Sensitivity of bolometric ββ0ν experiments

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Introduction

- provide **sensitivity estimation** for different planned and hypothetical configurations of bolometric double beta decay detectors
  - from CUORE-0, to CUORE, to future experiments with active background reduction

- understand how far one can push the search for double beta decay with the bolometric approach
  - interest in possible future bolometric experiments in North America
- spell out the assumptions behind the calculations and sensitivity numbers to avoid misunderstandings, especially when comparing with other experiments

Where we stand

effective Majorana neutrino mass

$$T_{1/2}^{0\nu} \sim \frac{1}{G^{0\nu}\left|M^{0\nu}\right|^2 \left\langle m_{\beta\beta}\right\rangle^2} \qquad \left\langle m_{\beta\beta}\right\rangle = \left|\sum_{i=1}^{N} \lambda_i \left|U_{ei}\right|^2 m_i\right|$$

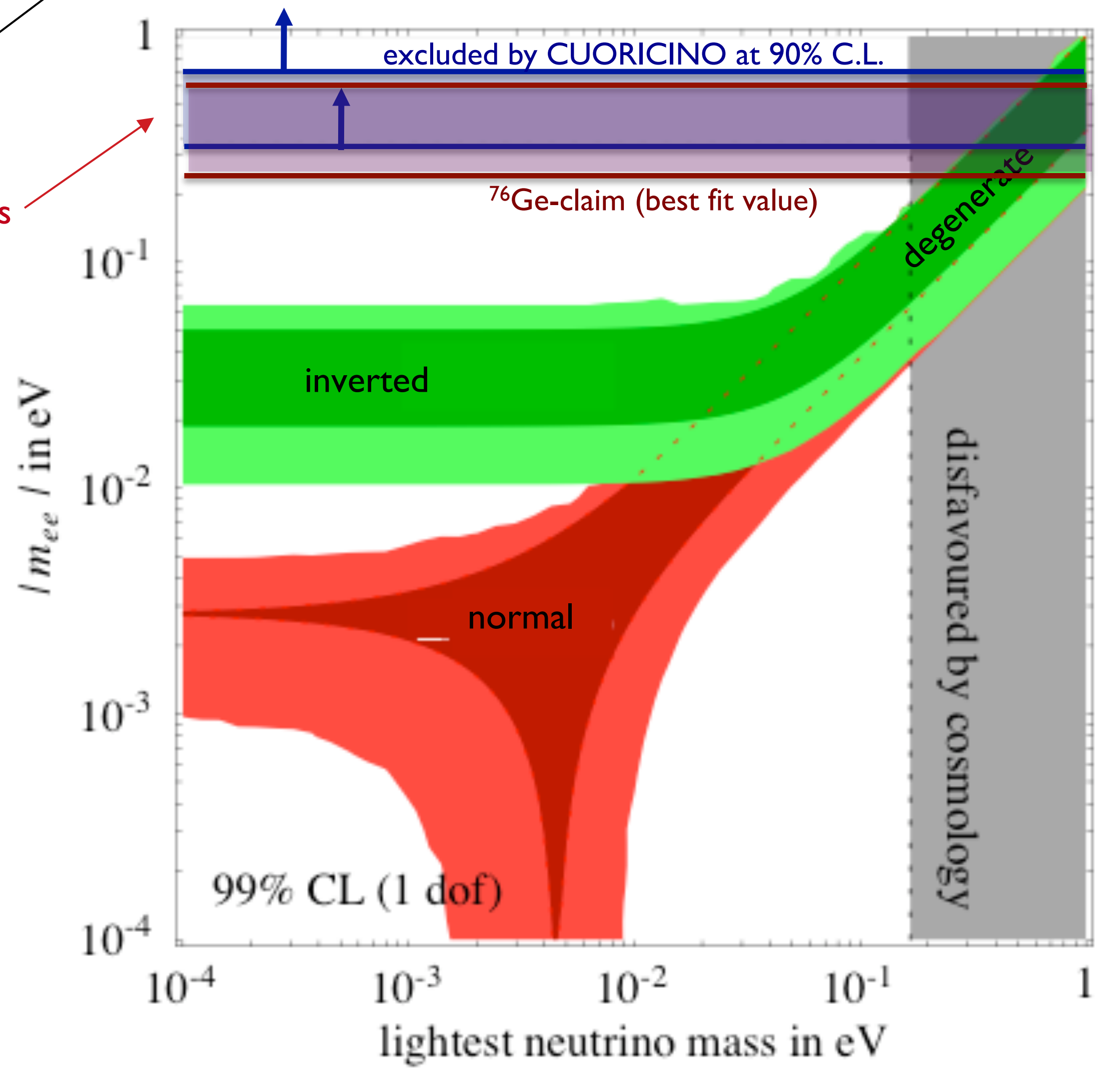
phase space factor
~ Q^5

nuclear matrix elements
» uncertainties

So far:

- Heidelberg-Moscow (^{76}Ge)
- NEMO-3 (^{82}Se + others)
- Cuoricino (^{130}Te)

and a controversial claim by Klapdor et al on ^{76}Ge



Strumia, Vissani arXiv:hep-ph/0606054v2

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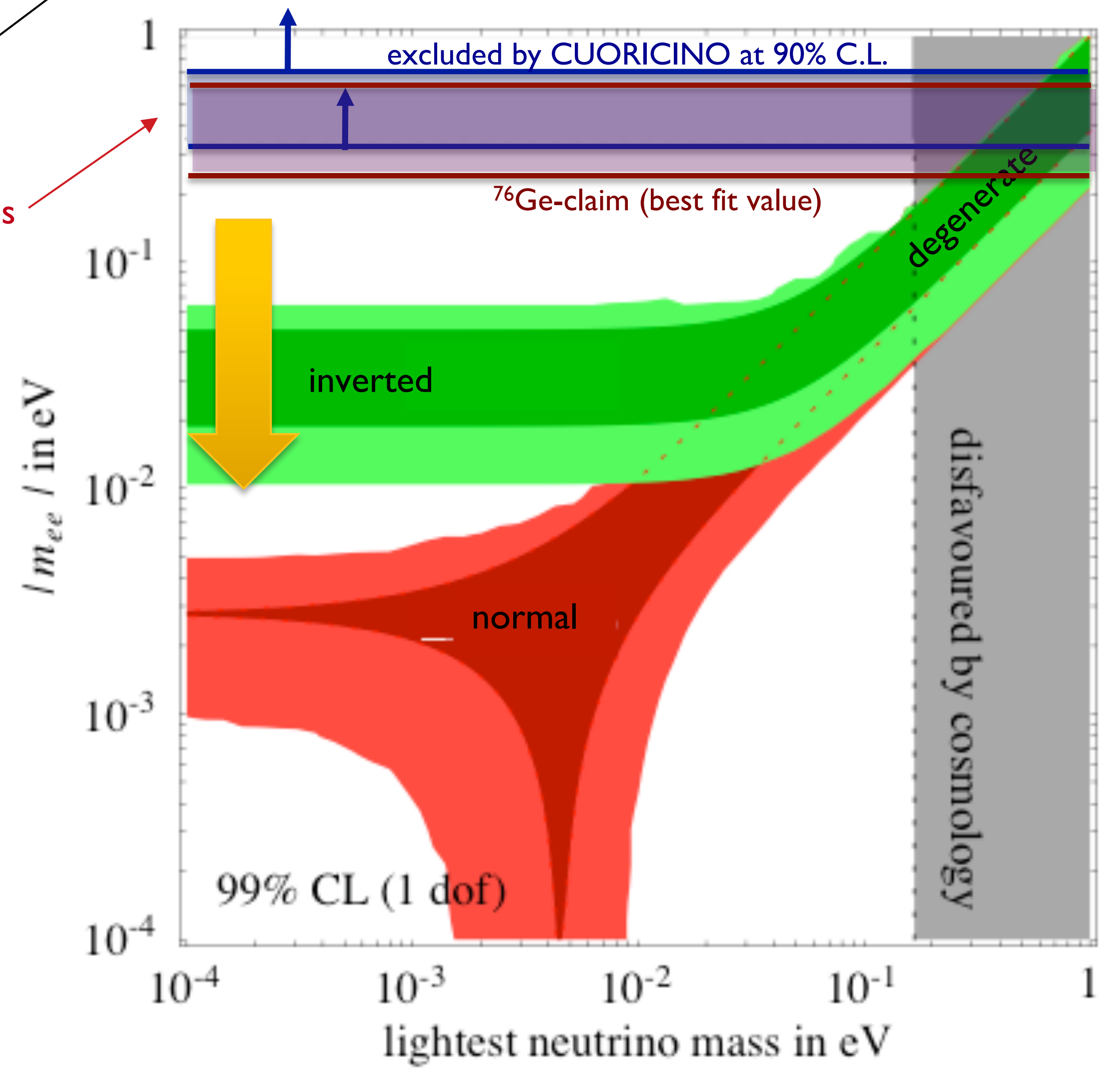
Future goal:

- check ^{76}Ge claim
- probe the inverted hierarchy region



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Signal & Background

expected number of ββ0ν events

$$S = \frac{M \cdot N_A \cdot a}{W} \cdot \ln(2) \cdot \frac{t}{T_{1/2}^{0\nu}} \cdot \varepsilon$$

- M: detector mass
- N_A · a: isotopic abundance
- W: molecular mass
- t: live time
- $T_{1/2}^{0\nu}$: ββ0ν half-life
- ε: efficiency

Signal & Background

expected number of ββ0ν events

$$S = \frac{M \cdot N_A \cdot a}{W} \cdot \ln(2) \cdot \frac{t}{T^{0\nu}_{1/2}} \cdot \varepsilon$$

detector mass (M), isotopic abundance (a), live time (t), efficiency (ε), molecular mass (W), ββ0ν half-life ($T^{0\nu}_{1/2}$)

mean number of background counts around the Q-value

$$B = b \cdot M \cdot \Delta E \cdot t$$

background rate in counts/keV/kg/y (b), detector mass (M), energy resolution (detector FWHM) (ΔE), live time (t)

Underlying assumptions:

1. the background is approximately constant over the interval ΔE
2. the background rate ***b*** is independently and precisely measured i.e. by a fit over a large energy range
3. the background scales with the total detector mass. For example, surface background may scale differently

Experimental Sensitivity

Minimum number of expected signal events that are n_σ standard deviations above background

$$S = n_\sigma \sqrt{B}$$

$$n_\sigma = \begin{cases} 1 & \text{sensitivity} \\ 3 & \text{evidence} \\ 5 & \text{discovery} \end{cases}$$

Experimental Sensitivity on ββ0ν half-life

$$T^{0\nu} \sim \frac{1}{n_\sigma} \frac{a}{W} \sqrt{\frac{M \cdot t}{b \cdot \Delta E}}$$

- a: isotopic abundance
- W: molecular mass
- M: detector mass
- t: live time
- b: background level
- ΔE: energy resolution

Experimental Sensitivity

Minimum number of expected signal events that are n_σ standard deviations above background

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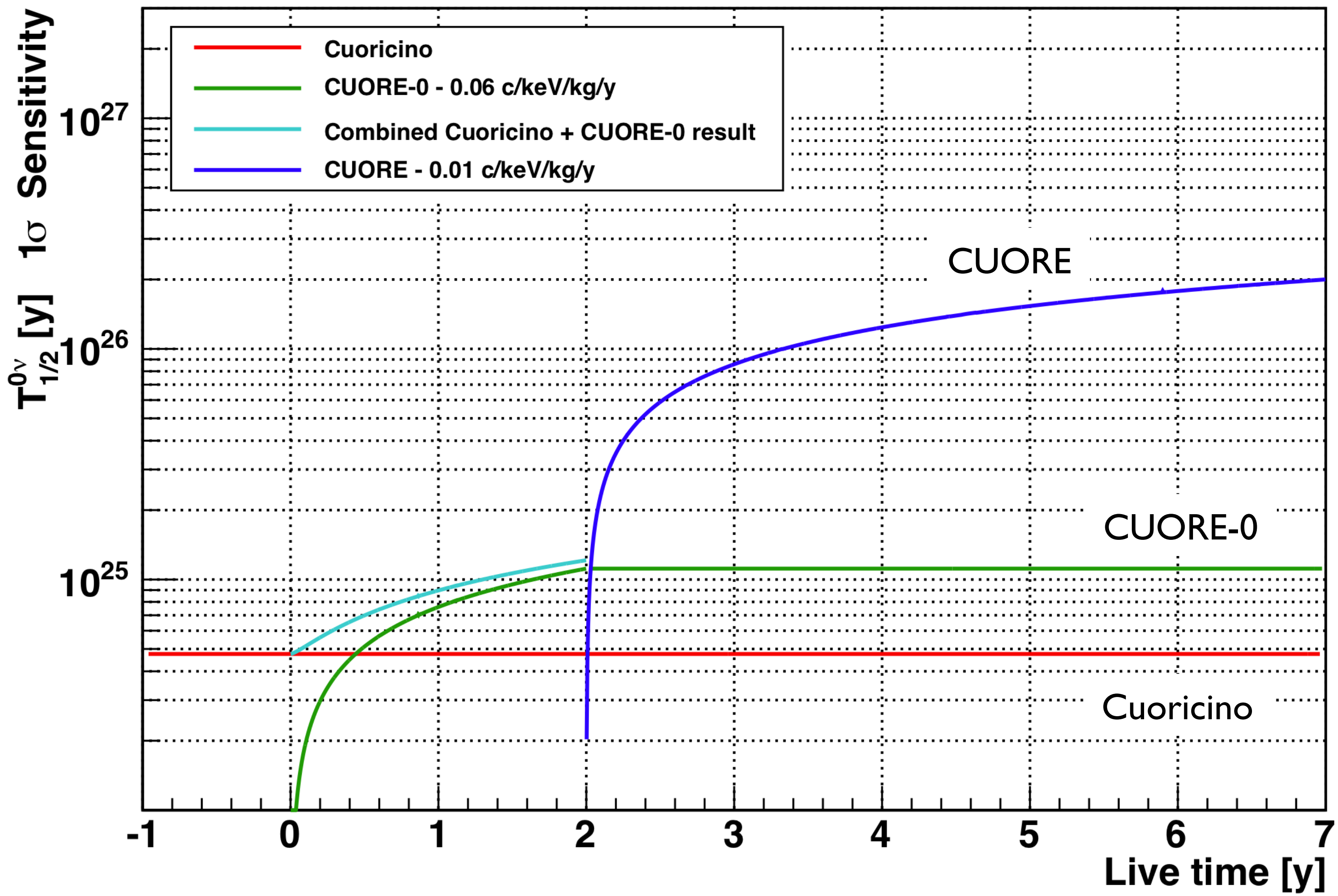
Experimental Sensitivity on ββ0ν half-life

$$T^{0\nu} \sim \frac{1}{n_\sigma} \frac{a}{W} \sqrt{\frac{M \cdot t}{b \cdot \Delta E}}$$

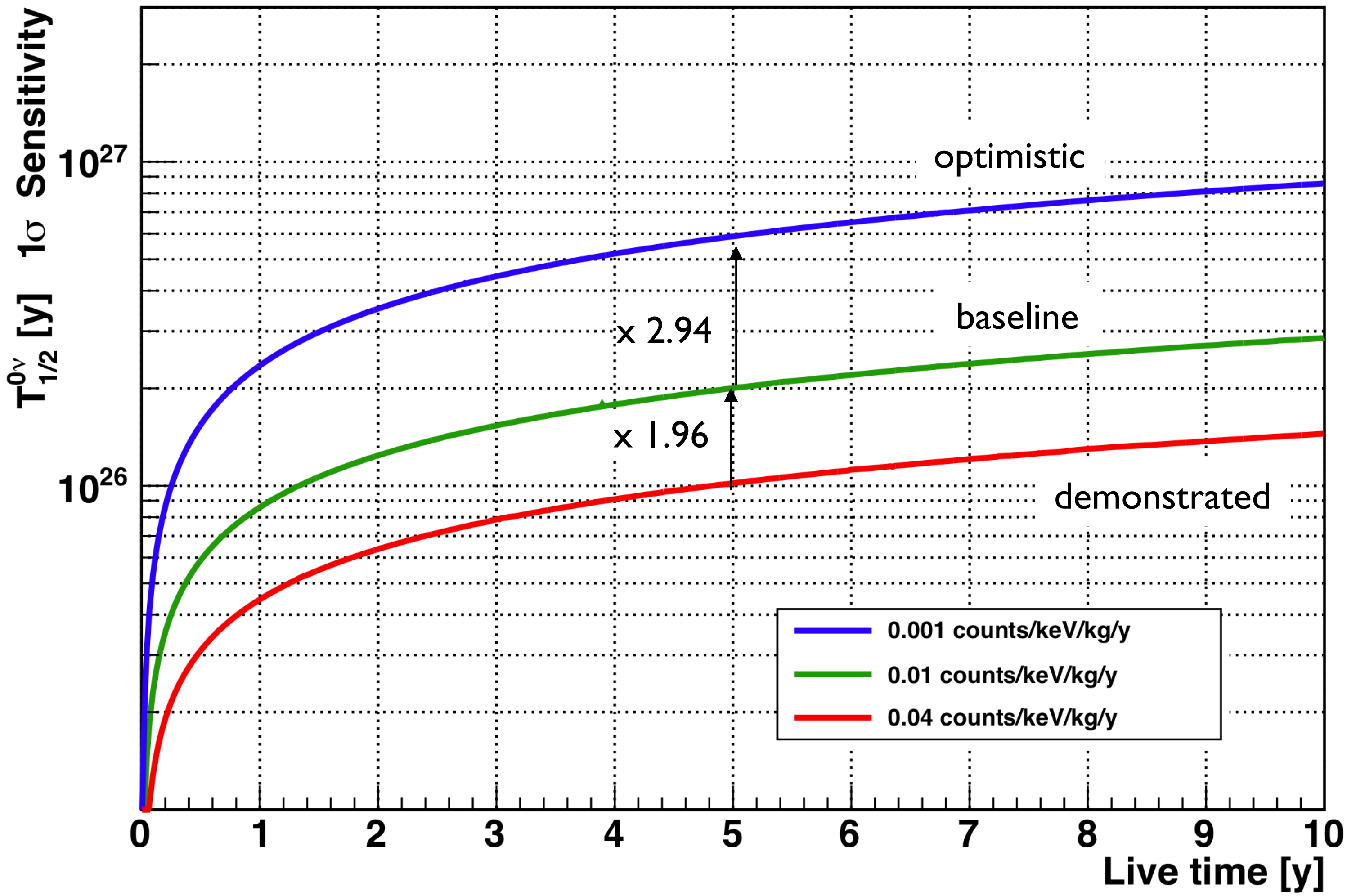
- a: isotopic abundance
- W: molecular mass
- M: detector mass
- t: live time
- ΔE: energy resolution
- b: background level

- statistical meaning: if the true value of the half-life is $T^{0\nu}$ then 50% of the experiments will see $S = n_\sigma \sqrt{B}$ or more signal events
- assumes gaussian approximation which is not appropriate for future experiments → extend the same concept to Poisson-distributed variables

From Cuoricino to CUORE



CUORE sensitivity with different background



improvement factors
are calculated at 5y

Projected sensitivity for CUORE

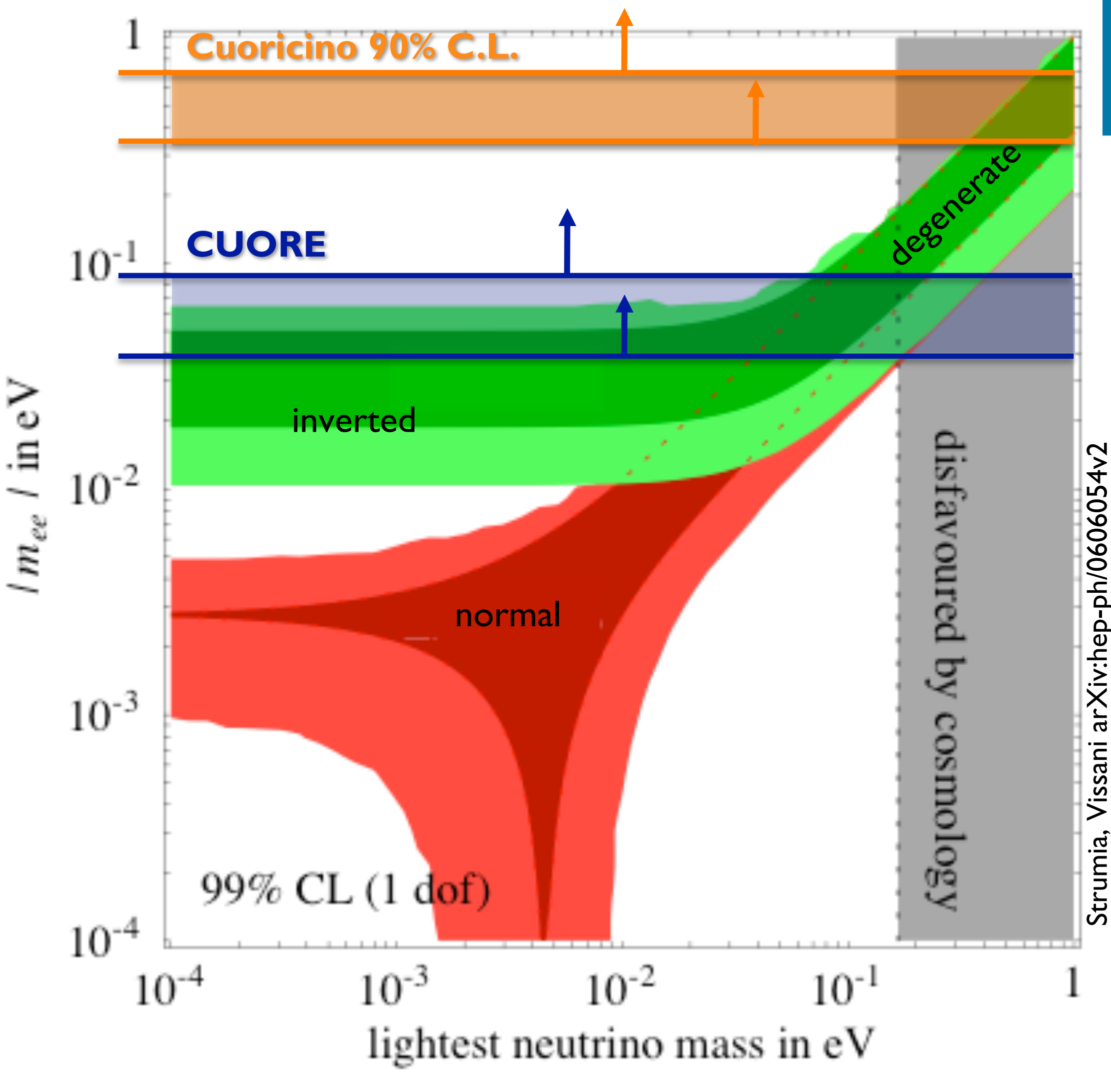
Detector resolution: ~ 5 keV
Live time: 5 years

Background in 0νββ region
(baseline goal)
0.01 c/keV/kg/y

$T_{1/2}^{0\nu}$ (^{130}Te) > 2.0 x 10^{26} y (1σ)
$m_{\beta\beta}$ < 42 - 87 meV

Background in 0νββ region
(demonstrated so far)
0.04 c/keV/kg/y **(PRELIMINARY)**

$T_{1/2}^{0\nu}$ (^{130}Te) > 1.0 x 10^{26} y (1σ)
$m_{\beta\beta}$ < 59 - 122 meV



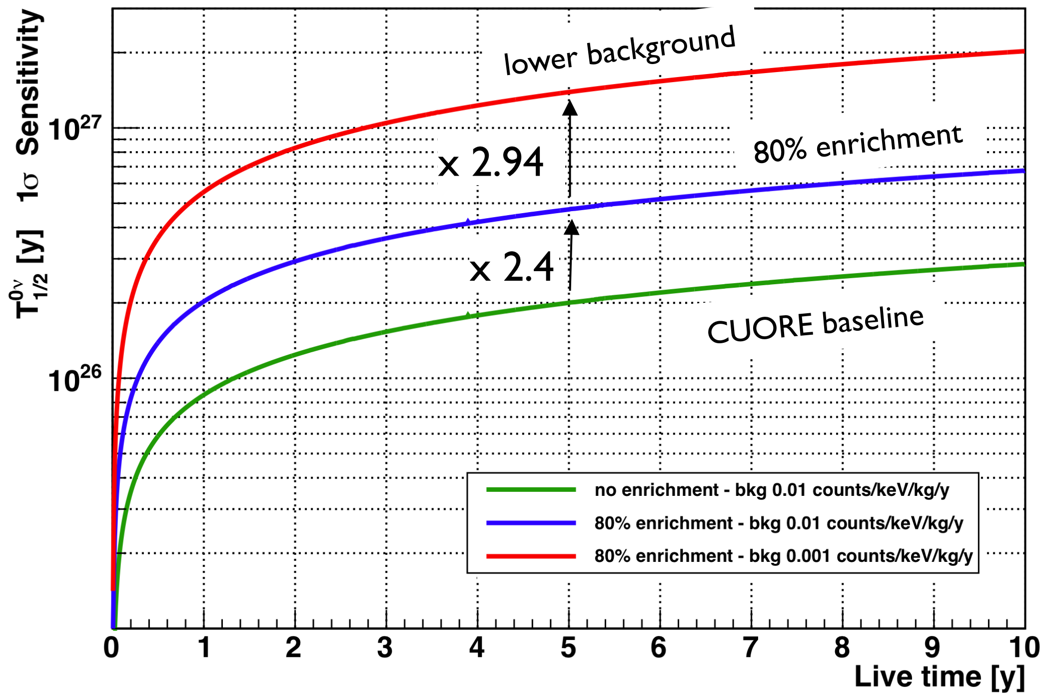
NME from Faessler et al, PRC 77, 045503 (2008), Suhonen et al, Int. J. Mod. Phys. E 17, 1 (2008), Poves et al, PRL 100, 052503 (2008), Iachello and Barea, PRC 79, 044301 (2009)

Beyond CUORE

$$T^{0\nu} \sim \frac{a}{W}\sqrt{\frac{M \cdot t}{b \cdot \Delta E}}$$

isotopic abundance (a), atomic mass (W), detector mass (M), live time (t), background level (b), energy resolution (ΔE)

- increase mass
  - impractical due to cryogenics
- enrichment
  - no changes needed to the experimental setup



improvement factors are calculated at 5y

Beyond CUORE

$$T^{0\nu} \sim \frac{a}{W}\sqrt{\frac{M \cdot t}{b \cdot \Delta E}}$$

isotopic abundance (a); atomic mass (W); detector mass (M); live time (t); background level (b); energy resolution (ΔE)

- increase mass
  - impractical due to cryogenics
- enrichment
  - no changes needed to the experimental setup
- reduce background
  - so far: passive approach i.e. materials selection, treatment & handling
  - next: active discrimination of surface radioactivity

Advanced detector R&D ongoing →

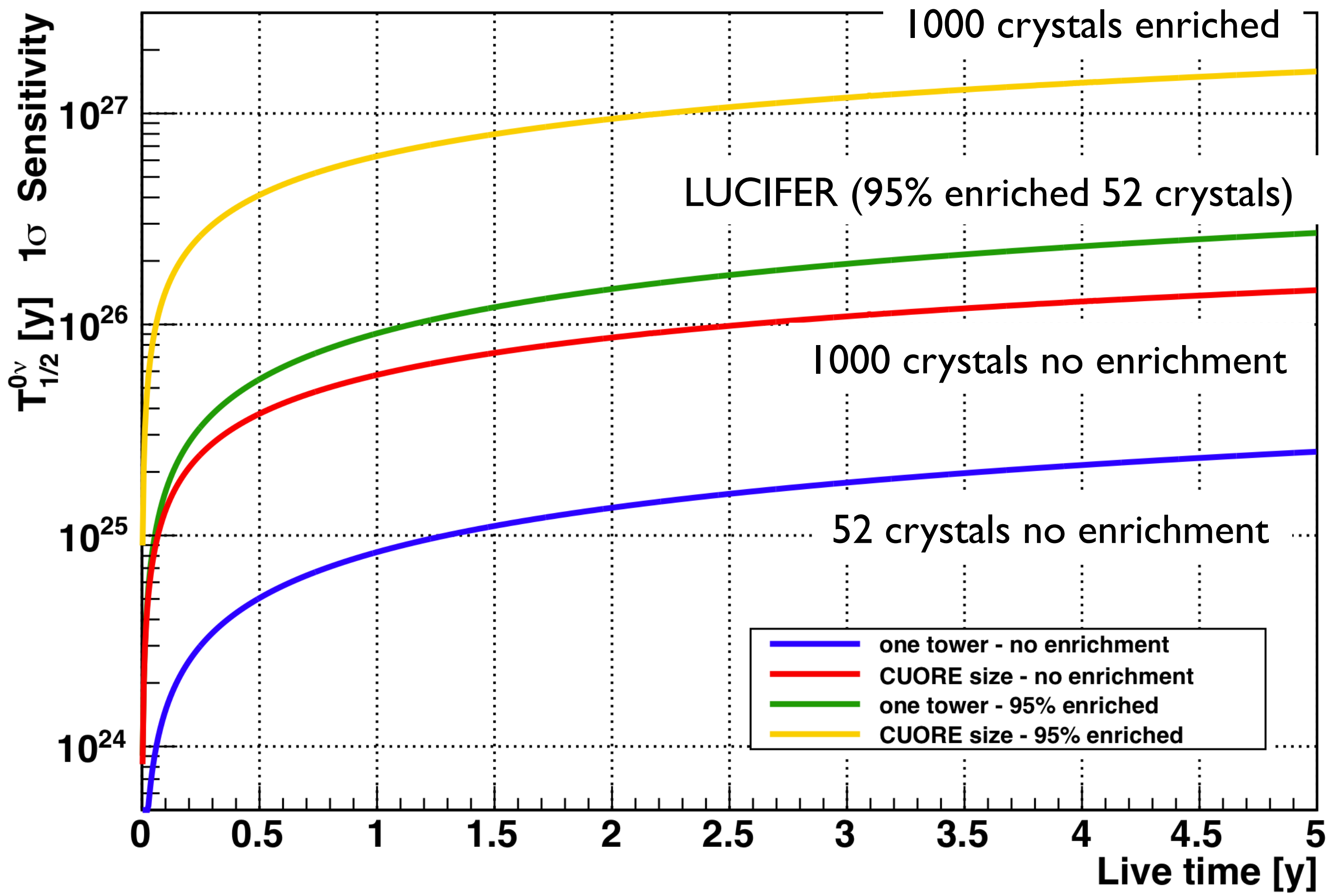
Surface Sensitive Bolometers
Appl. Phys. Lett. **86**, 134106 (2005)

Scintillating Bolometers
S. Pirro, *presentation at this workshop*

Sensitivity with scintillating bolometers

- Large R&D effort in Italy
- several compounds successfully tested as bolometers
- $CdWO_4$ and ZnSe seem the most promising

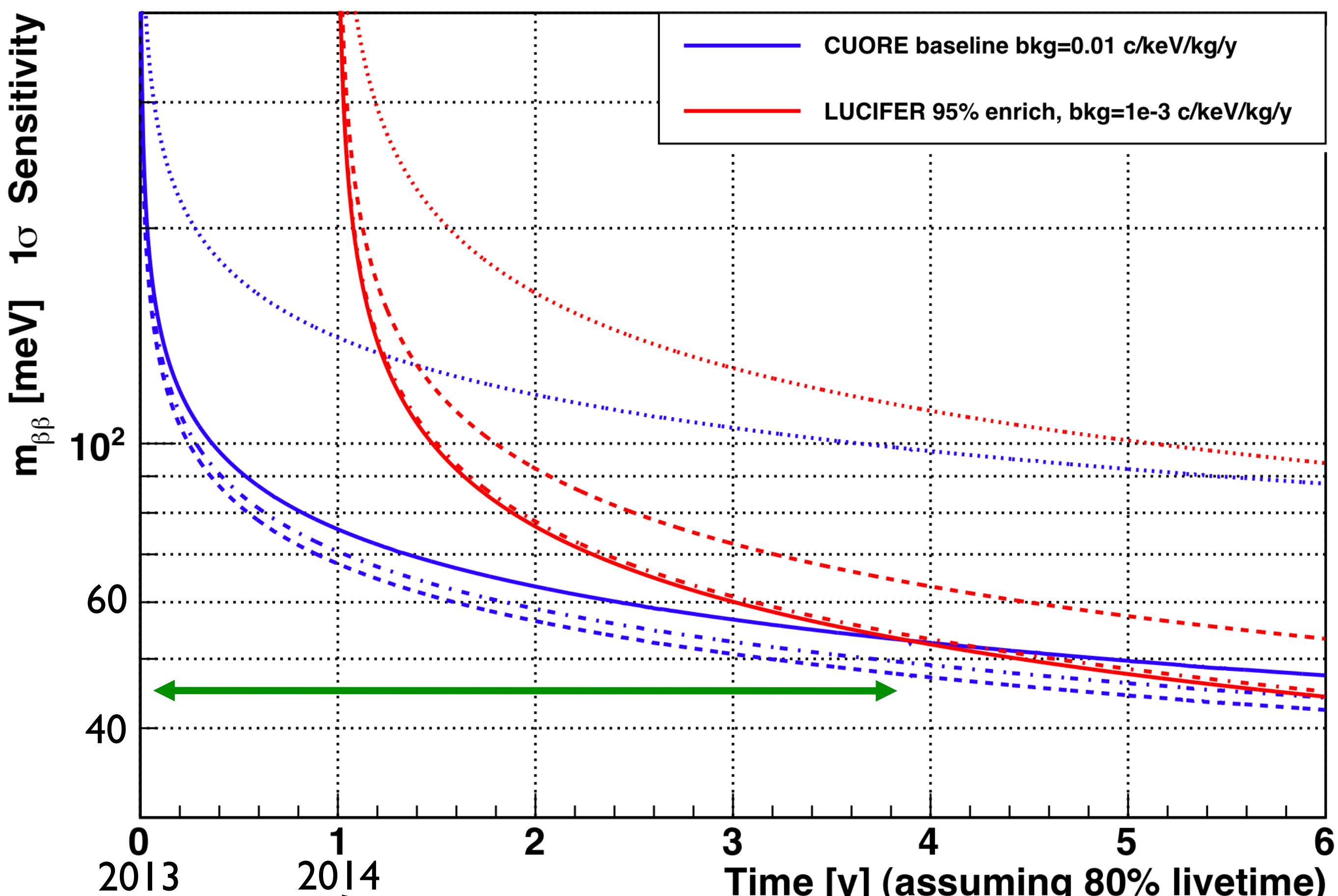
Sensitivity of
ZnSe scintillating bolometer experiment
assuming background ~ 10^{-3} c/keV/kg/y



enrichment and background values from Lucifer presentations

CUORE and LUCIFER

Sensitivity on the Majorana neutrino mass for different NME calculations



from CUORE project schedule

from F. Ferroni slides on LUCIFER
http://agenda.infn.it/conferenceDisplay.py?confId=1881

NME from Faessler et al, PRC 77, 045503 (2008), Suhonen et al, Int. J. Mod. Phys. E 17, 1 (2008), Poves et al, PRL 100, 052503 (2008), Iachello and Barea, PRC 79, 044301 (2009)

Sensitivity of Future Bolometric Experiments

CUORE enriched

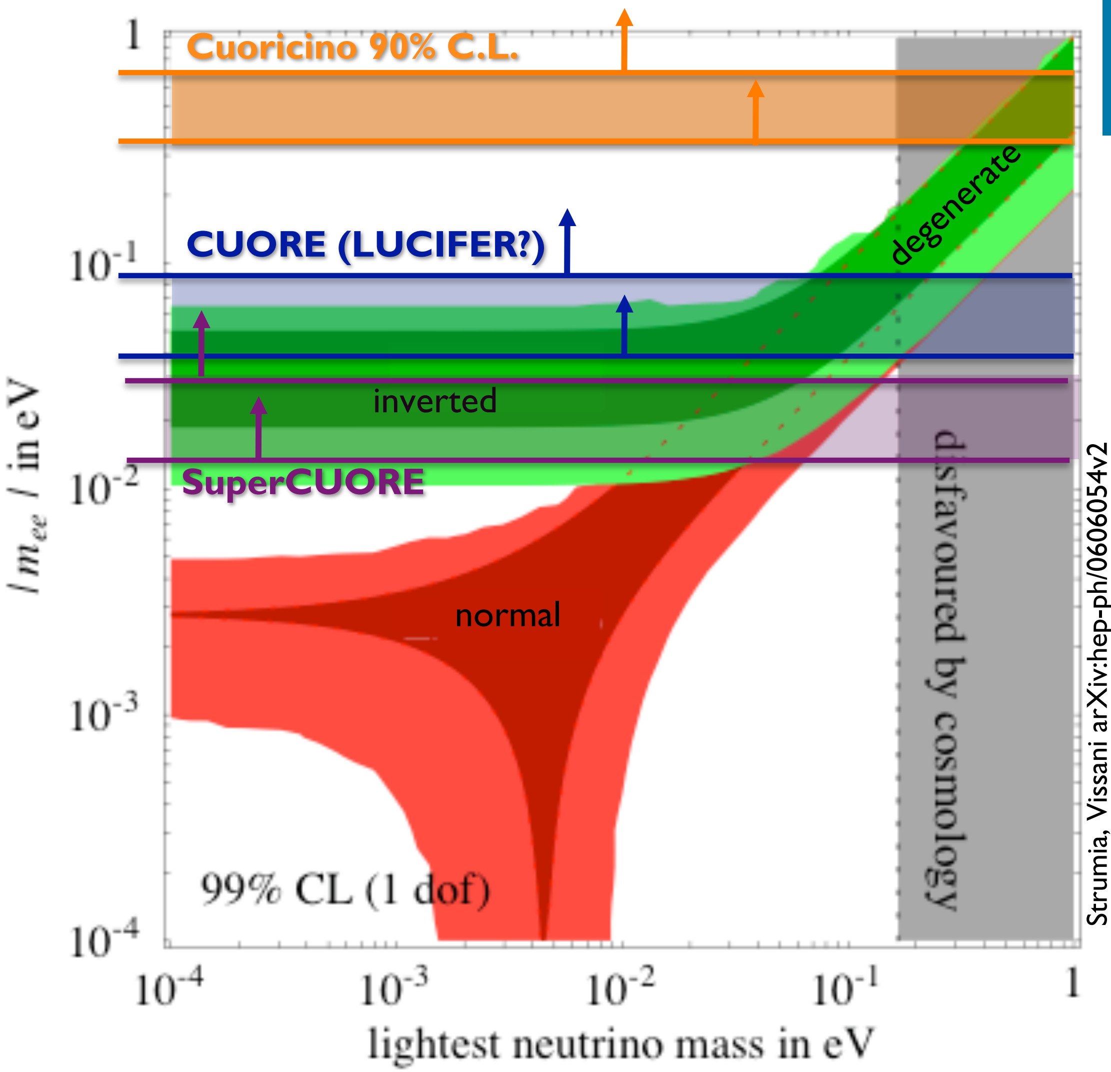
- bkg: 10^{-2} counts/keV/kg/y
- 80% ^{130}Te enrichment
- 5 year live time
- $<m_{\beta\beta}> < 27 – 57$ meV (1σ)

LUCIFER (scintillating ZnSe)

- bkg: 10^{-3} counts/keV/kg/y
- 95% ^{82}Se enrichment
- one tower, 5 year live time
- $<m_{\beta\beta}> < 42 – 89$ meV (1σ)

SuperCUORE w/ scintillating ZnSe

- bkg: 10^{-4} counts/keV/kg/y
- 95% ^{82}Se enrichment
- CUORE-size, 5 year live time
- $<m_{\beta\beta}> < 11 – 23$ meV (1σ)



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Summary table

Sensitivities at 1σ after 5 years of livetime

	Configuration	bkg [c/keV/kg/y]	$T_{1/2}$ 1σ sens [10^{26} y]	m_ν 1σ sens [meV]
Result	Cuoricino	**0.18**	**0.029** (90%CL)	**350-720** (90%CL)
Construction	Cuoricino + CUORE-0	**0.06**	**0.12***	**170-350***
	CUORE baseline	**0.01**	**2.0**	**42-87**
R&D	LUCIFER (ZnSe 95% enrich)	**0.001**	**2.7**	**42-89**
	CUORE 80% enriched	**0.01**	**4.7**	**27-57**
	CUORE enriched w/ TeO_2 SSB	**0.001**	**14**	**16-33**
	$CdWO_4$ enriched 1000crystals	**0.001**	**8**	**21-29**
	ZnSe enriched 1000crystals	**1e-4**	**41**	**11-23**

*) after 2 years live time

EXO 1ton w/ Ba^+ tagging: $\langle m_{\beta\beta}\rangle < 12 - 25$ meV (1σ)

Majorana/GERDA 1-ton: $\langle m_{\beta\beta}\rangle < 15 - 38$ meV (1σ)

NME from Faessler et al, PRC 77, 045503 (2008), Suhonen et al, Int. J. Mod. Phys. E 17, 1 (2008), Poves et al, PRL 100, 052503 (2008), Iachello and Barea, PRC 79, 044301 (2009)