



# **NEUTRINO FLOOR WITH NSI**

**WEI CHAO**

**BEIJING NORMAL UNIVERSITY**

**2020.09.26@Mini-workshop: low energy recoils from deep  
underground, CHEP**

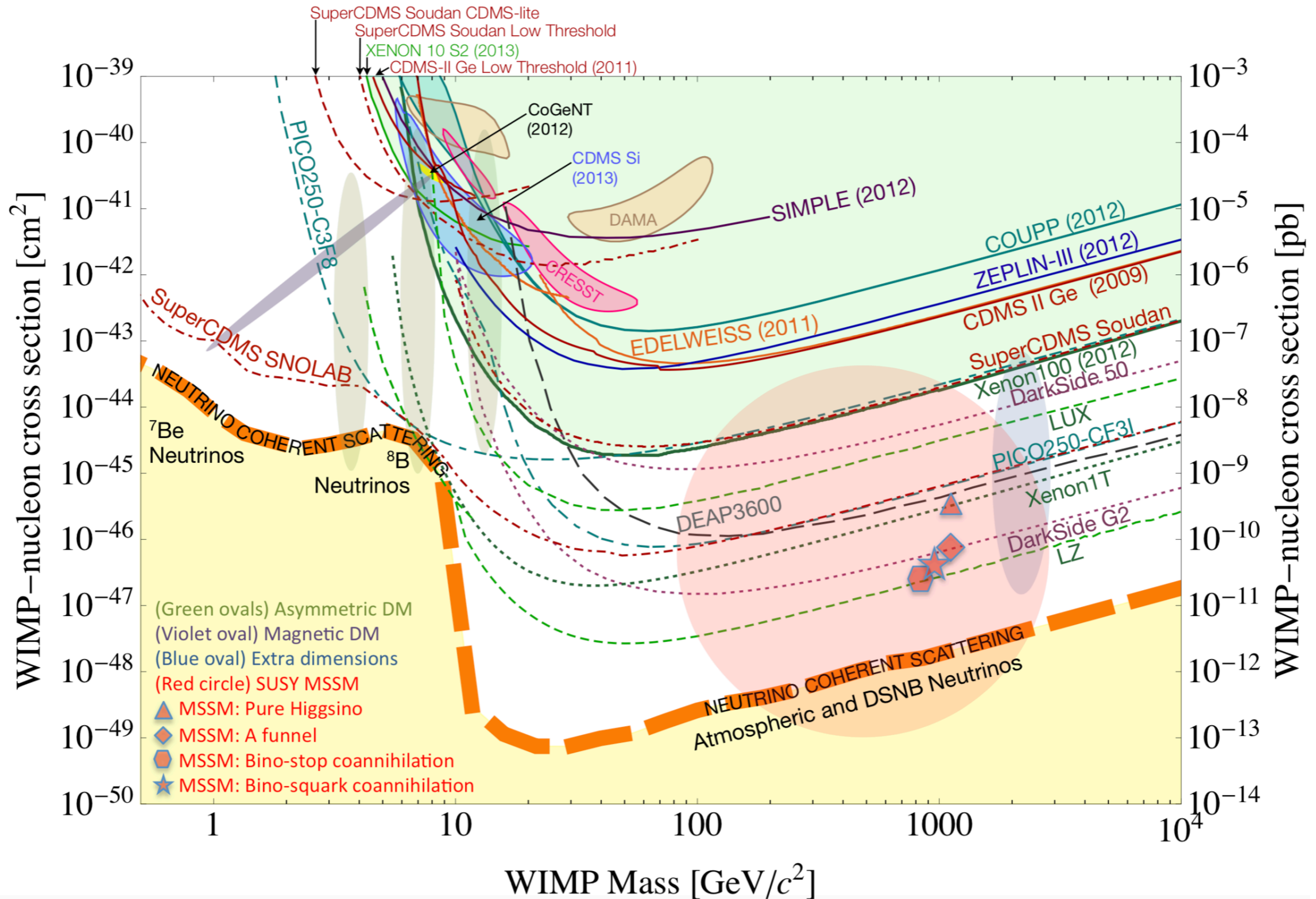
# Preview

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, JCAP1908,010

# Where to go for Direct detections



# Two relevant issues

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**Precision calculations of the direct detection cross section.**

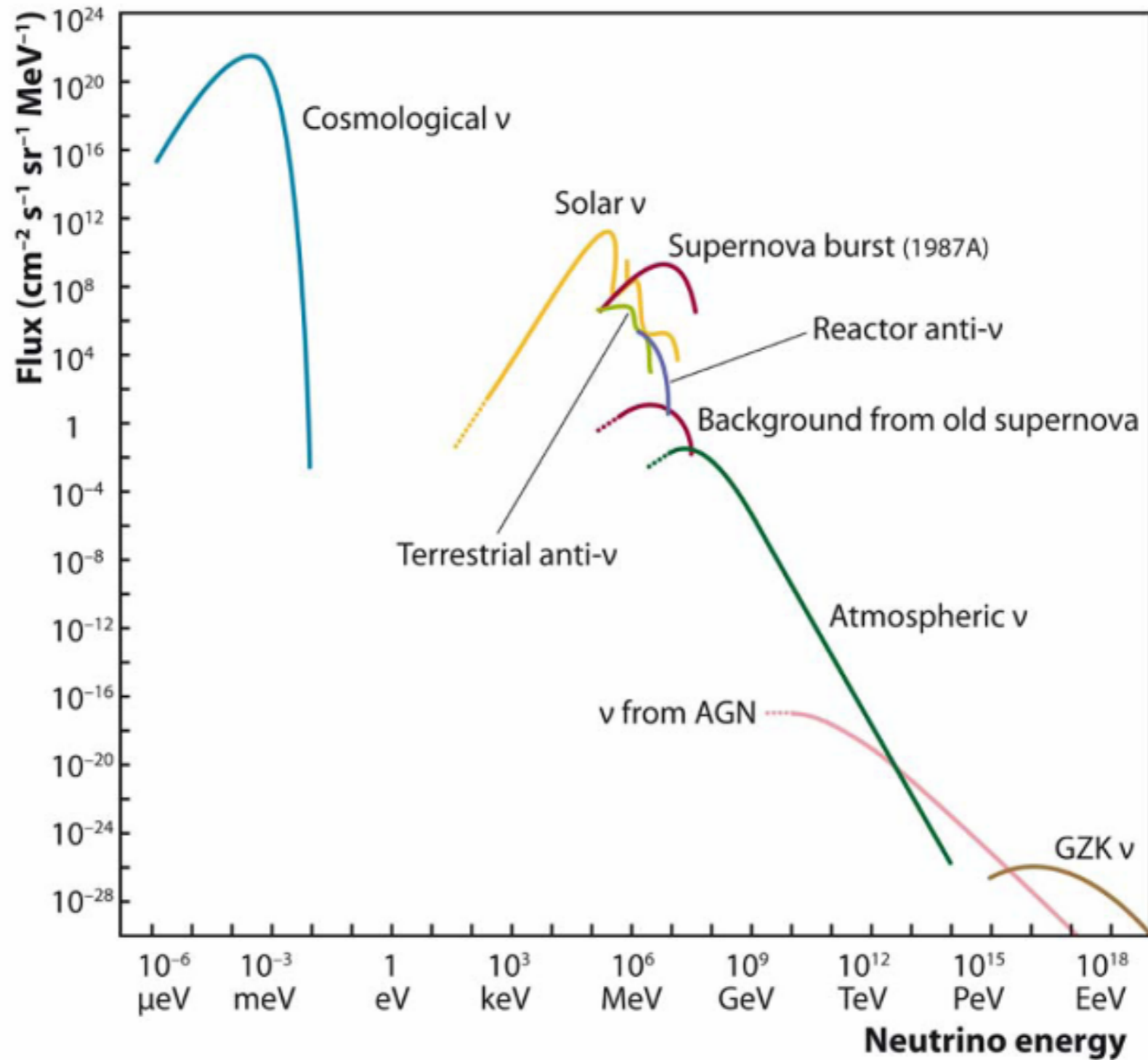
**Understanding the neutrino floor.**



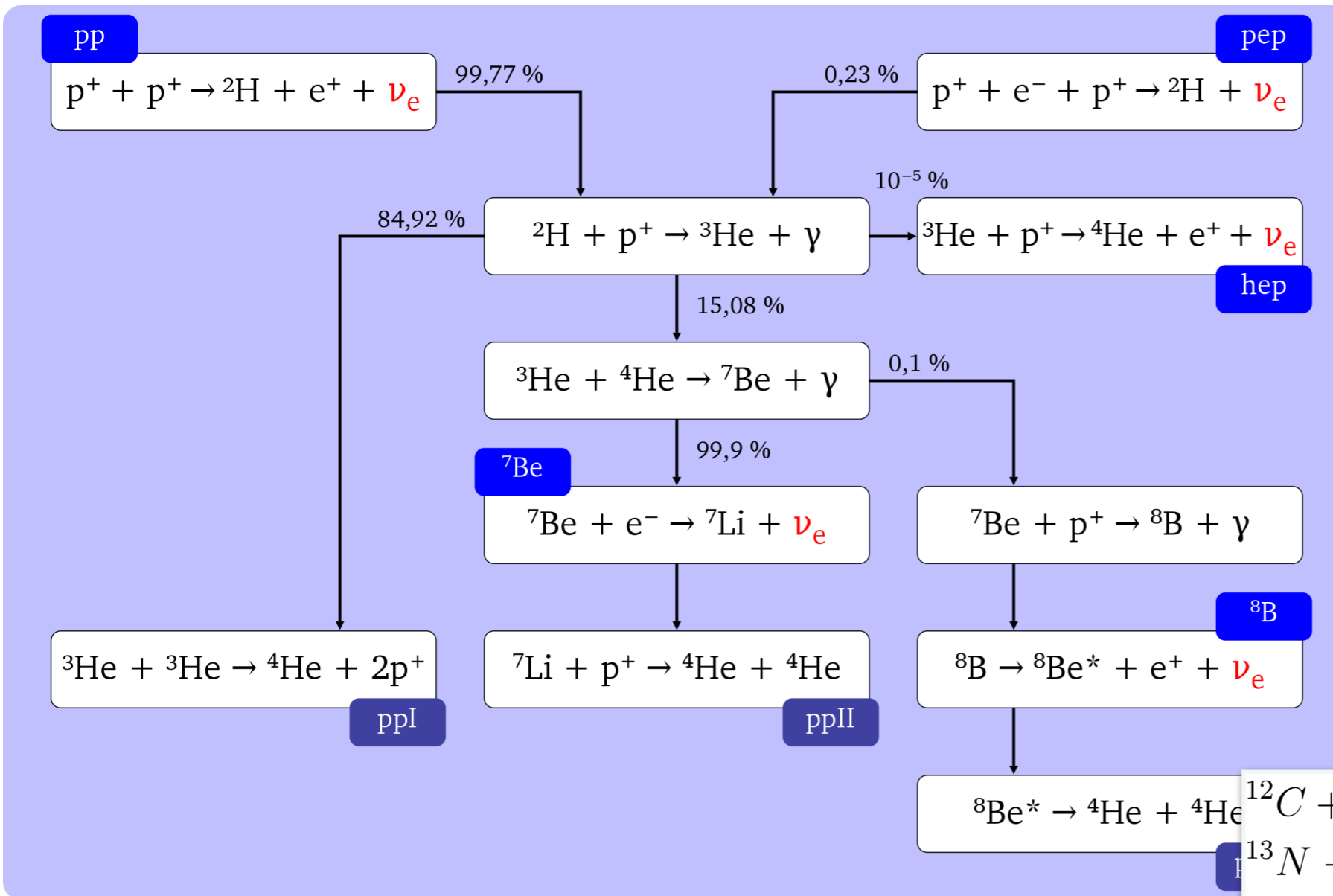
**Neutrino flux**

**Neutrino interactions**

# Neutrino flux from the universe

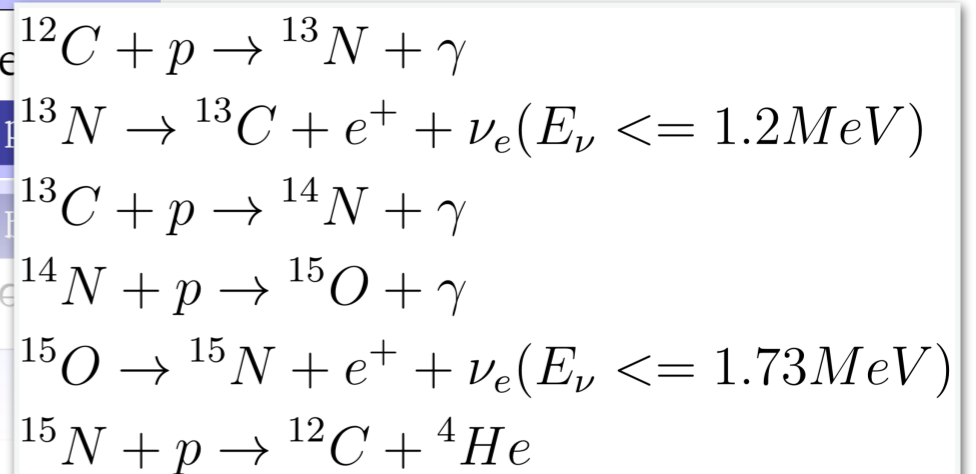


# Sun as the source of neutrinos

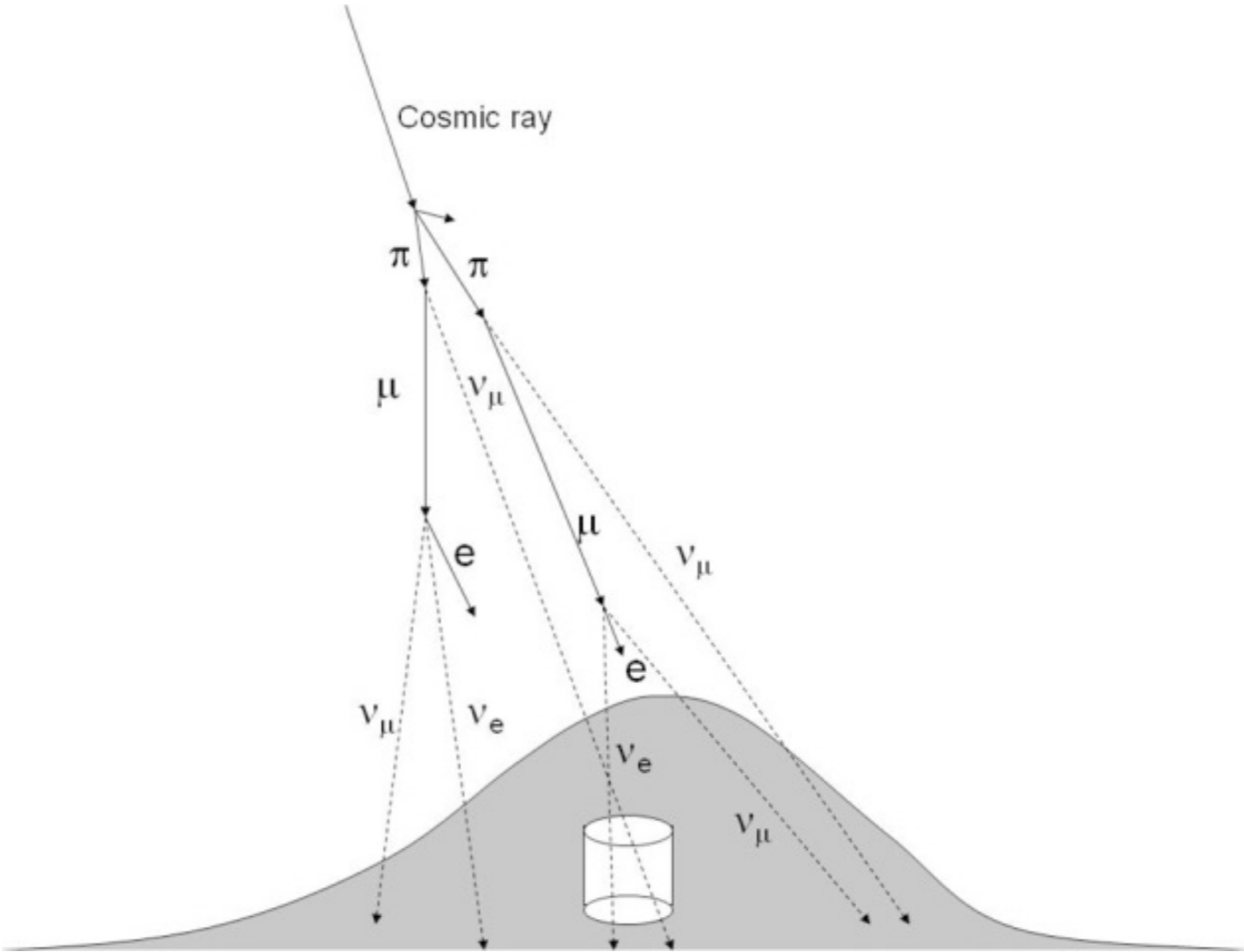
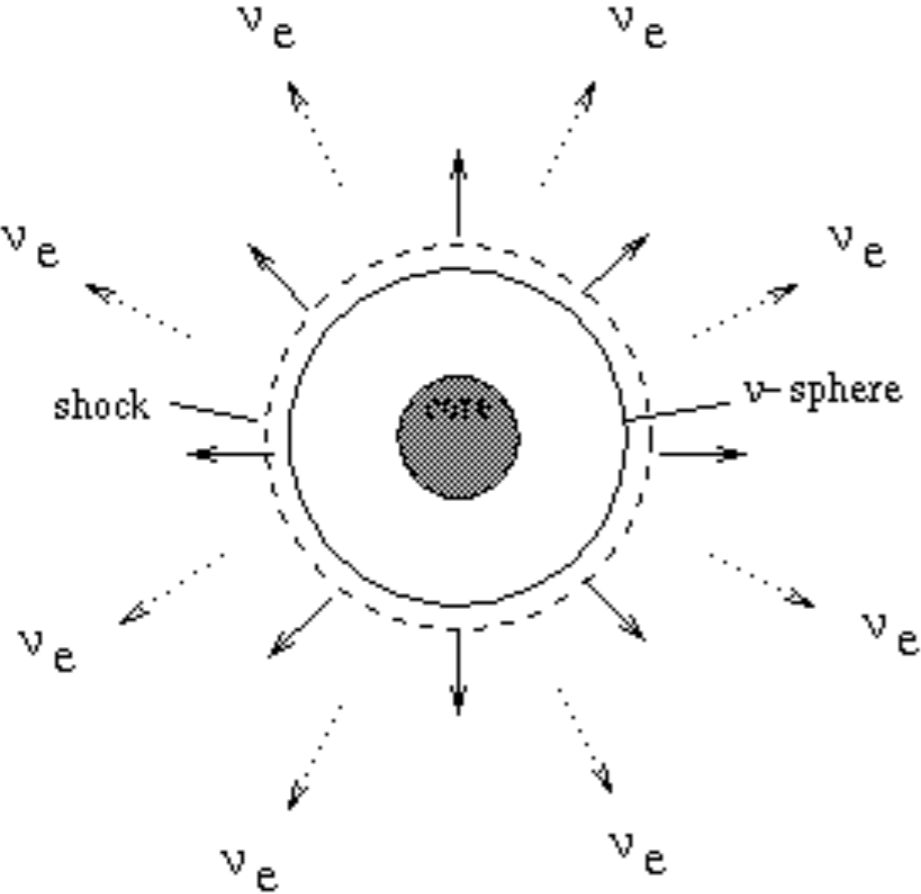


The p-p chain is responsible for 98.4% of the solar output

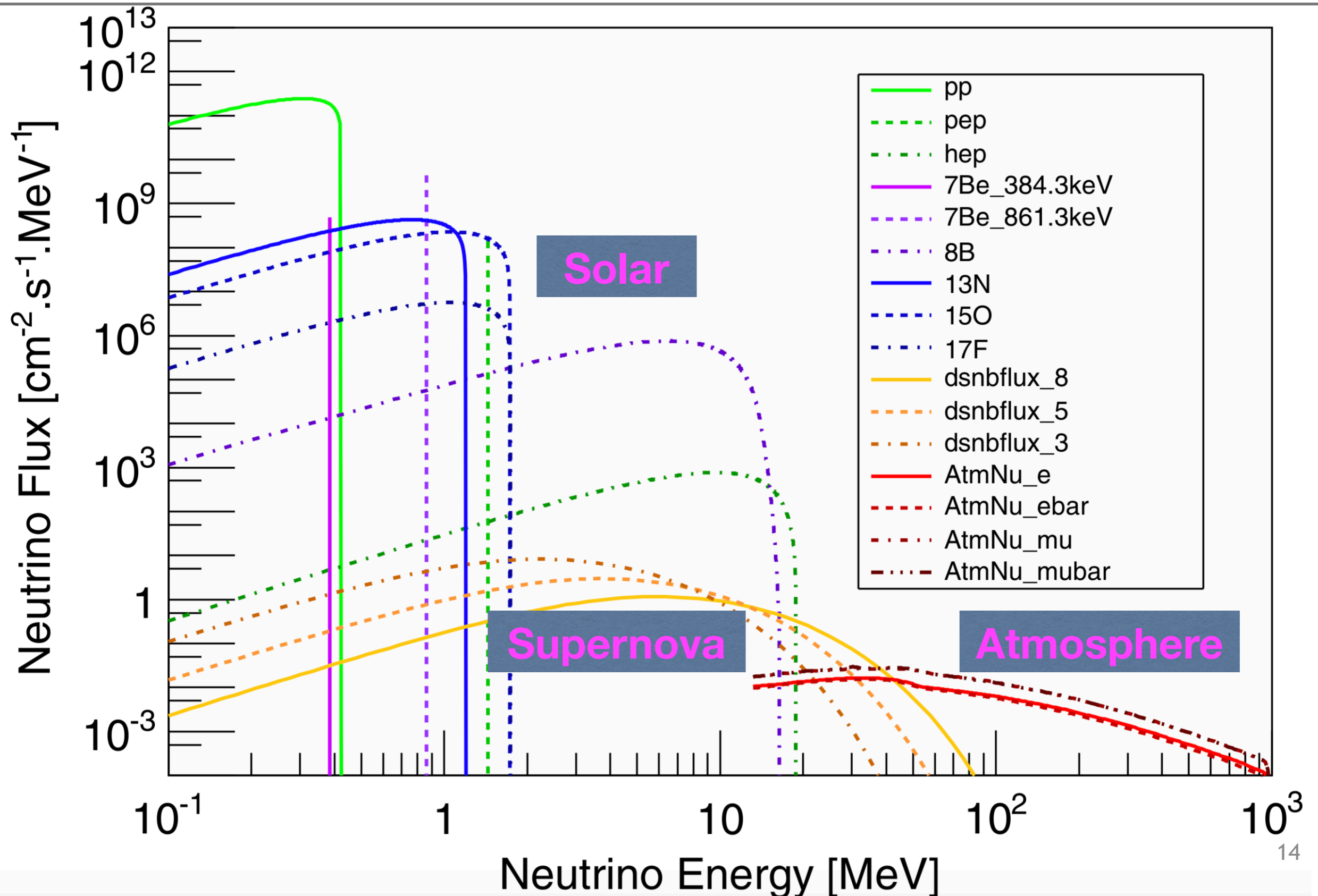
Carbon-Nitrogen-Oxygen cycle is responsible for 1.6% of the solar output



# Supernova and atmosphere neutrino



# Neutrino flux on the earth





# Neutrino-nuclei scattering

Charged currents coupling to electroweak gauge boson

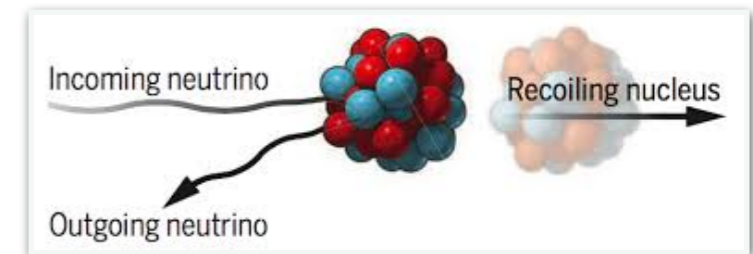
$$\sum_{\alpha=e,\mu,\tau} W_{\mu}^{+} (\bar{\nu}_{\alpha} \gamma^{\mu} \alpha) + \text{h.c.}$$

Neutral currents coupling to electroweak gauge boson

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

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

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

# Neutrino floor in the SM

The WIMP event rate

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

Exposure
DM density
Nuclear Form Factor

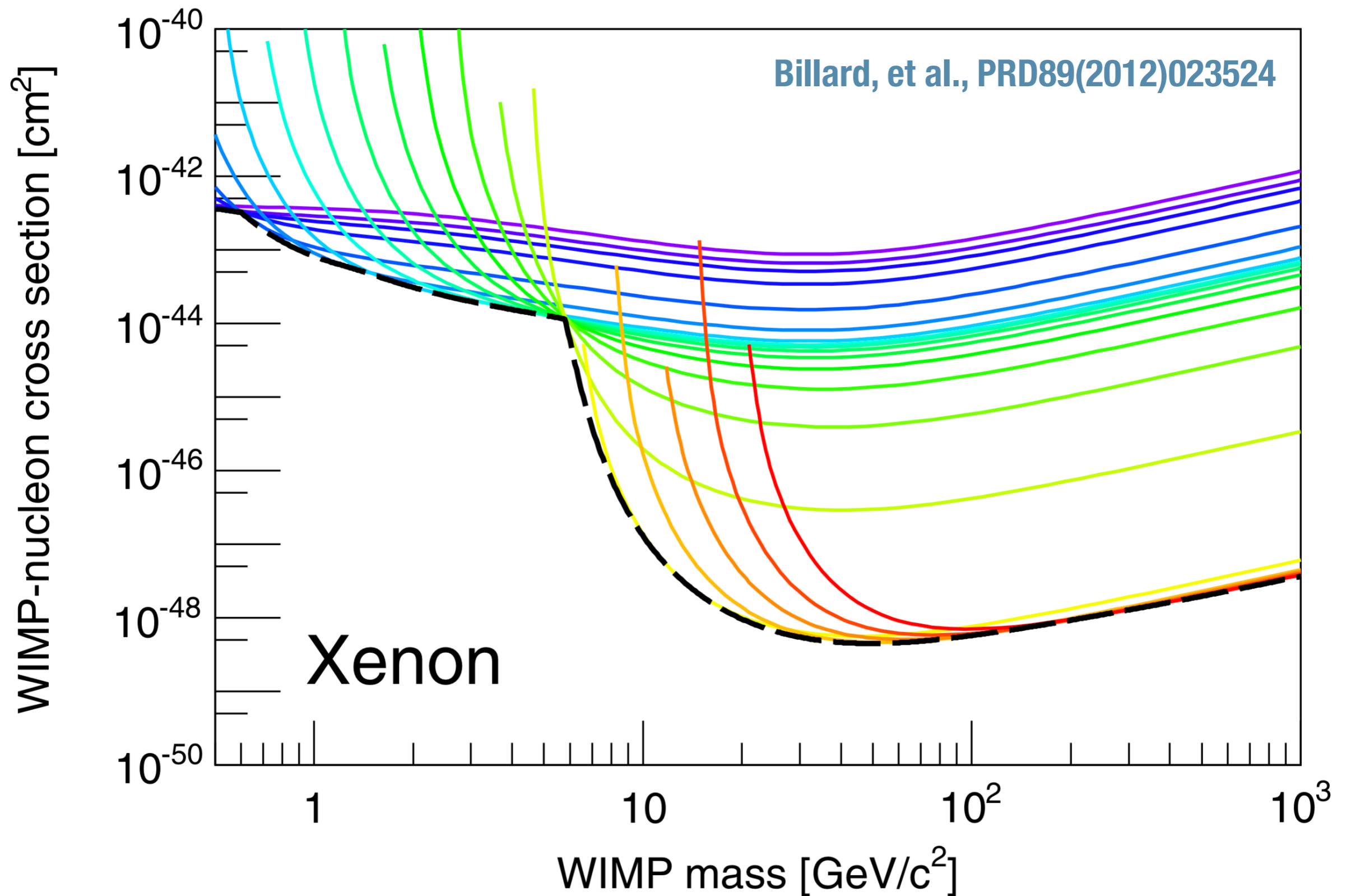
Neutrino event rate

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

Neutrino floor

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

# Neutrino floor in the SM



# Non-standard Neutrino interactions

Charged currents coupling to electroweak gauge boson

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

Neutral currents coupling to electroweak gauge boson

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

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

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

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

Charged current NSI: Production and detection

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

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

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

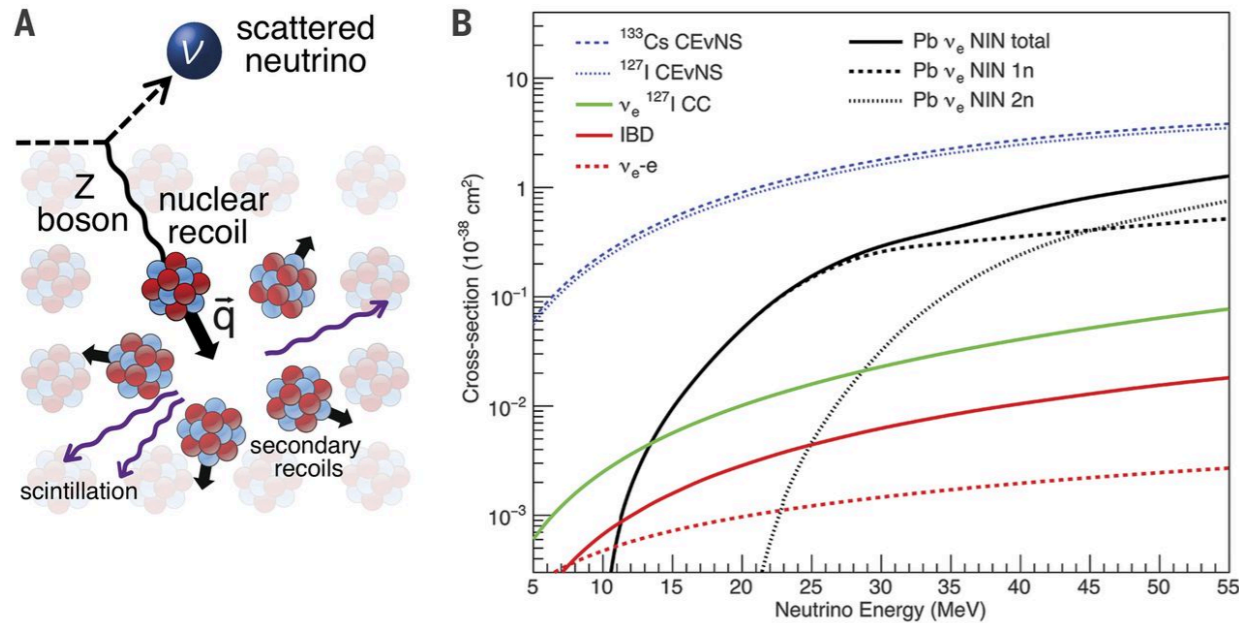
$$-0.008 < \varepsilon_{ee}^{uV} < 0.618$$

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

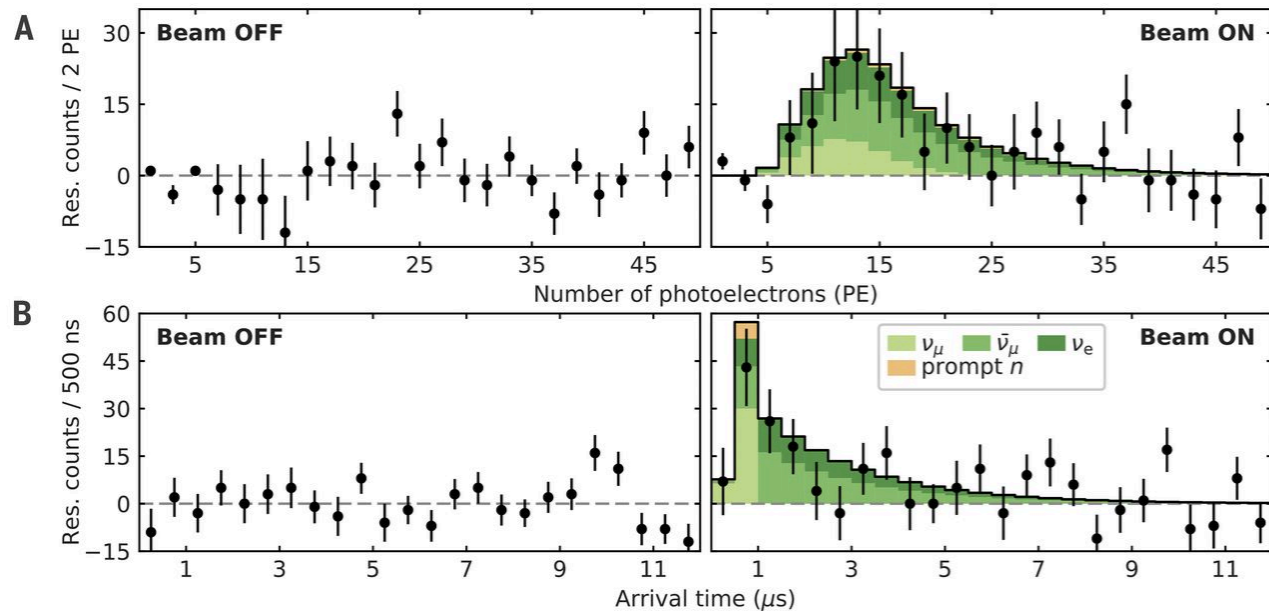
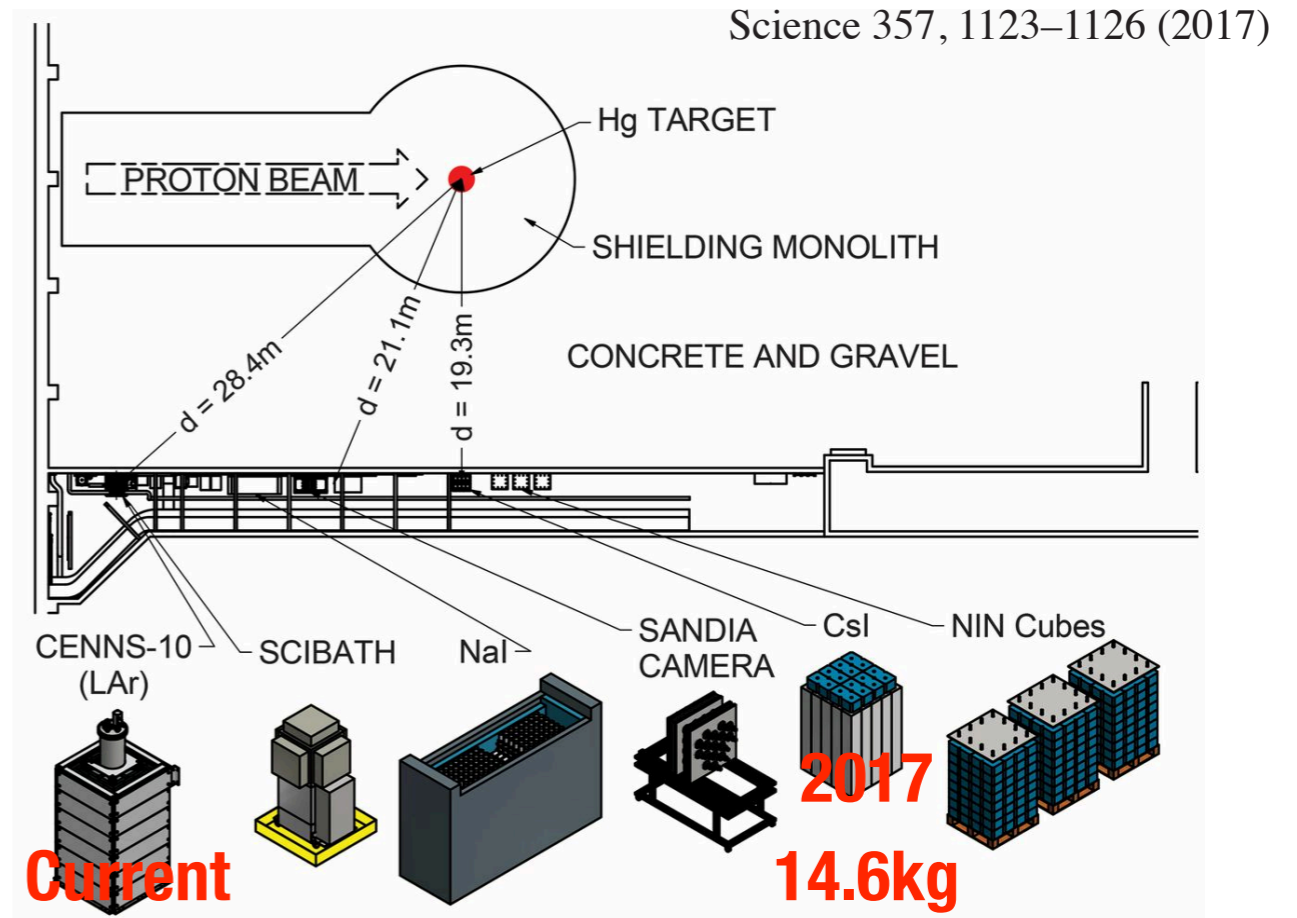
$$-0.111 < \varepsilon_{\mu\mu}^{uV} < 0.402$$

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

# CONHERENT



**GOAL: Measure  $N^2$  dependence of CEvNS process**



**Confirm CEvNS at 6.7 sigma**

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

# CHARM

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

CHARM, PLB180,303

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

CHARM, Z. Phys. C36,611

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

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

Falkowski, et al., 1706.03783

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$$R_e^{\text{NSI}} = R_e^{\text{SM}} + \frac{\Delta\sigma_{\text{NSI}}}{\sigma_{\text{CC}}}$$

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

# Combined constraints

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



# Neutrino floor with exotic neutrino interactions

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

$$W_M^{\alpha\beta}(q^2) \sim A^2$$

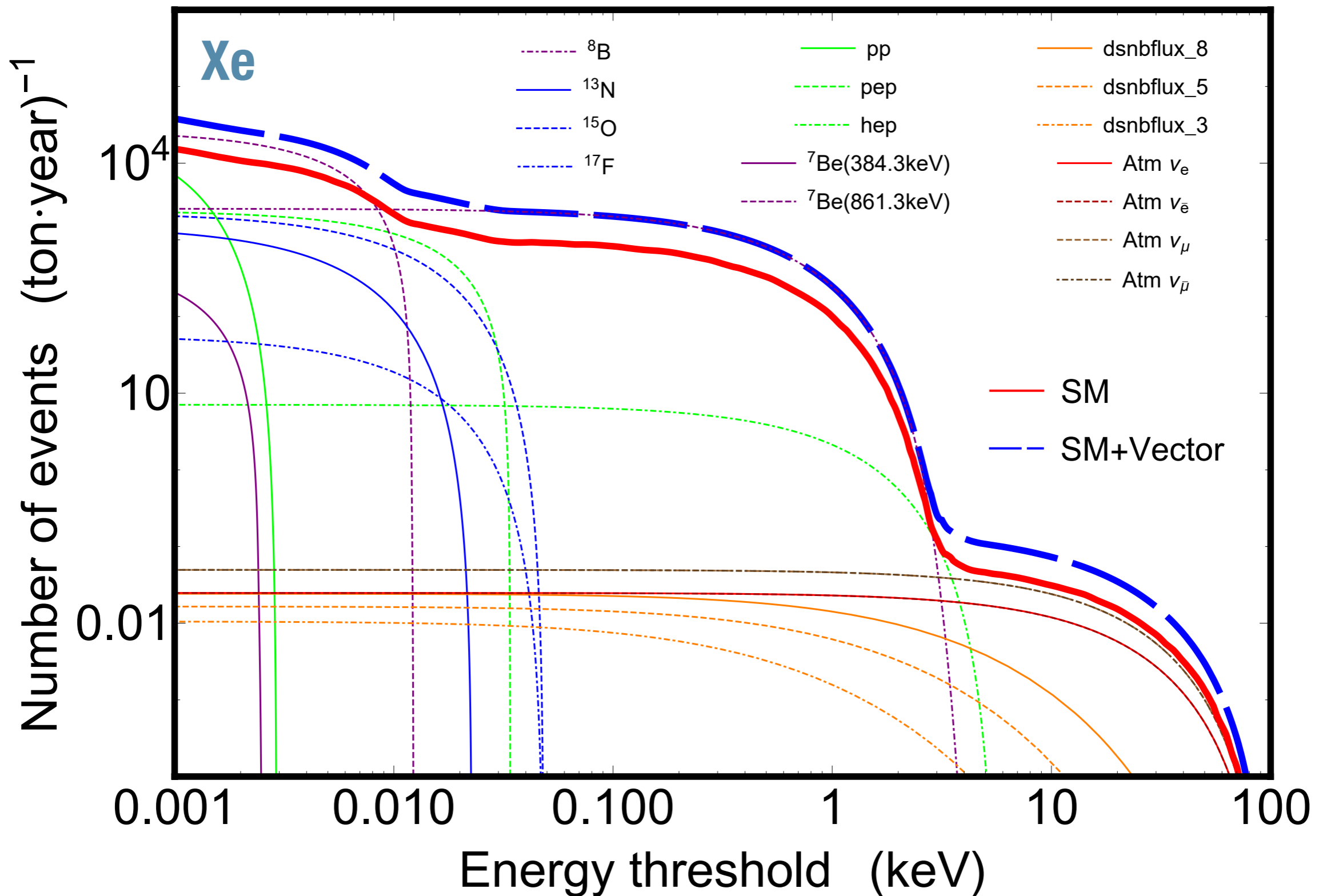
$$W_{\Sigma'}^{\alpha\beta}(q^2) \sim 1$$

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

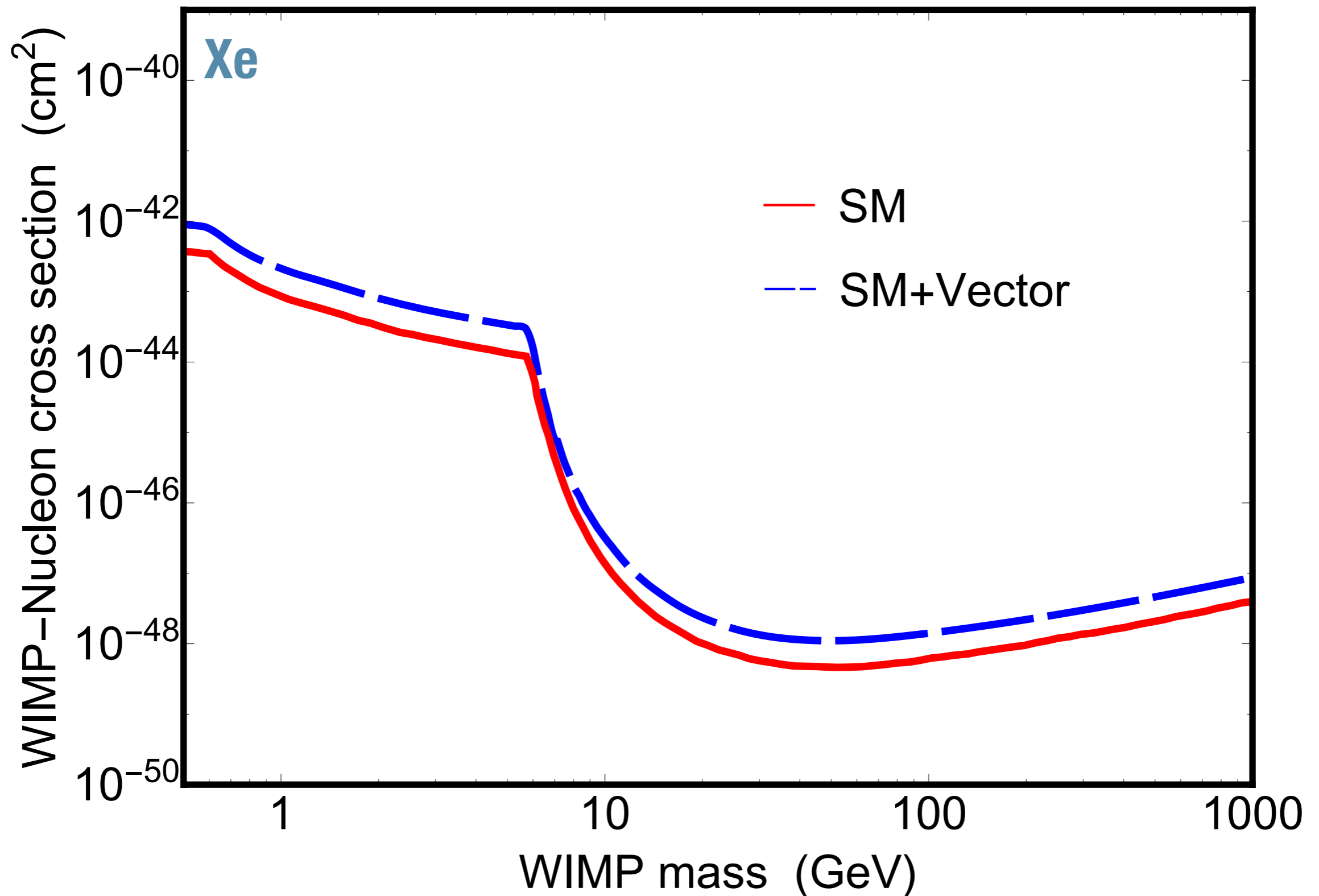
$$\zeta_\alpha^0 = \frac{1}{2} (\zeta_\alpha^p + \zeta_\alpha^n) \quad \zeta_\alpha^1 = \frac{1}{2} (\zeta_\alpha^p - \zeta_\alpha^n)$$

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

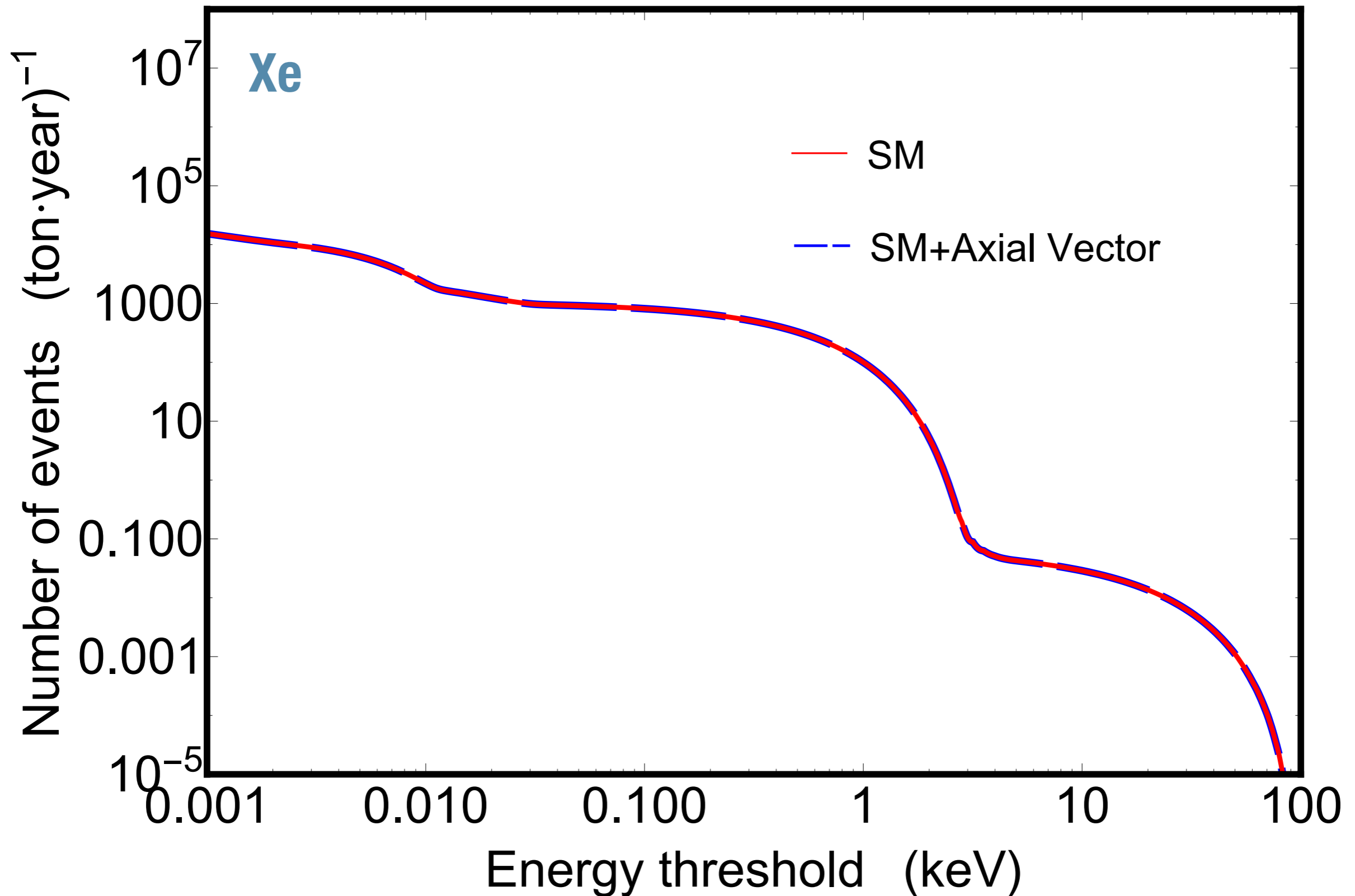
# Numerical results-1: vector interactions with **Xe131**



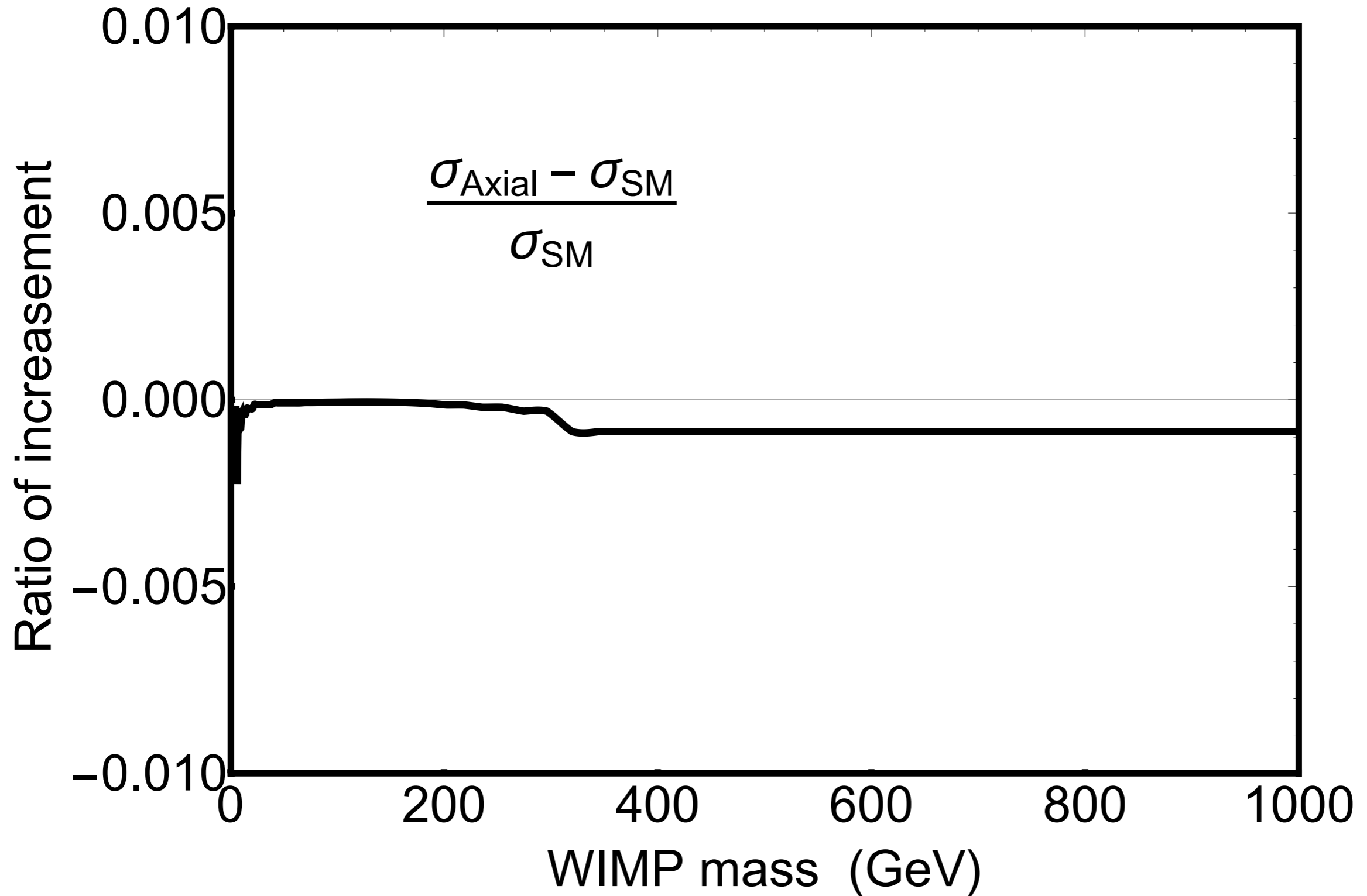
# Numerical results-1: vector interactions with **Xe131**



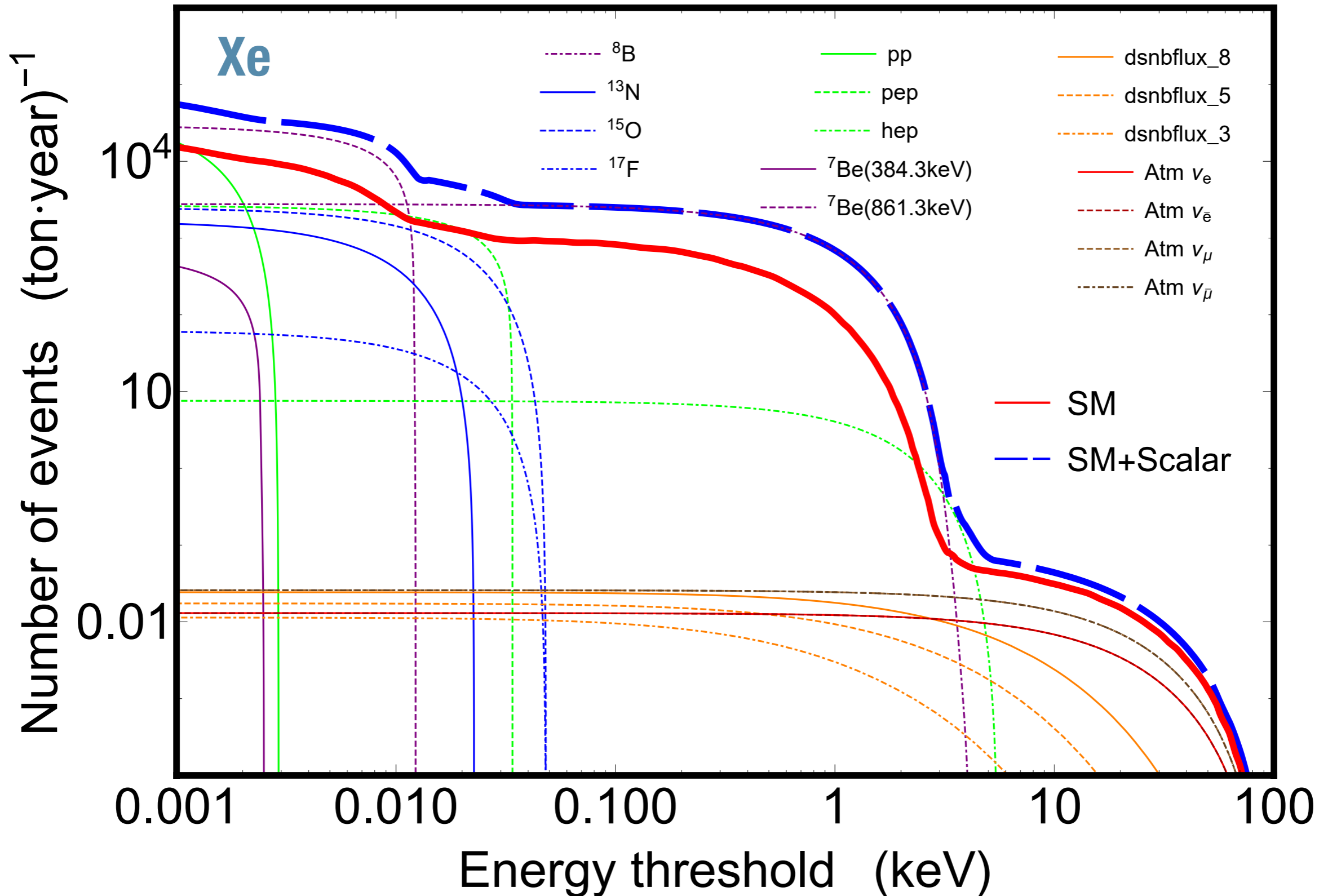
# Numerical results-2: axial-vector interactions with **Xe131**



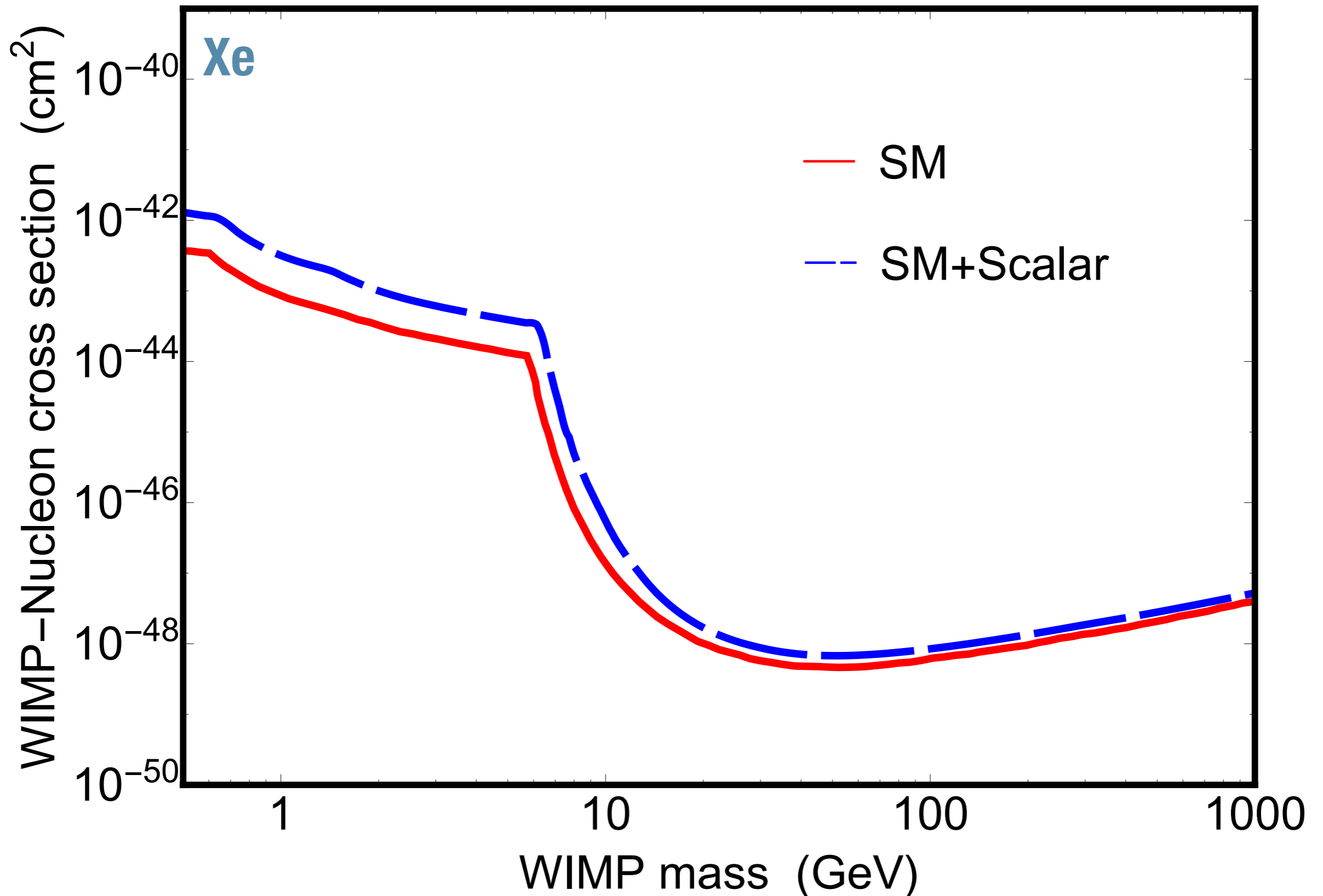
# Numerical results-2: axial-vector interactions with **Xe131**



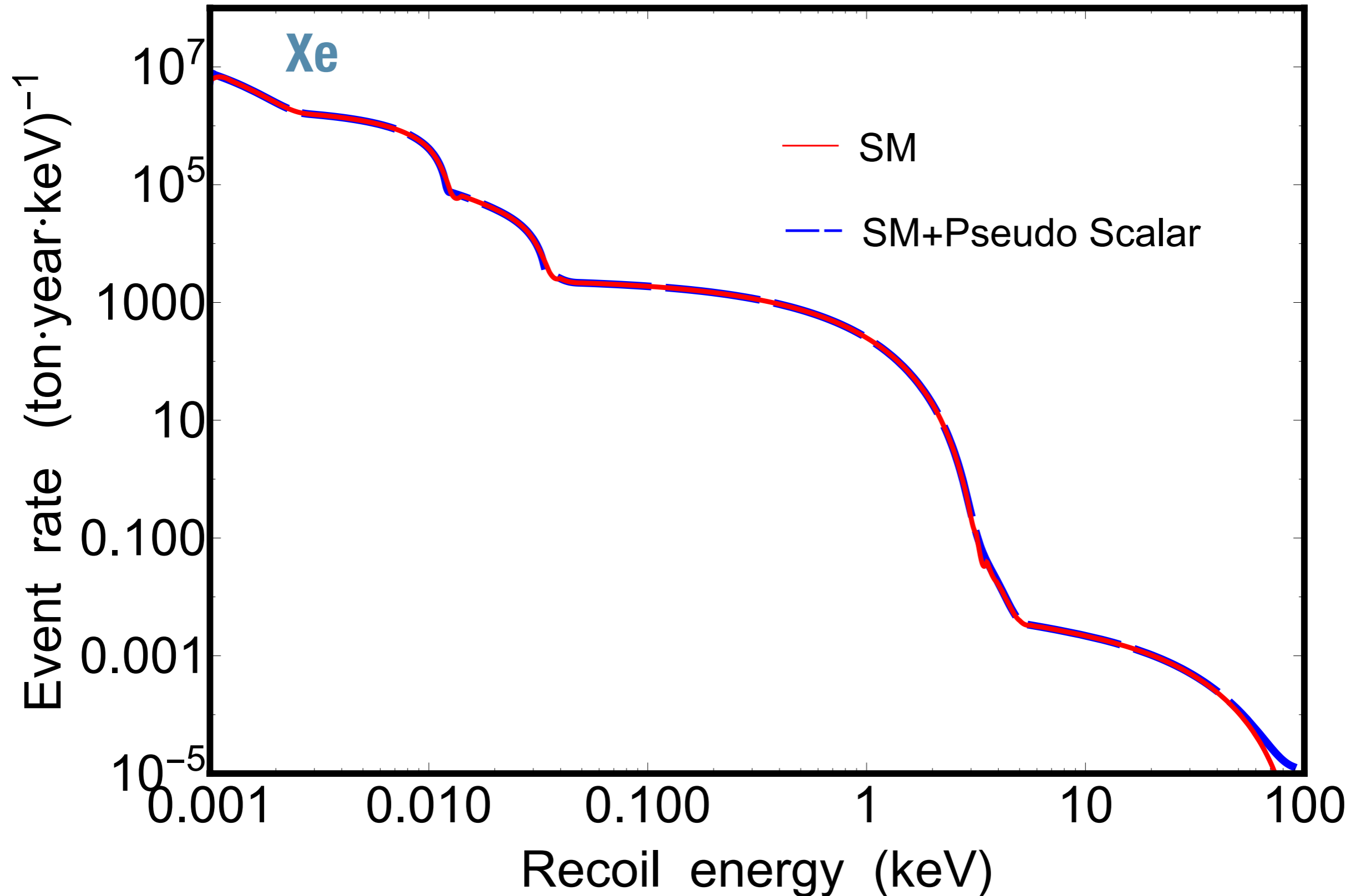
# Numerical results-3: scalar interactions with **Xe131**



# Numerical results-3: scalar interactions with **X131**

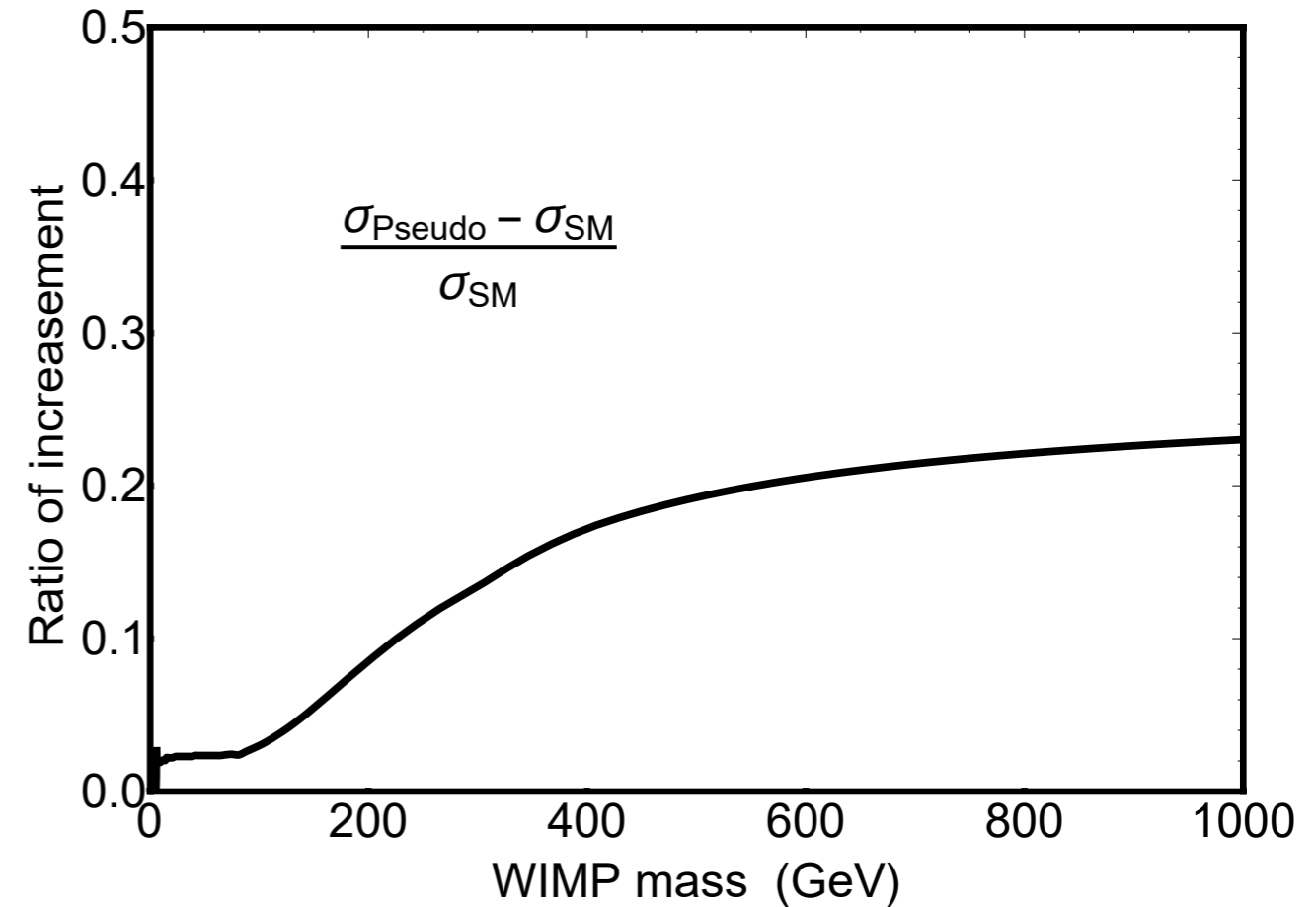
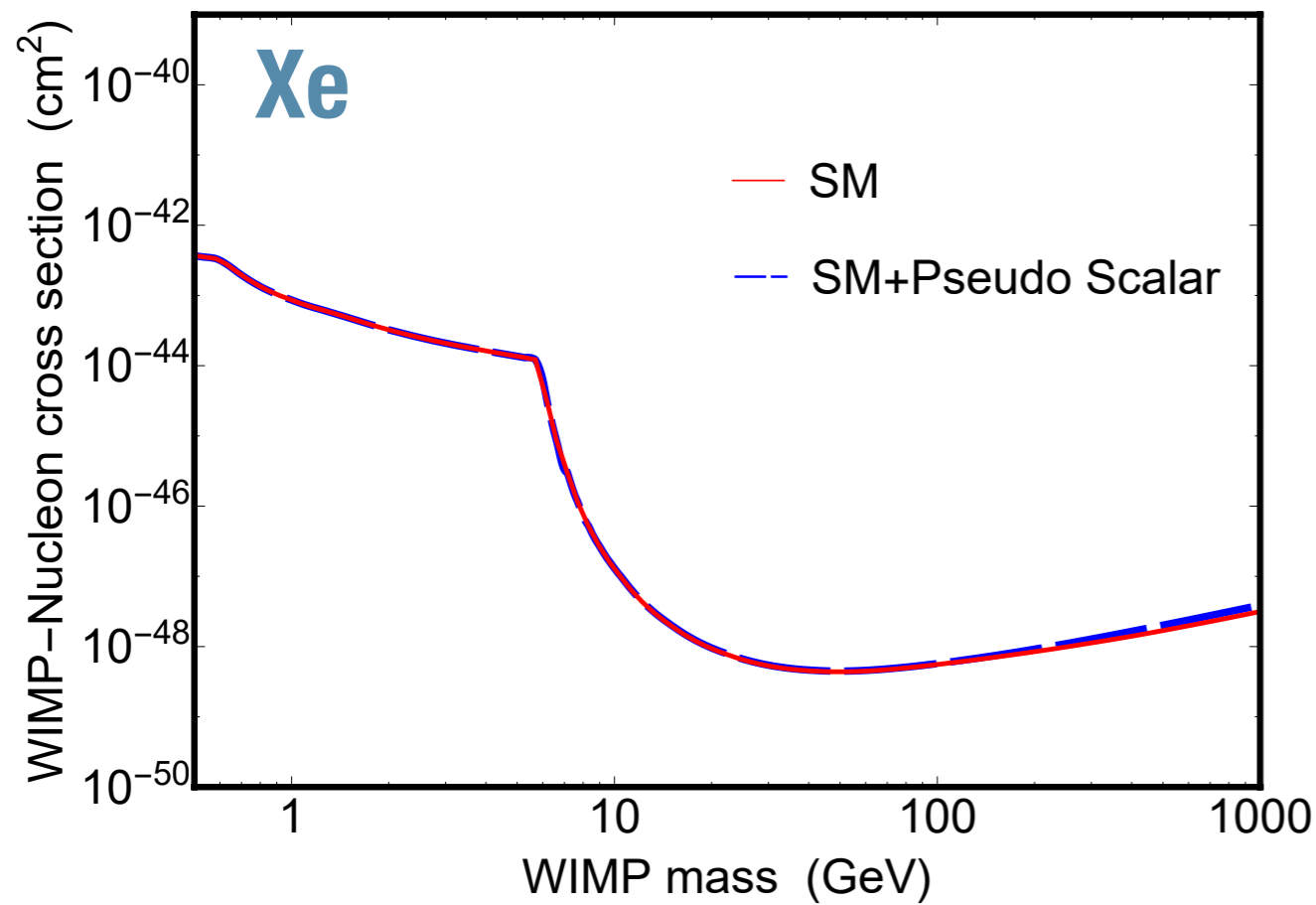


# Numerical results-4: pseudo-scalar interactions with **Xe131**

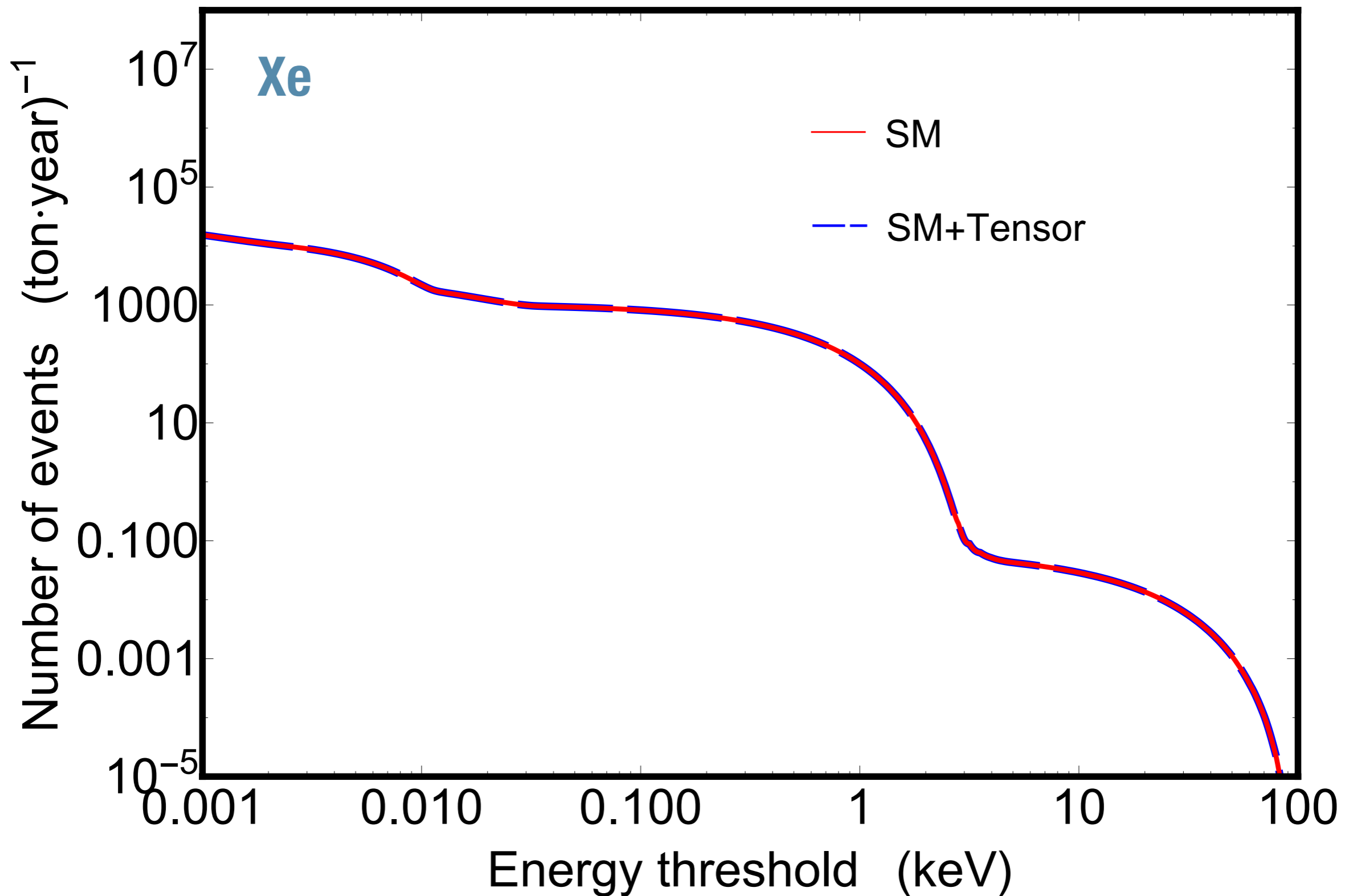




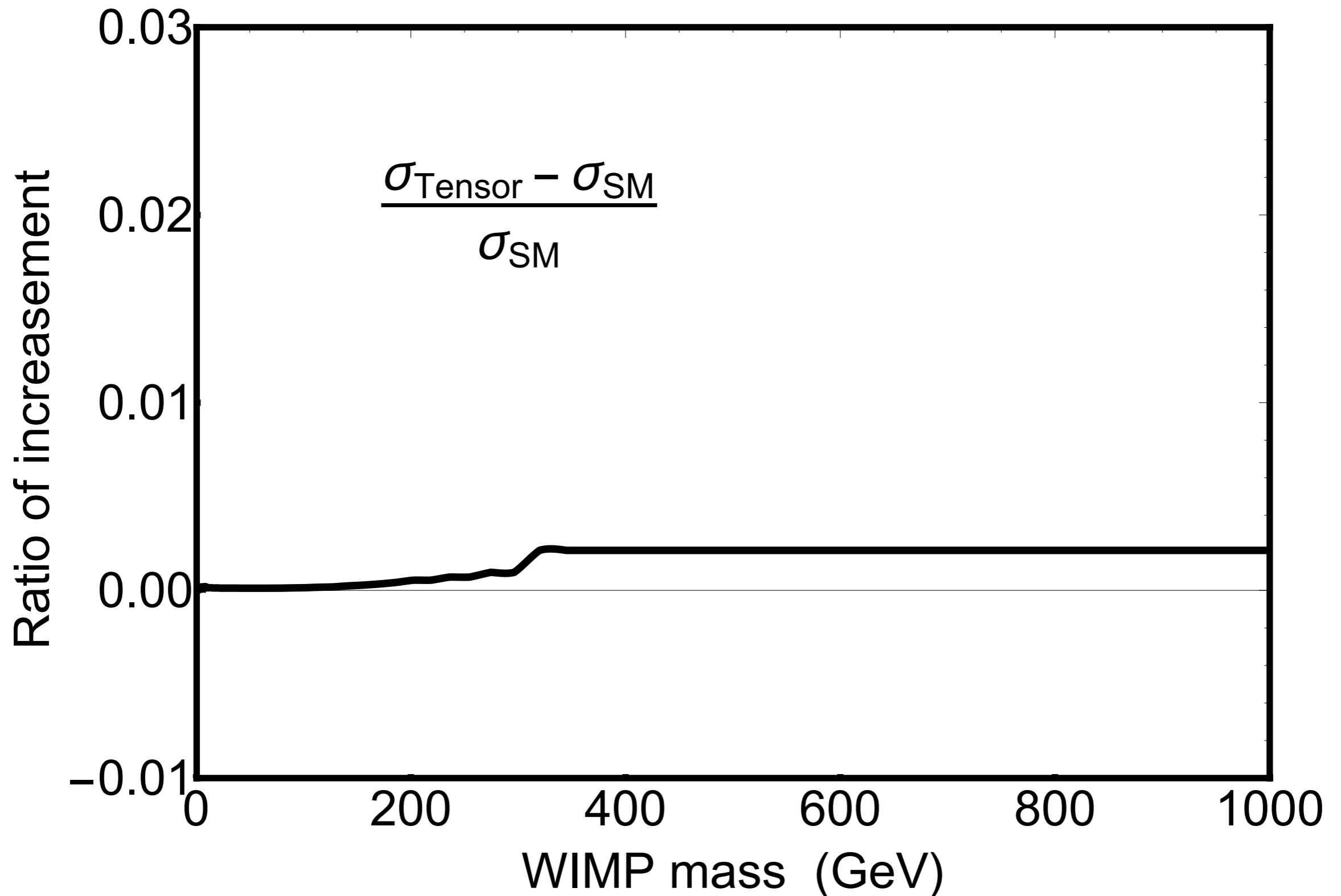
# Numerical results-4: pseudo-scalar interactions with X131



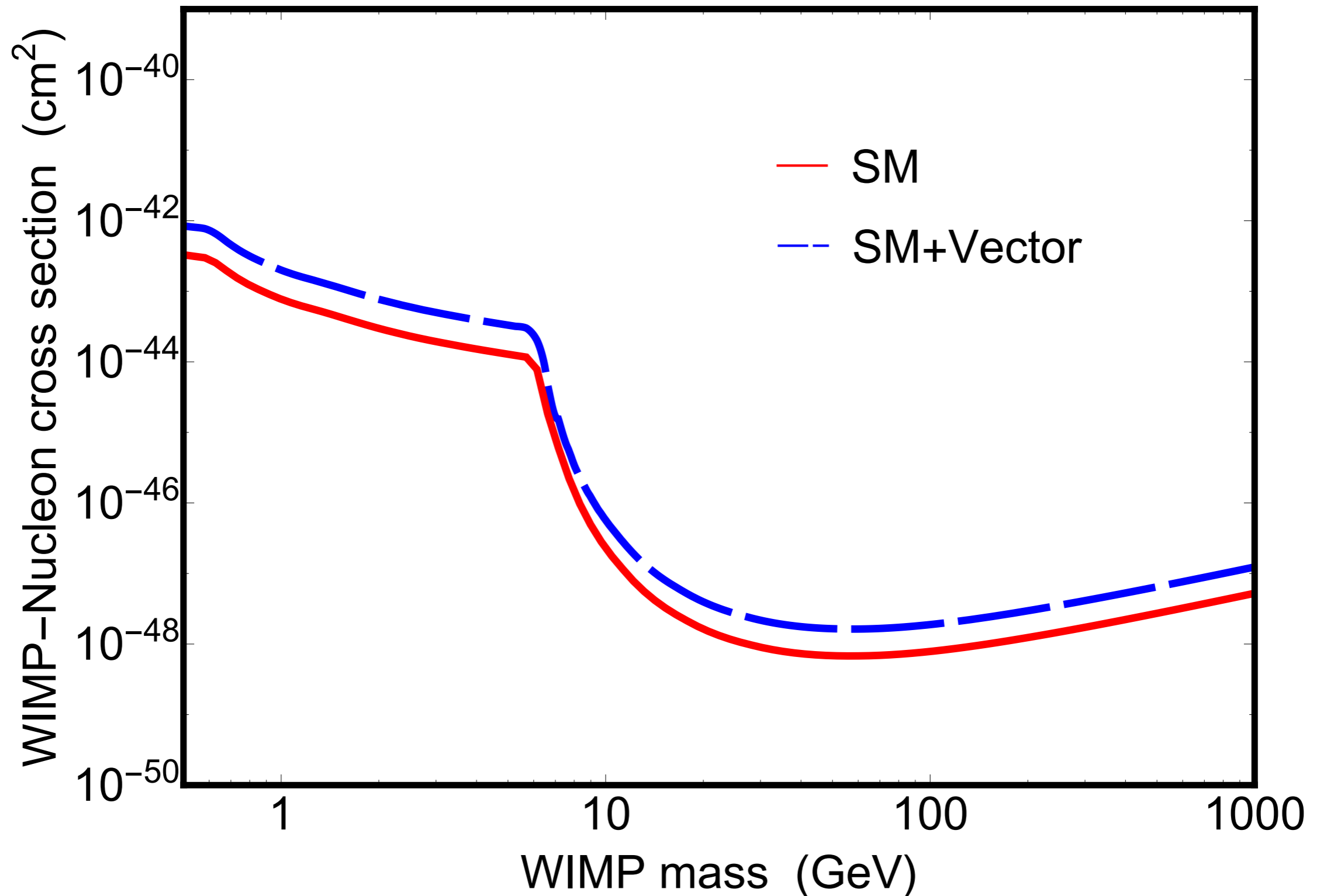
# Numerical results-5: tensor interactions with **Xe131**



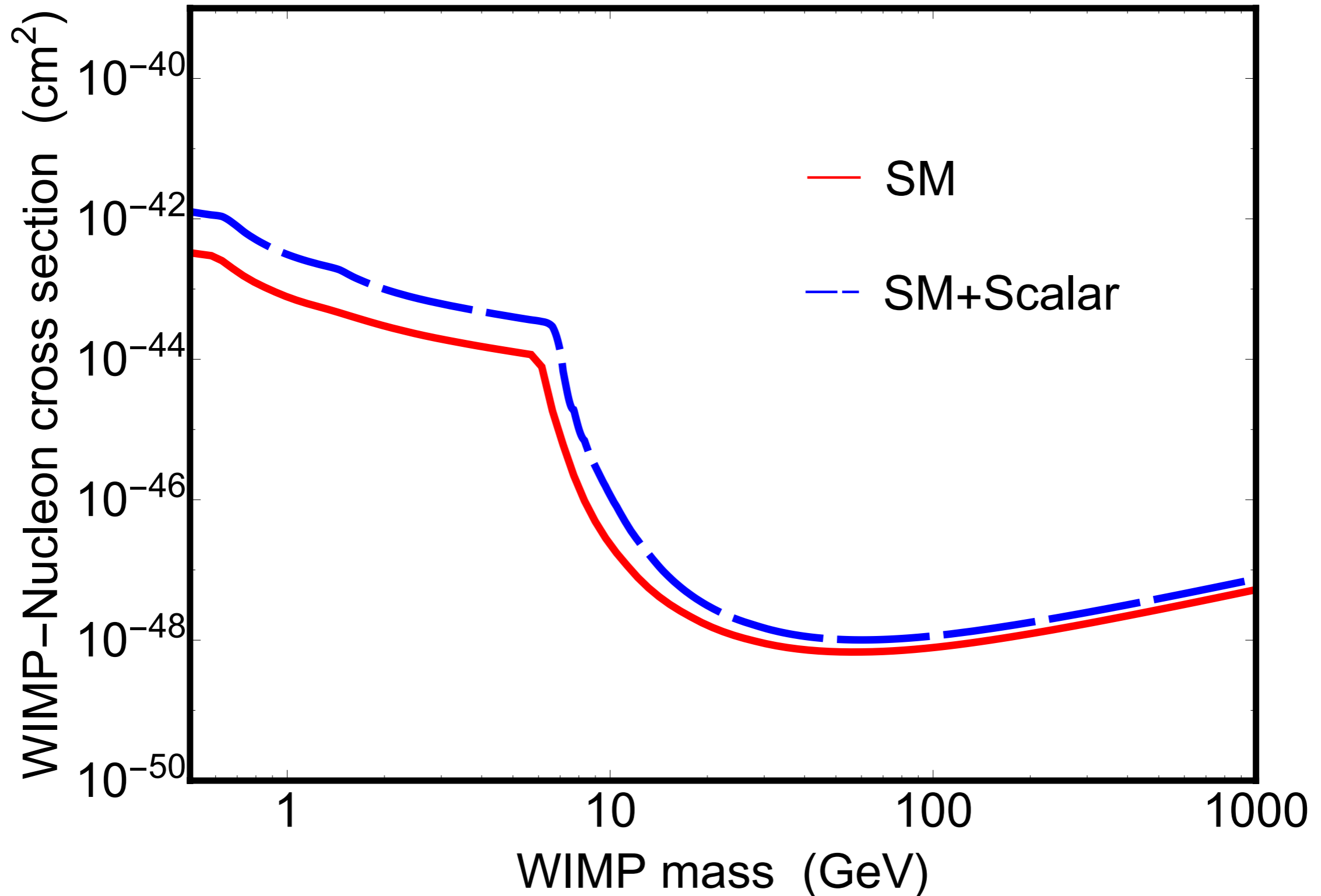
# Numerical results-5: tensor interactions with **Xe131**



# Numerical results-6: vector interactions with Ge72



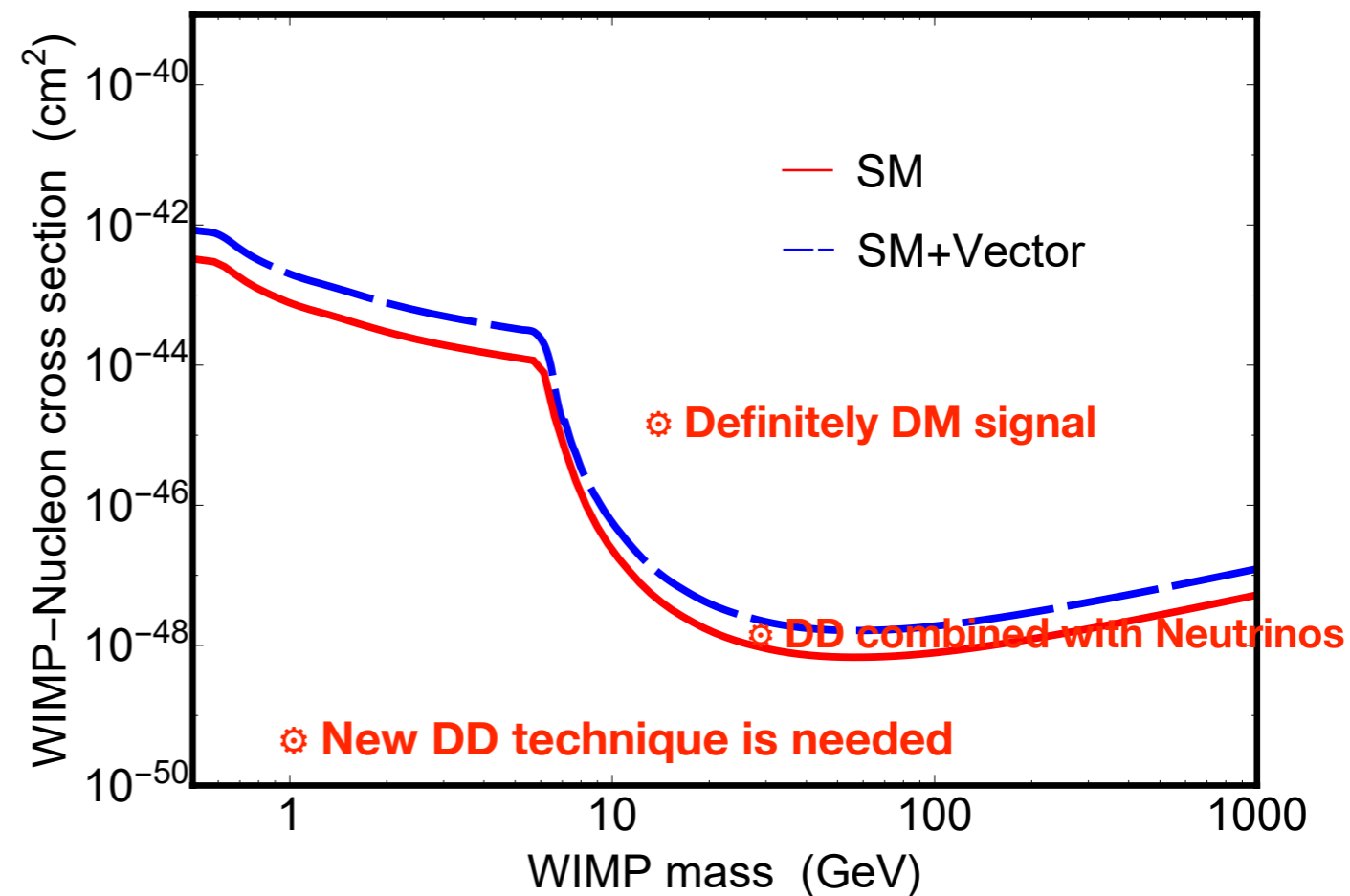
# Numerical results-6: scalar interactions with **Ge72**



# Conclusions

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

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



# Thanks