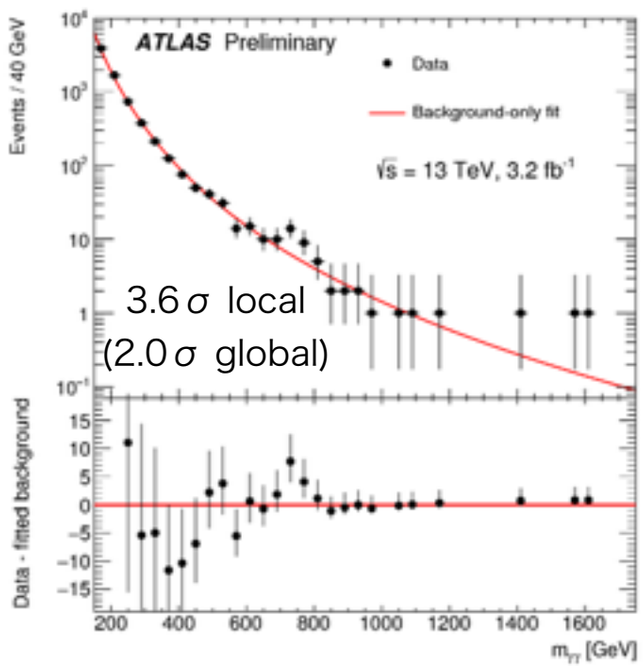
Supersymmetric ttH production

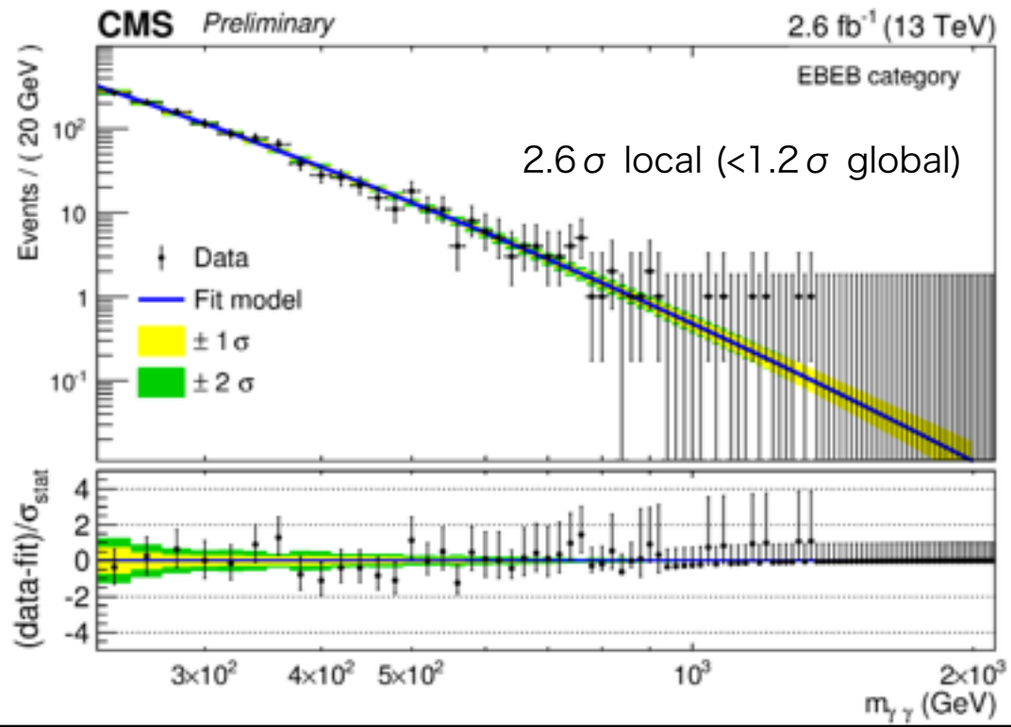
Michihisa Takeuchi (Kavli IPMU, Univ. of Tokyo)
in collaboration with Kazuki Sakurai and Dorival Goncalves

before and after ICHEP

before ICHEP

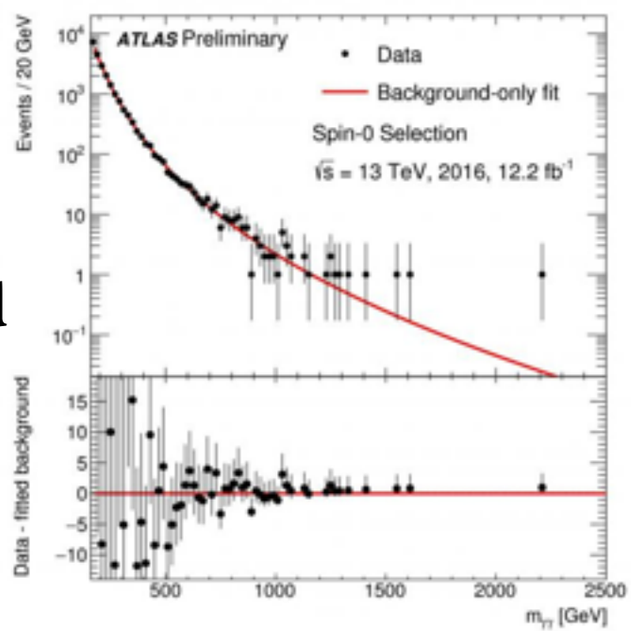
$m_{\gamma\gamma} \sim 750\mathrm{GeV}$

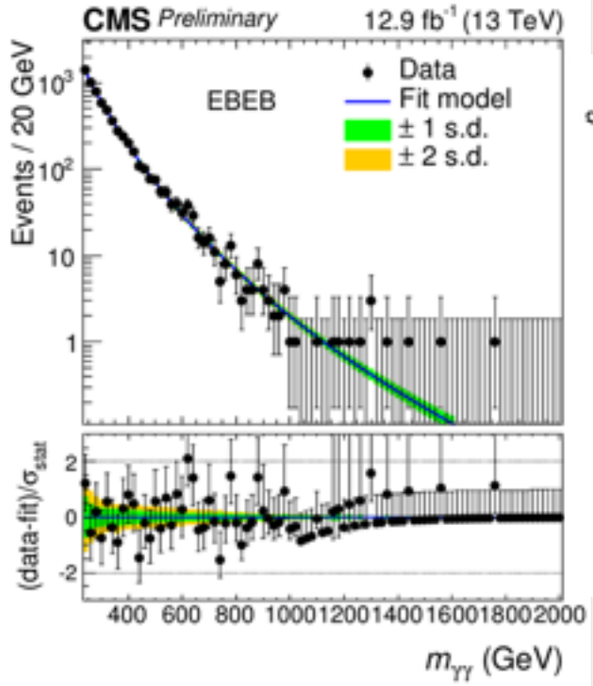


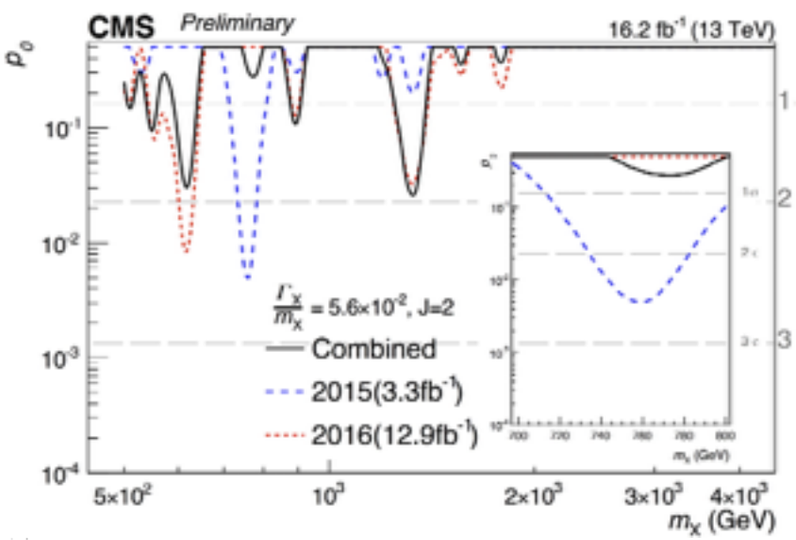


after ICHEP

signal disappeared



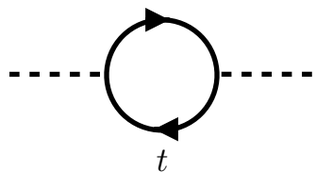




many theorists disappointed, but not only diphoton, lets move back to more motivated signals

Stop search

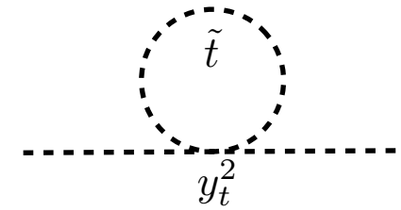
Solving hierarchy problem requires top partner: stop

$\delta m_h^2 \sim$  $\sim -\frac{3}{4\pi} y_t^2 \Lambda_{\rm SM}^2 \sim 10^{38}{\rm GeV}^2 (\Lambda_{\rm SM} = m_{\rm Pl})$

Higgs mass receives quantum corrections of the order of highest mass scale

⇨ New physics should appear around TeV scale to avoid fine tuning

SUSY: popular candidate

$\delta m_h^2 \sim$  $\sim +\frac{3}{4\pi} y_t^2 \Lambda^2$

new particle, same coupling by symmetry

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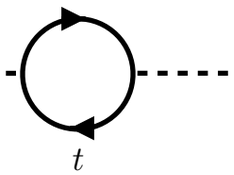
$$\delta m_h^2 \sim$$  $$\sim -\frac{3}{4\pi} y_t^2 \Lambda_{\rm SM}^2 \sim 10^{38}{\rm GeV}^2 (\Lambda_{\rm SM} = m_{\rm Pl})$$

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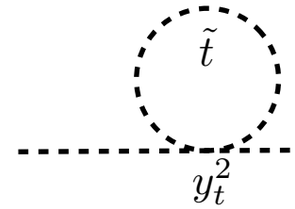
$$\delta m_h^2 \sim$$  $$\sim +\frac{3}{4\pi} y_t^2 \Lambda^2$$

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current status (Bino LSP: tt+missing)

CMS-PAS-SUS-16-028
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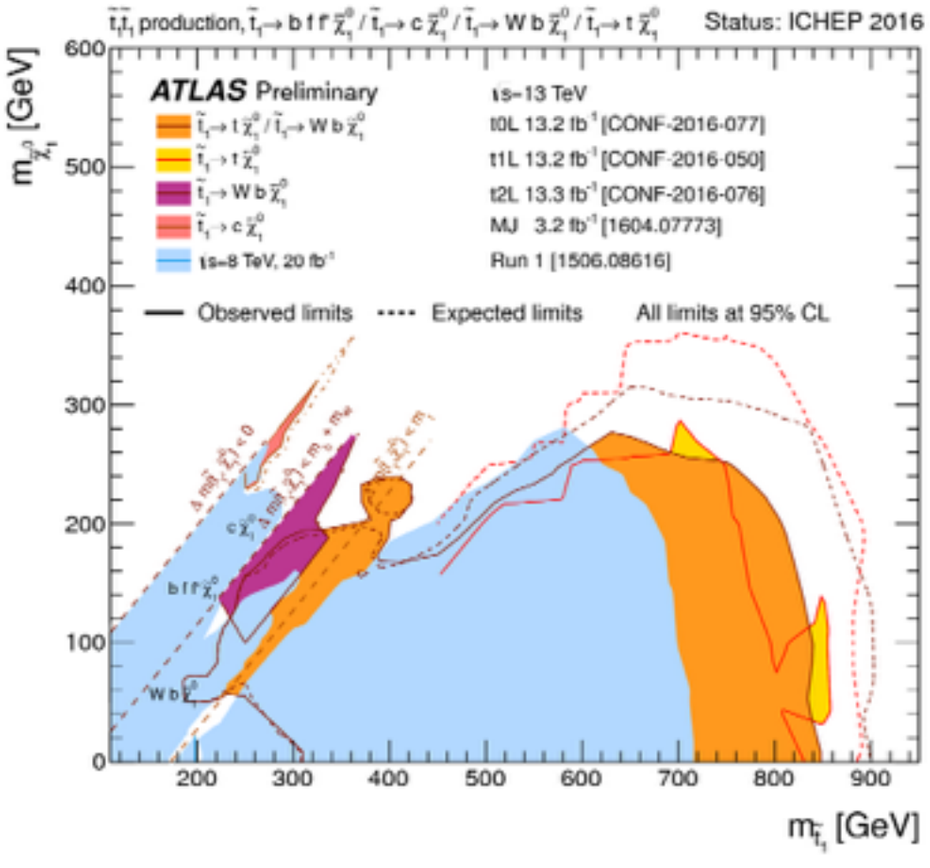
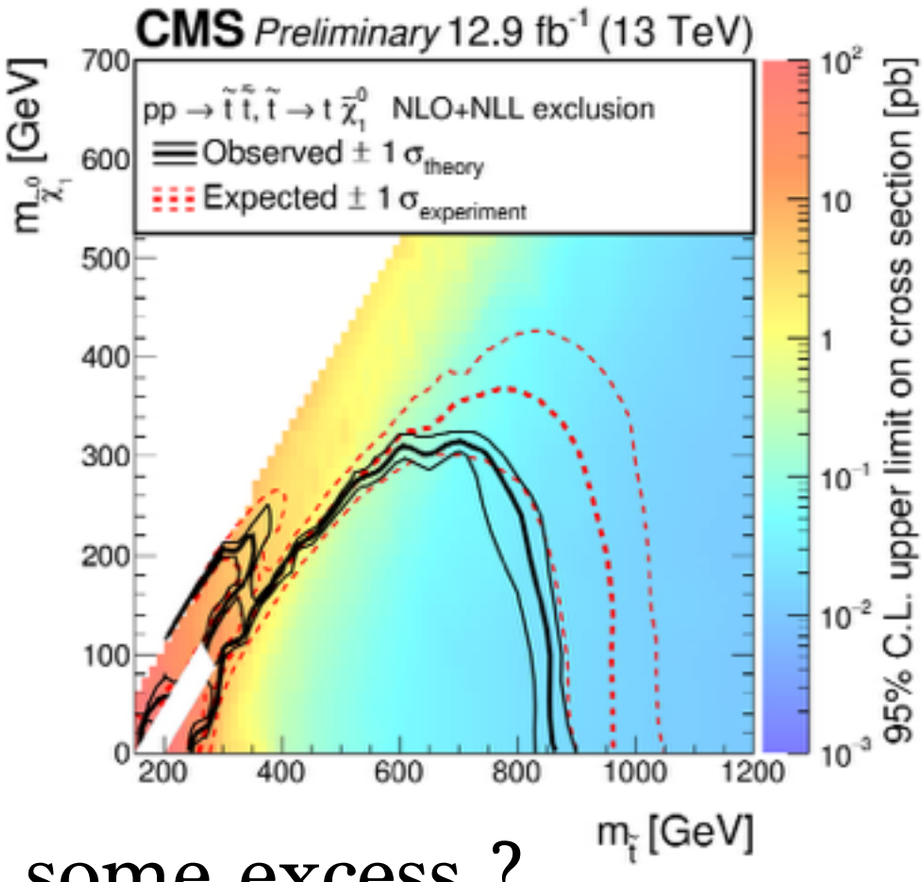




up to ~800 excluded ?

some excess ?

Natural SUSY

natural spectrum: light higgsino and light stop

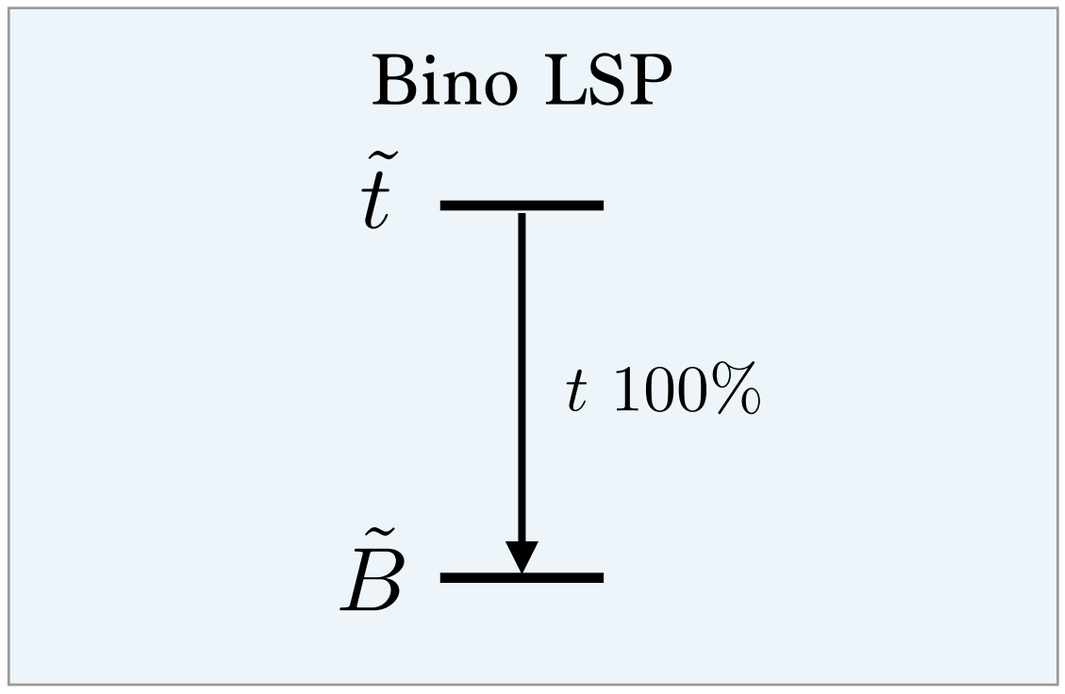
EWSB condition:

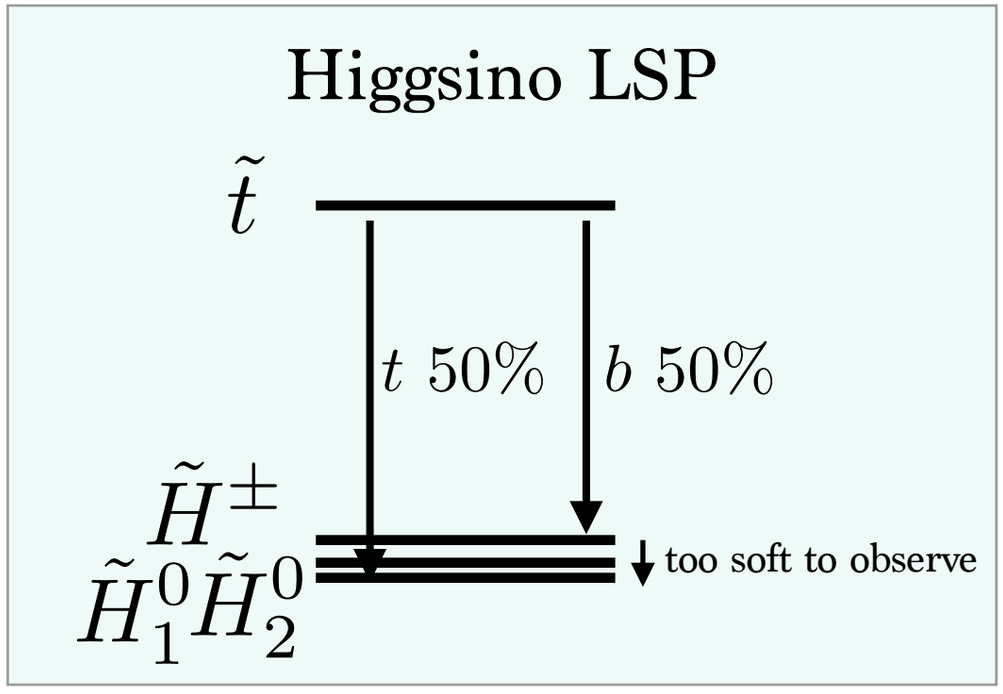
$$-\frac{m_Z^2}{2} \simeq |\mu|^2 + m_{H_u}^2 - \frac{3y_t^2}{8\pi^2} m_{\tilde{t}}^2 \log\left(\frac{\Lambda^2}{m_{\tilde{t}}^2}\right)$$

↑ higgsinos ↑ stop

Higgsino-LSP preferable

$\chi_1^0, \chi_2^0, \chi_1^\pm$ degenerate





BR has info in stop/neutralino sector
depending on decay mode, search strategy differs

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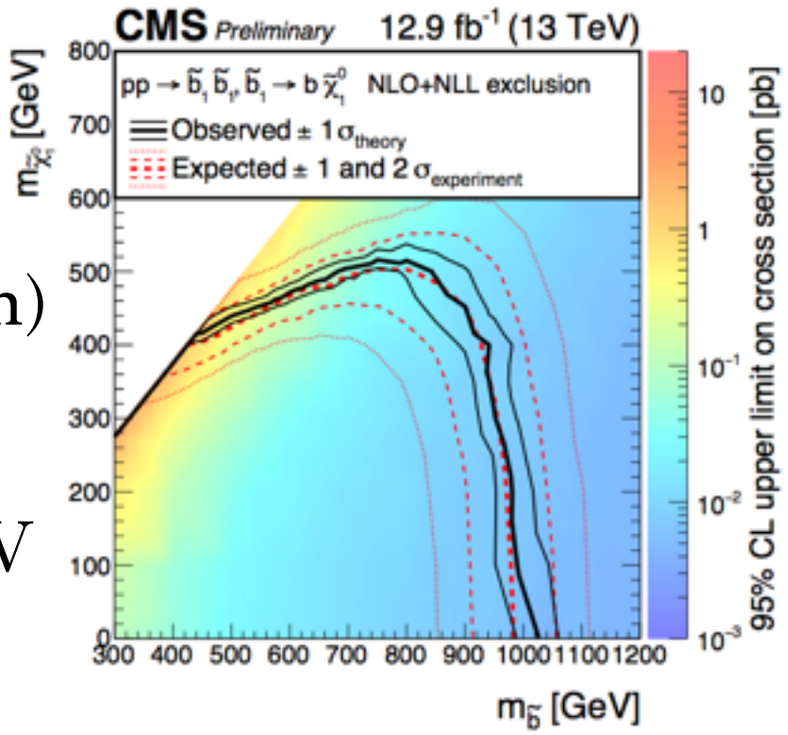
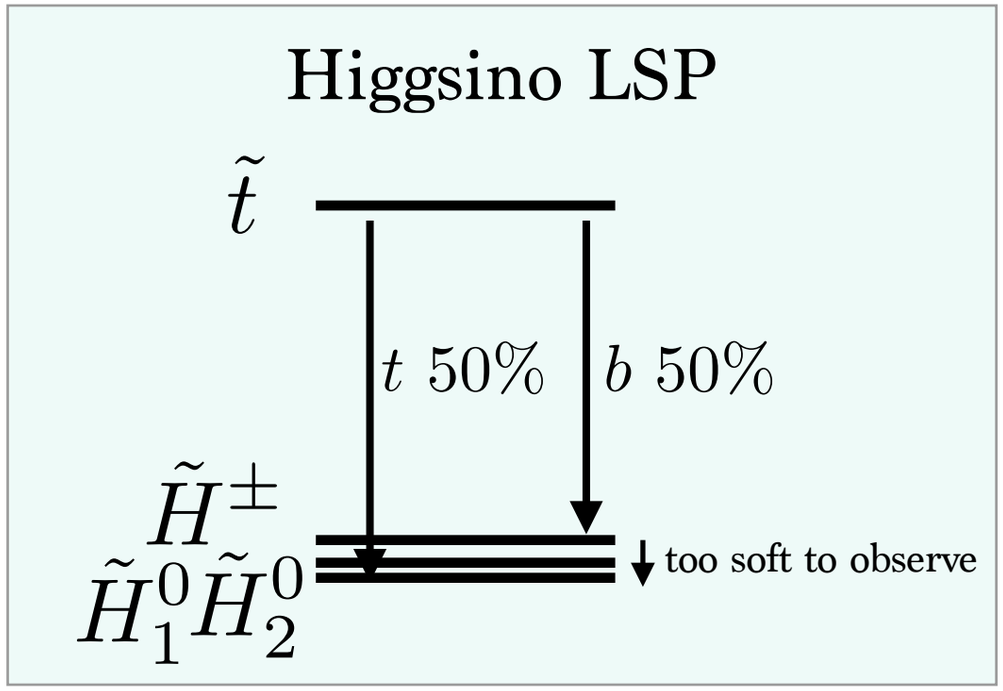
bb + missing
(sbottom search)

estimate

$m_{\tilde{t}} \gtrsim 800\mathrm{GeV}$





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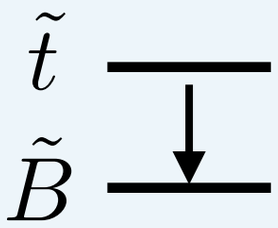
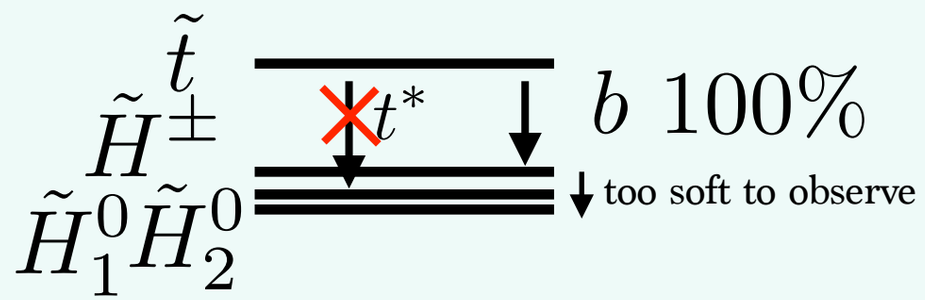
Bino LSP stop-coannihilaiton



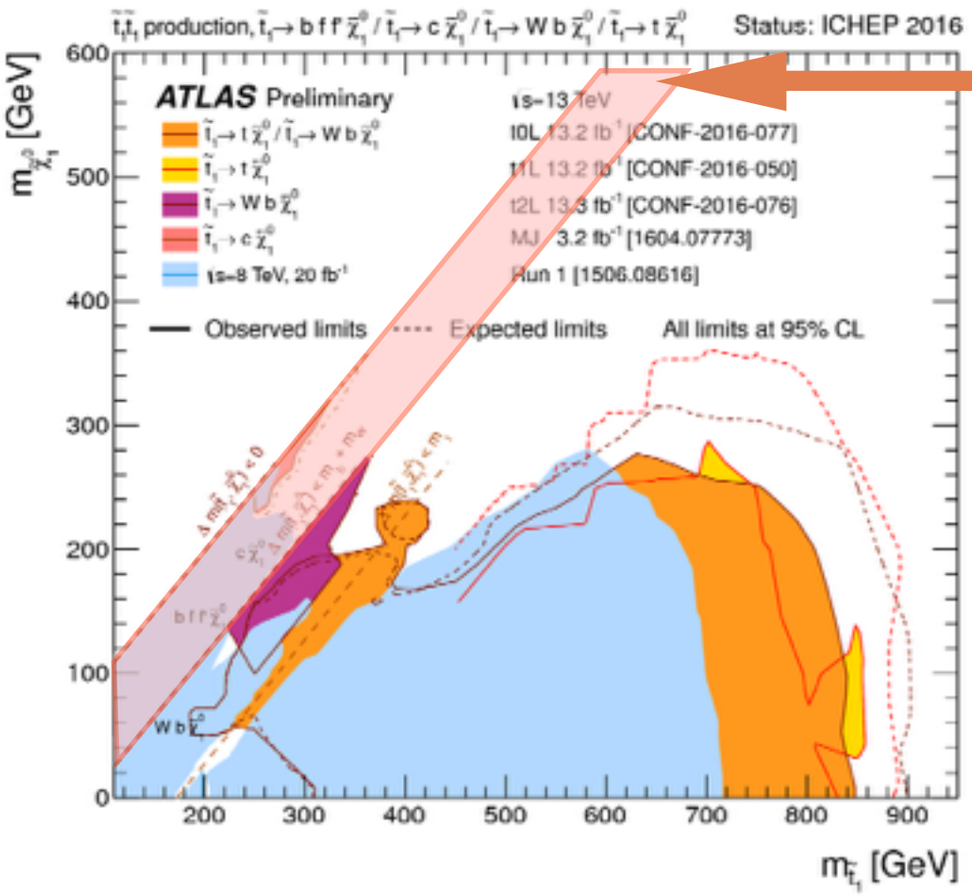
Higgsino LSP



essentially we cannot observe any stop decay products

Stop search (degenerate)

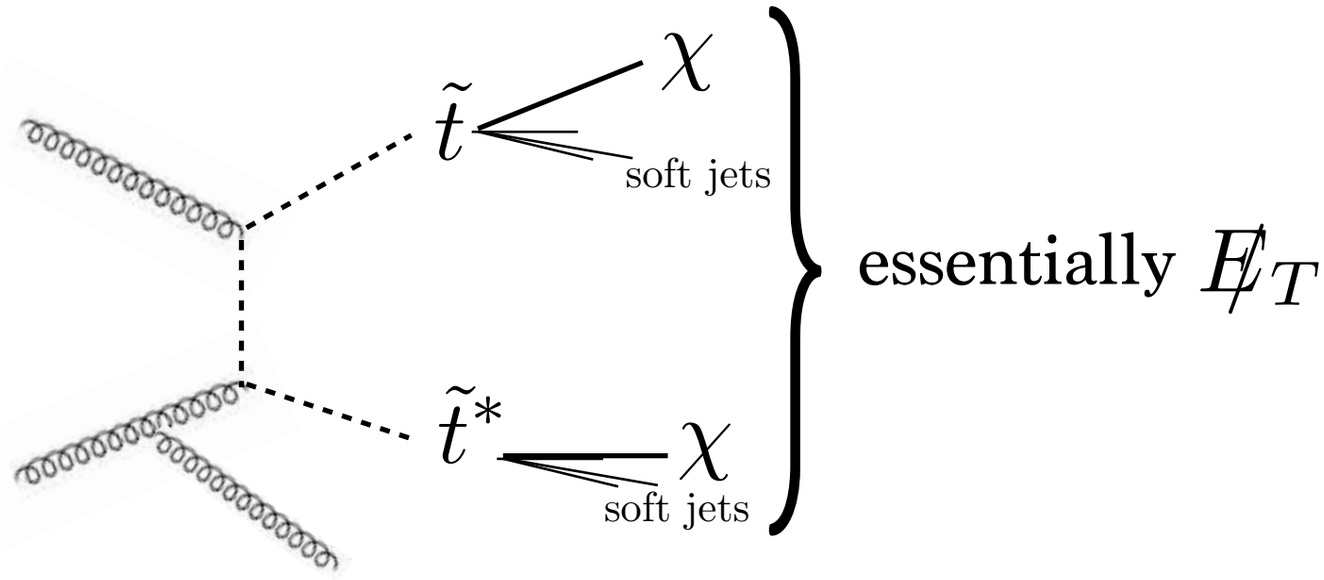
current status



today's focus: degenerate mass spectrum

$$m_{\tilde{t}} \sim m_{\chi}$$

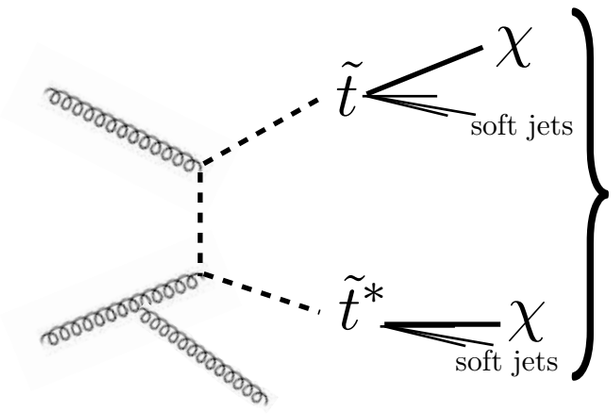
mono-jet search: sensitive to this region



mono-jet search

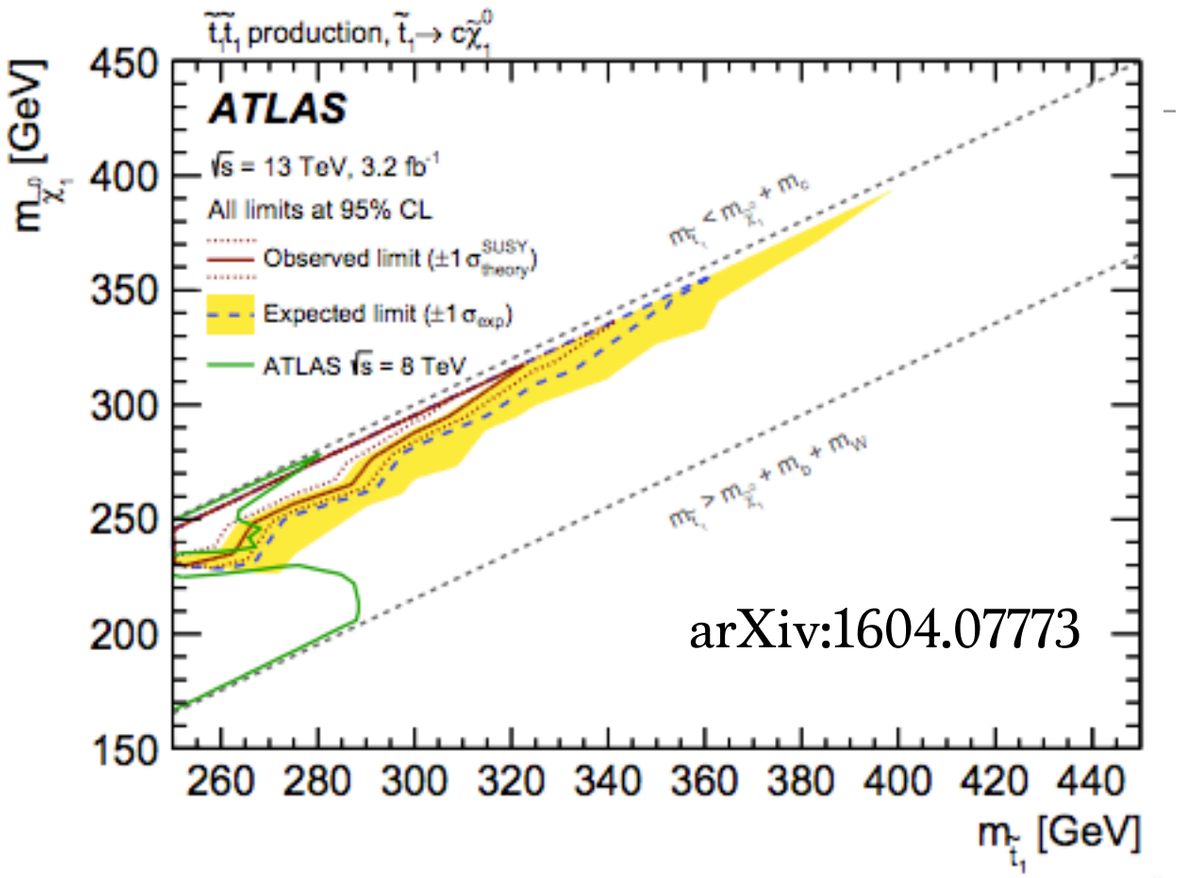
simple strategy

BG: Z+jets



essentially $\not{E}_T$

ISR jet



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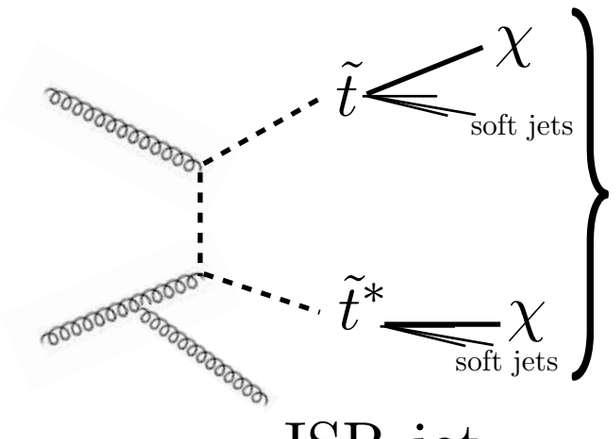

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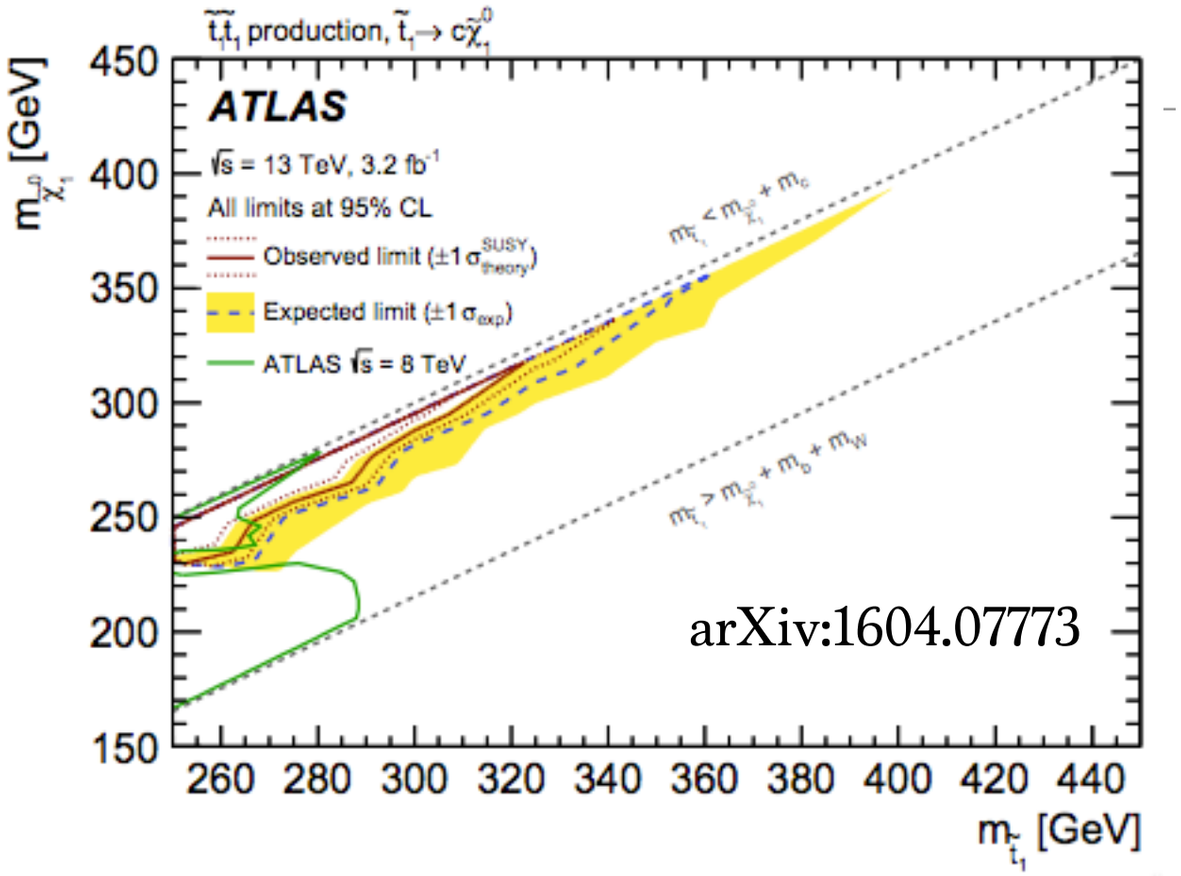
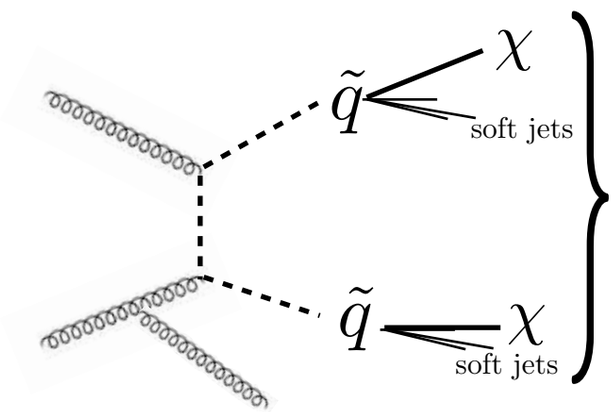


however, the same signal expected for whatever with a degenerate spectrum



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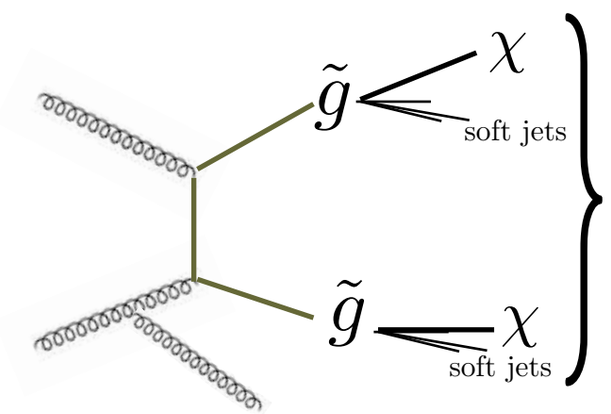


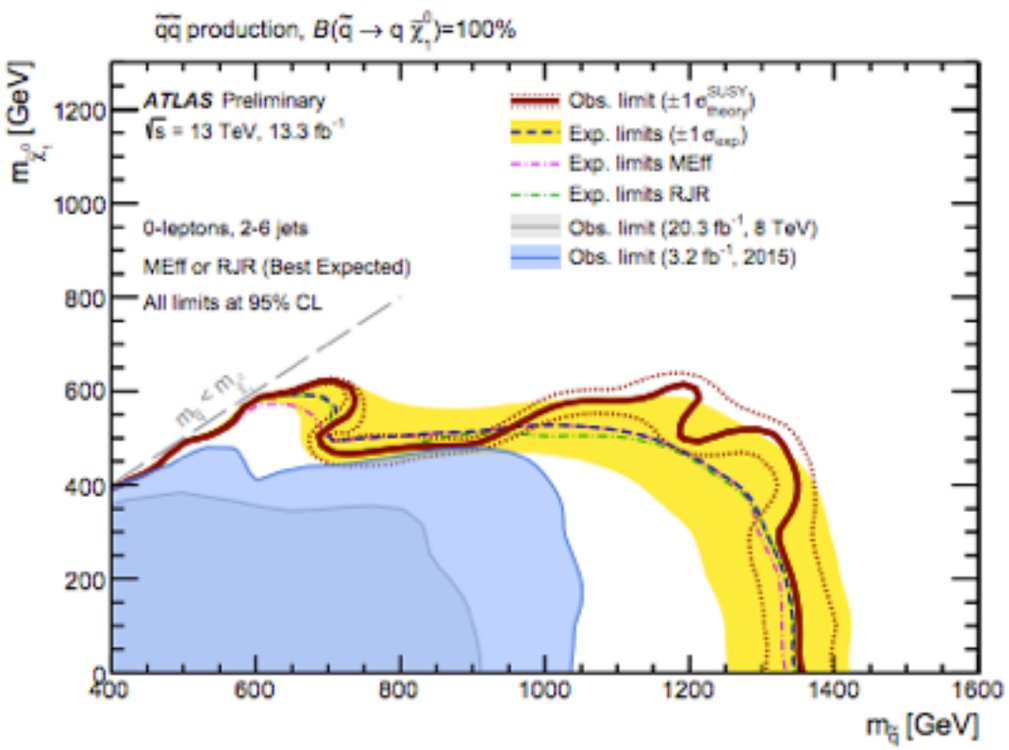
essentially $\not{E}_T$

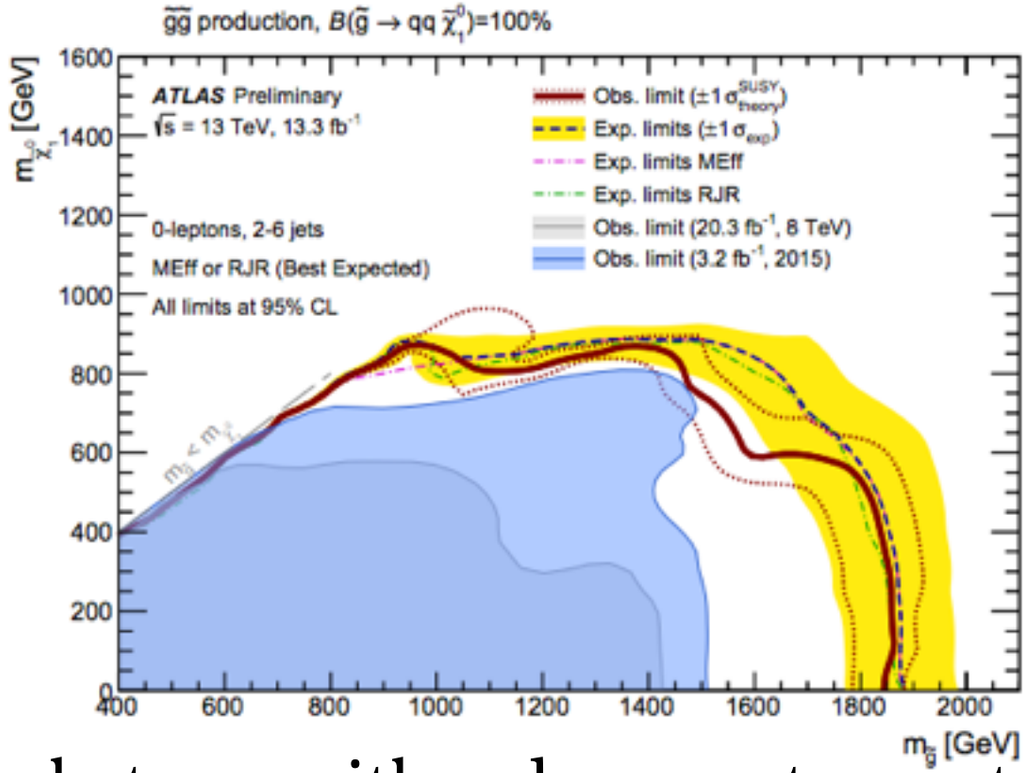
ISR jet

gluino, squark, other simplified model, for whatever sensitive http://arxiv.org/pdf/1409.2893.pdf

mono-jet search

(ATLAS-CONF-2015-062)
(1605.03814)
ATLAS-CONF-2016-078





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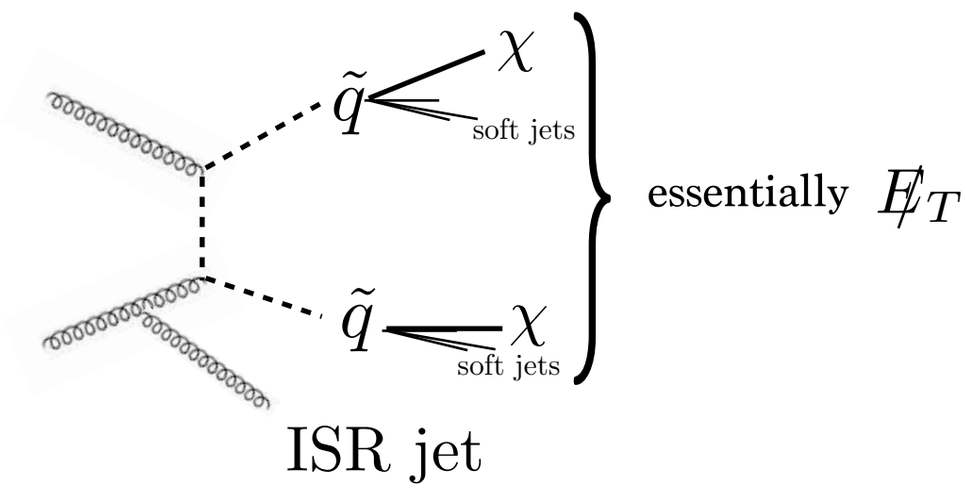
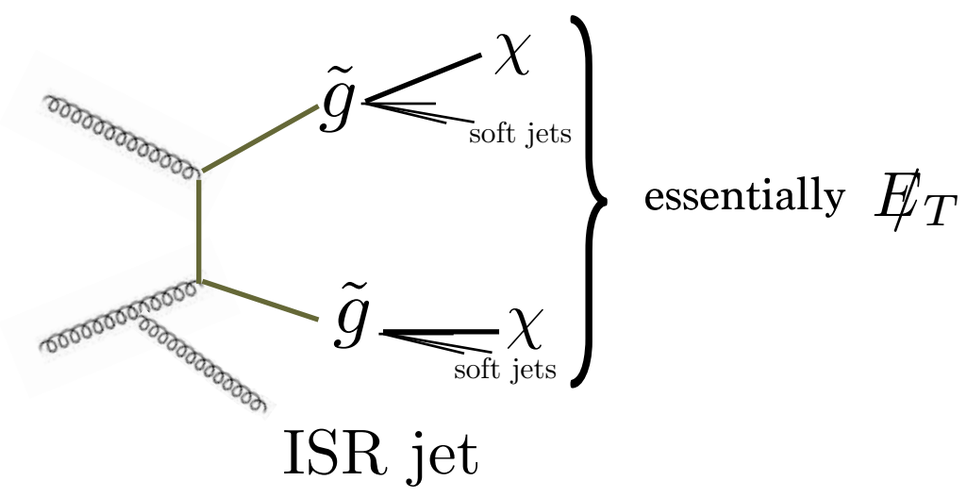




gluino, squark, other simplified model, for whatever sensitive http://arxiv.org/pdf/1409.2893.pdf

mono-jet search

for degenerate stop, mono-jet search is sensitive

Good

whatever particles degenerate with DM can be probed

robust prediction based on QCD (only depends on mass, color, spin)

Bad

whatever particles degenerate with DM can be probed

= we cannot distinguish among the particles

cross section α_S suppressed

large QCD BG (Z + jets)

➡ **Welcome to collect information as much as possible**

jet substructure

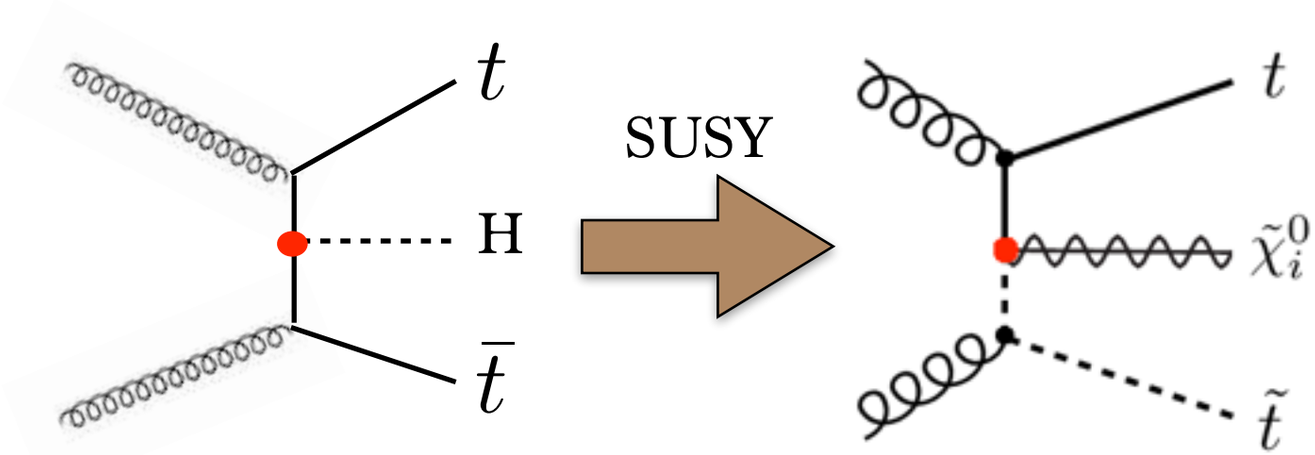
jet correlation using 2j + missing

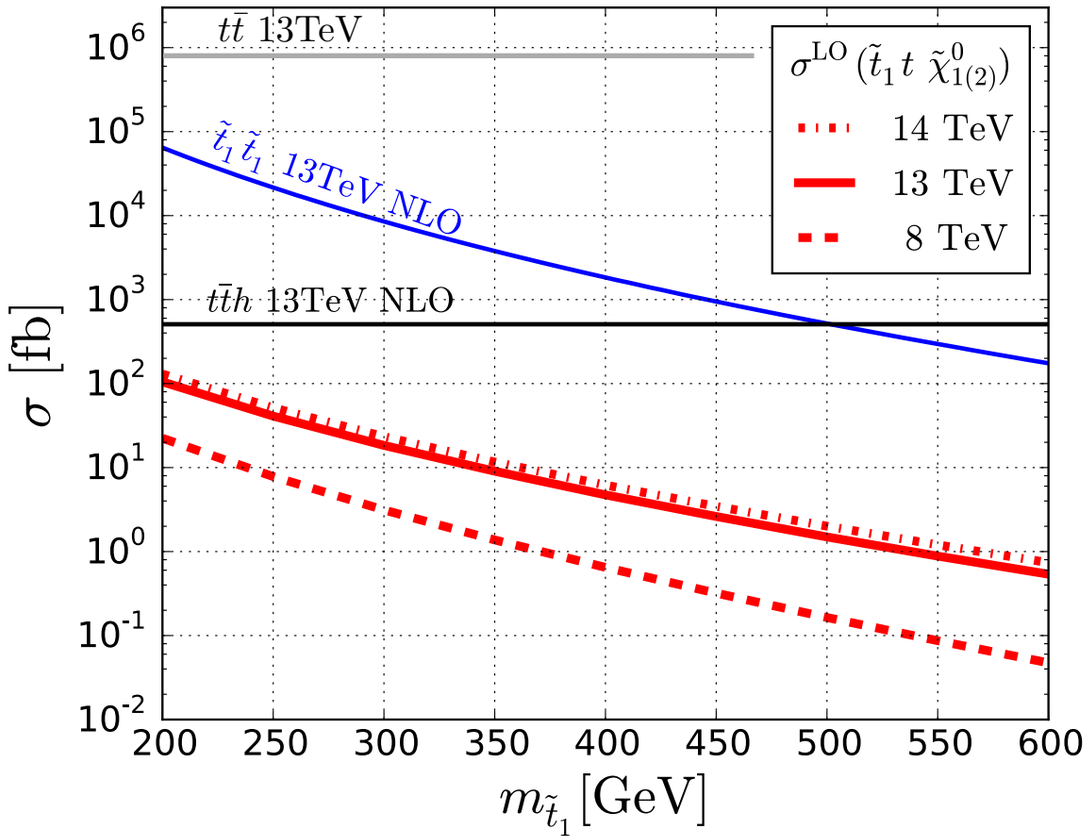
SUSY ttH process $\tilde{t}^* t \tilde{h}_u^0$

[D. Goncalves, K. Sakurai, MT arXiv:1604.03938]

motivation: Natural susy (light higgsino + stop)

top yukawa is large, 3body production is not so small





direct measurement of the coupling

same relation between tt and ttH (tt for top mass, ttH for top yukawa.)

can access to stop/neutralino mixing information

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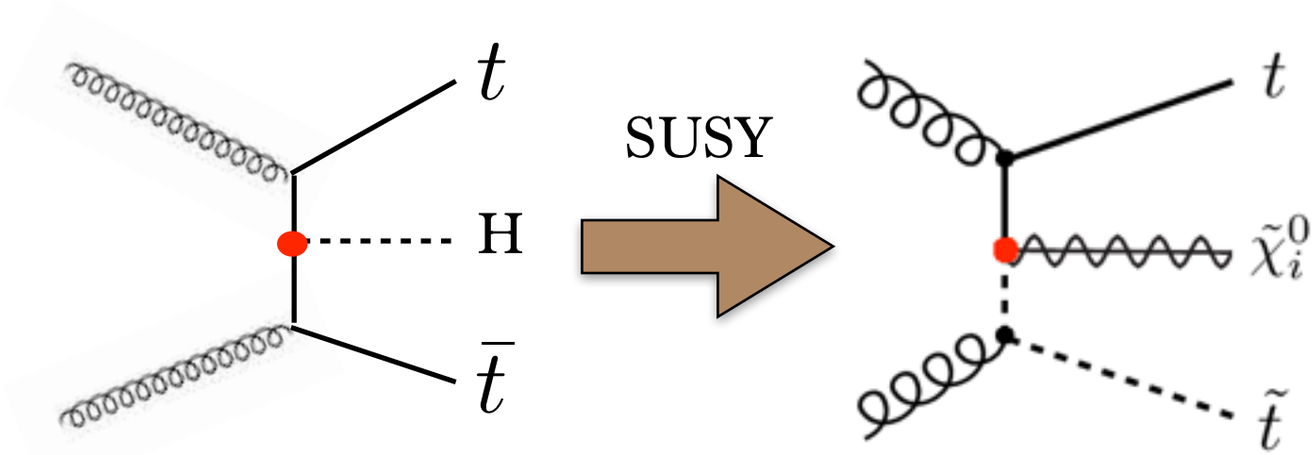

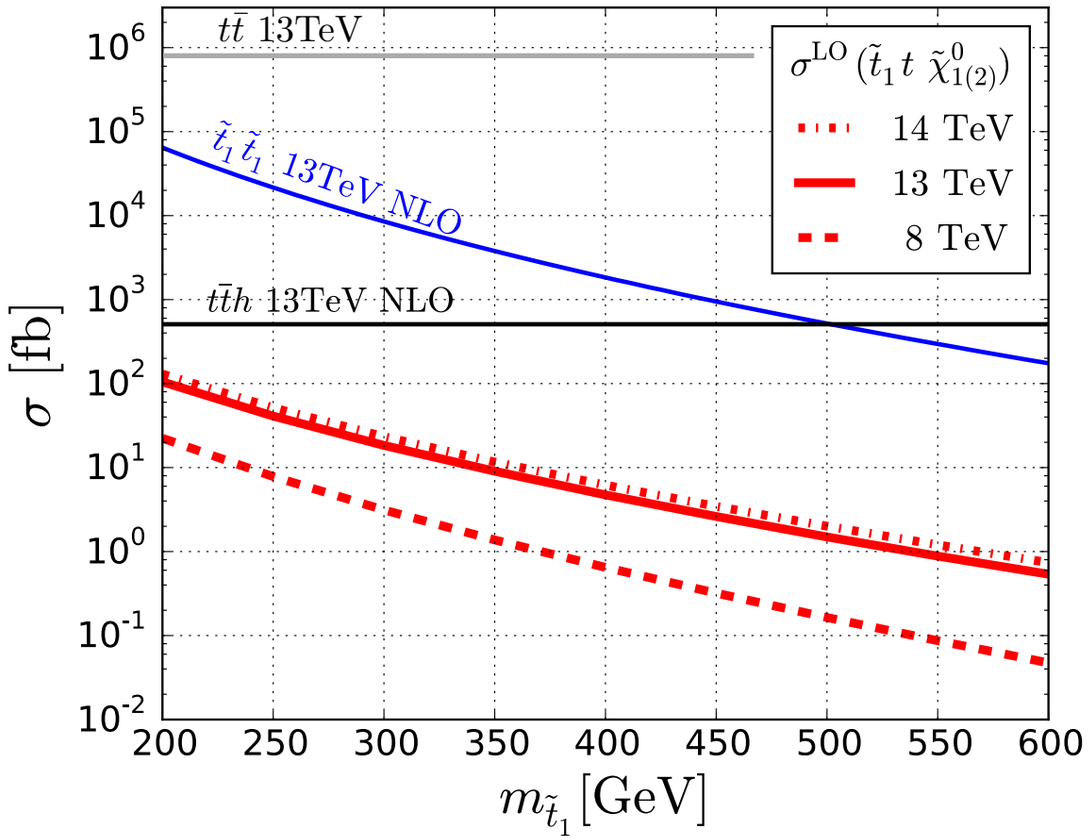

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$y_t T_R H_u Q_{3L}$ in super potential $\rightarrow \tilde{t}_R \tilde{h}_u t_L, t_R \tilde{h}_u \tilde{t}_L$ $(\sin^2\theta_{\tilde{t}} + \cos^2\theta_{\tilde{t}} = 1)$

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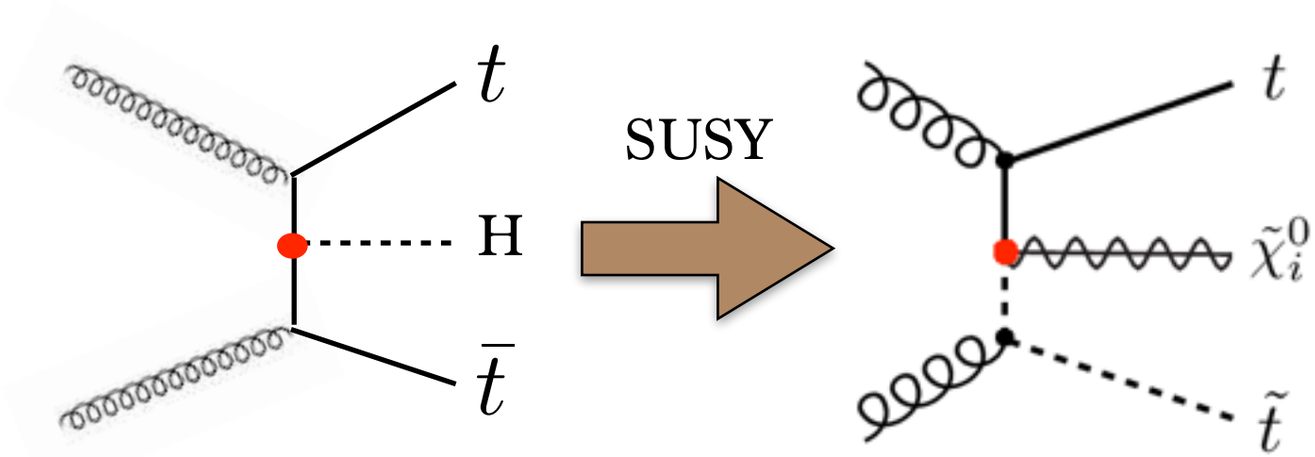

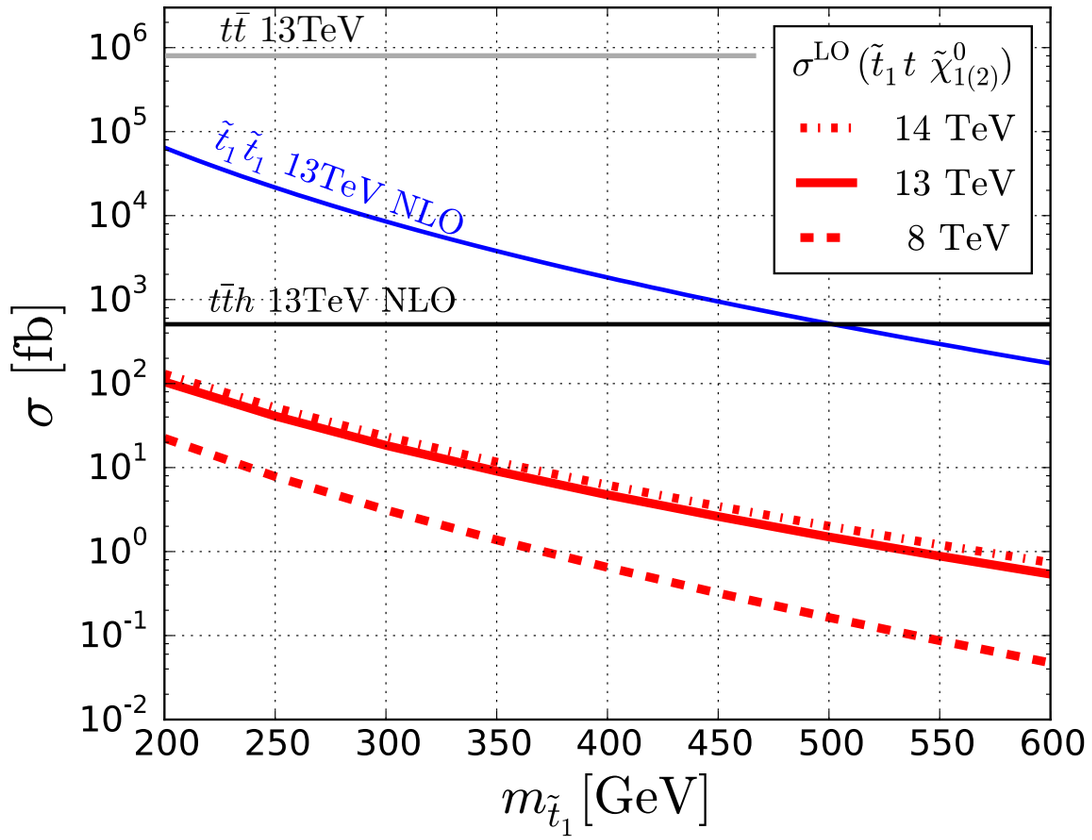

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but depend on neutralino mixing matrix: N_{14}, N_{24} ($\tilde{h}_u$ in χ^0_1, χ^0_2)

measuring $\sigma(\tilde{t}_1 t \chi^0_{1(2)}) = \mathcal{R}\sigma_{\tilde{h}}$ to access LSP nature

($\sigma_{\tilde{h}}$: pure higgsino limit)

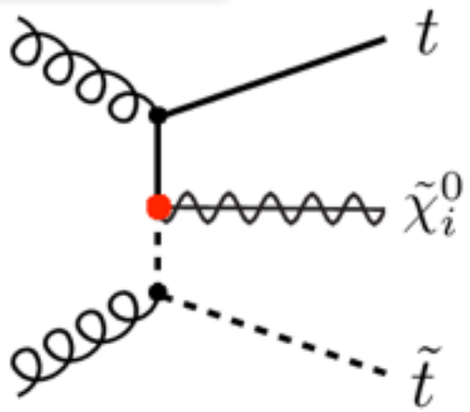
higgsino measure: $\mathcal{R} \simeq \dfrac{|N_{14}|^2 + |N_{24}|^2}{\sin^2\beta}$

New signature: mono-top

[D. Goncalves, K. Sakurai, MT arXiv:1604.03938]

consider even degenerate case

$$m_{\tilde{t}} \sim m_{\chi}$$



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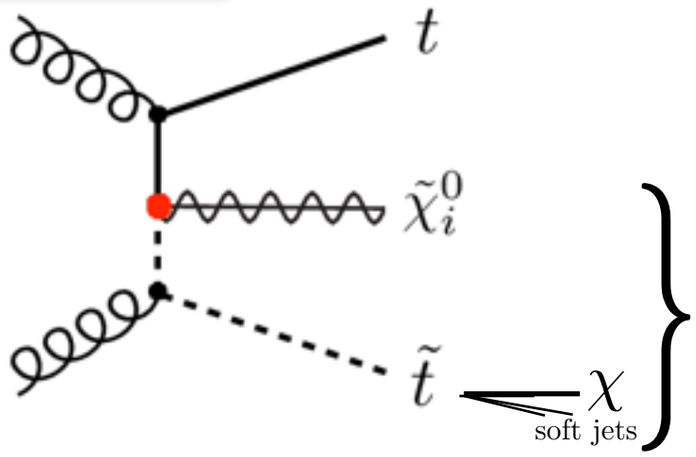

essentially $\not{E}_T$

$\rightarrow$ interesting signature: mono-top

often considered in top flavor violation

J. Andrea, B. Fuks, F. Maltoni

mono-top with no flavor violation, kinematically suppressed

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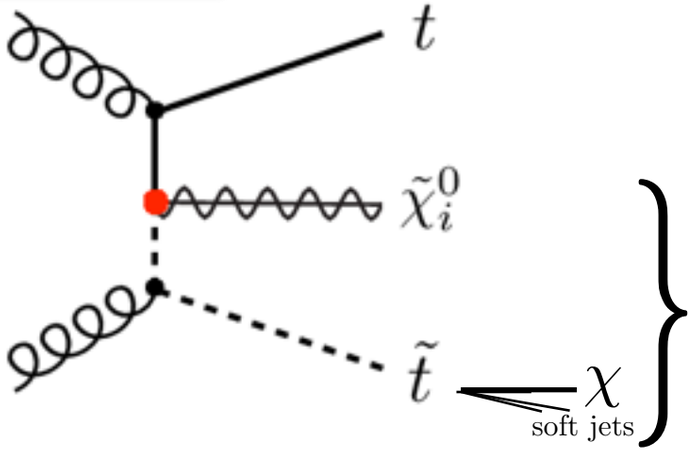

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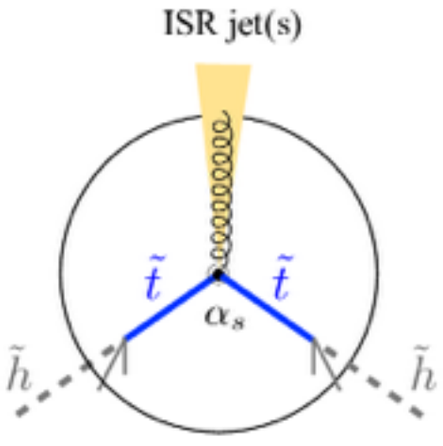
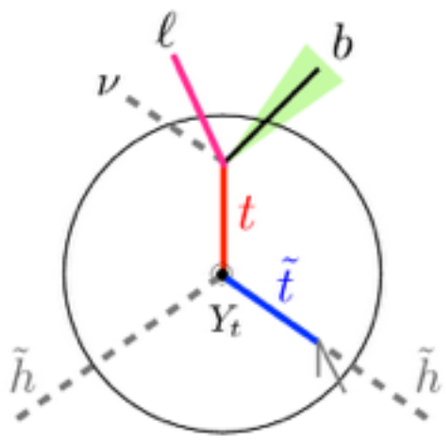


mono jet + E_T^{miss} + soft

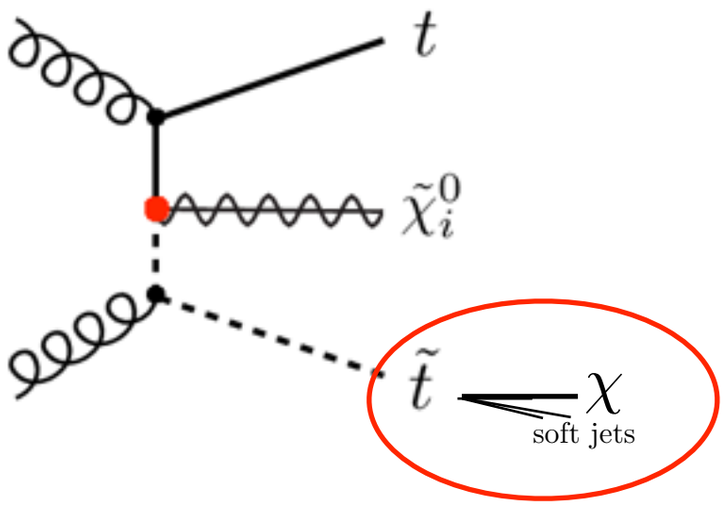


mono top + E_T^{miss} + soft

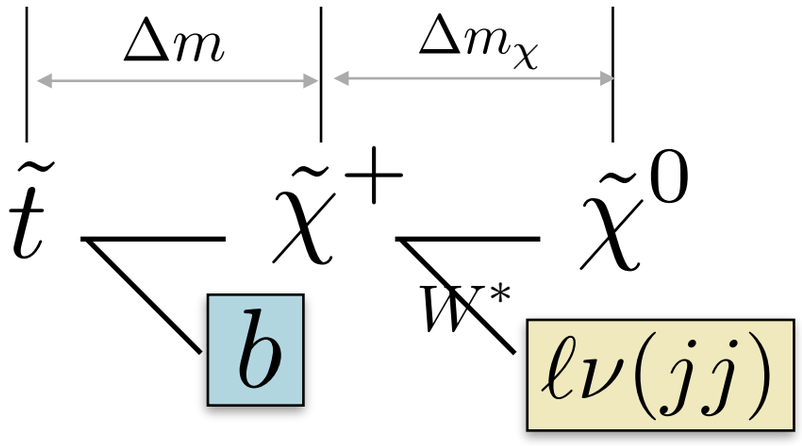
combine mono-jet and mono-top allow to access both *stop mass* $m_{\tilde{t}}$ and *higgsino measure* $\mathcal{R}$

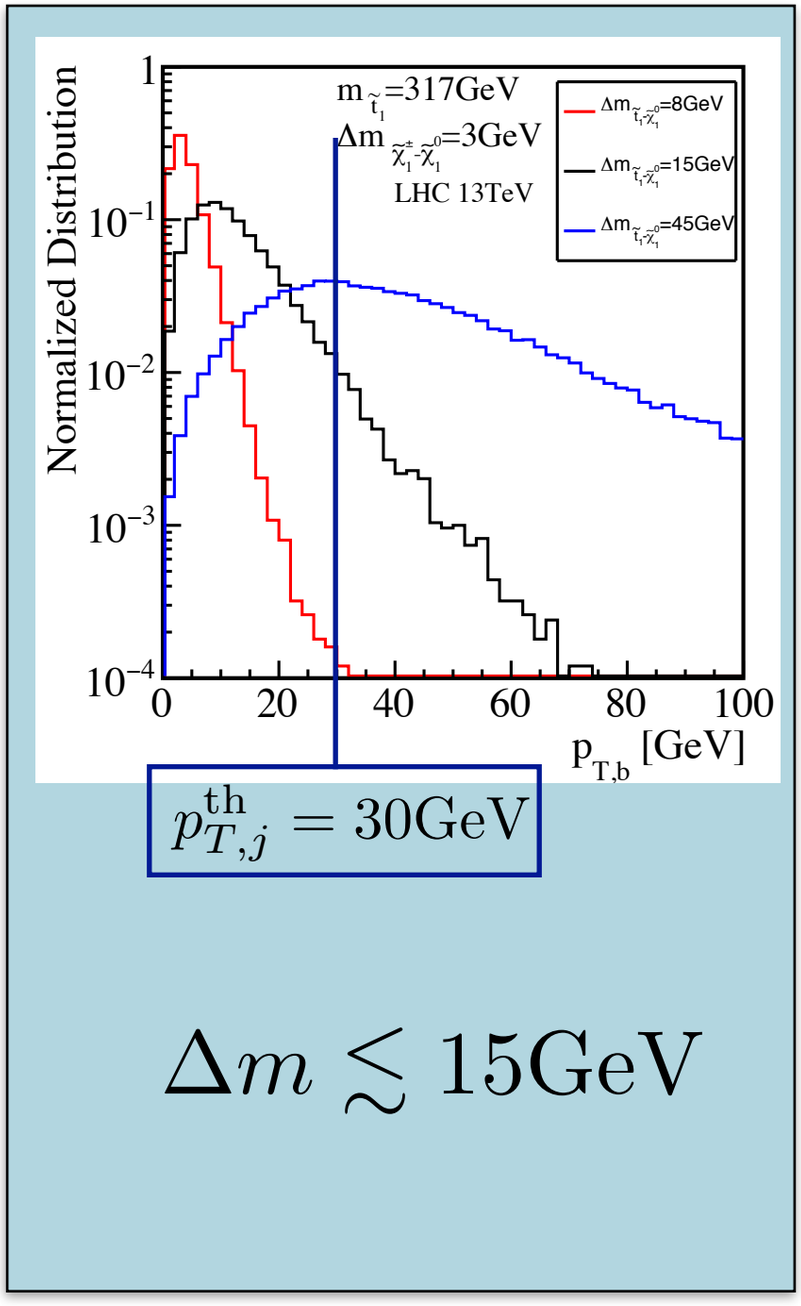
invisible stop decay

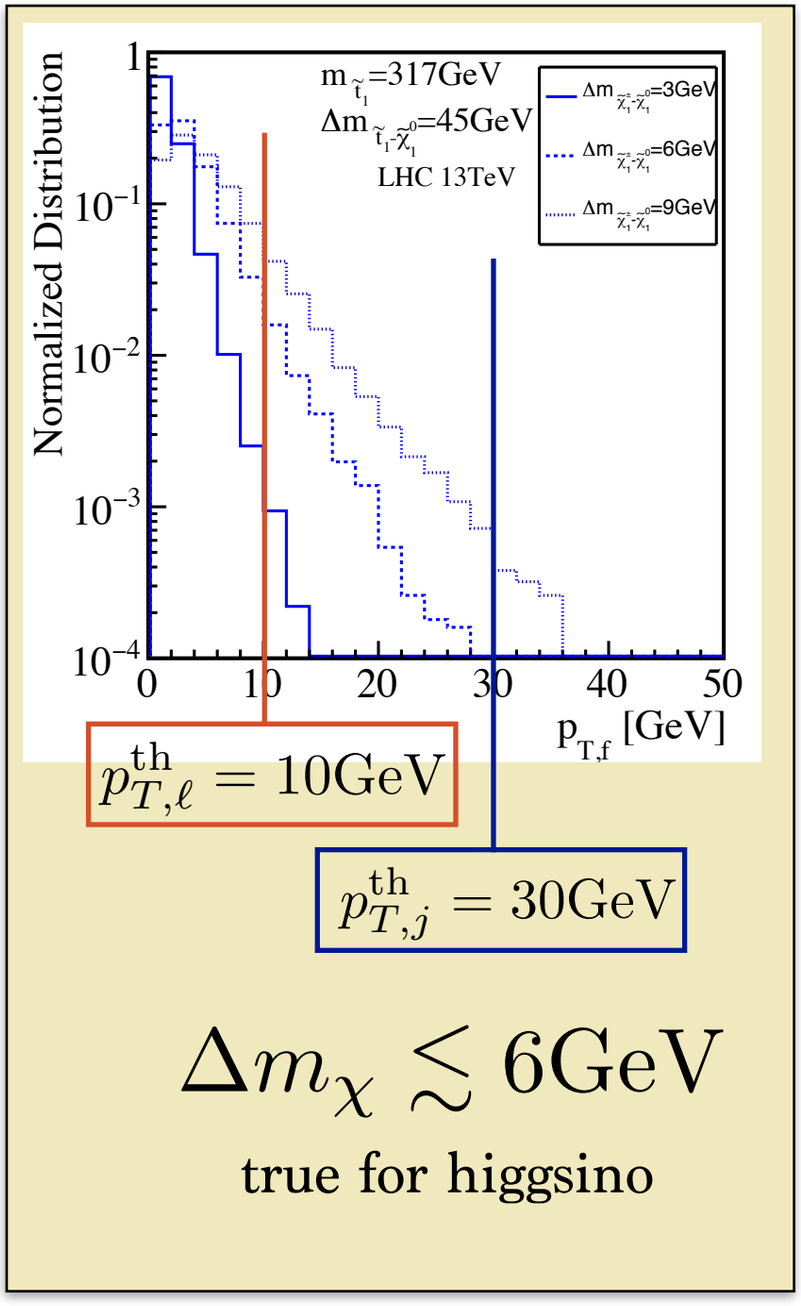
[D. Goncalves, K. Sakurai, MT arXiv:1604.03938]



when stop invisible?







* soft-activity might be able to use [A. Chakraborty, S. Chakraborty, T. S. Roy 1606.07826]

Search strategy

[D. Goncalves, K. Sakurai, MT arXiv:1604.03938]

focus on easiest channel ($t_\ell + \not{E}_T$) Baseline: $n_\ell = 1 \quad n_b = 1 \quad n_j \leq 3$ $(p_{T,j} > 30\text{GeV})$

Process	σ	Baseline
$t\bar{t}$	831 pb	$206 \cdot 10^6$
tW	71 pb	$26.2 \cdot 10^6$
tZ	0.88 pb	$22.8 \cdot 10^3$
$W + b\bar{b}$	7.65 pb	$1.82 \cdot 10^6$
BG total	903 pb	$226 \cdot 10^6$
BP(317, 309)	23.7 fb	5883
BP(317, 272)	30.8 fb	6522

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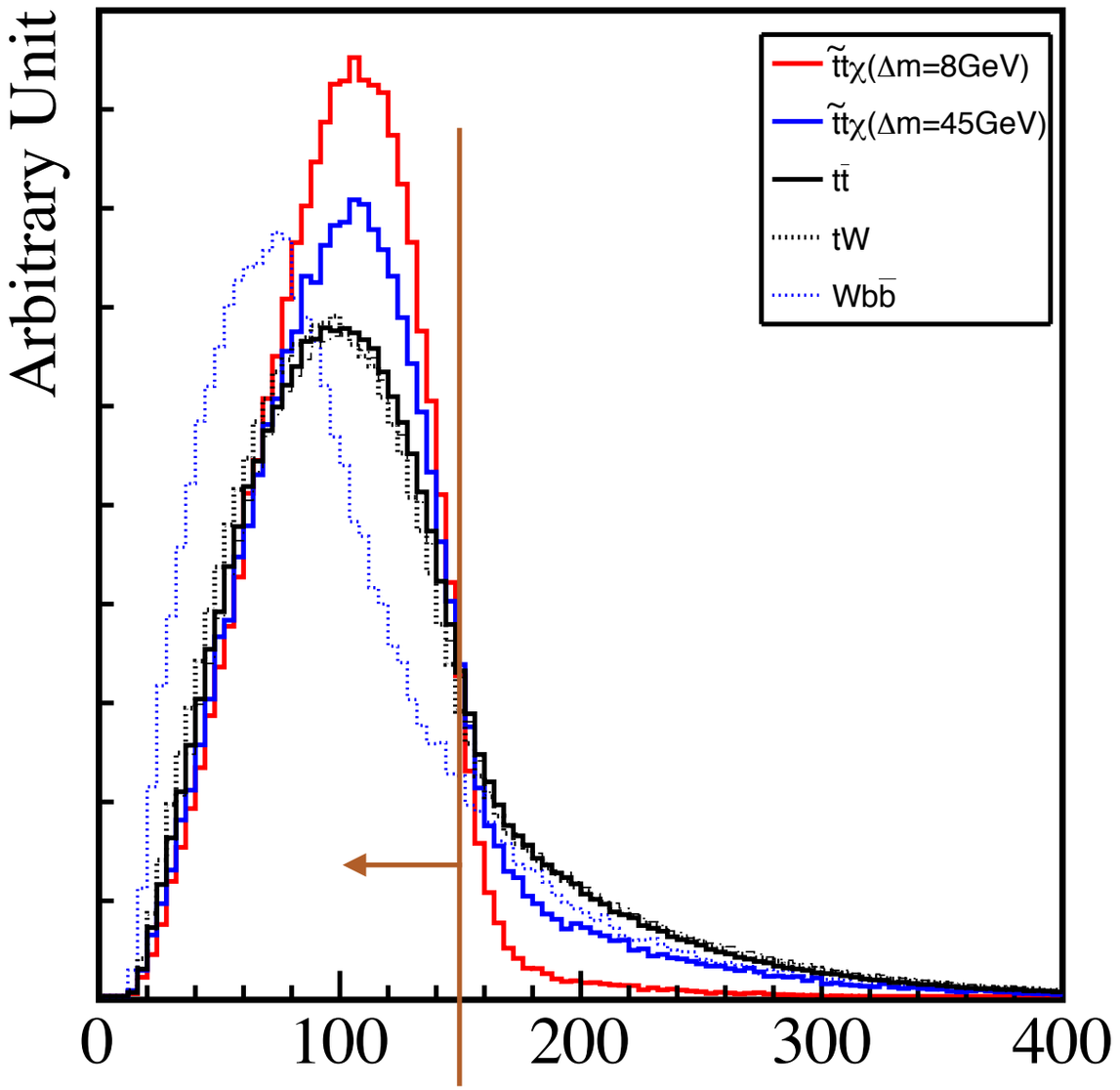
BP(317, 309)	23.7 fb	5883
BP(317, 272)	30.8 fb	6522

consistency check with top kinematics

to reduce non top BG (Wbb)
combinatorial BG



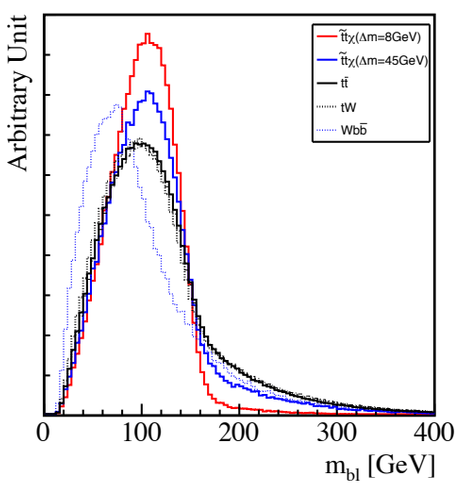
$m_{b\ell} < 150\text{GeV}$

Search strategy

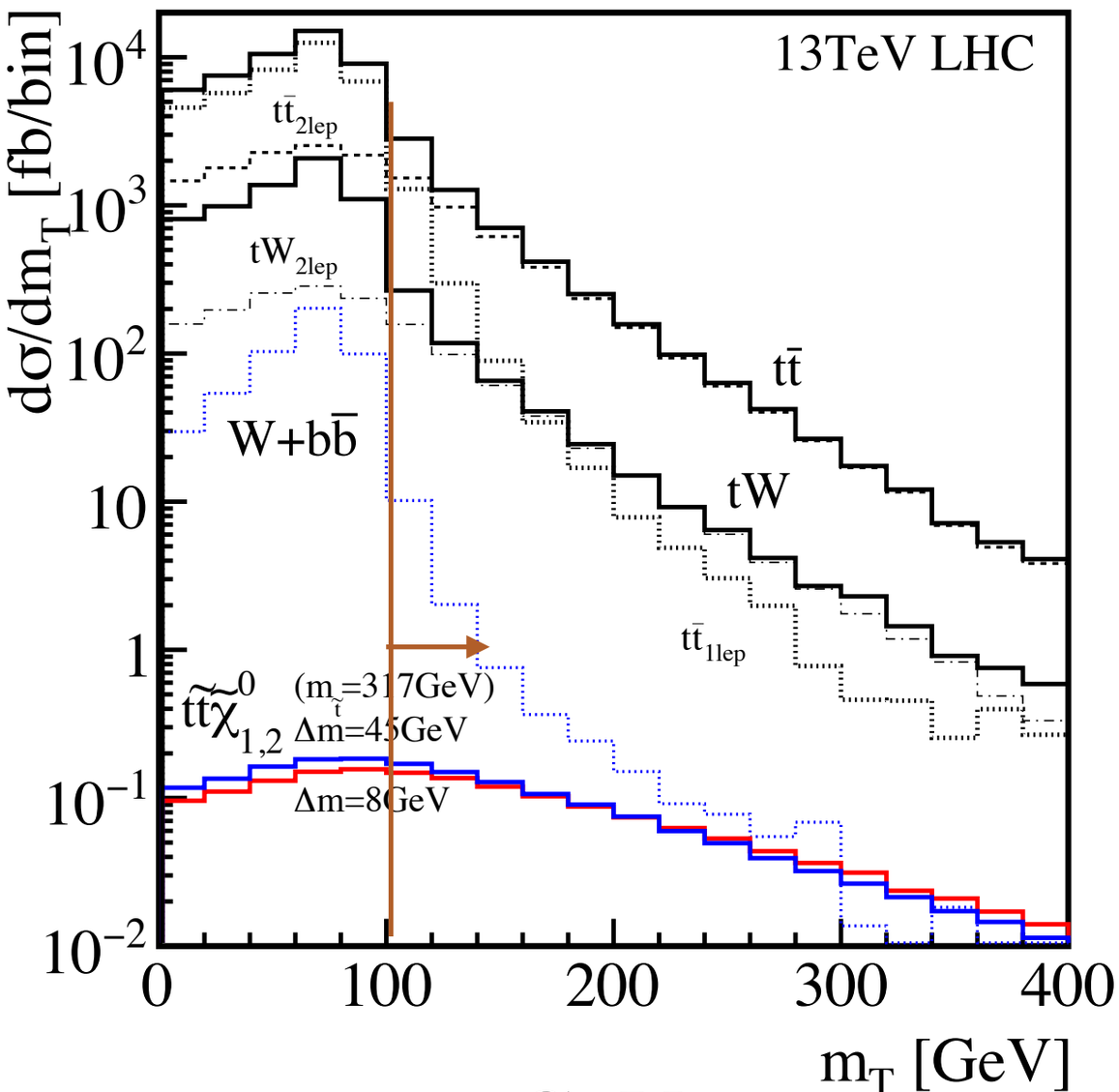
[D. Goncalves, K. Sakurai, MT arXiv:1604.03938]

focus on easiest channel ($t_\ell + \not{E}_T$) Baseline: $n_\ell = 1 \quad n_b = 1 \quad n_j \leq 3$

Process	σ	Baseline	$m_{b\ell} < 150$
$t\bar{t}$	831 pb	$206 \cdot 10^6$	$165. \cdot 10^6$
tW	71 pb	$26.2 \cdot 10^6$	$20.7 \cdot 10^6$
tZ	0.88 pb	$22.8 \cdot 10^3$	$21.6 \cdot 10^3$
$W + b\bar{b}$	7.65 pb	$1.82 \cdot 10^6$	$1.51 \cdot 10^6$
BG total	903 pb	$226 \cdot 10^6$	$41.1 \cdot 10^6$
BP(317, 309)	23.7 fb	5883	5491
BP(317, 272)	30.8 fb	6522	5491



$m_{b\ell} < 150\text{GeV}$



$m_T > 100\text{GeV}$

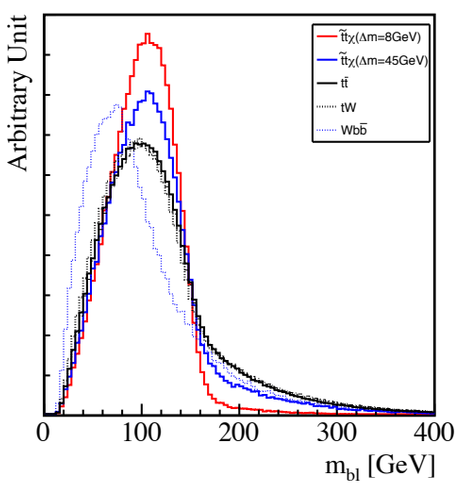
reject events only $\not{E}_T$ from W: $2\ell(t\bar{t}, tW)$ left

Search strategy

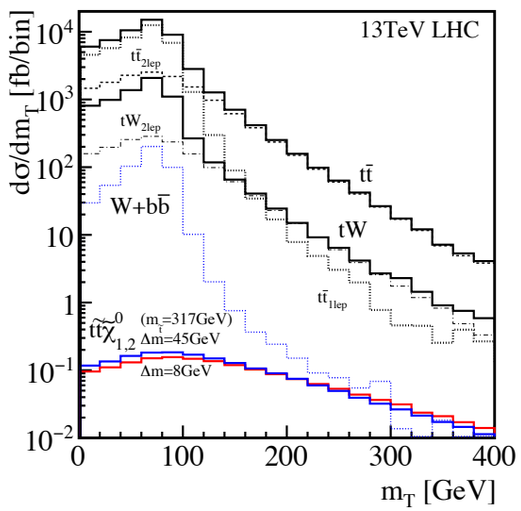
[D. Goncalves, K. Sakurai, MT arXiv:1604.03938]

focus on easiest channel ($t_\ell + \not{E}_T$) Baseline: $n_\ell = 1 \quad n_b = 1 \quad n_j \leq 3$

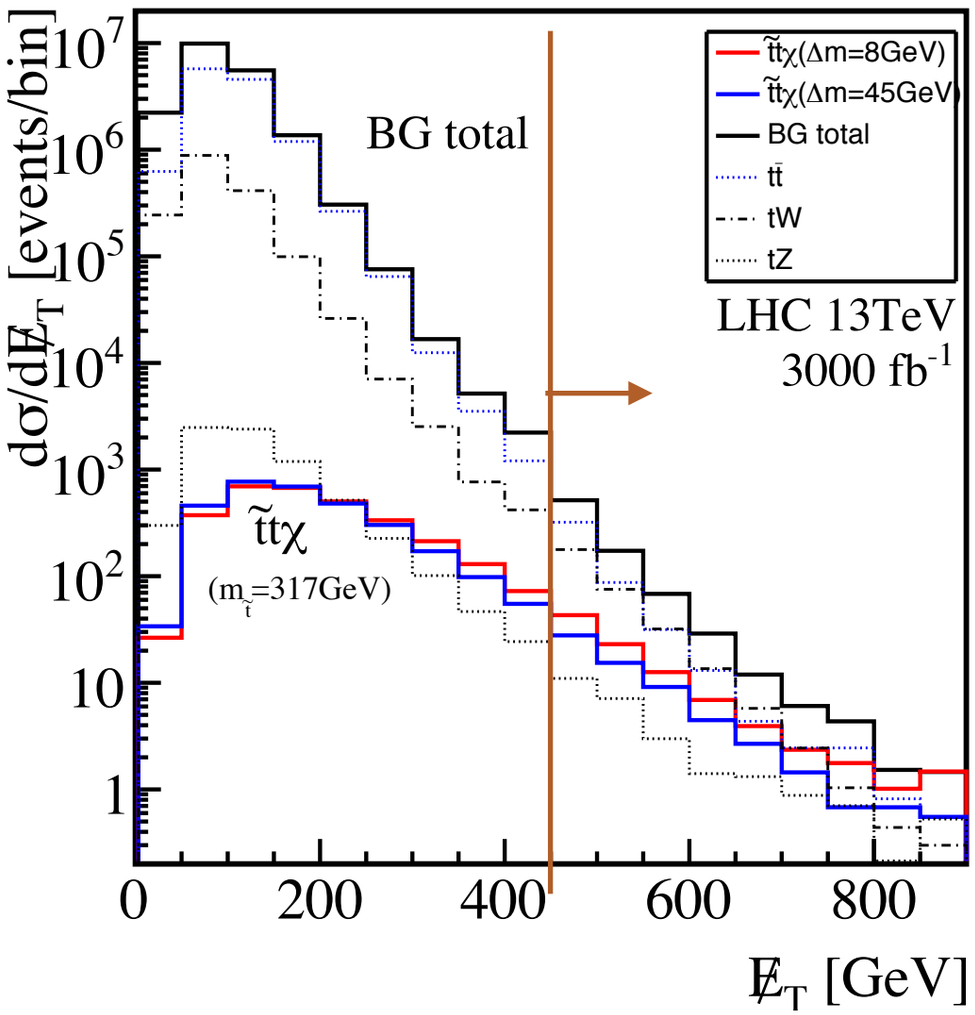
Process	σ	Baseline	$m_{b\ell} < 150$	$m_T > 100$
$t\bar{t}$	831 pb	$206 \cdot 10^6$	$165. \cdot 10^6$	$17.7 \cdot 10^6$
tW	71 pb	$26.2 \cdot 10^6$	$20.7 \cdot 10^6$	$1.68 \cdot 10^6$
tZ	0.88 pb	$22.8 \cdot 10^3$	$21.6 \cdot 10^3$	$7.3 \cdot 10^3$
$W + b\bar{b}$	7.65 pb	$1.82 \cdot 10^6$	$1.51 \cdot 10^6$	$42.3 \cdot 10^3$
BG total	903 pb	$226 \cdot 10^6$	$41.1 \cdot 10^6$	$19.4 \cdot 10^6$
BP(317, 309)	23.7 fb	5883	5491	3387
BP(317, 272)	30.8 fb	6522	5491	3123



$m_{b\ell} < 150\text{GeV}$



$m_T > 100\text{GeV}$



require high $\not{E}_T > 450\text{GeV}$

BG from back to back (2ℓ)

$p_{T,\nu}$ partly cancel

Search strategy

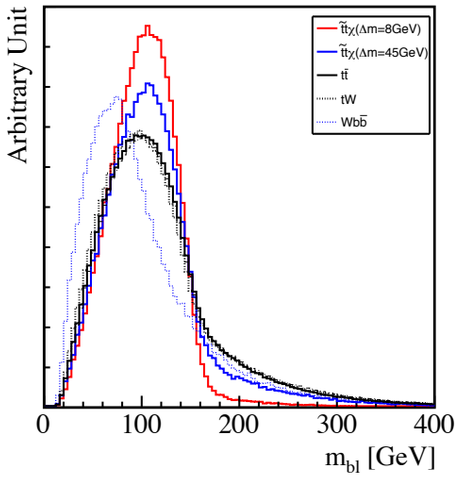
[D. Goncalves, K. Sakurai, MT arXiv:1604.03938]

focus on easiest channel ($t_\ell + \not{E}_T$) Baseline: $n_\ell = 1 \quad n_b = 1 \quad n_j \leq 3$

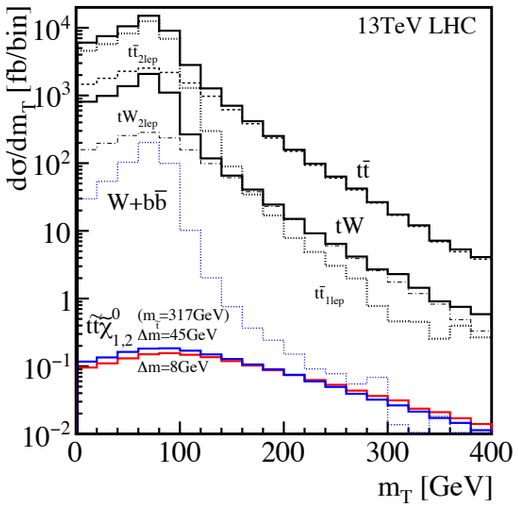
Process	σ	Baseline	$m_{b\ell} < 150$	$m_T > 100$	SR1
$t\bar{t}$	831 pb	$206 \cdot 10^6$	$165. \cdot 10^6$	$17.7 \cdot 10^6$	463.3
tW	71 pb	$26.2 \cdot 10^6$	$20.7 \cdot 10^6$	$1.68 \cdot 10^6$	308.5
tZ	0.88 pb	$22.8 \cdot 10^3$	$21.6 \cdot 10^3$	$7.3 \cdot 10^3$	26.1
$W + b\bar{b}$	7.65 pb	$1.82 \cdot 10^6$	$1.51 \cdot 10^6$	$42.3 \cdot 10^3$	5.9
BG total	903 pb	$226 \cdot 10^6$	$41.1 \cdot 10^6$	$19.4 \cdot 10^6$	803.8
BP(317, 309)	23.7 fb	5883	5491	3387	109 (3.8, 0.13)
BP(317, 272)	30.8 fb	6522	5491	3123	60.2 (2.1, 0.07)

for 3000fb^{-1}
$(S/\sqrt{B}, S/B)$

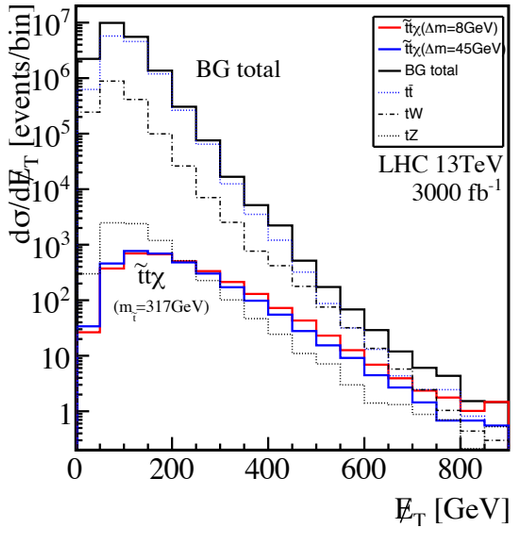
compressed case
smaller cross section
better significance
(better efficiency)



$m_{b\ell} < 150\text{GeV}$



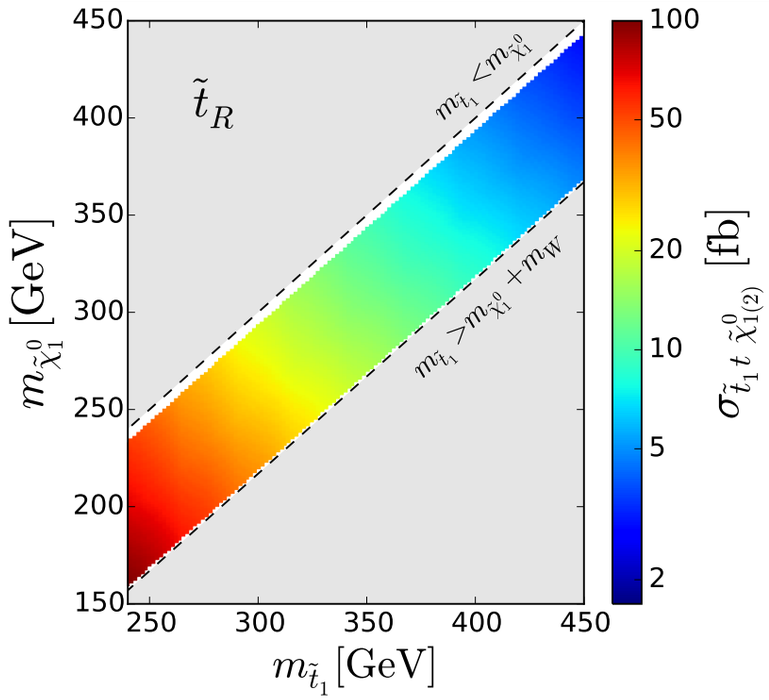
$m_T > 100\text{GeV}$

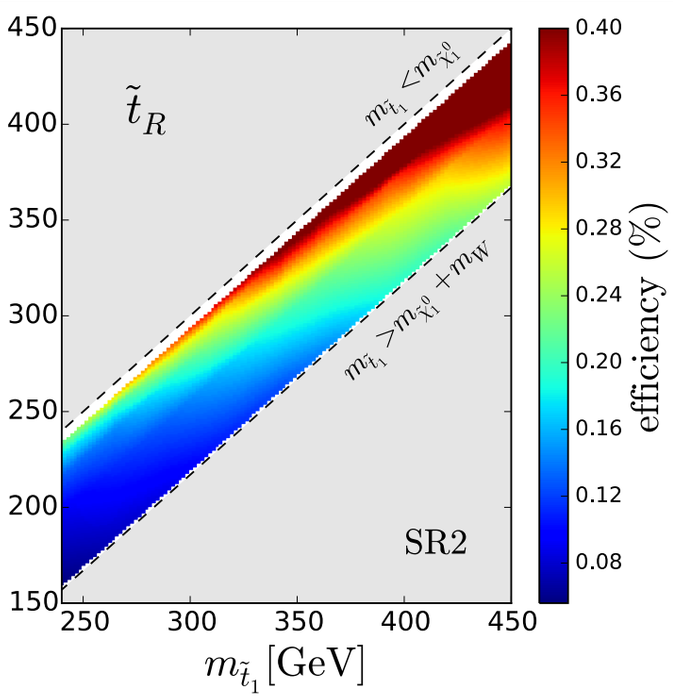


$\not{E}_T > 450\text{GeV}$

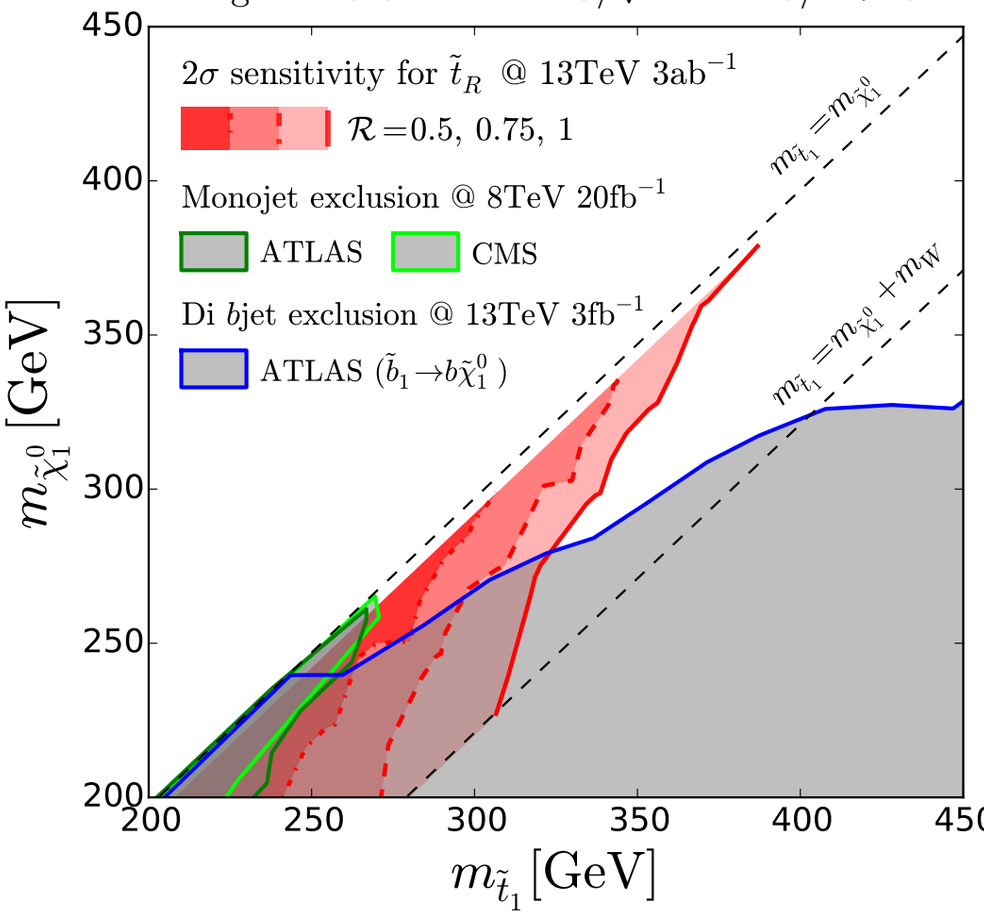
sensitivity

[D. Goncalves, K. Sakurai, MT arXiv:1604.03938]





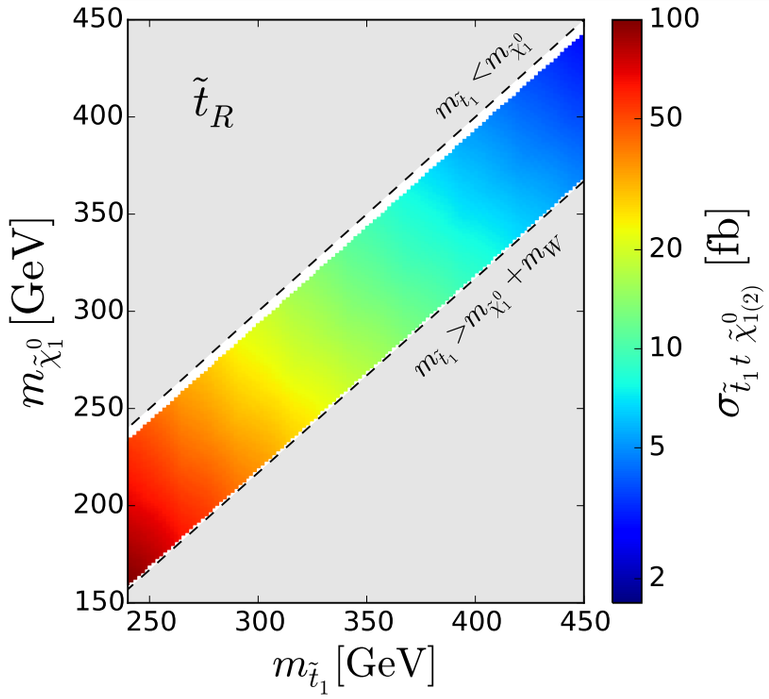
using best SR with best $S/\sqrt{B}$ with $S/B > 0.1$

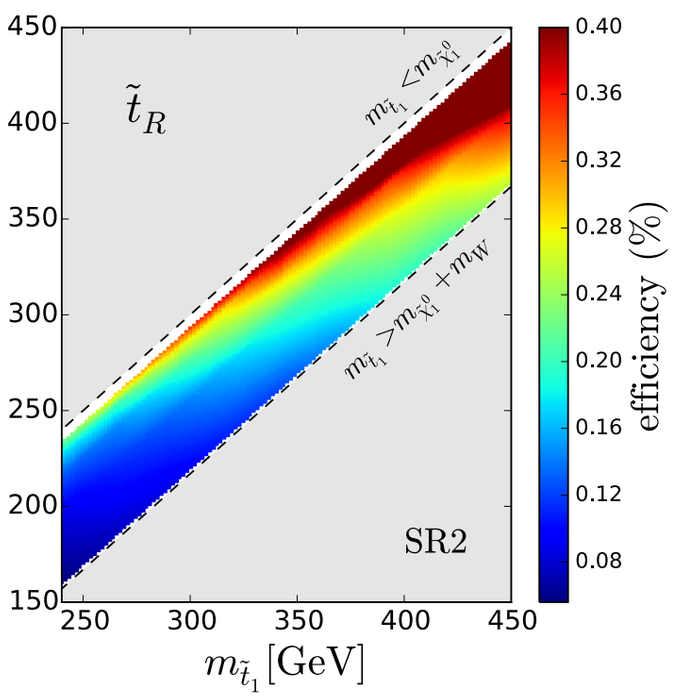


up to 380 GeV sensitive

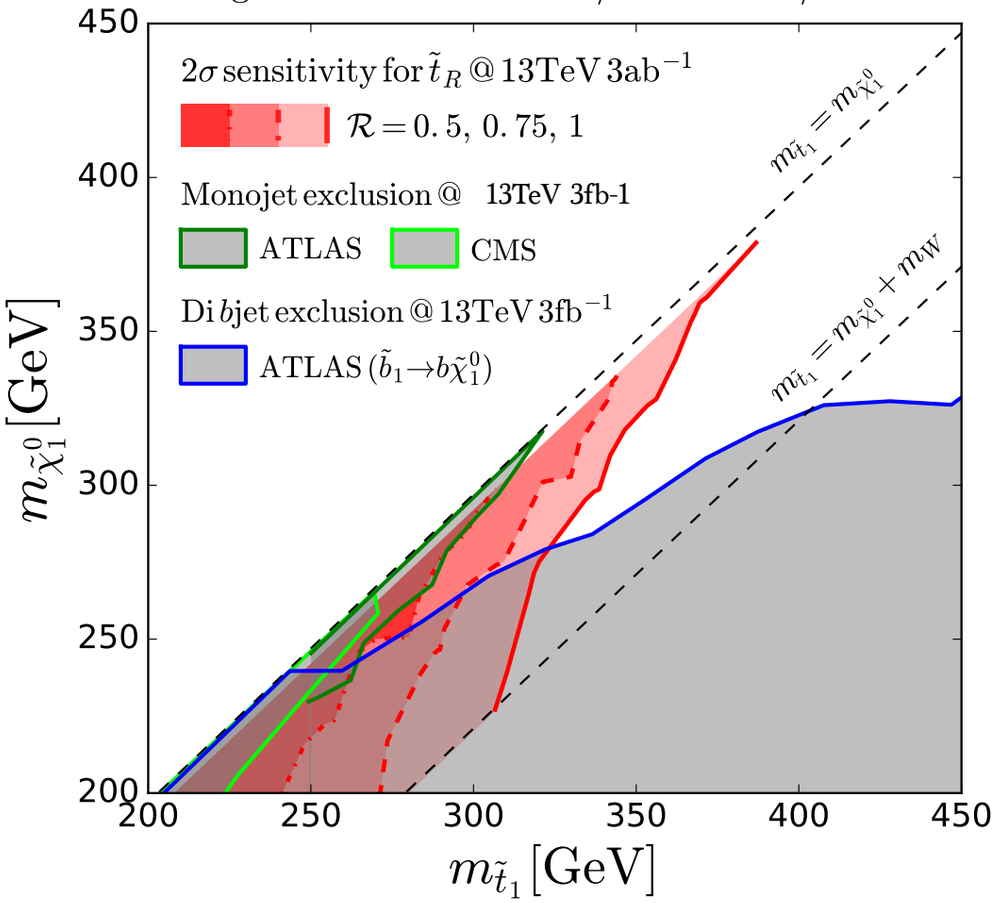
sensitivity

[D. Goncalves, K. Sakurai, MT arXiv:1604.03938]





using best SR with best $S/\sqrt{B}$ with $S/B > 0.1$



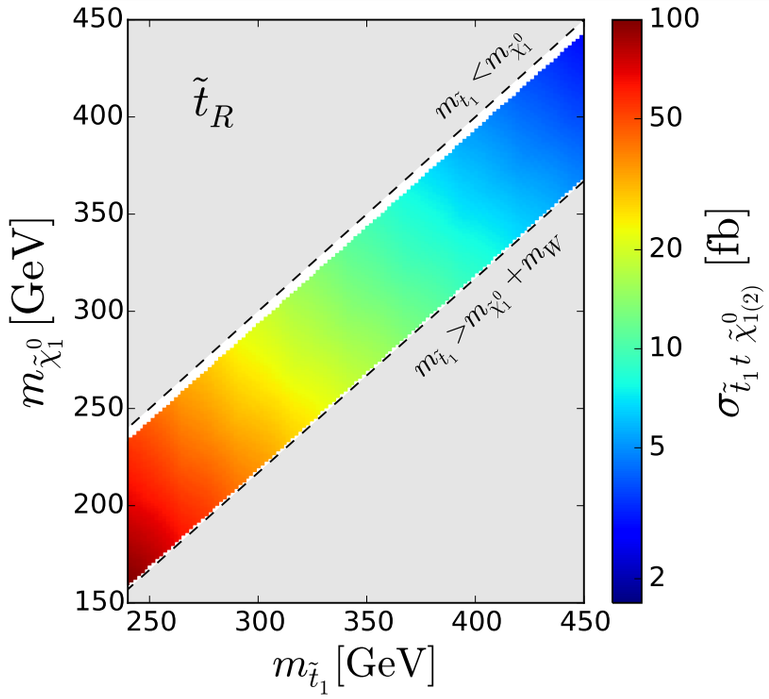
up to 380 GeV sensitive

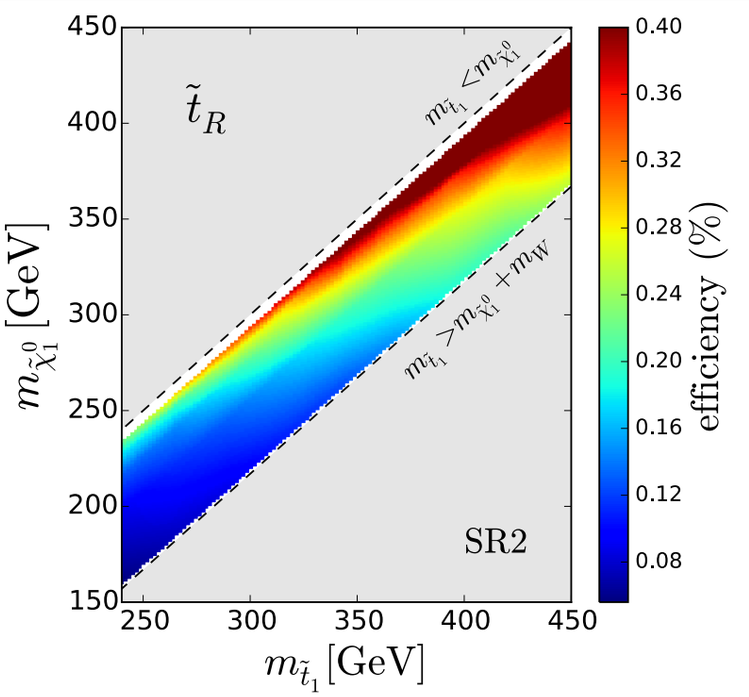
new mono jet data out (13TeV 3fb-1)
finally up to 500 GeV

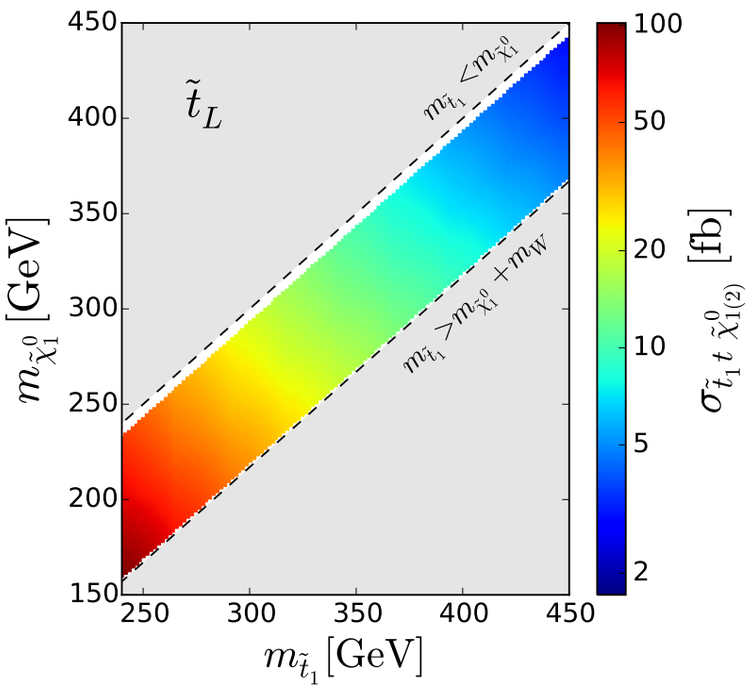
[M.Low, L.T.Wang JHEP08(2014)161]

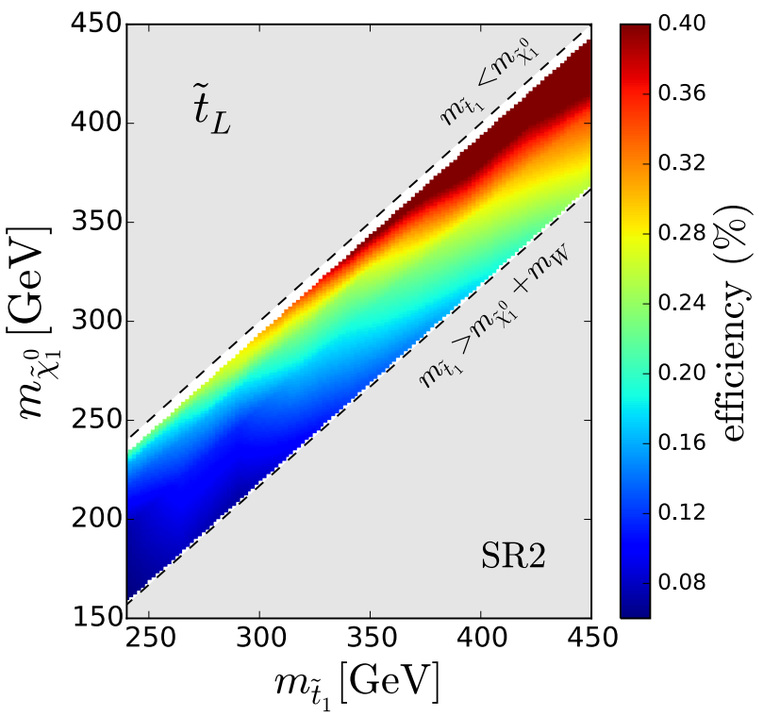
sensitivity

[D. Goncalves, K. Sakurai, MT arXiv:1604.03938]

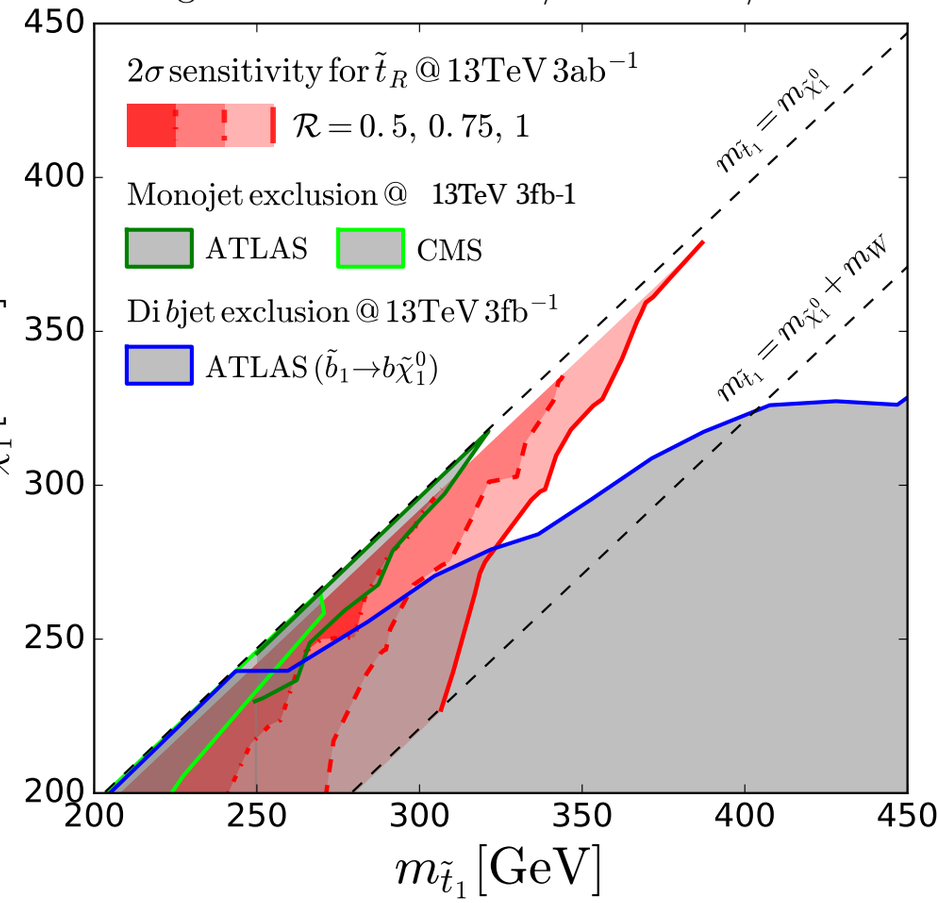








using best SR with best $S/\sqrt{B}$ with $S/B > 0.1$



up to 380 GeV sensitive

new mono jet data out (13TeV 3fb-1)
finally up to 500 GeV
[M.Low, L.T.Wang JHEP08(2014)161]

L-handed stop case almost the same

[D. Goncalves, K. Sakurai, MT arXiv:1604.03938]

helicity structure in stop sector

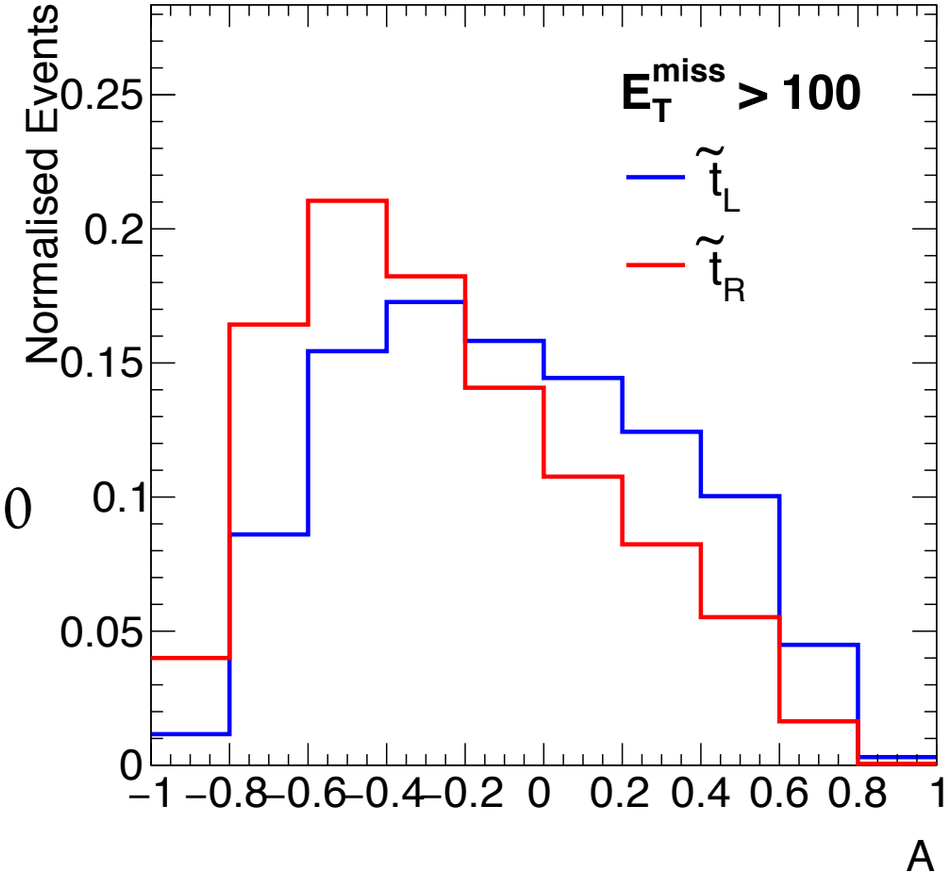
$\sigma(\tilde{t}_1 t \chi^0_{1(2)})$: no dependence on stop mixing: $\theta_{\tilde{t}}$

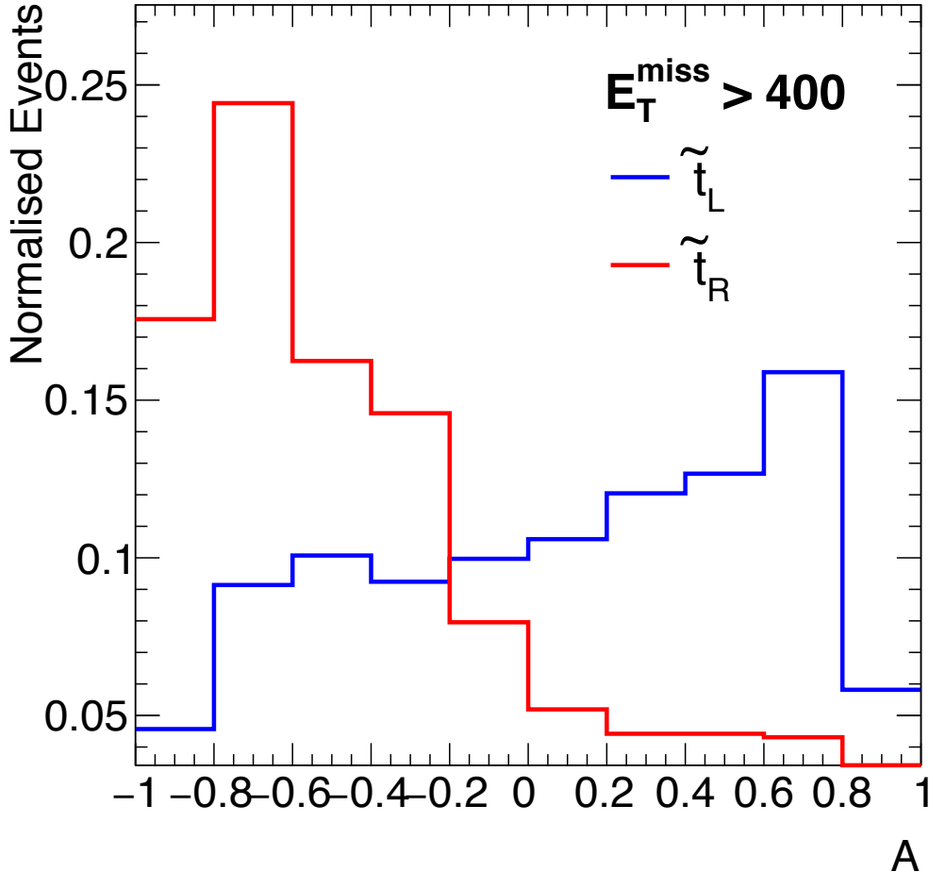
L-handed stop -> R-handed top produced

$$\frac{1}{\Gamma_f}\frac{d\Gamma_f}{d\cos\theta_f} = \frac{1}{2}(1+\omega_f P_t \cos\theta_f) \qquad \omega_b = -0.41, \omega_\ell = 1$$

bottom: backward, lepton: forward

$$\mathcal{A} \equiv \frac{p_T(\ell) - p_T(b)}{p_T(\ell) + p_T(b)} > 0$$





sensitive for L-R, or $\theta_{\tilde{t}}$

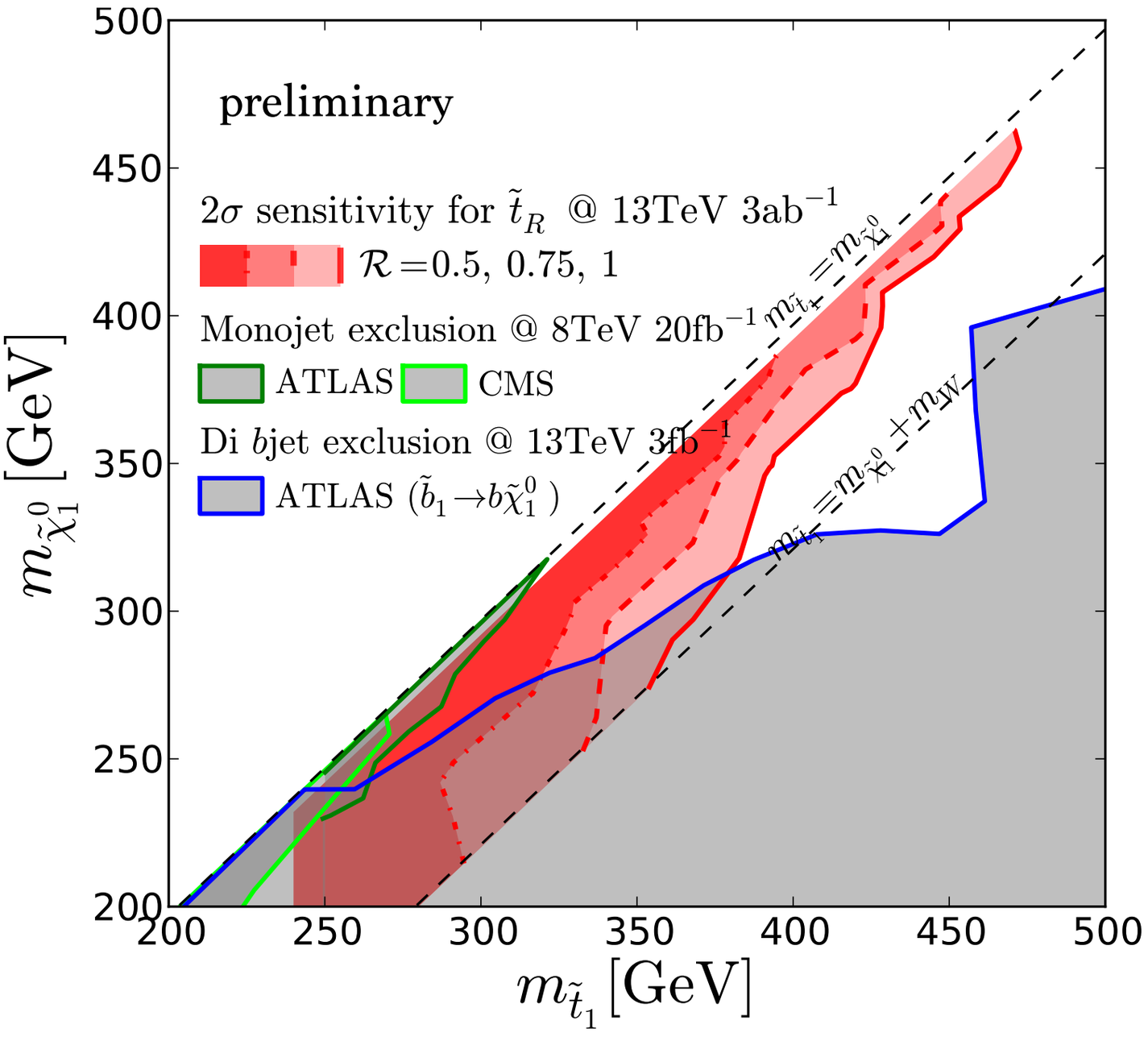
more prominent in boosted regime

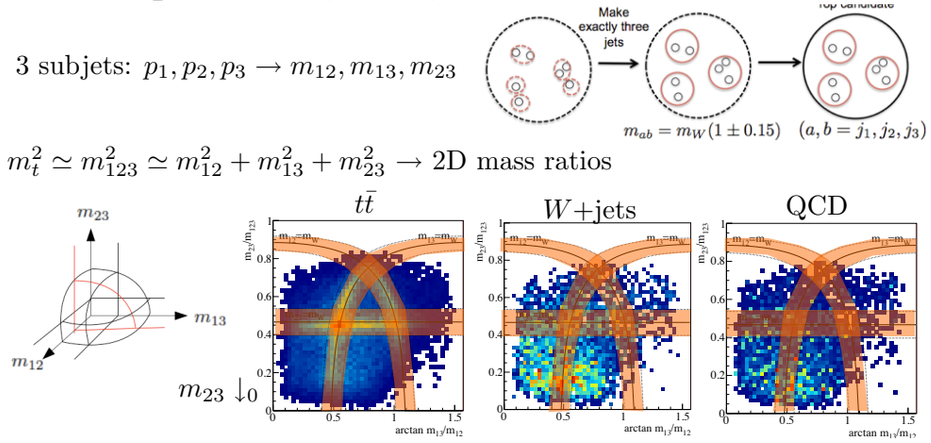
Hadronic channel

[D. Goncalves, K. Sakurai, MT arXiv:1609.0XXXX]

large Emiss, large boost needed -> Top Tagging (HEPTopTagger)

[T. Plehn, M. Spannowsky, MT, D. Zerwas JHEP 1010 (2010) 078]





hadronic case, no $\not{E}_T$ from ν in t_ℓ

(To generate large Emiss in BG,
large top pT required, however,
back to back configuration partly cancels)

more stat, better sensitivity

up to 470GeV sensitive

should be possible to
access top helicity structure

Summary

Natural SUSY: light stop, light higgsino
stop and higgsino naturally degenerate: mono-jet signature.
mono-jet signature has limitation

We propose mono-top signature for additional information.
Measuring $\sigma(\tilde{t}_1 t\chi^0_{1(2)}) = \mathcal{R}\sigma_{\tilde{h}}$ can probe LSP nature (higgsino component)
$p_{T,\ell}, p_{T,b}$ probe stop mixing

We have checked that up to 380 GeV mono-top signature can be probed.
It would be extended up to 470 GeV with hadronic mode combined.

There are interesting excess in stop searches, in a mono-jet search