Experience of gas purification and radon control in BOREXINO

G. Zuzel

Jagiellonian University, Cracow, Poland

on behalf of the Borexino collaboration

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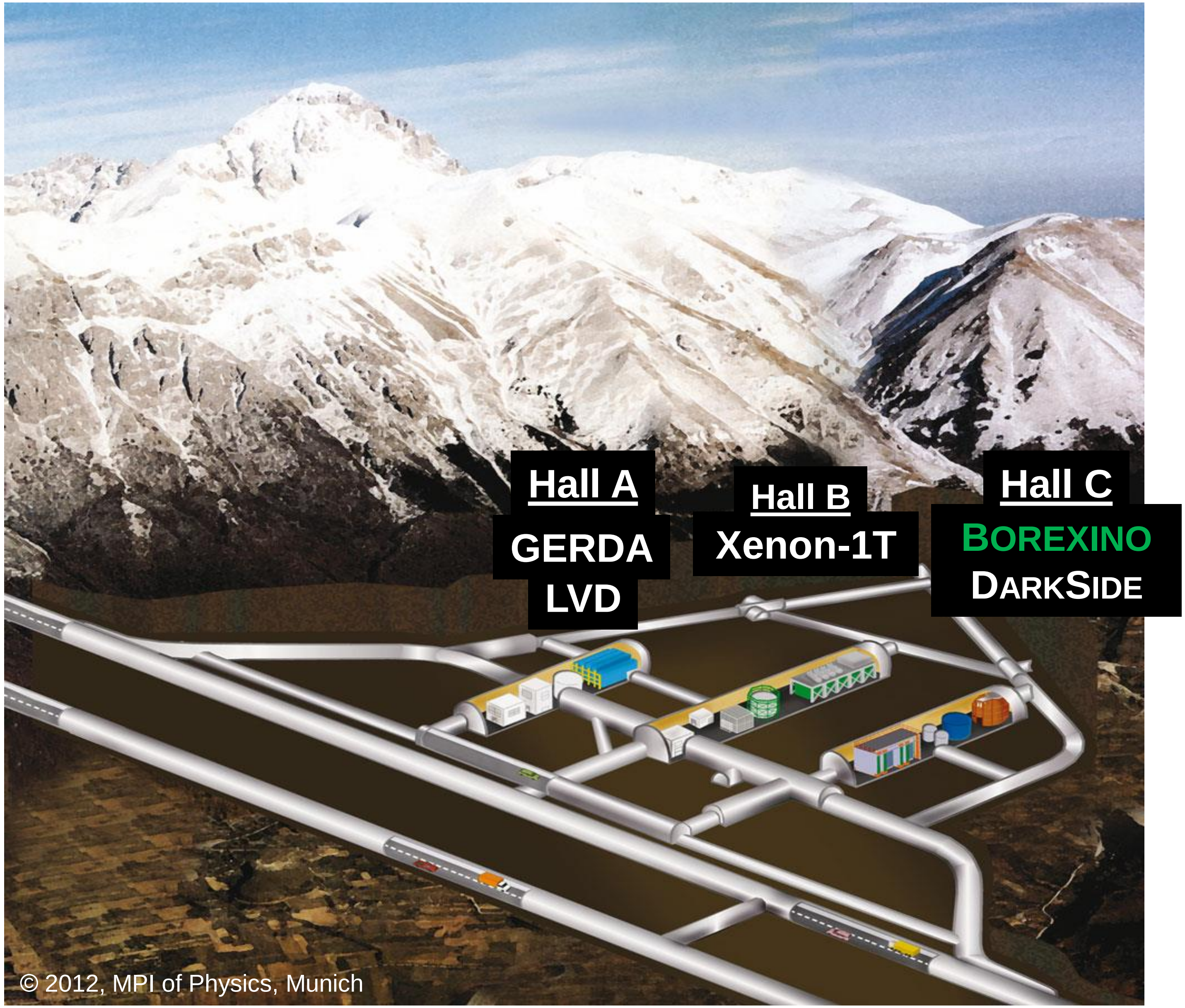
Outline

- BOREXINO
- ^{222}Rn control
- Purification of nitrogen
- Summary

BOREXINO at LNGS

- **BOREXINO**
- ^{222}Rn control
- N_2 purification
- Summary



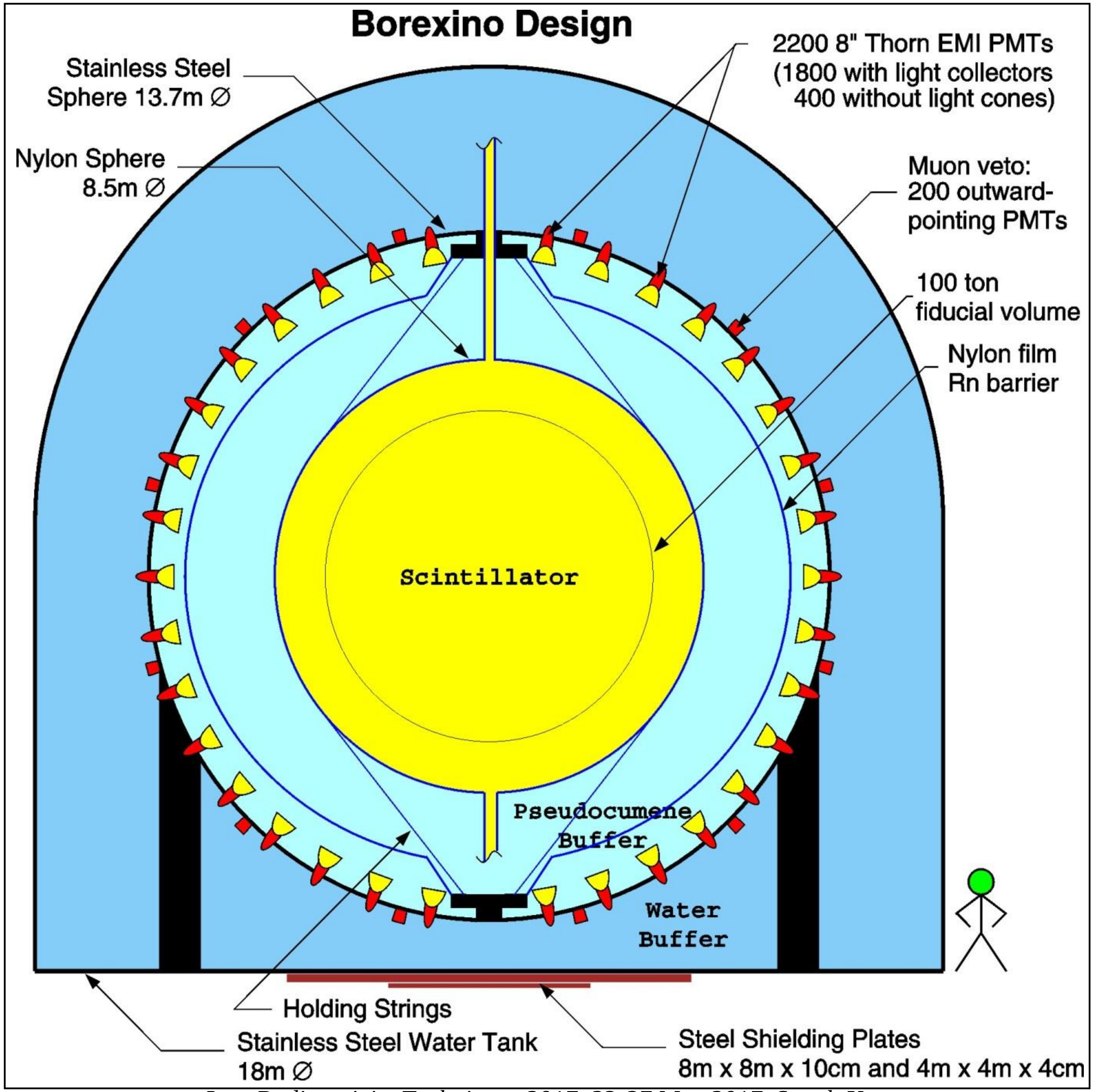
BOREXINO design

BOREXINO

^{222}Rn control

N_2 purification

Summary



BOREXINO radio-purity

BOREXINO
^{222}Rn control
N_2 purification
Summary

In a nutshell: the radio-purest detector ever built

Isotope	Specification for LS	Before purification	After purification
^{238}U	$\leq 10^{-16}$ g/g	$(5.3 \pm 0.5)\cdot 10^{-18}$ g/g	**$< 0.8\cdot 10^{-19}$ g/g**
^{232}Th	$\leq 10^{-16}$ g/g	$(3.8 \pm 0.8)\cdot 10^{-18}$ g/g	**$< 1.0\cdot 10^{-18}$ g/g**
^{14}C/^{12}C	$\leq 10^{-18}$	$(2.69 \pm 0.06)\cdot 10^{-18}$ g/g	unchanged
^{40}K	$\leq 10^{-18}$ g/g	$\leq 0.4\cdot 10^{-18}$ g/g	unchanged
^{222}Rn	$\leq$ 1 cpd/100 t	see ^{238}U	see ^{238}U
^{85}Kr	$\leq$ 1 cpd/100 t	(30 ± 5) cpd/100 t	$\leq$ 5 cpd/100 t
^{39}Ar	$\leq$ 1 cpd/100 t	<< ^{85}Kr	<< ^{85}Kr
^{210}Po	not specified	~ (70) 1 dpd/100 t	unchanged
^{210}Bi	not specified	(20) 70 dpd/100 t	**(20 ± 5) cpd/100 t**

Sources of ^{222}Rn in BOREXINO

BOREXINO

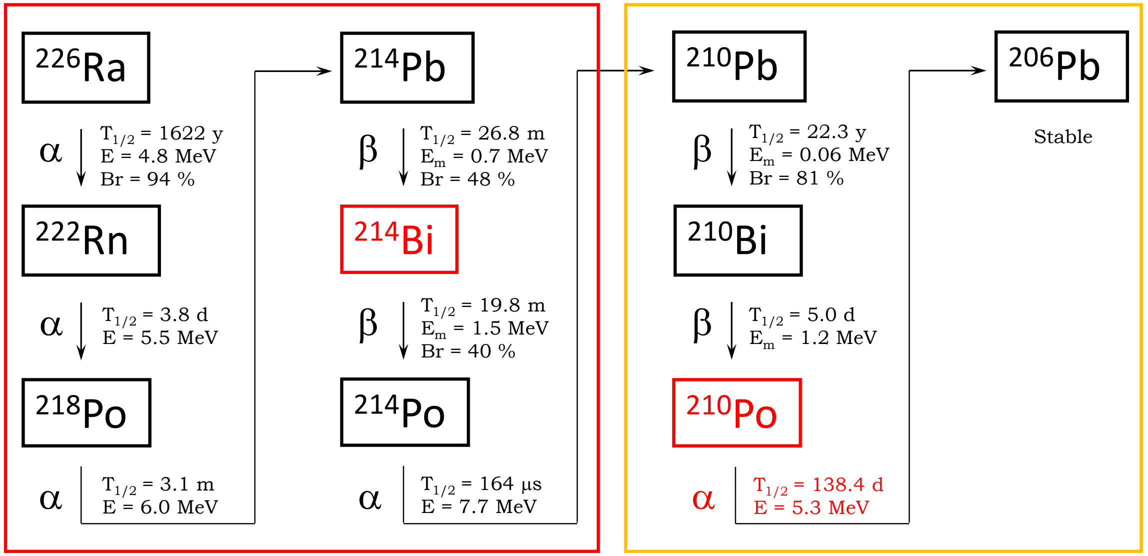
^{222}Rn control

N_2 purification

Summary

- All external systems wetted by LS and nitrogen (LS storage tanks, LS purification systems: water extraction column, stripping column, nitrogen lines, *etc.*)
- Emanation from the Stainless Steel Sphere and from the PMTs
- Emanation from the nylon scintillator vessel
- Nitrogen

Decays of ^{222}Rn and it short-lived daughters can directly contribute to the detector's background, but even more important is the accumulation of the long-lived ^{210}Pb (followed by ^{210}Bi and ^{210}Po) in the scintillator.



Control of ^{222}Rn in BOREXINO

- Check of all subsystems for ^{222}Rn emanation (extensive screening campaign)
- Minimization of ^{222}Rn diffusion through the Inner Vessel (identification of material with low diffusion coefficient) + installation of the Rn barrier
- Identification of the IV material with sufficiently low ^{226}Ra content (12 μBq/kg)
- Nitrogen purification

Detection of ^{222}Rn – counters

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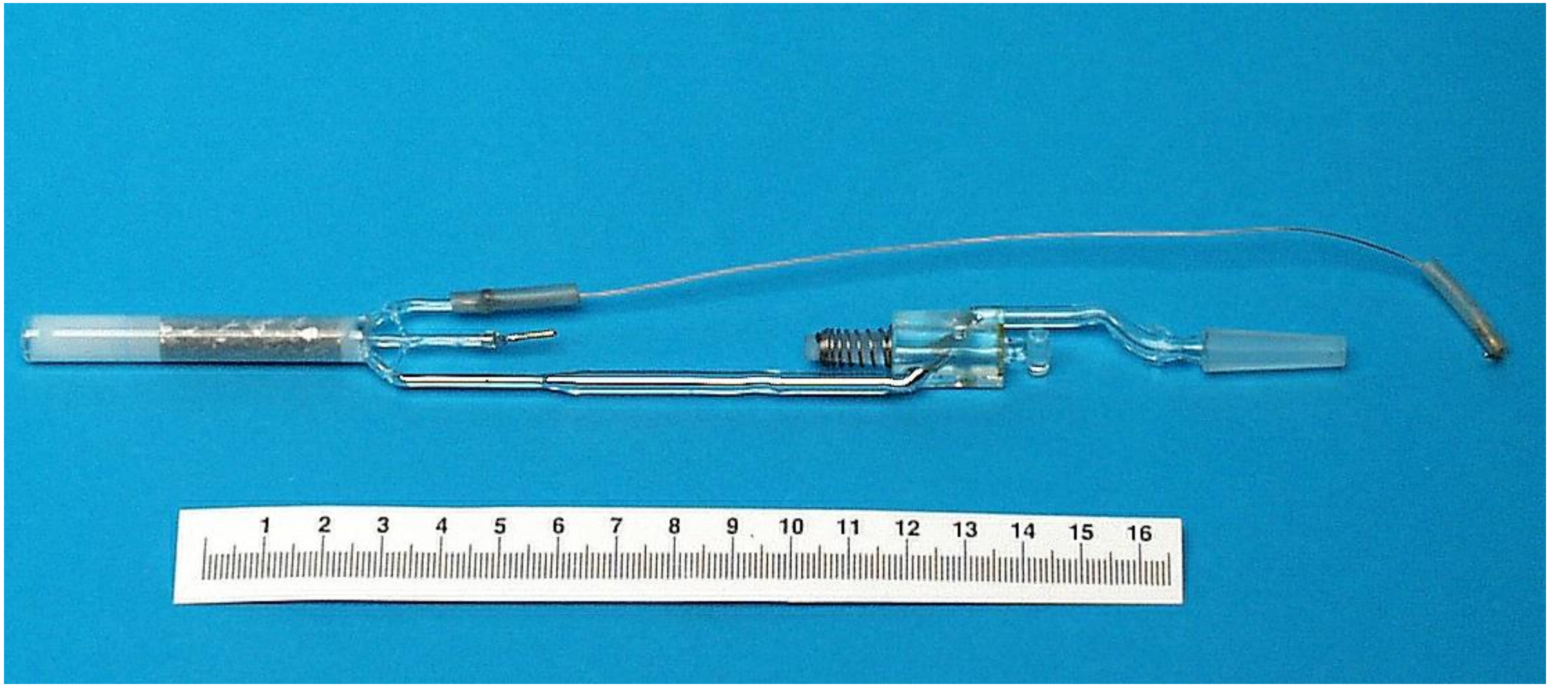
^{222}Rn control

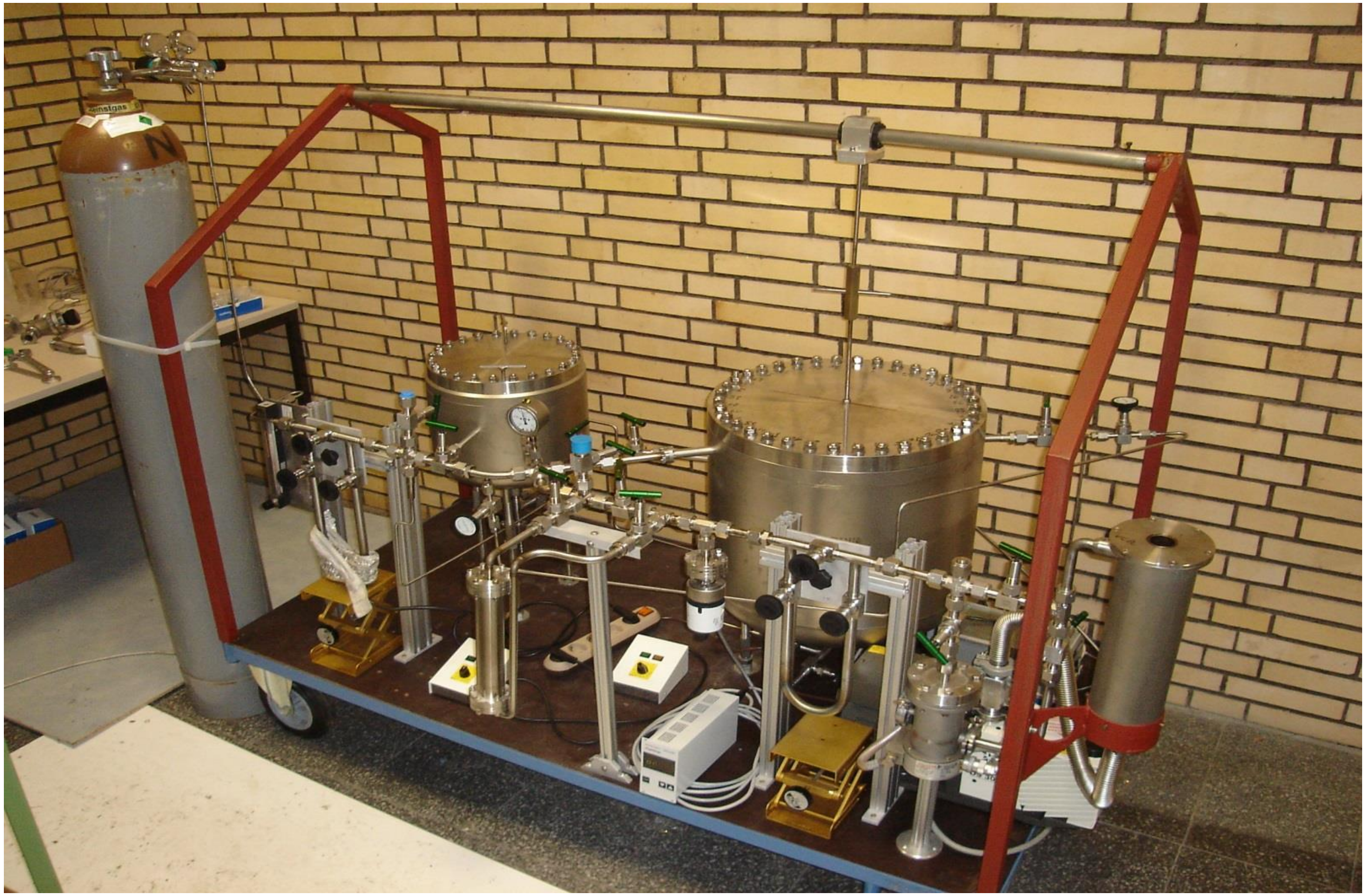
N_2 purification

Summary



- Developed for the GALLEX/GNO experiment
- Hand-made at MPI-K (~ 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
- **Absolute detection limit ~ 30 µBq (15 atoms)**

^{222}Rn emanation (MPI-K)



Blanks:
20 l → 50 μBq
80 l → 80 μBq

Absolute sensitivity
~100 μBq [50 atoms]

Appl. Rad. Isot. 53 (2000) 371

^{222}Rn emanation: examples

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^{222}Rn control

N_2 purification

Summary

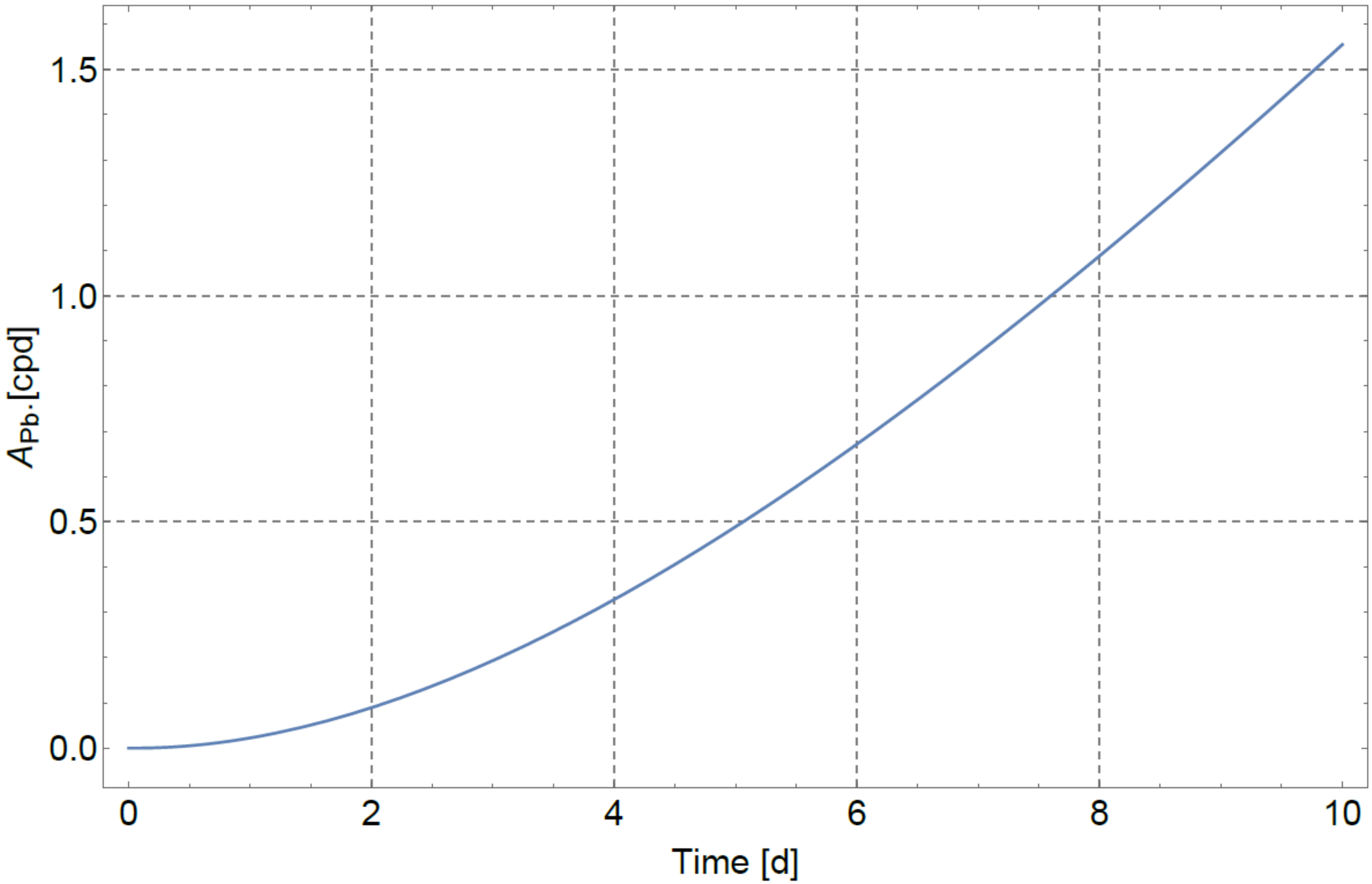
System	Sample	Description	^{222}Rn em. rate
LS storage area	SS vessel TK1	114 m^3	< 60 mBq
	SS vessel TK2	114 m^3	(45 ± 8) mBq
	SS vessel TK3	114 m^3	(24 ± 5) mBq
N_2 distribution line	Electrical heater		(0.92 ± 0.29) mBq
	Particle Filter		(0.34 ± 0.13) mBq
	1.5" distrib. line	~ 100 m long	(0.47 ± 0.13) mBq
LS purification plant	SS package	25 m^2	< 0.12 mBq
	H_2O extraction column + 24 SS packages	0.6 m^3 / 608 m^2	(4.83 ± 0.70) mBq
	N_2 sparging column + 26 SS packages	0.2 m^3 / 280 m^2	(1.78 ± 0.21) mBq

Over 1000 entries in the DB!

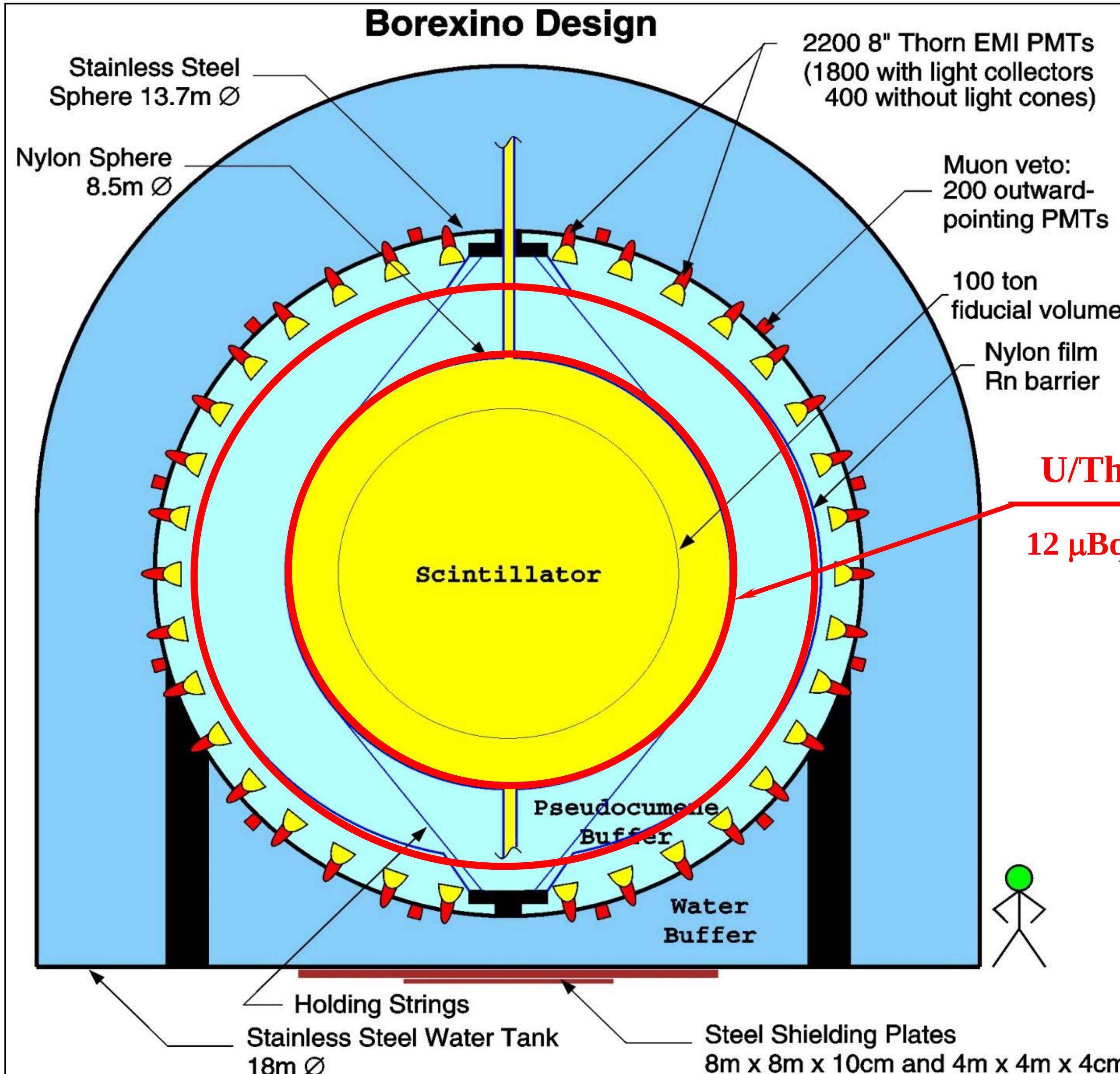
Astroparticle Physics 18 (2002) 1
LRT 2004 proceedings, p. 141 – 149
Int. J. Mod. Phys. A29 (2014) 1442009

^{222}Rn emanation: examples

Expected ^{210}Pb activity in 100 ton of the BOREXINO scintillator as a function of the storage time in a tank with the ^{222}Rn emanation rate of 40 mBq. 1 cpd of ^{210}Pb is reached already after 7.5 d.



BOREXINO design



U/Th: ~1 ppt

12 μBq/kg ^{226}Ra

^{222}Rn diffusion

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^{222}Rn control
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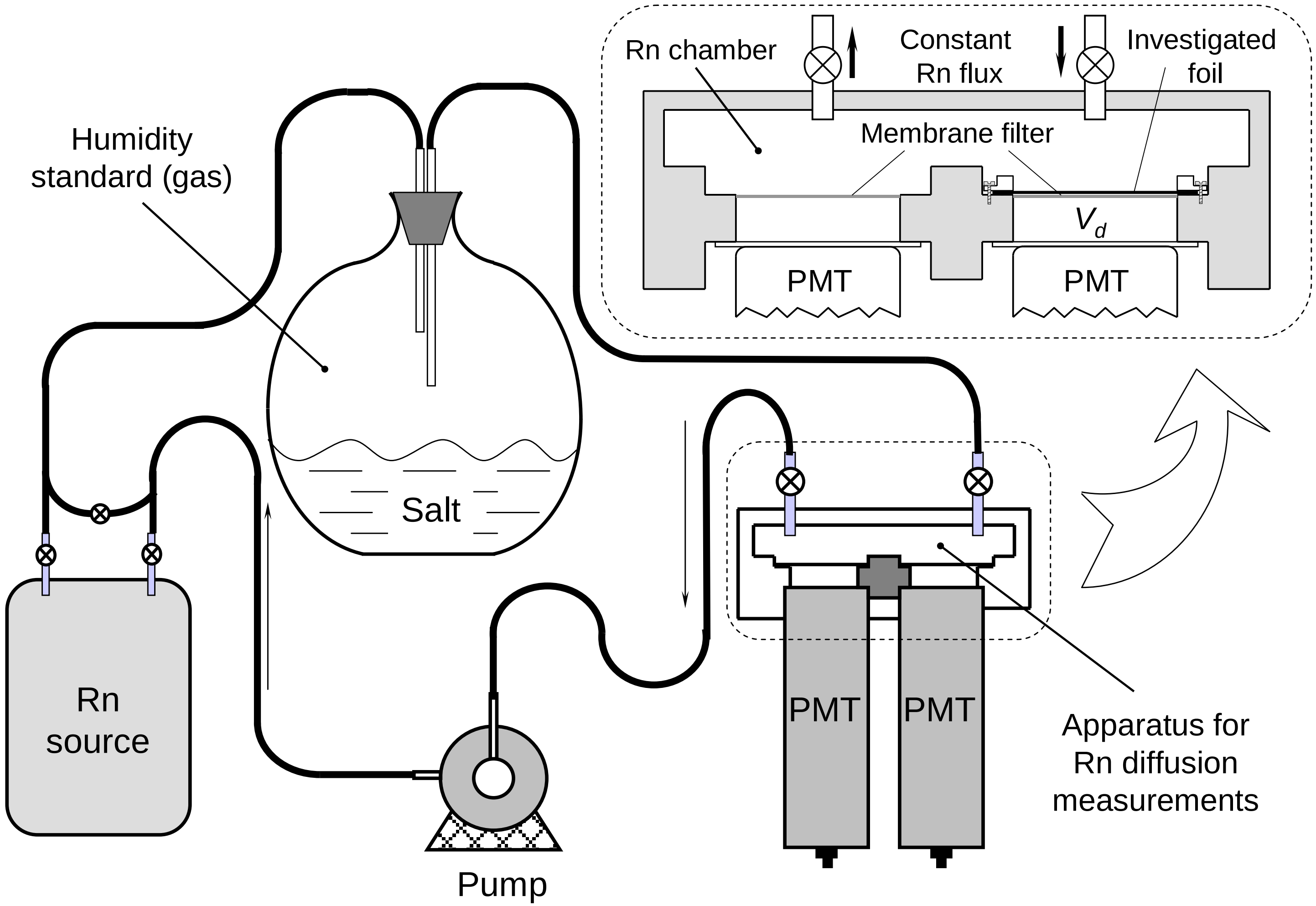
Summary



Sensitivity: D ~ 10^{-13} cm^2/s
d_e ~ 2 μm

^{222}Rn diffusion

Results obtained for the 0.018 mm thick C38F film (BOREXINO)

RH standard salt	RH in gas phase (%)	Water amount in nylon, M (%)	Diffusion coefficient, D (cm^2/s)	Solubility, S
$Mg(ClO_4)_2$	~ 0	~ 0	$(2.1 \pm 0.4) \times 10^{-12}$	4.5 ± 0.7
$H_3PO_4 \cdot \frac{1}{2}H_2O$	9 ± 1	0.72 ± 0.04	$(2.3 \pm 0.3) \times 10^{-12}$	2.5 ± 0.3
$LiCl_2 \cdot H_2O$	12 ± 1	0.87 ± 0.04	$(2.2 \pm 0.3) \times 10^{-12}$	2.2 ± 0.3
$CaCl_2 \cdot 6H_2O$	32 ± 2	2.09 ± 0.04	$(4.3 \pm 0.5) \times 10^{-12}$	1.8 ± 0.2
$Na_2Cr_2O_7 \cdot 2H_2O$	52 ± 2	3.74 ± 0.05	$(1.9 \pm 0.3) \times 10^{-11}$	1.4 ± 0.2
$Na_2S_2O_3 \cdot 5H_2O$	76 ± 2	6.35 ± 0.05	$(6.5 \pm 0.9) \times 10^{-11}$	1.5 ± 0.2
K_2CrO_4	88 ± 3	7.60 ± 0.05	$(1.3 \pm 0.2) \times 10^{-10}$	1.5 ± 0.2
$Na_2SO_4 \cdot 10H_2O$	93 ± 3	9.12 ± 0.07	$(3.3 \pm 0.4) \times 10^{-10}$	1.0 ± 0.1
H_2O vapors	100 ± 3	10.14 ± 0.09	$(1.3 \pm 0.2) \times 10^{-9}$	0.7 ± 0.1

There is 3 orders of magnitude difference between the diffusion in the dry and in the foil saturated with water!

Nucl. Instr. Meth. A 449 (2000) 158
Nucl. Instr. Meth. A 524 (2004) 355

$$d_e = \sqrt{\frac{D}{\lambda}} \qquad d_e^d = 7\,\mu m \qquad d_e^w = 270\,\mu m$$

^{226}Ra in/on BOREXINO nylon

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^{222}Rn control

N_2 purification

Summary

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

$D_{dry} = 2\times10^{-12}$ cm^2/s (d_{dry}= 7 µm)
$D_{wet} = 1\times10^{-9}$ 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 (1.2 ppt U eqiv.)

NIM A 498 (2003) 240

Construction of nylon vessels

Princeton clean room class 100 with ^{222}Rn-reduced air (VSA filter): $C_{Rn} \sim 1$ Bq/m^3

A. Pocar, PhD Thesis (2003)

Inflation of vessels in SSS

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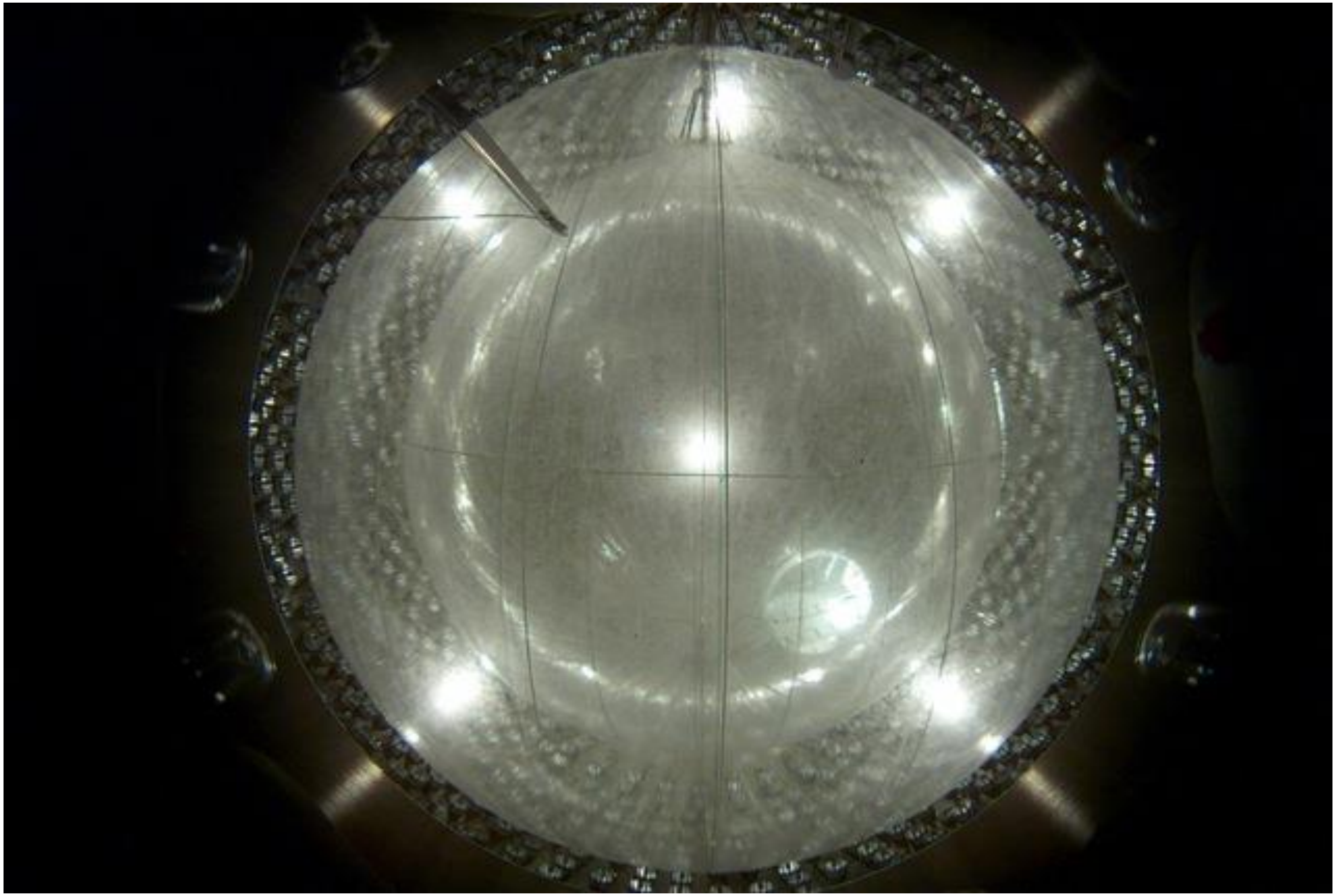
N_2 purification

Summary



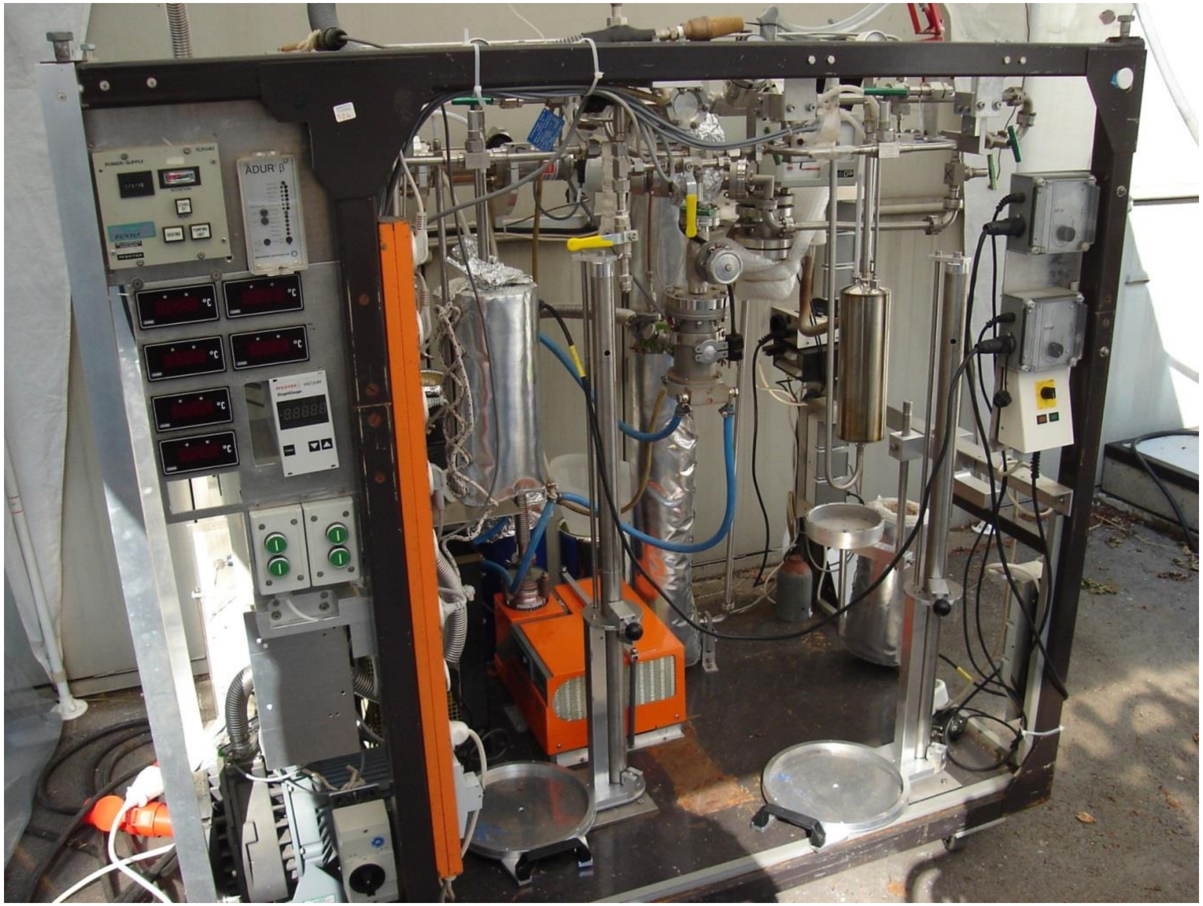
The nylon vessels were inflated in the sphere with synthetic air: $C_{Rn} < 0.1$ mBq/m^3

Int. J. Mod. Phys. A29 (2014) 1442009

^{222}Rn in gases

- ^{222}Rn adsorption on activated carbon
- Several AC traps available (MoREx, MPIK-HD)
- Pre-concentration from 100 – 200 m^3 →

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



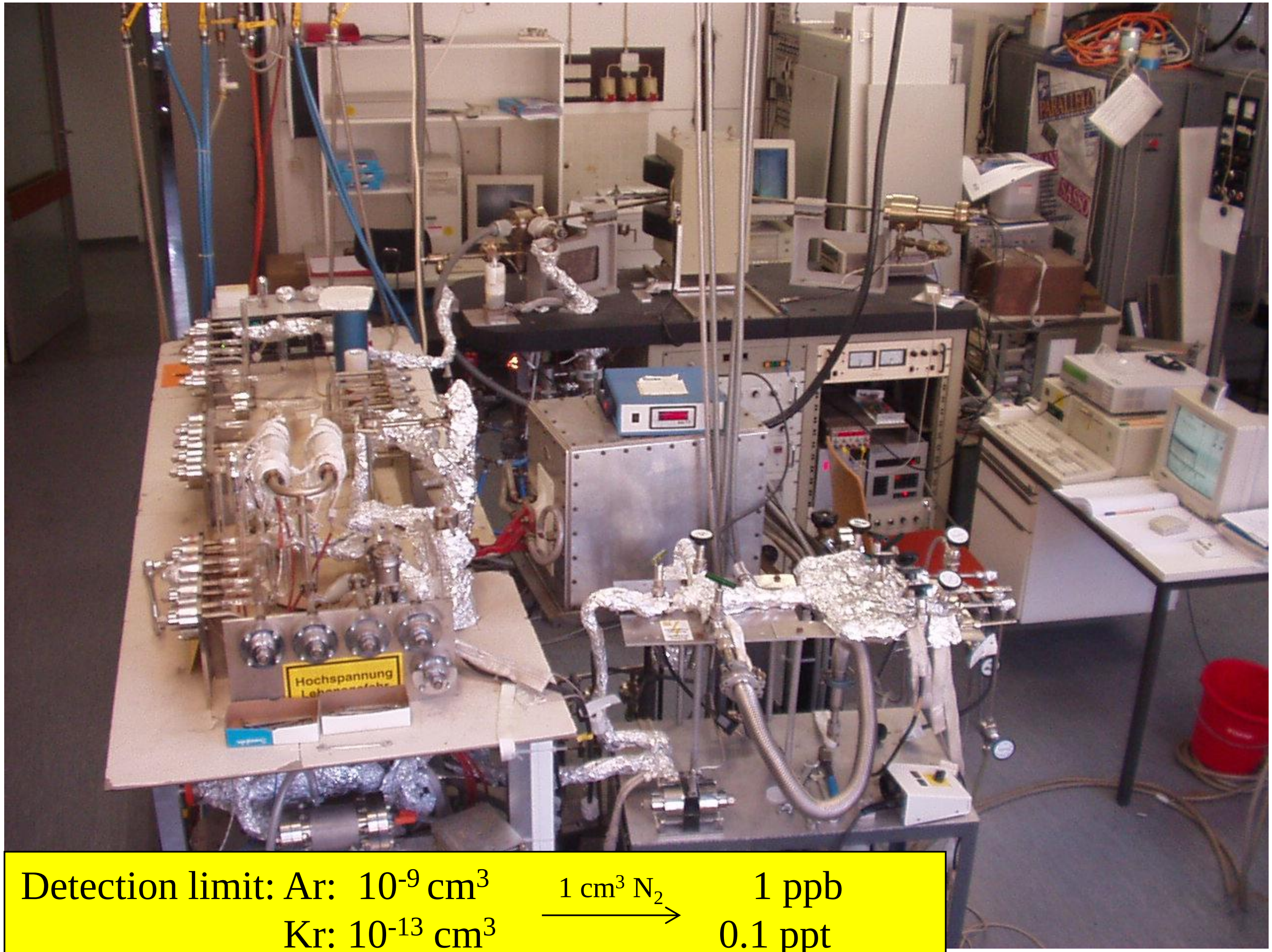
Appl. Rad. Isot. 52 (2000) 691

^{222}Rn removal from LN_2

BX N_2 purification plant: LTA – Low Temperature Adsorber

Production rate: 100 m^3/h
$^{222}Rn \leq 0.5\ \mu Bq/m^3$ (STP)

Ar and Kr in nitrogen



Detection limit: Ar: 10^{-9} cm^3 $\xrightarrow{1\ \text{cm}^3\ N_2}$ 1 ppb

Kr: 10^{-13} cm^3 0.1 ppt

BOREXINO nitrogen

Regular Purity Nitrogen:
- Technical 4.0 quality, not purified
- Production rate up to 100 m3/h (STP)
- ^{222}Rn (30 – 70) μBq/m^3
  Ar ~ 10ppm, Kr ~ 30 ppt

High Purity Nitrogen:
- ^{222}Rn adsorption on charcoal (LTA)
- Achieved concentration **(0.30 ± 0.09) 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

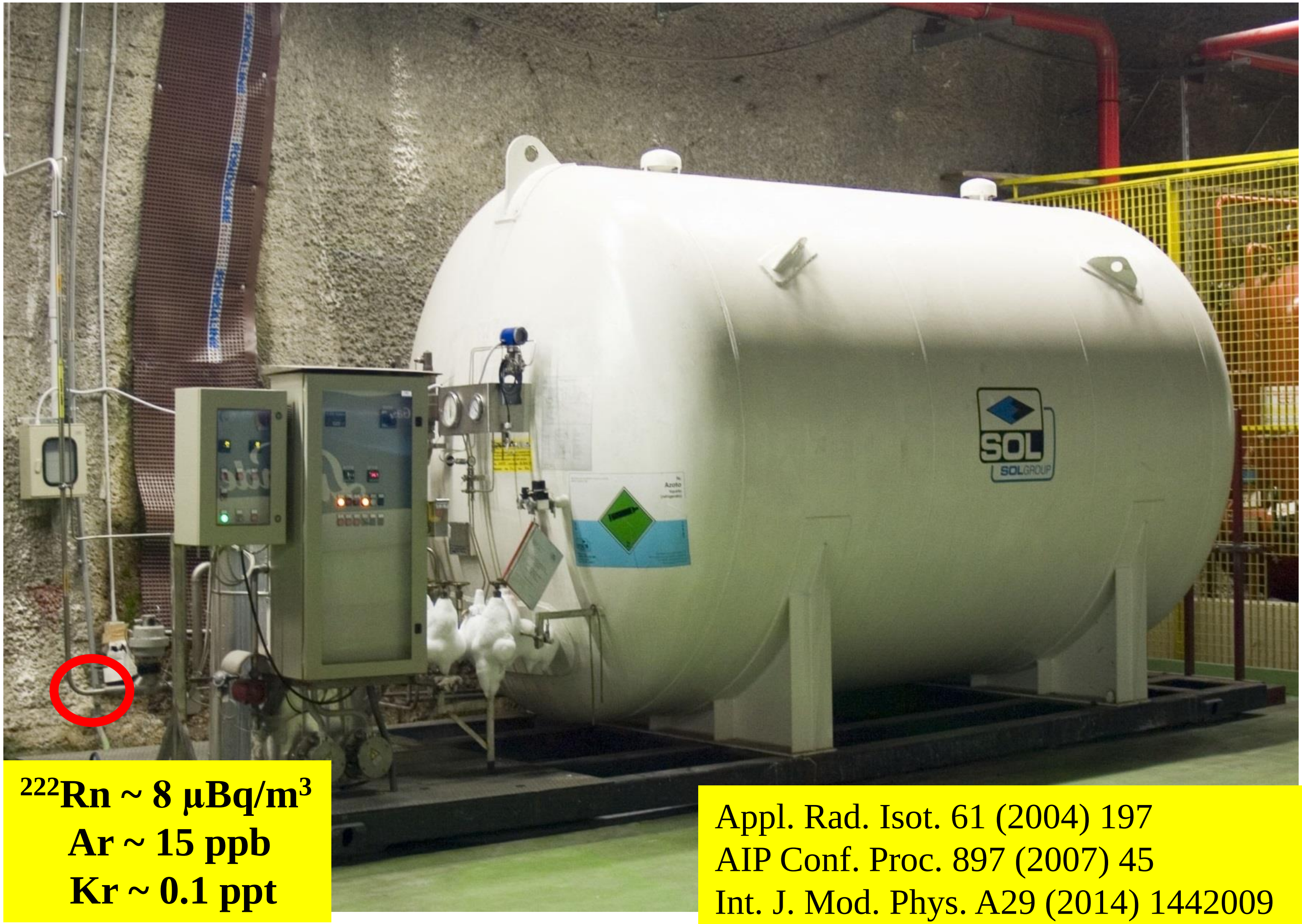
Nitrogen sample	C_{Ar} [ppm]	C_{Kr} [ppt]
MESSER (4.0)	200 ± 30	1680 ± 240
Air Liquide (4.0)	11.0 ± 1.3	40 ± 5
Linde AG, (7.0)	0.031 ± 0.004	2.9 ± 0.4
SOL (6.0)	0.0063 ± 0.0006	0.04 ± 0.01
Westfalen AG (6.0)	0.00050 ± 0.00008	0.06 ± 0.02
Goal (BOREXINO)	< 0.4	< 0.2

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

BOREXINO LAK nitrogen

LAK Nitrogen tank installed at Gran Sasso



^{222}Rn ~ 8 μBq/m^3
Ar ~ 15 ppb
Kr ~ 0.1 ppt

Appl. Rad. Isot. 61 (2004) 197
AIP Conf. Proc. 897 (2007) 45
Int. J. Mod. Phys. A29 (2014) 1442009

Purification of nitrogen from Kr

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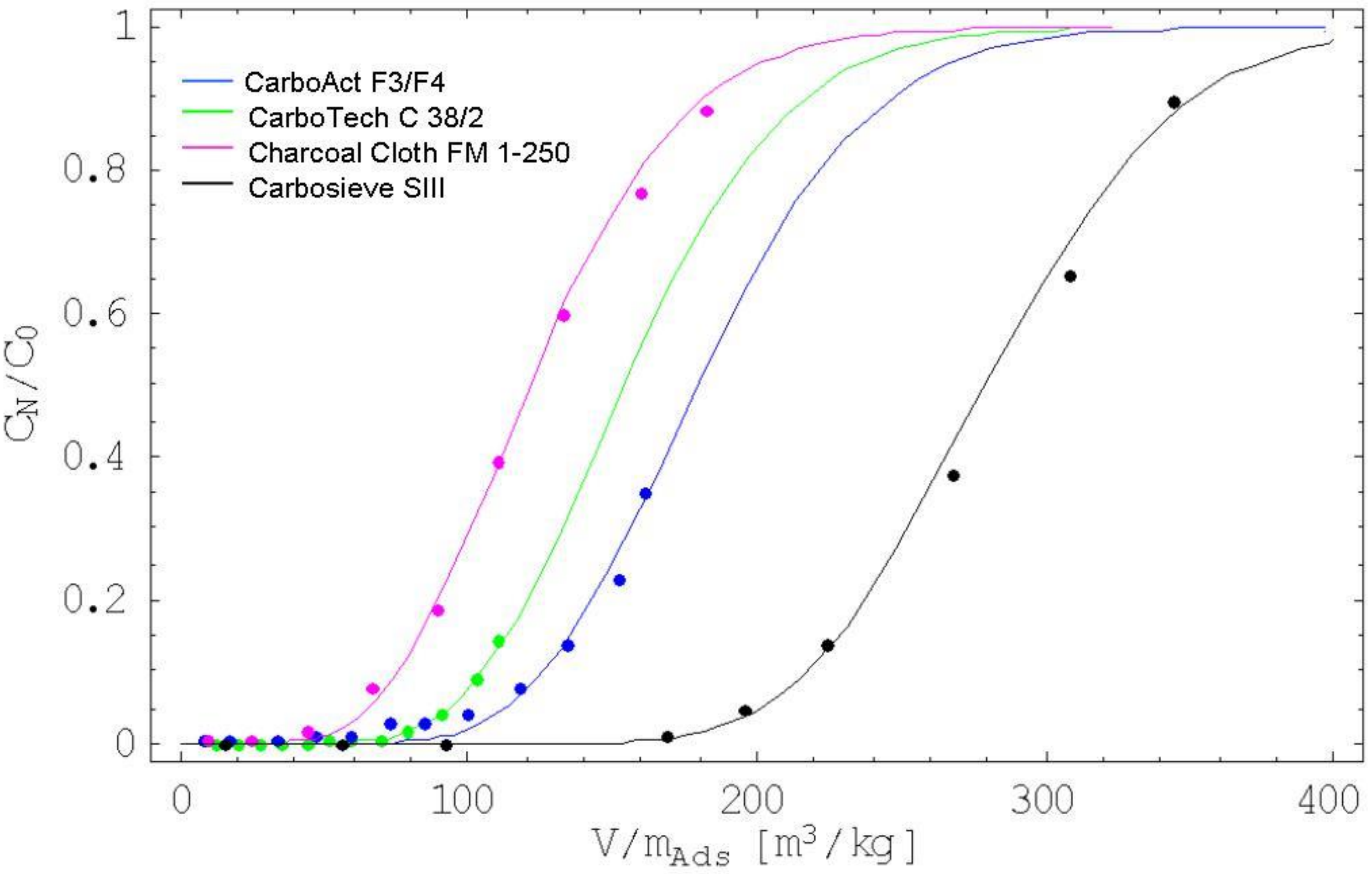
Summary



Conclusions

BOREXINO
^{222}Rn control
N_2 purification
Summary

- BOREXINO has achieved an unprecedented background level in the liquid scintillator
- Strict quality control program including the assay of all components of the detector during its construction
- **+10 years of R&D, many people/institutions involved**
- Several detectors and experimental methods were developed allowing measurements even at a single atom level
- Most of the developed techniques are world-wide most sensitive (gamma-ray spectroscopy, ^{222}Rn detection, ^{222}Rn diffusion) and are applied in next-generation experiments (GERDA, XENON, DARKSIDE,…)