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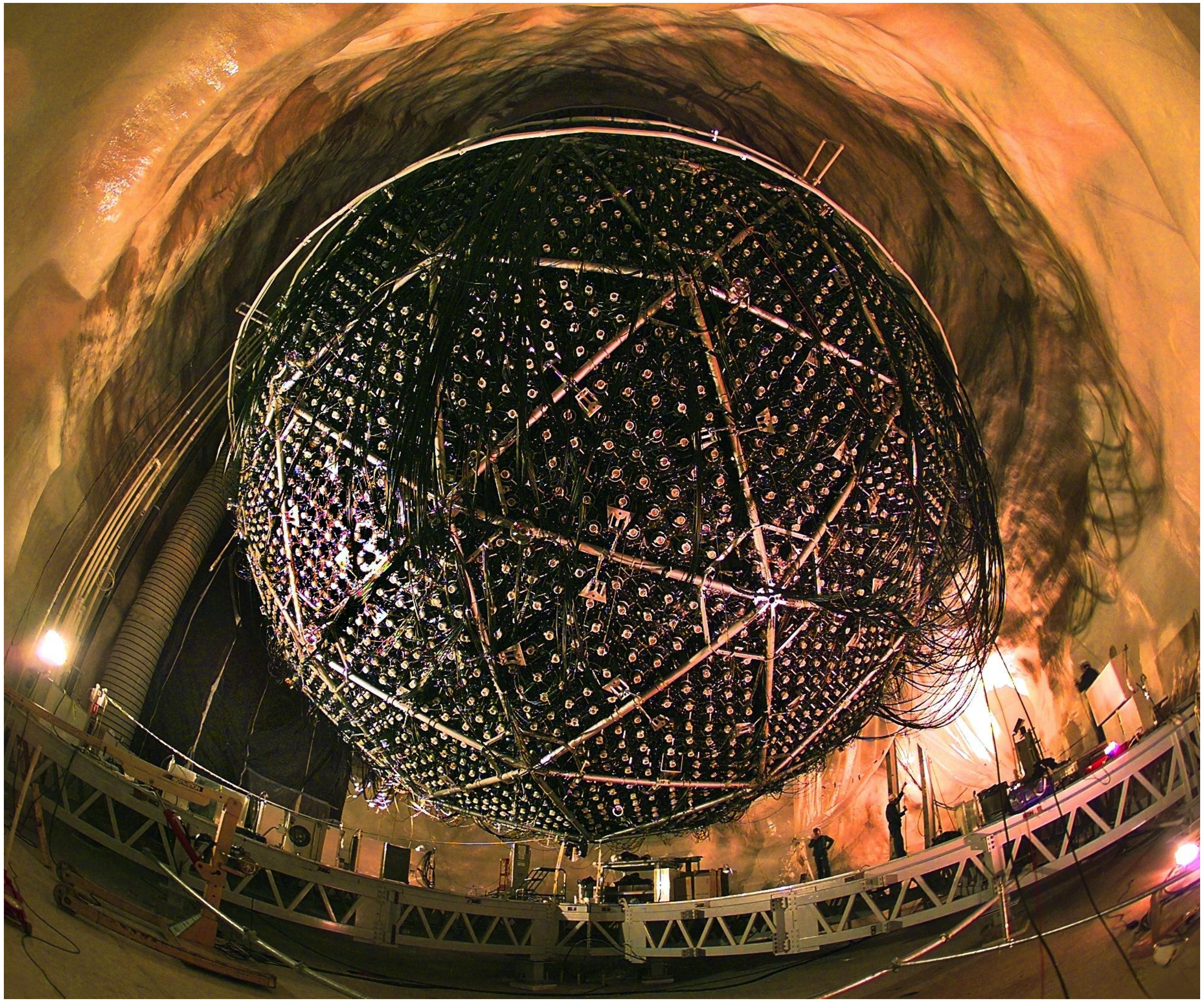
Neutrinoless double-beta decay

Simon JM Peeters

IoP joint HEPP/APP meeting, QMUL, April 2012

Content

- Introduction
  - $2\nu\beta\beta$
  - $0\nu\beta\beta$
- Current and future experiments
- Overview
- Conclusions



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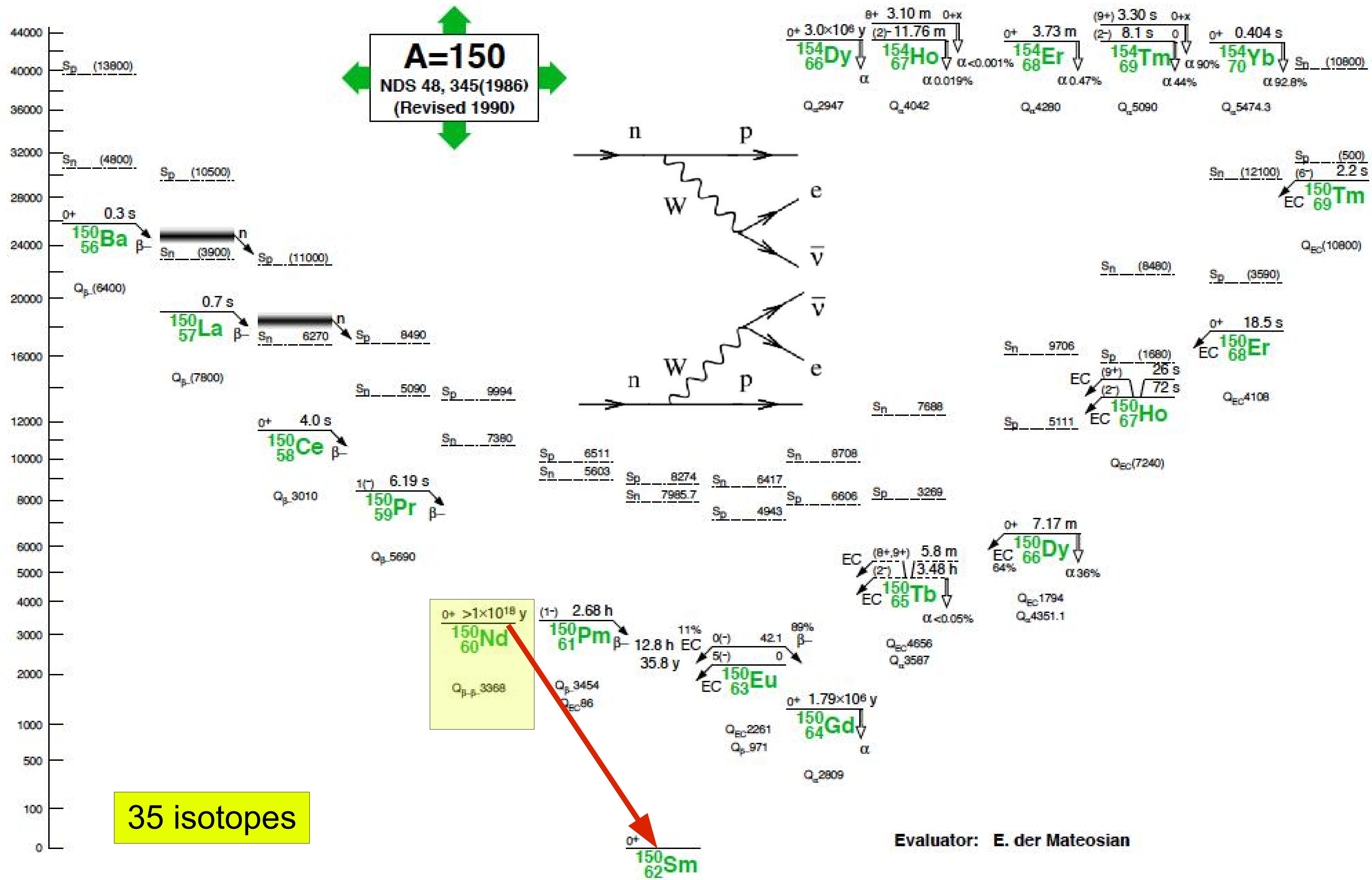
Double beta decay



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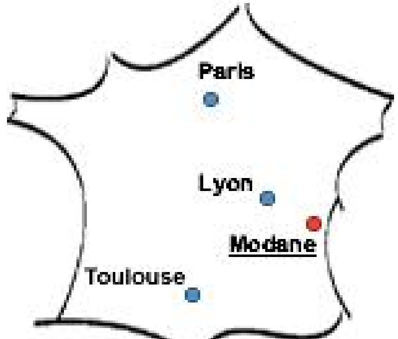
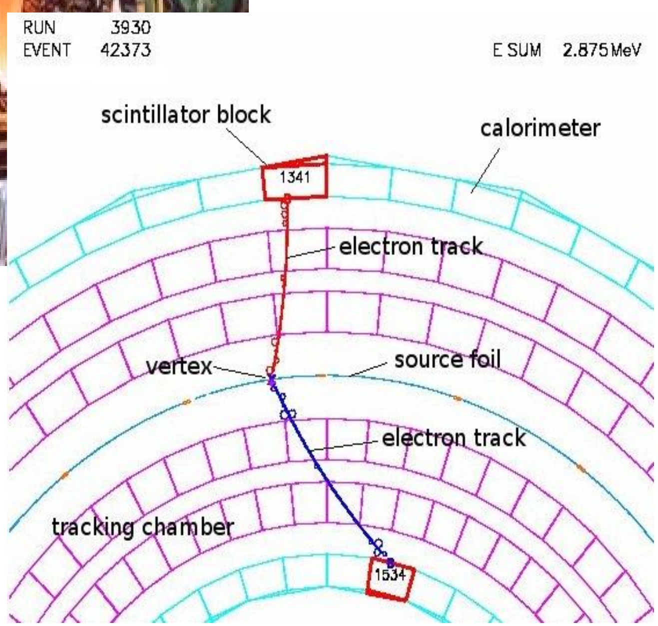
NEMO-3

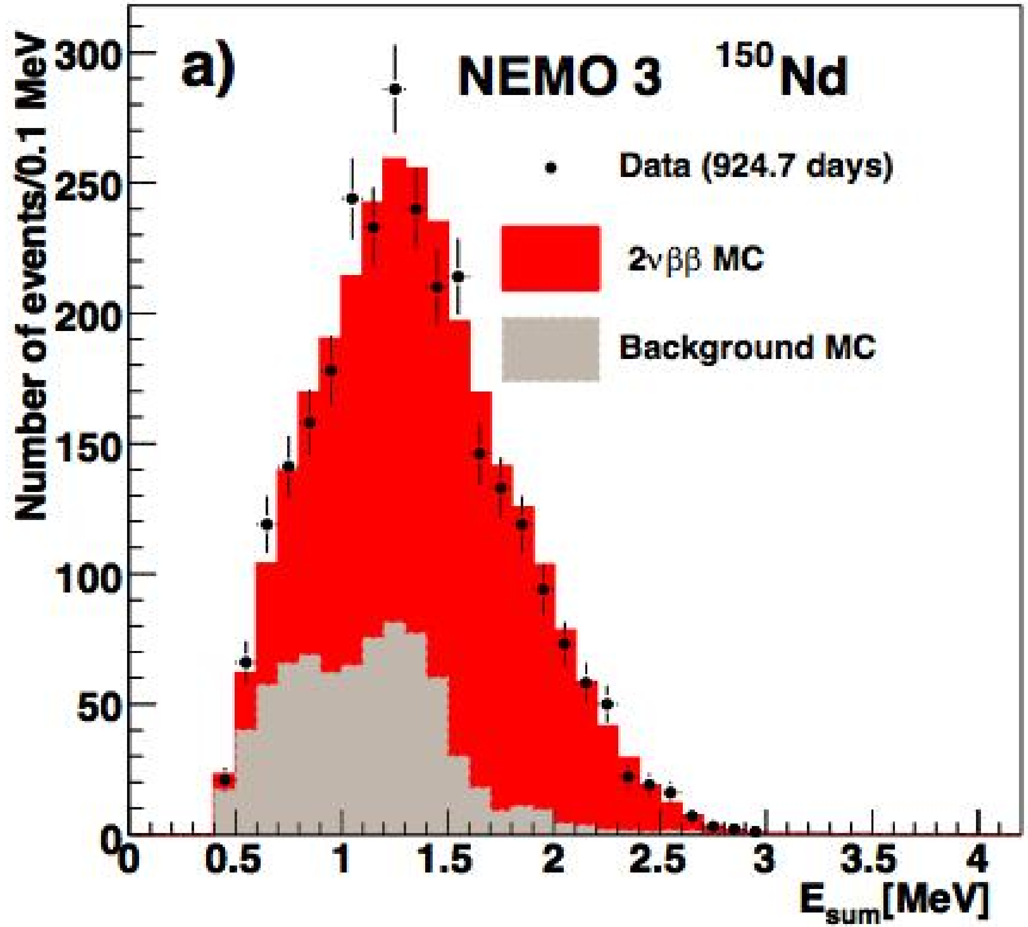
ArXiv:0810.0248

Fréjus





^{100}Mo $2\nu\beta\beta$ candidate



$$T^{2\nu}_{1/2} = (9.11^{+0.25}_{-0.22}(\text{stat.}) \pm 0.63\ (\text{syst.})) \times 10^{18}\ \text{y}$$

Also measured half-lifes for: ^{100}Mo, ^{82}Se, ^{48}Ca, ^{96}Zr, ^{116}Cd, ^{130}Te

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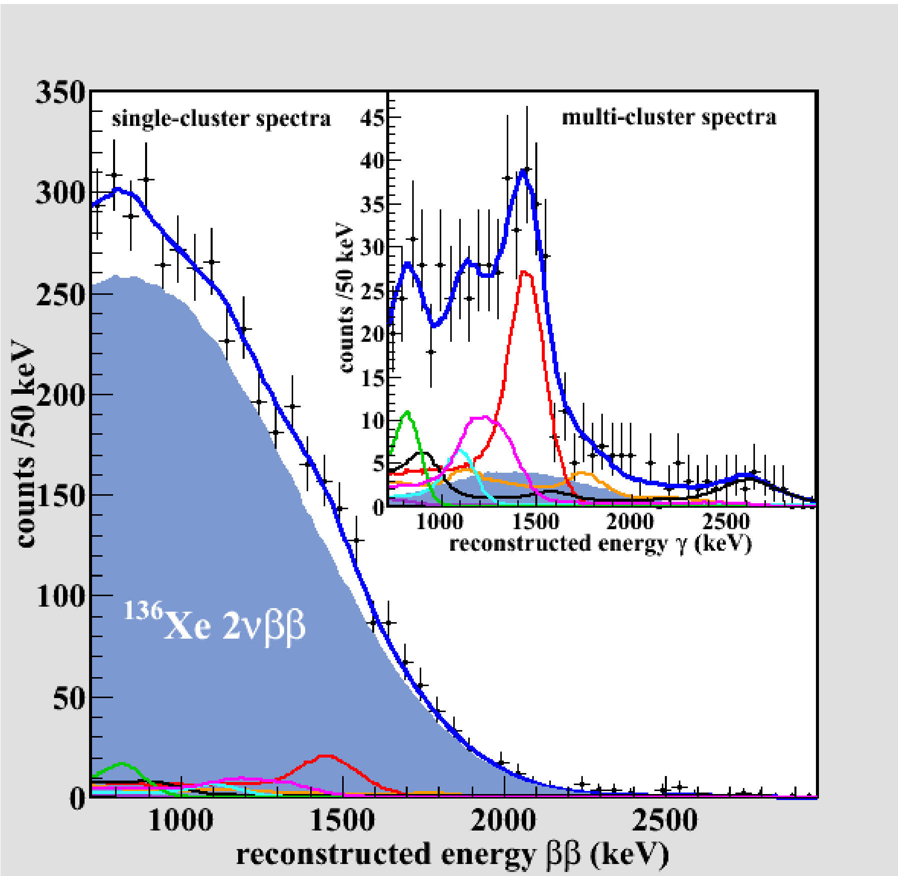
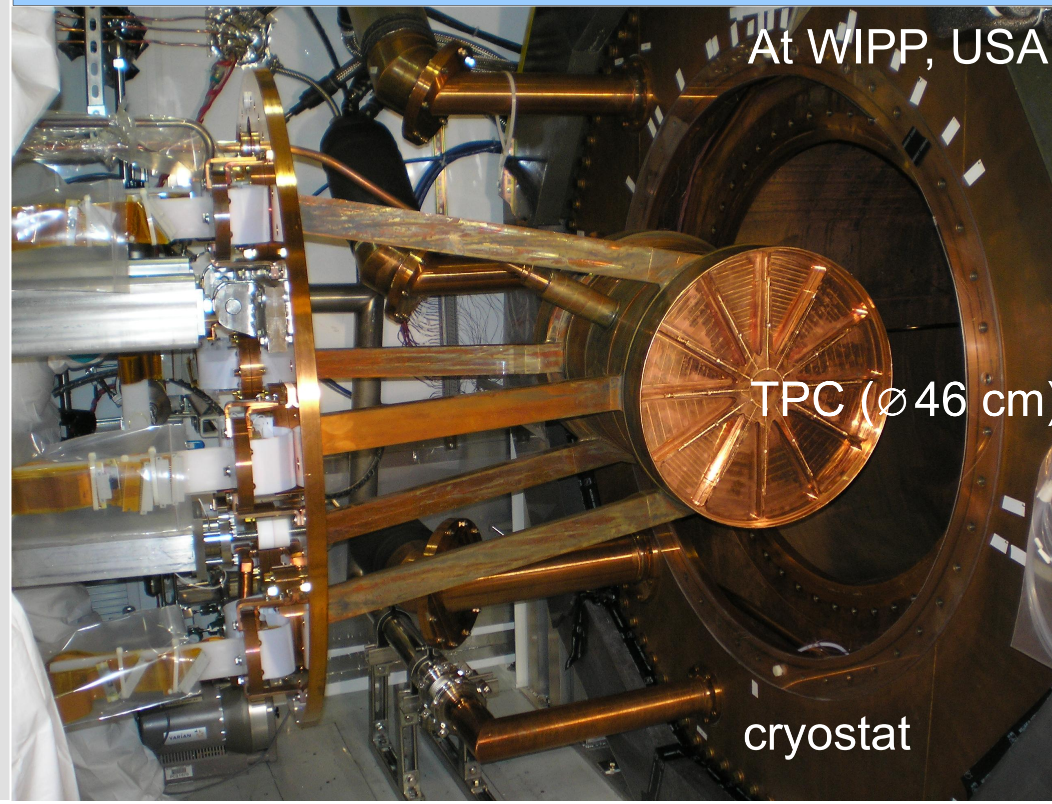
EXO-200



175 kg enriched ^{136}Xe to 80.6% **arXiv:1108.4193**



$$T_{1/2} = 2.11 \pm 0.04(\text{stat.}) \pm 0.21(\text{sys.}) \times 10^{21}\ \text{yr}$$

Previous numbers:
2.1 x 10^{22} (Th) Europhys. Lett. 13 (1990) 31
> 1.0 x 10^{22} (Exp) Phys. Let. B 546 (2002) 23–28
> 8.5 x 10^{21} (Exp) Phys. At. Nucl. 69 (12), 2129–2133 (2006)
New result confirmed by KamLAND – more later

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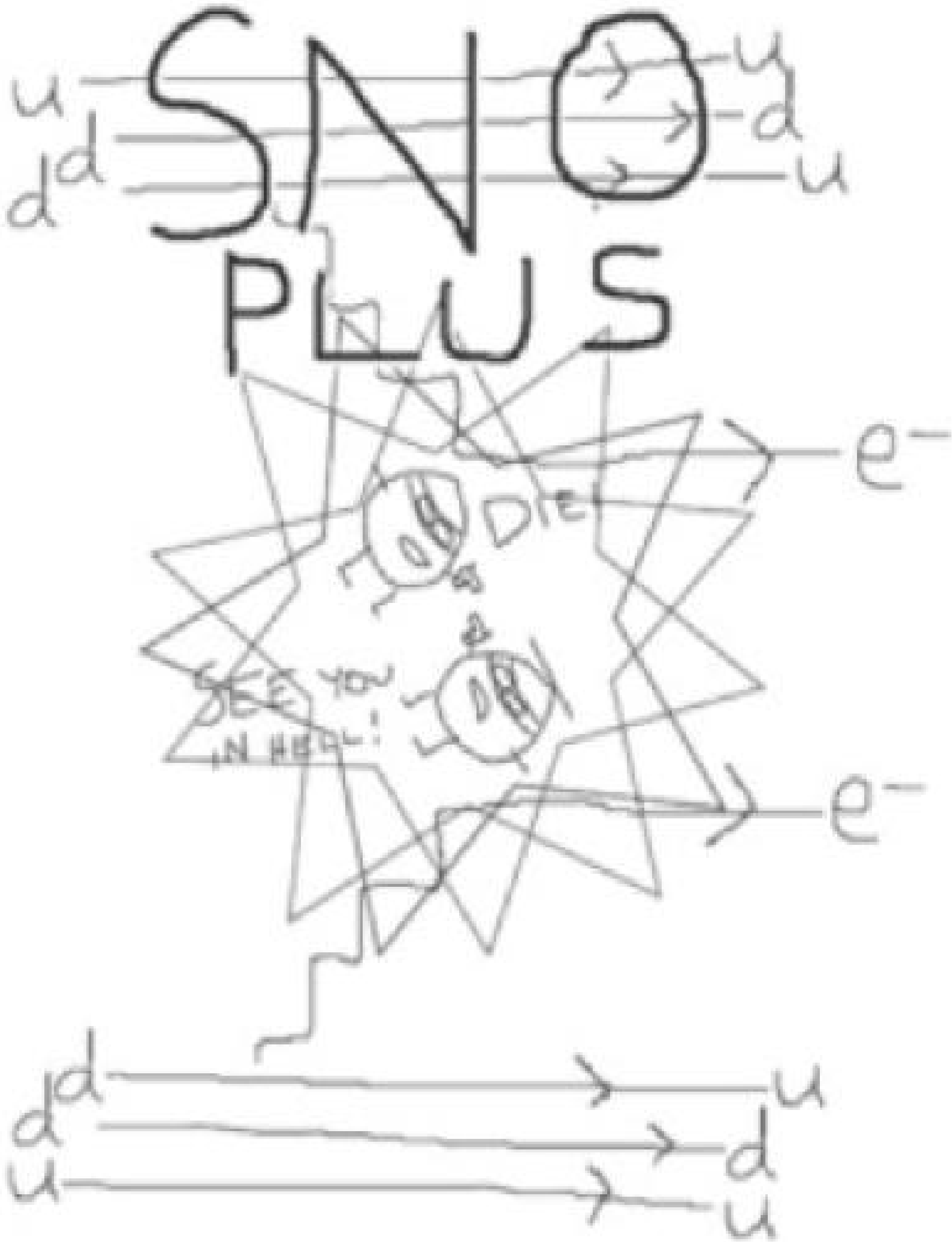
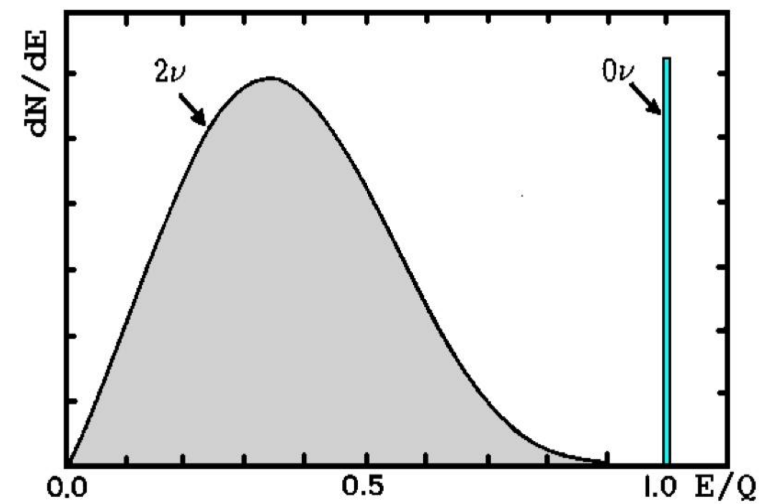
0νββ decay



$$Q = E_{\text{parent}} - E_{\text{progeny}} - 2m_e$$



$$\left(T^{0\nu}_{1/2}\right)^{-1} = G^{0\nu}\left|M^{0\nu}\right|^2\langle m_{\beta\beta}\rangle^2$$

Phase factor
Matrix element
Effective neutrino mass

$$\langle m_{\beta\beta}\rangle = \left|\sum_{i=1}^{3} U_{ei}^2 m_i\right|$$

Neutrino oscillation matrix element

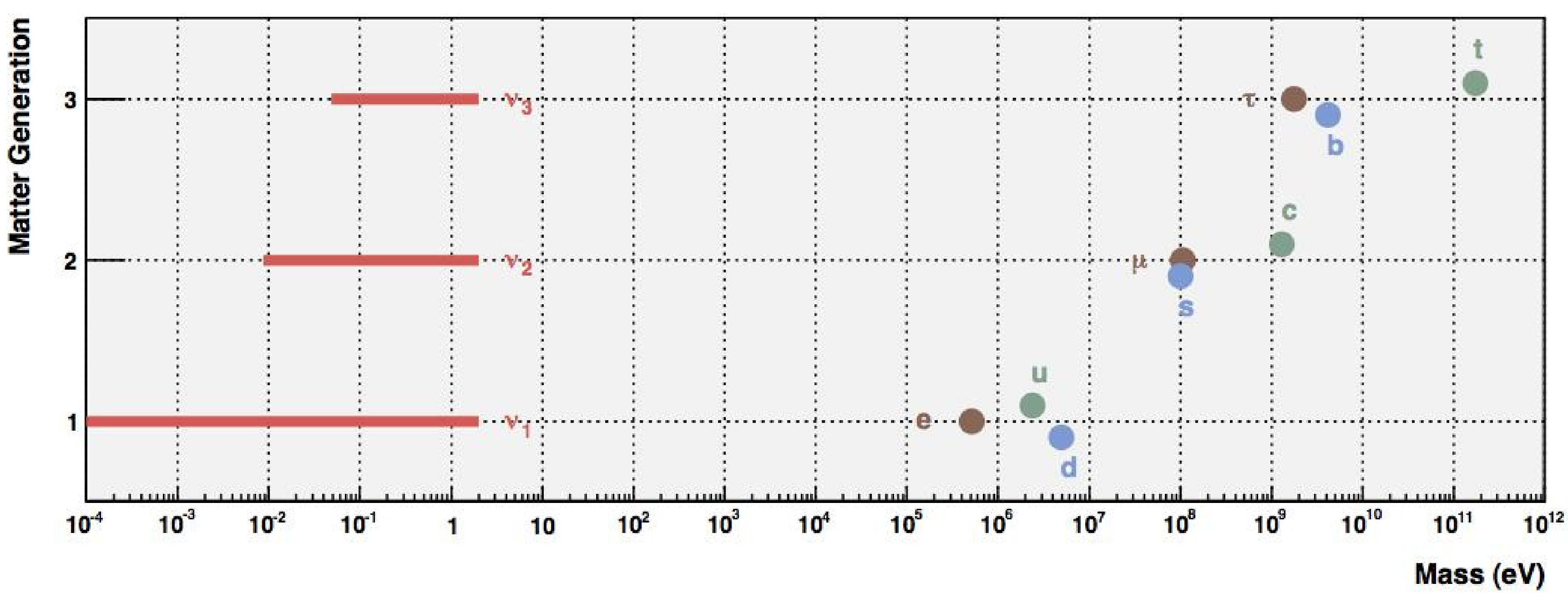
0νββ decay

Observation of this process would imply:

- Violation of lepton number (by 2!)
- Neutrinos have Majorana masses (different than quarks and leptons, Schlechter and Valle, 1982)
- Neutrinos are their own anti-particles

It would tell us something about:

- The seesaw model and why neutrinos are so much lighter than other particles
- Leptogenesis, a possible origin of the baryon-antibaryon assymmetry in the Universe
- Neutrino absolute mass scale



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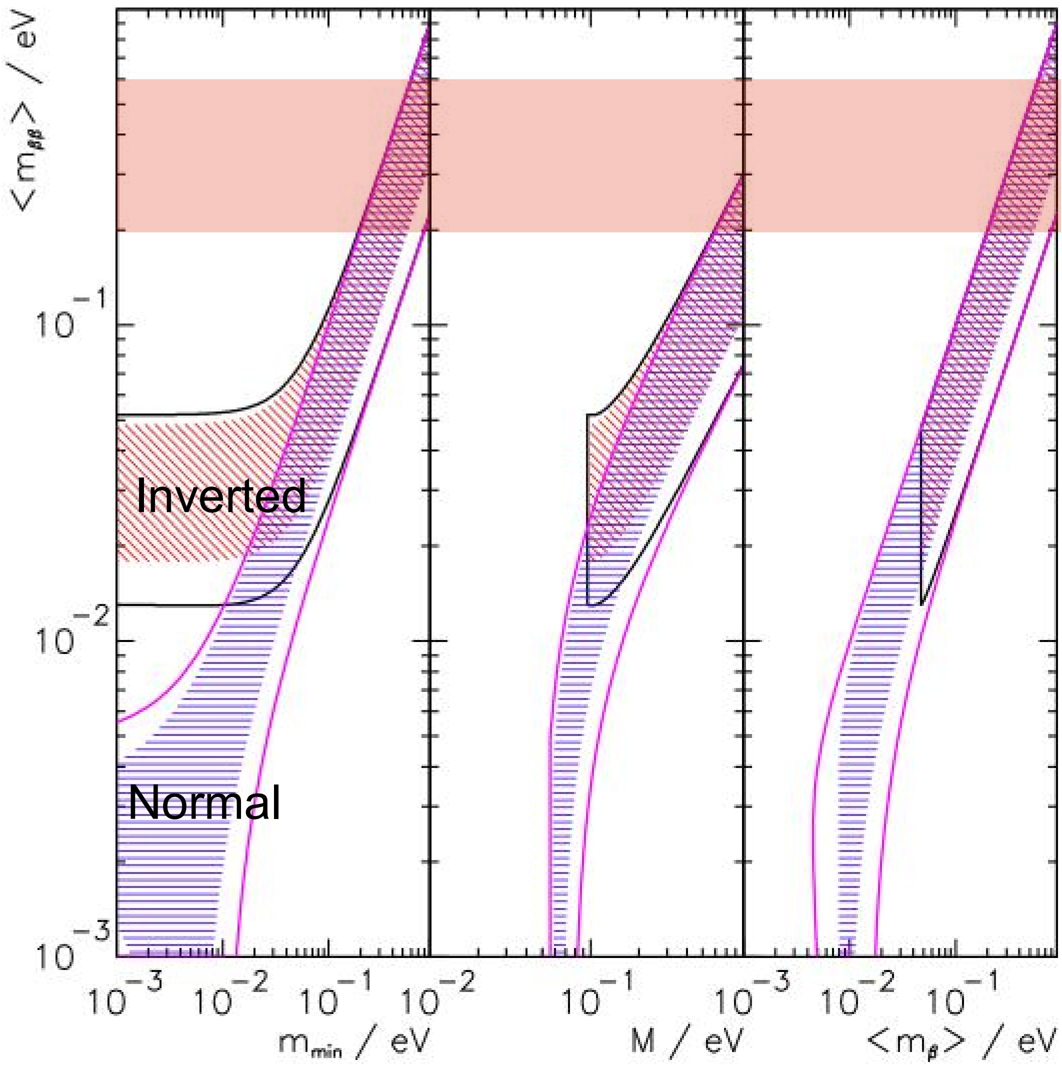
Neutrino mass

Information from:

- SN1987A
- WMAP
- Decays
  - μ, τ decays (poor)
  - KATRIN
  - ββ decay ~450 meV
- Neutrino oscillations (mass differences)



$$\langle m_{\beta\beta}\rangle \approx \left|\cos^2\theta_{12}m_1 + e^{i\Delta\alpha_{21}}\sin^2\theta_{12}m_2 + e^{i\Delta\alpha_{31}}\sin^2\theta_{13}m_3\right|^2$$

Klapdor claim

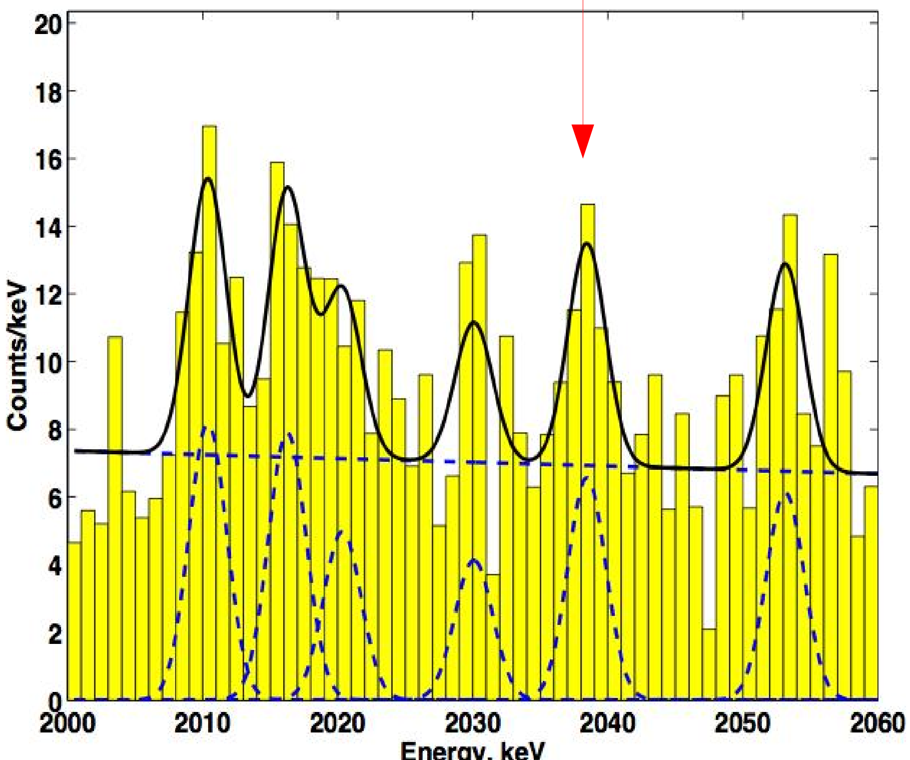
5 isotopically enriched ^{76}Ge detectors, Nov 1995 – May 2000

Published by only a part of the Heidelberg-Moscow collaboration,
H.V. Klapdor-Kleingrothaus et al.,
Phys. Lett. B 586, 198 (2004), Mod.Phys.Lett.A21:1547-1566,2006

$$T_{1/2}^{0\nu} = 2.23^{+0.44}_{-0.31} \times 10^{25}\ \mathrm{y}$$

$m_{\beta\beta}$ = 200 – 600 meV

- Inclusion of unidentified (non-existing?) peaks increases the significance
- In tension with astrophysical bounds on the neutrino mass
- In tension with other $0\nu\beta\beta$ limits (CUOROCINO)



Needs to be verified

Matrix elements

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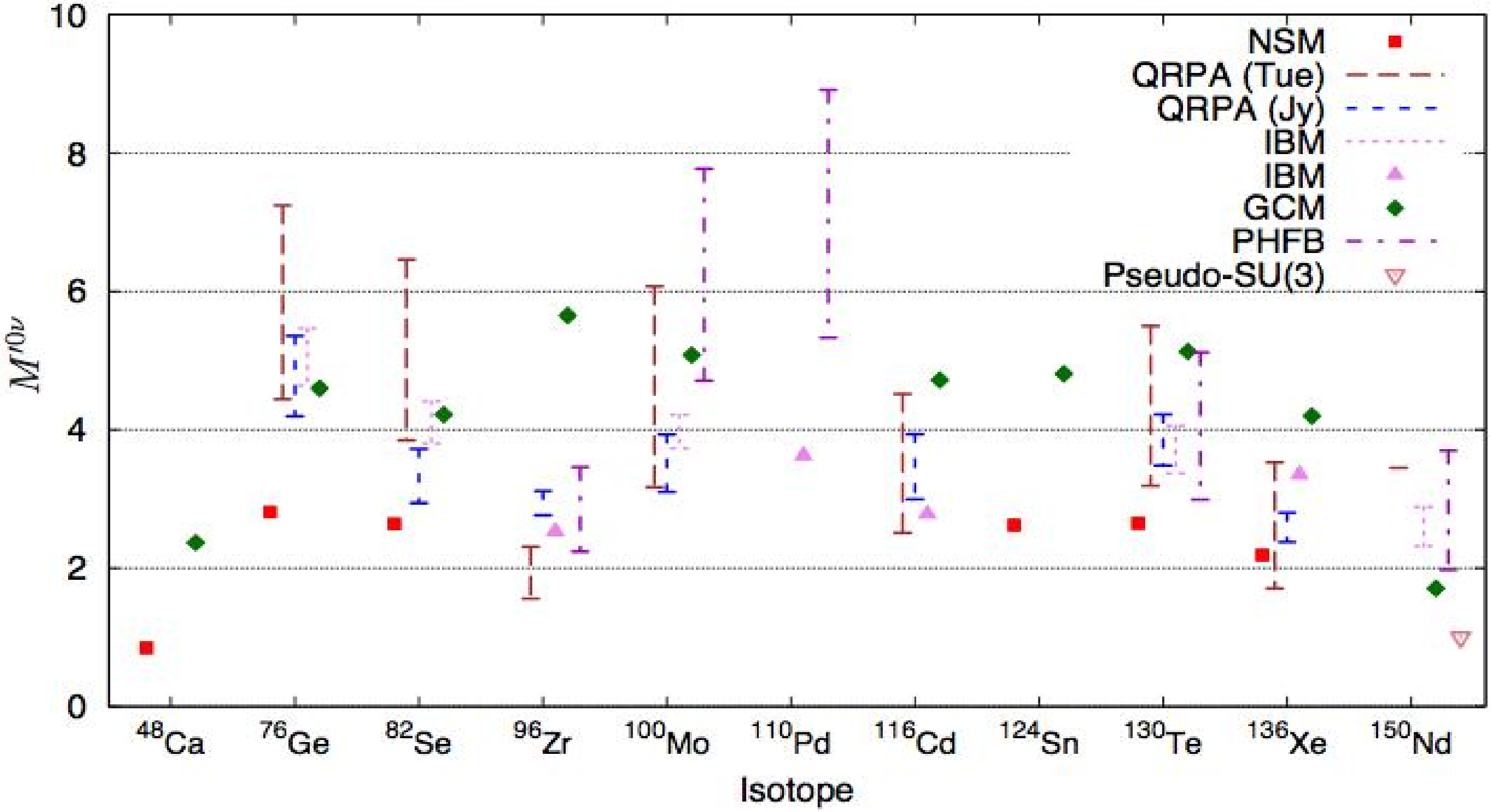
$r_0 = 1.2$ fm

$g_A = 1.25$

Arxiv:1201.4665



Comparison of 0nbb to 2nbb is complicated as 2nbb is sensitive to only a few excited states of the intermediate states whereas 0nbb probes all intermediated states.

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Experimental considerations

$$T^{0\nu}_{1/2} = \frac{M}{A} \cdot a \cdot t \cdot \frac{N_A}{N_{\beta\beta}}$$

$$T^{0\nu}_{1/2} \propto \frac{1}{\sigma_{\mathrm{detection}}}$$

$$\left(T^{0\nu}_{1/2}\right)^{-1} = G^{0\nu} \left|M^{0\nu}\right|^2 \langle m_{\beta\beta} \rangle^2$$

With backgrounds

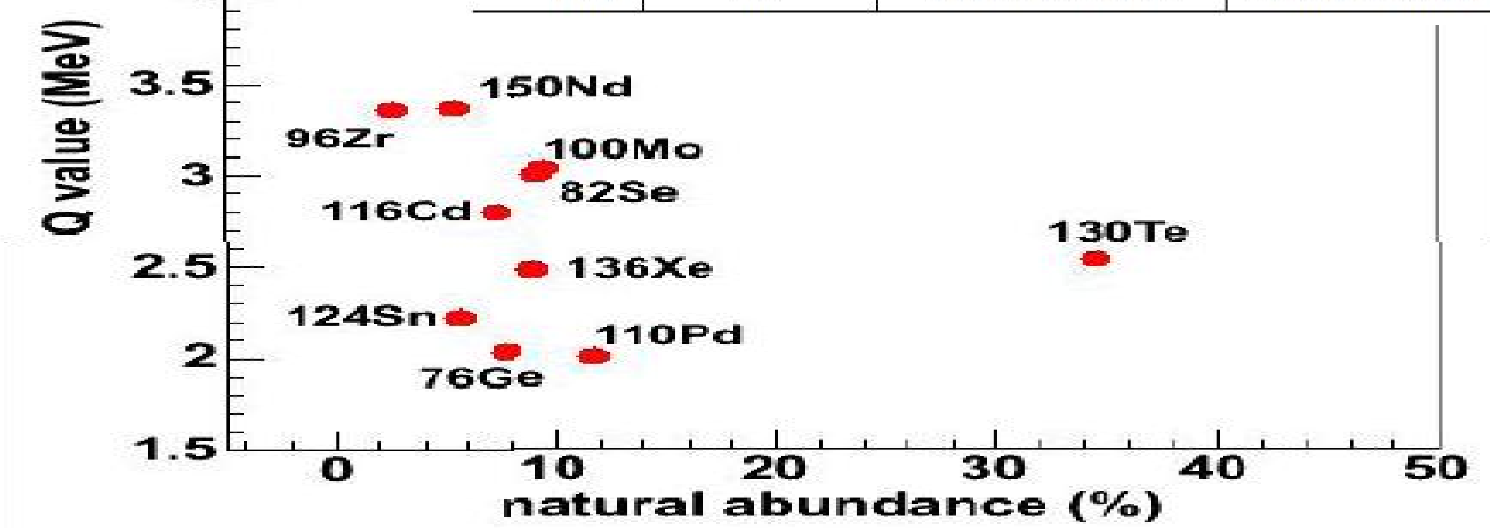
$$\sigma_{\mathrm{detection}} \propto \frac{S}{\sqrt{B}} \approx \frac{MT}{\sqrt{MT\Delta E}}$$

$$\langle m_{\beta\beta} \rangle_{\mathrm{limit}} \propto \left(\frac{\Delta E}{MT}\right)^{\frac{1}{4}}$$

To probe the inverted mass hierarchy region, an isotope mass of 100-200 kg is needed.

Current & upcoming experiments

Isotope	nat. abund. (%)	Q-value (keV)	$T^{2\nu}_{1/2}$ (10^{20}yrs)	Experiment
^{48}Ca	0.187	4272 ± 4	$0.44^{+0.06}_{-0.05}$	CANDLES
^{76}Ge	7.8	2039.006 ± 0.050	15 ± 1	GERDA, MAJORANA
^{82}Se	9.2	2995.5 ± 1.9	0.92 ± 0.07	SuperNEMO, LUCIFER
^{96}Zr	2.8	3347.7 ± 2.2	0.23 ± 0.02	-
^{100}Mo	9.6	3034.40 ± 0.17	0.071 ± 0.004	AMoRE
^{110}Pd	11.8	2017.85 ± 0.64	-	-
^{116}Cd	7.5	2813.50 ± 0.13	0.28 ± 0.02	COBRA, $CdWO_4$
^{124}Sn	5.64	2287.8 ± 1.5	-	-
^{130}Te	34.5	2527.518 ± 0.013	$6.8^{+1.2}_{-1.1}$	CUORE
^{136}Xe	8.9	2457.83 ± 0.37	21.1 ± 2.5	EXO, NEXT
				KamLAND-Zen
^{150}Nd	5.6	3371.38 ± 0.20	0.082 ± 0.009	SNO+, DCBA



Cuore

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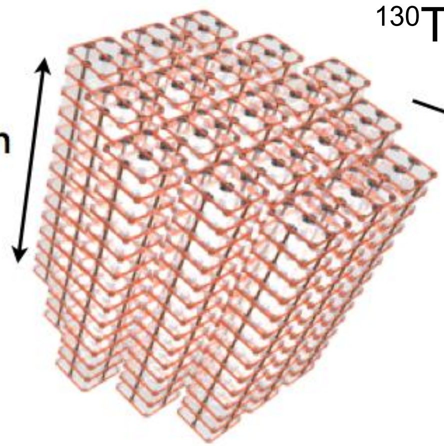
Array of 988 detectors. 19 CUORICINO-like towers M = 0.741 ton of TeO_2 (~200 kg ^{130}Te) to measure 0ν-DBD of ^{130}Te with bolometric detector.

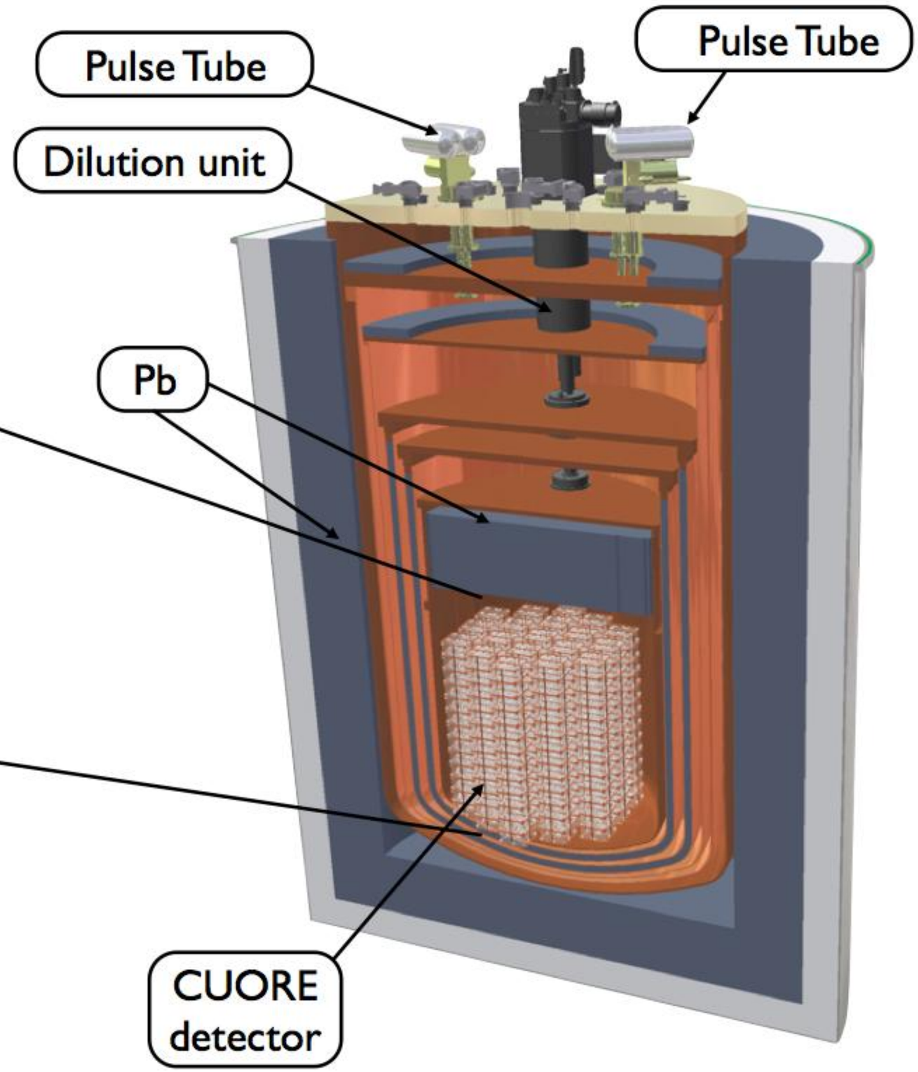


At LGNS, Italy

Sensitivity (5 y): $T_{1/2} = 1.6 \times 10^{26}$ y

$m_{\beta\beta}$ = 41-95 meV

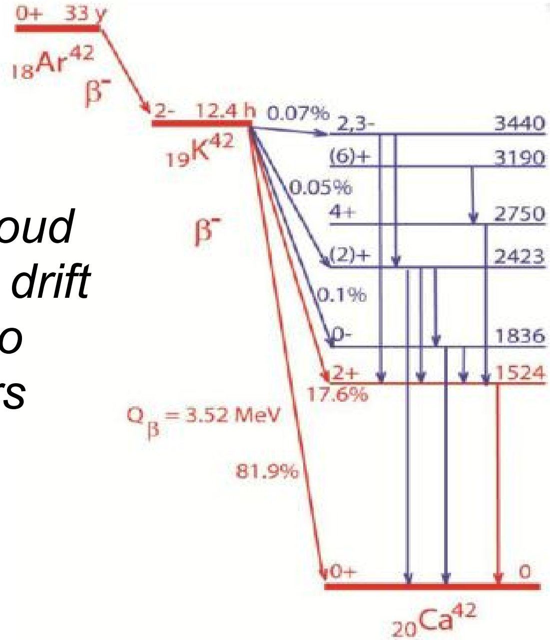
NME from F.Simkovic et al. Phys.Rev. C77 - J.Suhonen et al. Int.Jou.Mod.Phys. E17 - J.Menendez et al. Nucl. Phys.A818 - J.Barea et al. Phys. Rev. C79



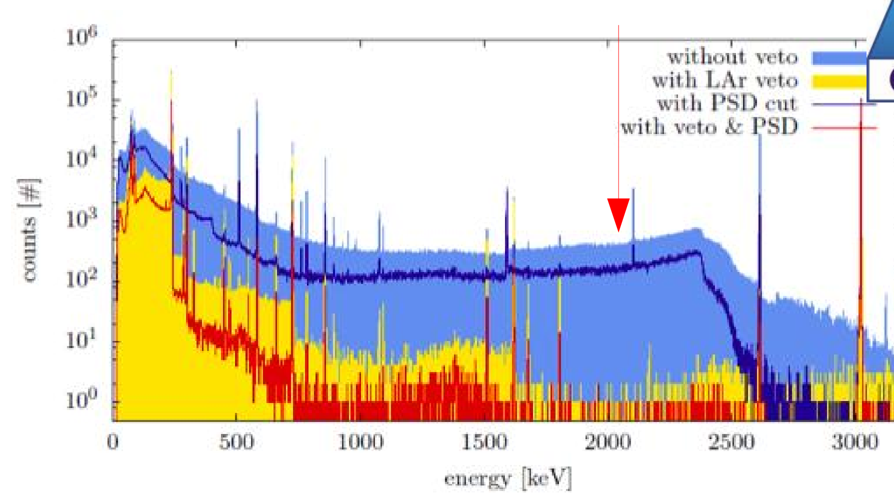
Design goal: 0.01 counts/kg/keV/yr – almost, but not yet achieved

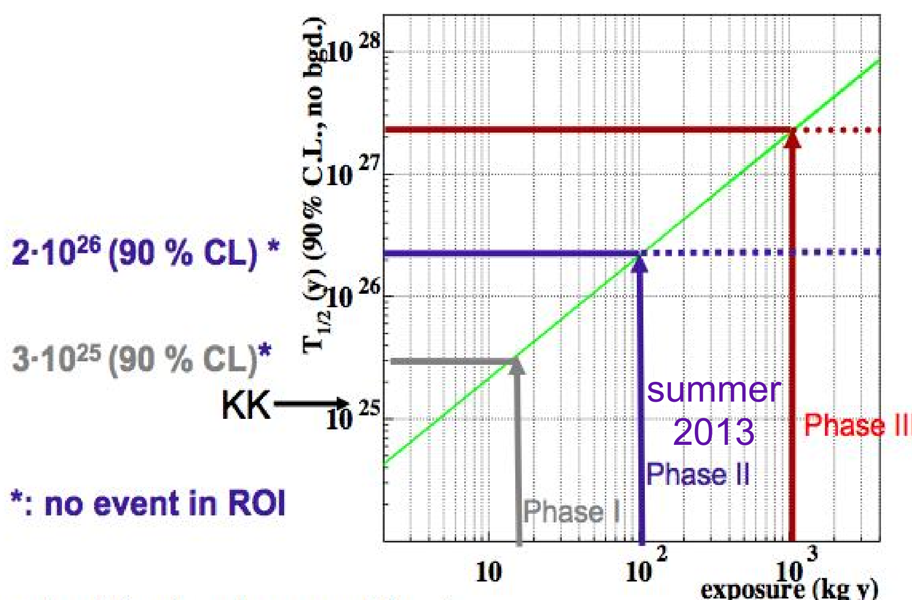
Data taking starts in 2014

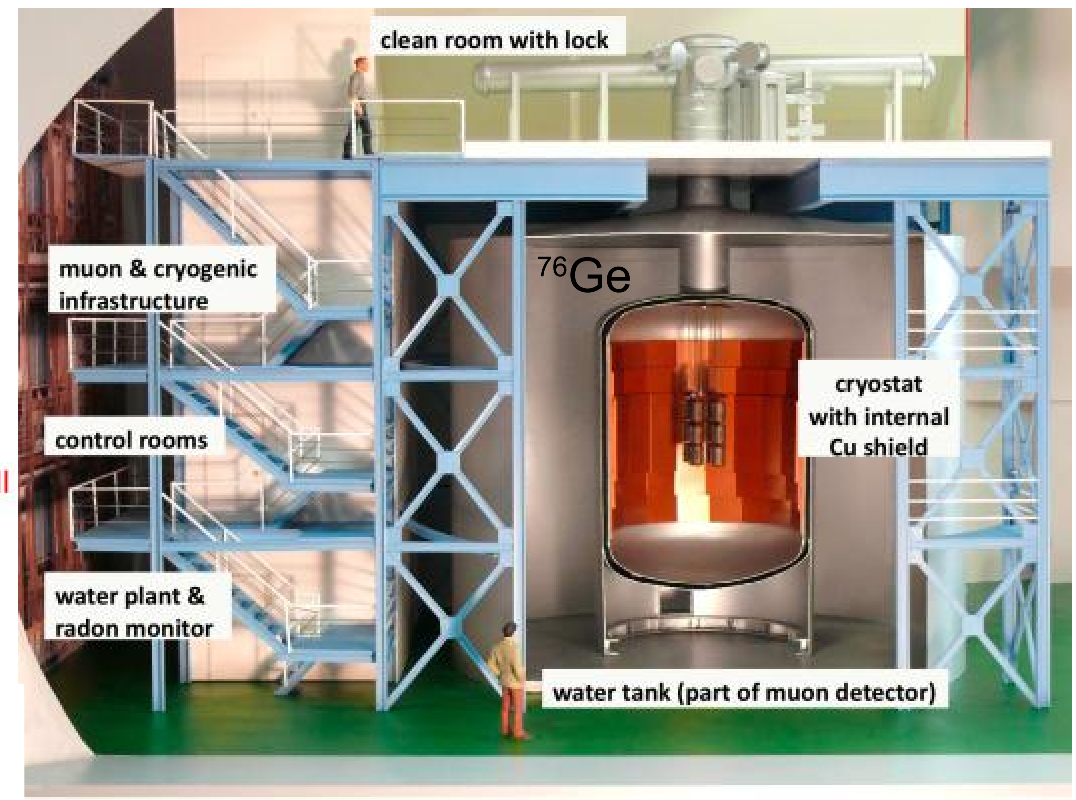
Gerda



Add shroud to avoid drift of ions to detectors







required for 'background free' exp. with $\Delta E \sim 3.3$ keV (FWHM): $O(10^{-3})$ $O(10^{-4})$

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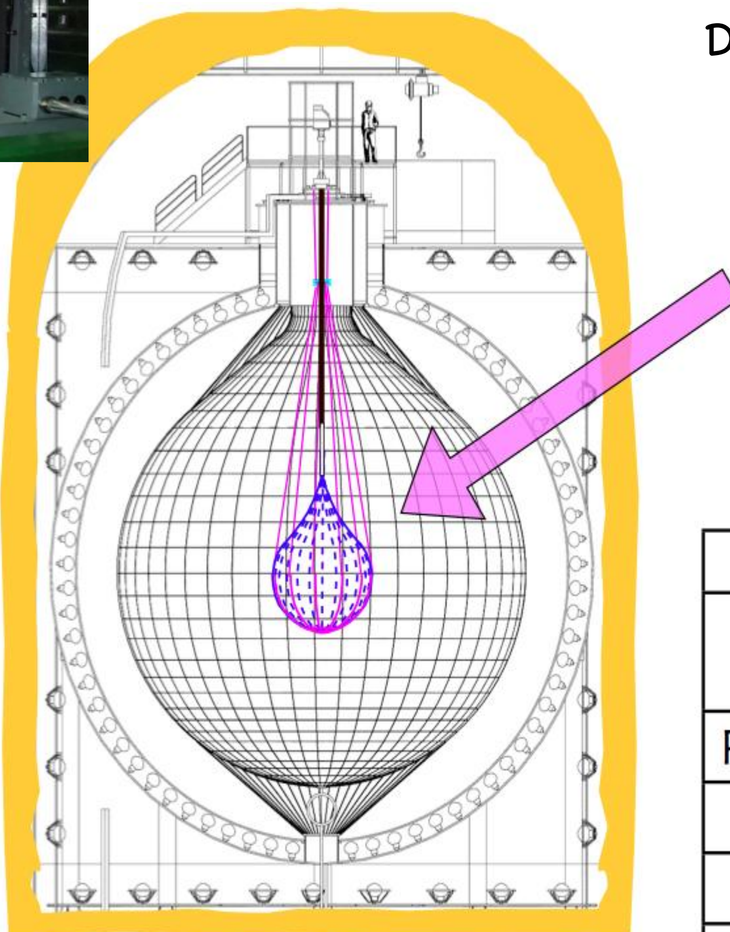
KamLAND ZEN

Kamioka Mine, Japan

Xe system

Data taking Oct 2011 – Jan 2012



Mini-balloon : 3.08m ϕ
made of thin (25 μm) nylon film
filled with Xe-LS containing
330kg 91%-enriched ^{136}Xe.

Special nylon without filler

balloon

	Xe-LS	KL-LS
Primary oil	Decane 82%	Dodecane 80%
Pseudocumene	18%	20%
PPO (g/ℓ)	2.7	1.36
Rel. Density	+0.1%	1
Rel. Light Y.	-3%	1

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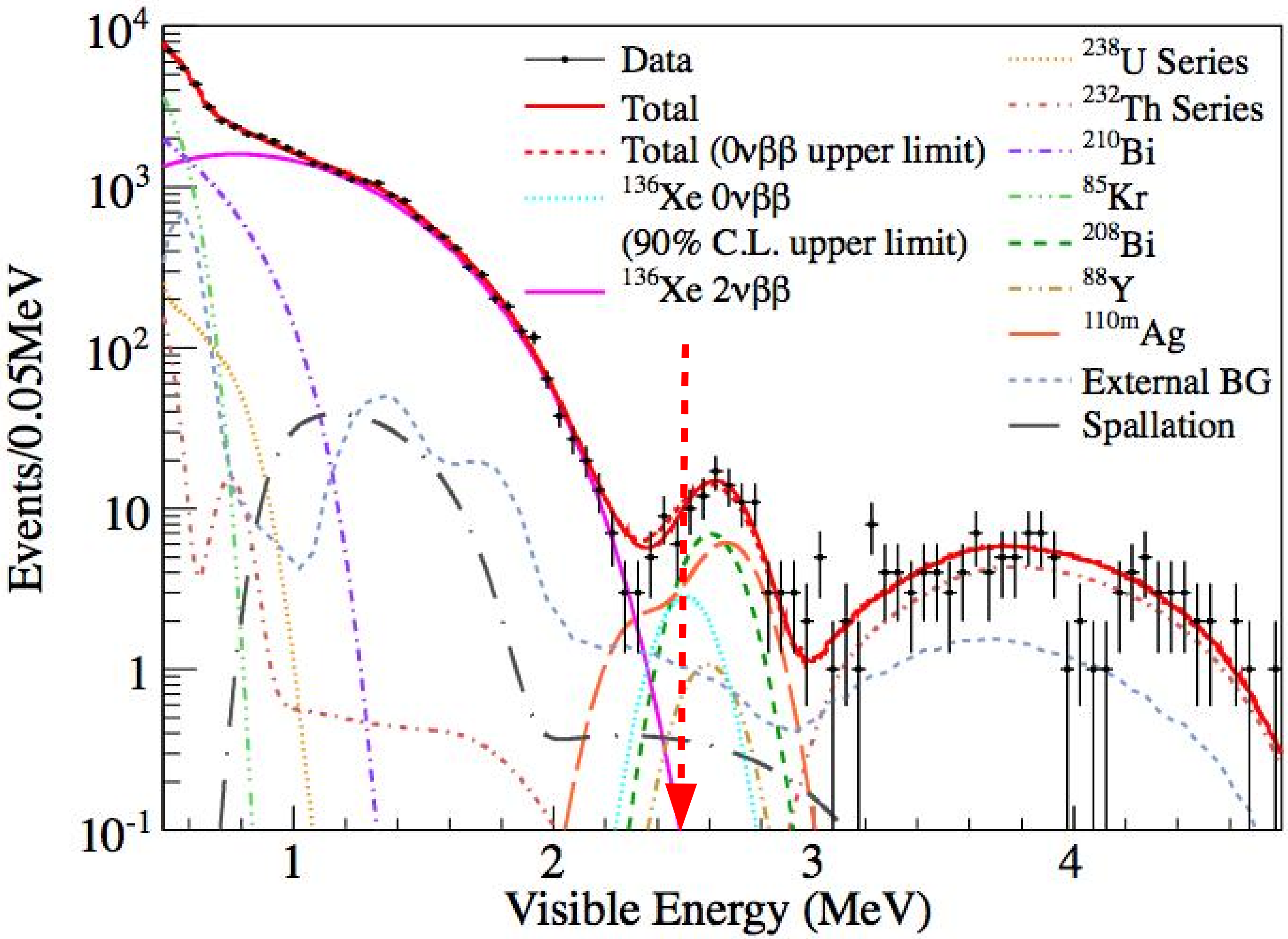
KamLAND ZEN



Arxiv:1201.4664

Three candidates for the unexpected background peak:
^{110m}Ag
^{208}Bi
^{88}Y

(5 x better) $T^{0\nu}_{1/2} > 5.7 \times 10^{24}$ yr (90%CL)

$T^{2\nu}_{1/2} = 2.38 \pm 0.02\ (\text{stat}) \pm 0.14\ (\text{sys}) \times 10^{21}$ yr

Current efforts:
Filtration, thinner, cleaner balloon
Future plans for 1000 kg experiment

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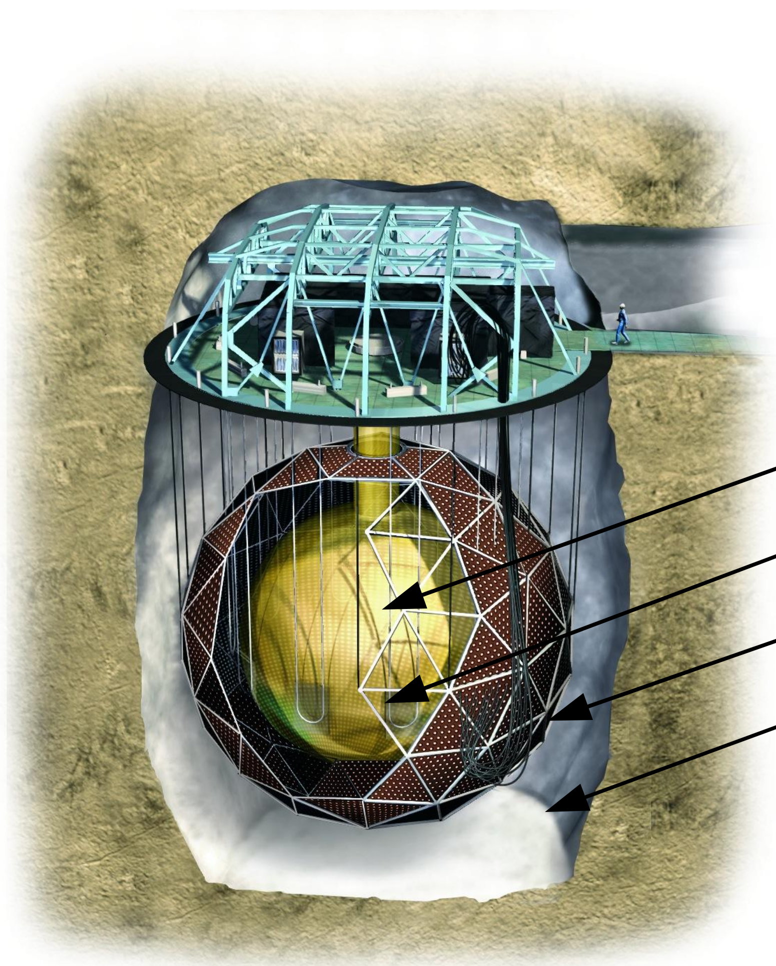
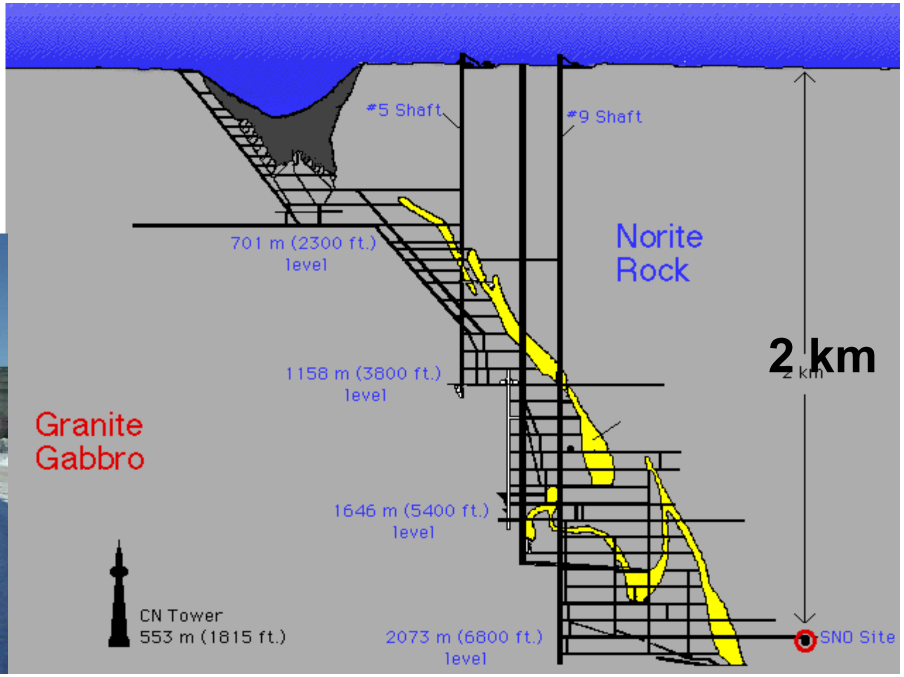
SNO+



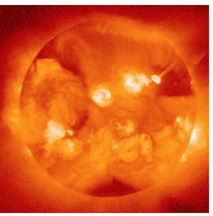
Located at 2 km underground @ SNOLAB
Vale nickel mine Sudbury, Ontario, Canada

- 780 tonnes of LS (LAB)
- 12 m diameter acrylic vessel
- 9,500 PMTs with 54% coverage
- 7 ktonne ultapure water shield

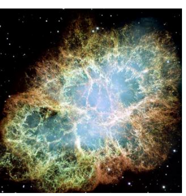


Wide physics impact

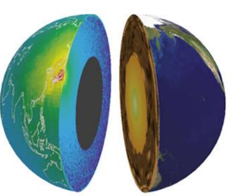
Neutrinoless Double Beta Decay



- Observe solar neutrinos, in particular:
  - pep neutrinos
  - Observe CNO neutrinos
    SNO+ has the sensitivity to do
    the first measurement of CNO neutrinos.
    This could resolve the
    solar composition problem.



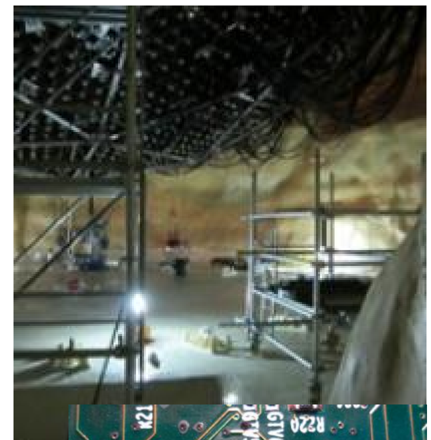
- Observe SN neutrinos
  Sensitivity to SN within our galaxy. Tests Supernova and is sensitive to neutrino mass hierarchy and θ_{13}.
  Part of SNEWS,
  the SN Early Warning System.

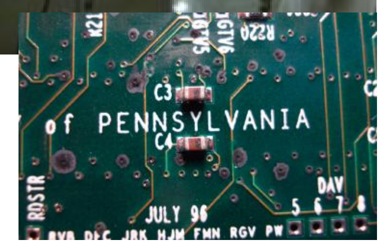


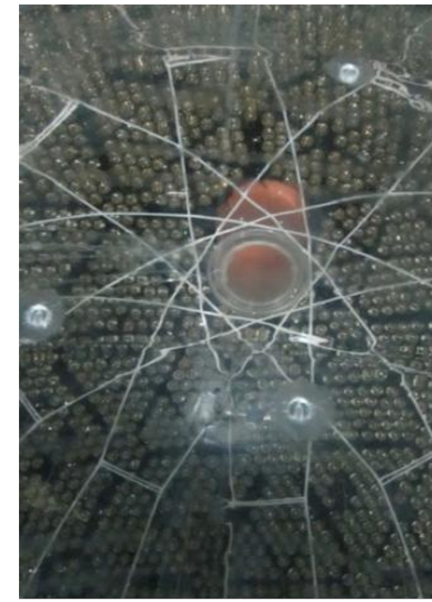
- Geo-neutrinos
  Contribute to the geological understanding of the earth.

- Reactor neutrinos
  Independent measurement of Δm_{12}^2
- Nucleon decay
  Unique sensitivity to invisible mode

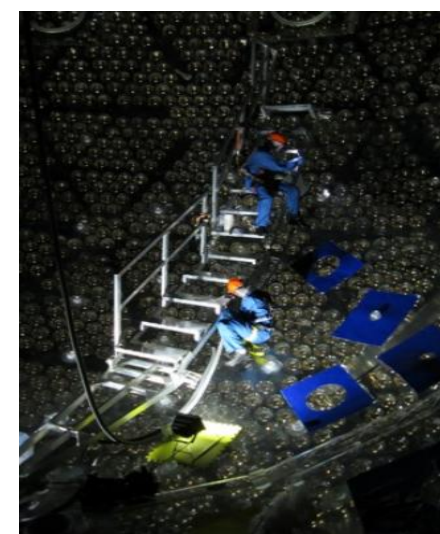
SNO refurbishment







Calibrations: Matt Mottram's parallel talk



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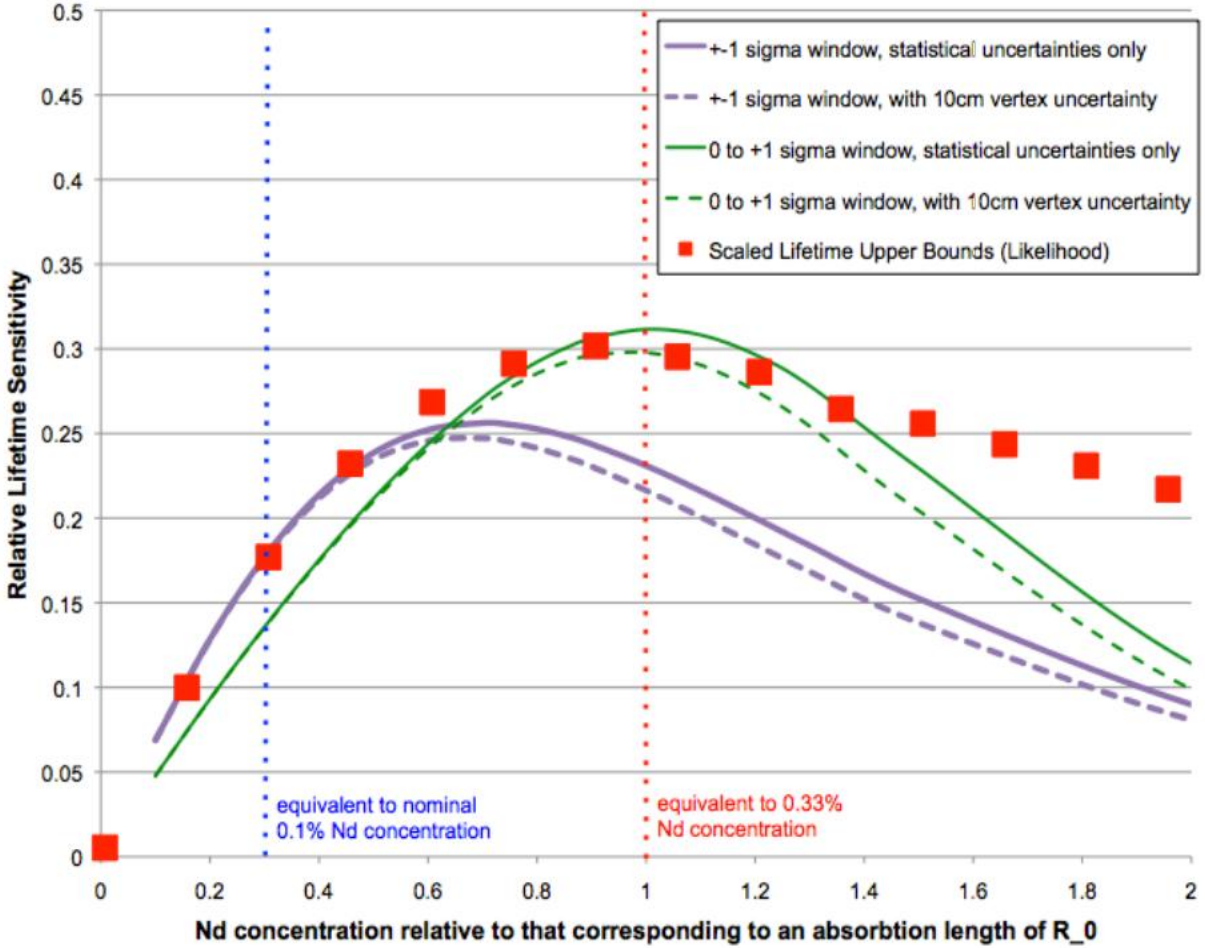
SNO+

^{150}Nd:

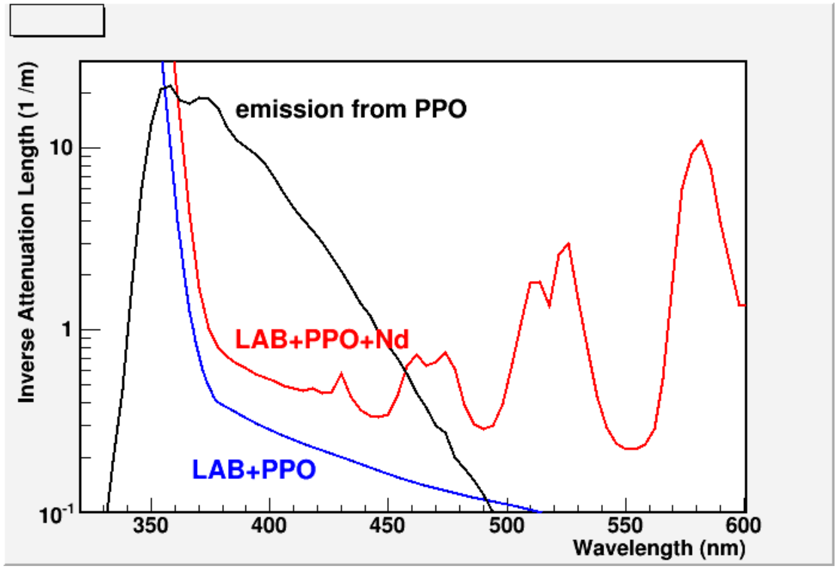
- ***Largest phase space of all 0νββ isotopes***
- ***High 3.3 MeV end-point***
- ***5.6% abundance***
- ***Relatively cheap***
- ***Demonstrated to be in solution in LAB for over 3 years at high concentrations***

Backgrounds: Phil Jones' parallel talk



Absorption of scintillator light by Nd: need for optimisation

0.3% loading is optimal



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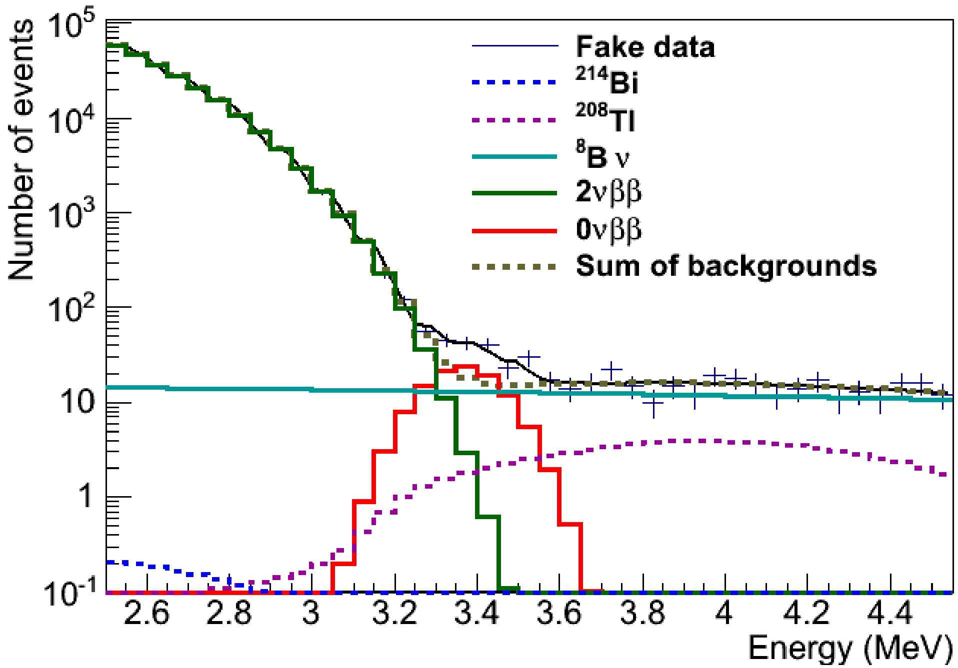
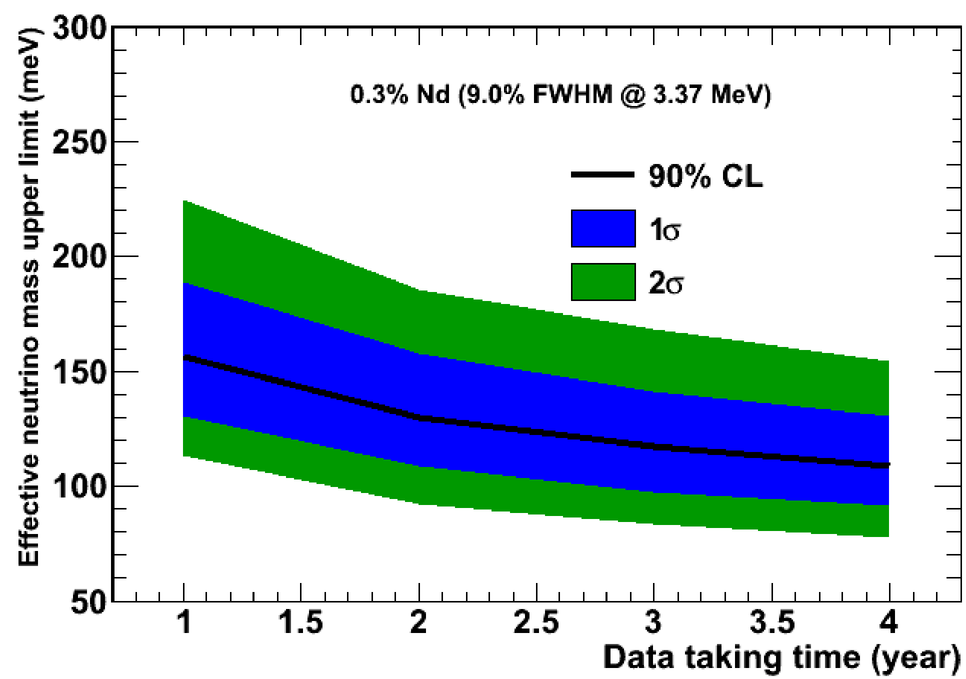
SNO+



SNO+ is expected to start data taking early 2014

Nuclear matrix NME = 2.5 (IBM-2)
Phase space factor: g_0=2.69 x 10^{13} $year^{-1}$



Effective neutrino mass: 320 meV

^{150}Nd mass: 44 kg (0.1% Nd conc)

400 hits/MeV (~ 6.5% @ 3.3 MeV)

3 years of data with 80% livetime

Fiducial cut: R =0.8x R_0
(50% of the mass)

Enrichment and/or other isotopes are also being considered

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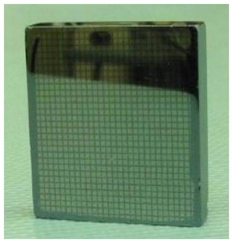
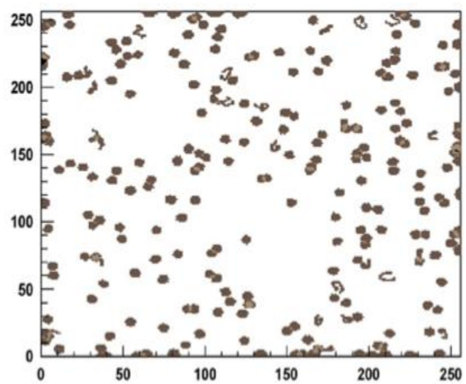
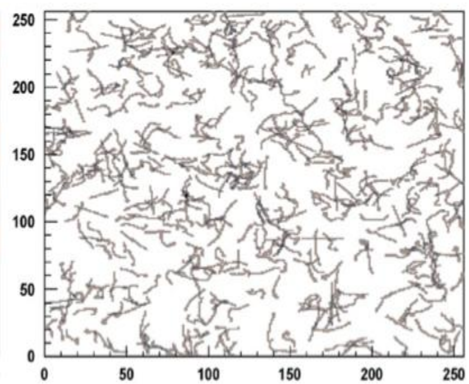
Energy Measurement and Tracking



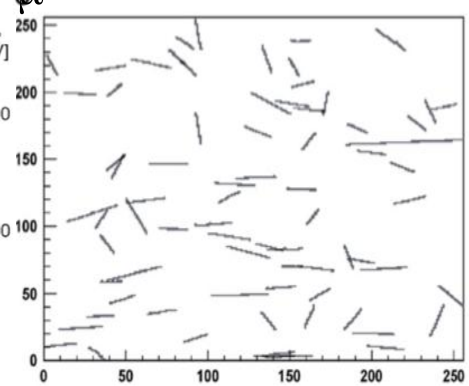
α

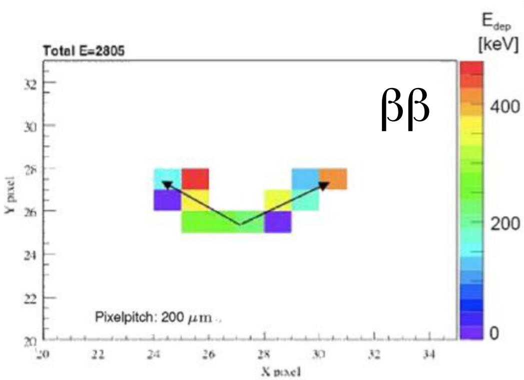


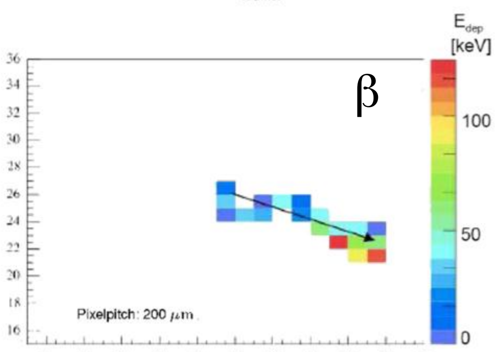
β



μ







Energy Measurement

CdZnTe pixel detectors (^{116}Cd)

- 32 crystals now (electrode structure allows surface vs bulk discrimination)
- 64 crystals my the end of the year
- Getting to 2νββ

on JM Peeters, IoP joint HEPP/APP meeting, April 2012, QMUL, London

SuperNEMO

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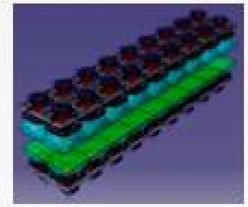
From NEMO-3 to SuperNEMO



R&D since 2006 →

NEMO-3		SuperNEMO
^{100}Mo	Isotope	^{82}Se (or ^{150}Nd or ^{48}Ca)
7 kg	Isotope mass M	100+ kg
^{208}Tl: ~ 100 μBq/kg ^{214}Bi: < 300 μBq/kg	Contaminations in the ββ foil	$^{208}Tl \leq 2$ μBq/kg $^{214}Bi \leq 10$ μBq/kg
Rn: 5 mBq/m^3	Rn in the tracker	Rn ≤ 0.15 mBq/m^3
8% @ 3MeV	Calorimeter energy resolution (FWHM)	4% @ 3 MeV
$T_{1/2}(\beta\beta0\nu) > 1 \div 2 \times 10^{24}$ y $<m_\nu> < 0.3 – 0.9$ eV	Sensitivity	$T_{1/2}(\beta\beta0\nu) > 1 \times 10^{26}$ y $<m_\nu> < 0.04 - 0.1$ eV

(SuperNEMO slides from R Saakyan)

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SuperNEMO

supernemo collaboration

SuperNEMO Demonstrator

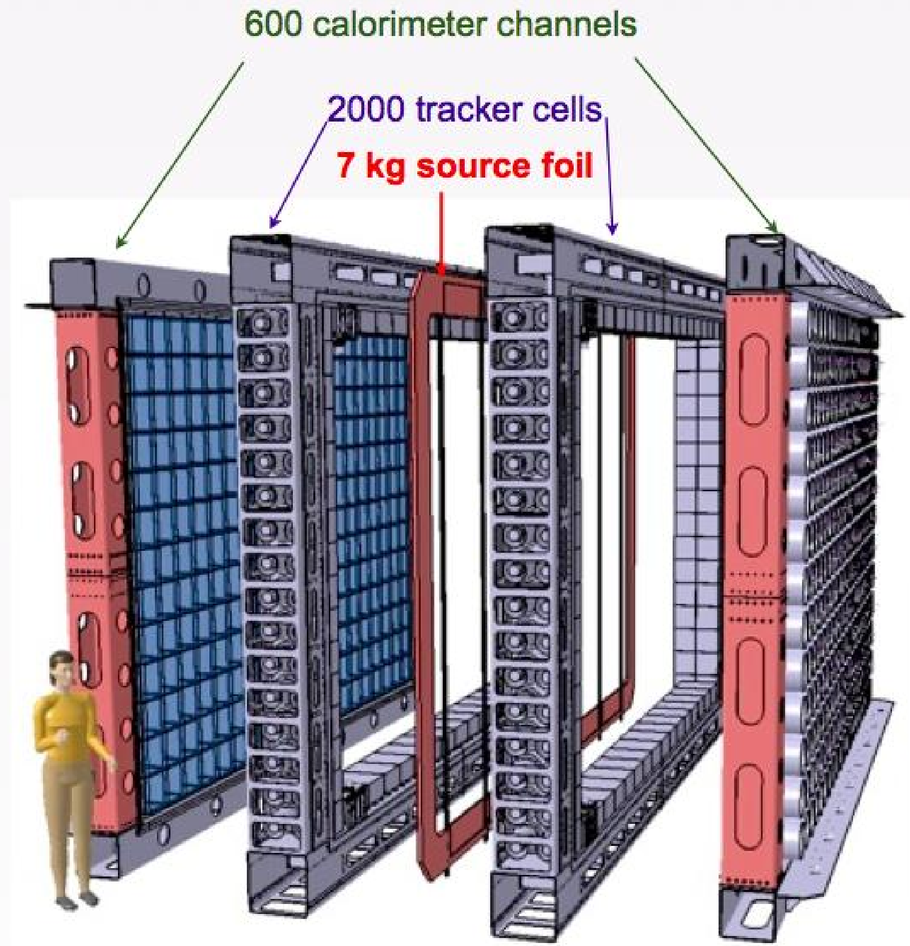
Technology
  Ultimate proof of BG levels
Physics
  Sensitive to K-K claim

7kg of ^{82}Se
  Bgrd ≤ 0.06 events/yr in the RoI

A Zero-Background Experiment

$$T^{0\nu}_{1/2}(90\%CL) = 2.56 \times 10^{24} \times t \ \text{ yrs}$$

Gerda-I sensitivity in 2.5 years -
6.5×10^{24} yr (equivalent to 3×10^{25}yr with ^{76}Ge)

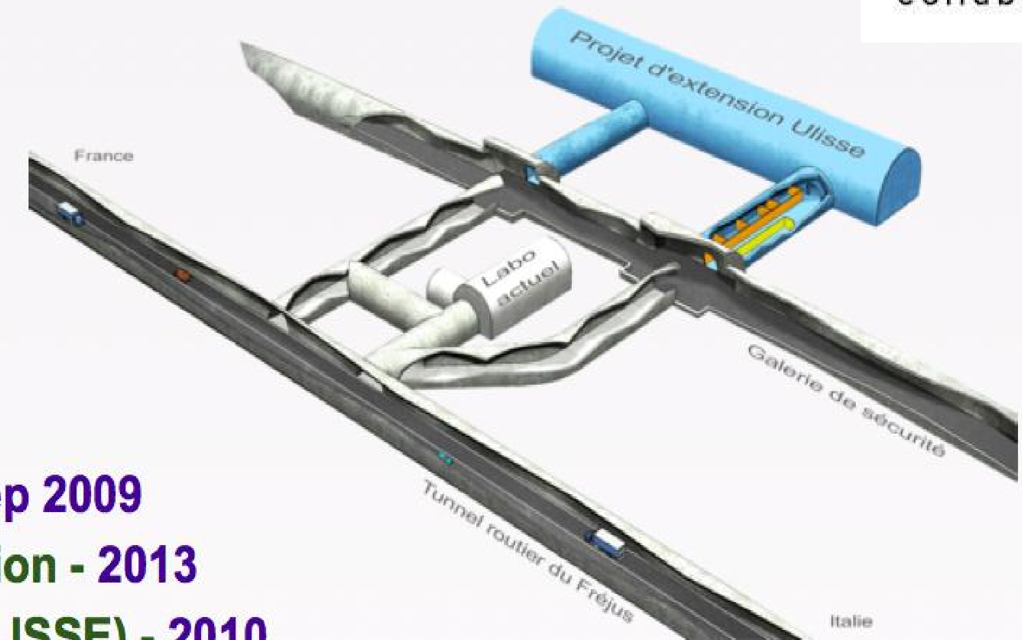


Expand to 20 modules with
5 kg isotope each (2014)

(SuperNEMO slides from R Saakyan)

SuperNEMO

LSM Extension



Schedule

- Safety tunnel construction start - Sep 2009
- Safety tunnel, end of civil construction - 2013
- Detailed study of LSM extension (ULISSE) - 2010
- Deadline for final decision/money commitment - 2012
- Excavation of new Lab completed - 2014
- Outfitting completed, Lab ready to host experiments - 2015

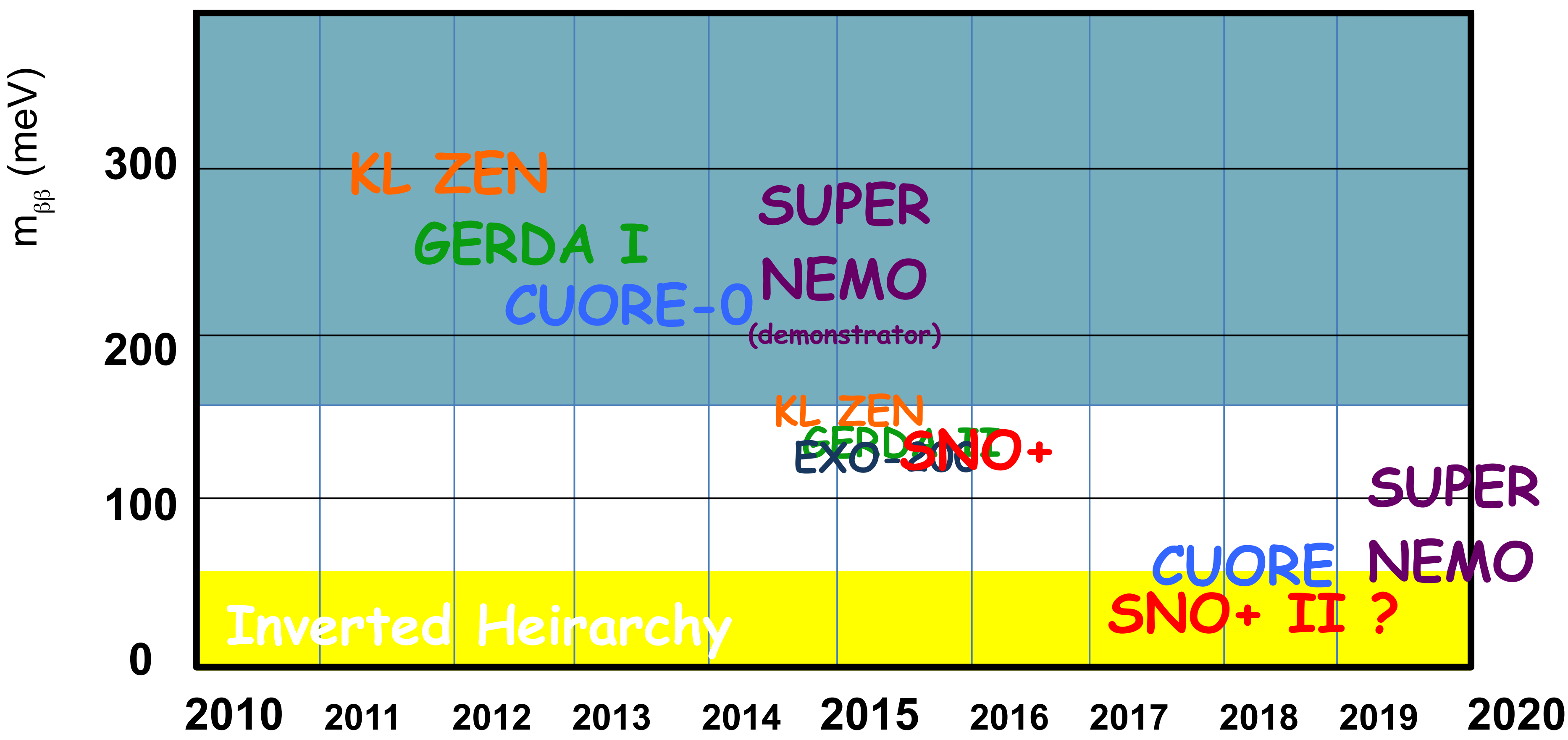
Full set of modules running by 2021

17,500m^3 (50m long), 7M€ excavation + 3M€ outfitting

(SuperNEMO slides from R Saakyan)

Overview

Please consider dates and limits as approximately only



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Summary

- Double beta decay is the gold-plated channel to explore the fundamental nature of neutrinos.
- Near term experiments are driven by the Klapdor claim.
- To explore the parameters space, many interesting approaches are being pursuit.
- Exciting times, stay tuned!