Dark Matter Stimulated Double Beta Decay

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Seesaw models and small ν mass

Neutrino oscillations imply that neutrinos have a mass.
To accommodate a neutrino mass, **new fermions N_R should exist**
N_R are singlets of the SM gauge groups
Beyond-SM Lagrangian terms can be considered (Seesaw models)

N_R kinetic term

Majoron Φ kinetic and potential terms

$$\mathcal{L} = \mathcal{L}_{\mathcal{SM}} + \boxed{i\overline{N}_R\gamma^\mu\partial_\mu N_R} + \boxed{\left(\partial_\mu\phi\right)^\dagger\left(\partial^\mu\phi\right) - V(\phi)}$$
$$\boxed{-\,y_j\bar{l}^j_L H N_R} - \boxed{\frac{\lambda}{2}\overline{N}^c_R\phi N_R +} h.c.$$

Higgs vev provides
Dirac mass *m* to ν

Majoron vev provides
Majorana mass *M* to ν

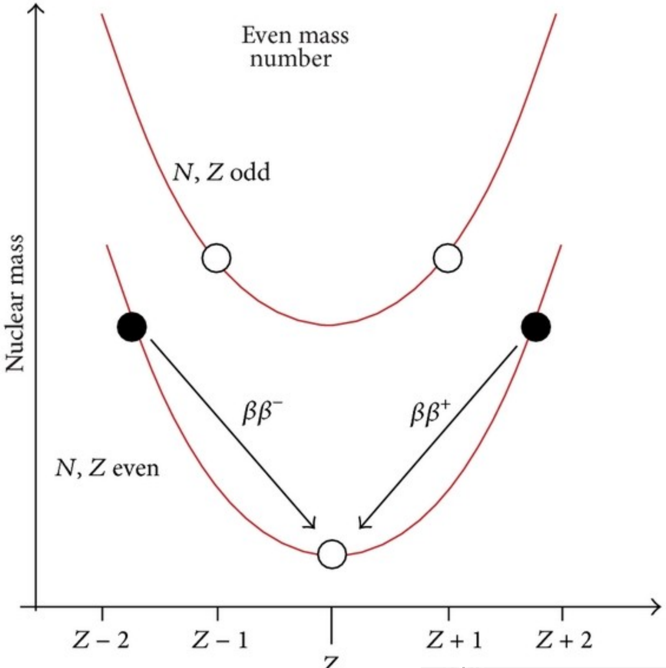
$$M^{\mathrm{D+Mj}} = \begin{pmatrix} 0 & m \\ m & M \end{pmatrix};\ \nu'_L = \begin{pmatrix} \nu_L \\ (N_R)^c \end{pmatrix}$$

$$m_1 = -\frac{M}{2} + \frac{1}{2}\sqrt{M^2 + 4\,m^2} \simeq \frac{m^2}{M} \ll m$$ Light “active” ν

$$m_2 = \frac{M}{2} + \frac{1}{2}\sqrt{M^2 + 4\,m^2} \simeq M$$ Heavy “sterile” ν

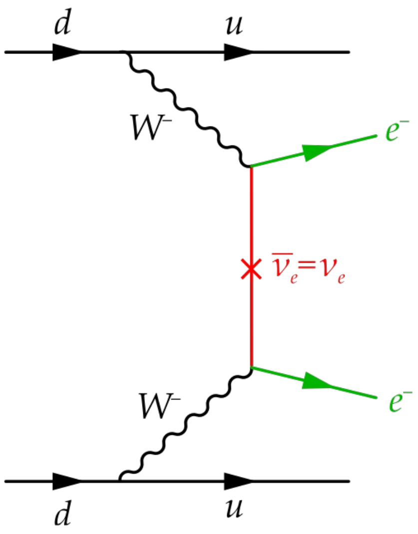
-Seesaw naturally provides the smallness of active neutrino masses
-Seesaw could provide a mechanism for Baryon asymmetry in the Universe
-Seesaw can accommodate two possible DM candidates: the Majoron and the Sterile Neutrino
-**Neutrinoless Double Beta Decay 0νββ is allowed by this model**

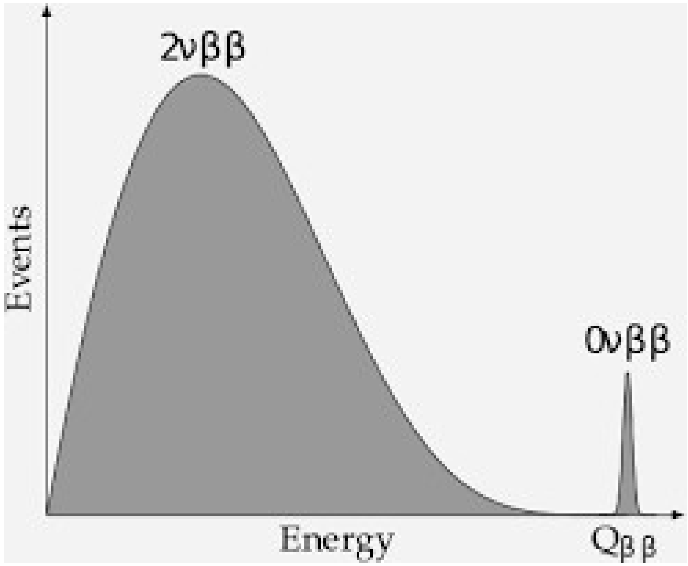
(neutrinoless-) Double Beta Decay



Double Beta Decay is a 2nd order process allowed by SM
Nuclei that can ββ-decay are long-living
For some nuclei Q-values are in the 2-3 MeV range

Neutrinoless ββ-decay is forbidden in the SM
0νββ violates Leptonic number
0νββ imply neutrino majorana nature



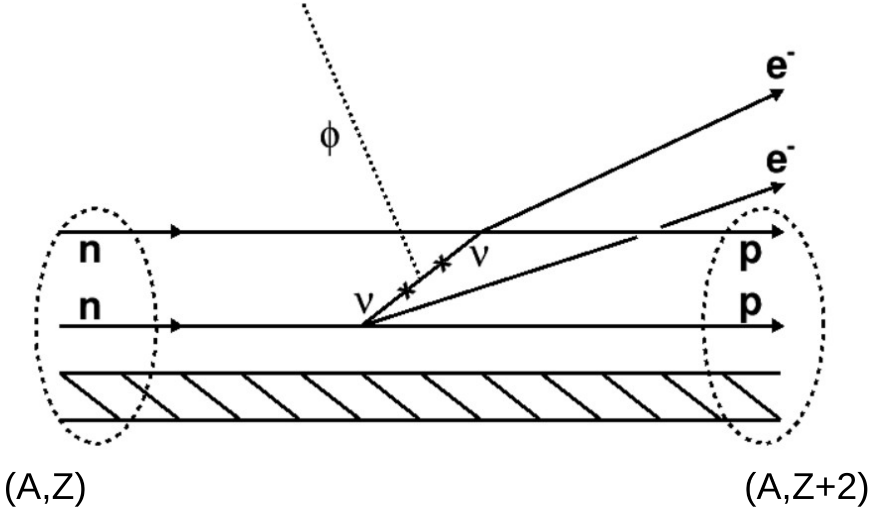


Electron spectrum for the two processes is very different.

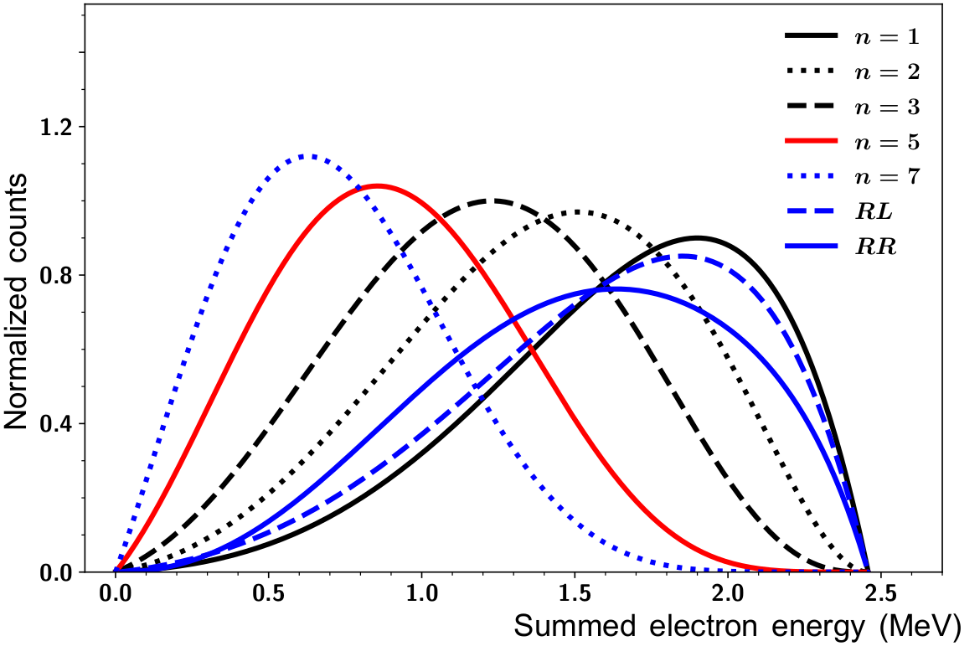
0νββM neutrinoless ββ decay with Majoron emission

0νββM:

if M_{Φ} < Q-value a Majoron Φ can be radiated



Spectrum of detected energy for 0νββM in ^{136}Xe (assuming massless Φ for different spectral index *n*)



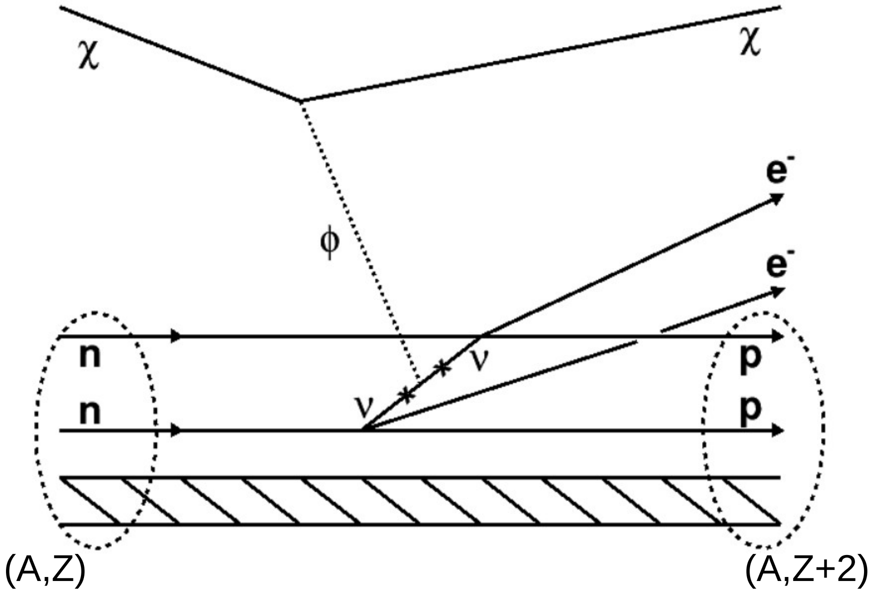
$$\frac{dN}{dK} \sim G \sim (Q_{\beta\beta} - K)^n$$

Spectrum of detected energy is model dependent.
The shape is dominated by *n* that is the spectral index of the phase space factor.
In some models 2 Majorons can be simult. emitted.

This process is investigated in current experiments, **exp. lower limits to partial half-lifes exist**.

(DM-0$\nu\beta\beta$) DM stimulated neutrinoless $\beta\beta$ decay

A sterile neutrino or other DM particle χ could stimulate 0$\nu\beta\beta$ decay mediated by a Majoron



Also other diagrams are possible in principle, moreover other Majorana fermion DM candidates beyond sterile neutrino are also possible (e.g. SUSY Neutralino, Axino, Gravitino …)

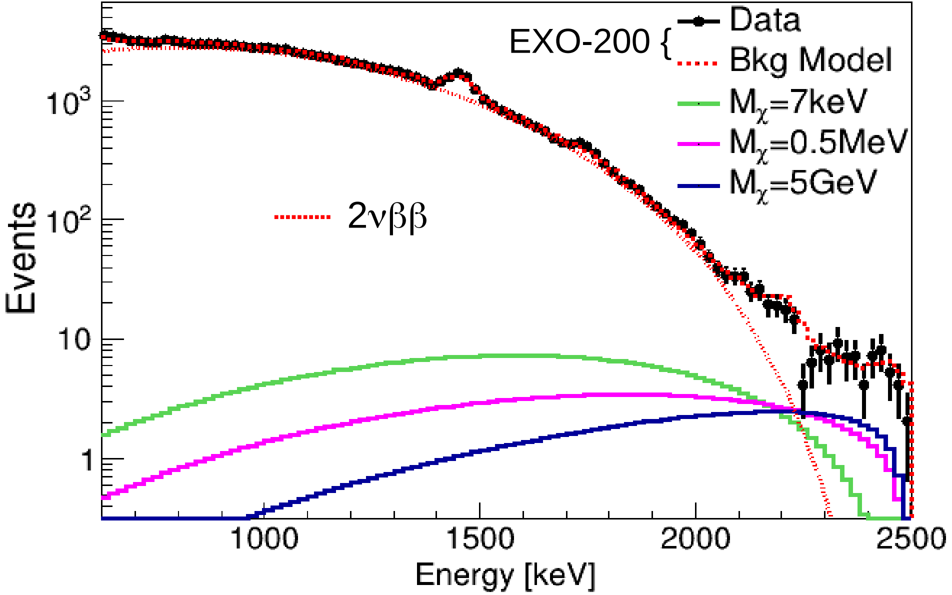
T_{fi} is model dependent: we assume a constant value and we focus on the phase space factor.

$$d\Gamma = \frac{|T_{fi}|^2}{4\pi^2\hbar}\frac{d^3P_1}{(2\pi)^3}\frac{d^3P_2}{(2\pi)^3}\frac{d^3P_\chi}{(2\pi)^3}\delta(K_1+K_2+K_\chi-Q)$$

Spectrum of detected energy depends on M_χ because the DM is upscattering removing energy

Example of expected distributions for ^{136}Xe:

Data points: Phys. Rev. D 104, 112002 (2021)



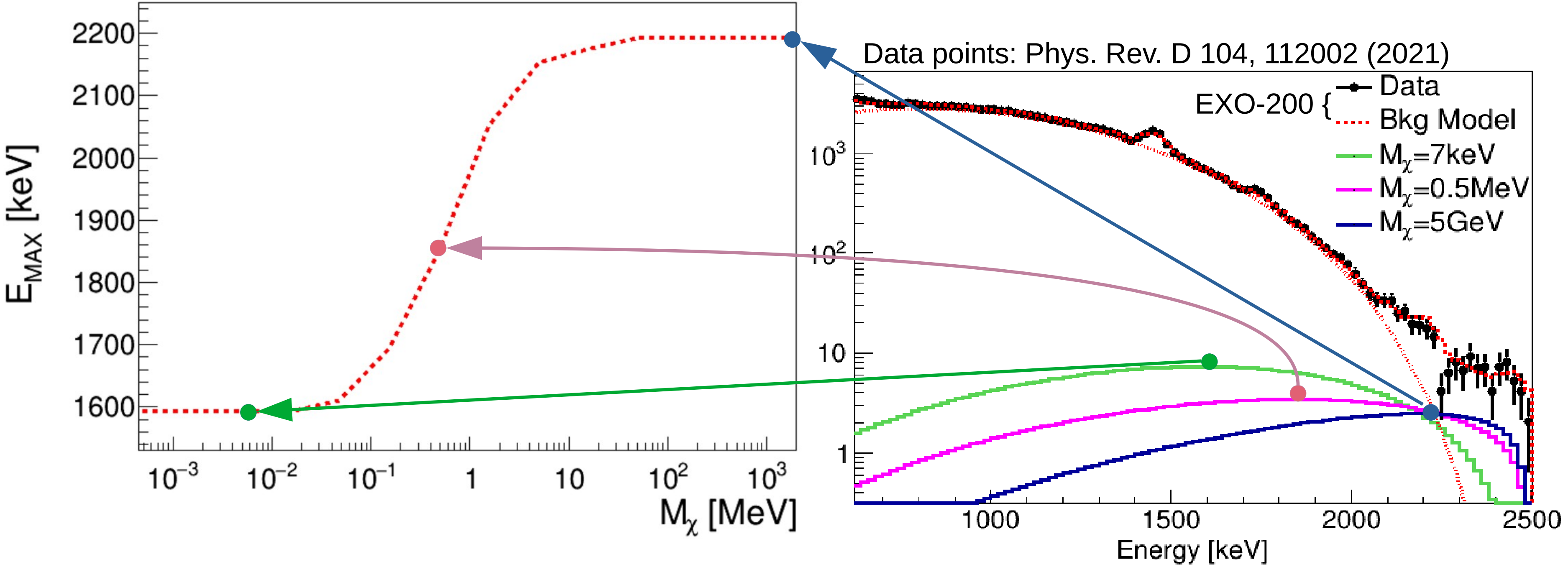
for $M_\chi \ll m_e$ the spectrum is similar to n=2 0$\nu\beta\beta$M
for $M_\chi = m_e$ the spectrum is similar to n=1 0$\nu\beta\beta$M
for $M_\chi \gg m_e$ the spectrum is harder than 0$\nu\beta\beta$M
The spectrum is very different from 0$\nu\beta\beta$ and 2$\nu\beta\beta$

(DM-0$\nu\beta\beta$) sensibility to DM mass measurement

The maximum of electrons sum-energy distribution increases with M_χ

Spectrum of detected energy depends on M_χ because the DM is upscattering removing energy

Example of expected distributions for ^{136}Xe:



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-A direct measurement of M_χ could be feasible (in principle) for 100keV – 10MeV DM particles

-Also DM with very low mass could be detected

for $M_\chi \ll m_e$ the spectrum is similar to n=2 0$\nu\beta\beta$M
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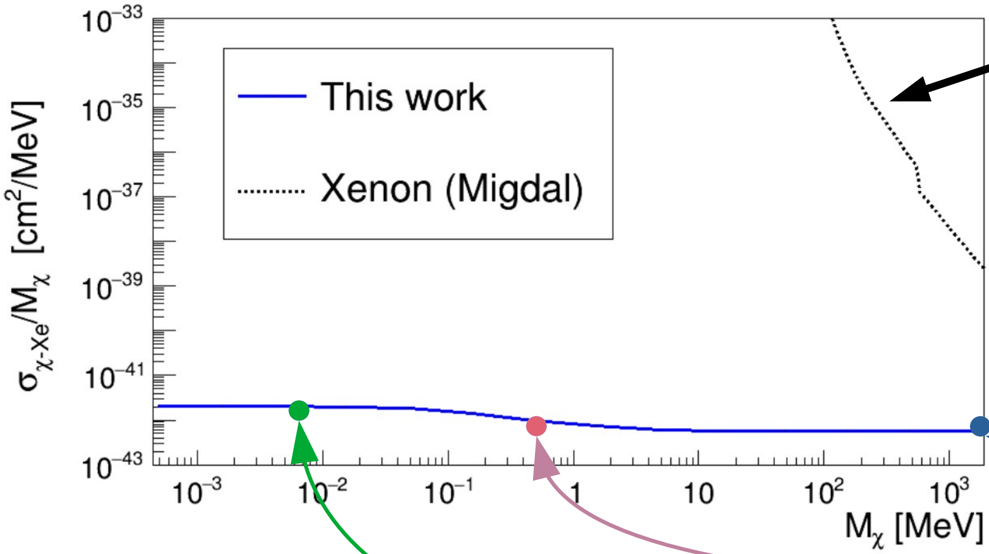
The spectrum is very different from 0$\nu\beta\beta$ and 2$\nu\beta\beta$

(DM-0νββ) DM-nucleus scattering cross-section limits



Existing limits from DM elastic scattering (Migdal “shake-off” effect in recoiling nucleus) Xenon-1T PRL 123, 241803 (2019)

Cross section upper limits obtained comparing the expected distributions with EXO-200 Phase-II data (116.7kg x d) and their bkg model:

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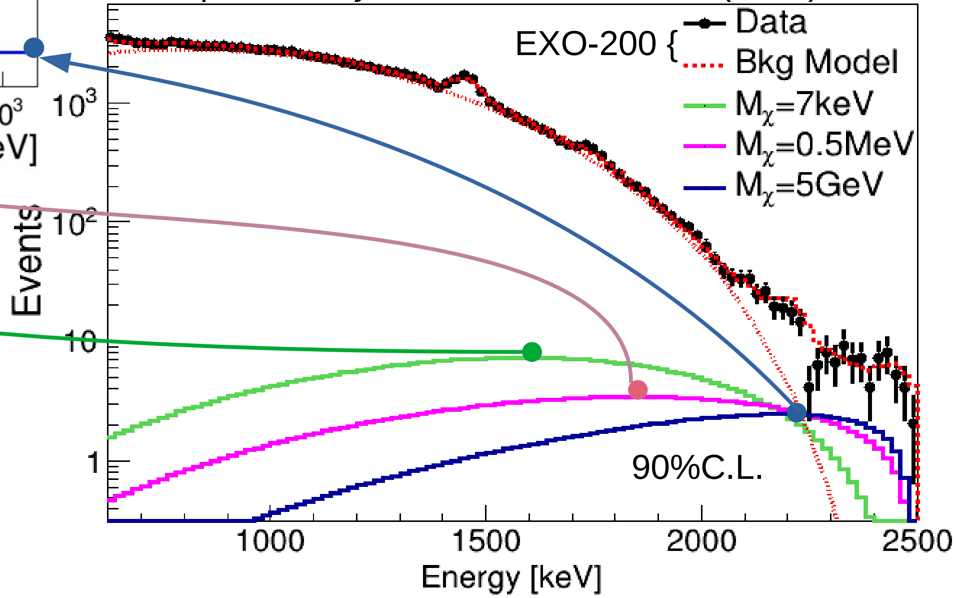


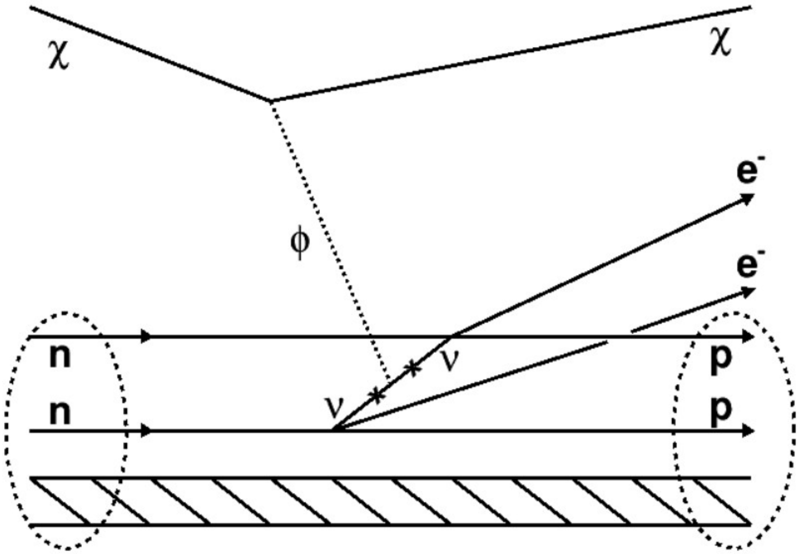
$$\sigma_{\chi-Xe} < \frac{M_\chi}{v_{DM}\,\rho_{DM}}\,\frac{N_{limit}}{T_{\exp}\,N^{det}_{nuclei}}$$

This is a promising technique to investigate low mass fermionic DM (like the possible 7.1keV sterile neutrino)

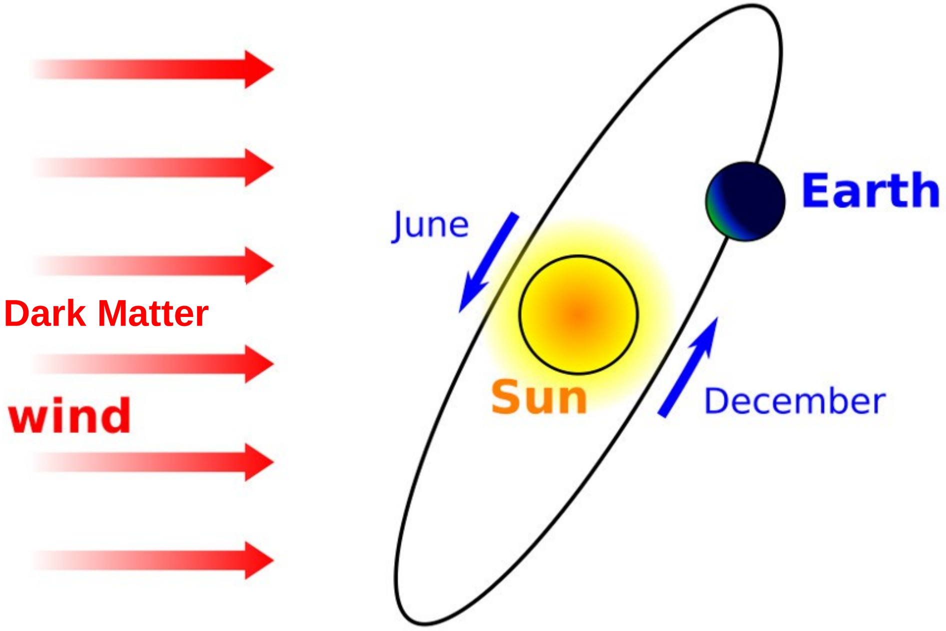
Upper limits to the spectrum of the DM-0νββ are very similar to the one for n=1,2 0νββM

Comparison and disentangle DM-$0\nu\beta\beta$ from $0\nu\beta\beta$M

-$0\nu\beta\beta$M decay requires light Majorons
-DM-$0\nu\beta\beta$ is possible also for heavy Majorons



-$0\nu\beta\beta$M decay is not dependent on DM flux
-for DM-$0\nu\beta\beta$ the annual modulation is expected



CONCLUSIONS:

- **A new signature to investigate light fermionic DM is proposed**
- **A detailed analysis in terms of neutrino & Majoron couplings will be addressed in future works**
- **Thank you for the attention**