Double-Beta Decay Experiments

Outline

- Double-Beta Decay Basics
- Experiment Classifications
- Another 10 years
- Open for Discussion

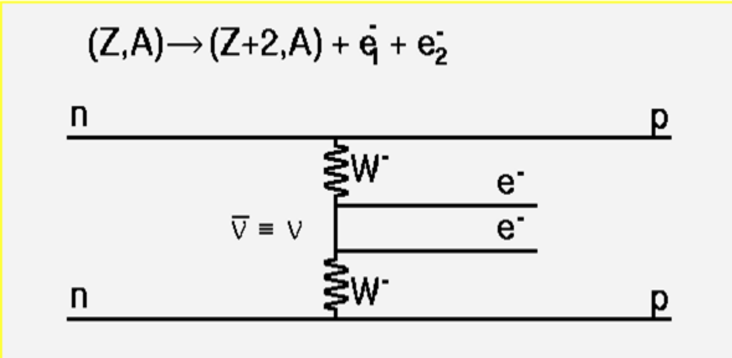
Most Recent Reviews

- J.J. Gomez-Cadenas et al., arXiv:1109.5515
- A.S. Barabash, arXiv:1104.2714
- A.S. Barabash, arXiv:1109.6423
- TAUP11 conference: http://taup2011.mpp.mpg.de

Physics topics in double-beta decay

- Theory of Flavour
  - Neutrino mass, Majorana or Dirac nature
  - Mass mechanism = physics at high energy scales
- Exotic interactions = Beyond SM interactions
  - (Scalar and tensor contributions to V-A from any BSM theory, Lepton number violation → Leptogenesis, …)
- See the previous presentations

Double Beta Decay Experiments

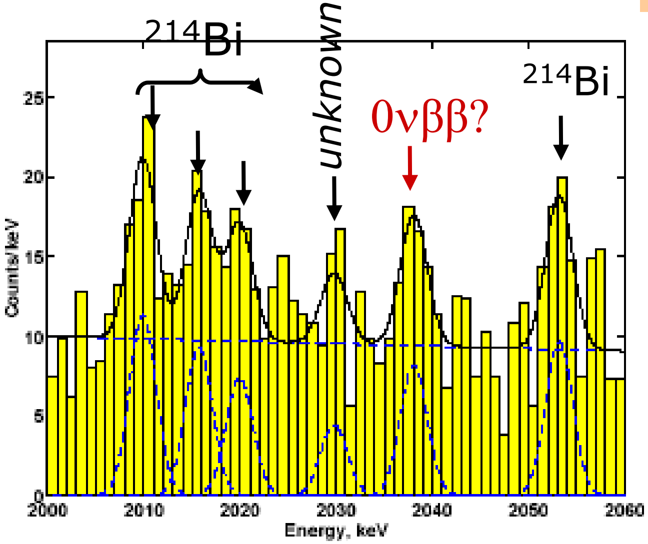


$$T_{1/2} \propto \varepsilon \frac{a}{A}\sqrt{\frac{M \times t}{\Delta E \times B}}$$

$$\langle m_{\nu_e} \rangle \propto 1/\sqrt{T_{1/2}}$$

Two approaches

Source = detector (calorimeters)

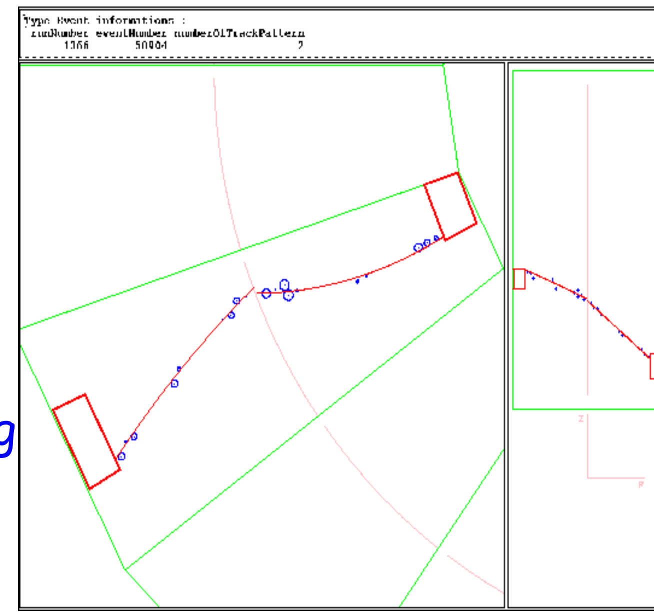


e.g. Heidelberg-Moscow

Great ΔE/E
high efficiency

Source ≠ detector
(foil+tracking+calorimetry)

Isotope flexibility
"smoking" gun
Topological bkg suppression



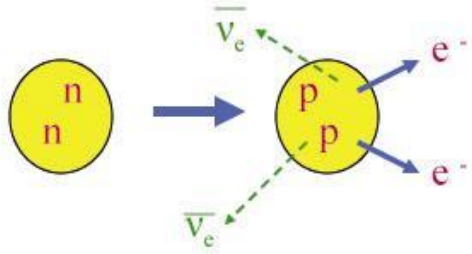
e.g. NEMO-III

THE UNIVERSITY OF WARWICK

Double Beta Decay

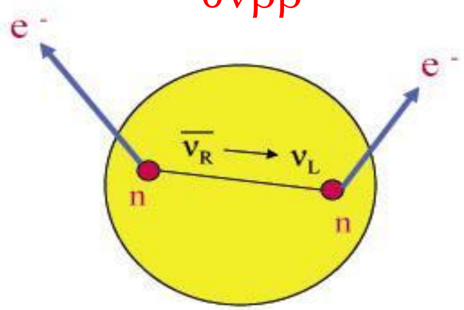
Double Beta Decay: $$\left|\langle m \rangle\right| = \left|\sum_k U_{ek}^{\ 2} m_k\right|$$

2νββ



Allowed and observed

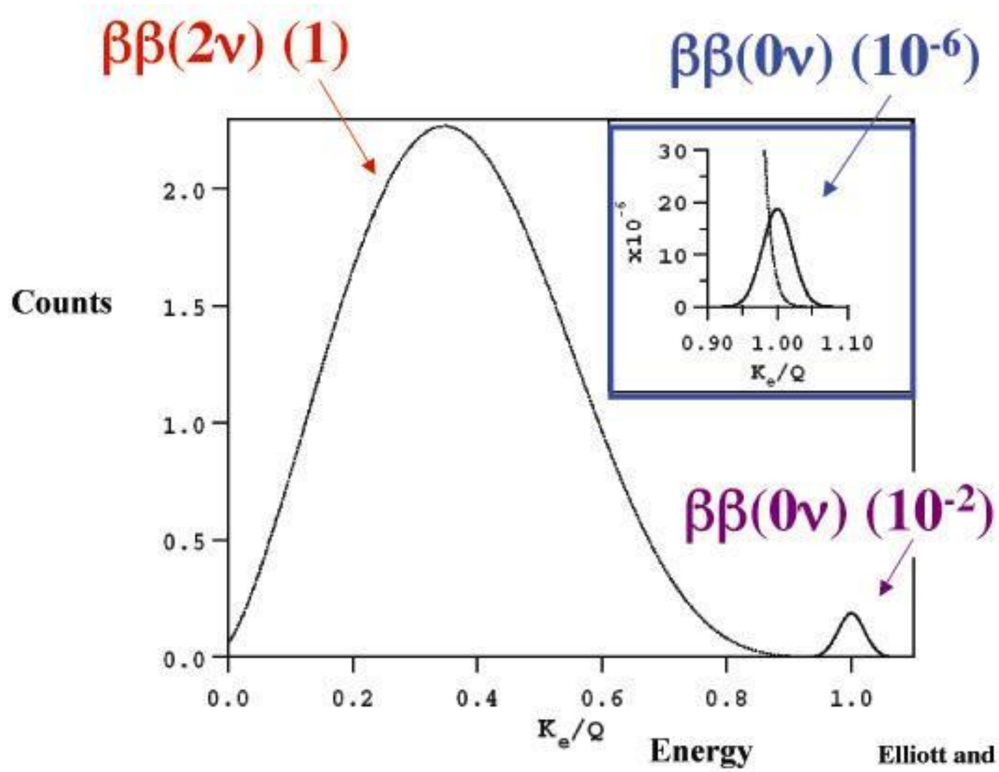
0νββ



Forbidden – Interesting !

Neutrinos must be massive Majorana particles

Experimental signature



Elliott and Vogel, 2002

Success and further improvements: HowTo

$$T_{1/2} \propto \varepsilon \frac{a}{A}\sqrt{\frac{M \times t}{\Delta E \times B}}$$

$$\langle m_{\nu_e} \rangle \propto 1/\sqrt{T_{1/2}}$$

On the way to 100meV: Missing factor 2-5 gained by

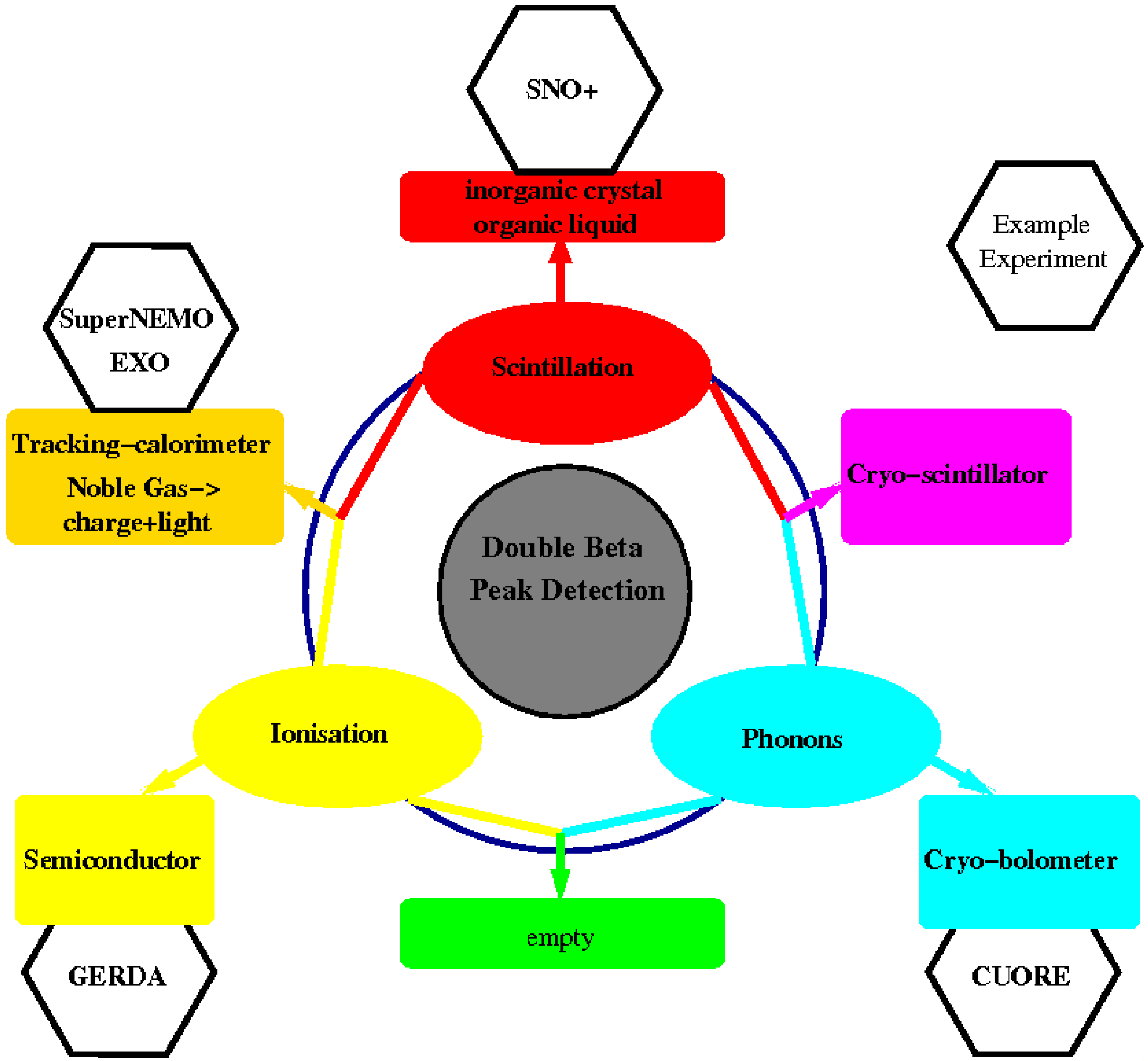
a) 16-625 fold increase in exposure (Mt) and/or

b) 16-625 fold reduction of background, B

On the way to 10meV : Extrapolate existing experiments over 5-6 orders of magnitude !!!

Not at all hopeless, but a challenge !

Techniques


SNO+
inorganic crystal
organic liquid
Example
Experiment
SuperNEMO
EXO
Scintillation
Tracking–calorimeter
Noble Gas–>
charge+light
Cryo–scintillator
Double Beta
Peak Detection
Ionisation
Phonons
Semiconductor
Cryo–bolometer
empty
GERDA
CUORE

Experiment List

TABLE 3. Seven most developed and promising projects. Sensitivity at 90% C.L. for three (1-st step of GERDA and MAJORANA, SNO+, and KamLAND-Xe) five (EXO, SuperNEMO and CUORE) and ten (full-scale GERDA and MAJORANA) years of measurements is presented. M - mass of isotopes.

Experiment	Isotope	M, kg	Sensitivity $T_{1/2}$, y	Sensitivity $\vert\langle m_\nu \rangle\vert$, meV	Status
CUORE [20]	^{130}Te	200	2.1×10^{26}	35–90	in progress
GERDA [21]	^{76}Ge	40	2×10^{26}	70–300	in progress
		1000	6×10^{27}	10–40	R&D
MAJORANA [22, 23]	^{76}Ge	30–60	$(1–2) \times 10^{26}$	70–300	in progress
		1000	6×10^{27}	10–40	R&D
EXO [24]	^{136}Xe	200	6.4×10^{25}	95–220	in progress
		1000	8×10^{26}	27–63	R&D
SuperNEMO [25, 26, 27]	^{82}Se	100–200	$(1–2) \times 10^{26}$	40–110	R&D
KamLAND-Xe [28]	^{136}Xe	400	4.5×10^{26}	40–80	in progress
		1000	$\sim 10^{27}$	25-50	R&D
SNO+ [29]	^{150}Nd	56	$\sim 4.5 \times 10^{24}$	100–300	in progress
		500	$\sim 3 \times 10^{25}$	40-120	R&D

A.S. Barabash, arXiv:1109.6423

A hypothetical ββ-experiment

All reviews agree on one point: There is no optimal ββ-experiment!
So, pick out what is good and compromise for a practical solution:
A highly subjective procedure

(A) Simple
detector technology
(best possible energy res.
highest efficiency)

$$T_{1/2} \propto \varepsilon \frac{a}{A} \sqrt{\frac{M \times t}{\Delta E \times B}}$$

(C) Lowest possible B

- Tracking
  SuperNEMO, NEXT, COBRA
- Intrinsic cleanliness
  GERDA, CUORE, EXO
- Active veto shielding
  GERDA, EXO, SNO+

(B) Best practical ββ-isotope
(high-Q value, enrichment costs)

More than finding DBD

Tracking+
Calorimeter

TPC

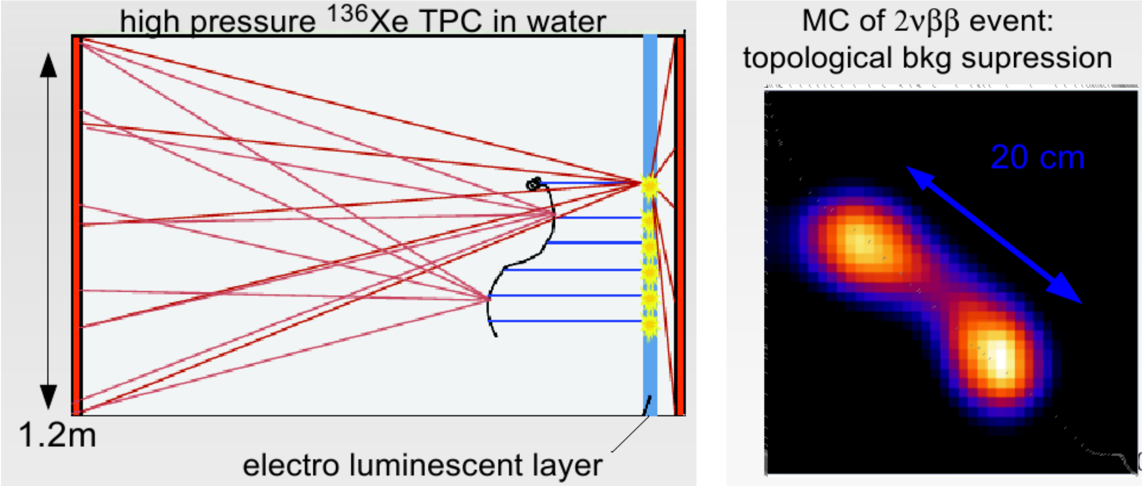
NEXT

SuperNEMO

COBRA

See Stefano's talk

NEXT, arXiv:1106.3630



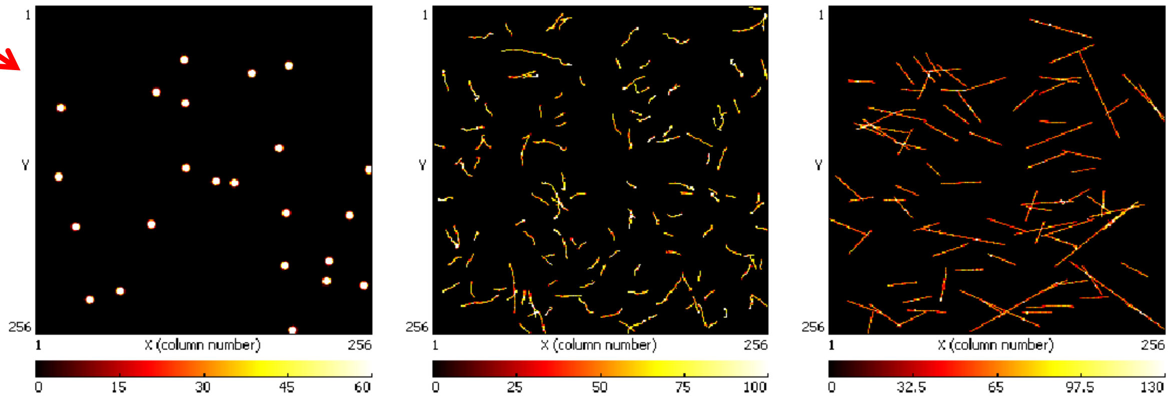


Fig. 4: Preselected sample of alpha (left) and beta particles (middle) as well as muons (right) obtained by COBRA with a 55μm pixel detector. Evident is the particle identification and the potential tracking option.

K. Zuber, arXiv:1002.4313

Energy resolution issues?

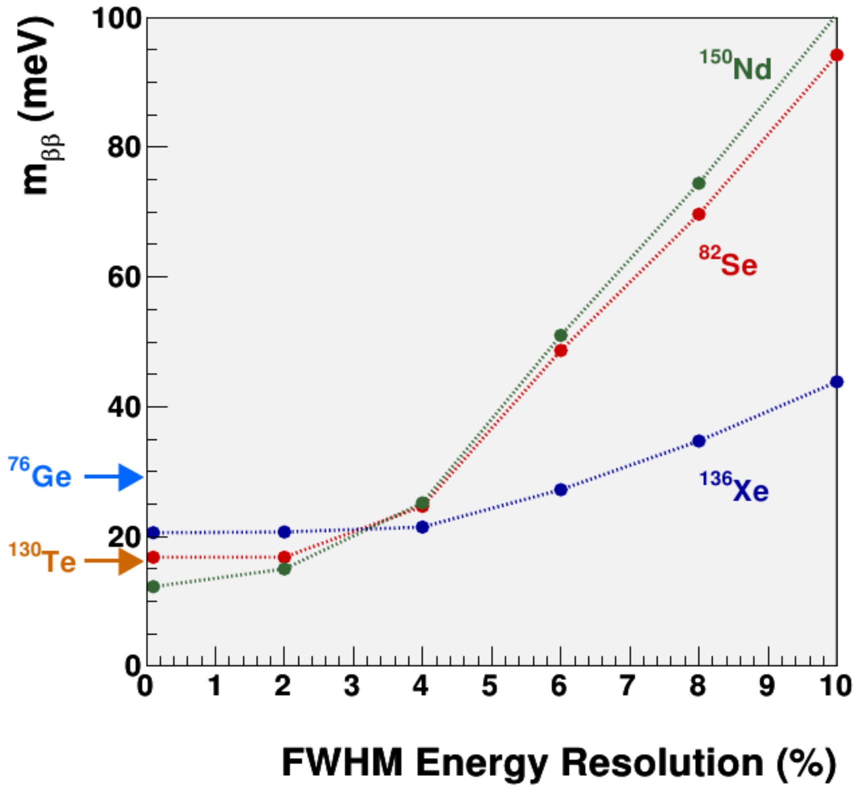
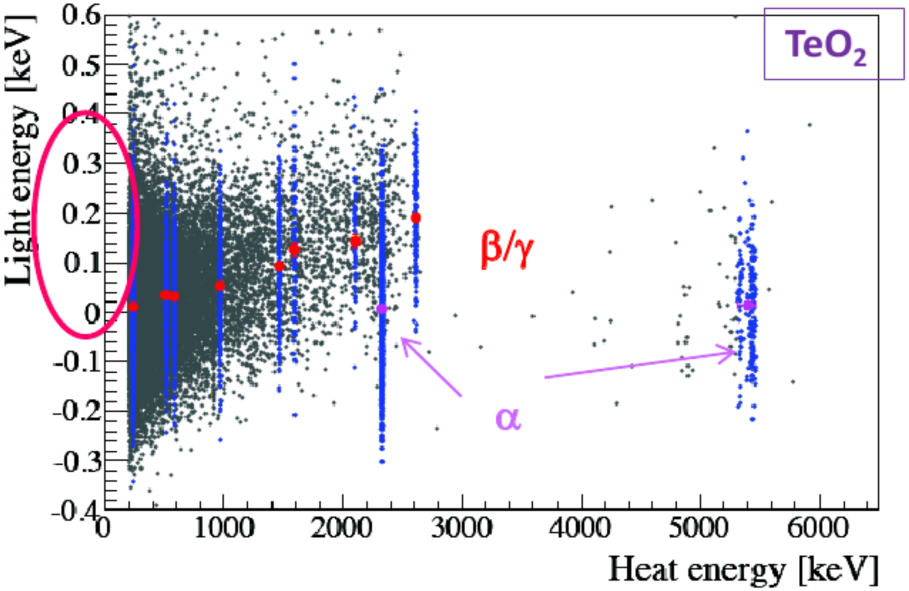


Fig. 18. – Sensitivity to $m_{\beta\beta}$ at 90% CL as a function of FWHM energy resolution, for ideal experiments using five different isotopes, each with 100 $kg_{\beta\beta}$ of $\beta\beta$ emitter mass and 5 years of data-taking. The experiments are assumed to have perfect efficiency and to be affected only by $\beta\beta2\nu$ backgrounds. In practice, experiments using ^{76}Ge and ^{130}Te always feature an excellent energy resolution and are therefore not affected by $\beta\beta2\nu$ backgrounds, hence only the background-free sensitivity limit is shown in those cases, with an arrow.

J.J. Gomez-Cadenas et al., arXiv:1109.5515

Exotic Backgrounds



Cardani, TAUP2011

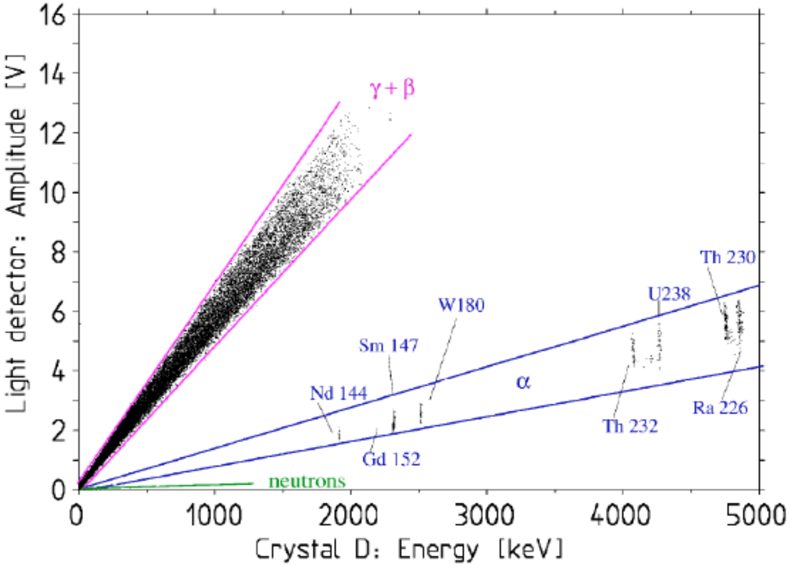
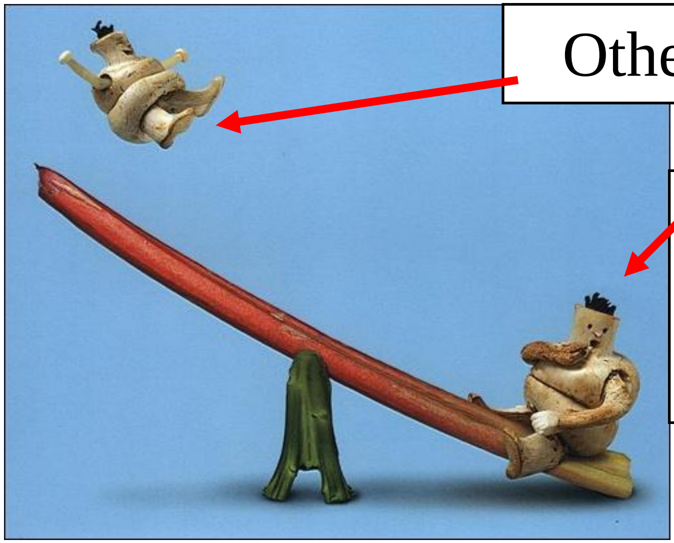


FIG. 1. Pulse amplitude in the light channel vs energy in the $CaWO_4$ crystal D from run 28. Three clearly separated event populations appear. The solid lines border the three different bands: the upper band is due to γ's and β's, the lowest one to neutrons and the middle one is due to α's. Each peak in the α band has been identified (see text) and is here labeled accordingly.

Cozzini et al, Phys. Rev. C70, 064606

- Rare α decays
- Rare β decays from short-lived daughter isotopes, see GERDA talk
- Neutrinos (de Barros, Zuber, arXiv:1103.5757)

An X-ton device?



Other constraints: Background, ΔE, tracking

1 ton enriched
Double Beta
Material cost?

Least amount of compromises currently(!) results in an:
Enriched Xenon TPC (high pressure gas)
NEXT and(?) EXO

THE UNIVERSITY OF WARWICK

An X-ton device?

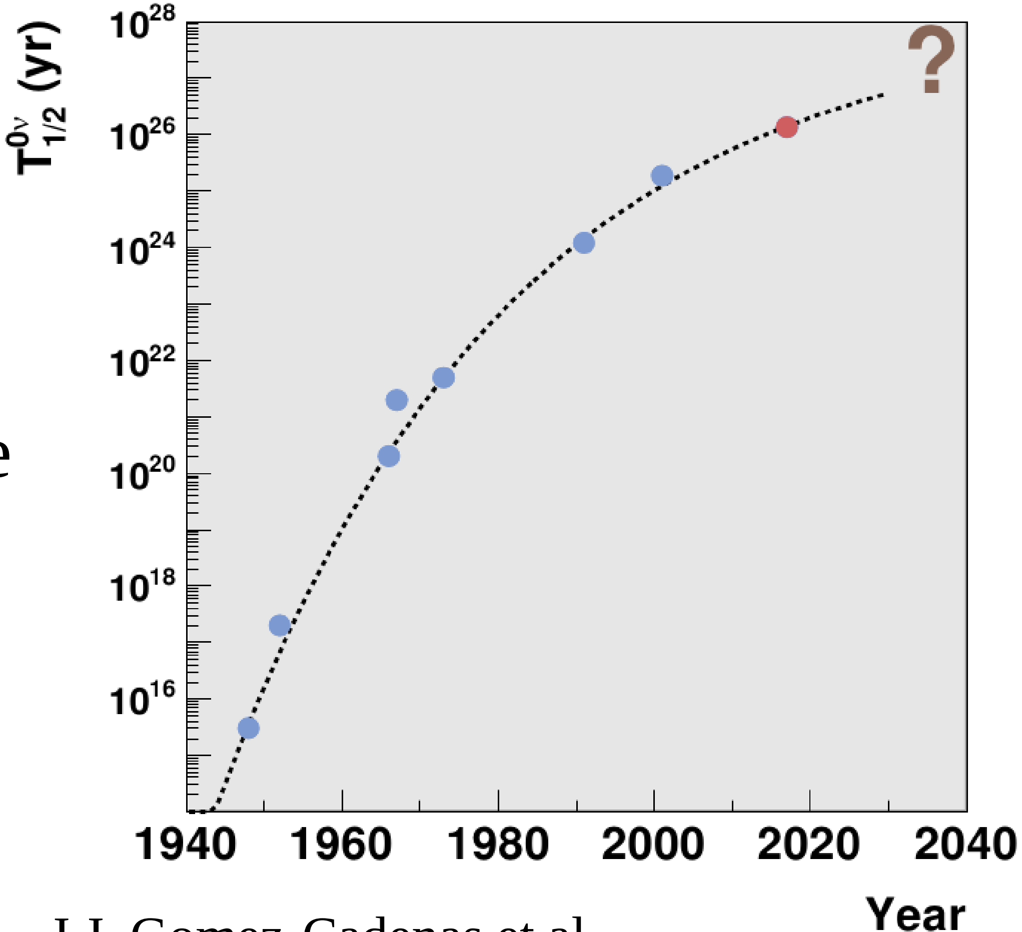
TABLE 7. Approximate price of 2β isotopes obtained by senrifugation. *) Taking into account 20% reduction for mass production case.

Isotope	Abundance	Price per kg, kS	Cost of 10 t, $M
^{76}Ge	7.61	~ 80	800 (640)*)
^{82}Se	8.73	~ 120	1200 (1000)*)
^{100}Mo	9.63	~ 80	800 (640)*)
^{116}Cd	7.49	~ 180	1800 (1440)*)
^{130}Te	34.08	~ 20	200 (160)*)
^{136}Xe	8.87	$\sim$ 5-10	50-100 (40-80)*)
^{150}Nd (?)	5.6	> 200	> 2000

A.S. Barabash, arXiv:1109.6423

Summary

- Exciting times ahead
  - New experiments starting
  - New backgrounds
  - Test of DBD evidence
- 'Going beyond' starts now – ideas most welcome



J.J. Gomez-Cadenas et al., arXiv:1109.5515