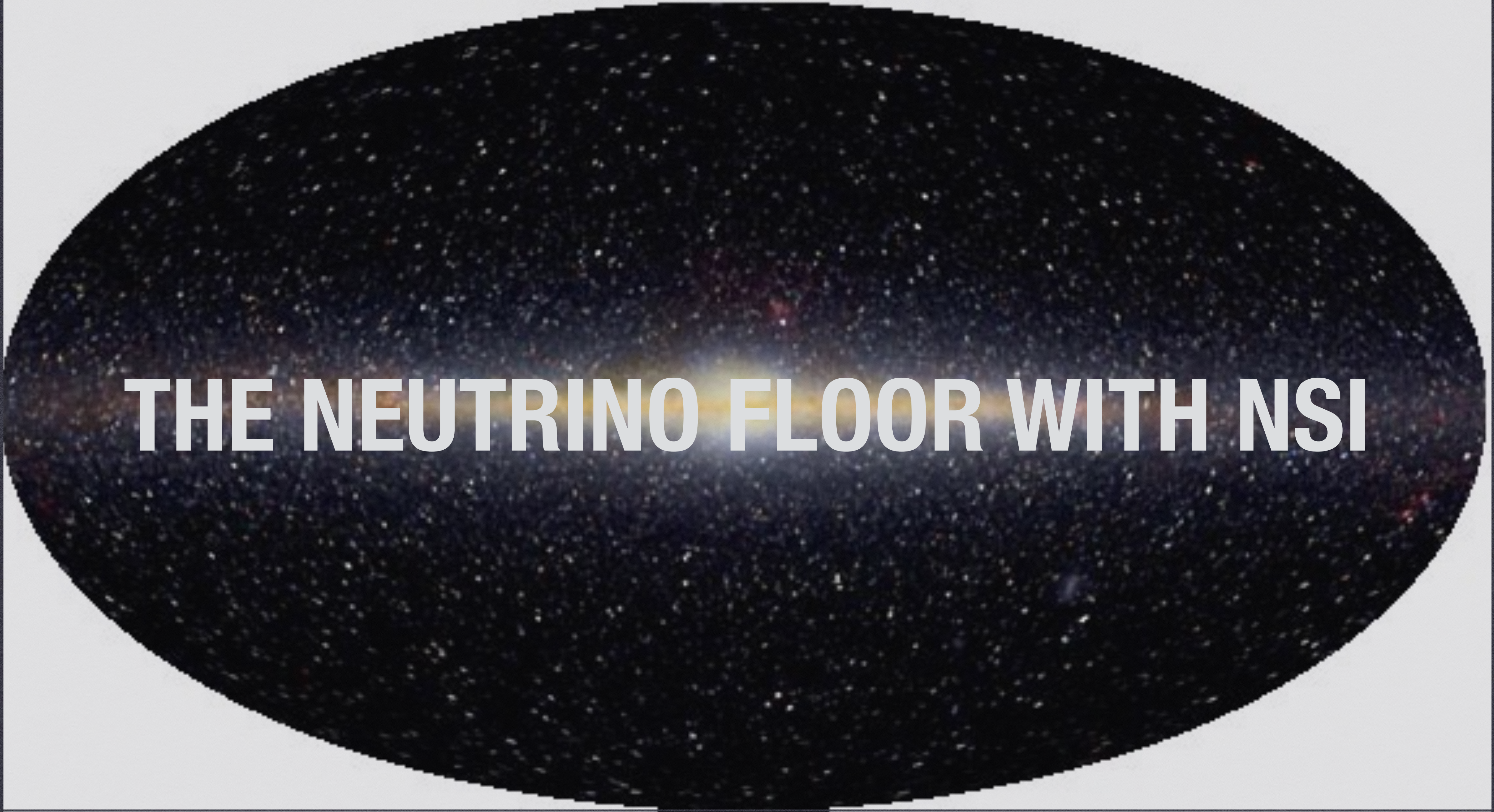


THE NEUTRINO FLOOR WITH NSI

WEI CHAO

BEIJING NORMAL UNIVERSITY

2019.07.22@Flasy2019

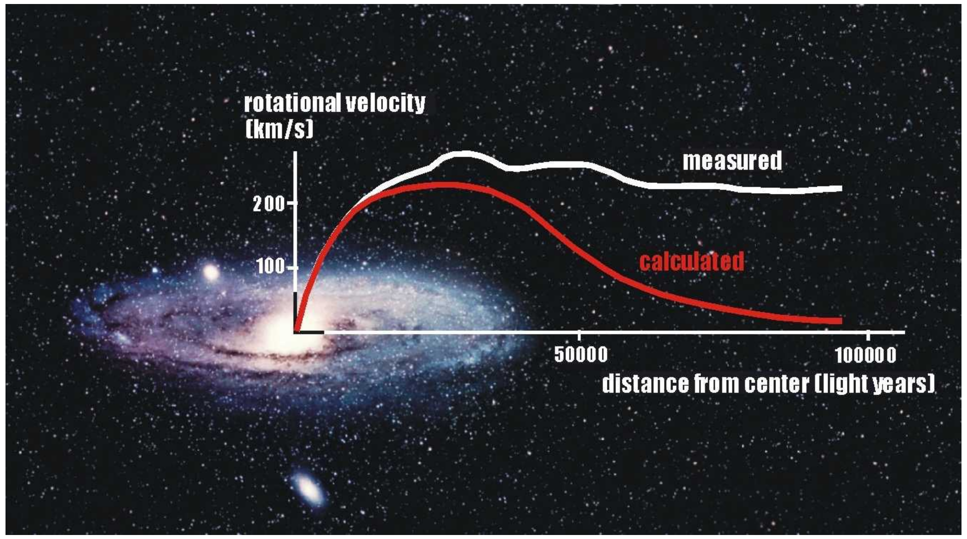
Preview

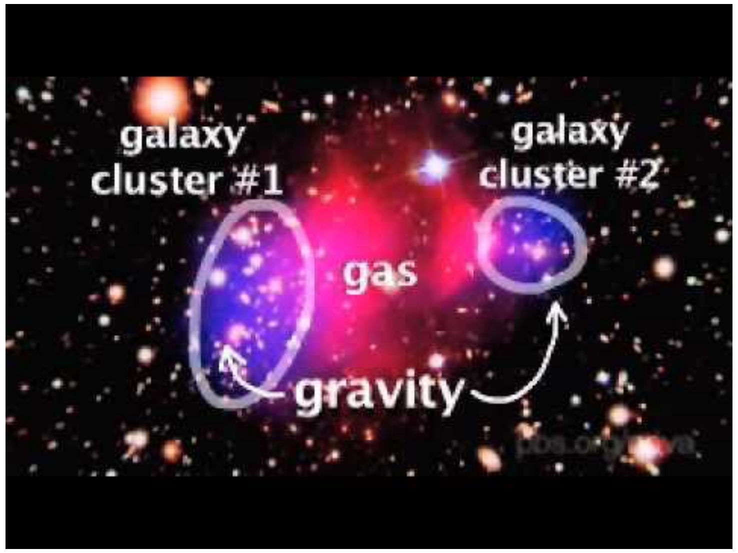
We study impacts of non-standard neutrino interactions to the neutrino floor

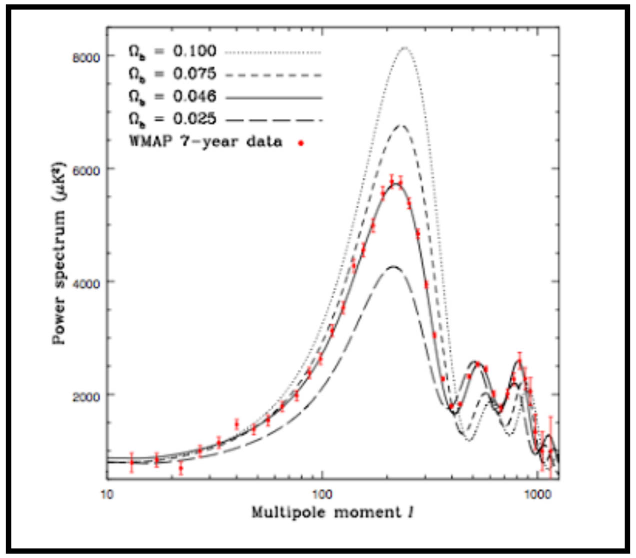
NSI	Enhancement	Estimated values
Vector	✓	~several times
Axial-vector	✗	✗
Tensor	✗	✗
Scalar	✓	~several times
Pseudo-scalar	✓	~30%

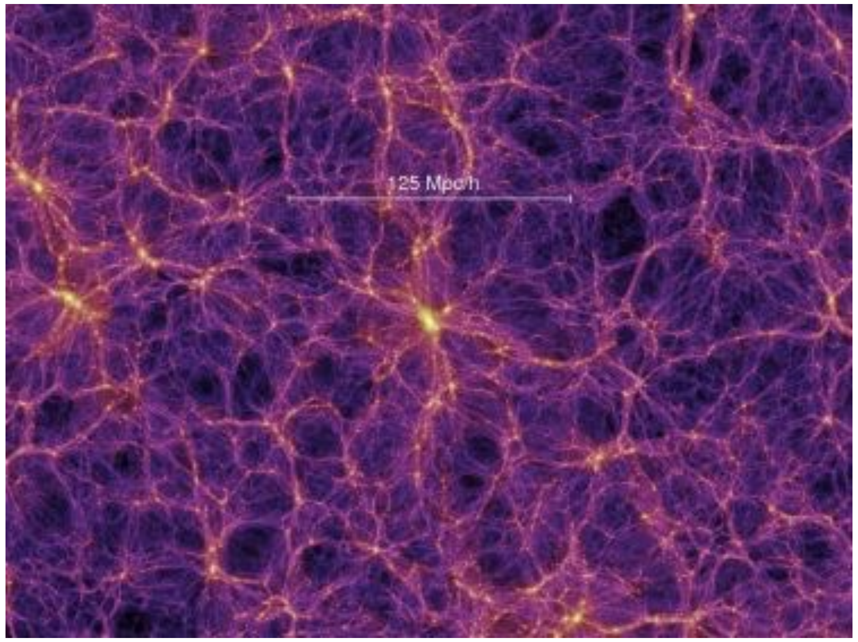
Wei Chao, J. Zhang, X. Wang and X. Zhang, arXiv:1904.11214

Evidence of DM

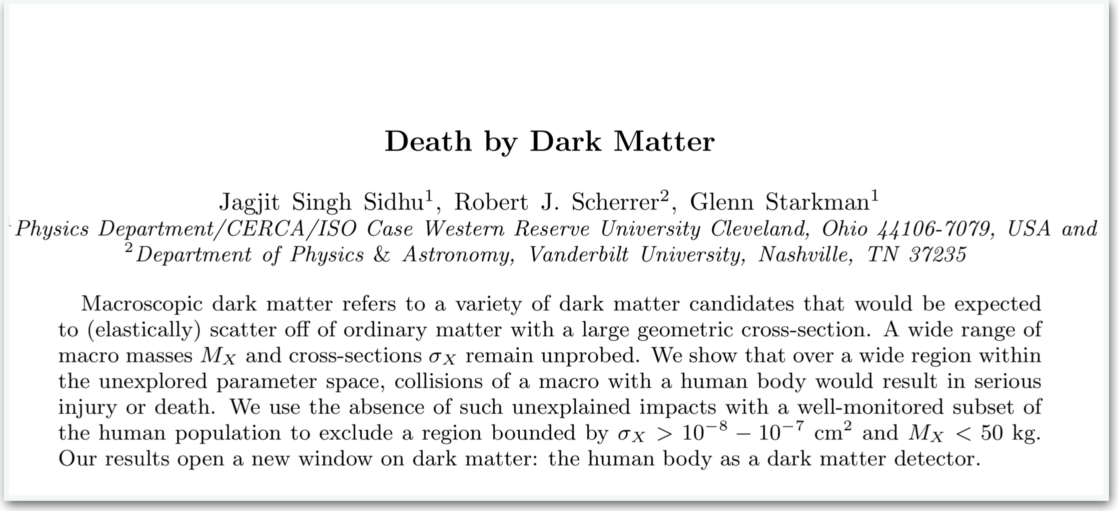








DM incidents, 1907.06674



Death by Dark Matter

Jagjit Singh Sidhu[1], Robert J. Scherrer[2], Glenn Starkman[1]
[1]Physics Department/CERCA/ISO Case Western Reserve University Cleveland, Ohio 44106-7079, USA and
[2]Department of Physics & Astronomy, Vanderbilt University, Nashville, TN 37235

Macroscopic dark matter refers to a variety of dark matter candidates that would be expected to (elastically) scatter off of ordinary matter with a large geometric cross-section. A wide range of macro masses M_X and cross-sections σ_X remain unprobed. We show that over a wide region within the unexplored parameter space, collisions of a macro with a human body would result in serious injury or death. We use the absence of such unexplained impacts with a well-monitored subset of the human population to exclude a region bounded by $\sigma_X > 10^{-8} - 10^{-7}$ cm^2 and $M_X < 50$ kg. Our results open a new window on dark matter: the human body as a dark matter detector.

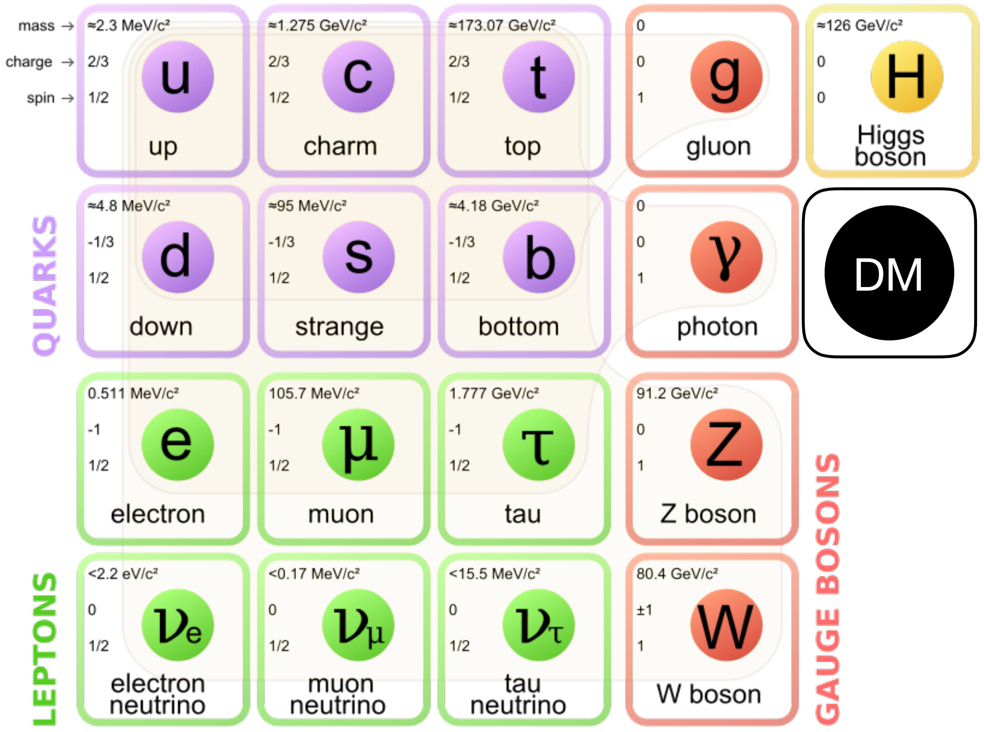
What is dark matter

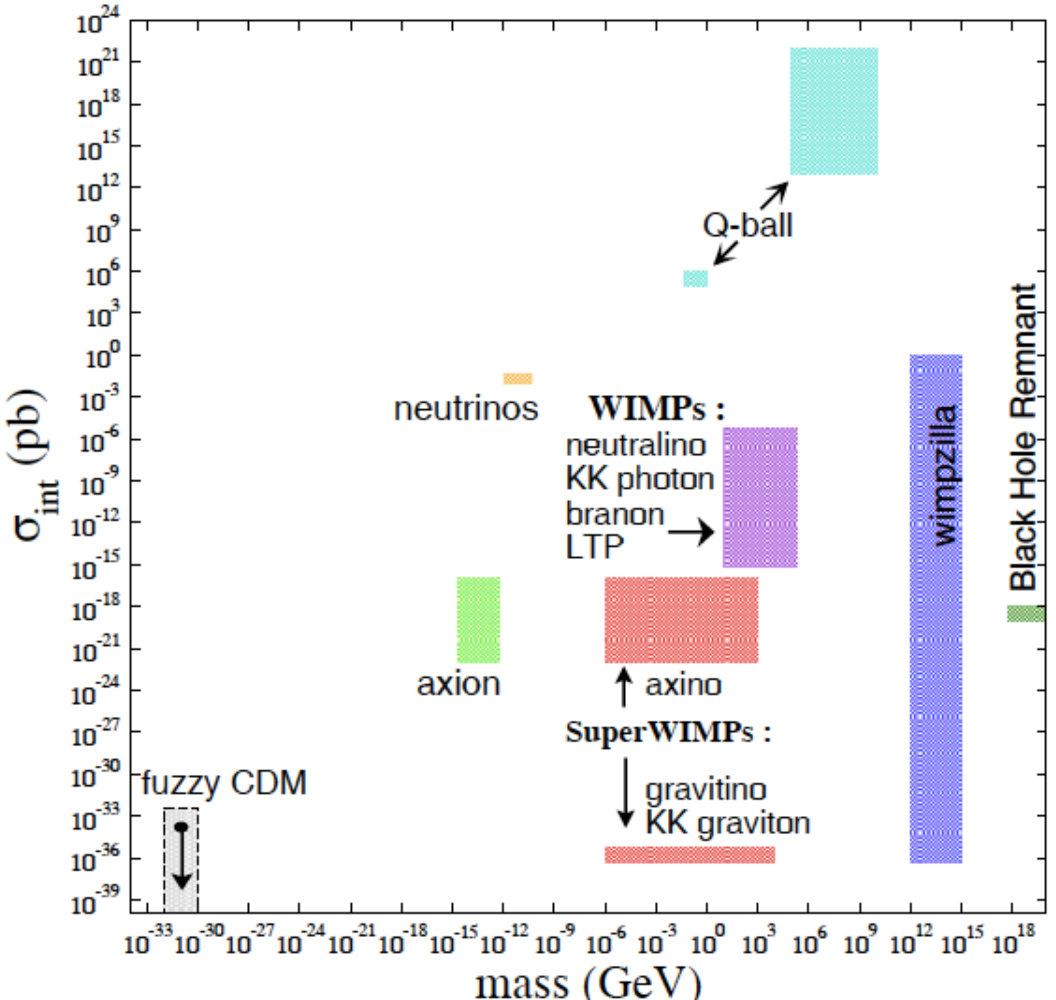
We do not exactly know!

Mass ✗ Spin ✗ Interactions ✗

Neutral, non-baryonic, weakly interacting particle!

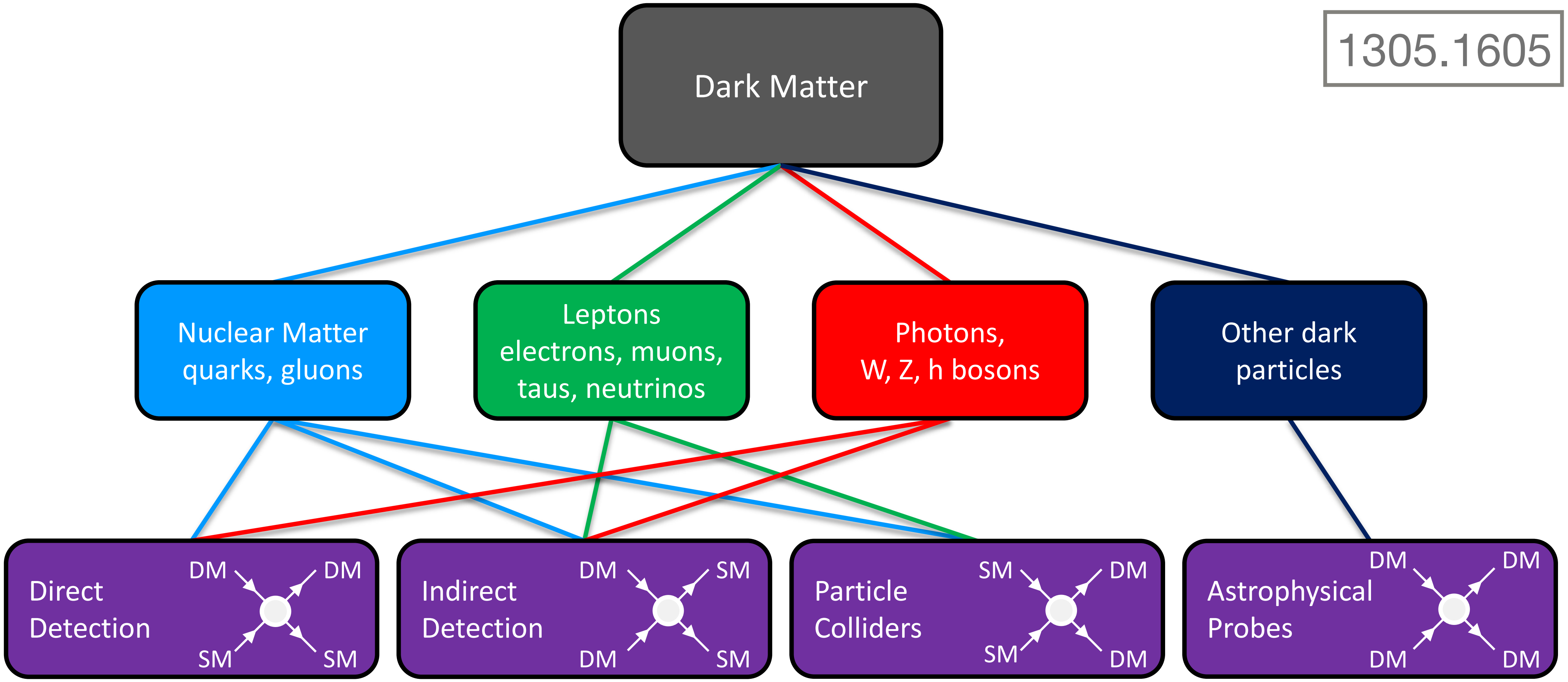
Particle Zoo





Ways of probing DM

1305.1605



Dark Matter

Nuclear Matter
quarks, gluons

Leptons
electrons, muons,
taus, neutrinos

Photons,
W, Z, h bosons

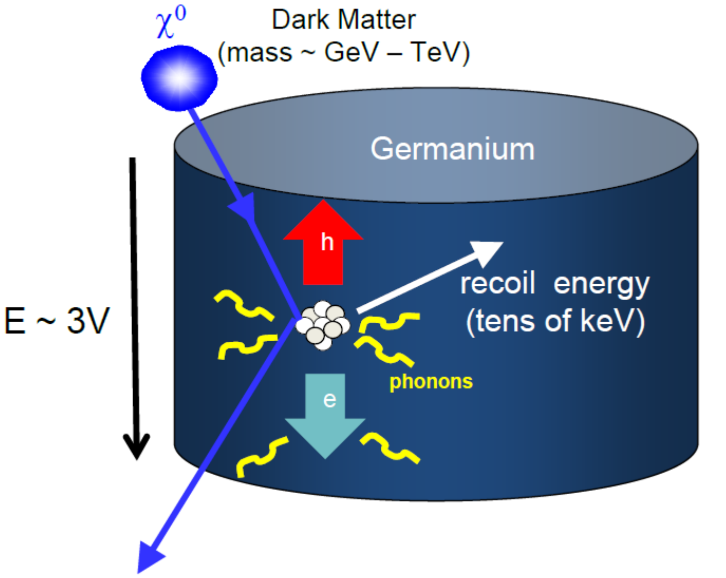
Other dark
particles

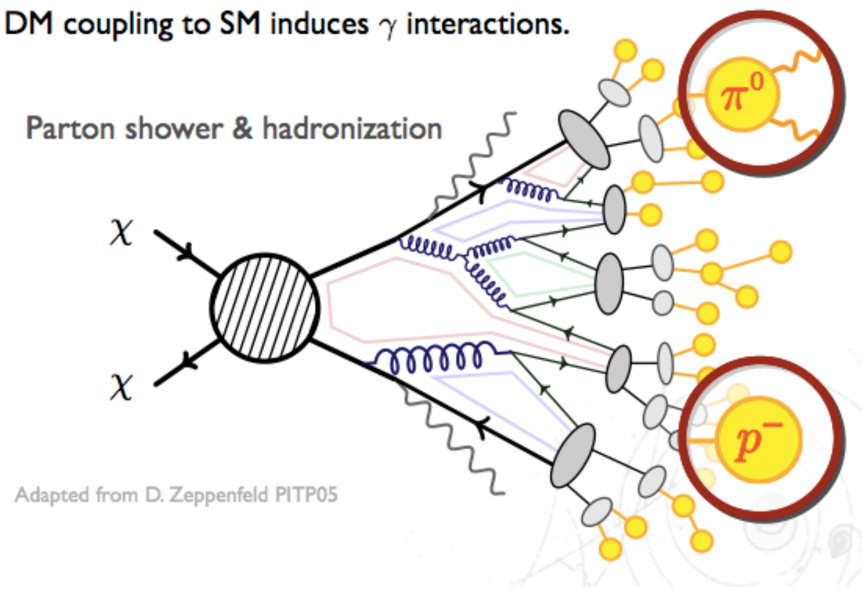
Direct
Detection

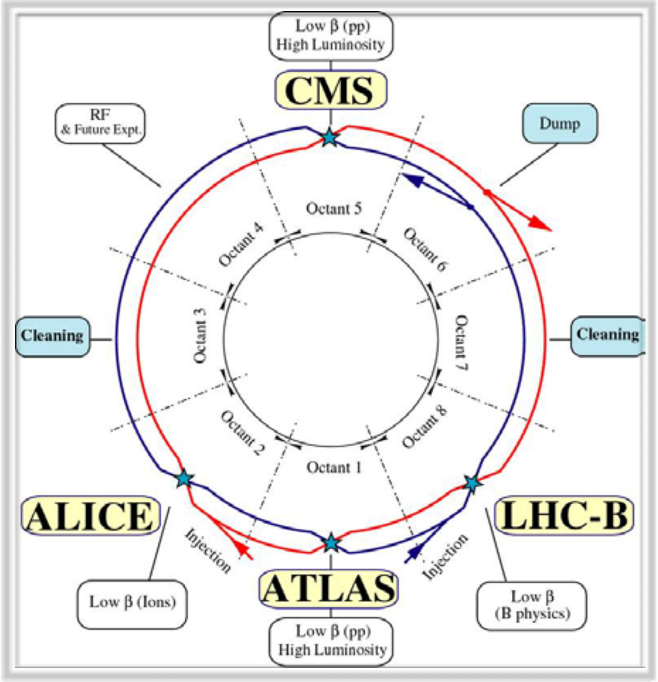
Indirect
Detection

Particle
Colliders

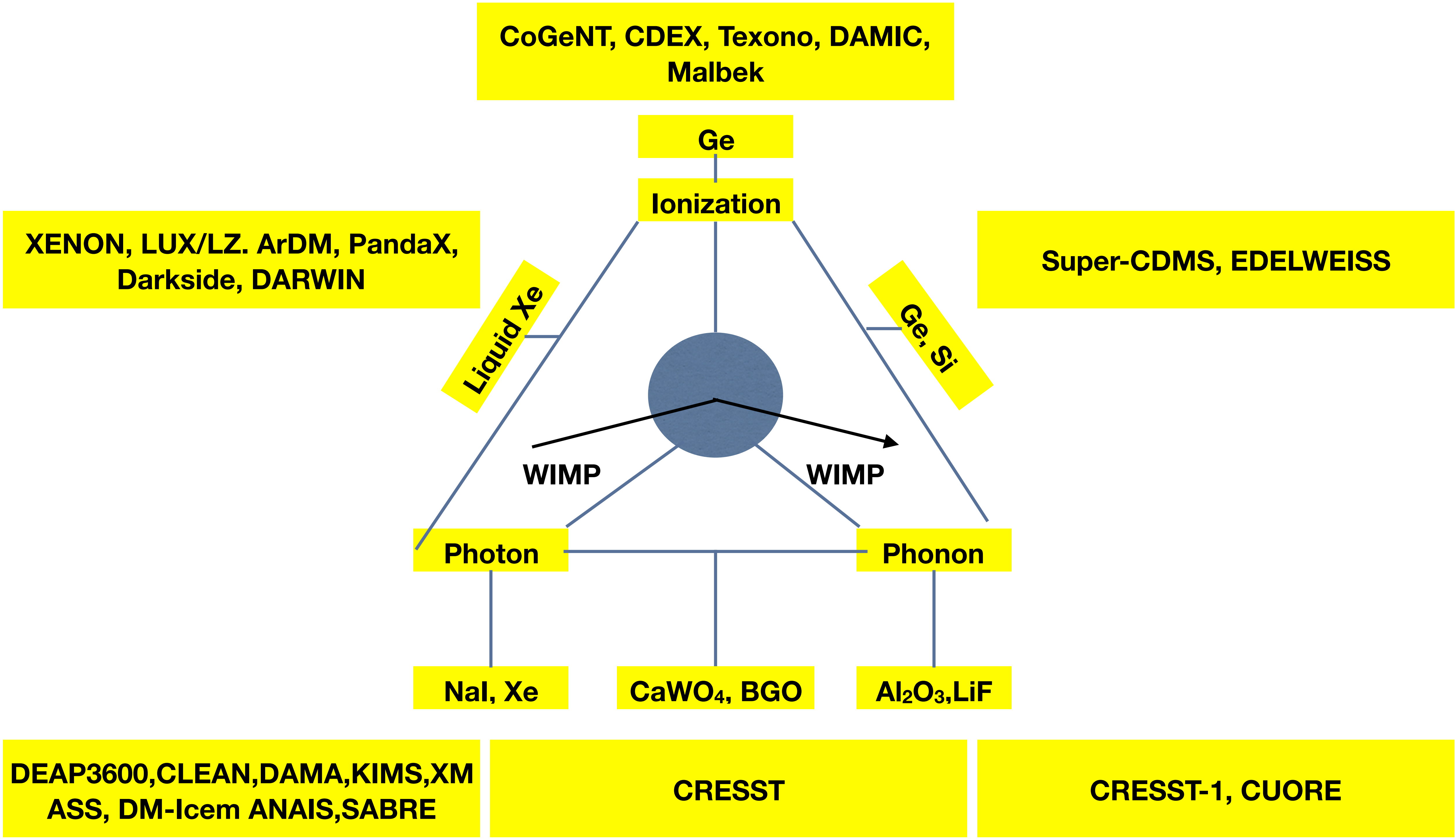
Astrophysical
Probes







Detecting technologies



CoGeNT, CDEX, Texono, DAMIC, Malbek

Ge

Ionization

XENON, LUX/LZ. ArDM, PandaX, Darkside, DARWIN

Liquid Xe

Super-CDMS, EDELWEISS

Ge, Si

WIMP

WIMP

Photon

Phonon

NaI, Xe

CaWO$_4$, BGO

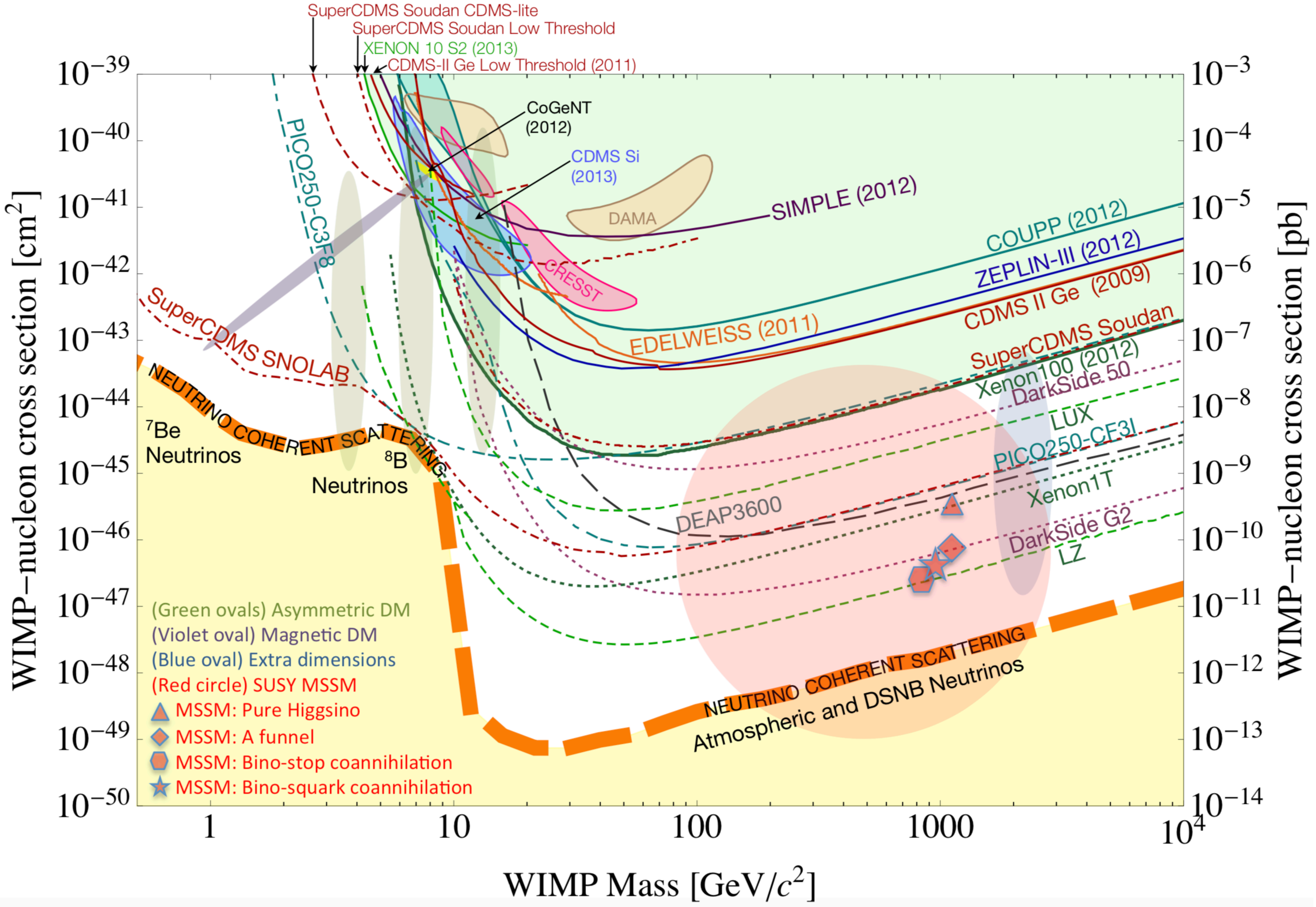
Al$_2$O$_3$,LiF

DEAP3600,CLEAN,DAMA,KIMS,XMASS, DM-Icem ANAIS,SABRE

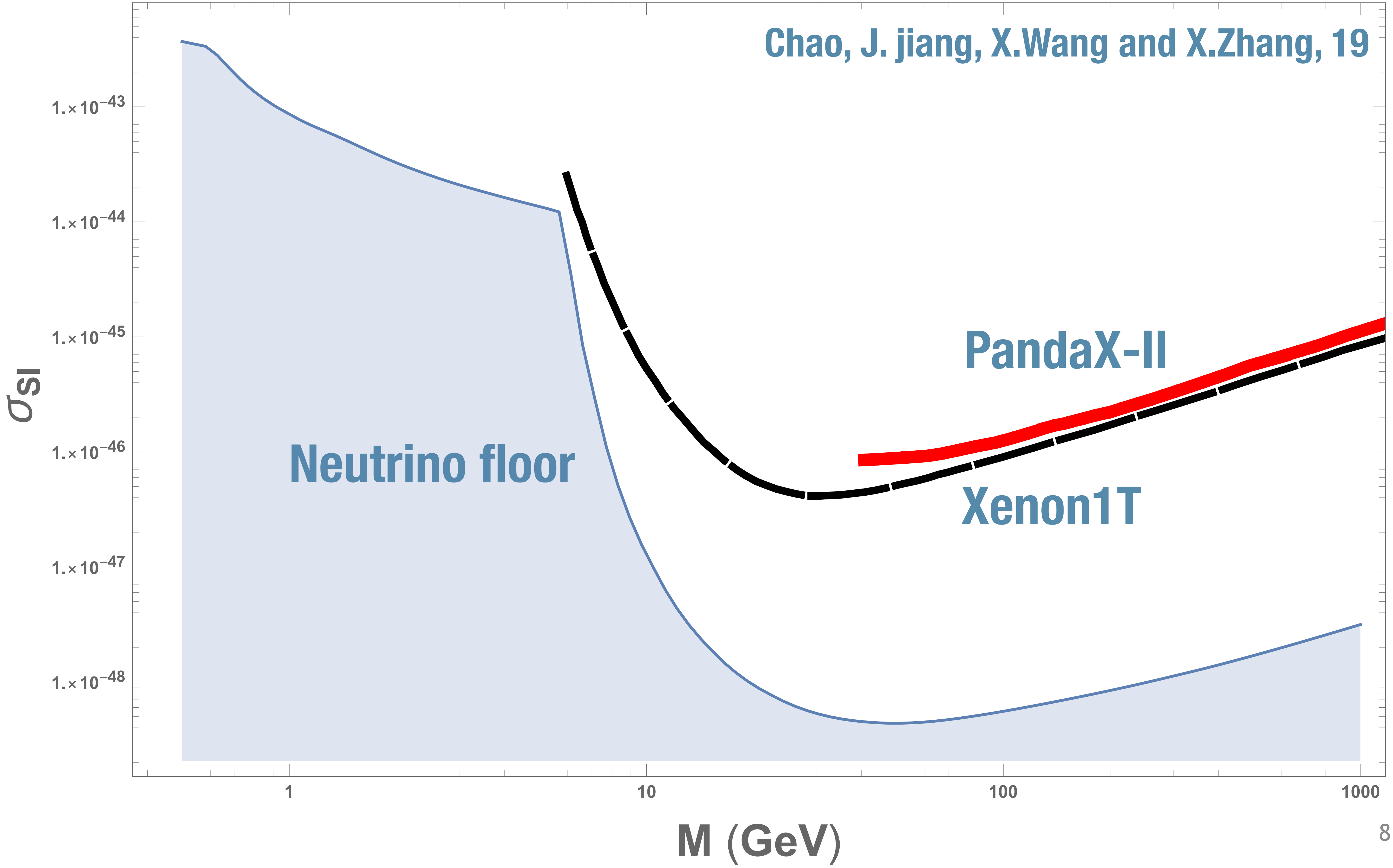
CRESST

CRESST-1, CUORE

Where to go for Direct detections



Status of direct detections



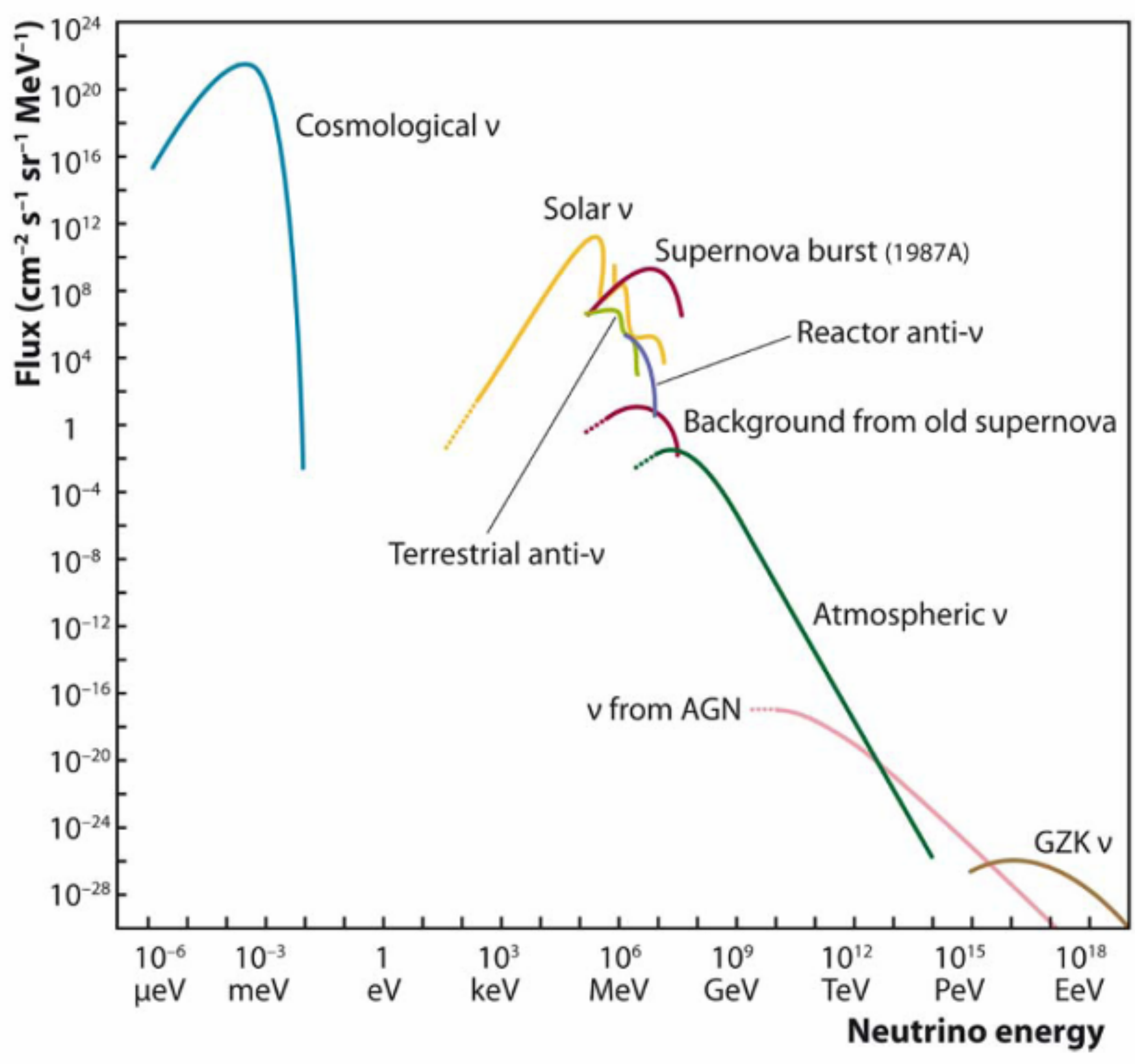
Two relevant issues

Precision calculations of the direct detection cross section.

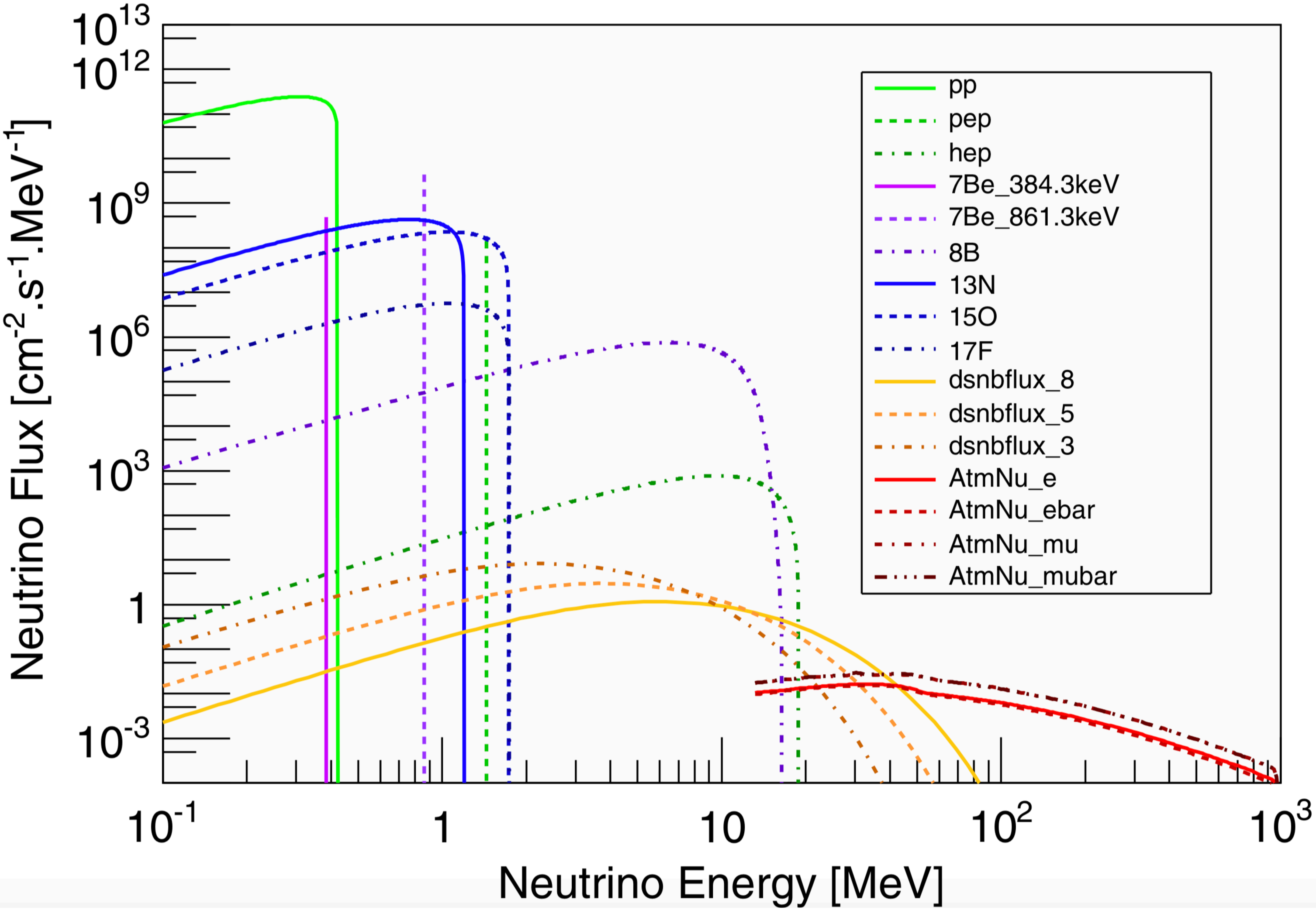
Understanding the neutrino floor.

- Neutrino flux
- Neutrino interactions

Neutrino sources in the universe



Neutrino sources in the universe



Neutrino interactions

Charged currents coupling to electroweak gauge boson

$$\sum_{\alpha=e,\mu,\tau} W_\mu^+(\bar{\nu}_\alpha \gamma^\mu \alpha) + \mathrm{h.c.}$$

Neutral currents coupling to electroweak gauge boson

$$\sum_{\alpha=e,\mu,\tau} Z_\mu(\bar{\nu}_\alpha \gamma^\mu \nu_\alpha) + \mathrm{h.c.}$$

NSI {

- New effective interactions with matter
- New gauge interactions
- New Yukawa interactions

Exotic neutrino interactions in our talk.

$$\sqrt{2} G_F \zeta_i \sum_i \bar{\nu}_\alpha \Gamma_i P_L \nu_\beta \bar{q}_f \Gamma_i q_f$$

$$\Gamma_i = \{1,\ i\gamma_5,\ \gamma_\mu,\ \gamma_\mu\gamma_5,\ \sigma_{\mu\nu}\}$$

Neutrino oscillations

Neutral current NSI： Propagation of neutrinos in matter

Charged current NSI： Production and detection

$$i\frac{d}{dx}\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = H\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}$$

$$H = H_{\text{vac}} + H_{\text{matt}}$$

$$H_{\text{vac}} = U\text{Diag}\left(\frac{m_1^2}{2E}, \frac{m_2^2}{2E}, \frac{m_3^2}{2E}\right)U^\dagger$$

$$H_{\text{matt}} = \sqrt{2}G_F N_e\begin{pmatrix}1 & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\end{pmatrix}$$

$$H_{\text{matt}} = \sqrt{2}G_F N_e\begin{pmatrix}1 & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\end{pmatrix} + \sqrt{2}G_F\sum_{f=e,u,d}\begin{pmatrix}\varepsilon_{ee}^f & \varepsilon_{e\mu}^f & \varepsilon_{e\tau}^f\\ \varepsilon_{\mu e}^f & \varepsilon_{\mu\mu}^f & \varepsilon_{\mu\tau}^f\\ \varepsilon_{\tau e}^f & \varepsilon_{\tau\mu}^f & \varepsilon_{\tau\tau}^f\end{pmatrix}$$

$$-0.008 < \varepsilon_{ee}^{uV} < 0.618$$

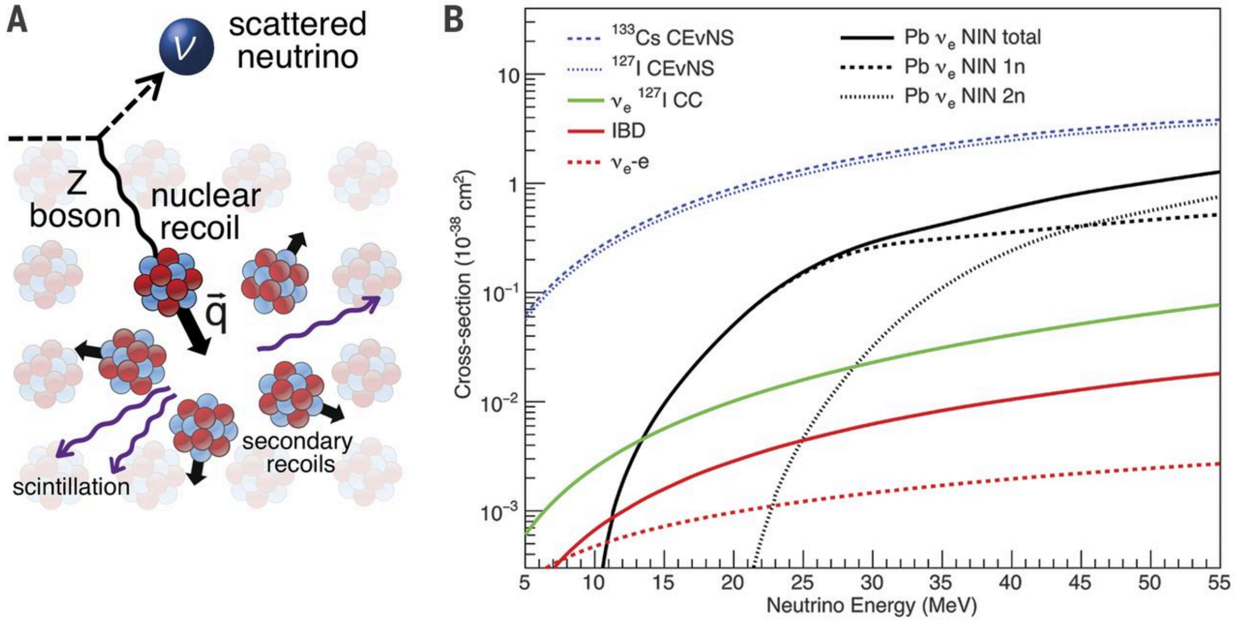
$$-0.012 < \varepsilon_{ee}^{dV} < 0.361$$

$$-0.111 < \varepsilon_{\mu\mu}^{uV} < 0.402$$

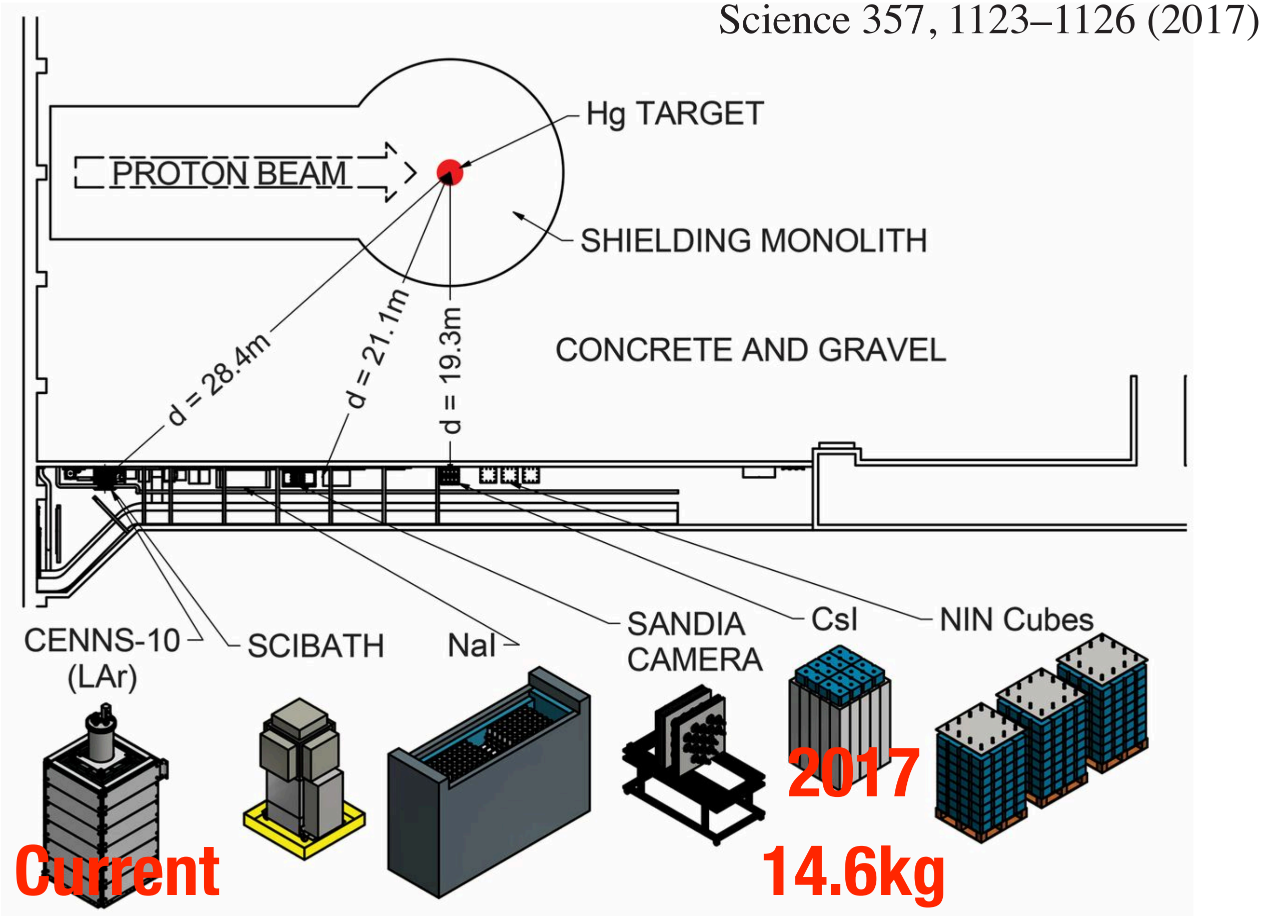
$$-0.103 < \varepsilon_{\mu\mu}^{dV} < 0.361$$

Altmannshofer, et al., 1812.02778

CONHERENT



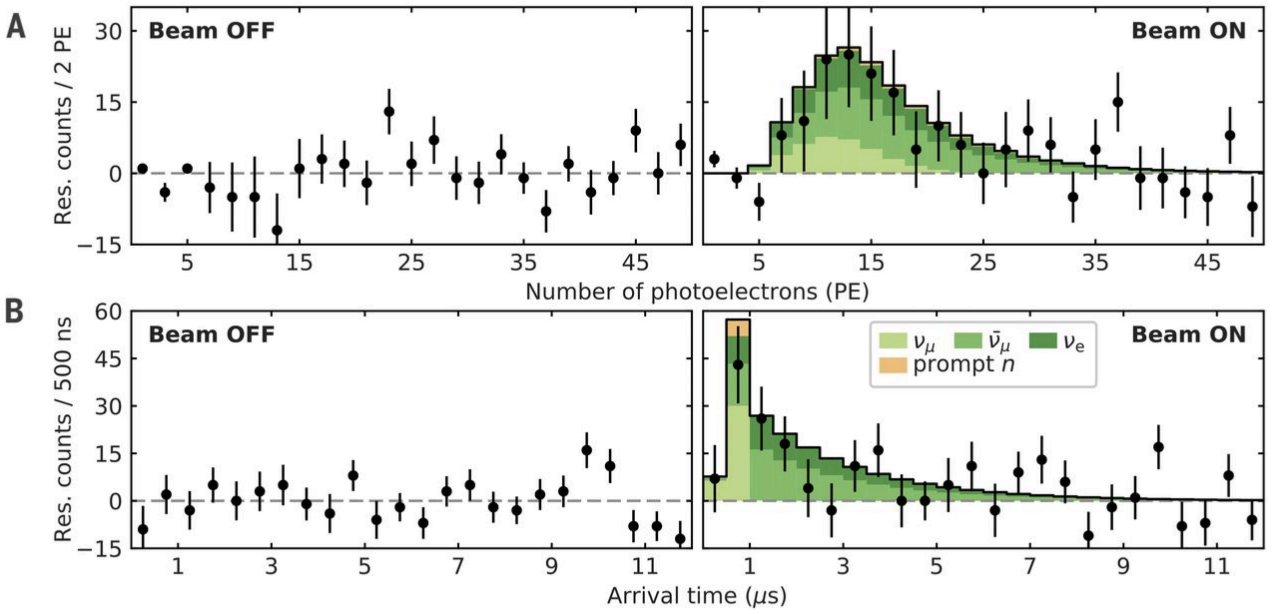
GOAL: Measure N^2 dependence of CEvNS process


Science 357, 1123–1126 (2017)

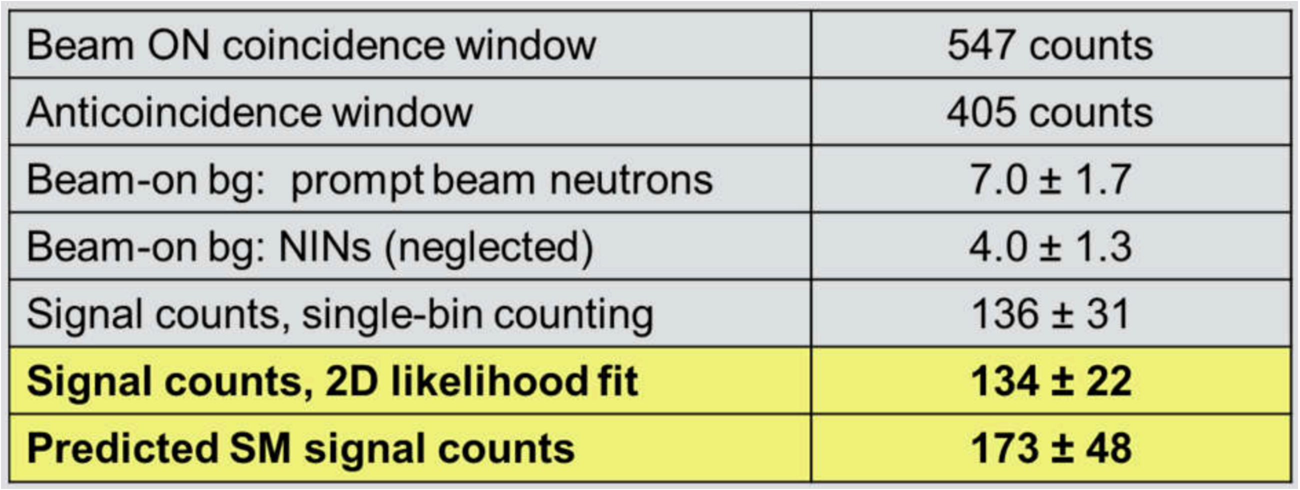
Current

2017

14.6kg



Confirm CEvNS at 6.7 sigma



Beam ON coincidence window	547 counts
Anticoincidence window	405 counts
Beam-on bg: prompt beam neutrons	7.0 ± 1.7
Beam-on bg: NINs (neglected)	4.0 ± 1.3
Signal counts, single-bin counting	136 ± 31
Signal counts, 2D likelihood fit	**134 ± 22**
Predicted SM signal counts	**173 ± 48**

CHARM

$$R_e = \frac{\sigma(\nu_e N \to \nu_e X) + \sigma(\bar{\nu}_e N \to \bar{\nu}_e X)}{\sigma(\nu_e N \to e^- X) + \sigma(\bar{\nu}_e N \to e^+ X)} = 0.406 \pm 0.140$$

CHARM, PLB180,303

$$R_\mu = \frac{\sigma(\nu_\mu N \to \nu_\mu X)}{\sigma(\nu_\mu N \to \mu^- X)} = 0.3093 \pm 0.0031$$

CHARM, Z. Phys. C36,611

$$R_e^{\mathrm{SM}} = 0.3221 \pm 0.0006$$

$$R_{\nu_\mu}^{\mathrm{SM}} = 0.3156 \pm 0.0006$$

Falkowski, et al., 1706.03783

$$R_e^{\mathrm{NSI}} = R_e^{\mathrm{SM}} + \frac{\Delta\sigma_{\mathrm{NSI}}}{\sigma_{\mathrm{CC}}} \qquad R_{\nu_\mu}^{\mathrm{NSI}} = R_{\nu_\mu}^{\mathrm{SM}} + \frac{\Delta\sigma_{\mathrm{NSI}}}{\sigma_{\mathrm{CC}}^{\nu_\mu}}$$

Combined constraints

Couplings	Constraints	Couplings	Constraints	Couplings	Constraints	Couplings	Constraints
$\zeta^{eX}_{u,S}$	0.051	$\zeta^{\mu X}_{u,S}$	0.035	$\zeta^{eX}_{u,P}$	4.863	$\zeta^{\mu X}_{u,P}$	0.484
$\zeta^{eX}_{d,S}$	0.051	$\zeta^{\mu X}_{d,S}$	0.034	$\zeta^{eX}_{d,P}$	6.256	$\zeta^{\mu X}_{d,P}$	0.686
$\zeta^{eX}_{s,S}$	0.866	$\zeta^{\mu X}_{s,S}$	0.579	$\zeta^{eX}_{s,P}$	11.87	$\zeta^{\mu X}_{s,P}$	1.603
$\zeta^{eX}_{u,T}$	0.632	$\zeta^{\mu X}_{u,T}$	0.064	$\zeta^{eX}_{u,A}$	0.996	$\zeta^{\mu X}_{u,A}$	0.178
$\zeta^{eX}_{d,T}$	0.866	$\zeta^{\mu X}_{d,T}$	0.093	$\zeta^{eX}_{d,A}$	0.996	$\zeta^{\mu X}_{d,A}$	0.250
$\zeta^{eX}_{s,T}$	1.680	$\zeta^{\mu X}_{s,T}$	0.215	$\zeta^{eX}_{s,A}$	2.123	$\zeta^{\mu X}_{s,A}$	0.500
$\zeta^{eX}_{u,V}$	0.123	$\zeta^{\mu X}_{u,V}$	0.084				
$\zeta^{eX}_{d,V}$	0.112	$\zeta^{\mu X}_{d,V}$	0.072				
$\zeta^{eX}_{s,V}$	2.123	$\zeta^{\mu X}_{s,V}$	0.566				

Neutrino floor in the SM

Coherent neutrino-nucleus scattering in the SM

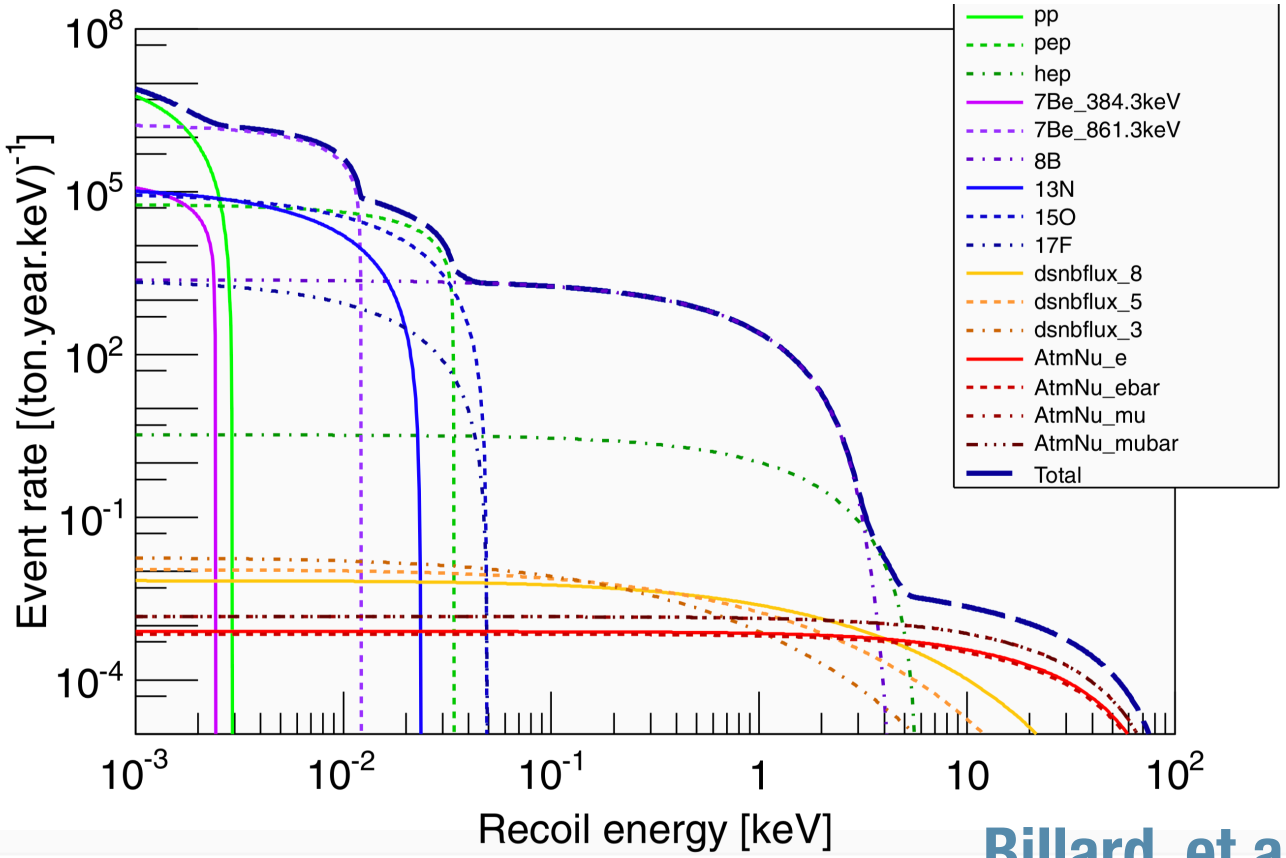
$$\frac{d\sigma_\nu}{dE_R} = \frac{G_F^2}{4\pi} Q_{\nu N}^2 m_N \left(1 - \frac{m_N E_R}{2E_\nu^2}\right) F^2(E_R)$$

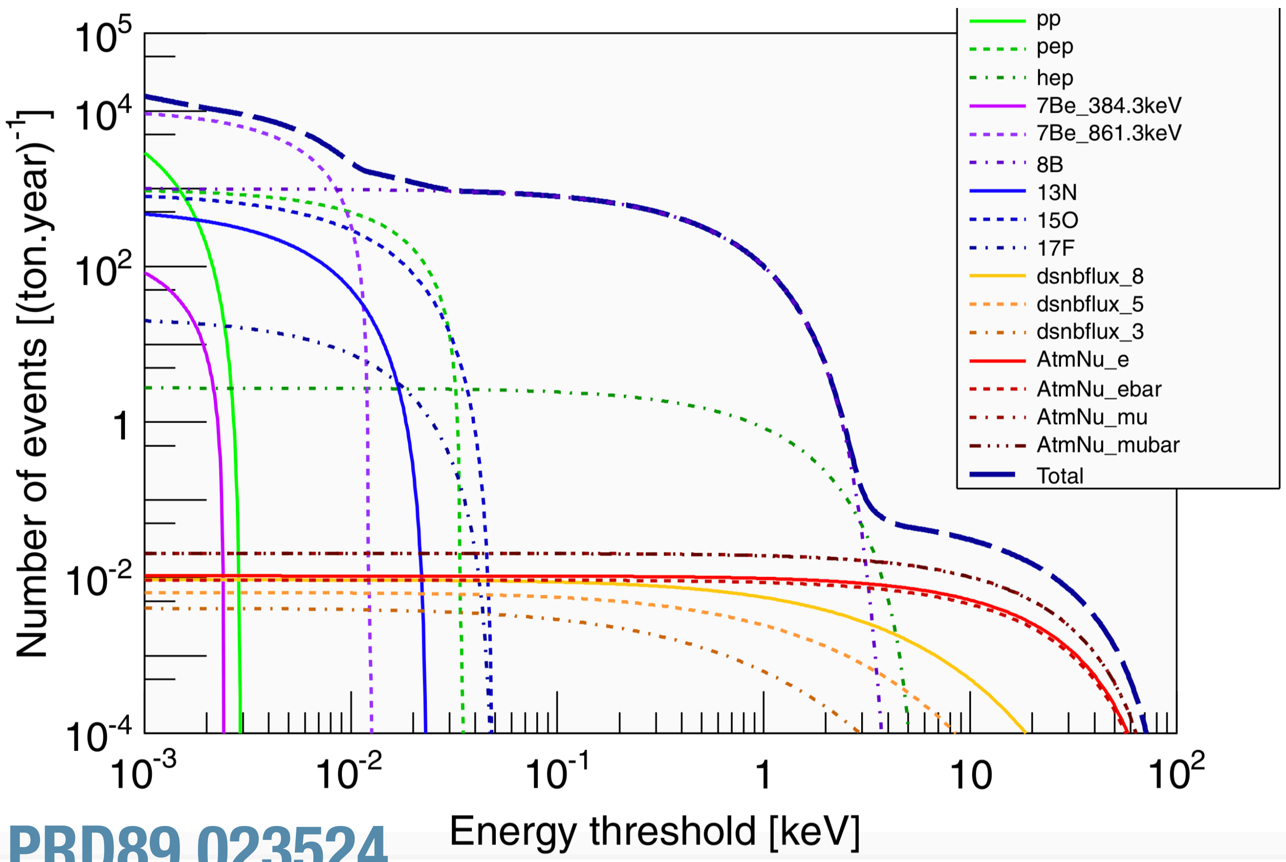
Weak hyper-charge of target nucleus

Nuclear form factor

Number of expected events

$$N = \frac{\varepsilon}{m_N} \int_{E_T}^{E_{max}} dE_R \int dE_\nu \frac{d\phi_\nu}{dE_\nu} \frac{d\sigma_\nu}{dE_R}$$





Billard, et al., PRD89,023524

Neutrino floor in the SM

The WIMP event rate

$$\frac{dR}{dE_R} = \underbrace{MT}_{\text{Exposure}} \times \frac{\underbrace{\rho_{\mathrm{DM}}}_{\text{DM density}}\sigma_n^0 A^2}{2m_{\mathrm{DM}}\mu_n^2}\underbrace{F^2(E_R)}_{\text{Nuclear Form Factor}}\int_{v_{\min}}\frac{f(\vec{v})}{v}d^3v$$

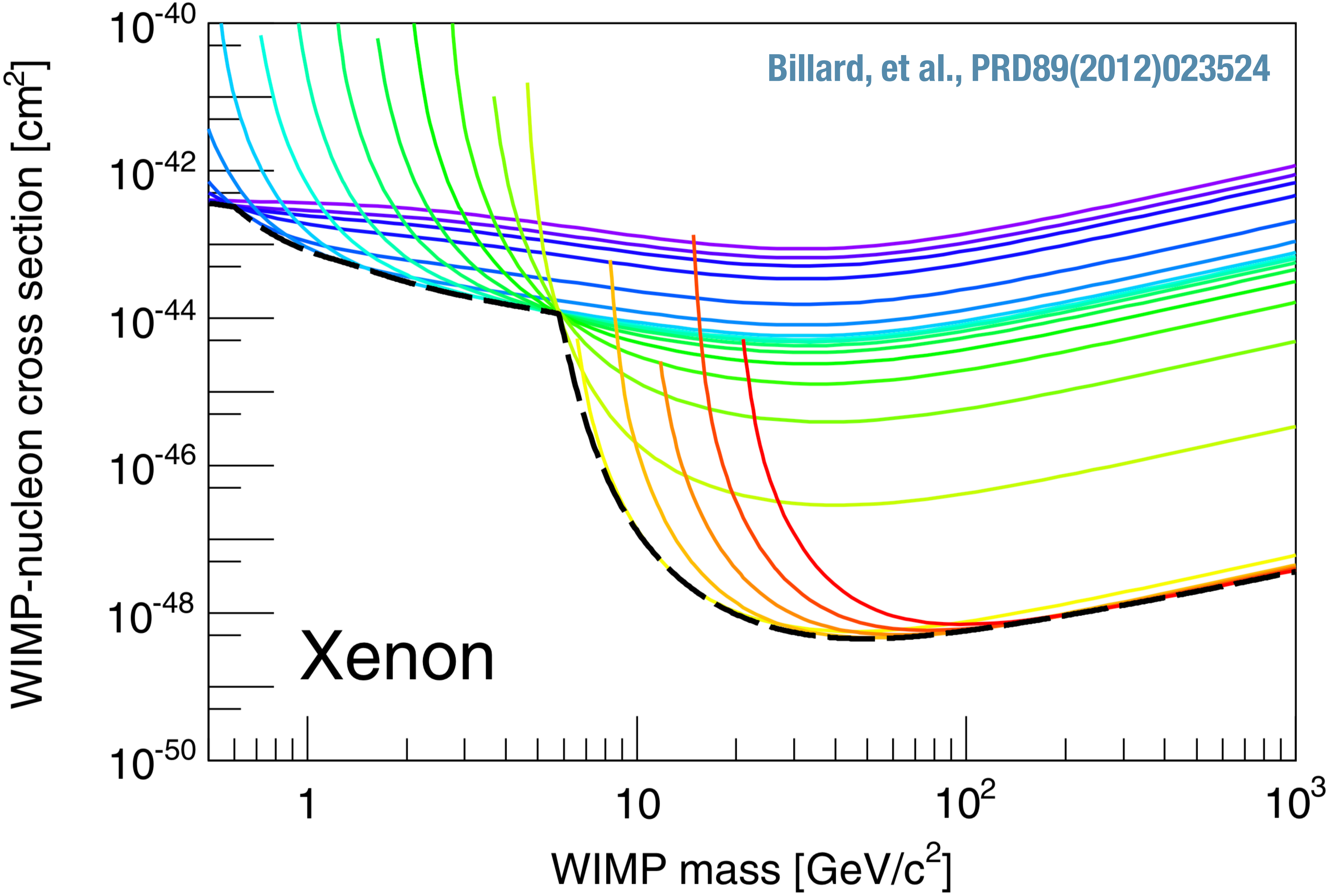
Neutrino event rate

$$\frac{dR_\nu}{dE_R} = MT \times \frac{1}{m_N}\int_{E_\nu^{\min}}\frac{d\phi_\nu}{dE_\nu}\frac{d\sigma_\nu}{dE_R}$$

Neutrino floor

$$\sigma_n^0 = \frac{2.3}{m}\int_{E_R}\left(\frac{1}{m_N}\int_{E_\nu^{\min}}\frac{d\phi_\nu}{dE_\nu}\frac{d\sigma_\nu}{dE_R}\right)\left(\frac{\rho_{\mathrm{DM}}A^2}{2m_{\mathrm{DM}}\mu_n^2}\int_{E_R}^{E_R^{\max}}F^2(E_R)dE_R\int_{v_{\min}}\frac{f(\vec{v})}{v}d^3v\right)^{-1}$$

Neutrino floor in the SM



Neutrino floor with exotic neutrino interactions

$$\frac{d\sigma_\nu}{dE_R} = \frac{2G_F^2 m_A}{(2J_A+1)E_\nu^2}\Bigg\{\sum_{\alpha\beta=0,1}\underline{(4E_\nu^2 - 2m_A E_R)\zeta_V^\alpha \zeta_V^{\beta *} W_M^{\alpha\beta}(q^2)+}$$
$$\sum_{\alpha,\beta=0,1}\left(E_\nu^2 + \frac{1}{2}m_A E_R\right)\zeta_A^\alpha \zeta_A^{\beta *} W_{\Sigma'}^{\alpha\beta}(q^2) + \sum_{\alpha\beta=0,1}\frac{E_R}{4m_A}(2E_\nu^2 - m_A E_R)\zeta_A^\alpha \zeta_A^{\beta *} W_{\Sigma''}^{\alpha\beta}(q^2) +$$
$$8(2E_\nu^2 - m_A E_R)\zeta_T^2 W_{\Sigma'}^{00}(q^2) + 16E_\nu^2 \zeta_T^2 W_{\Sigma''}^{00}(q^2) + 2m_A E_R \zeta_S^2 W_M^{00}(q^2) +$$
$$\sum_{\alpha\beta=0,1}\frac{E_R^2 m_A^2}{m_N^2}\zeta_P^\alpha \zeta_P^{\beta *} W_{\Sigma''}^{\alpha\beta}(q^2)\Bigg\}$$

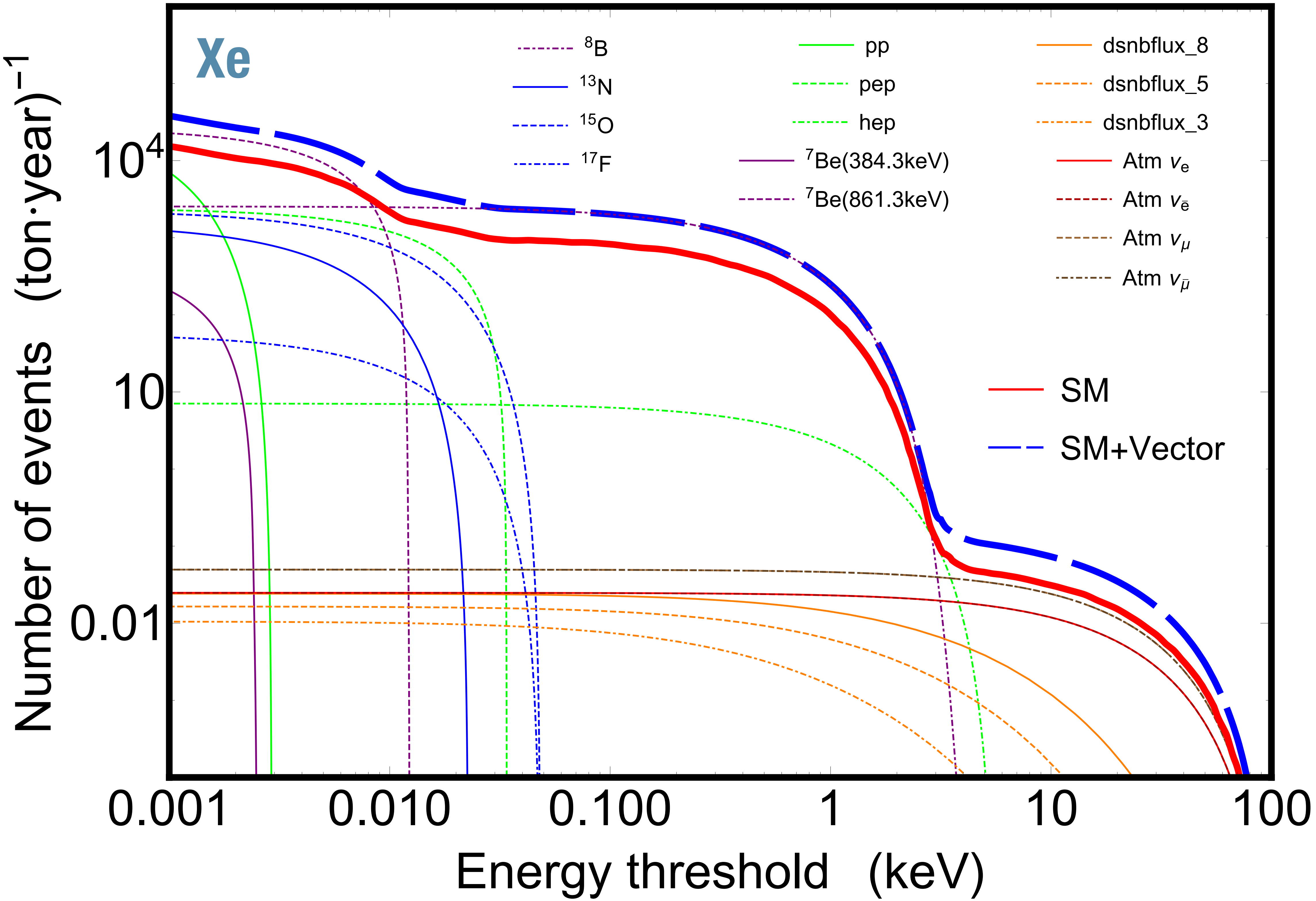
(4

$$W_M^{\alpha\beta}(q^2) \sim A^2$$
$$W_{\Sigma'}^{\alpha\beta}(q^2) \sim 1$$
$$W_{\Sigma''}^{\alpha\beta}(q^2) \sim 1$$

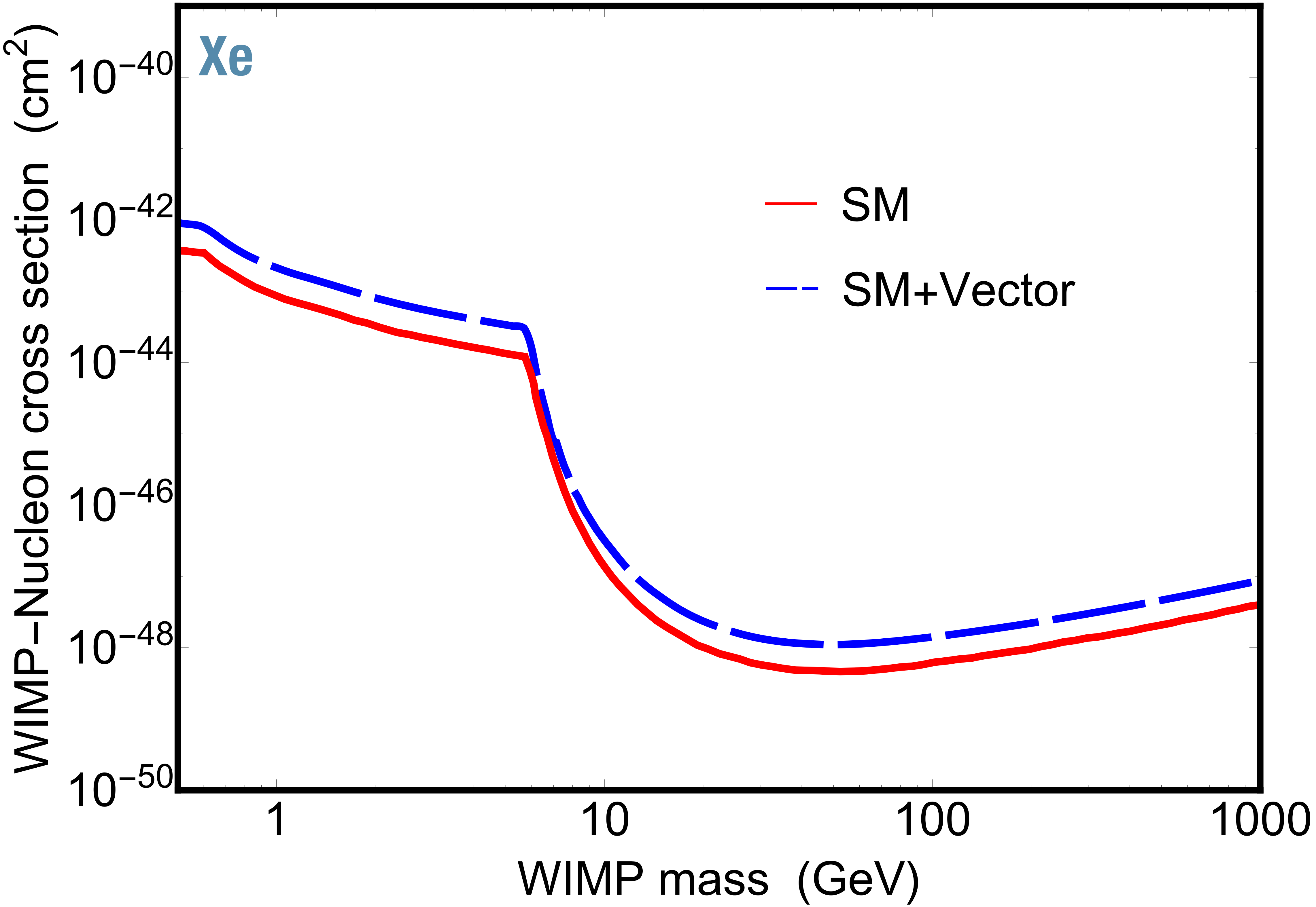
$$\zeta_\alpha^0 = \frac{1}{2}\left(\zeta_\alpha^p + \zeta_\alpha^n\right) \qquad \zeta_\alpha^1 = \frac{1}{2}\left(\zeta_\alpha^p - \zeta_\alpha^n\right)$$

Quark level	Nucleon level	Matching conditions
$\frac{G_F}{\sqrt{2}}\zeta_{q,S}\bar{\nu}_\alpha P_L \nu_\beta \bar{q}q$	$\frac{G_F}{\sqrt{2}}\zeta_{N,S}\bar{\nu}_\alpha P_L \nu_\beta \bar{N}N$	$\zeta_{N,S} = \sum_{q=u,d}\zeta_{q,S}\frac{m_N}{m_q}f_{T_q}^N$
$\frac{G_F}{\sqrt{2}}\zeta_{q,P}\bar{\nu}_\alpha P_L \nu_\beta \bar{q}i\gamma^5 q$	$\frac{G_F}{\sqrt{2}}\zeta_{N,P}\bar{\nu}_\alpha P_L \nu_\beta \bar{N}i\gamma^5 N$	$\zeta_{N,P} = \sum_{q=u,d}\zeta_{q,P}\frac{m_N}{m_q}\left(1 - \frac{\bar{m}}{m_q}\right)\Delta_q^N$
$\frac{G_F}{\sqrt{2}}\zeta_{q,V}\bar{\nu}_\alpha \gamma_\mu P_L \nu_\beta \bar{q}\gamma^\mu q$	$\frac{G_F}{\sqrt{2}}\zeta_{N,V}\bar{\nu}_\alpha \gamma_\mu P_L \nu_\beta \bar{N}\gamma^\mu N$	$\zeta_{p,V} = 2\zeta_{u,V} + \zeta_{d,V}; \quad \zeta_{n,V} = \zeta_{u,V} + 2\zeta_{d,V}$
$\frac{G_F}{\sqrt{2}}\zeta_{q,A}\bar{\nu}_\alpha \gamma_\mu P_L \nu_\beta \bar{q}\gamma^\mu \gamma^5 q$	$\frac{G_F}{\sqrt{2}}\zeta_{N,A}\bar{\nu}_\alpha \gamma_\mu P_L \nu_\beta \bar{N}\gamma^\mu \gamma^5 N$	$\zeta_{N,A} = \sum_q \zeta_{q,A}\Delta_q^N$
$\frac{G_F}{\sqrt{2}}\zeta_{q,T}\bar{\nu}_\alpha \sigma_{\mu\nu} P_L \nu_\beta \bar{q}\sigma^{\mu\nu} q$	$\frac{G_F}{\sqrt{2}}\zeta_{N,T}\bar{\nu}_\alpha \sigma_{\mu\nu} P_L \nu_\beta \bar{N}\sigma^{\mu\nu} N$	$\zeta_{N,T} = \sum_q \zeta_{q,T}\delta_q^N$

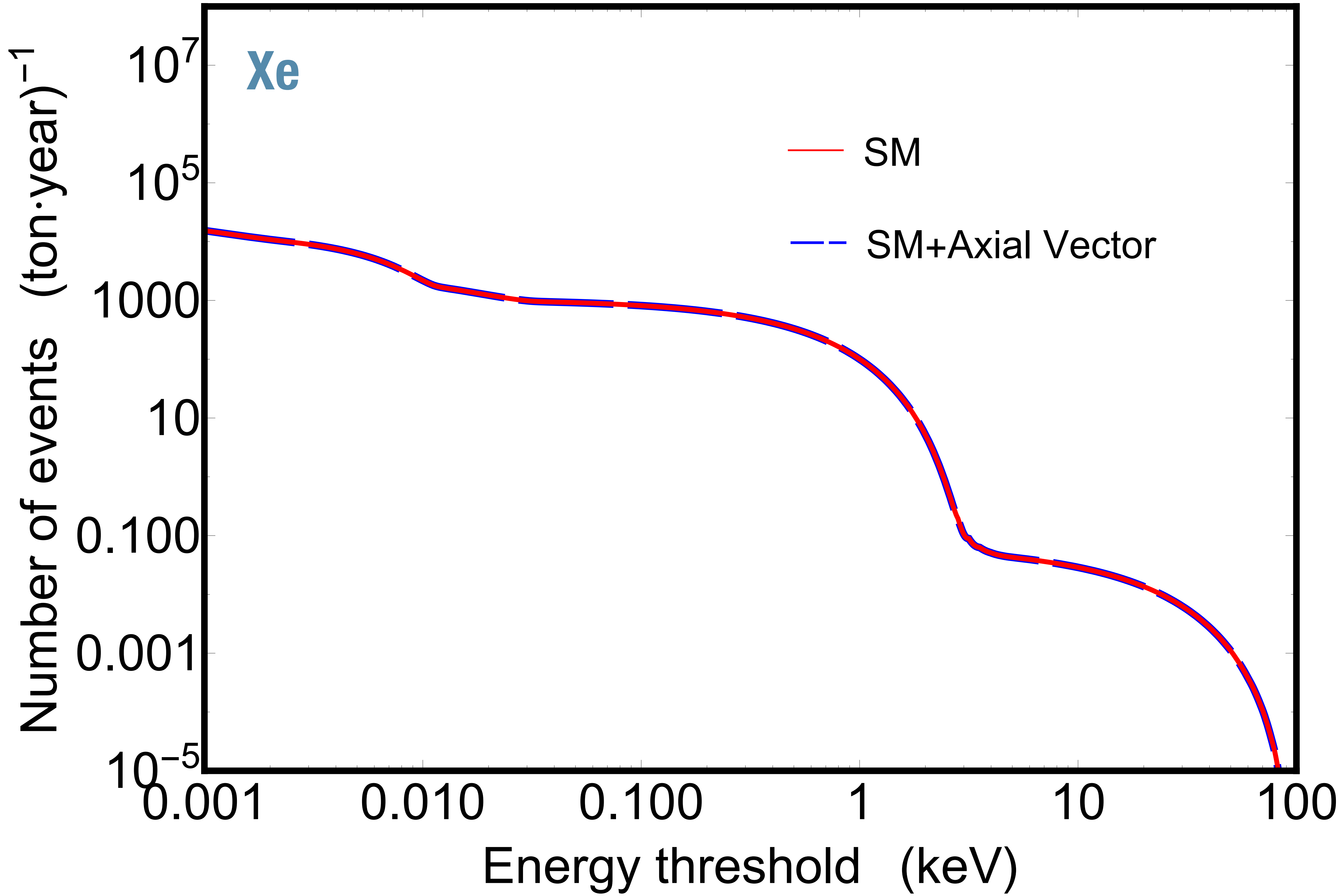
Numerical results-1: vector interactions with Xe131



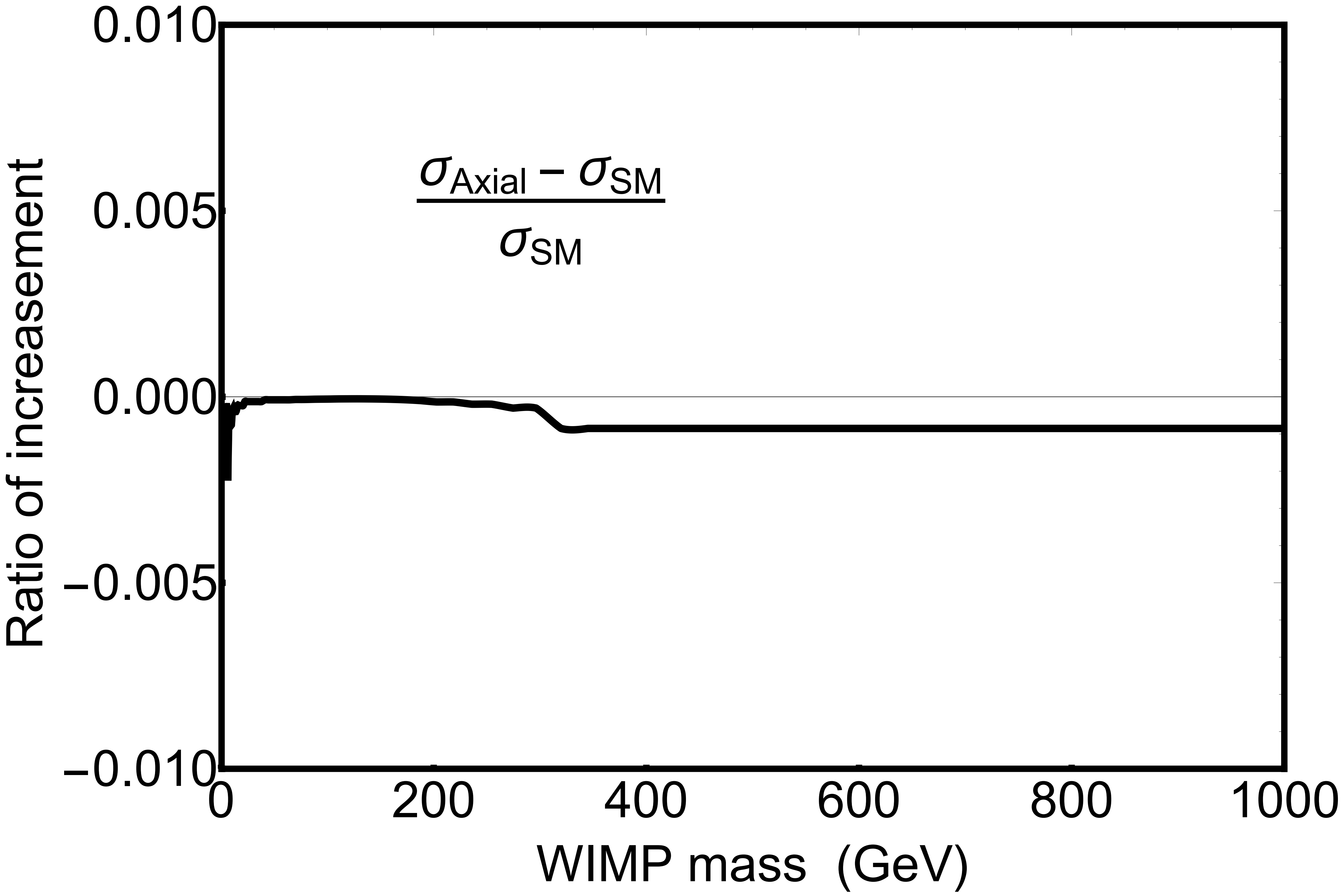
Numerical results-1: vector interactions with X131



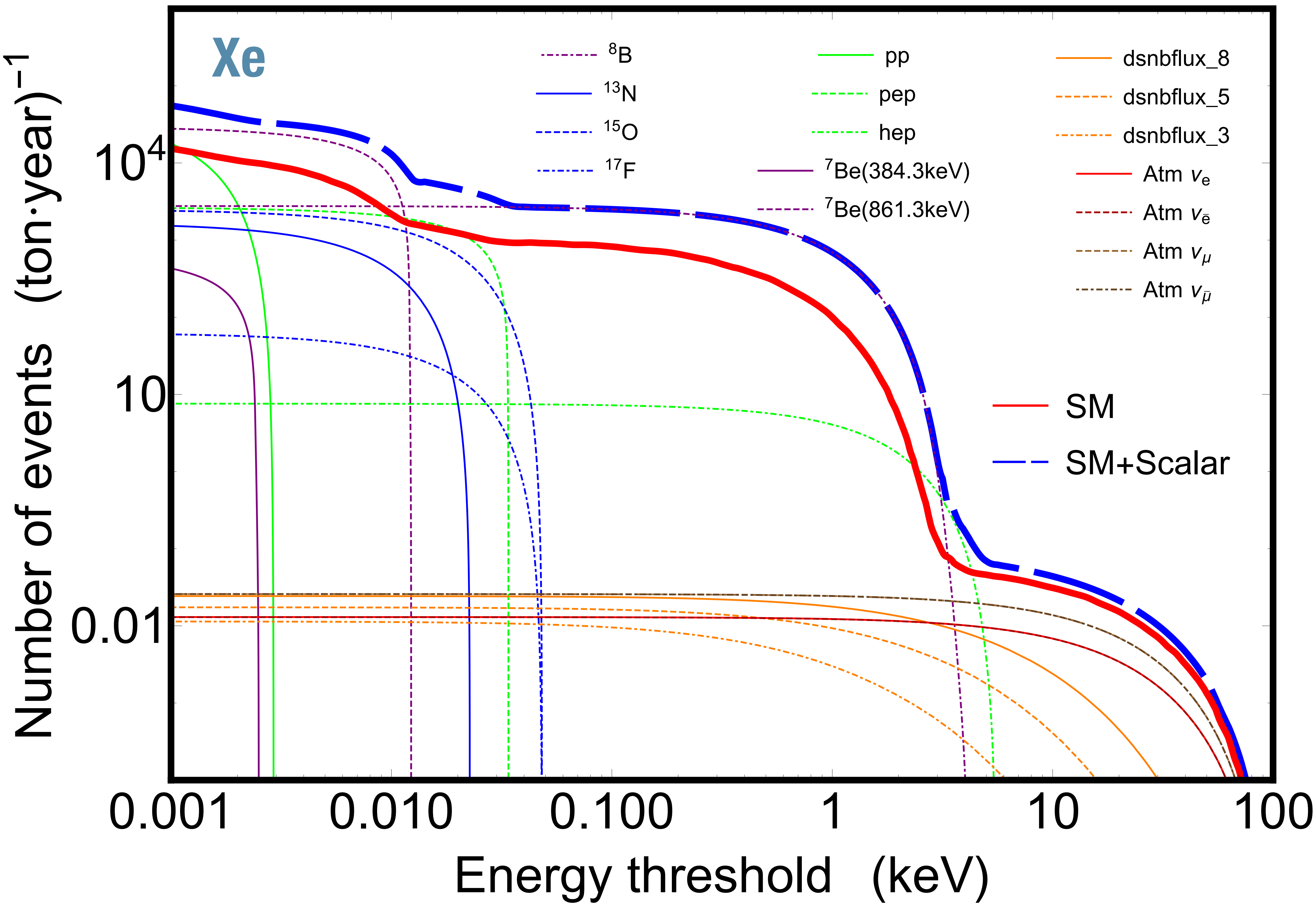
Numerical results-2: axial-vector interactions with Xe131



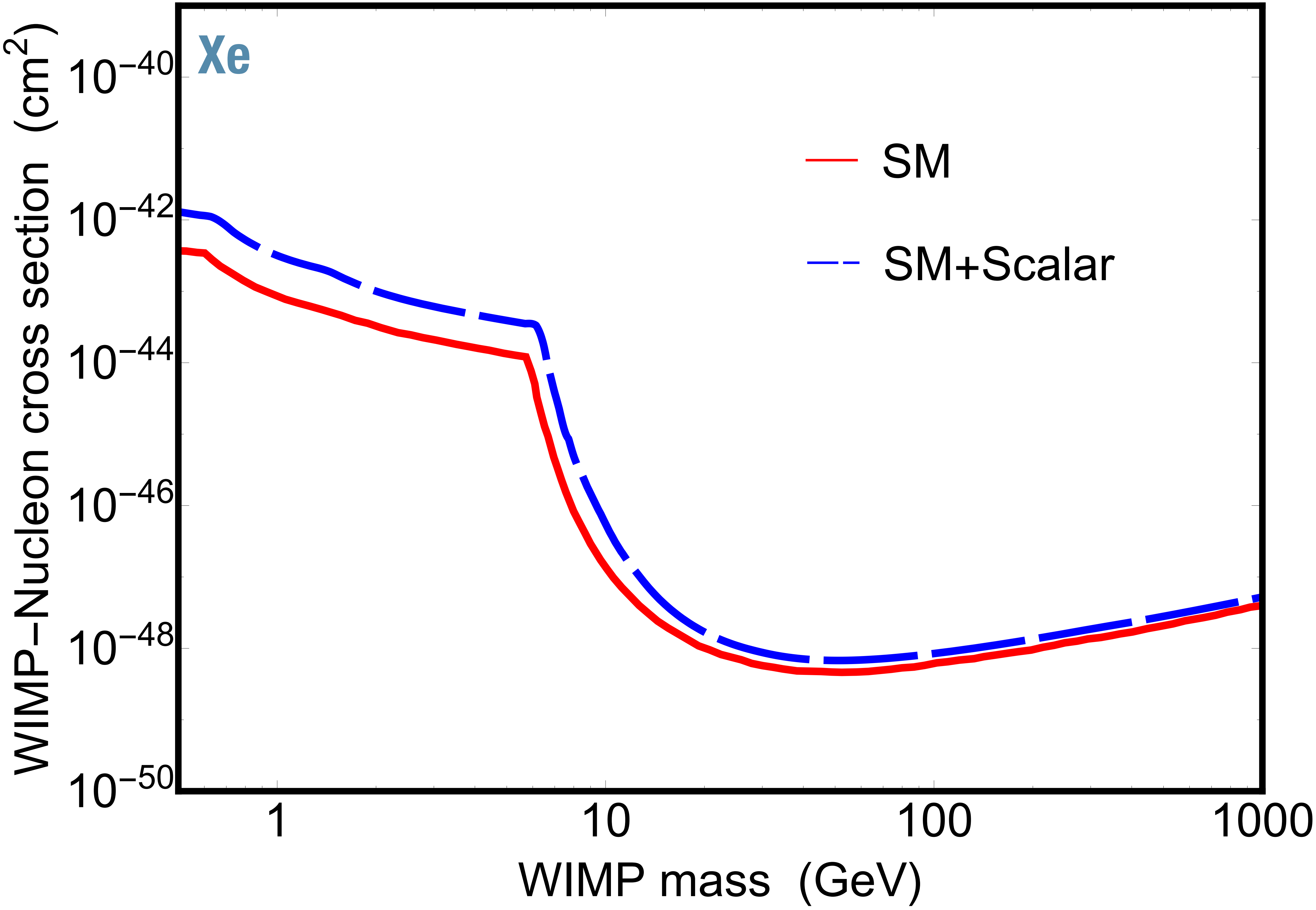
Numerical results-2: axial-vector interactions with Xe131



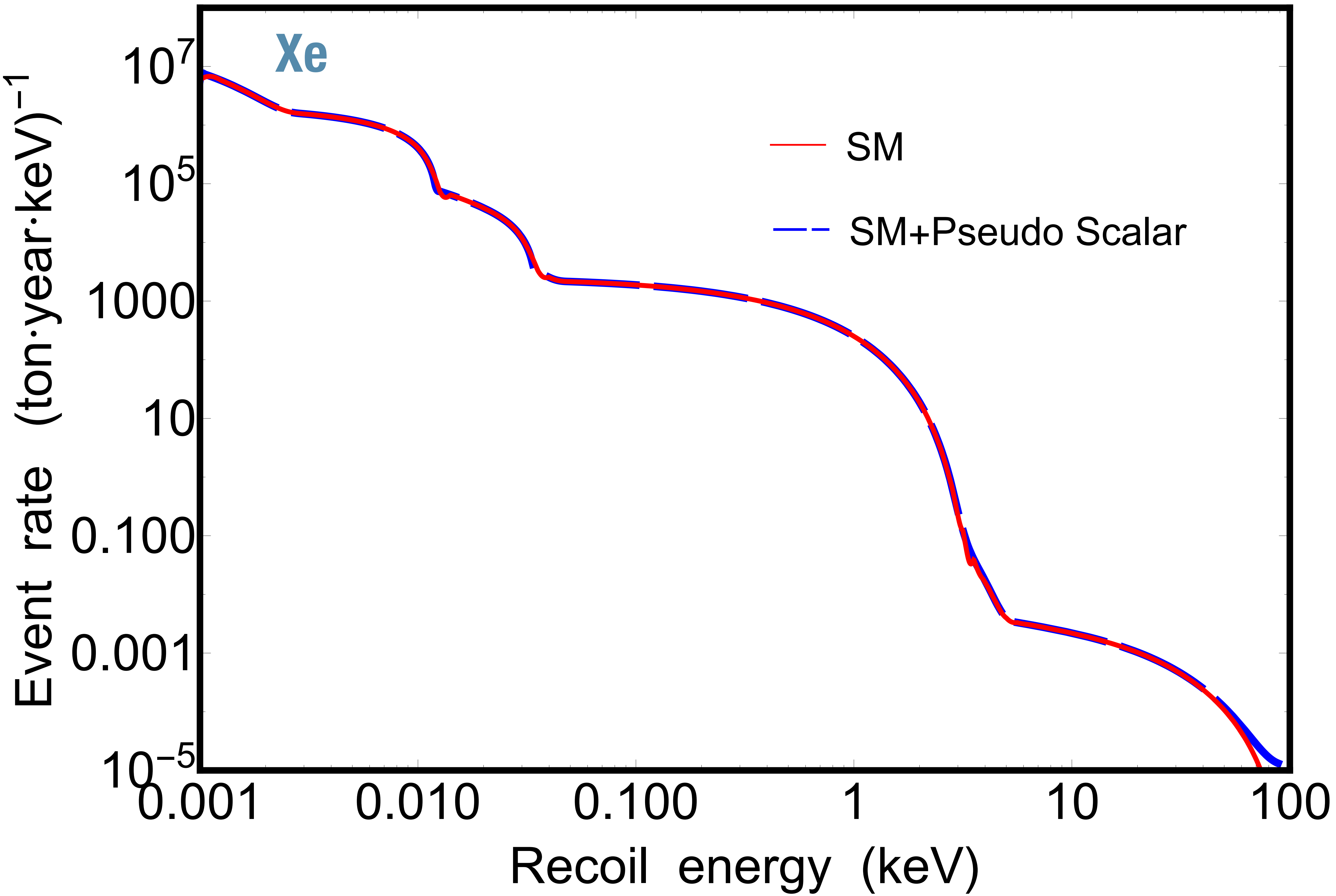
Numerical results-3: scalar interactions with **Xe131**



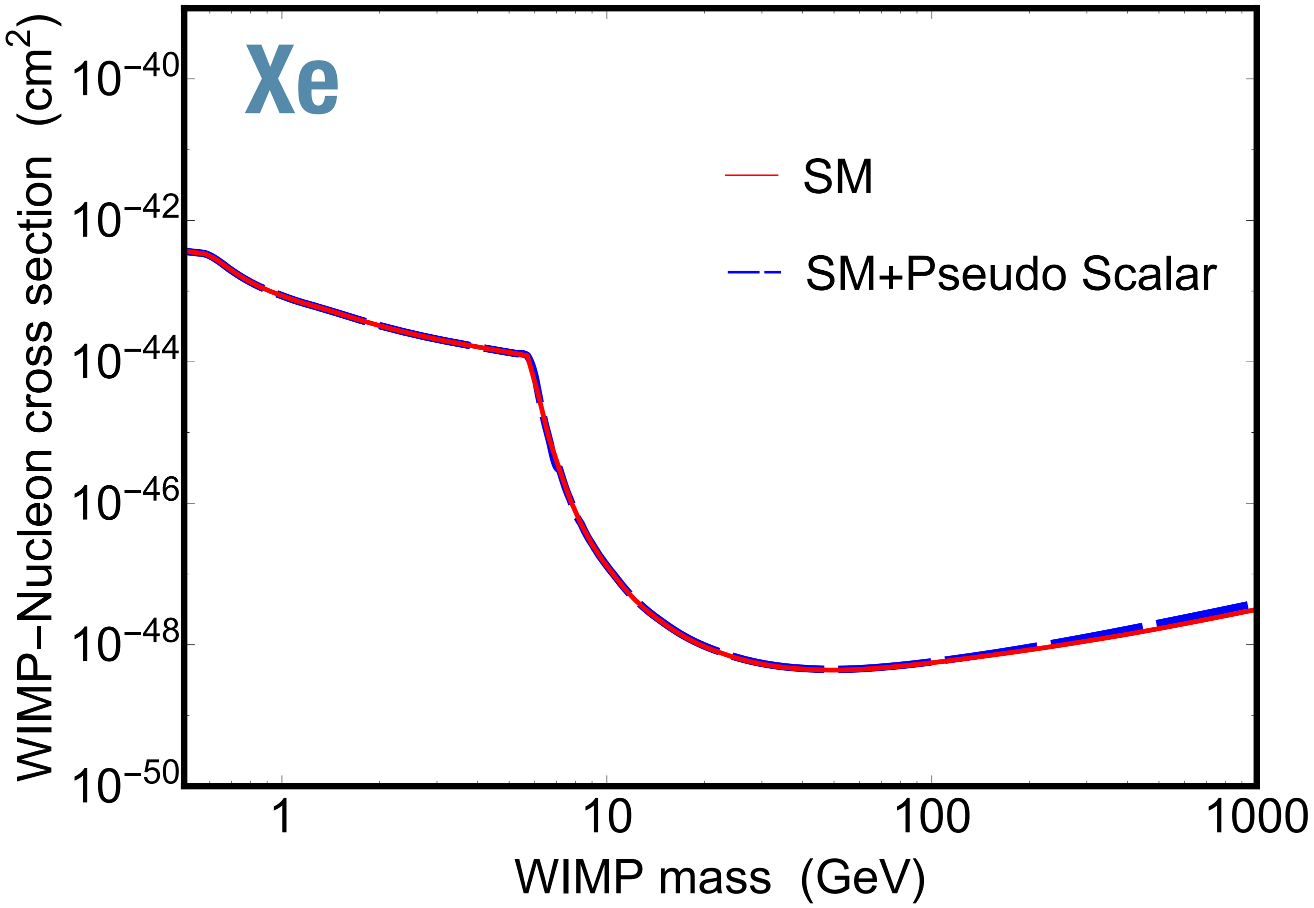
Numerical results-3: scalar interactions with X131

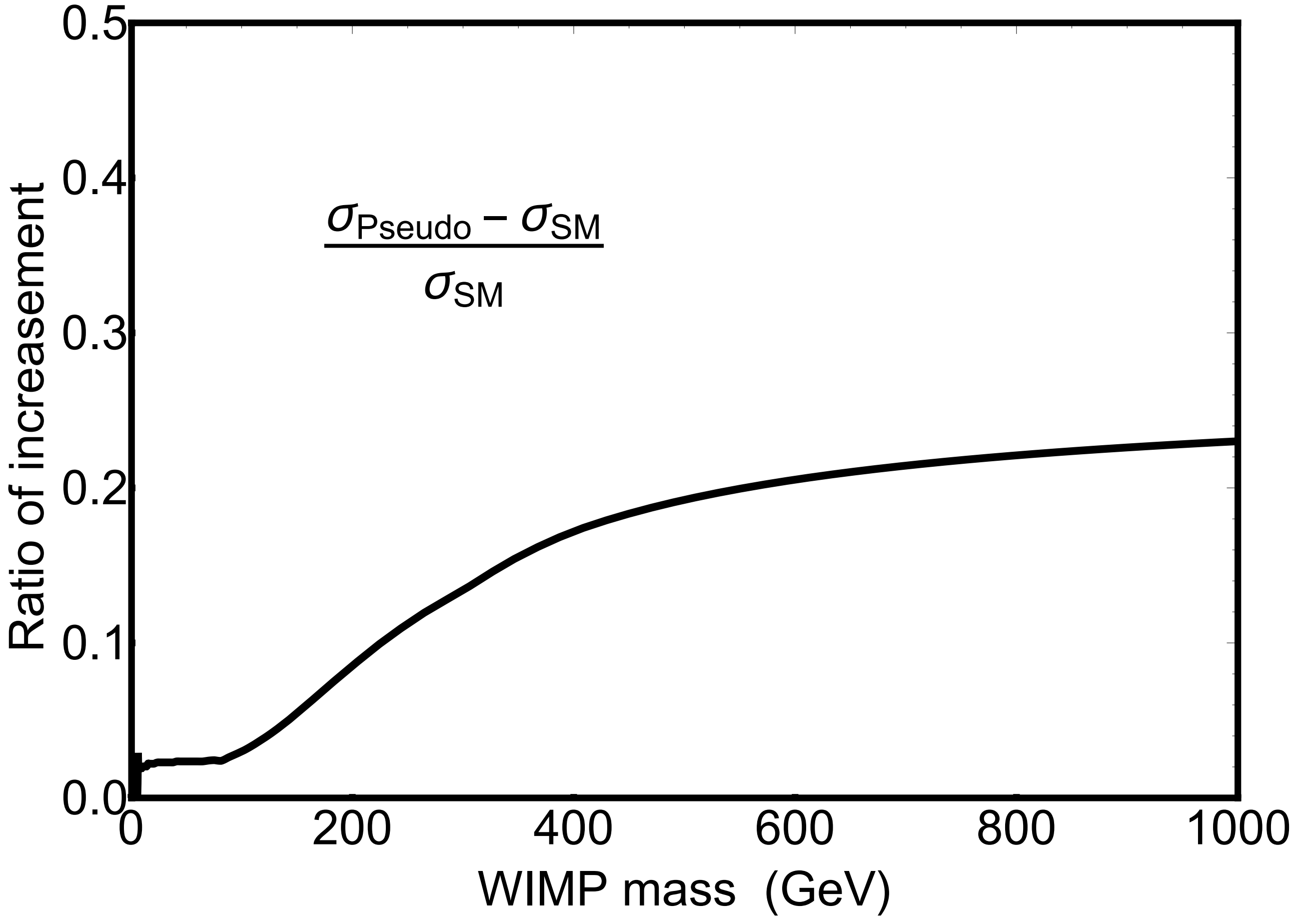


Numerical results-4: pseudo-scalar interactions with Xe131

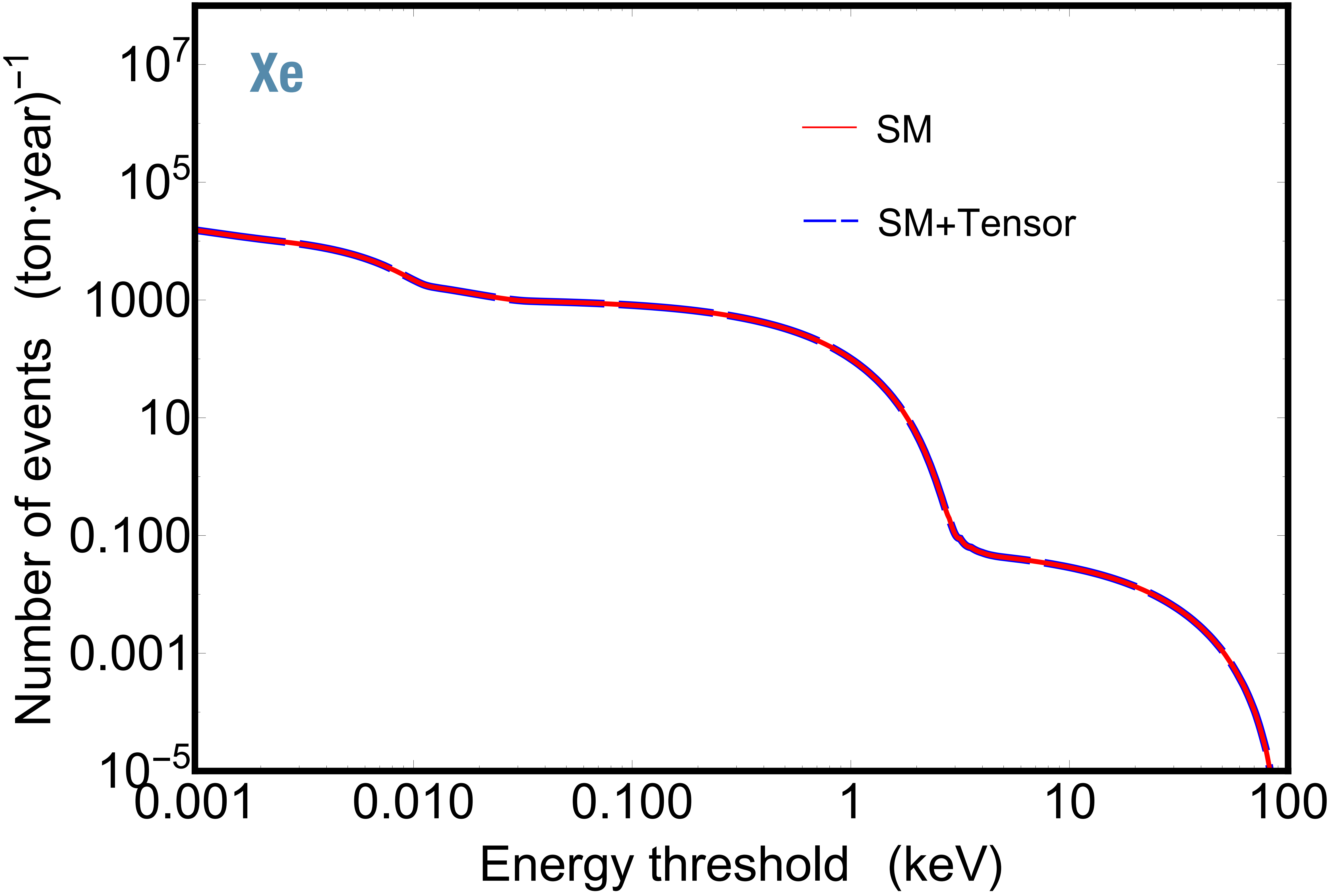


Numerical results-4: pseudo-scalar interactions with X131

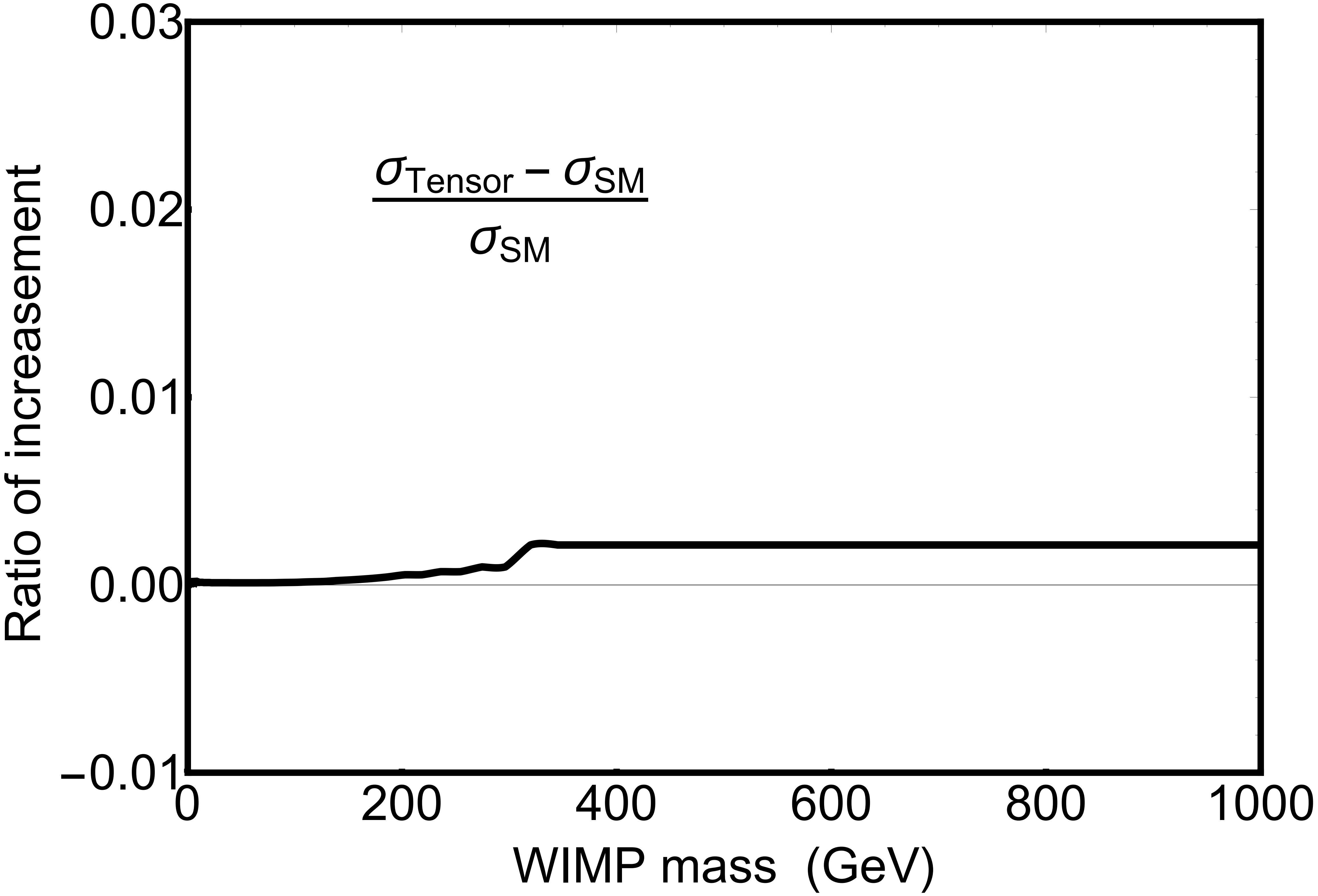




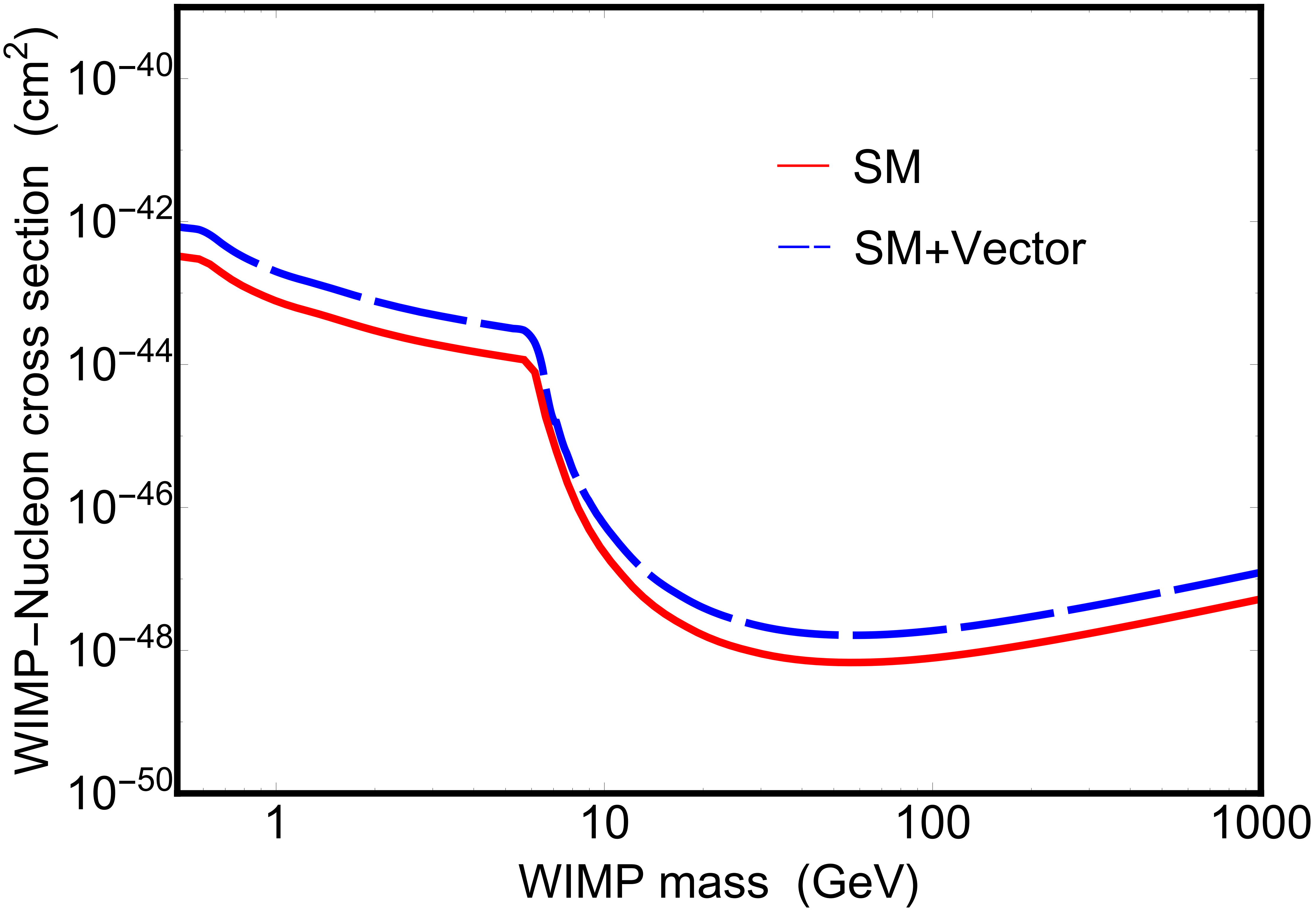
Numerical results-5: tensor interactions with Xe131



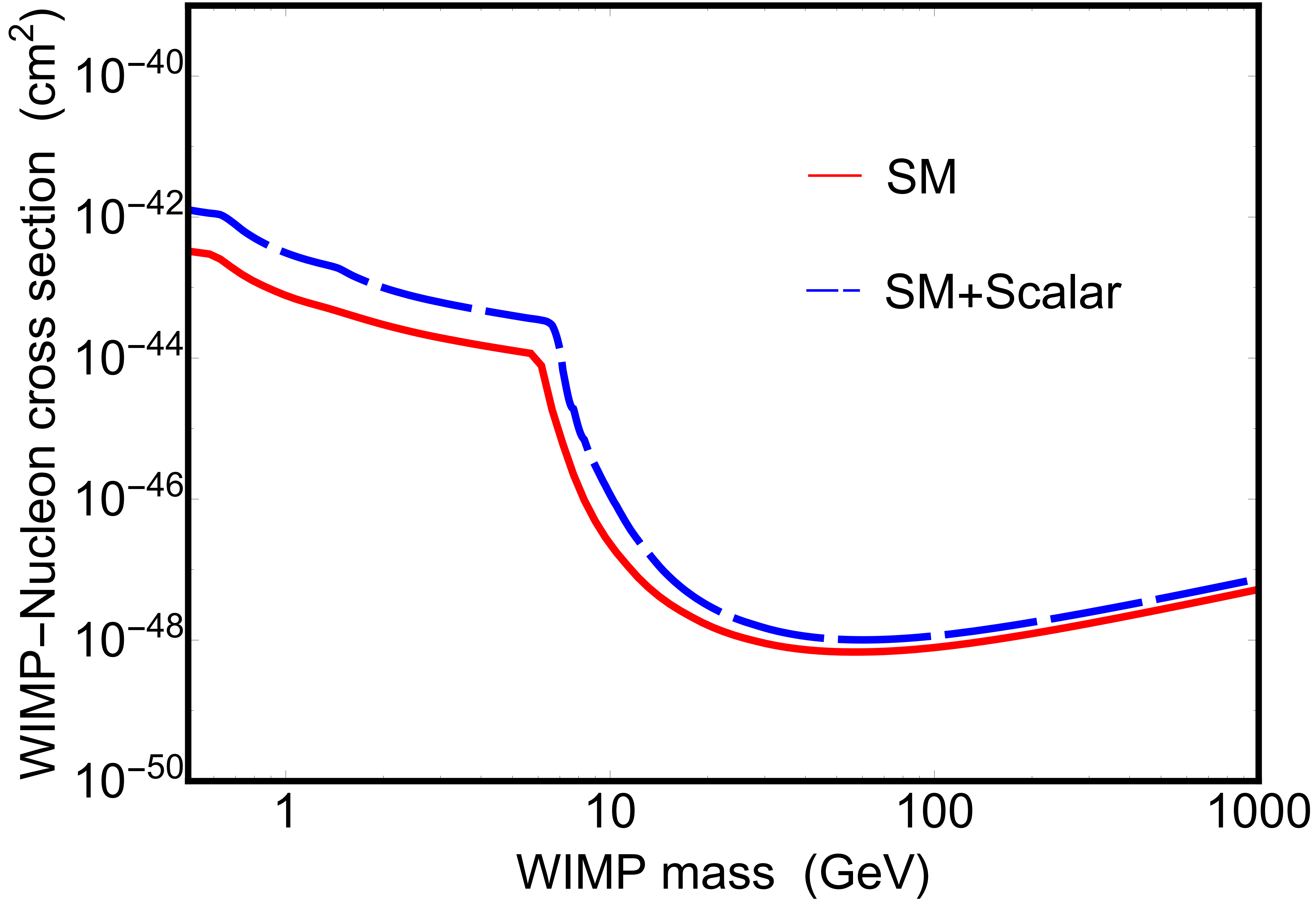
Numerical results-5: tensor interactions with X131



Numerical results-6: vector interactions with Ge72



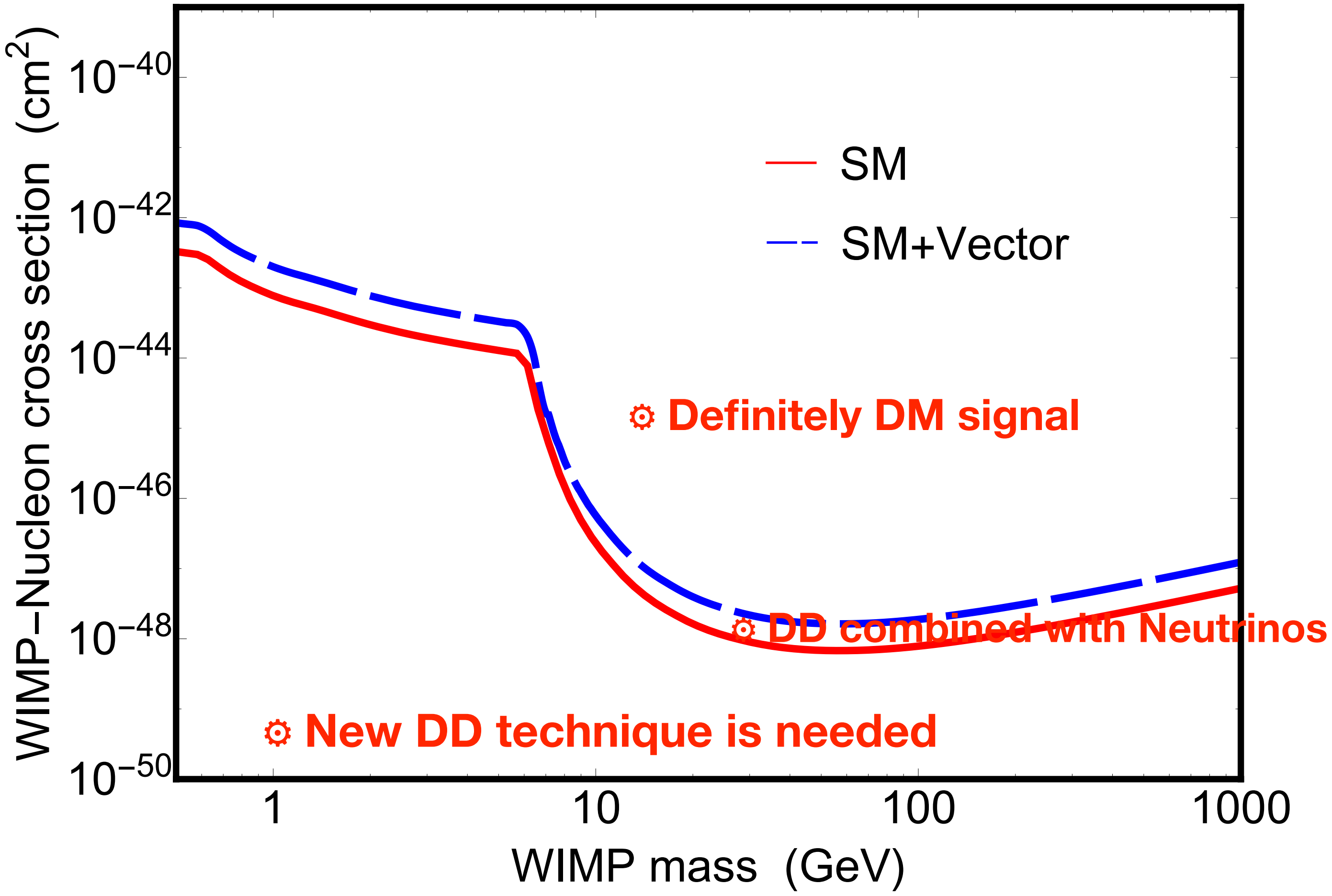
Numerical results-6: scalar interactions with Ge72



Conclusions

Impacts of non-standard neutrino interactions to the neutrino floor was studied

NSI	Enhancement
Vector	✓
Axial-vector	✗
Tensor	✗
Scalar	✓
Pseudo-scalar	✓



Thanks