Neutrino properties in Underground labs

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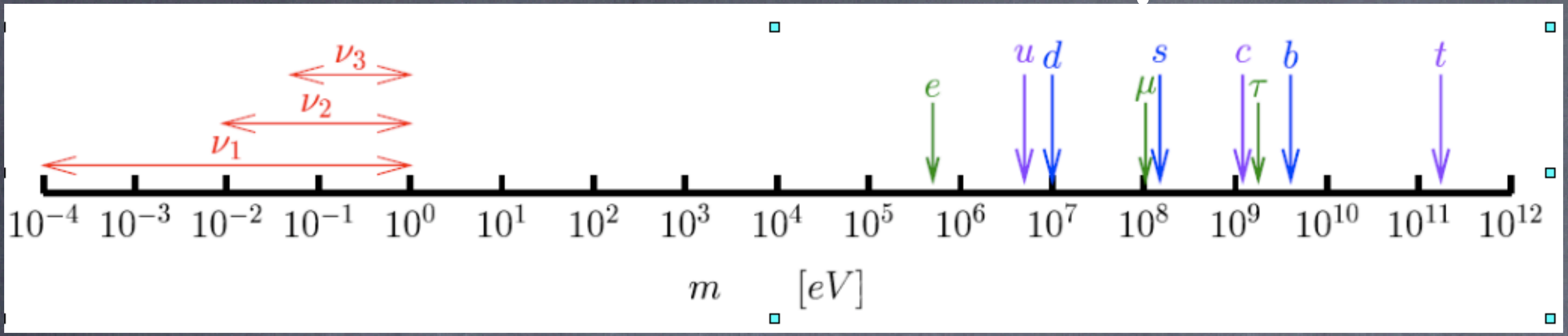
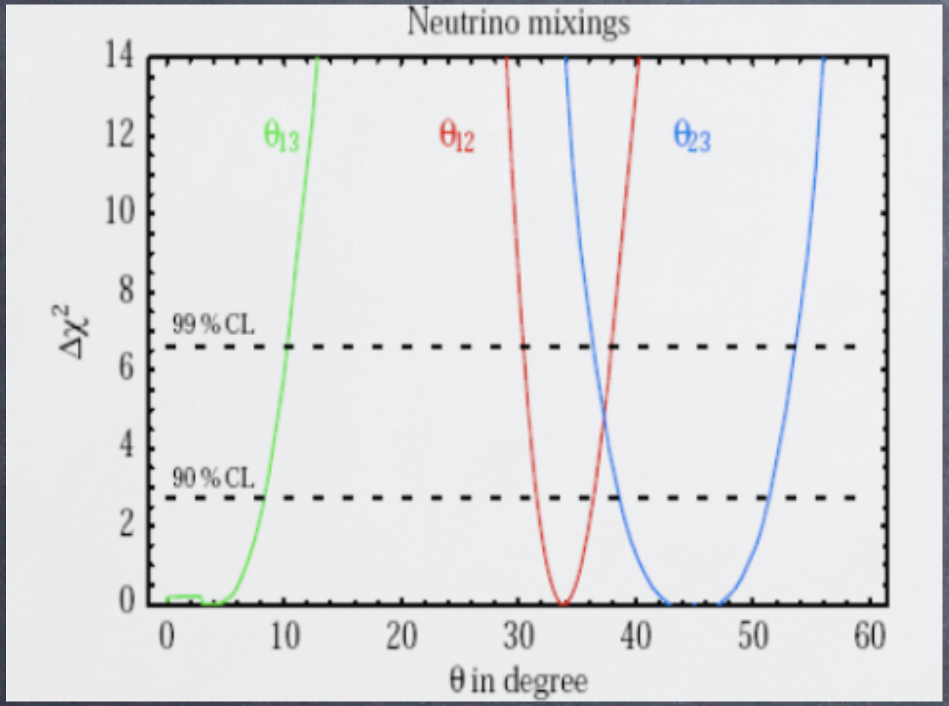
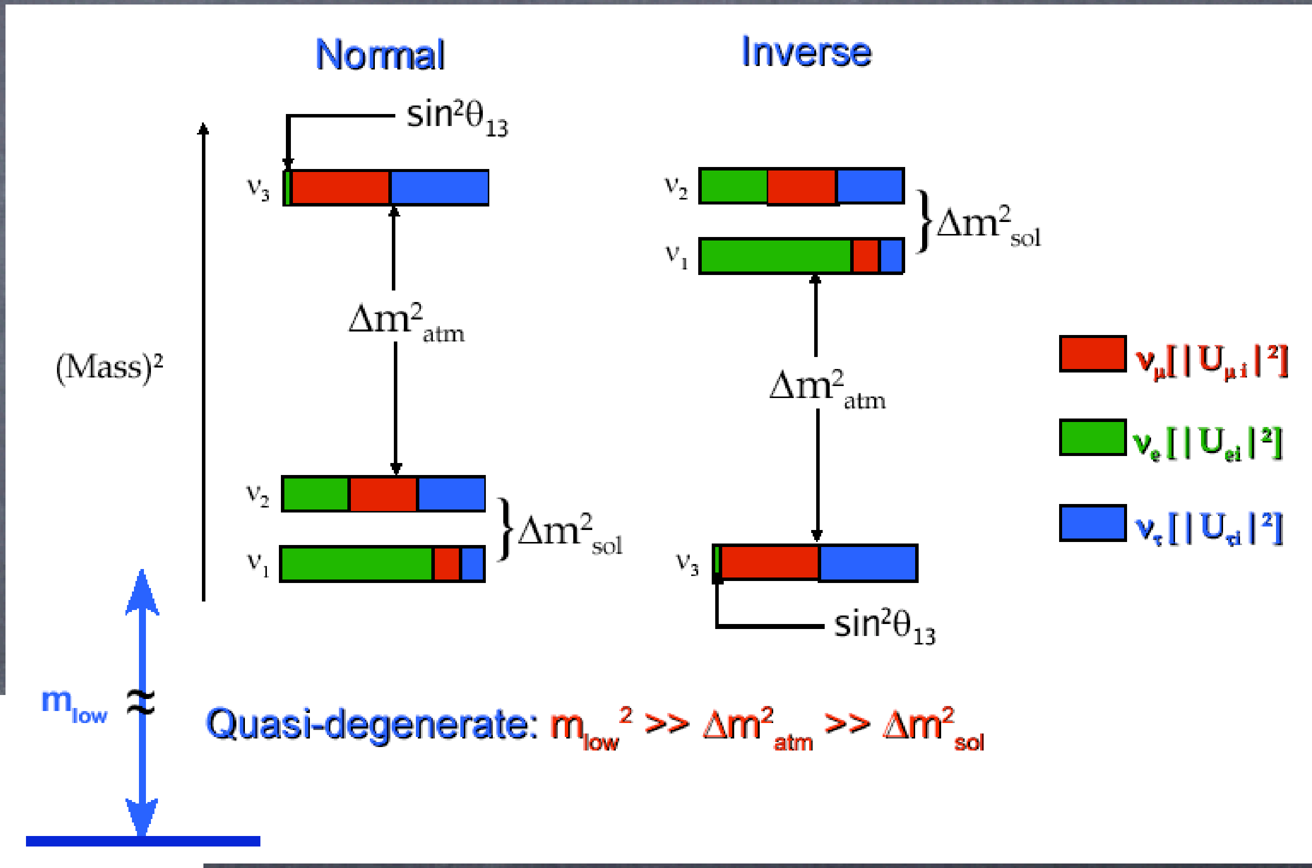
Outline

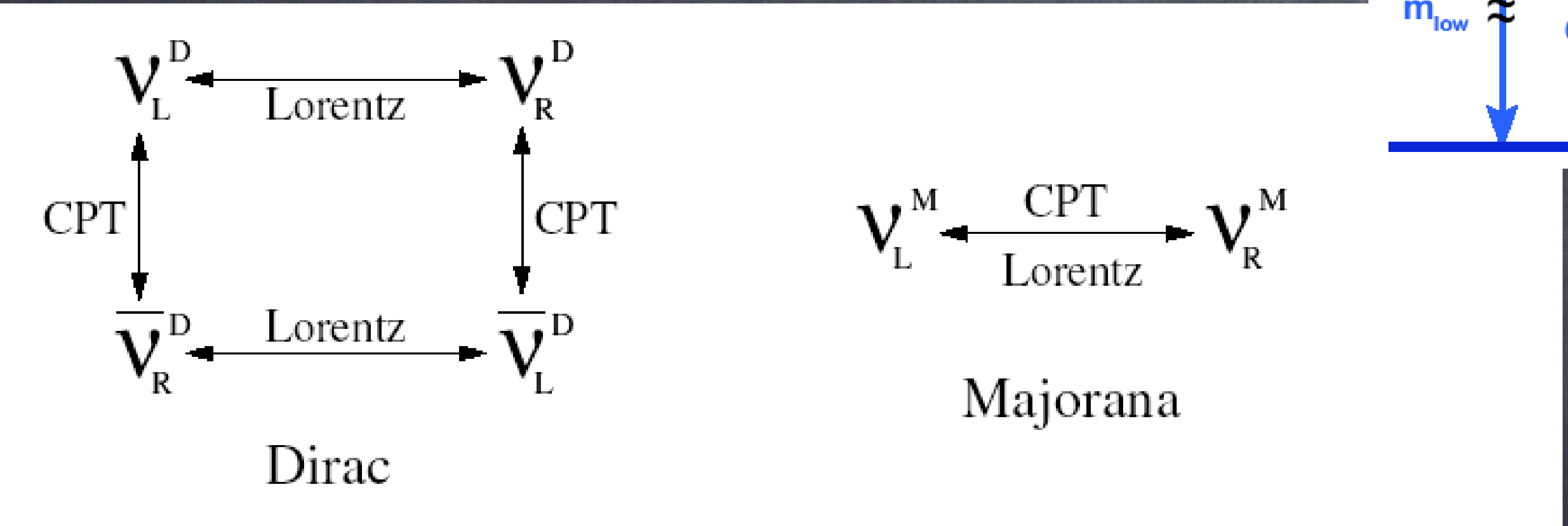
- what is hot in ν-physics
- why ν-physics underground
- European Undeground Labs
- The best use-case : **0ν-DBD**
- **CUORE**

The neutrino picture









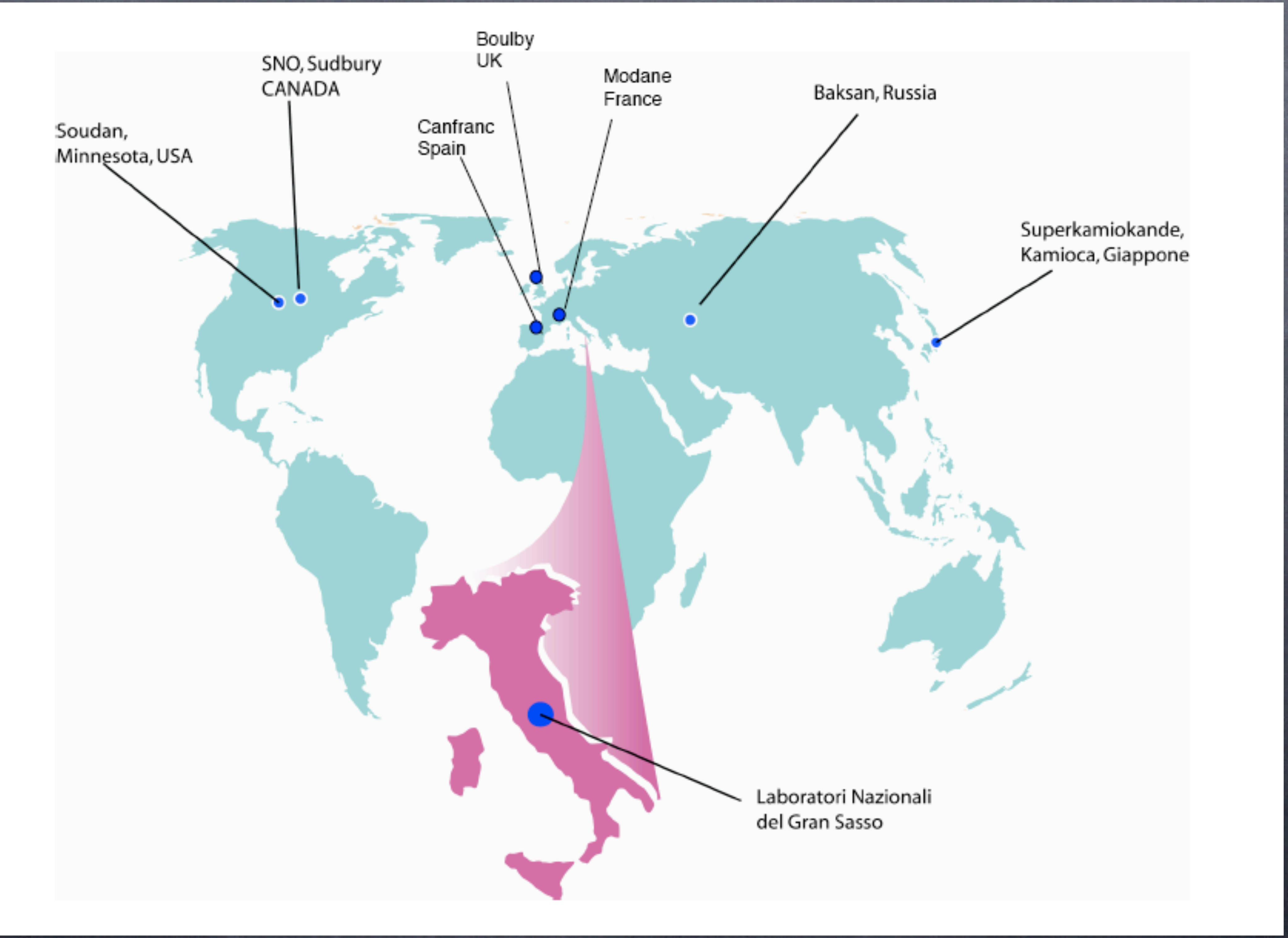
is broken

Questions

- What is the origin of the neutrino mass (M or D)
- Do we understand P-MNS from prime principles ?
- We better measure it first (Θ_{13}, CP-phase) !
- How the U-labs enters the picture ?

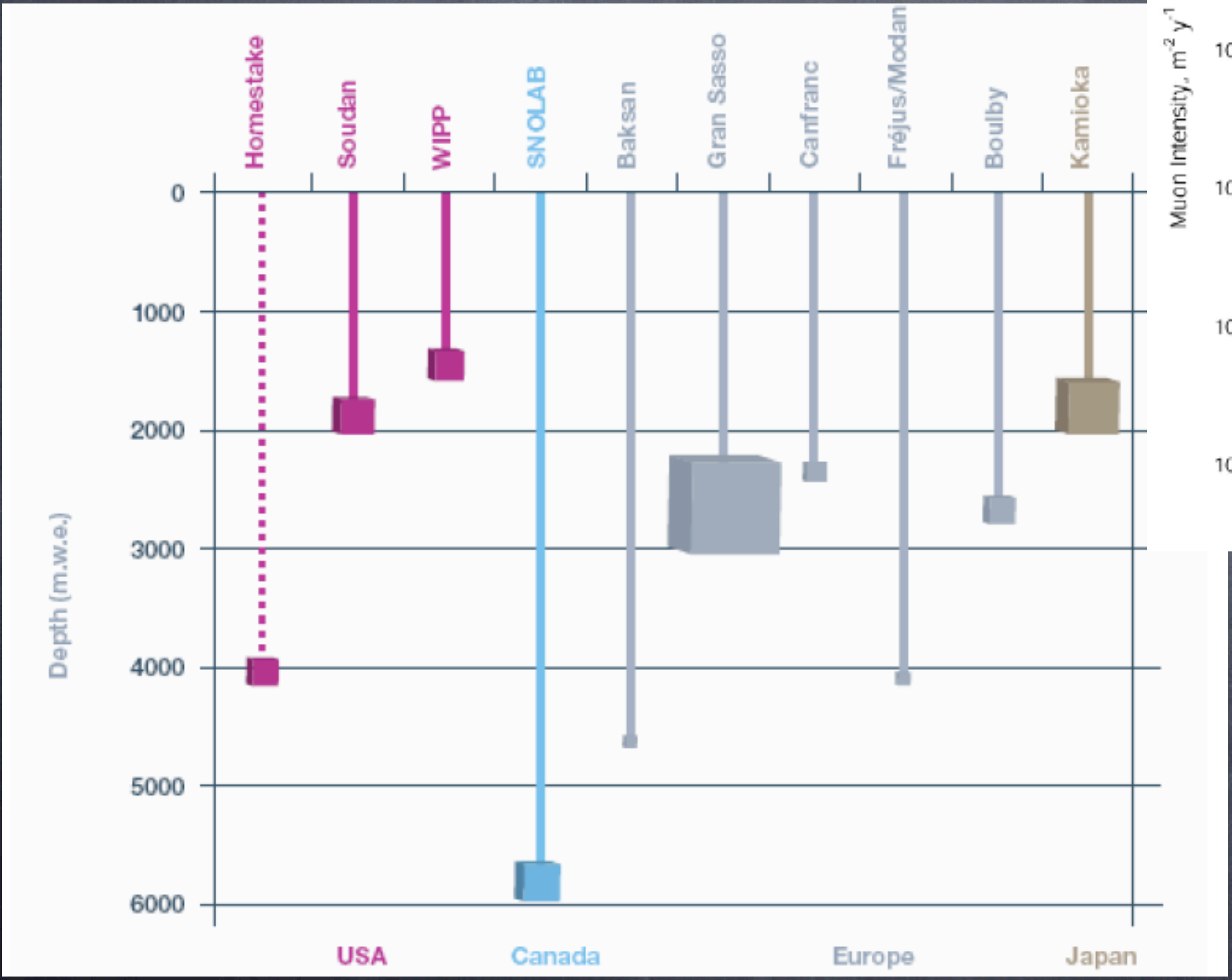
Underground labs

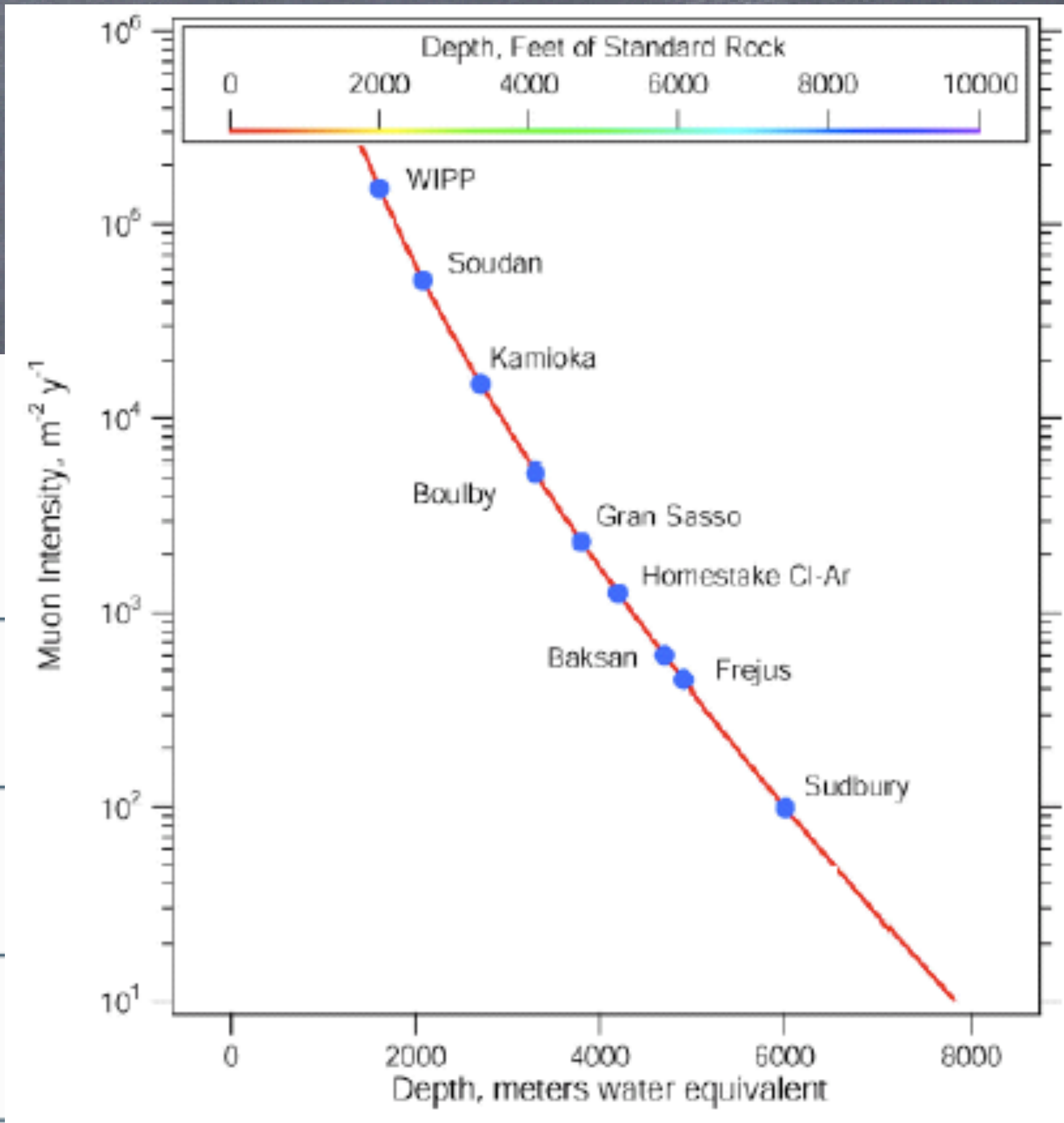
(with a bias)



bias comes from the number of experiments on different topics carried out in a lab

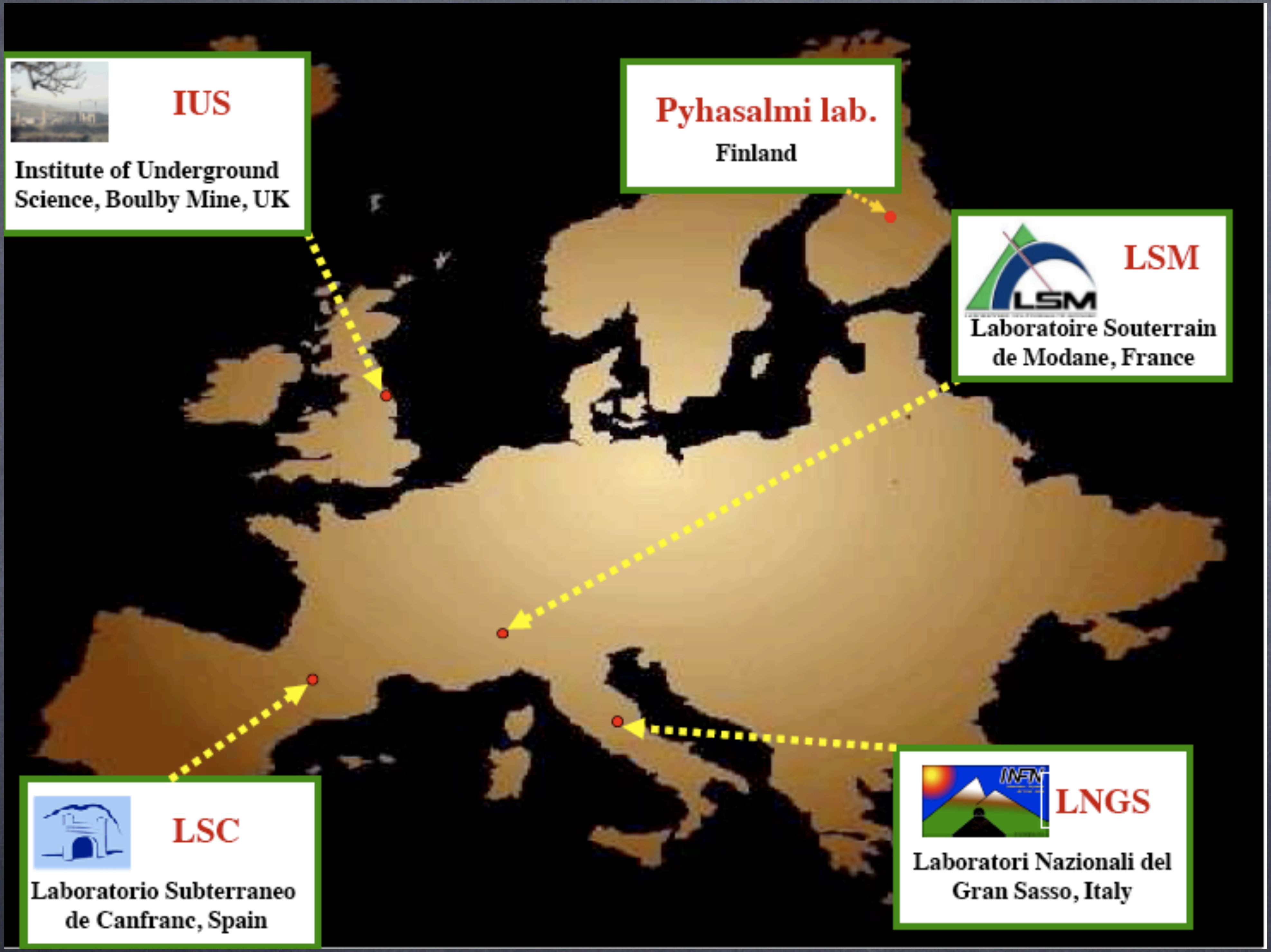
Depth and Volume





μ flux

Underground Europe



in detail

Parameters of the six large European Underground sites

Infrastructure	LNGS Gran Sasso	LSM Fréjus	LSC Canfranc	IUS Boulby	BNO Baksan	CUPP Pyhäsalmi
Year of completion	1987	1982	1986, 2005	1989	1977, 1987	1993 (2001)
Area (m^2)	13000	500	150+600	500+1000	550, 600	500-1000
Volume (m^3)	180000	3500	8000	3000	6400, 6500	100-10000
Access	Horizontal	Horizontal	Horizontal	Vertical	Horizontal	Slanted truck road
Depth (m.w.e.)	3700	4800	2450	2800	850, 4800	1050, 1444 up to 4060
Surface profile	Mountain	Mountain	Mountain	Flat	Mountain	Flat
Muon flux (m^{-2} day^{-1})	24	4	406	34	4320, 2.6	8.6 @ 4060m
Neutron flux (>1 MeV) (10^{-6} cm^{-2} s^{-1})	$\mathcal{O}(1)$	$\mathcal{O}(1)$	$\mathcal{O}(1)$	$\mathcal{O}(1)$	- , $\mathcal{O}(1)$	?
Radon content (Bq/m^3)	$\mathcal{O}(100)$	$\mathcal{O}(10)$	$\mathcal{O}(100)$	$\mathcal{O}(10)$	$\mathcal{O}(100)$	$\mathcal{O}(100)$
Main past and present scientific activities	- DM - ββ - solar ν - SN ν - atmos. ν - monopole - nuclear astrophysics - CRs (μ) - LBL ν's	Eighties: - Proton decay - atmos.ν Now: - DM (Edelweiss) - ββ (NEMO, TGV)	- DM (IGEX-DM, ROSEBUD, ANAIS) - ββ (IGEX)	- DM (Zeplin I,II, III, DRIFT)	*BUST:* - solar ν - SN ν - atmos. ν - CRs (μ) - monopoles *SAGE:* - solar ν	- CRs (test set-up)

Deep is good !

- Double Beta Decay experiments need unbelievably low background. Very deep is part of the solution.(GERDA, EXO, CUORE, SuperNEMO)
- Large neutrino experiments utilizing solar or reactor sources need to minimize cosmic background. Deep (not necessarily very) is the solution. (SuperK, Kamland, Borexino, SNO, DayaBay, Double Chooz)
- Experiments making use of accelerator produced neutrino might or might not need cosmic shielding. Depends rather on technology.(OPERA, T2K)

Select first item: 0ν-DBD

- GERDA (as an extrapolation of Ge ionization calorimeters) at LNGS
- SuperNemo (improved tracking detectors) at Modane (?)
- EXO (LXe with a super, yet daring feature) at WIMPP (DUSEL ?)
- CUORE (as a safe extrapolation of Cuoricino) at LNGS

once upon a time

TEORIA SIMMETRICA DELL'ELETTRONE E DEL POSITRONE

Nota di Ettore Majorana

Il Nuovo Cimento, **14** (1937) 171

Sunto. - *Si dimostra la possibilità di pervenire a una piena simmetrizzazione formale della teoria quantistica dell'elettrone e del positrone facendo uso di un nuovo processo di quantizzazione. Il significato delle equazioni di* Dirac *ne risulta alquanto modificato e non vi è più luogo a parlare di stati di energia negativa; nè a presumere per ogni altro tipo di particelle, particolarmente neutre, l'esistenza di « antiparticelle » corrispondenti ai « vuoti » di energia negativa.*

(when Science could still be described in Italian !)

courtesy of Luciano Maiani

the Majorana conjecture

$$\nu = \bar{\nu}$$

Practical consequence :
Lepton Number Violation

Caveat: massless neutrinos do not allow testing of the Majorana nature

Indeed nobody payed much attention to the Furry hypothesis (1939) that a Majorana neutrino could induce Neutrino-less DBD via helicity flip

one elegant explanation (beyond the SM)

Mass Term $\frac{1}{2}\left[\nu_L \quad (\nu_R)^C\right] C \begin{pmatrix} M_{M,L} & m_D \\ m_D & M_{M,R} \end{pmatrix} \begin{bmatrix} \nu_L \\ (\nu_R)^C \end{bmatrix} + h.c.$

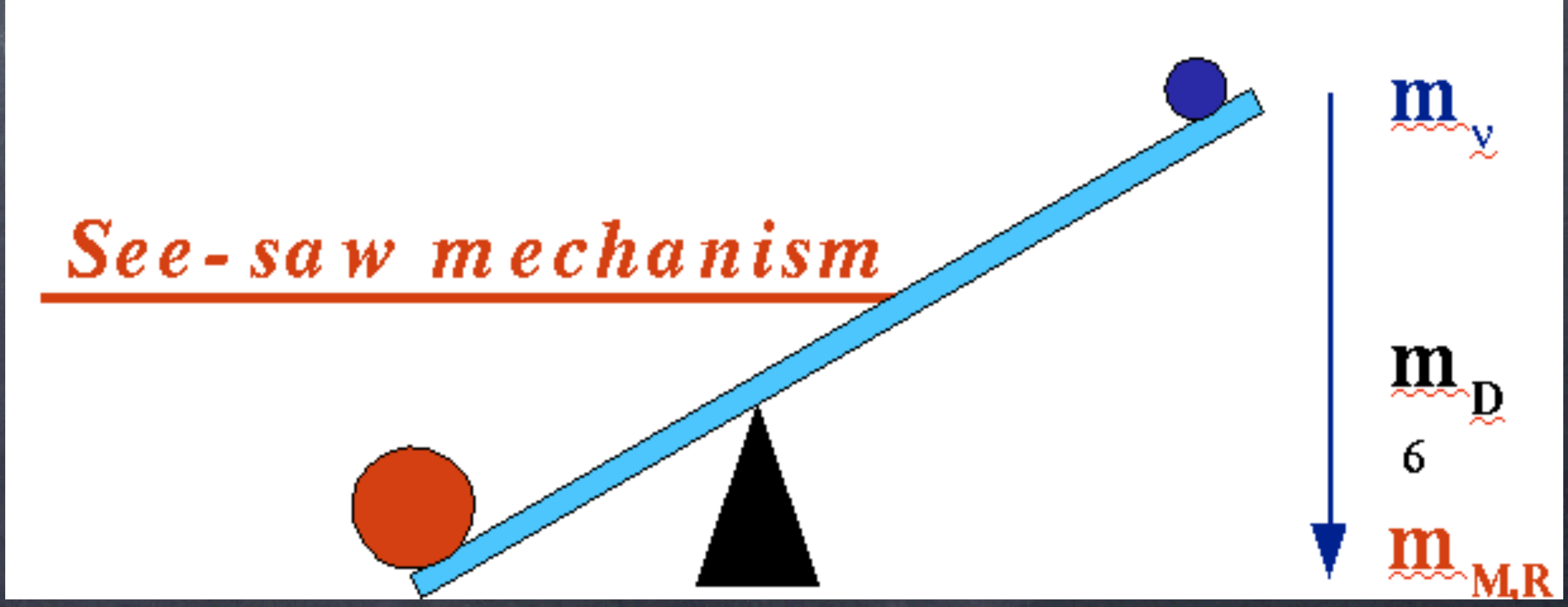
where $M_{M,L} \sim 0$

$M_D \sim M_{EW} \sim 100$ GeV

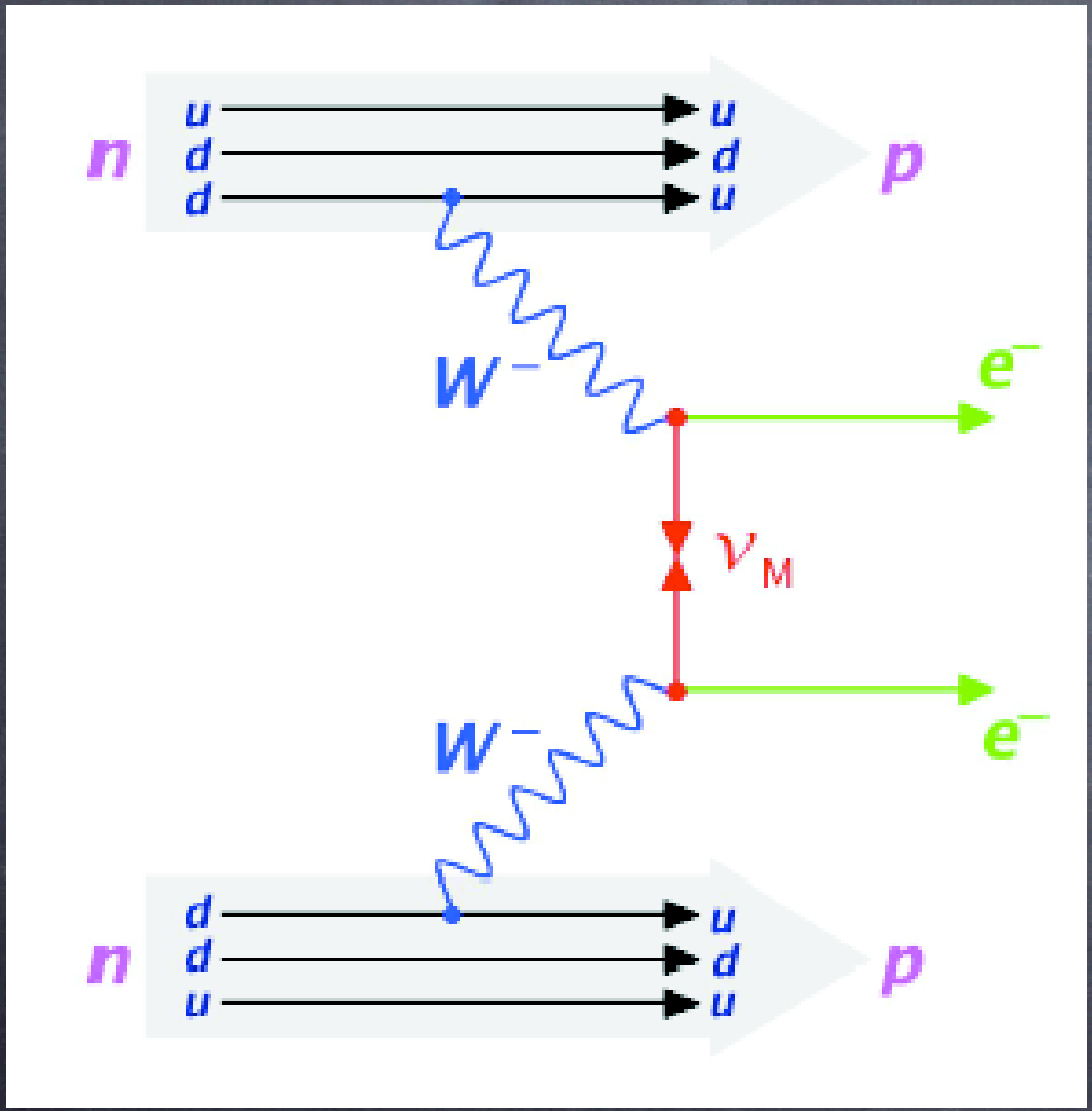
$M_{M,R} \sim$ Gauge singlet unprotected $\sim M_{GUT}$

$$m_N \simeq M_{M,R}$$

$$m_\nu \simeq \frac{m_D^2}{M_{M,R}}$$



Neutrino-less DBD (0νββ)



Only if:

Majorana Neutrinos

Massive Neutrinos

If observed:

Proof of the Majorana nature of Netrino

Does it also measure the mass ?

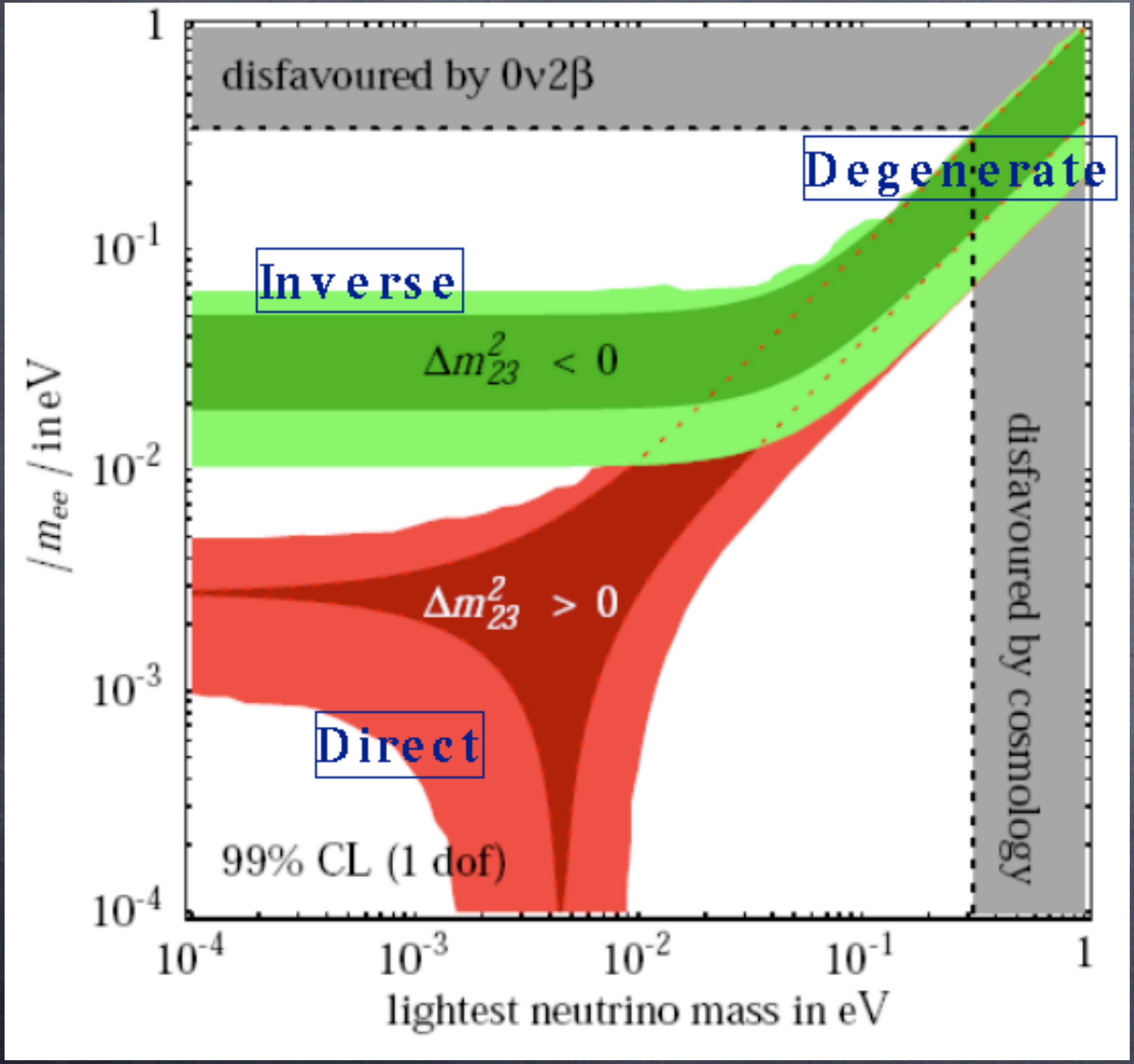
$$m_{\beta\beta} = \sum m_{\nu_k} U_{ek}^2 = \cos^2\theta_{13}(m_1\cos^2\theta_{12} + m_2 e^{2i\alpha}\sin^2\theta_{12}) + m_3 e^{2i\beta}\sin^2\theta_{13}$$

well...not so straight. It comes as a combination of the three neutrino masses, the mixing angles and the Majorana phases.

Exercise: parameterize as a function of the known parameters:

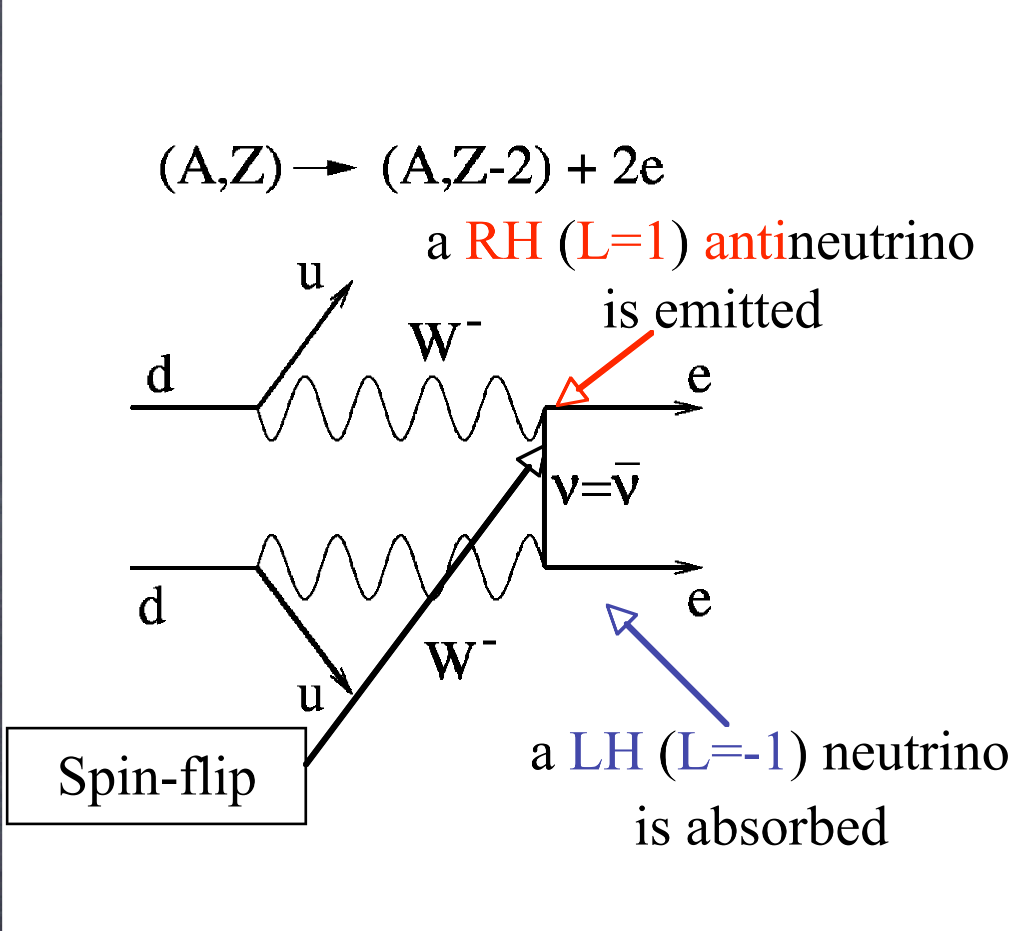
$$m_{\beta\beta} = f(U_{ek}, m_{lightest}, \delta m_{sol}, \Delta m_{atm})$$

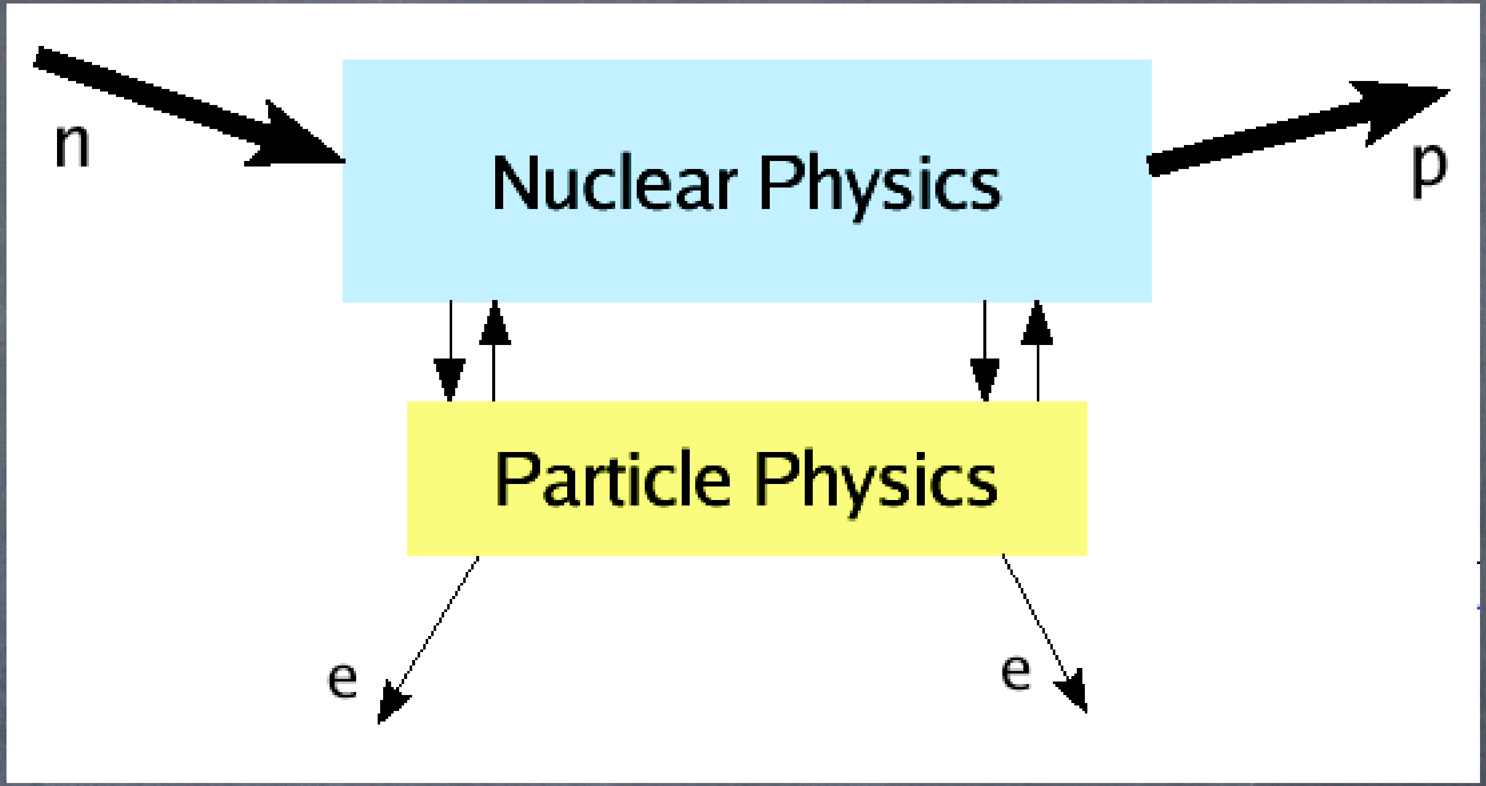
that translates into a nice plot



The question is which, if any, part of this phase space can be attained by a realistic experiment.

The elements of the game





0ν-DBD rate

Phase space ∝ Q^5

Nuclear matrix element

Effective neutrino mass

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

The name of the game: sensitivity

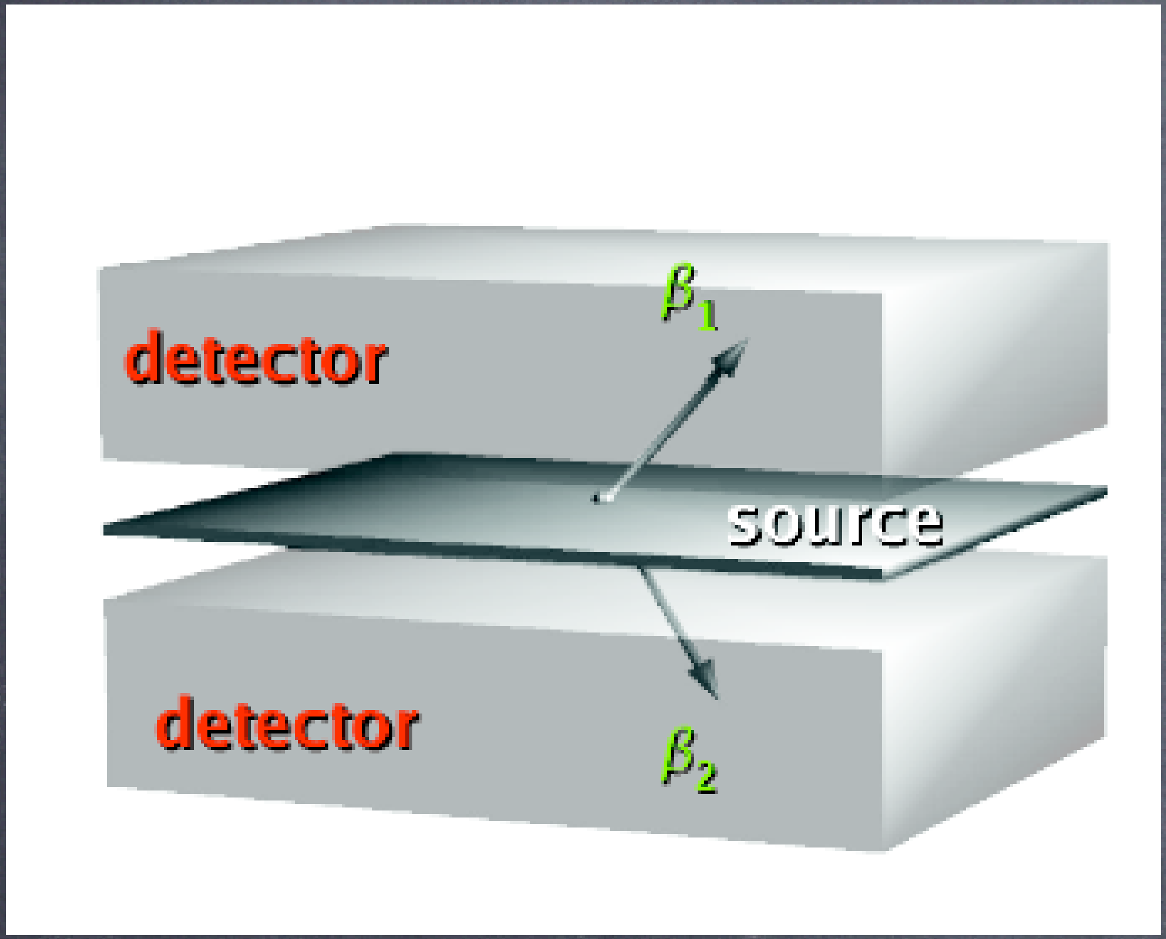
$$S^{0\nu}_{n\sigma} \propto \frac{a}{A}\left(\frac{M\,T}{b\,\Delta E}\right)^{1/2} \times \varepsilon$$

- a: Isotopic abundance
- M: Mass(Kg)
- T: Time (y)
- ε: efficiency
- A: Atomic Mass
- b: background (counts/keV/Kg/y)
- ΔE: Energy Resolution (KeV)

Sensitivity: half life corresponding to the minimal number of detectable events above background, for a given C.L

Two techniques (and a few variations)

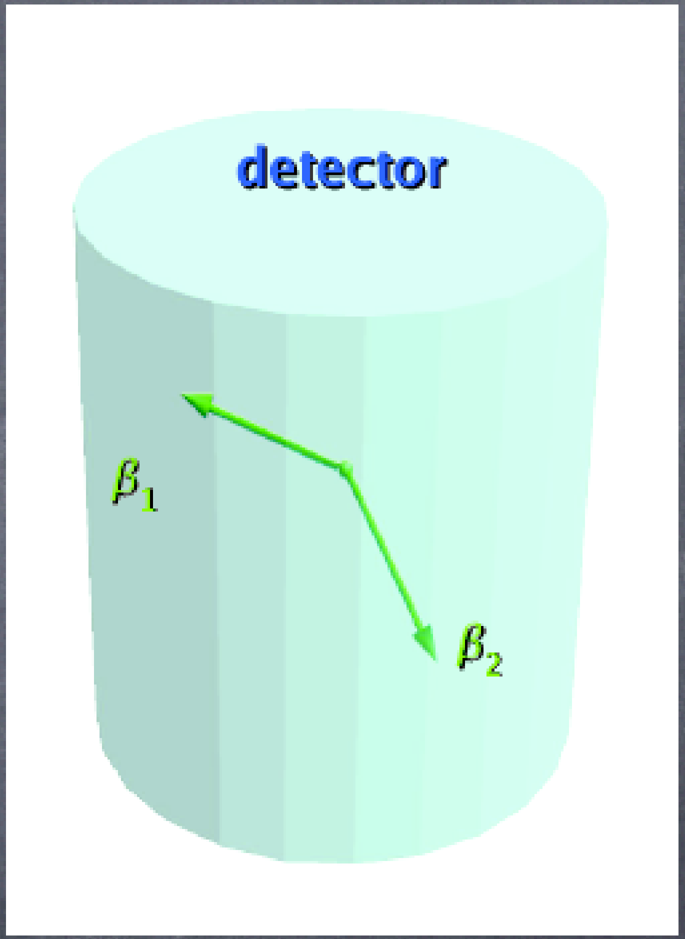
Source ≠ Detector



+++ Topology, Background

--- M, ΔE, ε

Source ⊆ Detector

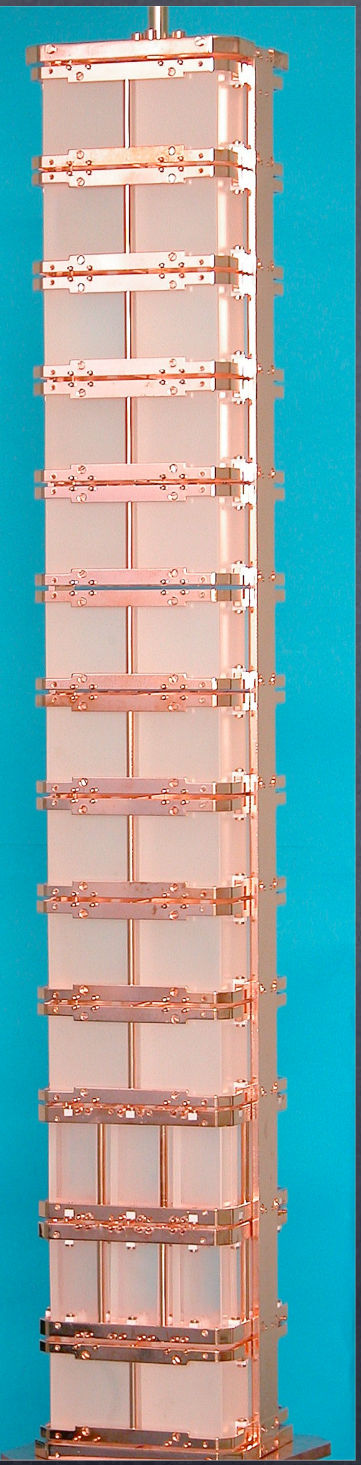


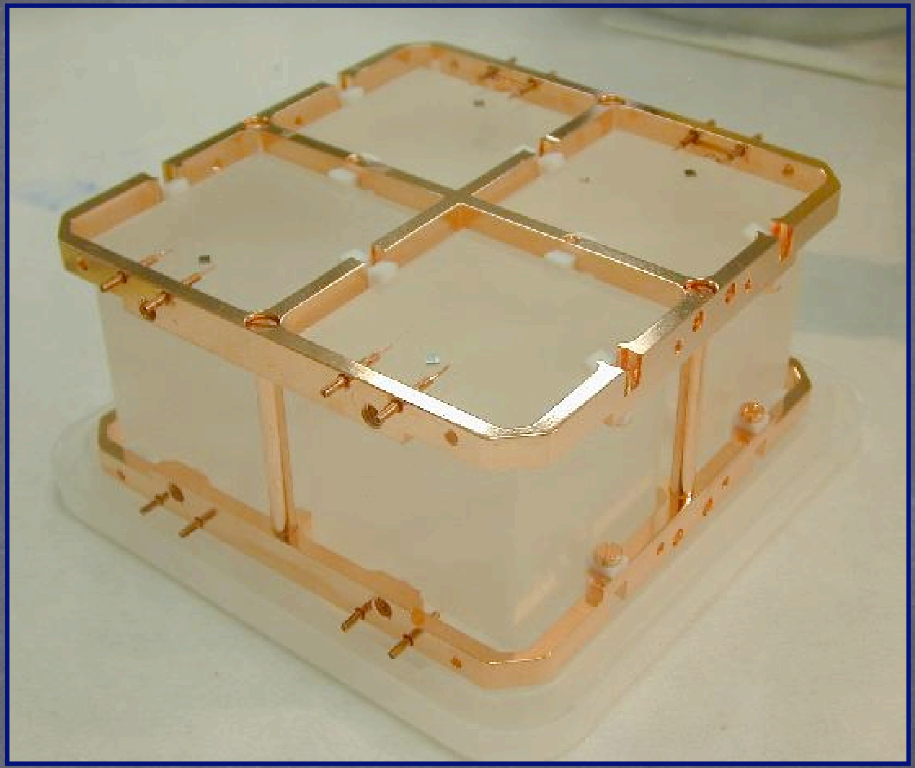
+++ M, ΔE, ε

--- Topology, Background

The present

Cuoricino



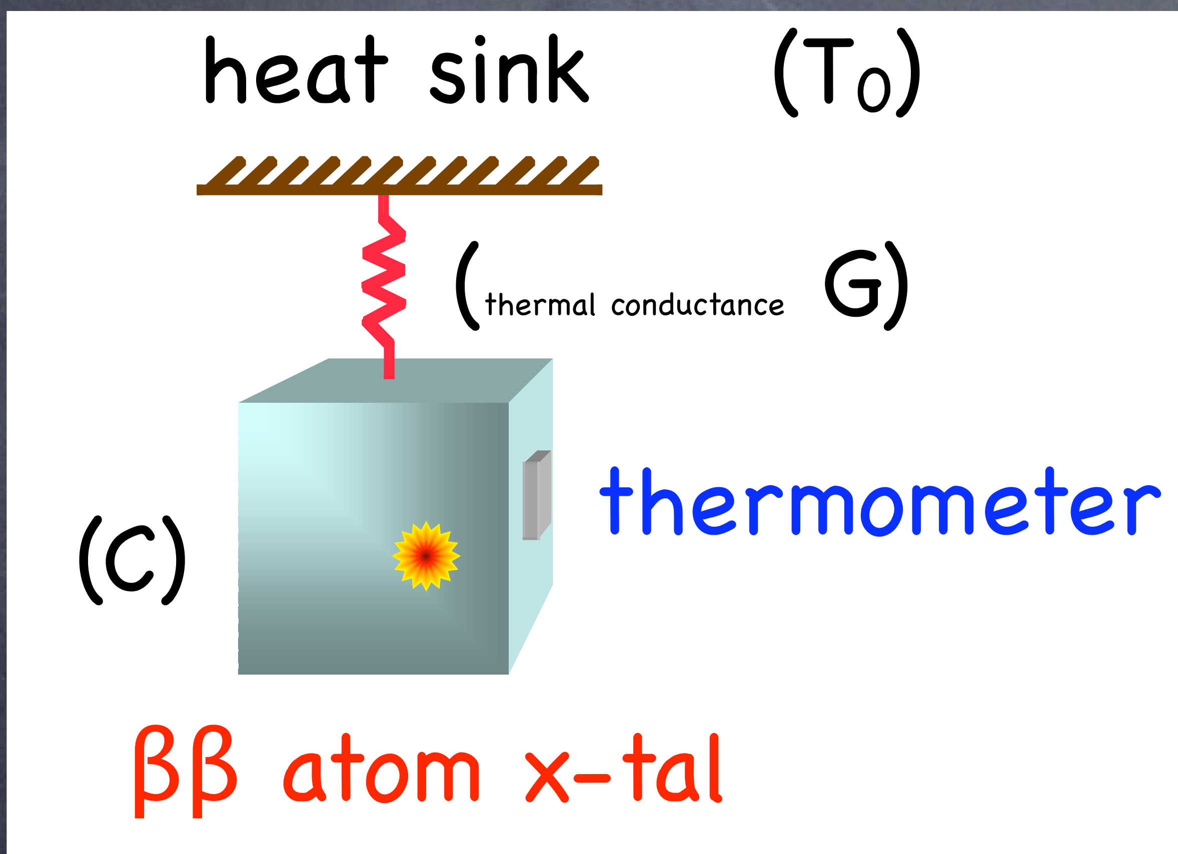


The bulk of Cuoricino calorimeter is made by 44 TeO_2 crystals of 5x5x5 cm^3 (790 gr of weight).
There are 18 additional crystals of 3x3x6 cm^3 (330 gr)

Total mass = 40.7 Kg
$^{130}Te \sim 11.2$ Kg

(very) Low Temperature Calorimeter

A True Calorimeter



Basic Physics: $\Delta T = E/C$

(Energy release/ Thermal capacity)

Implication: Low C ⇒ Low T

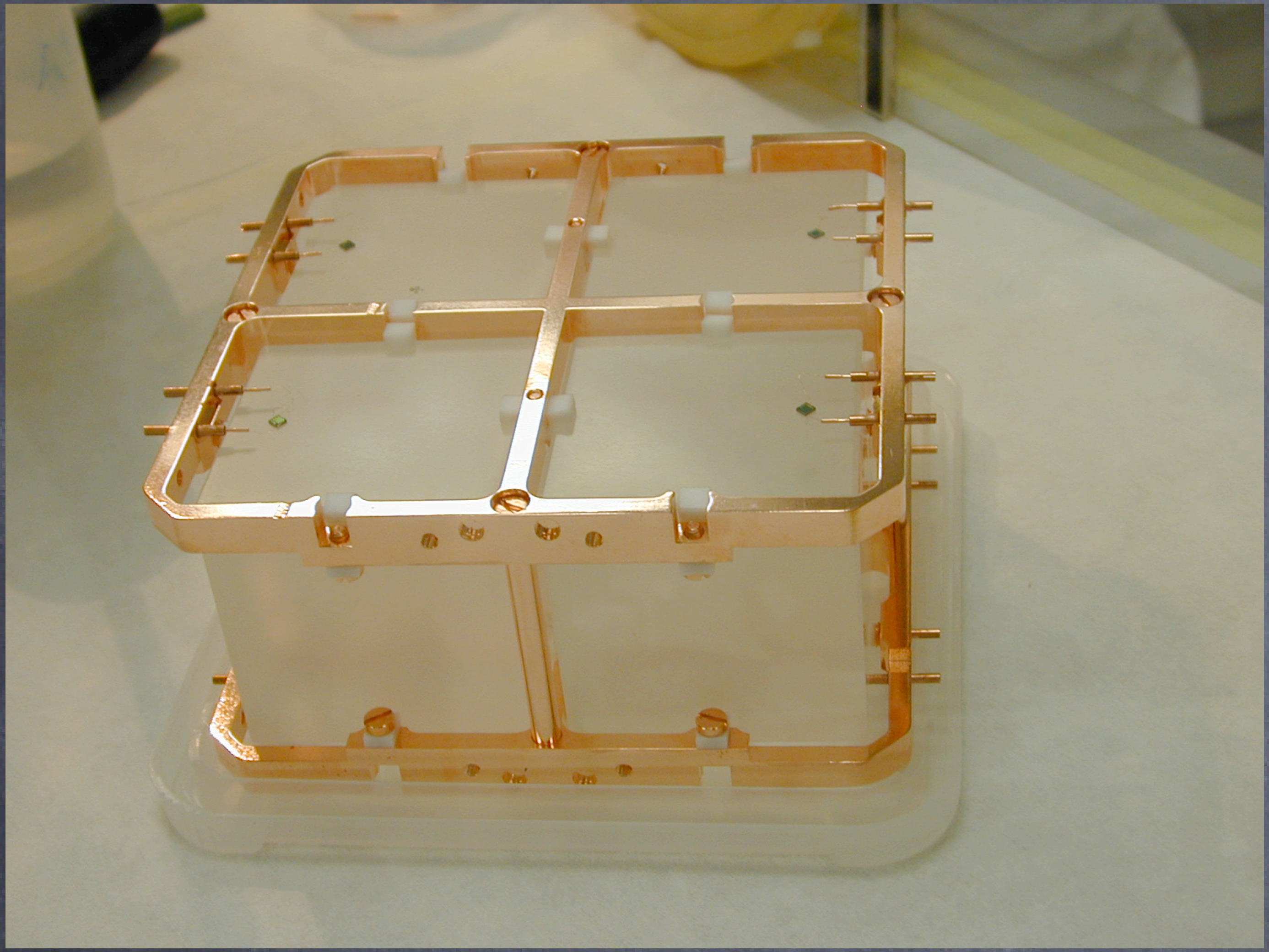
Bonus: (almost) No limit to ΔE ($k_B T^2 C$)

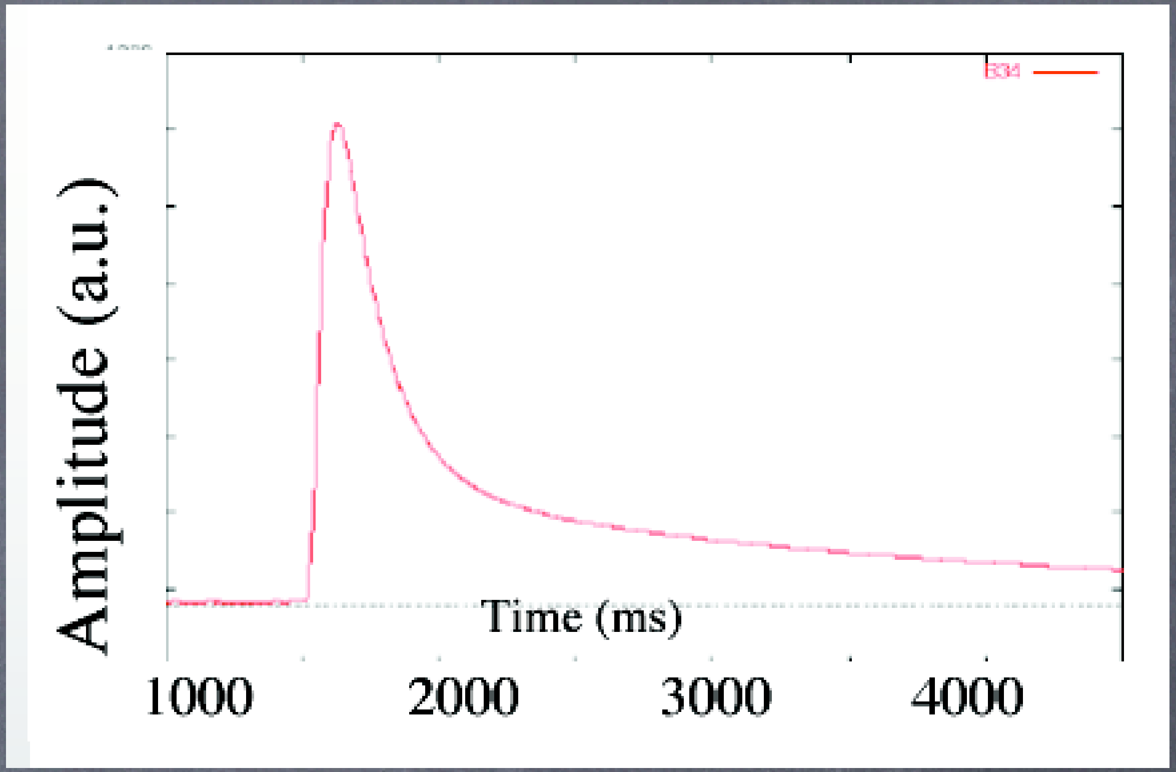
Not for all : $\tau = C/G \sim 1s$

$$C(T) = \beta \frac{m}{M} \left(\frac{T}{\Theta_D} \right)^3$$

$$\Delta T(t) = \frac{\Delta E}{C} \exp\left(-\frac{t}{\tau} \right)$$

TeO_2 : a viable (show)case





$T_0 \sim 10$ mK

Numerology:

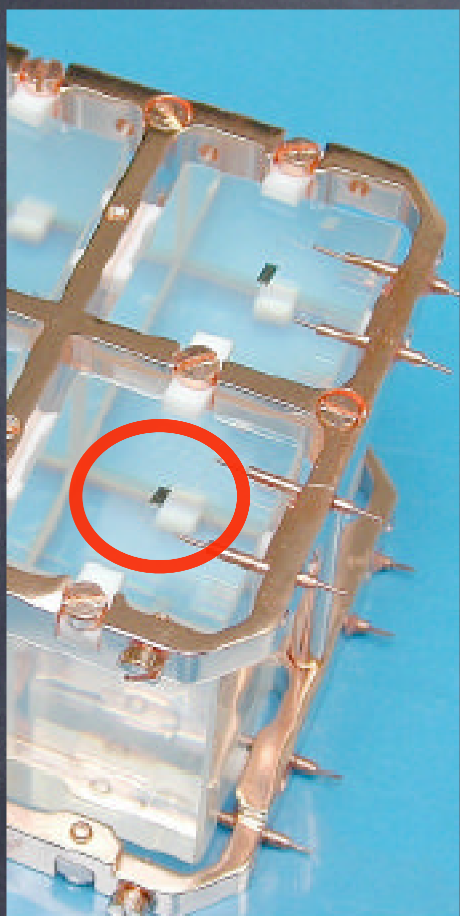
$C \sim 2$ nJ/K ~ 1 MeV/0.1 mK

$G \sim 4$ pW/mK

Need to be able to detect temperature jumps of a fraction of μK (per mil resolution on MeV signals)

to read the temperature you need a thermometer

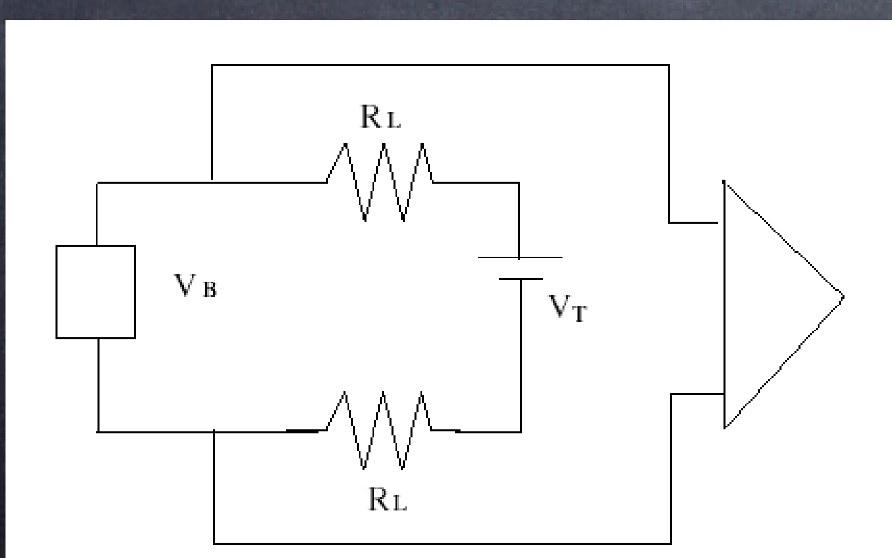
$$A(T) = \left| \frac{d \ln R}{d \ln T} \right|$$

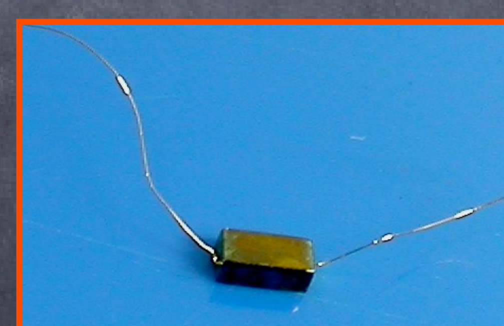


Neutron Transmutation Doped (NTD) Germanium Thermistor

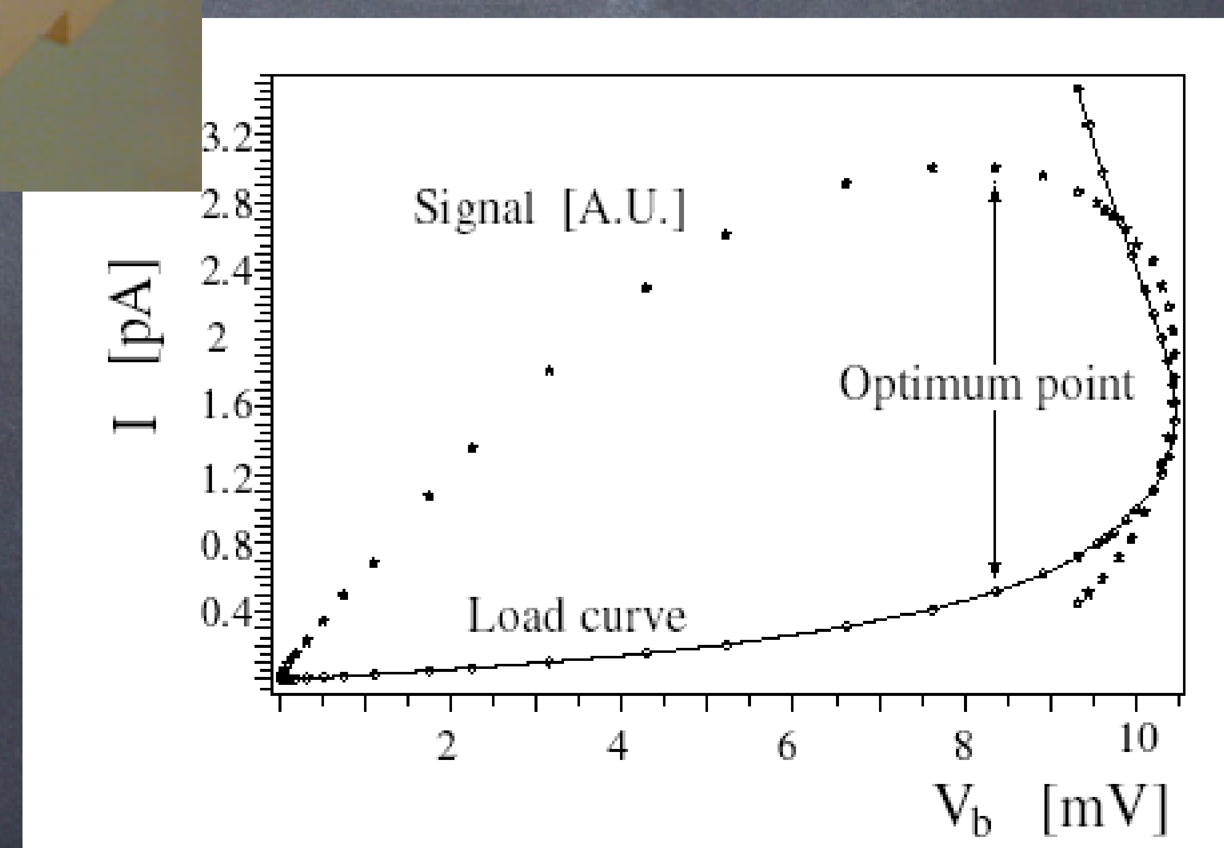
I ~ 50 pA
dR/dE ~ 20kΩ/KeV

0.2mV/MeV

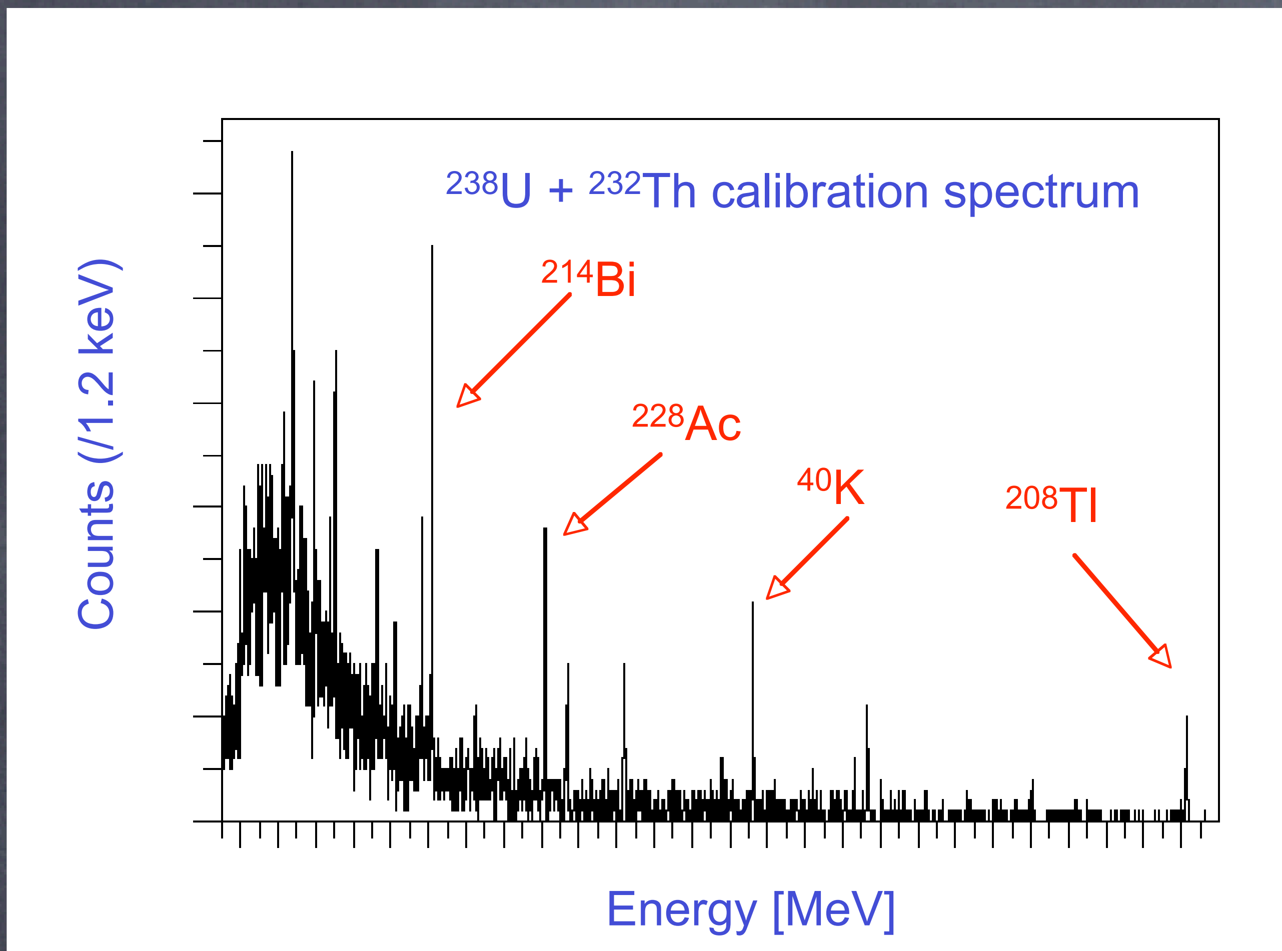




$$T_b = T_0 + \frac{P}{G}$$

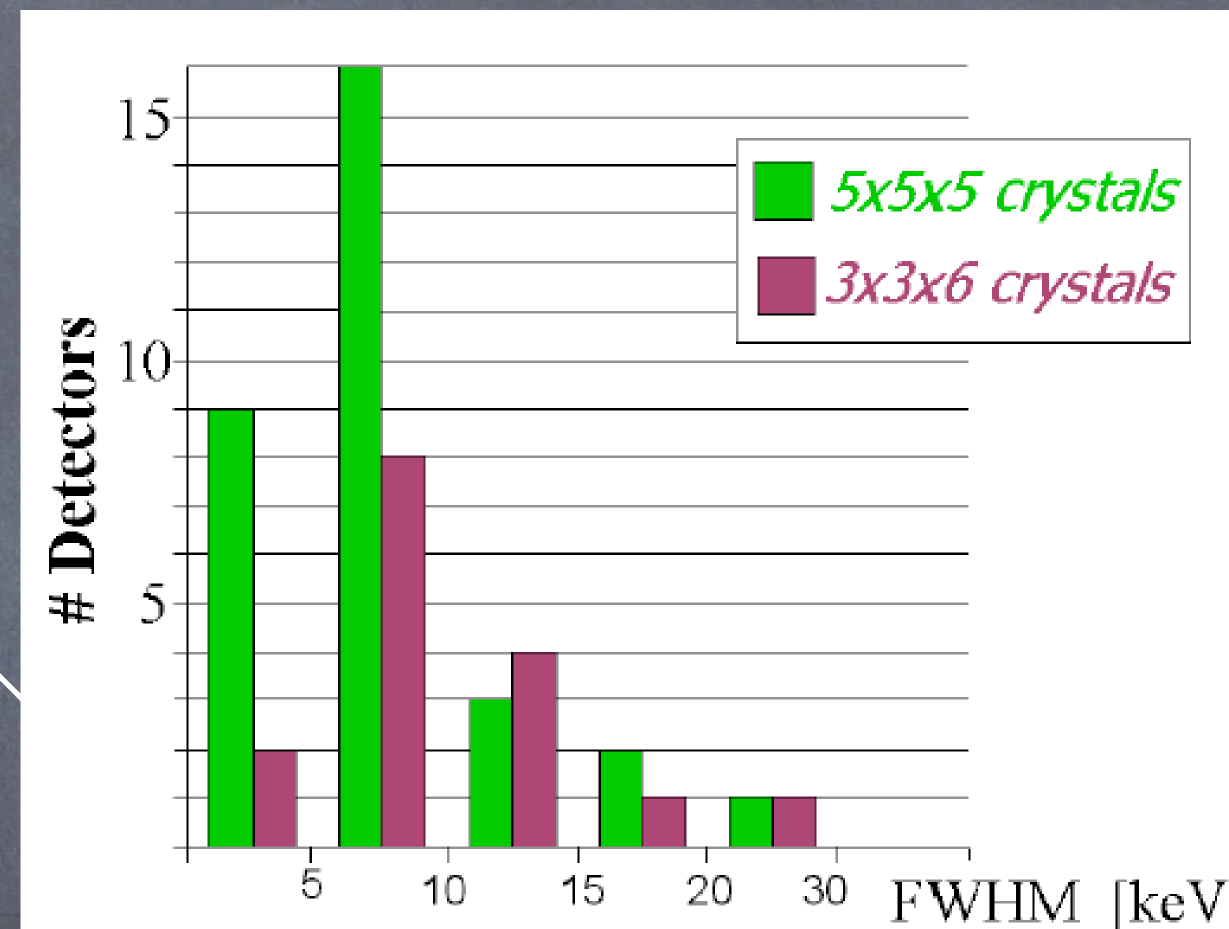


Energy resolution



Sum all over the crystals

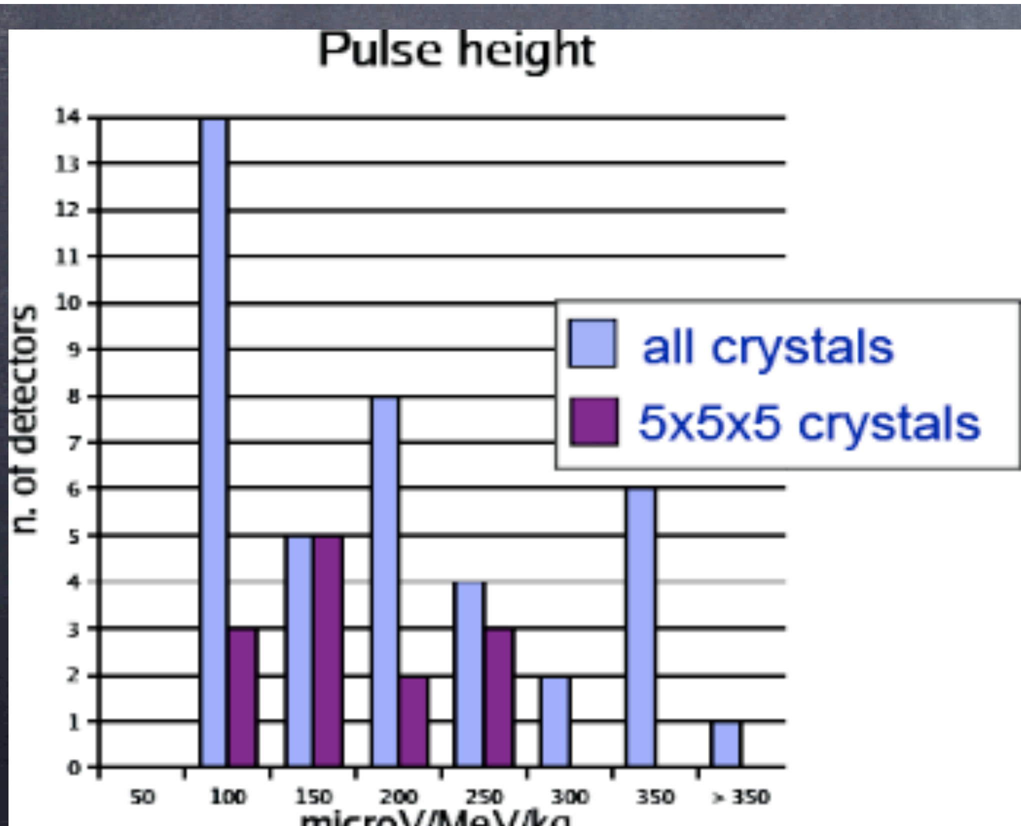
(calibration with ^{232}Th source)



Average resolution 5x5x5 : 7.5 keV

Average resolution 3x3x6 : 9.6 keV

Best of all : 3.9 keV



Resolution limited by

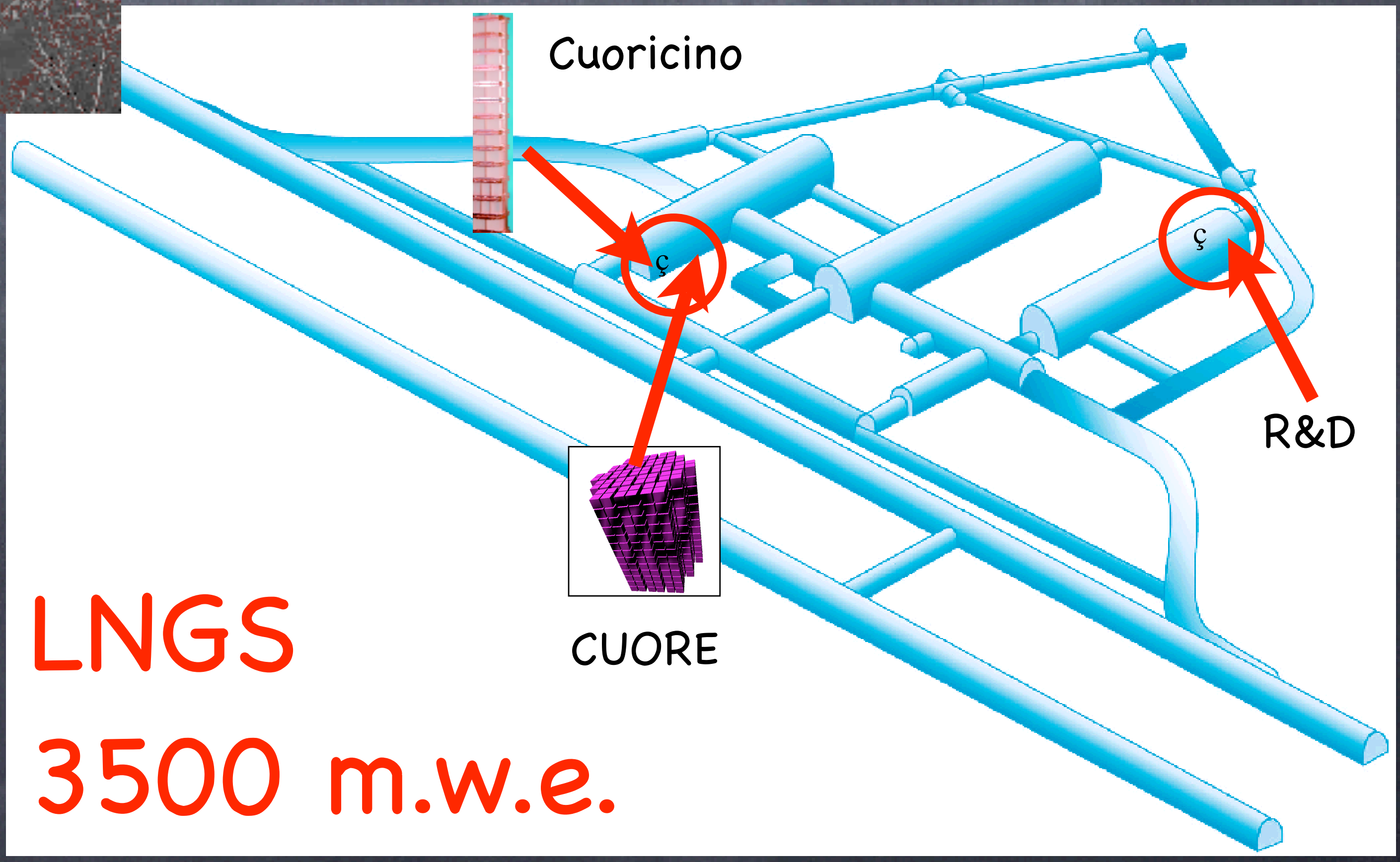
- Thermal/Phononic (Δ ~ eV)
- Electronic noise (Δ ≤ 1 keV)
- Microphonics Δ ~ 3-5 keV
- Detector responses Δ ~ keV

Cuoricino, where ?

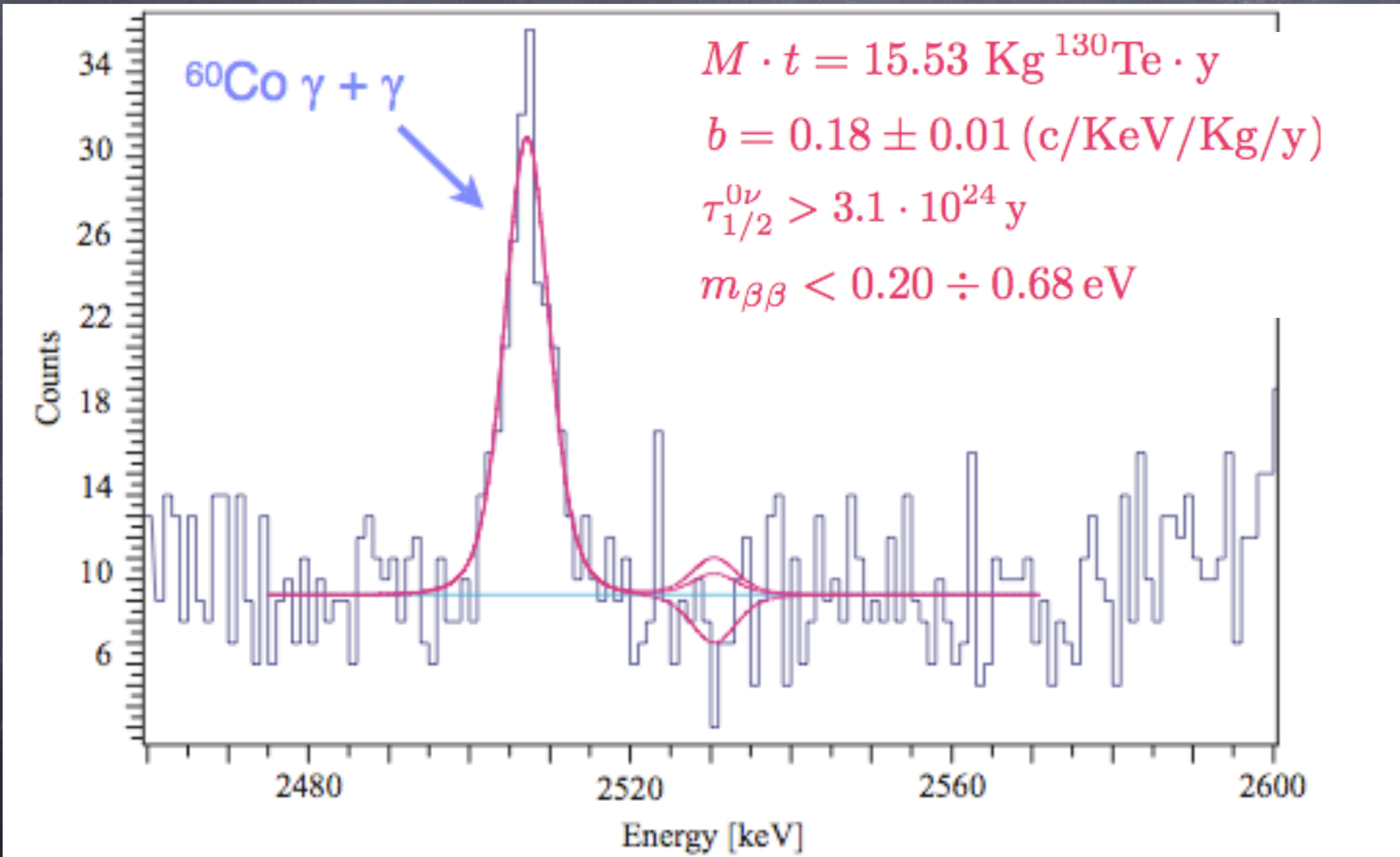
The Shield

Corno Grande 2916 m

A National Park providing great opportunity for walking, trekking, climbing, cross and backcountry skiing

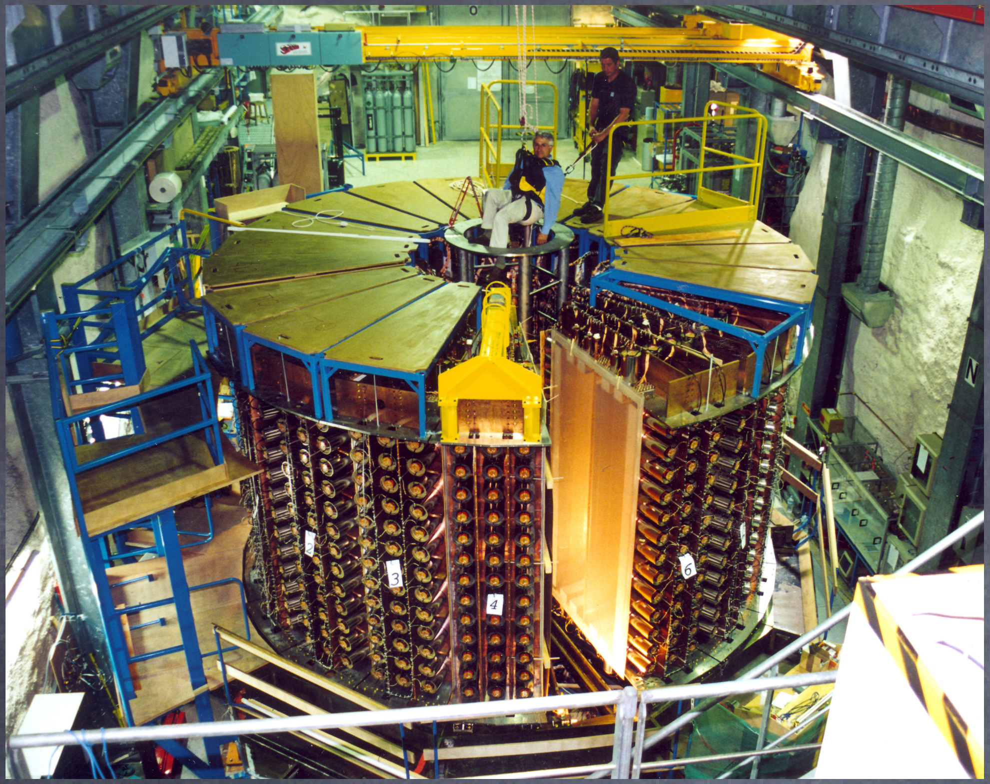


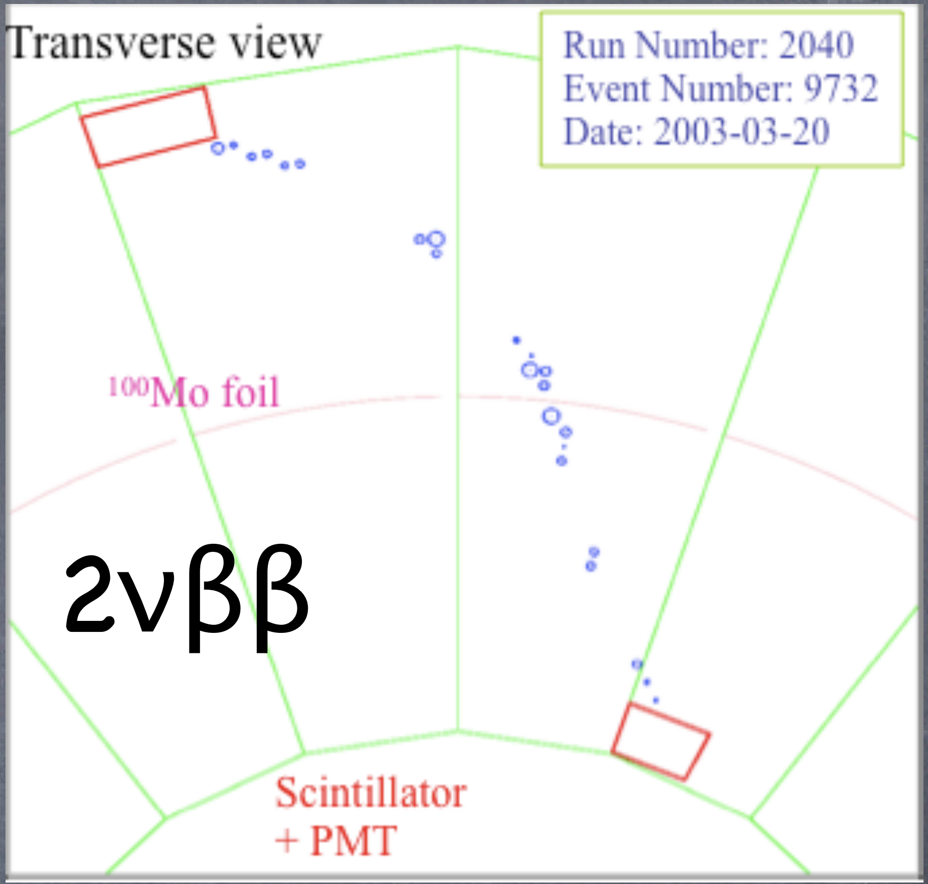
Cuoricino: result



A digression on the truly alternative road: a tracking device

NEMO at Frejus LSM

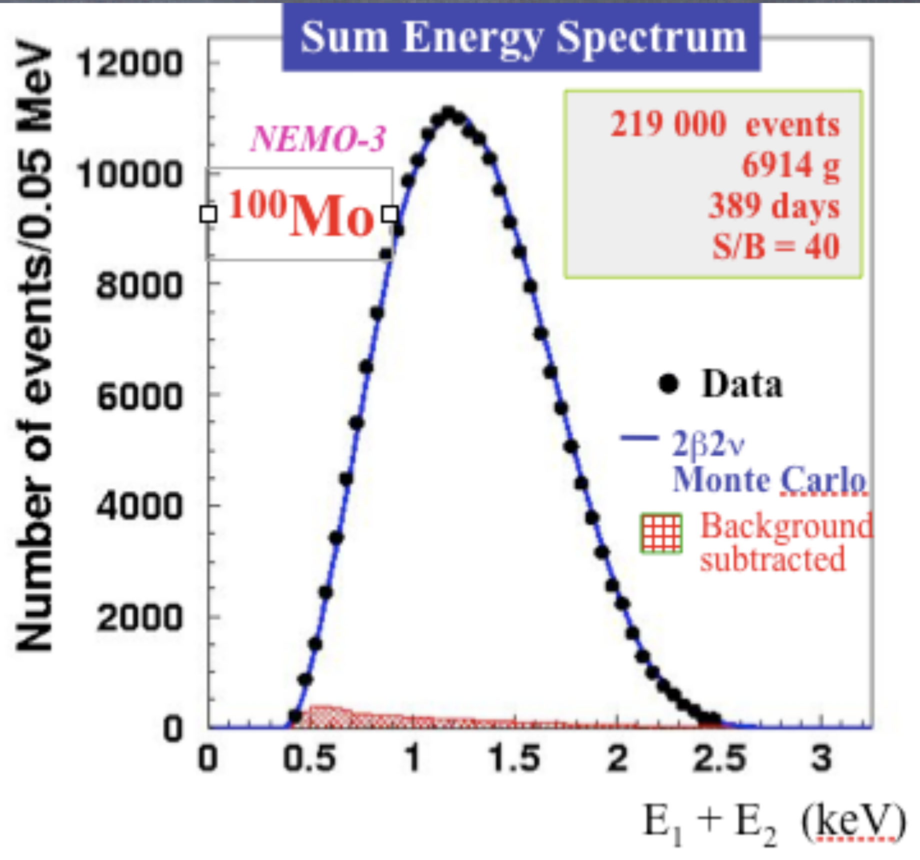




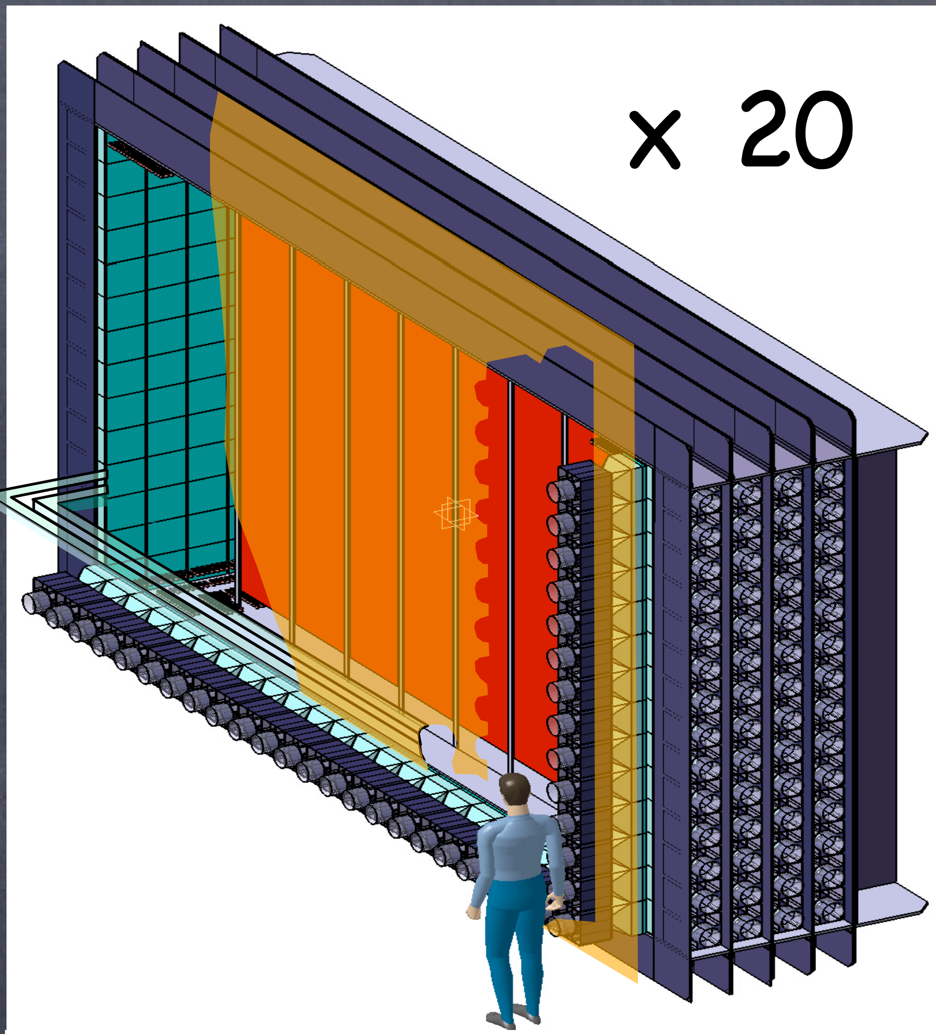
Source: **10 kg of ββ isotopes**
cylindrical, S = 20 m², e ~ 60 mg/cm²

Tracking detector:
drift wire chamber operating
in Geiger mode (6180 cells)
Gas: He + 4% ethyl alcohol + 1% Ar + 0.1% H_2O

Calorimeter:
1940 plastic scintillators
coupled to low radioactivity PMTs

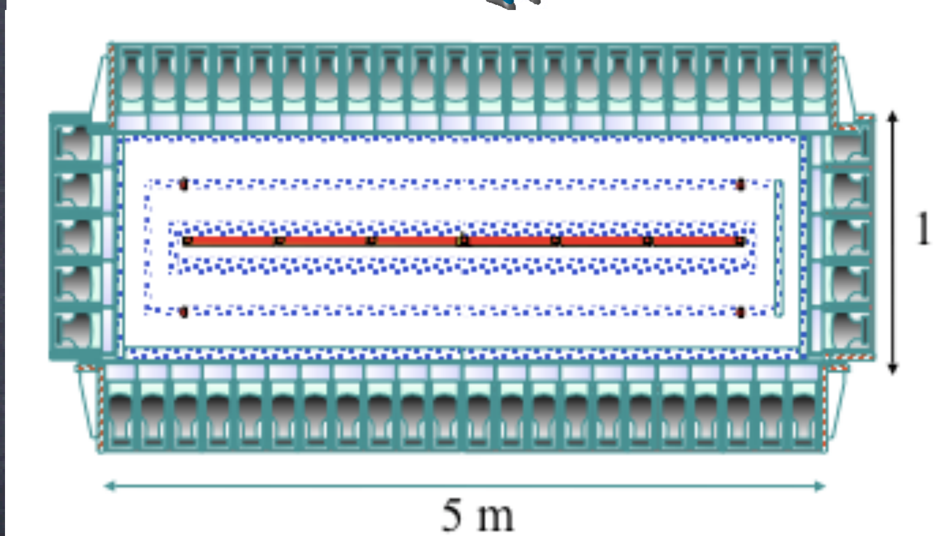


Magnetic field: 25 Gauss
Gamma shield: Pure Iron (e = 18cm)
Neutron shield:
30 cm water (ext. wall)
40 cm wood (top and bottom)
(since march 2004: water + boron)

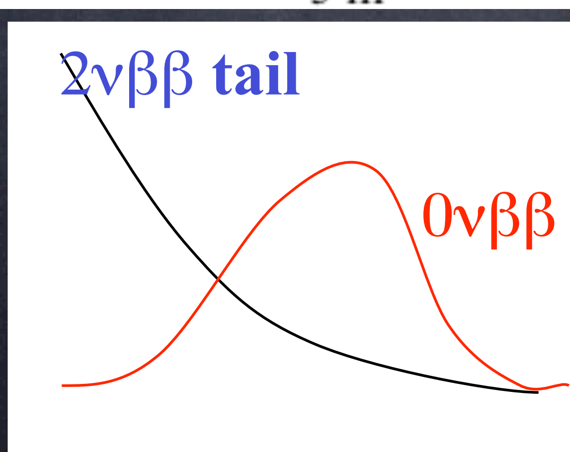


SuperNEMO at ?

challenge: a lot of improvement
at the same time in a huge detector



NEMO-3		SuperNEMO
^{100}Mo $T_{1/2}(\beta\beta2\nu) = 7.\ 10^{18}$ y	Choice of isotope	^{82}Se (and/or ^{150}Nd) $T_{1/2}(\beta\beta2\nu) = 10^{20}$ y
7 kg	Isotope mass **M**	100 - 200 kg
$\varepsilon(\beta\beta0\nu)$ = 8 %	Efficiency ε	$\varepsilon(\beta\beta0\nu) \sim$ 30 %
^{214}Bi < 300 µBq/kg ^{208}Tl < 20 µBq/kg ^{208}Tl, ^{214}Bi) ~ 1 evt/ 7 kg /y ββ2ν ~ 2 evts / 7 kg / y	N_{exclu} = f(BKG) *Internal contaminations* ***^{208}Tl and ^{214}Bi** in the ββ foil* ββ(2ν)	^{214}Bi < 10 µBq/kg ^{208}Tl < 2 µBq/kg (^{208}Tl, ^{214}Bi) ~ 1 evt/ 100 kg /y ββ2ν ~ 1 evt / 100 kg/ y
FWHM(calo)=8% @3MeV	*IF*	FWHM(calo)=4% @3MeV
$T_{1/2}(\beta\beta0\nu)$ > 2. 10^{24} y **$<m_\nu>$ < 0.3 – 0.7 eV**	**SENSITIVITY**	**$T_{1/2}(\beta\beta0\nu)$ > 2 10^{26} y** **$<m_\nu>$ < 50 meV**



1) ββ source production
2) Energy resolution
3) Radioprurity
4) Tracking

CUORE

Pulse Tube Cooler

988 TeO_2 Crystals

19 Towers of 52 crystals each

741 Kg of TeO_2

Active Mass 204 Kg

Toward CUORE: the 3 towers

Step 1

Decide which Cu cleaning

Test in ex-Cuoricino cryostat 3 alternative methods

By Spring 2009 pick the best

Legnaro cleaning

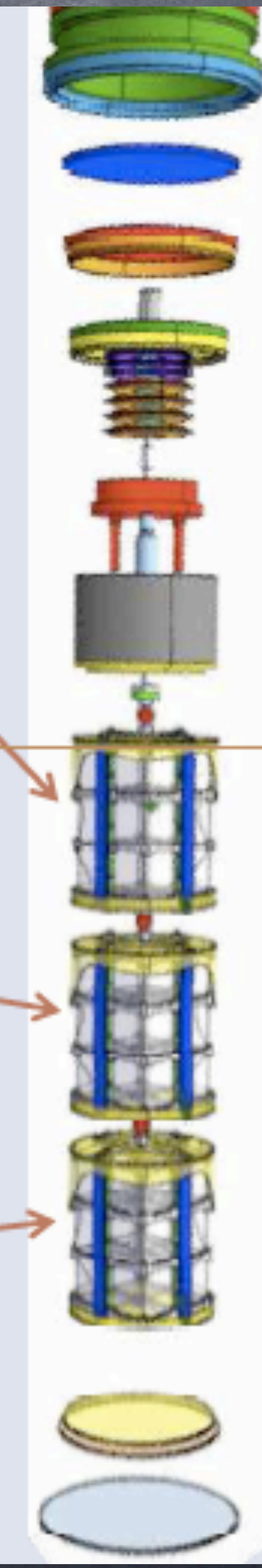
- Tumbling: mechanical barrel polishing
- Electropolishing: removal of ~100 μm of material
- Chemical etching: removal of ~10 μm of material
- Magnetron sputtering: removal of a few μm
- Ion beam cleaning: removal of a few nm

LNGS cleaning

- Electropolishing
- Chemical etching
- Passivation

LNGS alternative cleaning

- Chemical etching
- Passivation
- 50 μm PET coverage of Cu components



Toward CUORE: CUORE-0

Step 2

Final proof of everything

Test in ex-Cuoricino cryostat one CUORE tower

By end 2009 take data

CUORE-0: the first CUORE tower to be assembled & installed in the Hall A dilution refrigerator (ex-Cuoricino)

CUORE-0 has its reasons!

- CUORE-0 will test with high statistics the assembly procedure, which has been largely improved during the R&D years (gluing, holder, zero-contact approach, wires, …)
- It will be possible to verify the background reduction expected, approximately 1/3 of the Cuoricino background in the DBD energy region: it should be close to the CUORE target in the energy degraded alpha region
- CUORE-0 will be a powerful experiment that will overtake soon the Cuoricino sensitivity

Scaling Cuoricino to CUORE

$$\frac{a}{A}\left(\frac{M\,T}{b\,\Delta E}\right)^{1/2}$$

$M = m \times 20$

$T = t \times 6$

$b = B / 20$

$\Delta E = \Delta E / 1.5$

$S_{CUORE} = \sqrt{3600}\ S_{Cuoricino} \sim 60\ S_{Cuoricino}$

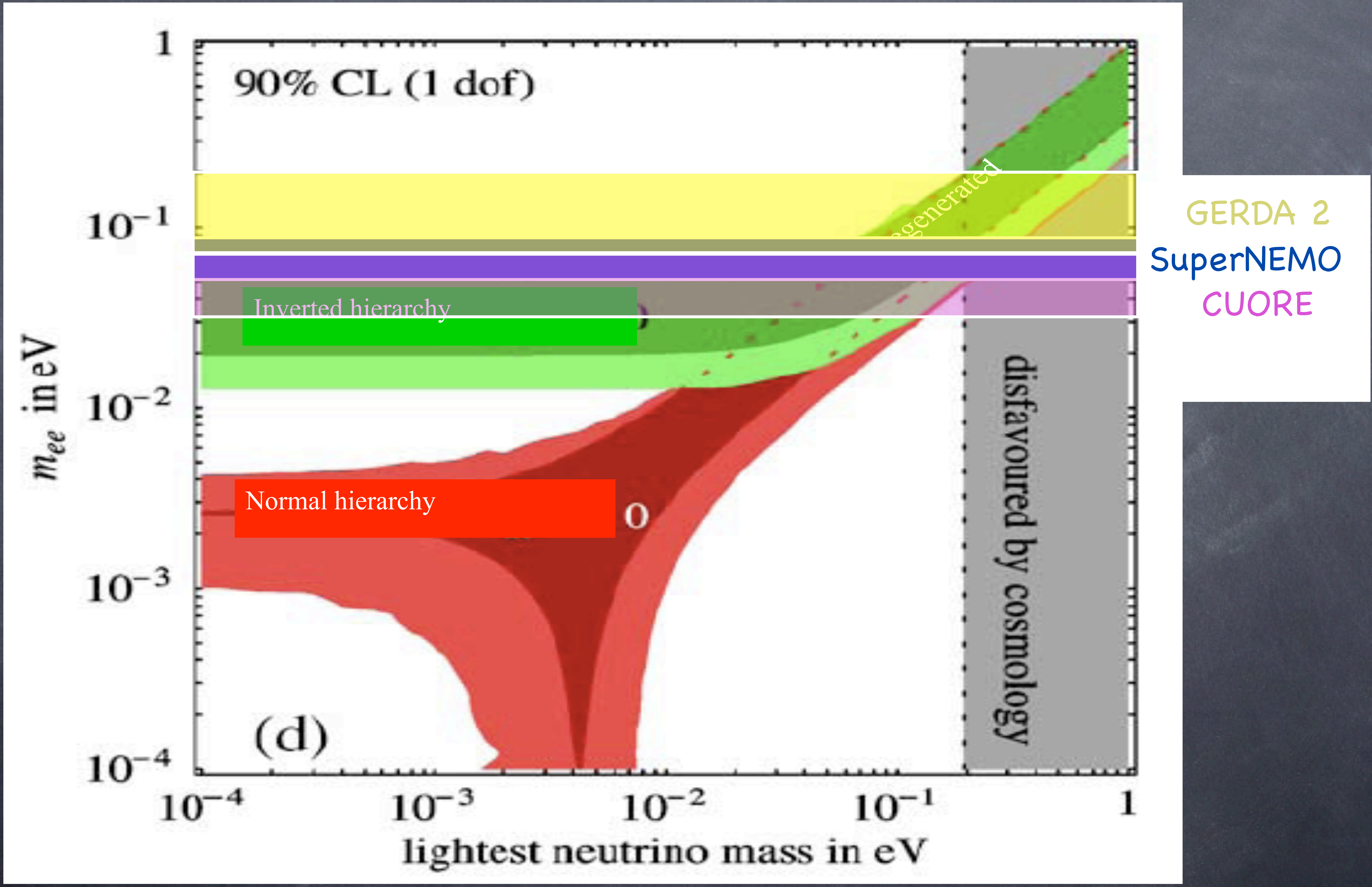
$\tau_{1/2\,(CUORE)} \sim 1.7 \times 10^{26}$

$\langle m_\nu \rangle_{CUORE} \sim \langle m_\nu \rangle_{Cuoricino} / 9 \sim 20 \div 100$ meV

One step is non trivial. Getting to 0.01 c/Kg/y/KeV

(CUORE is 1 Ton. It means 10 c/y/KeV)

The next generation goal



Conclusions

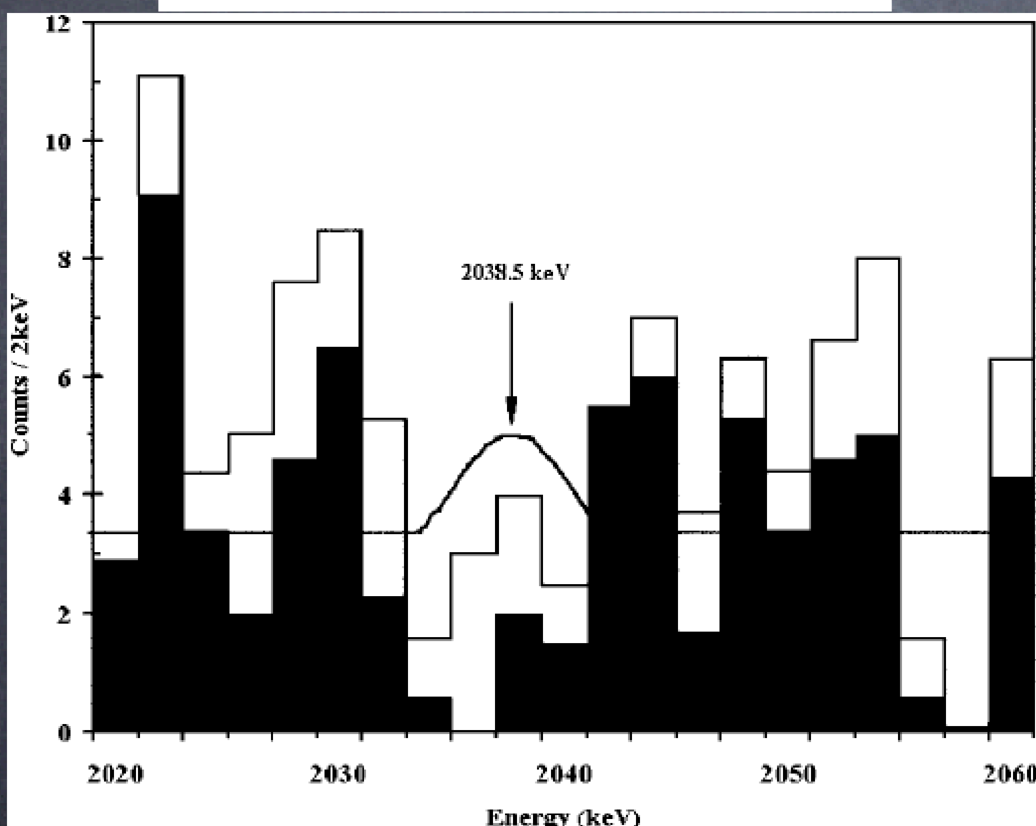
- Neutrino Physics is one of the leading field in HEP today
- Dirac or Majorana nature of neutrino mass is a fundamental question that needs to be answered at (almost) all cost(s)
- Neutrino-less DBD might possibly be the sole chance to give a measure of neutrino mass
- The second generation experiments can either win or show the path to victory

More material

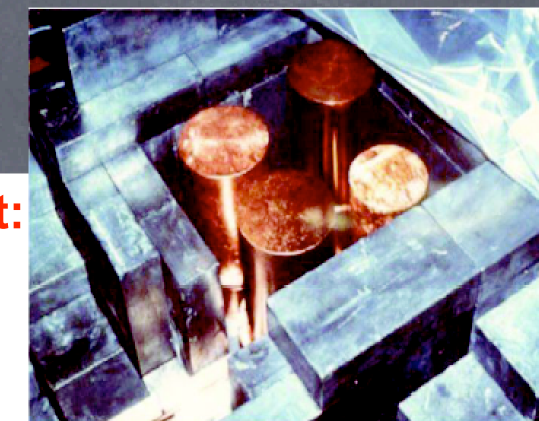
The past

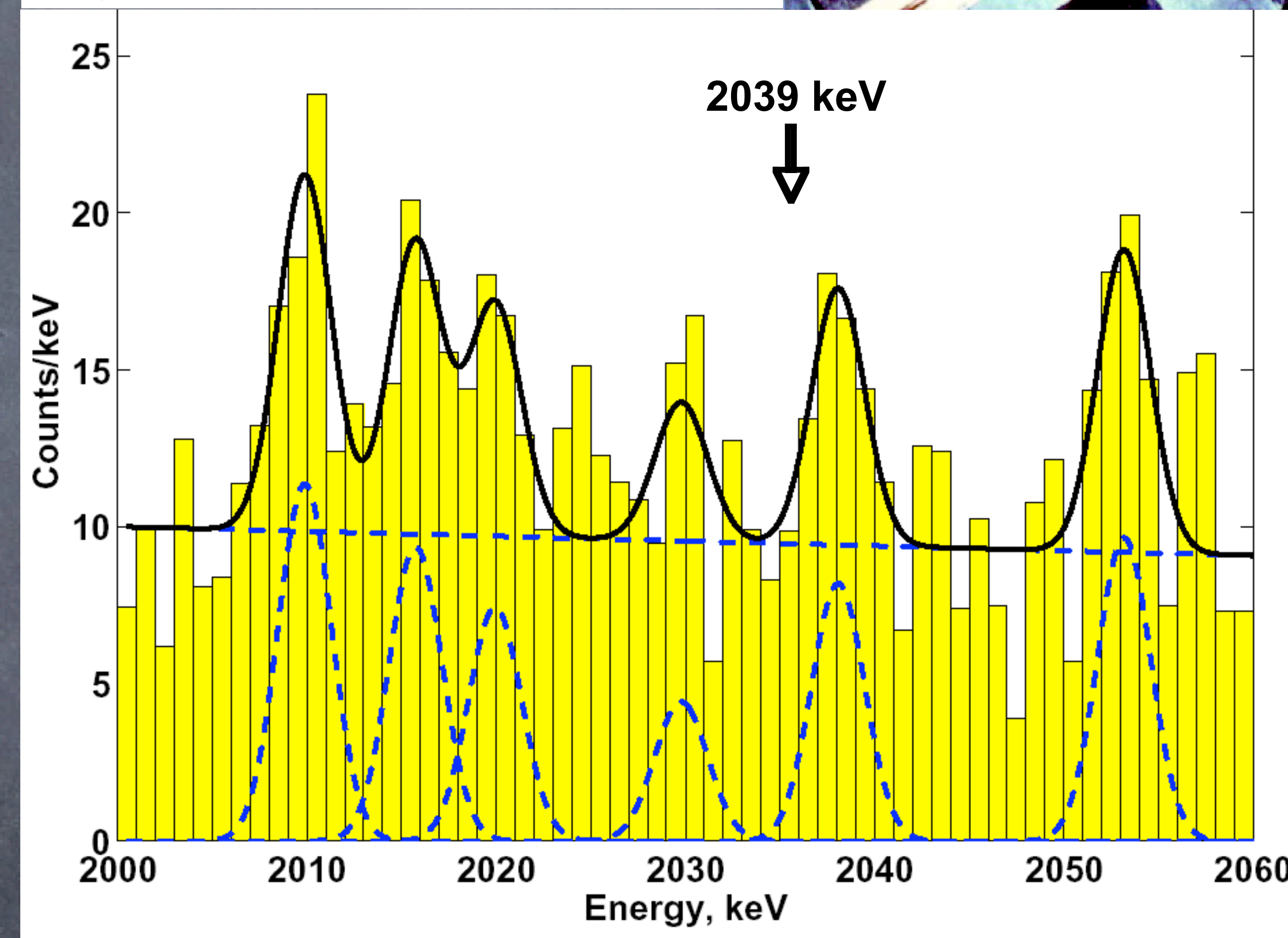
^{76}Ge $0\nu\beta\beta$

IGEX experiment:
C. Aalseth et al., Phys. Rev. D 65, 092007.
$T_{1/2} > 1.6 \cdot 10^{25}$ y (90% C.L.)



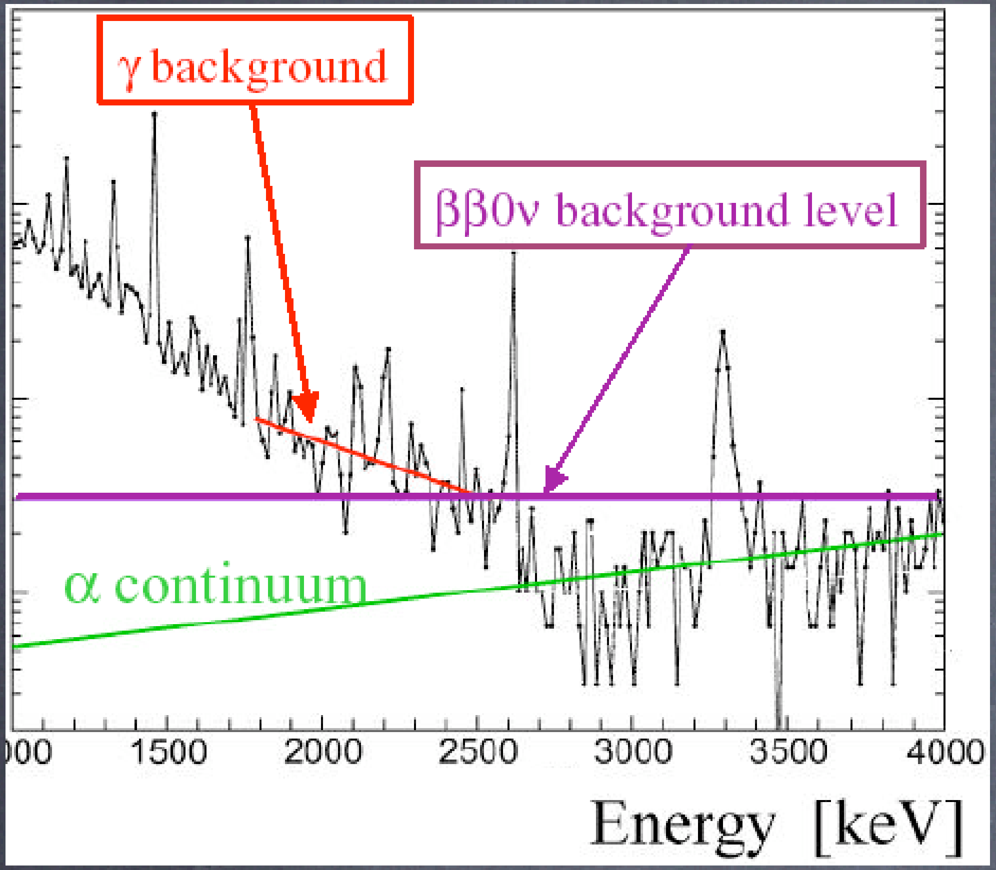
Heidelberg-Moscow experiment:
H.V.Klapdor-Kleingrothaus et al., Phys. Lett. B586 (2004) 198.
$T_{1/2} = (0.7 - 4.2) \cdot 10^{25}$ y





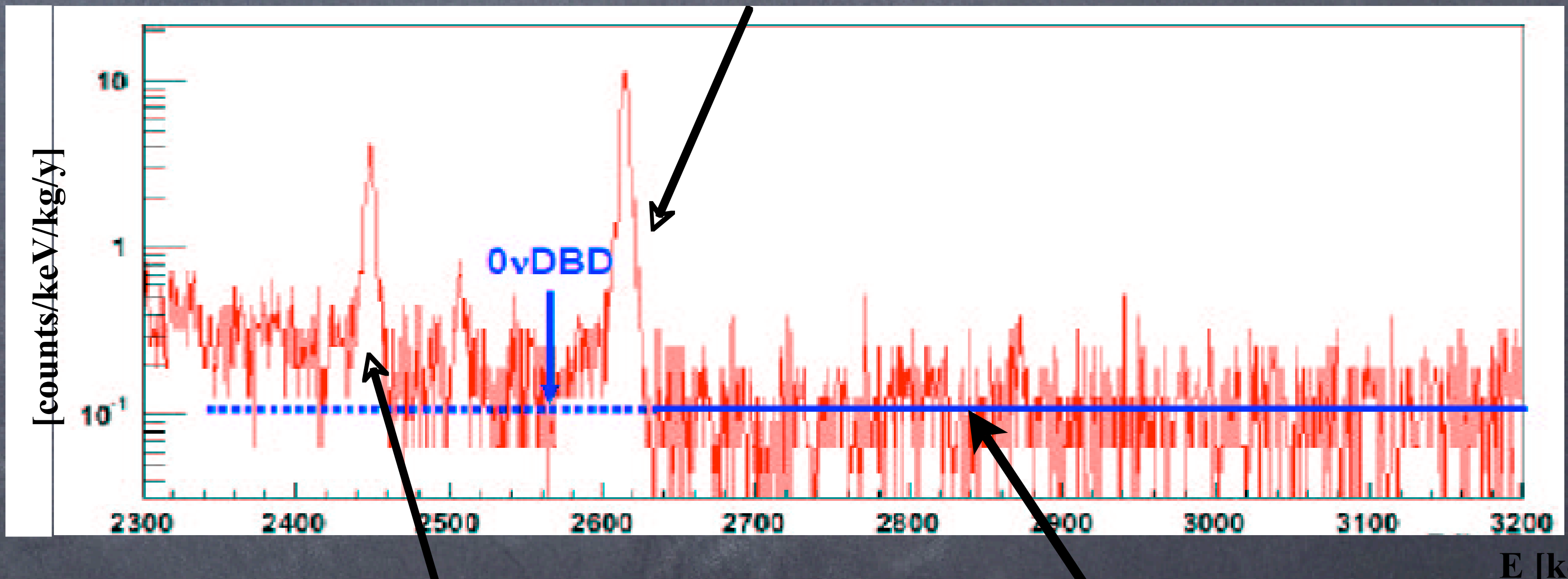
whatever your feeling is, you will agree that the claim need to be scrutinized with more mass and different elements

Cuoricino: Background



2615 keV Tl line: contribution to the DBD bkg due to a Th contamination (multicompton). .

Th (Tl) contribution to DBD background: **~ 40%**



2505 keV line: sum of the 2 ^{60}Co gammas (1173 and 1332 keV)

Most probable source: neutron activation of the Copper

Contribution to DBD background: negligible

Cuoricino

b=0.18 ± 0.02 c/keV/kg/y

Flat background in the energy region above the ^{208}Tl 2615 line

Contribution to the counting rate in the 0νDBD region: ~ 60%

Degraded alpha particles