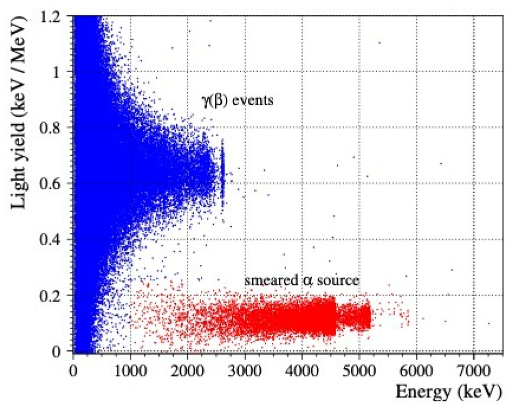
SEARCHING FOR NEW PHYSICS IN 2νββ WITH CUPID

EMANUELA CELI ON BEHALF OF THE CUPID COLLABORATION

The development of cryogenic calorimeters to search for neutrinoless double-beta decay (0νββ) has given in the last years increasingly promising results. To achieve a nearly background-free condition, scintillating crystals for 0νββ have been developed. Thanks to the light-assisted particle discrimination, this technology demonstrated the complete rejection of the dominant alpha background. In addition, the possibility of achieving ton-scale exposures, maintaining an excellent energy resolution, lays the foundations for the CUPID project. CUPID is a next-generation experiment aiming to exploit ^{100}Mo enriched scintillating Li_2MoO_4 crystals, operating as cryogenic calorimeters, to investigate the entire inverted hierarchy region for Majorana neutrino masses. Thanks to the high $Q_{\beta\beta}$ of ^{100}Mo and the α-discrimination, the CUPID goal is to achieve a background level in the region of interest of 10^{-4} counts/(keV kg yr). Although the 0νββ is the main objective of CUPID, other processes are open to experimental investigation, particularly those inducing a distortion of the 2νββ spectral shape. Given the relatively fast half-life of ^{100}Mo 2νββ, we expect to reach unprecedented sensitivities in the search for distortions induced by physics beyond the Standard Model.

THE CUPID PROJECT

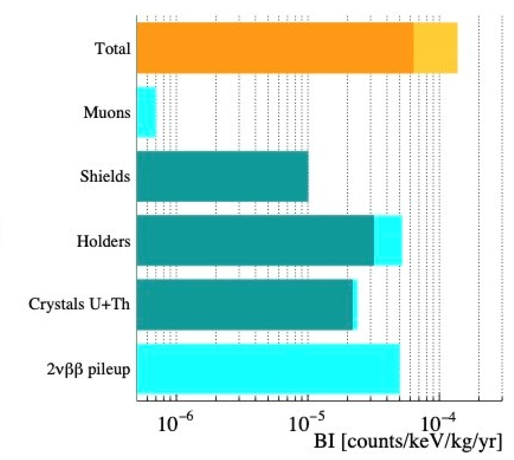
- Re-use of CUORE cryogenic infrastructure at LNGS
- Li_2MoO_4 scintillating crystals
- Enrichment > 95%
- 45×45×45 mm^3 crystals
- 1596 crystals for 240 kg of ^{100}Mo
- Goal FWHM: 5 keV at $Q_{\beta\beta}$
- Target background index ~10^{-4} counts/(keV kg yr)
- 1710 light detectors for particle ID

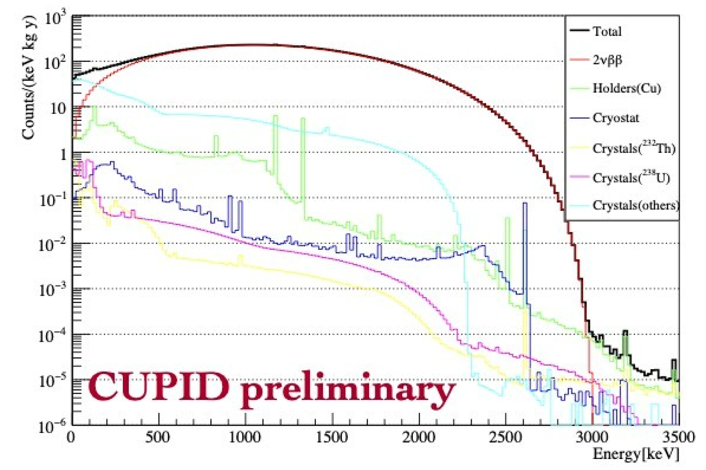


THE BACKGROUND BUDGET

Simulations made with a Geant4 based software taking into account the detector preliminary geometry.

- ^{232}Th, ^{238}U and crystals internal contaminations taken from CUPID-Mo background model (^{40}K, ^{90}Sr, ^{87}Rb);
- ^{232}Th and ^{238}U in near copper taken from CUORE-0 background model;
- ^{232}Th and ^{238}U in cryostat taken from CUORE background studies;
- Activity of cosmogenic activated isotopes simulated with ACTIVIA;

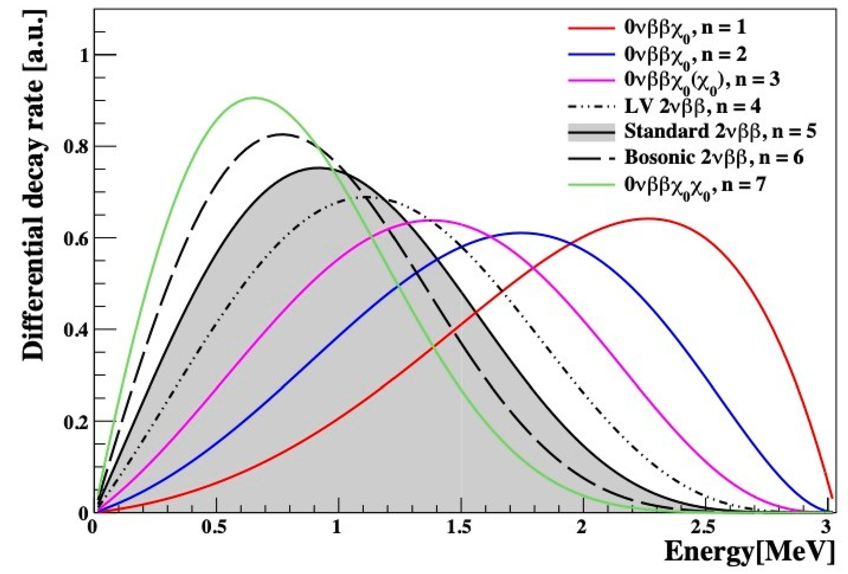




SENSITIVITY STUDIES

Several beyond the Standard Model (bSM) processes induce a distortion of the 2νββ spectrum changing the spectral index n according to the formula $G \sim (Q_{\beta\beta} - T)^n$ where G is the phase space factor, $Q_{\beta\beta}$ is the Q-value and T is the summed kinetic energies of the two emitted electrons.

- Majoron emitting decays: exotic 0νββ decays characterized by the emission of a massless Goldstone boson, called Majoron
- Lorentz-Violating (LV) 2νββ: The Standard Model Extension (SME) provides a general framework for Lorentz Invariance Violation introducing a tensor field permeating all the space-time. Such theories predict a perturbative effect on the 2νββ trough the parameter $\mathring{a}^{(3)}_{of}$, the SME operator acting in the neutrino sector
- Bosonic neutrinos: the existence of a bosonic component would induce an effect on the total decay rate of 2νββ and its shape



The analysis strategy consist of producing CUPID mock data according to the Background Budget with the equivalent statistic of 1yr of data taking and make a Bayesian fit including new physics hypotheses. Preliminary systematics are also considered including effects of different binnings and thresholds. A large influence of threshold systematic was observed for n = 2,3,4 due to correlation effects of bSM spectra and pure beta-decays (^{90}SrY). More systematic effects induced by the source location and pile-up will be studied in the future.

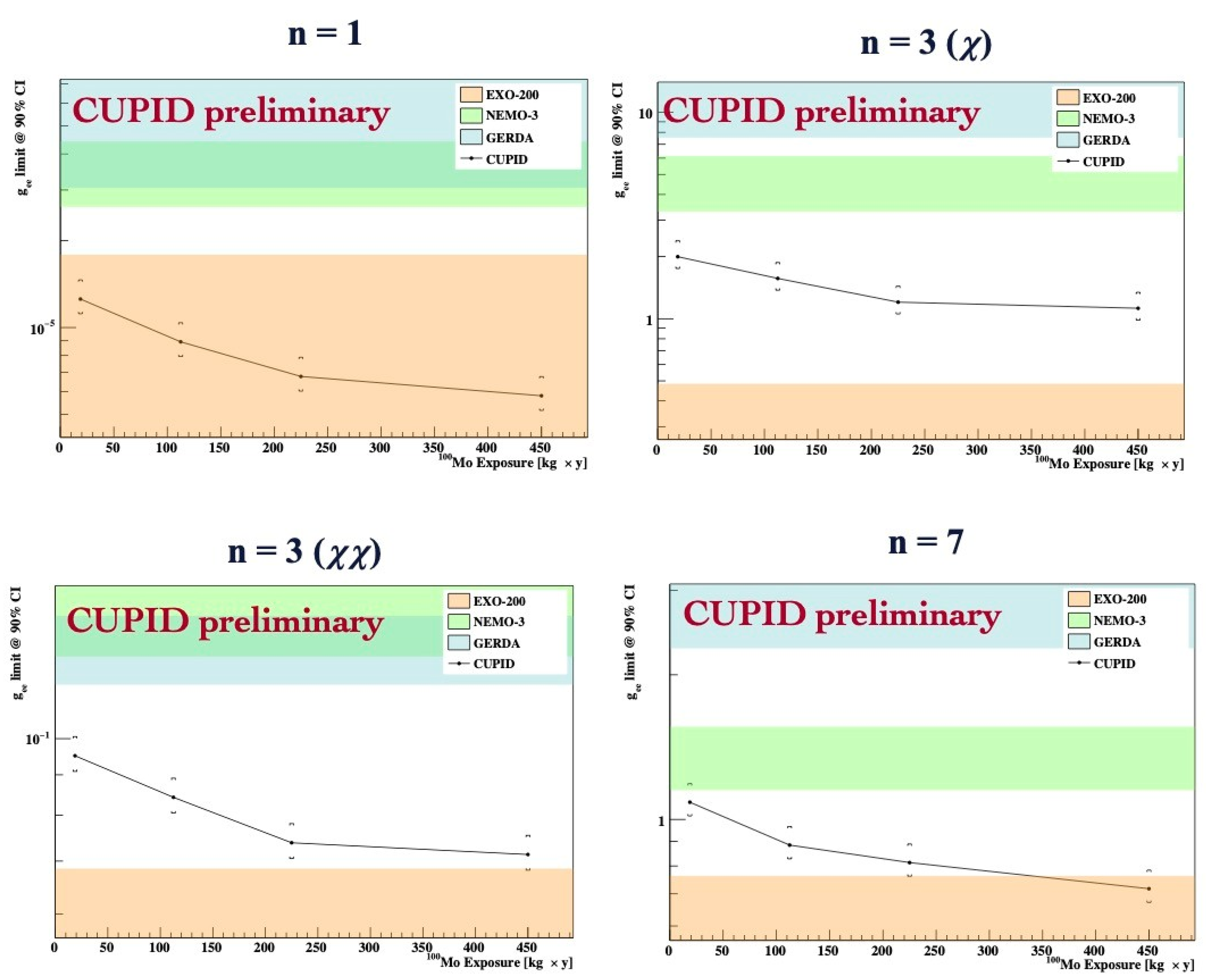
Decay mode	Exclusion sensitivity on $T_{1/2}$ @90% C.I.	Systematic effect	Actual limit with ^{100}Mo on $T_{1/2}$ @90% C.L.
Majoron ($n = 1$)	9.3×10^{23} yr	+6.5%	4.4 ×10^{22} yr
Majoron ($n = 2$)	1.4×10^{23} yr	+44%	9.9 ×10^{21} yr
Majoron ($n = 3$)	4.4×10^{22} yr	+70%	4.4 ×10^{21} yr
Majoron ($n = 7$)	9.0×10^{21} yr	+1.5%	1.2 ×10^{21} yr
Bosonic ν ($n = 6$)	4.4×10^{21} yr	+2%	1.2 ×10^{21} yr

MAJORON EMITTING DECAYS

The limit on the half-life can be easily converted into a limit on the Majoron-neutrino coupling constant:

$$\frac{1}{T_{1/2}} = |g_{ee}|^{2m} G\,|M|^2$$

Where G is the phase space factor [4], M the nuclear matrix element [5] and m is the number of Majorons emitted.



LORENTZ VIOLATING 2νββ and BOSONIC NEUTRINOS

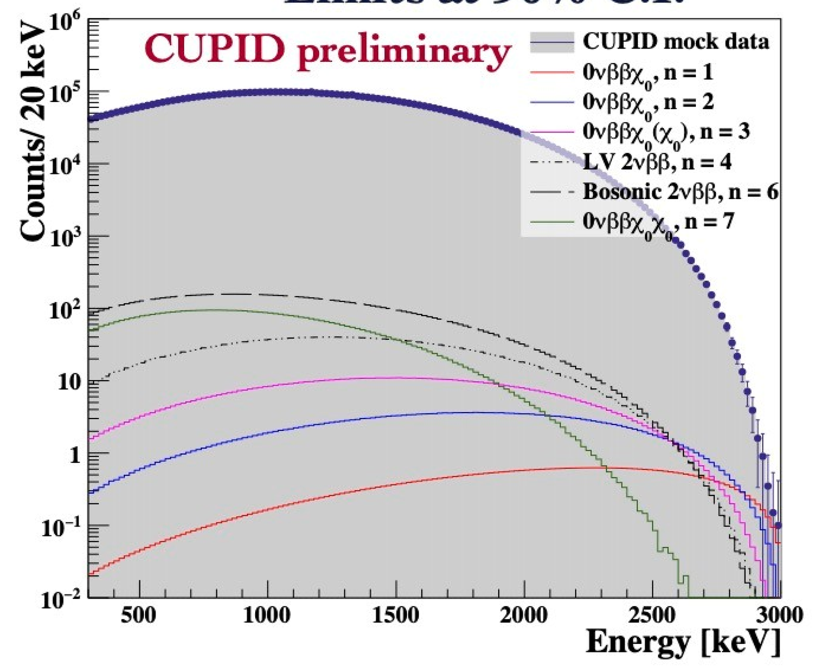
The sensitivity predicted on $\mathring{a}^{(3)}_{of}$ amplitude can be calculated considering the formula

$$\mathring{a}^{(3)}_{\text{of}} = \frac{1}{10}\frac{I^{\text{Theo}}_{2\nu}}{I^{\text{Theo}}_{\text{LV}}} \cdot \frac{\Gamma^{\text{Exp}}_{\text{LV}}}{\Gamma^{\text{Exp}}_{2\nu}}$$

where the factor $\frac{1}{10}\frac{I^{\text{Theo}}_{2\nu}}{I^{\text{Theo}}_{\text{LV}}} \sim 171$ GeV for ^{100}Mo.

The contribution of bosonic neutrinos to the 2νββ can be parametrised as $W_{tot} = \cos^4\chi W_f + \sin^4\chi W_b$ where W_f and W_b are the decay rates corresponding to the fermionic and bosonic emission. An upper limit on the bosonic neutrino contribution $\sin^2\chi$ to the ^{100}Mo 2νββ can be extracted from a detailed spectral shape study according to [3].

Limits at 90% C.I.



bSM parameter	Sensitivity @90% C.I.	Systematic effect	Actual limit [NEMO-3]
$\mathring{a}^{(3)}_{\text{of}}$	< 9.8 ×10^{-8} GeV	+93%	< 3.5 ×10^{-7} GeV
$\sin^2\chi$	< 0.14	+2%	< 0.27

REFERENCES

[1] CUPID pre-CDR. 7 2019.
[2] Eur. Phys. J. C 79(2019) no.5, 440
[3] Nucl. Phys. B 783, 90 (2007)
[4] Phys.Rev.C 91 (2015) 6, 064310
[5] Phys.Rev.C 103 (2021) 4, 044302
[7] Eur. Phys. J. C (2017) 77:13
[8] arXiv:2202.06279

GRAN SASSO SCIENCE INSTITUTE

INFN Istituto Nazionale di Fisica Nucleare

The CUPID Collaboration thanks the directors and staff of theLaboratori Nazionali del Gran Sasso and the technical staff of our laboratories. This work was supported by the Istituto Nazionale di Fisica Nucleare, the Italian Ministry of University and Research (Italy), the European Research Council and European Commission, the US Department of Energy (DOE) Office of Science, the DOE Office of Science, Office of Nuclear Physics, the National Science Foundation (USA), the Russian Science Foundation (Russia), and the National Research Foundation (Ukraine). This research used resources of the National Energy Research Scientific Computing Center (NERSC). This work makes use of both the DIANA data analysis and APOLLO data acquisition software packages, which were developed by the CUORICINO, CUORE, LUCIFER and CUPID-0 Collaborations.