

# How, Then, Will We Find BSM Physics?

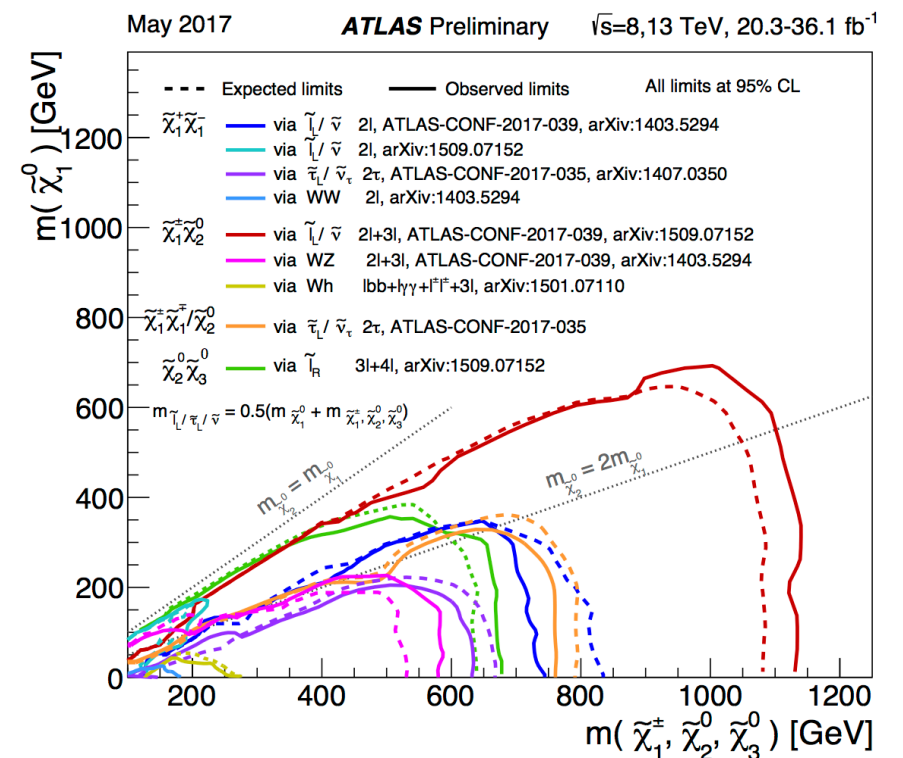
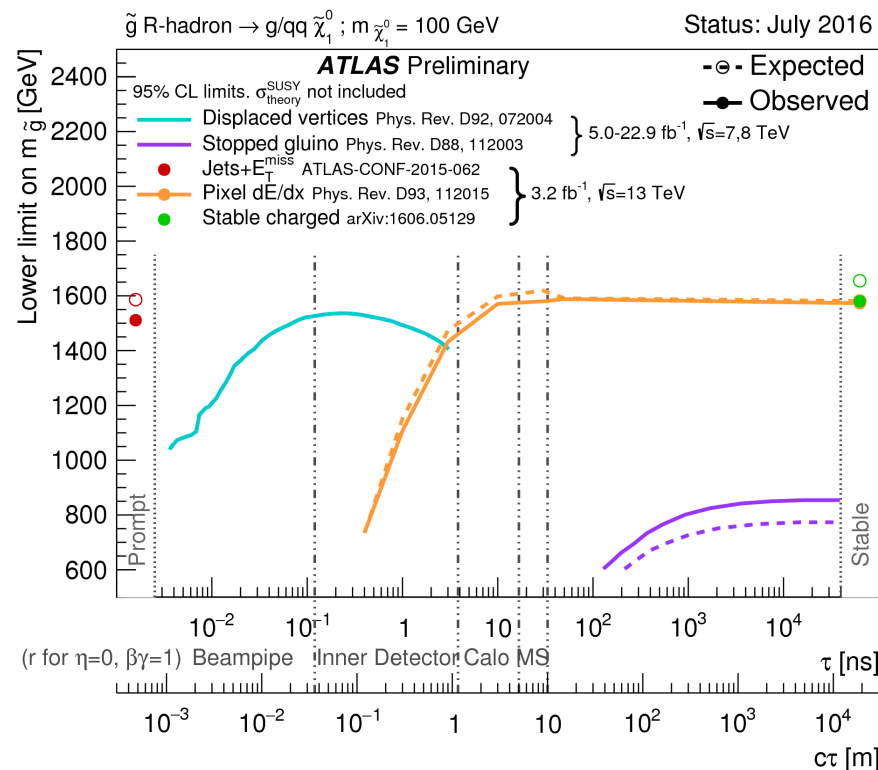
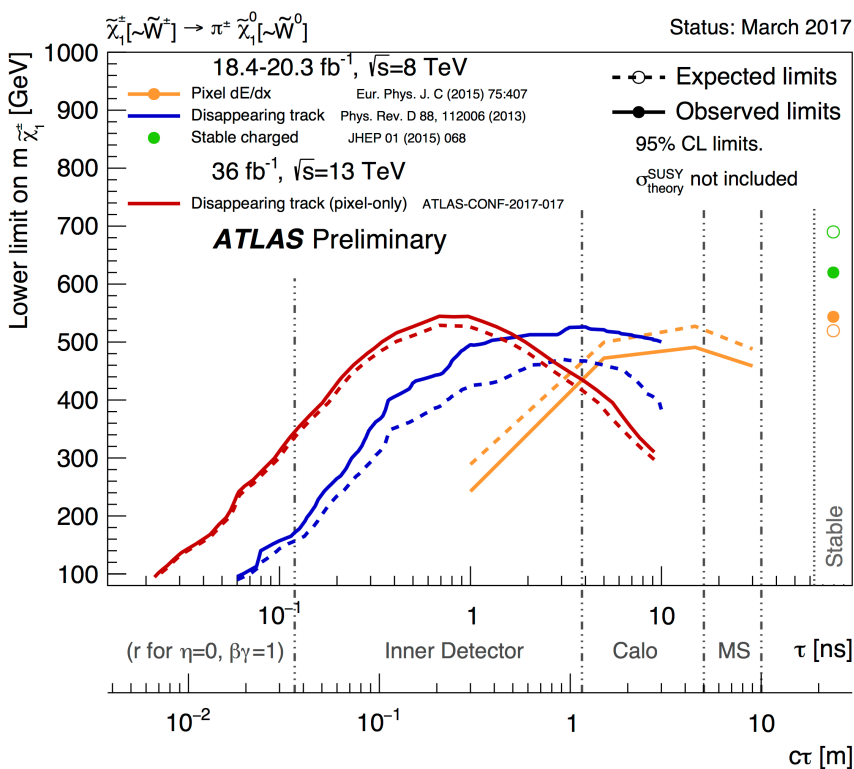
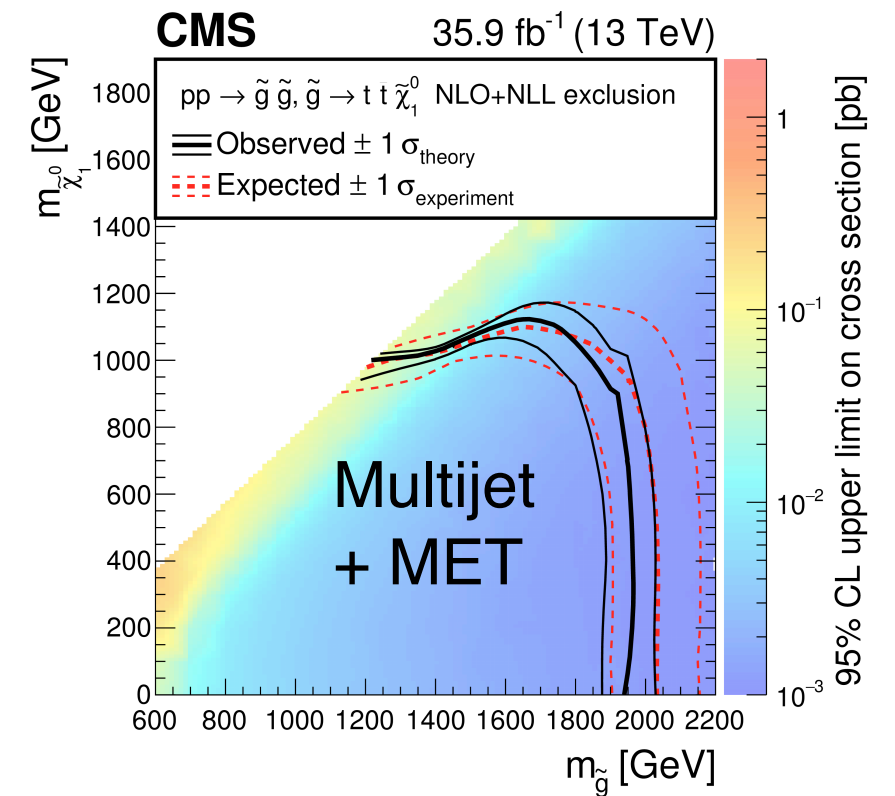
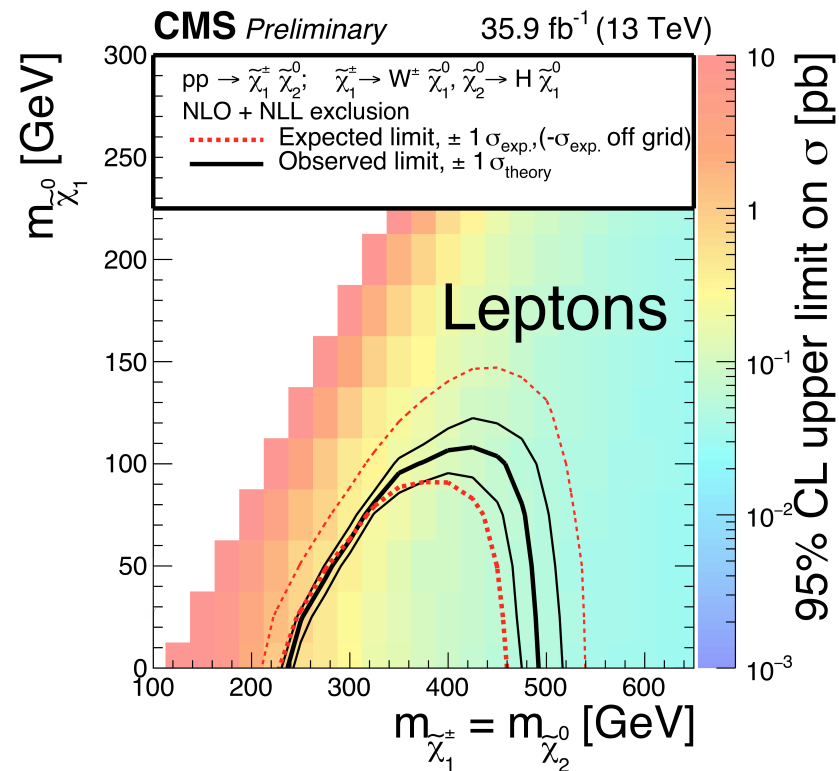
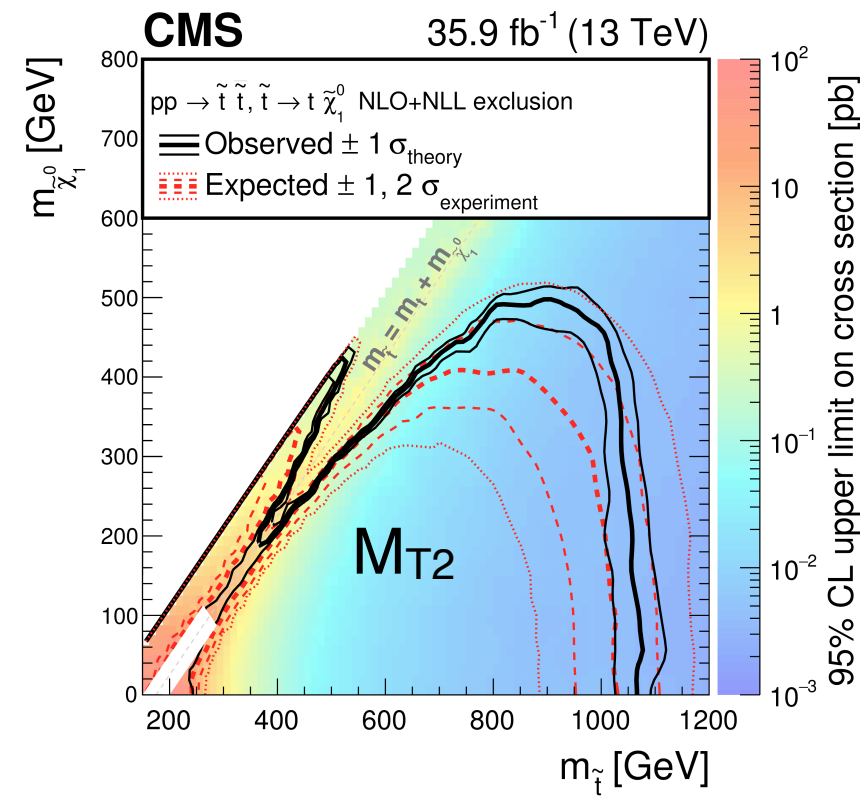
Gustaaf Brooijmans



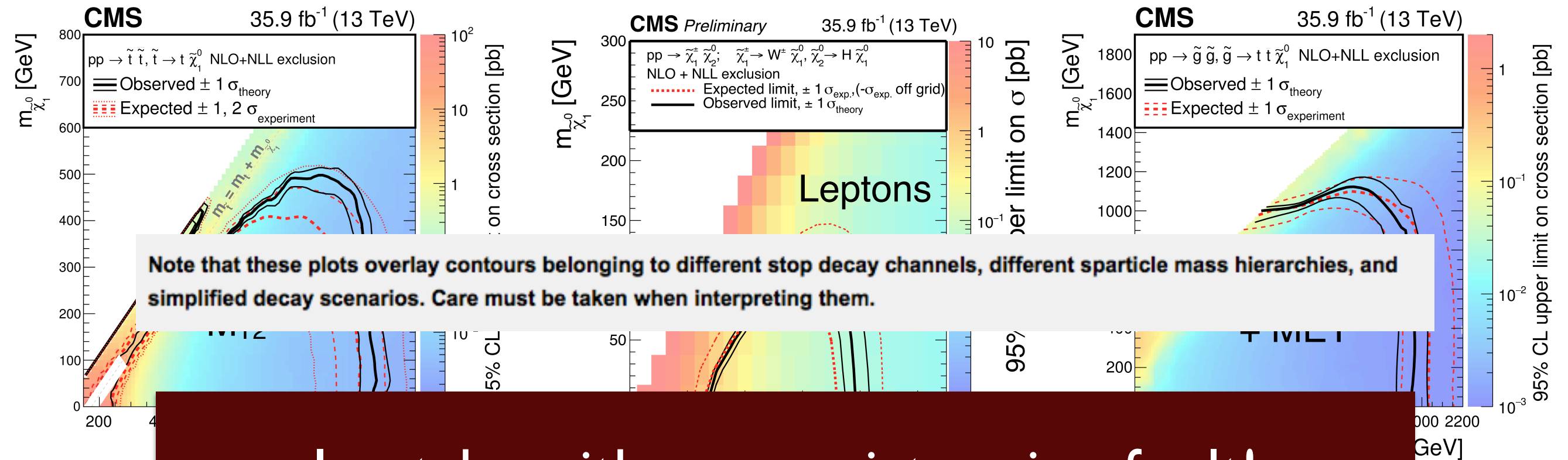
# Experimental Thoughts

- ❖ What's new?
  - ❖ LHC 13 TeV era underway
    - ❖  $\sim 36 \text{ fb}^{-1}$  so far, partially analyzed
      - ❖  $3 \text{ ab}^{-1}$  for full LHC run, too early to despair...
    - ❖ Another  $\sim 50 \text{ fb}^{-1}$  this year
    - ❖ Expect 120-150 (?)  $\text{fb}^{-1}$  from run 2
    - ❖ Start next long shutdown in 2019
  - ❖ Higgs exists, light
    - ❖ Naturalness: Increased focus on new physics closely linked to top, W, Z, i.e. producing top, W, Z ...
    - ❖ ... and Higgs
  - ❖ Strong limits in place
    - ❖ Natural to ask: did we miss it?

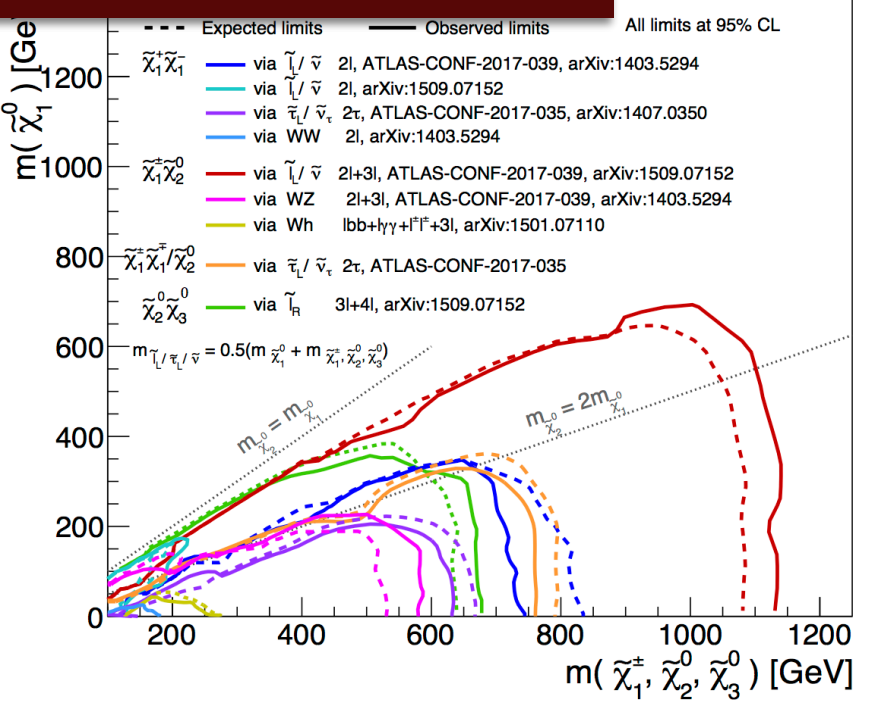
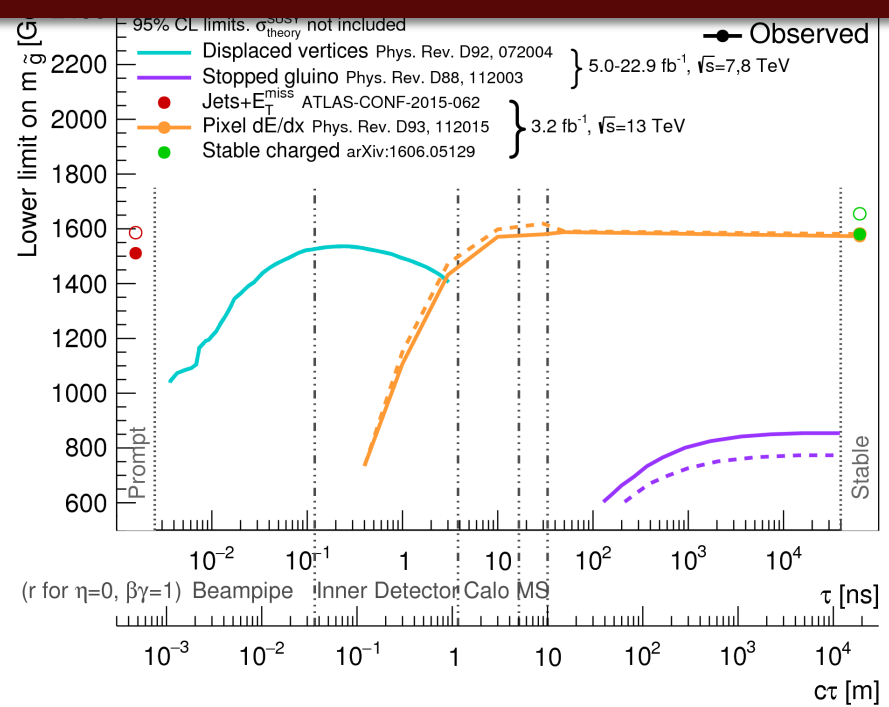
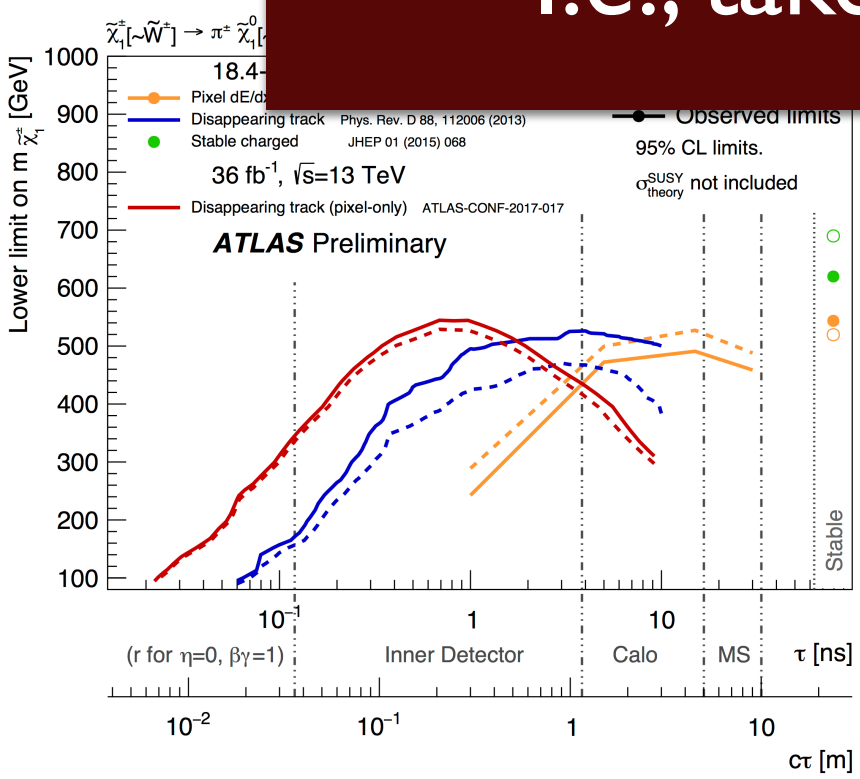
# Current Limits: With Dark Matter



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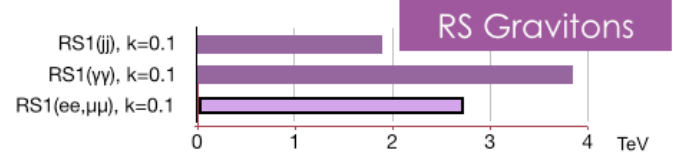
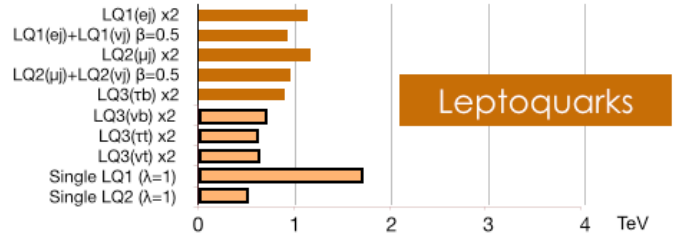
I.e., take with appropriate gain of salt!



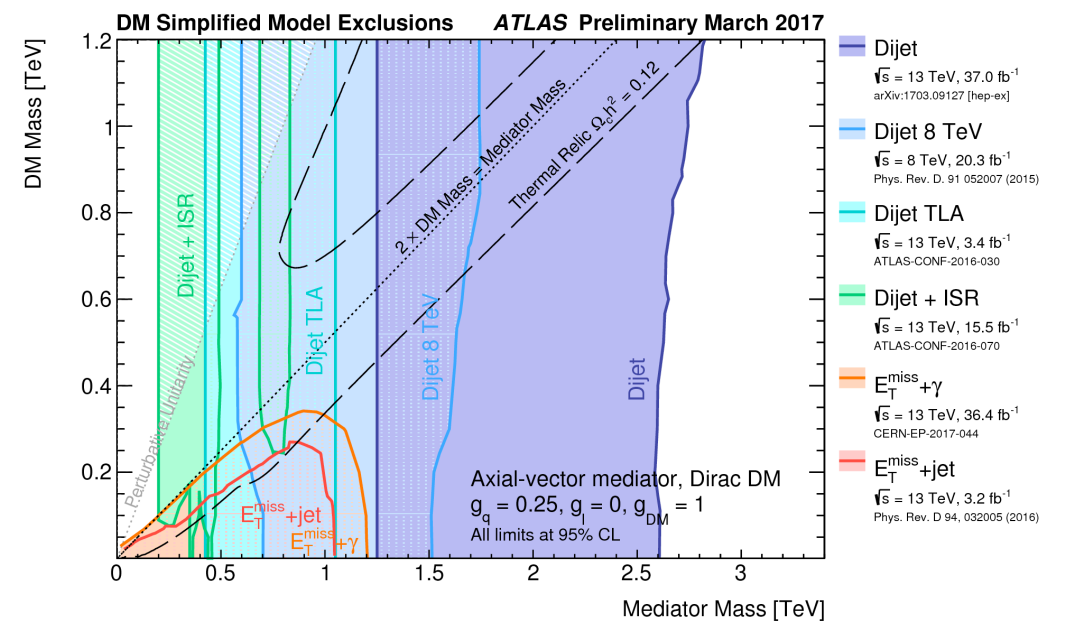
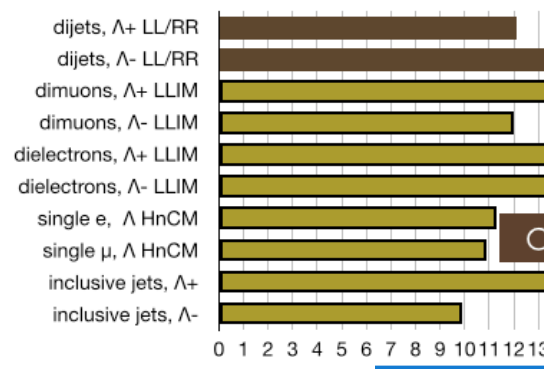
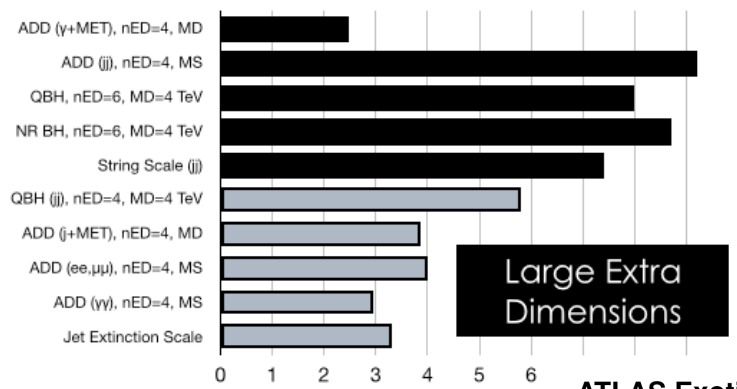
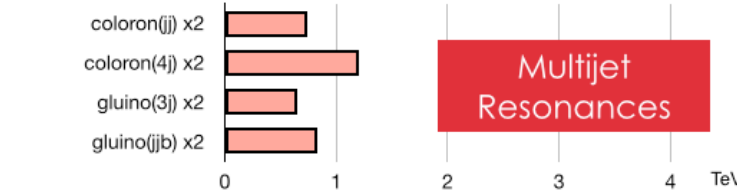
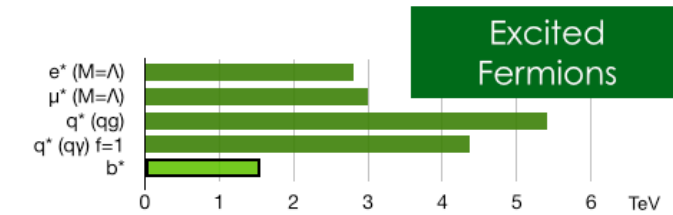
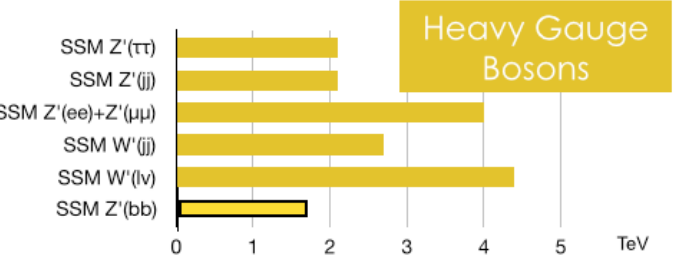


# Current Limits: Non-SUSY

13 TeV 8 TeV



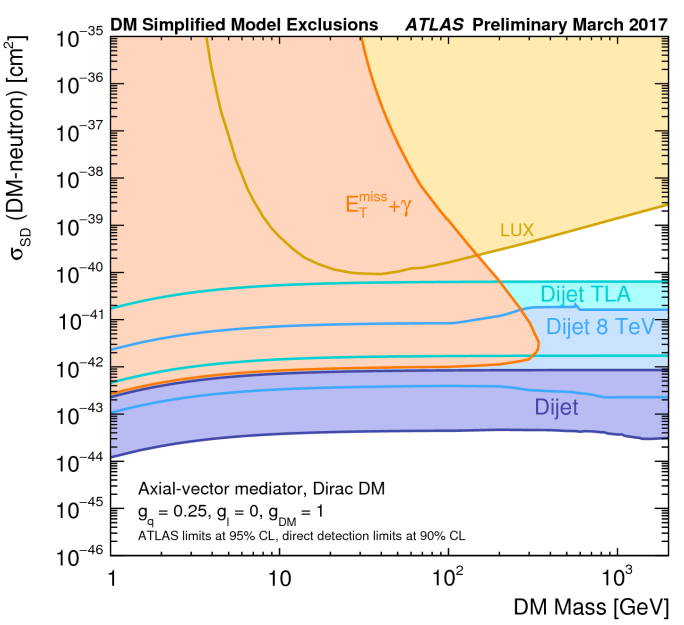
## CMS Preliminary



## ATLAS Exotics Searches - 95% CL Exclusion

Status: August 2016

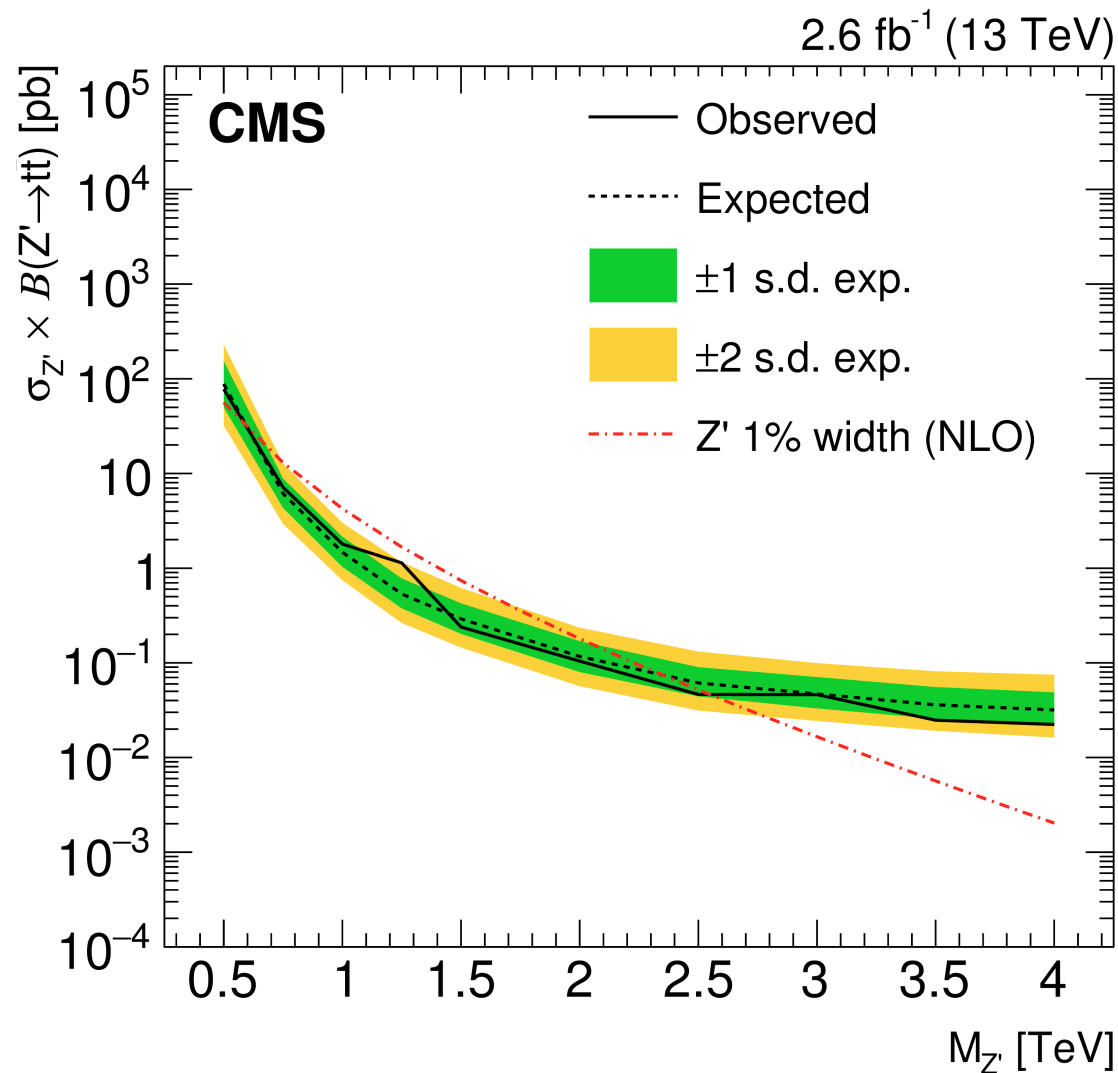
Model	$\ell, \gamma$	Jets $\dagger$	$E_T^{\text{miss}}$	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
Extra dimensions	ADD $G_{KK} + g/q$	-	$\geq 1j$	Yes	3.2	$M_0$ 6.58 TeV
	ADD non-resonant $\ell\ell$	$2e, \mu$	-	-	20.3	$M_s$ 4.7 TeV
	ADD QBH $\rightarrow \ell q$	$1e, \mu$	$1j$	-	20.3	$M_{th}$ 5.2 TeV
	ADD QBH	-	$2j$	-	15.7	$M_{th}$ 8.7 TeV
ADD BH high $\Sigma p_T$	$\geq 1e, \mu$	$\geq 2j$	-	3.2	$M_{th}$ 8.2 TeV	
ADD BH multijet	-	$\geq 3j$	-	3.6	$M_{th}$ 9.55 TeV	
RS1 $G_{KK} \rightarrow \ell\ell$	$2e, \mu$	-	-	20.3	$G_{KK}$ mass 2.68 TeV	
RS1 $G_{KK} \rightarrow \gamma\gamma$	$2\gamma$	-	-	3.2	$G_{KK}$ mass 3.2 TeV	
Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	$1e, \mu$	$1j$	Yes	13.2	$G_{KK}$ mass 1.24 TeV	
Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	-	$4b$	-	13.3	$G_{KK}$ mass 360-860 GeV	
Bulk RS $g_{KK} \rightarrow tt$	$1e, \mu$	$\geq 1b, \geq 1J/2j$	Yes	20.3	$G_{KK}$ mass 2.2 TeV	
2UED / RPP	$1e, \mu$	$\geq 2b, \geq 4j$	Yes	3.2	$KK$ mass 1.46 TeV	
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2e, \mu$	-	-	13.3	$Z'$ mass 4.05 TeV
	SSM $Z' \rightarrow \tau\tau$	$2\tau$	-	-	19.5	$Z'$ mass 2.02 TeV
	Leptophobic $Z' \rightarrow bb$	-	$2b$	-	3.2	$Z'$ mass 1.5 TeV
	SSM $W' \rightarrow \ell\nu$	$1e, \mu$	-	Yes	13.3	$W'$ mass 4.74 TeV
HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	$0e, \mu$	$1j$	Yes	13.2	$W'$ mass 2.4 TeV	
HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model B	-	$2j$	-	15.5	$W'$ mass 3.0 TeV	
HVT $V' \rightarrow WH/ZH$ model B	multi-channel	-	-	3.2	$V'$ mass 2.31 TeV	
LRSM $W'_R \rightarrow tb$	$1e, \mu$	$2b, 0-1j$	Yes	20.3	$W'_R$ mass 1.92 TeV	
LRSM $W'_R \rightarrow tb$	$0e, \mu$	$\geq 1b, 1j$	-	20.3	$W'_R$ mass 1.76 TeV	
CI	CI $qqqq$	-	$2j$	-	15.7	$A$ 19.9 TeV $\eta_{LL} = -1$
	CI $\ell\ell qq$	$2e, \mu$	-	-	3.2	$A$ 25.2 TeV $\eta_{LL} = -1$
	CI $uutt$	$2(SS) \geq 3e, \mu \geq 1b, \geq 1j$	Yes	20.3	$A$ 4.9 TeV $ C_{RR}  = 1$	
DM	Axial-vector mediator (Dirac DM)	$0e, \mu$	$\geq 1j$	Yes	3.2	$m_A$ 1.0 TeV $g_0=0.25, g_1=1.0, m(\chi) < 250 \text{ GeV}$
	Axial-vector mediator (Dirac DM)	$0e, \mu, 1\gamma$	$1j$	Yes	3.2	$m_A$ 710 GeV $g_0=0.25, g_1=1.0, m(\chi) < 150 \text{ GeV}$
	$ZZ\chi\chi$ EFT (Dirac DM)	$0e, \mu$	$1j, \leq 1j$	Yes	3.2	$M_s$ 550 GeV $m(\chi) < 150 \text{ GeV}$
LQ	Scalar LQ 1 <sup>st</sup> gen	$2e$	$\geq 2j$	-	3.2	LQ mass 1.1 TeV $\beta = 1$
	Scalar LQ 2 <sup>nd</sup> gen	$2\mu$	$\geq 1b, \geq 2j$	-	3.2	LQ mass 1.05 TeV $\beta = 1$
	Scalar LQ 3 <sup>rd</sup> gen	$1e, \mu$	$\geq 1b, \geq 3j$	Yes	20.3	LQ mass 640 GeV $\beta = 0$
Heavy quarks	VLQ $TT \rightarrow Ht + X$	$1e, \mu$	$\geq 2b, \geq 3j$	Yes	20.3	T mass 855 GeV
	VLQ $YY \rightarrow Wb + X$	$1e, \mu$	$\geq 1b, \geq 3j$	Yes	20.3	Y mass 770 GeV
	VLQ $BB \rightarrow Hb + X$	$1e, \mu$	$\geq 2b, \geq 3j$	Yes	20.3	B mass 735 GeV
	VLQ $BB \rightarrow Zb + X$	$2(\geq 3e, \mu)$	$\geq 2(\geq 1b)$	-	20.3	B mass 755 GeV
	VLQ $QQ \rightarrow WqWq$	$1e, \mu$	$\geq 4j$	Yes	20.3	Q mass 690 GeV
VLQ $T_{5/3} T_{5/3} \rightarrow WtWt$	$2(SS) \geq 3e, \mu \geq 1b, \geq 1j$	Yes	3.2	$T_{5/3}$ mass 990 GeV		
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	$1\gamma$	$1j$	-	3.2	$q^*$ mass 4.4 TeV
	Excited quark $q^* \rightarrow qg$	-	$2j$	-	15.7	$q^*$ mass 5.6 TeV
	Excited quark $b^* \rightarrow b\gamma$	-	$1b, 1j$	-	8.8	$b^*$ mass 2.3 TeV
	Excited quark $b^* \rightarrow Wt$	$1 \text{ or } 2e, \mu$	$1b, 2-0j$	Yes	20.3	$b^*$ mass 1.5 TeV
	Excited lepton $\ell^*$	$3e, \mu$	-	-	20.3	$\ell^*$ mass 3.0 TeV
Excited lepton $\nu^*$	$3e, \mu, \tau$	-	-	20.3	$\nu^*$ mass 1.6 TeV	
Other	LSTC $a_T \rightarrow W\gamma$	$1e, \mu, 1\gamma$	-	Yes	20.3	$a_T$ mass 960 GeV
	LRSM Majorana $\nu$	$2e, \mu$	$2j$	-	20.3	$N^0$ mass 2.0 TeV
	Higgs triplet $H^{\pm\pm} \rightarrow ee$	$2e$ (SS)	-	-	13.9	$H^{\pm\pm}$ mass 570 GeV
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3e, \mu, \tau$	-	-	20.3	$H^{\pm\pm}$ mass 400 GeV
	Monotop (non-res prod)	$1e, \mu$	$1b$	Yes	20.3	spin-1 invisible particle mass 657 GeV
	Multi-charged particles	-	-	-	20.3	multi-charged particle mass 785 GeV
	Magnetic monopoles	-	-	-	7.0	monopole mass 1.34 TeV
						$m(W_R) = 2.4 \text{ TeV}$ , no mixing
						DY production, $BR(H^{\pm\pm} \rightarrow ee)=1$
						DY production, $BR(H^{\pm\pm} \rightarrow \ell\tau)=1$



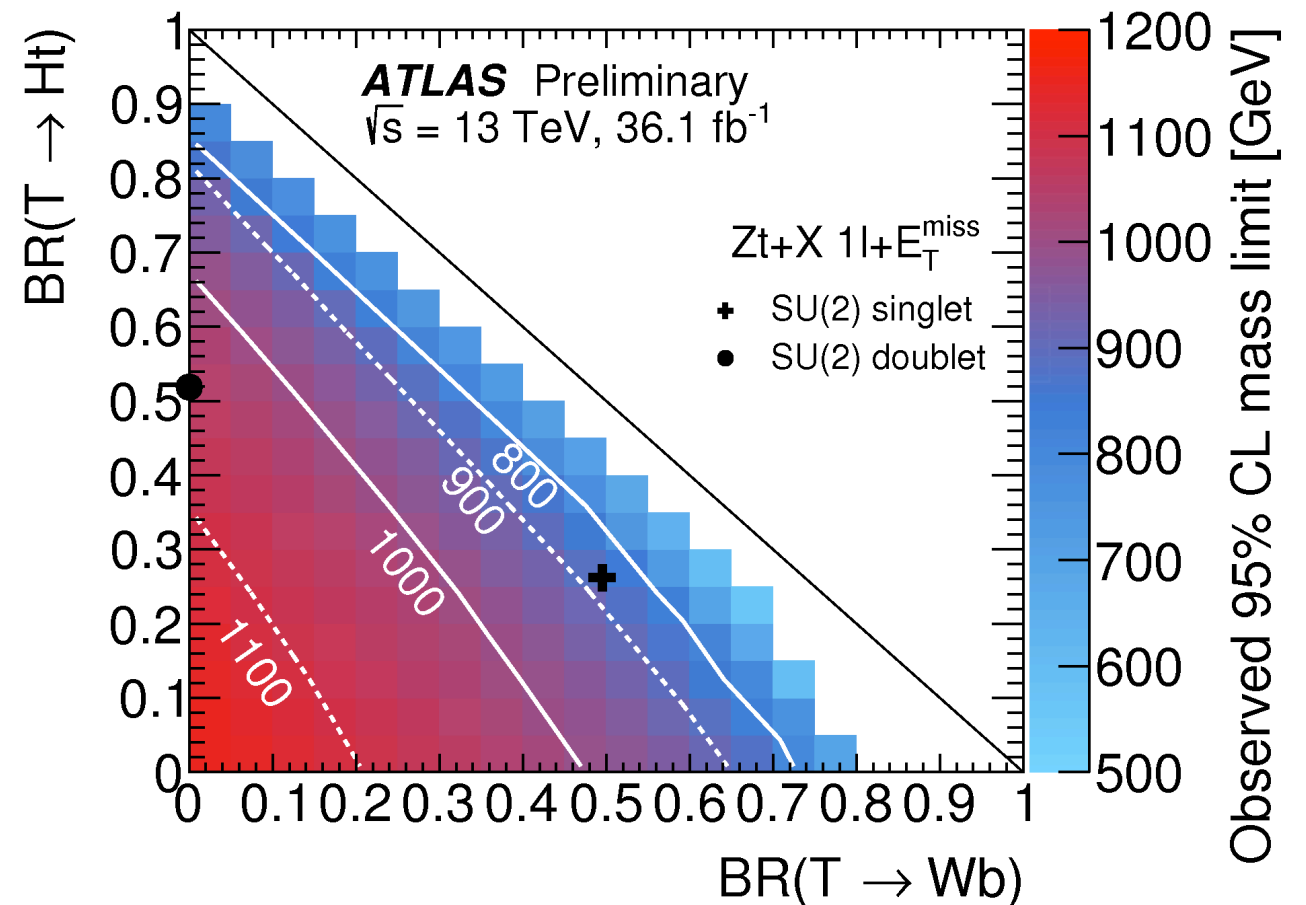
\*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.  
 †Small-radius (large-radius) jets are denoted by the letter j (J).

# Current Limits: 3<sup>rd</sup> Generation

No New Summary Plots...



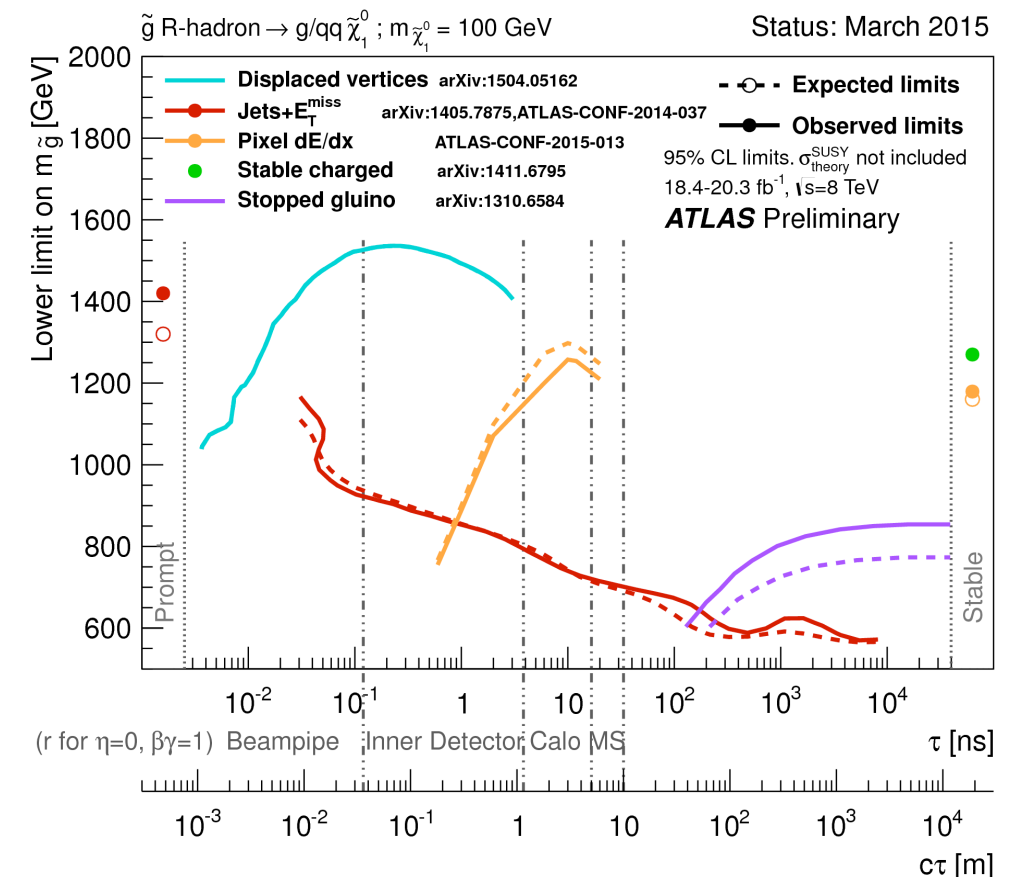
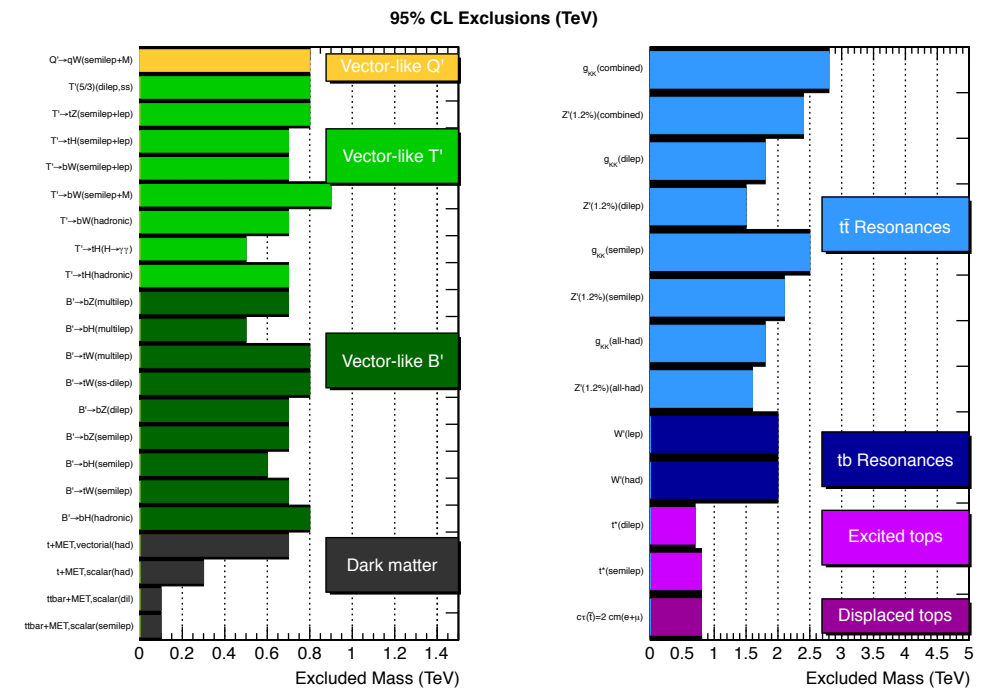
Even here, grain of salt appropriate:  
E.g. tt resonance at 380 GeV viable  
even with substantial coupling



# Top-Down vs Bottom-Up

- ❖ Theory: model  $\Rightarrow$  signatures
- ❖ Experiment: signature  $\Rightarrow$  discovery (or limit)
- ❖ Resonant?
  - ❖ Many many things done, still gaps though...
- ❖ Dark matter in the decay chains?
  - ❖ Novel signatures from complex dark matter
- ❖ (Semi-)long-lived?
  - ❖ Can gaps be addressed?
- ❖ Are we missing something?

CMS Searches for New Physics Beyond Two Generations (B2G)



# Experimenters at Les Houches

- ❖ Profit from many discussions with theorists - learn
- ❖ Help theorists understand what is (not) possible
  - ❖ Particularly important to fill “gaps”
    - ❖ What can we trigger on?
    - ❖ How soft a lepton can we tag with low background?
    - ❖ The realities of hadronic calorimetry
    - ❖ Experimental uncertainties
    - ❖ ...
  - ❖ Can we get around these limitations by being smart?



- ❖ Collaborate (with theorists) on studying sensitivity to new approaches/signatures
  - ❖ Enough theorists here to generate 1000(s) years of experimental work
    - ❖ Be selective
  - ❖ Remember that publication in proceedings (important!) requires the use of generic tools, e.g. Delphes (which are also faster)
    - ❖ Approval of MC studies using ATLAS/CMS tools will be difficult
    - ❖ Similarly, do not discuss non-approved work/results

# Organizationally

- ❖ Conveners try to facilitate interactions
  - ❖ “Group” people with similar interests
    - ❖ Subgroups will coalesce in next few days
  - ❖ Wiki!
- ❖ ... but encourage participation well beyond primary topic of interest during stay in Les Houches
  - ❖ Exchange of ideas, brainstorming are key to making this productive
    - ❖ Ideas developed in one context often valuable in another
- ❖ No talks scheduled; favor black-board discussions (leave time to get some work started though)
  - ❖ Do project plots
  - ❖ Work towards write-ups continues after our stay