Results of the NEMO-3 experiment

(Summer 2009)

Outline

- The $\beta\beta0\nu$ decay
- The NEMO-3 experiment
- Measurement of the backgrounds
- $\beta\beta2\nu$ and $\beta\beta0\nu$ results

Xavier Sarazin
On behalf of the NEMO-3 Collaboration

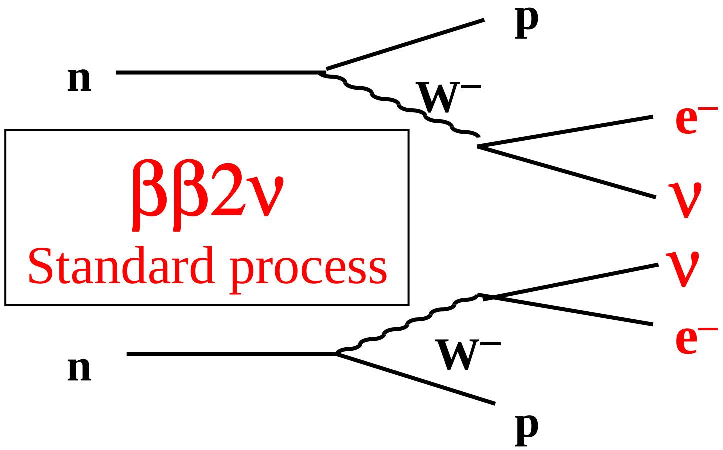
2nd LSM-Extension Workshop - October 16 2009 - Modane, France

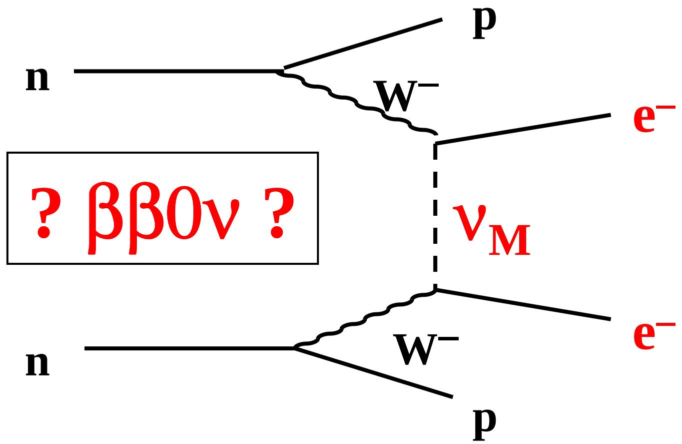
Goal of the NEMO-3 experiment:

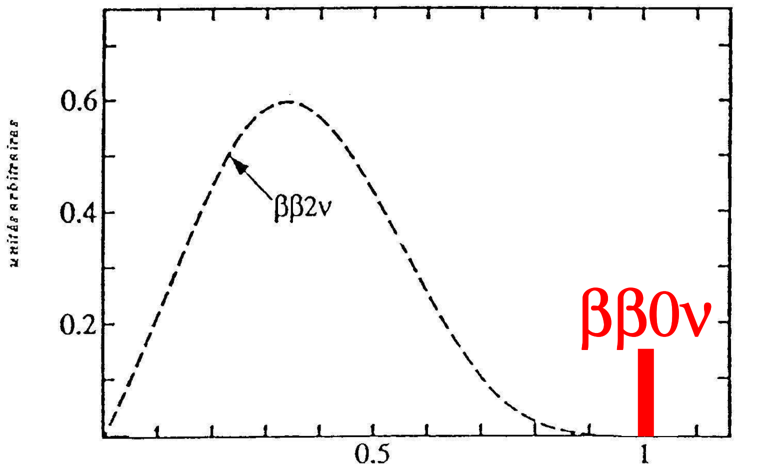
The search for the neutrinoless double beta (ββ0ν) decay

Process beyond the Standard Model

If ββ0ν decay is observed ⇒ the neutrino is a Majorana particle $\nu = \bar{\nu}$







(Energy sum of the two e⁻) / $Q_{\beta\beta}$

The NEMO-3 detector

Modane Underground Laboratory : 4800 m.w.e.

Source: 10 kg of ββ isotopes

cylindrical, S = 20 m^2, e ~ 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

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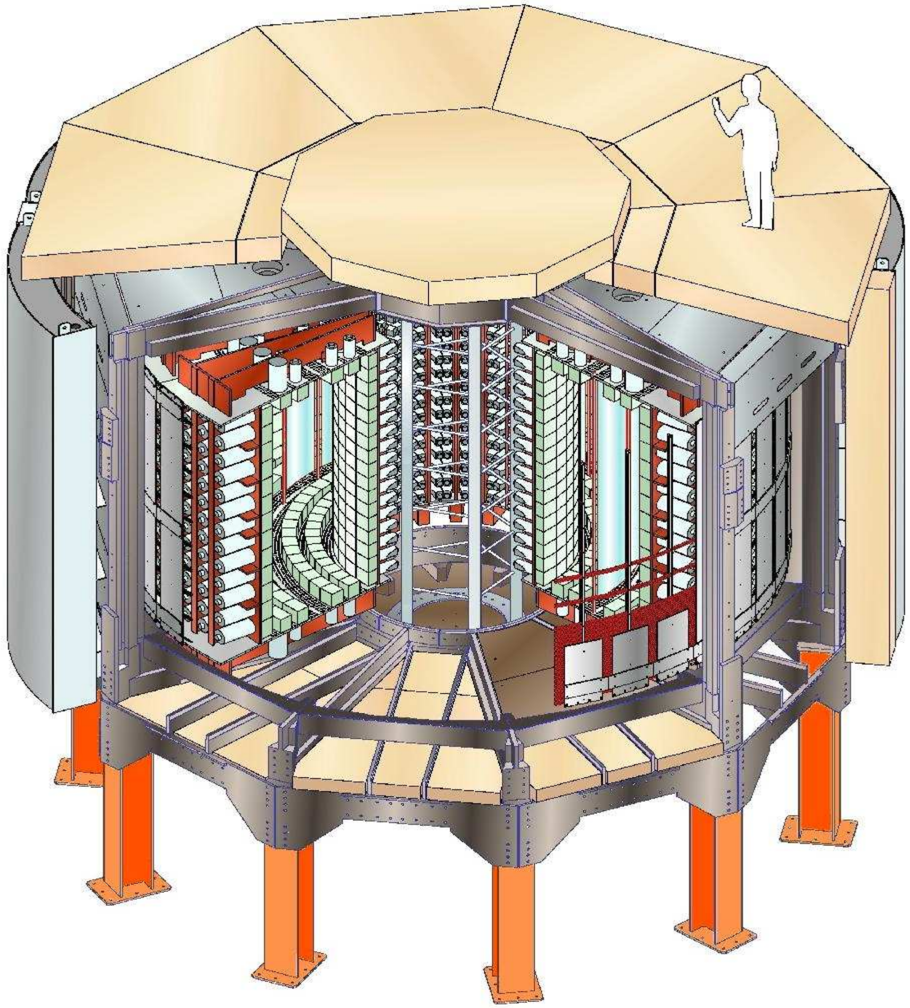

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Magnetic field: 25 Gauss
Gamma shield: Pure Iron (e = 18 cm)
Neutron shield: 30 cm water (ext. wall)
40 cm wood (top and bottom)
(since march 2004: water + boron)

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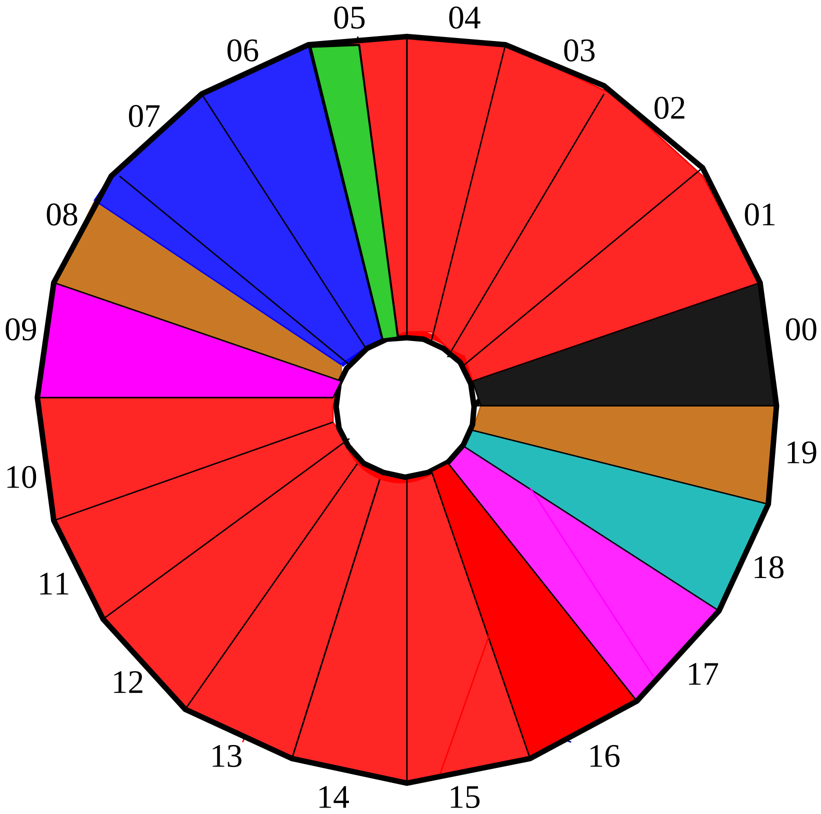
Radon-free air around the detector

- Phase I (Feb 2003 oct. 2004): High Radon
- Phase II (Dec 2004 today): Low Radon
  (Radon cont. reduced by factor 6)

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

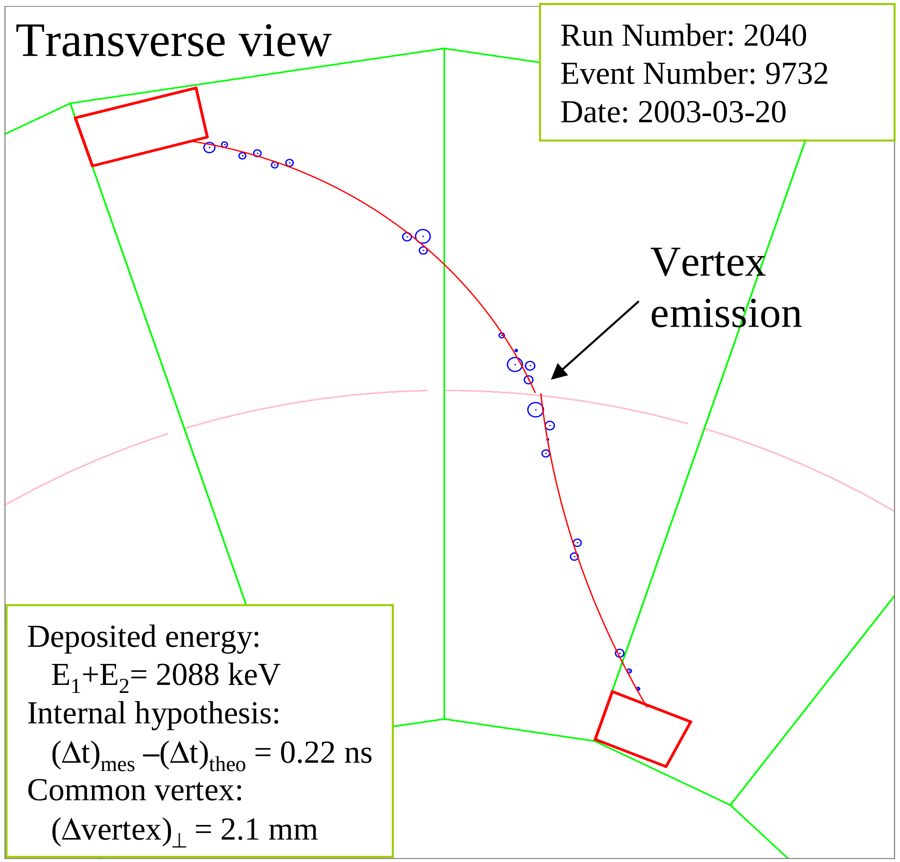
Cu 621 g

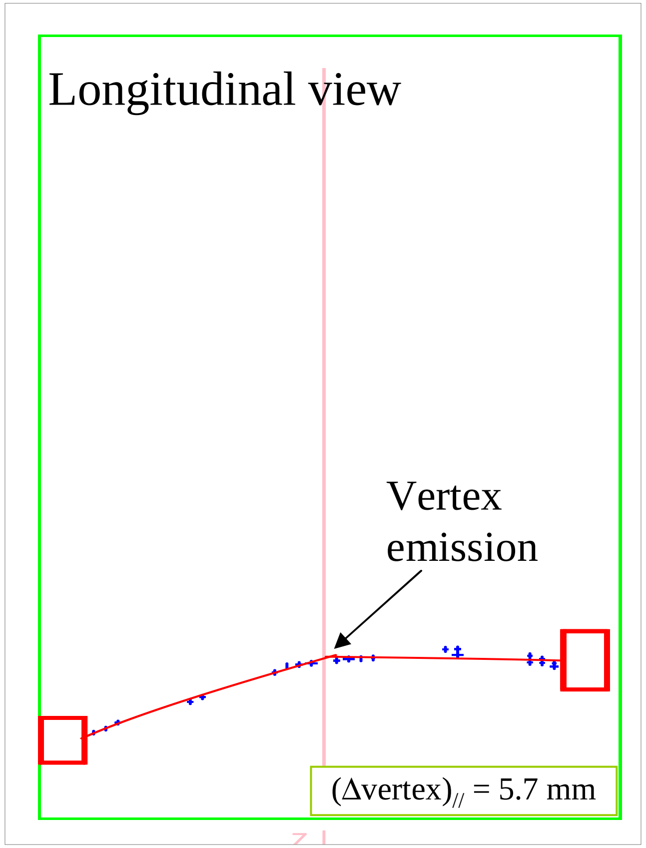
External bkg measurement

(Enriched isotopes produced by centrifugation in Russia)

ββ event in NEMO3

Typical ββ2ν event observed from ^{100}Mo





Trigger: 1 PM > 150 keV

3 Geiger hits (2 neighbour layers + 1)

Trigger Rate ~ 5.5 Hz

ββ evts: 1 event every 2 minutes

ββ events selection

- 2 tracks with charge < 0
- 2 PM, each E> 200 keV
- PM-track association
- Common vertex
- Internal hypothesis Δt~0ns
- No isolated PM (γ rejection)
- No delayed track (^{214}Bi rejection)

Measurement of the different components of background in NEMO-3

Recent publication in NIM A606 (2009) 449-465)

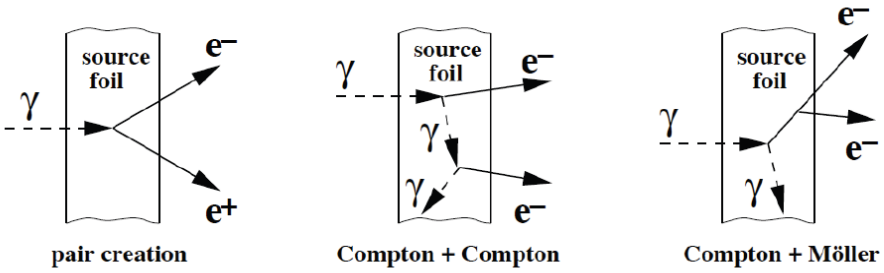
NEMO-3 Backgrounds for ββ

- **External γ** (if the γ is not detected in the scintillators)

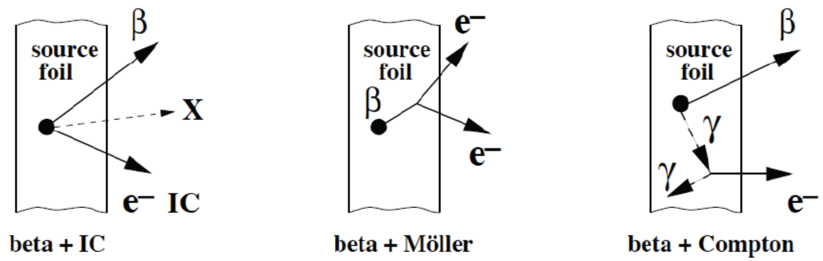
  Origin: natural radioactivity of the detector or neutrons

  Main bkg for ββ2ν but negligeable for ββ0ν

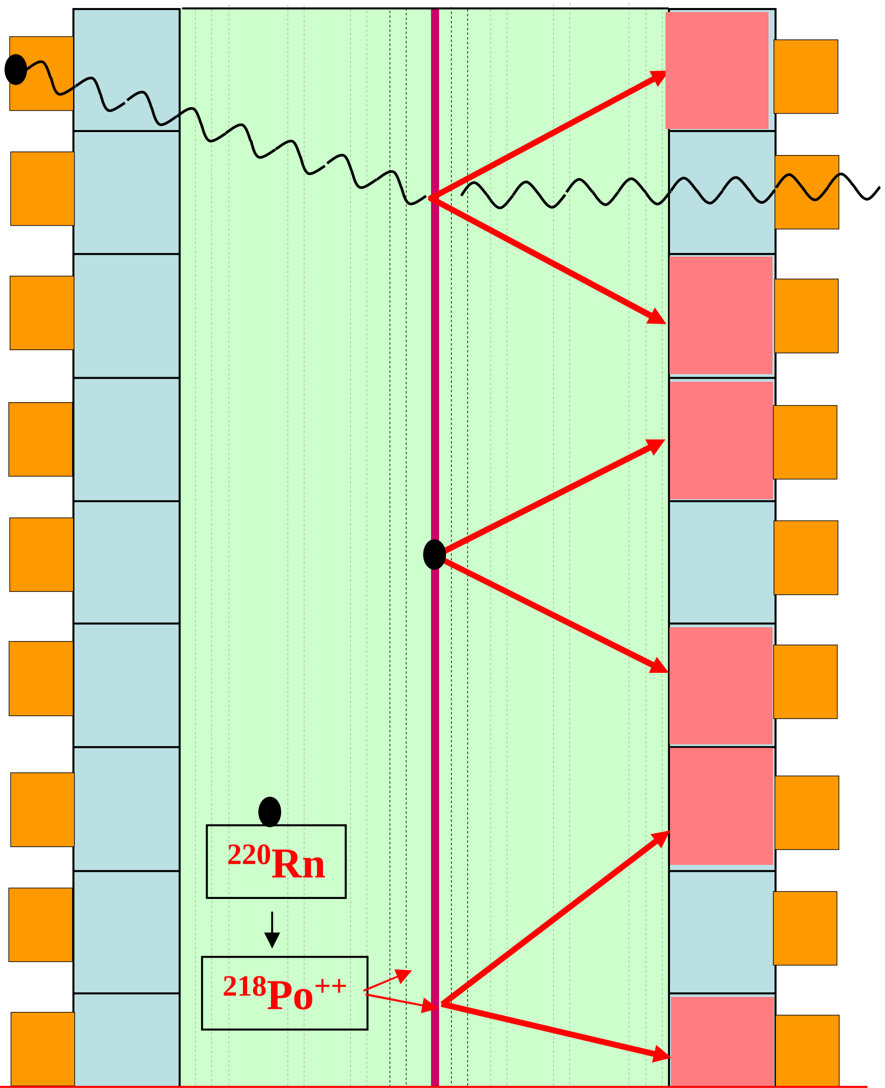
  (^{100}Mo and ^{82}Se $Q_{\beta\beta}$~ 3 MeV > Eγ(^{208}Tl) ~ 2.6 MeV)



- **^{232}Th (^{208}Tl) and ^{238}U (^{214}Bi) contamination inside the ββ source foil**



- **Radon (^{214}Bi) inside the tracking detector**
  - deposits on the wire near the ββ foil
  - deposits on the surface of the ββ foil

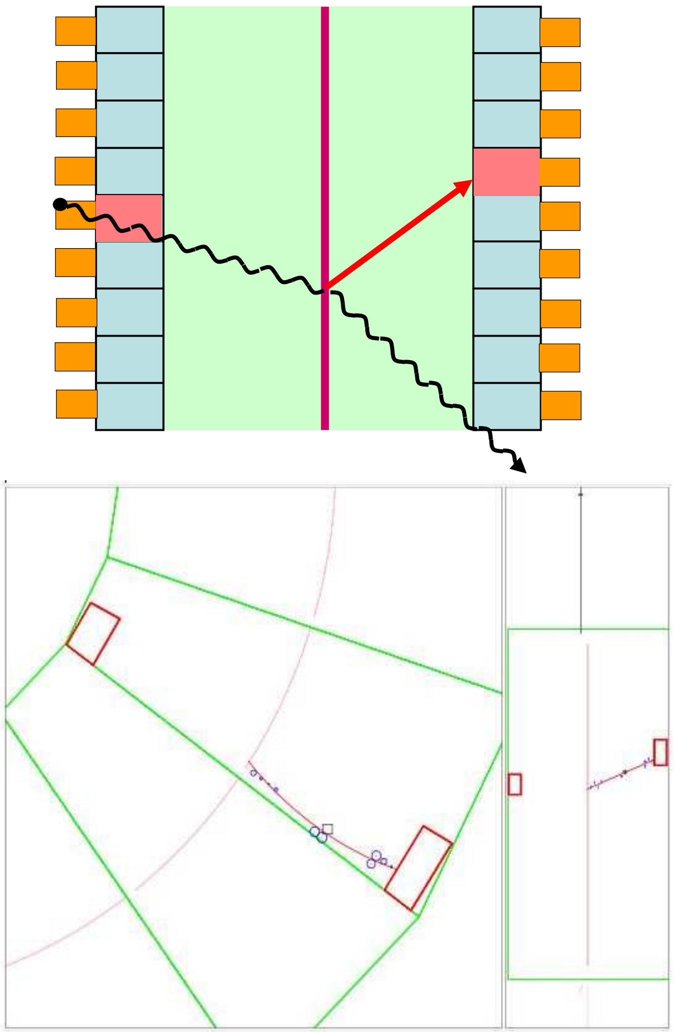


Each bkg is measured using the NEMO-3 data

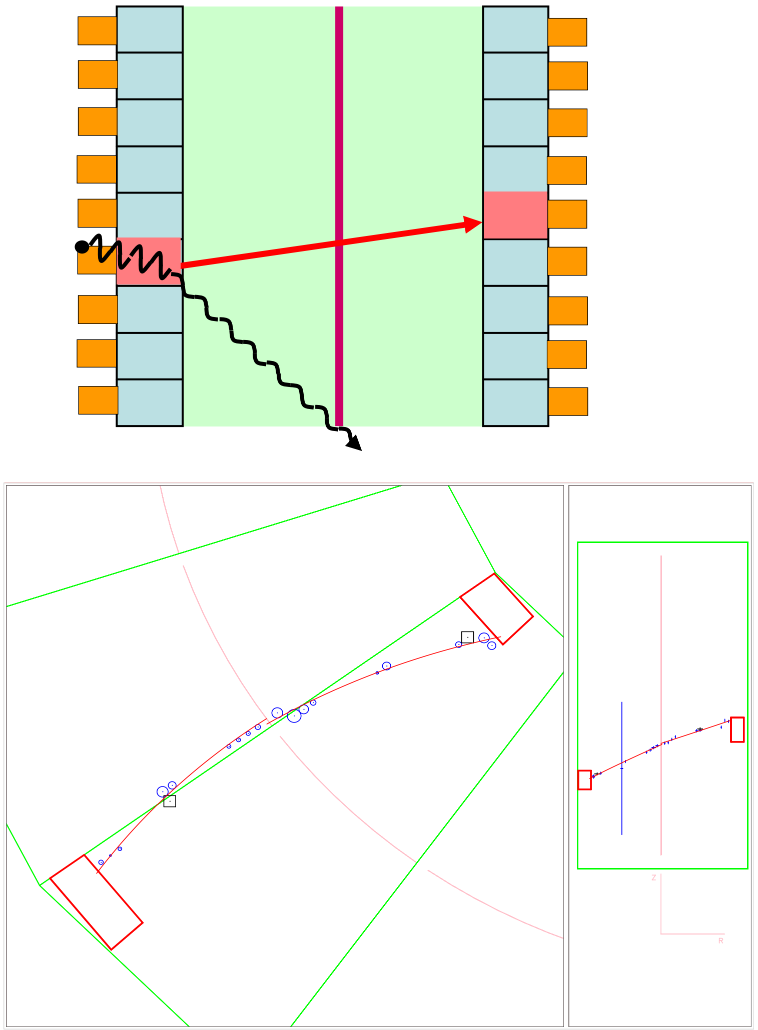
Measurement of the external γ background

Two topologies to measure the components of external γ bkg

external (e^-,γ)



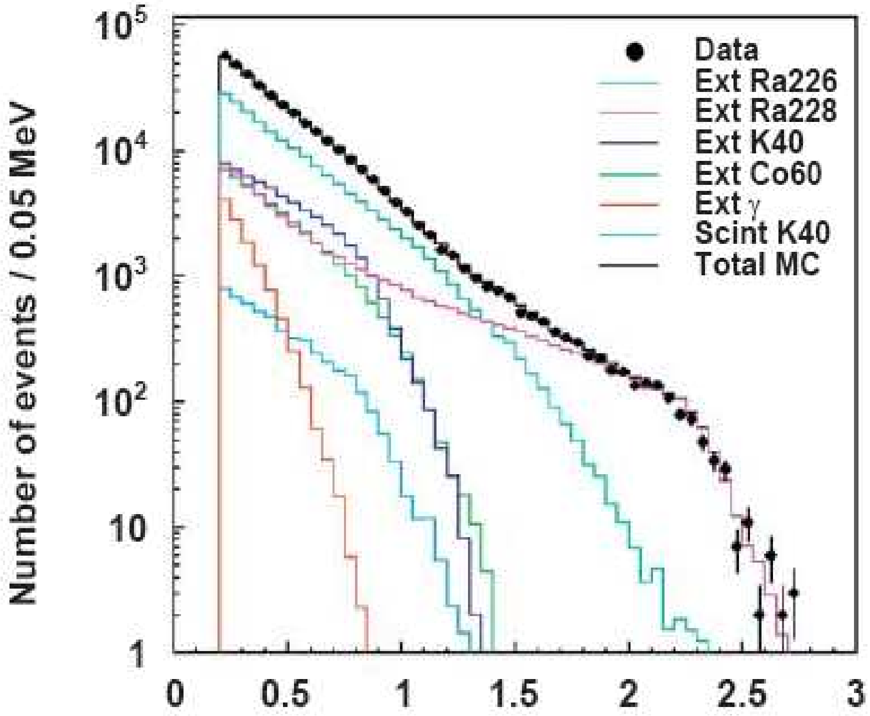
crossing e^-



Measurement of the external γ background

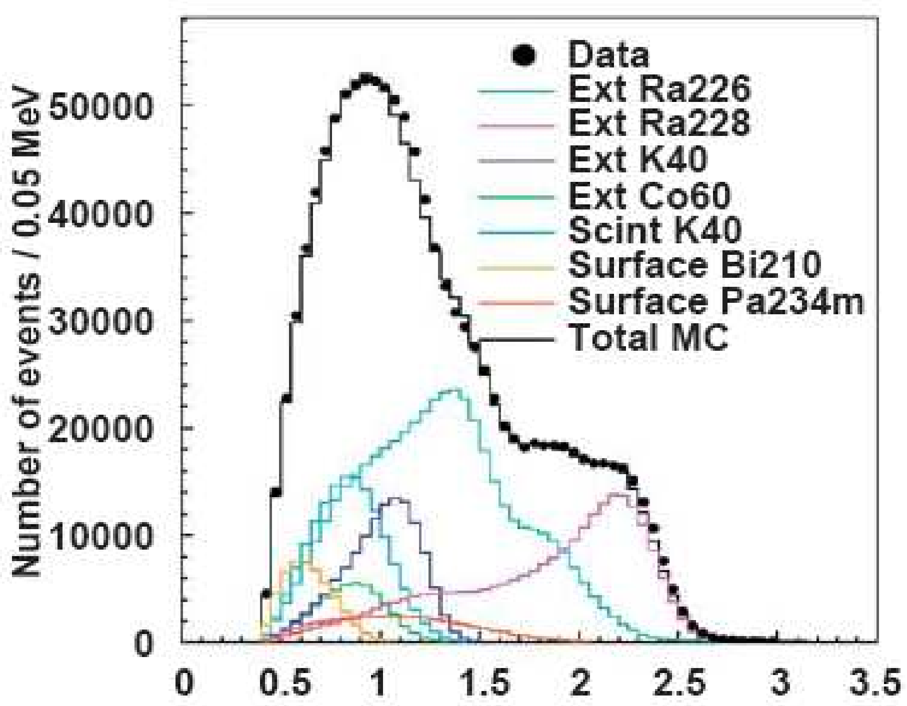
External γ-ray flux model: the simulations fit very well the NEMO-3 data both in (e^-,γ) and crossing e^- channels

External (e^-,γ) channel



Energy of the single e^- (MeV)

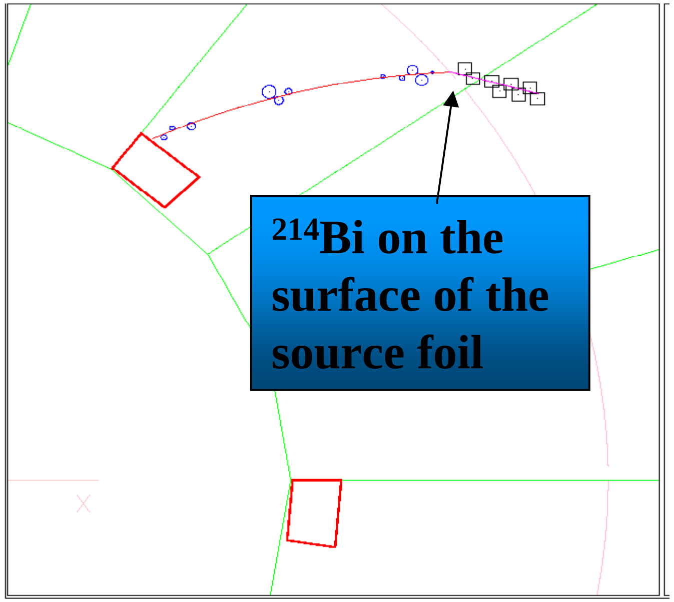
Crossing e^- channel



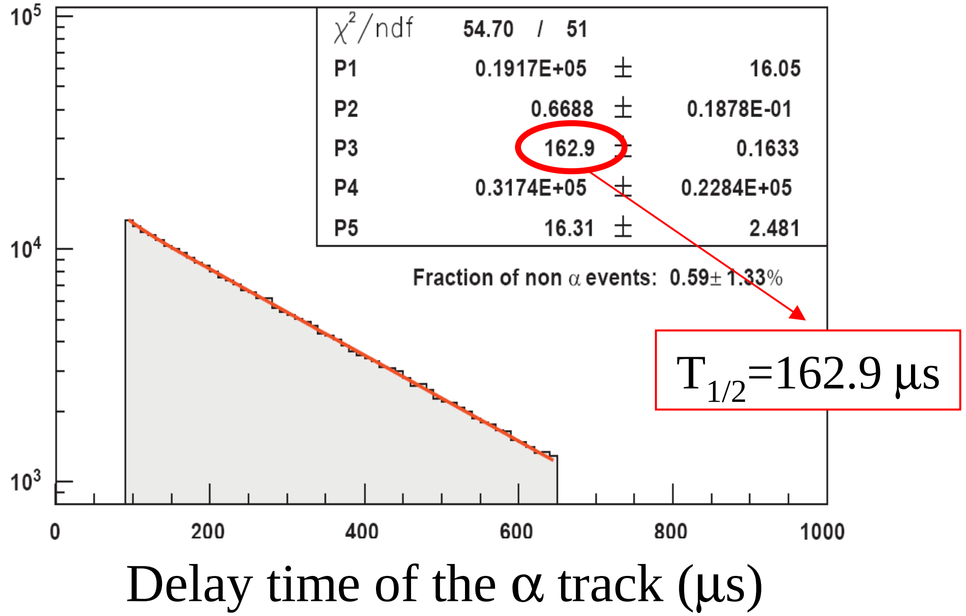
Energy Sum of the two scintillators (MeV)

Measurement of the Radon inside the tracking detector

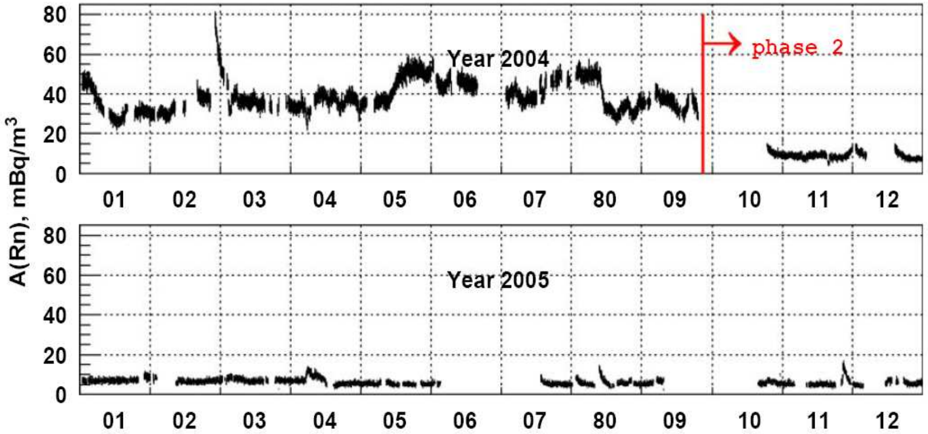
$^{214}Bi \xrightarrow{\beta} {}^{214}Po \xrightarrow{\alpha} {}^{210}Pb$ (164 µs)



Pure sample of $^{214}Bi - {}^{214}Po$ events

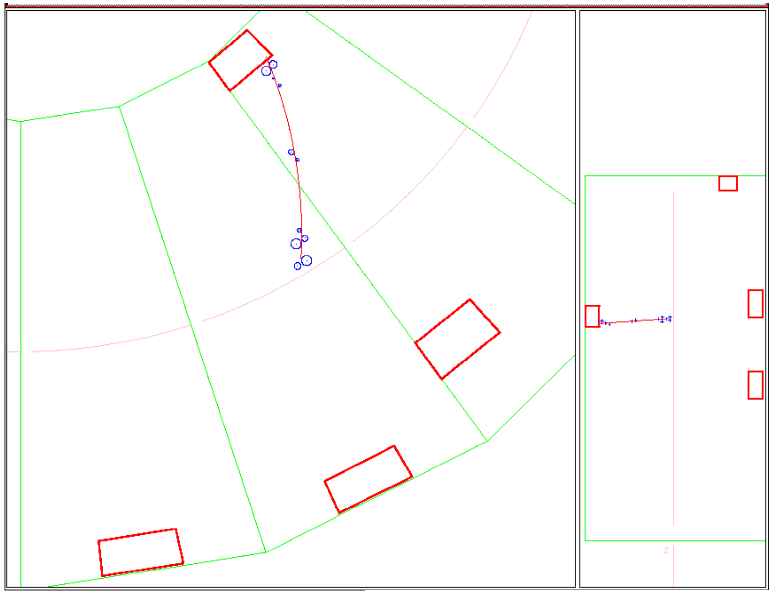


Monitoring of the Radon bkg every day



- Phase 1: Feb. 2003 → Sept. 2004 Radon Contamination
- Phase 2: Dec. 2004 → Today **A (Radon) ≈ 5 mBq/m³**

Measurement of the ^{208}Tl (^{232}Th) inside the ββ source foil



^{208}Tl contamination inside the ββ source foils is measured using **internal (e^-,γ,γ) or (e^-,γ,γ,γ) channels**

ββ material	*N*	A (mBq/kg)	A_{HPGe} (mBq/kg)
^{100}Mo(m)	666	0.11 ± 0.01	$<0.13; <0.1; <0.12^{*}$
^{100}Mo(c)	1628	0.12 ± 0.01	<0.17
^{82}Se(I)	446	0.34 ± 0.05	<0.670
^{82}Se(II)	507	0.44 ± 0.04	$0.4 \pm 0.13^{**}$
^{48}Ca	42	1.15 ± 0.22	$<2.$
^{96}Zr	158	2.77 ± 0.25	$<10.; <5.^{*}$
^{150}Nd	1002	9.32 ± 0.32	$10. \pm 1.7$
^{130}Te	448	0.23 ± 0.05	<0.5
^{nat}Te	495	0.27 ± 0.04	<0.08
^{116}Cd	196	0.17 ± 0.05	$<0.83; <0.5^{*}$
Cu	66	0.03 ± 0.01	<0.033

Agreement with HPGe measurements

^{208}Tl contamination in the Mo foils:

A(^{208}Tl) ~ 100 μBq/kg

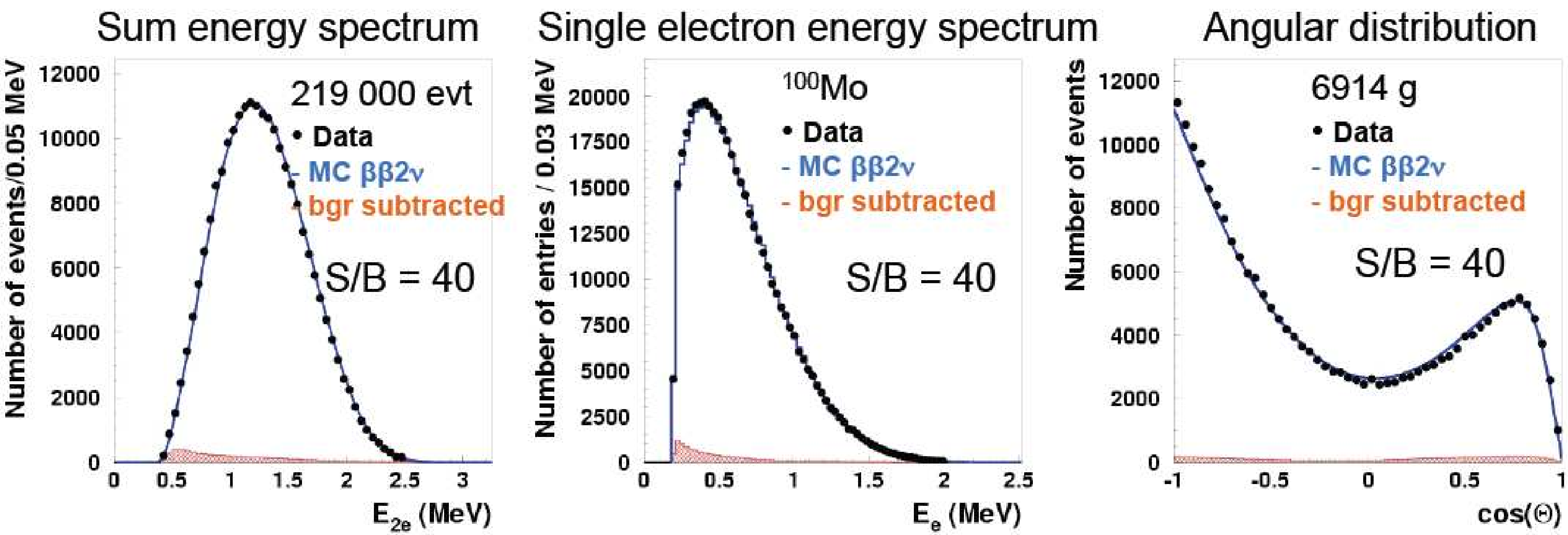
⇒ ^{100}Mo foils should be measured later inside the BiPo detector

ββ2ν and ββ0ν results

(summer 2009)

ββ2ν result with ^{100}Mo

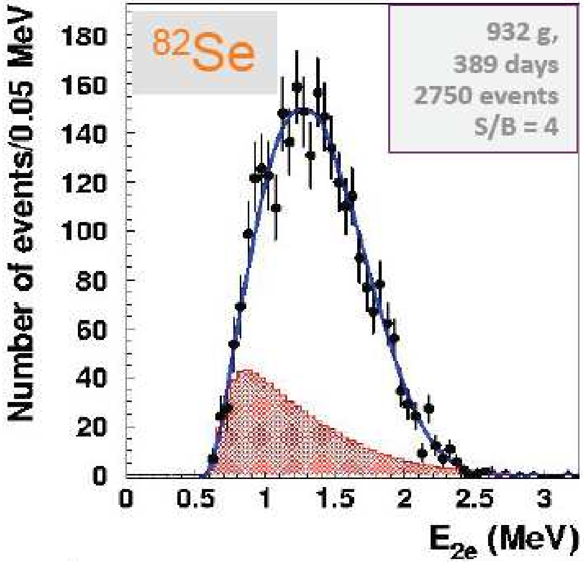
Phase I (high Radon): Feb 2003 – Dec 2004 (389 days)



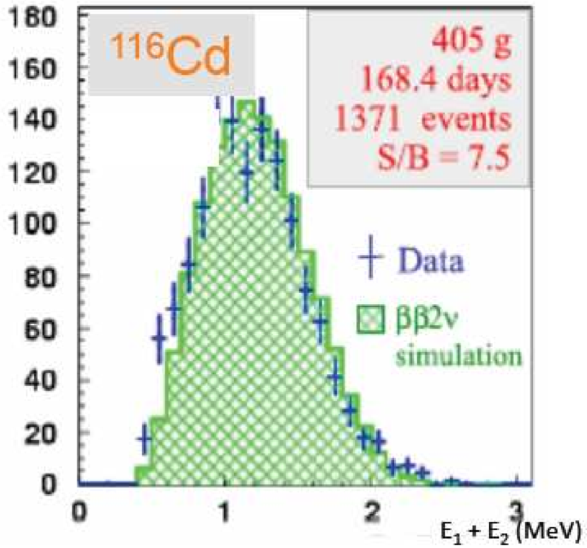
^{100}Mo: $T_{1/2}(\beta\beta2\nu)$ =(7.11 ± 0.02(stat) ± 0.54(syst))·10^{18} y

Phys.Rev.Lett. 95, 182302 (2005)

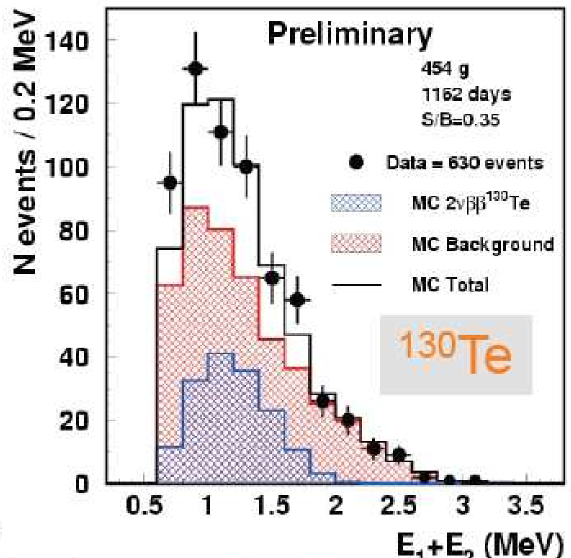
ββ2ν results with the other isotopes



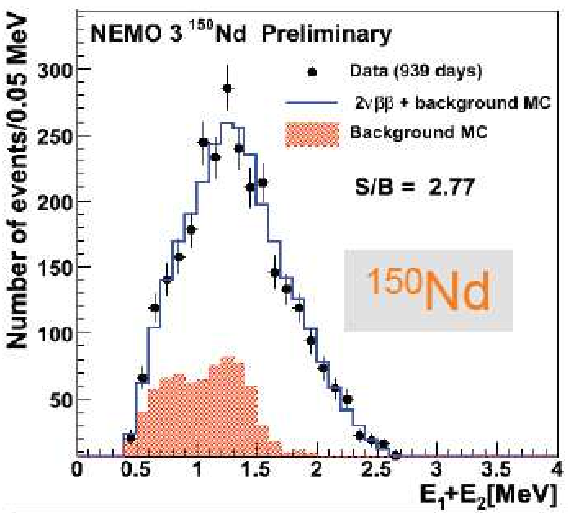
9.6 ± 0.3 (stat) ± 1.0 (sys) 10^{19} y



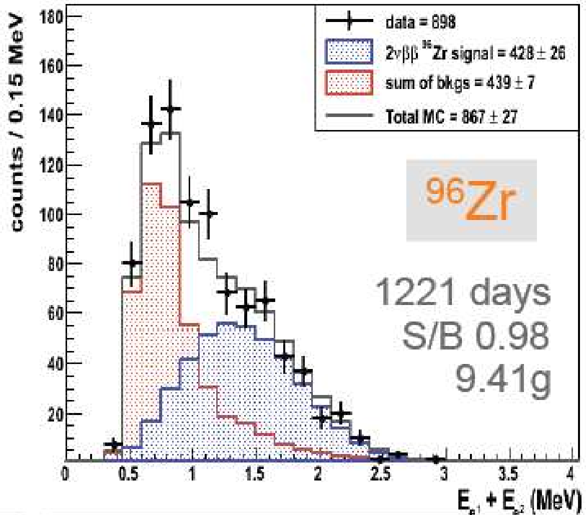
2.8 ± 0.1 (stat) ± 0.3 (sys) 10^{19} y



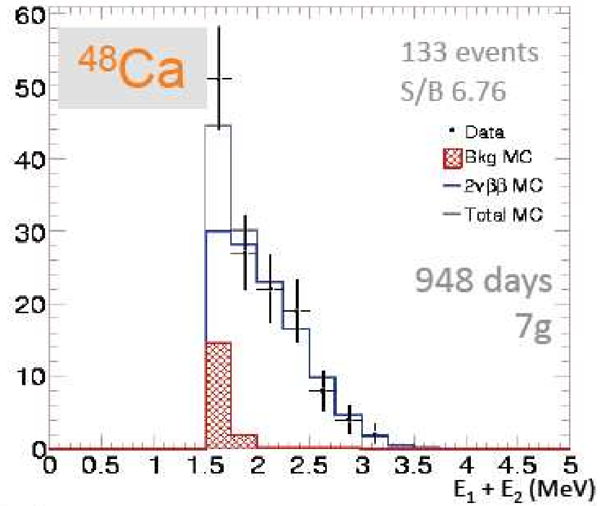
6.9 ± 0.9 (stat) ± 1.0 (sys) 10^{20} y



9.11 $^{+0.25}_{-0.22}$(stat) ± 0.63 (sys) 10^{18} y



2.35 ± 0.14 (stat) ± 0.16 (sys) 10^{19} y

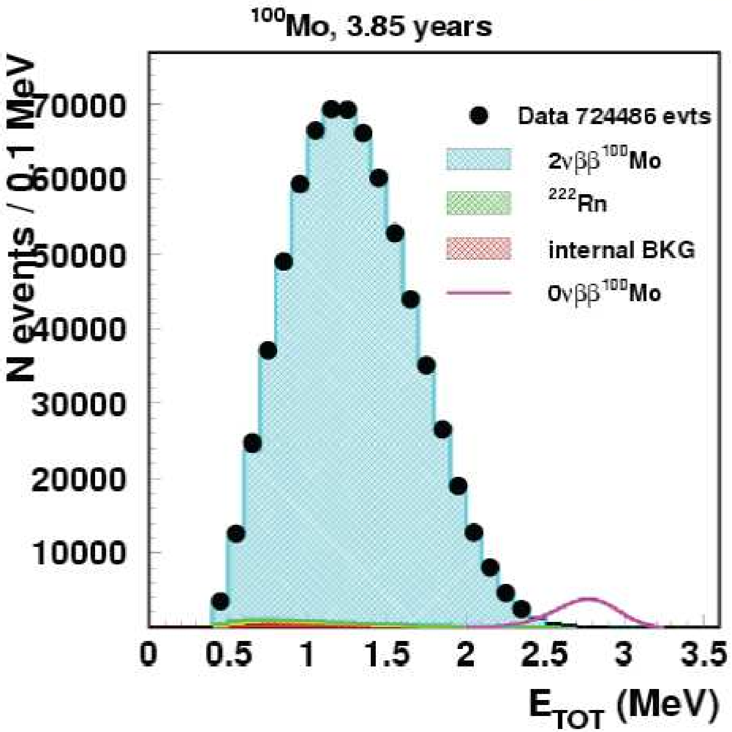


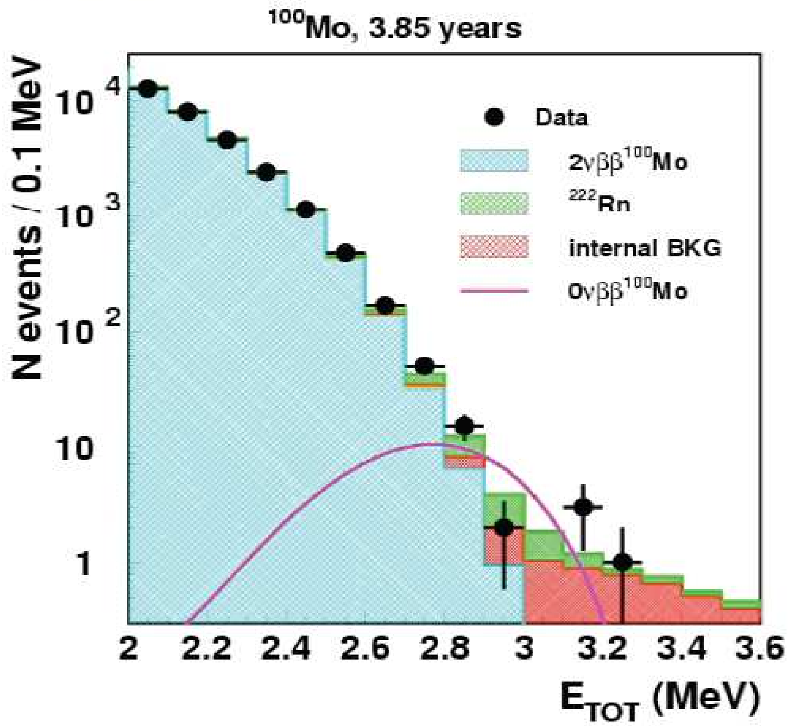
4.4 $^{+0.5}_{-0.4}$ (stat)± 0.4 (sys) 10^{19} y

ββ0ν results with ^{100}Mo

T_{obs} = 3.85 years
M(^{100}Mo) = 6.914 kg

Data until the end of 2008





[2.8 , 3.2] MeV:
Data: 20 events, Expected: 18.6 events
Excluded at 90% C.L. 9.6 events
Efficiency ε= 0.0726

MCLIMIT : [2.0, 3.2] eV
18 events excluded
Total mean 0ν efficiency ε = 0.174

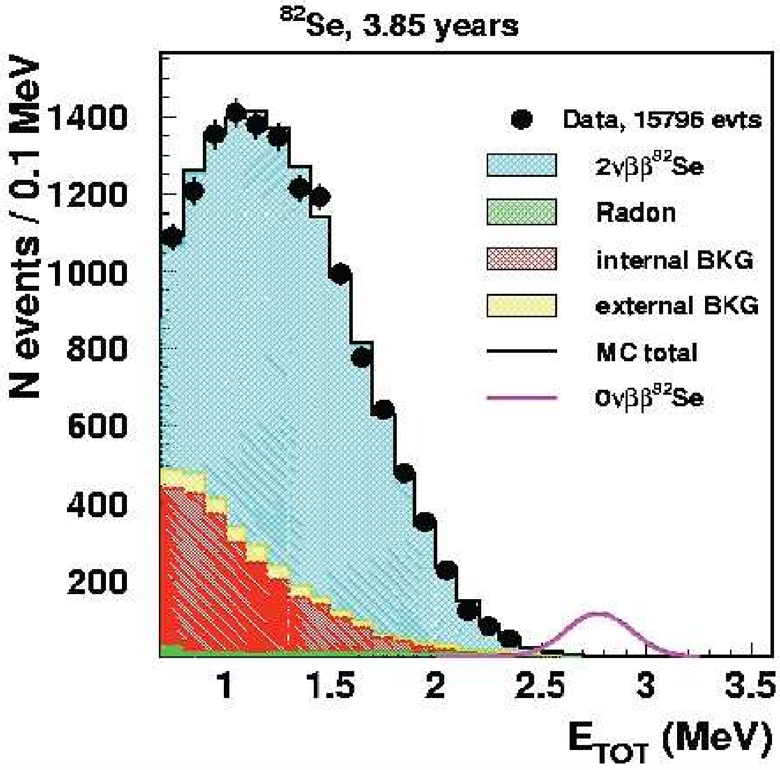
Both simple counting and likelihood methods are consistent

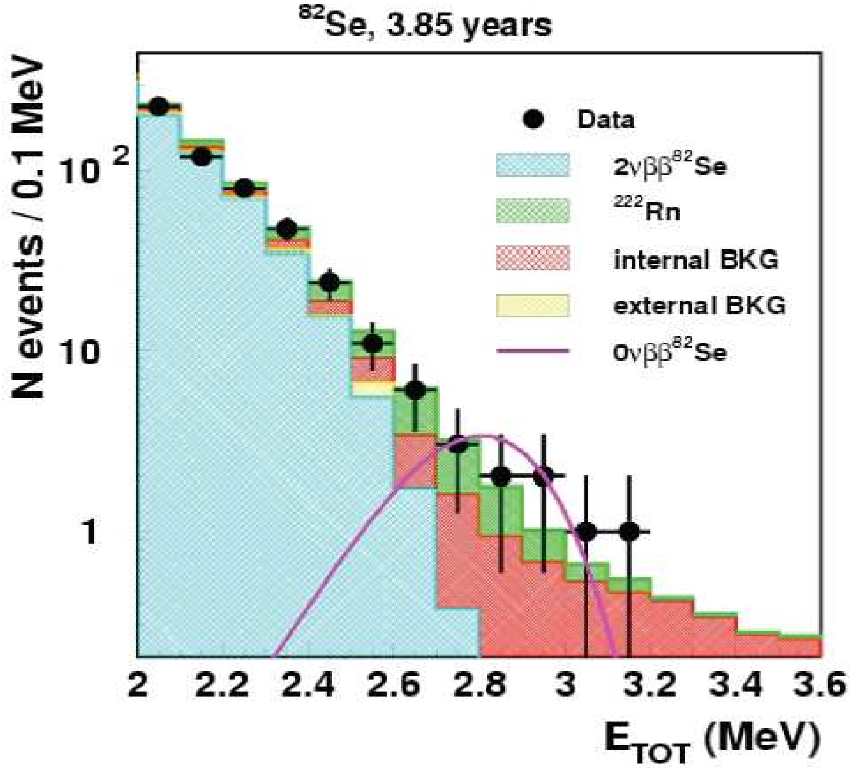
$T_{1/2}$ (0νββ) > 1.1 x 10^{24} y @ 90% C.L.
$\langle m_\nu \rangle$ < 0.45 – 0.93 eV

ββ0ν results with ^{82}Se

T_{obs} = 3.85 years
$M(^{82}Se)$ = 932 g

Data until the end of 2008





[2.6 , 3.2] MeV:
Data: 15 events, Expected: 13.2 events
Excluded at 90% C.L. 8.9 events
Efficiency ε= 0.151

MCLIMIT : [2.0, 3.2] MeV
9.8 events excluded
Total mean 0ν efficiency ε = 0.182

$T_{1/2}$ (0νββ) > 3.6 x 10^{23} y @ 90% C.L.
$\langle m_\nu \rangle$ < 0.89 – 1.61 eV

Summary

- **NEMO-3 running** until end 2010

- **The backgrounds have been measured** from the experimental data using different topologies of event (***NIM A606 (2009) 449-465***)

- **$T_{½}(\beta\beta2\nu)$ measured for 7 isotopes**: ^{48}Ca, ^{82}Se, ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{130}Te, ^{150}Nd

- **Activities of Radon (^{214}Bi) and ^{208}Tl**, the two most troublesome sources of bkg for $\beta\beta0\nu$ decay, have been measured with adequate precision.

  Bkg for ^{100}Mo (Phase 2) in the $\beta\beta0\nu$ energy window [2.8 – 3.2] MeV

  $\Rightarrow$ bkg ~ 0.5 cts/kg/year
  - $\beta\beta2\nu$ ~ 50%
  - Radon (~5 mBq/m^3) ~ 30%
  - ^{208}Tl (~100µBq/kq) ~ 20%

- **Preliminary results for $\beta\beta0\nu$ with ^{100}Mo and ^{82}Se**

  ^{100}Mo $T_{1/2}(\beta\beta0\nu) > 1.1\ 10^{24}$ years (90% C.L.) $\Rightarrow$ $<m_\nu> < 0.45 – 0.93$ eV

  ^{82}Se $T_{1/2}(\beta\beta0\nu) > 3.6\ 10^{23}$ years (90% C.L.) $\Rightarrow$ $<m_\nu> < 0.89 – 1.61$ eV

BACKUP

Summary of the different background components for ^{100}Mo in the $\beta\beta0\nu$ energy window [2.8 – 3.2] MeV

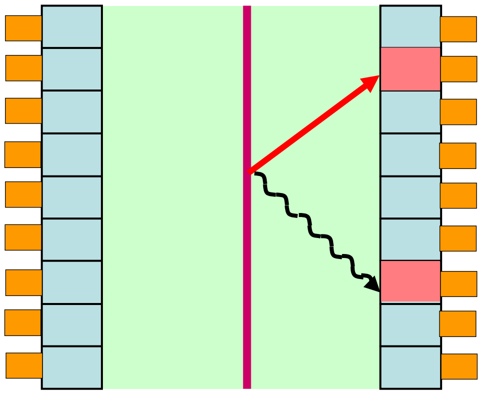
		# cts/kg/year [2.8 – 3.2] MeV	Fraction
$\beta\beta2\nu$	$T_{1/2}=7.10^{20}$y	0.25	**50%**
Radon ***(Phase 2)***	**5 mBq/m^3**		**30%**
– on the wires		0.1	
– on surface of the foil		0.05	
^{208}Tl in the foil	**~ 100 µBq/kg**	0.1	**20%**
TOTAL		**0.5**	*100%*

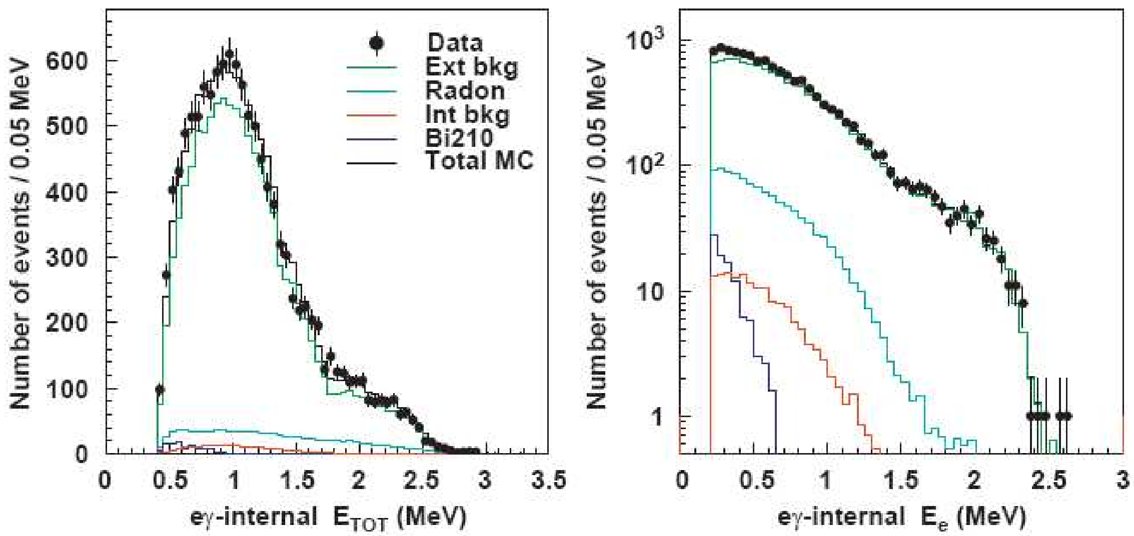
Bkg ~ 0.5 cts/kg/year
in the $\beta\beta0\nu$ energy window [2.8 – 3.2] MeV

Test of the background measurement with the Cu foils

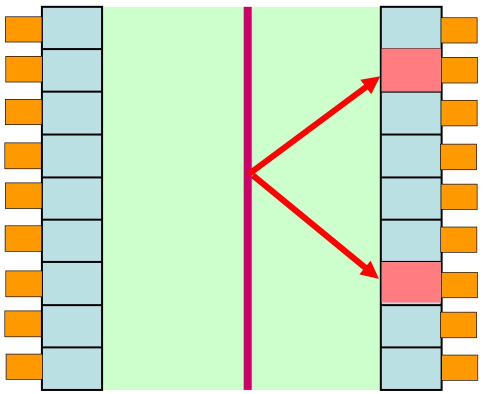
1 sector is equiped with very pure Copper foils

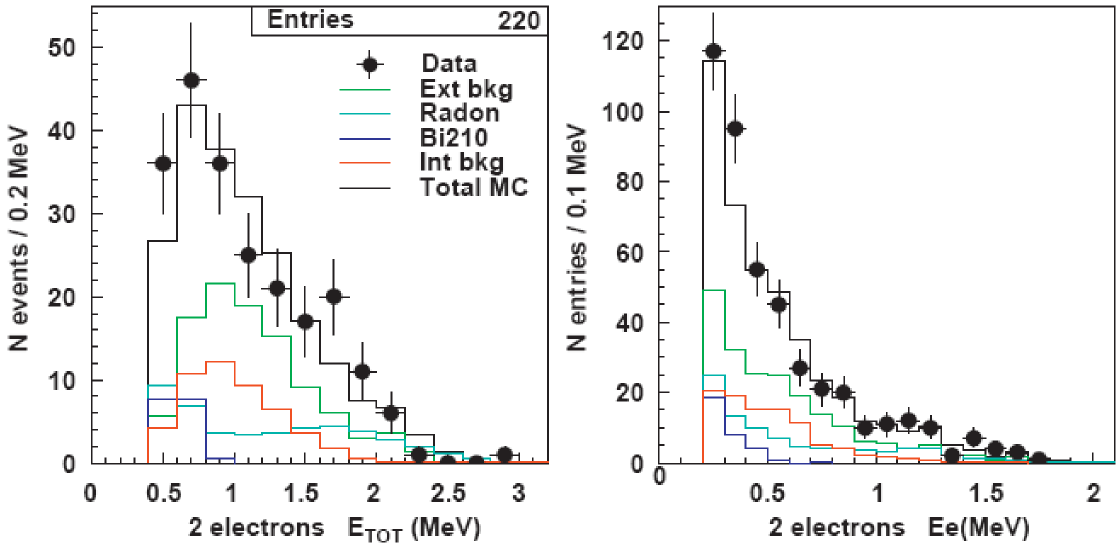
Internal e⁻,γ channel



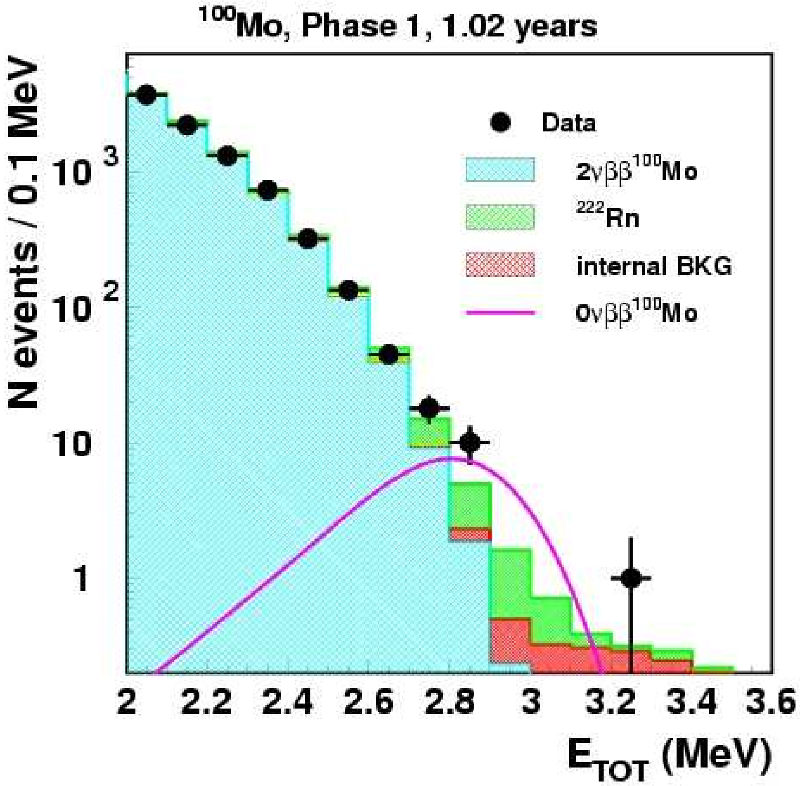


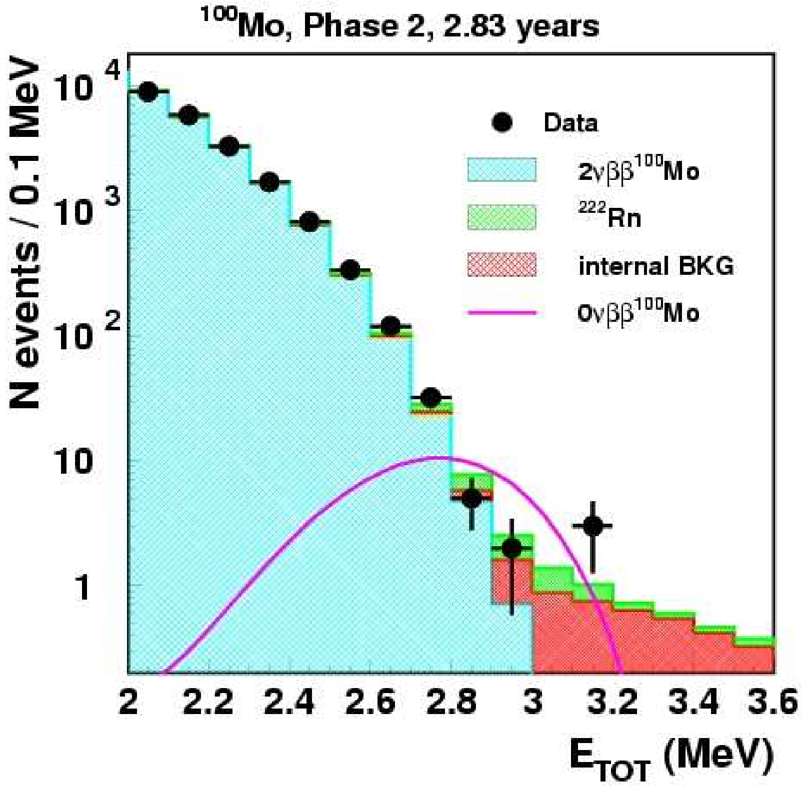
Internal e⁻,e⁻ channel
(ββ-like events)





$0\nu\beta\beta$ of ^{100}Mo

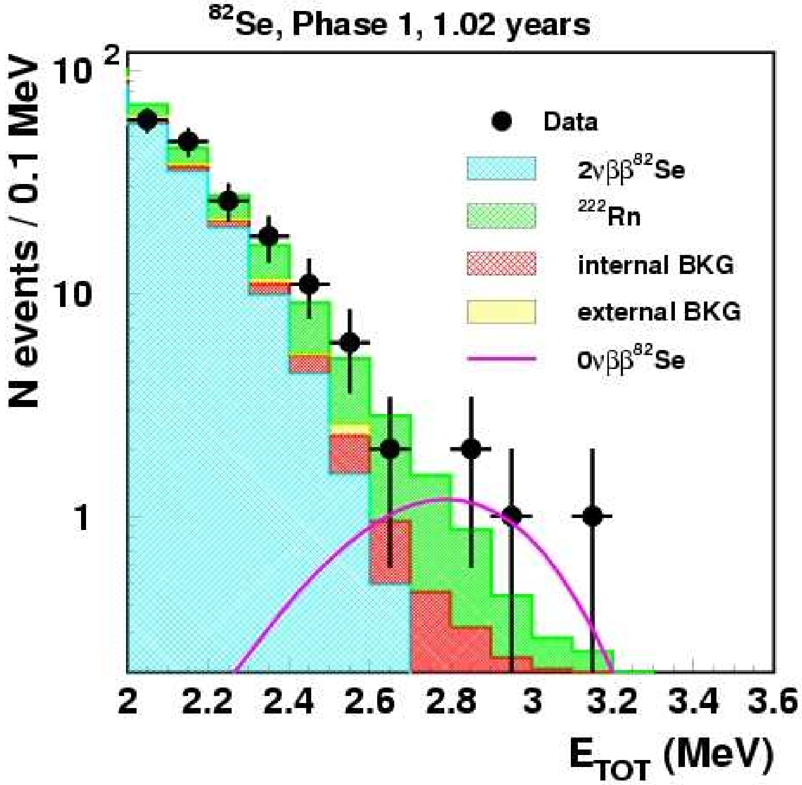


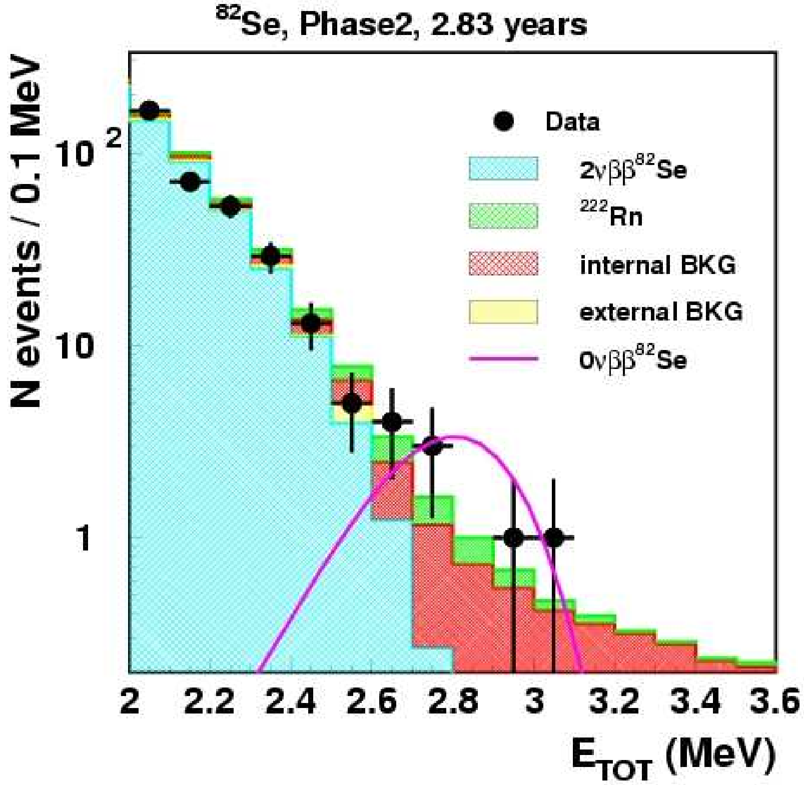


[2.8 , 3.2] MeV:
Data: 10 events, Expected: 7.4 events
Excluded at 90% C.L. 8.3 events
Efficiency ε= 0.0786

[2.8 , 3.2] MeV:
Data: 10 events, Expected: 11.2 events
Excluded at 90% C.L. 6.1 events
Efficiency ε= 0.0706

$0\nu\beta\beta$ of ^{82}Se





[2.6 , 3.2] MeV:
Data: 6 events, Expected: 5.8 events
Excluded at 90% C.L. 5.6 events
Efficiency ε= 0.159

[2.6 , 3.2] MeV:
Data: 9 events, Expected: 7.4 events
Excluded at 90% C.L. 7.4 events
Efficiency ε= 0.148

Summary of the ββ0ν results obtained with NEMO-3

- No evidence for non conservation of the lepton number
- Current limits on 0νββ (at 90% C.L.):

Isotope	Exposure (kg·y)	$T_{1/2}(0\nu\beta\beta)$ [years]	$\langle m_\nu \rangle$ [eV]	NME reference
^{100}Mo	26.6	$> 1.1 \cdot 10^{24}$	**< 0.45 – 0.93**	1-3
^{82}Se	3.6	$> 3.6 \cdot 10^{23}$	**< 0.9 – 1.6**	1-3
			< 2.3	7
^{150}Nd	0.095	$> 1.8 \cdot 10^{22}$	**< 1.5 – 2.5**	4,5
			< 4.0 – 6.8	6
^{130}Te	1.4	$> 9.8 \cdot 10^{22}$	**< 1.6 – 3.1**	2,3
^{96}Zr	0.031	$> 9.2 \cdot 10^{21}$	**< 7.2 – 19.5**	2,3
^{48}Ca	0.017	$> 1.3 \cdot 10^{22}$	**< 29.6**	7

- Nuclear Matrix Elements references:

[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] F.Simkovic, et al. Phys.Rev. C 77 (2008) 045503
[4] V.A. Rodin et al. Nucl.Phys. A 793 (2007) 213
[5] V.A. Rodin et al. Nucl.Phys. A 766(2006) 107
[6] J.H.Hirsh et al. Nucl.Phys. A 582(1995) 124
[7] E.Caurrier et al. Phys.Rev.Lett 100 (2008) 052503