NEUTRINO 2024

XXXI International Conference on Neutrino Physics and Astrophysics

Milano (Italy) - June 16-22, 2024

Poster Award Contest

Davide D'Angelo, Andrea Nava, Massimo Girola
for the LOC

So many good posters!

We received ~ 640 abstracts divided among 16 tracks

- Accelerator neutrinos
- Astrophysical neutrinos
- Atmospheric neutrinos
- Beyond Standard Model searches in the neutrino sector
- Geo neutrinos
- Neutrino interactions
- Neutrino mass
- Neutrino oscillations
- Neutrino role in cosmology
- Neutrinoless Double Beta Decay
- New technologies for neutrino physics
- Reactor neutrinos
- Solar neutrinos
- Sterile neutrinos
- Supernova neutrinos
- Theory of neutrino masses and mixing, Leptogenesis

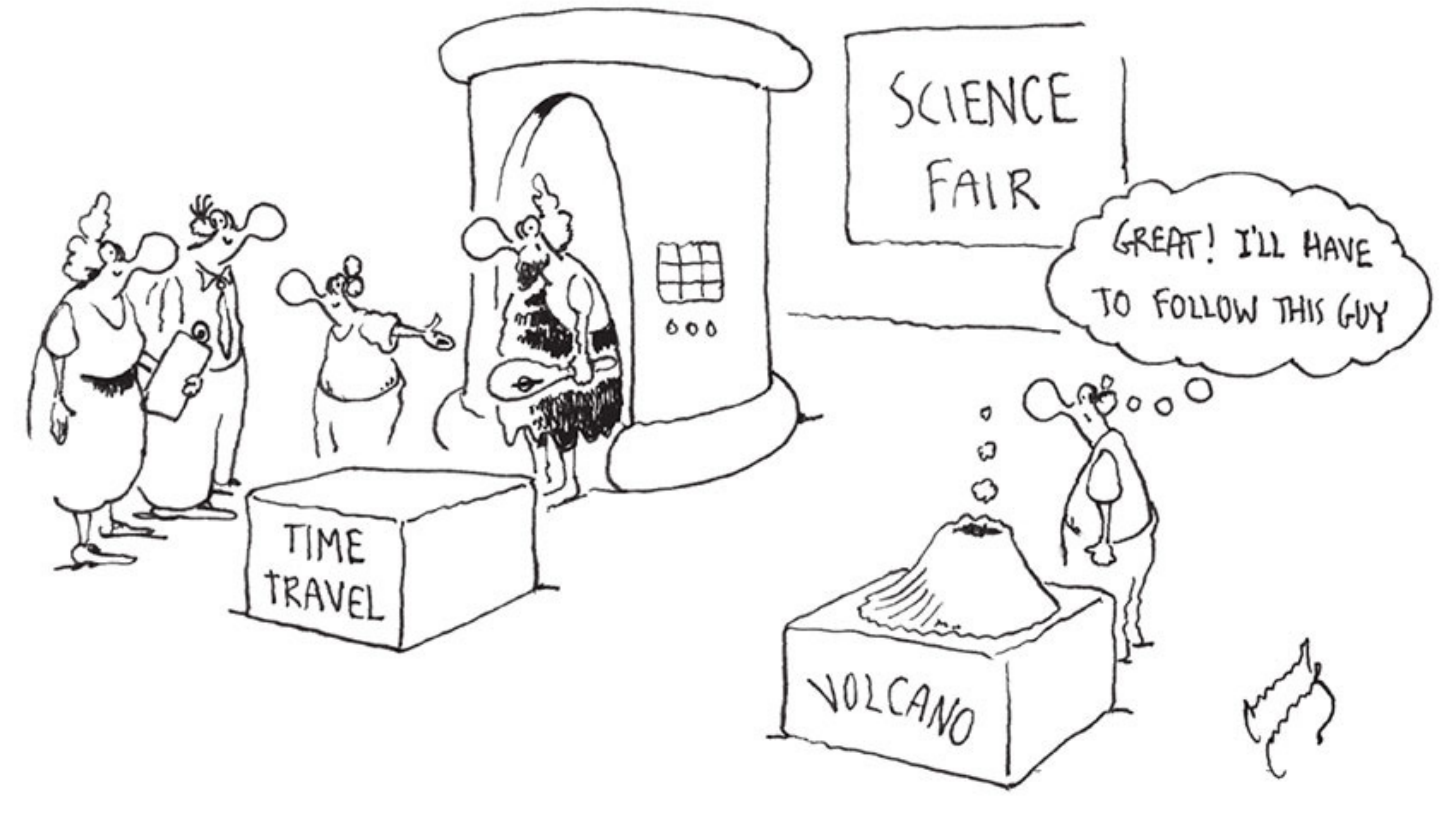
Selection process

- Poster group decided acceptance based on the abstracts.
- About 460 posters accepted
- 319 eligible for the Best Poster Award contest
  - ☞ i.e. the presenter(s) is within 4 yr since her/his Ph.D.
  - ☞ 30.6% identified themselves as females
- 201 presenters uploaded the poster in time for the contest:
  - ☞ one week before the start of the conference
- Two-step evaluation process
  - ☞ Many many people involved

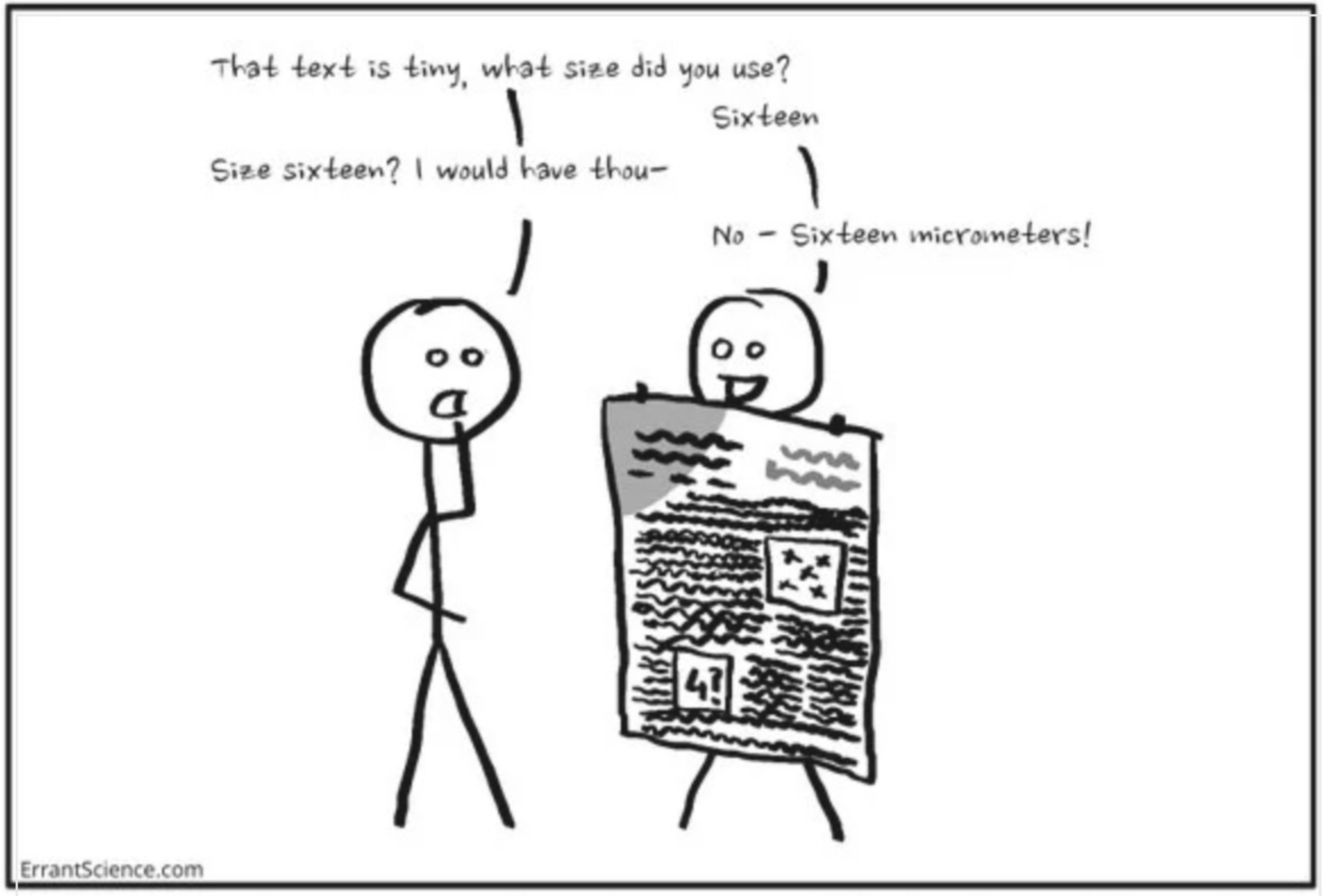
Step1: forming a short-list

- 10 commissions worked in parallel, evaluating the PDF posters
  1. ~ 40 commissars involved (30 IAC + 10 LOC) members
  2. Why not 16? : less numerous tracks were grouped to ensure the same success rate
- Produced a “not-so-short” list of 29 posters
  - 29.7% females (not imposing any gender consideration)
  - Proud to be naturally gender-invariant!

Evaluation criterion 1: scientific merit



Evaluation criterion 2: Readability



Step2: selecting the top 2%

Three Grand Jury members toured the two poster sessions in incognito

Wolfgang

Bruno

Lise

They gave up drinking for this!

Evaluation criterion 3: presentation skills (step-2 only)

[In addition to the previous two, evaluated beforehand]

And the winners are…

The winners receive a prize of **250 €** donated by our sponsor:

CAEN
Tools for Discovery

Background decomposition of the CUORE experiment and measurement of the $2\nu\beta\beta$ half-life of ^{130}Te

Stefano Ghislandi[1,2], on behalf of the CUORE Collaboration
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CONTRIBUTION ID: 76

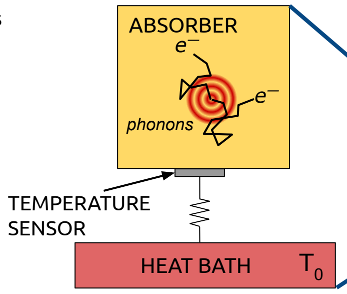
The CUORE experiment

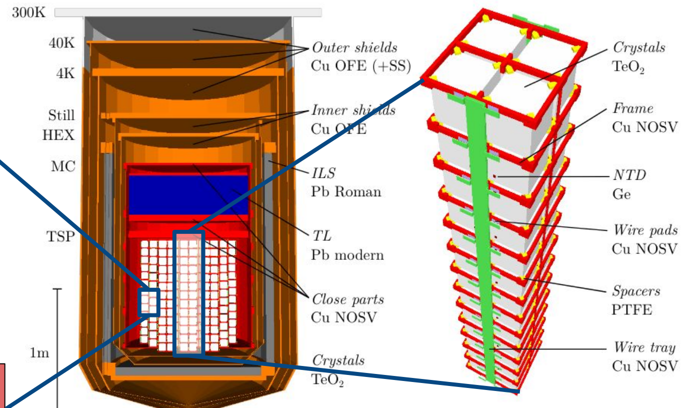
The CUORE (Cryogenic Underground Observatory for Rare Events) main search is $0\nu\beta\beta$ in ^{130}Te (Q-value~2527 keV), a beyond Standard Model process whose discovery would:

1. Assess the Majorana nature to neutrinos
2. Give essential information about neutrino masses
3. Provide an example of leptogenesis mechanism

The CUORE experiment

- Underground experiment at LNGS (Italy), *~1400 m under the Gran Sasso mountain*
- Searching $0\nu\beta\beta$ exploiting ***close-packed array*** of 988 TeO_2 crystals operated as ***cryogenic calorimeters*** and ***cooled down at ~15 mK***
- Stable data taking since 2019, latest limit (90% C.I) [1]: $T^{0\nu}_{1/2} > 3.8 \cdot 10^{25}$ yr





[1] arXiv:2404.04453v1 (2024)

The CUORE background model fit

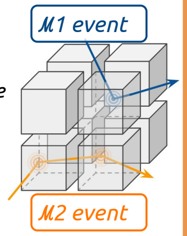
Rare events physics → *Low background* in the region of interest (~10^{-2} counts/keV/kg/yr); Deep knowledge of current backgrounds → ***Data driven model of the backgrounds***

Aims:

- Characterize the setup → *essential* for the next-gen *CUPID experiment*
- Understand the background and *extract material contamination*
- Base for *high-level analyses* ($2\nu\beta\beta$, $0\nu\beta\beta$-$\mathcal{M}2$, etc)

How to build it:

1. Look for *signatures in the data* (peaks, continuum, etc)
2. *Geant4 Monte Carlo simulation for each background source* in each volume of the experimental setup → ~80 contributions
3. *Bayesian simultaneous fit* of $\mathcal{M}1$ (1 spectrum) and $\mathcal{M}2$ diagonal bands (39 spectra) with a linear combination of the background sources
4. Priors given by *extensive assays* and *previous experiments*



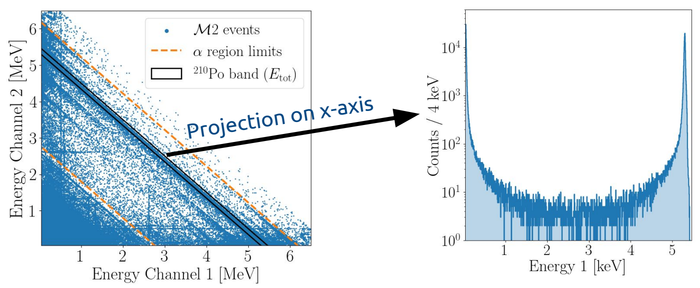
Model (bin counts)

$$\nu_{\kappa,i} = \sum_j N_j (w_{\kappa,i})_j$$

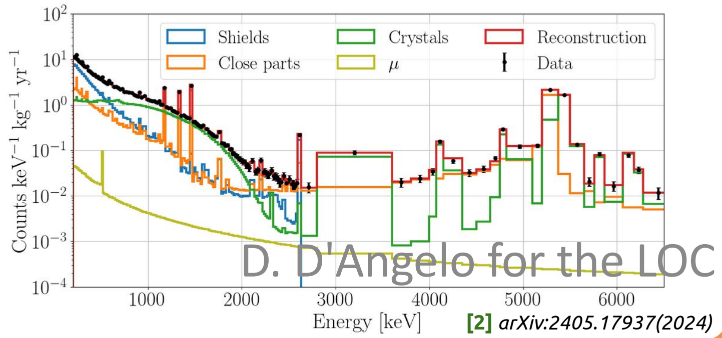
Fit Likelihood

$$\mathcal{L}(\{N_j\} \mid \text{data}) = \prod_{\kappa} \prod_i Pois(n_{\kappa,i}, \nu_{\kappa,i})$$

$\mathcal{M}2$ diagonal bands "technique" (example with ^{210}Po peak)



Satisfying data reconstruction in all the detector range [200,7000] keV [2]

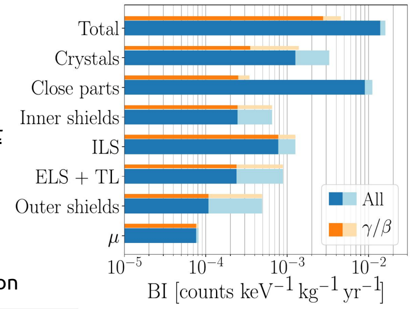


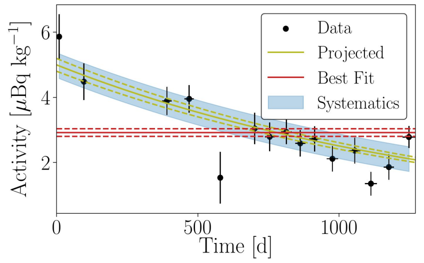
[2] arXiv:2405.17937(2024)

Further results

Studies of the $0\nu\beta\beta$ region of interest [2490, 2575] keV:

- ✔ *Measurement of the background index (BI) in the region of interest*
- ✔ Precise determination of each background component
- ✔ *Check and validations* of CUORE background *projections* [3]
- ✔ Analysis of recontaminations happened during the construction





Several studies on the single background sources:

- ✔ Time-development of activation isotopes (example of ^{125}Sb in TeO_2)
- ✔ Localization of non-uniform contaminations
- ✔ Muon flux measurement

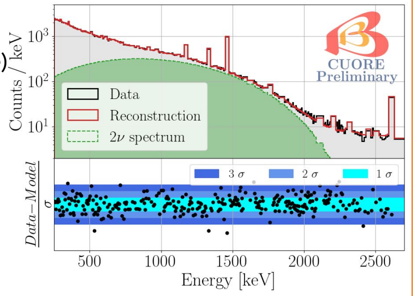
[3] Eur. Phys. J. C 77, 543 (2017)

Measurement of $2\nu\beta\beta$ half-life of ^{130}Te

Studies of the $2\nu\beta\beta$ half-life and spectral shape with the single state dominance model (1 ton-yr exposure)

Fit optimization:

- Fitting range
- Thinner binning to highlight spectral shapes
- Detector selection (only innermost towers)



Most precise measurement of the $2\nu\beta\beta$ decay half-life for ^{130}Te to date

$$T^{2\nu}_{1/2} = 9.323^{+0.052}_{-0.037}(\text{stat.}) \times 10^{20}\text{yr}$$

Systematics (~1%) under finalization

Near future:

Performed fits with the improved formalism, of primary importance for nuclear models. ***Soon out!!***

- Systematics not dominant, (to be added)
- Studies of the "Taylor expanded" shape for this decay
- Effective axial coupling g_A^{eff} measurement

GS SI — CUORE — INFN LNGS — NEUTRINO 2024

D. D'Angelo for the LOC

NEUTRINO 2024

KM3NeT's sensitivity to the next core-collapse supernova

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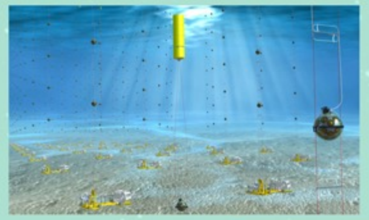
*: presenter (goos@apc.in2p3.fr)

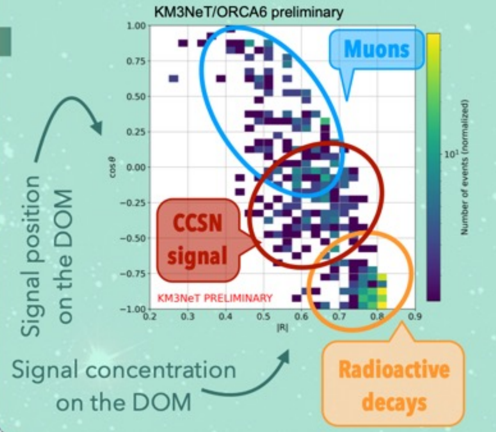
Motivation: Core-Collapse supernovae (CCSNe) are the end of life of heavy stars (8$M_\odot$ and above), whose core collapses in a fraction of a second, often leading to a powerful explosion whose mechanism is not yet completely understood. The detection of 25 neutrinos from supernova 1987A has demonstrated that CCSNe are associated with an intense neutrino emission. If another CCSN occurs in or near our Galaxy, the detection of the resulting $\mathcal{O}(10)$ MeV neutrino burst would provide invaluable information on the CCSN mechanism and neutrino properties. This burst could be intense enough to be detectable at experiments targeting higher-energy neutrinos such as KM3NeT.

KM3NeT: 3D grid of digital optical modules (DOMs) in the Mediterranean Sea, currently under construction at two different sites: ORCA (Toulon, France) and ARCA (Sicily, Italy) [1].



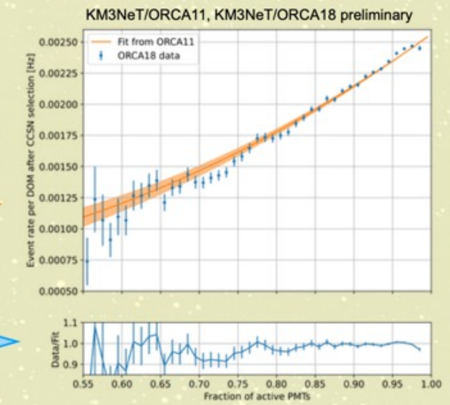
CCSN neutrinos will activate individual DOMs: Each KM3NeT DOM (radius of 21.6 cm) hosts 31 small photomultipliers (PMTs) [2]. We use single-DOM observables to maximise the signal-to-noise ratio: the multiplicity (number of PMT hits in a DOM within 10 ns), $|R|$, $\cos\theta$, Δt (temporal spread of the signal) and the total time over threshold (signal intensity).

DOM with an example of an event of **multiplicity 4**



Boosted decision trees (BDTs): we train them on these features to distinguish signal from background.

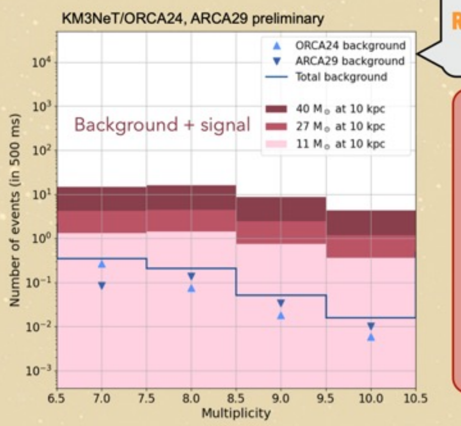
Adaptive background estimation at KM3NeT: During bioluminescence bursts, a small fraction of PMTs is suppressed. We fit the background dependence on the fraction of active PMTs using recent data and rescale to the current detector configuration to obtain an estimate of the present expected background.



Fit performed on **ORCA11 data** and rescaled and compared to **ORCA with 18 lines**

Introduction of an uncertainty of ~5%

Search for CCSN neutrinos: If the neutrino burst from a nearby CCSN is intense enough, associated events will register as a rise of the number of recorded single-DOM events at ORCA & ARCA.



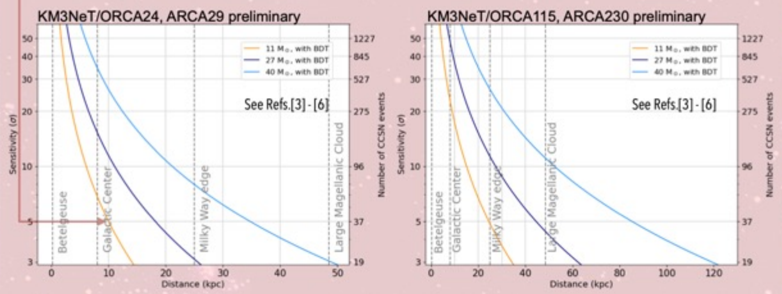
Muons & Radioactive decays

Maximisation of the signal-to-noise ratio using the BDT scores: only events are kept that are very signal-like.

How far can KM3NeT reach?

With the **near future ORCA and ARCA configurations** at KM3NeT, it is possible to probe the **dense region around the center of the Milky Way**, even for the case of the lightest CCSN progenitor. If the exploding star were particularly massive, **almost all our Galaxy** would be covered.

ORCA24 & ARCA29 — ORCA115 & ARCA230



The method described in this contribution is already implemented in **KM3NeT's real-time analysis platform** (see *M. Mastrodicasa et al., poster 375*).

[1] J. Phys. G: Nucl. Part. Phys. 43, 8, 084001 (2016).
[2] JINST 17, 7, 07038 (2022).
[3] Phys. Rev. Lett. 111, 12, 121104 (2013).
[4] Phys. Rev. D 90, 4, 045032 (2014).
[5] Phys. Rev. D 101, 12, 123013 (2020).

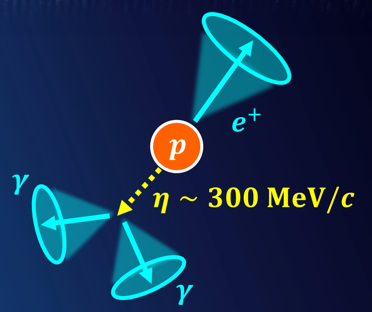
UnivEarthS — Région ÎledeFrance — DIM ORIGINES

Search for Proton Decay via $p \to e^+\eta$ and $p \to \mu^+\eta$ in Super-Kamiokande

Natsumi Taniuchi for the Super-Kamiokande Collaboration
The University of Tokyo and University of Cambridge

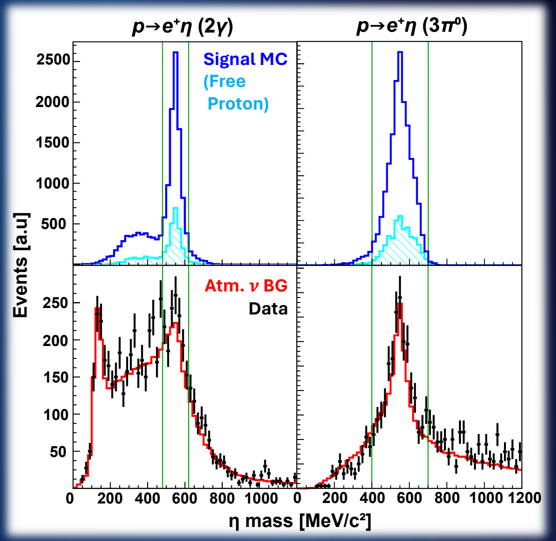
Proton Decay – Key to Probe GUTs

- Grand Unified Theories permit baryon-number-violating proton decay [1].
- Super-Kamiokande (SK), a water Cherenkov detector, leverages numerous proton targets to probe various decay channels [2]:
  $p \to l^+\eta$ ($l^+ = e^+/\mu^+$) exhibits one of the highest detection efficiencies.
- This work incorporates improved estimations of intranuclear η interaction cross sections and includes ~15% more data than previous analysis [3].



Event Selections at Water Cherenkov Detector

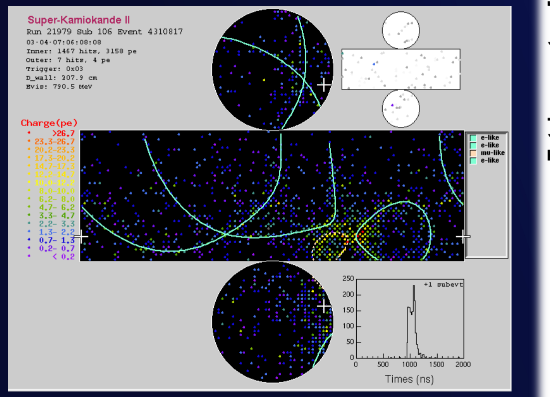
- η Decay Modes: $\eta \to 2\gamma$ (39%) & $\eta \to 3\pi^0$ (33%).
- SK detects e/γ as fuzzy rings, and μ as a ring with sharp edges.
- **Event selection cuts on reconstructed invariant masses of η and p, and p momentum** effectively identify signals from BGs.
- Backgrounds: π^0/η via atmospheric ν interaction on ^{16}O.

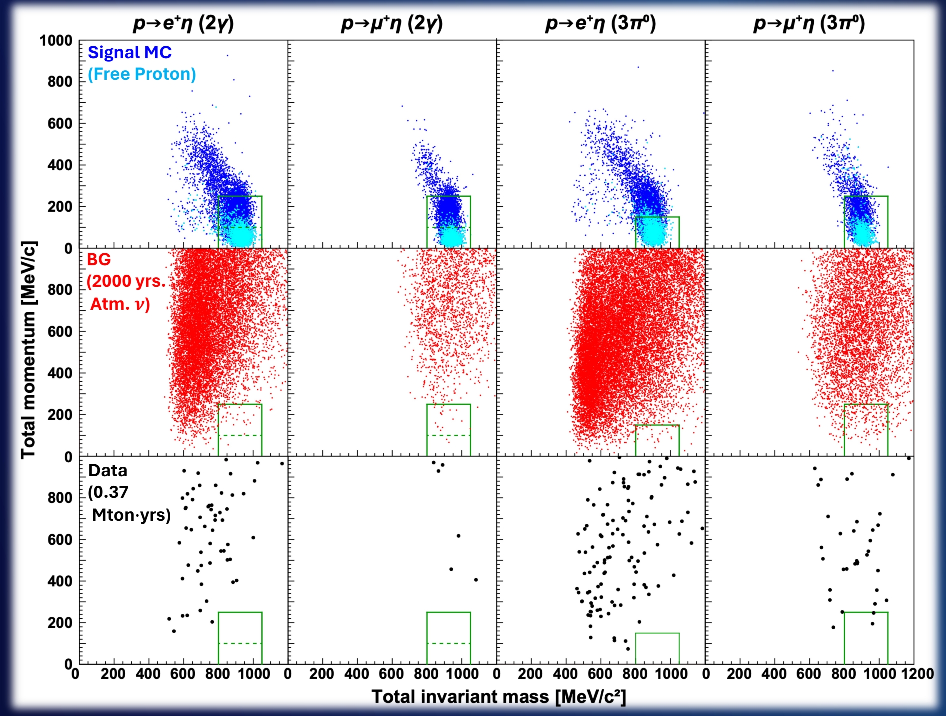


Search Results with World's Best Sensitivity

- Analysed over 0.37 Mton·years exposure of SK data.
- Updated nuclear effect led to improvements in signal efficiency (~10%) and a reduction in systematic uncertainty by a factor of 3.
- **2 candidates remain in the final signal region of $p \to \mu^+\eta, \eta \to 3\pi^0$ search. No significant data excess was observed above the expected background rate.**
- Sets most stringent limits on proton's lifetime for $p \to l^+\eta$ by ~50%.

Modes	$p \to e^+\eta$	$p \to \mu^+\eta$
Efficiency [%]	29.0 ± 4.6	24.2 ± 3.7
#Background	0.42 ± 0.13	0.93 ± 0.25
#Candidate	0	2
Lifetime Limit at 90% C.L.	1.4×10^{34} years	7.3×10^{33} years





References:
[1] P. Nath and P. Fileviez Perez, Phys. Rep. 441, 191 (2007).
[2] Y. Fukuda et al. (Super-Kamiokande Collaboration), Nucl. Instrum. Methods Phys. Res., Sect. A 737, 253 (2014).
[3] K. Abe et al. (Super-Kamiokande Collaboration), Phys. Rev. D 96, 012003 (2017).

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UNIVERSITY OF CAMBRIDGE

NEUTRINO 2024

Direct Experimental Constraints on the Spatial Extent of a Neutrino Wavepacket from ^{7}Be Electron Capture Decay with the BeEST Experiment

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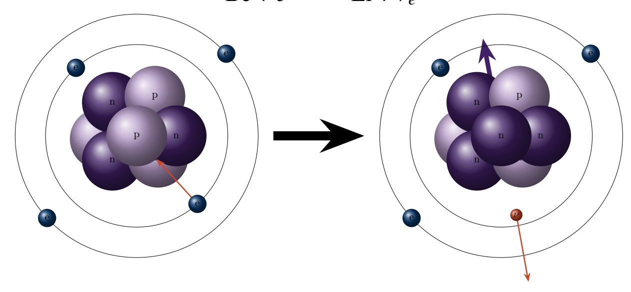
[1]Department of Physics, Colorado School of Mines, Golden, CO, 80401, United States

COLORADO SCHOOL OF MINES

Electron Capture

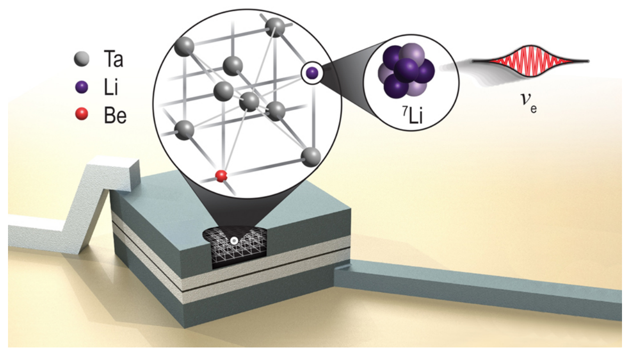
$$^7\text{Be} + e^- \to {}^7\text{Li} + \nu_e$$



- ^{7}Be is the lightest mass pure electron capture (EC) decaying isotope
- The electron is captured either from 1s (K shell) or 2s (L shell) orbital
- The final state ^{7}Li nucleus can be in the ground state (GS) or an excited state (ES)
- The entangled ^{7}Li – ν_e pair share inherent uncertainties in energy and momentum at their creation

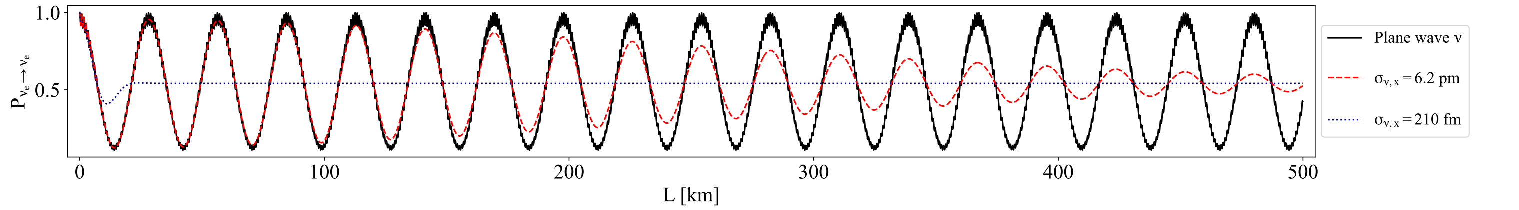
The BeEST Experiment

- Superconducting tunnel junctions (STJs) are implanted with ^{7}Be at TRIUMF
- STJs are cooled to ~0.1 K in an adiabatic demagetization refrigerator (ADR) for readout at LLNL
- ^{7}Be EC produces recoiling ^{7}Li which break Cooper pairs and create an energy dependent current
- Precision measurements of ^{7}Li recoil energies are used to study the entangled ν_e



Quantum Uncertainty of Neutrinos

- Uncertainty relations between position and momentum are inherent in quantum measurements: $\sigma_x\sigma_p \geq \hbar/2$
- Environmental interactions serve as measurements of radioactive decay ν sources, resulting in ν with finite widths: $\sigma_{\nu,x}$
- The scale of localizing interactions that set this width is an open question and dampen oscillation probabilities as wavepackets separate
- By measuring ^{7}Li recoil energies from ^{7}Be EC decays in STJs, the BeEST experiment places direct limits on ^{7}Li and ν_e wavepackets



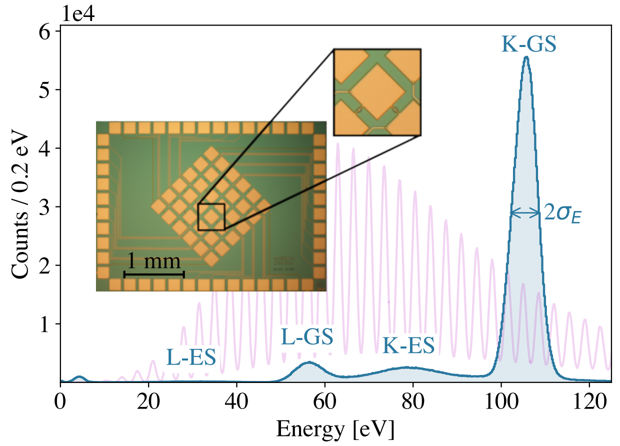
Measurement and Uncertainty

- This analysis uses ~20 hours of data from a single pixel in the 36-pixel array
- The K-GS peak width is conservatively used as an upper limit on quantum uncertainty:

$$\sigma_{\text{Li},E} \leq 2.9 \text{ eV}$$

- From this, we obtain a limit on the spatial width (localization scale) of the Li recoil:

$$\sigma_{\text{Li},x} \geq 6.2 \text{ pm}$$



Extraction of Neutrino Wavepacket Size: Two Theoretical Methods

^{7}Li–ν share energy uncertainty

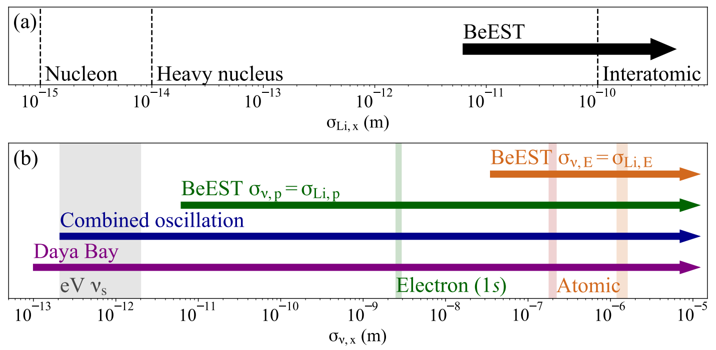
1. $\sigma_{\nu,E} = \sigma_{\text{Li},E}$
2. $\sigma_{\nu,x} \geq \frac{\hbar}{2\sigma_{\nu,p}} = \frac{\hbar c}{2\sigma_{\nu,E}}$

$$\sigma_{\nu,x} \geq 35 \text{ nm}$$

^{7}Li–ν share momentum uncertainty

1. $\sigma_{\text{Li},p} = \sqrt{m/2E}\,\sigma_{\text{Li},E}$
2. $\sigma_{\nu,x} = \sigma_{\text{Li},x} \geq \frac{\hbar}{2\sigma_{\text{Li},p}}$

$$\sigma_{\nu,x} = \sigma_{\text{Li},x} \geq 6.2 \text{ pm}$$



(a) The lower-limit on the spatial width of ^{7}Li produced in ^{7}Be EC decays in STJs, with vertical lines at approximate nuclear and atomic scales for comparison.

(b) Experimental limits on $\sigma_{\nu,x}$ using BeEST [1] and reactor data [2,3]. The 3 vertical bands on the right show predictions based on localization via atomic interactions [4,5] or sub-atomic interactions [6]. The left vertical band shows the range that can improve eV-scale ν_s model fits to data [7,8].

Summary

- New experimental paradigm to measure neutrino properties and the fundamental nature of quantum mechanics at subatomic scales
- The BeEST limit on $\sigma_{\text{Li},x}$ is the first direct limit on the scale of localization in weak decay and ν_e wavepacket size
- The limits on $\sigma_{\nu,x}$ exclude wavepacket separation as the cause of the dampening preferred by eV-scale ν_s fits to data [7,8]

Funding Acknowledgements

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- FCT-Fundação para a Ciência e Tecnologia (Portugal): UID/04559/2020 (LIBPhys)
- TRIUMF through National Research Council of Canada
- LLNL under contract DE-AC52-07NA27344
- PNNL under contract DE-AC05-76RL01830
- FRIB under DE-SC0000661

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1. The BeEST Collaboration, arXiv:2404.03102 (2024)
2. Daya Bay Collaboration, EPJ C **77**, 606 (2017)
3. de Gouvéa et al., JHEP **2020**, 18 (2020)
4. Akhmedov et al., JHEP **11**, 82 (2022)
5. Krueger et al., EPJ C 83, 578 (2023)
6. Jones et al., arXiv:2404.19746 (2024)
7. Argüelles et al., Phys. Rev. D **107**, 036004 (2024)
8. Hardin et al., JHEP **2023**, 9 (2023)

And the winners are…

Track	ID	Title	Author
DBD	76	Background decomposition of the CUORE experiment and measurement of the $2\nu\beta\beta$ half-life of ^{130}Te	Stefano Ghislandi
SN	357	KM3NeT's sensitivity to the next core-collapse supernova	Isabel Astrid Goos
BSM	59	Search for proton decay via $p \to e^{+} + \eta$ and $p \to \mu^{+} + \eta$ in Super-Kamiokande	Natsumi Taniuchi
new tech	458	Direct Experimental Constraints on the Spatial Extent of a Neutrino Wavepacket from Measurements of ^{7}Be Electron Captures with the BeEST Experiment	Joseph Smolsky

The winners receive a prize of **250 €** donated by our sponsor:

CAEN Tools for Discovery

A great experience

- We had an excellent level of poster contributions
- Our compliments go to all partecipants, not only the winners!
- Our thanks go to all the people that worked hard to make this possible
- Thanks to CAEN S.p.A.

Muffins are an integral part of any academic conference