粒子物理前沿问题研讨会

Natural SUSY at the LHC

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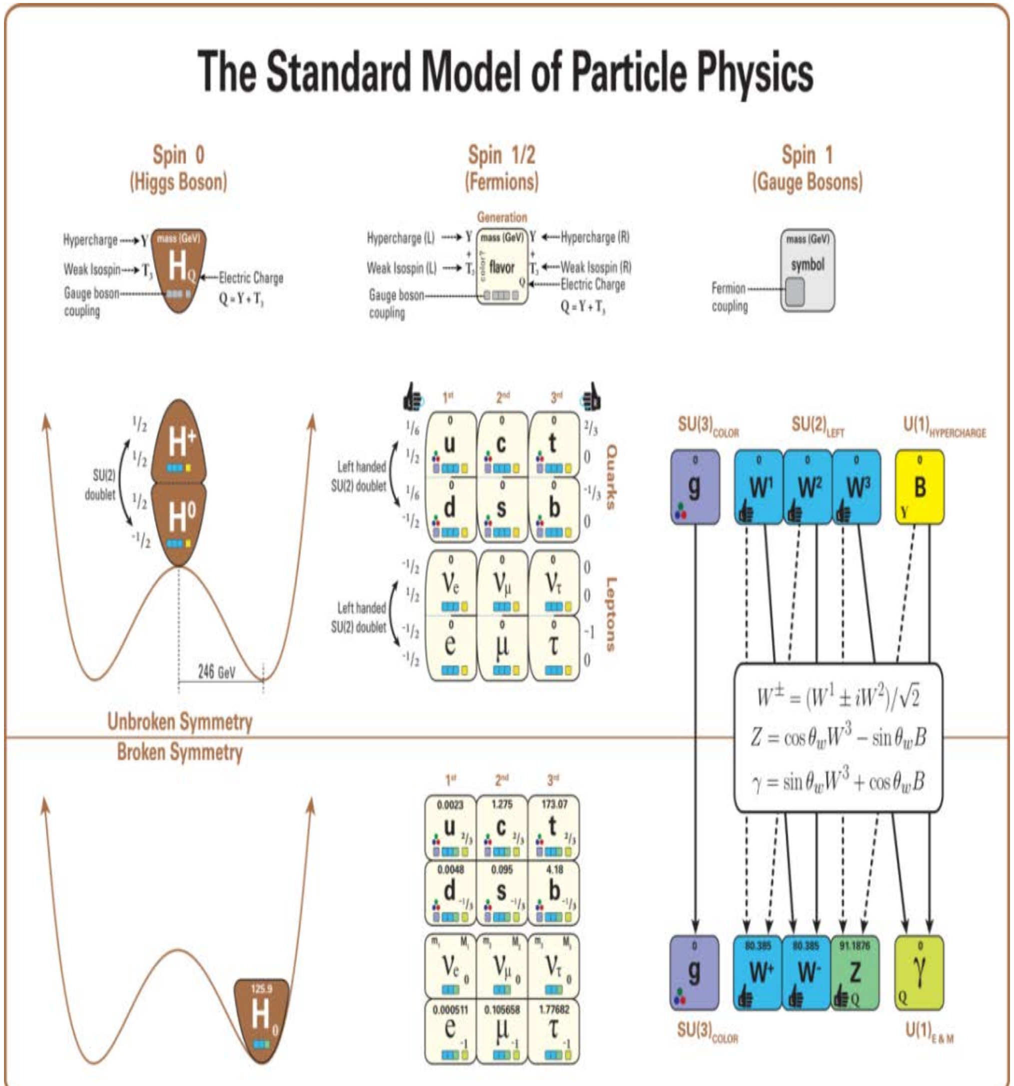
Outline of Topics

- **Implications of SUSY naturalness for LHC**
- **Light Higgsinos @ LHC**
- **Stop with light Higgsinos @ LHC**

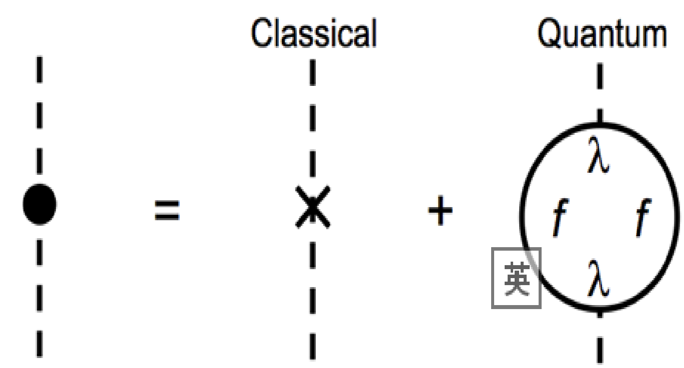
arXiv:1811.08573, arXiv:1807.09088,
JHEP 1709 (2017) 037, JHEP 1703 (2017) 091,
EPJC 77 (2017) 93, PLB 769 (2017) 470-476,
PRD 93 (2016) 035003, PLB 755 (2016) 76-78,
PRD 92 (2015) 075008, JHEP 1402 (2014) 049,
JHEP 1310 (2013) 216, JHEP 1211 (2012) 039

1. Implications of SUSY naturalness for LHC



- **Discovery of Higgs boson completes the SM particle zoo. But the origin of the EWSB is still unclear.**

- **Naturalness problem**



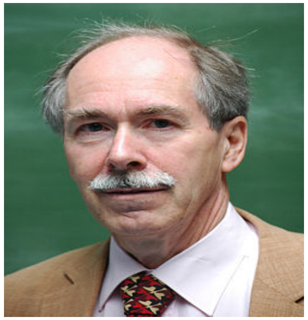
$$m_h^2 = (m_h^2)_0 - \frac{1}{16\pi^2}\lambda^2\Lambda^2$$

What are the natural sizes of parameters in the QFT?

- **Dirac Naturalness (Large Numbers Hypothesis):**

"Any two of the very large dimensionless numbers occurring in Nature are connected by a simple mathematical relation, in which the coefficients are of the order of magnitude unity." P. A. M. Dirac, "New basis for cosmology," Proc. Roy. Soc. Lond. A165 (1938) 199-208.

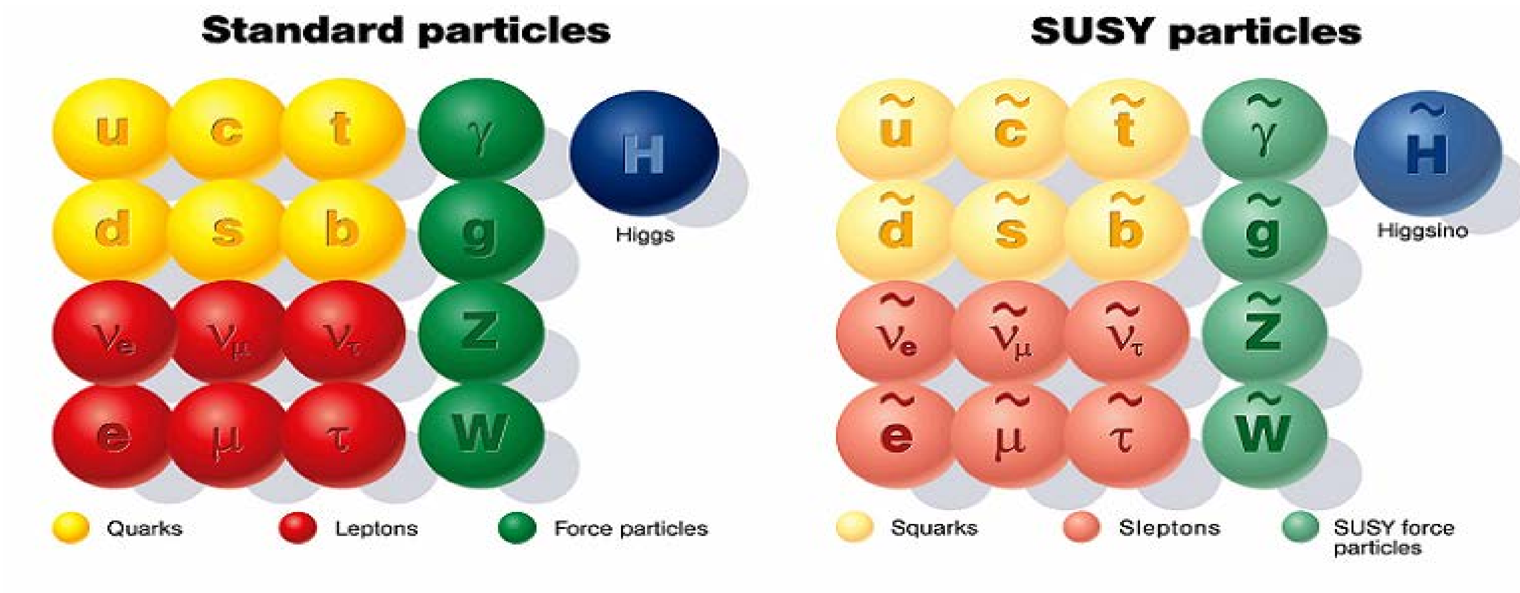
- **'t Hooft Naturalness (Technical Naturalness):**

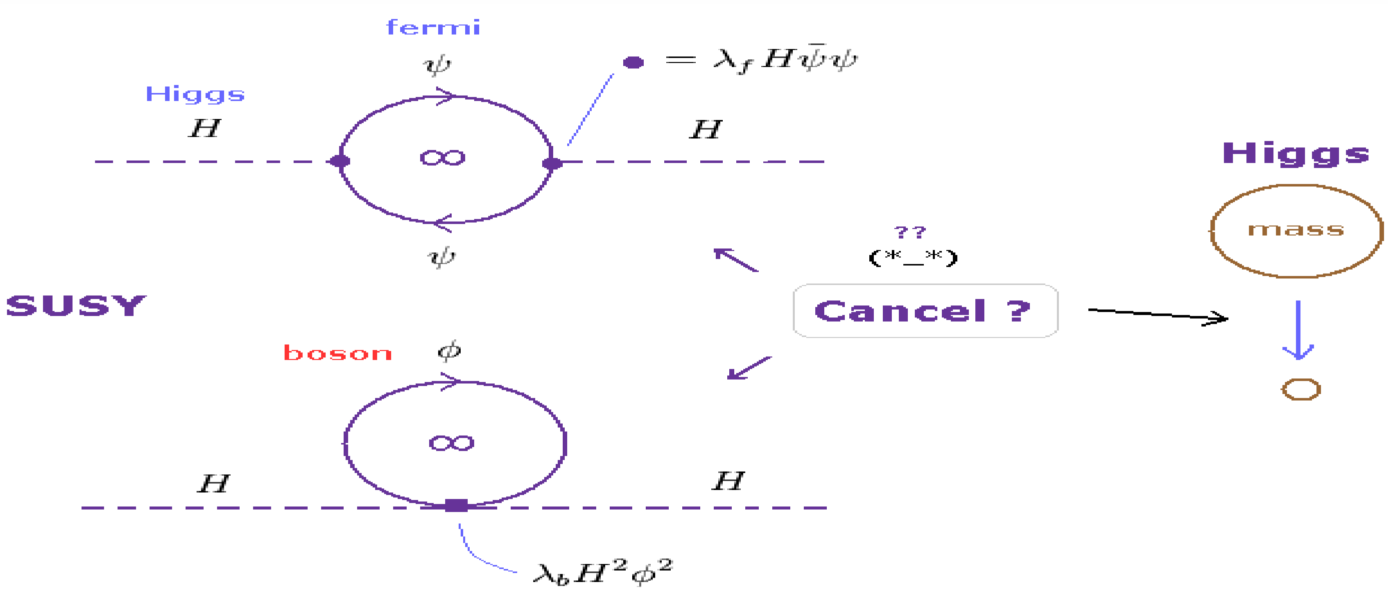


"Coefficients can be much smaller than their Dirac natural value if there is an enhanced symmetry of the theory when the coefficient is taken to zero. e.g. fermion mass and chiral symmetry." G.'t Hooft et al. Plenum Press, New York, 1980, page 135.

Naturalness is one of guiding principles to extend the SM.

SUSY


Standard particles
SUSY particles
Higgs
Higgsino
Quarks
Leptons
Force particles
Squarks
Sleptons
SUSY force particles


fermi
ψ
$\bullet = \lambda_f H \bar{\psi} \psi$
Higgs
H
∞
H
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Higgs
mass
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SUSY
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boson
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H
$\lambda_b H^2 \phi^2$

In the MSSM there are two doublets of complex scalar fields of opposite hypercharges:

$$H_u = \begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}, \qquad H_d = \begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}.$$

$$V^{(0,MSSM)} = m_1^2|H_u|^2 + m_2^2|H_d|^2 - B\mu\epsilon_{\alpha\beta}(H_u^\alpha H_d^\beta + h.c.)$$

$$+\frac{g^2+g'^2}{8}(|H_u|^2 - |H_d|^2)^2 + \frac{g^2}{2}|H_u^\dagger H_d|^2,$$

where $m_{1,2}^2 = m_{H_{u,d}}^2 + \mu^2$.

$$\Delta V^{(1,MSSM)} = \sum_i \frac{(-1)^{2s_i}}{64\pi^2}(2s_i+1)c_i m_i^4 \left[\ln(\frac{m_i^2}{Q^2} - \frac{3}{2})\right].$$

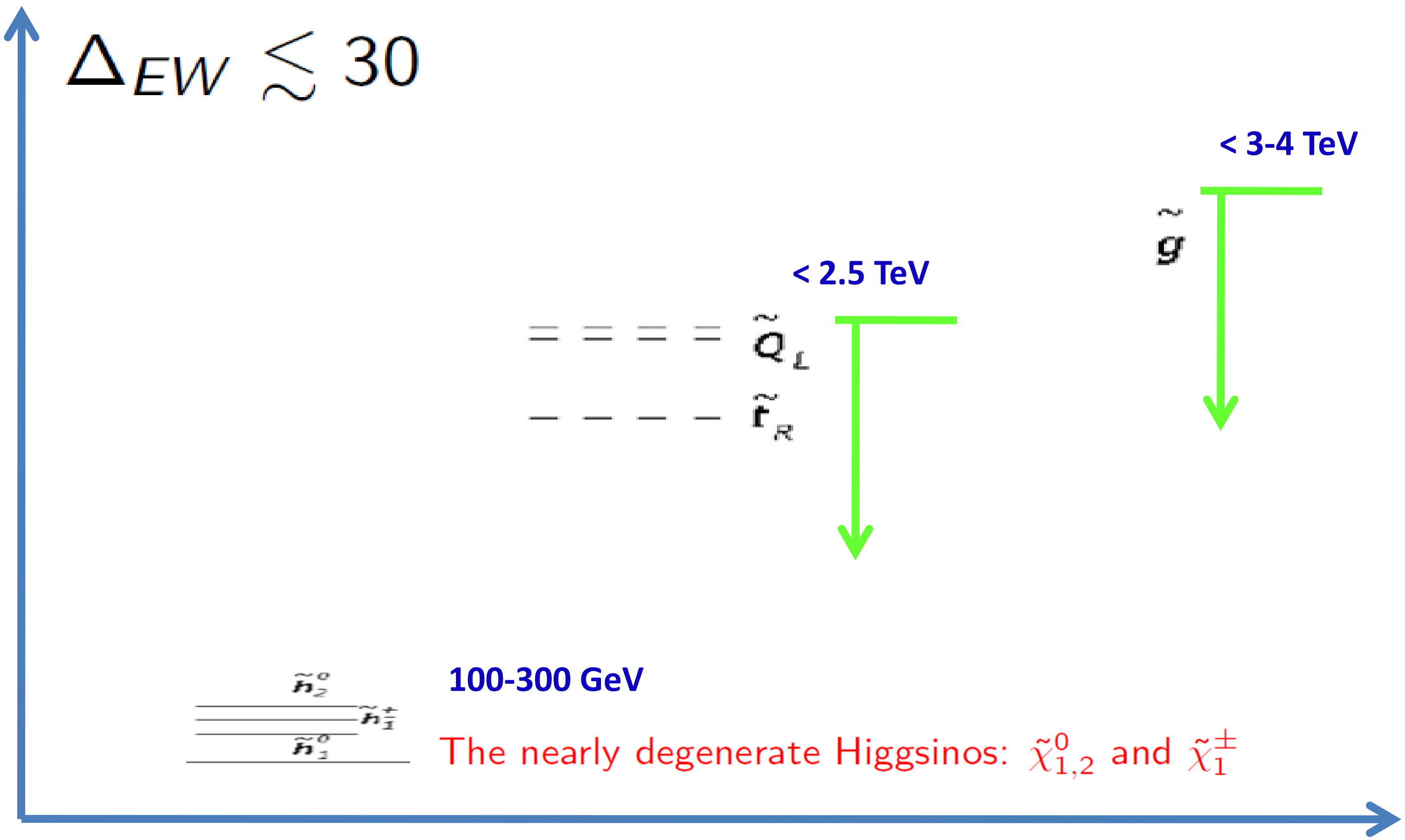
In this case, the minimization conditions can be expressed as

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

To obtain a natural value of M_Z on the left-hand side, one would like each term C_i (with $i = H_u, H_d, \mu, \Sigma_u^u(k), \Sigma_d^d(k)$) on the right-hand side to have an absolute value of order $M_Z^2/2$.

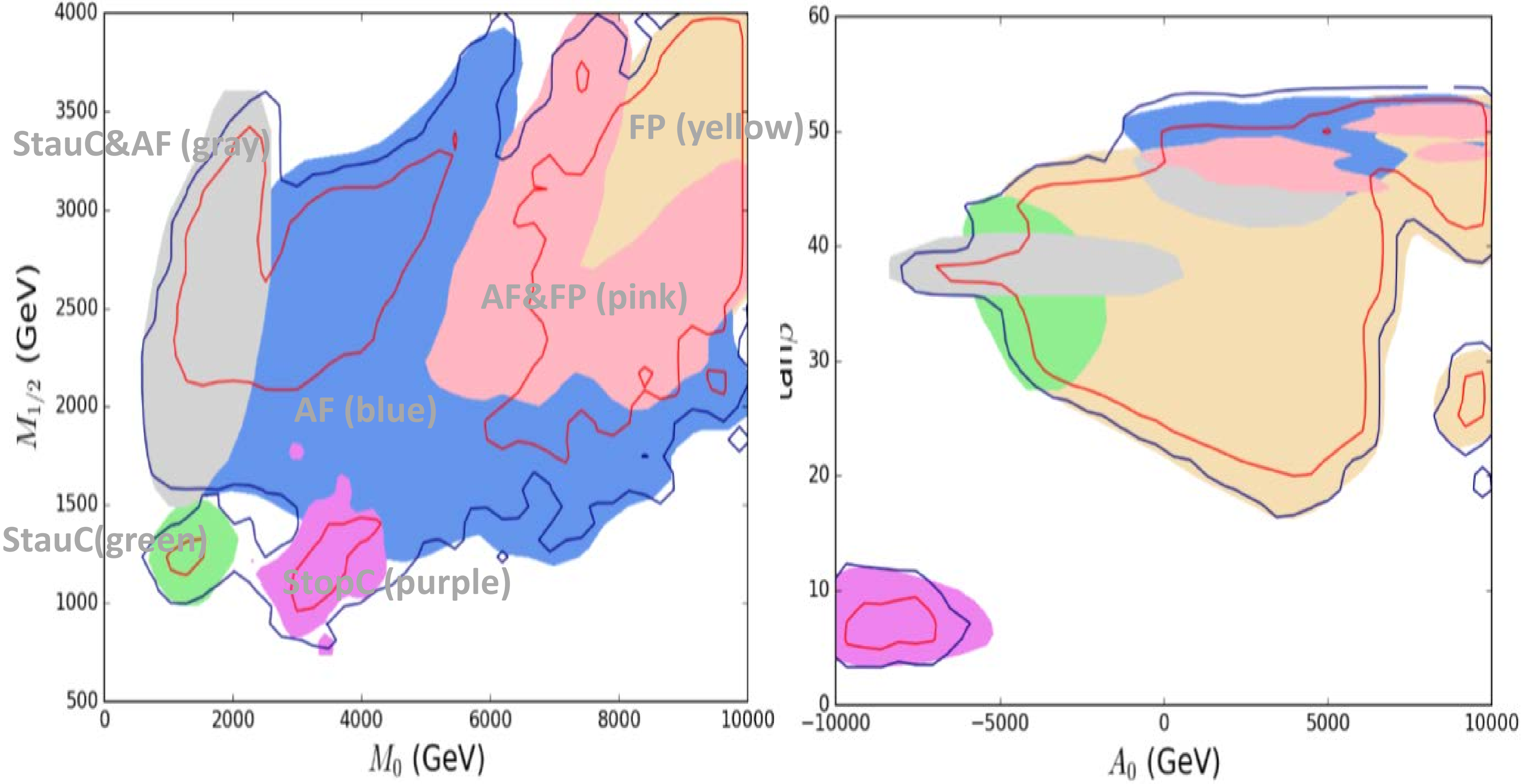
$$\Delta_{EW} \equiv max(C_i)/(M_Z^2/2)$$

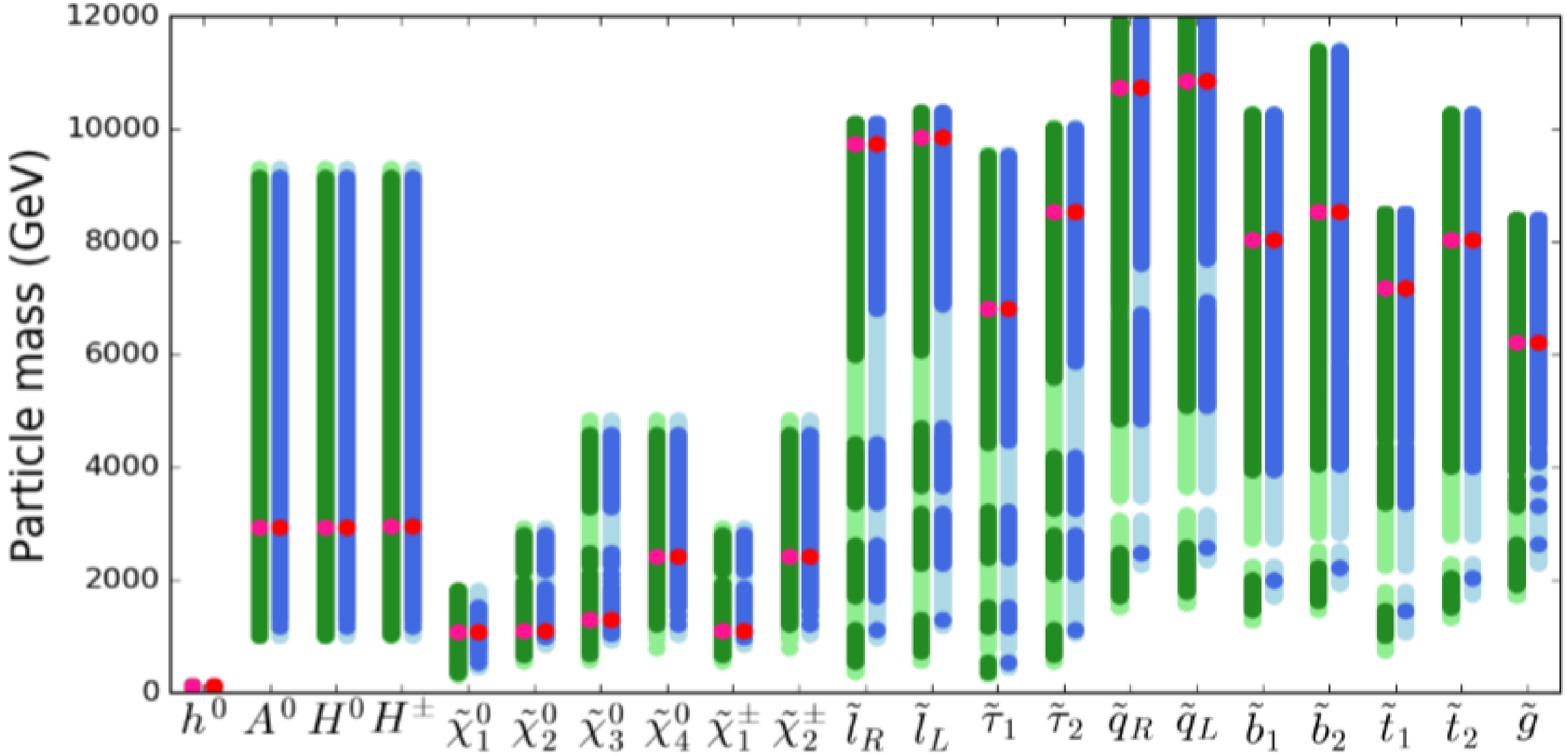
Roadmap of NSUSY at LHC



Is CMSSM still natural?

Han, Hikasa, LW, Yang, PLB 769 (2017) 470-476





Point	M_0	$M_{1/2}$	A_0	$\tan\beta$	(μ)	m_h	m_A	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\tau}_1}$	$m_{\tilde{\chi}_1^\pm}$	Ωh^2	σ_P^{SI}	Δa_μ	$\mathcal{L}(\eta)$	Δ
FP	9701	2881	8869	50.3	+	125.1	2947	1089	6823	1095	0.119	1.4E-09	2.3E-11	10.6	4315
AF	8925	2598	9531	51.2	+	124.6	2488	1167	5947	1691	0.125	1.9E-10	2.8E-11	10.9	3445
StopC	4145	1400	-9891	5.6	−	125.3	6116	628	4139	1199	0.122	7.77.E-13	-3.0E-12	11.0	11817
StauC	1026	1221	-3397	31.5	+	123.6	1928	531	531	1005	0.123	5.9E-12	2.3E-10	11.5	2106
StauC′	728	1110	-2774	26.3	+	123.1	1800	479	479	908	0.120	8.6E-12	2.9E-10	11.1	1641
Hybrid	1872	3199	-4897	37.8	−	125.4	2923	1440	1441	2662	0.118	8.81E-13	-5.2E-11	11.1	8079

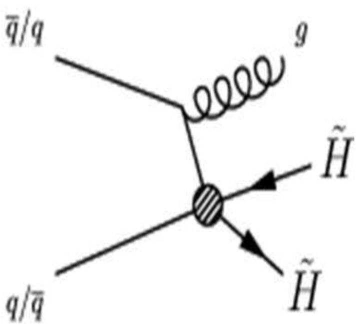
UV models: RNS, NUGM, SuperNSUSY, Deflected AMSB…

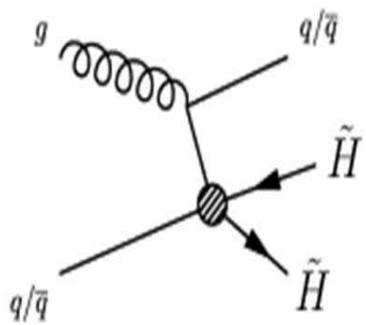
- Compressed SUSY
- Stealth SUSY
- Dirac gaugino
- R-parity violation
- …….

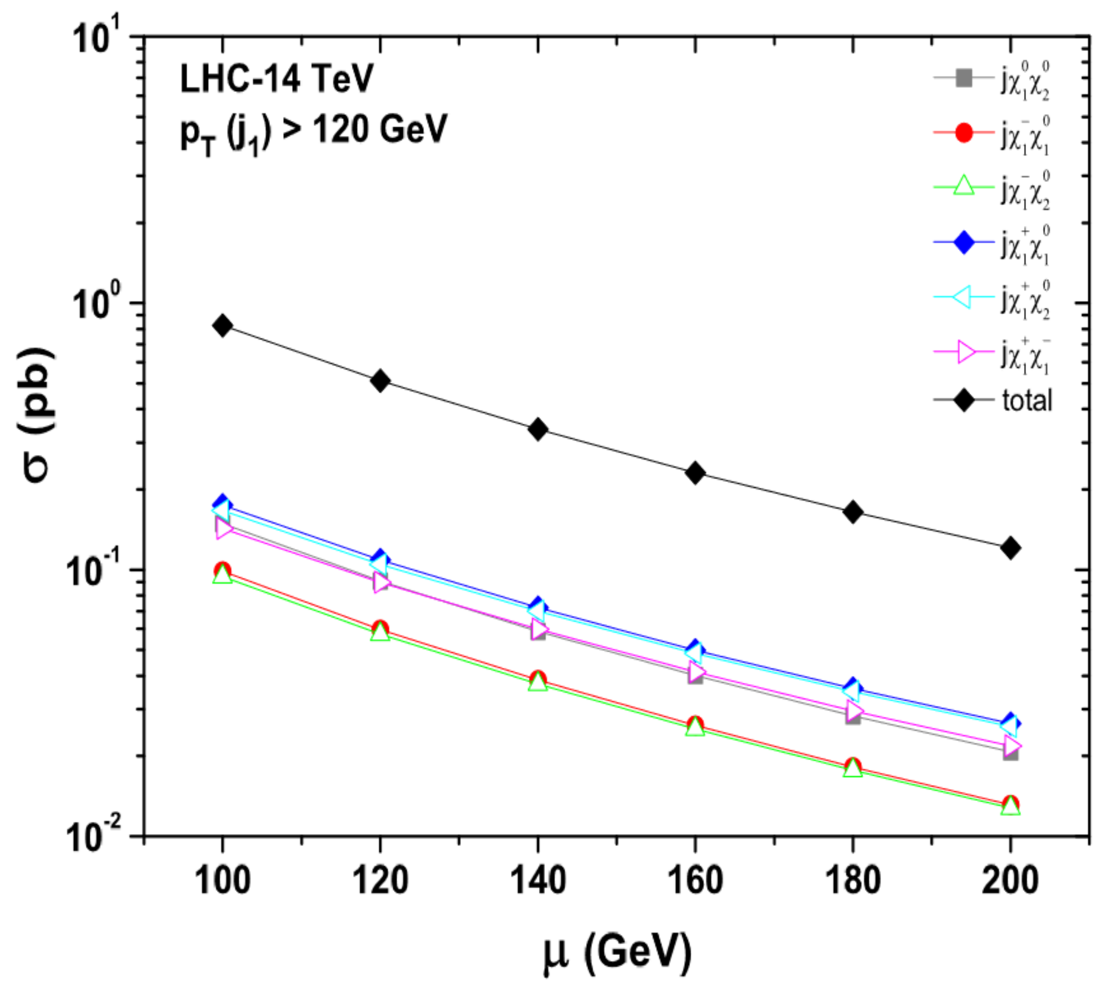
On the other hand, bottom-up study is needed!

2. Light Higgsinos @ LHC

$$
\begin{aligned}
m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0} &= \frac{M_W^2}{2M_2}\left(1 - \sin 2\beta - \frac{2\mu}{M_2}\right) \\
&\quad + \frac{M_W^2}{2M_1}\tan^2\theta_W(1 + \sin 2\beta), \\
m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} &= \frac{M_W^2}{2M_2}\left(1 - \sin 2\beta + \frac{2\mu}{M_2}\right) \\
&\quad + \frac{M_W^2}{2M_1}\tan^2\theta_W(1 - \sin 2\beta)
\end{aligned}
$$



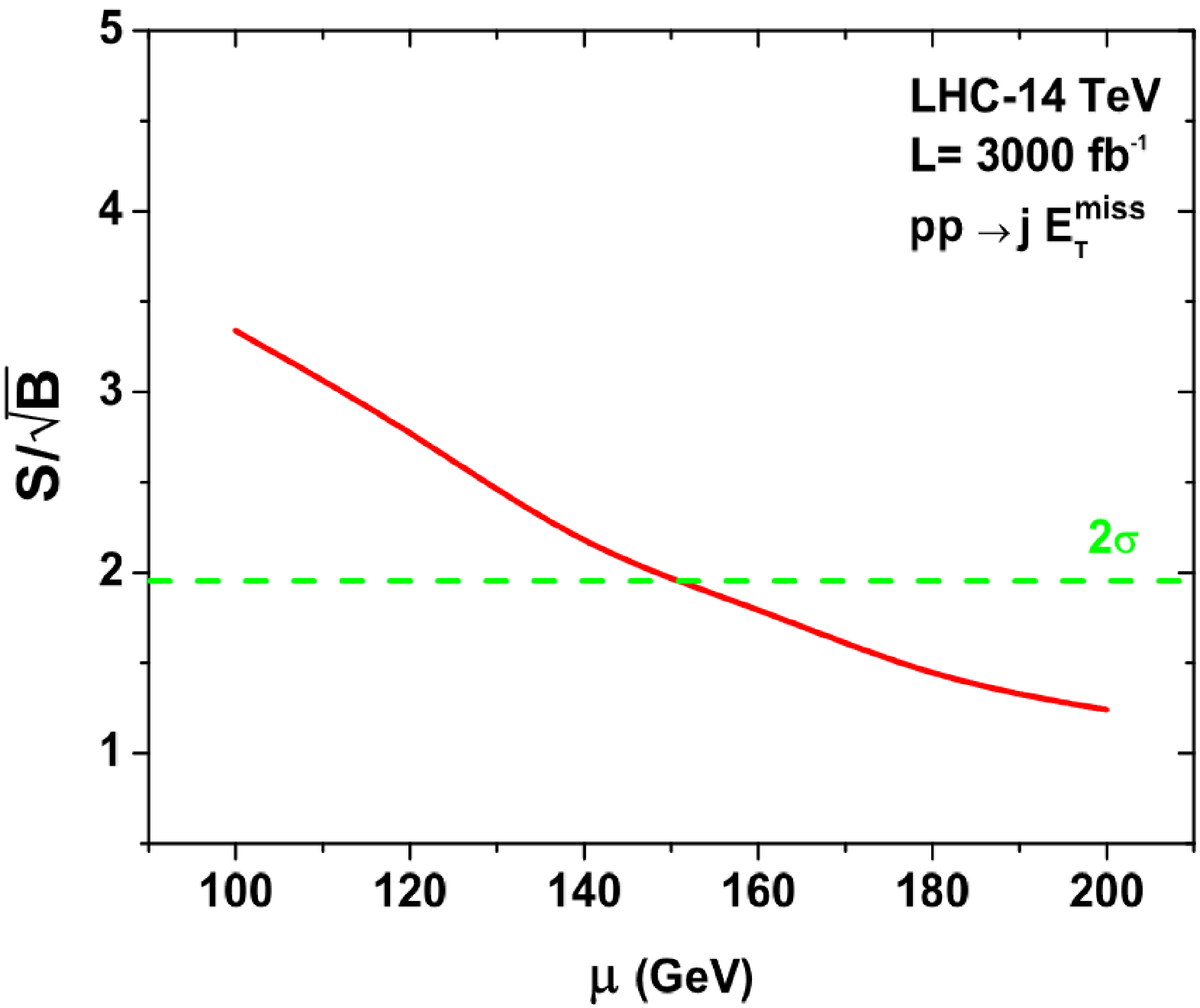




- $pp \to Z(\to \nu\bar{\nu}) + j$, which is the main irreducible background with the same topology as our signals;
- $pp \to W(\to \ell\nu) + j$, this process fakes the signal only when the charged lepton is outside the acceptance of the detector or close to the jet;
- $pp \to W(\to \tau\nu) + j$, this process may fake the signal since a secondary jet from hadronic tau decays tend to localize on the side of $\not{E}_T$;
- $pp \to t\bar{t}$, this process may resemble the signal, but also contains extra jets and leptons. This allows to highly suppress $t\bar{t}$ background by applying a b-jet, lepton and light jet veto.

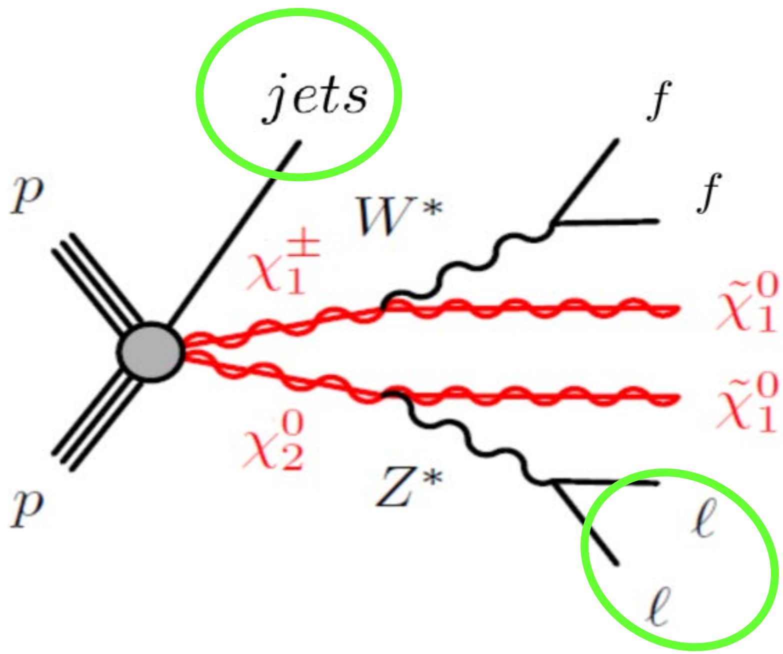
cut	$Z(\nu\bar{\nu})+j$	$W(\ell\nu_\ell)+j$	$W(\tau\nu_\tau)+j$	$t\bar{t}$	Signal ($\mu = 100$ GeV)	Signal ($\mu = 200$ GeV)
$p_T(j_1) > 500$GeV	69322	241740	119078	210943	1242	415
$\not{E}_T > 500$GeV	26304	28209	16513	2786	950	335
veto on $p_T(j_2) > 100$, $p_T(j_3) > 30$	16988	12194	7577	306	602	223
veto on e, μ, τ	16557	3963	3088	102	597	220
veto on $b-$jets	16303	3867	3046	56	576	214

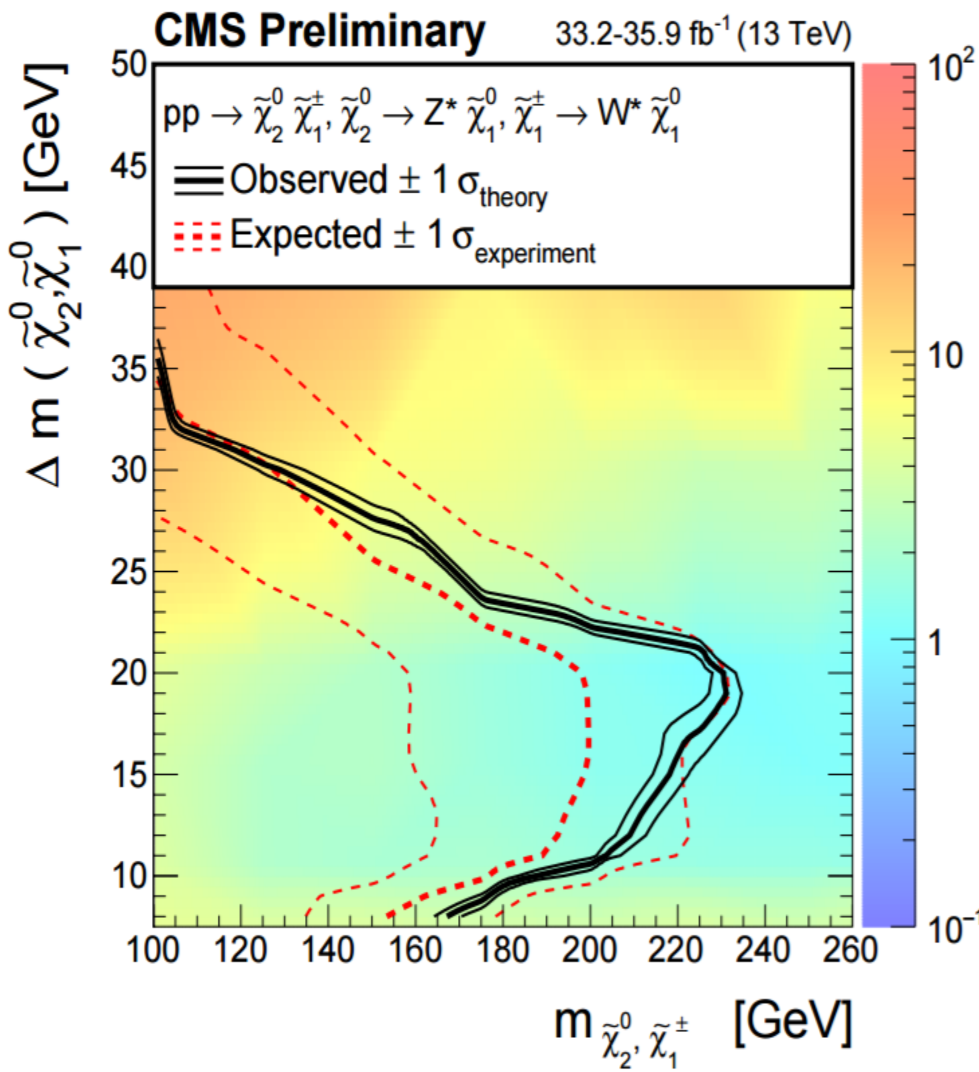
Han, Kobakhidze, Liu, LW, Yang
arXiv:1310.4274. JHEP
Cited by CMS Collaboration (arXiv:1709.04896)



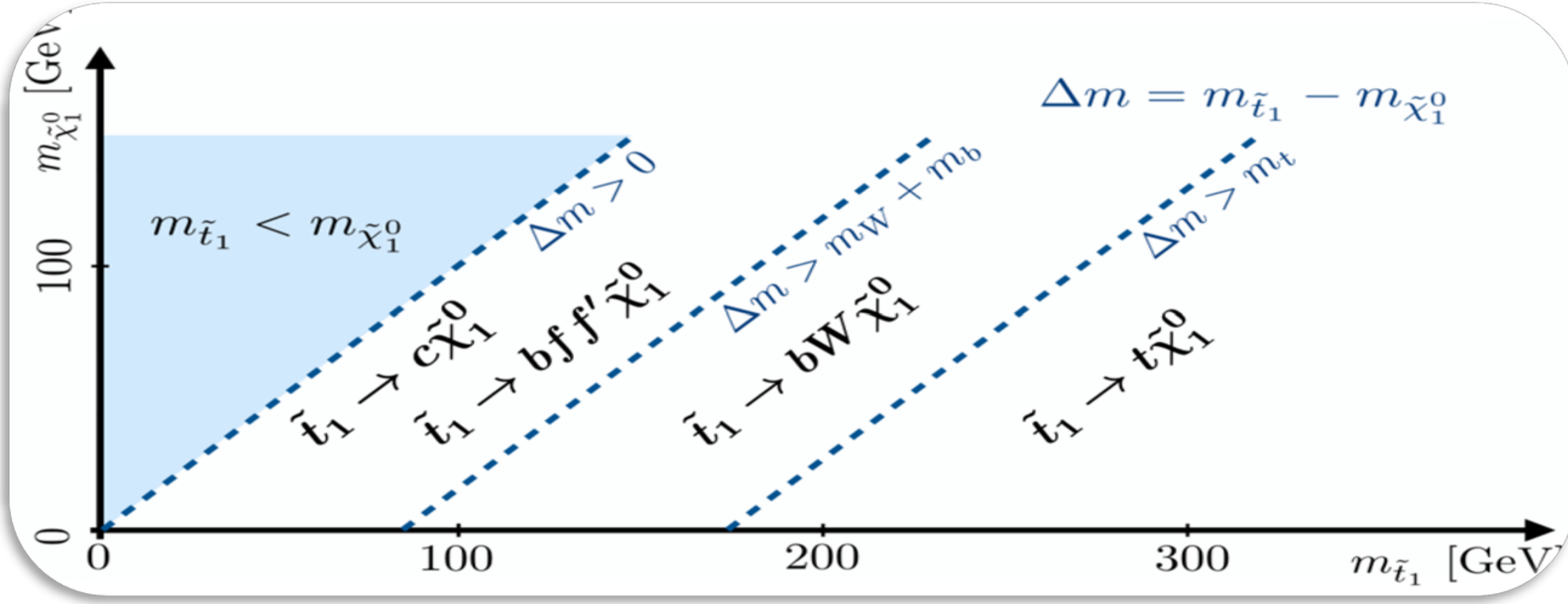
CMS PAS SUS-16-048

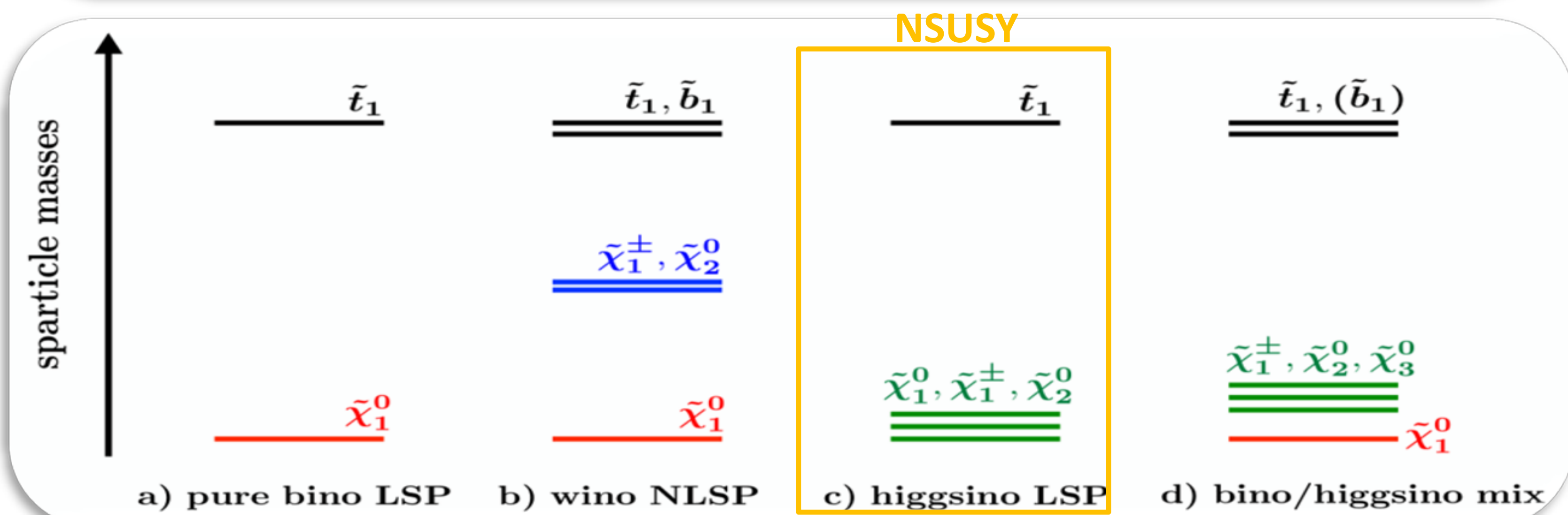
Monojet-like





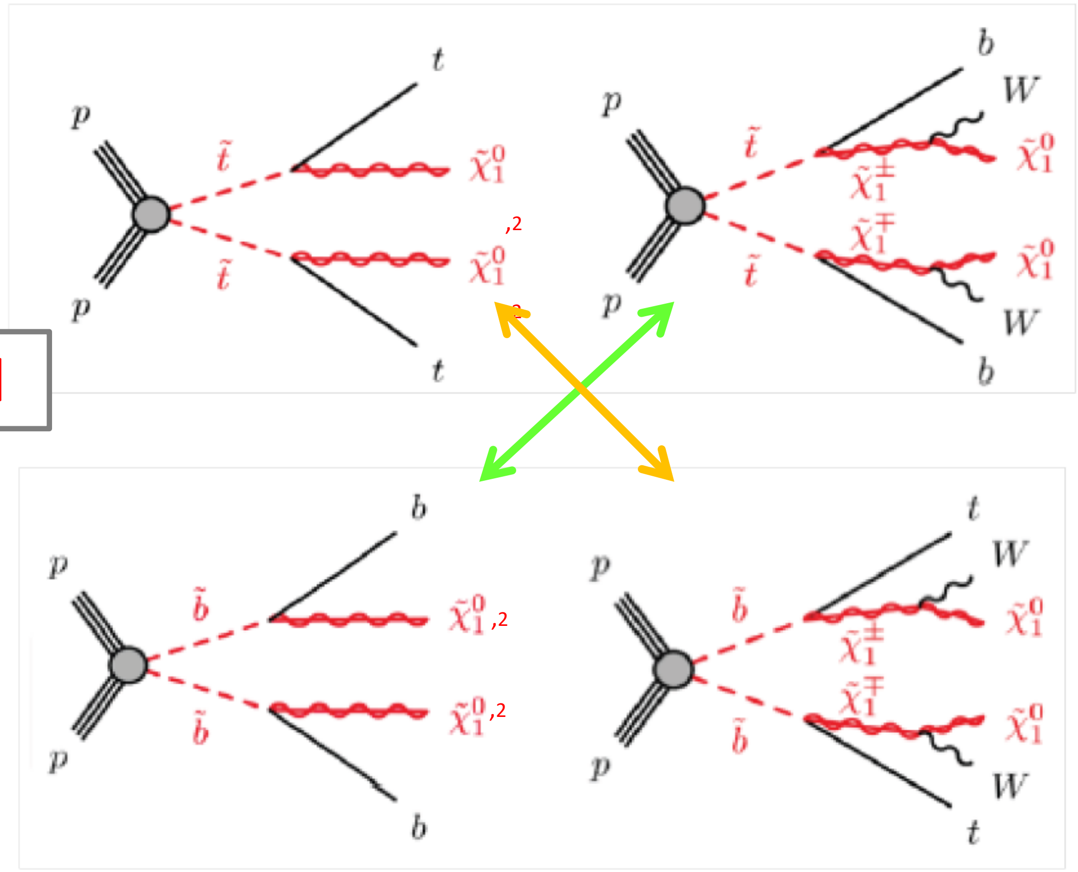
2. Stop with Light Higgsinos @ LHC





Stop pair production

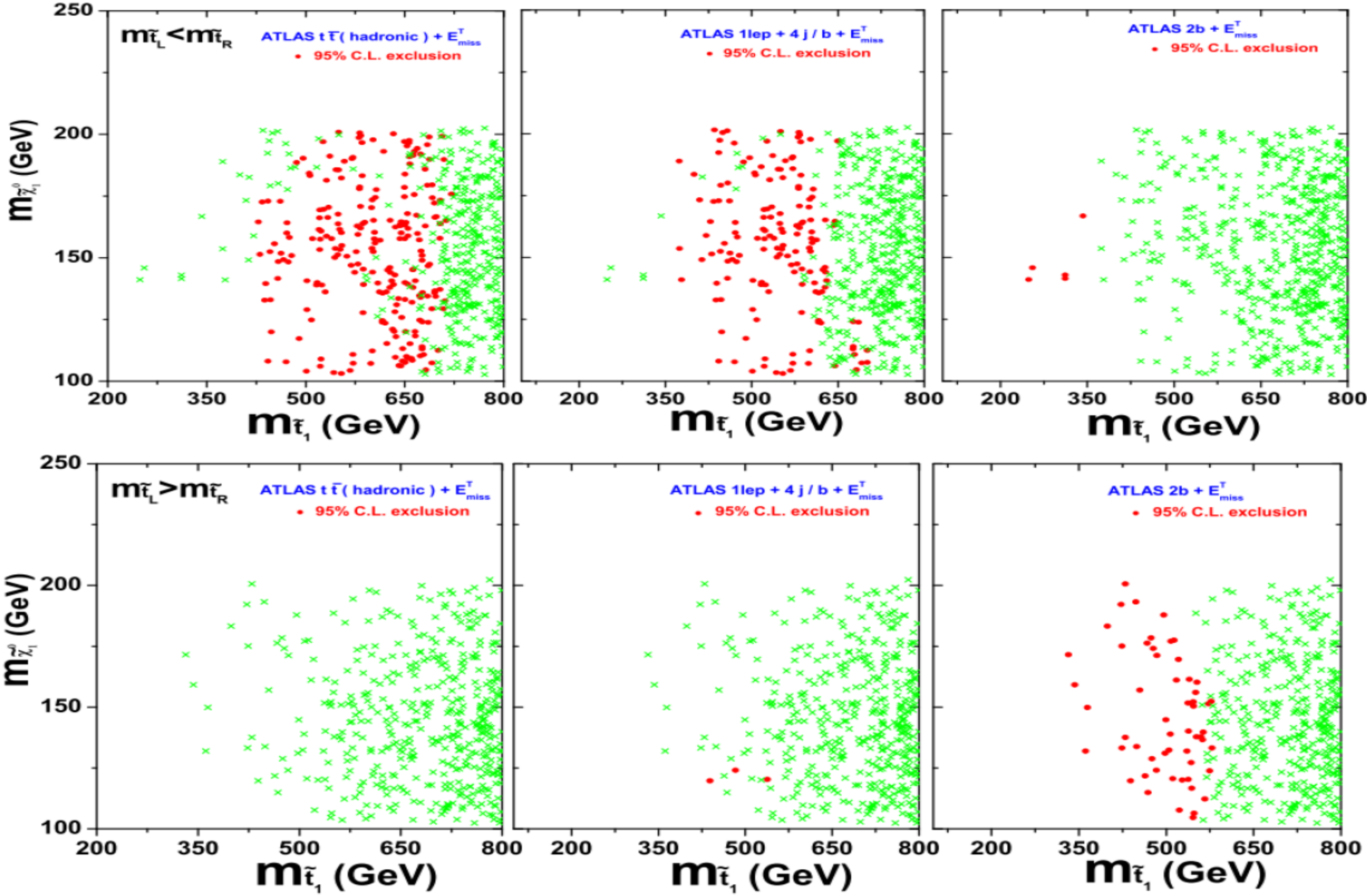
Note that: the stop and sbottom pair production will produce the same topologies due to the degenerate Higgsinos $\tilde{\chi}^0_{1,2}$ and $\tilde{\chi}^\pm_1$.



Left-handed

Han, Hikasa, LW, Yang, Zhang
arXiv:1308.5307, JHEP

LHC-8TeV, 20 fb-1

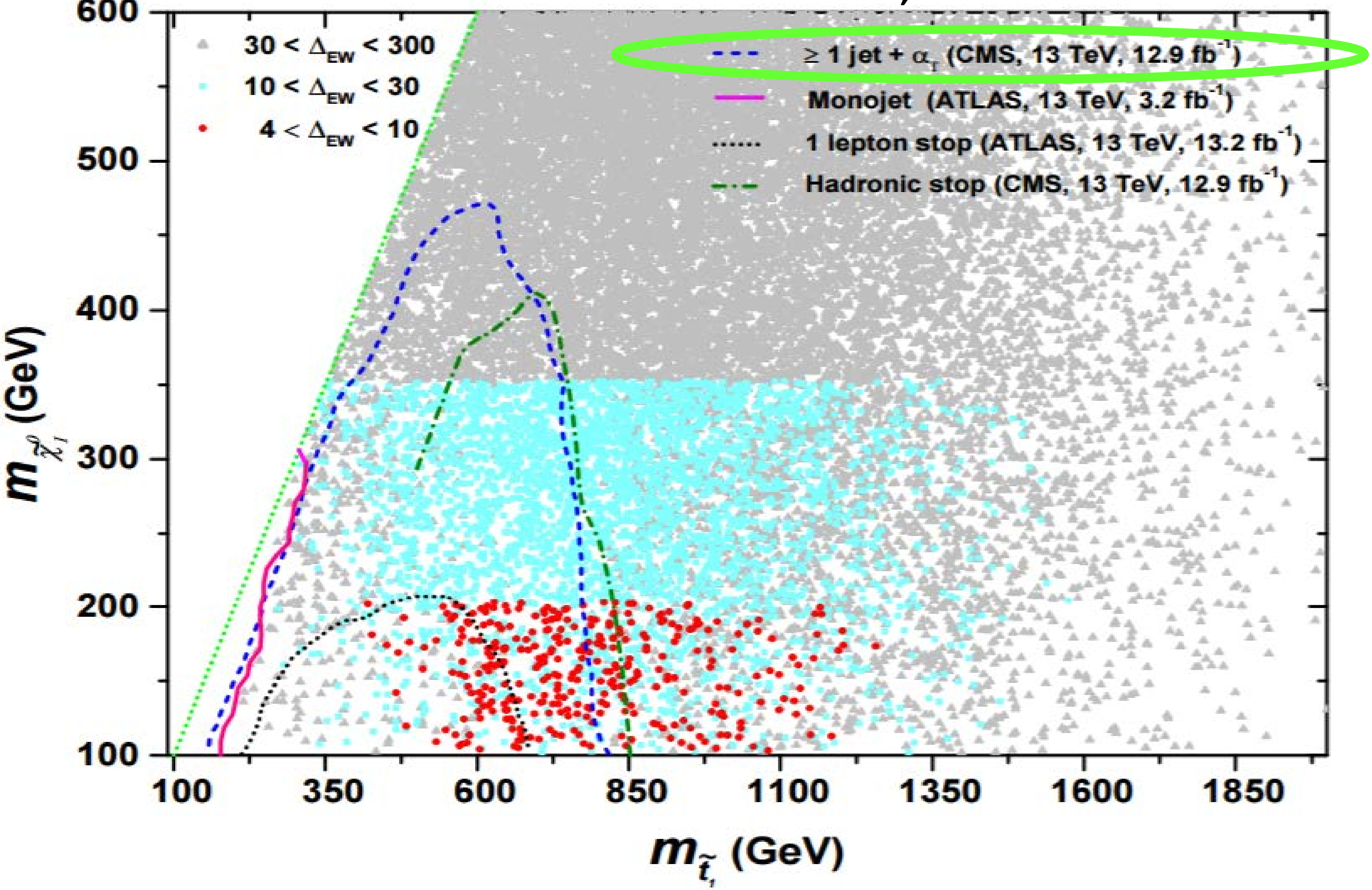


Left-handed stop is constrained more tightly than right-handed stop!

Kobakhidze, Liu, LW, Yang, Zhang
arXiv:1511.02371, PLB

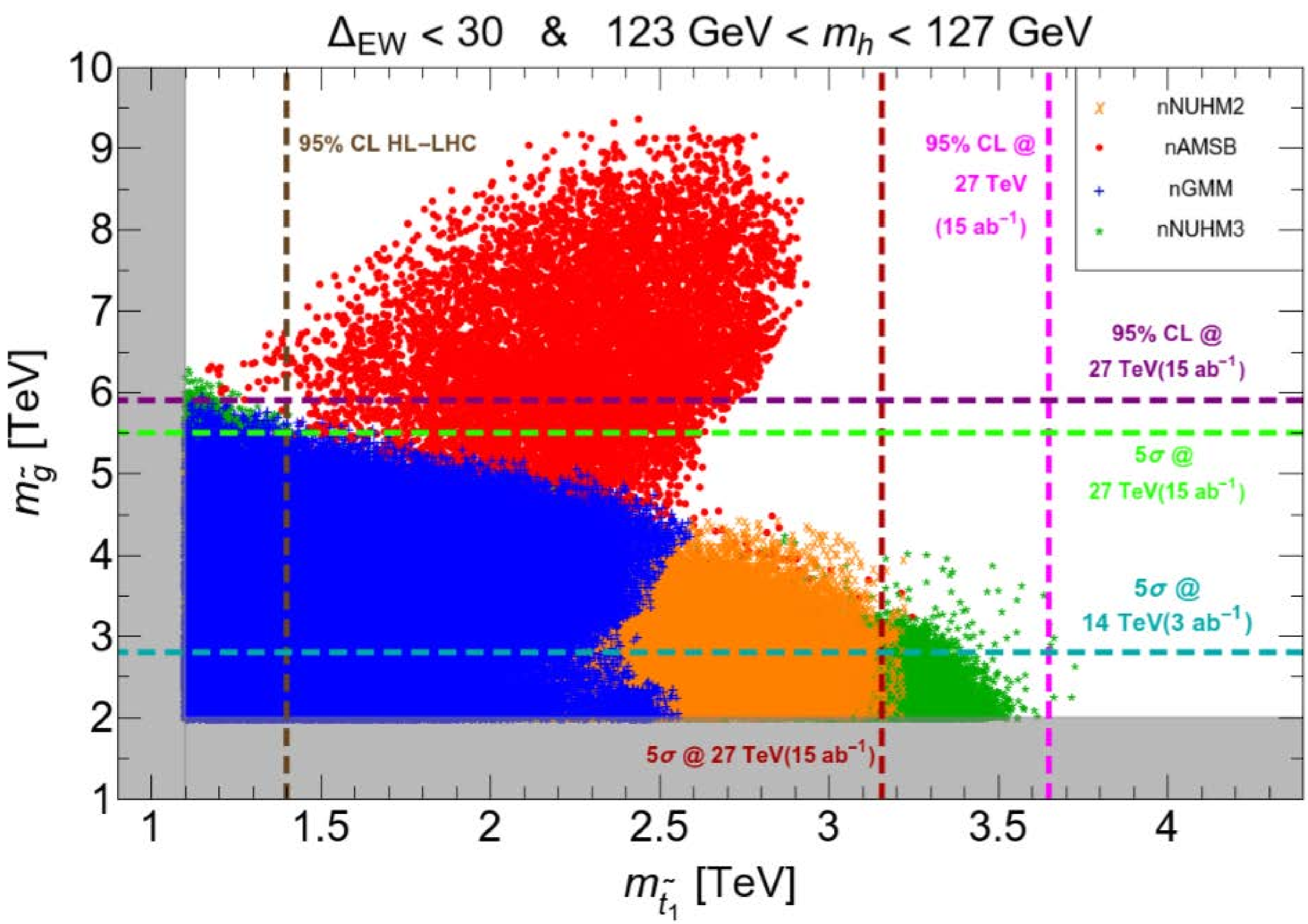
Han, Ren, LW, Yang, Zhang
arXiv:1609.02361, EPJC

13 TeV, 13 fb^-1



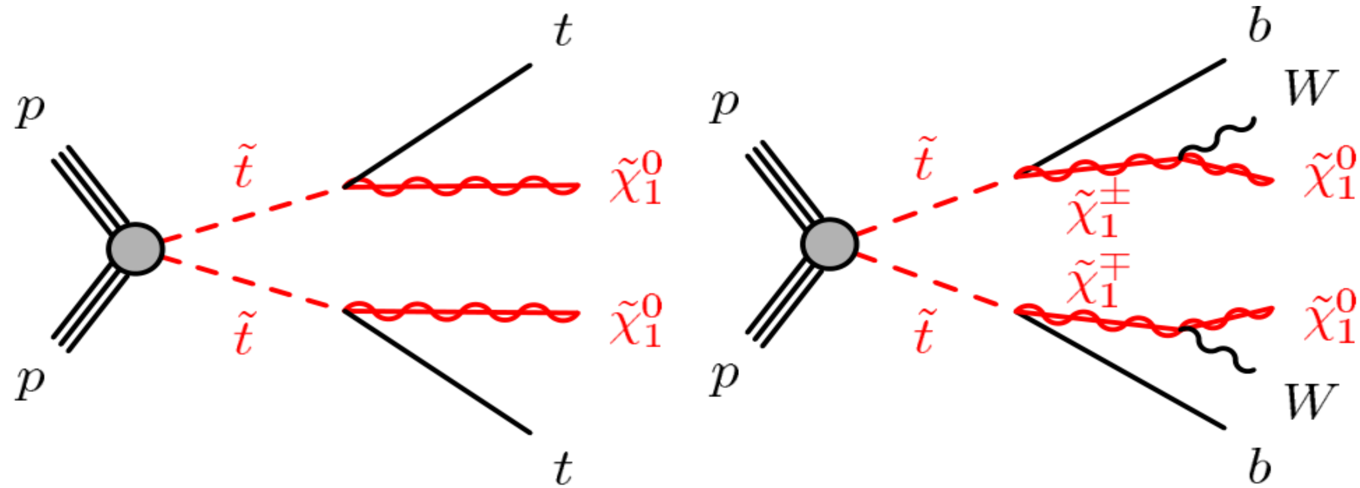
Inclusive SUSY analysis can give a stronger bound than specific stop searches

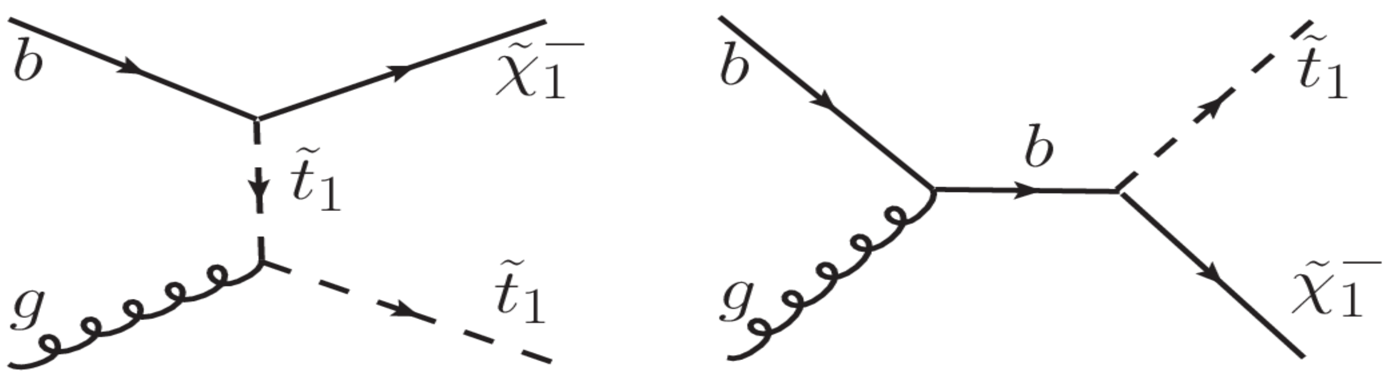
Baer, Barger, Gainer, Sengupta, Serce, Tata, arXiv:1808.04844



Single stop production

Phys.Rev. D93 (2016) no.3, 035003





Mono-top: $pp \to \tilde{t}_1 \tilde{\chi}_1^- \to t\tilde{\chi}_{1,2}^0 \tilde{\chi}_1^- \to bjj + \not{E}_T,$

Backgrounds:

- The main background is the semi- and full-hadronic $t\bar{t}$ events, where the missed lepton and the limited jet energy resolution will lead to the relatively large missing transverse energy;
- The processes $W + \text{jets}$ and $Z + \text{jets}$ can also fake the signal when one of those light-flavor jets are mis-tagged as a b-jet;
- The single top and $t\bar{t} + V$ backgrounds are not considered in our simulations due to their small missing energy or cross sections compared to the above backgrounds.

Event selections:

- We keep the events with the exact one reconstructed top quark and require 150 GeV $< m_t^{\rm rec} <$ 200 GeV;
- The extra leading jet j_1 outside the reconstructed top quark object is vetoed if $p_T(j_1) > 30$ GeV and $|\eta(j_1)| < 2.5$;
- We define eight signal regions for each sample according to $(\not{E}_T, p_T(j_{\rm top}))$ cuts: (200, 100), (250, 150), (300, 200), (350, 250), and $(p_T(b), \not{E}_T)$ cuts: (200, 50), (250, 50), (300, 100), (350, 100) GeV.

Mono-b: $pp \to \tilde{t}_1 \tilde{\chi}_1^- \to b \tilde{\chi}_1^+ \tilde{\chi}_1^- \to b + \not{E}_T$

Backgrounds:

- The main background is the processes $W + \text{jets}$ and $Z + \text{jets}$ when the light-flavor jets are mis-identified as b-jets;
- The $t\bar{t}$ events become the sub-leading backgrounds due to their large multiplicity.

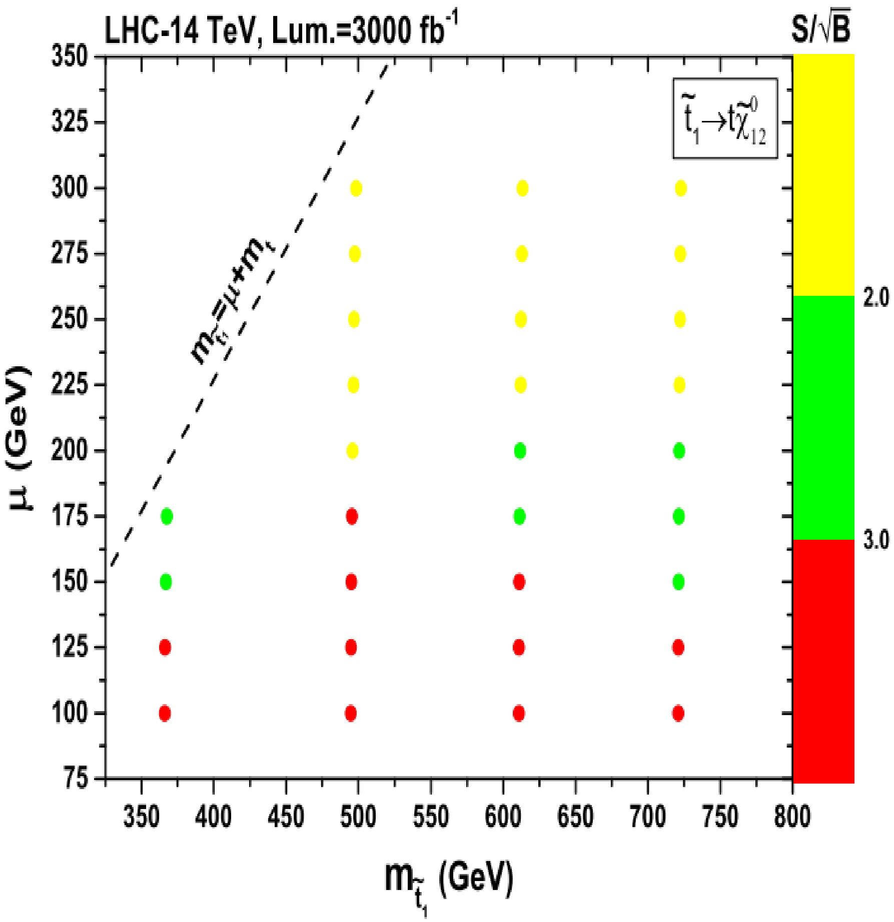
Event slections:

- Events with any isolated leptons are rejected;
- Exact one hard b-jet in the final states, but allow an additional softer jet with $p_T(j_1) < 30$ GeV and $\Delta\phi(\not{E}_T, p_T(j_1)) > 2$.
- Since the hardness of b-jet from stop decay depends on the mass splitting between $\tilde{t}_1$ and $\tilde{\chi}_1^-$, we define four signal regions for each sample according to $(\not{E}_T, p_T(b))$ cuts: (30, 20), (70, 40), (150, 100) and (250, 200) GeV.

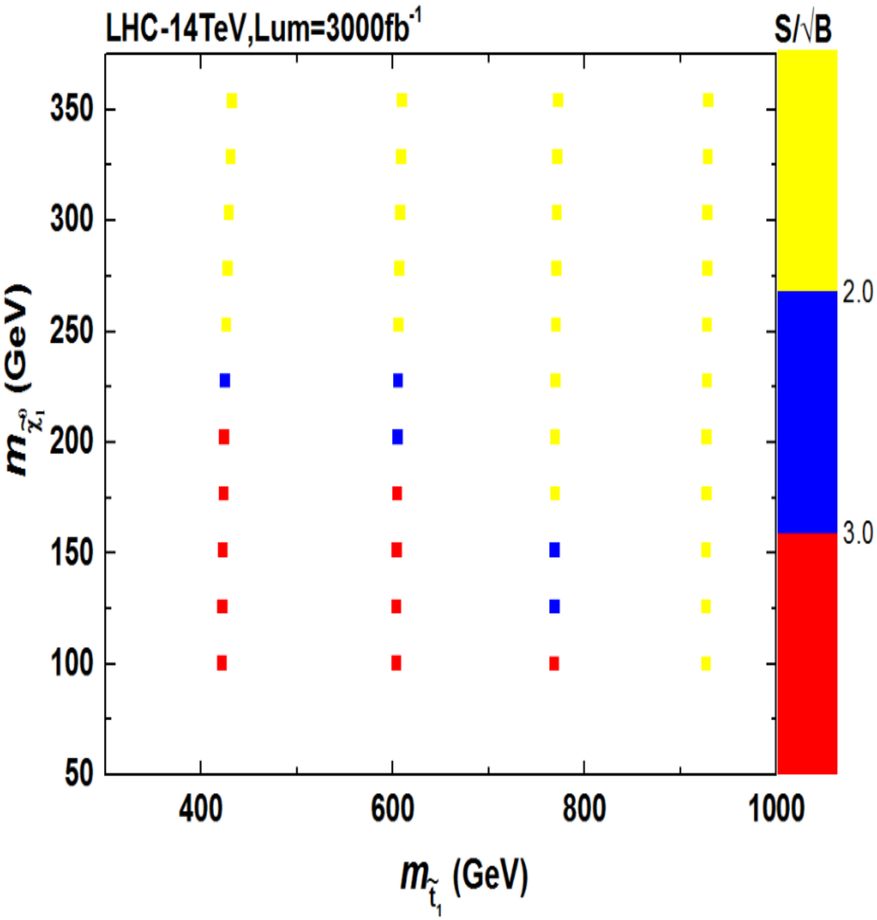
Li, Hikasa, LW, Yang,
arXiv: PRD

Duan, Hikasa, LW, Yang, Zhang,
arXiv: JHEP

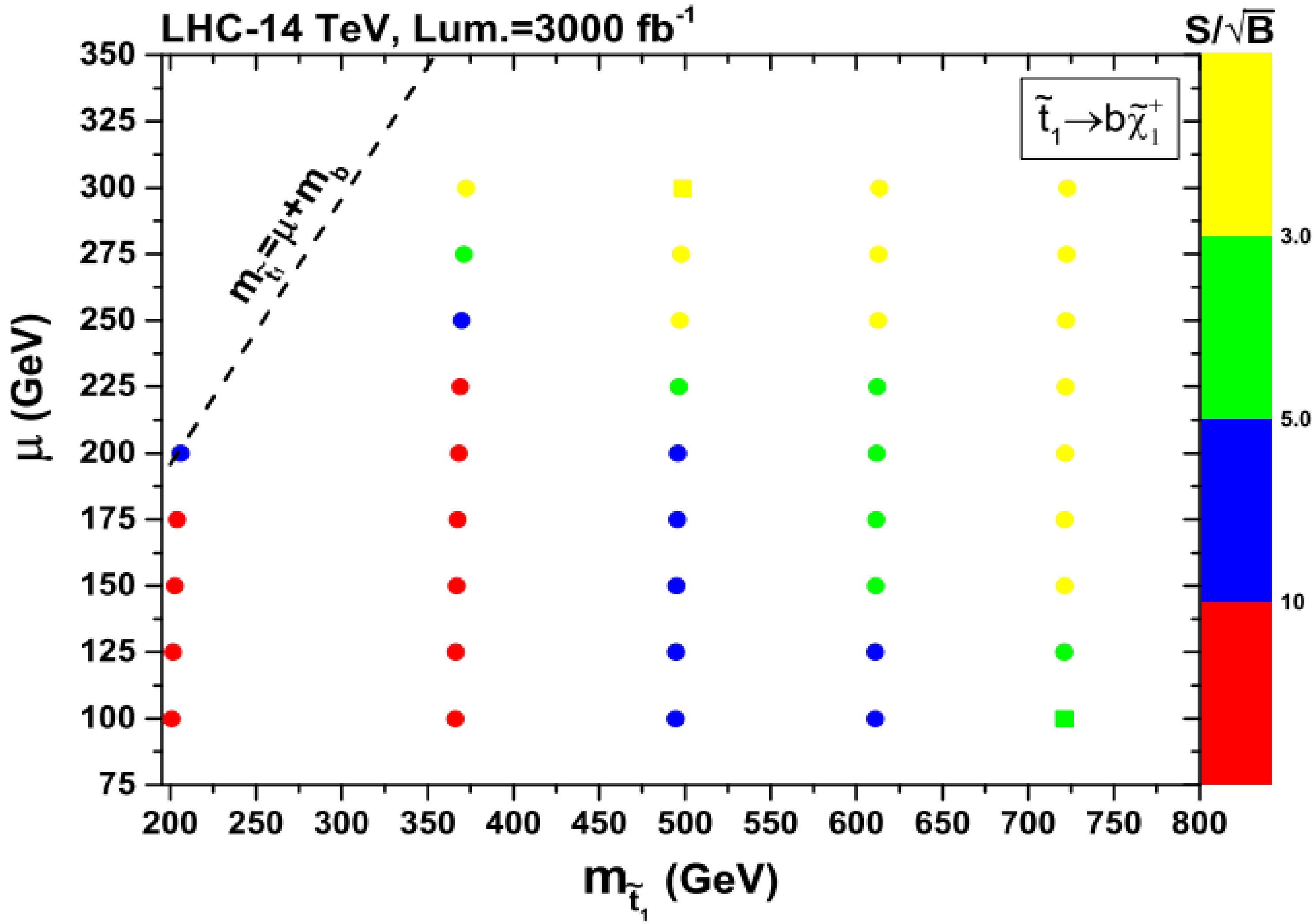
Mono-top(hadronic)



Mono-top(leptonic)

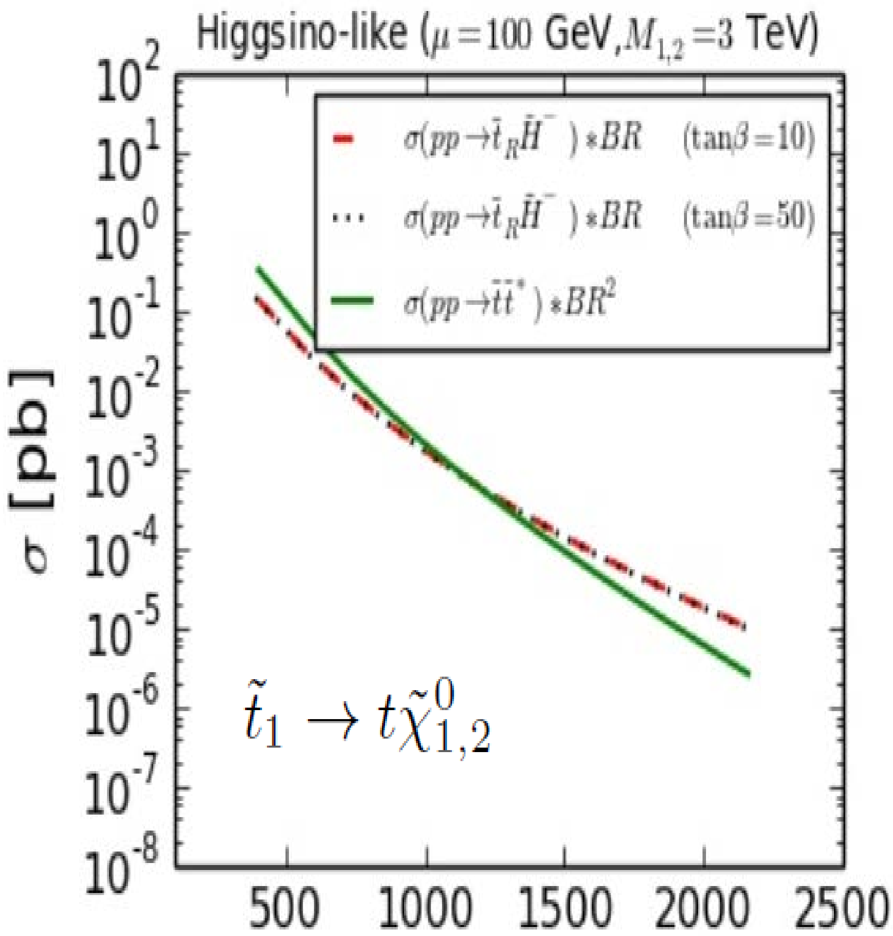


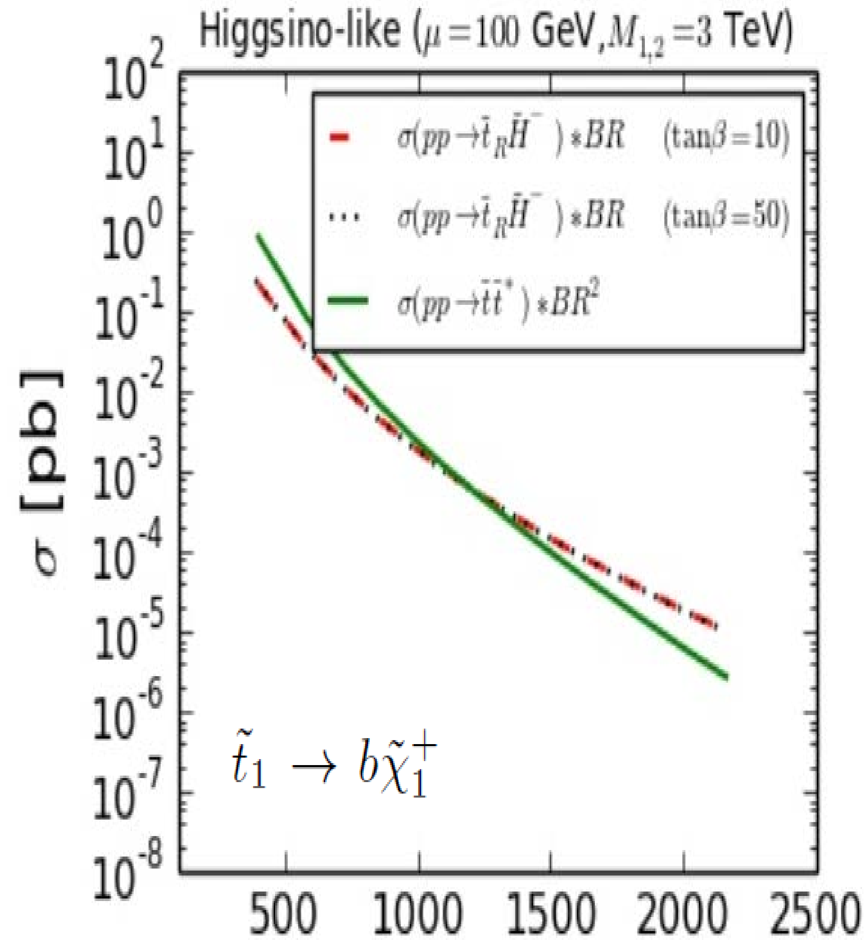
Mono-bottom



LHC-14 TeV, Lum.=3000 fb-1
S/√B
3.0
5.0
10
$\tilde{t}_1 \to b\tilde{\chi}_1^+$
$m_{\tilde{t}_1}=\mu+m_b$
350
325
300
275
250
225
200
175
150
125
100
75
μ (GeV)
200
250
300
350
400
450
500
550
600
650
700
750
800
$m_{\tilde{t}_1}$ (GeV)

Tang, LW, arXiv:1902.xxxxx



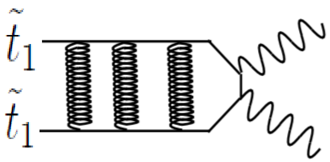


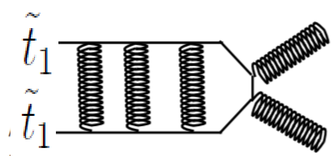
Its cross section is larger than that of stop pair when stop heavier than about 1.2 TeV

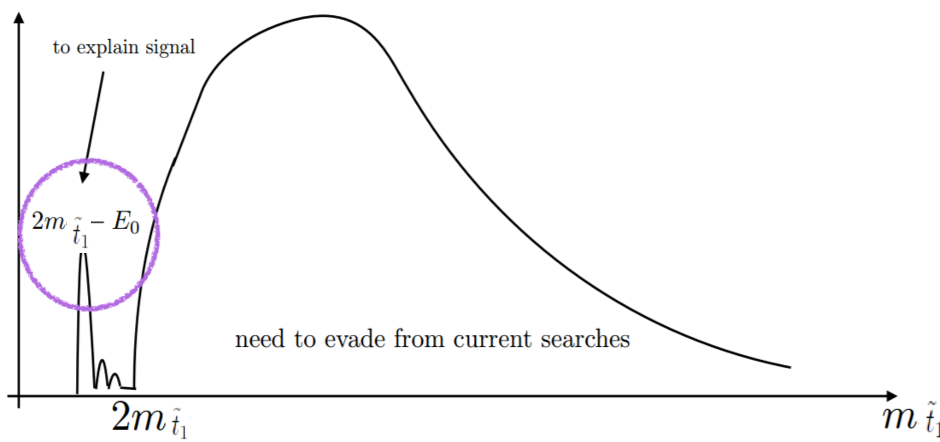
Bound state of Stop

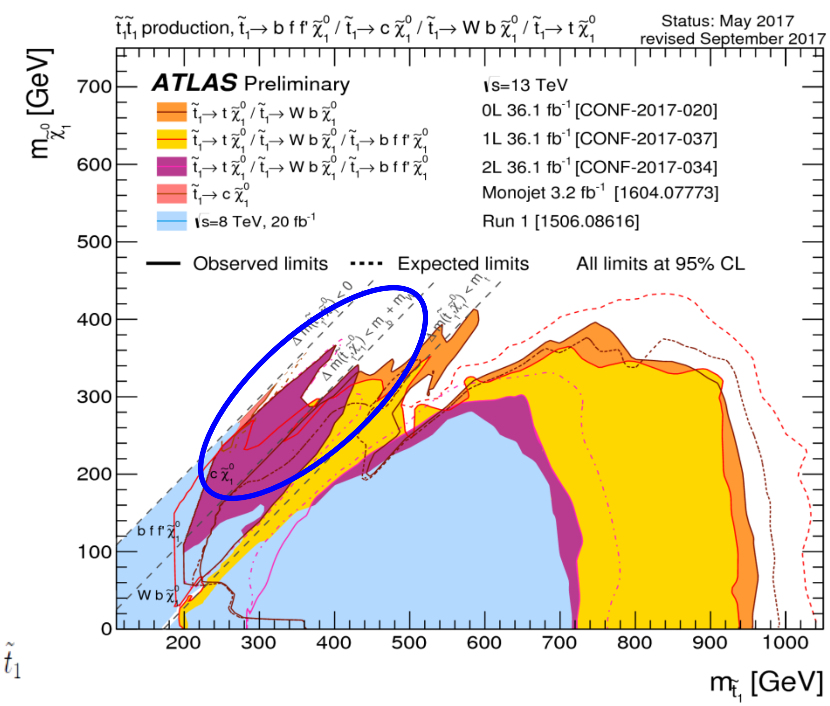
When two-body decay of stop are forbidden, the stops can form bound state near the threshold, if :

$$\Gamma_{\tilde{t}_1} \lesssim E_b = \frac{C^2 \bar{\alpha}_S^2 m_{\tilde{t}}}{4} \quad (\sim 1 \text{ GeV})$$









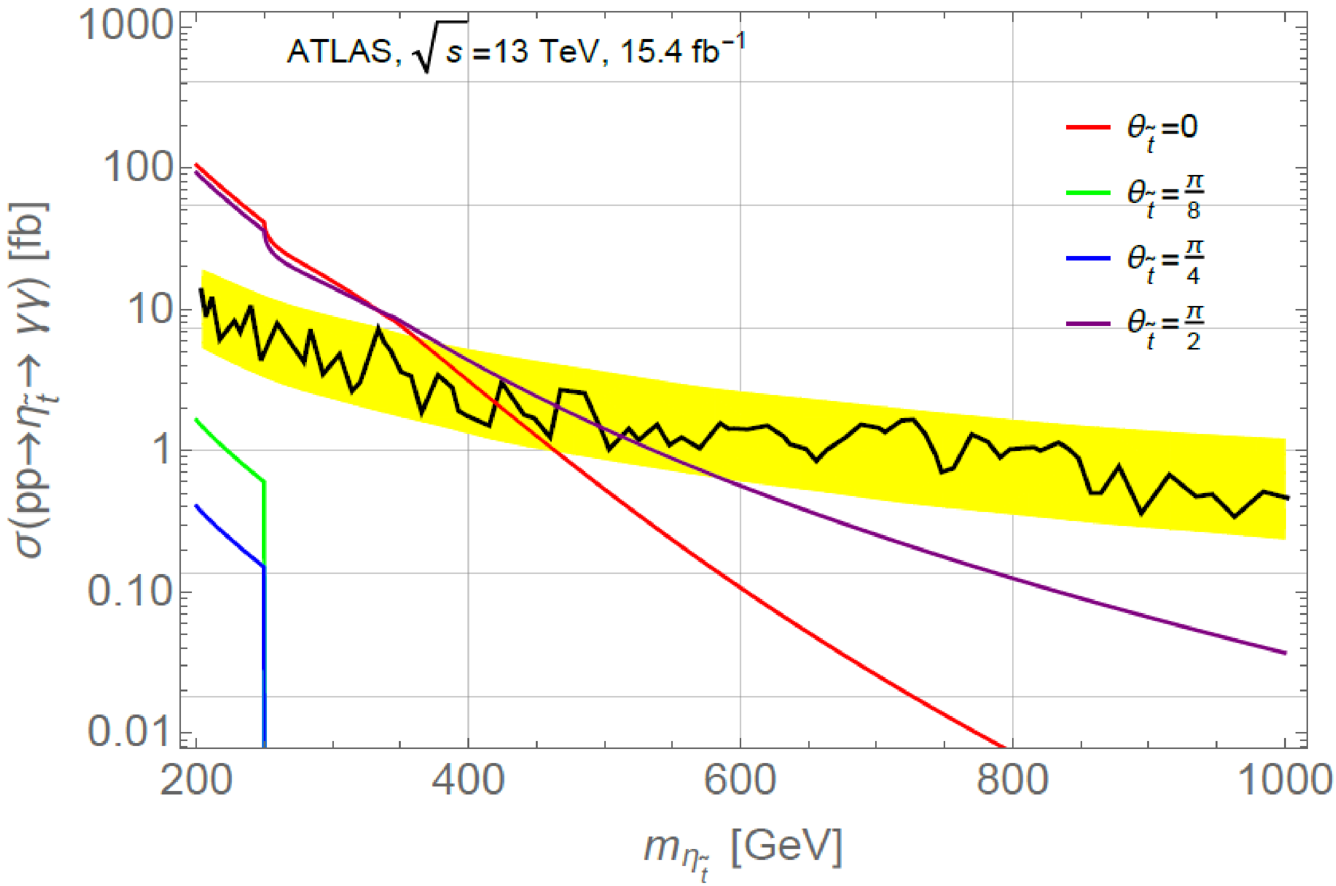
In contrast to existing direct stop pair searches, stoponium if formed,

- **will resonantly decay to a pair of the SM particles and**
- **can be independent of the assumptions of the LSP mass and the branching ratios of the stop.**

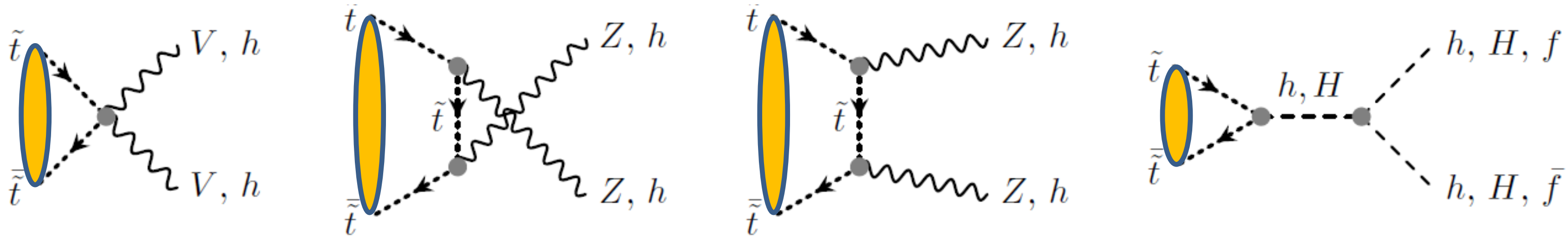
Therefore, the search of stoponium can provide a complementary probe to the direct stop pair production at the LHC.

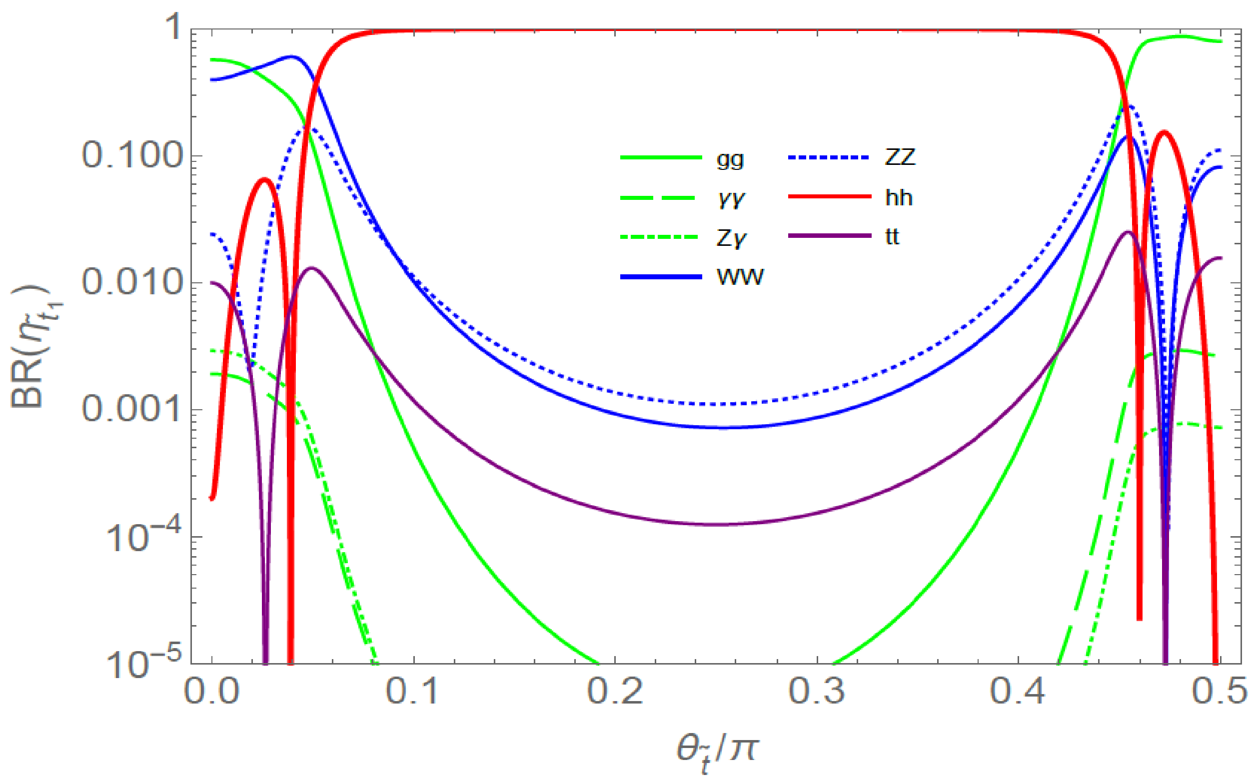
Duan, LW, Zheng
arXiv:1706.07562, JHEP

$$\sigma_{\rm LO}(pp \to \eta_{\tilde{t}}) = \frac{\pi^2}{8m_{\eta_{\tilde{t}}}^3}\Gamma(\eta_{\tilde{t}} \to gg)\mathcal{P}_{gg}(\tau),$$



$$pp \to \eta_{\tilde{t}} \to hh \to b\bar{b}\tau^+\tau^-$$





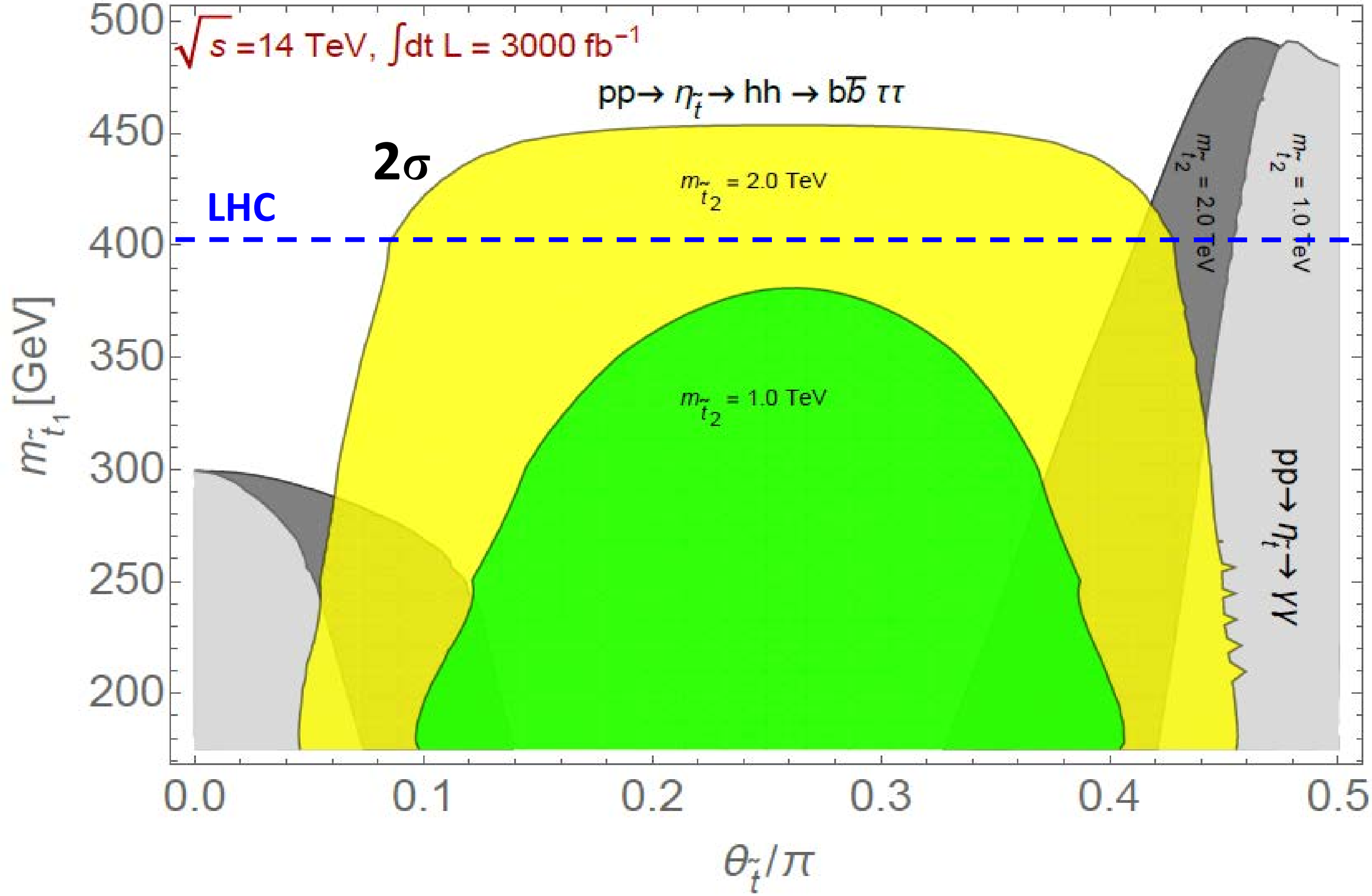
$$pp \to \eta_{\tilde{t}} \to hh \to b\bar{b}\tau^+\tau^-$$

- We require exactly one lepton (e or μ) with $p_T(\ell) > 26$ GeV , $|\eta_e| < 2.47$ or $|\eta_\mu| < 2.5$. We further require the presence of a hadronically decayed tau τ_h carrying opposite electric charge with $p_T(\tau_h) > 20$ GeV and $|\eta_{\tau_h}| < 2.5$.
- We require at least two jets with $p_T(j) > 30$ GeV and $|\eta_j| < 2.5$ and two of them are b tagged.
- We require 80 GeV $< m_{bb} <$ 150 GeV, 80 GeV $< m_{\tau\tau} <$ 150 GeV, $m_T^{\ell\nu} <$ 50 GeV, $p_T^{\tau\tau} >$ 120 GeV and $|m_{bb\tau\tau} - m_{\eta_{\tilde{t}}}| < 0.08 m_{\eta_{\tilde{t}}}$.

Table 1: Cut flow analysis of the cross sections (fb) for the signal and backgrounds at 14 TeV LHC. The benchmark point is chosen as $m_{\eta_{\tilde{t}}} = 500$ GeV and $\sigma(gg \to \eta_{\tilde{t}} \to hh) = 1$ pb.

Cuts	m_{bb} $\in [80, 150]$ GeV	$m_{\tau\tau}$ $\in [80, 150]$ GeV	$m_T^{\ell\nu}$ < 50GeV	$p_T^{\tau\tau}$ > 120GeV	$\lvert m_{bb\tau\tau} - m_{\eta_{\tilde{t}}}\rvert$ $< 0.08 m_{\eta_{\tilde{t}}}$
$t\bar{t}$	445.48	128.79	55.32	12.46	0.29
$Z(\tau\tau)bb$	7.40	5.35	4.70	0.62	< 0.02
$Z(\tau\tau)jj$	11.87	7.92	7.04	1.62	0.13
signal($m_{\eta_{\tilde{t}}} = 500$ GeV)	1.55	0.82	0.64	0.54	0.25

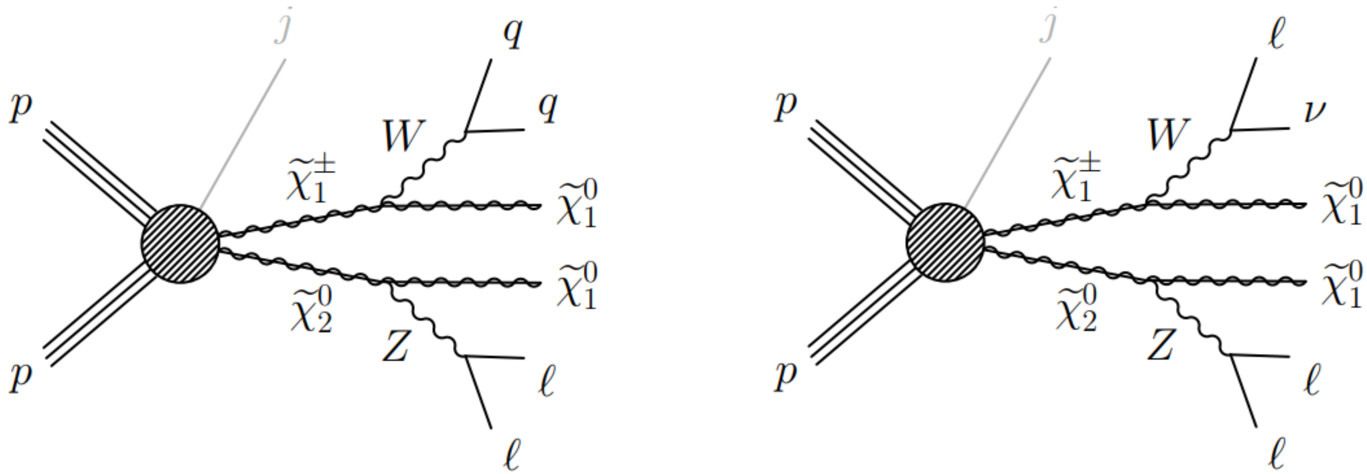
$$pp \to \eta_{\tilde{t}} \to hh$$



Conclusions

- LHC实验数据（Higgs和超粒子）正在改变我们对自然性的认识。
- SUSY模型构建可以多样，但简洁性和自然性似乎不易调和。
- 最小自然超对称虽受到了压力，但仍有大量参数空间存活。限制自然性主要来自LHC，而非其他。期待150 fb-1的新结果。

Excess?



Signal Region	Observed Events	BG Events	Events above BG	Significance (Z)
SR$2\ell_{\mathrm{Low}}$	19	8.4 ± 5.8	10.6 ± 5.8	1.39
SR$2\ell_{\mathrm{ISR}}$	11	$2.7^{+2.8}_{-2.7}$	$8.3^{+2.8}_{-2.7}$	1.99
SR$3\ell_{\mathrm{Low}}$	20	10 ± 2	10 ± 2	2.13
SR$3\ell_{\mathrm{ISR}}$	12	3.9 ± 1.0	8.1 ± 1.0	3.02

第十四届TeV物理工作组学术研讨会

19-22 April 2019
Nanjing Normal University
Asia/Shanghai timezone

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"第十四届TeV物理工作组学术研讨会"兹定于2019年4月19日-22日在南京师范大学召开。会议由清华大学、中国高等科学技术中心、南京师范大学资助并联合主办，南京师范大学承办，南京《物理之友》杂志社有限公司协办。

大会组委会诚挚地邀请各位同仁参加本届会议！由于会务组邮件列表不全，请各位老师帮忙转发给您的同事及研究生。

本次会议的主要目的是交流国内外TeV物理领域最新研究成果和进展，促进我国在TeV物理方面的研究和合作，尤其是理论与实验的合作。会议内容涉及LHC实验的进展和最新结果；新物理理论进展及唯象研究；Higgs物理；Top夸克物理；重味物理和CP破坏；暗物质、中微子及宇宙学；散射振幅及精确计算；未来高能加速器物理等方面。竭诚鼓励青年学者积极参加。

会议有关事项：

一、会议时间：
2019年4月19日一4月22日，4月19日报到。

二、会议注册：
网上注册截止日期：2019年4月05日
会议网址：https://indico.ihep.ac.cn/event/8979/
现场注册日期：2019年4月19日
现场注册地点：物理科学与技术学院（行健楼）

三、报告提交：
请于注册截止日期之前，网上提交报告题目和内容简介。或邮件发送地方会务组。

四、注册费：
注册费为教师、博士后1000元/人，硕士、博士生800元/人，
家属800元/人（1.1米以下儿童免费）。
会议统一安排食宿，费用自理。

五、会议代表住宿：
1、仙林宾馆(三星级，南师大校内)
2、新地酒店(五星级，距离会场大约2.3km)

六、会务组：
负责人：邝宇平、王青、韩涛、安海鹏、陈新。
地方会务组：武雷 (leiwu@njnu.edu.cn，18305160892)
肖振军、平加仑、孙鹏、刘宁、周航、朱瑞林、何秉然、黄日俊、郭立波、何军、王琦、金立刚、钟彬、黄红霞

Backup

Some predictions of SUSY

- Top quark mass, is within the range required to trigger a radiatively-driven breakdown of electroweak symmetry

- Higgs mass, fall squarely with the narrow window of MSSM prediction

In the MSSM, the stop mass matrix in the gauge-eigenstate basis $(\tilde{t}_L,\tilde{t}_R)$ is given by

$$M_{\tilde{t}}^2 = \begin{pmatrix} m_{\tilde{t}_L}^2 & m_t X_t^\dagger \\ m_t X_t & m_{\tilde{t}_R}^2 \end{pmatrix} \tag{2.1}$$

with

$$m_{\tilde{t}_L}^2 = m_{\tilde{Q}_{3L}}^2 + m_t^2 + m_Z^2\left(\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right)\cos 2\beta, \tag{2.2}$$

$$m_{\tilde{t}_R}^2 = m_{\tilde{U}_{3R}}^2 + m_t^2 + \frac{2}{3}m_Z^2 \sin^2\theta_W \cos 2\beta, \tag{2.3}$$

$$X_t = A_t - \mu\cot\beta. \tag{2.4}$$

Here $m_{\tilde{Q}_{3L}}$ and $m_{\tilde{U}_{3R}}$ are the soft-breaking mass parameters for the third generation left-handed squark doublet $\tilde{Q}_{3L}$ and the right-handed stop $\tilde{U}_{3R}$, respectively. A_t is the stop soft-breaking trilinear parameter. The generation mixing is neglected here. This hermitian matrix can be diagonalized by a unitary transformation:

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{t}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_{\tilde{t}} & \sin\theta_{\tilde{t}} \\ -\sin\theta_{\tilde{t}} & \cos\theta_{\tilde{t}} \end{pmatrix}\begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix}, \tag{2.5}$$

where $\theta_{\tilde{t}}$ is the mixing angle between left-handed $(\tilde{t}_L)$ and right-handed $(\tilde{t}_R)$ stops. In the mass eigenstates, the relevant interactions of the stop and electroweakinos are given by

$$\mathcal{L}_{\tilde{t}_1\bar{b}\tilde{\chi}_i^+} = \tilde{t}_1\bar{b}(f_L^C P_L + f_R^C P_R)\tilde{\chi}_i^+ + h.c.\,, \tag{2.6}$$

$$\mathcal{L}_{\tilde{t}_1\bar{t}\tilde{\chi}_i^0} = \tilde{t}_1\bar{t}(f_L^N P_L + f_R^N P_R)\tilde{\chi}_i^0 + h.c.\,, \tag{2.7}$$

where $P_{L/R} = (1 \mp \gamma_5)/2$, and

$$f_L^N = -\left[\frac{g_2}{\sqrt{2}} N_{i2} + \frac{g_1}{3\sqrt{2}} N_{i1}\right] \cos\theta_{\tilde{t}} - y_t N_{i4} \sin\theta_{\tilde{t}} \tag{2.8}$$

$$f_R^N = \frac{2\sqrt{2}}{3} g_1 N_{i1}^* \sin\theta_{\tilde{t}} - y_t N_{i4}^* \cos\theta_{\tilde{t}}, \tag{2.9}$$

$$f_L^C = y_b U_{i2}^* \cos\theta_{\tilde{t}}, \tag{2.10}$$

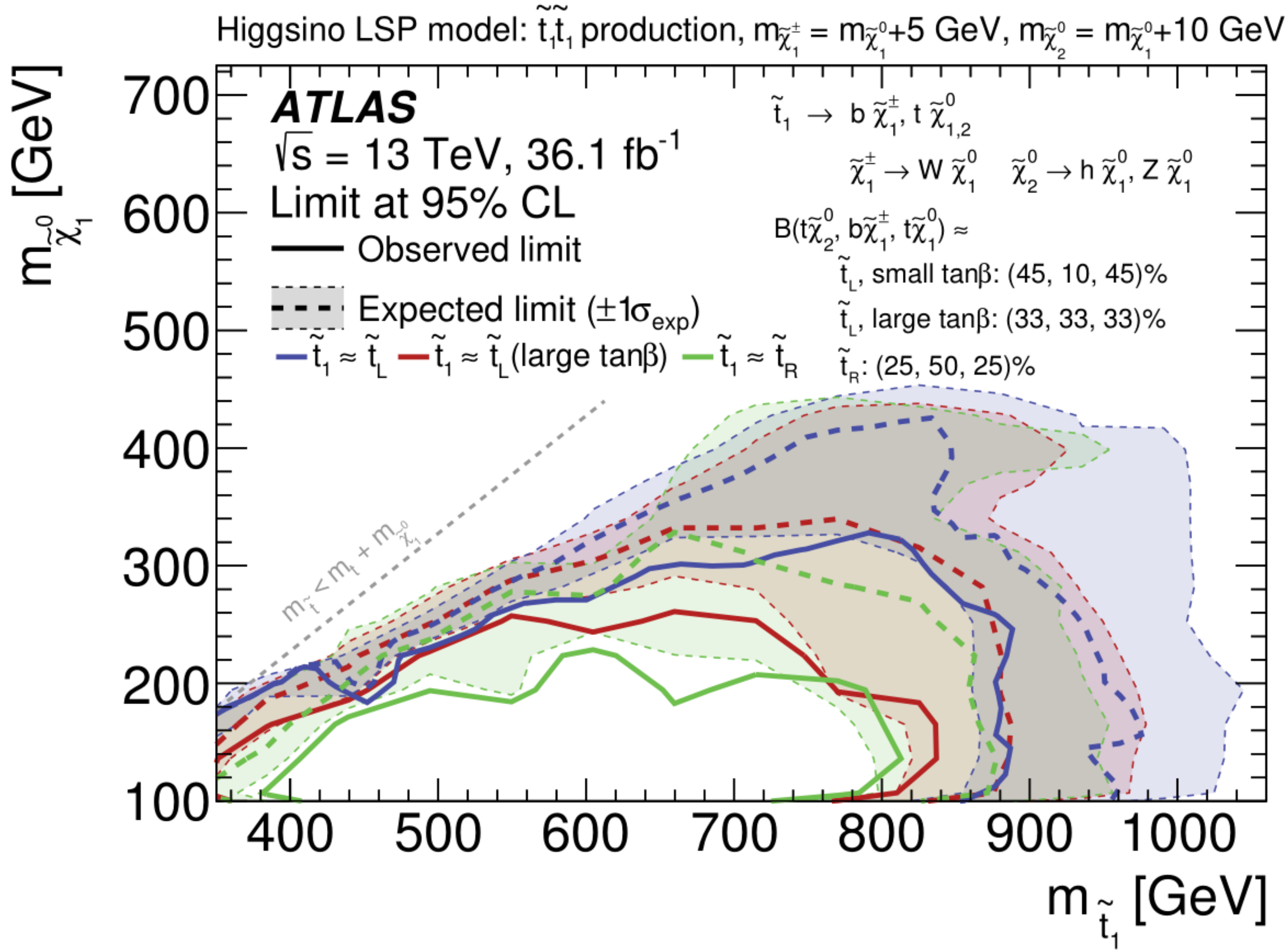
$$f_R^C = -g_2 V_{i1} \cos\theta_{\tilde{t}} + y_t V_{i2} \sin\theta_{\tilde{t}}, \tag{2.11}$$

with $y_t = \sqrt{2} m_t/(v \sin\beta)$ and $y_b = \sqrt{2} m_b/(v\cos\beta)$ being the top and bottom Yukawa couplings, respectively. When $\tan\beta$ is large, the values of y_b can be sizable. The neutralino and chargino mixing matrices N_{ij}, U_{ij}, V_{ij} are defined in [50]. The compressed electroweakino spectrum, $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} \ll m_{\tilde{\chi}_1^0}$, can be realized in two limits:

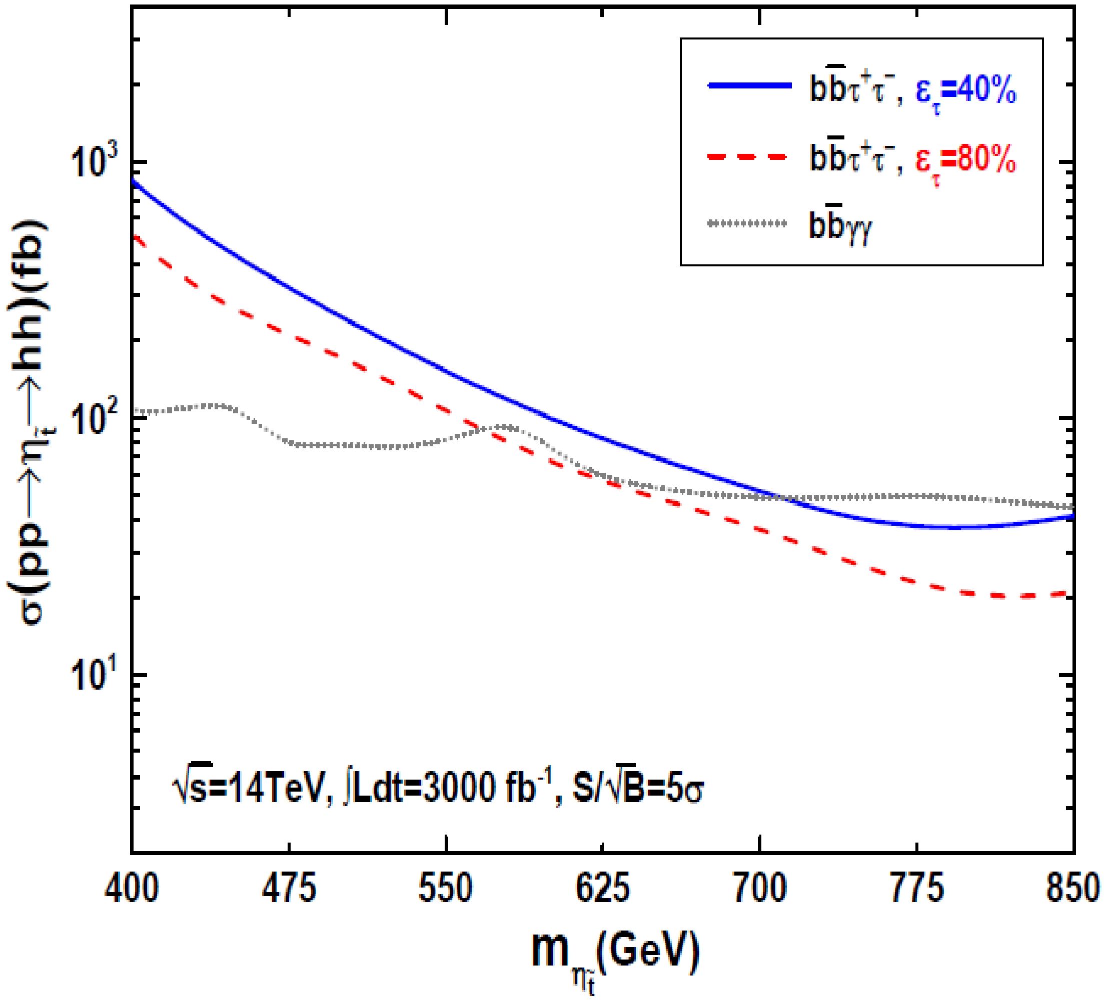
(i) $\mu \ll M_{1,2}$, $V_{11}, U_{11}, N_{11,12,21,22} \sim 0$, $V_{12} \sim \mathrm{sgn}(\mu)$, $U_{12} \sim 1$ and $N_{13,14,23} = -N_{24} \sim 1/\sqrt{2}$. In this limit, the two neutralinos $\tilde{\chi}_{1,2}^0$ and the chargino $\tilde{\chi}_1^\pm$ are nearly degenerate higgsinos ($\tilde{H}^\pm$). Such a higgsino LSP scenario may be probed at the high luminosity LHC [51–55].

(ii) $M_2 \ll \mu, M_1$, $V_{11}, U_{11} \sim 1$, $V_{12}, U_{12} \sim 0$, $N_{11,13,14}$, $N_{22,23,24} \sim 0$, and $N_{12,21} \sim 1$. In this case, the lightest neutralino $\tilde{\chi}_1^0$ and the lighter chargino $\tilde{\chi}_1^\pm$ are nearly degenerate winos ($\tilde{W}^\pm$). If the small splitting between $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ is not too small, the mono-jet with soft photon events can be used to detect this wino LSP scenario at the LHC [56–58].

$$
\begin{aligned}
\Sigma_u^u(\tilde{t}_{1,2}) &= \frac{3}{16\pi^2} F(\tilde{t}_{1,2}) \times \left[y_t^2 - g_Z^2 \mp \frac{y_t^2 A_t^2 - 8 g_Z^2 (\frac{1}{4} - \frac{2}{3} s_w^2) \Delta_t}{m_{\tilde{t}_2} - m_{\tilde{t}_1}} \right]. \\
\Sigma_d^d(\tilde{t}_{1,2}) &= \frac{3}{16\pi^2} F(\tilde{t}_{1,2}) \times \left[g_Z^2 \mp \frac{y_t^2 \mu^2 + 8 g_Z^2 (\frac{1}{4} - \frac{2}{3} s_w^2) \Delta_t}{m_{\tilde{t}_2} - m_{\tilde{t}_1}} \right]. \\
F(m^2) &= m^2 \left(\ln \frac{m^2}{Q^2} - 1 \right); \quad Q^2 = m_{\tilde{t}_1} m_{\tilde{t}_2}; \quad \Delta_t = (m_{\tilde{t}_L}^2 - m_{\tilde{t}_R}^2)/2
\end{aligned}
$$



Higgsino LSP model: $\tilde{t}_1\tilde{t}_1$ production, $m_{\tilde{\chi}_1^\pm} = m_{\tilde{\chi}_1^0}$+5 GeV, $m_{\tilde{\chi}_2^0} = m_{\tilde{\chi}_1^0}$+10 GeV
ATLAS
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
Limit at 95% CL
Observed limit
Expected limit ($\pm1\sigma_{exp}$)
$\tilde{t}_1 \approx \tilde{t}_L$
$\tilde{t}_1 \approx \tilde{t}_L$(large tanβ)
$\tilde{t}_1 \approx \tilde{t}_R$
$\tilde{t}_1 \rightarrow b\,\tilde{\chi}_1^\pm, t\,\tilde{\chi}_{1,2}^0$
$\tilde{\chi}_1^\pm \rightarrow W\,\tilde{\chi}_1^0$ $\tilde{\chi}_2^0 \rightarrow h\,\tilde{\chi}_1^0, Z\,\tilde{\chi}_1^0$
$B(t\tilde{\chi}_2^0, b\tilde{\chi}_1^\pm, t\tilde{\chi}_1^0) \approx$
$\tilde{t}_L$, small tanβ: (45, 10, 45)%
$\tilde{t}_L$, large tanβ: (33, 33, 33)%
$\tilde{t}_R$: (25, 50, 25)%
$m_{\tilde{t}} < m_t + m_{\tilde{\chi}_1^0}$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]



$b\bar{b}\tau^+\tau^-$, ε_τ=40%
$b\bar{b}\tau^+\tau^-$, ε_τ=80%
$b\bar{b}\gamma\gamma$
$\sqrt{s}$=14TeV, $\int Ldt$=3000 fb^{-1}, S/$\sqrt{B}$=5σ
$\sigma(pp\to\eta_{\tilde{t}}\to hh)$(fb)
10^1
10^2
10^3
400
475
550
625
700
775
850
$m_{\eta_{\tilde{t}}}$(GeV)