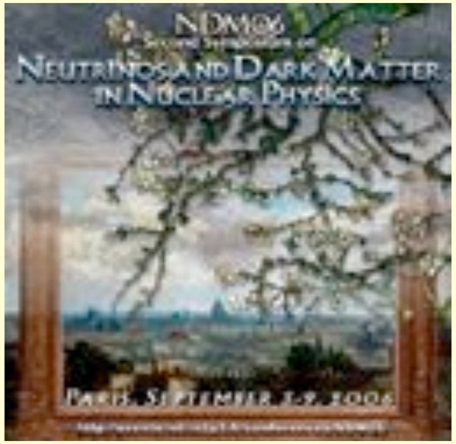

Double Beta Decay: future experiments

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- crucial role of DBD for the future of neutrino physics
- from where we start…and where we want to go to
- the DBD experimental program: challenges and techniques
- overview of the experiments
- discovery potential and branching points

0ν-DBD and neutrino physics

how **0ν-DBD** is connected to neutrino mixing matrix and masses
in case of process induced by mass mechanism

neutrinoless Double Beta Decay **rate**

Phase space

Nuclear matrix elements

Effective **Majorana mass**

$$1/\tau = G(Q,Z)\,|M_{nucl}|^2 \langle M_{\beta\beta}\rangle^2$$

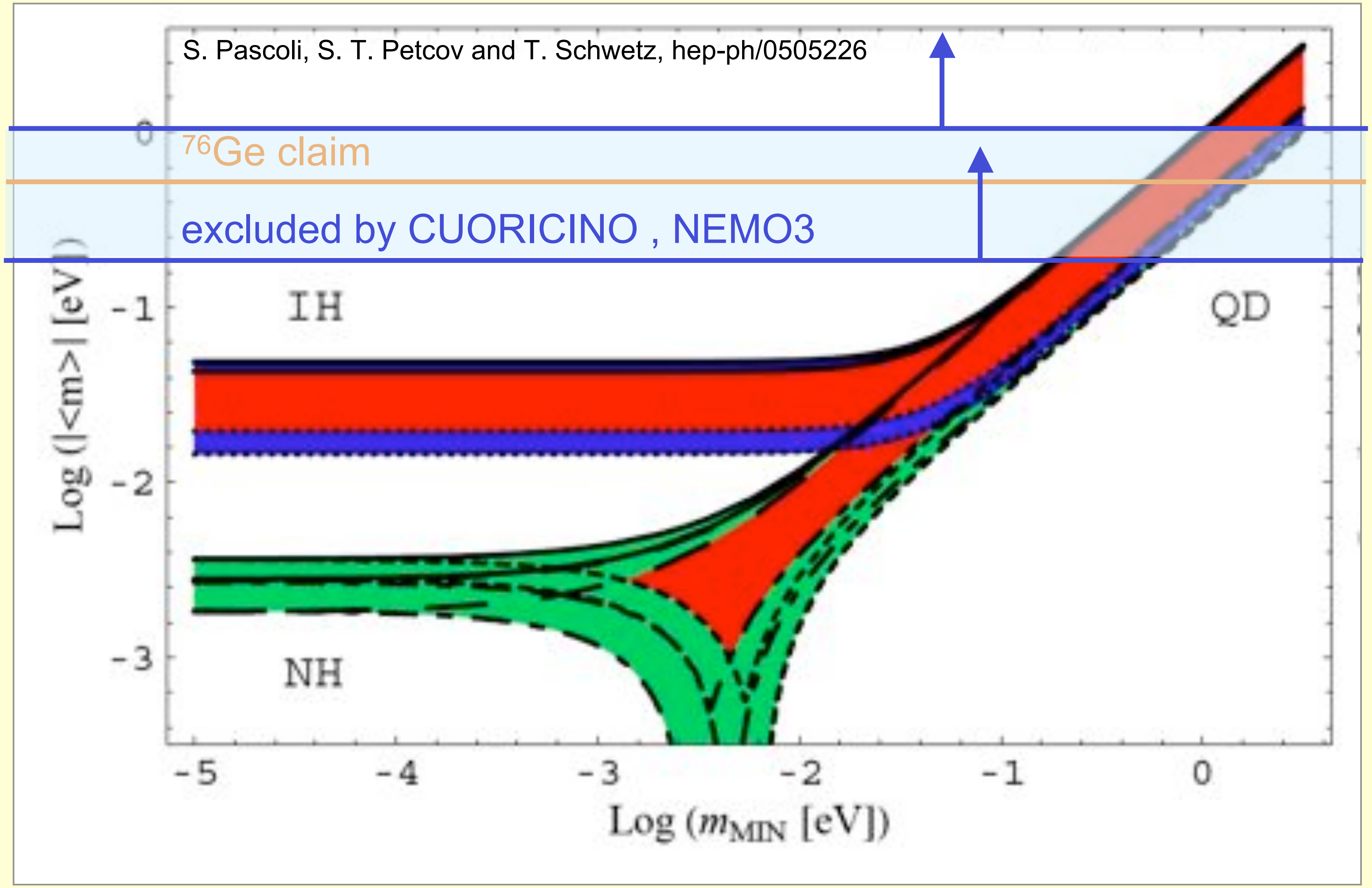
what the experimentalists try to measure

what the nuclear theorists try to calculate

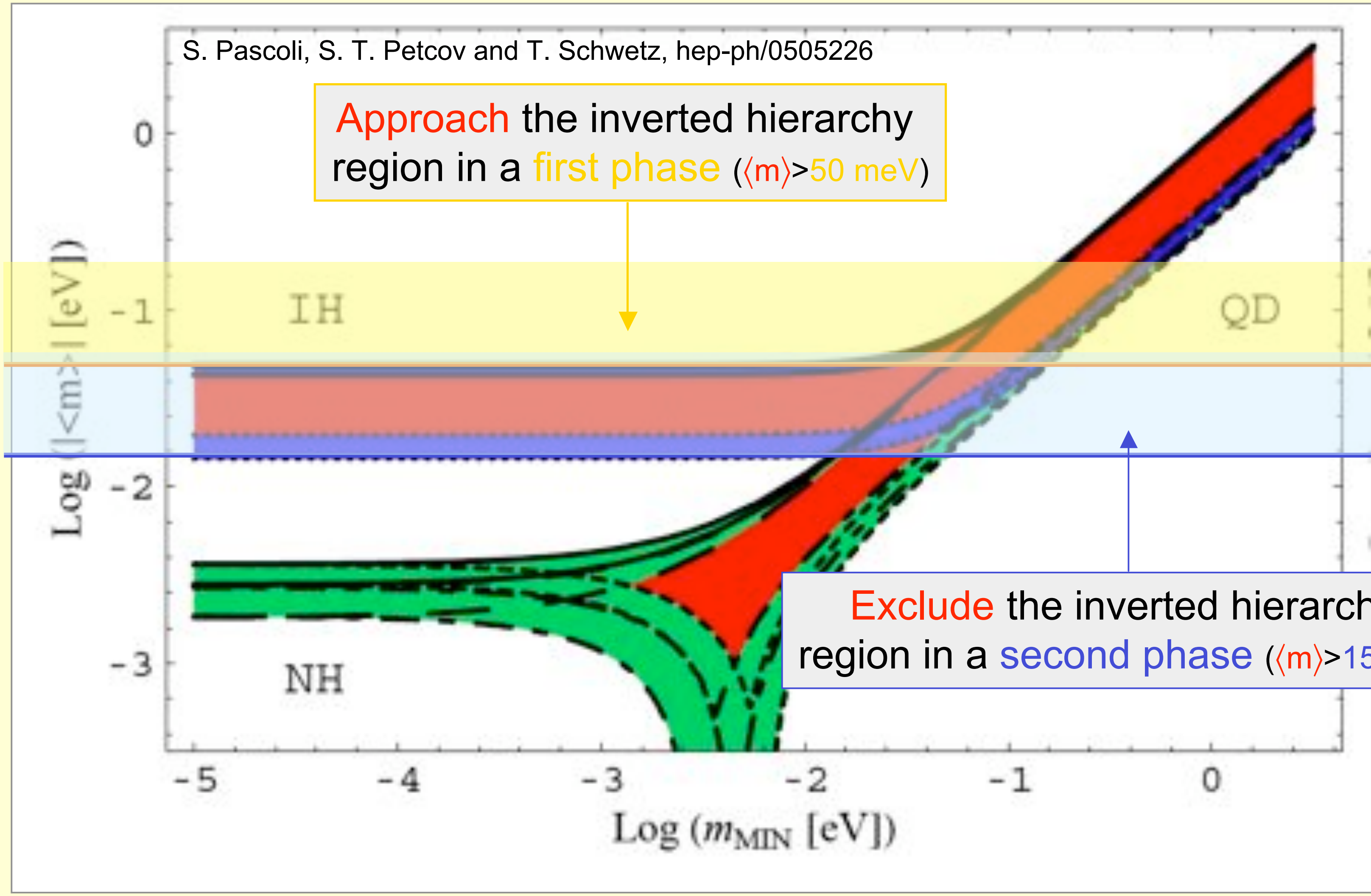
parameter containing the physics

$$\langle M_{\beta\beta}\rangle = \left|\,|U_{e1}|^2 M_1 + e^{i\alpha_1}\,|U_{e2}|^2 M_2 + e^{i\alpha_2}\,|U_{e3}|^2 M_3\,\right|$$

From where we start…

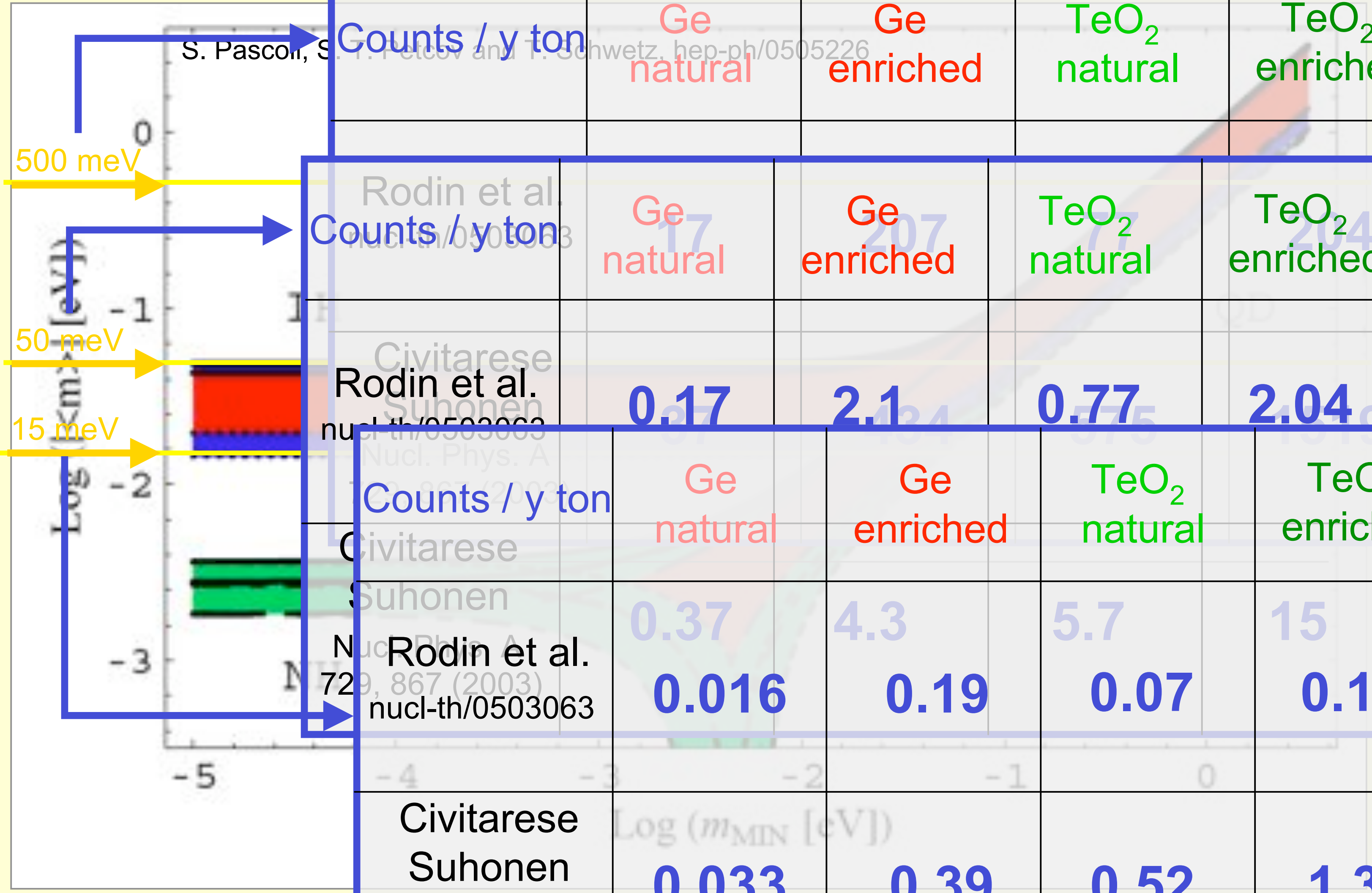


…and where we want to go



There are techniques and experiments in preparation which have the potential to reach these sensitivities

The size of the challenge



Counts / y ton	Ge natural	Ge enriched	TeO_2 natural	TeO_2 enriched
Rodin et al. nucl-th/0503063	17	207	77	204
Civitarese Suhonen Nucl. Phys. A 729, 867 (2003)	37	434	575	1519

Counts / y ton	Ge natural	Ge enriched	TeO_2 natural	TeO_2 enriched
Rodin et al. nucl-th/0503063	0.17	2.1	0.77	2.04
Civitarese Suhonen Nucl. Phys. A 729, 867 (2003)	0.37	4.3	5.7	15

Counts / y ton	Ge natural	Ge enriched	TeO_2 natural	TeO_2 enriched
Rodin et al. nucl-th/0503063	0.016	0.19	0.07	0.18
Civitarese Suhonen Nucl. Phys. A	0.033	0.39	0.52	1.37

Sensitive masses at the 1 ton scale are required

Background requirements

To start to explore the inverted hierarchy region

Sensitivity at the level of 1-10 counts / y ton

To cover the inverted hierarchy region

Sensitivity at the level of 0.1 -1 counts / y ton

The order of magnitude of the target bakground is
~ 1 counts / y ton

- Natural ra
  (source its
- Neutrons
- Cosmogen
- $2\ \nu$ Double Beta Decay

seful

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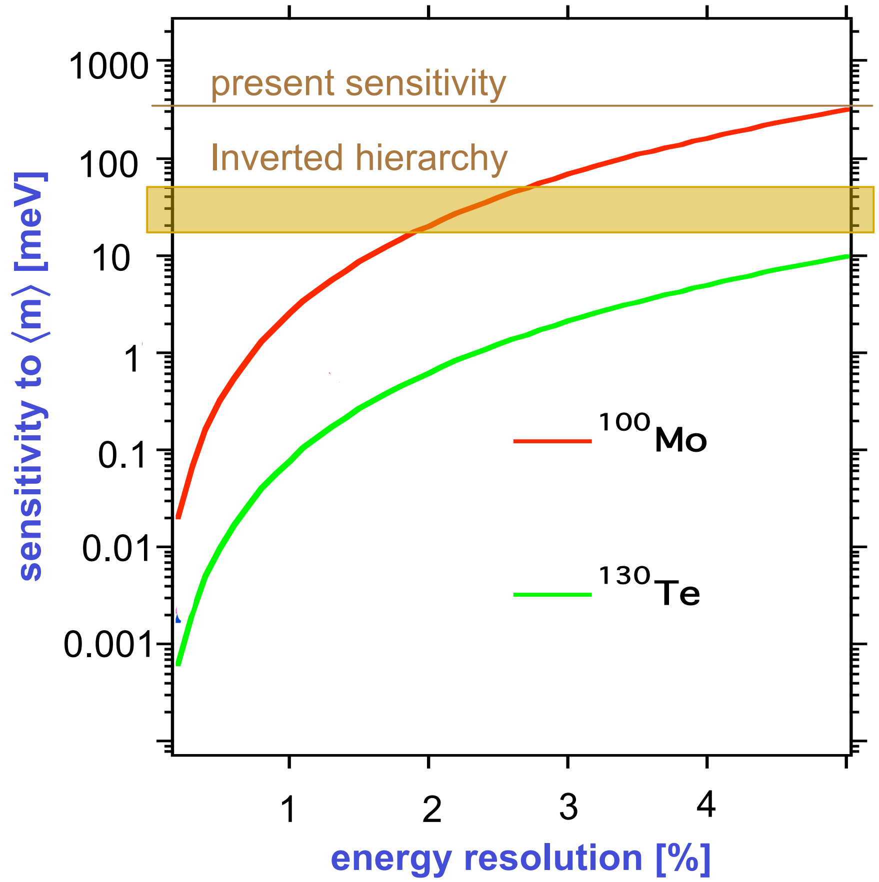
A challenge for the space-resolving techniques, which normally have low energy resolution (~ 10 %)



Experimental sensitivity to 0ν-DBD

sensitivity F: lifetime corresponding to the minimum detectable number of events over background at a given confidence level

b: specific background coefficient **[counts/(keV kg y)]**

$b \neq 0$

source mass, live time, energy resolution, background level

$$F \propto (MT / b\Delta E)^{1/2}$$

$b = 0$

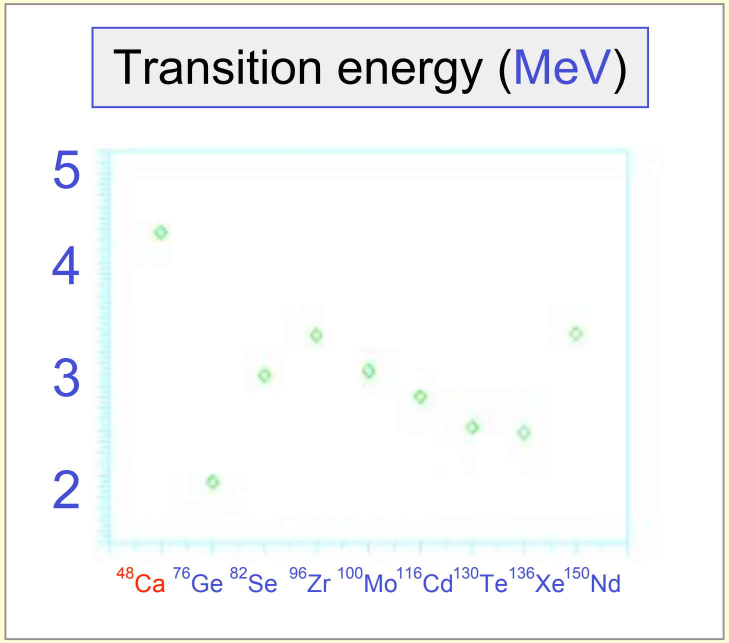
$$F \propto MT$$

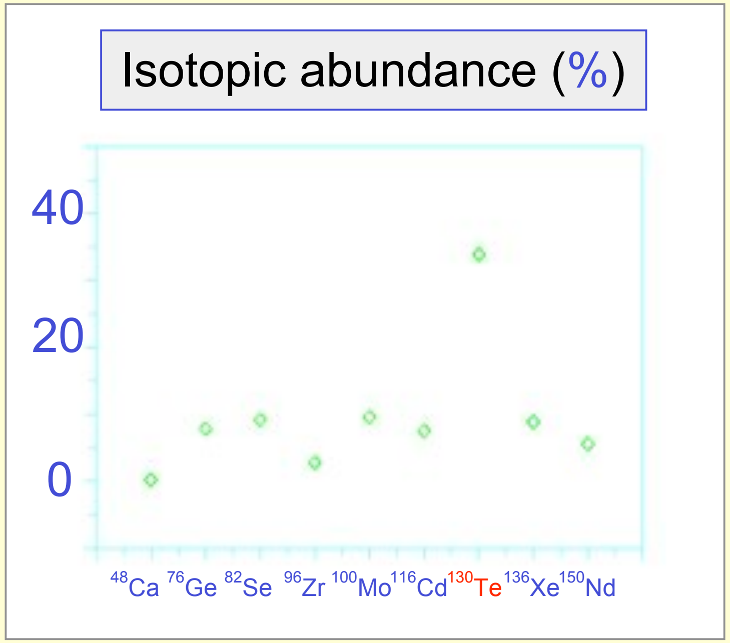
importance of the nuclide choice

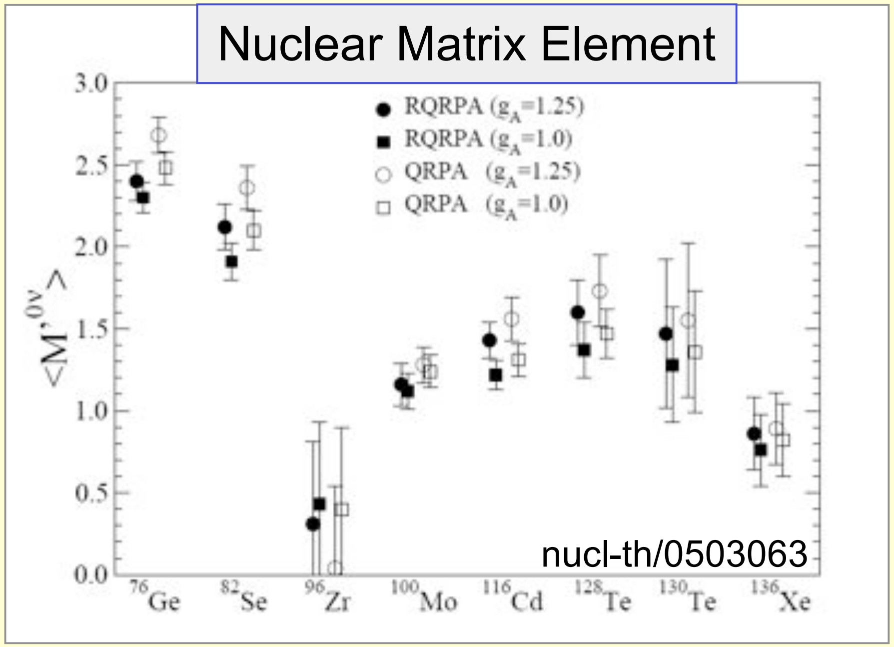
(but large uncertainty due to nuclear physics)

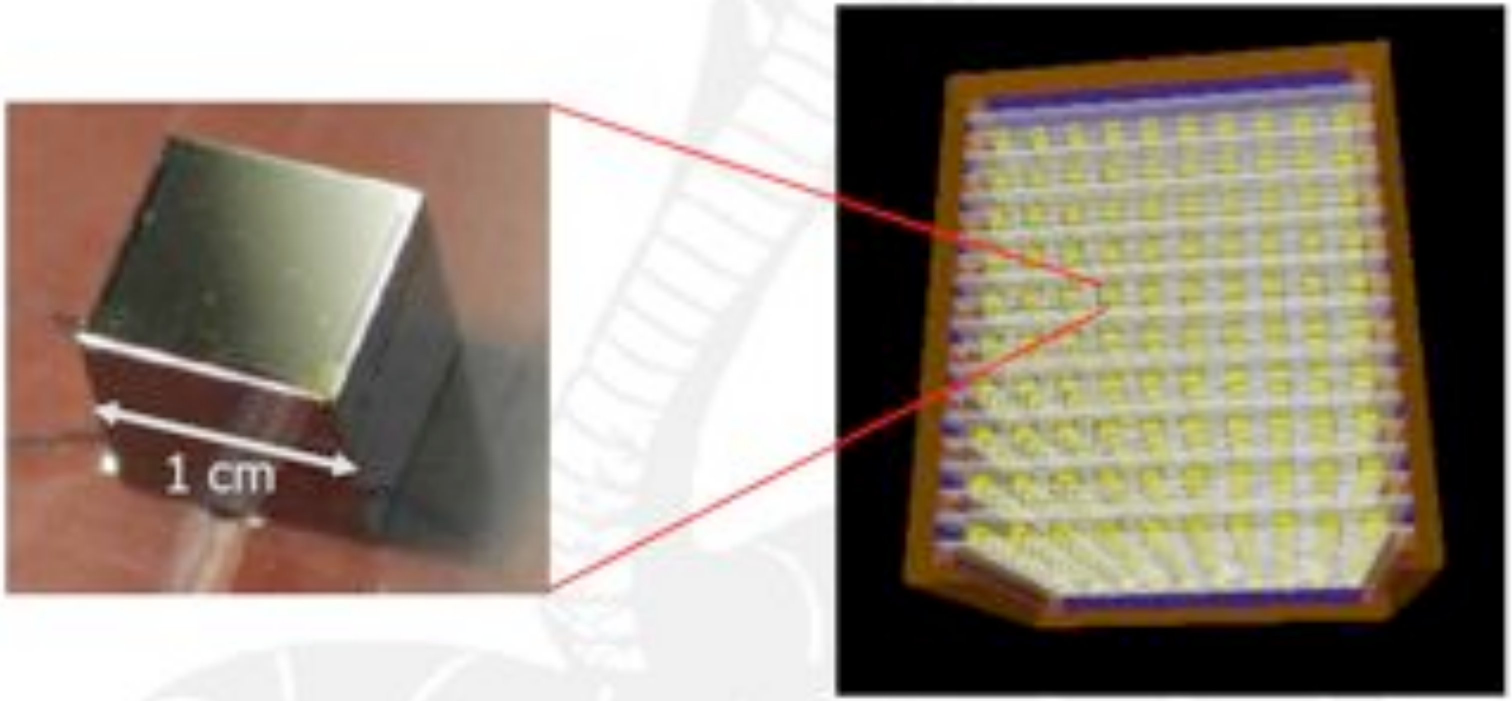
sensitivity to $\langle M \rangle \propto (F/Q\,|M_{nucl}|^2)^{1/2} \propto \dfrac{1}{Q^{1/2}\,|M_{nucl}|}\left(\dfrac{b\Delta E}{MT}\right)^{1/4}$

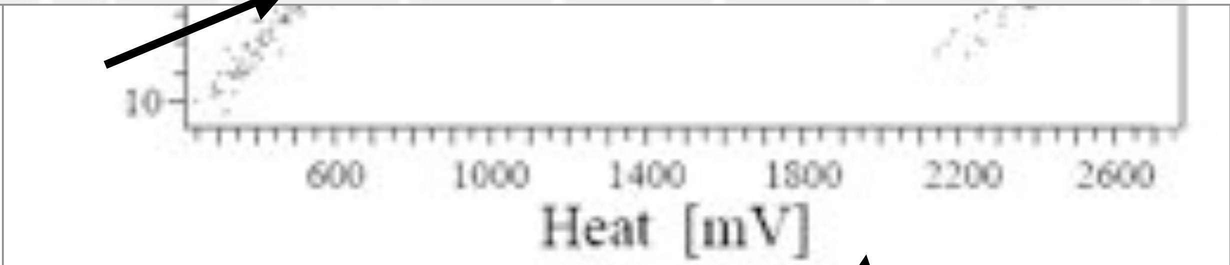
Choice of the nuclide

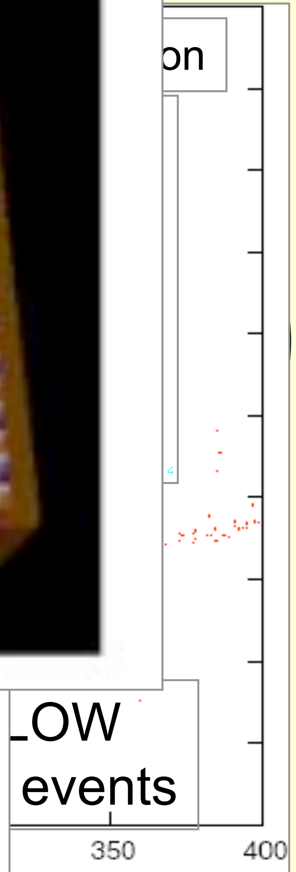












Granularity can be achieved through electrodes segmentation

⇒ R&D in progress for GERDA, MAJORANA, COBRA

SURFACE SENSITIVITY in bolometers

- R&D in progress in CUORE against energy-degraded α and β background

Simultaneous LIGHT and PHONON detection in bolometers

- R&D in progress in CUORE-like detectors for α / γ rejection

S

Easy

2%)

bility

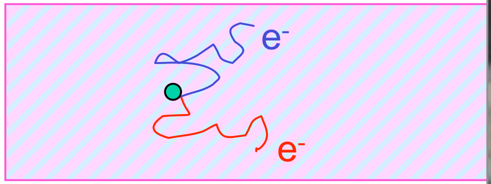
nd

es

Small scale prototype at LNGS

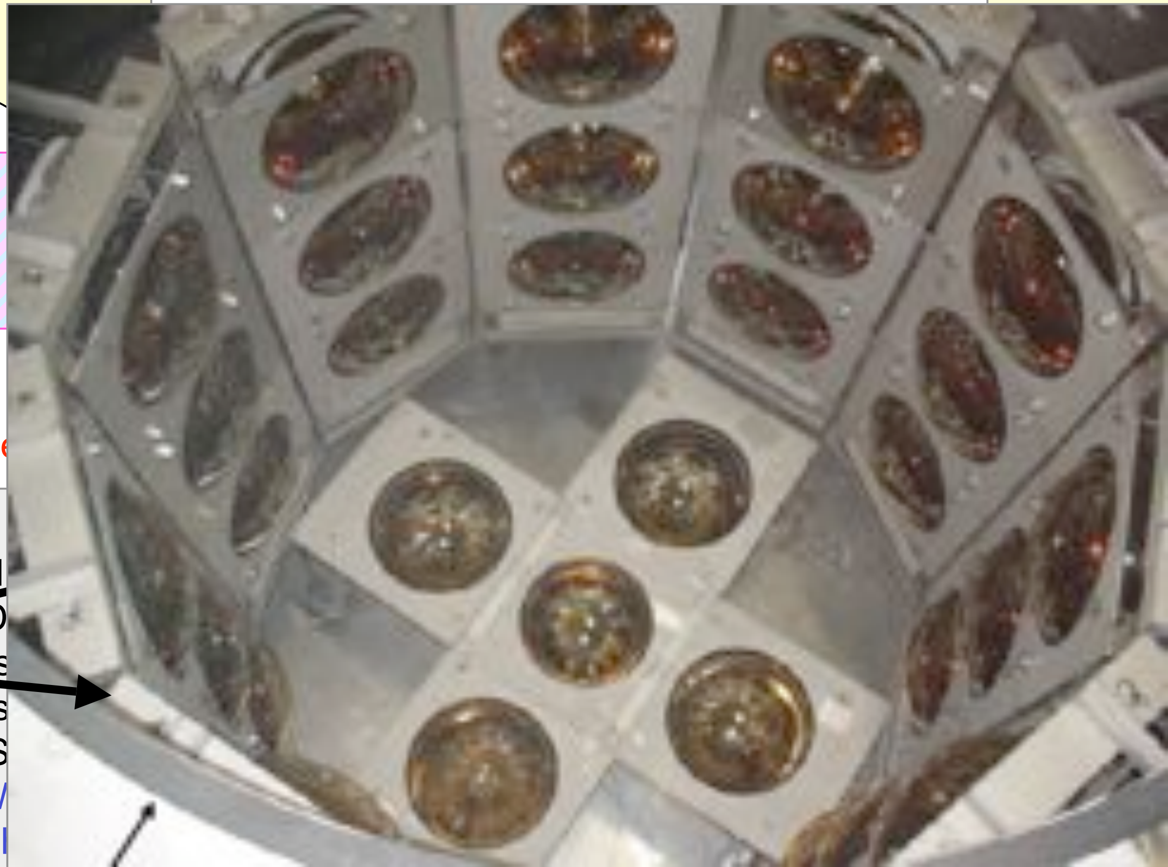
Proved energy resolution: 1.9% FWHM

Experiments and techniques



Source ≡ Detector

Easy to approach the ton scale



CANDLES – ^{48}Ca

Array of natural pure (not Eu doped

Prove of principle completed (CAND

Next step (CANDLES III: under cons

Further step (CANDLES IV: requires

Final goal (CANDLES V): 100 ton (S

Proved energy resolution: 3.4 % FW

The good point of this search is the l

⇒out of γ (2.6 MeV end point), β (3.3 MeV end point) and α (max 2.5 MeV with quench) natural radioactivity

Other background cuts come from PSD (α/β different timing) and space-time correlation for Bi-Po and Bi-Tl

detector

Source ≠ Detector

Easy to get tracking capability

Low energy resolution (>2%)

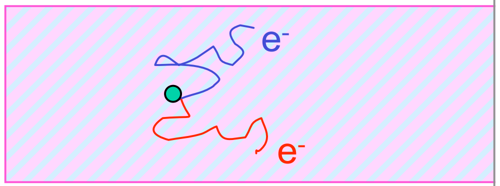
Tracking / topology capability

Easy to approach zero backround

(with the exception of

2ν DBD component)

Experiments and techniques



Source ≡ Detector

Easy to approach the ton scale

EXO – ^{136}Xe

TPC of enriched liquid Xenon

Event position and topology: in prospe

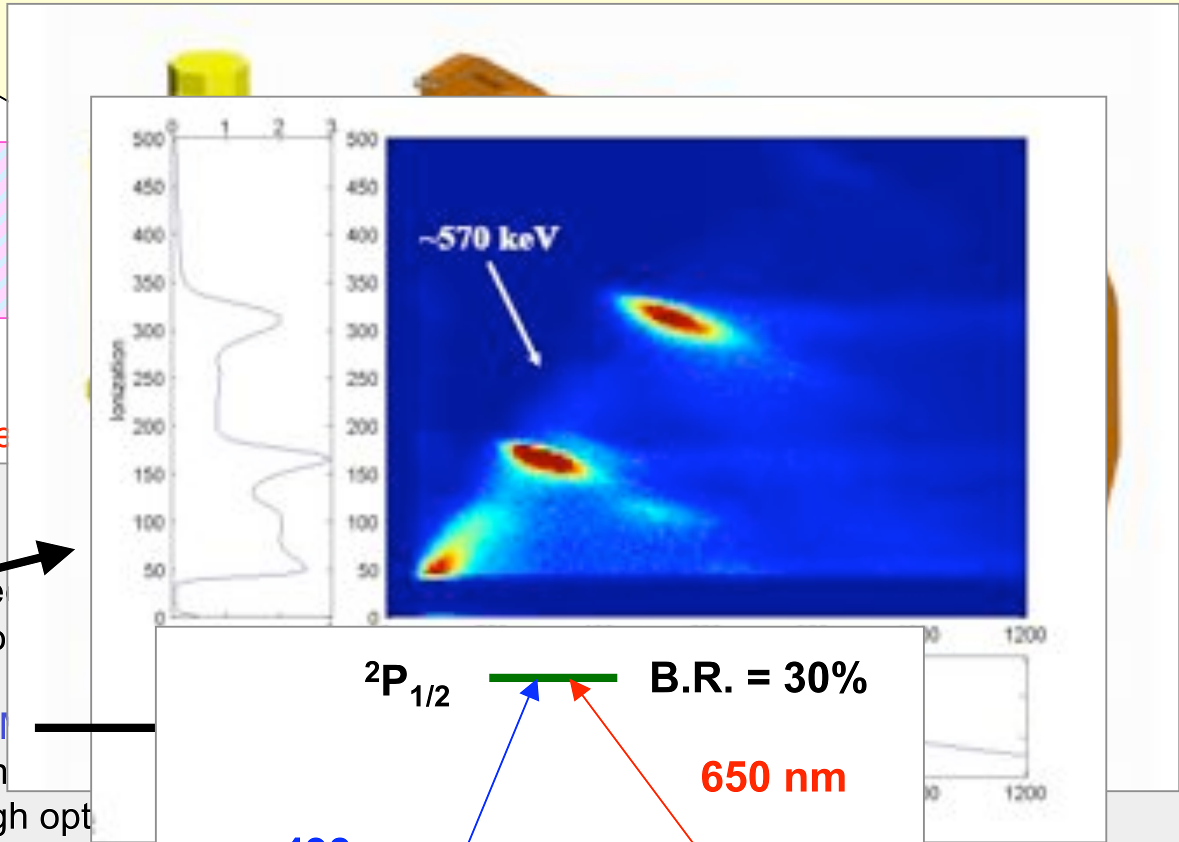
Next step (EXO-200: funded, under co

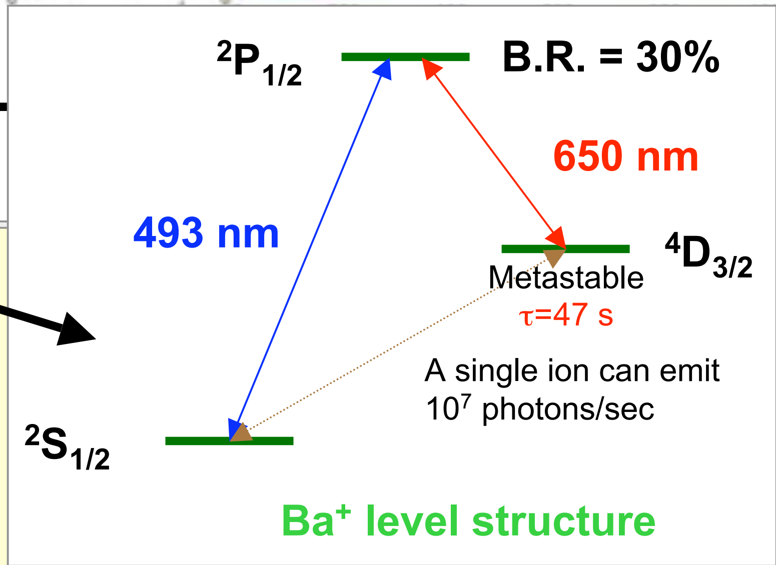
Further steps: 1-10 ton

Proved energy resolution: 3.3 % FWHI

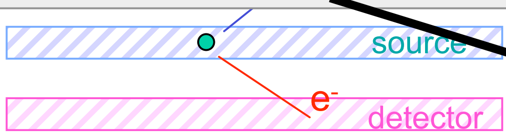
In parallel with the EXO-200 developm

Ba^{++} e- e- final state is identified through opt





Ba^+ level structure



Source ≠ Detector

Easy to get tracking capability

on (>2%)

capability

ackround

of

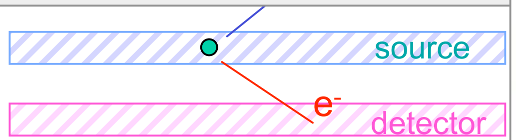
nt)

Experiments and techniques

SUPERNEMO - ^{82}Se or ^{150}Nd
Modules with source foils, tracking (drift
Magnetic field for charge sign
Possible configuration: 20 modules with
Energy resolution: 4 % FWHM
Ii can take advantage of NEMO3 experi

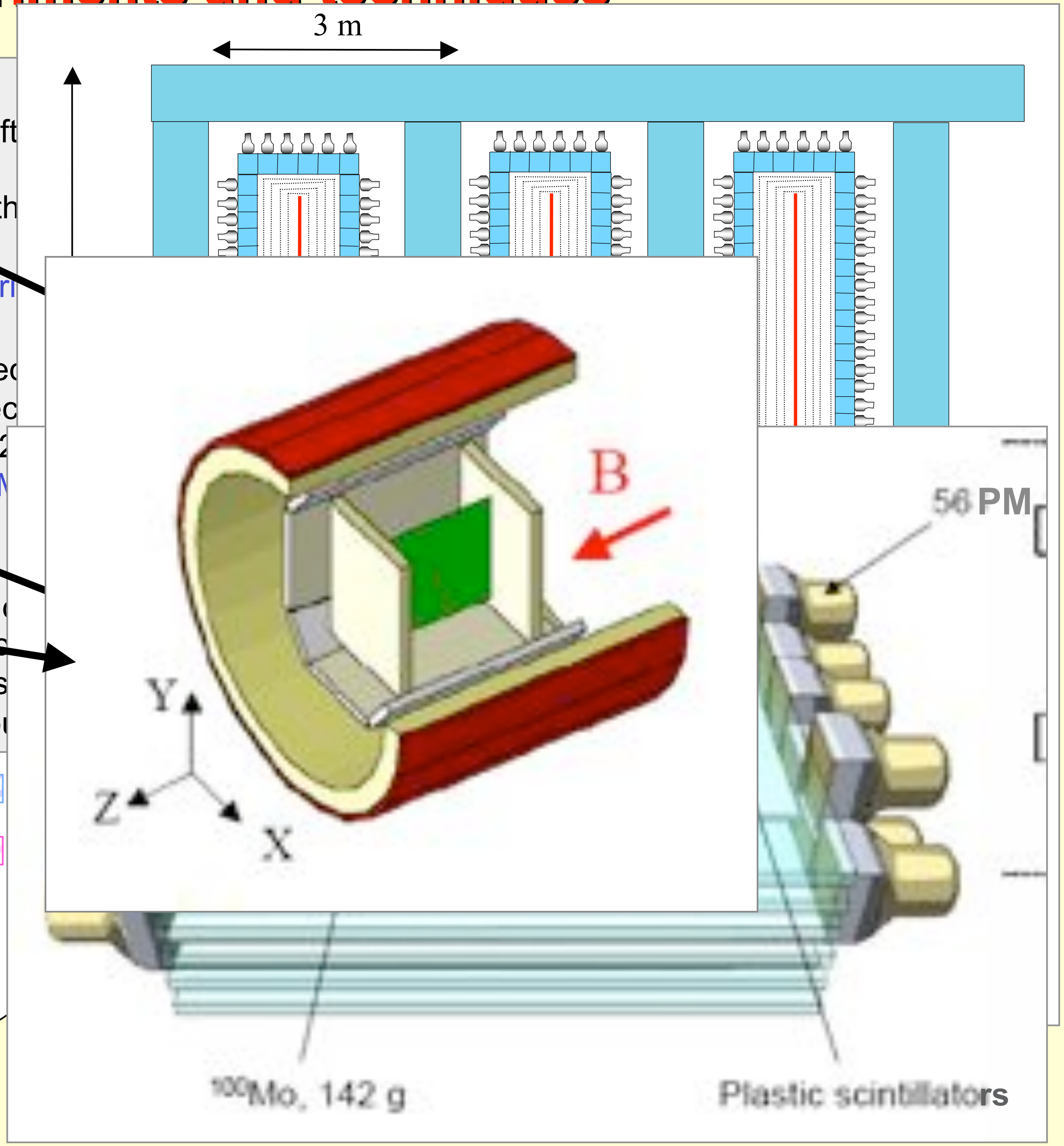
MOON - ^{100}Mo or ^{82}Se or ^{150}Nd
Multilayer plastic scintillators interleaved
MOON-1 prototype without tracking sec
MOON-2 prototype foreseen for 2006-2
Proved energy resolution: 6.8 % FWHM
Final target: collect 5 y x ton

DCBA - ^{82}Se or ^{150}Nd
Momentum analyzer for beta particles
Prototype under construction: Nd_2O_3 fo
Space resolution ~ 0.5 mm; energy res
Final target: 10 modules with 84 m^2 sou



Source ≠ Detector

Easy to get tracking capability



GERDA sensitivity

- Phase I: operate refurbished HM & IGEX enriched detectors (~20 kg)
  Background: 0.01 counts/ keV kg y
  Scrutinize ^{76}Ge claim with the same nuclide (exclude 99% c.l. or confirm 5σ)
  Half life sensitivity: 3×10^{25} y

- Phase II: additional ~20 kg ^{76}Ge diodes (segmented detectors)

  Background: 0.001 counts / keV kg y
  Sensitivity after 100 kg y (~3 years): 2×10^{26} y

  $\langle M \rangle < 90 - 290$ meV

- Phase III (depending on physics results of Phase I/II)

  $\Rightarrow$ ~ 1 ton experiment in world wide collaboration with MAJORANA

$\langle M \rangle < 20 - 50$ meV

EXO 200 sensitivity

Assumptions on detector performance and background:

- 200 kg of Xe enriched to 80% in 136
- $\sigma(E)/E = 1.4\%$ obtained in EXO R&D
- Low but finite radioactive background: 20 events/year in the $\pm 2\sigma$ interval centered around the 2.481 MeV endpoint
- Negligible background from 2v DBD ($T_{1/2} > 1 \cdot 10^{22}$ yr R.Bernabei et al. measurement)

Background: 40 counts in 2 y
Sensitivity (2 years, 90% c.l.): 6.4×10^{25} y

$\langle M \rangle < 270 - 380$ meV

QRPA NSM

If ^{76}Ge claim is correct :

- Worst case (QRPA, upper limit) 15 events (40 events bkg) $\Rightarrow 2\sigma$
- Best case (NSM, lower limit) 162 events (40 events bkg) $\Rightarrow 11\sigma$

CUORE sensitivity

Montecarlo simulations of the background show that

b = 0.001 counts / (keV kg y)

is possible with the present bulk contamination of detector materials

The problem is the surface background (alpha, beta energy-degraded)

it must be reduced by a factor 10 – 100 with respect to Cuoricino

work in progress! (only a factor 2 from the conservative assumption)

5 y sensitivity (1 σ) with conservative assumption: b = 0.01 counts/(keV kg y)

$$F^{0\nu} = 9.2 \times 10^{25} \times (T [y])^{1/2}$$

$$\langle M \rangle < 20 - 100 \text{ meV}$$

5 y sensitivity (1 σ) with aggressive assumption: b = 0.001 counts/(keV kg y)

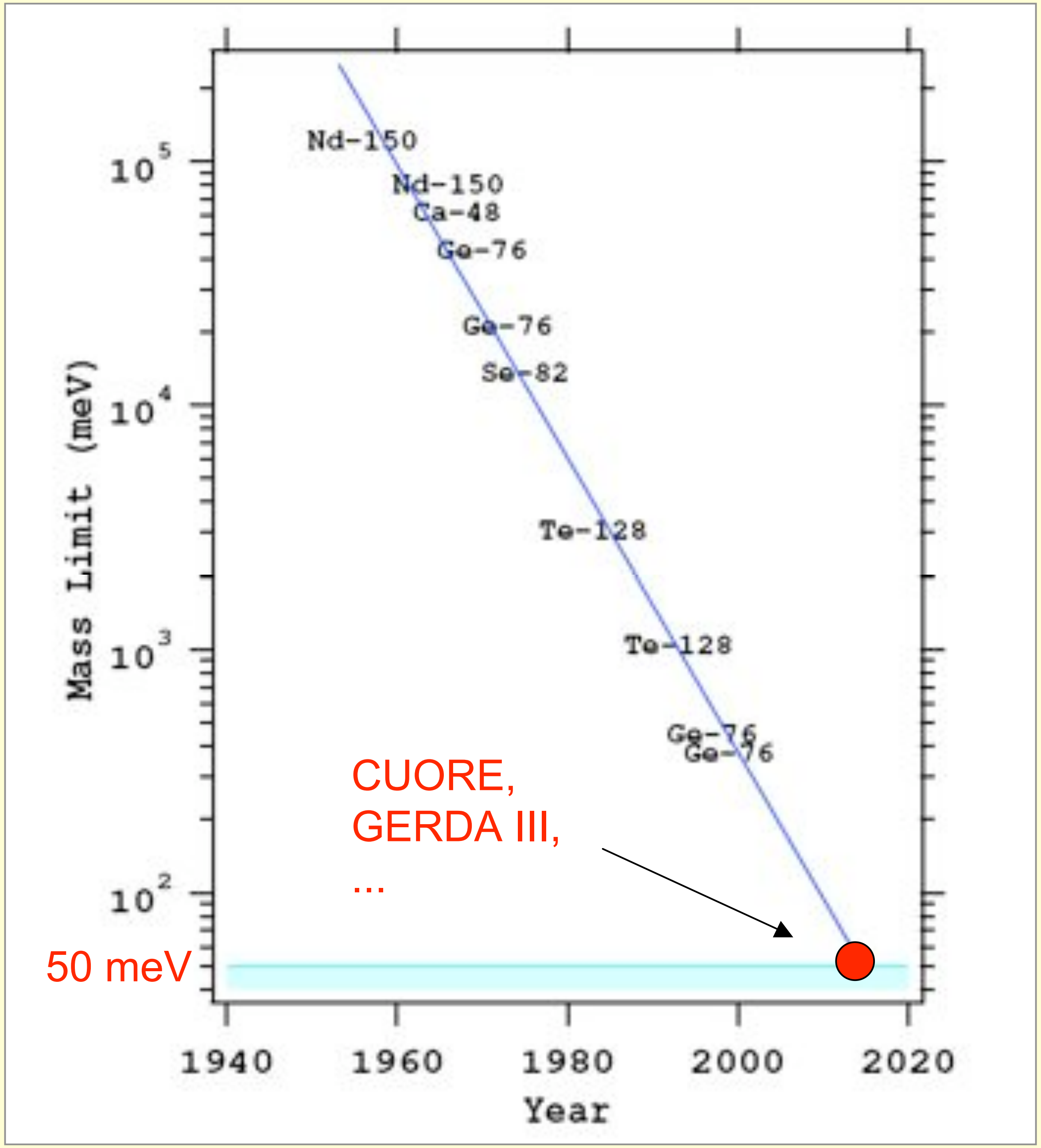
$$F^{0\nu} = 2.9 \times 10^{26} \times (T [y])^{1/2}$$

$$\langle M \rangle < 11 - 60 \text{ meV}$$

$$\langle M \rangle < 7 - 38 \text{ meV}$$

enriched CUORE

Prediction of the Moore's law for the sensitivity



Future scenarios and branching points in terms of discovery

sensitivity to

100 - 500

15 - 50

2 - 5

if this range holds:
- SUPERNEMO could marginally see it in ^{82}Se or ^{150}Nd
- GERDA phase III could see it in ^{76}Ge
- CUORE could see it in a couple of isotopes in sequence (after ^{130}Te, ^{116}Cd ?)

discovery in 3 or 4 isotopes necessary (and possible...)

stimate

EMO

if this range holds:
- new strategies have to be developed
- it is worthwhile to start to elaborate them now
- next generation experiments are precious for the selection of the future approaches
- a large investment in enrichment is mandatory

if

Se or ^{150}Nd)

-

-

-

multi-isotope searches simultaneously
(^{130}Te - ^{116}Cd - ^{100}Mo)
large scale enrichment required
reduction of uncertainties in NME

precision measurement era for 0ν-DBD!

unpredictable time scale