^{96}Zr analysis with the NEMO-3 detector

Young Scientists Forum
Rencontres de Moriond EW 2015

Guillaume EURIN
for the NEMO Collaboration

LAL Orsay, UCL London

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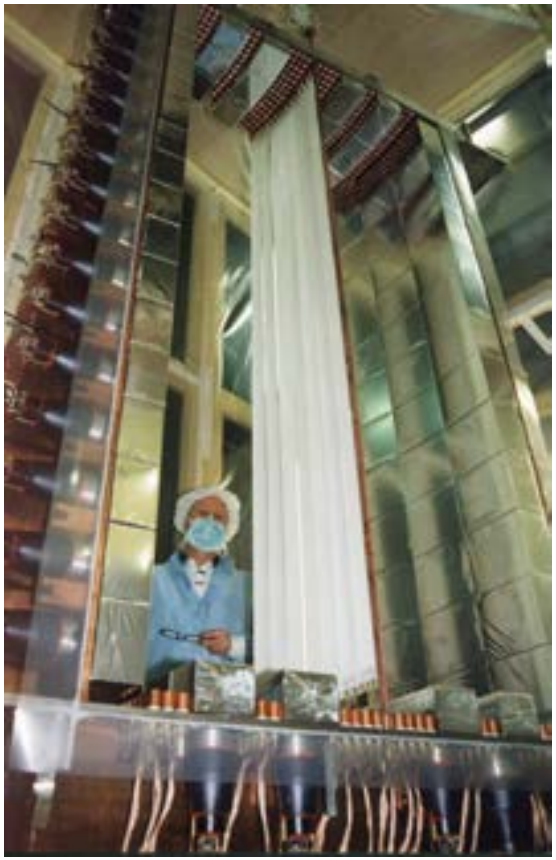
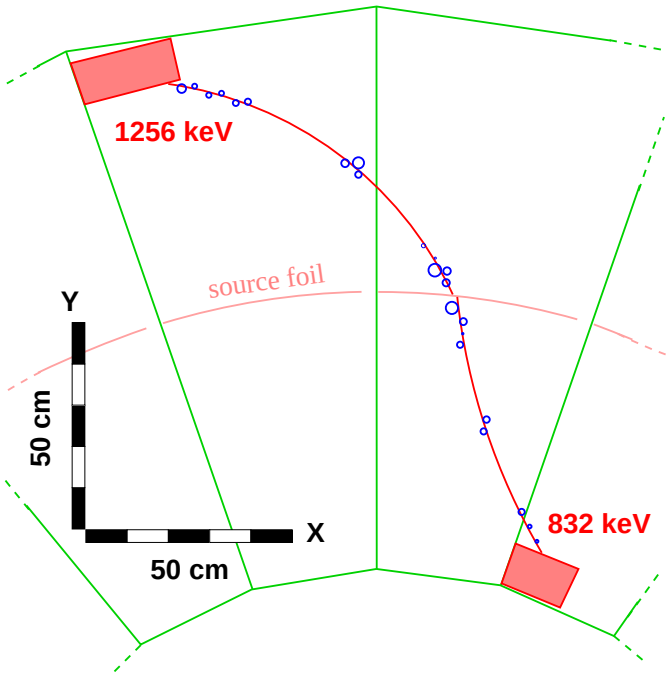
NEMO-3 : the Neutrino Ettore Majorana Observatory

- 2003 to 2011 in the Modane Underground Lab (4800 m.w.e.)
- Unique 2β experiment : tracking and calorimetry
  direct $2e^-$ reconstruction $\Rightarrow$ powerful background rejection
- Background mainly from natural radioactivity
- Measurement in individual analysis channels ($1e^-$, $1e^-n\gamma$, ...)

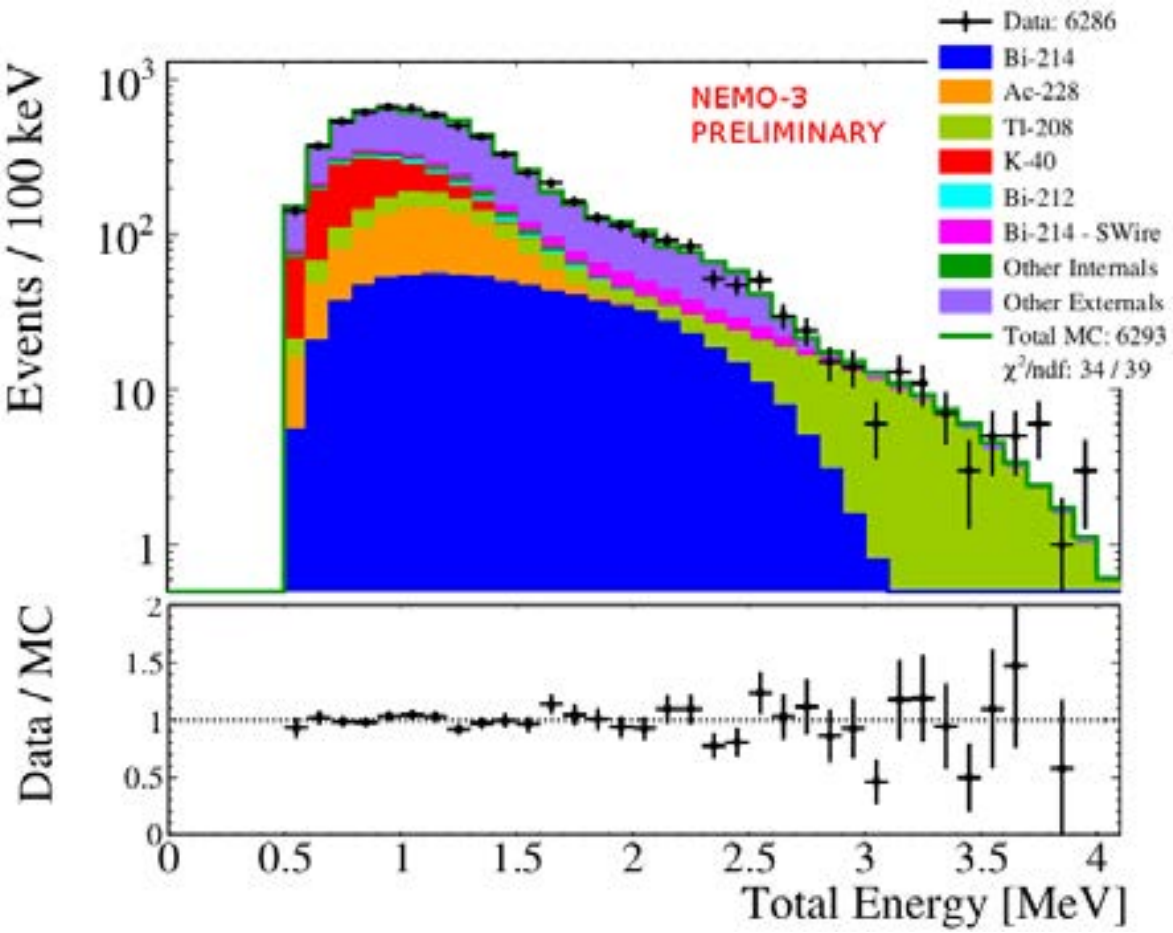




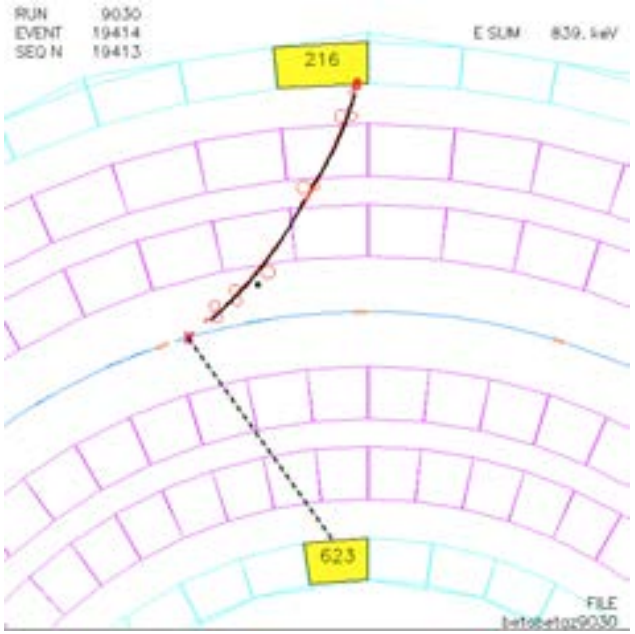
Kinematic variables : individual energies, time of flight, curvature, ...

Example of a background channel : 1 electron - 1 γ

- Background activities needed for signal measurement
- 1e1γ : activity measurements for β-γ emitters
- Fit of the total energy $E_{tot} = E_e + E_\gamma$



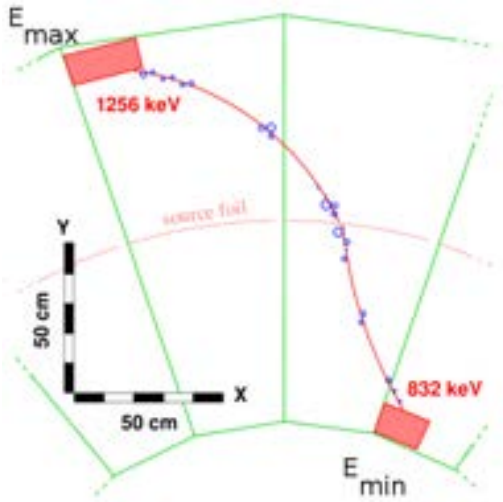
$E_e + E_\gamma$ [MeV]



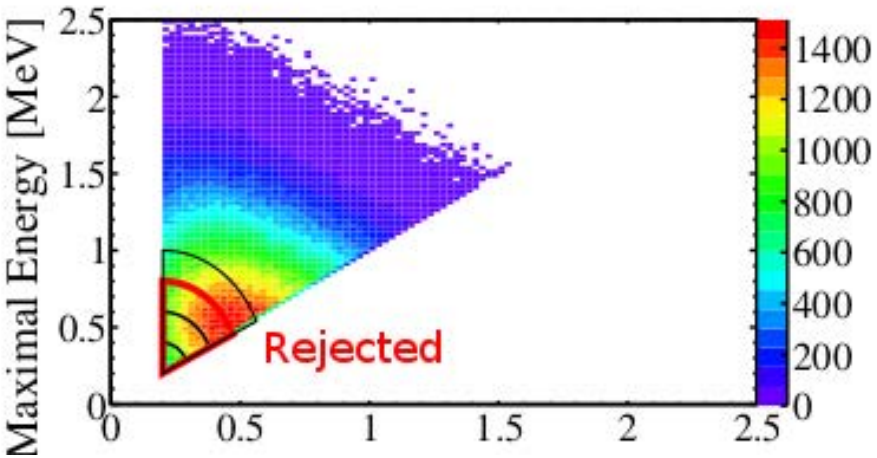
- ^{208}Tl : one of the main backgrounds for the neutrinoless double-β decay

Rejection of ^{40}K

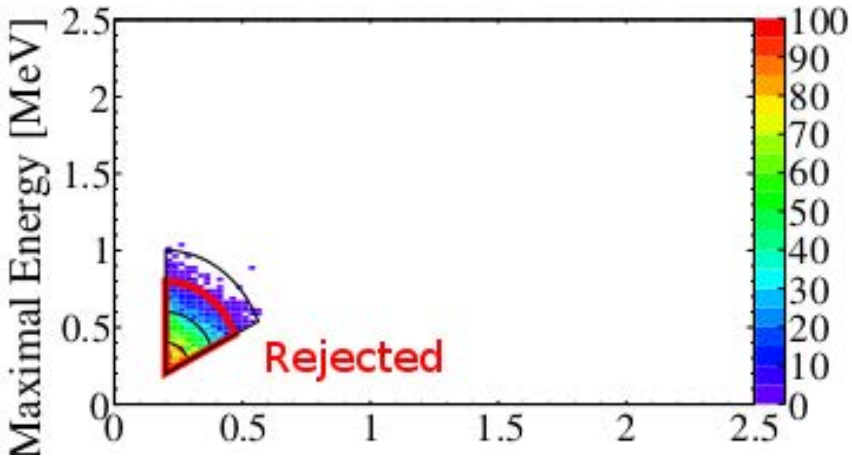
- Rejection optimised on MC
- Elliptic cut on individual energies (E_{min}, E_{max}) :
- 96 % of ^{40}K rejected
- 79 % of $2\nu2\beta$ selected



$2\nu2\beta$

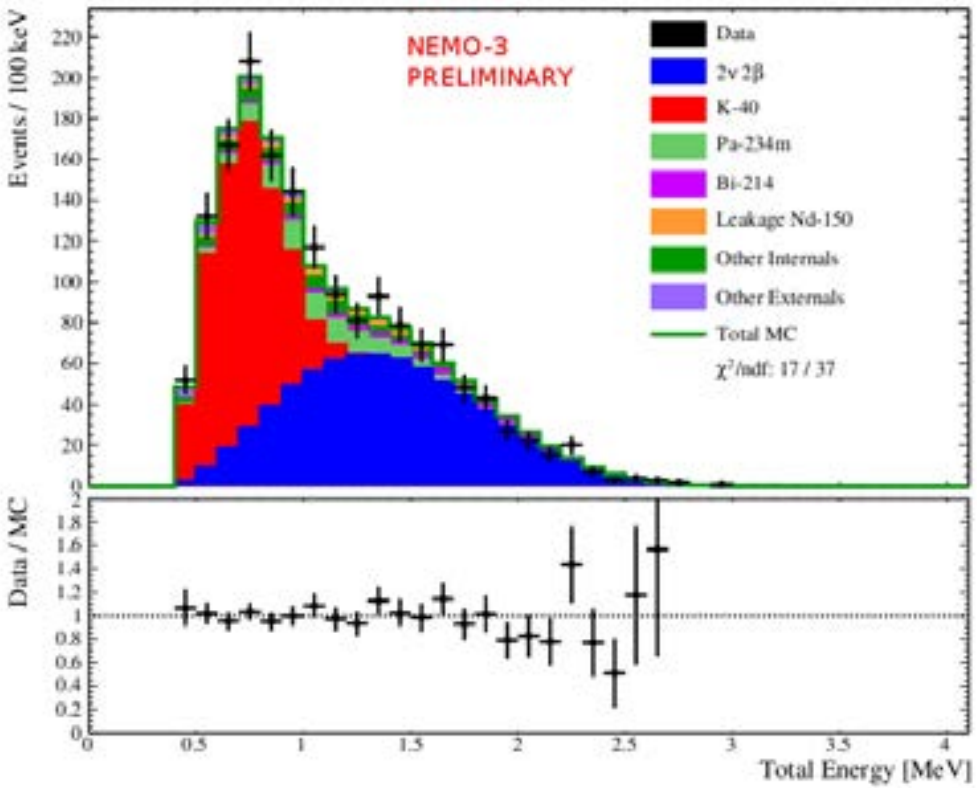


^{40}K



NEMO-3 $2\nu2\beta$ Measurement before ^{40}K rejection

- Half-life measurement under approval
  compatible with previously published value :
  $T^{2\nu}_{1/2} = 2.35 \pm 0.14 \pm 0.16\ 10^{19}$ yr (Nuclear Physics A, 847, 168-179, 2010)
- S/B increased by a factor of 3-4
- Exposure increased by $\sim$ 30 %



$E_1 + E_2$ [MeV]

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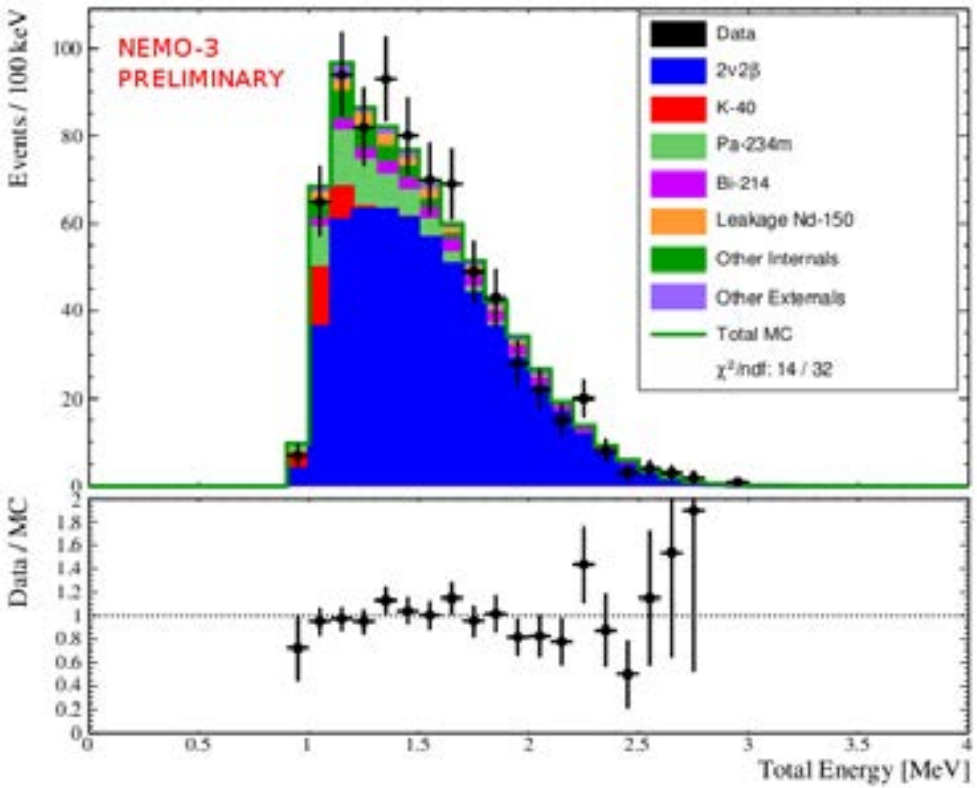
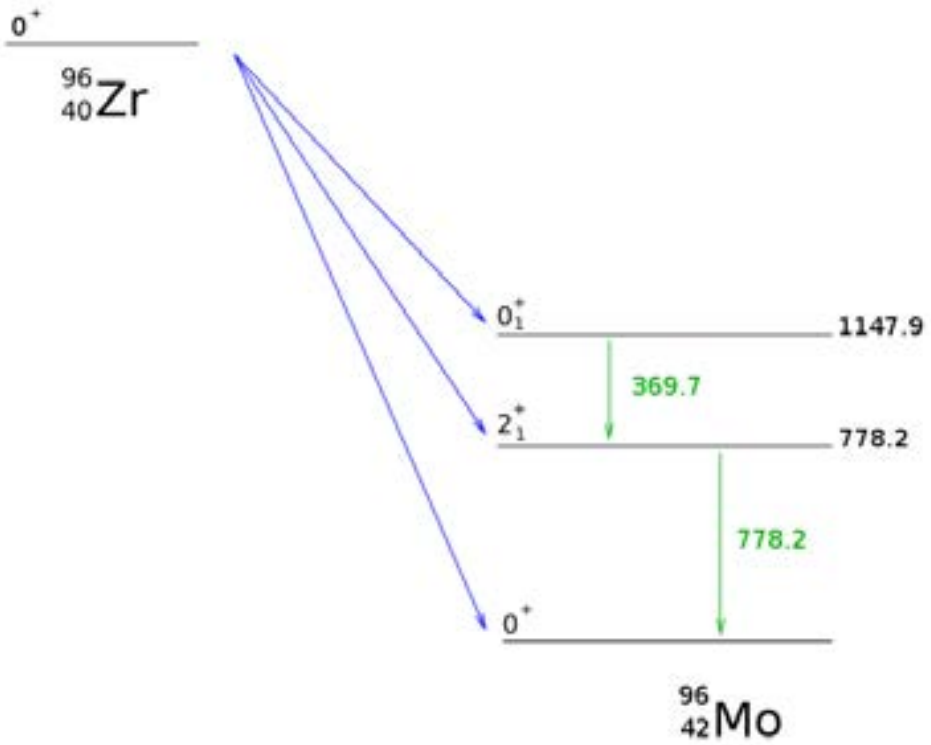
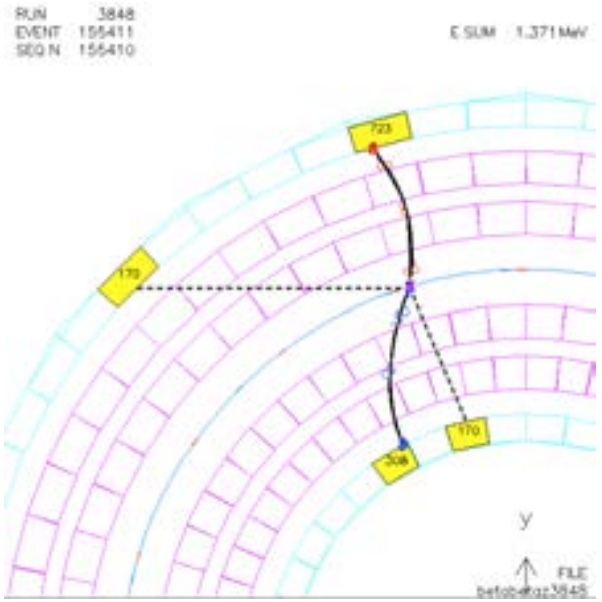


$E_1 + E_2$ [MeV]

$2\nu2\beta$ decay of ^{96}Zr to excited states

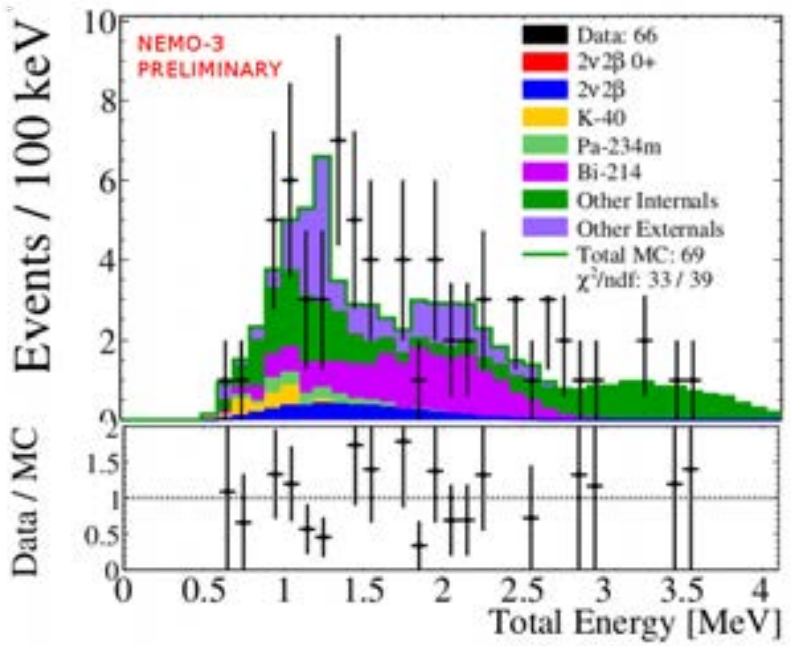
- Rarer than decay to ground state (phase space) and lower detection efficiency
- Two γ-particles in cascade accompanying the two electrons :
  - Strong kinematic signature only accessible with NEMO detection technique

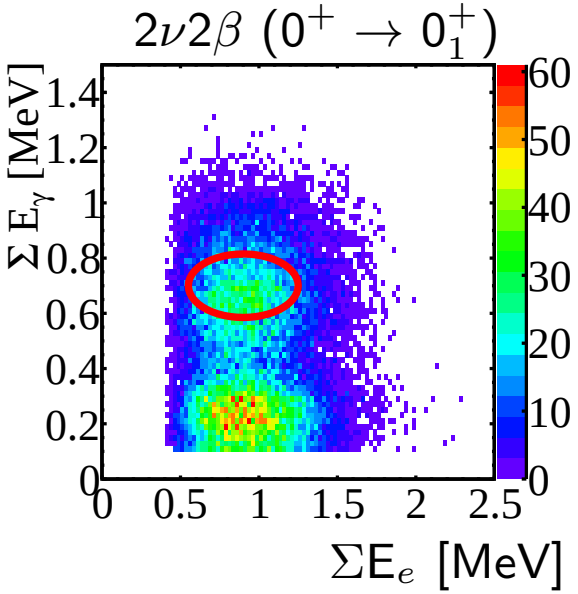


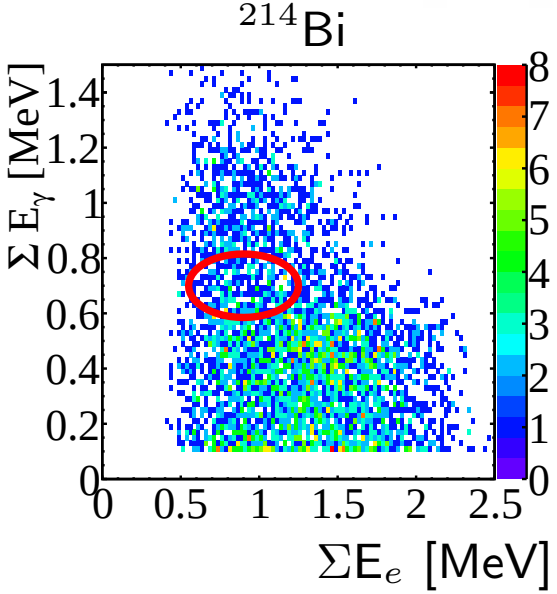


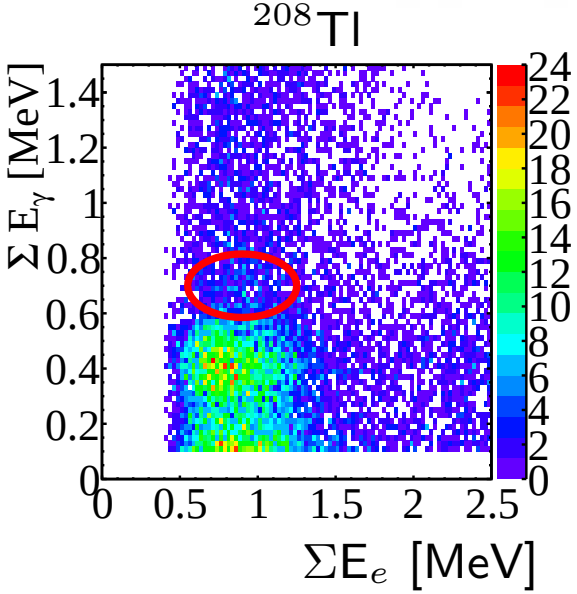
NEMO-3 $2\nu2\beta$ decay to excited states

- 2 electrons and 1 or 2 γ-particles channel
- S/B optimisation in $(\Sigma E_e, \Sigma E_\gamma)$ on Monte Carlo simulations



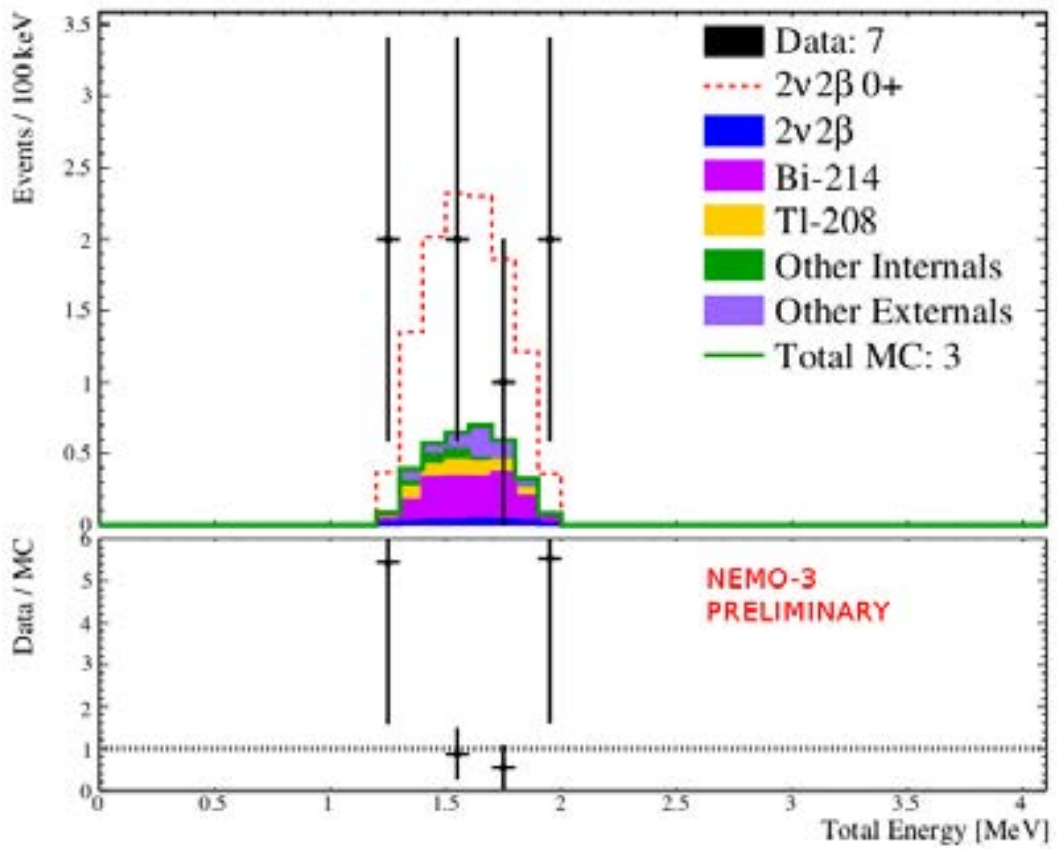






NEMO-3 $2\nu2\beta$ decay to excited states

- Distribution of $E_{tot} = E_1 + E_2 + E_{N\gamma}$
- Small excess of events over expected background
- Careful study of systematic effects of backgrounds
- First limit on the decay of ^{96}Zr to excited states with NEMO-3 under approval

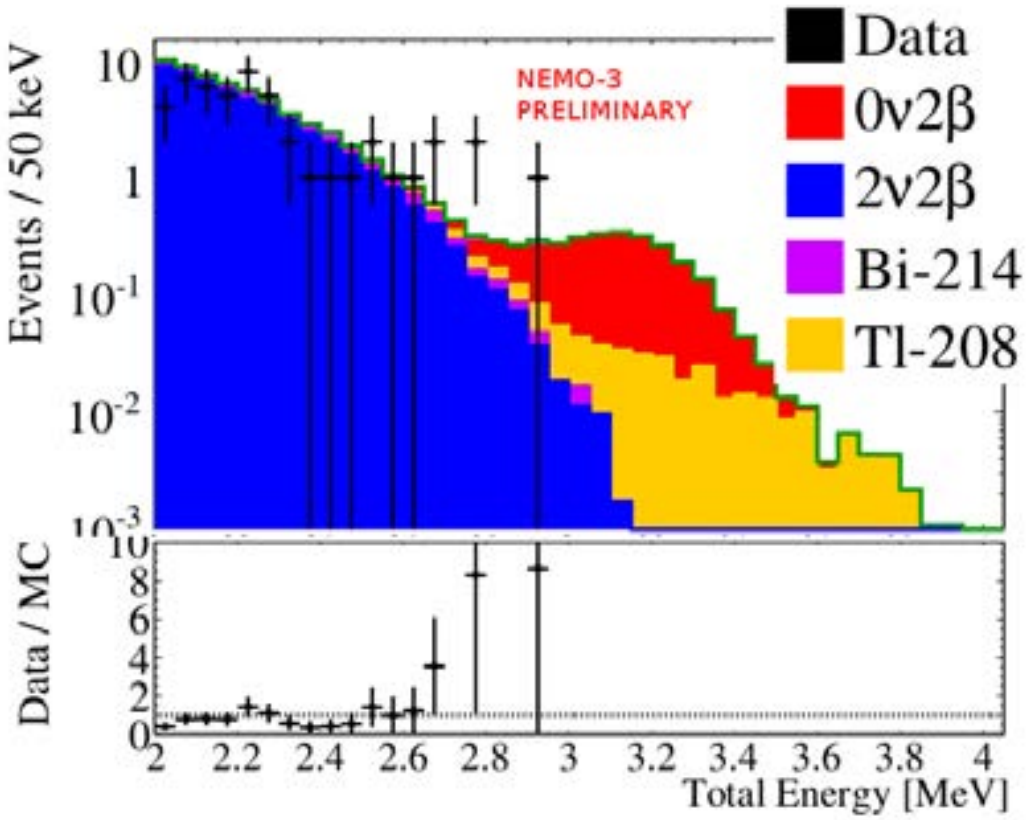


Summary

- NEMO-3 : Unique experiment capable of measuring the full kinematics of the 2β events
- Individual channels available for background measurement
- Signal over background ratio optimisations for decay to the ground state and the excited states
- $2\nu2\beta$ half-life measurement under approval, compatible with the current published value
- Limit on $0\nu2\beta$ half-life under approval
- First limit on the decay to excited states with NEMO-3 to be approved

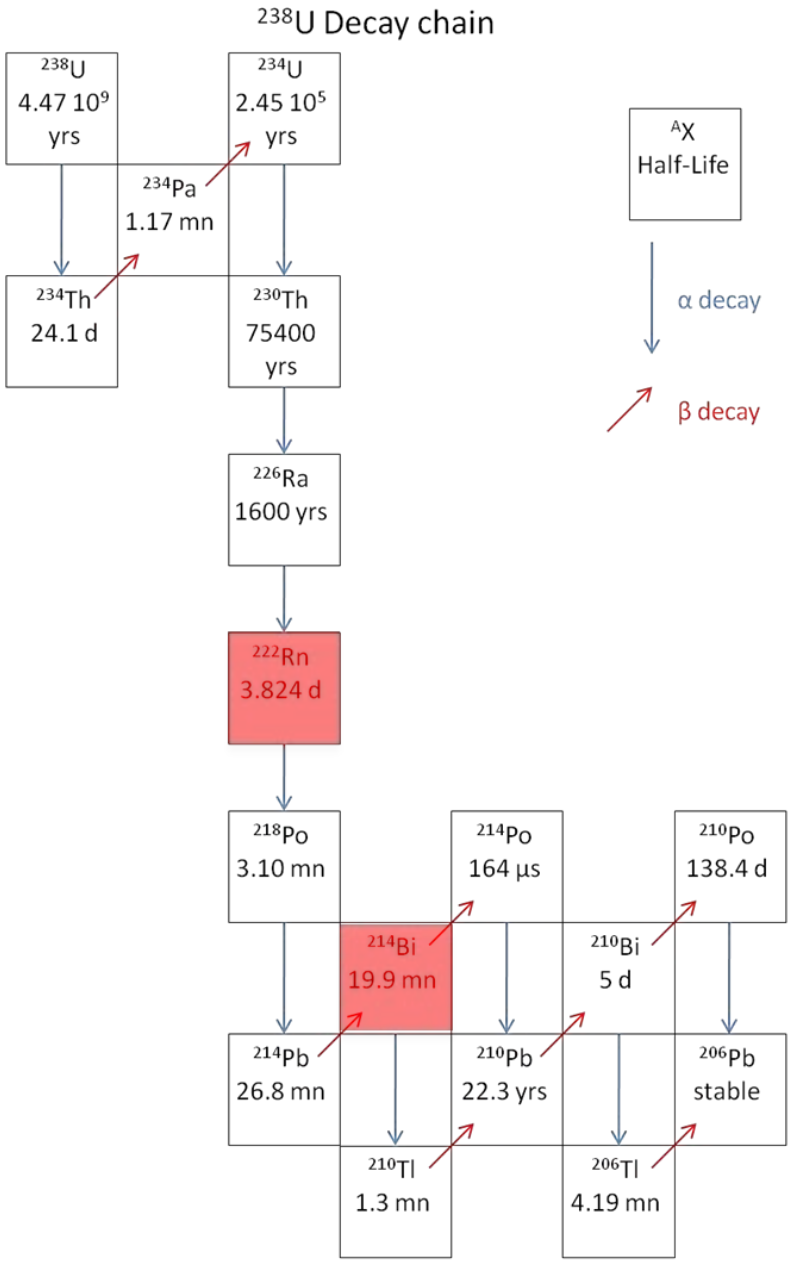
Backup

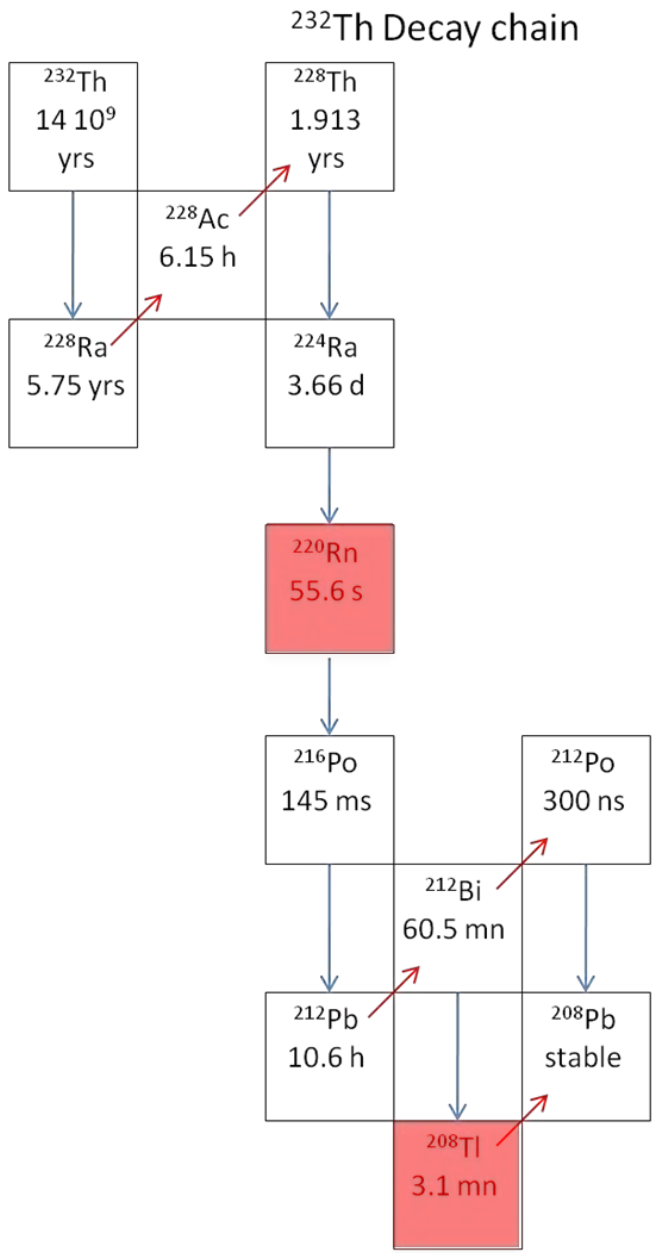
$0\nu2\beta$ Search



- 9.4 g of ^{96}Zr - $Q_{\beta\beta} = 3.35$ MeV
- ROI optimised on MC : 1 event observed
- NEMO-3 unique : no event observed above 3 MeV
- After approval, would be the best limit on 0ν process of ^{96}Zr
  Current best limit : $T^{0\nu}_{1/2} > 9.2\ 10^{21}$ yr (Nuclear Physics A, 847, 168-179, 2010)

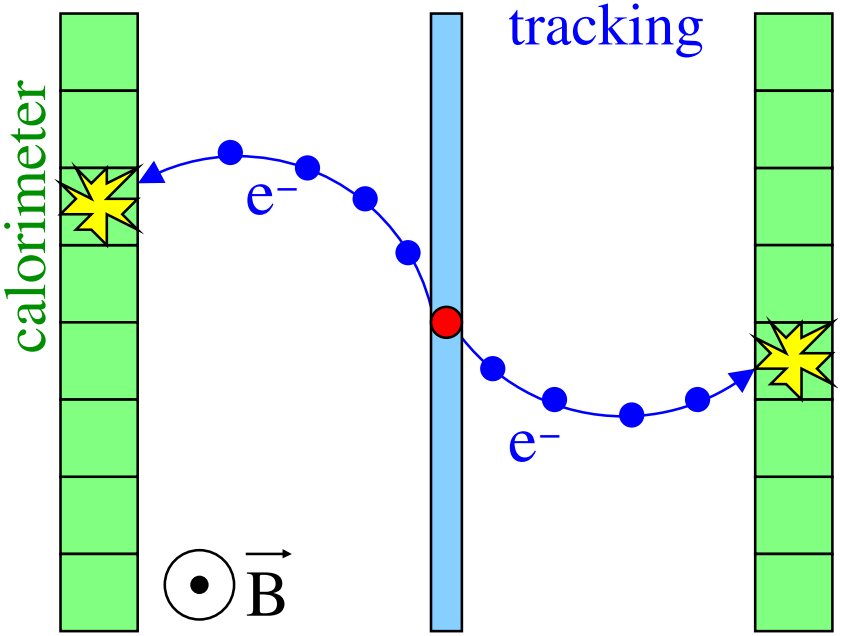
Natural radioactivity decay chains





NEMO Experimental Techniques

- Low-background detectors in deep underground laboratories
- Passive $\beta\beta$ enriched source foil in the center
- Magnetised tracking device to identify the two electrons
- Segmented calorimeter to measure the (individual and total) energies and the time of flight of the two e^- (with the tracker)
- Shielded against neutrons and γ from the laboratory



NEMO-3 : the Neutrino Ettore Majorana Observatory

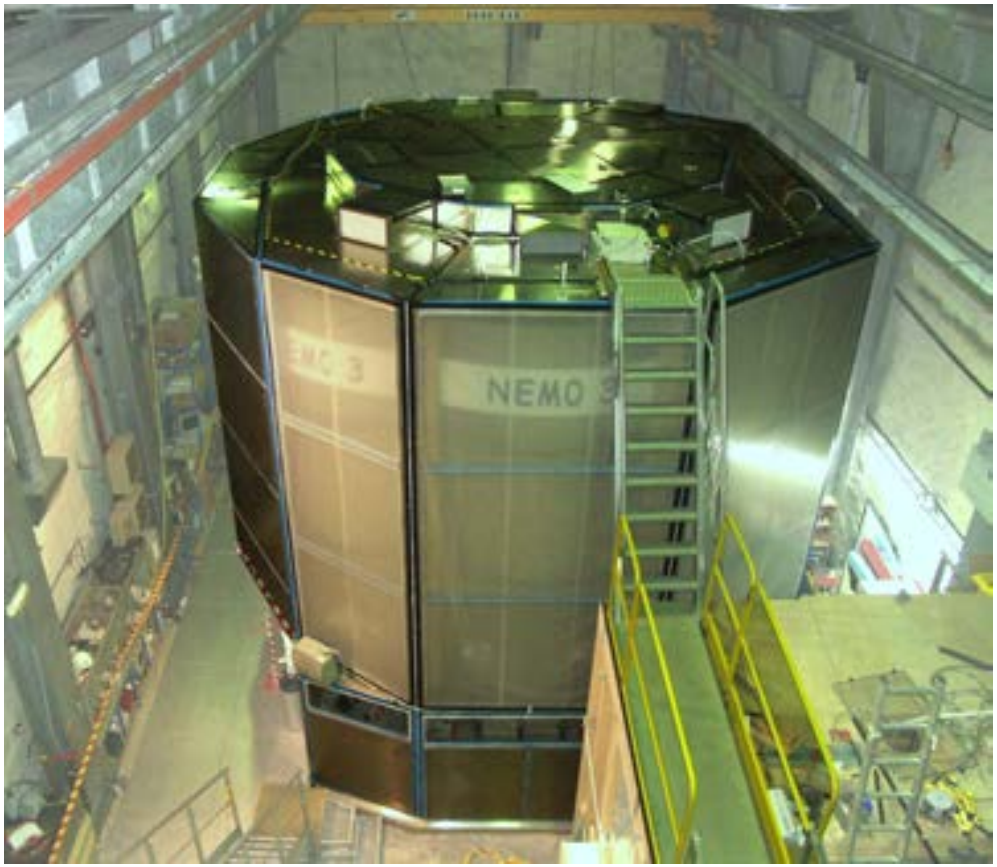
- NEMO-3 results for the $2\nu2\beta$ process half-life
- Each of them are the current world's best

isotope	mass [g]	$Q_{\beta\beta}$ [keV]	$T^{2\nu}_{1/2}$ [10^{19} y]
^{48}Ca	6.99	4272	4.4 $\pm$ 0.6
^{82}Se	932	2996	9.6 $\pm$ 1.0
^{96}Zr	9.43	3350	2.35 $\pm$ 0.21
^{100}Mo	6914	3034	0.72 $\pm$ 0.05
^{116}Cd	405	2814	2.8 $\pm$ 0.3
^{130}Te	454	2528	70 $\pm$ 14
^{150}Nd	37	3371	0.9 $\pm$ 0.07

- Analyses still in progress on most of the isotopes (^{82}Se, ^{48}Ca, ^{96}Zr, ...)

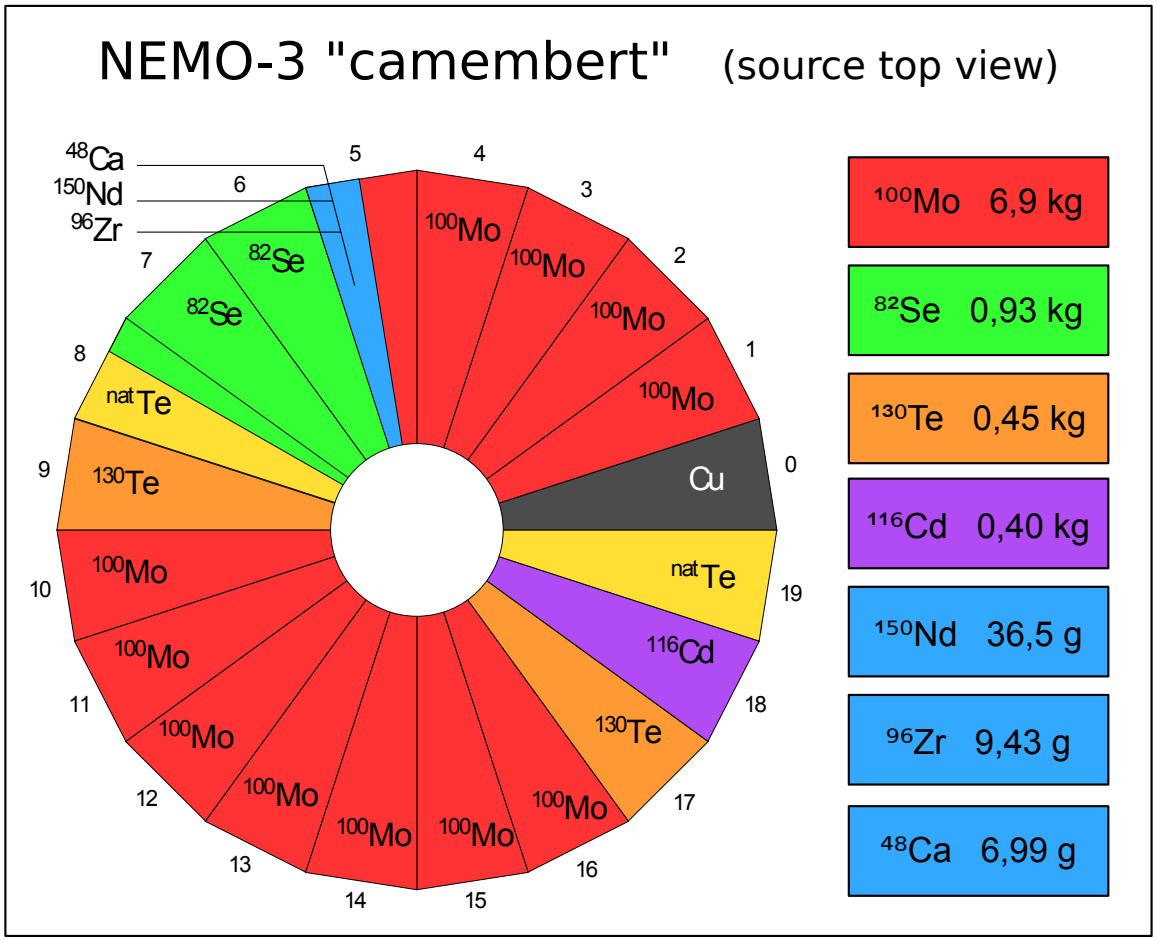
NEMO-3 : Description

- NEMO-3 ran from 2003 to 2011
- Two phases :
  - Phase 1 : high radon background phase
  - Phase 2 : low radon phase (reduction factor of 6)



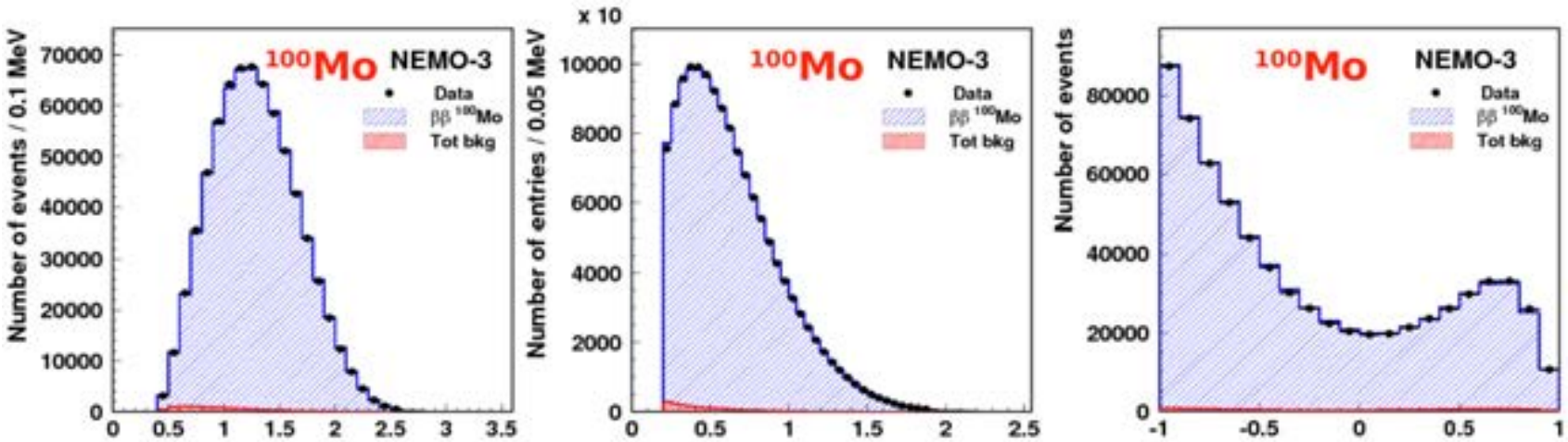
NEMO-3 : the Neutrino Ettore Majorana Observatory

- Several double-β isotopes studied ($\sim$ 9kg)
- Background checked on copper and natural tellurium sources



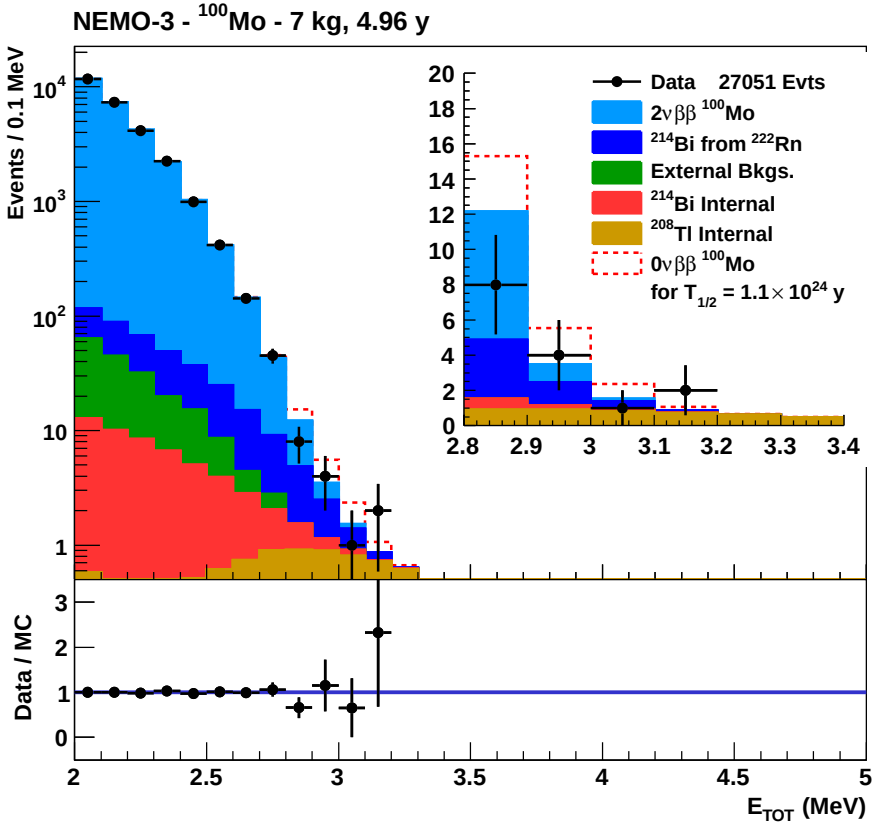
NEMO-3 $2\nu2\beta$ Measurement

- 6.9 kg of ^{100}Mo
- $\sim$700 000 $2\nu2\beta$ events collected
- Efficiency $\mathcal{E}_{2\nu} = 4.3$ %
- Signal to background ratio S/B = 76
- Preliminary half-life :
  $\mathcal{T}^{2\nu}_{1/2} = 7.16 \pm 0.01$ (stat) ± 0.54 (syst) 10^{18} y
  compatible with previously published [Phys. Rev. Lett. 95, 182302 (2005)]



$E_1 + E_2$ [MeV] E_{min} [MeV] cos θ

$0\nu2\beta$ Results

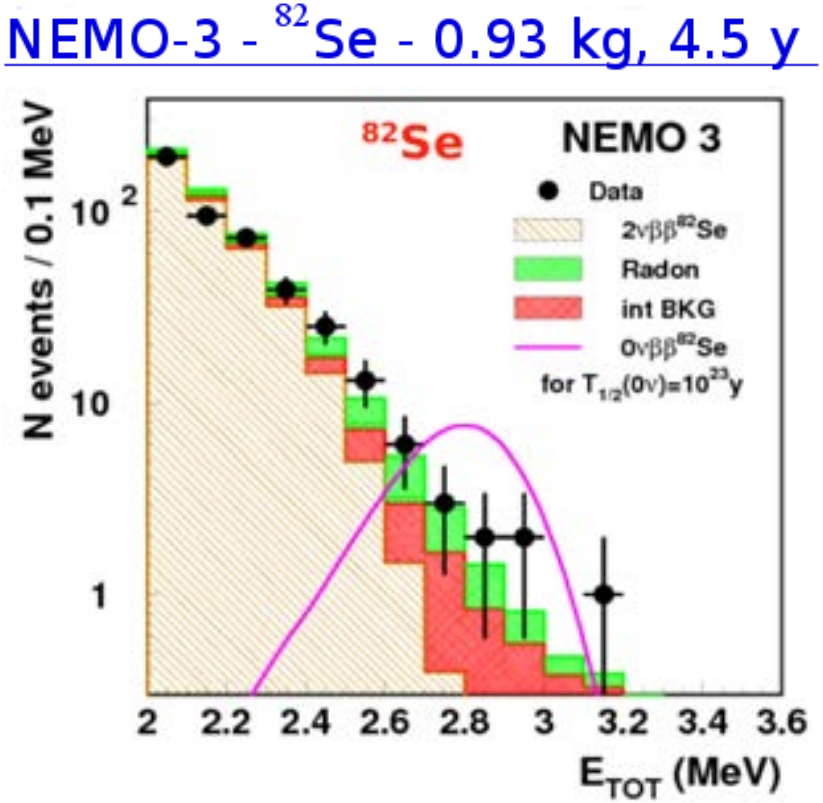


Phys. Rev. D 89, 111101, 2014

- in [2.8 – 3.2] MeV : 15 events obs., 18.0 $\pm$ 0.6 expect.
  No event excess
  $\mathcal{T}^{0\nu}_{1/2}(^{100}\mathrm{Mo}) > 1.1 \times 10^{24}$ yr (90 % C.L.)
  $\langle m_{\beta\beta} \rangle \quad < 0.33 - 0.87$ eV

NEMO-3 $0\nu2\beta$ Results

- Current last results on ^{82}Se



in [2.6 – 3.2] MeV :
14 events obs., 11.1 $\pm$ 1.3 expect.
$\mathcal{T}^{0\nu}_{1/2}(^{82}\mathrm{Se}) > 3.2\ 10^{23}$ yr & $\langle m_{\beta\beta}\rangle \quad < 0.85 - 2.08$ eV