NuDoubt^{++}

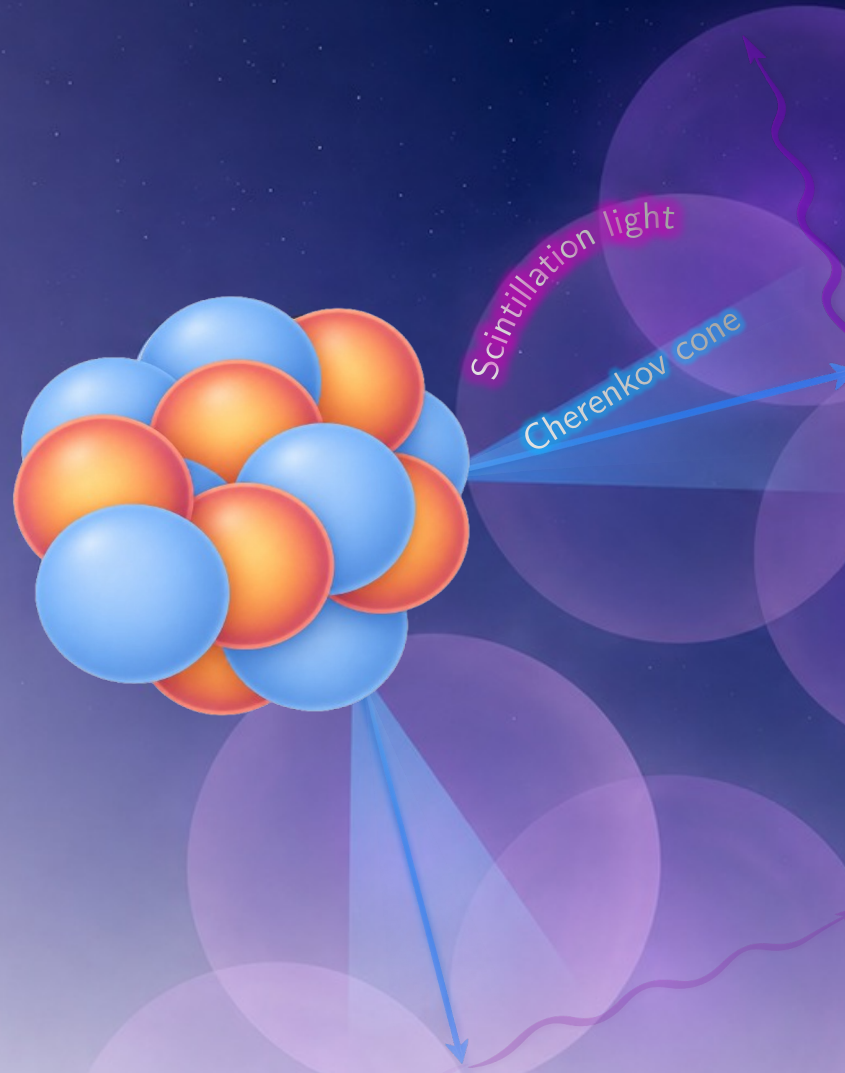
Search for Double Beta Plus Decays

Veronika Palusova - on behalf of NuDoubt^{++} collaboration

NNN

October 28, 2026

Seoul, South Korea



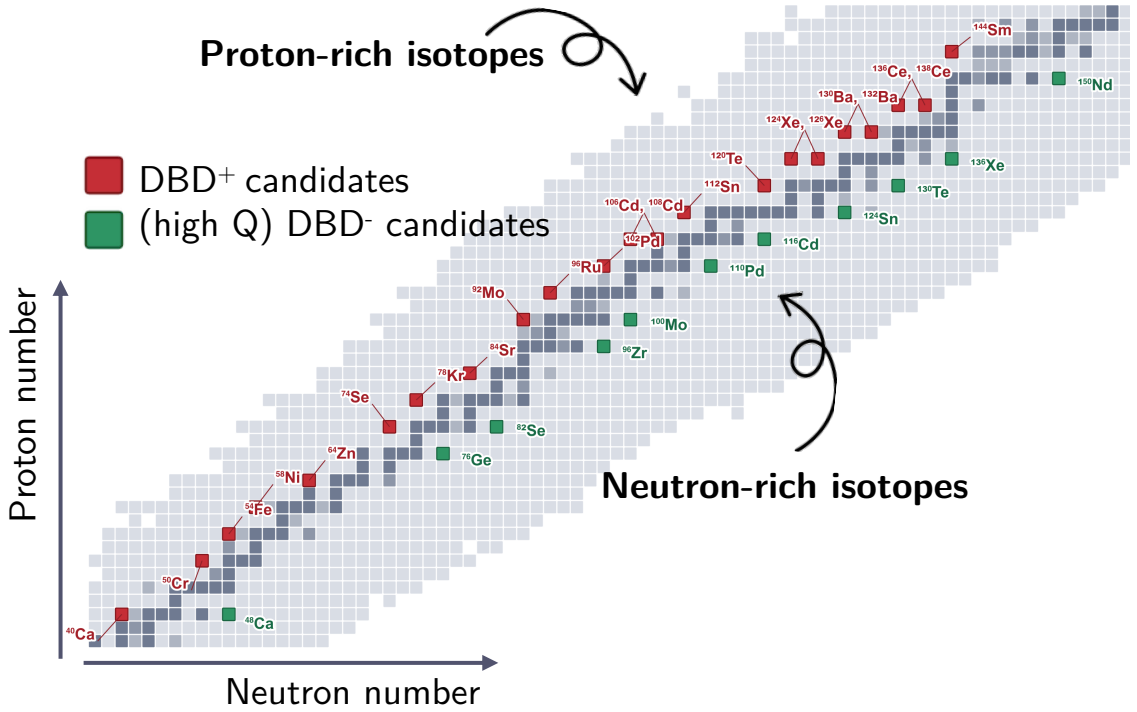
JGU
PRISMA DETECTOR LAB
Funded by the European Union
erc European Research Council Established by the European Commission
Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation
GSPD Graduate School Particle Detectors

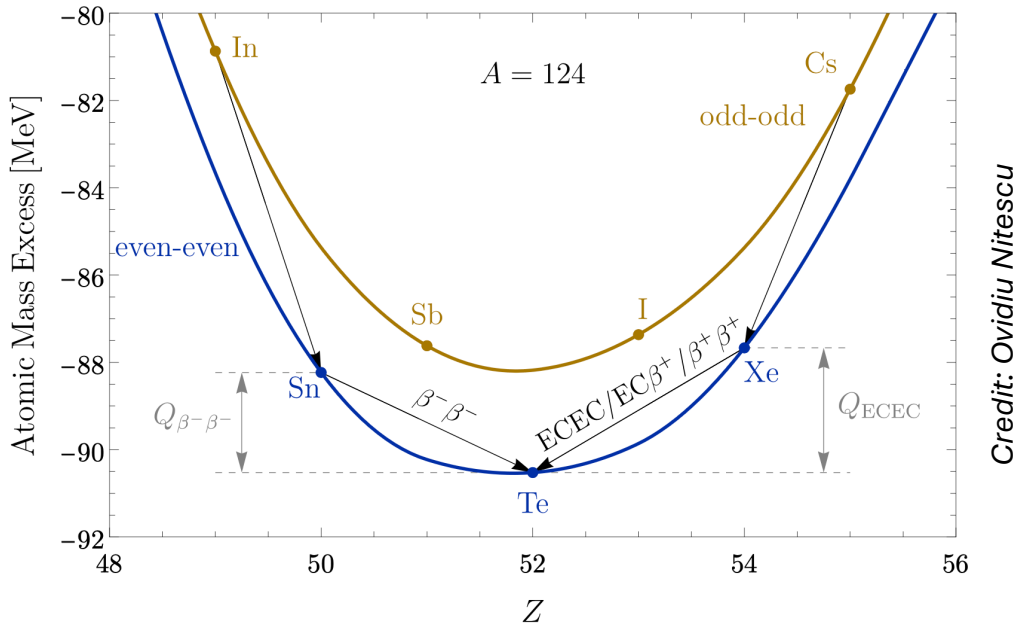
Double beta plus decays
Introduction

- Same second-order weak transition as "ordinary" double beta$^-$ decay

In some proton-rich isotopes:

- Single beta-plus (β^+) decay is energetically forbidden
  → Simultaneous decay of two protons can be allowed





- Electron capture competes with positron emission in proton-rich nuclei
- Same nuclear conversion, different charged-lepton channels

$$\beta^+\beta^+: (A,Z+2) \rightarrow (A,Z) + 2e^+ + 2\nu_e$$

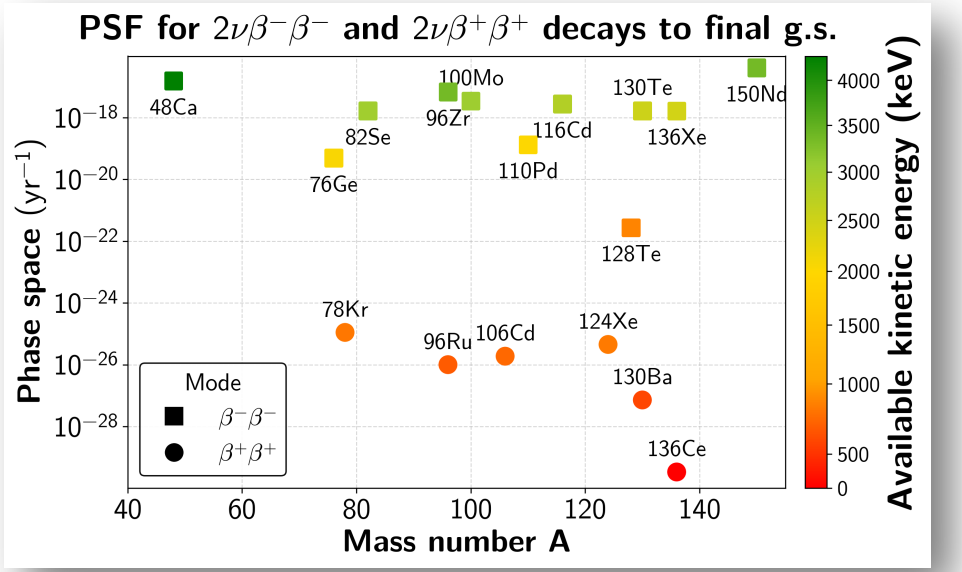
$$\text{ECEC: } 2e^- + (A,Z+2) \rightarrow (A,Z) + 2\nu_e$$

$$\beta^+\text{EC: } e^- + (A,Z+2) \rightarrow (A,Z) + e^+ + 2\nu_e$$

Double beta plus decays

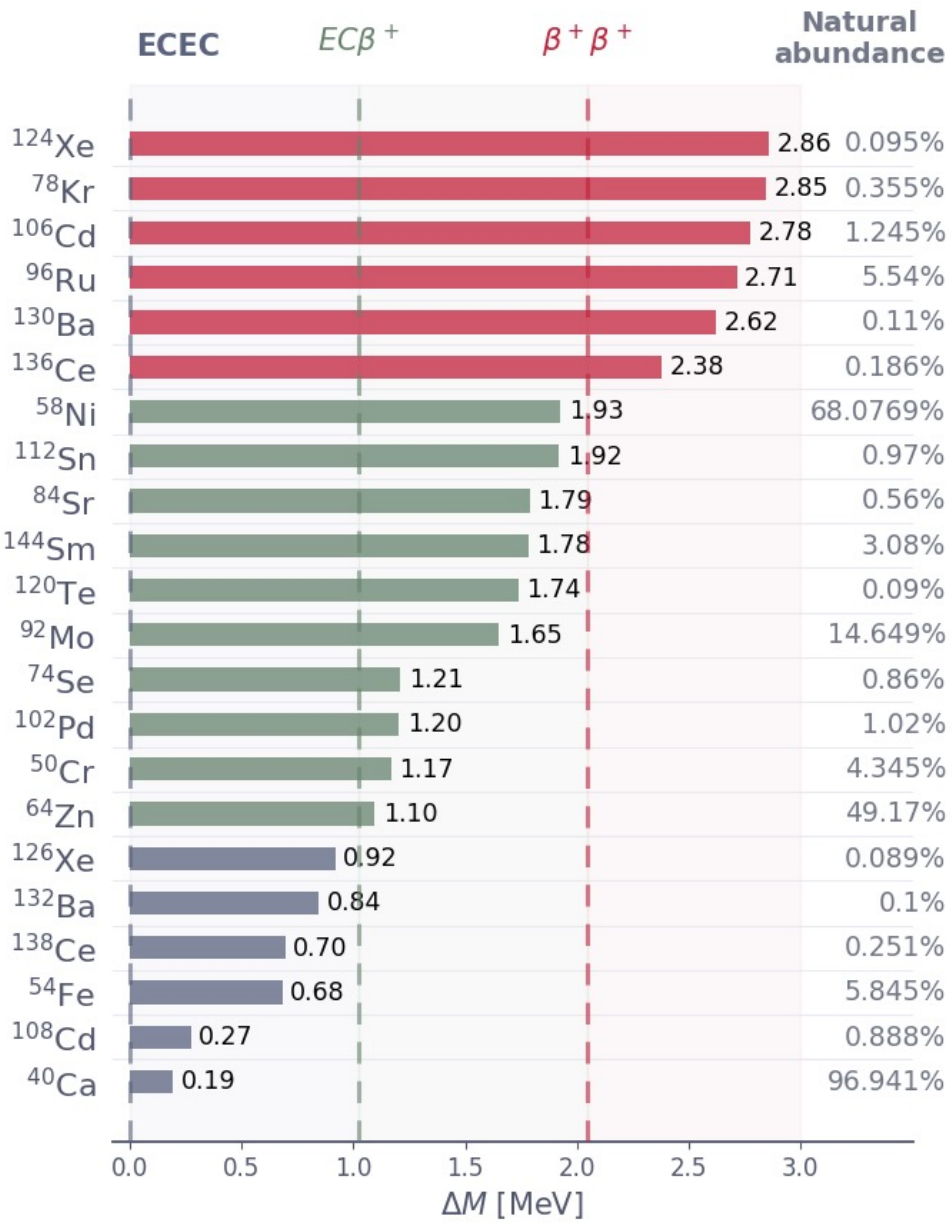
Introduction

- Every emitted positron reduces the available kinetic energy
  - → Less favorable Q values, more energetic decay → easier to separate from background
- Available energy determines which positive modes are open
  - → Only 6 isotopes can undergo all 3 DBD$^+$ modes
- $\beta^+\beta^+$ is strongly phase-space suppressed compared to $\beta^-\beta^-$
  - → Even longer expected $T_{1/2}$ than $\beta^-\beta^-$



PSF data from: S. Stoica and M. Mirea, Front. Phys. 7 (2019) 12

$Q(\beta^+EC) \approx \Delta M - 2m_e$ $Q(\beta^+\beta^+) \approx \Delta M - 4m_e$



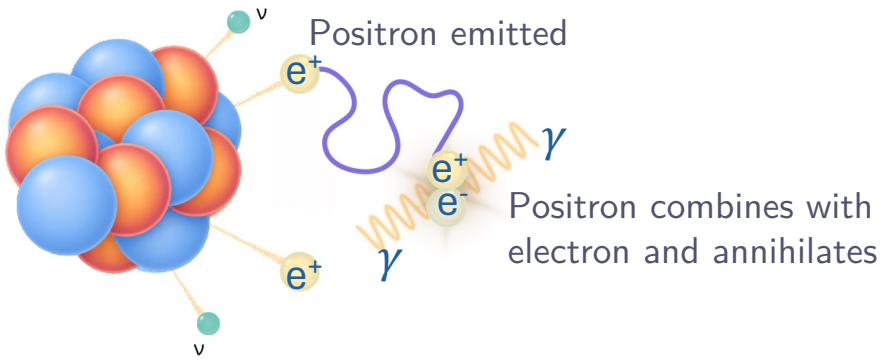
- Most nuclei also have very low natural abundance

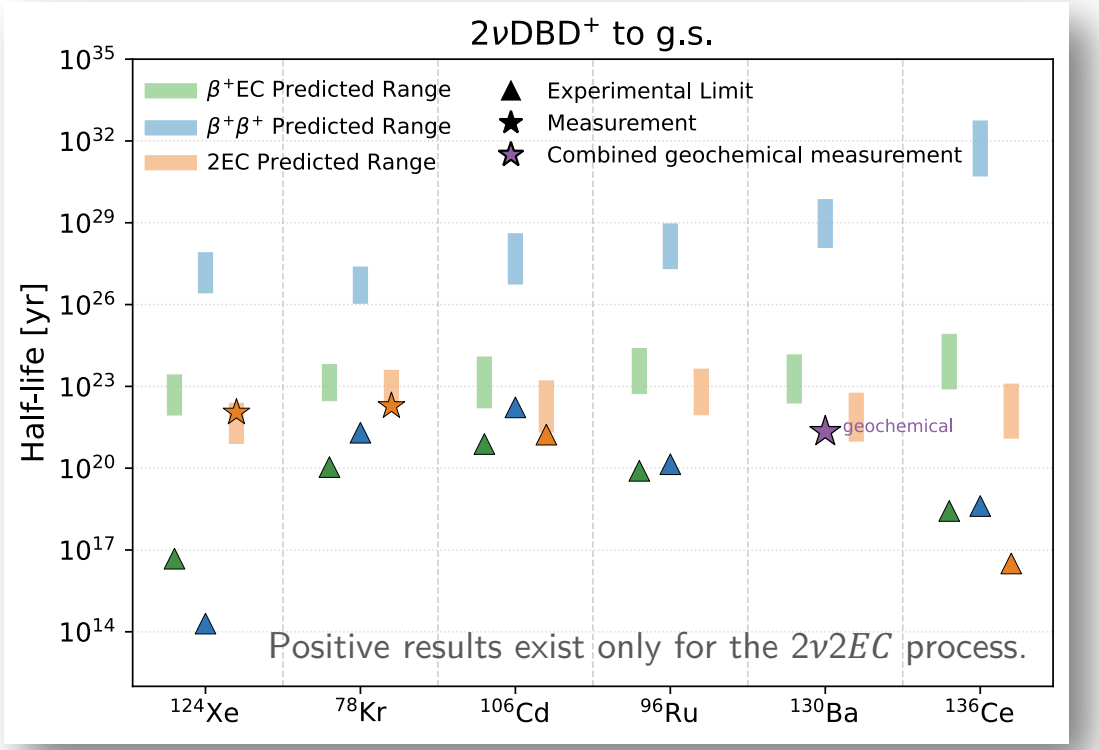
Double beta plus decays

Introduction

$T_{1/2}$ data from: Šimkovic and Nitescu (2026) & Gráf, Kotila, Scholer (2026)

- The phase-space suppression is severe, but positron annihilation provides a distinctive multi-site signature.



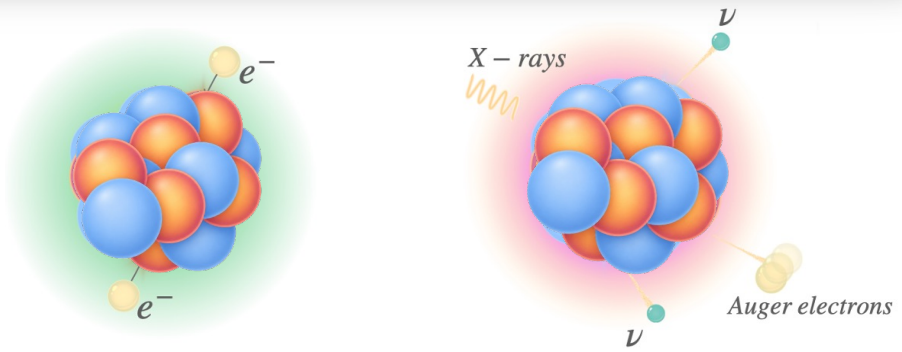


- If the positron energy, annihilation photons and atomic radiation are contained:

$$E_{max} \approx Q_{2\beta+} + 4m_e \approx QEC_{\beta+} + 2m_e \approx \Delta M$$

- **2EC:** Very weak direct signature: X-rays + Auger electrons, but larger PS

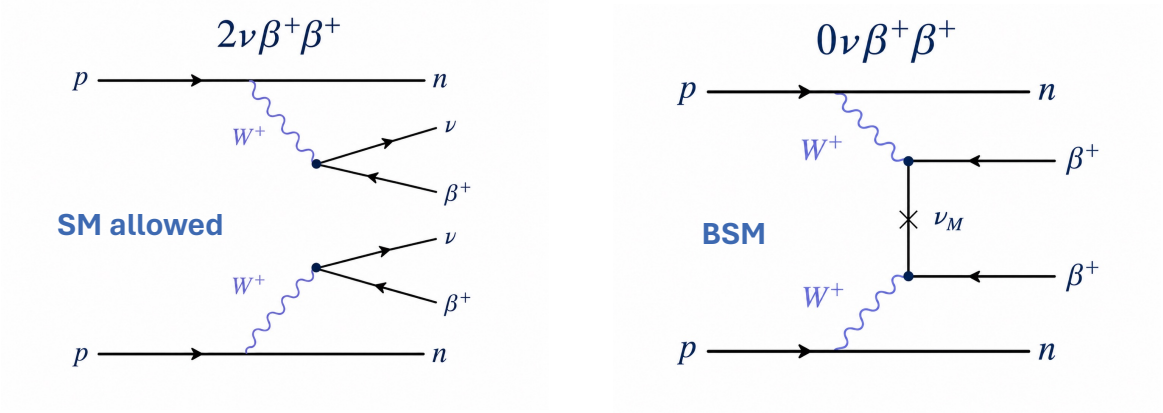
→ Emitted when atomic shell vacancies (from captured electrons) are filled, the neutrinos carrying away the energy Q are undetected



Double Beta Plus Decays

Beyond Standard Model

- The same nuclei support lepton-number-conserving 2ν decays and LNV 0ν searches

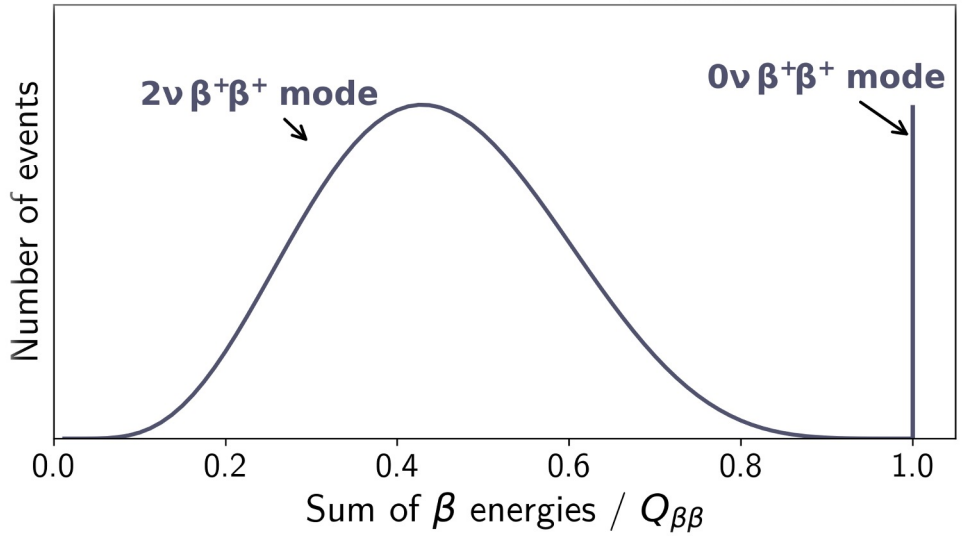


$0\nu\beta^+\beta^+$: (A,Z+2) → (A,Z) + $2e^+$

0νECEC: $2e^-$ + (A,Z+2) → (A,Z)

$0\nu\beta^+$EC: e^- + (A,Z+2) → (A,Z) + e^+

$\Delta L = 2$



- The released energy is carried by the charged leptons and electromagnetic de-excitation products
- Their nuclear and leptonic responses differ from $0\nu\beta^-\beta^-$, making them complementary probes of the underlying LNV mechanism.

No positive 0ν mode (and no $2\nu EC\beta^+$ or $2\nu\beta^+\beta^+$) has yet been observed

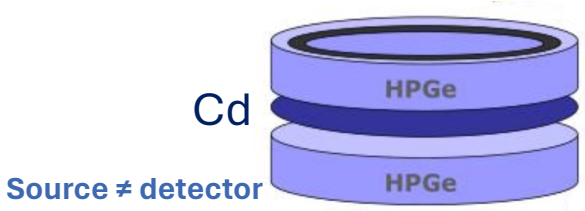
Double Beta Plus Decays

Experimental approaches

- **Geochemical and radiochemical** - Daughter-isotope accumulation over long timescales; integrated decay rate only (e.g. ^{130}Ba $\rightarrow ^{130}$Xe result)
- **Direct detection** - event-by-event energy measurement, often combined with coincidence signatures

Coincidence-based approaches using enriched ^{106}Cd

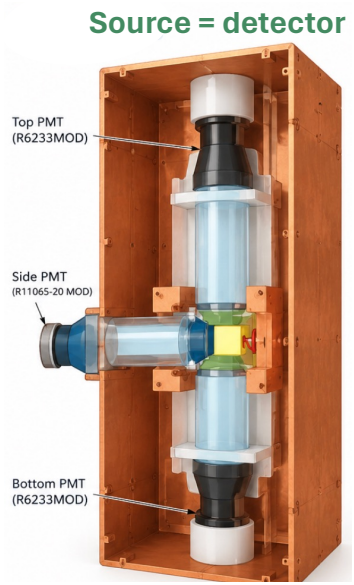
Enriched ^{106}Cd source + HPGe or $^{106}CdWO_4$ counters



TGV-2: J. Phys. Conf. Ser. 2156 (2022) 012134

- Enriched $^{106}CdWO_4$ crystal as source and detector
- Two external $CdWO_4$ scintillators for 511 keV coincidence tagging
- Three PMTs (top, bottom, side)

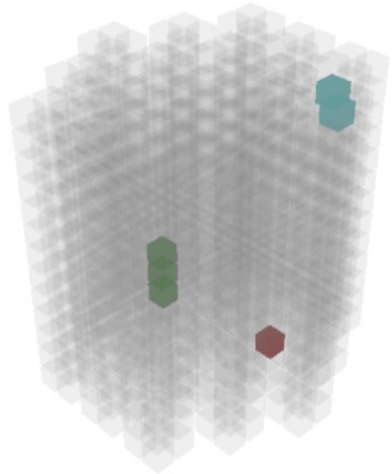
Universe 11(4), 123 (2025)

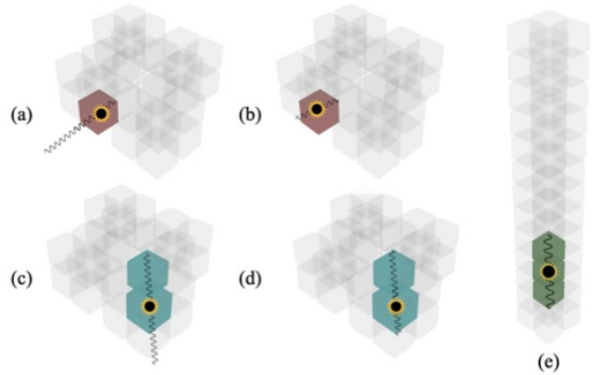


$\lim T_{1/2} = 10^{20} - 10^{22}$ years

^{120}Te CUORE — Segmented TeO_2 bolometer array

$0\nu EC\beta^+$: primary deposit plus one or two 511-keV deposits





limit of $2.9 \cdot 10^{22}$ yr

CUORE Collaboration, Phys. Rev. C 105, 065504 (2022)

Multiple final-state particles complicate energy containment but provide coincidence and topology handles

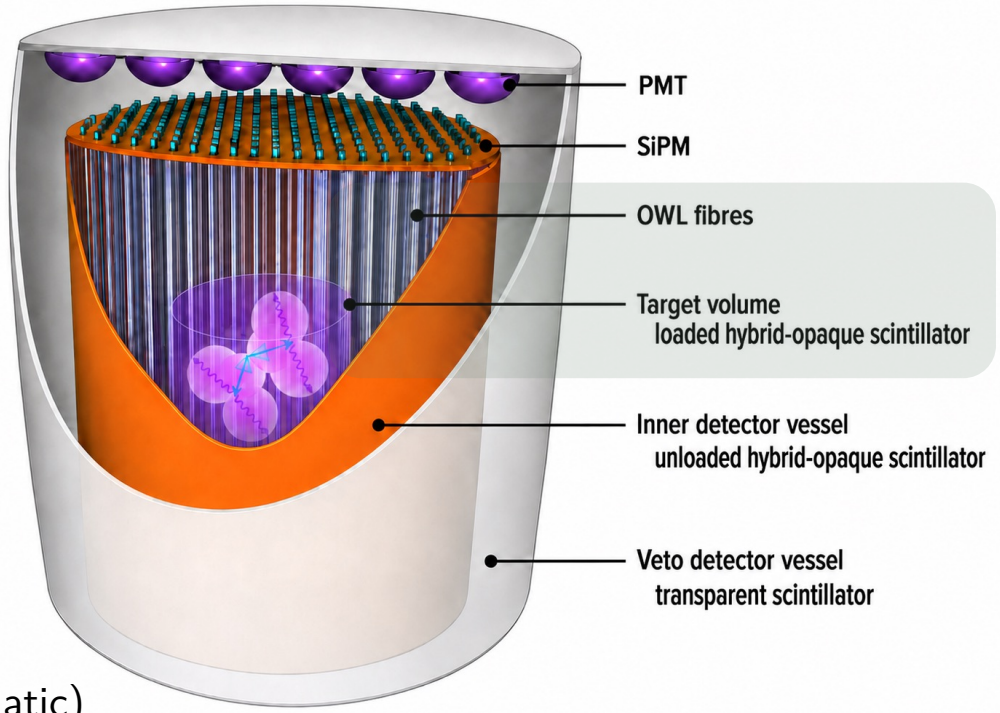
NuDoubt^{++}

Neutrino Double Beta Plus Plus

Combining **hybrid** and **opaque scintillator** techniques paired with **novel light read-out** in the search for the unobserved DBD^{+}

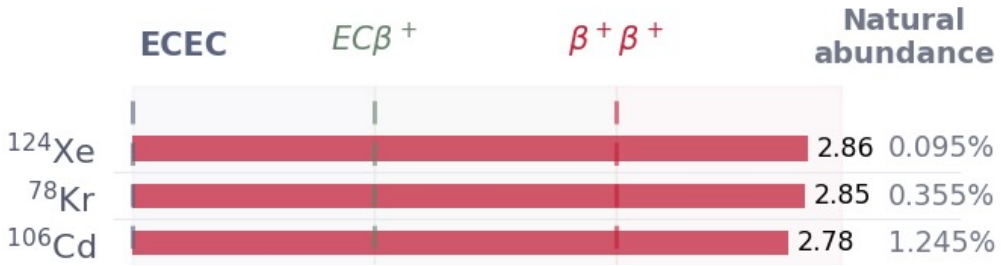
The idea

→ highly isotope-loaded slow opaque scintillation detector
→ instrumented with grid of wavelength-shifting light guides



Multi-isotope programme

- Three $\beta^+\beta^+$ isotopes have Q-values above ^{208}Tl background
  - Two noble gases Kr and Xe → high pressure isotope loading
  - Cd → high loading in opaque medium (loss in transparency is unproblematic)
  - All three DBD^{+} modes accessible



→ **First prototype:**

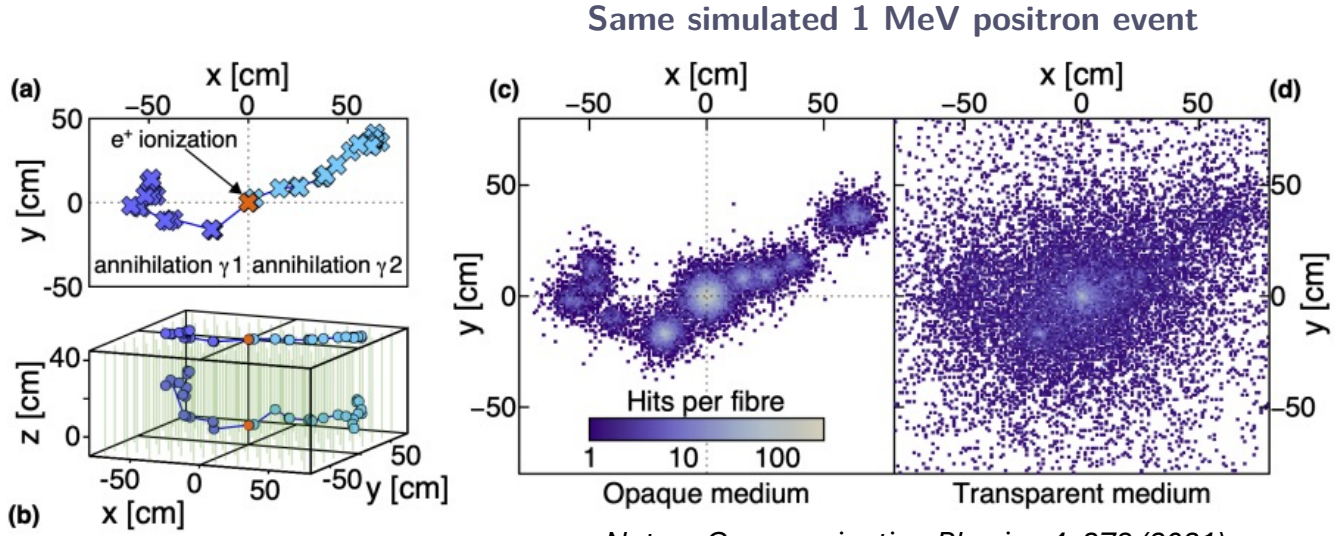
- 50% enriched Krypton-78 gas
- 5 bar overpressure
- 10kg scintillator mass in central fiducial vessel

Opaque Scintillator

Light Confinement

- Counter-intuitively, strong diffusion sharpens the reconstructed pattern
- Detector idea pioneered by LiquidO

Cabrera et al. (LiquidO Consortium)



Nature Communication Physics 4, 273 (2021)

Scintillation photons remain close to each energy deposition instead of crossing the detector.

Localized light helps separate the positron deposit from the spatially distributed 511-keV γ interactions.

1 Short scattering length

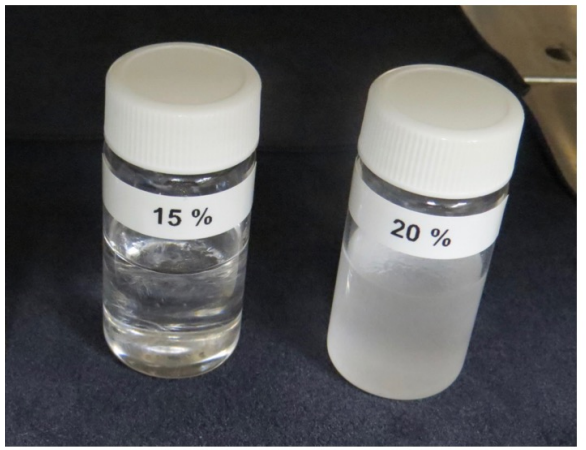
Photons random-walk around their creation point and form a local light cloud.

2 WLS fibre lattice

Fibres inside the active volume sample these localized clouds throughout the detector.

3 Event topology

Separate energy deposits remain identifiable; in a transparent medium the pattern washes out.



C. Buck et al., 2019

First implementation of opaque scintillator: adding wax to LS (NoWaSH)

Opaque Scintillator

Properties

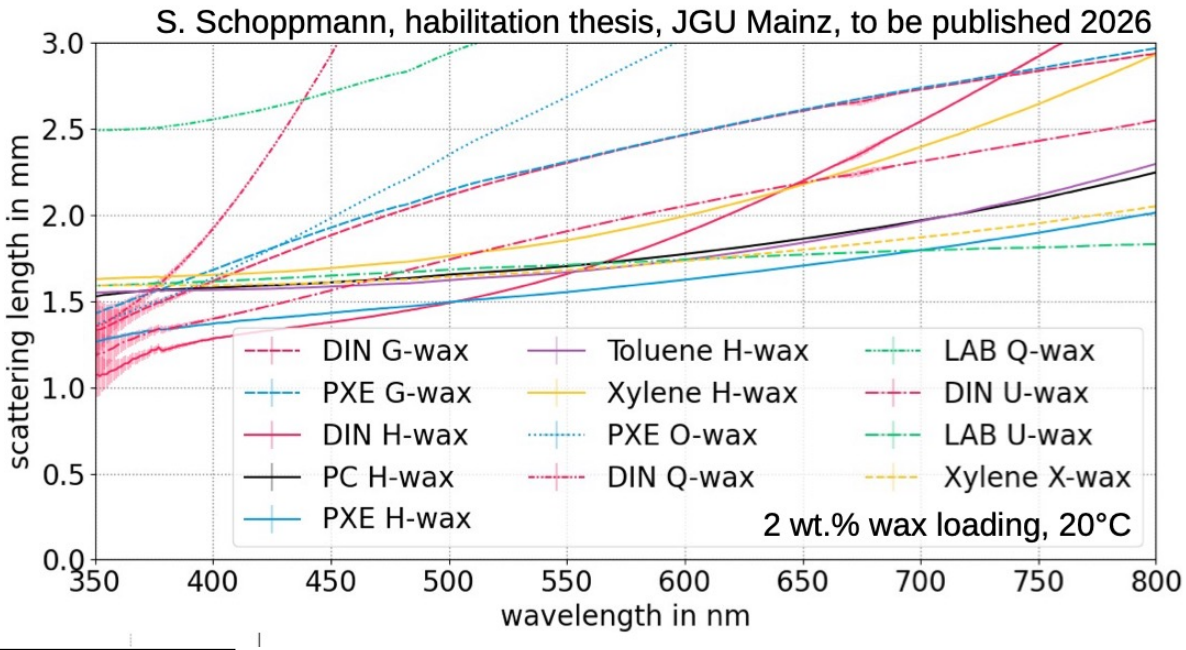
- Opaque scintillators require engineered scattering, minimal absorption, high light yield, and stable, radiopure formulations.

Scattering length tunable via:
→ NoWaSH: wax type / wax concentration / temperature (in some NoWaSH formulations) → ~ 0.3–3 mm in tested NoWaSH formulations

→ wax content reduced to ~2 wt.%
→ full light yield
→ liquid, viscous or solid

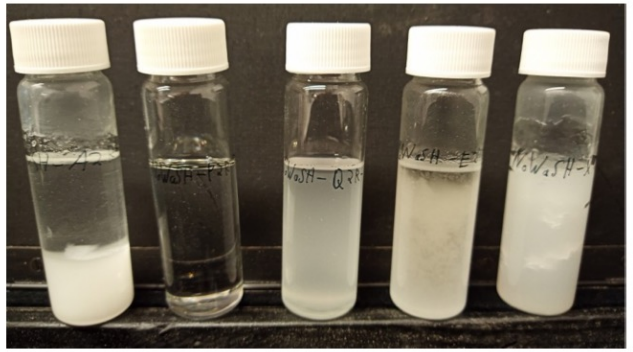
High metal loading possible
→ relaxed requirement on absorption length
→ proof of principle via boron / TBB in NoWaSH

→ low radioactivity



Isotope	Activity [mBq/kg]
U-238	< 86.5
Ra-226	< 2.17
Th-228	< 2.79
Ra-228	< 1.66
Cs-137	< 0.85
Co-60	< 0.40
K-40	< 5.26

>1 year stability testing



Examples of unstable/unsuitable combinations



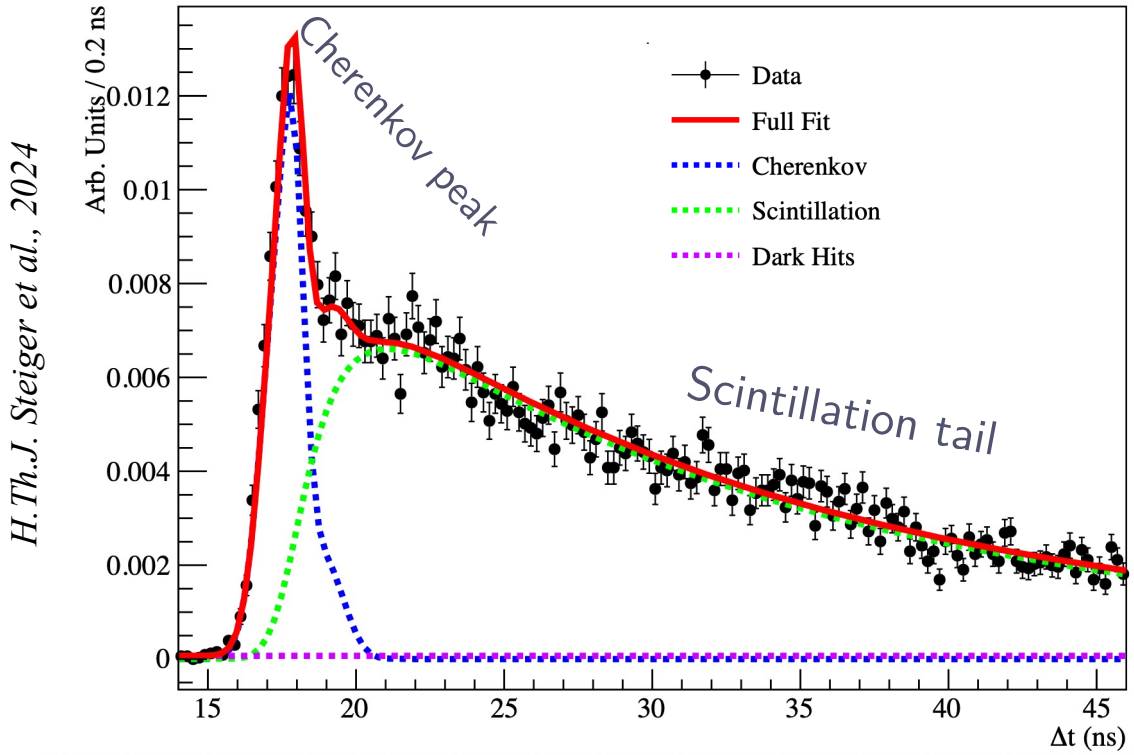
Example of stable combination

Credit: Stefan Schoppmann

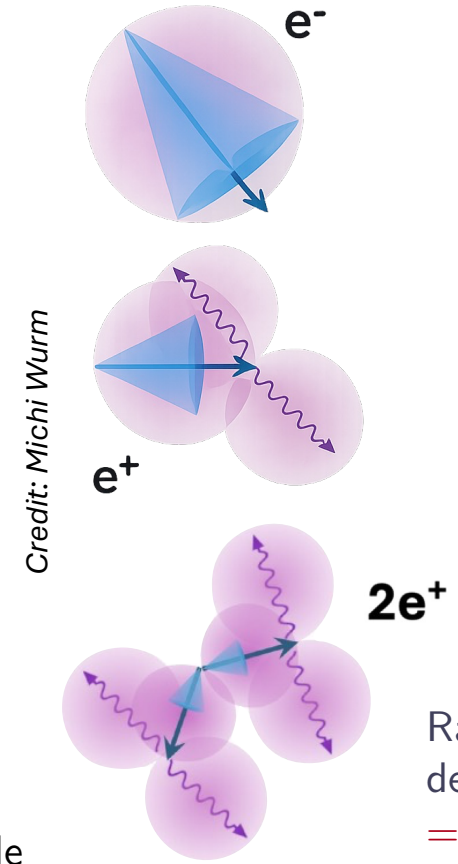
Hybrid-Slow Scintillator

Cherenkov/scintillation light separation

- **Slow organic scintillators** delay scintillation by ~10 ns, enabling Cherenkov/scintillation separation
  → Uses slow fluors to delay scintillation light
- Pioneered by Theia/Eos/Annie-Sandi



The measured emission timing for β excitation of PPO-10 sample



Prompt Cherenkov light

- Small fraction of the detected light
- Emitted promptly (and directionally)
- Provides particle-response information

Delayed scintillation light

- Dominates the total light yield
- Isotropic and delayed by the slow fluor
- Provides calorimetric energy information

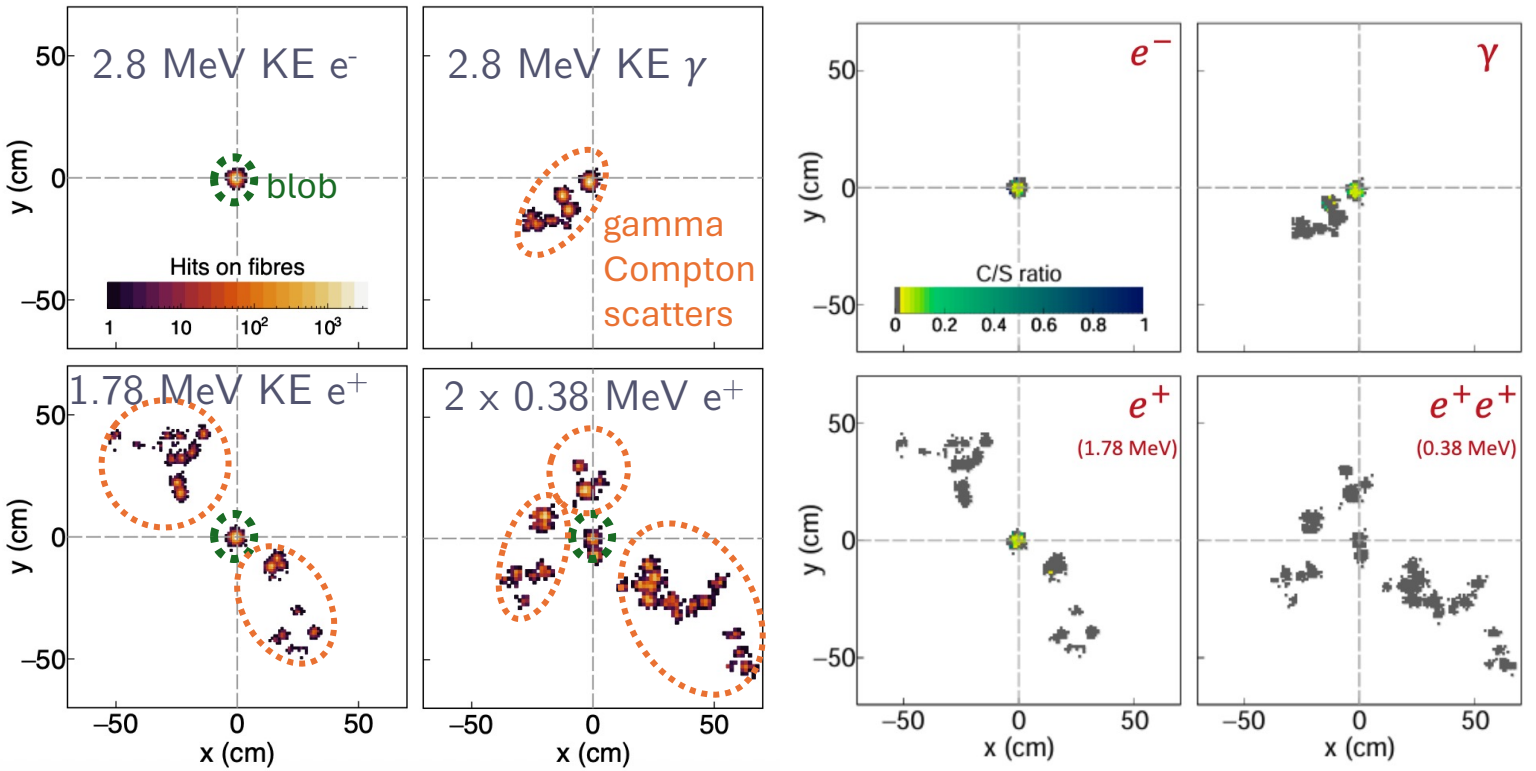
Ratio of Cherenkov to scintillation light depends on particle type
=> Particle ID from Č/S ratio

Slow-Hybrid Opaque Scintillator

Combining Techniques

- First time combination of slow hybrid and opaque scintillation technologies

Local energy-deposition pattern + Č/S ratio



Simulation: Particle discrimination in hybrid opaque scintillator

- Hybrid and opaque scintillators provide complementary particle-identification information.

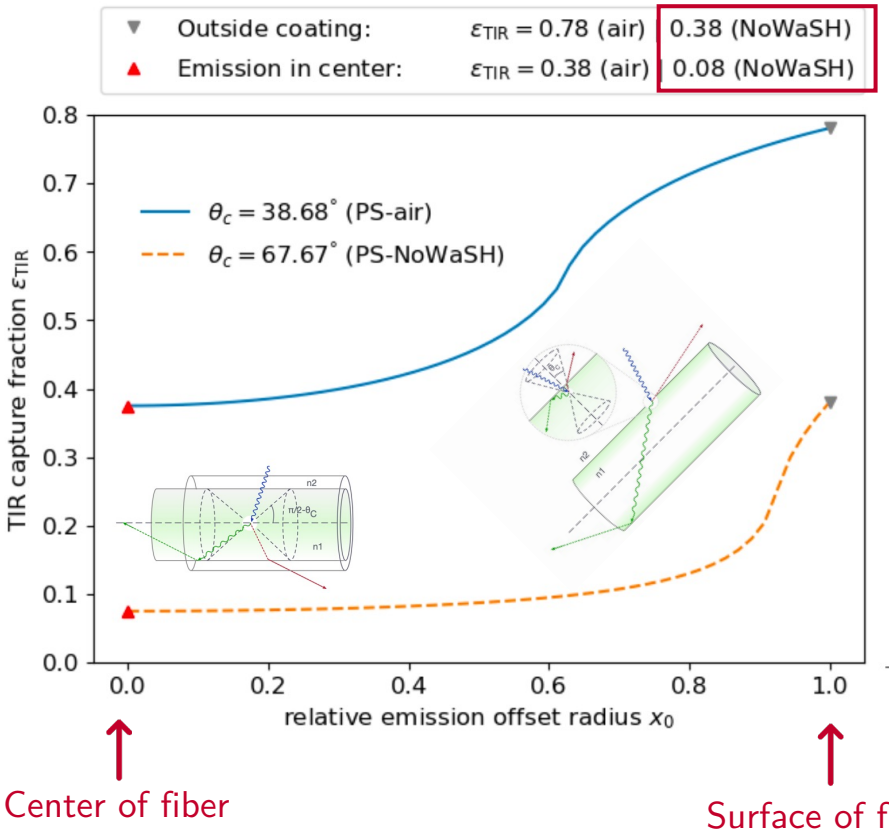
e^-	Cherenkov-rich compact charged-particle deposit (blob)
γ	Multi-site Compton topology
e^+	Primary deposit + annihilation topology
e^+e^+	Highest characteristic multiplicity

- Annihilation γ rays lower Č/S by producing mainly scintillation light.

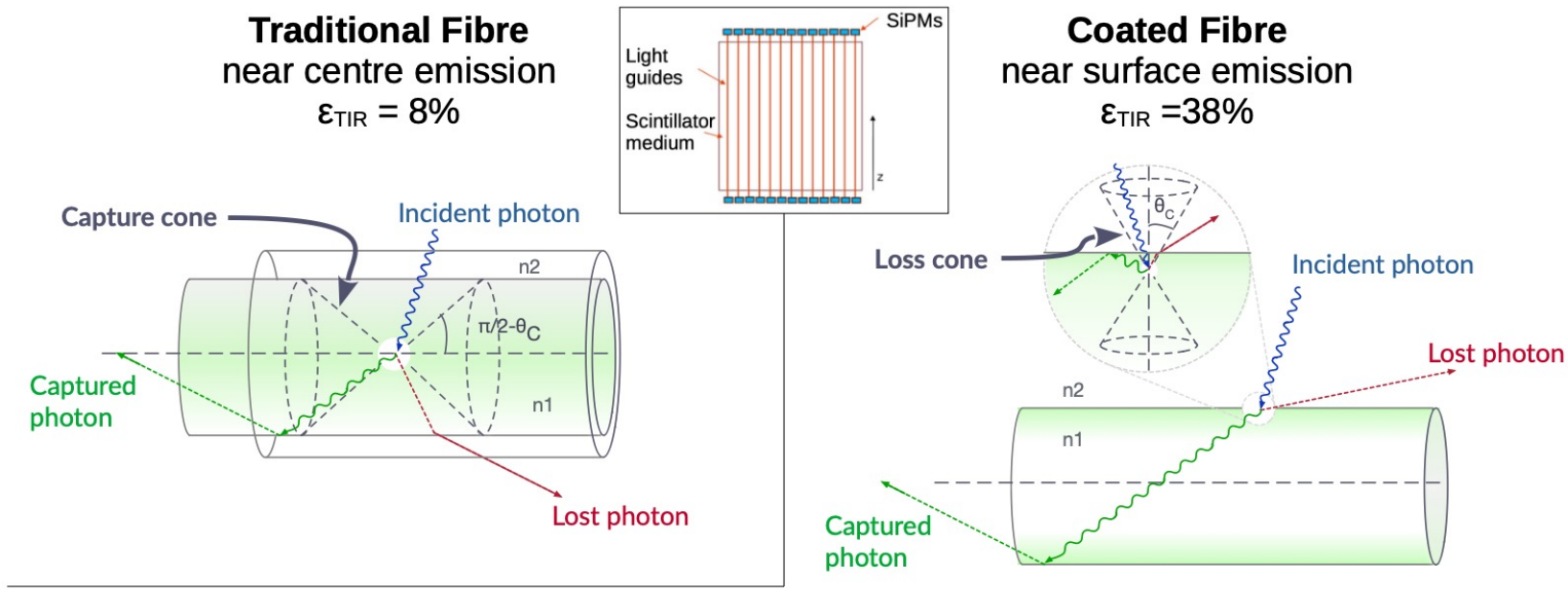
OWL Fibres

Optical Light Collection

- A new fibre concept optimised in terms of **capture efficiency** called **optimised wavelength-shifting fibres (OWLs)**



Polystyrene (PS) OWL-fibre immersed in air (solid line)
or the scintillator NoWaSH (dashed line)



Based on IceCube WOM technology, now adapted to fibres.

Boost light capture → improved resolution

Projected sensitivity of NuDoubt^{++}

2ν vs 0ν

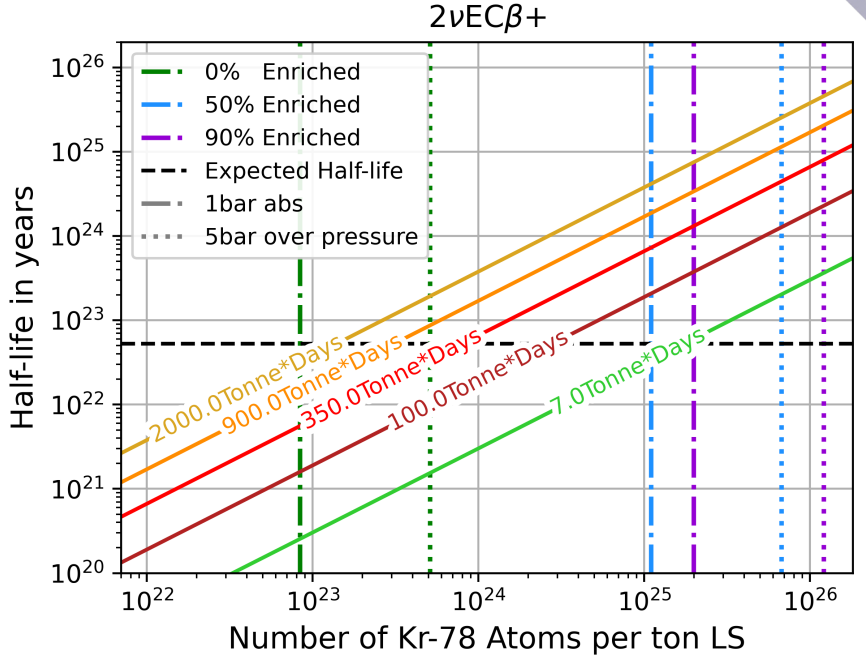
Prototype: ^{78}Kr · 50% enriched · 5 bar

Near-term measurement

2ν MODES · DISCOVERY

PRELIMINARY

Expected 5σ observation sensitivity



5σ · theory range reached in <1 tonne-week (≈20 kg · yr)

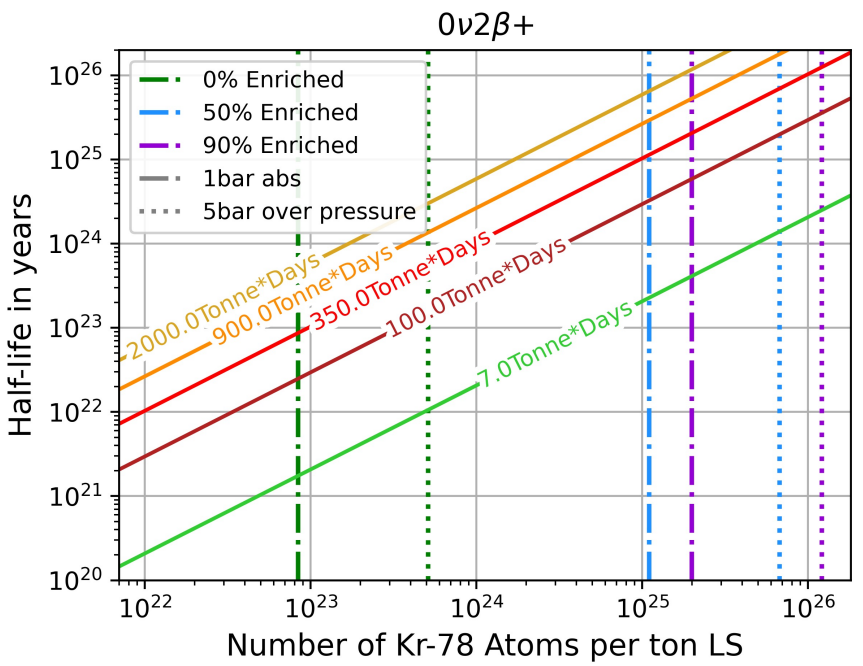
Comparable reach for 2νβ$^+$β$^+$ · primary goal: first Standard-Model DBD$^+$ observation

Complementary LNV reach

0ν MODES · EXCLUSION

PRELIMINARY

Expected 90% C.L. exclusion sensitivity

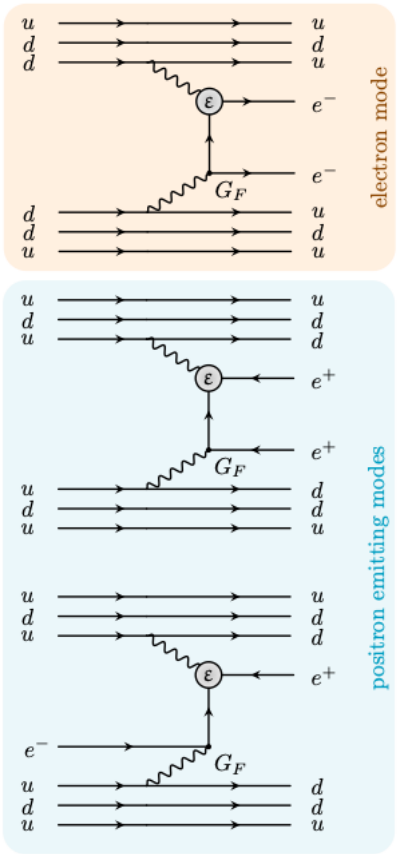


90% C.L. · $T_{1/2} \sim 10^{24}$ yr after 1 tonne-week

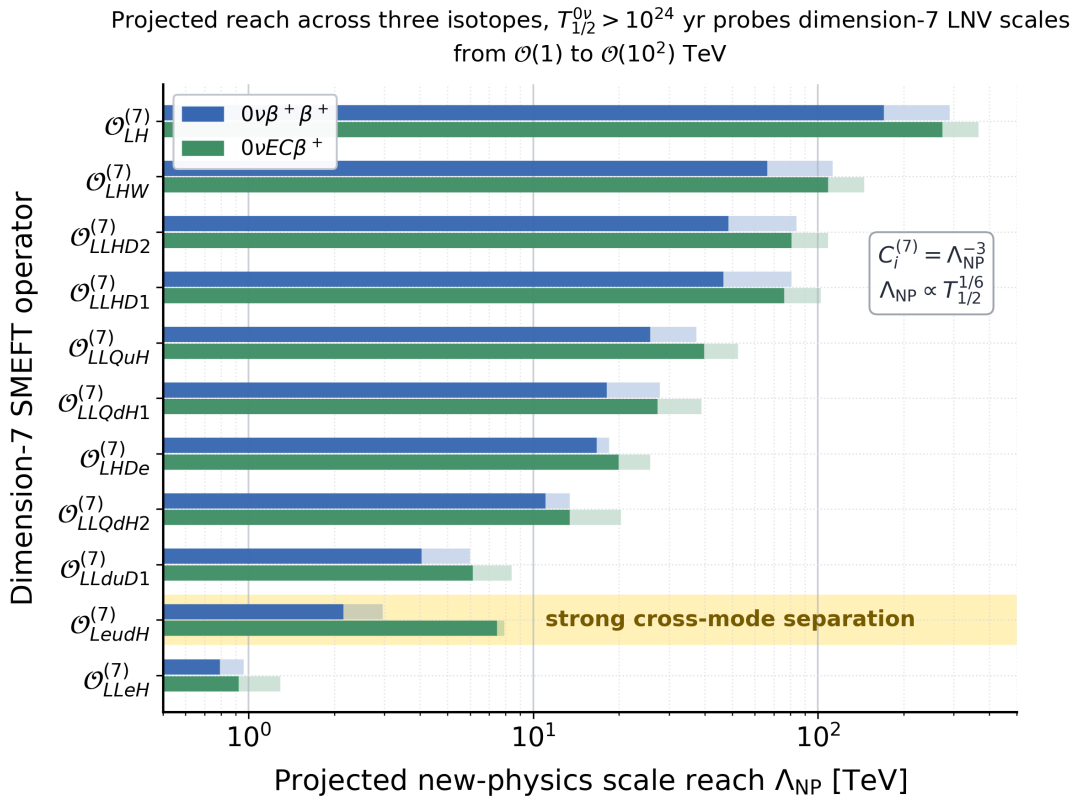
Light-Majorana benchmark: not designed to compete with leading 0νβ$^-$β$^-$ searches.

BSM reach & potential

Pinpointing the mechanism of 0ν with positrons



Projected exclusion sensitivity of the **NuDoubt^{++}** towards LNV dimension-7 SMEFT operators.

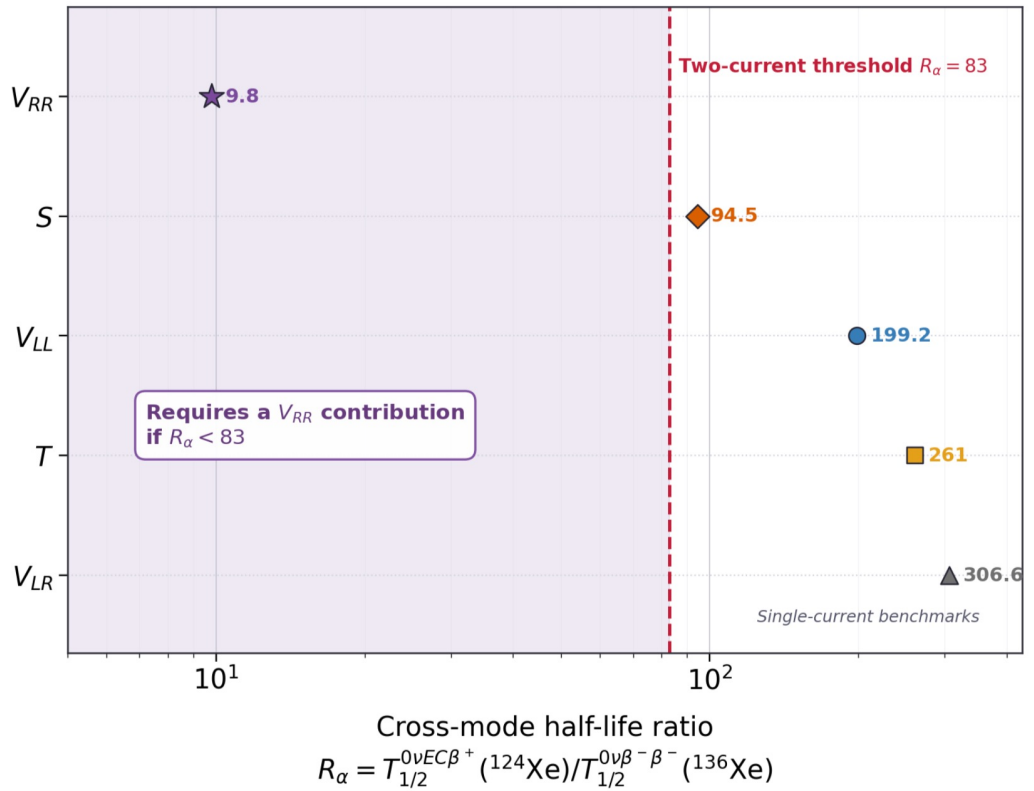


Data from: Gráf, Kotila, Scholer 2026
arXiv:2606.26097v1 [hep-ph] 24 Jun 2026

Using ^{124}Xe $0\nu EC\beta^+$ to probe the underlying leptonic current.

$$\frac{1}{T^{0\nu}_{1/2}[X]} = C_i[X]\, c_i^2\,,$$

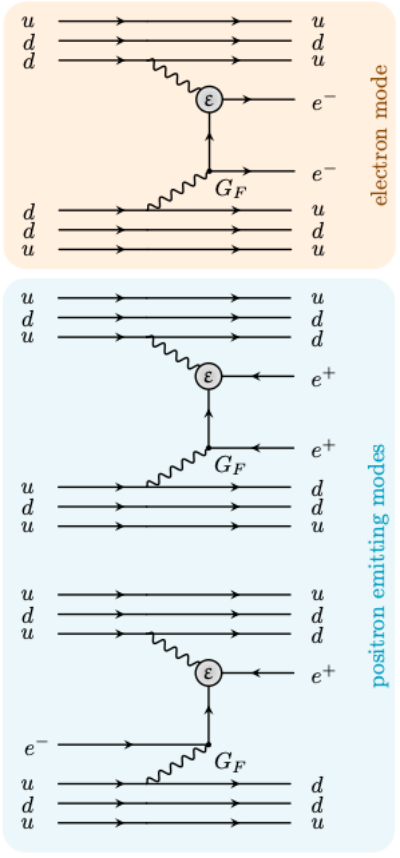
$$c_i \in \{V_{LL},\ V_{LR},\ V_{RR},\ T,\ S\}$$



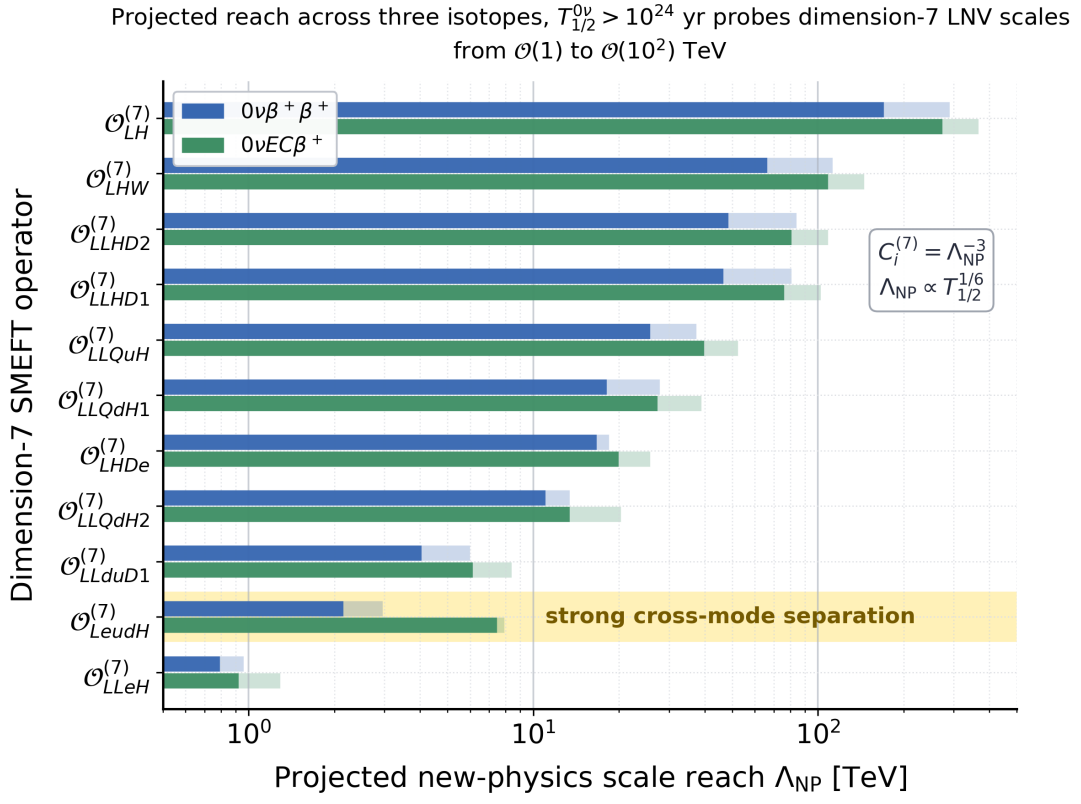
Data from: Harz & Parker 2026
arXiv:2608.04187v1 [hep-ph] 4 Aug 2026

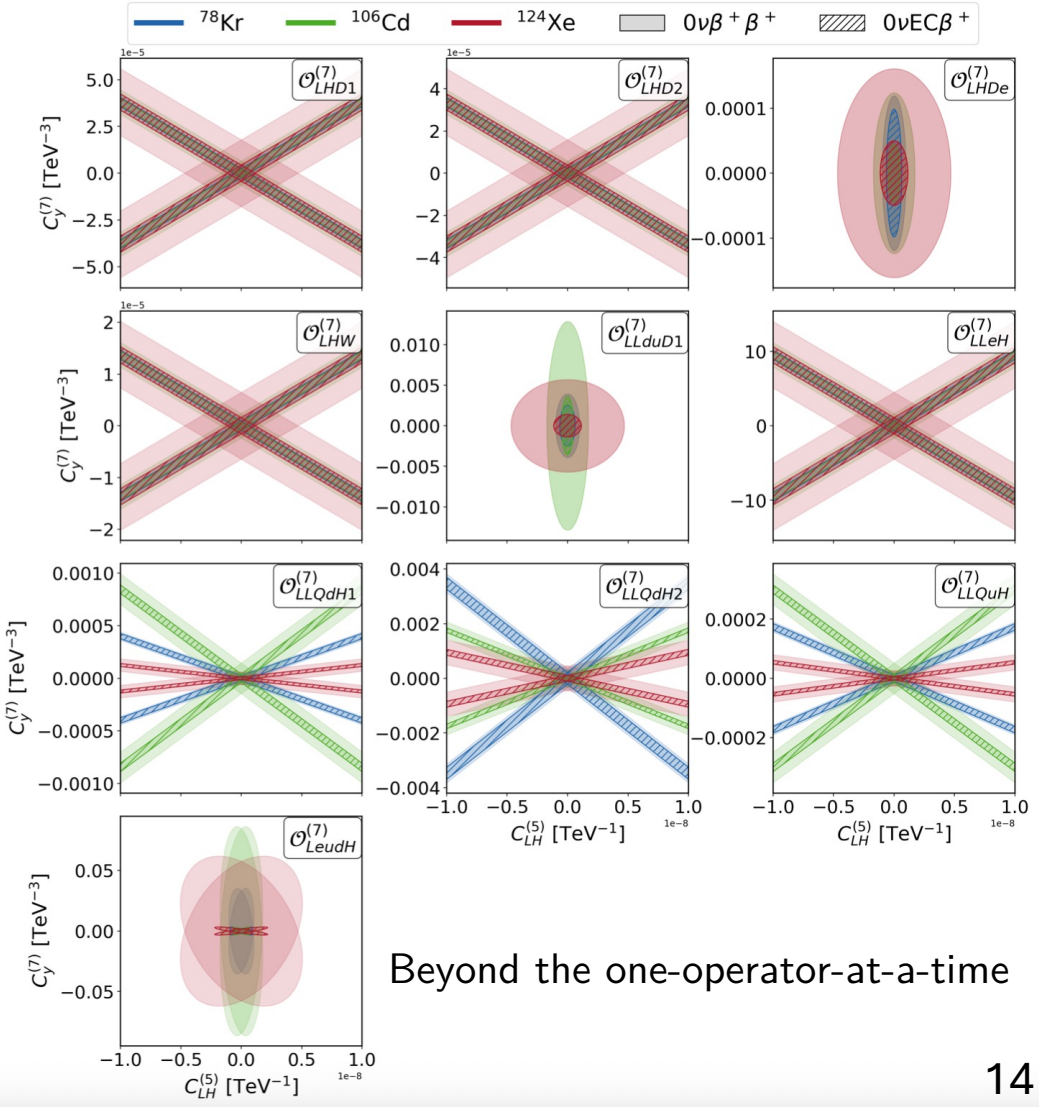
BSM reach & potential

Pinpointing the mechanism of 0ν with positrons



Projected exclusion sensitivity of the **NuDoubt^{++}** towards LNV dimension-7 SMEFT operators.





Beyond the one-operator-at-a-time

Data from: Gráf, Kotila, Scholer 2026
arXiv:2606.26097v1 [hep-ph] 24 Jun 2026

NuDoubt^{++}

Timeline

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK · JG|U · SNOLAB · NuDoubt^{++}

UC Berkeley · BERKELEY LAB · Queen's UNIVERSITY

≈30 collaborators

New experimental participation

Heidelberg, Berkeley, SNOLAB and Mainz nuclear physics

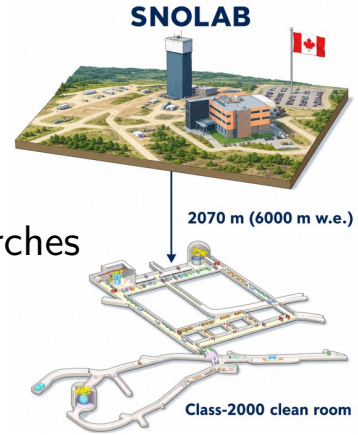
Theory partnerships

Bratislava, Măgurele, Berkeley/Prague and Mainz

Underground deployment in SNOLAB

Liquid-scintillator compatibility, space, overburden, local support and a realistic schedule

- Located at a depth of 2 kilometres in Vale's Creighton Mine near Sudbury
- Low-background environment for rare-event searches
- Low muon flux ~0.27 μ/m^2/day, reducing cosmogenic ^{10}C and ^{11}C production



Prototype development

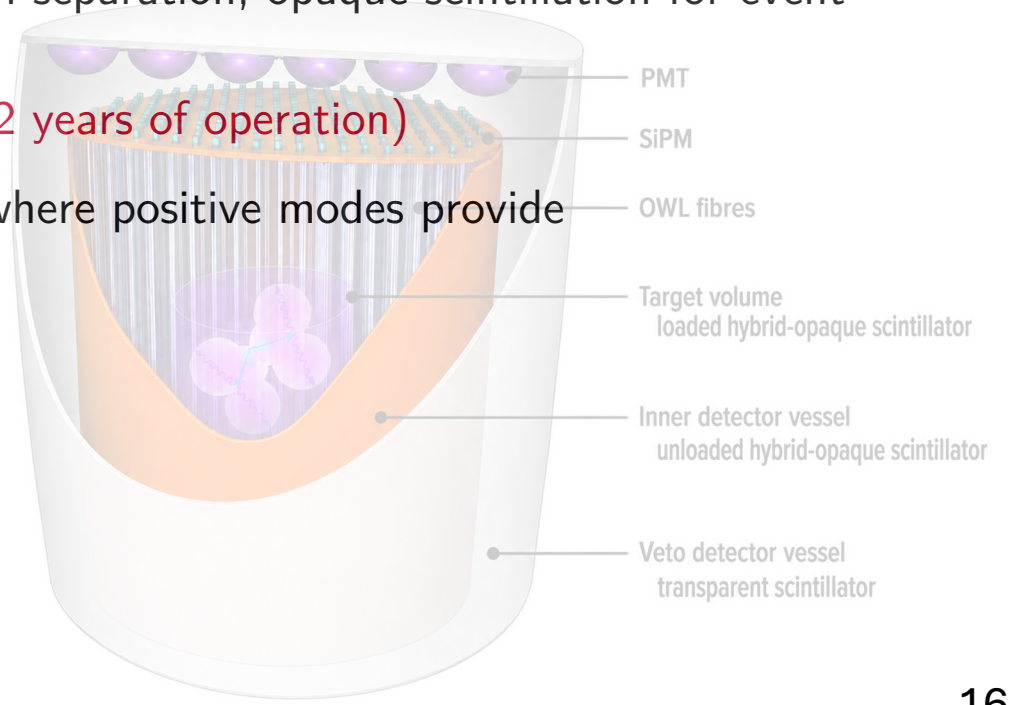
YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEARS 6-11
2026	2027	2028	2029	2030	2031-2036

Today

Design phase · **Construction** · **Surface tests** · **Underground physics run** Initial ^{78}Kr measurement · **Multi-isotope follow-up**

Summary & Conclusions

- **DBD$^+$ modes ($2\beta^+$, $EC\beta^+$, 2EC):** Complementary probes of nuclear physics, despite suppressed phase space.
- **^{78}Kr:** Promising candidate ($E_{det} \approx 2.85$ MeV); enrichment required.
- **Experimental signatures** include characteristic 511 keV annihilation γ-rays from positron-emitting modes.
- **NuDoubt^{++} technology:** Hybrid scintillation for Cherenkov/scintillation separation, opaque scintillation for event topology, and OWL fibres for efficient light collection.
- **NuDoubt^{++}** can reach theoretical half-lives in **<20kg.year** exposure (2 years of operation)
- The longer-term multi-isotope programme targets $0\nu2\beta^+$ and $0\nu EC\beta^+$, where positive modes provide complementary sensitivity to non-standard LNV interactions.



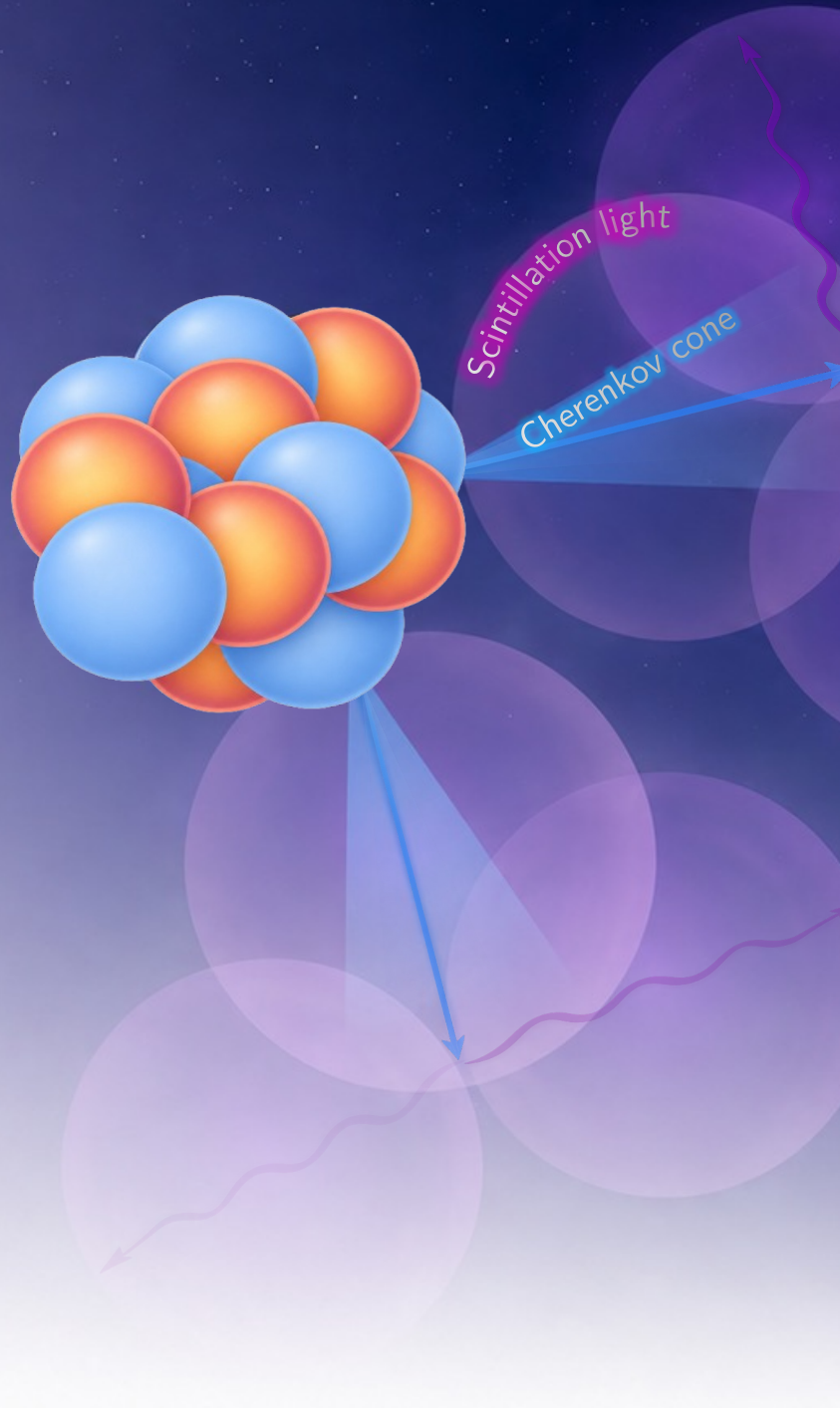
NuDoubt++

Thank you!

NuDoubt collaboration meeting in Mainz, October 2026



Back-up Slides



NuDoubt^{++}

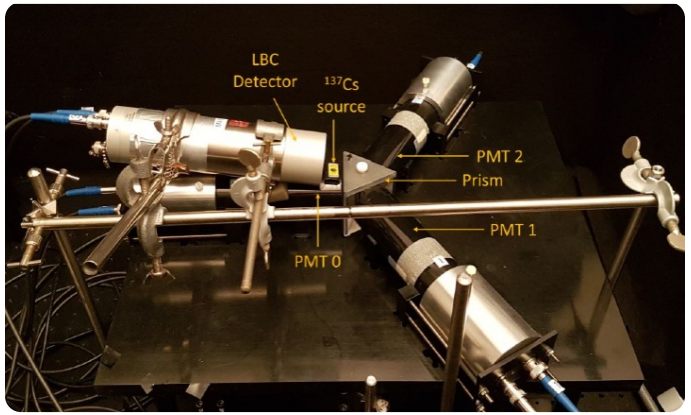
Ongoing experimental work

Krypton loading

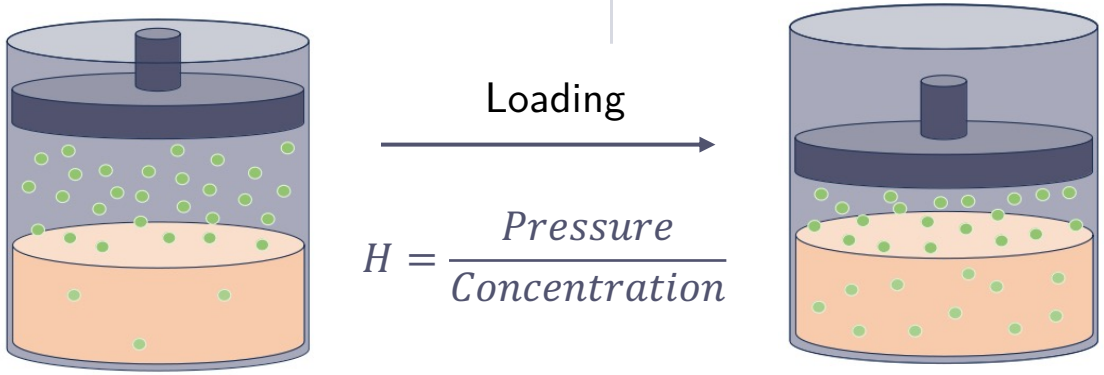


The overpressure cell is built; proof-of-concept tests are complete.

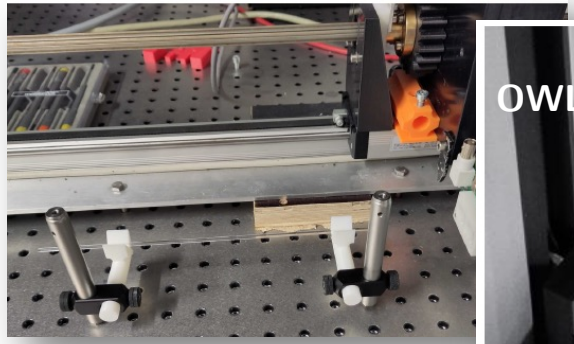
Slow scintillator



SCHLYP studies Cherenkov/scintillation separation in candidate slow scintillators.



OWL fibres





The team can produce coated fibres with high photon-detection efficiency.

OWL measurement setup
- pulsed, dim light source move along fiber
- light detected with SiPMs

‣ slower measurement
‣ dedicated wavelength
‣ full timing information

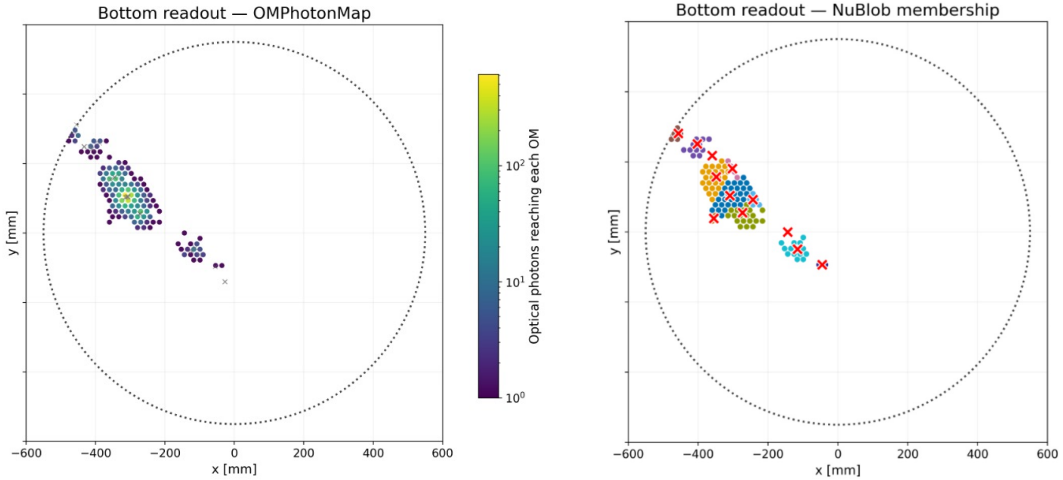
NuDoubt^{++}

Simulation and analysis framework status

NuTray connects generated decays to detector-level observables

STEP 0	STEP 1	STEP 2	STEP 3	OUTPUT
Generate primaries	**Propagate physics**	**Simulate response**	**(Clean +) cluster**	**NuBlob with charge, pulse count, photon count, channels, …**
Particle, energy, position, direction	Geant4 deposits and optical photons	MCHits, waveforms, triggers, RecoPulses	Inputs: PhotonMap, MCHits, or RecoPulses	

Reconstructed topology in simulation



2 MeV positron

Implemented

Decay generation and radioactive backgrounds with BxDecay0

Geant4 particle propagation and optical-photon tracking

SiPM response, waveform digitization and trigger simulation

Coincidence cleaning and two-dimensional CA clustering

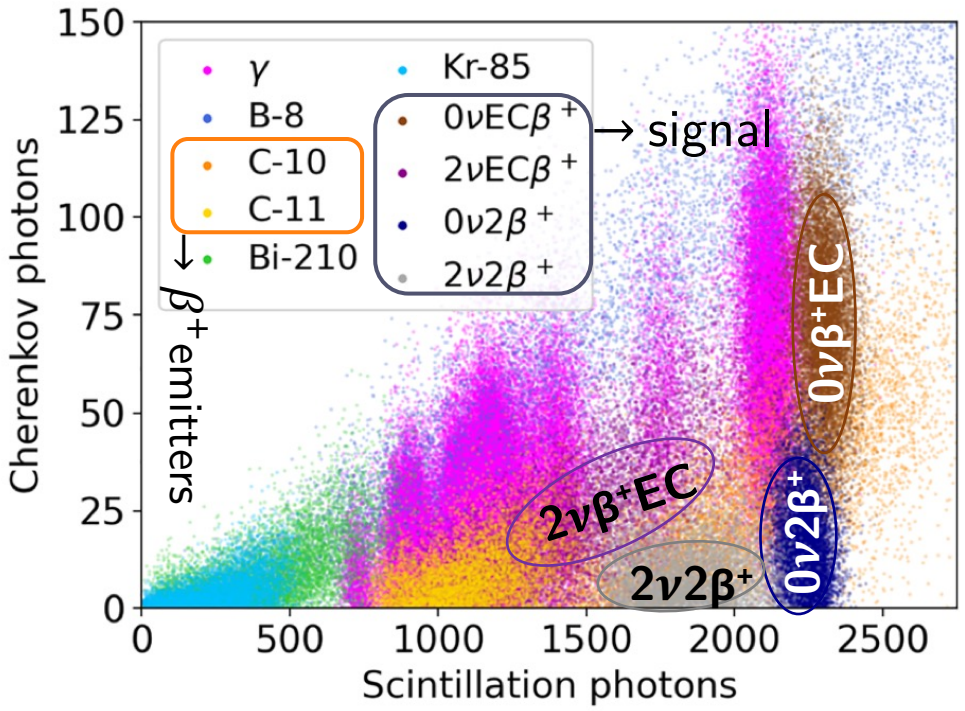
Based on IceTray - an open-source repository with all the tools we need.

NuDoubt++

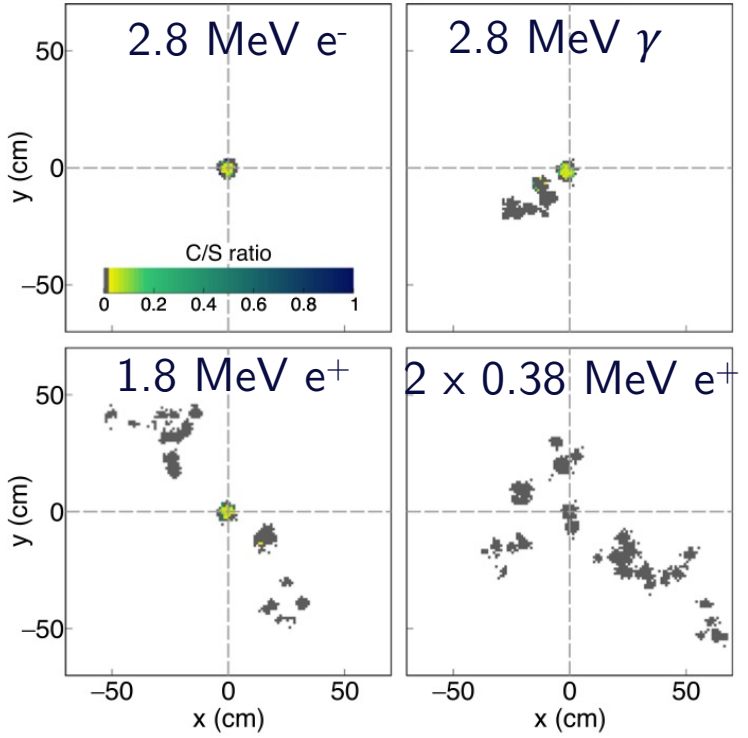
Background Suppression

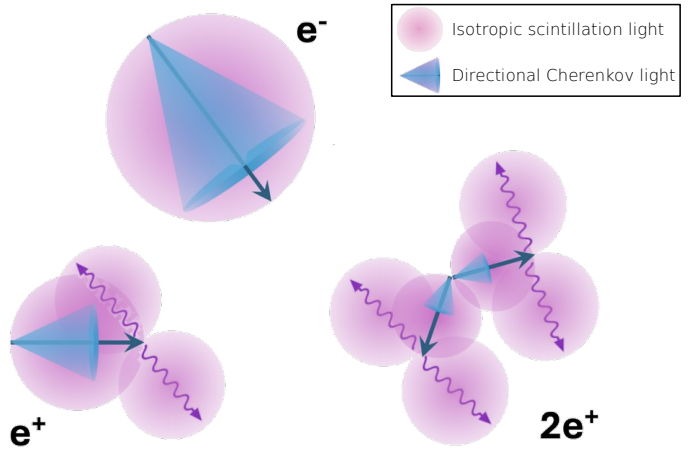
Geant4 simulation

Separation of the event categories based on Cherenkov and scintillation light



Event topologies based on the blob-dependent Č/S ratio



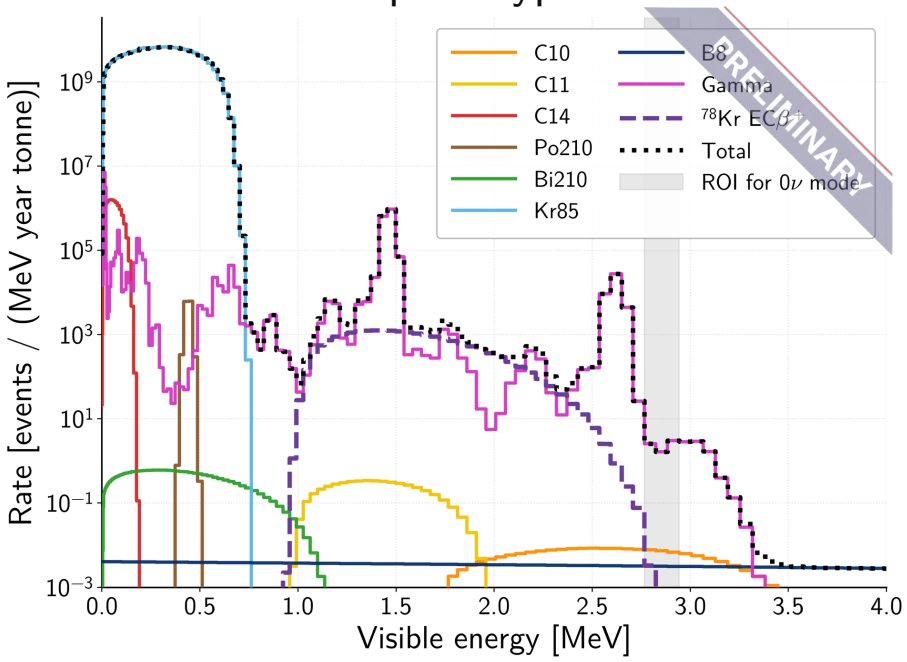


Complementary background rejection capabilities of **hybrid and opaque detector technologies** – background suppression based on counting blobs and separation of events based on Cherenkov to scintillation light ratio.

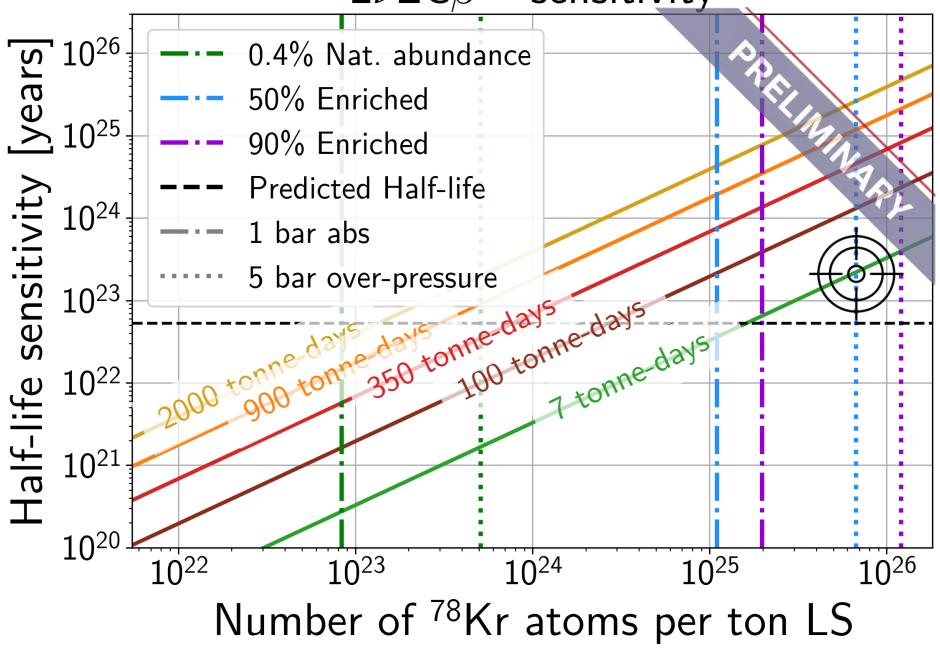
NuDoubt^{++} in SNOLAB

Expected Sensitivity to 2ν Modes

Expected background and $2\nu\beta^+EC$ signal spectra for a NuDoubt^{++} prototype located at SNOLAB.



Expected 5σ observation sensitivity $2\nu\mathrm{EC}\beta^+$ sensitivity



Projected Sensitivity of NuDoubt^{++} prototype

→ Sensitivity to theoretical $2\nu\mathrm{EC}\beta^+$ half-life achieved in $<$**1 tonne week** exposure ($\sim<$**20 kg · yr**)

→ Comparable reach also for $2\nu2\beta^+$ decay.

Solid lines: detectable half-life vs. decaying ^{78}Kr atoms/tonne for various exposures

Horizontal dashed: theoretical 2vECβ$^+$ half-life (*PRC 87, 034318 2013*)

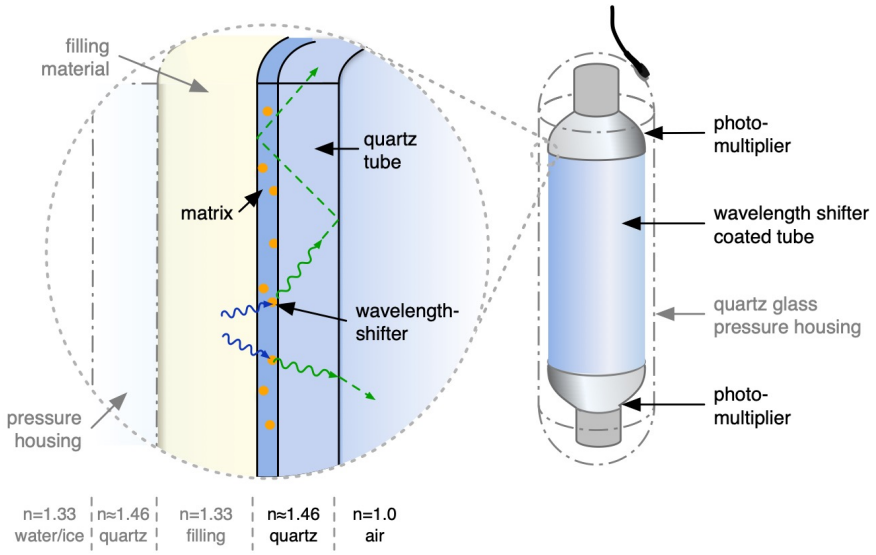
Vertical dashed: loading/enrichment scenarios

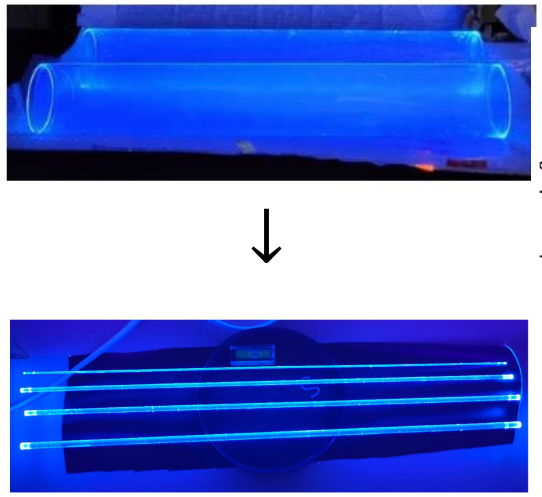
OWL Fibres

Wavelength-shifting Optical Module

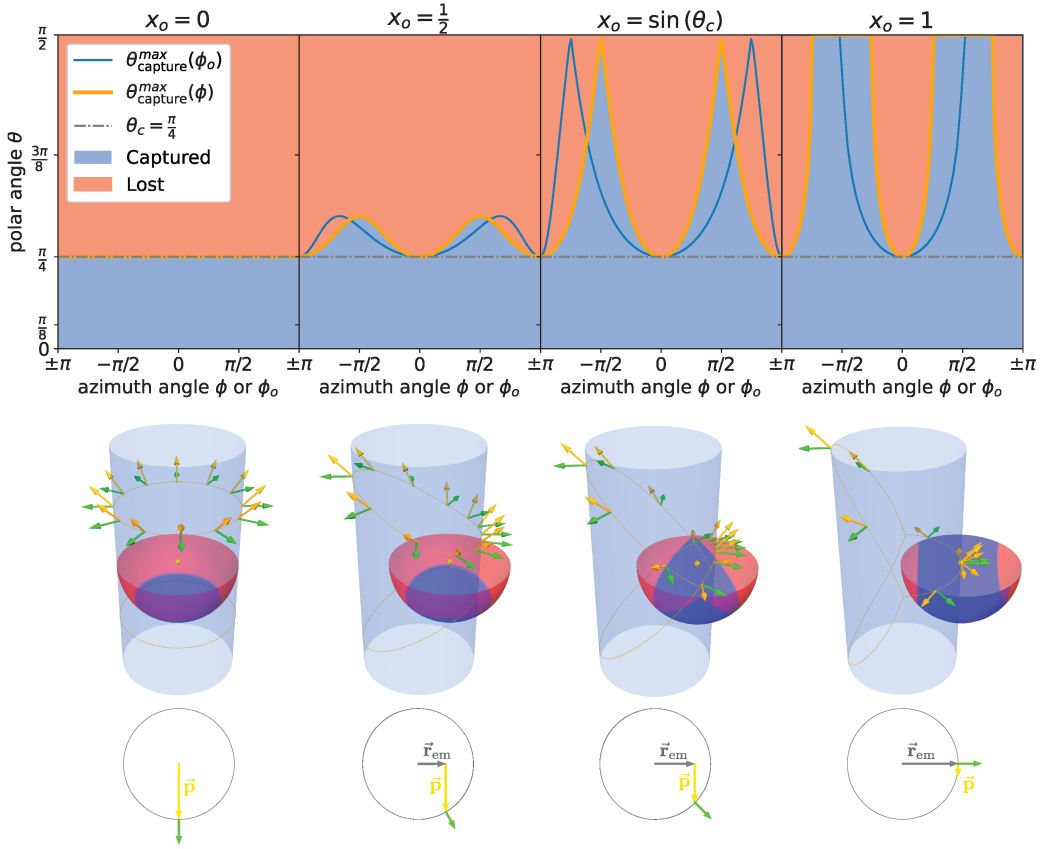
Based on IceCube WOM technology, now adapted to fibres.

B. Bastian-Querner et al., 2022





Photon-capture solid angle for total internal reflection as a function of emission position inside the cylindrical light guide.



What is the WOM?

- **W**avelength-shifting **O**ptical **M**odule designed for large-volume neutrino detectors (e.g. IceCube Upgrade)
- Tube coated with WLS paint, with photosensors on both ends
- Converts and traps UV/blue photons via isotropic re-emission + total internal reflection (TIR)

Opaque Scintillators

Properties

→ emission like transparent scintillator
→ light yield like transparent scintillator
→ high isotope loading possible (relaxed requirement on absorption length)

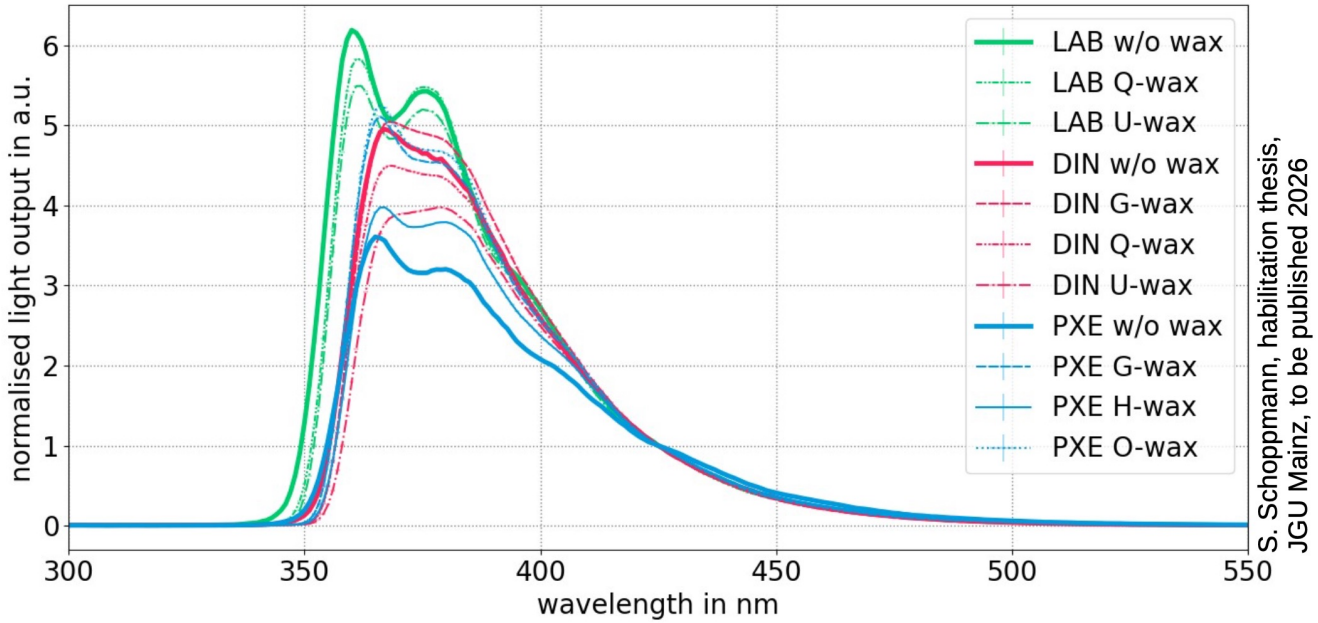
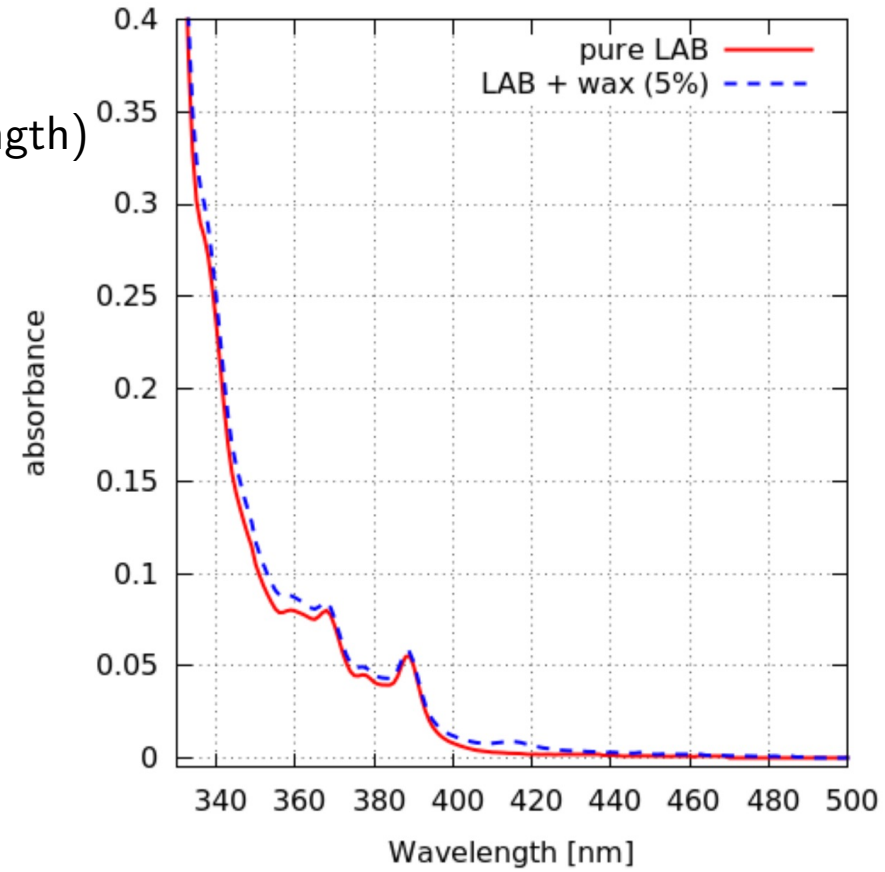


Table 1. Upper limits on activities from different radioisotopes in the paraffin wax (90% C.L.).

Isotope	U-238	Ra-226	Th-228	Ra-228	Cs-137	Co-60	K-40
Activity [mBq/kg]	< 86.5	< 2.17	< 2.79	< 1.66	< 0.85	< 0.40	< 5.26

The wavelength dependent absorbance is shown for pure LAB and a LAB/wax mixture with 5 wt.% paraffin.



JINST 14 (2019) P11007

→ no significant impurities from wax
→ attenuation length >> scattering length

Credit: Stefan Schoppmann

Opaque Scintillators

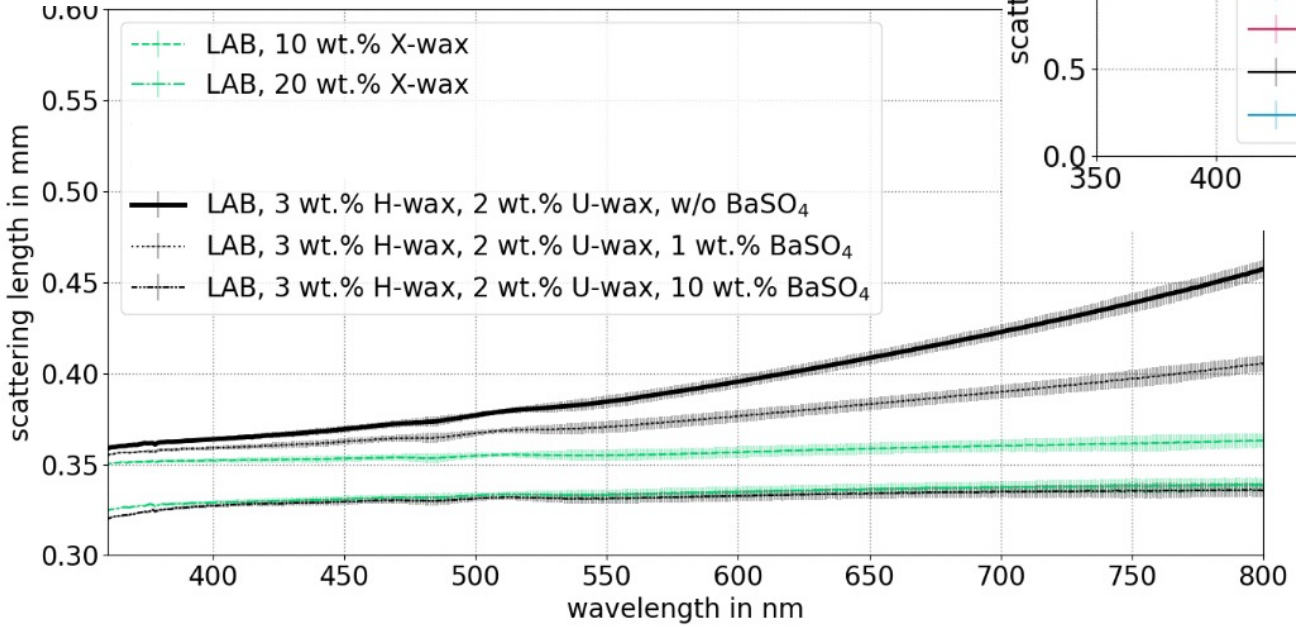
Properties

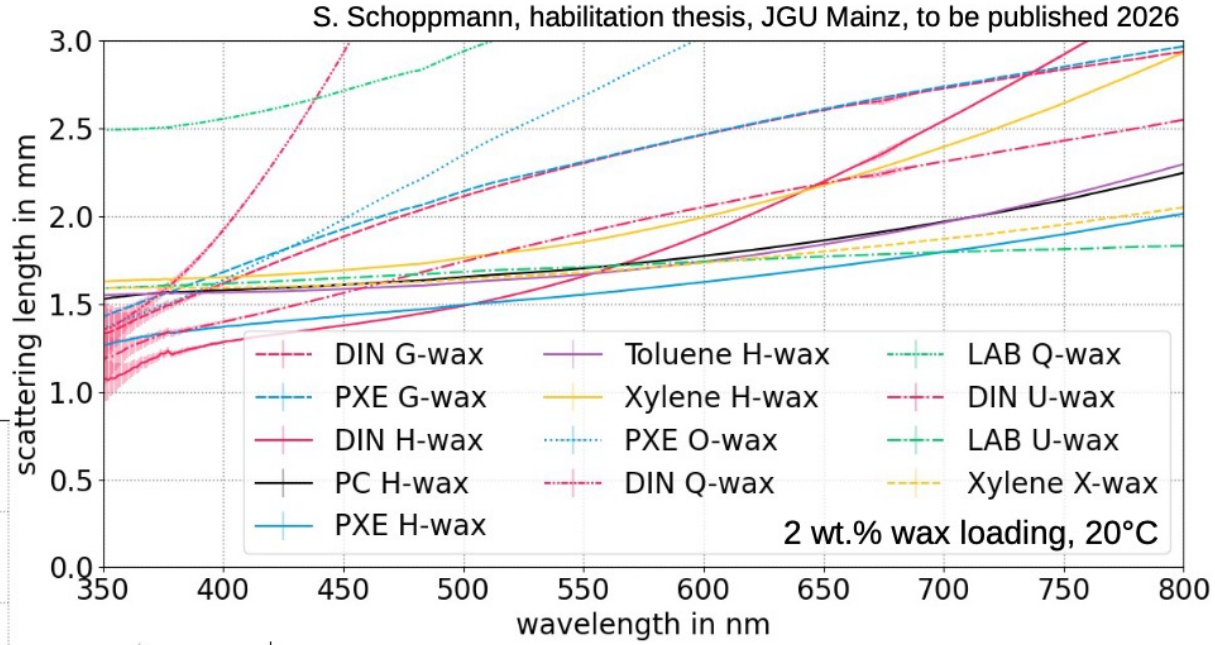
NoWaSH: wax-based opaque scintillator

→ transparent solvent + O(1-10 wt.%) wax + fluorophore(s)

JINST 14 (2019) P11007, Patent applications EP 25 195 873.2 & EP 25 195 874.0

→ opaqueness through scattering without absorption (Mie scattering, scattering length of millimetres)





→ wax content reduced to ~2 wt.%

→ full light yield

→ liquid, viscous or solid

→ scattering length adjustable (0.3 to 3 mm) by

- → wax type
- → wax concentration
- → temperature (some formulations)
- → blending technique

Credit: Stefan Schoppmann

arXiv:2606.26097v1 [hep-ph] 24 Jun 2026

BSM scale reach

- Start with **SMEFT operators** and study the projected exclusion sensitivity of the NuDoubt^{++} towards LNV dimension-7 SMEFT operators.

- At SMEFT level, LNV appears only at odd operator dimensions with the neutrino mass generating Weinberg operator at dimension 5 and 12 different $\Delta L = 2$ operators at dimension-7 SMEFT.

$d = 5$: $C^{(5)} \sim \Lambda_{NP}^{-1}$

$d = 7$: $C^{(7)} \sim \Lambda_{NP}^{-3}$

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_{d\geq 5} \sum_{i} C_i^{(d)} \mathcal{O}_i^{(d)}.$$

SMEFT → LEFT → chiral EFT → nucleus

$$T_{1/2}^{-1} = g_A^4 \sum_k G_{0k} \left| \mathcal{A}_k \left(C_i \right) \right|^2 .$$

➢ sub-amplitudes $A_k(C_i)$ that depend on the precise Wilson coefficients C_i of the LNV model studied as well as the relevant NMEs and low-energy constants

Class	Structure	Operator	Definition
1	$\psi^2 H^4$	$\mathcal{O}_{LH}^{(7)}$	$\epsilon_{ij}\epsilon_{mn} \left(L_i^T C L_m\right) H_j H_n \left(H^\dagger H\right)$
2	$\psi^2 H^2 D^2$	$\mathcal{O}_{LHD1}^{(7)}$	$\epsilon_{ij}\epsilon_{mn} \left(L_i^T C (D_\mu L)_j\right) H_m (D^\mu H)_n$
		$\mathcal{O}_{LHD2}^{(7)}$	$\epsilon_{im}\epsilon_{jn} \left(L_i^T C (D_\mu L)_j\right) H_m (D^\mu H)_n$
3	$\psi^2 H^3 D$	$\mathcal{O}_{LHDe}^{(7)}$	$\epsilon_{ij}\epsilon_{mn} \left(L_i^T C \gamma_\mu e\right) H_j H_m (D^\mu H)_n$
4	$\psi^2 H^2 X$	$\mathcal{O}_{LHB}^{(7)}$	$\epsilon_{ij}\epsilon_{mn} g' \left(L_i^T C \sigma^{\mu\nu} L_m\right) H_j H_n B_{\mu\nu}$
		$\mathcal{O}_{LHW}^{(7)}$	$\epsilon_{ij}(\epsilon\tau^I)_{mn} g_2 \left(L_i^T C \sigma^{\mu\nu} L_m\right) H_j H_n W_{\mu\nu}^I$
5	$\psi^4 D$	$\mathcal{O}_{LLduD1}^{(7)}$	$\epsilon_{ij} \left(d \gamma_\mu u\right) \left(L_i^T C (D^\mu L)_j\right)$
6	$\psi^4 H$	$\mathcal{O}_{LLeH}^{(7)}$	$\epsilon_{ij}\epsilon_{mn} \left(e L_i\right) \left(L_j^T C L_m\right) H_n$
		$\mathcal{O}_{LLQdH1}^{(7)}$	$\epsilon_{ij}\epsilon_{mn} \left(d L_i\right) \left(Q_j^T C L_m\right) H_n$
		$\mathcal{O}_{LLQdH2}^{(7)}$	$\epsilon_{im}\epsilon_{jn} \left(d L_i\right) \left(Q_j^T C L_m\right) H_n$
		$\mathcal{O}_{LLQuH}^{(7)}$	$\epsilon_{ij} \left(Q_m u\right) \left(L_m^T C L_i\right) H_j$
		$\mathcal{O}_{LeudH}^{(7)}$	$\epsilon_{ij} \left(L_i^T C \gamma_\mu e\right) \left(d \gamma^\mu u\right) H_j$

Lepton-number-violating $\Delta L = 2$ operators at SMEFT dimension 7.

arXiv:2608.04187v1 [hep-ph] 4 Aug 2026

Pinpoiting the mechanism of 0ν weak decays with positrons - 1 current at a time

- Each LNV current predicts a characteristic ratio R_i through its different NME + PSF dependence.

$$\frac{1}{T^{0\nu}_{1/2}[X]} = C_i[X]\, c_i^2 \,,$$

$$c_i \in \{ V_{LL},\ V_{LR},\ V_{RR},\ T,\ S \}$$

Crossover half-life

$$T^{\mathrm{EC}\beta^+}_{124} = T^{\beta^-\beta^-}_{136} \frac{C^{\beta^-\beta^-}_{i,136}}{C^{\mathrm{EC}\beta^+}_{i,124}}$$

Cross-mode half-life ratio

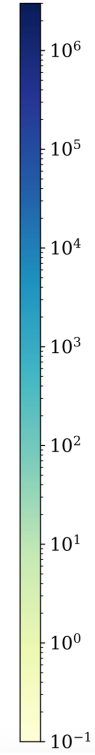
$$\mathcal{R}_i = \frac{C^{\beta^-\beta^-}_{i,136}}{C^{\mathrm{EC}\beta^+}_{i,124}} = \frac{T^{\mathrm{EC}\beta^+}_{124}}{T^{\beta^-\beta^-}_{136}}$$

	$0\nu\beta^-\beta^-$	$0\nu\beta^-\beta^-$			
	^{136}Xe	^{76}Ge	^{82}Se	^{130}Te	^{136}Xe
V_{LL}	1.0	2.0	0.50	0.88	1.0
V_{LR}	1.0	2.1	0.55	0.78	1.0
V_{RR}	1.0	2.3	0.28	0.82	1.0
T	1.0	2.5	0.59	0.83	1.0
S	1.0	1.5	0.38	0.74	1.0

$$\mathcal{R} = T^{\mathrm{mode}}_X \,/\, T^{\beta^-\beta^-}_{136}$$

- Ratios between different $\beta^-\beta^-$ isotopes show only modest mechanism dependence.

	$0\nu\mathrm{EC}\beta^+$						$0\nu\beta^+\beta^+$					
	^{78}Kr	^{96}Ru	^{106}Cd	^{124}Xe	^{130}Ba	^{136}Ce	^{78}Kr	^{96}Ru	^{106}Cd	^{124}Xe	^{130}Ba	^{136}Ce
V_{LL}	749	535	424	199	254	321	1825	5844	5506	3350	2e4	2e5
V_{LR}	1204	398	245	307	401	553	1770	2521	1908	3224	2e4	2e5
V_{RR}	33.3	30.1	26.2	9.8	14.8	21.9	7832	6e4	5e4	2e4	2e5	6e6
T	1015	330	206	261	331	441	2472	3610	2675	4389	2e4	3e5
S	298	703	505	94.5	125	159	725	7682	6568	1590	8219	9e4



- V_{RR} sits almost an order of magnitude below all the other currents.
- Considering ratios of half-lives of different modes is similarly powerful.