Proposal to join NEMO-3 $\beta\beta$ decay experiment

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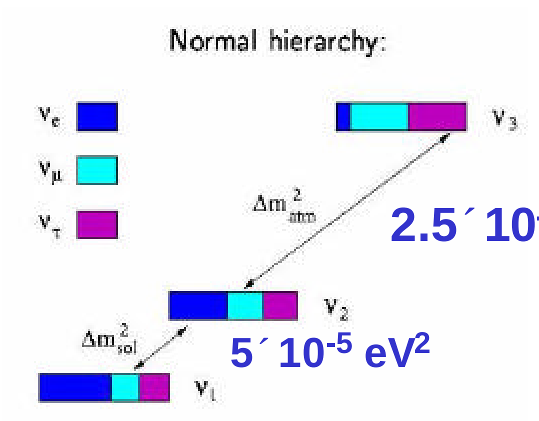
27 January 2003

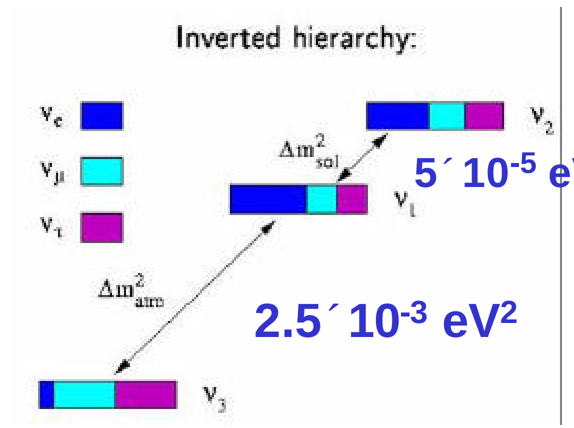
Motivation

Neutrino oscillations



2.5×10^{-3} eV^2

5×10^{-5} eV^2



5×10^{-5} eV^2

2.5×10^{-3} eV^2

$m_{scale} = 0.01$ eV

$m_{scale} = 0.05$ eV

Motivation

What neutrino oscillations can not do?

✓ **Nature of neutrino mass**

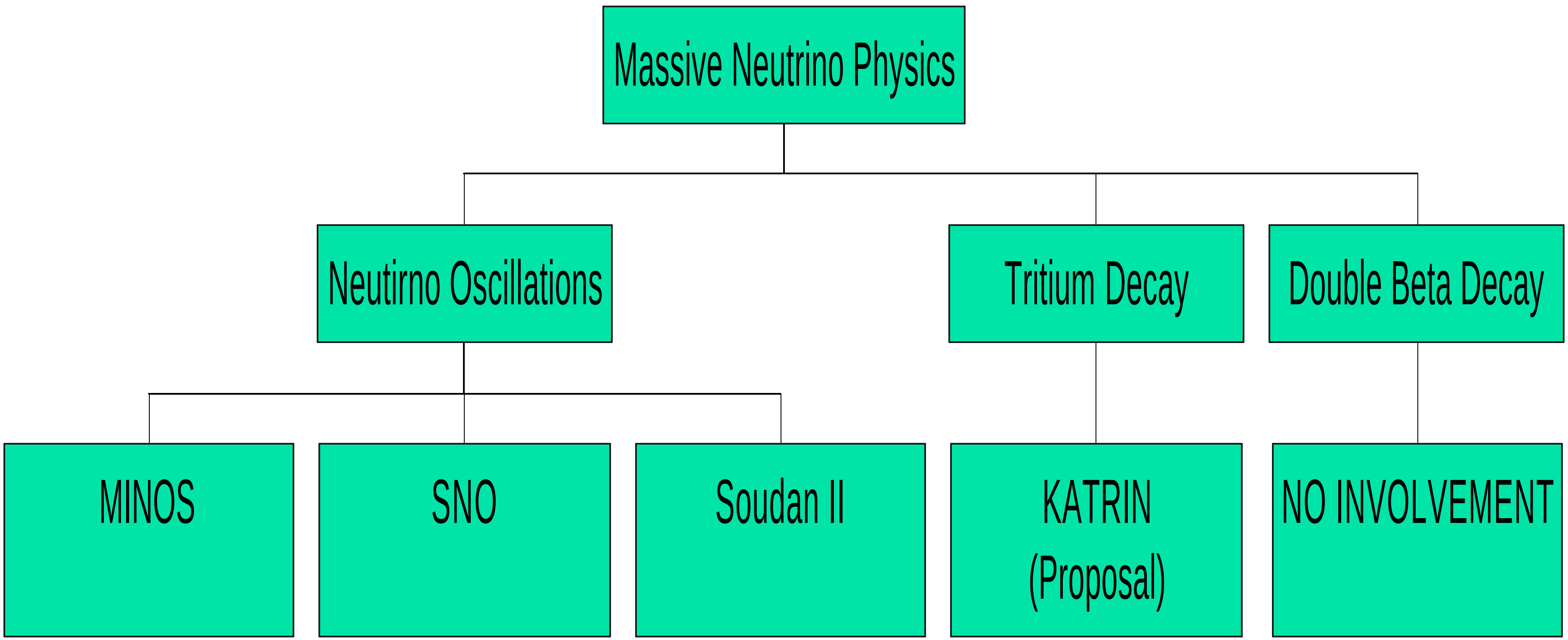
$$n \equiv \tilde{n}\ (Majorana)\ OR\ n \neq \tilde{n}\ (Dirac)$$

✓ **Absolute mass scale**

$$bb\ decay\ \ and\ direct\ kinematic\ searches$$

$$({}^{3}H\ b\ decay)$$

UK Involvement. Current Picture

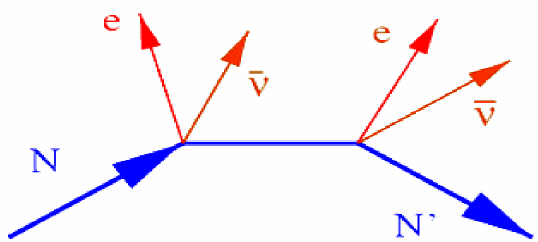


ββ decay basics

Most sensitive neutrino mass measurements
can be obtained from double-beta decay

2ν ββ decay: a standard process in nuclear physics

~ 10^{20} yr

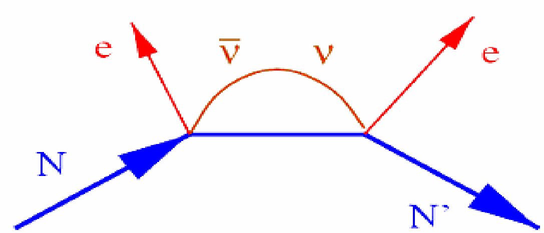


0ν ββ decay: a hypothetical process

→ $m_\nu \neq 0$ since helicity has to "flip"

→ $\bar{\nu} = \nu$

> 10^{25} yr



$$< m_n >^2 = \left| \sum_i^N U_{ei}^2 m_i \right|^2 = \left| \sum_i^N |U_{ei}|^2 e^{a_i} m_i \right|^2$$

Mixing matrix

Majorana CP phases

$$(A,Z) \rightarrow (A,Z+2) + \underbrace{e^- + e^-}_{T_{kin}} + \tilde{n} + \tilde{n} \qquad 2n$$

$$(A,Z) \rightarrow (A,Z+2) + \underbrace{e^- + e^-}_{T_{kin}} \qquad 0n$$

$$(A,Z) \rightarrow (A,Z+2) + \underbrace{e^- + e^-}_{T_{kin}} + c^0 \qquad 0n\ c$$

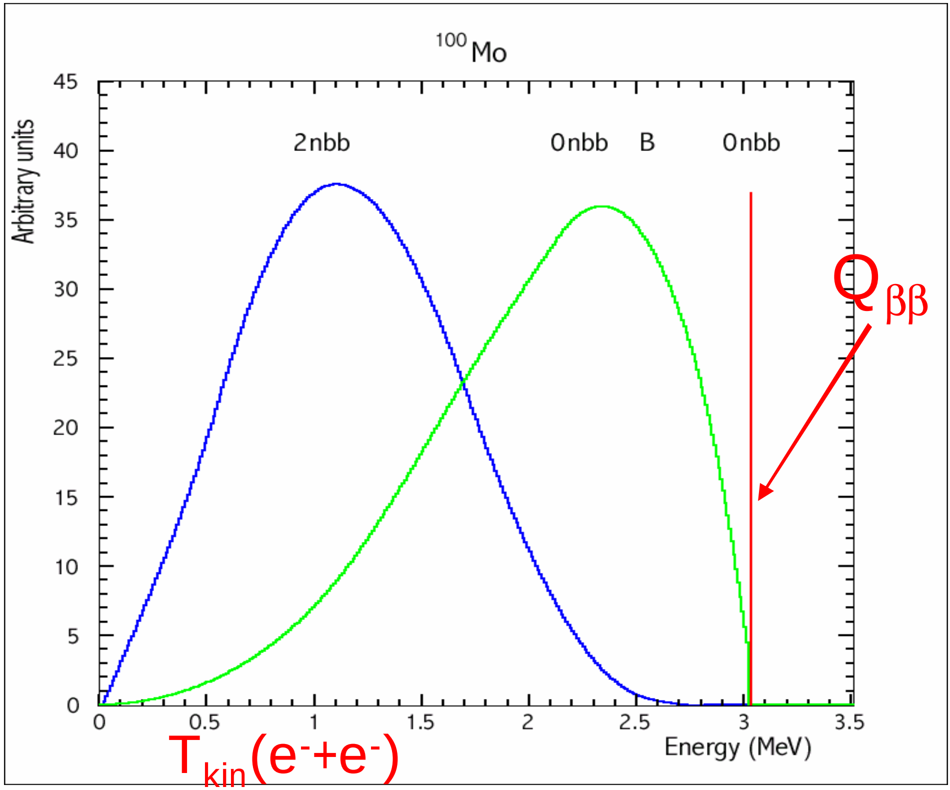
$$\left[T_{1/2}^{0n}\right]^{-1} = G^{0n}(Q_{bb})\left|M^{0n}\right|^2 < m_n >^2$$

Phase space

Nuclear matrix element

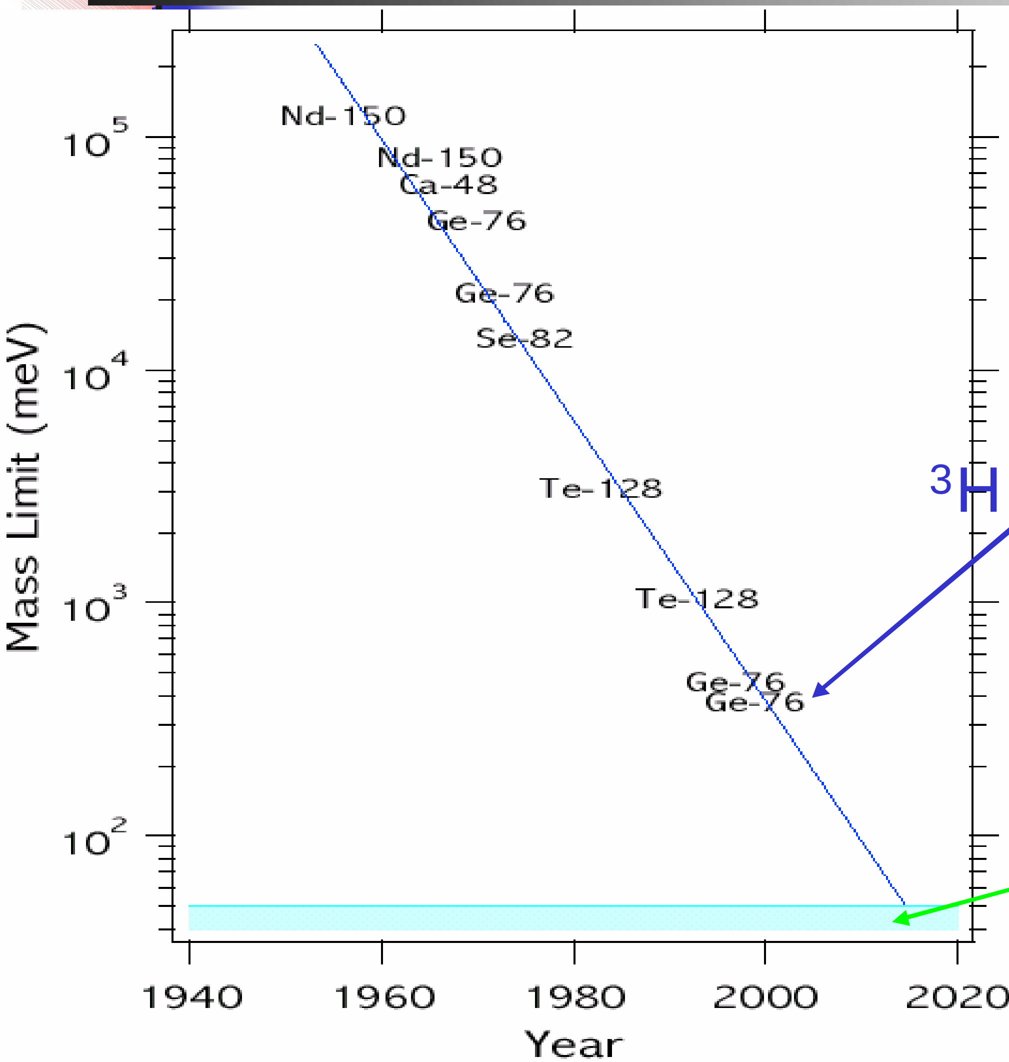
(0.35 – 1 eV)

^{48}Ca, ^{76}Ge, ^{100}Mo, ^{150}Nd, ^{136}Xe, ^{116}Cd, ^{96}Zr, ^{82}Se, ^{130}Te



Due to uncertainties in M^{0n} we have to study as many isotopes as possible!

ββ decay reach

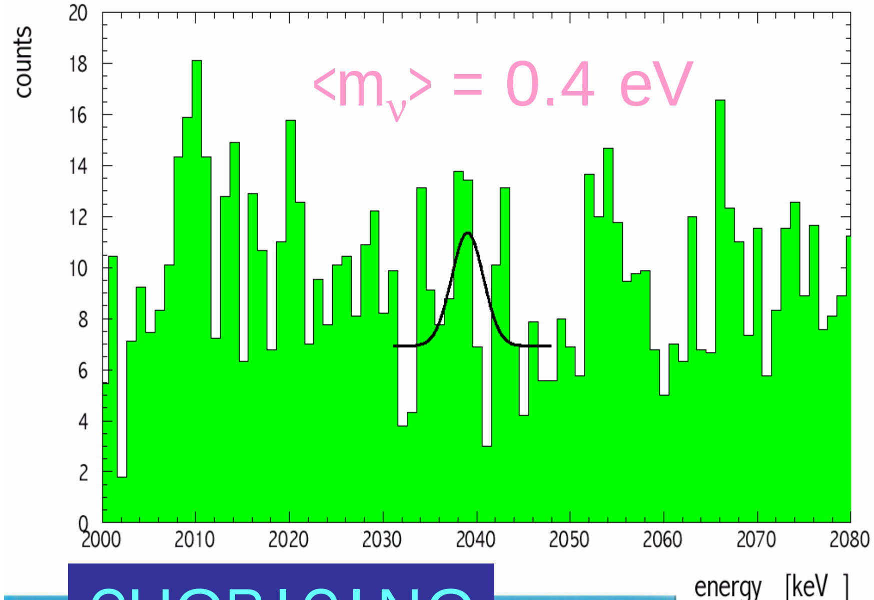


Future ββ projects: CUORE, Majorana, EXO, etc to have ≤ 0.05 eV sensitivity (~ 2008 – 2010)

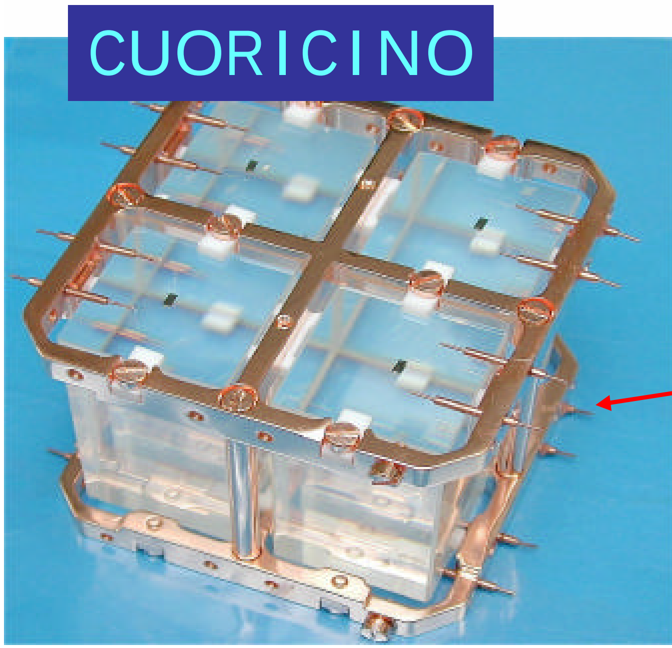
^{3}H expts sensitivity in ~ 2008

m_{scale} ~ 0.01 – 0.05 eV from oscillation expts

Short-term future: now - 2007



"Evidence" strongly criticized by bb community



by 2007
0.1 – 0.7 eV
with
^{130}Te
and
(^{100}Mo, ^{82}Se, ^{116}Cd)

NEMO-3 Collaboration

50 physicists and engineers

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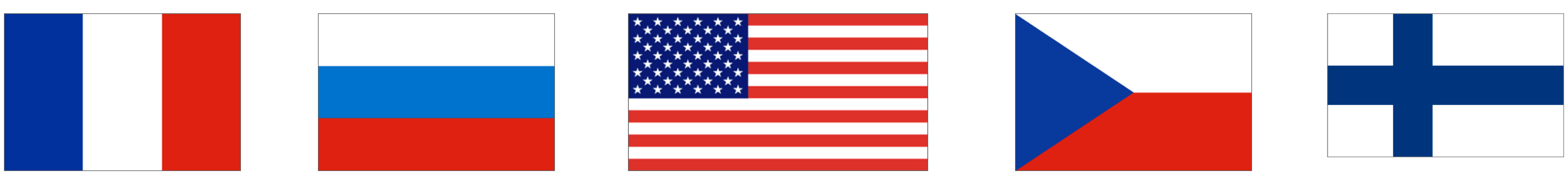
12 Laboratories/Universities

•

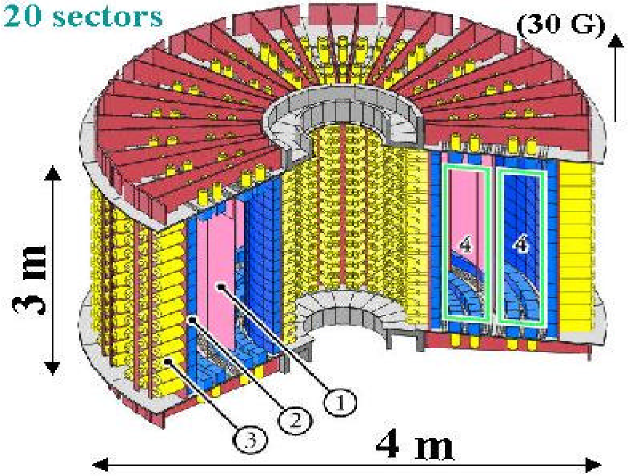
5 Countries



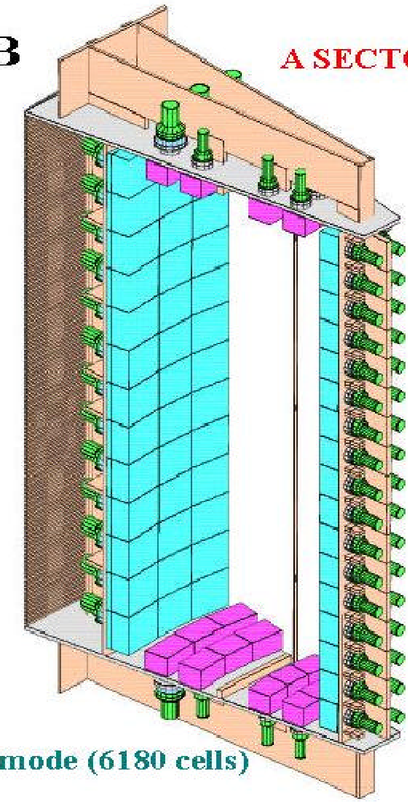
The NEMO3 detector

Fréjus Undergroud Laboratory : 4800 m.w.e.

20 sectors



A SECTOR



Source :

10 kg of ββ isotopes

cylindrical, S = 20 m², e = 50 μm

Tracking detector :

Gas mixture of Helium + ethyl alcohol

Drift wire chamber operating in Geiger mode (6180 cells)

Calorimeter :

1940 plastic scintillators coupled to low radioactivity PMs ;

σ(E)/E at 3 MeV ~ 3.5%

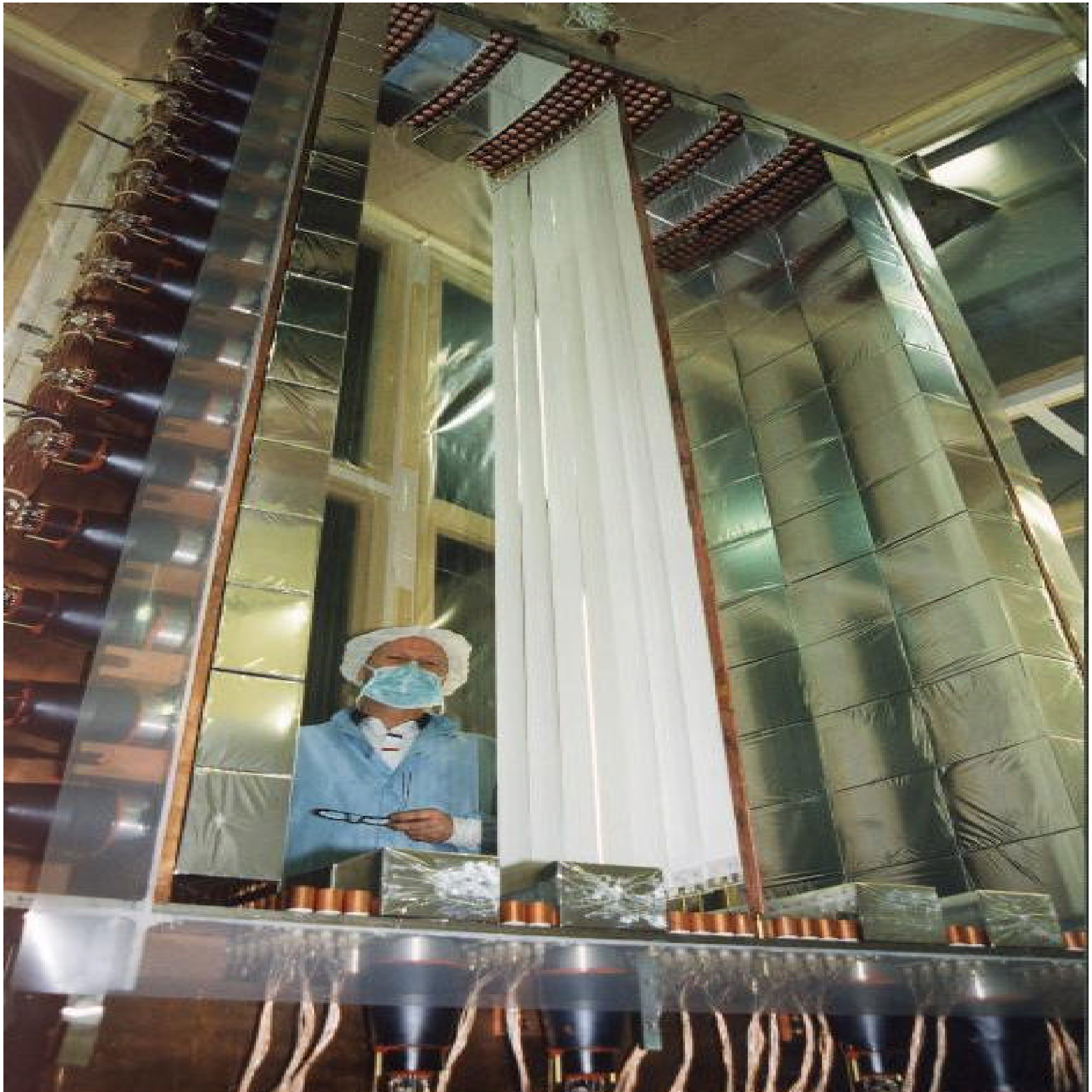
+ Magnetic field + Iron shielding + Neutron shielding

Identification : e^-, e^+, γ, n and delayed-α

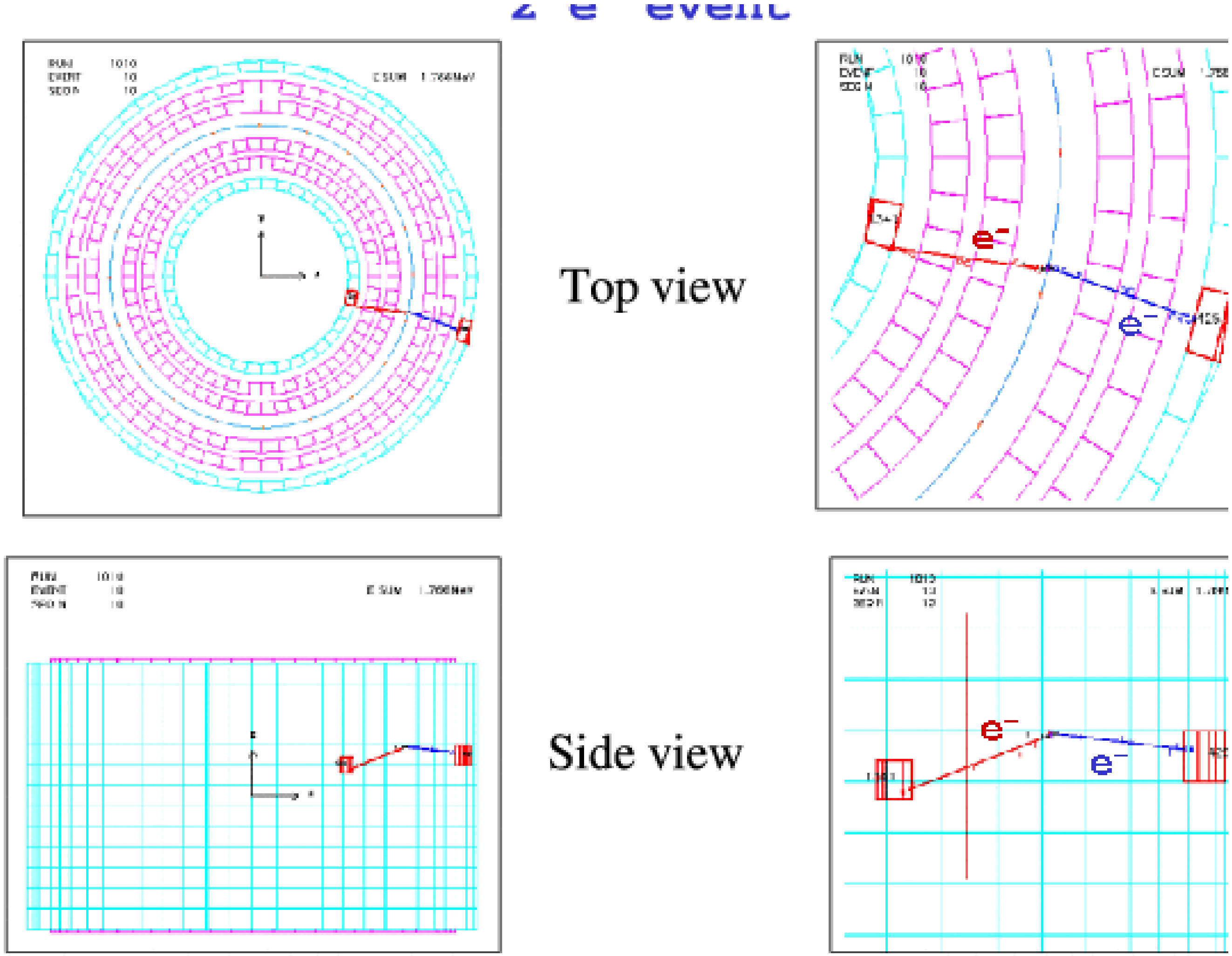
→ ββ events detection

→ Measurement of source radiopurity

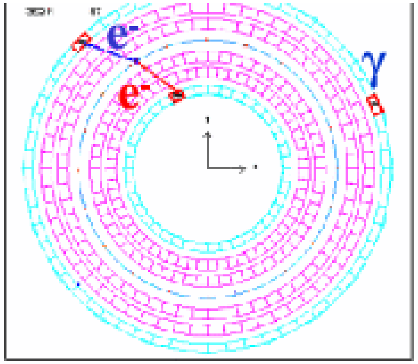
→ Background rejection



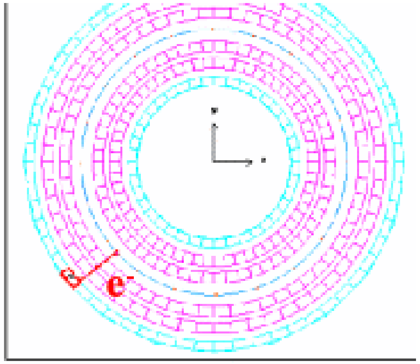
Data taking



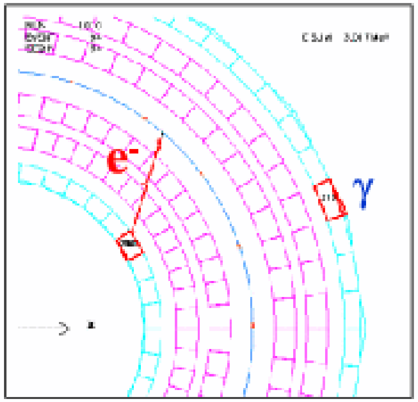
Data taking

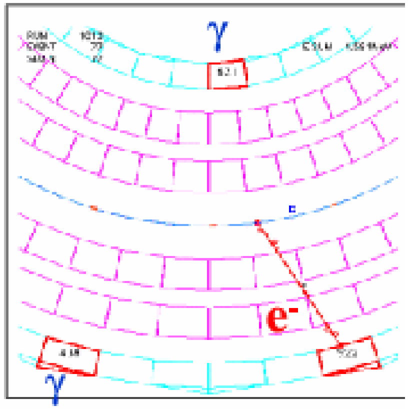


2 e^- + γ channel → ββ excited states



e^- channel → backgrou





e^- + γ channel → Internal contaminations ← e^- + γ γ channel

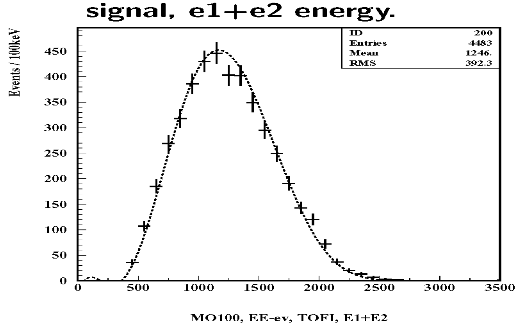
✓Complicated analysis

- ββ detection (10^5 2ν events/y !!! for ^{100}Mo)
- BG rejection techniques
- Source contamination measurements (for future developments)

✓Running since June'02 but only 200 hrs ^{100}Mo carefully analysed

Vladimir Vasiliev, ITEP Dubna, October 2002

NEMO-3 first data ($\sim$ 200h). ^{100}Mo $2\beta2\nu$ signal, e1+e2 energy.

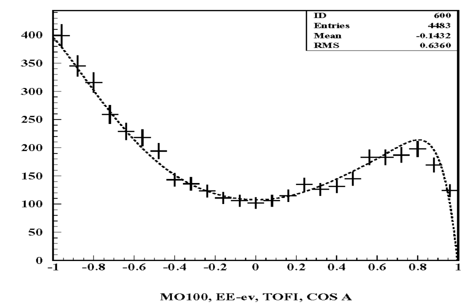


$$T_{1/2}^{2\beta2\nu} = (0.8 \pm 0.1(\mathrm{stat.} + \mathrm{syst.})) \cdot 10^{19}\mathrm{y.}$$
$$T_{1/2}^{2\beta0\nu} > 3.3 \cdot 10^{22}\mathrm{y.}(90\%\mathrm{C.L.})$$
$$T_{1/2}^{2\beta0\nu M} > 1.6 \cdot 10^{21}\mathrm{y.}(90\%\mathrm{C.L.})$$

1

Vladimir Vasiliev, ITEP Dubna, October 2002

^{100}Mo $2\beta2\nu$ signal, angle between the electrons.



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October visit summary: Significant shortage in manpower for data analysis. We are welcome to start right away

Possible UK involvement in data analysis

Isotope	Mass, g
^{100}Mo	7200
^{130}Te	1300
^{82}Se	1000
^{116}Cd	600
^{150}Nd	50
^{96}Zr	20
^{48}Ca	10

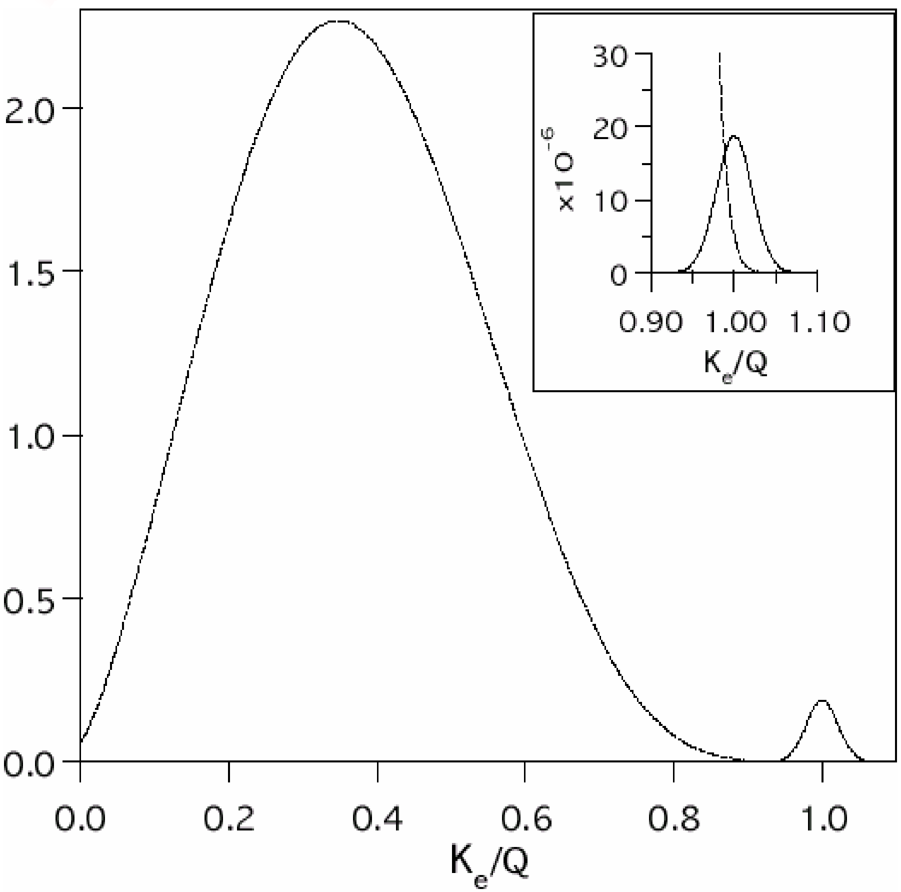
- Isotopes "distributed" between institutions
- We are suggested to take up analysis of ^{82}Se (NEMO3 upgrade isotope)

NEMO-3 sensitivity
5 years

E = 2.8 – 3.2 MeV

^{100}Mo	^{82}Se
7 kg $Q_{\beta\beta}$ =3.034 MeV	1 kg $Q_{\beta\beta}$ =2.995 MeV
External BG: 0	External BG: 0
Internal BG:	Internal BG:
radioactivity < 0.04 event/y/kg	radioactivity < 0.01 event/y/kg
$2\nu\beta\beta$ = 0.11 event/y/kg	$2\nu\beta\beta$ = 0.01 event/y/kg
⇓	⇓
$T_{1/2} > 5 \times 10^{24}$ yr	$T_{1/2} > 1 \times 10^{24}$ yr
⇓	⇓
$\langle m_\nu \rangle < 0.2 – 0.7$ eV	$\langle m_\nu \rangle < 0.6 – 1.2$ eV

Possible UK involvement Upgrade of NEMO-3



- 12 kg ^{82}Se
- Why ^{82}Se?

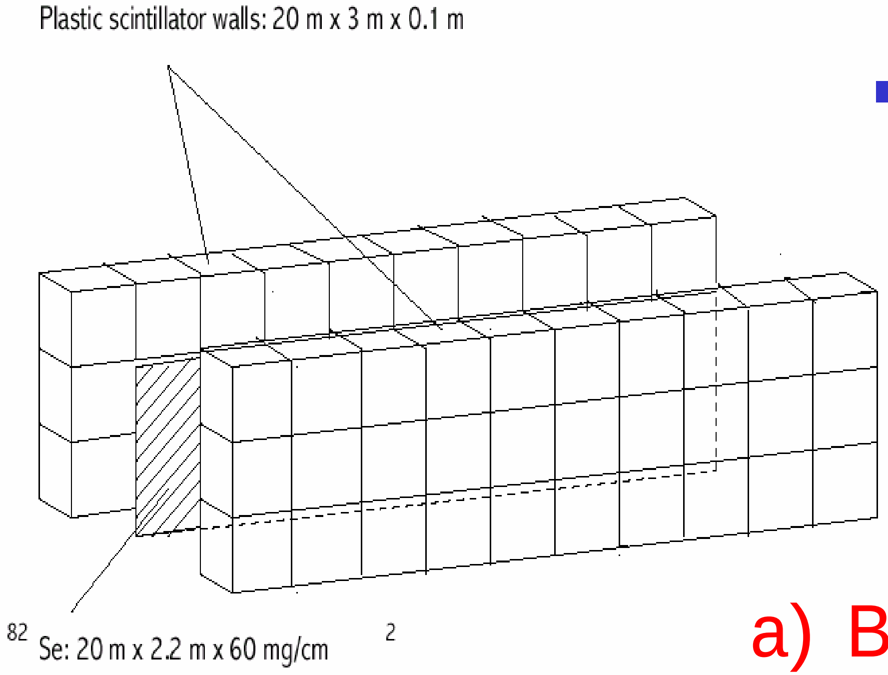
$$\frac{T_{1/2}^{2n}(^{82}Se)}{T_{1/2}^{2n}(^{100}Mo)} \;\square\; 10$$

And theory says there is NO $T_{1/2}^{2n}$ □ $T_{1/2}^{0n}$ scaling

- Improve S/B by ~10
- Sensitivity $\langle m_\nu \rangle$~0.14 eV in 5 yr

SuperNEMO

~ 100 kg ^{82}Se (or other)



4 supermodules, planar geometry

- Sensitivity
  $\langle m_\nu \rangle \sim 0.05$ eV in 5 yr

Feasible if:

a) BG only from 2ν (NEMO3)

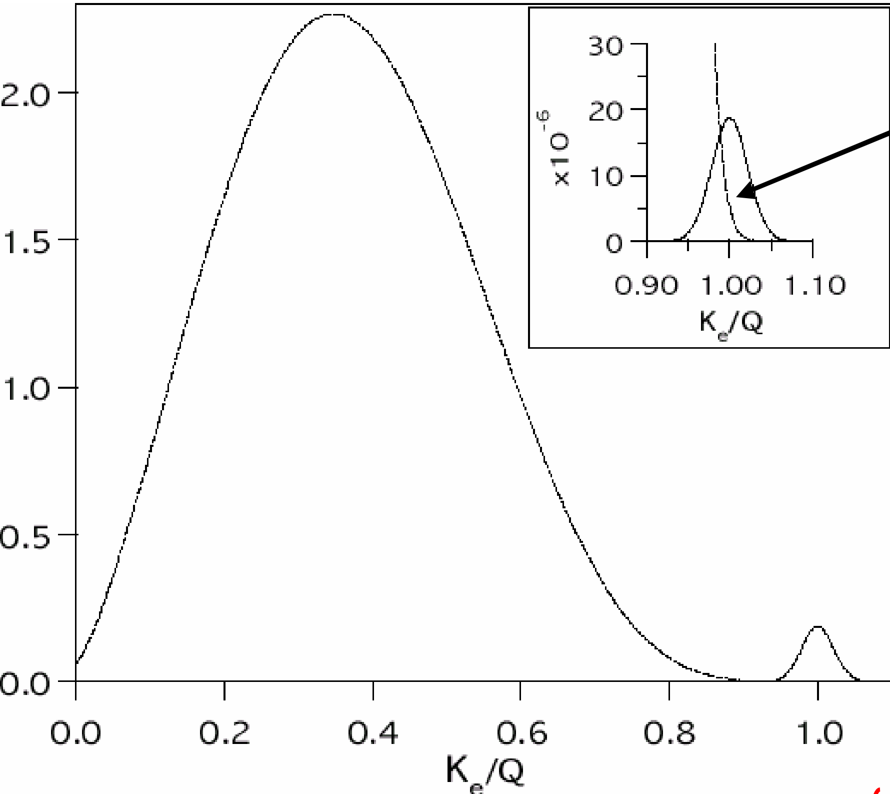
b) $\Delta E/E$ = 10-11% at 1 MeV (R&D needed)

Future ββ projects comparison "Conservative" approach

Experiment	Source and Mass	Sensitivity to $T_{1/2}$ (y)	Sensitivity to $\langle m_\nu \rangle$ (eV)*
Majorana	^{76}Ge, 500kg	3×10^{27}	0.03 – 0.07
CUORE	^{130}Te, 750kg(nat)	2×10^{26}	0.05 – 0.17
EXO (or other Xe-expt)	^{136}Xe 1 ton	8×10^{26}	0.05 – 0.12
SuperNEMO	^{82}Se(or other) 100 kg	2×10^{26}	0.05 – 0.11

* 5 different latest NME calculations

SuperNEMO – UK involvement
Scintillator R&D



$$Fraction(2n) \propto \left(\frac{\Delta E}{Q_{bb}}\right)^6$$

Improving ΔE/E from 9% to 6% (at 3 MeV) will reduce BG by a factor of ~ 10

Increase light output

- ✓ Scintillator studies
- ✓ Light collection
- ✓ PMT-scntillator optical coupling
- ✓PMT studies

matches our experience (MINOS)

Milestones & Responsibilities 2003-2004

- MC of 2e and BG events from ^{82}Se (Saakyan, New PostDoc)
- Off-line DA for ^{82}Se, cross-check with other isotopes (Adamson, NewPostDoc, Saakyan, Thomas)
- Laser LI calibration/monitoring (Adamson, Thomas)
- Scintillator R&D for SuperNEMO (Saakyan, Thomas, NewPostDoc, Technician)
- DAQ/electronics for R&D setup (Adamson, NewPostDoc, Software Engineer)
- DA from R&D setup (Adamson, NewPostDoc, Saakyan, Thomas)

Costs

Item	2003	2004
Rolling Grant Costs		
UCL Technician Saakyan	20% 30%	20% 30%
Extra costs to PPARC		
Equipment Travel Responsive RA	£10K £5K £50K	£10K £5K £50K
PPARC Fellows		
Adamson Thomas	30% 30%	30% 30%

Concluding Remarks

- Absolute m_ν is a hottest topic
- $0\nu\beta\beta$ is the only practical approach for Majorana ν's
- Next generation DBD experiments to probe ~ 0.05 eV scale
- Participation in NEMO-3 is a good opportunity to understand feasibility of this technique...
- ...and to put UK in the DBD arena