Probing non-standard neutrino interactions with low energy neutrino-electron elastic scattering in reactor experiments

arXiv : 2108.XXXXX

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In collaboration with

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Motivation

- Leptophilic interactions occur in many extensions of the Standard model such as $\boldsymbol{L_\mu - L_e},\ \boldsymbol{L_e - L_\tau}$, light scalar models etc. These models include NSI with new weakly coupled mediating particles.
  R. Foot, **Mod. Phys. Lett. A 6, 527 (1991) ,**
  X. G. He, G. C. Joshi, H. Lew and R. R. Volkas, **Phys. Rev. D 44, 2118 (1991)**
  X. G. He, G. C. Joshi, H. Lew and R. R. Volkas, **Phys. Rev. D 43, 22 (1991),**
  Dutta, Ghosh and Li,**2006.01319**

- Xenon1t , Borexino, GEMMA etc experiments provide constraints on the parameter space of such models. . Sierra *et al.*, 2020 **2006.12457,** Boehm *et al.* **2006.11250 …..**

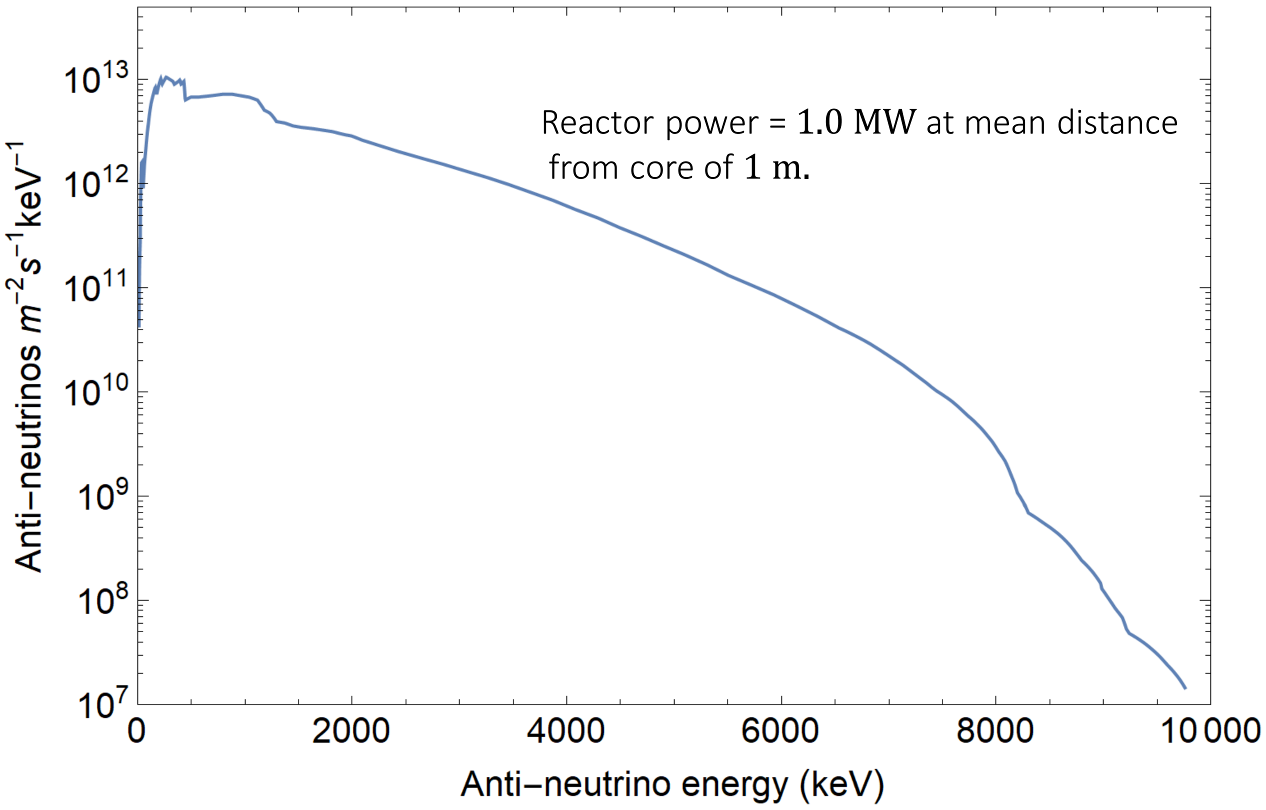
- Ongoing and future reactor experiments such as MINER, CONUS, CONNIE, VIOLETTA etc. can also provide a particularly important probe of such light mediator models.

- We study the prospects for probing Neutrino NSI via light scalar and vector mediators using reactor neutrino sources in combination with low threshold electron recoil detectors such as Si, Ge

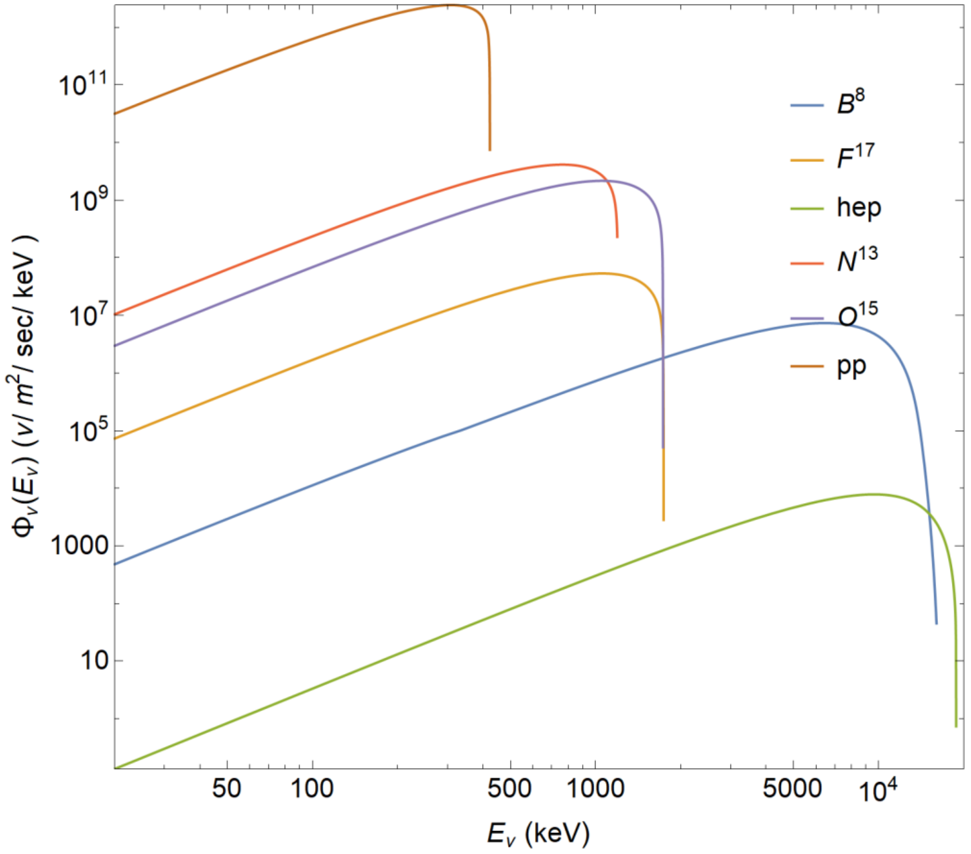
Reactor and Solar Neutrino Flux

- The MW reactors have a similar energy flux profile to solar neutrinos with characteristic neutrino energies <1 MeV
- At the typical incident neutrino energy $\lesssim$ 200keV atomic /crystal effects should be considered . (arXiv:1411.0574v1)

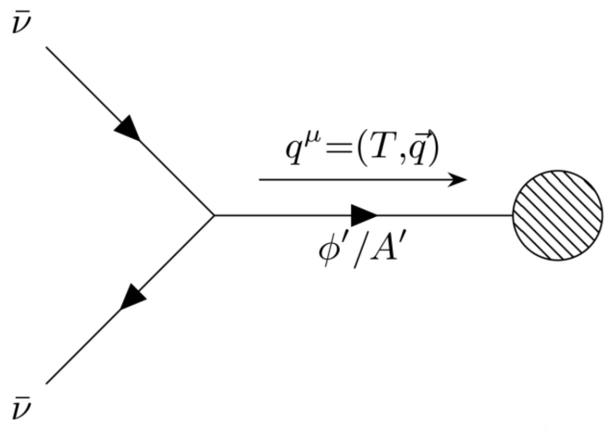
Reactor Antineutrino flux



Solar flux



Neutrino-electron scattering



Scalar NSI: $\mathcal{L}_S \supset \phi\left(g_{\nu,\phi}\bar{\nu}\nu + g_{\ell,\phi}\bar{\ell}\ell\right)$

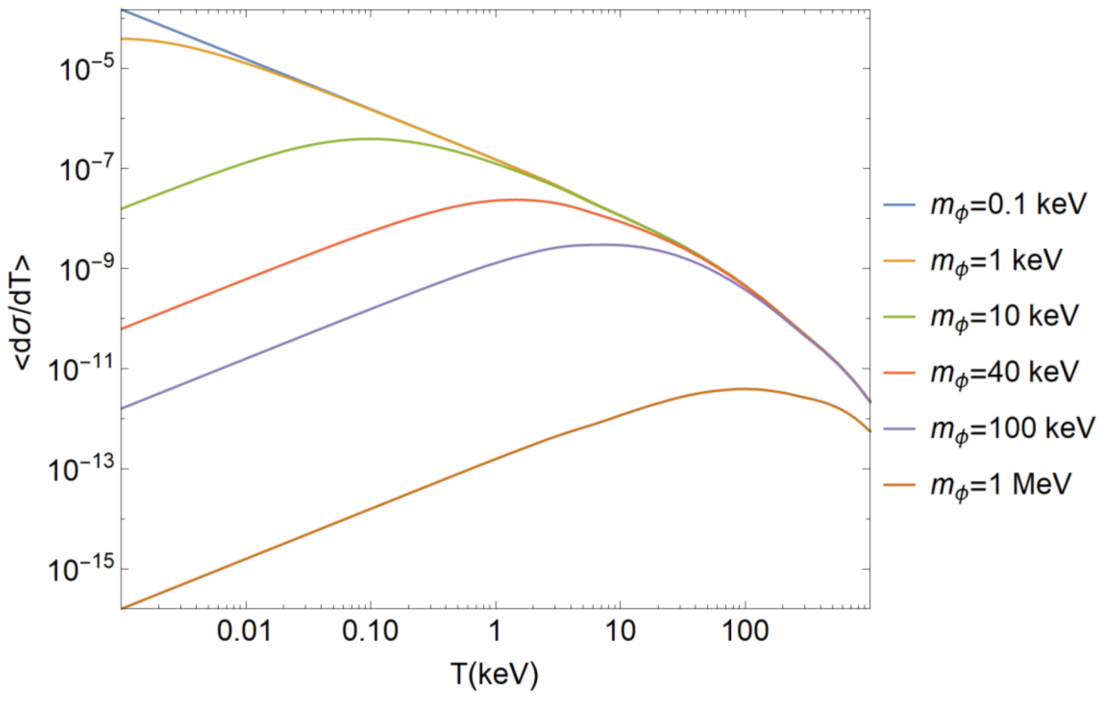
Vector NSI: $\mathcal{L}_V \supset Z'_\mu\left(g_{\nu,Z'}\bar{\nu}_L\gamma^\mu\nu_L + g_{\ell,Z'}\bar{\ell}\gamma^\mu\ell\right)$

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

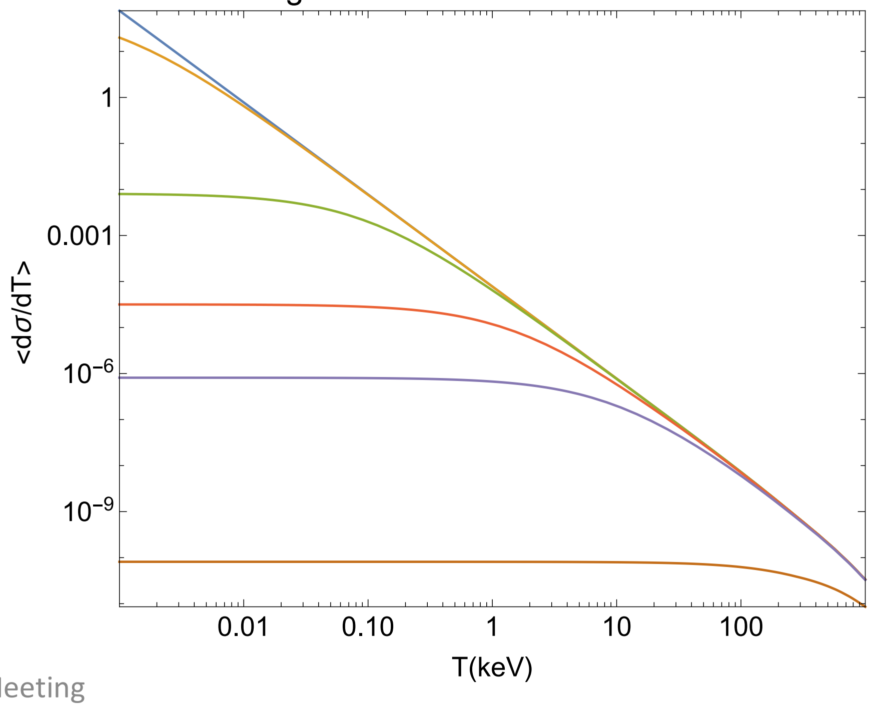
Ionization form factor-describes the likelihood that a given momentum transfer results in a particular electron recoil energy

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**

dσ/dT averaged over Reactor flux for scalar mediator

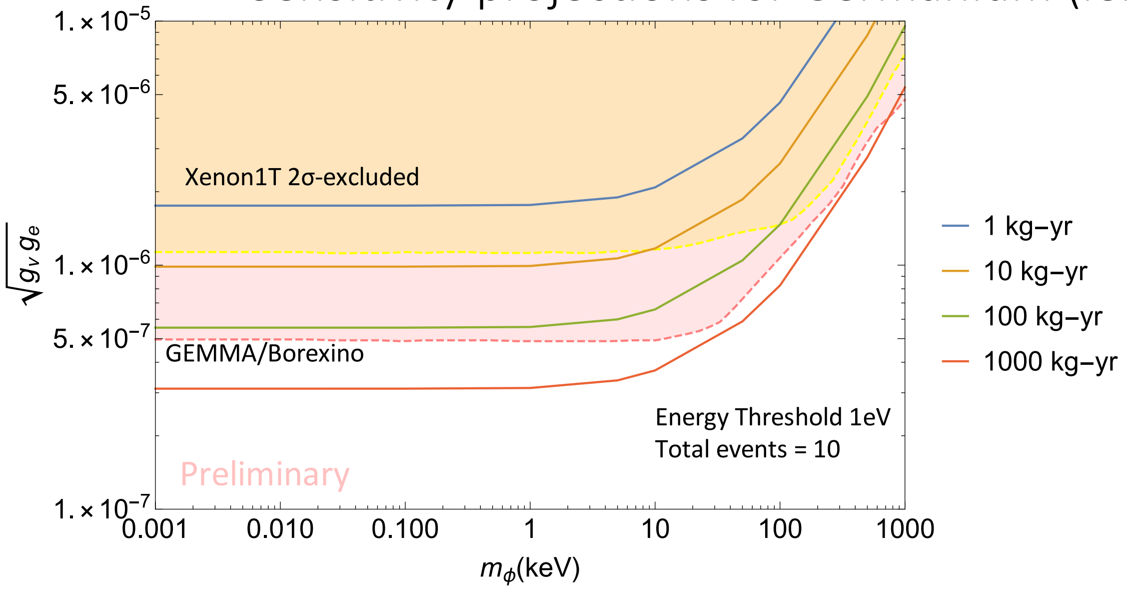


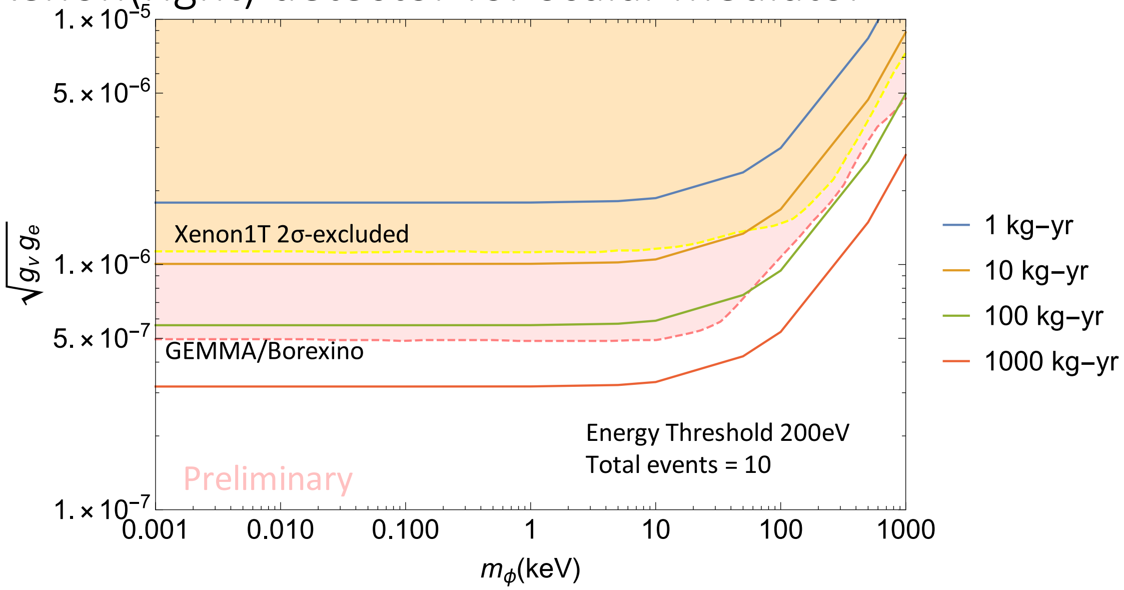
dσ/dT averaged over Reactor flux for vector mediator



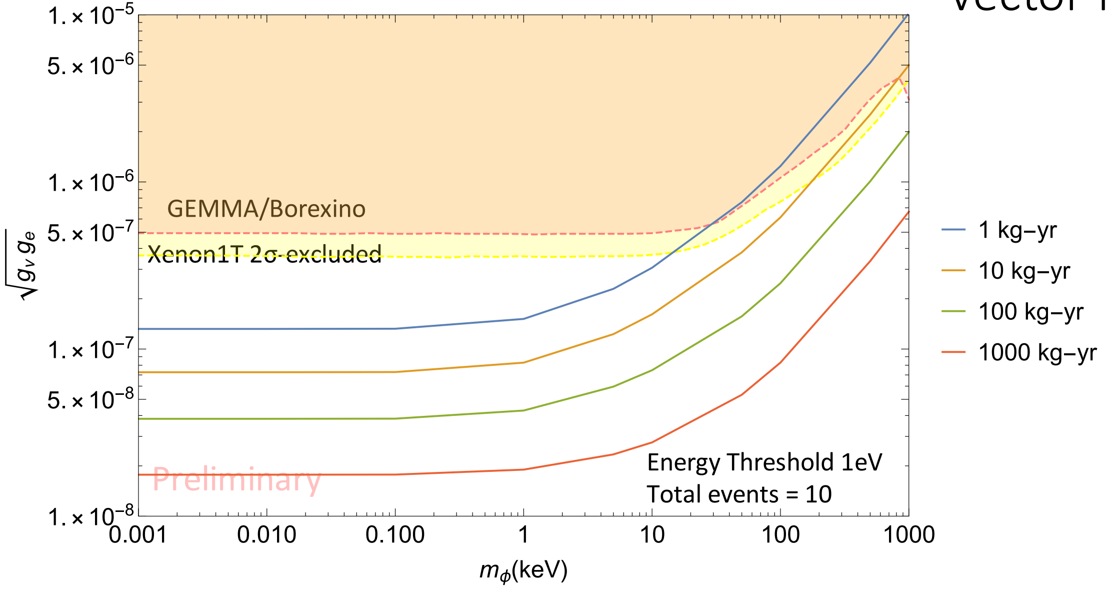
Results-

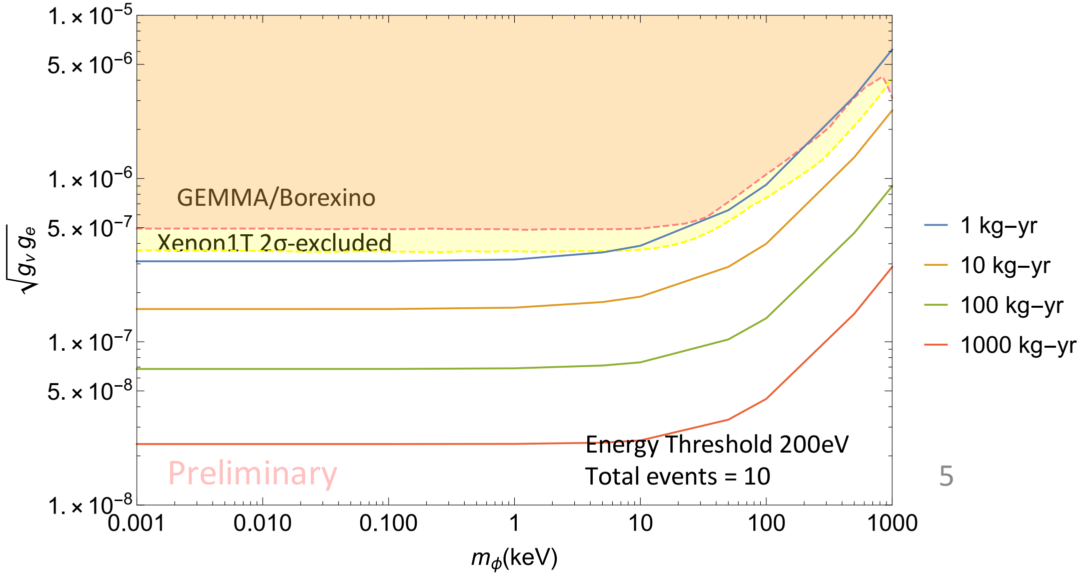
Sensitivity projections for Germanium (left) and Xenon(right) detector for scalar mediator



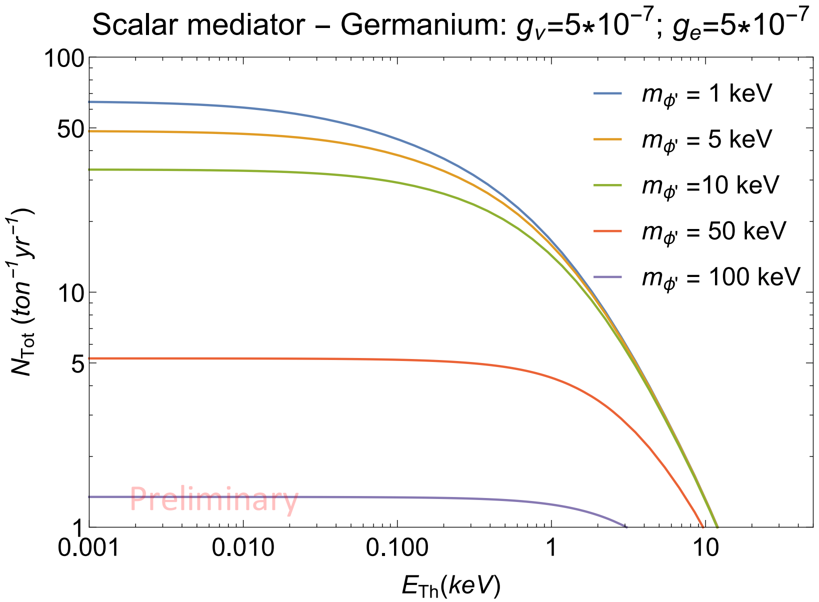


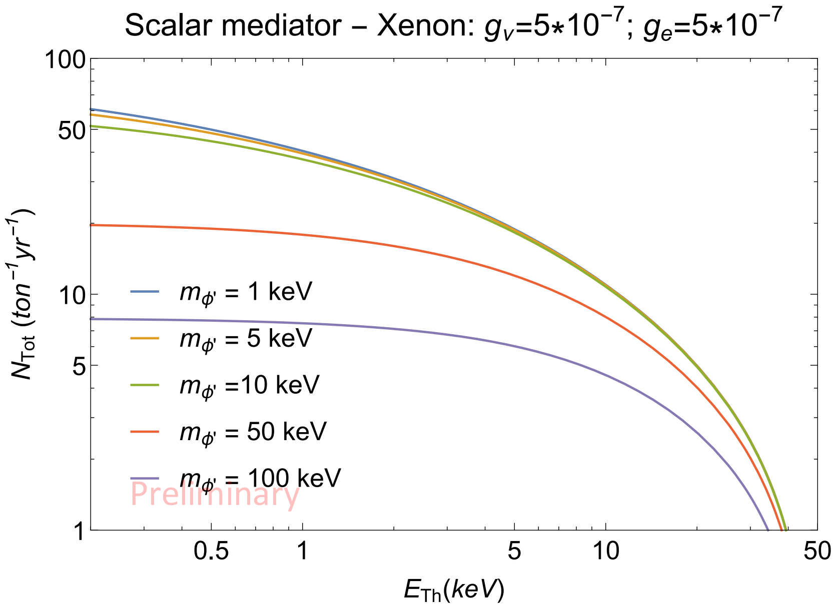
Vector mediator

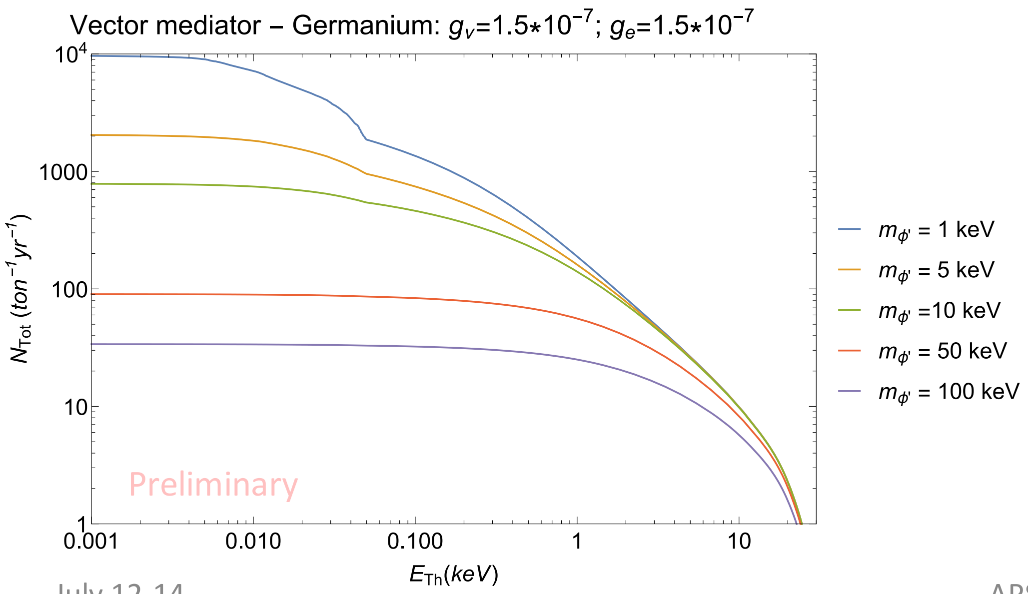


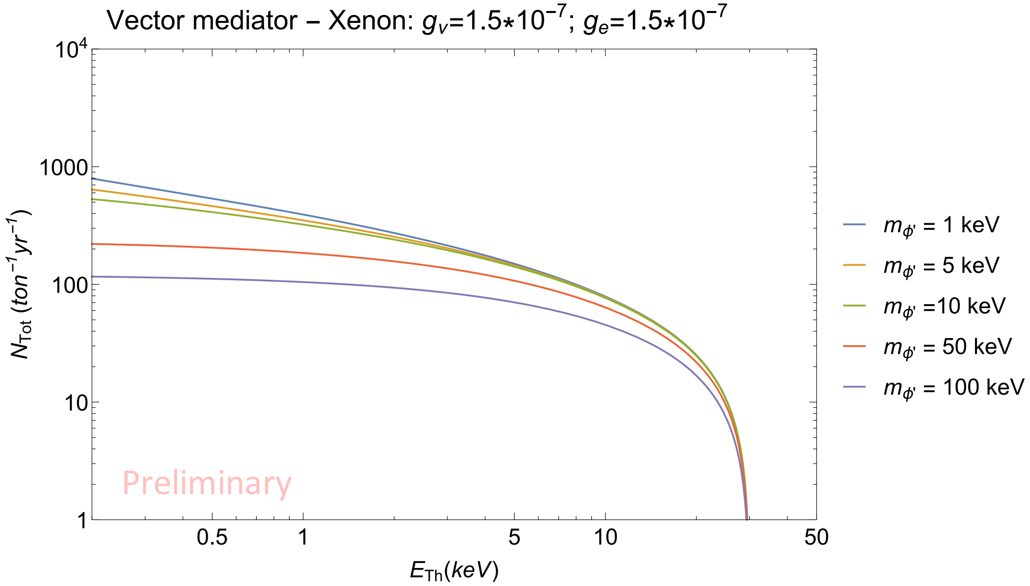


Electron recoil integrated rates as a function of Experimental Threshold energy



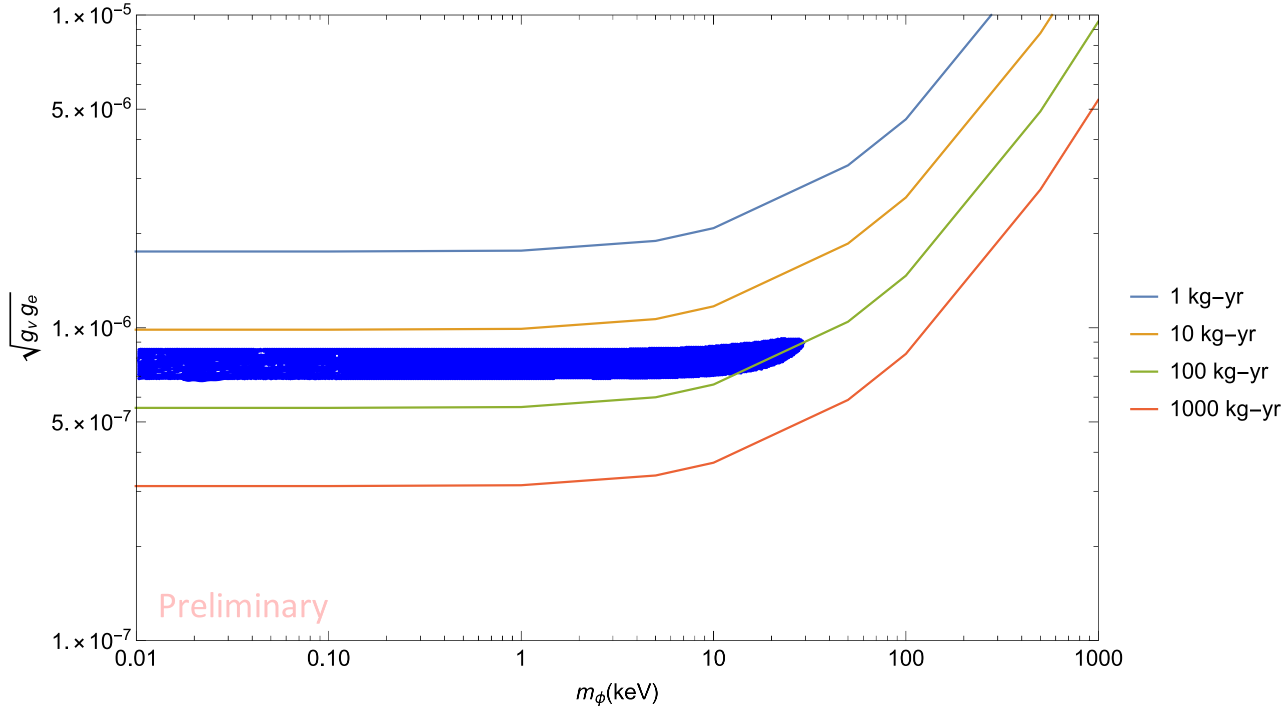




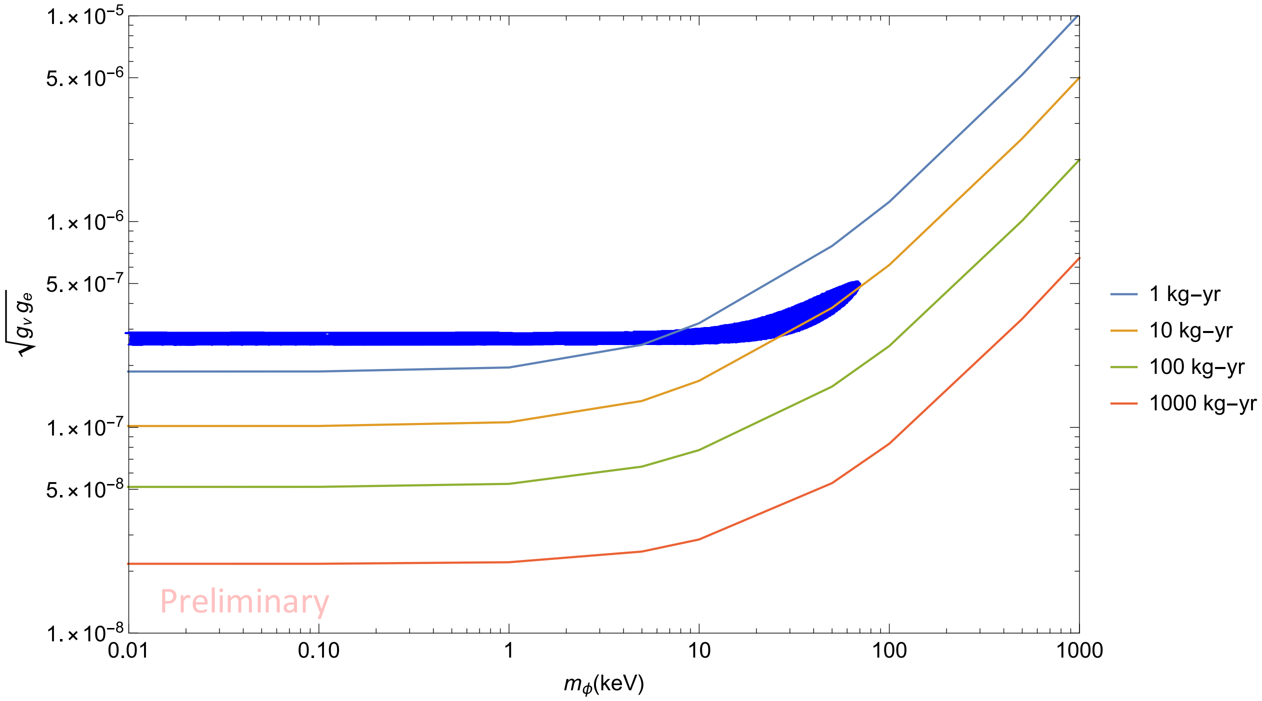


Xenon1T excess at Reactor based experiments

Sensitivity projections for Germanium detector for scalar mediator



Sensitivity projections for Germanium detector for vector mediator



• Xenon1t 2σ–preferred region

Conclusion

- We investigated light leptophilic mediators via neutrino interactions at ongoing/upcoming reactor experiments.
- Including atomic and crystal effects we calculated the projected electron recoil event rates in low threshold detectors using reactor flux.
- We compared the parameter space sensitivity with the Xenon1T/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.
- The explanation of the excess in the recent Xenon1t result can also be investigated at the reactor experiments.

Backup

Neutrino-electron scattering

Scalar NSI: $\mathcal{L}_S \supset \phi\left(g_{\nu,\phi}\bar{\nu}\nu + g_{\ell,\phi}\bar{\ell}\ell\right)$

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

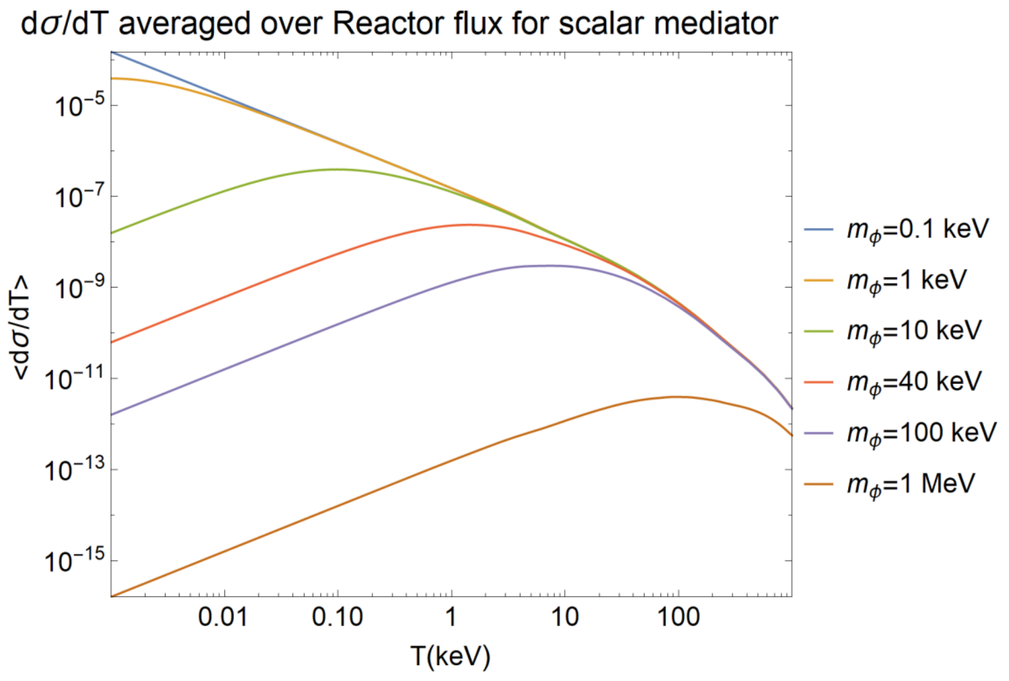
Vector NSI: $\mathcal{L}_V \supset Z'_\mu\left(g_{\nu,Z'}\bar{\nu}_L\gamma^\mu\nu_L + g_{\ell,Z'}\bar{\ell}\gamma^\mu\ell\right)$

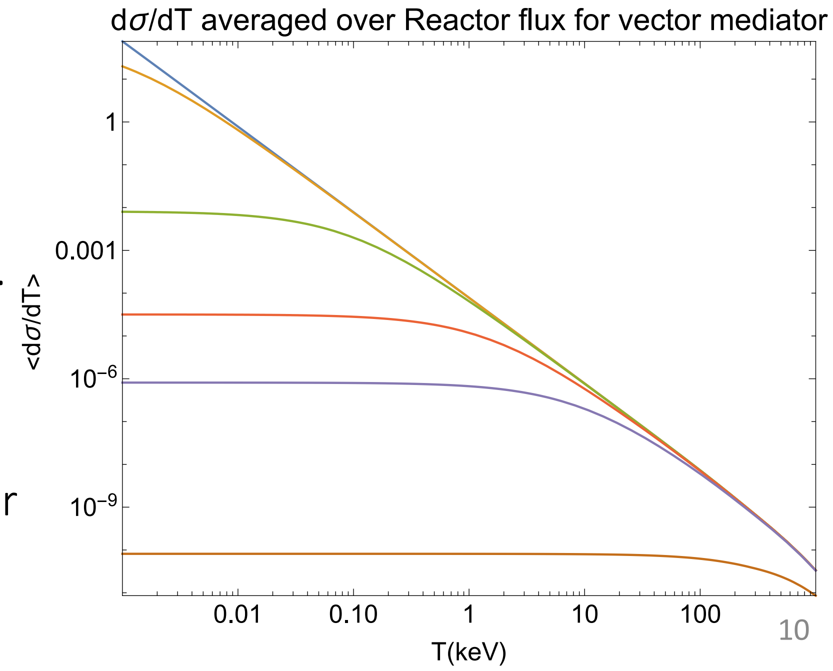
$$d\,\sigma_e/d\,T - d\,\sigma_e^{\mathrm{SM}}/d\,T = \frac{\sqrt{2}G_F m_e g_\nu g_{\nu,Z'} g_{e,Z'}}{\pi\left(2Tm_e + m_{Z'}^2\right)} + \frac{m_e g_{\nu,Z'}^2 g_{e,Z'}^2}{2\pi\left(2Tm_e + m_{Z'}^2\right)^2}$$

$$E_{R,max} = \frac{2E_\nu^2}{\left(m_N + 2E_\nu\right)}$$

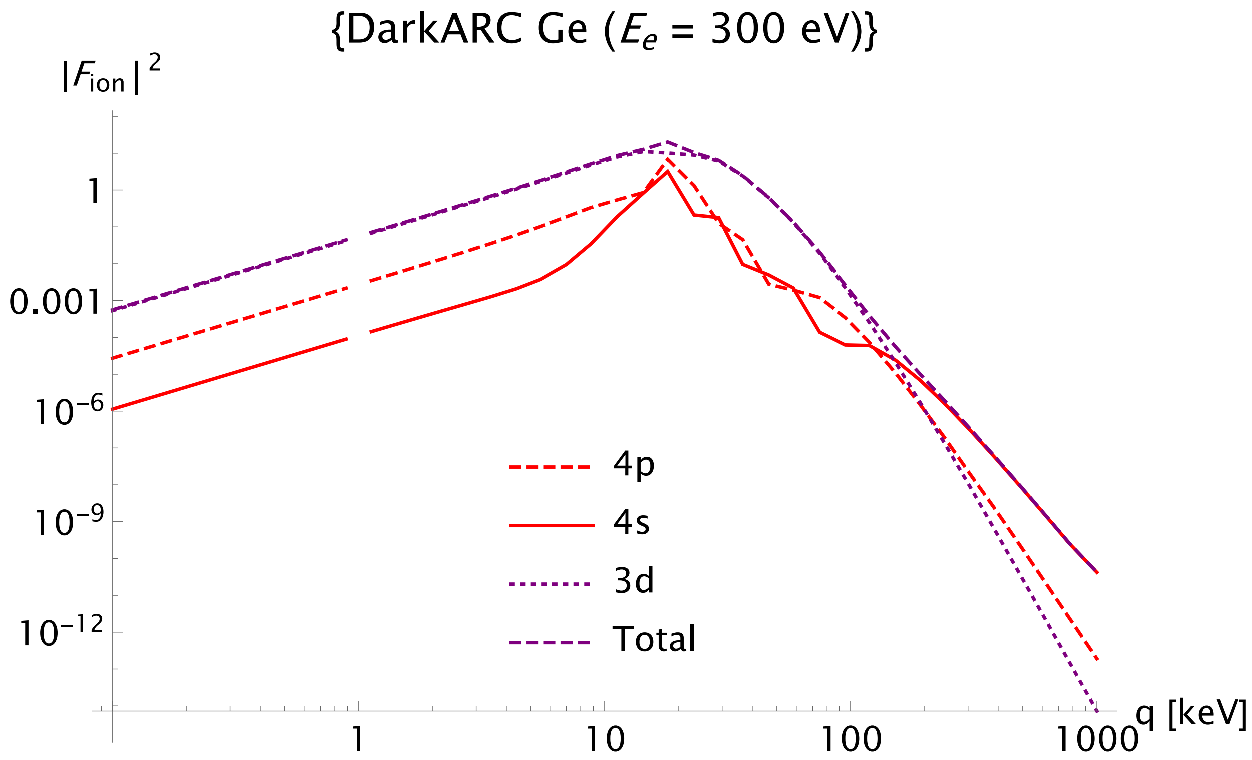
- The typical energy transfer is small enough that atomic effects should be considered but large enough that we can ignore the crystal effects in Si/Ge. Significant contribution comes from the atomic form factor

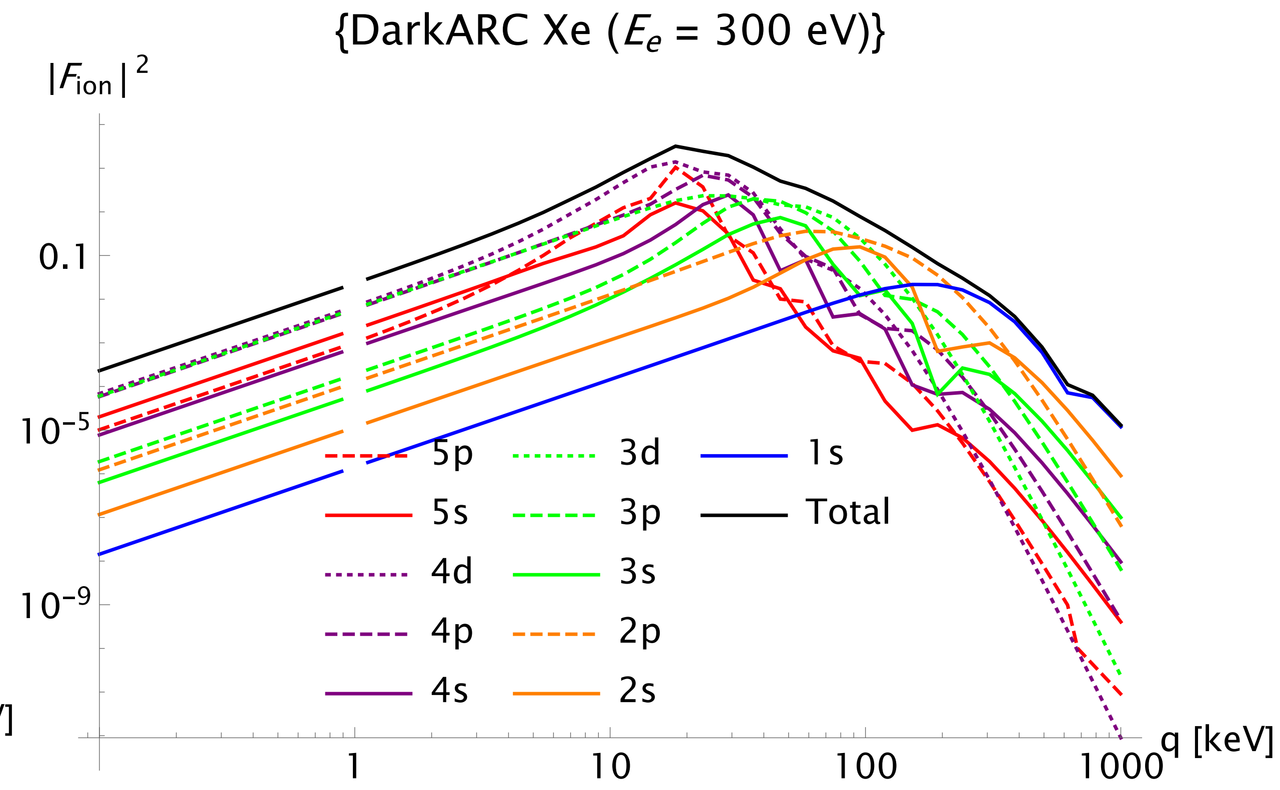
- Unlike the case of sub-GeV Dark matter where the maximum energy transfer is severely restricted by the kinematic cutoff, neutrinos can transfer large energy to the electrons so that valence to free transition rate dominates over valence to conduction state transitions.



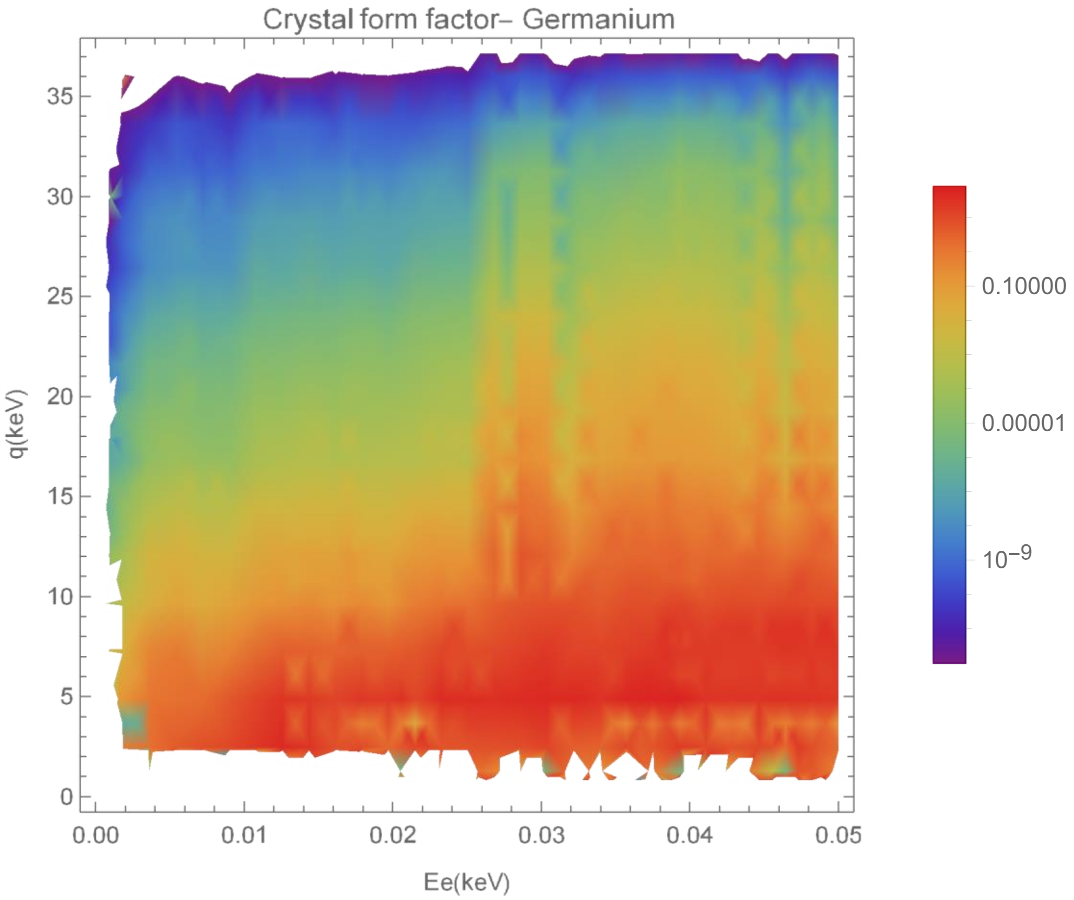


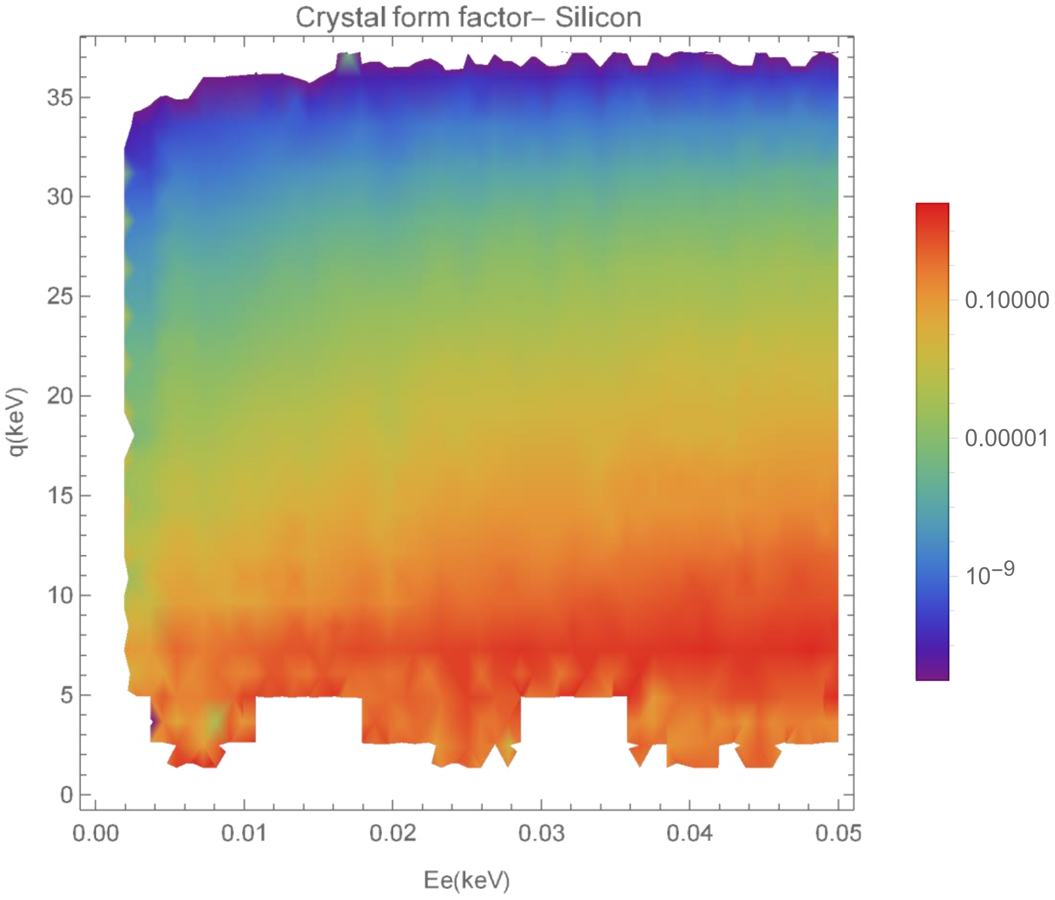
Ionization Form factor for Germanium and Xenon



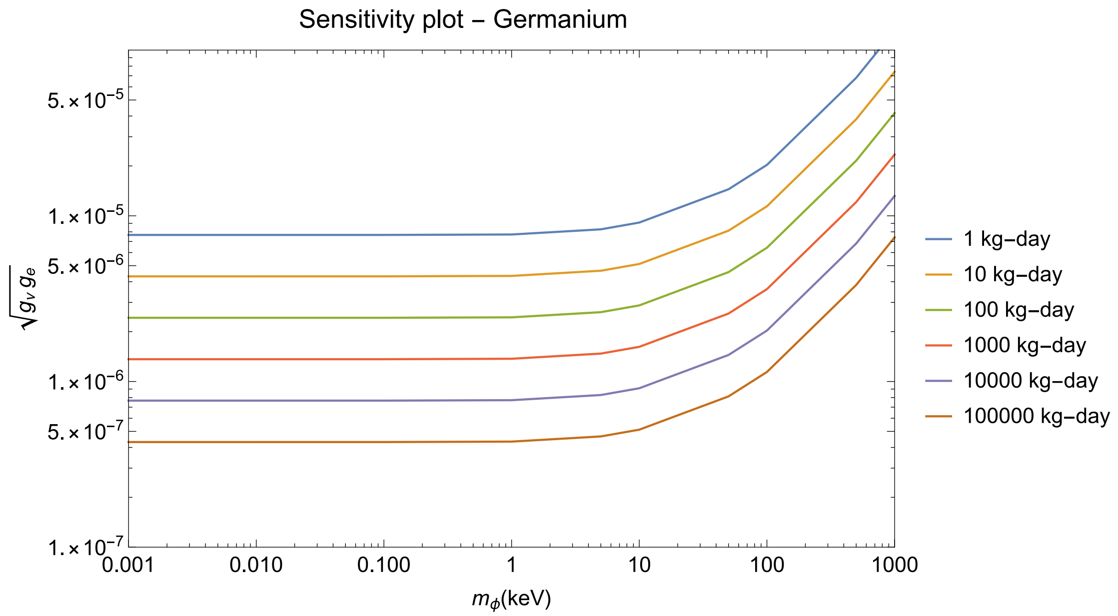


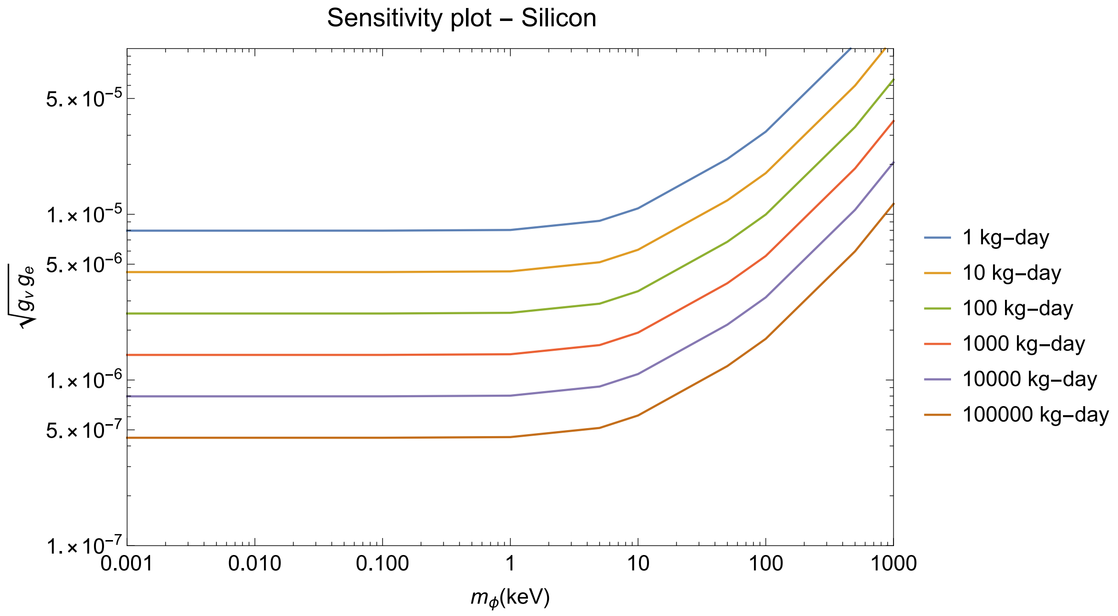
Crystal Form factor for Germanium and Xenon

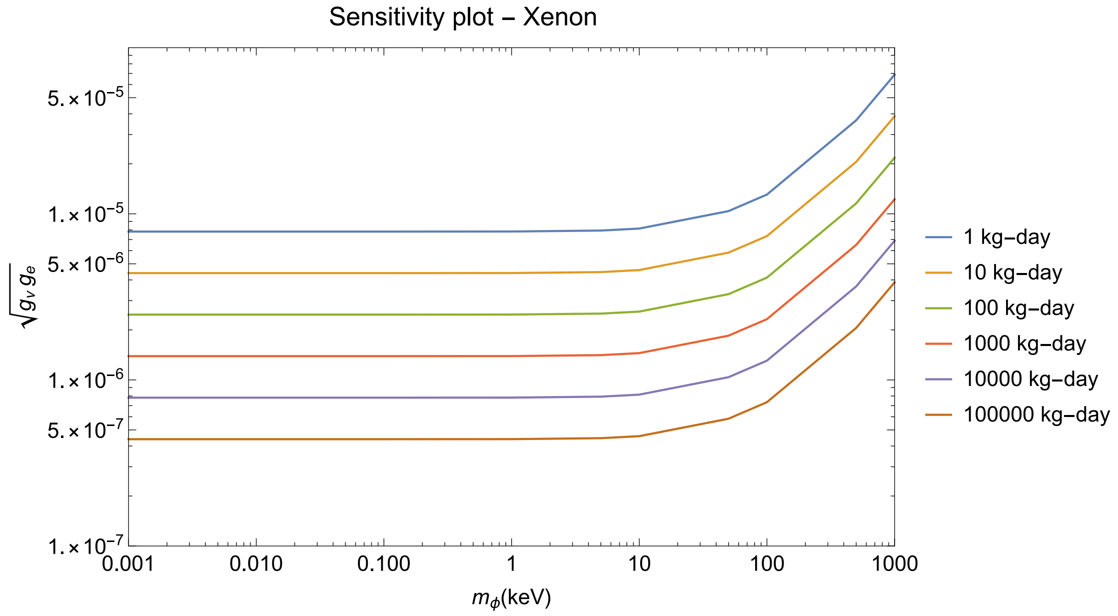




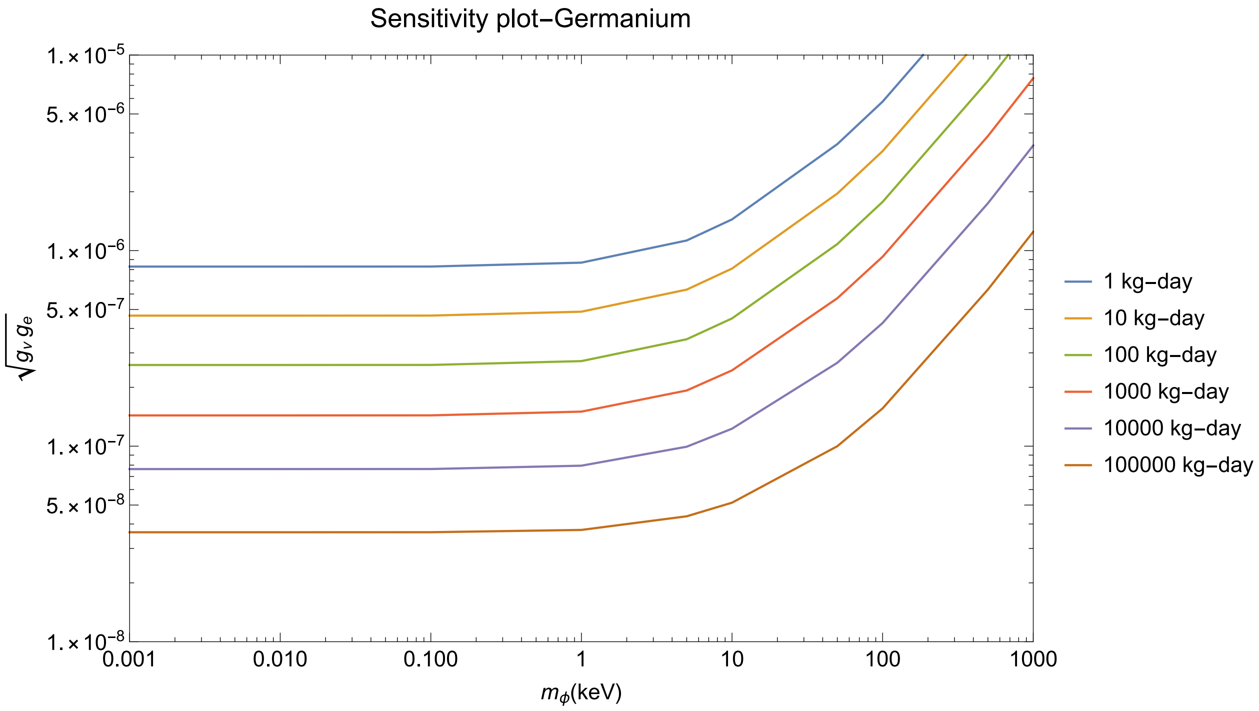
Sensitivity plots for scalar mediator(using formfactor)

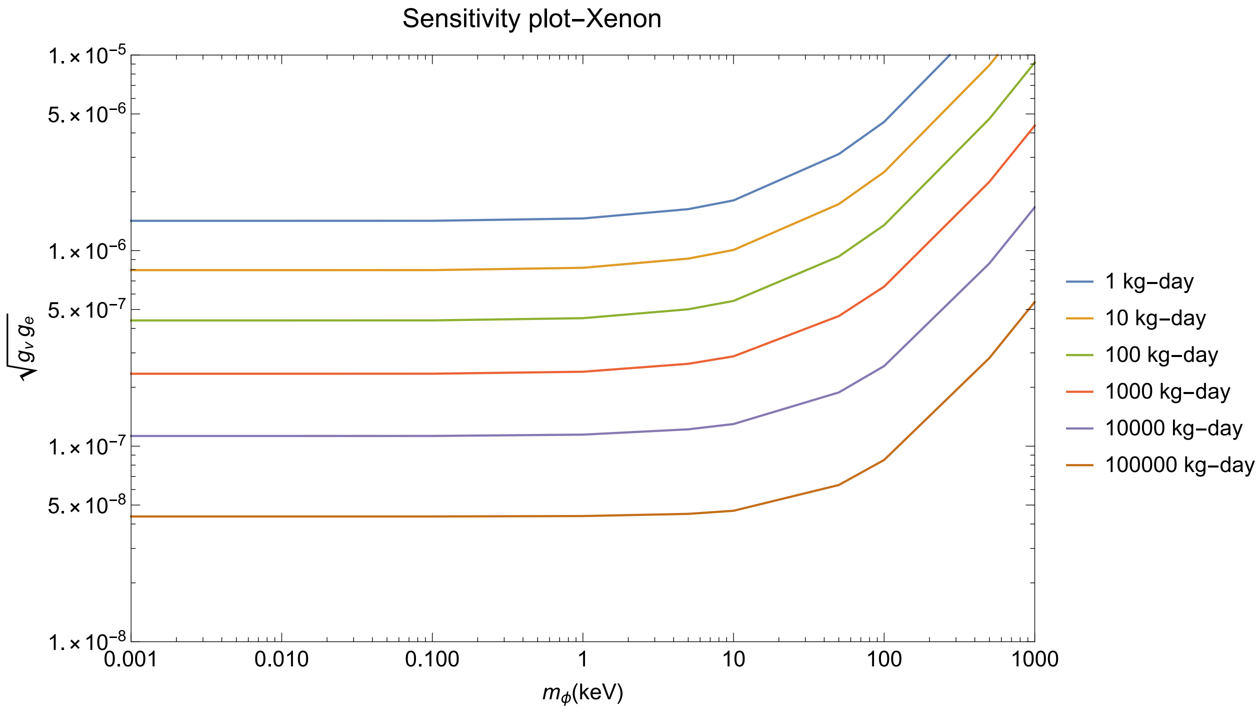




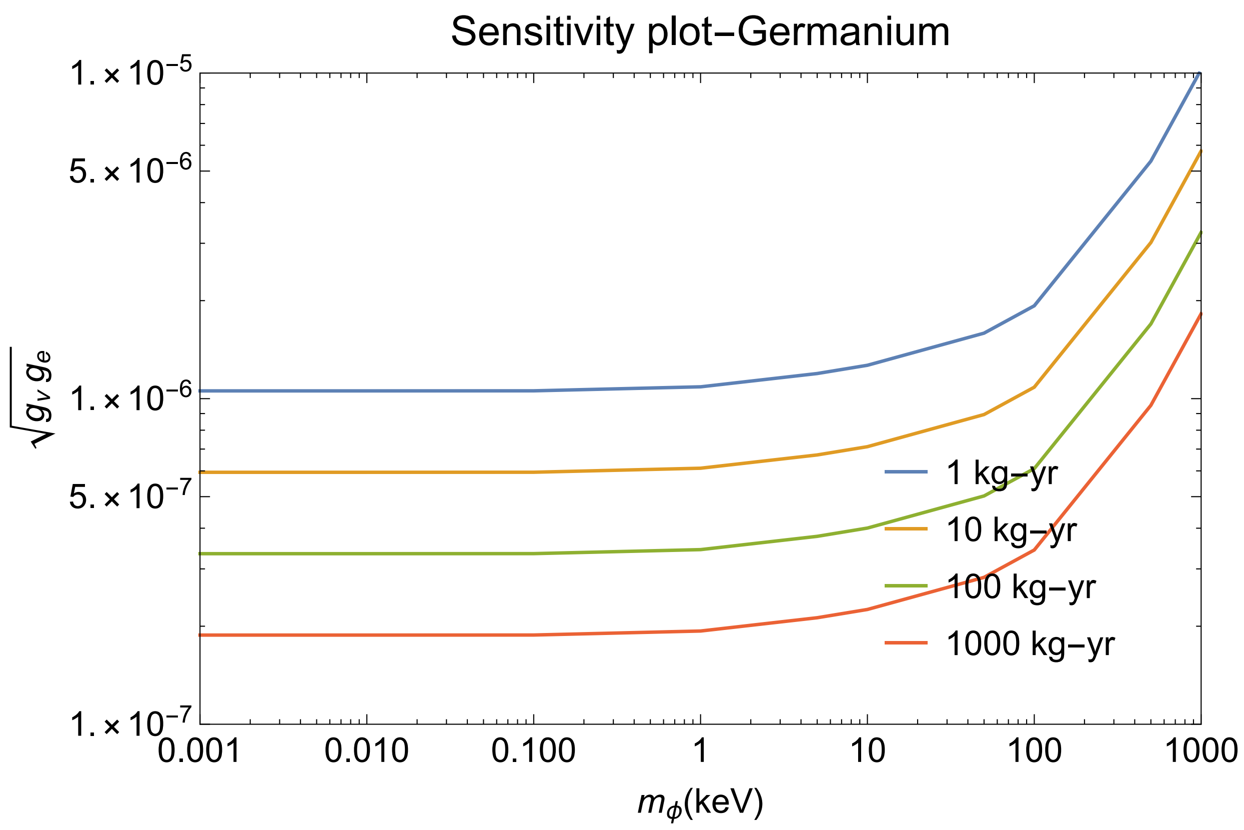


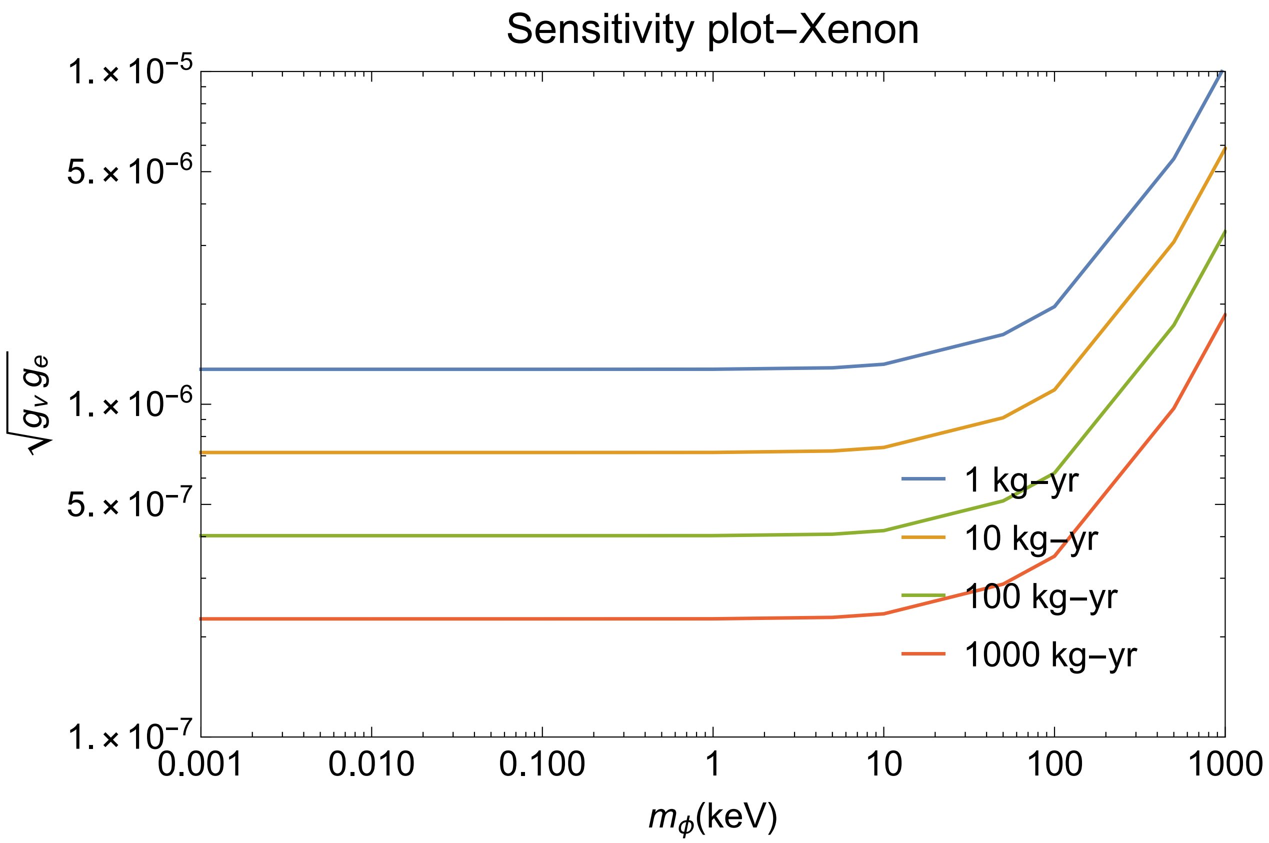
Sensitivity plots for vector mediator(using formfactor)



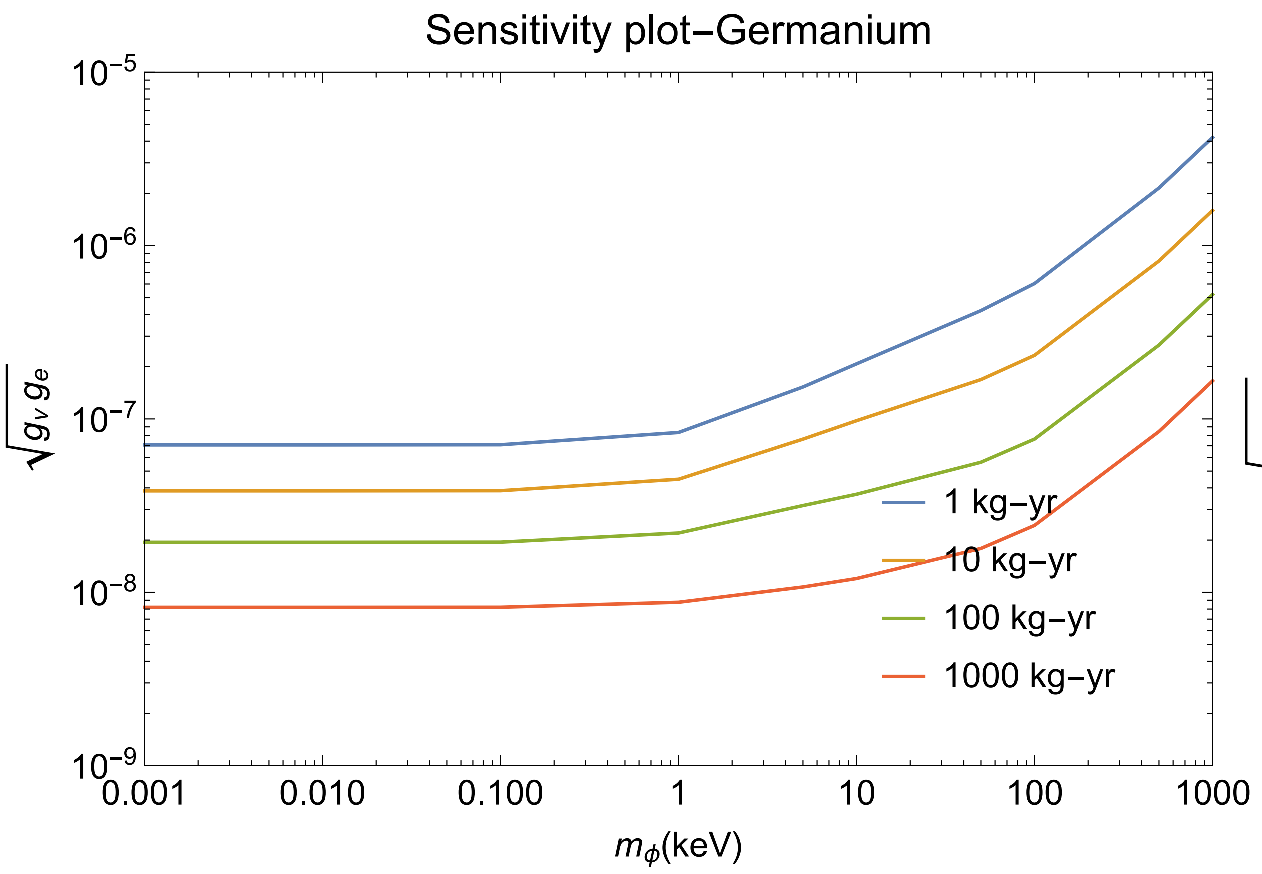


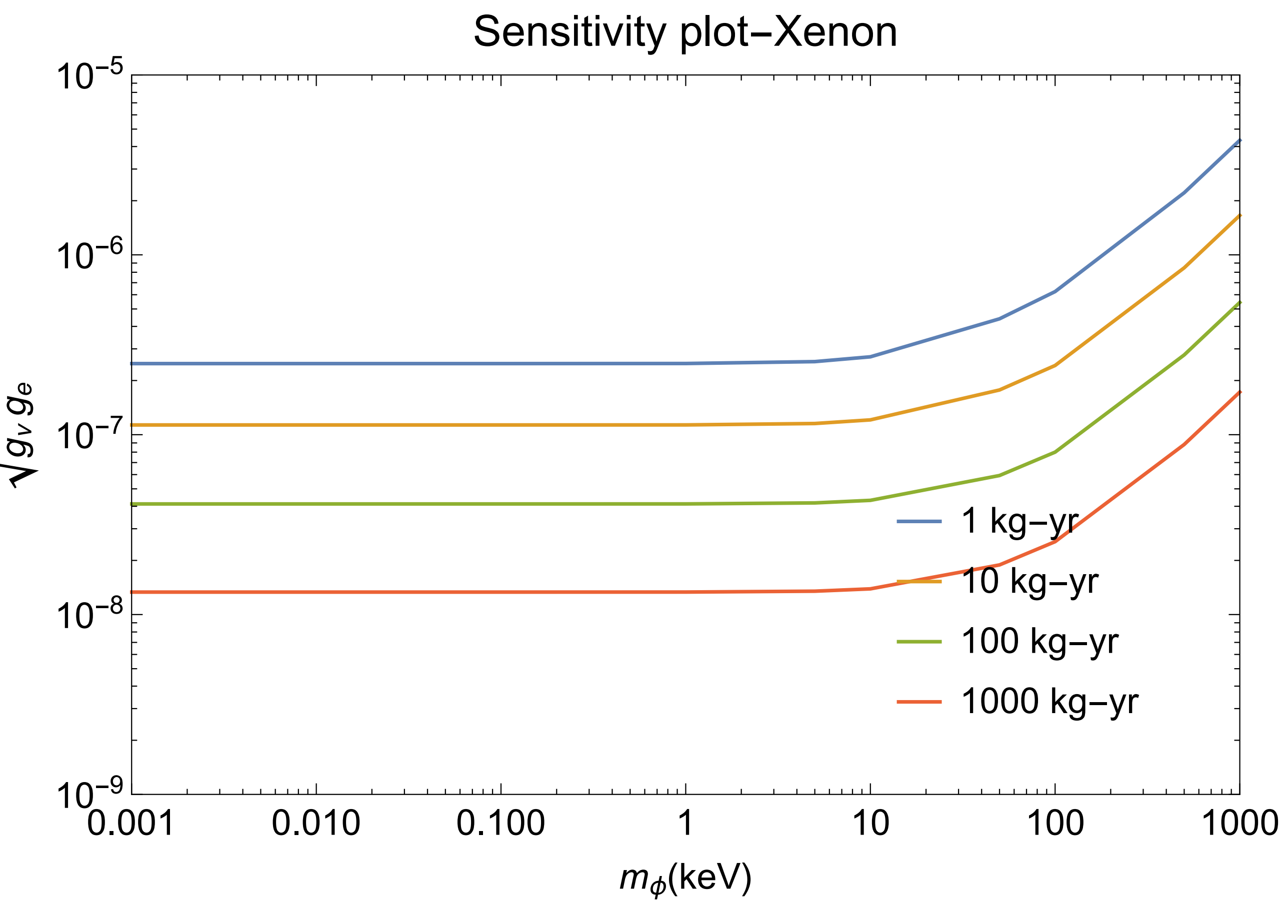
Sensitivity plots for scalar mediator(FEA)



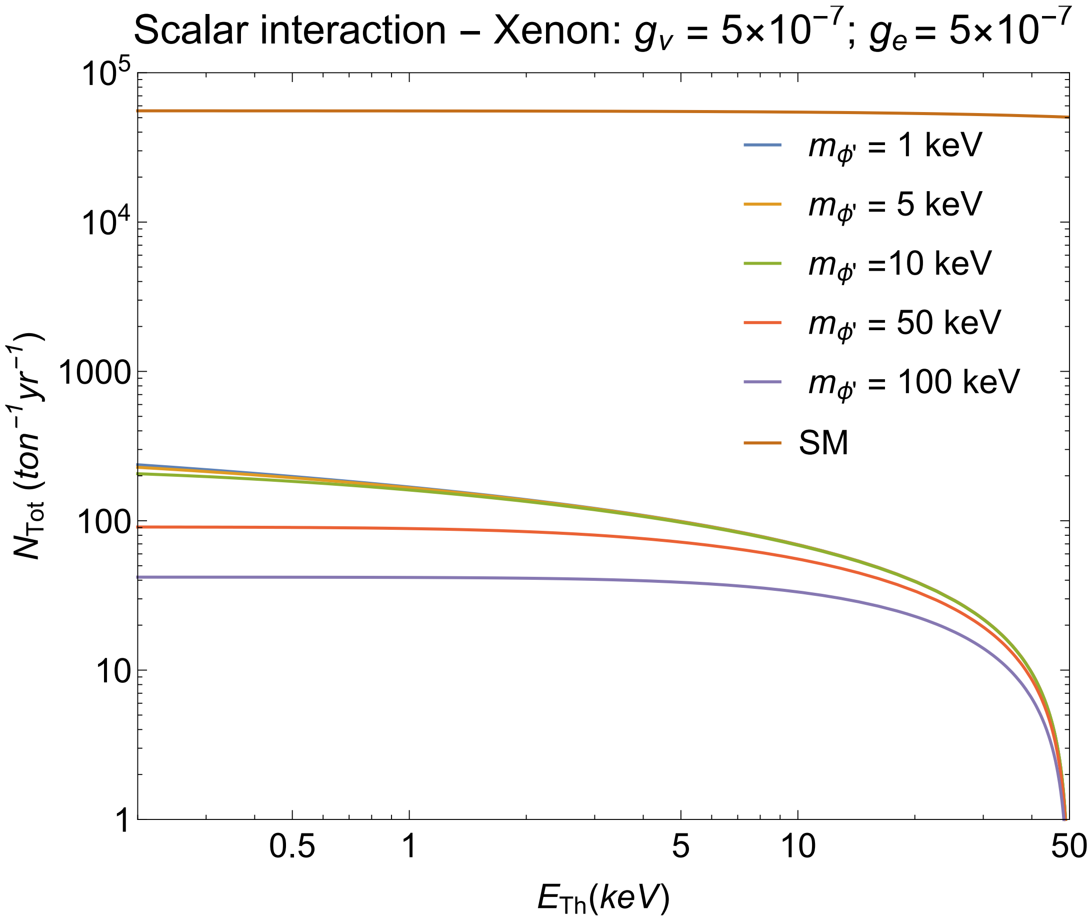


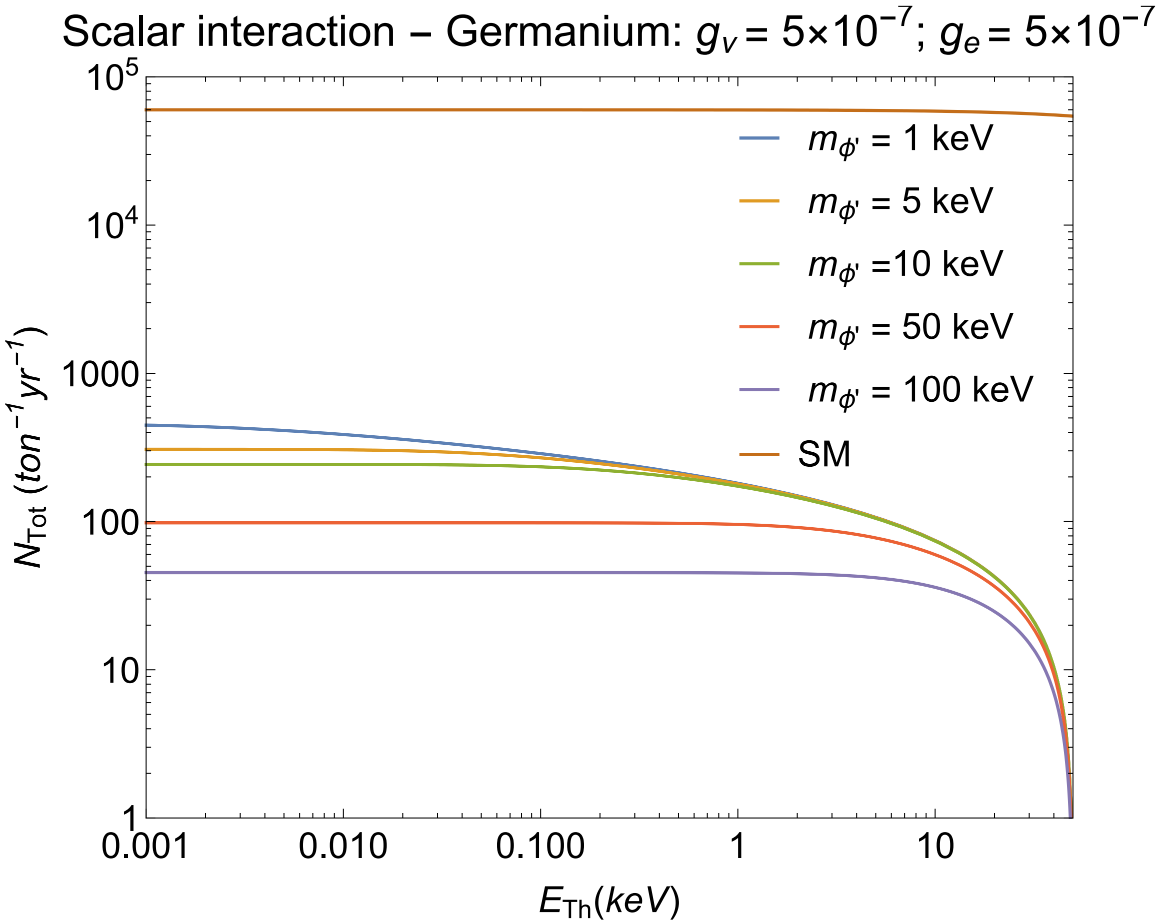
Sensitivity plots for vector mediator(FEA)





Electron recoil integrated rates as a function of Experimental Threshold energy (FEA)





Electron recoil integrated rates as a function of Experimental Threshold energy (FEA)