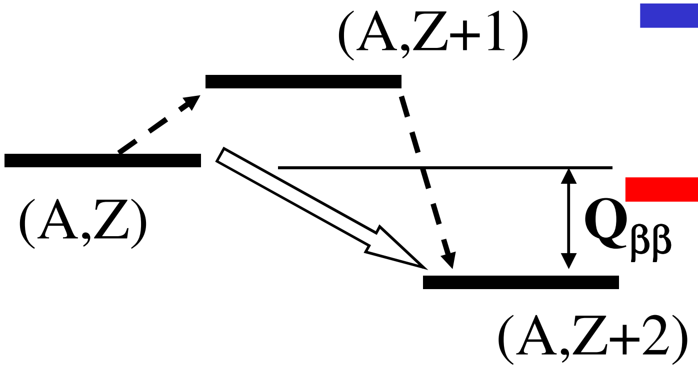
Search for neutrinoless double beta decay in NEMO 3 and SuperNEMO

Yu. Shitov, IC

- **Introduction to the ββ-decay theory/experiment**
- **NEMO-3 detector and its results**
- **SuperNEMO: basic R&D directions and its current status**
- **Conclusion**

Double beta decay basic statements



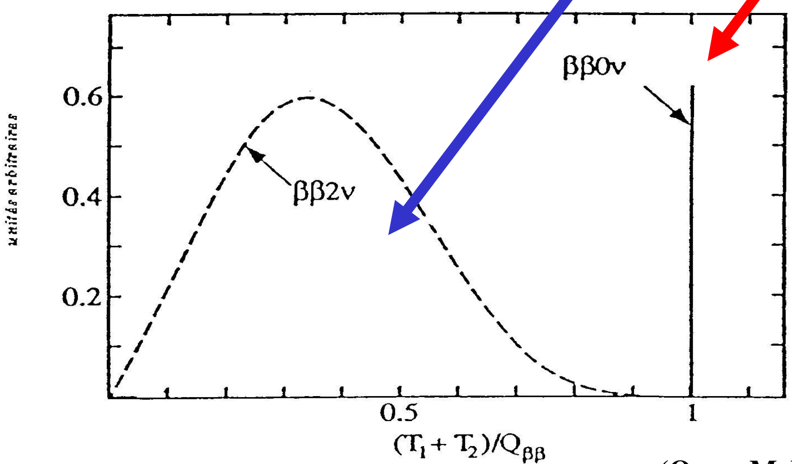
$\beta\beta2\nu$: allowed SM process $T_{1/2} \sim 10^{20}$y

(A,Z)→(A,Z+2) + $2e^-$ + 2ν (2n → 2p + $2e^-$ + 2ν)

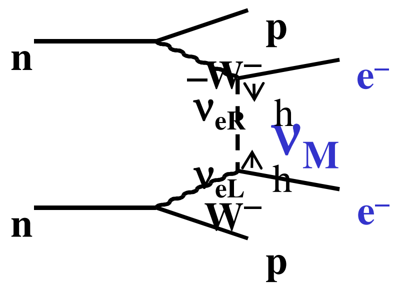
$\beta\beta0\nu$: beyond the SM $T_{1/2} \geq 10^{25}$y

(A,Z)→(A,Z+2) + $2e^-$ (2n → 2p + $2e^-$)

Massive Majorana neutrinos
(particle≡antiparticle)
Happiness for theoreticians
(many mechanisms proposed to describe the process)



($Q_{\beta\beta}$ ~ MeV)



Double beta decay basic formulas

$$A^{0\nu} = (T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2 \left\langle m_\nu \right\rangle^2 / m_e^2 \sim Q^7 Z^2 \,|M^{0\nu}|^2$$

$$< m_\nu >= |U_{e1}|^2\, m_1 + |U_{e2}|^2 e^{i\,\alpha_1}\, m_2 + |U_{e3}|^2 e^{i\,\alpha_2}\, m_3$$

- effective neutrino Majorana mass

$M^{0\nu}$: nuclear matrix element

$G^{0\nu}$: phase space factor

THEORY

$$T'^{\,0\nu}_{1/2}(y) > \frac{\ln 2 \,.\, \mathcal{N}}{k_{C.L.}} \,.\, \frac{\varepsilon}{A} \,.\, \sqrt{\frac{M \,.\, t}{N_{Bckg} \,.\, \Delta E}}$$

M : mass (g)

ε : efficiency

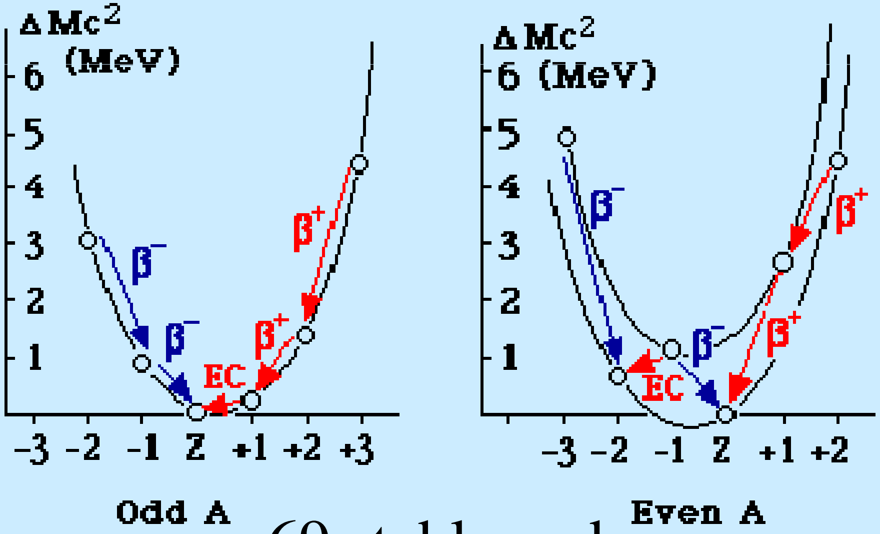
$K_{C.L.}$: confidence level

N : Avogadro number

t : exposition time (y)

N_{Bckg} : background events/ (keV/kg/y)

ΔE : energy resolution (keV)



~ 69 stable and

28 α-unstable ββ isotopes

EXPERIMENT

Resent interest to 0νββ-decay search

Great recent success in neutrino oscillation branch

↓

Strong support of 3 light active neutrino mixing theory

↓ Parameters defined

Δm_{sol}, θ_{sol}, Δm_{atm}, θ_{atm}

New oscillation experiments →

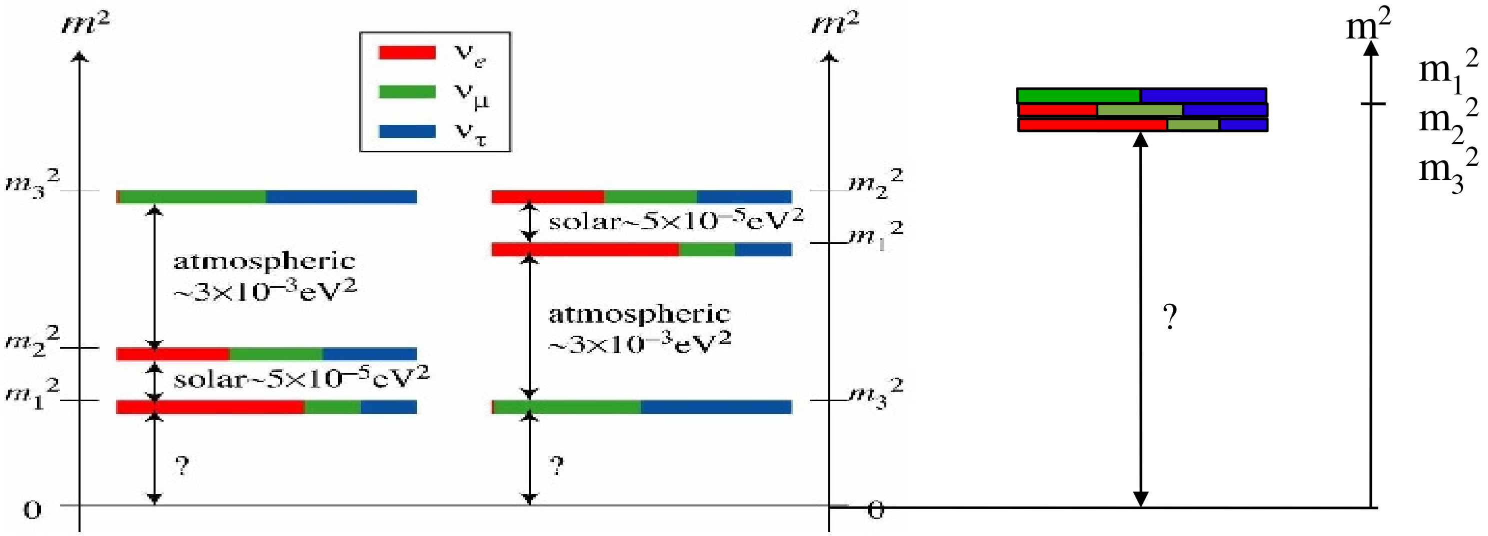
- existence of sterile neutrino(s)
- θ_{13} measurements
- precision of oscillation parameters

↓ Hot questions

0νββ-decay →

- neutrino nature (Dirac/Majorana)
- neutrino absolute scale and hierarchy pattern

Neutrino mass hierarchy patterns and 0νββ-decay



Normal hierarchy
$m_3 > m_2 \sim m_1$

Inverted hierarchy
$m_2 \sim m_1 > m_3$

Degenerate
$m_1 \approx m_2 \approx m_3 \gg |m_i - m_j|$

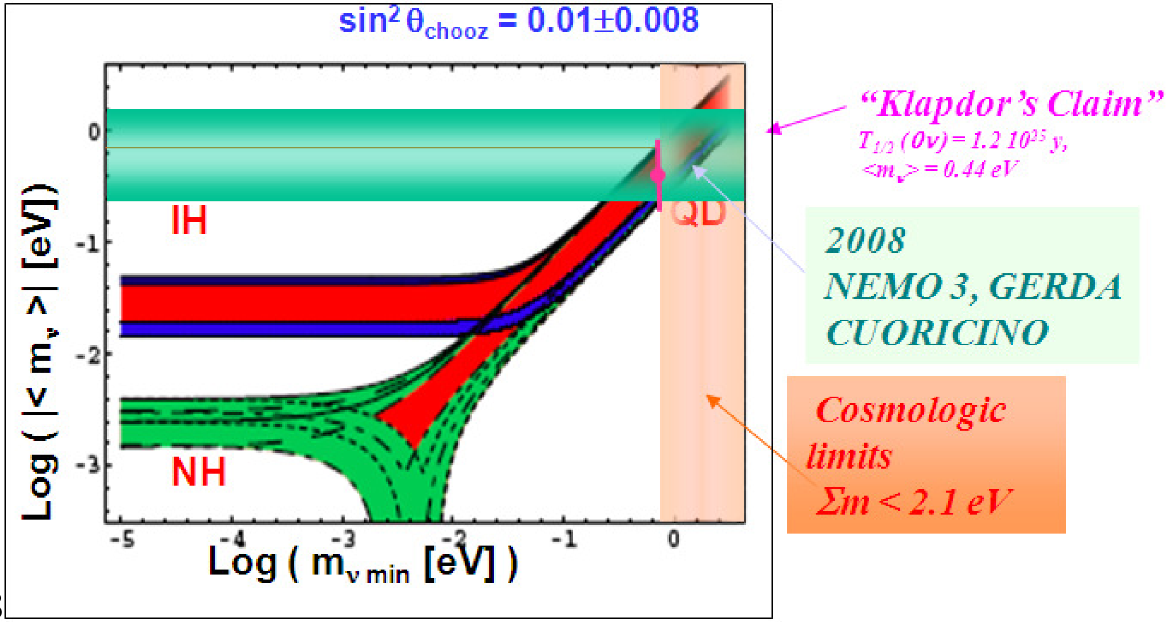
For $\sin^2\theta_{chooz} = 0.03$

Quasi-Degenerated(QD) :
$|\langle m_\nu\rangle| \lesssim 0.7$ eV (cosmology)

Inverted hierarchy (IH) :
20 meV $\lesssim |\langle m_\nu\rangle| \lesssim$ 55 meV

Normale hierarchy(NH) :
$|\langle m_\nu\rangle| \lesssim$ 20 meV

S. Pascoli, S.T. Petcov and T. Schwetz
hep-ph/0505226, Mai 2005



Experimental difficulties to observe 0νββ-decay

$T_{1/2} \geq 10^{26} > N_A = 6 \cdot 10^{23}$ → **1 decay per 50 kg per year!**

Large mass of enriched ββ-isotope

Now: tens of kg	⇒	Nearest future: hundreds of kg	⇒	Long-term future: tons

Background

- Natural background (<2614 keV) - extra-low setup radiopurity

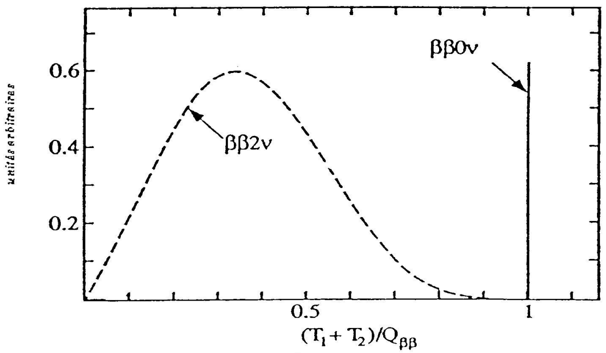
NEMO-3 (200 t) activity ~300 Bq, human body (60 kg) ~5000 Bq

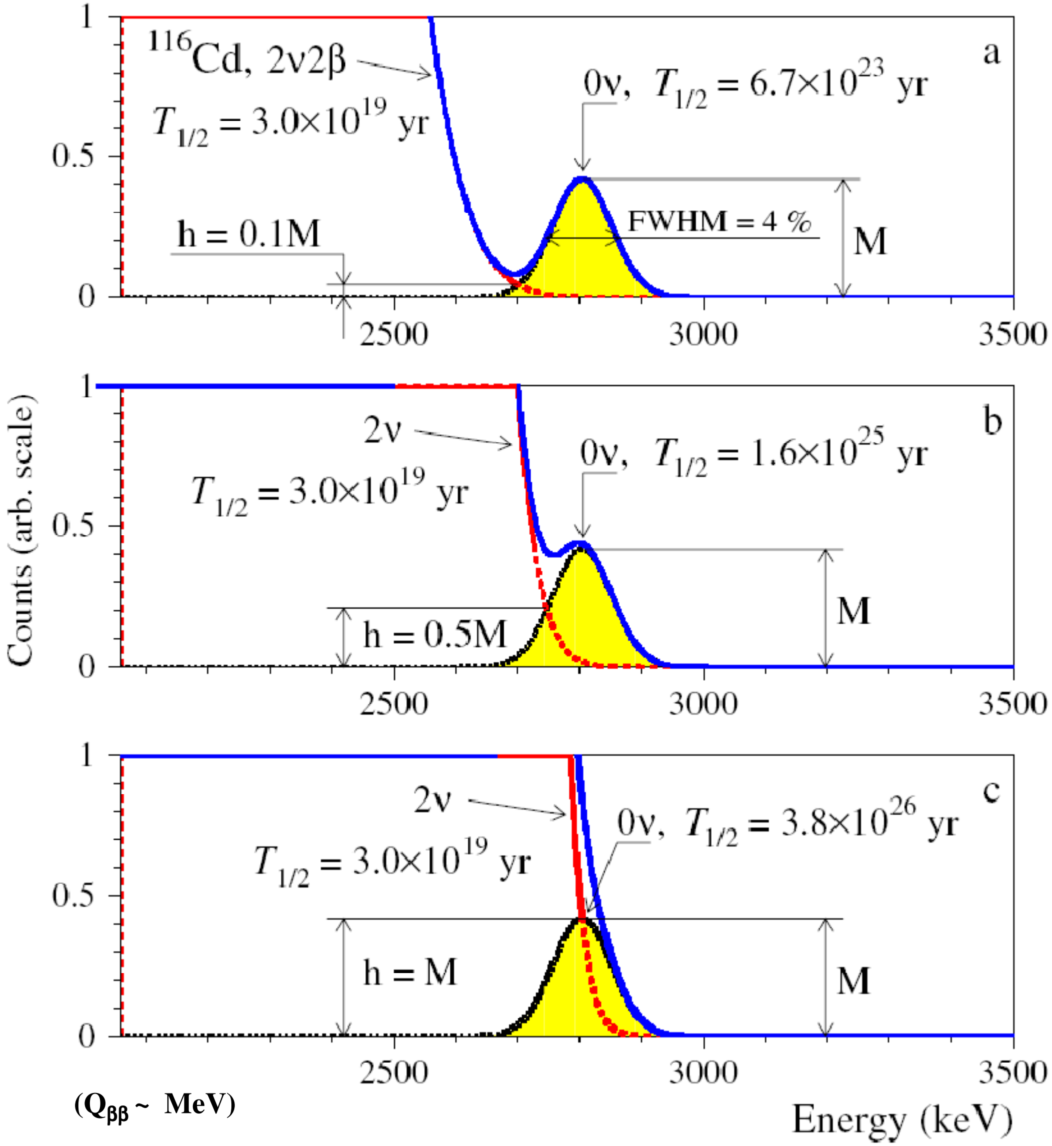
- Neutrons – active/passive shielding
- Cosmics – deep underground sites for setup location

Long-time exposition

- years of data taking - setup stability required

Resolution as key point

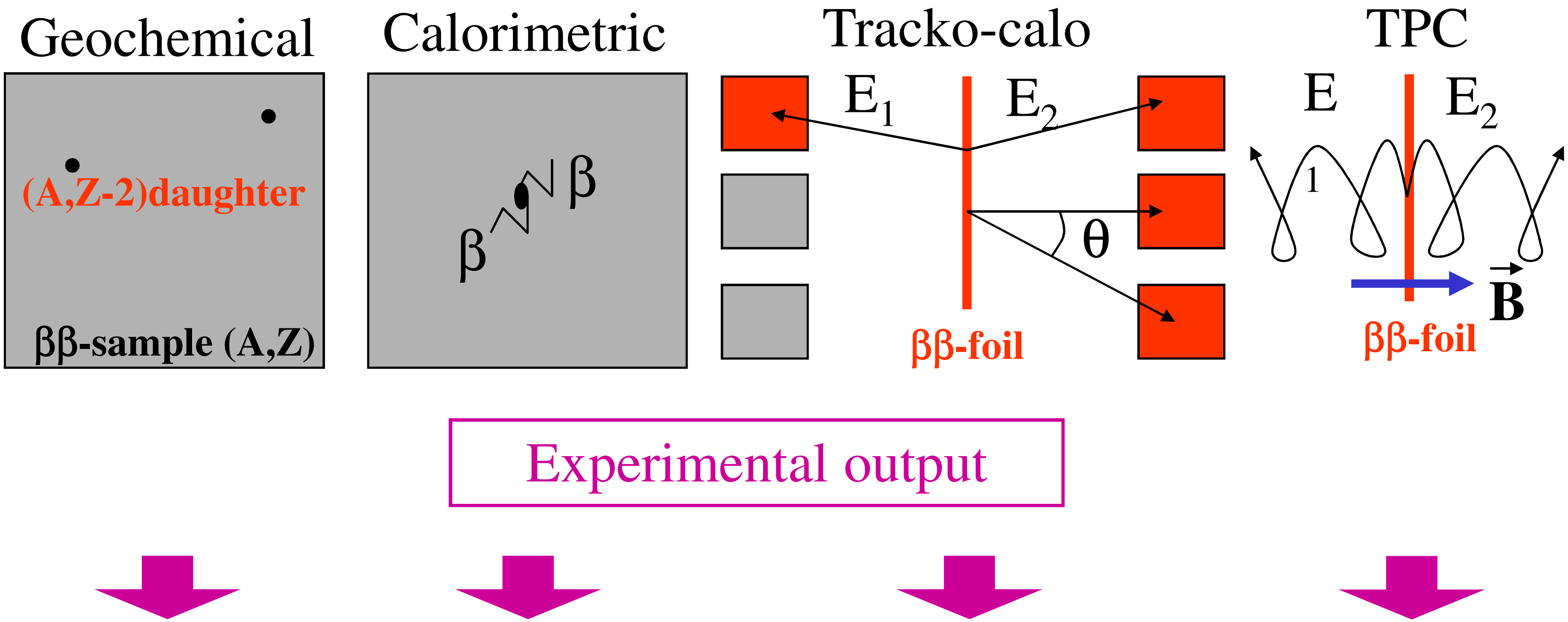




Avignone, King, Zdesenko, New Journal of Physics ***7*** *(2005) 6*

Experimental techniques to observe ββ-decay

Experimental methods



Experimental output

ββ-daughter rate **E1+E2 spectrum** **E1, E2, θ**

Calorimeter versus tracko-calo/TPC detectors

Calorimetric

Tracko-calo/TPC

Experimental advantages

Calorimetric:

- **Larger mass**
- **Better resolution**
- **~ 100% efficiency**

Tracko-calo/TPC:

- **Real ββ-observation.**
- **Any ββ-source can be measured**
- **Potentially zero-background exp.**
- **Test of different ββ0ν mechanisms in the case of observation.**

Experimental drawbacks

Calorimetric:

- **A few ββ-isotopes can be measured ^{76}Ge, ^{130}Te up to now.**
- **Unavoidable natural background.**
- **We don't see electrons, just energy released - no absolute proof, that we see ββ0ν-peak and not something else (γ-line)!**

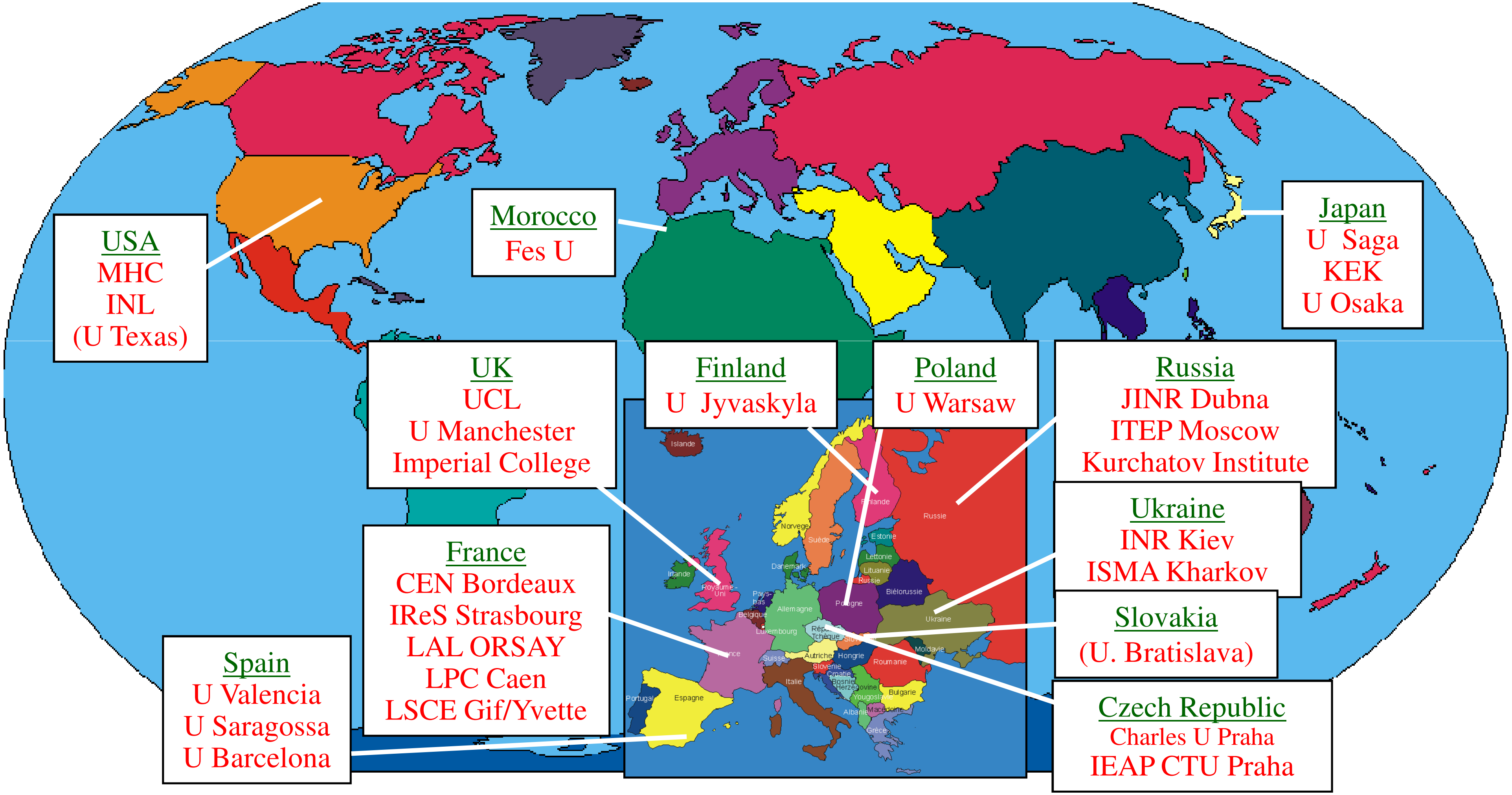
Tracko-calo/TPC:

- **difficult to accept large mass**
- **smaller efficiency (for tracko-calo)**
- **worth resolution**
- **background (for TPC)**

NEMO-3/SuperNEMO collaboration

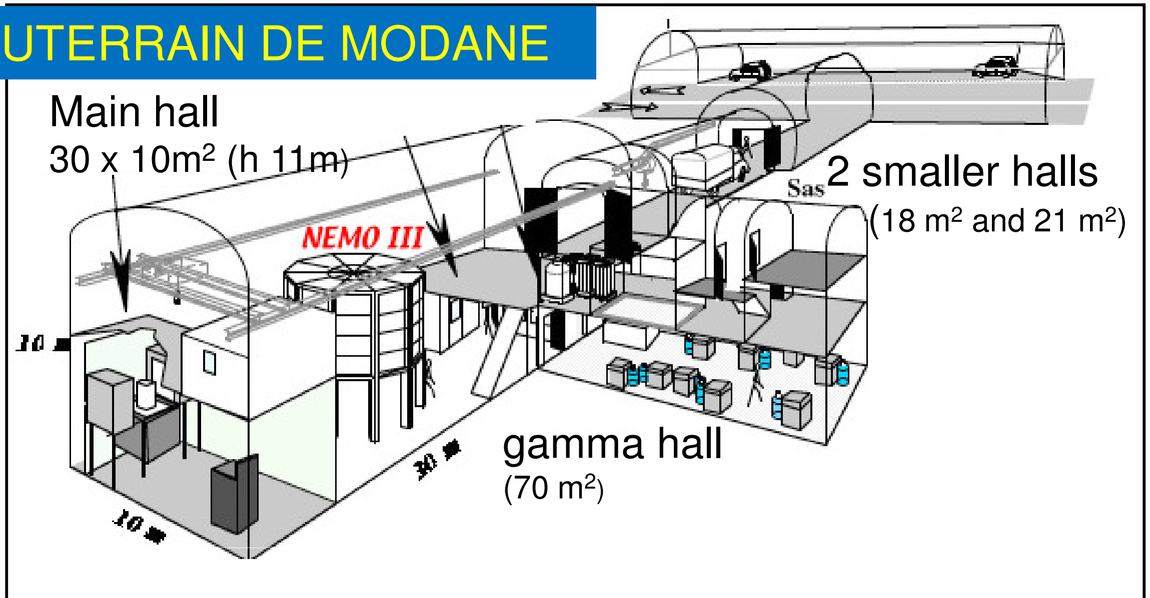
Neutrino **E**ttore **M**ajorana **O**bservatory

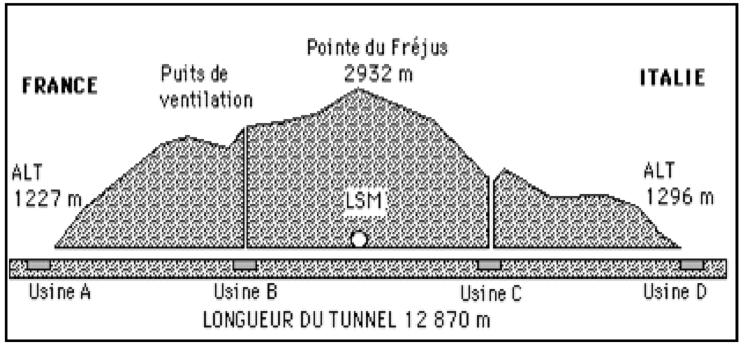
(**N**eutrino **E**xperiment on **MO**lybdenum – historical name)



~ 80 physicists, 12 countries, 27 laboratories

The NEMO3 host laboratory

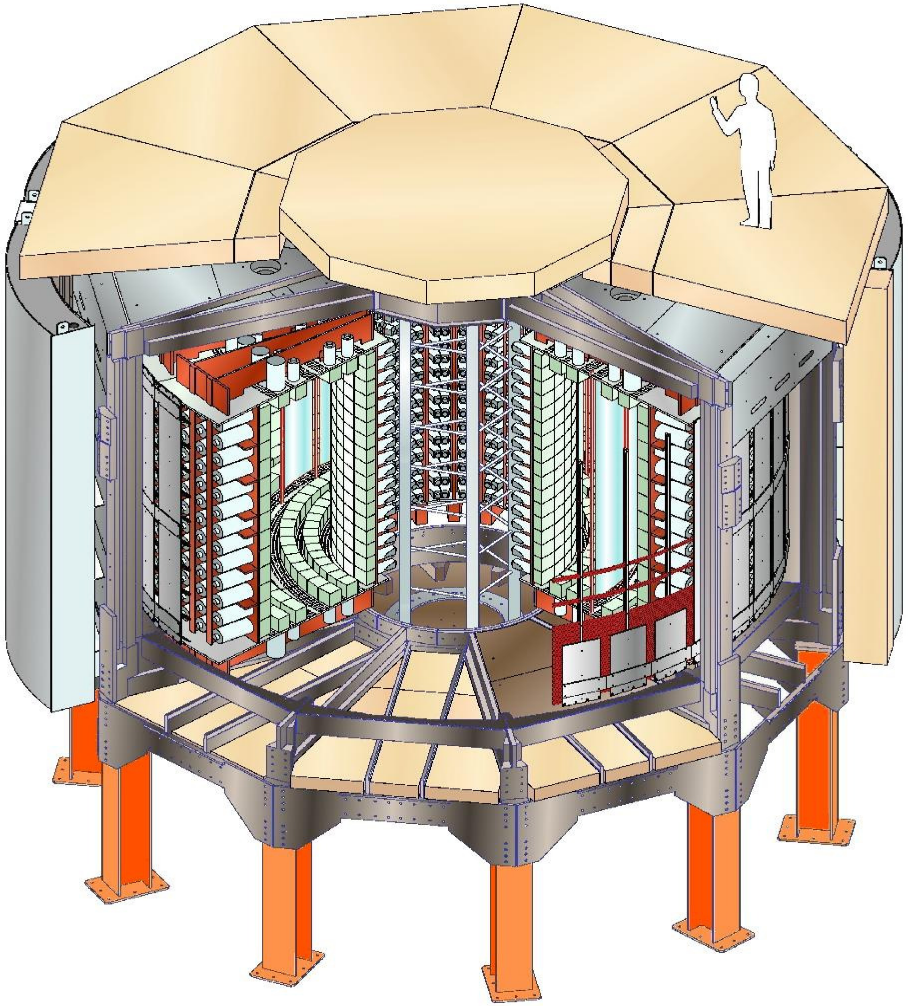




Operators	**CEA/DSM & CNRS/IN2P3**
Location	**Fréjus Tunnel (Italian-French border)**
Excavation	**1983**
Underground area	**main hall (30x10x11 m) + γ-spectroscopy hall (70 m^2) + 2 secondary halls of 18/21 m^2**
Depth	**1700 m (4800 mwe)**
Surface	**> 400 m^2**
Permanent staff	**8**
Scientists users	**100**

The NEMO3 detector

Fréjus Underground Laboratory : 4800 m.w.e.



Source: 10 kg of ββ isotopes
cylindrical, S = 20 m^2, 60 mg/cm^2

Tracking detector:
drift wire chamber operating in Geiger mode (6180 cells)
Gas: He + 4% ethyl alcohol + 1% Ar + 0.1% H_2O

Calorimeter:
1940 plastic scintillators
coupled to low radioactivity PMTs

Magnetic field: 25 Gauss
Gamma shield: Pure Iron (18 cm)
Neutron shield: borated water (~30 cm) + **Wood (Top/Bottom/Gapes between water tanks)**

Able to identify e$^-$, e$^+$, γ and α–delayed

NEMO3 sector

PMTs

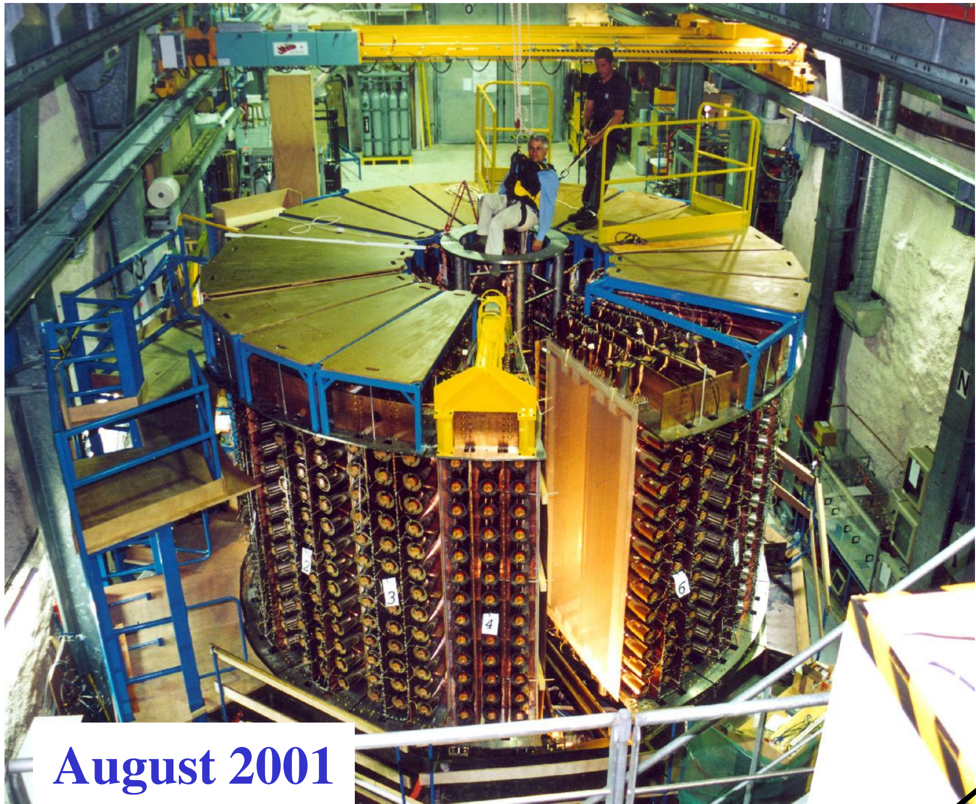
scintillators

ββ isotope foils

Cathodic rings
Wire chamber

Calibration tube

Assembling of NEMO 3



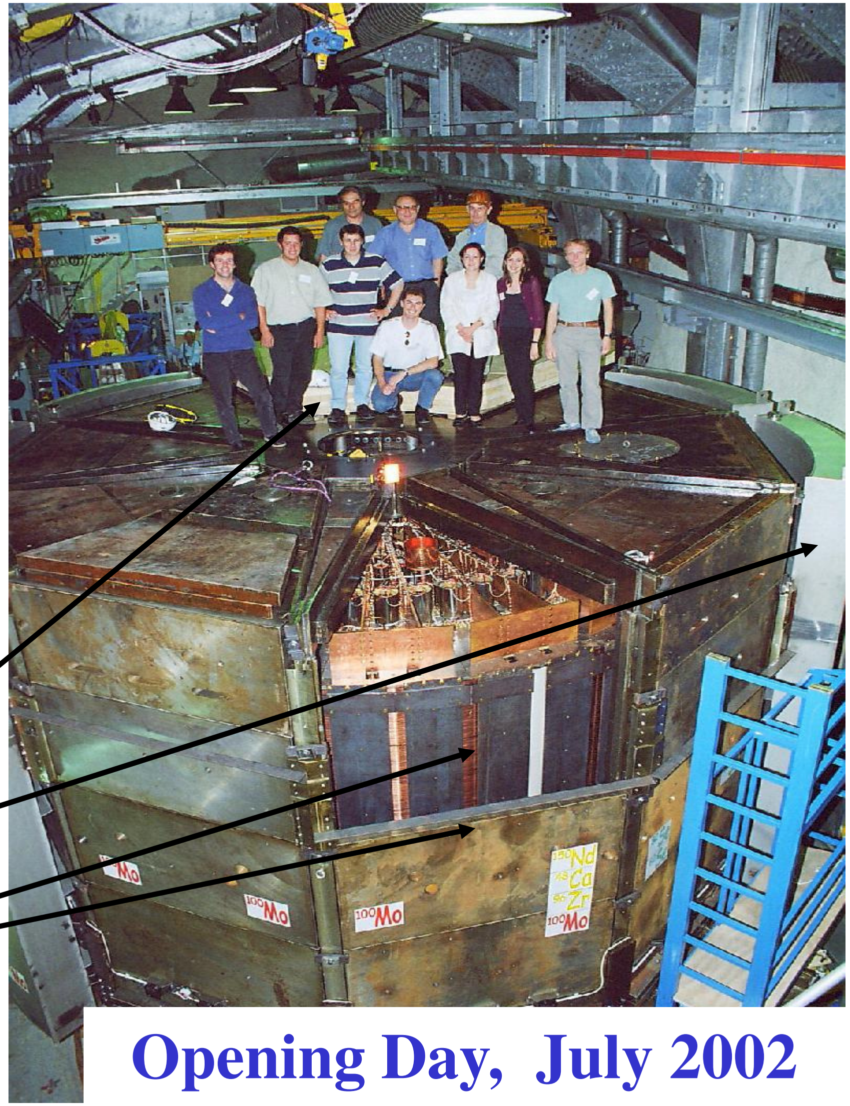
August 2001

Location: LSM
(Modane, France)

Start taking data

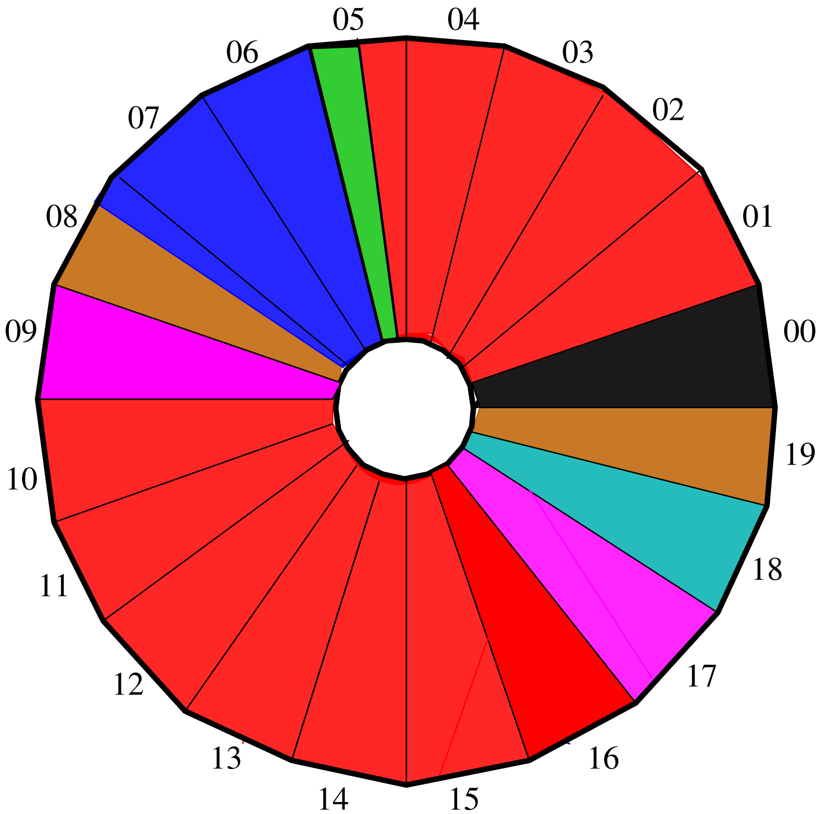
14 February 2003

wood shield
water tanks
magnet coil/shield
iron shield



Opening Day, July 2002

ββ decay isotopes in NEMO-3 detector



^{100}Mo 6.914 kg
$Q_{\beta\beta}$ = 3034 keV

^{82}Se 0.932 kg
$Q_{\beta\beta}$ = 2995 keV

ββ0ν search

ββ2ν measurement

^{116}Cd 405 g
$Q_{\beta\beta}$ = 2805 keV

^{96}Zr 9.4 g
$Q_{\beta\beta}$ = 3350 keV

^{150}Nd 37.0 g
$Q_{\beta\beta}$ = 3367 keV

^{48}Ca 7.0 g
$Q_{\beta\beta}$ = 4272 keV

^{130}Te 454 g
$Q_{\beta\beta}$ = 2529 keV

^{nat}Te 491 g

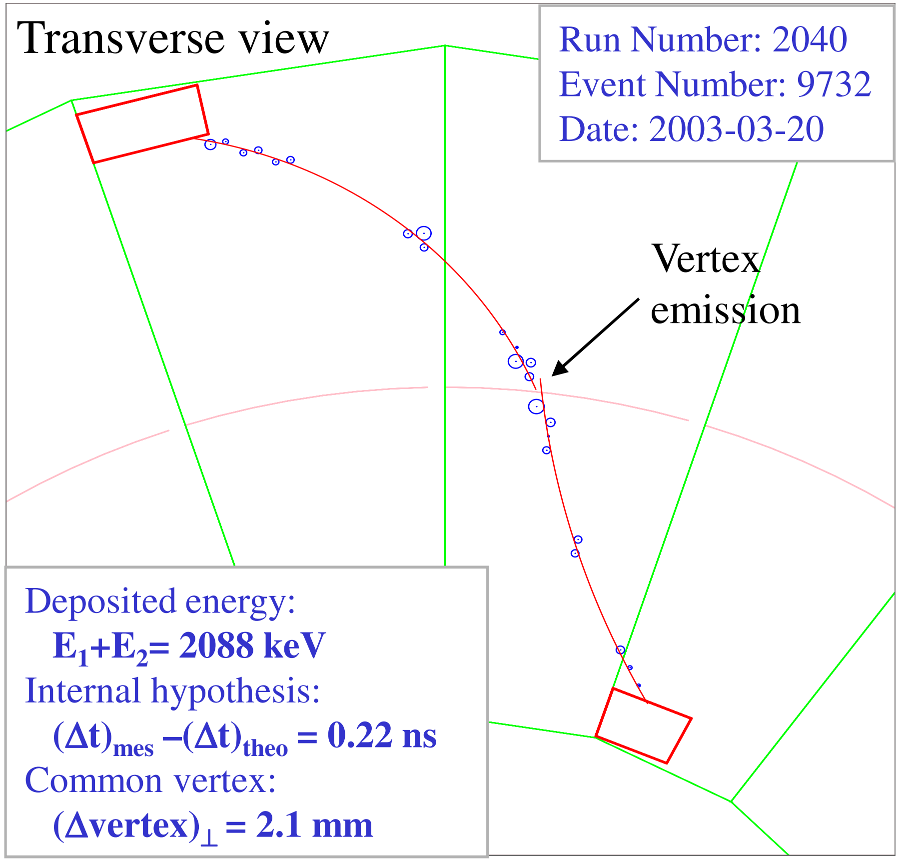
Cu 621 g

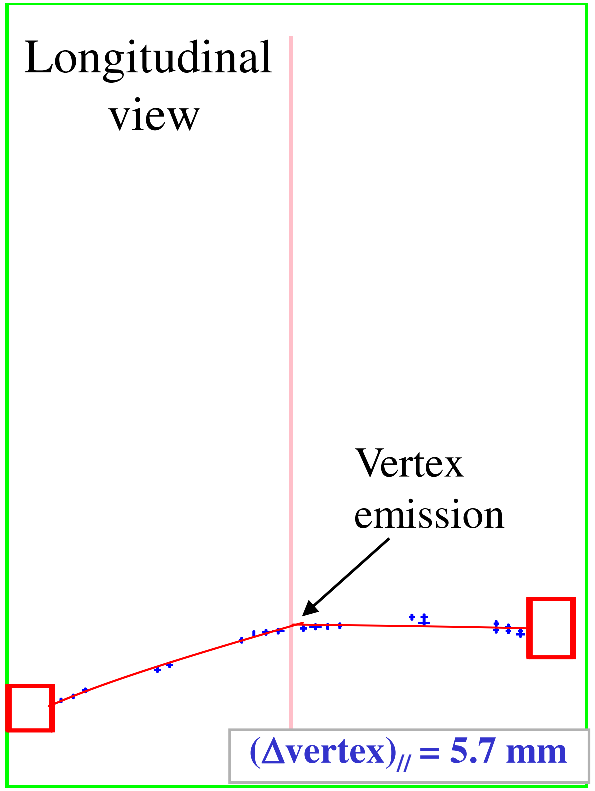
External bkg measurement

(All enriched isotopes produced in Russia)

ββ-events selection in NEMO-3

Typical ββ2ν event observed from ^{100}Mo





Criteria to select ββ events:

- 2 tracks with charge < 0
- 2 PMT, each > 200 keV
- PMT-Track association
- Common vertex
- external event rejection by TOF
- No other isolated PMT hit (γ rejection)
- No delayed track (^{214}Bi rejection)

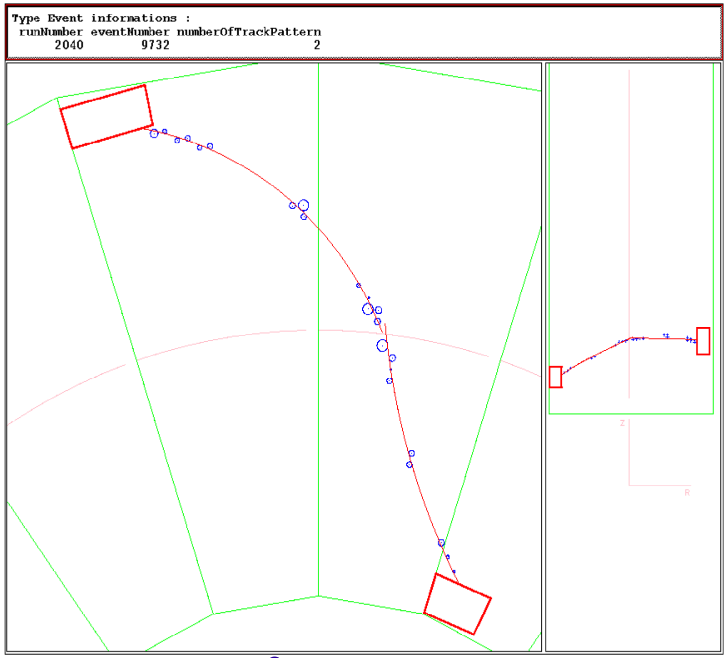
Trigger: **at least 1 PMT > 150 keV**

≥ 3 Geiger hits (2 neighbour layers + 1)

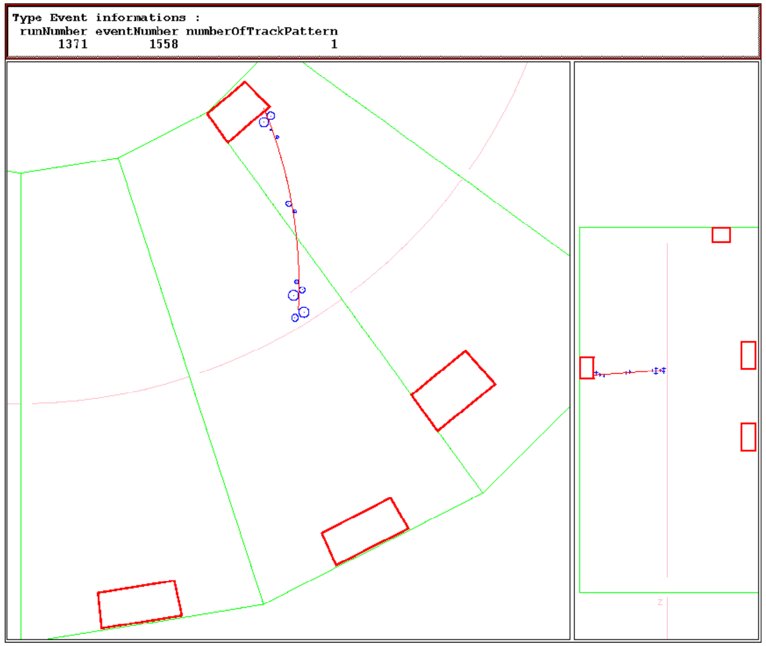
Trigger rate = 7 Hz

ββ events: 1 event every 2.5 minutes

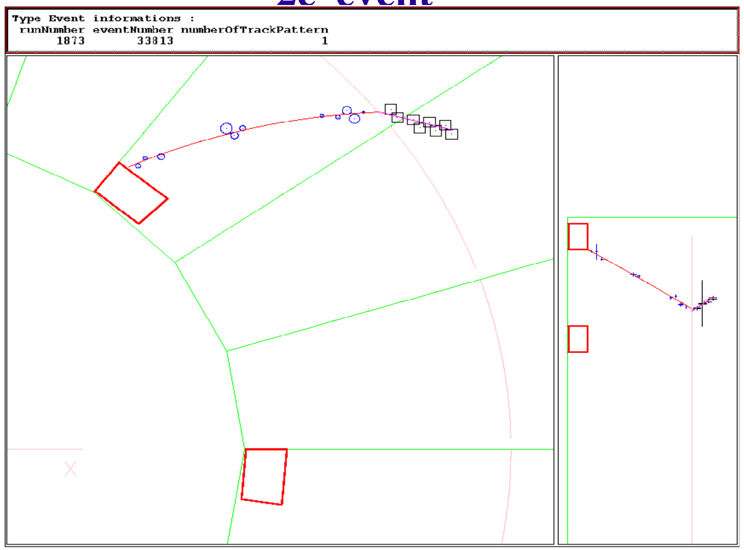
Background tagging in NEMO-3



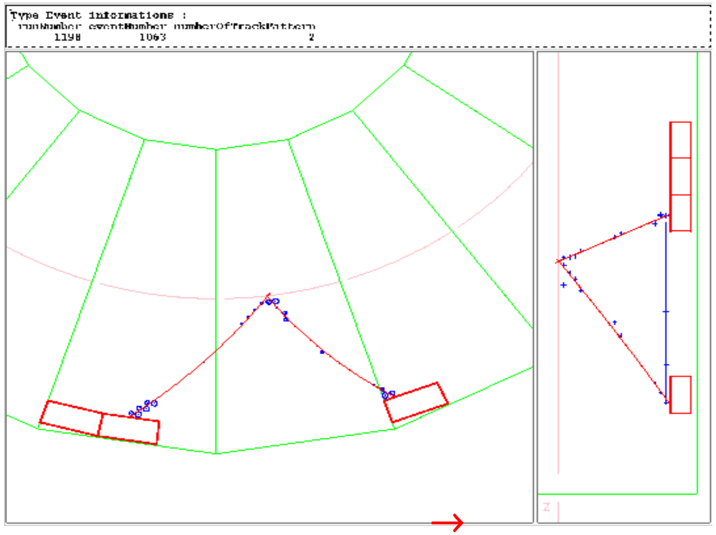
$2e^-$ event



$e^-N\gamma$ event to measure ^{208}Tl

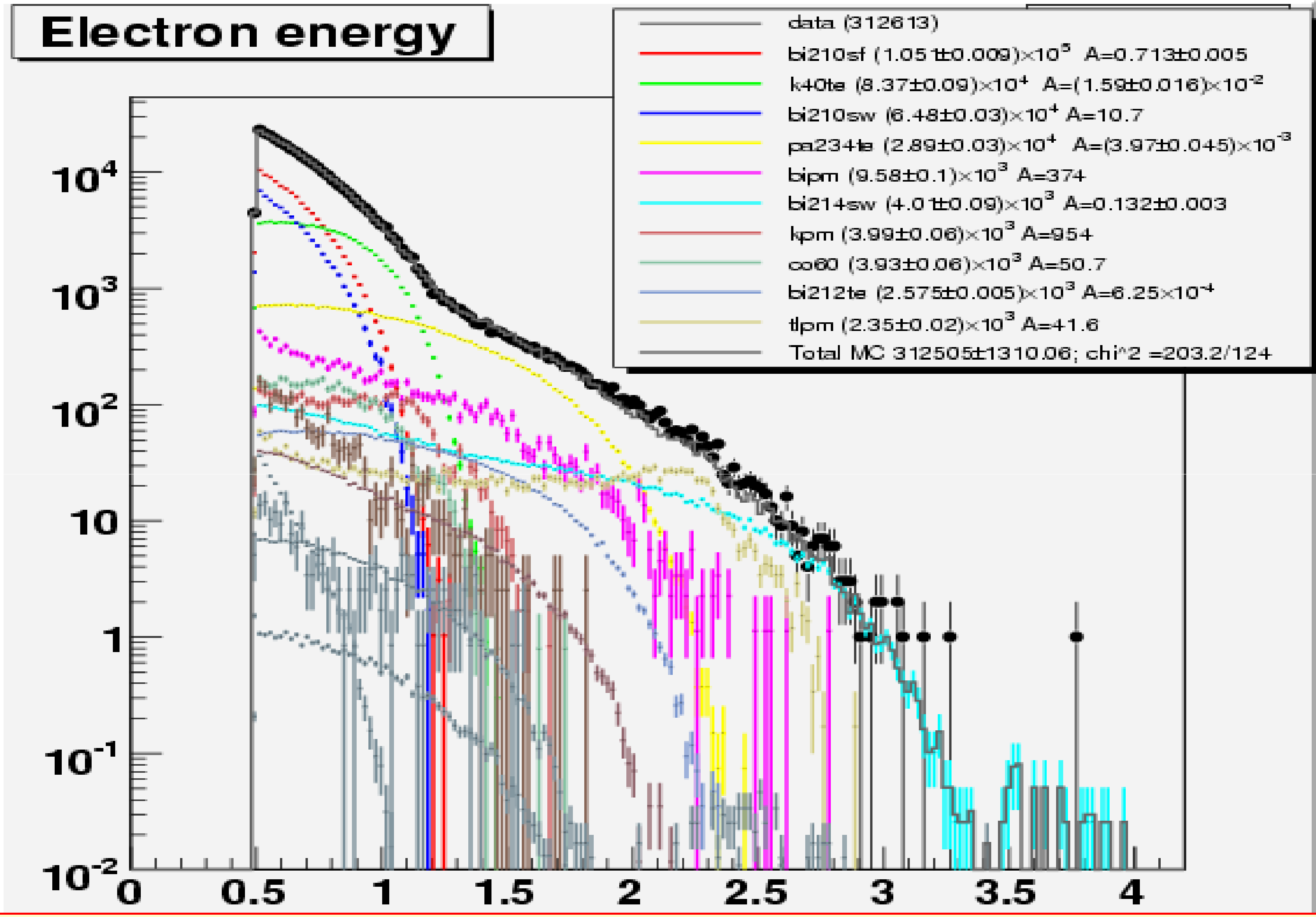


β - α-delayed event $^{214}Bi \rightarrow {}^{214}Po \rightarrow {}^{210}Pb$



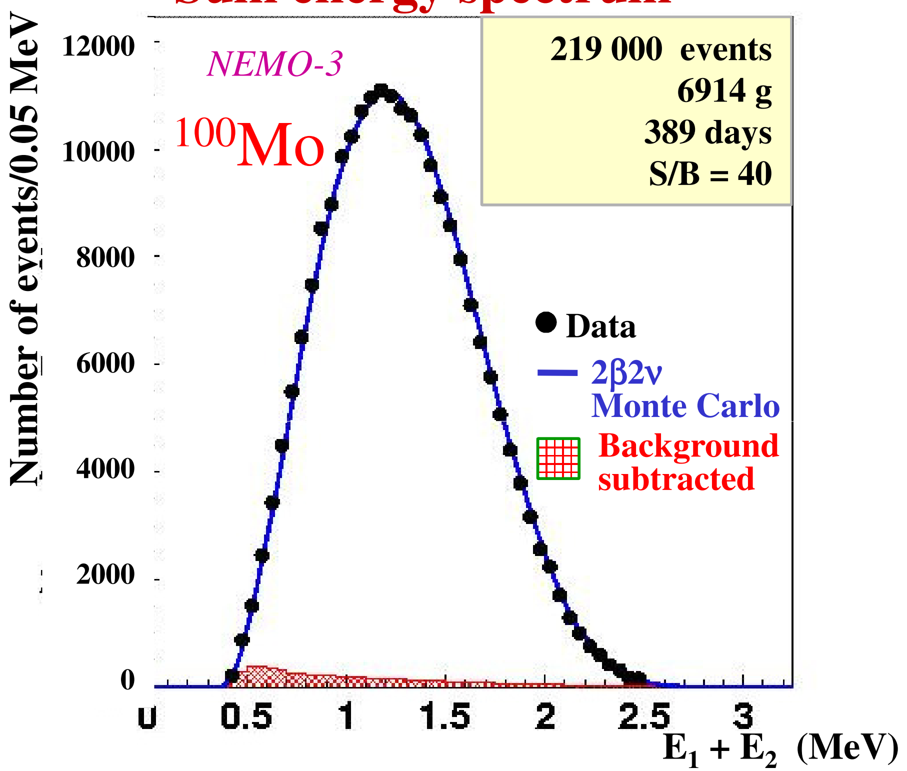
$e^+ - e^-$ pair event $\vec{B}$ rejection

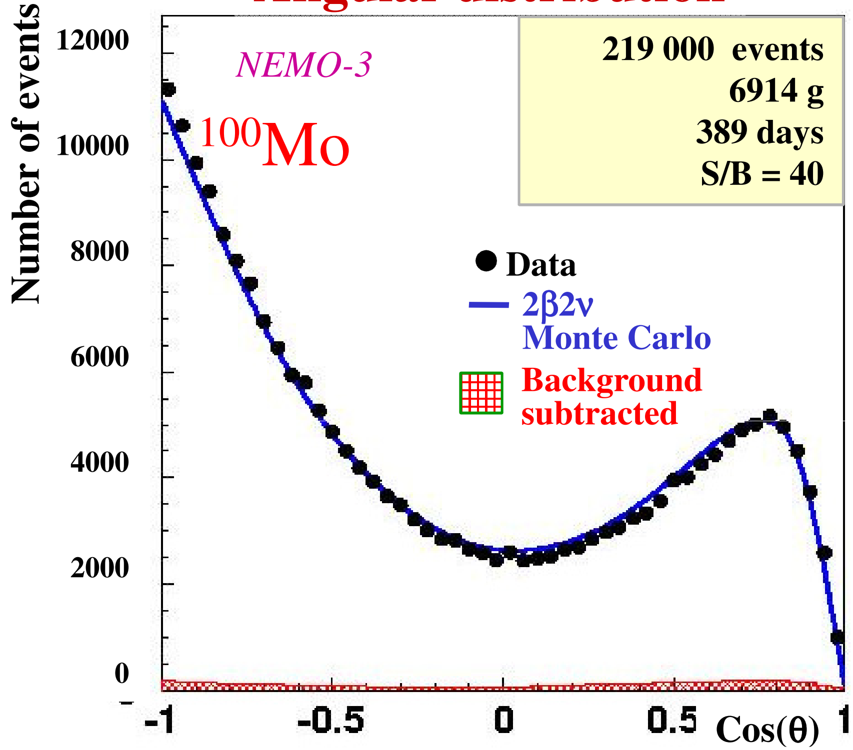
Background



Unprecedented understanding, control and rejection of backgrounds

^{100}Mo 2β2ν results (2003-2004)



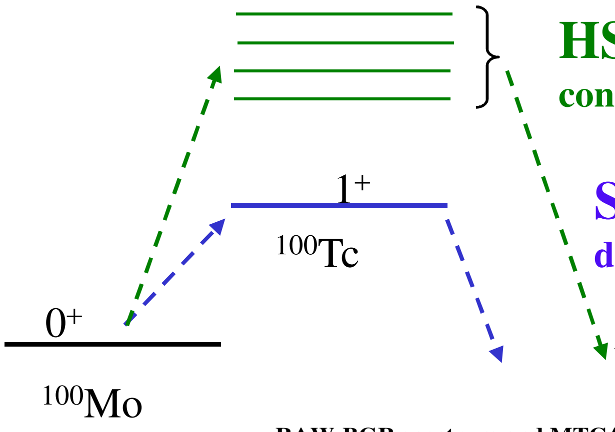


$T_{1/2}(\beta\beta2\nu) = 7.11 \pm 0.02$ (stat) ± 0.54 (syst) $\times 10^{18}$ years

Phys. Rev. Lett. 95 182302 (2005)

«ββ factory» → tool for precision test

^{100}Mo 2νββ single energy spectrum as probe of 2νββ mechanism

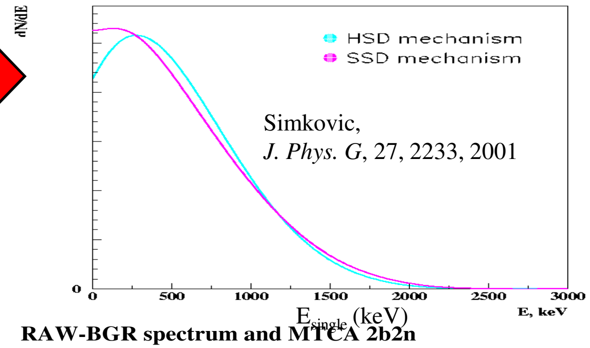


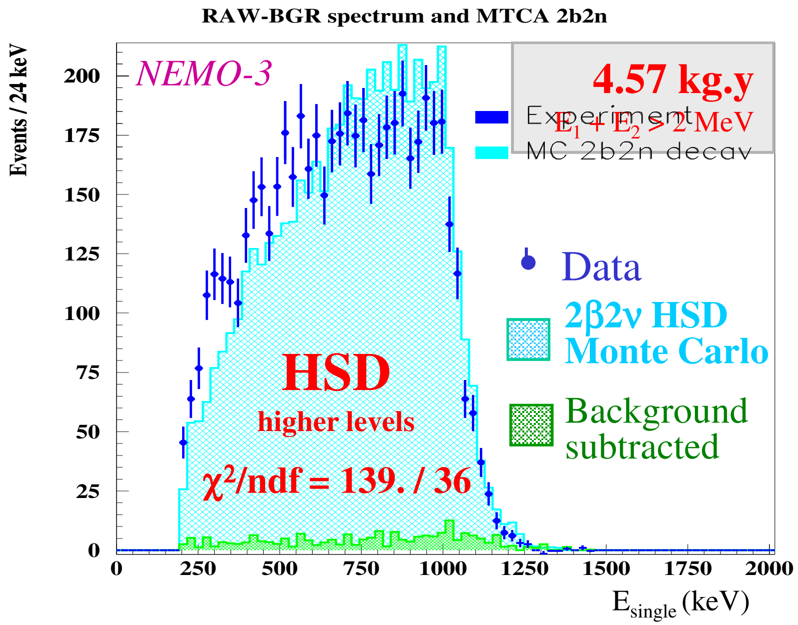
HSD, higher levels contribute to the decay

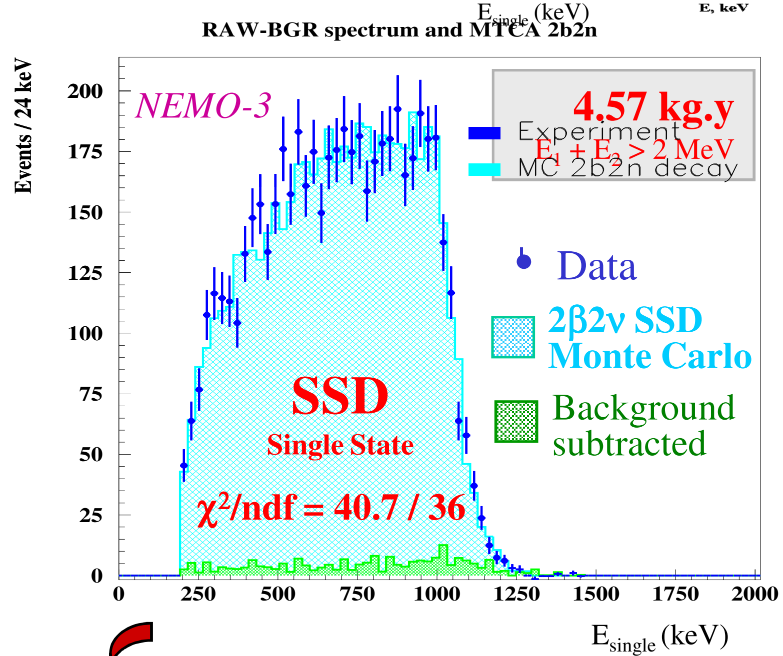
SSD, 1^+ level dominates in the decay

(Abad et al., 1984, *Ann. Fis.* A 80, 9)

Single electron spectrum different between SSD and HSD





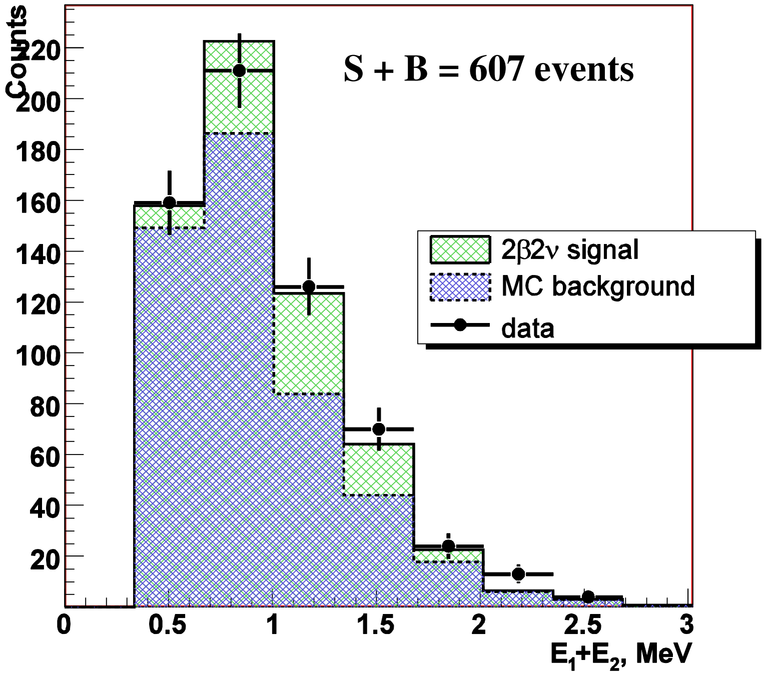


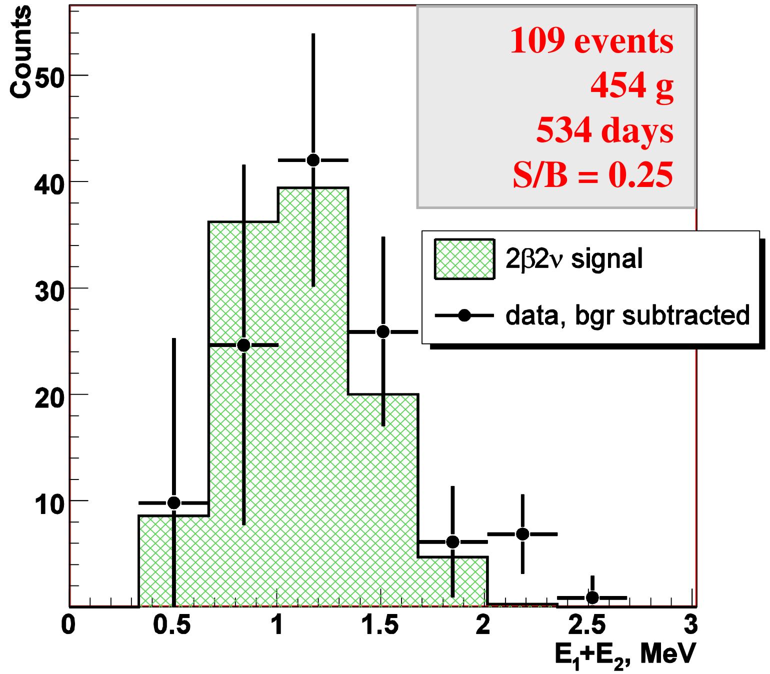
HSD: $T_{1/2} = 8.61 \pm 0.02$ (stat) ± 0.60 (syst) $\times 10^{18}$ y

SSD: $T_{1/2} = 7.72 \pm 0.02$ (stat) ± 0.54 (syst) $\times 10^{18}$ y

^{100}Mo 2β2ν single energy distribution in favour of Single State Dominant (SSD) decay

New results: ^{130}Te ββ2ν





Preliminary result:

^{130}Te: $T_{1/2}$ = [7.6 ± 1.5 (stat) ± 0.8 (syst)] × 10^{20} y

Previous indication on effect from a direct experiment

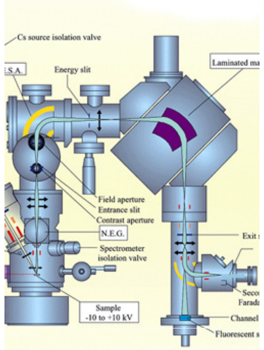
(6.1 ± 1.4 (syst) ± 2.9 3.4) x 1020 years (Arnaboldi 2003)

ββ and Fermi coupling constant G_f

ββ is sensitive to G_f variations ($\sim G_f^4$)

old minerals ($\sim 10^6 - 10^9$ yr)

extractor and mass-spectrometer



ββ decay was first detected in geochemical experiments ($^{130}Te \rightarrow {}^{130}Xe$)

Daughter isotope (^{130}Xe) extracted from an old mineral and number of atoms counted

^{130}Te geochemical measurements:

(25 ± 2) x 10^{20} yrs (Kirsten 83)

(27 ± 2) x 10^{20} yrs (Bernatowicz 93)

→ "old" samples ($\sim 10^9$ yrs)

(8 ± 1) x 10^{20} yrs (Manuel 91, Takaoka 96) → "new" samples (few x 10^6 yrs)

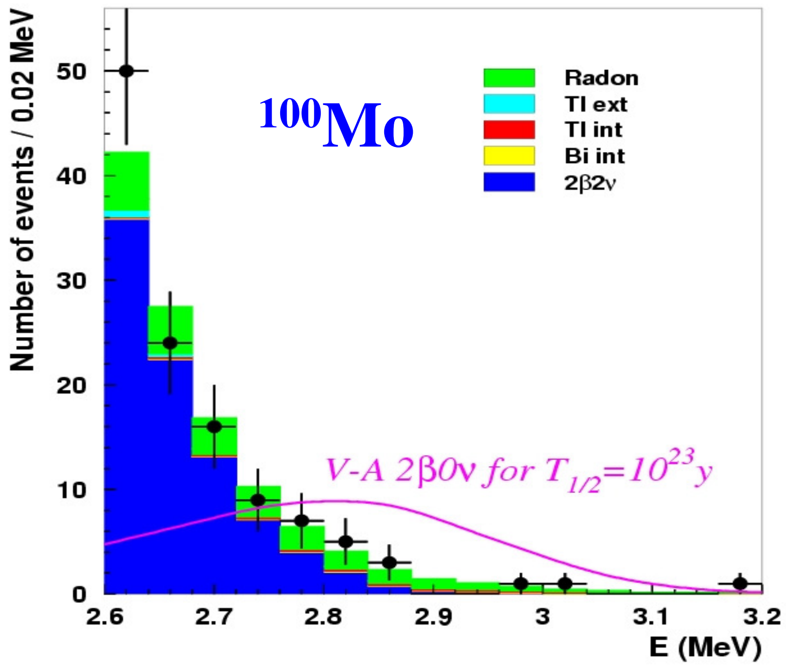
NEMO3 result ("present" ββ rate): <u>(7.6 ± 1.7) x 10^{20} yrs</u>

Difference between ββ rates in past and present due to time dependence of Fermi constant???

Suggestion: Carry out geochemical isotope analyses with $^{100}Mo \rightarrow {}^{100}Ru$, $^{96}Zr \rightarrow {}^{96}Mo$ (daughter not gas) etc and compare with direct measurements (<u>precise</u> NEMO3 results available).

^{100}Mo 0β2ν preliminary limits (data until spring 2006)

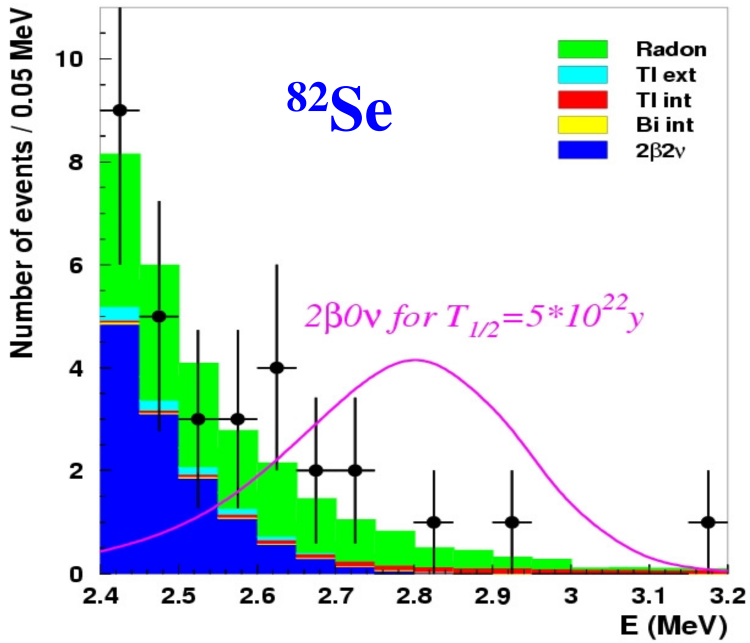
693 days of data
Phase I + Phase II



$T_{1/2} > 5.8 \times 10^{23}$ y @ 90% C.L.

$\langle m_\nu \rangle < (0.8 – 1.3)$ eV [1-3]

693 days of data
Phase I + Phase II



$T_{1/2} > 2.1 \times 10^{23}$ y @ 90% C.L.

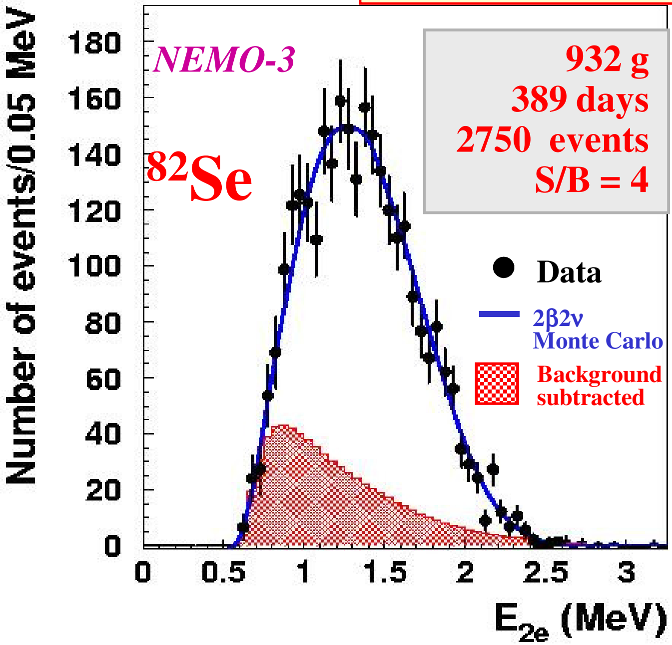
$\langle m_\nu \rangle < (1.4 – 2.2)$ eV [1-3]

NME:

[1] M.Kortelainen and J.Suhonen, Phys.Rev. C 75 (2007) 051303(R).
[2] M.Kortelainen and J.Suhonen, Phys.Rev. C 76 (2007) 024315.
[3] V.A.Rodin et al., Nucl.Phys. A 793 (2007) 213.
[5] M.Aunola et al., Nucl.Phys. A 463 (1998) 207.

Expected 2009 sensitivity:
$T_{1/2}(\beta\beta0\nu) > 2 \times 10^{24}$ (90 % CL)
$<m_\nu> < 0.3 – 1.3$ eV

2β2ν preliminary results for other nuclei



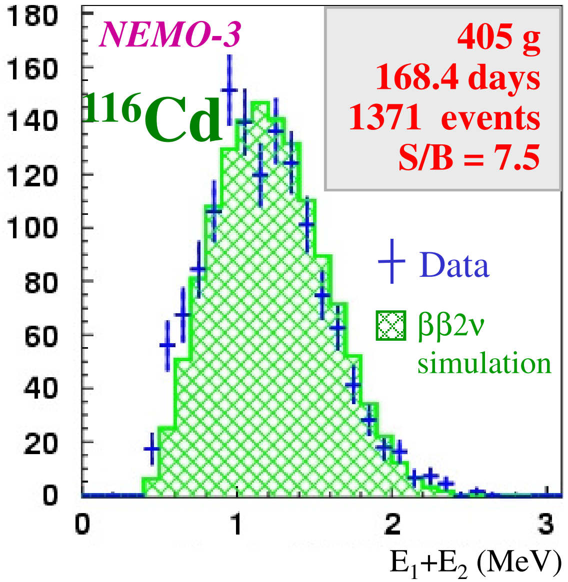
^{82}Se $T_{1/2} = 0.98 \pm 0.2\ (stat) \pm 0.1\ (syst) \times 10^{20}$ y

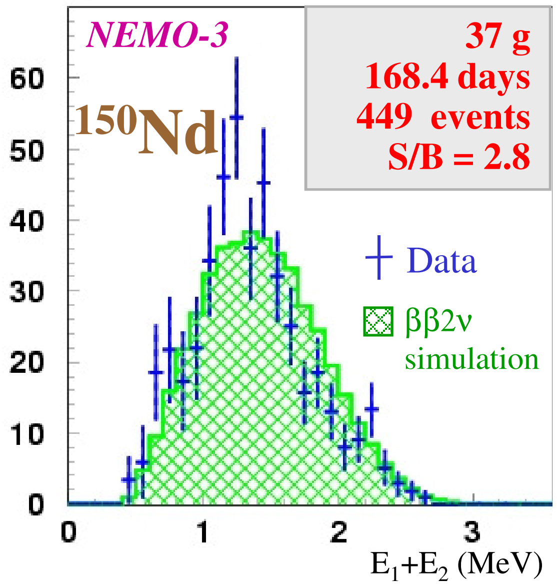
^{116}Cd $T_{1/2} = 2.8 \pm 0.1\ (stat) \pm 0.3\ (syst) \times 10^{19}$ y

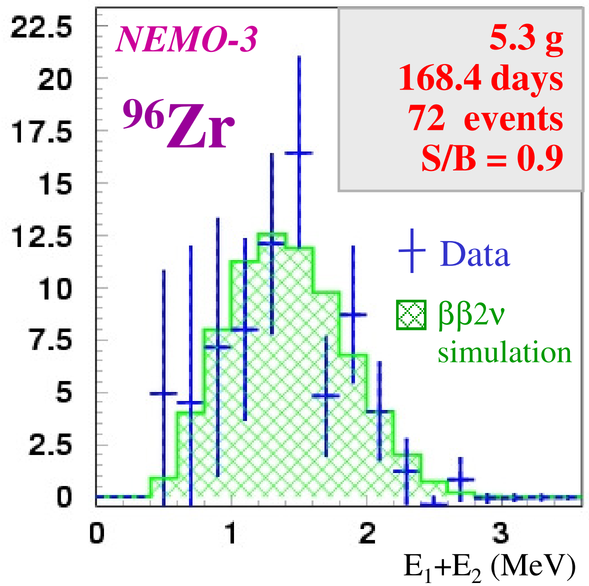
^{150}Nd $T_{1/2} = 9.7 \pm 0.7\ (stat) \pm 1.0\ (syst) \times 10^{18}$ y

^{96}Zr $T_{1/2} = 2.0 \pm 0.3\ (stat) \pm 0.2\ (syst) \times 10^{19}$ y

Background subtracted







Our knowleges&experience from NEMO 3

- to identify and measure all sources of background
- to control internal and external backgrounds at the level of 10 kg of enriched isotopes
- to purify ββ isotopes by removing ^{214}Bi and ^{208}Tl contaminants
- to prove the reliability of the chosen techniques
- to remove radon background
- to develop ultra low background HPGe detectors
- to develop radon detectors sensitive to 1 mBq/m^3

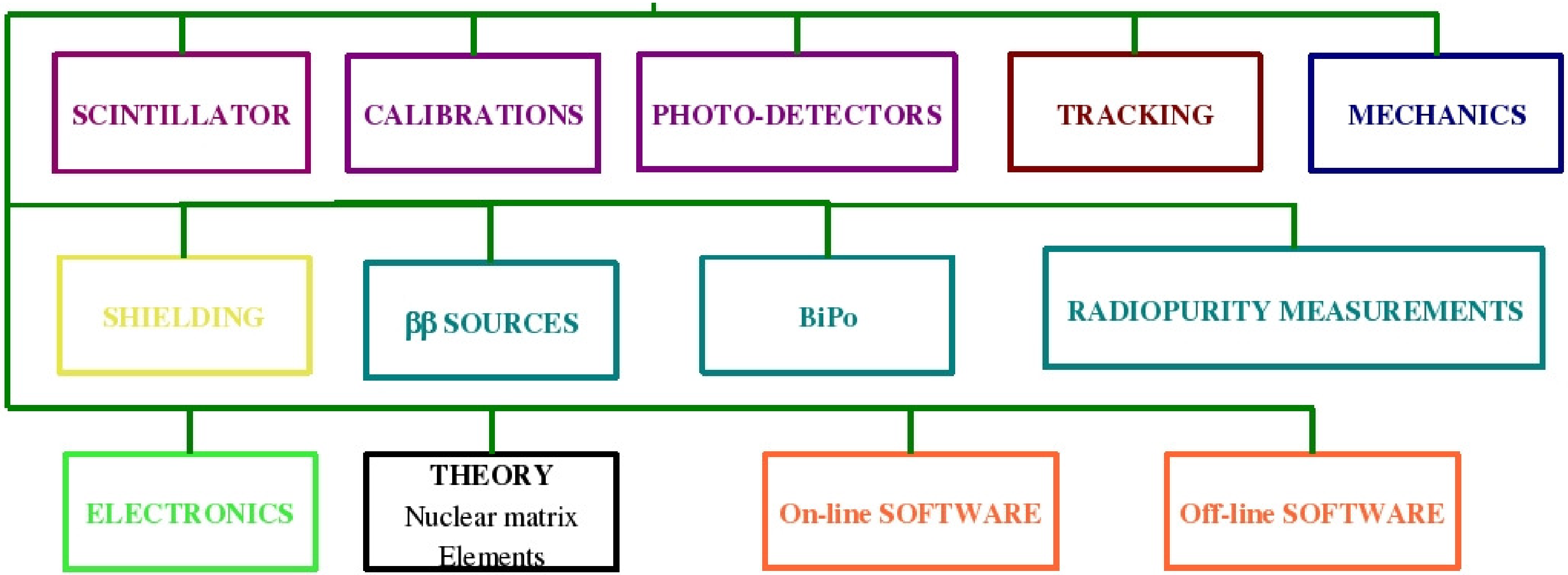
Technique can be extrapolated for larger mass next generation detector to reach 50 meV!

Program for 2005-2008 R&D is carring out.
Major contributors: UK, France, Spain

From NEMO to SuperNEMO

NEMO-3		SuperNEMO
7 kg ^{100}Mo $T_{1/2}(\beta\beta 2\nu) = 7.\ 10^{18}$ y	Mass of isotope	100-200 kg $^{82}Se \| ^{150}Nd$ $T_{1/2}(\beta\beta 2\nu) = 10^{20} \| 10^{19}$ y
$T_{1/2}(\beta\beta 0\nu) > 2.\ 10^{24}$ y $\langle m_\nu \rangle < 0.3 – 1.3$ eV	Sensitivity	$T_{1/2}(\beta\beta 0\nu) > 2.\ 10^{26}$ y $\langle m_\nu \rangle < 40 – 110$ meV
FWHM ~ 12% at 3 MeV (dominated by calorimeter ~ 8%)	Energy resolution (FWHM of the $\beta\beta 0\nu$ ray)	Total: FWHM ≤8 % at 3 MeV Calorimeter: ≤4 % at 3 MeV
$\varepsilon(\beta\beta 0\nu) = 8$ %	Efficiency	$\varepsilon(\beta\beta 0\nu) \sim 30$ %
^{214}Bi < 300 μBq/kg ^{208}Tl < 20 μBq/kg	Internal contaminations in the source foils in ^{208}Tl and ^{214}Bi	(If ^{82}Se) ^{214}Bi < 10 μBq/kg ^{208}Tl < 2 μBq/kg
Longit: 1.3 cm Transv: 0.6 cm	Vertex resolution	Longitudinal: 1.3 cm Transversal: 0.3 cm
$\beta\beta 2\nu$ ~ 2 cts / 7 kg / y (^{208}Tl, ^{214}Bi) ~ 0.5 cts/ 7 kg /y	Background	$\beta\beta 2\nu$=1, ^{208}Tl =0.5 ^{214}Bi=0.5 counts/y
3 MEuro (without source & PS)	Price	~50 MEuro

Main NEMO/SuperNEMO R&D tasks



Collaborative competition between labs for tasks and detector design

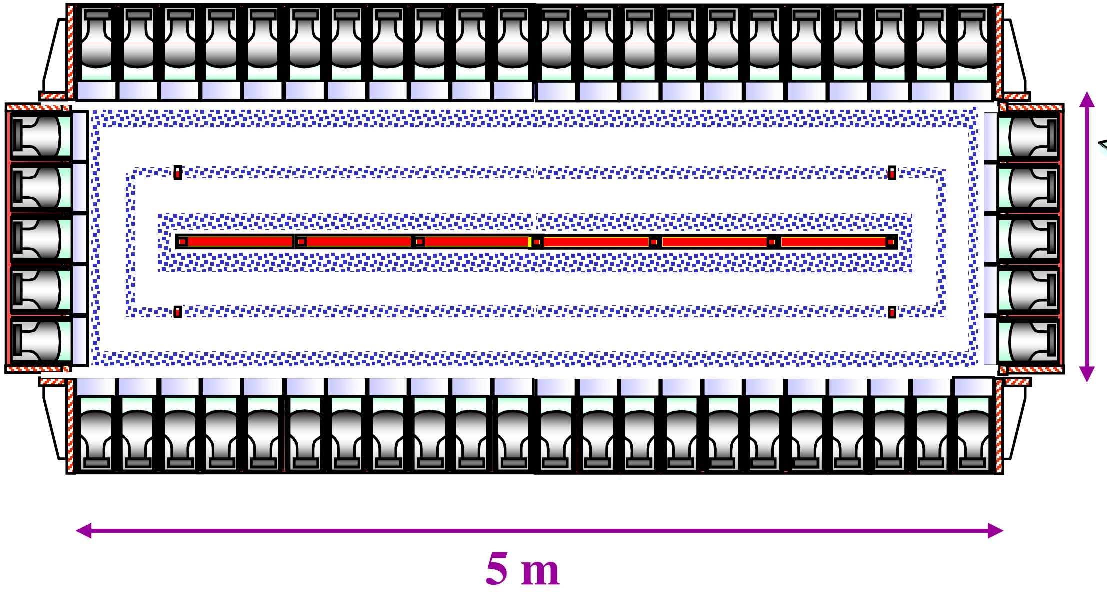
SuperNEMO basic design

Plane geometry

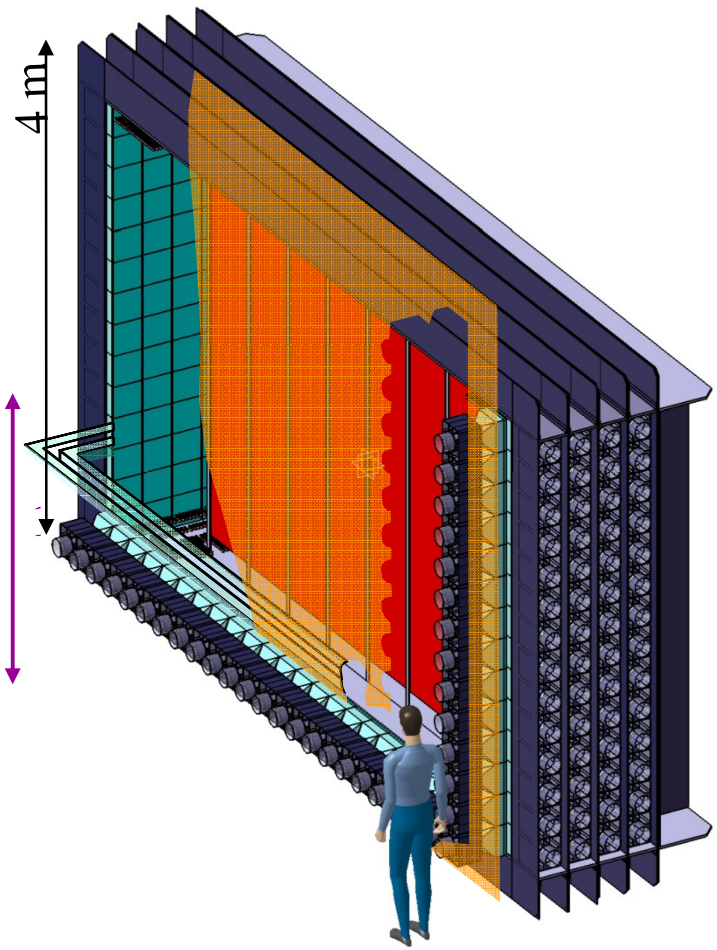
Source (40 mg/cm^2) 12m^2, tracking volume (~3000 channels) and calorimeter (~1000 PMT)

Modular (~5 kg of enriched isotope/module)

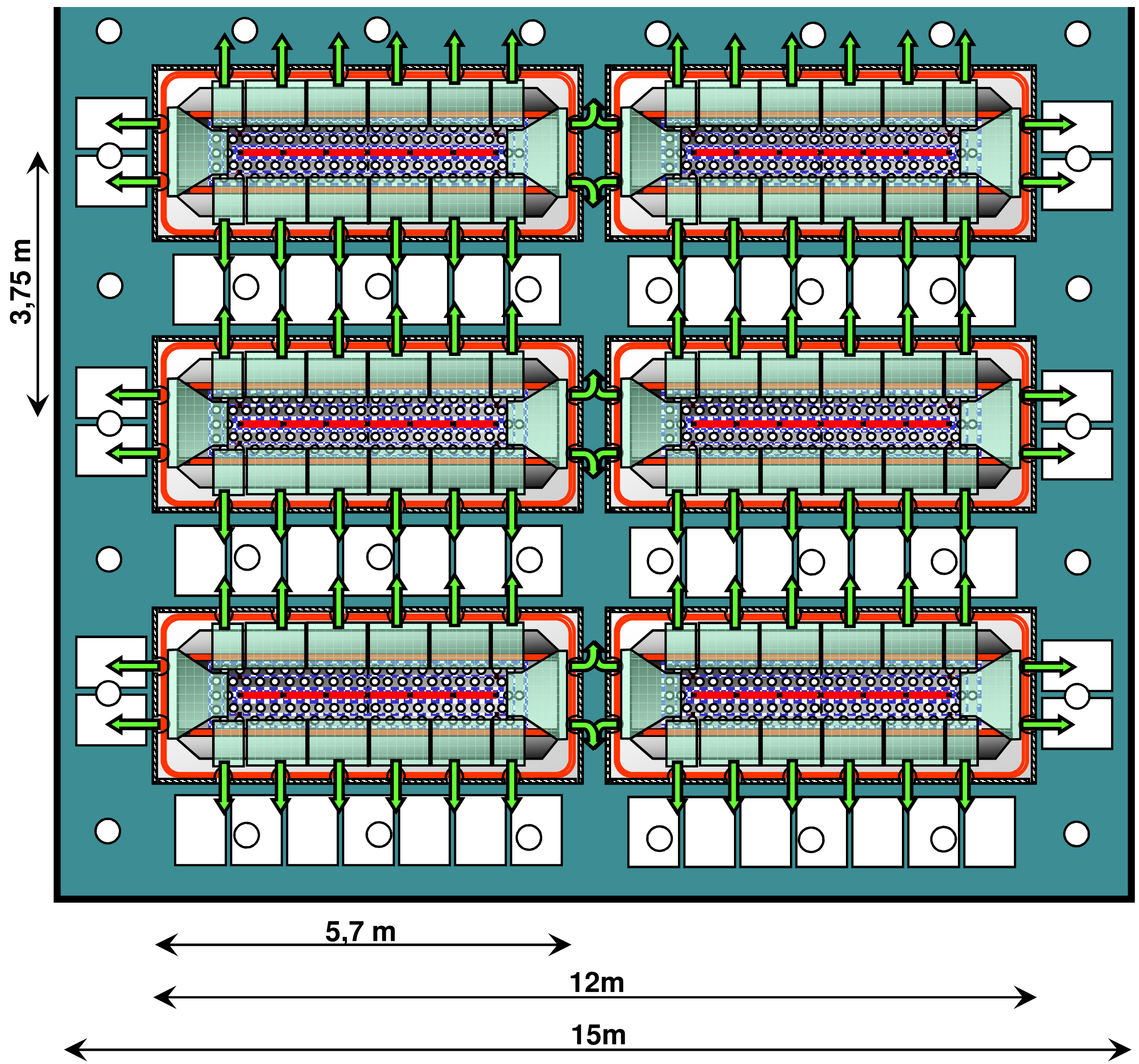
100 kg: 20 modules
~ 60 000 channels for drift chamber
~ 20 000 PMT



Top view



Water shielding

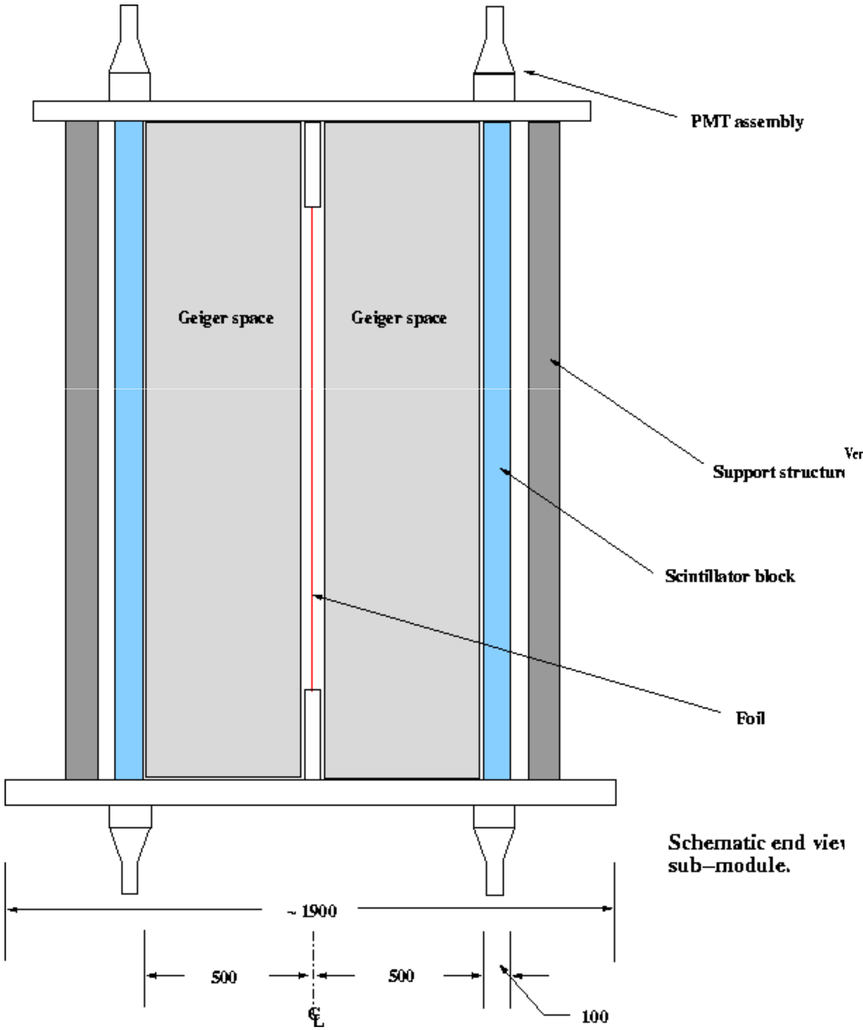


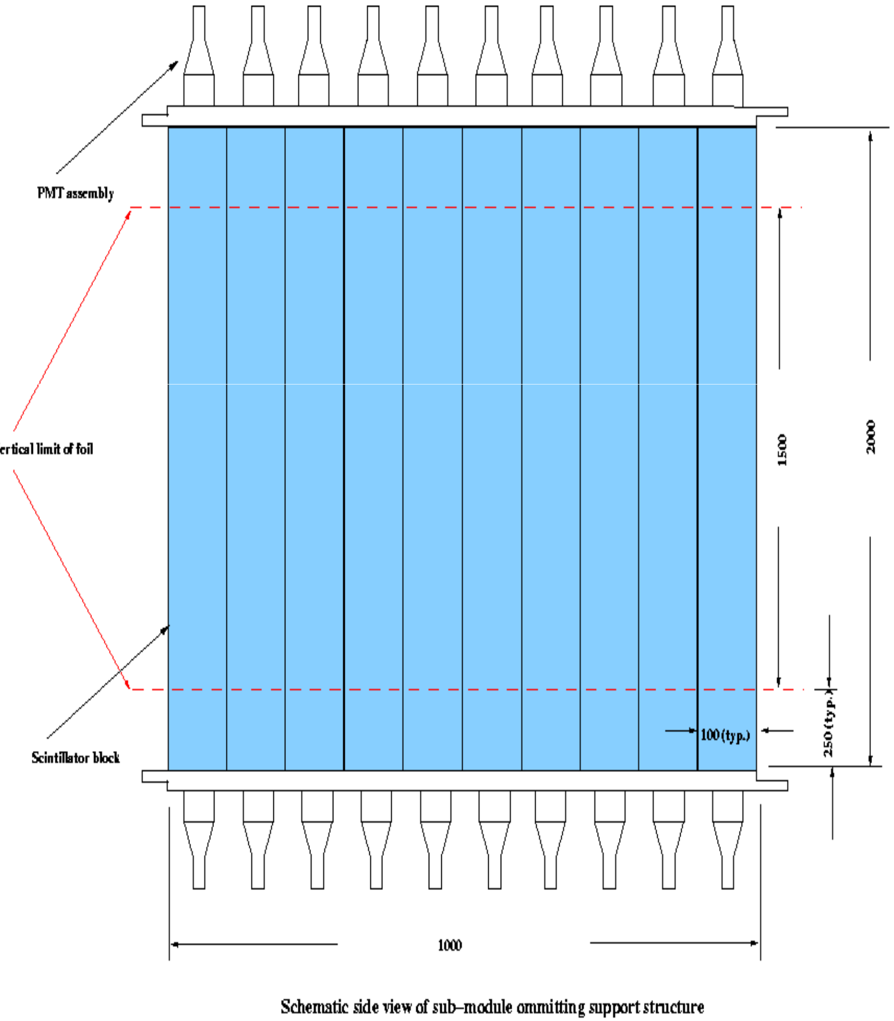
NEED A CAVITY
~ 60m x 15m x15m

Possible in LNGS (Gran Sasso, 3500 m.w.e) or in LSM (Modane, 4800 m.w.e) if there is a new excavation

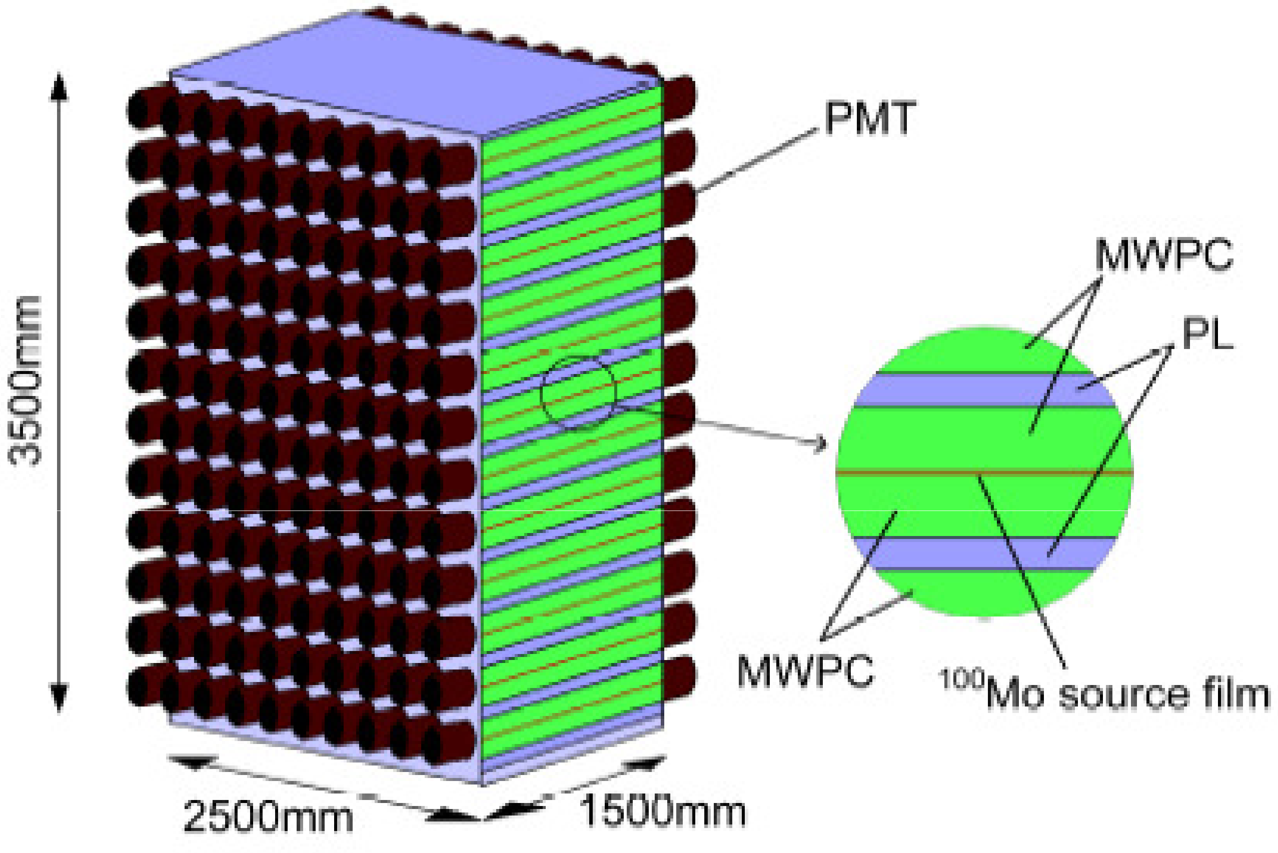
Alternative SuperNEMO bar design

Bars of scintillators
Double sided readout PM
Only ~ 2000 PM for 100 kg of ^{82}Se



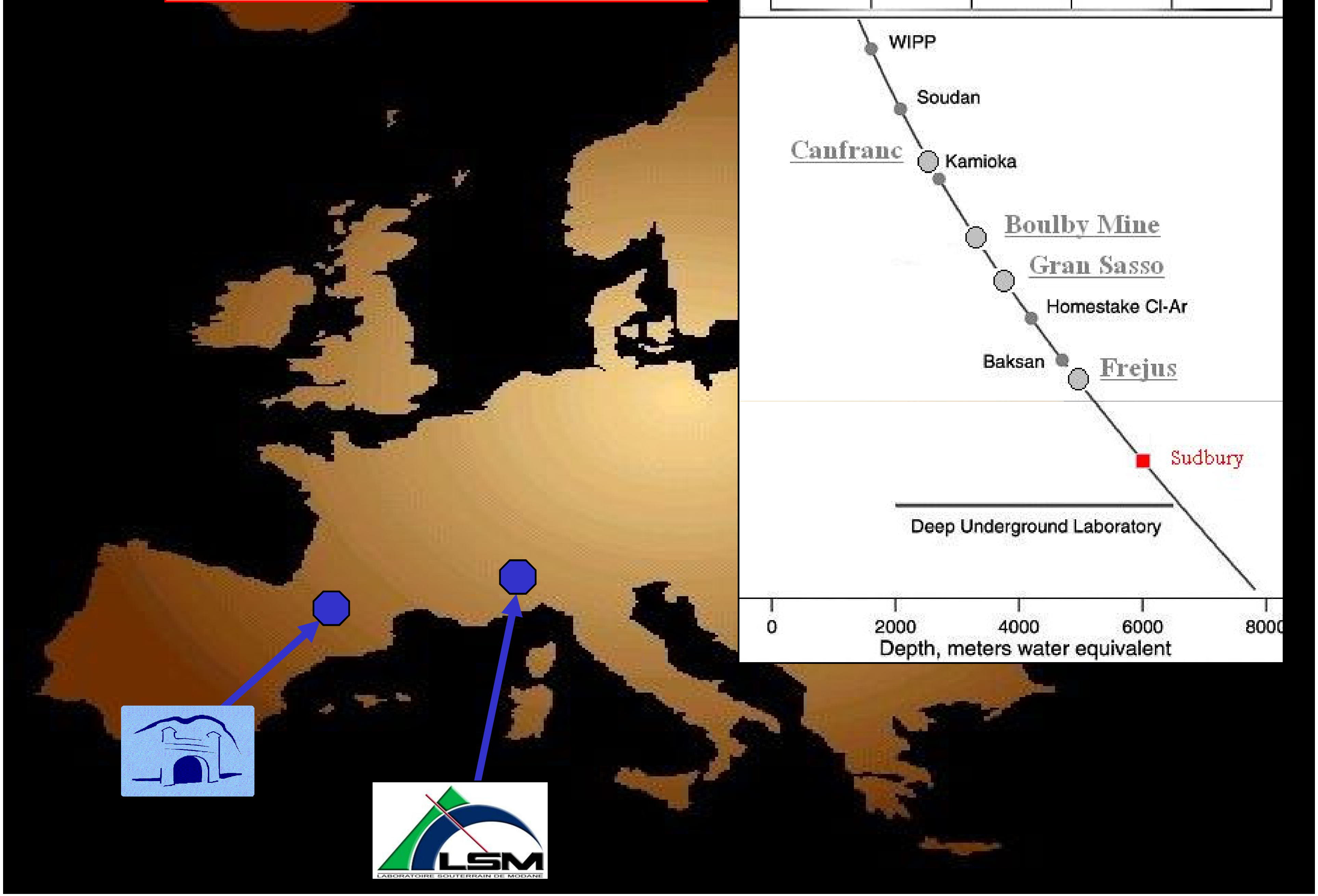


Alternative SuperNEMO MOON-like design

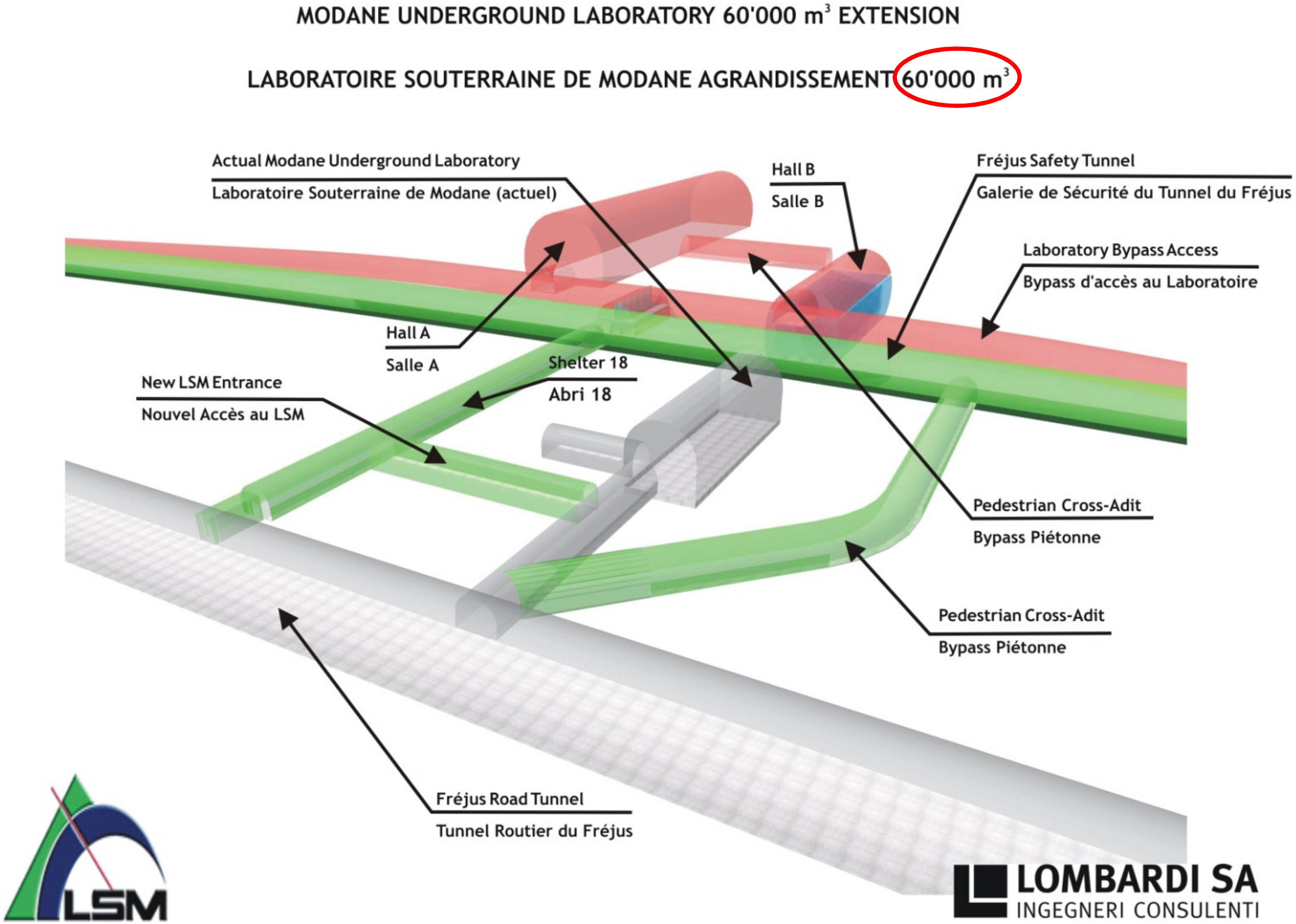


MOON module with 20kg of source

SuperNEMO location



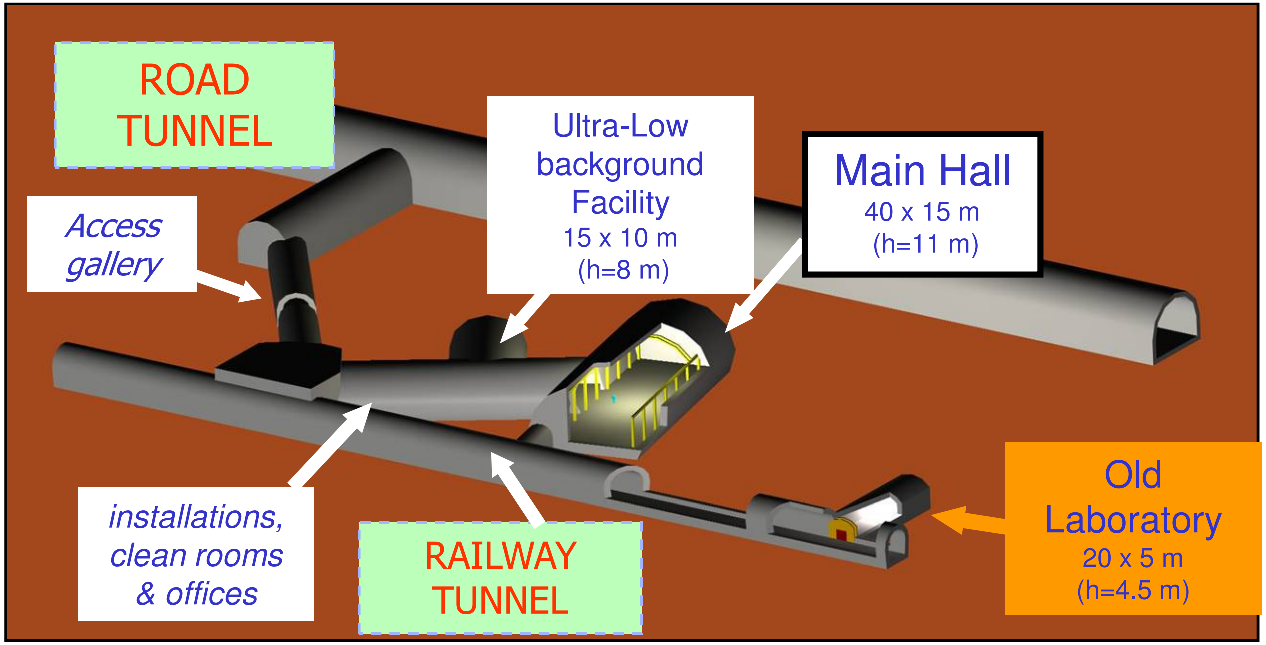
SuperNEMO location: future extension of LSM laboratory



Could be available for 2012

SuperNEMO location: new LSC Canfranc laboratory

Characteristic of the new LSC	
Depth	**900 m (2450 mwe)**
Main experimental hall	**600 m^2 (oriented to CERN)**
Low background lab	**150 m^2**
Clean room	**45 m^2 (100/1000 type)**
General services	**135 m^2**
Offices	**80 m^2**



-BiPo
-SuperNEMO
-- Dark matter
-- ….

R&D plans for calorimeter

Goal: main:

To reach 4% (FWHM) at 3 MeV (7% at 1 MeV) with plastic scintillators coupled to PMTs

others:

To reduce number of PMT
To control quality with test mass production of ~100 units
To reduce backscattering in order to improve ββ0ν efficiency

Scintillators: search for maximal light yields, homogenity of response.

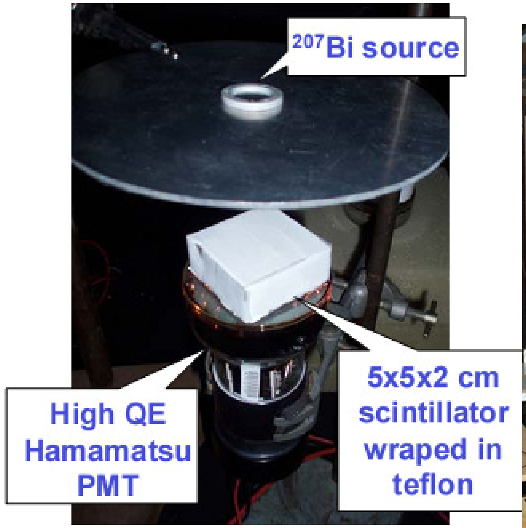
- **scintillator materials tests (organic plastic PS or liquid LS, non-organic plastic), improvement and developement of new scintillators (Kharkov&Dubna)**
- **design of scintillator cell: sizes, shapes, entrance window (minimal e- backscaterring) , coating, reflectors, optical contacts, lightguide shape, etc.**
- **Studies of scintillator bars**

Photomultipliers: hunting for maximal resolution and low radioactivity keeping resonable other parameters: big size, timing, linearity, and high CR stability

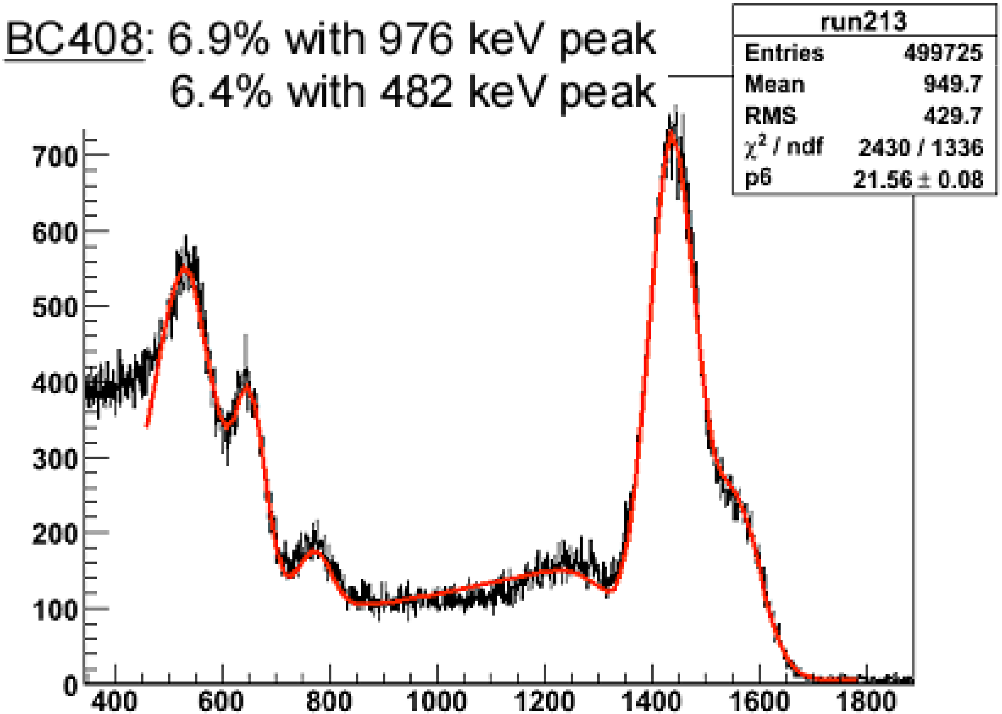
- **In France, joint studies with Photonis company according to special agreement.**
- **In US and UK, tests of new Hamamatsu and ETL PMTs, work in close connections with companies.**

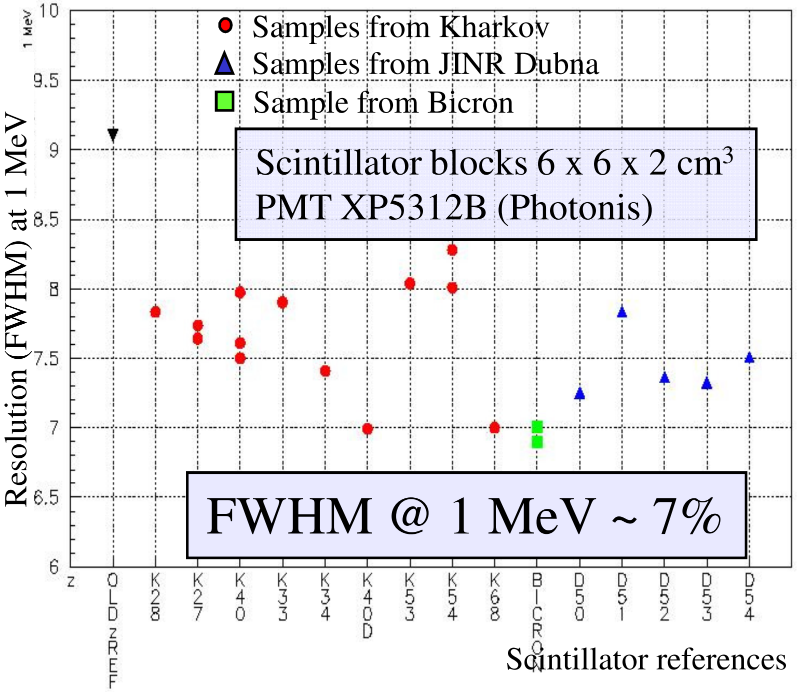
R&D for PS

Resolution required has been reached for small sizes (up to ~ 6 x 6 x 2 cm)



Tests realised with e- spectrometer

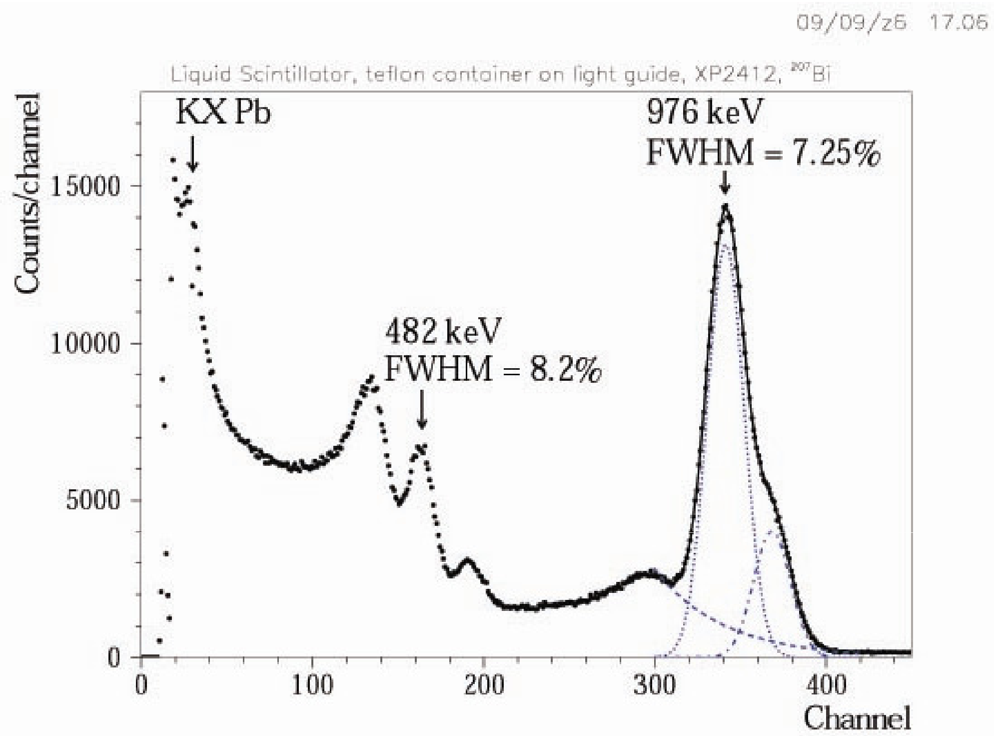




R&D for LS

Advantages: high light yield + very good uniformity and transparency

Challenge: mechanical contraints particularly for the entrance window (electron detection)



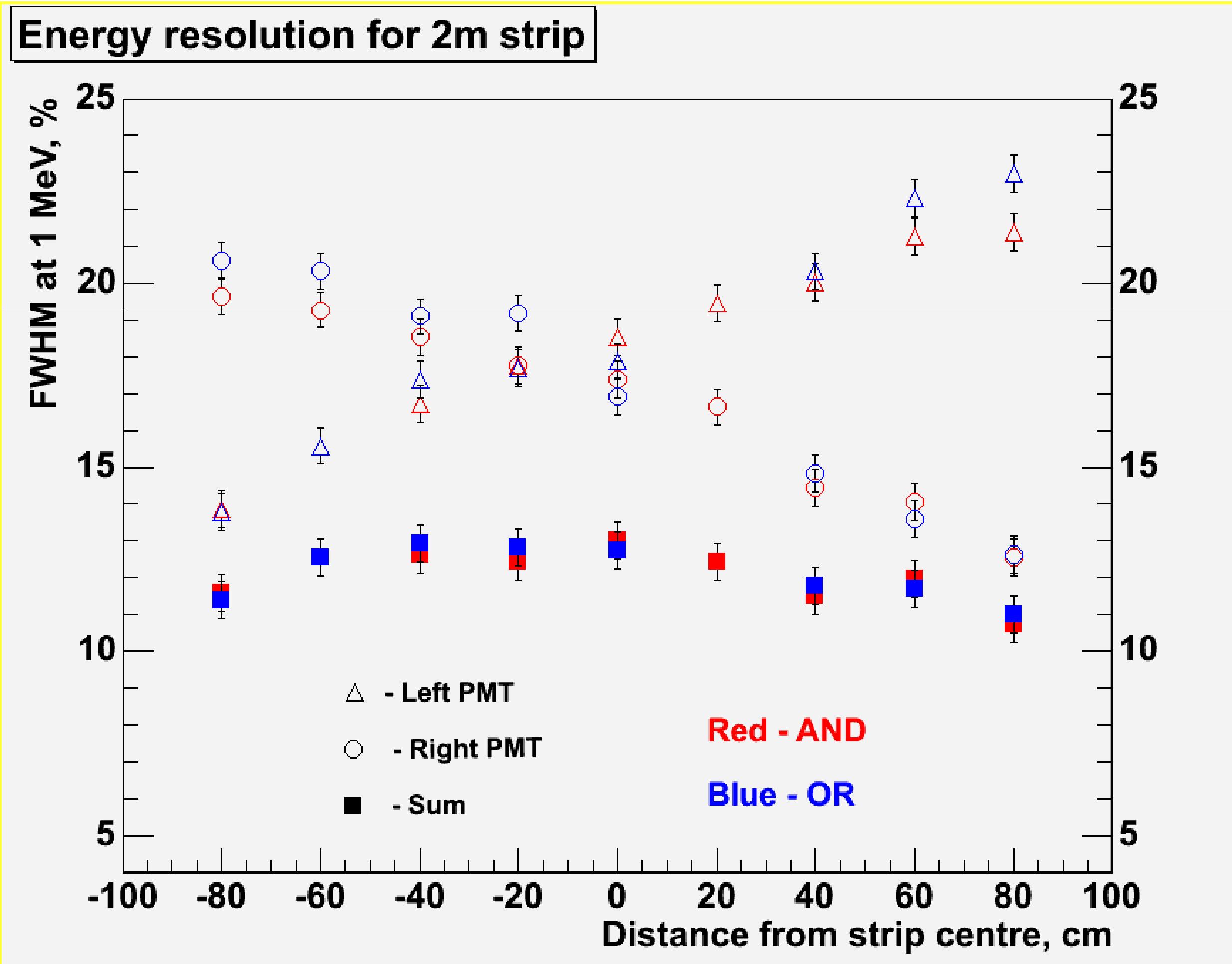
Energy resolution 4.2% at 3 MeV was measured with
75×75×20 mm LS + light guide + 3" PMT

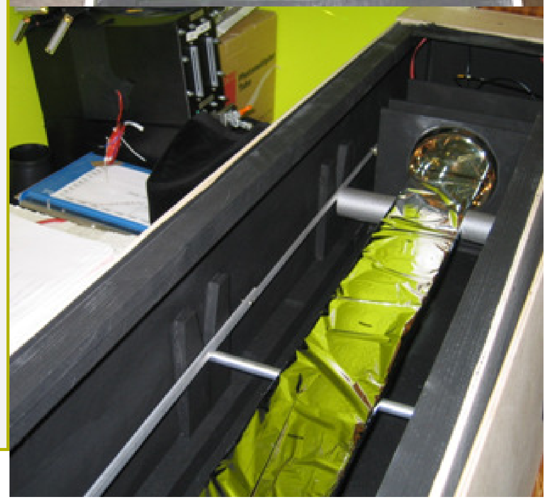
Relative pulse amplitude is 16% more than that with plastic of the same sizes

Comparable results have been obtained for LS and PS with small samples

R&D for bar scintillators

11-12% resolution has been obtained without optimization
New tests with improved setup will be done in 2008





R&D calorimeter status

Scintillators:

- Demonstrated the 7% at 1 MeV (FWHM) resolution for small samples
- The focus now is to retain this for larger blocks (8’’ PMT)

Photomultiplier tubes:

- 3’’ high (35–40%) quantum efficiency PMT developed by Hamamatsu/Photonis
- 8’’ PMT will be available by the end of the year
- Ultra-low background PMT glass – intensive R&D at Photonis

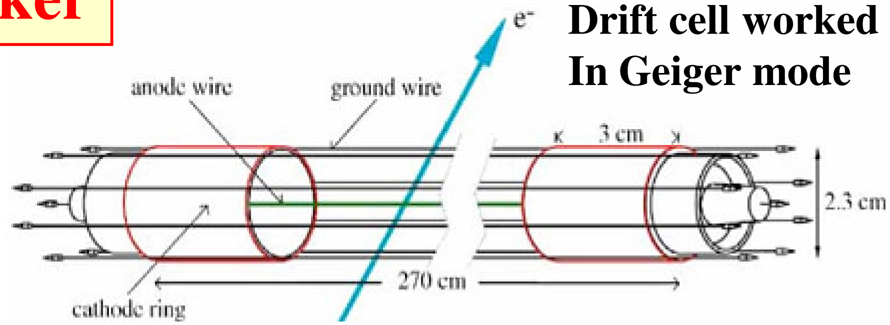
Four main options for the final calorimeter design:

- Plastic scintillator with a large hemispherical PMT (>= 8’’)
- Liquid scintillator in a container with a large PMT and an ultra-thin window
- Hybrid detector. Liquid scintillator as a light guide and for gamma detection, and a 2 cm entrance window from plastic scintillator for electron detection
- 2 m long scintillator bars read out at both ends by 3’’ or 5’’ PMT

R&D for tracker

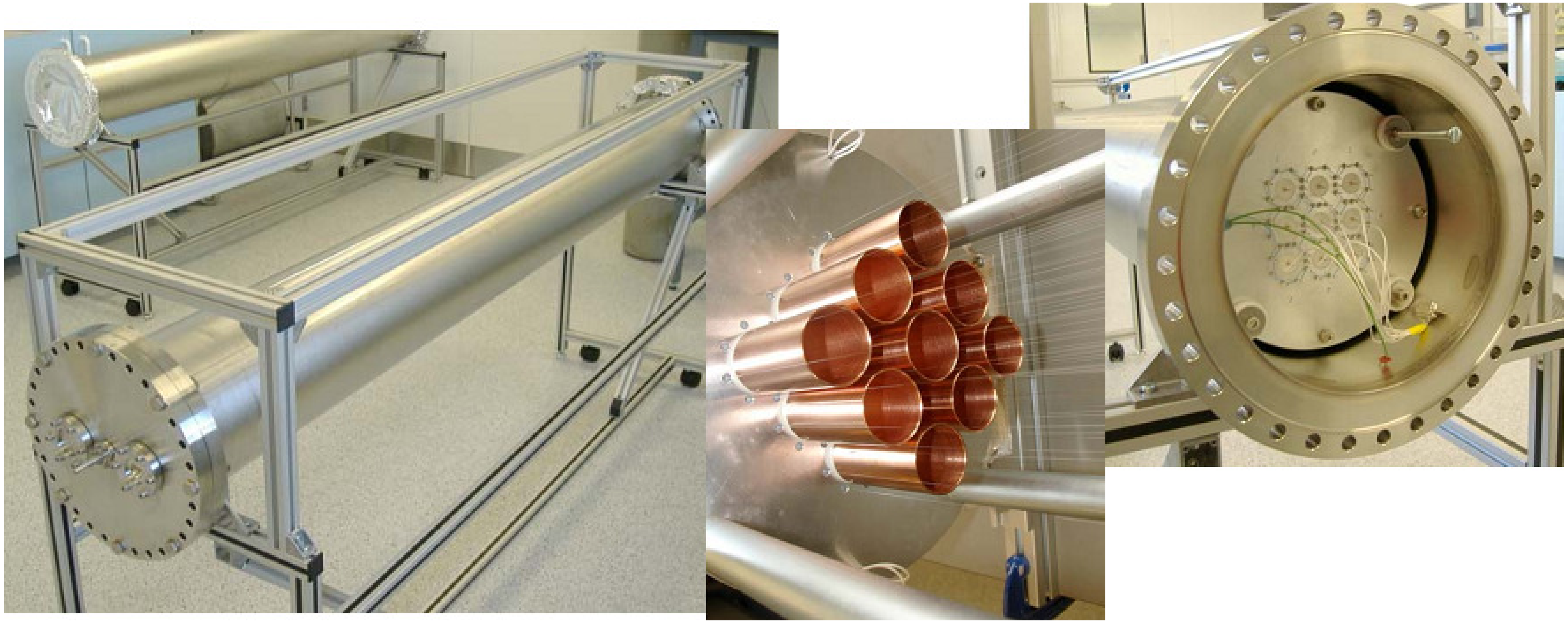
Goal: optimization of tracker operating performance

- sizes of wires and cell
- wire material, gas mixture
- simulation for optimal tracker desing
- readout
- desing of automatic wiring equipment



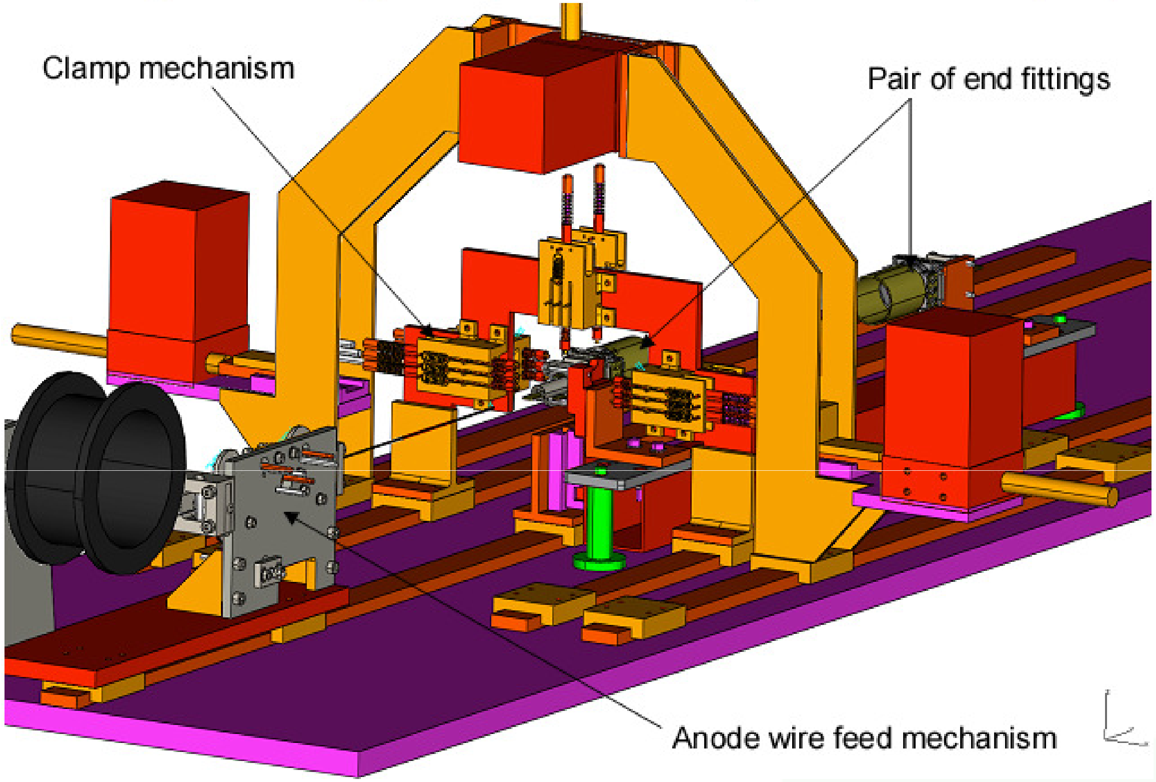
Drift cell worked In Geiger mode

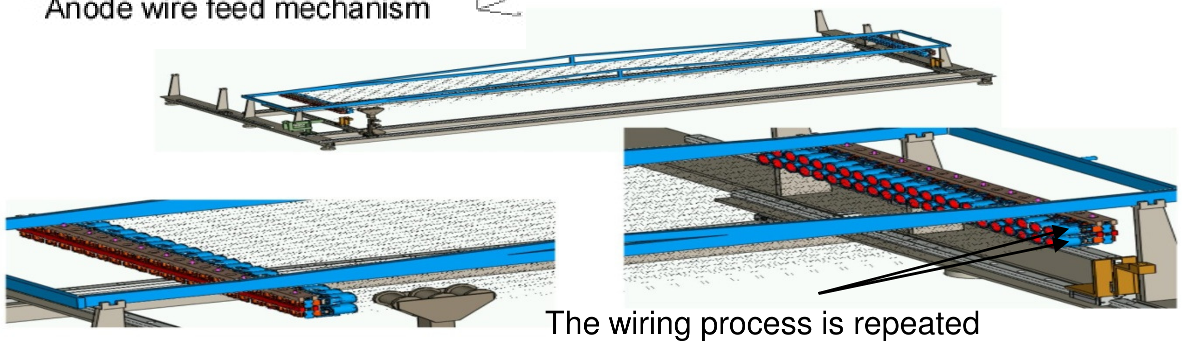
- 9-cell prototype has been built (see photos) in Manchester U. and is testing with cosmics
- 100-cell prototype in 2008
- 300-cell prototype is discussing



R&D for wiring robot

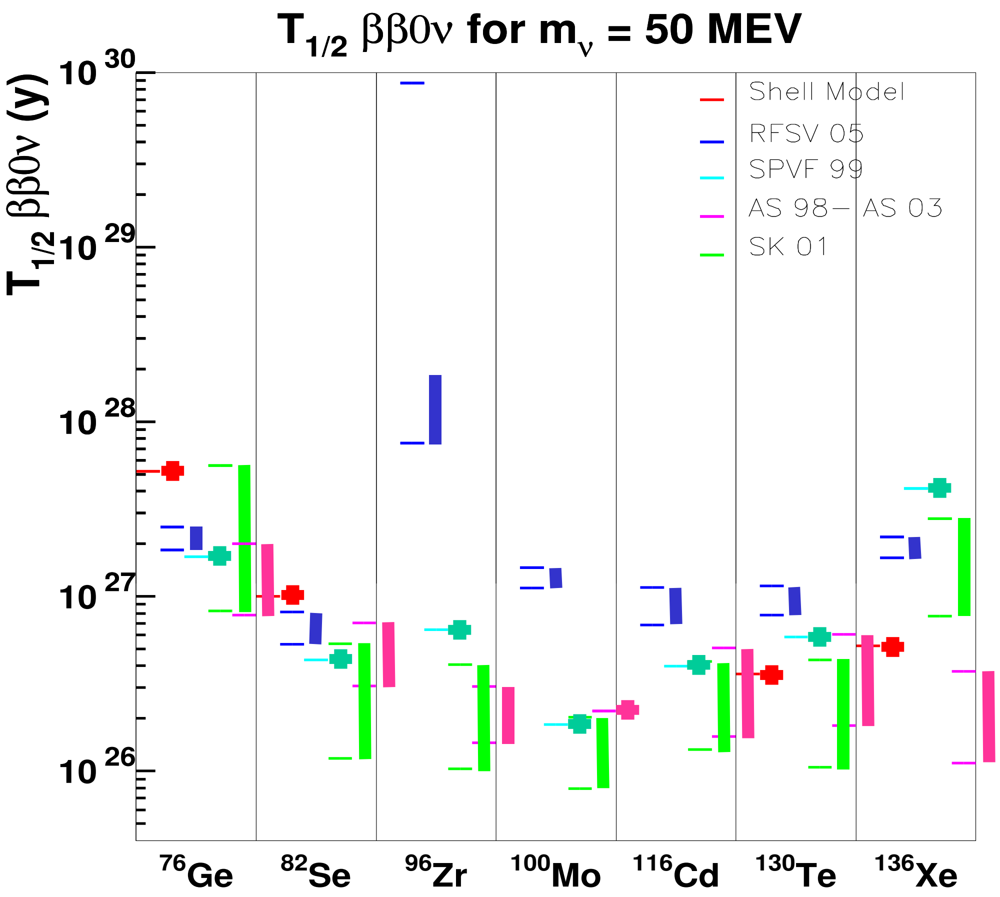
- About 500 000 wires to be strung, crimped, terminated
- Wiring robot is being developed at Mullard Space Science Lab (UCL)





The wiring process is repeated until two complete rows have been produced.

Choise of nucleus for measurements



Nuclear matrice elements
Theoretical calculations

Recent calculation done systematically on several experimental interesting nuclei

- Shell Model: Caurier et al. (2004)&private com.
- QRPA Simkovic et al. (1999)
- Stoica et al. (2001)
- Suhonen et al. (1998 and 2003)
- Rodin, Simkovic (2005)

Nucleus choice depends on:

- **enrichment possibilities**
- **experimental techniques**
- **NME value (not very strong due to calculation uncertainties**
- **$Q_{\beta\beta}$ values (phase space factor, background)**
- **high ββ(2ν) life-time**

Choise of nucleus for measurements

$$(T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q,Z)\,|\,M^{0\nu}\,|^2 \left\langle m_\nu \right\rangle^2 / m_e^2 \sim Q^7 Z^2\,|\,M^{0\nu}\,|^2$$

Nucleus	$Q_{\beta\beta}$(keV)	$T_{1/2}(\beta\beta2\nu)$, y	$G^{0\nu}$, 10^{-14} y^{-1}	$\sqrt{G^{0\nu}/G^{0\nu}_{76Ge}}$	$M^{0\nu}$ a)	Abundance(%)
^{48}Ca	4272	$4.2{\cdot}10^{19}$	6.43	3.19	0.76 b)	0.187
^{76}Ge	2039	$1.74{\cdot}10^{21}$	0.63	1	2.58-6.36	7.4
^{82}Se	2996	$9.2{\cdot}10^{19}$	2.73	2.08	2.49-4.60	9.2
^{96}Zr	3350	$2{\cdot}10^{19}$	5.7	3.00	1.12-4.32	2.8
^{100}Mo	3034	$7.11{\cdot}10^{18}$	4.58	2.70	2.78-4.85	9.6
^{116}Cd	2805	$3.1{\cdot}10^{19}$	4.68	2.73	1.96-4.93	7.5
^{128}Te	867	$2.5{\cdot}10^{24}$ (geo)	0.17	0.52	2.54-5.84	32
^{130}Te	2529	$7.6{\cdot}10^{20}$	4.14	2.56	2.34-5.44	34.5
^{136}Xe	2468	-	4.37	2.63	1.26-3.72	9
^{150}Nd	3367	$9{\cdot}10^{18}$	13.4	4.61	4.16-4.74 c)	5.6

a) Compilation of QRPA & Shell model $M^{0\nu}$ calculations from MEDEX'07 workshop
b) Shell model only
c) For completeness only. Deformation is not included in the calculations

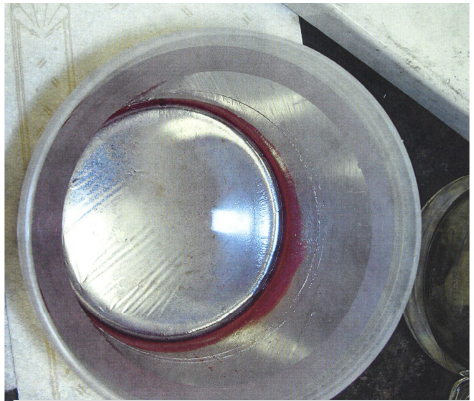
R&D for ^{82}Se sources

ECP (Electro-Chemical Plant, Svetlana) Zelenogorsk (Siberia)

Enrichment

Goal: To be able to produce 100 kg of ^{82}Se

- Facilities exist in Russia
  - 30 kg of ^{76}Ge for GERDA
  - 100 kg of ^{82}Se possible in 3 years
  - Distillation of ^{82}Se (for purification) possible
    Distillation of ^{116}Cd tested with NEMO3
  - 3.5 kg of ^{82}Se funded by ILIAS(*) (2005-2007)



Chemical purification at INL (US)

Purification

Goal: $^{208}Tl < 2\ \mu Bq/kg$

$^{214}Bi < 10\ \mu Bq/kg$

- Collaboration with INL (chemical method)
  - 600 g of ^{nat}Se done
  - 1 kg ^{82}Se done

All funded by ILIAS

Installation of NEMO3 foils (LSM)

Source foils production

Goal: 250 m^2 of ^{82}Se foils of 40 mg/cm^2

NEMO3: ITEP (Moscow) powder + glue (60mg/cm^2)

=>Extrapolation 100 kg possible if very clean conditions

Or new technique in test in LAL

- Collaboration with Kurchatov and Nijni-Novgorod Institutes (distillation)
  - 2 kg of ^{nat}Se done

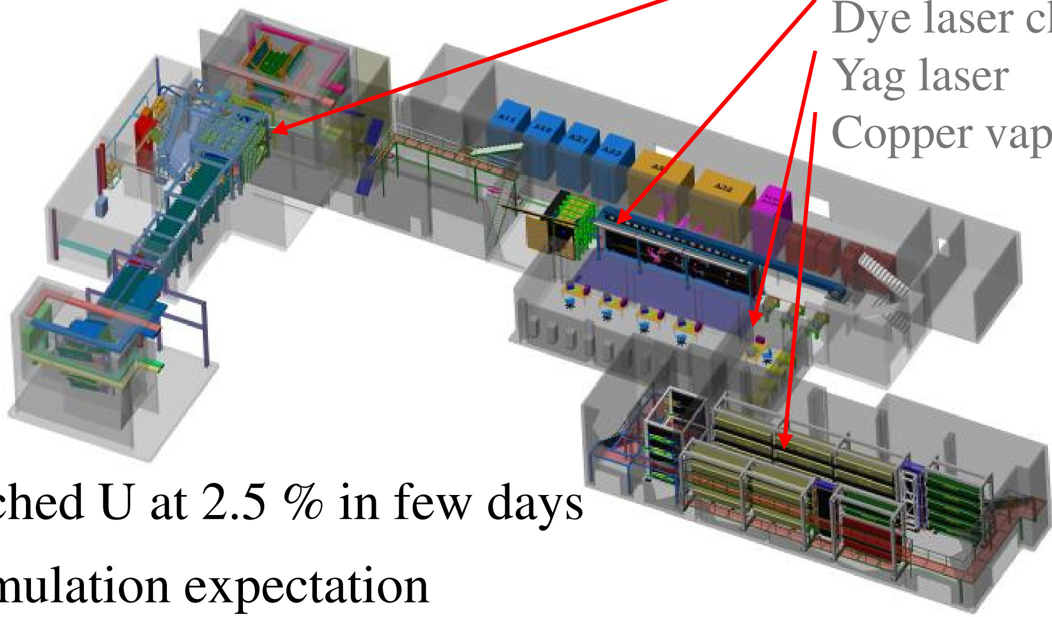
R&D for ^{150}Nd

- technically it is potencially possible to enrich Nd (MENPHIS/CEA), strongly supported by the international double beta decay community
- ^{150}Nd advantages
  - no constraint for Radon and ^{214}Bi
  - constraint less severe for ^{208}Tl
  - phase space: 100 kg ^{150}Nd ≈ 1 700 kg of ^{76}Ge ≈ 400 kg of ^{82}Se or ^{130}Te ≈ 4000 kg of ^{136}Xe
  - nuclear matrix element : could be good but ?
  - if SUSY is a mediator : very good for Nd
  - search to ββ-transition to excited state level very promising too
- Nd is the candidate for SuperNEMO (2 electrons search) and for SNO++ (pure calorimeter)

^{150}Nd R&D: MENPHIS facility support

Based on AVLIS (Atomic Vapor Laser Isotope Separation) method of enrichement

Design : 2001
Building : 2002
1st test : early 2003
1st full scale exp. : june 2003



- Production of 200 kg of enriched U at 2.5 % in few days
- Results in agreement with simulation expectation

MENPHIS simulation shows that enrichment of ^{150}Nd is doable (ton scale), ~ 100 kg in few weeks !!!

^{48}Ca enrichment is theoriticaly doable. Studies must be done

Expression of Interest of SuperNEMO, SNO++ and Japan to keep MENPHYS for Nd enrichment

R&D for low radioctivity measurements

Goals: To develop detector capable to meausre 5 kg of foil (12 m^2, 40 mg/cm^2) in one month with sensitivity of 2 μBq/kg in ^{208}Tl and 10 μBq/kg in ^{214}Bi

To improve HPGe detectors for selection of materials for SuperNEMO

To develop detectors sensitive to 0.1 mBq/m^3 of radon

Ge detectors

Today best NEMO HPGe 400 cm^3 sensitive to 60 μBq/kg in ^{208}Tl and 200 μBq/kg in ^{214}Bi (1 month, 1 kg)

Development with Canberra-Eurysis: larger volume (up to 1000 cm^3), background reduced by a factor 10 and higher mass measurement.

Need of new set of measurements to select very pure materials for both cryostat and shielding.

This development is done in the frame of ILIAS.

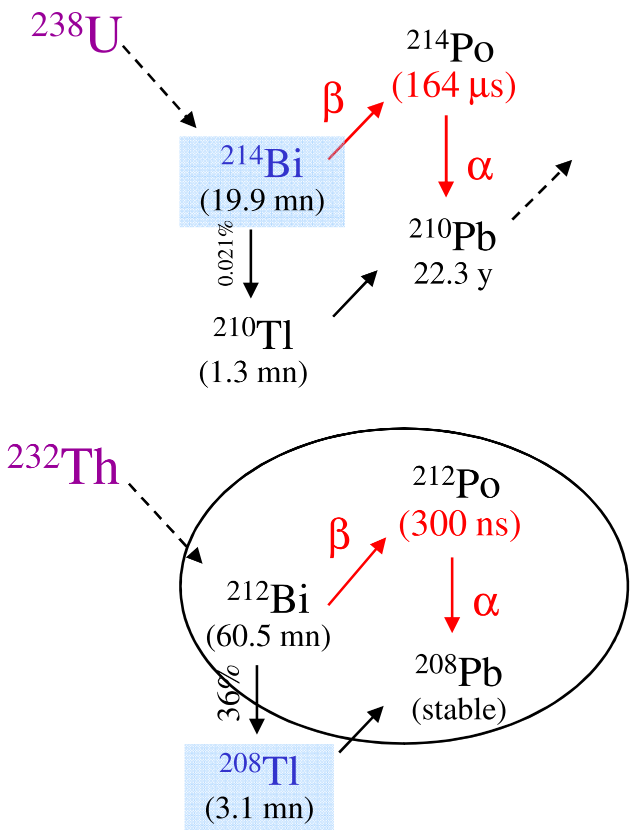
Radon detectors

Present radon detector sensitive to 1 mBq/m^3 (based on Po ions collection in 70 l volume)

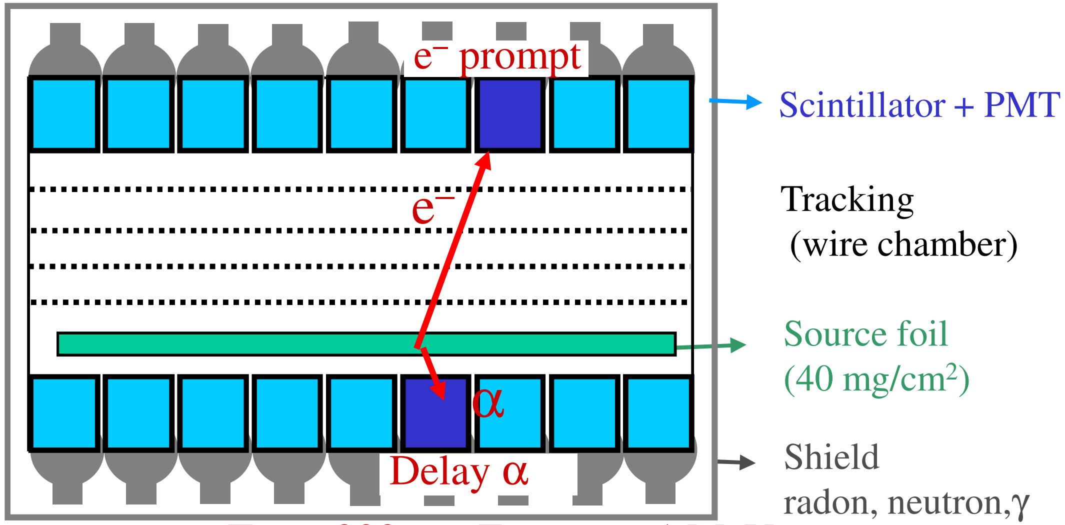
Development of 1000 l detectors or new methods like drift chambers or using liquid scintillator.

R&D for BiPo detector

Bi-Po Process



Q_β (^{212}Bi) = 2.2 MeV



$T_{1/2}$ ~ 300 ns $E_{deposited}$ ~ 1 MeV

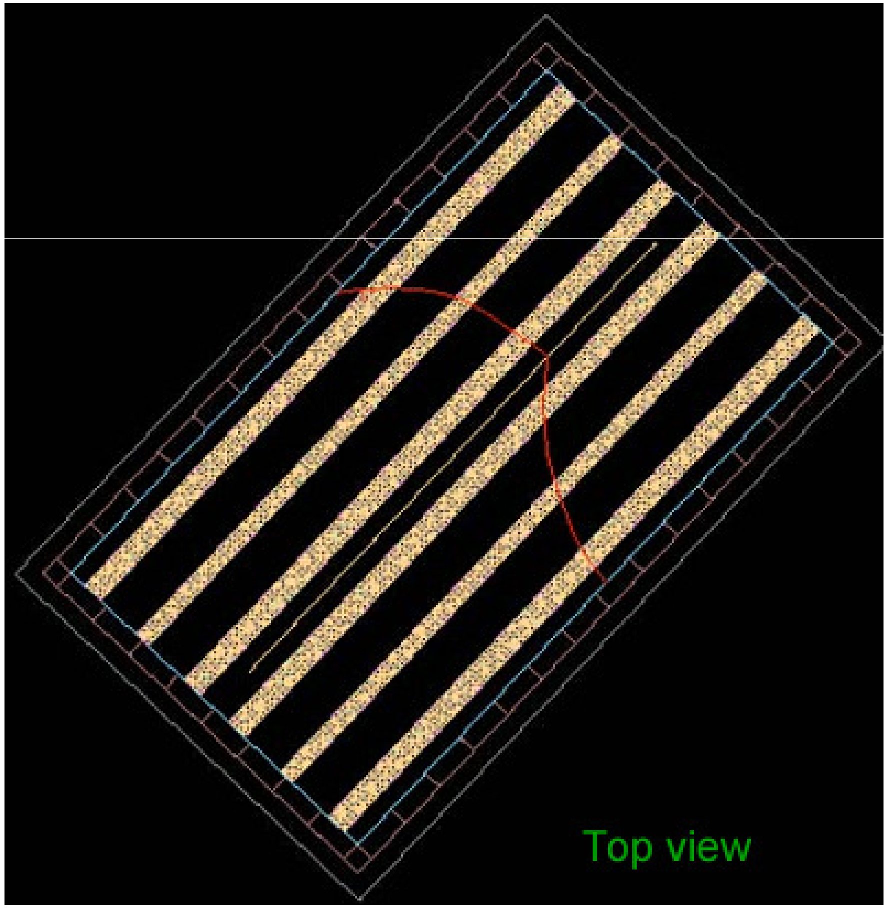
2 modules 2×3 m² → 12 m²
Background < 1 event / month

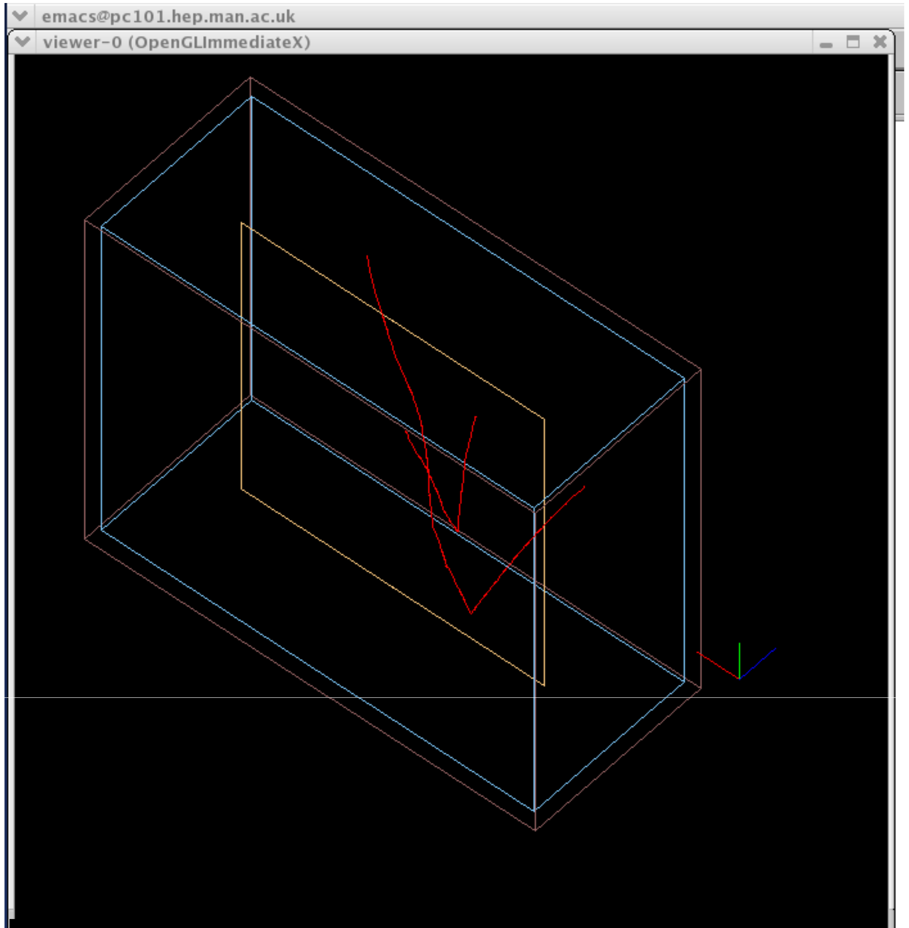
Current status:

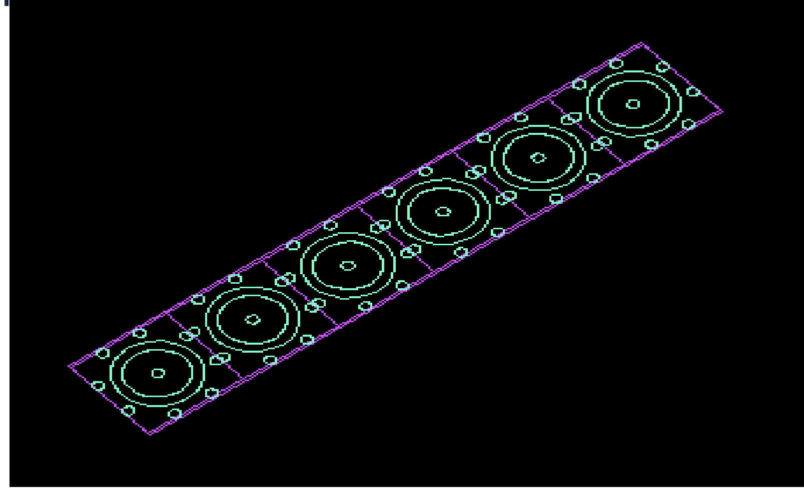
- **BiPo-I protype is testing now in LSM (calibration, background measurements, development of β–α-discrimination technique)**
- **BiPo-II will be tested in 2008**

Simulations

- SuperNemO VAlidation (SNOVA)
- Geant4 based application







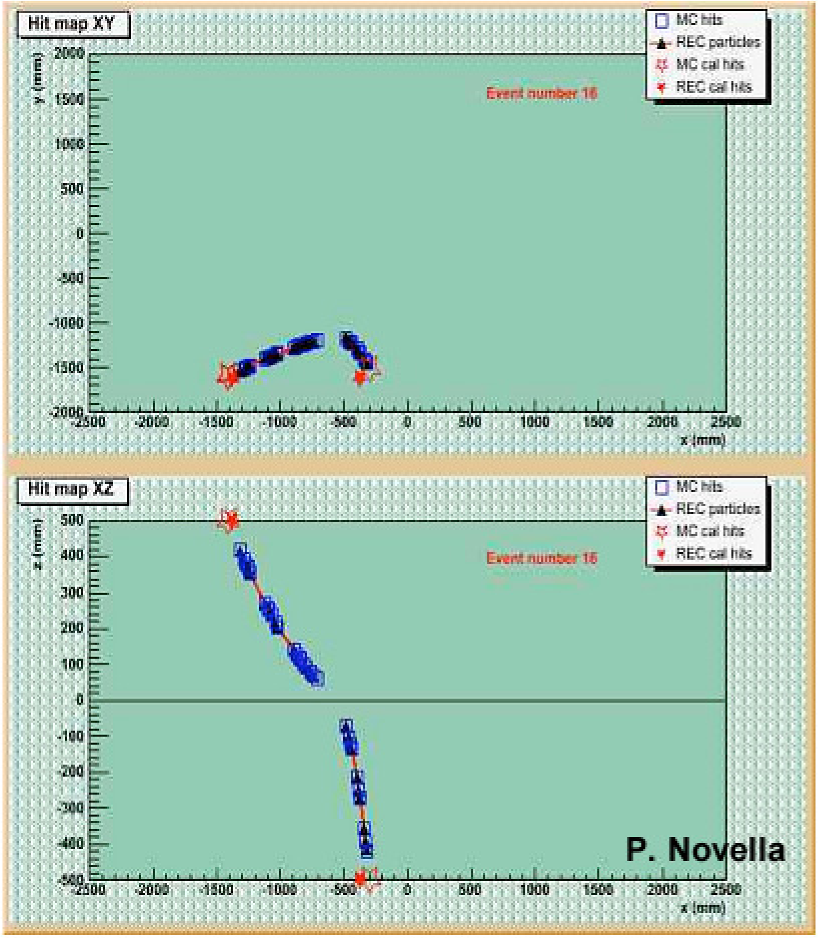
Simulations: tracking performance

- Full detector simulation – GEANT4
- Reconstruction

- Tracks reconstructed from tracker hits
- Event vertex found in the foil
- Tracks matched with calorimeter hits
- Charge measured from curvature

- Track reconstruction efficiency ~ 90%
- Charge id efficiency ~ 98%
- Vertex reconstruction efficiency ~99%
- Vertex resolution ~2 cm

Overall efficiency ~30%



Simulations: sensitivity estimations for basic design setup

An example toy Monte Carlo:

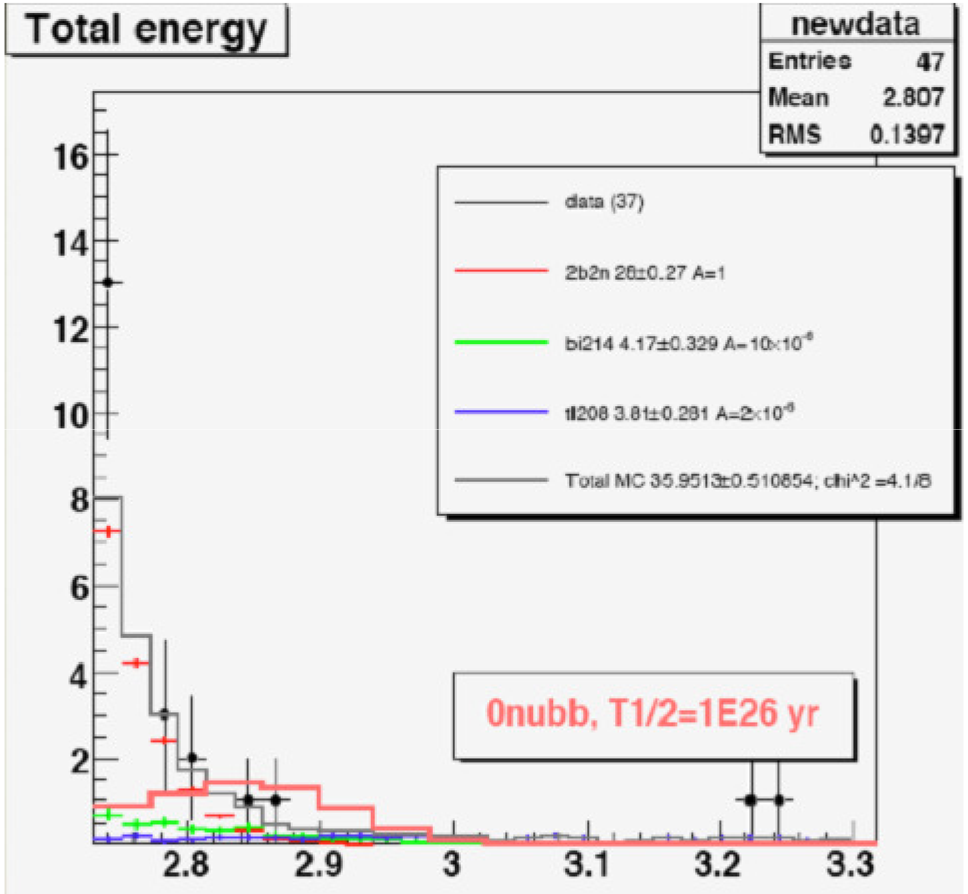
- Running with ^{82}Se 100 kg for 5 years (500 kg y)
- Data points simulated according to the total MC mean
- Energy resolution 7% at 3 MeV

Internal backgrounds:

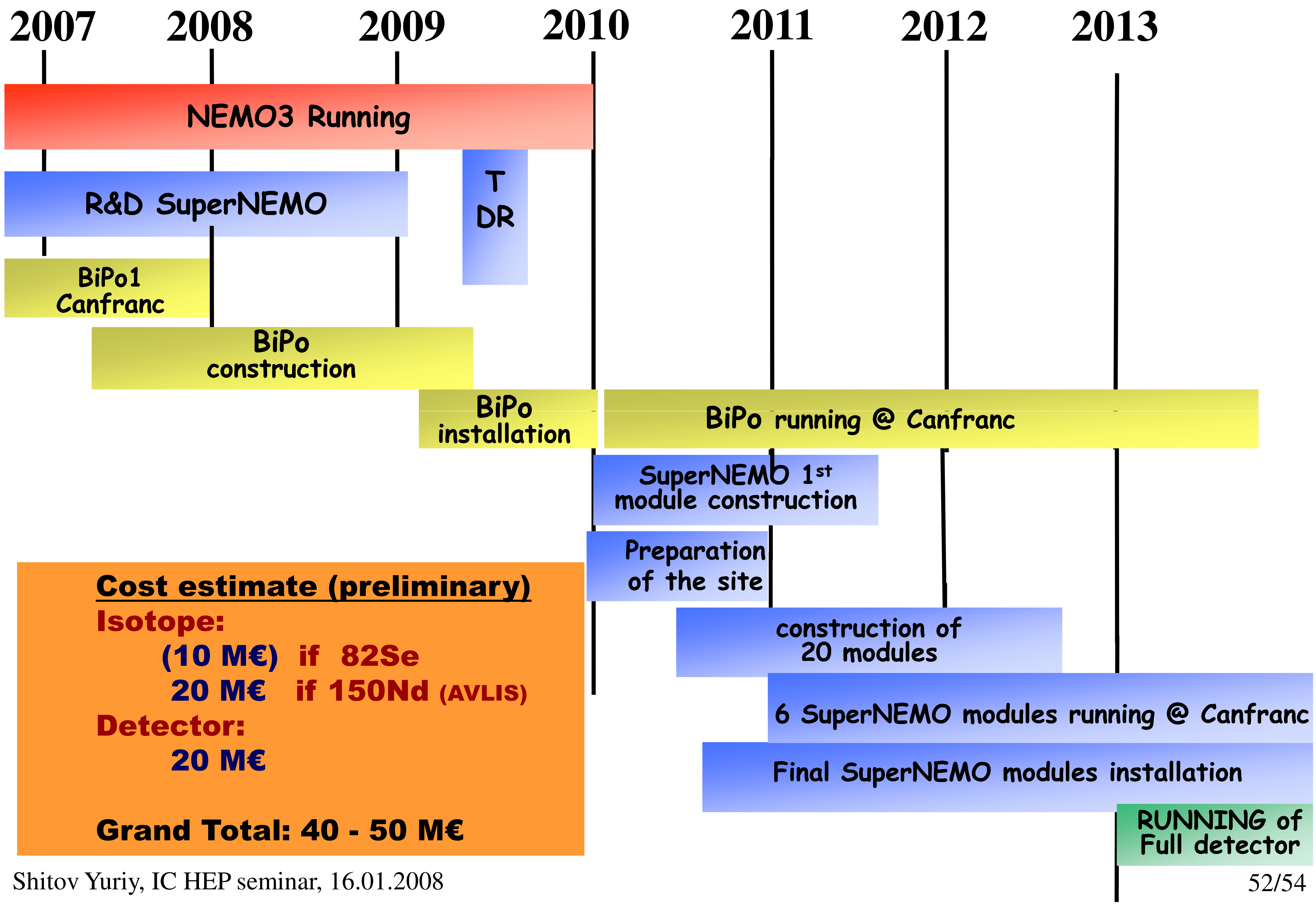
- ^{214}Bi activity = 10 μBq/kg
- ^{208}Tl activity = 2 μBq/kg

Can put a limit on $0\nu\beta\beta$ decay:

- $T_{1/2} > 1.02 \times 10^{26}$ years
- $\langle m_\nu \rangle < 75 - 100$ meV



SuperNEMO schedule summary



Cost estimate (preliminary)

Isotope:

(10 M€) if 82Se

20 M€ if 150Nd (AVLIS)

Detector:

20 M€

Grand Total: 40 - 50 M€

Expected sensitivity in comparison with other projects

Experiment	Nucleus	Mass (kg)	FWHM at $Q_{\beta\beta}$ (keV)	Background Counts/ fwhm.kg.y	$T_{1/2}(0\nu)$ limit (years)	$<m_{\beta\beta}>$ limit (meV)	Starting taking data
NEMO 3	^{100}Mo ^{82}Se	7 1	350 350	~ 0.5 ~ 0.1	$2.\ 10^{24}$ $8.\ 10^{23}$	300 - 1300 600 – 1500	
CUORICINO	^{130}Te	10	7	~ 0.2	$4.\ 10^{24}$	250 – 850	
GERDA Phase 1 **Phase 2** **Phase 3**	^{76}Ge	15 35 300	4 4 4	0.04 0.004 0.004	**$3.\ 10^{25}$** **$2.\ 10^{26}$** **$6.\ 10^{27}$**	**250 – 780** **100 – 320** **20 – 65**	2008 ? ?
SuperNEMO	^{82}Se ^{150}Nd	100	210	0.01	**$1.\ 10^{26}$** **$6.\ 10^{25}$**	**45 – 130** **70**	2012 2012
CUORE **if enrich^{mt} ^{130}Te**	^{nat}Te ^{nat}Te ^{130}Te	700 700 700	5 5 5	0.05 0.005 0.005	**$2.\ 10^{26}$** **$6.6\ 10^{26}$** **$2.\ 10^{27}$**	**35 – 120** **20 – 65**	2012 ? ?

Nuclear Matrice elements: Shell Model: Caurier (2004) private com.
Stoica et al. (2001)
Suhonen et al. (1998 and 2003)
QRPA Rodin, Simkovic, Faessler (2005)

Conclusion

- The 0νββ–decay is a test of physics beyond the Standard Model by the search of the leptonic number violation and would determine the nature of the neutrino (Majorana)

-NEMO-3 works stable with perfomance expected. Backround was precisely measured and reduced (radon). New results for both 2nbb and 0nbb-decay to ground and exited states have been obtained for a set of nuclei

- NEMO technique can be extrapolated at ~100 kg to be sensititive to 2.10^{26} y
Only tracko-calo and gas TPC can identify the 2 emitted electrons. It also allows to measure single energy and angular correlation to determine the process leading to ββ(0ν) : light neutrino exchange, right-handed current, supersymetry,…

- SuperNEMO R&D program is carrying out and it is in good shape

- Several experiments are needed to measure different sources with several techniques

- SuperNEMO detector will be competitive with the other next generation 0νββ-experiments

- The next generation of ββ(0ν) detectors will improve by a factor of 100 the sensitivity on the $T_{1/2}$ period for the search of leptonic number violation.
The sensitivy on the physical $<m_\nu>$, $<g_M>$, … will be improve by a factor 10.