Results from CUORICINO and Prospects for CUORE

(Cryogenic Underground Observatory for Rare Events)

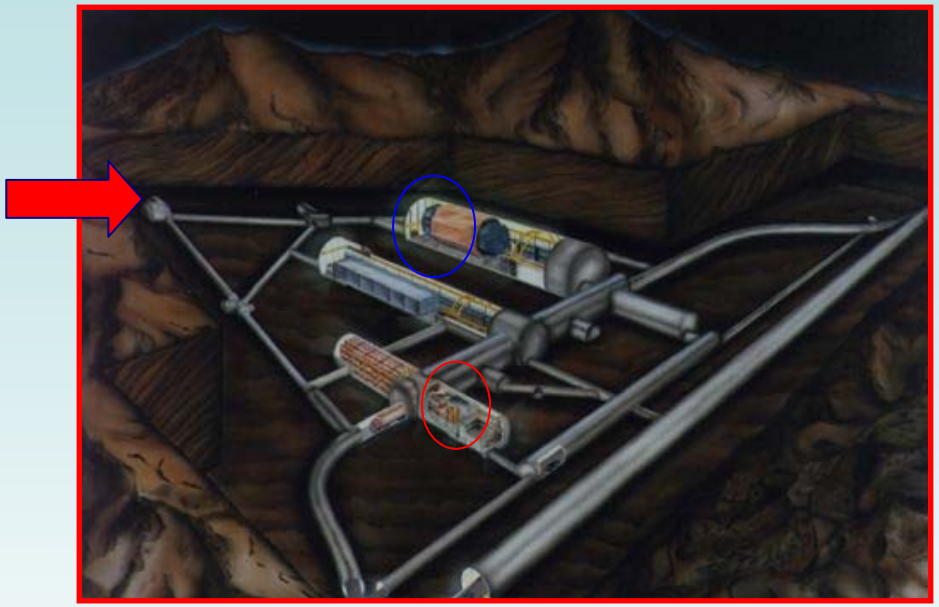
S. Cebrián, on behalf of the **CUORE Collaboration**

Università di Milano-Bicocca (Italy) / Universidad de Zaragoza (Spain)

IDM 2004 Edinburgh (Scotland), 6th-10th September 2004

Presentation

- **CRYOGENIC**: using massive bolometers of TeO_2
- **UNDERGROUND:** working at Laboratori Nazionali del Gran Sasso (Italy) at a depth of 3500 m.w.e.
- **OBSERVATORY for RARE EVENTS:**
  - 2β
  - WIMPs
  - solar axions
  - …



Two dilution refrigerators at LNGS:
Hall A (CUORICINO)
Hall C (R&D final tests for CUORE)

CUORICINO is the first step towards CUORE but also an independent experiment running now

The CUORE Collaboration

•Dipartimento di Fisica dell'Università di Milano-Bicocca e Sezione di Milano dell'INFN, Milano I-20126, Italy

•Dipartimento di Ingegneria Strutturale del Politecnico di Milano, Milano I-20133, Italy

•Department of Physics and Astronomy, University of South Carolina, Columbia S.C. 29208 USA

•Laboratori Nazionali del Gran Sasso, I-67010, Assergi (L'Aquila), Italy

•Dipartimento di Fisica dell' Università di Firenze e Sezione di Firenze dell' INFN, Firenze I-50125, Italy

•Lawrence Berkeley National Laboratory, Berkeley CA 94720, USA

•Laboratorio de Física Nuclear y Altas Energías, Universidad de Zaragoza, 50009 Zaragoza, Spain

•Kamerling Onnes Laboratory, Leiden University, 2300 RAQ Leiden, The Netherlands

•Dipartimento di Scienze Chimiche, Fisiche e Matematiche dell'Università dell'Insubria e Sezione di Milano dell' INFN, Como I-22100, Italy

•Dipartimento di Fisica dell'Università di Genova e Sezione di Genova dell' INFN, Genova I-16146, Italy

•Departmentof Materials Science and Engineering, University of California, Berkeley CA 94720, USA

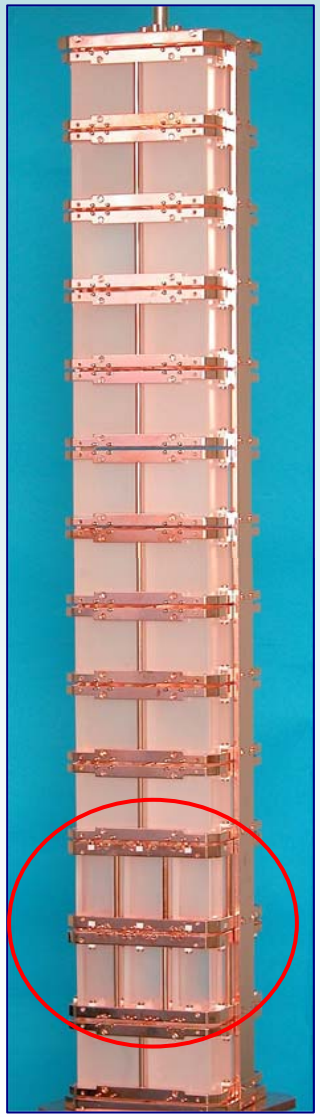
•Laboratori Nazionali di Legnaro, I-35020 Legnaro (Padova), Italy

•Dipartimento di Fisica dell' Universita' di Roma e Sezione di Roma1 dell' INFN, Roma, I-16146, Italy

Results from CUORICINO

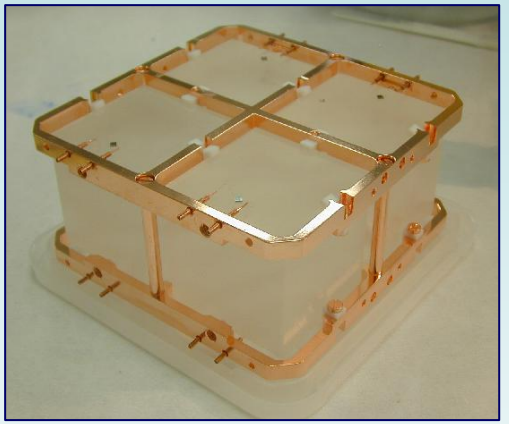
- Detector and set-up
- Performance
- Background analysis
- First results

CUORICINO detector



0.8 m

- 18 TeO_2 crystals 3x3x6 cm^3 + 44 TeO_2 crystals 5x5x5 cm^3
- Read by NTD Ge thermistors



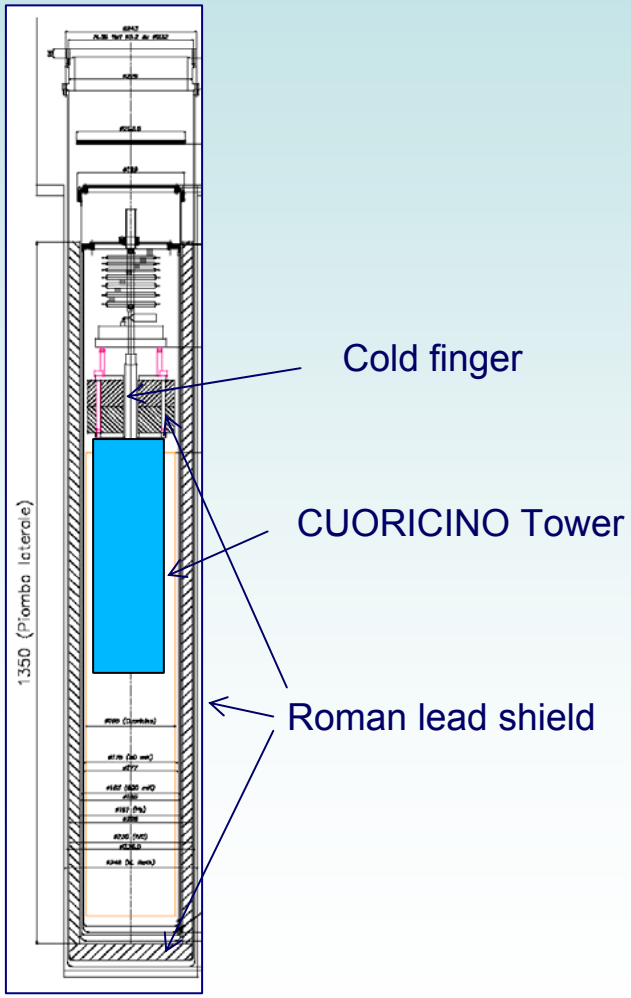
2 modules, 9 detector each,
crystal dimension 3x3x6 cm^3
crystal mass 330 g
2 enriched in ^{130}Te, 2 in ^{128}Te
9 x 2 x 0.33 = 5.94 kg

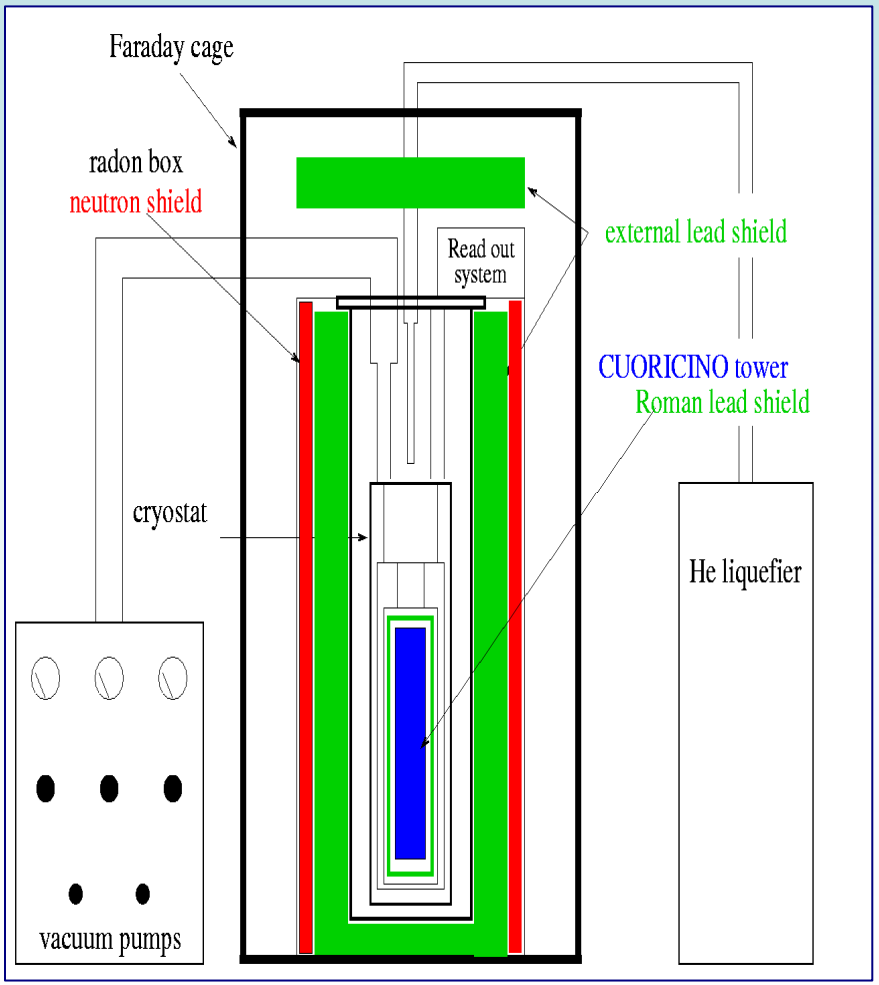
11 modules, 4 detector each,
crystal dimension 5x5x5 cm^3
crystal mass 790 g
4 x 11 x 0.79 = 34.76 kg

CUORICINO TOTAL MASS: **40.7 kg of TeO_2** (14.1 kg ^{130}Te)

CUORICINO set-up

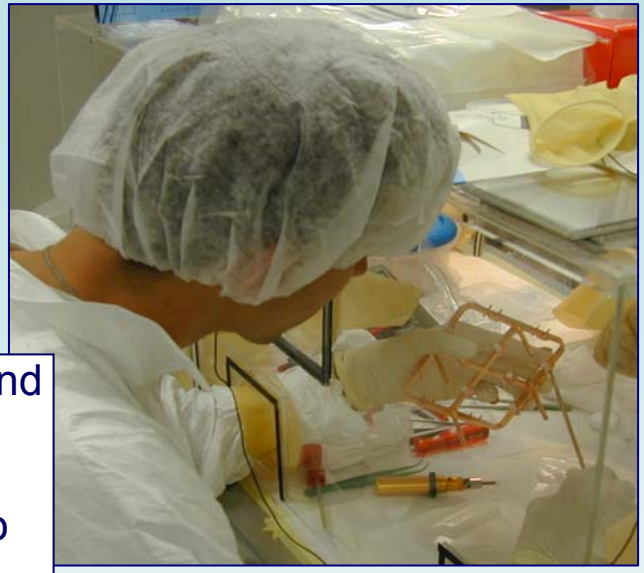
- With the same dilution refrigerator of the Mi-DBD 20-crystal array, operation ~10 mK
- At Hall A of LNGS

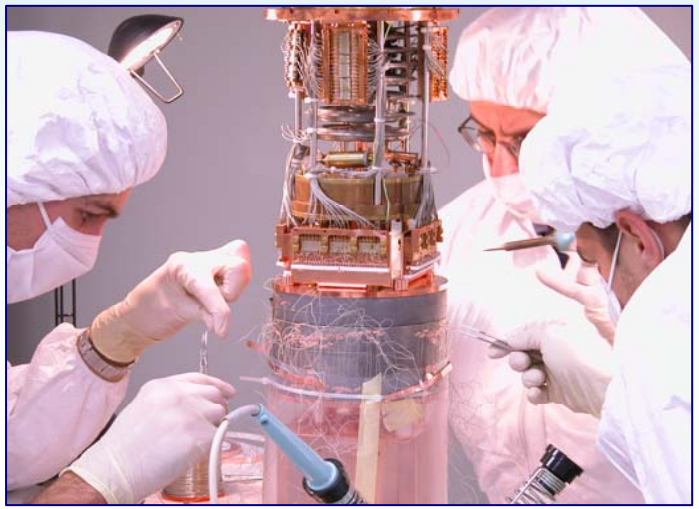




CUORICINO assembly

In clean room and in nitrogen atmosphere to avoid radon contamination





CUORICINO performance

2003
- Wiring system failure during first cool-down: 14 detectors not operative
- Data taking from April to October (with some stops)
- First results for $2\beta|_{0\nu}$ published *C. Arnaboldi et al, Phys. Lett. B 584 (2004) 260*

2004
- Wiring system repaired and maintenance for cryogenics and electronics
- New cool-down in March losing only two electric contacts
- Data taking restarted in May and progressing

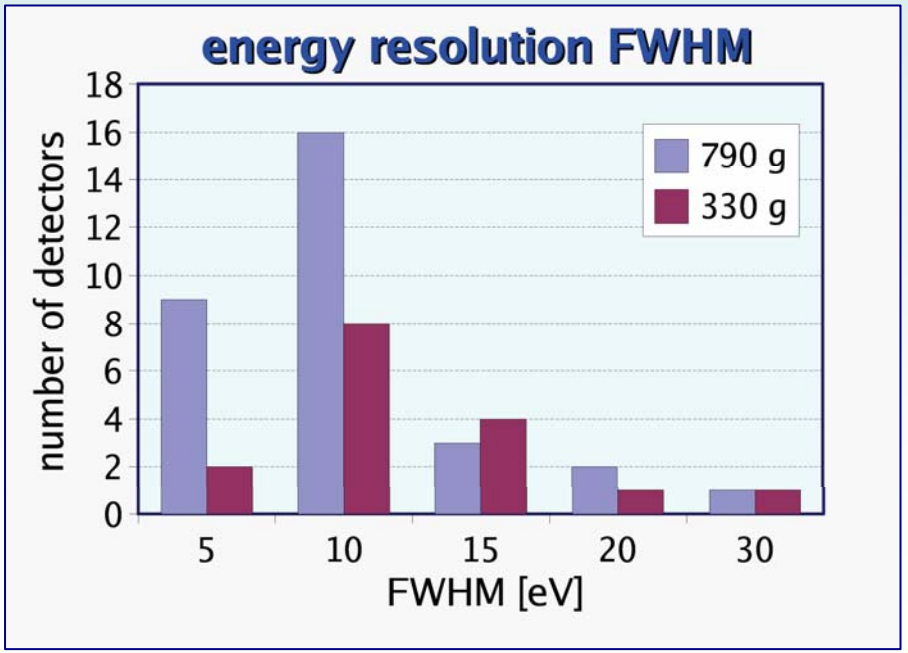
- **Energy resolution**

@ 2615 keV:

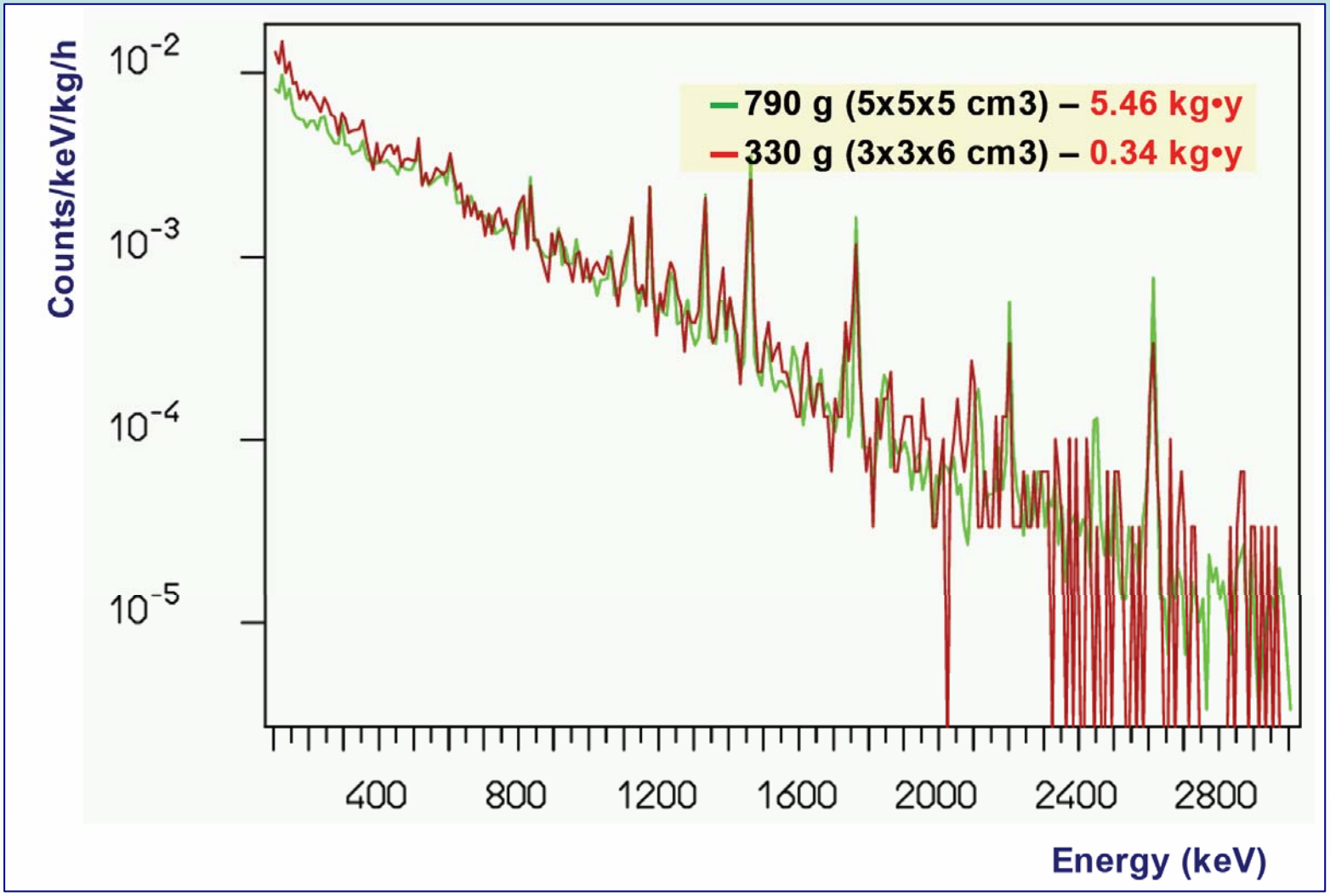
<Γ> ~ 7 keV for big crystals
<Γ> ~ 9 keV for small crystals

@ 122 keV:

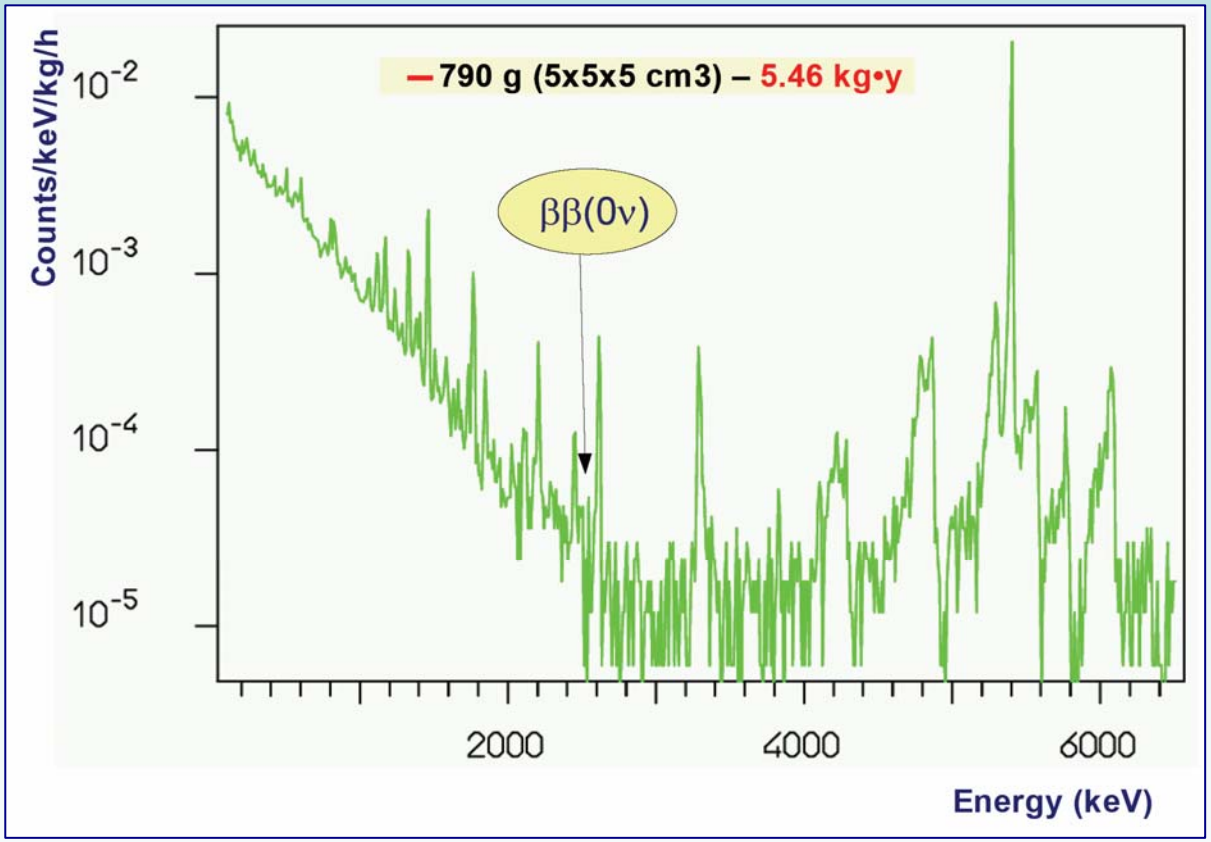
<Γ> ~ 2.8 keV for big crystals
<Γ> ~ 1.5 keV for small crystals



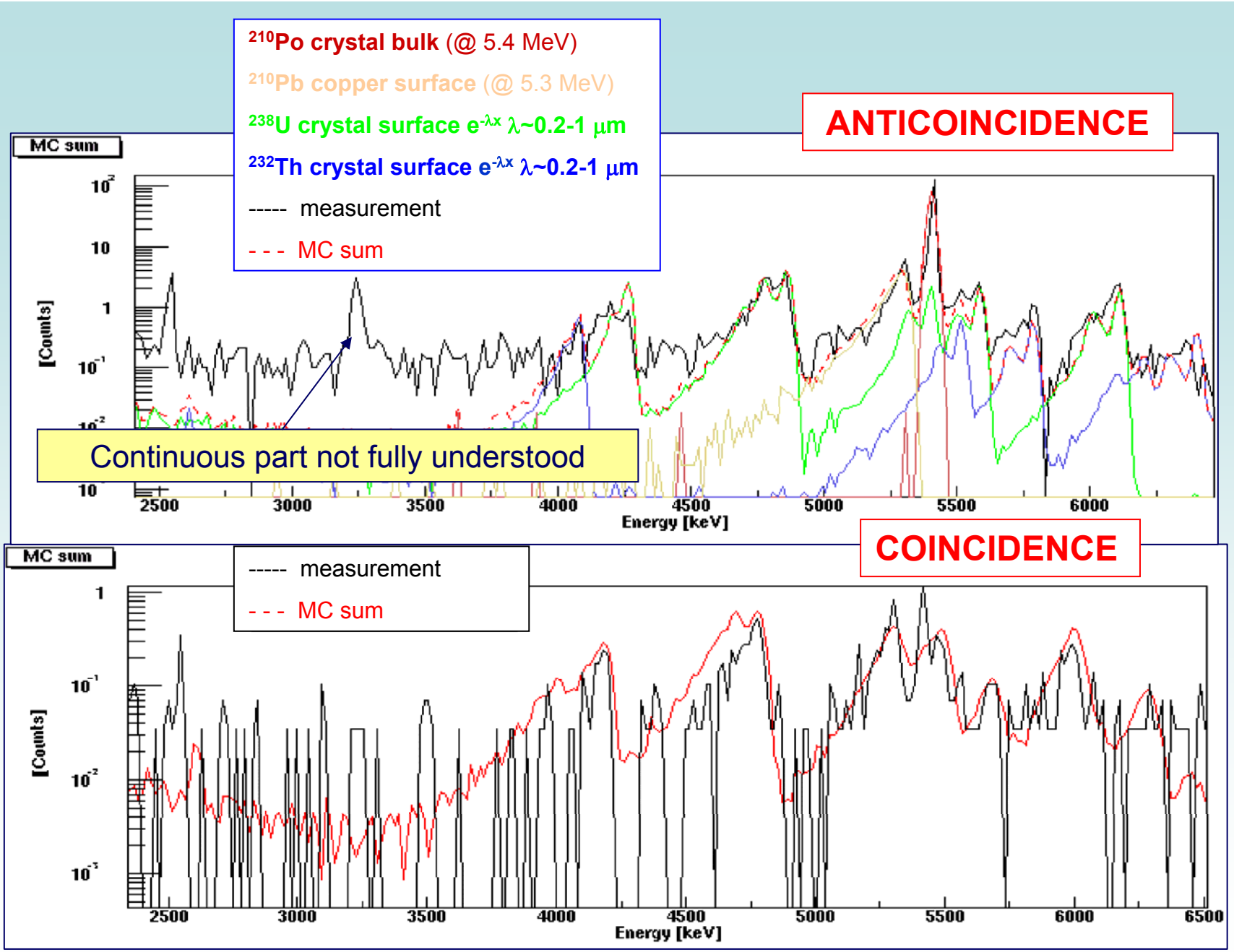
Background measurement: γ region



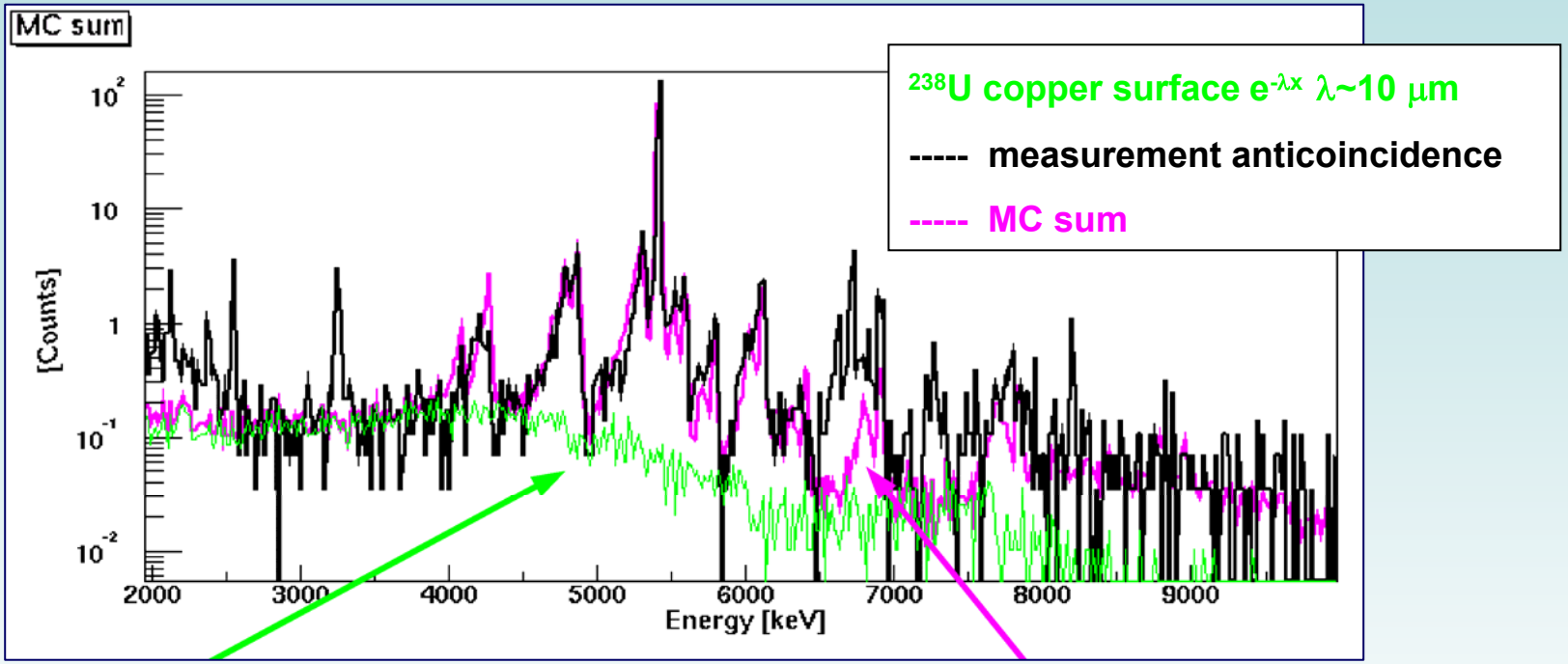
Background measurement: α region



Source	^{208}Tl	$\beta\beta(0\nu)$ region	3-4 MeV region
TeO_2 ^{238}U and ^{232}Th surface contamination	-	20± 15%	20± 10%
Cu ^{238}U and ^{232}Th surface contamination	~15%	50± 20%	80± 10%
^{232}Th contamination of cryostat Cu shields	~85%	30± 10%	-


^{210}Po crystal bulk (@ 5.4 MeV)
^{210}Pb copper surface (@ 5.3 MeV)
^{238}U crystal surface $e^{-\lambda x}$ λ~0.2-1 μm
^{232}Th crystal surface $e^{-\lambda x}$ λ~0.2-1 μm
----- measurement
- - - MC sum
ANTICOINCIDENCE
MC sum
[Counts]
Energy [keV]
Continuous part not fully understood
COINCIDENCE
MC sum
----- measurement
- - - MC sum
[Counts]
Energy [keV]

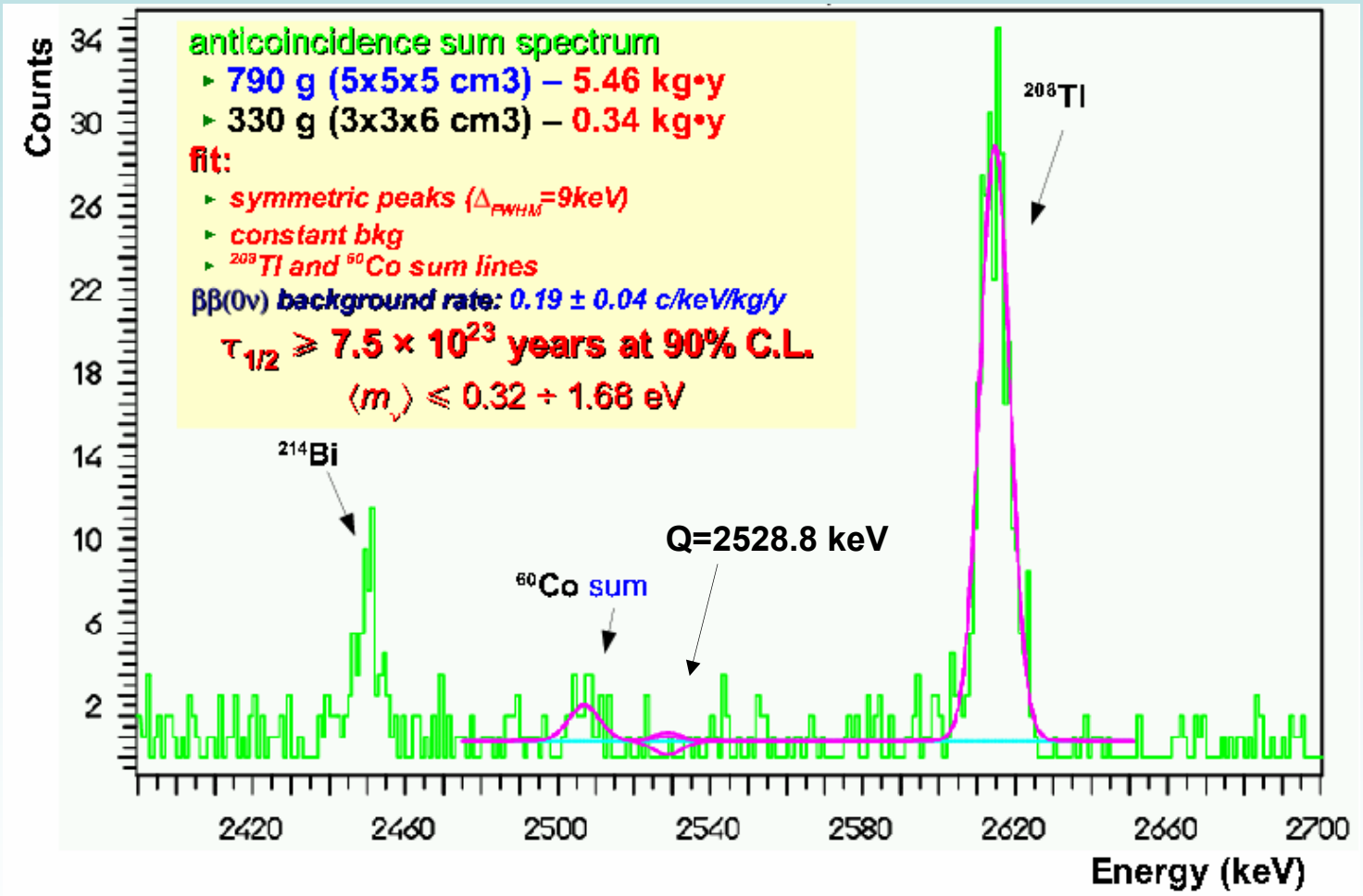
Surface contamination on the copper holders added:



CUORICINO **background in α region** reproduced assumming surface contaminations on crystals and mounting copper structures:

- Exponential density profile: exp(-λx) with λ~0.1-10 μm
- Contamination levels ~10^{-9} g/g (2-3 order of magnitude greater than in bulk)

Present results for $2\beta|_{0\nu}$ of ^{130}Te



CUORICINO sensitivity (1σ) in 3 years: $T_{1/2} \geq 6\ 10^{24}$ y, $\langle m_\nu \rangle \leq 0.11\text{-}0.60$ eV

Prospects for CUORE

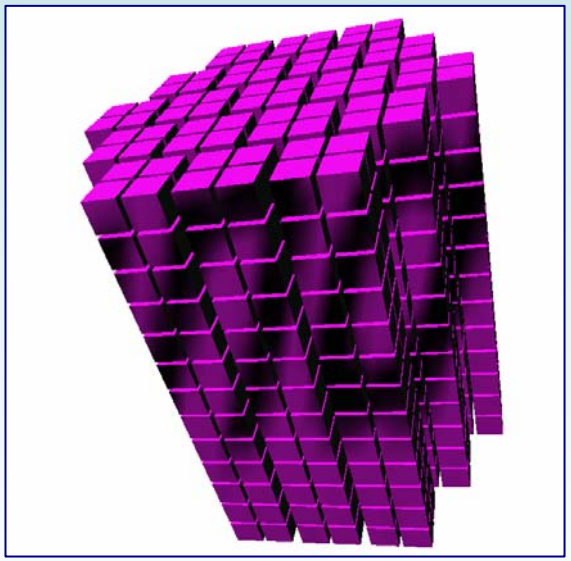
- Detector and set-up
- R&D
- Sensitivity

CUORE Proposal, http://crio.mib.infn.it/wig/

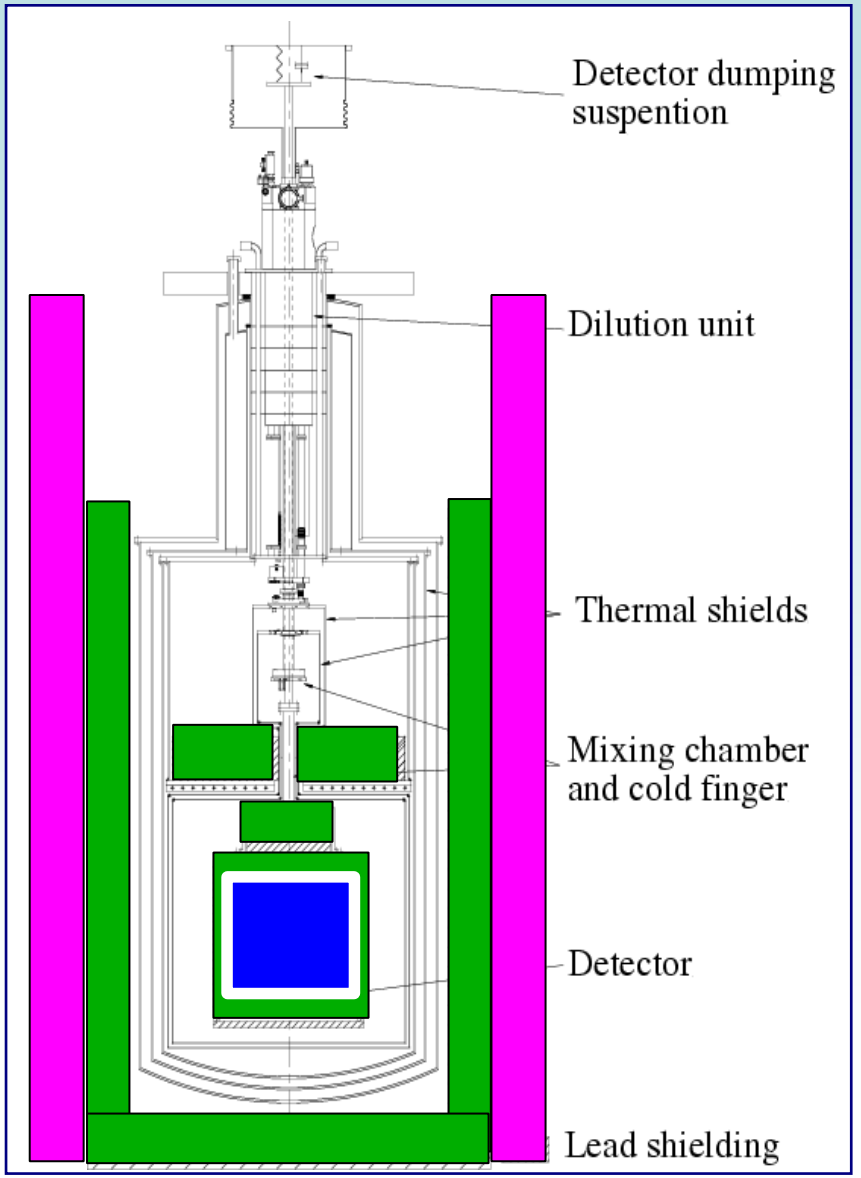
CUORE detector and set-up

- A single high granularity detector: an array of 19 towers, each tower having 13 modules with 4 5x5x5 cm^3 crystals

988 crystals, 740 kg TeO_2, 200 kg ^{130}Te



- **$^3He/^4He$ dilution refrigerator** T~10 mK
- **Shield:** roman lead + low activity lead + borated polytehylene



CUORE R&D

➢ **Direct measurement** of surface contamination on copper holders at Gran Sasso/Ispra:

dissolve different superficial layers of copper in ultra pure acid: time of acid attack ↔ Cu thickness removed

analyze the solutions taken at different times with ICPMS

Inductively Coupled Plasma Mass Spectroscopy
(sensitivity ~ 10^{-12} g/g **)**

determine the U/Th contamination as a function of depth

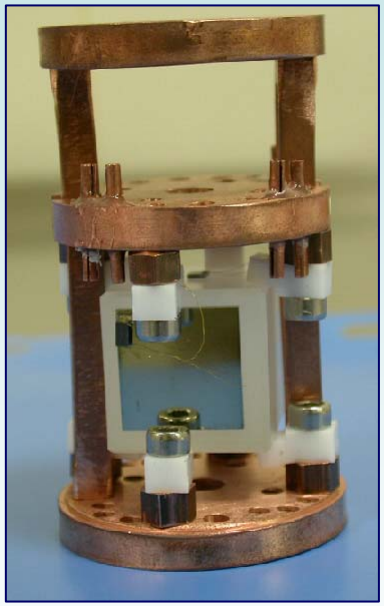
$$f(x) = A \exp(-x/\lambda)$$

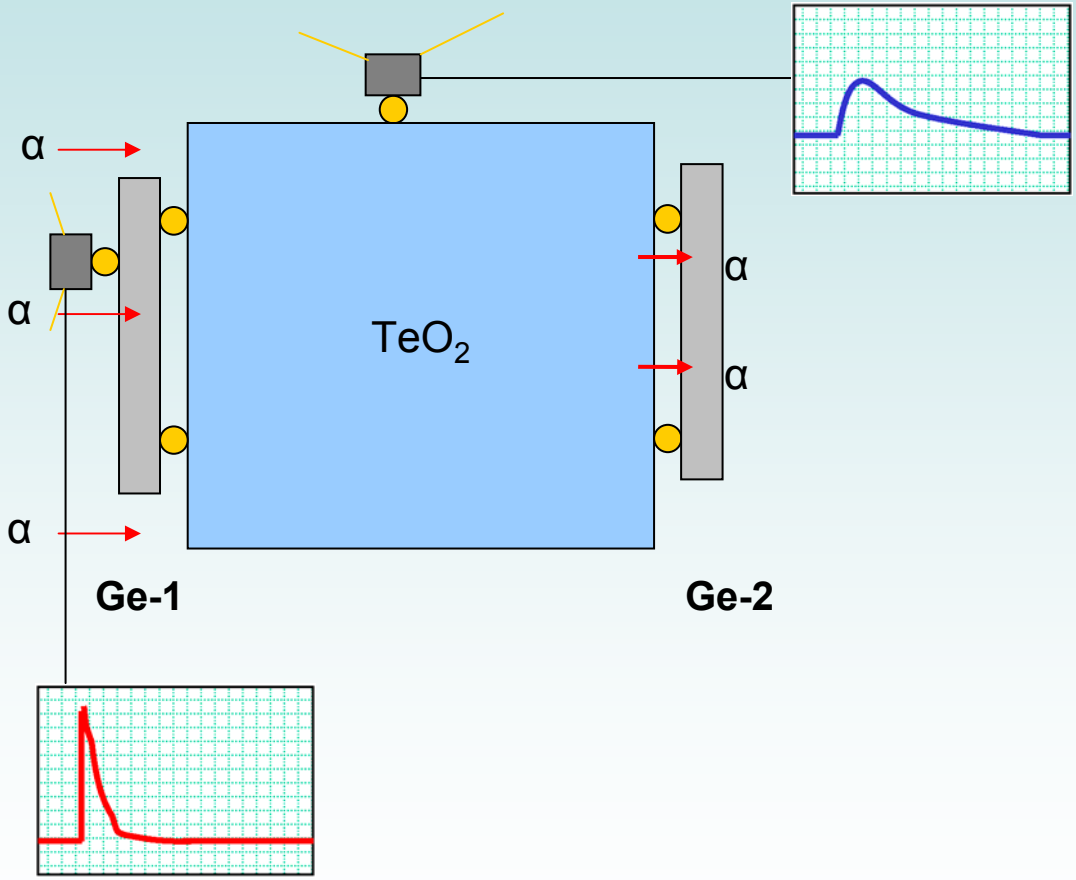
preliminary result of a measurement on a sample of the CUORICINO copper **in agreement with MC estimate** for both contamination level and density profile

➢ **Bolometric measurement** underway to study surface contaminations:

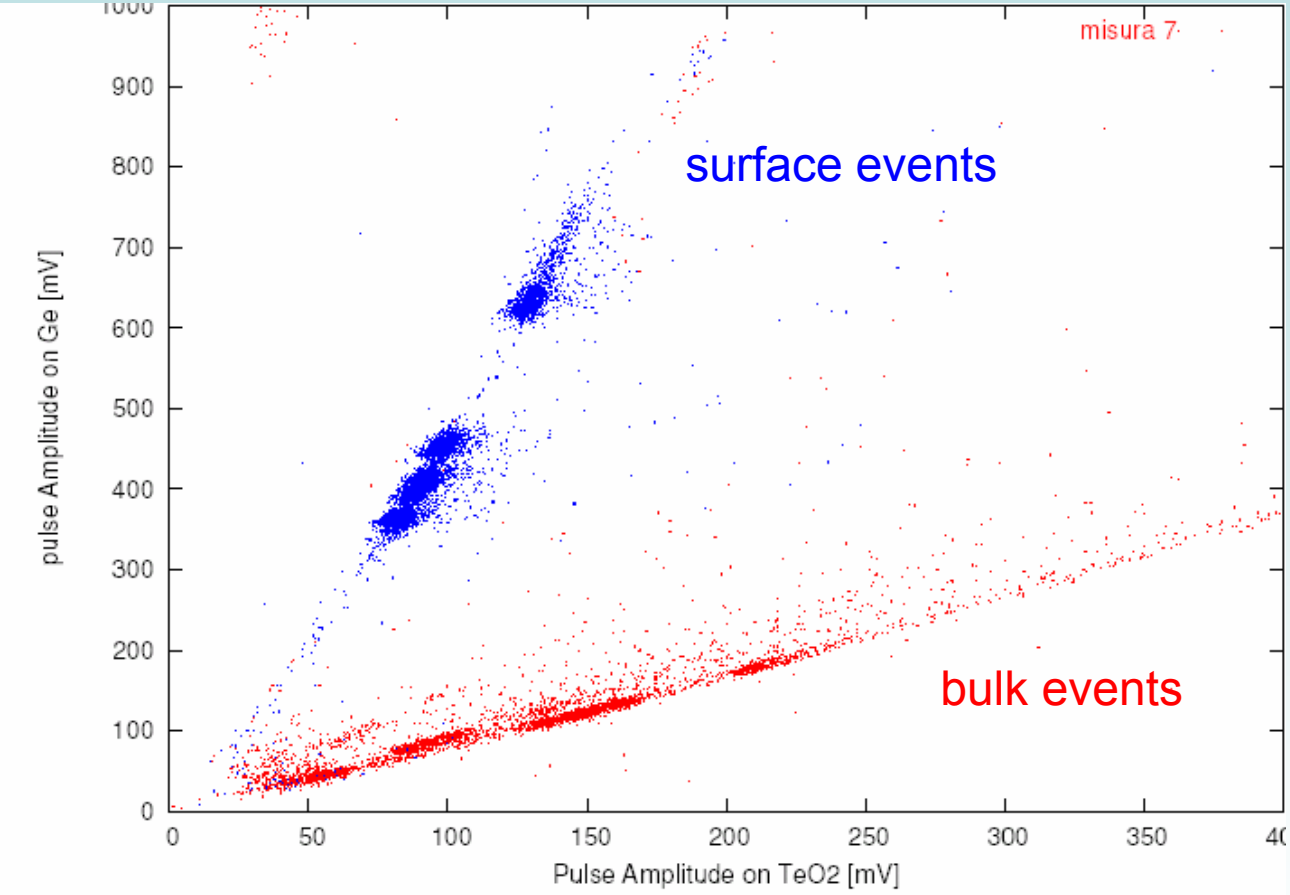
- At Hall C in LNGS with 8 5 x 5 x 5 cm^3 TeO_2 crystals
- Check for surface treatments on crystals and copper holders

- **Active rejection of surface contaminations**:
  - Proved and under investigation at the University of Insubria in Como
  - Composite bolometer: TeO_2 crystal + thin Ge/Si crystal read by two thermistors





• Plotting Ge versus TeO_2 pulse amplitudes allows to separate events from bulk and surface



The first results prove the potential of this technique

CUORE sensitivity

➢ **Background predictions:** see details at CUORE Proposal http://crio.mib.infn.it/wig/

✓ Based on **MC simulations and data** from CUORICINO

✓ Contribution from **bulk and surface** radioactive contaminations:

• Values for bulk impurities are limits from CUORICINO data and Ge measurements

• A reduction of a factor ~20 assumed for surface contaminations respect to CUORICINO

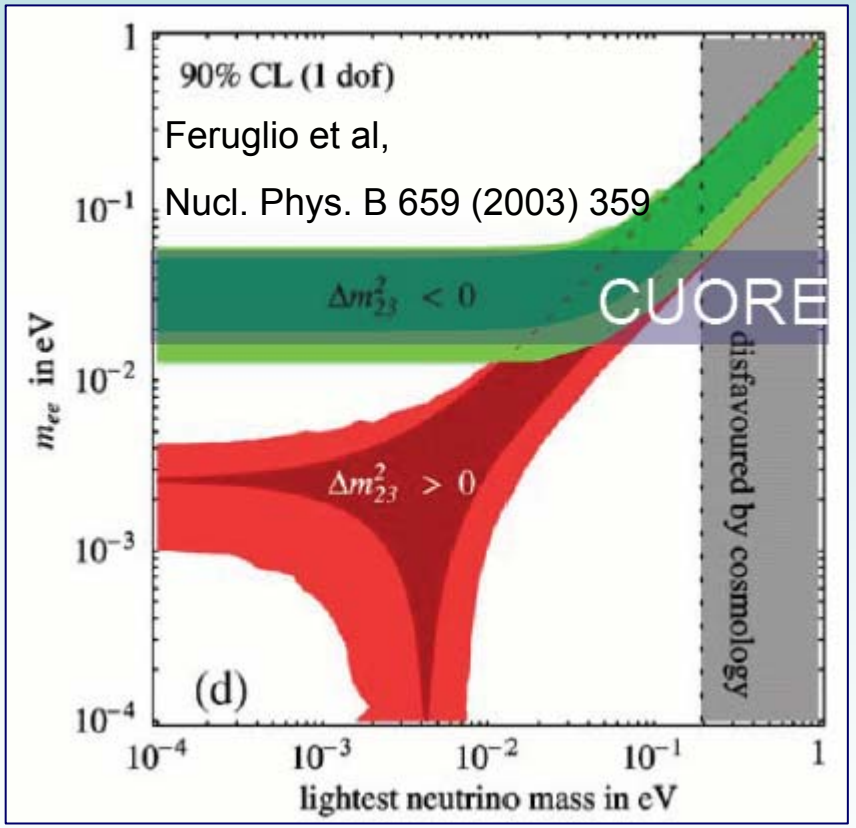
	bulk	surface
$2\beta\|_{0\nu}$ region (counts/keV/kg/y)	**3.8×10^{-3}**	**2.8×10^{-3}**
dark matter region (counts/keV/kg d)	**2.4×10^{-2}**	**1.2×10^{-3}**

✓ Contribution from **other sources**: environmental radioactivity, cosmogenics, $2\beta|_{2\nu}$ much less important at the present level of sensitivity

➢ **Sensitivity for $2\beta|_{0\nu}$ of ^{130}Te:** for T=5 y

$$T_{1/2}^{0\nu} \propto \varepsilon \frac{a}{A}\sqrt{\frac{MT}{\Gamma b}}$$

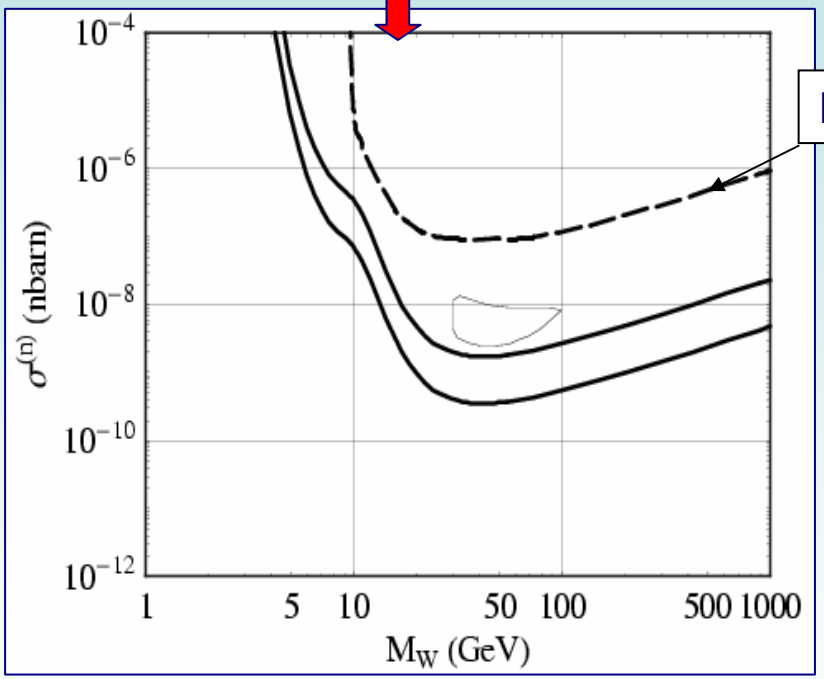
b (c/keV/kg/y)	Γ (keV)	$T_{1/2}$ (y)	$\langle m_\nu \rangle$ (meV)
0.01	10	**$1.5\ 10^{26}$**	**23-118**
0.01	5	**$2.1\ 10^{26}$**	**19-100**
0.001	10	**$4.6\ 10^{26}$**	**13-67**
0.001	5	**$6.5\ 10^{26}$**	**11-57**



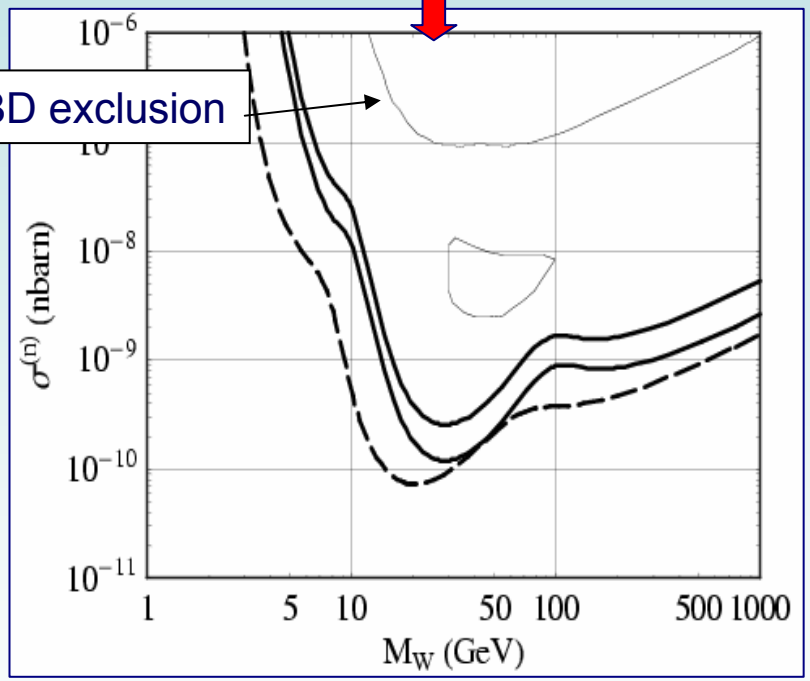
➢ **Sensitivity for WIMPs:**

exclusion plots for scalar Spin Independent Interactions

sensitivity plots for the **annual modulation** effect (regions of WIMPs which produce a 90% CL positive signal with a 50% probability)



MiDBD exclusion

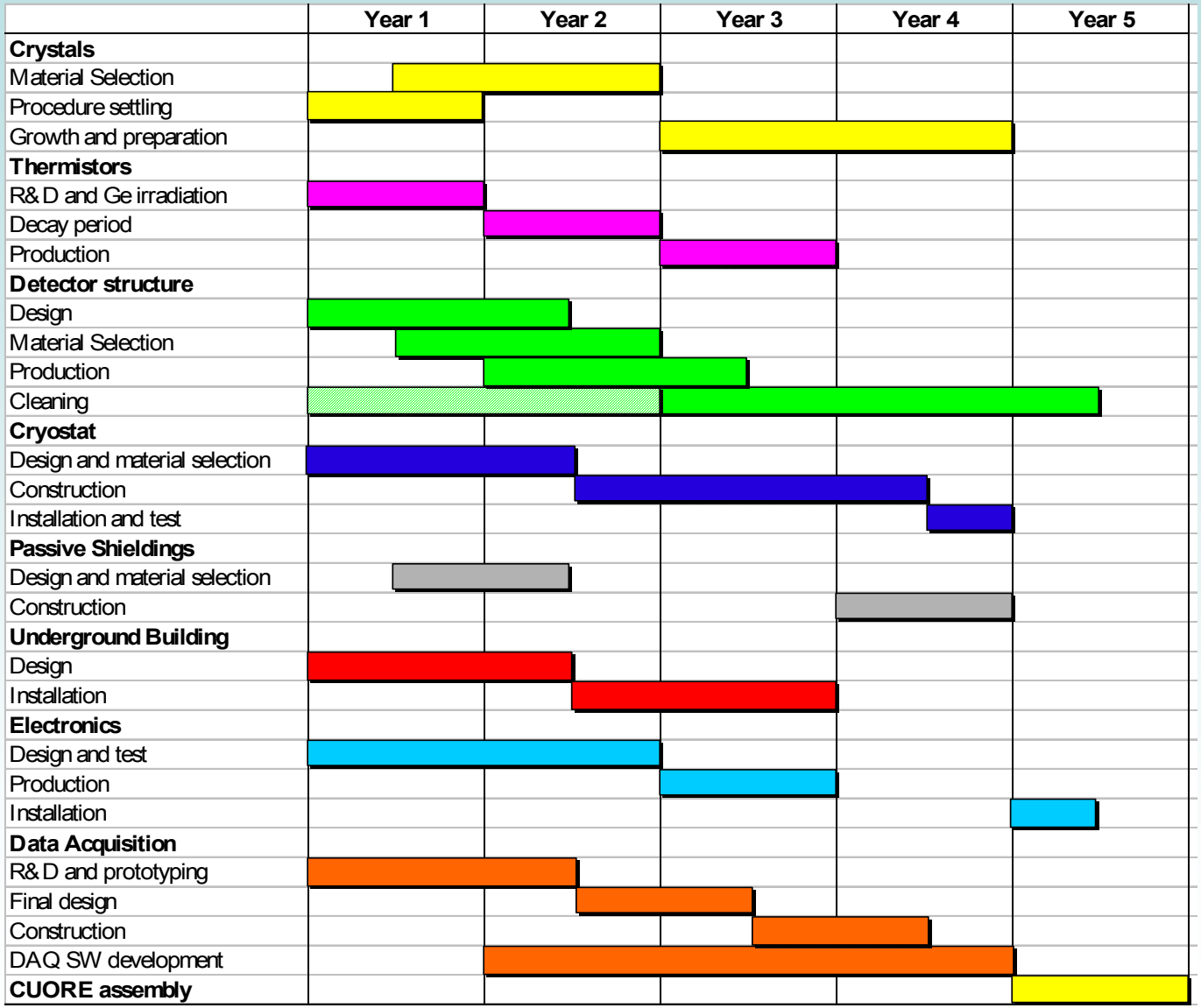


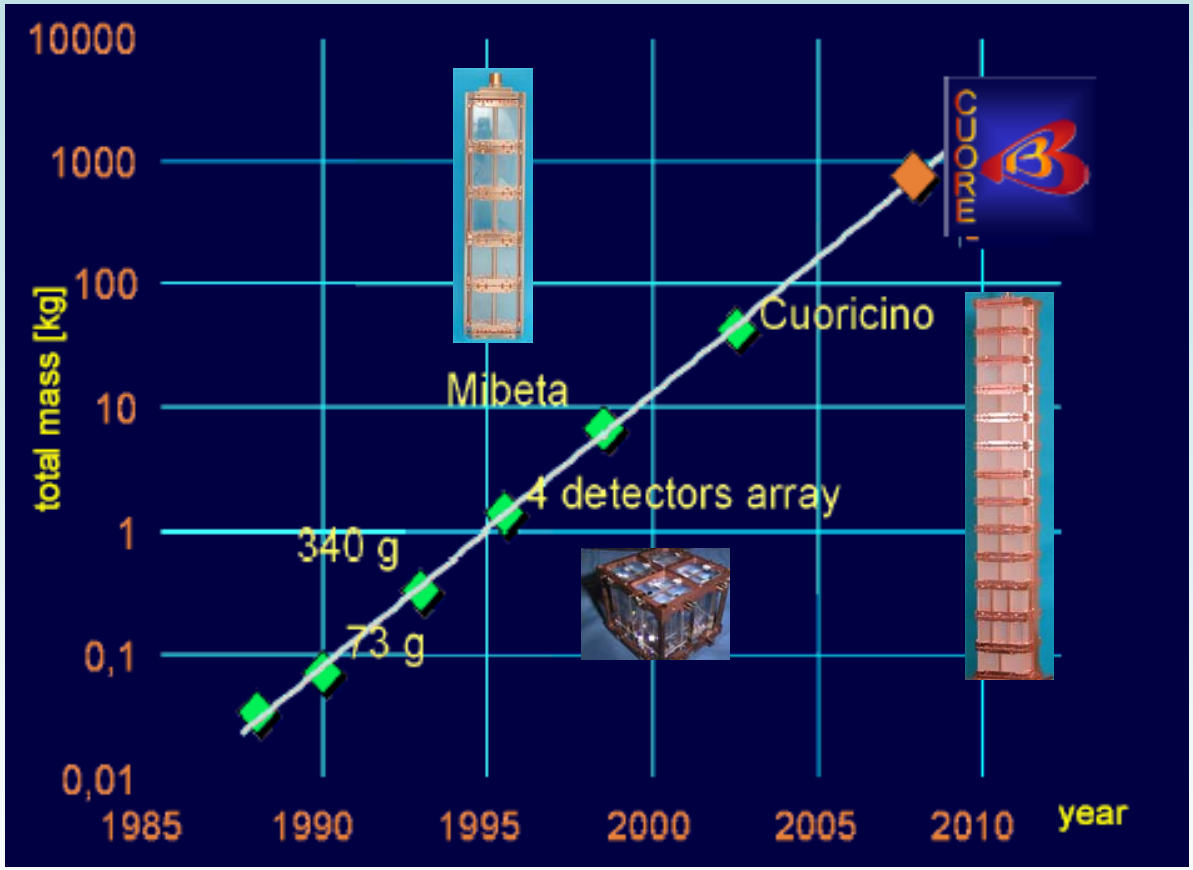
Ethr =10 keV, T = 1 year, B = 0.05, 0.01 c/(keV kg d), FWHM =1 keV

Ethr = 10, 5 keV, T = 2 years, B = 0.05, 0.01 c/(keV kg d), FWHM =1 keV

➢ Searches for other rare events are also envisaged (see *C. Arnaboldi et al, Astrop. Phys. 20 (2003) 91*)

CUORE Time Schedule




10000
1000
100
10
1
0,1
0,01
total mass [kg]
1985
1990
1995
2000
2005
2010
year
Mibeta
Cuoricino
4 detectors array
340 g
73 g
CUORE

Summary

- **CUORICINO** is being operated successfully at Gran Sasso
  - *As an independent experiment:* first CUORICINO results (90% CL) with data taken in 2003:

$$T_{1/2}^{0\nu}(^{130}\mathrm{Te}) \geq 7.5 \times 10^{23}\ \mathrm{y}$$

$$\langle m_\nu \rangle \leq 0.32 - 1.68\ \mathrm{eV}$$

  - *As a first step towards CUORE*: background analysis and technical performance results are essential to prepare CUORE

- **CUORE R&D** is going on, with special attention to the **surface contamination** problem

- **CUORE** will be a next generation DBD experiment able to explore **neutrino masses of some tens of meV** having a good sensitivity for other rare event searches like the **detection of WIMPs**