Interpretations for the tth excess without an enhanced tth

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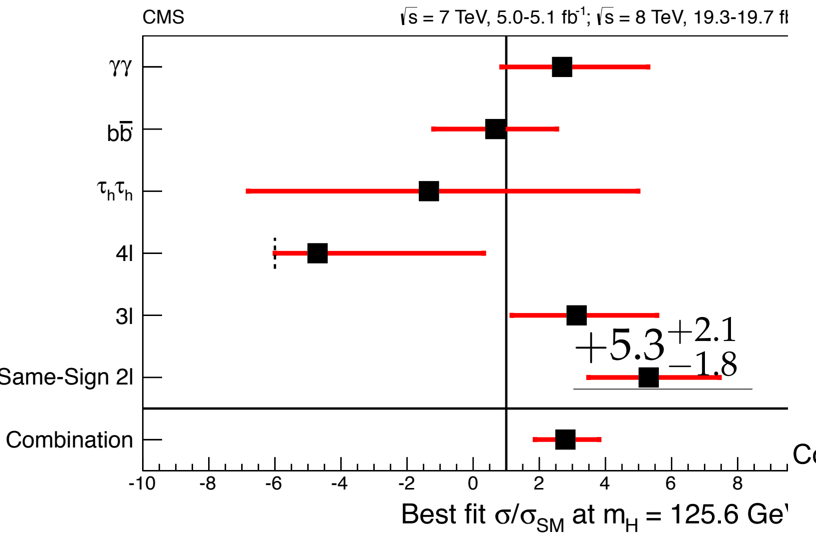
Work with A. Ismail, I. Low, C. Wagner, 1507.01601

New Physics Interpretations at the LHC workshop

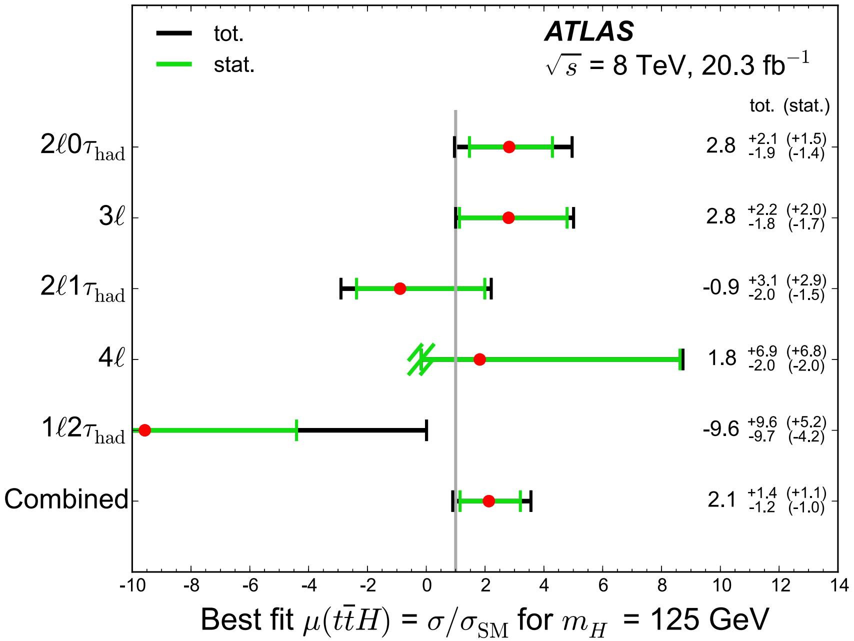
Argonne National Laboratory, 05/03/2016

What have seen at both experiments and both runs?

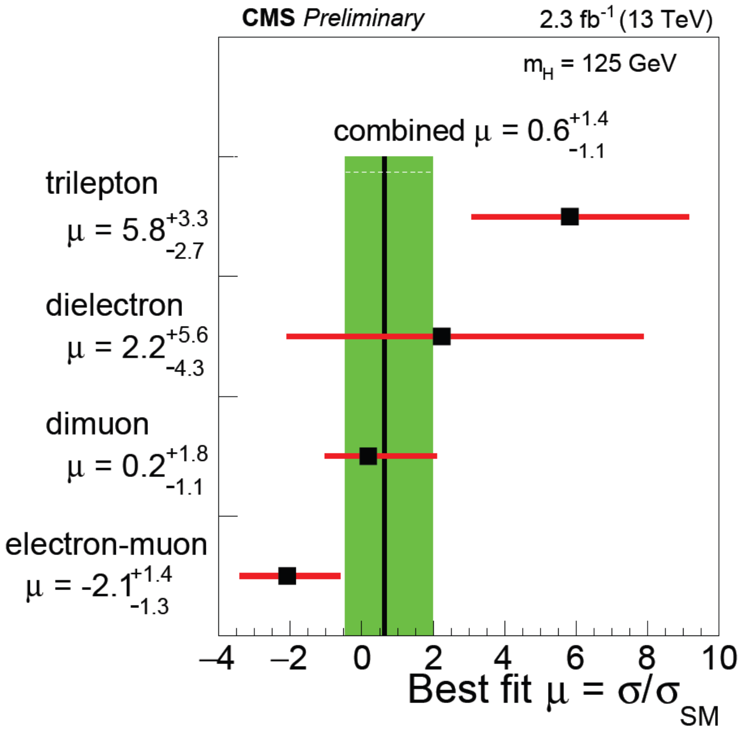
ttH, H->W+W-



CMS 1408.1682, local significance 2.6σ



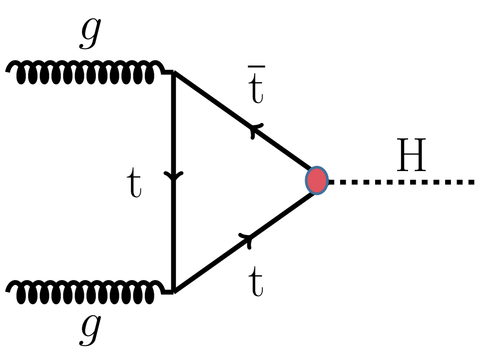
ATLAS 1506.05988

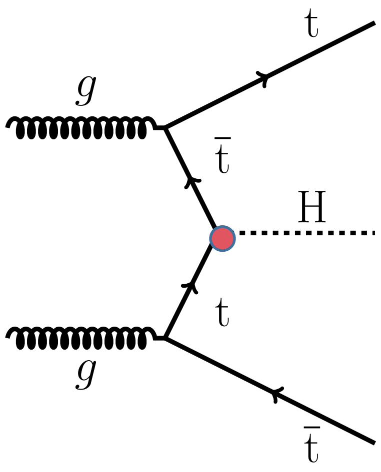


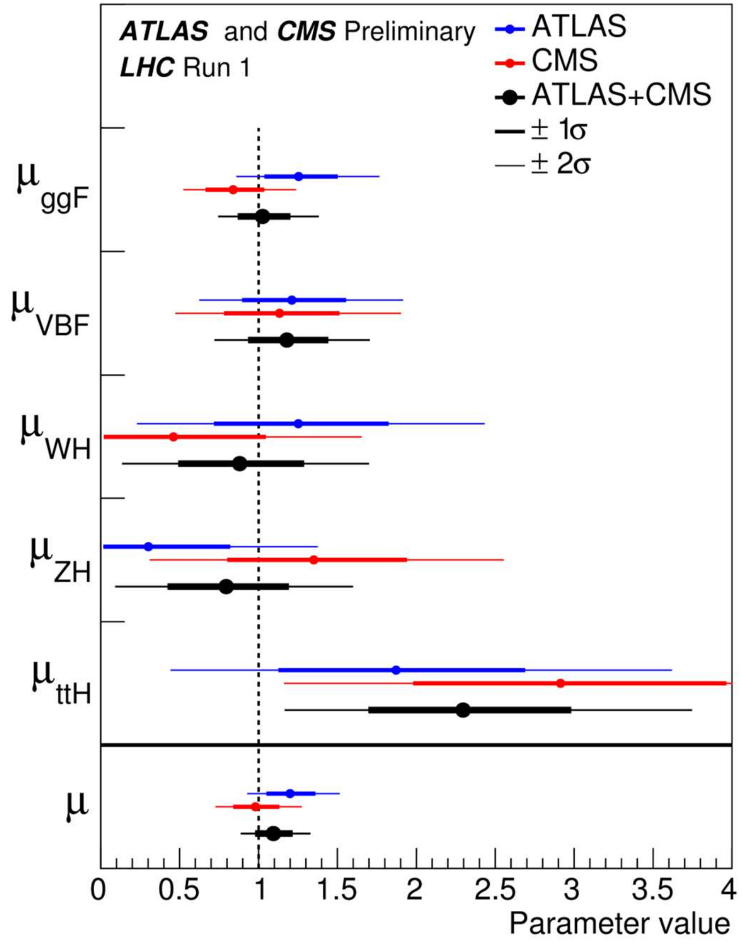
J. Hauk, Moriond EW 2016

What does it mean that ttH is high?

SM+A larger top Yukawa?



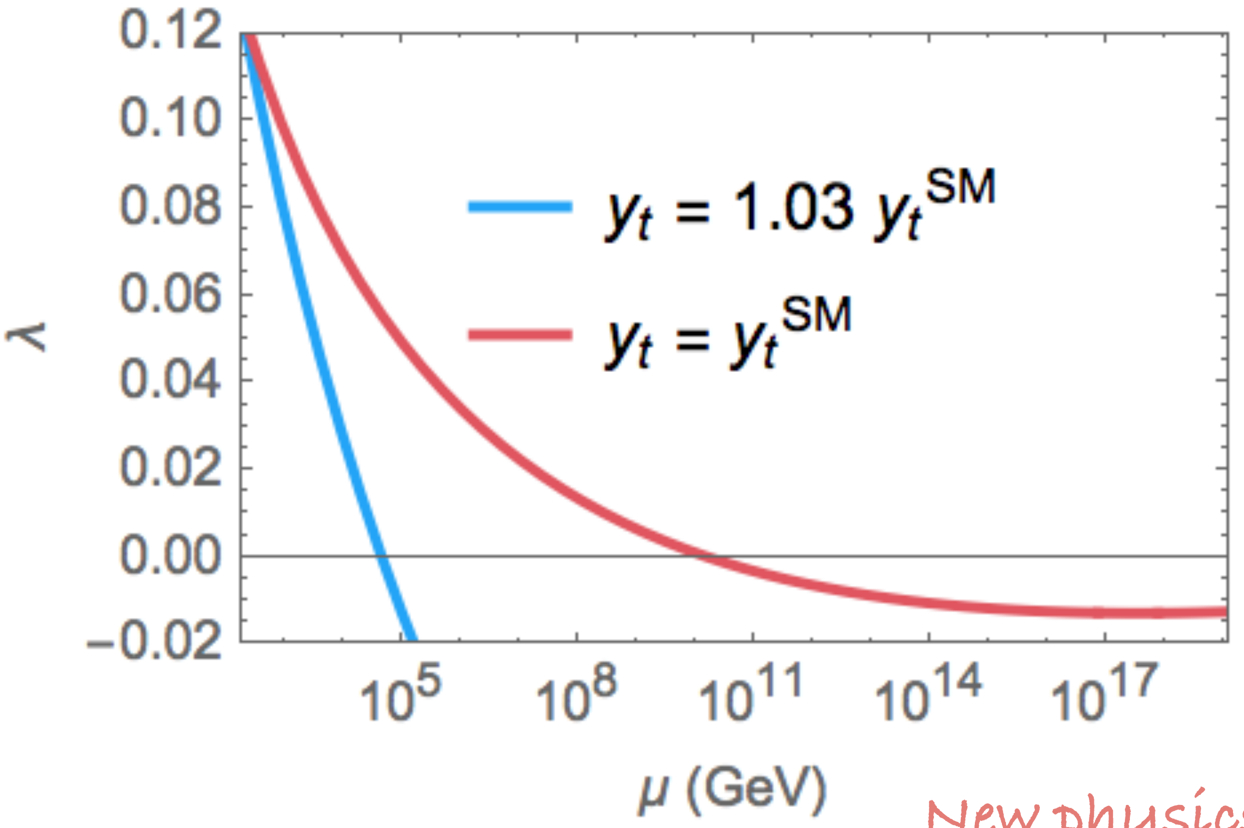




Would expect gluon fusion to be high as well

A large Yukawa coupling is very dangerous

$$16\pi^2 \frac{d\lambda}{d\ln\mu} = 24\lambda^2 + 12\lambda y_t^2 - 9\lambda(g^2 + \frac{1}{3}g'^2) - 6y_t^4 + \frac{9}{8}g^4 + \frac{3}{8}g'^4 + \frac{3}{4}g^2 g'^2$$



A small perturbation in the top Yukawa would completely change the fate of our universe.

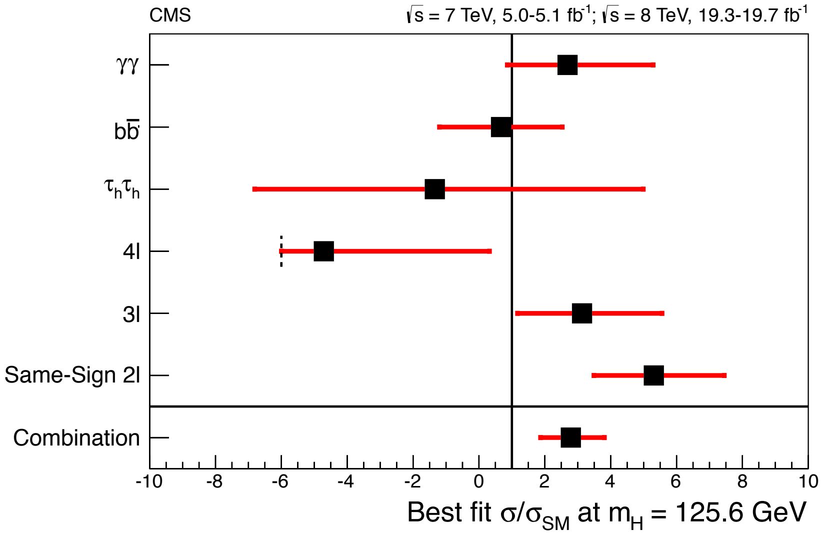
$y_t > 1.00045 y_t^{SM}$, the life time of our vacuum is smaller than the age of the universe.

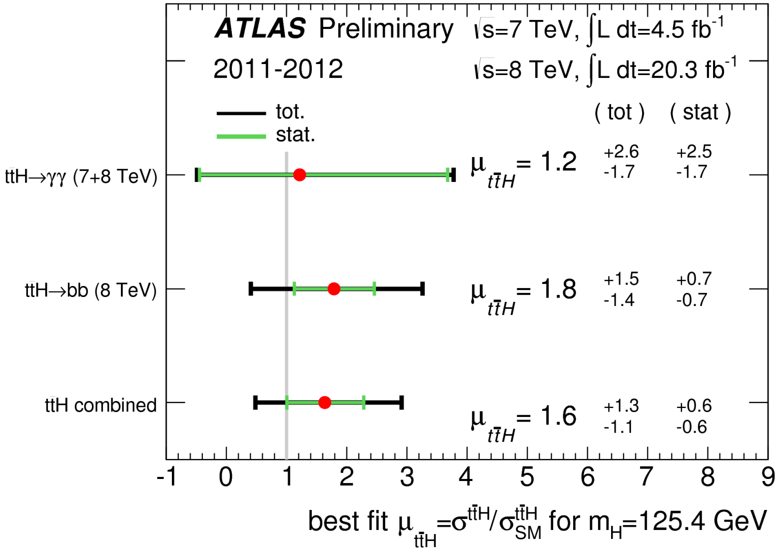
Bezrukov, Shaposhnikov

New physics for an enhanced tth, see M. Badziak's talk

Before worrying about the fate of our universe

If combine all channels in tth searches,





The excess became less significant, or the signal strength is more SM-like

What we call a tth search may have nothing to do with tth

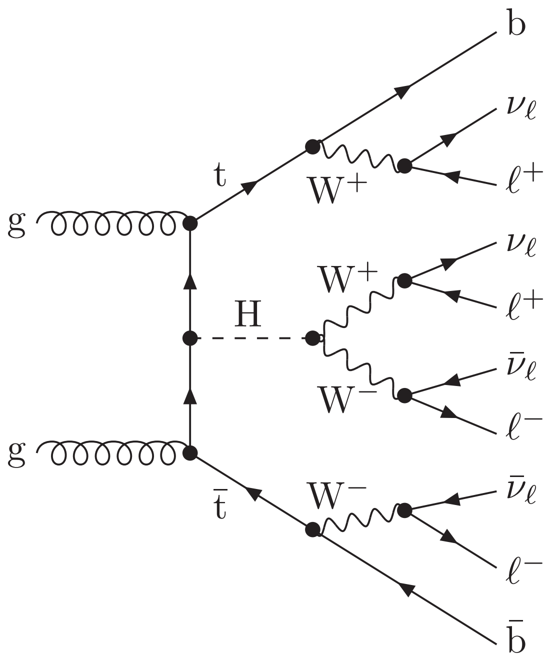
What are we seeing exactly?

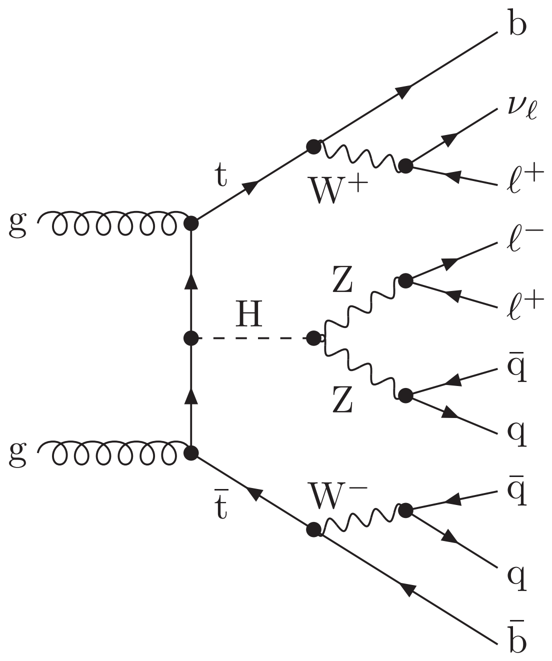
tth, h->W^+W^-

It is really a search for 2t + 2W, or equivalently 2b+4W final states

2b + 4W gives rise to the multi-lepton + multi-(b)jets + MET signatures

tth, h->W+W- is really not about tth, but about new physics!





ATLAS&CMS SUSY SS2L Search

	SR3b	SR0b	SR1b	SR3Llow	SR3Lhigh
Observed events	1	14	10	6	2
Total expected background events	2.2 ± 0.8	6.5 ± 2.3	4.7 ± 2.1	4.3 ± 2.1	2.5 ± 0.9
$p(s=0)$	0.50	0.03	0.07	0.29	0.50

SR	Leptons	$N_{b-\text{jets}}$	Other variables	Additional requirement on m_{eff}
SR3b	SS or 3L	≥ 3	$N_{\text{jets}} \geq 5$	$m_{\text{eff}} > 350$ GeV
SR0b	SS	$= 0$	$N_{\text{jets}} \geq 3$, $E_{\text{T}}^{\text{miss}} > 150$ GeV, $m_{\text{T}} > 100$ GeV	$m_{\text{eff}} > 400$ GeV
SR1b	SS	≥ 1	$N_{\text{jets}} \geq 3$, $E_{\text{T}}^{\text{miss}} > 150$ GeV, $m_{\text{T}} > 100$ GeV, SR3b veto	$m_{\text{eff}} > 700$ GeV

1404.2500

CMS, in the >=2 bjets, H_T > 400 GeV, 50 GeV < MET < 120 GeV region, 7.2 expected, 18 observed

ATLAS vector-like quark searches

	SRVLQ5/SR4t2	SRVLQ6/SR4t3	SRVLQ7/SR4t4
$t\bar{t}W/Z$	$1.87 \pm 0.09 \pm 0.80$	$2.46 \pm 0.11 \pm 1.06$	$0.57 \pm 0.05 \pm 0.25$
$t\bar{t}H$	$0.31 \pm 0.04 \pm 0.05$	$0.44 \pm 0.04 \pm 0.06$	$0.08 \pm 0.02 \pm 0.02$
Dibosons	$0.33 \pm 0.14 \pm 0.10$	$0.04 \pm 0.12 \pm 0.03$	$0.00 \pm 0.12 \pm 0.00$
Fake/Non-prompt	$1.03 \pm 0.97 \pm 0.60$	$0.00 \pm 1.02 \pm 0.28$	$0.04 \pm 0.83 \pm 0.24$
Q mis-Id	$1.17 \pm 0.16 \pm 0.38$	$1.09 \pm 0.14 \pm 0.34$	$0.30 \pm 0.09 \pm 0.10$
Other bkg.	$0.16 \pm 0.08 \pm 0.02$	$0.23 \pm 0.08 \pm 0.05$	$0.14 \pm 0.08 \pm 0.08$
Total bkg.	$4.9 \pm 1.0 \pm 1.0$	$4.3 \pm 1.1 \pm 1.1$	$1.1 \pm 0.9 \pm 0.4$
Data	6	12	6
p-value	0.46	0.029	0.036

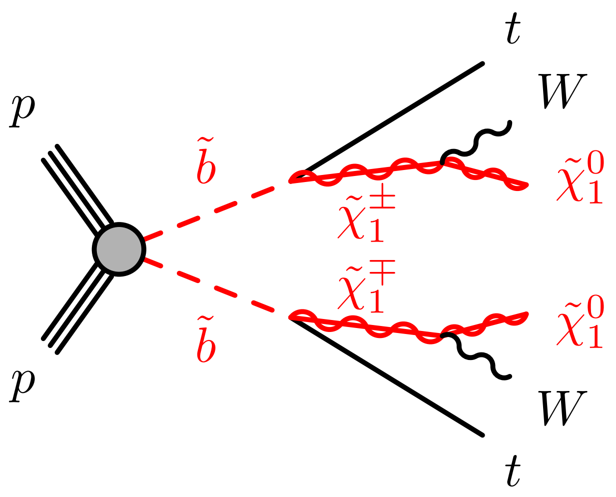
Definition			Name	
$e^{\pm}e^{\pm} + e^{\pm}\mu^{\pm} + \mu^{\pm}\mu^{\pm} + eee + ee\mu + e\mu\mu + \mu\mu\mu$, $N_j \geq 2$				
$400 < H_{\mathrm{T}} < 700$ GeV	$N_b = 1$	$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV	SRVLQ0	
	$N_b = 2$		SRVLQ1	SR4t0
	$N_b \geq 3$		SRVLQ2	SR4t1
$H_{\mathrm{T}} \geq 700$ GeV	$N_b = 1$	$40 < E_{\mathrm{T}}^{\mathrm{miss}} < 100$ GeV	SRVLQ3	
		$E_{\mathrm{T}}^{\mathrm{miss}} \geq 100$ GeV	SRVLQ4	
	$N_b = 2$	$40 < E_{\mathrm{T}}^{\mathrm{miss}} < 100$ GeV	SRVLQ5	SR4t2
		$E_{\mathrm{T}}^{\mathrm{miss}} \geq 100$ GeV	SRVLQ6	SR4t3
	$N_b \geq 3$	$E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV	SRVLQ7	SR4t4

Excess in 6 searches!

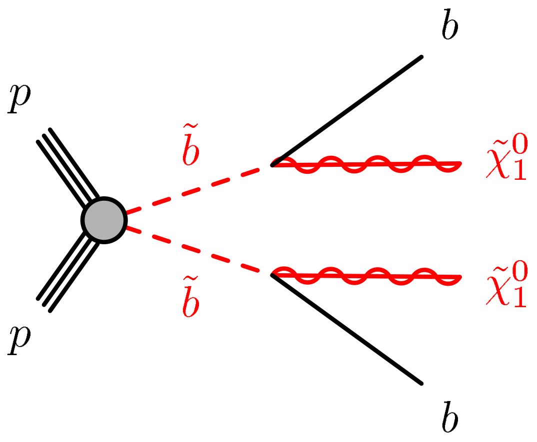
- Six different analyses looking at multilepton + b-jets + MET all see excesses with varying degrees of significance (2 from CMS run-I, 1 from CMS run-II, 3 from ATLAS run-I)
- These analyses looked at three independent data sets, with different background subtraction methods
- Including
  - SUSY SS2l, ATLAS + CMS
  - tth search, CMS Run-I and Run II, ATLAS Run-I
  - Vector-like quark search ATLAS

When you see excesses in multi-lepton + b-jets + MET

2b + 4W final states,
exactly what you
would do when you
search for sbottoms

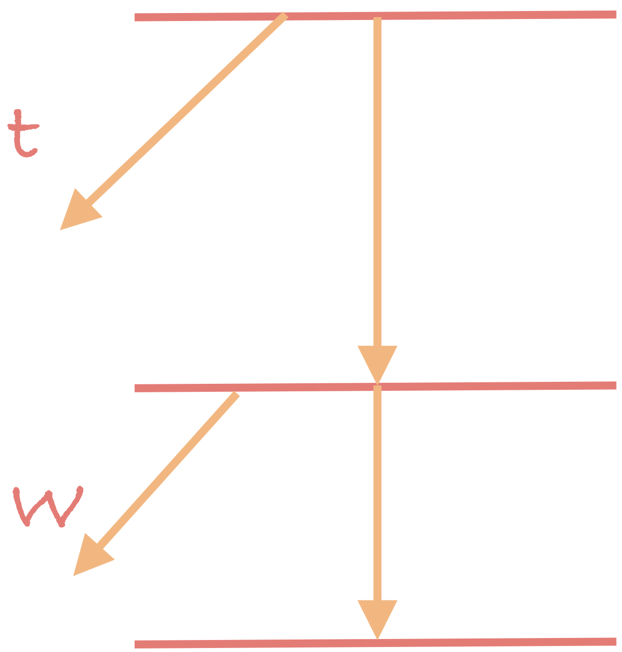


A little complicated,
can not have 100%
Branching Ratio



1506.08616, ATLAS third generation squark searches

Just an example, a right-handed stop



Stops are pair produced, 2t + 2W

$$\tilde{t}_1 = \tilde{t}_R \; ;$$

A pure right-handed stop does not couple to winos, 100% BR

$$\tilde{\chi}_2^0 = \tilde{B} \; ;$$

$$\tilde{\chi}_1^\pm = \tilde{W}^\pm; \;\; \tilde{\chi}_1^0 = \tilde{W}^0;$$

The neutralino mass difference is smaller than the Higgs mass, 100% BR

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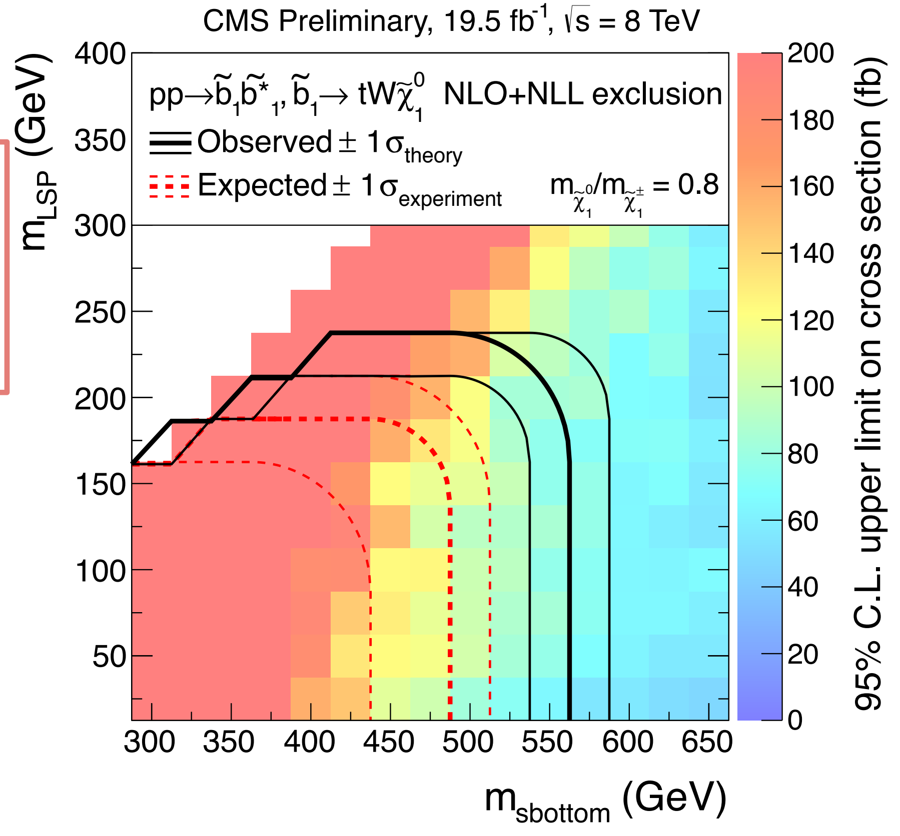
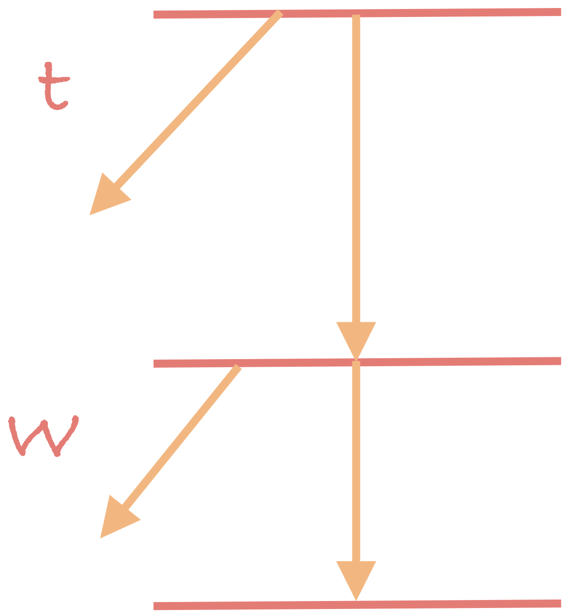
More on the spectrum

Follow the CMS tth analysis, normalize the signal strength to the SM tth

Bounds disappear once the LSP is heavier than 240 GeV





$\tilde{t}_1 = \tilde{t}_R$;

550 GeV, a signal strength for ss2l~ 2.83

$\tilde{\chi}^0_2 = \tilde{B}$;

No decay through a higgs
< 260 + 125, call it 340 GeV

$\tilde{\chi}^\pm_1 = \tilde{W}^\pm$; $\tilde{\chi}^0_1 = \tilde{W}^0$;

260 GeV

$$\text{ATLAS} : \mu = 2.8^{+2.1}_{-1.9}$$

$$\text{CMS} : \mu = 5.3^{+2.1}_{-1.8}$$

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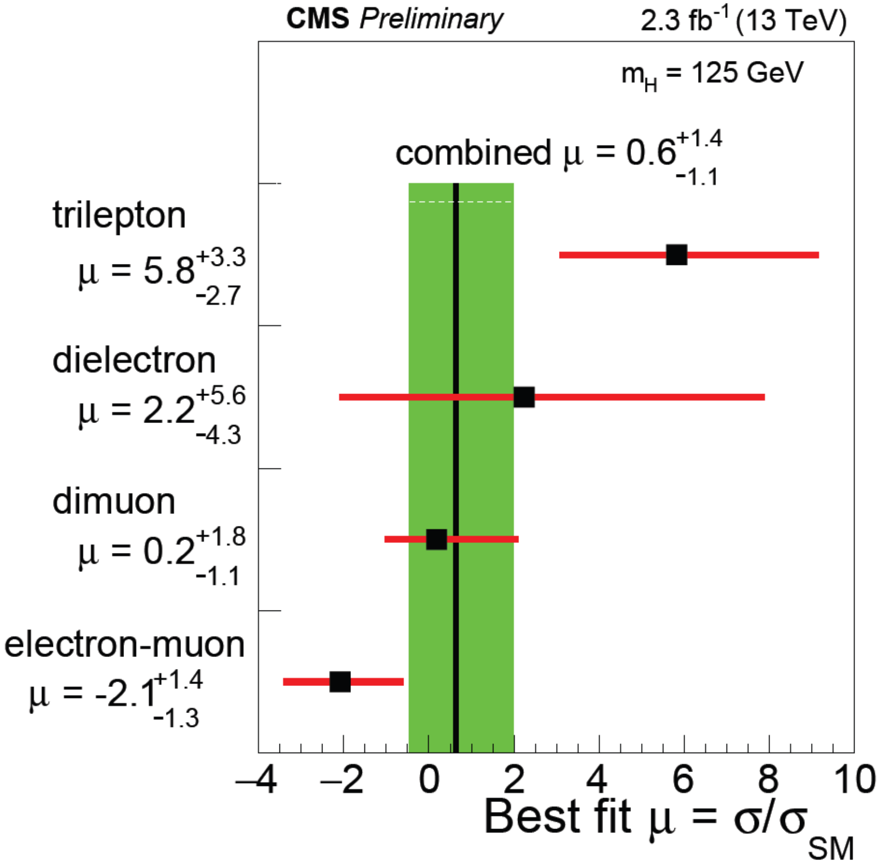
13 TeV



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ATLAS SUSY SS2L

Signal region	$N_{\text{lept}}^{\text{signal}}$	$N_{b-\text{jets}}^{20}$	N_{jets}^{50}	E_T^{miss} [GeV]	m_{eff} [GeV]
SR0b3j	≥3	=0	≥3	>200	>550
SR0b5j	≥2	=0	≥5	>125	>650
SR1b	≥2	≥1	≥4	>150	>550

	SR0b3j	SR0b5j	SR1b
Observed events	3	3	7
Total background events	1.5 ± 0.4	0.88 ± 0.29	4.5 ± 1.0
$p(s = 0)$	0.13	0.04	0.15

1602.09058

What to expect with more data at 13 TeV?

	σ(8 TeV)	σ(13 TeV)	Ratio(13 TeV/8 TeV)
$\sigma(pp \to \mathrm{ttH})$	129 fb	509 fb	3.9
$\sigma(pp \to \tilde{t}_1 \tilde{t}_1^*)$	45 fb	296 fb	6.6

Expect a signal strength ~ 3.69 at 13 TeV

Enhance the signal strength? / tell stops from tth?

More missing energy from stop than tth

In the stop events, b-jets are more centrally produced, while the b-jets from ttH tend to be more forward, from the t-channel kinematics.

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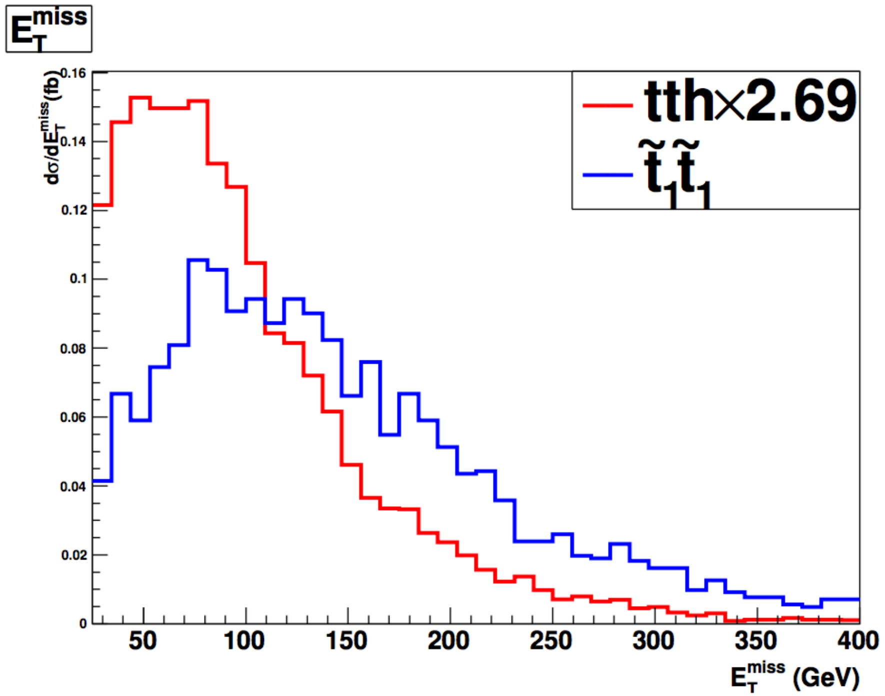
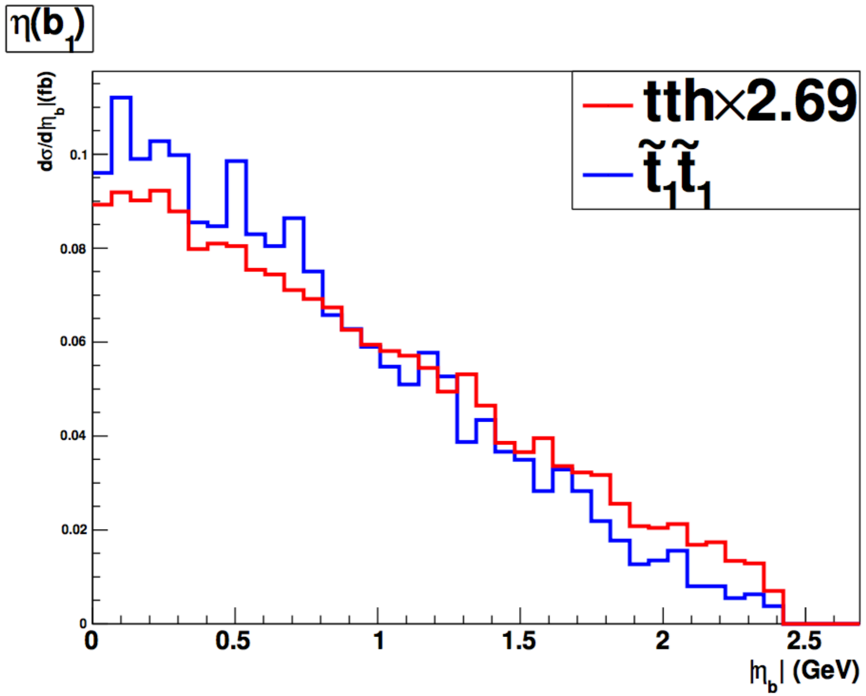
Enhance the signal strength





Change the MET cut from MET > 25 GeV to MET > 125 GeV

Change the $|\eta_b|$ cut from $|\eta_b| < 2.4$ to $|\eta_b| < 1.0$

μ (13 TeV) ~ 6.94

reach 5 σ with about 40 fb^{-1}

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Other signatures

Charged winos: disappearing tracks

For a 260 GeV pure wino, the mass splitting between the neutral wino and the charge wino $\sim$ 160 MeV (about the CMS limit)

A small amount of the higgsino mixing, would significantly increase the mass splitting

A 1 TeV Higgsino, the mass splitting is $\sim$ 240 MeV

Same Sign trilepton

$$\tilde{t}_R \to t + \tilde{B} \to t + (\tilde{W}^{\pm} + W^{\mp})$$

- Ws from the Bino decay are charge symmetric
- Expect same sign trileptons
- With 40 fb^{-1}, expect about 5 same sign trilepton events

Conclusion

- Moderate excesses in various searches in the multi-lepton + b-jets + MET channel at Run-I by both ATLAS and CMS
- Those excesses are hinted at Run-II as well.
- Should NOT be interpreted only in the context of tth
- While waiting for the discovery of a completely unexpected friend(the 750 GeV friend), it is worth thinking of welcoming an old friend (stop) in expected(SUSY searches) and completely unexpected ways(tth).