Neutrinoless Double Beta Decay

Phys 135c Spring 2007

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Theory Overview

neutrino Lagrangian

$$\nu^c \equiv i\gamma^2\gamma^0\overline{\nu}^{\mathrm{T}}$$

$$\mathcal{L}_\nu = \underbrace{M_D\left[\overline{\nu}_R\nu_L + \overline{\nu}^c_L\nu^c_R\right]}_{\text{Dirac}} + \underbrace{M_L\left[\overline{\nu}^c_L\nu_L + \overline{\nu}_L\nu^c_L\right] + M_R\left[\overline{\nu}^c_R\nu_R + \overline{\nu}_R\nu^c_R\right]}_{\text{Majorana}}$$

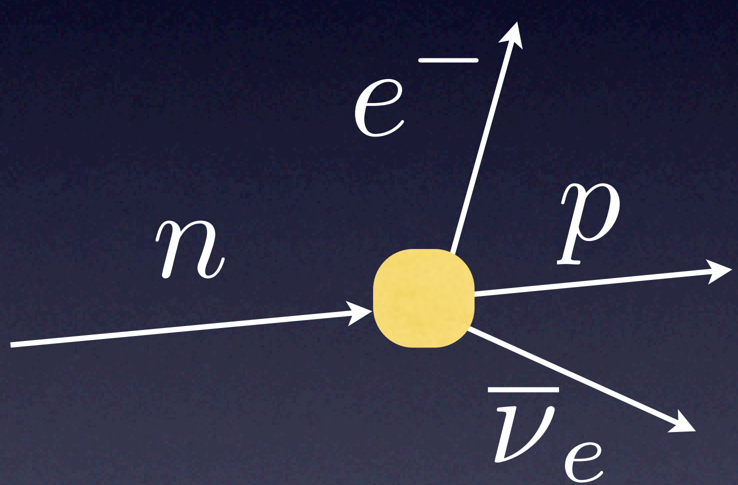
seesaw mechanism

$$\begin{bmatrix} 0 & M_D \\ M_D & M_R \end{bmatrix} \quad M_R \gg M_D \gg M_L \sim 0$$

$$\lambda_\pm = \frac{M_R \pm \sqrt{M_R^2 + 4M_D^2}}{2} \sim \begin{cases} M_R \\ -\frac{M_D^2}{M_R} \end{cases}$$

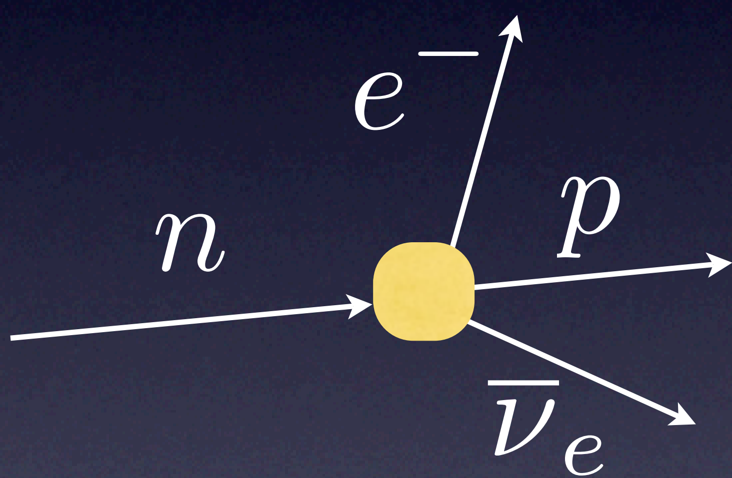
neutrinoless double beta decays

neutrinoless double beta decays

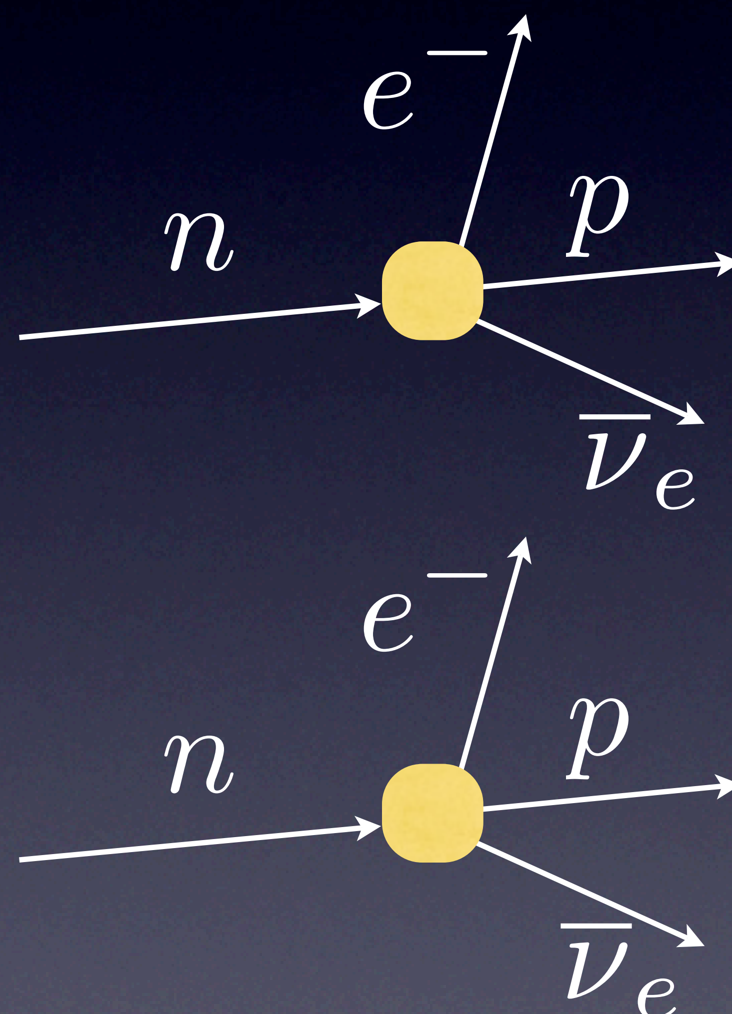


beta decay

neutrinoless double beta decays

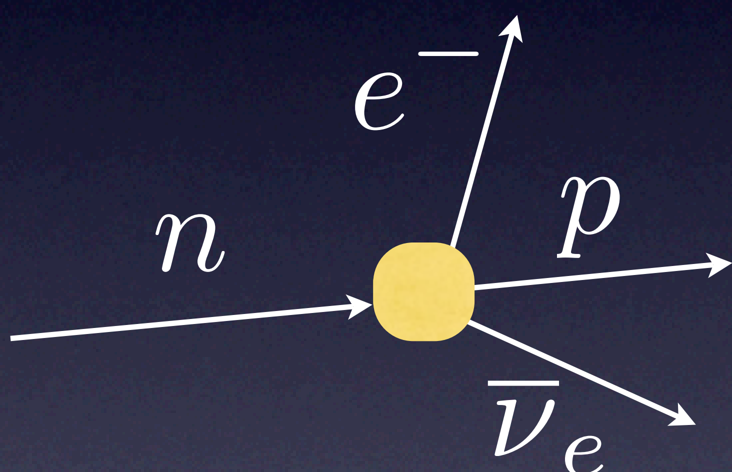


beta decay

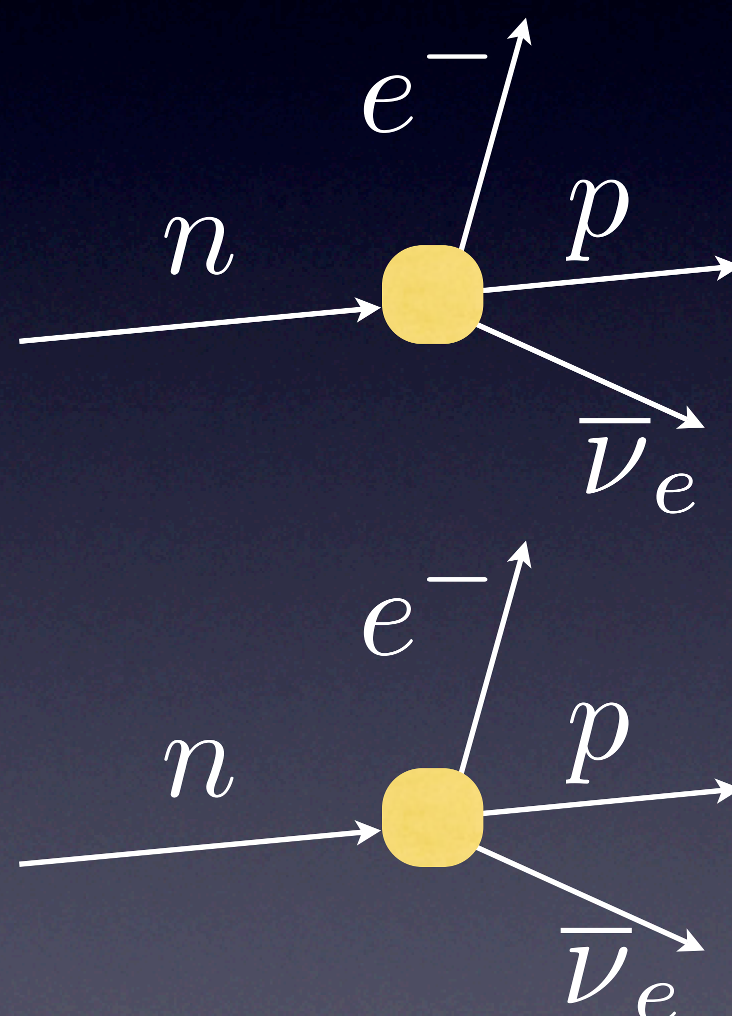


double beta decay

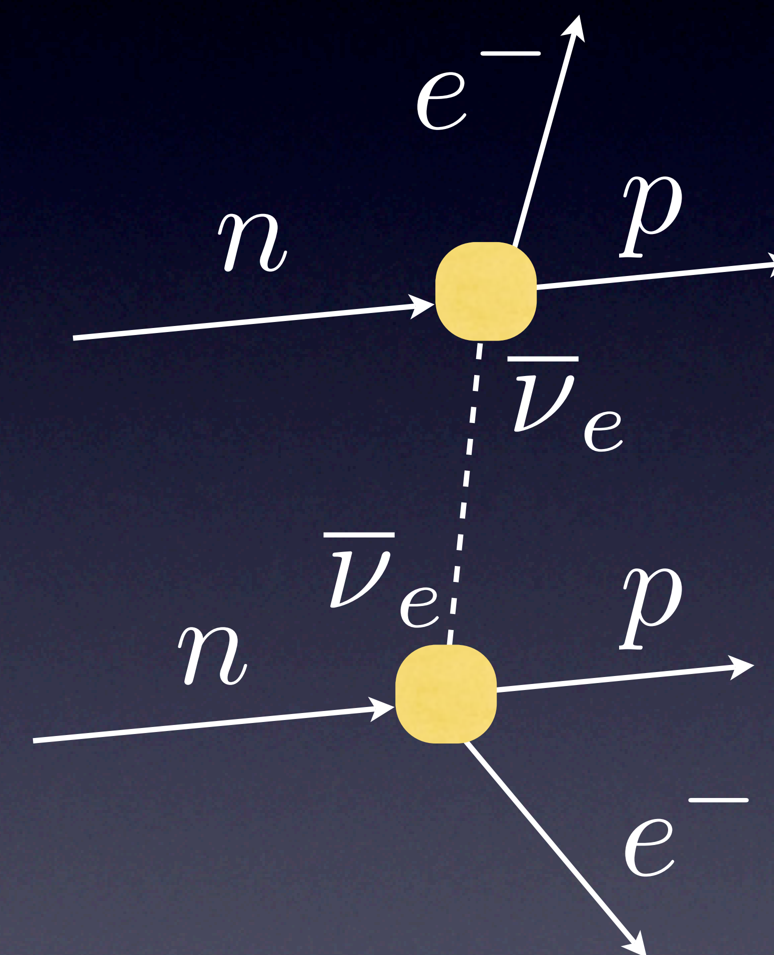
neutrinoless double beta decays



beta decay



double beta decay



neutrinoless double beta decay

double beta decay candidates

- $^{48}_{20}\mathrm{Ca}$
- $^{76}_{32}\mathrm{Ge}$
- $^{82}_{34}\mathrm{Se}$
- $^{96}_{40}\mathrm{Zr}$
- $^{116}_{48}\mathrm{Cd}$
- $^{100}_{42}\mathrm{Mo}$
- $^{128}_{52}\mathrm{Te}$
- $^{130}_{52}\mathrm{Te}$
- $^{136}_{54}\mathrm{Xe}$
- $^{134}_{54}\mathrm{Xe}$
- $^{150}_{60}\mathrm{Nd}$
- $^{160}_{64}\mathrm{Gd}$

decay rates

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$$\Gamma^{2\nu} = G^{2\nu} \left| M_{GT}^{2\nu} \right|^2$$

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$$\Gamma^{0\nu} = G^{0\nu} \left| M_{GT}^{0\nu} - \frac{g_V^2}{g_A^2} M_F^{0\nu} \right|^2 \langle m_\nu \rangle^2 \propto \langle m_\nu \rangle^2$$

double beta decay rates

TABLE 1 Summary of experimentally measured $\beta\beta(2\nu)$ half-lives and matrix elements[a]

Isotope	$T_{1/2}^{2\nu}$ (y)	References	$M_{GT}^{2\nu}$ (MeV^{-1})
^{48}Ca	$(4.2 \pm 1.2) \times 10^{19}$	(55, 56)	0.05
^{76}Ge	$(1.3 \pm 0.1) \times 10^{21}$	(57–59)	0.15
^{82}Se	$(9.2 \pm 1.0) \times 10^{19}$	(60, 61)	0.10
^{96}Zr†	$(1.4^{+3.5}_{-0.5}) \times 10^{19}$	(62–64)	0.12
^{100}Mo	$(8.0 \pm 0.6) \times 10^{18}$	(65–70), (71)†	0.22
^{116}Cd	$(3.2 \pm 0.3) \times 10^{19}$	(72–74)	0.12
^{128}Te[b]	$(7.2 \pm 0.3) \times 10^{24}$	(75, 76)	0.025
^{130}Te[c]	$(2.7 \pm 0.1) \times 10^{21}$	(75)	0.017
^{136}Xe	$>8.1 \times 10^{20}$ (90% CL)	(77)	<0.03
^{150}Nd†	$7.0^{+11.8}_{-0.3} \times 10^{18}$	(68, 78)	0.07
^{238}U[d]	$(2.0 \pm 0.6) \times 10^{21}$	(79)	0.05

(Elliott & Vogel 2002)

neutrinoless rates

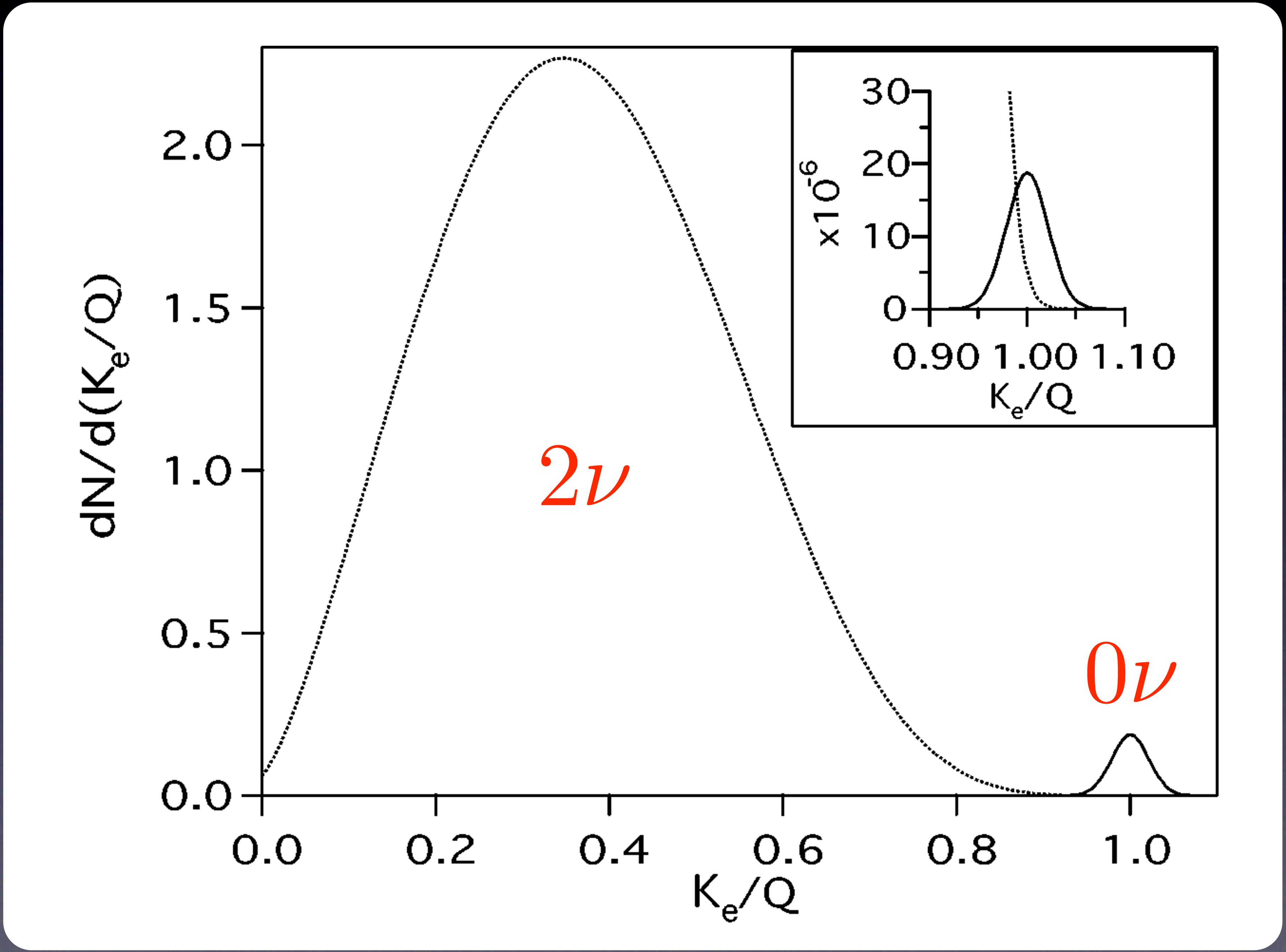
TABLE 2 $\beta\beta(0\nu)$ half-lives in units of 10^{26} y corresponding to $\langle m_\nu \rangle = 50$ meV for nuclear matrix elements evaluated in the references indicated

	References					
Nucleus	**(20)**	**(80)**	**(81)**	**(82)**	**(24, 83)**	**(84)**
^{48}Ca	12.7	35.3	—	—	—	10.0
^{76}Ge	6.8	70.8	56.0	9.3	12.8	14.4
^{82}Se	2.3	9.6	22.4	2.4	3.2	6.0
^{100}Mo	—	—	4.0	5.1	1.2	15.6
^{116}Cd	—	—	—	1.9	3.1	18.8
^{130}Te	0.6	23.2	2.8	2.0	3.6	3.4
^{136}Xe	—	48.4	13.2	8.8	21.2	7.2
^{150}Nd[a]	—	—	—	0.1	0.2	—
^{160}Gd[a]	—	—	—	3.4	—	—

[a]deformed nucleus; deformation not taken into account.

(Elliott & Vogel 2002)

experimental signal



(Elliott & Vogel 2002)

experimental uncertainty

Upper limit on neutrino mass

$$\langle m_\nu \rangle = (2.67 \times 10^{-8}\text{eV}) \left[\frac{W}{f x \epsilon G^{0\nu} |M^{0\nu}|^2} \right]^{1/2} \times \frac{1}{\sqrt{MT}}$$

no background, usual √n counting statistics

experimental uncertainty

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[redacted]

experimental uncertainty

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no background, usual √n counting statistics

$$\langle m_\nu \rangle = (2.50 \times 10^{-8}\mathrm{eV}) \left[\frac{W}{f x \epsilon G^{0\nu} |M^{0\nu}|^2} \right]^{1/2} \times \left[\frac{b \Delta E}{MT} \right]^{1/4}$$

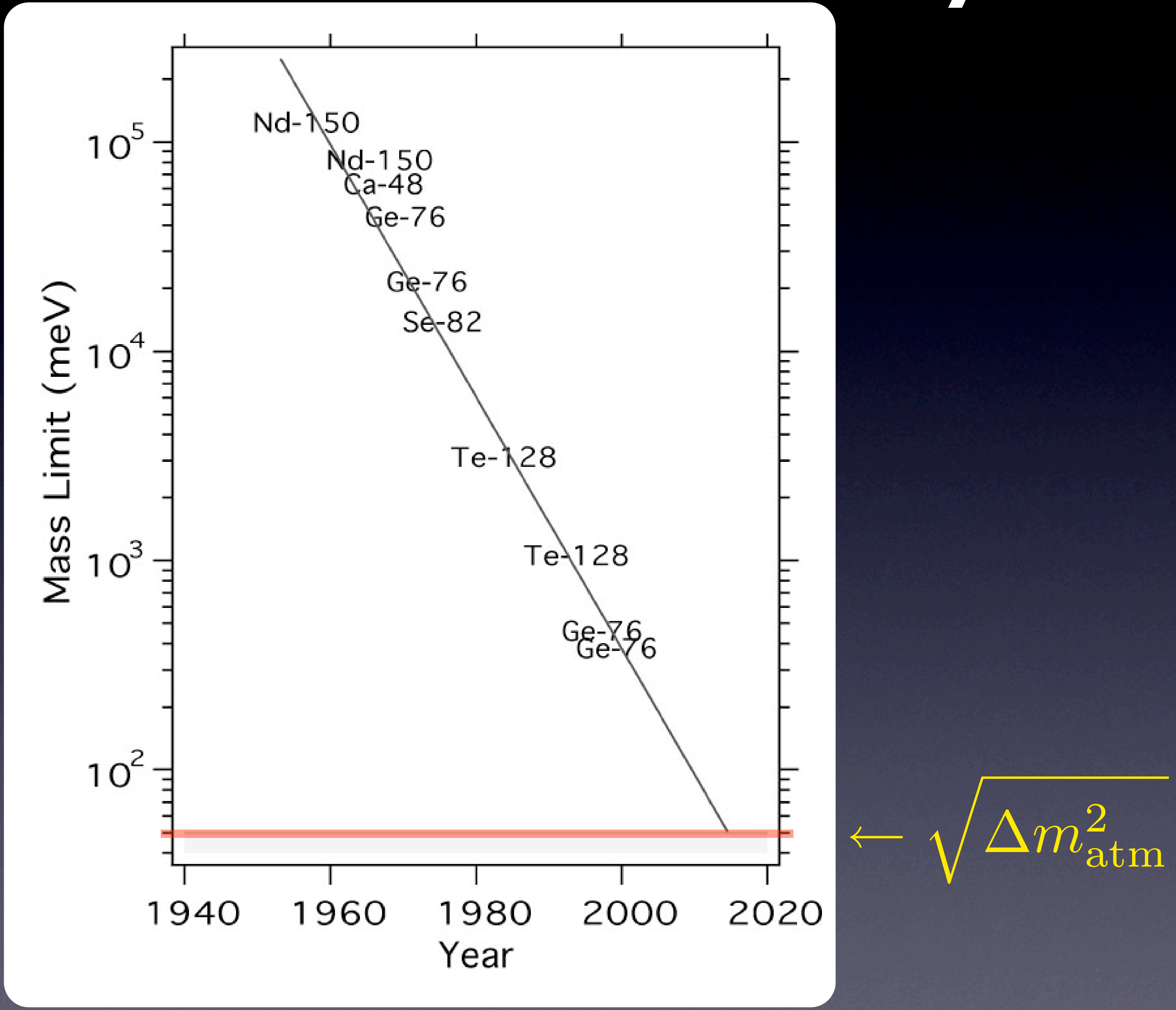
real experiments with background

lowering the limit

$$\langle m_\nu \rangle = (2.50 \times 10^{-8}\text{eV}) \left[\frac{W}{f x \epsilon G^{0\nu} |M^{0\nu}|^2} \right]^{1/2} \times \left[\frac{b \Delta E}{MT} \right]^{1/4}$$

- Good shielding
- Purified materials
  - Underground lab to avoid cosmogenics
- Minimize excess material
- High energy resolution
- Particle tracking
- End product tagging

experimental history

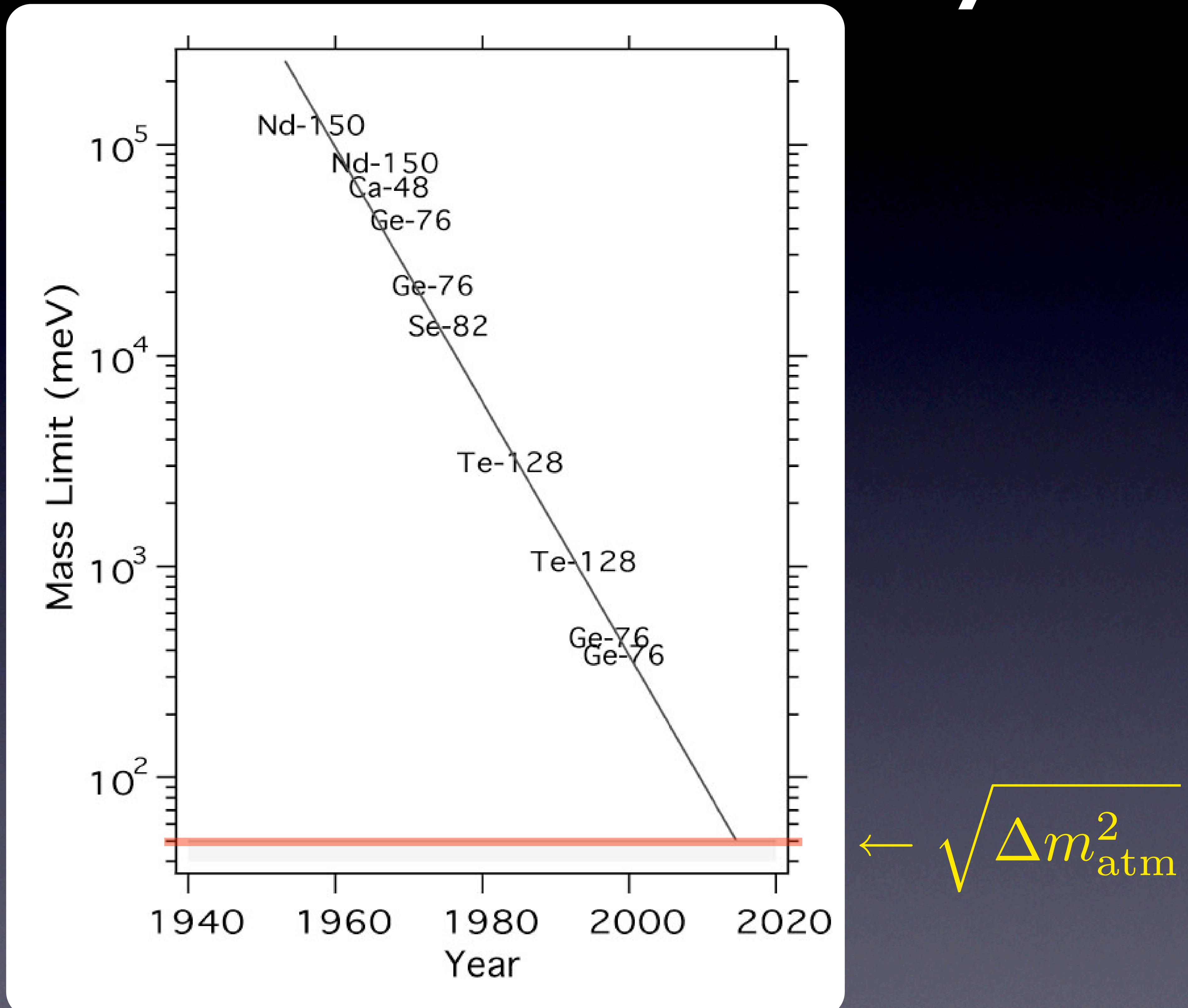


(Elliott & Vogel 2002)

questions?

Experiments

experimental history



(Elliott & Vogel 2002)

$^{76}_{32}\mathrm{Ge}$

Heidelberg-Moscow

10.9 kg 86% enriched Ge   1990-2003

best results to date

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Heidelberg-Moscow

10.9 kg 86% enriched Ge 1990-2003

best results to date

GENIUS

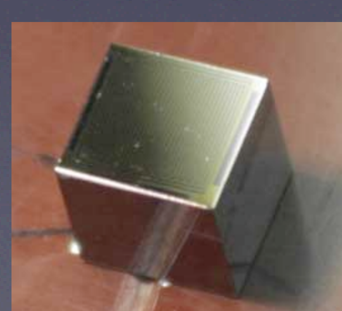
GErmanium NItrogen Underground Setup

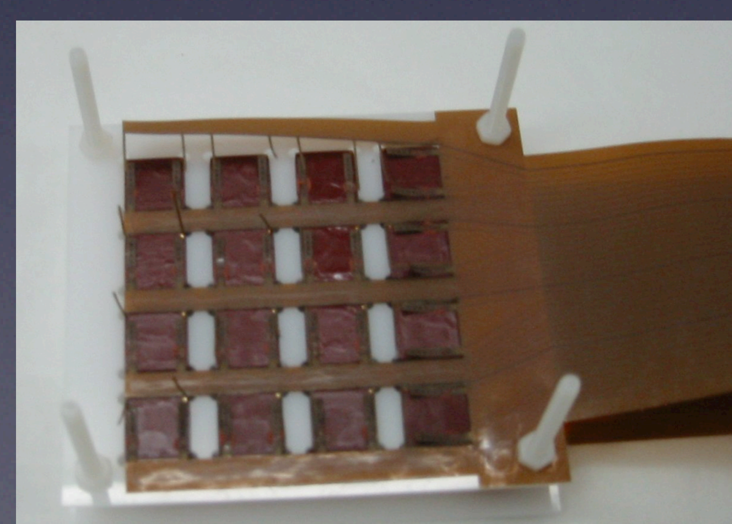
COBRA

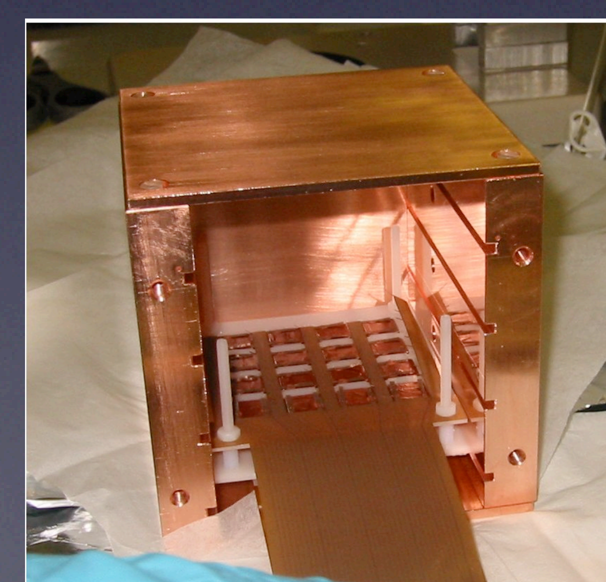
Cadmium-telluride 0-neutrino double-Beta Research Apparatus

- Cd-Zn-Te detectors
- 400 kg as 40x40x40 1cm^3 crystals
- Sensitivity up to 10^{26} yr half life

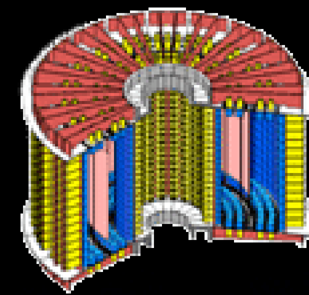
$^{106}_{48}\mathrm{Cd}$	$^{108}_{48}\mathrm{Cd}$
$^{114}_{48}\mathrm{Cd}$	$^{116}_{48}\mathrm{Cd}$
$^{64}_{30}\mathrm{Zn}$	$^{70}_{30}\mathrm{Zn}$
$^{120}_{52}\mathrm{Te}$	$^{128}_{52}\mathrm{Te}$
$^{130}_{52}\mathrm{Te}$	





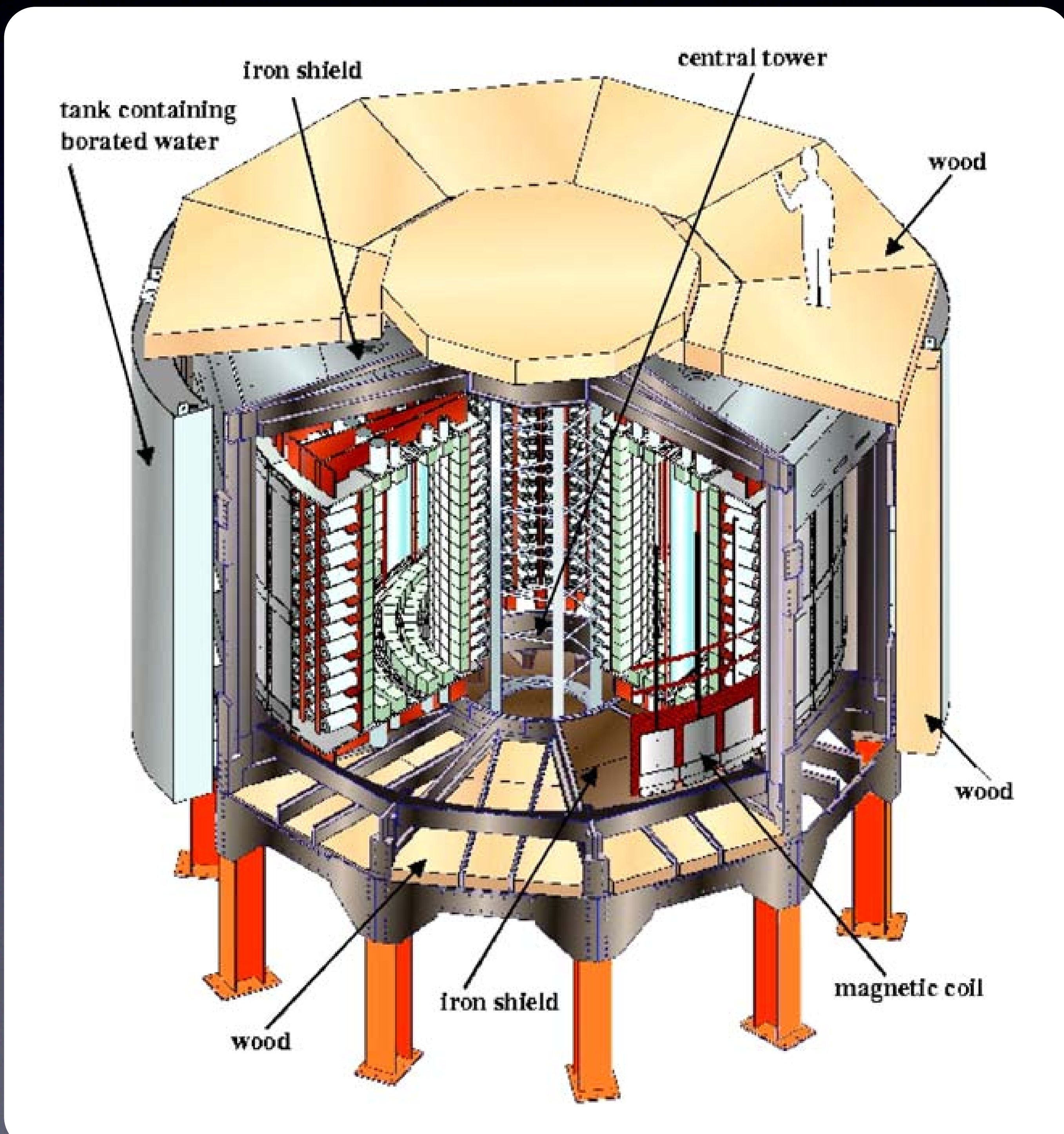


$^{100}_{42}Mo$ $^{82}_{34}Se$



NEMO

Neutrino Ettore Majorana Observatory



- 7 kg Mo, 1kg Se in thin foils (40-60mg/cm^2)
- 6180 gas tracking drift cells
- 1940 cell plastic scintillator calorimeter

NEMO 3 detector

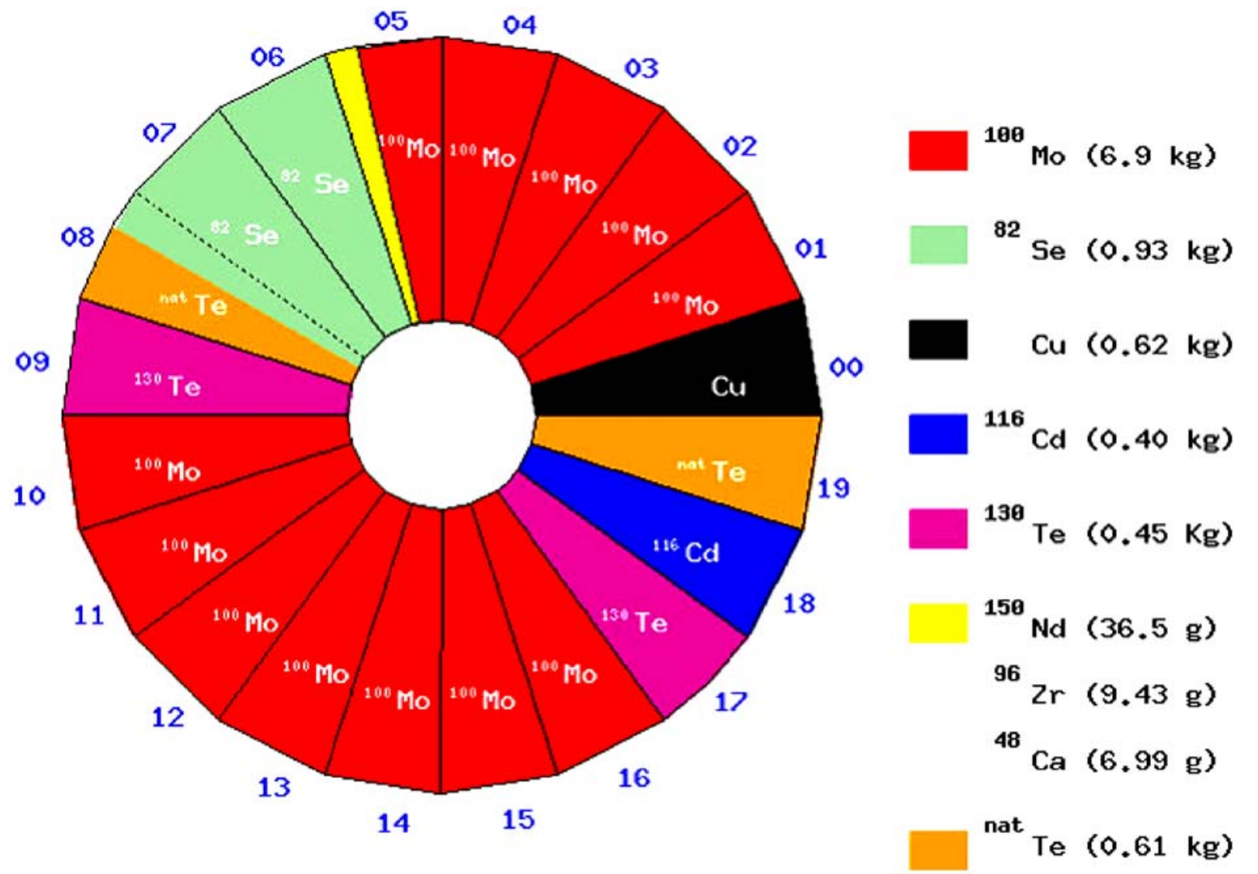
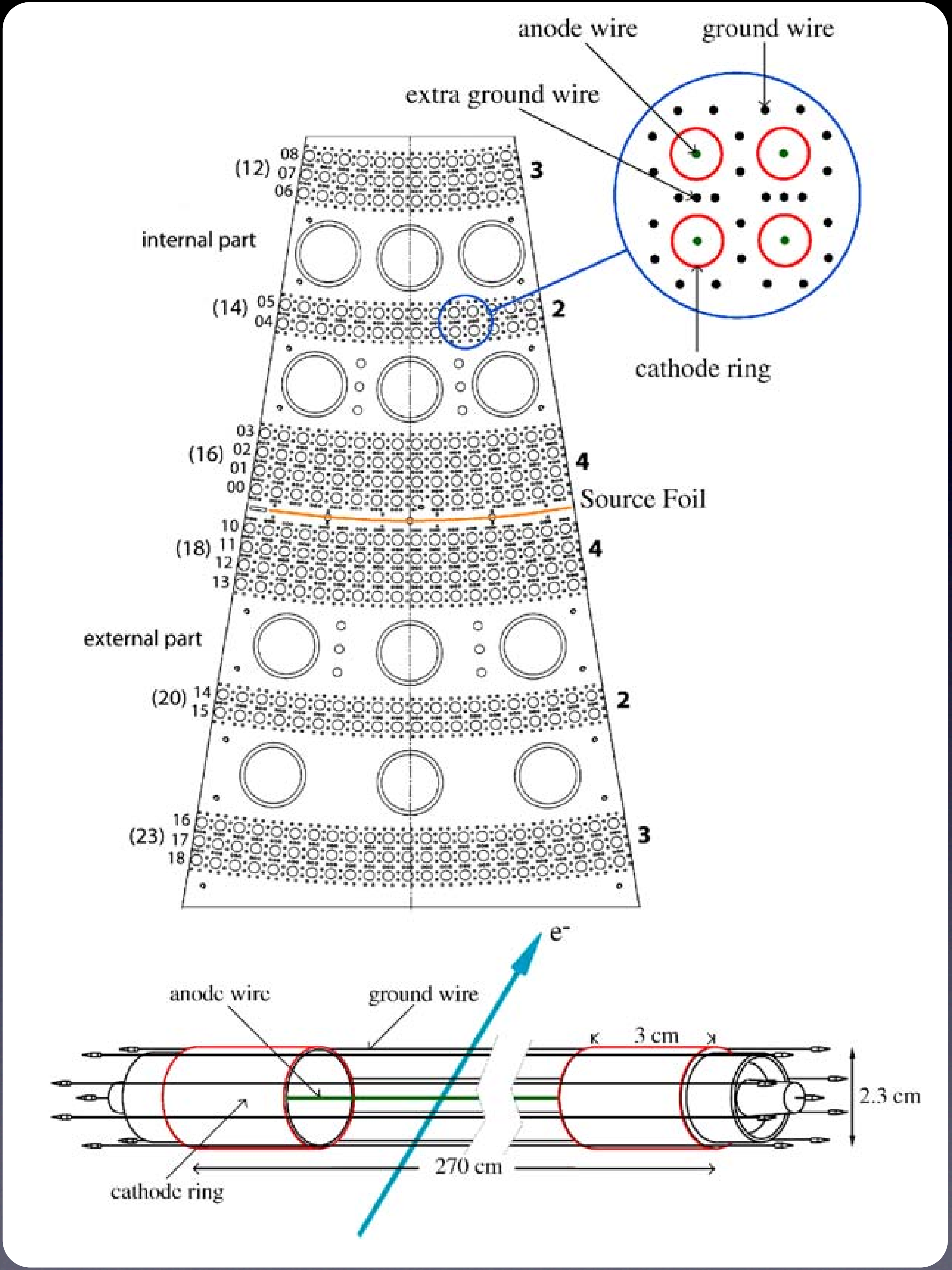


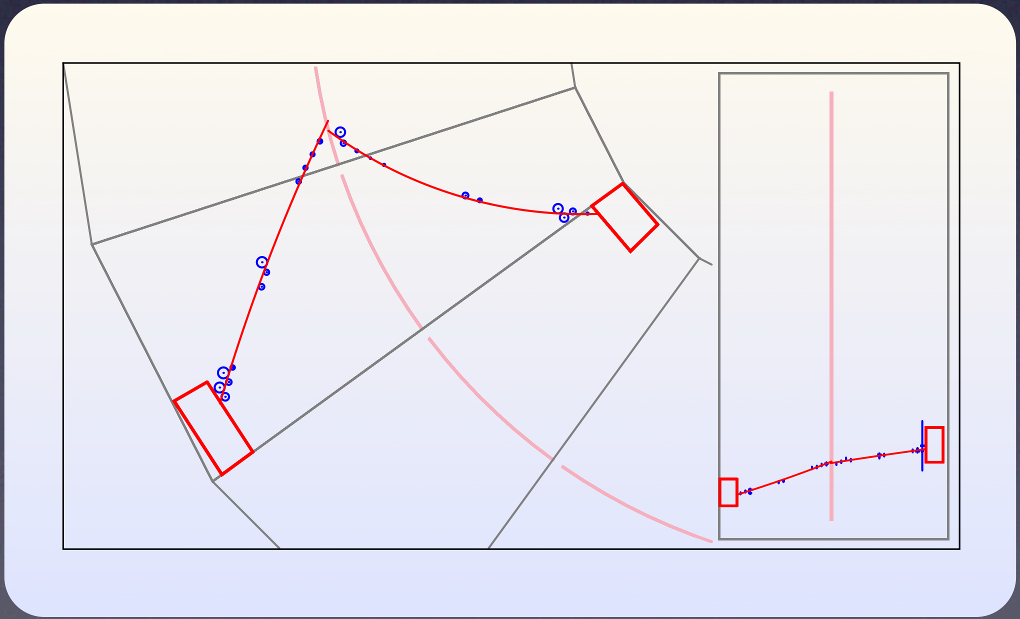
Fig. 5. The source distribution in the 20 sectors of NEMO 3.

foil compositions

wire chamber



electron pair track

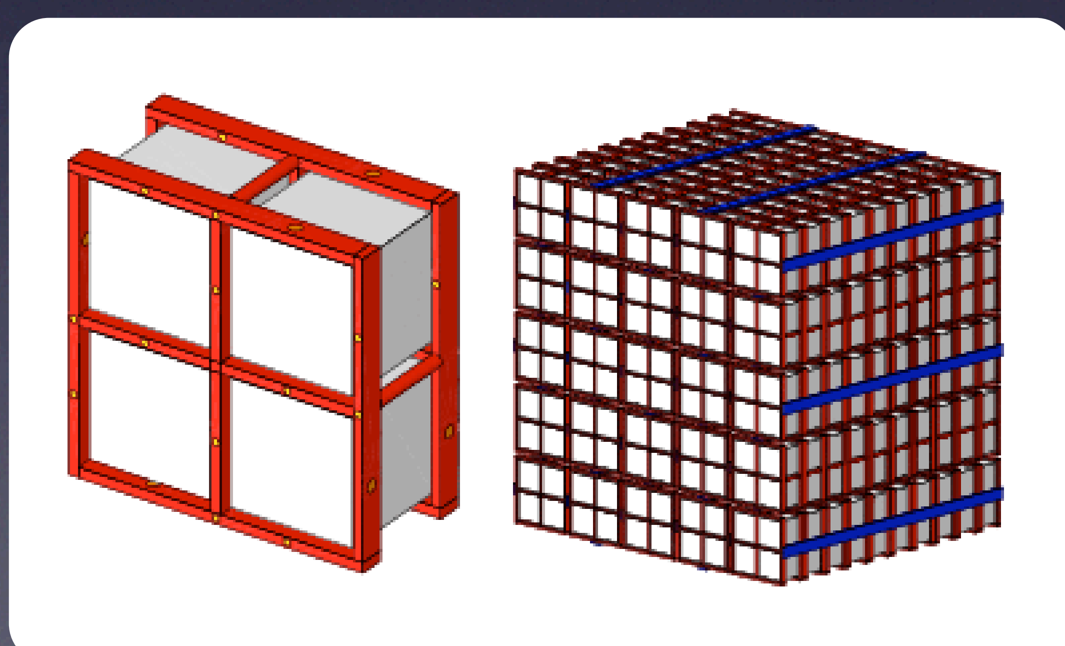


$^{130}_{52}\mathrm{Te}$

CUORE

Cryogenic Underground Observatory for Rare Events

- 988 (5cm)^3 750g TeO_2 bolometer cubes
- 7-10mK operating temperature by dilution refrigeration



$$c_v \propto T^3$$

"All right,
but apart from the sanitation,
the medicine, education, wine,
public order, irrigation, roads,
a fresh water system, and public health,
what have the Romans ever done for us?"

-Monty Python, *Life of Brian*

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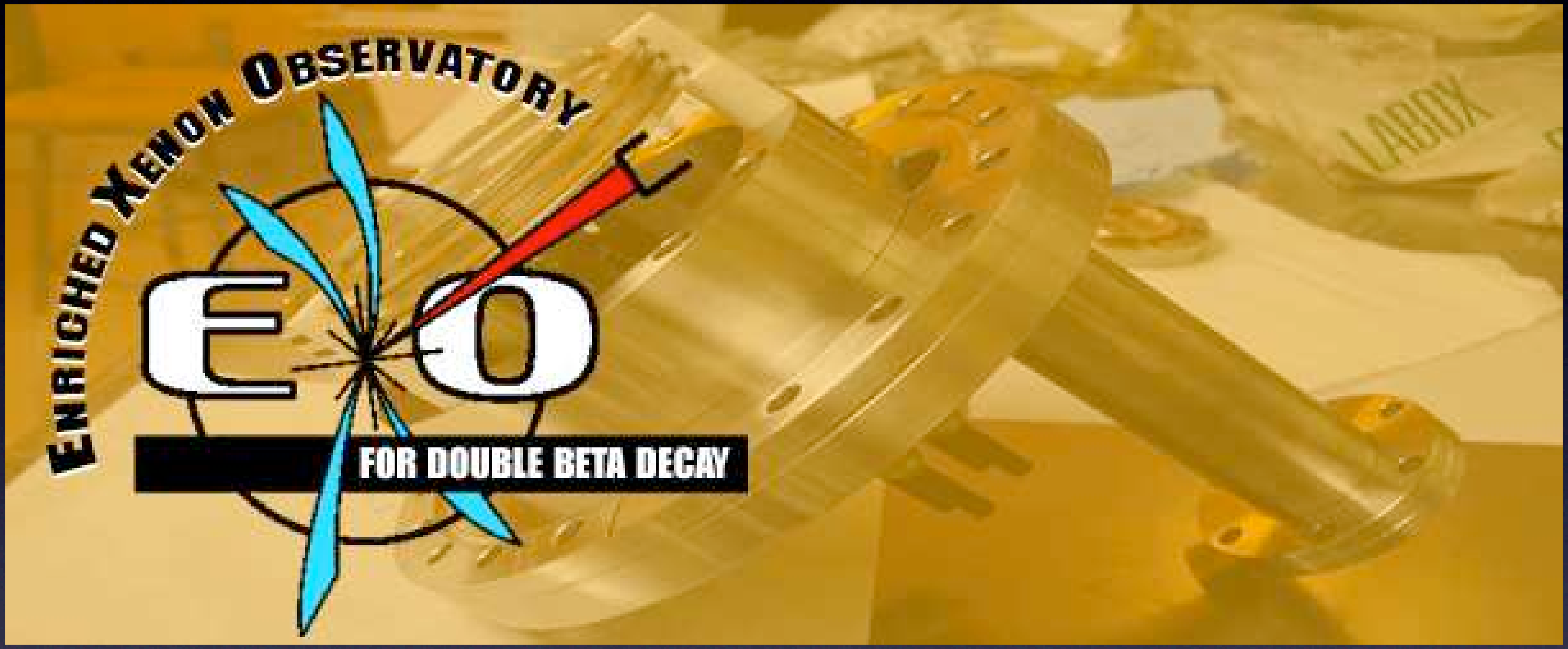
answer: low radiation lead

$^{136}_{54}Xe$

EXO

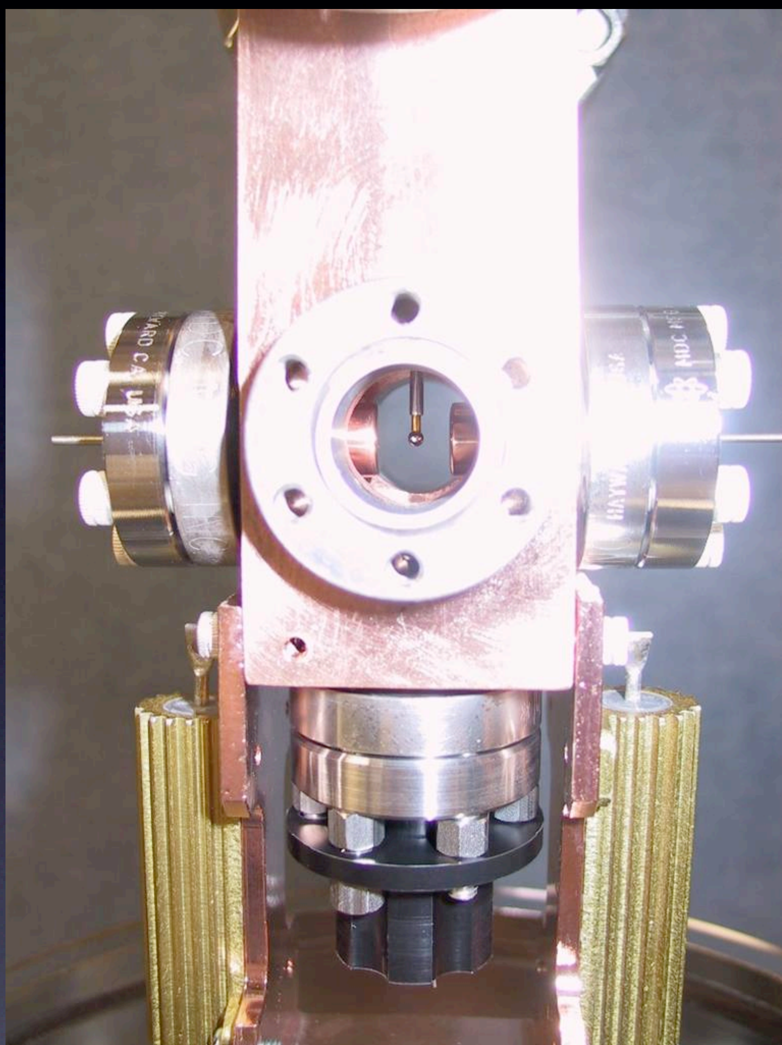
Enriched Xenon Observatory



prototype: 200kg Xe, to be installed at WIPP

full: 10 Tons (!) enriched liquid Xe

$^{136}_{54}\mathrm{Xe}$



"ion grabber"

- Easy to enrich and purify
- Acts as a scintillator
- "Time Projection Chamber" (TPC) configuration gives full electron tracking
- No long-lived activation isotopes
- Possible to identify resulting ^{136}Ba

questions?