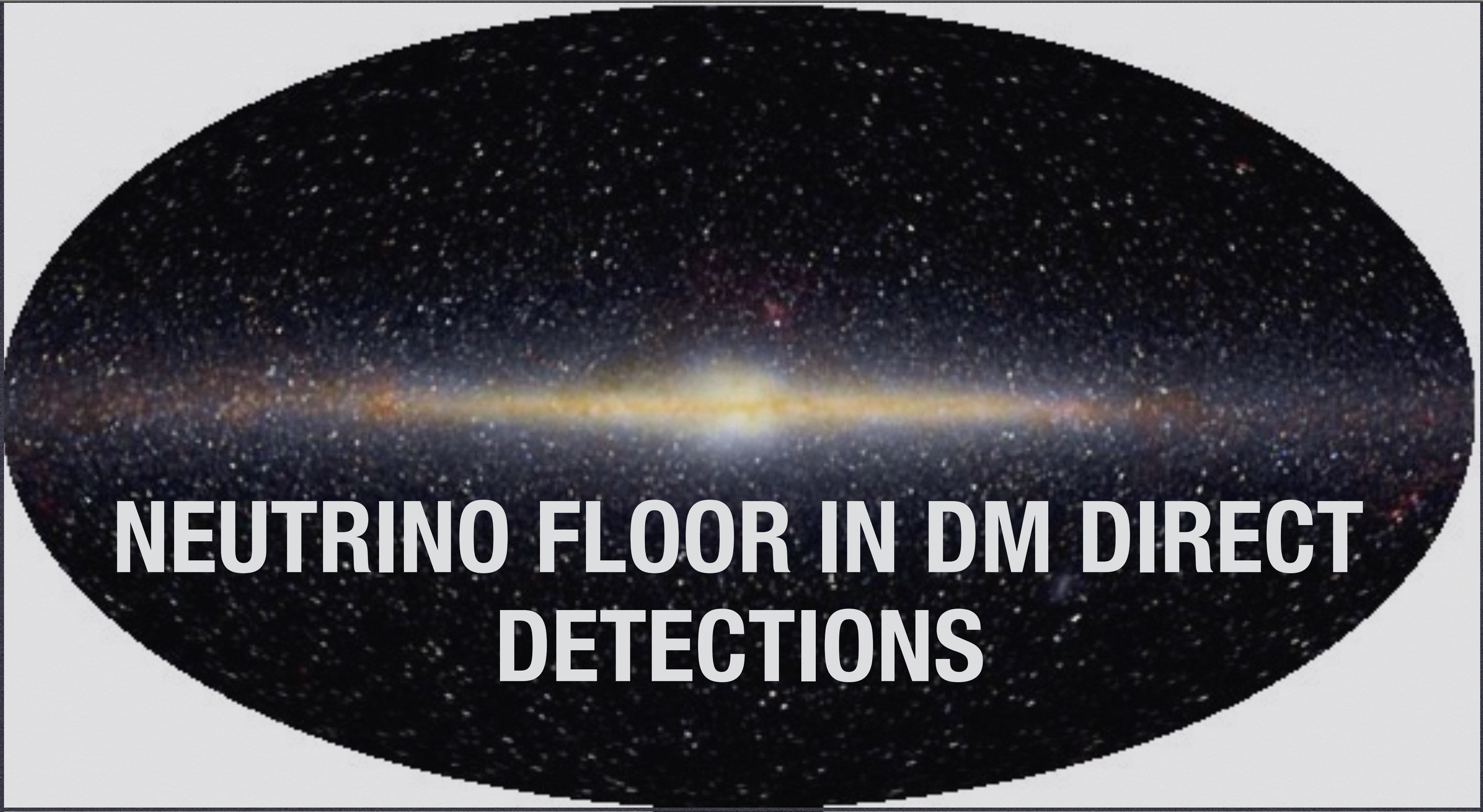


NEUTRINO FLOOR IN DM DIRECT DETECTIONS

WEI CHAO

BEIJING NORMAL UNIVERSITY

2019.11.22@composite2019, SYSU

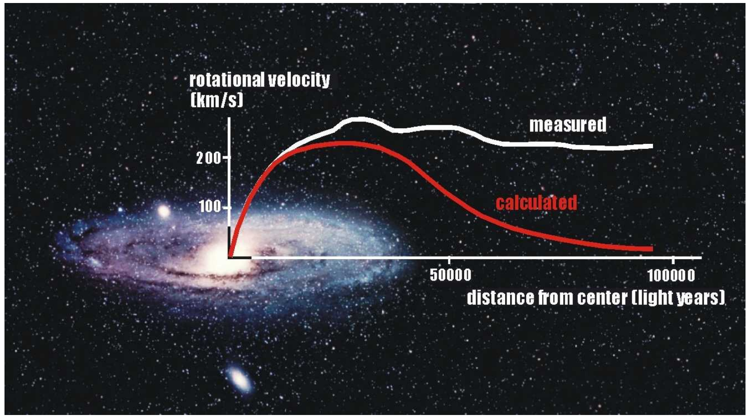
Preview

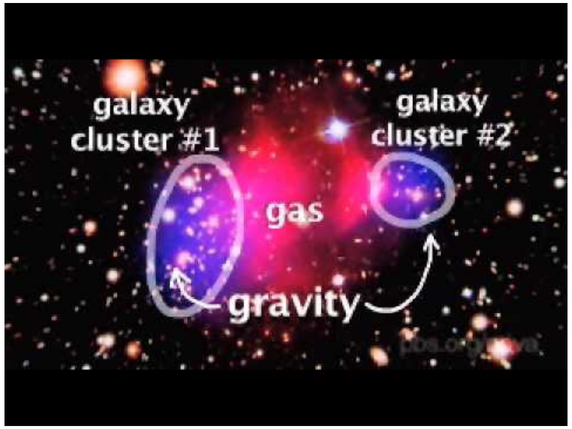
We study impacts of non-standard neutrino interactions to the neutrino floor

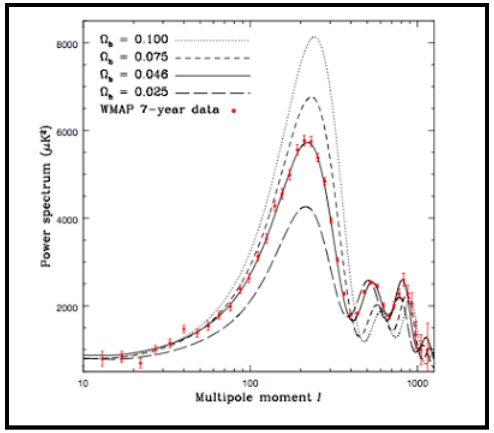
NSI	Enhancement	Estimated values
Vector	✓	~several times
Axial-vector	✗	✗
Tensor	✗	✗
Scalar	✓	~several times
Pseudo-scalar	✓	~30%

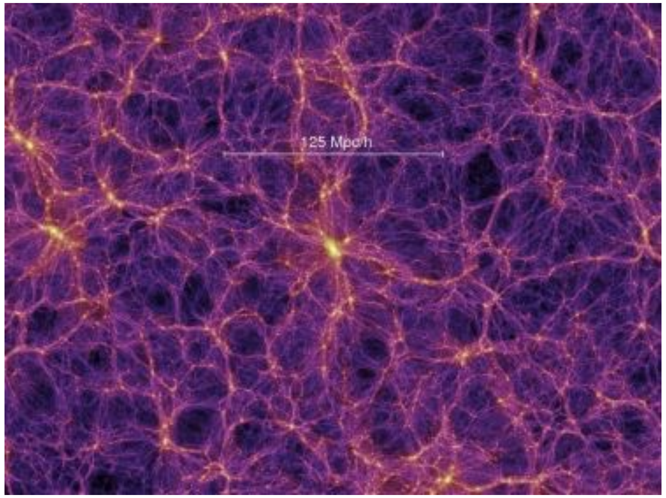
Wei Chao, J. Zhang, X. Wang and X. Zhang, JCAP1908,010

Evidence of DM

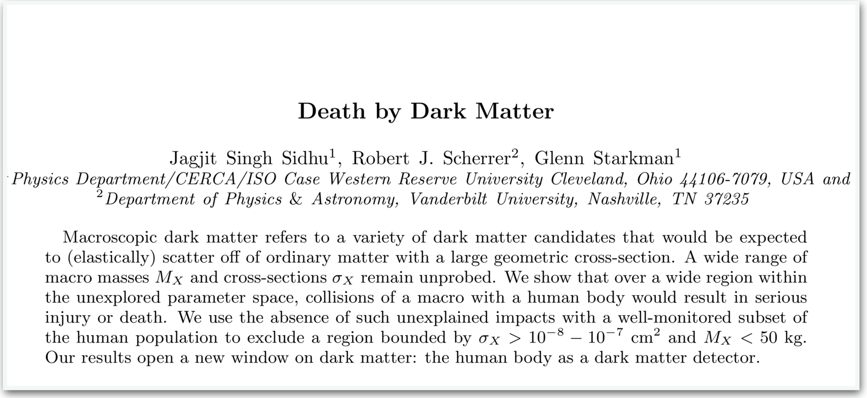








DM incidents, 1907.06674



Death by Dark Matter

Jagjit Singh Sidhu[1], Robert J. Scherrer[2], Glenn Starkman[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!

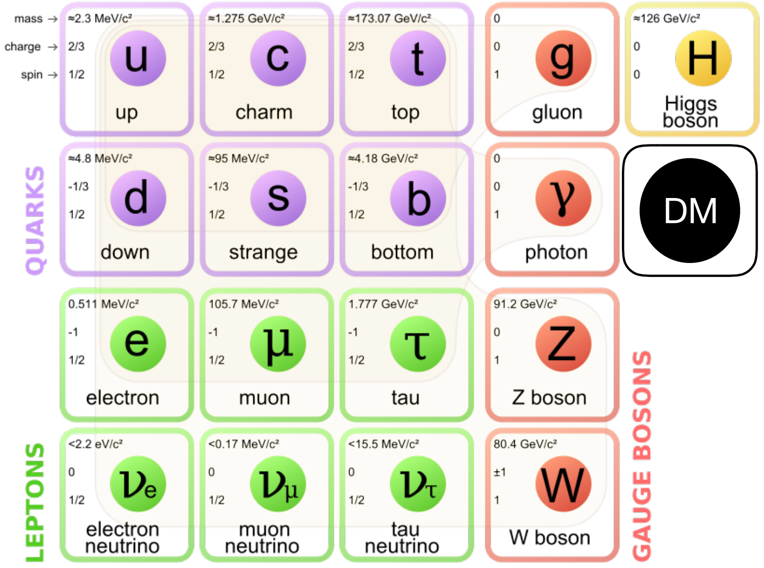
Mass

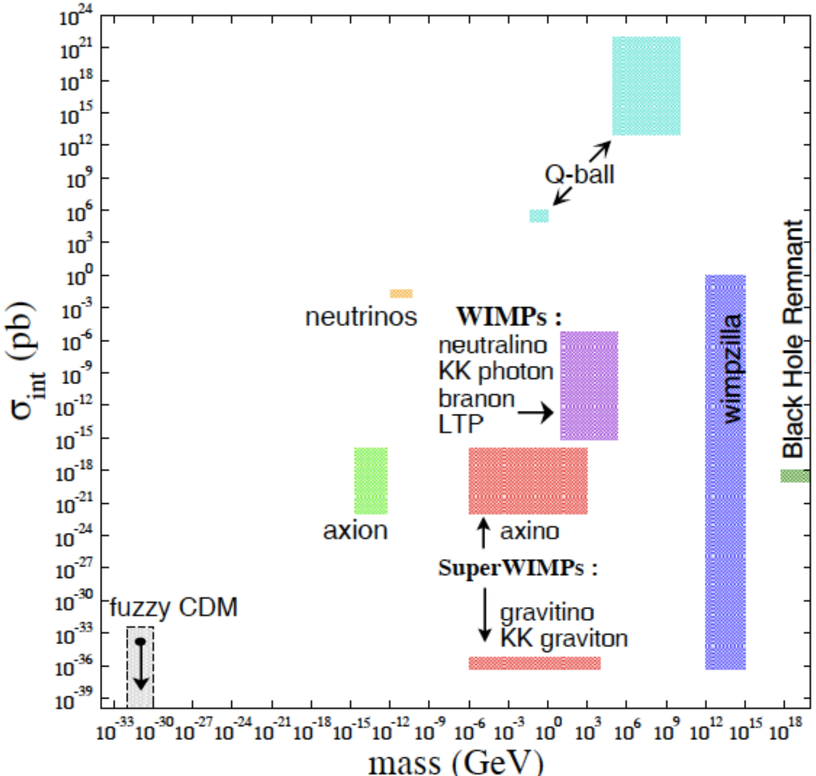
Spin

Interactions

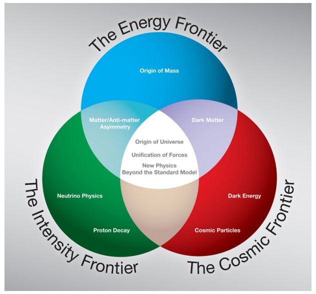
Neutral, non-baryonic, weakly interacting particle!

Particle Zoo





Ways of probing WIMP



1305.1605

Dark Matter

Nuclear Matter
quarks, gluons

Leptons
electrons, muons,
taus, neutrinos

Photons,
W, Z, h bosons

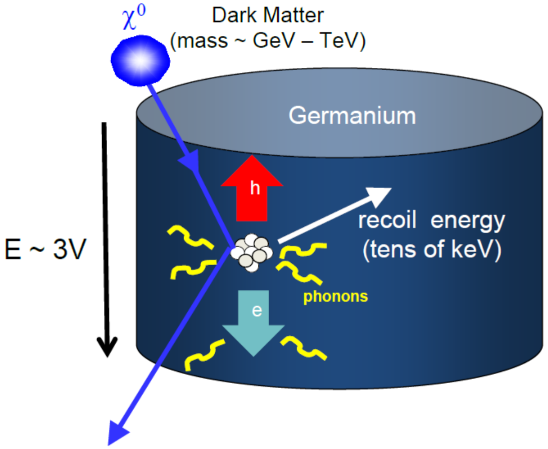
Other dark
particles

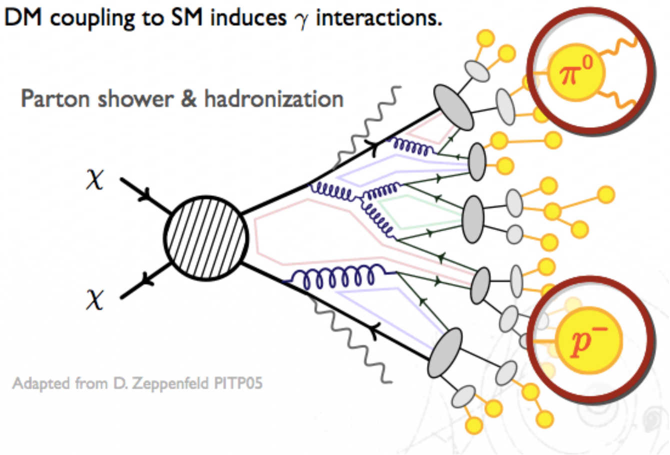
Direct Detection DM DM SM SM

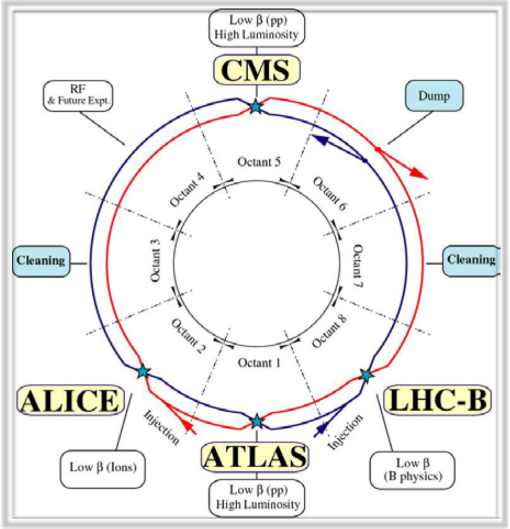
Indirect Detection DM SM DM SM

Particle Colliders SM DM SM DM

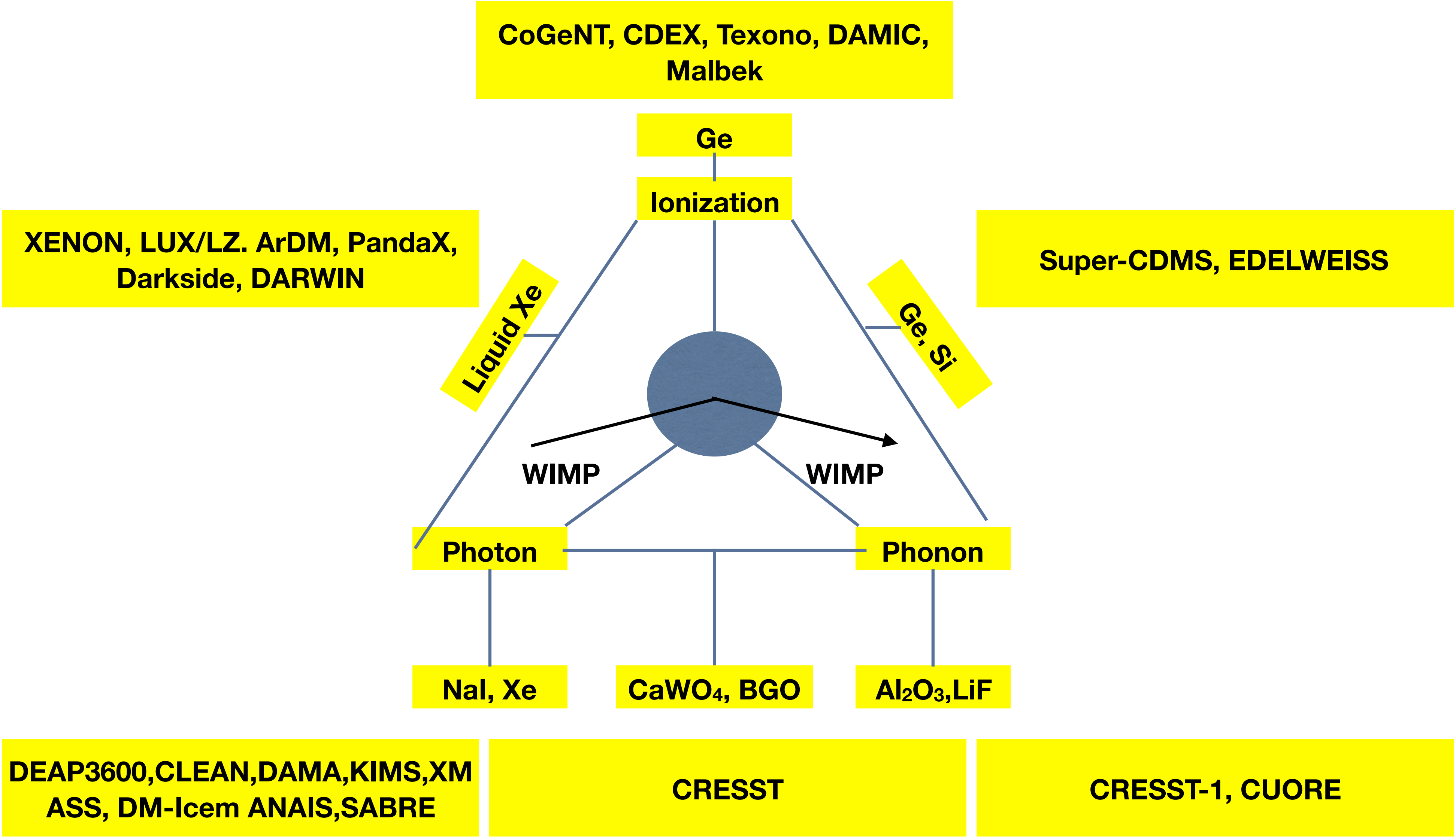
Astrophysical Probes DM DM DM DM







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_2O_3,LiF

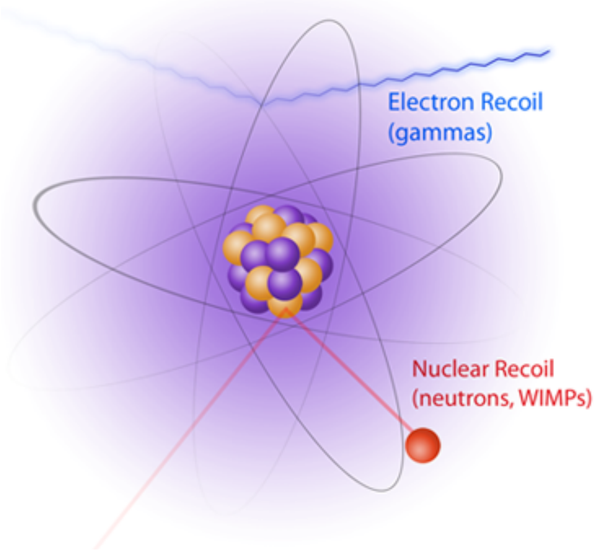
DEAP3600,CLEAN,DAMA,KIMS,XMASS, DM-Icem ANAIS,SABRE

CRESST

CRESST-1, CUORE

DM direct detections

The WIMP event rate



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

Exposure

DM density

Nuclear Form Factor

Two uncertainties:

ρ_{DM}

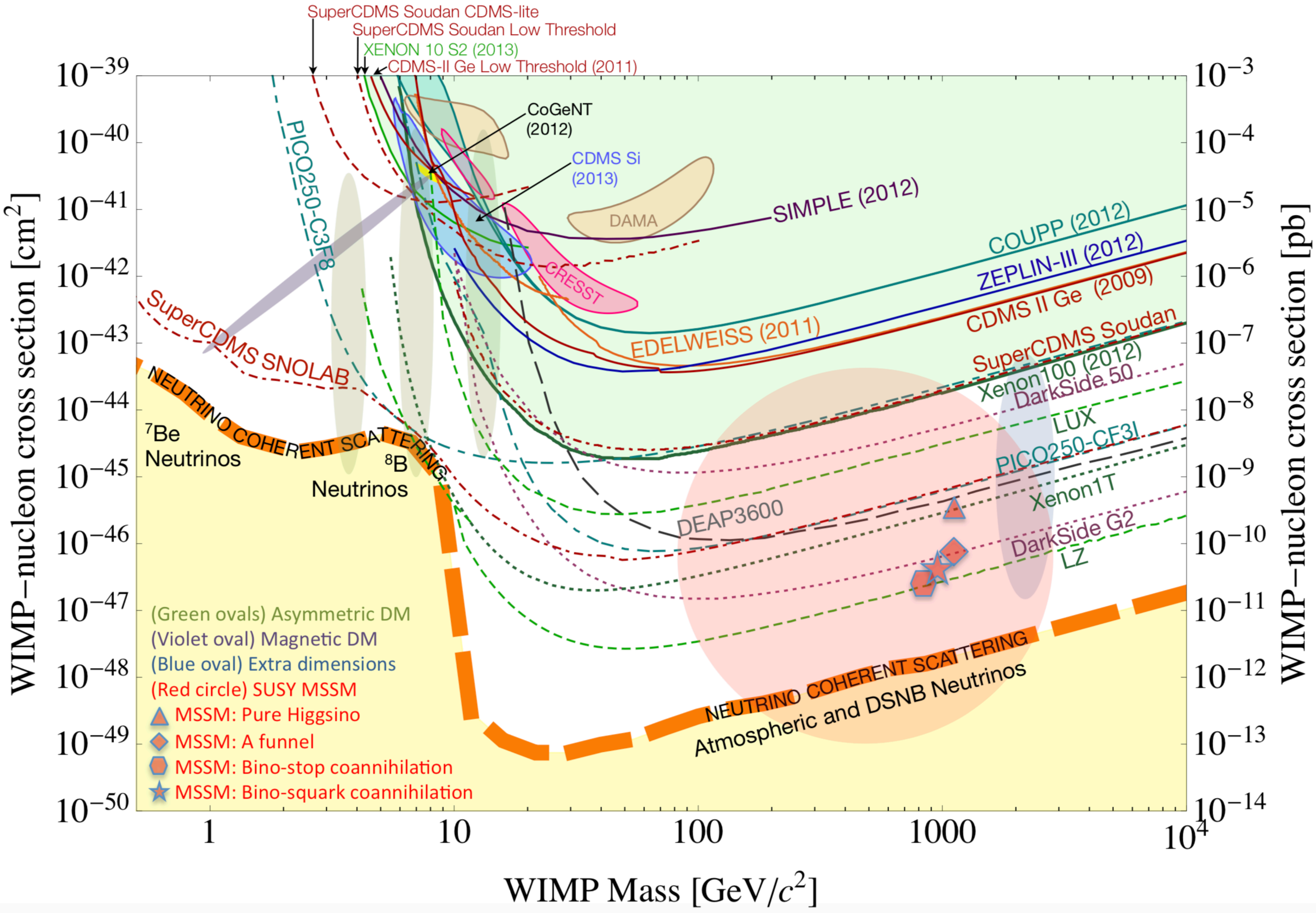
- local measures use the vertical kinematics of stars near the Sun
- Global measurement extrapolate rho from rotation curve

Maxwell Boltzmann distribution:

$$\rho_{\mathrm{DM}} \in [0.2,\ 0.6]\ \mathrm{GeV}$$

$$\boxed{\int_{v_{\min}} \frac{f(\vec{v})}{v} d^3v = \frac{1}{2v_0\eta_E}\left[\mathrm{erf}(\eta_+) - \mathrm{erf}(\eta_-)\right] - \frac{1}{\pi v_0\eta_E}(\eta_+ - \eta_-)e^{-\eta_{\mathrm{esc}}^2}}$$

Where to go for Direct detections



Why neutrinos relevant?

They are similar!

Neutrino { Neutral, Non-baryonic, Weakly interactions, Relics in universe } DM

Sterile neutrino can be DM candidate

There might be neutrino portals to the DM

Their experiments can detect both neutrino&DM

Two relevant issues

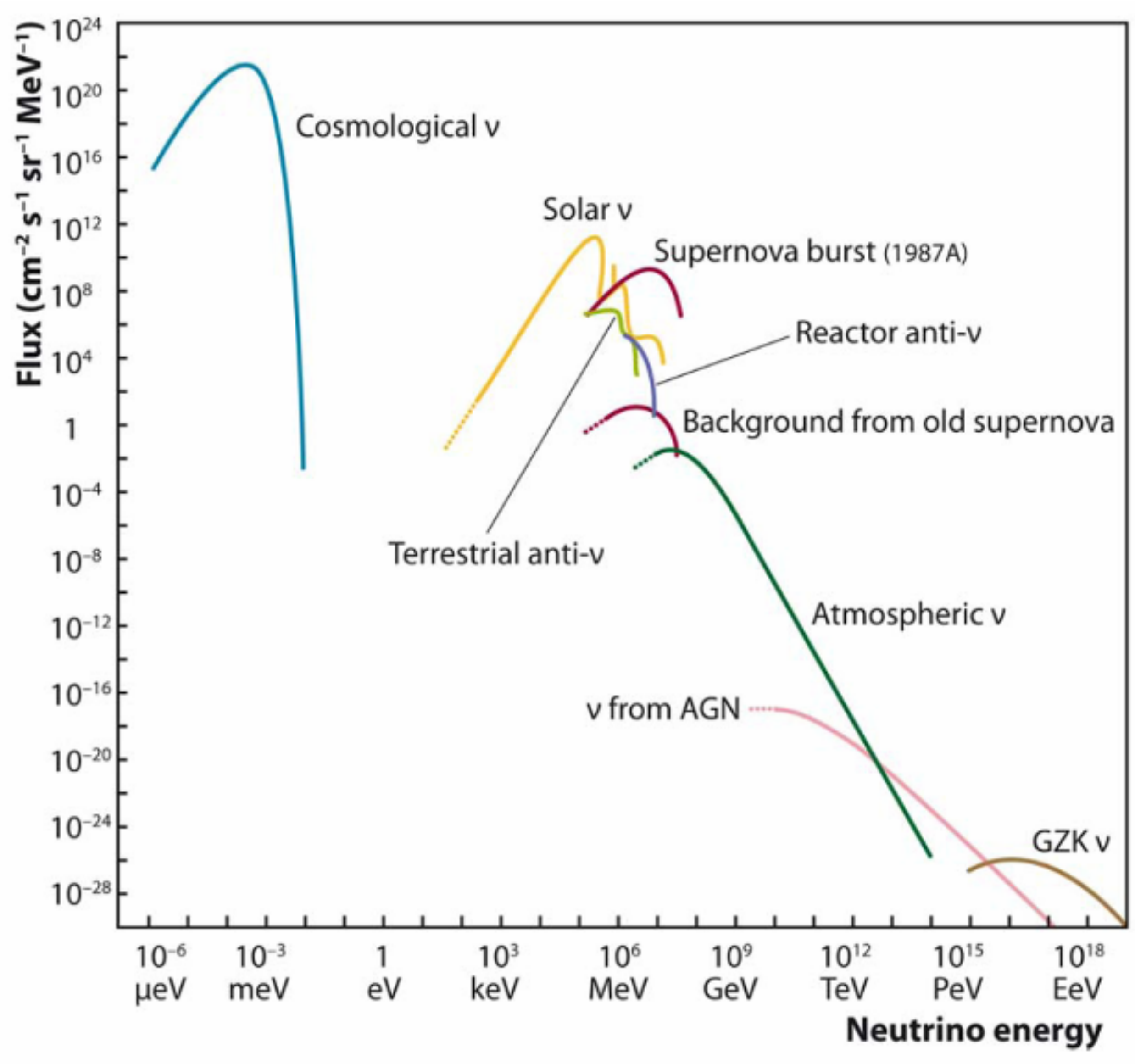
Precision calculations of the direct detection cross section.

Understanding the neutrino floor.

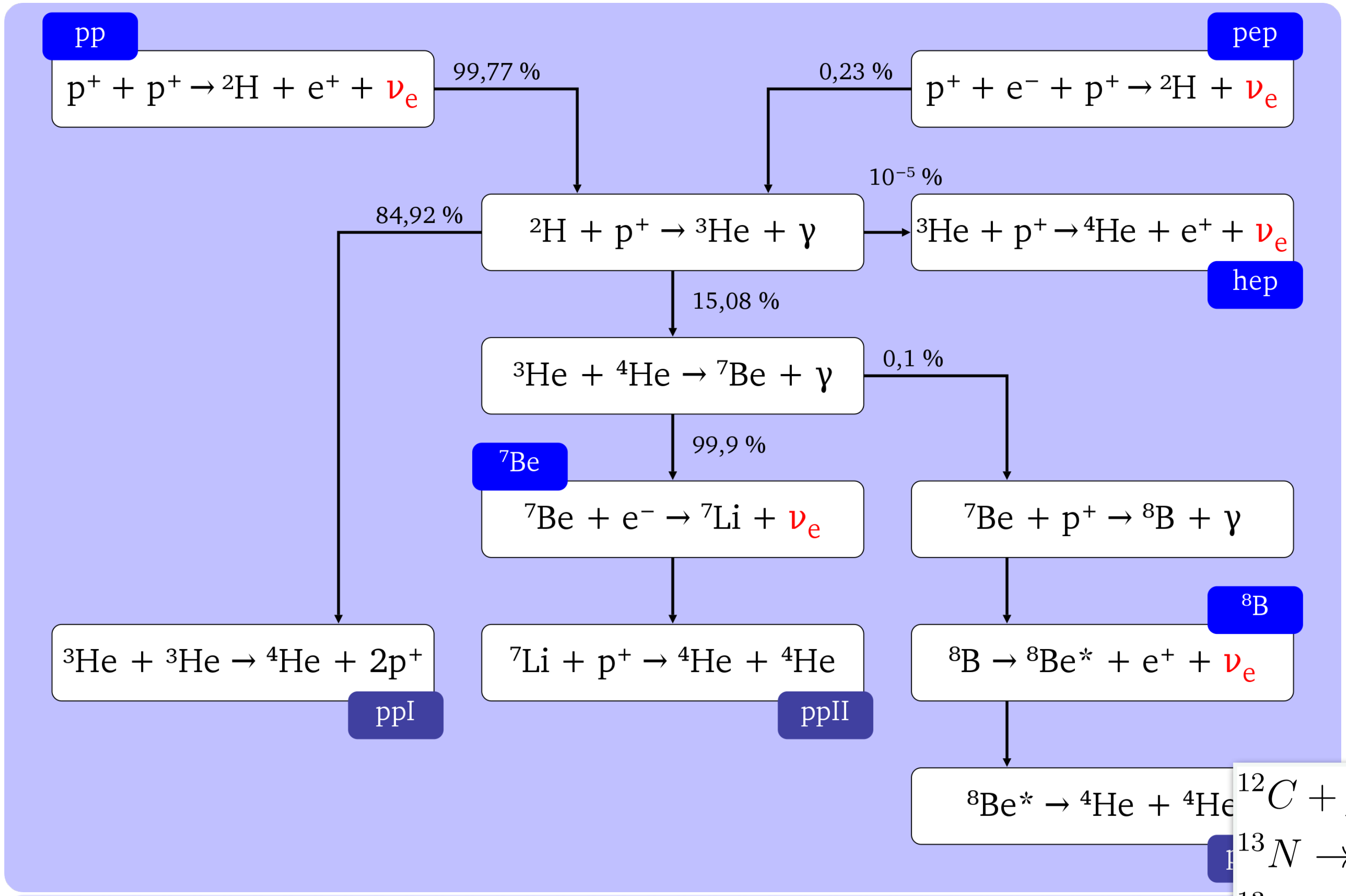
Neutrino flux

Neutrino interactions

Neutrino flux from the universe



Sun as the source of neutrinos



pp

$p^+ + p^+ \rightarrow {}^2H + e^+ + \nu_e$

99,77 %

pep

$p^+ + e^- + p^+ \rightarrow {}^2H + \nu_e$

0,23 %

84,92 %

$^2H + p^+ \rightarrow {}^3He + \gamma$

10⁻⁵ %

$^3He + p^+ \rightarrow {}^4He + e^+ + \nu_e$

hep

15,08 %

$^3He + {}^4He \rightarrow {}^7Be + \gamma$

0,1 %

99,9 %

^7Be

$^7Be + e^- \rightarrow {}^7Li + \nu_e$

$^7Be + p^+ \rightarrow {}^8B + \gamma$

^8B

$^3He + {}^3He \rightarrow {}^4He + 2p^+$

ppI

$^7Li + p^+ \rightarrow {}^4He + {}^4He$

ppII

$^8B \rightarrow {}^8Be^* + e^+ + \nu_e$

$^8Be^* \rightarrow {}^4He + {}^4He$

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

$$^{12}C + p \rightarrow {}^{13}N + \gamma$$

$$^{13}N \rightarrow {}^{13}C + e^+ + \nu_e(E_\nu <= 1.2MeV)$$

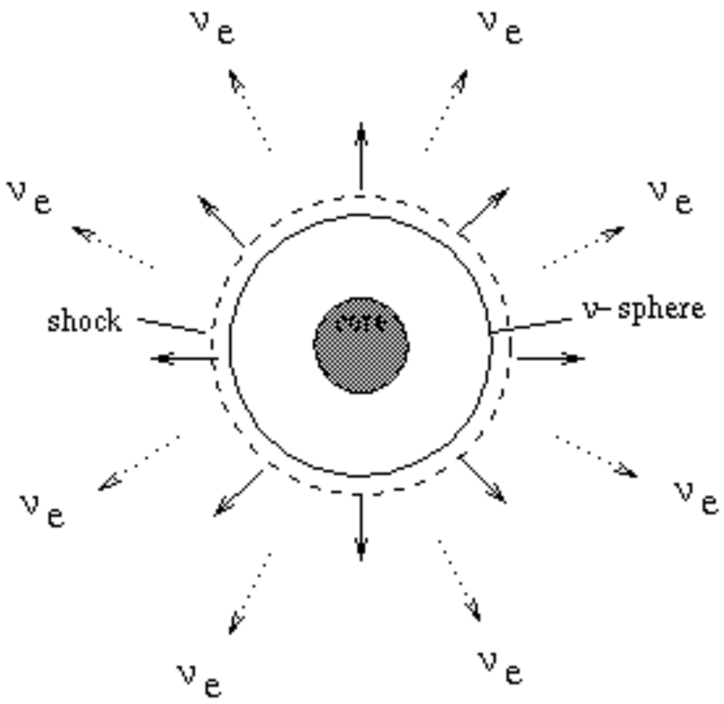
$$^{13}C + p \rightarrow {}^{14}N + \gamma$$

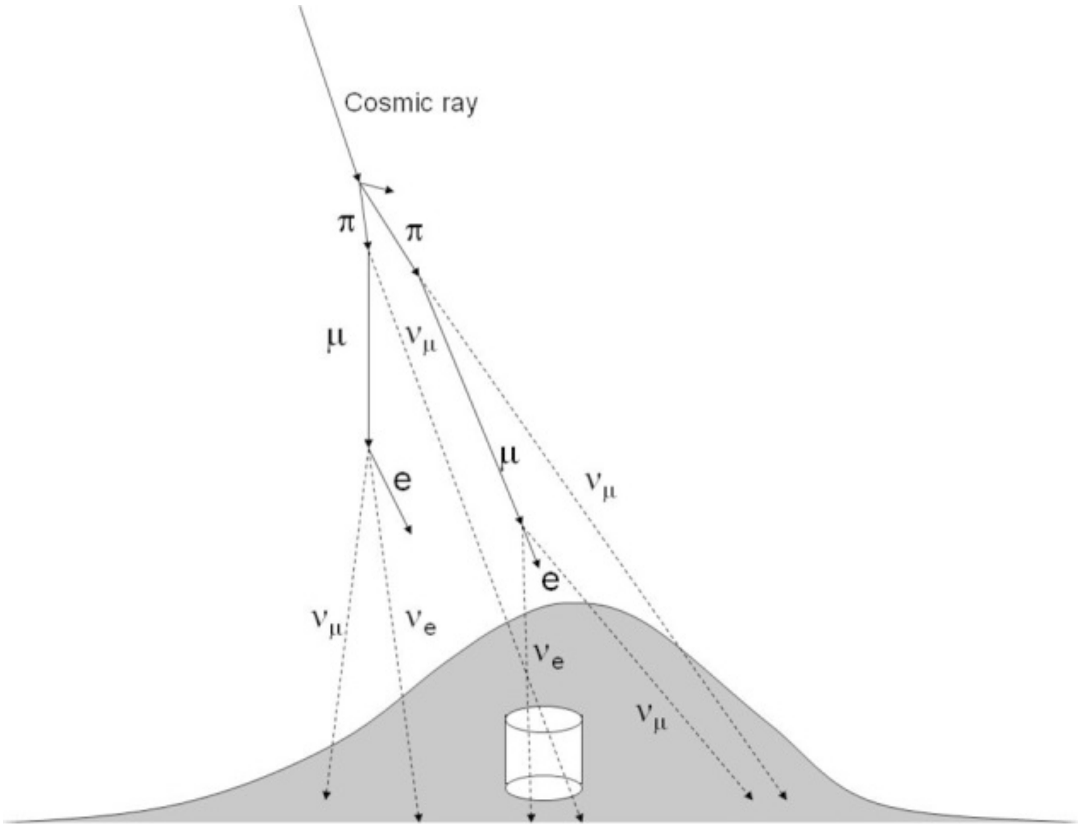
$$^{14}N + p \rightarrow {}^{15}O + \gamma$$

$$^{15}O \rightarrow {}^{15}N + e^+ + \nu_e(E_\nu <= 1.73MeV)$$

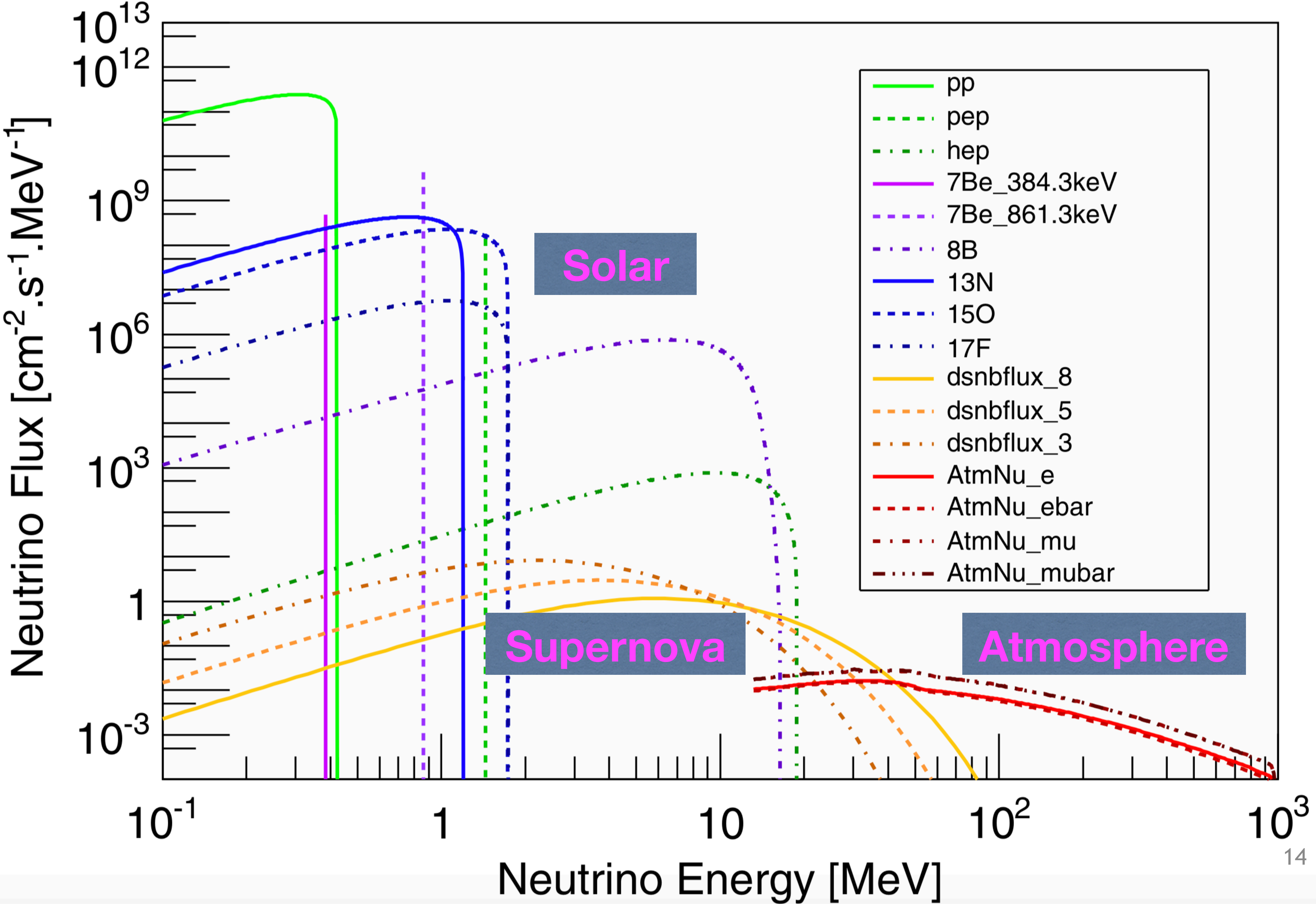
$$^{15}N + p \rightarrow {}^{12}C + {}^4He$$

Supernova and atmosphere neutrino





Neutrino flux on the earth



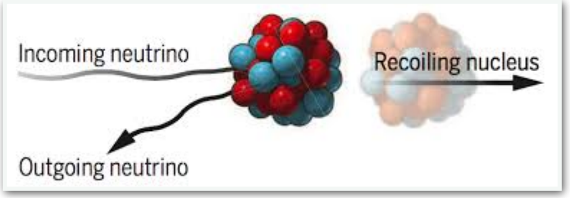
Neutrino-nuclei scattering

Charged currents coupling to electroweak gauge boson

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

Neutral currents coupling to electroweak gauge boson

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



Coherent neutrino-nucleus scattering in the SM

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

Weak hyper-charge of target nucleus

Nuclear form factor

Number of expected events

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

Neutrino floor in the SM

The WIMP event rate

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

Exposure

DM density

Nuclear Form Factor

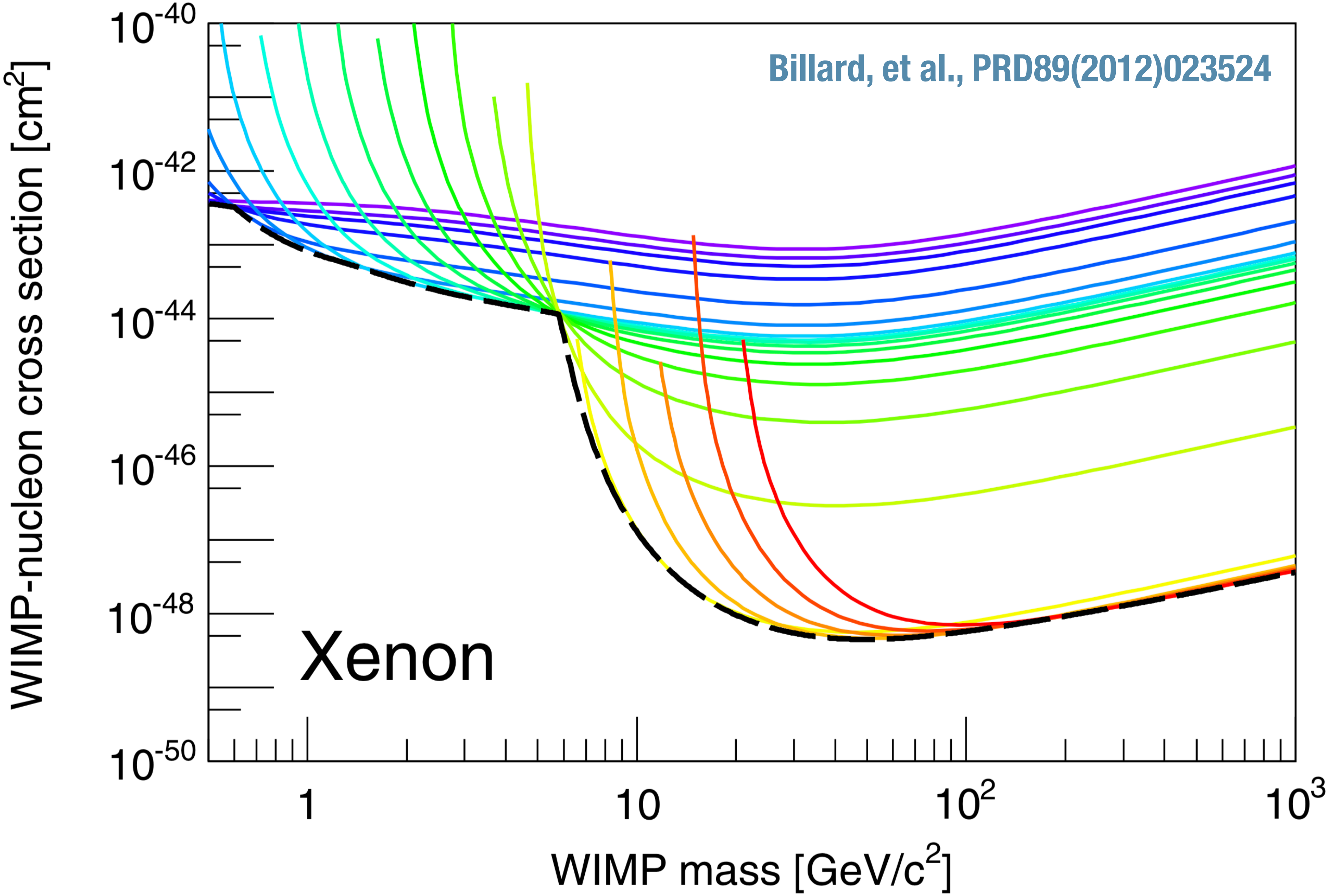
Neutrino event rate

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

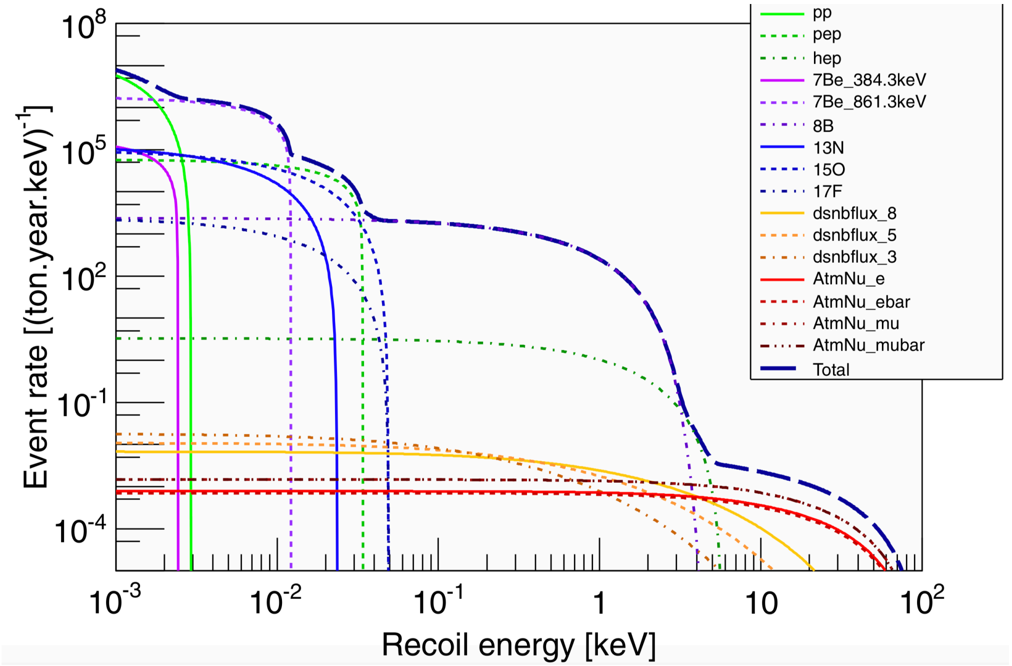
Neutrino floor

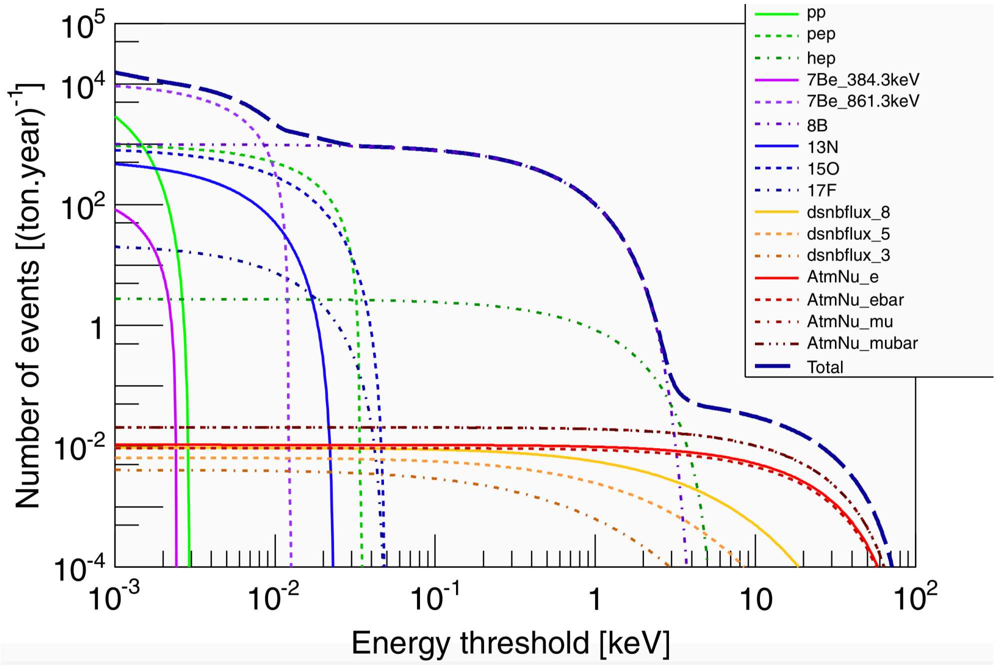
$$\sigma_n^0 = \frac{2.3}{m} \int_{E_R} \left(\frac{1}{m_N} \int_{E_\nu^{\rm min}} \frac{d\phi_\nu}{dE_\nu} \frac{d\sigma_\nu}{dE_R} \right) \left(\frac{\rho_{\rm DM} A^2}{2m_{\rm DM}\mu_n^2} \int_{E_R}^{E_R^{\rm max}} F^2(E_R) dE_R \int_{v_{\rm min}} \frac{f(\vec{v})}{v} d^3v \right)^{-1}$$

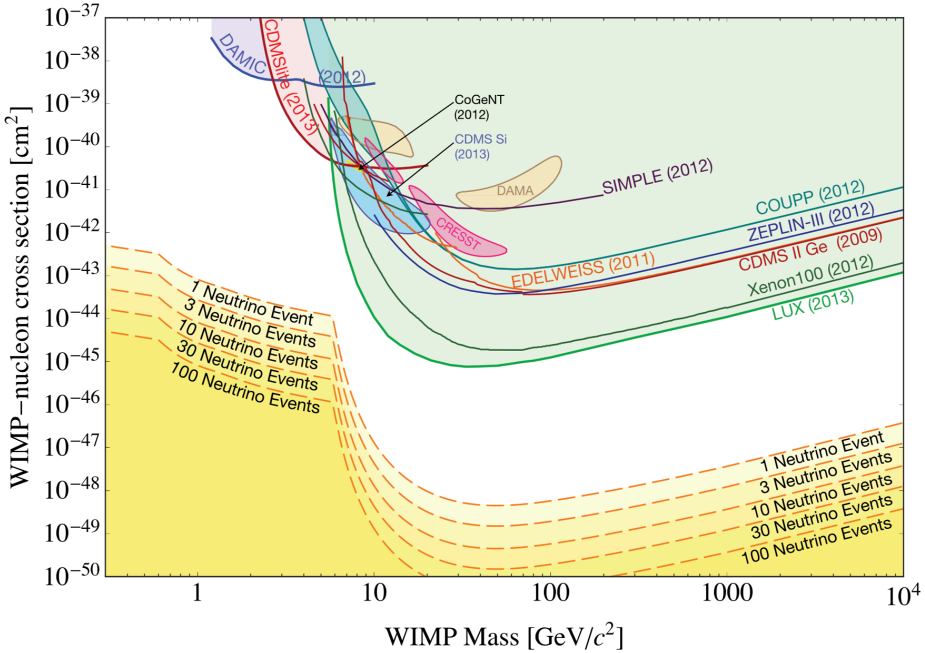
Neutrino floor in the SM



Neutrino floor in the SM







Billard, et al., PRD89,023524

Non-standard 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

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

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

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

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

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

$$-0.008 < \varepsilon^{uV}_{ee} < 0.618$$

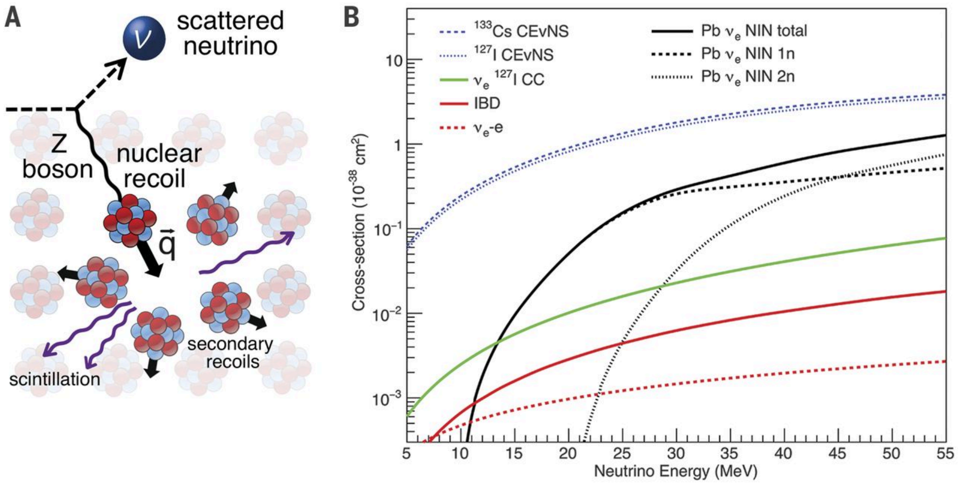
$$-0.012 < \varepsilon^{dV}_{ee} < 0.361$$

$$-0.111 < \varepsilon^{uV}_{\mu\mu} < 0.402$$

$$-0.103 < \varepsilon^{dV}_{\mu\mu} < 0.361$$

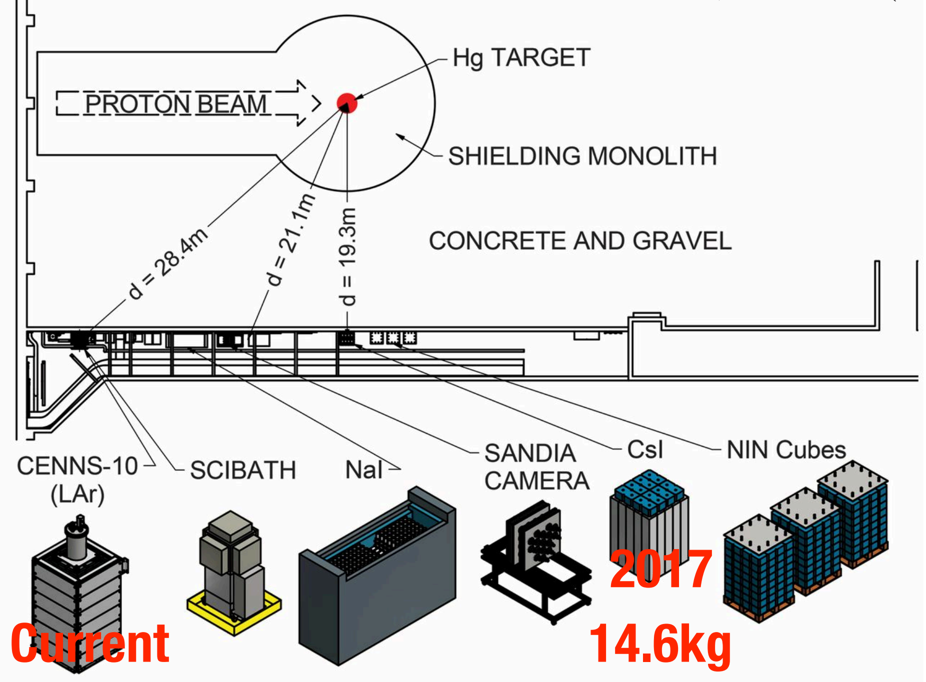
Altmannshofer, et al., 1812.02778

CONHERENT



GOAL:Measure N² dependence of CEvNS process

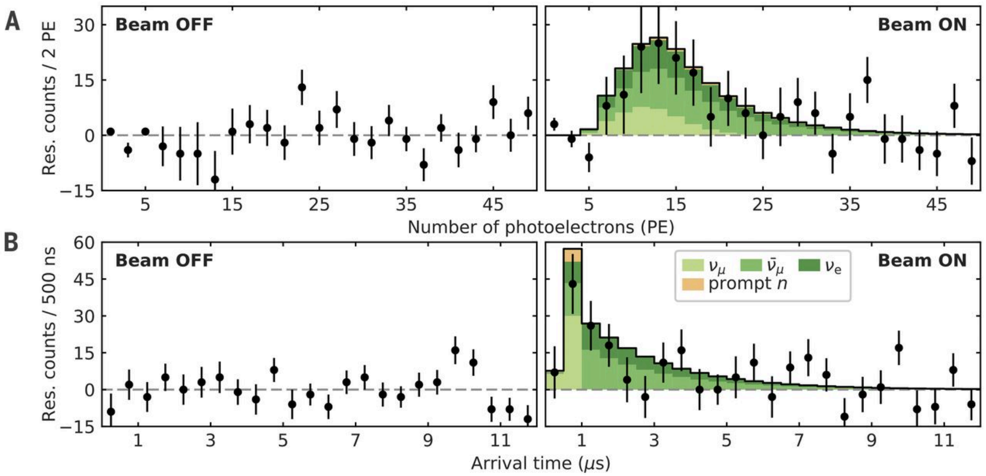
Science 357, 1123–1126 (2017)



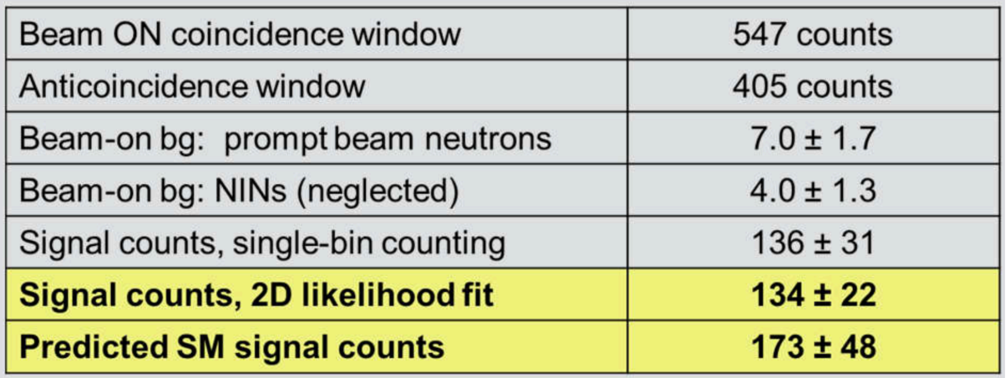
Current

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

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

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

Falkowski, et al., 1706.03783

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

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 with exotic neutrino interactions

$$\frac{d\sigma_\nu}{dE_R} = \frac{2G_F^2 m_A}{(2J_A+1)E_\nu^2}\Bigg\{\sum_{\alpha\beta=0,1}\underline{(4E_\nu^2 - 2m_A E_R)\zeta_V^\alpha\zeta_V^{\beta *}W_M^{\alpha\beta}(q^2)+}$$

$$\sum_{\alpha,\beta=0,1}\left(E_\nu^2 + \frac{1}{2}m_A E_R\right)\zeta_A^\alpha\zeta_A^{\beta *}W_{\Sigma'}^{\alpha\beta}(q^2) + \sum_{\alpha\beta=0,1}\frac{E_R}{4m_A}(2E_\nu^2 - m_A E_R)\zeta_A^\alpha\zeta_A^{\beta *}W_{\Sigma''}^{\alpha\beta}(q^2) +$$

$$8(2E_\nu^2 - m_A E_R)\zeta_T^2 W_{\Sigma'}^{00}(q^2) + 16E_\nu^2\zeta_T^2 W_{\Sigma''}^{00}(q^2) + \underline{2m_A E_R \zeta_S^2 W_M^{00}(q^2) +}$$

$$\underline{\sum_{\alpha\beta=0,1}\frac{E_R^2 m_A^2}{m_N^2}\zeta_P^\alpha\zeta_P^{\beta *}W_{\Sigma''}^{\alpha\beta}(q^2)\Bigg\}}$$

(4

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

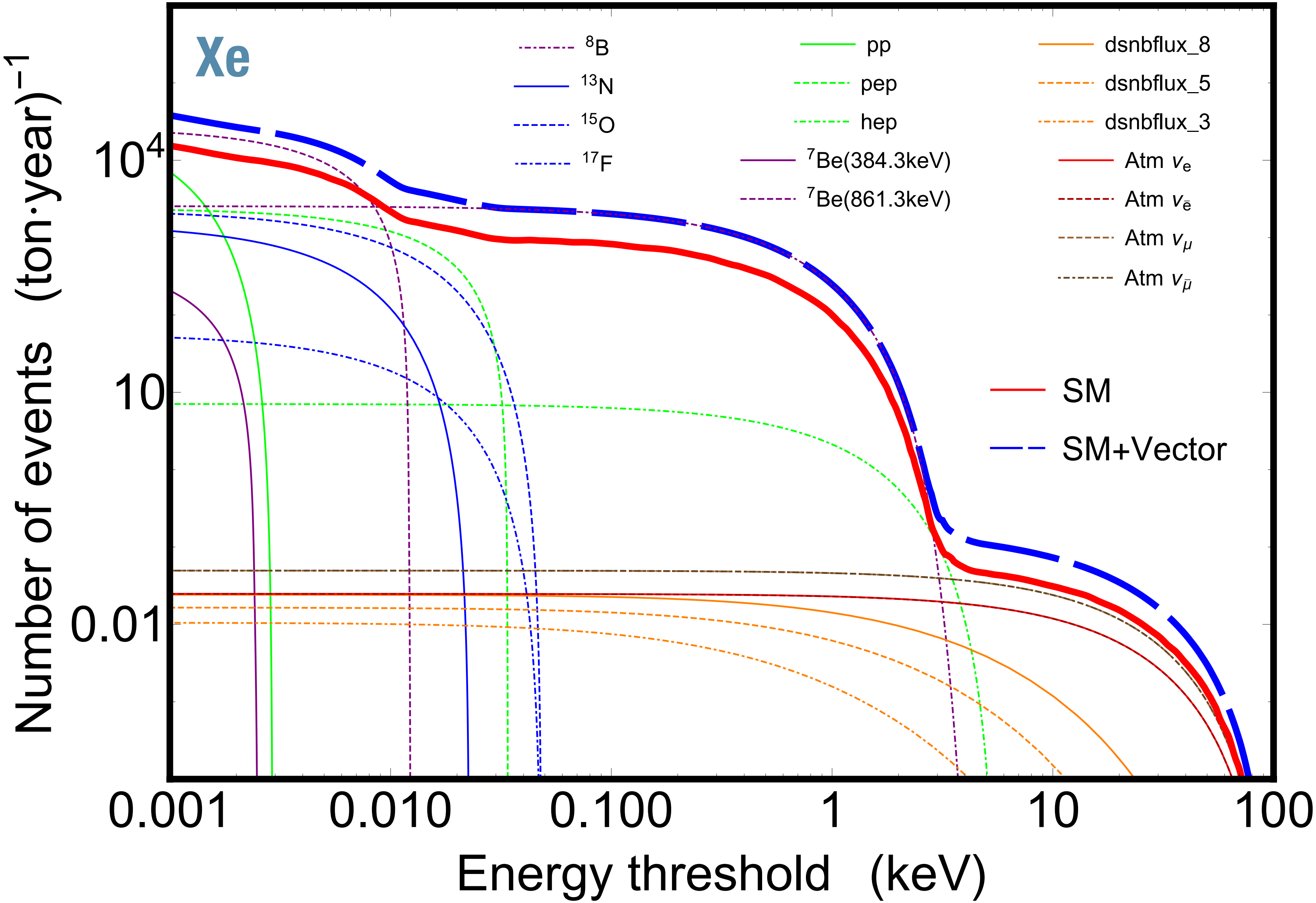
$$W_{\Sigma'}^{\alpha\beta}(q^2) \sim 1$$

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

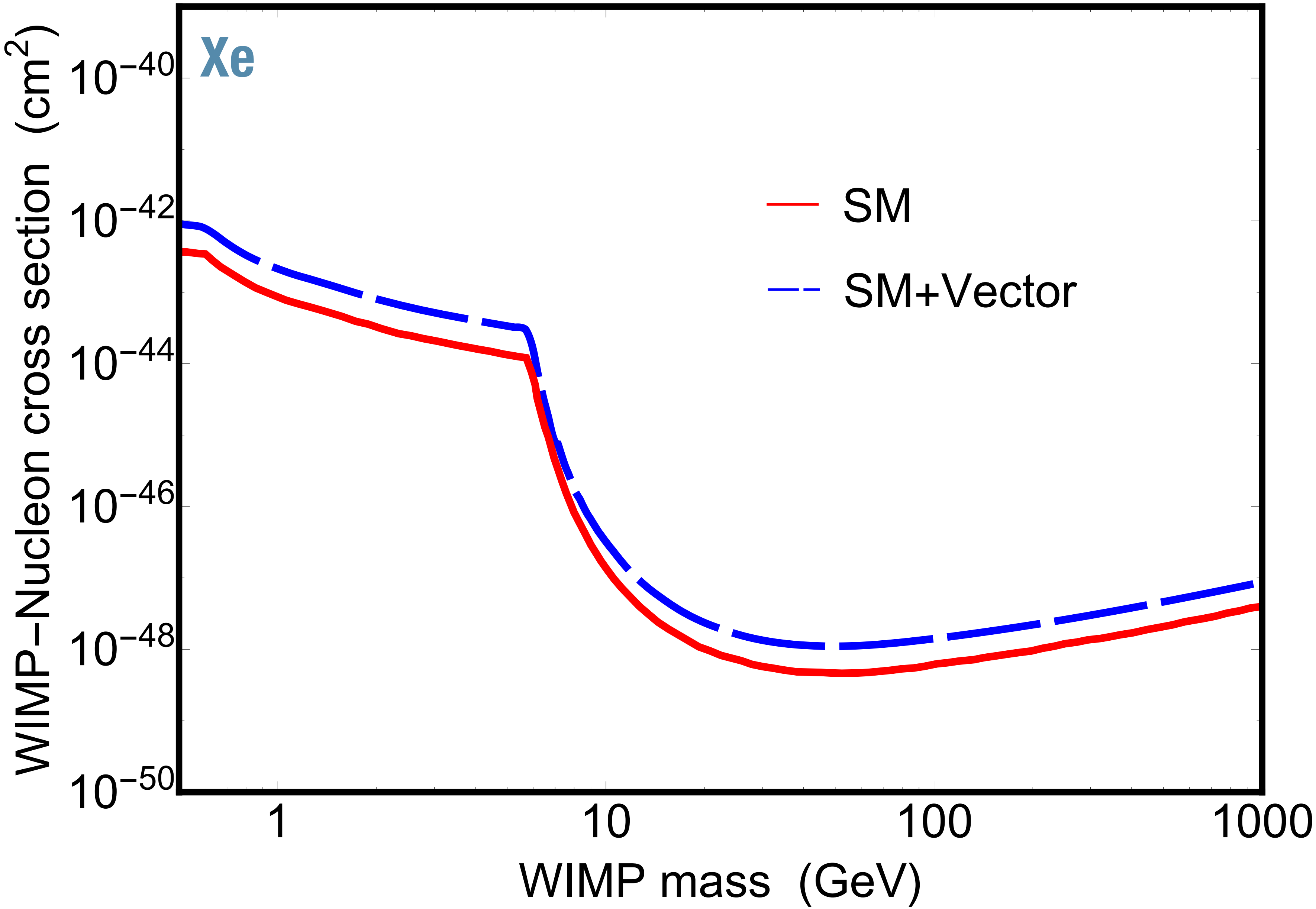
$$\zeta_\alpha^0 = \frac{1}{2}\left(\zeta_\alpha^p + \zeta_\alpha^n\right) \qquad \zeta_\alpha^1 = \frac{1}{2}\left(\zeta_\alpha^p - \zeta_\alpha^n\right)$$

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

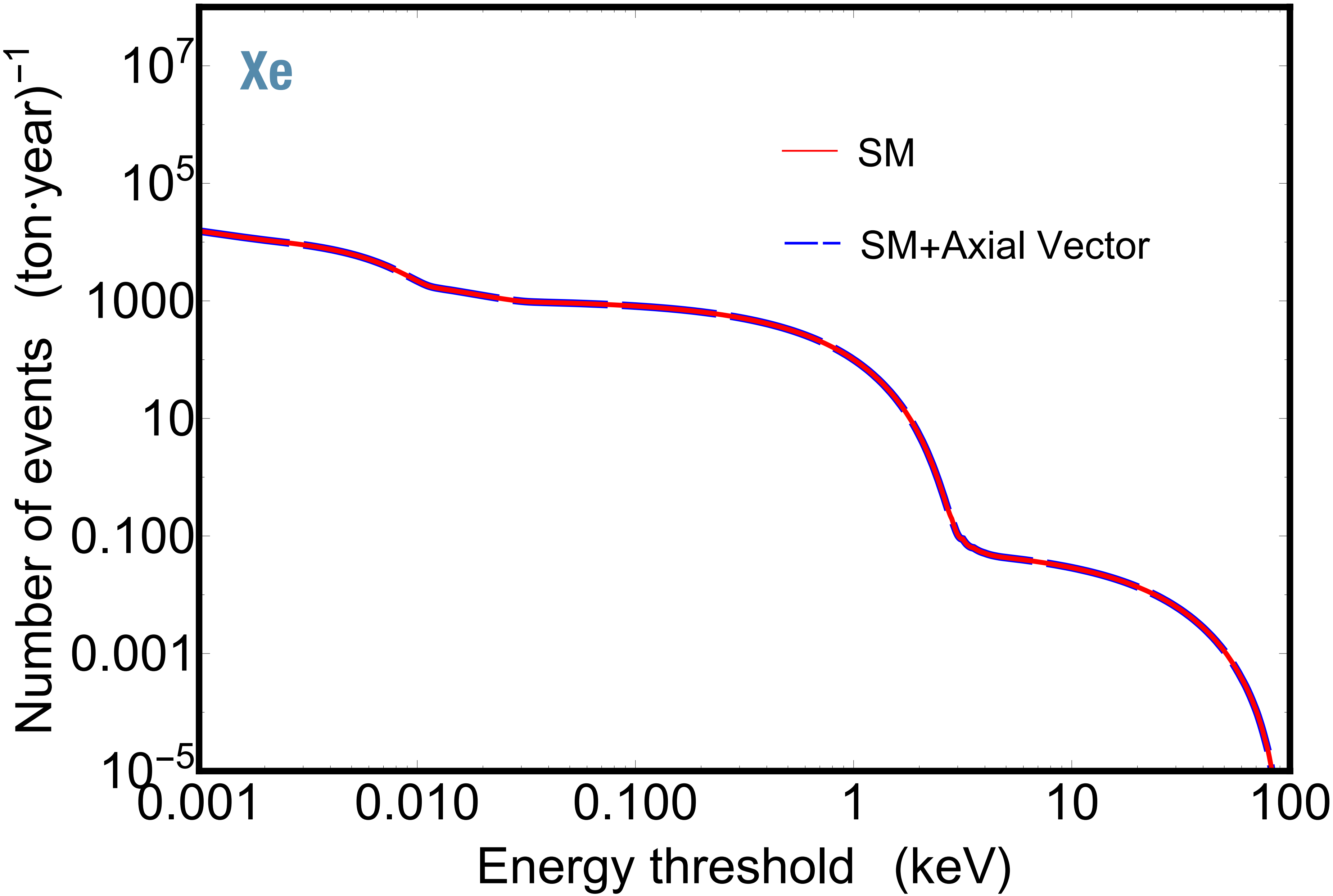
Numerical results-1: vector interactions with Xe131



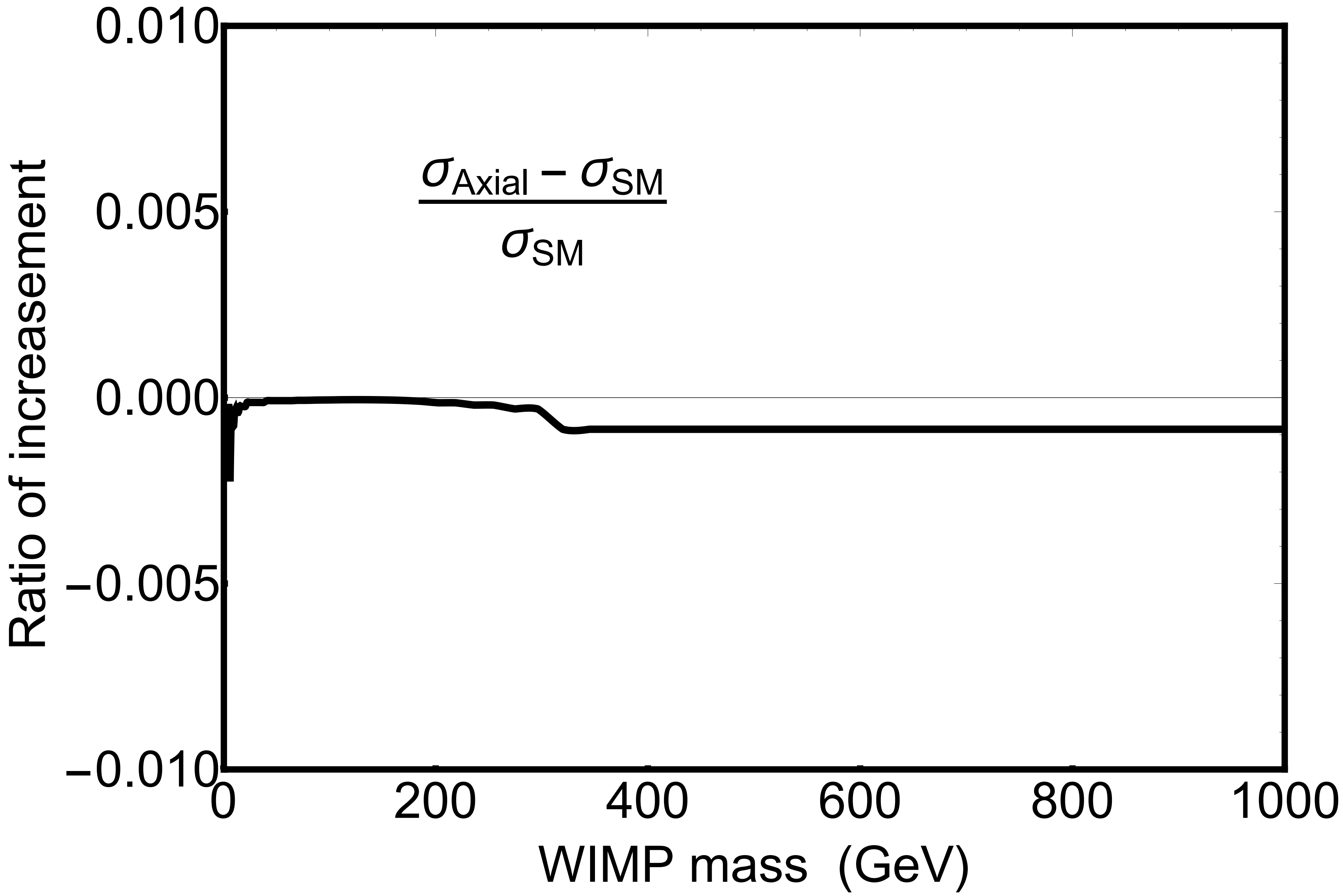
Numerical results-1: vector interactions with **X131**



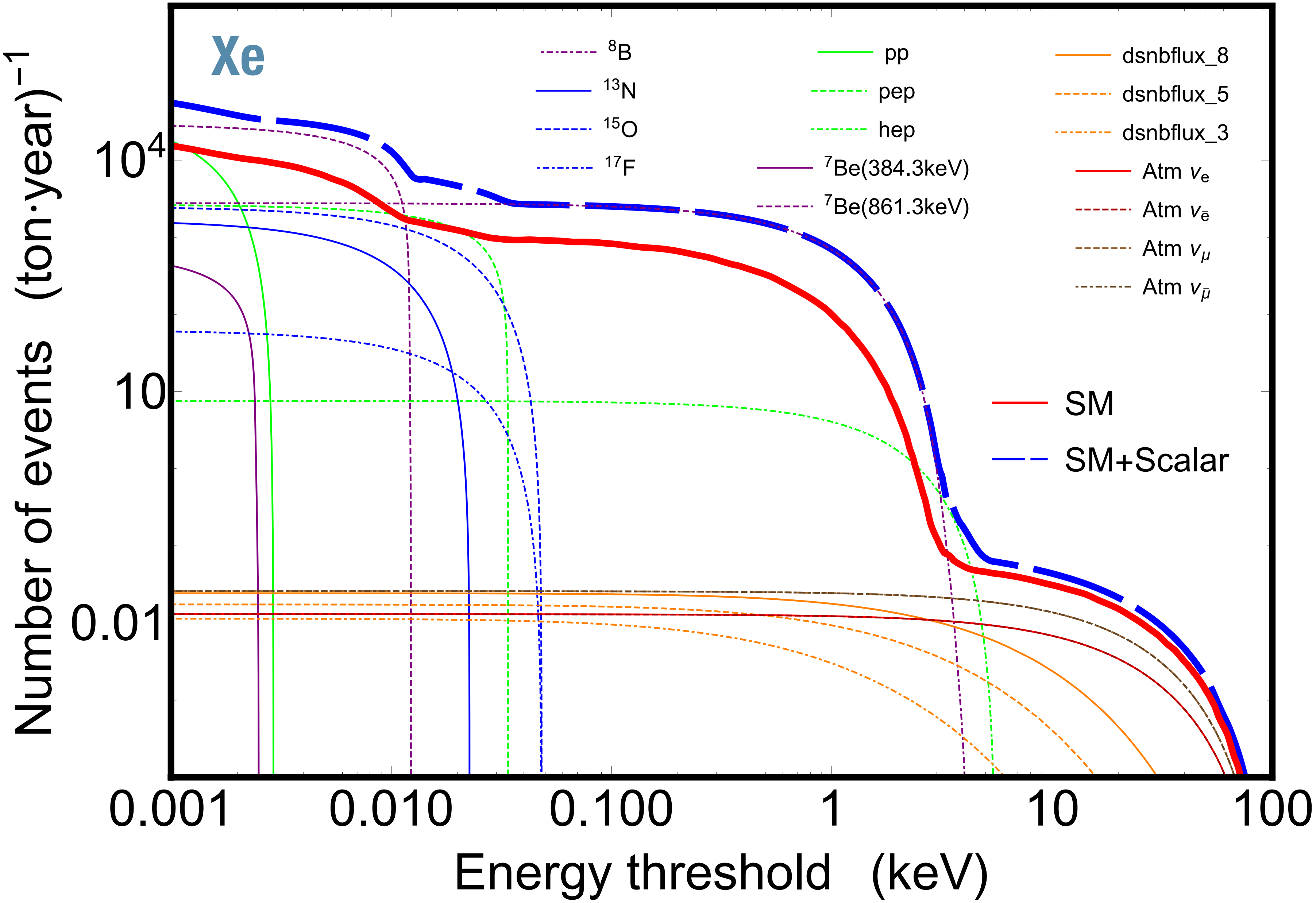
Numerical results-2: axial-vector interactions with **Xe131**



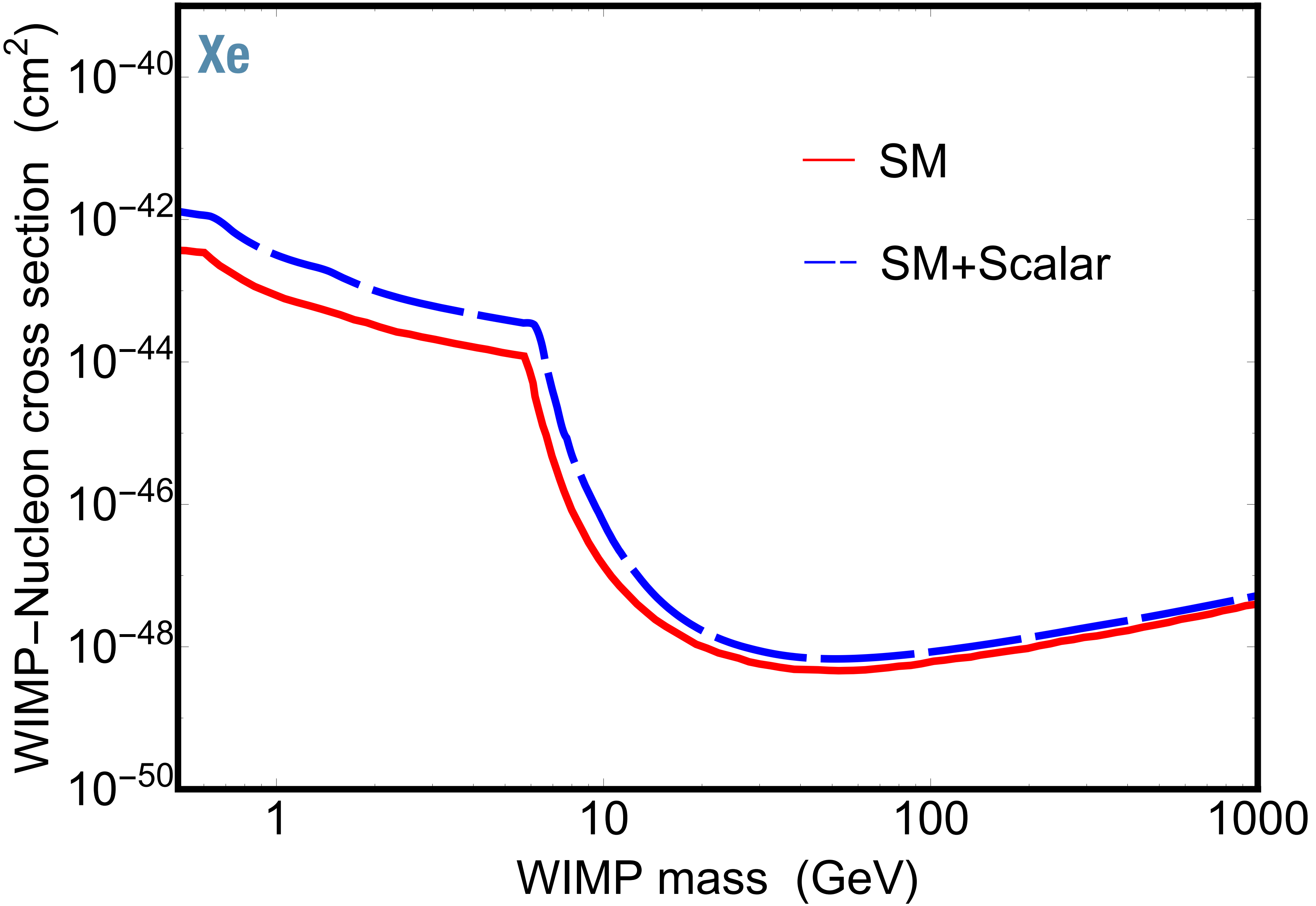
Numerical results-2: axial-vector interactions with Xe131



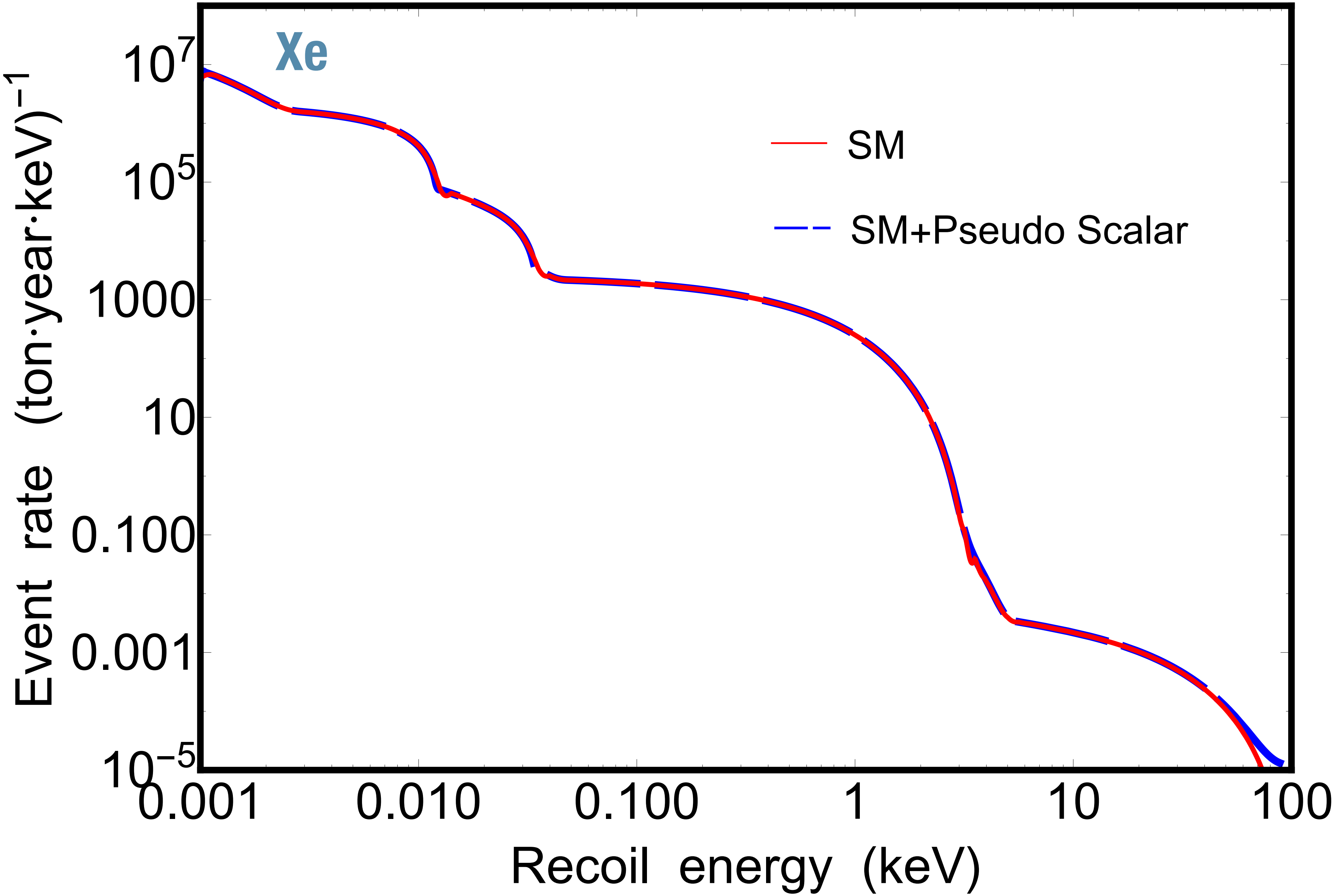
Numerical results-3: scalar interactions with **Xe131**



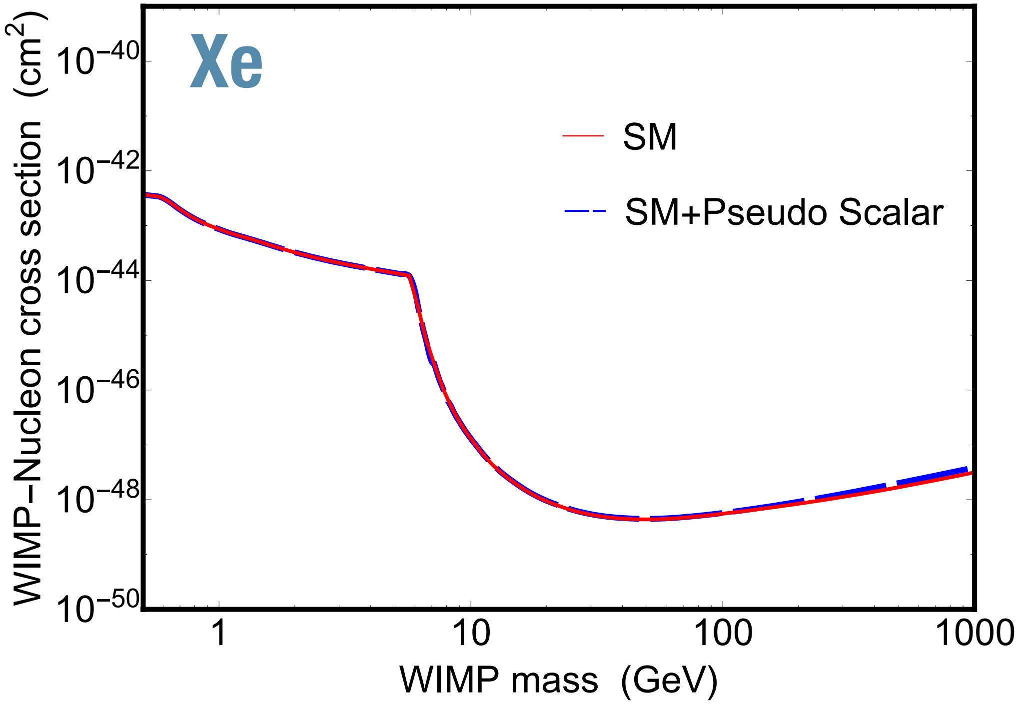
Numerical results-3: scalar interactions with X131

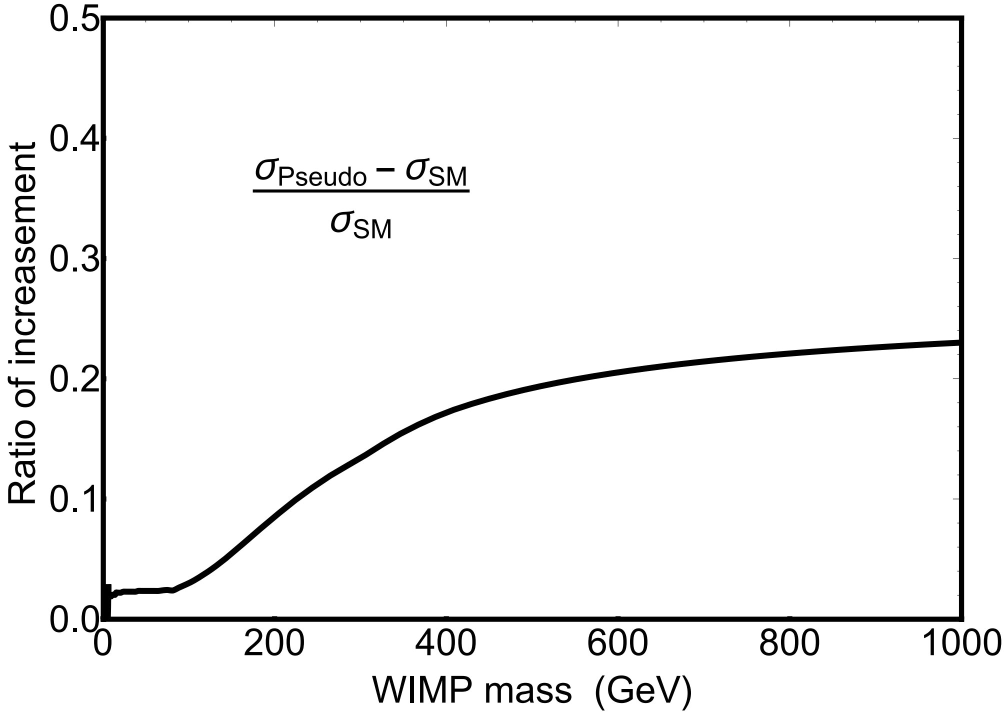


Numerical results-4: pseudo-scalar interactions with Xe131

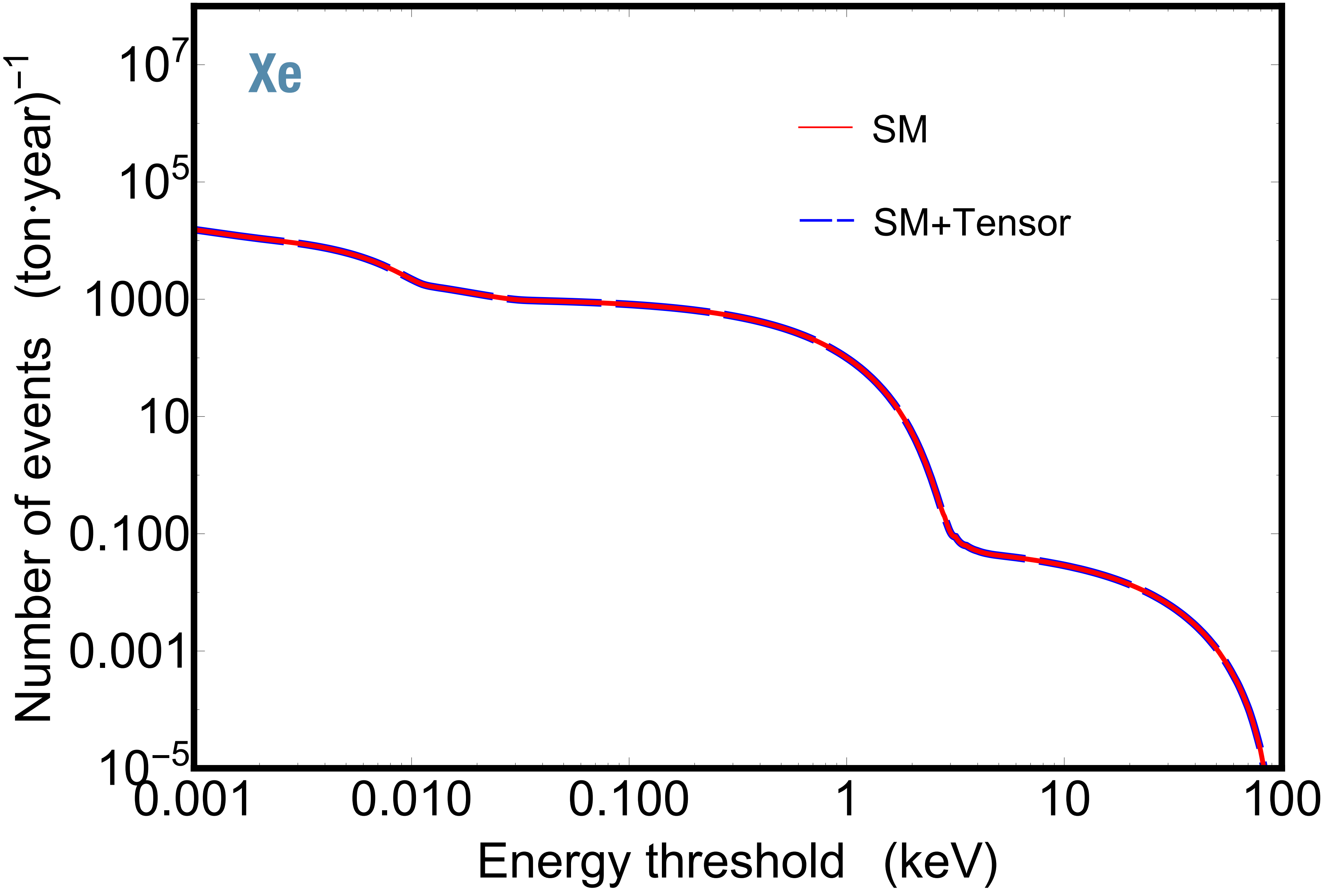


Numerical results-4: pseudo-scalar interactions with X131

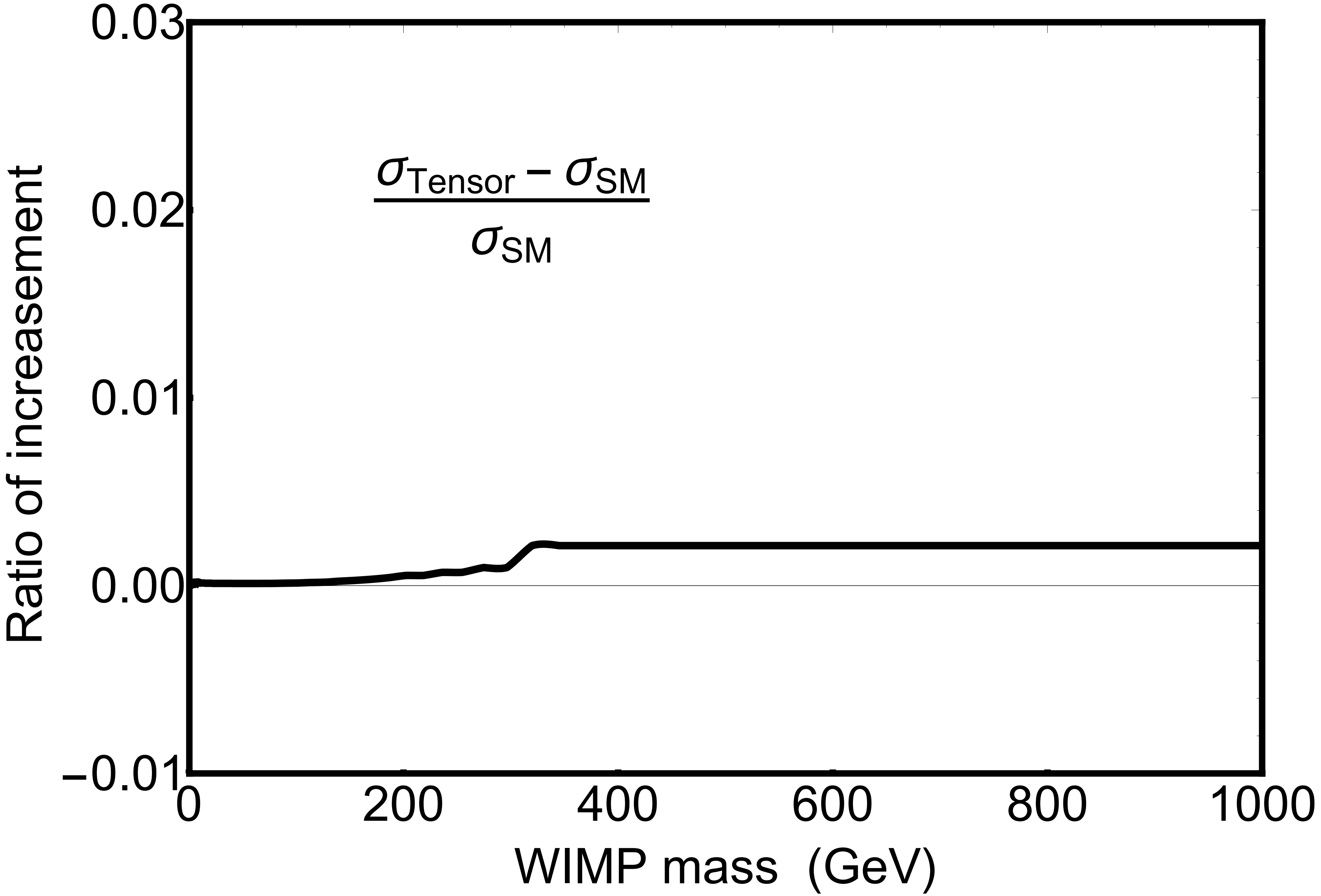




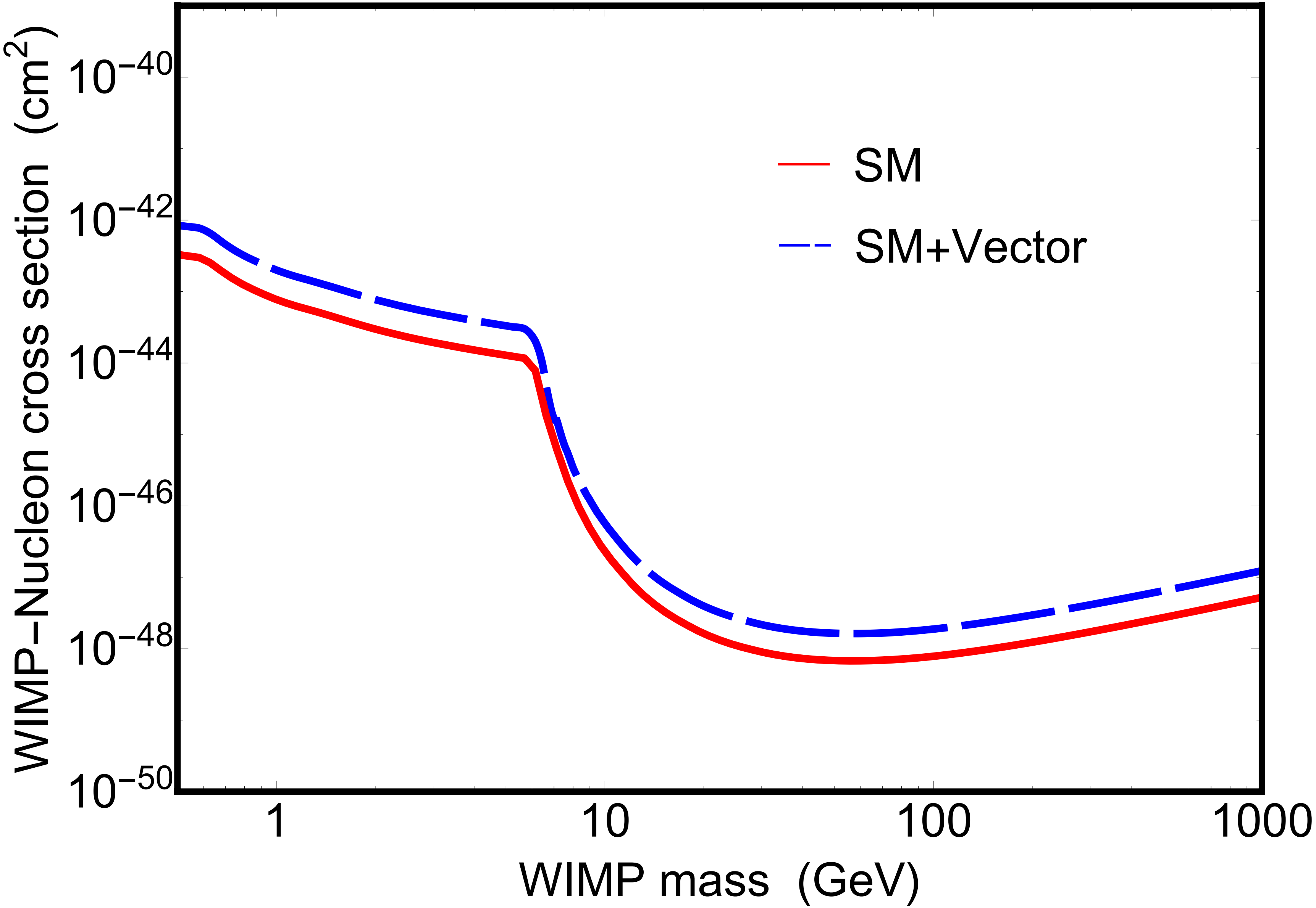
Numerical results-5: tensor interactions with Xe131



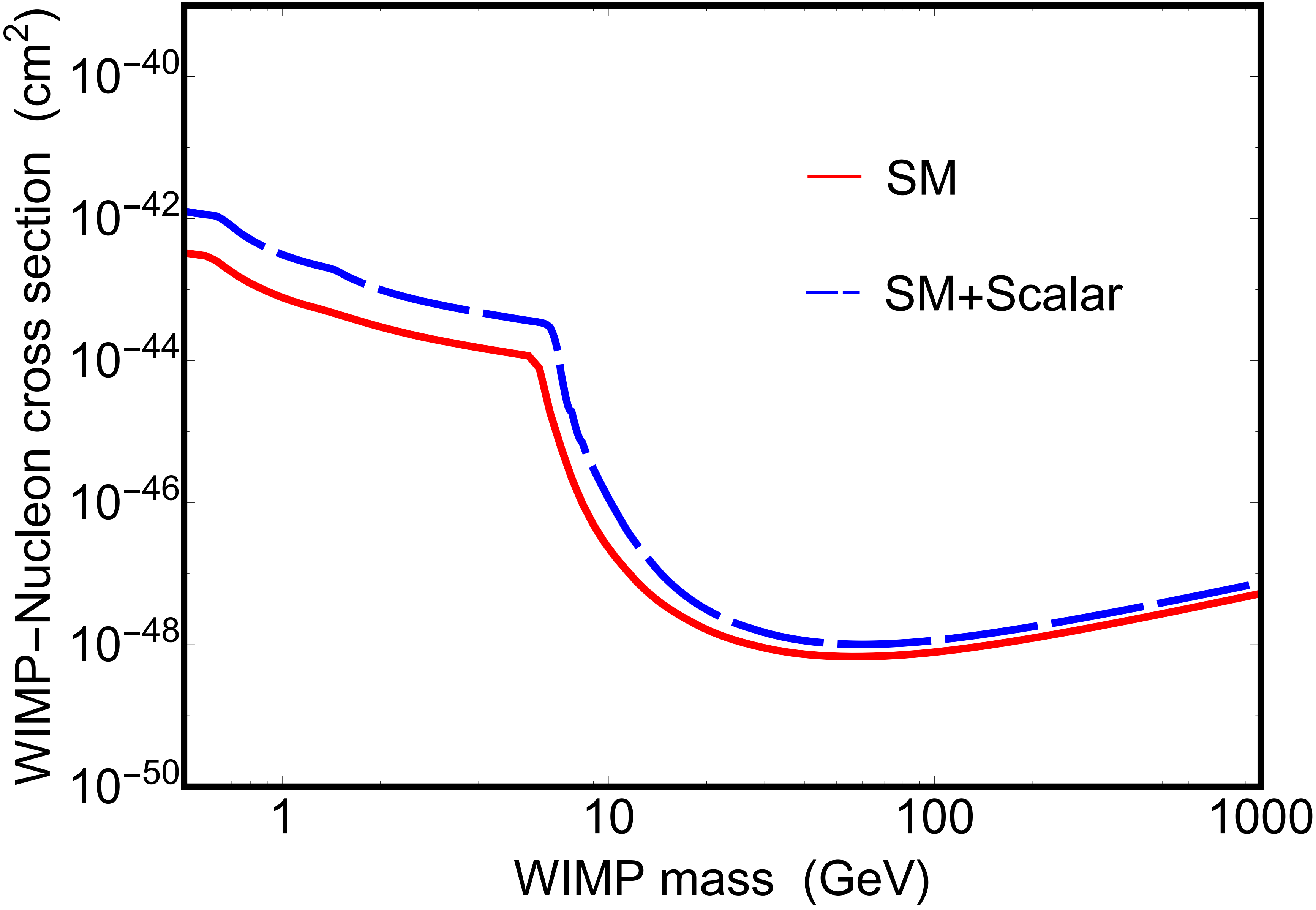
Numerical results-5: tensor interactions with **X131**



Numerical results-6: vector interactions with **Ge72**



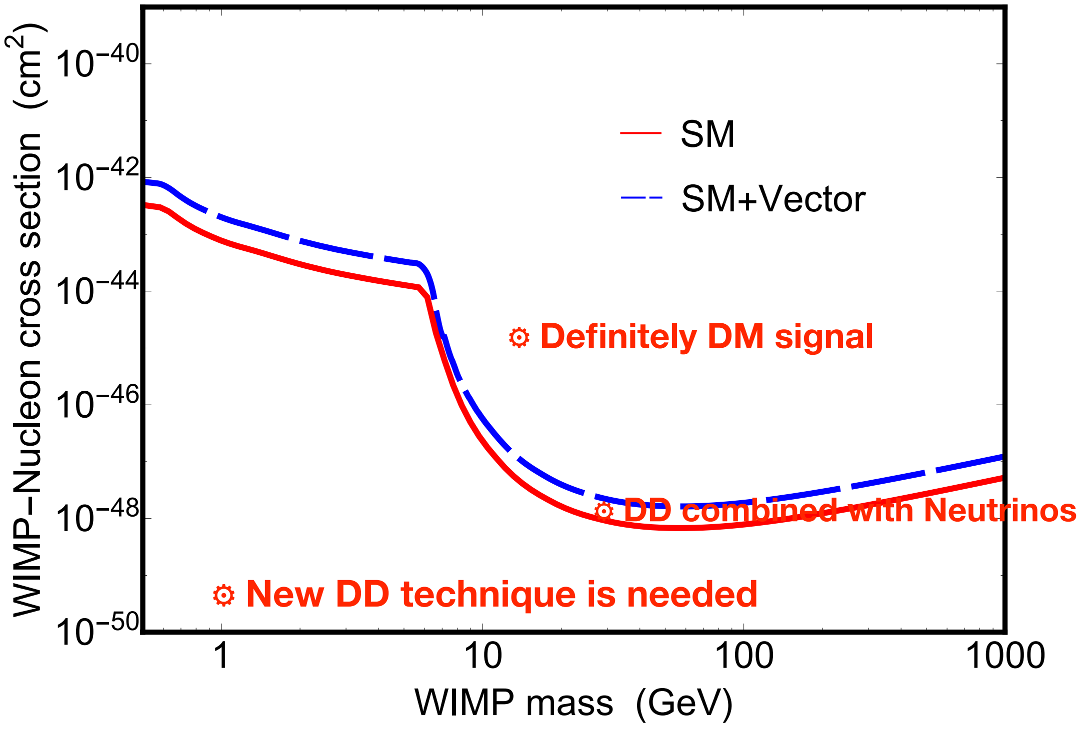
Numerical results-6: scalar interactions with Ge72



Conclusions

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

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



⚙ **Definitely DM signal**

⚙ **DD combined with Neutrinos**

⚙ **New DD technique is needed**

Thanks

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第三届北师大暗物质研讨会

6-9 December 2019
Asia/Shanghai timezone

暗物质是具有确凿实验证据的超出标准模型的新物理，也是当前高能物理实验和理论研究的前沿热点课题。近年来，暗物质的实验研究不断取得突破性进展，暗物质-核子弹性散射截面的排除线精度不断提高、COHERENT实验观测到中微子-核子相干弹性散射（暗物质直接探测的主要背景）、XENON1T实验观测到双β衰变。此外，WIMP的直接探测也进入了关键时期，各种新的针对轴子和Sub-GeV暗物质的直接探测思想不断涌现。这些都为中国的暗物质研究提供了机遇和挑战。

为了促进国内高能物理界学术交流、推动我国暗物质理论和实验研究的发展、寻求高能物理与其他学科领域交叉的可能性，北京师范大学和北京大学高能物理研究中心将于2019年12月07日至09日在北京师范大学珠海校区联合举办第三届北师大暗物质研讨会。会议主题将针对所有暗物质相关的课题。
诚挚邀请您参加此次会议。

会议地点：北师大珠海校区，珠海市
注册费：1200元（老师和博士后），600元（学生）
注册截止：2019年10月31日。

主办单位：北京师范大学、北京大学高能物理研究中心
指导委员会：曹庆宏、季向东、岳骞、张丰收、周宇峰、涂展春
组织委员会：晁伟、黄文宏、刘晓辉、刘言东、王力、杨硕尧

会务联系人：
杨硕尧（北京师范大学）：yangshuoyao@bnu.edu.cn

Starts Dec 6, 2019 08:00
Ends Dec 9, 2019 18:00
Asia/Shanghai

https://indico.ihep.ac.cn/event/10365/

Thanks