1st limit on the radiative 0νECEC decay of ^{36}Ar

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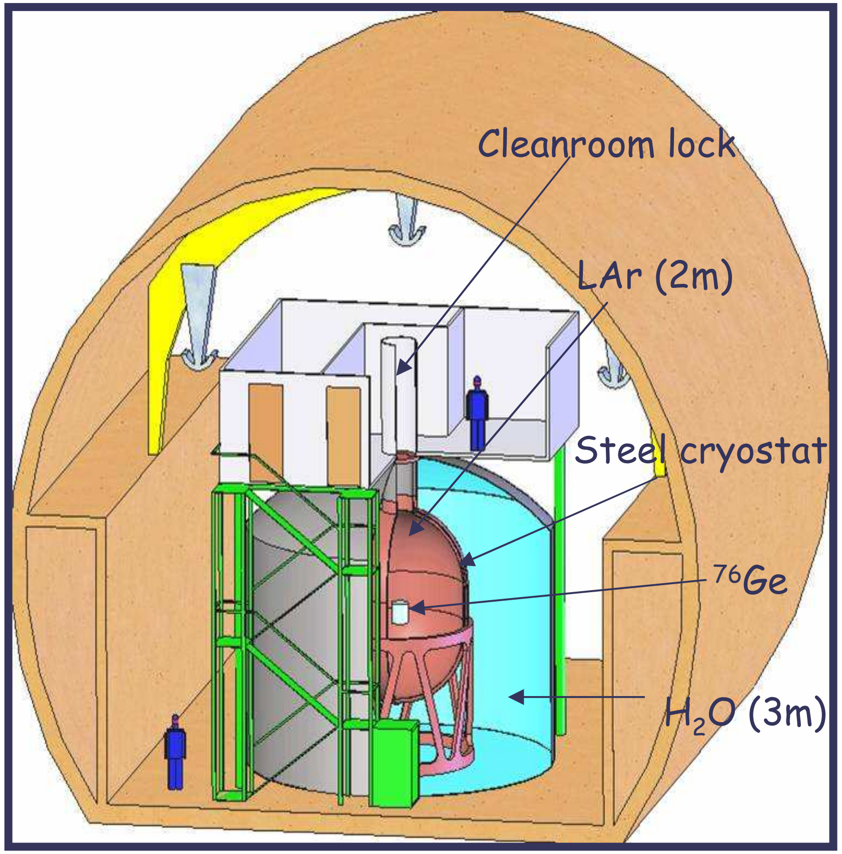
Marik Barnabé Heider, LAUNCH meeting, Heidelberg 03/2007

Outline

- Process of double electron capture in ^{36}Ar
- Experimental setup: test bench of **G**erda **D**etector **L**aboratory, not dedicated experiment
- Results of measurement and analysis
- Conclusions and outlook

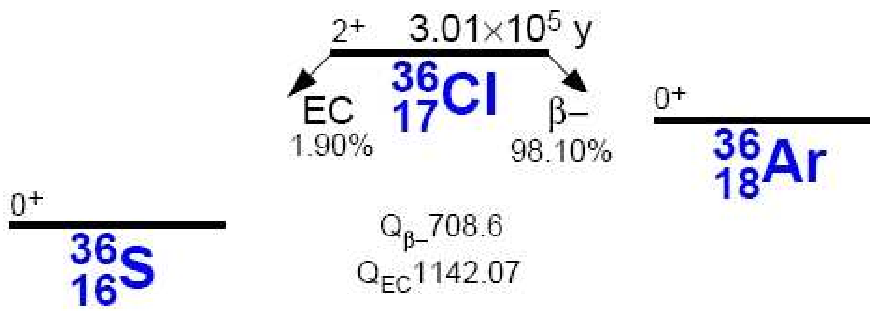
GERmanium Detector Array for the search of neutrinoless ββ decays of ^{76}Ge

- Bare enriched HPGe detectors in LAr (shield against external radioactivity and cooling medium). GERDA main goal: 0νββ of ^{76}Ge.
- By-product : 0νECEC of ^{36}Ar
  - Argon contains ^{36}Ar isotope which is expected to undergo ECEC



^{36}Ar double electron capture (ECEC)

- Energetically allowed process
- No low energy excited states for ^{36}S → decay can only go to the ground state
- 0ν mode of decay happened if ν is Majorana particle
- Theory half lives estimates:
  - 2ν - 10^{29} y, 0ν - 10^{35} y



Q_{ECEC}=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

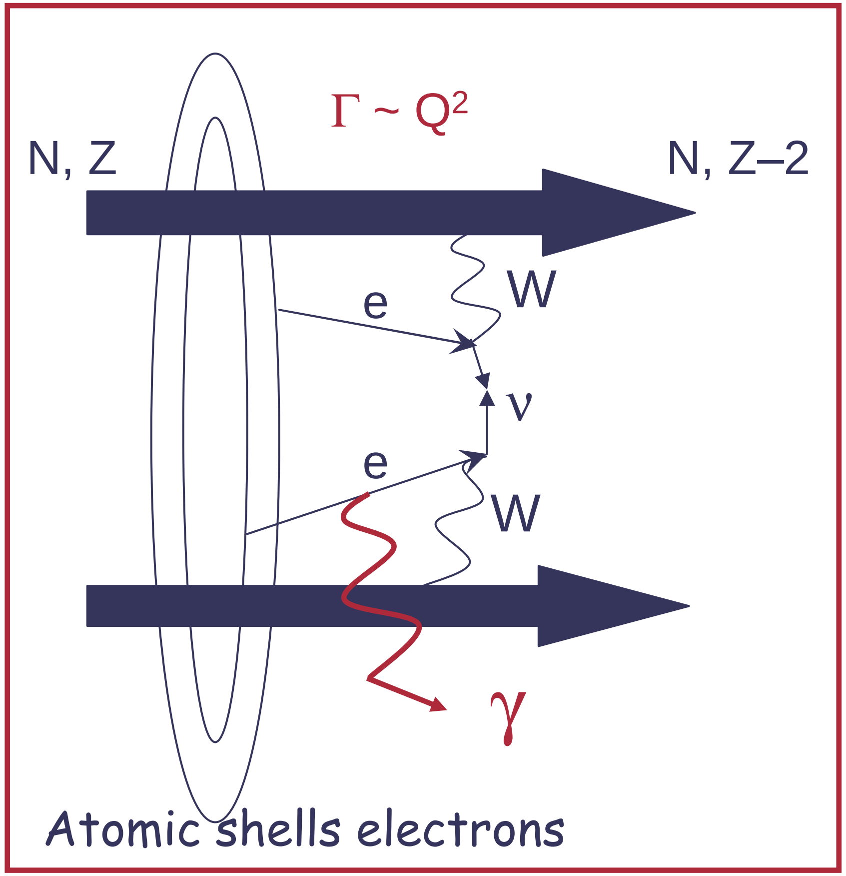
${}^{A}_{Z}X - {}_{Z\pm2}^{A}Y$ ΔM_A in keV δ in %	Type of result	Decay channel	Level of daughter nucleus	Decay mode	$T_{1/2}$ (yr)	CL in % or Theor. Model	Reference	Note
${}^{36}_{18}Ar - {}^{36}_{16}S$	Exp.	2ε			–			
433.5(0.4)	Th.	2ε	g.s.	2ν	$\simeq 1.7 \times 10^{29}$	SM	Nak96	
0.3365(0.0030)								

No Data

Tretyak, Zdesenko, At.Nucl.Data, 2002

Radiative 0νECEC process

- 2 X-rays emitted when outer electrons produced holes
- Emission of one internal bremsstrahlung γ is one possible mechanisms to release energy
- Emission of one γ in K-K capture to ground state is forbidden (AM conservation)
- K-L, L-L, … captures are allowed



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

Measurement of ^{36}Ar 0νECEC

- Operation of a bare HPGe detector inside liquid Argon (*source and cooling media)*
- Argon contains 0.336% of ^{36}Ar isotope
- The radiative neutrinoless ECEC process signature is a sharp peak in the area of the Q value of the ECEC reaction:

$$E\gamma = Q - E_k - E_L$$

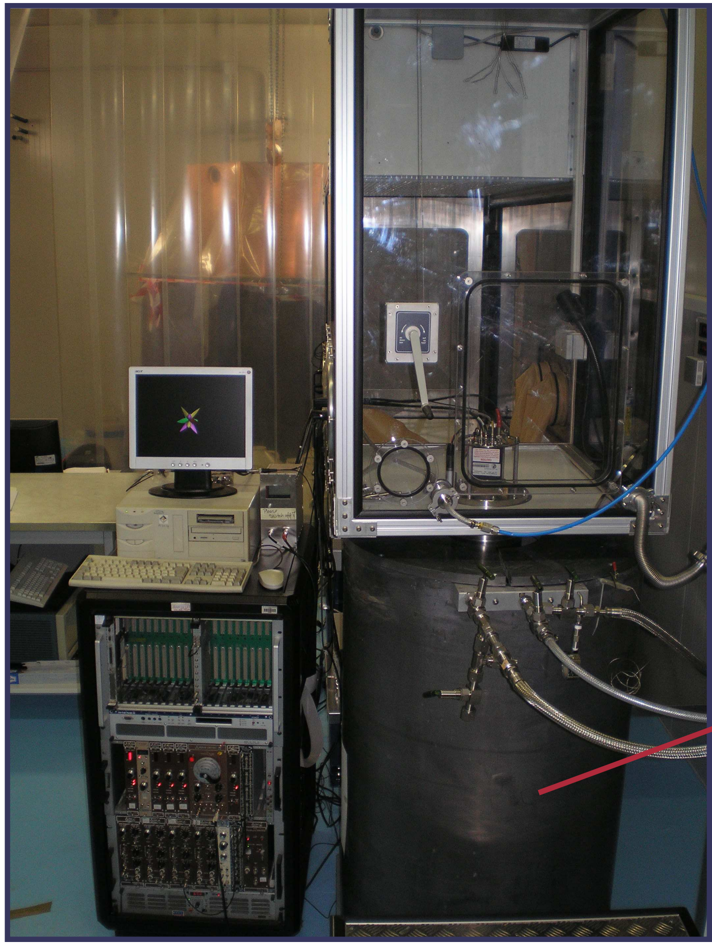
$$E\gamma = 433.5\ \text{keV} - 2.47\ \text{keV} - 0.23\ \text{keV} = 430.8\ \text{keV}$$

Experimental Setup in Gerda Detector Laboratory, LNGS

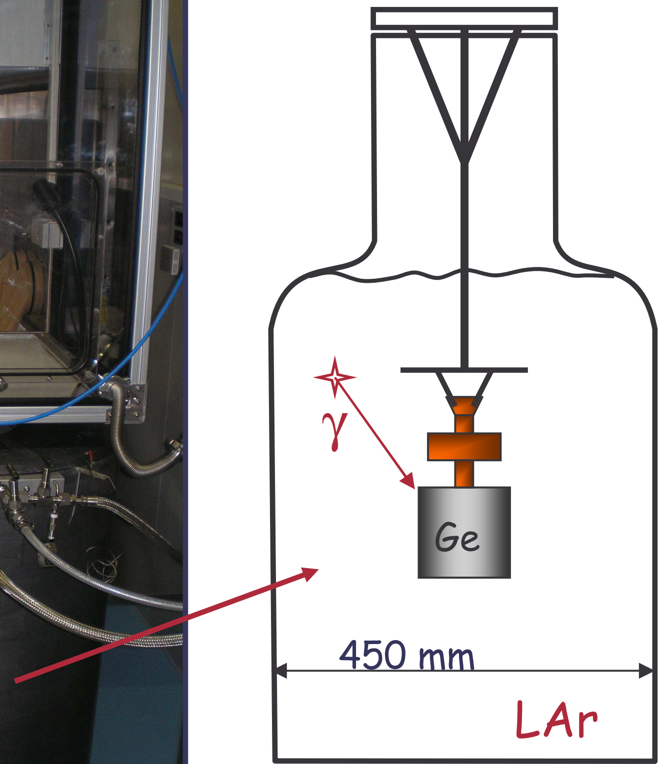
- Detector test bench for GERDA experiment
  - study of detectors operation in cryoliquids
- 1.6 kg HPGe detector mounted in GERDA phase I low mass holder
- Long term stability in LAr runs in September – October 2006
  - Spectroscopy measurements with a ^{60}Co source
  - Background measurement for 10 days → 0νECEC limit on ^{36}Ar

Experimental Setup in Gerda Detector Laboratory, LNGS

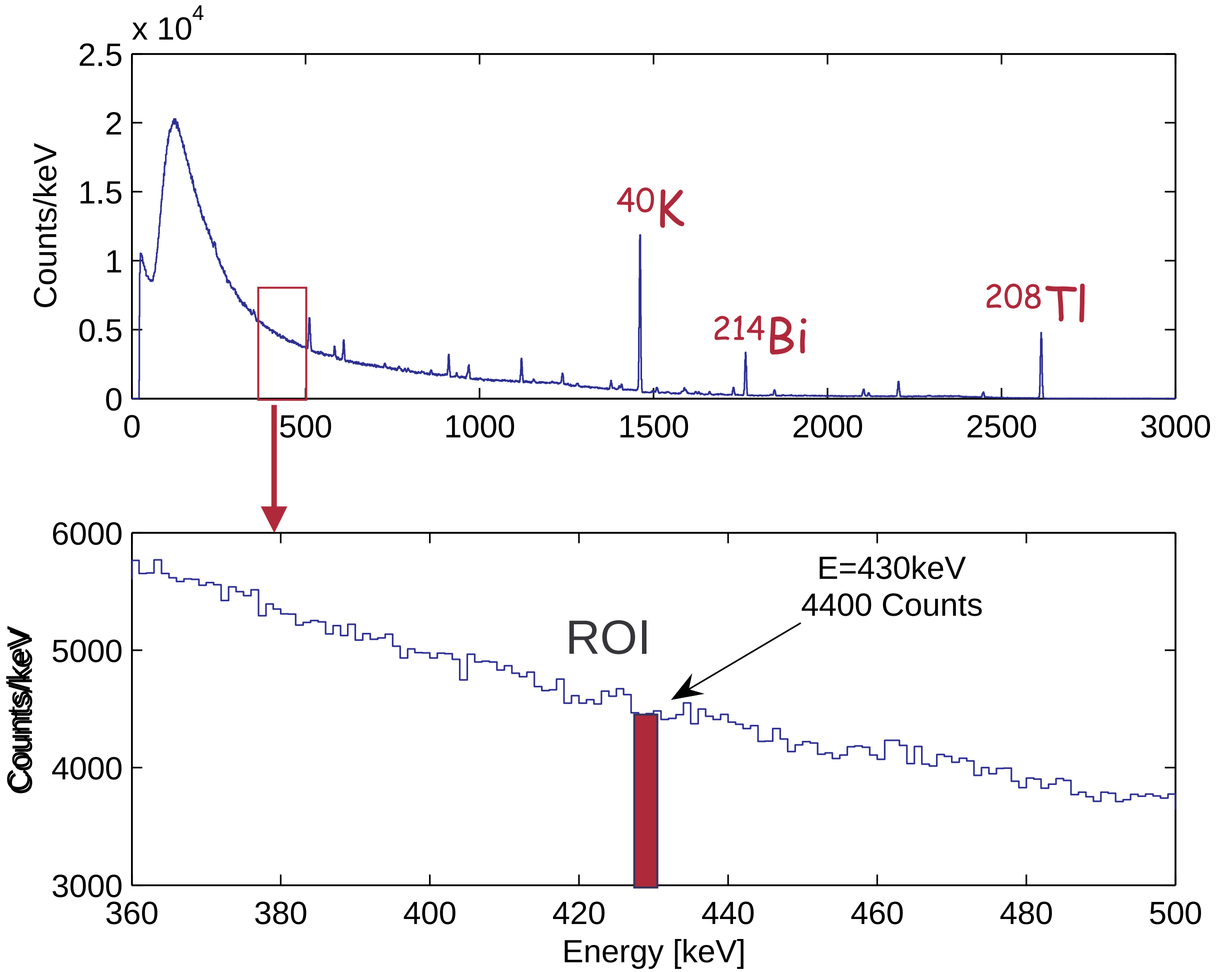
- Very modest shielding
  - 2.5 cm lead, 20 cm LAr
  - 10 x suppression of external background
  - Not considered as a low background experiment



Radon-free test bench of the **GDL**



Background spectrum of the bare HPGe detector in LAr at LNGS

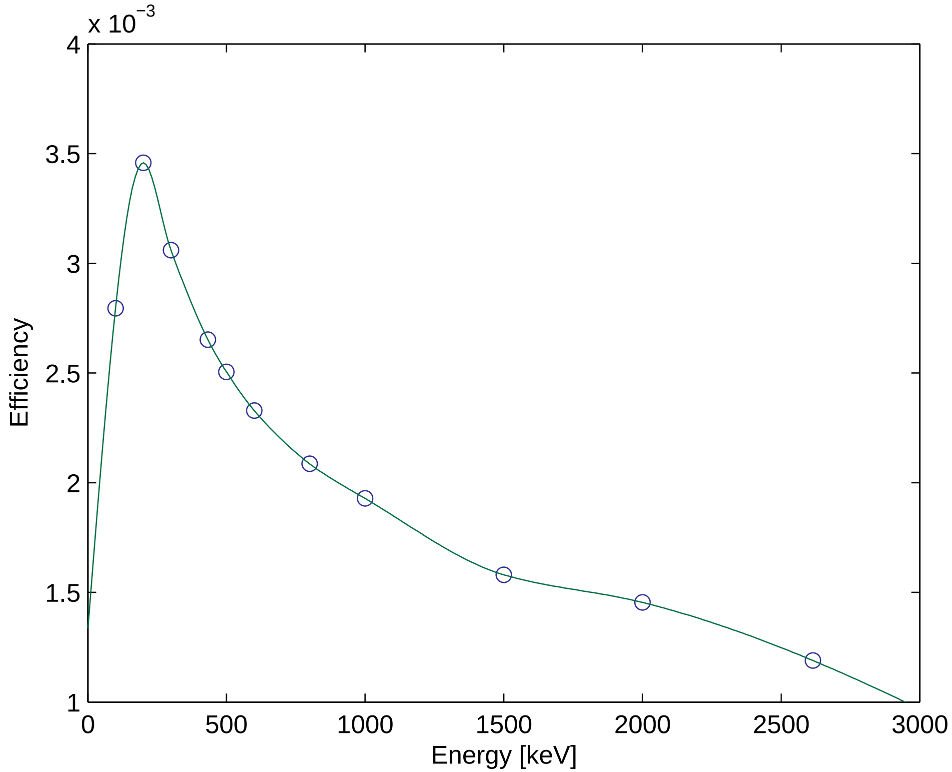


FWHM = 4keV
at 1332 keV

ΔT = 10.0 days

Efficiency of detection

- Monte-Carlo simulation performed
- Geometry
  - Cylinder (H=50 cm and D=45 cm)
  - V_{LAr} = 70 l
- Source is uniformly distributed in LAr
- Ge detector located in the center of cylinder



Results

- Lower limit is expressed as follows:

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

  - ε is the efficiency of detection, 0.26% at 430 keV
  - $N_{^{36}Ar}$ is the number of ^{36}Ar atoms in 100 kg of Ar,
with the abundance = 0.336%, $5.9 \cdot 10^{24}$ atoms
  - 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 radiative 0νECEC of ^{36}Ar:

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

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

- Our result is comparable with experimental results of the recent dedicated experiments searching ECEC processes with transition to the ground state
- The 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 low efficiency of detection (<1%)

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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]
		0νEC$\beta+$	$1.3 \cdot 10^{20}$ (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	0νEC$\beta+$	$2.0 \cdot 10^{17}$ (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

- **LArGe** setup
  - Will be used to test background of GERDA phase I detectors
  - Up to 9 Ge detectors (~15 kg): natural Ge detectors from the GENIUS-TF experiment, enriched Ge detectors from HdM and IGEX experiments
  - Operated in ~1 ton of liquid Argon
  - Massive shielding (copper, steel, polyethylene) and HPGe detectors coincidences with LAr scintillations → low background experiment
- Background in the 0-500 keV region
  - Bremsstrahlung of ^{39}Ar beta decay (Q=550 keV, $T_{1/2}$=269 y). Estimation for GERDA: 3 counts/(keV·kg·y) in ROI (430 keV)
  - $2\nu\beta\beta$ of ^{76}Ge ($T_{1/2} = 1.7\cdot10^{21}$y) : ~1 counts/(keV·kg·y) ROI.
    - Solution: depleted ^{76}Ge material leftovers after enrichment for GERDA
- Expected half life sensitivity to radiative ECEC decay after one year of measurements:

  10^{23} years

Conclusions

- 1st limit on the radiative 0νECEC of ^{36}Ar with the emission of a single γ has been derived.
- 1st physical results obtained with a bare HPGe detector operated in cryogenic liquids in the framework of GERDA experiment.
- Sensitivity of the present experiment is limited by external background of the detector test stand which is not designed as low-background setup.

Perspectives

- A several order improvement of the half life limit is possible with the LArGe setup utilizing HPGe detectors coincidences with LAr scintillations and massive low background shielding. Ultimate sensitivity will be achieved in GERDA with the operation of 40 kg of phase I and II detectors.
- Method is limited by ^{39}Ar beta decay and ^{76}Ge $2\nu\beta\beta$.