SUSY Dark Matter

Kazunori Nakayama (University of Tokyo)

LHC研究会＠Nagoya University (2013/5/25)

Dark Matter SUSY

~~SUSY Dark Matter~~

Kazunori Nakayama (University of Tokyo)

LHC研究会＠Nagoya University (2013/5/25)

LHCで何かNew Physics が見えると期待する理由

- Naturalness, g-2 $\longleftarrow$ (浜口さんのトーク)
- WIMP DM シナリオ

$$\Omega_{\rm DM} h^2 \sim 0.1 \left(\frac{1\,{\rm pb}}{\langle \sigma v \rangle} \right) \sim 0.1 \left(\frac{(20\,{\rm TeV})^{-2}}{\langle \sigma v \rangle} \right)$$

PLANCK : $\Omega_{\rm DM} h^2 = 0.1199 \pm 0.0027$

LHCで何かNew Physics が見えると期待する理由

- Naturalness, g-2 $\longleftarrow$ (浜口さんのトーク)
- WIMP DM シナリオ

$$\Omega_{\rm DM}h^2 = 0.1199 \pm 0.0027$$

PLANCK : $\Omega_{\rm DM}h^2 = 0.1199 \pm 0.0027$

$$= 0.1199$$

PLANCK : $\Omega_{\mathrm{DM}} h^2 = 0.1199 \pm 0.0027$

$$= 0.1199$$

$$\pm 0.0027$$

LHCで何かNew Physics が見えると期待する理由

- Naturalness, g-2 $\longleftarrow$ (浜口さんのトーク)
- WIMP DM シナリオ

$$\Omega_{\rm DM}h^2 \sim 0.1 \left(\frac{1\,{\rm pb}}{\langle \sigma v \rangle} \right) \sim 0.1 \left(\frac{(20\,{\rm TeV})^{-2}}{\langle \sigma v \rangle} \right)$$

PLANCK : $\Omega_{\rm DM}h^2 = 0.1199 \pm 0.0027$

WIMP DM という観点からSUSYパラメータ領域を見直してみる(CMSSM & AMSB)

他の (Gravitinoとか) は今回とりあえず考えない

CMSSM

Bino-like neutralino は対消滅断面積が小さいので (helicity suppression)、何らかのメカニズムが必要

- Light-bino — 非常に軽いBino 既にexcluded
- Well-tempered — Large Bino-Higgsino mixing
  $\tilde{\chi}\tilde{\chi} \to W^+W^-$
- A-pole (funnel) — Resonance via CP-odd Higgs
  $\tilde{\chi}\tilde{\chi} \to A^0 \to f\bar{f}$
- Stau coannihilation — Stauとして消える $m_{\tilde{\chi}} \sim m_{\tilde{\tau}}$
- Stop coannihilation — Stopとして消える $m_{\tilde{\chi}} \sim m_{\tilde{t}}$

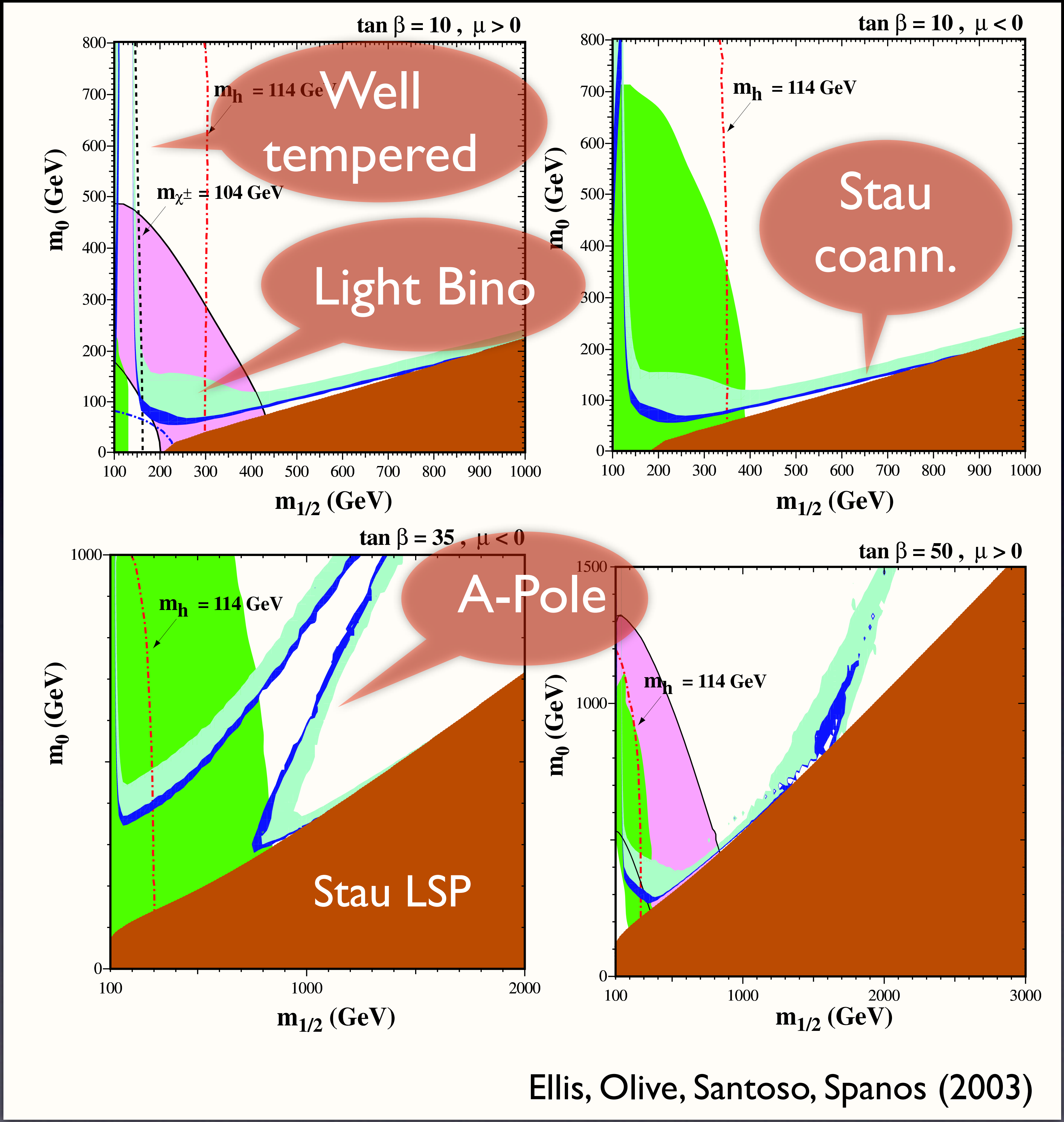
ちょっと

昔の絵 ⟶

水色の領域が

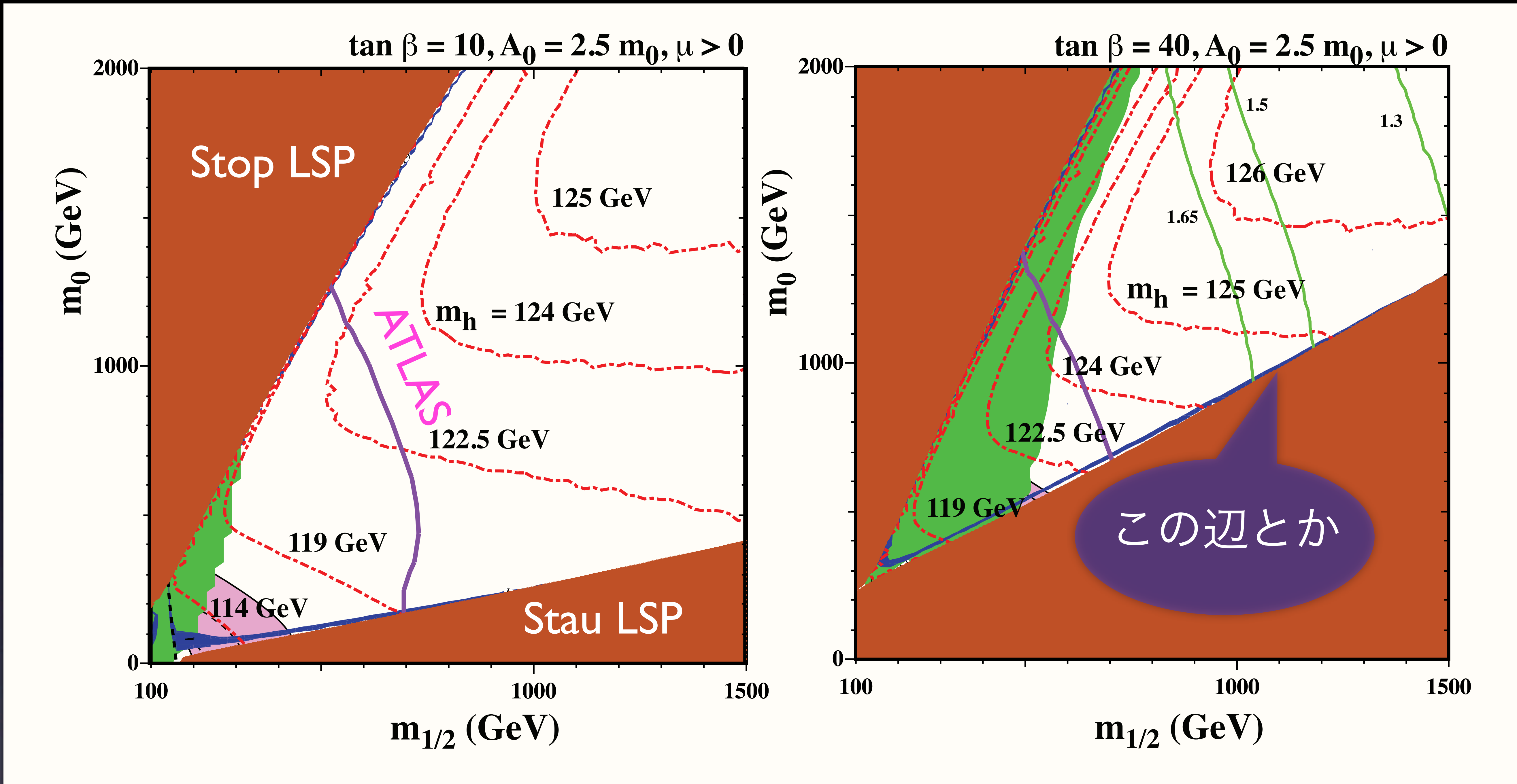
DMを説明

出来るところ



最近の状況(CMSSM)

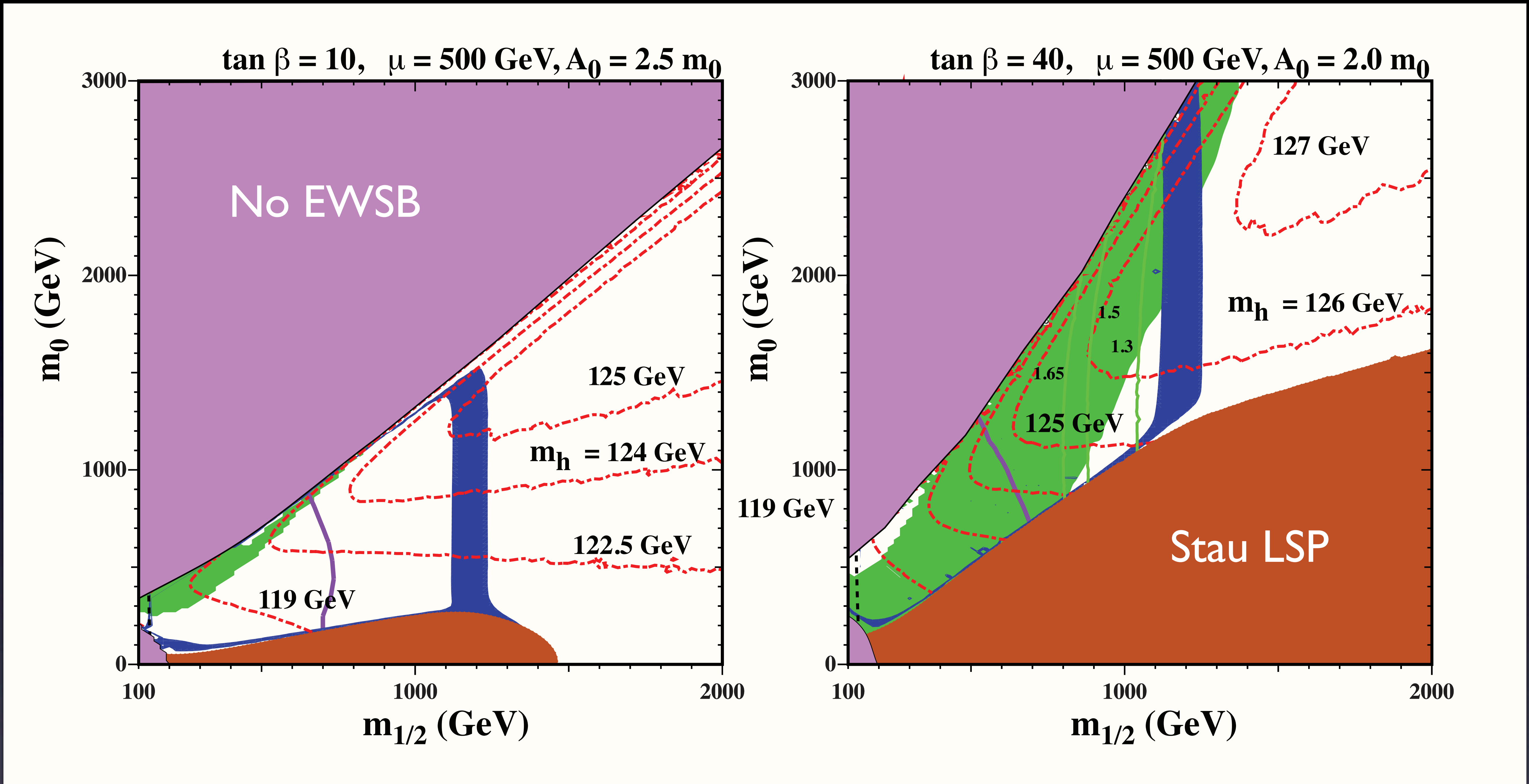
Ellis, Luo, Olive, Sandick, 1212.4476



何か結構狭くなったように見えますが...

最近の状況 (NUHM)

Ellis, Luo, Olive, Sandick, 1212.4476



まだまだOKという気も。

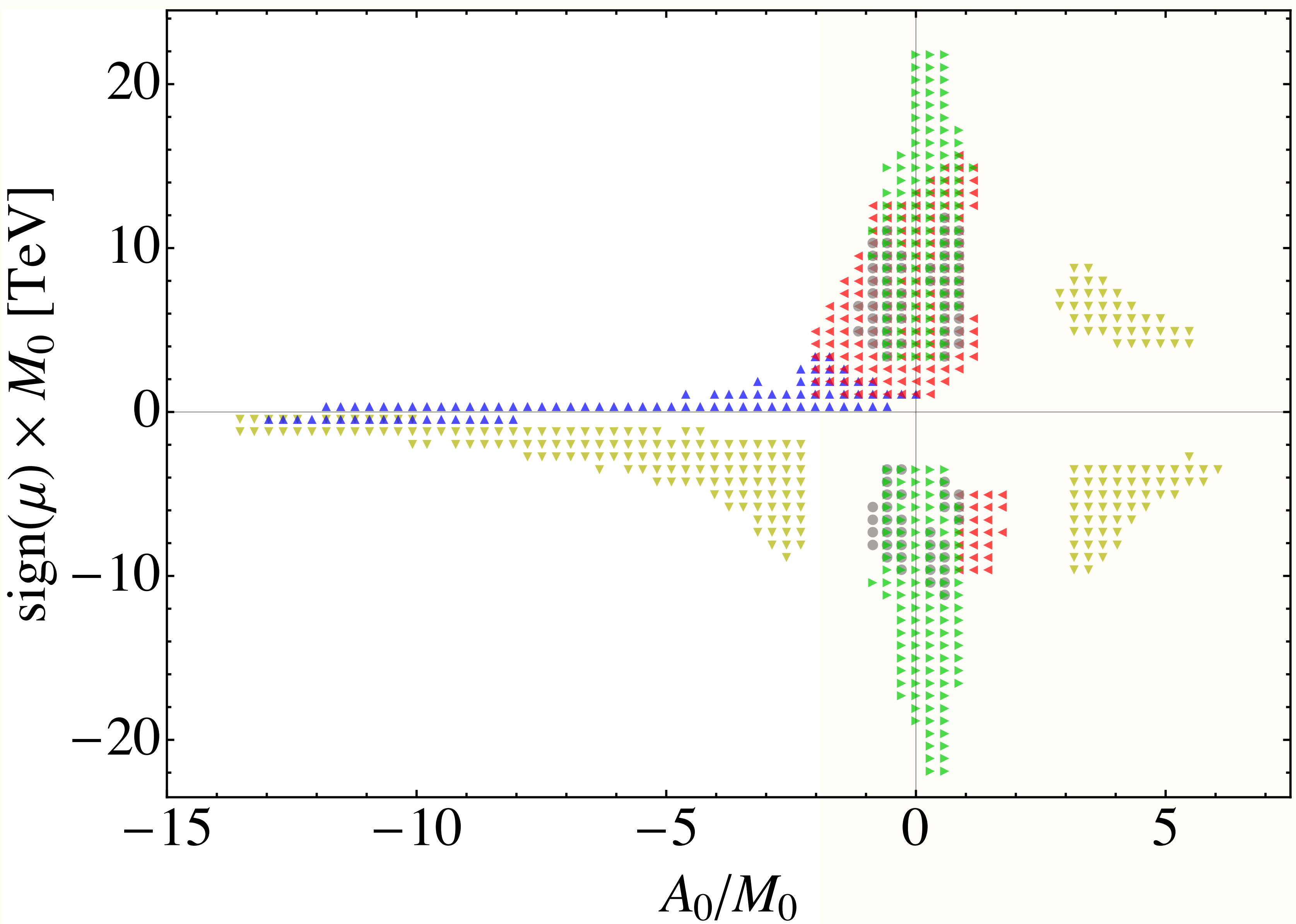
$$\mathrm{NUHM} \;:\; m_{H_u}^2 = m_{H_d}^2 \neq m_0^2$$

CMSSMでDMが再現できる領域をサーチ

T.Cohen, J.G.Wacker, 1305.2914

条件：

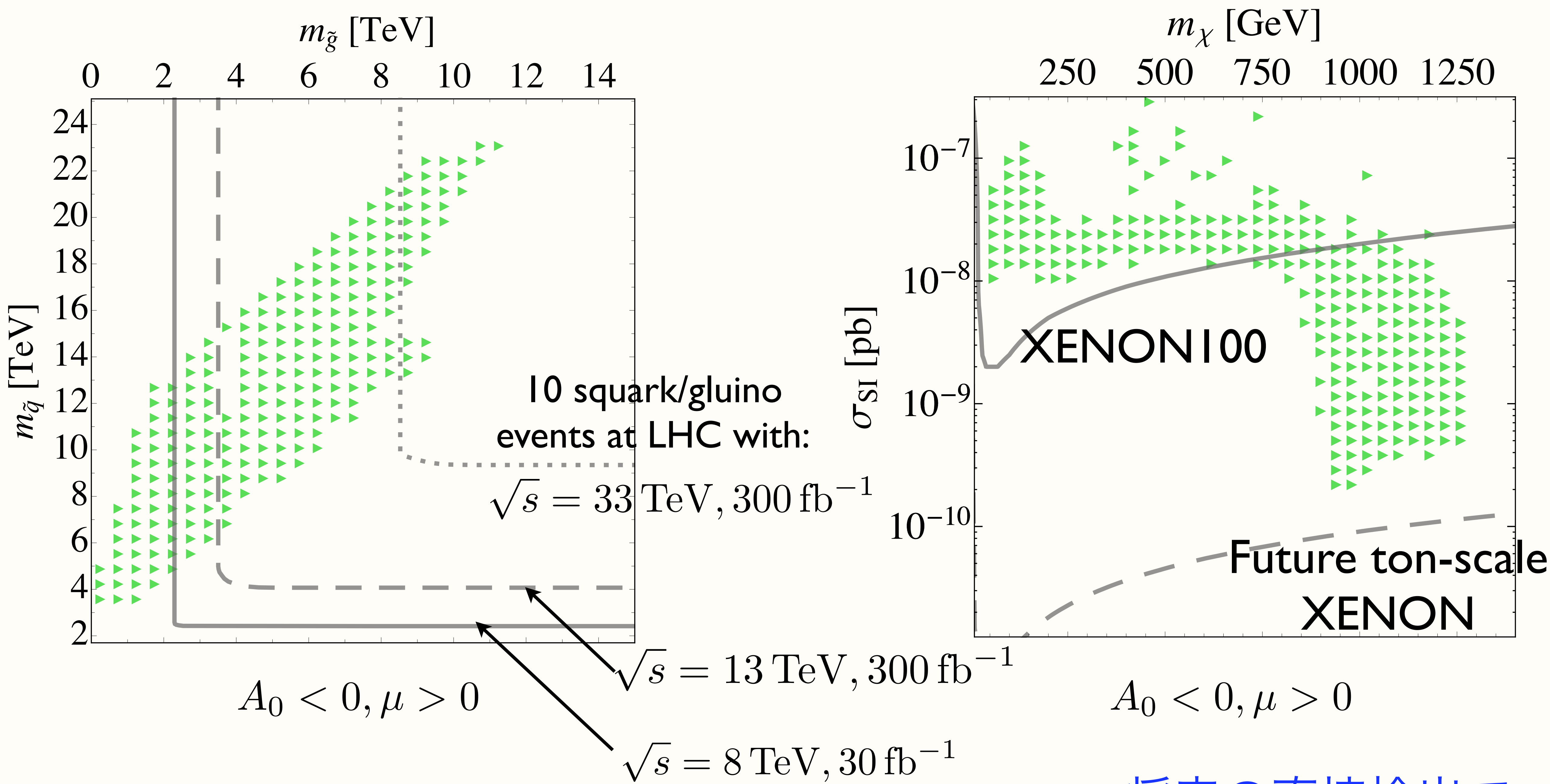
- $122\,\mathrm{GeV} < m_h < 128\,\mathrm{GeV}$
- $0.08 < \Omega_c h^2 < 0.14$
- Vacuum (meta)stability



Green: well-tempered
Red: A-pole
Blue: stau-coann.
Yellow: stop-coann.

それぞれの領域についてもう少し詳しく見てみる

Well-tempered



Pure higgsino limitで DM mass ~ 1TeV

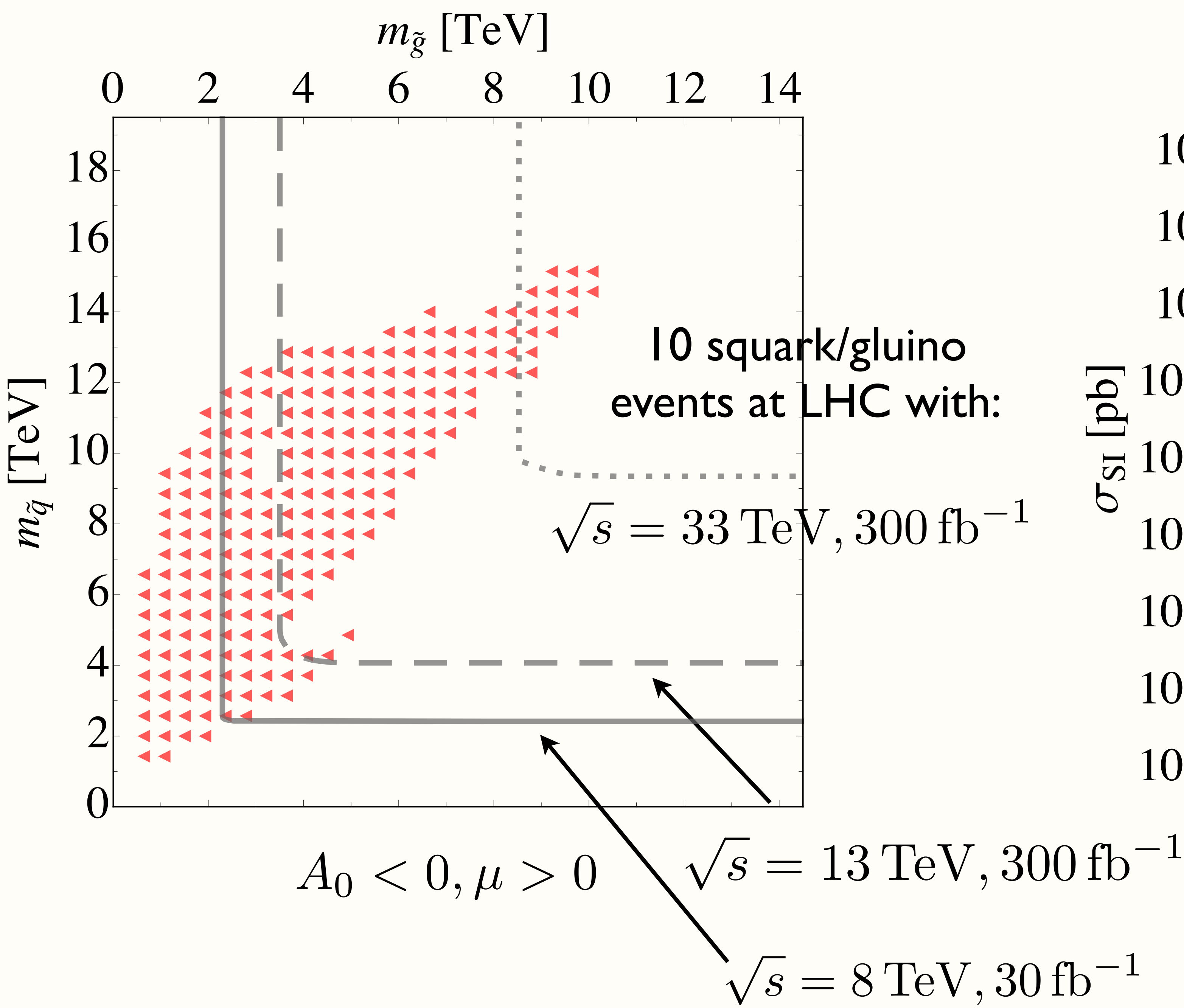
かなり重い領域までである

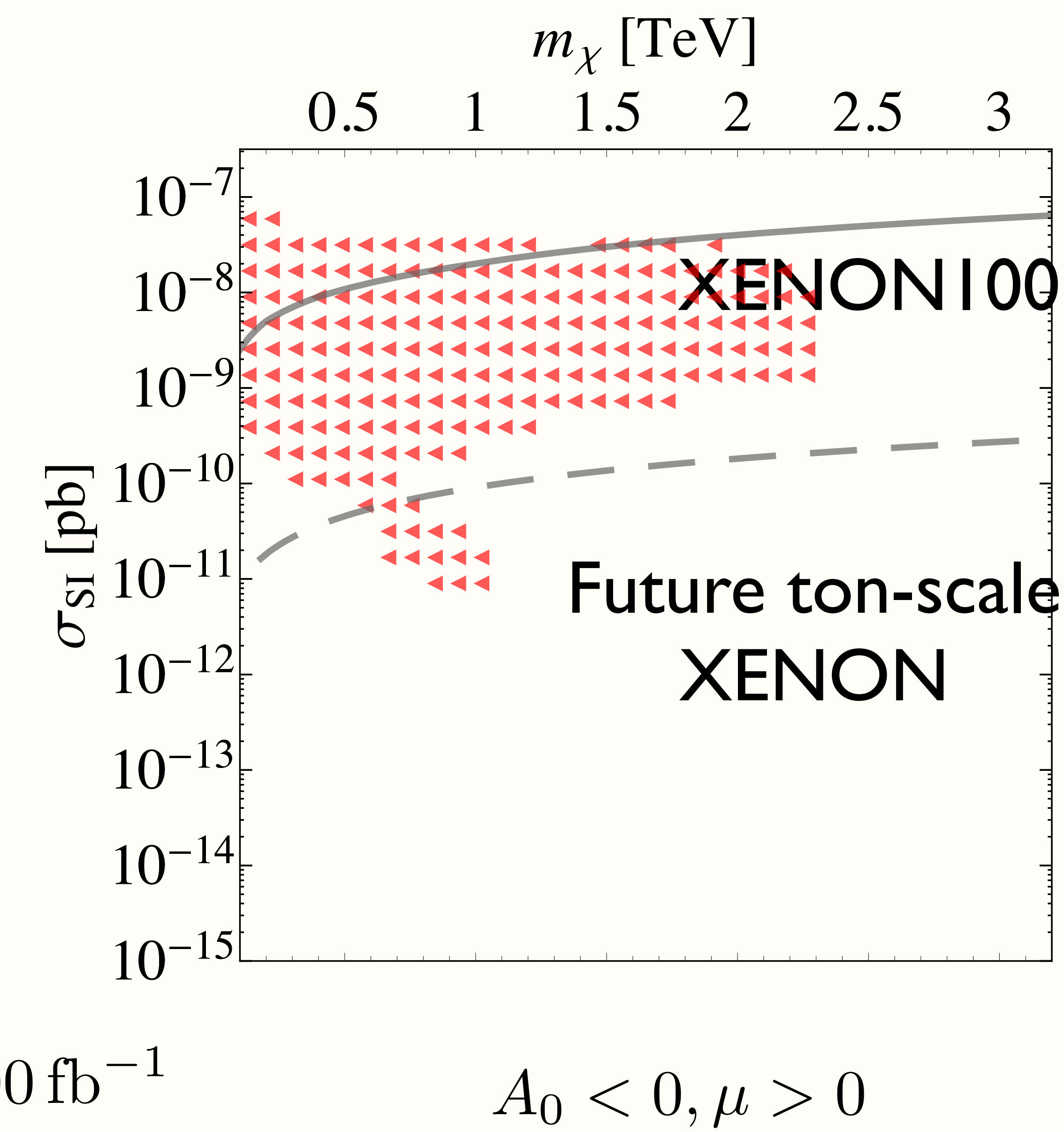
将来の直接検出で

ほとんどカバー

出来る

A0-Pole

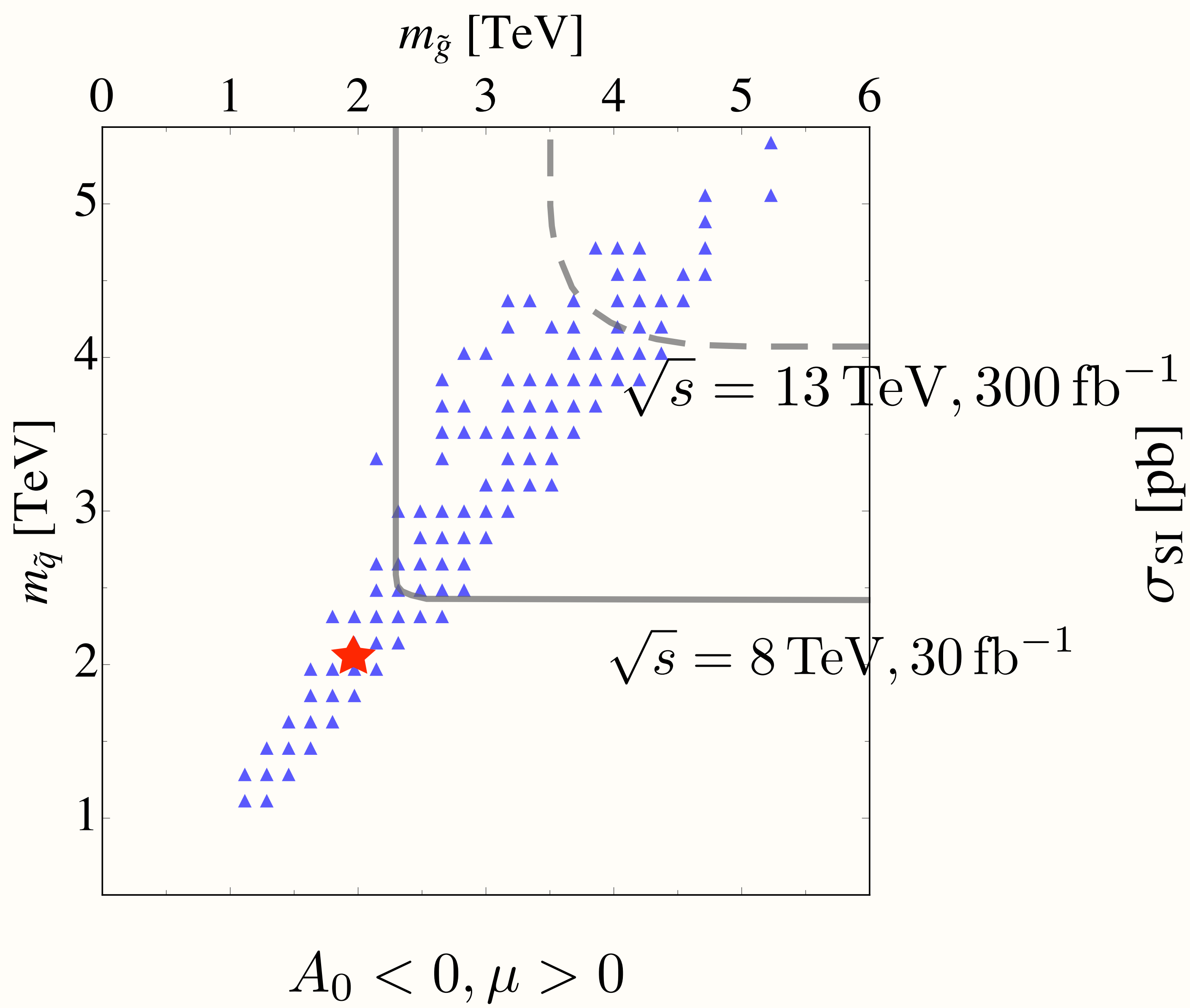


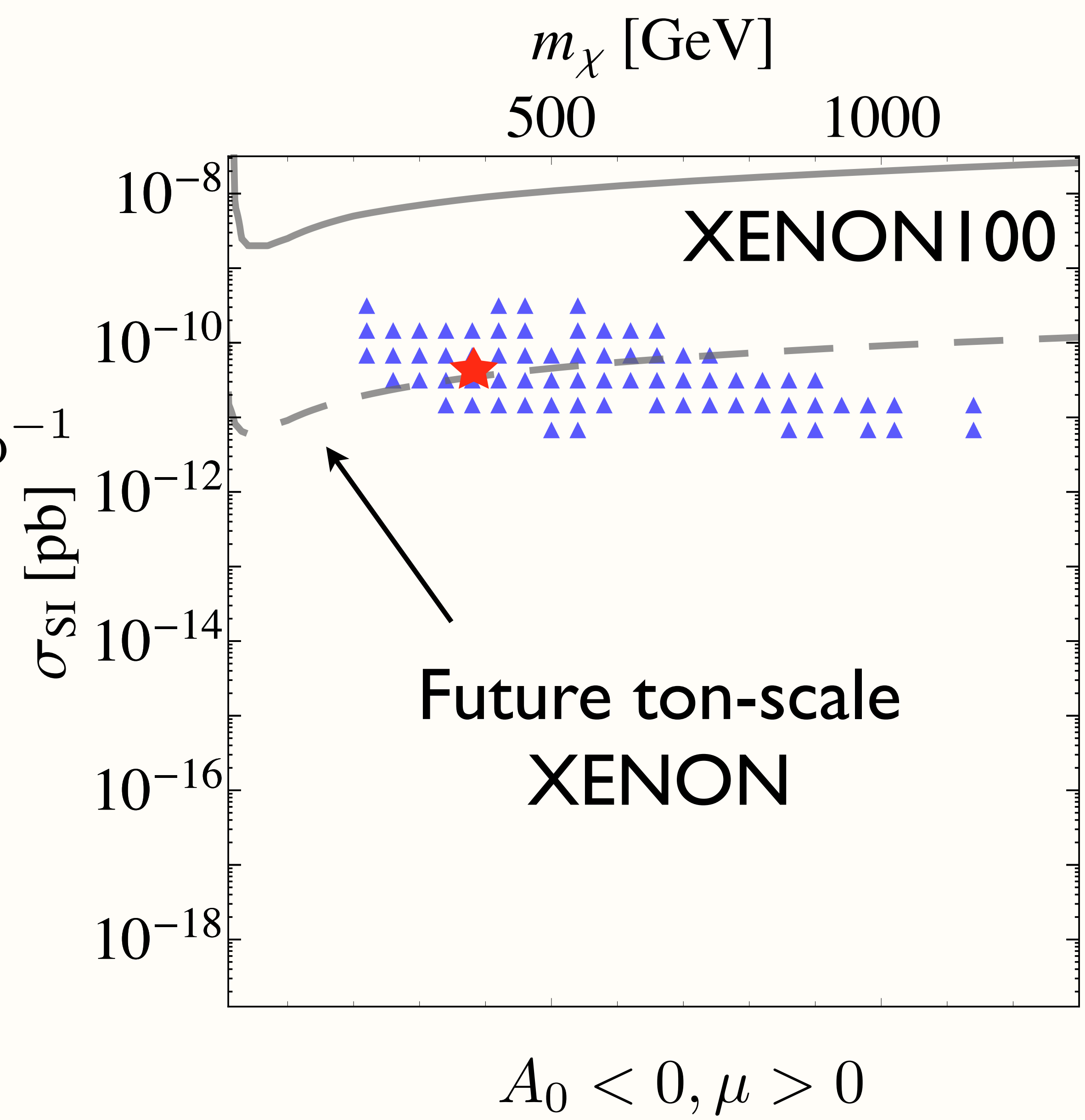


DM mass ~ 3TeVでもOK　　そこそこのbino-higgsino mixingは必要

直接検出は比較的大きめ

Stau coannihilation





M0もM1/2も割と小さいので
LHC 的には比較的見易い

Direct detection は
厳しい

Benchmark point (stau coann.) I

Input parameters						
M_0	$M_{\frac{1}{2}}$	A_0	$\tan\beta$	$\mathrm{sign}(\mu)$	$\lvert\mu\rvert$	$\mathrm{sign}(B_\mu)\sqrt{\lvert B_\mu\rvert}$
765.97	900.	-2882.83	28.3588	1	1736.46	31794.6

Low energy spectrum											
$m_{\tilde{g}}$	$m_{\tilde{q}}$	$m_{\tilde{t}_1}$	$m_{\tilde{\tau}_1}$	m_χ	$m_{\chi_1^\pm}$	m_h	m_A	Ωh^2	σ_{SI} [pb]	Δ_v	Δ_Ω
1990	1950	988	389	386	736	125	1580	0.103	2.21×10^{-11}	1400	160

$m_{\tilde{\tau}} - m_{\tilde{\chi}} = 3.36\,\mathrm{GeV}$ $\quad\tilde{\tau} \to (\mathrm{soft})\ \tau + \tilde{\chi}$

$\sigma(pp \to \tilde{\chi}_2^0 \tilde{\chi}_1^\pm) = 2.3\,\mathrm{fb}$ @ 13 TeV

$\tilde{\chi}_2^0 \to \tilde{\tau}^\pm \tau^\mp,\ \tilde{\chi}_1^+ \to \tilde{\tau}^+ \nu_\tau$: Challenging

$\sigma(pp \to \tilde{q}\tilde{q}) = 6.0\,\mathrm{fb}$ @ 13 TeV

$\tilde{u}_L \to d\tilde{\chi}_1^+,\ \tilde{\chi}_1^+ \to \tilde{\tau}^+ \nu_\tau$

Benchmark point (stau coann.) 2

Input parameters						
M_0	$M_{\frac{1}{2}}$	A_0	$\tan\beta$	$\text{sign}(\mu)$	$\lvert\mu\rvert$	$\sqrt{B_\mu}$
259.515	900.862	-2296.71	9.23077	-1	1555.68	8702.87

Low energy spectrum											
$m_{\tilde{g}}$	$m_{\tilde{q}}$	$m_{\tilde{t}_1}$	$m_{\tilde{\tau}_1}$	m_χ	$m_{\chi_1^\pm}$	m_h	m_A	Ωh^2	$\sigma_{\rm SI}$ [pb]	Δ_v	Δ_Ω
1980	1820	1070	384	384	732	122	1680	0.116	1.52×10^{-14}	1300	33

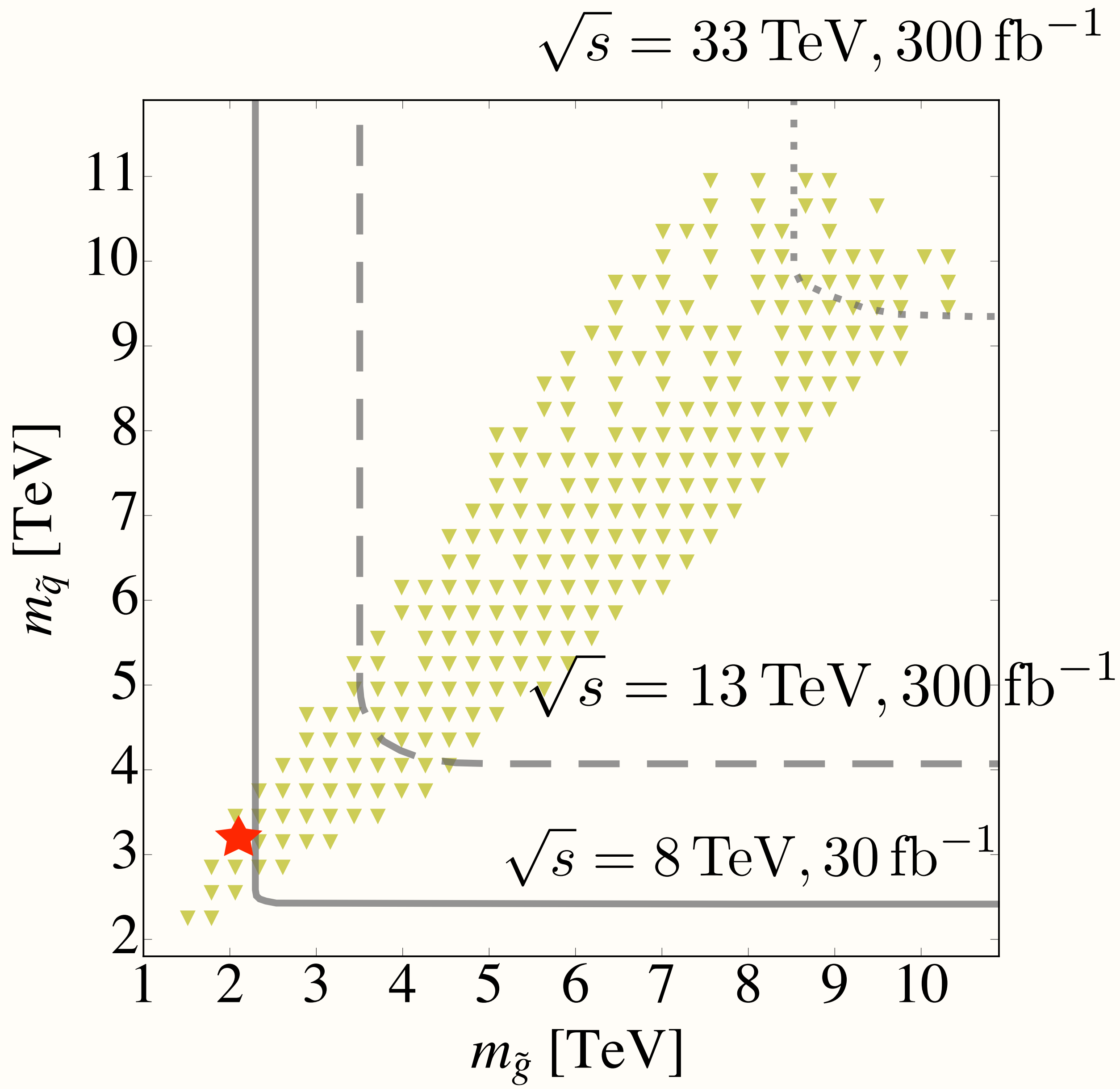
$m_{\tilde{\tau}} - m_{\tilde{\chi}} = 0.28\,\text{GeV}$: Long-lived stau (lifetime ~ 0.01s)

$$\sigma(pp \to \tilde{\tau}^+\tilde{\tau}^-) = 0.59\,\text{fb @ 13 TeV}$$

$$\sigma(pp \to \tilde{\tau}^\pm + j + X) = 1.4\,\text{fb @ 13 TeV}$$

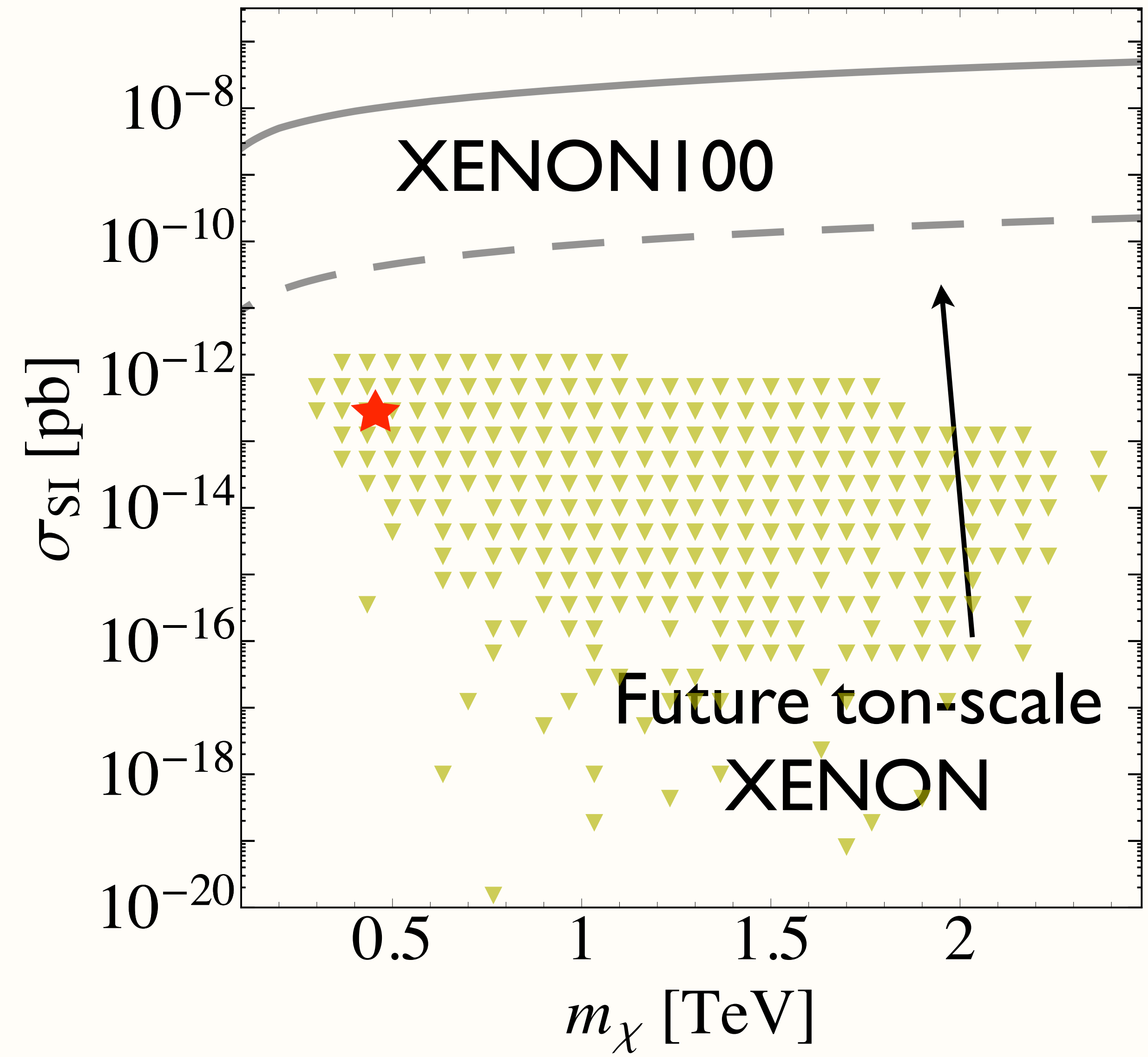
Eg) $\tilde{u}_L \to d\tilde{\chi}_1^+, \quad \tilde{\chi}_1^+ \to \tilde{\tau}^+\nu_\tau$

Stop coannihilation



$A_0 < 0, \mu < 0$

基本大体重い



$A_0 < 0, \mu < 0$

直接検出は

絶望的

Benchmark point (stop coann.)

Input parameters						
M_0	$M_{\frac{1}{2}}$	A_0	$\tan\beta$	sign(μ)	$\vert\mu\vert$	$\sqrt{B_\mu}$
2666.67	933.333	-6444.	8.52015	-1	2794.86	18094.8

Low energy spectrum											
$m_{\tilde{g}}$	$m_{\tilde{q}}$	$m_{\tilde{t}_1}$	$m_{\tilde{\tau}_1}$	m_χ	$m_{\chi_1^\pm}$	m_h	m_A	Ωh^2	$\sigma_{\rm SI}$ [pb]	Δ_v	Δ_Ω
2170	3200	446	2640	411	791	124	3880	0.116	2.06×10^{-13}	4500	800

$$\sigma(pp \to \tilde{t}\tilde{t}) = 0.96\text{pb@13TeV}$$

しかし...

$$\tilde{t}_1 \to \begin{cases} c\,\chi_1^0 & 69\% \\ b\,(W^+)^*\,\chi_1^0 & 31\% \end{cases}$$

$$\sigma(pp \to \tilde{g}\tilde{g}) = 0.23\text{fb@13TeV} \qquad \tilde{g} \to \bar{t}\tilde{t}$$

$$\longrightarrow \quad \sigma(pp \to ttE_{\rm miss}) = 0.22\text{fb@13TeV}$$

- DM-CMSSM まとめ

	Parameter	LHC	直接検出
Well tempered	$m_{\tilde{B}} \sim \mu$ $m_{\tilde{\chi}_0} = 0.3 - 1\mathrm{TeV}$	△	Ton scale で大体カバー
A0-Pole	$m_{\tilde{B}} \sim m_A/2$ $m_{\tilde{\chi}_0} = 0.5 - 3\mathrm{TeV}$	△	Ton scale で結構カバー
Stau coann.	$m_{\tilde{B}} \sim m_{\tilde{\tau}}$ $m_{\tilde{\chi}_0} = 0.3 - 1\mathrm{TeV}$	○	難
Stop coann.	$m_{\tilde{B}} \sim m_{\tilde{t}}$ $m_{\tilde{\chi}_0} = 0.5 - 1.5\mathrm{TeV}$	△	難

AMSB
(Pure-gravity mediation)

- Sfermion ~ O(100)TeV
  Gaugino ~ O(1)TeV (AMSB) $m_{\tilde{B}} : m_{\tilde{W}} : m_{\tilde{g}} \sim 3:1:8$

$\longrightarrow$ Wino LSP

- Thermal relic とすると $m_{\tilde{W}} \sim 2.7\,\mathrm{TeV}$ **絶望**

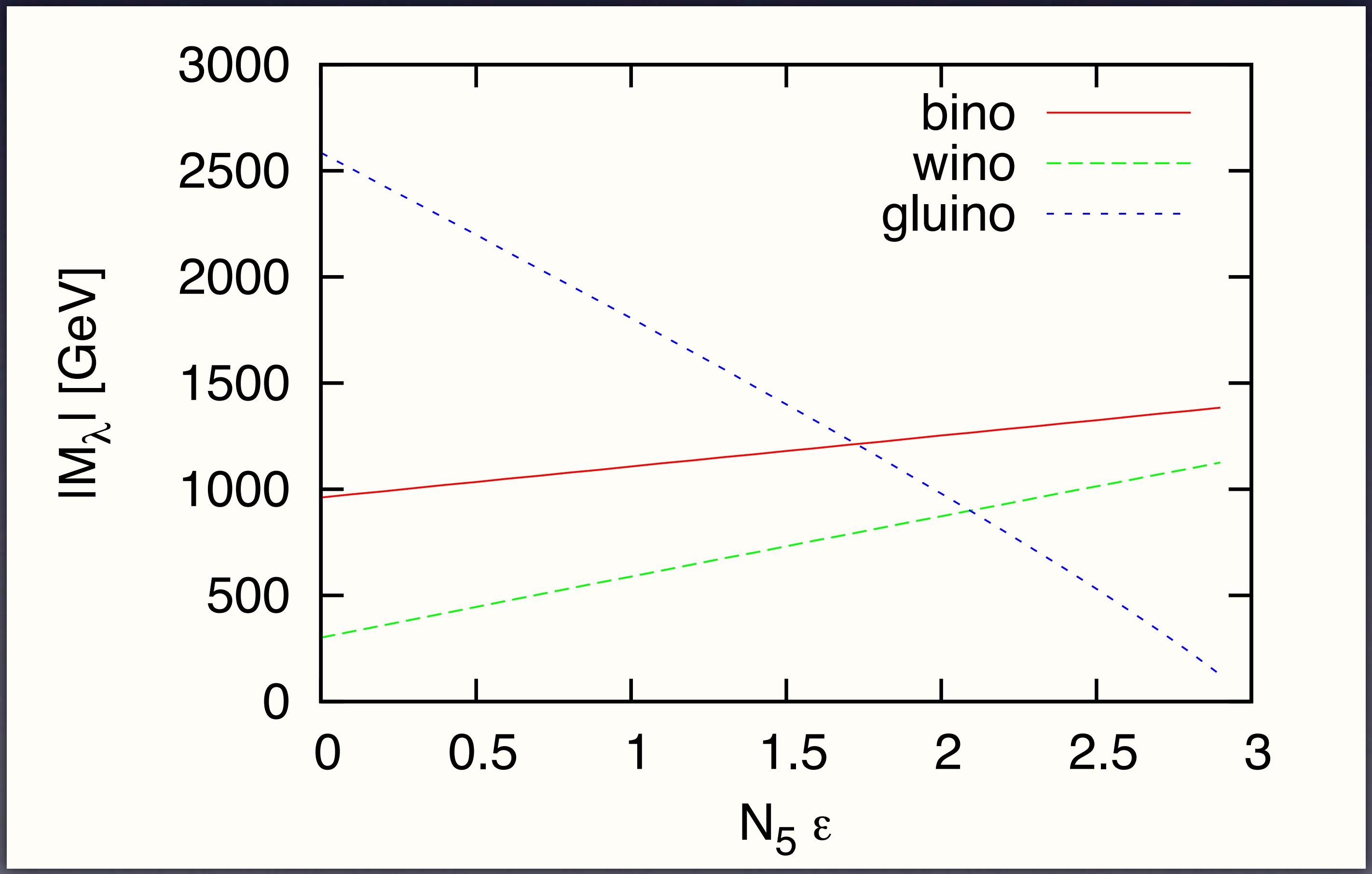
Hisano, Matsumoto, Nagai, Saito, Senami (2007)

- 非熱的に作れば $m_{\tilde{W}} \gtrsim 300\,\mathrm{GeV}$ ぐらいでOK

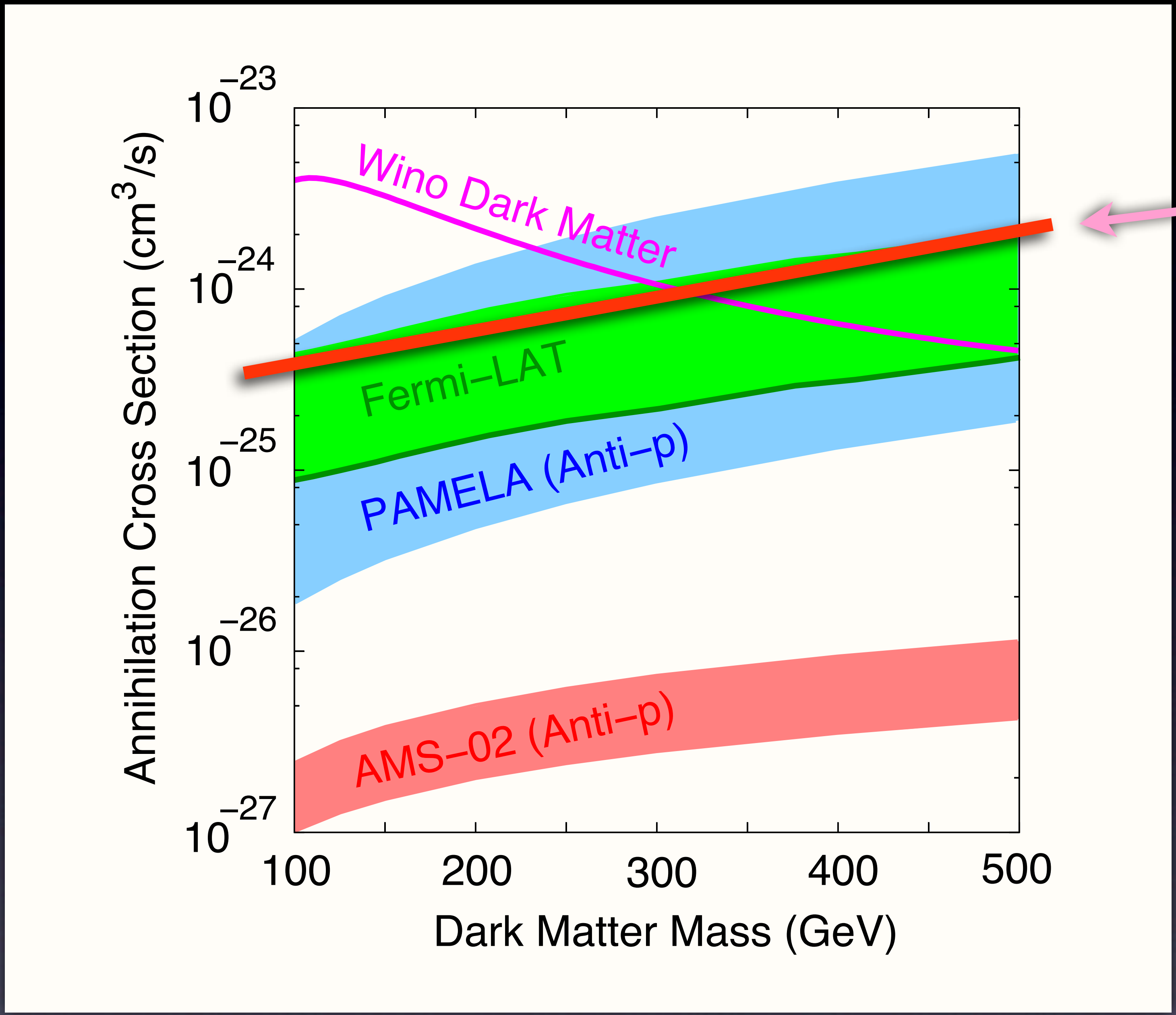
  この位なら...？

- ちなみにgluino mass
  は結構下げられる

KN, T.Yanagida, 1302.3332



- Lower bound on Wino DM mass



Bound from WMAP

Hisano, Kawasaki, Kohri, Moroi, KN, Sekiguchi (2011)

Both Fermi & WMAP

$$m_{\tilde{W}} \gtrsim 300\,\mathrm{GeV}$$

Ibe, Matsumoto, Yanagida (2012)

PLANCK データを用いて解析中

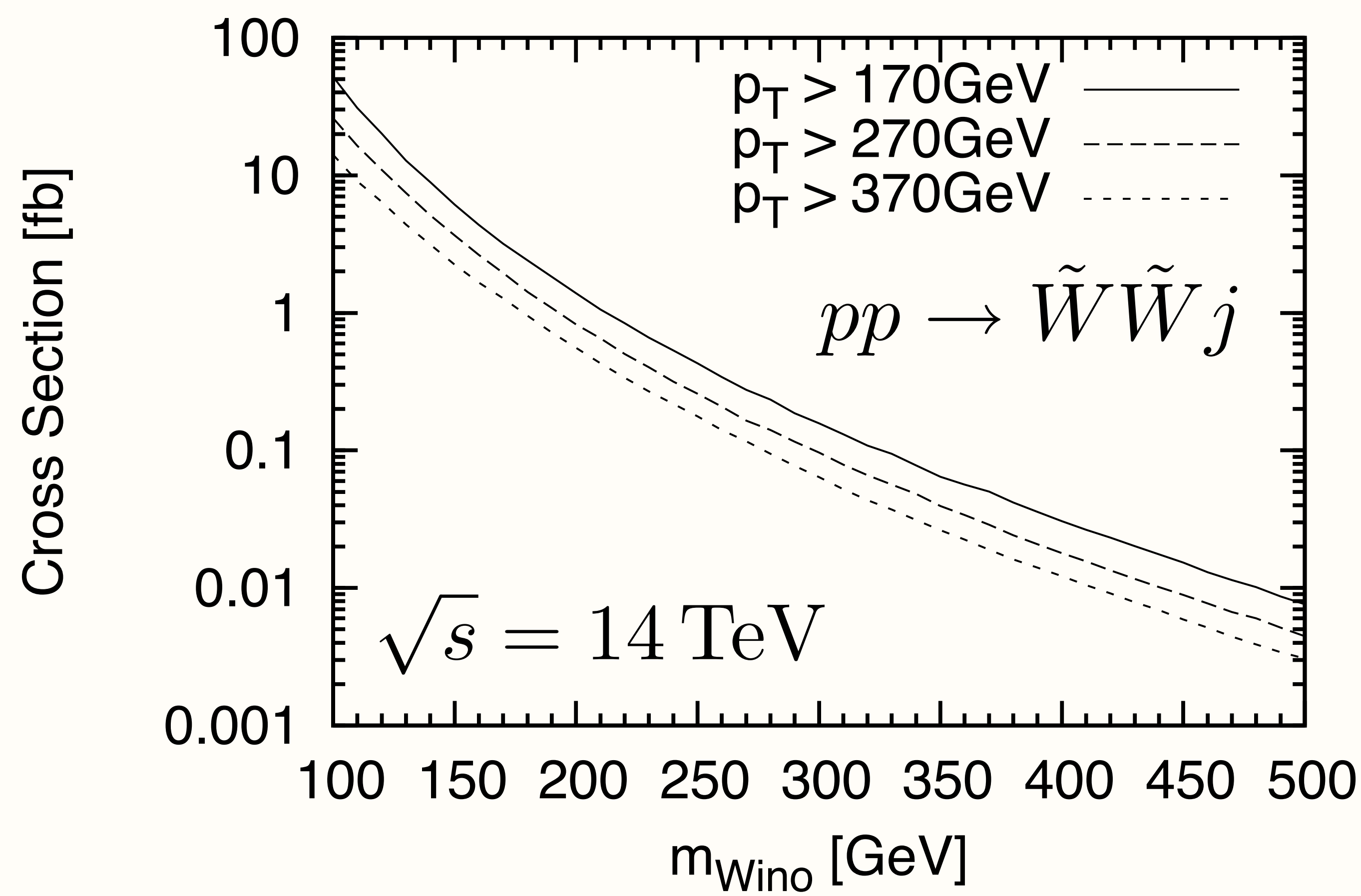
Kawasaki, KN, Sekiguchi, in prep.

T.Moroi, KN, (2012)

- LHC

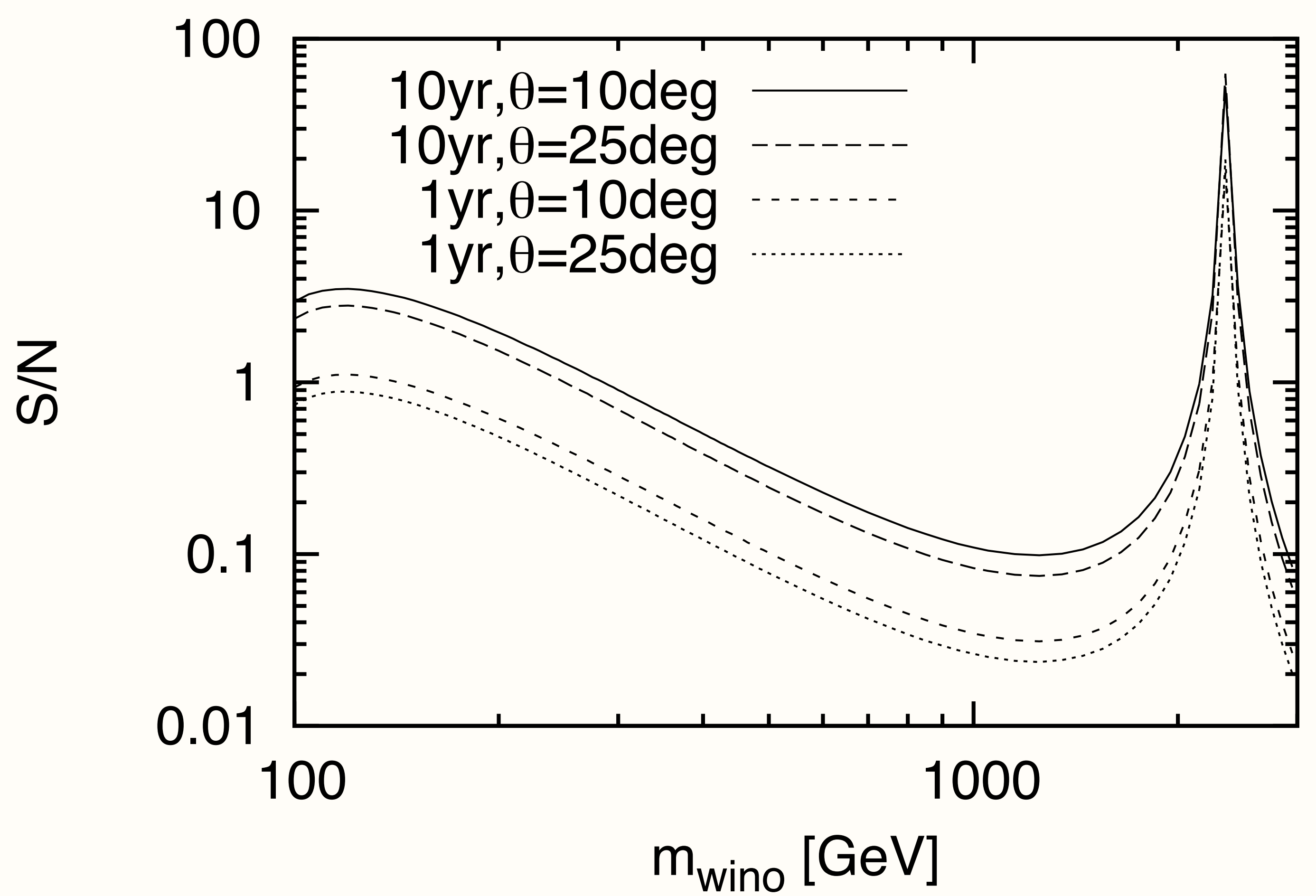
Chargino Track

Ibe, Moroi, Yanagida (2006)
Asai, Moroi, Nishihara, Yanagida (2007)



- IceCube DeepCore

Neutrino-induced cascade muon events



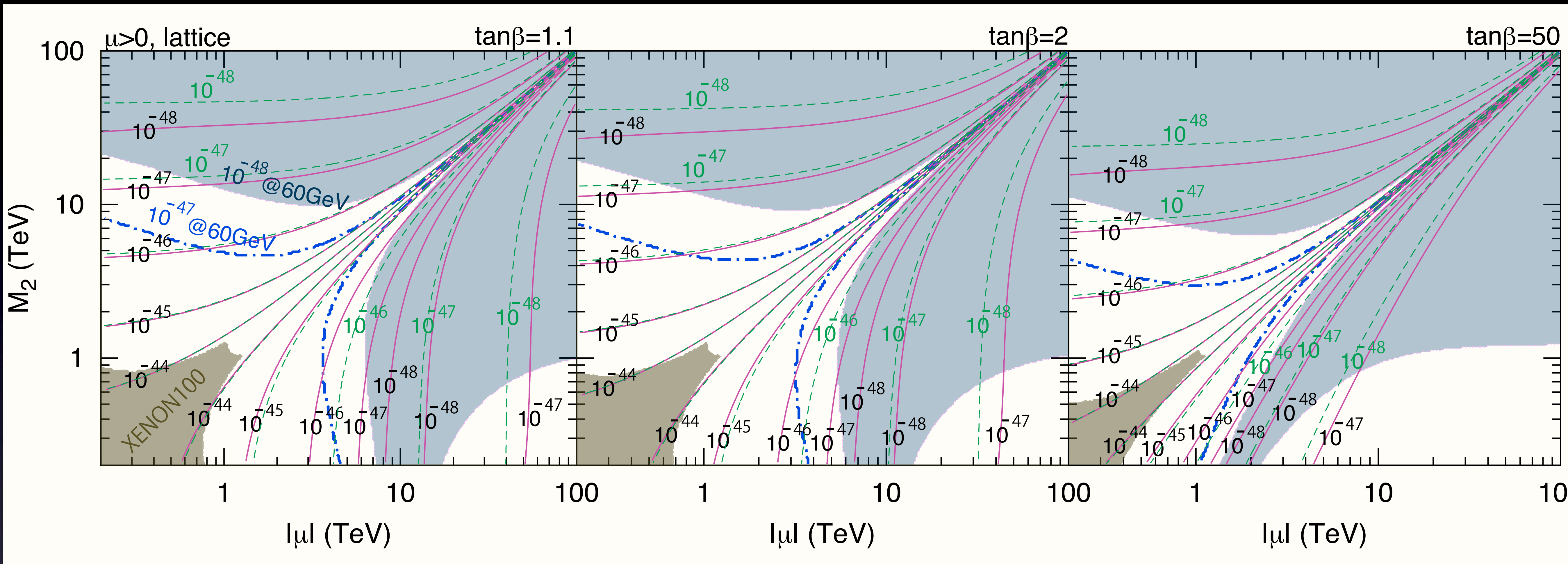
いずれも

$m_{\tilde{W}} \lesssim 300\,\mathrm{GeV}$ 位

13年5月25日土曜日

- Direct detection

Hisano, Ishiwata, Nagata, 1210.5985

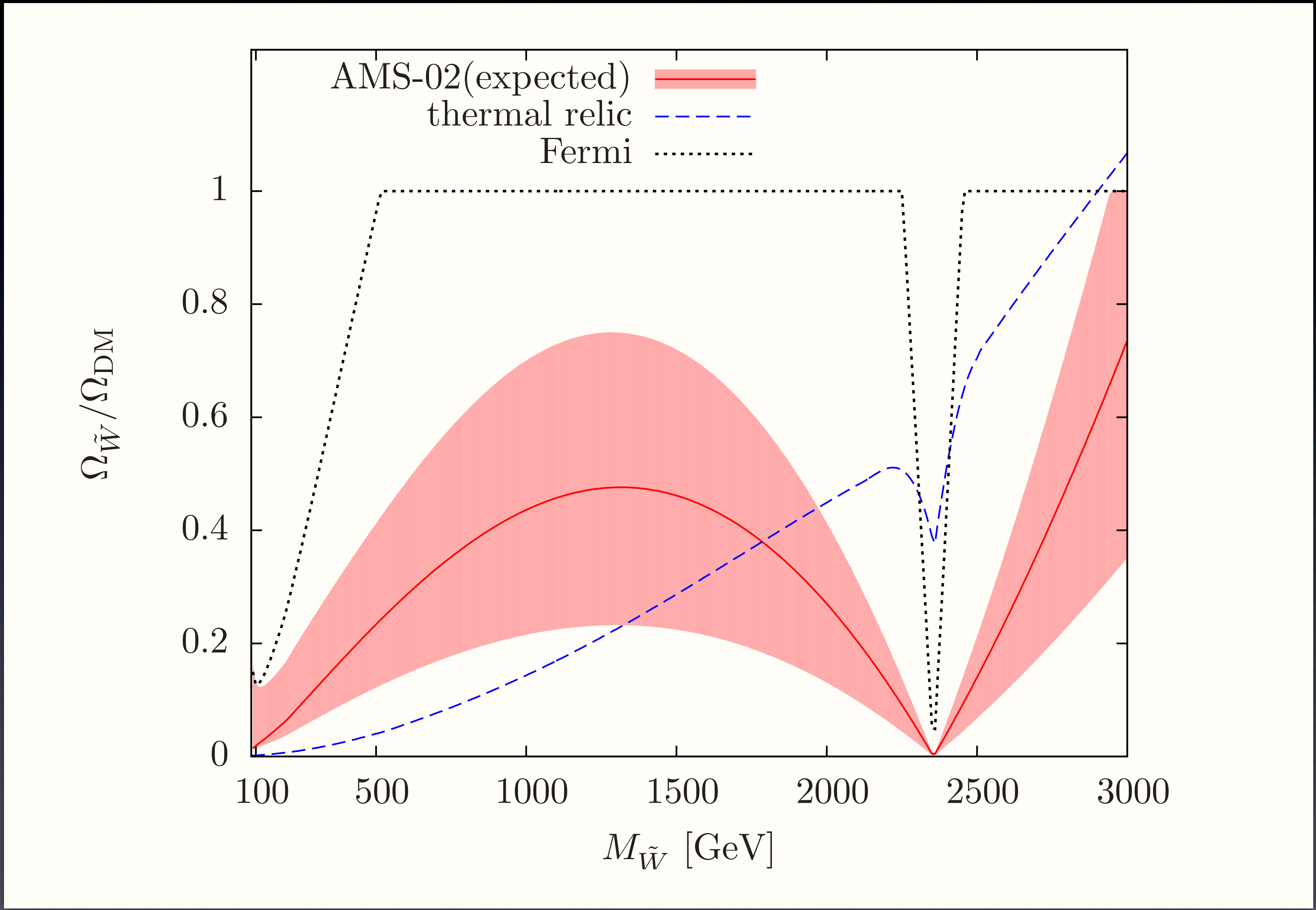


Pure-Wino limit で $\sigma_{\mathrm{SI}} \sim 10^{-47} - 10^{-48}\,\mathrm{cm}^2$

ちょっと辛いか？

- Anti-Proton

AMS-02でかなりいける。Wino検出の最有力？



Hall, Nomura, Shirai, 1210.2395

DM SUSY まとめ

- CMSSM + Dark Matter + 125GeV Higgs という領域はかなり残っている。13TeV LHC + direct で相補的に割とカバーできそう
- LHC的には Stau coannihilation 領域が面白い (Colored particle search & CHAMP search)
- AMSB は差し当たりAMS (反陽子) に期待

Backup

Benchmark point (Well-tempered)

Input parameters						
M_0	$M_{\frac{1}{2}}$	A_0	$\tan\beta$	sign(μ)	$\lvert\mu\rvert$	$\sqrt{B_\mu}$
4103.76	525.385	905.88	13.6663	-1	292.034	10805.

Low energy spectrum											
$m_{\tilde{g}}$	$m_{\tilde{q}}$	$m_{\tilde{t}_1}$	$m_{\tilde{\tau}_1}$	m_χ	$m_{\chi_1^\pm}$	m_h	m_A	Ωh^2	$\sigma_{\rm SI}$ [pb]	Δ_v	Δ_Ω
1330	4180	2510	4040	218	292	122	4000	0.139	5.15×10^{-9}	400	37

$$\sigma(pp \to \tilde{g}\tilde{g}) = 30\text{fb@13TeV}$$

$$\sigma(pp \to \tilde{\chi}_2^0\tilde{\chi}_1^\pm) = 73\,\text{fb @ 13 TeV}$$

Benchmark point (A-Pole)

Input parameters						
M_0	$M_{\frac{1}{2}}$	A_0	$\tan\beta$	$\mathrm{sign}(\mu)$	$\lvert\mu\rvert$	$\mathrm{sign}(B_\mu)\sqrt{\lvert B_\mu\rvert}$
2311.11	666.667	-3021.77	55.8605	1	1708.6	-99290.9

Low energy spectrum											
$m_{\tilde{g}}$	$m_{\tilde{q}}$	$m_{\tilde{t}_1}$	$m_{\tilde{\tau}_1}$	m_χ	$m_{\chi_1^\pm}$	m_h	m_A	$\Omega\, h^2$	σ_{SI} [pb]	Δ_v	Δ_Ω
1610	2640	1430	1110	292	564	122	564	0.138	6.11×10^{-10}	870	91

$$\sigma(pp \to \tilde{g}\tilde{g}) = 8.0\mathrm{fb}@13\mathrm{TeV}$$

$$\sigma(pp \to \tilde{\chi}_2^0\tilde{\chi}_1^\pm) = 14\,\mathrm{fb}\ @\ 13\,\mathrm{TeV}$$