Recent stop search in the Natural SUSY

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Based on:
arXiv:1609.02361, with J. Ren, L. Wu, J. M. Yang and M. Zhang
arXiv:1609.09303, with M. M. Nojiri, M. Takeuchi and T. T. Yanagida

The 6th KIAS Workshop on Particle Physics and Cosmology
and 2nd Durham-KEK-KIPMU-KIAS Joint Workshop

Outline

- Brief introduction and motivation
- Status of stop in Natural SUSY
- ATLAS 1-lepton excess in Natural SUSY
- Summary and conclusion

The status of LHC

- 13fb-1 luminosity data disclosed at the 13 TeV LHC. (Maybe accumulated 25 fb-1 up to now)
- No evidence of new particles (sadly, 750 GeV di-photon excess disappears)
- Fortunately, Higgs is still there.
- What is the next?

Naturalness say:
New particles might exist at TeV scale!

A natural SUSY model

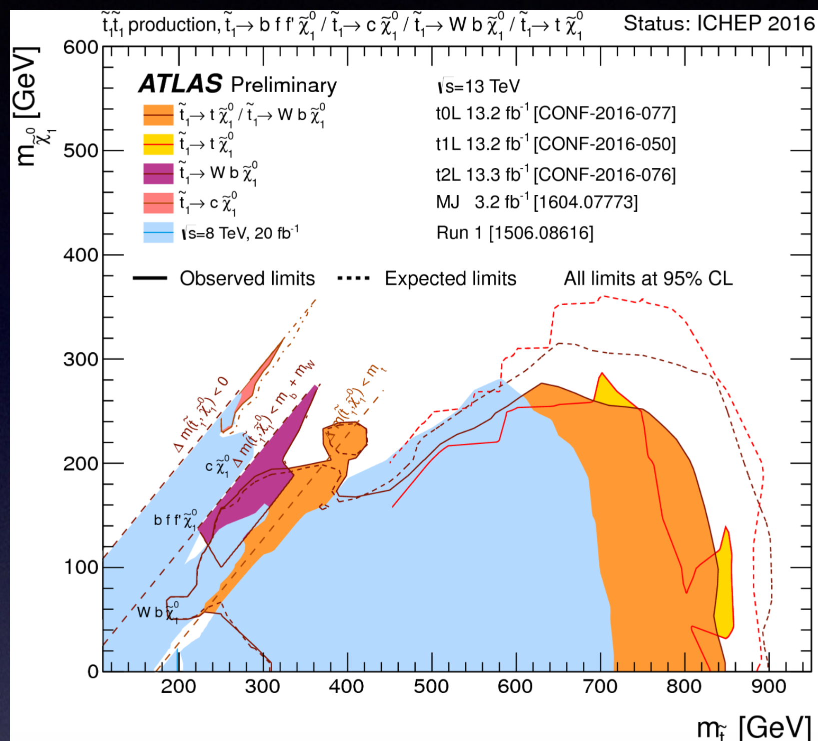
From the minimization of the Higgs potential:

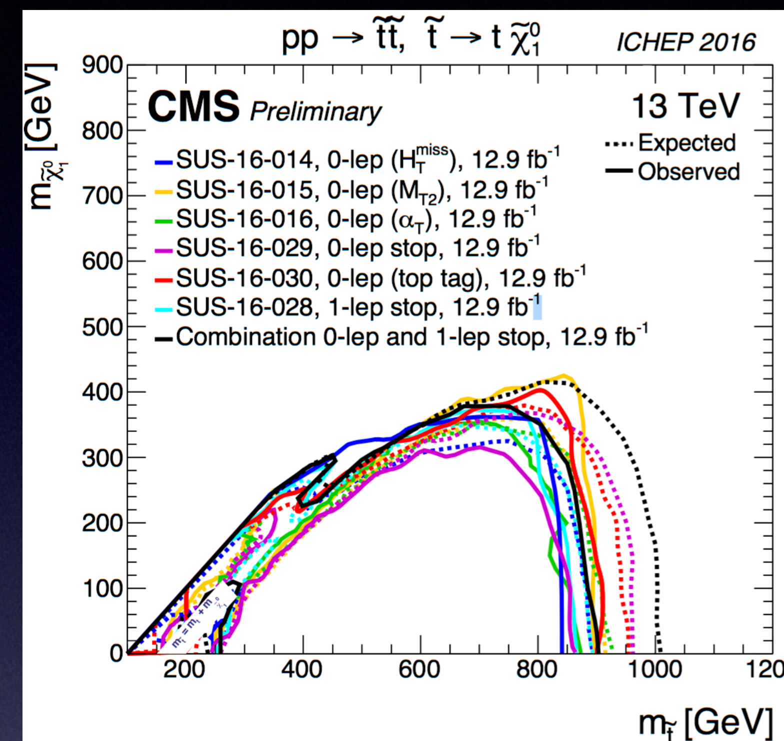
$$\frac{M_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d) - (m_{H_u}^2 + \Sigma_u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2$$
$$\simeq -(m_{H_u}^2 + \Sigma_u) - \mu^2,$$

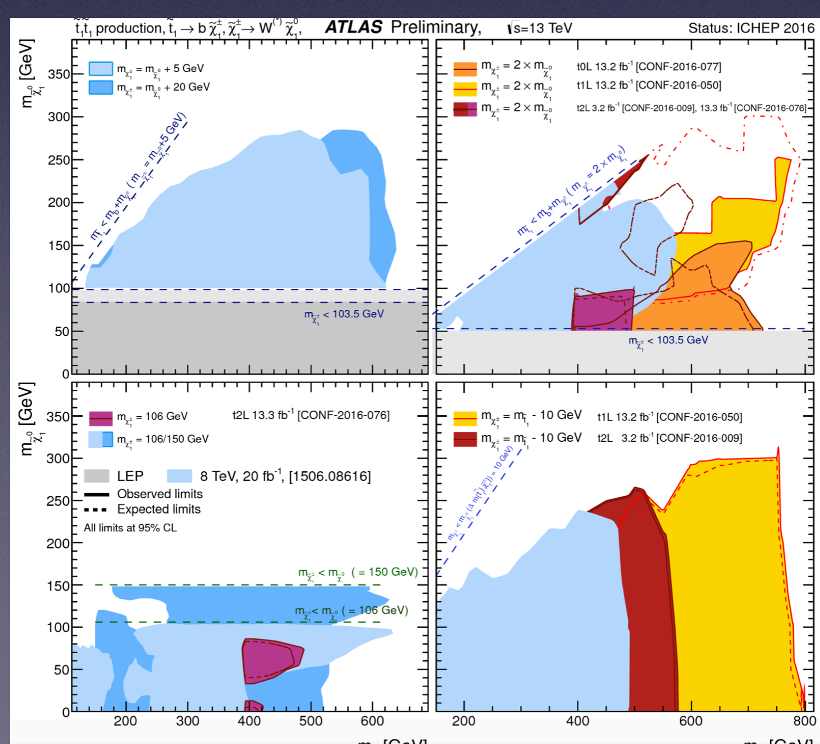
To avoid large cancelation(fine tuning),

Light stop and Higgsino!

Stop searches at the LHC



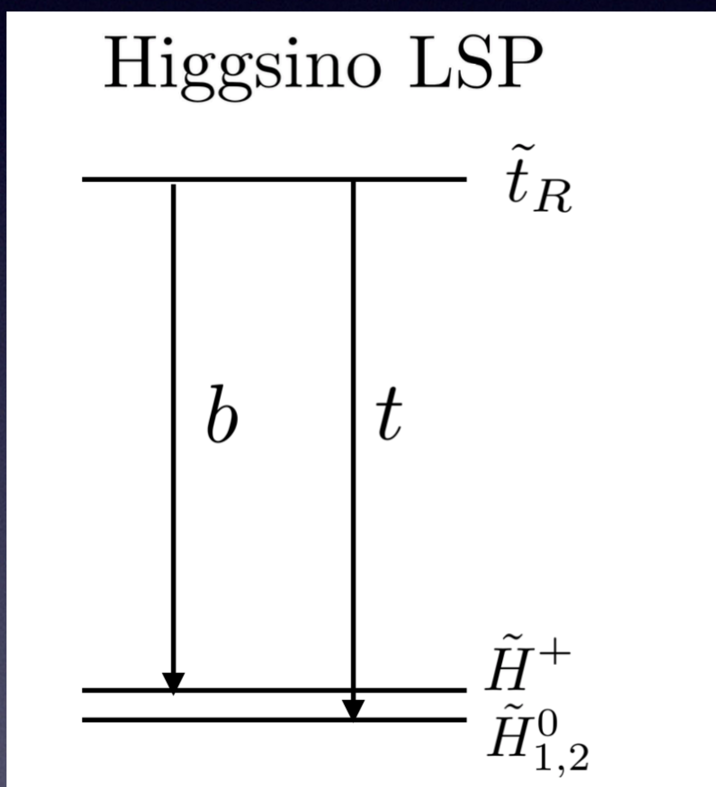




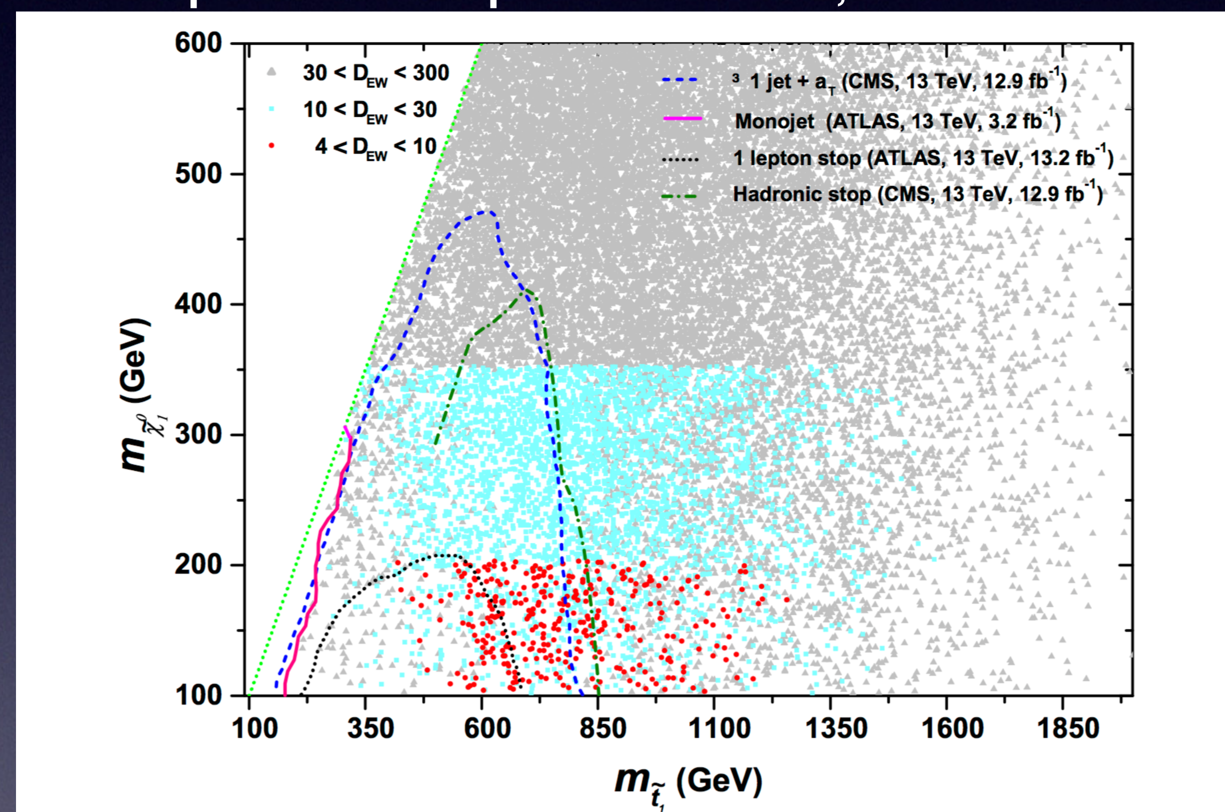
1. Stop mass limit around 900 GeV for very light neutralino. For compressed spectrum, much weaker.
2. Based on Simplified model branching ratio 100%.
3. If stop decays into chargino+b, weaker limit(based on assumptions)

Stop searches in natural SUSY

Assuming right hand like stop and higgsino is the LSP



Re-interpreted the stop search results, more details see Zhang's talk



From arXiv:1609.02361, C. Han, J. Ren, L. Wu, J. M. Yang and M. Zhang

1. A stop mass around 850 GeV with 100 GeV higgsino has been excluded.
2. For a compressed spectrum, only 320 GeV(see Michihisa's talk)
3. A not so fine-tuned stop mass around 600-900GeV

Possible signature of stop?

ATLAS 1-lepton stop search results(13fb-1):

ATLAS-CONF-2016-050

Signal region	SR1	tN_high	bC2x_diag	bC2x_med	bCbv	DM_low	DM_high
(n_j, n_b)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$	$(\geq 4, \geq 2)$	$(\geq 4, \geq 2)$	$(\geq 2, = 0)$	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$
E_T^{miss} [GeV]	260	450	230	210	360	300	330
m_T [GeV]	170	210	170	140	200	120	220
am_{T2} [GeV]	175	175	170	210	-	140	170
Total background	24 ± 3	3.8 ± 0.8	22 ± 3	13 ± 2	7.8 ± 1.8	17 ± 2	15 ± 2
Observed	37	5	37	14	7	35	21
$p_0(\sigma)$	0.012(2.2)	0.26(0.6)	0.004(2.6)	0.40(0.3)	0.50(0)	0.0004(3.3)	0.09(1.3)
$N_{obs.}^{limit}$(95% CL)	26.0	7.2	27.5	9.9	7.2	28.3	15.6

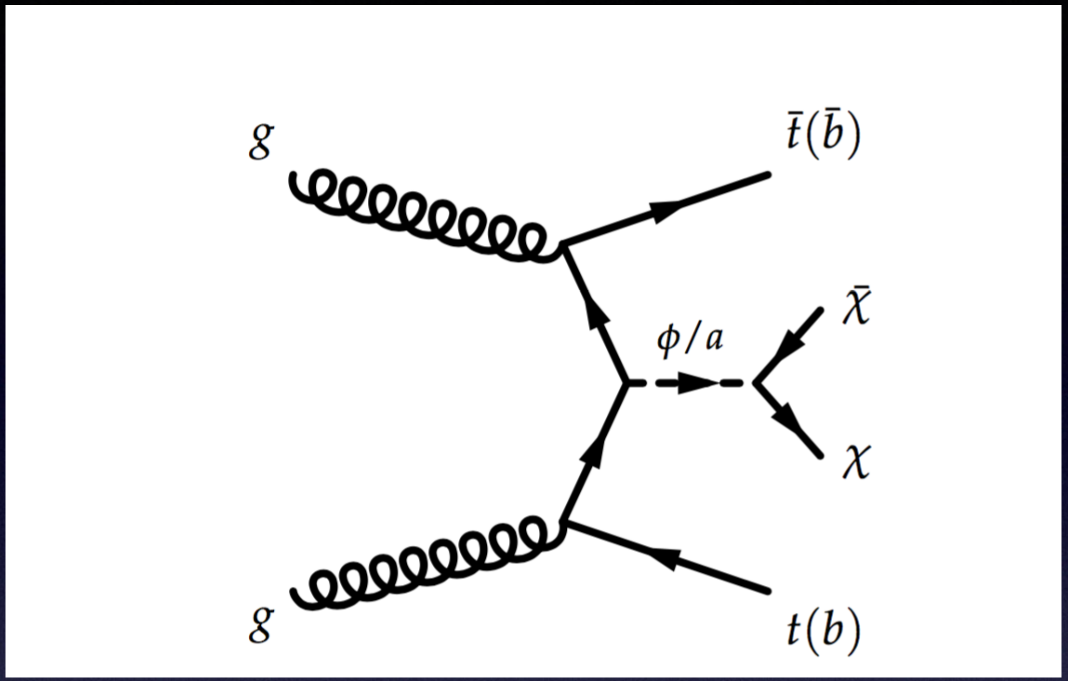
3 signal regions more than 2sigma excess, DM_low 3.3sigma

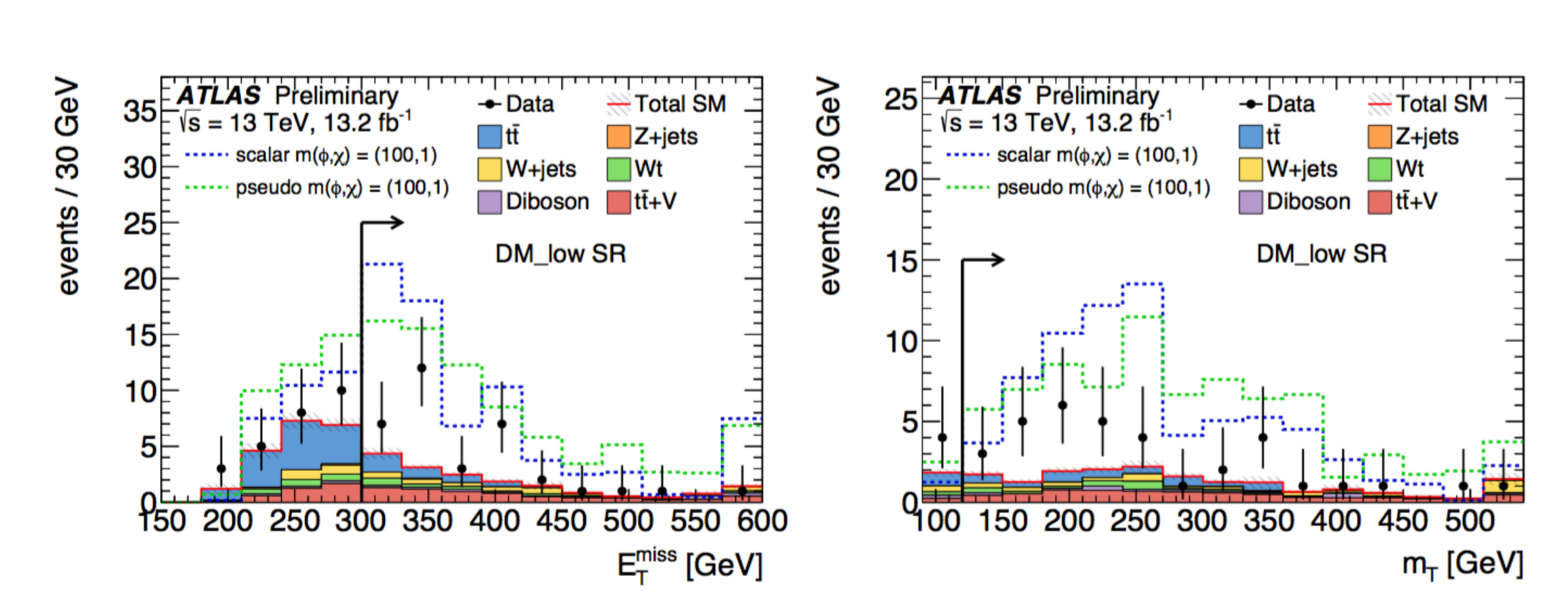
No excess in CMS same channel, same cuts not available

DM_low from ATLAS

Aiming at simplified top-philic models

$$\mathcal{L}_\phi = -(g_t \bar{t}t + g_\chi \bar{\chi}\chi)\phi$$
$$\mathcal{L}_a = -i(g_t \bar{t}\gamma^5 t + g_\chi \bar{\chi}\gamma^5\chi)a$$





Interpreting the excess by stop pair production

1. Only focus on DM_low. Needed signal event in our analysis

Signal region	2σ upper	1σ upper	central	1σ lower	2σ lower
DM_low	32.6	24.7	18.0	12.2	7.4

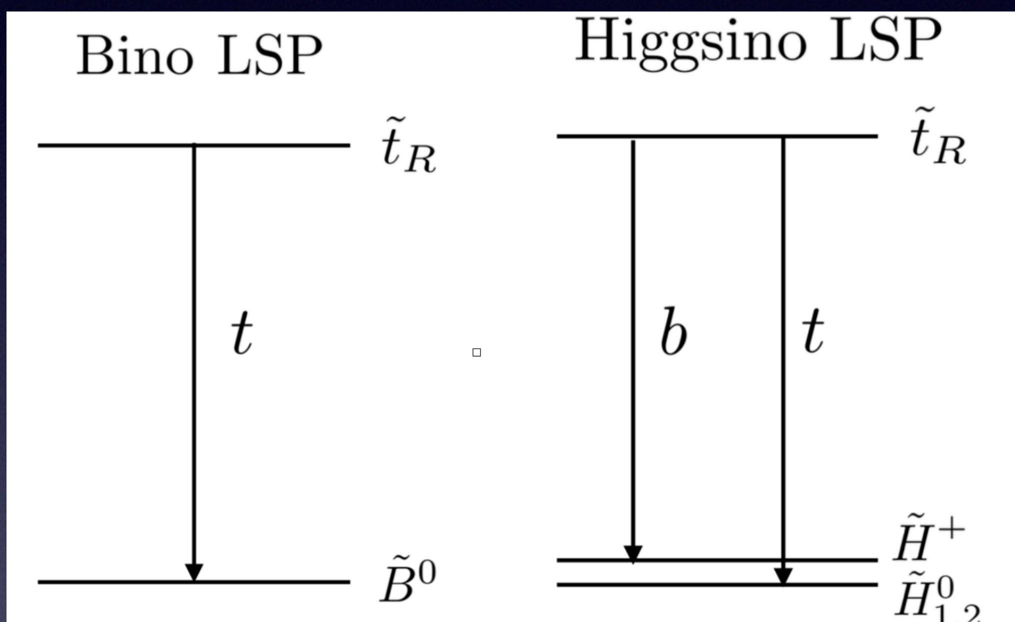
2. Assuming right hand like stop.

3. other searches (95% C.L. limit)

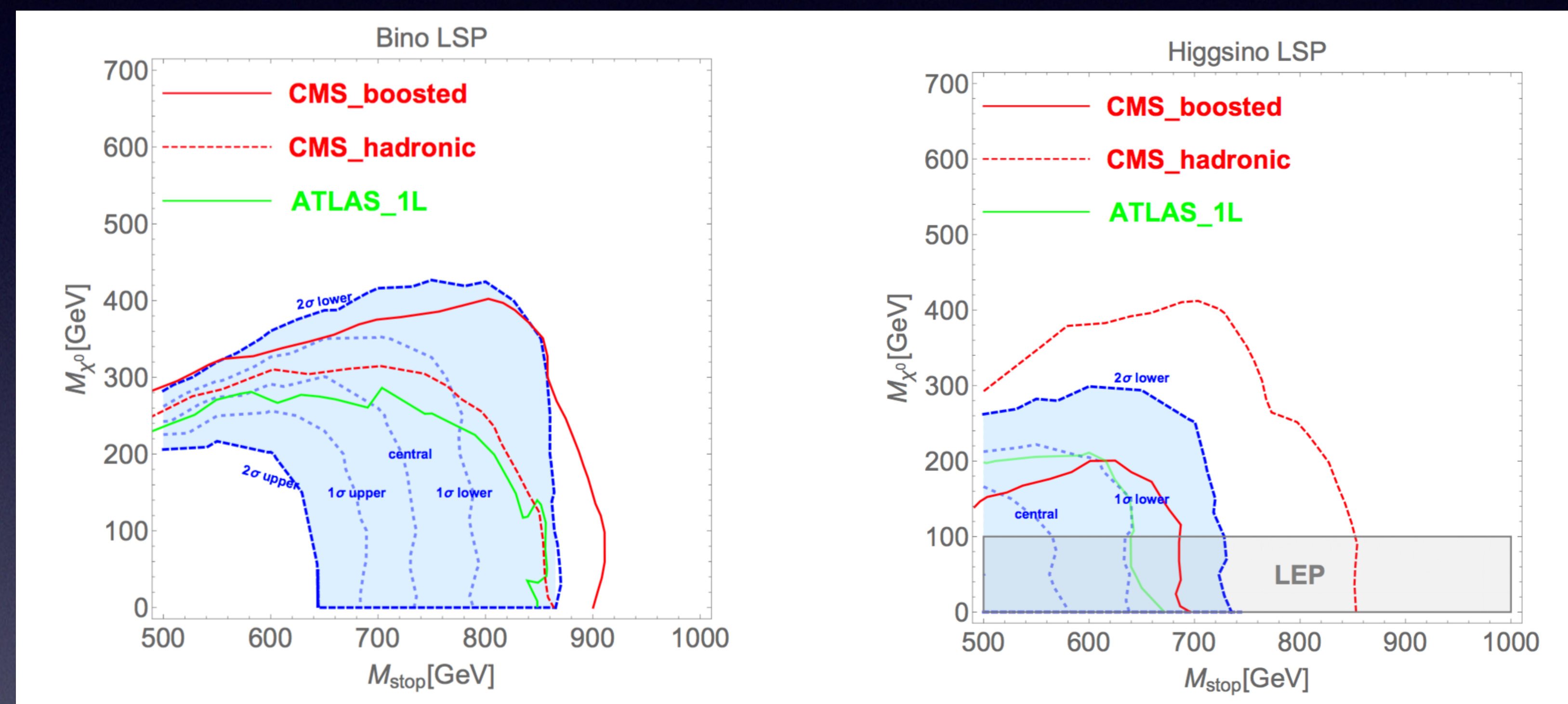
- CMS boosted top (top tagging) channel.
- CMS hadronic channel (2b+jets+missing).
- ATLAS 1-lepton other channels (1l+2b+jets+missing).
- No CMS 1-lepton limit(similar limit with ATLAS 1-lepton channel).

Two simplified models

Decay mode

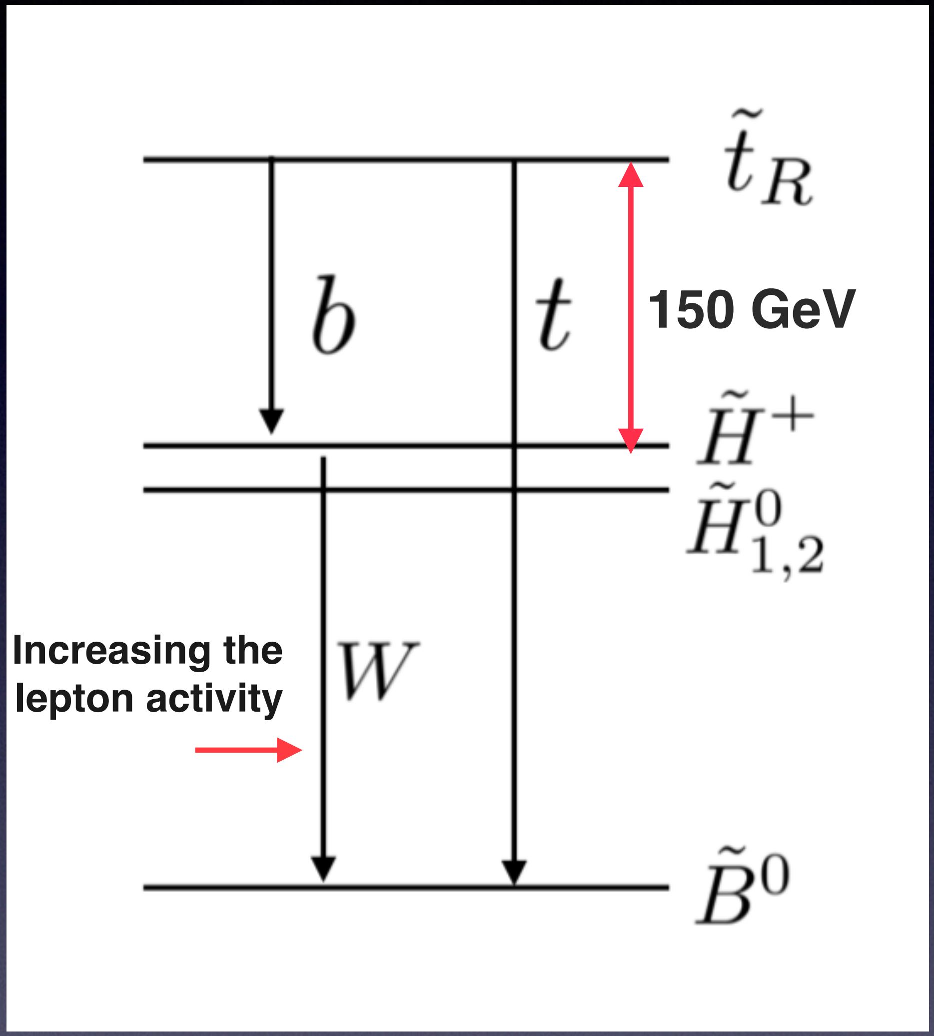


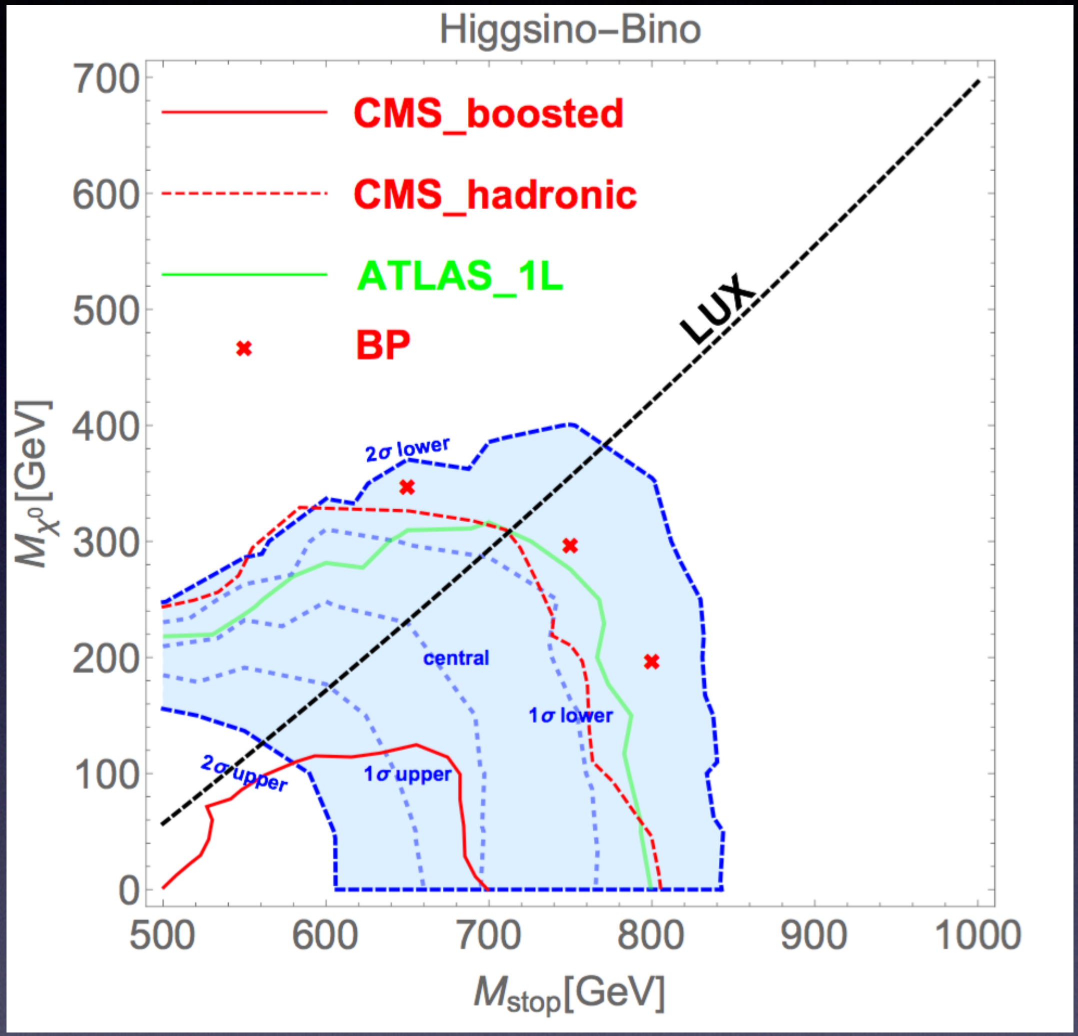
parameter space



1. Bino LSP suffers from CMS boosted search(2 top tagging).
2. Higgsino LSP can effective reduce CMS boosted limit, at the same time reduce the lepton signal. CMS_hadronic is still very strong.

More complicate spectrum

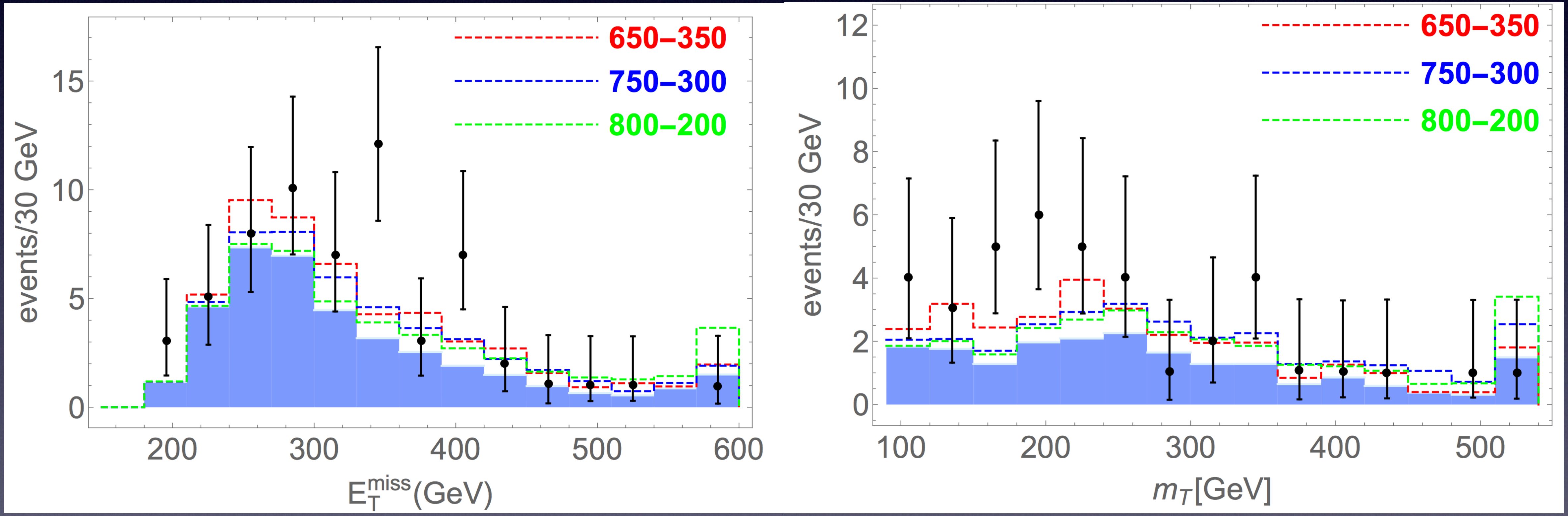




1. Still some parameter space explaining the signal at 2sigma level.
2. Inserting the slepton with a mass close to bino will not essentially change the topology. (Higgsino-H-Bino coupling)
3. Dark matter direct search can also help to probe this scenario. But for opposite sign of higgsino and bino, a blind spot region exist.
4. To explain the excess, a low fine-tuned stop is favored(600-850 GeV)

Kinematics distribution for different BPs

Different mass parameters can be distinguished by kinematics variable distribution



Lower missing ET and MT is preferred!

Other possibilities

Stop-LSP

Model	LSP	comments
A	$\tilde{B}$	
B	$\tilde{H}$	
C	$\tilde{W}$	Not favored by right hand stop decay

Stop-NLSP-LSP

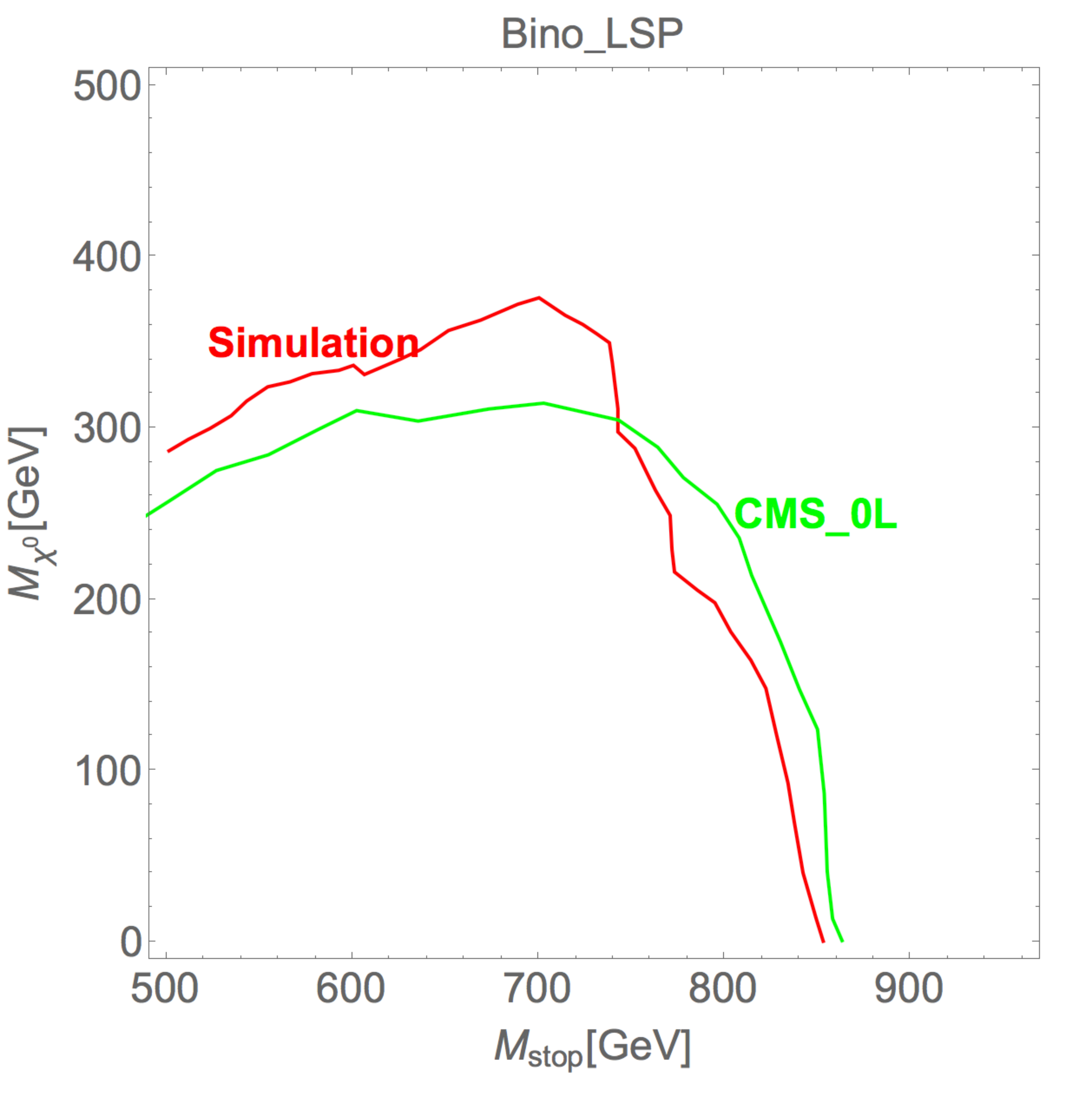
Model	NLSP	LSP	comments
D	$\tilde{H}$	$\tilde{B}$	
E	$\tilde{H}$	$\tilde{W}$	
F	$\tilde{B}$	$\tilde{H}$	similar to model B
H	$\tilde{B}$	$\tilde{W}$	
I	$\tilde{W}$	$\tilde{B}$	similar to model A
J	$\tilde{W}$	$\tilde{H}$	similar to model B

LSP Wino mass >270 GeV(8TeV)
Long-lived chargino search

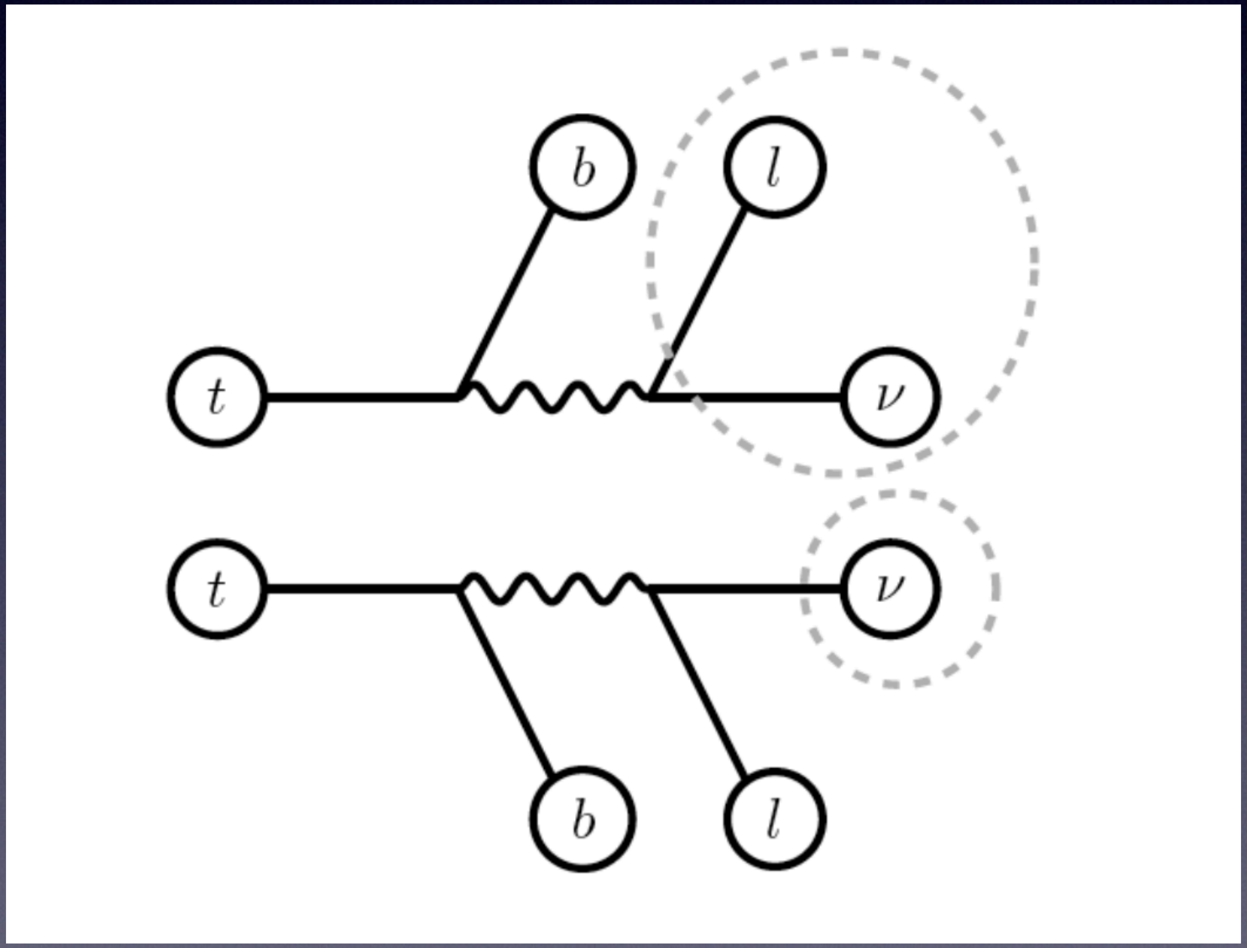
Summary and Conclusion

- To explain the excess by stop, we need a natural SUSY frame, and the stop mass is just around the low-fined preferred region.
- If the signal confirmed, future dark matter direct search can also cross check it.
- Let us wait for the new data!

Simulation consistency



aMT2



Common event selection	
Trigger	E_T^{miss} trigger
Lepton	exactly one signal lepton (e, μ), no additional baseline leptons
Jets	at least two signal jets, and $\lvert\Delta\phi(\text{jet}_i, \vec{p}_T^{miss})\rvert > 0.4$ for $i \in \{1, 2\}$
Hadronic τ veto*	veto events with a hadronic τ decay and $m_{T2}^{\tau} < 80$ GeV

Variable	SR1	tN_high
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$
Jet $p_T >$ [GeV]	(80 50 40 40)	(120 80 50 25)
E_T^{miss} [GeV]	> 260	> 450
$E_{T,\perp}^{miss}$ [GeV]	–	> 180
$H_{T,sig}^{miss}$	> 14	> 22
m_T [GeV]	> 170	> 210
am_{T2} [GeV]	> 175	> 175
topness	> 6.5	–
m_{top}^{χ} [GeV]	< 270	–
$\Delta R(b, \ell)$	< 3.0	< 2.4
Leading large-R jet p_T [GeV]	–	> 290
Leading large-R jet mass [GeV]	–	> 70
$\Delta\phi(\vec{p}_T^{miss}, 2^{nd}\text{large-R jet})$	–	> 0.6

Variable	bC2x_diag	bC2x_med	bCbv
Number of (jets, b-tags)	$(\geq 4, \geq 2)$	$(\geq 4, \geq 2)$	$(\geq 2, = 0)$
Jet $p_T >$ [GeV]	(70 60 55 25)	(170 110 25 25)	(120 80)
b-tagged jet $p_T >$ [GeV]	(25 25)	(105 100)	–
E_T^{miss} [GeV]	> 230	> 210	> 360
$H_{T,sig}^{miss}$	> 14	> 7	> 16
m_T [GeV]	> 170	> 140	> 200
am_{T2} [GeV]	> 170	> 210	–
$\lvert\Delta\phi(\text{jet}_i, \vec{p}_T^{miss})\rvert (i = 1)$	> 1.2	> 1.0	> 2.0
$\lvert\Delta\phi(\text{jet}_i, \vec{p}_T^{miss})\rvert (i = 2)$	> 0.8	> 0.8	> 0.8
Leading large-R jet mass [GeV]	–	–	[70, 100]
$\Delta\phi(\vec{p}_T^{miss}, \ell)$	–	–	> 1.2

Variable	DM_low	DM_high
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$
Jet $p_T >$ [GeV]	(60 60 40 25)	(50 50 50 25)
E_T^{miss} [GeV]	> 300	> 330
$H_{T,sig}^{miss}$	> 14	> 9.5
m_T [GeV]	> 120	> 220
am_{T2} [GeV]	> 140	> 170
$\min(\Delta\phi(\vec{p}_T^{miss}, \text{jet}_i))(i \in \{1-4\})$	> 1.4	> 0.8
$\Delta\phi(\vec{p}_T^{miss}, \ell)$	> 0.8	–

(1) These seven signal regions are not exclusive. `SR1`, `bC2x_diag` and `DM_low`, where the excesses are observed, could share the same signal events.

(2) The `DM_low` and `DM_high` applies similar cuts except a lower m_T cut and a tighter $\Delta\phi(\not{E}_T^{miss}, j_i)$ cut in `DM_low`. Since no excess is observed in the `DM_high`, hard m_T events are not preferred.

(3) The `bC2x_med` requires very high p_T bottoms compared with the `bC2x_diag` . Since no excess is observed in the `bC2x_med`, presence of hard bottoms is not preferred.

SM Higgs invisible decay?

ttH production with H decay invisible

From our simulation, we find 100% branching ratio needed!