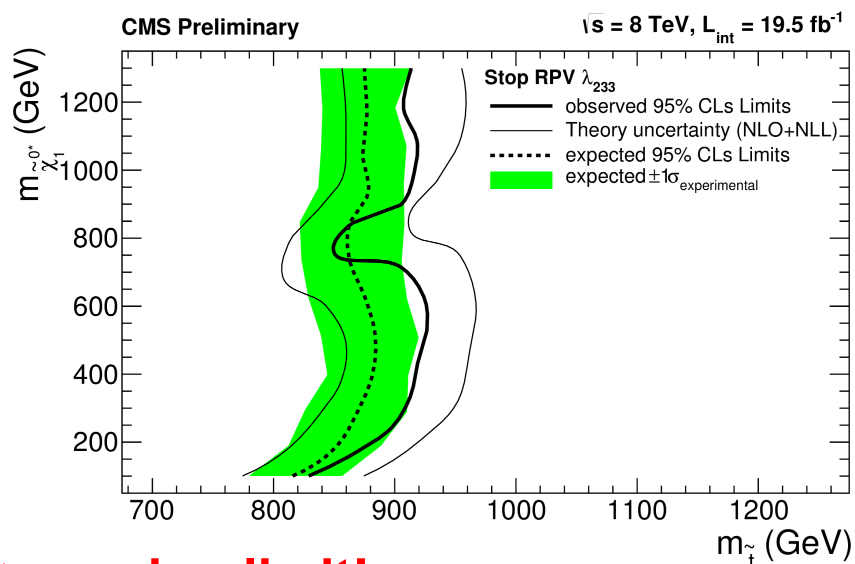
e/μ e/μ ν top





LLE233 coupling

e/μ τ ν top .or. τ τ ν top



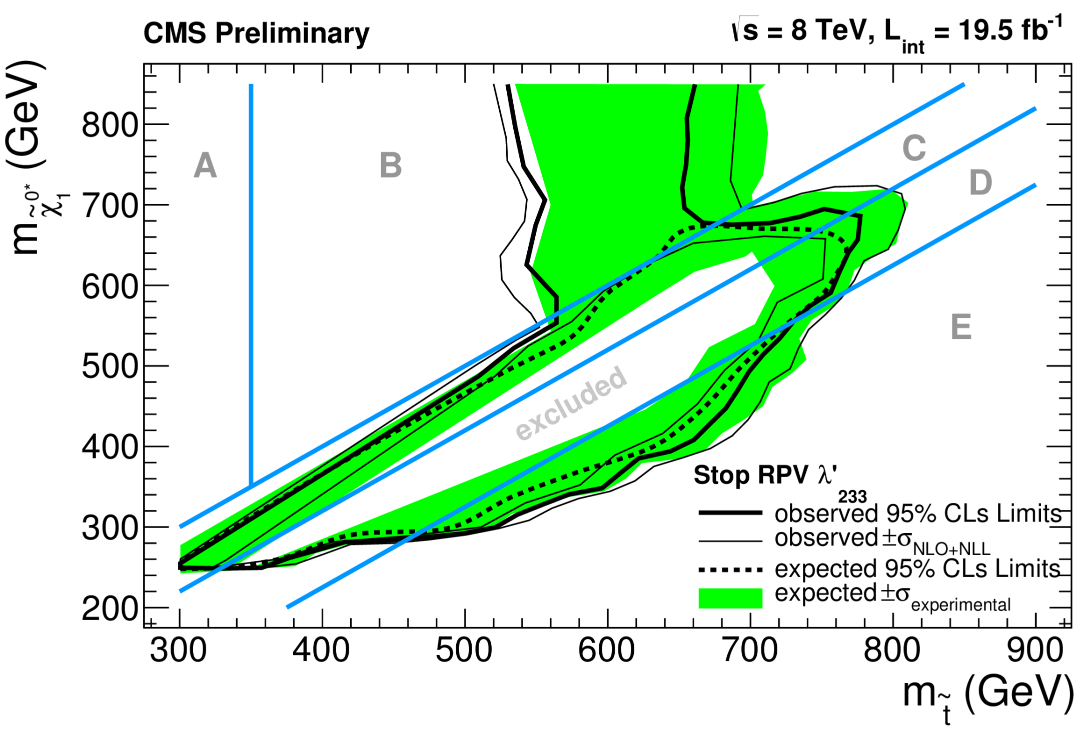
Smaller eff. for tau => weaker limit!

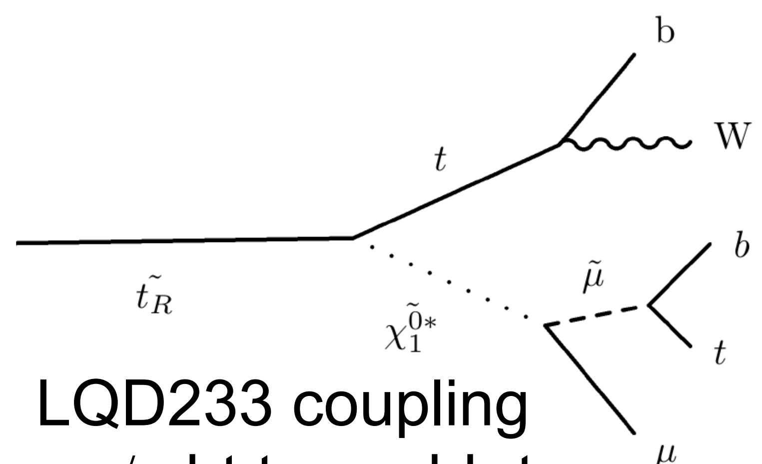
≥3 leptons Results

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 $\tilde{b}_R$

Aside on Relationship between Pheno Community and Experiments

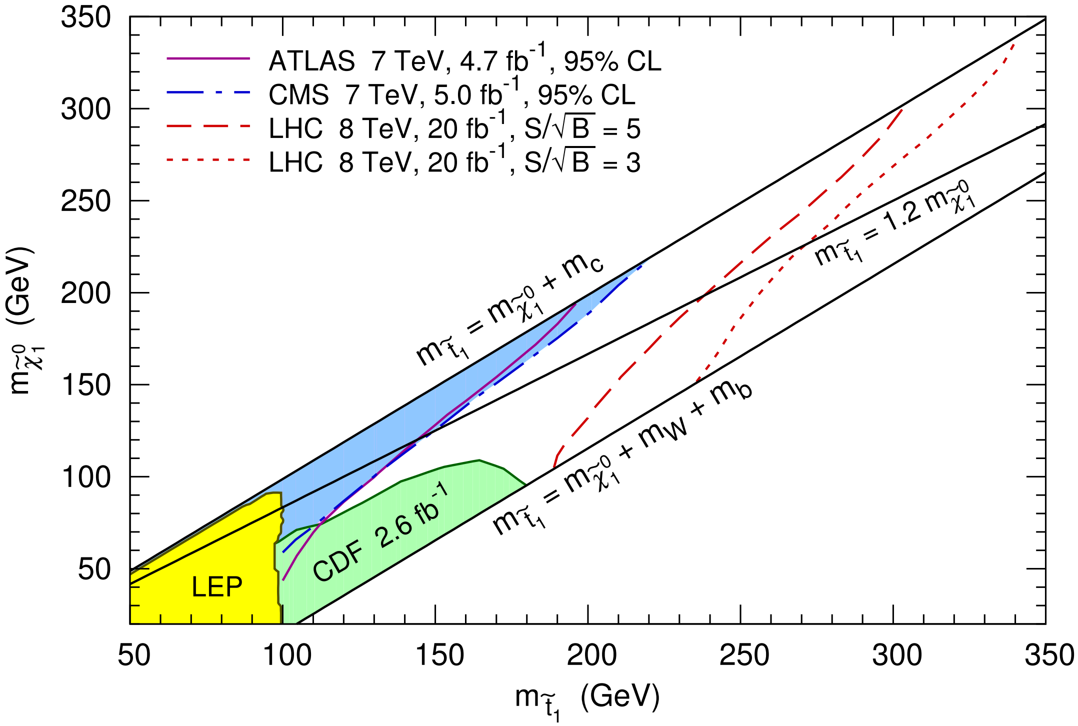
- Doing interpretations is a major effort for the experiments given their culture.
- What should the experiments do to enable interpretations by others?
- Is there a guiding principle towards what interpretations should be done inside versus outside the experiments?

Status of RPC Stop SMS

- Presently, ATLAS and CMS use:
  - "T2tt" = stop to top X^0 only for real top
  - "T2bw" = stop to b X^+ followed by X^+ to W X^0
    - Half a dozen different variants, all of which are essentially arbitrary and close to impossible to defend with a straight face.
- At the same time, the most serious low mass stop limit still comes from CDF.
  - Plus several phenomenology papers estimating the ATLAS and CMS exclusion:
    - 1211.2997, 1211.4981, 1212.6847, …

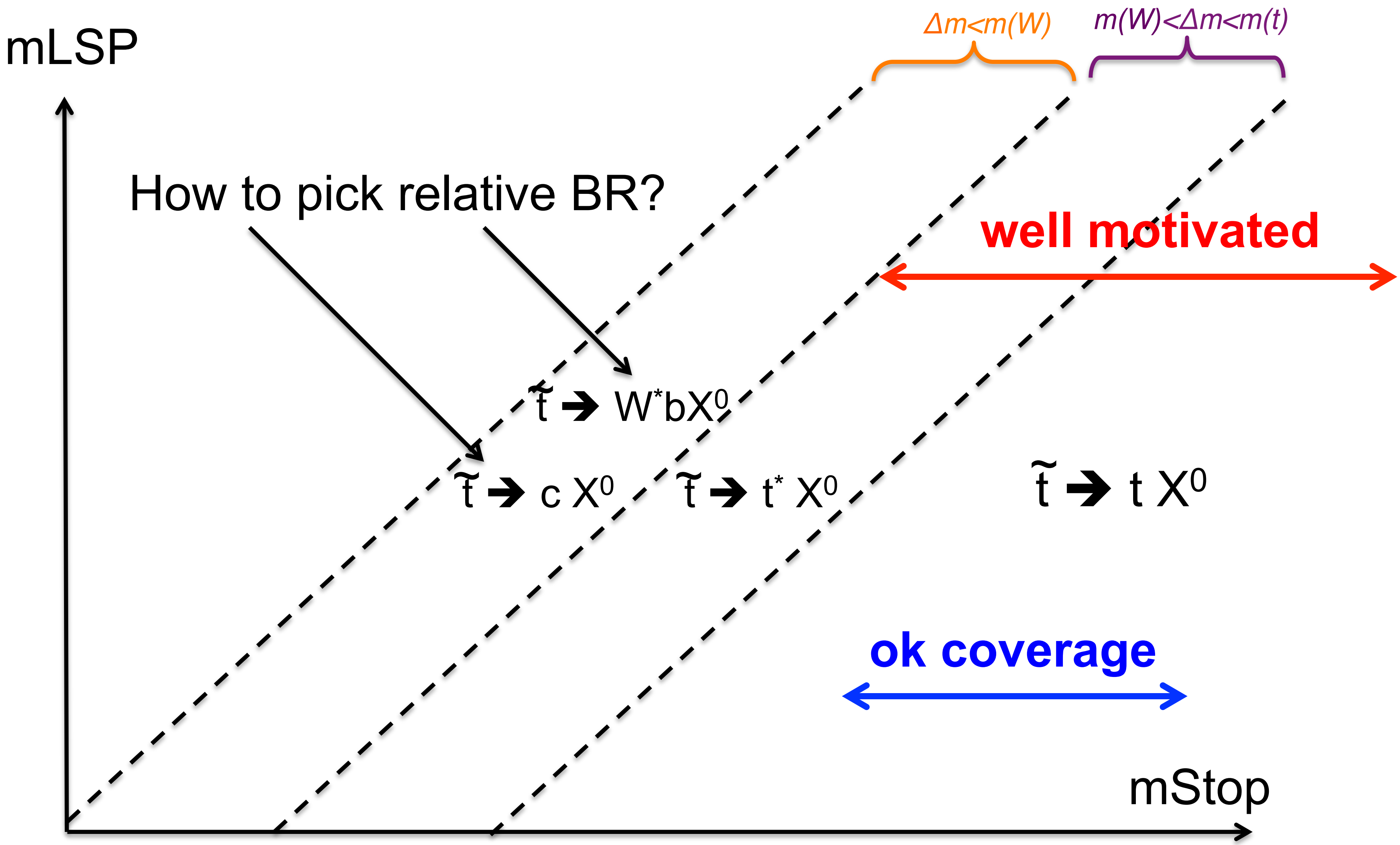
Example: 1211.2997

Reinterpreting ATLAS & CMS Monojet results assuming stop to c X^0 has BR = 100%



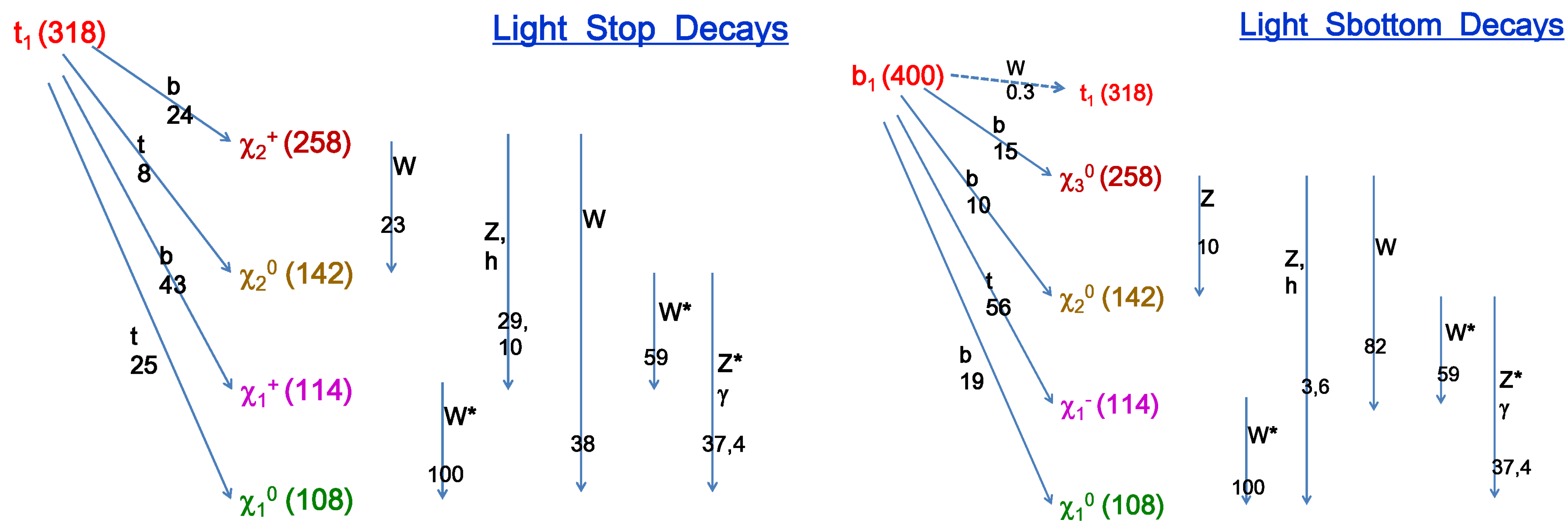
The only curve done by an experiment in this plot is CDF

What could we do that is defensible and complete?



Is there a limit to the usefulness of SMS?

Example from 1206.5800



If this is what a "typical" spectrum looks like, what's the point of an SMS ?

Options for Full Models

- cMSSM
  - Is this still worth doing?
- pMSSM
  - Plus: large "coverage"
  - Cons: not very efficient in providing models that
    - Satisfy naturalness criteria
    - Are consistent with higgs
    - Are consistent with dark matter abundance
    - Motivate anything other than all hadronic searches
- "Natural SUSY" subspace of pMSSM ?
- NMSSM ?

Looking Ahead

What is the HL-LHC physics objective?

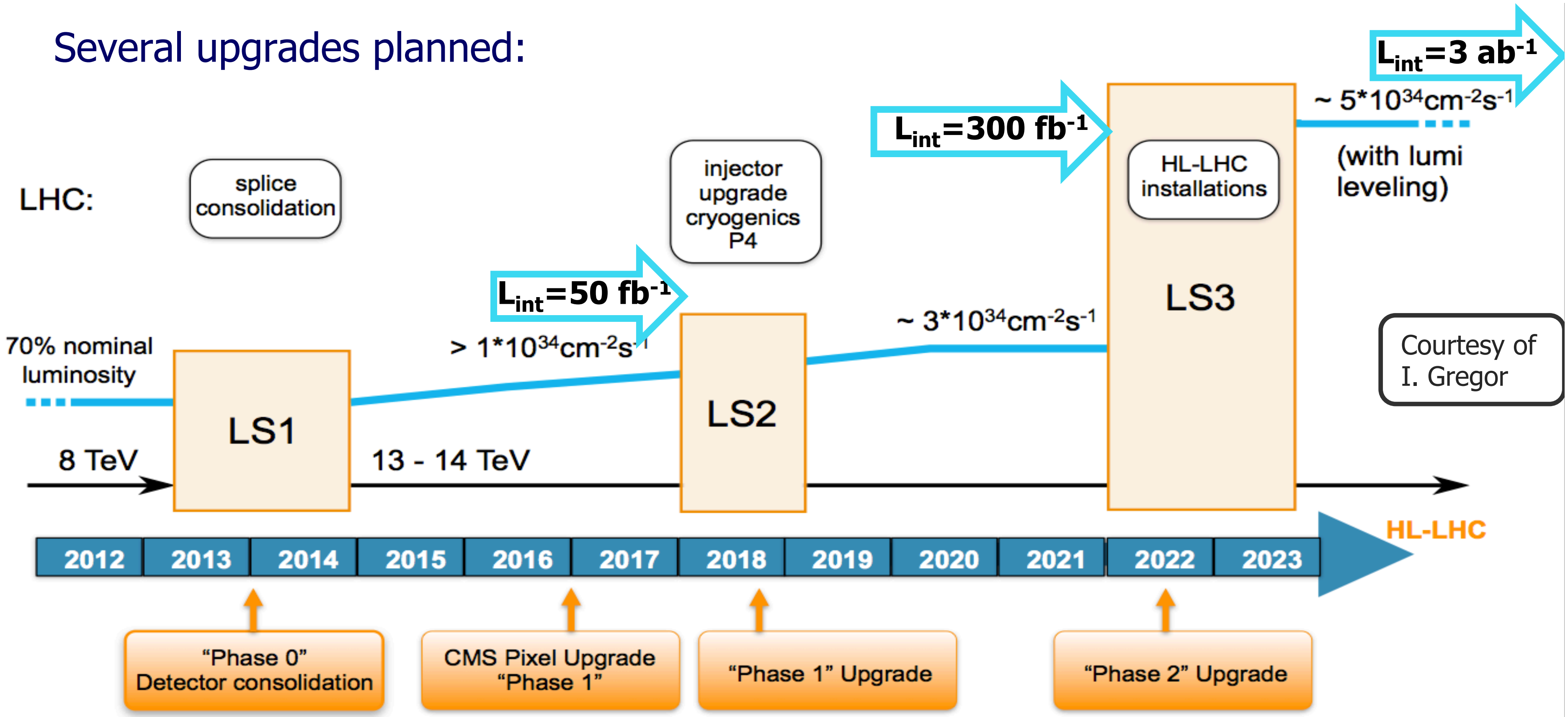
What matters to CMS?

How can pheno help?

A personal perspective

Defining the "Future"

Several upgrades planned:



Already planned, e.g. HCAL/Pixel/L1 TDR

Still to be defined…

Big Picture

- If we don't see any new colored particles in 300/fb @ 14TeV then we won't see any in 3000/fb either.
- Whatever limit the LHC can place on dark matter production sets the minimum energy scale worthwhile for the ILC.

To me this means there are 2 Questions worth asking.

Questions worth asking

- If we discover an excess in MET+Jets+btags (+lepton(s)) in 50/fb @ 13TeV, what phase 2 detector do we need to build to study this excess to understand what we have discovered?

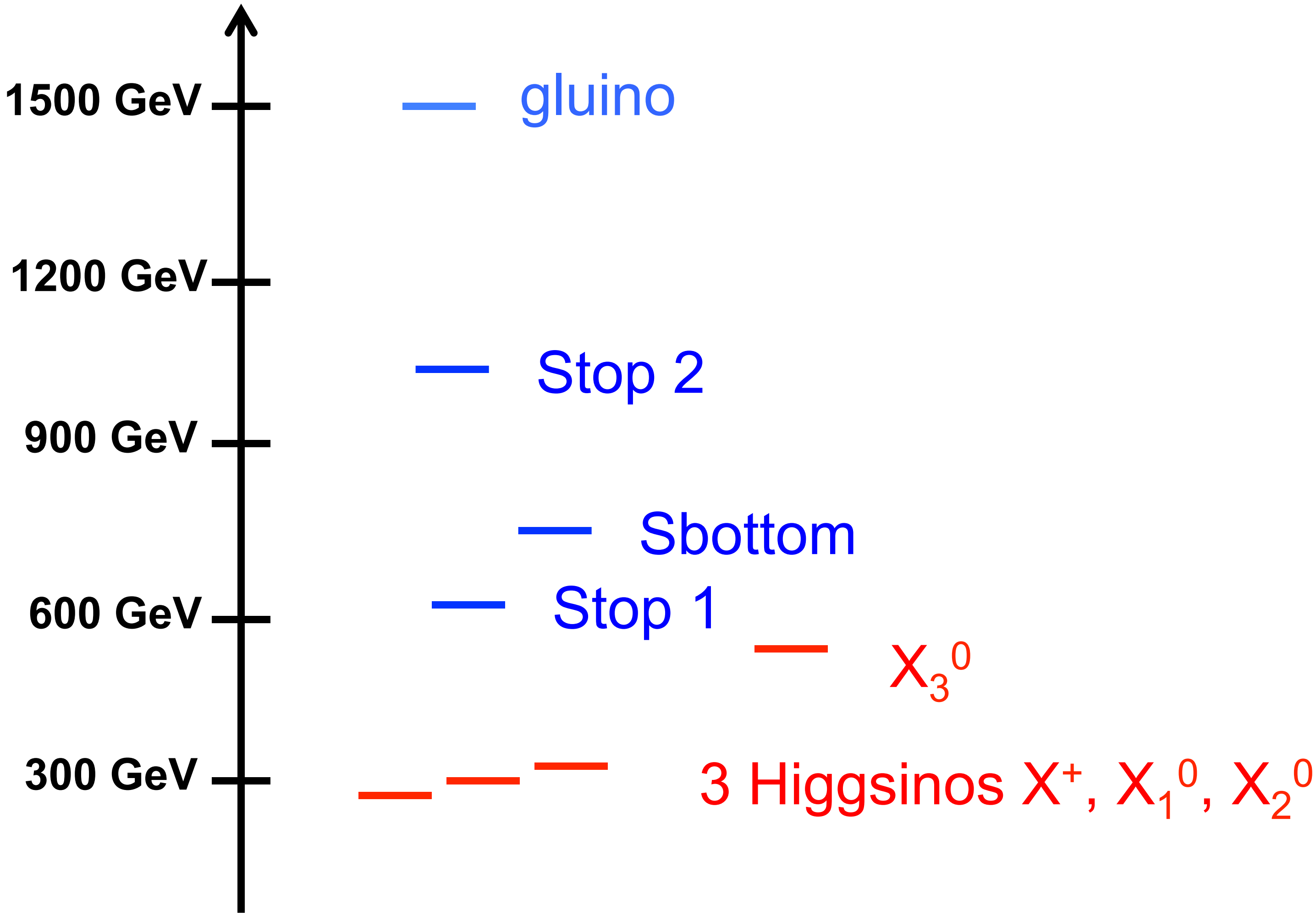
- What is the discovery reach for pp ➔ nothing?

We need help with the first question!

The help we need (I)

- First, let's pick a "typical" natural susy spectrum that satisfies the constraints:
  - Higgs mass and other SM constraints
  - Dark Matter Abundance
  - Feature richness to motivate a wide range of detector upgrade studies.

Prototype Spectrum



The help we need (II)

- What can we learn about the underlying physics of such a spectrum from measurements of the characteristics of the excess yield?
  - 2,4,6 b-quarks ?
    - E.g. 2b + MET final state vs 4W + 2b + MET as indication of sbottom branching fractions?
  - Z's vs Higgs vs γ in the cascades ?
    - E.g. as indication of the nature of the neutralinos ? tanβ ?
  - 1,2,3,4 and more leptons ?
    - E.g. presence or absence of low/high pT leptons as indication of mass splittings between particles that decay into each other by emitting a W?
      - Muons (electrons) down to 5 (10)GeV
    - Same-flavor dileptons below the Z mass as signature of mass differences?
  - Boosted hadronic decays of W's or top's as signature of large mass splittings?
  - Can we distinguish tanβ ~ O(1), O(10), O(100), or even better ?
  - Anything else you can think of !!!

Conclusions

- Anybody who tells you the LHC is done with its 8TeV searches is just plain wrong. We got lot's of work left to do !!!
- What part of the interpretations program should we leave for the pheno community?
- We need help with charting the course for the future !!!