One-loop Corrections to The Spin-independent Blind Spot

Hongkai Liu

University of Pittsburgh

With Tao Han, Satyanarayan Mukhopadhyay, and Xing Wang

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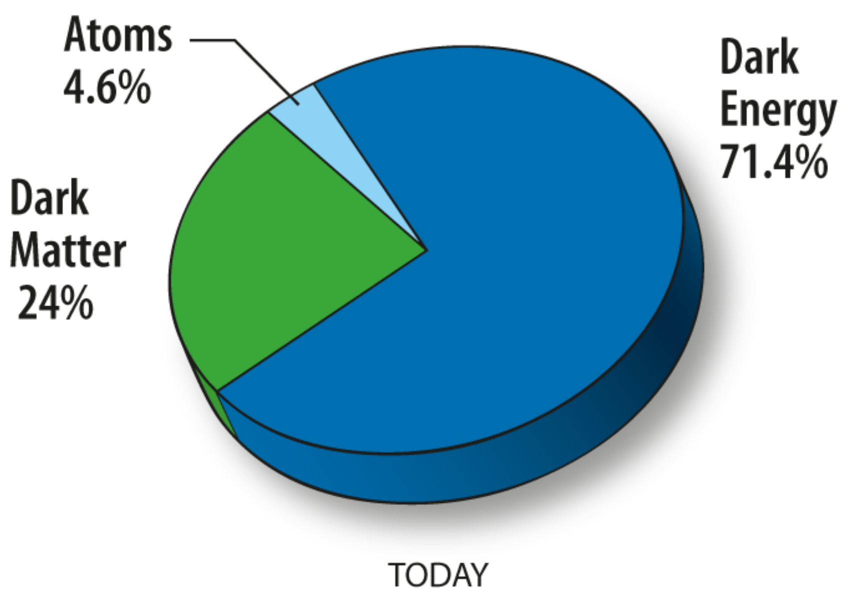
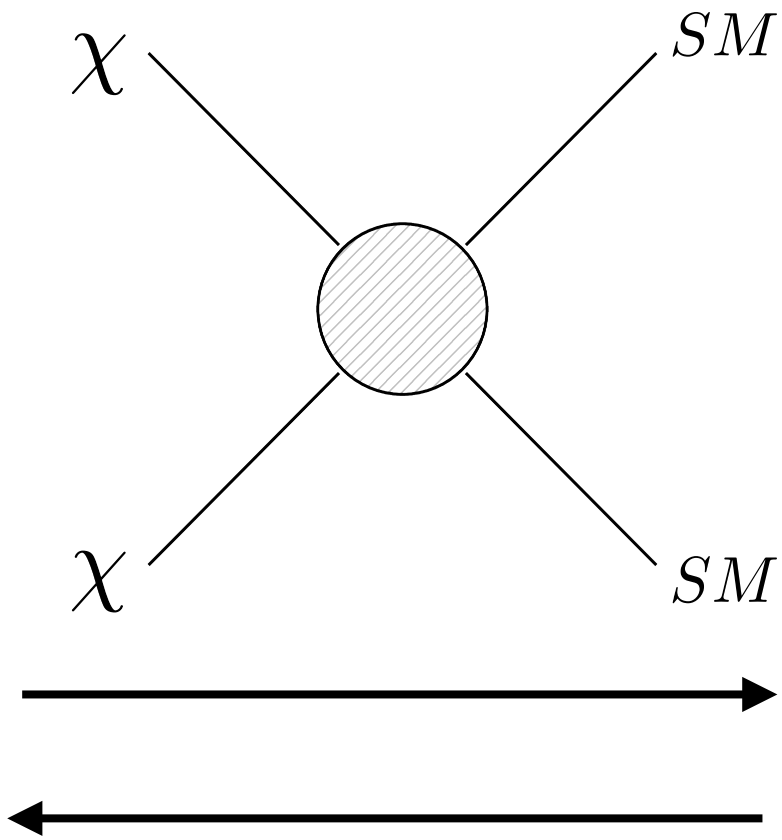
Introduction



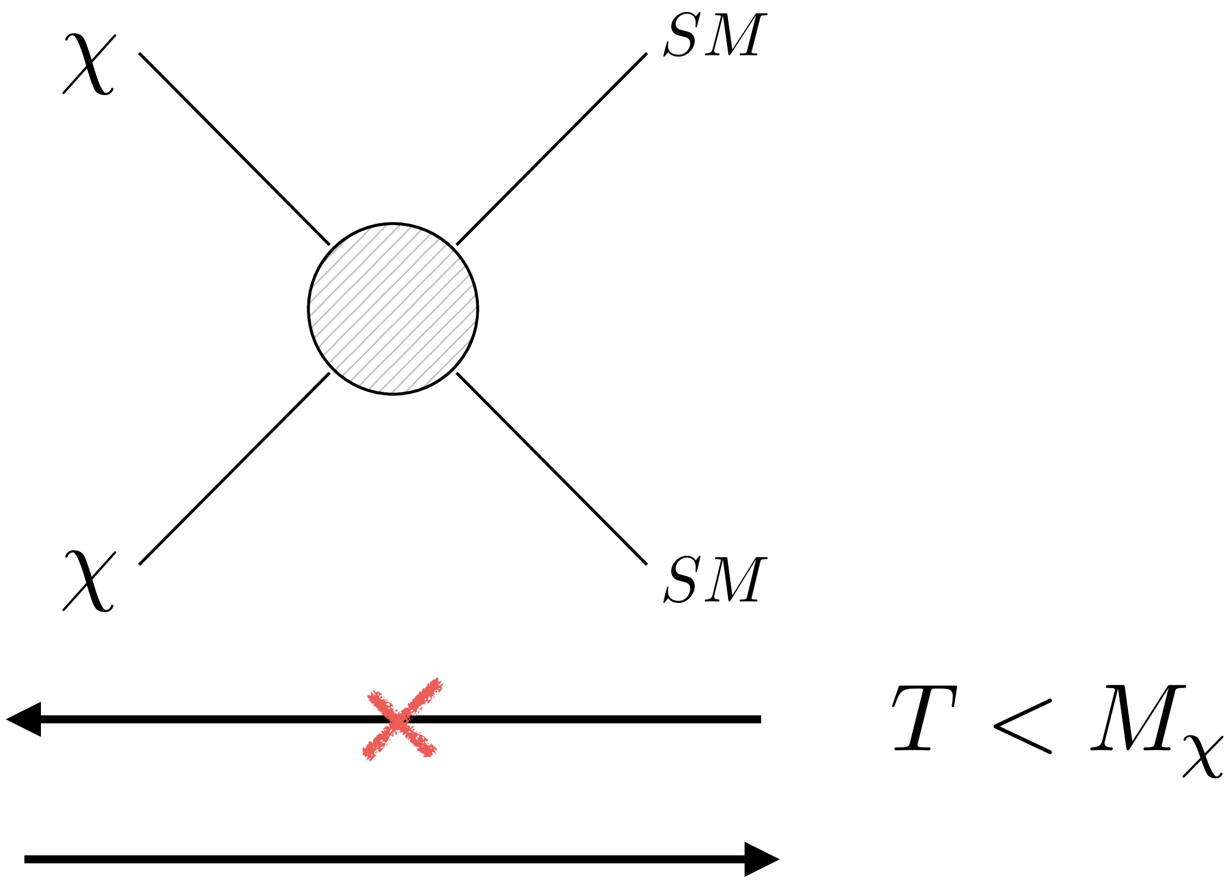
Assumptions about dark matter production

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

Introduction

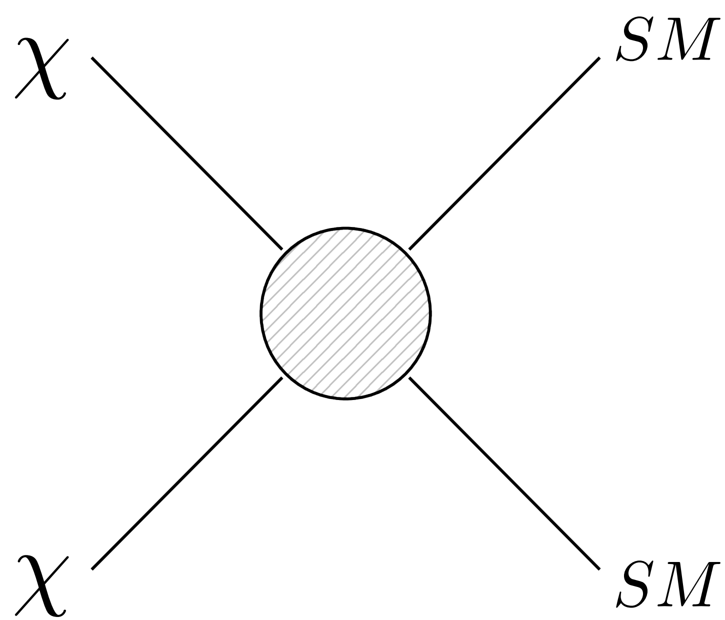


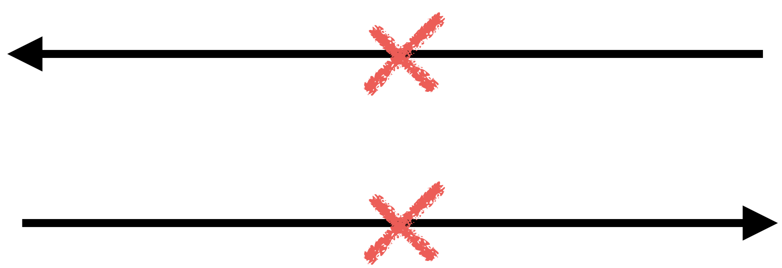
Introduction



thermal decoupling

Introduction





$$T < M_\chi$$

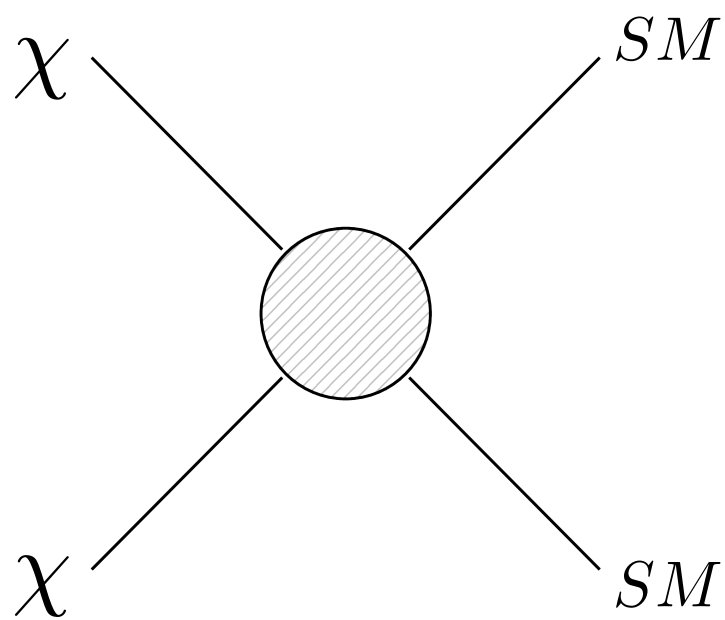
$$\Gamma < H$$

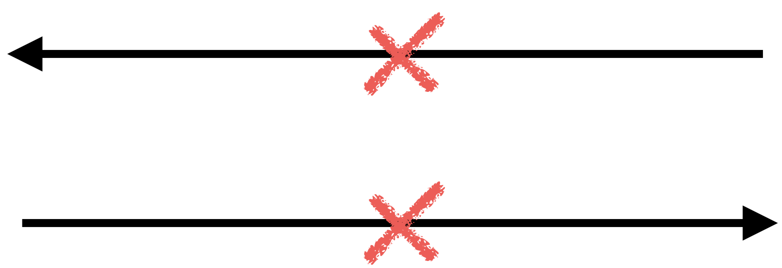
Annihilation rate per dark matter particles

Expansion rate of the Universe

Chemical decoupling

Introduction





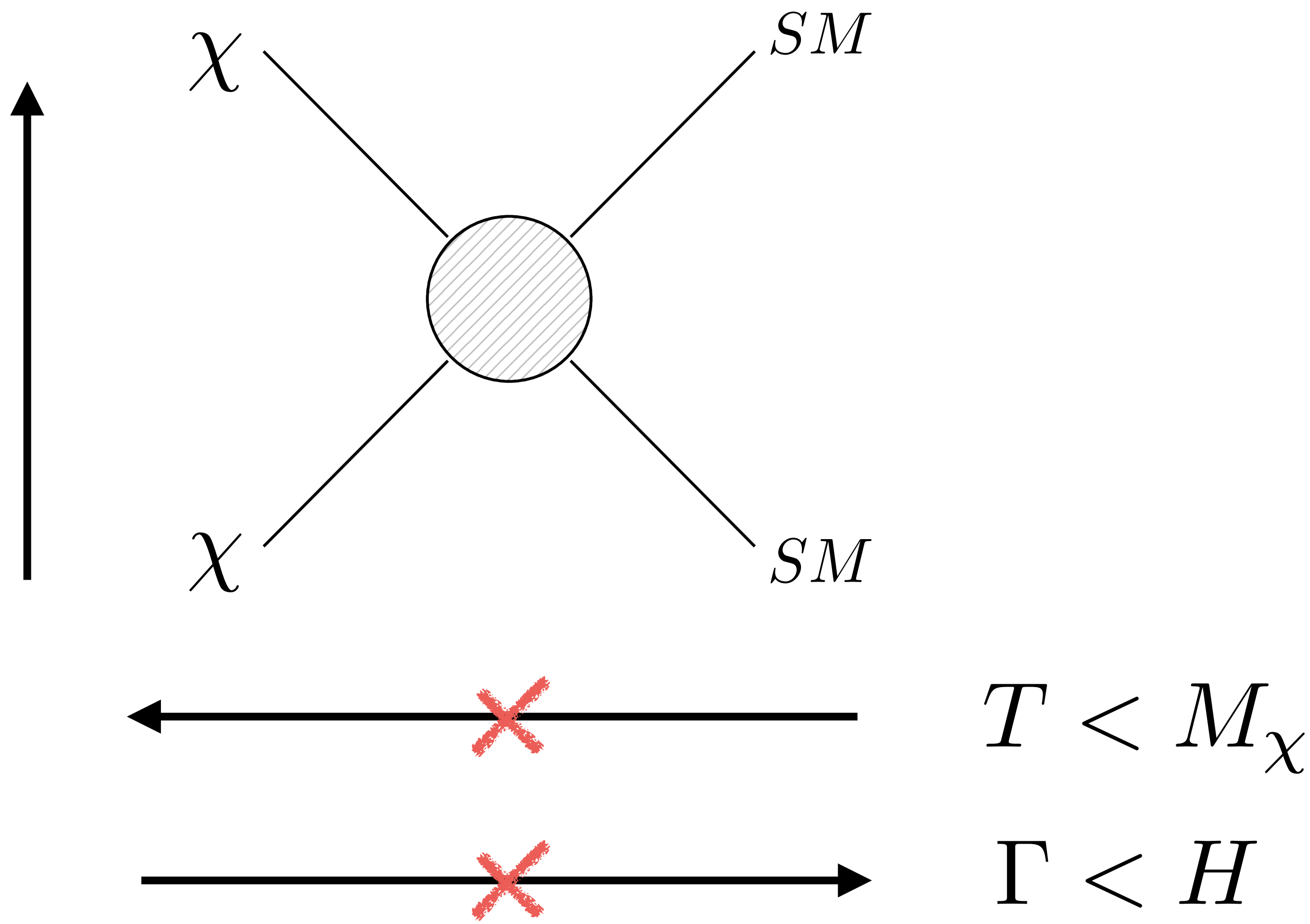
$$T < M_\chi$$

$$\Gamma < H$$

$$\Omega_\chi h^2 \approx 0.12 \frac{x_{dec}}{28} \frac{\sqrt{g_{eff}(T_{dec})}}{100} \frac{2 \times 10^{-26} cm^3/s}{< \sigma_{\chi\chi} v >}$$

WIMP miracle

Introduction



Kinetic coupling

Direct detection

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

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

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

Evaluate those operators in nucleon states

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

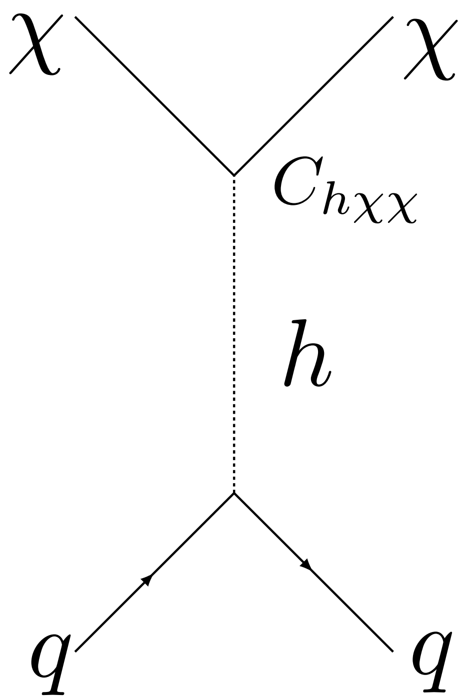
$$f_N / M_N = \sum_{q=u,d,s} f_q f^N_{Tq} - \frac{8}{9} f_G f^N_{TG}$$

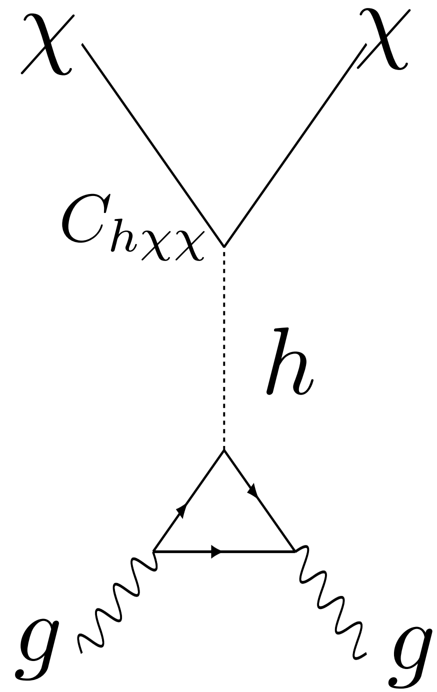
$$f^P_{Tu} = 0.0153$$

$$f^P_{Td} = 0.0191$$

$$f^P_{Ts} = 0.0447$$

Direct detection

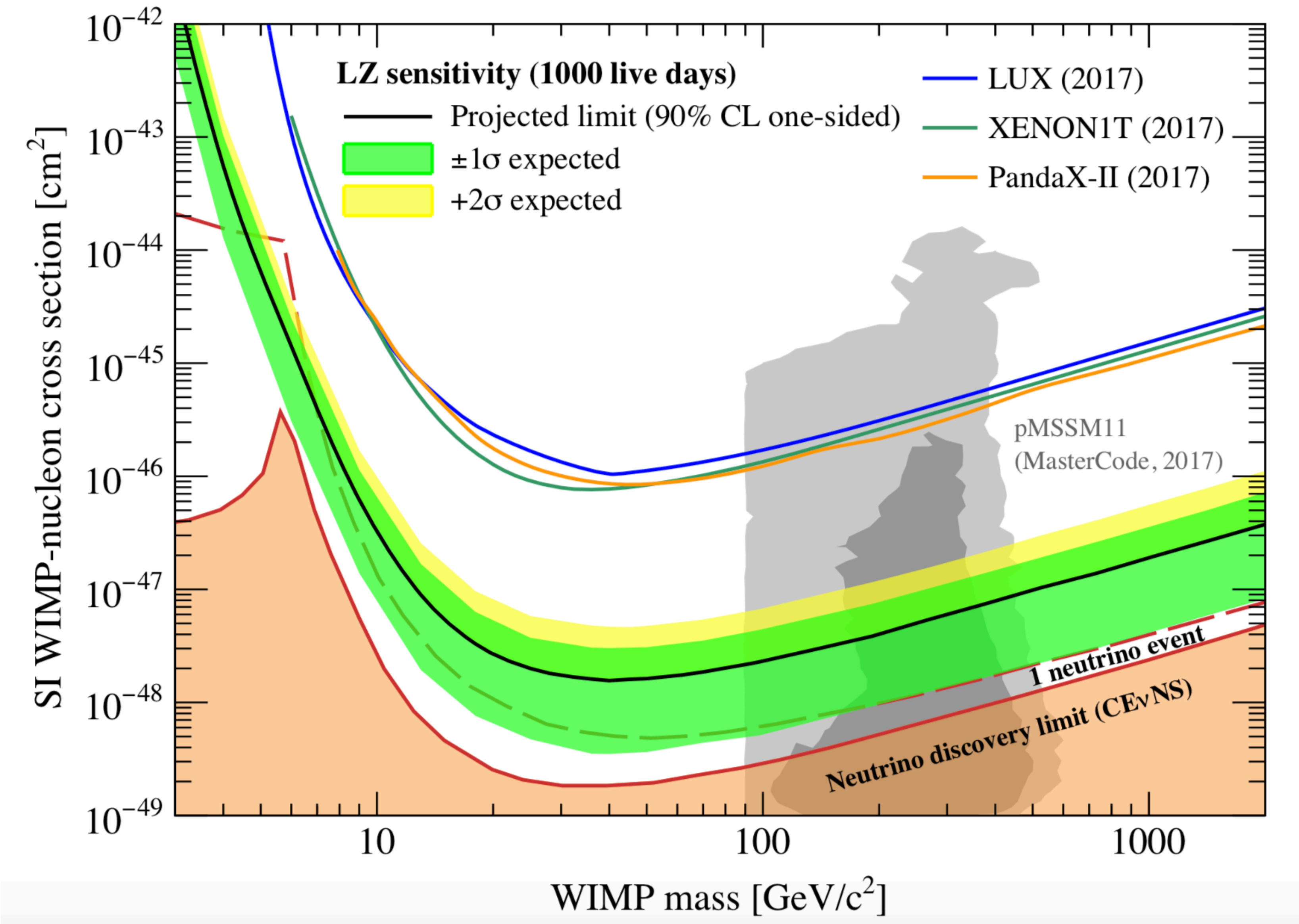




$$f_N/M_N = -\frac{C_{h\chi\chi}}{v m_h^2}[\sum_{q=u,d,s} f_{Tq}^N + \frac{2}{9} f_{TG}^N]$$

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

Direct detection



arXiv:1802.06039

Direct detection

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
…

Loop corrections become dominant in such region

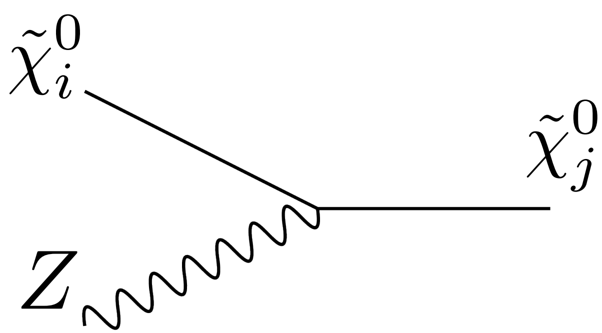
Singlet-doublet model

The SM is supplemented by a Majorana fermion singlet χ_s

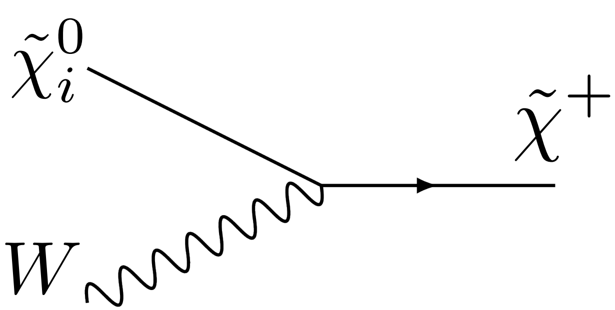
and two fermion doublets $\chi_{D1} = \begin{pmatrix} \chi_1^+ \\ \chi_1^0 \end{pmatrix}$ $\chi_{D2} = \begin{pmatrix} \chi_2^0 \\ \chi_2^- \end{pmatrix}$

$$L_{kin} = \chi_s^+ i D_\mu \sigma_-^\mu \chi_s + \chi_{D1}^+ i D_\mu \sigma_-^\mu \chi_{D1} + \chi_{D2}^+ i D_\mu \sigma_-^\mu \chi_{D2}$$

Gauge couplings



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



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

Singlet-doublet model

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

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

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

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

Singlet-doublet model

Assume the mass of lightest mass eigenstate is M_1

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

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

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 $M_1 = M_s \quad : \quad -M_D > M_s \qquad \sin 2\beta = M_s/(-M_D)$

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

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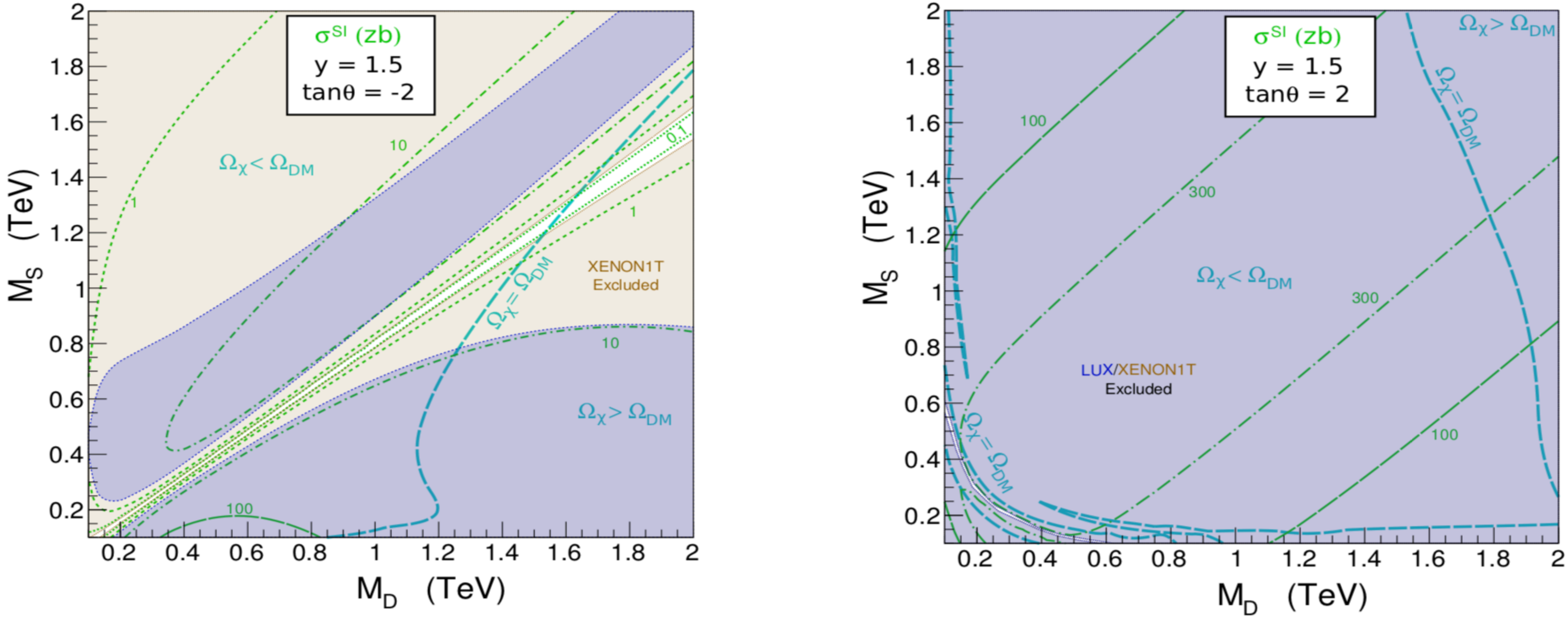
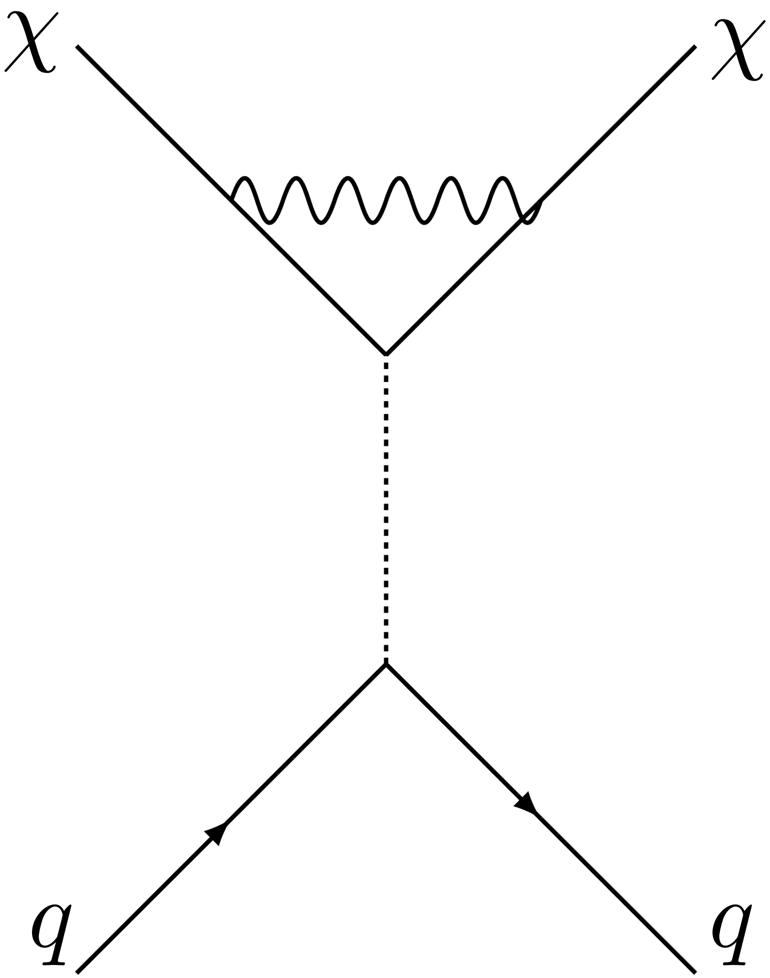
Singlet-doublet model

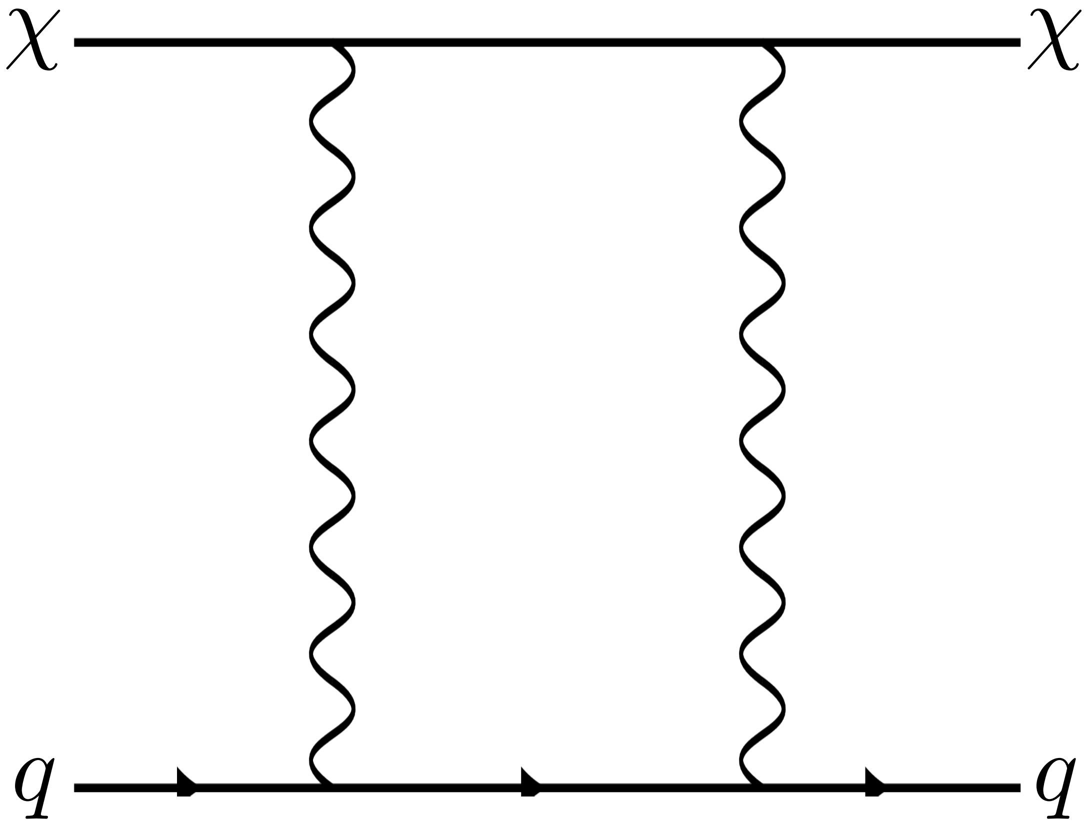


arXiv: 1311.5896 C. Cheung, D. Sanford

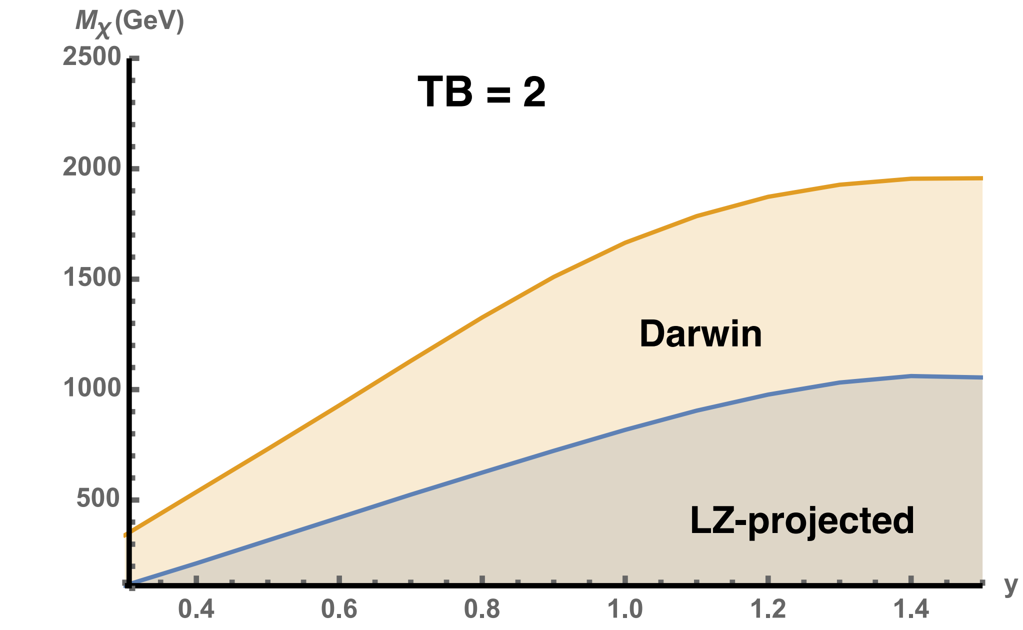
One-loop corrections

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



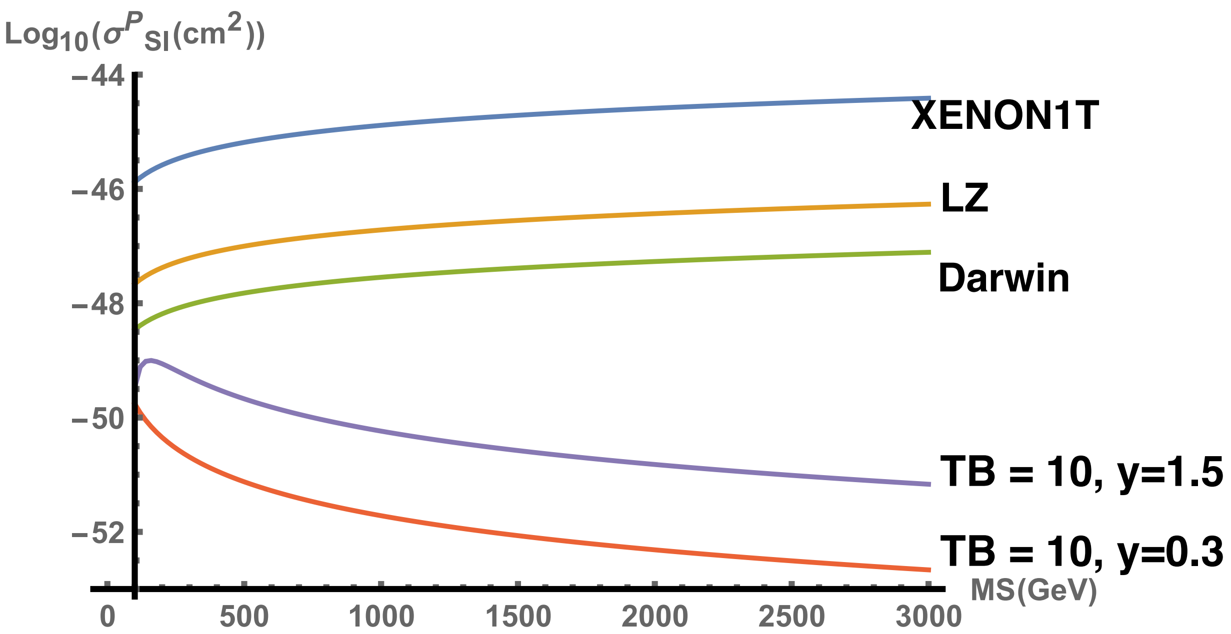


One-loop corrections



M_D is fixed by using blind spot conditions

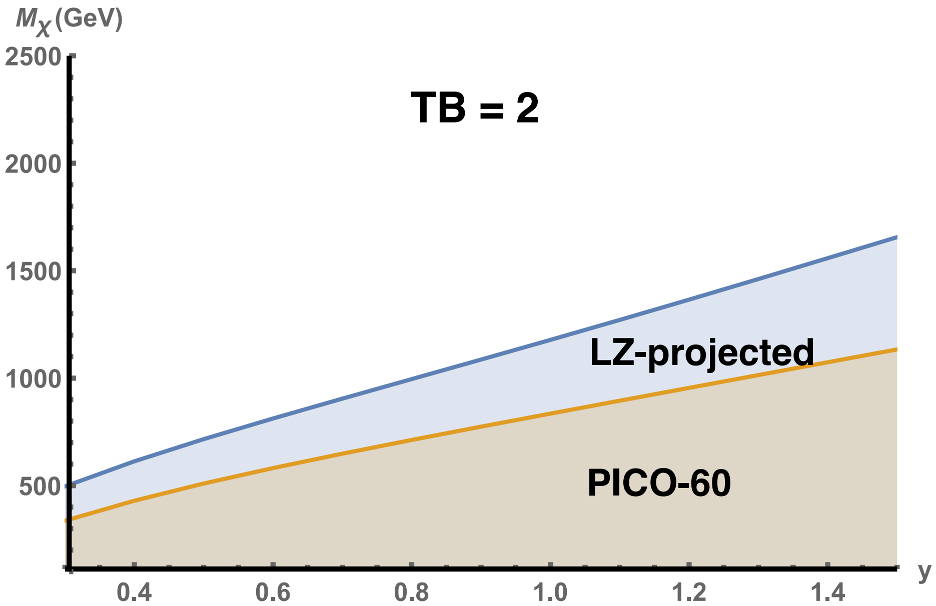
LZ projected can reach up to ~ 800 GeV
Darwin can reach up to ~ 2 TeV

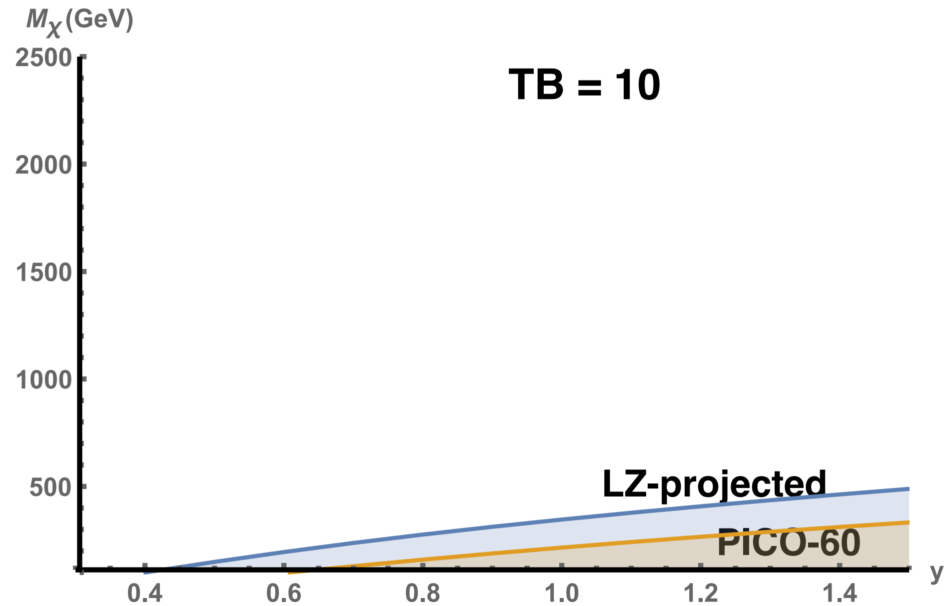


Larger TB and smaller y will be more difficult for direct detection

Spin-dependent scattering

SD cross section at tree-level blind spot



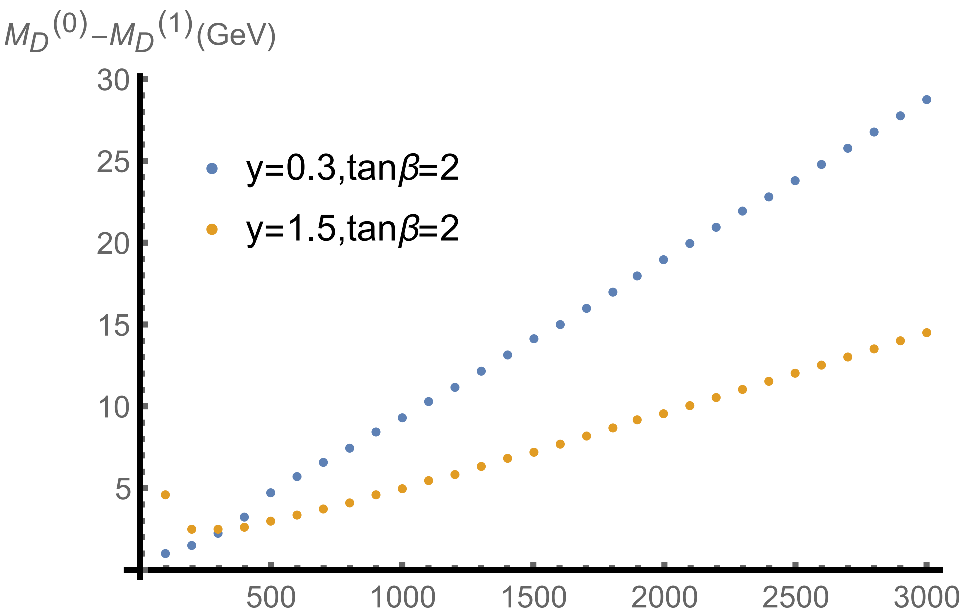


Collider searches: arXiv: 1612.0238 T. Han, F. Kling, S. Su, Y. Wu

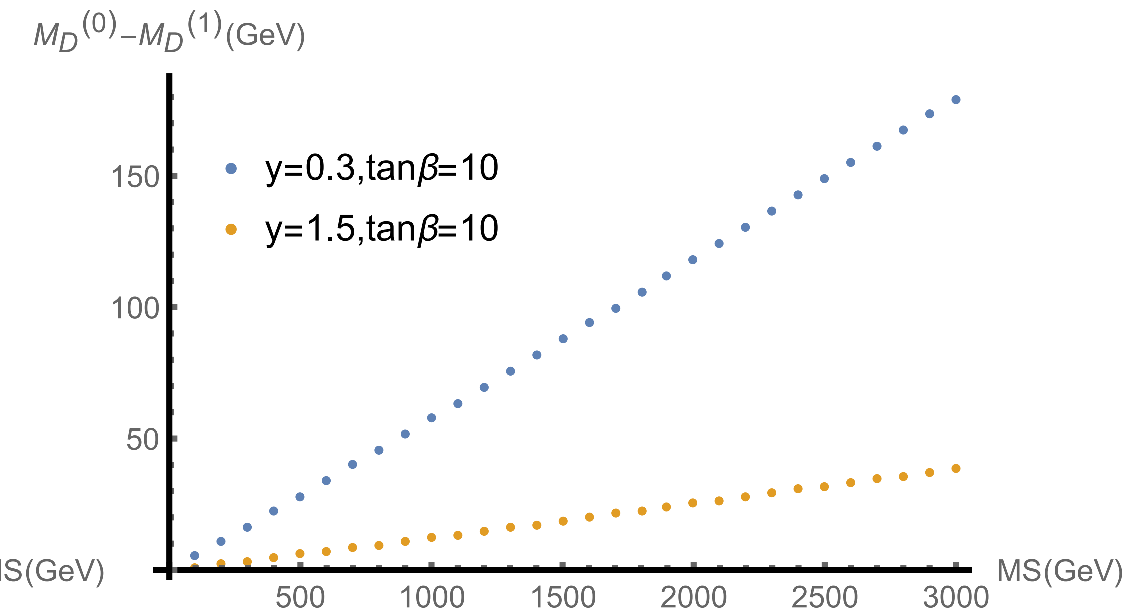
One-loop corrections

Shift of blind spots

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



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



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

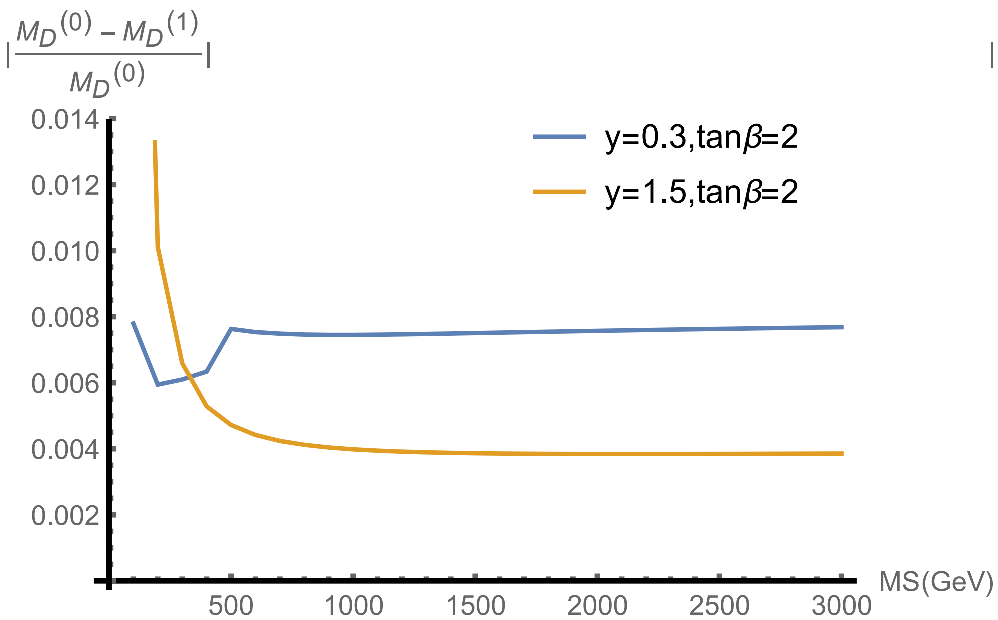
$$\delta g \propto yv^2 \frac{2tb}{1+tb^2} \delta M_D$$

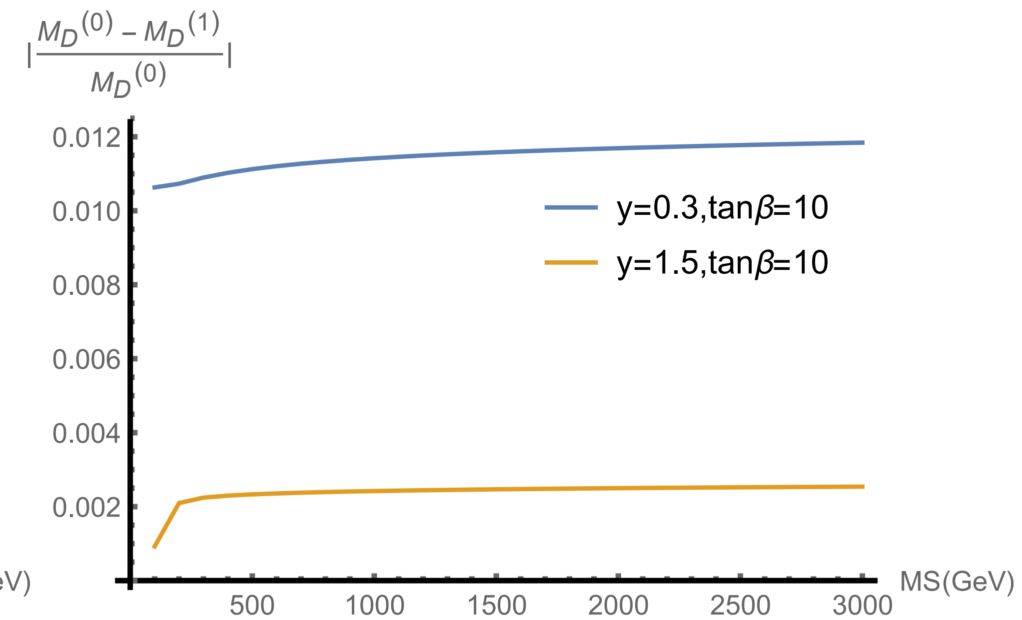
Conclusions

- **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 $\tan\beta$, singlet-doublet mixing is small. One-loop corrections 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 collider searches.**

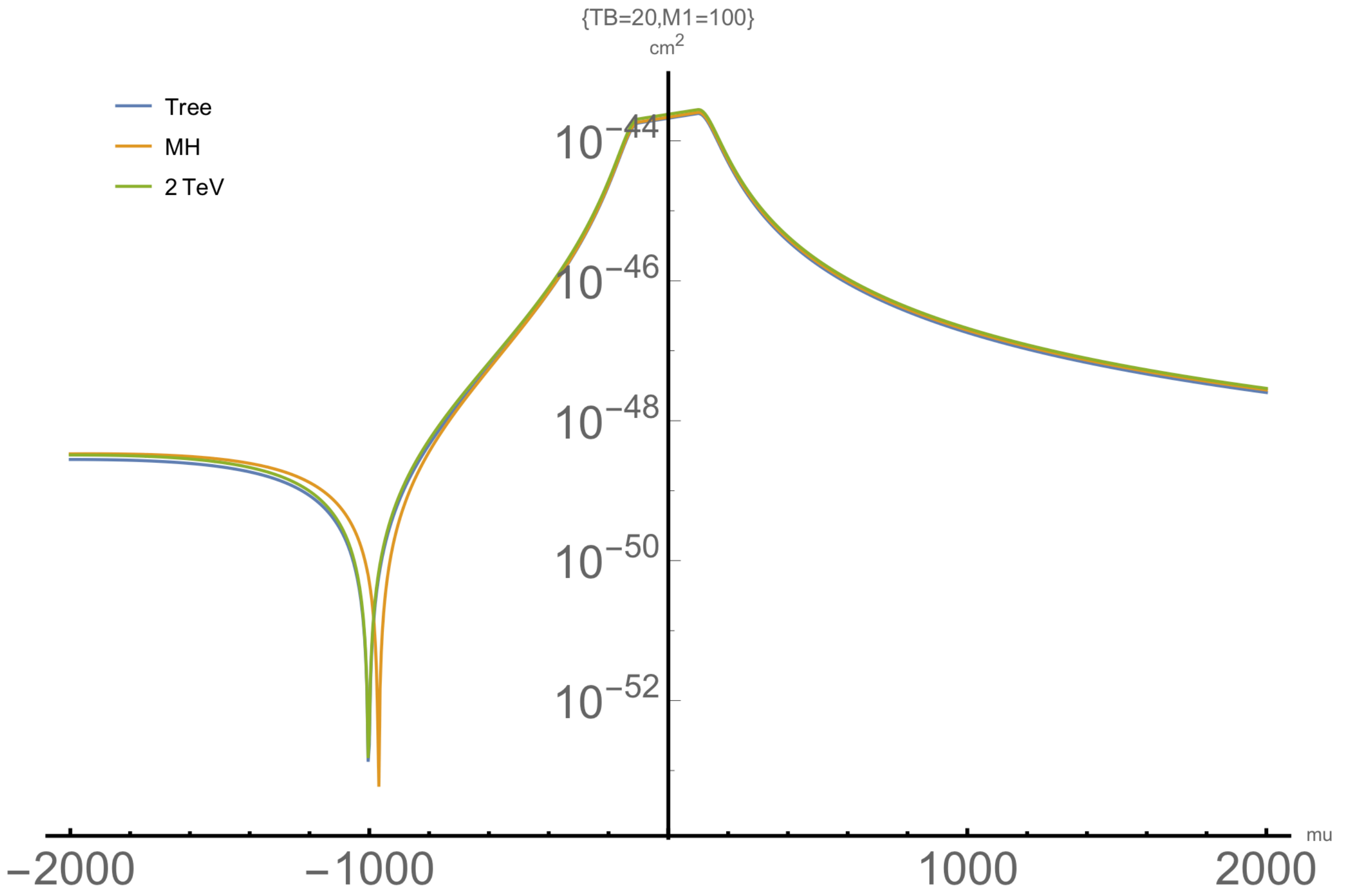
Back-up slides

Back up


$|\frac{M_D^{(0)} - M_D^{(1)}}{M_D^{(0)}}|$
0.014
0.012
0.010
0.008
0.006
0.004
0.002
y=0.3,tanβ=2
y=1.5,tanβ=2
500
1000
1500
2000
2500
3000
MS(GeV)


$|\frac{M_D^{(0)} - M_D^{(1)}}{M_D^{(0)}}|$
0.012
0.010
0.008
0.006
0.004
0.002
y=0.3,tanβ=10
y=1.5,tanβ=10
500
1000
1500
2000
2500
3000
MS(GeV)

Back up



{TB=20,M1=100}
cm2
Tree
MH
2 TeV
10−44
10−46
10−48
10−50
10−52
mu
−2000
−1000
1000
2000