Exploring the singlet scalar dark matter from direct detections and neutrino signals via its annihilation in the Sun

Wan-Lei Guo and Yue-Liang Wu, arXiv:1103.5606

Wan-lei Guo

郭万磊

中国科学院理论物理研究所

2011兩岸粒子物理與宇宙學研討會

Cross Strait Meeting on Particle Physics and Cosmology

2011-04-03

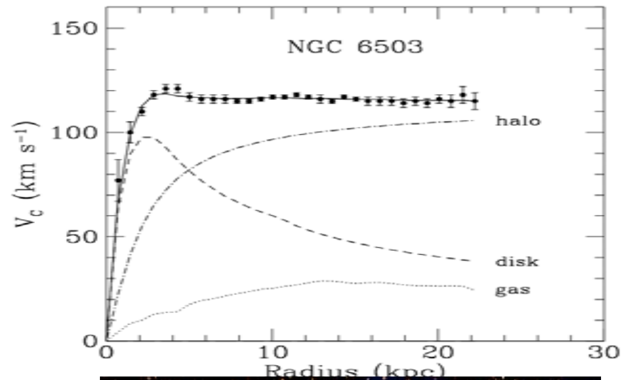
Outline

- The DM annihilation in the Sun
- Direct detections in two singlet scalar DM (SSDM) models:
  - SSDM-SM Z2
  - SSDM-2HBDM P and CP
- Neutrino signals in the Super-K and IceCube
- Summary

Evidences for dark matter

(1) **The galactic scale:**

Flat rotation curves



(2) **The scale of galaxy clusters:**

The velocity of galaxies in clusters

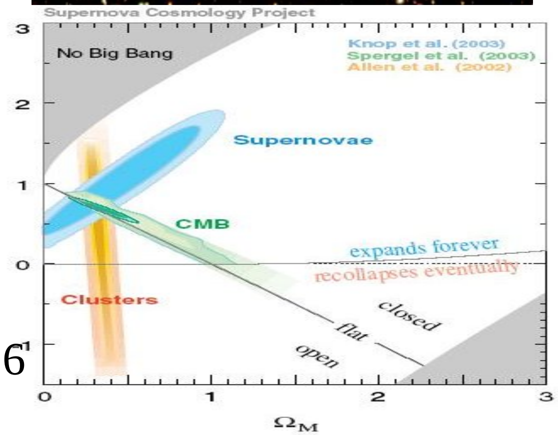
The X-rays trace the hot gas

The gravitational lensing

(3) **The cosmological scale:**

Large scale structure

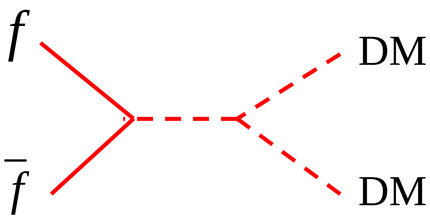
CMB



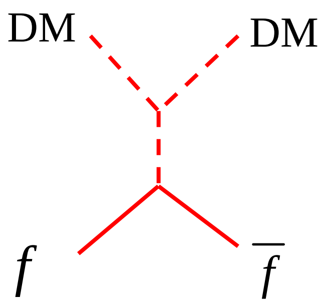
WMAP 7: $\Omega_\Lambda = 0.728^{+0.015}_{-0.016}; \Omega_{DM} = 0.227 \pm 0.014; \Omega_b = 0.0456 \pm 0.0016$

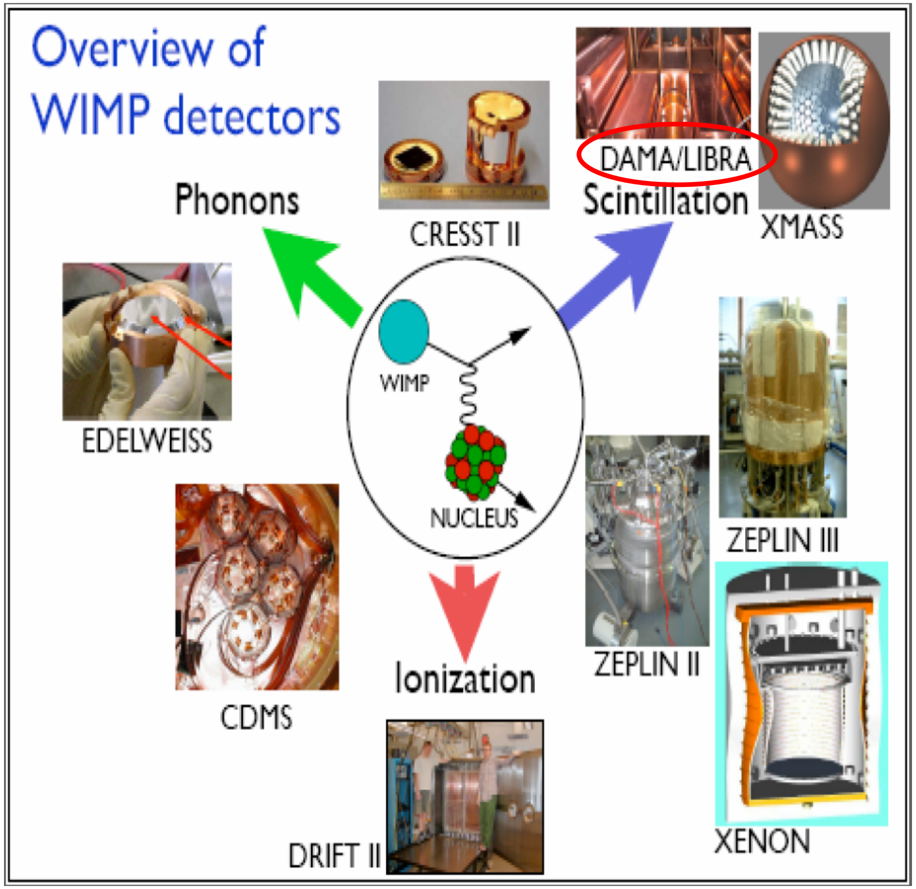
Dark matter searches

(1) Collider search:

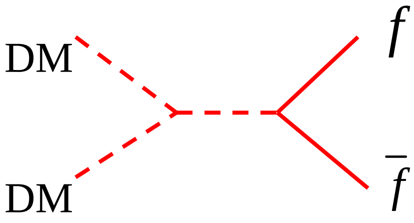


(2) Direct search:





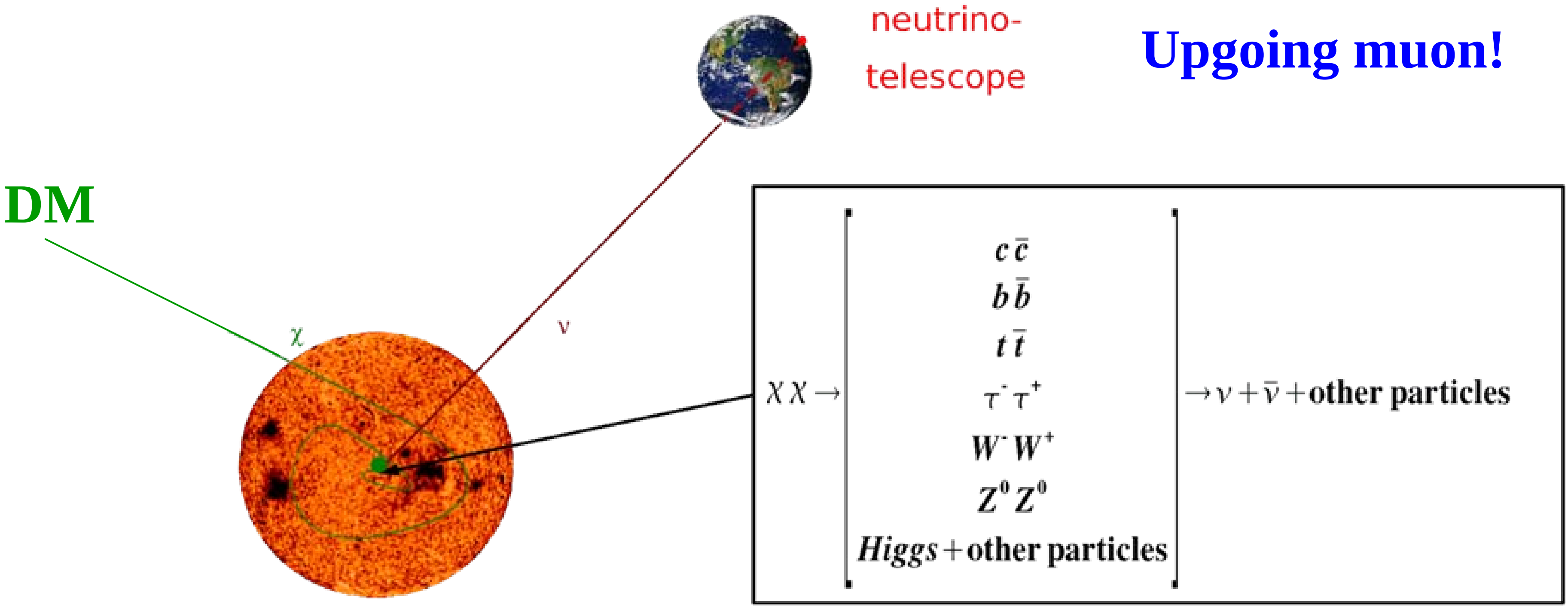
(3) Indirect search:



Annihilation productions:

Gamma rays, Neutrinos, electrons, Positrons
Protons and antiprotons etc.

DM capture and annihilation in the Sun

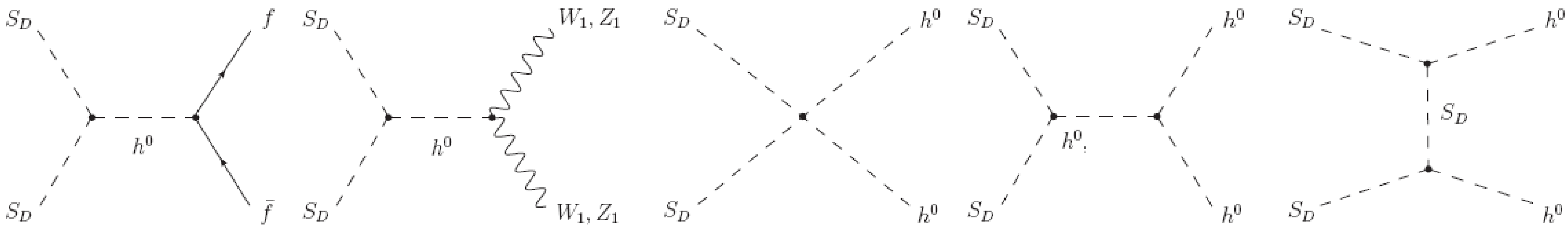


DM elastic scattering in the Sun ➡ DM is captured when $V_{DM} < V_{esc}$ ➡ Instantaneous thermalization

Real singlet scalar DM model as an extension of SM

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{2}\partial_\mu S\,\partial^\mu S - \frac{m_0^2}{2}S^2 - \frac{\lambda_S}{4}S^4 - \lambda S^2 H^\dagger H$$

Z2



$$\hat{\sigma}_{ff} = \sum_f \frac{\lambda^2 m_f^2}{\pi}\frac{1}{(s-m_h^2)^2 + m_h^2\Gamma_h^2}\frac{(s-4m_f^2)^{1.5}}{\sqrt{s}},$$

3 parameters

$$\hat{\sigma}_{ZZ} = \frac{\lambda^2}{4\pi}\frac{s^2}{(s-m_h^2)^2+m_h^2\Gamma_h^2}\sqrt{1-\frac{4m_Z^2}{s}}\left(1-\frac{4m_Z^2}{s}+\frac{12m_Z^4}{s^2}\right),$$

$$\hat{\sigma}_{WW} = \frac{\lambda^2}{2\pi}\frac{s^2}{(s-m_h^2)^2+m_h^2\Gamma_h^2}\sqrt{1-\frac{4m_W^2}{s}}\left(1-\frac{4m_W^2}{s}+\frac{12m_W^4}{s^2}\right),$$

$$\hat{\sigma}_{hh} = \frac{\lambda^2}{4\pi}\sqrt{1-\frac{4m_h^2}{s}}\left[\left(\frac{s+2m_h^2}{s-m_h^2}\right)^2 - \frac{16\lambda v_{\rm EW}^2}{s-2m_h^2}\frac{s+2m_h^2}{s-m_h^2}F(\xi) + \frac{32\lambda^2 v_{\rm EW}^4}{(s-2m_h^2)^2}\left(\frac{1}{1-\xi_h^2}+F(\xi)\right)\right]$$

Dark matter relic density

Boltzmann Equation:

$$\langle \sigma v \rangle = \frac{1}{n_{EQ}^2} \frac{m_D}{64\pi^4 x} \int_{4m_D^2}^{\infty} \hat{\sigma}(s) \sqrt{s} K_1\left(\frac{x\sqrt{s}}{m_D}\right) ds \, ,$$

$$\frac{dY}{dx} = -\frac{x\,\mathbf{s}(x)}{H} \langle \sigma v \rangle (Y^2 - Y_{EQ}^2) \, , \quad (11)$$

where $Y \equiv n/\mathbf{s}(x)$ denotes the dark matter number density. The entropy density $\mathbf{s}(x)$ and the Hubble parameter H evaluated at $x = 1$ are given by

$$n_{EQ} = \frac{g_i}{2\pi^2} \frac{m_D^3}{x} K_2(x) \, ,$$

$$\hat{\sigma}(s) = \hat{\sigma}\, g_i^2 \sqrt{1 - \frac{4m_D^2}{s}} \, ,$$

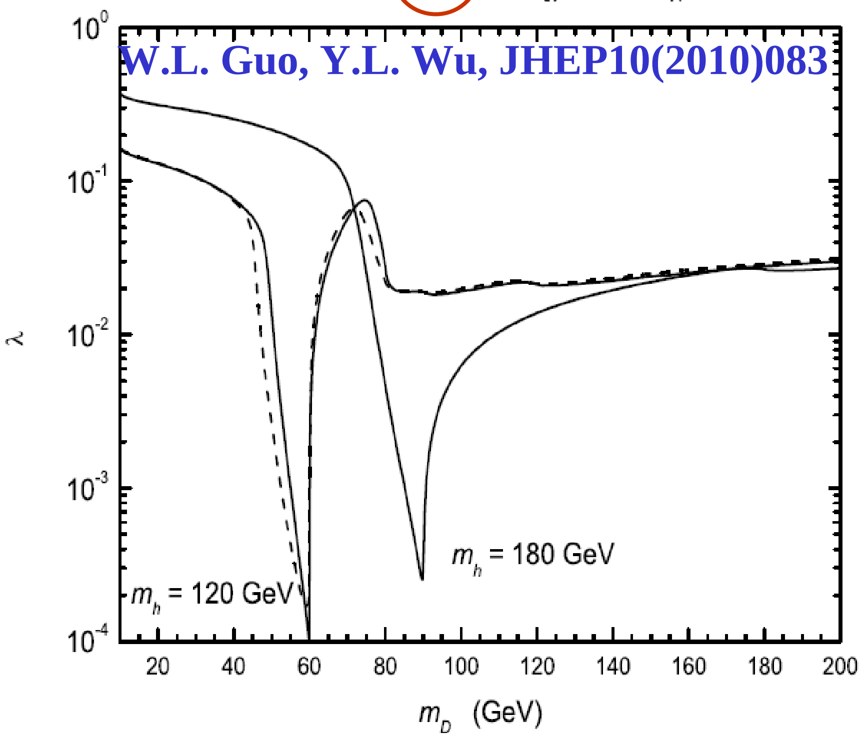
$$\mathbf{s}(x) = \frac{2\pi^2 g_*}{45} \frac{m^3}{x^3} \, ; \quad (12)$$

$$H = \sqrt{\frac{4\pi^3 g_*}{45}} \frac{m^2}{M_{PL}} \, , \quad (13)$$

where $M_{PL} \simeq 1.22 \times 10^{19}$ GeV is the Planck energy. g_*

$$\Omega_D h^2 = 2.74 \times 10^8 \frac{m}{\text{GeV}} Y_0$$

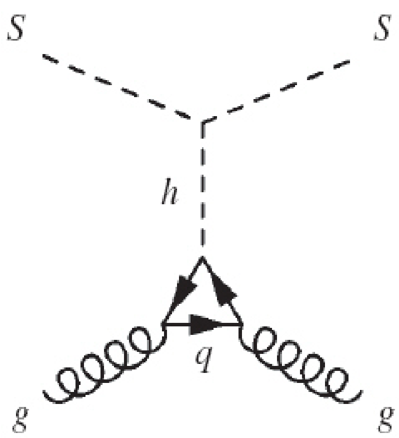
$$0.1088 \leq \Omega_D h^2 \leq 0.1158$$

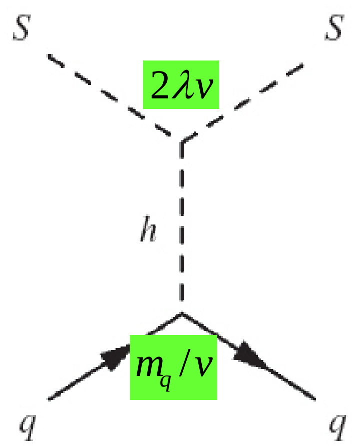


The dark matter direct detection

WIMP-nucleon cross section:

$$\sigma_n^{\rm SI} \approx \frac{\lambda^2}{\pi} f^2 \frac{m_n^2}{m_h^4 m_D^2} \left(\frac{m_D\, m_n}{m_D + m_n} \right)^2$$





$$f = (7/9) \sum_{q=u,d,s} f_{Tq}^{p} + 2/9$$

J. Ellis, et. al., PRD81,085004,(2010) [0912.3137]

$$f \approx 0.56 \pm 0.17$$

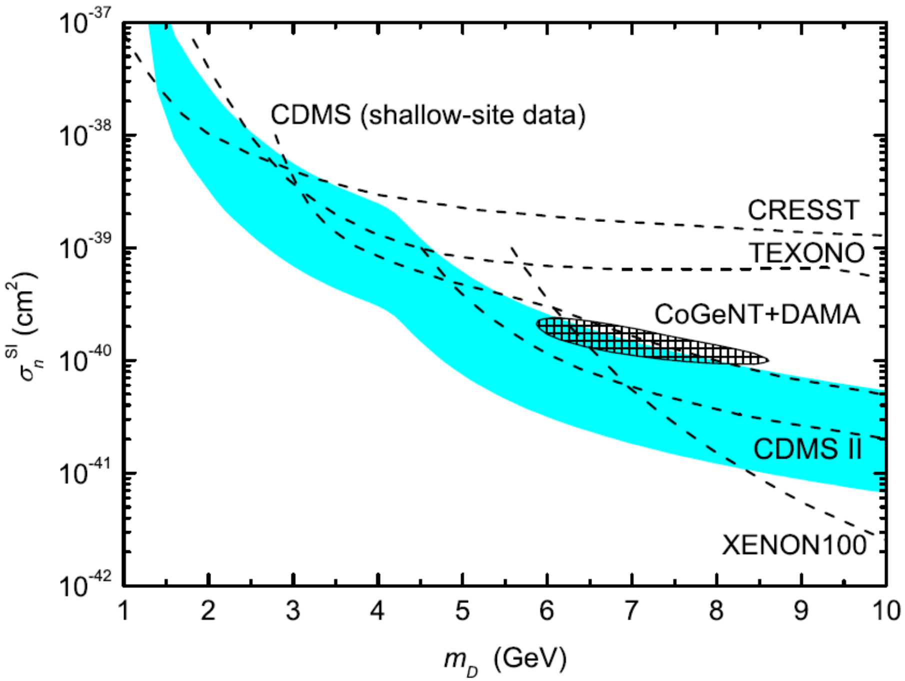
J. Giedt, et. al., PRL103,201802,(2009) [0907.4177]

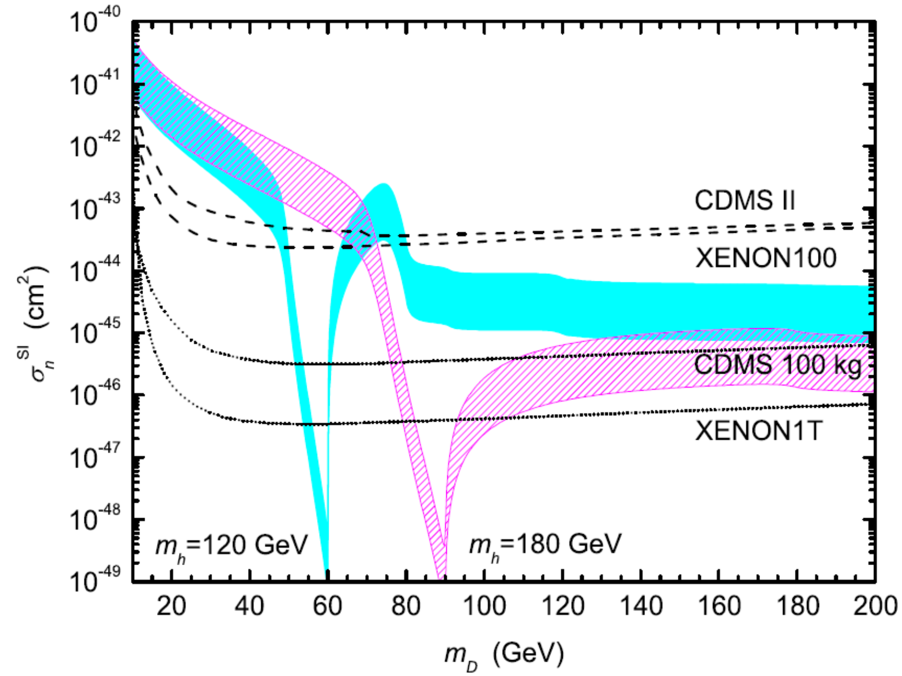
$$f \approx 0.29 \pm 0.03$$

$$0.26 \le f \le 0.73$$

Constraints from the DM direct search

W.L. Guo, Y.L. Wu, arXiv:1103.5606





CoGeNT+DAMA

Exclude *f* > 0.63

Two excluded regions!

Future experiments

Complex SSDM model as an extention of 2HBDM:SSDM-2HBDM

Left-right symmetric two Higgs bidoublet model:

Y.L. Wu and Y.F. Zhou,0709.0042; 0711.3891

$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

right-handed gauge bosons, right-handed neutrinos and

$$\phi = \begin{pmatrix} \phi_1^0 & \phi_1^+ \\ \phi_2^- & \phi_2^0 \end{pmatrix}, \ \chi = \begin{pmatrix} \chi_1^0 & \chi_1^+ \\ \chi_2^- & \chi_2^0 \end{pmatrix}$$

$$\Delta_{L,R} = \begin{pmatrix} \delta_{L,R}^+/\sqrt{2} & \delta_{L,R}^{++} \\ \delta_{L,R}^0 & -\delta_{L,R}^+/\sqrt{2} \end{pmatrix}$$

P and CP properties:

W.L. Guo, Y.L. Wu and Y.F. Zhou, PRD82,095004(2010)

If we introduce a gauge singlet $S = \frac{S_\sigma + iS_D}{\sqrt{2}}$ with $S \xrightarrow[\text{CP}]{\text{P}} \begin{matrix} S \\ S^* \end{matrix}$ and $S^* \xrightarrow[\text{CP}]{\text{P}} \begin{matrix} S^* \\ S \end{matrix}$

	P	CP		P	CP		P	CP
ϕ	$\phi^\dagger$	ϕ^*	$S + S^*$	+	+	$S - S^*$	+	-
χ	$\chi^\dagger$	χ^*	$S S^*$	+	+	$\mathrm{Tr}(\phi^\dagger \phi)$	+	+
$\Delta_{L(R)}$	$\Delta_{R(L)}$	$\Delta^*_{L(R)}$	$\mathrm{Tr}(\phi^\dagger \tilde{\phi} + \tilde{\phi}^\dagger \phi)$	+	+	$\mathrm{Tr}(\phi^\dagger \tilde{\phi} - \tilde{\phi}^\dagger \phi)$	-	-
S	S	S^*	$\mathrm{Tr}(\Delta_L^\dagger \Delta_L + \Delta_R^\dagger \Delta_R)$	+	+	$\mathrm{Tr}(\Delta_L^\dagger \Delta_L - \Delta_R^\dagger \Delta_R)$	-	+

Unique way!

A light DM mass and DM annihilation

For WIMP: $1\ \text{GeV} \le m_D \le 1\ \text{TeV}$

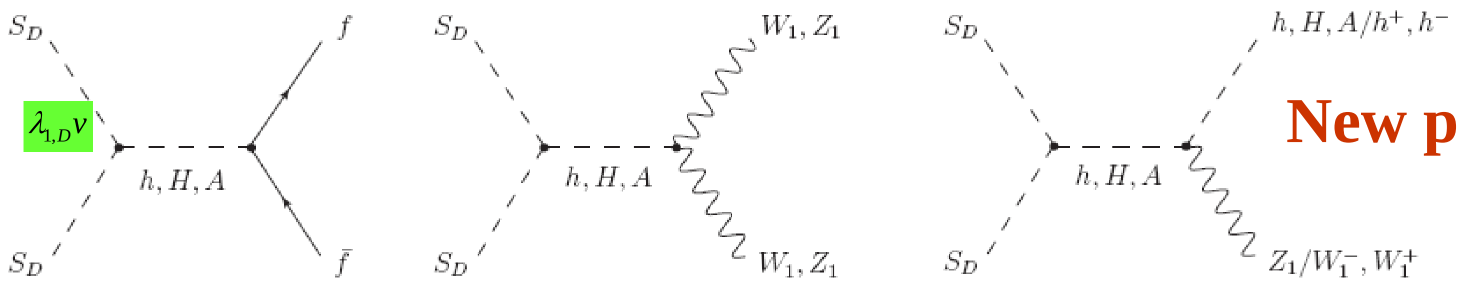
$v_R \sim 10\ \text{TeV} \Rightarrow$ An approximate global symmetry:

$$S \xrightarrow{\text{U(1)}} e^{iq}S \quad \Rightarrow \quad \text{light DM mass}$$

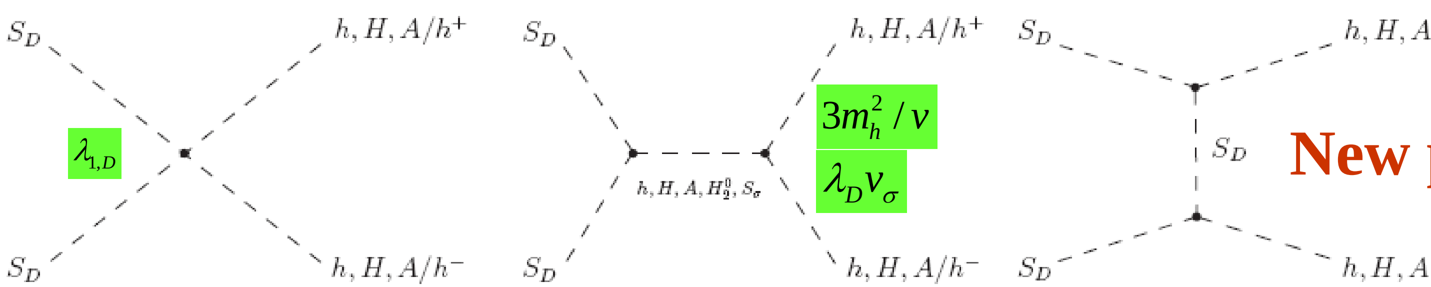
Higgs potential related to the Singlet:

$$\mathcal{V}_S = -\mu_D^2 S S^* + \lambda_D (S S^*)^2 + \sum_{i=1}^{3} \lambda_{i,D} S S^* O_i - \frac{m_D^2}{4}(S - S^*)^2$$

$$O_1 = \text{Tr}(\phi^\dagger \phi),\ O_2 = \text{Tr}(\phi^\dagger \tilde{\phi} + \tilde{\phi}^\dagger \phi) \text{ and } O_3 = \text{Tr}(\Delta_L^\dagger \Delta_L + \Delta_R^\dagger \Delta_R).$$



New processes



New products

Yukawa couplings in the SSDM-2HBDM

$$\phi = \begin{pmatrix} \phi_1^0 & \phi_1^+ \\ \phi_2^- & \phi_2^0 \end{pmatrix}, \ \chi = \begin{pmatrix} \chi_1^0 & \chi_1^+ \\ \chi_2^- & \chi_2^0 \end{pmatrix} \xrightarrow[\kappa_2 \sim w_2 \sim 0]{\text{SSB}} \phi' = \begin{pmatrix} \frac{h_1+v}{\sqrt{2}} & \phi'^+_1 \\ 0 & \phi'^0_2 \end{pmatrix}, \ \chi' = \begin{pmatrix} \frac{h_2+ih_3}{\sqrt{2}} & \chi'^+_1 \\ h^- & \chi'^0_2 \end{pmatrix}$$

Light Higgs mixing:

$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = \begin{pmatrix} c_x c_z & s_x c_z & s_z \\ -c_x s_y s_z - s_x c_y & -s_x s_y s_z + c_x c_y & s_y c_z \\ -c_x c_y s_z + s_x s_y & -s_x c_y s_z - c_x s_y & c_y c_z \end{pmatrix} \begin{pmatrix} h \\ H \\ A \end{pmatrix}$$

Case I: $\theta_x = 60^\circ$, $\theta_y = 60^\circ$, $\theta_z = 150^\circ$

Case II: $\theta_x = 30^\circ$, $\theta_y = 0^\circ$, $\theta_z = 0^\circ$

Case III: $\theta_x = 0^\circ$, $\theta_y = 90^\circ$, $\theta_z = 75^\circ$

Yukawa interactions:

$$-\mathcal{L}_Y = \overline{Q_L}\left(Y^\phi \phi' + \tilde{Y}^\phi \tilde{\phi}' + Y^\chi \chi' + \tilde{Y}^\chi \tilde{\chi}'\right) Q_R + h.c.,$$

Complex symmetric!

$$-\mathcal{L}_{LH} = \frac{h_1 + v_{\rm EW}}{\sqrt{2}}\left(\overline{u'_L} Y^{\phi'} u'_R + \overline{d'_L} \tilde{Y}^{\phi'} d'_R\right) + \frac{h_2 + ih_3}{\sqrt{2}} \overline{u'_L} Y^{\chi'} u'_R + \frac{h_2 - ih_3}{\sqrt{2}} \overline{d'_L} \tilde{Y}^{\chi'} d'_R + h.c.$$

$\Rightarrow$ $Y^{\phi'}_{qq} = \sqrt{2} m_q / v_{\rm EW}$ and $\tilde{Y}^{\phi'}_{qq} = \sqrt{2} m_q / v_{\rm EW}$

$Y^{\chi'}_{qq} = R\, Y^{\phi'}_{qq}$ and $\tilde{Y}^{\chi'}_{qq} = R\, \tilde{Y}^{\phi'}_{qq}$

Diagonal!

$R_q = 1$

$R_l = 10$

Dark matter annihilation in the SSDM-2HBDM

WIMP-nucleon cross section:

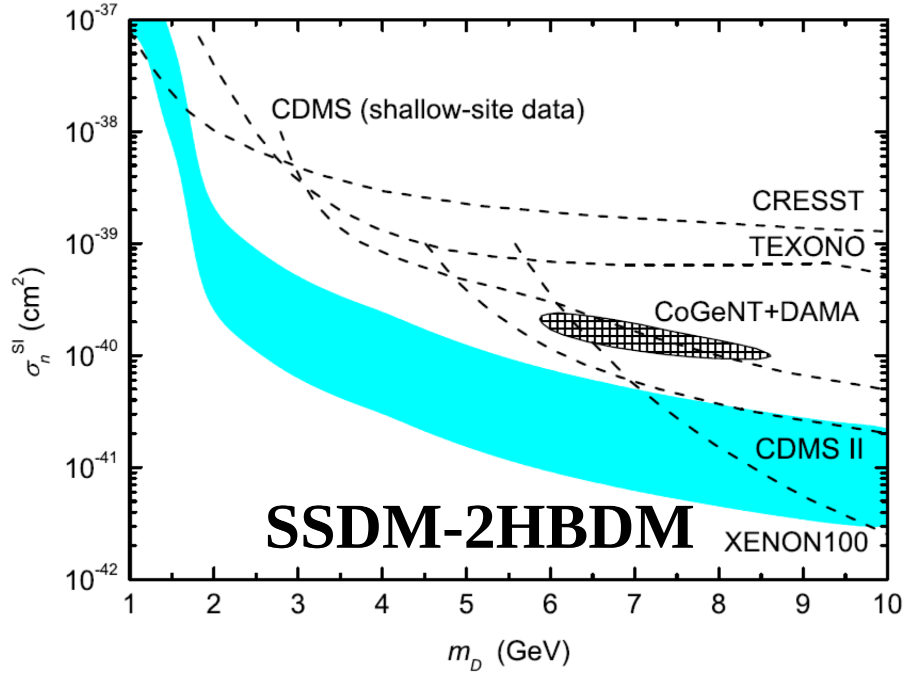
$$\sigma_n^{SI} \approx \frac{\lambda_{1,D}^2}{4\pi} f^2 \frac{m_n^2}{m_D^2} \left(\frac{m_D\, m_n}{m_D + m_n} \right)^2 \left(\frac{f_1}{m_h^2} + \frac{f_3}{m_H^2} + \frac{f_5}{m_A^2} \right)^2$$

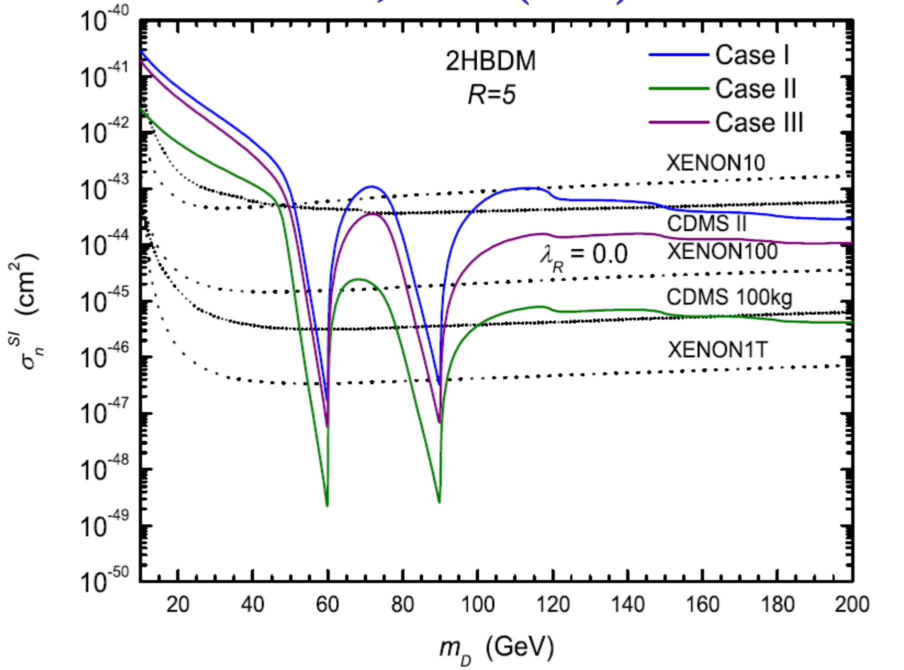
$$f_1 = c_x c_z - R c_y s_x - R c_x s_y s_z \,,$$

$$f_3 = R c_x c_y + c_z s_x - R s_x s_y s_z \,,$$

$$f_5 = R s_y c_z + s_z \,,$$

W.L. Guo, Y.L. Wu, Y.F. Zhou, PRD82,095004(2010)





DM capture and annihilation rates

The evolution of DM number in the Sun:

$$\dot{N} = C_\odot - C_E N - C_A N^2$$

$$C_\odot \approx 4.8\times 10^{24}\,\mathrm{s}^{-1}\frac{\rho_{\rm DM}}{0.3\,\mathrm{GeV/cm^3}}\frac{270\,\mathrm{km/s}}{\bar{v}}\frac{1\mathrm{GeV}}{m_D}\sum_i F_i(m_D)\frac{\sigma^{\rm SI}_{{\rm N}_i}}{10^{-40}\mathrm{cm}^2}f_i\phi_i S\left(\frac{m_D}{m_{{\rm N}_i}}\right)\frac{1\mathrm{GeV}}{m_{{\rm N}_i}}$$

G. Jungman, M. Kamionkowski, K. Griest Phys. Rept. 267, 195 (1996)

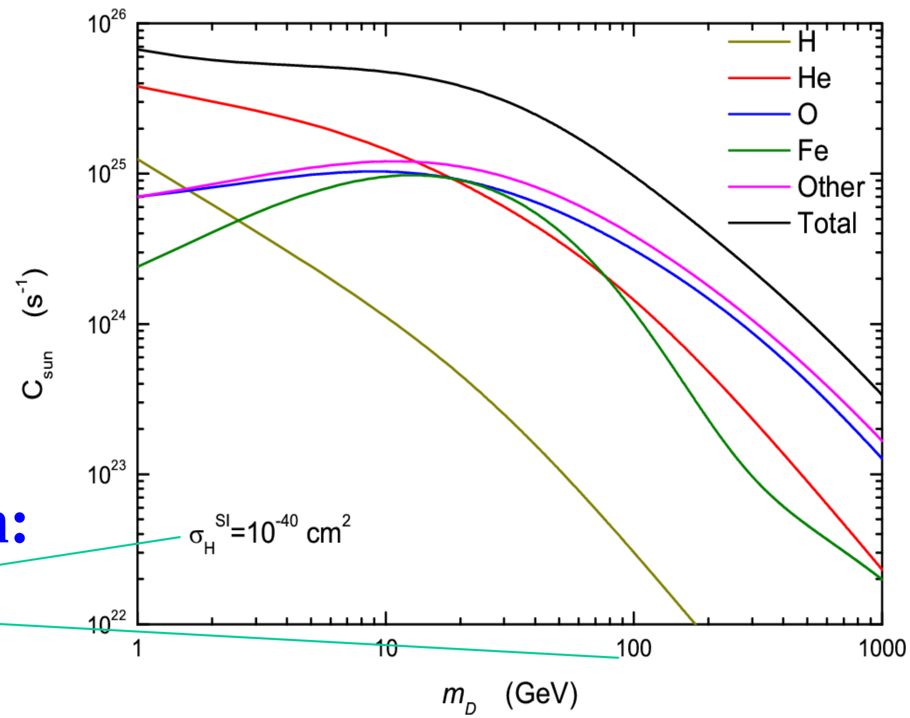
$$C_E \approx 10^{-3.5(m_D/\mathrm{GeV})-4}\mathrm{s}^{-1}\frac{\sigma^{\rm SI}_{\rm H}}{5\times 10^{-39}\mathrm{cm}^2}$$

$$C_A = \frac{\langle\sigma v\rangle}{V_{\rm eff}}\,,\quad V_{\rm eff} = 5.8\times 10^{30}\ \mathrm{cm}^3\left(\frac{1\mathrm{GeV}}{m_D}\right)^{3/2}$$

DM annihilation rate in the Sun:

$$\Gamma_{\rm ANN} = \frac{1}{2}C_A N^2 = \frac{1}{2}C_\odot \tanh^2(t_\odot\sqrt{C_\odot C_A})$$

$>> 1$

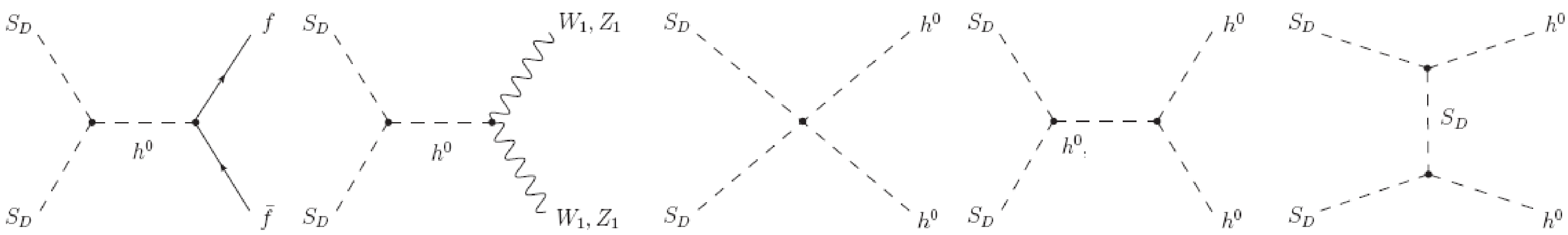


Total captured DM mass in the Sun:

M_DM~ 2*10^17 g

M_Sun= 2*10^33 g

The neutrino fluxes at the surface of Earth



$$\frac{d\Phi_{\nu_\mu}}{dE_{\nu_\mu}} = \frac{\Gamma_{\rm ANN}}{4\pi R^2}\frac{dN_{\nu_\mu}}{dE_{\nu_\mu}}$$

$$\frac{dN_{\nu_\mu}}{dE_{\nu_\mu}} = \sum_{fs} B_{fs} \boxed{\frac{dN^{fs}_{\nu_\mu}}{dE_{\nu_\mu}}},$$

- Final state interactions
- Neutrino interactions
- Neutrino oscillations

T. Schwetz, et. al., 0808.2016V3

$$\sin^2\theta_{12} = 0.318,\quad \sin^2\theta_{23} = 0.50,\quad \sin^2\theta_{13} = 0.0,$$

$$\Delta m^2_{21} = 7.59\times 10^{-5}\mathrm{eV}^2,\quad \Delta m^2_{31} = 2.40\times 10^{-3}\mathrm{eV}^2.$$

WIMPSIM !

M. Blennow, et. al., 0709.3898

Neutrino induced upward muon flux in Super-K

Neutrino induced upward muon flux:

$$\Phi_\mu = \int_{E_{\rm thr}^{\rm SK}}^{m_D} dE_\mu \int_{E_\mu}^{m_D} dE_{\nu_\mu} \frac{d\Phi_{\nu_\mu}}{dE_{\nu_\mu}} \int_0^\infty dL \int_{E_\mu}^{E_{\nu_\mu}} dE'_\mu g(L, E_\mu, E'_\mu) \sum_{a=p,n} \frac{d\sigma^a_{\nu_\mu}(E_{\nu_\mu}, E'_\mu)}{dE'_\mu}\rho_a$$
$$+(\nu_\mu \to \bar{\nu}_\mu),$$

E_{thr} = 1.6 GeV

$$\rho_p \approx 1/2N_A\rho \text{ and } \rho_n \approx 1/2N_A\rho$$

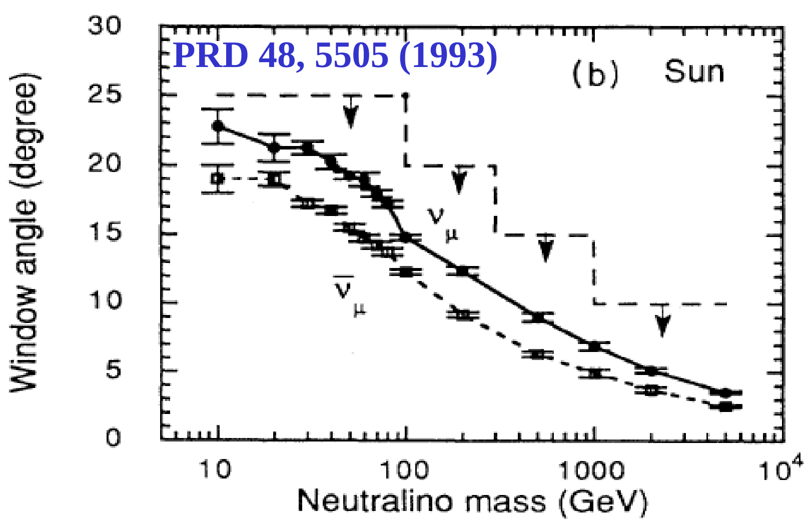
Approximation: **T.K. Gaisser and T. Stanev, PRD 30,985 (1984)**

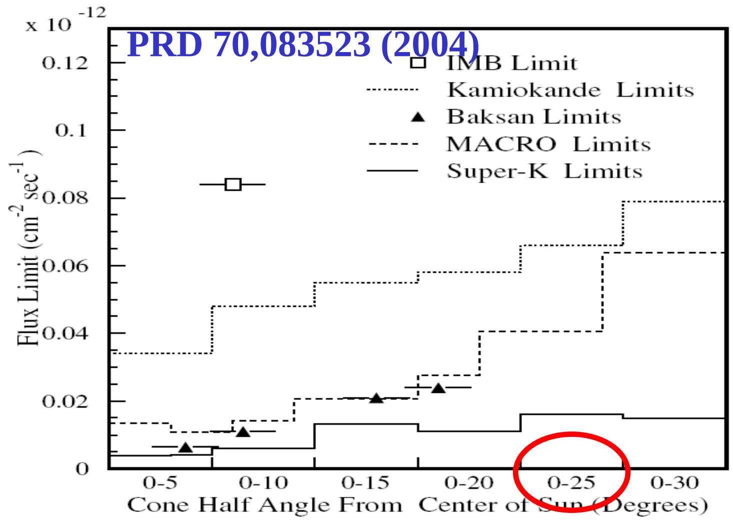
g is the probability that a muon of initial energy E`_\mu has energy E_\mu after propagating a distance L in rock.

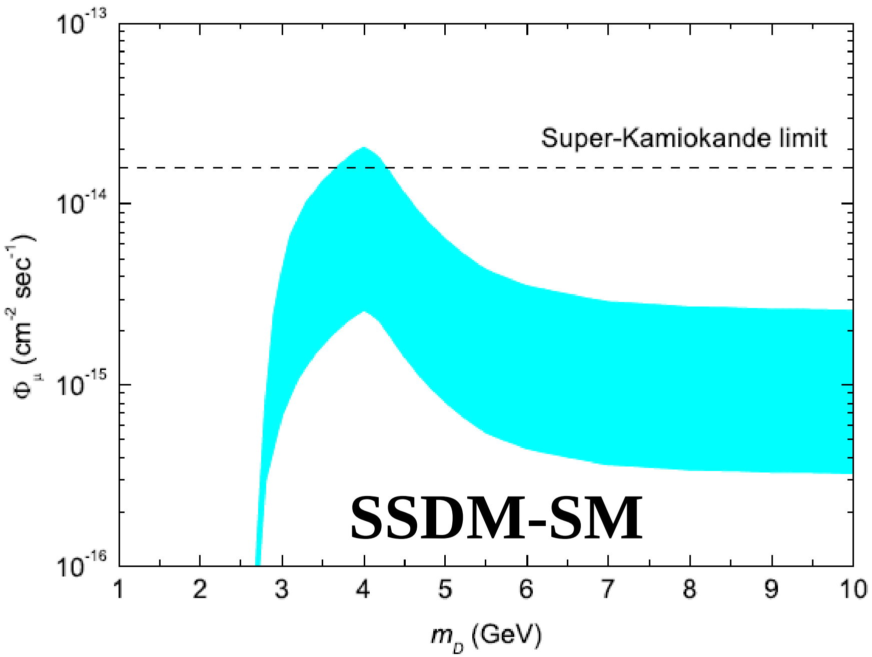
$$g(L, E_\mu, E'_\mu) = \frac{\delta(L - L_0)}{\rho(\alpha + \beta E_\mu)}, \qquad L_0 = \frac{1}{\rho\beta} \ln \frac{\alpha + \beta E'_\mu}{\alpha + \beta E_\mu},$$

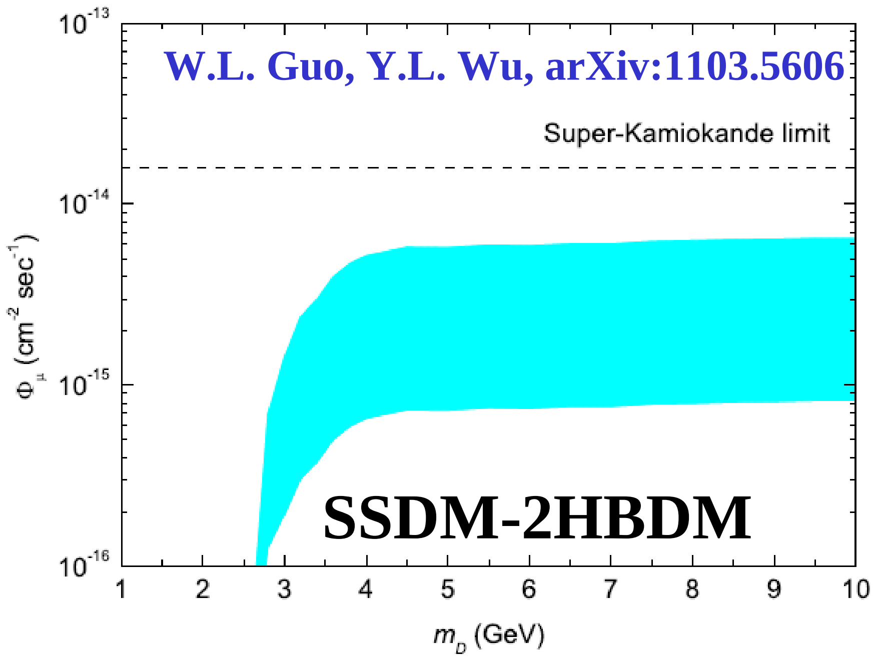
$$\Phi_\mu = \int_{E_{\rm thr}^{\rm SK}}^{m_D} dE_\mu \frac{1}{\rho(\alpha + \beta E_\mu)} \int_{E_\mu}^{m_D} dE_{\nu_\mu} \frac{d\Phi_{\nu_\mu}}{dE_{\nu_\mu}} \int_{E_\mu}^{E_{\nu_\mu}} dE'_\mu \sum_{a=p,n} \frac{d\sigma^a_{\nu_\mu}(E_{\nu_\mu}, E'_\mu)}{dE'_\mu}\rho_a + (\nu_\mu \to \bar{\nu}_\mu).$$

Super-K results (1)

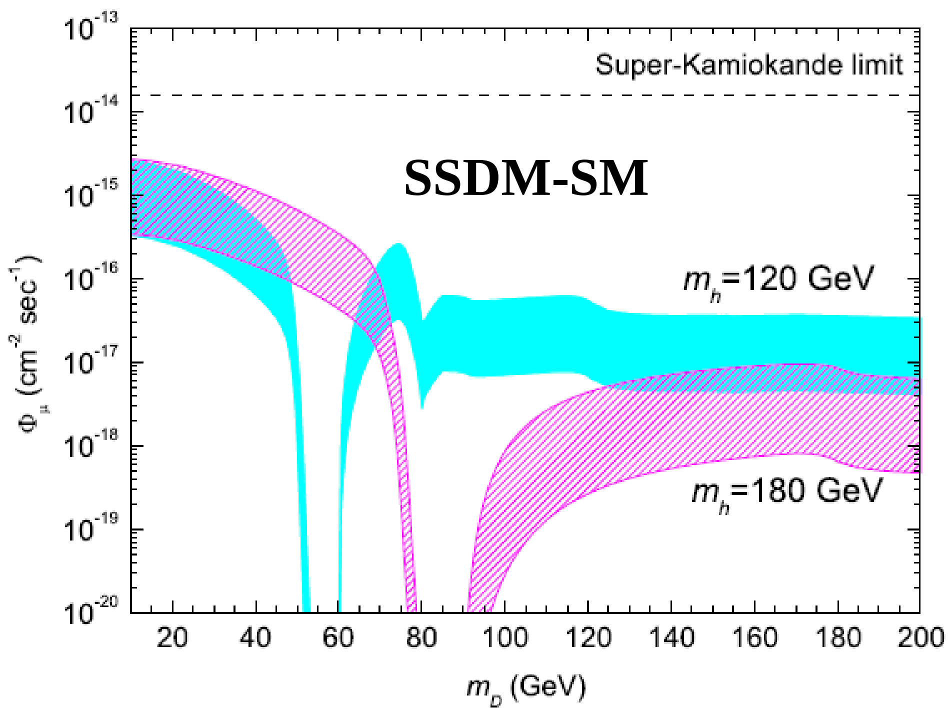


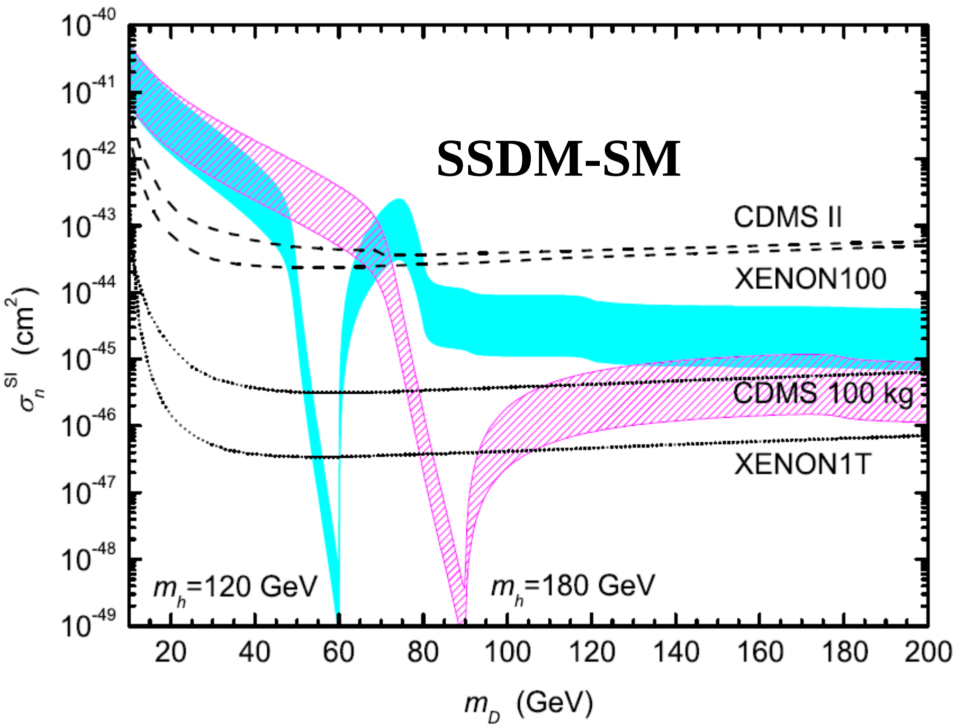






Super-K results (2)





SSDM-2HBDM!

IceCube

Neutrino induced upward muon numbers per year :

$$N_\mu = \int_{E_{\rm thr}^{\rm IC}}^{m_D} dE_\mu A_{\rm eff}(E_\mu) \frac{\langle R(\cos\theta_z)\rangle}{2} \frac{1}{\rho(\alpha+\beta E_\mu)} \int_{E_\mu}^{m_D} dE_{\nu_\mu} \frac{d\Phi_{\nu_\mu}}{dE_{\nu_\mu}} \int_{E_\mu}^{E_{\nu_\mu}} dE'_\mu \sum_{a=p,n} \frac{d\sigma^a_{\nu_\mu}(E_{\nu_\mu}, E'_\mu)}{dE'_\mu}\rho_a + (\nu_\mu \to \bar{\nu}_\mu)$$

E_{thr} = 50 GeV

$\rho_p \approx 5/9 N_A \rho$ and $\rho_n \approx 4/9 N_A \rho$

Effective area:

M.C. Gonzalez-Garcia, F. Halzen, S. Mohapatra, 0902.1176

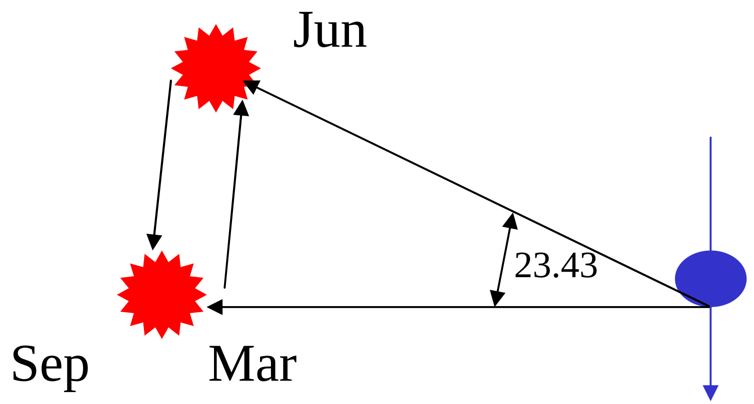
$$A_{\rm eff}(E_\mu \le 10^{1.6}{\rm GeV}) = 0,$$

$$A_{\rm eff}(10^{1.6}{\rm GeV} < E_\mu < 10^{2.8}{\rm GeV}) = 0.748[\log(E_\mu/{\rm GeV}) - 1.6]\,{\rm km}^2,$$

$$A_{\rm eff}(E_\mu \ge 10^{2.8}{\rm GeV}) = 0.9 + 0.54[\log(E_\mu/{\rm GeV}) - 2.8]\,{\rm km}^2.$$

Average R:

$$R(\cos\theta_z) = 0.92 - 0.45\cos\theta_z$$



Atmosphere Background

Atmosphere Background: $\left\langle \frac{d\Phi_{\nu_\mu}}{dE_{\nu_\mu}}(\cos\theta_z)R(\cos\theta_z) \right\rangle$

TABLE XXII. ν_μ flux (m^{-2} sec^{-1} sr^{-1} GeV^{-1}) above 10 GeV.

	cosθ_z										
E_ν (GeV)	1.–.9	.9–.8	.8–.7	.7–.6	.6–.5	.5–.4	.4–.3	.3–.2	.2–.1	.1–.0	*Norm*
1.000×10^1	2.557	2.625	2.703	2.799	2.911	3.052	3.232	3.482	3.824	4.172	10^{-1}
1.259×10^1	1.295	1.331	1.370	1.419	1.479	1.554	1.646	1.778	1.964	2.166	10^{-1}
1.585×10^1	0.654	0.673	0.694	0.720	0.751	0.789	0.840	0.906	1.009	1.121	10^{-1}
1.995×10^1	3.297	3.397	3.505	3.653	3.811	4.001	4.269	4.612	5.154	5.807	10^{-2}
2.512×10^1	1.659	1.710	1.770	1.848	1.930	2.033	2.167	2.349	2.627	2.997	10^{-2}
3.162×10^1	0.831	0.858	0.891	0.931	0.974	1.033	1.100	1.197	1.340	1.542	10^{-2}
3.981×10^1	4.144	4.291	4.463	4.663	4.898	5.205	5.572	6.091	6.852	7.935	10^{-3}
5.012×10^1	2.055	2.136	2.225	2.329	2.457	2.612	2.819	3.085	3.482	4.051	10^{-3}
6.310×10^1	1.014	1.056	1.104	1.161	1.228	1.308	1.420	1.556	1.762	2.059	10^{-3}
7.943×10^1	0.499	0.519	0.545	0.576	0.609	0.653	0.710	0.783	0.897	1.054	10^{-3}
1.000×10^2	2.443	2.551	2.679	2.838	3.012	3.248	3.541	3.930	4.524	5.345	10^{-4}
1.259×10^2	1.194	1.253	1.315	1.394	1.487	1.606	1.761	1.967	2.259	2.676	10^{-4}
1.585×10^2	0.583	0.611	0.643	0.684	0.732	0.790	0.869	0.979	1.129	1.338	10^{-4}
1.995×10^2	2.837	2.969	3.134	3.340	3.568	3.876	4.270	4.843	5.619	6.676	10^{-5}
2.512×10^2	1.371	1.439	1.521	1.621	1.732	1.897	2.092	2.384	2.785	3.322	10^{-5}
3.162×10^2	0.658	0.695	0.737	0.786	0.844	0.923	1.022	1.168	1.378	1.646	10^{-5}
3.981×10^2	3.146	3.328	3.547	3.792	4.096	4.482	4.988	5.700	6.771	8.124	10^{-6}
5.012×10^2	1.496	1.585	1.696	1.819	1.975	2.171	2.425	2.776	3.308	3.990	10^{-6}
6.310×10^2	0.706	0.753	0.806	0.869	0.949	1.045	1.172	1.353	1.617	1.950	10^{-6}
7.943×10^2	3.307	3.537	3.807	4.123	4.521	5.008	5.643	6.568	7.855	9.512	10^{-7}
1.000×10^3	1.535	1.643	1.781	1.940	2.133	2.386	2.708	3.167	3.796	4.634	10^{-7}
1.259×10^3	0.705	0.759	0.825	0.905	1.001	1.125	1.288	1.515	1.840	2.250	10^{-7}
1.585×10^3	0.320	0.347	0.378	0.418	0.465	0.526	0.608	0.722	0.886	1.088	10^{-7}
1.995×10^3	1.441	1.568	1.717	1.908	2.141	2.439	2.848	3.416	4.222	5.239	10^{-8}
2.512×10^3	0.643	0.702	0.775	0.861	0.973	1.119	1.318	1.597	2.007	2.511	10^{-8}
3.162×10^3	0.285	0.312	0.346	0.387	0.438	0.508	0.605	0.742	0.945	1.197	10^{-8}
3.981×10^3	1.251	1.375	1.530	1.724	1.965	2.286	2.757	3.422	4.400	5.675	10^{-9}
5.012×10^3	0.548	0.602	0.675	0.759	0.878	1.024	1.243	1.553	2.047	2.670	10^{-9}
6.310×10^3	0.238	0.264	0.296	0.335	0.389	0.457	0.556	0.706	0.944	1.237	10^{-9}
7.943×10^3	1.032	1.156	1.284	1.473	1.694	2.021	2.466	3.196	4.304	5.676	10^{-10}
1.000×10^4	0.444	0.497	0.556	0.635	0.732	0.882	1.079	1.410	1.946	2.615	10^{-10}

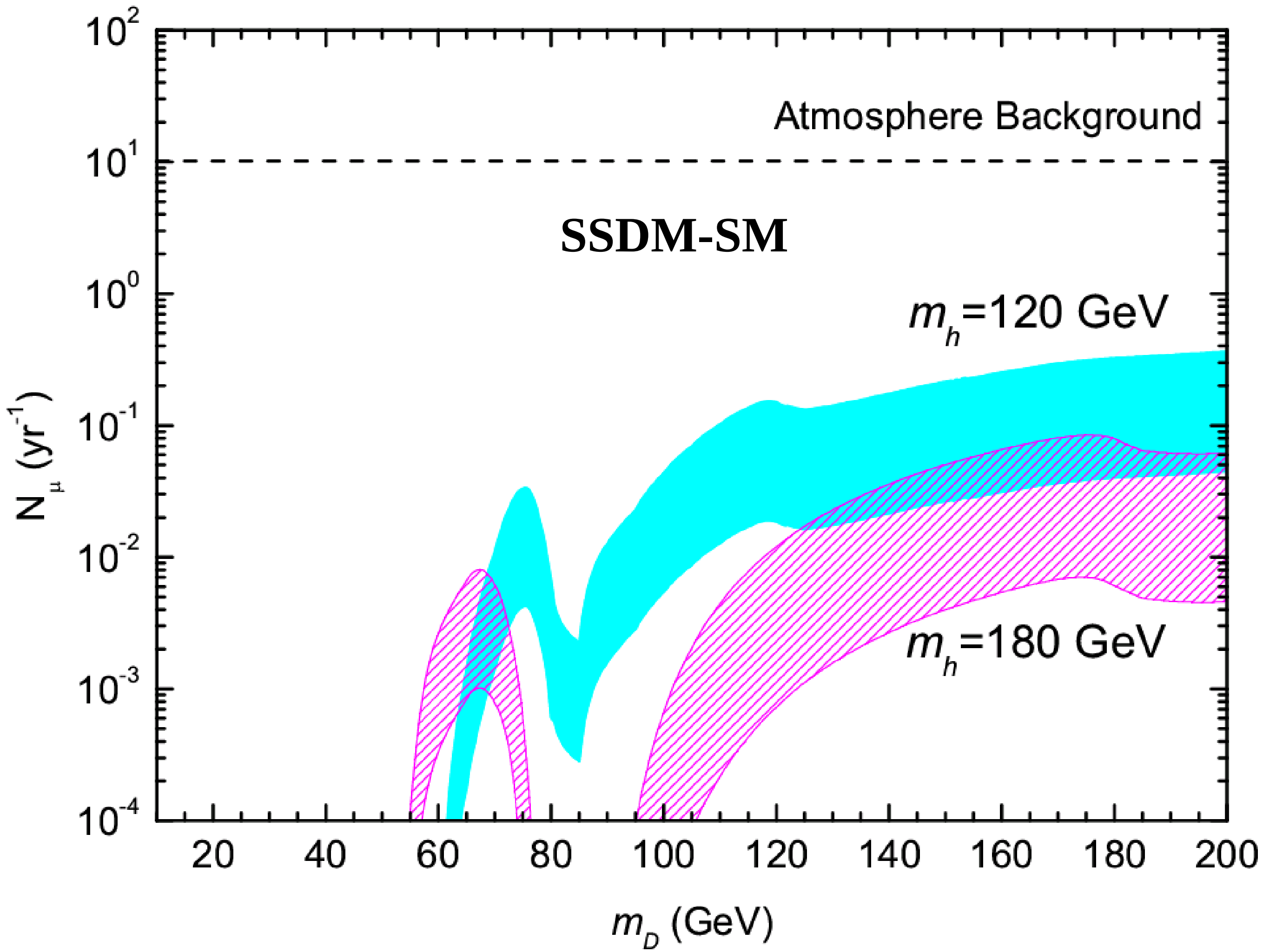
M. Honda, et. al, PRD 75,043006 (2007)

Take half-angle to be 2 degree!

E_\mu **from 50 to 200 GeV**

10.2 yr^-1

IceCube results



Summary

- The current DM direct search experiments can exclude parts of parameter space: f>0.63 (m_D <10), 8<m_D< 50GeV......
- The predicted muon fluxes in 3.7<m_D<4.2 GeV and f>0.65 slightly exceed the SK limit. The CDMS excludes this region.
- For the SSDM-2HBDM, one can adjust the Yukawa couplings to avoid the direct detection limits and enhance the predicted muon fluxes.
- For the allowed parameter space of SSDM-SM and SSDM-2HBDM, the predicted muon fluxes in Super-K and the muon event rates in IceCube are less than the Super-K limits and atmosphere background, respectively.

Thanks !