Study of ^{36}Ar double electron capture

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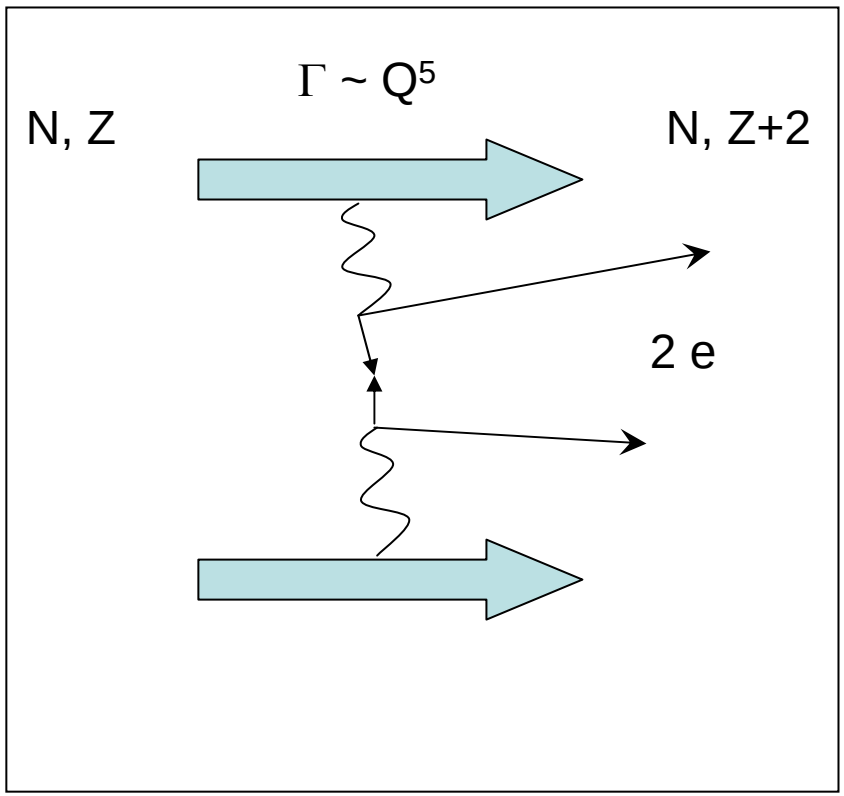
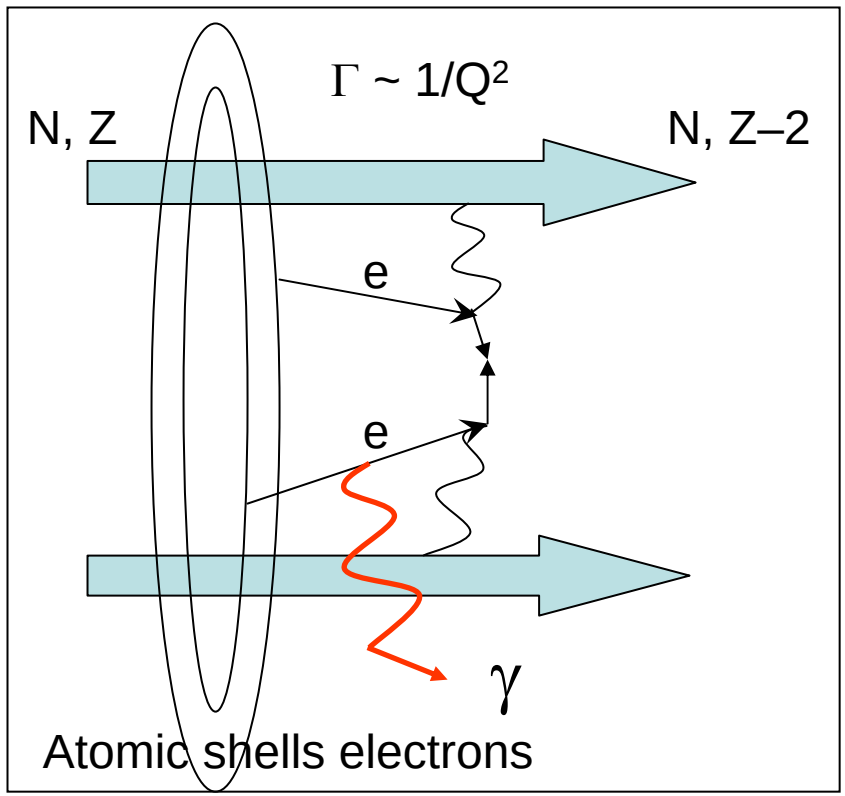
“Conventional” $0\nu2\beta$ decay and “radiative” 0νECEC process.

Emission of internal bremsstrahlung photons is one of possible mechanisms to release reaction energy. Two 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 AM conservation. The K-L, L-L … captures are allowed.

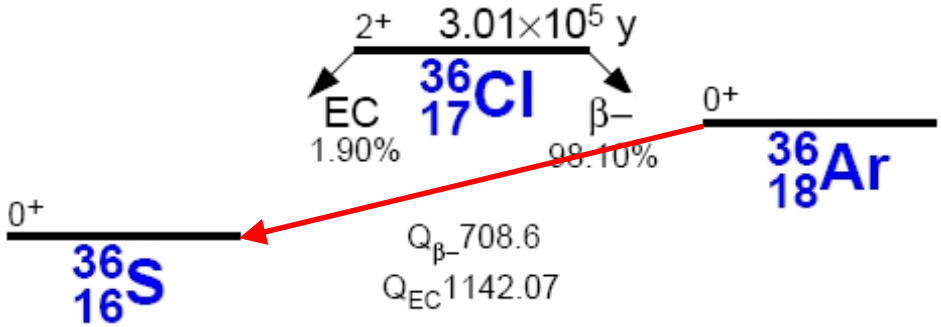
Detailed discussion of possible mechanisms is in e.g. Doi, Kotani, 1993, Vergados, 1983.





^{36}Ar double electron capture – ECEC - is an allowed ECEC process. There is no low energy excited states for ^{36}S.

No measurements exist.



Atomic Data and Nuclear Data Tables **80,** 83–116 (2002)
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ECEC Q=433.8 keV

TABLES OF DOUBLE BETA DECAY DATA—AN UPDATE

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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

$^{A}_{Z}X-{}^{A}_{Z\pm2}Y$ 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)								

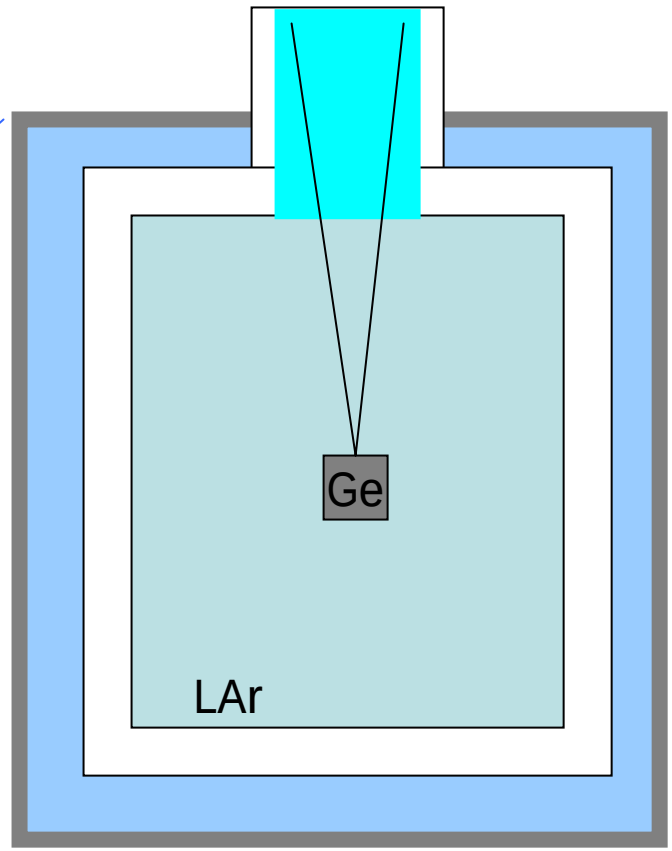
New look to routine measurements can lead to unusual and unexpected results

- Natural argon contain 0.336% of ^{36}Ar isotope
- With a bare HPGe detector operating inside the source and cooling media – liquid Argon
- The 'radiative' neutrinoless ECEC process signature is a 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

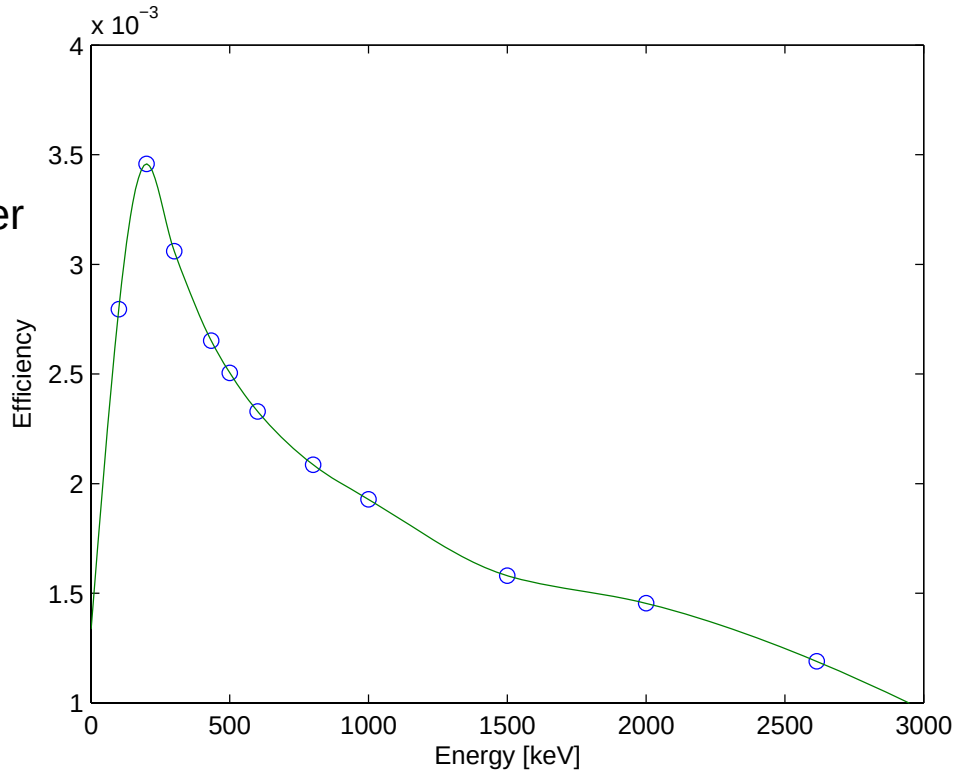
Experimental Setup at LNGS – test bench has very modest lead shielding (2.5 cm) and 20 cm of LAr – only ten times suppression of external background. It is not considered as a low background experiment.

Radon-free test bench in the LArGe detector laboratory

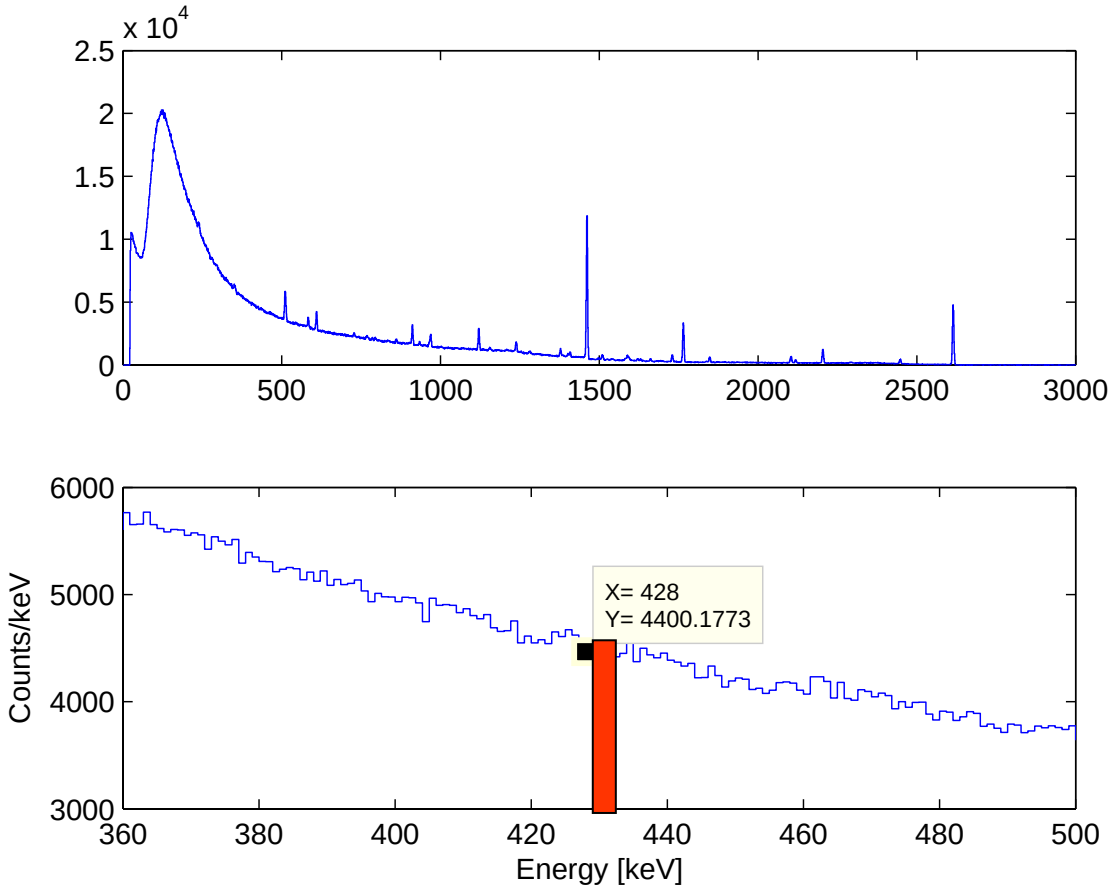


Efficiency of detection calculated with Monte-Carlo simulation

- 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.



Analysis of background spectrum of the 1.6 kg HPGe detector in liquid argon at LNGS



Preliminary result

- Lower limit is expressed as following:

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

- The efficiency ε of detection is 0.26%,
- Number of isotope atoms in 100 kg LAr with abundance = 0.336% is $N_{36Ar} = 5.9*10^{24}$ atoms,
- B = 440 counts/keV/day,
- Measurement live time, Δt = 10.0 days,
- Energy interval, ΔE = 4 keV,

Half life lower limit : $T_{1/2} > 1.9 * 10^{18}$ y 68% c.l.

Experimental results of the recent experiments (2003-2006) searching ECEC processes with transition to ground state.

The values are in the range 10^{16}-10^{19} years.
This level of sensitivity is defined by the usually very small abundance (<1%) of ECEC isotopes and also 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	$(0\nu+2\nu)$ECβ^+	$1.3 \cdot 10^{18}$ (95%)	Bikit et al. (2003) [12]
^{64}Zn	48.63	0νECEC	$1.0 \cdot 10^{18}$ (68%)	Danevich et al. (2005) [13]
		0νECβ^+	$1.3 \cdot 10^{20}$ (90%)	Kim et al. (2003) [13]
^{74}Se	0.89	0νECEC	$6.4 \cdot 10^{18}$ (90%)	Barabash et al. (2006) [14]
		$(0\nu+2\nu)$ECβ^+	$1.9 \cdot 10^{18}$ (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	$(0\nu+2\nu)$ECβ^+	$1.5 \cdot 10^{18}$ (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	0νECβ^+	$2.0 \cdot 10^{17}$ (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 LArGe

- Mass of Argon ~1 ton
- Mass of detectors ~ 30 kg , 8 enriched and 6 former GENIUS-TF nat. Ge.
- Background in the 0-500 keV region is limited by the bremsstuhlung photons from beta decay of Ar-39. Estimations of Hardy Simgen for GERDA give 3 counts/keV/kg/y in region of interest.
- LArGe half life sensitivity to ECEC after one year of measurements will be at 10^{23} y.

Conclusions and perspectives

- For the first time a limit on the 0nuECEC of 36Ar has been derived
- The first physical result obtained with a bare HPGe detector operated in cryogenic liquids
- A several order improvement of half life limit is possible with the LArGe setup utilizing HPGe detectors coincidences with LAr scintillations from X-rays and also massive low background shielding. Method is limited by 39Ar beta decay.