Nd150 ENRICHMENT IN FRANCE

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- LIS and MENPHIS in France
- Perspectives : ^{150}Nd, ^{96}Zr (?)
- SuperNEMO collaboration statements :

  ^{150}Nd sensitivity

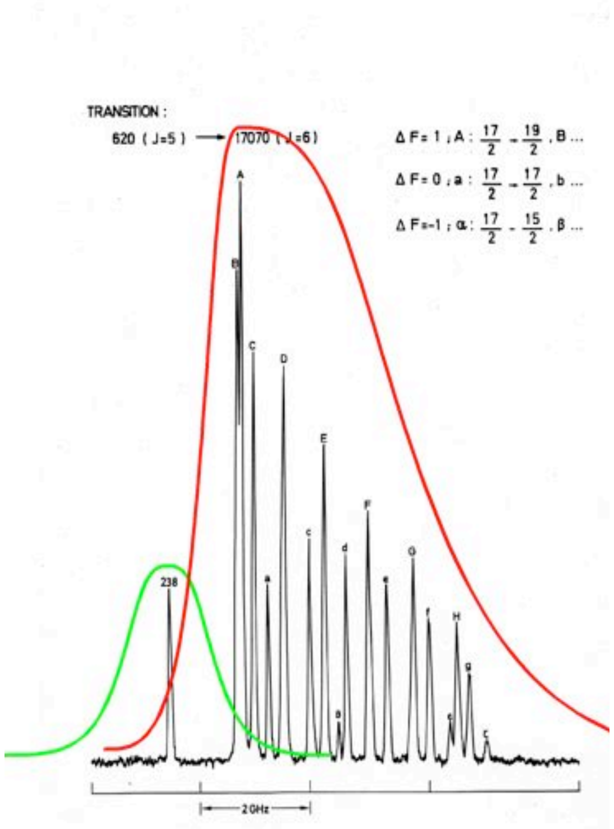
OUTLINE

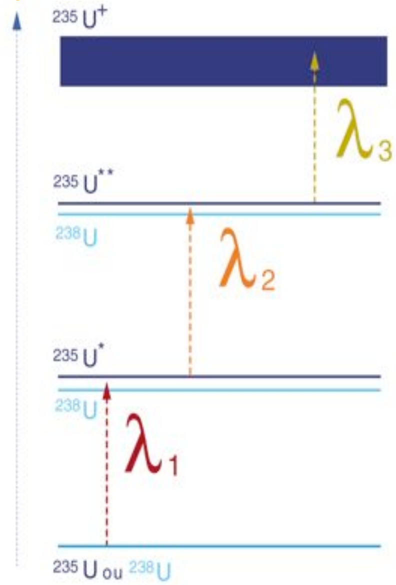
- Introduction
- Basic of the AVLIS Process
- Main milestones of the AVLIS Process
- Necessity of modelling
- 2000-2003 program in France
- Description of Menphis Facility
- Results and conclusions

Basics of the SILVA/AVLIS process (1/4)

- Selective photoionization

$$^{235}U + 3 \text{ photons} \rightarrow ^{235}U^{+} + e^{-}$$



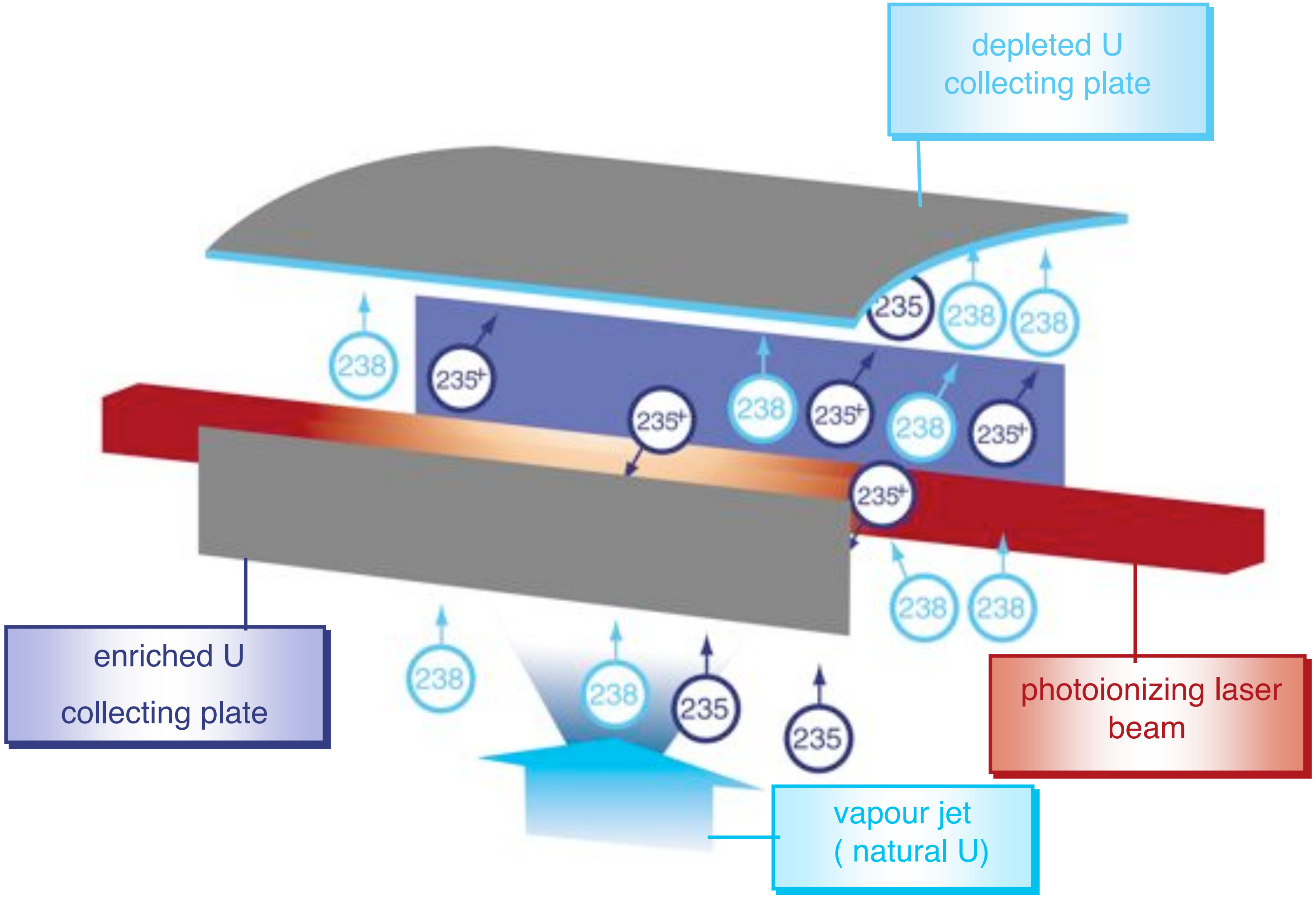


Choosing an efficient photoionization scheme is a very difficult task

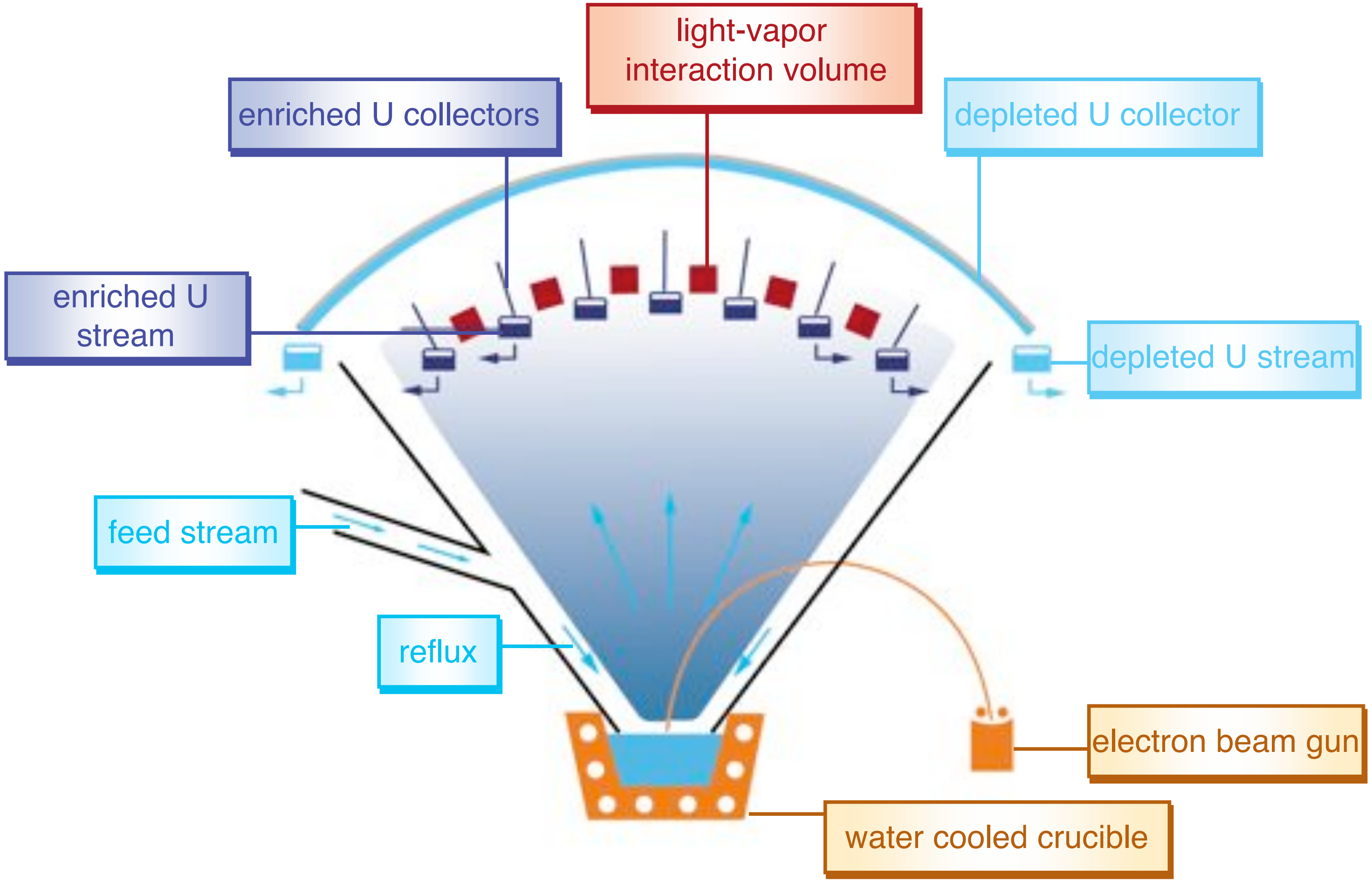
⇓

3 wavelengths λ_1, λ_2, λ_3

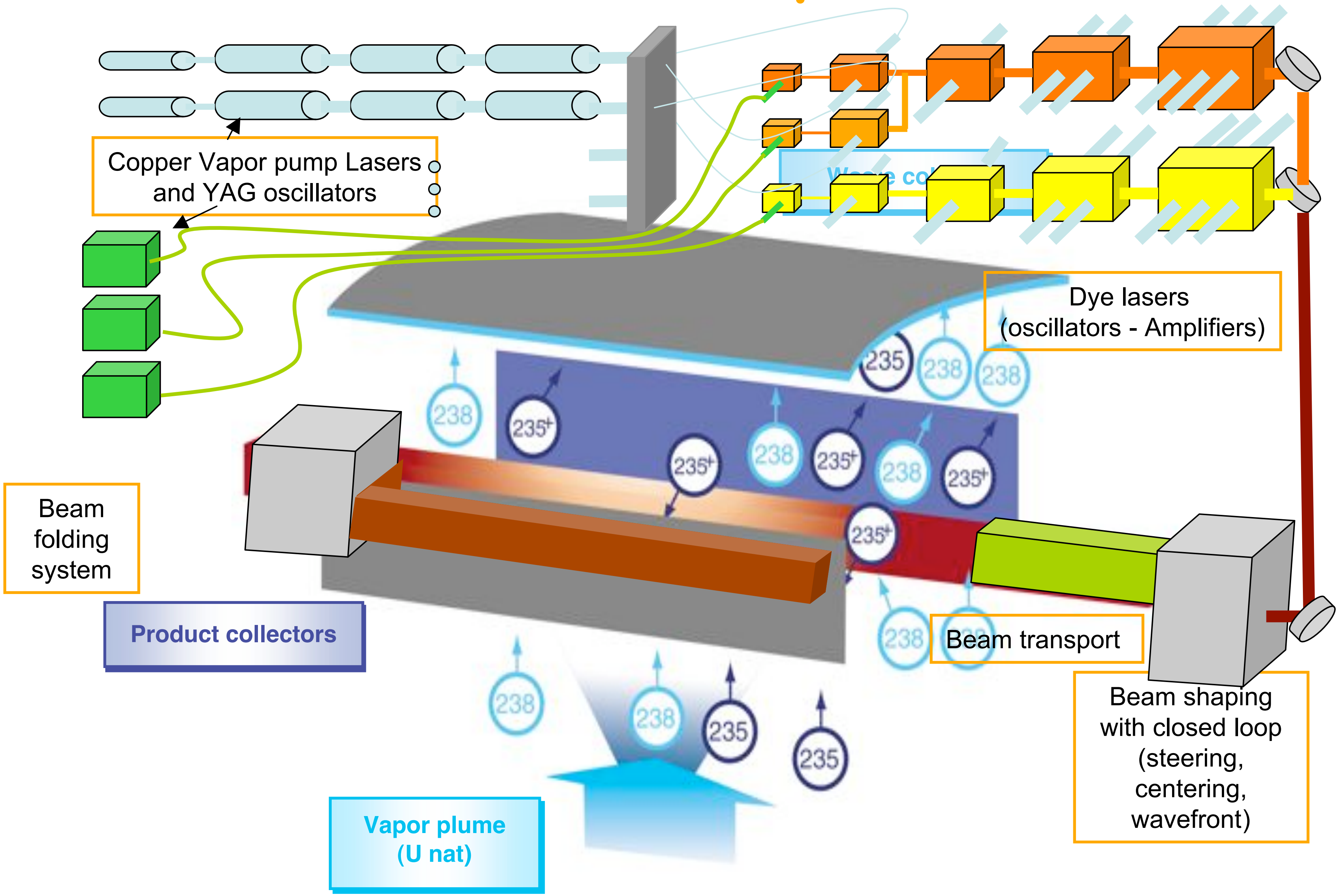
Basics of the SILVA/AVLIS process (2/4)



Basics of the SILVA/AVLIS process (3/4)



Basics of the SILVA process (4/4)



Milestones of the SILVA process

1973 : Atomic isotope separation by laser : initial patent
1980 : Basic research at CEA (spectroscopy, evaporation)
1985 : SILVA/AVLIS selected as advanced process :
USA, France, Japan

1994 : Tens of grams produced at the industrial assay
1994-1998 : Technological demonstrations (by parts)
Mid 1999 : AVLIS shut down in US ; early 2003 in Japan
2000 : Decision for a conclusive 4 years program
2000 - 2003 : MENPHIS construction and preliminary R&D.

2003 : Demonstrations on MENPHIS

Milestones of the AVLIS process (USA)

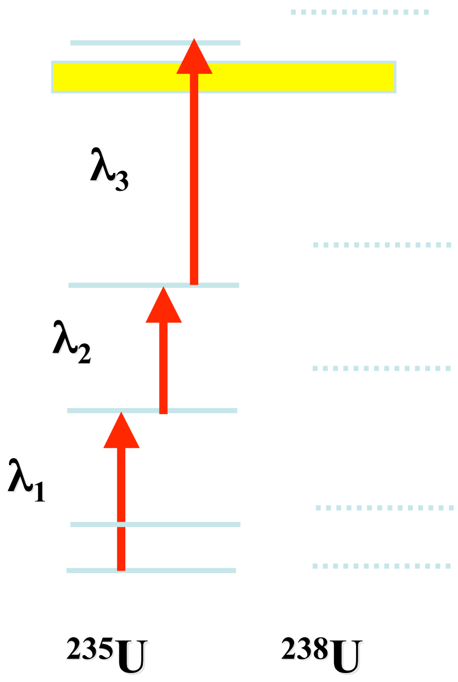
1972 : Beginning of the AVLIS Project at Los Alamos
1992 : 150 kg (2%); 112 hours (9 hours full flow)
1992-95 : Work on Gd and Er

1997 : 400 hours (280 hours for enrichment)

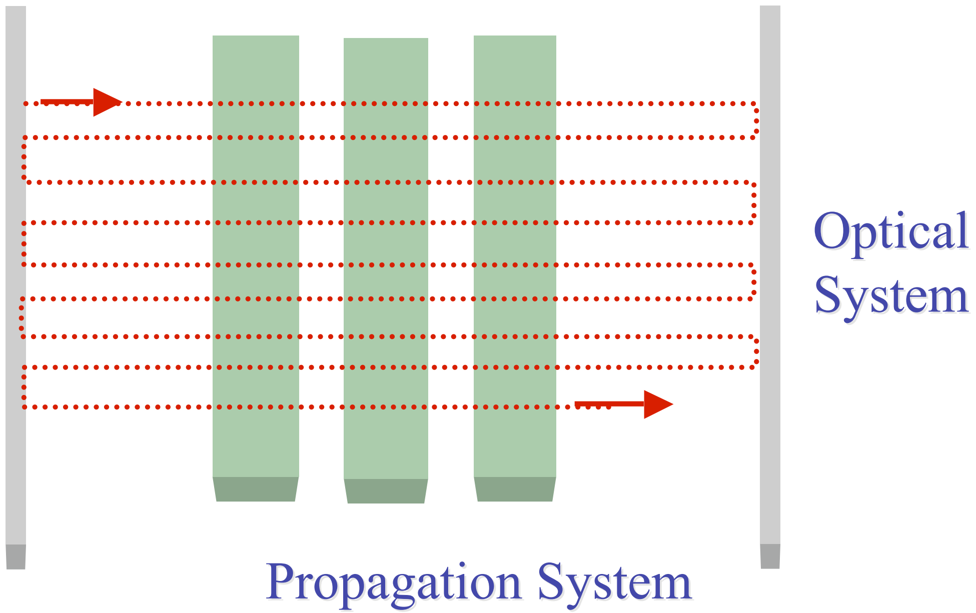
1999 : the AVLIS program is stopped in USA

Laser-vapor interaction Modelling in SILVA

- 2 Isotopes ^{235}U and ^{238}U
- 5 energy levels and 4 transitions



Photoionization



Propagation

2000-2003 Program : Objectives

- **Complementary R&D on both illumination and uranium management**
- **Building a large scale demonstrator facility MENPHIS**

Demonstrating the technical ability for SILVA to produce at least 200 kg of enriched uranium at an assay around 3% ^{235}U

- **Demonstrating the photoionisation efficiency over a one kilometer propagation length in the uranium full density vapor**

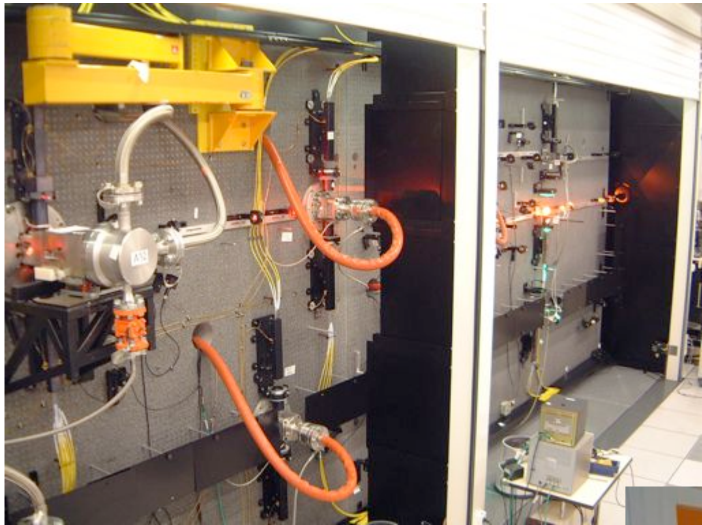
(multiple beam folding and propagation in several evaporator units)

2000-2003 Program : Menphis construction

Menphis =

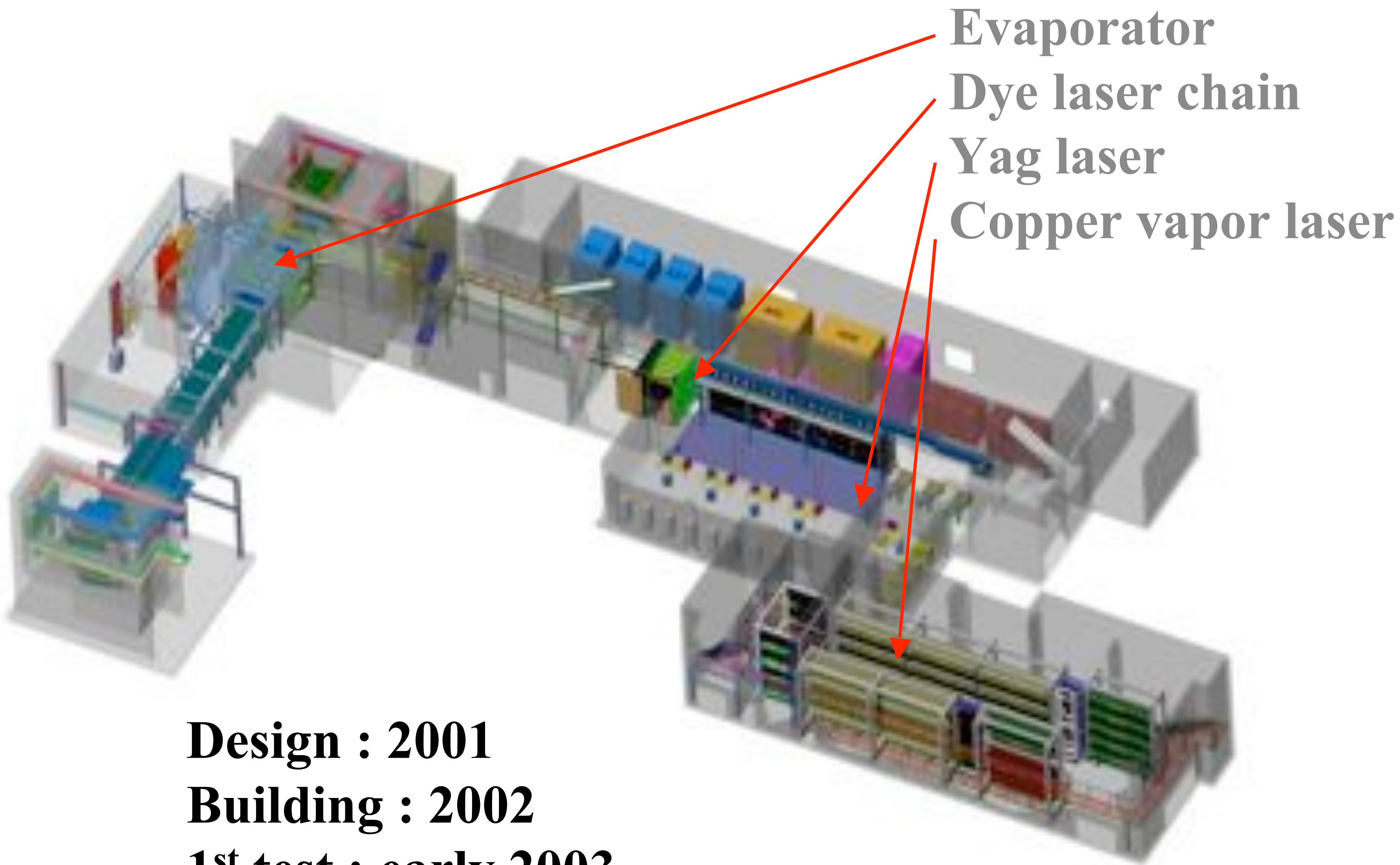
- Menelas separator (plant scale module)

- + laser system



- on line product & tail assay analysis lab

2000-2003 Program : Menphis facility



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

Menphis enrichment experiment results

<u>Main results for the process</u> :

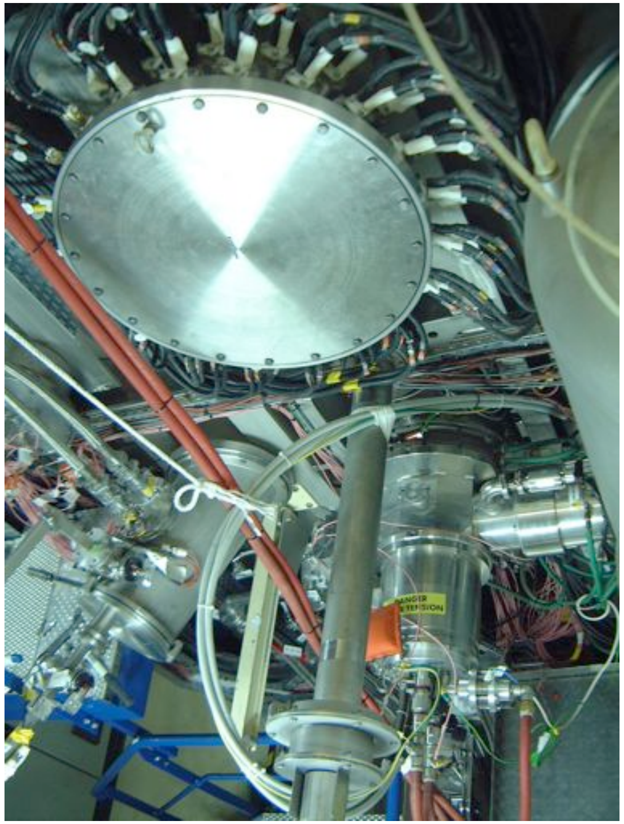
- **204 kg of enriched uranium at**
- **≈ 2.5 % mean (predicted) value**

- **About 2000 kg natural U evaporated**
- **≈400 “on line” assay measurements**

Menphis experiment technological results

LASER :

- ≥ 600 hours for each CVL
- 170 hours for dye laser at full power

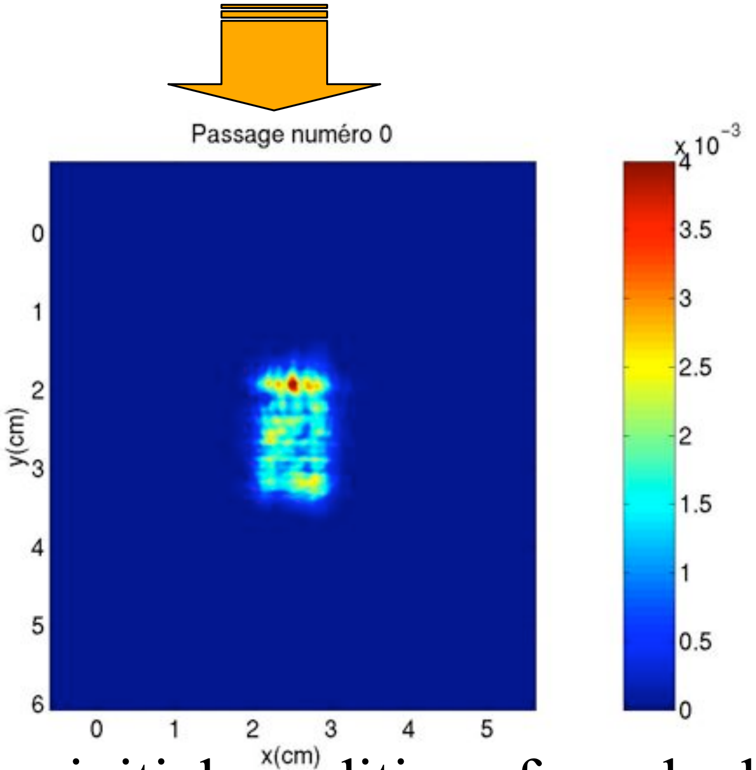


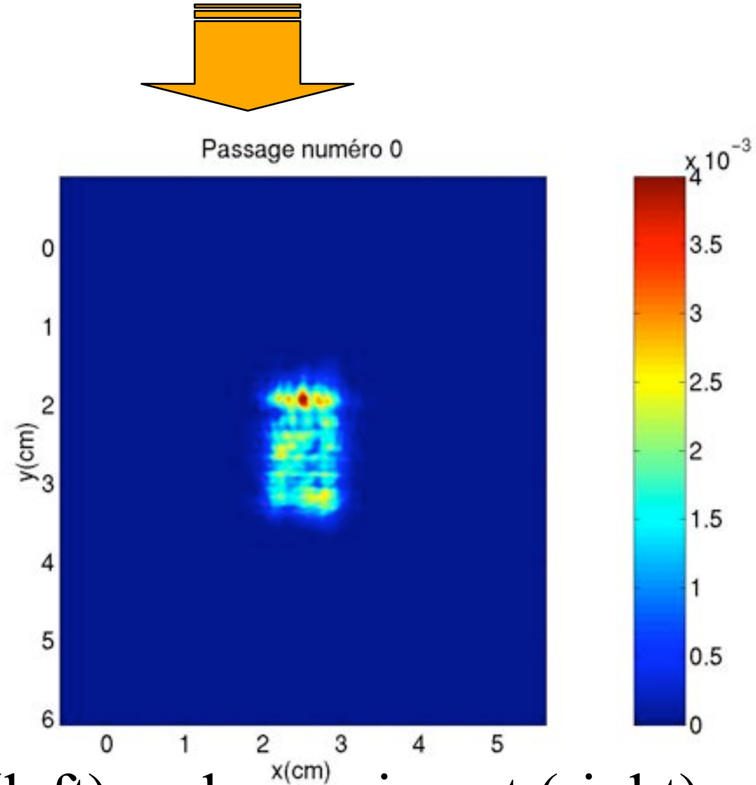
SEPARATOR :

- Several hundred hours at the operational temperature and extractor voltage without significant failures nor material damages
- Long time evaporation

Menphis propagation experiment results

Laser beam profile at the separator entrance





Used as initial conditions for calculation (left) and experiment (right)

Result of the calculations by
Prodige 3D code

PLS measurements X,Y profile

After 21 round trip for a very sensitive
wavelength which amplifies distortion

2000-2003 Program : CONCLUSIONS (1/2)

•The results of both the preliminary R&D on separator and illumination, and of the integration large scale experiments

(204 kg of enriched uranium around 2.5 %),

demonstrate the capability of SILVA to produce large amounts of enriched uranium in one evaporator.

• Demonstration to maintain the photoionisation efficiency over one kilometer propagation length in the uranium full density vapor is obtained from a 3D code benchmarked with an experiment in similitude

The scientific and technical feasibility of the process is now established.

2000-2003 Program : CONCLUSIONS (2/2)

- Many countries have demonstrated with AVLIS a g/h production of low enriched uranium
- But only a few have been able to raise the production up to a few kg/hour (USA, Japon, France)
- To get such a production level : 20 years :
  - high power electron gun
  - high laser power
- Nd has been enriched in ^{150}Nd at 60% with a production yield of 40mg/h

(Kurchatov Institute QE 35(10), 879 (2005))

Future of MENPHIS ?

R&D to design the operation of the set-up to enrich Nd (Zr ? to be confirmed)

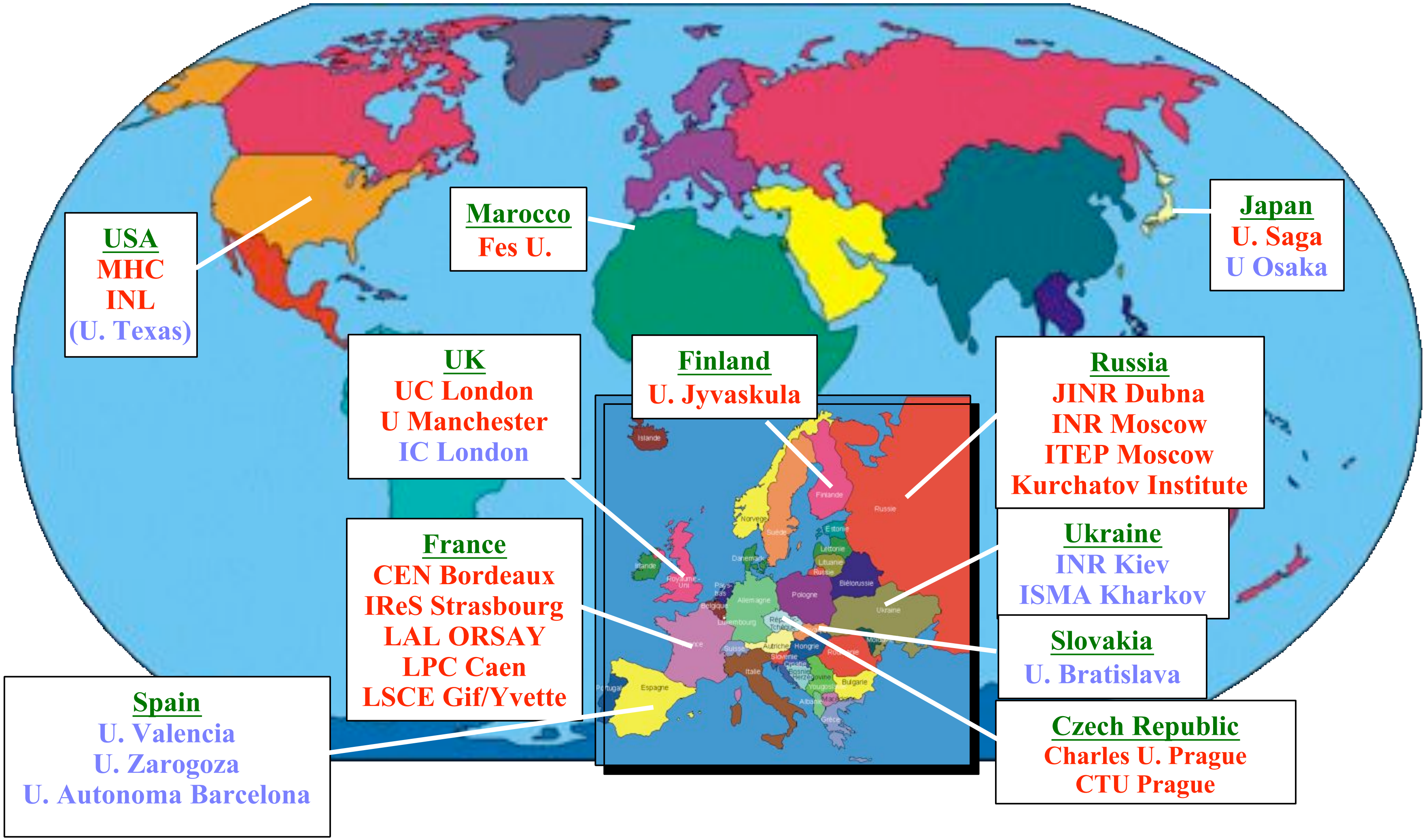
Large device which must be operated by a professional team

^{150}Nd in SuperNEMO ?

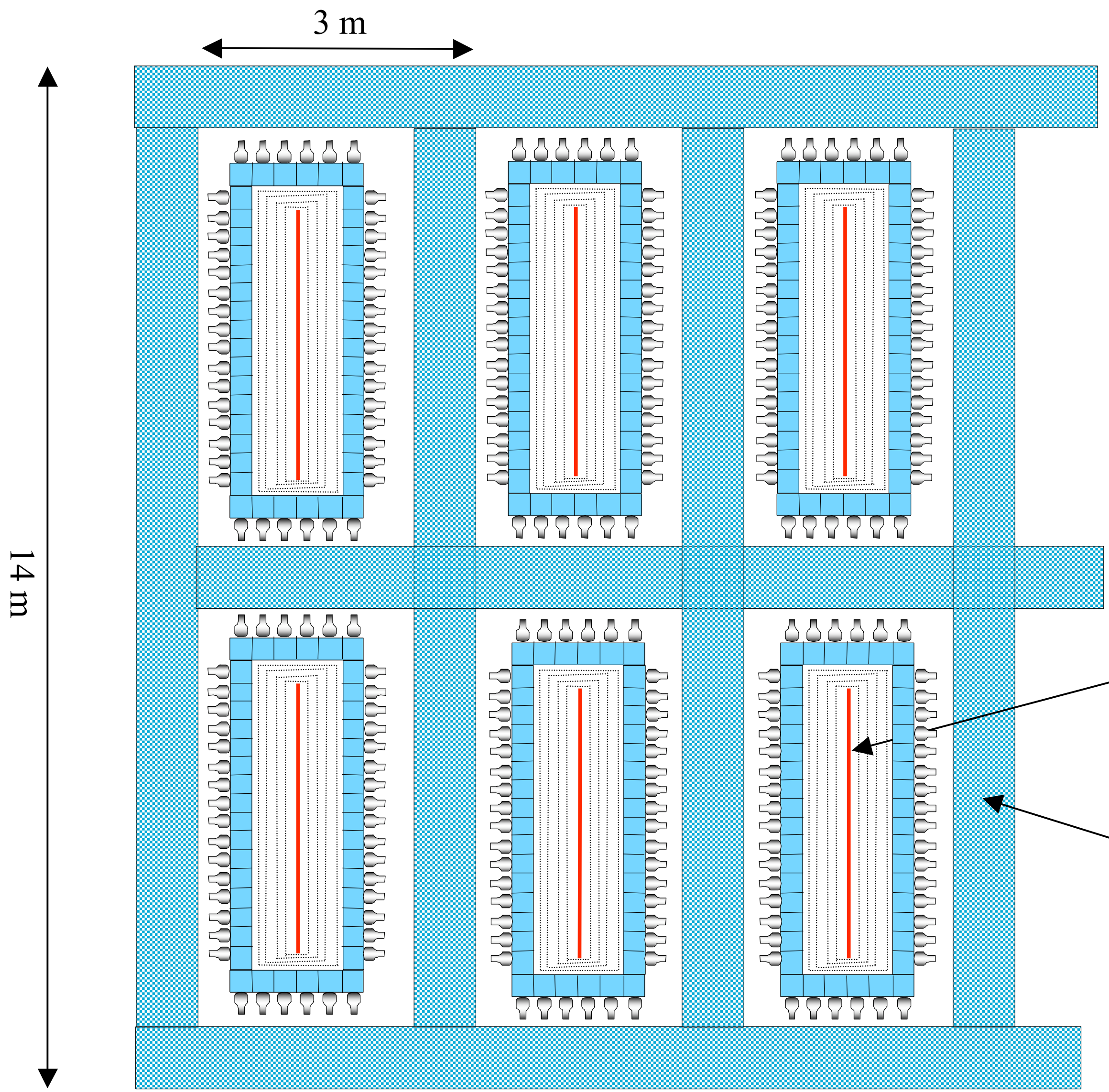
- Q = 3.336
  - space factor ↗
  - no ^{214}Bi no Radon
- End-point tail depressed
- Statement of the SuperNEMO collaboration

SuperNEMO collaboration

NEMO collaboration + new labs ~ 60 physicists, 11 countries, 27 laboratories



SuperNEMO detector: possible design



Number of Modules = 20

For each module

Calorimeter : 300 to 1000 PMT's
(depending on the final design)
Resolution (FWHM) at 3MeV = 4%

Tracking : drift chamber (3000 cells in Geiger mode)

Magnetic field : 25 gauss

Source foil:
5 kg of enriched ^{150}Nd or ^{82}Se

Water shield:
2kT of water for 20 modules

$\varepsilon(\beta\beta0\nu) \sim 30\ \%$

SuperNEMO ββ source: ^{82}Se, ^{150}Nd

Goal : $T_{1/2} > 10^{26}$ y
$< m_\nu > \leq 50$ meV

$$\frac{1}{T_{0\nu}} = G_{0\nu} M_{0\nu}^2 \langle m_\nu \rangle^2$$

^{82}Se

$Q_{\beta\beta} = 2.995$ MeV

Phase space factor $G_{0\nu} = 1.08 \times 10^{-25}$ $y^{-1}eV^{-2}$

Radiopurity requirements for the ββ source:
- ^{214}Bi < 10 μBq/kg
- ^{208}Tl < 2 μBq/kg
- Radon < 2 μBq/m^3

$T_{2\nu} = 9 \times 10^{19}$ y

Expected background from 2β2ν = 1.4 evt/500kg.y in 200 keV (200 keV energy window at $Q_{\beta\beta}$)

Enrichment by ultracentrifugation

^{150}Nd

$Q_{\beta\beta} = 3.367$ MeV

Phase space factor $G_{0\nu} = 8.00 \times 10^{-25}$ $y^{-1}eV^{-2}$

Radiopurity requirements for the ββ source: ^{208}Tl < 2 μBq/kg

$T_{2\nu} = 9 \times 10^{18}$ y

Expected background from 2β2ν = 2.2 evt/500kg.y in 200 keV (200 keV energy window at $Q_{\beta\beta}$)

Enrichment by laser

The best choice for phase space and background

International Letter of Interest for Double Beta Decay Experiments with Neodymium 150
July 2006

Signatories :

José Díaz (Spain), Juan-Jose Gomez (Spain), Serge Jullian (France), Dominique Lalanne (France), Karol Lang (Texas, USA), Julio Morales (Spain), Fabrice Piquemal (France), Ruben Saakyan (UK), Federico Sánchez (Spain), (SuperNEMO collaboration)
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Richard Hahn, Minfang Yeh (Brookhaven National Laboratory, USA, SNO+)
Mark Chen, Aksel Hallin, Aksel Hallin, Christine Kraus, Art McDonald, Peter Skensved, (Queen's University, Canada, SNO+)
Clarence Virture (Laurentian University, Canada, SNO+)
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SNO+

Mark Chen
Queen's University

Double Beta Decay: SNO++

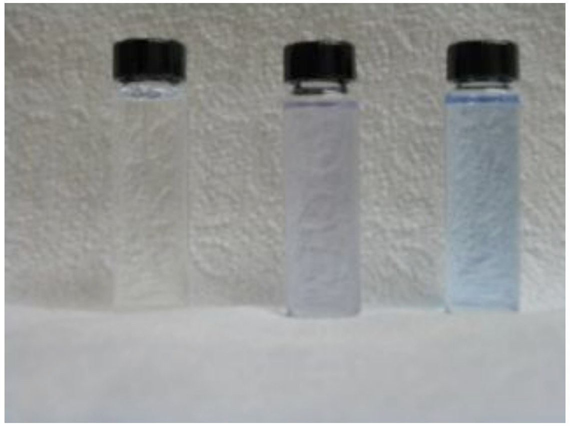
- SNO plus liquid scintillator plus double beta isotopes: SNO++
- add $\beta\beta$ isotopes to liquid scintillator
  - dissolved Xe gas (2%)
  - organometallic chemical loading (Nd, Se, Te)
  - dispersion of nanoparticles (Nd_2O_3, TeO_2)

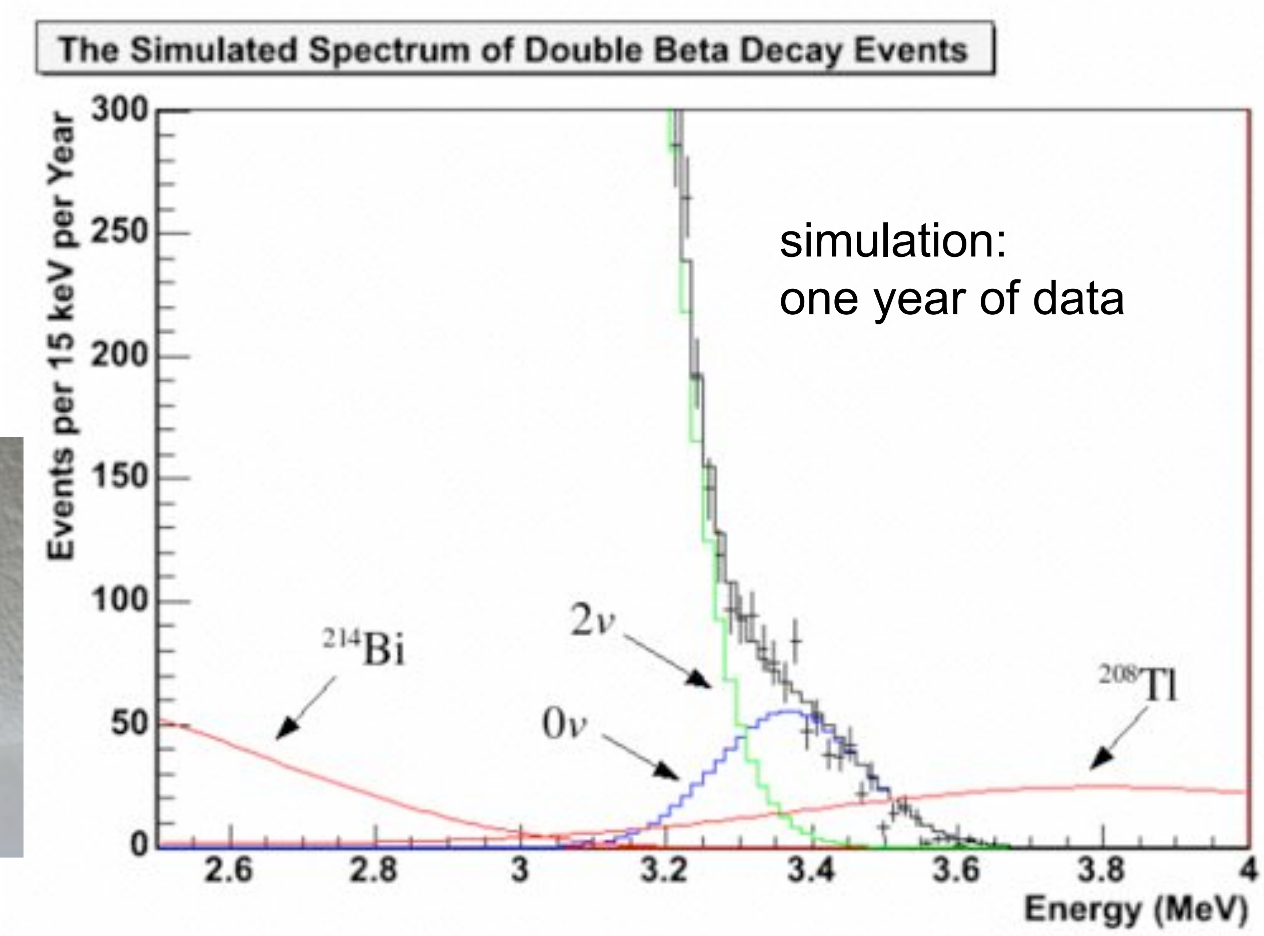
- enormous quantities (high statistics) and low backgrounds help compensate for the poor energy resolution of liquid scintillator
- possibly source in–source out capability

Test $<m_\nu> = 0.150$ eV

Klapdor-Kleingrothaus et al., Phys. Lett. B **586,** 198, (2004)

0ν: 1000 events per year with 1% natural Nd-loaded liquid scintillator in SNO++





maximum likelihood statistical test of the shape to extract 0ν and 2ν components…~240 units of $\Delta\chi^2$ significance after only 1 year!

SNO++ Double Beta Sensitivity

- insensitive to internal radon backgrounds
- insensitive to external backgrounds (2.6 MeV gamma)
- internal Th is the main concern
  - and 2ν background, of course
- homogeneous, well defined background model
- for m_ν = 50 meV, 0ν signal is ~60 events/yr in the upper-half of the peak, with S:B about 1:1
  - based upon KamLAND Th levels in scintillator and known 2ν double beta decay backgrounds
  - gives a 5σ exclusion of 50 meV after one year
- …shows the advantage of huge amounts of isotope, thus high statistics

SILVA : reconversion of MENPHIS to ^{150}Nd production

Phase 0 : 6 months, 2 persons, study of new parameters : report done

Phase 1 : Present situation : expert group CEA-IN2P3 for evaluation of the restarting

AFTER EVALUATION :

Phase 2 : restart of the facility, new collector to be designed
tests with new lasers, purchasing of 3 tons of natural Nd
POSSIBLE PRODUCTION OF A FEW KILOS (up to 10…)

Phase 3 : tests, tuning, running for final production

Thanks to Alain PETIT CEA Saclay