KATRIN and the dark MSW effect

Probing neutrino interactions with a dark background field

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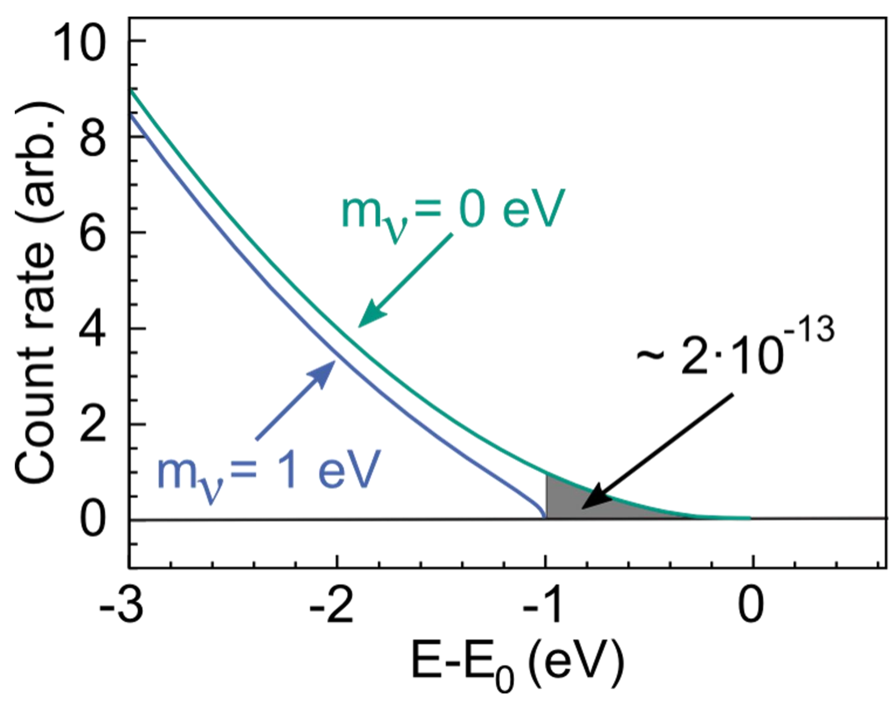
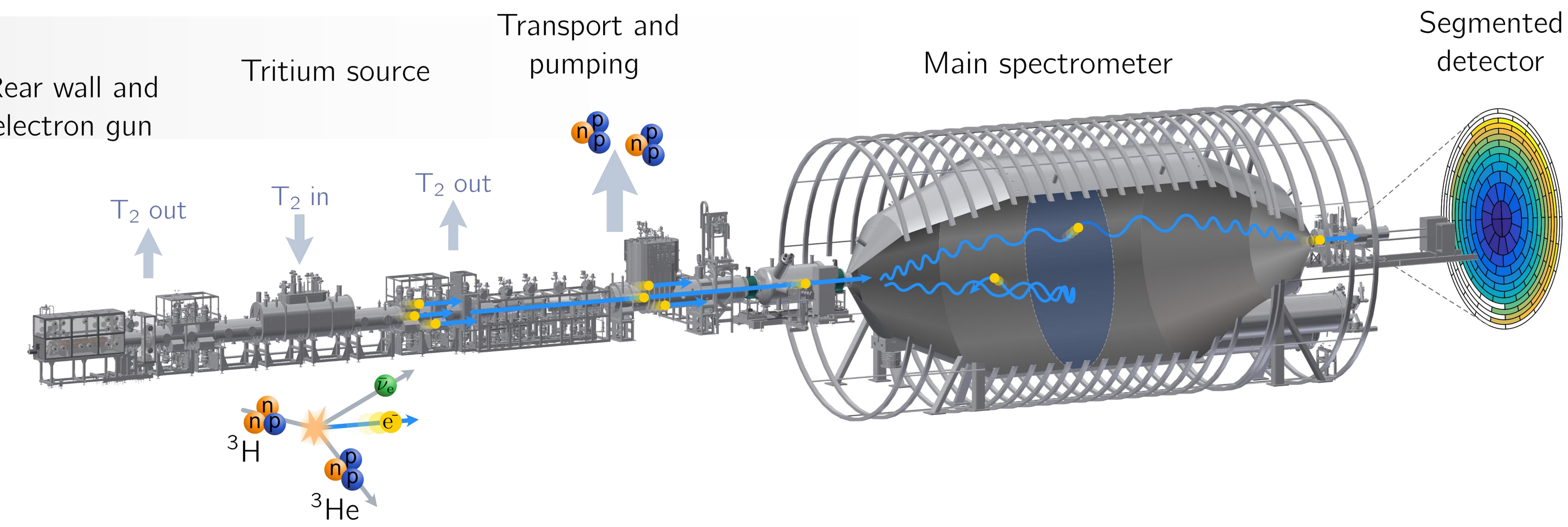
- KATRIN aims at measuring the **mass of the electron neutrino** with a sensitivity of better than 0.3 eV at 90 % CL.
- For this purpose **precision spectroscopy** of the **tritium β decay** is performed.





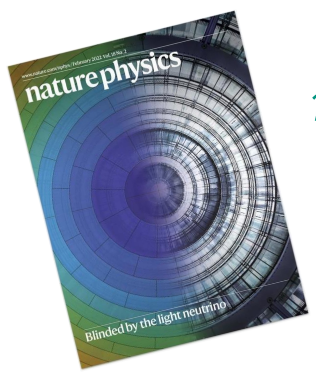
- Spectrum **shape for non-zero m_ν^2 is distorted** close to the Endpoint energy E_0:

$$\frac{d\Gamma}{dE} \propto (E_0 - E) \cdot \sqrt{(E_0 - E)^2 - m_{\nu_e}^2} \cdot \theta(E_0 - E - m_{\nu_e})$$

- With the **model-independent** kinematic approach, the **effective neutrino mass** is probed:

$$m_{\nu_e}^2 = \sum |U_{ei}|^2 \, m_i^2$$

- **MAC-E filter** principle: β spectrum is measured in an integrating mode.



$m_{\nu_e} < 0.8$ eV

(90 % CL)

10.1038/s41567-021-01463-1

Dark MSW Effect:

- Dark background field coupling to neutrino can have different forms:

$$-\mathcal{L} \supset (g_\phi \phi \bar{\nu}\nu + g_\varphi \varphi \bar{\nu}\gamma_5\nu + g_V V_\mu \bar{\nu}\gamma^\mu\nu + g_a a_\mu \bar{\nu}\gamma_5\gamma^\mu\nu + g_T T_{\mu\nu}\bar{\nu}\sigma^{\mu\nu}\nu)\ \delta_M$$

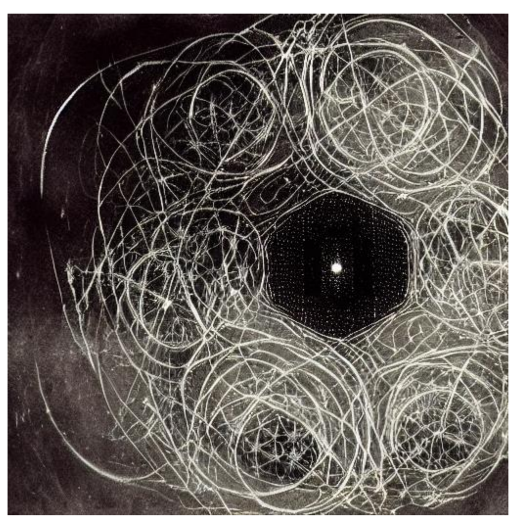
- Leads to modified neutrino dispersion relation:

$$(E_\nu - g_V V_0)^2 = (|p_\nu| - \hat{p}\cdot\Sigma g_a a_0)^2 + (\hat{M}_\nu + g_\phi\phi)^2 + (|g_\varphi|\varphi)^2$$

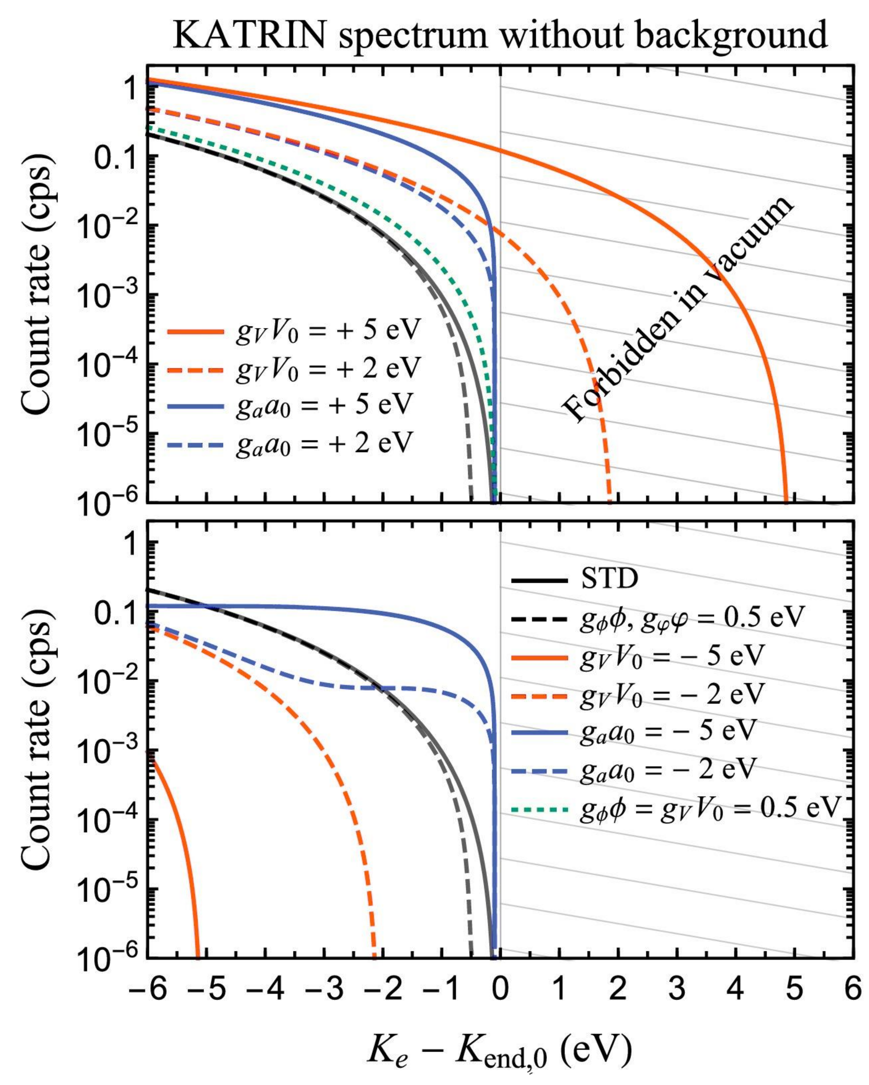
Motivation

- ν and DM sector call for extension of SM
- ν-DM interactions could alleviate several tensions (Hubble crisis, steriles, observations of small scale structures)
- There are hints for such interactions in Lyman α data (10.1103/PhysRevD.105.103504)
- Neutrino oscillation experiments not sensitive if coupling is equal between ν generations, if it originates from ultralight DM or if the field oscillates fast.

What AI thinks Neutrino-DM interactions look like



Effects on β-spectrum



Axial vector field $g_a a_\mu$

- Causes distinct modification of spectrum shape
- Effect is helicity dependent
- Search for shape variations in β-spectrum

Tensor field $g_T T_{\mu\nu}$

- No effect since field is assumed to be purely time-like, thus has no preference of spacial orientation

Studies at KATRIN:

(Pseudo)scalar field $g_\varphi\varphi / g_\phi\phi$

- Mimics neutrino mass
- Possibility of dark field being the origin of neutrino mass
- Two analysis scenarios (values based on KNM1+2 data):
  - *Case 1:*
    m_ν is purely generated by dark field
    $g_\phi\phi = g_\varphi\varphi < 0.87$ eV @ 95% CL
    Best fit: (0.1 ± 0.3) eV^2
  - *Case 2:*
    External constraint for m_ν from $0\nu\beta\beta$ assuming negligible LNV coupling (based on most recent results from GERDA and KamLAND-Zen @ 95% CL):
    IO: $g_\phi\phi = g_\varphi\varphi < (0.09 - 0.82)$ eV
    NO: $g_\phi\phi = g_\varphi\varphi < (0.09 - 0.66)$ eV

Vector field $g_V V_\mu$

- Causes global shift in neutrino energy E_ν, possibly beyond normal kinematic limit E_0
- Shift direction dependent on $\nu / \bar{\nu}$
  -> Possible cross check with ECHo and HOLMES
- Constraints can be derived from comparison of Q values with external penning trap measurements

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