Non-standard neutrino interactions in light mediator models at reactor experiments

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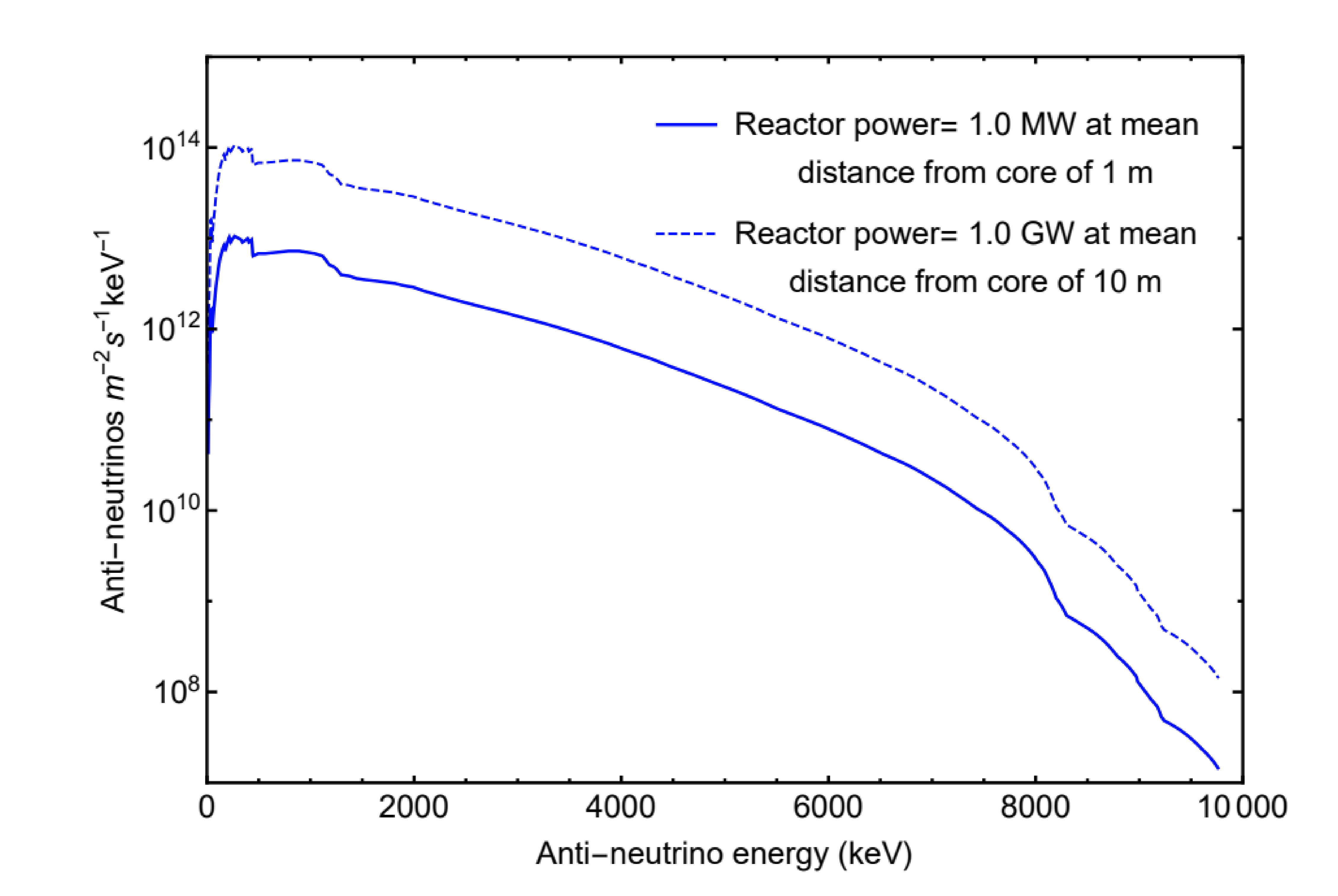
w/ B. Dutta, S. Ghosh , T. Li and A. Thompson

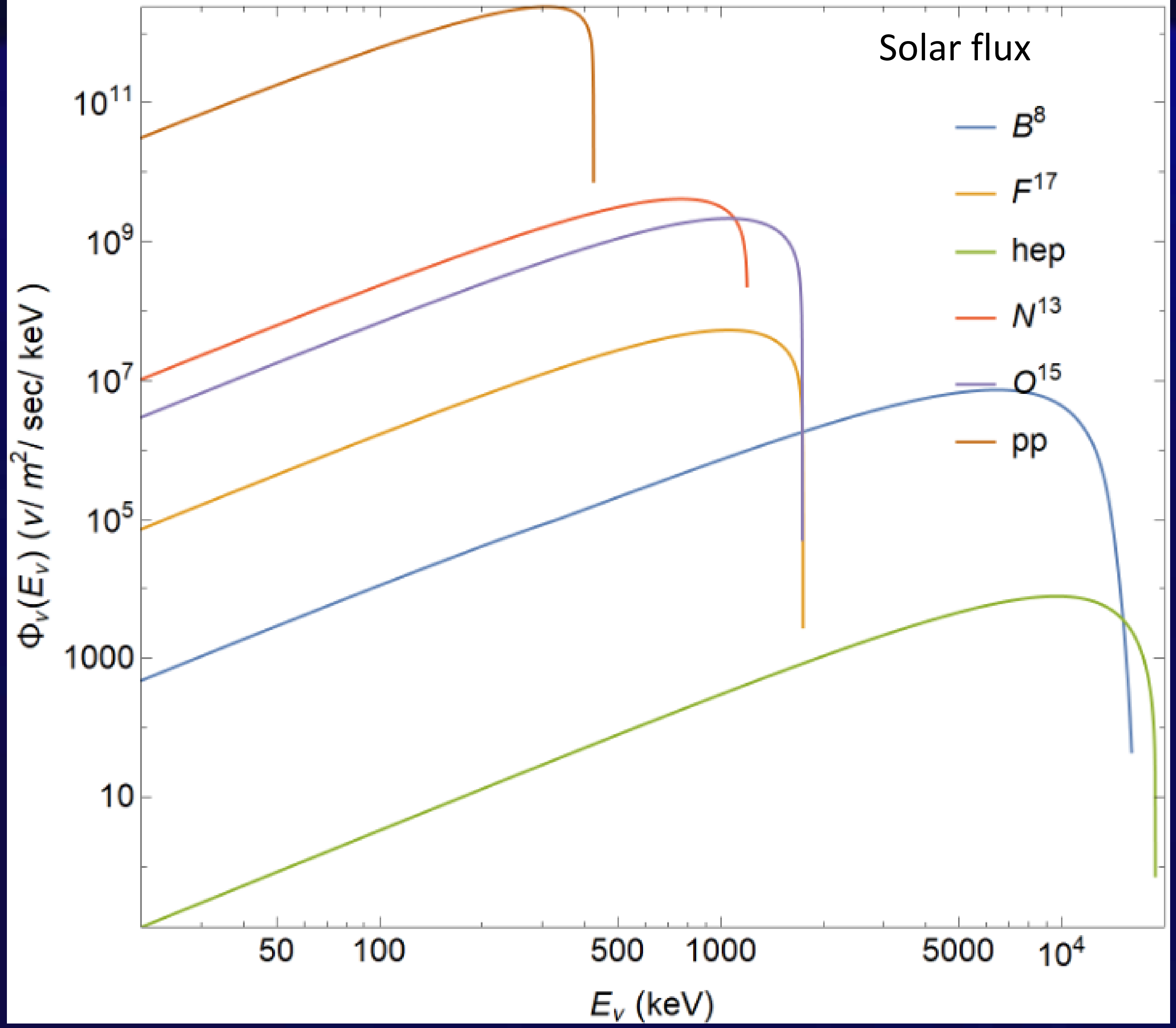
Motivations

- Neutrino mass and oscillations is a well known phenomenon. However, the neutrino mass generation mechanism remains unknown.
- So far, no experimental evidence for NSI of neutrinos, but if exist, directly indicate new physics beyond SM- well motivated from a phenomenological point of view.
- Recent interest in low-scale neutrino models containing new weakly coupled light mediating particles. Experiments such as GEMMA, Borexino, XENONnT constraint the parameter space.
  - Sierra *et al.*, 2020 2006.12457, Boehm *et al.* 2006.11250
- Ongoing/future reactor based neutrino experiments such as MINER, CONUS, CONNIE can investigate these low-scale models.
- Our strategy → investigate these low-scale models in reactor based neutrino experiment with low threshold Ge/Si detectors and find the prospect of probing/ruling out such models.

Reactor vs solar neutrino flux

- We use a MW scale reactor flux for our analysis. MW reactor has similar energy profile to the solar neutrino flux with characteristic energy $\lesssim 1$ MeV.
- Reactor antineutrino flux gets peaked around 200-300 keV and gives at least one order of magnitude more flux compared to solar flux at these keV energy scale.

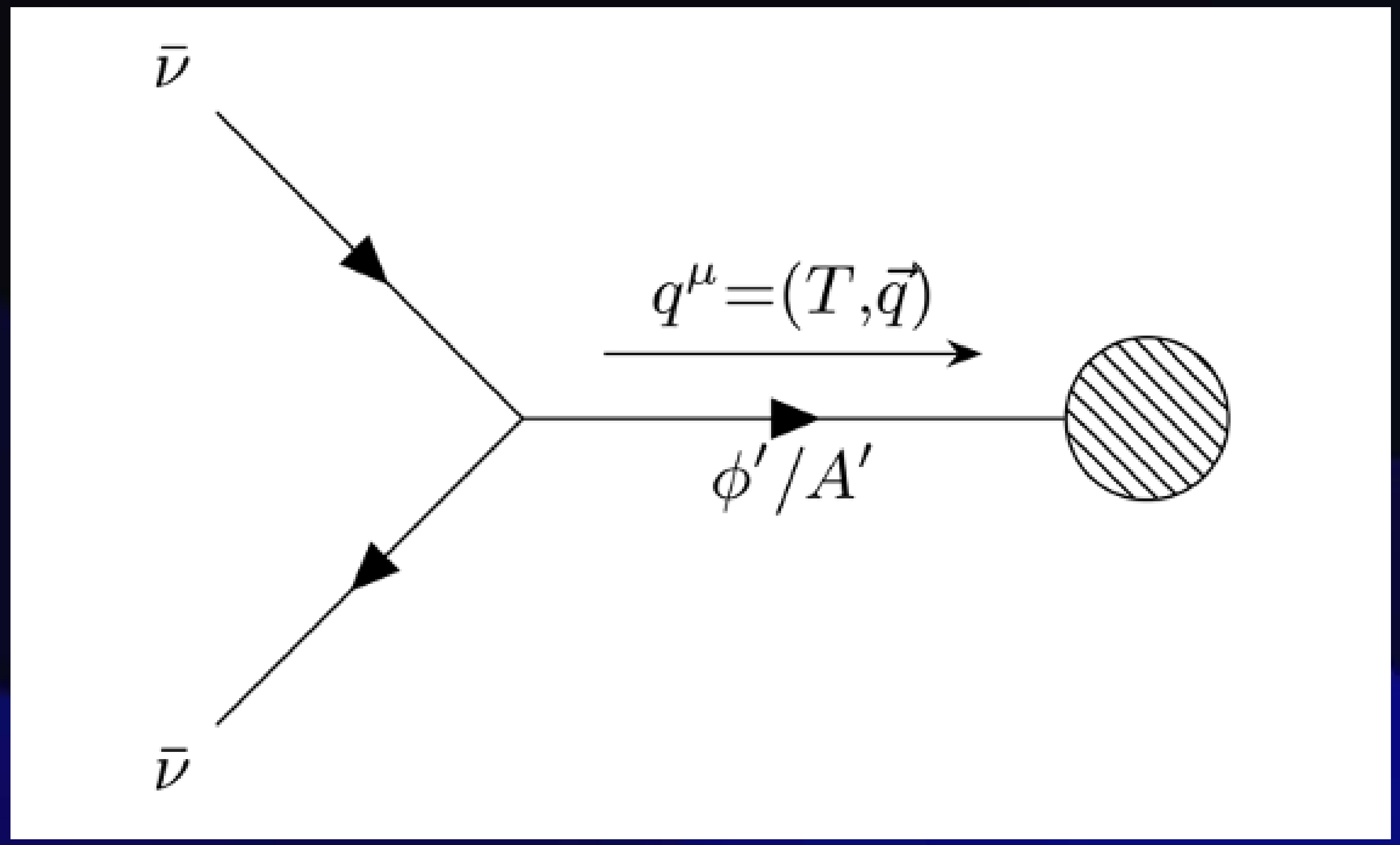




Non-Standard neutrino-electron scattering

- Scalar NSI: $\mathcal{L}_S \supset g_{e,\phi}\bar{e}e\phi + g_{\nu,\phi}\bar{\nu}\nu\phi$

$$\frac{d\sigma_e}{dT} - \frac{d\sigma_e^{\mathrm{SM}}}{dT} = \frac{{g_{\nu,\phi}}^2 g_{e,\phi}^2 T m_e^2}{4\pi E_\nu^2 (2Tm_e + m_\phi^2)^2}$$



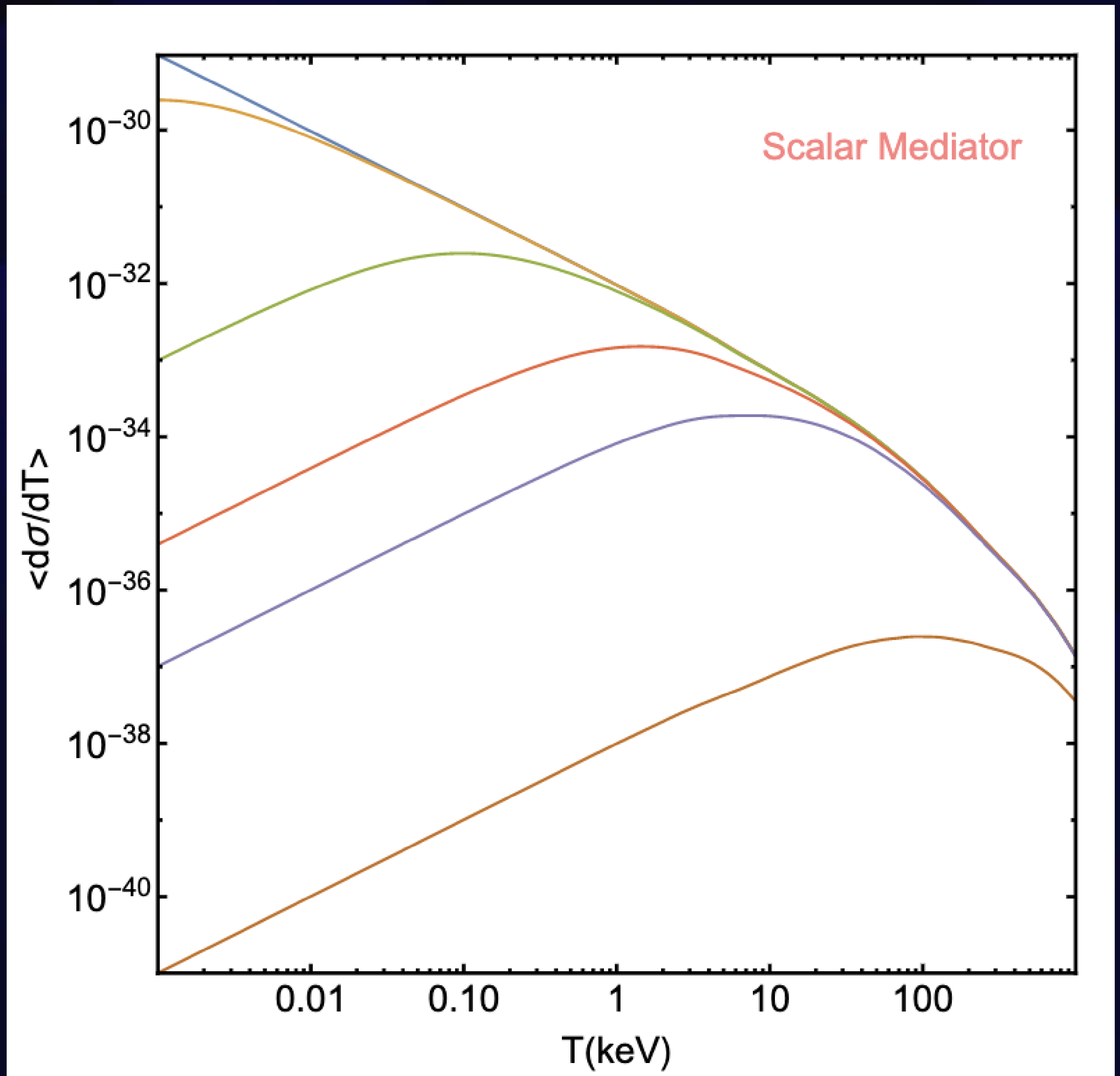
- Vector NSI: $\mathcal{L}_V \supset g_{e,A'}\bar{e}\gamma^\rho e A'_\rho + g_{\nu,A'}\bar{\nu}_L\gamma^\rho \nu_L A'_\rho$

$$T_{max} = \frac{2E_\nu^2}{(m_N + 2E_\nu)}$$

$$\frac{d\sigma_e}{dT} - \frac{d\sigma_e^{\mathrm{SM}}}{dT} = \frac{\sqrt{2} G_F m_e g_v g_{\nu,A'} g_{e,A'}}{\pi\left(2m_e T + m_{A'}^2\right)} + \frac{m_e g_{\nu,A'}^2 g_{e,A'}^2}{2\pi\left(2m_e T + m_{A'}^2\right)^2}$$

Neutrino-electron scattering cross-section

$$\langle\frac{d\sigma}{dT}\rangle = \frac{\int dE_\nu \Phi(E_\nu)\frac{d\sigma}{dT}}{\int dE_\nu \Phi(E_\nu)}$$

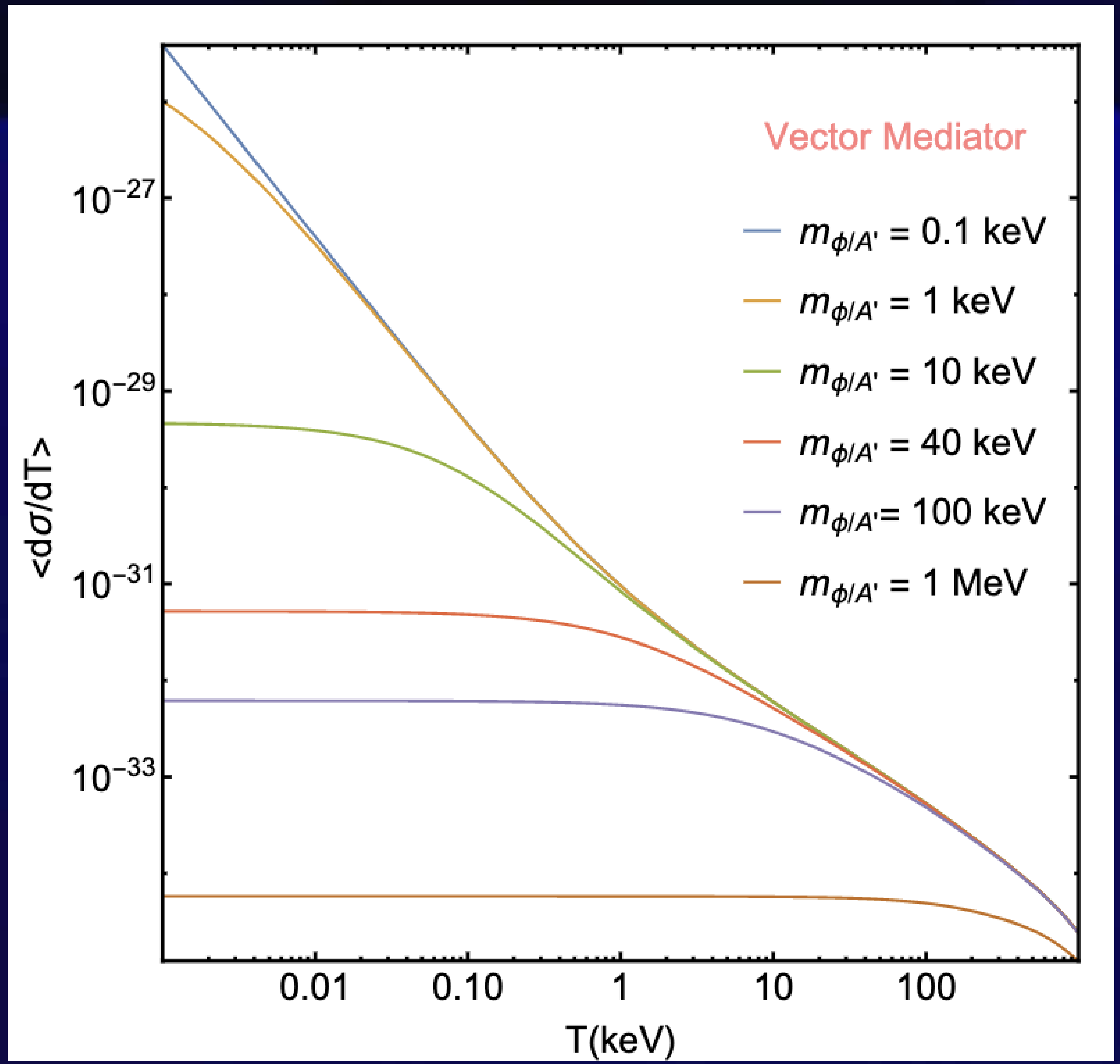


For scalar mediator:

$$g_e = g_\nu = 5\times 10^{-7}$$

For vector mediator:

$$g_e = g_\nu = 1.5\times 10^{-7}$$



Neutrino-electron scattering rate in detectors

- For getting a better understanding of detector responses at low recoil we include a proper treatment of many electron dynamics in ionization that can be encapsulated in atomic and crystal form factors.

- The total rate is sum of the rates obtained for

— atomic states to free states transition for deposited energy E_e >60 eV using atomic form factor from DarkARC code.

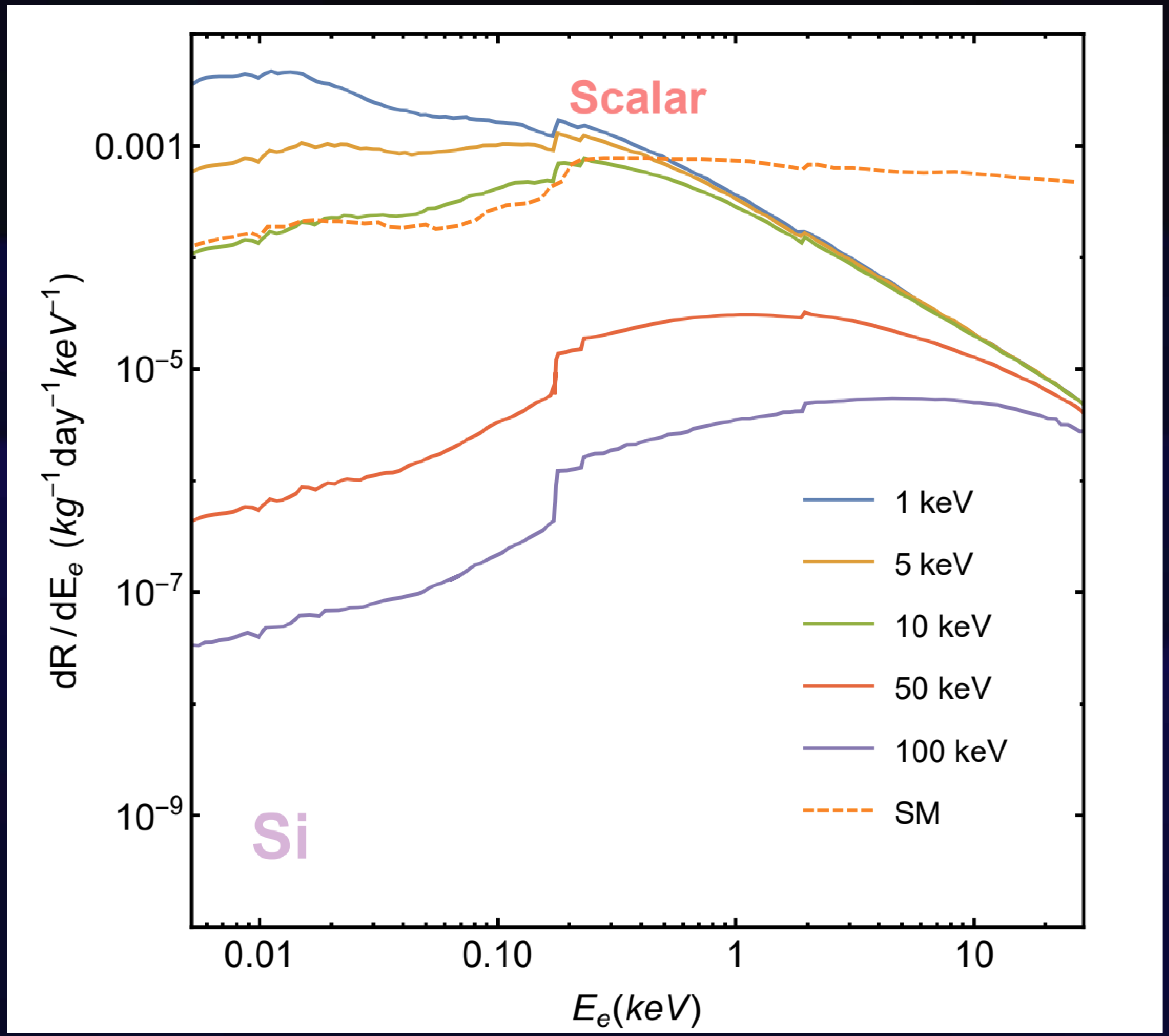
$$\frac{d\mathcal{R}_a}{d\ln E_e} = \frac{N_T}{4}\int dE_\nu \Phi(E_\nu) \int dq \left(\frac{d\sigma}{dq}\right) \left|f_{ion}^{n,l}(q, E_e)\right|^2$$

Catena *et al* 1912.08204
Catena *et al* 2105.02233
Essig, Mardon and Volansky, 2012
1108.5383
Essig *et al* 1509.01598
Essig *et al.* 1908.10881
Griffin, S. M. *et al.* (2021)
2105.05253

— valance to conduction band transition for deposited energy E_e ≤60 eV using crystal form factor from EXCEED-DM code.

$$\frac{d\mathcal{R}_{v\to c}}{d\ln E_e} = N_{cell} \int dE_\nu \Phi(E_\nu) \int dq \frac{d\sigma_e}{dq} |f_{v\to c}(q, E_e)|^2$$

Recoil Spectra: scalar mediator



For scalar mediator:

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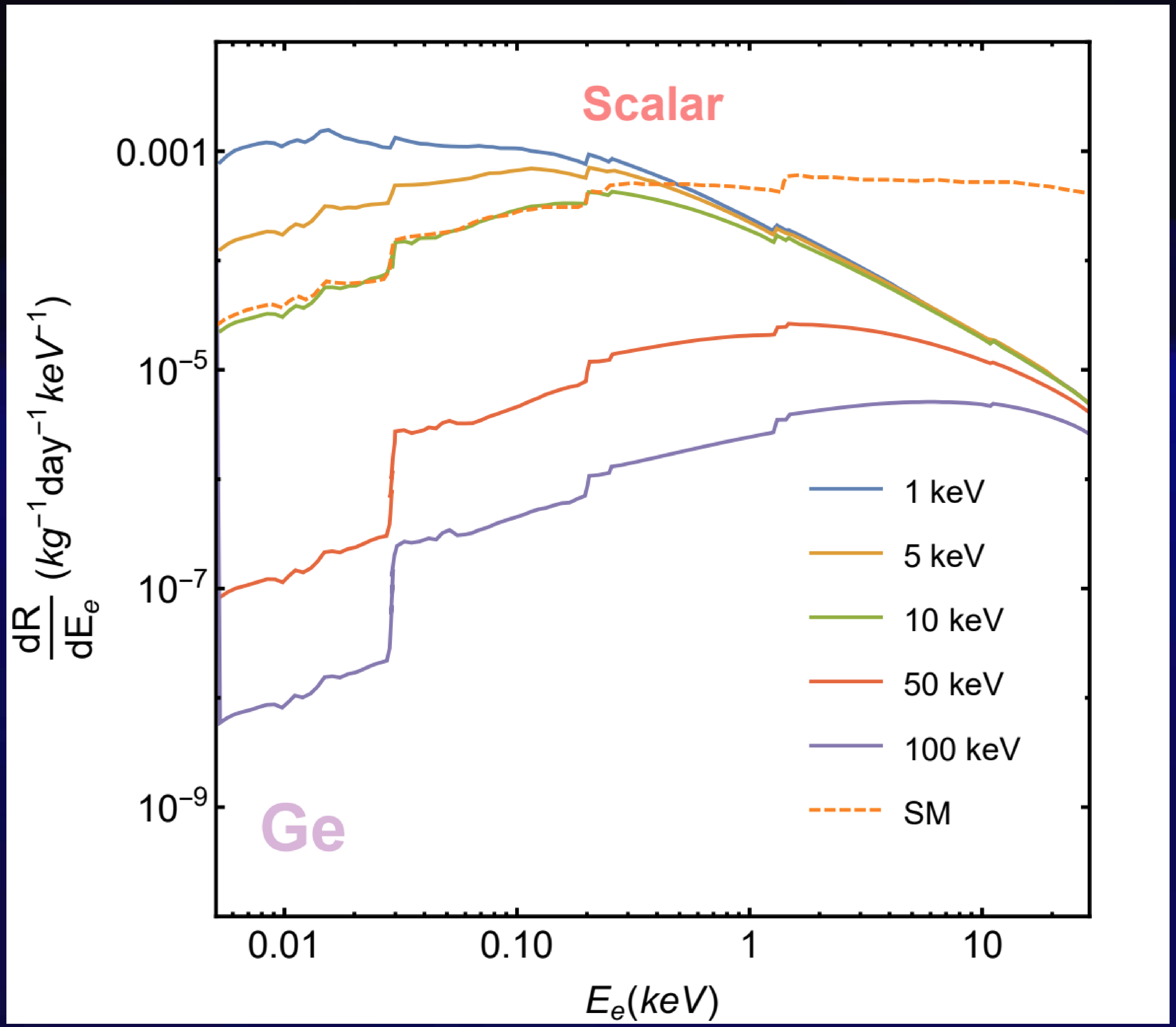
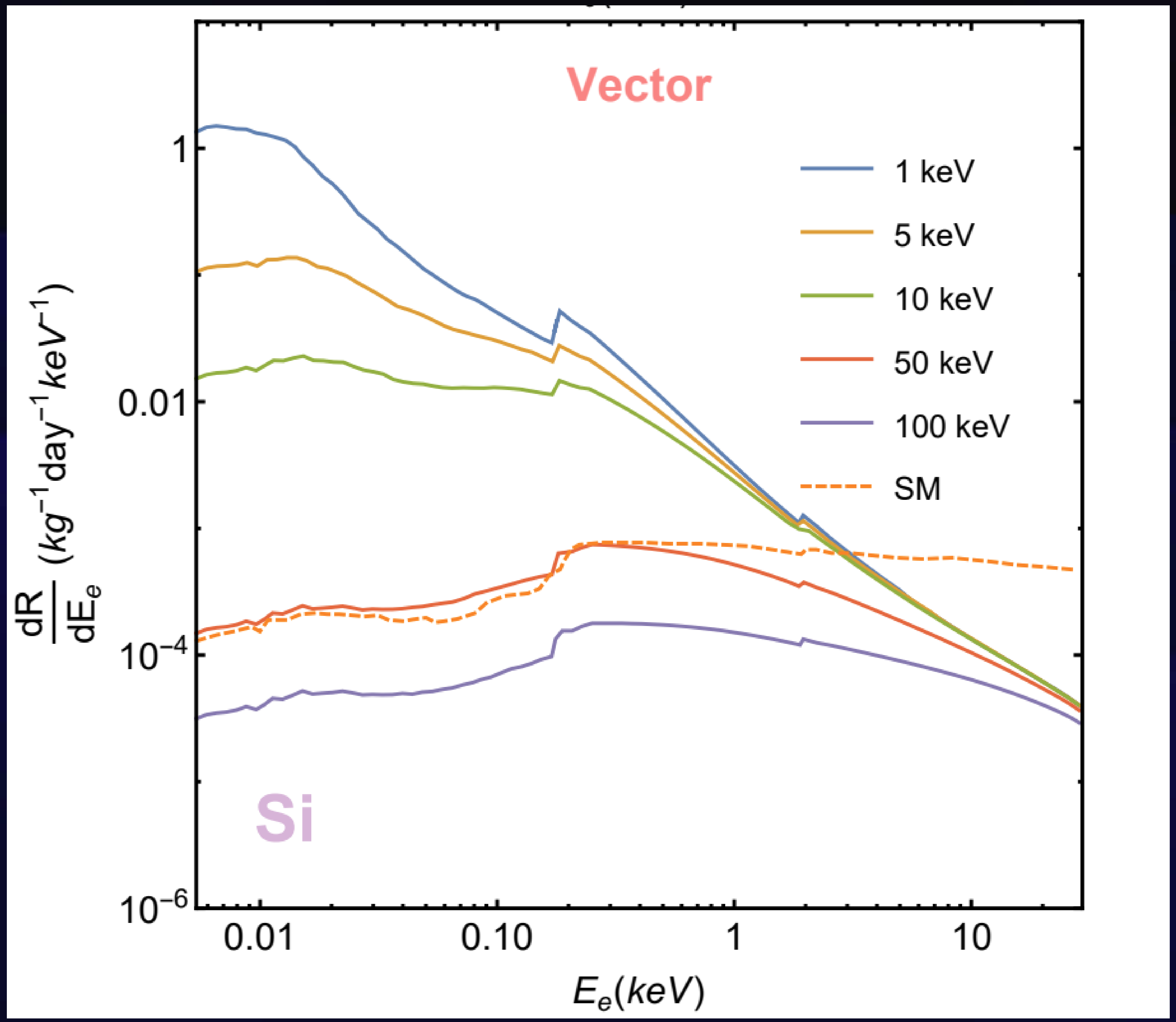
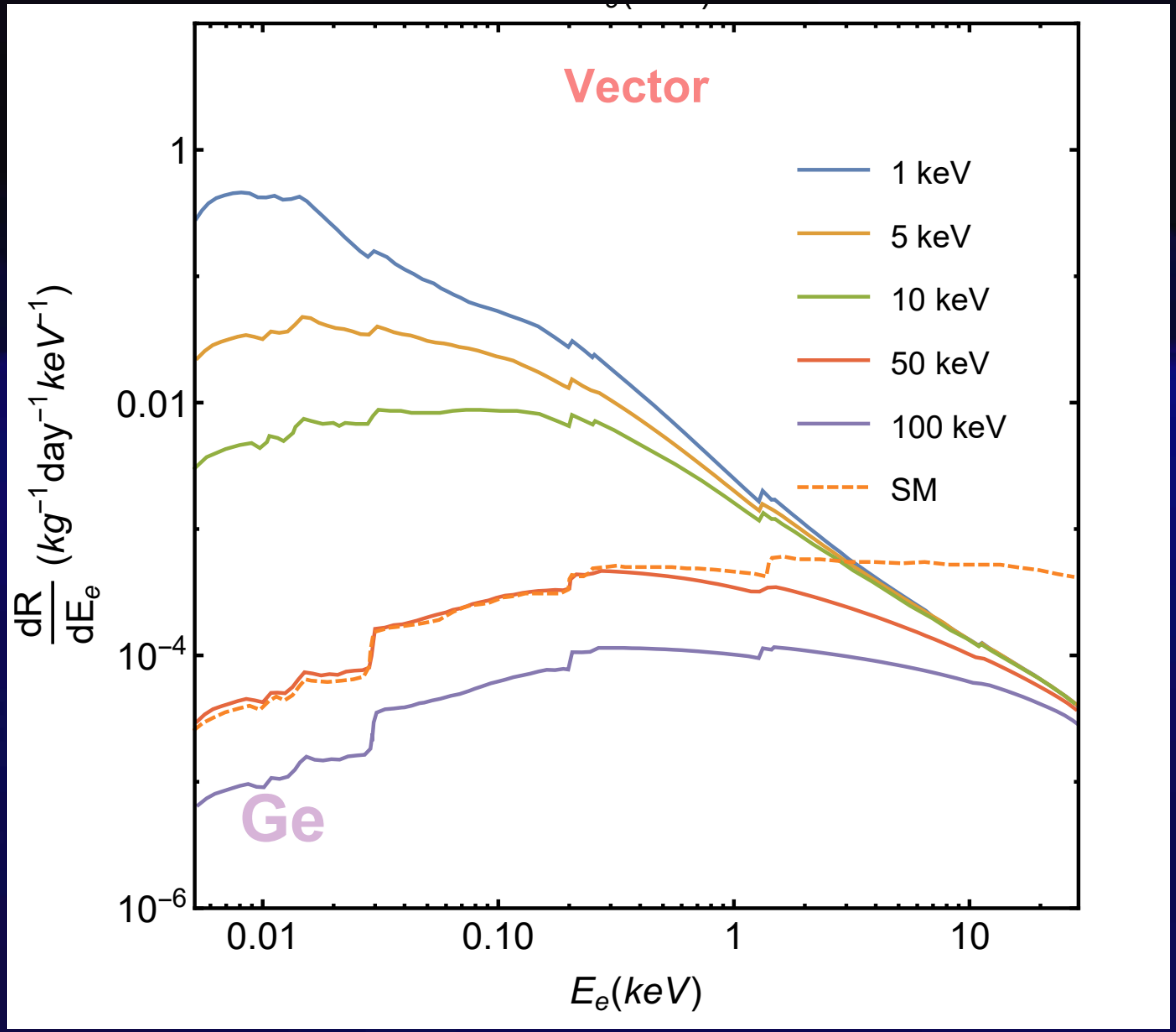


Recoil Spectra: vector mediator



For vector mediator:

$$g_e = g_\nu = 1.5 \times 10^{-7}$$



Result: sensitivity curve

- To obtain the sensitivity curve

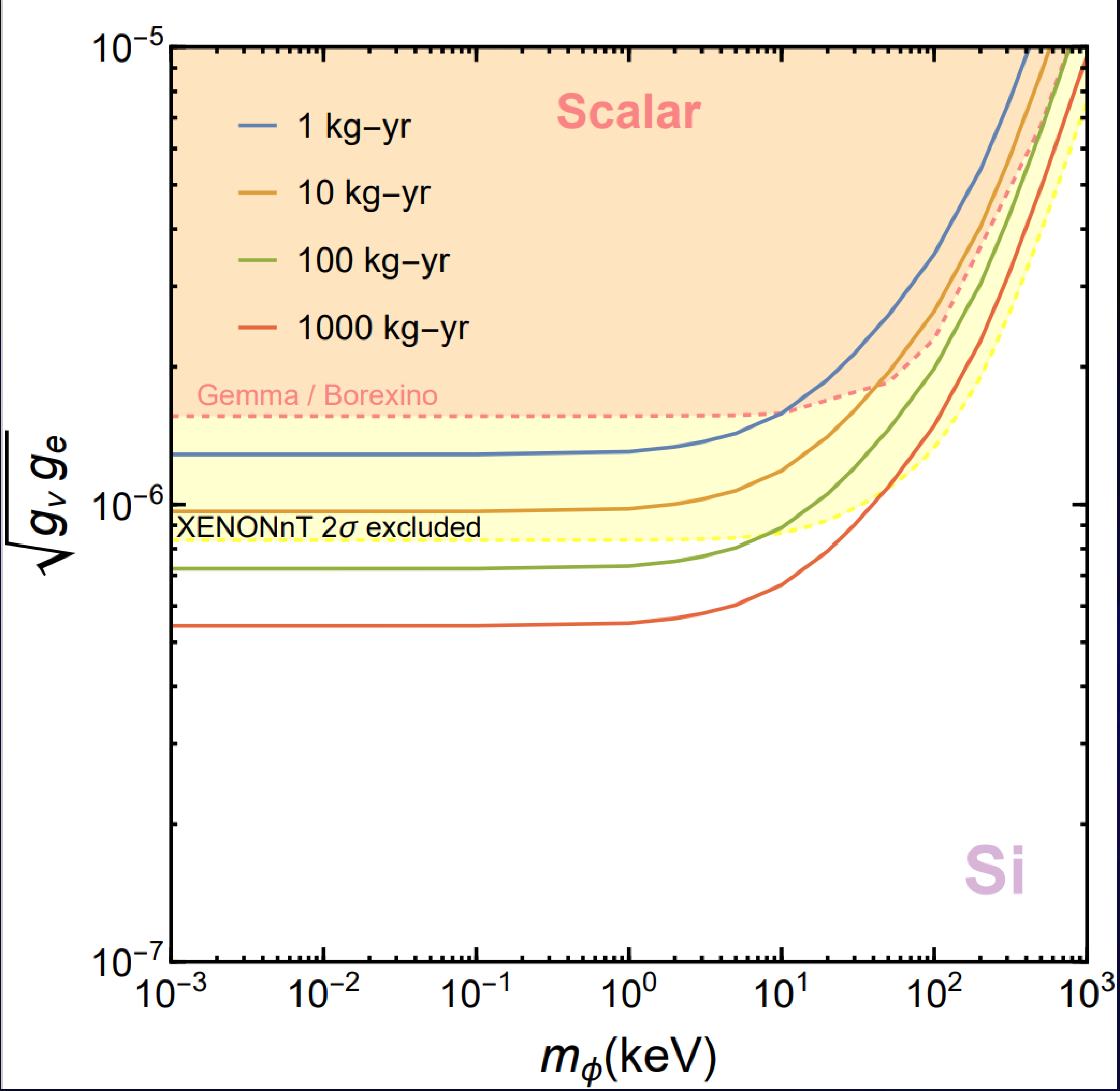
  — we show projected sensitivity at 90% confidence level.

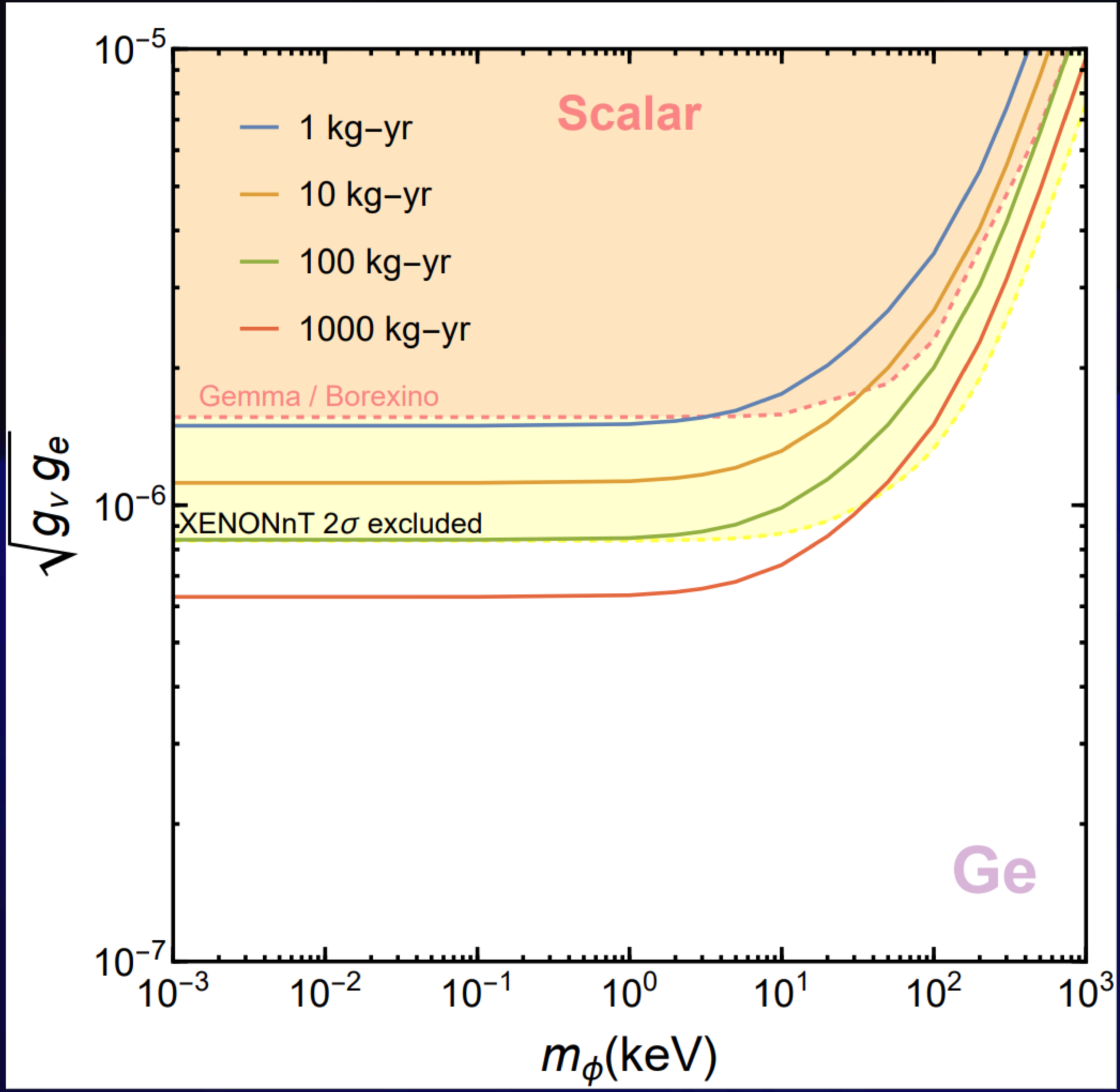
  — corresponding constraints from Borexino, GEMMA and XENONnT are shown.

  — we assume a constant background of 0.1 dru in addition to SM neutrino-electron background.

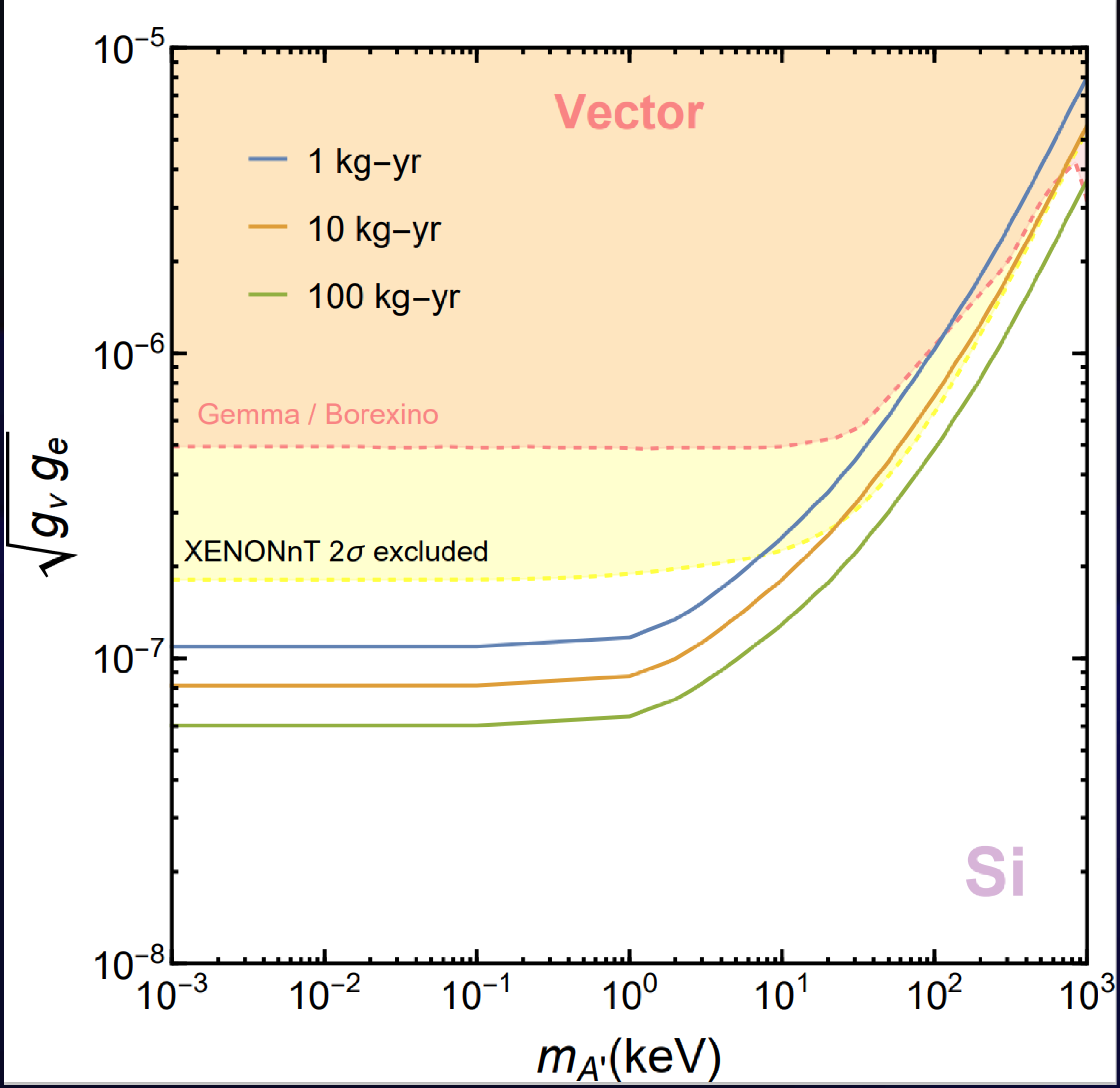
  — we also assume the detector is capable of discriminating between ER and NR signals down to the threshold of 5 eV.

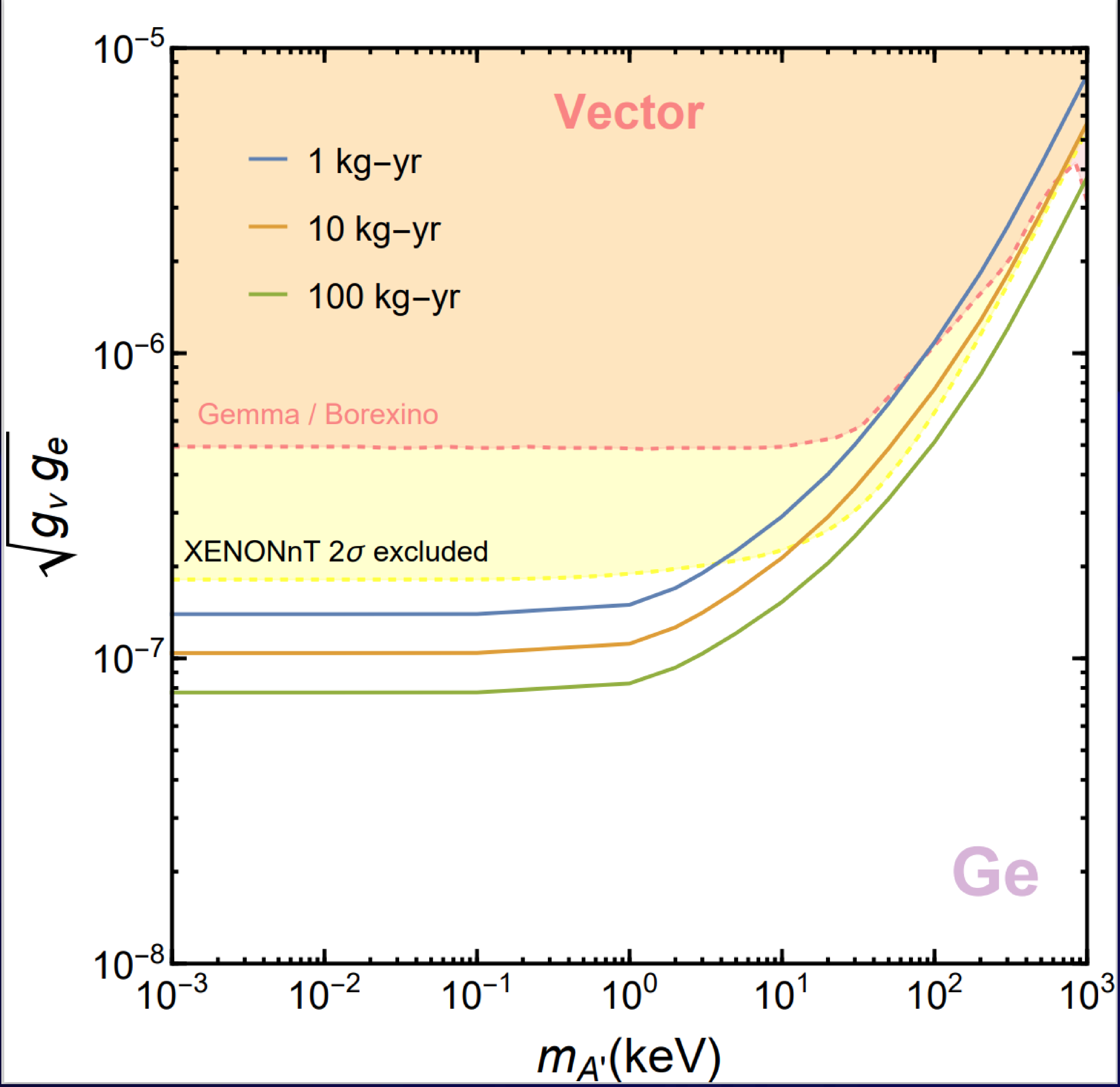
Sensitivity Plot: scalar mediator



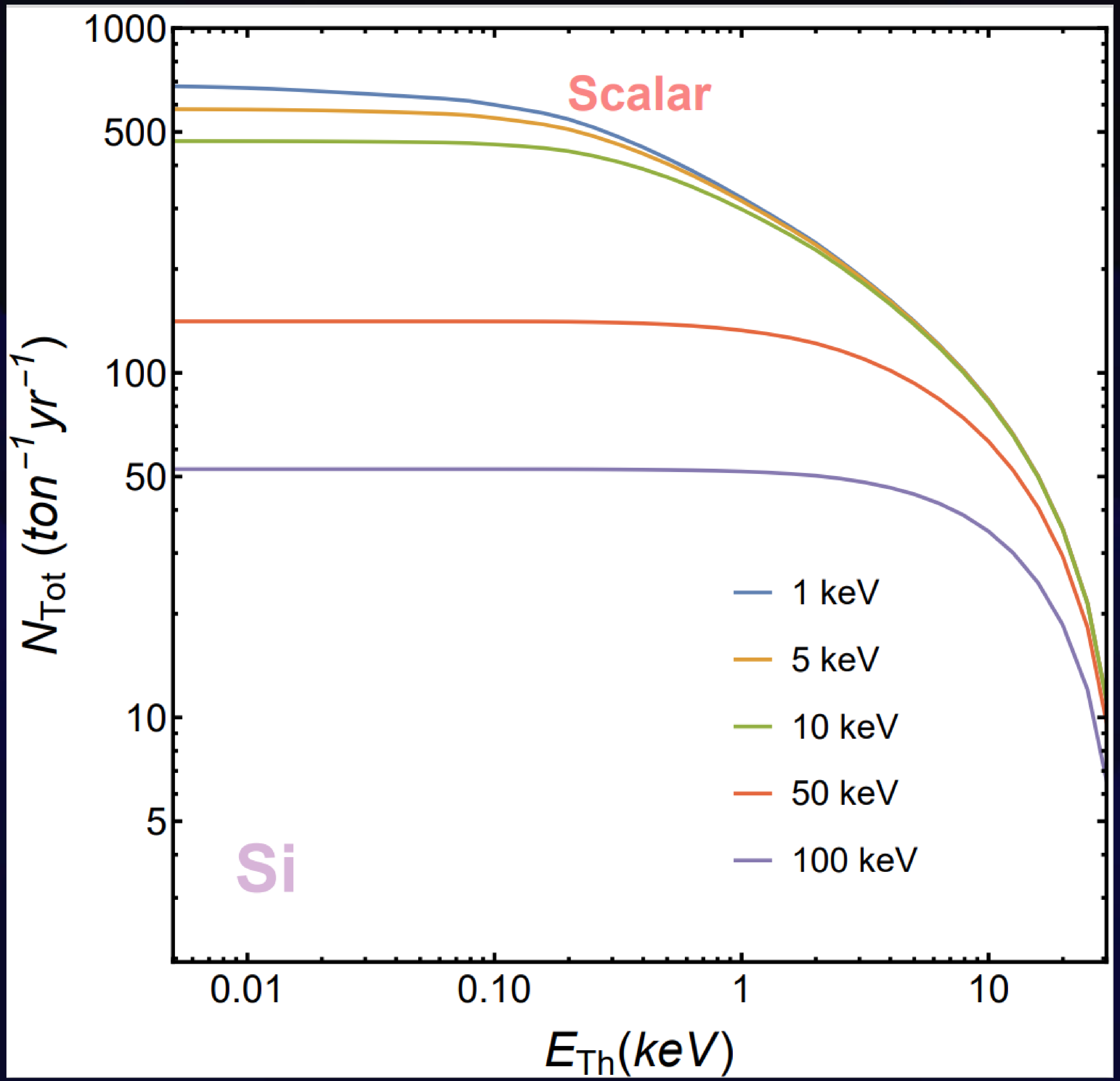


Sensitivity Plot: vector mediator





Integrated events: scalar mediator



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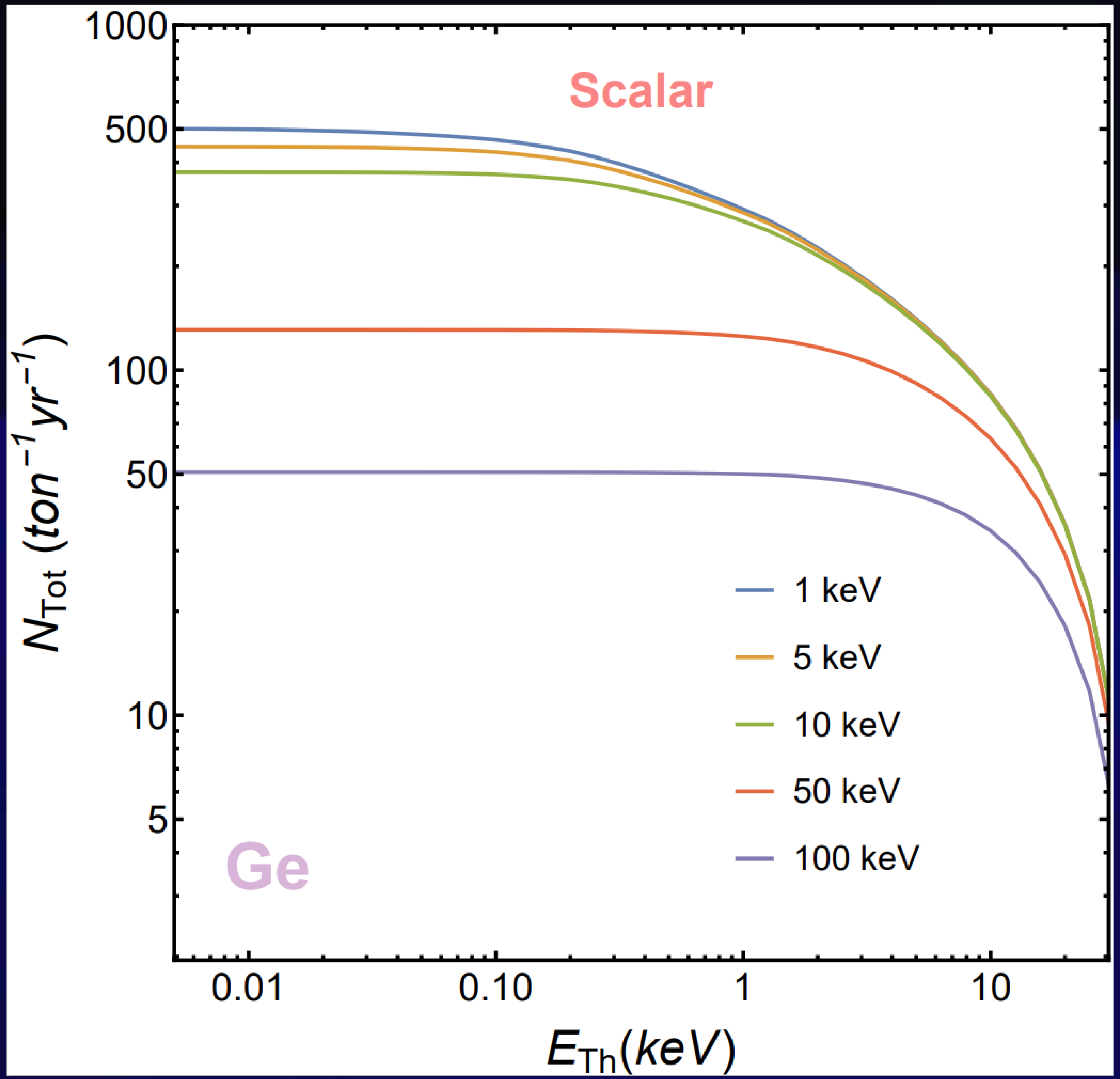
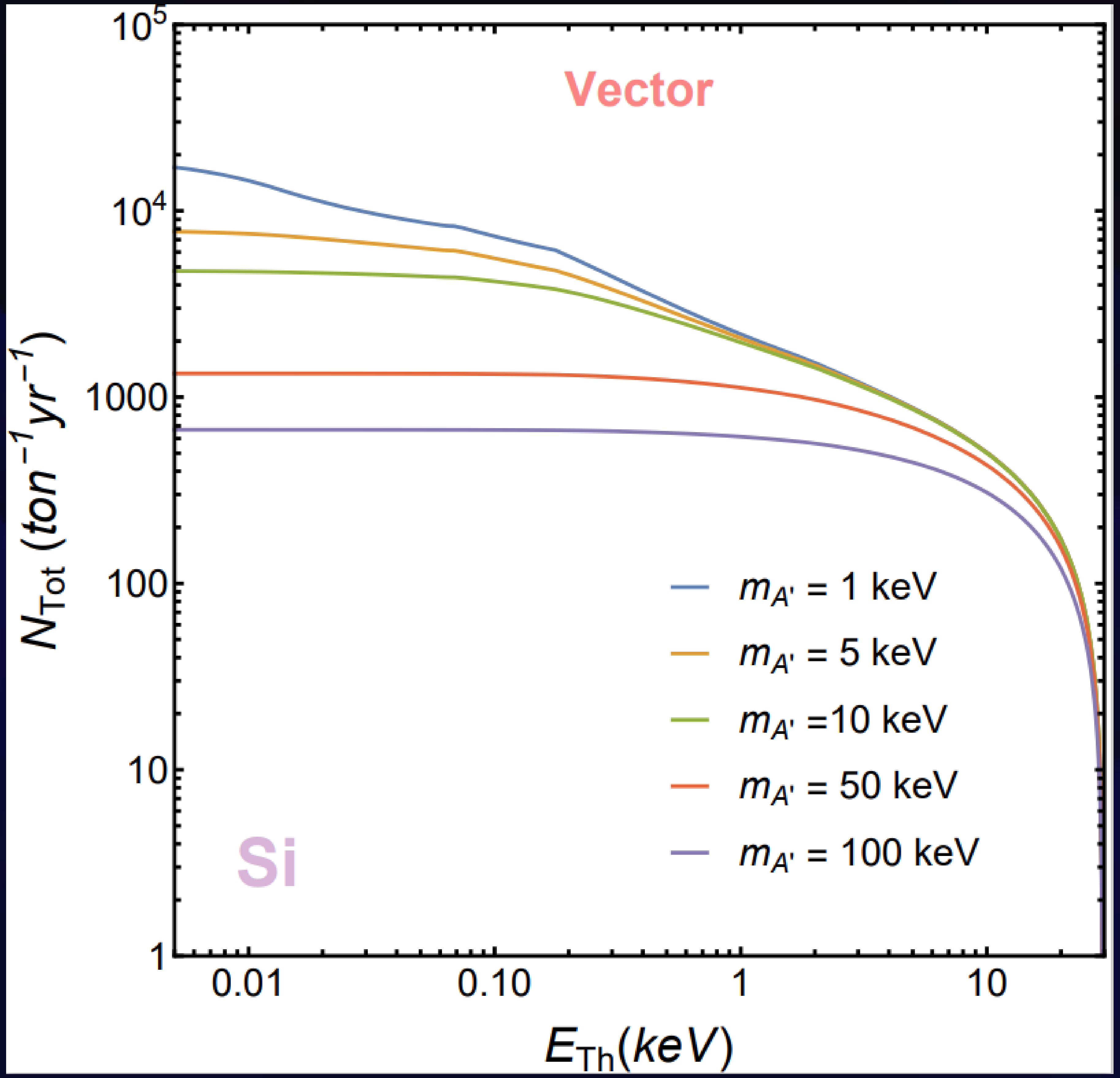
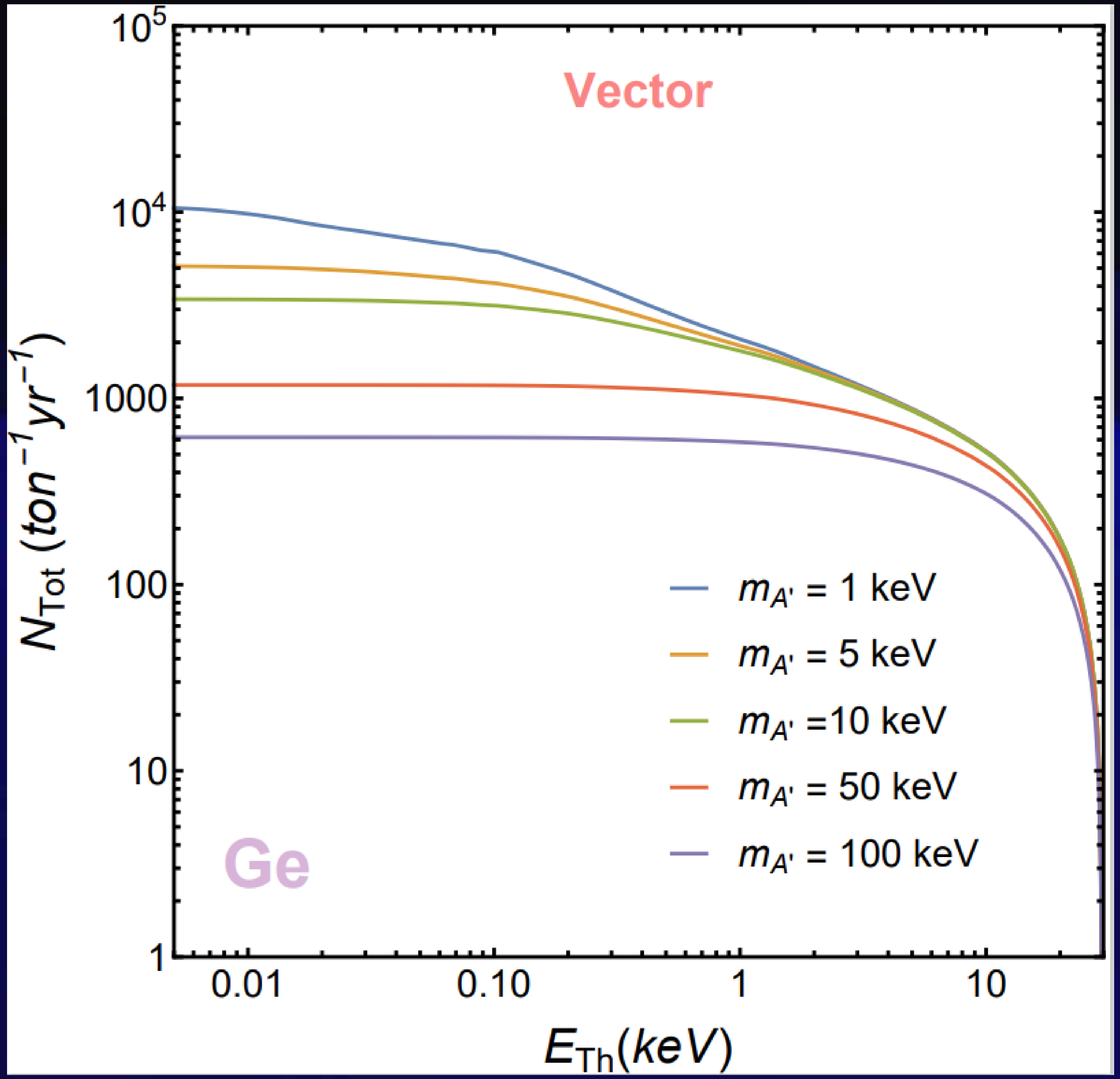


Integrated events: vector mediator



For vector mediator:

$$g_e = g_\nu = 1.5 \times 10^{-7}$$



Light Mediator Models: examples

- Light scalar mediator models: we propose one

— by extending the SM scalar sector by

$$H_1 \sim (2,1/2), H_2 \sim (2,1/2), \qquad \phi \sim (1,0), \Delta \sim (3,1).$$

— mixing in the scalar sector give rise to one $\mathcal{O}(1)$ keV scalar particle.

— Yukawa term $\overline{l}'^{c}_{L_i}(y')_{ij} i\sigma_2 \Delta l'_{L_j}$ gives NSI of neutrinos .

- Light vector models: the extension of SM by an anomaly-free $U(1)$ gauge group such as, $U(1)_{L_i-l_j}, U(1)_{B-L}, U(1)_{T3R}$ etc.

Light Mediator Models: constraints

- Neutrino-neutrino, neutrino-electron and electron-electron interactions induced by the new light mediator:

— Borexino , GEMMA and XENONnT are quite sensitive to the modification of the scattering cross-section by NSI with low mass mediators.

— different astrophysical processes such as energy loss of SN1987A, solar cooling process and cooling of star in globular clusters can put bounds. Can be evaded by Chameleon effect

— contribution to ΔN_{eff} can also put bounds.

— vector NSI induces flavor dependent matter potential and scalar NSI gives a correction to neutrino mass matrix. Can affect oscillations and scattering experiment.

Conclusions

- A well-motivated phenomenological approach to search for new physics, in neutrino sector, is that of NSI.

- With ER and NR discrimination and low background, the low threshold Si/Ge detector placed in reactor based experiment can probe large parameter space of light mediator induced NSI models.

- We compared the parameter space sensitivity with the XenonnT/Borexino experiment results which uses solar-pp flux. We find that ongoing reactor experiments can be sensitive to the parameter space which has not been probed by these experiments. These sensitivities could be further enhanced from a gigawatt-class reactor neutrino source.