WP4
Isotope radio-purity assessment with external source approach

The BiPo detector

Measure the purity in ^{208}Tl and ^{214}Bi

of the SuperNEMO ββ source foils

Required sensitivity:

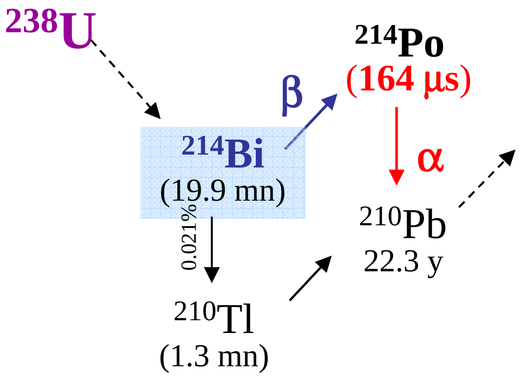
^{208}Tl < 2 μBq/kg   and ^{214}Bi < 10 μBq/kg

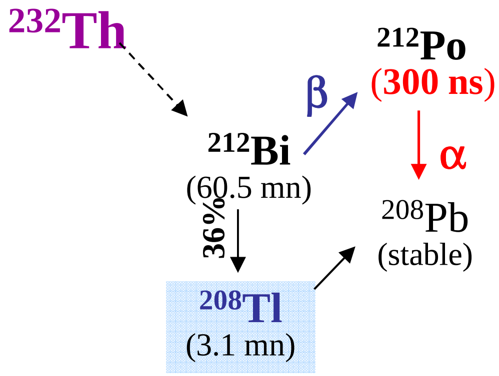
Best limits for NEMO-3 foils measurement with HPGe:

A(^{208}Tl) < 100 μBq/kg

Principle of BiPo detection

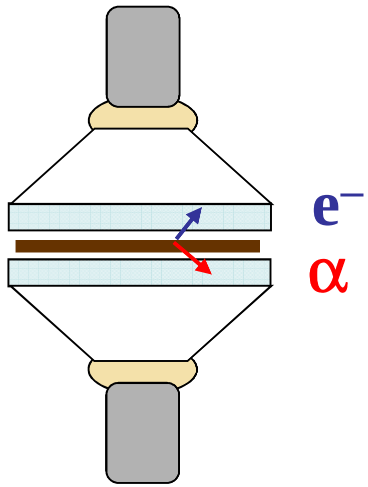
Detect the BiPo decay cascade: beta + delay alpha

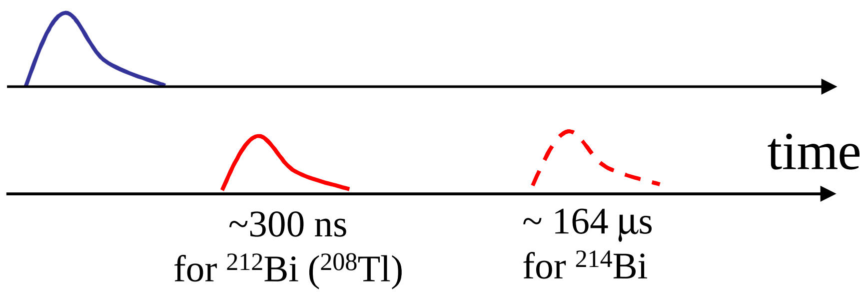




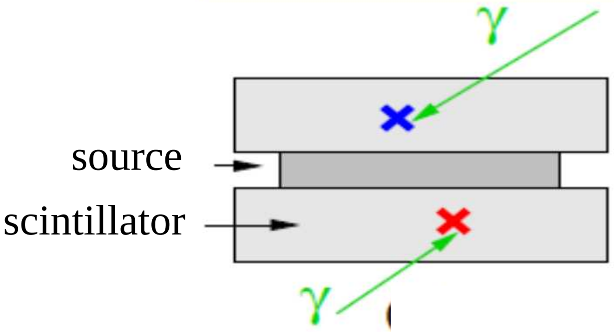
Sandwich of two low radioactive thin polystyrene plastic scintillators

Time topology signature: 1 hit + 1 delay hit (and no coincidence)

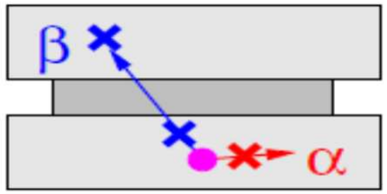




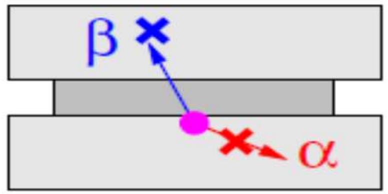
Sources of background



Random coincidence
(e^- Compton from ext. γ)

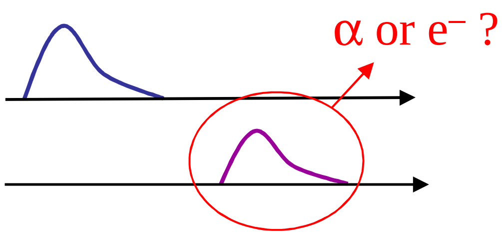


Bulk contamination
Scintillator

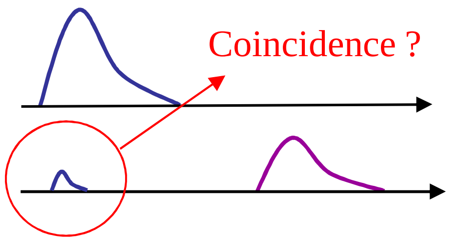


Surface contamination
^{238}U and ^{232}Th

- Low counting rate
  $\tau \times S \lesssim 1$ mHz.m^2
- Low background detector and shield in Canfranc Underground Lab (Spain)
- Discrimination e^-/α



- Low energy threshold to reject coincidence
  10 keV ≈ 100 μm
- Radiopure scintillator
  A(^{232}Th) $\lesssim$ 1 μBq/kg



- Ultra high surf. radiopurity
  (~100 μm deep)
  A(^{232}Th) $\lesssim$ 1μBq/m^2
- No Radon and Thoron
  A(Radon) $\lesssim$ 10 mBq/m^3
  (if gap = 200μm)

R&D Program

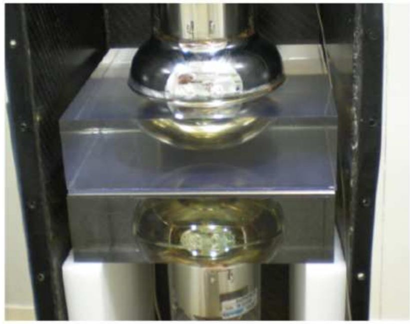
2007-2009: R&D program, funded by ANR

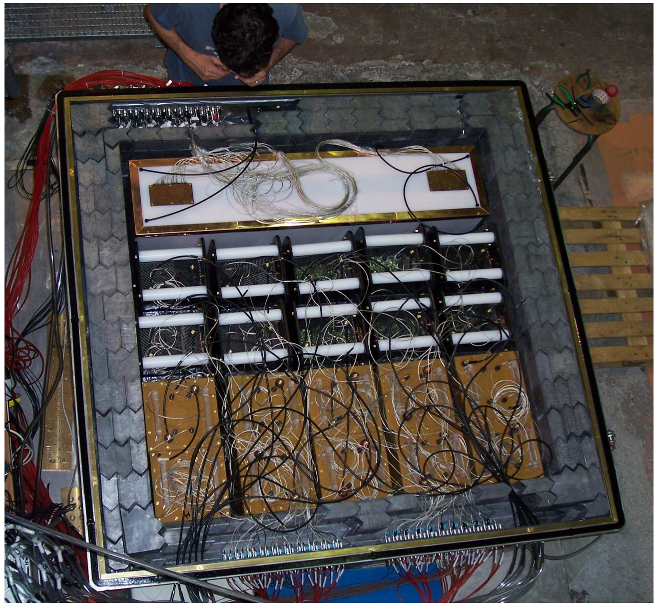
Development of 3 prototypes using different designs

- ✓ BiPo-1 prototype
- ✓ BiPo-2 prototype
- ✓ BiPo-1 phoswich (IFIC Valencia)

BiPo-1 prototype

20 modules of 20×20×0.3 cm^3 scintillators
Total surface = 0.8 m^2 running in LSM Modane





- ✓ Polystyrene based scintillators produced in JINR Dubna
- ✓ Surface machining in LAL
- ✓ Ultrapure aluminium sputtering in IPN Orsay
- ✓ Low radioactive 5” Hamamatsu PMTs

Mathieu Bongrand’s thesis

Results published in *N.IM. A 622 (2010) 120-128*

Validation of the detection efficiency

Measurement of a calibrated aluminium foil

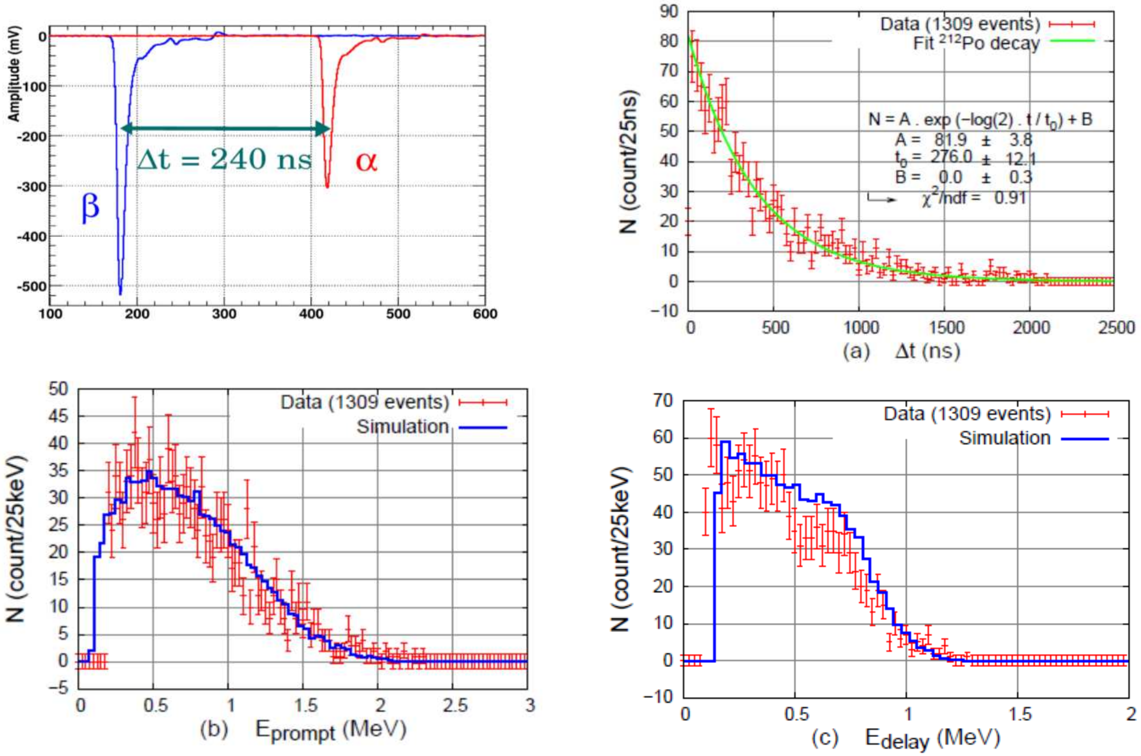
Activity measured with **HPGe γ spectroscopy: A(^{212}Bi→^{212}Po) = 0.19 ± 0.04 Bq/kg**

✓ After 160 days of data, 1306 BiPo events detected

⇒ Activity measured with **BiPo: A(^{212}Bi→^{212}Po) = 0.16 ± 0.01(stat) ± 0.03(syst.) Bq/kg**

✓ Delay distribution between the prompt β signal and the delay α signal: **$T_{1/2}$=276 ± 12 ns**

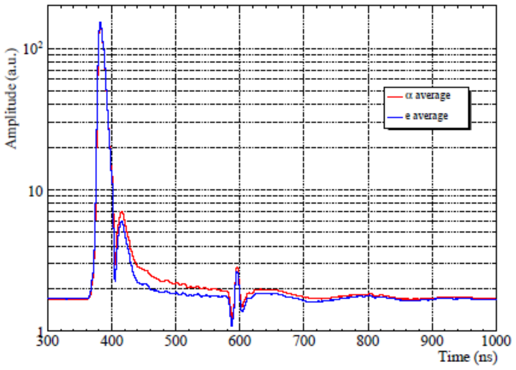
in agreement with $T_{1/2}$(^{212}Po) = 300 ns

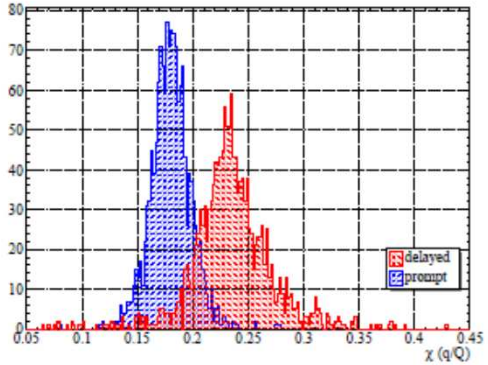


e^-/α pulse shape discrimination

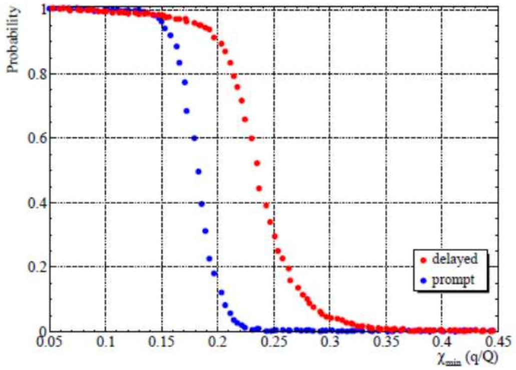
- ✓ High dE/dx for α enhances the slow component of the scintillation decay curve
- ✓ Already known in liquid scintillator
- ✓ Observed here also in plastic scintillator

Measurements with (prompt e^-, delayed α) sample from aluminium foil





χ



Fraction events > χ_{min}

Discrimination factor: $\chi = \frac{q_{slow}}{Q_{tot}}$

Condition $\chi > 0.2$ applied for the delayed signal

- ➢ Rejects 85% of random coincidence events
- ➢ Keep 90% of true BiPo events

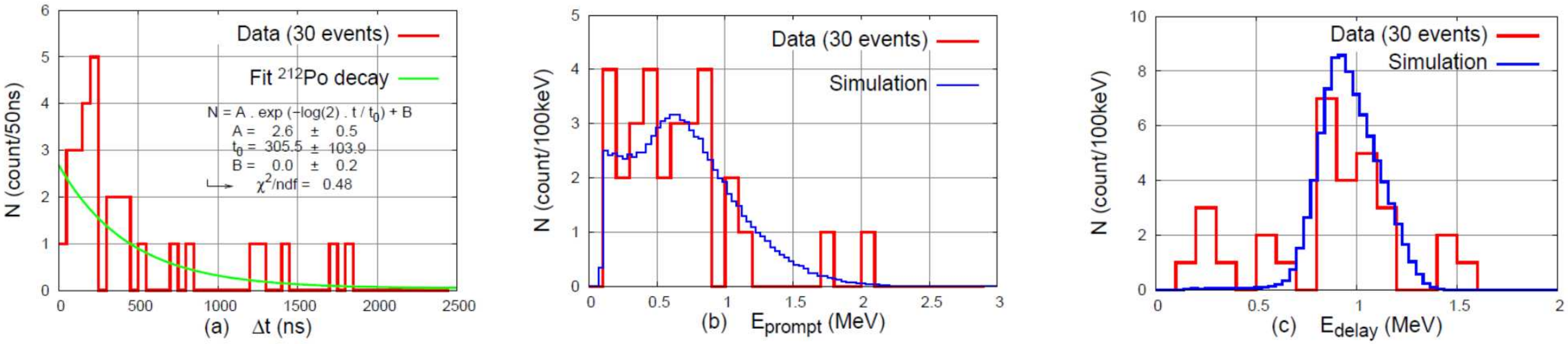
Background measurement

Channel $^{212}Bi \rightarrow {}^{212}Po$ for ^{208}Tl (^{232}Th) measurement

Background has been measured during 488 days in Modane (Dec. 2007 – Jul. 2009)

12 BiPo-1 modules ≡ detector surface area of 0.48 m^2

30 $^{212}Bi^{212}Po$ events observed



Surface bkg (per scint. surface unit)
$A(^{208}Tl) = 1.5 \pm 0.3$ (*stat*) ± 0.3 (*syst*) $\mu Bq/m^2$

Requirements:
$A(^{208}Tl) \lesssim 1\ \mu Bq/m^2$

Channel $^{214}Bi \rightarrow {}^{214}Po$ for ^{214}Bi (^{238}U) measurement

Radon contamination observed in BiPo-1

A(Radon) ~ few tens of mBq/m^3

Origins: emanation of PMTs, Radon purity of the gas…

⇒ Will require a dedicated Radon tightness design for BiPo-3

Part of $^{212}Bi \rightarrow {}^{212}Po$ bkg events may be due to Radon bkg. I hope so !...

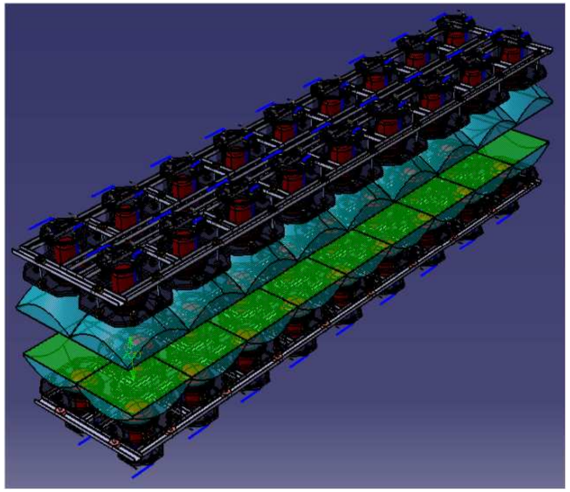
BiPo-3 detector

(Canfranc Underground Laboratory)

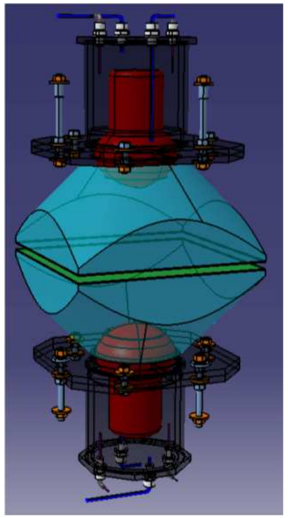
- ✓ **Total active area = 3.6 m^2**
- ✓ Detector composed of **2 modules**
- ✓ Each module is an array of **40 optical sub-modules**

  Optical sub-modules = thin aluminized scintillators coupled via PMMA optical guides to 5'' low-radioactive PMT

  ⇒ **Total of 80 PMTs + Optical guide + scintillators**
- ✓ **Scintillators:**
  - ✓ Polystyren based, size: **300×300×2 mm^3**
  - ✓ Produced by JINR Dubna and machined in France under N_2 flush
  - ✓ entrance active face **aluminized** with 200nm of ultra pure Aluminium



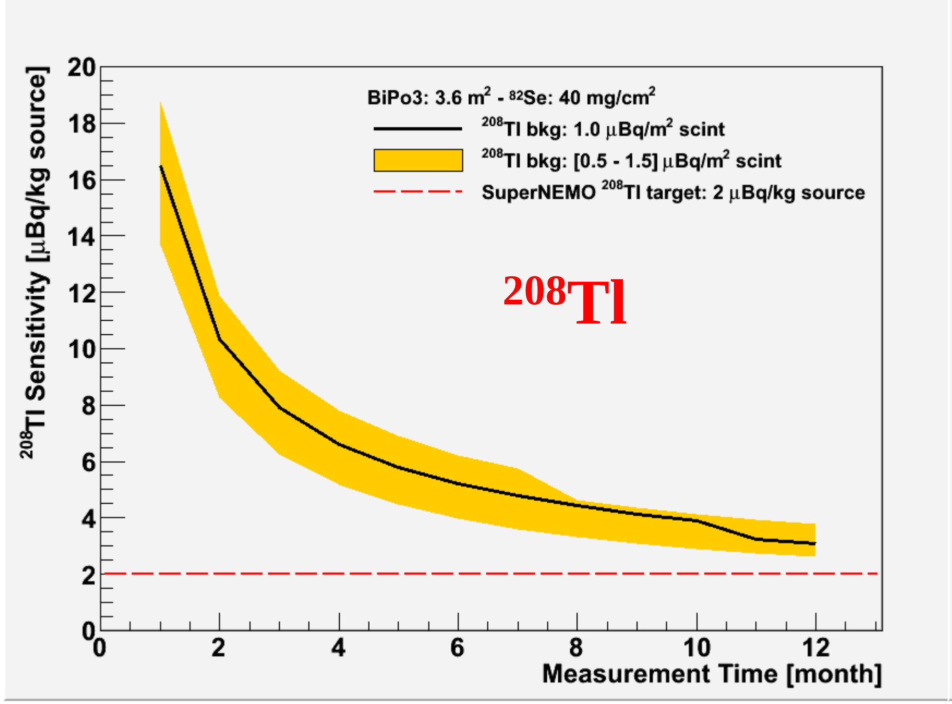
BiPo-3 module

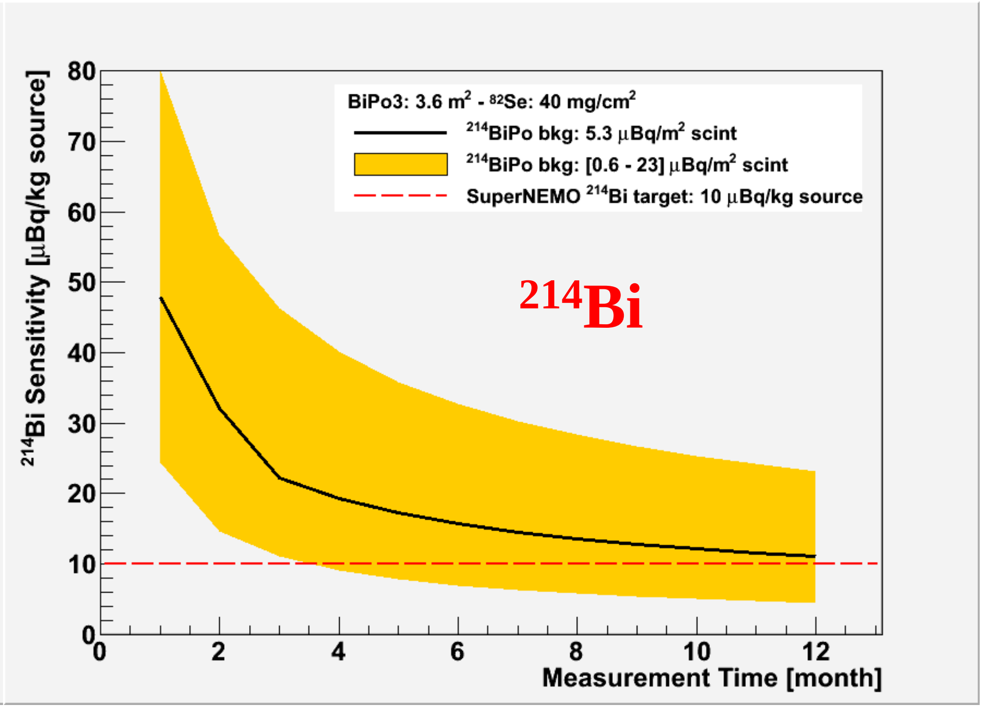


Two optical sub-modules

BiPo-3 sensitivity

Assuming: ^{82}Se foil 40 mg/cm^2
Total surface BiPo-3 = 3.6 m^2
Energy threshold = 100 keV for prompt and delay signals (ε ~5%)

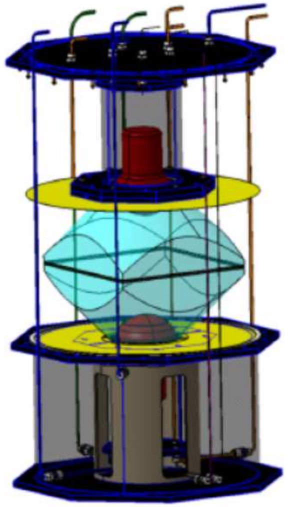




Number of expected ^{212}BiPo bkg event in BiPo-3 (assuming surface bkg as in BiPo-1)
~ 4.5 events/month with ^{82}Se foil (~14 events w/o foil)

The main systematic in BiPo is the correct knowledge of the "surface" background
⇒ Long background measurement
⇒ Avoid surface contamination when the Se foil is introduced inside the detector

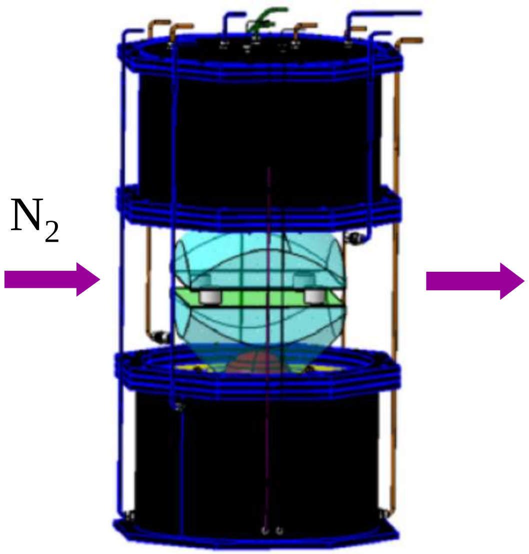
BiPo-3 prototype in Canfranc



- **Random coincidence background**
  - – measure the single counting rate with different γ shields
  - – choice of the scintillator thickness

- **Tl and Bi surface background**
  - – validation of the new aluminium evaporation chamber
  - – validation of the new scintillator surface machining

- **Radon background**



Radon strongly suppressed
A(Radon) < 1mBq/m^3
when pure N2 is flushed with flux ~ 1 vol/hour
(~ 200 l/h for total BiPo3 detector)

Assembly and test of the 80 optical sub-modules

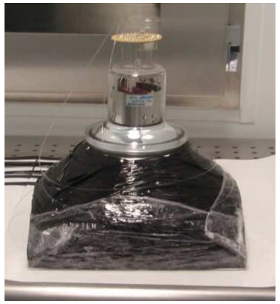

Light guide annealing

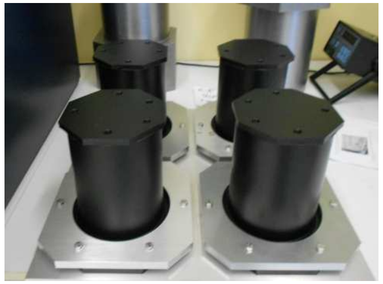

Gluing of the scintillator


aluminization


PMT gluing

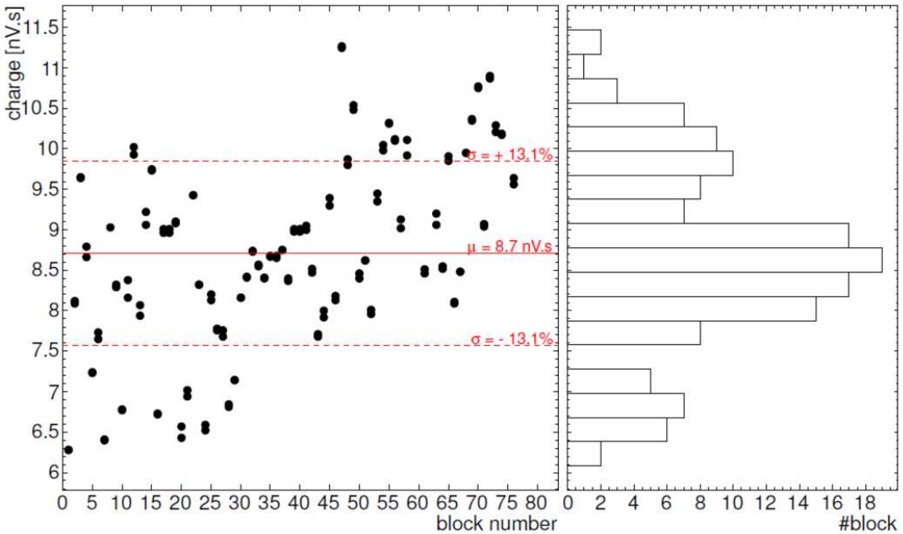

Tyvek wrapping


Black film


Light black box


80 optical modules assembled

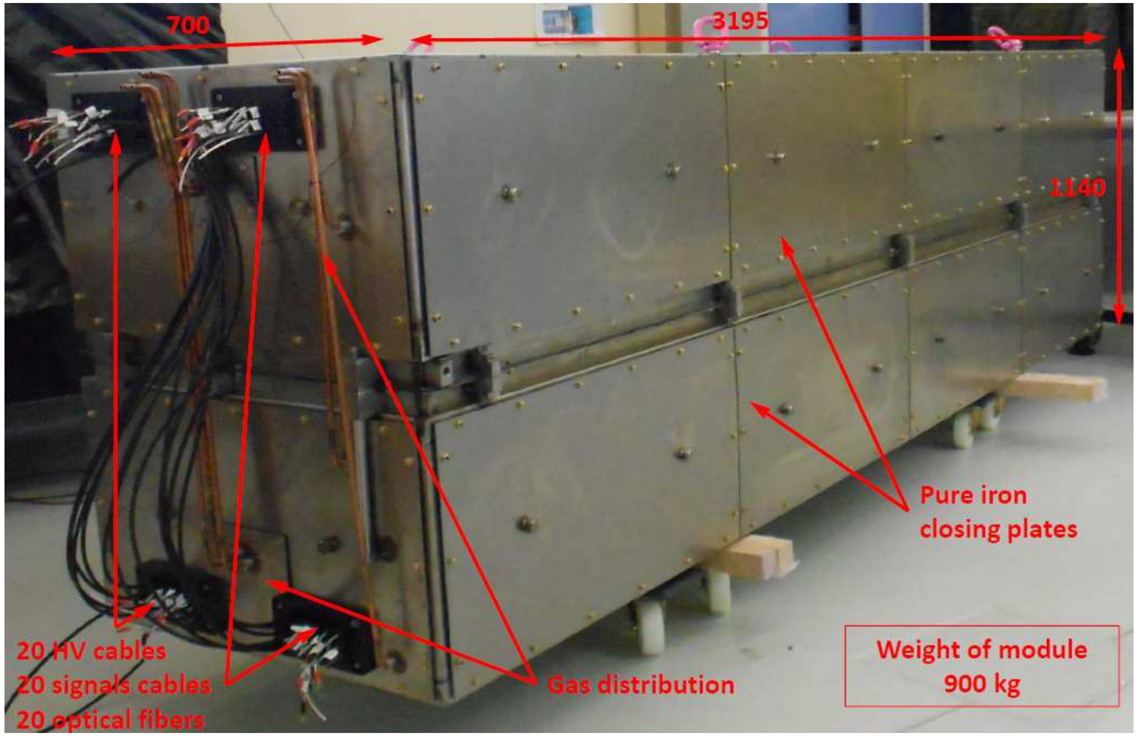
Calibration on test bench in LAL



Good light yield collected and good reproducibility

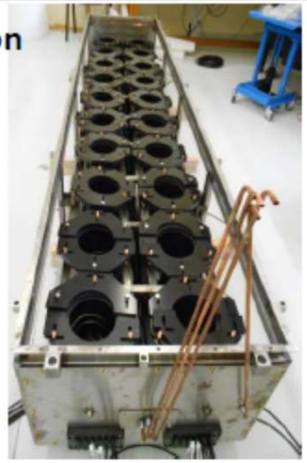
~ 250 photoelectrons / MeV

Assembly of the 1st BiPo-3 module in LAL Orsay

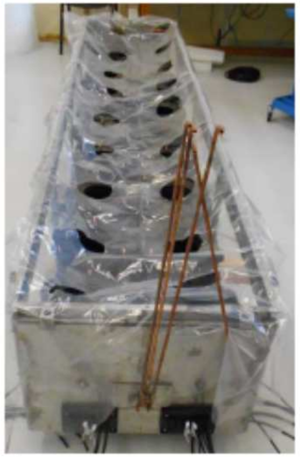


Assembly of the 1st BiPo-3 module in LAL Orsay

1 – Implementation of light boxes and connexion gas PMT



2 – Set of EVOH film

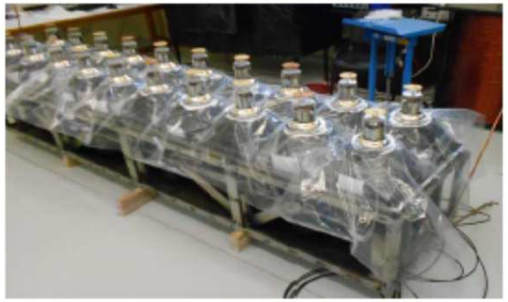


3 – Implementation of down light lines
And implementation of :
- cables,
- optical fibers
- connexion gas

4 – Adjustment of plan of scintillator with down support

5 - Implementation of up light lines

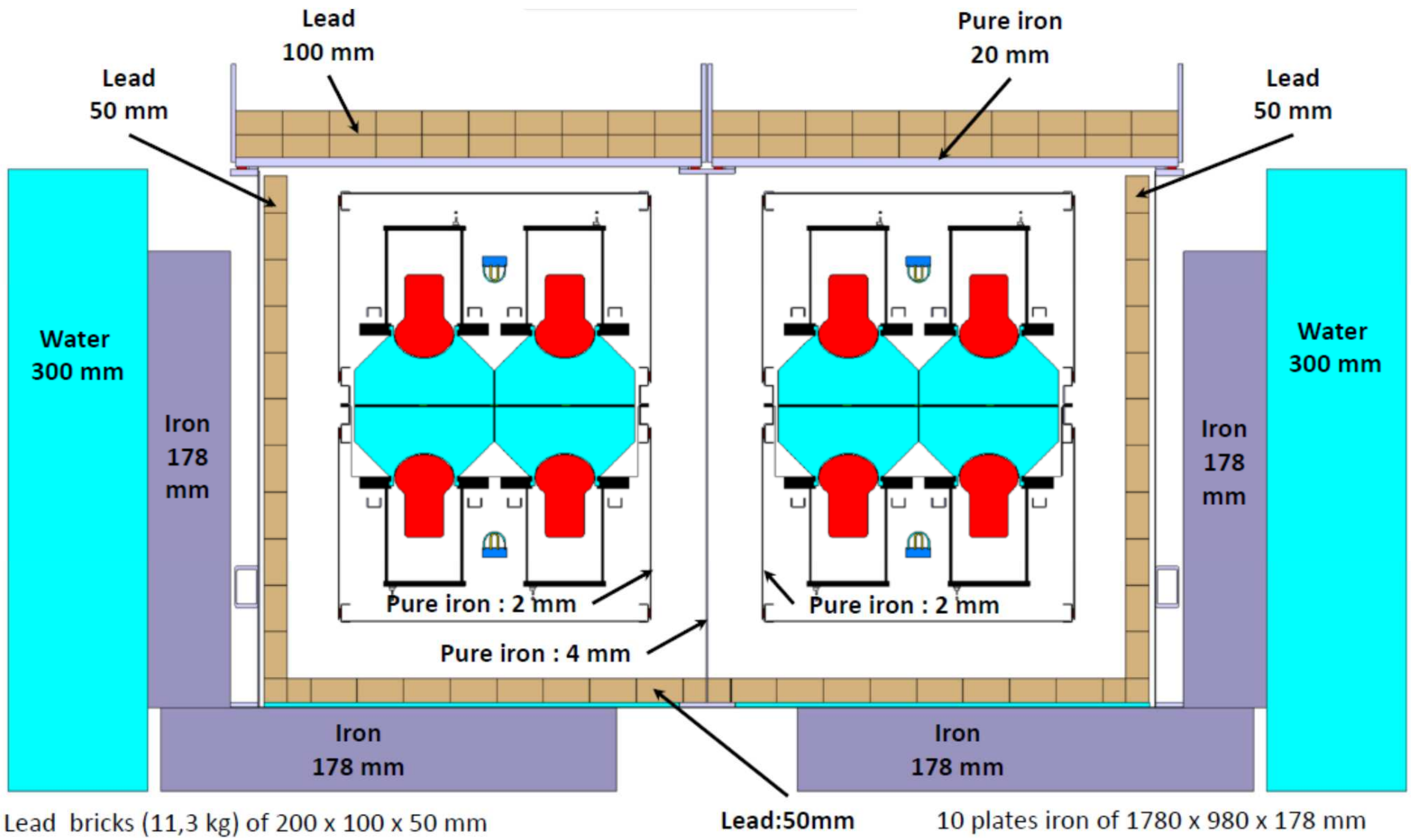
6 - Set of EVOH film



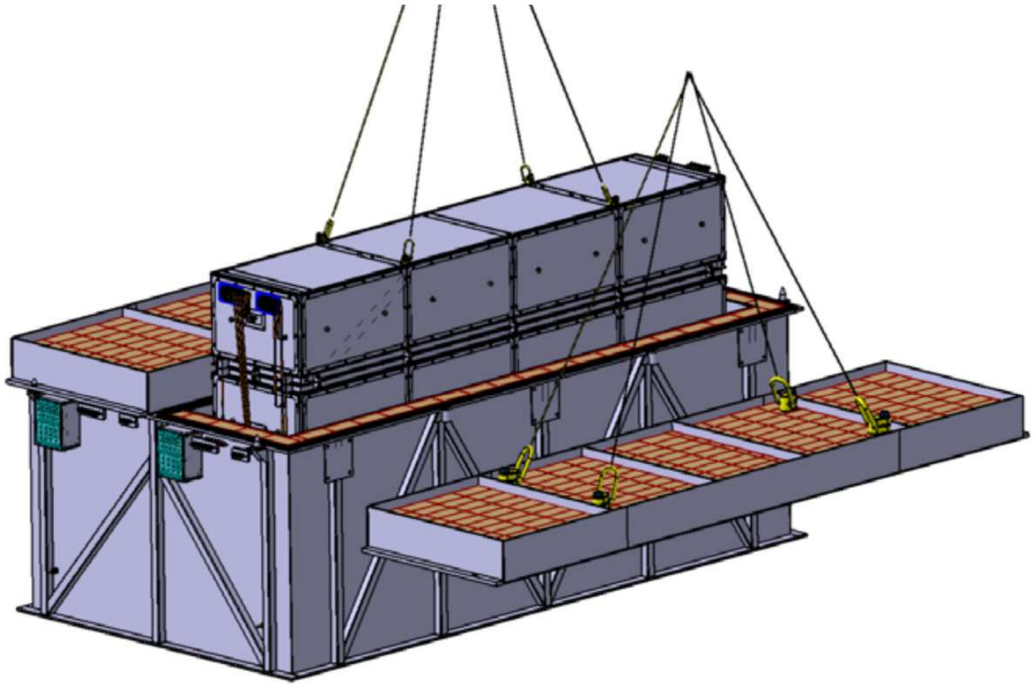
7 – Setting of 20 light boxes
Implementation of :
- cables
- optical fibers

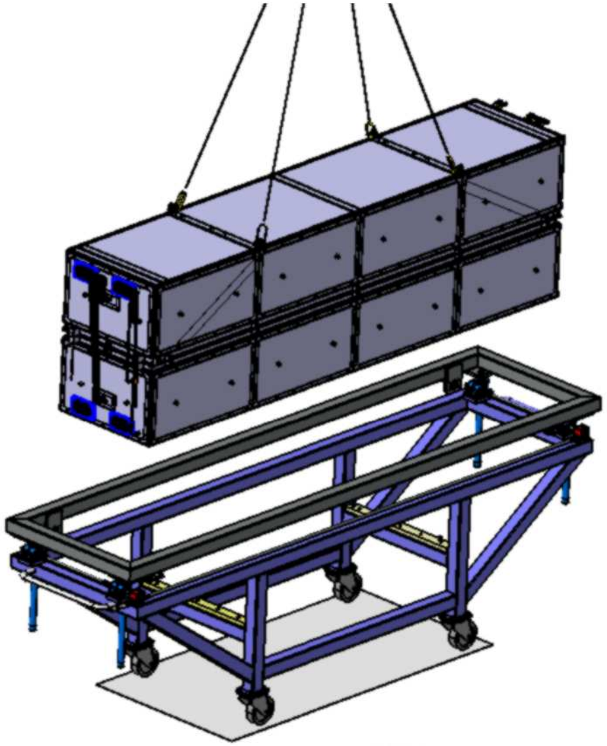
8 – Setting up of frame with monorail
Set up of supports and connexion gas

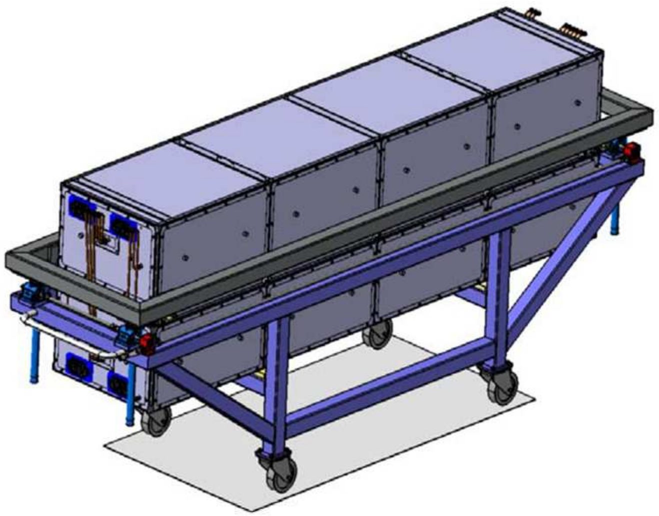
Design of the shield

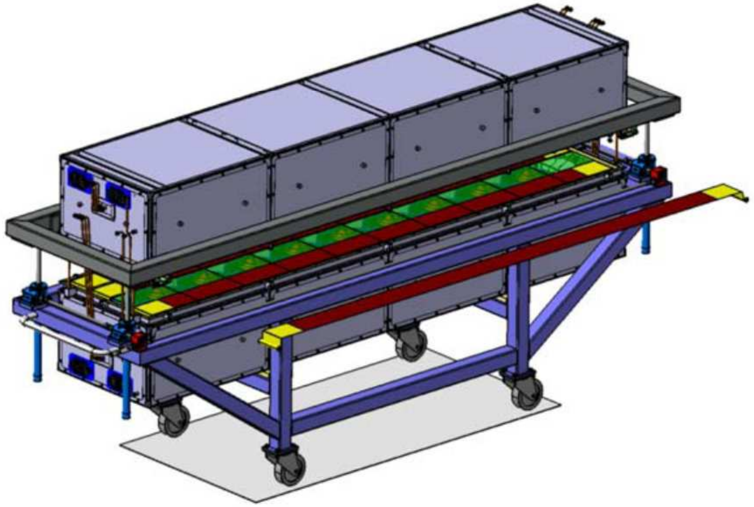


Operation in Canfranc Undergorund Lab.









BiPo-3 Schedule

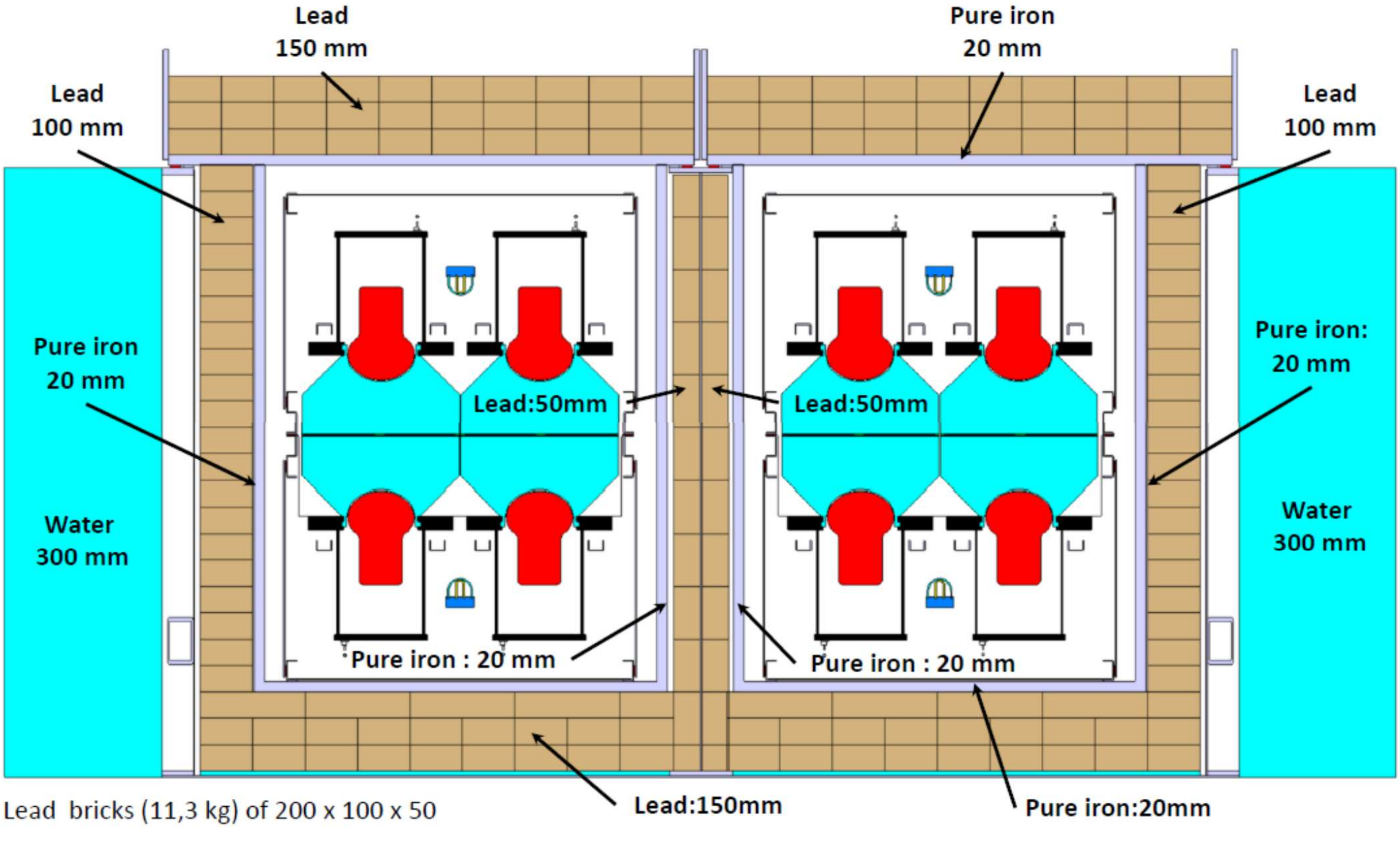
- **1st July 2012 :** installation of the 1st BiPo-3 module in Canfranc
- **Summer 2012**: start measuring the bkg of the 1st module
- **Oct. 2012**: installation of the 2nd BiPo-3 module in Canfranc
- **Fall 2012:** background measurement of the two modules
- **Year 2013**: measurement of SuperNEMO ^{82}Se foils

Possibility later to measure other thin materials like polyethylen film (used to screen copper surfaces) or reflecting films (used in scintillating bolometers)

$\Rightarrow$ could reach a sensitivity of ~10 μBq/kg in ^{208}Tl

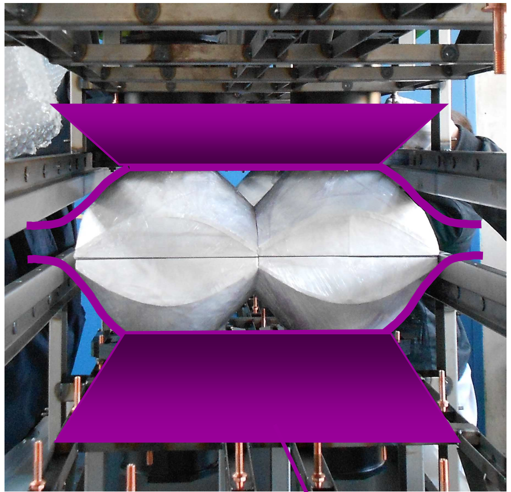
BACKUP

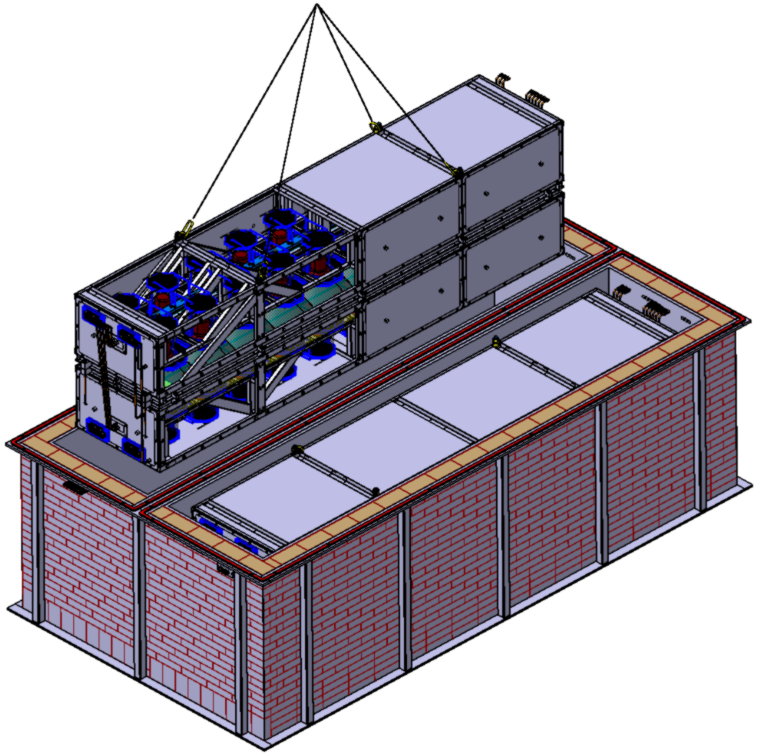
Initial design of the shield



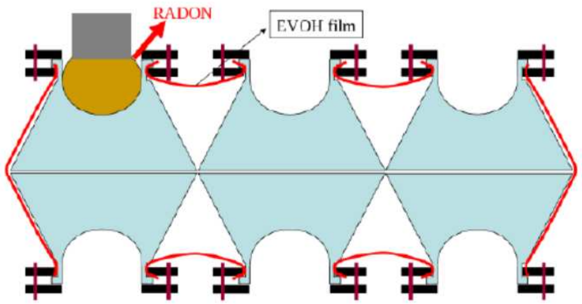
BiPo-3 detector

Welded mechanical structure (radiopure iron)
built in LAL Workshop





Inner volume closed by EVOH+polyethylene film
flushed by LSC N_2
to suppress Radon background

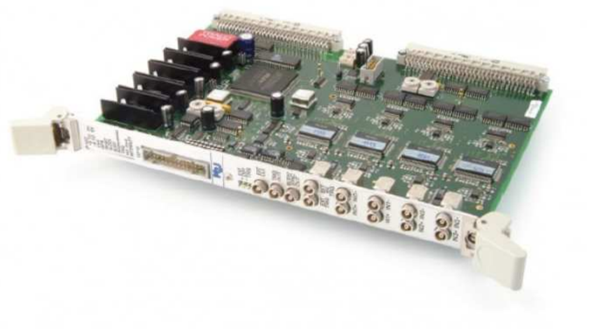


Shield: low active Pb
Inside stainless steal tank (tightness)

PMT's readout and acquisition

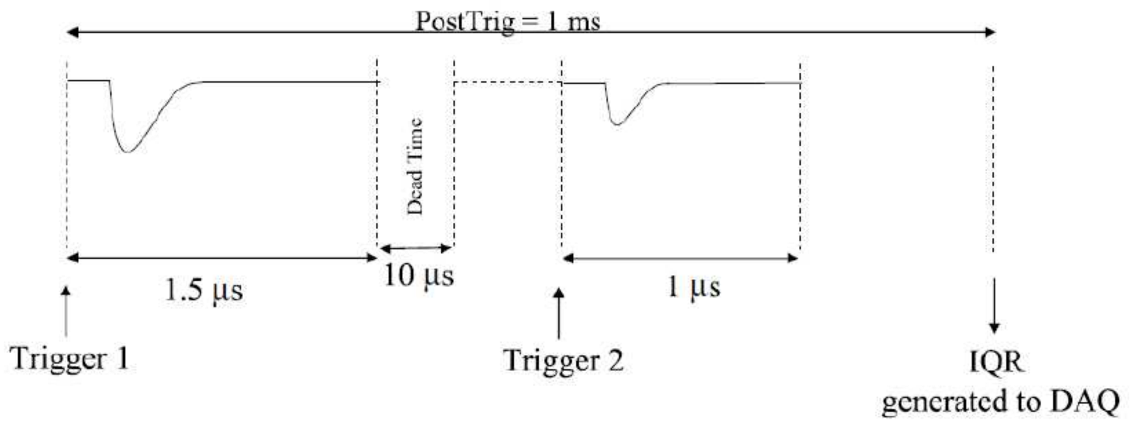
➢ PMT signals sampled with MATACQ VME digitizer boards (LAL & IRFU)

- 4 channels, 2.5ms time window
- 1 GS/s high sampling rate
- 12-bit amplitude resolution
- 1 Volt amplitude dynamic range
- Electronic noise ~ 250 µV (r.m.s.)



➢ Trigger (LAL)

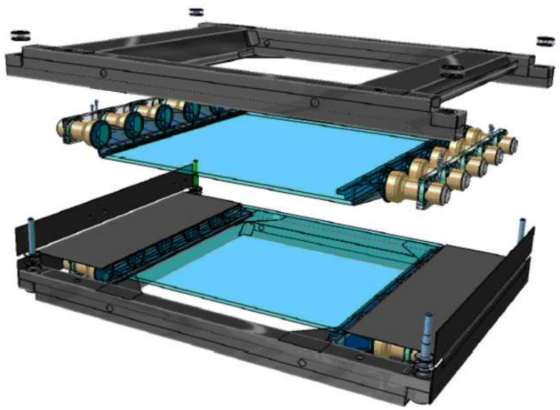
- MATACQ sampling of the PMT signal during 1.5 µs
- Dead time during 10 µs ⇒ avoid false trigger on PMT delay noise
- Start watch dog
- MATACQ sampling of the PMT signal during 1 ms in case of a 2nd trigger
- IQR generated after 1 ms

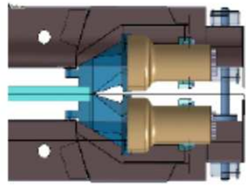


➢ Acquisition developed by LPC Caen

BiPo-2 prototype

- Two scintillators plates (molding production, Bicron BC-408) ⇒ S = 75×75×1 cm^3 (0.56 m^2)
- Scint. light collected by total internal reflectivity
- Read out on two opposite lateral sides of each plate with 3" radiopure PMT's ⇒ 20 PMT’s





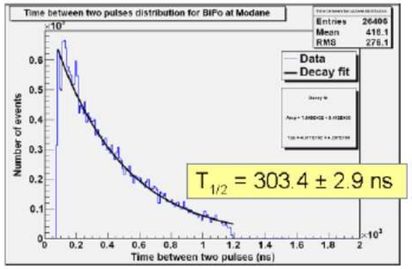
Possible advantages:

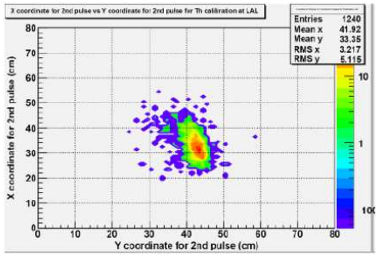
- ➢ Molded plate: no treatment of the entrance surface of the scintillators plates
- ➢ Same-side BiPo events could be used
- ➢ Random coincidence can be reduced if good resolution for the location of the event

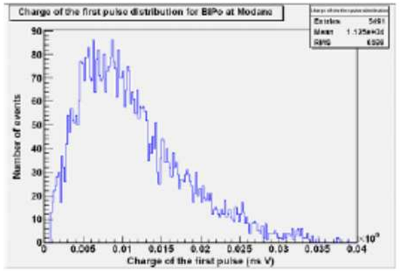
BiPo-2 prototype

Detection efficiency measured with aluminium foil in Modane

Efficiency BiPo-2 ~ BiPo-1 for back-to-back events
Efficiency can be increased if we use same-side events







BUT:

- ✓ Modest energy threshold ~ 100 keV
- ✓ Optical cross-talk ~ few 10 keV

} ⇒ Poor identification of coincidence background

- ✓ Spatial resolution : 90% of delayed α reconstructed with distance < 10 cm from prompt e^-
  ⇒ random coincidence ~ 4 times higher than BiPo-3
- ✓ No e^-/α discrimination (due to a relatively too low light collection)

It has been decided to extrapolate the BiPo-1 design for the large BiPo-3 detector