+ INR Kiev

Primi risultati sperimentali sullo studio di decadimenti ββ in ^{106}Cd con un cristallo scintillatore di $^{106}CdWO_4$ in coincidenza con quattro rivelatori HP-Ge

100° Congresso SIF
Pisa, 26 Settembre 2014

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INFN - LNGS

Double beta decay of ^{106}Cd

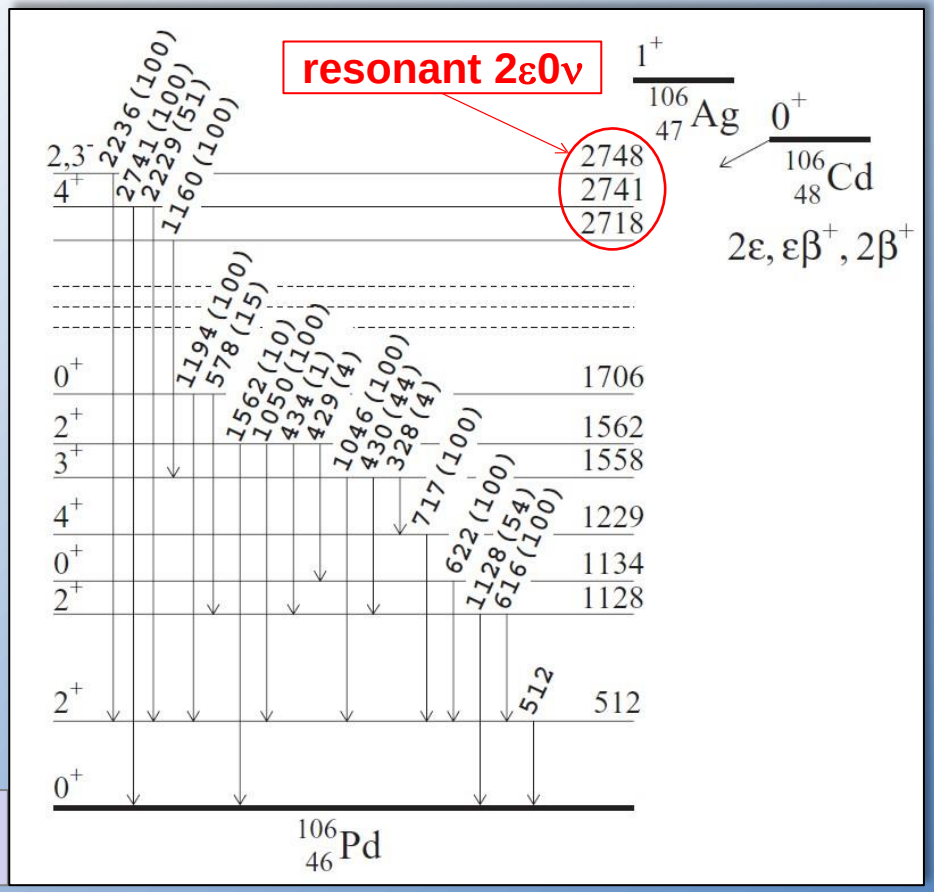
^{106}Cd is an attractive candidate:

- $Q_{2\beta}$ = (2775.39 ± 0.10) keV [one of only six $2\beta^+$ candidate nuclides]
- Quite high natural abundance δ = 1.25%
- Possibility of resonant 2ε0ν captures to excited levels of daughter ^{106}Pd
- Quite optimistic theoretical $T_{1/2}$:

$2\varepsilon 2\nu$	$(2.0\text{-}2.6)\times10^{20}$ yr [1]
	4.8×10^{21} yr [2]
$\varepsilon\beta^+2\nu$	$(1.4\text{-}1.6)\times10^{21}$ yr [1]
	2.9×10^{22} yr [2]

[1] S. Stoica et al., EPJA 17 (2003) 529

[2] J. Suhonen, PRC 86 (2012) 024301

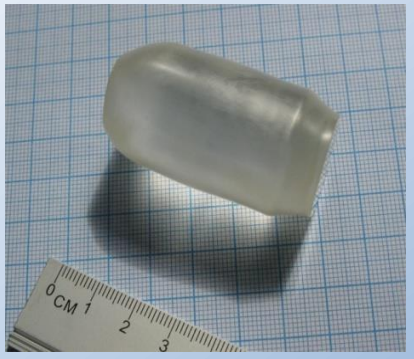


Decay scheme of ^{106}Cd

Our previous measurements with $^{106}CdWO_4$ crystal scintillator

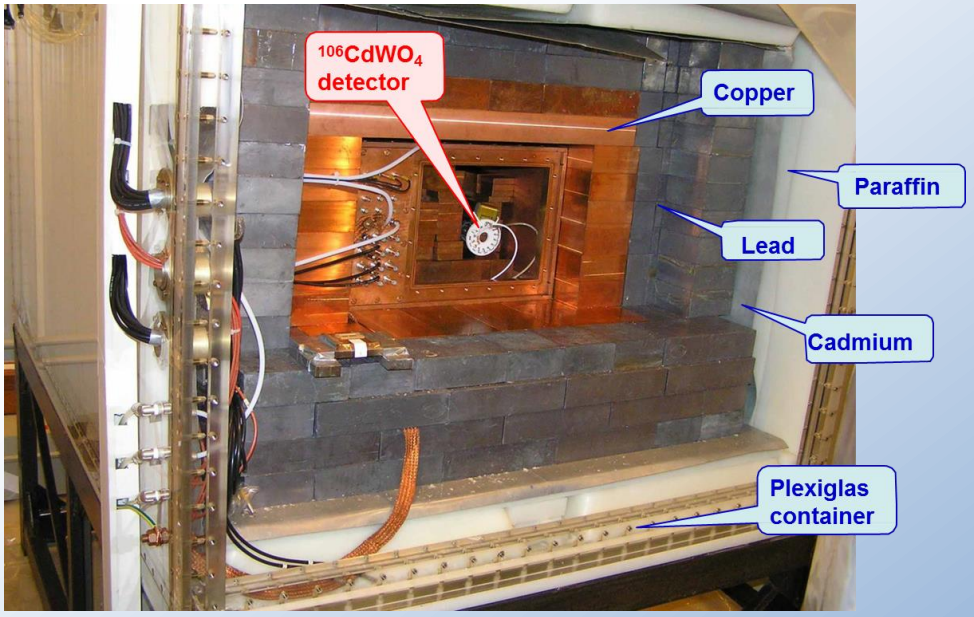
P. Belli et al., PRC 85 (2012) 044610

Excellent optical and scintillation properties thanks to special R&D to purify raw materials and Low-Thermal-Gradient Czochralski technique to grow the crystal
[P. Belli et al., NIMA 615 (2010) 301]

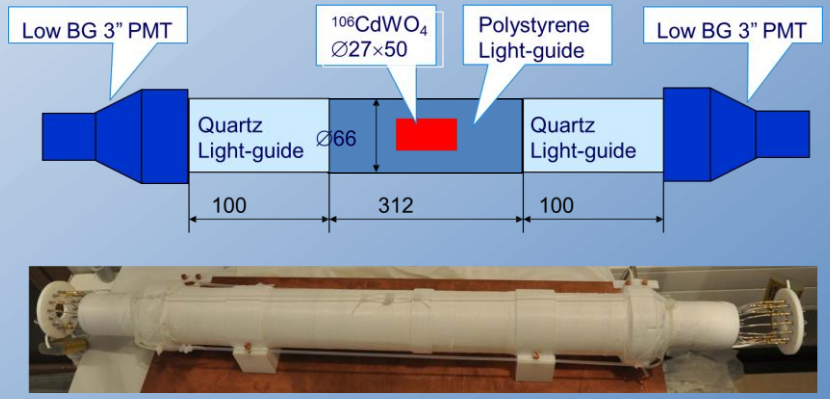


^{106}Cd enrichment: 66%

FWHM: 10% at 662 keV



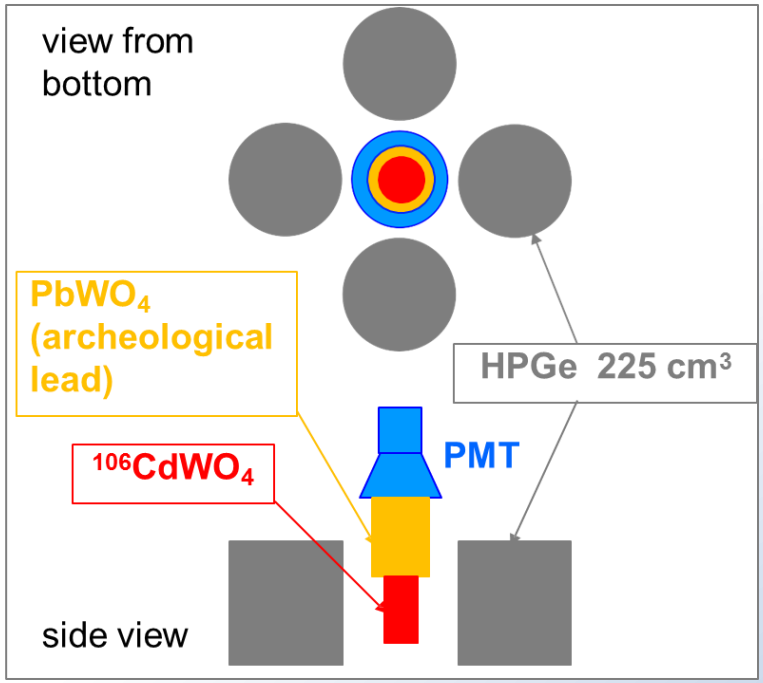
DAMA/R&D setup @ LNGS



$T_{1/2}$ limits for different modes: ~ 10^{20}–10^{21} yr (mostly the best limits)

$^{106}CdWO_4$ in the GeMulti setup with 4 HPGe detectors

STELLA facilities @ LNGS



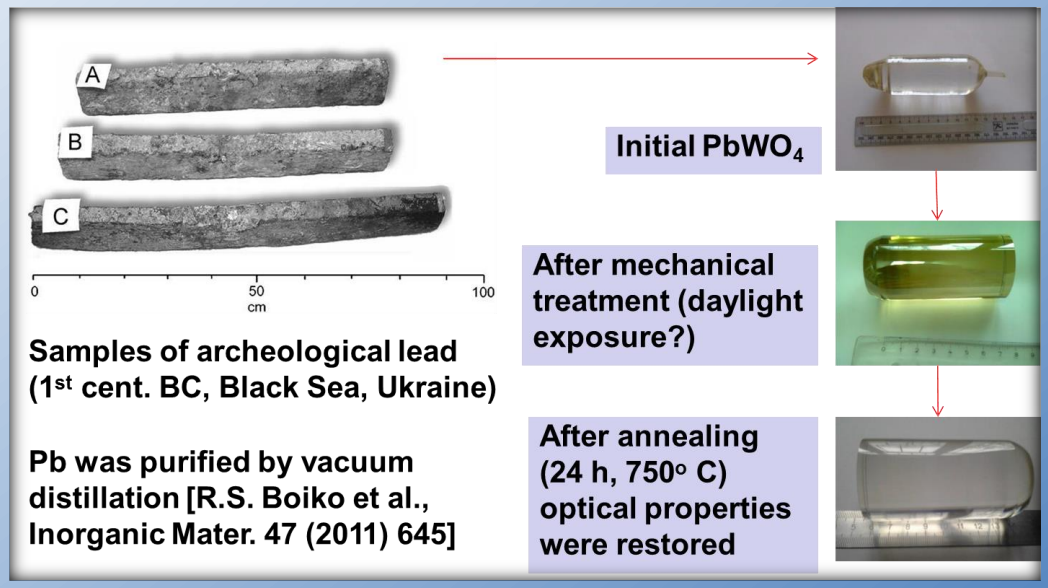
- ✓ $^{106}CdWO4$ crystal scintillator, 215 g mass
- ✓ $PbWO_4$ crystal light guide (∅40×83 mm)
- ✓ 4 HPGe, ~ 225 cm^3 each, in one cryostat
- ✓ $^{106}CdWO_4$ in coincidence/anticoincid. with HPGe
- ✓ Detection efficiency ~ 5 - 7%
- ✓ **Estimated sensitivity to two neutrino εβ⁺ and 2β⁺ in ^{106}Cd: $T_{1/2}$ ~ 10^{20} - 10^{21} yr**

To suppress radioactivity from PMT:

$PbWO_4$ light-guide

from archeological lead [a(^{210}Pb)<0.3mBq/kg]

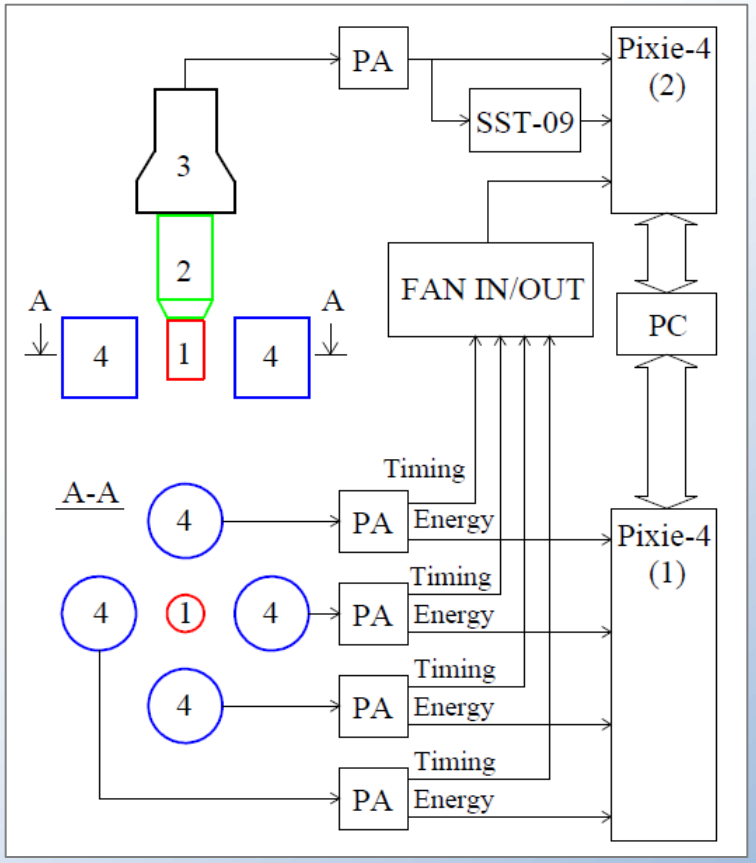
[F.A. Danevich et al., NIMA 603 (2009) 328]



$^{106}CdWO_4$ in the GeMulti setup with 4 HPGe detectors

DAQ:

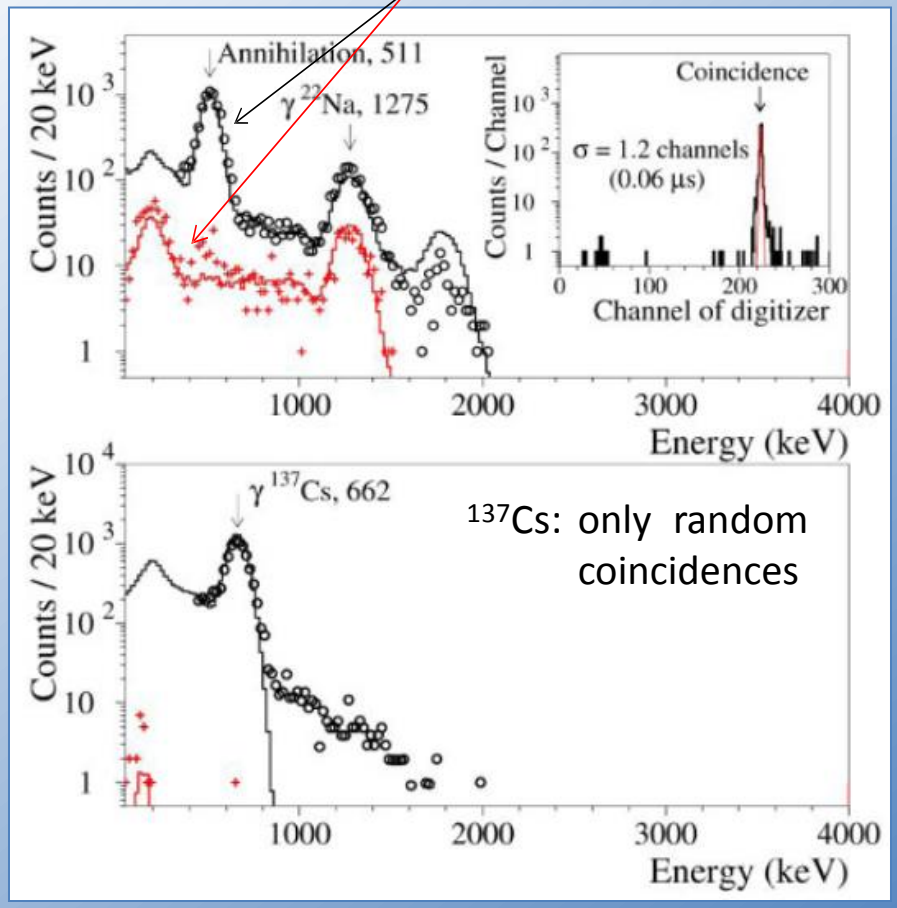
- time and energy for each HPGe;
- shape of signal for $^{106}CdWO_4$ (>0.6 MeV to exclude ^{113m}Cd β decay)
- different triggers (c/ac)



Calibration: ^{22}Na, ^{60}Co, ^{137}Cs, ^{228}Th

$^{106}CdWO_4$ – FWHM = $(20.4 \times E_\gamma)^{1/2}$

^{22}Na: no coincidence with HPGe and coincidence with 511 keV in HPGe



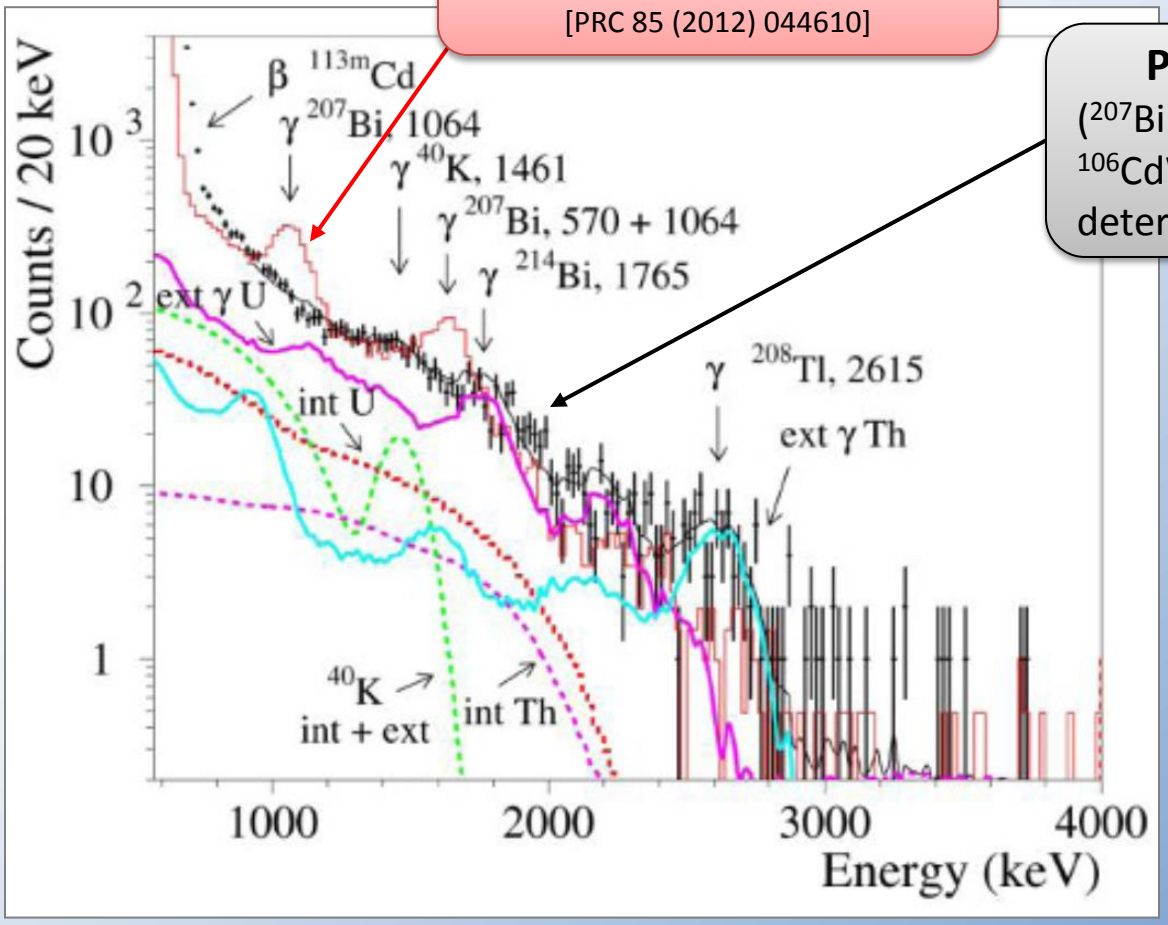
Energy spectrum of the β(γ) events

Mean-time PSD method used to discriminate β(γ) events from α events due to internal U/Th contamination of the crystal

T=3233 h

Previous measurements
(normalised to 3233 h)
[PRC 85 (2012) 044610]

Points: current measurements
(^{207}Bi disappeared thanks to cleaning of $^{106}CdWO_4$ by ultra-pure nitric acid + K-free detergent)



Background model:

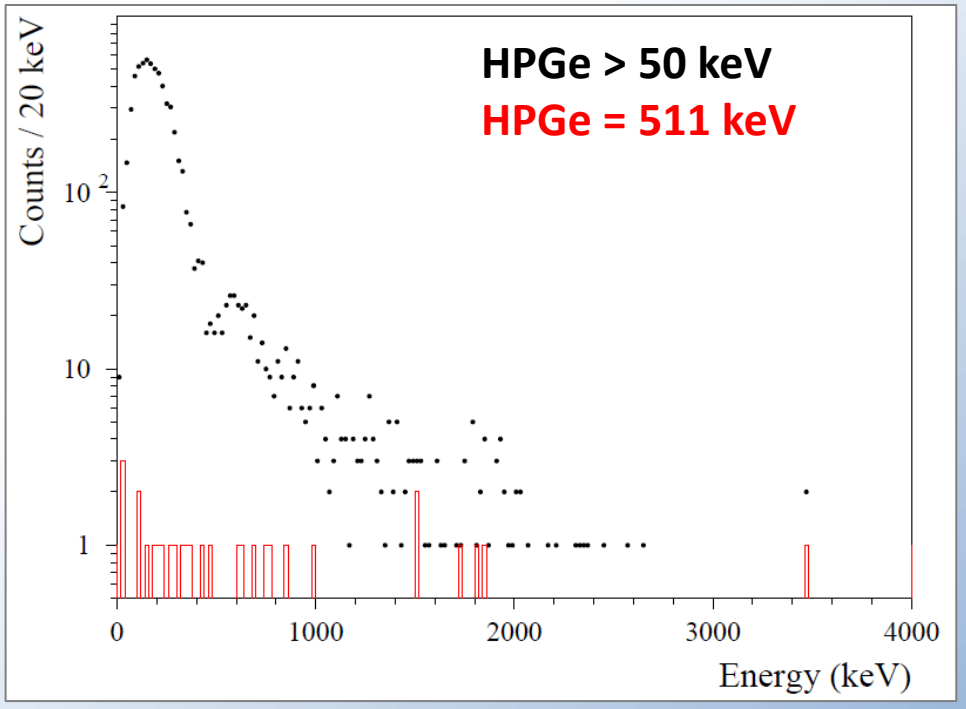
- $^{106}CdWO_4$ contaminations
- PMT
- $PbWO_4$ light guide
- Cu shield
- Al cryostat

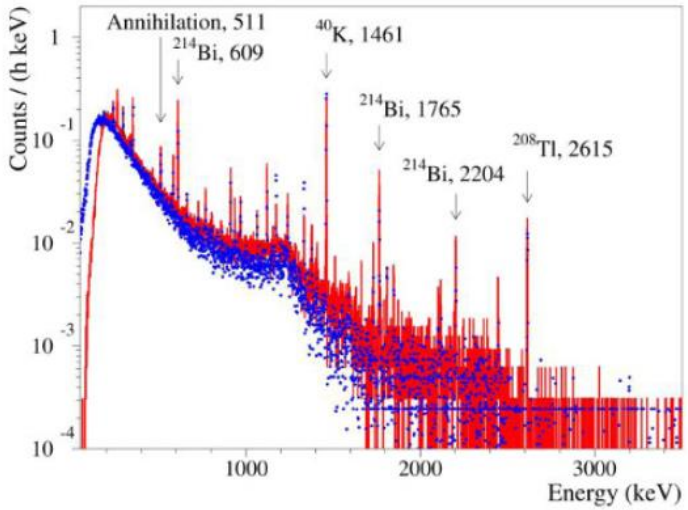
Coincidences $^{106}CdWO_4$ - HPGe

Counting rate substantially suppressed by coincidence with 511 keV in HPGe detector

In agreement with the Monte Carlo simulation:

The counting rate of the coincidence data is in agreement with the calculated background using the parameters of the fit of the $^{106}CdWO_4$ detector background without coincidence



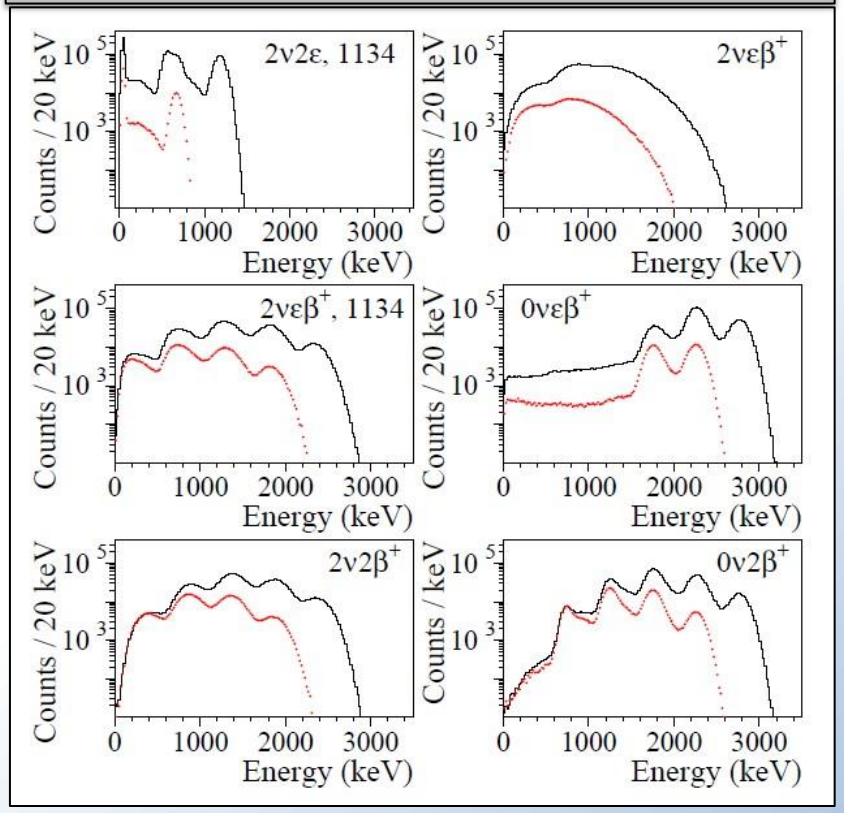


HPGe energy spectra with (red) and without (blue) the $^{106}CdWO_4$ counter (T=3233 h)

Data analysis

Simulation of 2β processes in ^{106}Cd

RED: coincidence $^{106}CdWO_4$ + HPGe 511 keV



No peculiarities in the data of $^{106}CdWO_4$ detector could be ascribed to the 2β processes in ^{106}Cd

$T_{1/2}$ limits on 2β processes in ^{106}Cd

$$\lim T_{1/2} = \frac{N \times \eta \times t \times \ln 2}{\lim S}$$

- ***N***: number of ^{106}Cd nuclei (2.42×10^{23})
- ***η***: detection efficiency
- ***t***: time of measurements (3233 h)
- **lim *S***: number of excluded events

lim S

Comparison between the measured number of events in the background spectrum and the expected background, estimated by using the result of the fit of the data accumulated by the $^{106}CdWO_4$ detector without coincidence

Results

Example for $2\nu\epsilon\beta^+$ decay to g.s.:

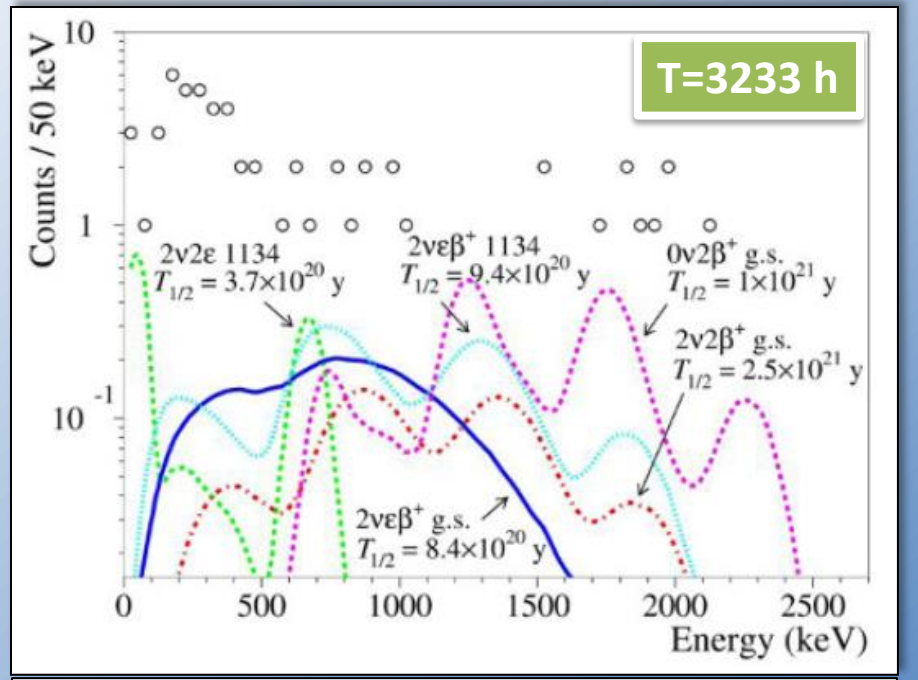
- Experimental number of coincidence events in 500–1200 keV = 13 counts
- Expected events from background model = 17.6 counts
- ⇒ Events upper limits (Feldman and Cousins): lim *S* = 3.7 counts (90% C.L.)
- $2\nu\epsilon\beta^+$ detection efficiency = 7.6%; energy interval = 67.0%, cut efficiency = 99% ⇒ η = 5.0%
- ⇒ $T_{1/2} > 8.4 \times 10^{20}$ yr (90% C.L.)

Preliminary $T_{1/2}$ limits

Decay channel, level of ^{106}Pd (keV)	$T_{1/2}$ limit (yr) at 90% C.L.	
	Present work	Previous limit
2ν2ε, 0_1^+ 1134	$\geq 3.7 \times 10^{20}$	$\geq 1.7 \times 10^{20}$ [1]
0ν2ε, g.s.	$\geq 2.4 \times 10^{19}$	$\geq 1.0 \times 10^{21}$ [1]
2νεβ$^+$, g.s.	$\geq 8.4 \times 10^{20}$	$\geq 4.1 \times 10^{20}$ [2]
2νεβ$^+$, 0_1^+ 1134	$\geq 9.4 \times 10^{20}$	$\geq 3.7 \times 10^{20}$ [1]
0νεβ$^+$, g.s.	$\geq 4.3 \times 10^{20}$	$\geq 2.2 \times 10^{21}$ [1]
2ν2β$^+$, g.s.	$\geq 2.5 \times 10^{21}$	$\geq 4.3 \times 10^{20}$ [1]
0ν2β$^+$, g.s.	$\geq 1.0 \times 10^{21}$	$\geq 1.2 \times 10^{21}$ [1]

[1] P. Belli et al., PRC 85 (2012) 044610
[2] P. Belli et al., APP 10 (1999) 115

Excluded distributions of 2β processes (90% CL)



Open circle
Experimental spectrum $^{106}CdWO_4$ + HPGe

Conclusions

New search for 2β decay processes in ^{106}Cd with the help of low background $^{106}CdWO_4$ scintillation detector (215 g) in coincidence with four HPGe (225 cm^3 each) is in progress at the STELLA facility of LNGS

After *3233 h* of measurements preliminary $T_{1/2}$ limits on 2β processes in ^{106}Cd are achieved on the level of $10^{19} – 10^{21}$ yr

Some of them are better than those obtained on the previous stage of the experiment and close to theoretical expectations

An increased statistics and the construction of a more precise model of the background could allow us to improve the sensitivity of the experiment to the level of theoretical predictions for $2\nu\epsilon\beta^+$ channel

Data collection is in progress