BOREXINO

★ **Real-time detector for**
^{7}Be - Solar Neutrinos
via elastic Neutrino-Electron
Scattering (CC + NC)

★ **Located at the Gran Sasso Underground Laboratory (Italy), shielded by 3400 m.w.e. of rock**

Collaboration:

Italy / Usa / Germany /France / Russia / Canada / Poland / Belgium

cf: Astropart. Phys. 16 (2002) 205-234; http://almime.mi.infn.it

★ **1/2002: Major detector components readily installed**
Start of data taking this year

T. Kirsten, WIN 2002, Christchurch, NZ , Jan 2002

Why ^{7}Be - Neutrinos ?

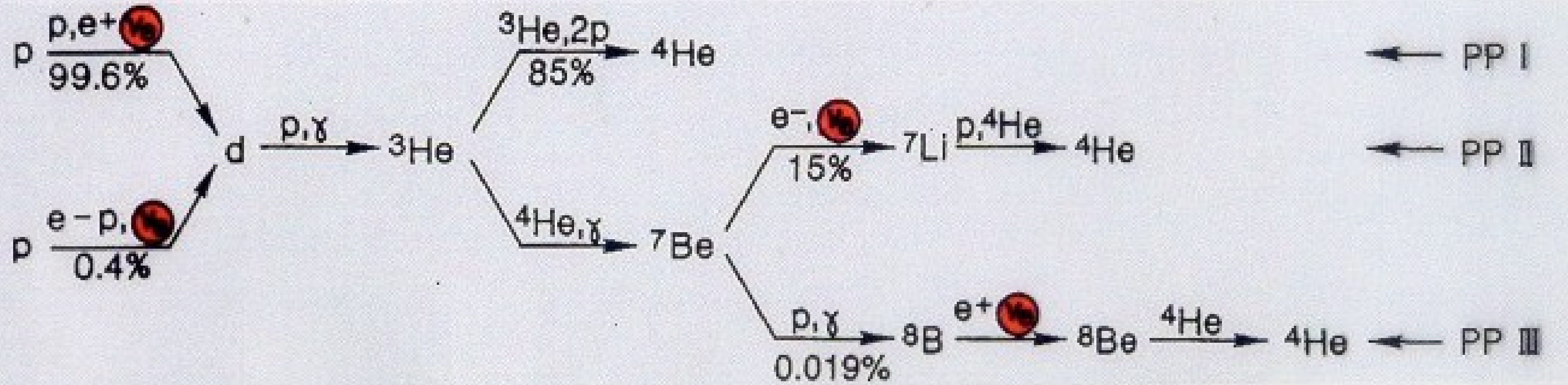
★ **98 % of all solar neutrinos are sub-MeV (Φ_7 ~ 7 % , Φ_{pp} ~ 91 %)**

The sub-MeV range is particularly discriminating among the various neutrino oscillation parameters that are still allowed by the presently available experimental data. So far this dominant part of the solar neutrino spectrum is explored only with Gallium, yet not in real-time.

FOR THE SUN THE PP-CYCLE DOMINATES

$$4\,H^{+} + 2e^{-} \rightarrow {}^{4}He^{++} + 2\,\nu_e + 26.73\ MeV$$

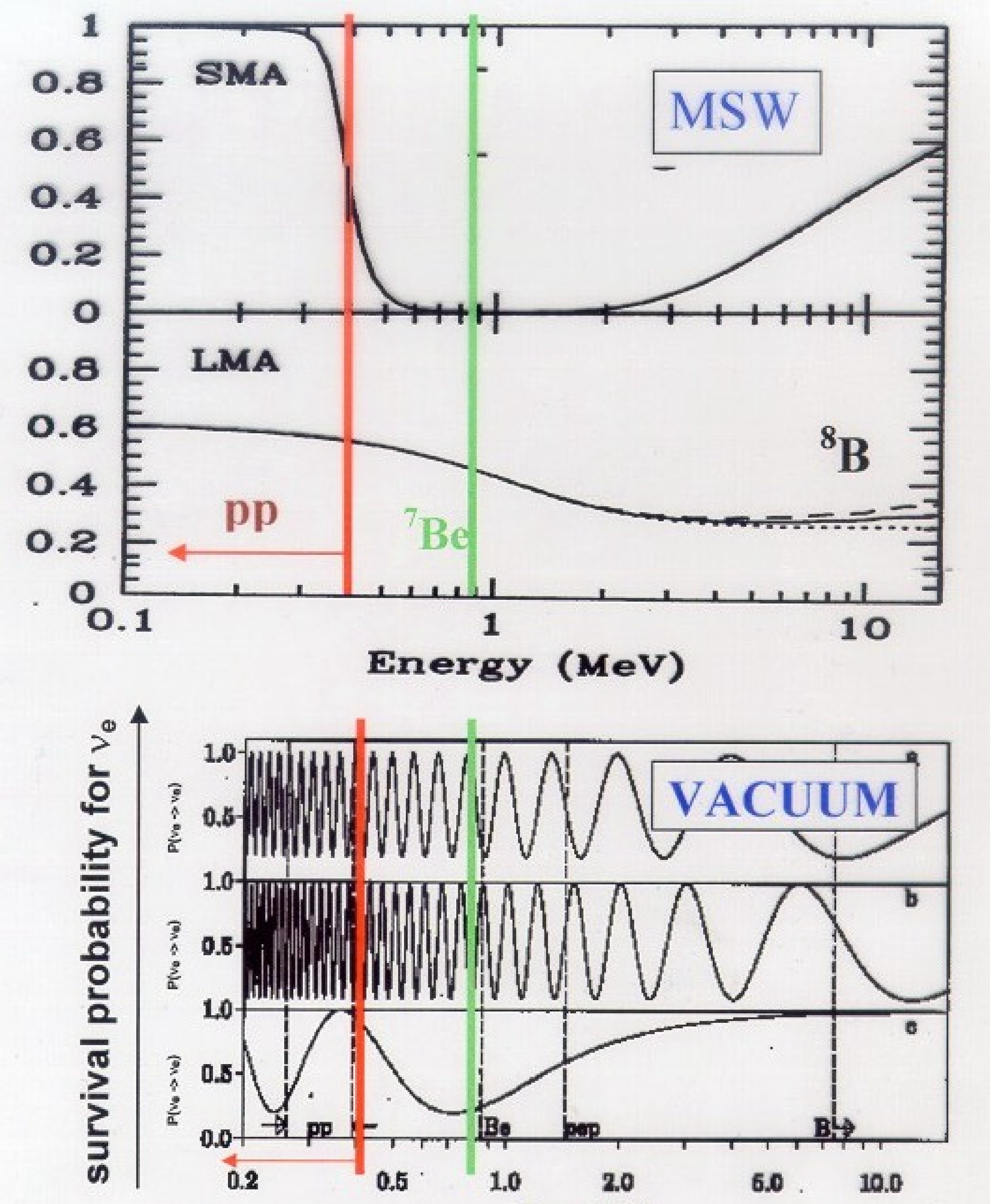
$$\langle E(2\nu_e) \rangle = 0.59\ MeV$$

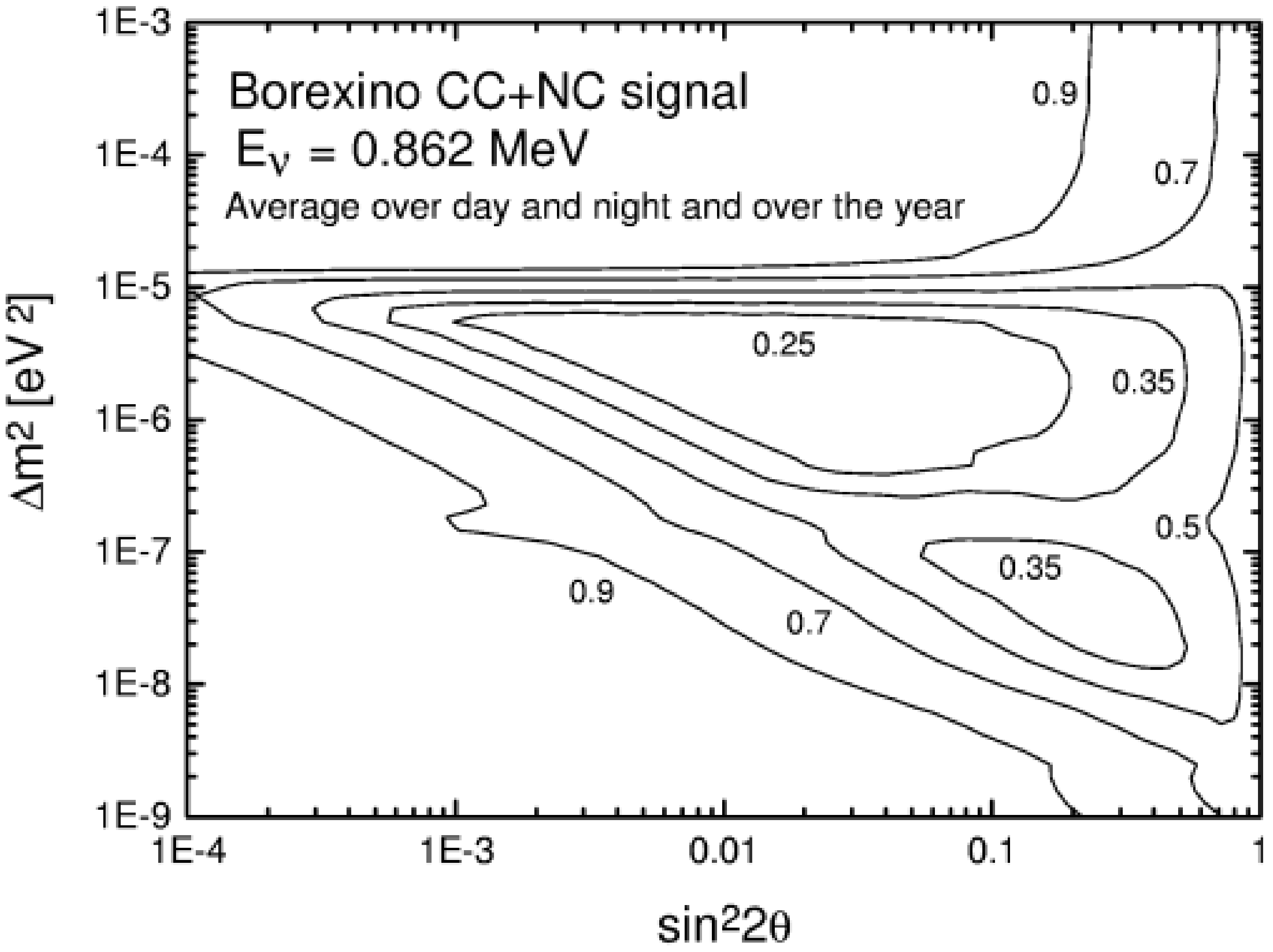


EXPECTED NEUTRINO FLUXES

predicted by the Standard Solar Model to arrive at the Earth:

pp - ν :		**60 billions /cm², s**	$\sim T_c^{-1}$
^{7}Be - ν :	~	**5 billions /cm², s**	$\sim T_c^{8}$
^{8}B - ν :	~	**5 millions /cm², s**	$\sim T_c^{18}$


MSW
SMA
LMA
pp
^{7}Be
^{8}B
Energy (MeV)
survival probability for ν_e
VACUUM
P(νe -> νe)
pp
Be
pep
B
Energy (MeV)

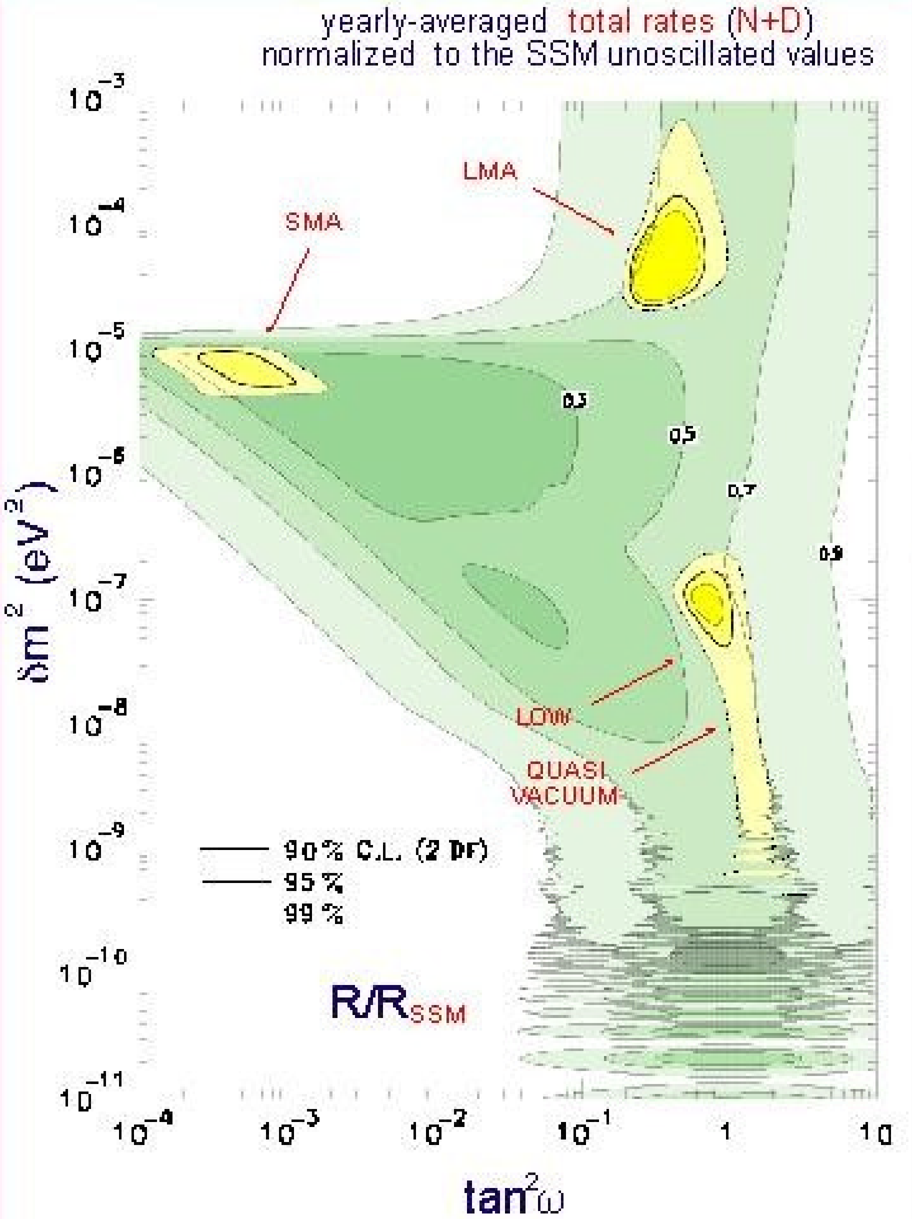


Borexino CC+NC signal
E_ν = 0.862 MeV
Average over day and night and over the year
0.9
0.7
0.25
0.35
0.5
0.35
0.9
0.7
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
1E-4
1E-3
0.01
0.1
1
Δm^2 [eV ^{2}]
$\sin^2 2\theta$

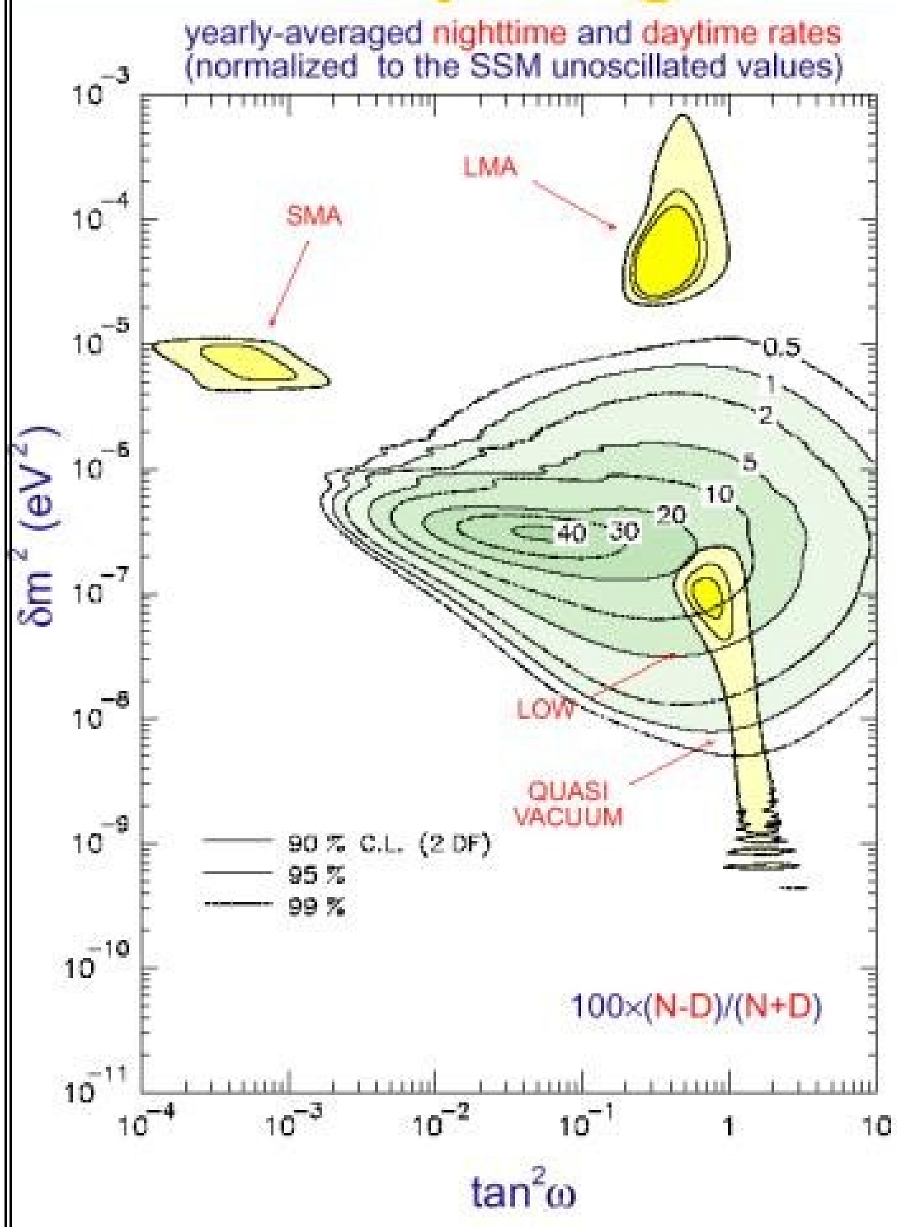
Specifically:

- confirm Standard Solar Model and presently favored oscillation scenario if Φ_7 = (66 ± 13)% of SSM prediction.
- final exclusion of SMA if $\Phi_7 \geq$ 34% of SSM prediction.
- Detect or reject LOW solution by presence or absence of strong day/night effect.
- establish sterile neutrinos if $\Phi_7 \leq$ 20% of SSM prediction.
- The measured rate in the gallium experiments (CC only) is due to both, Φ_{pp} and Φ_7. With Φ_7 measured by BOREXINO, the CC/NC ratio can be deduced

Rates



Day/Night



Detection Scheme

$\Phi_{(7Be-\nu)}$ (SSM) = $4.8 \cdot 10^9\ \nu/cm^2s$ E = 862 keV

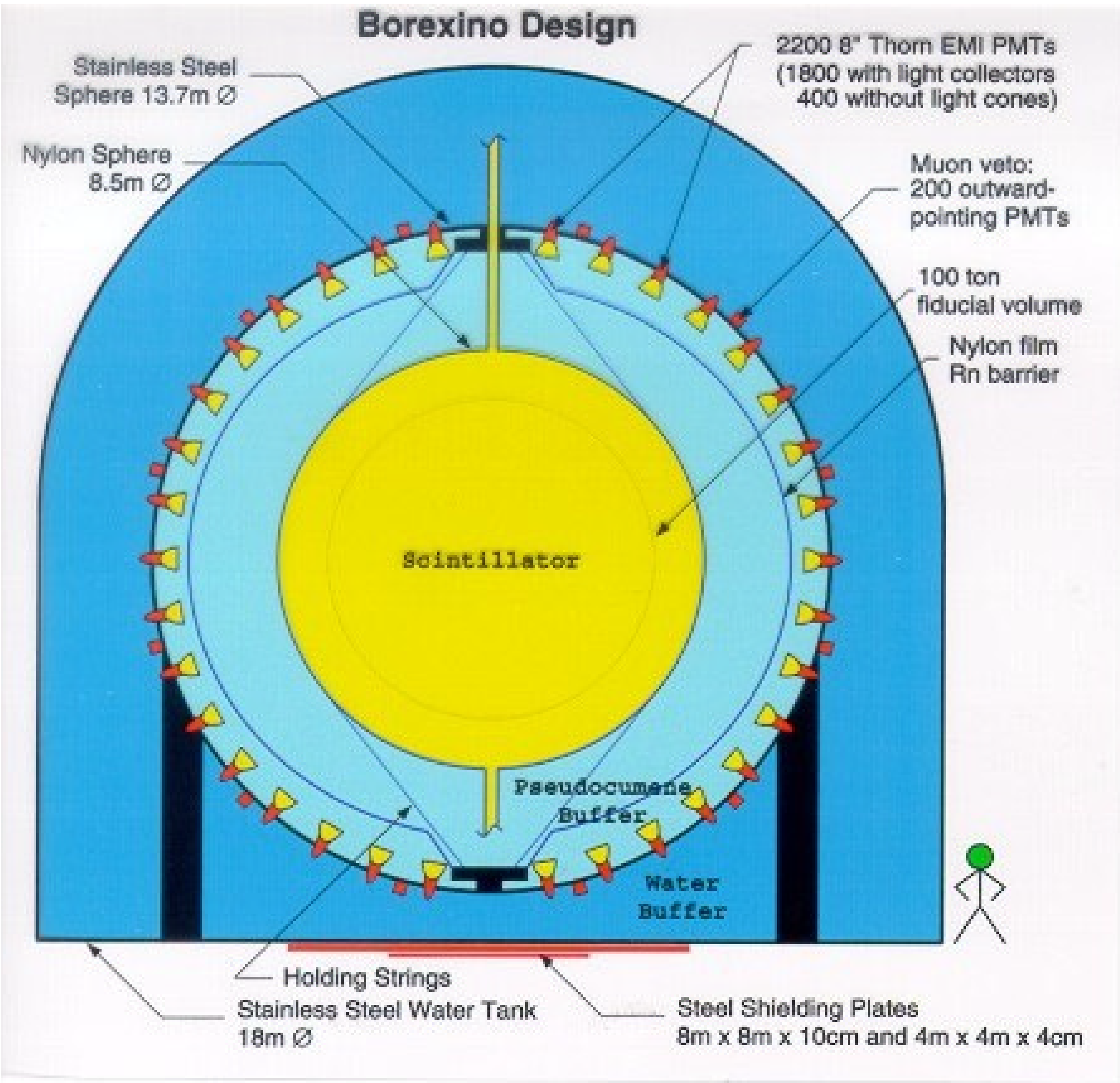
$\nu_e + e^- \rightarrow \nu_e + e^-$ CC + NC $\sigma \sim 6.3 \cdot 10^{-45}\ cm^2$

$\nu_{\mu\tau} + e^- \rightarrow \nu_{\mu\tau} + e^-$ NC only $\sigma \sim 1 \cdot 10^{-45}\ cm^2$

Detect scintillation light of recoil electrons in 300 t (100 t fid.) of a hyperpure organic liquid scintillator: Pseudocumene (C_9H_{12}), doped with 1.5 g/l flour (PPO).

The number of scintillation light photons is the measure of the energy of the recoil electron (~ 430 pe/MeV). Energy resolution ~7% at 500 keV

Spatial resolution (from photon arrival times) ~ 10 cm


Borexino Design
Stainless Steel Sphere 13.7m ∅
Nylon Sphere 8.5m ∅
2200 8" Thorn EMI PMTs (1800 with light collectors 400 without light cones)
Muon veto: 200 outward-pointing PMTs
100 ton fiducial volume
Nylon film Rn barrier
Scintillator
Pseudocumene Buffer
Water Buffer
Holding Strings
Stainless Steel Water Tank 18m ∅
Steel Shielding Plates 8m x 8m x 10cm and 4m x 4m x 4cm

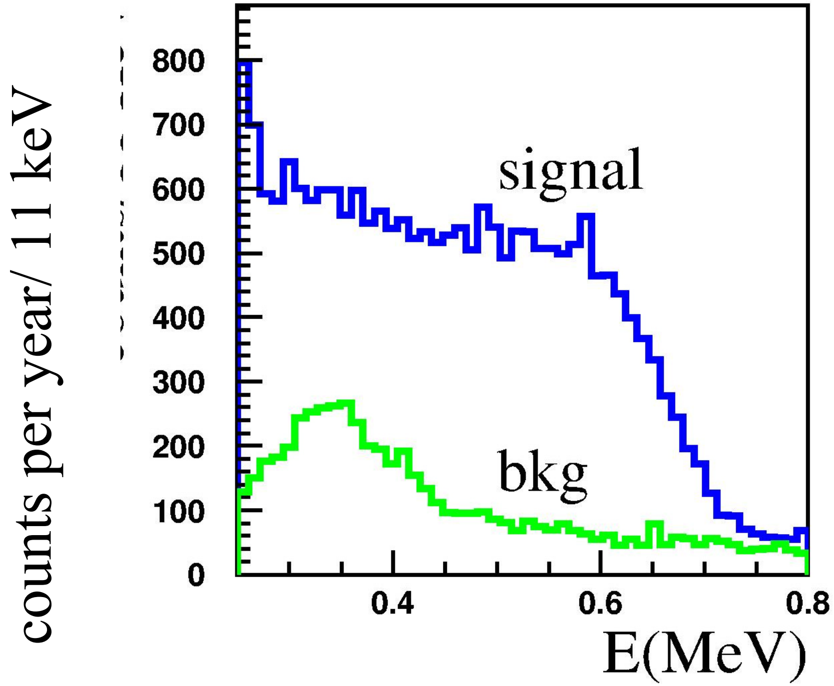
The ^{7}Be ν-Signal

Energy window: .25 -.8 MeV

Compton like e- spectrum,
Edge at 0.66 MeV
Signal: 55 /d, 100 ton (SSM)

Background

internal, after subtraction of
α- and Bi/Po events



The price to pay

★ Below 1 MeV, backgrounds in real time detectors appear overwhelming (realm of natural radioactivity)

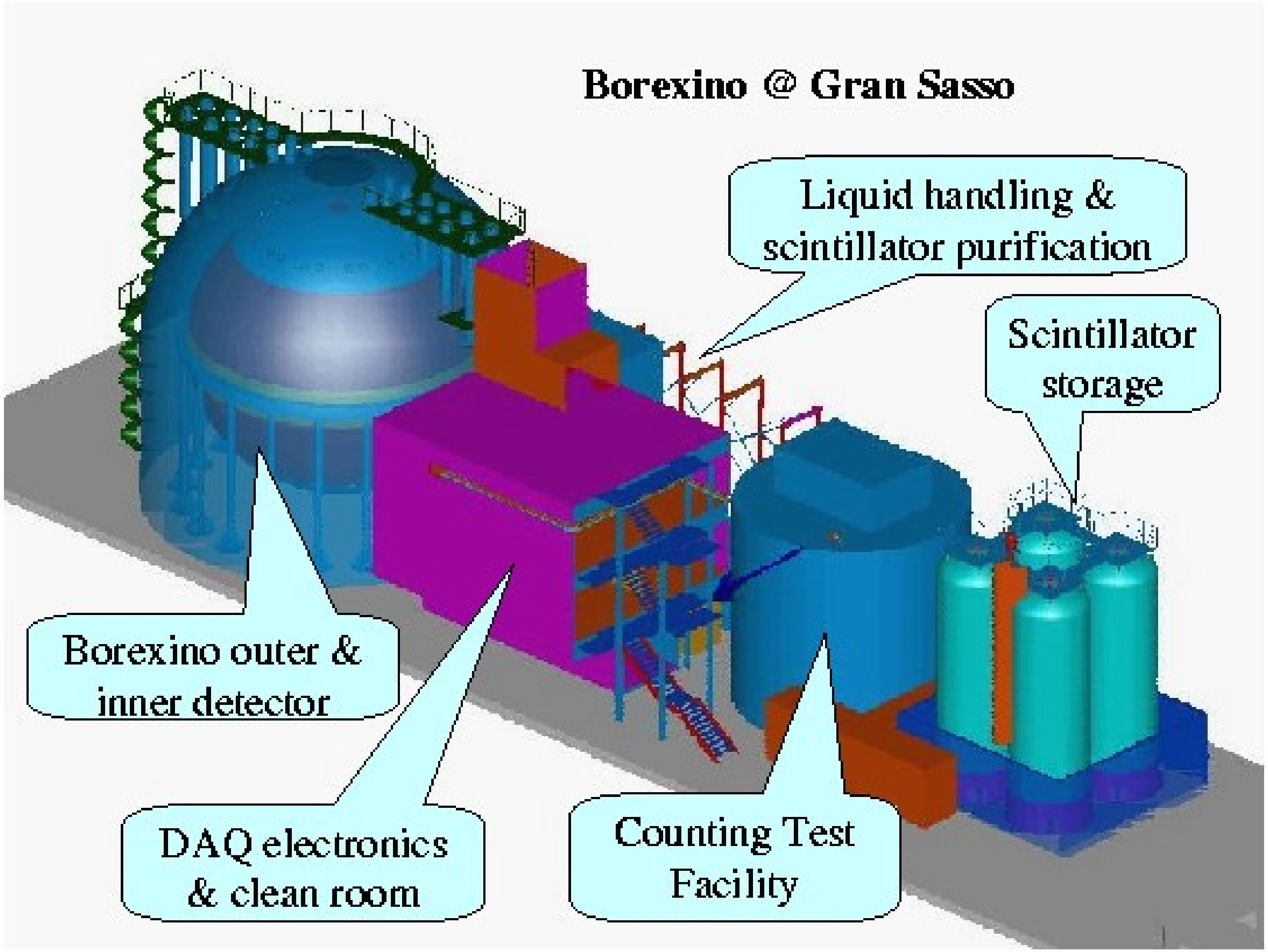
This requires:

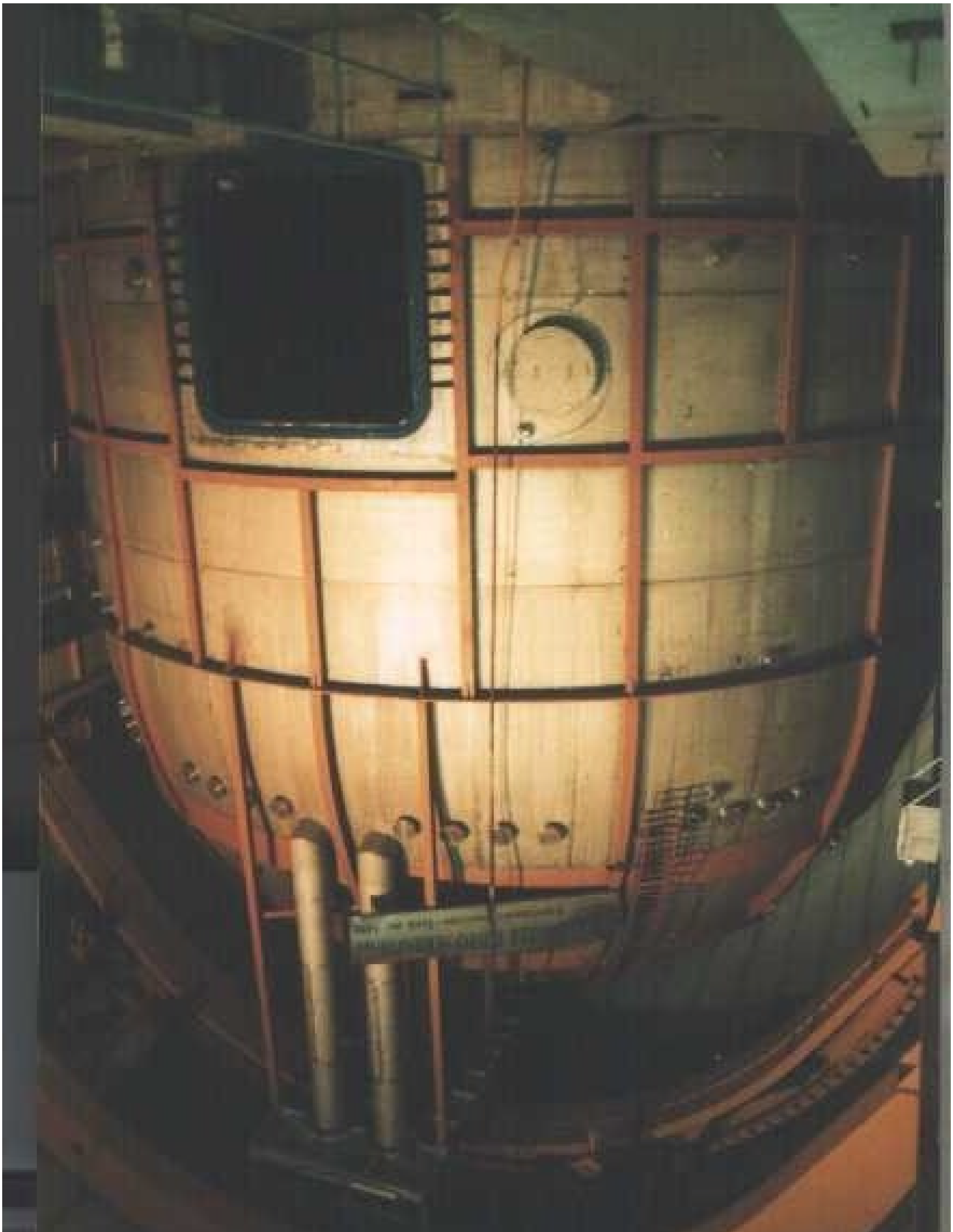
→ Extreme Radiopurity

→ Multiple shielding against external backgrounds

→ Background discrimination *(the signal itself is rather unspecific, yet backgrounds can be specific)*

★ The low cross section demands a large detector mass:O(100 tons fiducial) for rates of O(10 events/day)


Borexino @ Gran Sasso
Liquid handling & scintillator purification
Scintillator storage
Borexino outer & inner detector
DAQ electronics & clean room
Counting Test Facility

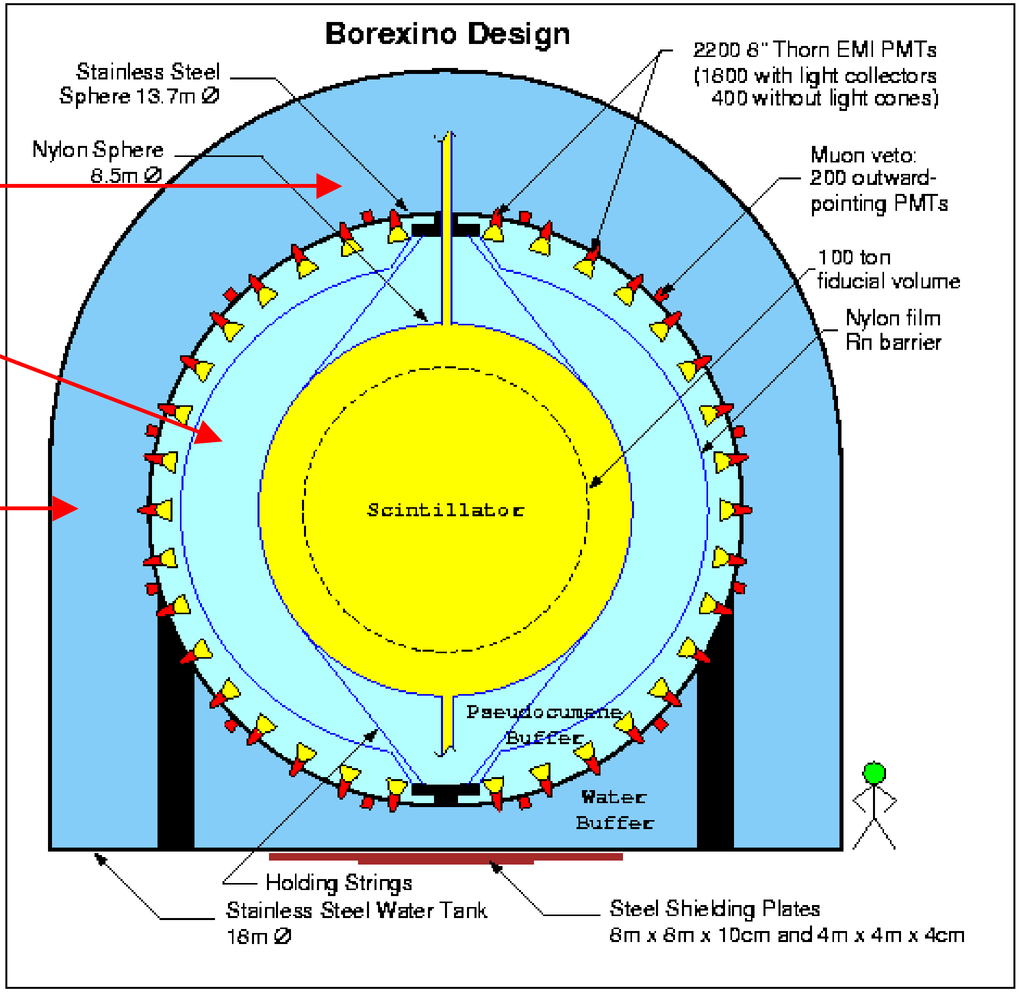


SHIELDS

- 1000 t PC buffer shield the radioactivity from the PMT's in addition, 2nd nylon shroud against Rn emanating from the PMT's)

- 2200 t water shield the radioactivity from the Gran Sasso rocks

- 3400 m.w.e. Gran Sasso rock (~1 residual muon/h, m^2)



NYLON BALLOONS

Preparation in clean room conditions, Rn-controlled

Inner Vessel (I.V.)

Sniamid ∅8m $d = 125\mu$ $w = 11$ kg $s = 208\ m^2$

$^{226}Ra \leq 0.07$ mBq/kg, equivalent to ≤ 6 ppt U in equ., causes background comparable to that from $\leq 0.6 \times 10^{-16}$ g/g U in the scintillator!

Outer Vessel (shroud)

Capron ∅ 11m $d = 125\mu$ $w = 20$ kg $s = 380\ m^2$

$^{226}Ra = 0.22$ mBq/kg, equivalent to ≈ 18 ppt U in equ.,


PRINCETON

SCINTILLATOR

produced at ENICHEM in Sardinia (near Cagliary)

Solvent Pseudocumene (**PC**)

$(CH_3)_3C_6H_3$ $\rho = 0.876\ g/cm^3$

Fluor Diphenyl Oxazole (**PPO**) 1.5 g/l dissolved in PC

$(C_6H_5)_2(C_3HNO)$ $\rho = 1.09\ g/cm^3$

emission range 330 – 450 nm

photon yield ≈ 12000 photons/MeV

transparent, stable, fast response (≈ 3 ns)

Buffer quencher Dimethylphthalate (**DMP**)

$C_6H_4(CO_2CH_3)_2$ $\rho = 1.19\ g/cm^3$

PHOTOMULTIPLIERS

2436 ∅20cm Thorn EMI, low radioactivity: K 60 mg; U 100 μg; Th 50 μg (all per PMT). All sealed, leak tested, installed

1800 with Al light concentrators (view I.V., 95% reflectance)

400 without concentrators, looking inward to veto muons crossing the buffer through their Cerenkov light

210 looking outward (μ-veto)

Coverage 30 %

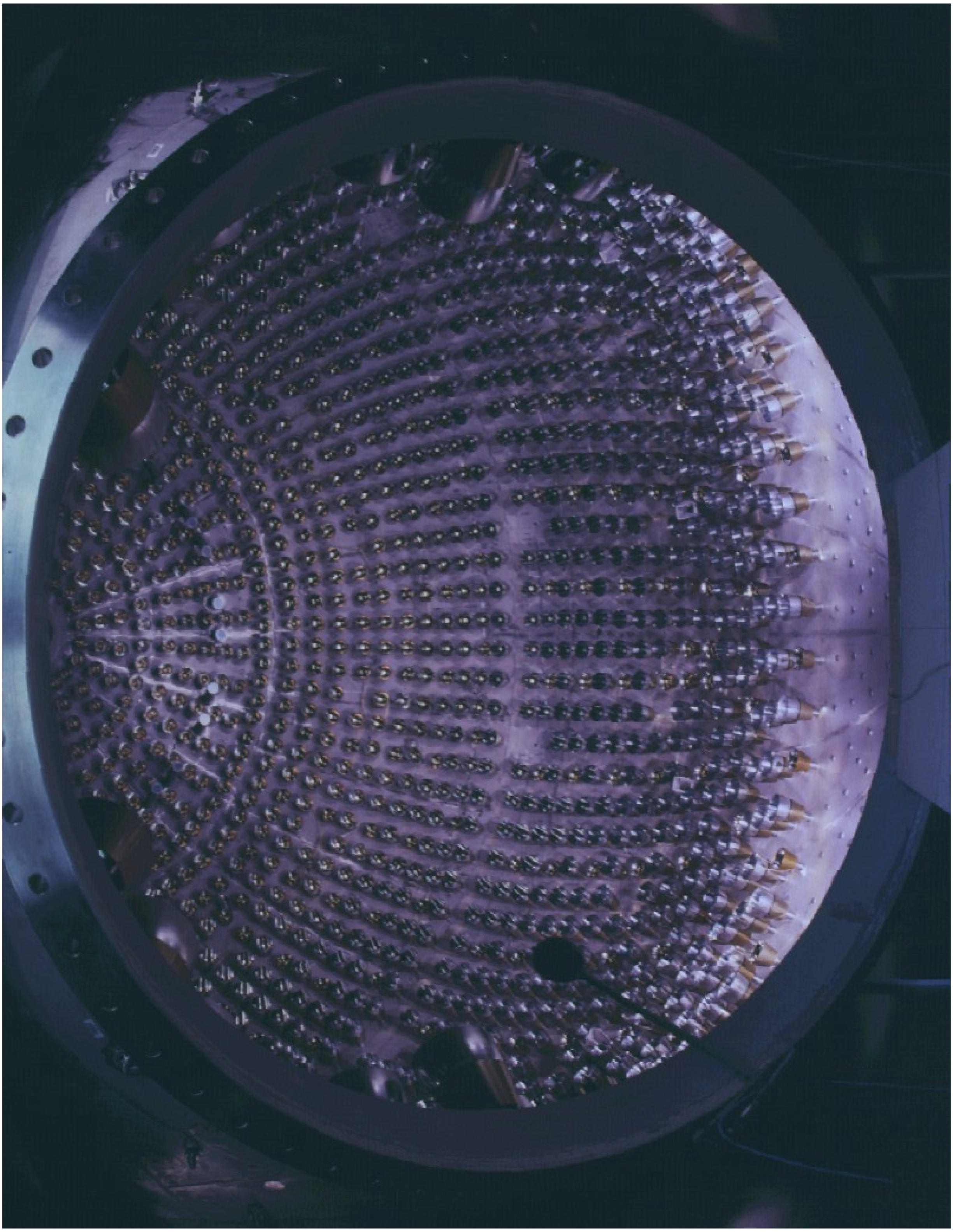
Light output ~ 500 pe/MeV

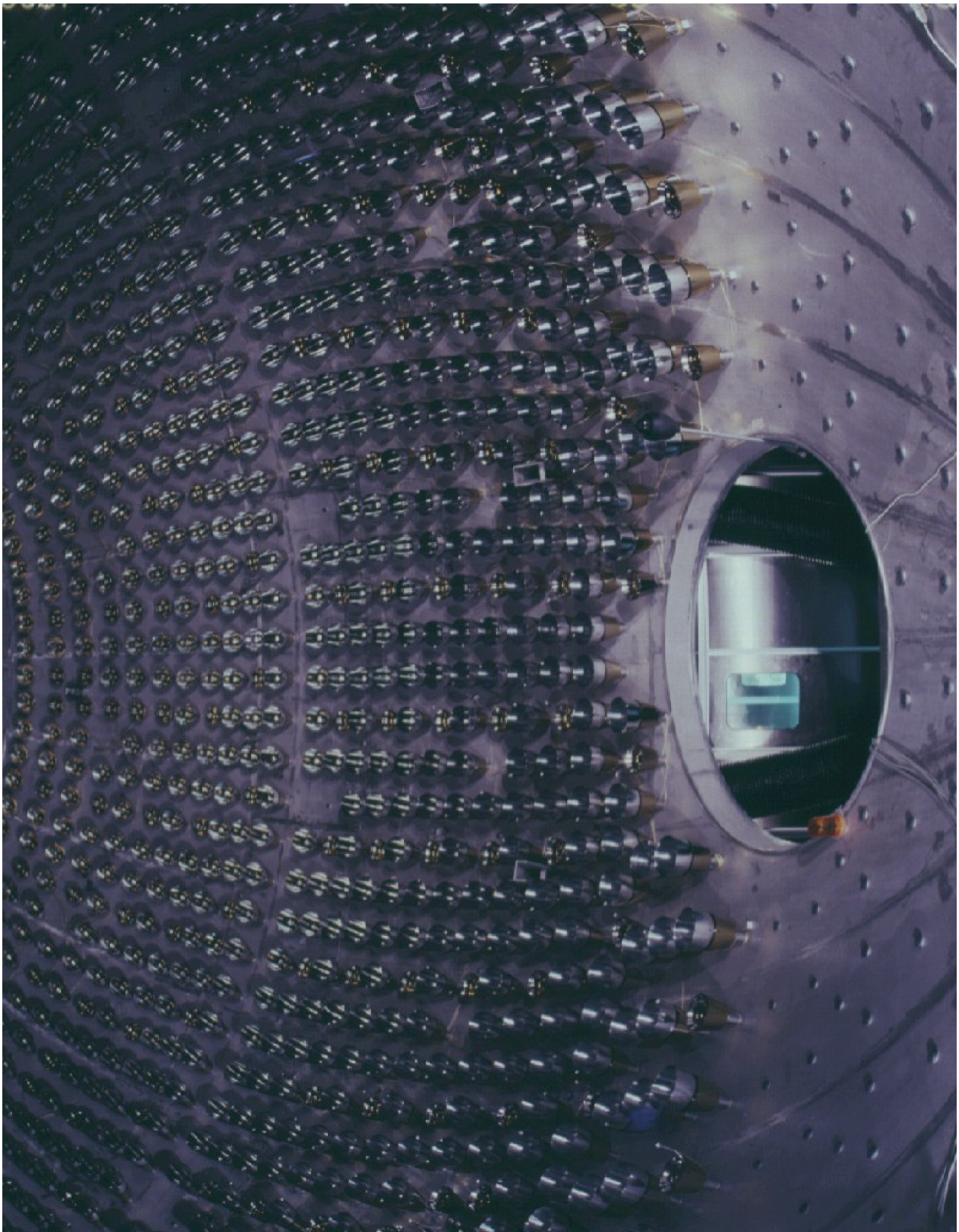
ADC signal calibrated with radioactive sources

Time resolution 1 ns

TDC signal calibrated with optical fiber (Laser calibration)

Sealing front side in PC, backside in water: Epoxy, bonds





ELECTRONICS, DAQ

Electronic processing for:

→ event position reconstruction

→ α - β pulse shape discrimination

→ delayed coincidences

charge resolution of ADC 8 bit, time resolution 0.4 ns

Trigger: sum of hits in time window of 60 ns

expect $N \approx 20$ (50 keV), depends on actual ^{14}C singles rate

DAQ: LINUX operating system. Web user interfaced

Event simulations: Monte Carlo/GEANT4

CALIBRATION

Energy $\rightarrow$ spectrum, also important for α-separation

Position $\rightarrow$ important for fiducial volume cut

(a) Laser monitor with optical fibers for PM calibration (λ=394 nm), vessel positioning, and clarity control. Cameras.

(b) internal contaminants: ^{14}C, 2.2 MeV γ's from n+p, α-lines. relatively low rates, but usefull

(c) movable external sources

^{7}Be (0.48 MeV) ^{32}P (1.71 MeV) ^{232}Th ^{113}Sn, ...

(d) Mega-Curie ^{51}Cr neutrino source (0.75 MeV), 2π-geometry

BOREXINO SOURCE RATES

Cr - SOURCE (positioned at 9 m periphery)

(100 t fiducial volume)

1 MCi $\rightarrow$ flux = $4 \cdot 10^9\ \nu$ / cm^2 s at center

1 MCi at start of exposure $\rightarrow$ initial rate = 24 c/d

$\rightarrow$ integral rate in 28 d ($T_{1/2}$) = 480 c

$\rightarrow$ mean rate during first 28 d = 17 c/d

Desirable:

3 $MCi_{SOE} \approx$ 3.3 MCi_{EOB} for $\approx$ 50 c/d during first 28 d

(1400 c during first 28 d)

After one half - live of use in Borexino, 1.5 MCi still useful for GNO: Transport time loss: 3 d $\rightarrow$ 7 % 7 d $\rightarrow$ 16 %

BACKGROUNDS

INTERNAL

^{14}C end point energy (156 keV) defines 'Be-window': 250 – 800 keV

$^{14}C/^{12}C \approx 10^{-18}$ yields 0.05 ev/d in the window in 100t fid. vol.

U,Th, K

10^{-16} g/g U,Th + 10^{-14} g/g K yield 100 ev/d in the window after α-β and anticoincidence discriminations (e.g. ^{212}Bi-^{212}Po, ^{85}Kr-^{85m}Rb, ^{214}Bi-^{214}Po): 15 ev/d

Rn and daughters

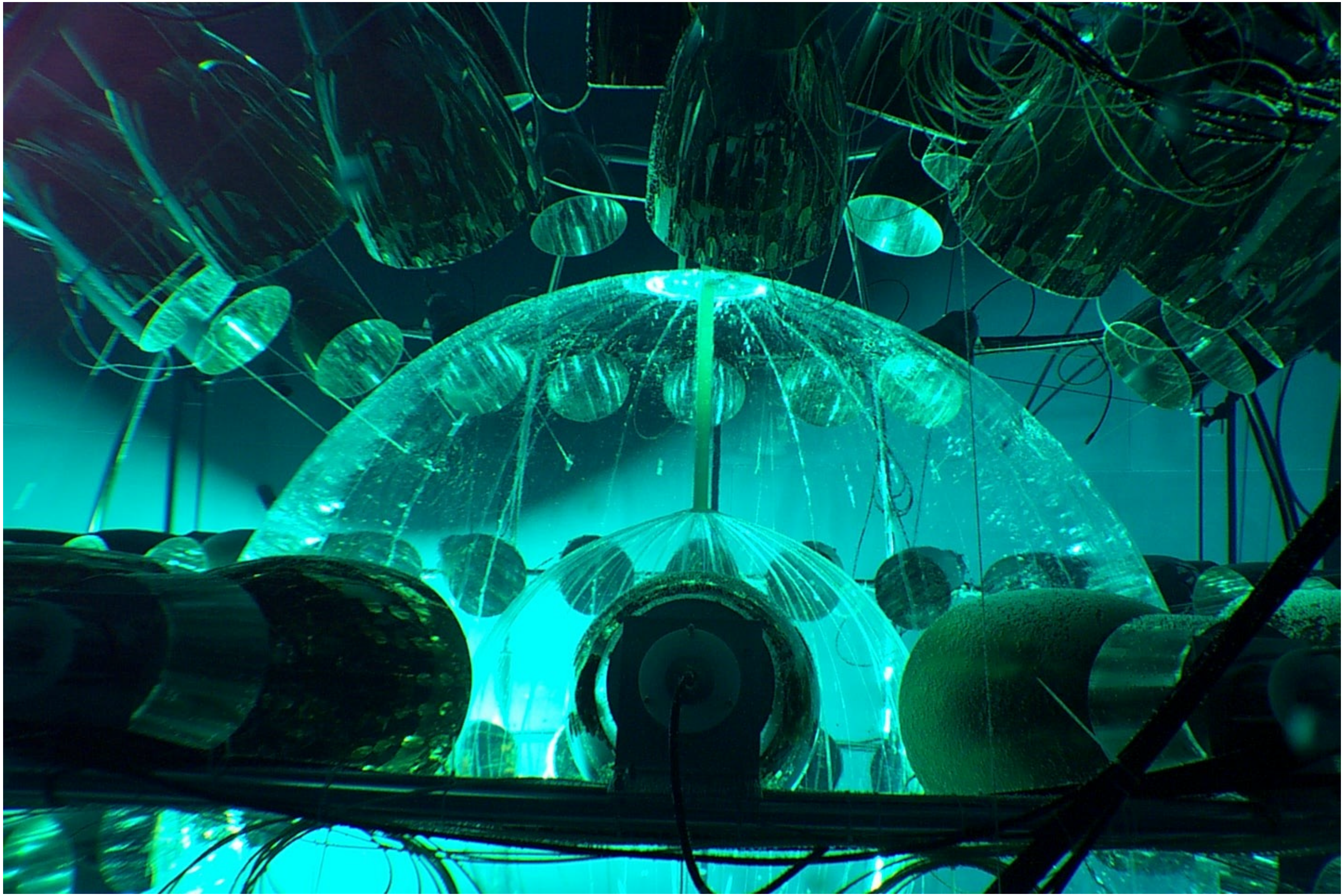
EXTERNAL

PMT's *self-shielding, shroud*

Cosmic ray muons *(direct, neutrons, spallation) Veto system*

Radiopurity of Borexino Detector Materials: Requirements vs. values measured in the CTF

Material	Borexino design	CTF achieved	Unit
Stainless steel	$\approx 10^{-9}$	$\approx 10^{-9}$	g/g of Th,U equiv.
External water	$\approx 10^{-10}$	$\approx 10^{-14}$	g/g of Th,U equiv.
PM	$\approx 10^{-8}$	$\approx 10^{-8}$	g/g of Th,U equiv.
Scintillator	$\approx 10^{-16}$	$\approx 10^{-16}$	g/g of Th,U equiv.
Scintillator	$\approx 10^{-18}$	$\approx 10^{-18}$	$^{14}C/^{12}C$



PURIFICATION PLANTS

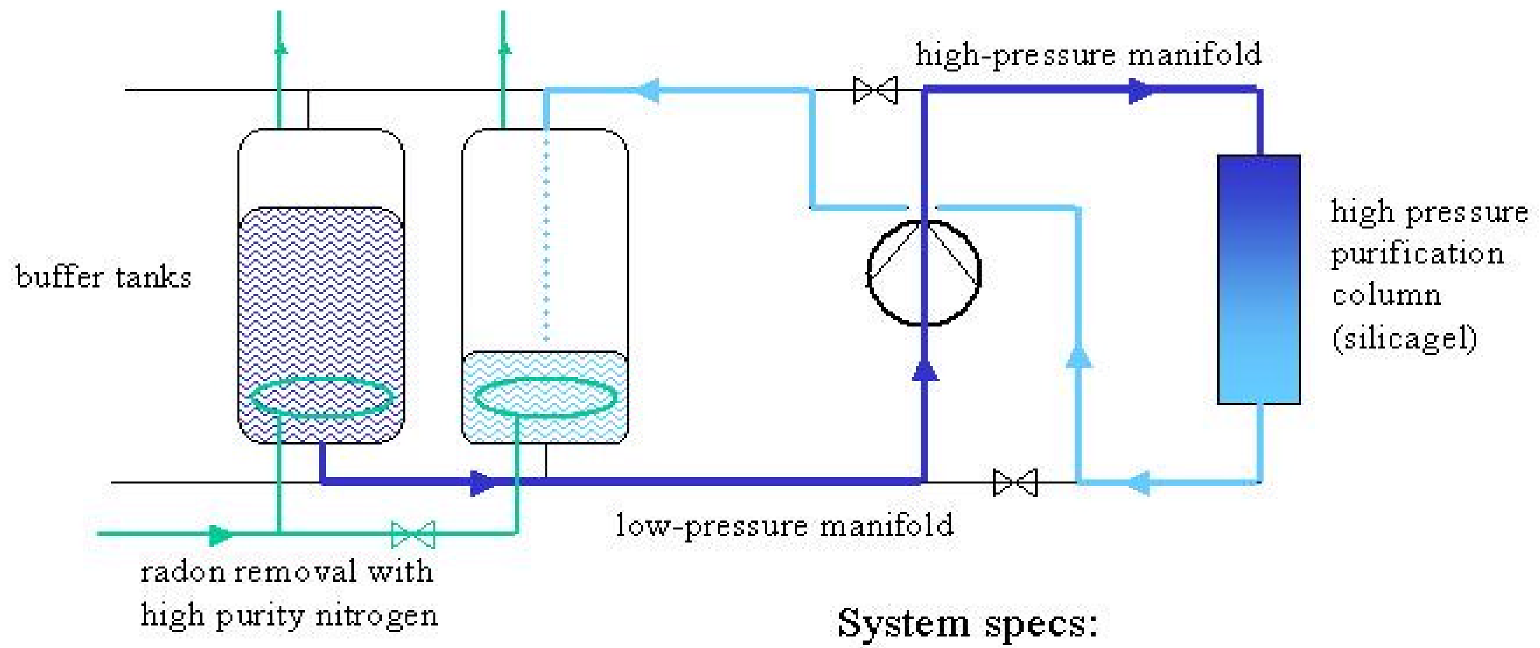
Fluid handling system interconnections

	MOD Ø	SKID TOWER
Ultra-filtration	√	√
Reverse osmosis	√	√
Nitrogen stripping	√	√
Water extraction	√	√
Solid column extraction (silicagel)	√	√
Destillation		√
max. throughput (l/h)	200	1000

Clean N_2 Factory
(fractionated adsorption)

Modes of operation: (a) batch/store
(b) in line (after filling)

MOD*0
A scintillator handling and purification system



System specs:

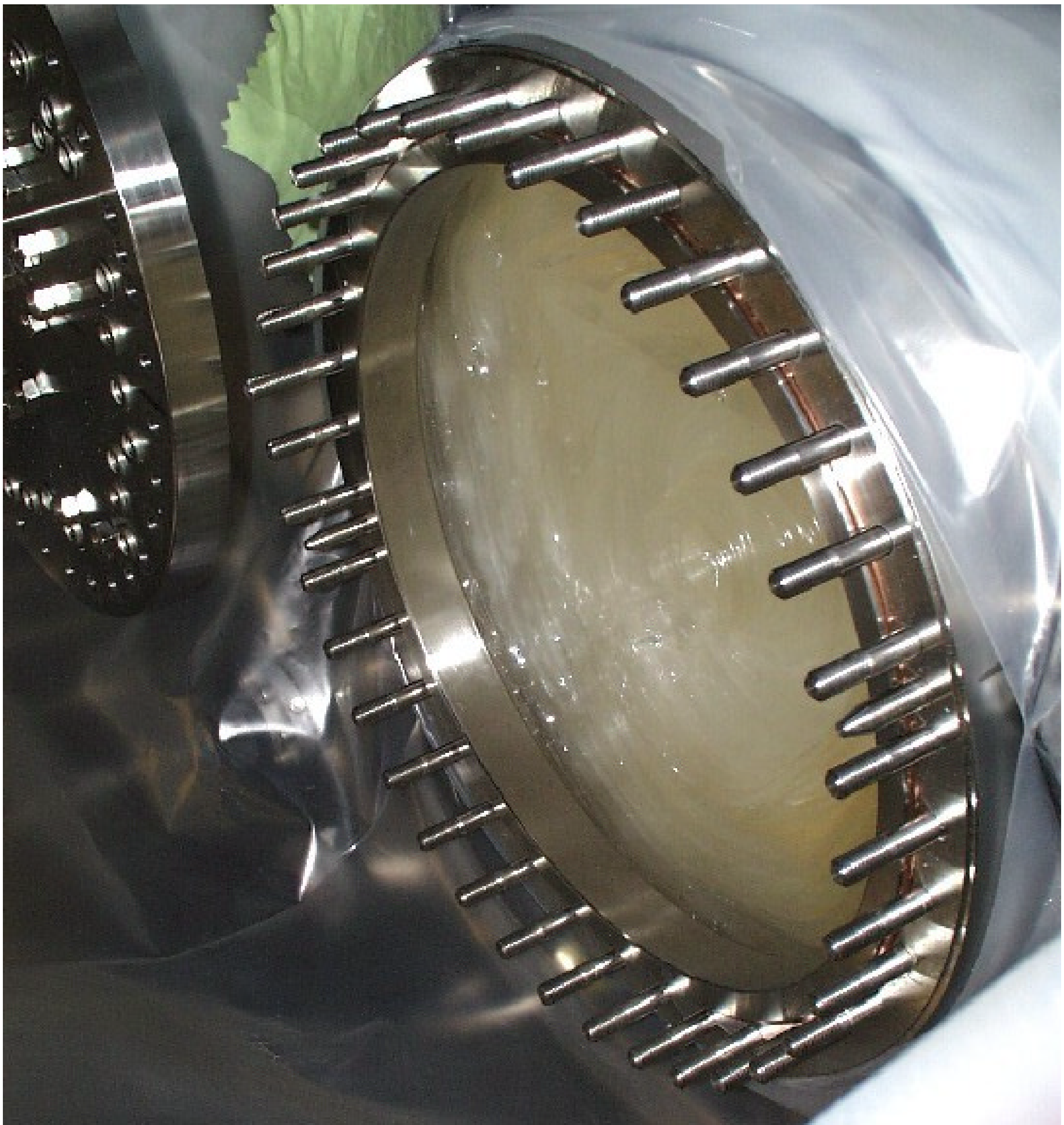
- UHV leak tight
- electropolished stainless steel
- special cleaning

Emanation measurements of solid samples

- collection of emanated Rn
  - at dry or humid/wet condition
  - hole parts or hackled pieces (specific per volume or surface)
  - glass vials (< 1 l) / stainless steel chambers (20 l / 80 l)
  - detection in proportional counter (detection limit: 50 μBq total)

W. Rau, G. Heusser, Appl.Rad. & Isot., 53 (1-2), (2000), 371 - 375

- various samples
  - adsorbents (chacoal, copper, molecular sieve)
  - gaskets (Buna, buthyl, polyethylen)
  - metalle (steel, copper, μ-metal)
  - nylon of the Inner Vessel



Sources of ^{222}Rn in BOREXINO liquid scintillator

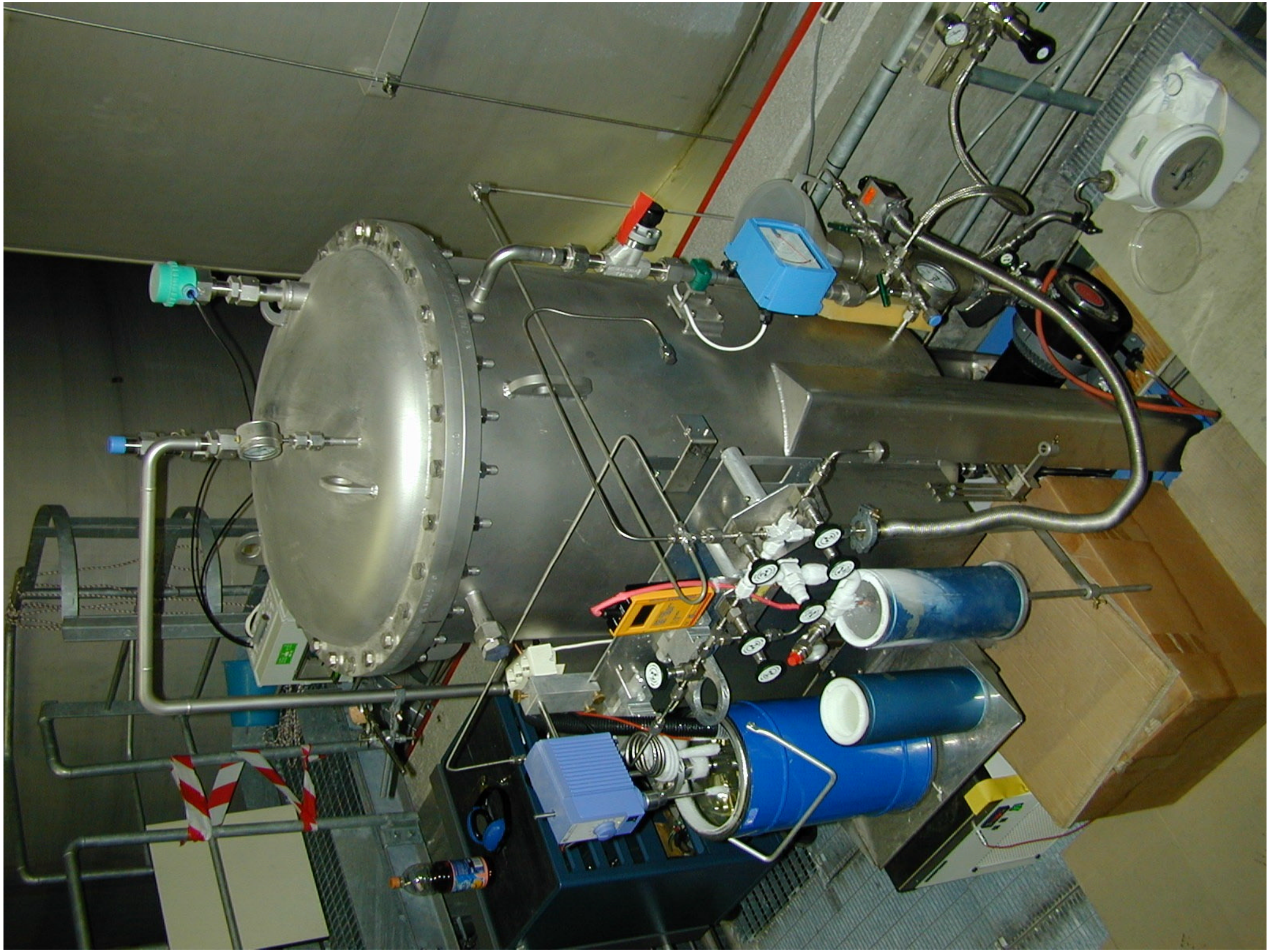
- during transport, storage and handling:
  - **ambient radon**
    (entering through leaks or diffusing through gaskets)
  - **emanation from all materials**
    (storage containments, piping, pumps, rubber gaskets, devices, valves etc.)
  - **emanation from purification columns**
    (steel packages, SiGel)
  - **Ra/Rn in water**
    (water extraction, also in buffer of CTF)
  - **Rn in nitrogen**
    (sparging)

- emanation inside the detector:
  - **radium in bulk of nylon vessel**
    (contamination during production of the nylon foil)
  - **contamination on the surface of inner vessel**
    (contamination during construction)
  - photo multiplier tubes and light cones, stainless steel sphere, cables etc.

Water purification

Conta-mination	Raw water	Borexino	
		design	achieved
^{238}U	10^{-3}	10^{-6}	10^{-7}
^{226}Ra	$3 \cdot 10^{-1}$	10^{-6}	$\approx 10^{-6}$
^{232}Th	10^{-3}	10^{-6}	10^{-7}
^{40}K	10^{-3}	$5 \cdot 10^{-6}$	$< 2 \cdot 10^{-6}$
^{222}Rn	10	10^{-6}	$\approx 3 \cdot 10^{-6}$

all in Bq / kg



Rn in various gases

- Monitoring:

  air in clean room - N_2 Blanket in CTF / containments

  - gas stream (Φ = 0,2 m^3/h) passes electrostatic chamber (418 l)
  - collection of radon progenies (^{218}Po, ^{214}Po)
    α - detection with pin-diode (working at 30 kV)
    detection limit: 0,1 mBq/m^3 (in SK experiment: 1,4 mBq/m^3 with sim. tech.)

    J. Kiko, NIM A 460 (2001) 272-277

- Production:

  synthetic ‚radon free' air during construction phases

  - necessary for safety reasons
  - specification: 0,1 mBq/m^3 with Φ = 10 m^3/d for 2 days
  - approach: standard purity nitrogen (evaporated on site)
    mixed with oxygen from low radiation combustibles,
    mixture purified by gas chromatography with activated carbon
  - in preparation

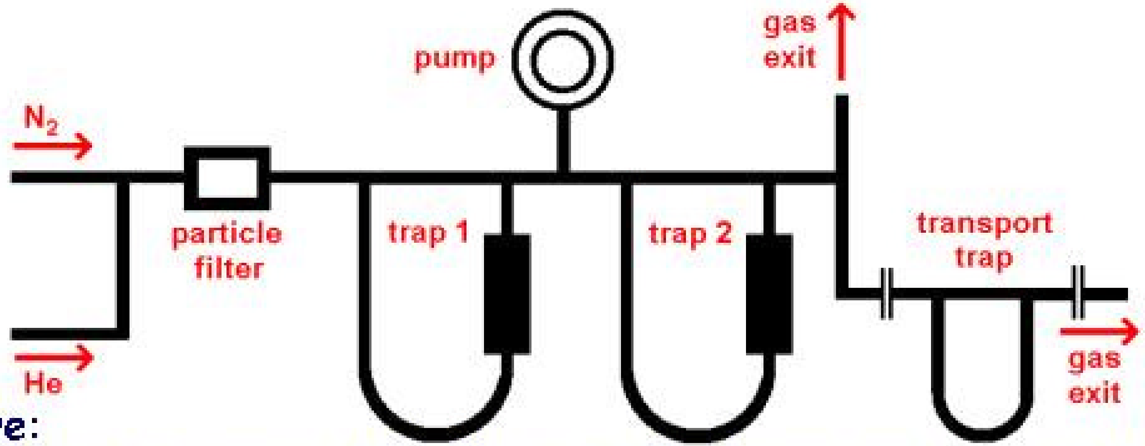
On site production of ‚Radon free' nitrogen

- Nitrogen used for flushing of detector segments and sparging of liquids (buffer, scintillator)
- supply of standard purity nitrogen ($A \approx 0.1$ mBq/m³)
- on site production of high purity N_2: liquid-solid-chromatography column
  - 11,5 l activated carbon
  - $A < 1$ µBq/m³ at $\Phi = 100$ m³/h permanent for 7 days
  - assembly of second column for continuous production (fall 2001)

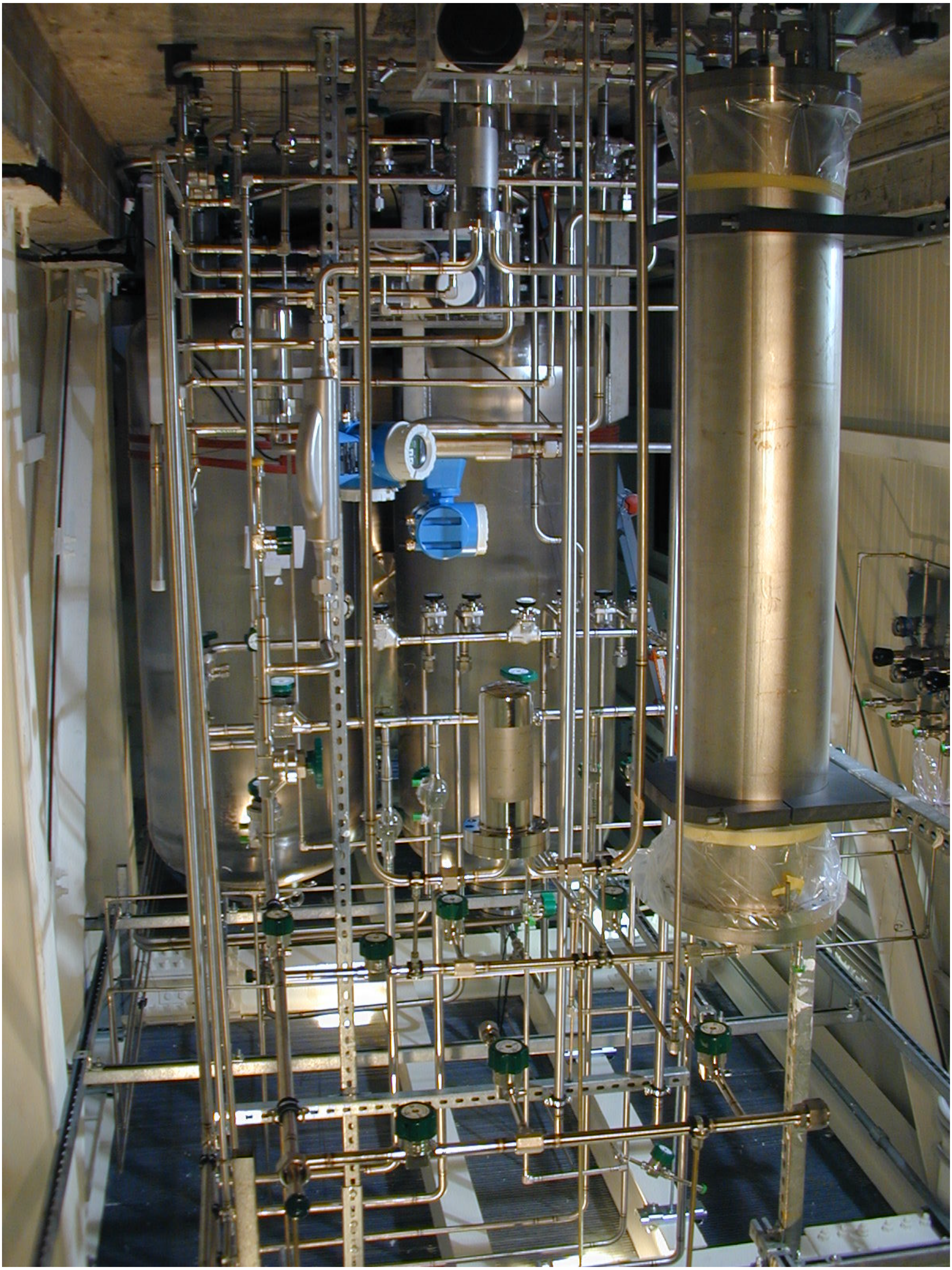
Rn in nitrogen

- concentration of ^{222}Rn from gas samples (sample size 200-500m³)
  detection limit: 0.5 μBq/m³
  G. Heusser et al., Appl.Rad. & Isot., 52 (3), (2000) 691-695

- nitrogen from cylinders: A ~ 0.1 - 1 mBq/m³
  (emanation from cylinder mantle, valve, gasket)



- compare:
  SNO blanket, preconc. of batch (ca. 1m³), Lucas cells, LD 1 mBq/m³,
  GNO in schielding tank, Lucas cell (7 l), LD 300 mBq/m³



Rn from large systems in the detector perifery

- **Process:**
  - flushing with pure N_2 and sealing
  - Rn emanates to gas filling (1-2 half life times = 4-8 days)
  - volume is either pumped or gas is flushed through charcoal trap
  - sample preparation and detection in proportional counter
  - ^{222}Rn-Signal $\{A_{total} = A_{System} + A_{gas}\}$

- **Results (^{222}Rn activity in saturation)**
  - „Scintillator Storrage Vessel"

Tank 1	< 60 mBq
Tank 2	(45 ± 8) mBq

  - „Liquid Handling System":

„Module Zero - Pressure Head"	< 0.033 mBq
„Module Zero – low pressure tube"	< 0.088 mBq
„Skids – buffer tank"	(0.74 ± 0.09) mBq
„Skids – water extract. col."	(4.9 ± 0.3) mBq
„Skids – N_2 sparging column"	(2.3 ± 0.2) mBq

STATUS AND FURTHER TIME SCHEDULE

Completed 01/2002

→ main detector structure

→ purification plants for water and scintillator (Mod0,Skid tower), clean N_2 plant

→ PMT-Installation incl. cables, connectors, calibration devices

→ Clean room, linked to main detector

→ Electronics, DAQ

→ Analytical facilities: CTF, MOREX

→ Storage tanks (4 x 114 m^3), 1 equipped with sparger

→ ISO Transport tanks (4 x 19 m^3)

→ Purity specifications defined, analytical procedures in place

Not yet completed (critical path items only)

→ Inner Vessels

Production ongoing. Installation in 3/2002

→ Scintillator procurement

started in 11/2001. ~60 m^3 PC on site. Ongoing.

→ Tank filling

120 m^3 PC (40 m^3 fiduc.) in 6/2002→ first 'data' ★

completion (300+1000 m^3 PC) in 11/2002

→ Calibration 'Air run' in 2/2002

else during 2002, as filling progress allows

★ 4 months later if water filling test is preceding


PLEASE PUT LABELS HERE
INFN PAVIA
1
22T6
88
RID/ADR,IMO1,IM101
4 M.A.W.P. BAR
PORTATA: 7t

OTHER PHYSICS WITH BOREXINO (or CTF)

Unique low background, low energy detector

Antineutrino – Spectroscopy $\bar{\nu}_e + p \rightarrow n + e^+$

Sun from spin/flavor conversion with magnetic moment
O(100/yr)

Earth ν mapping of global K,U/Th distribution
(heat sources!) ~ 20 events/yr

Nuclear Reactors European reactors: 800 km from GS
(long baseline experiment, Test LMA/Vac) ~ 30 ev/yr

Supernovae ~ 80 ν_e for SN at 10 kpc. Low energy part!

$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$ | $\bar{\nu}_e + {}^{12}C \rightarrow {}^{12}B + e^+$ | $\nu_x + {}^{12}C \rightarrow {}^{12}C + \nu_x$

Neutrino Magnetic Moment

with man-made Mega-Curie sources.

^{90}Sr $\bar{\nu}$; ^{51}Cr ν ; test 10^{-11} μ_B with ~10 MC sources.

Access tunnel in Borexino installed!

Double Beta Decay

dissolve in scintillator (CTF ?)

^{136}Xe (up to 2 t solvable in Borexino) ;

^{116}Cd (CdWO4 crystals). 'Cameo' project

Electron stability

$e \rightarrow \nu + \gamma$ (255 keV). CTF: $\tau > 10^{26}$ yrs