

A novel approach for the direct detection of light Dark Matter using 2β decay experiments

F. Nozzoli

INFN/TIFPA - Trento University



Trento Institute for
Fundamental Physics
and Applications

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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)

$$\mathcal{L} = \mathcal{L}_{SM} + i\overline{N}_R \gamma^\mu \partial_\mu N_R + (\partial_\mu \phi)^\dagger (\partial^\mu \phi) - V(\phi)$$

$$- y_j \bar{l}_L^j H N_R - \frac{\lambda}{2} \overline{N}_R^c \phi N_R + h.c.$$

N_R kinetic term Majoron ϕ kinetic and potential terms
 Higgs vev provides Dirac mass m to ν Majoron vev provides Majorana mass M to ν

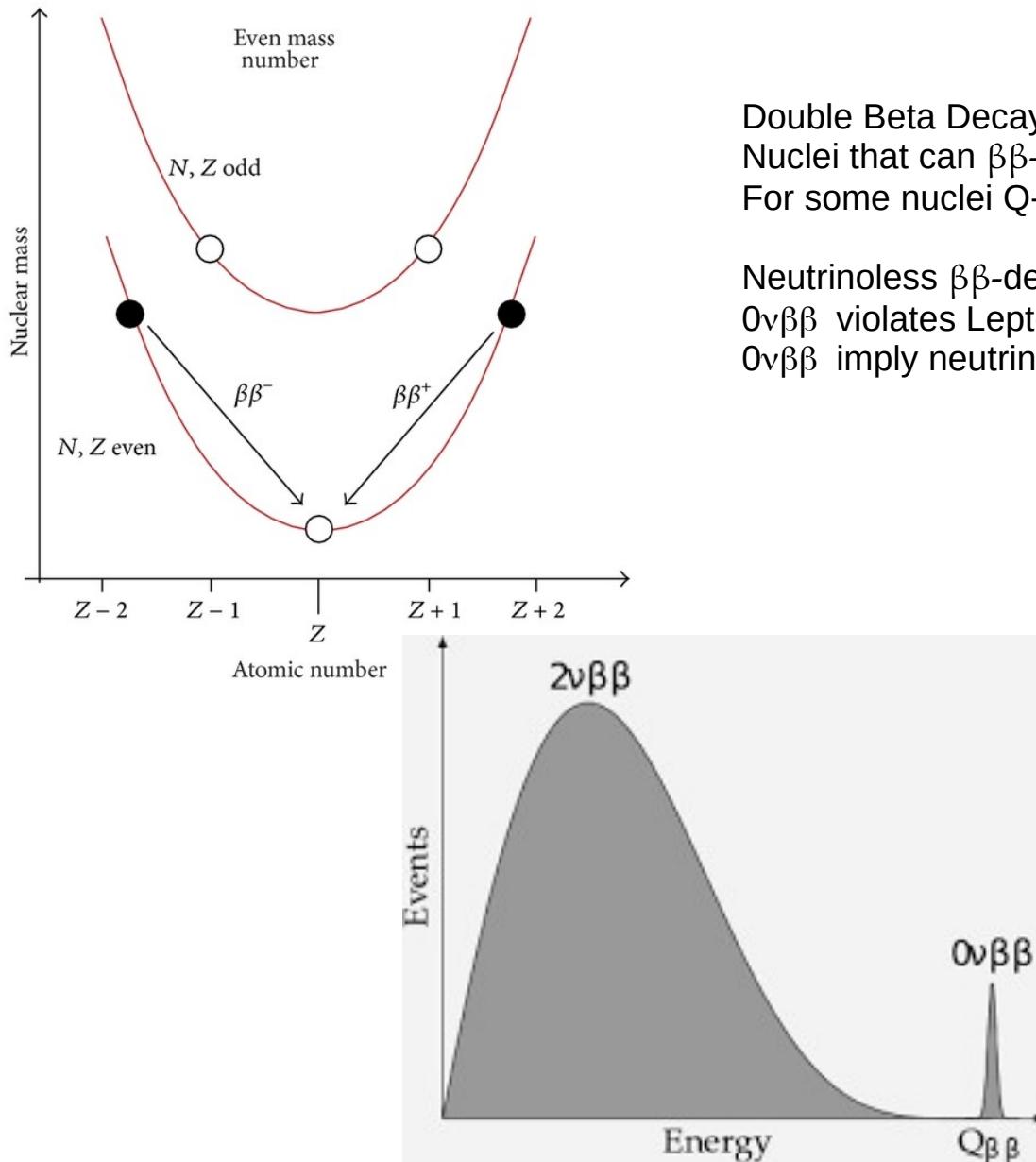
$$M^{D+Mj} = \begin{pmatrix} 0 & m \\ m & M \end{pmatrix}; \quad \nu'_L = \begin{pmatrix} \nu_L \\ (N_R)^c \end{pmatrix}$$

$$m_1 = -\frac{M}{2} + \frac{1}{2} \sqrt{M^2 + 4m^2} \simeq \frac{m^2}{M} \ll m \quad \text{Light "active" } \nu$$

$$m_2 = \frac{M}{2} + \frac{1}{2} \sqrt{M^2 + 4m^2} \simeq M \quad \text{Heavy "sterile" } \nu$$

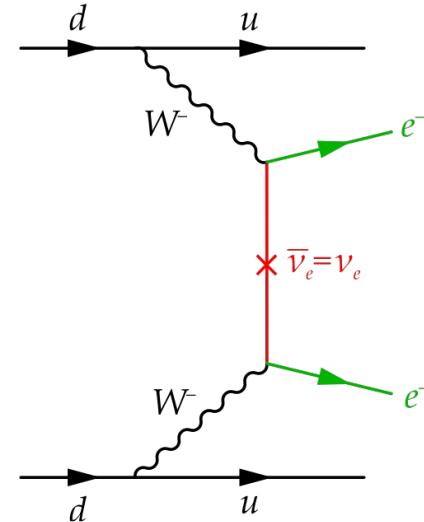
- Seesaw naturally provides the smallness of active neutrino masses
- Seesaw could provide a mechanism for Baryon asymmetry in the Universe
- Seesaw can accommodate two possible DM candidates: the Majoron and the Sterile Neutrino
- Neutrinoless Double Beta Decay $0\nu\beta\beta$ is allowed by this model**

(neutrinoless-) Double Beta Decay



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

Neutrinoless $\beta\beta$ -decay is forbidden in the SM
 $0\nu\beta\beta$ violates Leptonic number
 $0\nu\beta\beta$ imply neutrino majorana nature

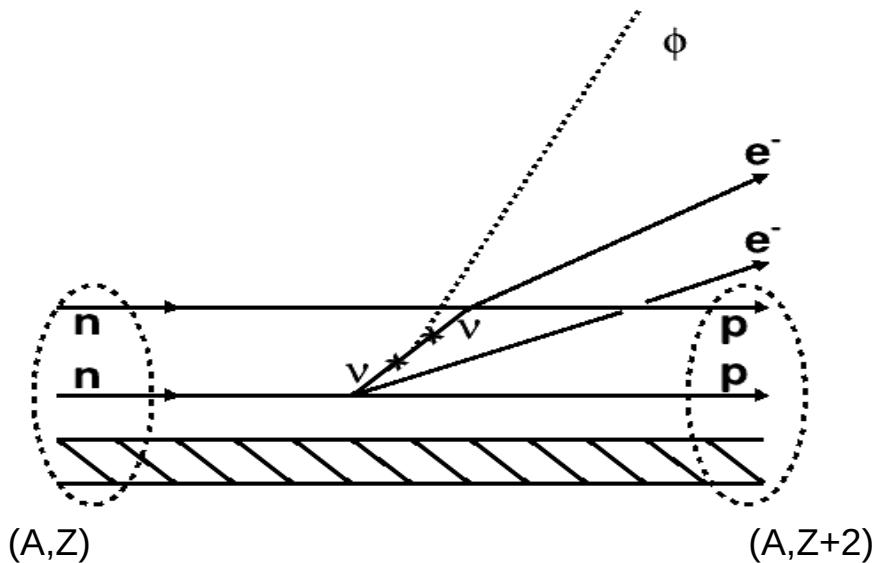


Electron spectrum for the two processes is very different.

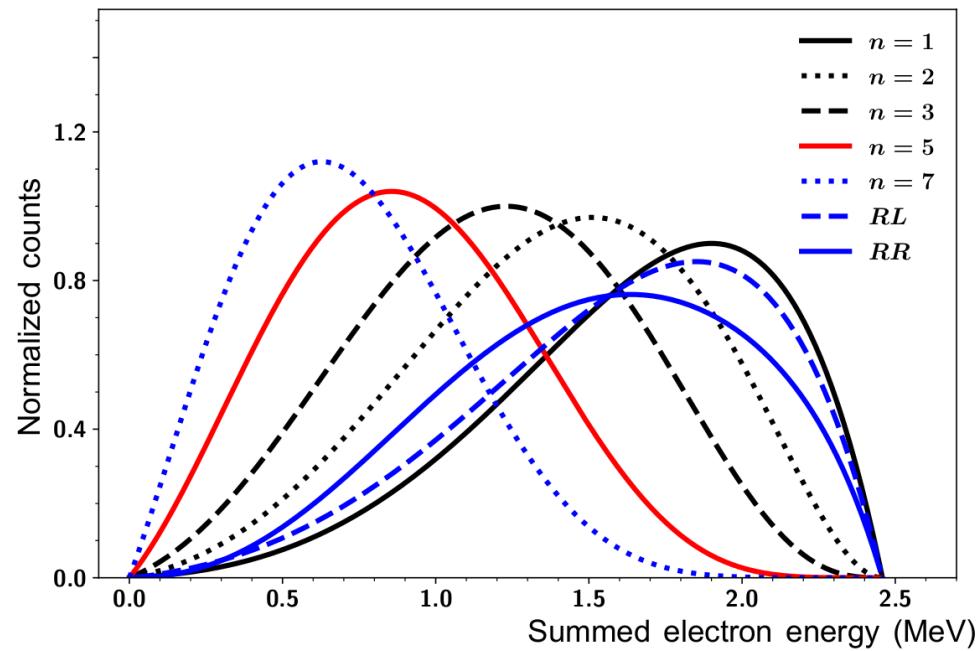
$0\nu\beta\beta M$ neutrinoless $\beta\beta$ decay with Majoron emission

$0\nu\beta\beta M$:

if $M_\phi < Q$ -value a Majoron Φ can be radiated



Spectrum of detected energy for $0\nu\beta\beta M$ in ^{136}Xe (assuming massless Φ for different spectral index n)



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

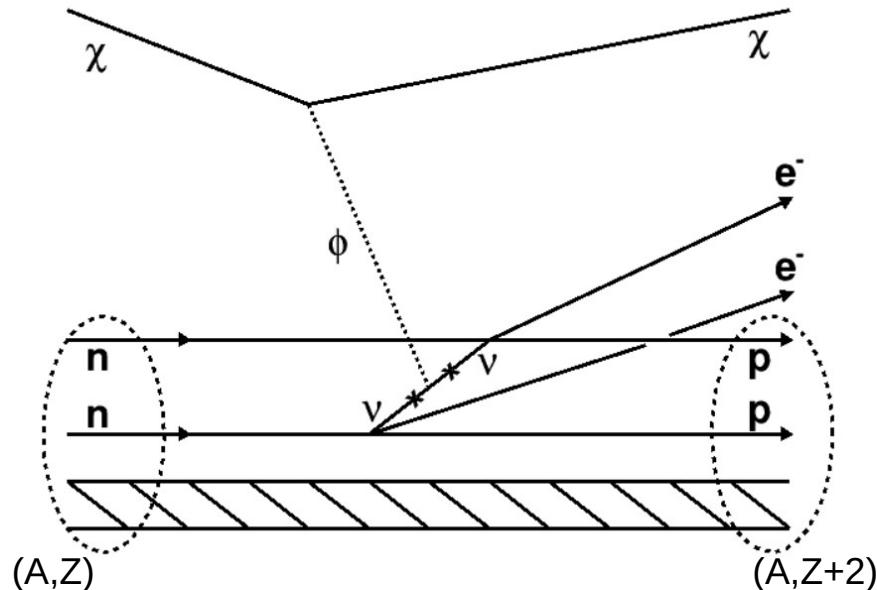
Spectrum of detected energy is model dependent.
The shape is dominated by n that is the spectral index of the phase space factor.

In some models 2Majorons simultaneously emitted.

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

(DM-0νββ) DM stimulated neutrinoless ββ decay

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



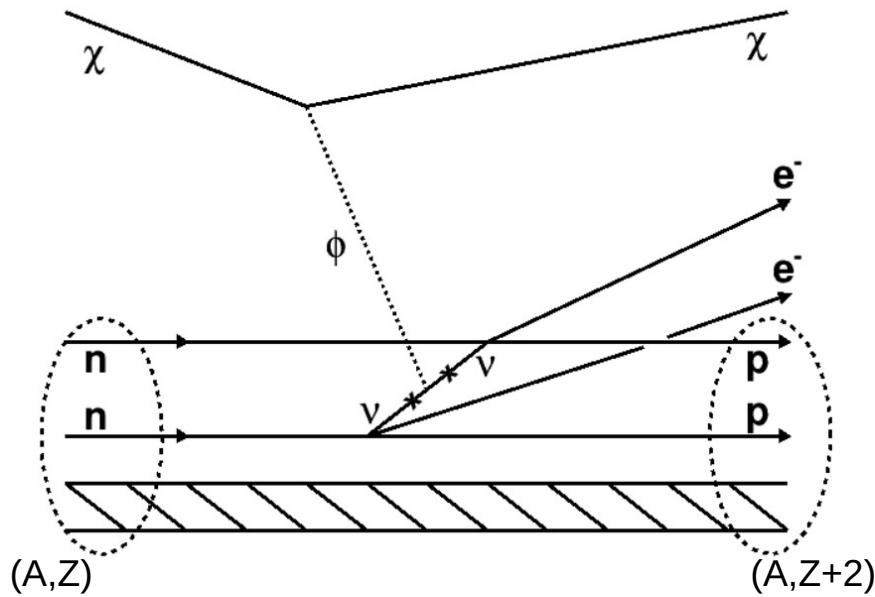
Also other diagrams are possible in principle,
moreover other Majorana fermion DM candidates
beyond sterile neutrino are also possible
(e.g. SUSY Neutralino, Axino, Gravitino ...)

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

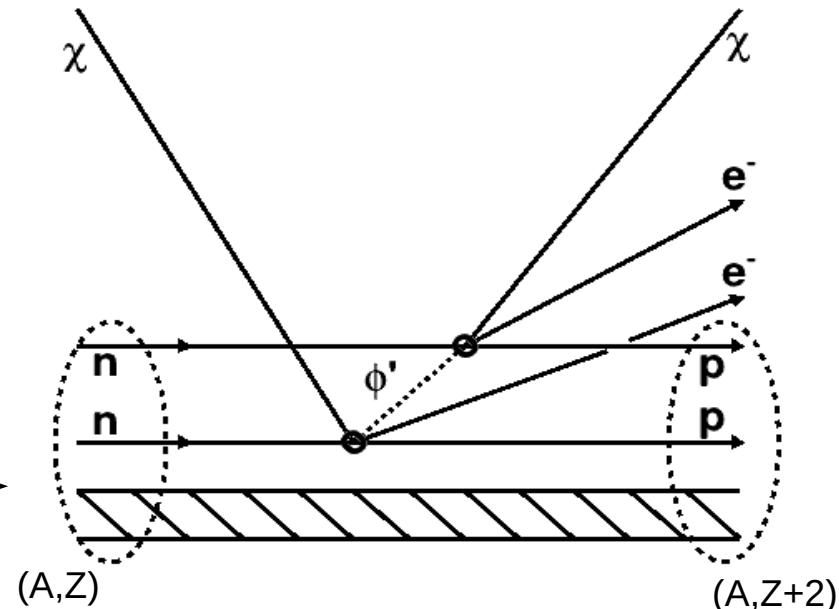
T_{fi} is model dependent: we assume a constant value and we focus on the phase space factor.

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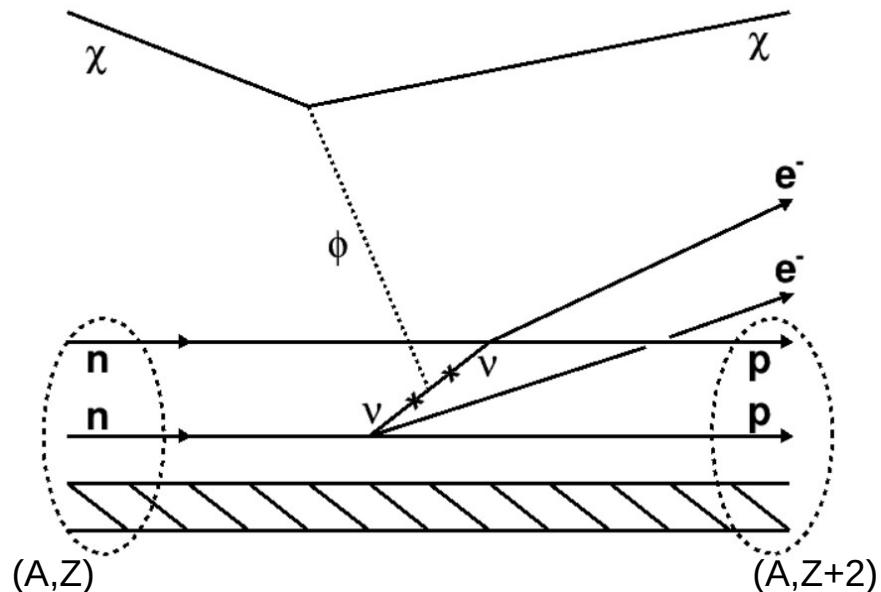
**These processes are possible also if Φ or Φ'
masses are much larger than decay Q-value**

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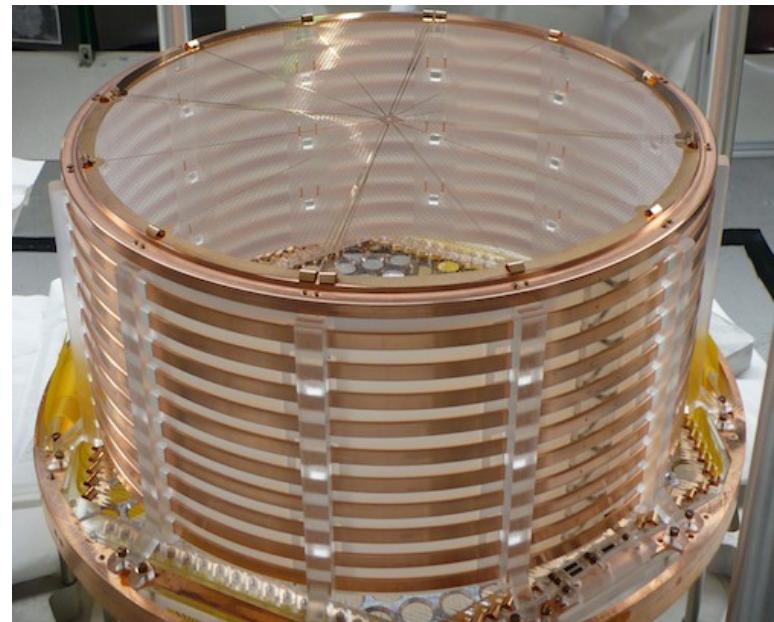
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T_{fi} is model dependent: we assume a constant value and we focus on the phase space factor.

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

Can be investigated in existing experiments:

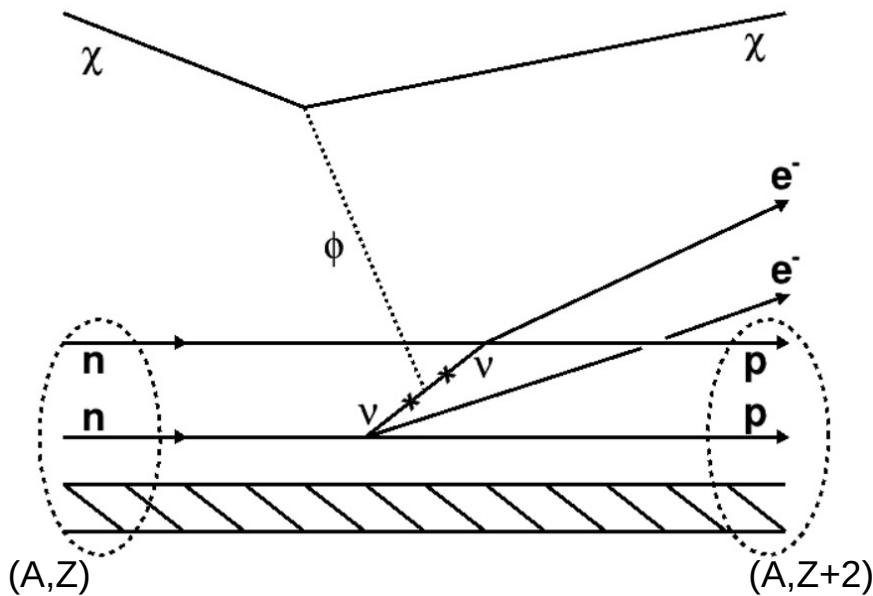
Example: Phys. Rev. D 104, 112002 (2021)
Enriched Xenon Observatory (EXO-200 @ WIPP):



200 kg of liquid Xenon (TPC) enriched (80%) in ^{136}Xe , contained in a class-100 cleanroom located 650m underground at WIPP Lab. (New Mexico)

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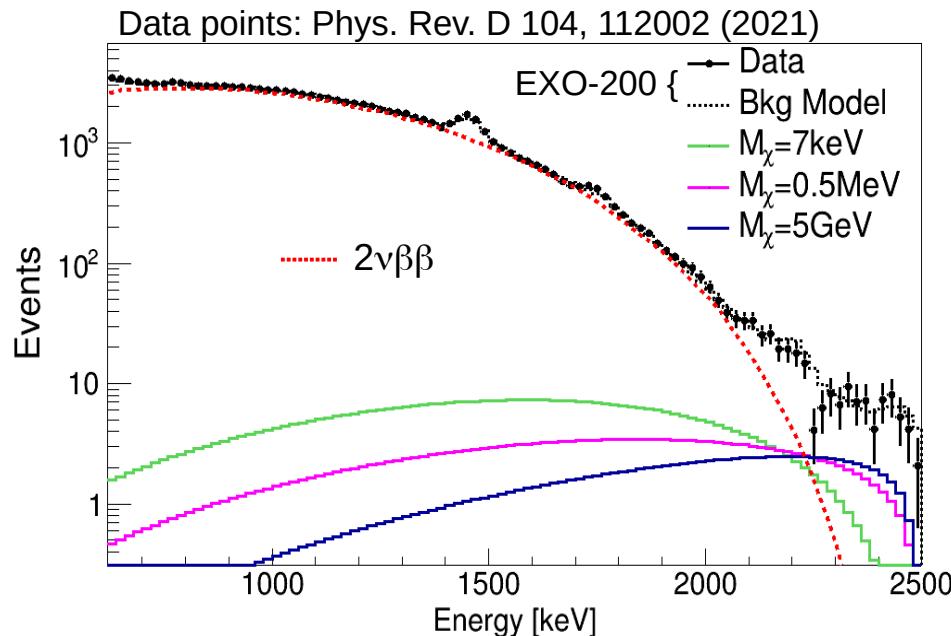
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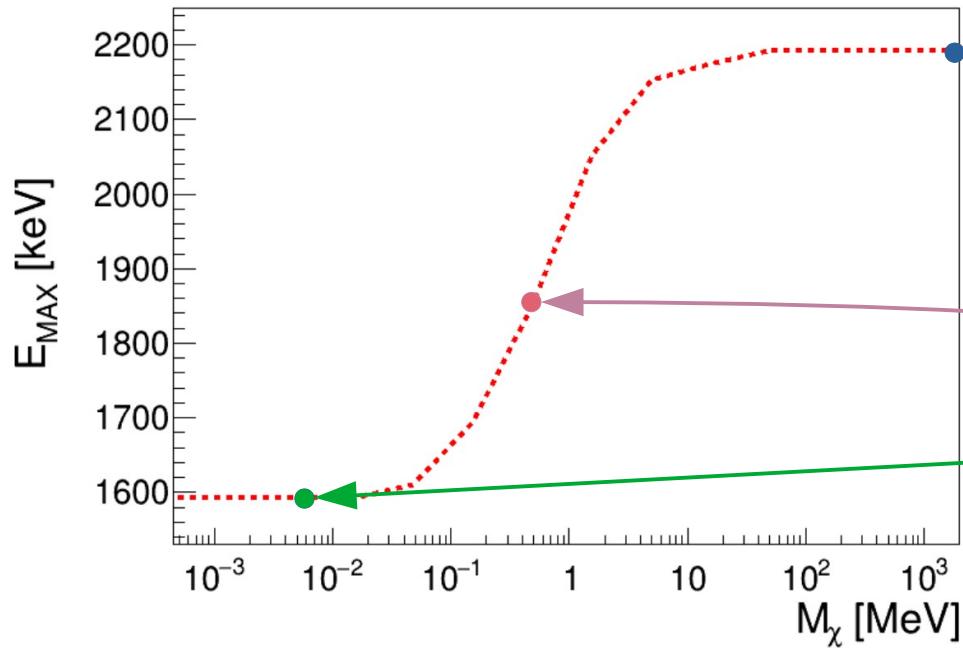
Example of expected distributions for ^{136}Xe :



for $M_\chi \ll m_e$ the spectrum is similar to $n=2$ $0\nu\beta\beta$
for $M_\chi = m_e$ the spectrum is similar to $n=1$ $0\nu\beta\beta$
for $M_\chi \gg m_e$ the spectrum is harder than $0\nu\beta\beta$
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

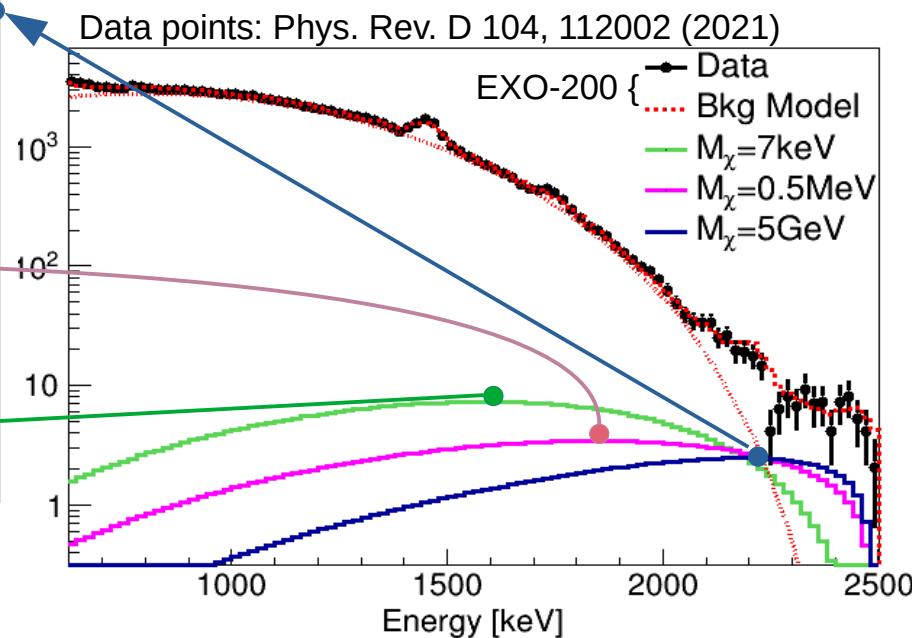
The maximum of electrons sum-energy distribution increases with M_χ



- 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

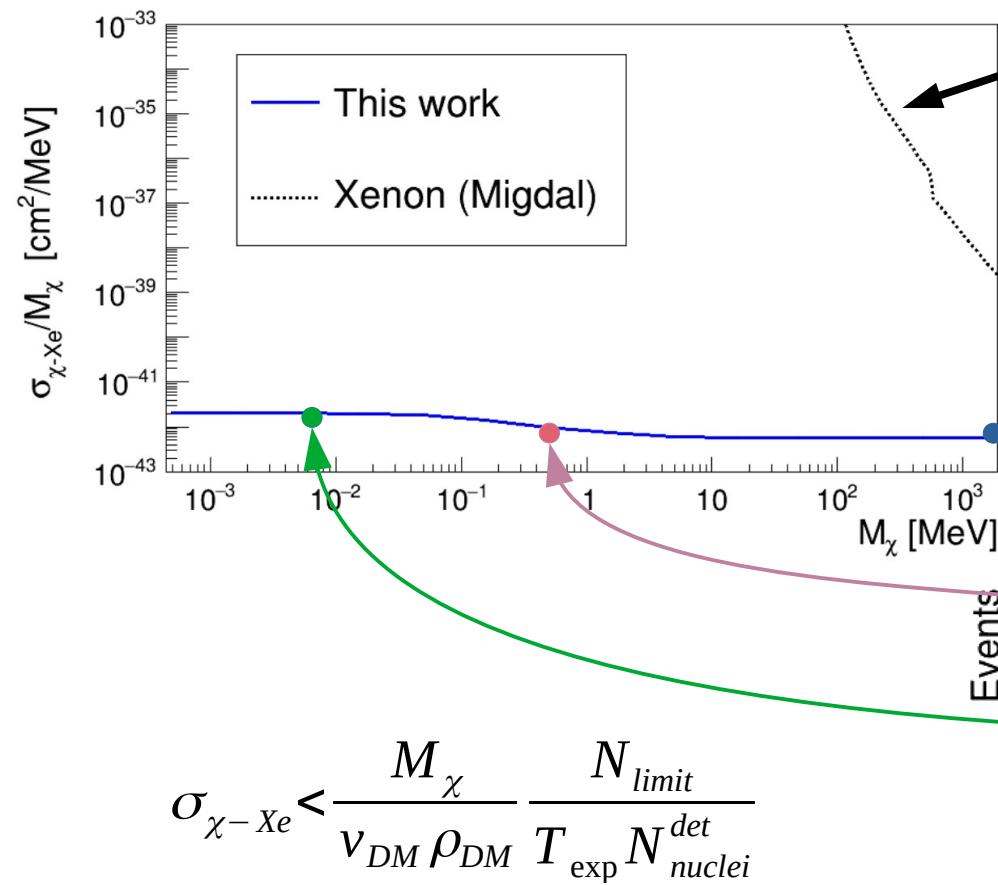
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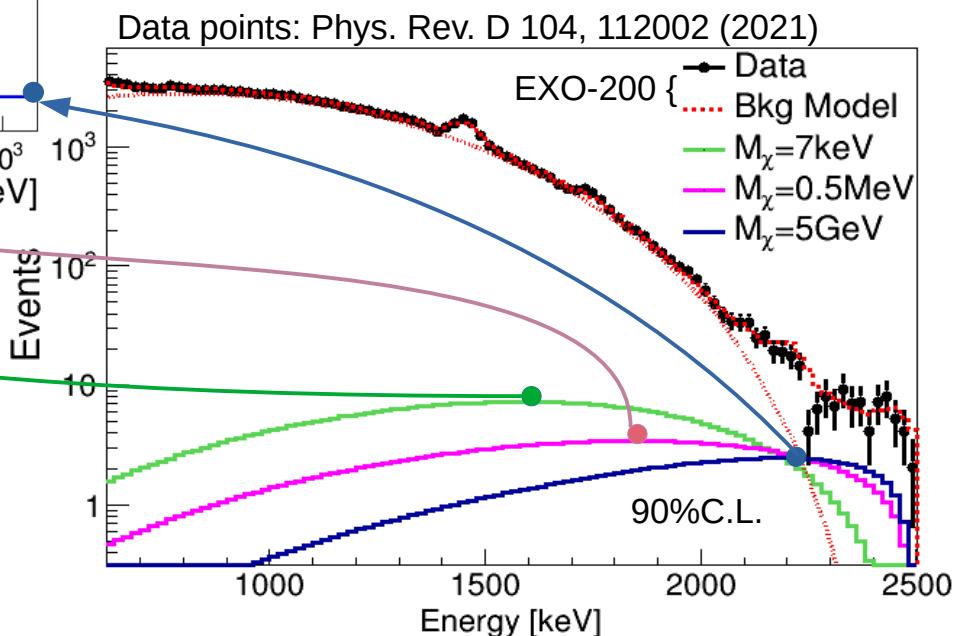
(DM-0νββ) DM-nucleus scattering cross-section limits



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

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

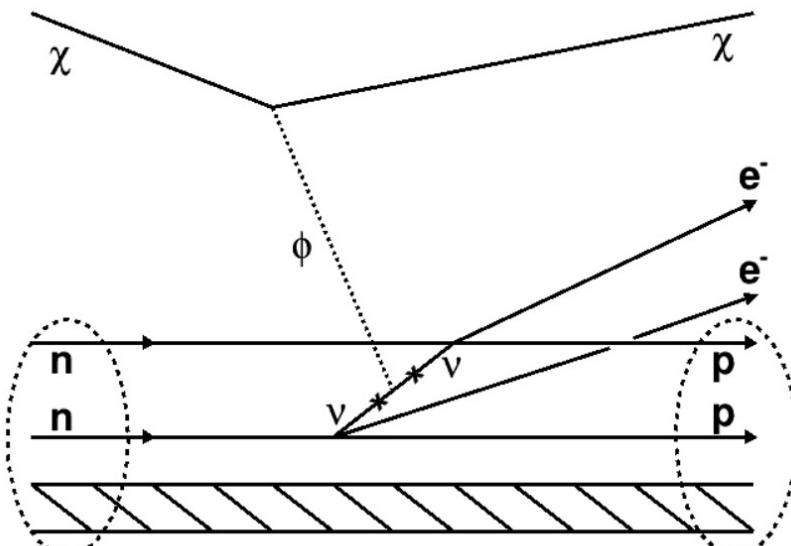
Cross section upper limits obtained comparing the expected distributions with EXO-200 Phase-II data (116.7kg x d) and their bkg model:



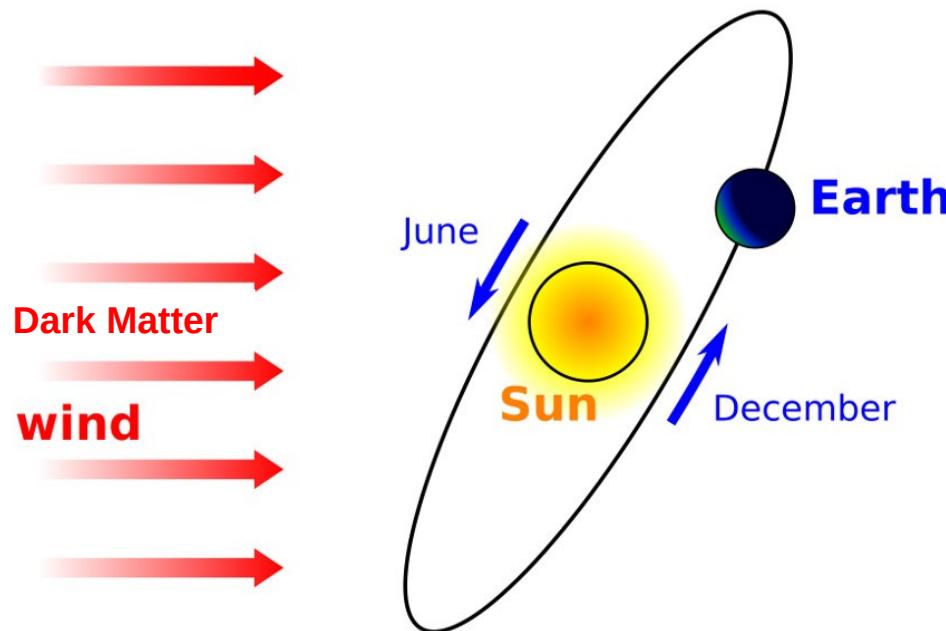
Upper limits to the spectrum of the DM-0νββ are very similar to the one for n=1,2 0νββM

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
(more details in: EPJC 83 (2023) 641)
- A specific analysis in terms of Φ couplings will be addressed in future works

Thank you for the attention