Low-level techniques applied in experiments looking for rare events

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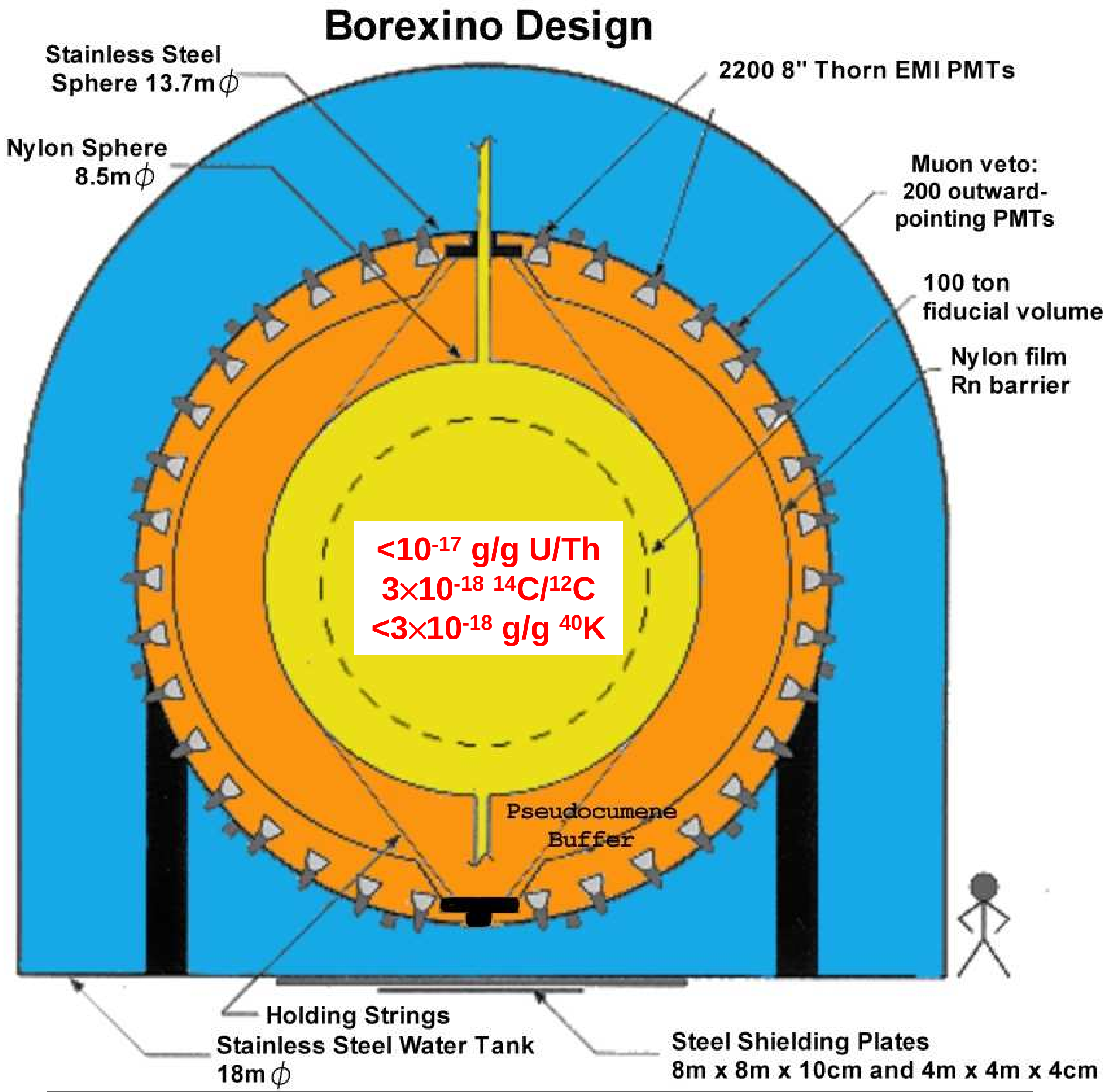


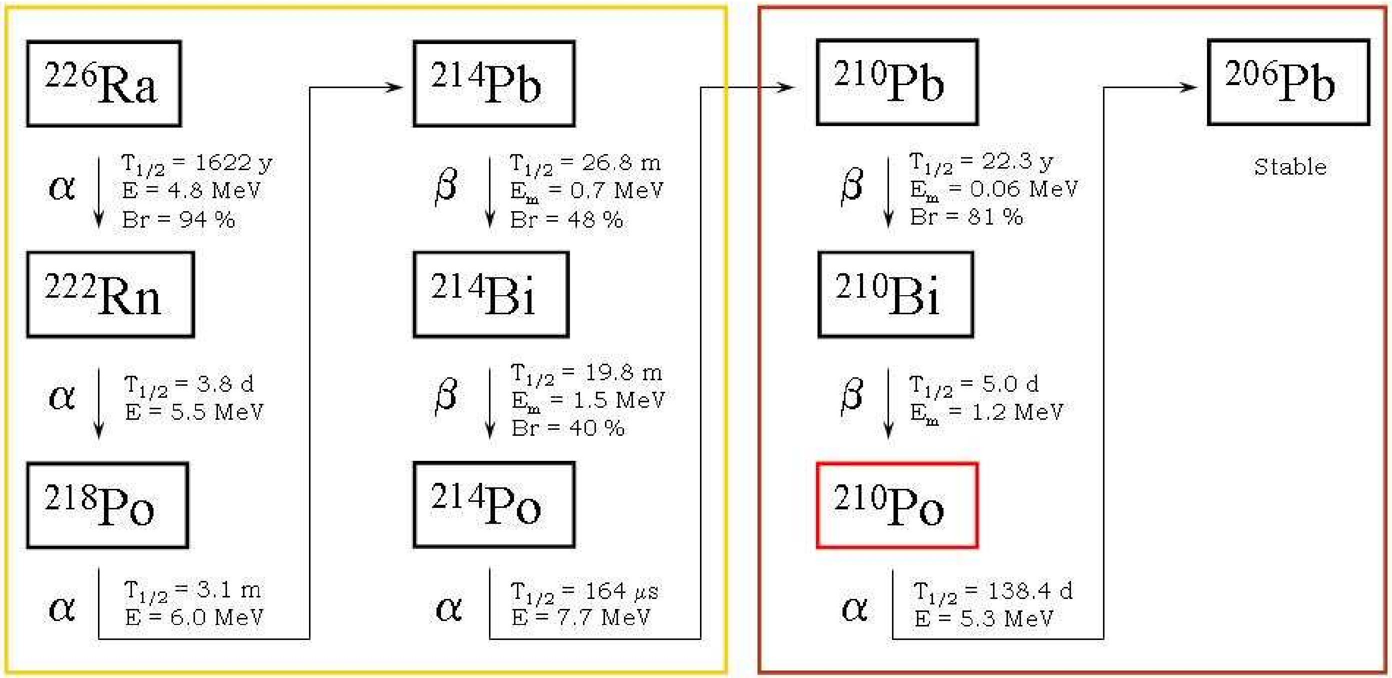
Borexino details: see the talks by G. Bellini and M. Pallavicini

Radon detection
Mass spectrometry
Germanium spectroscopy
Applications in Borexino
Applications in GERDA
Conclusions

1. Radon detection

Radon (^{222}Rn) and its daughters form one of the most dangerous sources of background in many experiments

- inert noble gas
- high diffusion and permeability
- belongs to the ^{238}U chain (present in any material)
- wide range of energy of emitted radiation (with the daughters)
- surface contaminations with radon daughters (heavy metals)
- broken equilibrium in the chain at ^{210}Pb level



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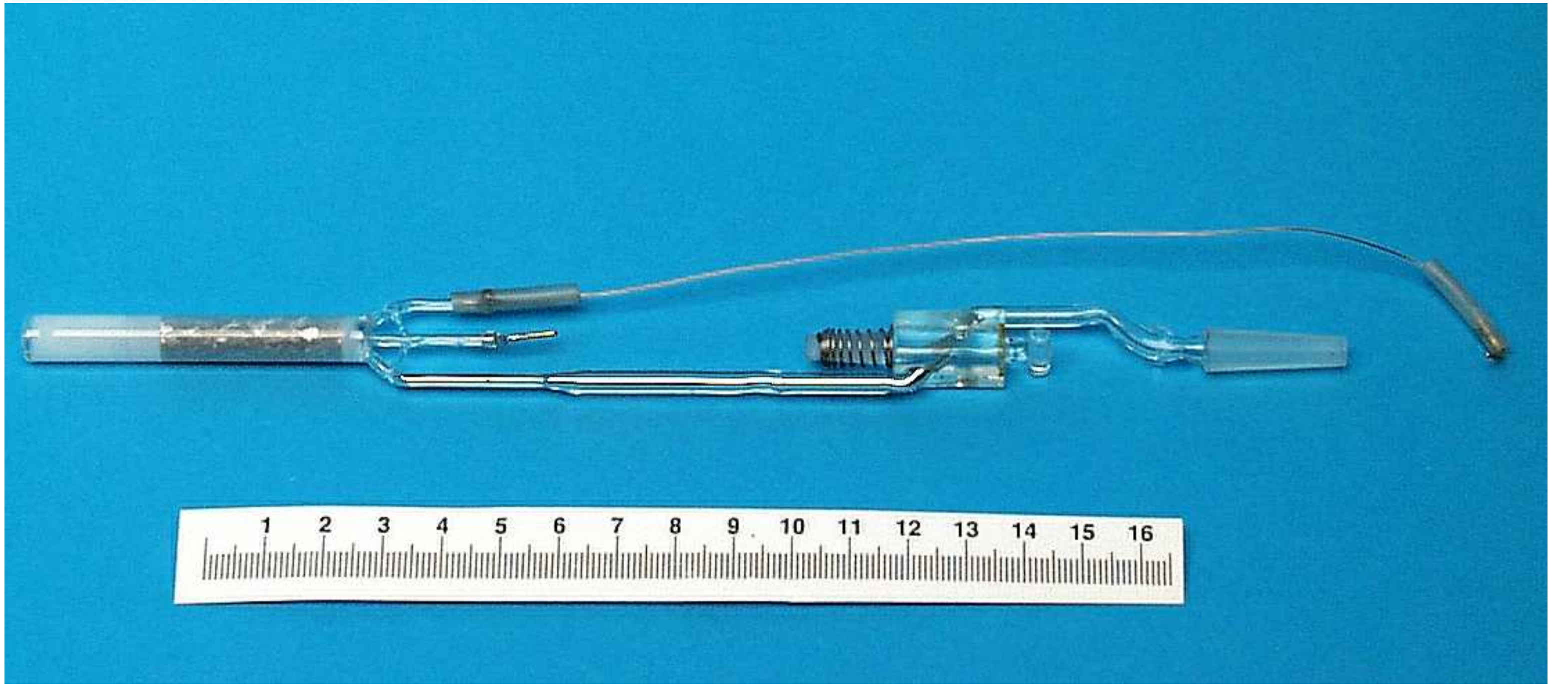
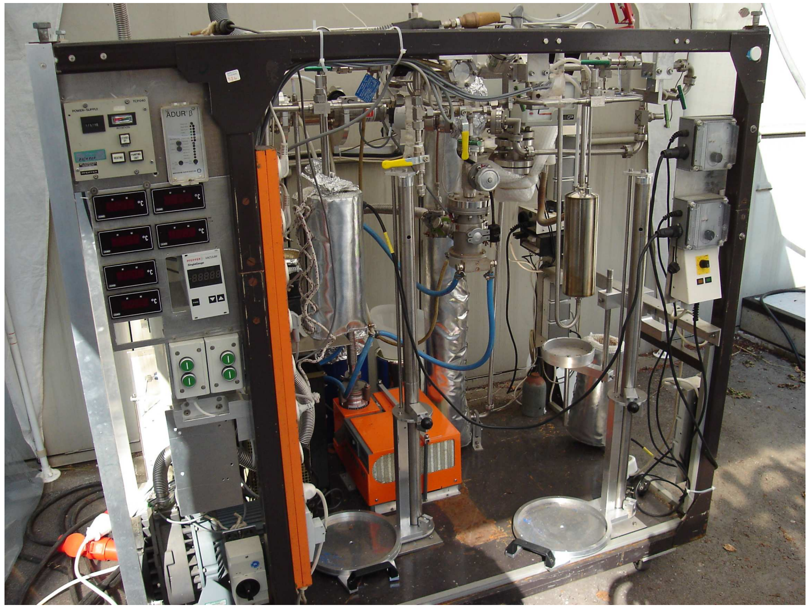
1. Radon detection

Proportional counters



- Developed for the GALLEX/GNO experiment
- Hand-made at MPIK (~ 1 cm^3 active volume)
- In case of ^{222}Rn only α-decays are detected
- 50 keV threshold
  - bcg: 0.1 – 2 cpd
  - total detection efficiency of ~ 1.5 (0.5/α)
- Absolute detection limit ~ 30 µBq (15 atoms)

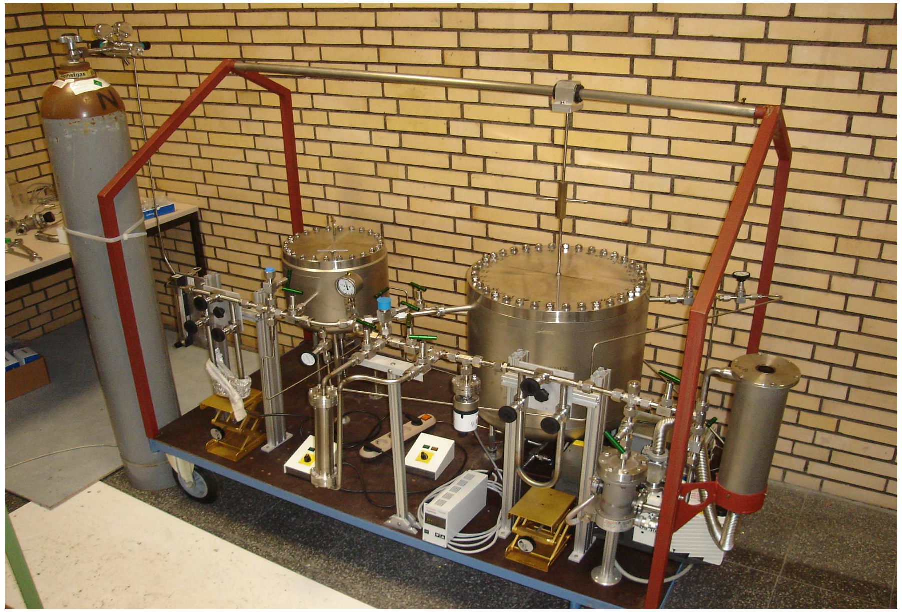
1. Radon detection



^{222}Rn in gases (N_2/Ar)

- ^{222}Rn adsorption on activated carbon
- several AC traps available (MoREx/MoRExino)
- pre-concentration from 100 – 200 m^3
- purification is possible (LTA)

^{222}Rn detection limit:
~0.5 µBq/m^3 (STP)
[1 atom in 4 m^3]



^{222}Rn emanation

- Emanation chambers
  - 20 l → 50 µBq
  - 80 l → 80 µBq
- Glass vials
  - 1 l → ~50 µBq

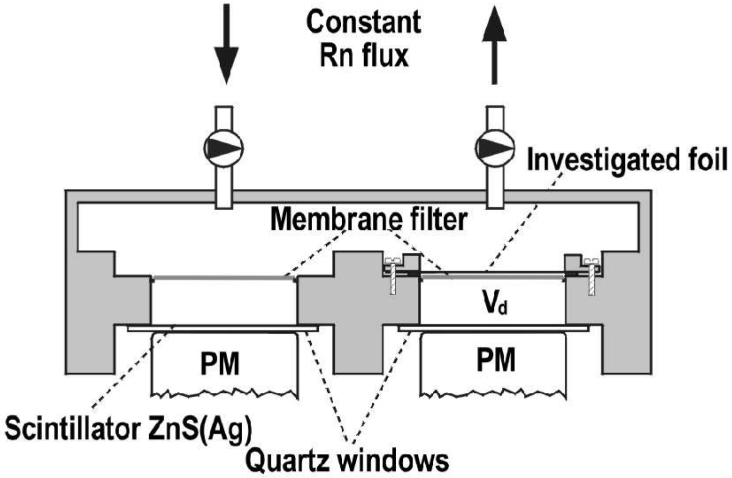
Absolute sensitivity
~100 µBq [50 atoms]

1. Radon detection

^{222}Rn/^{226}Ra in water

- ^{222}Rn extraction from 350 liters
- ^{222}Rn and ^{226}Ra measurements possible

^{222}Rn detection limit: ~0.1 mBq/m^3
^{226}Ra detection limit: ~0.8 mBq/m^3



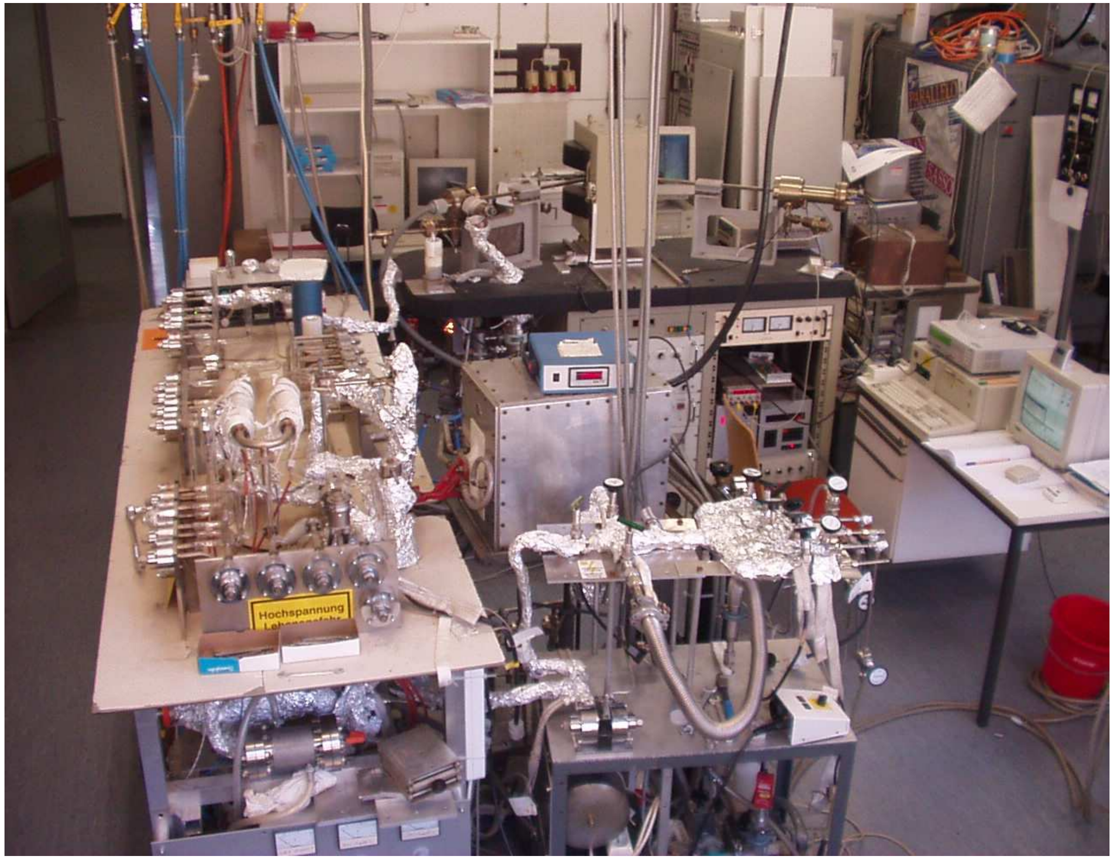
^{222}Rn diffusion in thin films

- Time dependent diffusion profile registered
- D reconstructed on the base of the mathematical model

Sensitivity ~ 10^{-13} cm^2/s

2. Mass spectrometry

Noble gas mass spectrometer



VG 3600 magnetic sector field spectrometer.

Used to investigate noble gases in the terrestial and extra-terrestial samples.

Adopted to test the nitrogen purity and purification methods.

Detection limits: Ar: 10^{-9} cm^3
Kr: 10^{-13} cm^3

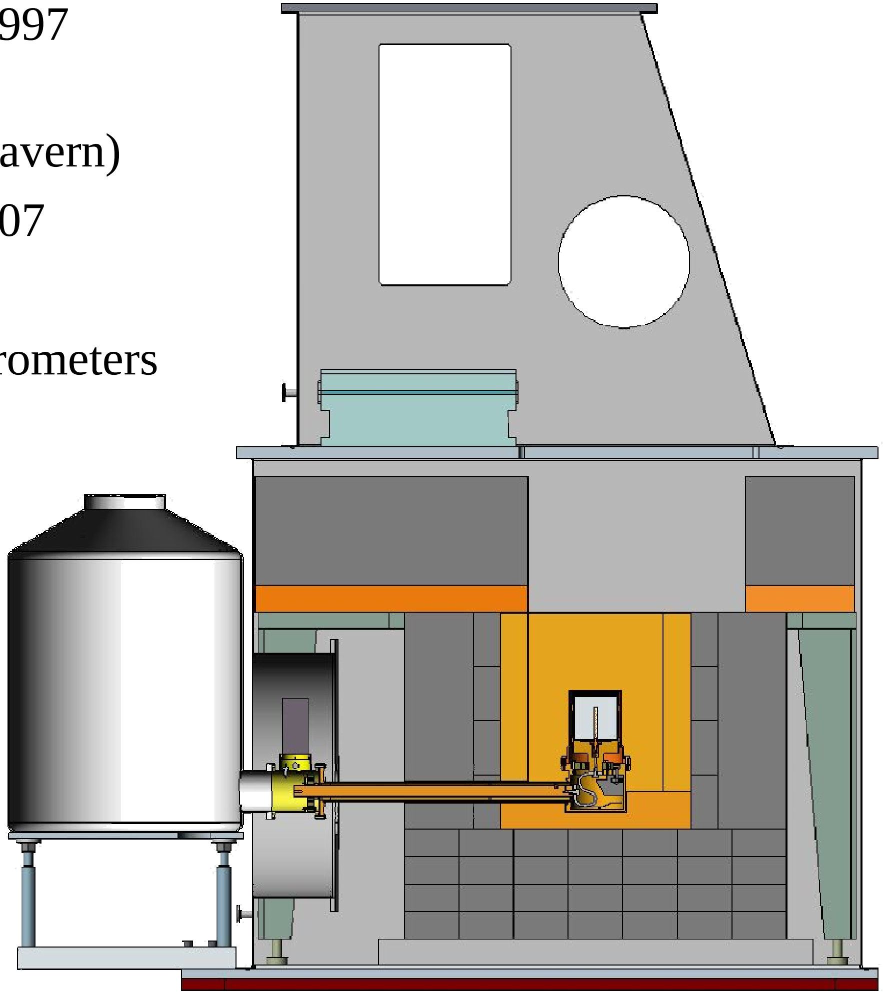
→

^{39}Ar: ~1.4×10^{-9} Bq/m^3 N_2 (STP)
^{85}Kr: ~1×10^{-7} Bq/m^3 N_2 (STP)

3. Germanium spectroscopy

GeMPIs at GS (3800 m w.e.)

- GeMPI I operational since 1997 (MPIK)
- GeMPI II built in 2004 (MCavern)
- GeMPI III constructed in 2007 (MPIK/LNGS)
- Worlds most sensitive spectrometers



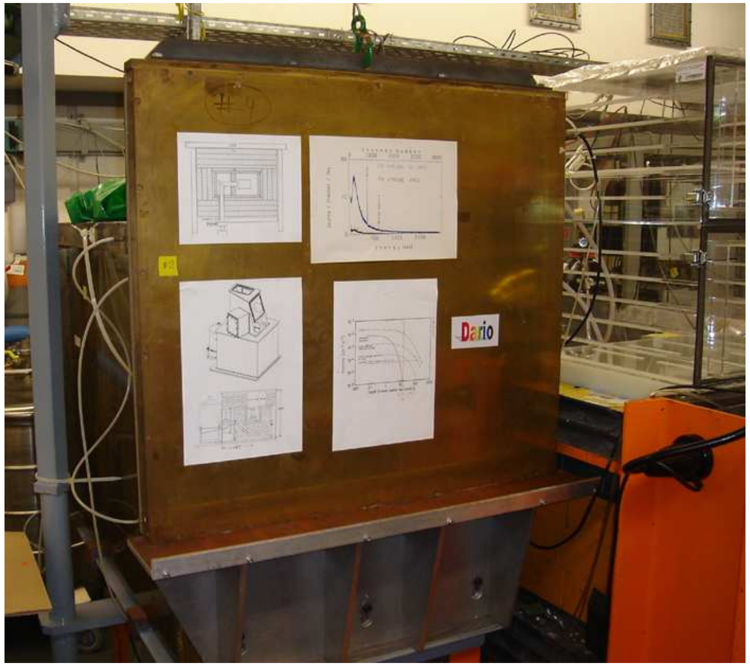
GeMPI I:

- Crystall: 2.2 kg, ε_r = 102 %
- Bcg. Index (0.1-2.7 MeV): 6840 cts/kg/year
- Sample chamber: 15 l

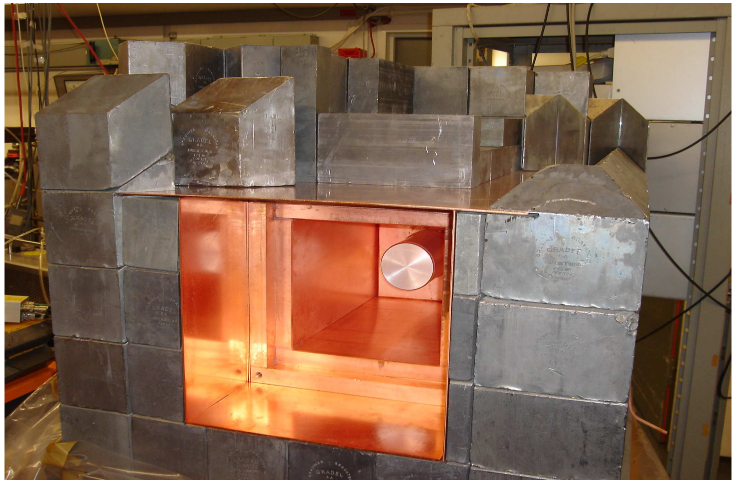
Sensitivity:
~10 µBq/kg

3. Germanium spectroscopy

Detectors at MPIK: Dario, Bruno and Corrado



MPIK LLL: 15 m w.e.



Sensitivity:
~1 mBq/kg

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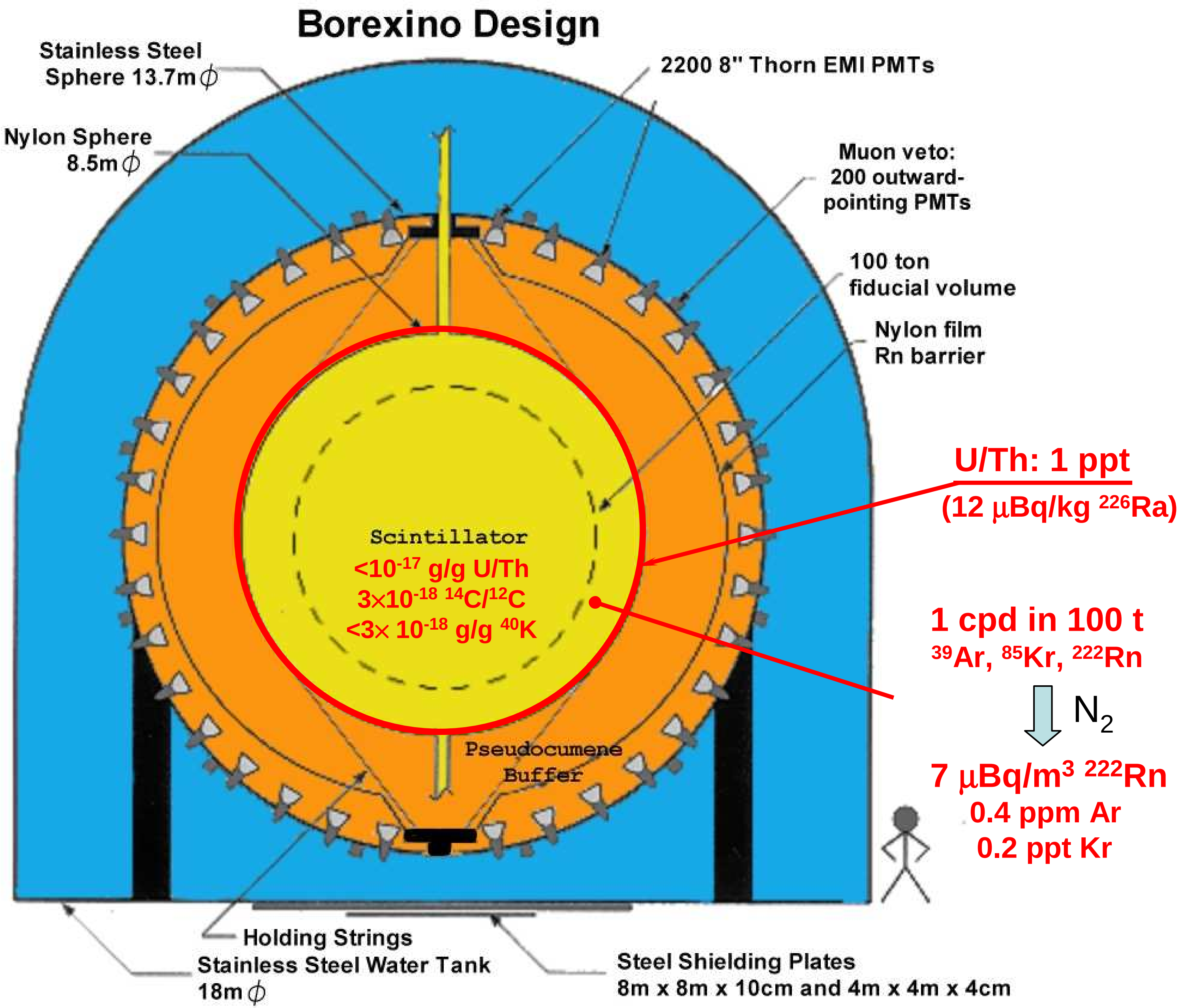
- Mass spectrometry
- Germanium spectroscopy
- **Applications in Borexino**
- Applications in GERDA
- Conclusions



5. Applications in Borexino - ^{226}Ra in the nylon foil

Borexino nylon foil

1 ppt U required
(~12 μBq/kg for ^{226}Ra)

D_{dry} = 2x10^{-12} cm^2/s (d_{dry} = 7 μm)
D_{wet} = 1x10^{-9} cm^2/s (d_{wet} = 270 μm)

$A_{dry} = A_{sf} + 0.14 \cdot A_{bulk}$
$A_{wet} = A_{sf} + A_{bulk}$

Separation of the bulk and surface ^{226}Ra conc. was possible through ^{222}Rn emanation

Very sensitive technique:
(C_{Ra} ~ 10 μBq/kg)

Bx IV foil: bulk ≤ 15 μBq/kg
surface ≤ 0.8 μBq/m^2
total = (16 ± 4) μBq/kg (1.3 ppt U eqiv.)

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5. Applications in Borexino – nitrogen

Regular Purity Nitrogen:
- Technical 4.0 quality, not purified
- Production rate up to 100 m3/h (STP)
- ^{222}Rn ~ 50 µBq/m^3, Ar ~ 10ppm, Kr ~ 30 ppt

High Purity Nitrogen:
- ^{222}Rn adsorption on charcoal (LTA)
- Achieved concentration < 0.3 µBq/m^3
- Production rate up to 100 m^3/h (STP)
-Ar and Kr not removed

LAK (Low Ar and Kr) Nitrogen:
- Spec. Ar < 0.4 ppm, Kr < 0.2 ppt
  ^{222}Rn < 7 µBq/m^3
- Purification by adsorption on different materials extensively studied (successfully!)
- Cooperation with companies on the nitrogen survey
- Tests of the nitrogen delivery chain

Nitrogen survey

Nitrogen sample	C_{Ar} [ppm]	C_{Kr} [ppt]
MESSER (4.0)	200 ± 30	1680 ± 240
Air Liquide (4.0)	11.0 ± 1.3	40 ± 5
Linde AG, (7.0)	0.031 ± 0.004	2.9 ± 0.4
SOL (6.0)	0.0063 ± 0.0006	0.04 ± 0.01
Westfalen AG (6.0)	0.00050 ± 0.00008	0.06 ± 0.02
Goal (BOREXINO)	< 0.4	< 0.2

Tests of the delivery chains

Supplier/setup	C_{Rn} [µBq/m^3]	C_{Ar} [ppm]	C_{Kr} [ppt]
Linde AG, 3-m^3 movable tank	1.2	0.018	0.06
SOL, 16-m^3 tank	8	0.012	0.02

5. Applications in Borexino – nitrogen

LAK Nitrogen tank installed at Gran Sasso

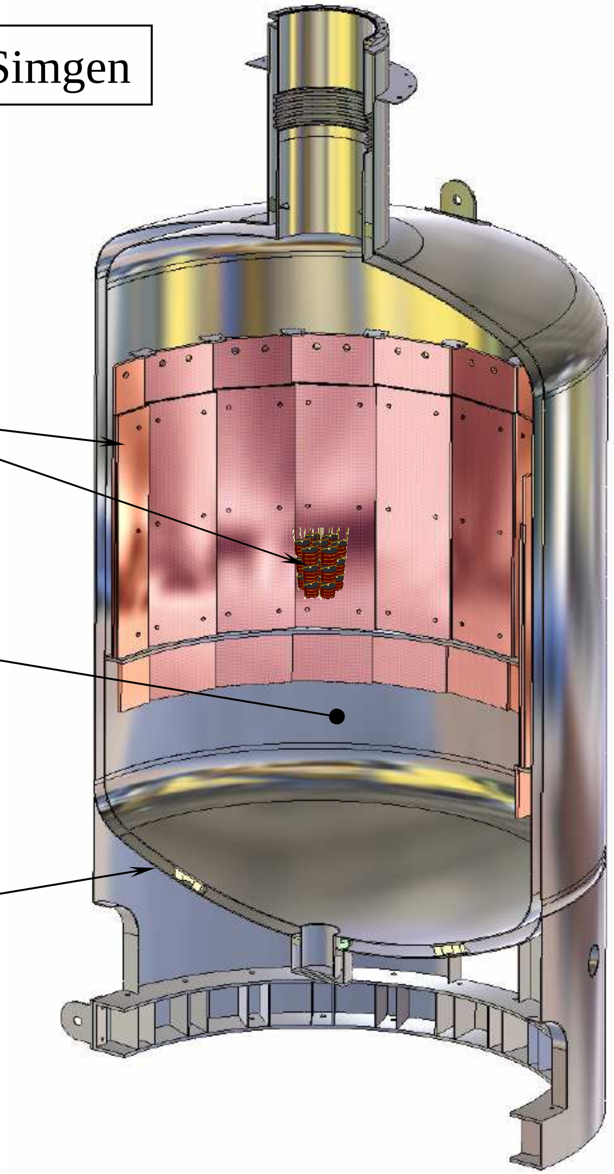
6. Applications in GERDA

GERDA details: see the talk by H. Simgen

Additional inner copper shield
detectors holders
U/Th ≤ 16 µBq/kg
clean surface

Liquid argon
^{222}Rn ≤ 1 µBq/m^3

Vacuum-insulated double
wall stainless steel cryostat
U/Th ≤ 5 – 10 mBq/kg
clean surface



6. Applications in GERDA – argon purity

^{222}Rn in argon (GERDA goal: $C_{Rn} \leq 1\ \mu Bq/m^3$)

Quality	**Company**	**Sample size [m^3]**	**C_m [mBq/m^3]**	**C_f [mBq/m^3]**
4.6	Westfalen	117	2.9 ± 0.2	>8
4.8	Air Liquide	80	0.27 ± 0.02	0.4
5.0	Westfalen	200	6.0 ± 0.1	8.4
5.0	Air Liquide (GS)	5	0.25 ± 0.04	0.3
6.0	Westfalen	104	0.11 ± 0.01	0.4

^{222}Rn in nitrogen

Quality	**Company**	**Sample size [m^3]**	**C_m [$\mu Bq/m^3$]**	**C_f [$\mu Bq/m^3$]**
4.5 – 5.0	Messer/Air Liquide	40	30 – 70	---
6.0 (7.0)	Linde	150	0.7 ± 0.2	1
6.0	SOL	100	15 ± 1	17

Argon purification required. In the gas phase requested purity achieved ($C_{Rn} \leq 0.5\ \mu Bq/m^3$), adsorption for liquid phase under investigations.

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6. Applications in GERDA – steel screening

GERDA goal for U/Th: ≤ 5 – 10 mBq/kg

No.	Specific activity [mBq/kg]			
	^{228}Th	^{226}Ra	^{40}K	^{60}Co
1 D	5.1 ± 1.0	2.9 ± 1.0	< 3.9	6.5 ± 0.5
2 G	< 0.27	< 0.35	< 1.1	13.0 ± 0.6
3 D	1.1 ± 0.4	< 0.84	< 3.3	15.1 ± 0.5
4 D	< 2.6	< 2.2	< 6.2	14.4 ± 1.0
5 D	< 1.1	< 1.2	< 2.8	11.6 ± 0.5
6 D	< 0.8	< 0.6	< 1.7	16.7 ± 0.4
7 G	< 0.20	< 1.3	< 2.8	45.5 ± 2.1
8 G	< 0.11	< 0.24	< 0.93	14.0 ± 0.1
9 G	< 0.41	< 0.74	< 1.1	13.8 ± 0.7
10 G	< 1.0	< 1.3	< 6.8	17.1 ± 0.7
11 G	1.5 ± 0.2	1.0 ± 0.6	< 0.81	18.3 ± 0.7

(SS 1.4571)

Radon detection

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6. Applications in GERDA – copper cleaning

^{222}Rn daughters on copper surface

- Screening of ^{210}Po with an alpha spectrometer
  50 mm Si-detector, bcg ~ 5 α/d (1-10 MeV)
  sensitivity ~ 20 mBq/m^2 (100 mBq/kg, ^{210}Po)
- Screening of ^{210}Bi with a beta spectrometer
  2$\times$50 mm Si(Li)-detectors, bcg ~ 0.18/0.40 cpm
  sensitivity ~ 10 Bq/kg
- Screening of ^{210}Pb (46.6 keV line) with a gamma spectrometer
  25 % - n-type HPGe detector with an active and a passive shield
  sensitivity ~ 20 Bq/kg
- Only small samples can be handled – artificial contamination needed: e.g. discs loaded with ^{222}Rn daughters

Copper cleaning tests

- Etching removes most of ^{210}Pb and ^{210}Bi (> 98 %) but **not** ^{210}Po
- Electropolishing is more effective for all elements but proper conditions have to be found (e.g. ^{210}Po reduction from 30 up to 200)

Etching: 1% H_2SO_4 + 3% H_2O_2 Electropolishing: 85 % H_3PO_4 + 5 % 1-butanol

7. Conclusions

- Low-level techniques have “natural” applications in experiments looking for rare events (low-energy neutrinos, neutrino-less double beta decay, search for dark matter/proton decay…)
- Several detectors and experimental methods were developed allowing measurements even at a single atom level
- Described experimental methods were very successfully applied in the Borexino experiment (very low background achieved) and can be adopted in other projects

  - material screening

  - purification and cleaning techniques

  - study of noble gases

6. Applications in GERDA – argon purificaion

^{222}Rn removal from gaseous/liquid argon
150 g- (gas phase) and 60 g-AC traps (liquid phase) used

Quality	Sample size [m³]	C_1 [mBq/m³]	C_2 [mBq/m³]	Red. factor [1/kg]	Remarks
4.6	141	0.20 ± 0.02	< 0.0005	> 2700	Gas phase
4.8	80	0.27 ± 0.02	0.0007 ± 0.0003	2500	Gas phase
4.6	67	0.050 ± 0.003	0.0020 ± 0.0005	420	Liquid phase
4.6	77	0.056 ± 0.004	0.0027 ± 0.0006	370	Liquid phase
4.8	140	0.20 ± 0.01	0.005 ± 0.001	640	Liquid phase
4.8	48	0.14 ± 0.01	0.003 ± 0.001	700	Liquid phase
5.0	200	6.0 ± 0.1	0.60± 0.02	170	Liquid phase
6.0	104	0.11 ± 0.01	0.006± 0.001	305	Liquid phase

Required reduction factor for GERDA: O(500)