Searching Well-Tempered DM: Singlet-Doublet mixing case

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This work is in collaboration with
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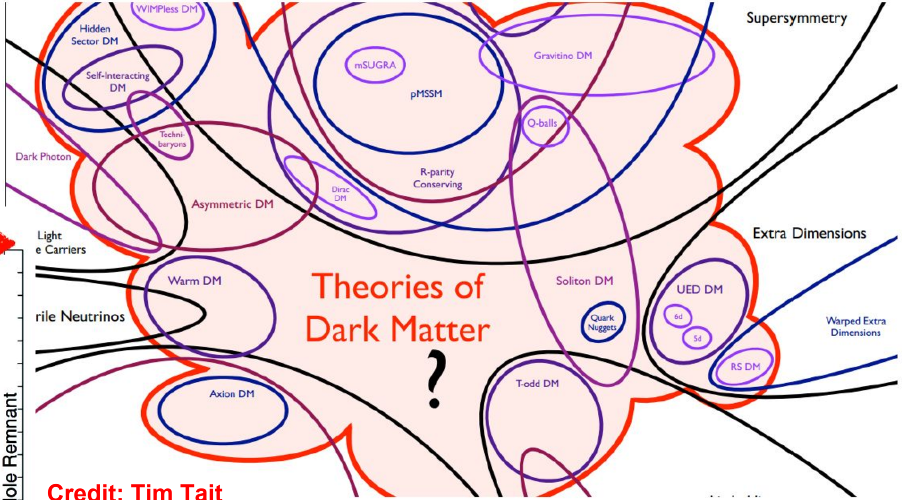
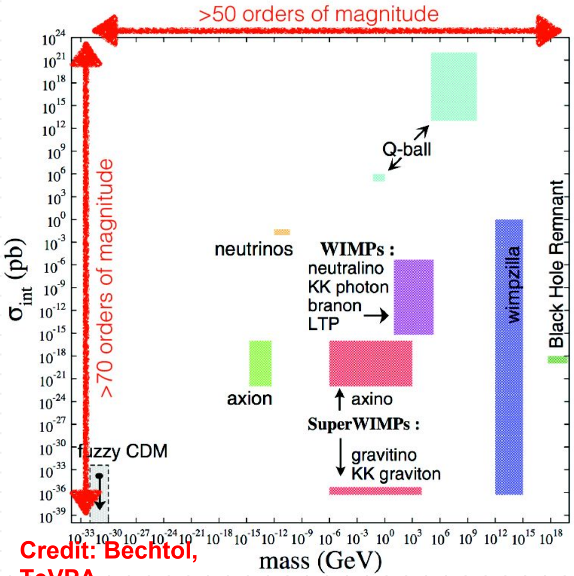
Outline

- Motivation
- Dark Matter effective theory operators
- Results of the present, the near future and the far future
- Summary



Credit: Tim Tait



Credit: Bechtol, TeVPA

Motivation

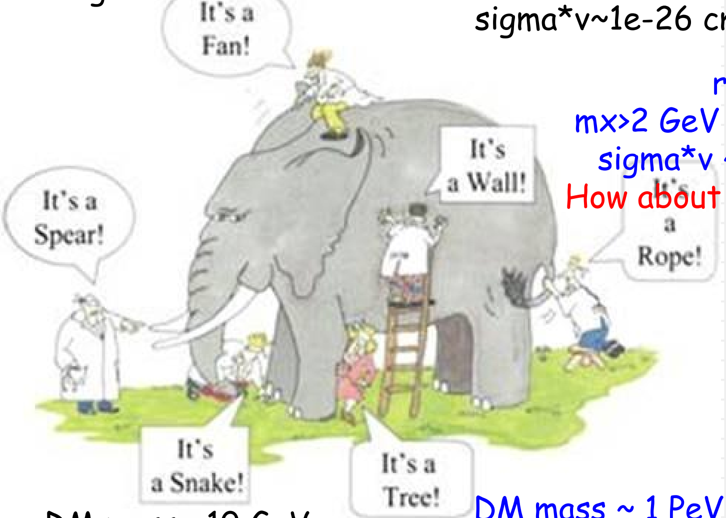
Let's start with "?"

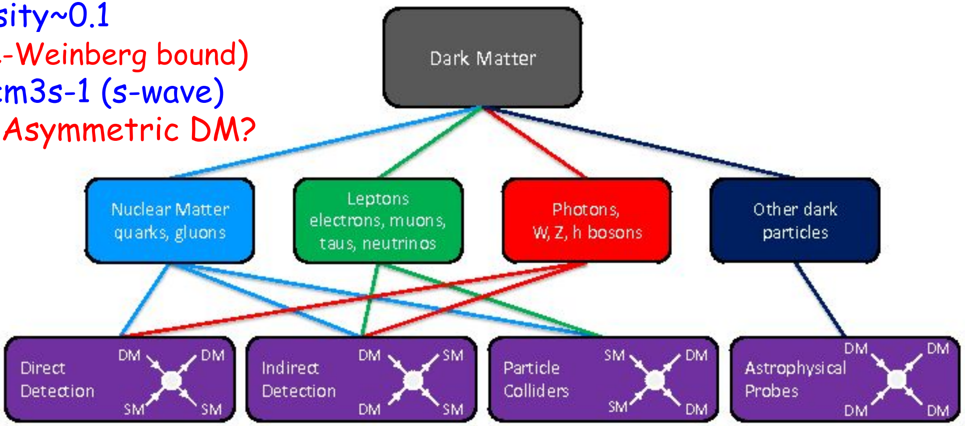
DM mass ~ 4 TeV
sigma*v~1e-24 cm3 s-1

DM mass ~40 GeV
sigma*v~1e-26 cm3 s-1

arXiv:1305.1605
snowmass

relic density~0.1
mx>2 GeV (The Lee-Weinberg bound)
sigma*v ~1e-26 cm3s-1 (s-wave)
How about p-wave?Asymmetric DM?

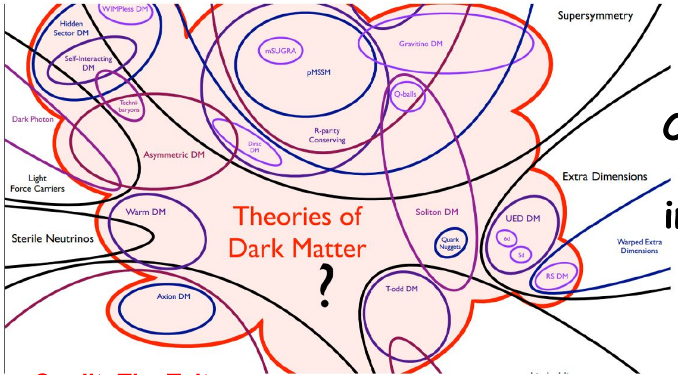




DM mass ~10 GeV
sigsip~1e-4 pb

DM mass ~ 1 PeV
sigma*v > unitarity (s-wave)
How about p-wave?

A global picture helps us carving the parameter space, efficiently and properly.



Credit: Tim Tait

Could we have a particle model independent DM study?

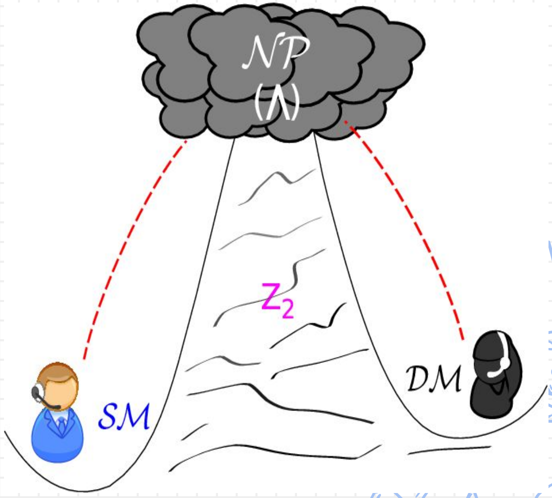
Phenomenological WIMP DM models

Scientific name	Popular name	Spin	$SU(2)_L$	$U(1)_Y$
Singlet scalar	The simplest DM	0	0	0
Doublet scalar	Inert Higgs DM	0	½	½
Triplet scalar		0	1	0
Triplet scalar II		0	1	1
...	...	...	...	...
Singlet fermion	Bino / Singlino	½	0	0
Doublet fermion	Higgsino	½	½	½
Triplet fermion	Wino	½	1	0
Triplet fermion II		½	1	1
...	...			
Singlet vector	Little Higgs DM	1	0	0
Doublet vector		1	½	½
Triplet vector		1	1	0
Triplet vector II		1	1	1
...	...			

Credit: Shigeki Matsumoto

DM still leaves a lot unknown:

- Spin
- Electroweak charge
- Real/Majorana or Complex/Dirac



Credit: Qing-Hong Cao, Chuan-Ren Chen, Chong Sheng Li, Hao Zhang (0912.4511)

Another option: mixed Dark Matter

$$DM = a \times |singlet\rangle + b \times |Doublet\rangle + c \times |Triplet\rangle + \ldots$$

	Weyl Fermion	$SU(2)_W$	$SU(3)_C$	$U(1)_Y$
Singlet-Doublets	S	1	1	0
	D_1	2	1	1/2
	D_2	2	1	−1/2
Doublets-Triplet	D_1	2	1	1/2
	D_2	2	1	−1/2
	T	3	1	0
Triplet-Quadruplets	T	3	1	0
	Q_1	4	1	1/2
	Q_2	4	1	−1/2

1. a=1, b=1, c=0;
2. ~~a=1, b=0, c=1;~~
3. a=0, b=1, c=1;
4. a=1, b=1, c=1;

Similar DM senario in SUSY

1. bino-higgsino mixing
2. Singlet won't mix with Triplet
3. higgsino-wino mixing
4. combination of 1+3

In this talk, we will focus on case 1.

DM effective theory operators

A simple approach for both experimentalists and theorists

DM effective operators

$$\mathscr{L}_{\rm SD} = \mathscr{L}_{\rm kin} - \left[\frac{1}{2}M_S SS + M_D D_1 \cdot D_2 + y_{12} S D_1 \cdot \tilde{H} + y_{13} S D_2 \cdot H + \text{H.c.}\right]$$

$$M_N = \begin{bmatrix} M_S & -y_{12}\langle H_0\rangle & y_{13}\langle H_0\rangle \\ -y_{12}\langle H_0\rangle & 0 & -M_D \\ y_{13}\langle H_0\rangle & -M_D & 0 \end{bmatrix} \quad M_C = \begin{bmatrix} M_S & \sqrt{2}y_{13}\langle H_0\rangle \\ \sqrt{2}y_{12}\langle H_0\rangle & M_D \end{bmatrix}$$

$$y_{12} = y\cos\theta;\ y_{13} = y\sin\theta;$$

the Bino/Higgsino case:

$$y \mapsto \frac{g'}{\sqrt{2}},\ M_S \mapsto M_1,\ M_D \mapsto \mu,\ \theta \mapsto \beta.$$

SM gauge couplings:
g1=0.35, g2=0.65,
g3=1.22

The simplest settings:

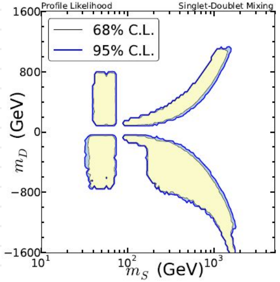
- Majorana fermion
- Singlet-Doublet mixing
- Z2-symmetry
- WIMP
- dimension<5

Results of the present, the near future and the far future

Present

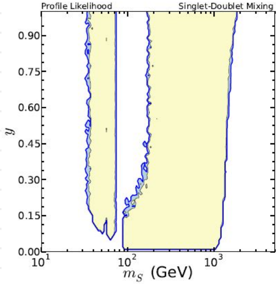
Near future
XENON1T

Far future
LZ

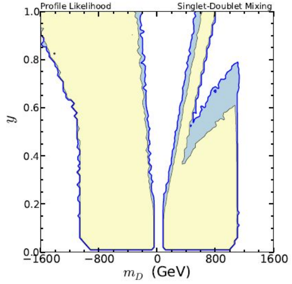


(a)

Constraints	PLANCK (relic)	LUX (SI)	PICO-60 (SD, xp)	X100 (SD, xn)	CMB	inv. Z	inv. H
Likelihood Type	Half Gaussian	Half Gaussian	Half Gaussian	Half Gaussian	Hard cut	Half Gaussian	Half Gaussian

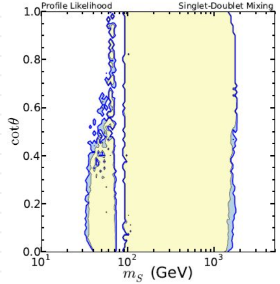


(b)

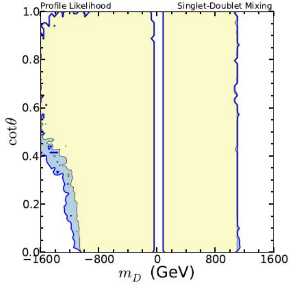


(c)

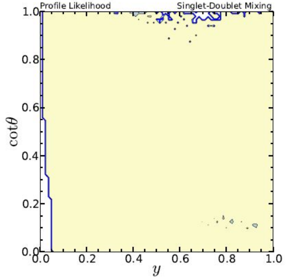
$$
\begin{aligned}
10.0 &\le M_S/\ \text{GeV} \le 2\times 10^3\,,\\
100.0 &\le |M_D|/\ \text{GeV} \le 2\times 10^3\,,\\
0.0 &\le y \le 1.0\,,\\
0.0 &\le \cot\theta \le 1.0\,.
\end{aligned}
$$



(d)



(e)

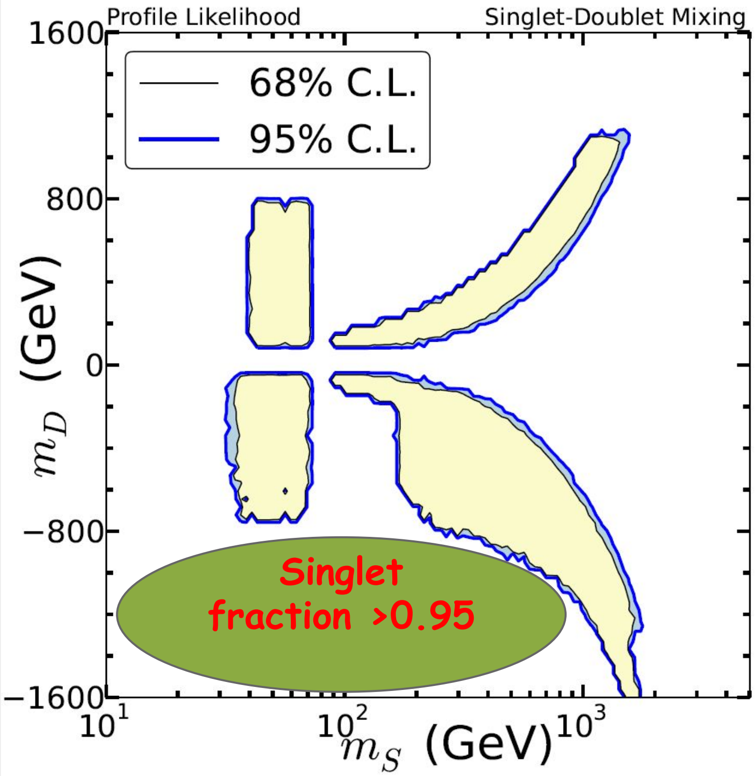


(f)

The simplest settings:

- Majorana fermion
- Singlet-Doublet mixing (0.05<Singlet fraction<0.95)
- Z2-symmetry
- WIMP (y<=1)
- dimension<5

Constraints	PLANCK (relic)	LUX (SI)	PICO-60 (SD, xp)	X100 (SD, xn)	CMB	inv. Z	inv. H



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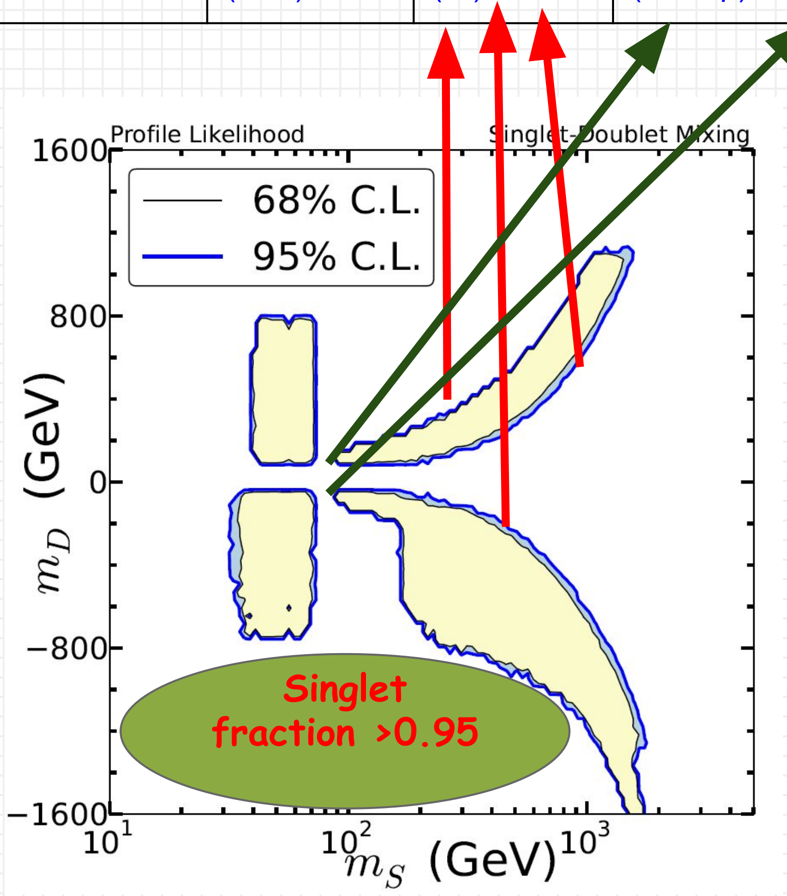
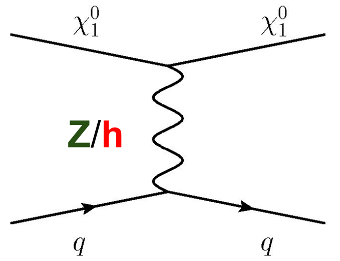
100.0 &\leq |M_D|/\text{ GeV} \leq 2\times 10^3\,,\\
0.0 &\leq y \leq 1.0\,,\\
0.0 &\leq \cot\theta \leq 1.0\,.
\end{aligned}
$$

Constraints	PLANCK (relic)	LUX (SI)	PICO-60 (SD, xp)	X100 (SD, xn)	CMB	inv. Z	inv. H





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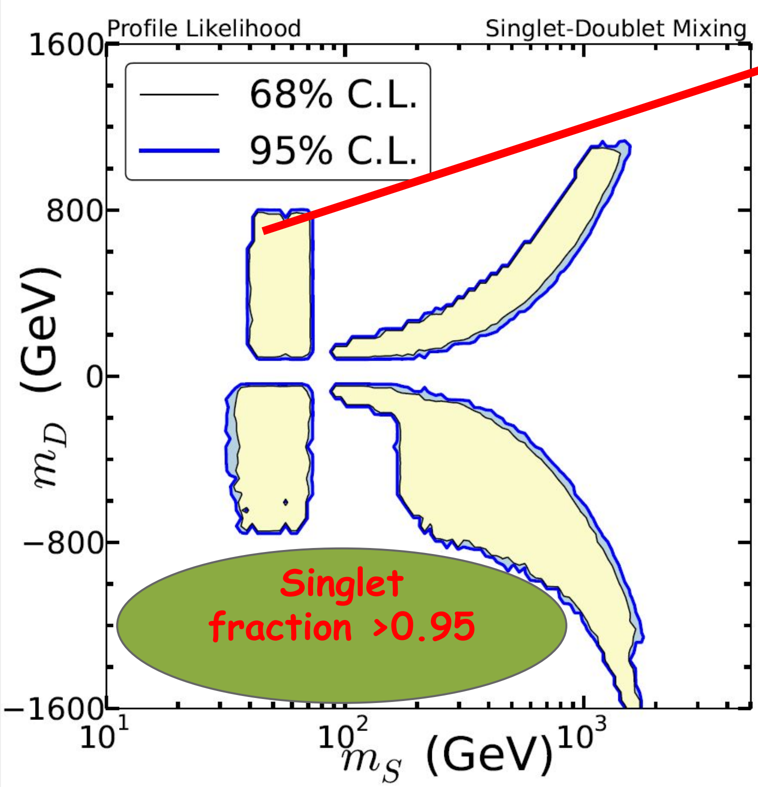
Constraints	PLANCK (relic)	LUX (SI)	PICO-60 (SD, xp)	X100 (SD, xn)	CMB	inv. Z	inv. H



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0.0 &\le y \le 1.0\,, \\
0.0 &\le \cot\theta \le 1.0\,.
\end{aligned}
$$

DM singlet fraction and charged doublet mass

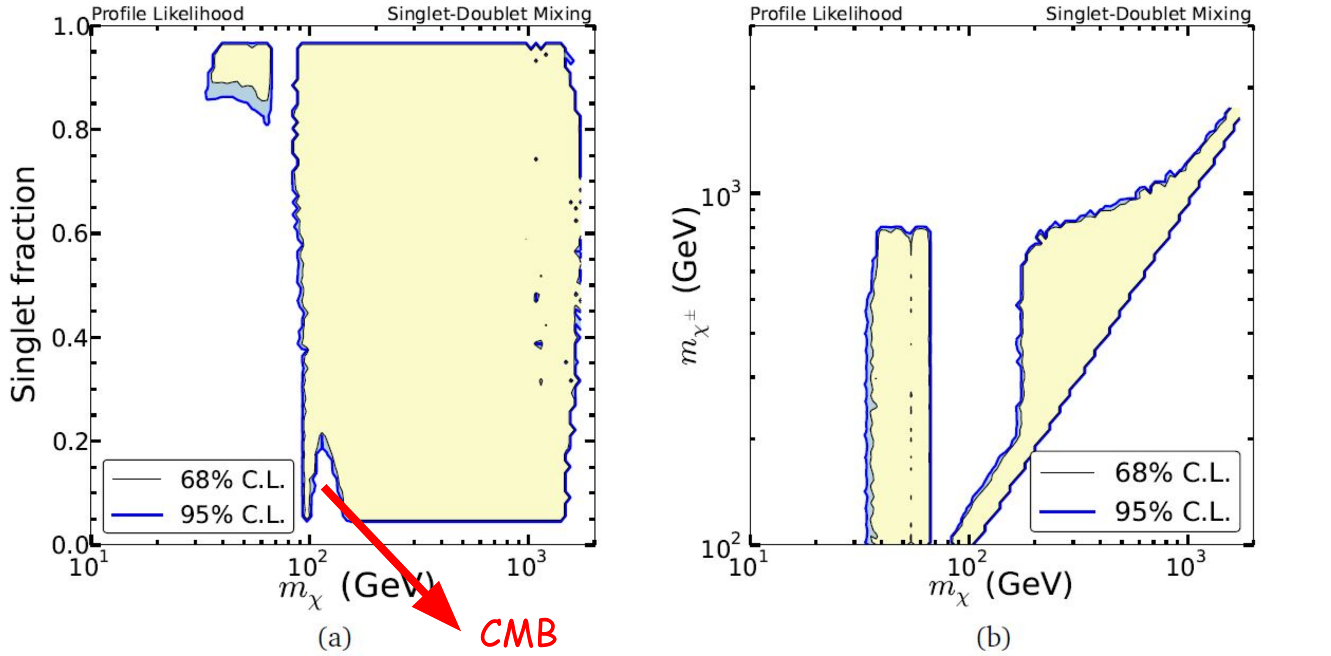
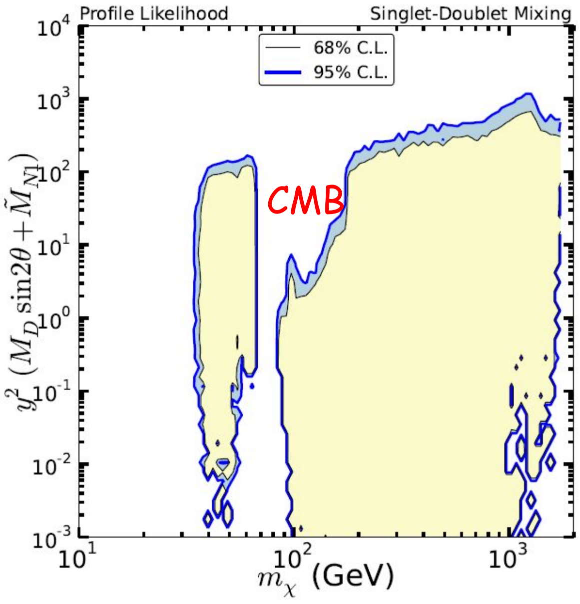
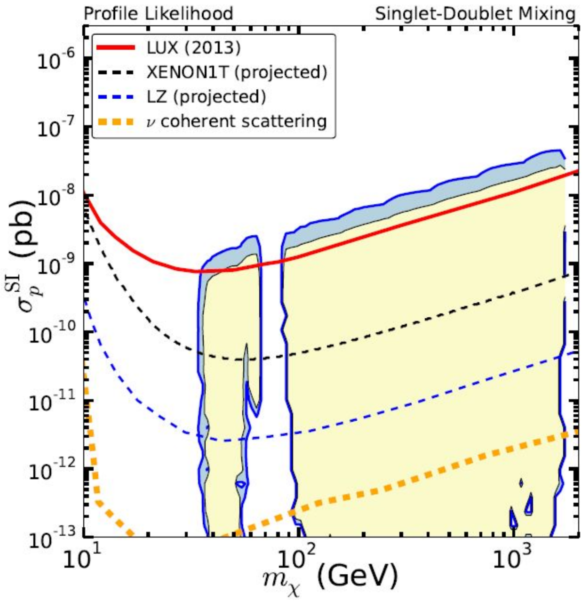


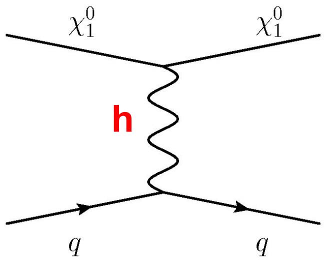
Figure 2: Profile likelihood contours in (a) the (m_χ, g_f) plane and (b) the $(m_\chi, m_{\chi^\pm})$ plane.

Higgs Blind spot region

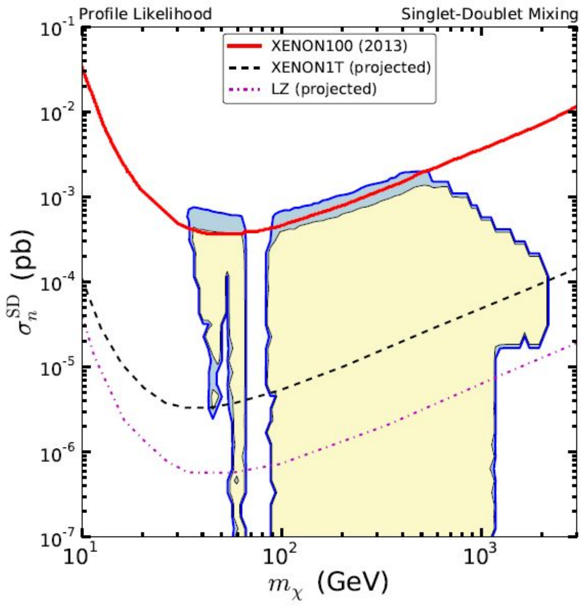
$$Y_{\rm eff}^{11} = Y_{\rm eff}^{11^*} = -y^2\eta_1^2 \frac{\left(M_D \sin 2\theta + \tilde{M}_{N1}\right)\nu}{2\left(M_D^2 + y^2\nu^2/2 + 2M_S\tilde{M}_{N1} - 3\tilde{M}_{N1}^2\right)}$$

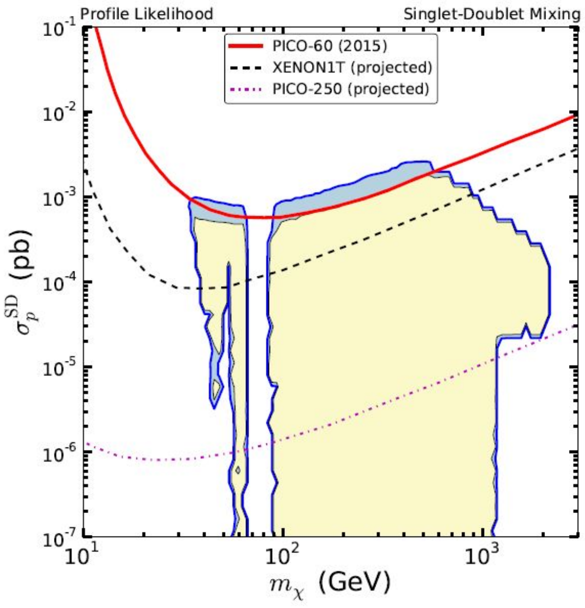


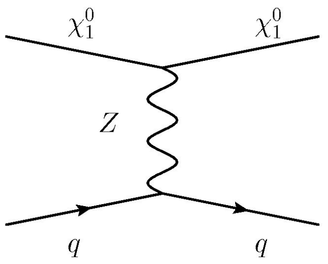




The impact of spin-dependent cross section constraints







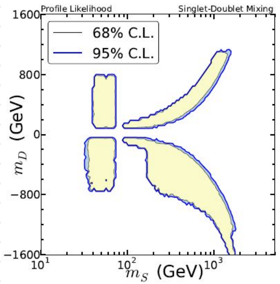
Results of the present, the near future and the far future

Present

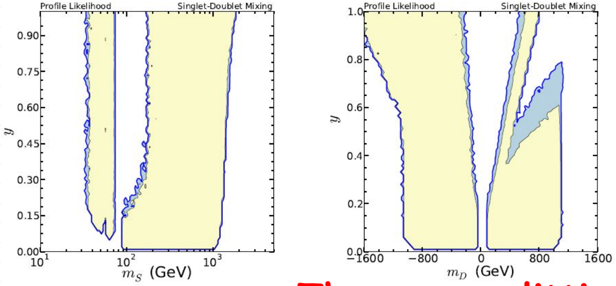
Near future
XENON1T

Far future
LZ

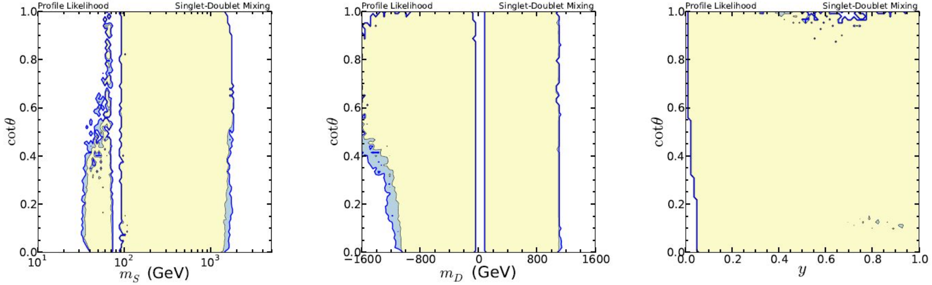
Present (2015)



(a)

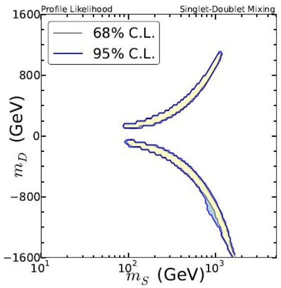


(b) (c)

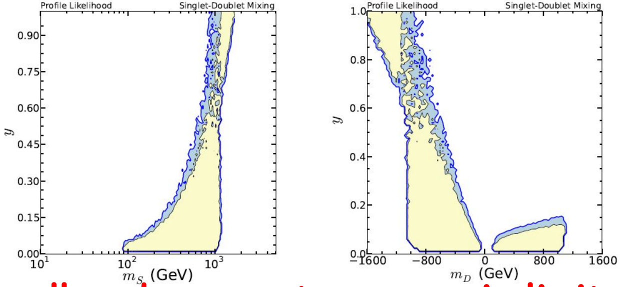


(d) (e) (f)

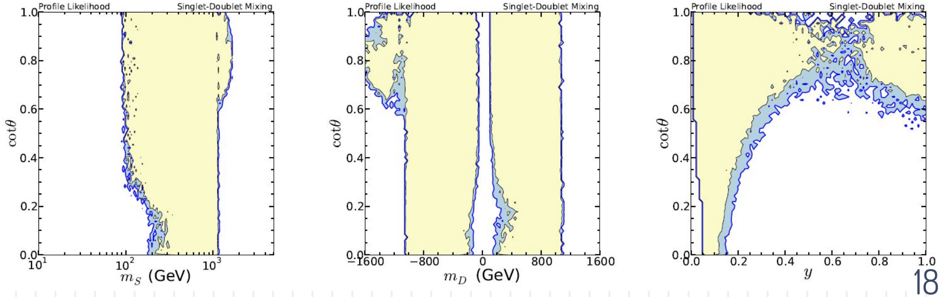
Near future
After XENON1T



(a)



(b) (c)



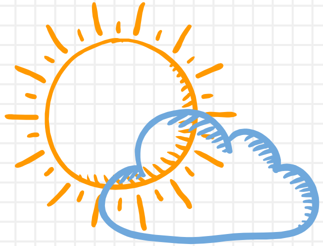
The mass splitting will be getting small and parameter space is limited.

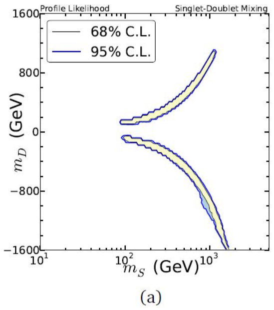
Results of the present, the near future and the far future

Present

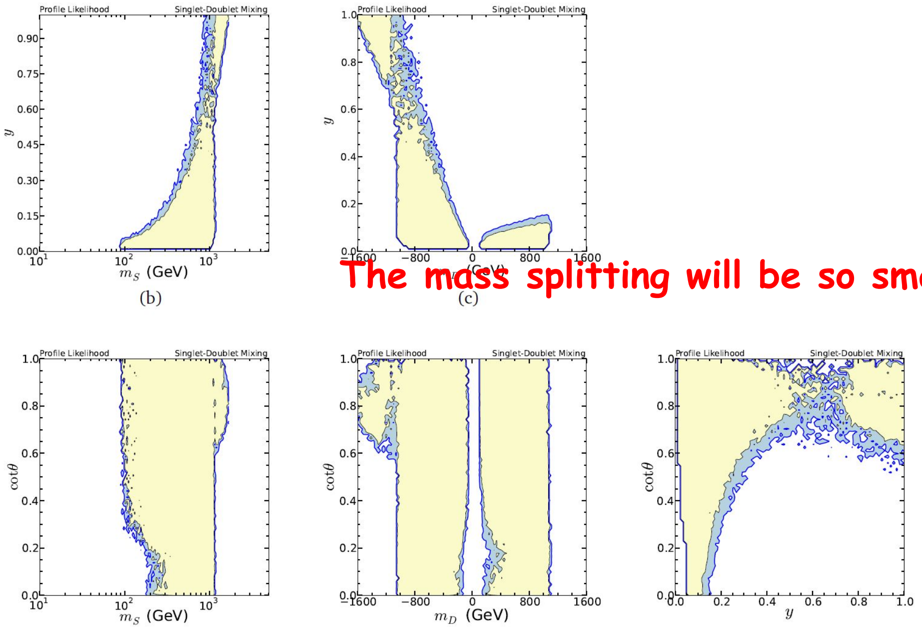
Near future
XENON1T

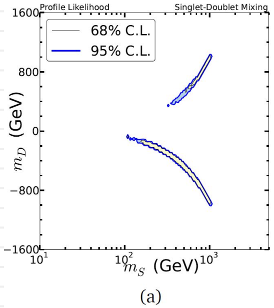
Far future
LZ



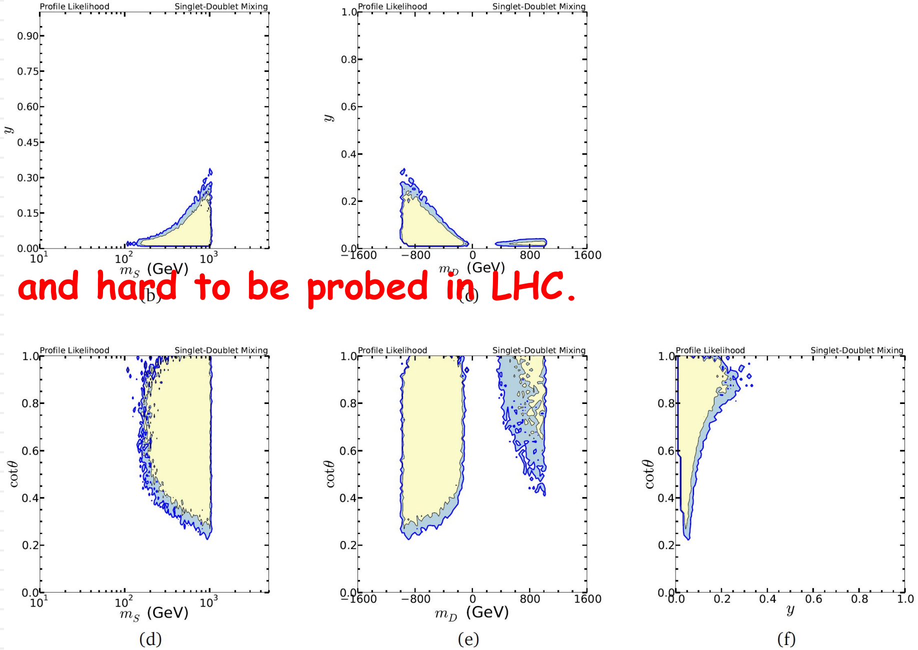


Near future
After XENON1T





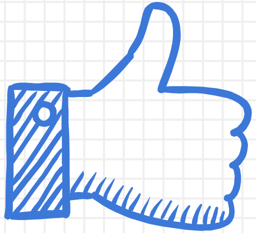
Far future
After LZ



The mass splitting will be so small and hard to be probed in LHC.

Summary

1. The main mechanisms to reduce relic density are Z/H resonance, X-X^\pm coannihilation, and focus point region (W+W- opens).
2. Current spin-dependent cross section from PICO60 puts a stringent limit on the blind spot region.
3. In the XENON1T era, the resonance will be totally excluded.
4. After LZ, the mass splitting between X and X^\pm is so small that the future colliders hard probe it directly. (maybe DM ID?)



THANKS!

Any questions?