Development of a low neutron emission ^{228}Th source for the calibration of GERDA

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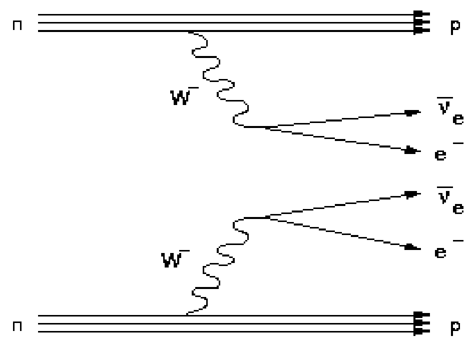
Overview

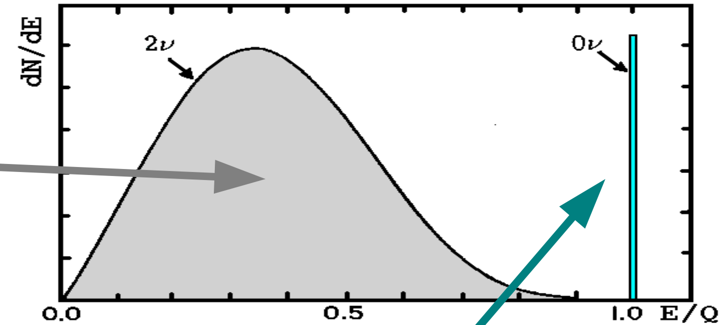
- Neutrinoless double beta decay
- The GERDA experiment
- Commercial ^{228}Th calibration source
- Custom ^{228}Th calibration source
- Neutron measurements
- Results / Conclusions

Neutrinoless double beta decay

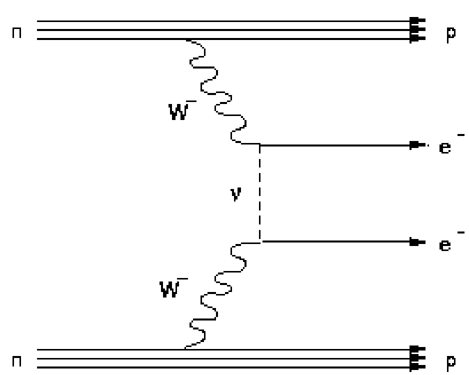
2νββ decay



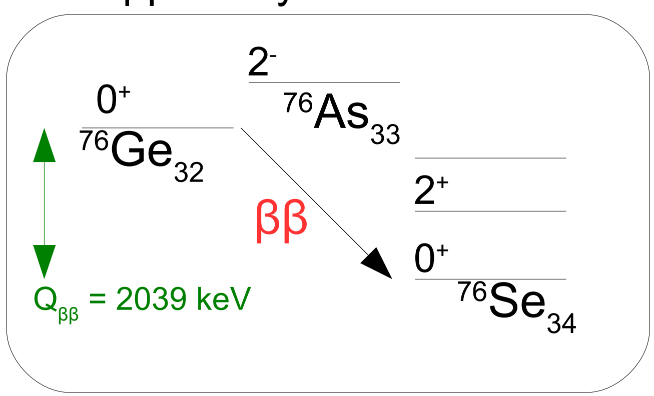
Allowed by SM
Observed in ^{76}Ge, ^{130}Te, ^{82}Se, ^{100}Mo, ^{150}Nd ...
Half life: 10^{19} – 10^{21} years



0νββ decay



0νββ decay scheme of ^{76}Ge



^{76}Ge → ^{76}Se + 2e$^-$
Halflife: >10^{25} years
$Q_{\beta\beta}$ = 2039 keV

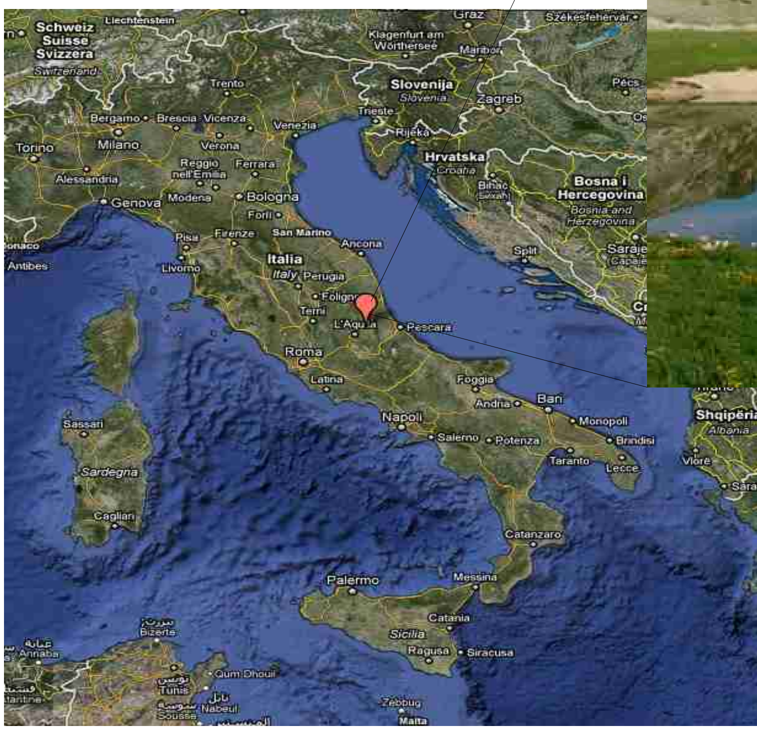
Requires: $\nu = \bar{\nu}$ & $m_\nu \neq 0$
Violation of lepton number : $\Delta L=2$
Not allowed in SM !!

19.3'10

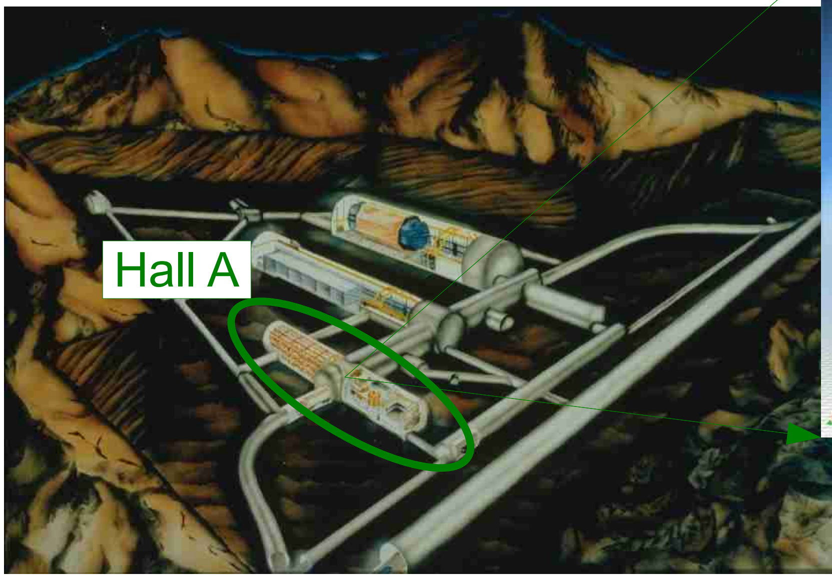
GERmaniumDetectorArray
Search for neutrino-less double beta decay of ^{76}Ge

17 institutions

GERDA Location:
Gran Sasso, Italy



3800 m.w.e.



Half life sensitivity: $T_{1/2} \sim \sqrt{M \cdot t / B \cdot \sigma(E)}$

M: active mass

t: exposure time

σ(E): energy resolution around $Q_{\beta\beta}$

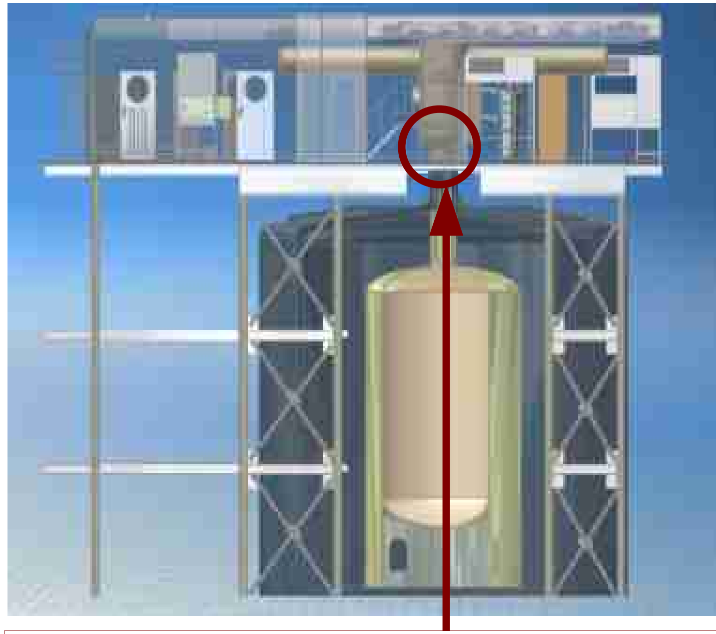
B: background index

- Enriched ^{76}Ge (86%) array consisting of max. 16 strings
- Source of $0\nu\beta\beta$ decay = sensitive volume

- Neutrons induced by cosmic ray muons
- Cosmogenic activation of Ge
- Natural activity (Th,U) , external & internal
- Background induced by the calibration source

- γ 's
- n's from spontaneous fission
- n's from (α-n) reactions

The GERDA experiment



Parking position of the calibration source

PHASE I

M (detector) : 20 kg
Exposure : 15 kg·y
B projected : 10^{-2} counts/keV·kg·year
Half life limit : $T_{1/2} > 2.2 \cdot 10^{25}$ years

PHASE II

M (detector) : 40 kg
Exposure : 100 kg·y
B projected : 10^{-3} counts/keV·kg·year
Half life limit : $T_{1/2} > 15 \cdot 10^{25}$ years

PHASE III

M (detector) : ~500 kg
B projected : 10^{-4} counts/keV·kg·year

^{228}Th

^{208}Tl: 2615 keV
^{208}Tl SEP: 2103 keV ◄──► $Q_{\beta\beta}$ = 2039 keV
^{212}Bi: 1621 keV
^{208}Tl DEP: 1592 keV

- γ - emission: 0.063 – 2.6 MeV ───► γ background supressed with a Ta absorber
- α - emission: 5.2 – 8.8 MeV ───► Neutron background induced by (α-n)-reactions with α irradiated materials ?

Commercial ^{228}Th source

^{228}Th chain

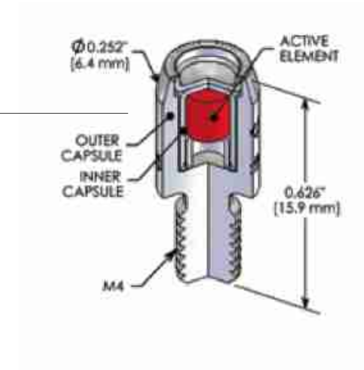
- $E_{mean}(\alpha) \sim 6.5$ MeV
- $E_{max}(\alpha) = 8.785$ MeV

(α-n) reaction
$\alpha + {}^{a}X_{b} \rightarrow {}^{a+4}Y^{*}_{b+2} \rightarrow {}^{a+3}Y_{b+2} + n$

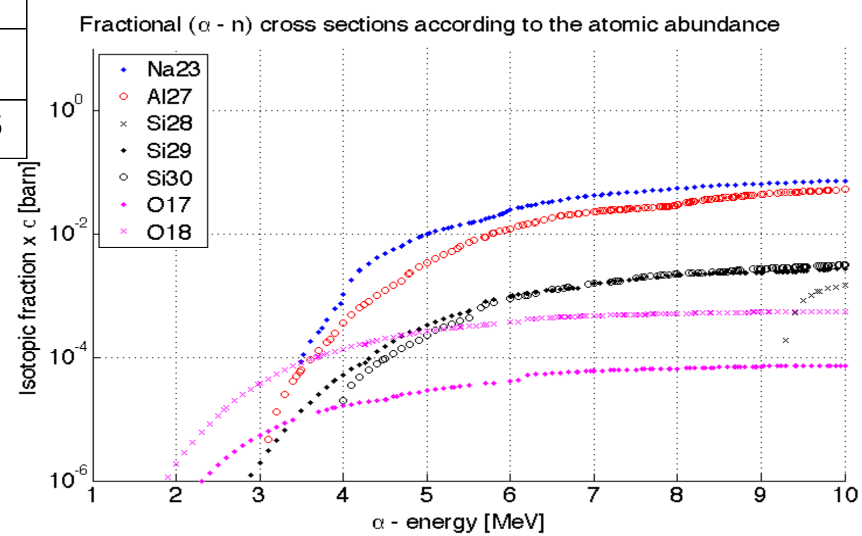
Activated ceramic
= target material

$NaAlSiO_2$, Al_2O_3, ...

Resulting n-flux
→ calculated with 'SOURCES'



Isotope	^{23}Na	^{27}Al	^{28}Si	^{29}Si	^{30}Si	^{16}O	^{17}O	^{18}O
Nat. abundance [%]	100	100	92	4.68	3.09	99.76	0.04	0.2
Threshold [MeV]	3.5	3.03	9.25	1.74	3.96	15.17	<0.1	0.85



- n-production dominated by Na & Al
- no (α-n) reactions in ^{28}Si & ^{16}O

^{228}Th chain

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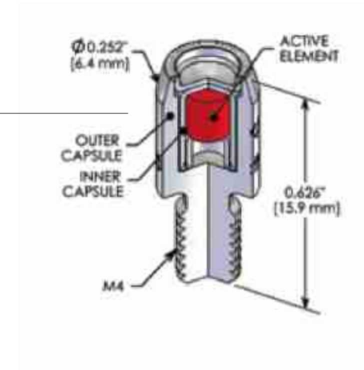

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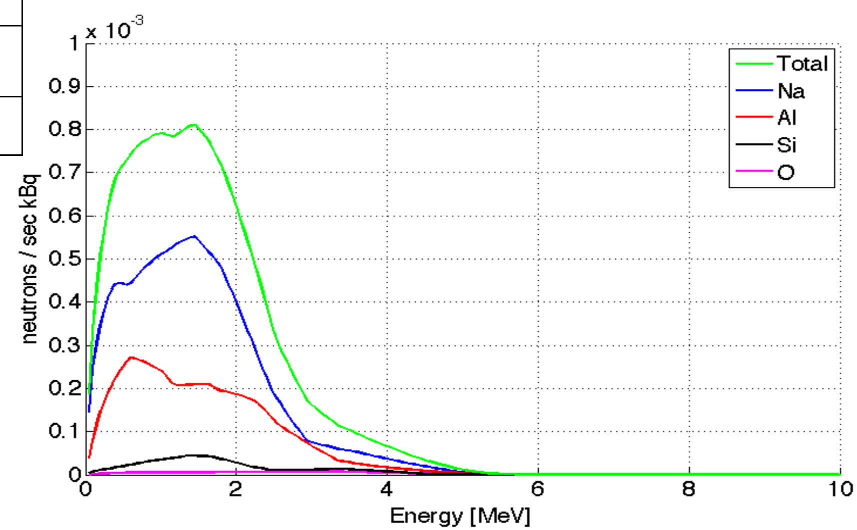

- n-production dominated by Na & Al
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Result for $NaAlSiO_2$ ceramic:
n rate = $3.8 \cdot 10^{-2}$ n/s/kBq
E_{mean} = 1.45 MeV

Commercial ^{228}Th source

MonteCarlo simulation

^{228}Th in parking position 350cm above Ge-array

B_0 ~ $1 \cdot 10^{-5}$ cts/(kg·y·keV·kBq) In an energy range: 1.5 -2.5 MeV

Example: 100kBq source → B_0 ~ **$1 \cdot 10^{-3}$ cts/(kg·y·keV)**

Background goal GERDA:

Phase I: **$1 \cdot 10^{-2}$ cts/(kg·y·keV)**
Phase II: **$1 \cdot 10^{-3}$ cts/(kg·y·keV)**
Phase III: **< $1 \cdot 10^{-4}$ cts/(kg·y·keV)**

Motivation for customized source

Basic concept:

Replace the ceramic by materials of high energy thresholds for (α-n) reactions

- Gold:
  → No oxidation
  → Threshold energy = 9.94 MeV > $E_{max}(\alpha)$
- Tungsten:
  → Threshold energy = 9.4 - 11.9 MeV > $E_{max}(\alpha)$
- ^{90}Zr:
  → Threshold energy = 7.95 MeV
  → Replacing $NaAlSiO_2$ ceramic by **ZrO_2** ceramic

Best candidate: Gold

- No (α-n) reactions
- easy to handle, Au-foils available
- chemically inert

Custom ^{228}Th source

Chemical treatment of a $ThCl_4$ solution on gold in collaboration with PSI, Villigen, CH

$3ThCl_4 + 16HNO_3 \rightarrow$ 200°C $\rightarrow$ $3Th(NO_3)_4$ + $4NOCl + 8H_2O + 4Cl_2$

in teflon crucible

In gold crucible

750 °C

Evaporation

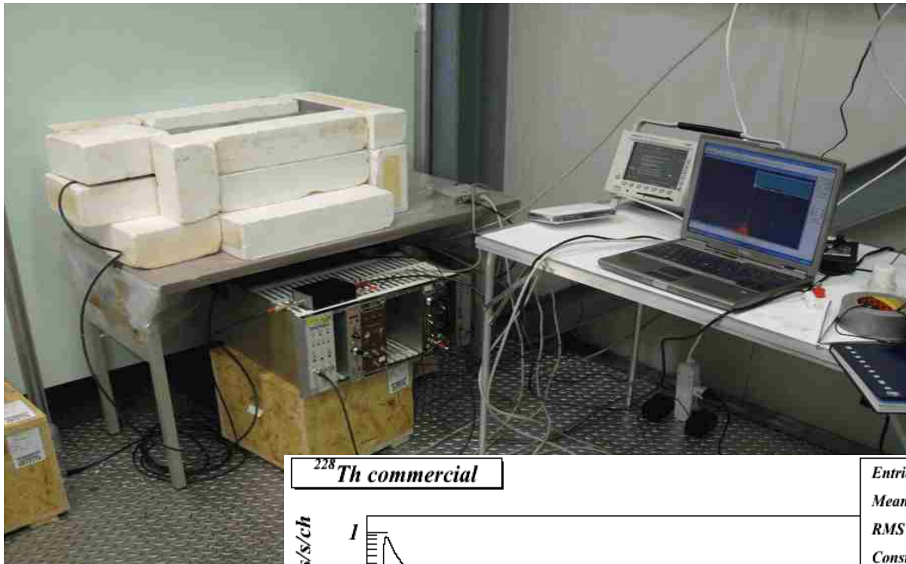
In gold crucible $3ThO_2$ + $12NO_2 + 3O_2$

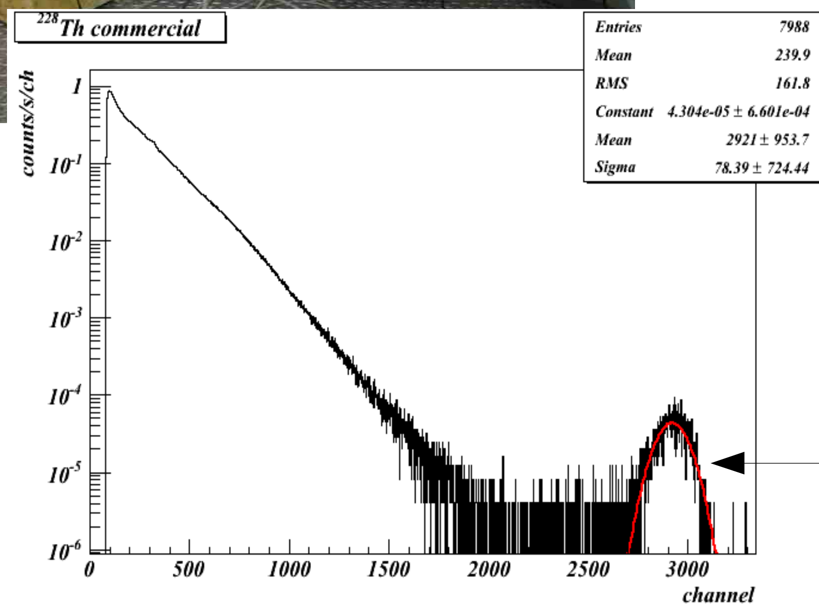
- ^{16}O: 99.757 %, E_{Th} = 15.171 MeV
- ^{17}O: 0.038 % , E_{Th} = < 0.1 MeV
- ^{18}O: 0,205 % , E_{Th} = 0.851 MeV

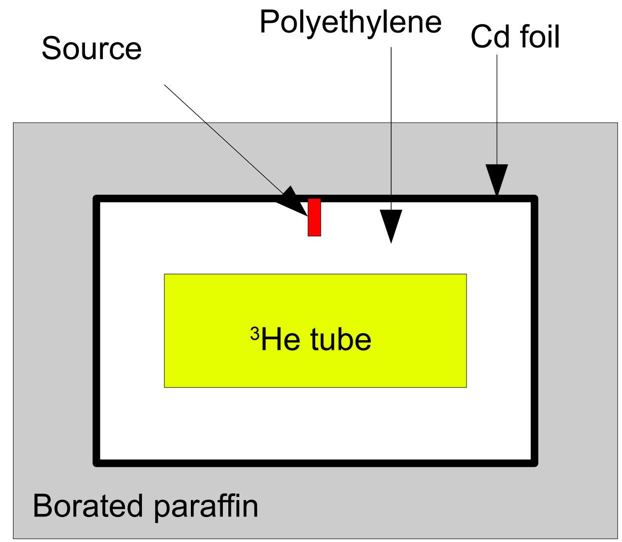
End product:
ThO_2 in goldfoil

Encapsulation at E&Z

Neutron measurements took place
at LNGS, 3800 m.w.e. with a ^{3}He counter







- Borated paraffin → n-thermalization+capturing
- Cd foil → capturing of therm. neutrons

⇩

Shielding against environmental neutrons

PE: thermalizes mainly neutrons from source
→ allows ^{3}He(n,p)^{3}H reaction at Q = 764 keV

Results & Conclusions

measured	Commercial ^{228}Th	Custom $^{228}ThO_2$
[n/s/kBq]	$(3.2+/-0.8)\cdot10^{-3}$	$(1.8+/-0.5)\cdot10^{-3}$

overestimation :12 :8

x4 underestimation

SOURCES calculations	^{228}Th in $NaAlSiO_2$	^{228}Th in Al_2O_3	$^{228}ThO_2$ (assuming a microscopic structure)
[n/s/kBq]	$3.8\cdot10^{-2}$	$2.6\cdot10^{-2}$	$5\cdot10^{-4}$

Real chemical composition of ceramic not known & depends on the company

Contribution of oxygen not known due to carrier material (Zr) & contaminations (Fe,...) in the $ThCl_4$ solution

solution: determine exact composition on the $ThCl_4$ solution

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Expected Background index
assuming 100 kBq source strength:

$1\cdot 10^{-4} – 5\cdot 10^{-5}$ counts/keV·kg·year

Phase I : $B \leq 1\cdot 10^{-2}$ counts/keV·kg·year

no danger

Phase II : $B \leq 1\cdot 10^{-3}$ counts/keV·kg·year

Phase III: $B \leq 1\cdot 10^{-4}$ counts/keV·kg·year

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Phase I : B ≤ $1\cdot10^{-2}$ counts/keV·kg·year — no danger

Phase II : B ≤ $1\cdot10^{-3}$ counts/keV·kg·year — potentially critical

Phase III: B ≤ $1\cdot10^{-4}$ counts/keV·kg·year

Results & Conclusions

measured	Commercial ^{228}Th	Custom $^{228}ThO_2$
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Phase II : $B \leq 1\cdot10^{-3}$ counts/keV·kg·year — potentially critical

Phase III: $B \leq 1\cdot10^{-4}$ counts/keV·kg·year — critical
Further n-reduction will be necessary

Thank You