Search for $\beta\beta0\nu$ decay with NEMO 3 and SuperNEMO experiments

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on behalf of the NEMO collaboration

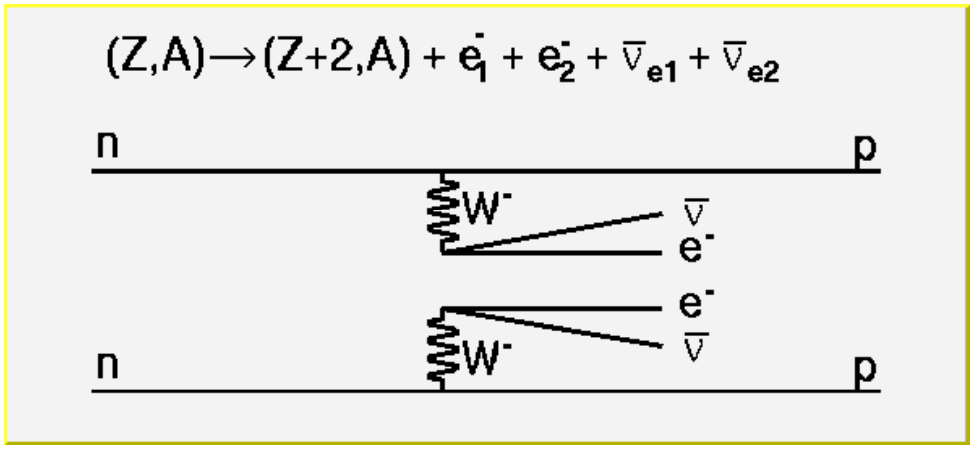
SUSY 2007

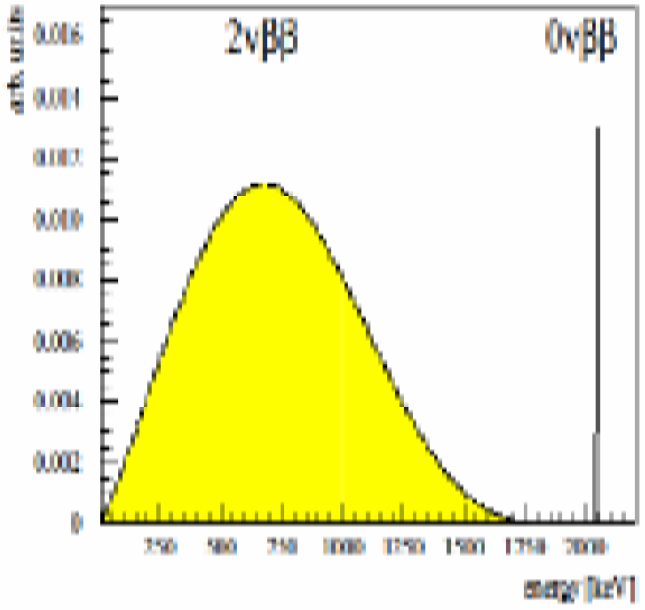
Karlsruhe, 28 July 2007

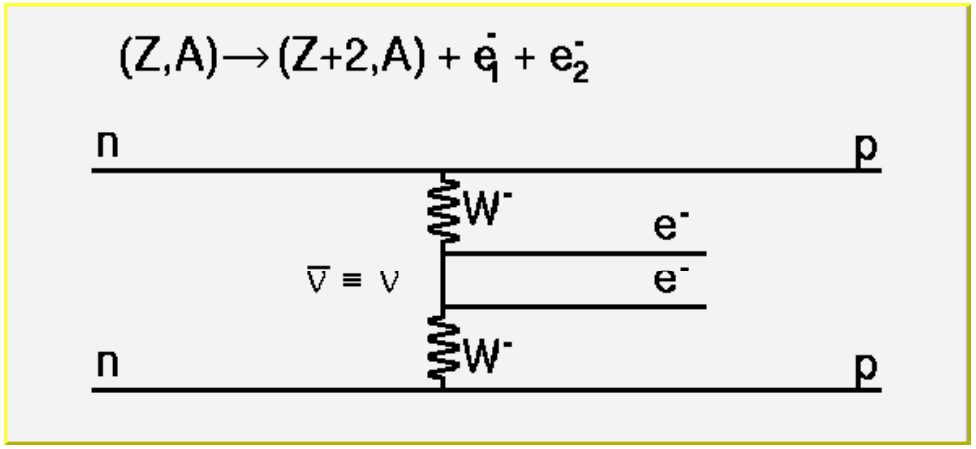
Outline

- ββ decay and SUSY
- NEMO-3 experiment
  - Overview of the NEMO-3
  - Highlights of the main NEMO-3 results
- SuperNEMO project
  - R&D program
  - Current status

ββ0ν decay, ν mass mechanism







$$\frac{1}{T^{0\nu}_{1/2}} = G^{0\nu}(Q,Z)|M^{0\nu}|^2\langle m_\nu\rangle^2$$

only possible for
Majorana neutrinos with mass > 0

Beyond the SM:
Lepton Number Violation !

ββ decay and SUSY: threelinear terms

$$L = \lambda_{ijk} LLE + \lambda'_{ijk} LQD + \lambda''_{ijk} UDD$$

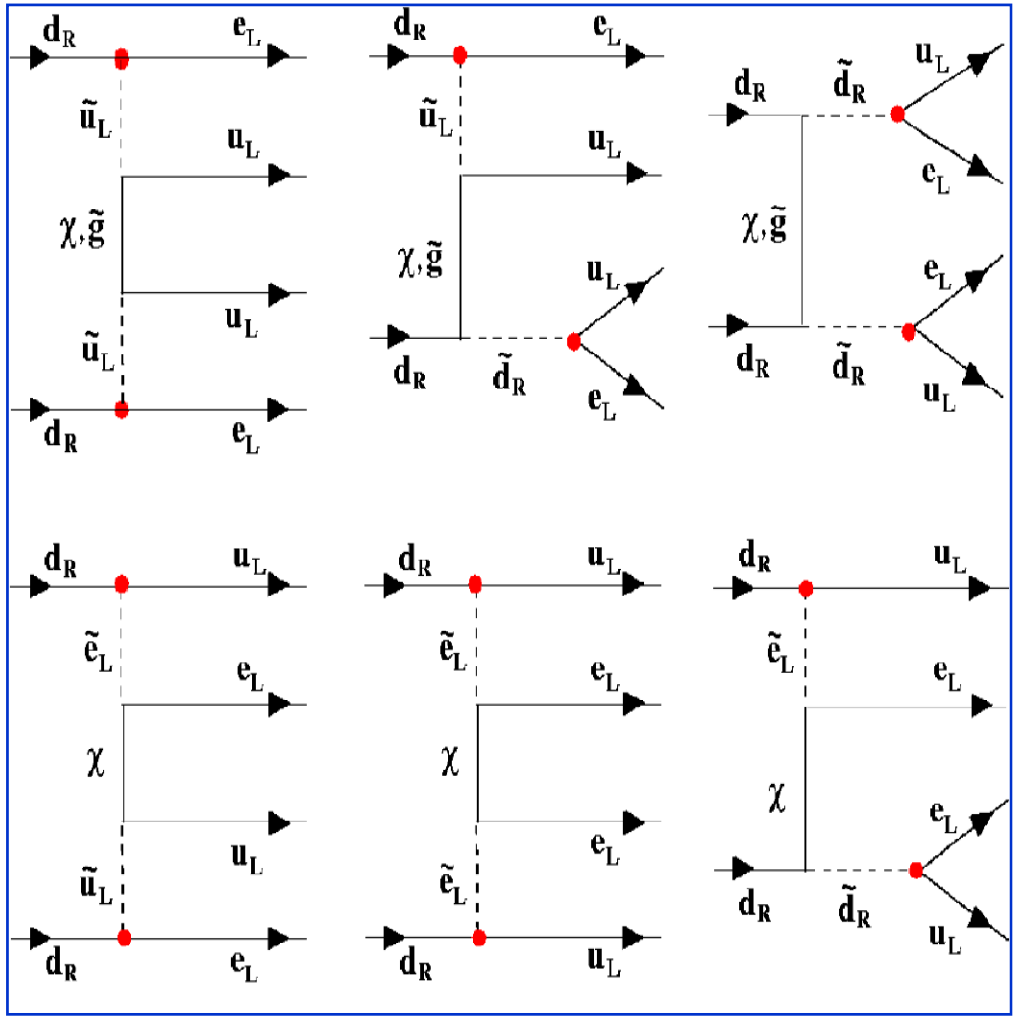
lepton number violation

ββ decay amplitude related to $(\lambda'_{111})^2$

$d_R + d_R \rightarrow u_L + u_L + e_L + e_L$

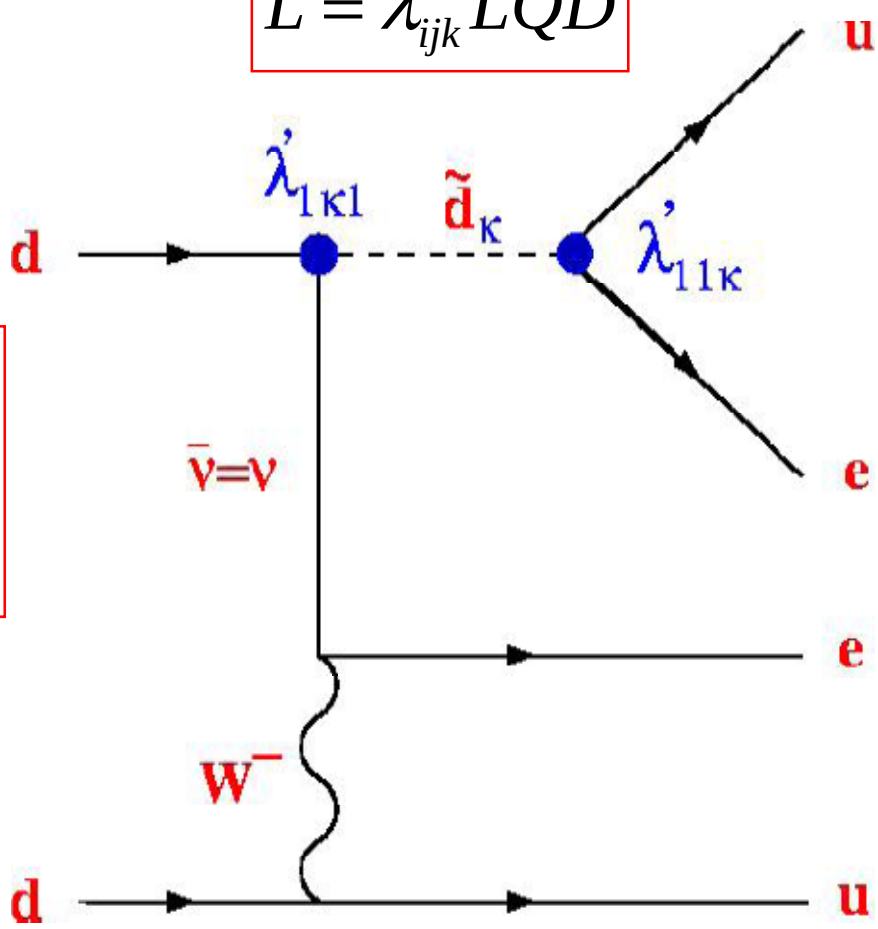
exchange with:

- squarks
- sleptons
- neutralinos
- gluinos



ββ decay and SUSY: squark mixing

$$L = \lambda'_{ijk} LQD$$



contribution from λ'_{1jk} possible via left- and right- squark mixing

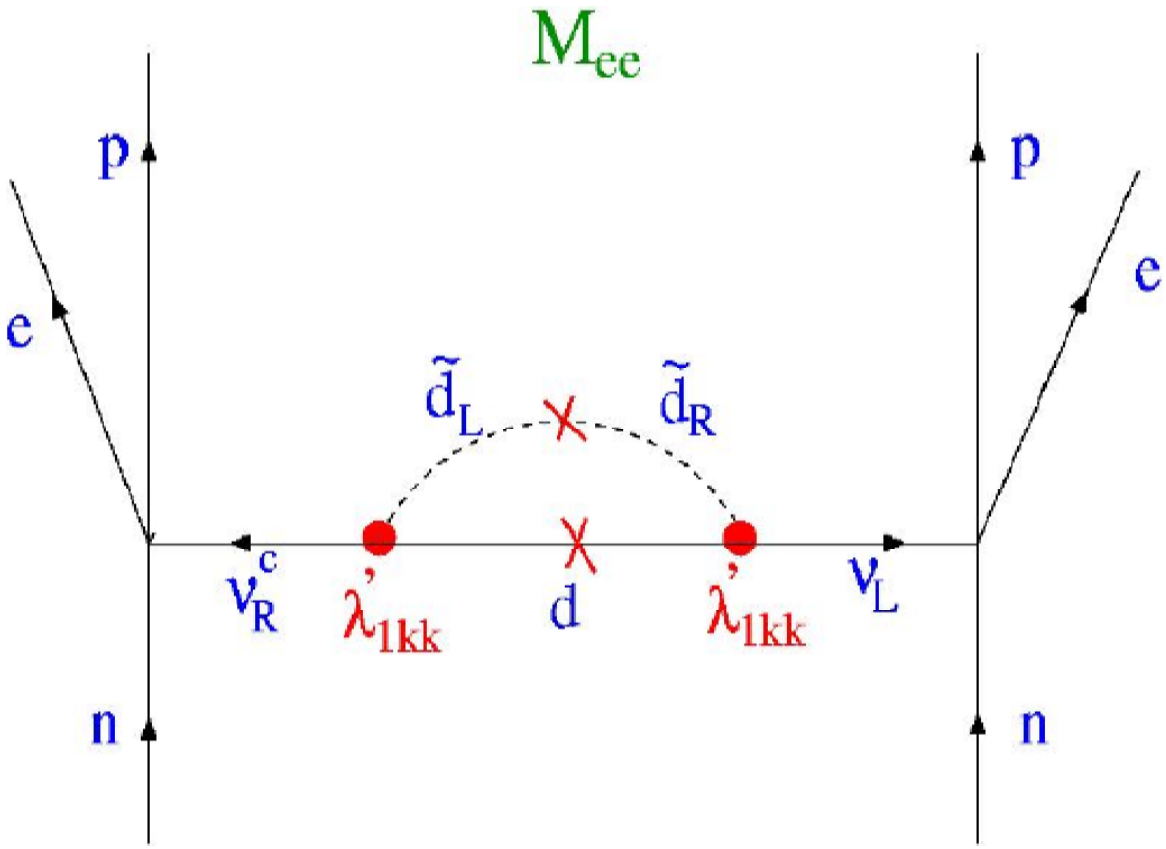
Hirsch,Klapdor-Kleingrothaus, Kovalenko, PLB 372 (1996) 181

Paes, Hirsch,Klapdor-Kleingrothaus, PLB 459(1999) 450

ββ decay and SUSY: radiative neutrino mass

$$L = \lambda'_{ijk} LQD$$

neutrino can acquire mass due to SUSY radiactive corrections, λ'_{1kk}



Gozdz, Kaminski, Šimkovic, PRD 70 (2004) 095005

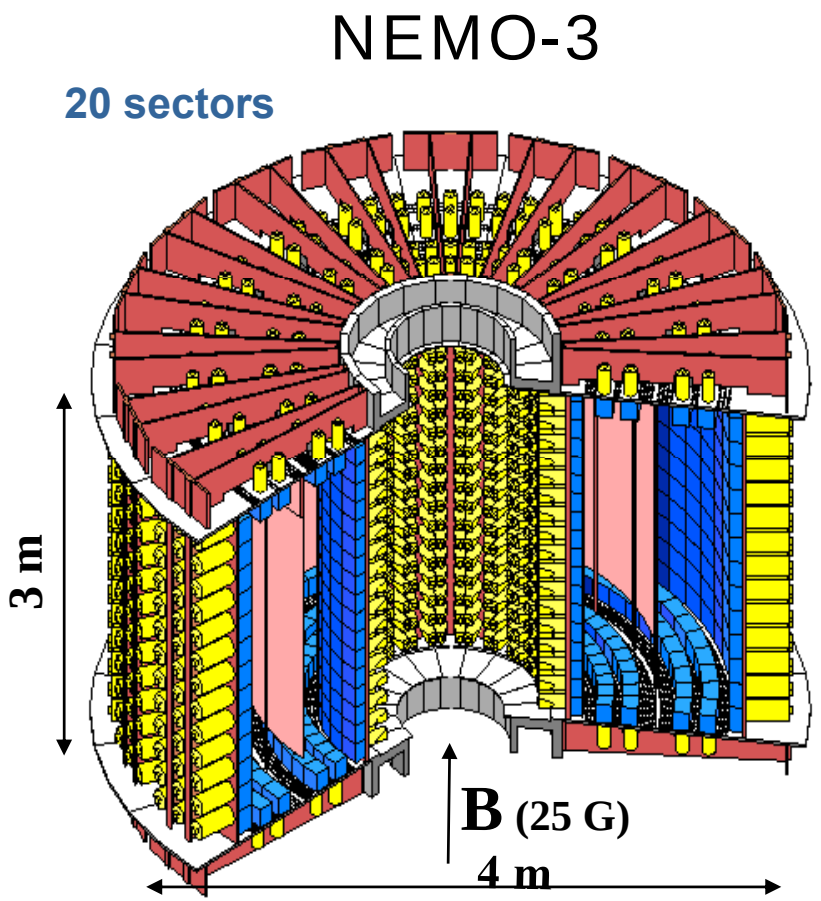
NEMO 3: Neutrino Ettore Majorana Observatory

- Czech Republic
- Finland
- France
- Japan
- Russia
- Spain
- UK
- Ukraine
- USA

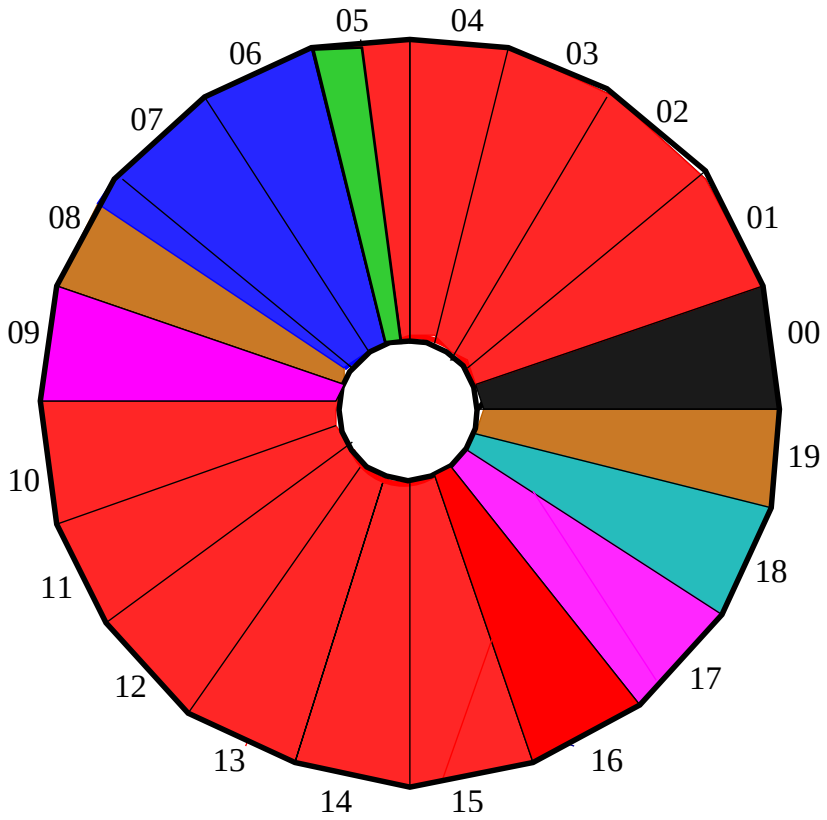
LS Modane, FR
Tunnel Frejus

key techniques: tracking, calorimetry, timing

- Goal: reconstruct 2 electrons of the final state
  - E1 + E2 = Q_{bb}
- Particle physics - like approach:
  - Measure several observables of the final state
    - Trajectories of 2 electrons
    - Energies of 2 electrons
    - Time
    - Magnetic field curvature ("+" vs "-")
  - Reconstruct the final state topology and kinematics
- Several requirements for candidate events
  - Topology (vertex, track-scintillator correlation)
  - Time coincidence
  - 2-electron invariant mass
  - Identify e^-, e^+, γ, α
  - Able to ***measure*** backgrounds



Multi source 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

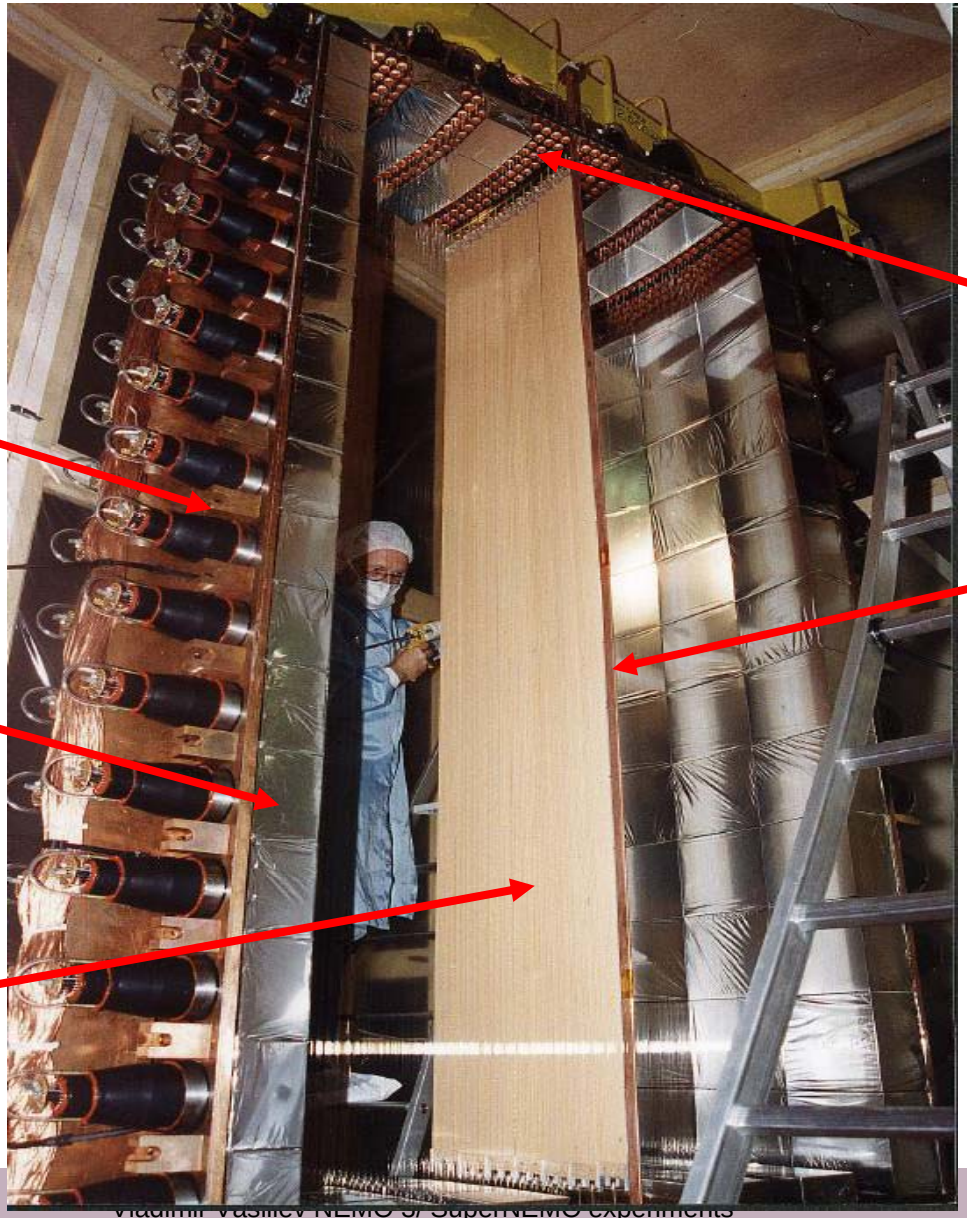
^{130}Te 454 g
$Q_{\beta\beta}$ = 2529 keV

^{nat}Te 893 g

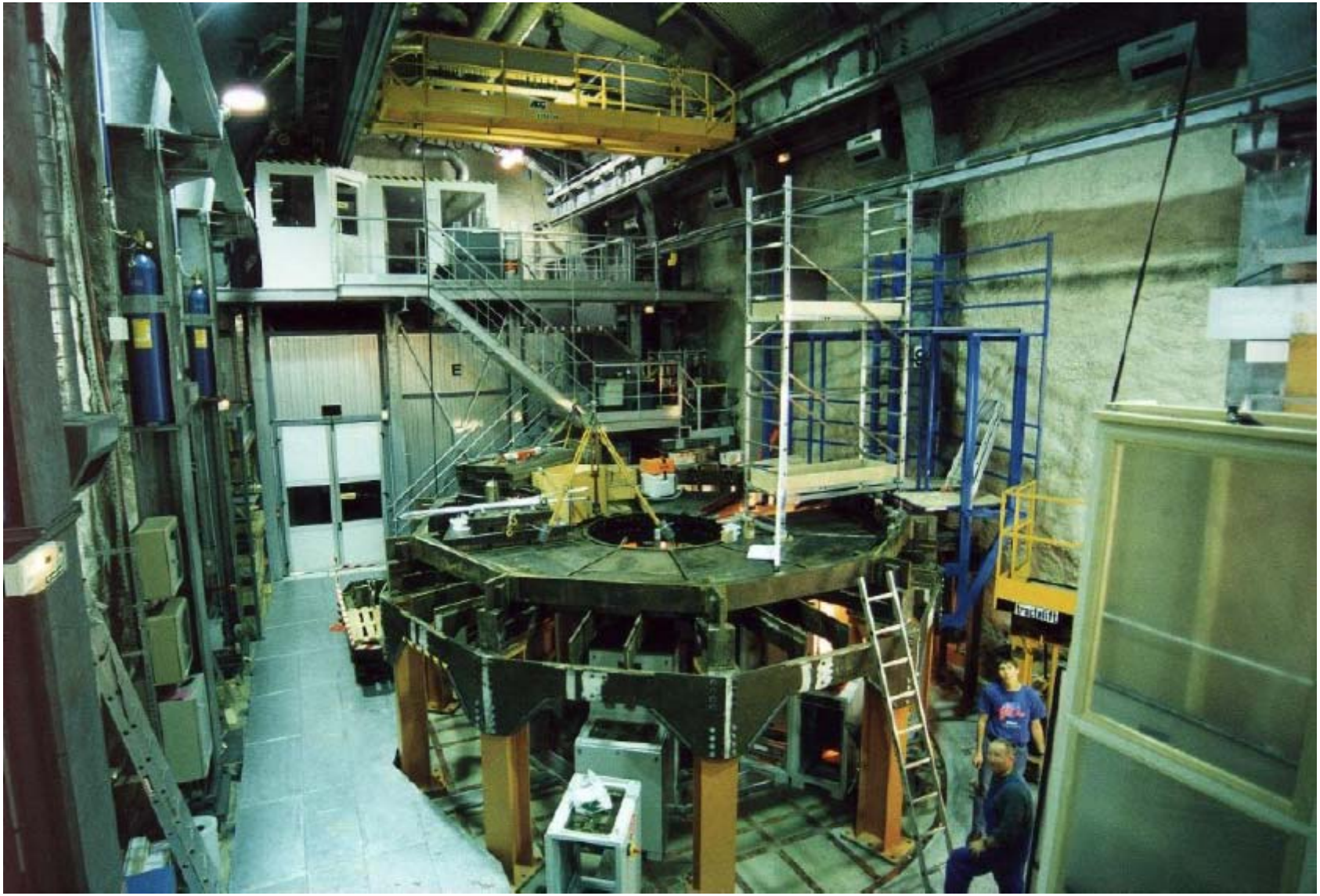
Cu 621 g

Detector bkg measurement

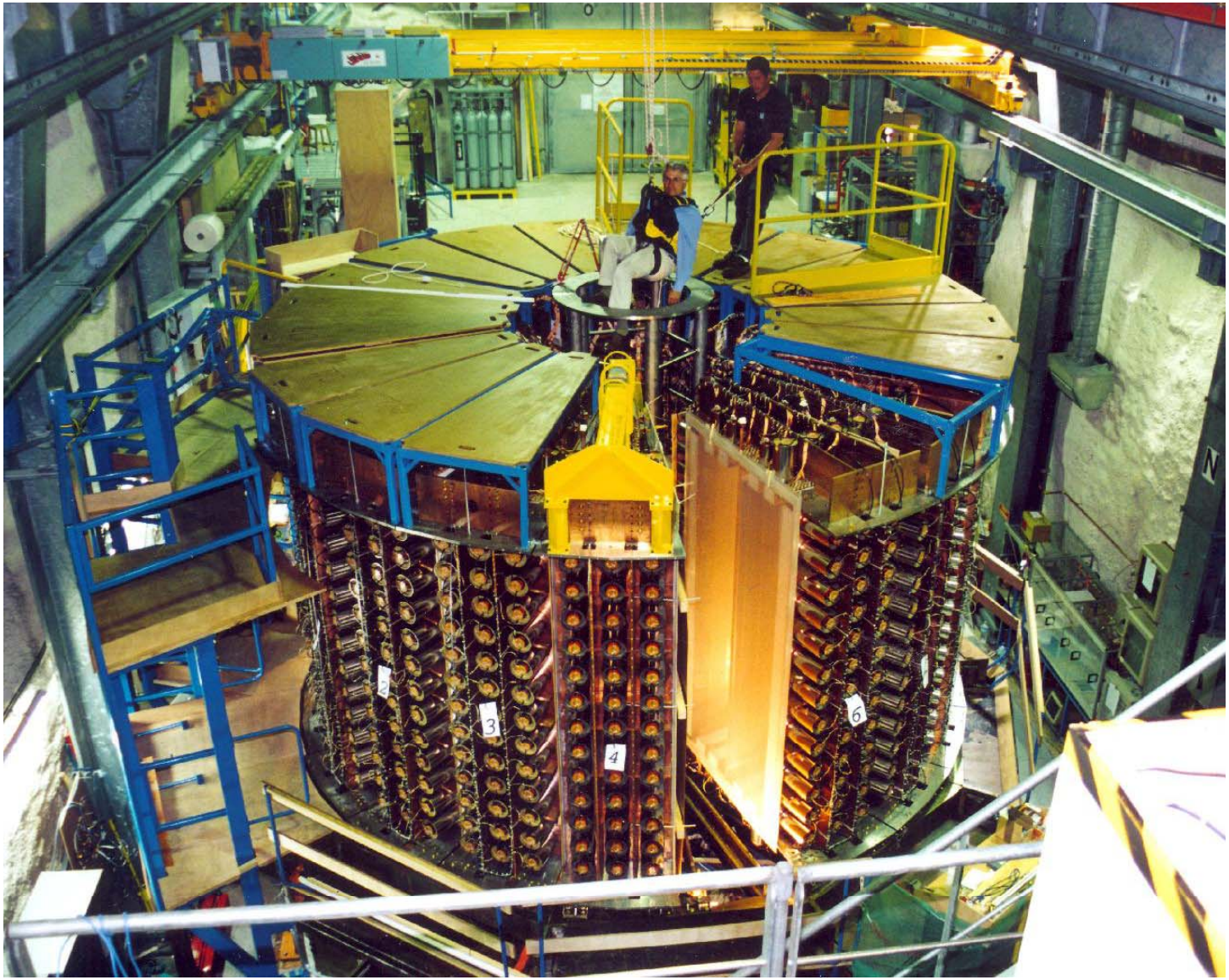
Sector interior view



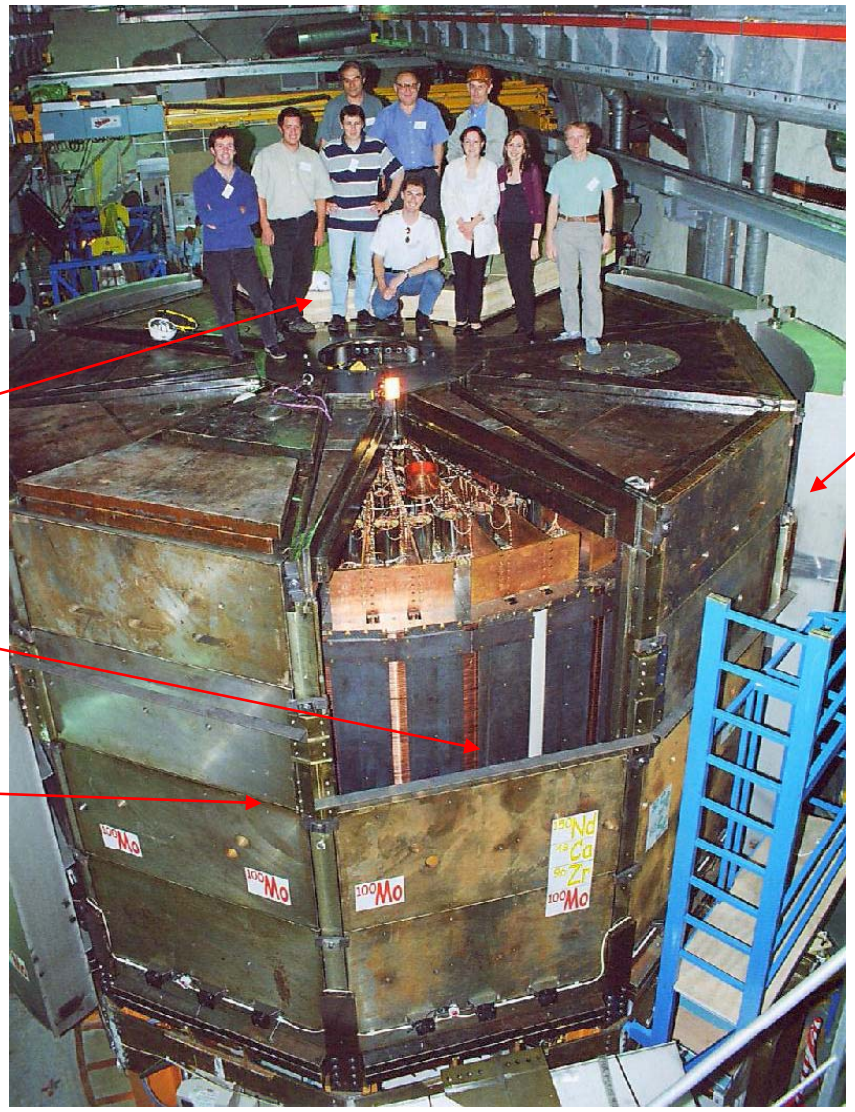
Installation in Modane



Installation in Modane

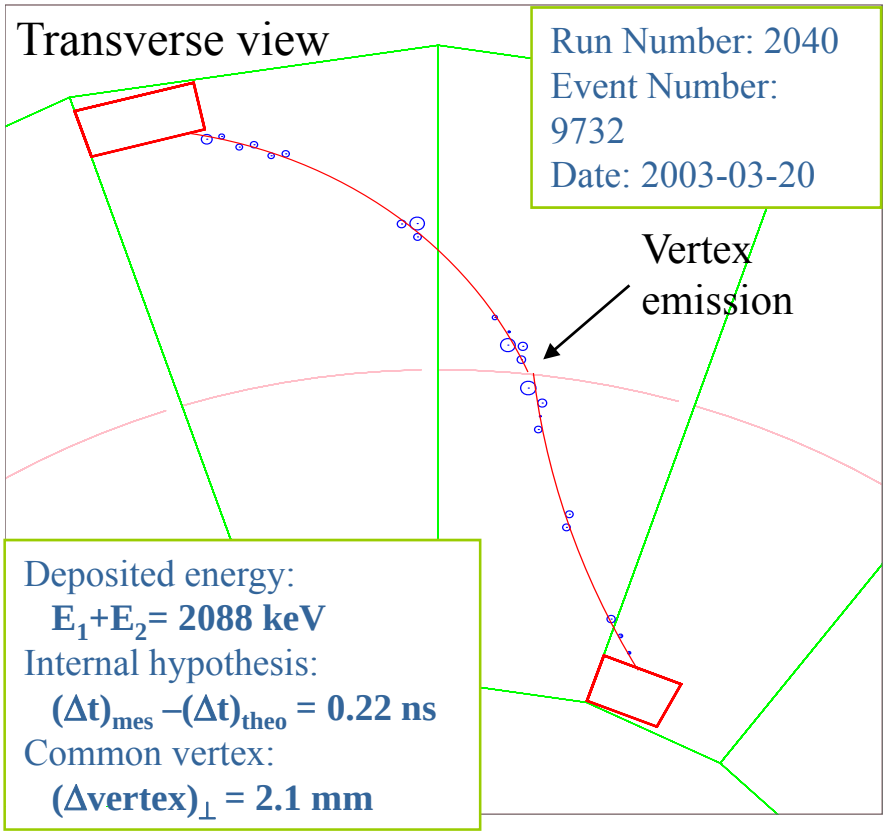


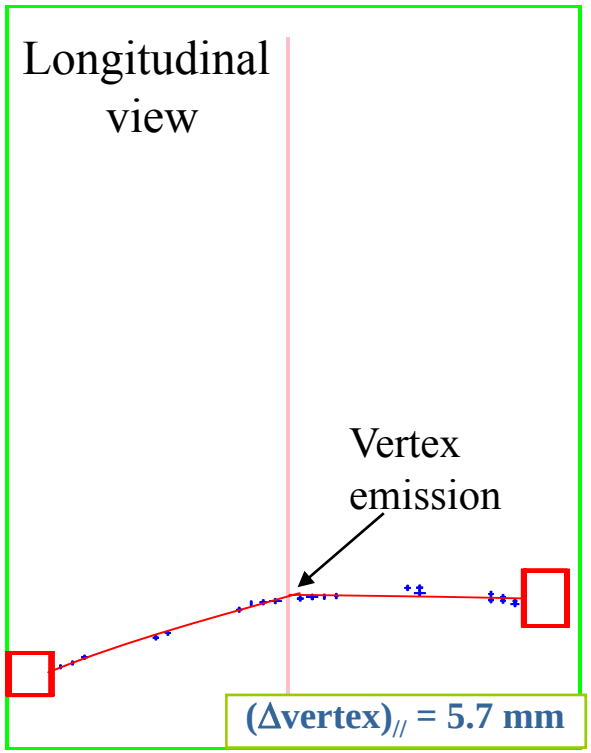
With shielding



Full detector now

Typical ββ2ν event observed from ^{100}Mo





^{100}Mo 6.914 kg

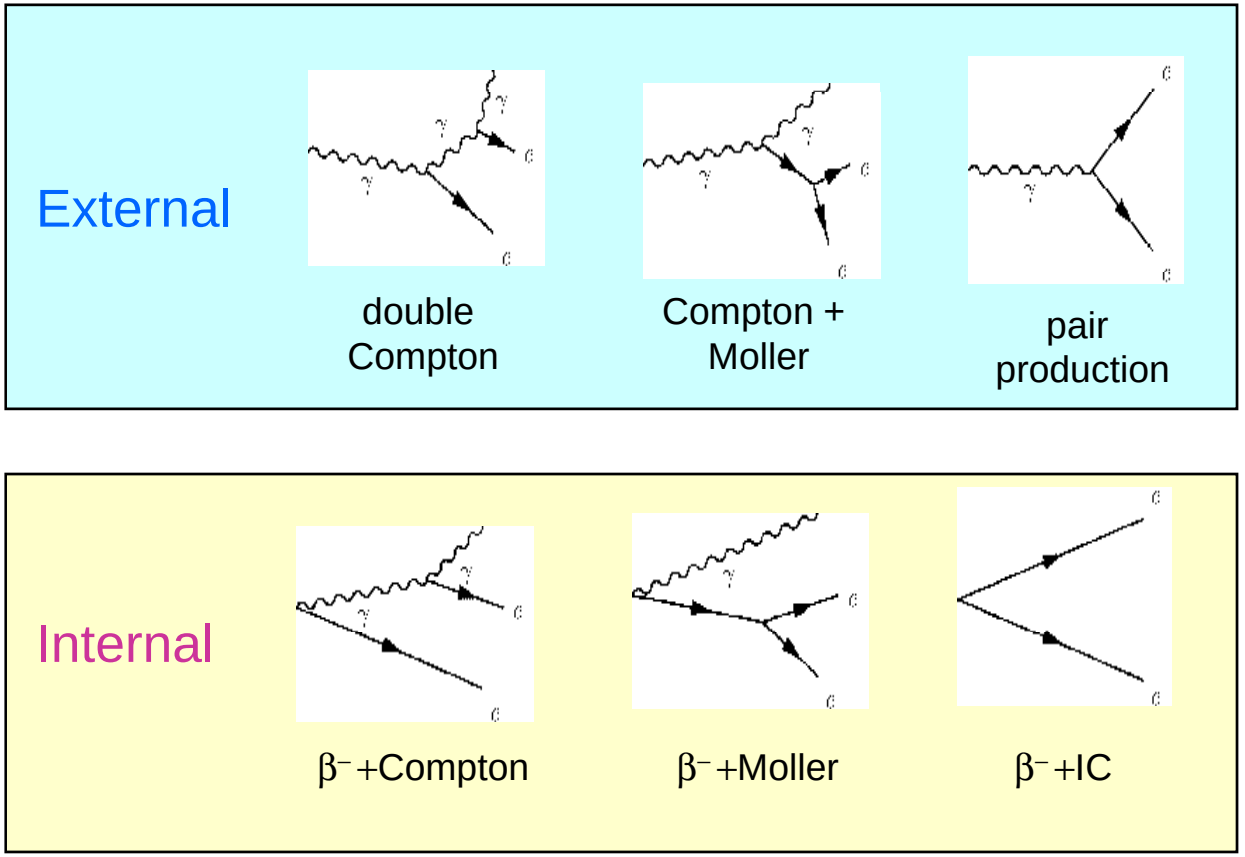
$Q_{\beta\beta}$ = 3034 keV

Criteria to select ββ events:

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

NEMO backgrounds

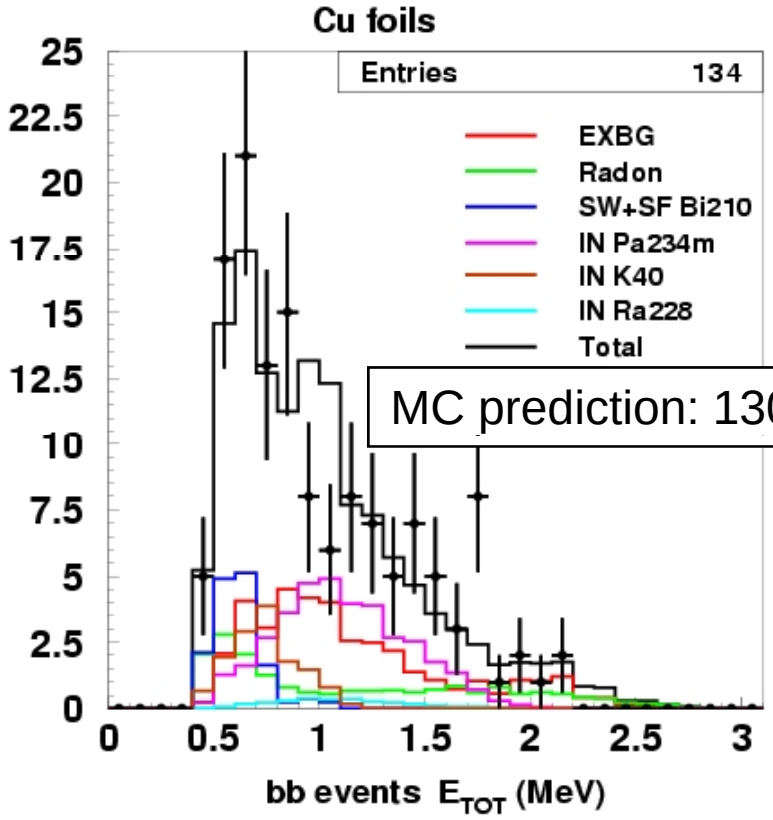
- Natural radioactivity:
  - U/Th chain
  - ^{40}K
  - Radon
- cosmic μ
- neutrons



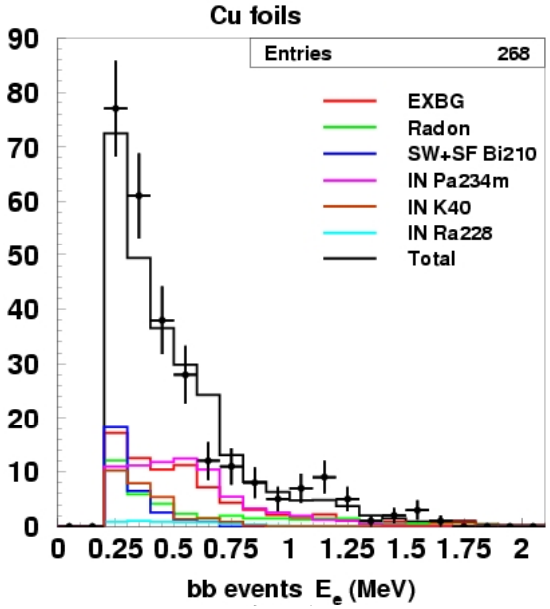
Backgrounds: ββ-like events from Cu

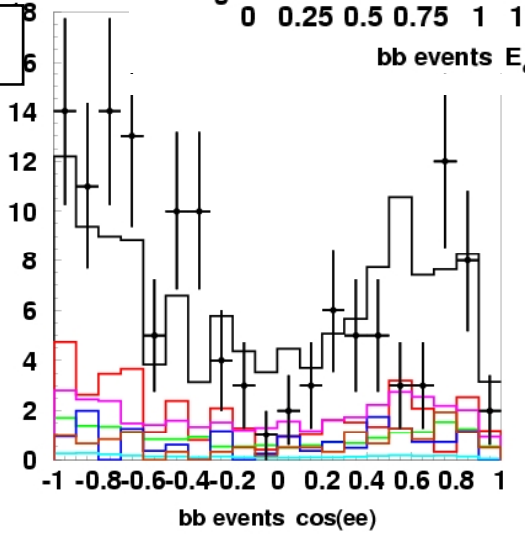
- background sources simulated using Monte Carlo
- radioactivity rates from material tests in HPGe and control channel meas's

Phase II data; 1.5 y x 0.6 kg ~ 1 kg y.



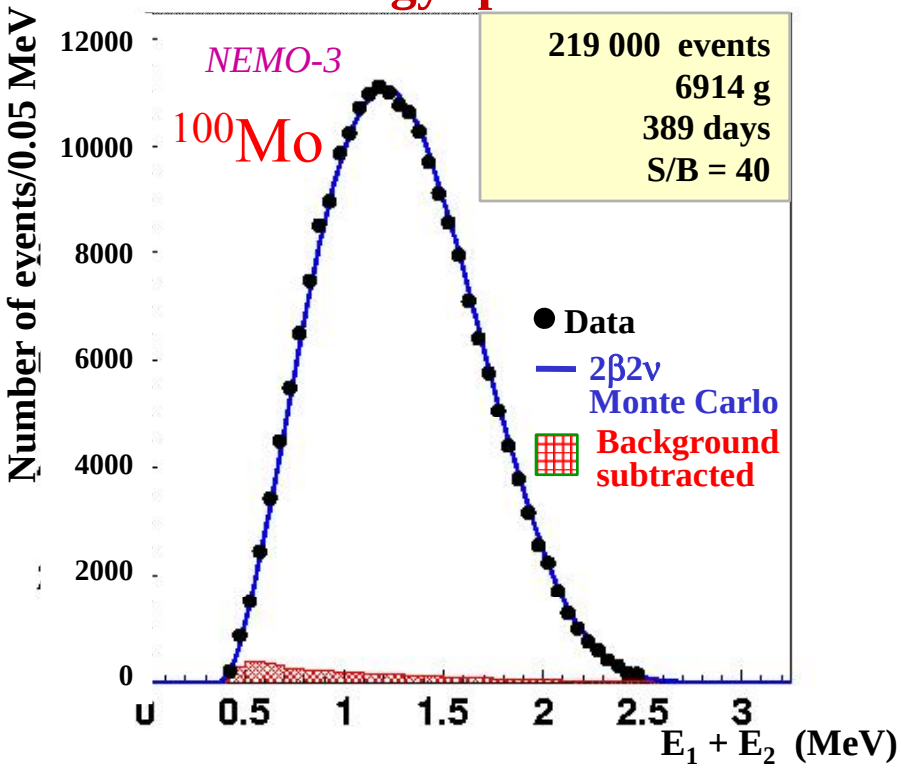
MC prediction: 130 ev.



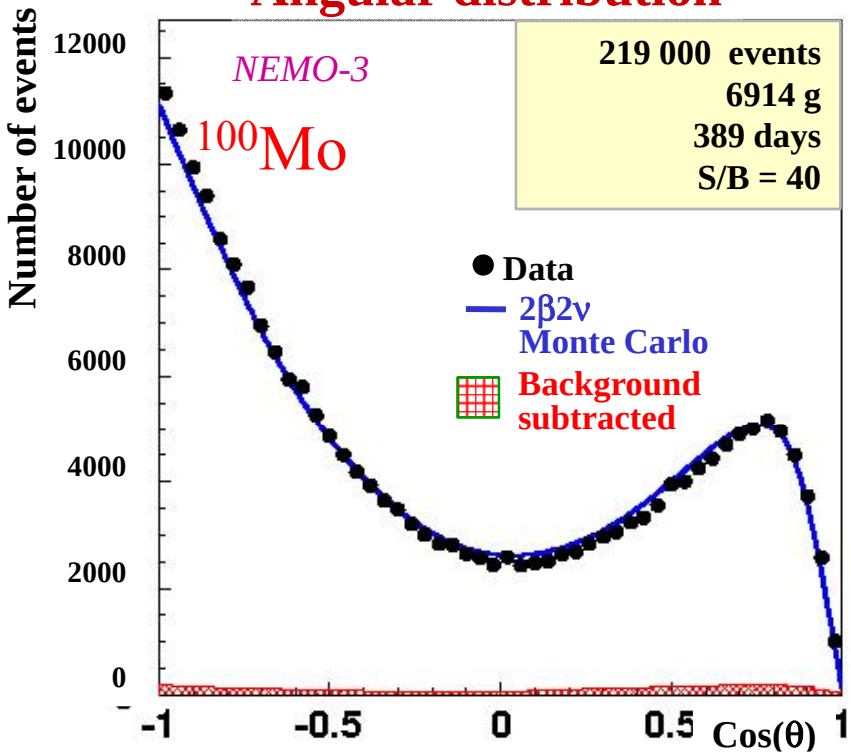


NEMO 3 highlights: 2β2ν ^{100}Mo

Sum energy spectrum



Angular distribution

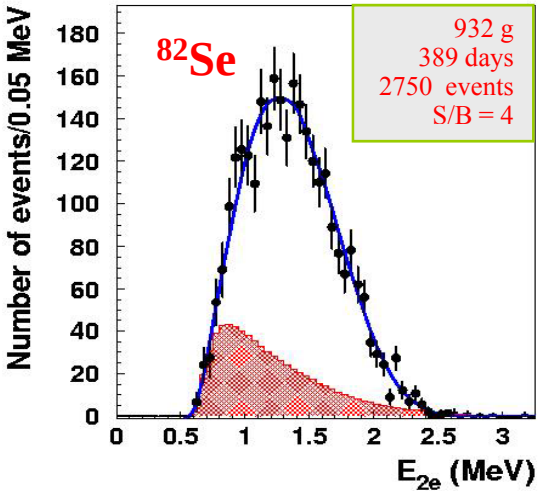


$T_{1/2}(\beta\beta2\nu) = 7.11 \pm 0.02\ (stat) \pm 0.54\ (syst) \times 10^{18}$ years

Phys. Rev. Lett. 95 182302 (2005)

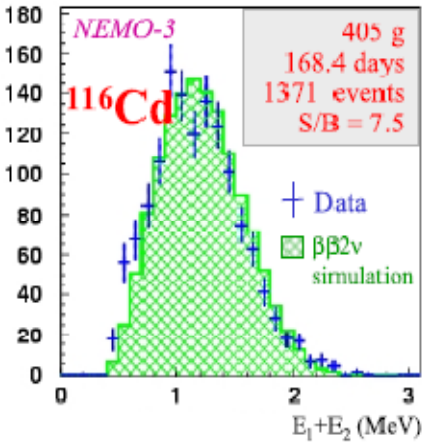
«ββ factory» → tool for precision test

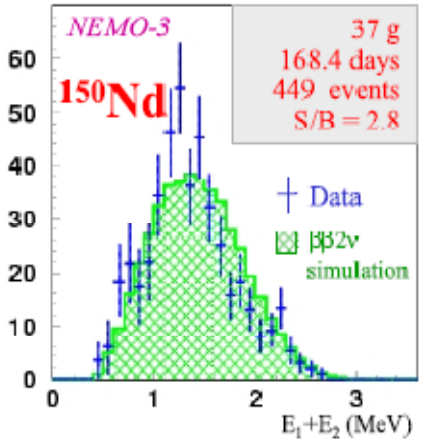
NEMO 3 highlights: 2β2ν preliminary

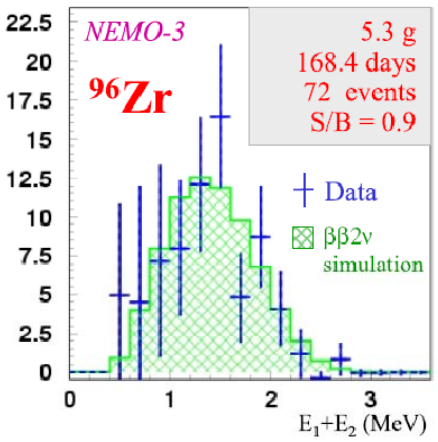


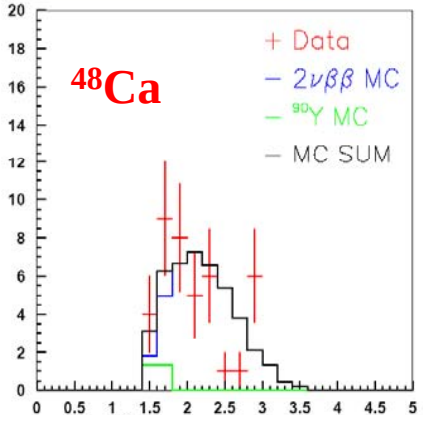
Preliminary results for ~360 d Phase I data. Additional statistics is being analysed and to be published soon.

^{82}Se	$T_{1/2} = 9.6 \pm 0.3\ (stat) \pm 1.0\ (syst) \times 10^{19}$ 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
^{48}Ca	$T_{1/2} = 3.9 \pm 0.7\ (stat) \pm 0.6\ (syst) \times 10^{19}$ y









Important ingridient for $M_{0\nu}$ calculation in QRPA

NEW in 2007: direct meas. of ^{130}Te 2β2ν

The ββ2ν half-life of ^{130}Te has been a long-standing mystery::

Geochemical:
- $(25 \pm 2) \times 10^{20}$ years (Kirsten 83)
- $(27 \pm 2) \times 10^{20}$ years (Bernatowicz 93)
- $(7.9 \pm 1) \times 10^{20}$ years (Takaoka 96)
- $\sim 8 \times 10^{20}$ years (Manuel 91)

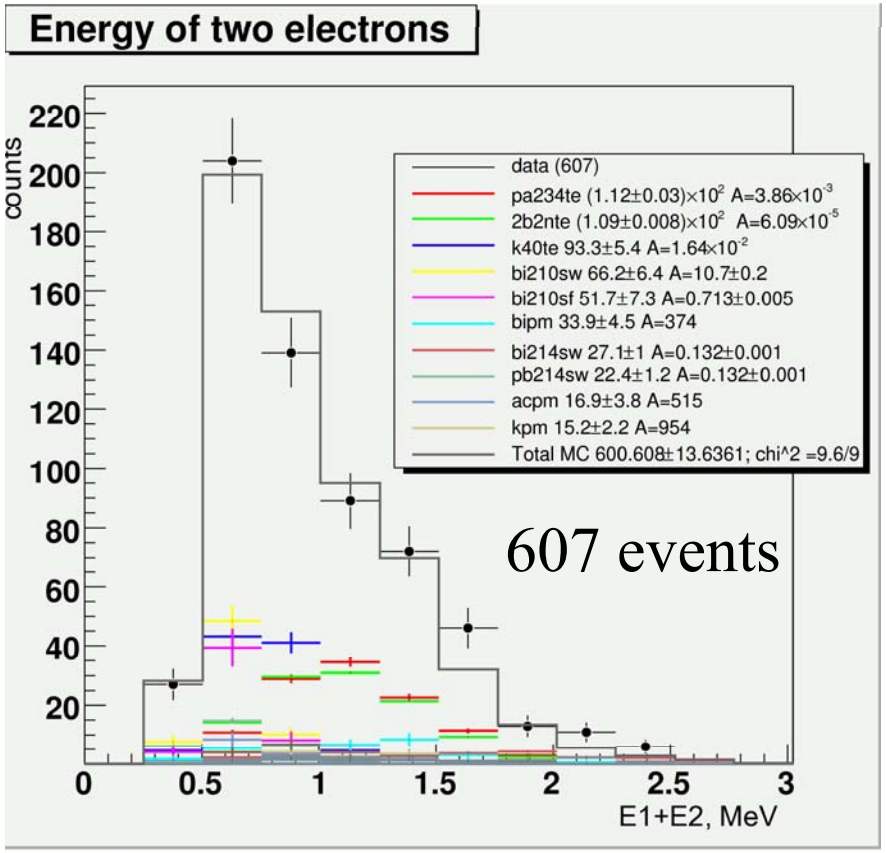
Difference between 'old' and 'young' ores due to time dependence of constants..?

Ratio of ^{82}Se/^{130}Te (less systematic):
-$(9 \pm 1) \times 10^{20}$ years (average by A. Barabash)

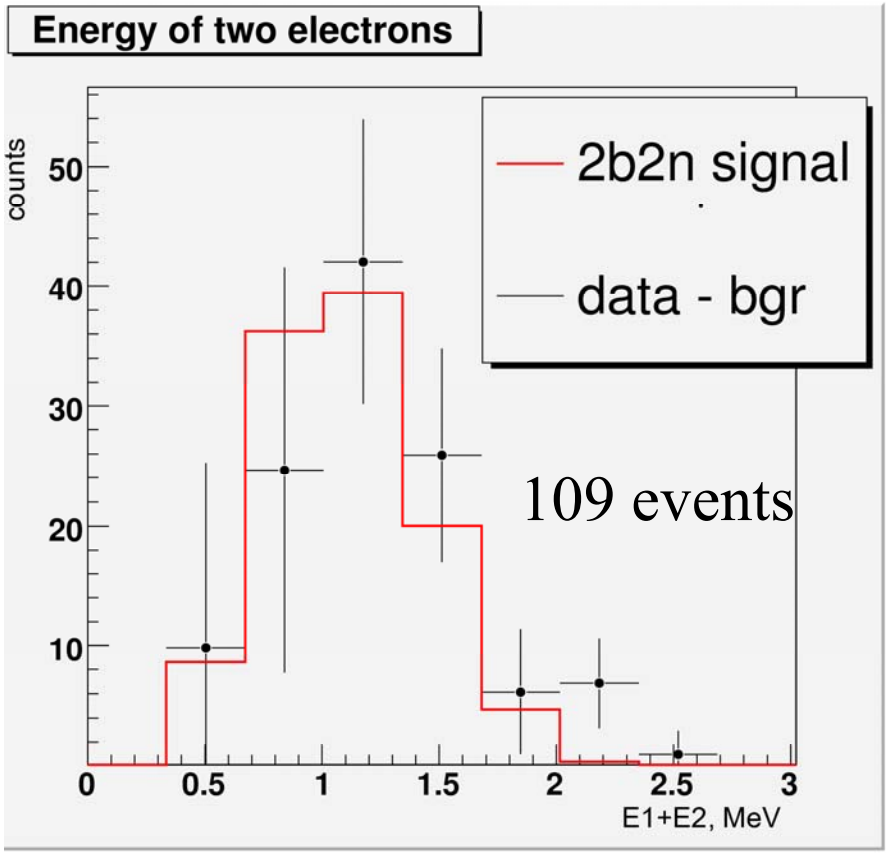
Direct measurement:
-$(6.1 \pm 1.4\ (\text{syst}) \pm {}^{2.9}_{3.4}(\text{stat})) \times 10^{20}$ years (Arnaboldi 2003)

NEW in 2007: direct meas. of ^{130}Te 2β2ν

$$T_{1/2}^{2\nu\beta\beta} = (7.6 \pm 1.5(stat) \pm 0.8(syst)) \cdot 10^{20}\ years$$



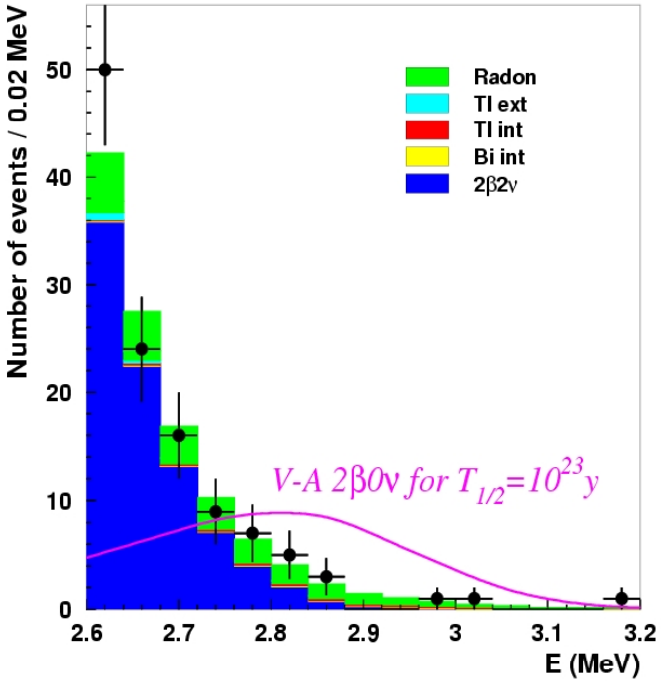
534 days, 454 g of ^{130}Te



background subtracted

NEMO 3 highlights: 2β0ν ^{100}Mo & ^{82}Se

^{100}Mo, Phase I + II, 693 days



$T_{1/2}^{\beta\beta0\nu} > 5.8 \times 10^{23}$ (90 % CL)

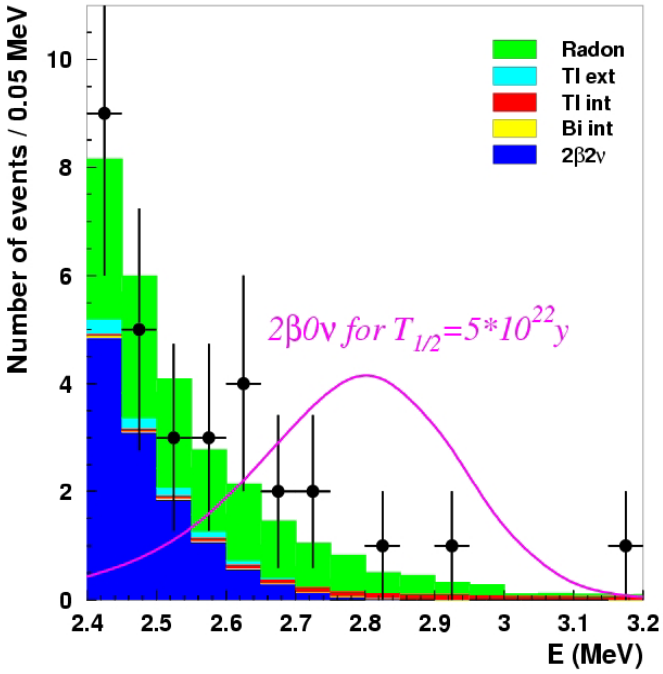
$\langle m_\nu \rangle^* < 0.8 - 1.3$ eV

$\lambda'_{111} < 1.5\ 10^{-4}$

expected in 2009: $T_{1/2}^{\beta\beta0\nu} > 2 \times 10^{24}$ (90 % CL)

$\langle m_\nu \rangle^* < 0.4 - 0.7$ eV

^{82}Se ,Phase I + II, 693 days



$T_{1/2}^{\beta\beta0\nu} > 2.1 \times 10^{23}$ (90 % CL)

$\langle m_\nu \rangle^* < 1.4\text{-}2.2$ eV

$\lambda'_{111} < 2.5\ 10^{-4}$

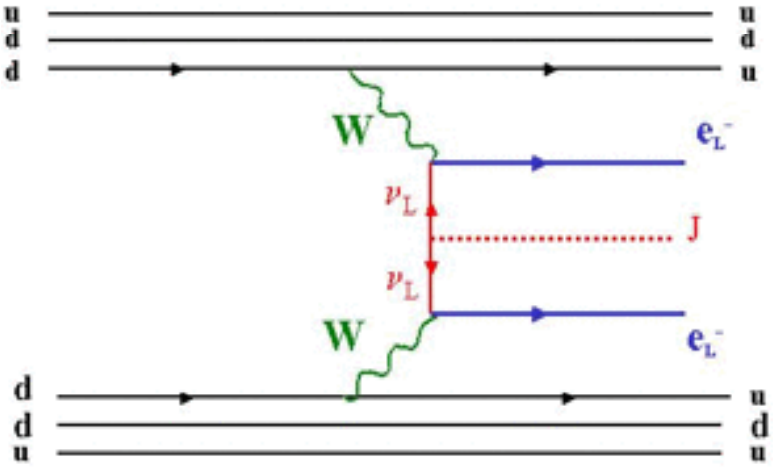
$T_{1/2}^{\beta\beta0\nu} > 8 \times 10^{23}$ (90 % CL)

$\langle m_\nu \rangle^* < 0.7\text{-}1.1$ eV

- Collaboration decided to perform blind analysis with mock data
- Plan to open the box and update the results ~ summer 2008 and again ~ early 2010.

* *Recent QRPA NME calculation as in MEDEX'07*

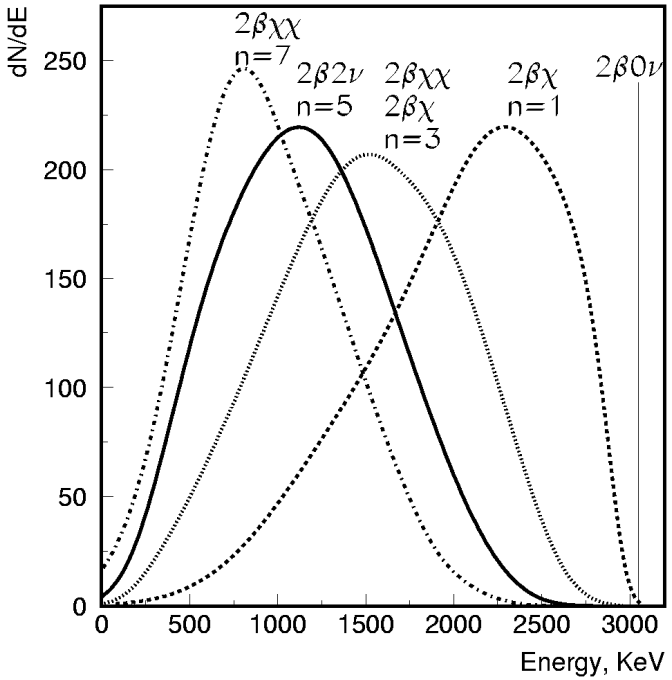
'Majoron' search



Lepton number violation due to local symmetry breaking

Axions χ ('Majorons') with coupling to neutrinos

$$(A, Z) \rightarrow (A, Z+2) + 2e^- + \chi^0(\chi^0)$$



best limits

	n=1 **	n=2 **	n=3 **	n=7 **
Mo	**$>2.7\cdot10^{22}$** $g<(0.4\text{-}1.8)\cdot10^{-4}$	**$>1.7\cdot10^{22}$**	**$>1.0\cdot10^{22}$**	**$>7\cdot10^{19}$**
Se	**$>1.5\cdot10^{22}$** $g<(0.7\text{-}1.9)\cdot10^{-4}$	**$>6.0\cdot10^{21}$**	**$>3.1\cdot10^{21}$**	**$>5.0\cdot10^{20}$**

n: spectral index, limits on half-life in years

** PI data, ***R.Arnold et al. Nucl. Phys. A765 (2006) 483***

SuperNEMO project

From NEMO-3 to SuperNEMO

$$T_{1/2}(\beta\beta 0\nu) > \ln 2 \times \frac{\mathcal{N}_A}{A} \times \frac{M \times \varepsilon \times T_{obs}}{N_{90\%\ CL}}$$

NEMO-3		SuperNEMO
^{100}Mo	isotope	^{150}Nd or ^{82}Se
7 kg	isotope mass M	100-200 kg
8 %	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 < 2 μBq/kg if ^{82}Se: ^{214}Bi < 10 μBq/kg
8% @ 3MeV	energy resolution (FWHM)	4% @ 3 MeV
$T_{1/2}(\beta\beta 0\nu) > 2 \times 10^{24}$ y $\langle m_\nu \rangle < 0.4 - 0.7$ eV		$T_{1/2}(\beta\beta 0\nu) > 2 \times 10^{26}$ y $\langle m_\nu \rangle < 40 - 70$ meV

Very preliminary SuperNEMO design

Planar and modular design: ~ 100 kg of isotope (~20 modules × 5-7 kg)

1 module:

Source (~40 mg/cm^2) 4 (length) x 3(height) m^2

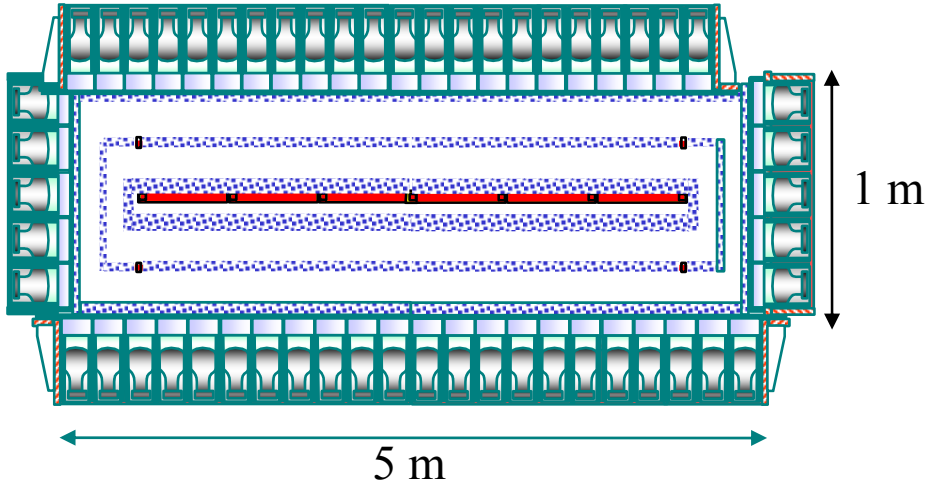
Tracking : drift chamber ~3000 cells in Geiger mode

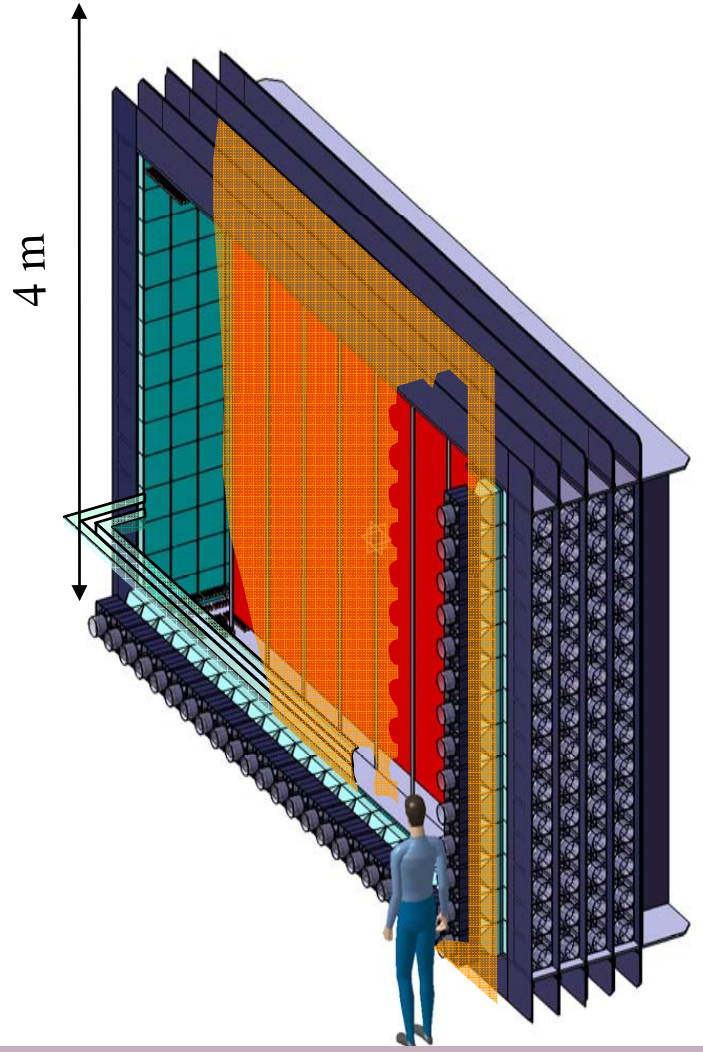
Calorimeter: scintillators + PM

~1 000 PM if scint. blocks

~ 100 PM if scint. bars

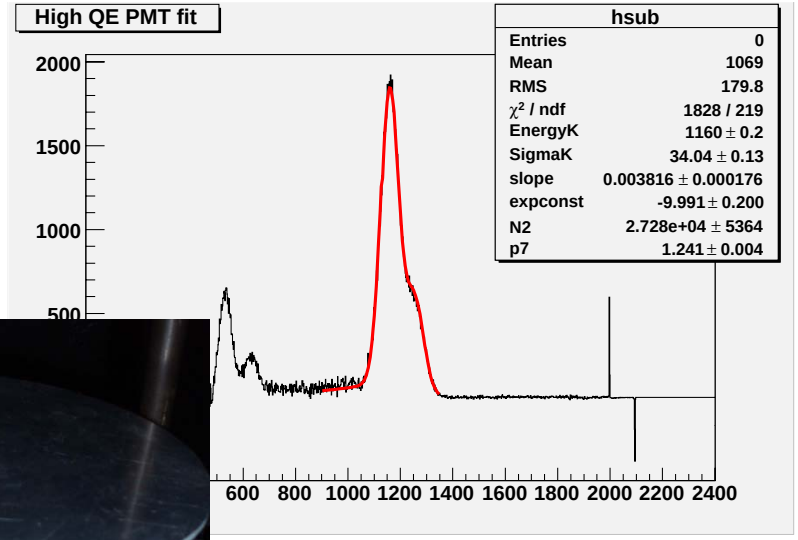
Top view

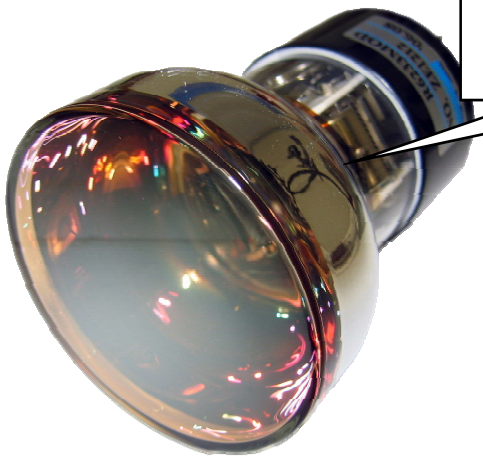




R&D: SuperNEMO calorimeter

- Goal: FWHM ≈ 7%/√E ⇒ 4% at 3 MeV (Currently 14-16%/√E in NEMO3)
- A combination of energy losses in the foil and calorimeter DE/E
- Studies
  - **Organic (plastic or liquid),**
  - **Shape, size, coating**
  - **PMTs (Photonis, Hamamatsu, ETL)**
  - **Light guides, optical contact**
  - **Chemistry**





High QE Hamamatsu tube

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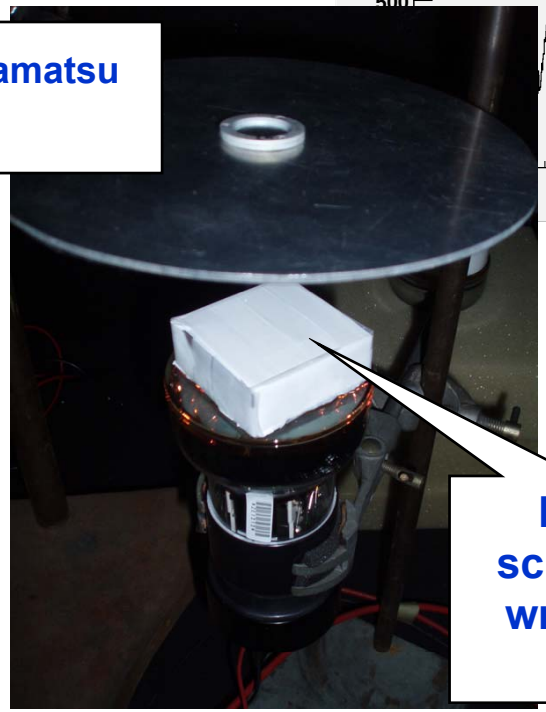

BC404 scintillator wraped in teflon

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ΔE/E = 6.5% at 1 MeV
⇓
3.8% at 3 MeV if 1/√E

R&D: isotope enrichment/ purification

- 4 kg of ^{82}Se funded by ILIAS have been delivered from Russia.
- purification at ILN (US) underway
- enrichment of Nd possible in France (MENPHIS, currently mothballed)

Choice of nucleus depends on:

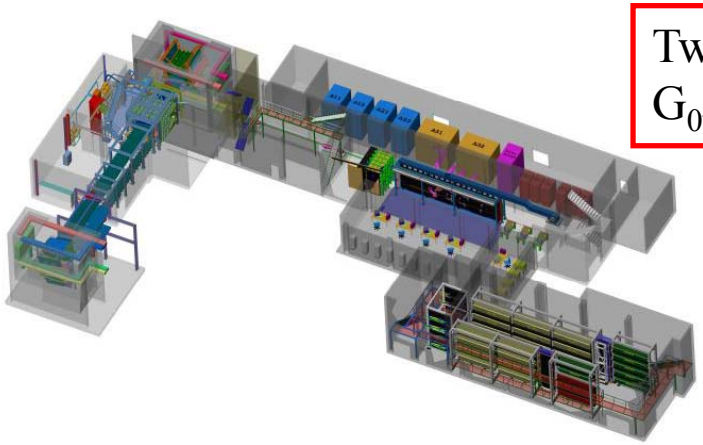
. enrichment possibilities

. high $Q_{\beta\beta}$ value

→ larger phase space

→ lower non-ββ background

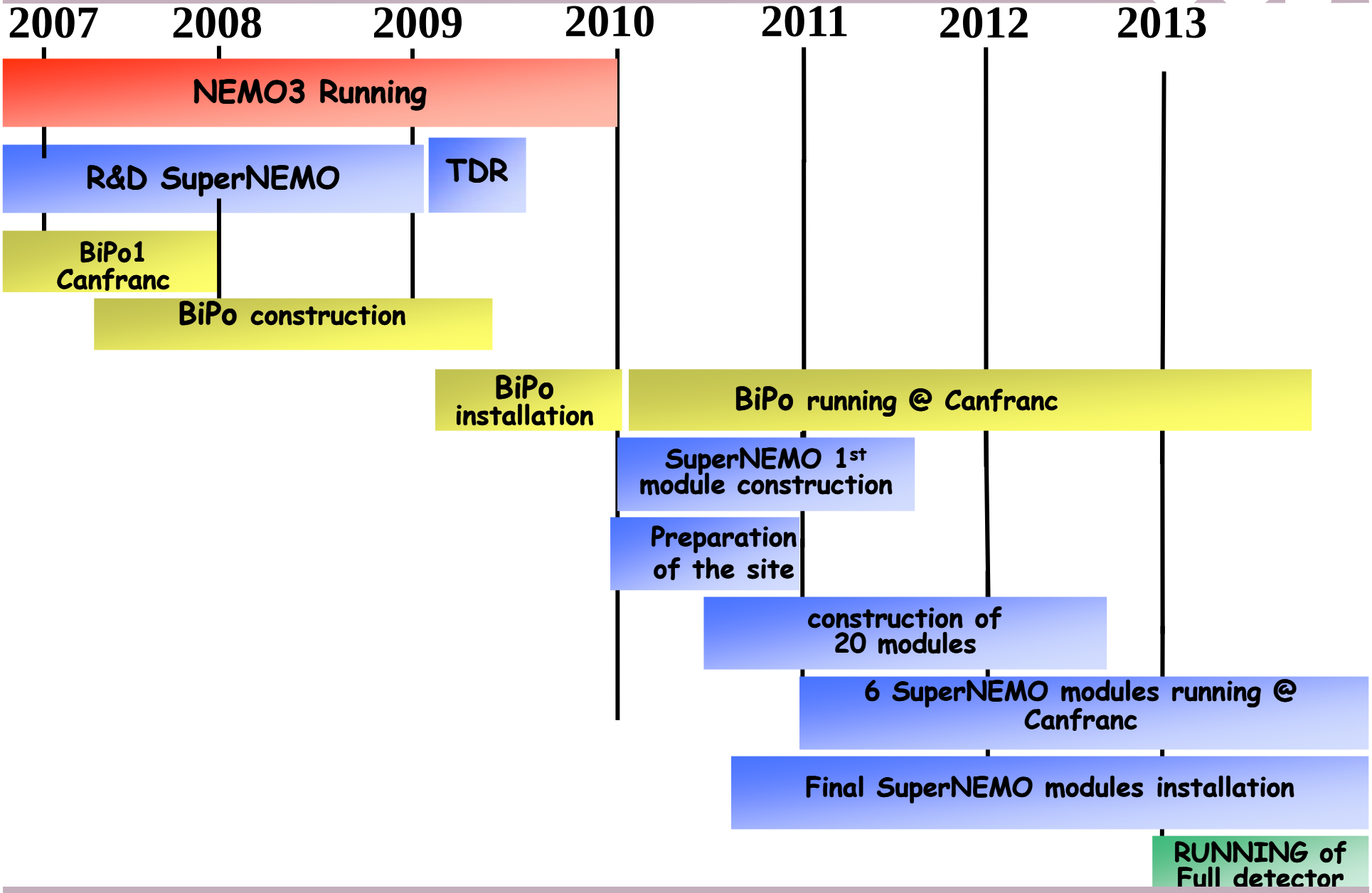
. small ββ2ν contribution



Two main options:
$G_{0\nu}(150Nd) / G_{0\nu}(82Se) = 8$

	$Q_{\beta\beta}$ (MeV)	Isotopic Abundance
$^{48}Ca \rightarrow ^{48}Ti$	4.271	0.187
$^{76}Ge \rightarrow ^{76}Se$	2.040	7.8
→ $^{82}Se \rightarrow ^{82}Kr$	2.995	9.2
$^{96}Zr \rightarrow ^{96}Mo$	3.350	2.8
$^{100}Mo \rightarrow ^{100}Ru$	3.034	9.6
$^{110}Pd \rightarrow ^{110}Cd$	2.013	11.8
$^{116}Cd \rightarrow ^{116}Sn$	2.802	7.5
$^{124}Sn \rightarrow ^{124}Te$	2.228	5.64
$^{130}Te \rightarrow ^{130}Xe$	2.533	34.5
$^{136}Xe \rightarrow ^{136}Ba$	2.479	8.9
→ $^{150}Nd \rightarrow ^{150}Sm$	3.367	5.6

SuperNEMO schedule summary



Conclusion

NEMO's Tracking+Calorimetry approach is unique:

- -high background rejection
- - choice of isotopes
- - reconstruction of kinematics

NEMO 3 is taking data:

- -$\beta\beta2\nu$ factory, important for understanding of backgrounds and NME
- -limits on $\beta\beta0\nu$ using different isotopes:
- -$T_{1/2}(0\nu) > 5.8 \times 10^{23}$ y @ 90% CL for ^{100}Mo $\rightarrow$ $\langle m_\nu \rangle$ < 0.8-1.3 eV (693 days); $\lambda'_{111} < 1.5 \times 10^{-4}$
- -limits on Majoron's coupling
- -$T_{1/2}(2\nu) = (7.6 \pm 1.5\ (stat) \pm 0.8(syst)) \times 10^{20}$ y for ^{130}Te

SuperNEMO R&D approved in France, the UK and Spain; TDR expected in 2008; full 20 modules in 2012-2013

- -choice of isotopes: ^{82}Se or ^{150}Nd

Backup slides