Neutrino spin precession from a majoron background

BNL, Oct 9th, 2025

Matheus Hostert matheus-hostert@uiowa.edu

University of Iowa

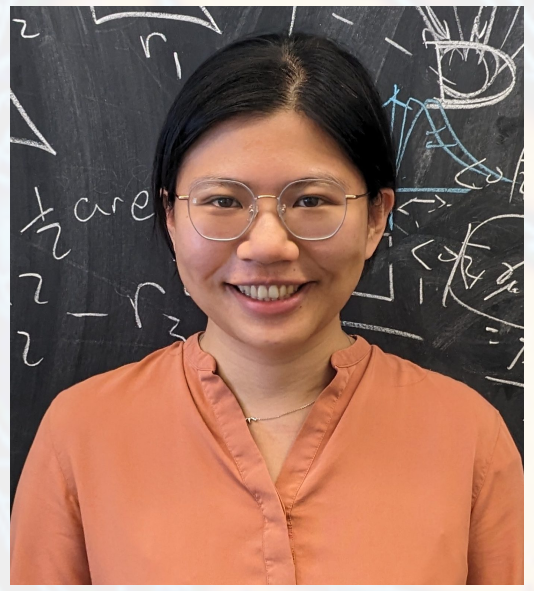
This talk

Neutrino masses and (ultra-light) majorons

Neutrino spin precession in a Majoron background

Solar and Supernova antineutrinos signals

2510.xxxx in collaboration with:
A. Berlin, R. Capdevilla, T. Cheng, P. Machado (FNAL)



STANDARD
MODEL

Incompleteness problems:

Neutrino masses and mixing

Dark matter

Predictivity problems:

No CP violation in strong force?

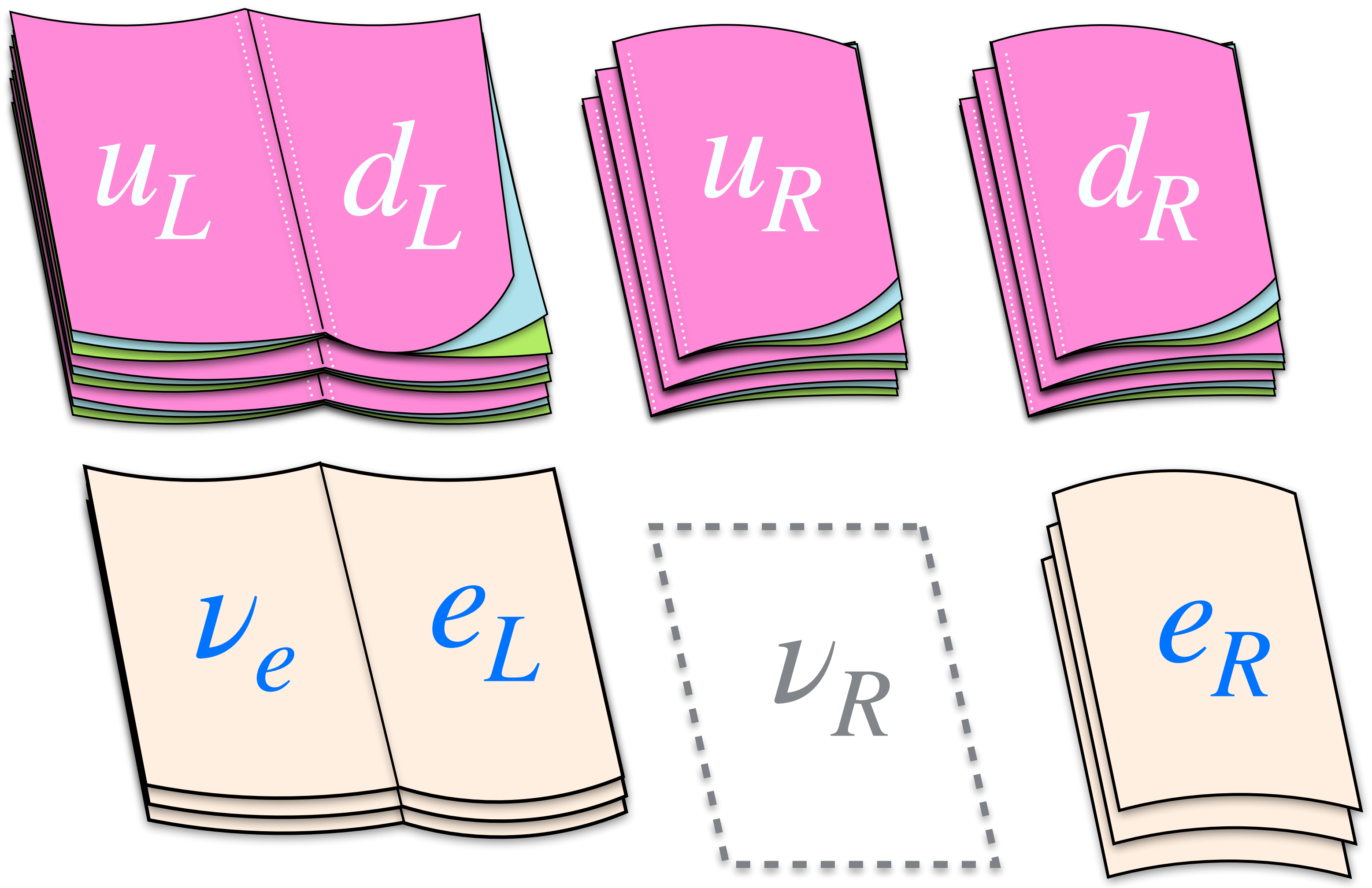
Fermion mass pattern?

Higgs mass and naturalness?

Matter-antimatter asymmetry?

The Standard Model

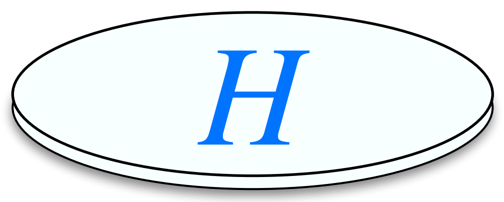
Matter Content



All Fermions

(Spin-1/2)

The Higgs



The Higgs Boson

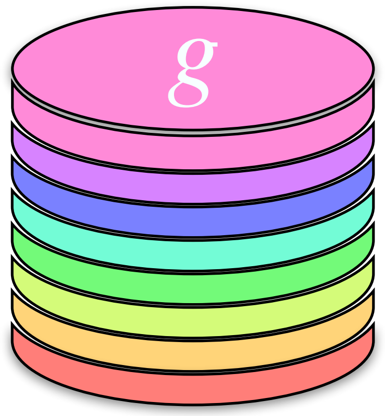
(Spin-0)

Dynamics

(Symmetries)

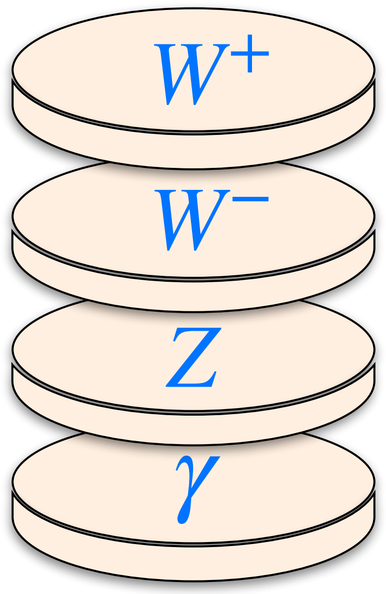
Strong Force

$\mathrm{SU}(3)$



Electroweak Force

$\mathrm{SU}(2) \times \mathrm{U}(1)$

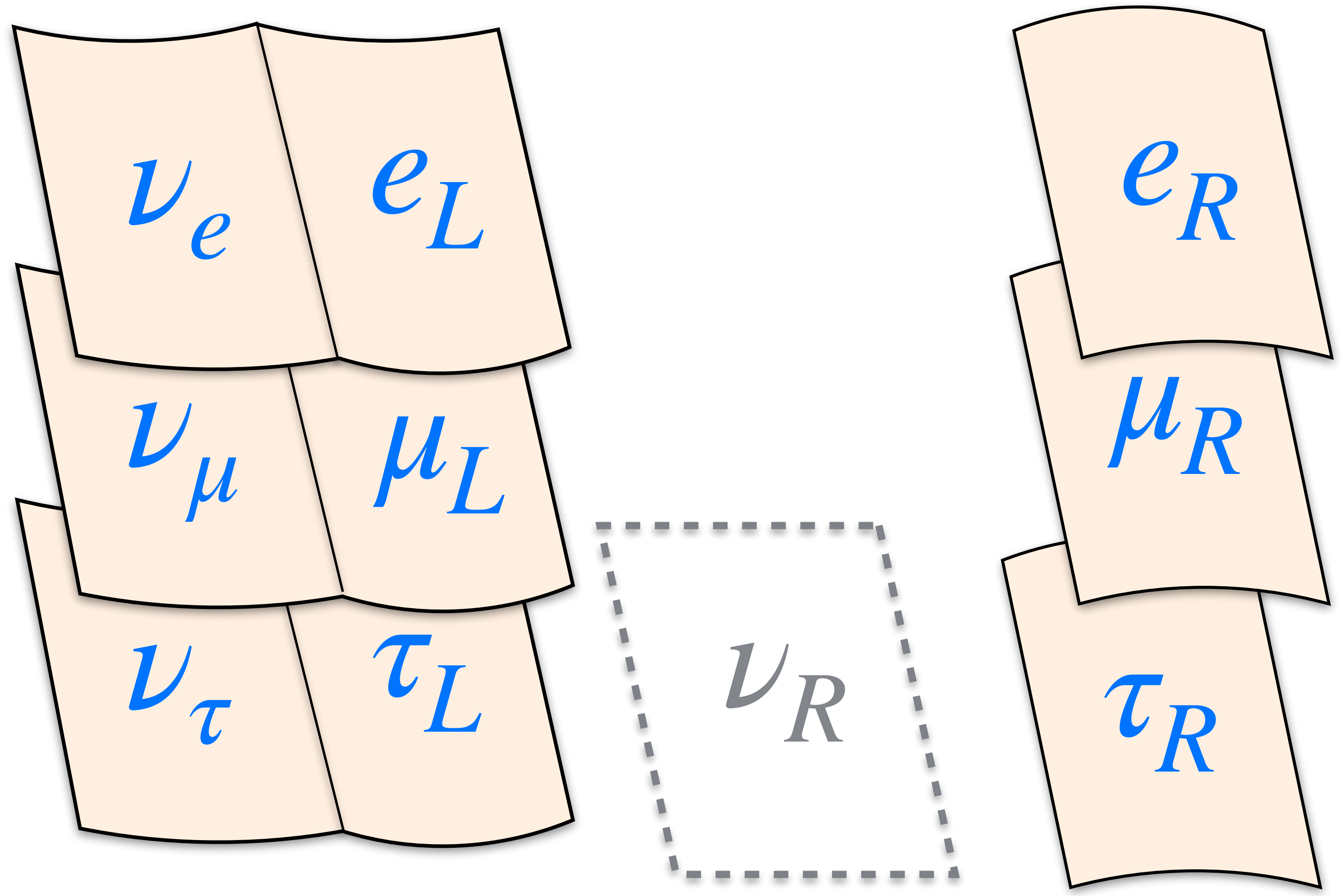


The “two" forces and their mediators

Bosons (Spin-1)

How many neutrinos?

Usual lepton flavors.



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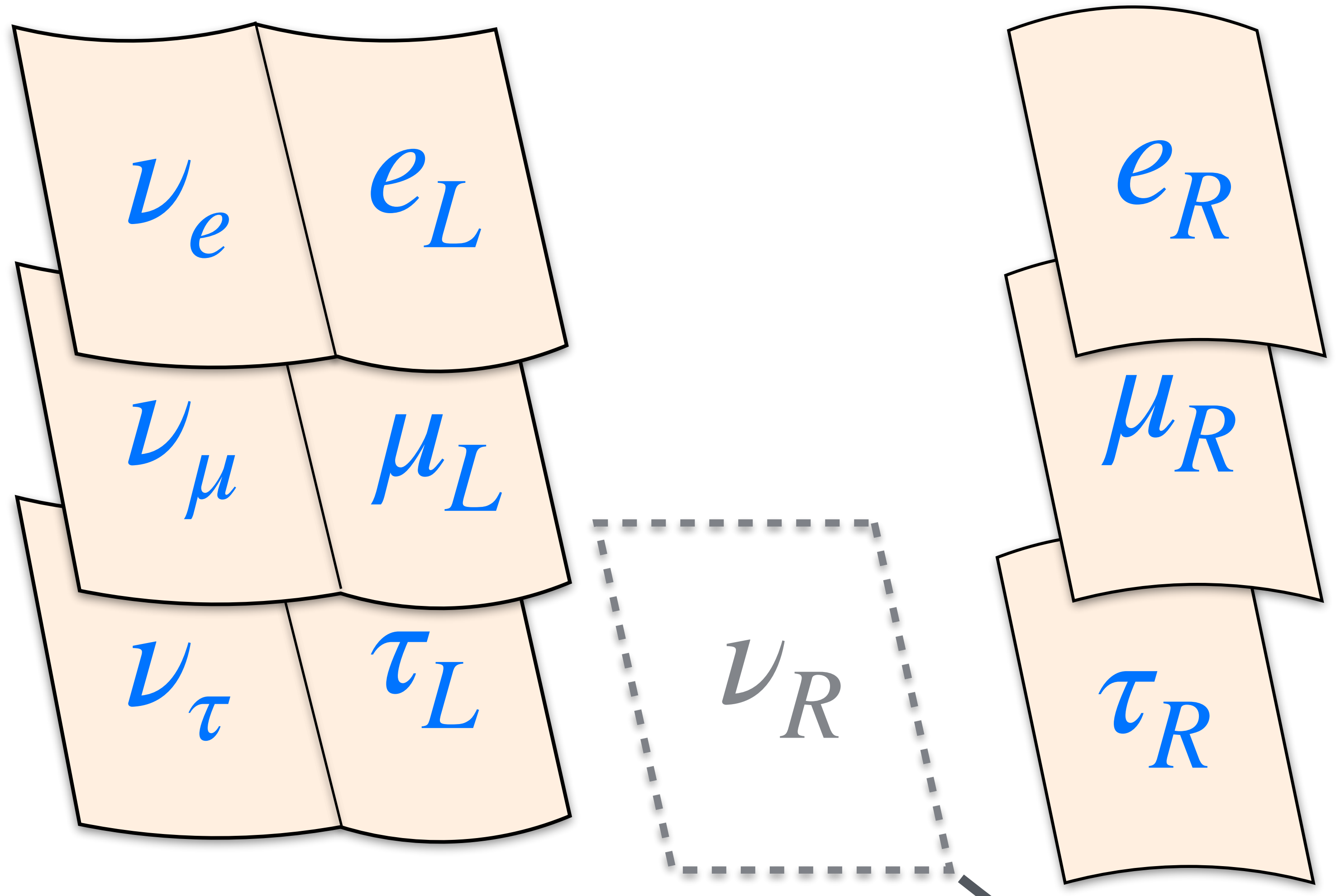
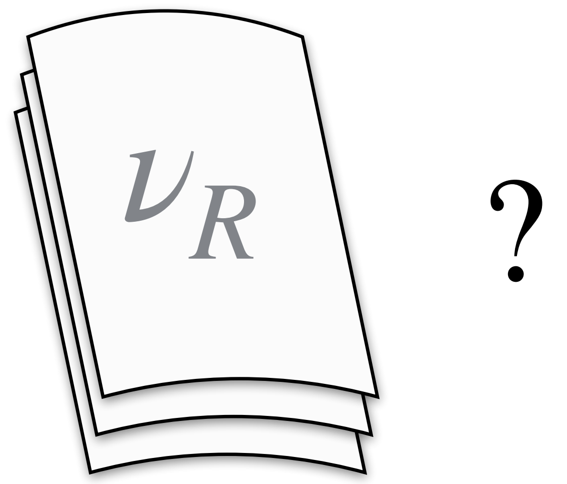


“Singlet” or “right-handed" neutrinos.



The first ambiguity when addressing neutrino masses

Neutrino Masses

$$(\nu_L \quad \nu_R) \begin{pmatrix} 0 & m_D \\ m_D & 0 \end{pmatrix} \begin{pmatrix} \nu_L \\ \nu_R \end{pmatrix}$$

Dirac Neutrinos: degenerate states

$$m_R = 0$$

$$\begin{cases} m_{\nu_+} = m_D & \nu_+ \\ m_{\nu_-} = m_D & \nu_- \end{cases}$$

Weakly-interacting neutrino (standard)

$$|\nu_L\rangle = \frac{|\nu_+\rangle + |\nu_-\rangle}{\sqrt{2}}$$

$$\theta = \frac{\pi}{4}$$

Sterile neutrino (new physics, not observed)

$$|\nu_R\rangle = \frac{|\nu_+\rangle - |\nu_-\rangle}{\sqrt{2}}$$

Neutrino Masses

$$(\nu_L \quad \nu_R) \begin{pmatrix} 0 & m_D \\ m_D & m_R \end{pmatrix} \begin{pmatrix} \nu_L \\ \nu_R \end{pmatrix}$$

Seesaw Mechanism: large Majorana masses

$$m_R \gg m_D$$

$$\begin{cases} m_\nu \sim \dfrac{m_D^2}{m_R} \\ m_N \sim m_R \end{cases}$$

Weakly-interacting neutrino (standard)

Sterile neutrino (new physics, not observed)

$$|\nu_L\rangle \sim |\nu\rangle + \theta |N\rangle \qquad \theta \ll 1 \qquad |\nu_R\rangle \sim |N\rangle - \theta |\nu\rangle$$

Neutrino Masses
(full picture)

$$\begin{pmatrix}\vec{\nu}_L & \vec{\nu}_R\end{pmatrix}\begin{pmatrix}0 & M_D \\ M_D & M_R\end{pmatrix}\begin{pmatrix}\vec{\nu}_L \\ \vec{\nu}_R\end{pmatrix}$$

In reality, this is a matrix multiplication problem:

$$\underset{(3\mathrm{x}3)}{M_\nu} \sim \underset{(3\mathrm{x}?)}{M_D}\,\underset{(?\mathrm{x}?)}{M_R^{-1}}\,\underset{(?\mathrm{x}3)}{M_D^T}$$

We know nothing about the matrix M_R:

How many right-handed neutrinos (how many entries in $\vec{\nu}_R$)?

Do they respect new kinds of symmetries?

Do they feel new interactions?

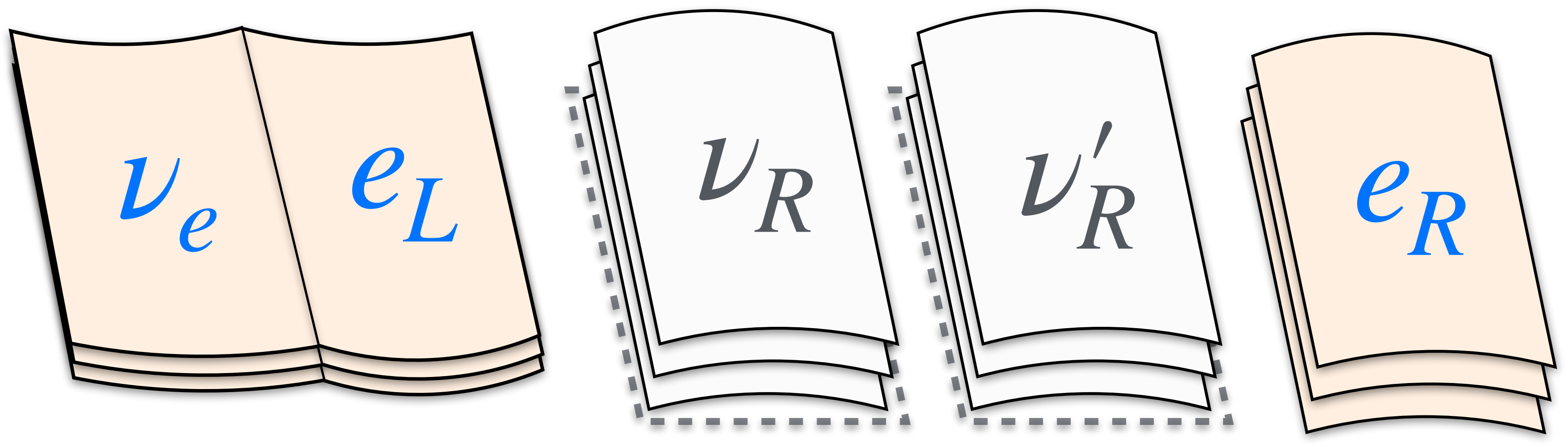
Neutrino Masses

(the *inverse* seesaw example)

Interaction (flavor) basis

$$\begin{pmatrix} \nu_L & \nu_R & \nu_R' \end{pmatrix} \begin{pmatrix} 0 & m_D & 0 \\ m_D & 0 & M \\ 0 & M & m_R \end{pmatrix} \begin{pmatrix} \nu_L \\ \nu_R \\ \nu_R' \end{pmatrix}$$

Two families of RH neutrinos for a single ν_L



$L = +1$ $L = +1$ $L = -1$ $L = +1$

You should find:

$m_1 = \frac{m_D^2}{M^2} m_R$ (Majorana particle) and $m_{2,3} \sim M \pm \frac{m_R}{2}$ (quasi-Dirac pair).

A “seesaw”, but the smaller the “Majorana” mass m_R is, the lighter neutrinos are.

Mass scale of quasi-Dirac pair can be much larger than the scale of LNV.


Neutrino masses
New scalar sectors
Ultra-light fields
ν_R exists
ν_L only
$m_R = 0$
$0 < m_R \ll m_D$
Seesaw(s)
$m_R \gg m_D$
SMEFT
Λ scale
Dirac νs
L symmetry
Quasi-Dirac ν
Tiny L violation
Majorana ν
L violation
Majorana ν
L violation

Where does m_R come from?

A theoretically attractive option to get the Majorana mass scale is, e.g.,
from spontaneous breaking of $B - L$ **local** symmetry.

Cannot gauge just L because of the anomaly, but a $U(1)_L$ **global** symmetry is also perfectly viable.

If spontaneously broken, we get a goldstone, dubbed the *majoron.*

Naturally light, even if $\not{L}$ scale is very heavy. Phenomenologically appealing.

Spontaneously Broken Lepton Number and Cosmological Constraints on the Neutrino Mass Spectrum

Y. Chikashige, R. N. Mohapatra,[a] and R. D. Peccei
Max-Planck-Institut für Physik und Astrophysik, D-8000 München 40, Federal Republic of Germany
(Received 7 October 1980)

ARE THERE REAL GOLDSTONE BOSONS ASSOCIATED WITH BROKEN LEPTON NUMBER?

Y. CHIKASHIGE [1], R.N. MOHAPATRA [1,2] and R.D. PECCEI
Max-Planck-Institut für Physik und Astrophysik, Munich, Fed. Rep. Germany

Received 10 September 1980

LEFT-HANDED NEUTRINO MASS SCALE AND SPONTANEOUSLY BROKEN LEPTON NUMBER

G.B. GELMINI
Sektion Physik, Ludwig-Maximilians-Universität, Munich, Fed. Rep. Germany

and

M. RONCADELLI [1]
Max-Planck-Institut für Physik und Astrophysik, Munich, Fed. Rep. Germany

Received 8 December 1980

Singlet Majoron model: RH neutrino ν_R and singlet complex scalar Σ.

$$\mathscr{L} \supset i\bar{\nu}_R \partial\!\!\!/ \nu_R + \partial_\mu \Sigma^\dagger \partial^\mu \Sigma - y\bar{L}\tilde{H}\nu_R - \lambda \overline{\nu_R^c} \Sigma \nu_R - V_\Sigma$$

Both carry lepton number $L(\nu_R) = 1$ and $L(\Sigma) = -2$.

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Both carry lepton number $L(\nu_R) = 1$ and $L(\Sigma) = -2$.

Σ develops a v.e.v. at scale f, breaking L by two units: $V_\Sigma \sim \left(\Sigma^\dagger \Sigma - \frac{f^2}{4} \right)^2$

$\Sigma \to \frac{(f + \sigma(x) + iJ(x))}{\sqrt{2}},$ and RH neutrinos acquire a Majorana mass $m_R = \frac{\lambda f}{\sqrt{2}}$

While $\sigma(x)$ is some heavy particle at the scale f, the (pseudo-)Goldstone $J(x)$ can be (almost) massless.

This is the Majoron.

Singlet Majoron model: RH neutrino ν_R and singlet complex scalar Σ.

$$\mathscr{L} \supset i\bar{\nu}_R \partial\!\!\!/ \nu_R + \partial_\mu \Sigma^\dagger \partial^\mu \Sigma - y\bar{L}\tilde{H}\nu_R - \lambda \overline{\nu_R^c} \Sigma \nu_R - V_\Sigma$$

How does it couple?

It will be advantageous to maintain a shift-symmetric form: $\Sigma = (f + \rho(x))e^{2iJ(x)/f}$.

Let us now perform a $U(1)_L$ rotation: $\nu_R \to e^{iJ(x)/f}\nu_R$, $L \to e^{iJ(x)/f}L$, $e_R \to e^{iJ(x)/f}e_R$

This moves $J(x)$ from the Yukawa interactions (the λ term, in particular) to the lepton kinetic terms:

$$\mathscr{L} \supset \frac{\partial_\mu J(x)}{f}\left(\bar{\nu}_R\gamma^\mu\nu_R + \bar{L}\gamma^\mu L + \bar{e}_R\gamma^\mu e_R\right) = \frac{\partial_\mu J(x)}{f}\mathcal{J}^\mu_L \longrightarrow \frac{J(x)}{f}\left(\partial_\mu \mathcal{J}^\mu_L\right)$$

Couples to the divergence of Lepton current
(Goldstone!)

Clarifying the couplings of the majoron:

$$\mathscr{L} \supset \frac{\partial_\mu J(x)}{f}\left(\bar{\nu}_R \gamma \nu_R + \bar{L}\gamma^\mu L + \bar{e}_R \gamma^\mu e_R\right) = \frac{\partial_\mu J(x)}{f} \mathcal{J}^\mu_L \longrightarrow \frac{J(x)}{f}\left(\partial_\mu \mathcal{J}^\mu_L\right)$$

Note that lepton current $\mathcal{J}^\mu_L$ contains the (conserved) vector current:

$\mathcal{J}^\mu_L = \mathcal{J}^\mu_{\text{QED}} + \mathcal{J}^\mu_\nu$, where $\partial_\mu \mathcal{J}^\mu_{\text{QED}} = 0$.

Hence, the majoron couples exclusively to neutrinos at tree-level.

From equations of motion for neutrinos: $i\partial\!\!\!/ \nu_R = m_D \nu_L + m_R \nu_R^c$ and $i\partial\!\!\!/ \nu_L = m_D \nu_R$

$$\partial_\mu \mathcal{J}^\mu_L = i m_R (\bar{\nu}_R^c \nu_R - \bar{\nu}_R \nu_R^c) + \textbf{anomaly terms}$$

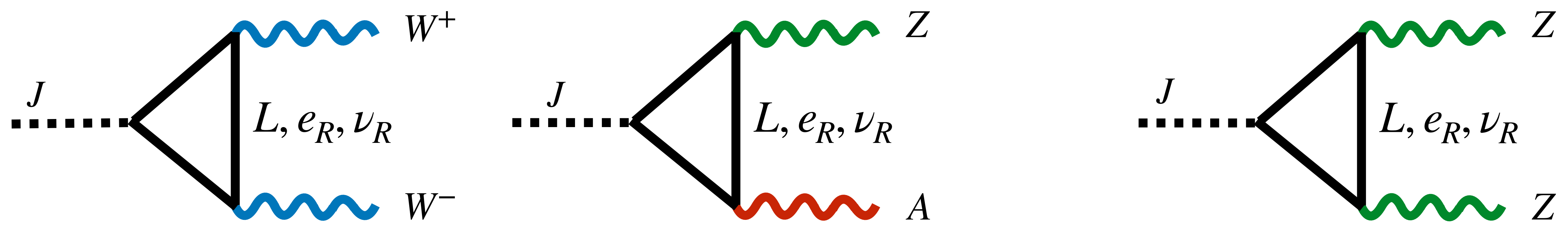
Couples to "Majorana mass", as this is the only breaking of L in our theory.

Clarifying the couplings of the majoron:

$$\mathscr{L} \supset \frac{\partial_\mu J(x)}{f}\left(\bar{\nu}_R\gamma\nu_R + \bar{L}\gamma^\mu L + \bar{e}_R\gamma^\mu e_R\right) = \frac{\partial_\mu J(x)}{f}\mathscr{J}^\mu_L \longrightarrow \frac{J(x)}{f}\left(\partial_\mu \mathscr{J}^\mu_L\right)$$

$$\partial_\mu \mathscr{J}^\mu_L = i m_R(\bar{\nu}^c_R\nu_R - \bar{\nu}_R\nu^c_R) \; + \; \textbf{anomaly terms}$$

anomaly terms: $$\frac{n_g}{16\pi^2}\left(g^2 W^+_{\mu\nu}\widetilde{W}^{-\mu\nu} + g g' Z_{\mu\nu}\widetilde{A}^{\mu\nu} + \frac{g^2 - g'^2}{2} Z_{\mu\nu}\widetilde{Z}^{\mu\nu}\right)$$



No two-photon coupling from anomalies (conservation of EM current)!

Other one and two loop contributions suppressed by soft-breaking parameter m_J.

For a more detailed discussion, see J. Heeck, H. H. Patel, PRD 100, 095015 (2019)

For an exception, see: Q. Liang, X. Ponce Díaz, T. T. Yanagida, PRL 134 (2025) 15, 151803

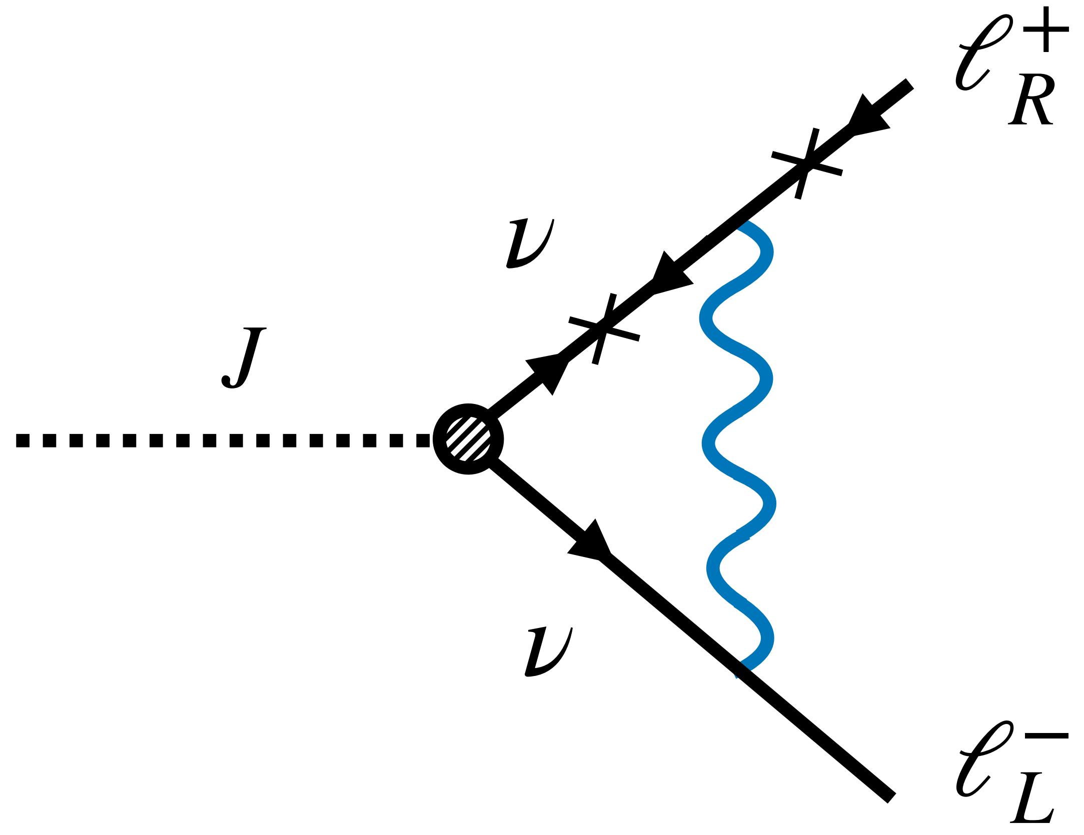
Clarifying the couplings of the majoron:

$$\mathscr{L} \supset \frac{\partial_\mu J(x)}{f}\left(\bar{\nu}_R \gamma \nu_R + \bar{L}\gamma^\mu L + \bar{e}_R \gamma^\mu e_R\right) = \frac{\partial_\mu J(x)}{f}\mathcal{J}^\mu_L \longrightarrow \frac{J(x)}{f}\left(\partial_\mu \mathcal{J}^\mu_L\right)$$

$$\partial_\mu \mathcal{J}^\mu_L = i m_R(\bar{\nu}^c_R \nu_R - \bar{\nu}_R \nu^c_R) + \textbf{anomaly terms}$$

Charged lepton couplings: From $\mathscr{L} \supset c_{\ell\ell} J \bar{\ell}\gamma^5 \ell$, literature agrees on

$$c_{\ell\ell} \sim \frac{G_F}{16\pi^2} m_\ell m_\nu \simeq 10^{-20}$$



Couplings to charged leptons is also extremely small and beyond reach of current experiments.

For example, for $m_\nu \sim 0.1$ eV and $m_\ell = m_\mu$, we have $\mathscr{B}(\mu^+ \to e^+ J) \sim 10^{-20}$.

See A. Herrero-Brocal, A. Vicente JHEP 01 (2024) 078

In more generality, we may work only at the level of the Weinberg operator:

$$\mathscr{L} \supset \frac{C_W}{\Lambda_{\rm UV}}(LH)^2 \longrightarrow m_\nu \bar{\nu}_L^c \nu_L$$ Weinberg operator with $m_\nu = \dfrac{C_W v_h^2}{2\Lambda_{\rm UV}}$

From equations of motion for neutrinos: $i\partial\!\!\!/ \nu_L = m_\nu \nu_L^c$

$$\partial_\mu \mathscr{J}^\mu_L = i m_\nu (\bar{\nu}_L^c \nu_L - \bar{\nu}_L \nu_L^c) \; + $$ **anomaly terms**

Note:

1) For seesaw mechanism to be in place, we only require $y v_h \ll \lambda f$

Hierarchy of scale and/or couplings.

Current data allows for this to be quite small, even at the scale of $f \sim \mathcal{O}$(keV $\to$ MeV).

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2) RH neutrinos and the radial mode $\sigma(x)$ **will be at the scale** f

In a full model, the phenomenology of these particles will be relevant.

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In a full model, the phenomenology of these particles will be relevant.

3) Any amount of soft or explicit breaking of the symmetry will give $J(x)$ a mass m_J

We treat m_J as a free parameter (bounds for $m_J \sim 10^{-18}$ eV).

(Conjectures of no global symmetries in QG point to $m_J > 0$, but ultimately, no guidance on the value.)

Some existing probes of majorons

Environmental changes to the neutrino mass

A lot of constraints derived on ultra-light bosons coupled to neutrinos a là:

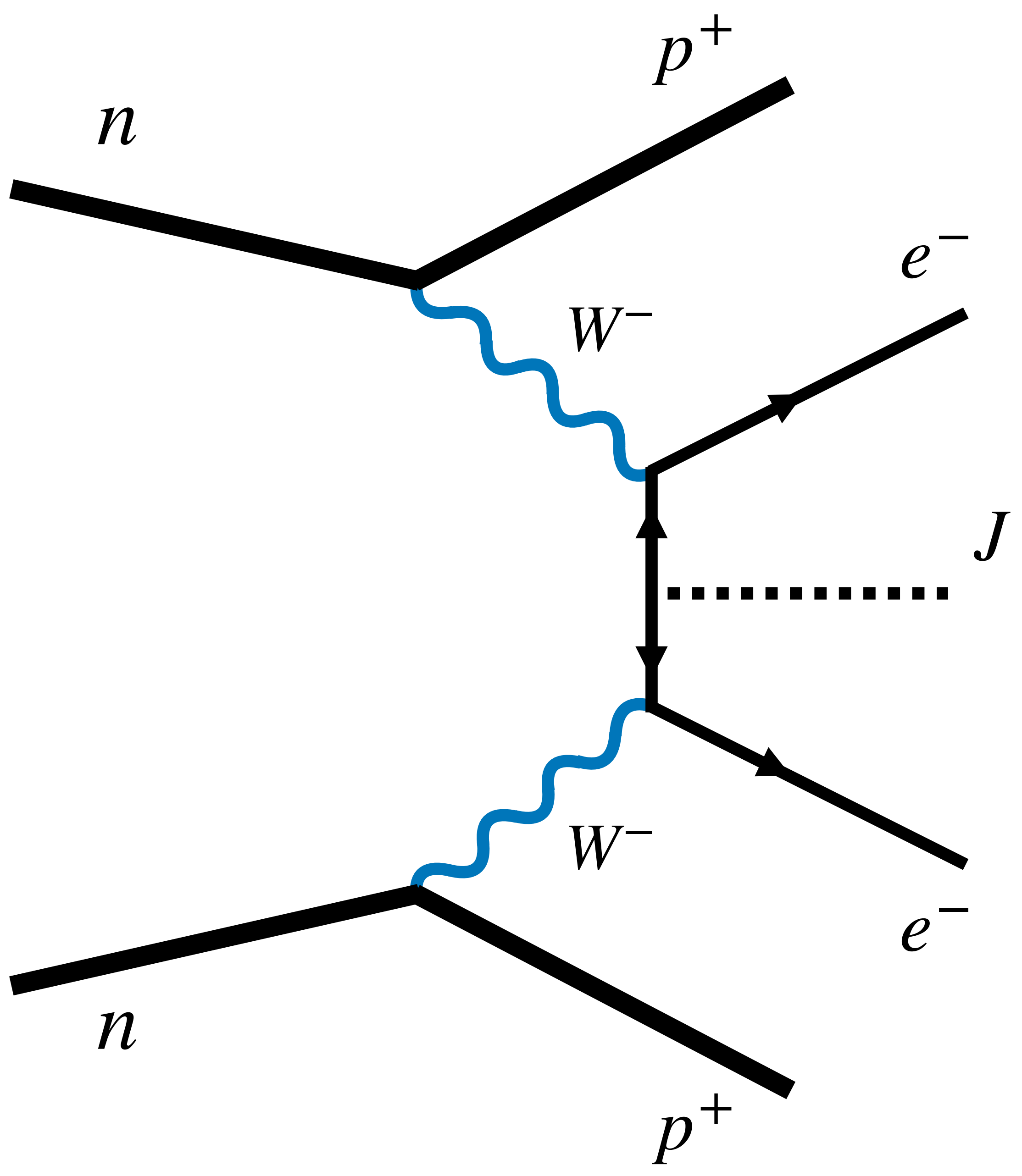
$$\mathscr{L} \supset \phi \bar{\nu}_L^c i\gamma^5 \nu_L$$

Many of these rely on environmental changes to neutrino masses and oscillations.

These limits **do not** apply to the derivatively-coupled J field.

The majoron couplings are explicitly shift symmetric.

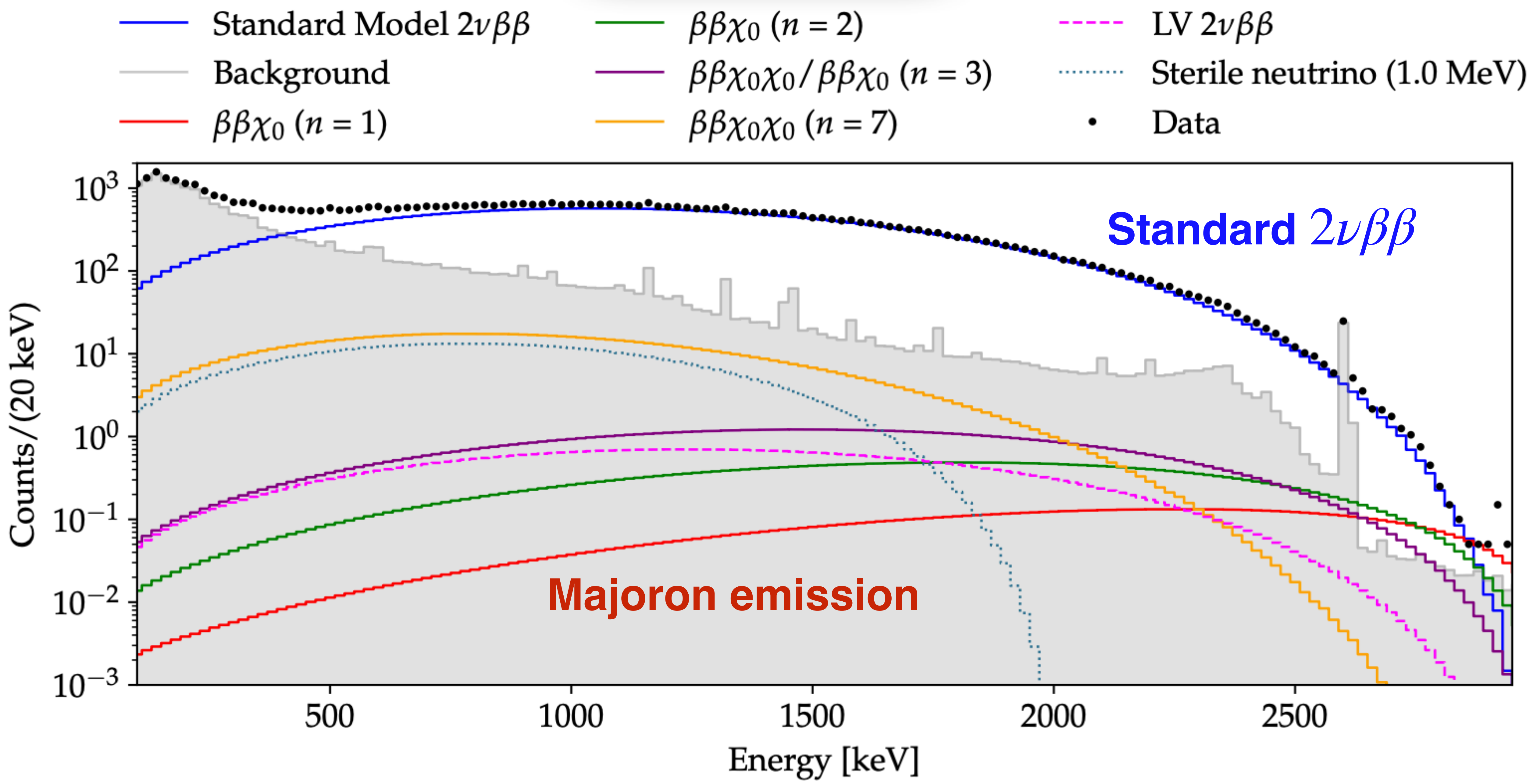
Majoron emission in double-beta decay “$0\nu\beta\beta$”



Two-neutrino double-beta decay

$$\frac{d\Gamma}{dT} \propto \left(Q_{\beta\beta} - T\right)^n$$

$$\chi_0 = J$$



CUPID Coll., Eur.Phys.J.C 84 (2024) 9, 925

EXO-200 data *PRD* 104 (2021) 11, 112002:

$T_{1/2}^{^{136}Xe} > 4.3 \times 10^{24}$ years $\quad \rightarrow \quad$ Limit of $m_\nu/f \lesssim 4 \times 10^{-6}$

Supernova neutrinos (cooling and spectral distortions)

Bounds from cooling and from spectral distortions from neutrino decay.

In extremely dense matter, $\nu_i \to \nu_j J$ is allowed due to background.

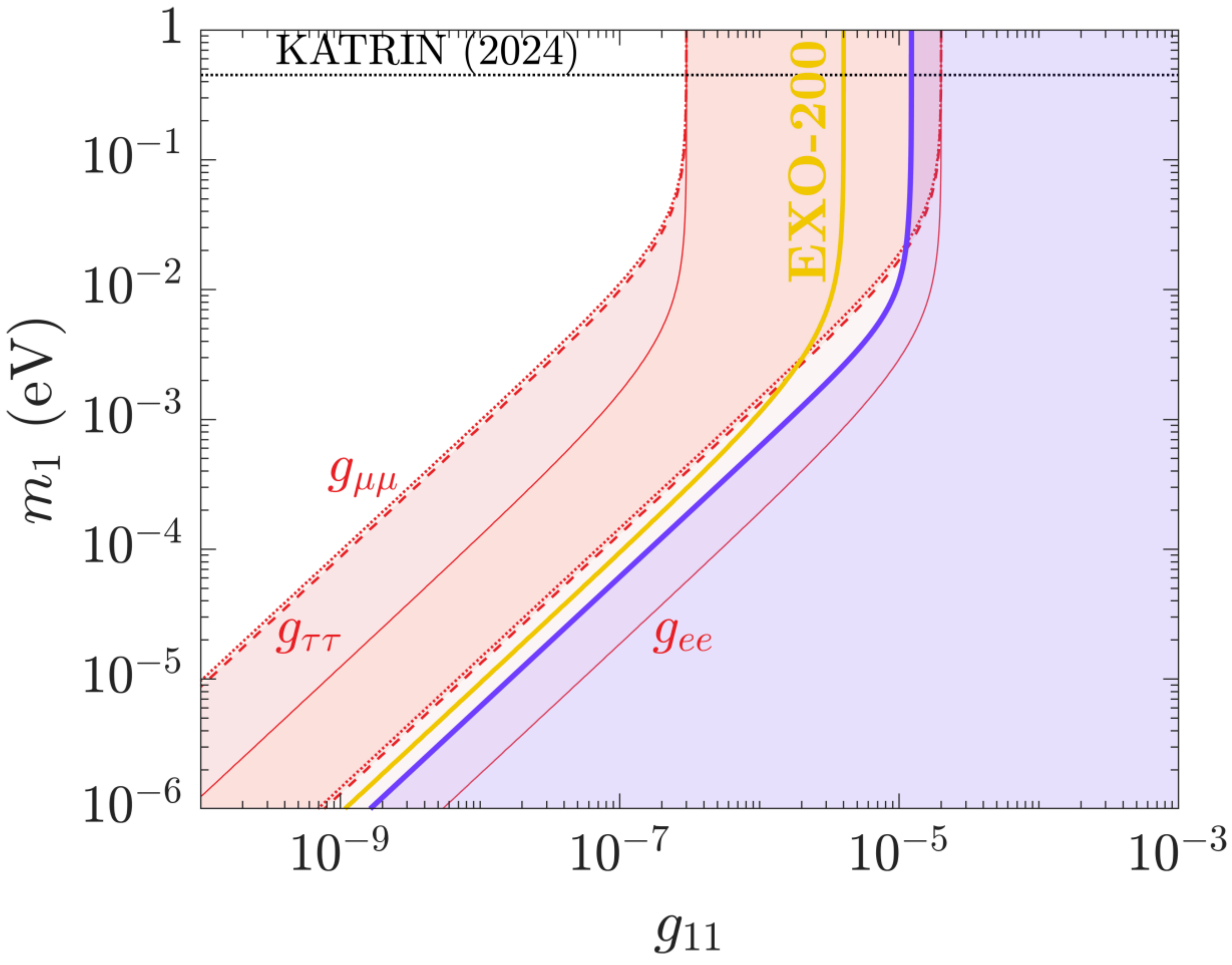
$$\mathcal{L}_{\rm int} \propto \sum_{i,j} g_{ij} \bar{\nu}_i \gamma_5 \nu_j J$$

In our language, these bounds will target $m_2/f \lesssim$ few $\times\, 10^{-7}$

Pilar Iváñez-Ballesteros, M. Cristina Volpe
2410.11517

+ many others over the decades.

Supernovae has always been a prime object to study for maroons.



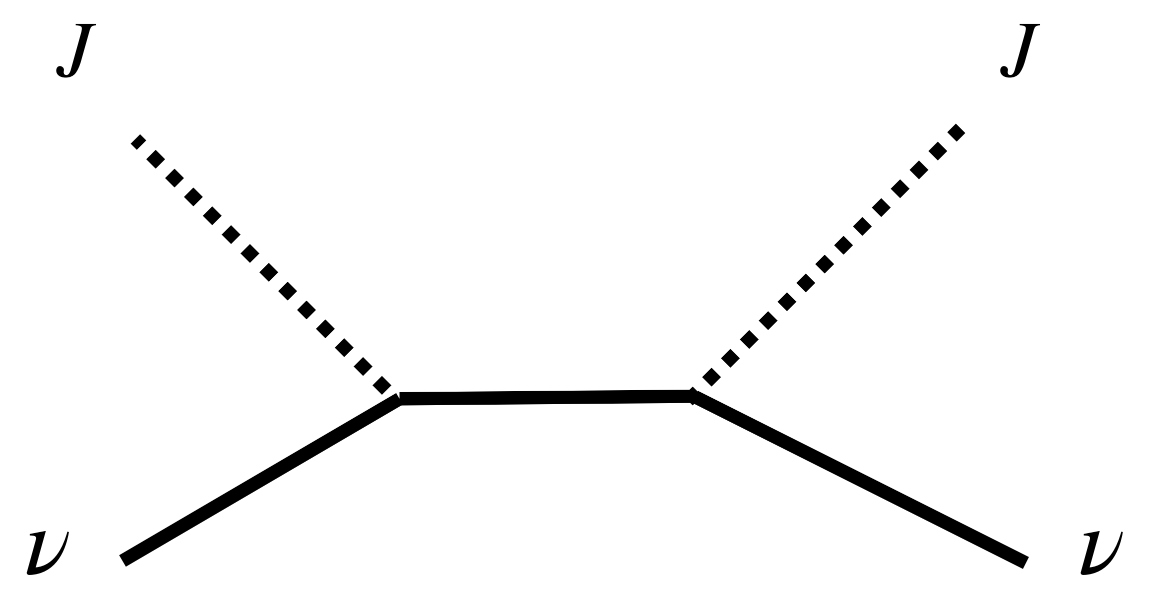
Cosmological probes

Couplings diagonal in mass basis imply no $\nu_2 \to J\nu_1$ decays.

Despite their tiny couplings, majorons may still be thermal equilibrium with neutrinos in the early Universe.

Additional radiation density.

Equilibrium typically guaranteed for $m_\nu/f \gtrsim$ few $\times\, 10^{-7}$.



To be extra safe, one can require majorons to either be in contact with a colder dark sector or be in non-standard cosmological scenario.

Detailed studies left for future literature.

Neutrino spin precession in a J background

Neutrinos in the majoron background

Switching to 2-component for now:

$$\mathscr{L} = \nu^\dagger i\bar{\sigma}^\mu \partial_\mu \nu - \left(\frac{m_\nu}{2}\,\nu^2 + \text{h.c.}\right) + \frac{\partial_\mu J}{f}\,\nu^\dagger \bar{\sigma}^\mu \nu \ .$$

Can show that the evolution of a neutrino at rest is just:

$$i\partial_t(e^{im_\nu t}\nu) = H(e^{im_\nu t}\nu)$$ with $$H = -\frac{p^2}{2m_\nu} + \frac{\dot{J}}{f}\frac{\vec{\sigma}\cdot\vec{p}}{m_\nu} + \frac{\vec{\nabla} J}{f}\vec{\sigma}$$ where $$\vec{p} = -i\vec{\nabla}$$

Neutrinos in the majoron background

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Second term is the **"axio-electric"** term. Effective "E-field" aligned with the neutrino spin.

Effective Lorentz force that pushes and pulls on neutrinos. Does not seem to be easy to detect experimentally.

See e.g., A. Berlin, A. J. Millar, T. Trickle, K. Zhou, JHEP 05 (2024) 314

Neutrinos in the majoron background

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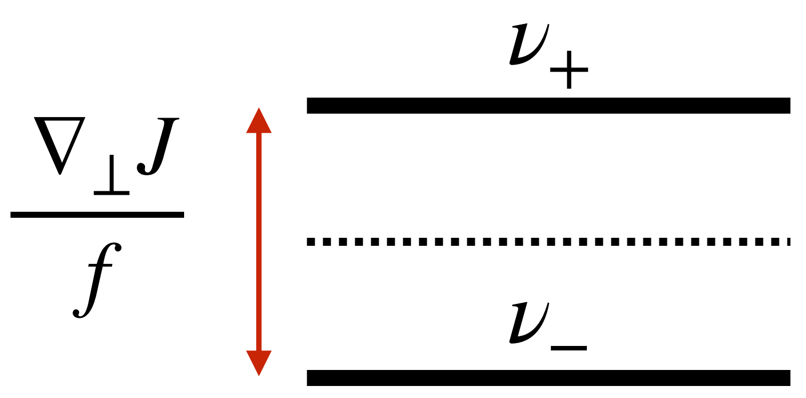
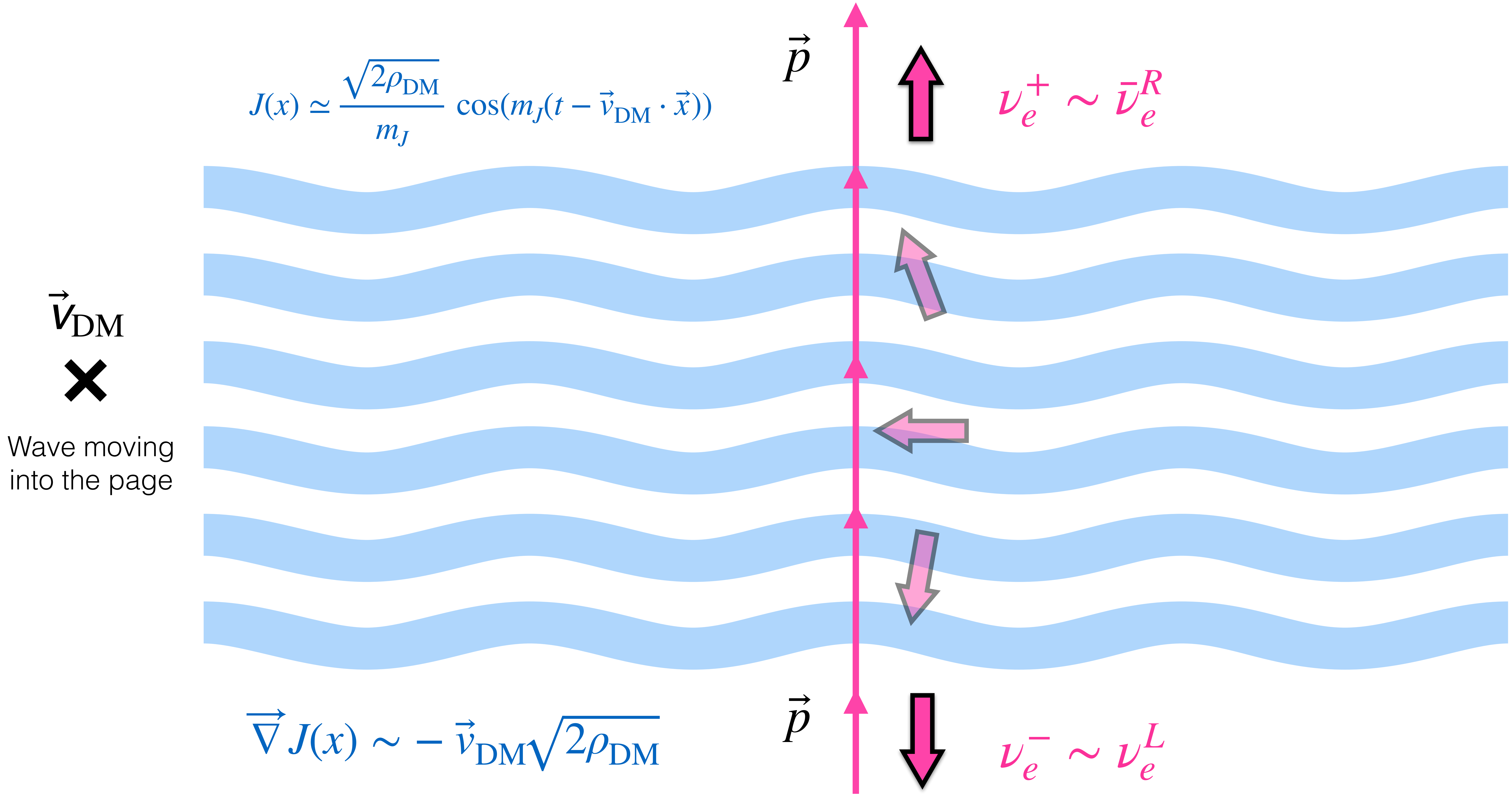


Last term is a **majoron wind** term: effective B-field coupling to neutrino spin.

Directly analogous to Zeeman splitting in a magnetic field.

By analogy with a spin in a magnetic field, we expect a precession of

$\frac{2t\,\nabla_\perp J}{f}$ in a time t, where $\nabla_\perp$ is perpendicular to the neutrino spin.



Same flavor $\nu_e \to \bar{\nu}_e$ oscillations.

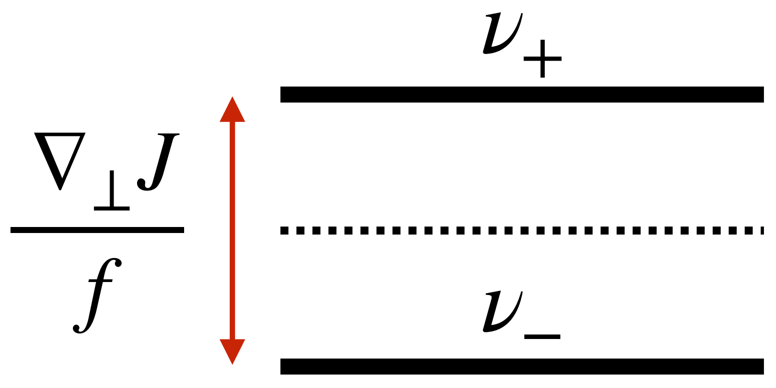
Neutrinos in the majoron background

With the classical and oscillating majoron background:

$$J(\vec{x}, t) \simeq \frac{\sqrt{2\rho_{\rm DM}}}{m_J} \cos(m_J(t - \vec{v}_{\rm DM} \cdot \vec{x}))$$

We derive the energy splitting between helicity states, which determines the transition probability over time

$$P_{\nu \to \bar{\nu}} = \sin^2\left(\frac{\sqrt{2\rho_{\rm DM}}}{f} \frac{m_\nu}{E_\nu} v_\perp \frac{\sin(m_J L)}{m_J} \right)$$



Clearly, even for $m_J \to 0$ (static majoron background), the effect survives thanks to the DM wind velocity $v_\perp$.

In principle, $J(\vec{x}, t)$ carries an additional phase. Within each coherence patch, this phase is constant and we set to it zero for simplicity.

Coherence guaranteed for about 10 years when m$m_J \sim 10^{-18}$ eV $\sim$ (1 AU)$^{-1}$.

Resonant spin-flavor rotation:
C.S. Lim, W. J. Marciano (1988)
E. Akhmedov (1988)

A large transition magnetic moment couples to background B-field to precess the neutrino spin and leads to:

$\nu_e^L \to \bar{\nu}_\mu^R$ (for Majorana)

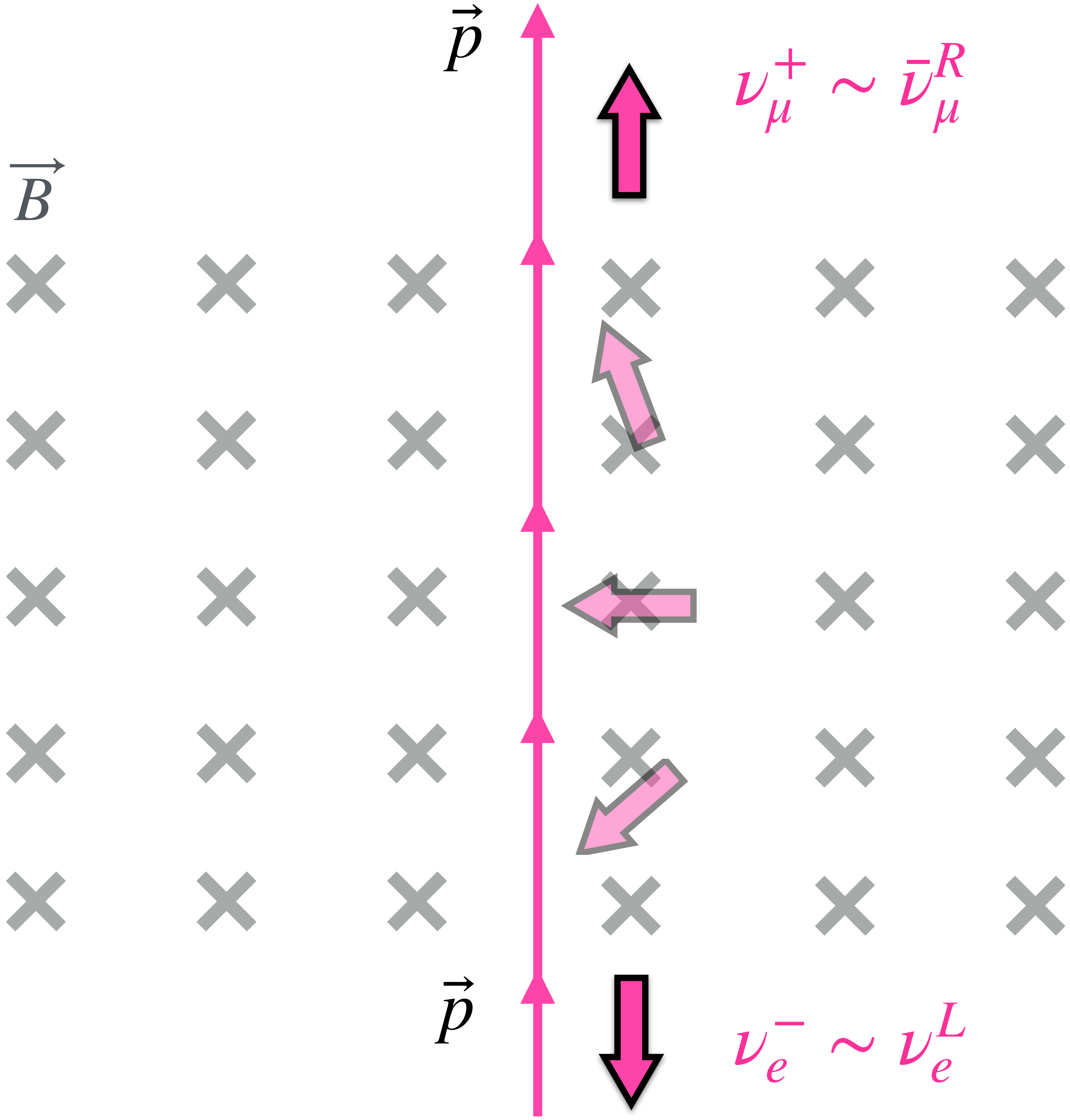
For Majorana, have flavor off-diagonal moments:

$$\mathscr{L} = \frac{\mu}{2}\bar{\nu}_e \sigma_{\mu\nu} F^{\mu\nu} \nu_\mu$$

Therefore, same-flavor transition is forbidden by Lorentz structure of the operator.

Not the case for the majoron effect, as the operator is

$$\mathscr{L} \supset \frac{\partial_\mu J}{f} \bar{\nu}_e \gamma^\mu \gamma^5 \nu_e$$



In the magnetic moment case, we have

$$P_{\nu_e \to \bar{\nu}_\mu} \sim \sin^2 2\theta \sin^2(\mu B_\perp t)$$

while in the majoron case we have an energy dependence

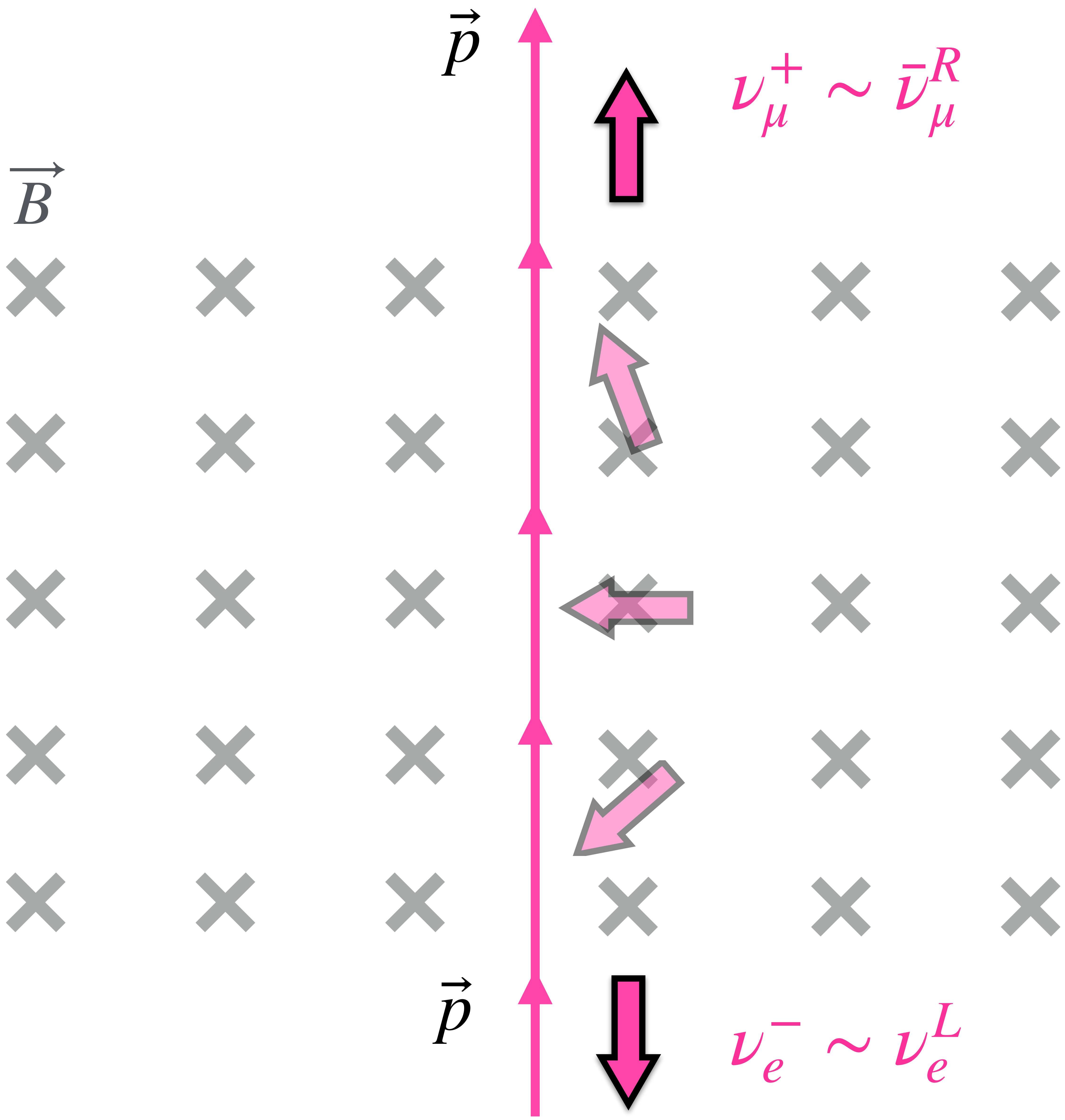
$$P_{\nu_e \to \bar{\nu}_e} \sim \sin^2 \left(\frac{m_\nu}{E_\nu} v_\perp \ldots \right).$$

Both are spin precession,
so why different E_ν dependence?

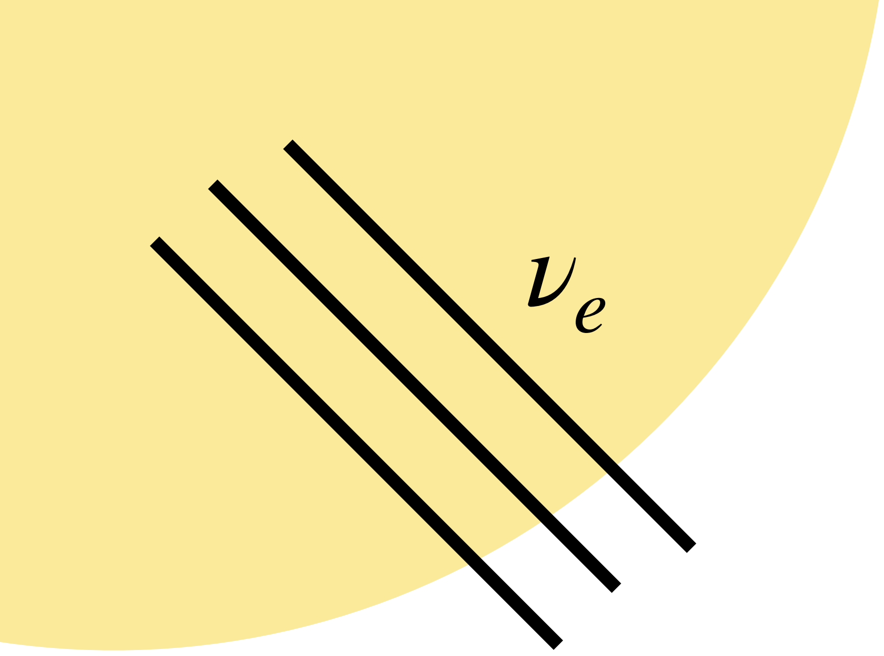
Easy to see if interpreted as a boost factor:

In $\vec{B}$ field case, for fixed lab-frame t
the boost shrinks the ν proper time $\tau = t/\gamma$,
but “squeezes” field lines in ν rest-frame, $B_\perp \to \gamma B_\perp$.

For J, the boost does not change perpendicular
motion of the field, so penalty from shrinking τ
is not compensated.



Solar and supernova antineutrinos



Standard Solar Models: pp / pep / hep / CNO / Be7 / B8 / ... $\longrightarrow \nu_e$

e.g. $\Phi_\nu^{^8B} \sim 6 \times 10^6 \ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ $\qquad E_\nu \lesssim 16\,\mathrm{MeV}$

Nuclear fusion *cauldron* of the Sun **massively overwhelms** antineutrino emission at MeV energies. R. A. Malaney, et al, Astrophys. J. 352, 767 (1990)

$\overline{\nu_e}$ from long-lived radioactive isotopes (232Th, 238U, ...): $\Phi_{\overline{\nu}_e} \sim 200 \ \mathrm{cm}^{-2} \ \mathrm{s}^{-1}$ with $E_\nu \lesssim 3$ MeV

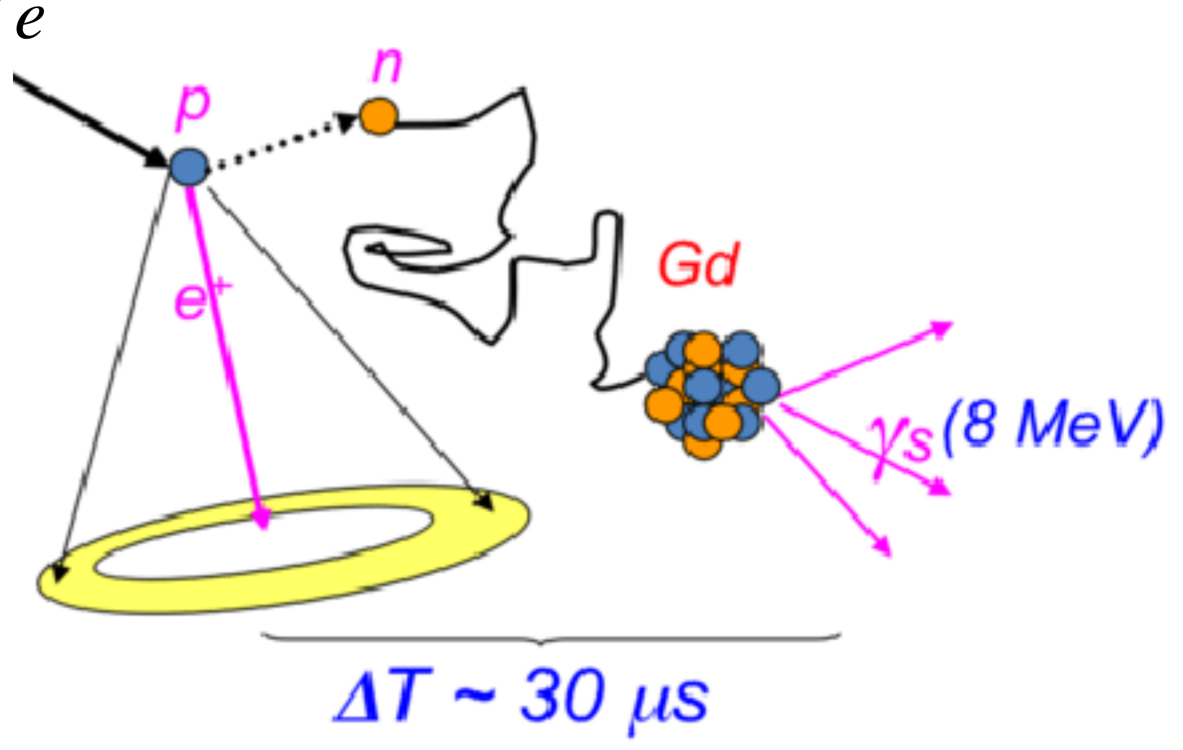
$\overline{\nu_e}$ from photo-fission reactions: $\Phi_{\overline{\nu}_e} \sim 10^{-3} \ \mathrm{cm}^{-2} \ \mathrm{s}^{-1}$ with $E_\nu \sim 3-9$ MeV

ν_e

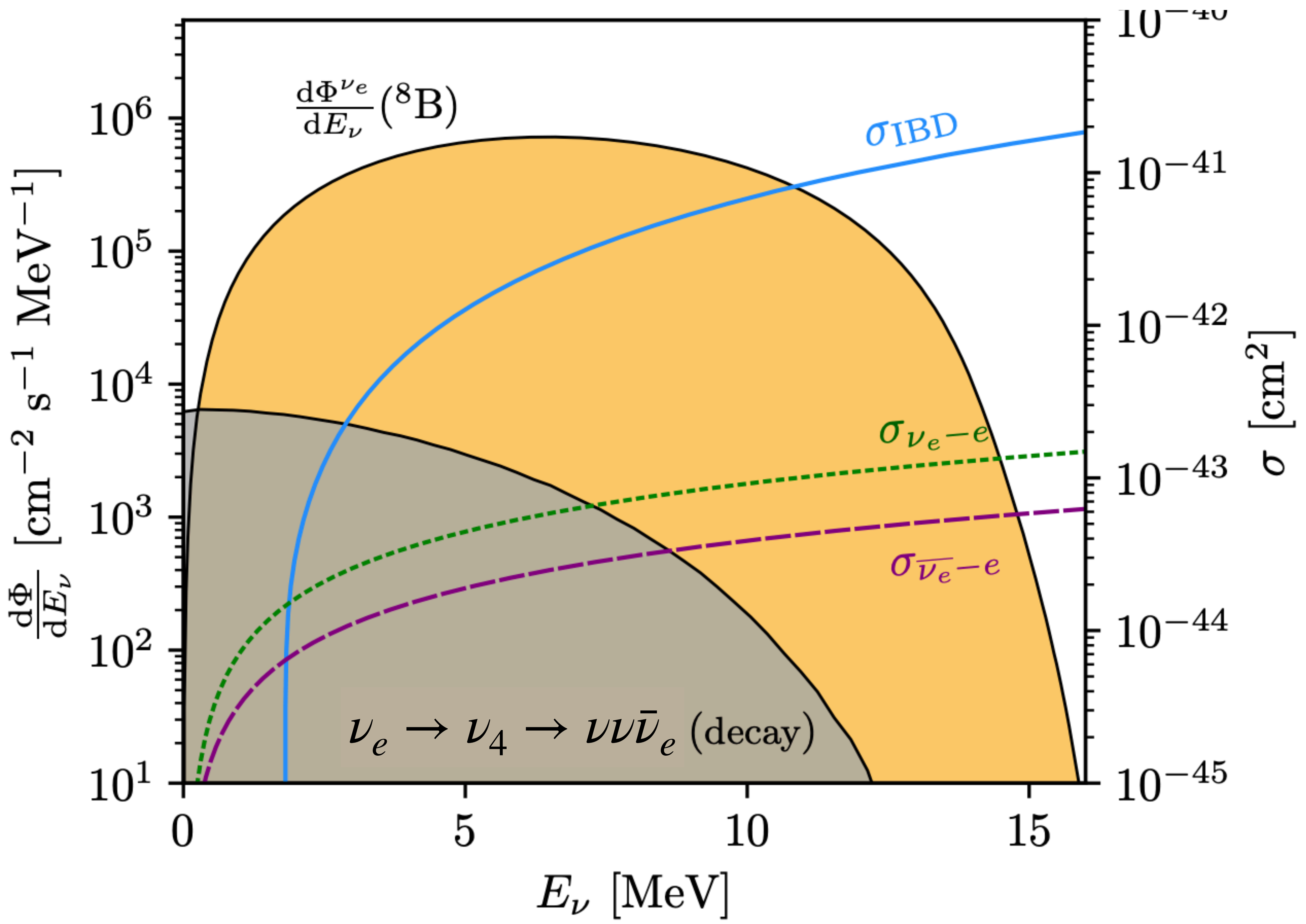
$\bar{\nu}_e$ detection through
Inverse Beta Decay

$$\overline{\nu_e} + p^+ \rightarrow e^+ + n$$

IBD has small backgrounds and much **larger cross section** than nu-e elastic!



Hostert, Pospelov, PRD 104, 055031 (2021)



Solar antineutrino signal estimation

To account for all mass eigenstates that leave the Sun,
we assume a factorization of the flavor evolution in the Sun
and the spin precession on the way to the Earth:

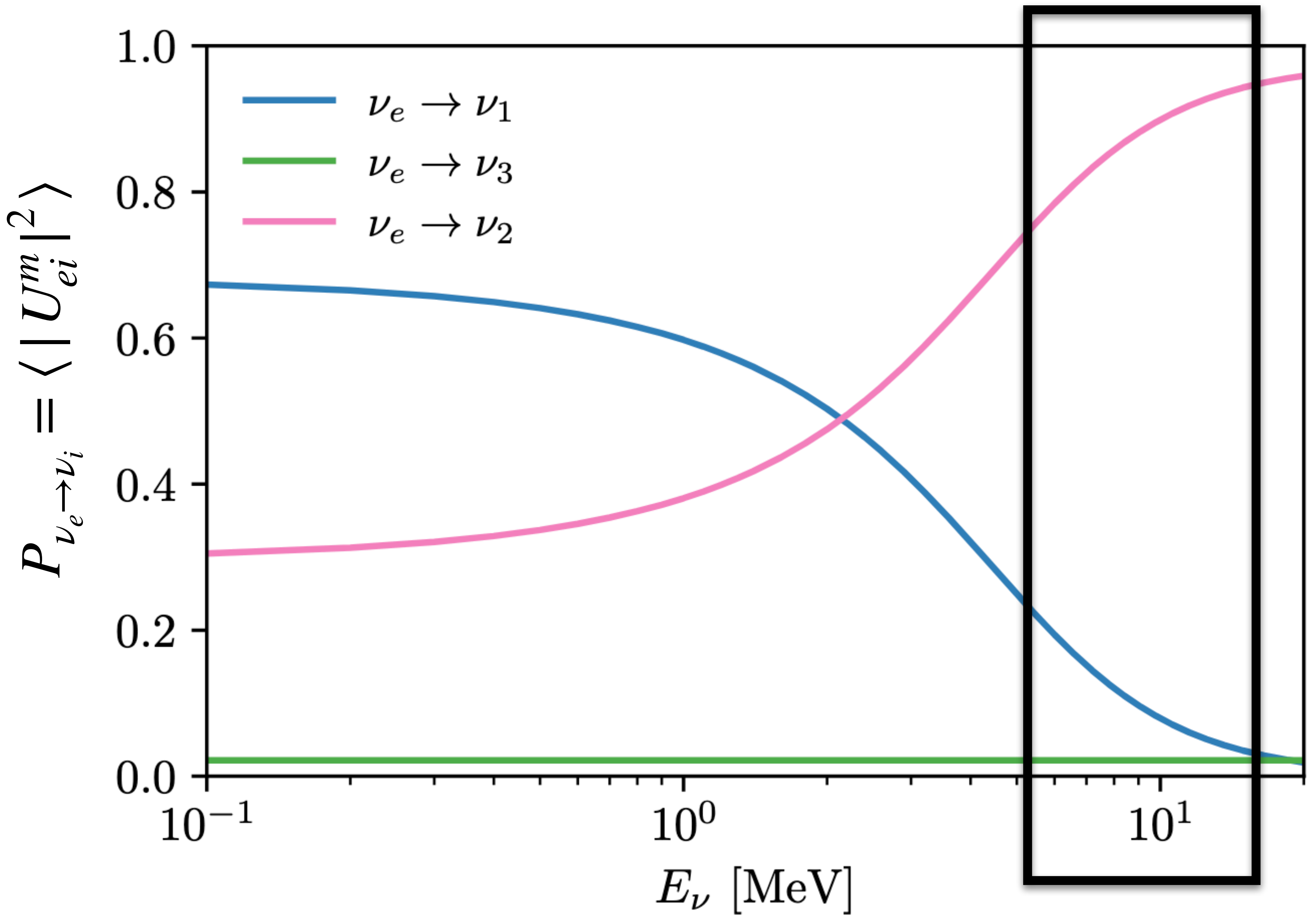
Conversion
$\nu_i \to \bar{\nu}_i$

Prob to exit the
Sun as a ν_i

Detected as ν_e

$$P_{\nu_e \to \bar{\nu}_e}(E_\nu, L) = \sum_{i=1}^{3} \langle |U_{ei}^m|^2 \rangle P_{\nu_i \to \bar{\nu}_i}(E_\nu, L) |U_{ei}|^2$$

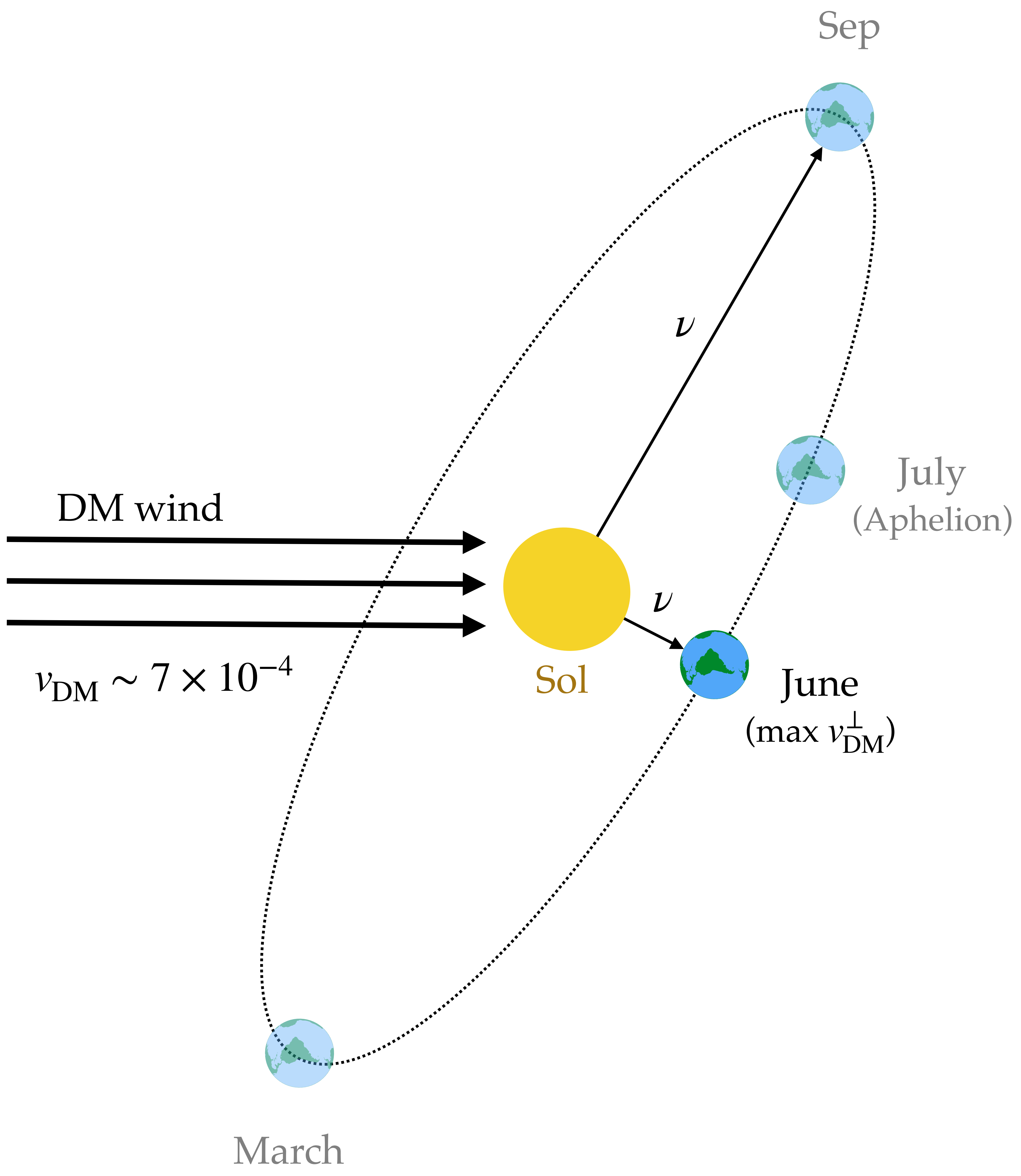
Fraction that leaves the Sun as ν_i



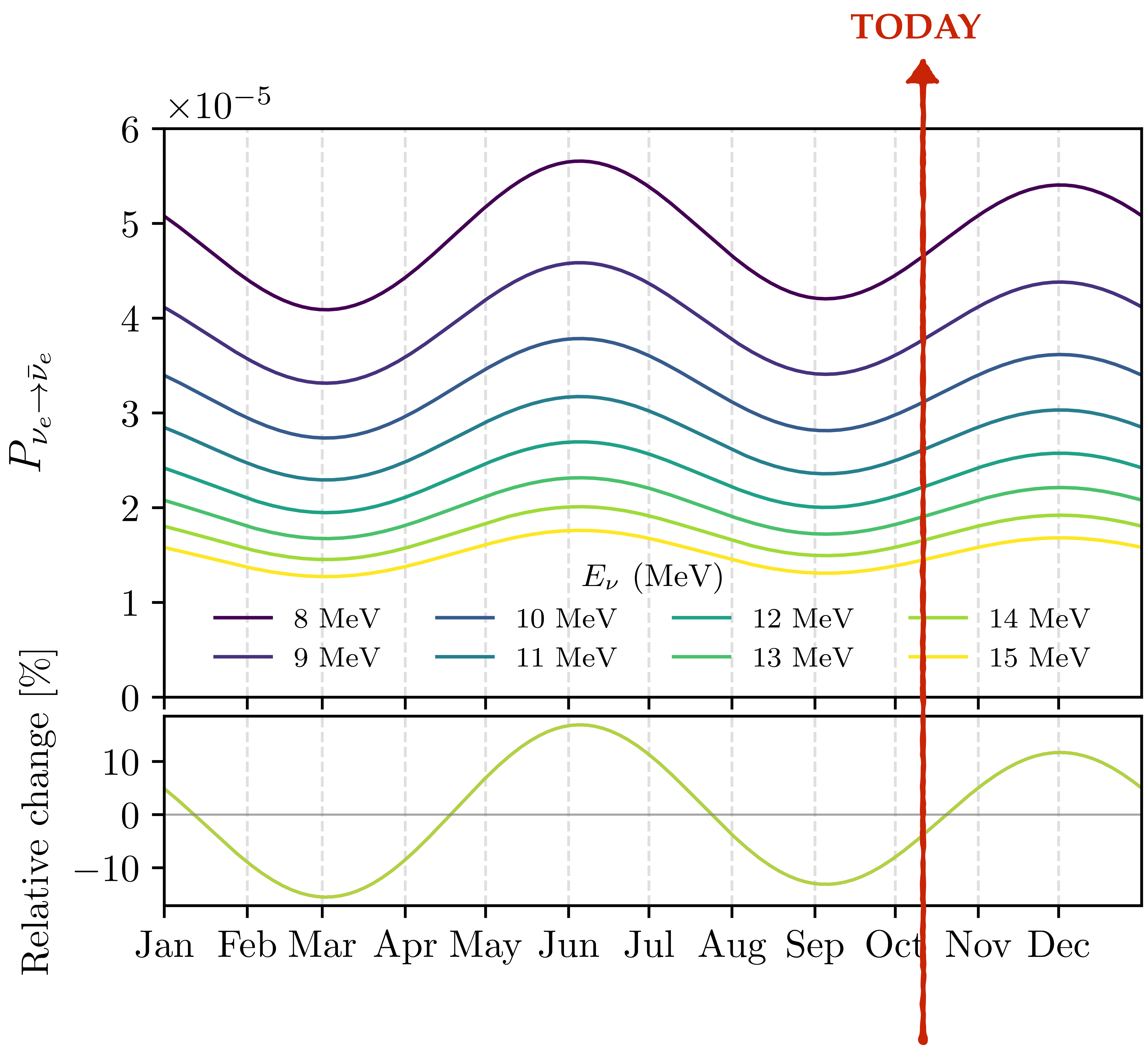
Bulk of exp
sensitivity
is here:

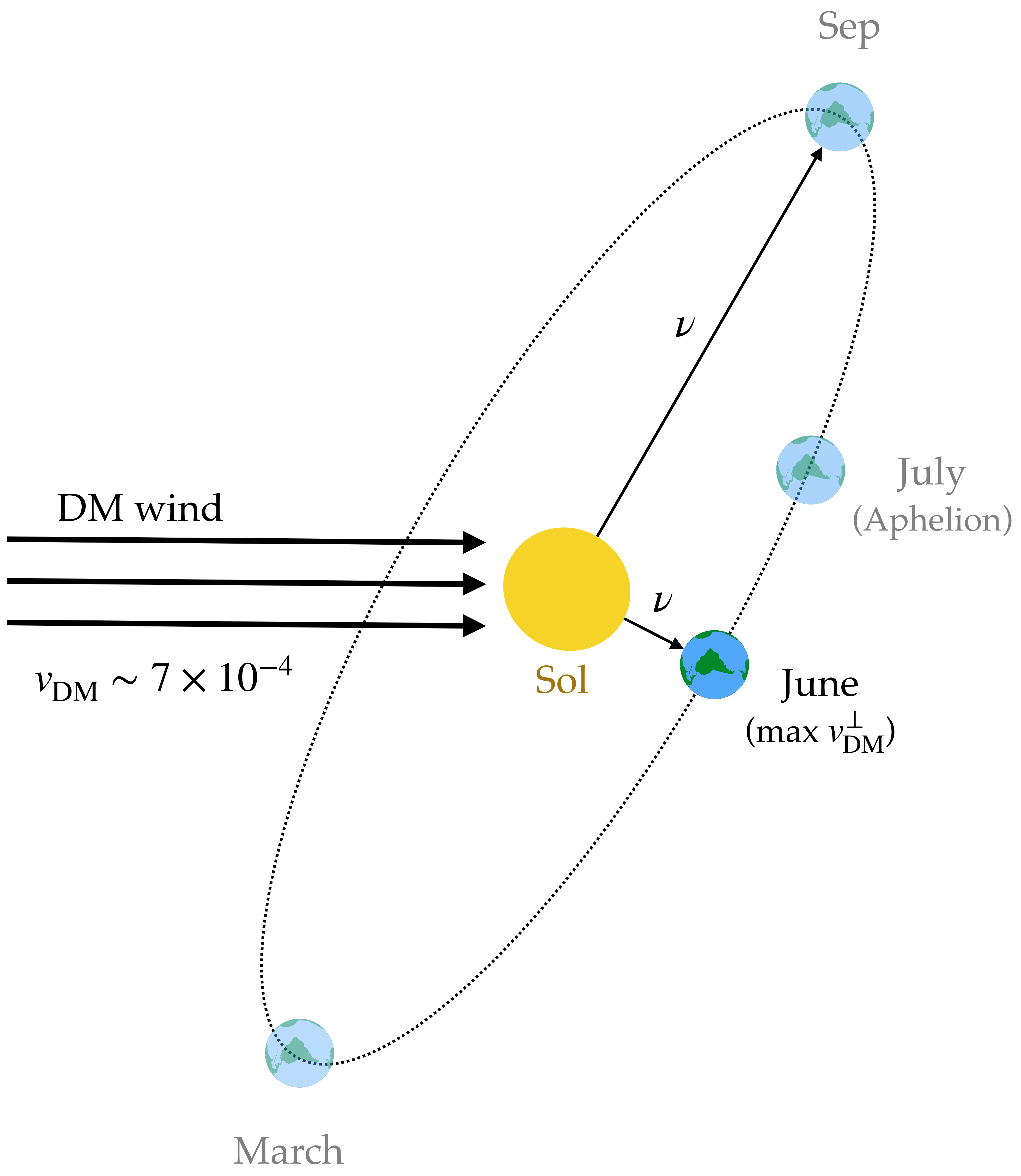
Solar antineutrino modulation

$$P_{\nu\to\bar{\nu}} = \sin^2\left(\frac{\sqrt{2\rho_{\rm DM}}}{f}\frac{m_\nu}{E_\nu}v_\perp\frac{\sin(m_J L)}{m_J}\right)$$



Solar antineutrino modulation



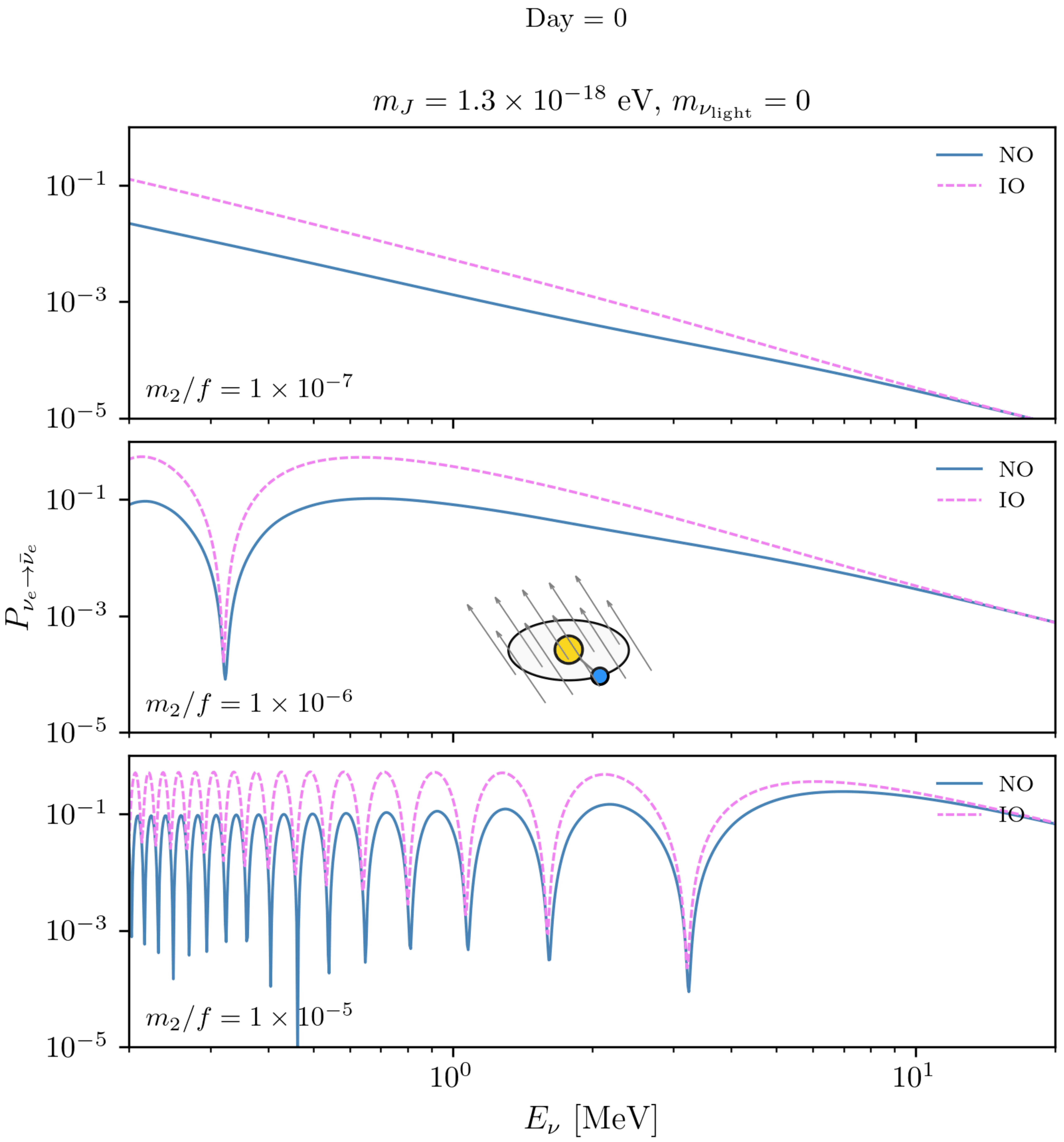


Solar antineutrino modulation

Largest antineutrino component
at low energies (hard to see).

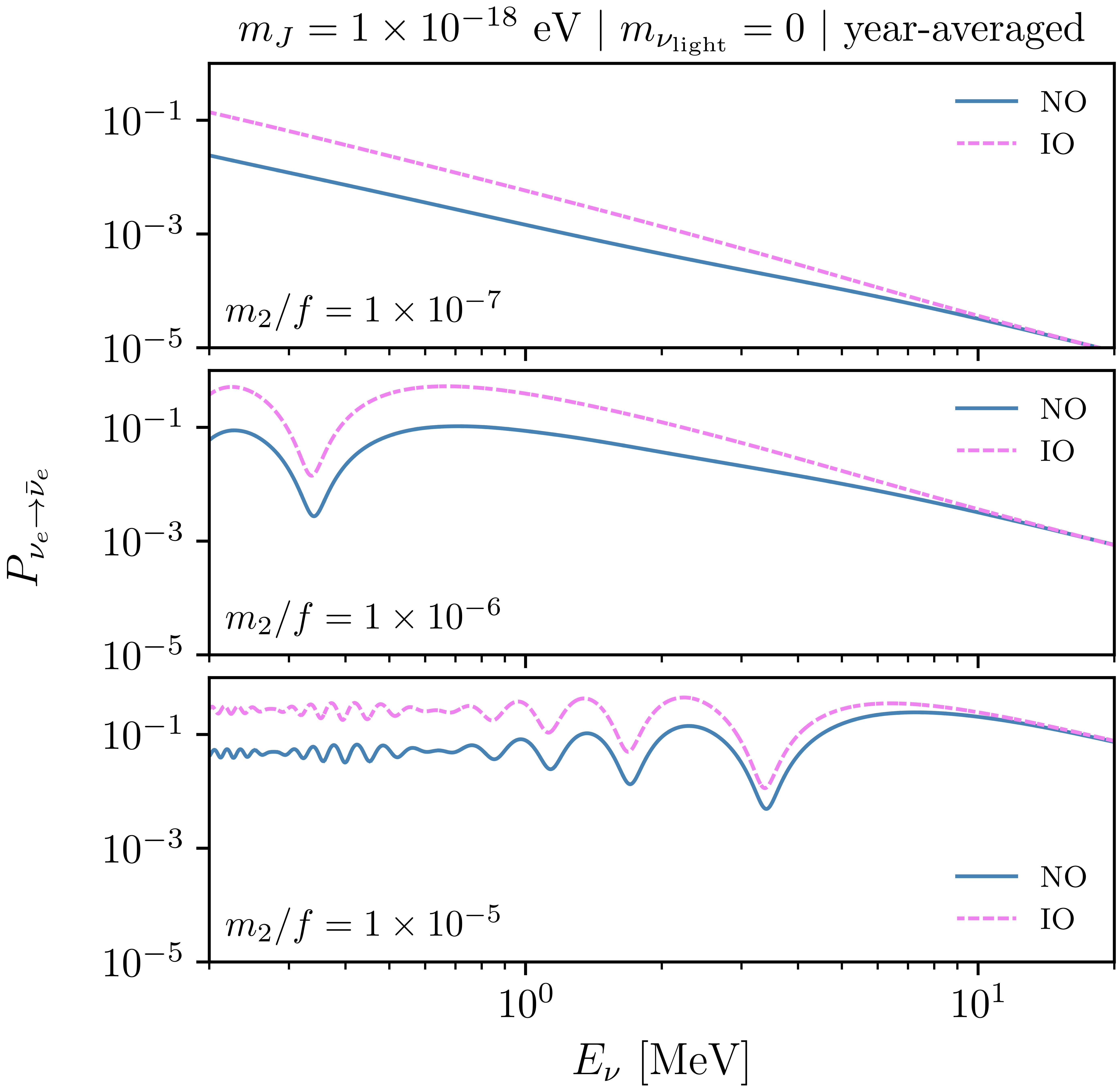
At 10 MeV, modulation is basically
a 10% shift up and down in rate.

Almost no difference between NO and IO.
(effect is dominated by ν_2)

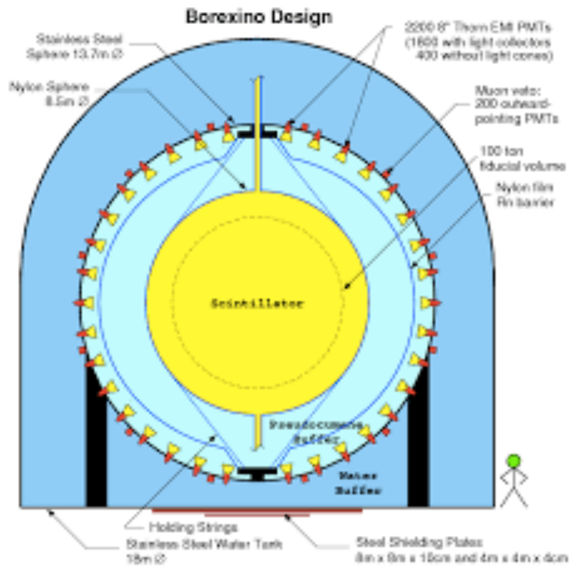


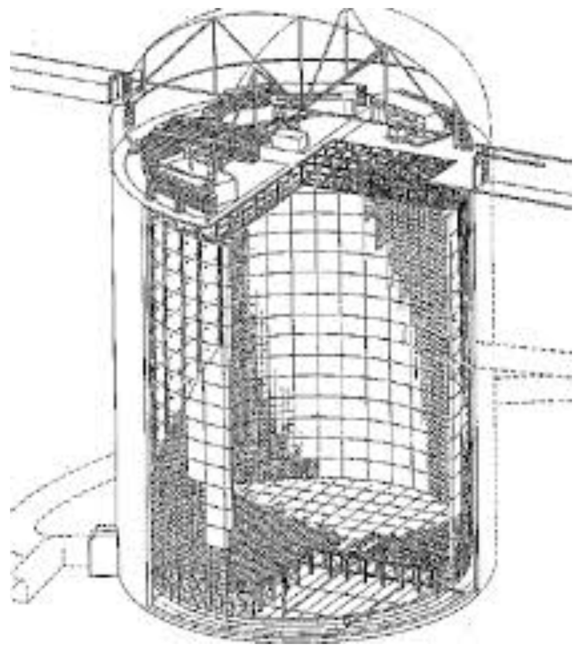
Solar antineutrino modulation

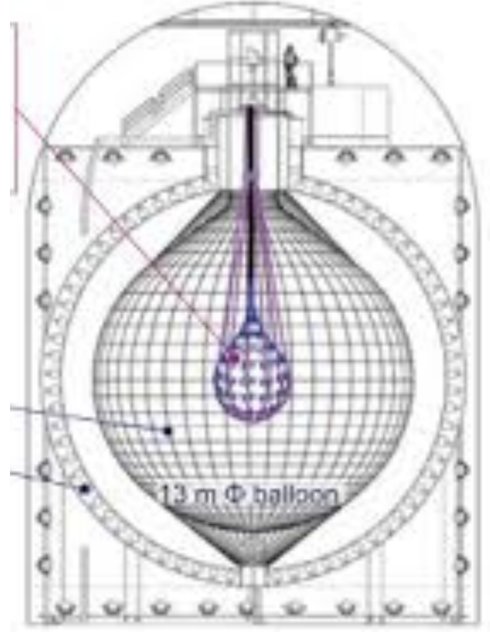
Yearly-average.



Solar antineutrino signal estimation



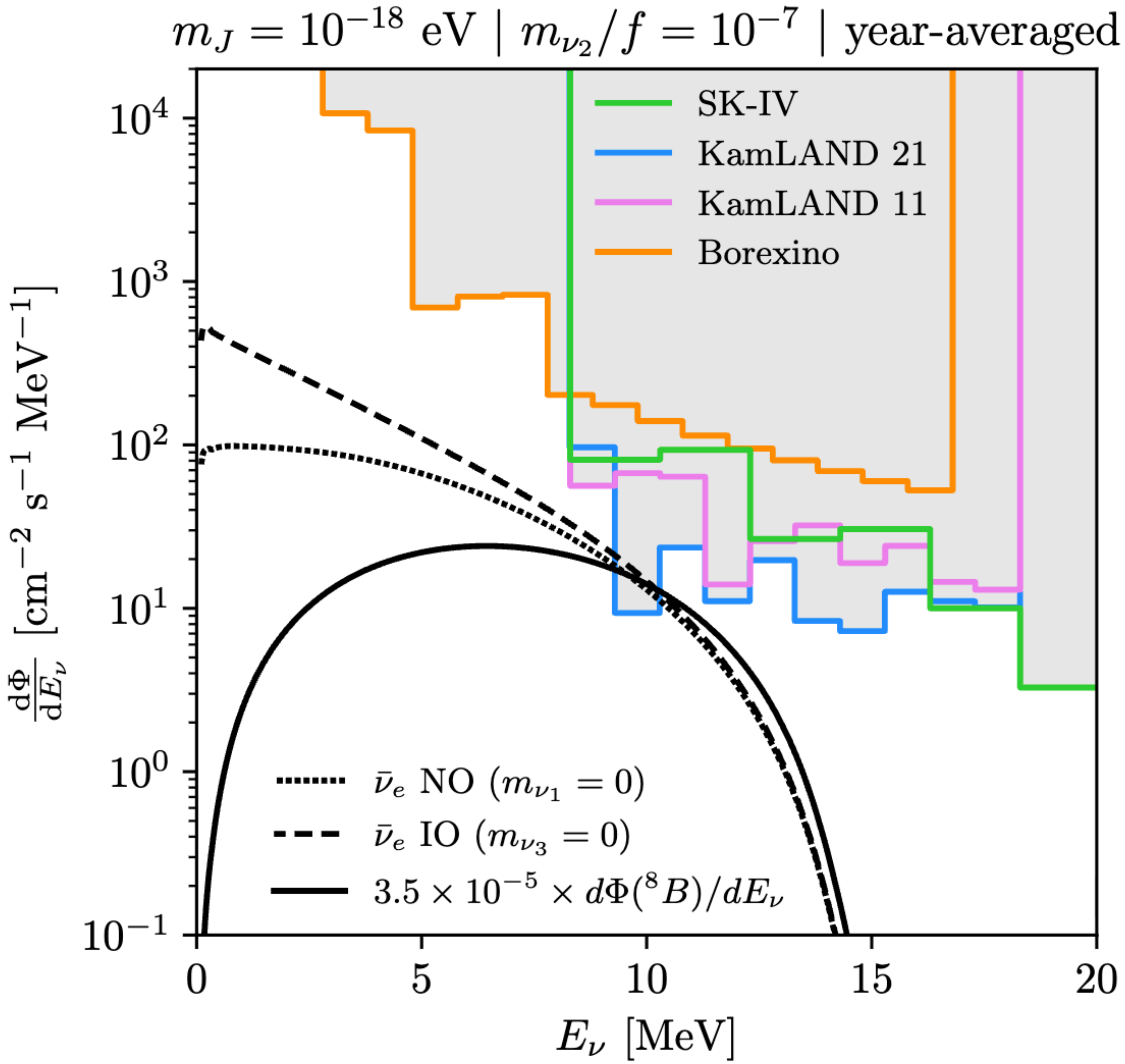




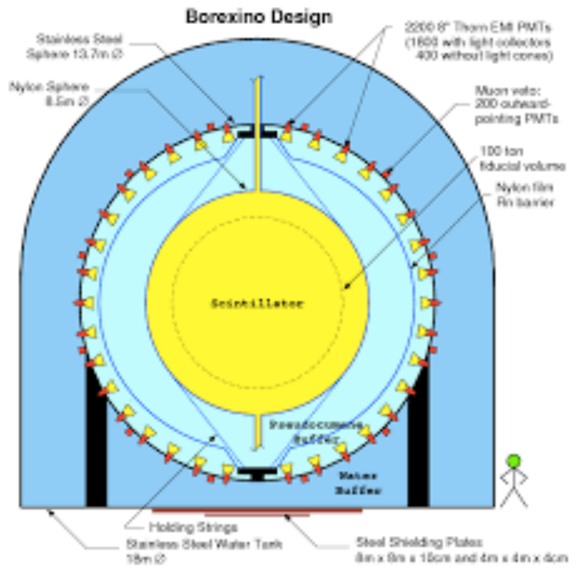
$$P^{\text{Borexino}}_{\nu_e \to \overline{\nu_e}}(E_\nu \geq 1.8 \text{ MeV}) < 7.2 \times 10^{-5}$$

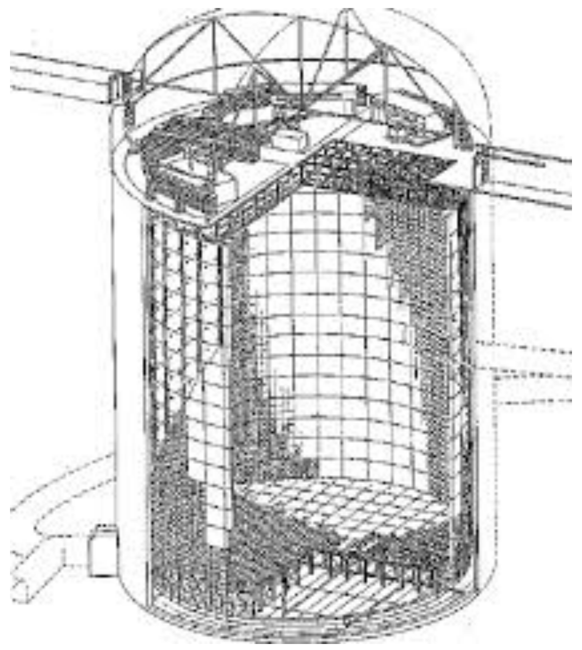
$$P^{\text{KamLAND}}_{\nu_e \to \overline{\nu_e}}(E_\nu \geq 8.3 \text{ MeV}) < 5.3 \times 10^{-5}$$

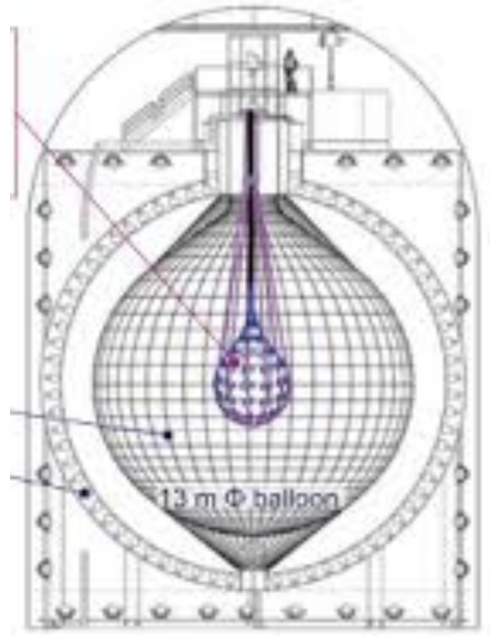
$$P^{\text{SK-IV}}_{\nu_e \to \overline{\nu_e}}(E_\nu \geq 9.3 \text{ MeV}) \lesssim 1.0 \times 10^{-4}$$

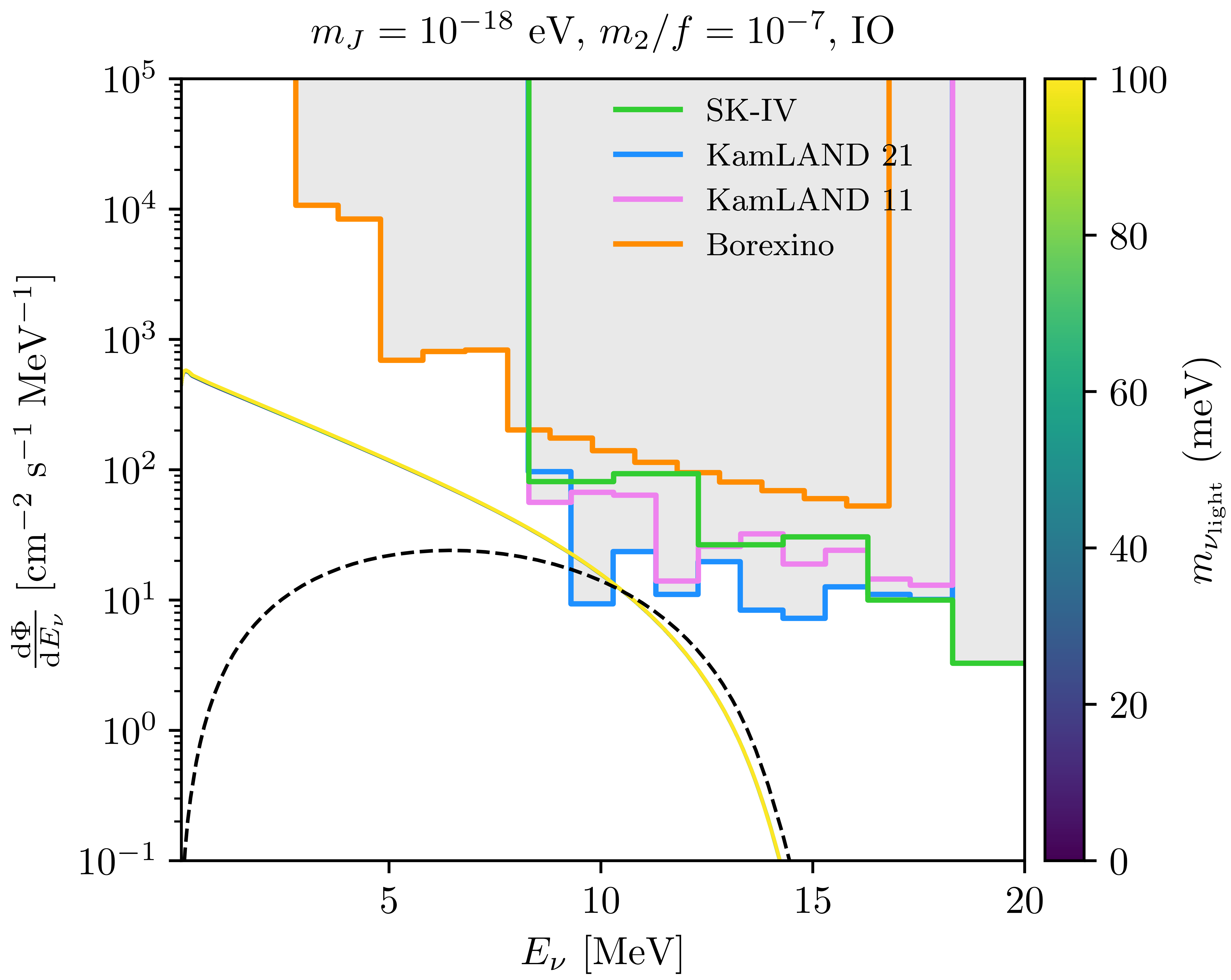


Solar antineutrino signal estimation









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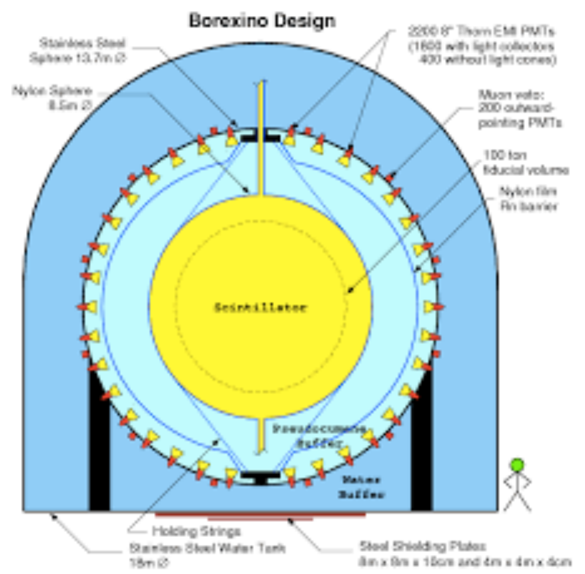
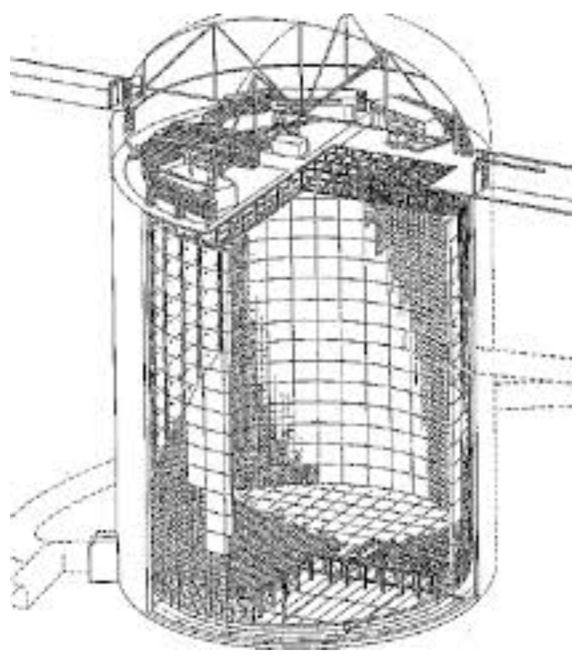
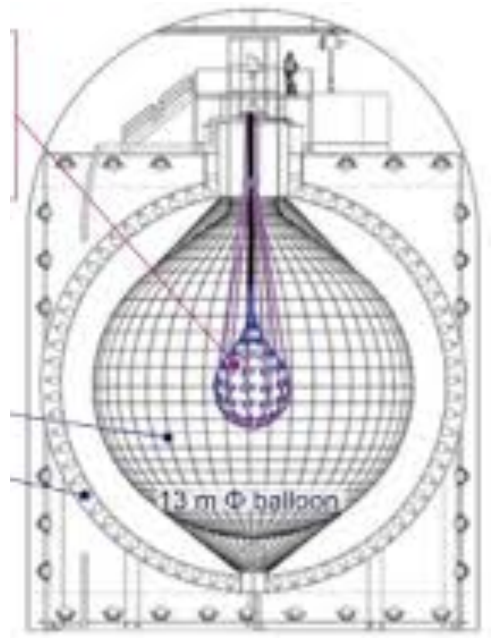
Solar antineutrino signal estimation







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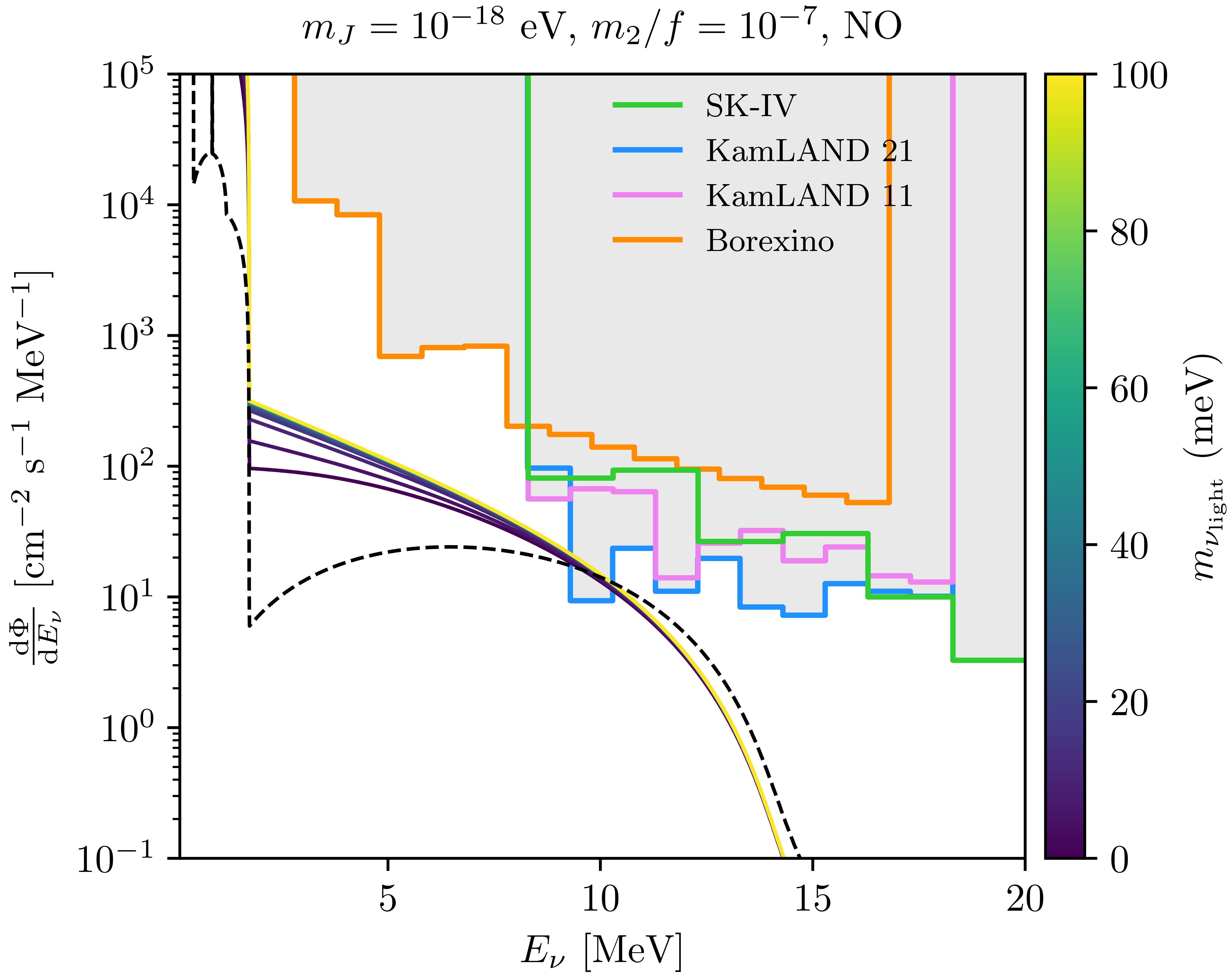
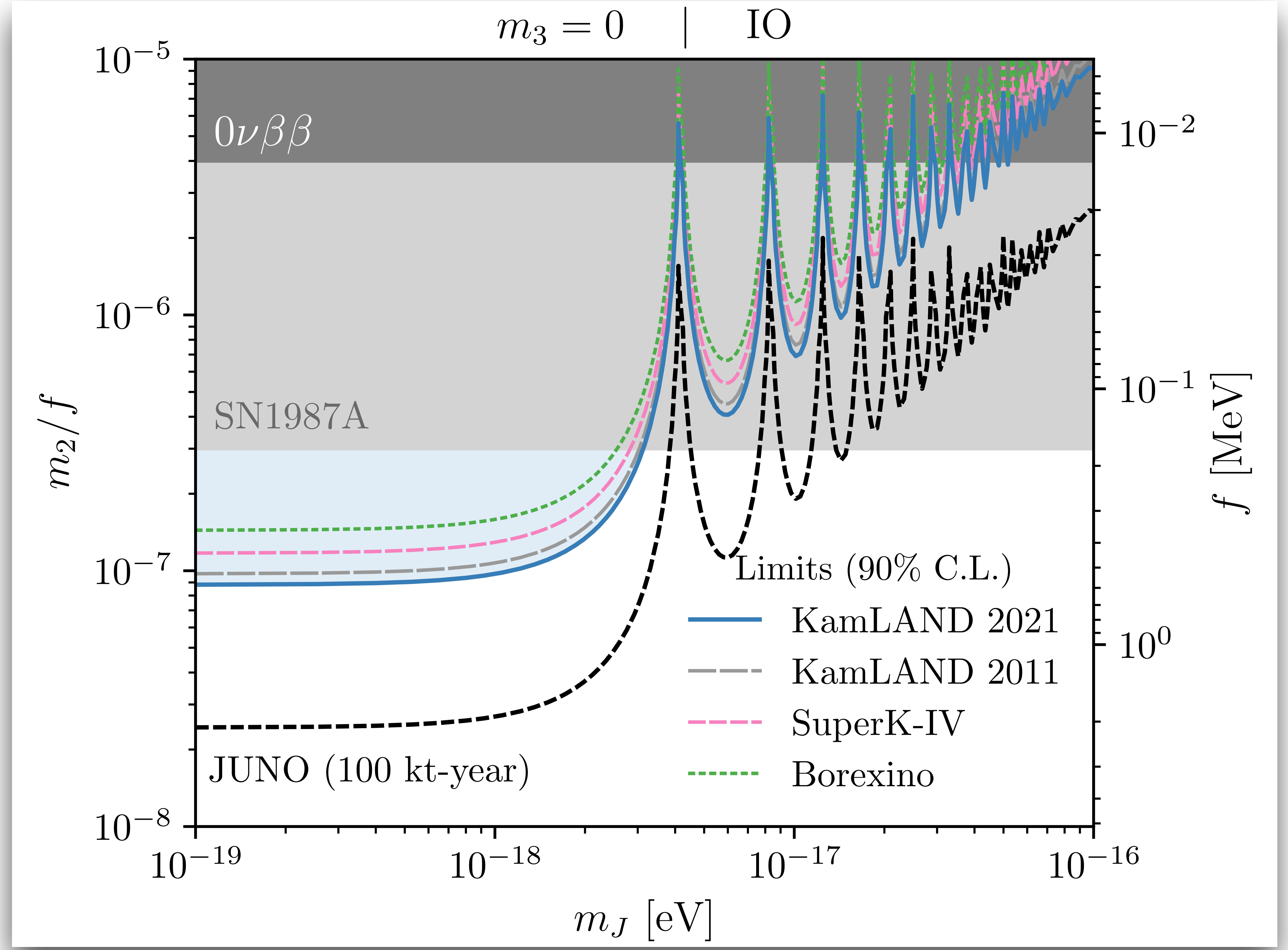


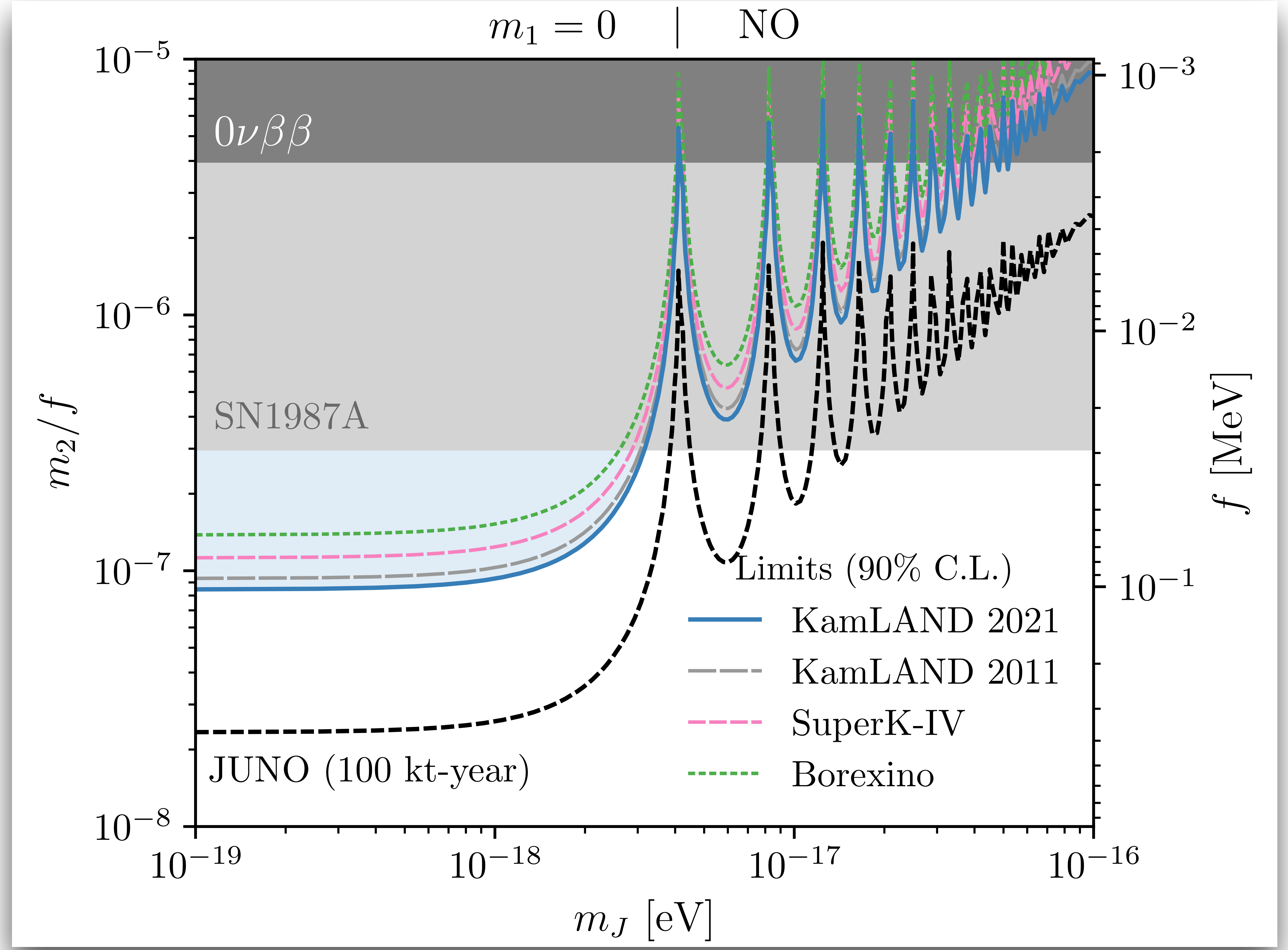
Solar antineutrino results

Inverted Ordering



Solar antineutrino results

Normal Ordering

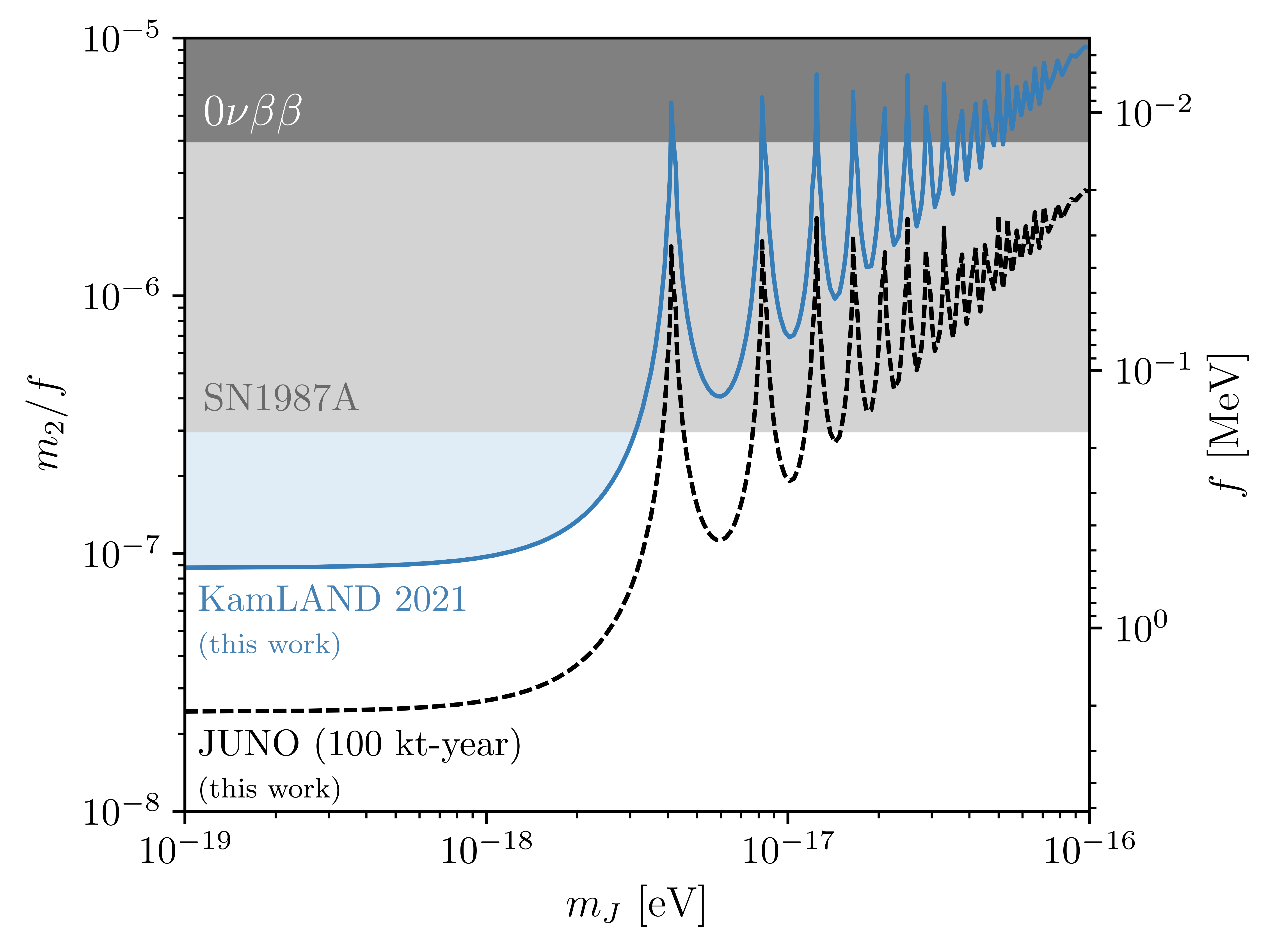


Solar antineutrino results

Dominant constraint up to:

Lyman-α: $m_J \lesssim 10^{-21}$ eV

M87* spin constrains:
$m_J \sim 3 \times 10^{-21}$ eV
(H. Davoudiasl, P. Denton)



Other superradiance:

$m_J \sim 10^{-13} - 10^{-12}$ eV

Supernova neutrino-antineutrino conversion

Huge ν_e burst from neutronization phase:

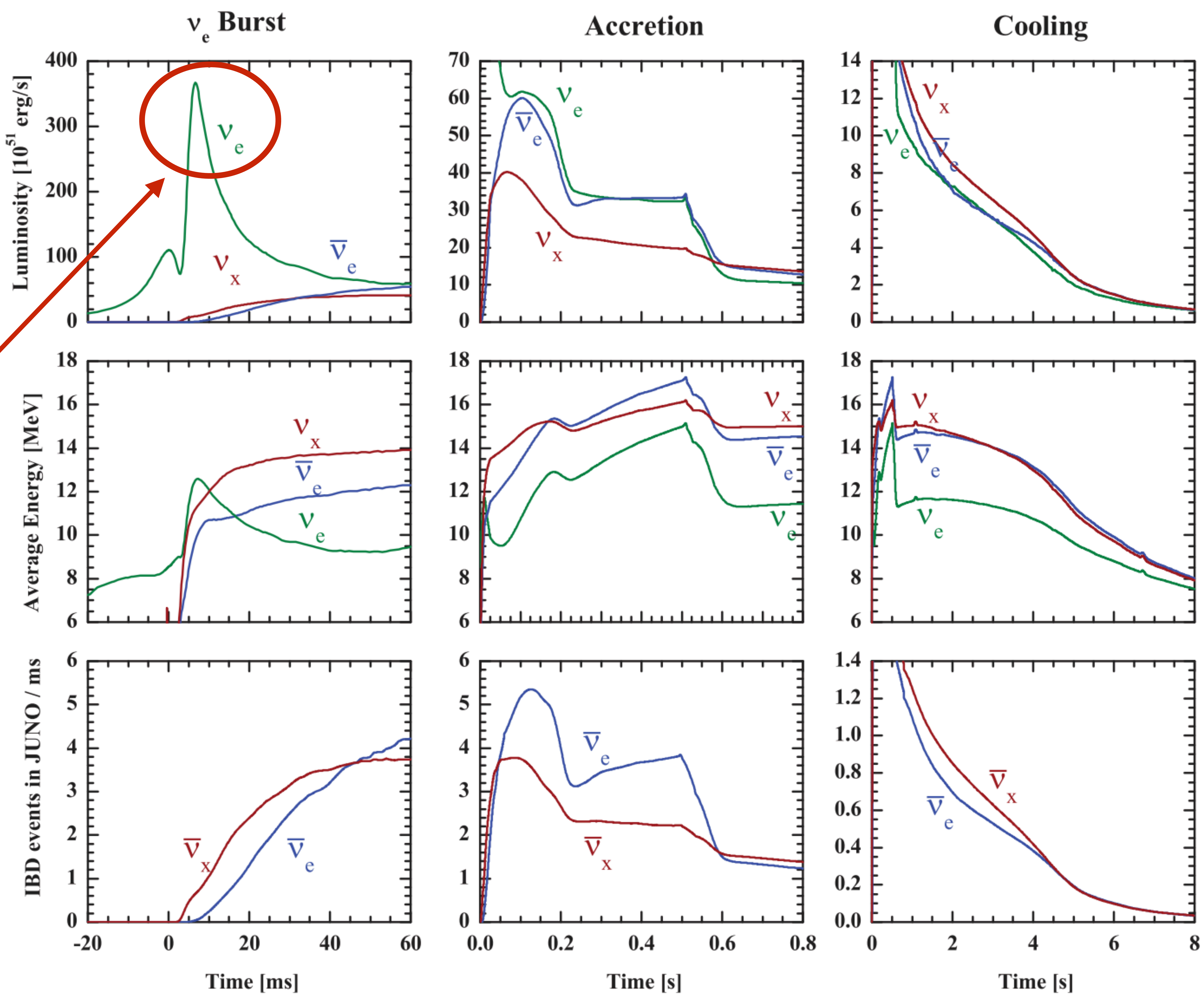
$$e^- + p^+ \to n + \nu_e$$

This feature is rather robust and independent of simulations and explosion mechanism.

This is especially interesting for detectors like **DUNE**, that can see ν_e**CC**

$$\nu_e + \text{Ar} \to e^- + \text{K}^*$$

The subsequent antineutrino components can then be detected with **IBD** at **JUNO** and **Hyper-K.**



Supernova neutrino-antineutrino conversion

Barring any major modification to the physics of supernovae, a majoron background would effectively convert the ν_e burst into a $\nu_e + \bar{\nu}_e$ **burst**

If an IBD signal is seen with similar strength to ν_eCC, then this could explain it. Similarly for **accretion** phase.

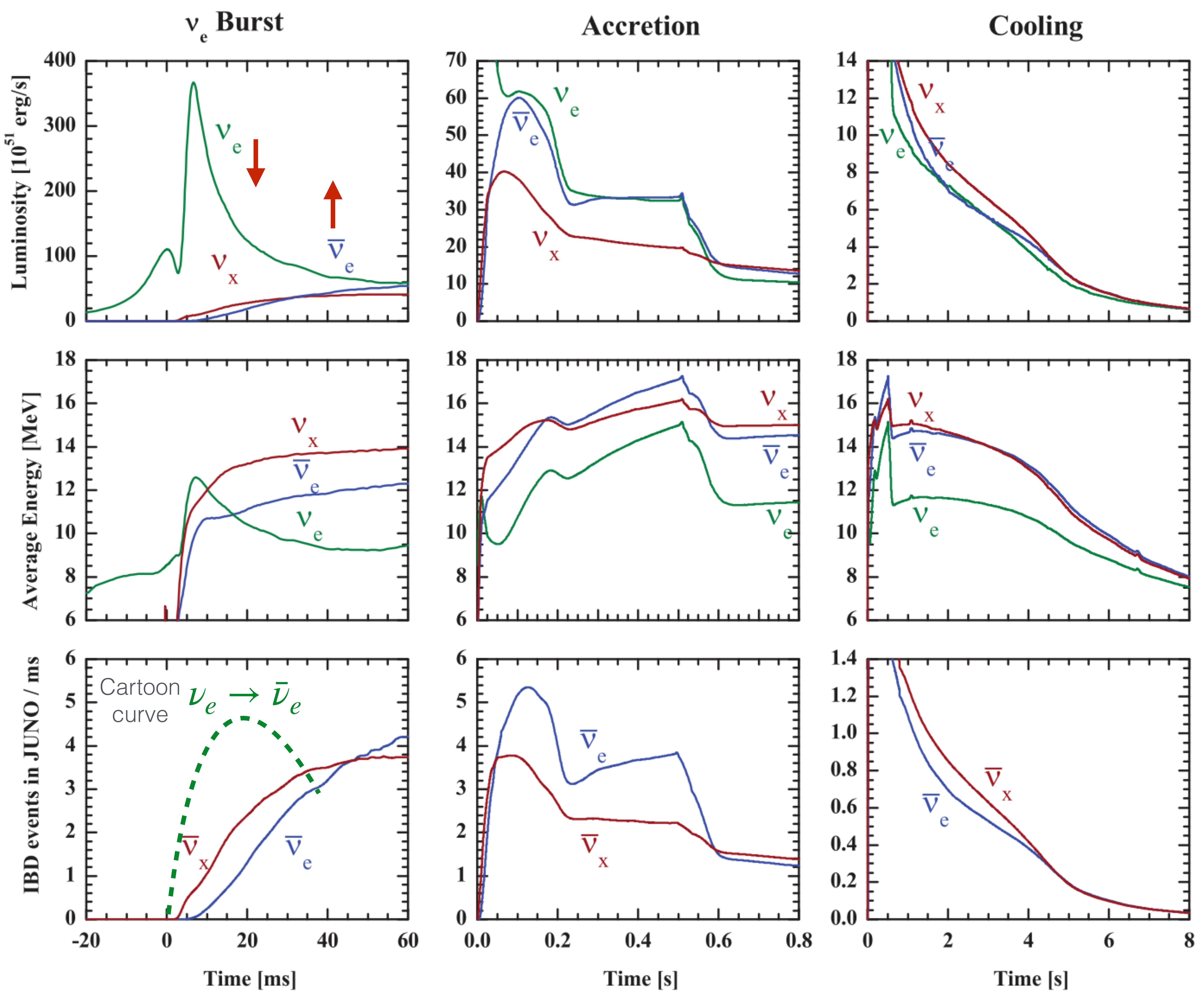
For neutrinos traveling 10 kpc, the conversion is maximized for $m_J \lesssim 10^{-27}$ eV.

Such low mass field must be a sub-component of DM (at most % level of total cosmological DM).

In that case, expect sensitivity to

$$m_\nu/f \sim \mathcal{O}(10^{-11})$$

far below other limits.



Conclusions

Reviewed some aspects of majoron couplings to matter.

Pointed out new effect from neutrino spin precession in J background.

New solar antineutrino limits exclude new parameter space for $m_J < 10^{-17}$ eV.

A galactic supernova would provide new opportunity for majorons as *fractional DM* with $m_J \lesssim 10^{-27}$ eV.