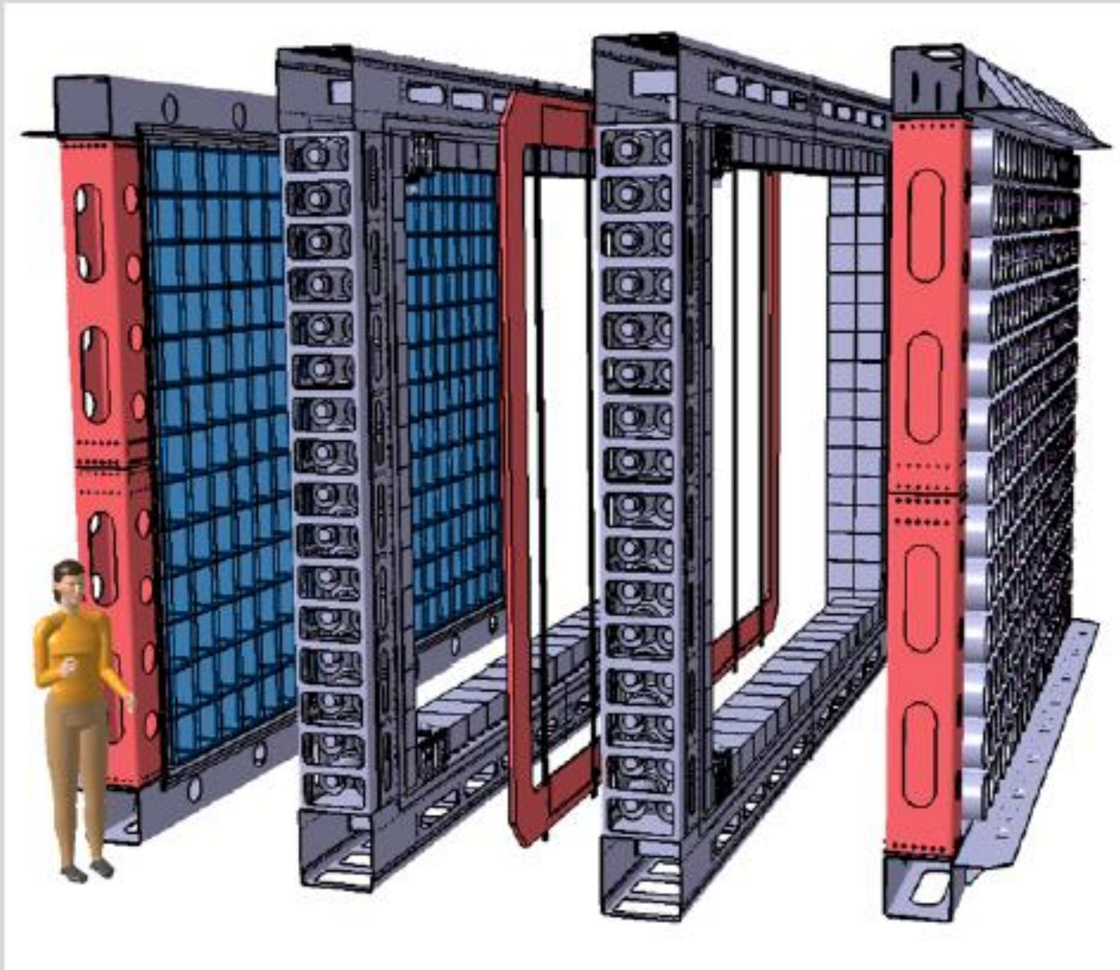
Status of SuperNEMO

ISOTTA meeting, 1-2 December 2014

The SuperNEMO detector



same detection technique as NEMO-3 :

- full reconstruction of the topology of the event [tracks of charged particle (and sign of charge) measured by the tracker + energy and time measured by the calorimeter]
- measurement of his backgrounds in independent channels with higher statistics than ββ

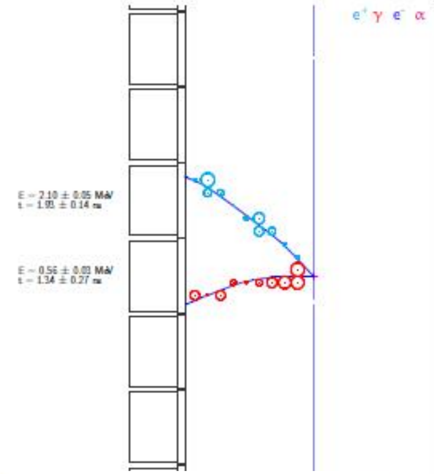
From NEMO-3 to SuperNEMO

	NEMO-3	**SuperNEMO**
Mass	6.9 kg	100 kg
Isotopes	^{100}Mo	^{82}Se
	7 isotopes	^{150}Nd, ^{48}Ca
Energy resolution (σ | FWHM)		
@ 3 MeV	3.4 | 8 %	1.7 | 4 %
Radon in tracker		
$\mathcal{A}(^{222}\mathrm{Rn})$	5.0 mBq/m^3	0.15 mBq/m^3
Sources contaminations		
$\mathcal{A}(^{208}\mathrm{Tl})$	$\sim$ 100 μBq/kg	$<$ 2 μBq/kg
$\mathcal{A}(^{214}\mathrm{Bi})$	60 - 300 μBq/kg	$<$ 10 μBq/kg
Total background		
cts·keV^{-1}·kg^{-1}·y^{-1}	1.3×10^{-3}	5×10^{-5}
Sensitivity (90 % CL)		
$\mathcal{T}^{0\nu}_{1/2}$	$> 1.1 \times 10^{24}$ y	$> 1 \times 10^{26}$ y
$\langle m_\nu \rangle$	$<$ 0.33 - 0.87 eV	$<$ 0.04 - 0.10 eV

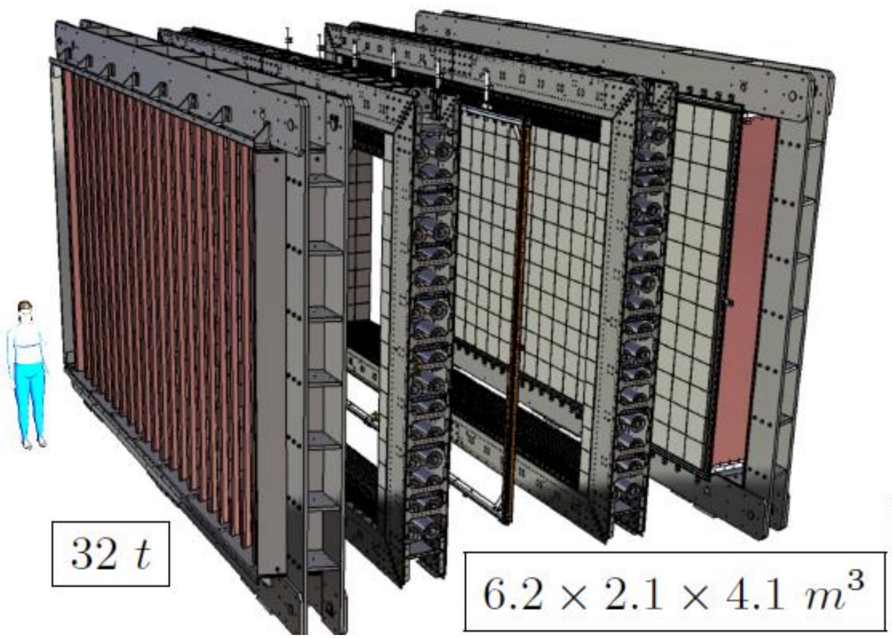
SuperNEMO Demonstrator Goals

[1st module, ~7 kg of source]

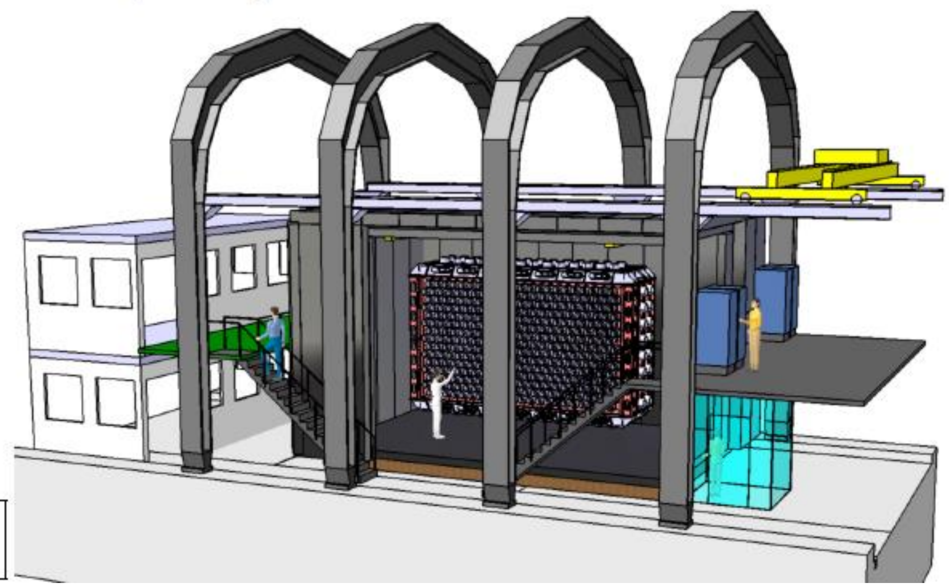
- SuperNEMO demonstrator module construction started in 2012
  - NEMO-3 sensitivity in only 5 months (90 % CL): $\mathcal{T}^{0\nu}_{1/2} > 1.1 \times 10^{24}$ y $\rightarrow \langle m_\nu \rangle < 0.33 - 0.87$ eV
  - No background in the $0\nu2\beta$ region in 2.5 years for 7 kg of ^{82}Se
  - Sensitivity after 17.5 kg·y exposure (90 % CL): $\mathcal{T}^{0\nu}_{1/2} > 6.5 \times 10^{24}$ y $\rightarrow$ $\langle m_\nu \rangle < 0.20 - 0.40$ eV



- Commissioning and data taking expected end of 2015



Replacing NEMO-3 in the actual LSM

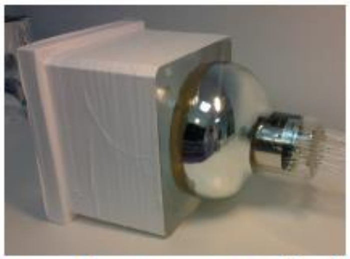


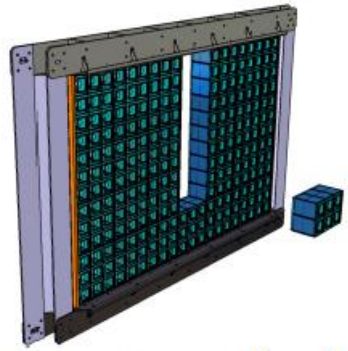
SuperNEMO Demonstrator Construction Status

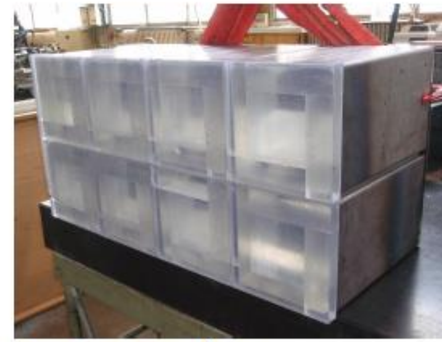
Calorimeter

- Optical modules: 5" under assembly and 8" modules under production
- FE digitizer boards built, control and trigger boards under development
- Magnetic shields produced and mechanical structure under construction

$256 \times 256 \times 194$ mm^3







Tracker

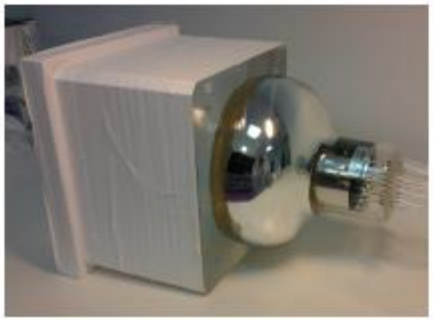
- Automated drift cells production ongoing with the wiring robot
- First 1/4 tracker C0 has been tested for radon emanation
- Cells population of C0 has reached its nominal rate: 144 cells installed

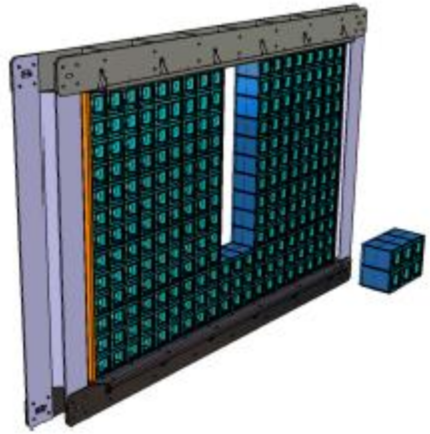
Sources

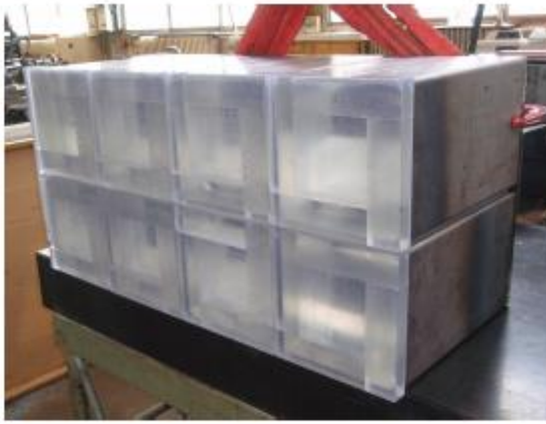
- Already 5.56 kg of enriched ^{82}Se and 4.56 kg purified
- Foils materials (glue, films...) under HPGe and BiPo selection processes
- Calibration sources deployment system and light injection under test

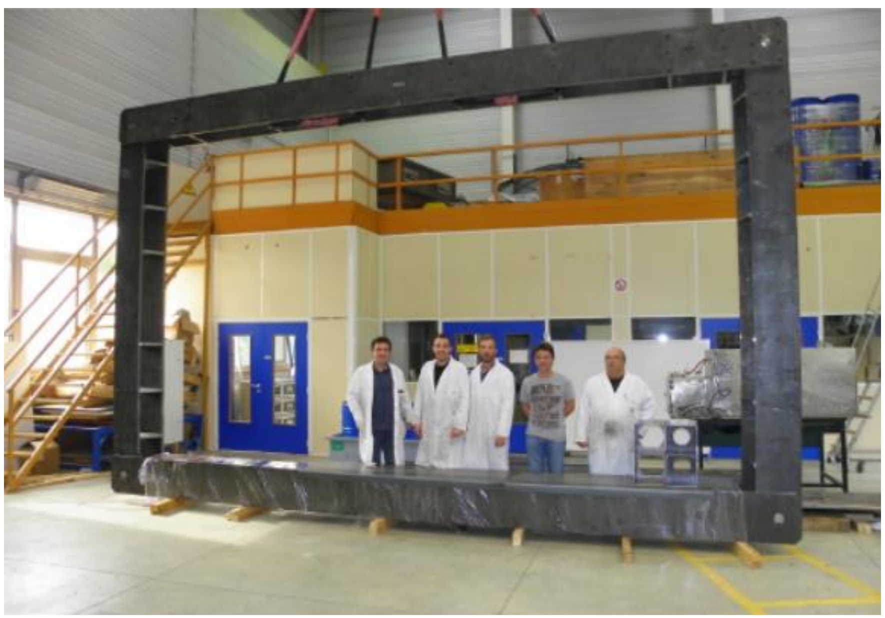
CALORIMETER [France]

$256 \times 256 \times 194\ \text{mm}^3$





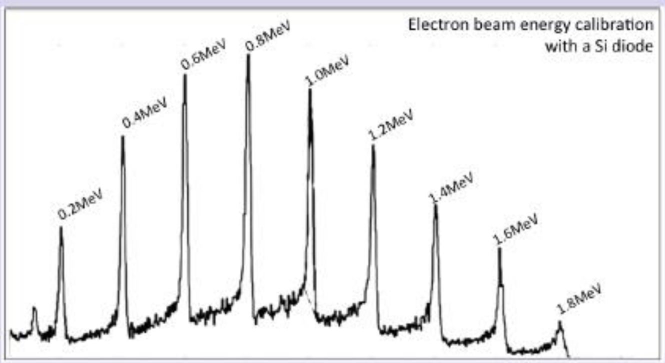


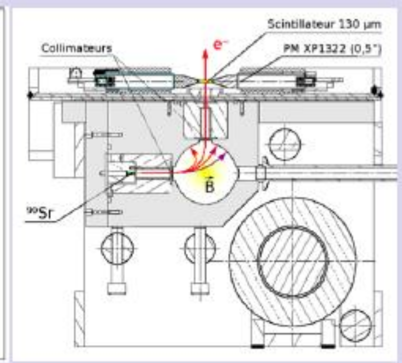


Unique characterisation tools

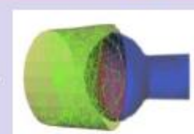
➢ 2 electron beam spectrometers to qualify the optical modules

- Mono-energetic electron beam from a ^{90}Sr 370 MBq β source
    - $\sigma_{x,y} \approx 3$ mm
    - Energy range [0.4-2.0] MeV
    - **FWHM @ 1 MeV = 1.0 ± 0.2 %**
- Automated X/Y scanning [2 m x 1 m]





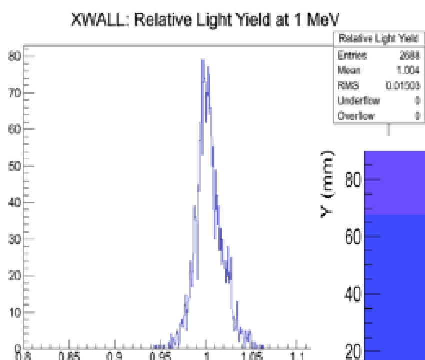
And a fine tuned optical simulations based on GEANT4

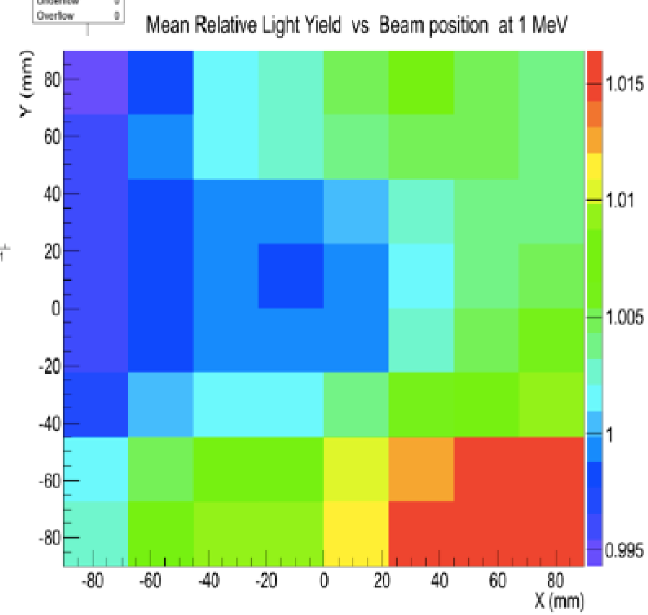


Uniformity of scintillator response

Polystyrene scintillator

- 10 L volume
- 10 000 γ/MeV
- Highly uniform Light Yield



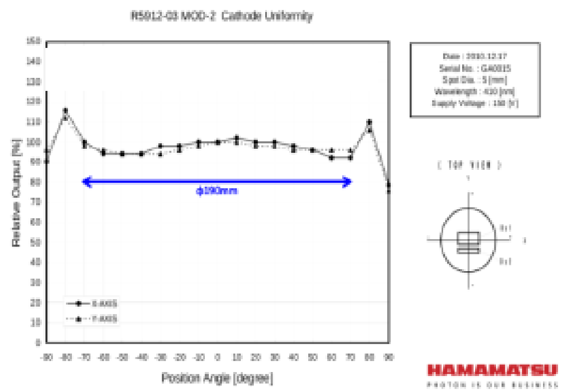


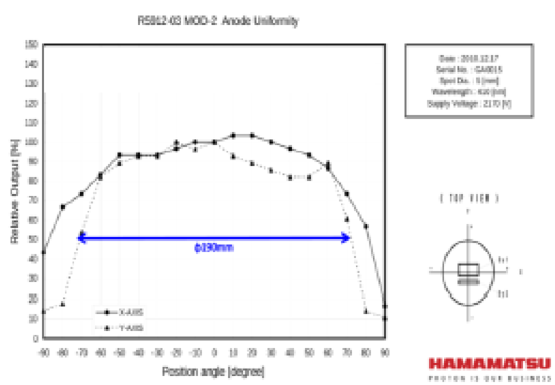
PMTs characteristics

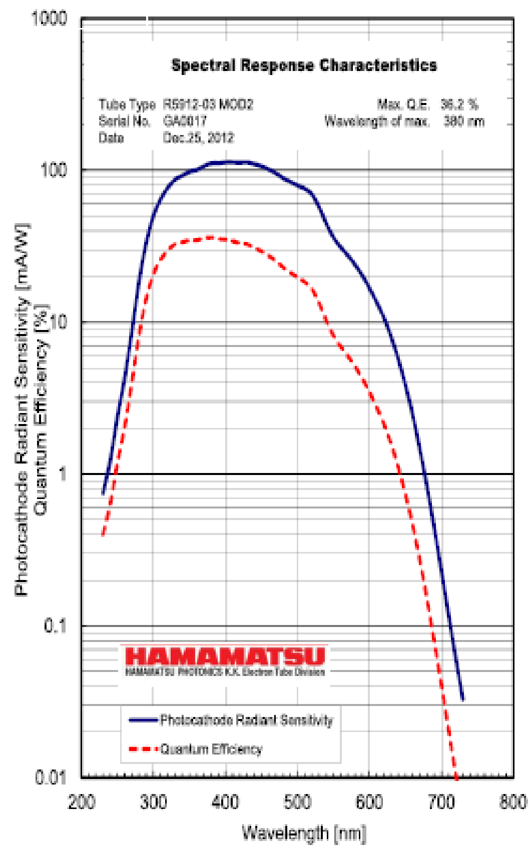
HAMAMATSU
HAMAMATSU PHOTONICS K.K. Electron Tube Division

New 8'' PMT (R5912-03 mod02)

- 8 stages → G = 2.10^5 - 10^6
- QE > 30 % @ 420 nm
- High uniformity

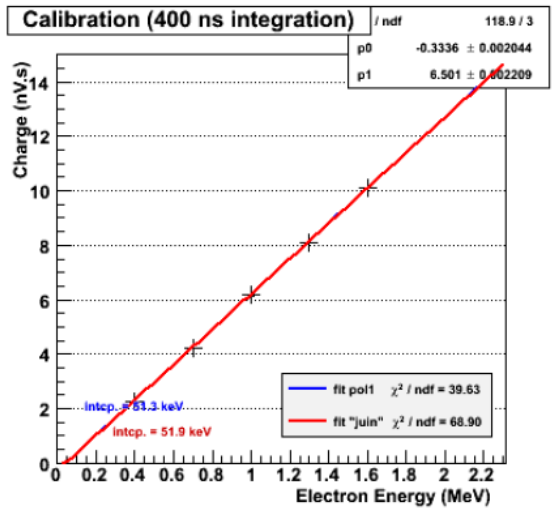




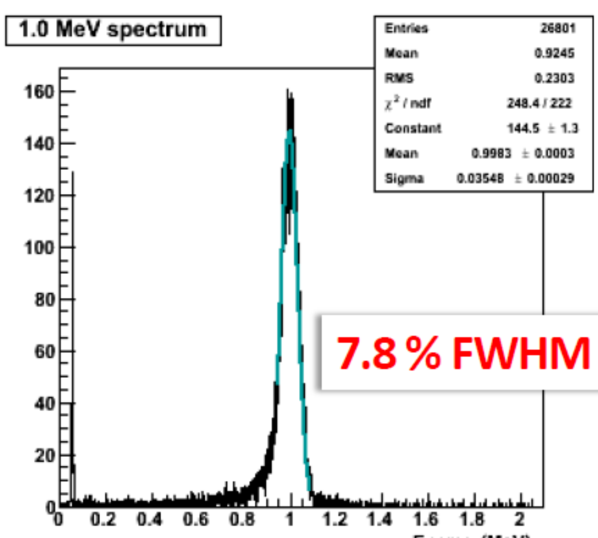


Optical modules energy resolution

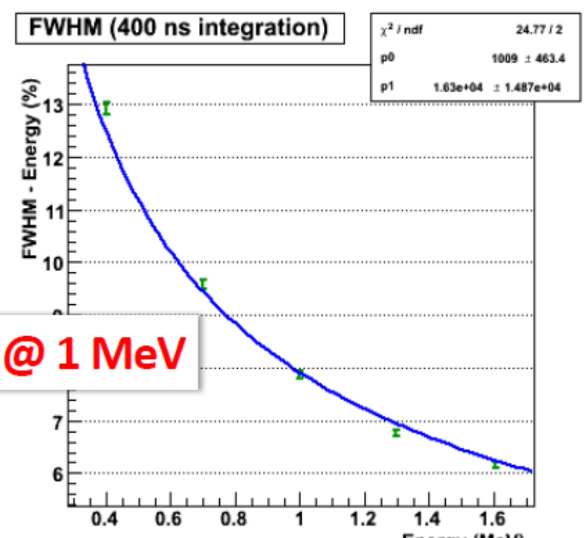
Gain linearity



Energy resolution @ 1 MeV



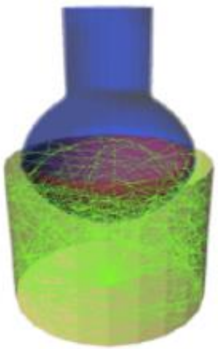
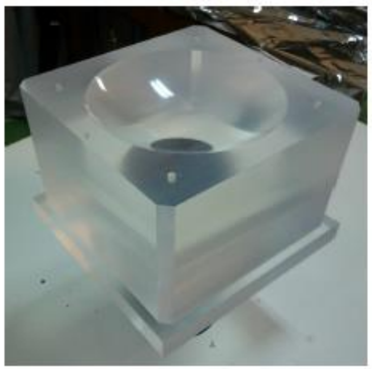
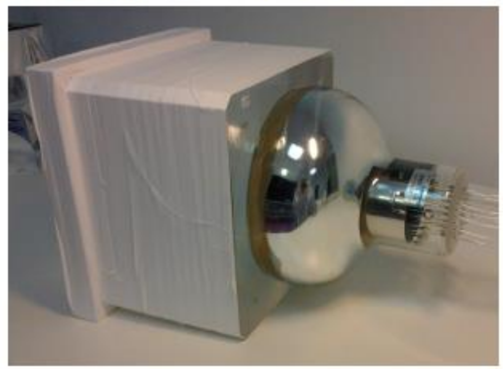
Energy resolution dependency

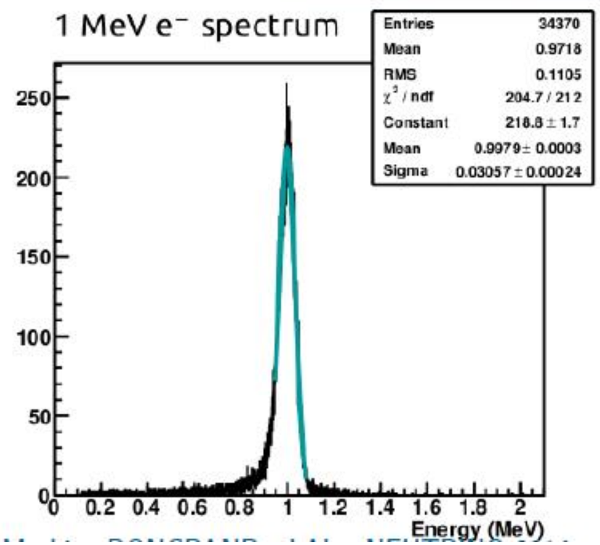


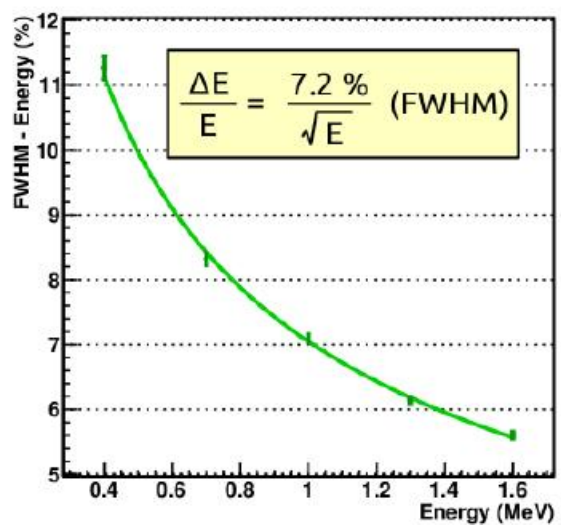
7.8 % FWHM @ 1 MeV

SuperNEMO Calorimeter Improvement

- Energy resolution of 7 % FWHM at 1 MeV achieved:
  - High QE large 8" PMTs (Hamamatsu R5912) directly coupled to the scintillator (no light guide) and improved HV divider
  - PVT plastic scintillators (also 8 % achieved for PS)
  - Optimization of the scintillator blocks geometry
  - Electronics sampling the PMT pulses $\sim$ 2 GS/s (MatAcq/SNFEB)





Status of the calorimeter

5 inches

70/80 OM [scintillators + PMTs] produced

70/80 characterized

40/80 in the magnetic shields

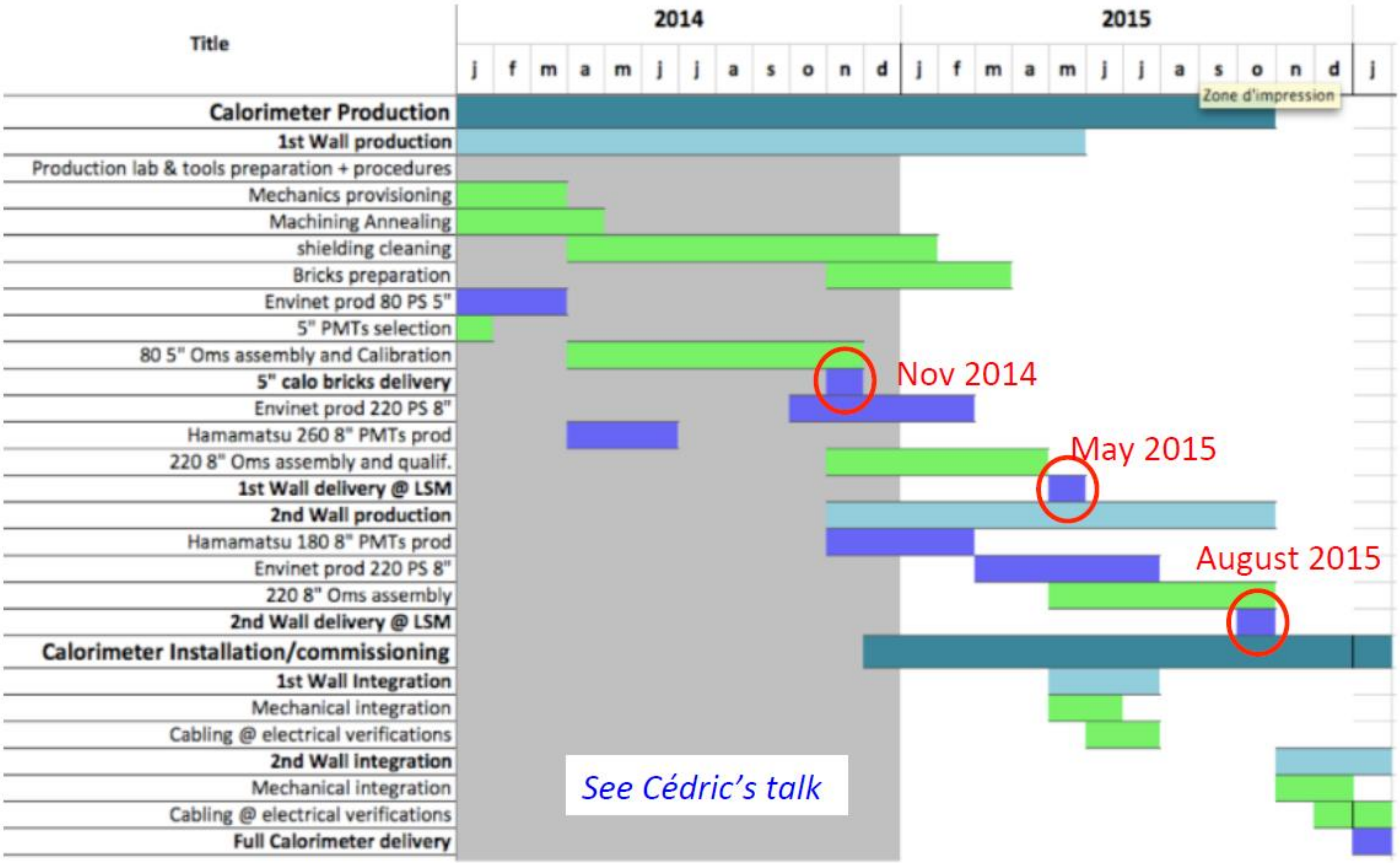
8 inches

40/460 scintillators already produced (arrived in CENBG)

400/460 PMTs already produced (arrived in CENBG)

6/460 OM produced (scintillators + PMTs)

MW SCHEDULE


Title
2014
2015
j f m a m j j a s o n d j f m a m j j a s o n d j
Zone d'impression
Calorimeter Production
1st Wall production
Production lab & tools preparation + procedures
Mechanics provisioning
Machining Annealing
shielding cleaning
Bricks preparation
Envinet prod 80 PS 5"
5" PMTs selection
80 5" Oms assembly and Calibration
5" calo bricks delivery
Envinet prod 220 PS 8"
Hamamatsu 260 8" PMTs prod
220 8" Oms assembly and qualif.
1st Wall delivery @ LSM
2nd Wall production
Hamamatsu 180 8" PMTs prod
Envinet prod 220 PS 8"
220 8" Oms assembly
2nd Wall delivery @ LSM
Calorimeter Installation/commissioning
1st Wall Integration
Mechanical integration
Cabling @ electrical verifications
2nd Wall integration
Mechanical integration
Cabling @ electrical verifications
Full Calorimeter delivery
Nov 2014
May 2015
August 2015
See Cédric's talk

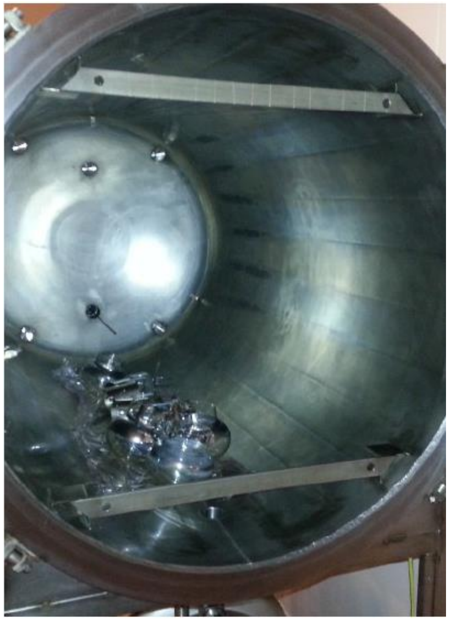
Calorimeter radon : PMTs emanation

- **PMT glass seems not emanate radon**
- Conclusion supported by
  - 30 x R6594 PMTs emanation measurement :

    $$\mathbf{E_m(CENBG) < 2.51 \,.\, 10^{-10}\ Bq.s^{-1}}\ (95\%\ \text{C.L.})$$

  - 5 x R6594 broken PMTs emanation measurement

    $$\mathbf{E_m(CENBG) < 6.01 \,.\, 10^{-9}\ Bq.s^{-1}}\ (95\%\ \text{C.L.})$$



TRACKER [UK]

- Production with the robot [weaving of the cells] + tests at Manchester
- Assembly of the tracker at MSSL : C0 (1/4) of the tracker completed, in commissionning
- Planning of installation at LSM

Tracker construction – Reminder of the procedure

Manchester

- Produce cassettes of 18 tracker cells
- Test each cassette
- Transport the cassettes down to MSSL

MSSL / UCL

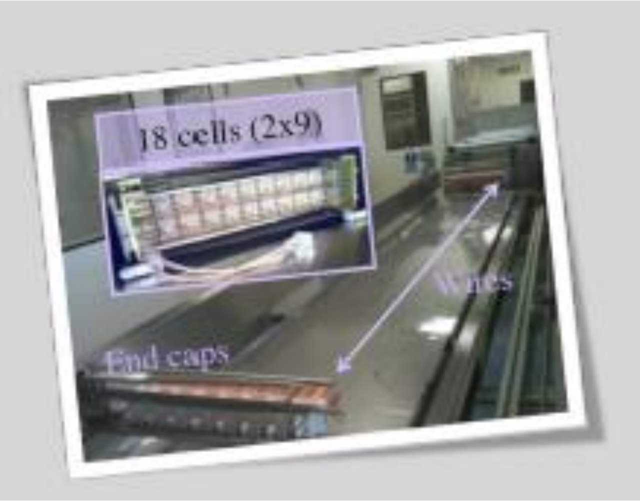
- Construct the tracker frame, one C-section at a time
- Populate with x-wall and veto optical modules
- Radon tests
- Insert the cassettes of cells
- Commission each C-section on the surface

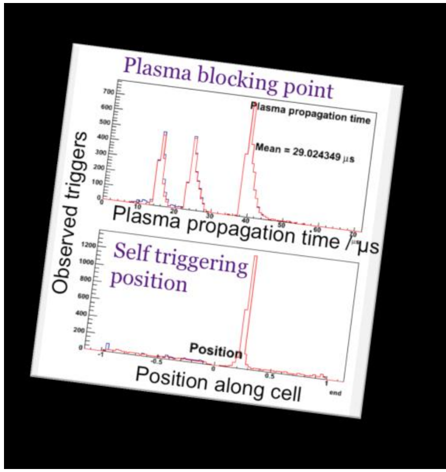
Radiopurity of the tracker

cells made of pure copper, delrin and inox
all components are cleaned : ultrasonic bath in a detergent solution followed by an ultrasonic bath in distilled water
all copper parts are passivated in citric acid to prevent corrosion

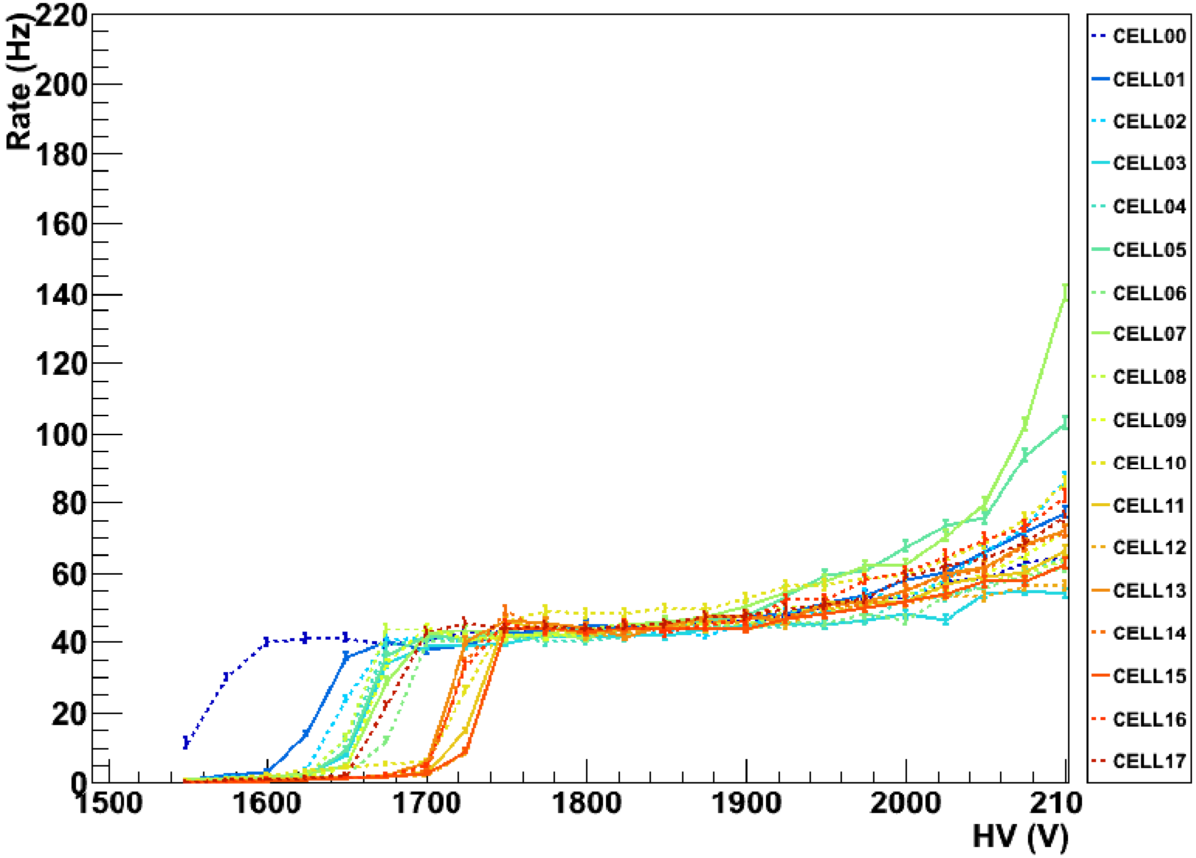
Cell production

To minimise human contact with the wires, the drift cells are produced by a wiring robot at the University of Manchester, in a cleanroom environment. Cells are produced in sets of 18. Each set of 18 cells is conditioned and tested immediately after production. The testing ensures there are no self-triggering or plasma-blocking points on any wires. The conditioning is continued until a good Geiger plateau is observed on all cells.



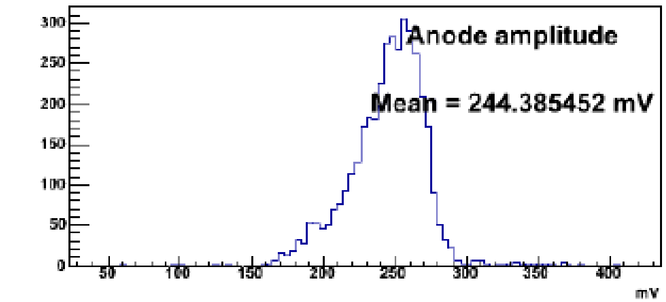


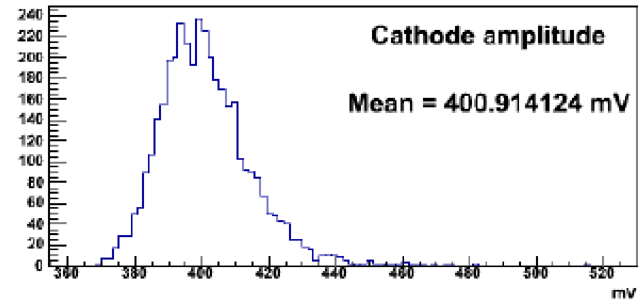
Tests of the Geiger cells

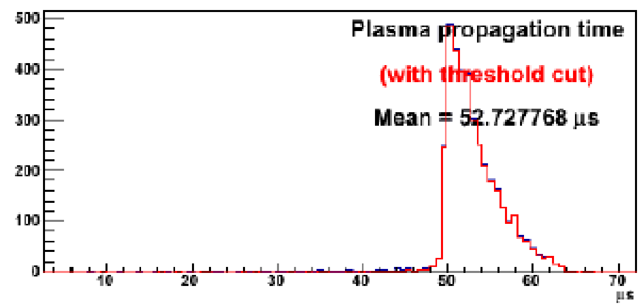


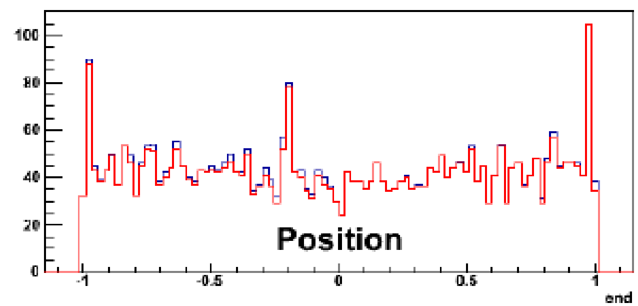
Test of 18 cells at Manchester : very stable (and wide) plateau

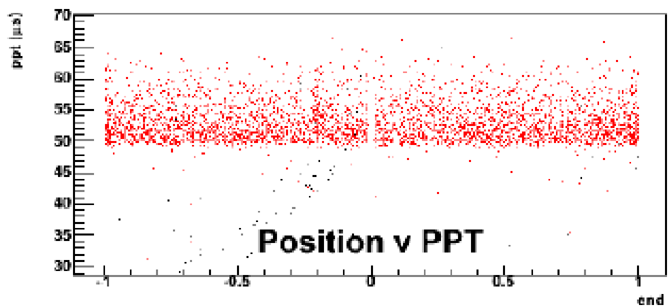
cell 12 @ 1775 V (last point in the "plateau")

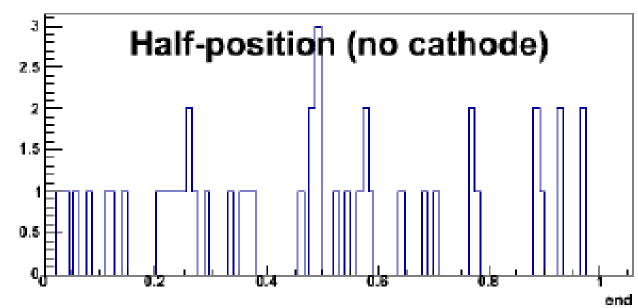


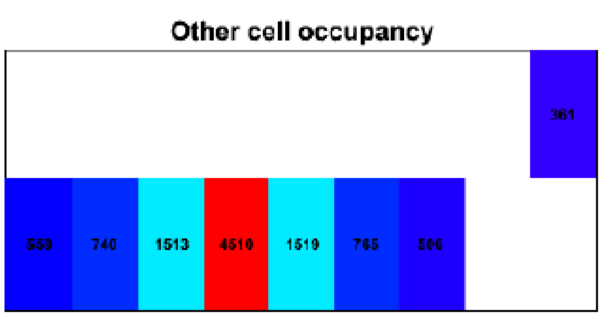












Cell 12 - HV 1775

Good rate: 47.61 Hz Noise rate: 0.03 Hz

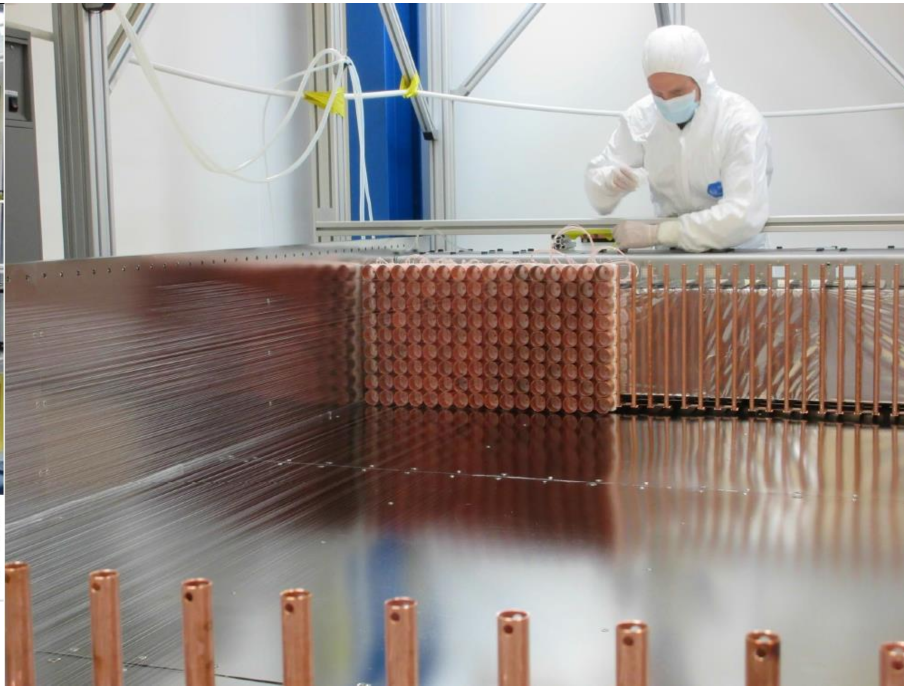
Cathode efficiency: 0.99

PPT efficiency: 0.97

2-spike: 0.99 0-spike: 0.00

Miss 1st spike: 0.00 2nd spike: 0.00

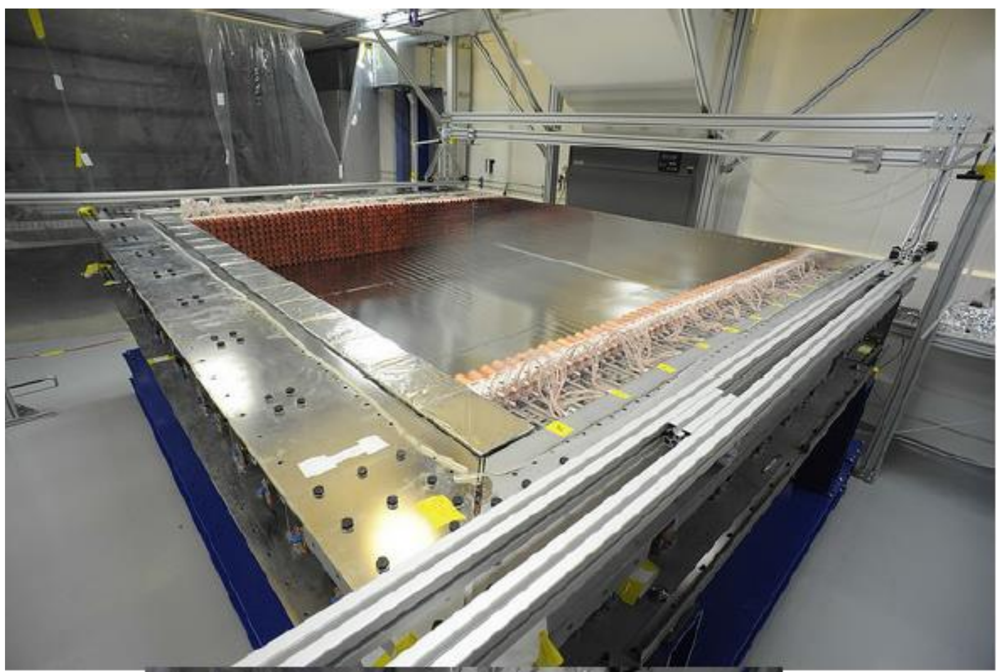
CO (1/4 of the tracker) is filled with drift cells…



TRACKER

C0 is complete

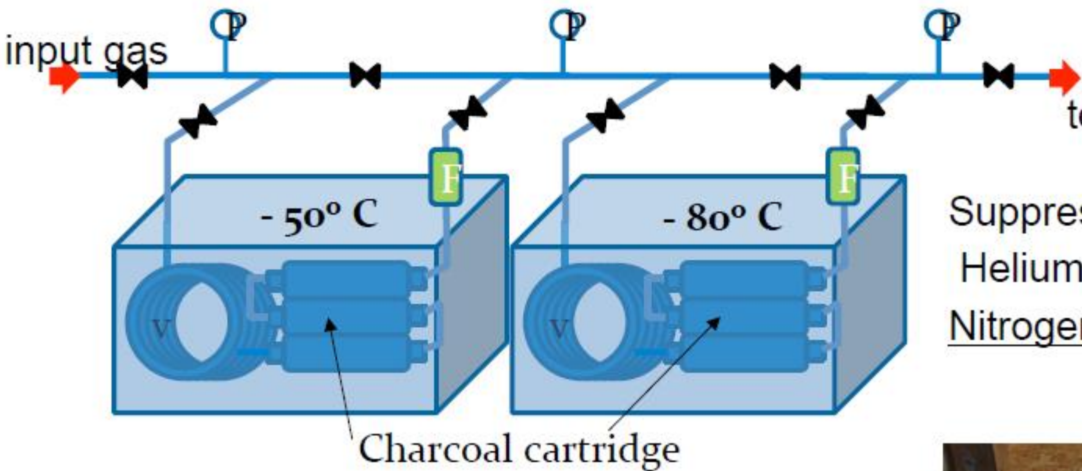
- It will now be leak-tested, radon-test and commissioned on the surface
- C1 will be built and populated while this happens
- Once C1 is populated, C0 can be moved out and delivered to LSM



To measure Radon emanation of C0

Radon Trap System designed and built at CPPM

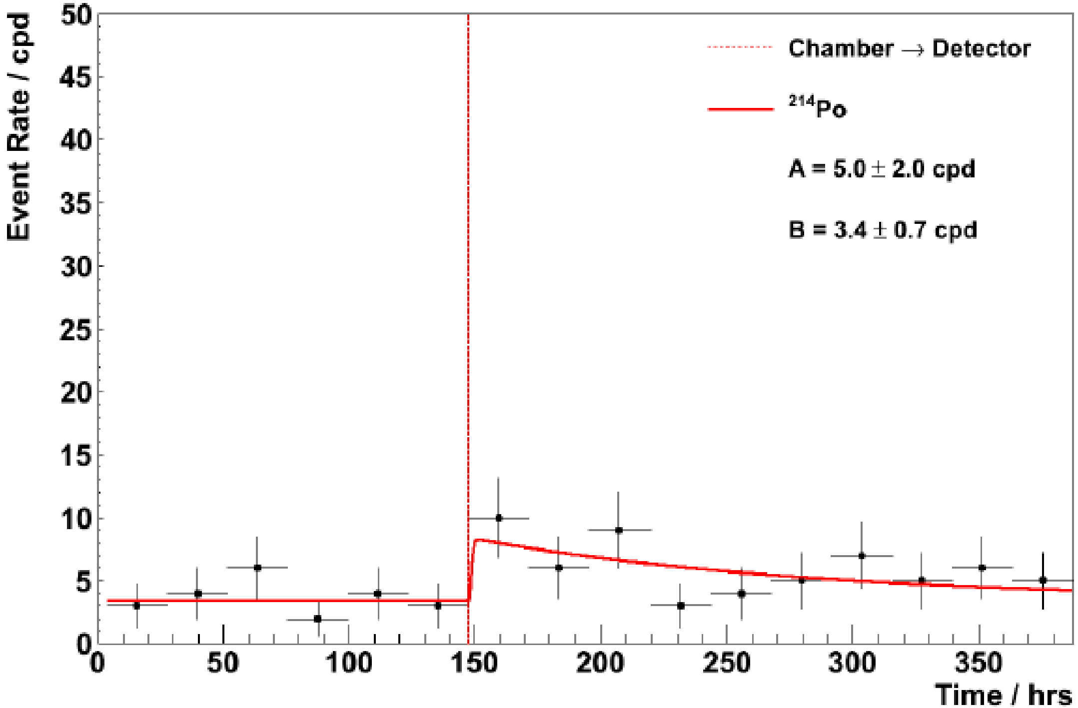
DocDB-3117 (J. Busto)



Suppression factor:
Helium: 5E+10
Nitrogen: ~10

Arrived to MSSL from Marseille
on 15-May-2014

Nitrogen Gas Measurement



Activity;

Po214 = 20.2 ± 12.5 μBq/m^3

Po218 = 35.0 ± 15.8 μBq/m^3

- Bottled nitrogen with a flow rate of 7 lpm for 20 hours.
- Expect 1.6 ± 0.5 cpd (doc-3267-v4) from trap background (flushed, then closed for 24 hours).

Gas	Source	Radon Level (μBq/m^3)
He	Cylinder	70 – 100
N_2	Cylinder	400 – 1000
N_2	Boil-off	90 – 140
N_2	J-Trap	20

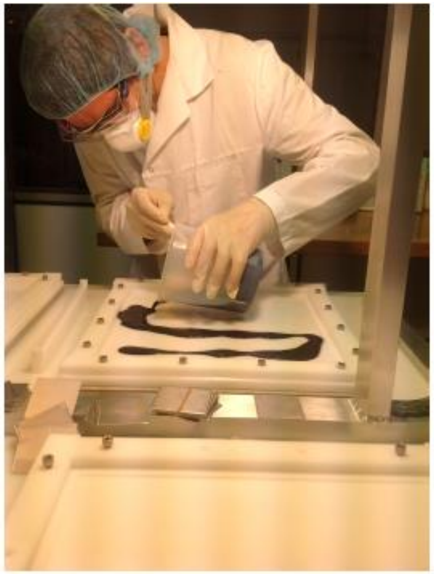
A Radon emanation of the C0 (1/4 of the tracker) is possible with a sensivity comparable to the demonstrator Radon requirement ~150 μBq/m^3

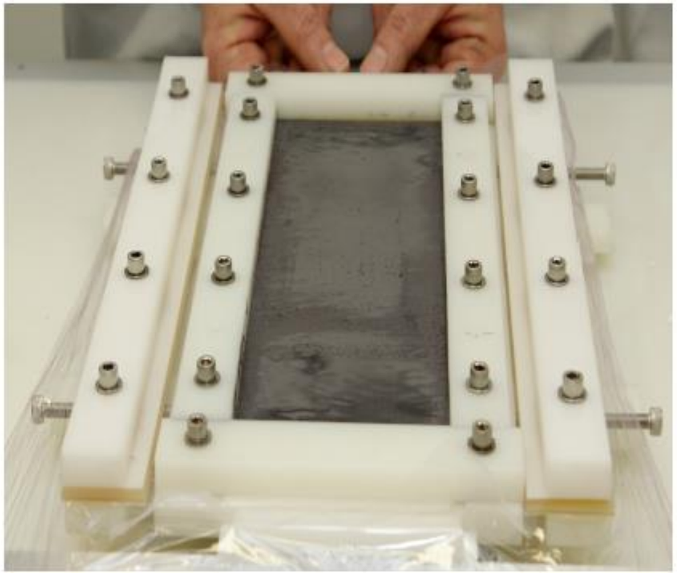
TRACKER Planning

Deliveries to LSM

C-section	Old schedule (Orsay)	New schedule
C0	March 2015	May 2015
C1	August 2015	November 2015
C2	March 2016	July 2016
C3	March 2016	July 2016

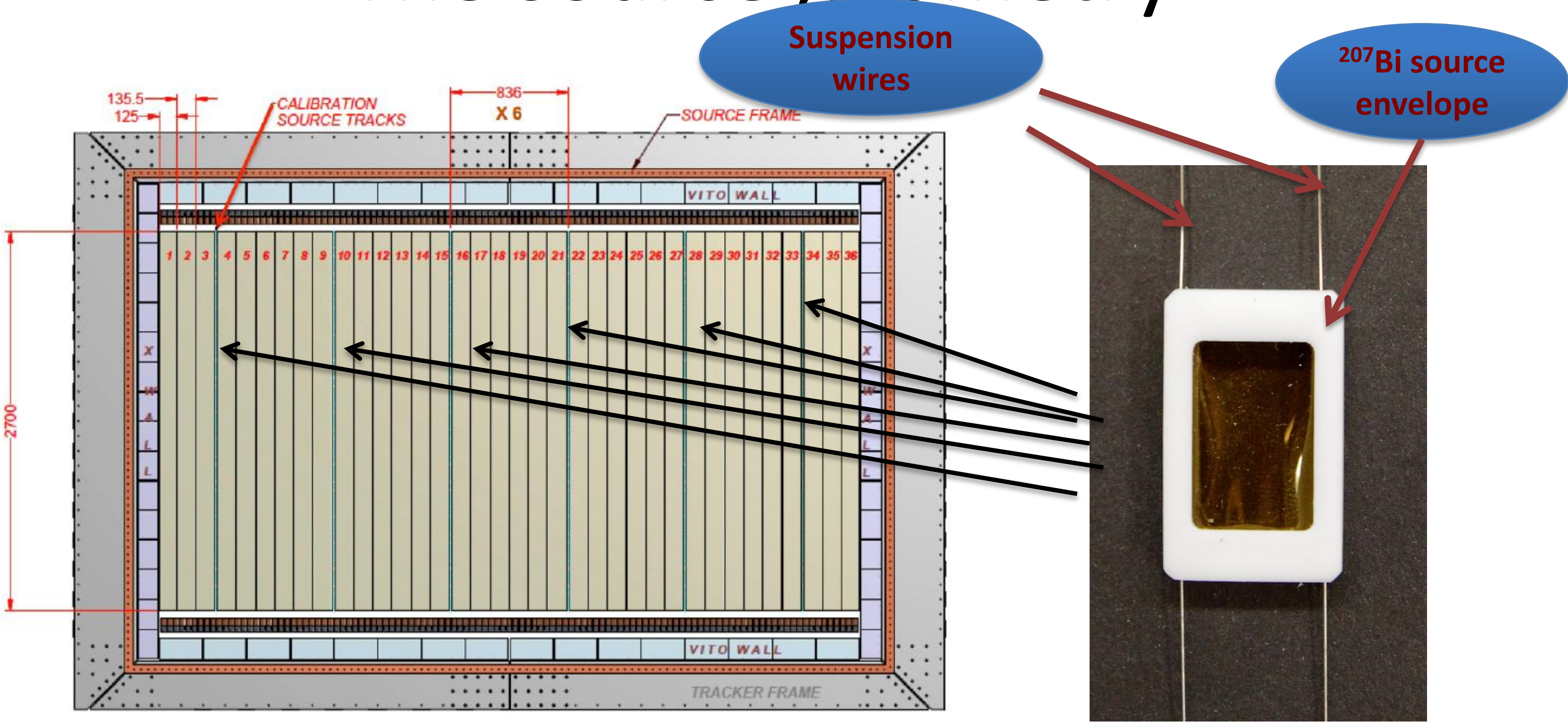
SOURCE [RUSSIA, FRANCE, USA]





- Already 5.56 kg of enriched ^{82}Se and 4.56 kg purified
- Foils materials (glue, films...) under HPGe and BiPo selection processes
- Calibration sources deployment system and light injection under test

The source geometry



very thin (~57 mg/cm^2) source to minimize energy loss in the foil
36 strips [2.7 m long, 13 cm wide, ~ 200 μm thick] placed in the middle of the detector

6 calibration tubes to introduce sources with an automated source deployment,
gas contamination free [to avoid penetration of Radon]

The 2 possibles source design under study

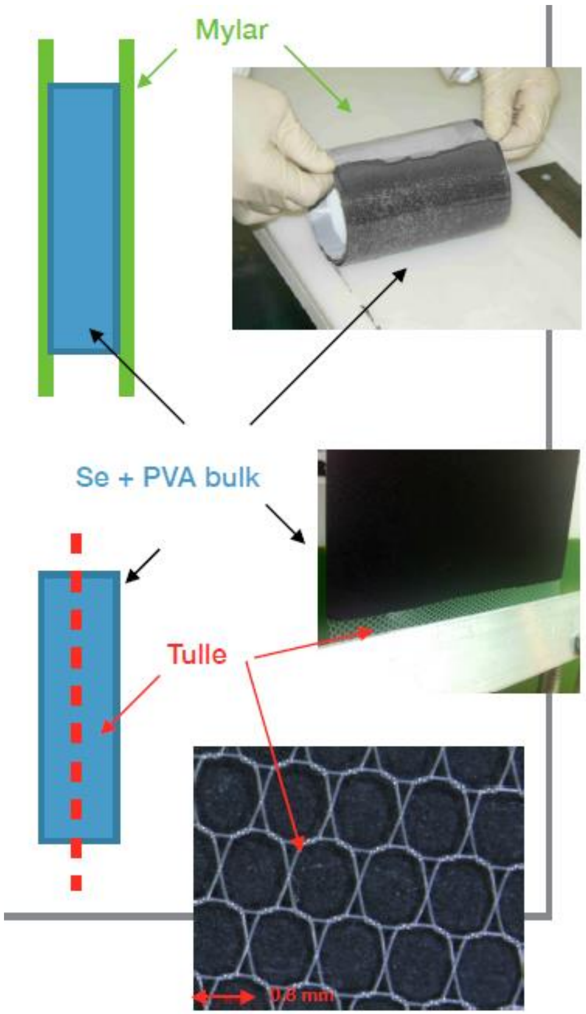
^{82}Se powder mix with PVA glue to produce a solid and uniform thin foil

MYLAR Design: Two thin layers of mylar film envelop the Se+PVA bulk.

The mylar acts as the physical bound of the foil, preventing loss of the powder. About 5-10 % of PVA is enough to glue the Se.

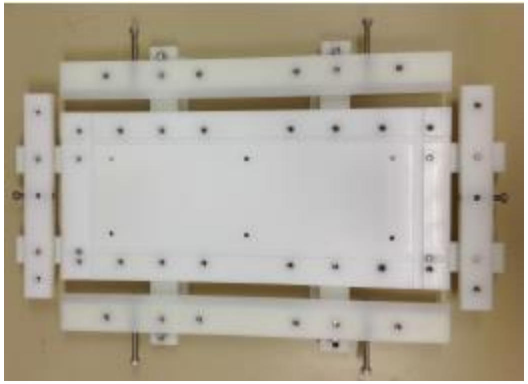
TULLE Design: A thin bobbinet tulle produced by warp & weft nylon monofilament is embedded in the foil.

The tulle is a lighter support w.r.t. to the Mylar inducing a lower background rate for a similar material contamination. About 10-15 % of PVA is required to glue the Se.



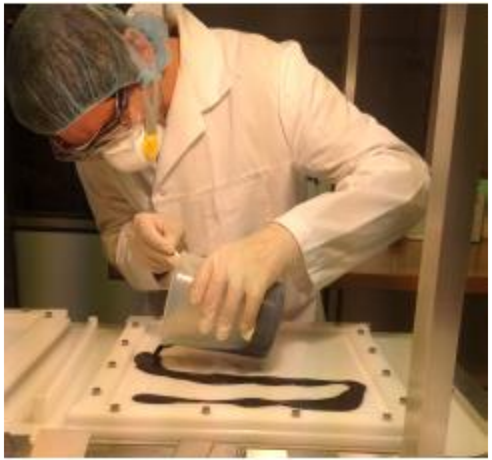
Foil production

The PVA glue is dissolved at 80^0C in ultrapure water and mixed with powder of Selenium.



The tulle (or the mylar) is installed on a dedicated support specifically to keep the tulle fabric in place.

The Se powder mixed with the liquid PVA is poured on the support and spread uniformly. Upon drying, the foil is resistant and flexible.



Measurement of the radiopurity of the first ^{82}Se source with BiPo-3

with 74 days of data, 240 g of source (1/4 of BiPo-3):

A(^{208}Tl) < 27 μBq/kg (90% CL)

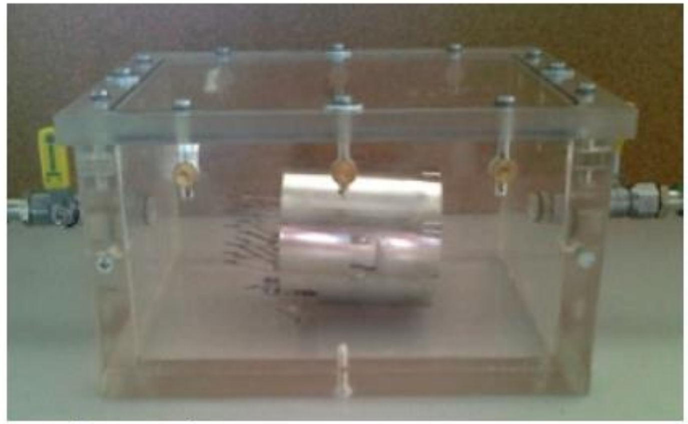
^{214}Bi analysis still on going : more complicated because of random coïncidences

source components [mylar, tulle, …] measured with BiPo-3

Reduce the Radon Background

- Goal: reduce the internal radon background to 0.15 mBq/m^3
- Select detector materials and protections (seals, films...)

Bordeaux emanation tank



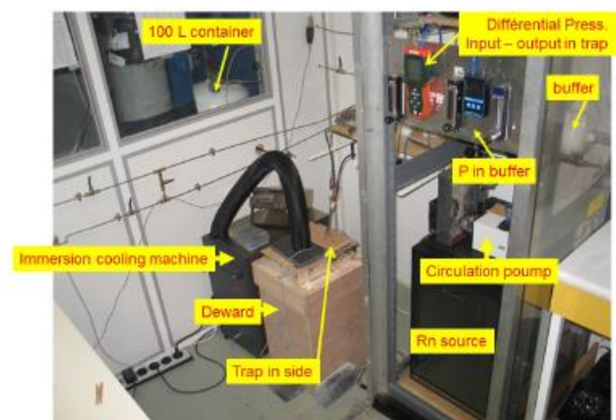
Bratislava emanation setup

Prague permeability setup

- Measure the radon in the detector or gases and radon purification

London concentration line

Gases purification



Marseille radon adsorption

Conclusion

- goals of the demonstrator :
- demonstrate that the extremely low background level for SuperNEMO can be reached ~ < 5-10 bckg events for 100 kg x 5 years
- obtain a sensitivity in exclusion at 90%CL of

  6.5×10^{24} y in $T_{1/2}$

  [0.2-0.4]eV in $\langle m_\nu \rangle$

  for 7 kg of ^{82}Se in 2.5 years
- planning :

- end of 2015 : calorimeter delivered at LSM, under commissioning. ½ of the tracker delivered to LSM. Under discussion : possible data taking without the source [commissionning of the detector, possible radon measurement ?]

- mid-2016 : full tracker deliver. Data taking

BACKUP

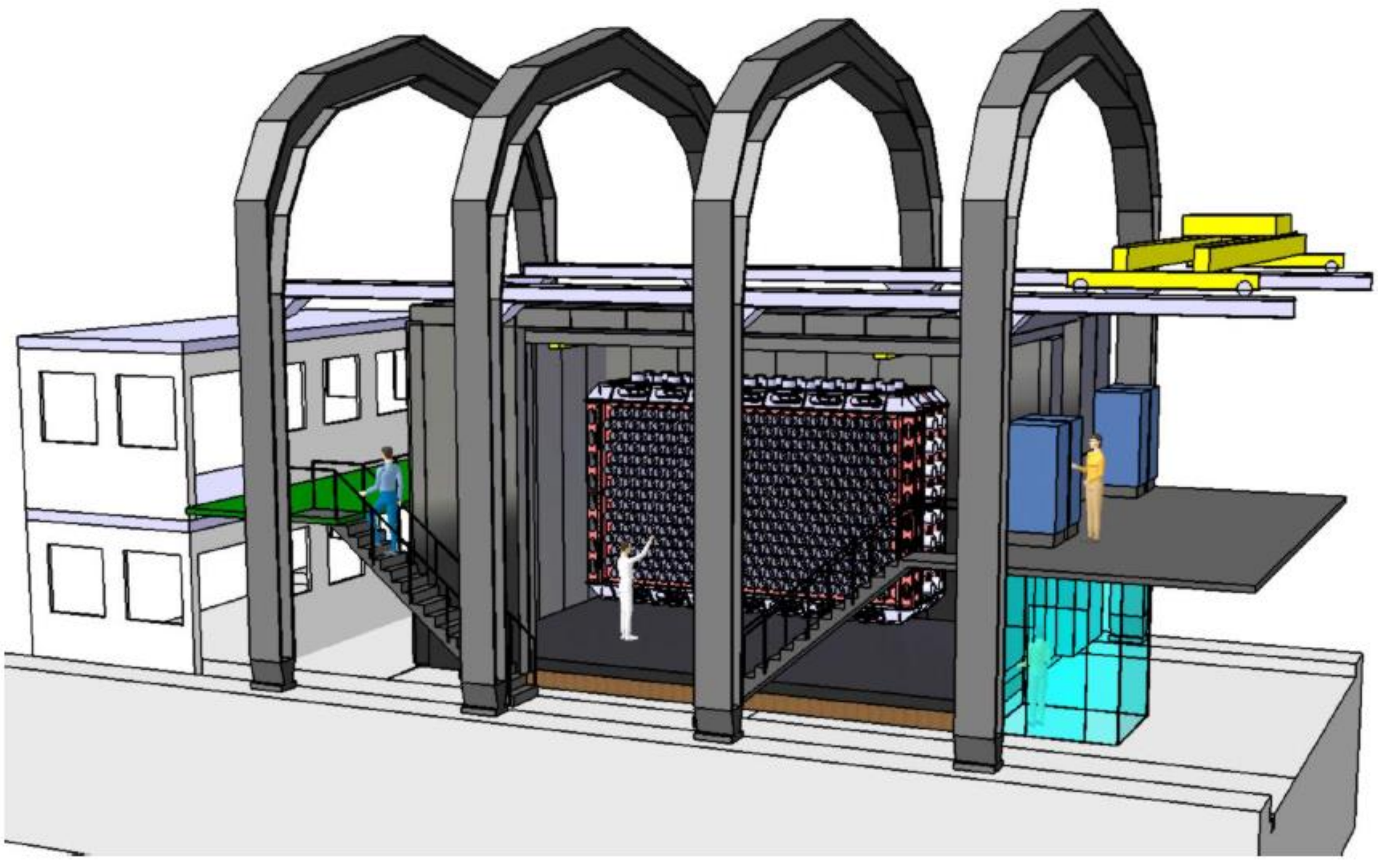
Current status of NEMO-3 sources

Place of Prod.	Year of Prod.	Mass (kg)	Purchased by	Owned by	Where now	Comments (Activities in mBq/kg)
Tomsk	2005-2006	2	France	ITEP	LSM	1 kg purified by INL, now in a powder form Bi-214 < 0.9 Tl-208 < 0.5 Ru-106 < 0.8 1 kg non-purified, now in a powder form Bi-214 ~ 2.6 Tl-208 ~ 1.5 Ru-106 ~ 20.8 (in 2006)
Tomsk	2007	1.5	France	France	LSM	Purified by distillation, now in a form of pellets Bi-214 < 1.9 Tl-208 < 1.2
ECP	1995	0.96	ITEP	ITEP	ITEP	Was used in NEMO-3. In 2012 was purified by distillation then into powder at ECP. Was not measured by HPGe.
ECP	2009-2010	1.1	ITEP	ITEP	ITEP	Purified by distillation; 0.6 kg is in a form of powder (not measured) 0.5 kg is in a form of pellets: Bi-214 < 1.9 Tl-208 < 1.2
?	2014	1.5	France	JINR	→ LSM	To be purchased*
TOTAL		7.06				Purified, in powder: 1.0 + 0.96* + 0.6* = 2.56 Not purified, in powder: 1.0 Purified, in pellets: 1.5 + 0.5 = 2.0 Not purified, in pellets: 0 To be purchased: 1.5* * Not measured by HPGe or BiPo

Present status:

Demonstrator construction started in 2012:

It will be installed at LSM in the place where NEMO-3 operated



Present status:

Demonstrator construction started in 2012:

It will be installed at LSM in the place where NEMO-3 operated

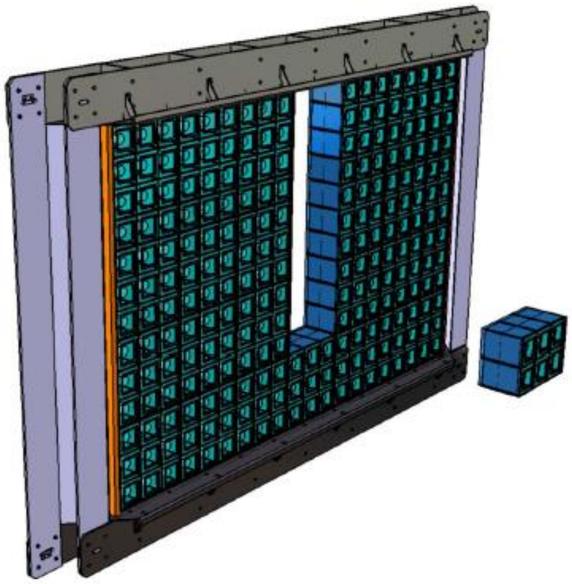
Calorimeter

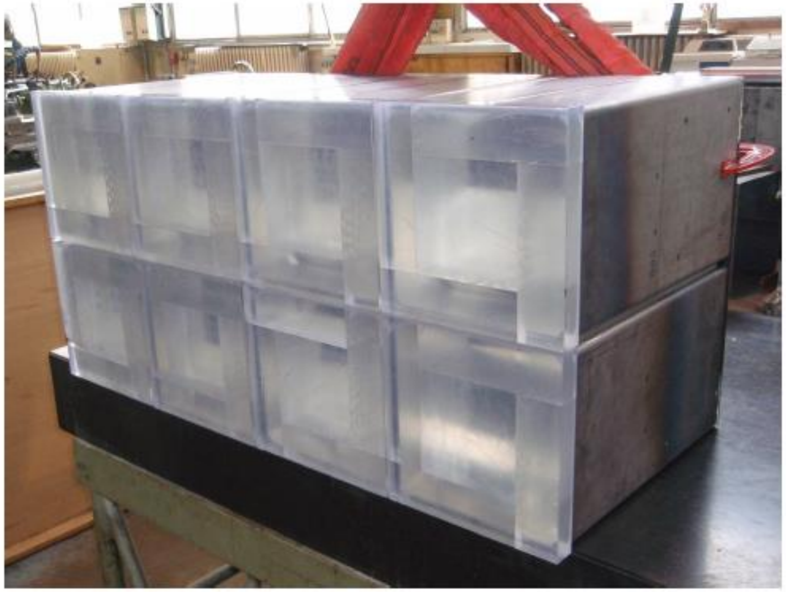
Optical modules: 5" under assembly and 8" under construction

FE digitizer boards built, control and trigger boards under development

DAQ components already done or under development

Construction of the calorimeter blocks, magnetic shields and mechanical structure started





Present status:

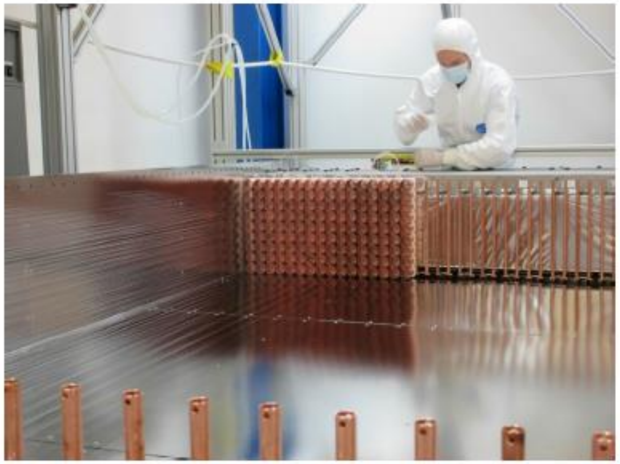
Demonstrator construction started in 2012:

- It will be installed at LSM in the place where NEMO-3 operated

Calorimeter

Tracker

- Wiring robot developed for automated drift cells production
- First quarter of the C0 (Tracker chamber) constructed and checked for Radon emanation (OK!)
    - Population of the Geiger drift cells started
- Commissioning of the full C0: currently at sea-level



Present status:

Demonstrator construction started in 2012:

It will be installed at LSM in the place where NEMO-3 operated

Calorimeter

Tracker

Sources

5.5 kg of ^{82}Se available with 0.5 kg already purified

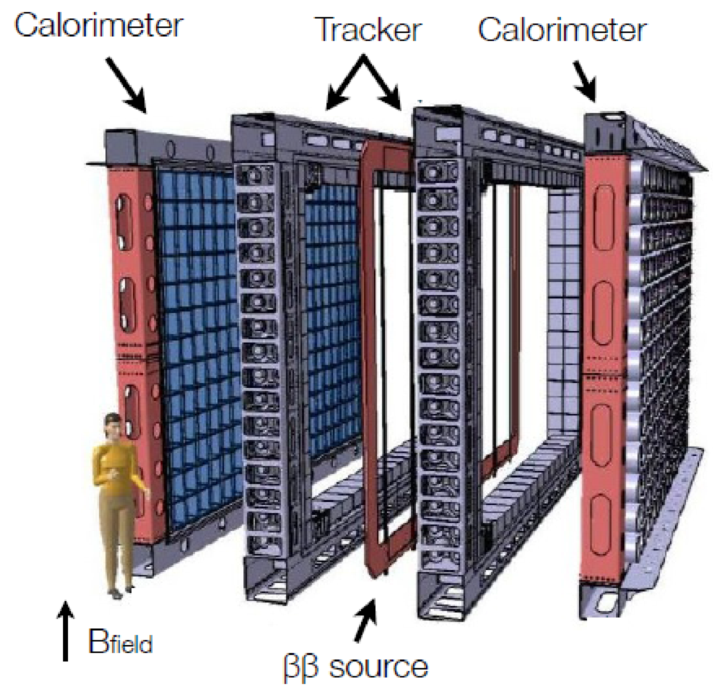
Screening of potential source components (glue, support mesh…) with HPGe and BiPo ongoing

Calibration sources deployment system prototype under test

SuperNEMO: toward the new generation

Extrapolate a well known technique:

- 100 kg of $\beta\beta$ emitter in 20 detection module
- Approach Inverted Hierarchy region



	NEMO-3	SuperNEMO
Isotope	7 kg ^{100}Mo	~100 kg ^{82}Se (^{150}Nd, ^{48}Ca)
Exposure	35 kg y	~500 kg y
Energy res.	8% @ 3 MeV	4% @ 3 MeV
^{208}Tl (source)	~100 μBq/kg	< 2 μBq/kg
^{214}Bi (source)	~ 300 μBq/kg	< 10 μBq/kg
Rn (in tracker)	5 mBq/m^3	0.15 mBq/m^3
$T_{1/2}$	10^{24} y	10^{26} y
$\langle m_\nu \rangle$	0.31 - 0.79 eV	0.04 - 0.1 eV

A challenge under many aspects:

- R&D program in the past years almost completed!
- Next step: Demonstrator module

SuperNEMO: the demonstrator module

One SuperNEMO module → 7 kg ^{82}Se running ~2.5 y

- To be installed @ LSM (replacing NEMO-3)

Match SuperNEMO requirements

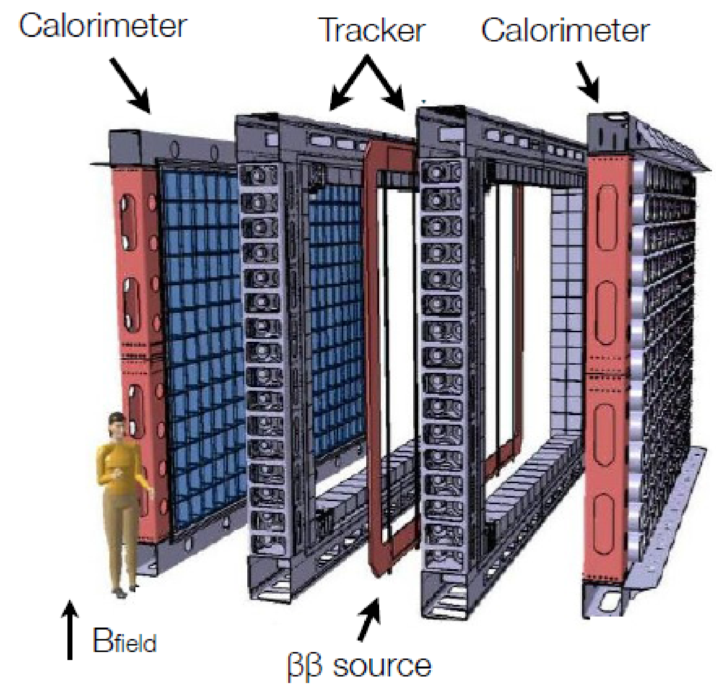
- Background level ~ 10^{-4} cts./(keV kg y)
- Background free at high energy (^{150}Nd)

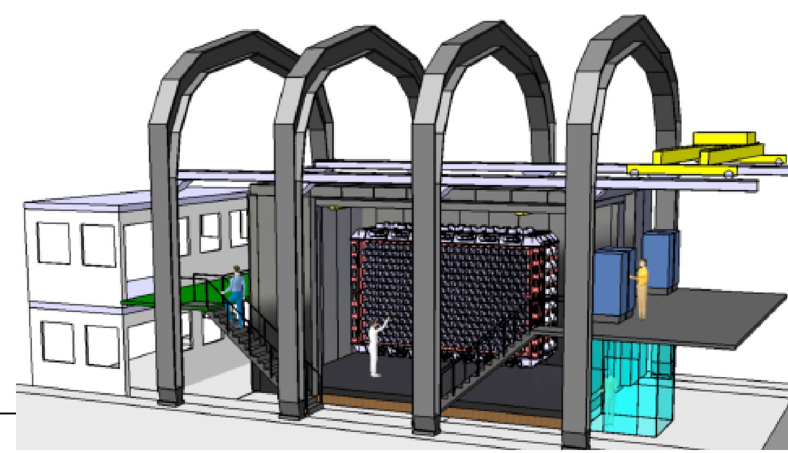
Reach NEMO-3 (^{100}Mo) sensitivity in 4.5 months

- Sensitivity: $\langle m_\nu \rangle$ ~ 0.20 - 0.40 eV

Schedule:

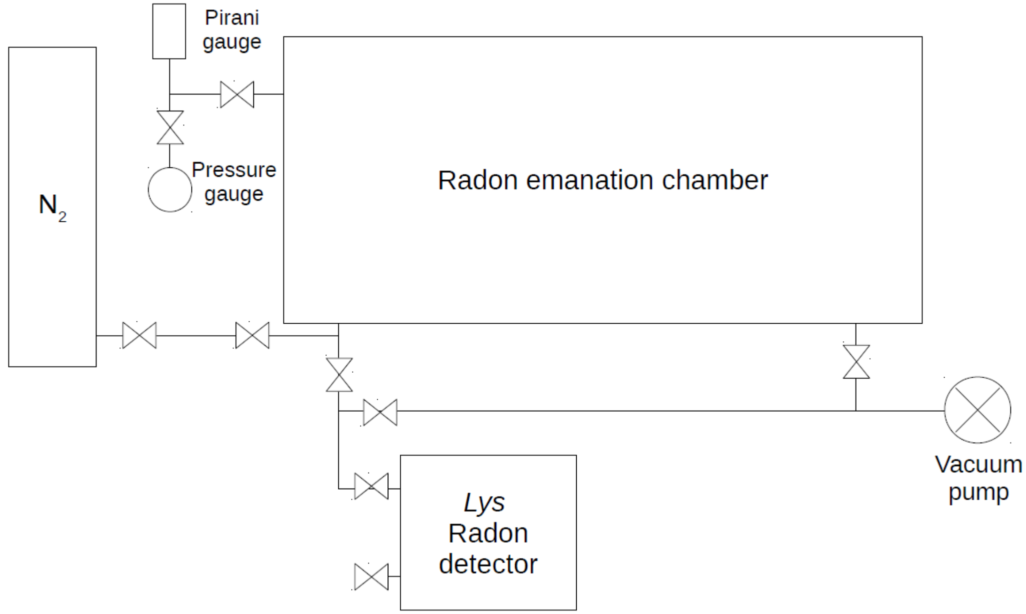
- Calorimeter & tracker under production
- Installation & commissioning in 2015
- First physics data by the end of 2015!



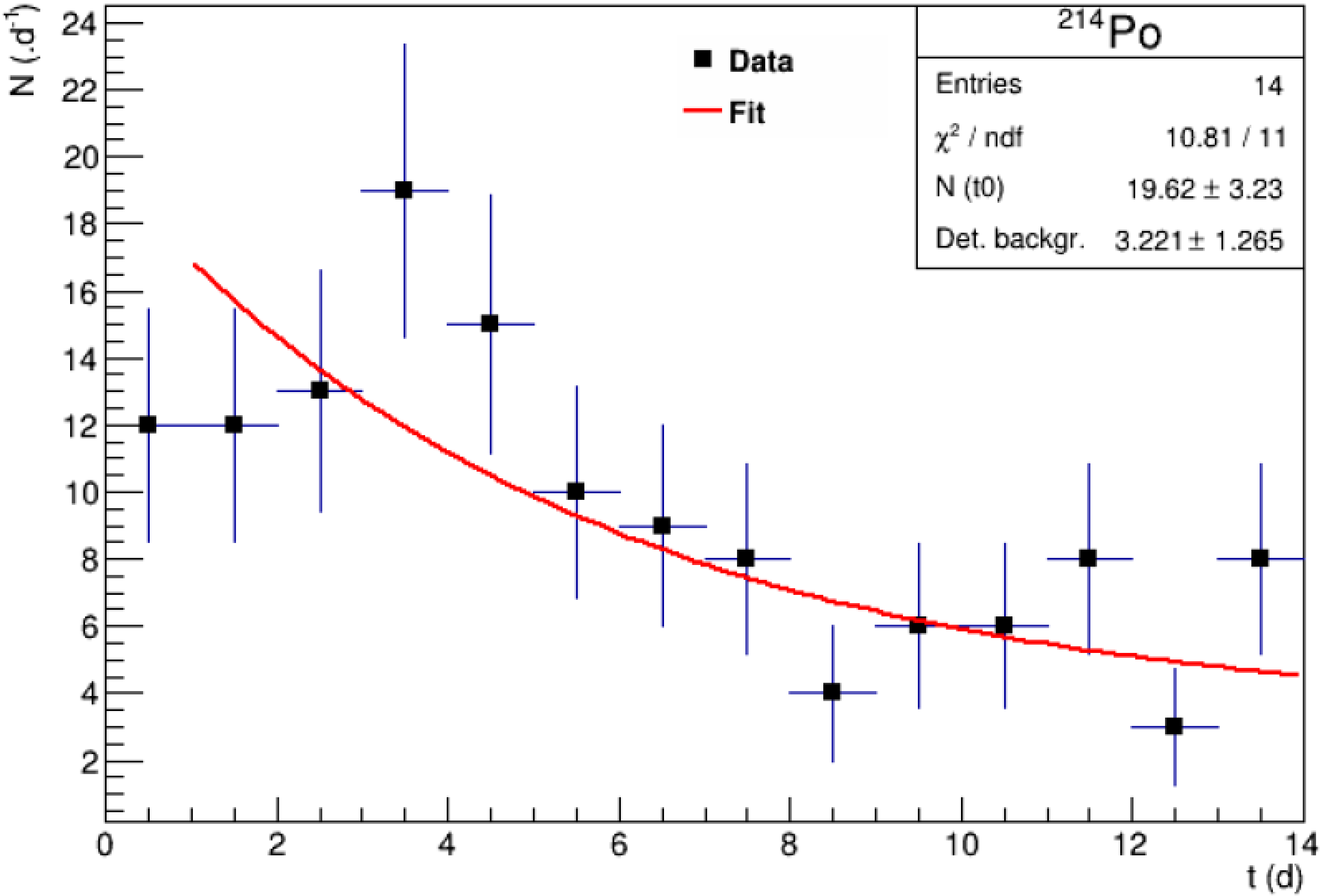


The calorimeter [France]

Radon emanation measurement



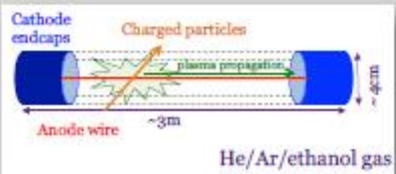
- While a sample is emanating inside the setup the chamber (710 L) is filled with N_2 with an overpressure (~ 1.1 bar)
- Before starting the measurement the detector (70 L) is emptied
- After emanation we open the valve between the chamber and the detector and balance the pressure (1 bar)
- Since 9 % of the gas from the chamber is transfered we expect 9 % of Radon from the chamber to be transferred
- We tested this hypothesis using a ^{226}Ra source



- Counting rate → **19.6 ± 3.2 cpd**

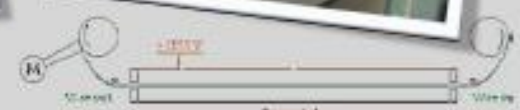
- Compatible with background value

Drift Cells



The tracking in the Demonstrator Module is performed by 2048 drift cells operating in Geiger mode. A central anode wire is surrounded by twelve cathode wires, in a helium-argon gas mixture. The passage of a charged particle ionises the gas, resulting in an electron avalanche. This produces a plasma that propagates along the anode wire. The time difference between the signal arriving at each end provides the longitudinal location of the charged particle.

Component cleaning



Radiopurity of all detector components is vital. Cells are made only from pure copper, steel and delrin. All components are cleaned, following a rigorous procedure: an ultrasonic bath in a detergent solution followed by an ultrasonic bath in distilled water. An automated spooling system takes the wire through the same procedure. All copper parts are then passivated in citric acid to prevent corrosion. After cleaning, all anode wire is tested before insertion into cells to check for plasma blockages or self-triggering points.