

One-loop Corrections to the Spin-independent Blind Spot

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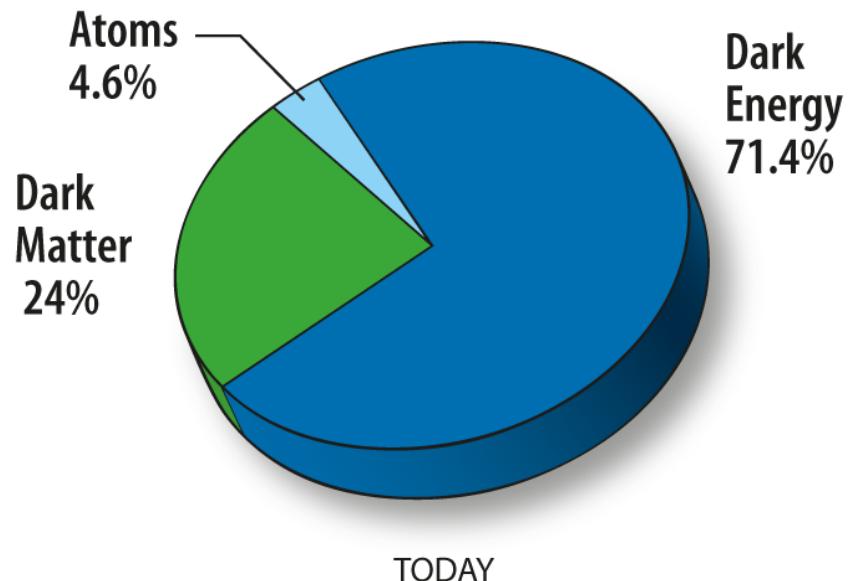
SI 2018

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- Introduction
- Direct detection
- Singlet-doublet model
- One-loop corrections results

Introduction

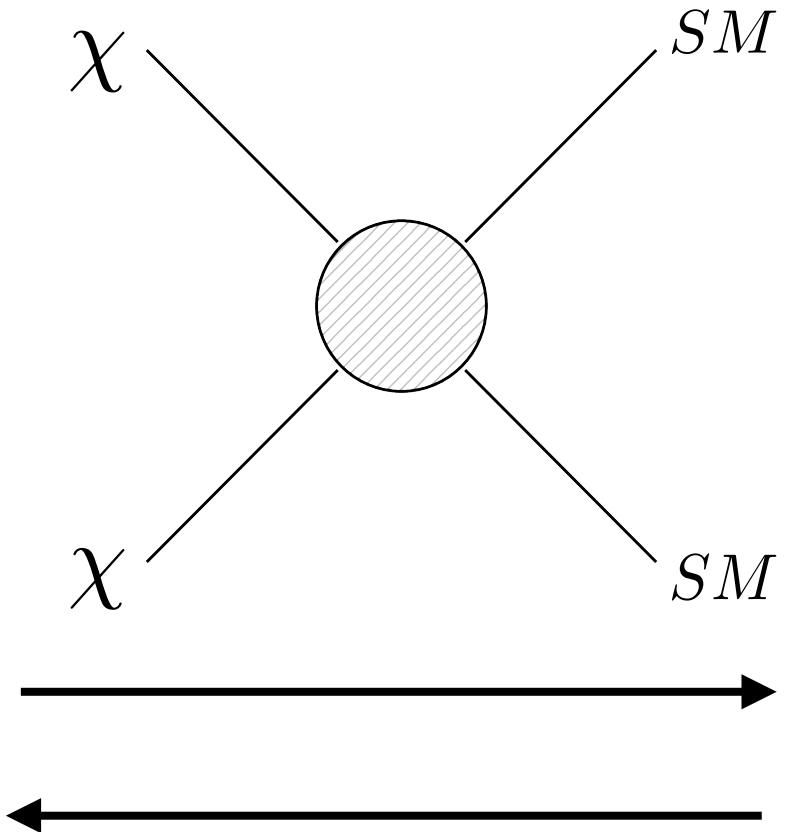


Assumptions about dark matter production

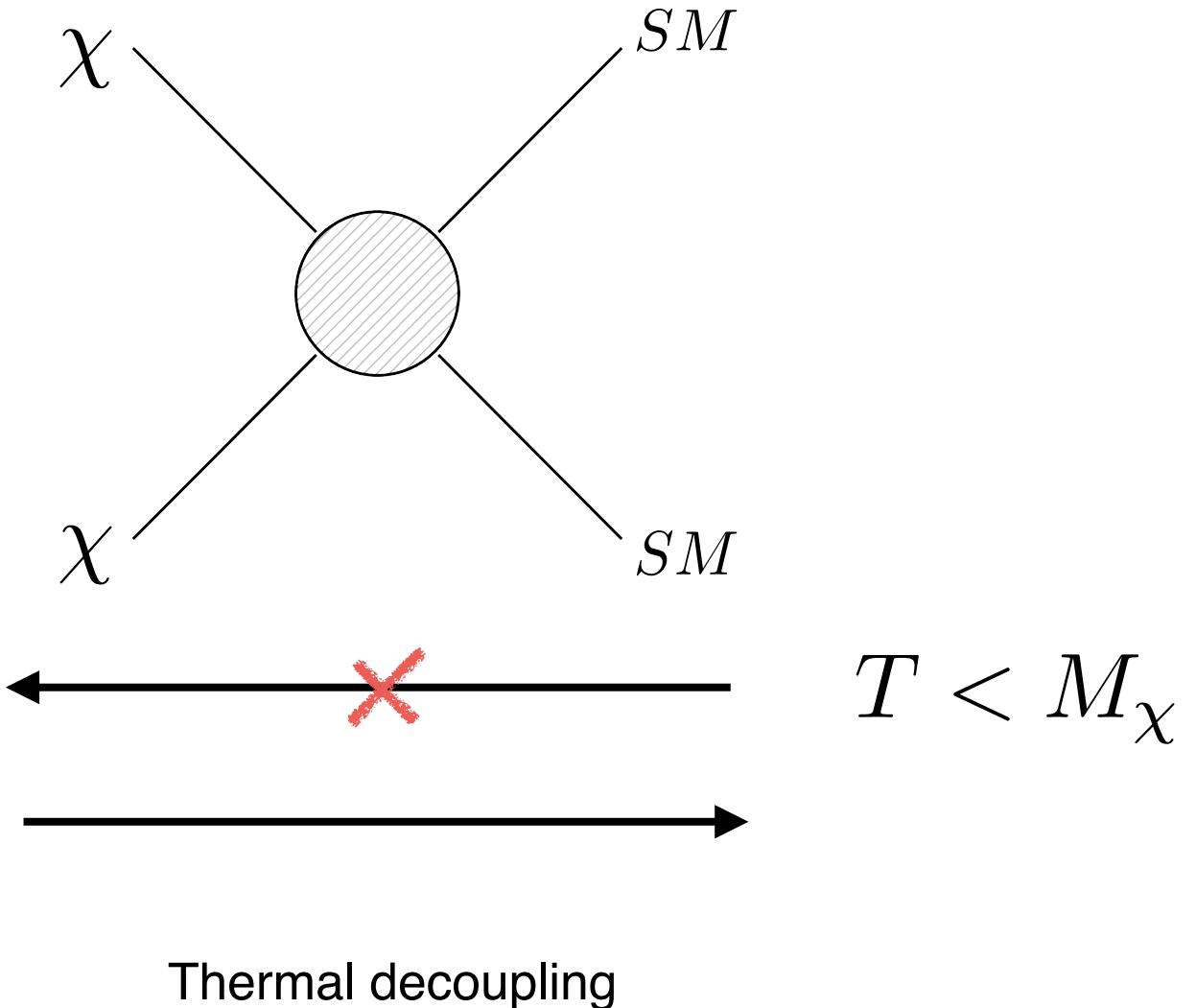
- Dark matter is produced from thermal bath.
- The observed relic density is determined by the freeze-out and expansion of the Universe

Introduction

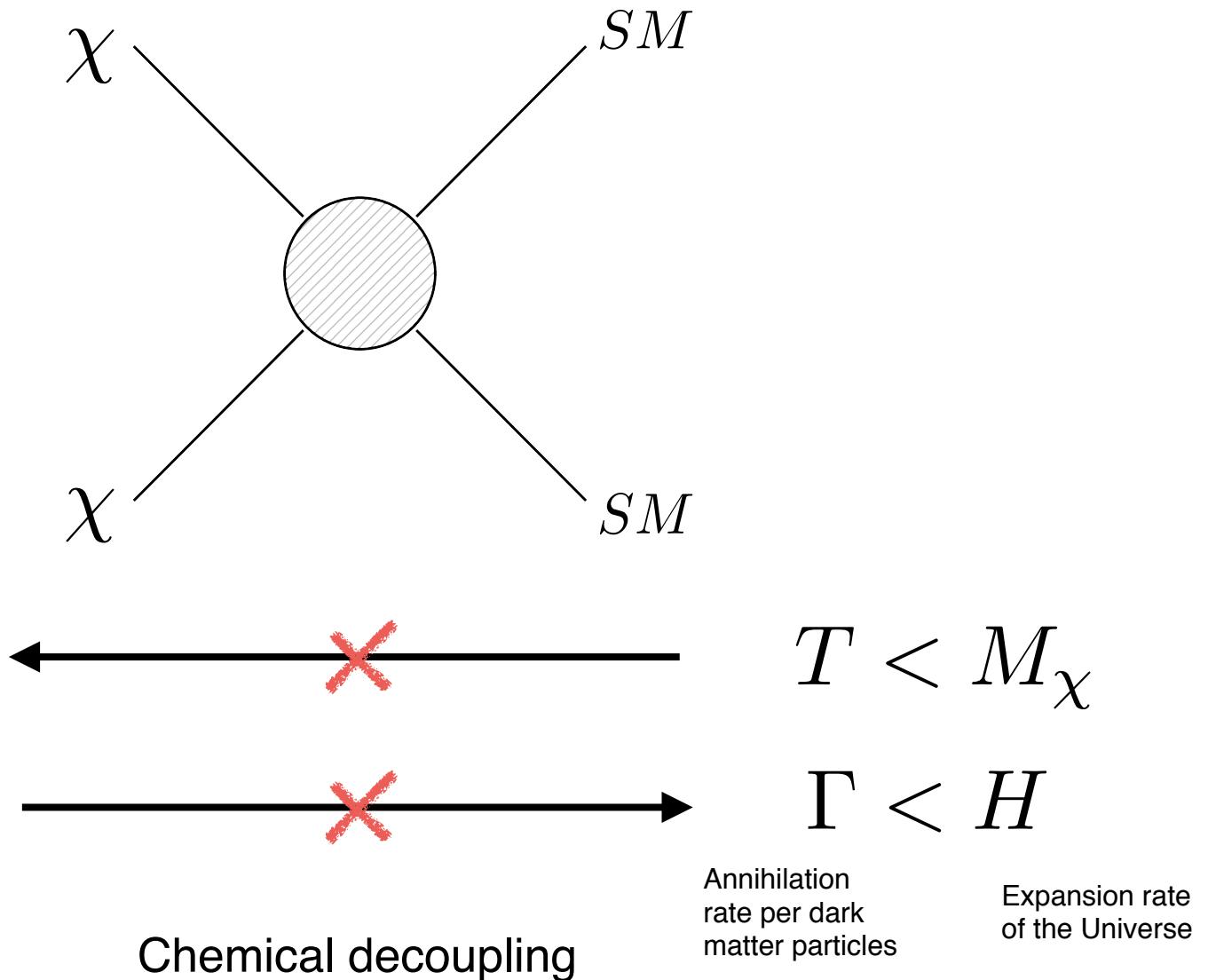
Initially, Universe is dense and hot



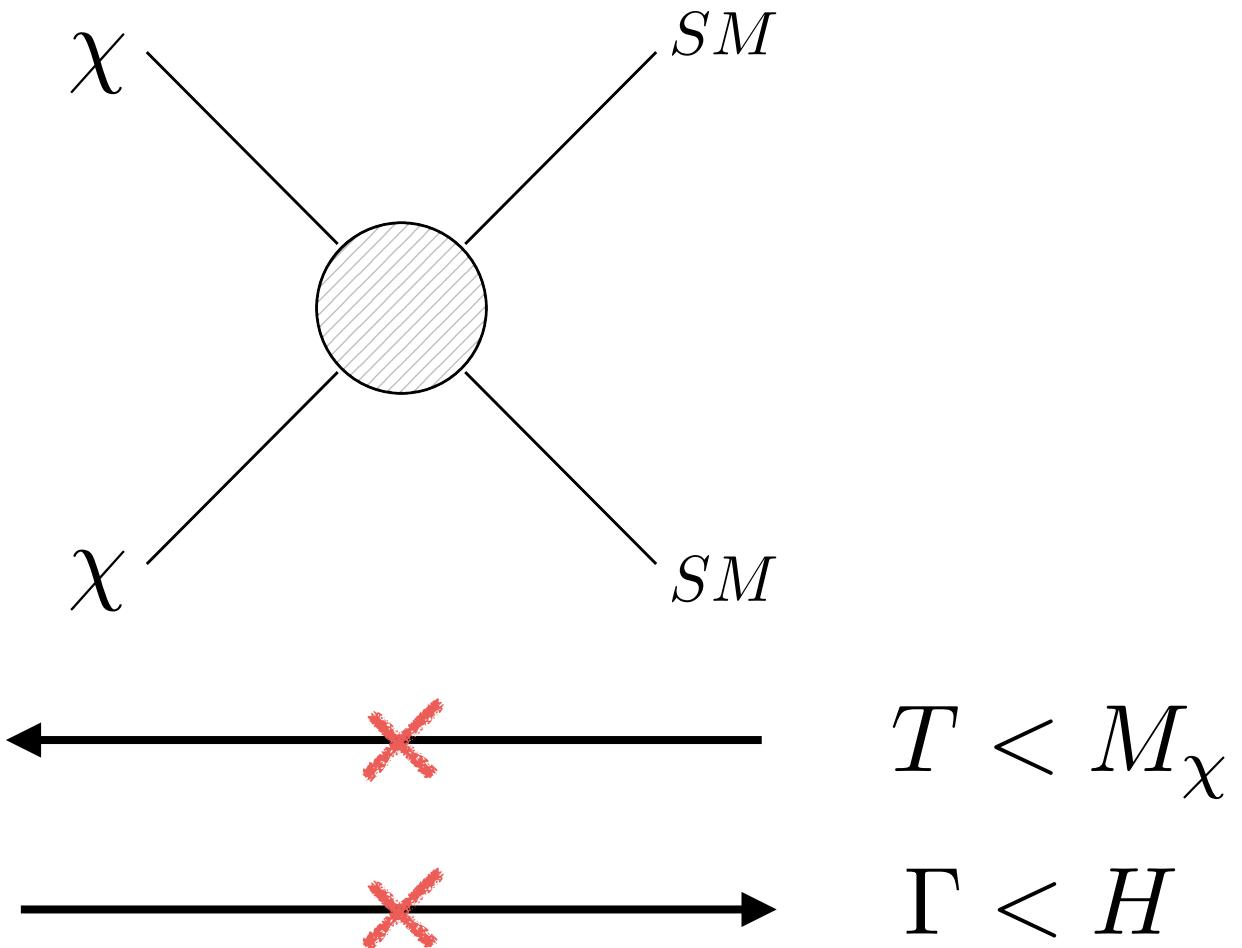
Introduction



Introduction

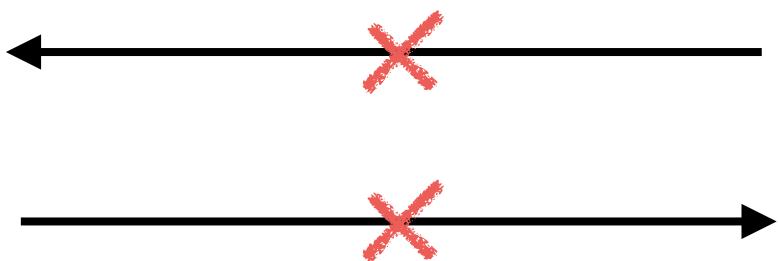
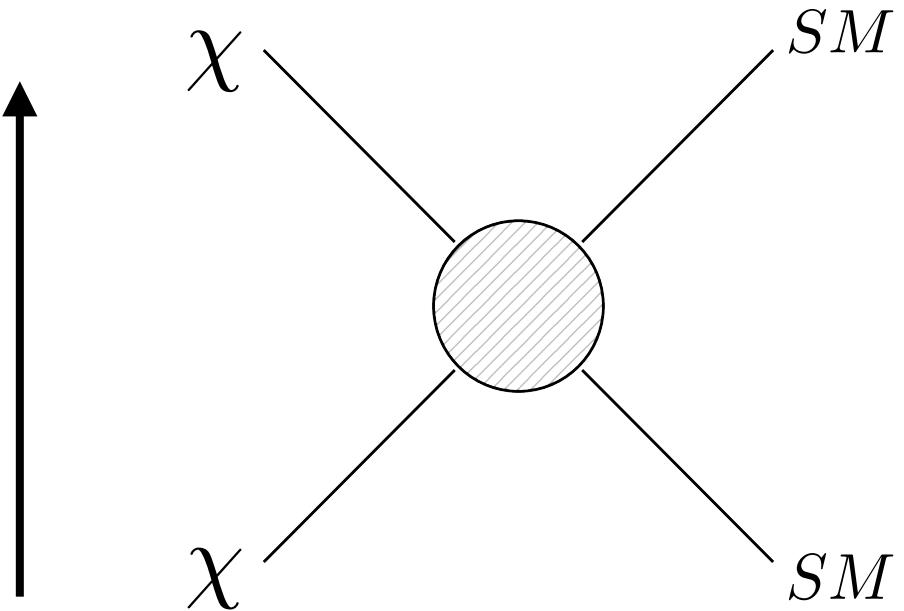


Introduction



WIMP miracle

Introduction



$$T < M_\chi$$

$$\Gamma < H$$

Kinetic coupling

Direct detection

The most relevant operator for spin-independent interaction at hadronic scale is

$$L_{eff} = \sum_{q=u,d,s} f_q O_q + f_G O_G$$

$$O^q \equiv \bar{\chi}\chi m_q \bar{q}q \quad O^g \equiv \bar{\chi}\chi \frac{\alpha_s}{\pi} G_{\mu\nu}^A G^{A\mu\nu}$$

Evaluate those operators in nucleon states

$$f_{Tu}^P = 0.0153$$

$$f_{Td}^P = 0.0191$$

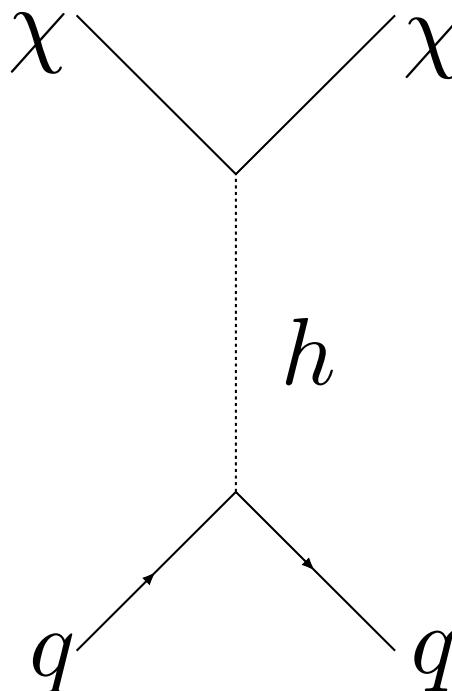
$$f_{Ts}^P = 0.0447$$

$$L_{eff} = f_N \bar{\chi}\chi \bar{N}N$$

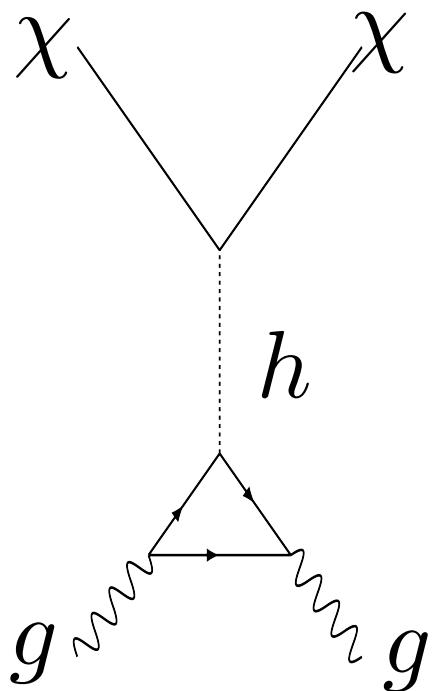
$$f_N/M_N = \sum_{q=u,d,s} f_q f_{Tq}^N - \frac{8}{9} f_G f_{TG}^N$$

$$f_{TG}^P = 1 - \sum_{q=u,d,s} f_{Td}^P = 0.9209$$

Direct detection



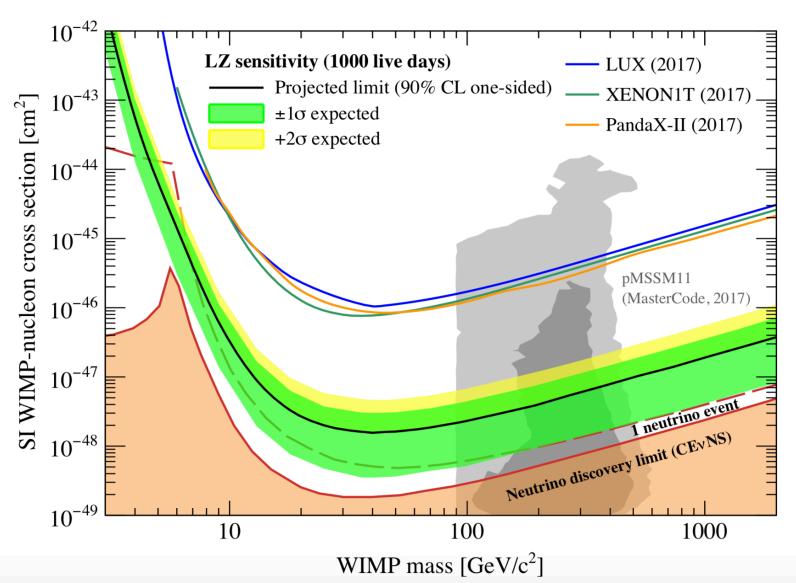
$$L_{int} = C_{h\chi\chi} h \bar{\chi} \chi$$



$$f_N/M_N = -\frac{C_{h\chi\chi}}{v m_h^2} \left[\sum_{q=u,d,s} f_{Tq}^N + \frac{2}{9} f_{TG}^N \right]$$

$$\sigma_{SI}^P = \frac{4m_r^2}{\pi} f_P^2 \approx 2 \times 10^{-42} \text{cm}^2 C_{h\chi\chi}^2$$

Direct detection



arXiv:1802.06039

Tree-level spin-independent blind spot $C_{h\chi\chi}^{(0)} = 0$

Such scenarios have been studied at tree level in many models

- arXiv: 1211.4873 C. Cheung, L. Hall, D. Pinner
- arXiv: 1612.0238 T. Han, F. Kling, S. Su, Y. Wu
- arXiv: 1603.07387 S. banerjee, S. matsumoto, K. Mukaida, Y. Tsai
- arXiv: 1404.0392 P. Huang, C. Wagner
- ...

One-loop corrections become dominant in such region

Singlet-doublet model

The SM is supplemented by a Majorana fermion singlet χ_s

and two fermion doublets $\chi_{D1} = \begin{pmatrix} \chi_1^+ \\ \chi_1^0 \end{pmatrix}$ $\chi_{D2} = \begin{pmatrix} \chi_2^0 \\ \chi_2^- \end{pmatrix}$

$$L_Y = -[\frac{1}{2}M_s\chi_s\chi_s + M_D\chi_{D1} \cdot \chi_{D2} - y_1\chi_s\chi_{D1} \cdot \tilde{H} - y_2\chi_s\chi_{D2} \cdot H + h.c.]$$

Mass matrix in the basis $\chi = \{\chi_s, \chi_1^0, -\chi_2^0\}$

$$M_N = \begin{pmatrix} M_s & \frac{y \sin \beta v}{\sqrt{2}} & \frac{y \cos \beta v}{\sqrt{2}} \\ \frac{y \sin \beta v}{\sqrt{2}} & 0 & M_D \\ \frac{y \cos \beta v}{\sqrt{2}} & M_D & 0 \end{pmatrix}$$

$M_s > 0, y > 0, \beta \in (0, \frac{\pi}{2})$
 M_D can be positive or negative

Singlet-doublet model

Assume the mass of lightest mass eigenstate is M_1

$$Det[M_N - M_1] = 0 \longrightarrow C_{h\chi\chi}^{(0)} = \frac{1}{2} \frac{\partial M_1(v)}{\partial v}$$

$$= \frac{y^2 v (M_D \sin 2\beta + M_1)}{6M_1^2 - 4M_s M_1 - 2M_D^2 - y^2 v^2}$$

Tree-level blind spot condition $M_D \sin 2\beta + M_1 = 0$

If the coupling is zero, lightest neutral particle's mass cannot get contributions from electroweak symmetry breaking. The physical mass has to be M_s or $-M_D$

Case A $M_1 = M_s$: $-M_D > M_s$ $\sin 2\beta = M_s / (-M_D)$

Case B $M_1 = -M_D$: $-M_D < (M_s + \sqrt{M_s^2 + (yv)^2})/2$ $\tan \beta = 1$

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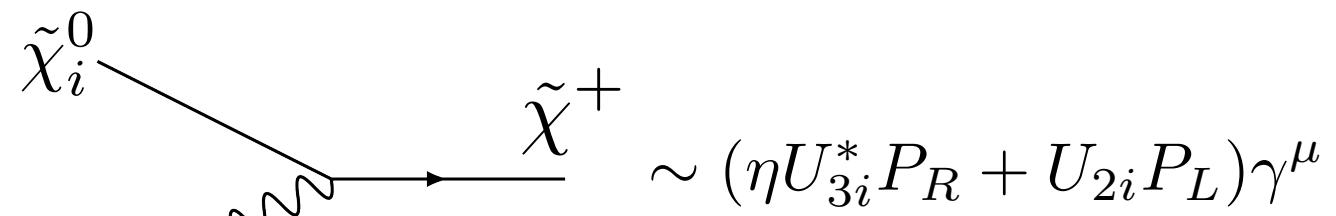
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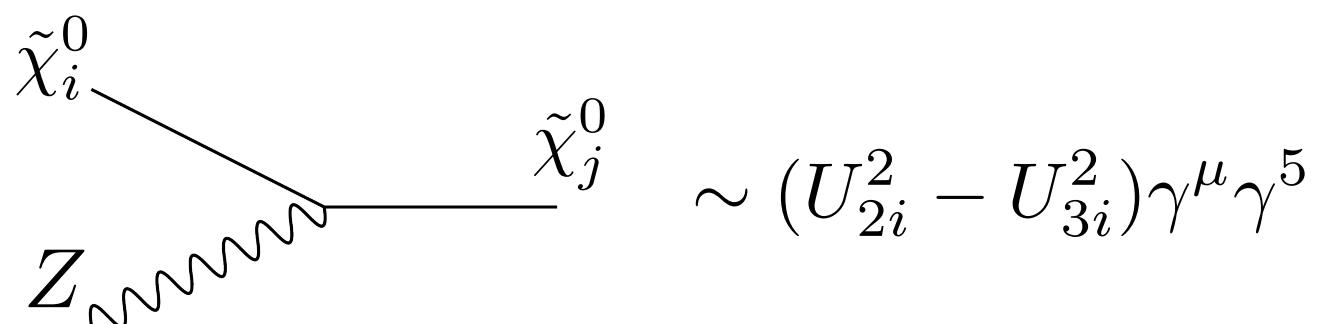
Singlet-doublet model

Gauge couplings

$$L_{kin} = \tilde{\chi}_s^+ i D_\mu \sigma_-^\mu \tilde{\chi}_s + \tilde{\chi}_{D1}^+ i D_\mu \sigma_-^\mu \tilde{\chi}_{D1} + \tilde{\chi}_{D2}^+ i D_\mu \sigma_-^\mu \tilde{\chi}_{D2}$$



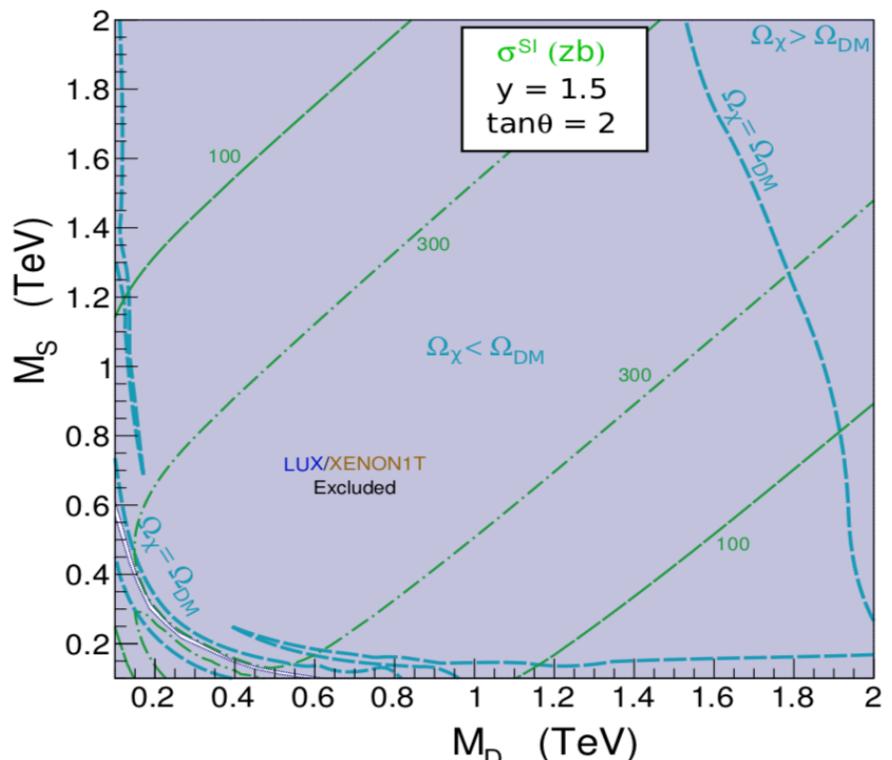
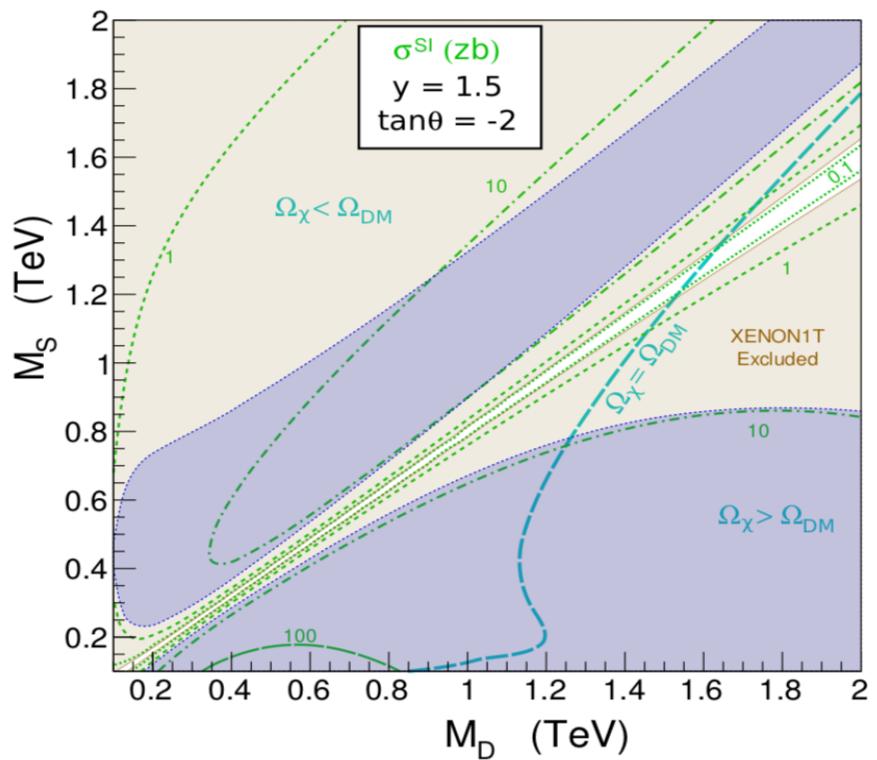
$$\sim (\eta U_{3i}^* P_R + U_{2i} P_L) \gamma^\mu$$



$$\sim (U_{2i}^2 - U_{3i}^2) \gamma^\mu \gamma^5$$

Singlet-doublet model

Tree-level blind spots

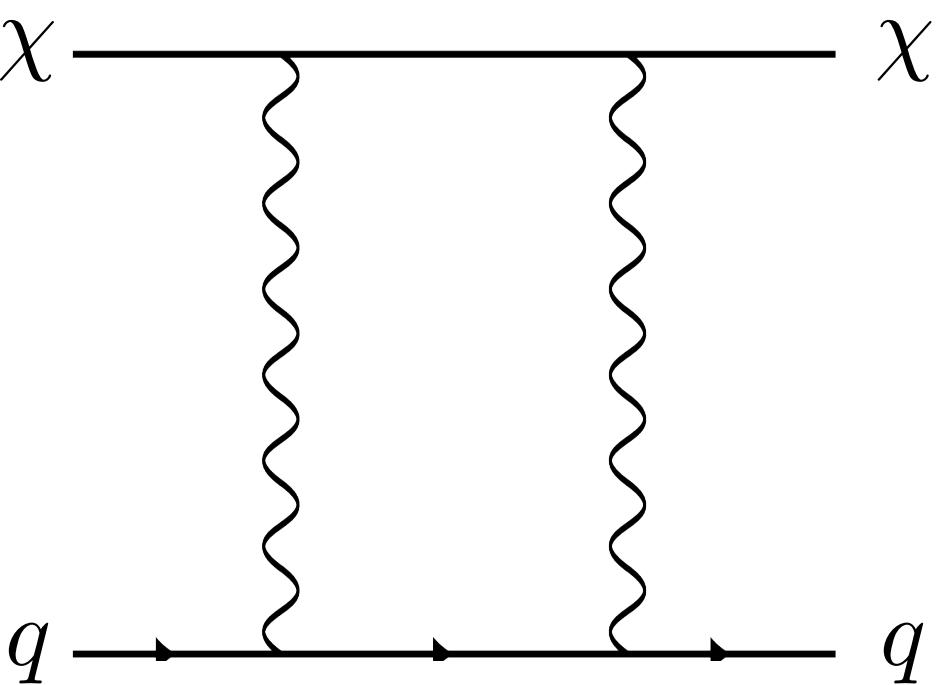
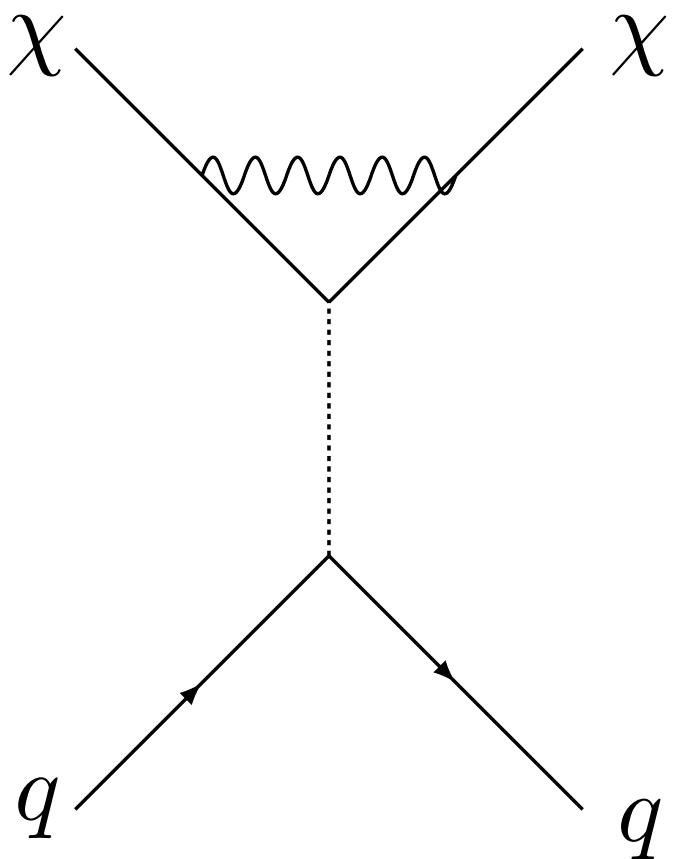


arXiv: 1311.5896 C. Cheung, D. Sanford

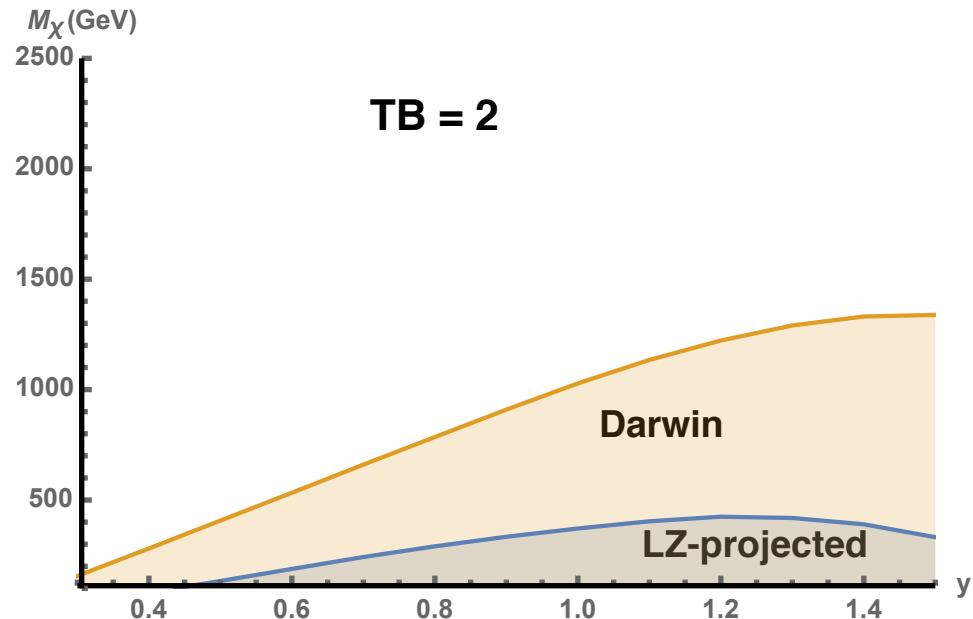
One-loop corrections

$$\sigma_{SI}^N = \frac{4m_r^2}{\pi} (f_N^{(0)} + f_N^{(1)})^2$$

One-loop corrections diagrams

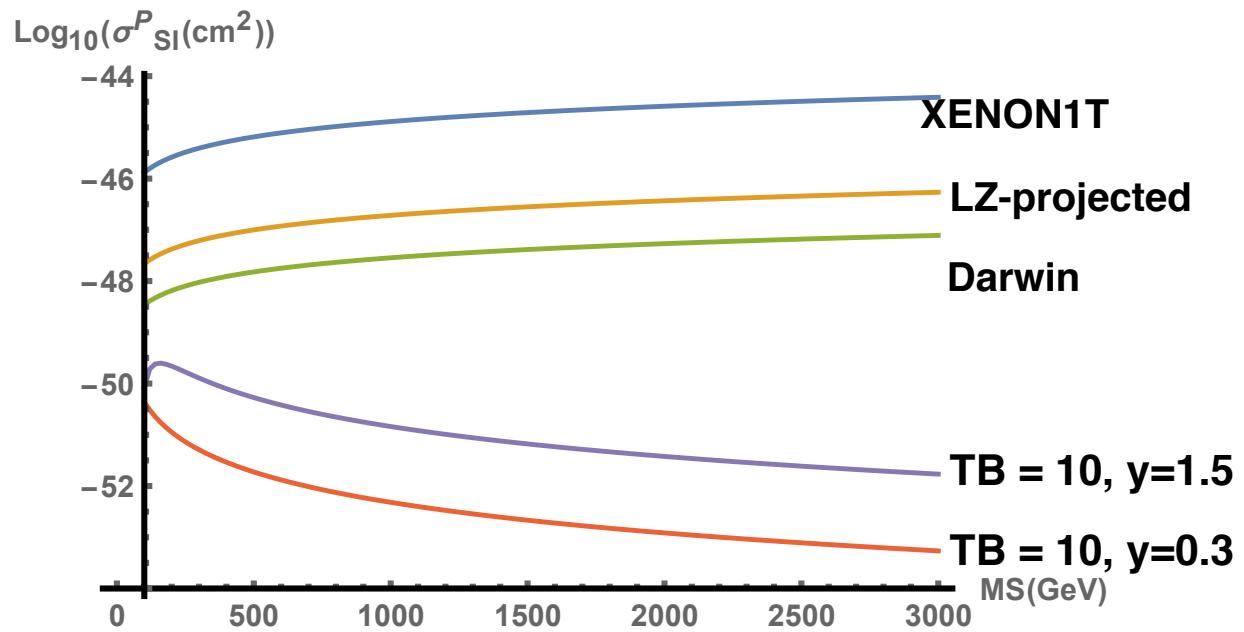


One-loop corrections



M_D is fixed by using blind spot conditions

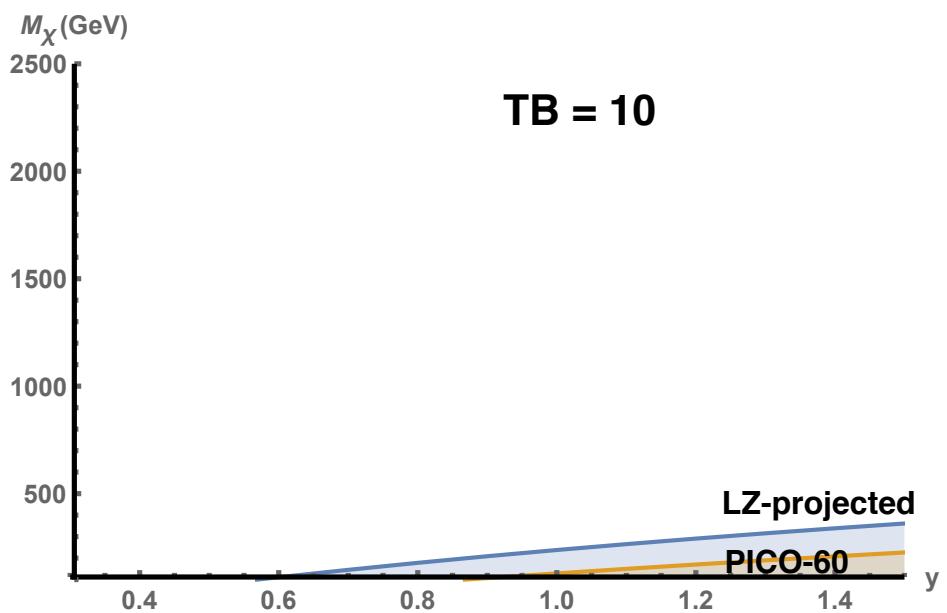
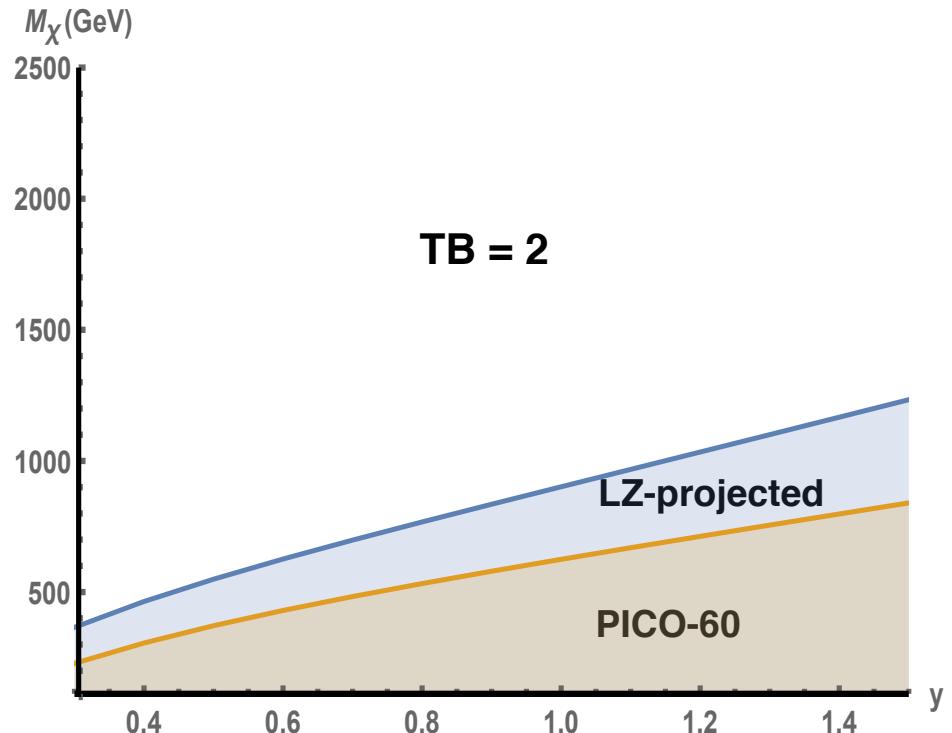
LZ projected can reach up to ~ 400 GeV
 Darwin can reach up to ~ 1.4 TeV



Larger TB and smaller y will be more difficult for direct detection

Spin-dependent scattering

SD cross section at tree-level blind spot



Complementary searches: arXiv: 1612.0238 T. Han, F. Kling, S. Su, Y. Wu

One-loop corrections

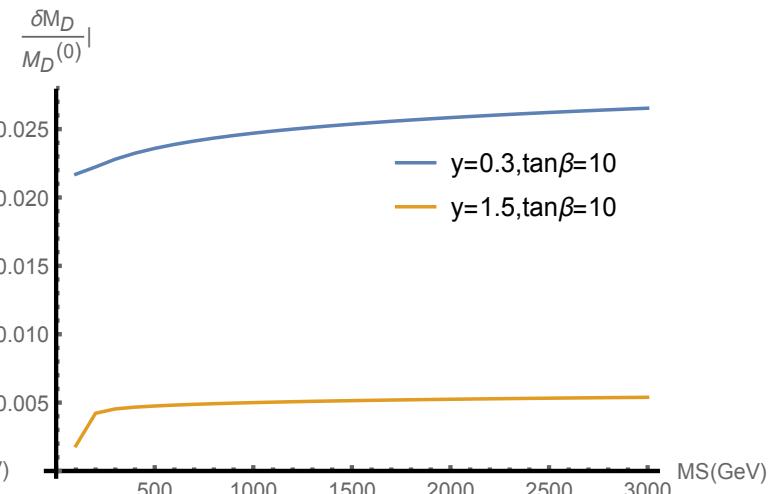
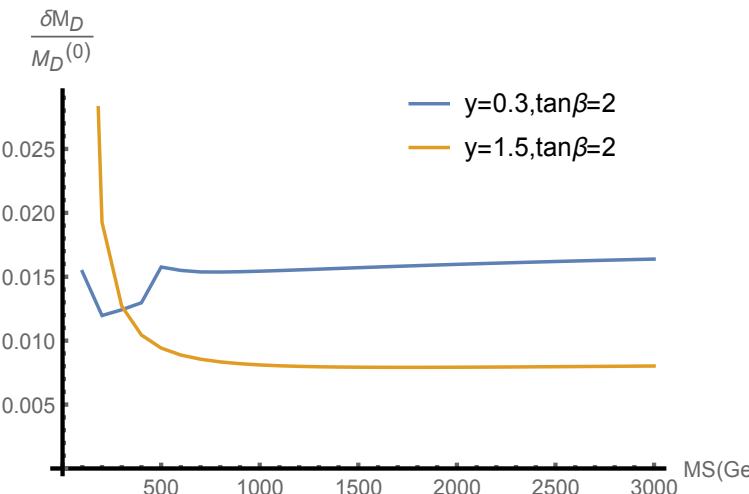
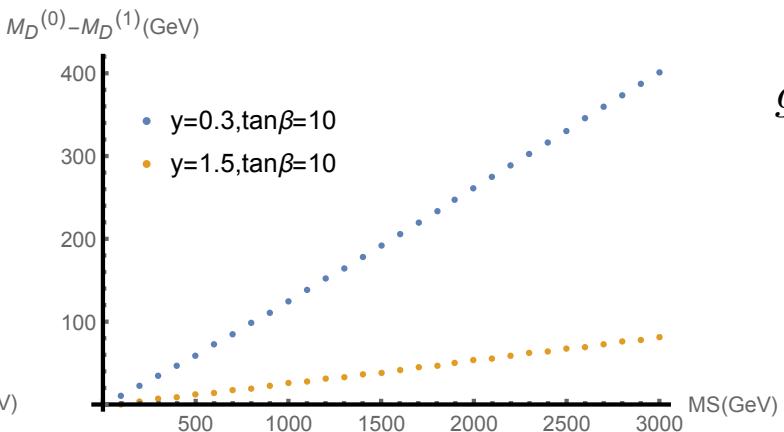
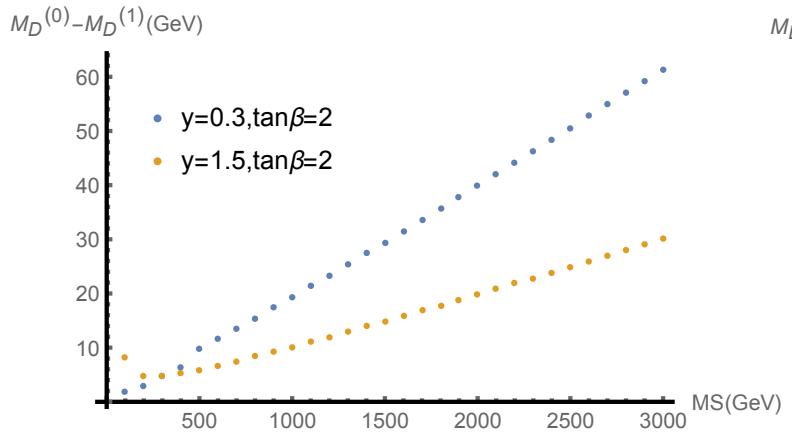
Shift of blind spots

$$-M_D^{(0)} = 1.25 * M_S$$

$$-M_D^{(0)} = 5.05 * M_S$$

$$g \propto yv^2(M_D \sin(2\beta) + M_1)$$

$$\delta g \propto yv^2 \frac{2tb}{1+tb^2} \delta M_D$$



larger TB and smaller y has bigger shift

Conclusions

- The singlet-doublet model is a generic model which can have blind spot.
- Tree-level coupling vanishes at the blind spot hence loop corrections become important.
- New blind spot will be shifted slightly after including one-loop corrections.
- At large TB or small value of y , singlet-doublet mixing is small. One-loop corrections of SI blind spot and SD scattering are both small.
- Direct detection cannot fully cover the parameter space near blind spot, thus need some complementary approaches, like indirect detections and collider searches.

Back-up slides

Back up

