Limit on the radiative neutrinoless ECEC decay of ^{36}Ar

O. Chkvorets
Max-Planck Institut fur Kernphysik, Heidelberg

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Outline

- Process of double electron capture in argon-36.
- Experimental setup.
- Results of measurement and analysis.
- Conclusions and outlook.

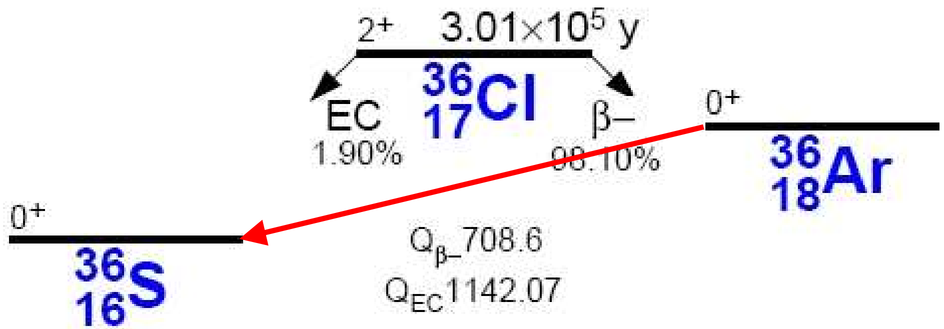
^{36}Ar double electron capture (ECEC)

It is energetically allowed process. Neutrinoless mode of decay happened if neutrino is Majorana massive particle.

There is no low energy excited states for daughter- 36S.

This decay can only go to the ground state.

Theory half lives estimates:
2ν - 10^{29} , 0ν - 10^{35} y



ECEC Q=433.5 keV

TABLE I. Experimental Values (or Limits) and Theoretical Estimates of Half-Lives for Various 2β Processes ($2\beta^-$; $2\beta^+$; $\varepsilon\beta^+$; 2ε)

See page 93 for Explanation of Tables

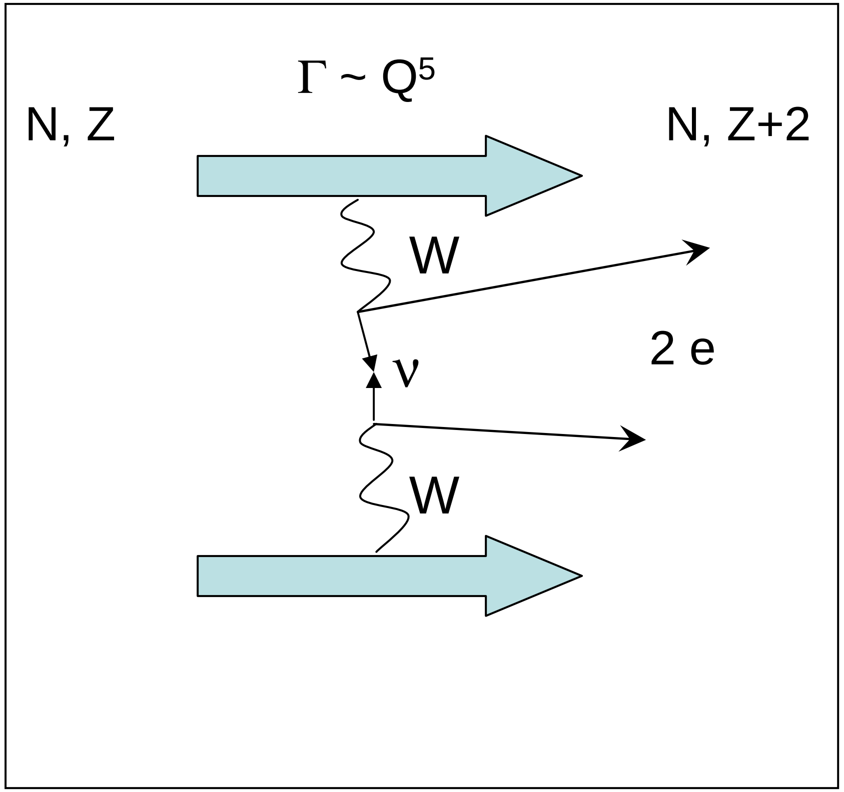
${}^A_ZX - {}_{Z\pm2}{}^AY$ ΔM_A in keV δ in %	Type of result	Decay channel	Level of daughter nucleus	Decay mode	$T_{1/2}$ (yr)	CL in % or Theor. Model	Reference	Note
${}^{36}_{18}$Ar$-{}^{36}_{16}$S	Exp.	2ε			–			
433.5(0.4)	Th.	2ε	g.s.	2ν	$= 1.7 \times 10^{29}$	SM	Nak96	
0.3365(0.0030)								

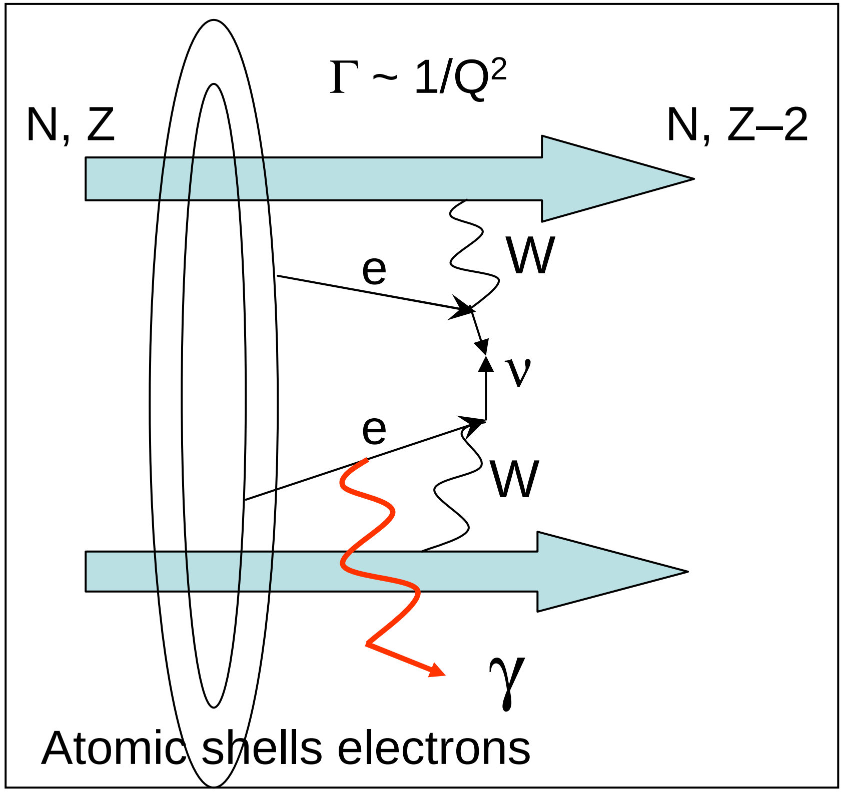
No Data

Tretyak, Zdesenko, At.Nucl.Data, 2002

0ν2β decay and radiative 0νECEC process.

Emission of internal bremsstrahlung photons is one of possible mechanisms to release reaction energy. Two low energy X-rays emitted when outer electrons fill produced holes in atomic shells.
Emission of one photon in K-K capture to ground state is forbidden due to ang. moment conservation. The K-L, L-L … captures are allowed.
Detailed discussion of possible mechanisms is in e.g. Doi, Kotani, 1993, Vergados, 1983.





How to measure radiative ECEC decay in argon?

- Natural argon contain 0.336% of ^{36}Ar isotope.

- Use a bare HPGe detector operating inside the *source and cooling media* – liquid Argon.

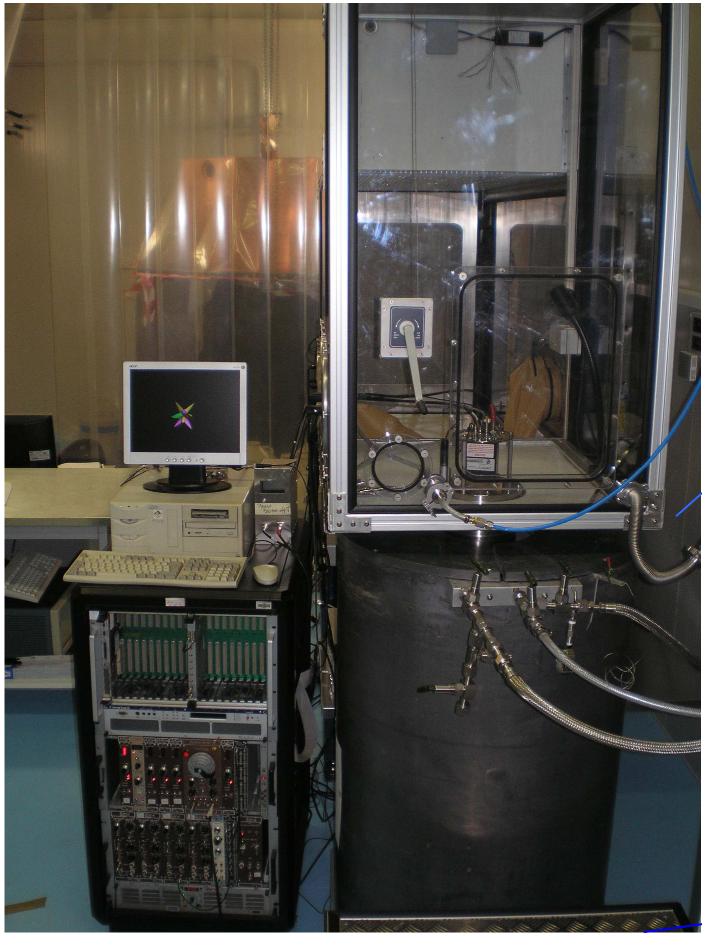
- The radiative neutrinoless ECEC process signature is a sharp peak in the area of Q value of 2EC reaction:

  $E\gamma = Q - E_K - E_L$ = 433.5 keV – 2.47 keV – 0.23 keV = 430.8 keV.

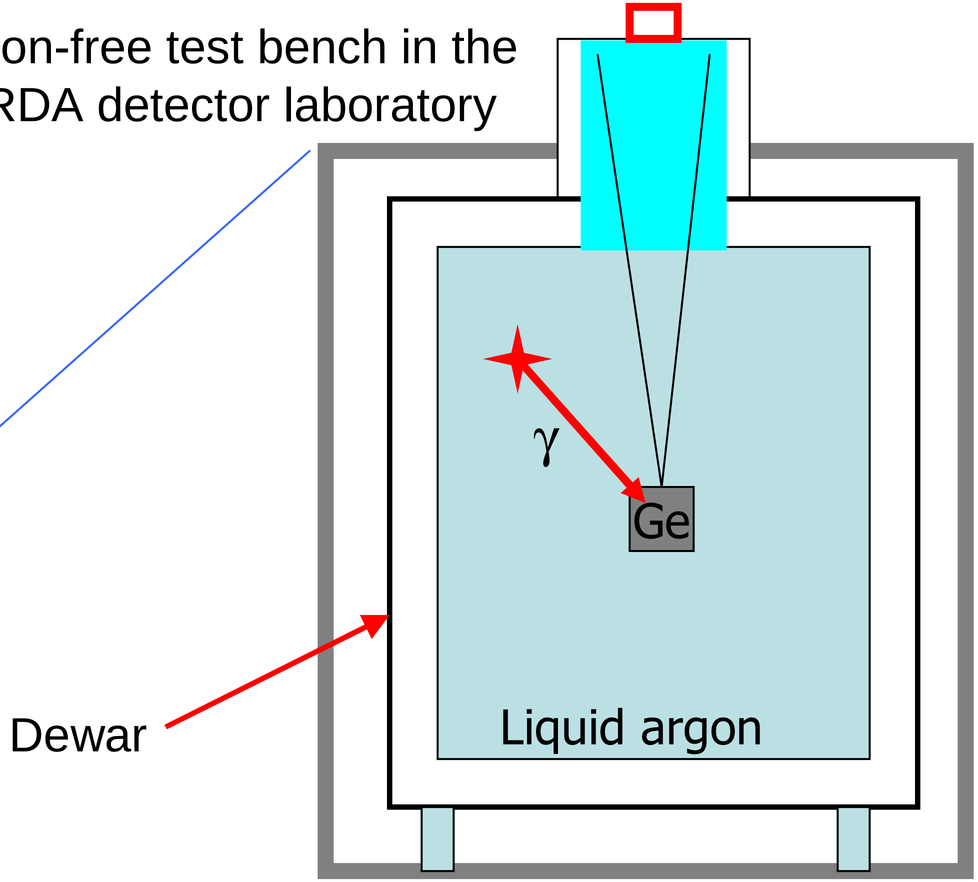
Experimental Setup at GERDA detector lab, LNGS

Detector test bench for GERDA experiment. It is used for study of detectors operation in cryoliquids. We made long term stability runs in September – October 2006.

Note: It has very modest lead shielding and 20 cm of LAr – only ten times suppression of external background. It is not considered as a low background experiment.

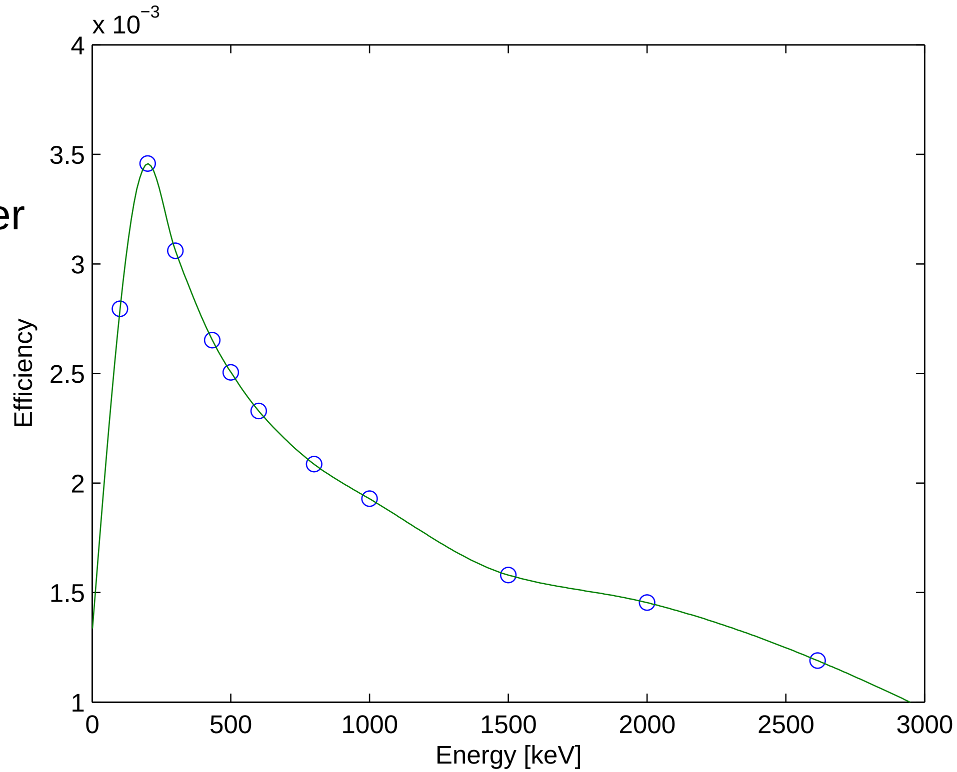


Radon-free test bench in the GERDA detector laboratory

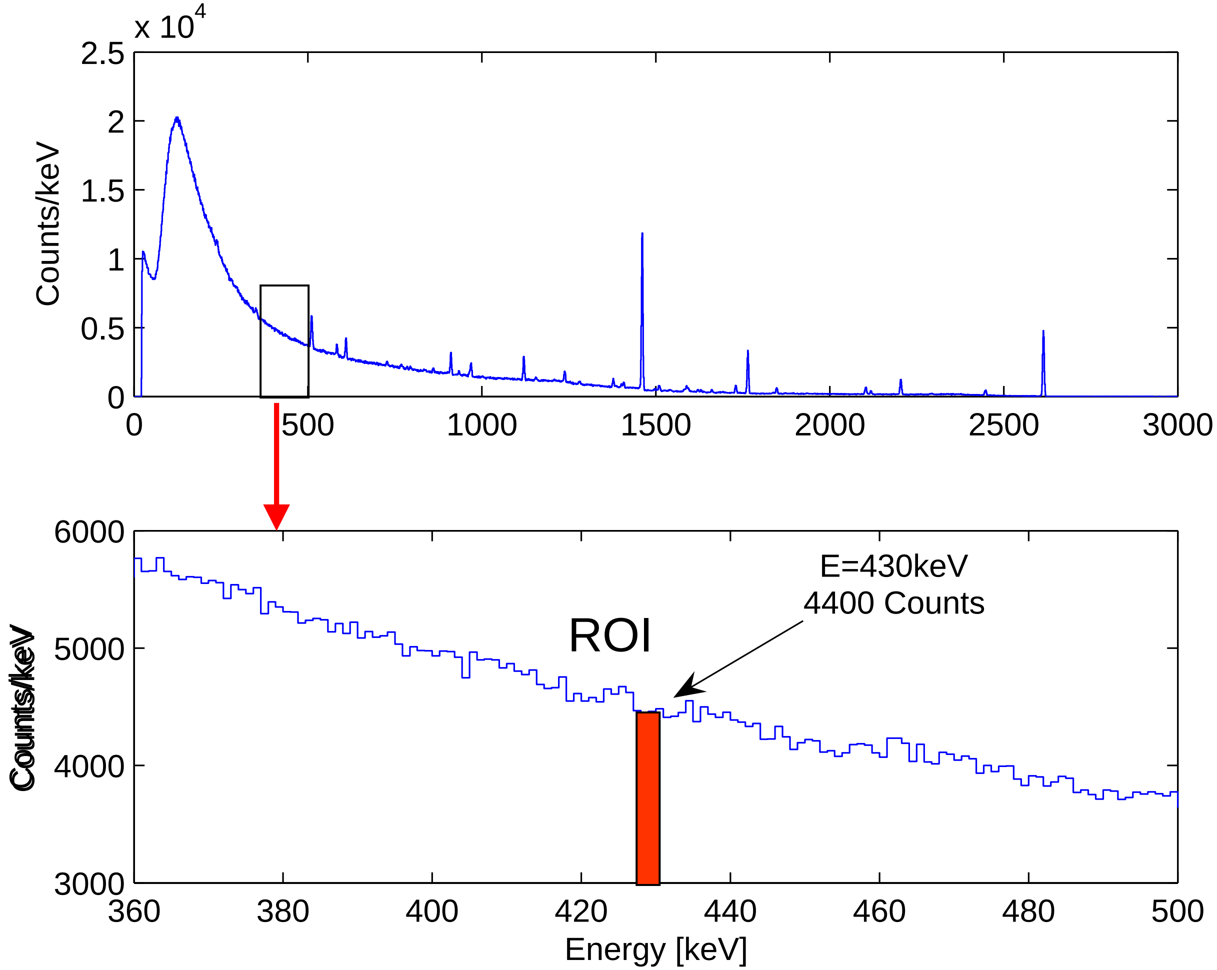


Efficiency of detection calculated with Monte-Carlo simulation

- Efficiency calculation was performed with the TEFF and EGS4 simulation code.
- A geometry for simulation is a cylinder H=50 cm and D = 45 cm with a 70 liters of liquid argon.
- The source is uniformly distributed in the argon.
- The 1.6 kg detector is located in the center of cylinder.



Measured background spectrum of the bare HPGe detector in liquid argon at LNGS



FWHM = 4keV
at 1332 keV

ΔT = 10.0 days

Results

Lower limit is expressed as follows:

$$T_{1/2} > \varepsilon * N_{36Ar} * (\Delta t / (B * \Delta E))^{1/2}, \text{ (68\% c.l.)}$$

Where:

ε is the efficiency of detection, 0.26% at 430 keV,

N_{36Ar} is the number of argone-36 atoms in 100 kg of natural argone, with the abundance = 0.336%, $5.9 * 10^{24}$,

B is the background rate, 440 counts/keV/day,

Δt is the measurement time, 10.0 days,

ΔE is the energy interval, 4 keV.

Half life limit for <u>radiative</u> 0νECEC:

$$T_{1/2} > 1.9 * 10^{18} \text{ y (68\% c.l.)}$$

Our result is comparable with experimental results of the recent dedicated experiments searching ECEC processes with transition to the ground state.
Typical values are in the range 10^{16}-10^{20} years.

Sensitivity is limited by the usually very small isotopic abundance (<1%) of ECEC candidates and by the low efficiency of detection (<1%).

Isotope	Abundance, %	Mode	$T_{1/2}$, y	Ref.
^{36}Ar	0.336	0νECEC	$1.9 \cdot 10^{18}$ (68%)	this work
^{50}Cr	4.345	$(0\nu+2\nu)EC\beta+$	$1.3 \cdot 10^{18}$ (95%)	Bikit et al. (2003) [12]
^{64}Zn	48.63	0νECEC	$1.0 \cdot 10^{18}$ (68%)	Danevich et al. (2005) [13]
		$0\nu EC\beta+$	$1.3 \cdot 10^{20}$ (90%)	Kim et al. (2003) [13]
^{74}Se	0.89	0νECEC	$6.4 \cdot 10^{18}$ (90%)	Barabash et al. (2006) [14]
		$(0\nu+2\nu)EC\beta+$	$1.9 \cdot 10^{18}$ (90%)	-"-
^{106}Cd	1.25	2νECEC	$4.8 \cdot 10^{19}$ (90%)	Stekl et al. (2006) [15]
^{108}Cd	0.89	0νECEC	$2.5 \cdot 10^{17}$ (68%)	Danevich et al. (2003) [16]
^{112}Sn	0.97	$(0\nu+2\nu)EC\beta+$	$1.5 \cdot 10^{18}$ (68%)	Kim et al. (2003) [17]
^{120}Te	0.09	2νECEC	$9.4 \cdot 10^{15}$ (90%)	Kiel et al. (2003) [18]
^{130}Ba	0.106	$0\nu EC\beta+$	$2.0 \cdot 10^{17}$ (90%)	Cerulli et al. (2004) [19]
^{136}Ce	0.185	2νECEC	$4.5 \cdot 10^{16}$ (68%)	Belli et al. (2003) [20]
^{138}Ce	0.251	2νECEC	$6.1 \cdot 10^{16}$ (68%)	-"-
^{180}W	0.12	0νECEC	$1.3 \cdot 10^{17}$ (68%)	Danevich et al. (2003) [21]

Prospects with the new detector test setup at LNGS

- Reduction of background in the 0-500 keV region is limited by the bremsstuhlung photons from beta decay of cosmogenic Ar-39. Estimations of Hardy Simgen for GERDA give 3 counts/keV/kg/y in the region of interest 430 keV.
- Background from two neutrino double beta decay (half-life $1.7*10^{21}$y) becomes significant ~1 counts/keV/kg/y in the region of interest, use depleted Ge material leftovers after enrichment for GERDA.
- With mass of natural argon ~1 ton and 6-9 detectors ~ 15 kg (e.g. reprocessed <u>natural</u> Ge detectors used before in the GENIUS-TF experiment), we can expect half life sensitivity to radiative ECEC decay after one year of measurements at 10^{23} years.

Conclusions and perspectives

- For the first time a limit on the 0nuECEC of 36Ar half life has been derived at 1.9 * 10^{18} y (68% c.l.).
- This measurements demonstrate long term stability of bare HPGe detectors operated in cryogenic liquids.
- A several order improvement of half life limit is possible with the new LNGS setup utilizing HPGe detectors coincidences with LAr scintillations from X-rays and massive low background shielding.