Recent investigations on rare processes by DAMA at LNGS

XIV-th International School
"PARTICLES and COSMOLOGY"
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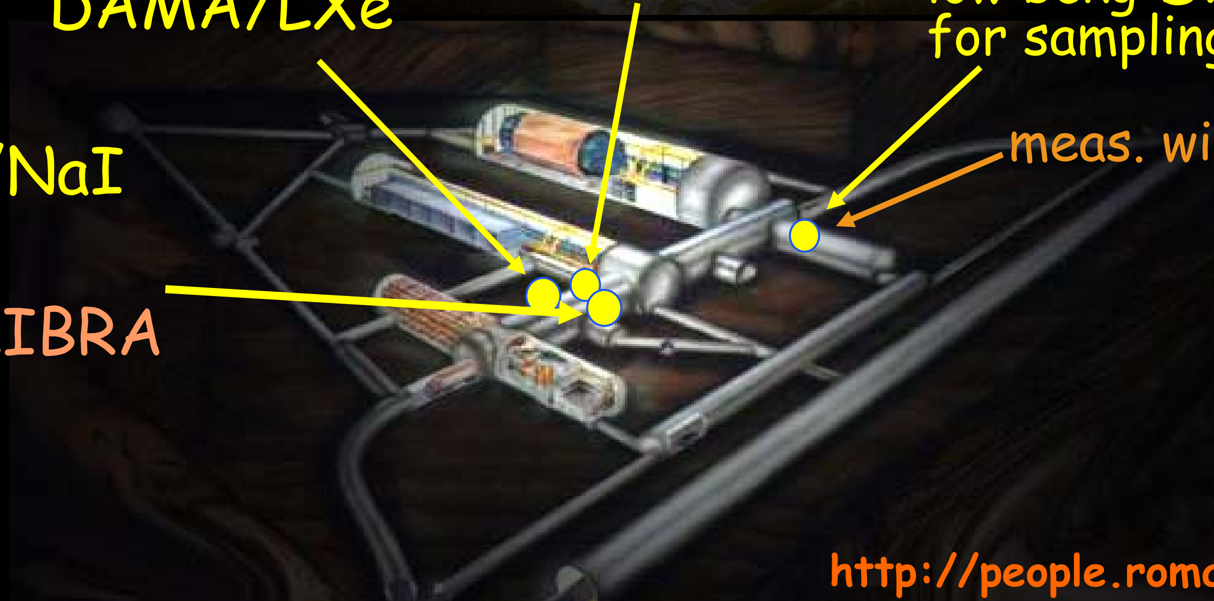
and INFN-Roma

Roma2, Roma1, LNGS, IHEP/Beijing

+ in some small scale expts and by-products results: **INR-Kiev**
+ in the framework of MAE activity: **IIT-Kharagpur**
+ neutron measurements: **ENEA- Frascati**

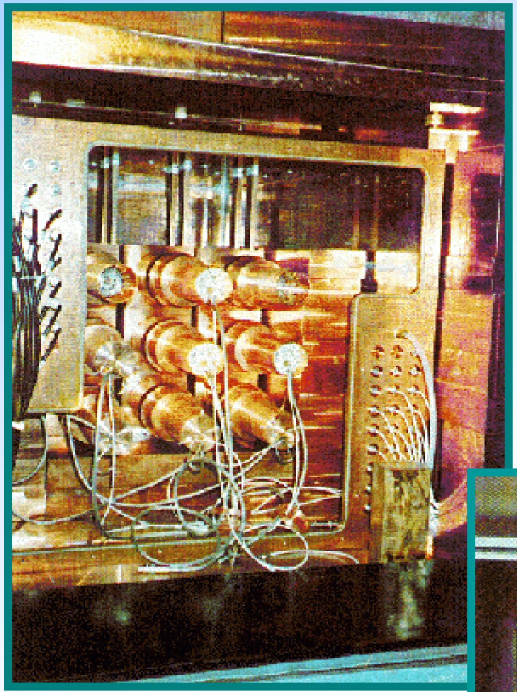
DAMA: an observatory for rare processes @LNGS



http://people.roma2.infn.it/dama

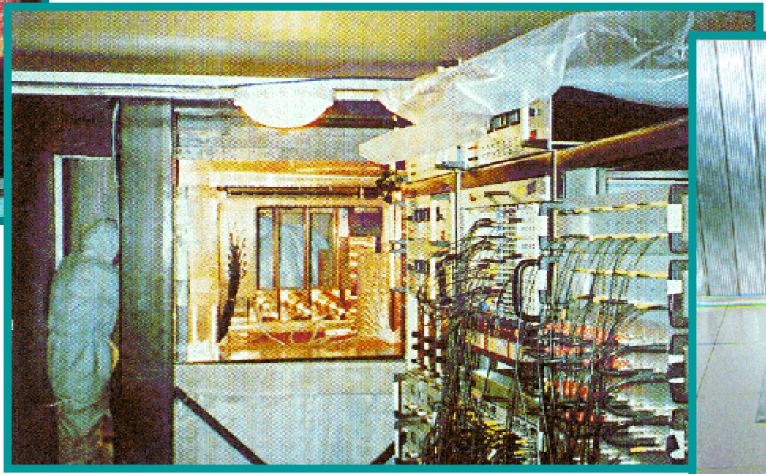
DAMA/NaI(Tl) ~100 kg

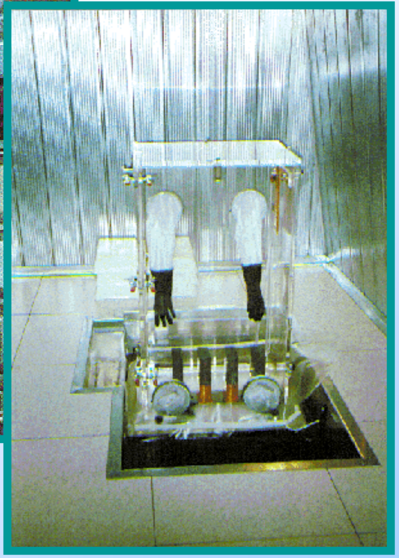
Performances: N.Cim.A112(1999)545-575, EPJC18(2000)283, Riv.N.Cim.26 n. 1(2003)1-73, IJMPD13(2004)2127



Results on rare processes:

- Possible Pauli exclusion principle violation PLB408(1997)439
- CNC processes PRC60(1999)065501
- Electron stability and non-paulian transitions in Iodine atoms (by L-shell) PLB460(1999)235
- Search for solar axions PLB515(2001)6
- Exotic Matter search EPJdirect C14(2002)1
- Search for superdense nuclear matter EPJA23(2005)7
- Search for heavy clusters decays EPJA24(2005)51





Results on DM particles:

- **PSD** PLB389(1996)757
- **Investigation on diurnal effect** N.Cim.A112(1999)1541
- **Exotic Dark Matter search** PRL83(1999)4918
- **Annual Modulation Signature**
  PLB424(1998)195, PLB450(1999)448, PRD61(1999)023512, PLB480(2000)23, EPJC18(2000)283, PLB509(2001)197, EPJ C23 (2002)61, PRD66(2002)043503, Riv.N.Cim.26 n.1 (2003)1-73, IJMPD13(2004)2127, IJMPA21(2006)1445, EPJC47(2006)263 + others in progress

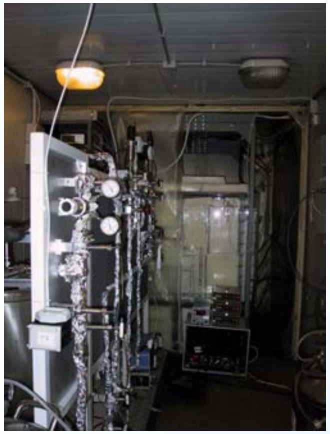
data taking completed on July 2002

total exposure collected in 7 annual cycles **107731 kg×d**

DAMA/LXe

Unique low-background 6.5 kg LXe set-up operating as pure scintillator filled by Kr-free Xenon enriched either in ^{129}Xe (99.5%) or in ^{136}Xe (68.8%)

(NIMA482(2002)728)



DARK MATTER investigations ...

- Limits on recoils investigating the DMp-^{129}Xe elastic scattering by PSD PLB436(1998)379
- Limits on DMp-^{129}Xe inelastic scattering PLB387(1996)222, NJP2(2000)15.1
- Neutron calibrations PLB436(1998)379, EPJdirectC11(2001)1

... and other rare processes

- Electron decay into invisible channels AstroP5(1996)217
- Nuclear level excitation of ^{129}Xe during CNC processes PLB465(1999)315
- N, NN decay into invisible channels in ^{129}Xe PLB493(2000)12
- Electron decay $e^- \rightarrow \nu_e \gamma$ PRD61(2000)117301
- 2β decay in ^{134}Xe PLB527(2002)182
- 2β in ^{134}Xe & ^{136}Xe PLB546(2002)23
- CNC decay ^{136}Xe → ^{136}Cs Beyond the Desert (2003) 365
- N, NN, NNN decay into invisible channels in ^{136}Xe EPJA27 s01 (2006)35

- stand-by during all the period of the problems related to the use of "liquids" underground because of Borexino accident.
- restarted on May 2004, running till December 2004; then stopped again waiting for the necessary restoring of circulating water in the underground lab.
- Full revision + new chiller -> restart of data taking in 2007

DAMA/R&D

- Particle Dark Matter search with CaF_2(Eu) NPB563(1999)97, AP7(1997)73
- 2β decay in ^{136}Ce and in ^{142}Ce Il N.Cim.A110(1997)189
- 2EC2ν ^{40}Ca decay AstroP7(1999)73
- 2β decay in ^{46}Ca and in ^{40}Ca NPB563(1999)97
- $2\beta^+$ decay in ^{106}Cd AstroP10(1999)115

- 2β and β decay in ^{48}Ca NPA705(2002)29
- 2EC2ν in ^{136}Ce, in ^{138}Ce and α decay in ^{142}Ce NIMA498(2003)352
- $2\beta^+0\nu$ and $EC\beta^+0\nu$ decay in ^{130}Ba NIMA525(2004)535
- Cluster decay in $LaCl_3$(Ce) NIMA555(2005)270
- CNC decay ^{139}La → ^{139}Ce UkrJP51(2006)1037
- Rare α decay of ^{151}Eu Nucl. Phys. A. (2007), doi: 10.1016/j.nuclphysa.2007.03.001

+several other results under analysis + data taking in progress + many other meas. scheduled

DAMA/Ge & LNGS Ge facility

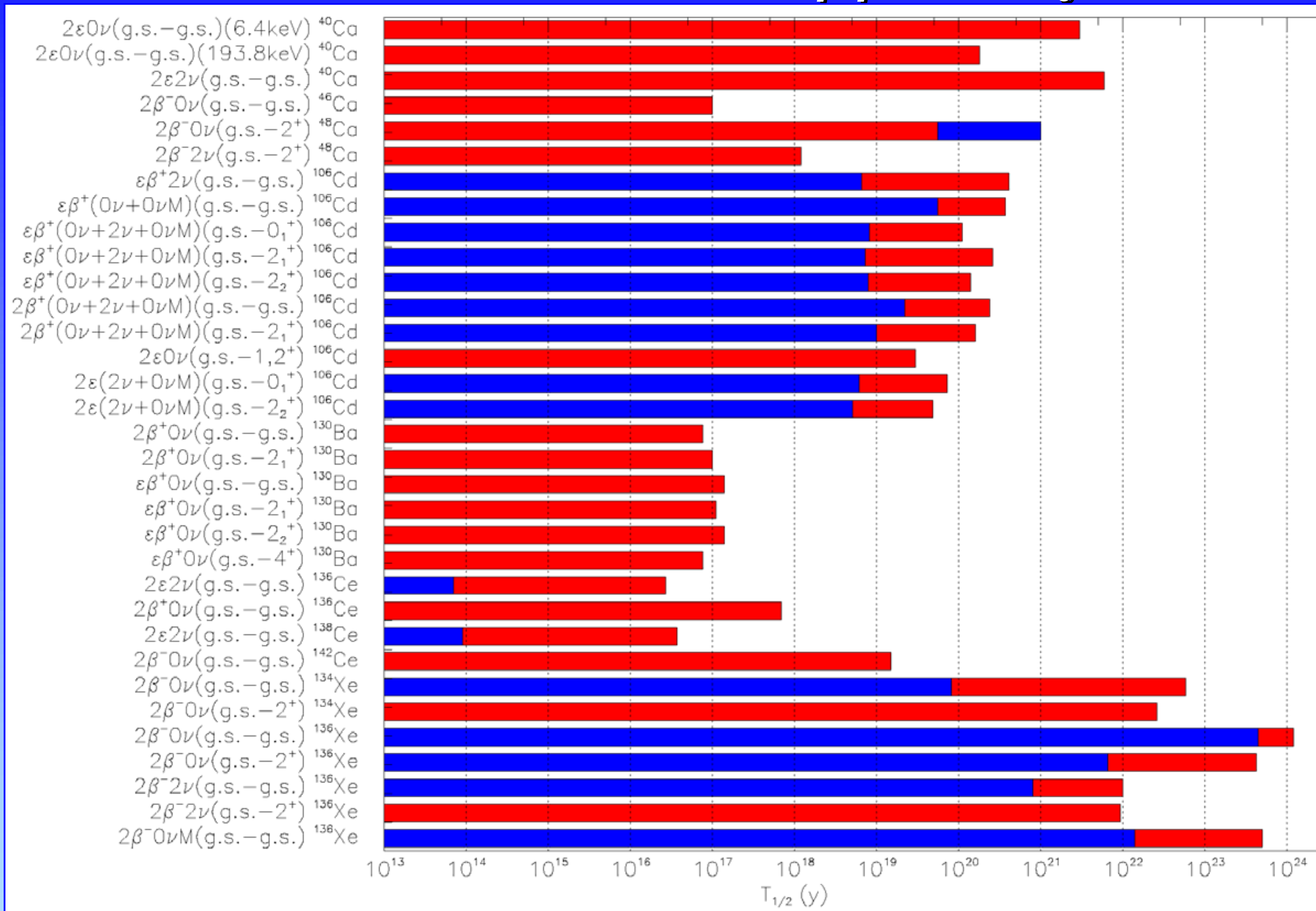
low background Ge detector operative in the Ge facility of LNGS mainly devoted to measurements and selections for:

- RD-I, RD-II and now RD-III on highly radiopure NaI(Tl) set-ups;
- several RDs on low background PMTs;
- qualification of many materials
- measurements with a $Li_6Eu(BO_3)_3$ crystal (NIMA572(2007)734)

- measurements with ^{100}Mo sample investigating some double beta decay mode in progress in the 4π low-background HP Ge facility of LNGS (to appear on Nucl. Phys. and Atomic Energy)

+ Many other meas. already scheduled for incoming years

DAMA results on ββ decay



Experimental limits on $T_{1/2}$ obtained by DAMA (red) and by previous experiments (blue)

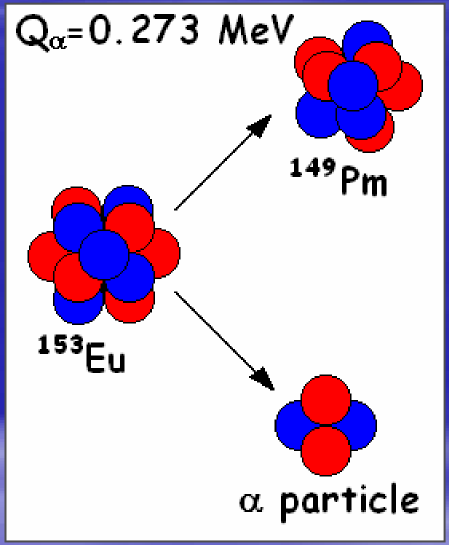
(all the limits are at 90% C.L. except for $2\beta^+0\nu$ in ^{136}Ce and $2\beta^-0\nu$ in ^{142}Ce - 68% C.L.)

Now in progress measurement on **$2\beta 2\nu$ decay** in ^{100}Mo to the first excited 0^+_1 level of ^{100}Ru by using ~1 kg of Molybdenum enriched in ^{100}Mo at 99.5% inserted in a 4 HP Ge detector array

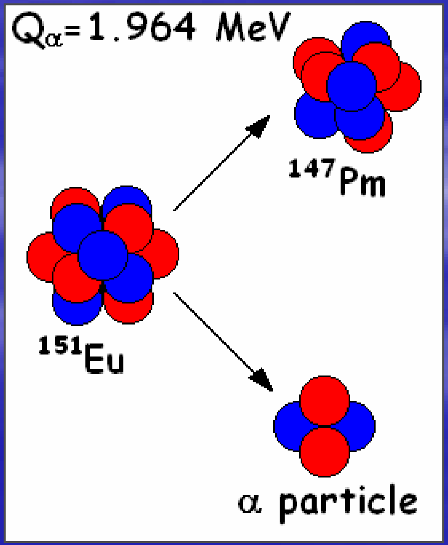
Search for α decay of natural Europium

Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001

Both natural Europium isotopes, ^{151}Eu (natural abundance δ = 47.81(6)%) and ^{153}Eu (δ = 52.19(6)%) have a positive energy release respectively to α decay and, thus, they are potentially α radioactive.



The low Q_α for ^{153}Eu gives no hope for experimental observation of its decay due to the very big expected half-life.



However, for ^{151}Eu estimations of half-life give values on the level of 10^{18} y, and such a sensitivity can be reached with current experimental techniques.

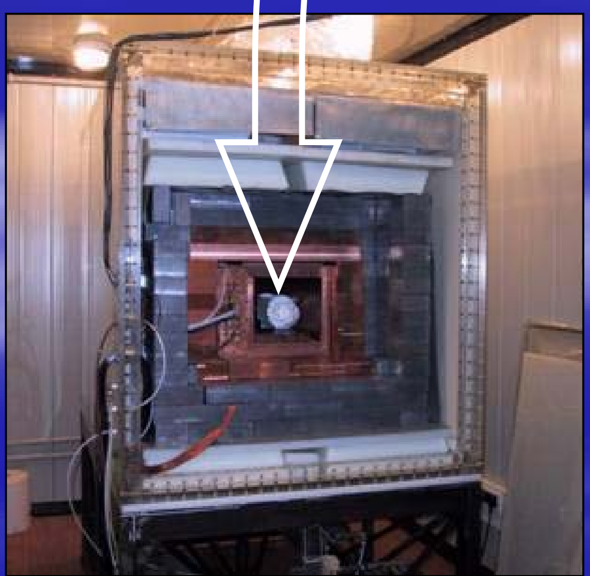
The experimental set-up

Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001

- Low background CaF_2(Eu) scintillator, 3" diameter, 1" in length → 370 g mass
- Pure quartz light guide (TETRASIL-B), 10 cm long to
- Low background photomultiplier (PMT) EMI9265-B53/FL.

(Scintillation crystal and light guide wrapped by PTFE reflection tape)

signals recorded by a 160 MSa/s Transient Digitizer over a 3125 ns time window



DAMA/R&D set-up at LNGS

Low radioactive Cu box flushed with HP N_2

Passive shield
- 10 cm of high purity Cu
- 15 cm of low radioactive lead
- 1.5 mm of cadmium and
- 4 to 10 cm of polyethylene/paraffin

The whole shield closed inside a Plexiglas box also flushed with HP N_2

Response to γ quanta and α particles

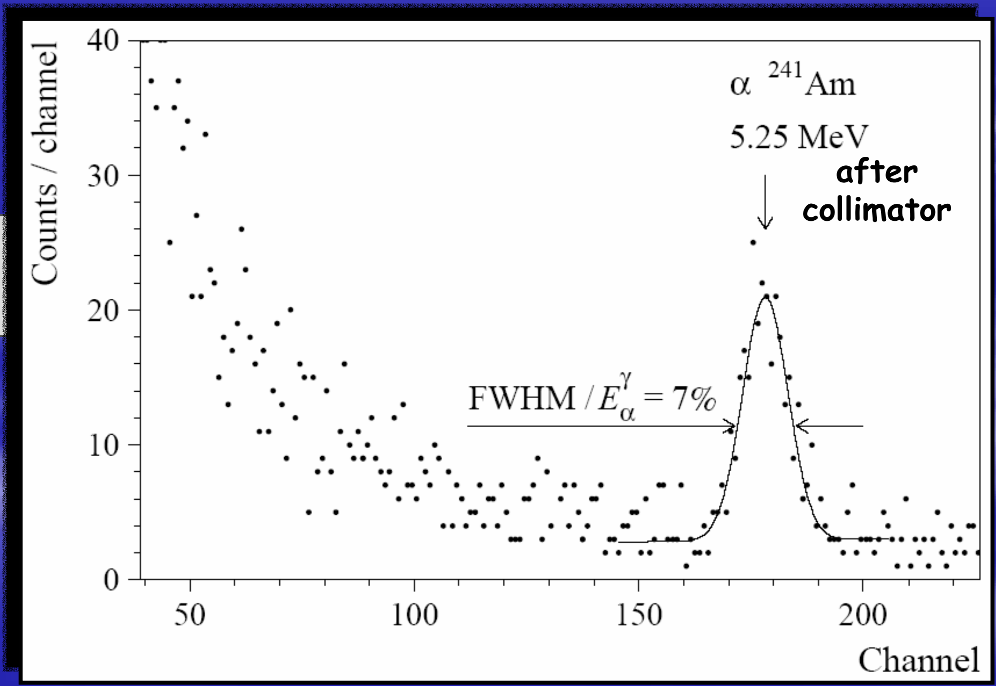
Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001

Energy scale and resolution for γ quanta measured with ^{22}Na, ^{133}Ba, ^{137}Cs, ^{228}Th and ^{241}Am sources.

$$\mathrm{FWHM}_\gamma(\mathrm{keV}) = \sqrt{3.7(4)\cdot E_\gamma[\mathrm{keV}]}$$

(e.g.: 28% @ 60 keV; 11.4% @ 356 keV and 7.5% @ 662 keV)

Response to α particles studied with a collimated ^{241}Am α source.

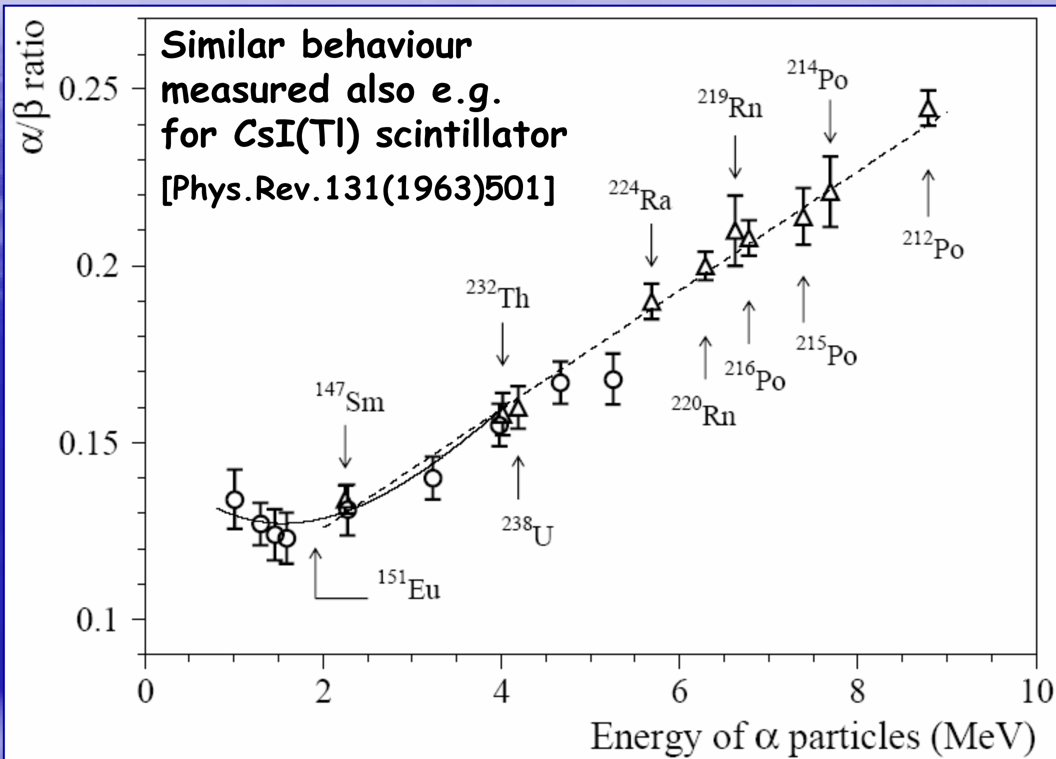


Specific α's energies in the interval 1.00–5.25 MeV obtained with a set of calibrated absorbers (mylar 0.65 mg/cm^2,air).

$$\mathrm{FWHM}_\alpha / E_\alpha^\gamma = 7\%$$

Energy dependence of the α/β ratio

Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001



o Points measured with ^{241}Am source (1.00, 1.30, 1.45, 1.59, 2.27, 3.23, 3.98, 4.66, 5.25 MeV)

Δ Peaks identified from the measured background

If E_α > 2 MeV (linear behaviour):

$$\alpha/\beta = 0.092(4) + 0.0168(7) \cdot E_\alpha [\mathrm{MeV}]$$

Non-linear behaviour near 2 MeV ⇒ fit by polynomial function (continuous line)

α/β = 0.128(19) at the energy of ^{151}Eu α particles

⇒ ^{151}Eu α peak expected at 245(36) keV (in gamma scale)

Pulse-shape discrimination between α and γ(β)

Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001

Shape Indicator (*SI*): numerical parameter of $CaF_2(Eu)$ signal

For each pulse:

$$SI = \frac{\sum_k f(t_k)P(t_k)}{\sum_k f(t_k)}$$

[0,2.25] μs

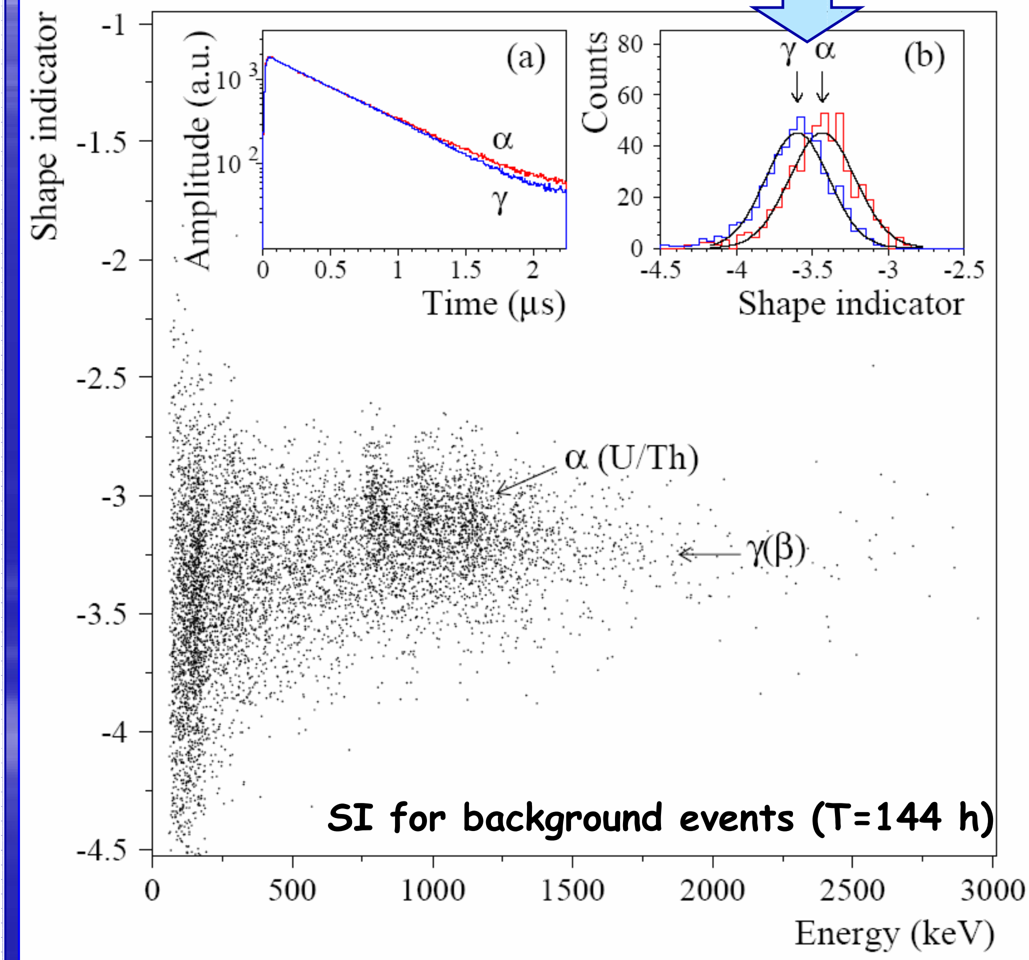
$$P(t) = \frac{f_\alpha(t) - f_\beta(t)}{f_\alpha(t) + f_\beta(t)}$$

$f(t_k)$ = digitized amplitude of signal

$P(t) = \{f_\alpha(t) - f_\gamma(t)\}/\{f_\alpha(t) + f_\gamma(t)\}$
(weight function)

$f_\alpha(t)$, $f_\gamma(t)$ = reference pulse shapes

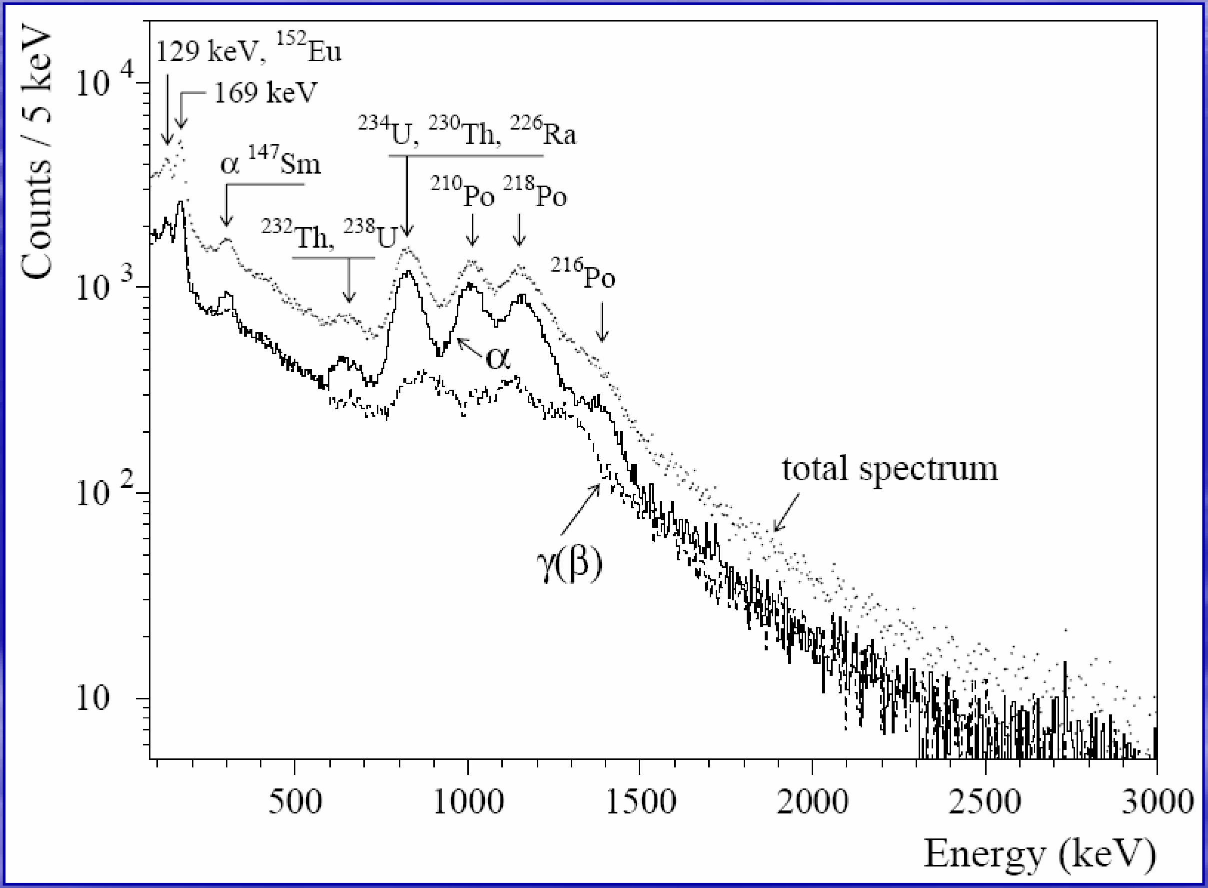
SI distribution for:
α particles (≈4 MeV) and
γ quanta (≈ 0.6 MeV)



Despite rather low discrimination, SI allows to check the nature of background

Measured energy spectrum (7426 h)

Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001



Data separated in 2 parts:

γ(β): with condition $SI < SI_\gamma$ (50% of γ(β) events)

α: with condition $SI > SI_\gamma$ (50% of γ(β) events but larger number of α)

Visible difference between the spectra

Pulse-shape discrimination useful to identify α active nuclides in the crystal.

Background identification: Time-amplitude analysis

Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001

Arrival time and energy of each event used for the selection of fast decay chains in ^{232}Th and ^{235}U families.

T = 7426 h

^{232}Th family

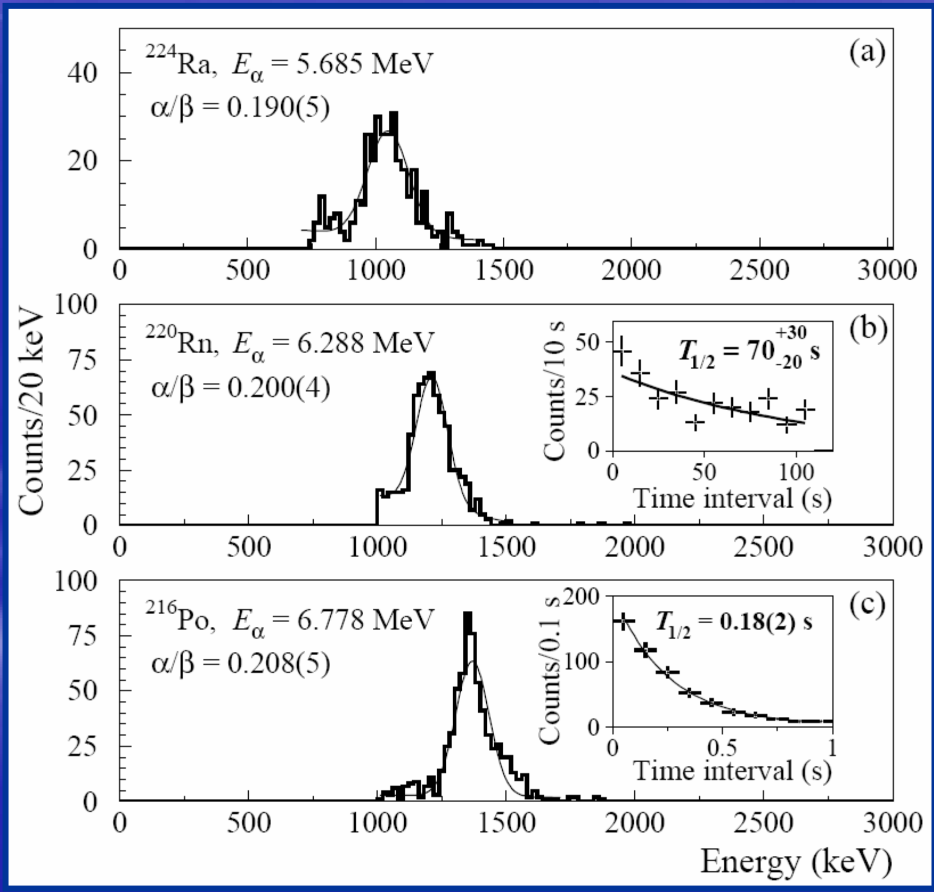
^{224}Ra (Q_α=5.789 MeV, $T_{1/2}$=3.66 d)

→ ^{220}Rn (Q_α=6.405 MeV, $T_{1/2}$=55.6 s)

→ ^{216}Po (Q_α=6.907 MeV, $T_{1/2}$=0.145 s)

→ ^{212}Pb

^{228}Th activity = 0.134(17) mBq/kg



^{235}U family

^{223}Ra (Q_α=5.98 MeV, $T_{1/2}$=11.44 d)

→ ^{219}Rn (Q_α=6.95 MeV, $T_{1/2}$=3.96 s)

→ ^{215}Po (Q_α=7.526 MeV, $T_{1/2}$=1.78 ms)

→ ^{211}Pb

^{227}Ac activity = 0.011(7) mBq/kg

Background identification: Bi-Po events

Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001

Selection of double pulses produced by very fast decay chains (the so called Bi-Po events)

T = 7426 h

depressed by a factor ≈ 110 because of the used TD time window

^{232}Th family

^{212}Bi (Q_β=2.254 MeV)

→ ^{212}Po (Q_α=8.954 MeV, $T_{1/2}$=0.299 μs)

→ ^{208}Pb

^{228}Th activity = 0.124(5) mBq/kg

(in agreement with time-amplitude analysis)

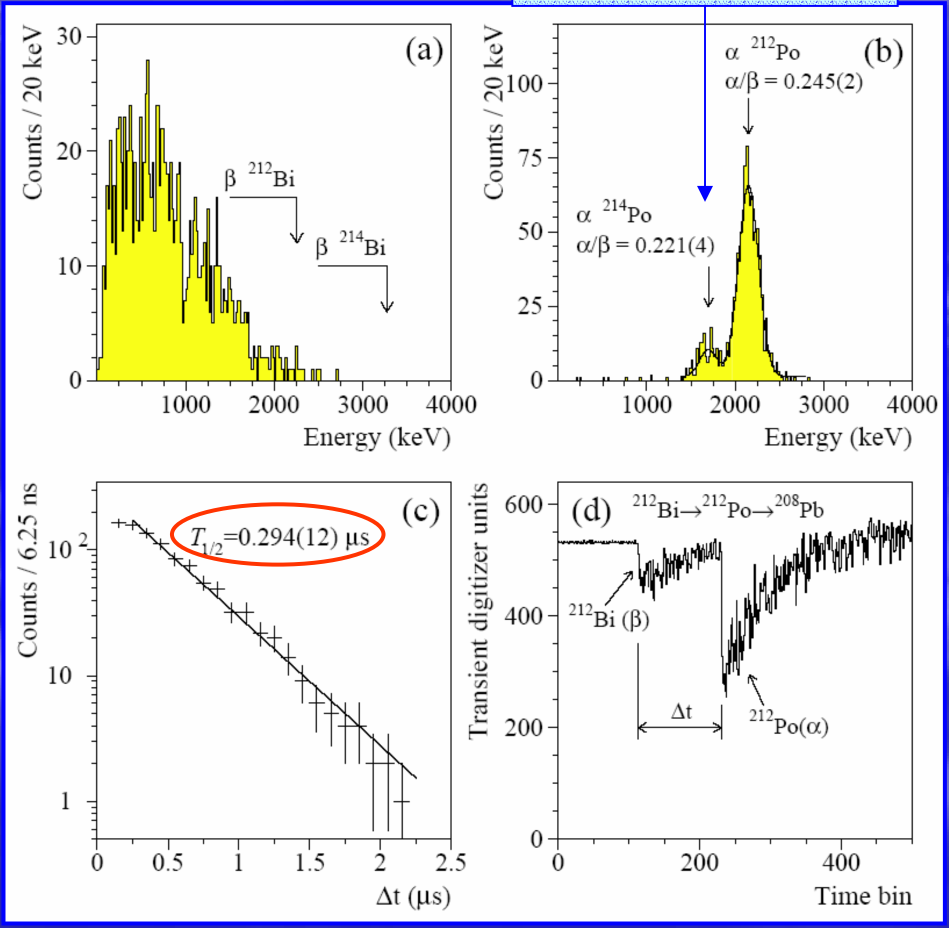
^{238}U family

^{214}Bi (Q_β=3.272 MeV)

→ ^{214}Po (Q_α=7.833 MeV, $T_{1/2}$=164 μs)

→ ^{210}Pb

^{226}Ra activity = 1.3(2) mBq/kg

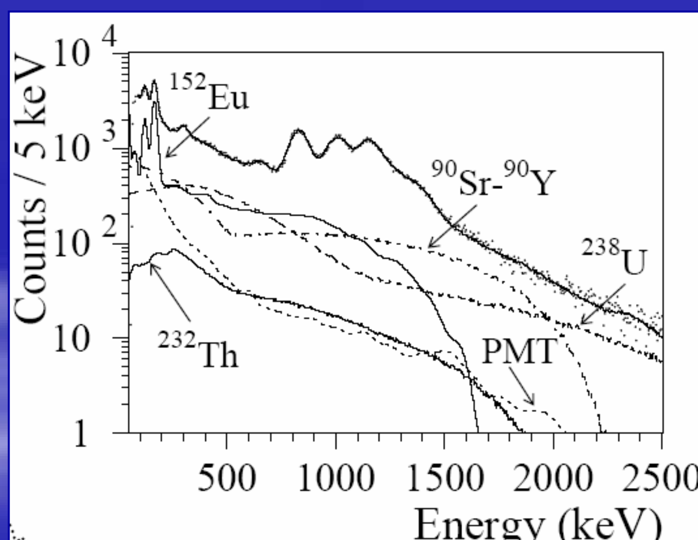


Radioactive contamination of the CaF_2(Eu)

Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001

Activities of α active nuclides in CaF2(Eu) estimated by analysis of identified α peaks

Presence in the crystal of β active isotopes (U/Th families, ^{40}K, ^{60}Co, ^{90}Sr-^{90}Y, ^{137}Cs, ^{154}Eu) and external γ rays simulated with GEANT4



At low energy the background is caused mainly by β decay of ^{152}Eu

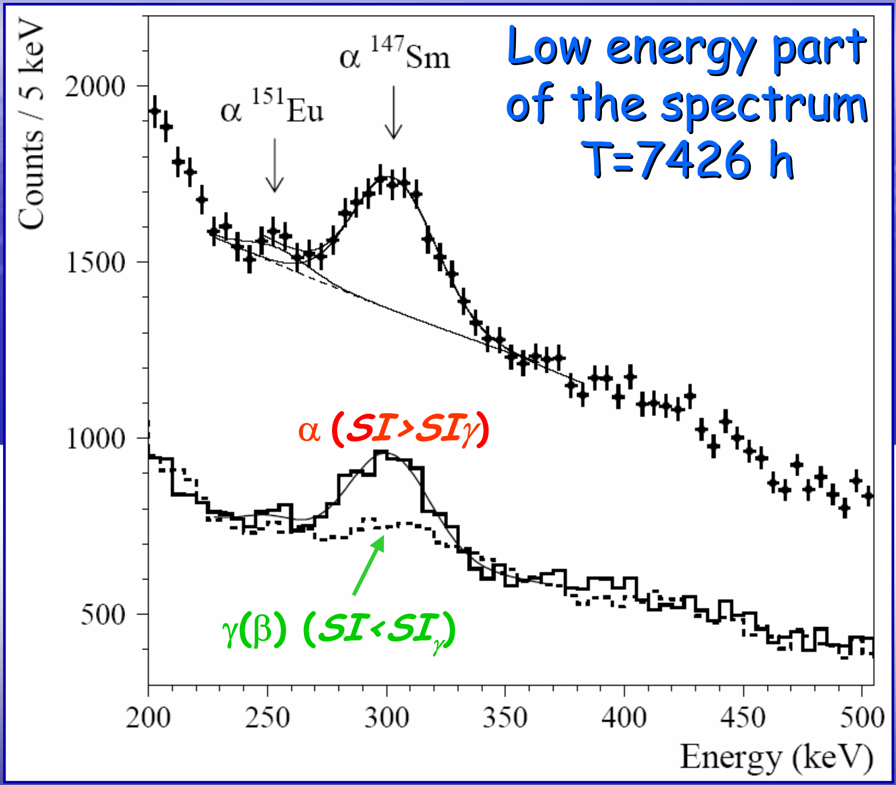
Chain	Nuclide	Activity mBq/kg
^{232}Th	^{232}Th	0.05(1)
	^{228}Ra	≤ 0.6
	^{228}Th	0.13(2)
^{235}U	^{227}Ac	0.011(7)
^{238}U	^{238}U	0.06(1)
	^{226}Ra	1.3(2)
	^{210}Po	0.9(2)
Total U/Th α activity		8(2)
	^{40}K	≤ 7
	^{60}Co	≤ 3
	^{90}Sr$-^{90}$Y	≤ 4
	^{137}Cs	≤ 0.3
	^{147}Sm	0.34(4)
	^{152}Eu	10(2)
	^{154}Eu	≤ 0.5

α decay $^{151}Eu \rightarrow {}^{147}Pm$

Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001

Peculiarity on the left of the ^{147}Sm peak can be attributed to the <u>α decay of ^{151}Eu</u> (expected peak at 1.912 MeV⇒245±36 keV)

Spectrum fitted by simple model:
2 Gaussian peaks (α decay of ^{151}Eu and ^{147}Sm)
+ exponential function (background)



1. Fit of the <u>total spectrum</u> [225,365 keV]:

S = (302 ± 232) counts (χ^2/ndf=0.42)

E_{peak} = (255±7) keV

$$T_{1/2} = 5.4^{+11.4}_{-2.4}(stat) \pm 1.4(syst) \times 10^{18} \text{ y}$$

2. Fit of the <u>α spectrum</u> (efficiency=68% from ^{147}Sm peak) in [225,365 keV] :

S = (374 ± 329) counts → $T_{1/2} = 4.4^{+11.3}_{-2.1}(stat) \times 10^{18}$ y

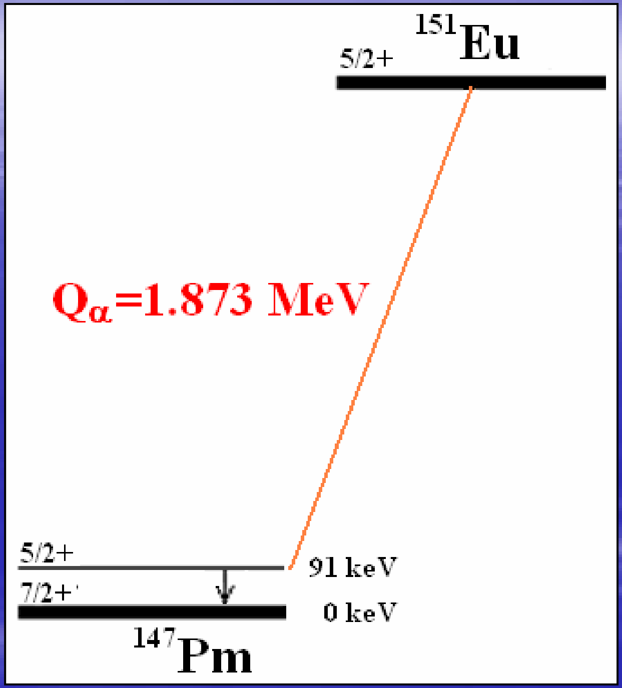
E_{peak} = (253±?) keV

^{151}Eu α decay: $T_{1/2} = 5^{+11}_{-3} \times 10^{18}$ y

… or in a conservative approach: $T_{1/2} \geq 1.7 \times 10^{18}$ y (68% C.L.)

α decay of ^{151}Eu to the first excited level of ^{147}Pm

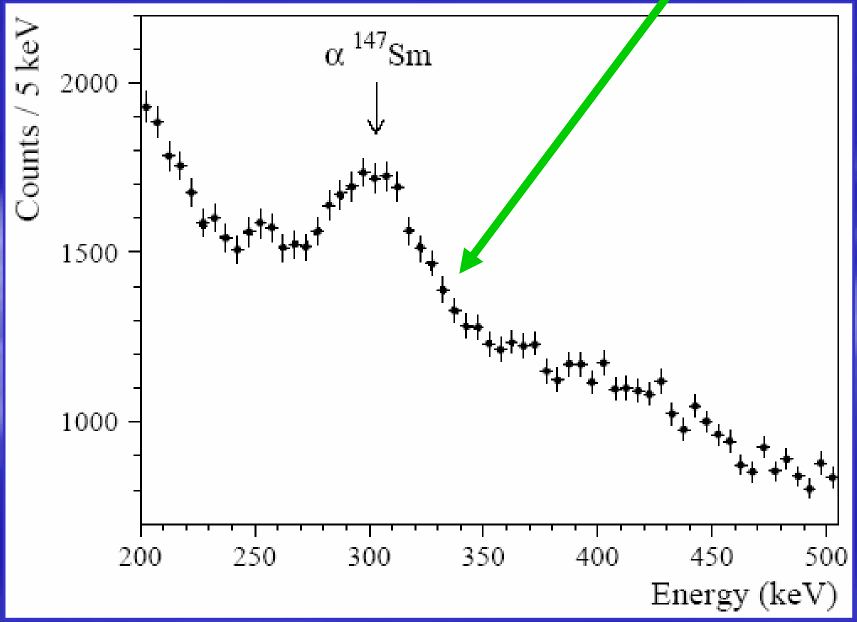
Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001



E_α = 1.823 MeV corresponds to energy 234 keV in the γ scale of the CaF2(Eu) detector.

Subsequent 91 keV deexcitation energy (γ, 33%, or X rays/Auger electrons, 67%) effectively absorbed

⇒ Expected peak at (325±33) keV



Fit model:

2 Gaussian peaks (α decay of ^{151}Eu and ^{147}Sm)
+ exponential function (background)

No evidence:

$$T_{1/2}(g.s. \rightarrow 5/2^+) \geq 6 \times 10^{17} \text{ yr}$$

(68% C.L.)

Implications

Nucl.Phys.A(2007), doi: 10.1016/j.nuclphysa.2007.03.001

Presence of Promethium in the Earth crust

- It is one of the rarest elements (all isotopes unstable with $T_{1/2}$<18 yr)
- Present only as temporal product (predominantly from ^{238}U spontaneous fission)
- It is possible to calculate about 560 g of natural Pm in the Earth crust

Observed α decay of ^{151}Eu opens additional source of natural Pm.

Taking into account the abundance of Europium in the crust (2×10^{-4}%)

⇒ additional 12^{+17}_{-8} g of natural Pm born by ^{151}Eu

Comparison with theory

[1] B. Buck et al., J. Phys. G 17 (1991) 1223; 18 (1992) 143.
[2] D.N. Poenaru, M. Ivascu, J. Physique 44 (1983) 791.
[3] G. Royer, J. Phys. G 26 (2000) 1149.
[4] M. Fujiwara et al., J. Phys. G 28 (2002) 643.
[5] D.N. Poenaru et al., Phys. Rev. C 32 (1985) 2198.

Populated level	Theoretical $T_{1/2}$, yr [1]	[2]	[3]	[4]	[5]	Experimental $T_{1/2}$, yr
ground state	3.0×10^{17}	3.6×10^{18}	6.3×10^{17}	5.9×10^{17}	1.6×10^{18}	$5^{+11}_{-3}\times10^{18}$
$5/2^+$, 91 keV	7.7×10^{18}	1.0×10^{20}	1.5×10^{19}	1.7×10^{19}	–	$\geq 6\times10^{17}$

G.S.: Measured $T_{1/2}$ is in agreement with theoretical value [2] and [5].

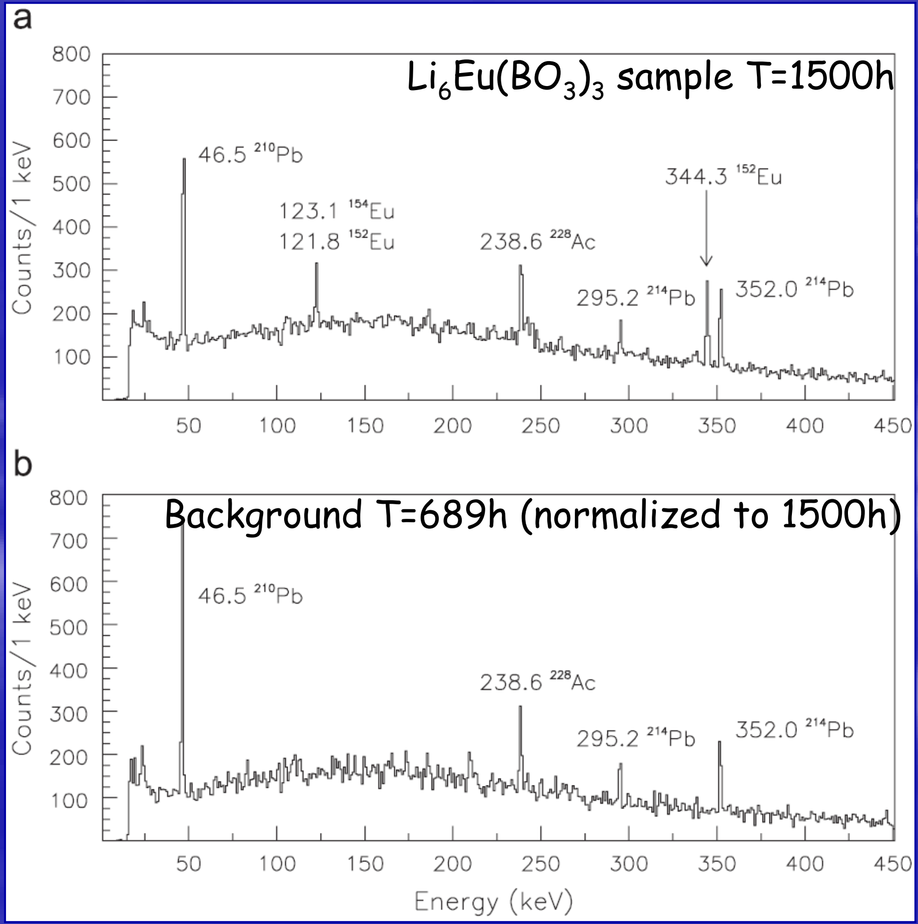
Search for α decays of Eu with a $Li_6Eu(BO_3)_3$ crystal

NIM A 572(2007)734

Greater content of Eu with respect to CaF_2(Eu), but poor scintillation properties and small size crystals

Exp set-up: $Li_6Eu(BO_3)_3$, 2.72 g, as external source + HP Ge detector (408 cm^3) in low-background set-up @ LNGS

Spectra measured with the HP Ge



Radioactive contamination in $Li_6Eu(BO_3)_3$:

Chain	Nuclide	Activity (Bq/kg)
^{232}Th	^{228}Ac	<0.20
	^{212}Pb	<0.25
	^{208}Tl	<0.13
^{238}U	^{214}Pb	<0.17
	^{214}Bi	<0.07
	^{40}K	<1.5
	^{60}Co	<0.026
	^{137}Cs	<0.081
	^{207}Bi	<0.009
	^{152}Eu	=0.949(48)
	^{154}Eu	=0.212(35)

Limits are given at 90% C.L.

^{152}Eu and ^{154}Eu contamination

Radioactive ^{152}Eu and ^{154}Eu nuclei were produced by neutron capture by ^{151}Eu and ^{153}Eu, respectively

Cross section for capture of thermal neutron: $\sigma_{151} = 5900 \pm 200$ b, $\sigma_{153} = 312 \pm 7$ b

Number of nuclei: $N_{151} = 7.78 \times 10^{20}$, $N_{153} = 8.49 \times 10^{20}$

Mass-spectrometric measurements showed that the Eu in the crystal was of normal composition

Decay constant: $\lambda_{152} = \frac{\ln 2}{13.537}$ yr^{-1}, $\lambda_{154} = \frac{\ln 2}{8.593}$ yr^{-1}

$$\Rightarrow \quad \frac{dN_d}{dt} = \phi \cdot \sigma_m \cdot N_m - \lambda_d \cdot N_d \quad \rightarrow \quad N_d(t) = \phi \cdot \sigma_m \cdot N_m \cdot \frac{\left(1 - e^{-\lambda_d t}\right)}{\lambda_d}$$

where $\begin{cases} m = 151\ (153) \\ d = 152\ (154) \end{cases}$

$$\frac{A_{152}}{A_{154}} = \frac{\lambda_{152} \cdot N_{152}(t)}{\lambda_{154} \cdot N_{154}(t)} = \frac{\sigma_{151} \cdot N_{151}}{\sigma_{153} \cdot N_{153}} \cdot \frac{\left(1 - e^{-\lambda_{152} t}\right)}{\left(1 - e^{-\lambda_{154} t}\right)}$$

$\Rightarrow$ for given N_m and σ_m: $11.00 < A_{152}/A_{154} < 17.33$

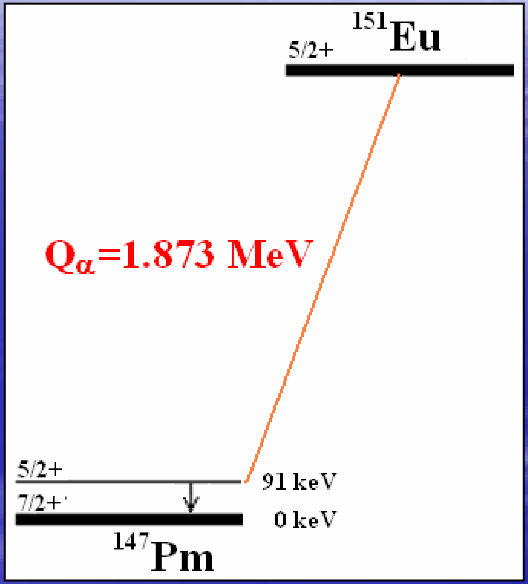
inconsistent with the measured ratio $A_{152}/A_{154} = 4.48 \pm 0.77$

Can be due to non-thermal neutrons flux from spontaneous fission of Th and U, and from (α,n) reactions in the monazite ores (which is a commercial source for both Eu and Th elements).

Alpha decays of Eu to Pm

NIM A 572(2007)734

^{151}Eu (g.s.) → ^{147}Pm (5/2$^+$)



No evidence for 91.1 keV γ in the spectrum:

$$\lim T_{1/2} = (\ln 2 \cdot \varepsilon \cdot y \cdot N_{151} \cdot T) / \lim S$$

ε=2.8%; y (yield)=0.327

1. One σ approach: $T_{1/2} > 4.0 \times 10^{16}$ yr (68% C.L.)
2. Fit by the sum of the background model (straight line) + Gaussian peak ⇒ S = 12±14 counts

$$T_{1/2} > 2.4 \times 10^{16} \text{ yr} \quad (90\% \text{ C.L.})$$

^{153}Eu (g.s.) → ^{149}Pm (g.s.) – very low Q_α=274 keV –

No evidence for 286 keV γ emitted in the β decay of ^{149}Pm (yield=3.1%, ε=11.0%)

$$T_{1/2} > 1.1 \times 10^{16} \text{ yr} \quad (90\% \text{ C.L.})$$

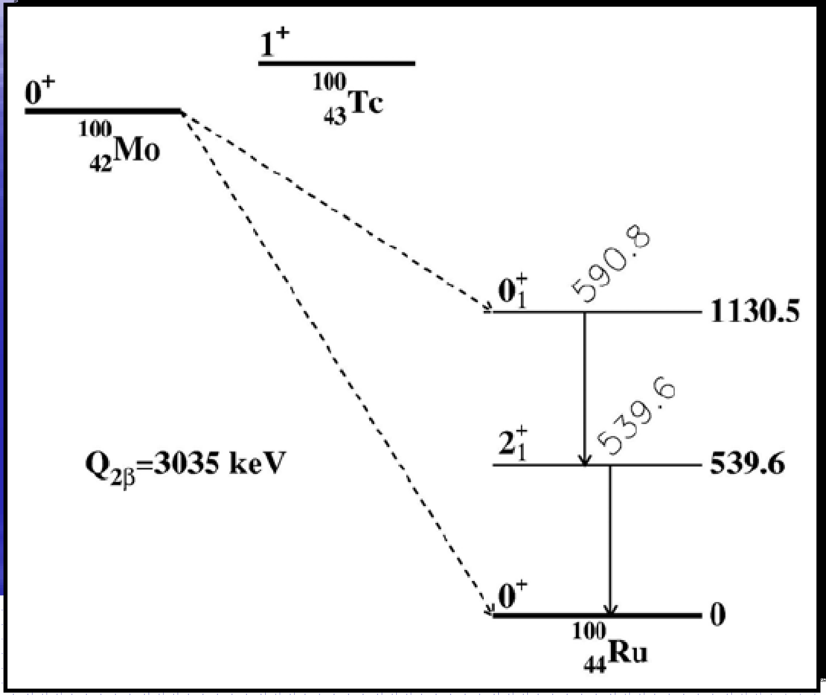
Search for $2\beta2\nu(0^+ \rightarrow 0^+_1)$ of ^{100}Mo

in the volume Nucl.Phys. and Atomic Energy, ed. INR-Kiev (2006), 479

For two nuclides, ^{100}Mo and ^{150}Nd, $2\beta2\nu$ decay has been observed also for transition to the first excited 0^+_1 levels of daughter nuclei

Transition (g.s.→g.s.) of ^{100}Mo has been observed in six experiments:

$T_{1/2} = 7.7 \pm 0.5 \times 10^{18}$ yr [JETP Letters 80(2004)377]



Transition of ^{100}Mo to 0^+_1 level of ^{100}Ru has been positively identified in four experiments:

$T_{1/2} = 6.1^{+1.8}_{-1.1} \times 10^{20}$ y [Phys.Lett.B 345(1995)408]
$T_{1/2} = 9.3^{+2.8}_{-1.7} \times 10^{20}$ y [Phys.At.Nucl. 62(1999)2039]
$T_{1/2} = 5.9^{+1.8}_{-1.3} \times 10^{20}$ y [Phys.Rev.Lett. 86(2001)3510]
$T_{1/2} \approx 6 \times 10^{20}$ y [To appear on Nucl.Phys. and Atom.Energy]

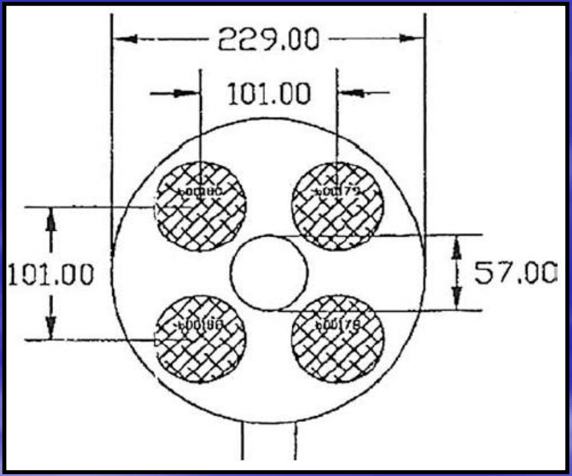
in agreement between themselves, but **in contradiction** with data of the fifth experiment: $T_{1/2} > 1.2 \times 10^{21}$ y at 90% C.L. [Phys.Lett.B 275(1992)506]

Experimental set-up

in the volume Nucl.Phys. and Atomic Energy,
ed. INR-Kiev (2006), 479

ARMONIA Collaboration: MeAsuReMent of twO-NeutrIno ββ decAy of ^{100}Mo to the first excited 0^{+} level of ^{100}Ru

Aim of the experiment: to confirm previous positive results or to set more stringent limit on the probability of the process



Data collected at LNGS in low-background set-up with 4 HP Ge detectors (each of ~225 cm^3).

Mo sample:

1009 g of Mo (metallic powder) enriched by ^{100}Mo at 99.5%, compressed to ~6 g/cm^3 to fill fully the well in the HP Ge set-up; some amount also above the detectors.

Germanium detectors parameters

	Detectors			
	ge178	ge179	ge180	ge188
Volume (cm^3)	225.2	225.0	225.0	220.7
Endcap and holder material	Electrolytical copper			
Energy resolution (FWHM) at 1332 keV	2.1	2.0	2.0	2.0

Measurements and preliminary results

in the volume Nucl.Phys. and Atomic Energy,
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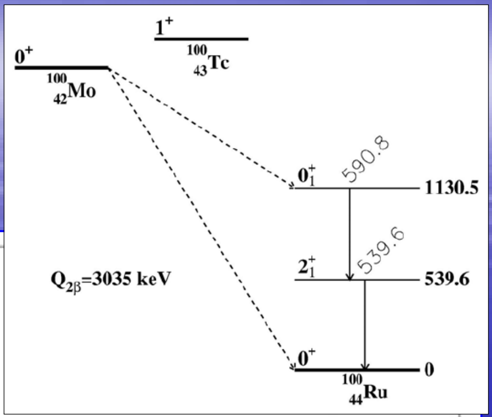
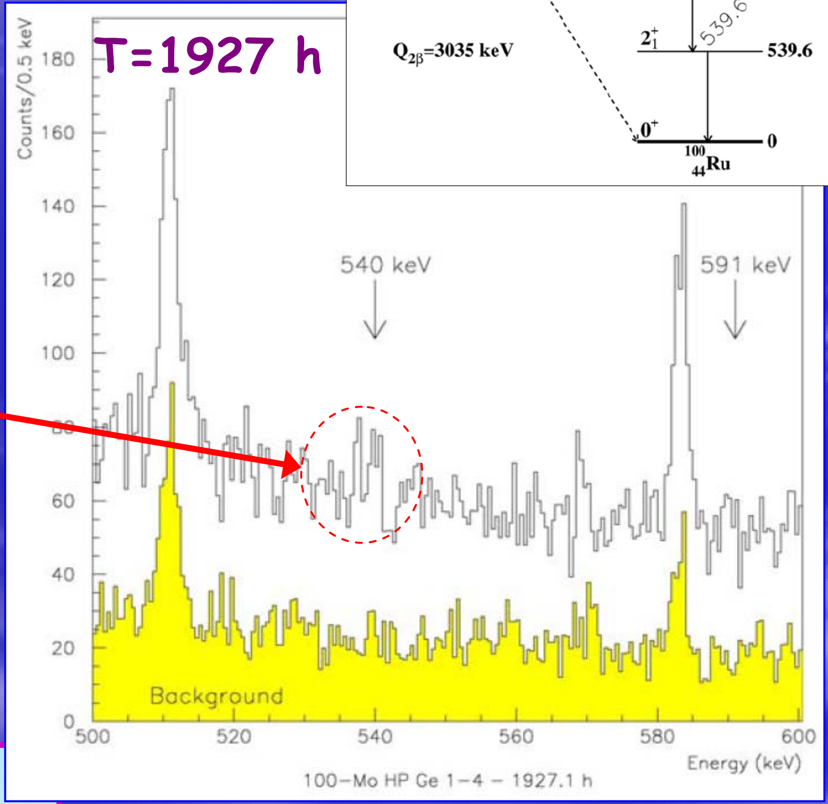


Search for 590.8 keV and 539.6 keV gamma quanta;
(detection efficiency ~2.5% -- Geant4)

Measured spectra (500-600 keV) with and without the Mo sample (T=1927 h)
Counting rate of the Mo sample is ~2.5 times higher than that of background in this region due to the Mo pollution

Considering this peak structure related with $2\beta2\nu$ decay of ^{100}Mo to 0^+_1 level of ^{100}Ru
$\Rightarrow T_{1/2} = 3\times10^{20}$ y

But no evidence of the second 591 keV peak
$\Rightarrow T_{1/2} > 6\times10^{20}$ y (90% C.L.)



New data taking in progress after chemical purification of the ^{100}Mo source at LNGS

$\Rightarrow$ Expected sensitivity (1y) ~ 3×10^{21} y
will allow to confirm or reject previous results

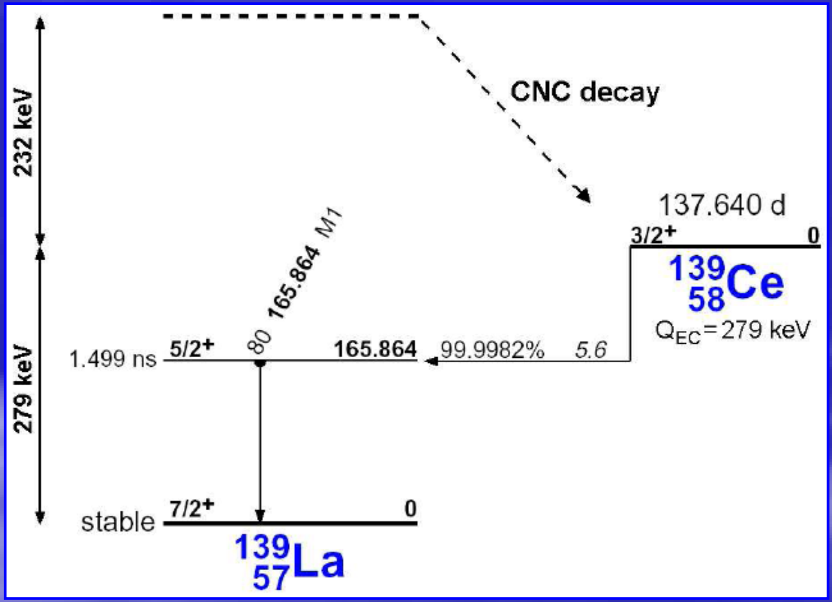
Peaks at 511 keV and 583 keV related with ^{208}Tl decay and annihilation process (511 keV)

Search for possible charge non-conserving decay $^{139}La \to ^{139}Ce$ with $LaCl_3(Ce)$ detector

Ukr. Journal of Physics 51(2006)1037

The possibility of CNC phenomena has widely been discussed in literature mainly in connection with future unified theory and with the possible existence of extra dimension

Dubovsky et al., JHEP 08(2000)041
Rubakov, Phys. Uspekhi 44(2001)871, hep-ph/0104152
Dubovsky et al., Phys.Rev.D62(2000)105011
Dolgov et al., hep-ph/0210267
Rubakov, Proc. NANPino 2000, Dubna, Russia



APPROACH:

If, in a β decay some massless uncharged particle was emitted instead of the electron (ν_e, γ, Majoron, …), an additional 511 keV energy release would occur:

⇒ usually forbidden decays would become energetically possible

Possible CNC decay $^{139}La \to ^{139}Ce$ can be identified searching for the electron capture $^{139}Ce \to ^{139}La$

"Source=detector" advantages:

- No chemical separation
- Real time approach
- Efficiency close to 1
- Background discrimination

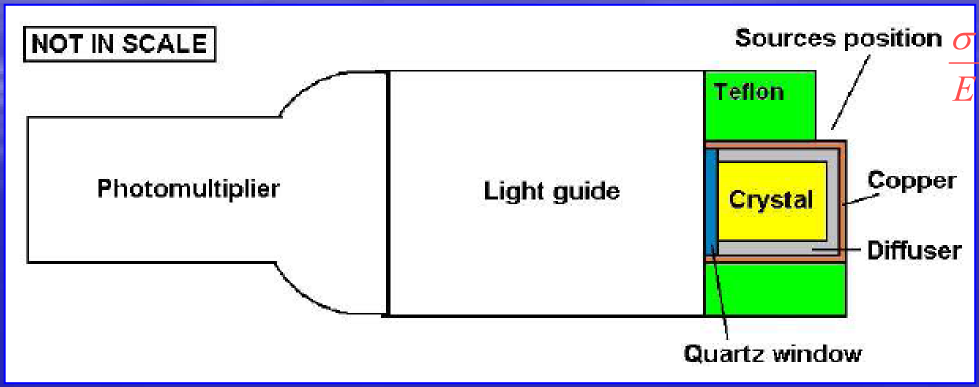
Experimental set-up

[Nucl.Instr.Meth A555(2005)270]

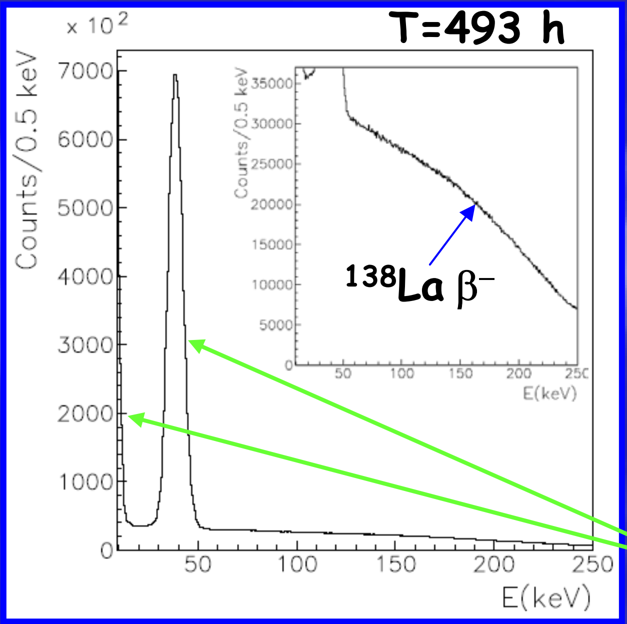
Detector: $LaCl_3$:(8.5±1.0%)Ce, mass = (49.7±1.3) g

Tetrasil-B light guide (10 cm)

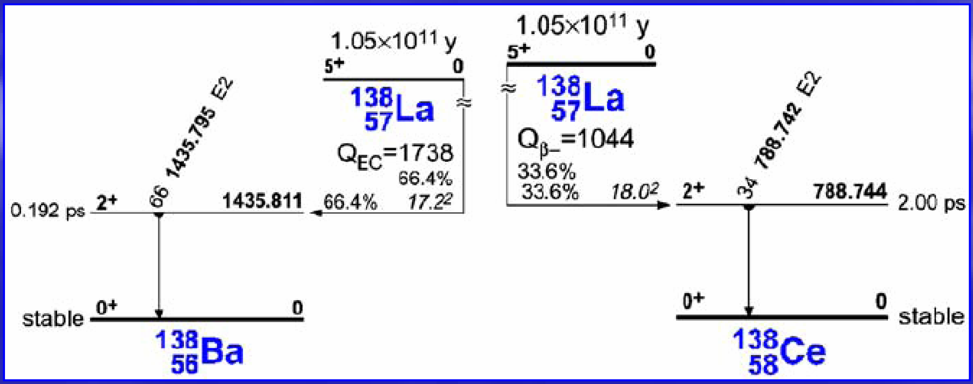
Low background EMI9265-B53/FL photomultiplier



$$\frac{\sigma}{E} = 0.004 + \frac{0.59}{\sqrt{E[keV]}}$$



Measured background is dominated by ^{138}La decays (δ=0.0902%)

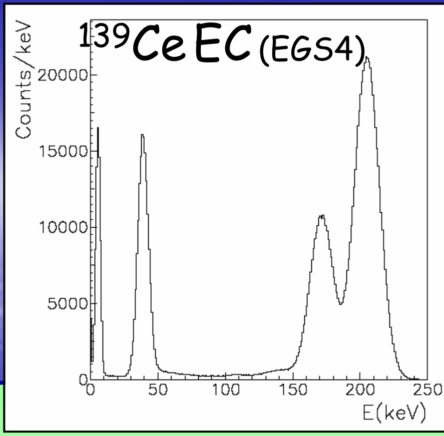


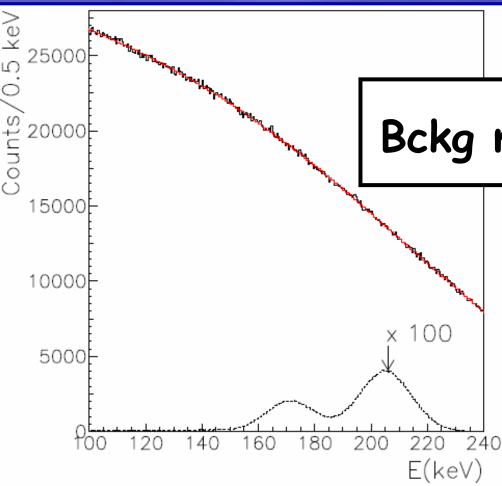
Shell K (38 keV) and shell L (6 keV) deexcitation peak

Data analysis and results

[Ukr.J.Phys. 51 (2006) 1037]

Fit of the experimental spectrum with: expected signal +
+ background model





Case 1

$$\text{Bckg model} = P_1 + P_2 E_k + \left[\sqrt{E_k\left(E_k + 2m_e c^2\right)}\left(Q_\beta - E_k\right)^2\left(E_k + m_e c^2\right)\right]\left(P_3 + P_4 E_k + P_5 E_k^2\right)$$

linear bckg — ^{138}La β spectrum

Fit[100-240keV]: N=-3810±4290 events → N<3810 events 90%CL

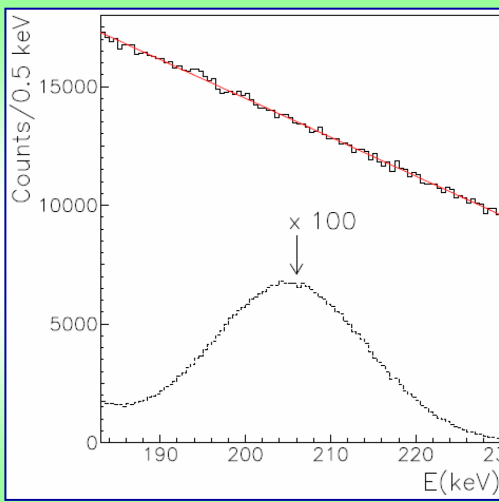
$\Rightarrow$ **$\tau > 1.6\times10^{18}$ y (90% C.L.)**

Case 2

$$\text{Bckg model} = P_1 + P_2 E_k$$

Fit[183-230 keV]: N=560±3530 eventi → N<6370 eventi 90%CL

$\Rightarrow$ **$\tau > 1.0\times10^{18}$ y** **(90% C.L.)**



First experimental limit for ^{139}La→^{139}Ce CNC decay

It holds for whatever decay channel with emission of massless uncharged particle

Conclusions

Recent results obtained in 2006-2007 by the DAMA collaboration in the investigation for some rare processes have been presented:

1. First measurement of α decay of ^{151}Eu with $CaF_2(Eu)$ detector
2. New limits on α decay modes with a $Li_6Eu(BO_3)_3$ crystal
3. New limit on $2\beta2\nu(0^+ \rightarrow 0^+_1)$ of ^{100}Mo with ~1 kg Mo sample
4. First experimental limit for the possible $^{139}La \rightarrow ^{139}Ce$ CNC decay