Some aspects of
some of

SUSY DM

candidates

(after Higgs discovery)

Koichi Hamaguchi (University of Tokyo)

@MIAPP Dark MALT workshop, February 19, 2015

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candidates

SUSY DM

(after Higgs discovery)

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partially based on……

KH, K.Mukaida (Wino DM from Q-ball), in preparation

KH, K.Ishikawa (light Bino-like DM), in preparation

M.Endo, KH, S.Iwamoto, T.Yoshinaga (DM + g-2), in preparation

KH, M.Ibe, T.T.Yanagida, N.Yokozaki ((gravitino DM in) GMSB), 1403.1398

Plan

- 126 GeV Higgs and SUSY
- Wino DM (in heavy sfermion scenario)
- gravitino DM (in GMSB)

- light Bino-like DM (h/Z-resonant Bino)
- g-2 and DM

Plan

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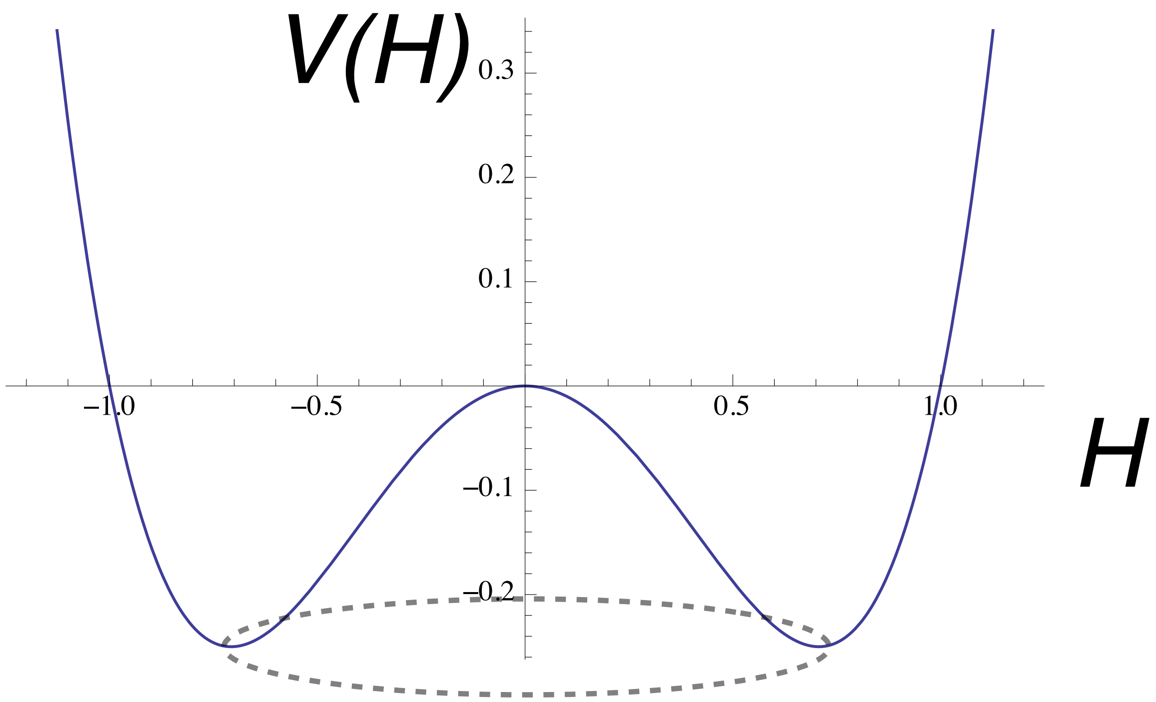
- **g-2** and DM

126 GeV Higgs

$$V(H) = -m^2(H^\dagger H) + \lambda_{\rm H}(H^\dagger H)^2$$



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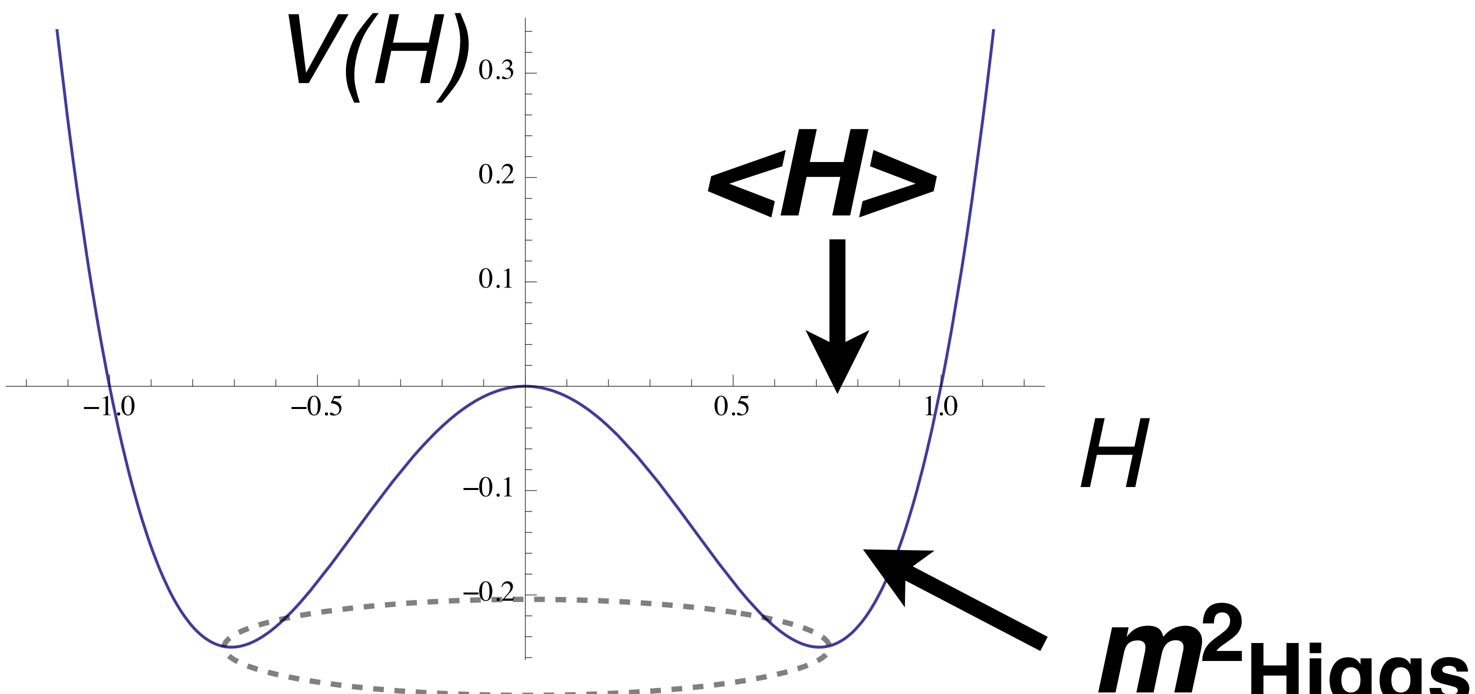
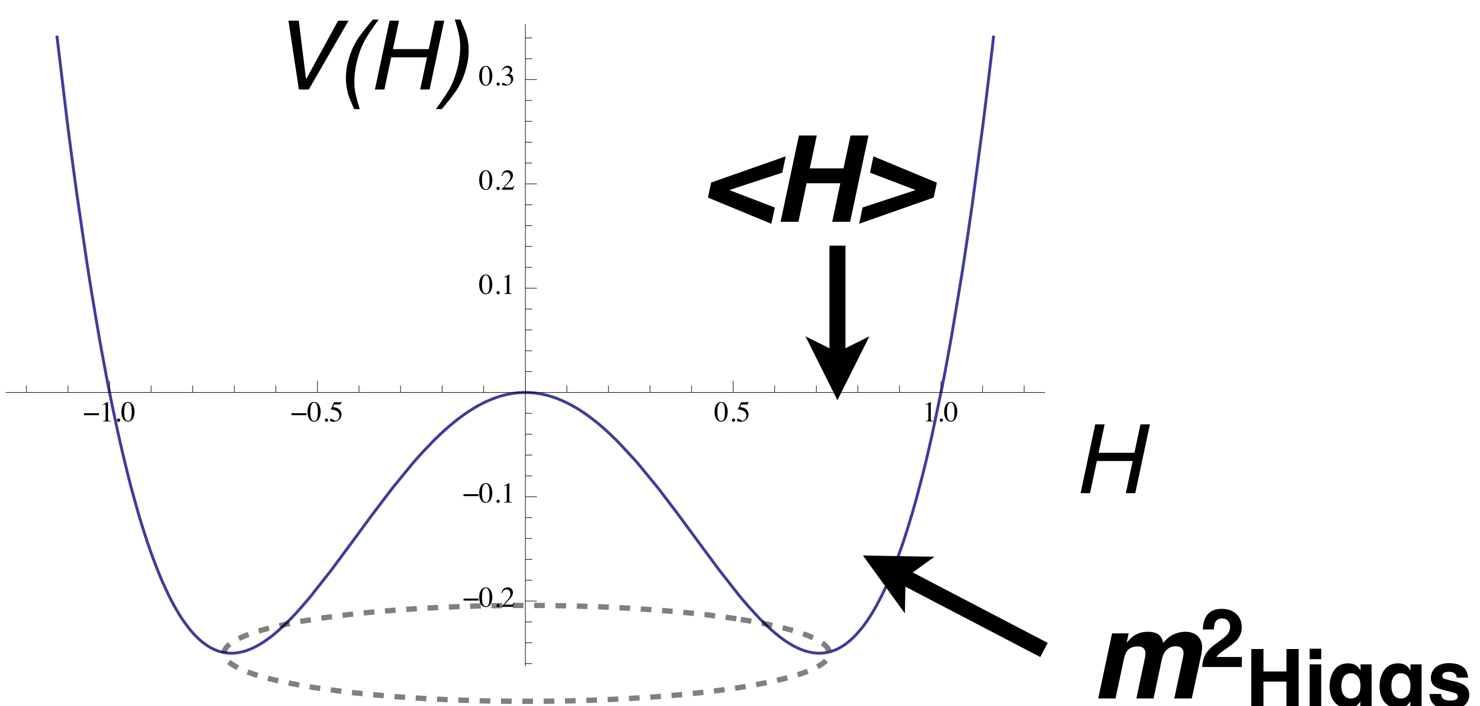


126 GeV Higgs

$$V(H) = -m^2 (H^\dagger H) + \lambda_{\mathrm{H}} (H^\dagger H)^2$$

$$\rightarrow \begin{cases} \langle H \rangle^2 = \dfrac{m^2}{2\,\lambda_{\mathrm{H}}} \\ \\ m^2_{\mathrm{Higgs}} = 2\, m^2 \end{cases}$$



126 GeV Higgs

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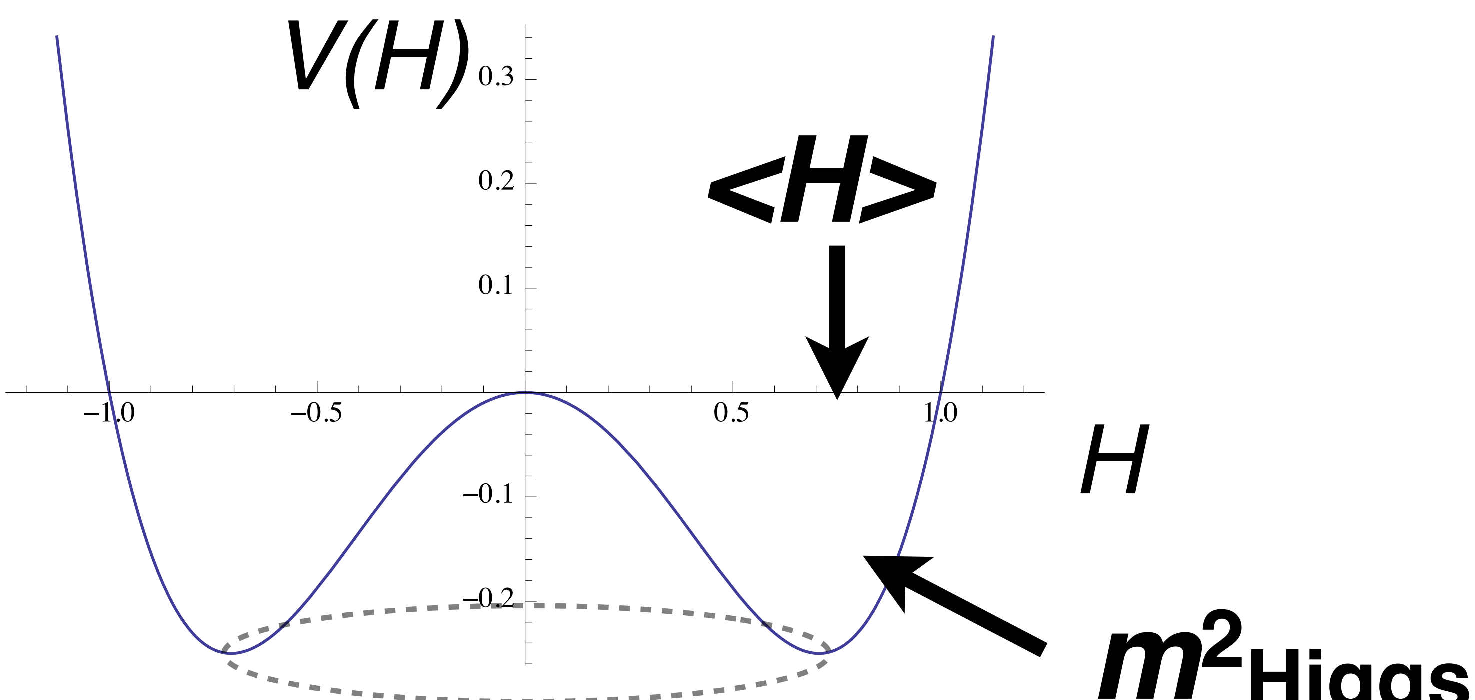
$$\rightarrow \begin{cases} \langle H \rangle^2 = \dfrac{m^2}{2\,\lambda_{\rm H}} = \dfrac{1}{2\sqrt{2}\,G_F} \simeq (174\ {\rm GeV})^2 \\[2ex] m^2_{\rm Higgs} = 2\,m^2 \end{cases}$$

We knew...

Fermi constant

$G_F \simeq 1.17 \times 10^{-5} {\rm GeV}^{-2}$



126 GeV Higgs

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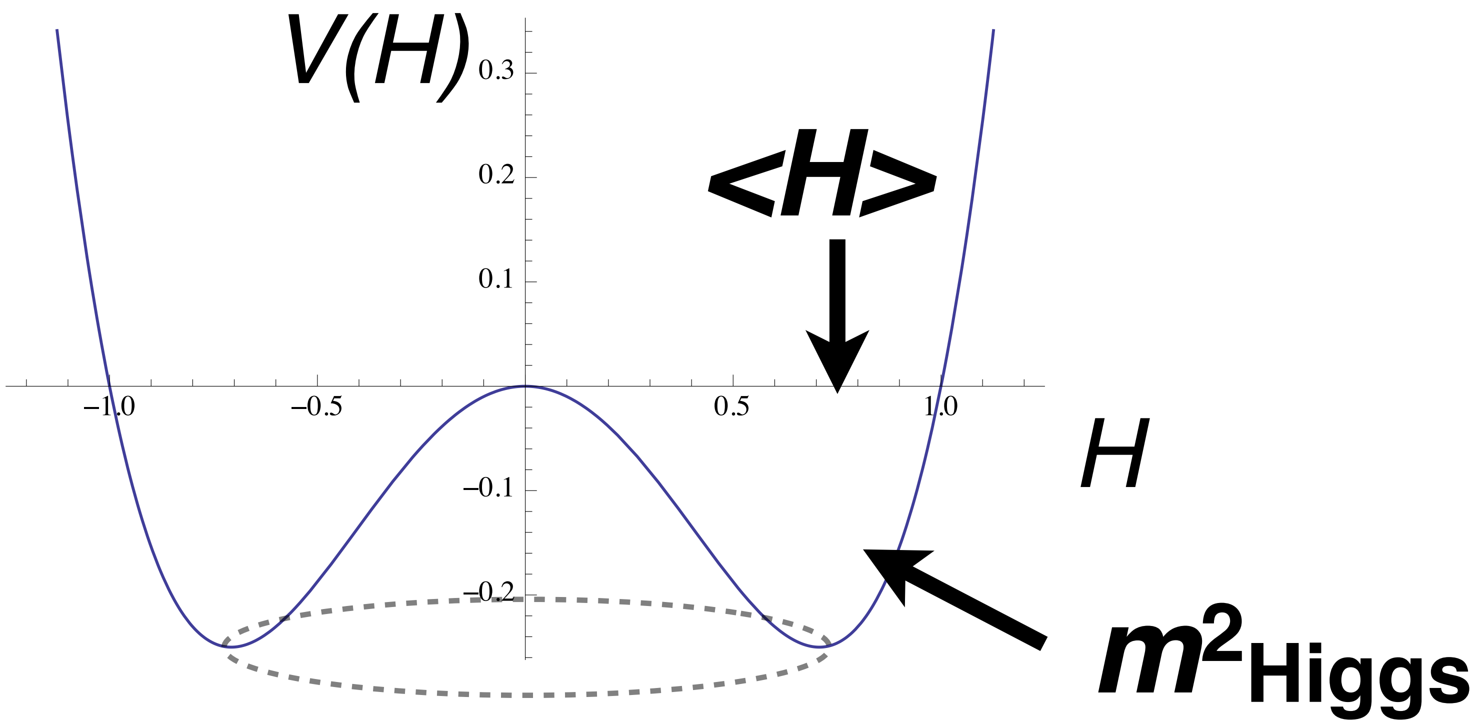
$$\to \begin{cases} \langle H \rangle^2 = \dfrac{m^2}{2\,\lambda_H} = \dfrac{1}{2\sqrt{2}\,G_F} \simeq (174\ \mathrm{GeV})^2 \\ m^2_{\mathrm{Higgs}} = 2\,m^2 \simeq (\mathbf{126\ GeV})^2 \end{cases}$$

Now we also know



126 GeV Higgs

$$V(H) = -m^2 (H^\dagger H) + \lambda_{\rm H} (H^\dagger H)^2$$

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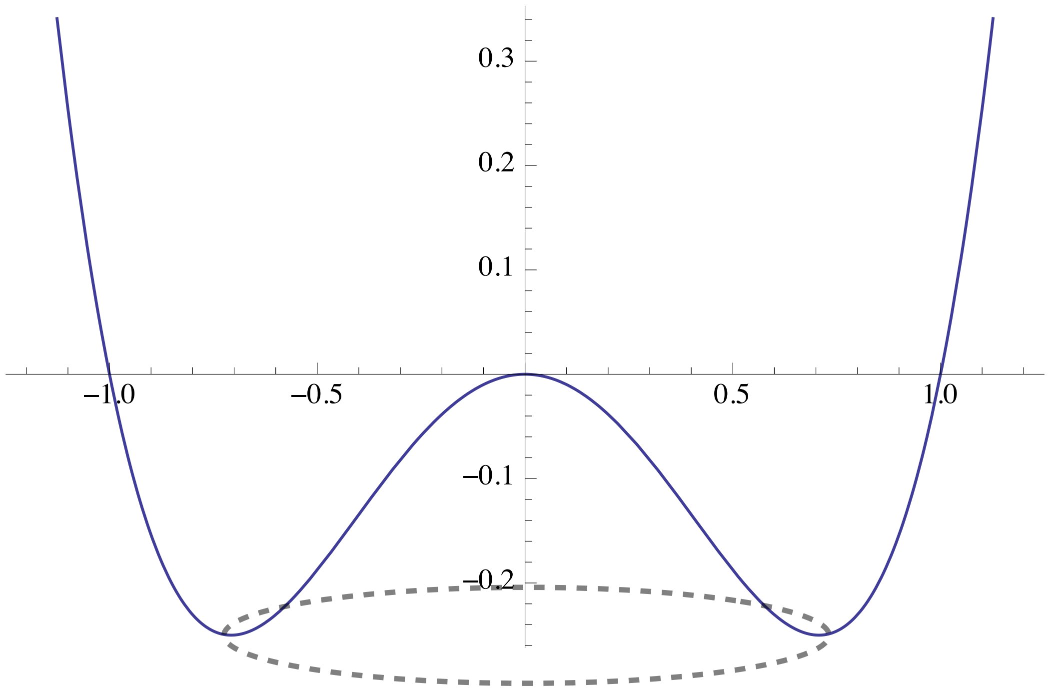


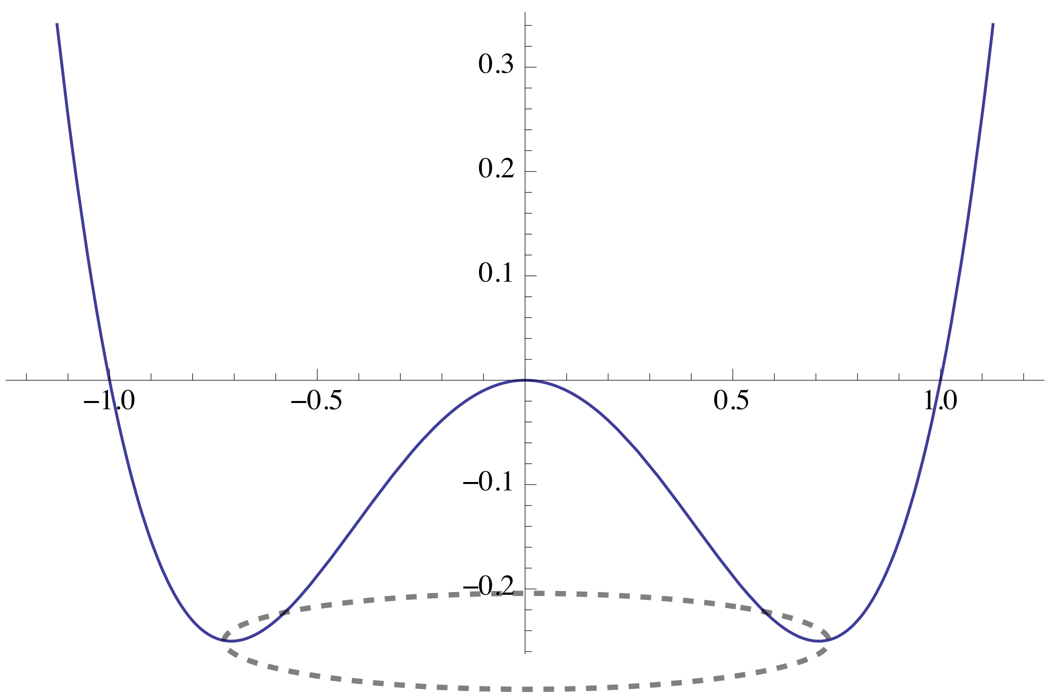
$$\rightarrow \begin{cases} m^2 = \dfrac{m^2_{\rm Higgs}}{2} \simeq \mathbf{(89\ GeV)^2} \\ \lambda_{\rm H} = \dfrac{m^2_{\rm Higgs}}{4\langle H \rangle^2} \simeq \mathbf{0.13} \end{cases}$$

126 GeV Higgs

$$V(H) = -m^2 (H^\dagger H) + \lambda_{\rm H} (H^\dagger H)^2$$

$$(\mathbf{89\ GeV})^2 \qquad \mathbf{0.13}$$

completely determined !



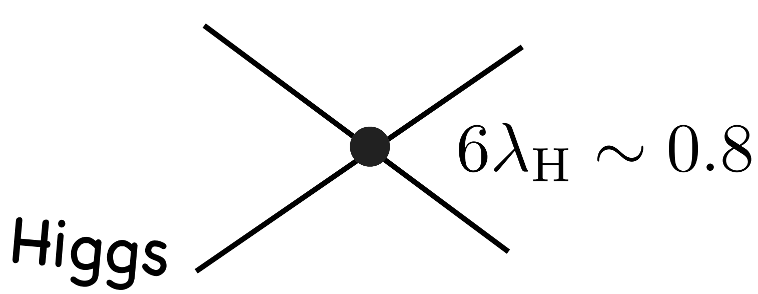
$$\rightarrow \begin{cases} m^2 = \dfrac{m_{\rm Higgs}^2}{2} \simeq (\mathbf{89\ GeV})^2 \\ \lambda_{\rm H} = \dfrac{m_{\rm Higgs}^2}{4\langle H \rangle^2} \simeq \mathbf{0.13} \end{cases}$$

126 GeV Higgs

$$V(H) = -m^2 (H^\dagger H) + \lambda_{\rm H} (H^\dagger H)^2$$

$(\mathbf{89\ GeV})^2$ $\qquad$ $\mathbf{0.13}$

It seems... Higgs sector is also described by weakly coupled, perturbative QFT.
(at least no sign of strong interaction etc, so far...)



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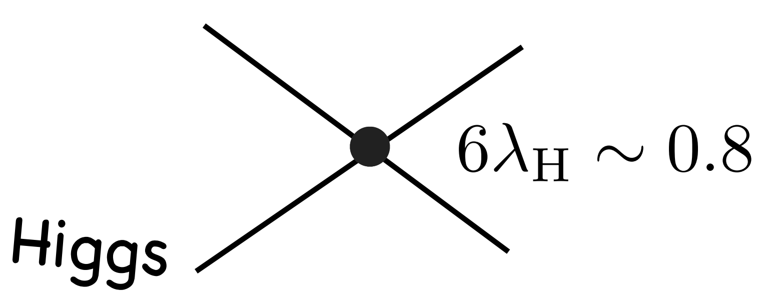
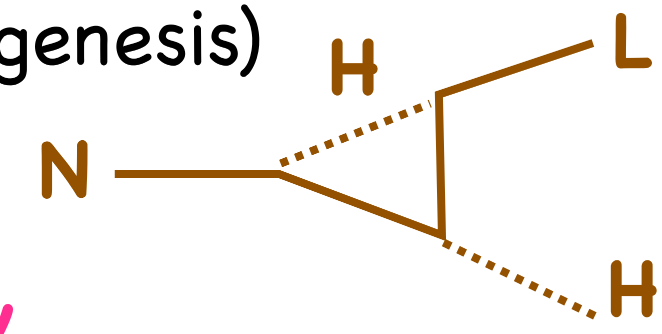


Imlications for BSM (in my opinion.....)

This is compatible with....

- **GUT and coupling unification** in perturbative QFT.
- **heavy right-handed neutrinos** (Seesaw + Leptogenesis)



- **Supersymmetry**

126 GeV Higgs

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$m^2 = (\mathbf{89\ GeV})^2$ $\qquad$ $\lambda_H = \mathbf{0.13}$

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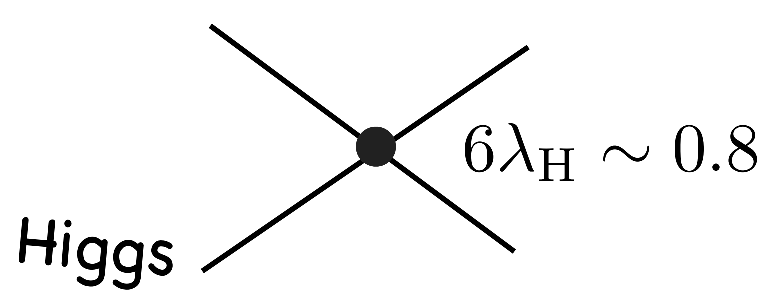

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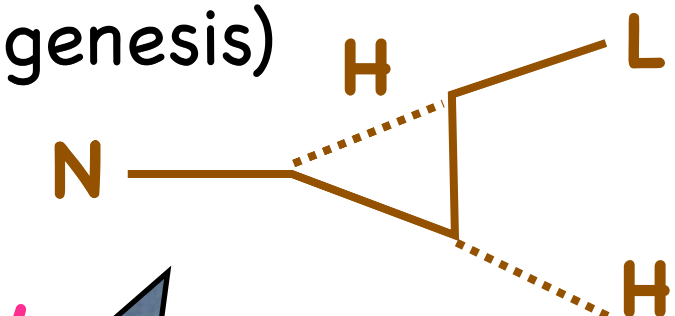


- **Supersymmetry**

Supersymmetry

boson ⇔ fermion

Supersymmetry (SUSY)

		spin		
quarks q	$\frac{1}{2}$	⟷	0	squarks $\tilde{q}$
leptons ℓ	$\frac{1}{2}$	⟷	0	sleptons $\tilde{\ell}$
gauge bosons A_μ	1	⟷	$\frac{1}{2}$	gauginos λ
Higgs bosons H	0	⟷	$\frac{1}{2}$	higgsinos $\tilde{h}$

naturalness

fine-tuning problem

$$m_H^2 = m_{H,0}^2 + \Lambda^2 \qquad (\Lambda \gg m_H)$$

(fine tuning like 1.0000000000000001 - 1)

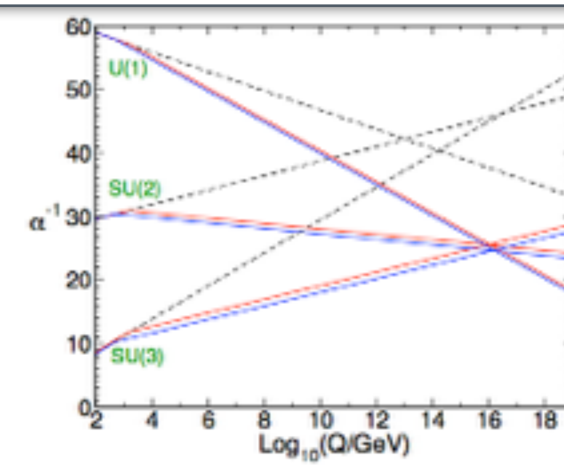
→ solved by the supersymmetry !

$$m_H^2 = m_{H,0}^2 + (\Lambda^2 - \Lambda^2)$$

fermion boson

coupling unification

Grand Unified Theory



without SUSY

with SUSY

Dark Matter = Lightest SUSY particle (with R-parity)

OK, then,....

What's the implications of

126 GeV Higgs for **SUSY** ??

126 GeV Higgs and SUSY

126 GeV Higgs and SUSY

$$V(H) = -m^2(H^\dagger H) + \lambda_{\mathrm{H}}(H^\dagger H)^2$$

$$\mathbf{(89\ GeV)^2} \qquad \mathbf{0.13}$$

in SUSY...

126 GeV Higgs and SUSY

$$V(H) = -m^2 (H^\dagger H) + \lambda_H (H^\dagger H)^2$$

$(89\ \mathrm{GeV})^2$ 0.13

in SUSY...

$$= \lambda_H^{\mathrm{tree}} + \delta\lambda_H^{\mathrm{loop}}$$

$$\frac{g^2 \cos^2 2\beta}{8 \cos^2 \theta_W} \simeq \mathbf{0.069} \cos^2 2\beta$$

too small...

parameters
in Standard Model
(known)

126 GeV Higgs and SUSY

$$V(H) = -m^2(H^\dagger H) + \lambda_{\rm H}(H^\dagger H)^2$$

m^2: $\mathbf{(89\ GeV)^2}$ $\lambda_{\rm H}$: **0.13**

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$$\frac{3y_t^4}{16\pi^2}\left(\log\left(\frac{m_{\rm stop}^2}{m_t^2}\right) + \alpha^2 - \frac{\alpha^4}{12}\right) + \cdots$$

for large $\tan\beta$. $(\alpha \simeq A_t/m_{\rm stop})$

...requires **heavy stop**

and/or **large A-term**

126 GeV Higgs and SUSY

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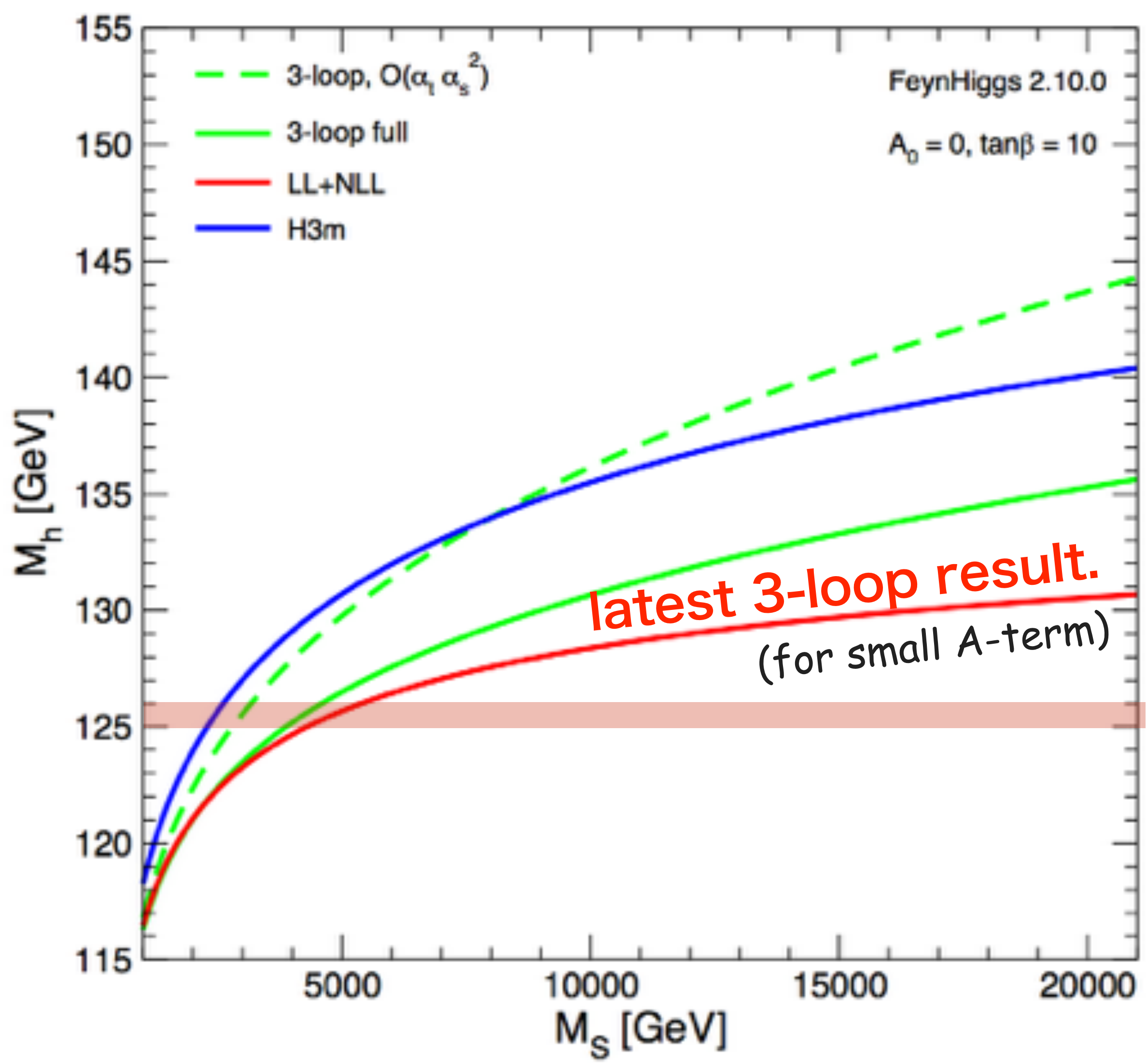

1404.0186 Hahn et.al.

$$\lambda_H^{\mathrm{tree}}: \quad \frac{g^2 \cos^2 2\beta}{8 \cos^2 \theta_W} \simeq 0.069 \cos^2 2\beta$$

$$\delta\lambda_H^{\mathrm{loop}}: \quad \frac{3 y_t^4}{16\pi^2} \left(\log\left(\frac{m_{\mathrm{stop}}^2}{m_t^2}\right) + \alpha^2 - \frac{\alpha^4}{12} \right) + \cdots$$

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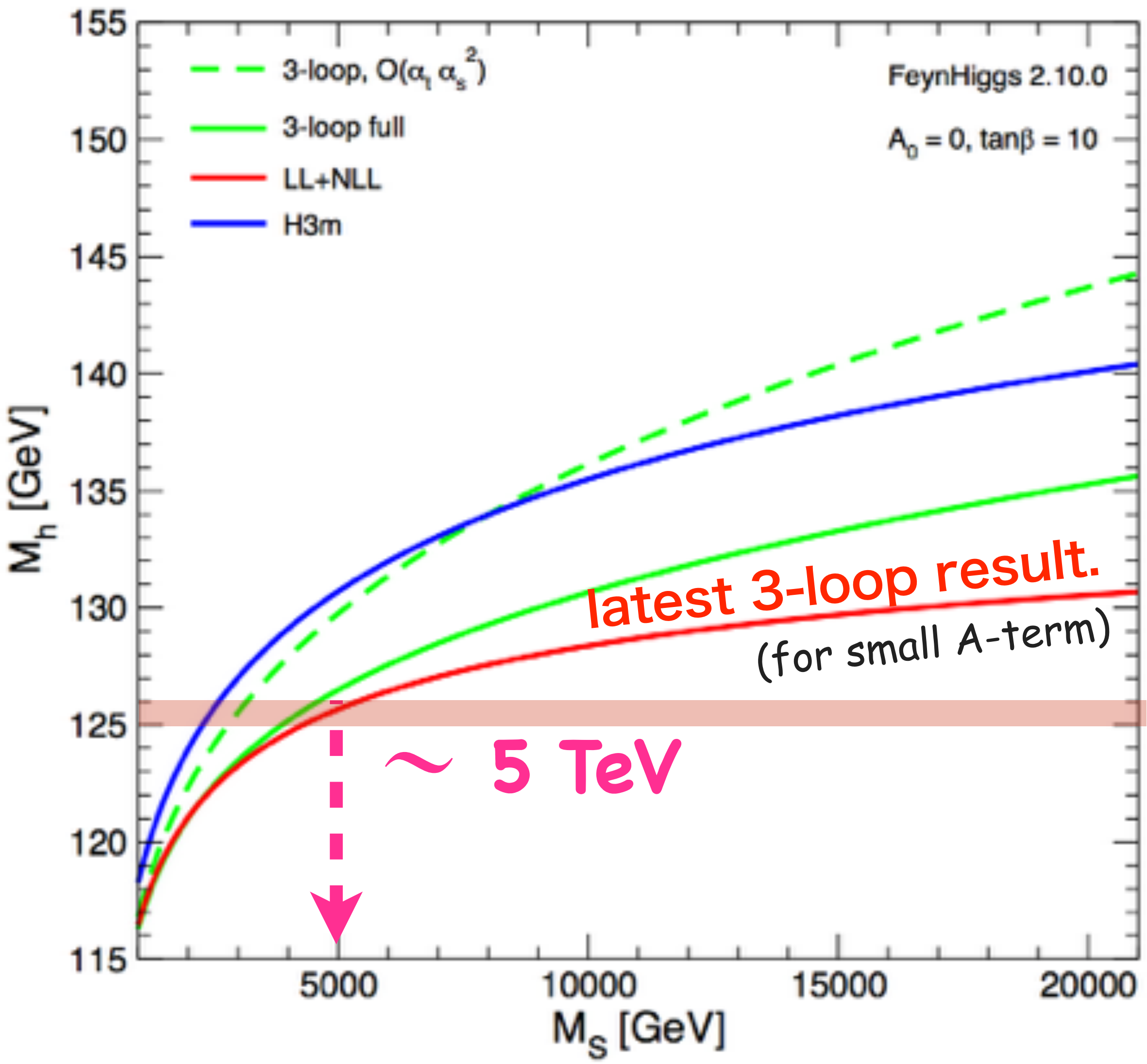

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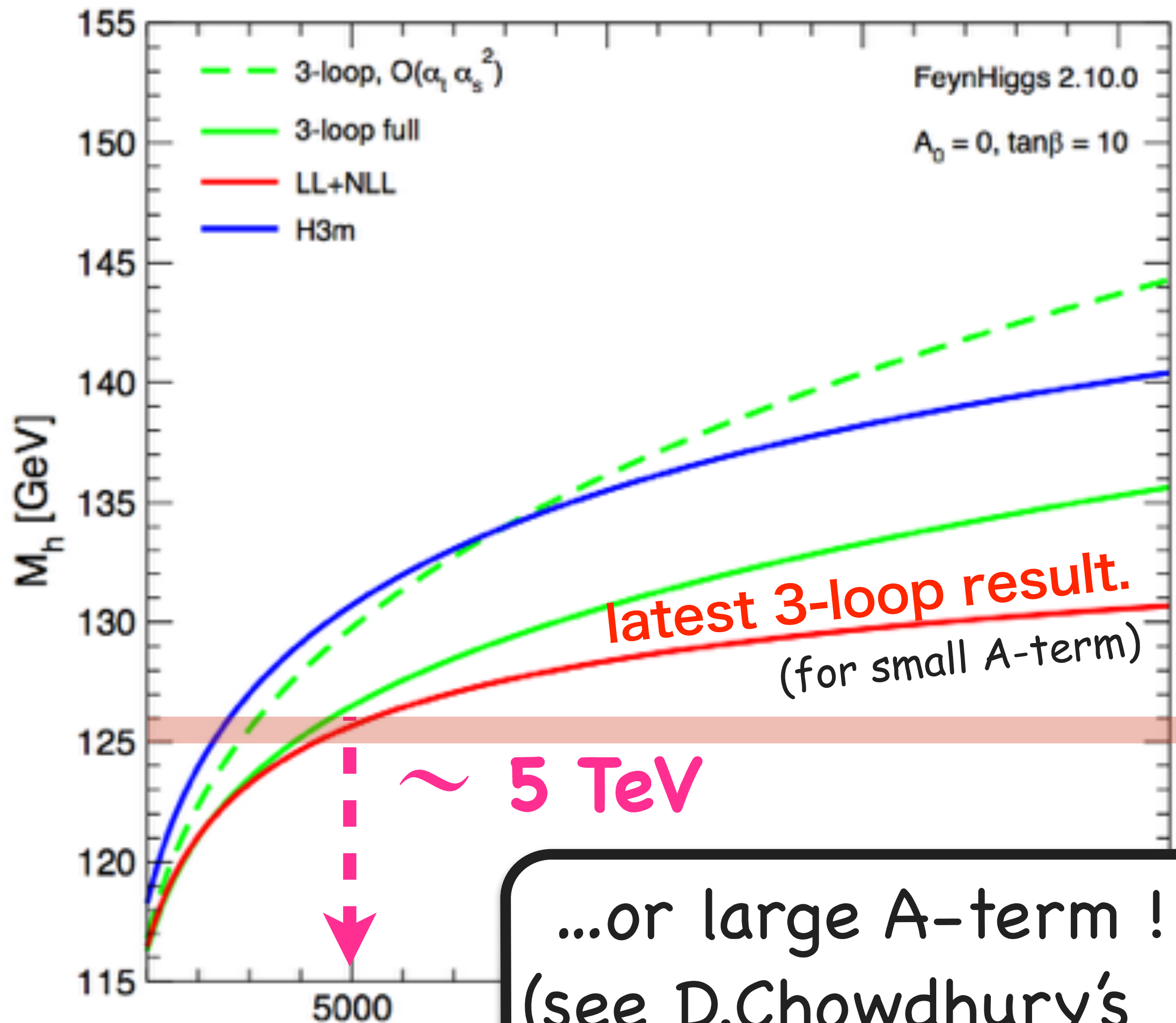

1404.0186 Hahn et.al.

...or large A-term !
(see D.Chowdhury's talk last week!)

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m^2: $(\mathbf{89\ GeV})^2$

λ_H: $\mathbf{0.13}$

on the other hand

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$(89\ \mathbf{GeV})^2$ 　　　　 $\mathbf{0.13}$

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on the other hand

$$-m^2 \simeq |\mu|^2 + m_{H_u}^{2\,({\rm tree})} + \delta m_{H_u}^{2\,({\rm loop})}$$

up to $\mathcal{O}\left(\frac{1}{\tan^2\beta}\right)$

$|\mu|^2$: Higgsino mass

$m_{H_u}^{2\,({\rm tree})}$: soft mass for up-type Higgs

$$\frac{g^2 \cos^2 2\beta}{8\cos^2\theta_W} \simeq \mathbf{0.069}\ \cos^2 2\beta$$

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up to $\mathcal{O}\left(\frac{1}{\tan^2\beta}\right)$

large μ -----> fine-tuning.

e.g., $\simeq (1000\ {\rm GeV})^2 - (1004\ {\rm GeV})^2$

for $|\mu| \simeq 1$ TeV

requires **Light Higgsino** to avoid a fine-tuning.

$$= \lambda_H^{\rm tree} + \delta\lambda_H^{\rm loop}$$

$$\lambda_H^{\rm tree} = \frac{g^2\cos^2 2\beta}{8\cos^2\theta_W} \simeq \mathbf{0.069}\cos^2 2\beta$$

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126 GeV Higgs and SUSY

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$(89\ \mathrm{GeV})^2$ 0.13

$$= \lambda_H^{\rm tree} + \delta\lambda_H^{\rm loop}$$

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$$-m^2 \simeq |\mu|^2 + m_{H_u}^{2\,({\rm tree})} + \delta m_{H_u}^{2\,({\rm loop})}$$

Moreover,

$$\delta m_{H_u}^{2\,({\rm loop})} \sim \frac{-3y_t^2}{8\pi^2}\left(m^2_{\tilde{t}_L} + m^2_{\tilde{t}_R} + |A_t|^2\right)\log\left(\frac{M_{\rm mess}}{m_{\tilde{t}}}\right) + \cdots$$

requires Light stop and small A-term to avoid a fine-tuning.

$$\frac{g^2\cos^2 2\beta}{8\cos^2\theta_W} \simeq 0.069\,\cos^2 2\beta$$

$$\frac{3y_t^4}{16\pi^2}\left(\log\left(\frac{m^2_{\rm stop}}{m_t^2}\right) + \alpha^2 - \frac{\alpha^4}{12}\right) + \cdots$$

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for large $\tan\beta$. ($\alpha \simeq A_t/m_{\mathrm{stop}}$)

...requires **heavy stop** and/or **large A-term**

inconsistent !!

126 GeV Higgs and SUSY

Fine-tuning worse than 1% seems unavoidable in MSSM.

(MSSM =Minimal SUSY Standard Model)

126 GeV Higgs and SUSY

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What does it imply ??

1. **No SUSY ?**

2. (It's anyway fine-tuned, then....)

   Very heavy SUSY ? (10-100 TeV, or even higher...)

3. (still.....)

   O(0.1-1) TeV SUSY ? (fine-tuned, but better than 1. and 2. ...)

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heavy sfermion scenario and Wino DM

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heavy sfermion scenario and Wino DM

(It's anyway fine-tuned, then....)

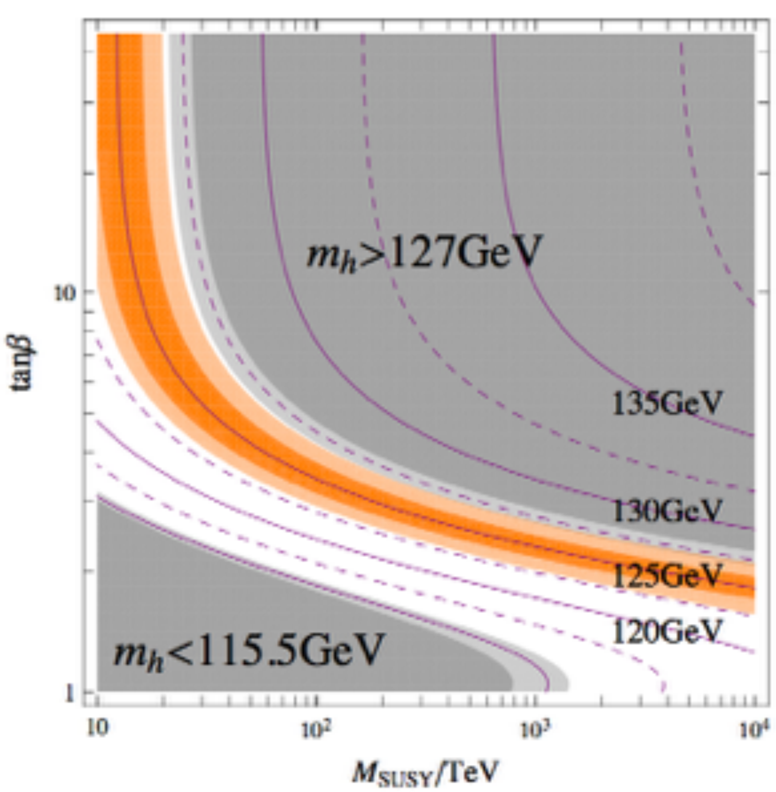
Very heavy SUSY

$$m_H^2 = 4\lambda_H \langle H \rangle^2$$

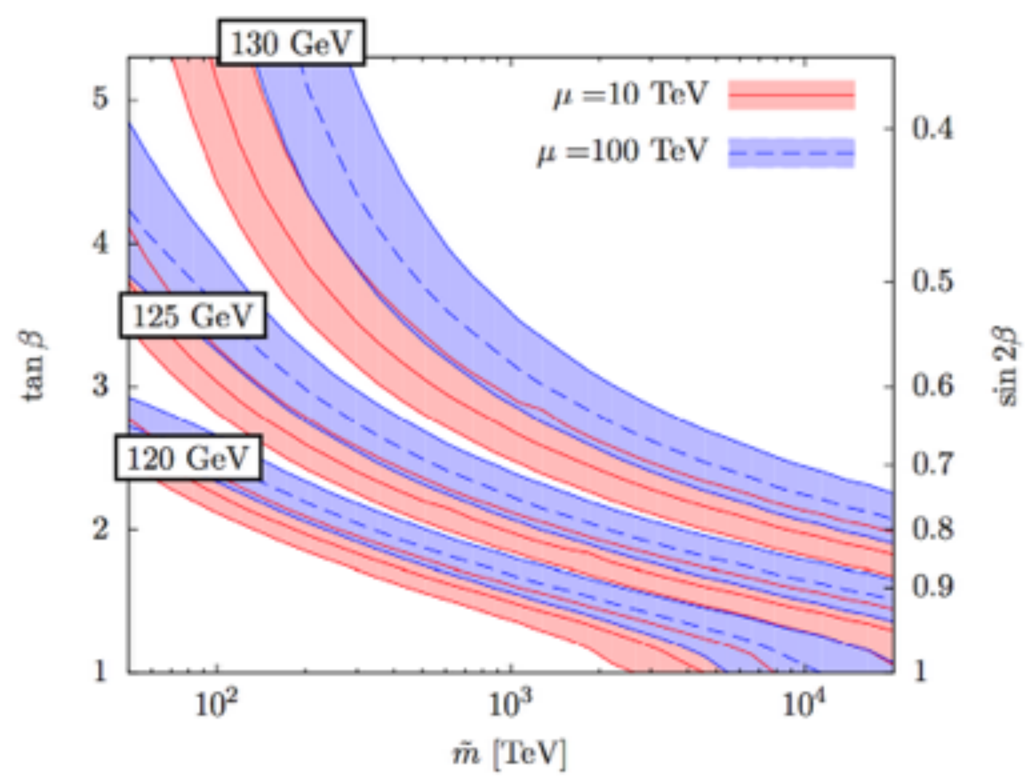
$$\to \lambda_H \simeq 0.13$$

$$= \underbrace{\lambda_H^{\text{tree}}}_{0.07\cos^2 2\beta} + \underbrace{\delta\lambda_H^{\text{loop}}}_{\sim \log(m_{\text{stop}}^2)}$$

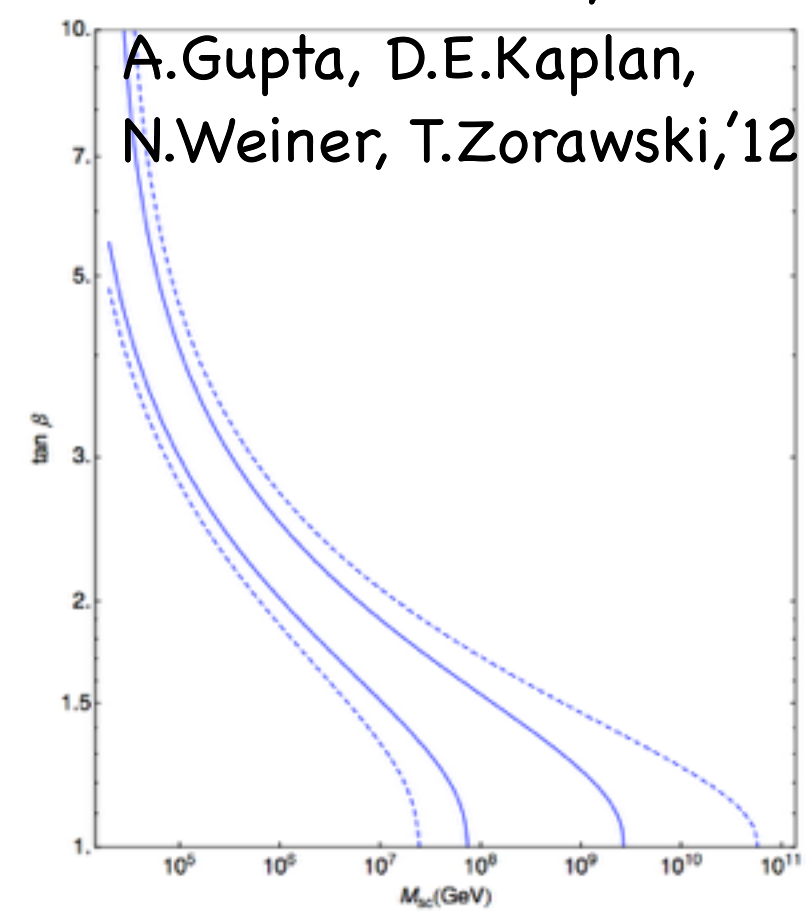
Ibe, Matsumoto, Yanagida,'12



L.Hall, Y.Nomura, S.Shirai '12



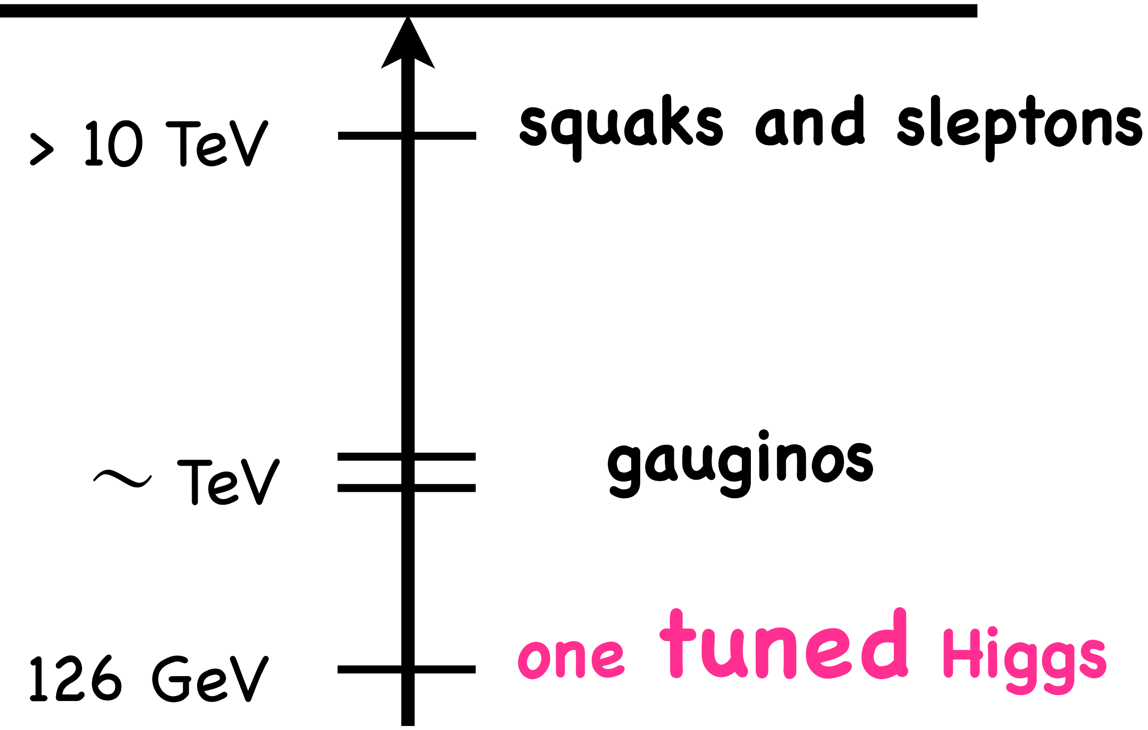
N.Arkani-Hamed, A.Gupta, D.E.Kaplan, N.Weiner, T.Zorawski,'12



heavy sfermion scenario and Wino DM

(It's anyway fine-tuned, then....)

Very heavy SUSY



- **consistent with 126 GeV Higgs**
- **No cosmological gravitino problem**

$$\tau_{\rm gravitino} = 0.03\ {\rm sec} \left(\frac{m_{\rm gravitino}}{100\ {\rm TeV}}\right)^{-3}$$ ...decays before BBN.

- Also, **no Polonyi problem** since gaugino masses can be induced without singlet (Anomaly-mediation).

- coupling unification is OK, and **DM is OK!**

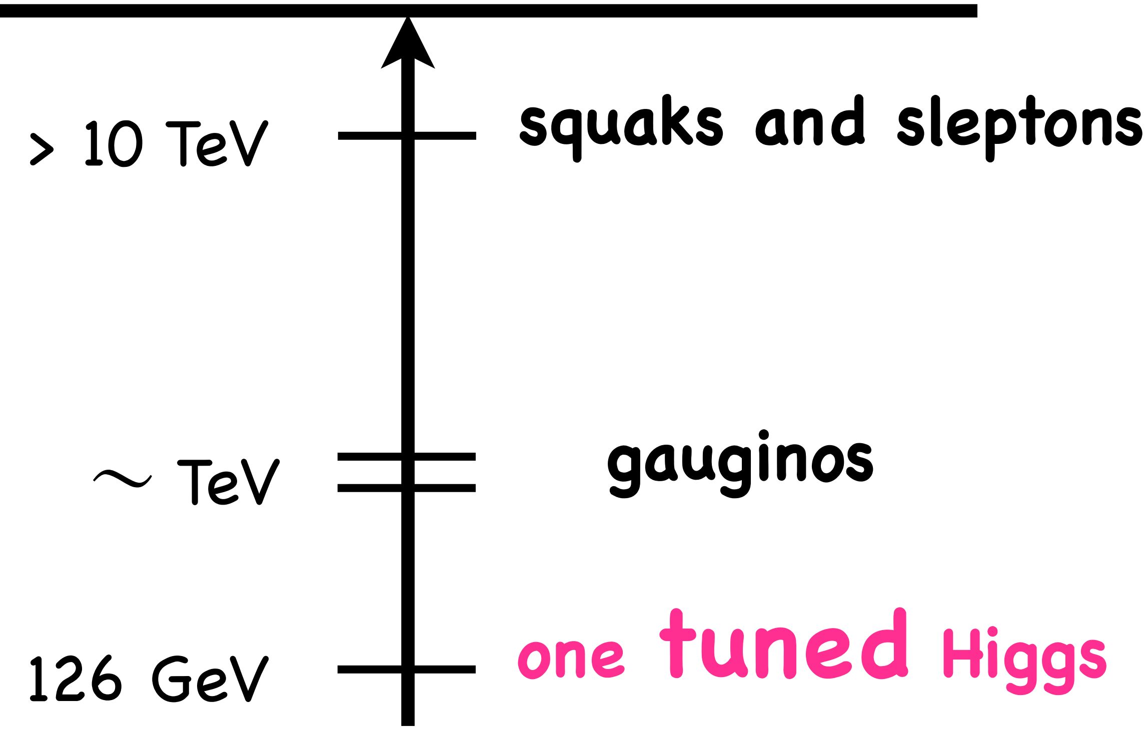
Many many related works recently..... (too many to list all...)

Ibe,Yanagida'11, Ibe,Matsumoto,Yanagida'12, Bhattacherjee,Feldstein,Ibe,Matsumoto,Yanagida'12,
Hall,Nomura'11, Hall,Nomura,Shirai'12,
Giudice,Strumia'11, Arvanitaki,Craig,Dimopoulos,Villadoro'12
Arkani-Hamed,Gupta,Kaplan,Weiner,Zorawski'12, Ibanez,Valenzuela'13,
Jeong,Shimosuka,Yamaguchi'11, Hisano,Ishiwata,Nagata'12, Sato,Shirai,Tobioka'12,
Moroi,Nagai'13, McKeen,Pospelov,Ritz'13,
Hisano,Kuwahara,Nagata'13, Hisano,Kobayashi,Kuwahara,Nagata'13, etc etc.....

heavy sfermion scenario and Wino DM

(It's anyway fine-tuned, then....)

Very heavy SUSY



LSP DM = (typically) Wino !!

(anomaly-mediation)

$$m_{\text{gluino}} = -\frac{g_3^2}{16\pi^2} \cdot 3m_{\text{gravitino}}$$

$$m_{\text{Wino}} = \frac{g_2^2}{16\pi^2} \cdot (m_{\text{gravitino}} + L)$$

$$m_{\text{Bino}} = \frac{g_1^2}{16\pi^2} \cdot \left(\frac{33}{5} m_{\text{gravitino}} + \frac{3}{5} L\right)$$

$$\left(L = \mu \sin 2\beta \frac{m_A^2}{|\mu|^2 - m_A^2} \ln \frac{|\mu|^2}{m_A^2}\right)$$

['98 Giudice,Luty,Murayama,Rattazzi, '98 Randall,Sundram]

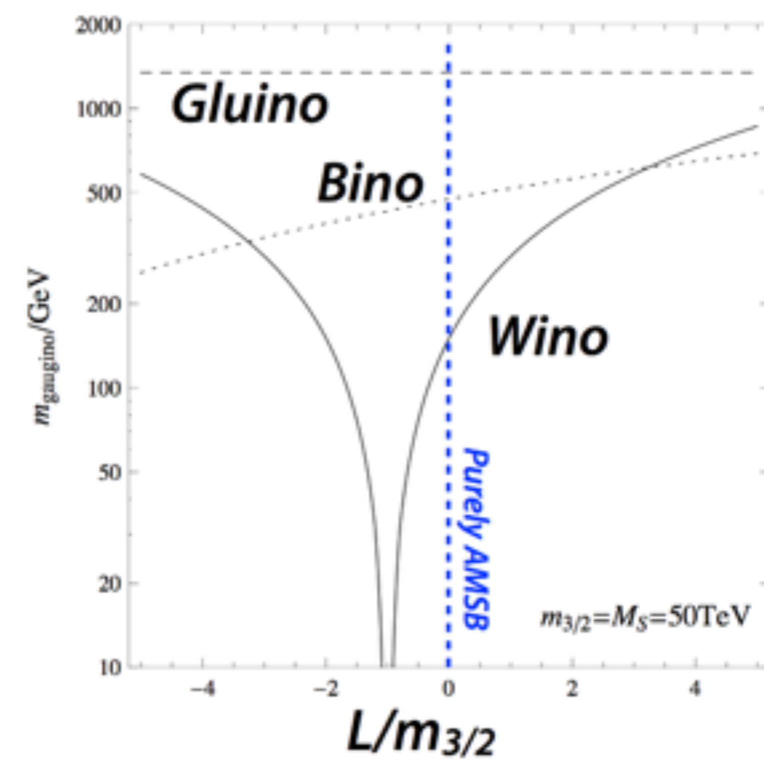


Fig. from **M.Ibe**'s talk at KIAS workshop 2014.

heavy sfermion scenario and Wino DM

(It's anyway fine-tuned, then....)

Very heavy SUSY

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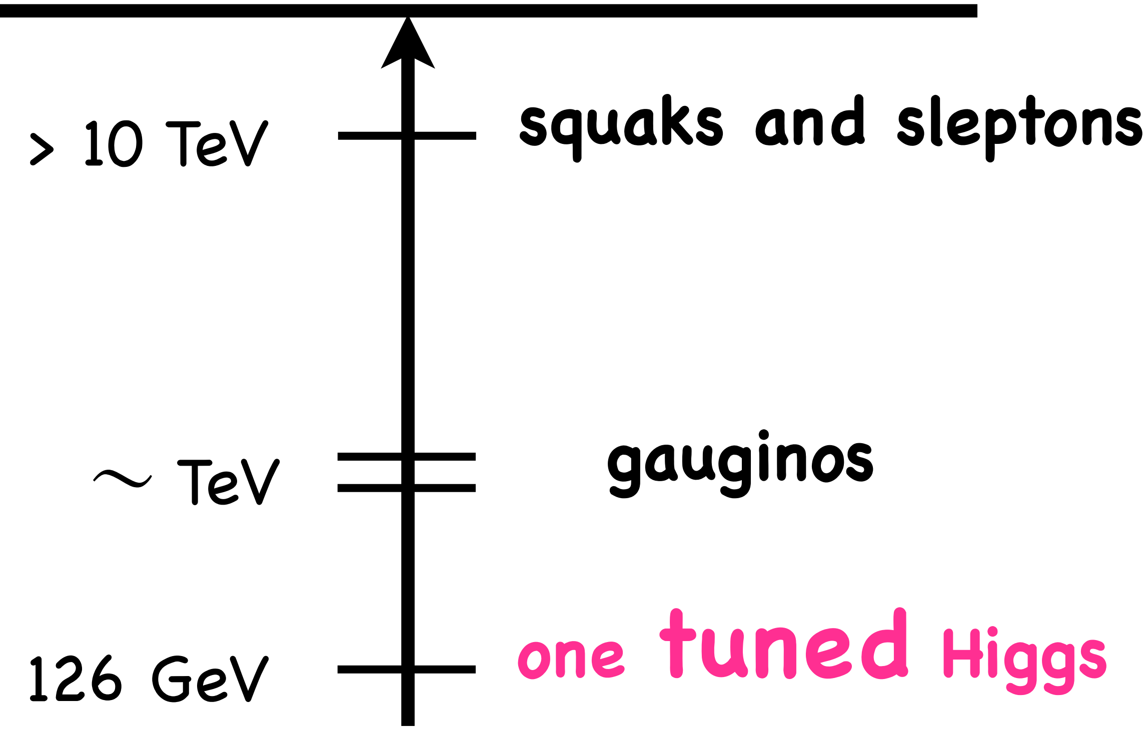

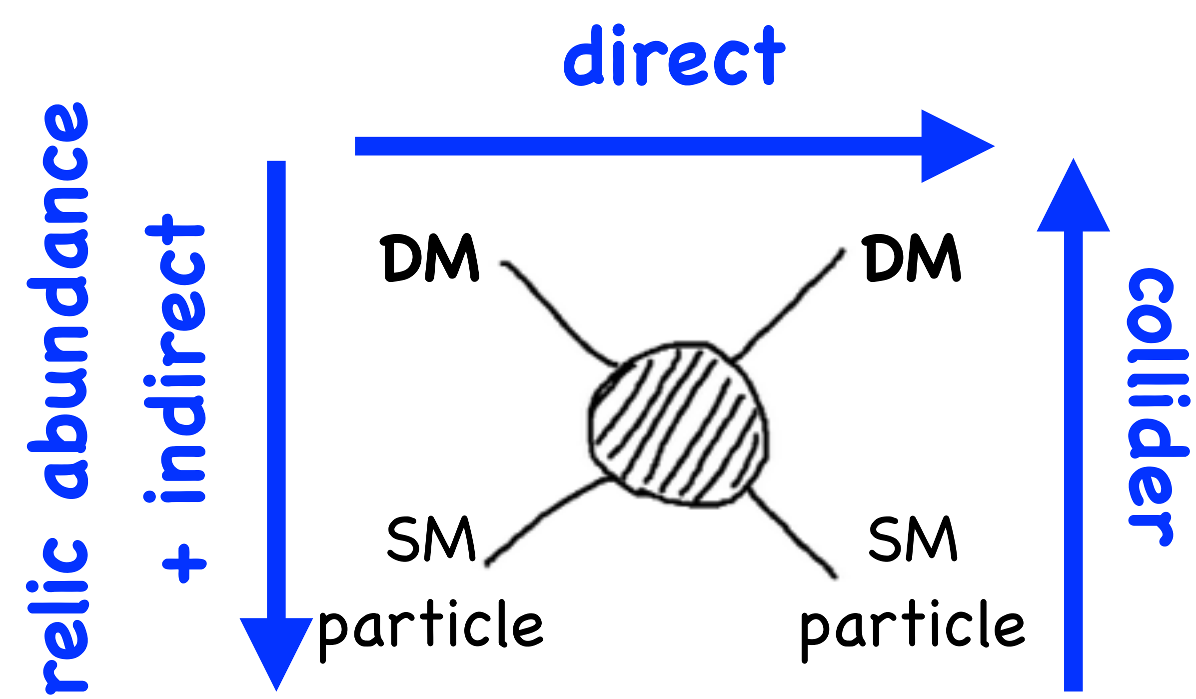

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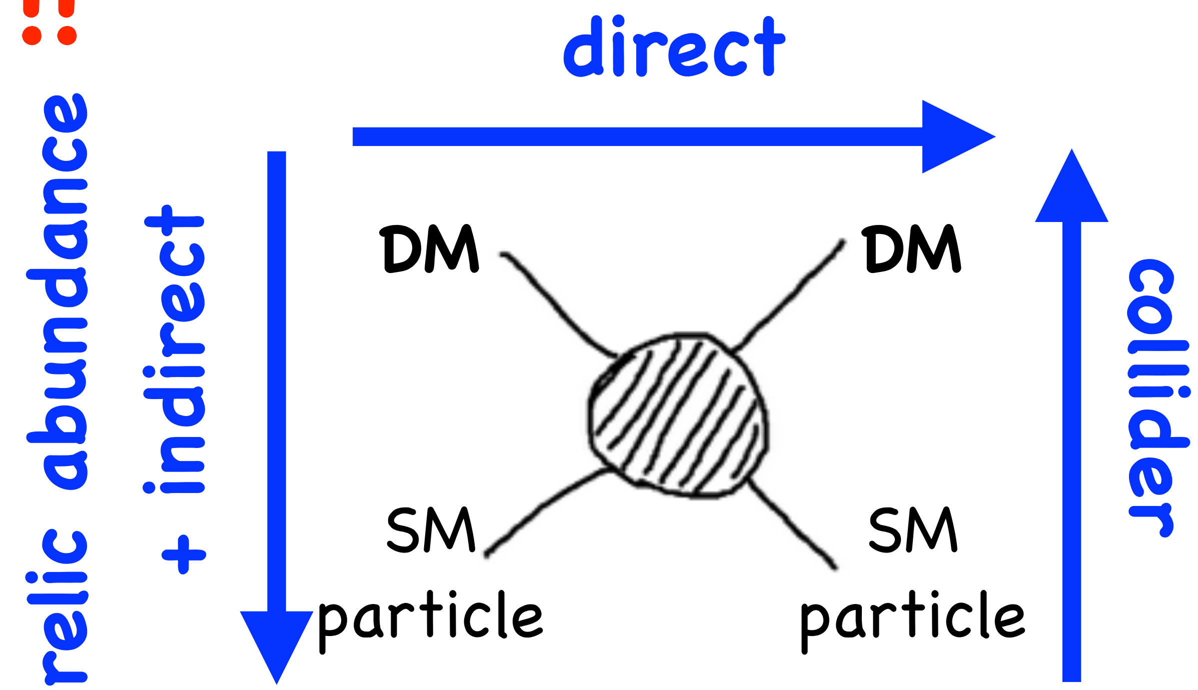

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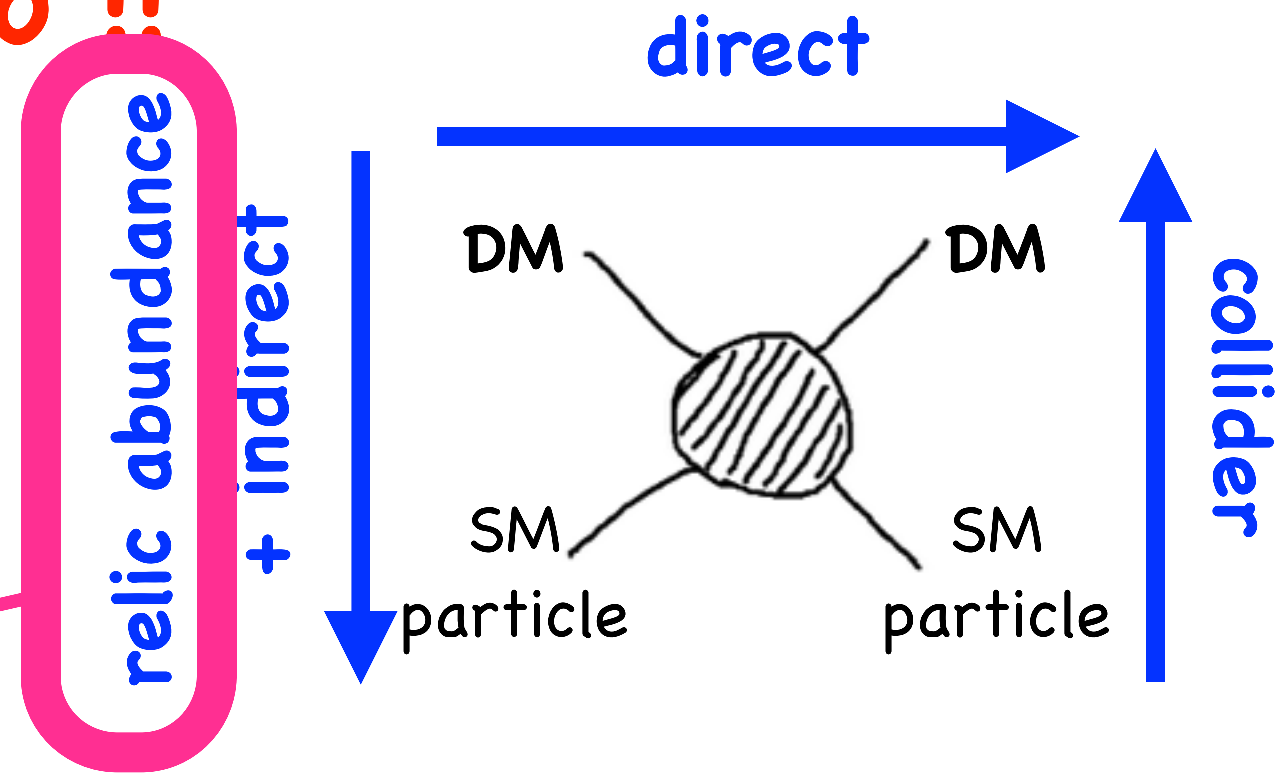
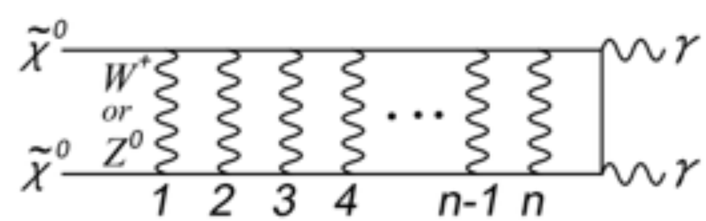
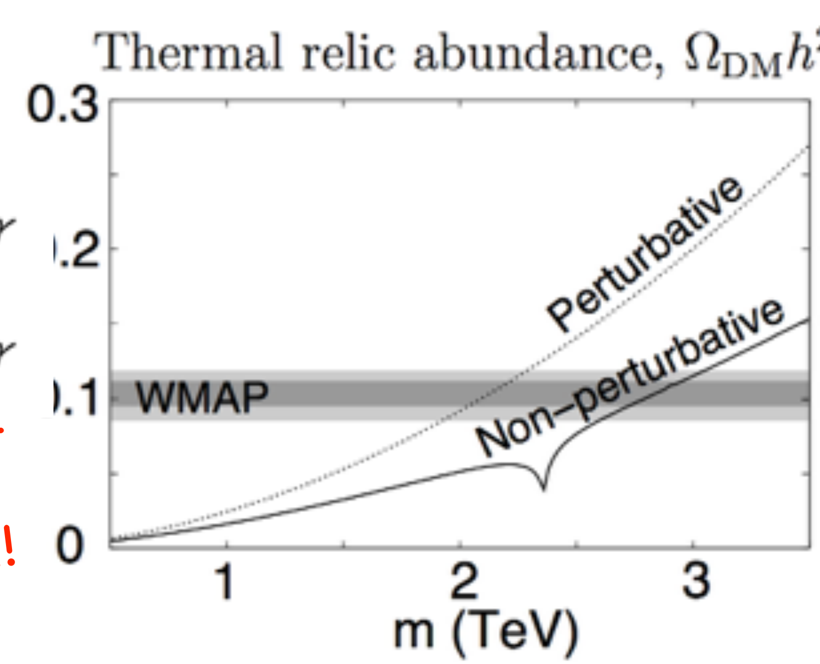


Relic abundance:

- M ~ 3 TeV if thermal relic. [Hisano-Matsumoto-Nagai-Saito-Senami'06]
- It can be lighter if non-thermal.
  (more on this later.)



Sommerfeld enhancement



☞ mini-workshop this afternoon!

heavy sfermion scenario and Wino DM

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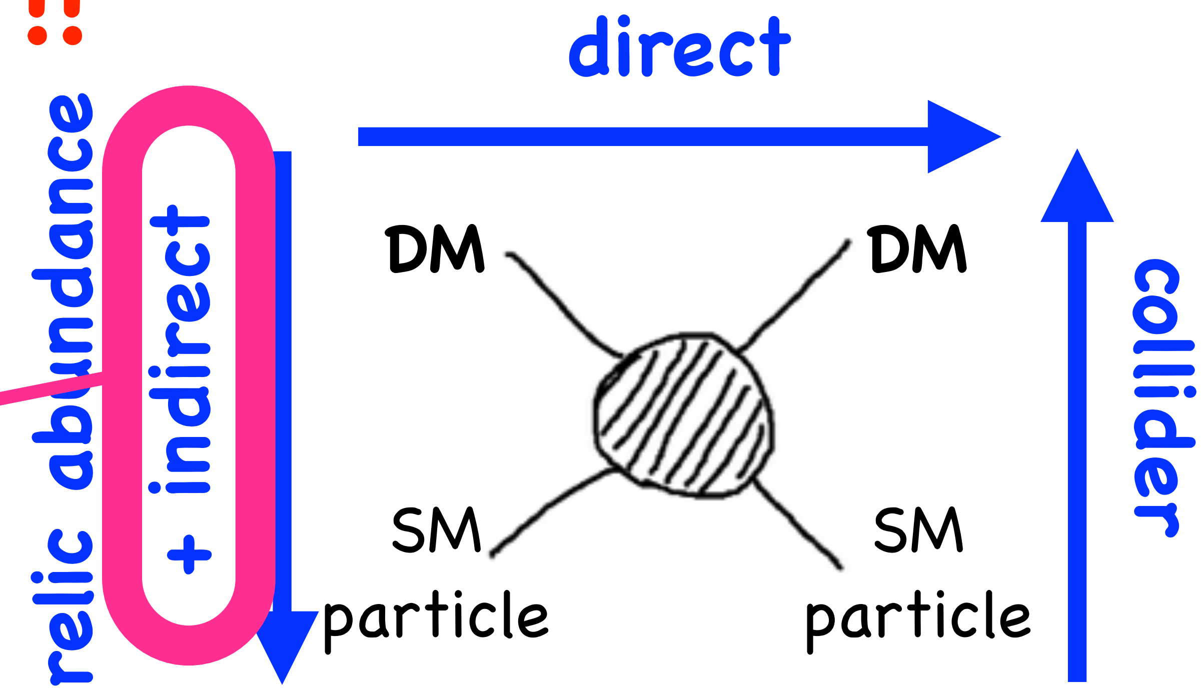

Indirect detection:

…… is very interesting !!

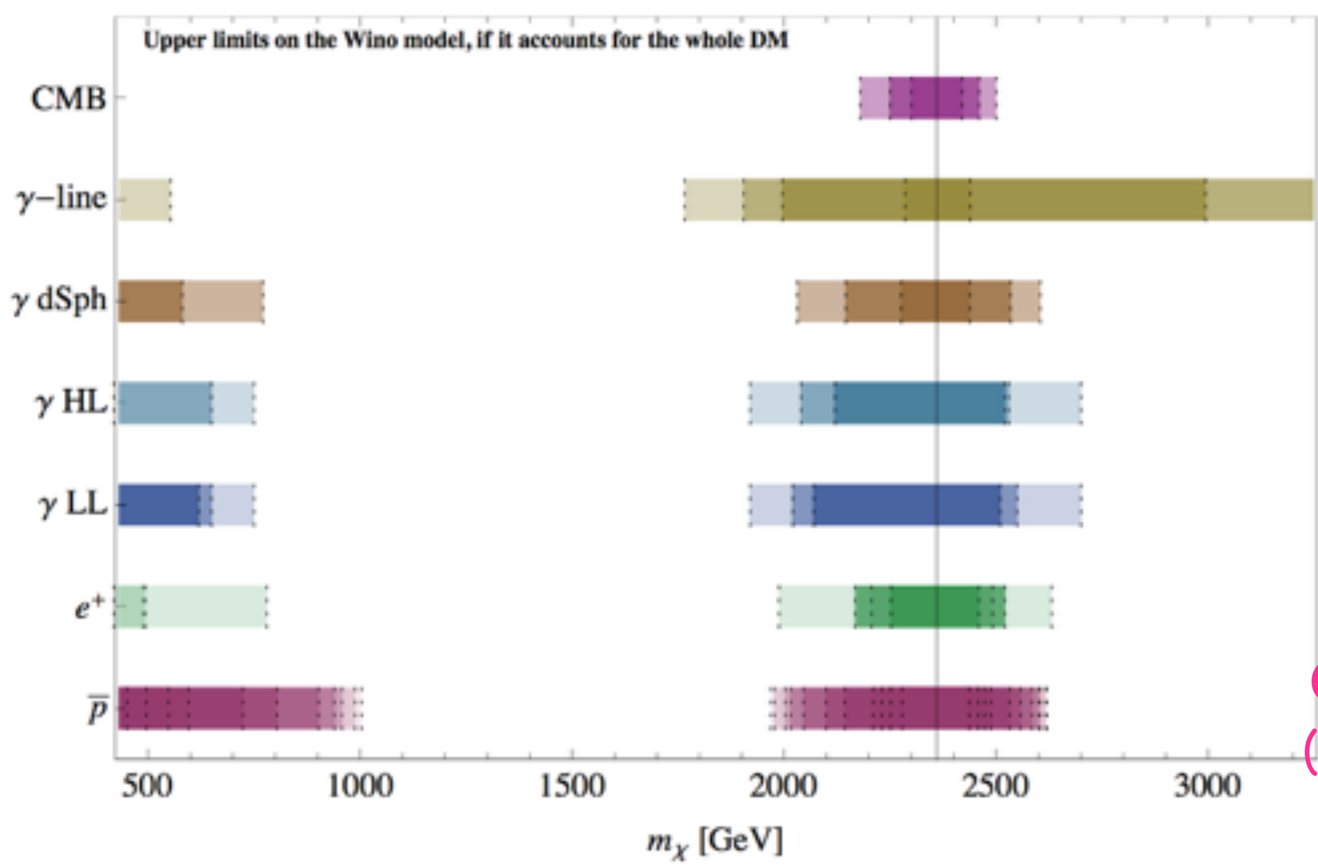

Fig. from A.Hryczuk, I.Cholis, R.Iengo, M.Tavakoli, P.Ullio,'14

Figure 16. Combination of the 95% CL upper limits for the Wino DM mass. The black vertical line shows the position of the peak of the resonance. For a given channel different shaded regions correspond to limits derived using different assumptions. For antiprotons ($\bar{p}$) this is related to the diffusion zone thickness, leptons (e^+) the local DM density and energy density in the ISRF and magnetic field, low latitude γ-rays (γ LL) the radiation field in the inner galaxy and interstellar gas, high latitude γ-rays (γ HL) the extragalactic DM substructures, for dwarf spheroidal galaxies (γ dSph) the J-factor and foreground emission, for γ-line the DM profile in the inner 1° and in the case of the CMB constraints different combinations of data sets. See text and sections corresponding to its given channel for details.

Can be probed/excluded by several channels !

(Fermi-LAT, GAMMA-400, CTA, AMS-02,……)

heavy sfermion scenario and Wino DM

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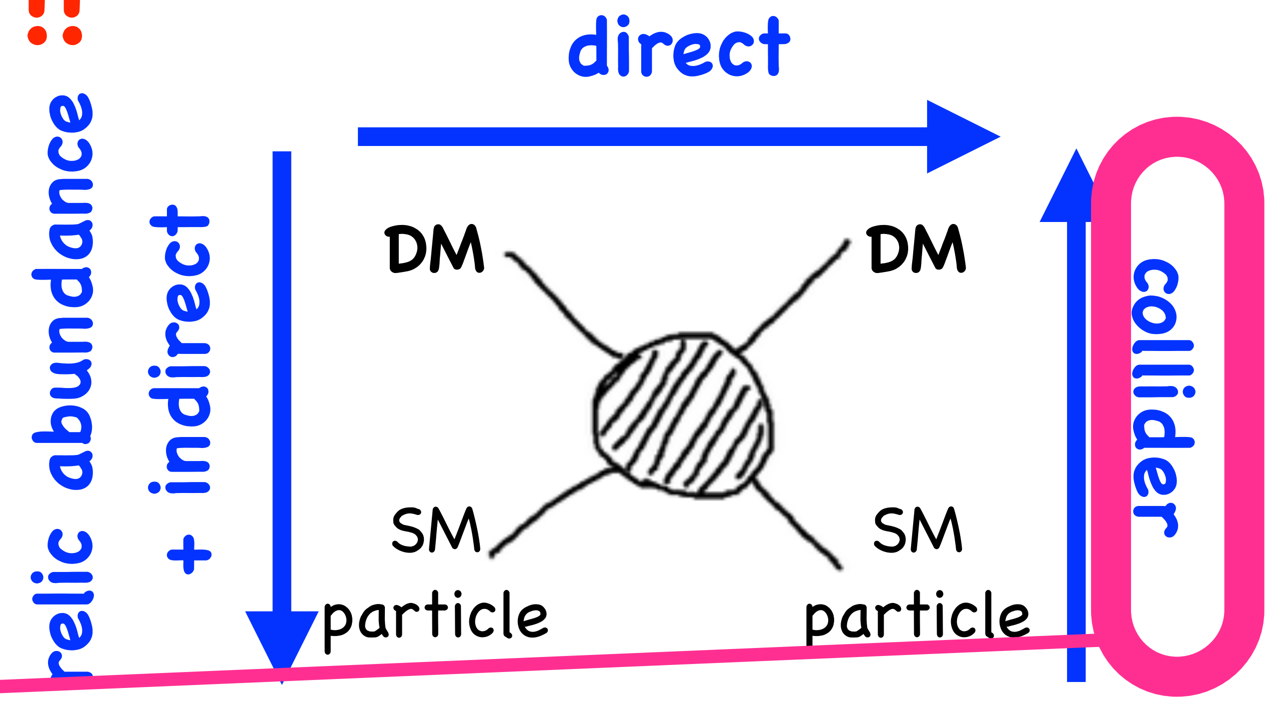
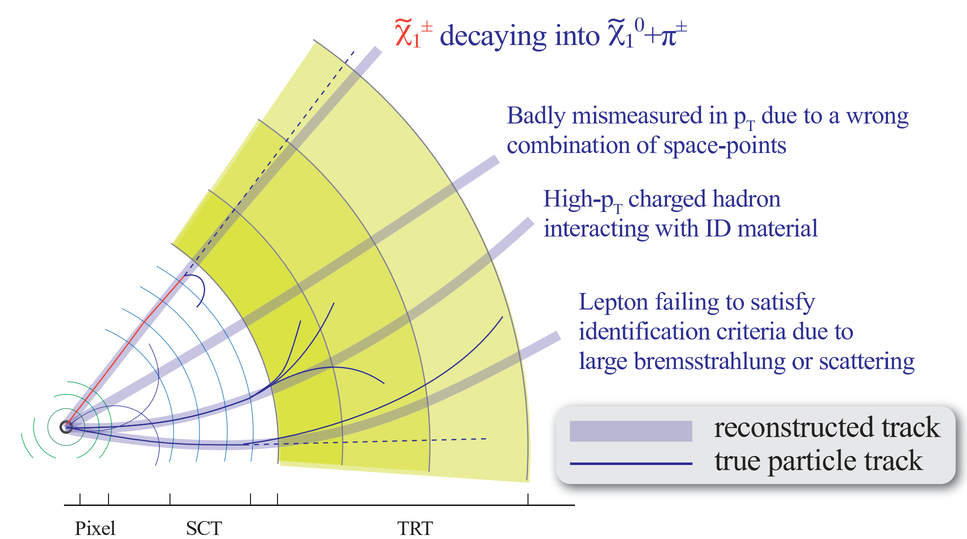


Collider signature:

= disappearing charged track !

$$\underbrace{\widetilde{W}^{\pm}}_{\text{charged track!}} \longrightarrow \underbrace{\widetilde{W}^{0}}_{\text{missing}} + \underbrace{\pi^{\pm}}_{\text{very soft}}$$

$$\text{lifetime} \sim O(10^{-10})\text{sec}$$



8 TeV bound:

m(Wino) > 270 (260) GeV

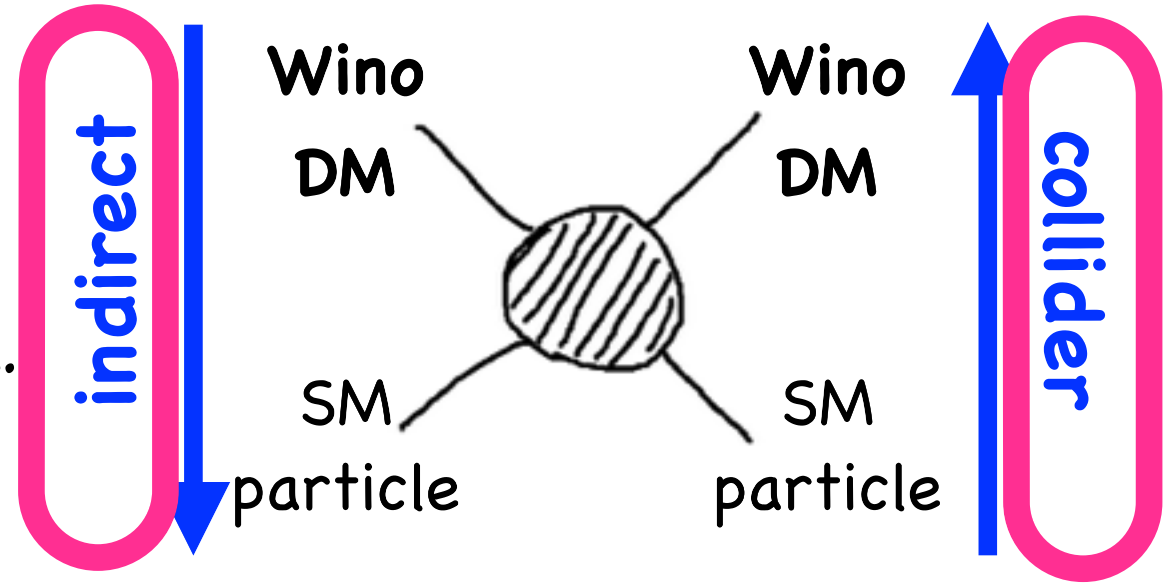
ATLAS:1310.3675 (CMS:1411.6006)

14 TeV discovery @300fb^{-1} (3000fb^{-1}) if

m(Wino) < 500 (650) GeV

heavy sfermion scenario and **Wino DM**

- antiproton @ AMS-02
- gamma-line @ CTA
- continuum gamma @ Fermi..



- Disappearing track @ 14 TeV LHC

< **500-600 GeV**

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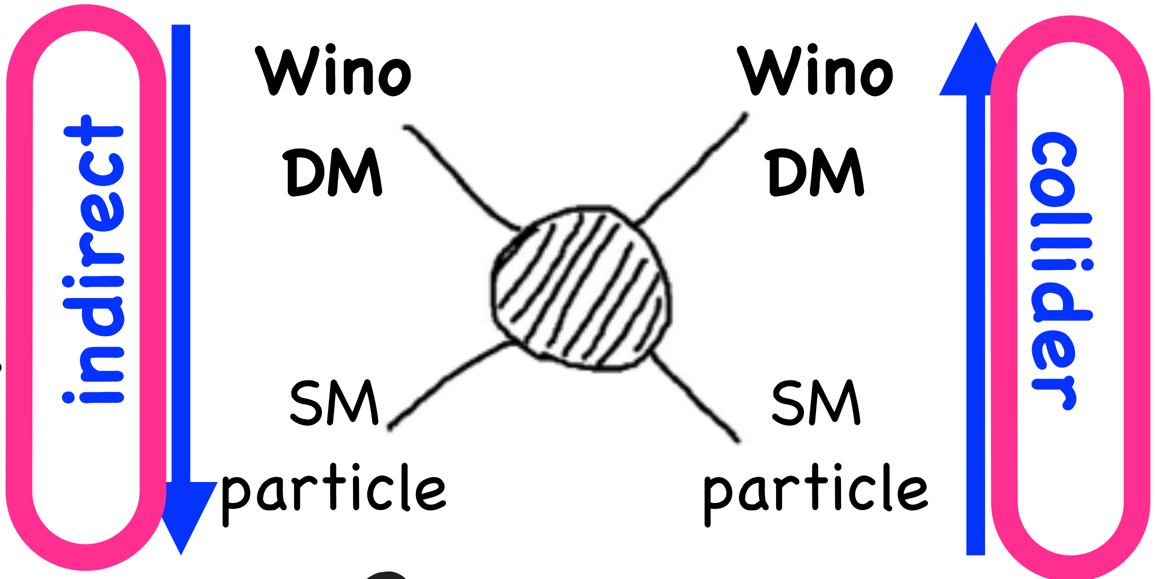

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If mass < 3 TeV, $\Omega_{\mathrm{thermal}} < \Omega_{\mathrm{CDM}}$.

→ requires **non-thermal production.**

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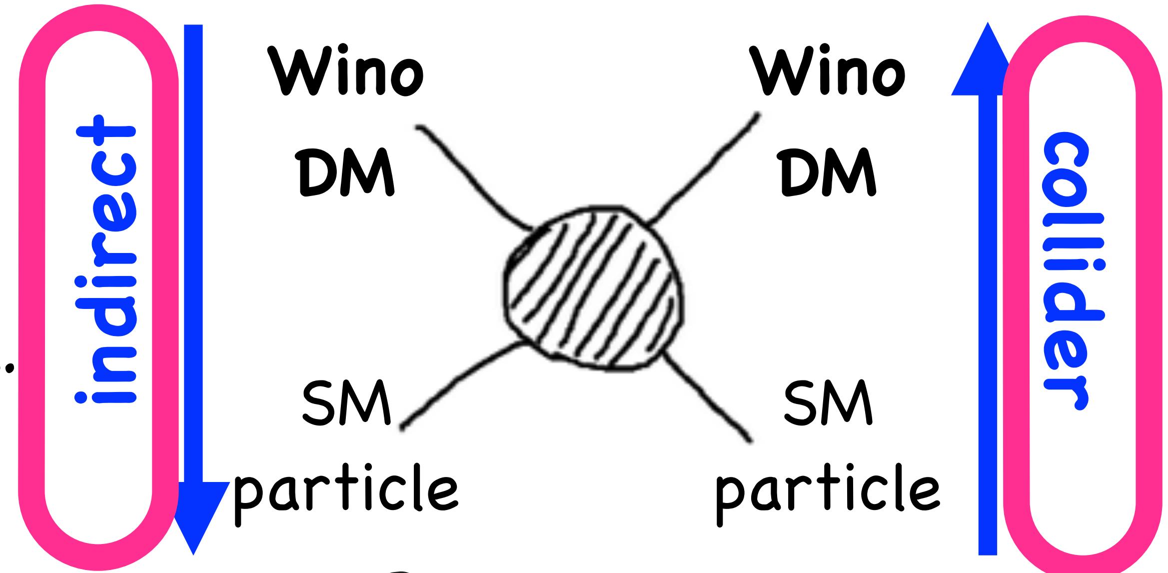

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- by **moduli** decay. [Moroi-Randall,'99]
- by **gravitino** decay.
  [Gherghetta-Giudice-Wells,'99, Moroi-Randall,'99, Ibe-Kitano-Murayama,'04, Ibe-Yanagida,'11]

e.g. thermal leptogenesis requires T_R > O(10^9) GeV. [Davidson-Ibarra,'02]

$$\Omega^{(NT)}h^2(M_2, T_R) \simeq 0.16 \times \left(\frac{M_2}{300\,\text{GeV}}\right)\left(\frac{T_R}{10^{10}\,\text{GeV}}\right).$$

- by **Q-ball** decay [Fujii-KH,'01'02, KH-Mukaida, in preparation]

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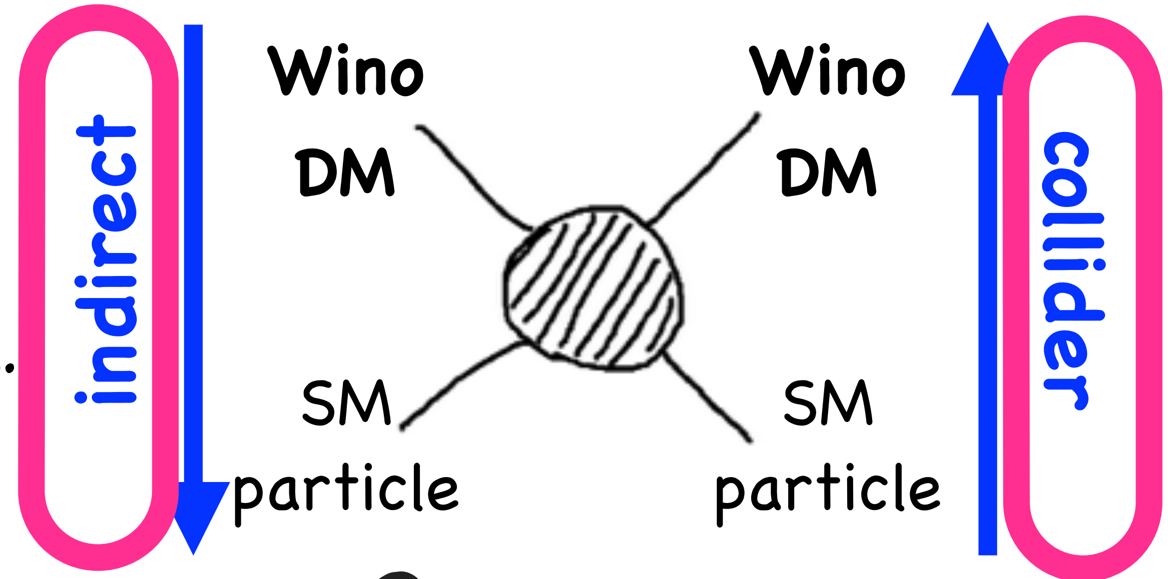

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Non-thermal Wino Dark Matter from Q-ball decay

[Fujii-KH, hep-ph/0110072, 0205044
KH-Mukaida, in preparation]

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- ϕ = a linear combination of squark fields, and flat direction in MSSM. (e.g., UDD flat direction)

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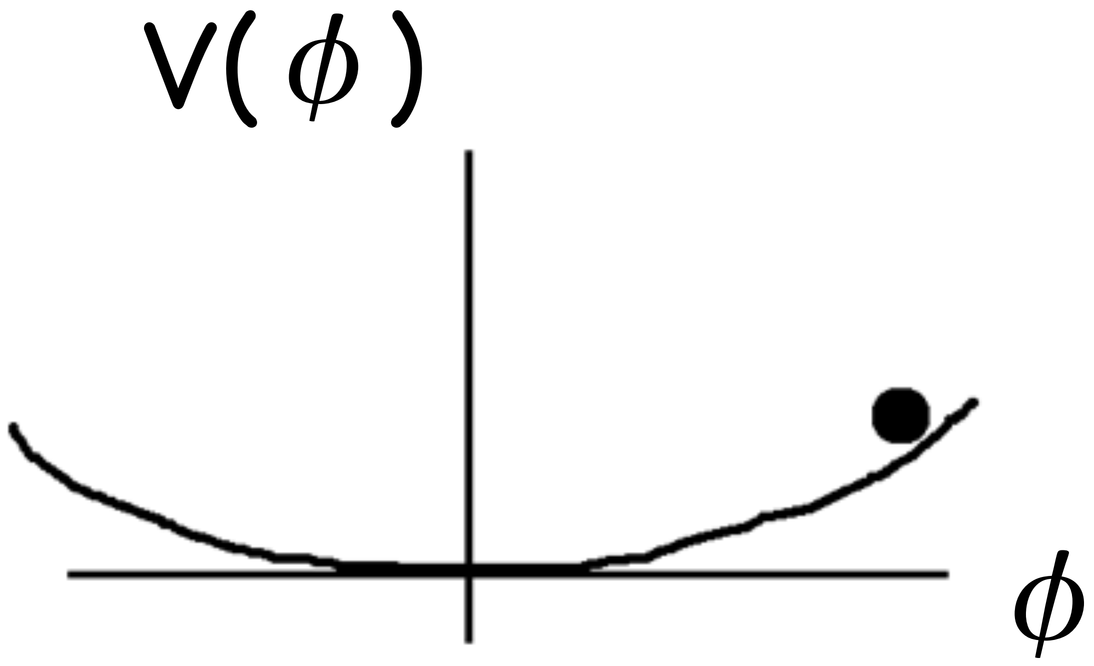

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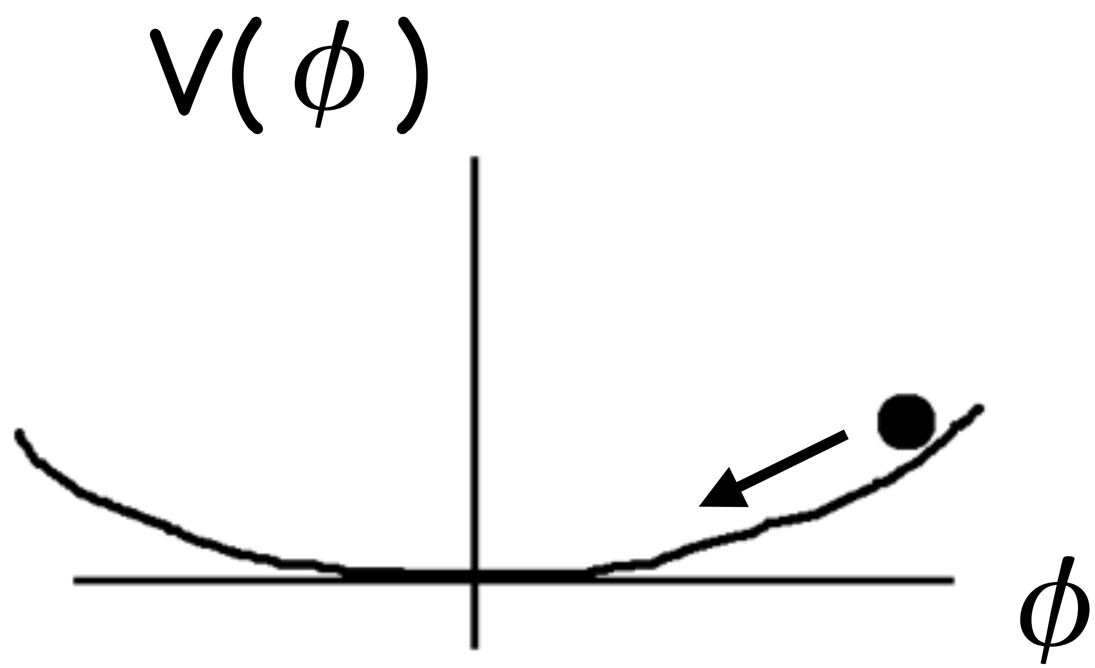
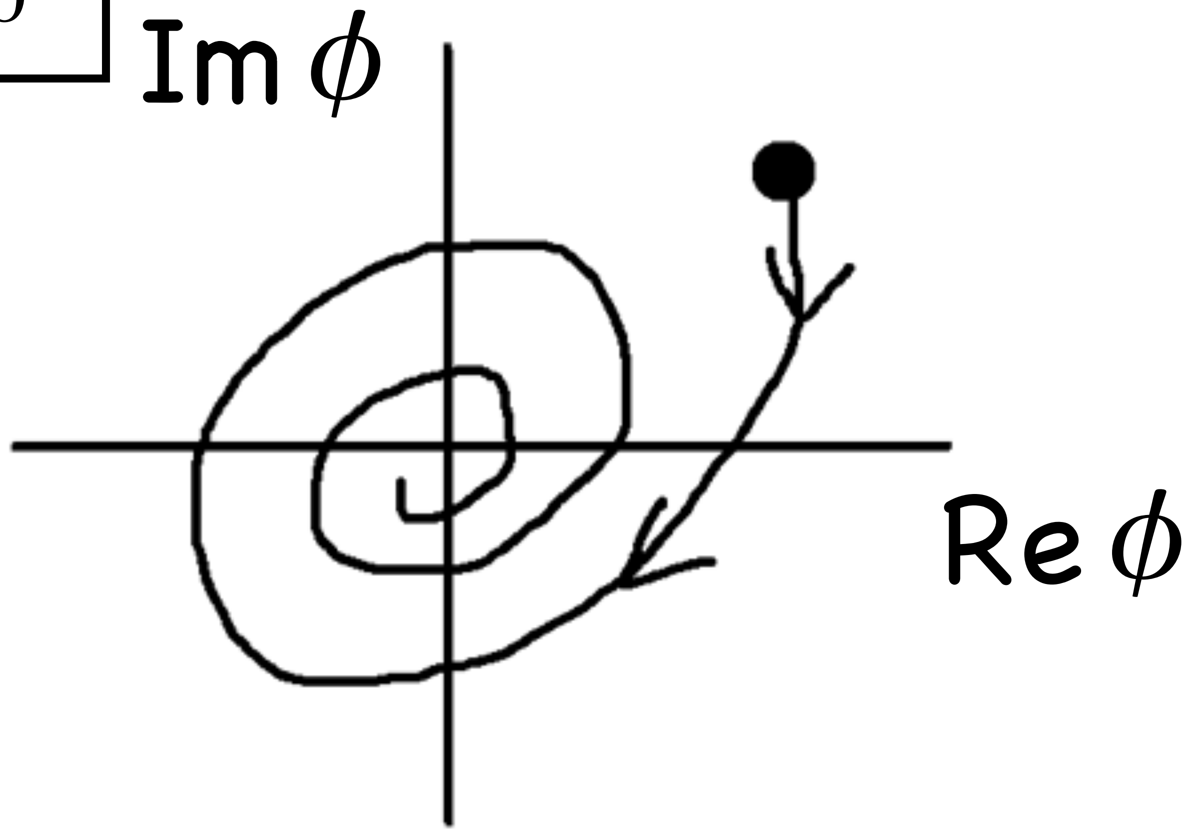
- after inflation, ϕ rotates in the field space, if B-violation exists. (e.g., W = $(UDD)^3/M^2$.)

$$n_B \propto n_\phi = i(\phi^* \dot{\phi} - \dot{\phi}^* \phi) \neq 0$$





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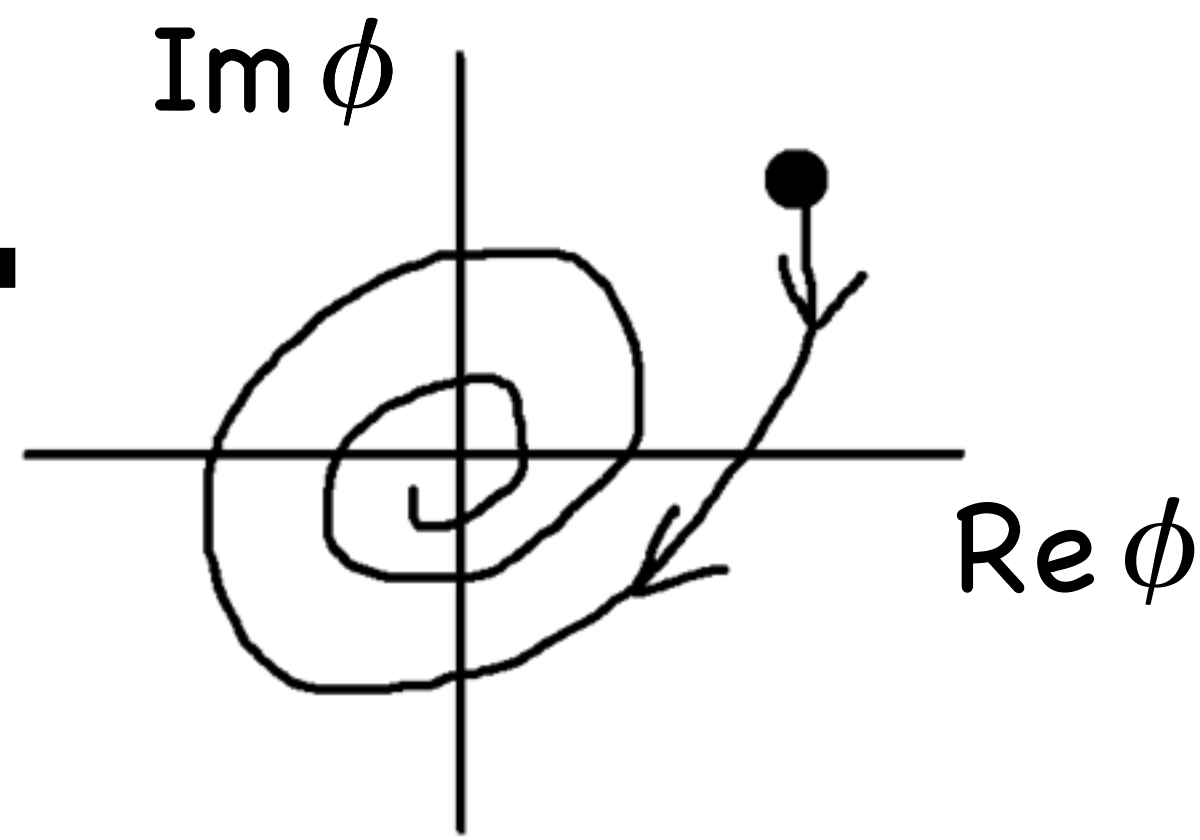
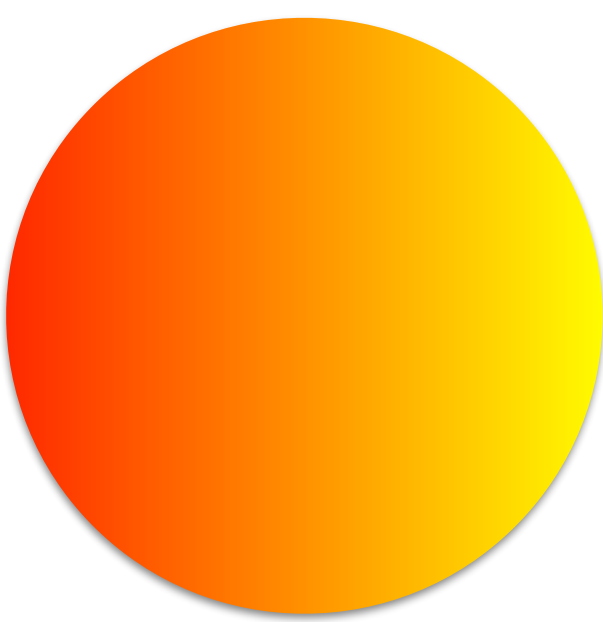
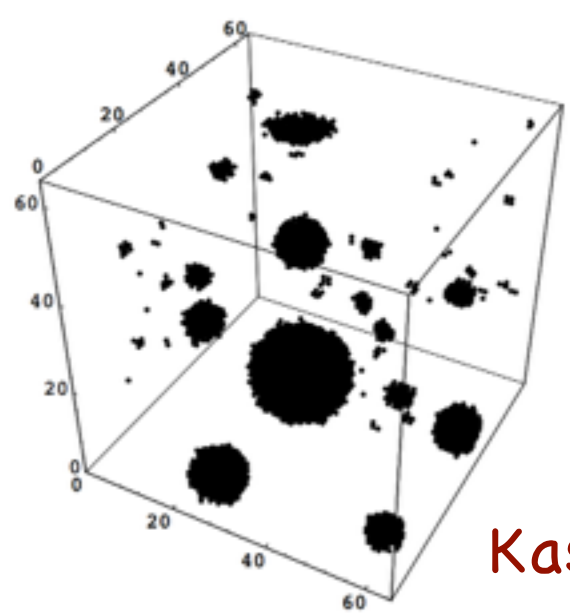




Q-ball



Kasuya-Kawasaki,'99

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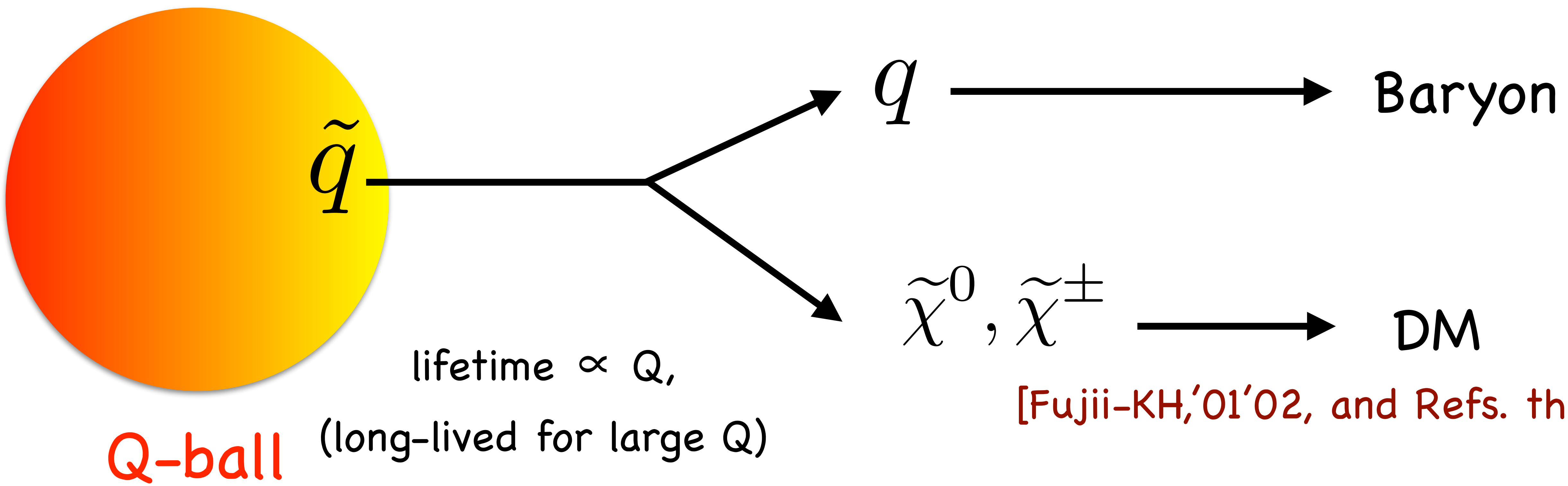

[Fujii-KH,'01'02, and Refs. therein.]

Non-thermal Wino Dark Matter from Q-ball decay

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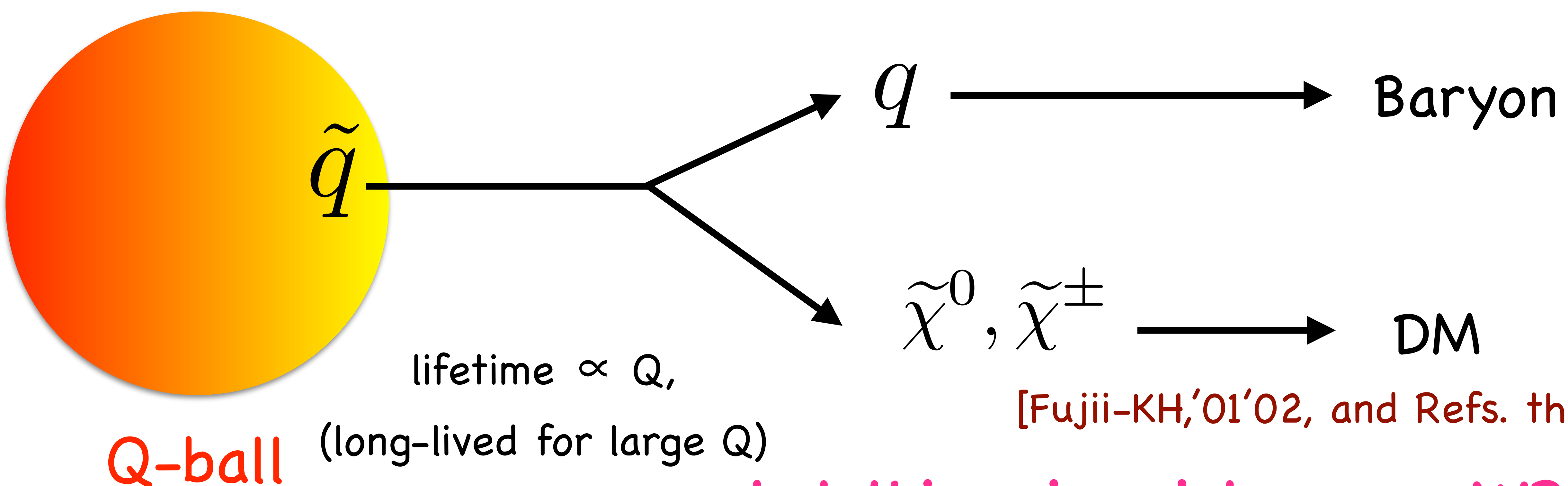


[Fujii-KH,'01'02, and Refs. therein.]

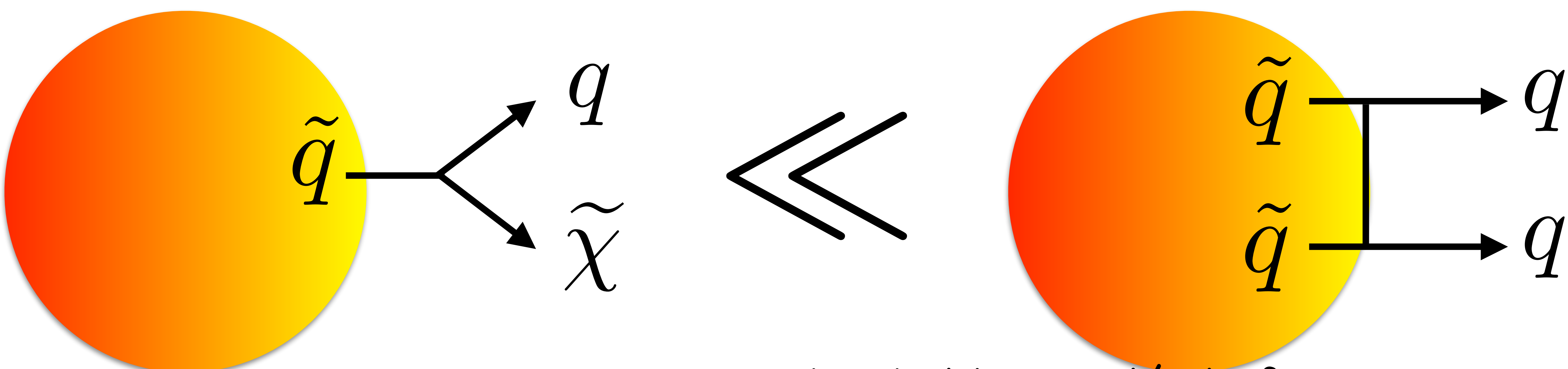
... but this naive picture was WRONG!

Non-thermal Wino Dark Matter from Q-ball decay

[Fujii-KH, hep-ph/0110072, 0205044
KH-Mukaida, in preparation]

Kawasaki-Yamada [1209.5781]

Kamada-Kawasaki-Yamada [1211.6813]



saturated by gaugino's d.o.f
= 1 (if Bino only)

saturated by quark's d.o.f.
= 3(color) x 6(flavor) x 2^3 (phase space)
(x2 depending on chirality)

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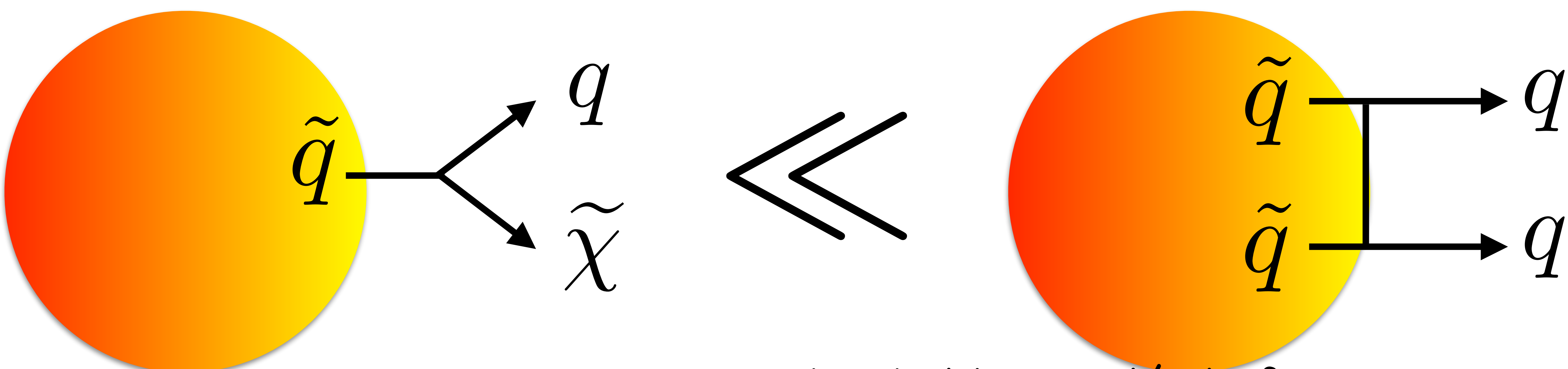
Revisiting the "Wino-from-Q-ball-decay" scenario by taking into account of

- **this effect,**
- large squark mass (**heavy sfermion scenario**)
- **Sommerfeld** enhancement of Wino annihilation.



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RESULT (for an example model point, **preliminary**)

[model point]:

udd -flat direction with $W \propto (udd)^2$.

$m_{\rm Wino} \simeq 600$ GeV $< m_{\rm Bino}, m_{\rm gluino} \ll m_{\rm Higgsino}, m_{\rm squark}, m_{\rm slepton} \sim 10$ TeV

$\Longrightarrow$ In order to obtain $\Omega_{\rm Wino}^{\rm non\text{-}thermal} \simeq \Omega_{\rm CDM} \to T_{\rm Q\text{-}ball\ decay} \sim 300$ MeV.

$\Longrightarrow$ Q-ball charge $Q \sim 10^{24}$ (new effect taken into account)

$\Longrightarrow$ initial amplitude of AD-field $\phi_0 \sim 0.03\, M_P$ $(\sim 7Q^{1/2} m_\phi)$

$\Longrightarrow$ correct baryon asymmetry is obtained by, e.g., $\delta_{\rm eft} \sim 10^{-3}$ and $T_R \sim 10$ GeV.

It works !

※ It requires very low TR or entrapy production.
(in contrast to Leptogenesis)

Plan

- 126 GeV Higgs and SUSY
- **Wino** DM (in heavy sfermion scenario)
- **gravitino** DM (in GMSB)

- **light Bino-like** DM (h/Z-resonant Bino)
- **g-2** and DM

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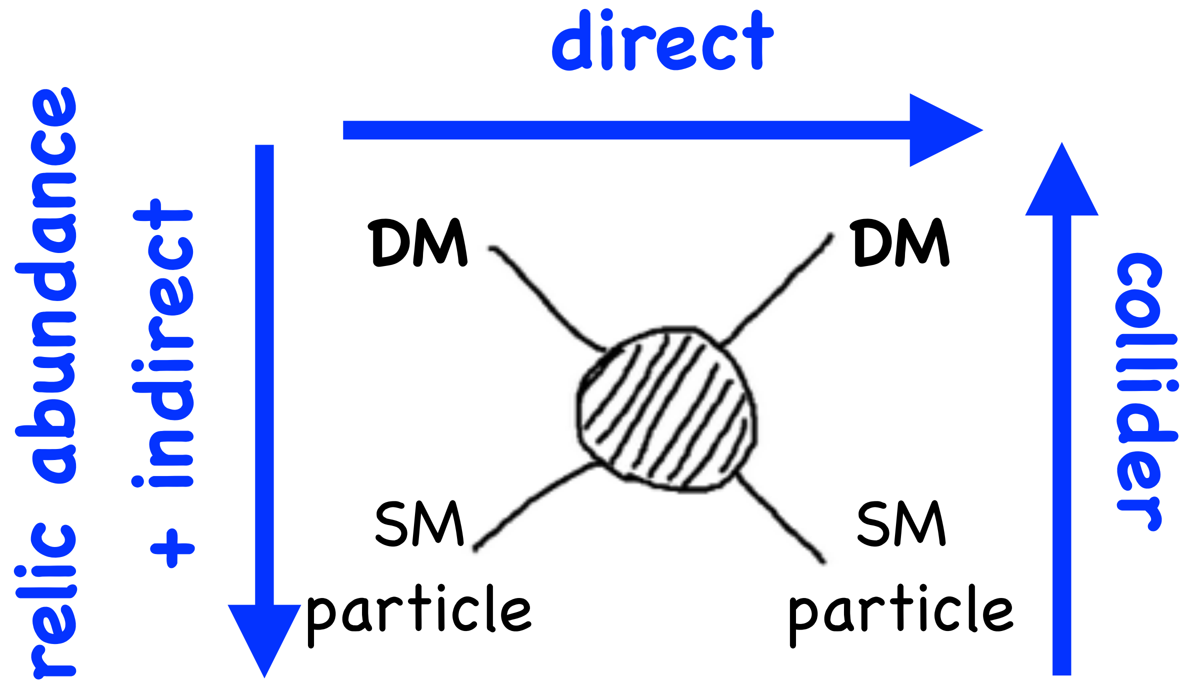
Gravitino DM (in GMSB)



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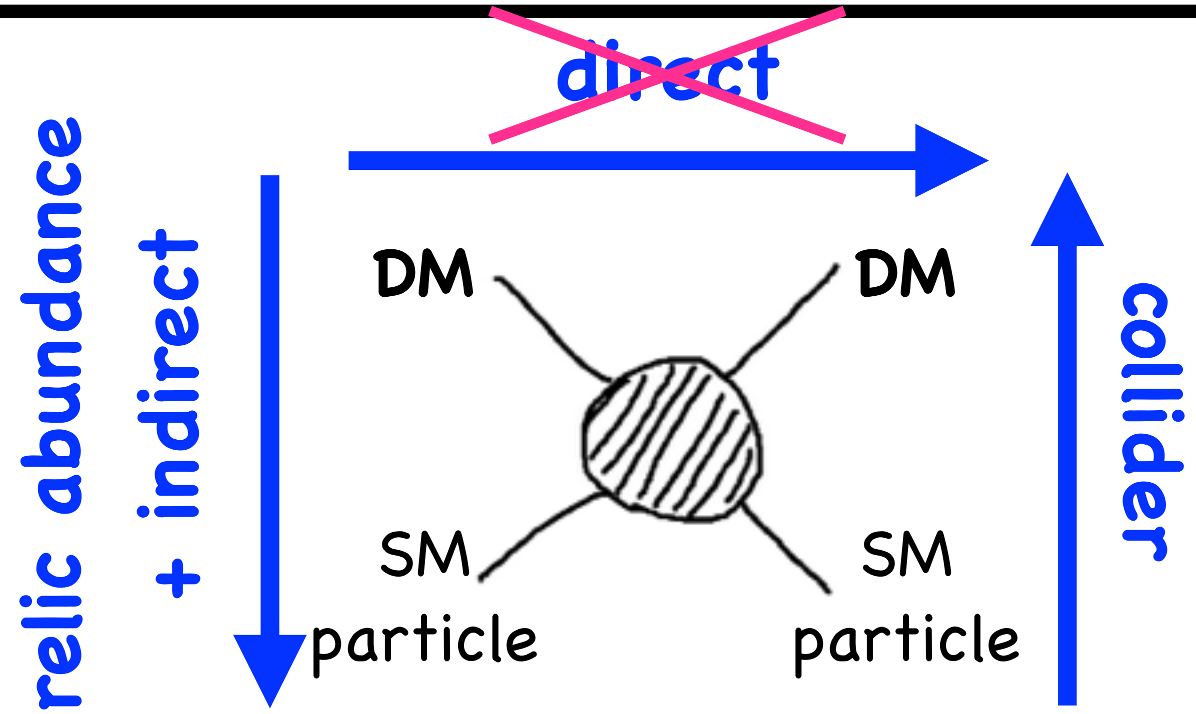

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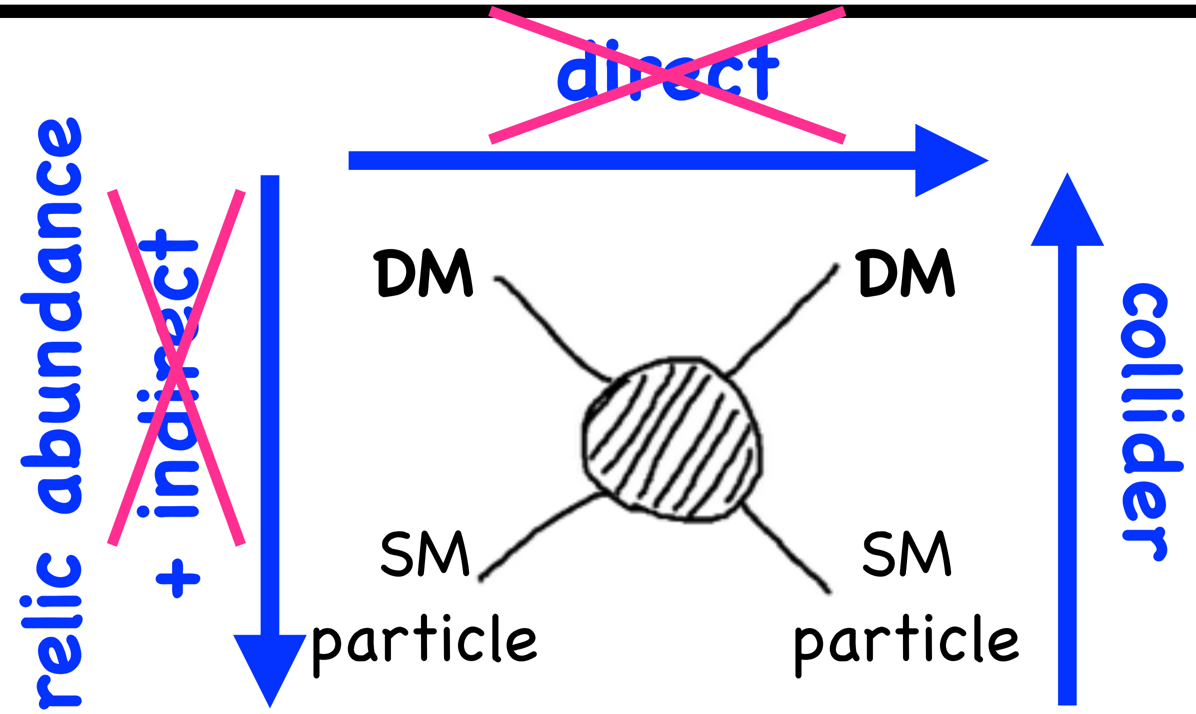

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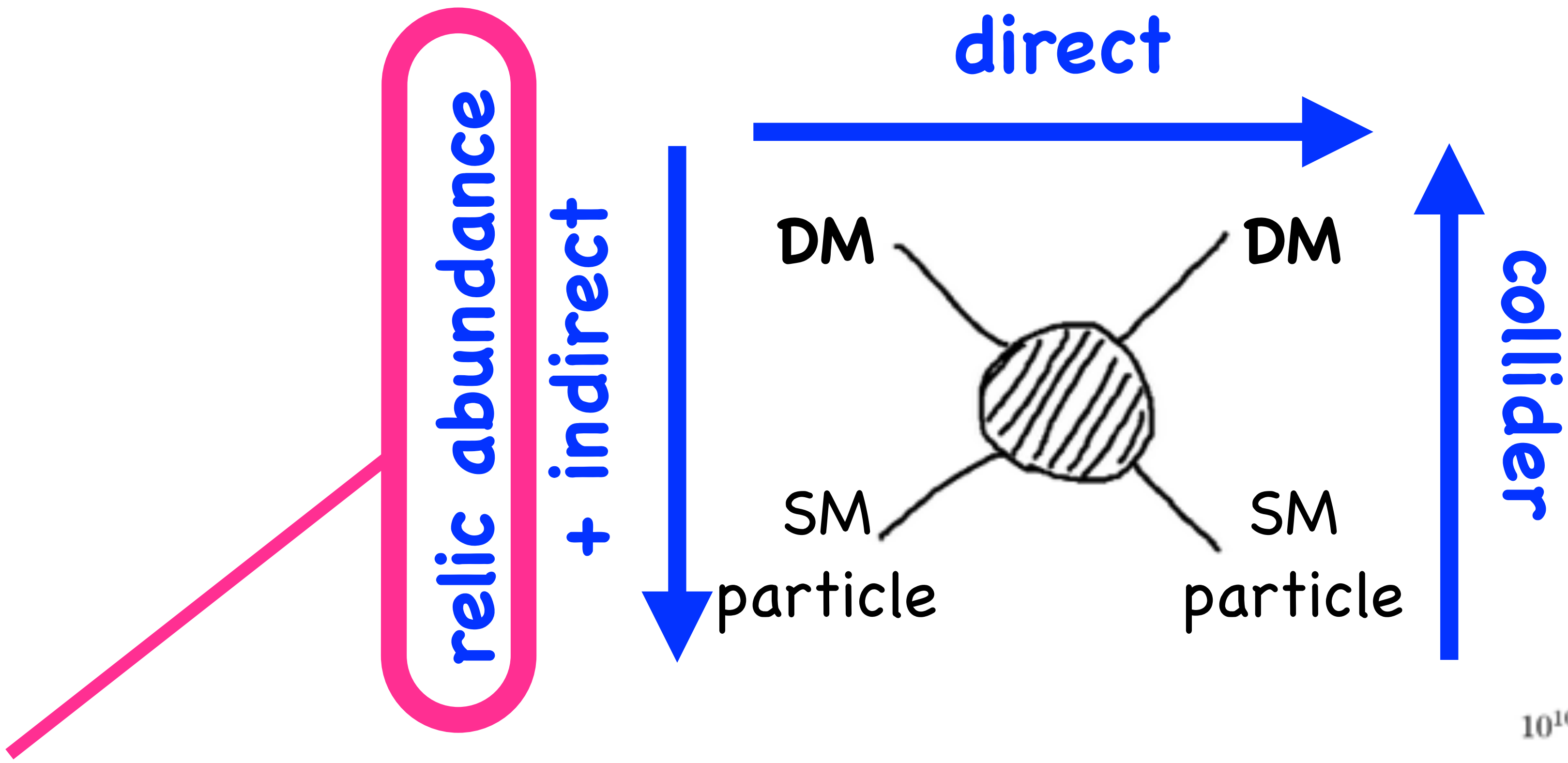


relic abundance

- "thermal" production (not freeze-out).

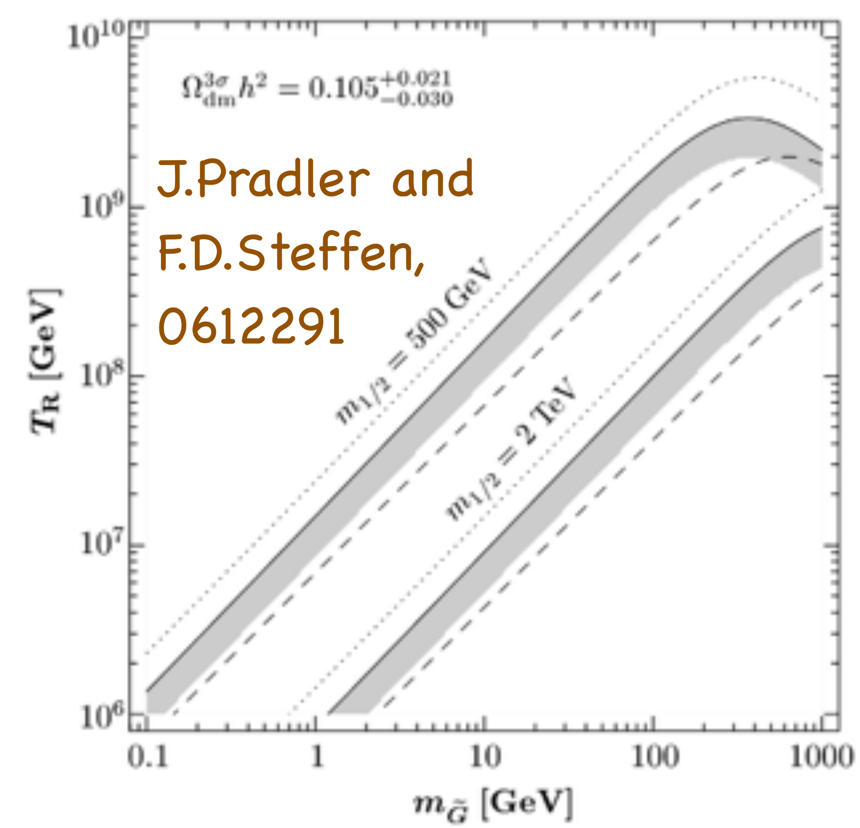
$$\Omega_{\widetilde{G}}^{\text{"thermal"}} \propto \frac{T_R}{m_{\widetilde{G}}} M_{\text{gluino}}^2 \quad (+\text{ corrections})$$

- NLSP decay.
- late-time dilution by messenger decay.

Very high T_R is allowed ! (Ω becomes independent of T_R.)

[cf. KH, M.Ibe, T.T.Yanagida, N.Yokozaki, '14]

$$\Omega_{3/2}h^2 \simeq \frac{1}{\Delta}\Omega_{3/2}^{\text{eq}}h^2$$
$$\simeq 0.16\left(\frac{f_3}{0.01}\right)\left(\frac{10}{g_*}\right)^{1/4}\left(\frac{\tan\beta}{50}\right)\left(\frac{m_{3/2}}{10\text{ MeV}}\right)^2\left(\frac{10^{10}\text{ GeV}}{M_{\text{mess}}}\right)^{5/2}$$



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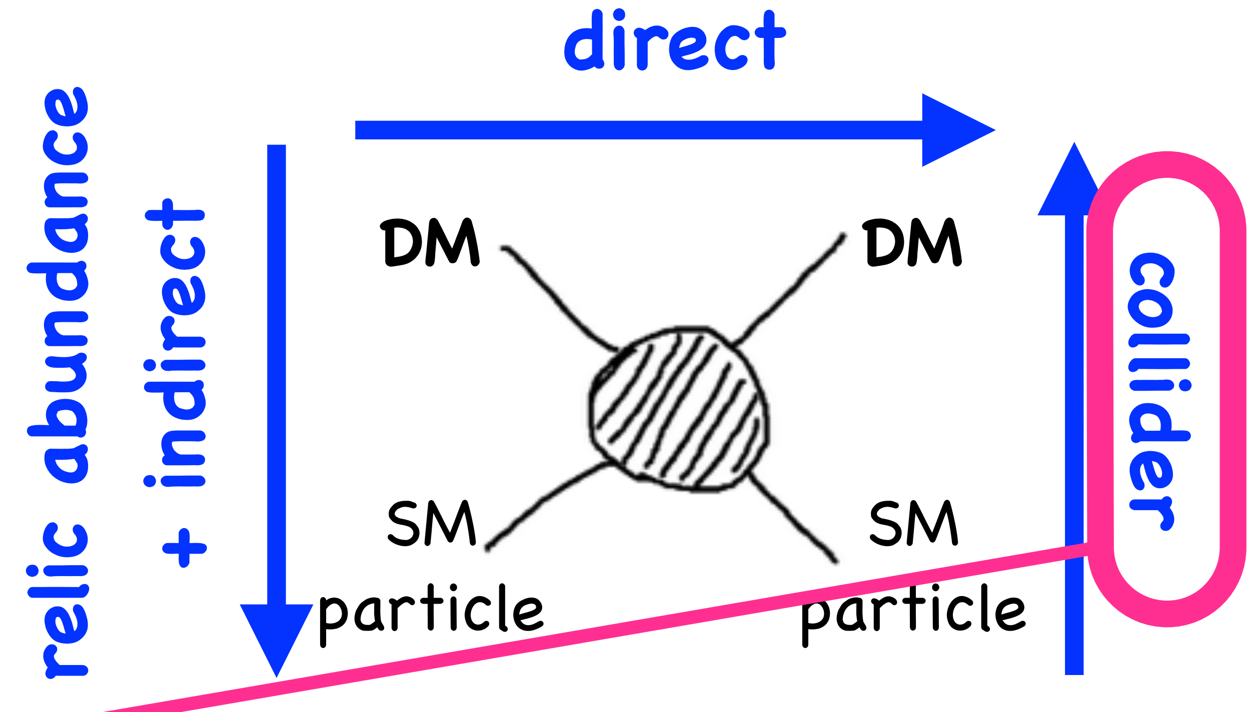


Collider signature: (…IF NLSP is charged (stau))

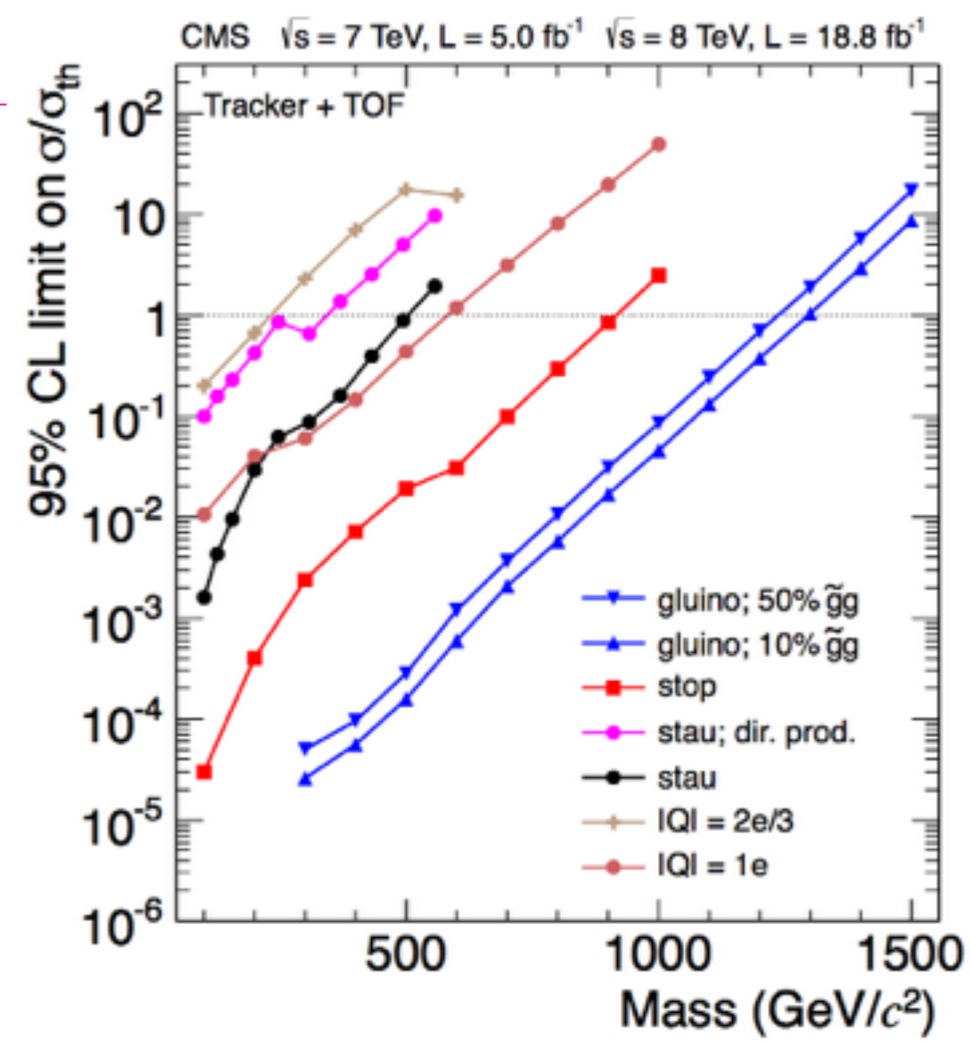
= long-lived charged track !

8 TeV bound:

m(stau) > 339 GeV

[CMS, 1305.0491]

[> 290 GeV by ATLAS:1411.6795]



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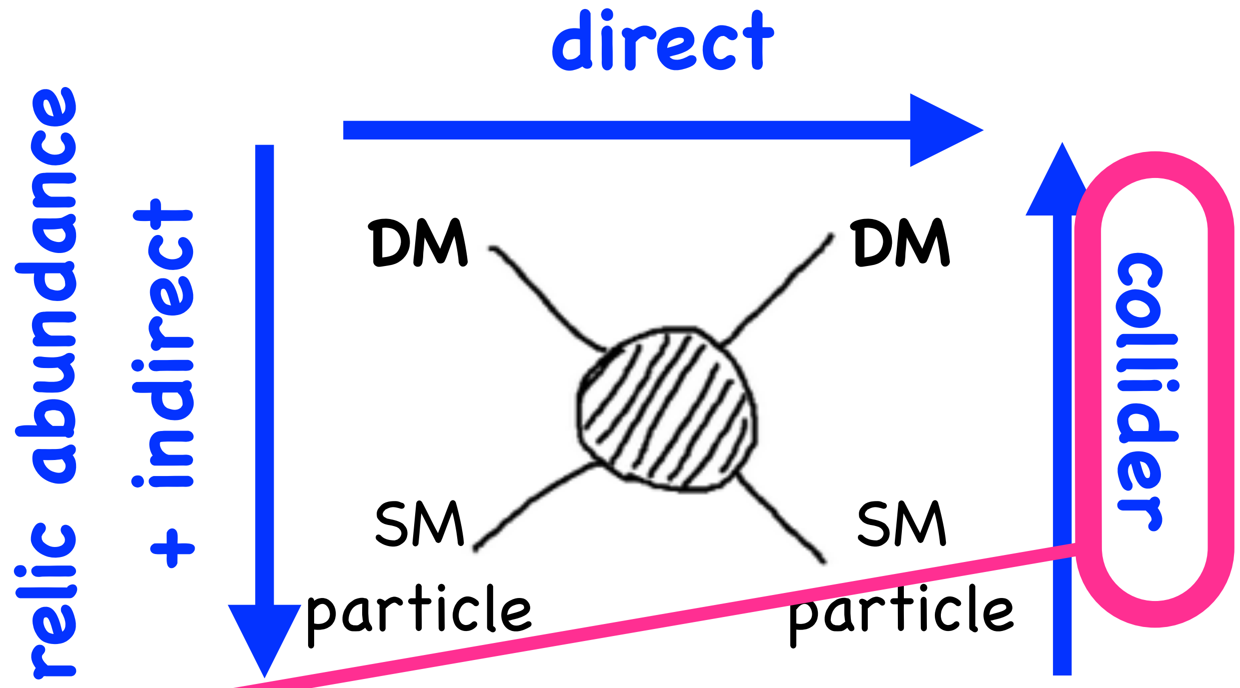

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… but **126 GeV Higgs** suggests

O(> TeV) SUSY particles in GMSB (where A-term is small).

Is it still possible to see it ?

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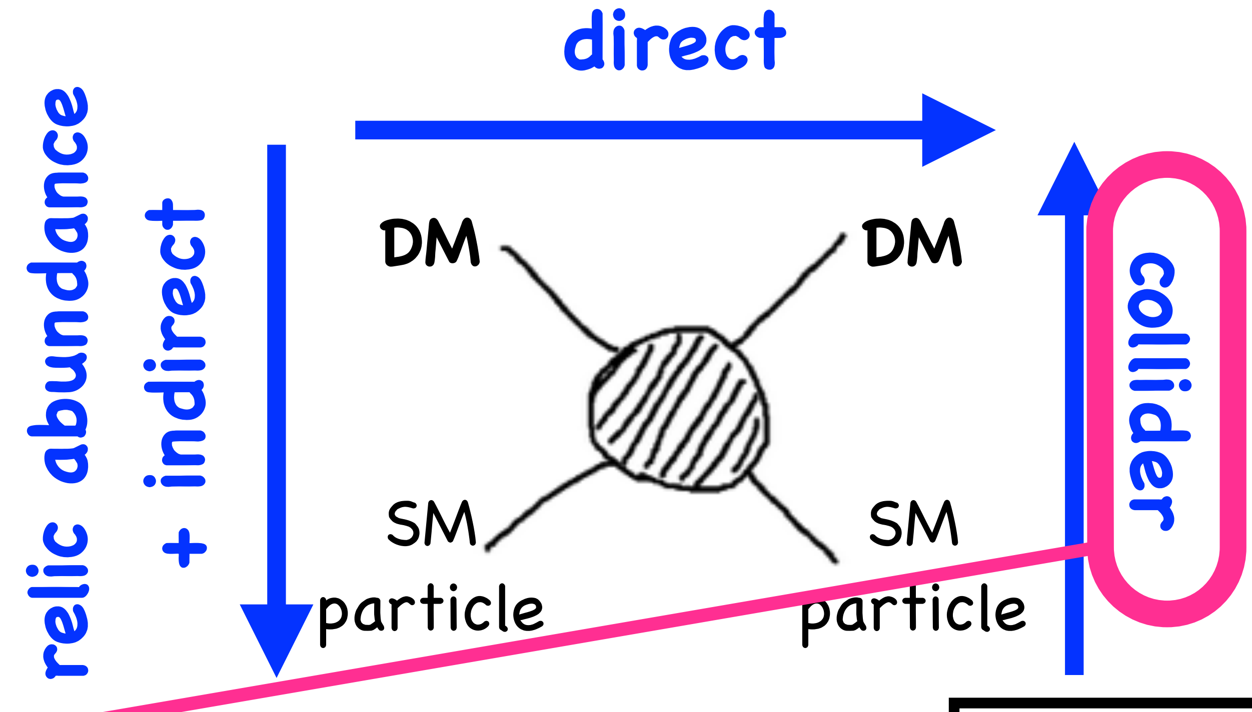

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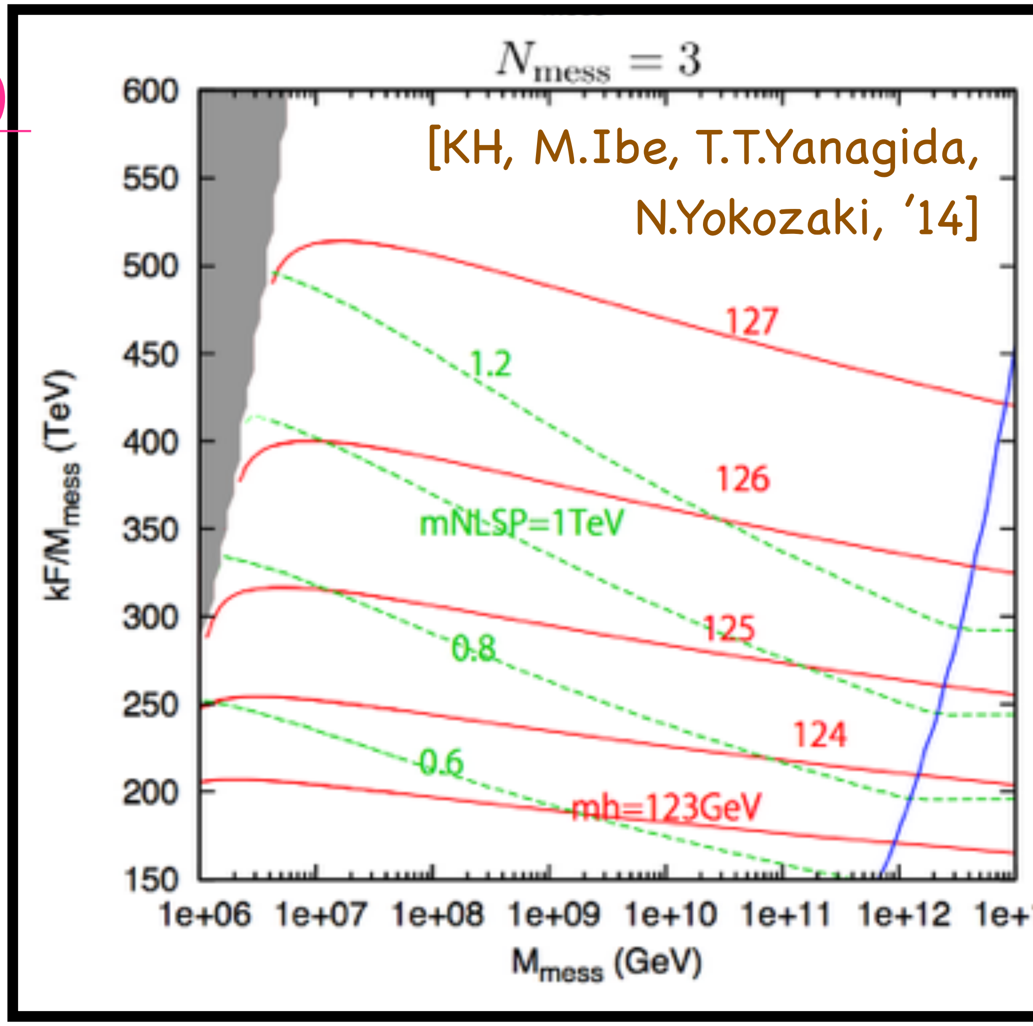
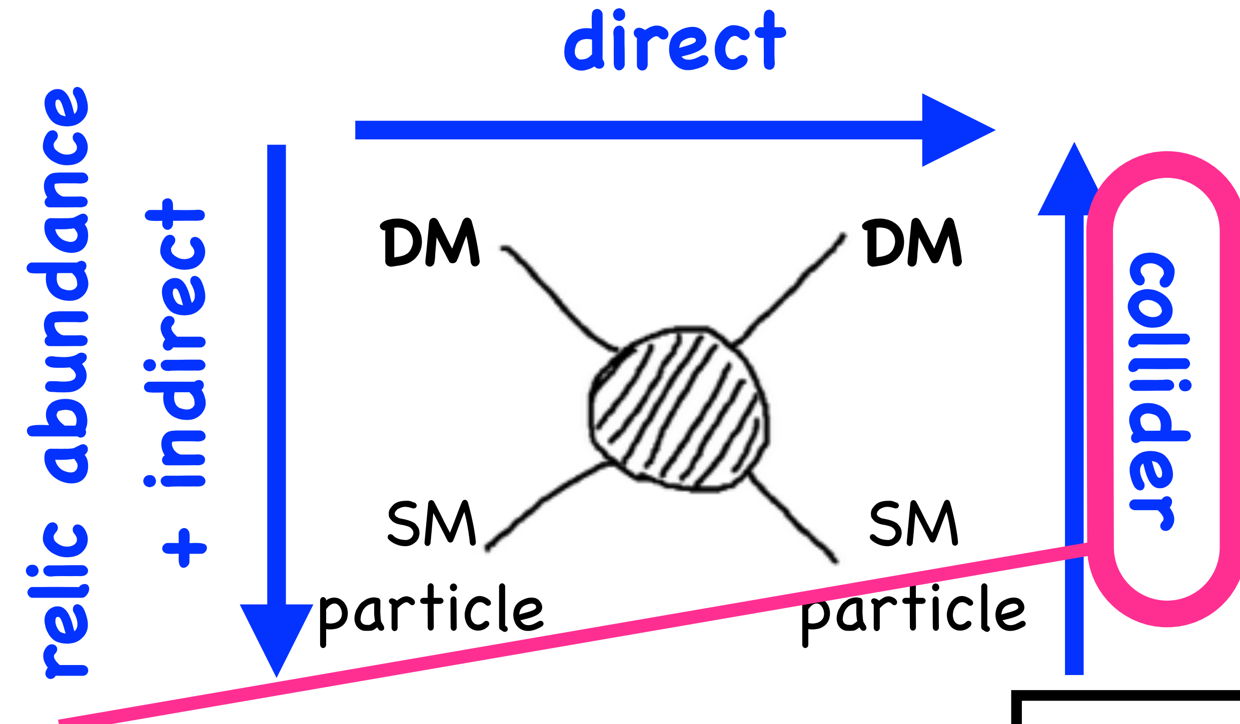


Is it still possible to see it ?

–> In a minimal direct GMSB ($B(M_{mess})=0$ to avoid CPV -> large $\tan\beta$)...

–> $m_{\rm NLSP} < 1.0\text{–}1.2\,\text{TeV}.$

Gravitino DM (in GMSB)



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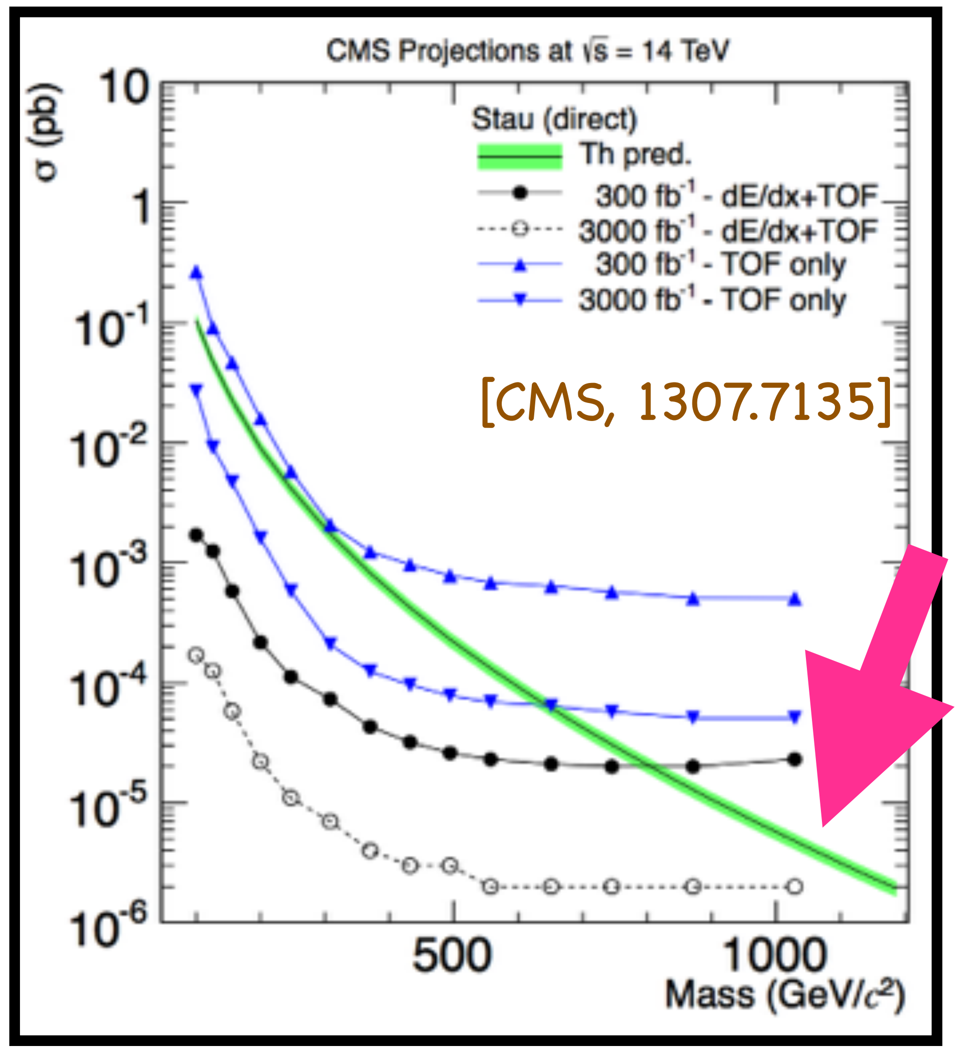

Is it still possible to see it ?

--> In a minimal direct GMSB ($B(M_{mess})=0$ to avoid CPV -> large $\tan\beta$)…

--> $m_{\rm NLSP} < 1.0\text{–}1.2\,{\rm TeV}.$

…… can be seen @ 3000fb^-1 !

Plan

- 126 GeV Higgs and SUSY
- Wino DM (in heavy sfermion scenario)
- gravitino DM (in GMSB)

- light Bino-like DM (h/Z-resonant Bino)
- g-2 and DM

Plan

- 126 GeV Higgs and SUSY

Assume that

$$m_{\tilde{q}} \gg m_{\tilde{\ell}},\ m_{\tilde{\chi}^{\pm}},\ m_{\tilde{\chi}^{0}},$$

>> 1 TeV
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= O(100 GeV)
for DM (and g-2)

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[KH, K.Ishikawa, in preparation]

Suppose M_1, μ << [all other SUSY particle masses]

-> Only 3 relevant parameters: M_1, μ, $\tan\beta$

$$M_{\text{neutralino}} = \begin{pmatrix} \mathbf{M_1} & -m_Z s_W \mathbf{c}_\beta & m_Z s_W \mathbf{s}_\beta \\ -m_Z s_W \mathbf{c}_\beta & 0 & -\mu \\ m_Z s_W \mathbf{s}_\beta & -\mu & 0 \end{pmatrix}$$

= One of the "well-tempered" scenarios.

[N.Arkani-Hamed, A.Delgado, G.F.Giucice, 0601041]

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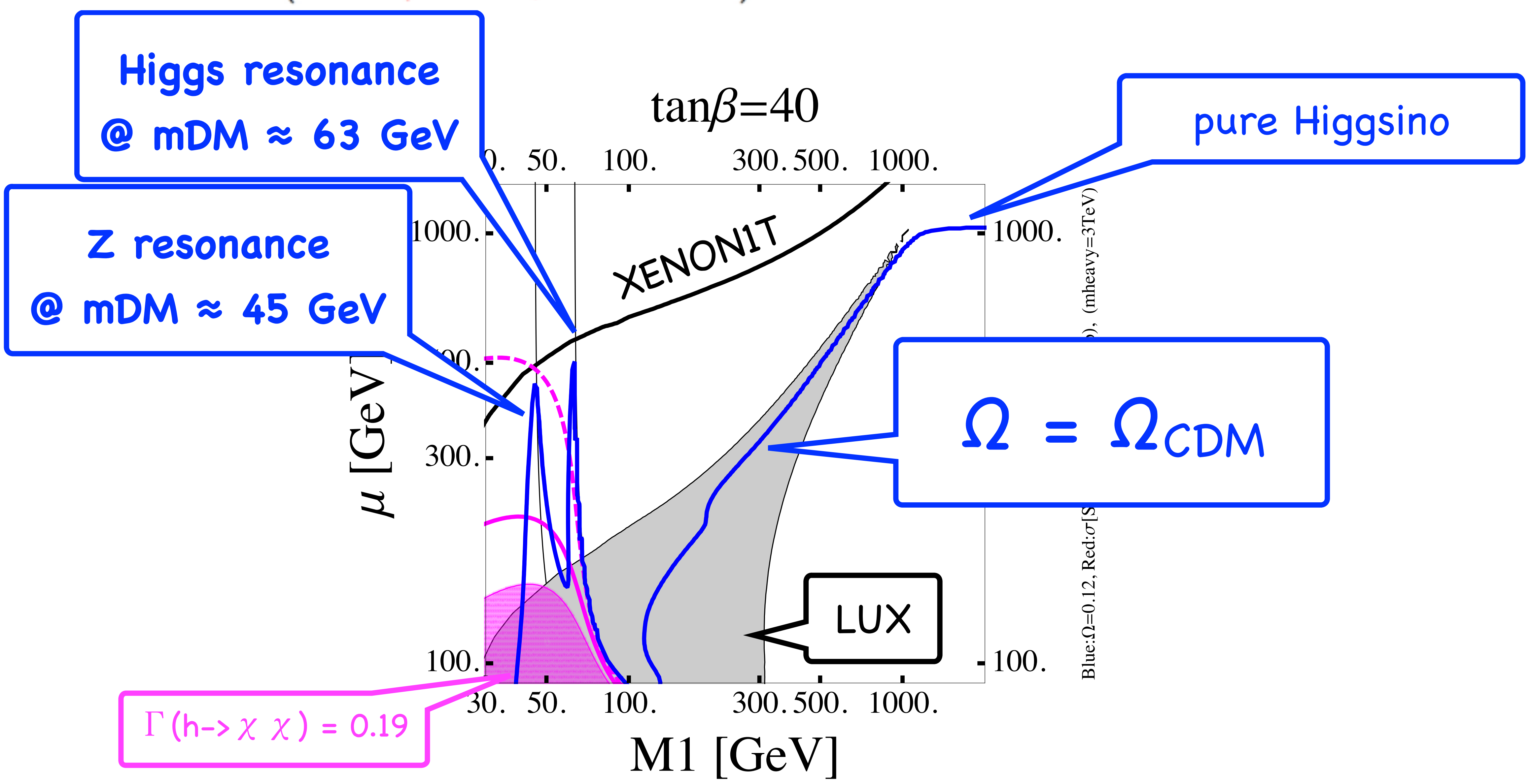

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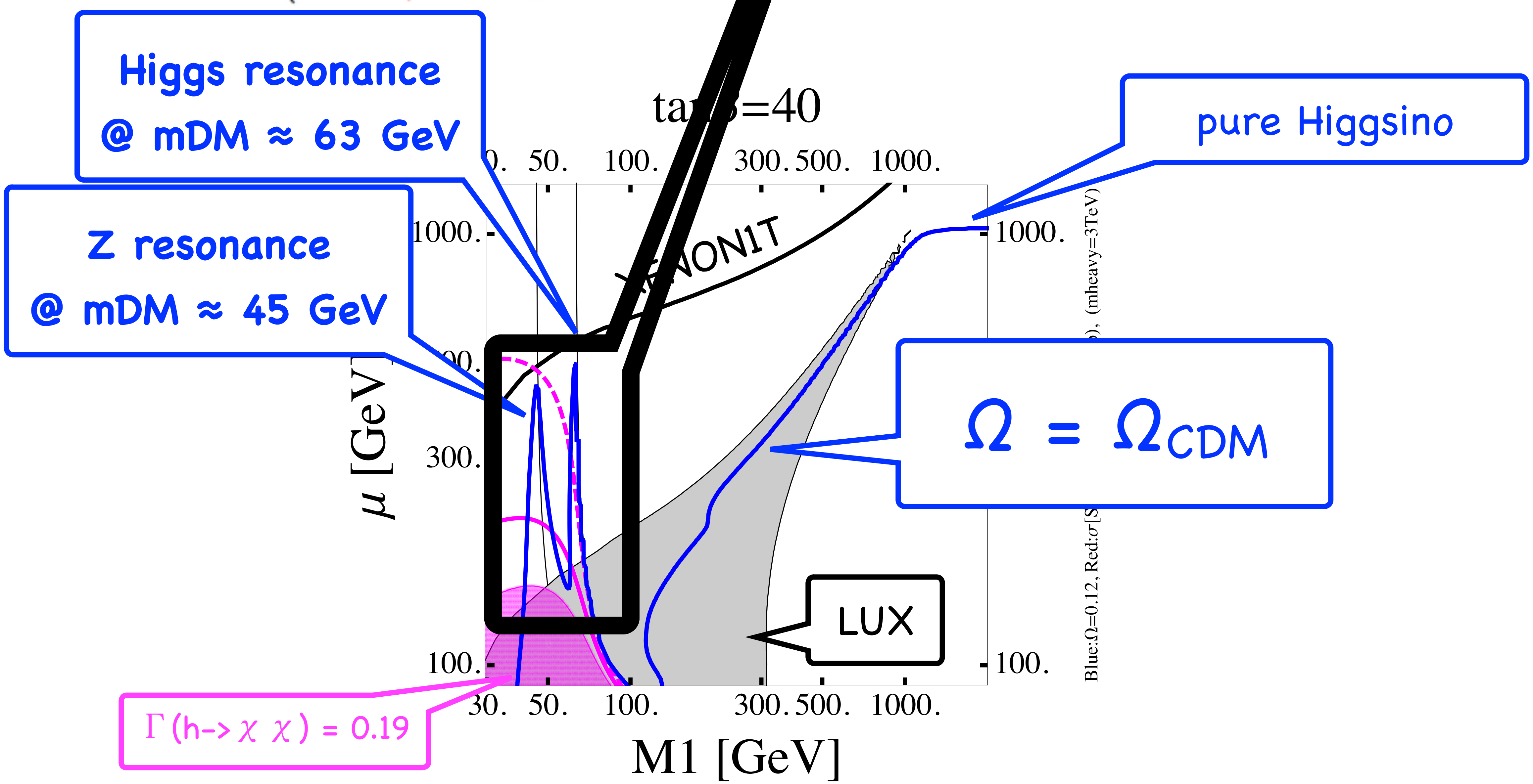

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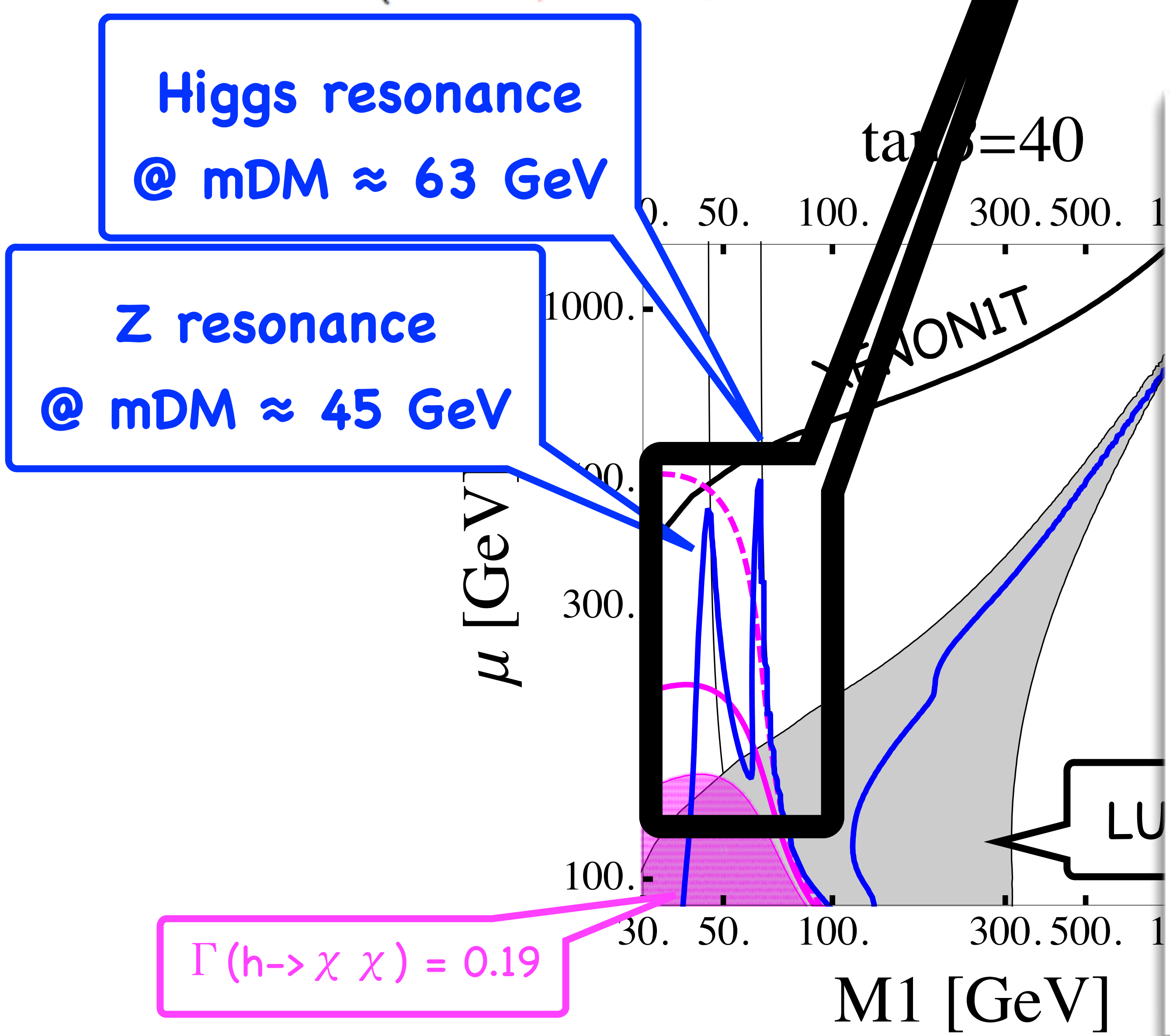


(of course) many earlier works...

including recent ones...

- 1211.4873 [C.Cheung, L.J.Hall, D.Pinner, J.T.Ruderman]
- 1409.7000 [C.Han]
- 1410.5730 [L.Calibbi, J.M.Lindert, T.Ota, Y.Takanishi]
- ......

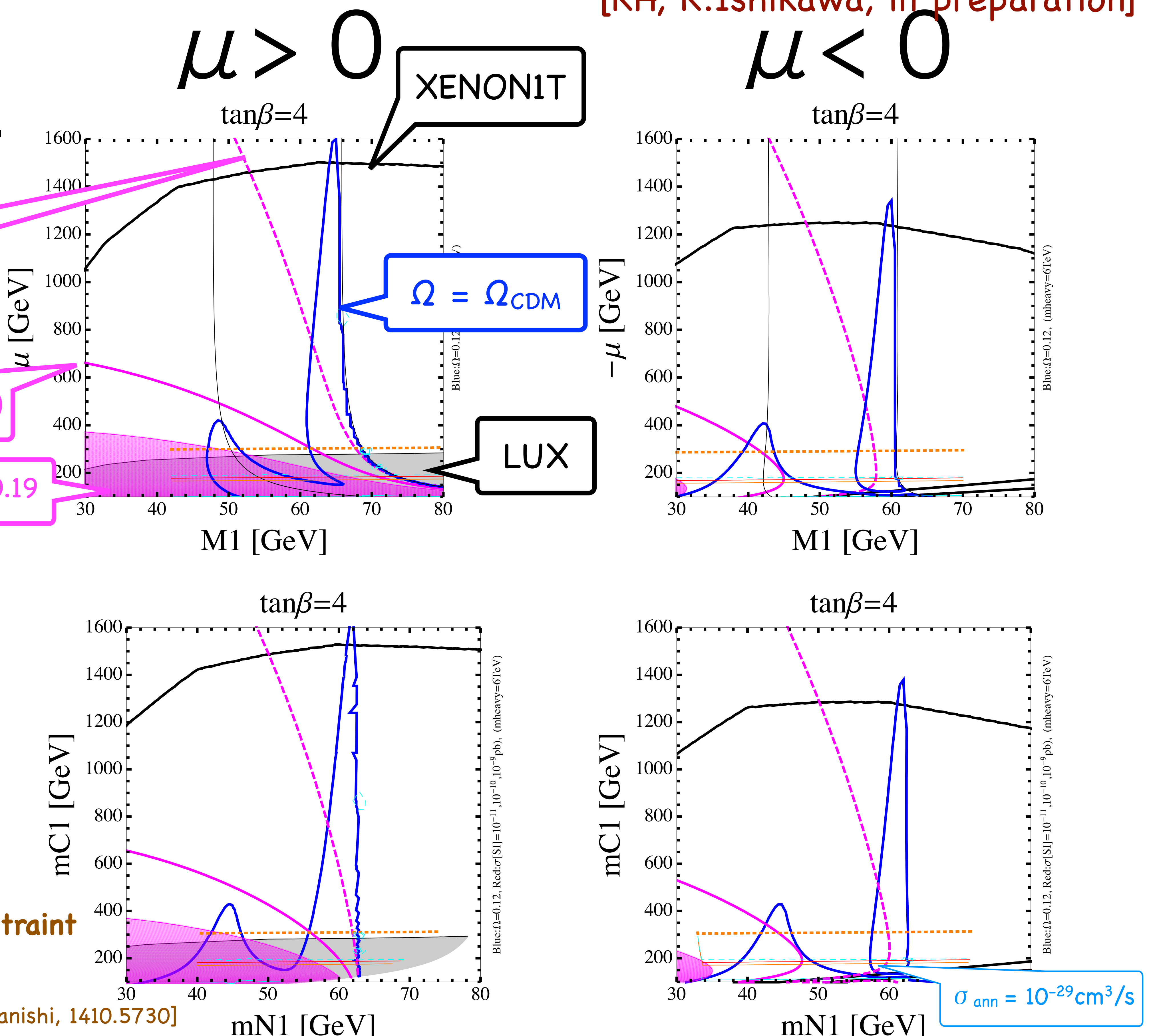
In our work...

Full parameter scan (not scatter plot!) in h/Z-resonant region with current bounds + future prospects..

light Bino-like DM (h/Z-resonant Bino)

[KH, K.Ishikawa, in preparation]

$\tan\beta = 4$



Γ(h->χ χ) = 0.004 (ILC)

Γ(h->χ χ) = 0.062 (HL-LHC)

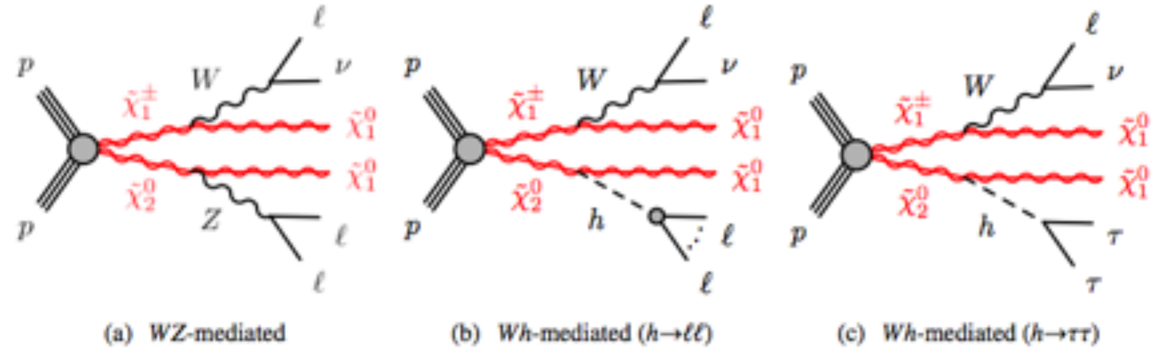
Γ(h->χ χ) = 0.19

mass eigenstates

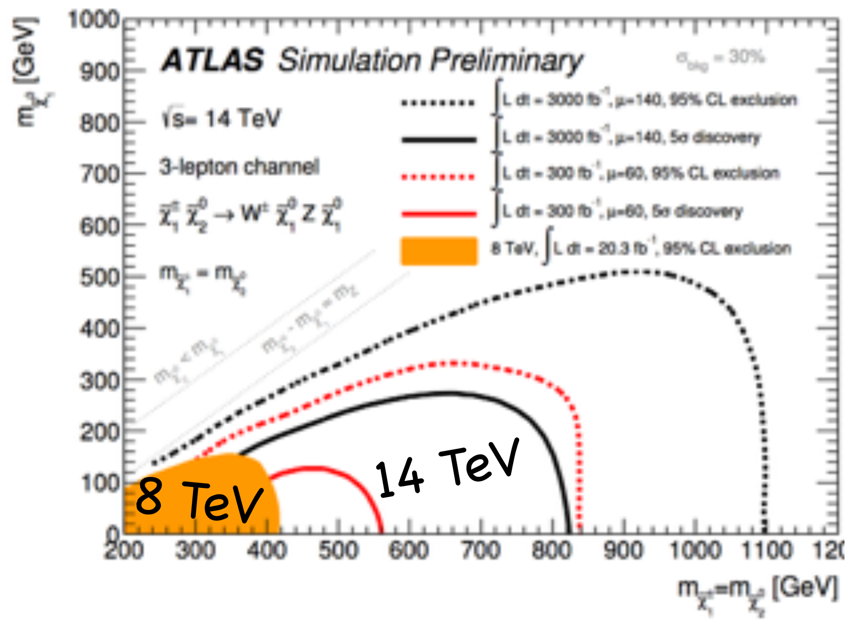
(*In addition, **8 TeV LHC constraint for $\mu \lesssim$ 250 GeV.**

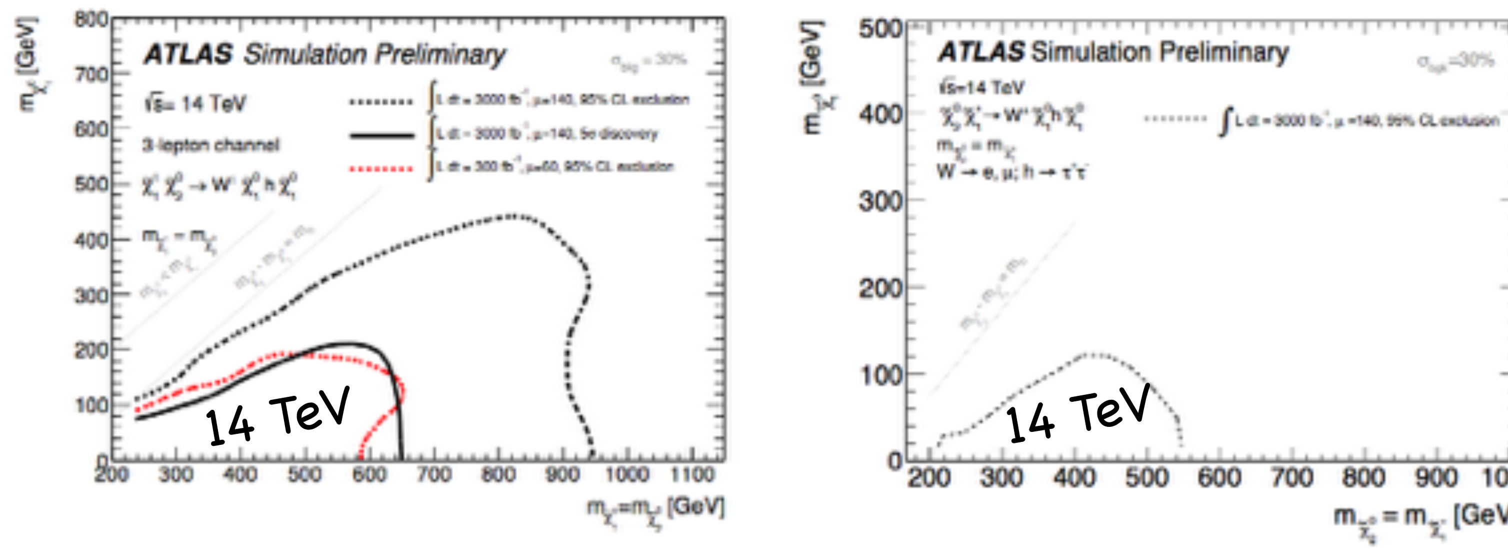
[cf .L.Calibbi, J.M.Lindert, T.Ota, Y.Takanishi, 1410.5730]

light Bino-like DM (h/Z-resonant Bino)



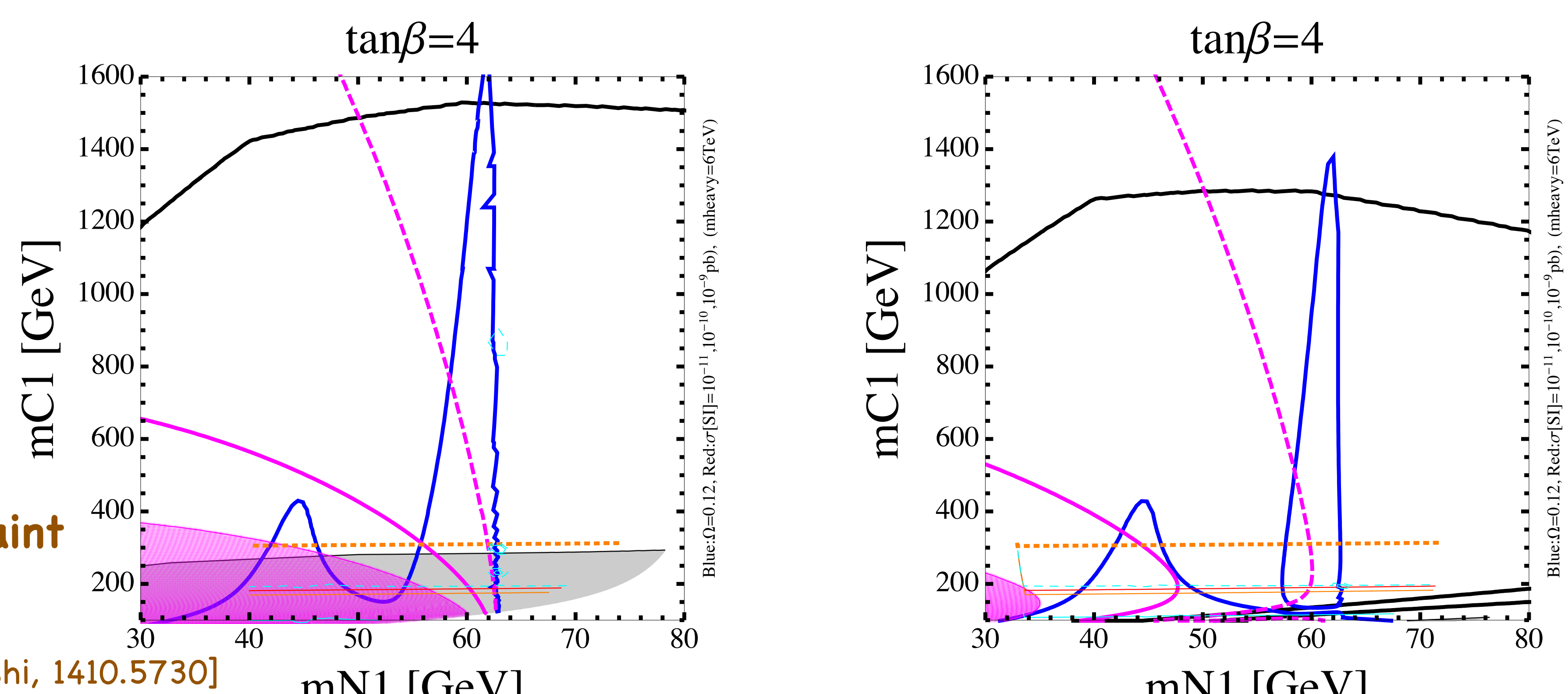
ATLAS [ATL-PHYS-PUB-2014-010]





(a) 3ℓ channel (b) 1ℓ2τ channel

in progress...



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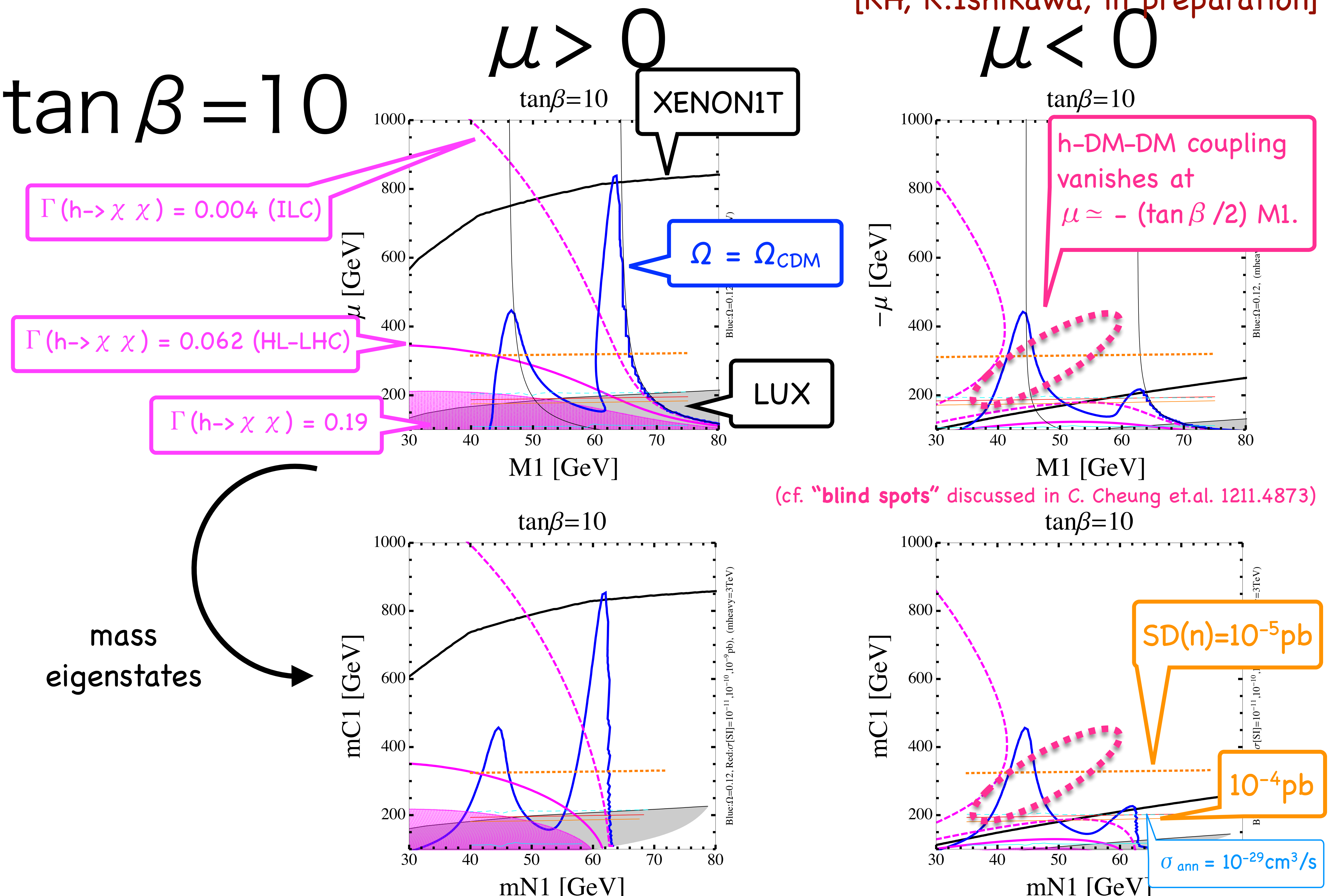

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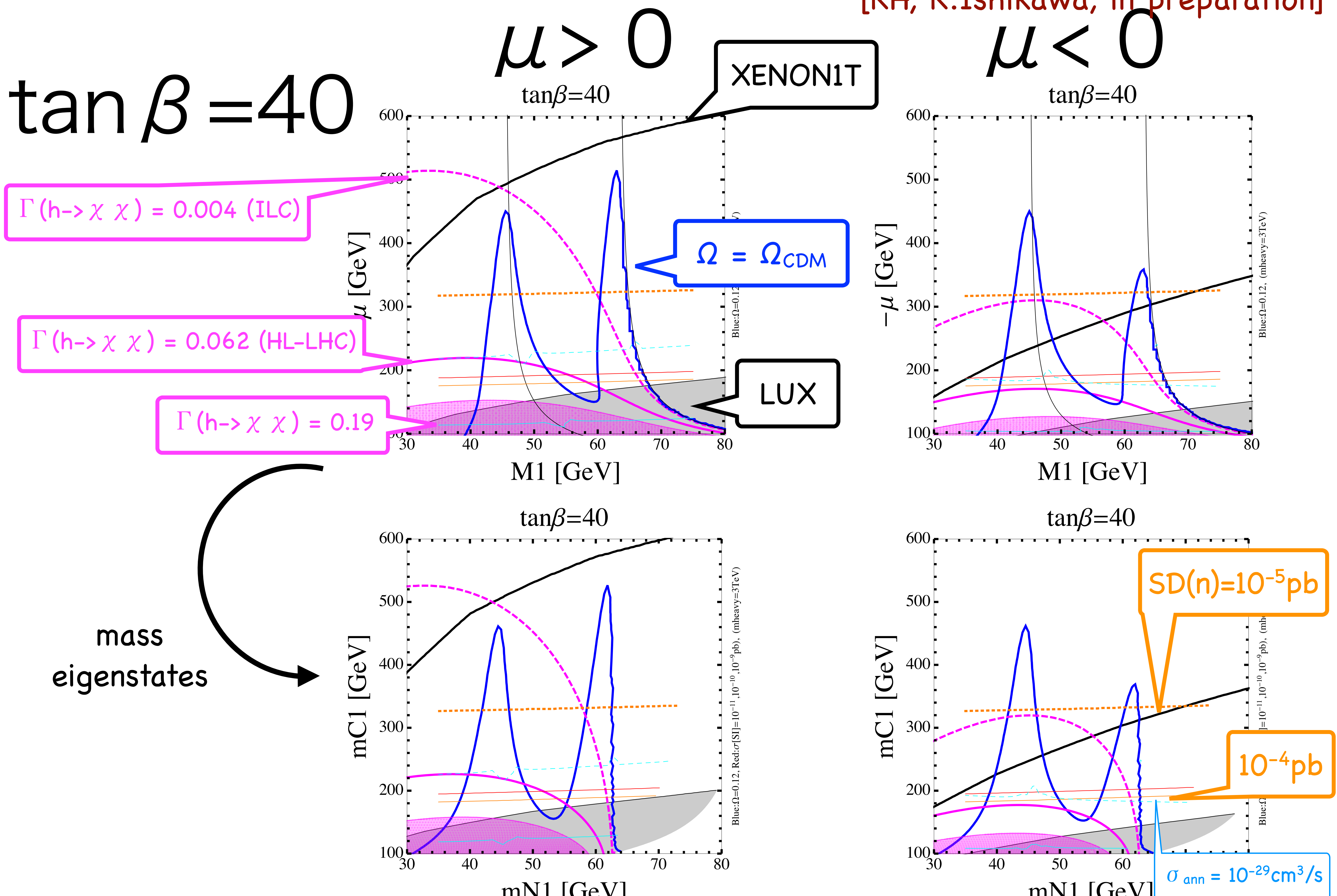

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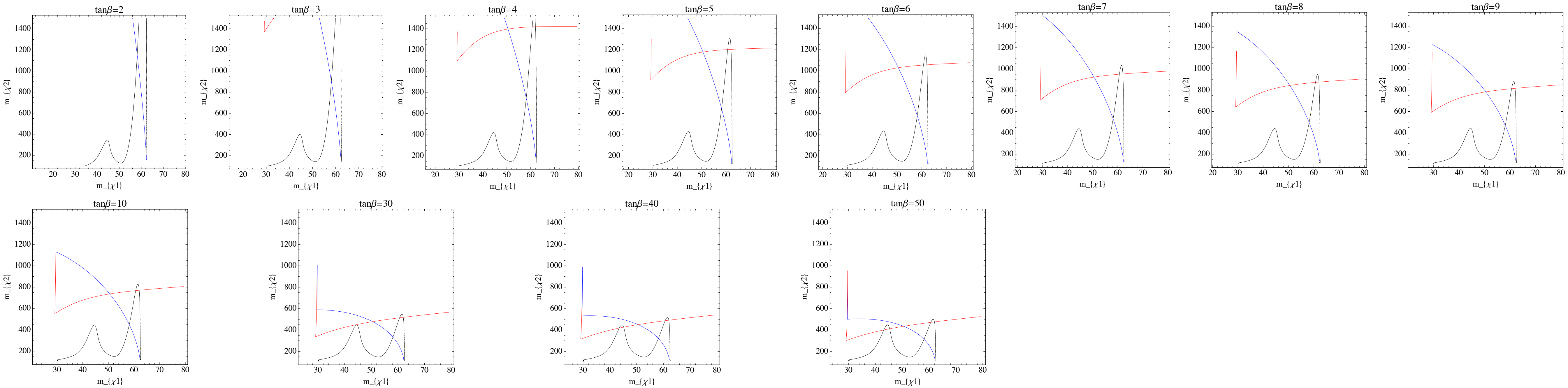
[KH, K.Ishikawa, in preparation]

$\mu > 0$



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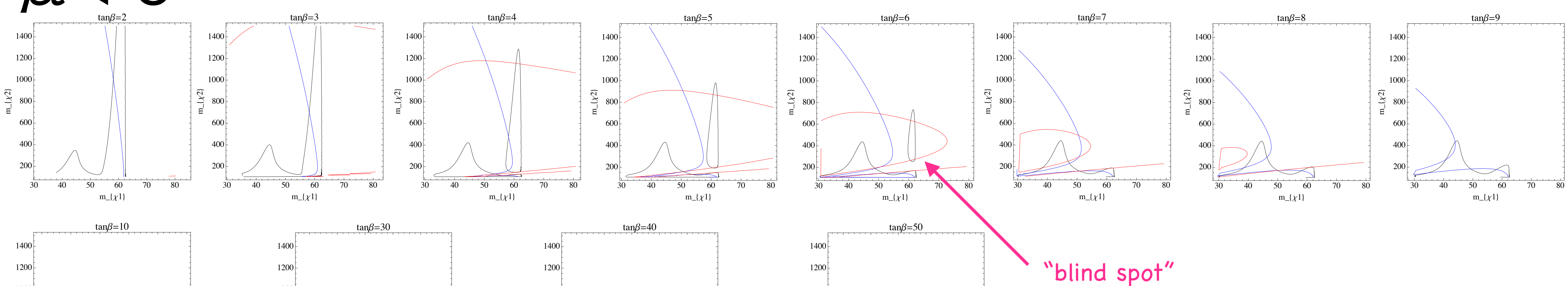

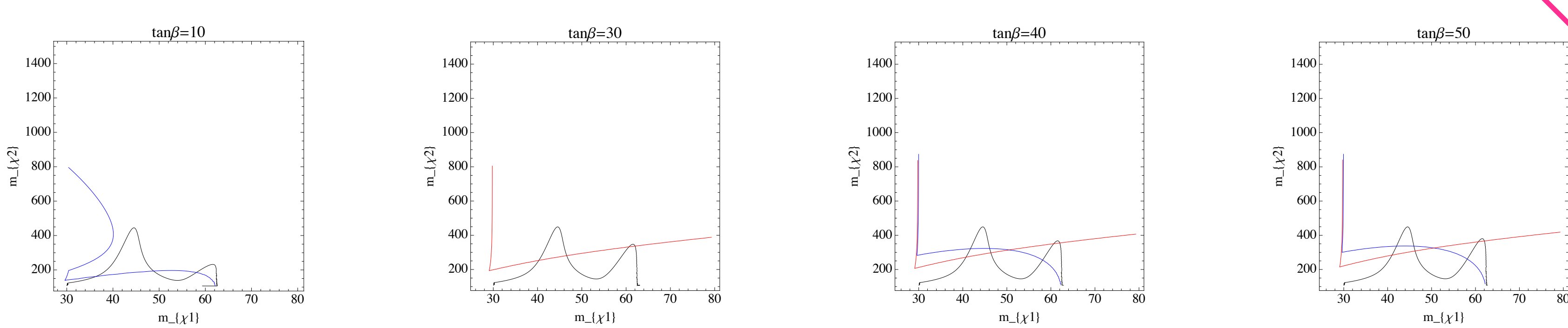

still in progress, but almost all the parameter region will be covered by XENON1T and/or LHC.

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>> 1 TeV
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See also D.Chowdhury's talk last week!

DM and g-2 in SUSY

[M.Endo, KH, S.Iwamoto, T.Yoshinaga, in preparation]

muon g-2

$$a_\mu^{\rm EXP} - a_\mu^{\rm SM} = (26.1 \pm 8.0) \cdot 10^{-10}$$

> 3 σ deviation !

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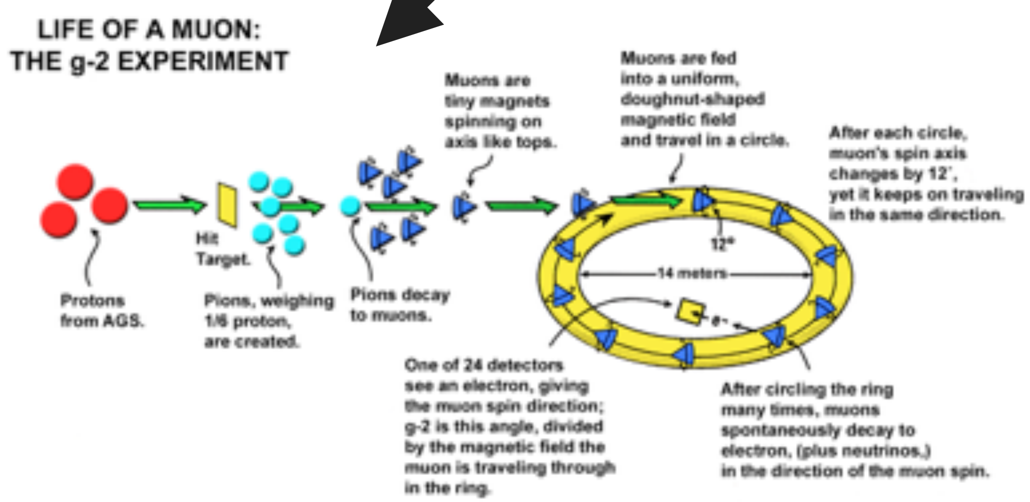


from E821 muon g-2 Home Page

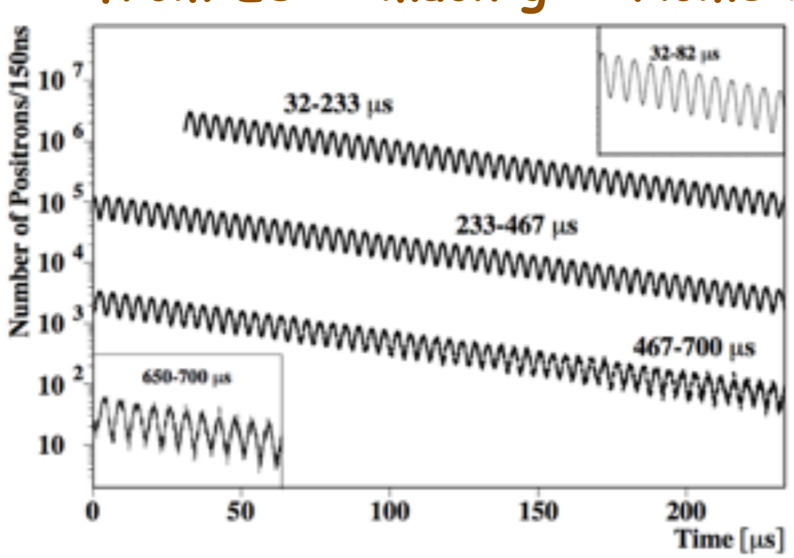
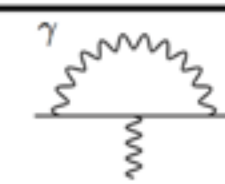
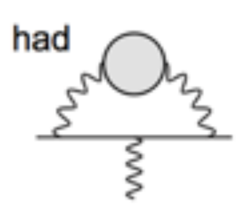
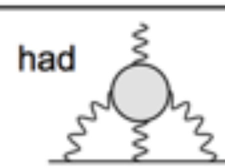


FIG. 3. Positron time spectrum overlaid with the fitted 10 parameter function (χ^2/dof= 3818/3799). The total event sample of 0.95×10^9 e^+ with $E \geq 2.0$ GeV is shown.

from hep-ph/0102017

Standard Model Prediction

Exp (E821)		116 592 089	(63) [10^{-11}]	
QED (α^5, Rb)		116 584 718.951	(0.080)	
EW (W/Z/H_{SM}, NLO)		154.0	(1.0)	
Hadronic (leading)	[HLMNT]	6 949.1	(43)*	
	[DHMZ]	6 923	(42)	
Hadronic (α higher)		-98.4	(0.7)	
Hadronic (LbL)	[RdRV]	105	(26)*	
	[NJN]	116	(39)	

from Talk by M.Endo @Hokkaido Winter School 2013

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[M.Endo, KH, S.Iwamoto, T.Yoshinaga,
in preparation]

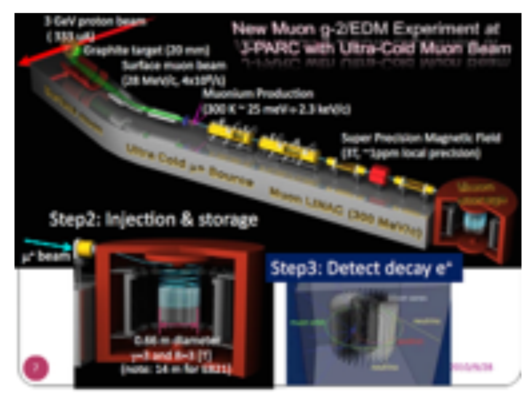
muon g-2

$$a_\mu^{\rm EXP} - a_\mu^{\rm SM} = (26.1 \pm 8.0) \cdot 10^{-10}$$

> 3 σ deviation !

New experiments also planned.

FermiLab Muon g-2



J-PARC g-2/EDM

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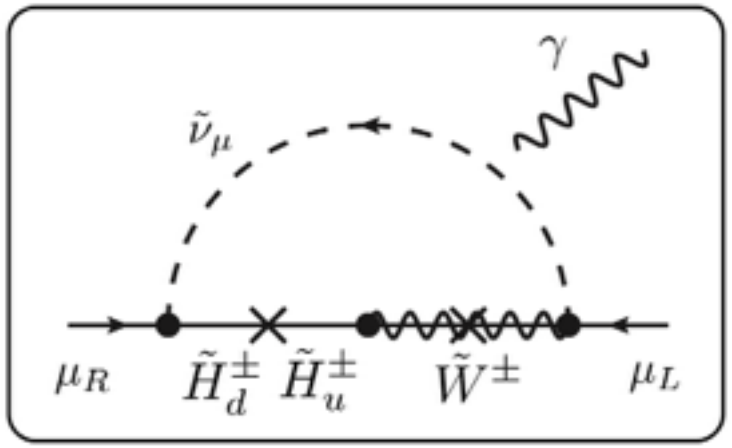
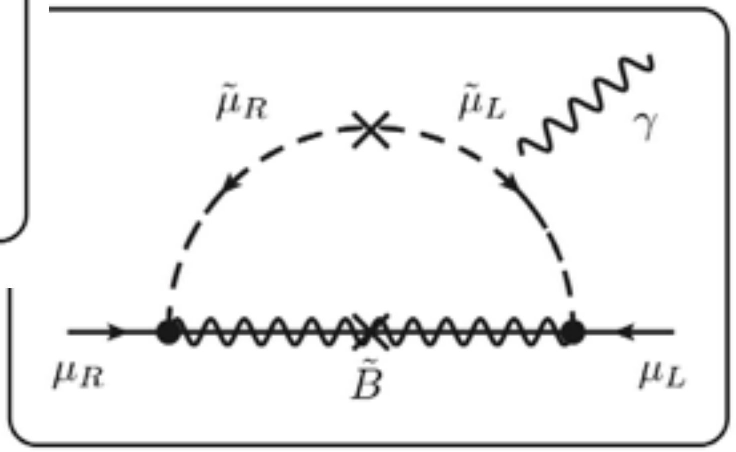
> 3 σ deviation !

...can be explained by SUSY.

chargino



neutralino



... if smuon and chargino/neutralino are O(100 GeV).

DM and g-2 in SUSY

[M.Endo, KH, S.Iwamoto, T.Yoshinaga, in preparation]

Idea: take slices of parameter space motivated by each physics (not scatter plot!) and study DM detection, LHC, ILC.....

DM

- pure Wino (≈ 3 TeV)
- pure Higgsino (≈ 1 TeV)
- Bino-slepton coann.
- h/Z-resonant Bino
- .....
- ......

X

g-2

$$\Delta a_\mu(\tilde{W}, \tilde{H}, \tilde{\nu}_\mu) = \frac{\alpha_2}{4\pi} \frac{m_\mu^2}{M_2 \mu} \tan\beta \cdot f_C\left(\frac{M_2^2}{m_{\tilde{\nu}}^2}, \frac{\mu^2}{m_{\tilde{\nu}}^2}\right),$$

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DM and g-2 in SUSY

[M.Endo, KH, S.Iwamoto, T.Yoshinaga,
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$$f_N(x,y) = xy\left[\frac{-3+x+y+xy}{(x-1)^2(y-1)^2} + \frac{2x\log x}{(x-y)(x-1)^3} - \frac{2y\log y}{(x-y)(y-1)^3}\right]$$

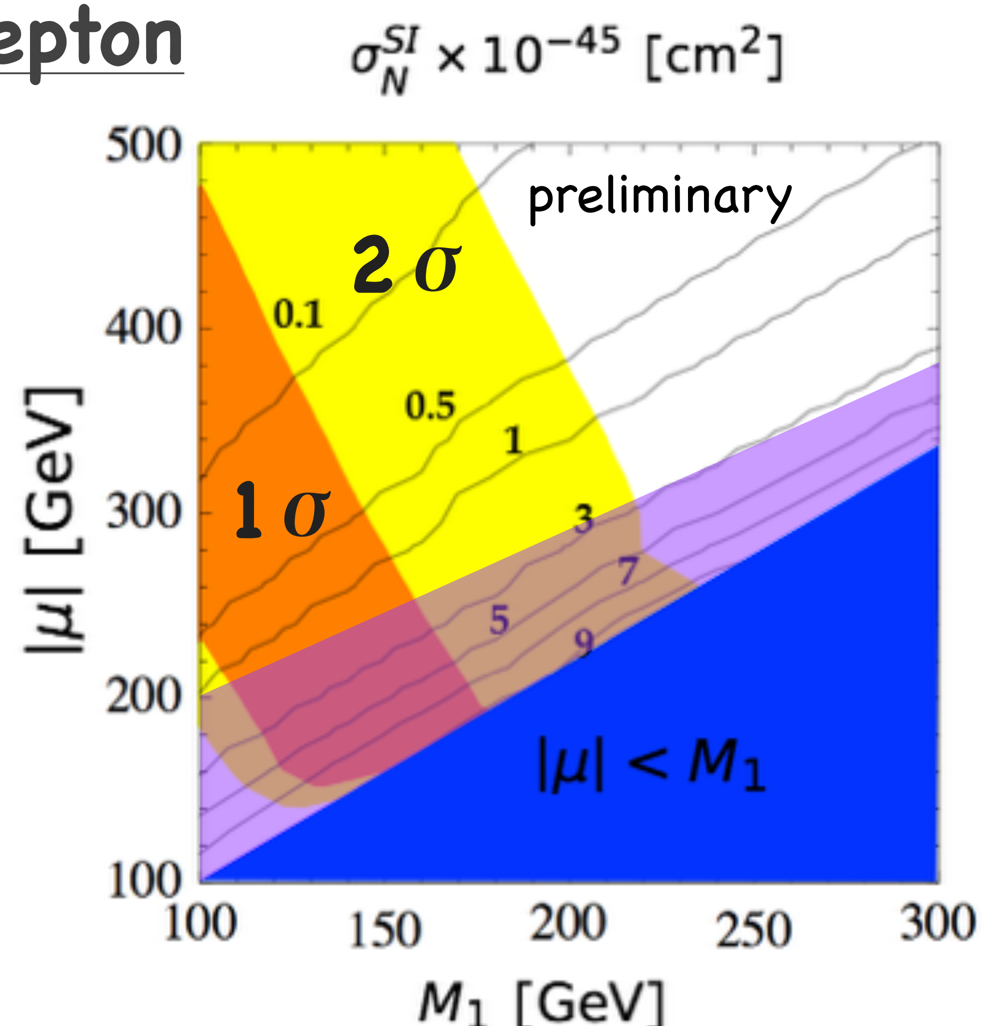
[M.Endo, KH, S.Iwamoto, T.Yoshinaga, in preparation]

DM and g-2 in SUSY

Idea: take slices of parameter space motivated by each physics (not scatter plot!) and study DM detection, LHC, ILC.....

For example,...

coannihilation with slepton



(Fig. from Talk by T.Yoshinaga at JPS meeting March 2014.)

$\tan\beta = 40$

DM and g-2 in SUSY

[M.Endo, KH, S.Iwamoto, T.Yoshinaga,
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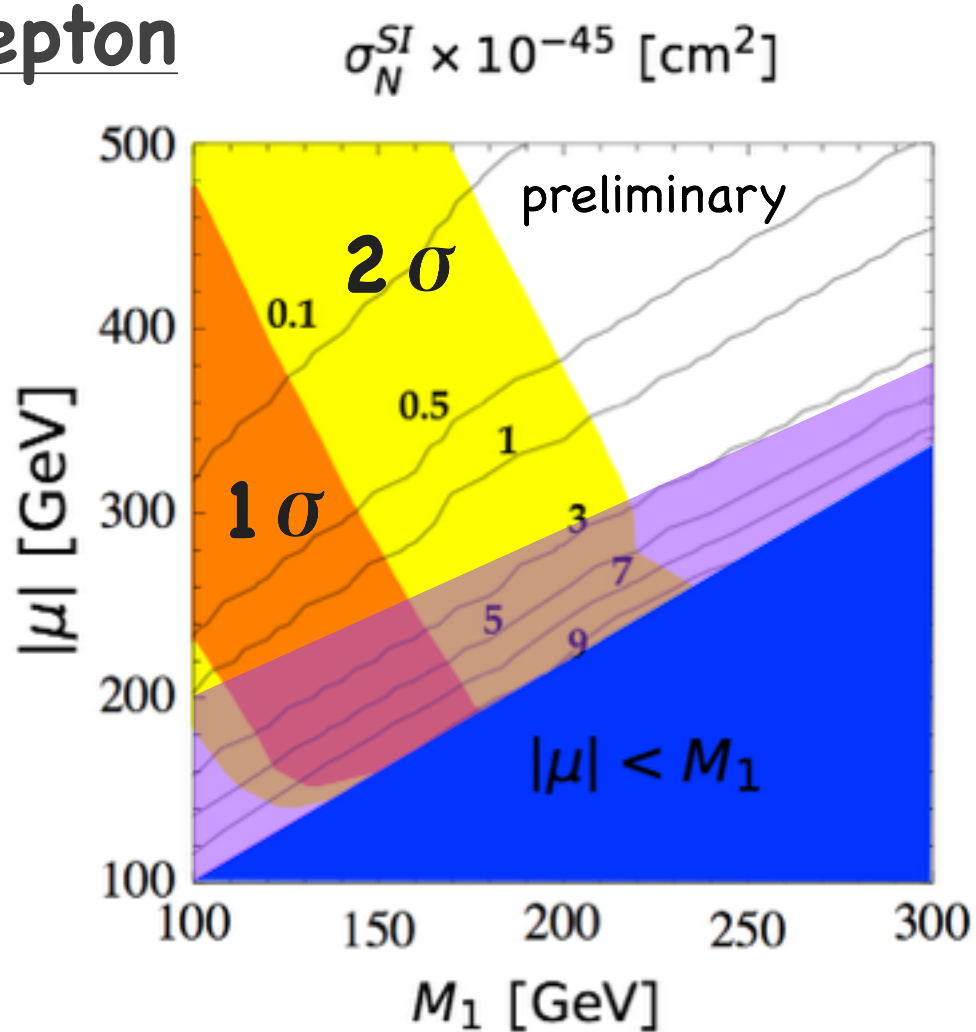

By adjusting m(slepton_R),

$\Omega_{thermal} = \Omega_{CDM}$

in all region of M1 < $|\mu|$.

Typically m(slepton)-m(Bino) = a few GeV.

(Fig. from Talk by T.Yoshinaga at JPS meeting March 2014.)

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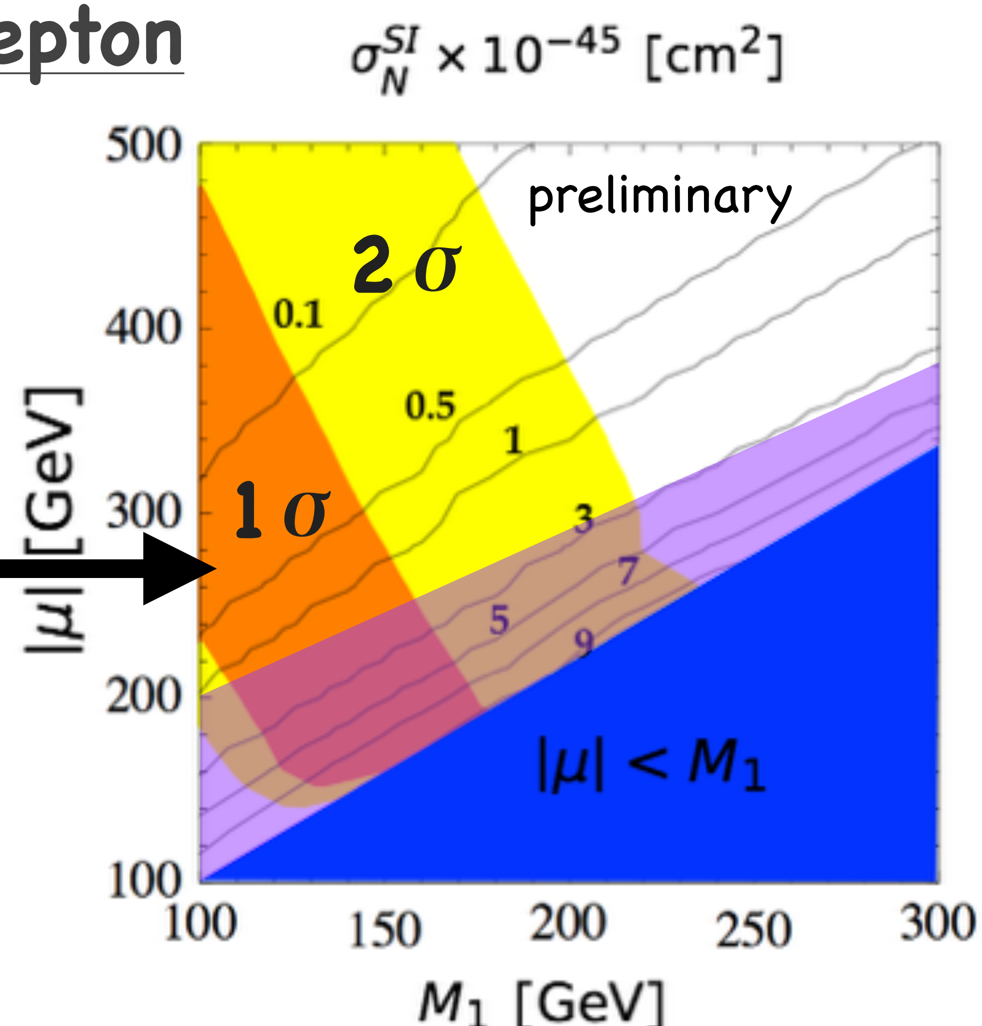
g_μ-2



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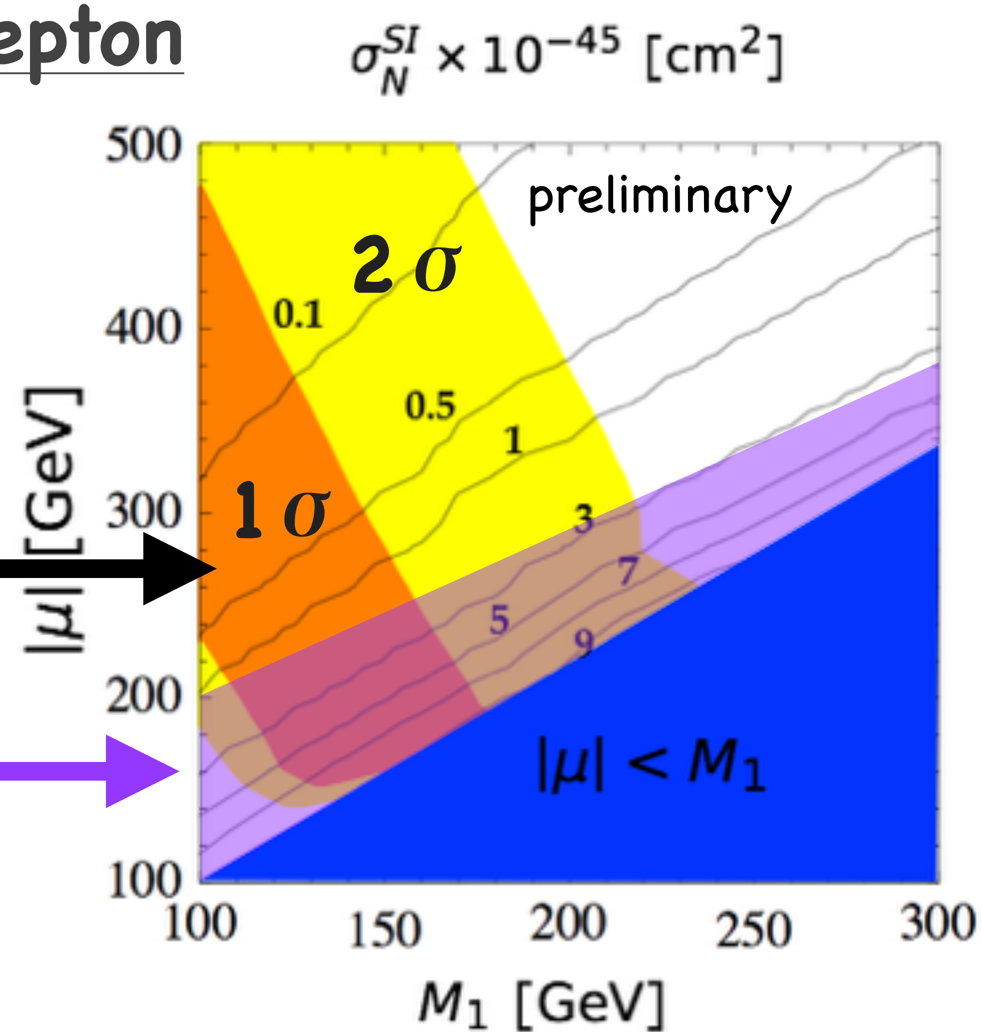

g_μ-2

LUX 85 days bound

(NOTE! rough estimate!!)

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$\Omega_{thermal} = \Omega_{CDM}$

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[M.Endo, KH, S.Iwamoto, T.Yoshinaga,
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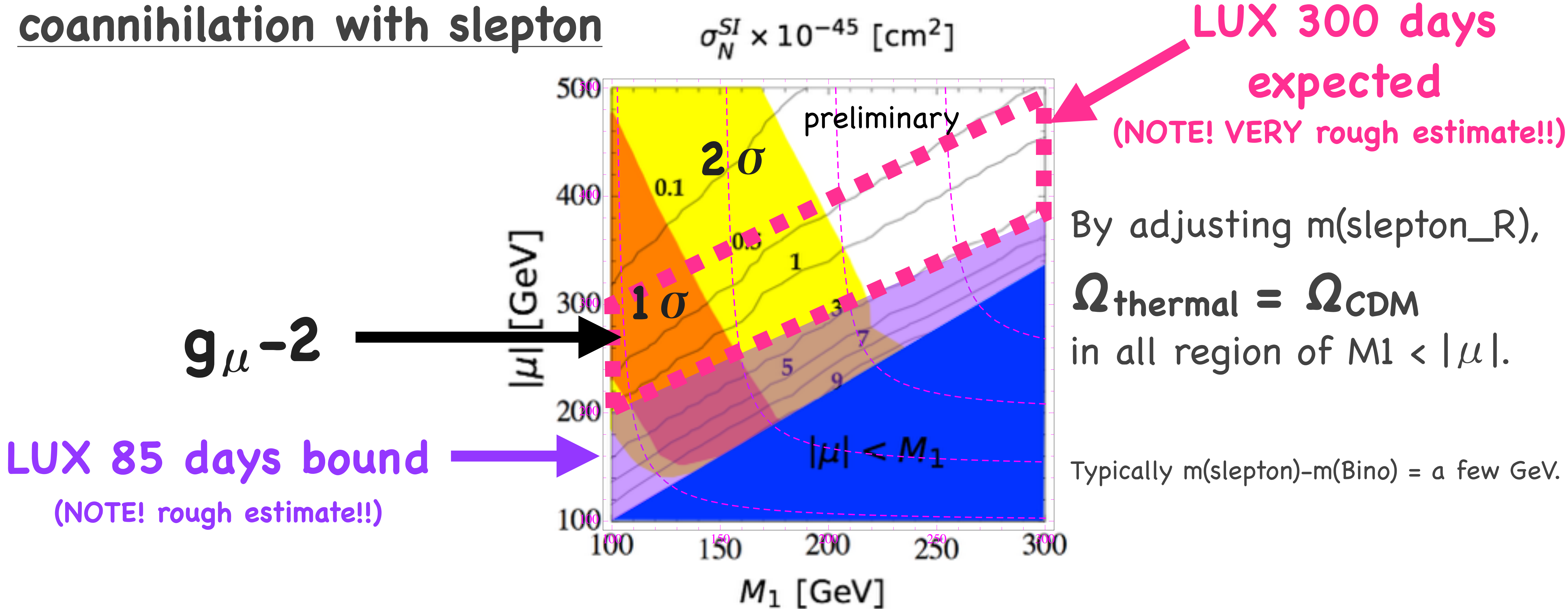
For example,...

coannihilation with slepton



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DM and g-2 in SUSY

[M.Endo, KH, S.Iwamoto, T.Yoshinaga,
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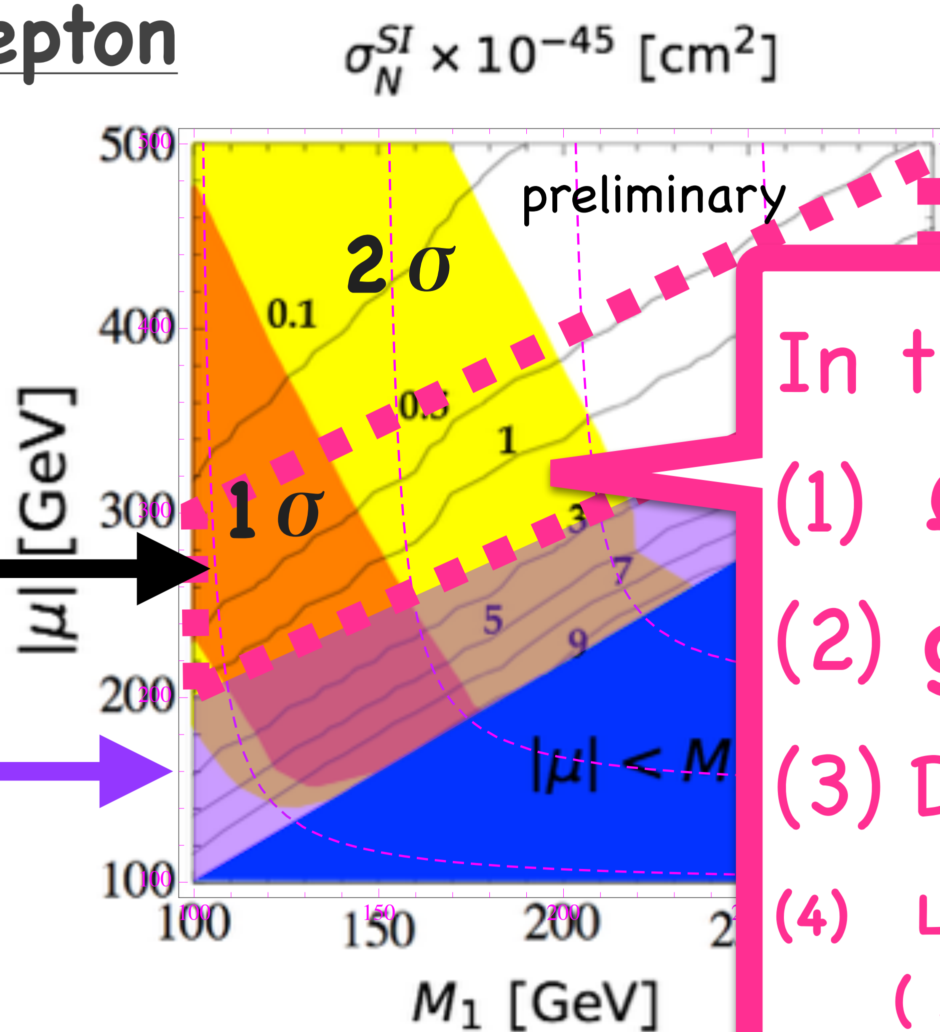
For example,...

coannihilation with slepton



LUX 300 days expected
(NOTE! VERY rough estimate!!)

g_μ-2

LUX 85 days bound
(NOTE! rough estimate!!)

In this region,

(1) $\Omega_{\rm thermal} = \Omega_{\rm CDM}$,

(2) g_μ-2 explained, and

(3) DM will be detected!

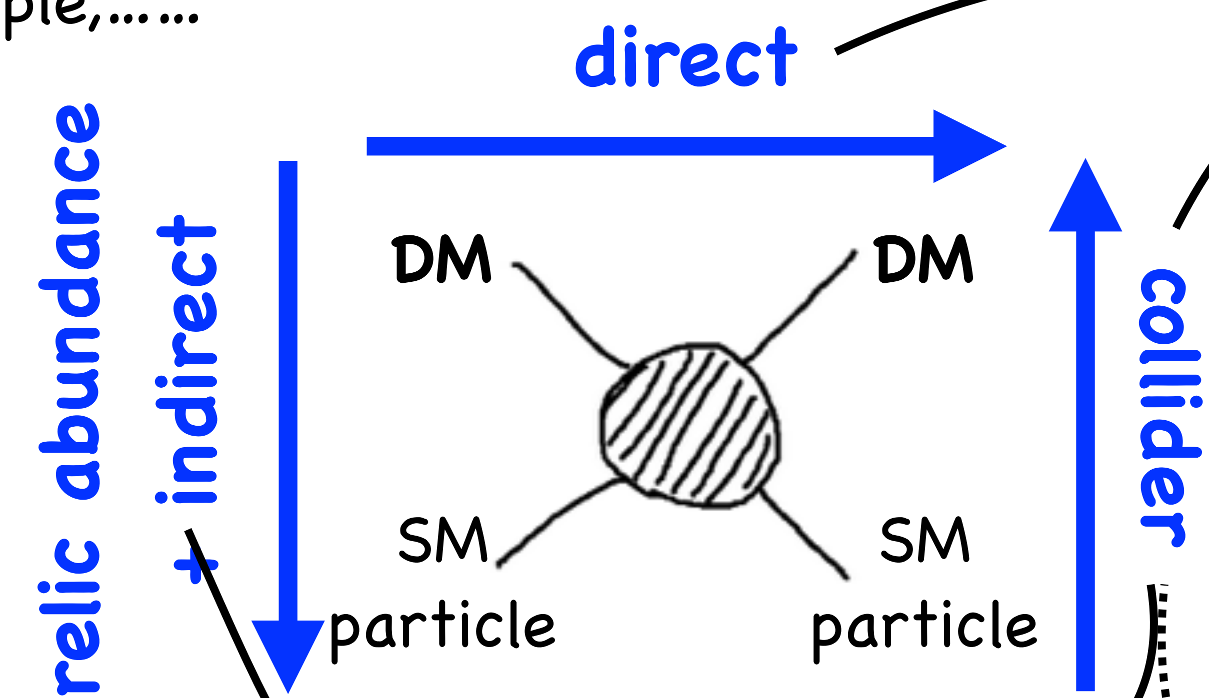
(4) LHC search — work in progress
(by WZ/Wh + ETmiss)

(Fig. from Talk by T.Yoshinaga at JPS meeting March 2014.)

Summary

- Higgs mass 126 GeV has a significant impact on SUSY.
- It may imply (some of) SUSY particles are (much) heavier than TeV scale...
- SUSY DM is still interesting, and testable in many ways!

For example,......



- **Bino-like DM**

+ Higgsino (+ slepton)
is an attractive scenario,

- can explain $\Omega_{thermal} = \Omega_{CDM}$,
  (and muon g-2.)
- can be tested by LHC /ILC
  as well as direct detection!

- **Wino DM may be seen in various ways.**

If mass < 3 TeV, **non-thermal production** is necessary.
(**Q-ball decay** is an interesting and viable options.)

- **gravitino DM + stau NLSP**

may be tested at 14 TeV LHC.