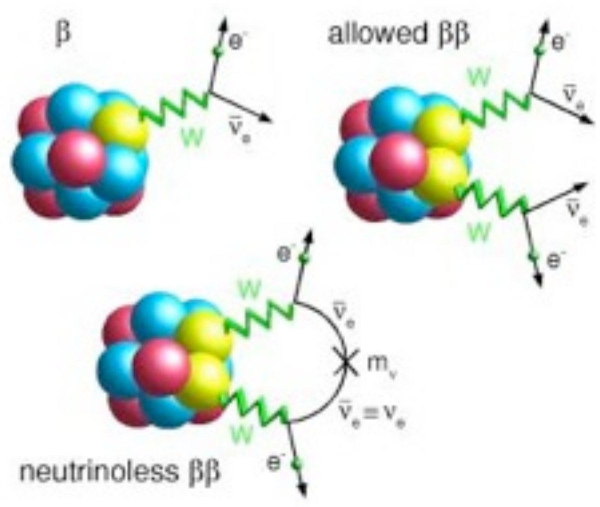
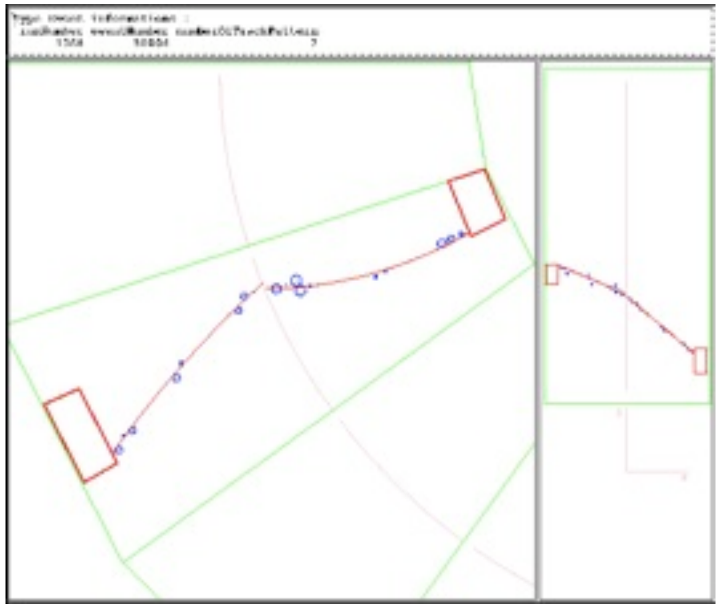
Probing neutrino mass with SuperNEMO



Ruben Saakyan

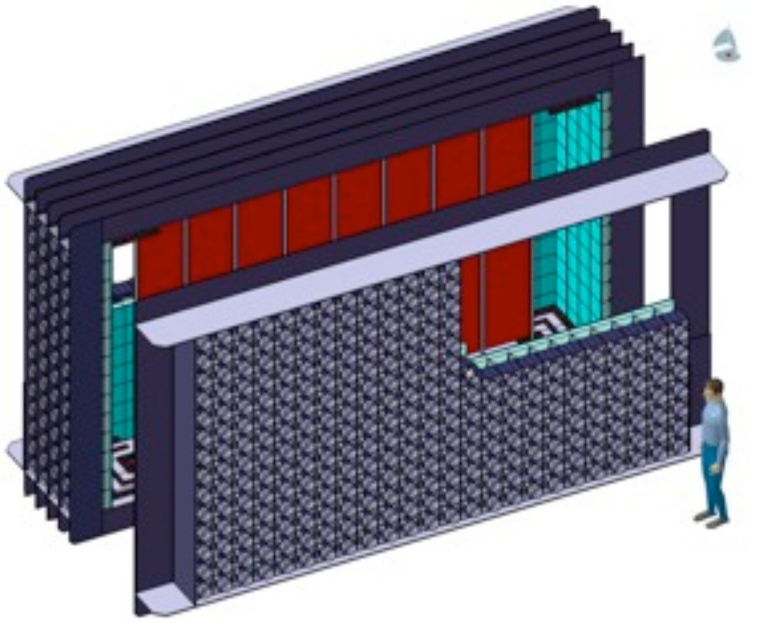
LSM Extension Workshop

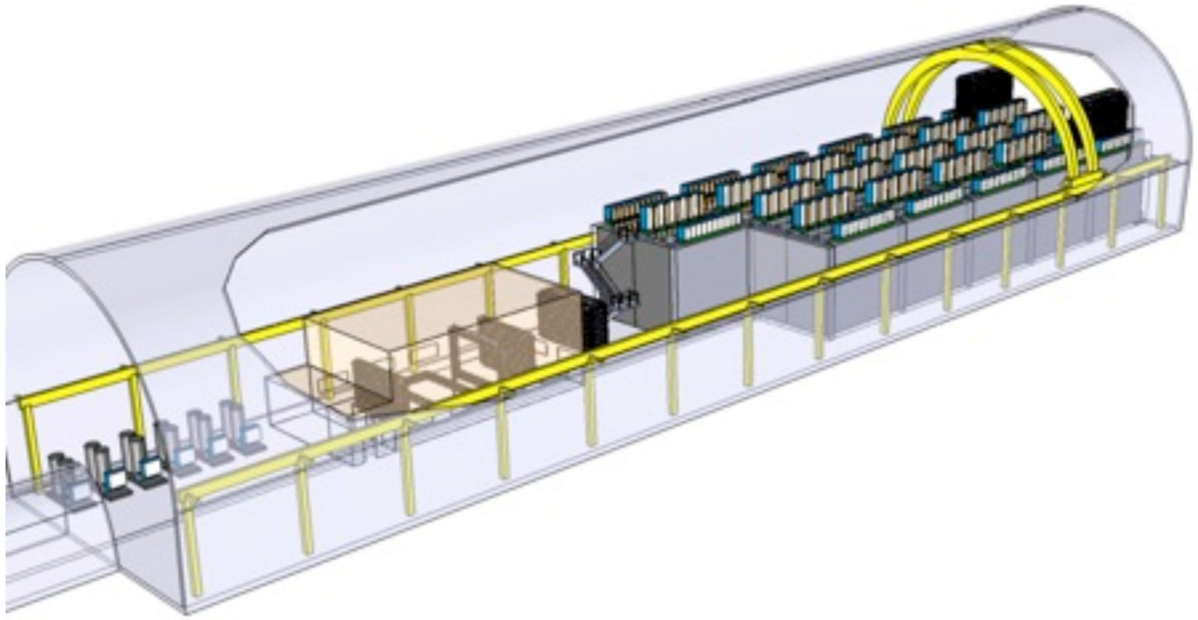
16 October 2009



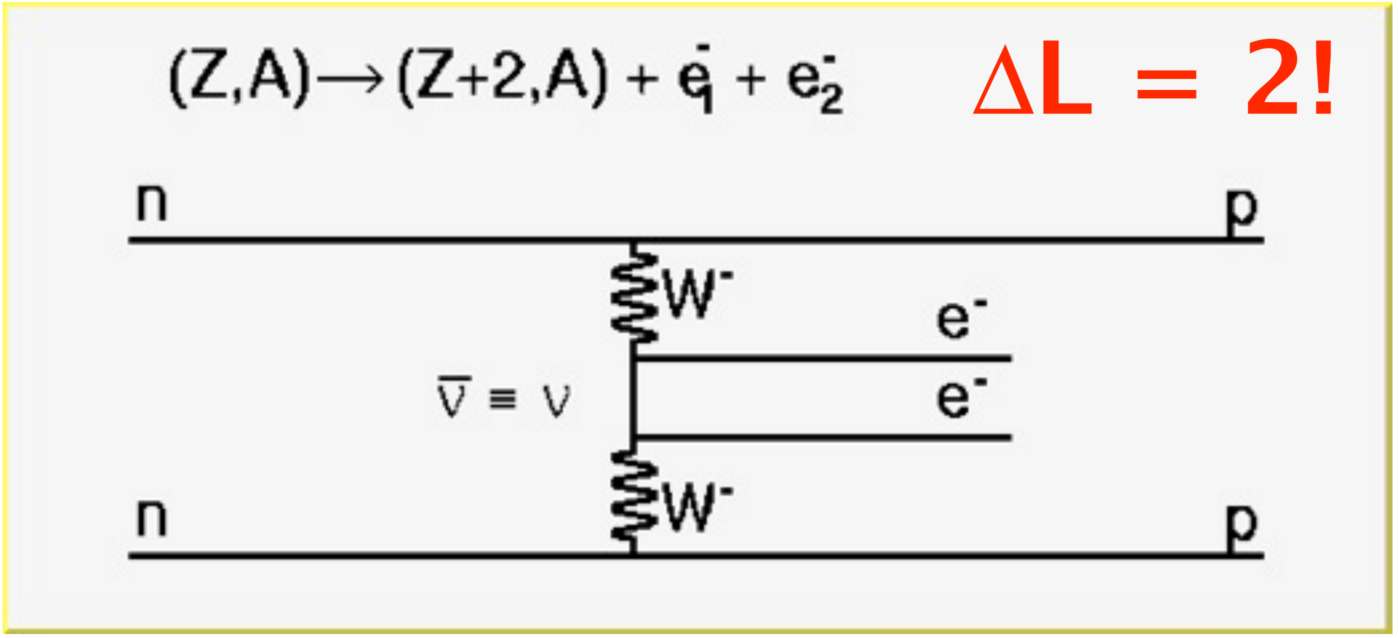
Outline

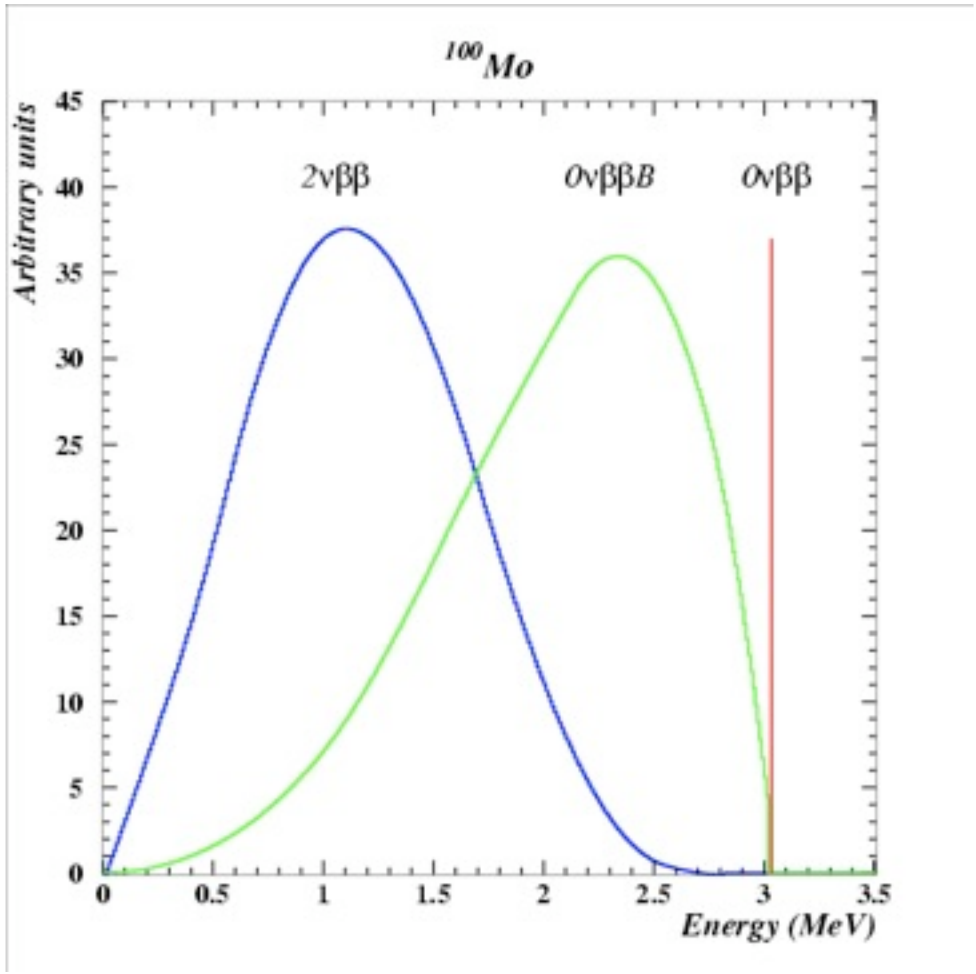
- The Concept
- The Detector
- Physics reach
- Status of design study
- Demonstrator
- SuperNEMO in new LSM
- Schedule





Neutrinoless double beta decay (0νββ)





$$\left[T_{1/2}^{0\nu}(0^{+} ® \ 0^{+})\right]^{-1} = G^{0\nu}(E_0, Z)\left|M^{0\nu}\right|^{2}\eta^{2}$$ ⟵ **Lepton number violation parameter**

η can be due to $\langle m_\nu \rangle$, V+A, Majoron, SUSY, H^{--} or a combination of them!

Need detectors which can probe different mechanisms (and different isotopes)

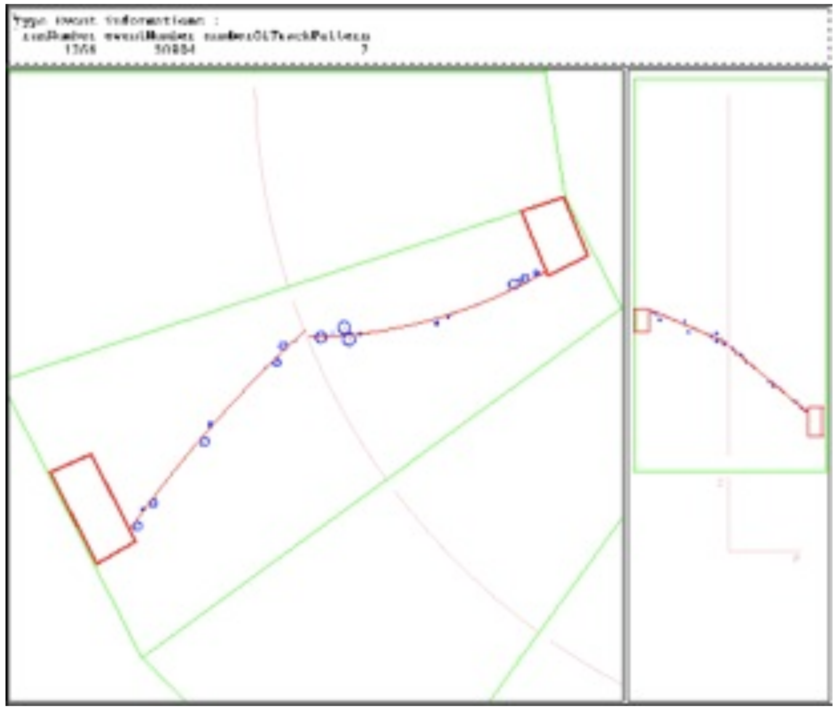
SuperNEMO experimental technique

$$T^{0\nu}_{1/2}(y) > \frac{\ln 2 \, . \, N}{k_{C.L.}} \, . \, \frac{\varepsilon}{A} \, . \sqrt{\frac{M \, . \, t}{N_{Bkg} \, . \, \Delta E}}$$

M: mass (g)
ε : efficiency
$K_{C.L.}$: Confidence level
N: Avogadro number
t: time (y)
N_{Bckg}: Background events ($keV^{-1}.g^{-1}.y^{-1}$)
ΔE: energy resolution (keV)

Calorimetry + Tracking

- Build on NEMO3 experience
- Reconstruct two electrons in the final state ($E_1+E_2 = Q_{\beta\beta}$)
- Measure several final state observables
  - Individual electron energies
  - Electron trajectories and vertices
  - time of flight
  - Angular distribution between electrons
- Background rejection through particle ID: e^-, e^+, α, γ
- Sources separated from detector ⇒ can measure different isotopes



➡ Focus on lowering N_{bkg} and
➡ **open-minded** search for **any** lepton violating process

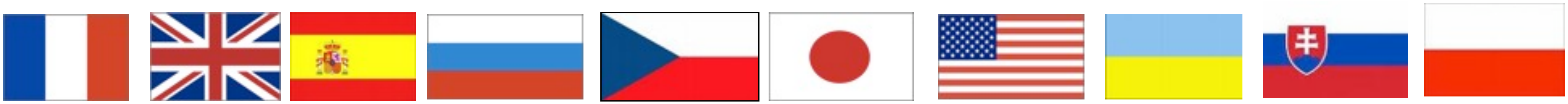
From NEMO-3 to SuperNEMO

NEMO-3		SuperNEMO
^{100}Mo	isotope	^{82}Se or other
7 kg	isotope mass M	100+ kg
18 %	efficiency ε	~ 30 %
^{208}Tl: < 20 μBq/kg ^{214}Bi: < 300 μBq/kg	internal contaminations ^{208}Tl and ^{214}Bi in the ββ foil	$^{208}Tl \leq 2$ μBq/kg *if* ^{82}Se: $^{214}Bi \leq 10$ μBq/kg
8% @ 3MeV	energy resolution (FWHM)	4% @ 3 MeV

$T_{1/2}(\beta\beta0\nu) > 2 \times 10^{24}$ y
$\langle m_\nu \rangle < 0.3 – 0.9$ eV

$T_{1/2}(\beta\beta0\nu) > 1 \times 10^{26}$ y
$\langle m_\nu \rangle < 0.04 - 0.11$ eV

SuperNEMO (~100 people)



Planar and modular design:

~ 100 kg of enriched isotopes (20 modules x 5 kg)

1 module (baseline):

Source (40 mg/cm^2)   4 x 2.6 m^2

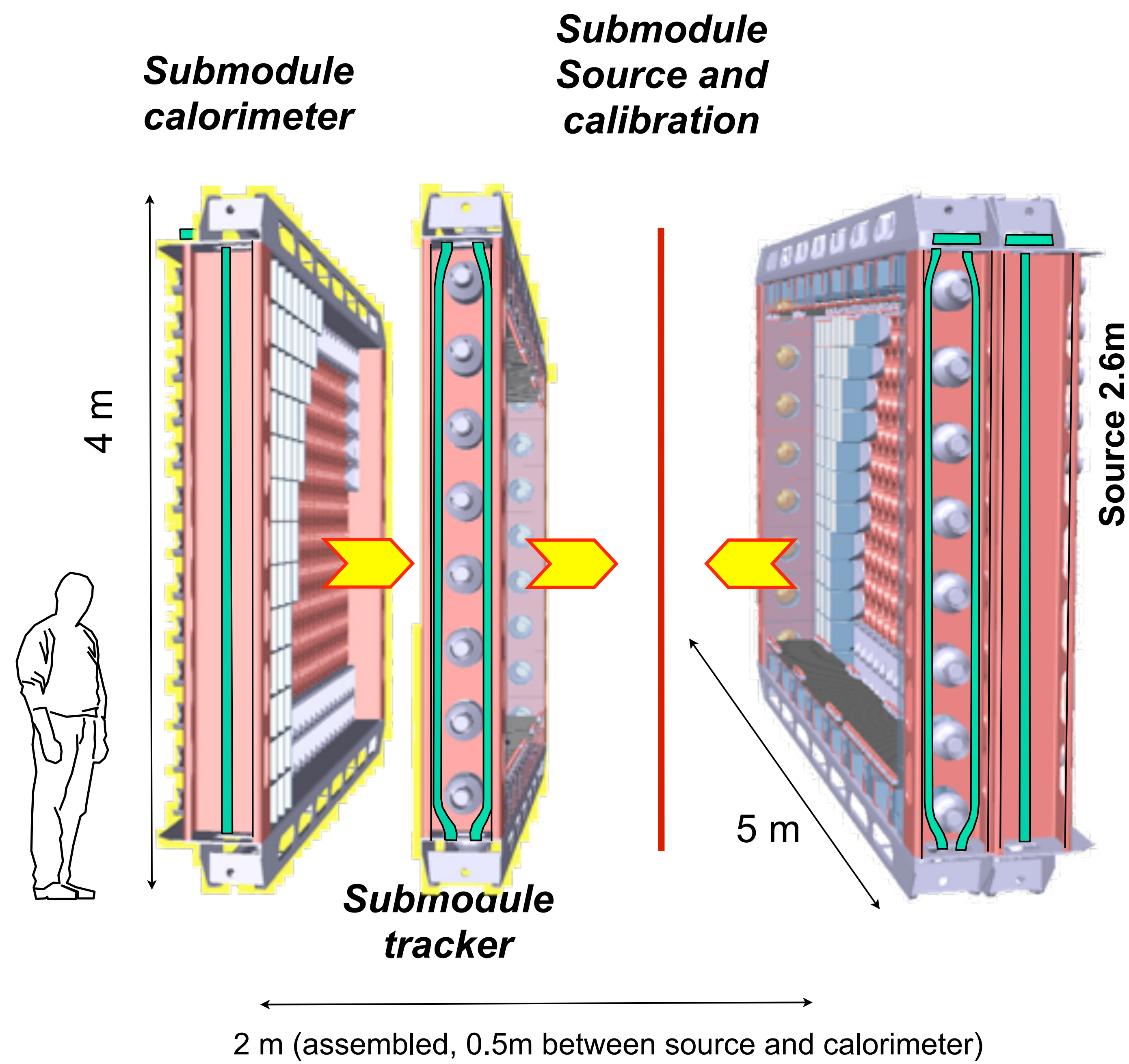
^{82}Se first but almost any isotope possible

(^{82}Se: High $Q_{\beta\beta}$, long $T_{1/2}(2\nu)$,
proven enrichment technology)

Tracking : drift chamber ~2000 cells in Geiger mode

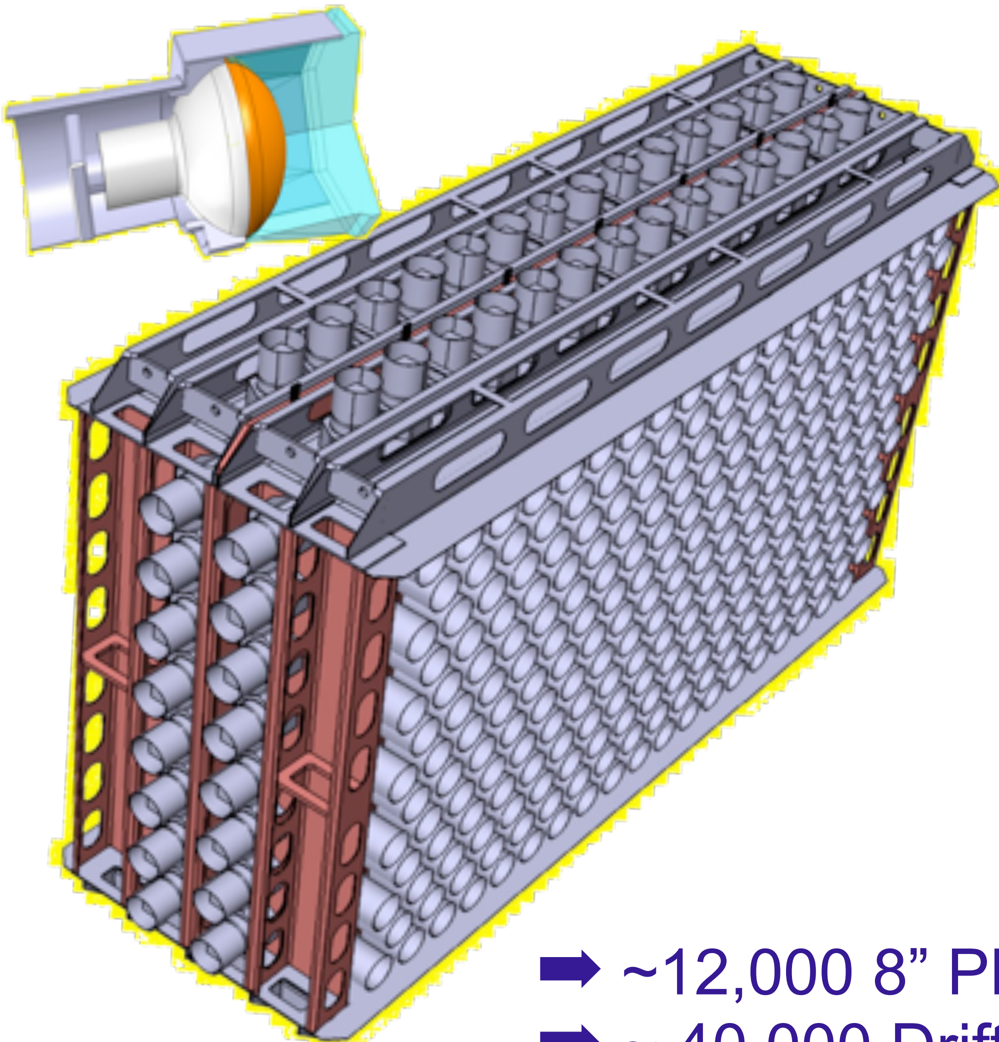
Calorimeter: scintillators + PMTs
~ 600 PMTs + scint. blocks

Modules surrounded by water passive shielding



Two designs under study

Calorimeter Blocks ("Baseline")

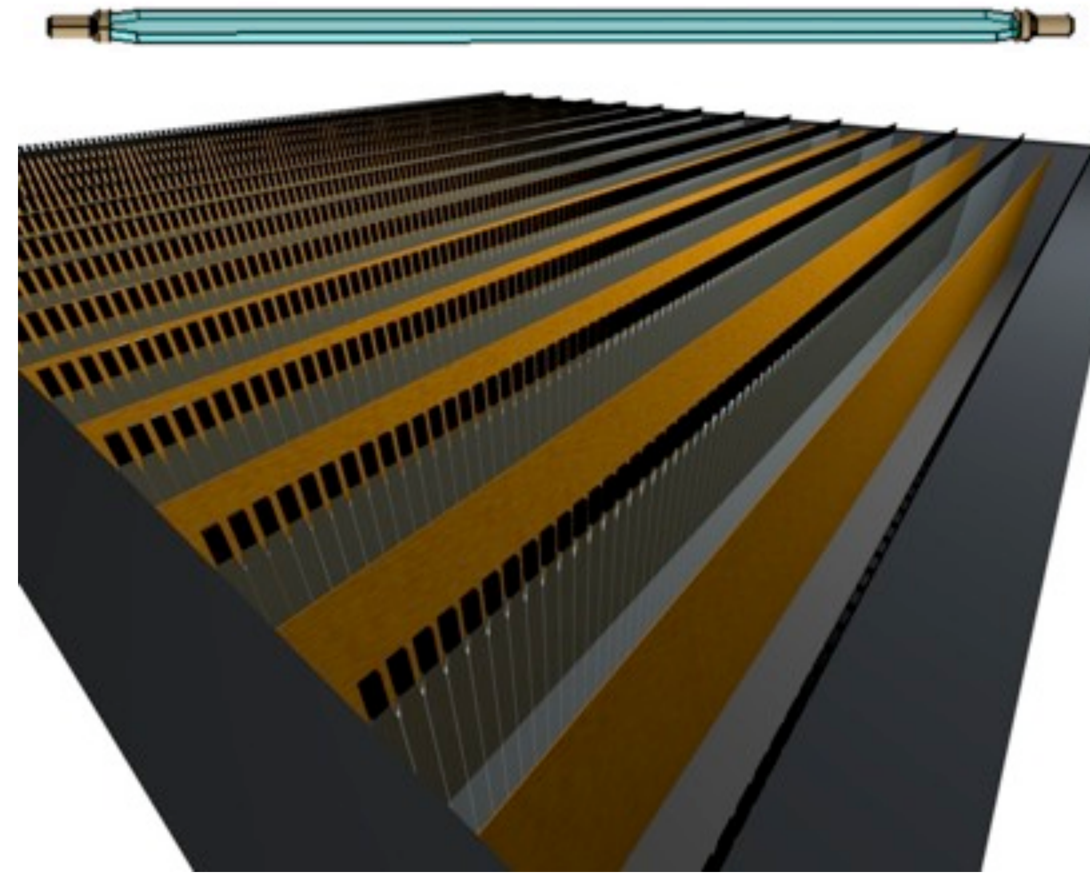


- ➡ ~12,000 8" PMTs
- ➡ ~ 40,000 Drift cells

Pros:
Proven technology (NEMO-3)
ΔE/E = 4% at 3 MeV demonstrated

Cons:
Radiopurity (large PMT mass)
Cost

Calorimeter Bars ("Alternative")



- ➡ ~6,000 3" PMTs
- ➡ ~ 80,000 Drift cells

Pros:
Better radiopurity + self-shielding
Cost (significantly cheaper)

Cons:
Possible issues with ageing
ΔE/E and σ_T is worse (but still 5.5% and 240ps at 3 MeV)

Design Study (2006 - 2009)

Physics Reach

- Full chain of GEANT4-based detector modelling, GRID interface
- Signal and background simulations, detector response
- **Deliverables: Physics sensitivity dependence on detector parameters**

Low background studies and source production

- BiPo detector for source contaminations measurements
- HPGe screening and Rn studies
- Source production technology
- **Deliverables: < 10 μBq/kg sensitivity for U and Th with BiPo**

Calorimeter and Calibration

- Energy and time resolution
- Calibration system design
- **Deliverables: 7-8% FWHM /√E(MeV), 1% calibration precision**.

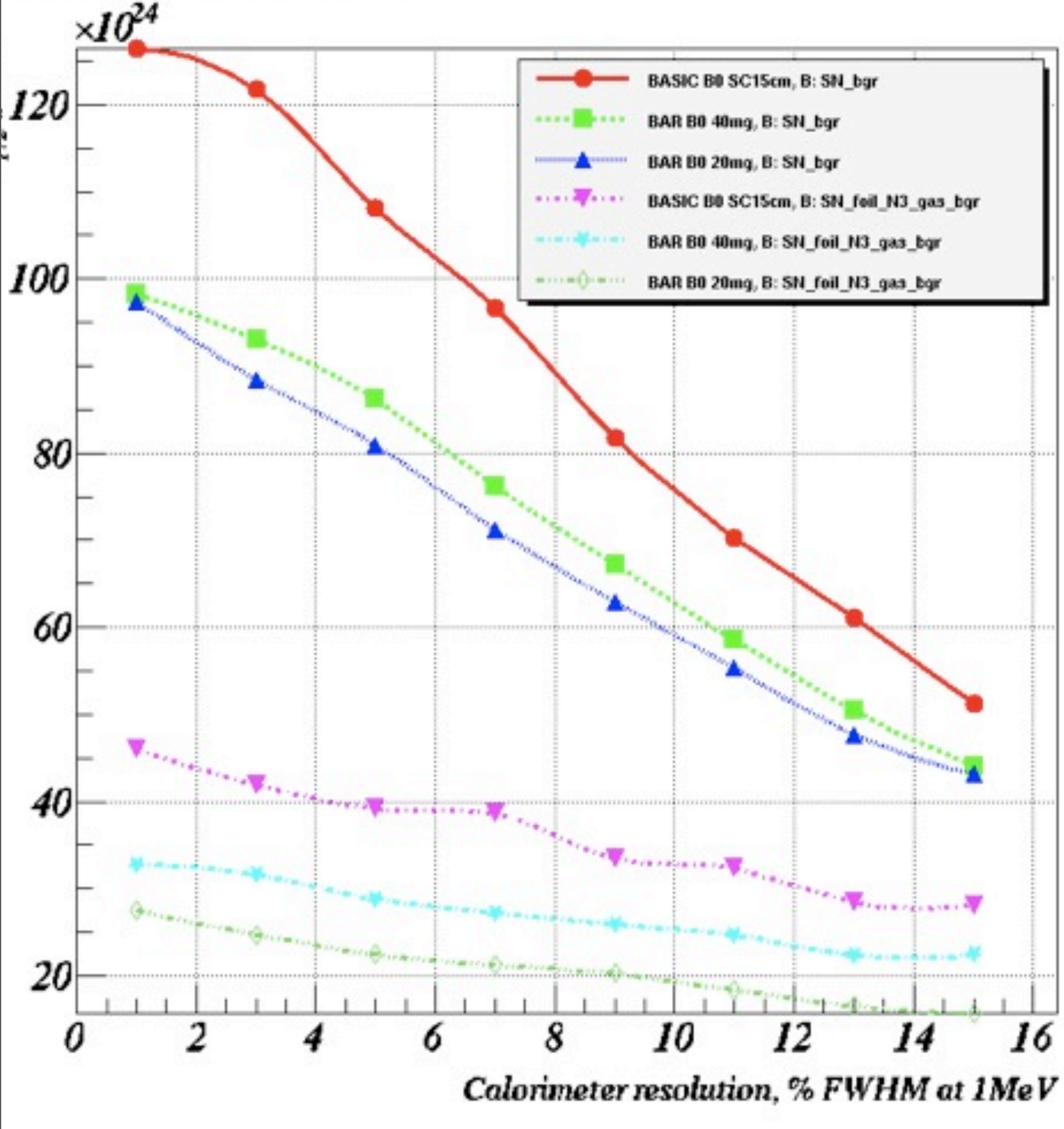
Tracker

- 1,9 and 90-cell prototypes for basic cell design
- Wiring process automation
- **Deliverables: Tracker module and wiring robot design**

Physics Studies

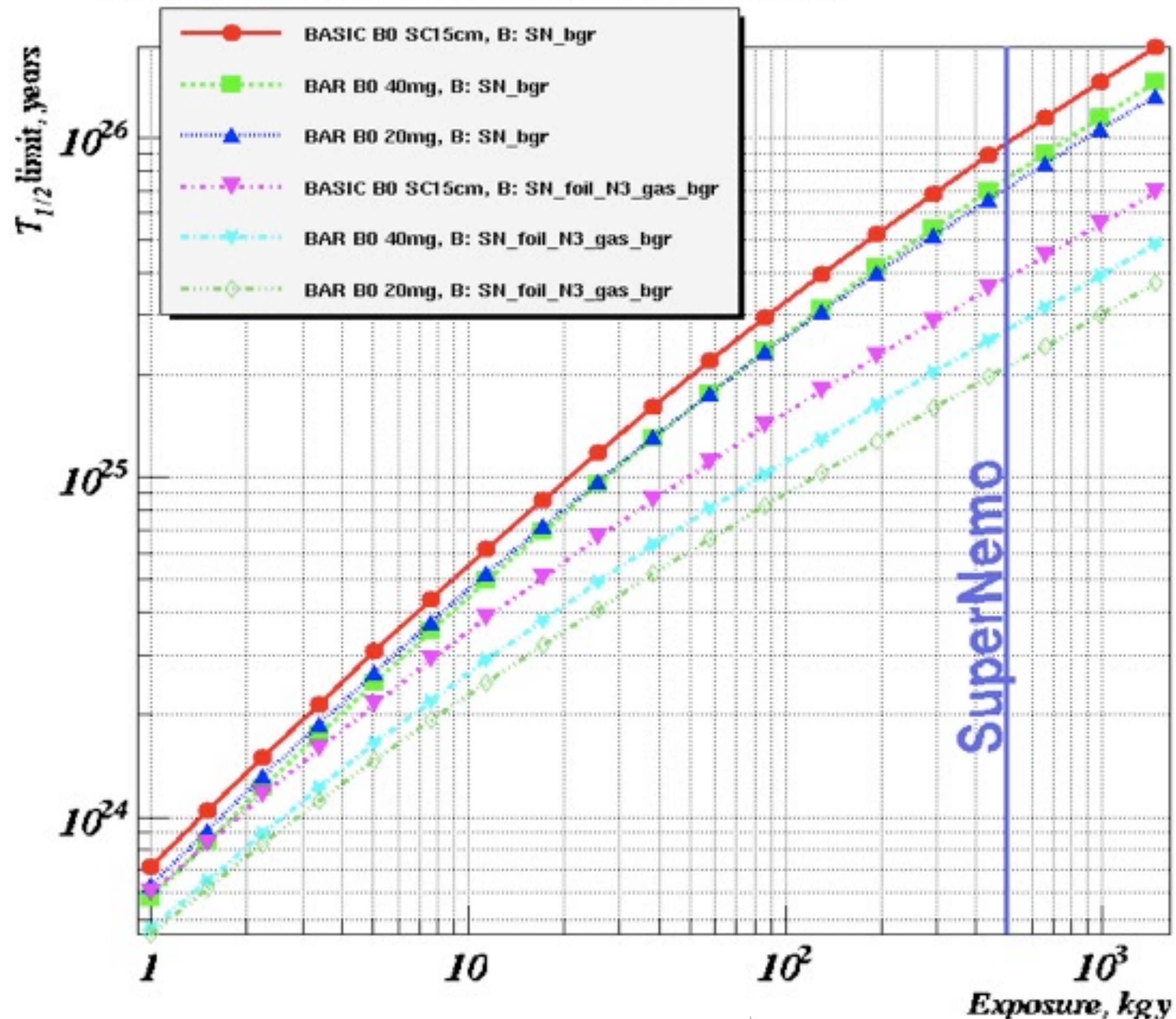
Full chain of GEANT-4 based software + detector effects + NEMO3 experience

Exposure 500 kg y



^{82}Se

Resolution 7 % FWHM at 1 MeV



5 yr with 100kg of ^{82}Se, $T_{1/2} > 10^{26}$ yr, $\langle m_\nu \rangle < 50$-$100$ meV at 90%CL with target detector parameters

Source production (^{82}Se)

Enriched Selenium

3.5 kg through ILIAS European Program (Tomsk facility)

1 kg in NEMO3 detector

Purification

Chemical purification of 1 kg natural Se at INL (US)

Sample	Measure-ment time (h)	^{40}K (mBq/kg)	^{60}Co (mBq/kg)	^{137}Cs (mBq/kg)	^{226}Ra (mBq/kg)	^{228}Ra (mBq/kg)	^{228}Th (mBq/kg)	Ru (mBq/kg)
Natural Se	447.33	668 ± 31	< 1	2.1 ± 0.9	**46 ± 2**	13 ± 2	11 ± 2	485
Purified Natural Se	436.56	< 20	< 0.7	1.0 ± 0.4	**< 0.9**	< 2.4	< 1.6	3
Reduction Factor		> 33	---	---	**> 51**	> 5.4	> 6.9	162

Foil Production

NEMO-3 composite foil method (Russia)

New coating test at LAL (France), discussion with INL

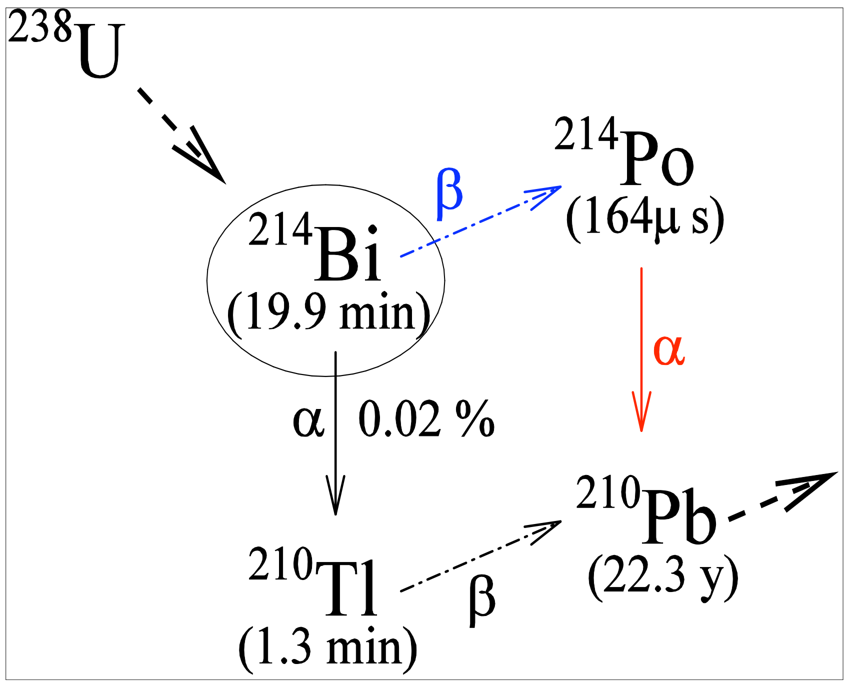
Mass Production

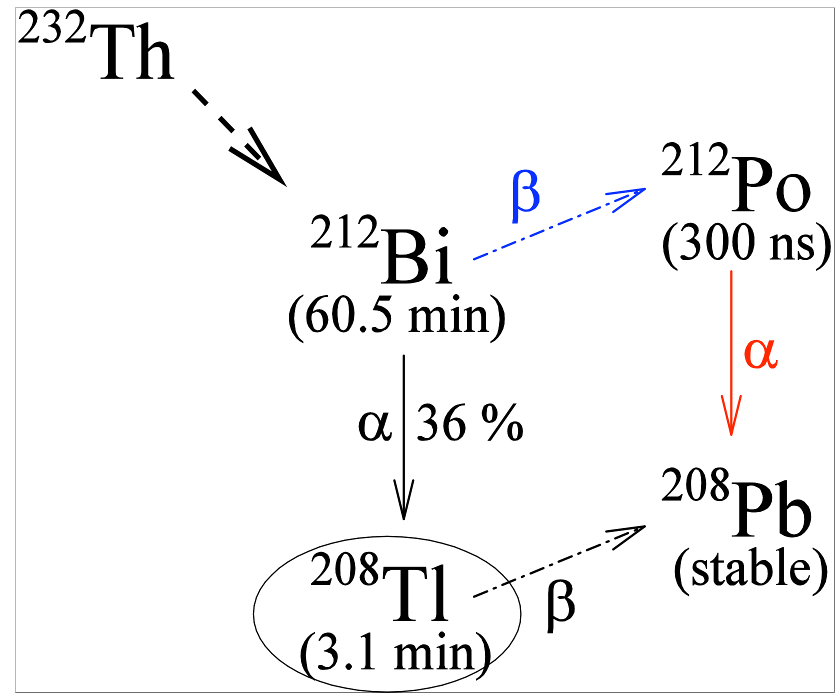
100 kg by centrifugation in Russia feasible

within the timescale required

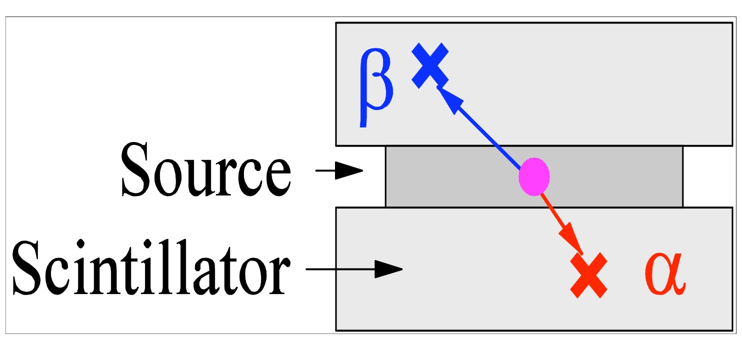
Source radiopurity: BiPo detector

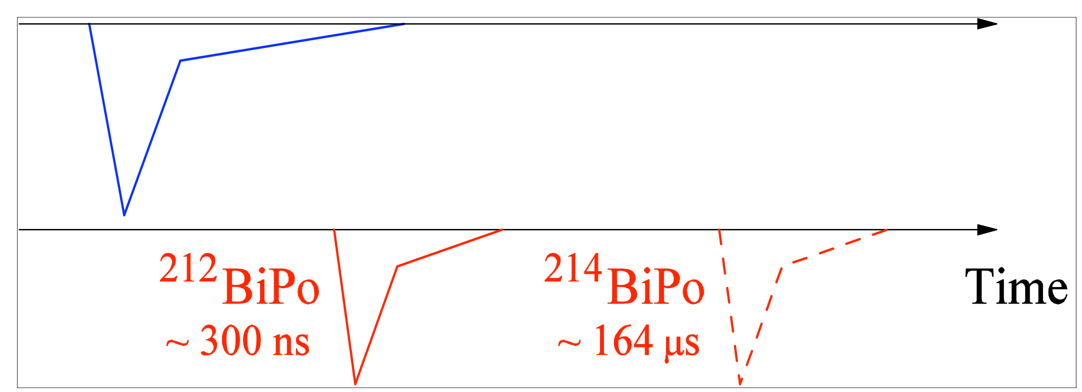
Detector dedicated to ultra-low leve radioactivity measurement in SuperNEMO source foils: **^{208}Tl < 2 µBq/kg, ^{214}Bi < 10 µBq/kg**





BiPo. The Idea



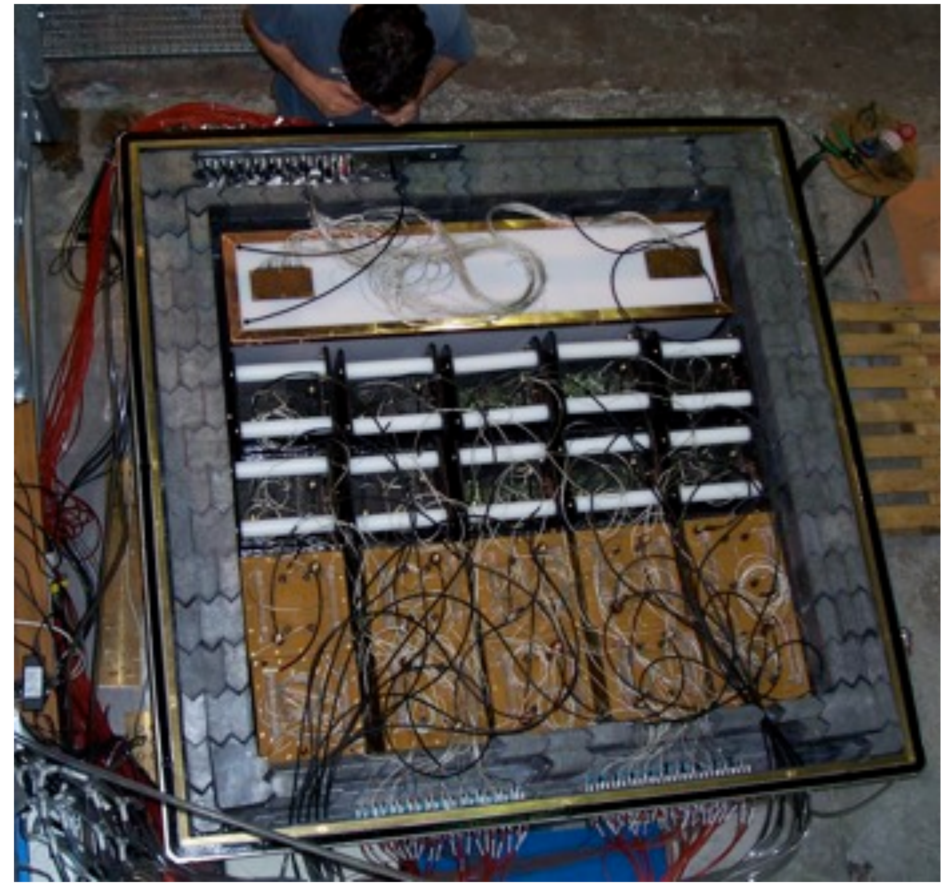


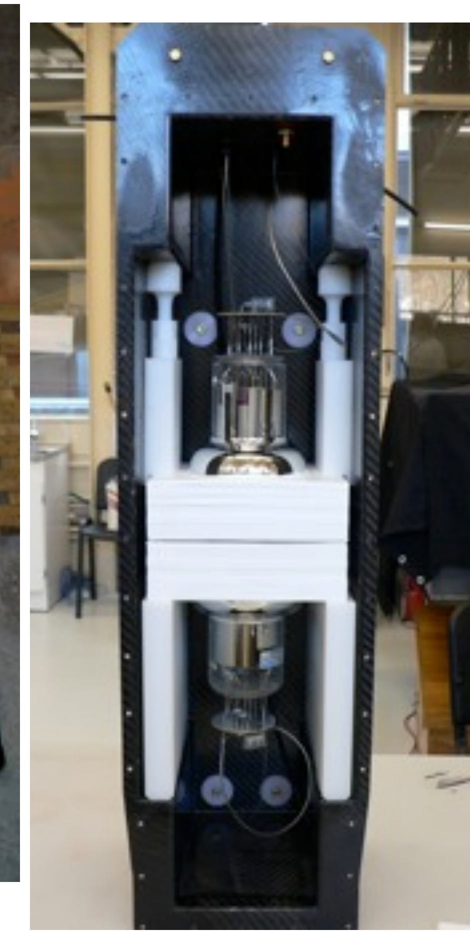
BiPo detectors

BiPo-1 prototype running in LSM
20 modules (20cm x 20cm scintillators and pmts)

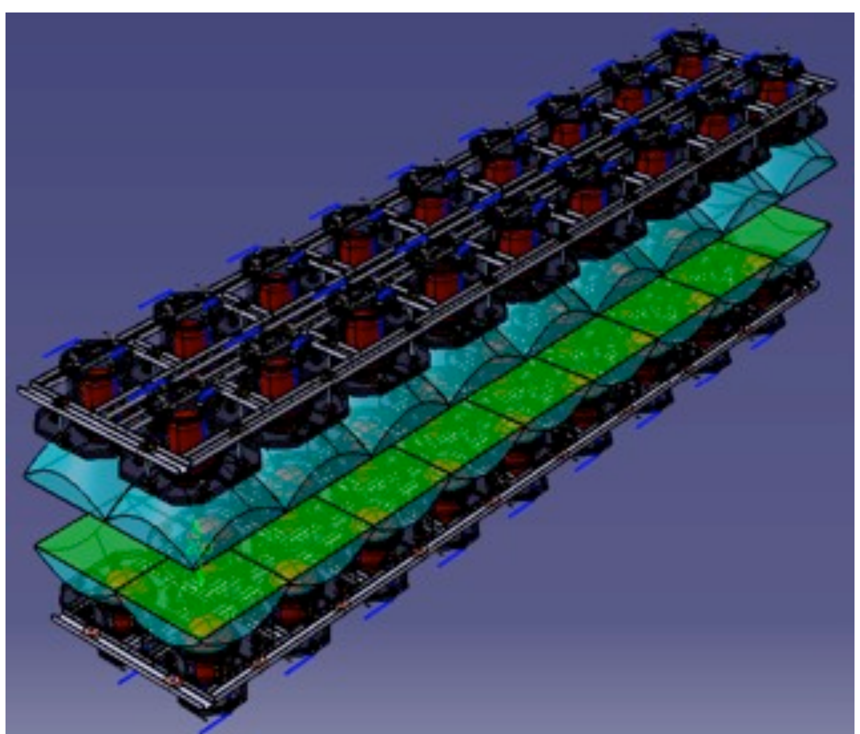
Goal: Detector background level measurement (scintillator surface radiopurity)

Results: < 10 **µBq/kg** possible

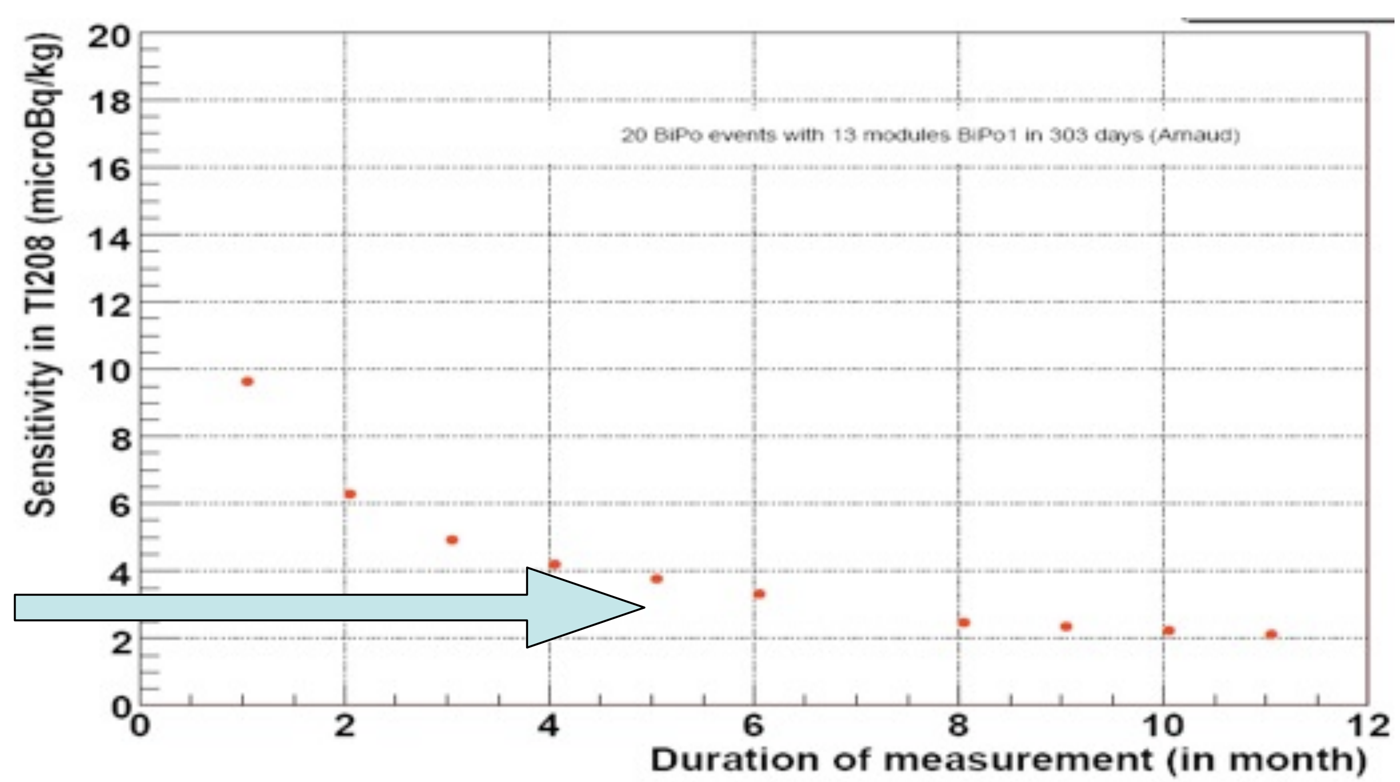




Next step: **BiPo-3** detector, 3.3 m^2, to measure source radiopurity for 1st module (**Demonstrator**). Construction in 2010, start running in 2011 possibly in Canfranc



3 µBq/kg in 6 months



HPGe and Radon detectors

All material have to undergo radiopurity control. Challenging levels!

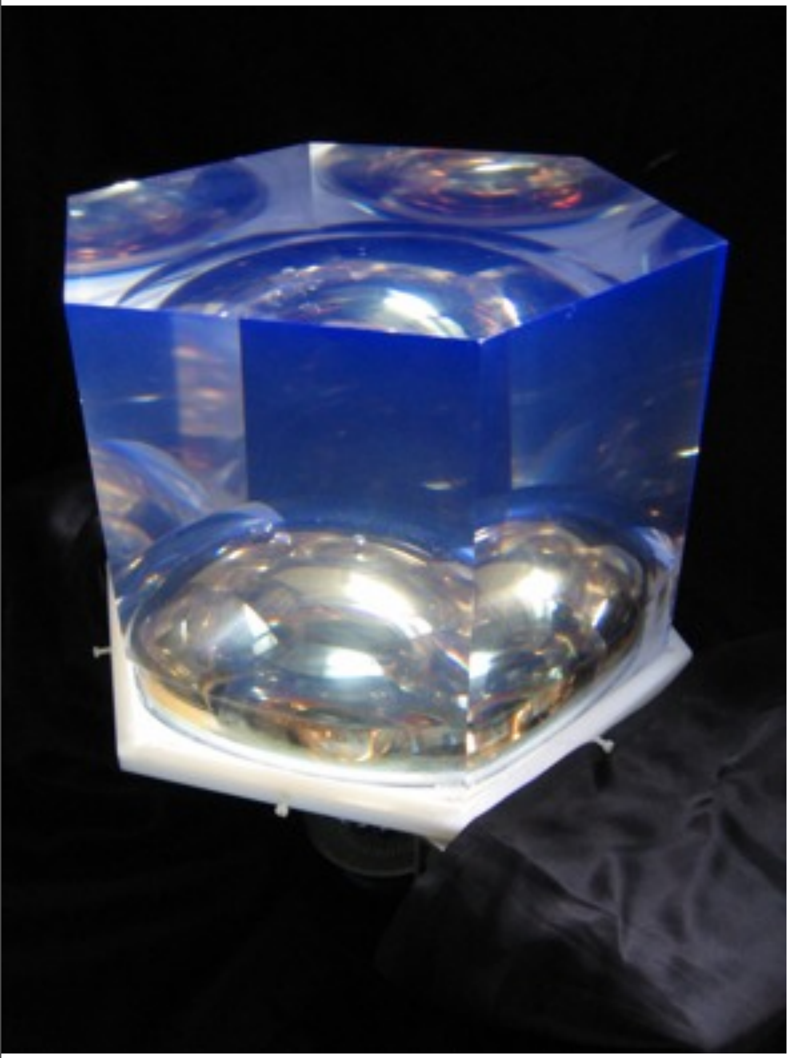
Radon emanation studies
Work in progress to develop detector with sensitivity 0.1 mBq/m^3

2x400 cm^3 HPGe ultra-LB detectors in LSM
Assuming 1kg x 1 month:

60 μBq/kg for ^{208}Tl
200 μBq/kg for ^{214}Bi

A new HPGe 600 cm^3 being developed,
better efficiency, lower background
More detectors available in several labs for pre-screening

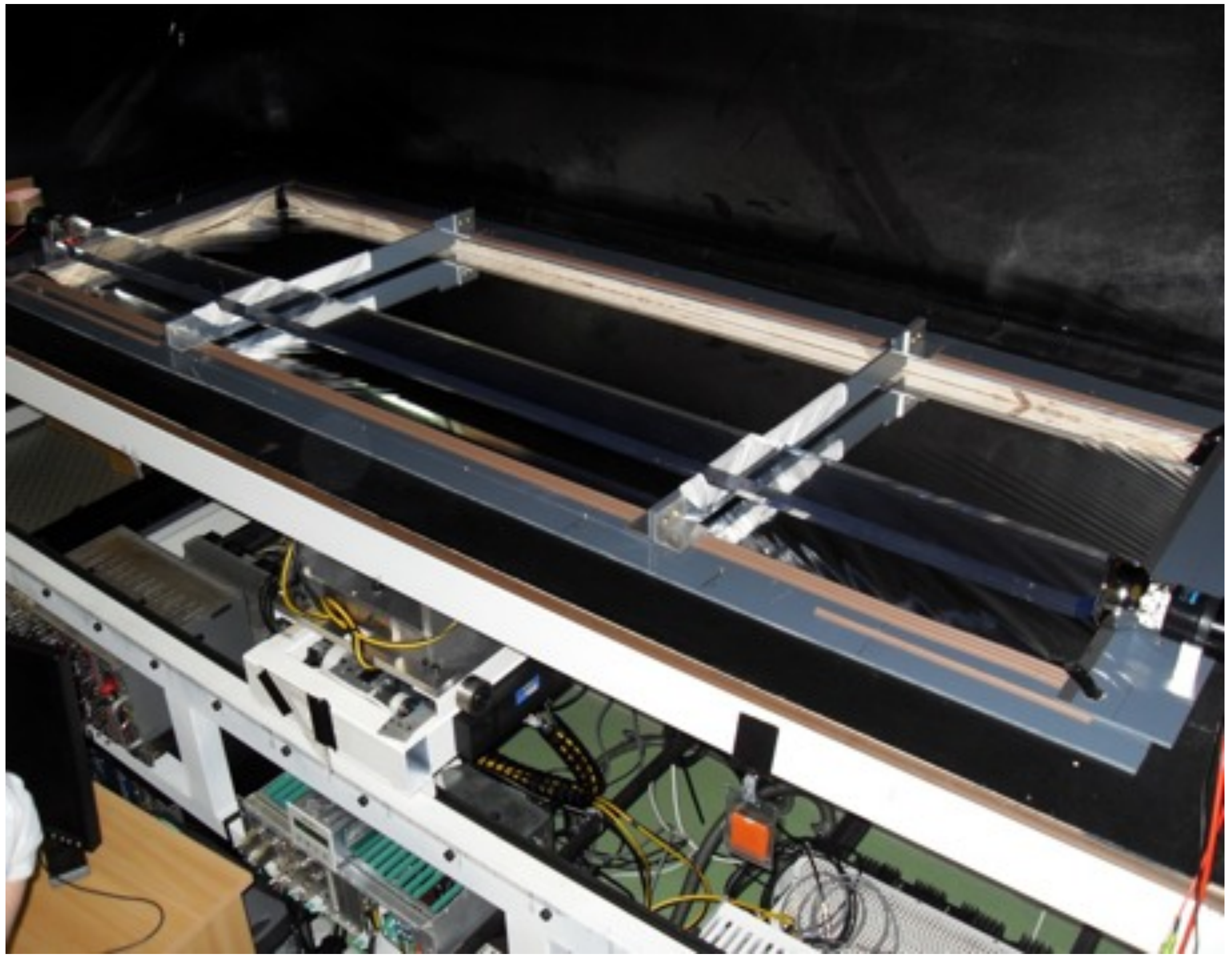
Calorimeter R&D



Large R&D effort to improve energy and time resolution

Scintillator
- Material
- Shape
- Size
- Coating

PMT
- QE
- Uniformity
- Collection efficiency
- Radiopurity



Goals for both designs reached

Blocks **ΔE/E (FWHM@1MeV) = 7% !!** → **FWHM 4% @ $Q_{\beta\beta}$ = 3 MeV**

Bars **ΔE/E (FWHM@1MeV) = 10% !!**

Calorimeter. Remaining R&D

Scintillator

- Final shape details for a feasible mechanical design

PMT blocks

- Better ΔE/E with Photonis than Hamamatsu
  - FWHM (1 MeV) 6.7% vs 7.5%

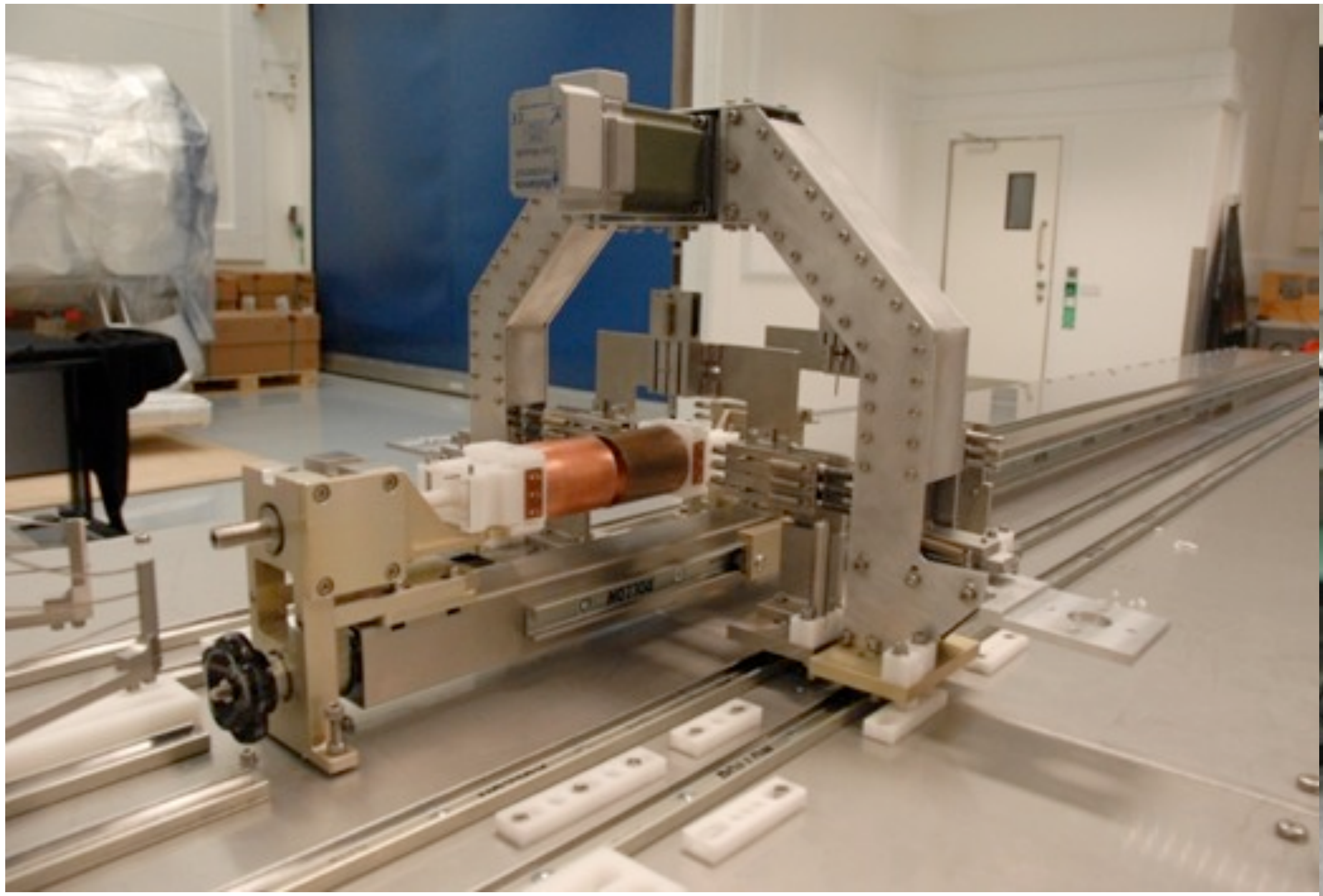
  but Photonis has gone out of business
- Work with Hamamatsu on improvements. Input from our joint R&D with Photonis
- Radiopurity. (Goal: ^{40}K < 0.1 Bq/kg, ^{214}Bi < 0.04 Bq/kg, ^{208}Tl <0.003 Bq/kg)
  - Synthetic silica instead of traditional glass under study

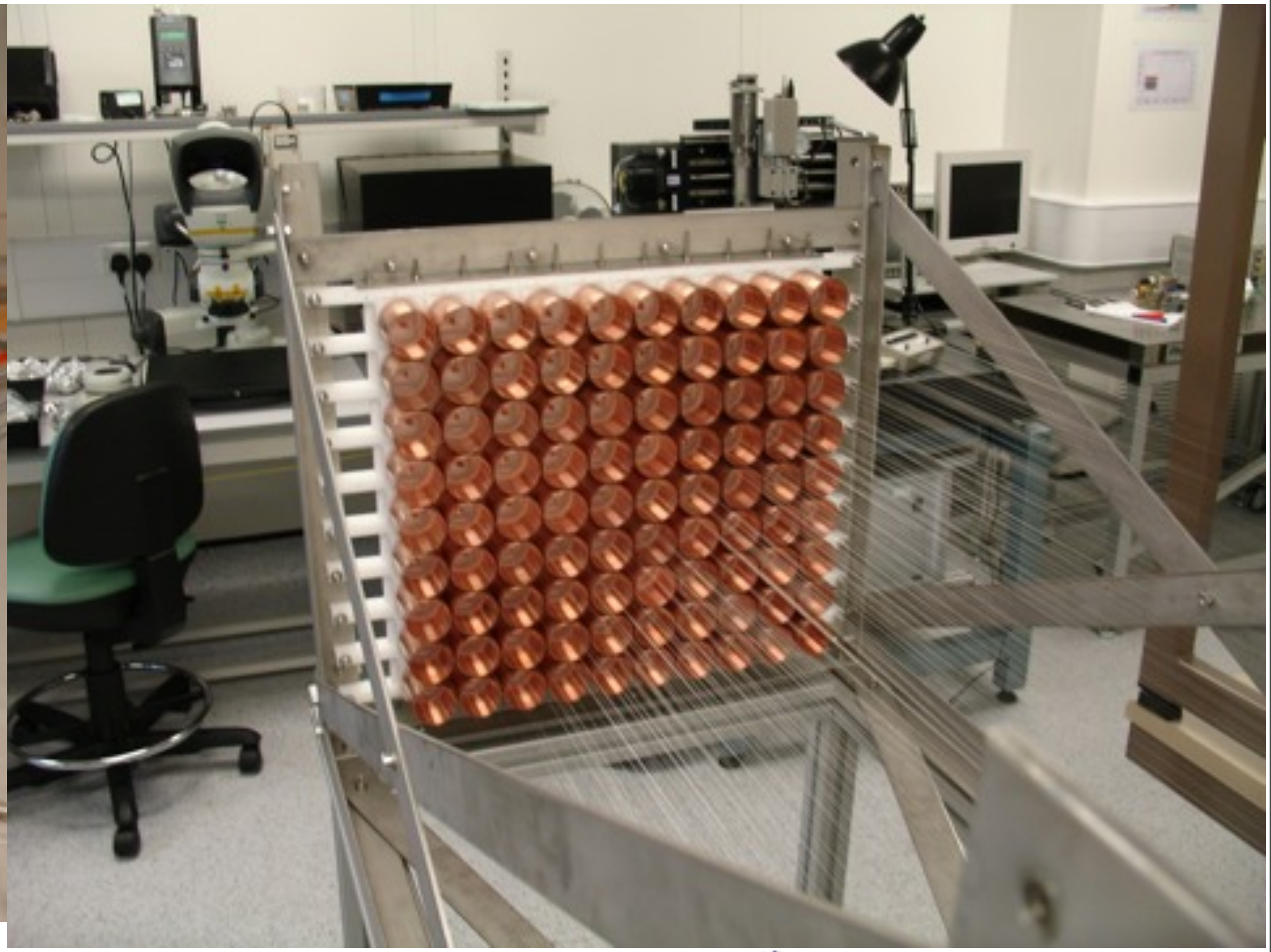
PMT bars

- Improve timing by changing faceplate from flat to plano-concave type

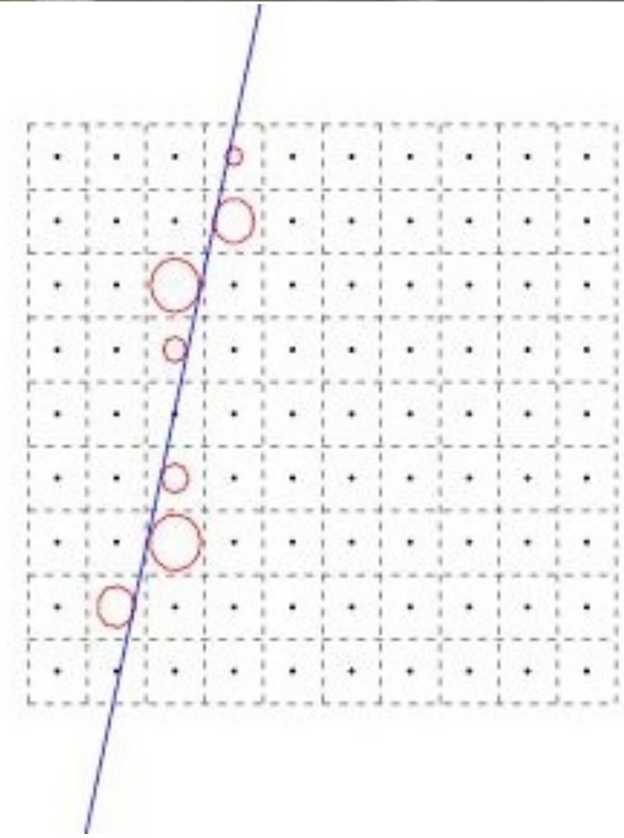
Finally, bars vs block decision

Tracker R&D





- Basic cell design developed and verified with 90-cell prototype
- Mechanical model of automated wiring robot
- Cosmic muon data collected.
  Required performance demonstrated
  - 0.7mm transverse, 1cm longitudinal resolution
  - Cells efficiency >98%



Next step: To build 1st SuperNEMO module - Demonstrator

Goals

- Demonstrate feasibility of large scale mass production
- To measure backgrounds especially from radon emanation
  - Only possible with a realistic super-module
- To finalise detector design
- To produce a competitive physics measurement

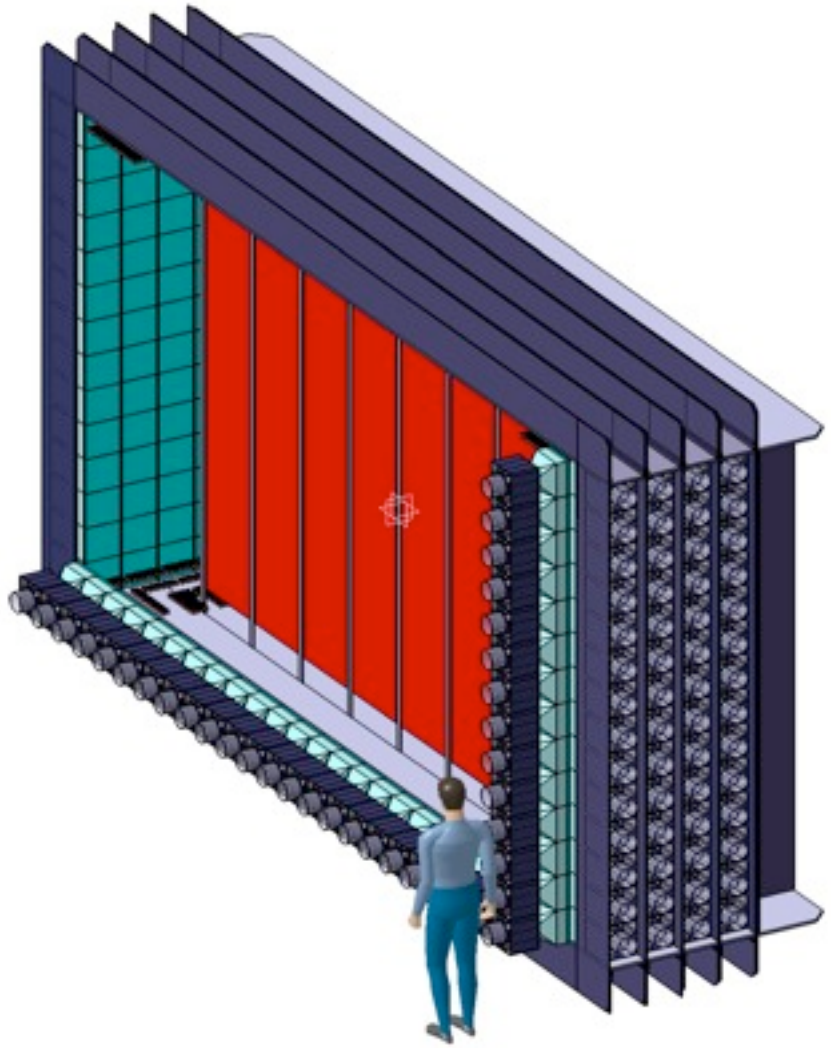
↓

0.3 expected bkg events in 2.8 - 3.2 MeV
with 7kg of ^{82}Se in 2 yr

Sensitivity by 2015: $6.5 \cdot 10^{24}$ yr (90% CL)

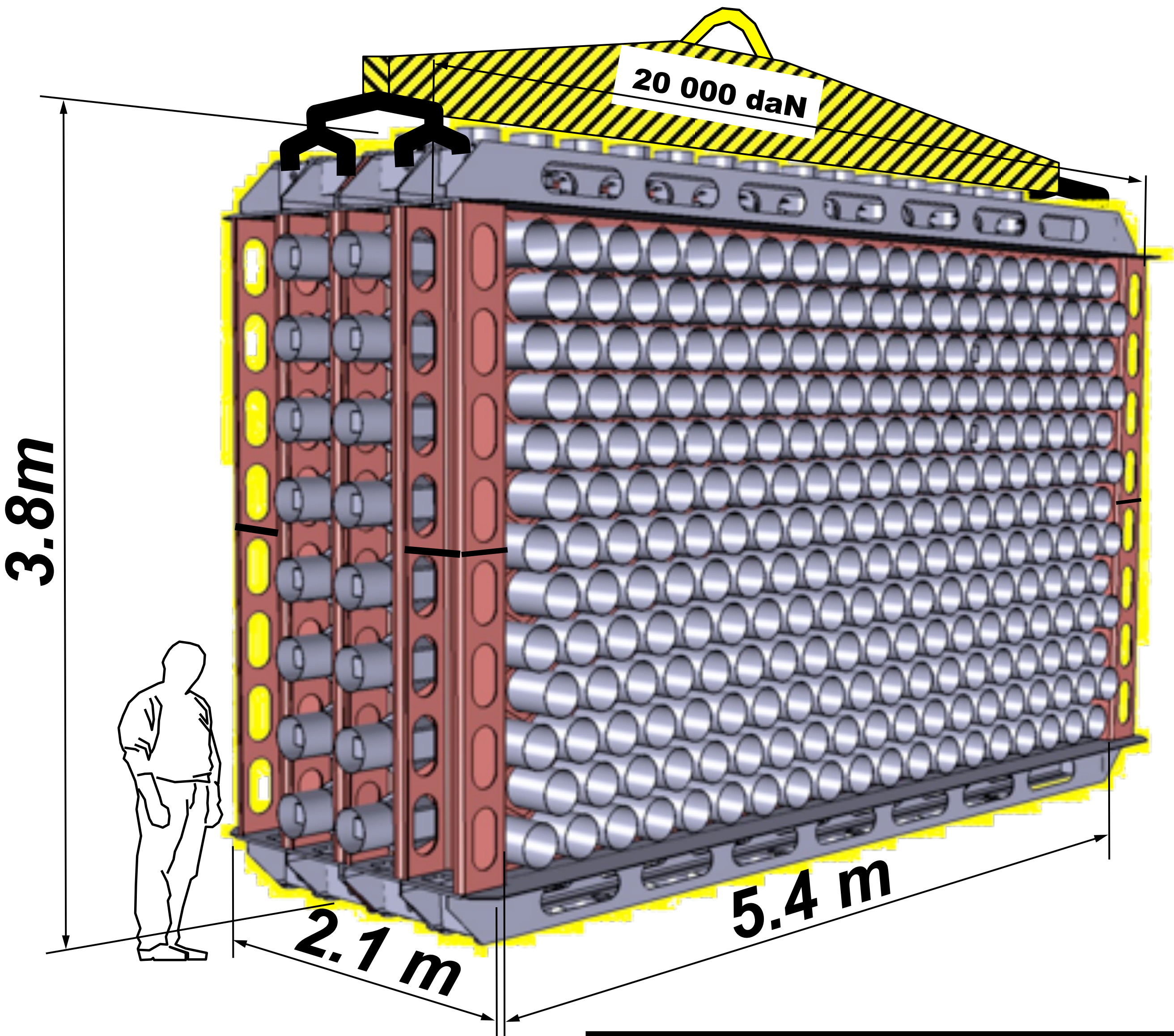
it is equivalent to **$3 \cdot 10^{25}$ yr** for ^{76}Ge (GERDA-PhaseI)

or ~4 expected "golden events" if Klapdor is right

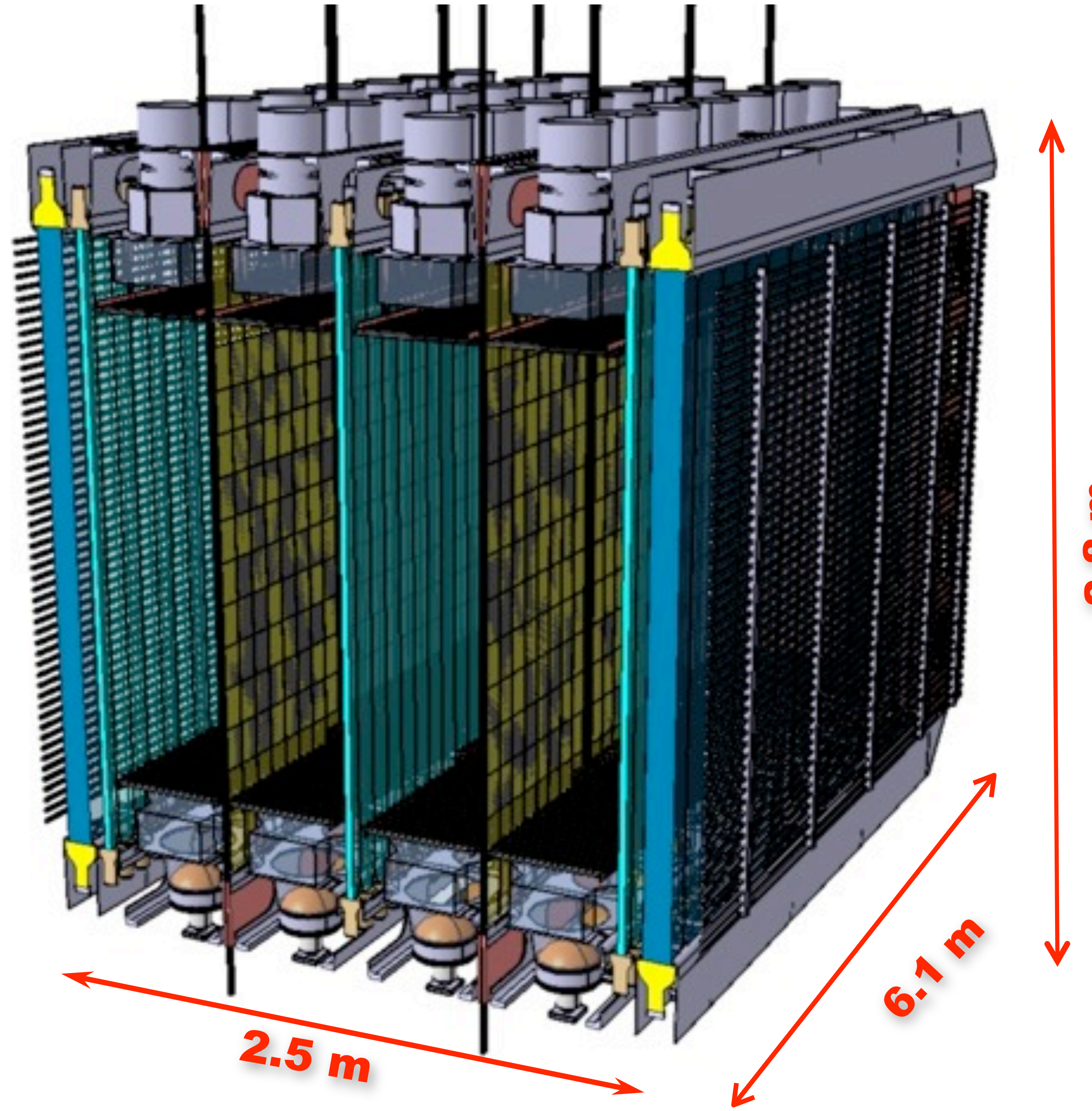


Demonstrator Design

Blocks



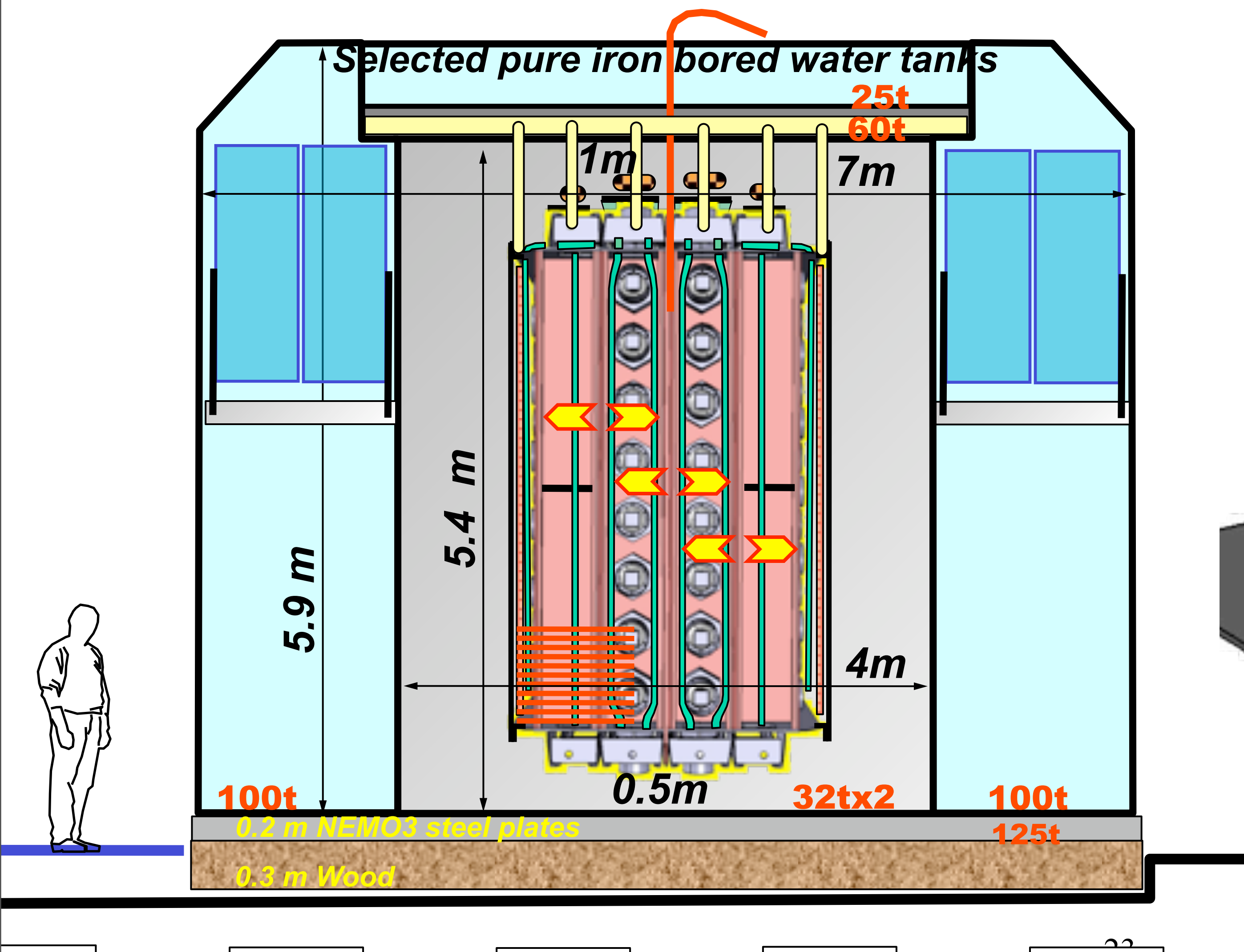
Bars

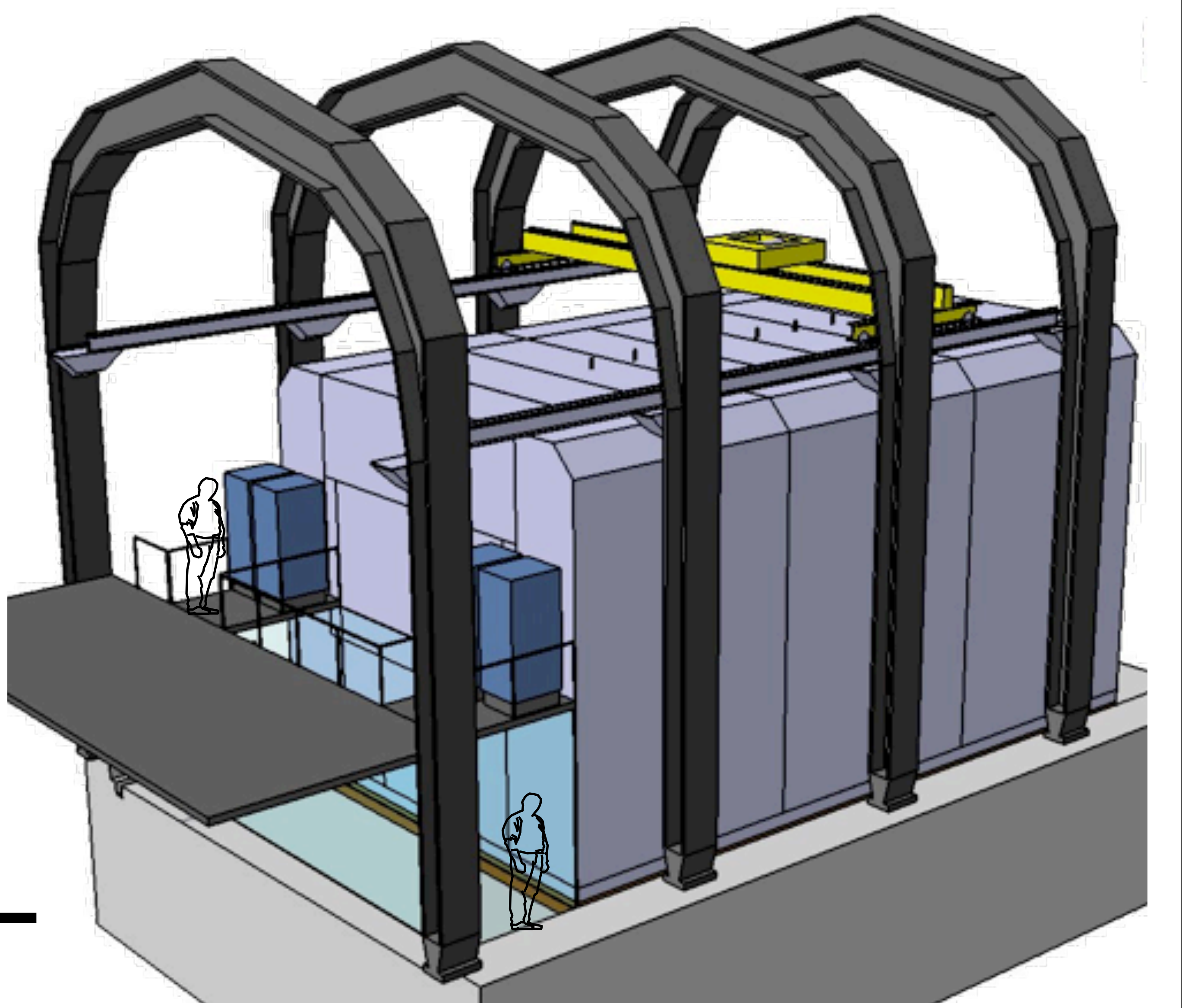


Demonstrator construction: 2010 - 2012
Start running 2013

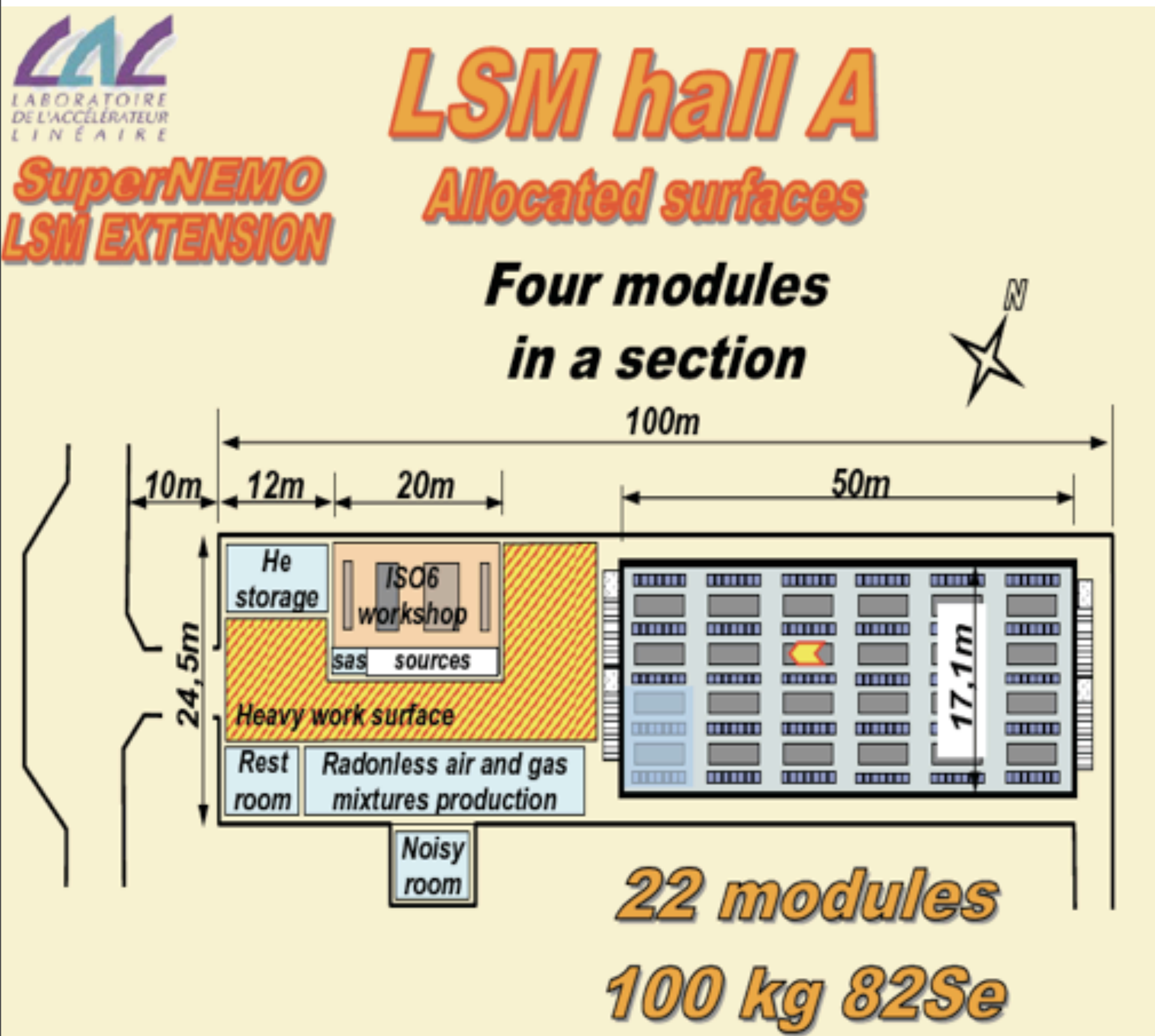
Demonstrator in LSM

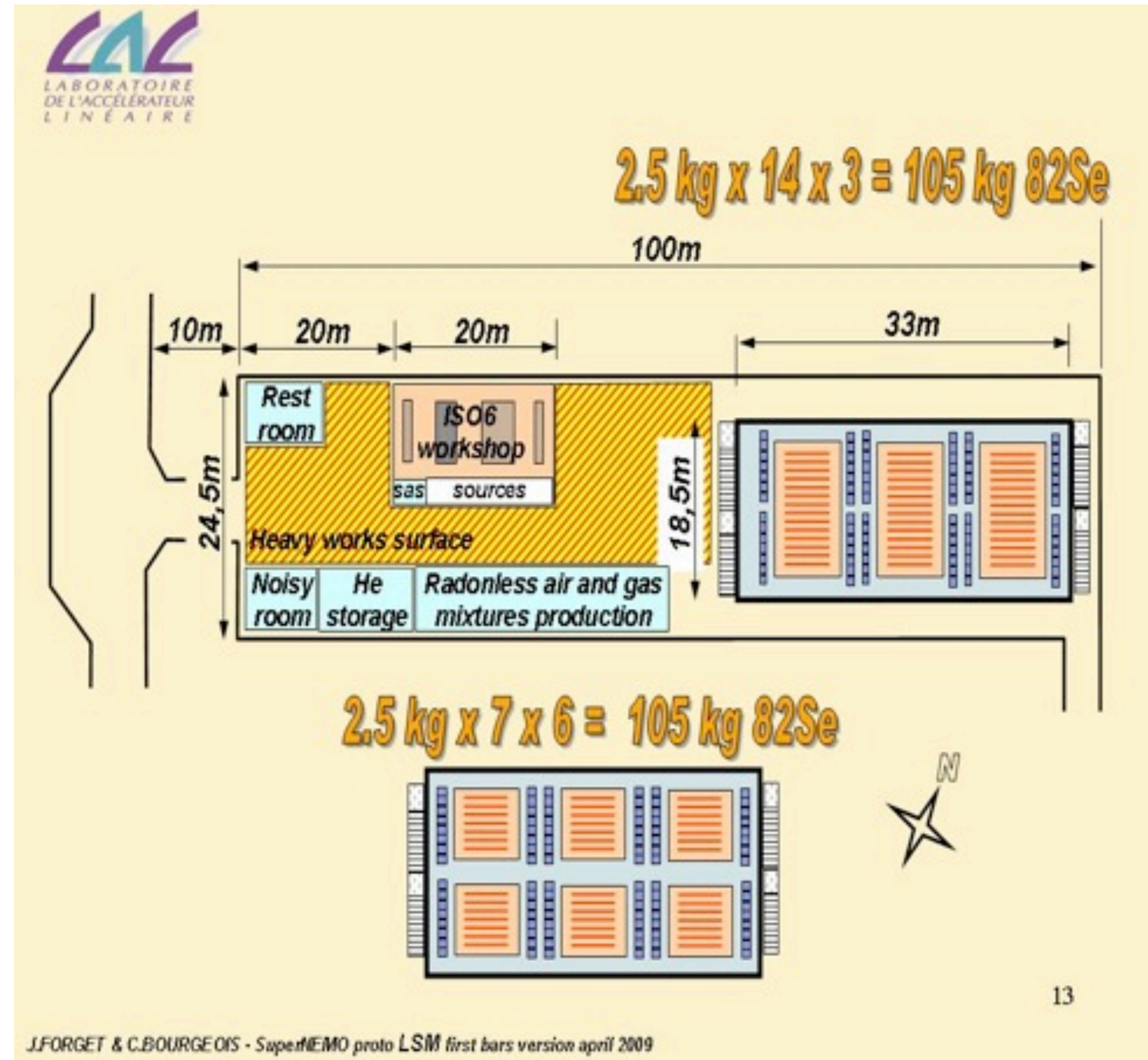
Originally expected to be hosted in “old” LSM (instead of NEMO-3) but, if LSM-extension ready in 2013, may go straight in the new lab.





Full SuperNEMO Detector in LSM (extension)



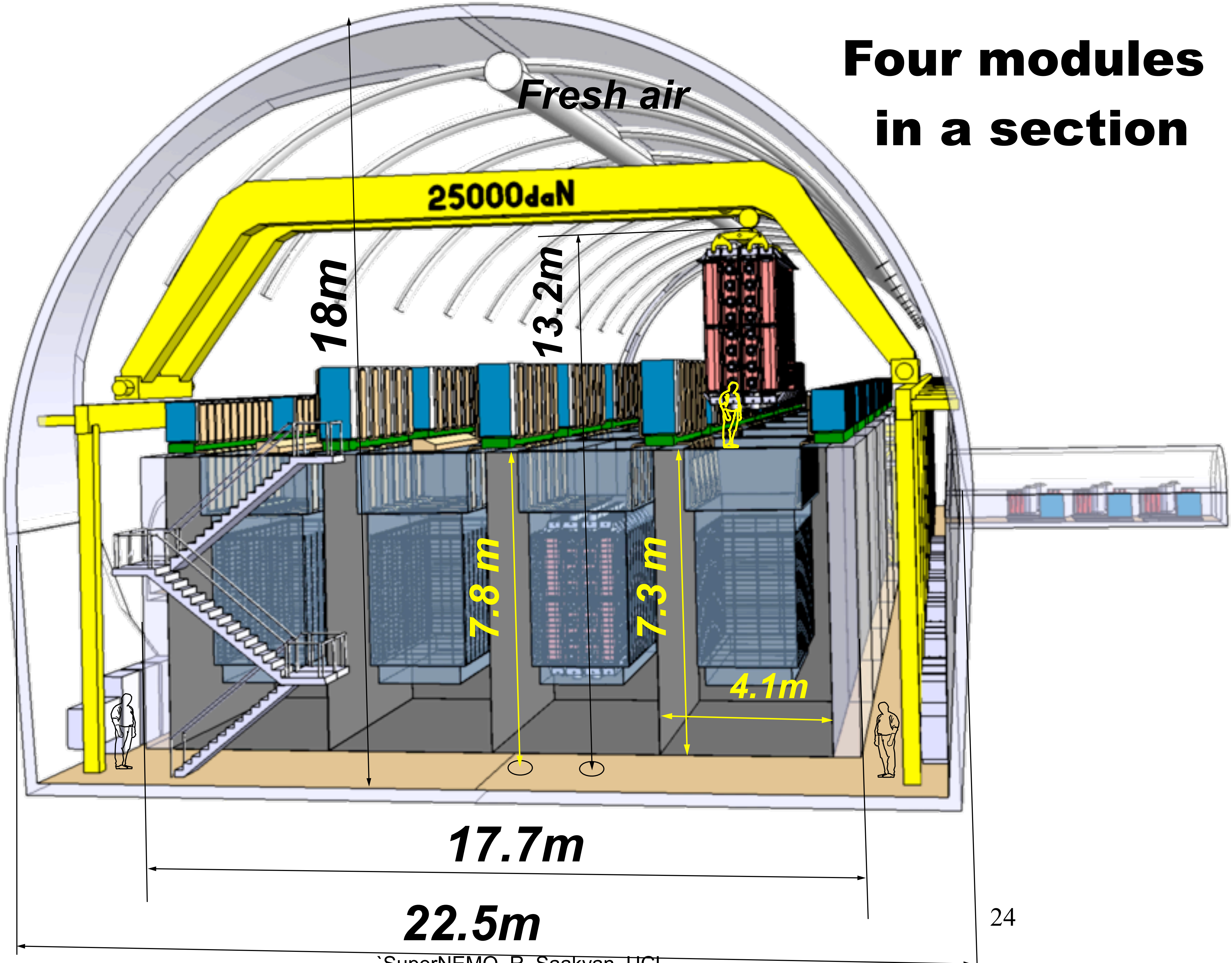


Blocks

Bars

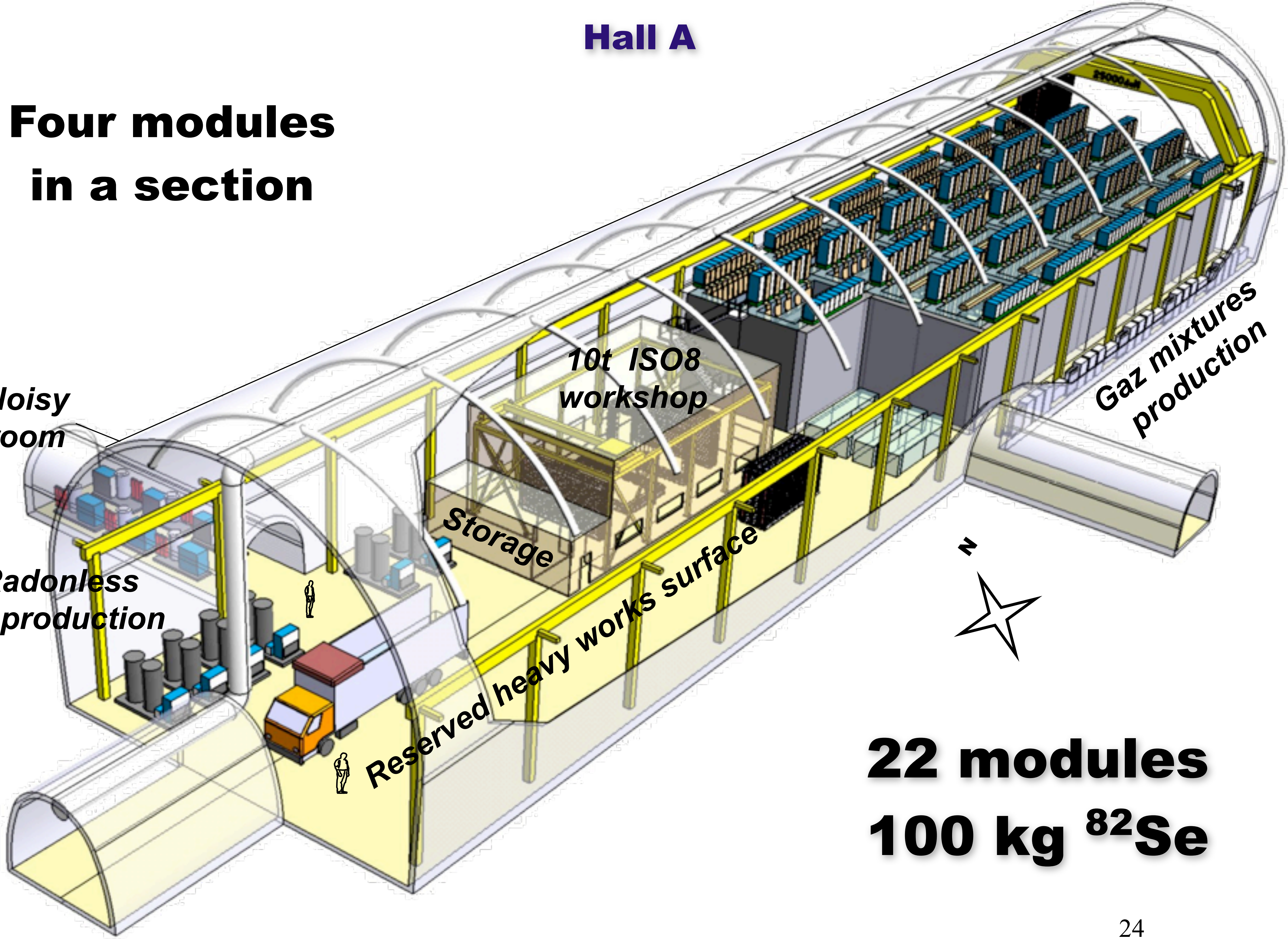
Letter of Intent submitted on 25 September 2009

Full SuperNEMO Detector in LSM (extension)



Full SuperNEMO Detector in LSM (extension)

Four modules in a section



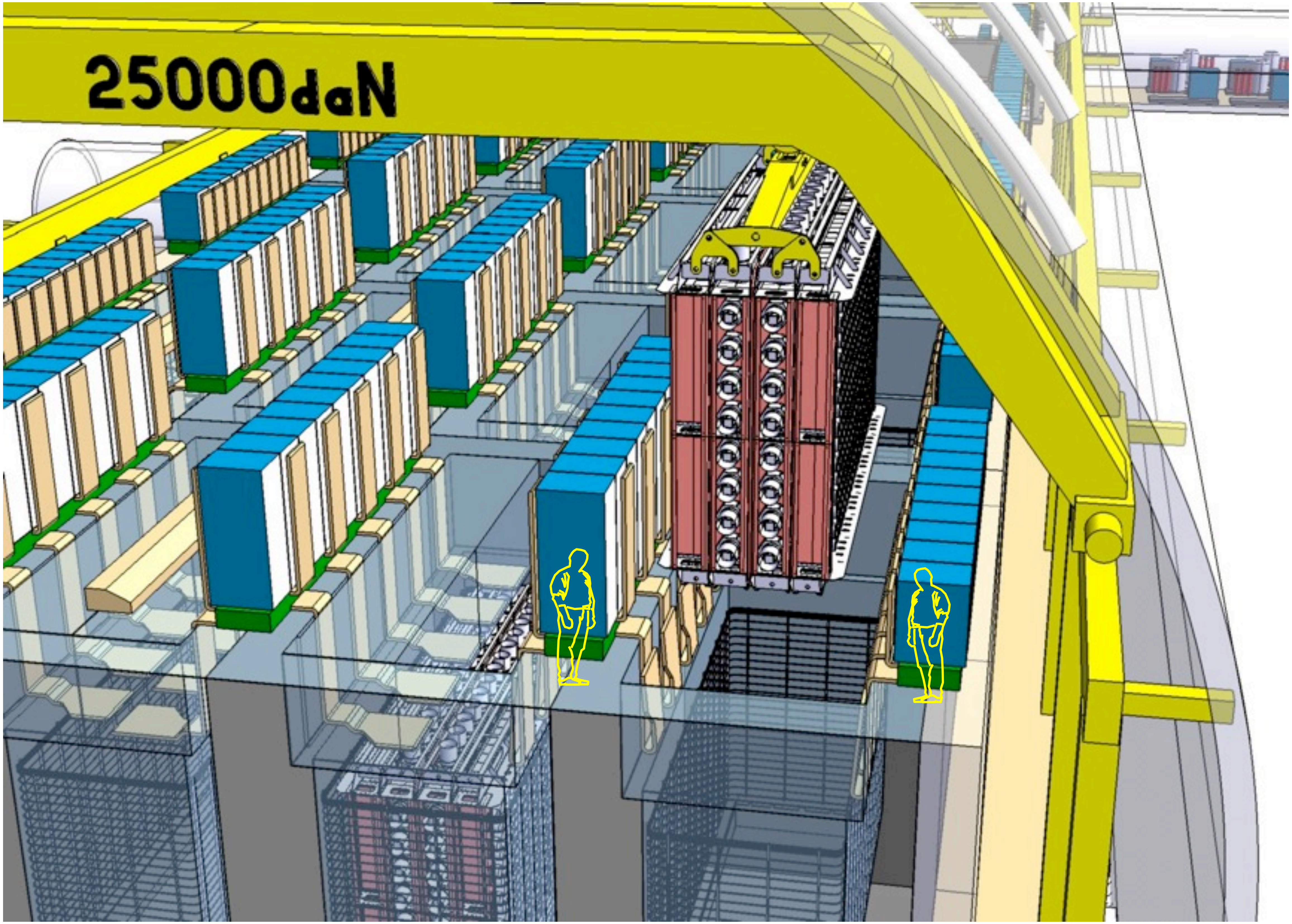
22 modules

100 kg ^{82}Se

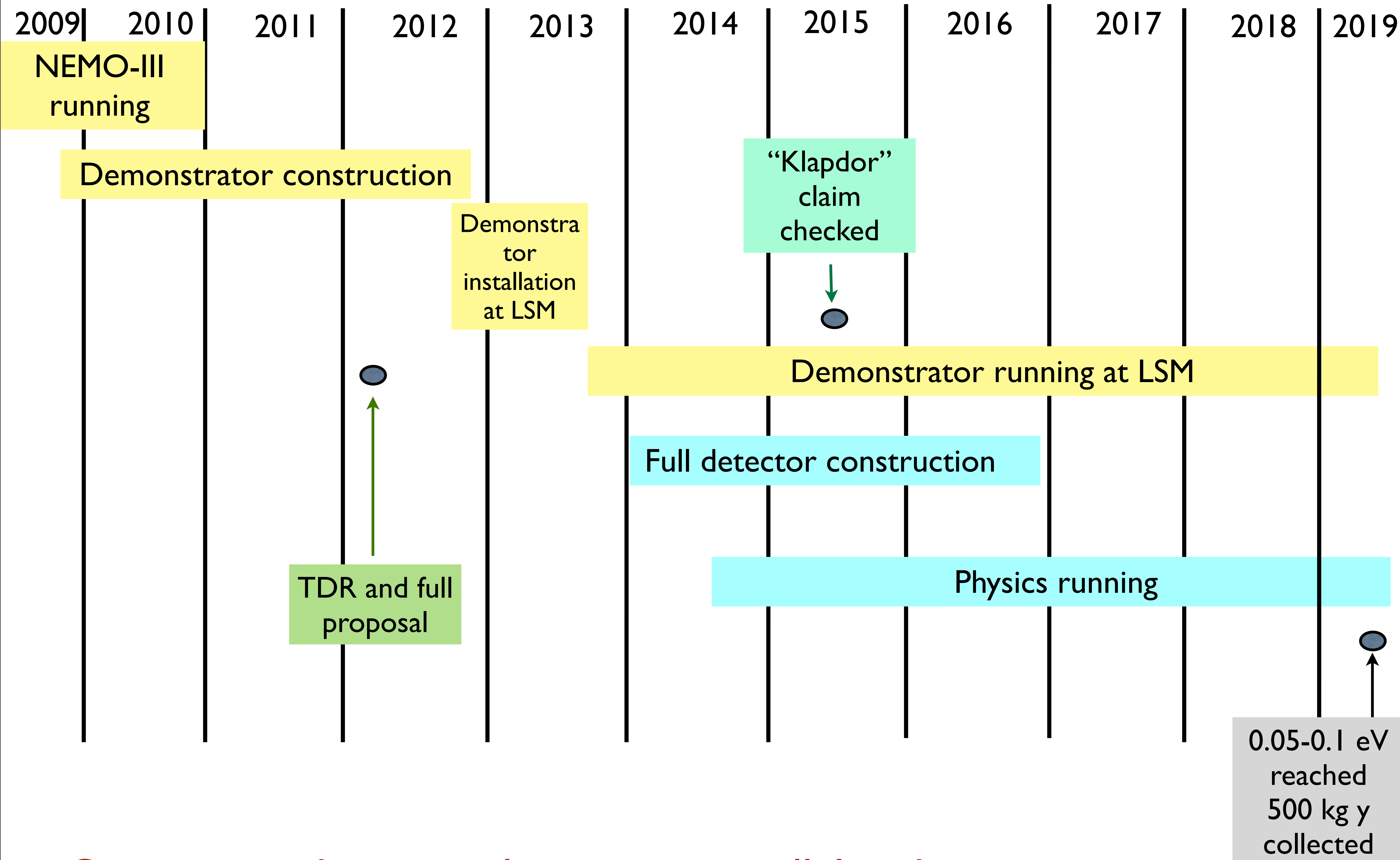
24

Full SuperNEMO Detector in LSM (extension)

Moving a module



SuperNEMO Schedule overview



Continuous physics exploitation in parallel with construction

Concluding Remarks

- SuperNEMO is capable of probing **new physics at 50-100 meV** neutrino mass scale
- As any other DBD experiment it is **high risk-high return**
- SuperNEMO approach is **unique**
  - Event topology fully reconstructed
  - Isotope flexibility
- LSM is a prime location for SuperNEMO

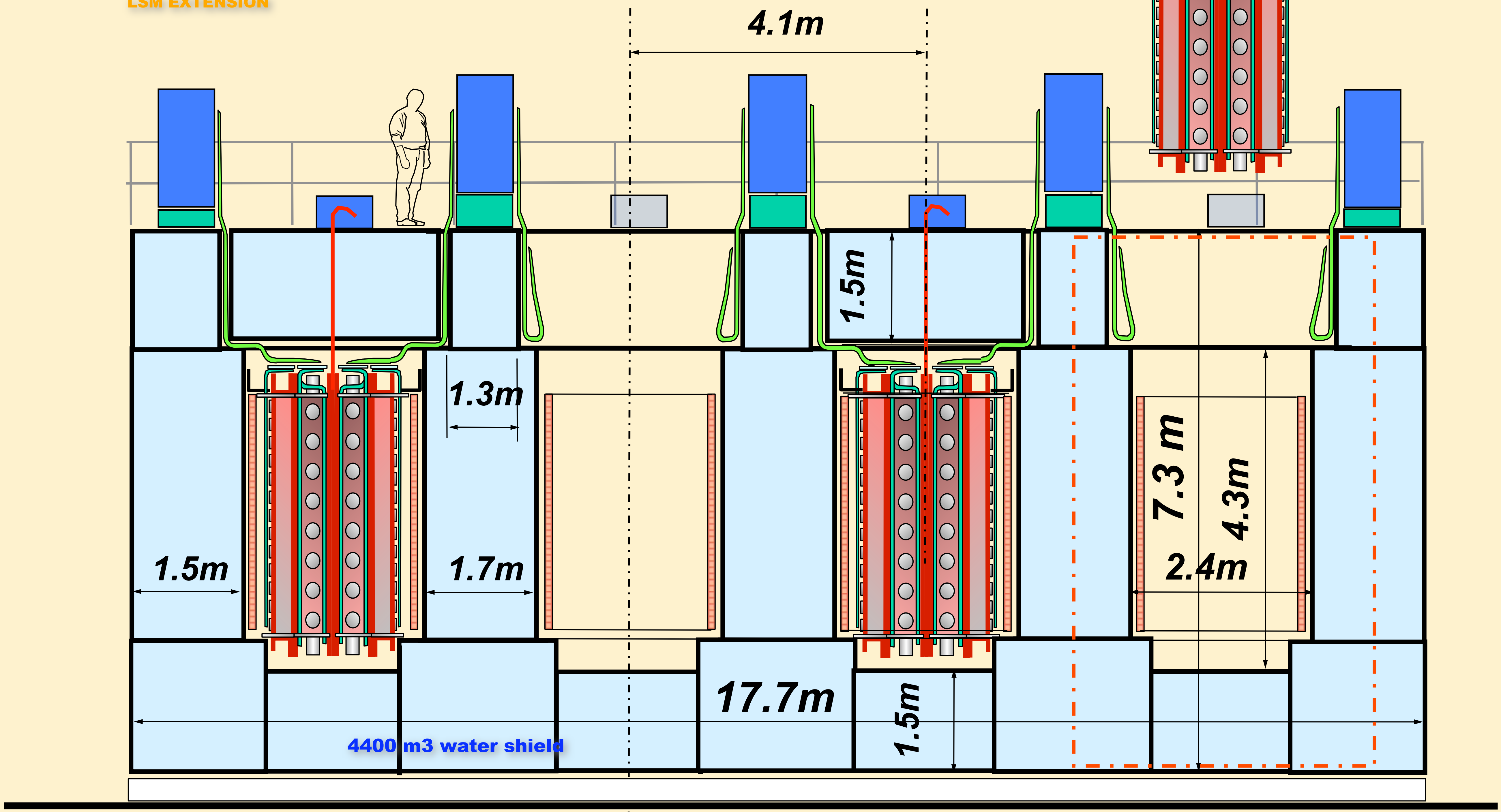
EXTRA

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE
IN2P3-CNRS et Université PARIS-SUD Centre Scientifique d'Orsay - Bât 200 - B.P. 34 91898 ORSAY Cedex (France)

SuperNEMO

LSM EXTENSION

Four modules in a section



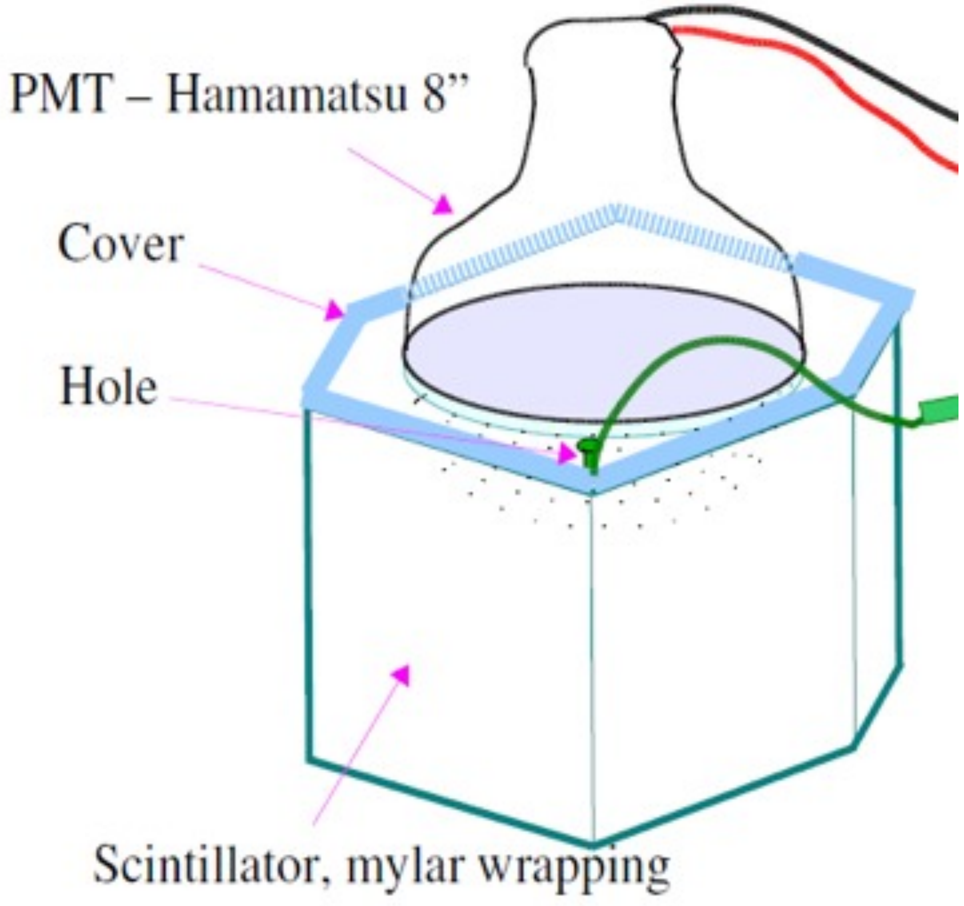
J.FORGET – sept 2009

R&D Calorimeter Calibration

Over more than 5 yr of data taking the gain of 12,000 PMTs must be controlled at 1% level.

Detector response must be linear, any non-linear effect controlled at 1% level

UV-LED based light injection system being developed



Linearity of Hamamatsu 8” PMT