FUTURE PROJECTS ON DARK MATTER DIRECT DETECTION

Angel Morales
University of Zaragoza

8th International Symposium on Neutrino Telescopes
Venice, February 22-26, 1999

FUTURE PROJECTS ON DARK MATTER DIRECT DETECTION

⇒ Purpose of the talk:

- To overview the developments and prospects in the detection of WIMPs through their interaction with nuclei.

⇒ Plan of the talk:

Basic strategies followed in the search for WIMPs
Main achievements accomplished
Outlook to future projects and techniques
The case for CUORE

FEATURES OF THE EXPECTED WIMP SIGNALS

◊ WIMPS (m~GeV-TeV) scatter off target nuclei producing nuclear recoils of T~1-100 keV. Only a fraction of this energy is visible in the detector E_v=QT ⇒ **Size of WIMP signal is small (keVs range)**

◊ The small interaction cross-section makes WIMP rates **very small (R<1—10^{-3} c/kg day)**.

The rate depends on many variables, not very well known.

- the halo model
- the WIMP (type of interaction, cross sections)…
- the nuclear target (nuclear mass and spin, form factors).
- the detector (energy threshold, energy resolution, quenching factor).

The wide choice of parameters entering the various levels of the WIMP-nucleus interaction make the predicted rate encompass various orders of magnitude (depicted in scatter plots), a fact which does not facilitate the planning of an experiment.

◊ The **small signal rate** is expected in a region **(low energy)** which is dominated by a large background accumulated from the continuum of all sources of radioactivity which deposit energy in the region but at a faster rate, ⇒ **small signal to noise ratio**

STRATEGIES FOR WIMP DETECTION

The **rarity and smallness** of the WIMP signal dictate the detection strategies.

⇒**Reduce the background** by **improving the radiopurity** of the detector, components and shielding.

⇒Use **discrimination mechanisms** to distinguish electron recoils (tracers of the background) from nuclear recoils (originated by WIMPs or neutrons).

- through statistical pulse shape analysis (PSD).
- identifying nuclear recoils by measuring at the same time ionization and heat or scintillation and heat (cryogenic hybrid detectors).
- other methods (range, S_2/S_1 scintillator pulses in LqXe ...)

The implementation of particle identification has been one of the main recent achievements in DM searches.

⇒ Make detectors of **low energy threshold and large quenching factor** to see most of the signal spectrum, not just the tail. (Bolometers) E. Fiorini & T. Niinikoski NIM. 224 (84) 83

⇒ Improve energy resolution

⇒ **Look for distinctive signatures to prove that you are seeing a WIMP** (for instance annual modulation with large mass of detector). Or to reduce the BKG in the case of non-appear

⇒ Select detectors with **favourable** nuclear targets

In the following we briefly overview how the new detectors' developments and projects are addressing these strategies.

WHERE WE STAND, WHERE WE GO

Future detectors are designed to improve the current performances in background, threshold and efficiency, as well as in sensitivity to distinctive signals.

1. Achievements and prospects in background reduction.

- Radiopurity selection

Ultralow background techniques and a thorough selection of materials of the highest radiopurity have provided very low background levels in the raw spectra in the 5-50 keV region.

Examples **B~0.05~0.2 c/keV kg day** in Ge detectors (PNL/USC/UZ; H/M; HDMS)
B~1 to 3 c/keV kg day in NaI scintillators (BPRS, UKDMC, DAMA)
B ≃ 2 c/KeV Kg day. MIBETA TeO_2 bolometers. (between 15-40 KeV, in one particular detector of the 20-array, run of ~500 hours)

-Statistical discrimination through Pulse Shape Analysis (PSD)

The timing behaviour of the pulses recorded for a data population is compared with that of templates produced by external gamma and neutron sources. It turns out that the data and gamma background behaviour are essentially identical, whereas nuclear recoils have on the average a shorter time constant. The **shorter decay times of nuclear recoils, allow to statistically separate them from electron recoils.**

When applied to NaI experiments, the fraction of data which might be due to nuclear recoils (and so to neutrons and WIMPs) results to be less than **10% to 1%** (DAMA), **10% to 3%** (UKDMC), or **30% to 12%** (Saclay), depending on the energy. The background is, then, substantially reduced from its measured level of 1 to 3 c/keV kg day **down to a few percent /keV kg day**.

⇒ One order of magnitude (and more) improvement in sensitivity

The σ(m) exclusion plots from NaI spectra pulse-shape analyzed have surpassed that obtained from (bare) Ge spectra.

Caution: stability of the pulse is essential

- Simultaneous measure of ionization and heat.

The energy released by the recoiling nucleus impinged by the WIMP (or the recoiling electron impinged by a particle) appears in form of phonons and electron-hole pairs.

Simultaneous measurement of both quantities for **each event** allows the discrimination of electron recoil events (tracers of the background) from nuclear recoil events (WIMP signal plus neutrons) because for a given deposited energy—measured as phonons—**the ionization produced by the recoiling nucleus is less than that generated by electrons** (CDMS, EDELWEISS).

Examples: **B≈0.1~0.3 c/keV kg day (above 15-20 keV) nuclear recoil background out of a measured background of 2~4 c/keV kg day** after phonon-ionization discrimination (>99%) in hybrid Ge, Si detectors (CDMS)
Similarly B~0.6 c/keV kg day (above 12 keV) in Ge hybrid detectors (EDELWEISS)

CDMS Goal: Stanford B~0.01 c/keV kg day
Soudan B~a few$\times 10^{-4}$ c/keV kg day

EDELWEISS-II: Goal B~10^{-4} c/keV kg day

- **Other discrimination techniques**

◊ **Measuring the range**. The difference in ranges between nuclear and electron recoils discriminates signal from background (CASPAR detector, UKDMC).

◊ The **ratio between the primary, direct scintillation pulse** in liquid Xenon **and a second proportional scintillation pulse** obtained by drifting the ionization is different for electron and nuclear recoils. $\left(S_2/S_1\right)_{elec} > \left(S_2/S_1\right)_{nucl}$

Proof-of-Principle: 2 kg ICARUS-like liquid Xe prototype (CERN-UCLA).

Future: ZEPLIN Program, large LqXe detector at Boulby (UKDM-UCLA-CERN-Torino-ITEP).

◊ In Superconducting Superheated Grains (SSG) a **single grain is expected to flip per WIMP** (or nucleon) interaction in contrast to several grains in the case of radioactivity background sources (background rejection estimated to be better than 97%) (PASS, ORPHEUS, SALOPARD detectors).

WHY BOLOMETERS

N. BOOTH, B. CABRERA, E. FIORINI
Ann. Rev. of Nucl. Sci. 46 (1996) 471

In the WIMP scattering on matter, only a small fraction of the energy delivered by the WIMP goes to ionization, the main part being released as heat. Consequently, thermal detectors (quenching factor close to one) should be suitable devices for dark matter and other rare event searches.

Bolometers measure the increase of temperature produced by the recoiling nucleus hit by a WIMP. The temperature pulse is detected with a sensor in thermal contact with the absorber.

An appealing feature of these detectors is that their energy resolution should be a priori much better than that of conventional detectors, as the energy deposition mechanism is made in terms of phonons (10^{-4}–10^{-6} eV). The energy resolution achieved is damped by several effects, but in the keV region, resolutions of the order of 100 to 300 eV have been achieved even for large mass crystals.

2. Achievements in detector performances:

◊ Energy thresholds:

Conventional detectors:
Visible energy (corresponding to an effective nuclear recoil energy $T=E_v/Q$)

- 1. 5 to 2 keV in Ge detectors (Canfranc, Gothard, HDMS)
- 2 to 4 keV in NaI scintillators (DAMA, UKDMC)

Low Temperature detectors
Effective recoil energy (quenching factor Q~1)

- 0.3 to 0.5 keV in small (30g) Al_2O_3 bolometers (CRESST, ROSEBUD)

- 0.5 keV in Al_2O_3 large (260g) bolometers (CRESST)

- 2 keV (phonon and ionization channels), 165 g Ge BLIP cryogenic hybrid detector (CDMS)

- 4 keV (phonon and ionizatin channels), 70 g Ge cryogenic hybrid detector (EDELWEISS)

- ~5–10 keV in very large (340g, 760g) TeO_2 bolometers (MIBETA) → 2-8 keV, in the 20-array, depending on the crystal.

◊ **Energy resolution**
Some examples:

COSME:	Γ=0.5 keV at 10 keV (240g Ge)
DAMA:	Γ=2 keV at 10-50 keV (9.7 kg NaI)
● CRESST:	Γ=133 eV at 1.5 keV (for 262 g Al_2O_3) (0.1 keV for 31g Al_2O_3)
ROSEBUD:	Γ=0.12 keV at 1.5 keV (25 g Al_2O_3)
BLIP:	Γ=0.5 keV thermal; Γ=1.5 keV ionization (at threshold 15 keV) (62 g Ge)
BLIP:	Γ=1 keV both thermal and ionization (165 g Ge)
FLIP:	Γ=7 keV thermal; Γ=2 keV ionization (100 g Si)
EDELWEISS:	Γ=1.25 keV both thermal and ionization (70 g Ge) at 122 keV
MIBETA:	Γ=10 keV at 2500 keV, Γ=2keV at 10–50 keV (4×340 g TeO_2)

Prototypes, forthcoming detectors, and future projects

A sample of some DM detector projects or prototypes follows.

1.- Conventional Detectors

⇒*NaI scintillators*:

- **ANAIS** (Zaragoza/Canfranc)
  107 kg (10×10.7 kg crystals) Low activity PM and light guide. Cooled by Peltier devices. Electroformed copper and archaeological lead shielding. Active veto and neutron shielding. Acquisition for Pulse Shape Analysis, E_{thr}~2 keV
  To start in winter 1999
- **NAIAD** (UKDMC, Boulby)
  50-100 kg crystals under construction.
  NaI unencapsulated to avoid surface problems and improve light collection. Pulse Shape Analysis. Cooled down to 10°C±0.1°C

⇒*LqXe scintillators*:

- **DAMA** (Roma - IHEP Beijing, Gran Sasso)
  2 ℓ LqXe detector (99.5% 129Xe).
- **ZEPLIN I** (UKDMC, Boulby)
  4 kg LqXe. Pulse Shape Discrimination. Ionization allowed to promptly recombine adding to the scintillation light and giving differences in scintillation pulse shape.
  Ready to run.
- **ZEPLIN II** (UKDMC/UCLA/CERN/Torino/ITEP)
  10-20 kg two phase liquid-gas Xe detector with ionization plus scintillation. Discrimination achieved through ratio of secondary to primary scintillation pulses. Prototype tested. UCLA/CERN
  First step of the project in 2001

⇒*CaF_2 Scintillators*

- **ELEGANTS VI** (Osaka, Otho)
  25 modules of CaF_2 (Eu) cubic crystals (0.45 cm side), total 3.5 kg of ^{19}F.
  4π scintillator active field. Now running.
  Goal: $\sigma^m(SD) \sim 10^{-4}$ nb for WIMPs of m=10-50 GeV.
- **DAMA** (Roma - IHEP Beijing, Gran Sasso)
  New 3″ ∅×1″ length CaF_2 (Eu) crystal selected for high radiopurity. Low activity PM and light guide. NaI shield for anticompton.
- **CASPAR** (UKDMC, Boulby)
  Grains of scintillating CaF_2 (Eu) suspended in an organic liquid scintillator. 98% discrimination nuclear/electron recoils through differences in recoil range: electrons recoils (originated anywhere) will pass through both materials giving combined scintillation pulse (two decay components fast and slow). Nuclear recoils (of same energy of e-recoils) originate and remain in the grain -shorter recoil range-giving one slow pulse. 120 g of CaF_2. Grains ∅ ~0.3 μm.
  $E_{thr} \sim 4$ keV, B~2 c/keV kg y

⇒*Ge detectors*

- **GEDEON** (MOZA Collaboration, Canfranc)
  Phase I: 28 natural abundance Ge detectors (860 g each) in one single common electroformed copper thin cryostat (∅ 20 cm× 32 cm long). IGEX technology. E_{th}~2 keV,Γ~1 keV.
  Archaeological lead shielding. Pure graphite neutron shielding.
  MC estimate B<10^{-2} to 5×10^{-3} c/kev kg d at 2-50 keV. Study design in course.
  Phase II: Four cryostates. 112 detectors. Total mass: 92 kg of Ge.

- **HDMS** (Heidelberg, Gran Sasso)
  200 g Ge detector within well-type large (2 kg) Ge crystal for shielding and anticoincidence. (BKG suppression factor 10-20). Goal: B~0.01 c/keV kg day (<50 keV).

- **GENIUS** (Heidelberg, Gran Sasso)
  ~300 naked ^{76}Ge detectors submerged in liquid nitrogen. Small version for WIMP searches: 100 kg of naked Ge crystals (40×2.5 kg) of natural abundance, directly in tank of liquid nitrogen (∅ 12 m×9 m high) of extreme radiopurity (CTF Borexino). Goal BKG~3×10^{-5} c/keV kg day (below 100 keV).
  Proof-of-Principle of GENIUS demonstrated.

⇒*Low pressure gas detectors*

- **DRIFT** (UKDMC /UCSD/Temple/LA)
  Sensitive to WIMP directions. Directional recoil identification by observation of tracks in low pressure Xe gas chamber (CS_2 negative ion drift).
  2001: 1 m^3 prototype test chamber
  2005: 20 m^3 apparatus

⇒*Moderate Superheated Droplets*

- **SIMPLE** (Paris VII /Lisbon Coll.)
  Dispersion of Freon-12 droplets (∅~50μm) of superheated liquid in aqueous gel. Energy disposition ⇒ vaporization droplet in bubble (∅~1 mm) detected acoustically. **Insensitive to most types of radiation except neutron recoils of a few keV**.
  Prototype: 100 g Freon in 30 ℓ water chamber. Shallow depth 40 km south of Paris.

2.- Cryogenic Detectors

⇒*Bolometers*:

- **ROSEBUD** (IAS Orsay/IAP/Zaragoza, Canfranc)
  2×25 g sapphire crystal with NTD Ge thermometer. Inner and outer archaeological lead shielding.
  E_{thr}~300 eV Γ~120 eV at 1.5 keV.
  Test in course.
  Pilot experiment for larger crystals.

- **CRESST-I** (MPI Munich/TUM Garching/Oxford, Gran Sasso)
  4×262 g sapphire crystals with Superconducting Phase Transition thermometers of tungsten.
  E_{thr}: 0.5 keV, Γ=133 keV at 1.5 keV.
  BKG: few counts/keV kg day above 30 keV; 1 c/keV kg day above 100 keV.
  Recent developments: low radioactivity materials for cold-box. Simultaneous measurement of scintillation and heat performed in 6 g $CaWO_4$ crystal. Rejection of electron recoil events 99.7% for nuclear recoil energies above 15 keV.

- **CUORE** (Berkeley / Florence / LNGS / Leyden / Milan / Neuchatel / South Carolina / Zaragoza, Gran Sasso)
  1020 crystals of TeO_2, (760 g each) with NTD Ge thermometers.
  Small version CUORICINO: 56 crystals, 42 kg
  Under construction. To start running by the end of 2000.

⇒ *Hybrid Detectors*:

- **CDMS-I** (CfPA / UC Berkeley / LLNL / UCSB / Stanford / LBNL / Baksan / Santa Clara / Case Western/Fermilab/San Francisco State)
  Bolometers with heat-ionization event-by-event discrimination. More than two orders of magnitude improvement of sensitivity against electron backgrounds. Readout with NTD (thermal) and QET (athermal) sensors (tungsten quasiparticle -trap - assisted electrothermal - feedback transition -edge thermometers) (resp. BLIP and FLIP).
  Sensitivity limitation identified: low energy electrons from outside the detectors, suffering reduced charge collection due to dead layer.
  Plans: Minimize this effect and regain full effectiveness of the event discrimination technique
  Stanford: 2×100 g Si + 4×250 g Ge FLIP detectors
  6×165 g Ge BLIP detectors
  New running 4×165 g Ge BLIP with improved charge collection. Only one (nuclear recoil) count in 1.7 kg d above 20-25 keV. Goal: $B=10^{-2}$ c/keV kg day

- **CDMS-II**
  Soudan: 20×250 g Ge FLIP detectors
  Goal: $B=\text{few}\times10^{-4}$ c/keV kg day
  Works for site preparation in course
  DOE-NSF reviewing by April 1999
  Begin moving in one year.

⇒Hybrid Detectors (cont.)

- **CRESST-II**
  Short term: 1999-2001: 1 kg $CaWO_4$ with light and heat measurement B=1 c/keV kg day plus rejection 99.7% above 15 keV.
  Long term: 2002 and beyond: 100 kg $CaWO_4$, B=0.1 c/keV kg day and 99.9% rejection

- **EDELWEISS-I**(Orsay/Lyon/Saclay/LSM/IAP, Frejus)
  70 g HP Ge bolometer with heat-ionization discrimination. B=0.6 c/keV kg day in 12-70 keV recoil energy (1.17 kg day exposure). Rejection 98% for surface events and > 99.7% for internal events.
  Plans 1999: 3×320 g Ge detectors.
  Goal: B=10^{-2} c/keV kg day

- **EDELWEISS-II**: Reverse DR (100 ℓ) under construction to host 50-100 detectors.
  20×300 g Ge detectors (by 2000-2001)
  Goal: Improve rejection up to 99.99%.
  B~10^{-4} c/keV kg day

CUORE

(Cryogenic Underground Observatory for Rare Events)

Berkeley - Florence - Gran Sasso - Leyden - Milan -
Neuchatel - South Carolina - Zaragoza Collaboration

Large mass (775 kg) modular detector of 1020 single bolometers of (TeO_2) tellurite ($5\times5\times5$ cm^3 size, 760 g each) at 7~10 mK with NTD Ge thermistors (Gran Sasso)

Physics motivations

✱ Double Beta Decay Search

Large mass of 2ß-emitter, high efficiency, good energy resolution

✱ Search for WIMPs

WIMP-nuclei scattering in a detector set of good energy resolution, low energy threshold, quenching factor of ~100% and big target mass for seasonal effects

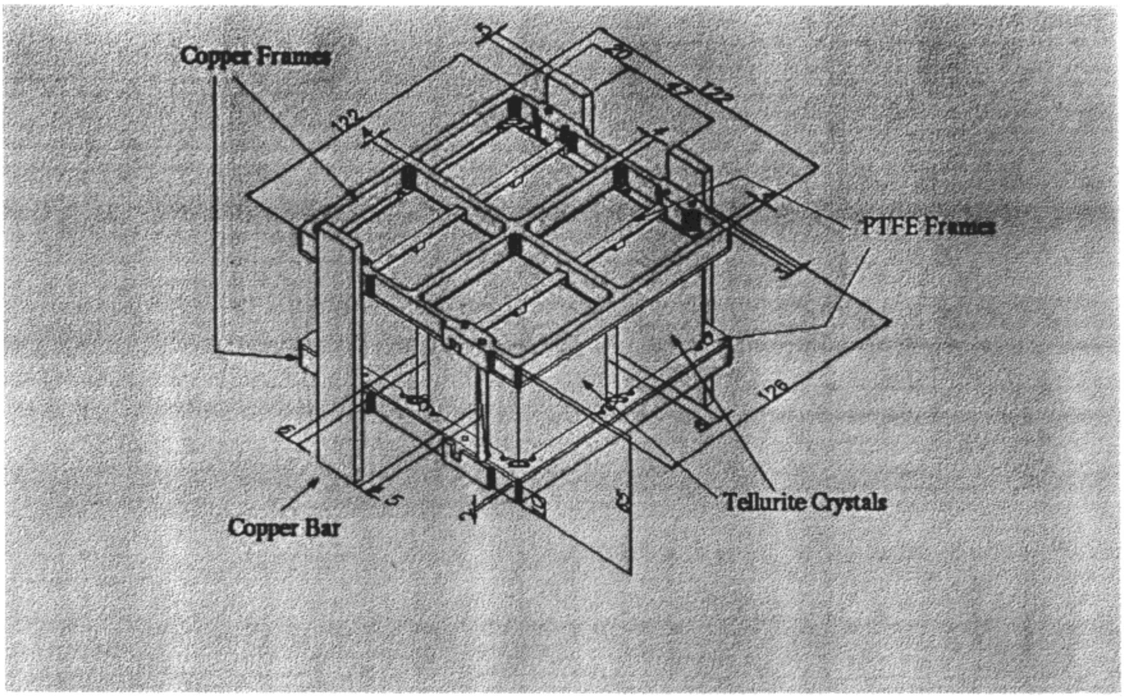
✱ Search for Solar Axions

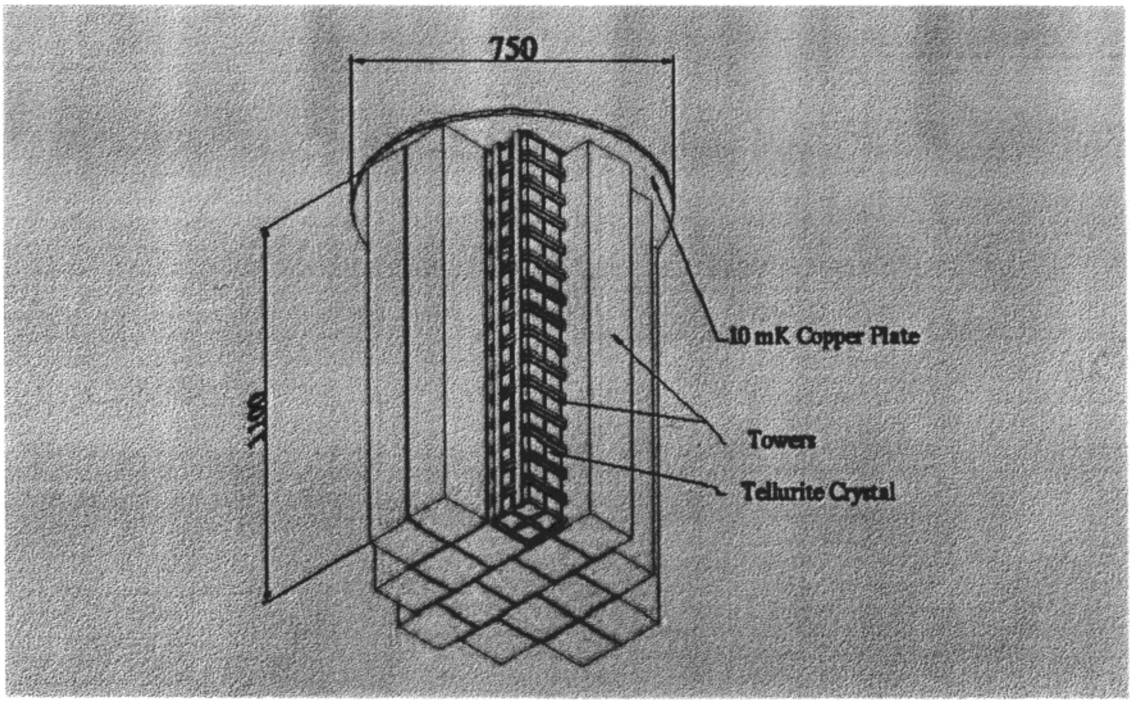
Coherent conversion into photons when their incident angle with a crystalline plane of the detector fulfills the Bragg condition. The relative position of the lattice planes with respect to to the sun results in a temporal pattern which provides a distinctive signature.

Structure of CUORE

- ✓ <u>Seventeen towers</u> in copper, each one containing <u>fifteen planes</u>, suspended from a copper plate (kept at about 7~10 mK) within the dilution refrigerator. Each plane consists of <u>four</u> cubic TeO_2 crystals.
- ✓ The array allows for effective anticoincidence operation.

- ✓ TeO_2 choice because of double beta decay of ^{130}Te.
- ✓ Other absorbers already tested (CaF_2, LiF, $CdWO_4$, Al_2O_3, Ge, $PbWO_4$), also possible.
- ✓ $PbWO_4$ promising for solar axion searches.
- ✓ Possibility to operate simultaneously various different targets.


Copper Frames
PTFE Frames
Tellurite Crystals
Copper Bar


750
10 mK Copper Plate
Towers
Tellurite Crystal

CUORE Previous Experience

- ➔ Large bolometers of TeO_2 (334 g) with NTD Ge-sensors, resolution of 1% at 60 keV and bkg. of ≈ 12 counts / keV.kg.day at $E_{thr} \approx 10$ keV already used for WIMPs searches by Milan group at Gran Sasso. Sensitivity of these bolometers to nuclear recoils proven.

- ➔ Nuclear recoil quenching factor measured:

  Q_{recoil}=1.025±0.01(stat)±0.02(syst), (from 10 to 200 keV).

- ➔ 20-crystal array now running (MIBETA experiment) for 2ß, WIMPs and solar axion searches

- ➔ Preliminary results (E_{thr}~10 keV) allow to expect improvements $E_{thr} \leq 5$ keV and $\Gamma \approx 1$-2 keV (few keV region).
  Reproducibility of the detectors proved: 20 detectors act as a single detector.

- ➔ CUORE is a large scale extension of this array with bigger bolometers.

- ➔ Two bolometers of CUORE have already been tested.

CALIBRATION SPECTRA OF TEN MIBETA BOLOMETERS (A1....A5 and B1...B5)

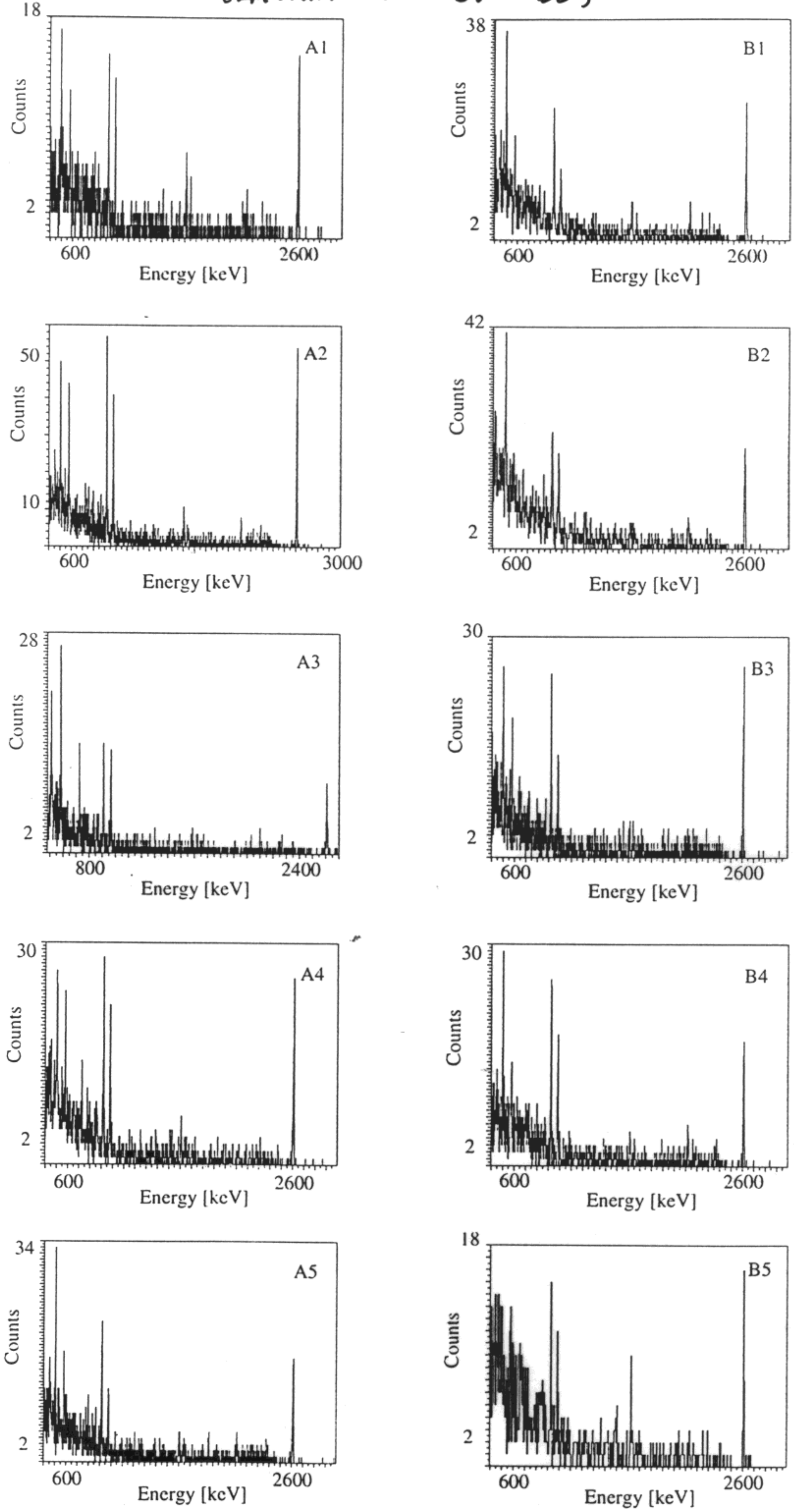


Fig. 2a

CALIBRATION SPECTRA OF TEN MIBETA BOLOMETERS (C1....C5 and D1....D5)

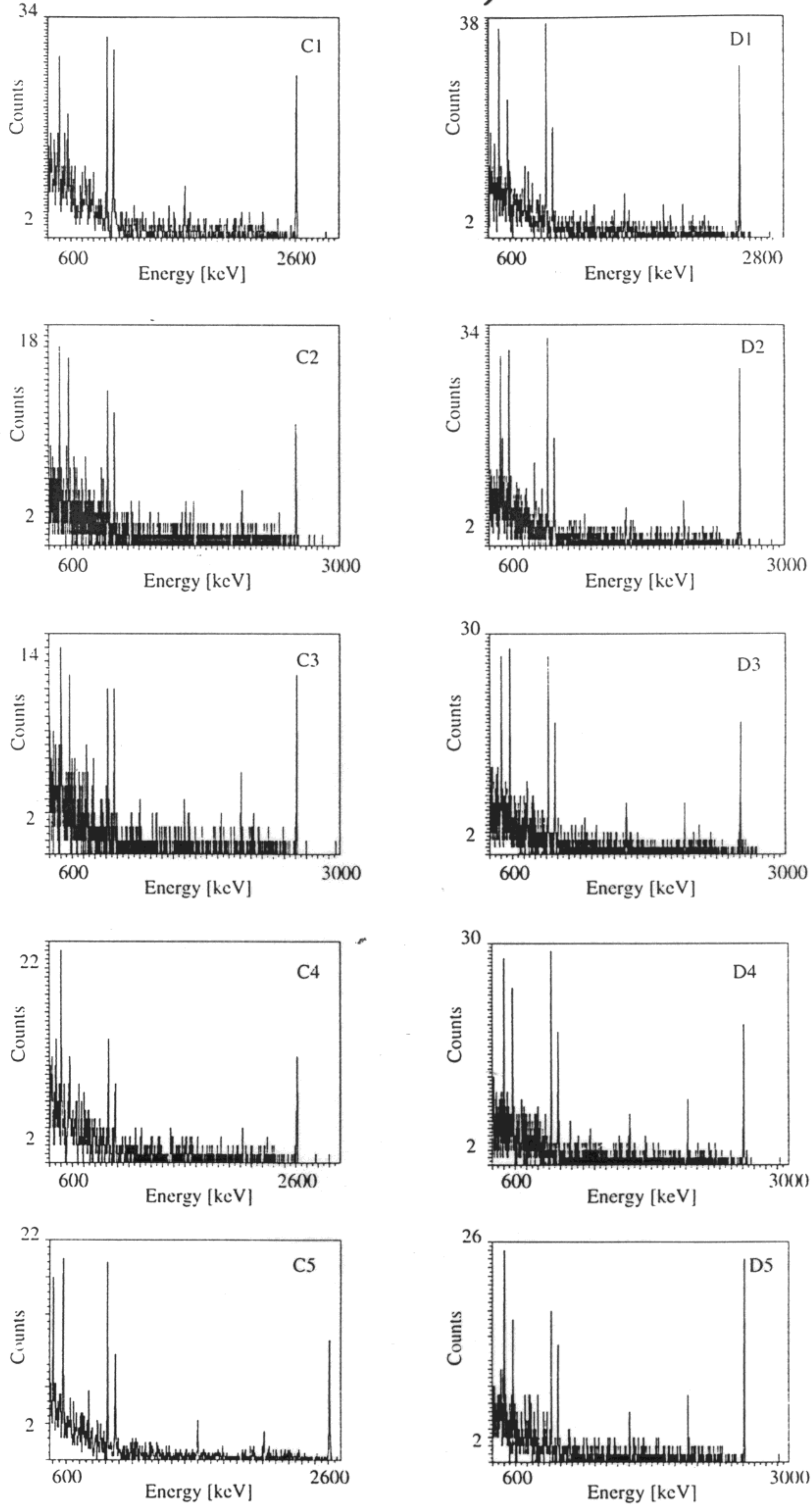
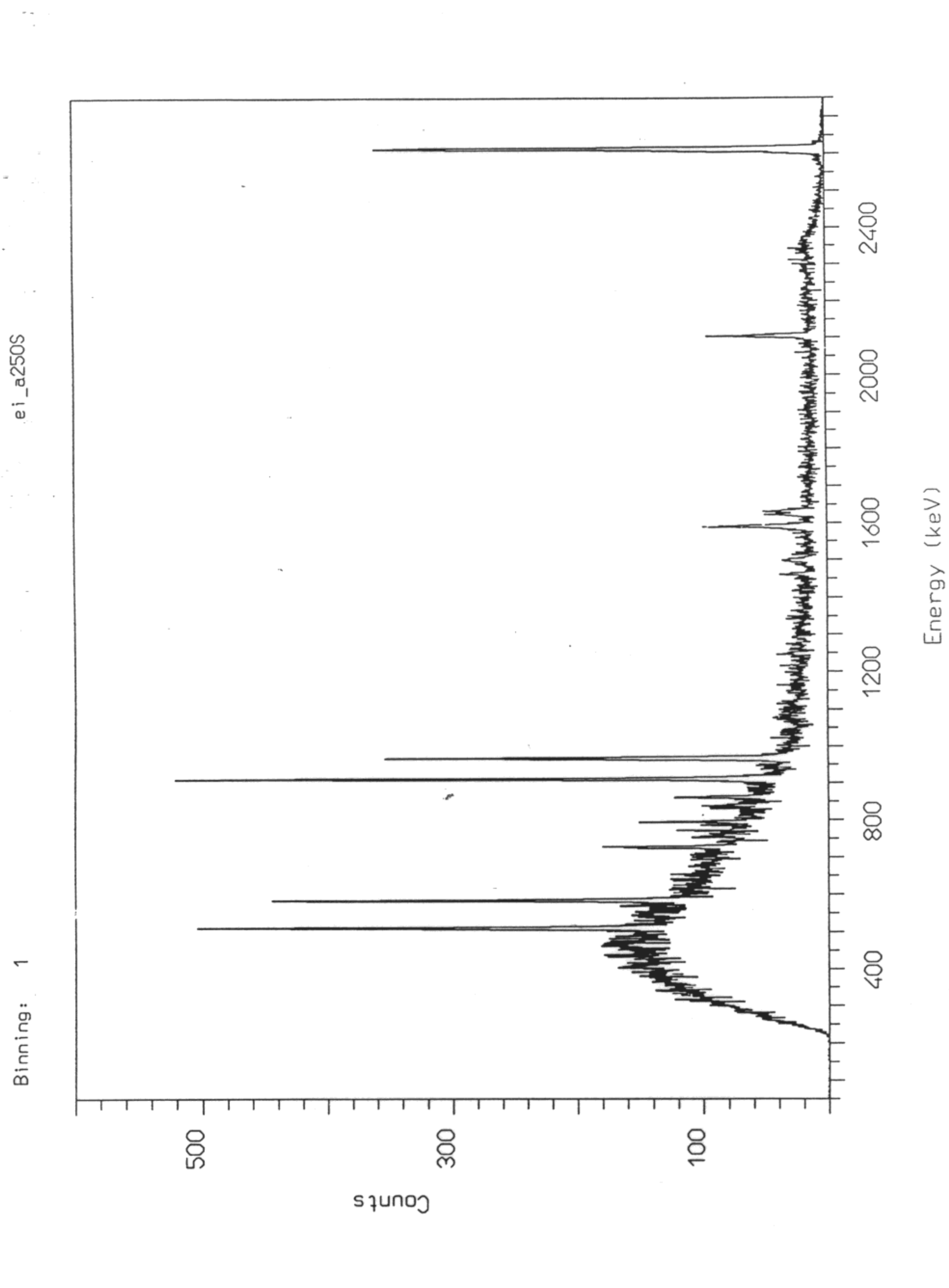


Fig. 2b



SUM OF THE 20 CONTEMPORARY CALIBRATION SPECTRA (WITH A SINGLE ^{232}Th SOURCE) OF THE 20-ARRAY OF 334 g. TeO_2 BOLOMETERS OF THE MIBETA EXPERIMENT

Fig. 3

VERY PRELIMINARY !!

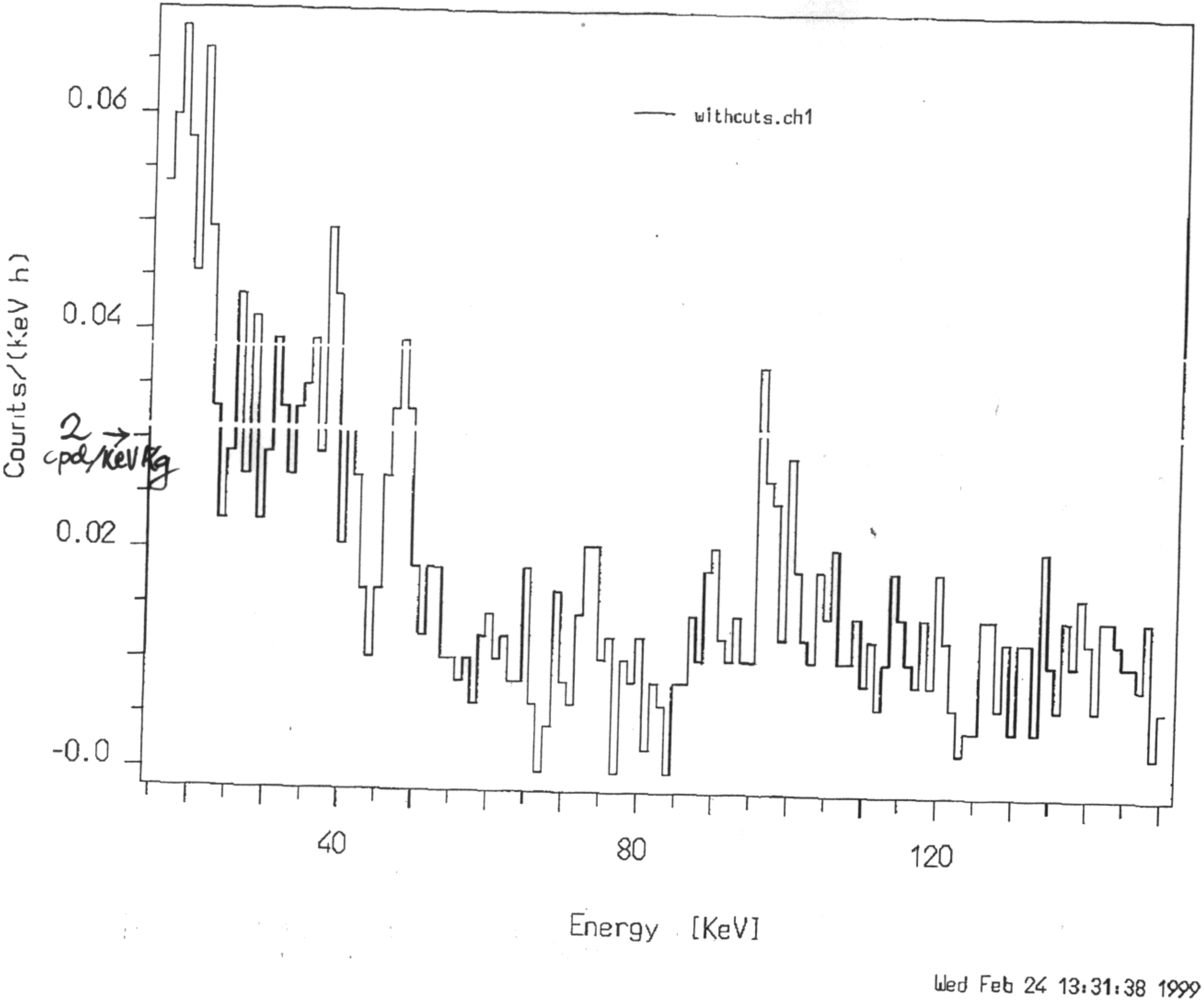


FIG. 1

LOW ENERGY BACKGROUND SPECTRUM OF ONE 334 g TeO_2 BOLOMETER OF THE 20-ARRAY IN THE MIBETA EXPERIMENT.

DATA FROM A RUN OF ~500 h.

Tests and Reproducibility

- ★ Two CUORE bolometers (760 g) crystals, following partially the prescriptions of a propossed thermal model have been tested in GS using thermistors with the same doping but with dimensions $3\times1\times3$ mm^3 (5 times larger than those used in the 20 crystal array).
- ★ The spectrum of a ^{232}Th source is shown in the Figure.
- ★ The resolution in the region of neutrinoless 2β decay is $\approx$10 keV.

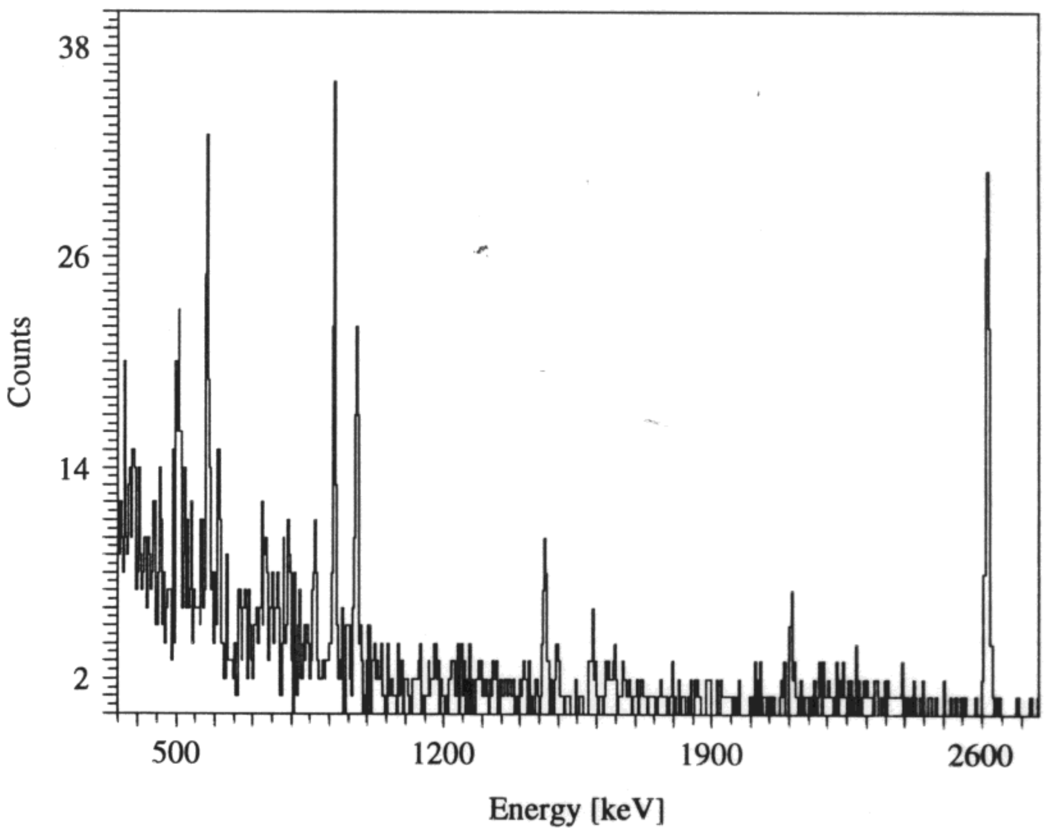
- ★ The reproducibility of the array of 20 bolometers of Mibeta can be appreciated in the Figure, where all the 20 contemporary calibration spectra with a single ^{232}Th source are reported.
- ★ The sum of these spectra (see Figure) shows that the array is indeed acting as a single detector.
- ★ The same reproducibility can therefore be achieved with the 56 CUORICINO bolometers.

IS CUORE FEASABLE? FIRST TEST

A 5×5×5 cm^3 crystal (M = 767.7 g) was cooled in these days

- Reached base temperature: ~ 7 mK
- Working temperature: ~ 9 mK
- Detector response: ≥ 200 μV/ MeV
- FWHM resolution: ~ 10 keV @ 2.6 MeV

VERY PRELIMINARY !!!



The CUORICINO Experiment

CUORICINO (for little CUORE)
Small version of CUORE consisting of a single tower of 14 planes: Total mass 42 kg of TeO_2 (56 crystals).

Objectives

- Test the CUORE principle
- Search for 2ß decays, WIMPs and solar axions in an experiment which is interesting by itself.

THE CUORICINO COLLABORATION

J. Beeman, E.B. Norman, E.E. Haller, R.J. McDonald, A.R. Smith
Materials Science Division, Lawrence Berkeley Nat. Lab. and Dept. of Materials Sci. and Mineral Engineering. University of California, Berkeley

G. Ventura
Dipartimento di Fisica dell'Università di Firenze and Sezione di Firenze dell'INFN

G.Frossati and A. de Waard
Kamerling Onnes Laboratory, Leiden University

C. Arpesella and C. Bucci
Laboratori Nazionali del Gran Sasso

A. Alessandrello, C. Brofferio, L. Carbone, O. Cremonesi, E. Fiorini, A. Giuliani, A. Nucciotti, M. Pavan, G. Pessina, S. Pirro, E. Previtali, L. Zanotti and M. Vanzini
Dipartimento di Fisica dell'Università di Milano and Sezione di Milano dell'INFN

G. Gervasio, Y. Gonin and J.L. Vuilleumier
Institut de Physique de l'Université de Neuchatel

F.T. Avignone, R.J. Creswick and H.A. Farrach
Dept. of Physics and Astronomy, University of South Carolina

S. Cebrián, E. García, D. González, I.G. Irastorza, A. Morales, J. Morales, A. Ortiz, A. Peruzzi, J. Puimedón, M.L. Sarsa, S. Scopel, J.A. Villar
Laboratory of Nuclear and High Energy Physics, University of Zaragoza.

Structure of CUORICINO

Single tower with 4 crystals per plane in two copper frames held by four copper bars. Small supports of Teflon tight the crystals.

The tower is placed within a closed cylindrical vessel in copper (the 50 mK radiation shield), surrounded by various coaxial vessels within the DR, and connected (via a copper cold finger) to the mixing chamber of the current MIBETA dilution refrigerator with minor modifications.

Inner shielding:

Roman lead cylinder (10 cm height) (top of the tower)

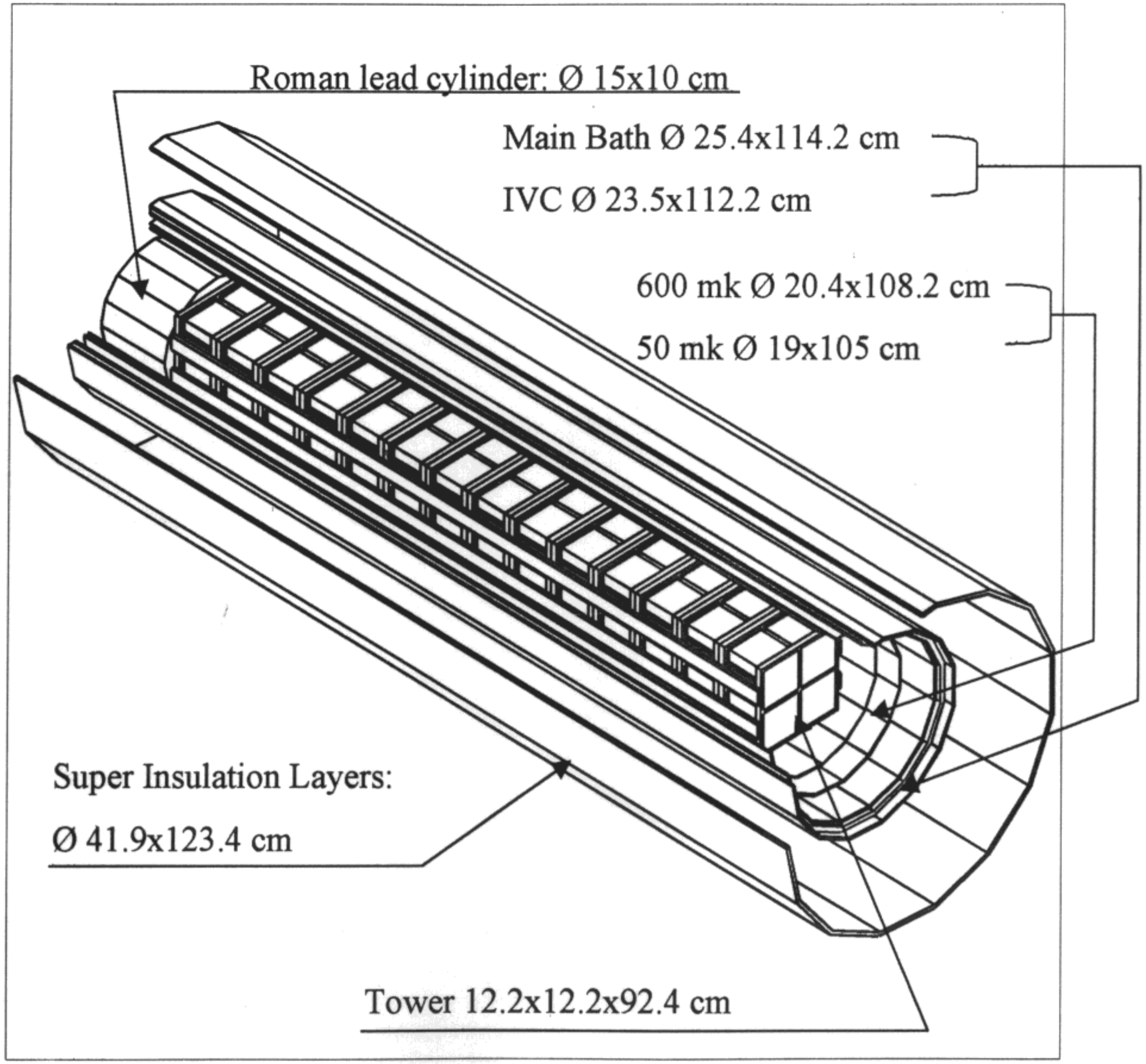
Outer shield of the DR:

2 cm of Roman lead ($^{210}Pb < 4$ mBq kg^{-1})
10 cm of lead (^{210}Pb of 16 ± 4 Bq Kg^{-1})
10 cm of lead (^{210}Pb of 150 ± 20 Bq kg^{-1})

Additional shield:

2 cm electrolytic copper (thermal shields)

Inside the Outer Vacuum Chamber



CUORE Zaragoza University

Radiopurity of the components

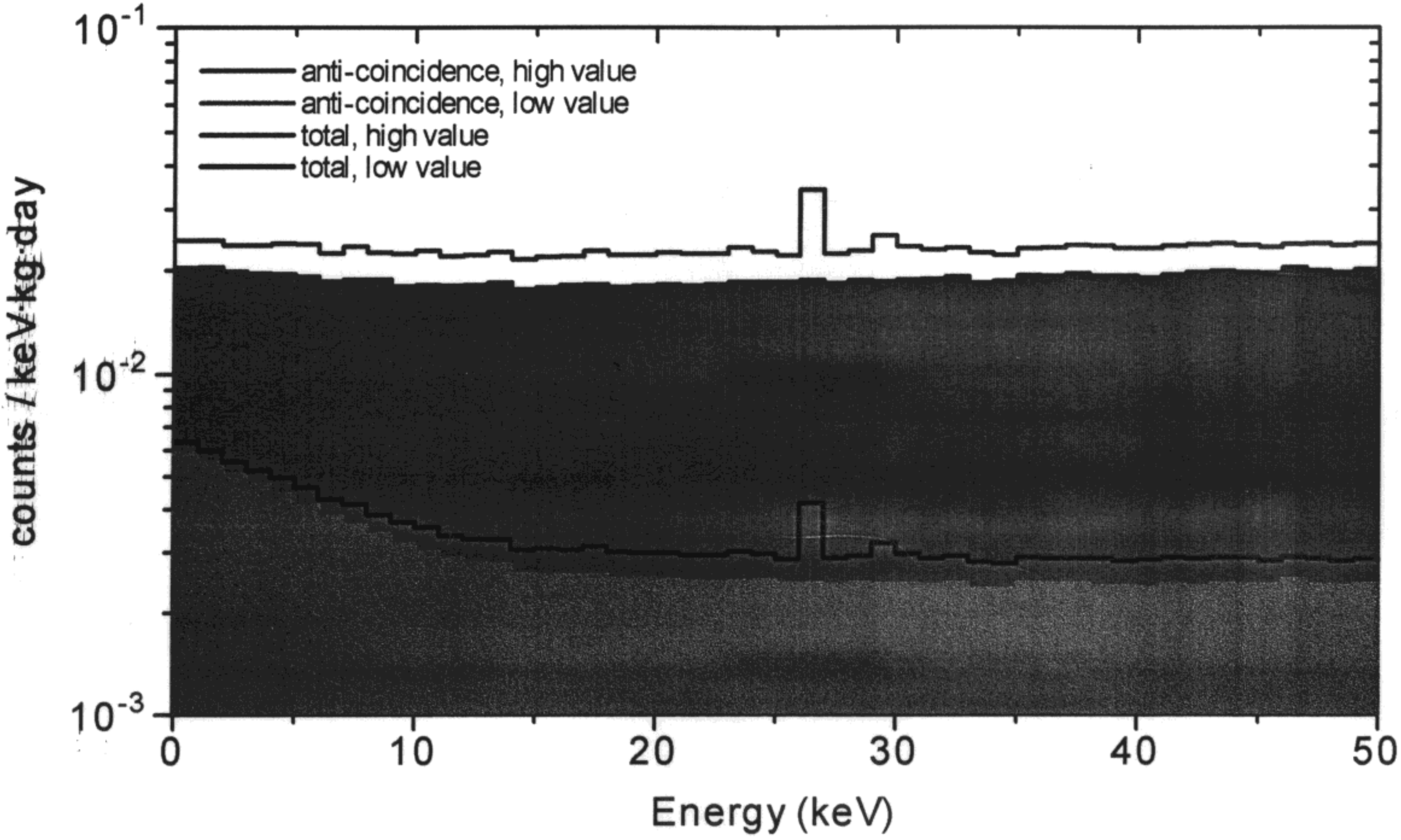
Main components (OFHC and electrolytic copper, Roman and normal lead, mylar in the SI layers) being measured with low background Ge detectors at Gran Sasso and Canfranc.

Radiopurity of TeO_2 crystals measured in Gran Sasso through their internal radioactivity during their operation as bolometers.

Results range between the low and high upper bounds of the Table.

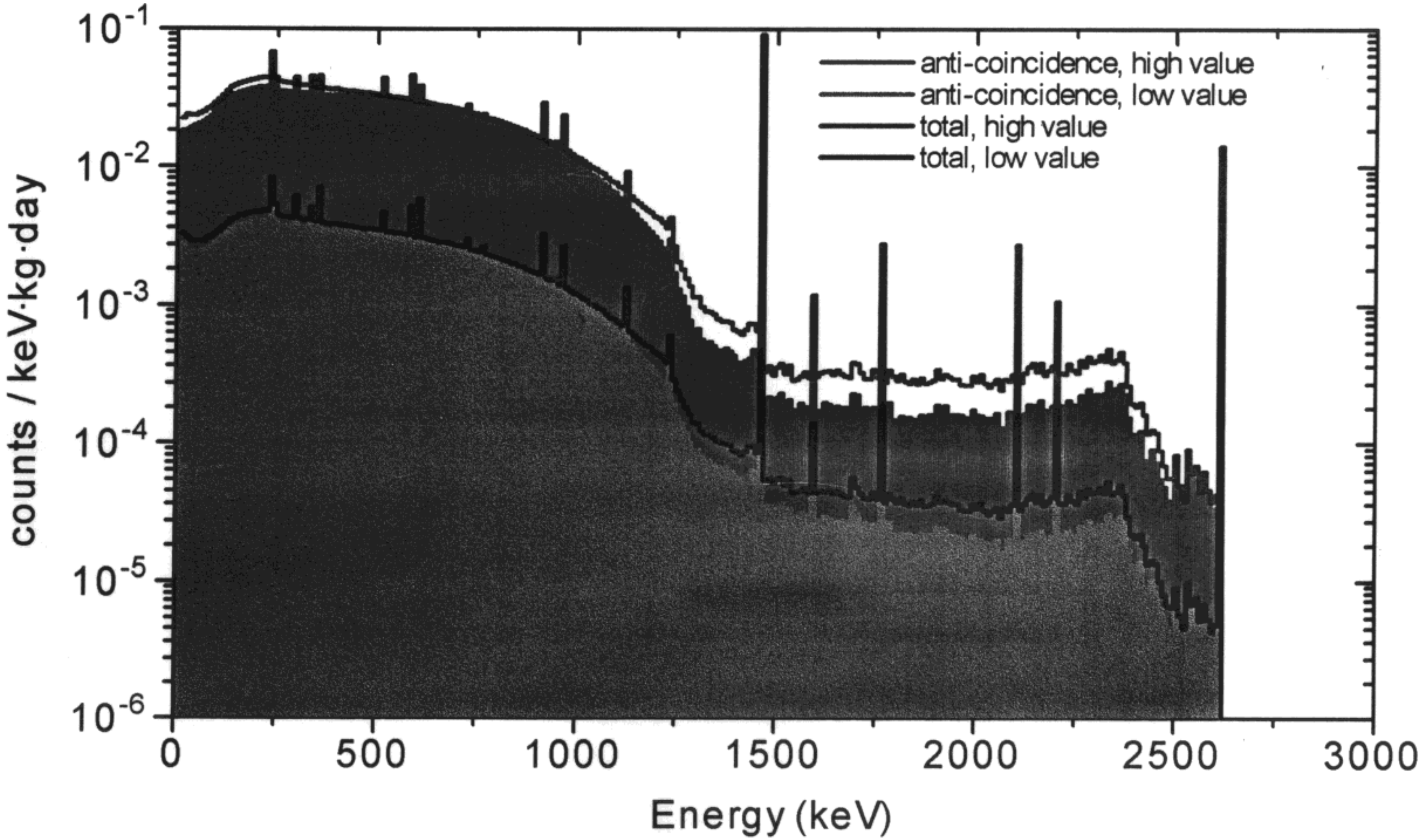
	Copper (pg/g)		Lead (pg/g)		Tellurite (pg/g)	
	low	high	low	high	low	high
U^{238}	0.1	1	0.1	1	0.1	0.1
Th^{232}	1	10	1	10	0.1	0.1
K^{40}	0.1	1	0.1	1	0.1	1
Co^{60}	200 μBq/kg		100 μBq/kg			
Cs^{137}	50 μBq/kg		50 μBq/kg			

Calculated background spectra showing the energy interval 1-50 keV



Zaragoza University

Calculated background spectra showing the energy interval 0-3 MeV



Zaragoza University

WIMPs Direct Searches with CUORICINO

- ✓ Expected Experimental Parameters of CUORICINO

  E_{thr}~ 2-5 keV Γ ~ 1 ~ 2 keV (at low E)

  Q ~ 1 and $B \leq 0.1 - 0.01$ c/keV.kg.day

  make it a very qualified device to look for WIMPs

- ✓ Also ~ all isotopes of O, Te are in 0^+

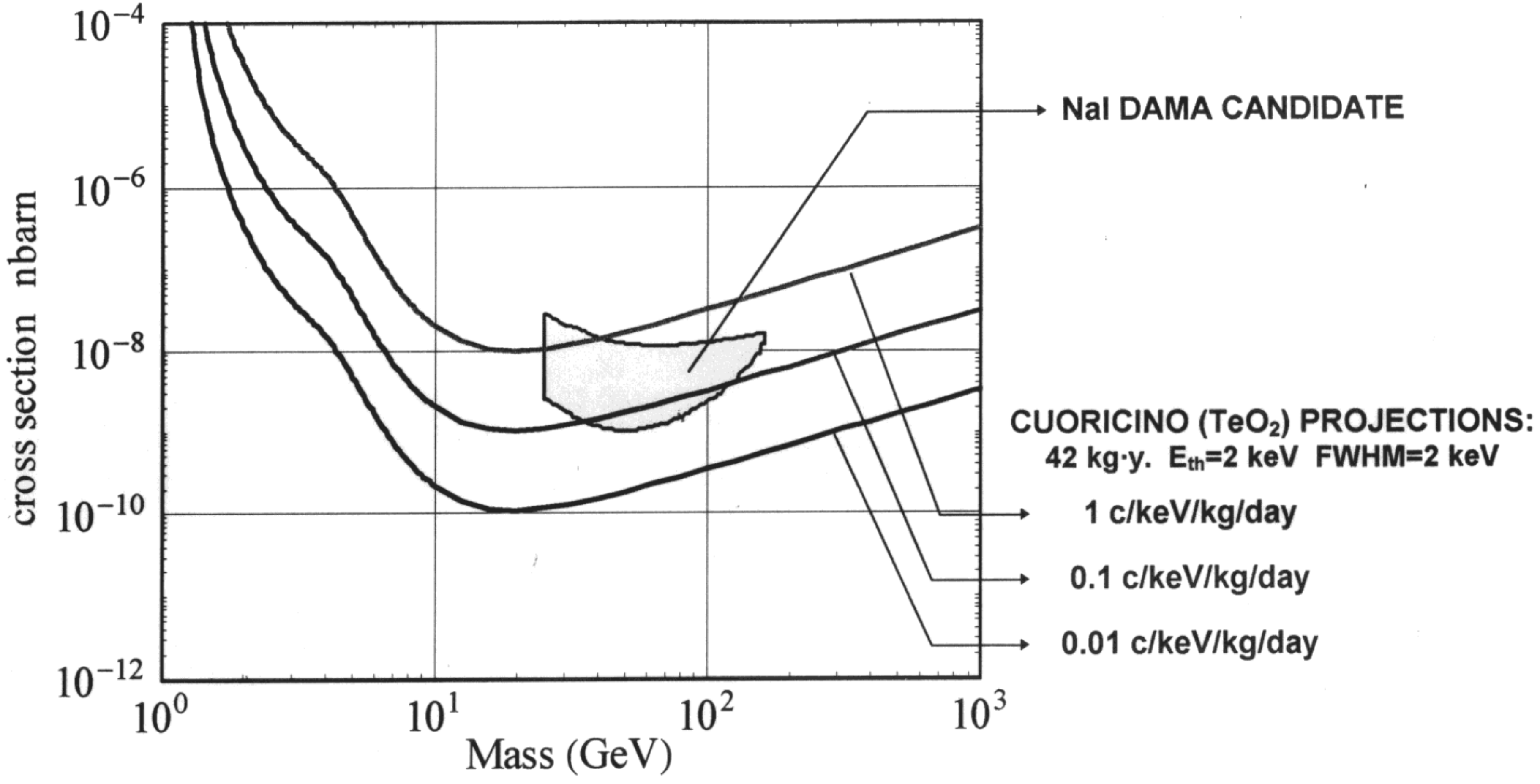
  suitable for coherent interactions

- ✓ The TeO_2 - CUORICINO has no ionization/heat mechanism of BKG rejection. Future version with other absorbers could have it

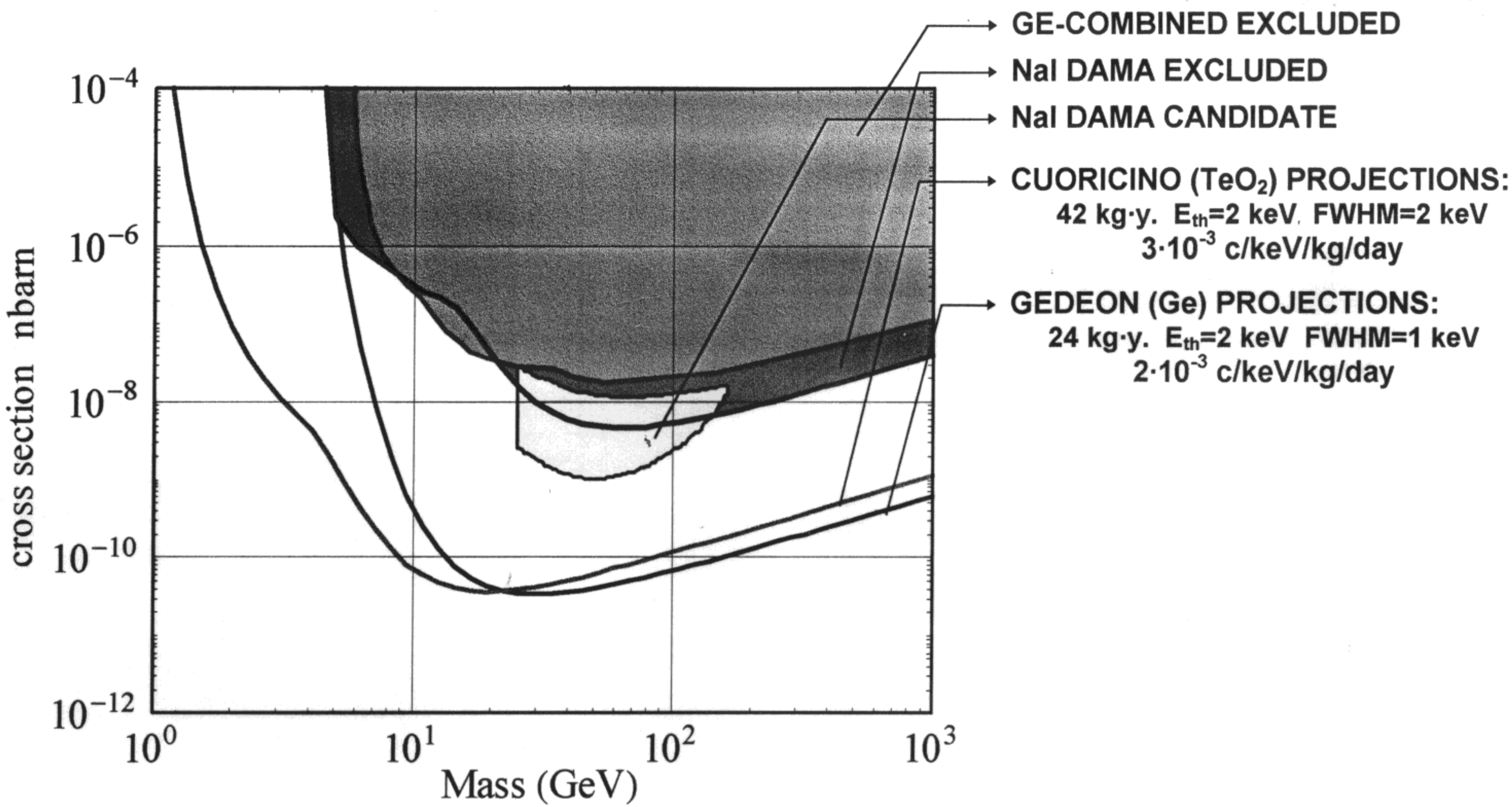
- ✓ See expected event rate in CUORICINO for a WIMP with m=60 GeV and $\sigma^n = 7\times10^{-6}$ pb

- ✓ See estimated exclusion plots $\sigma(m)$ expected from CUORICINO for various low-energy (flat) conservative backgrounds. Threshold 5 keV and 2 keV. Standard parameter values were used for the halo model, ρ=0.3 GeV cm^{-3}, v_{rms}=270 kms^{-1} and v_{esc}=650 km s^{-1}.

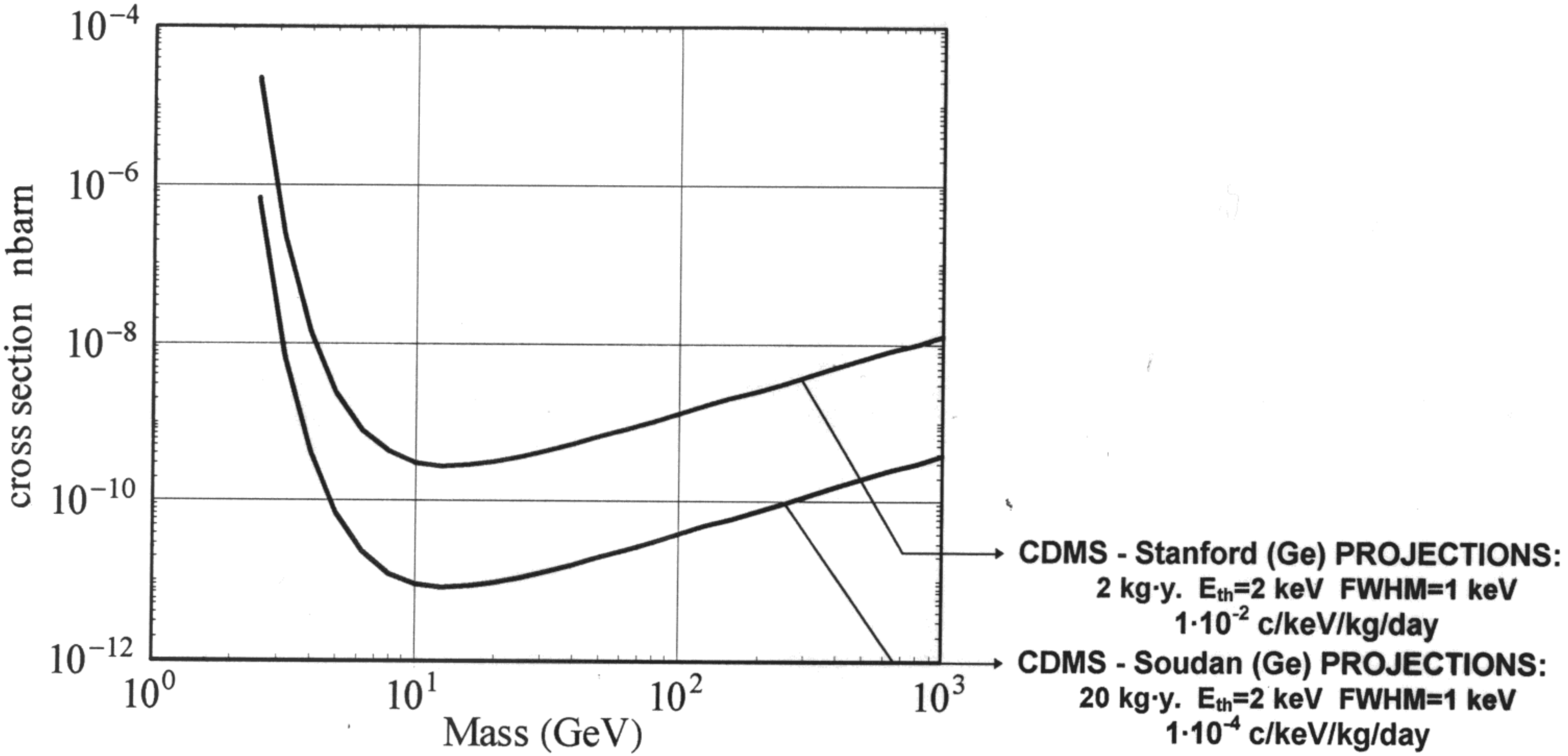
CUORE



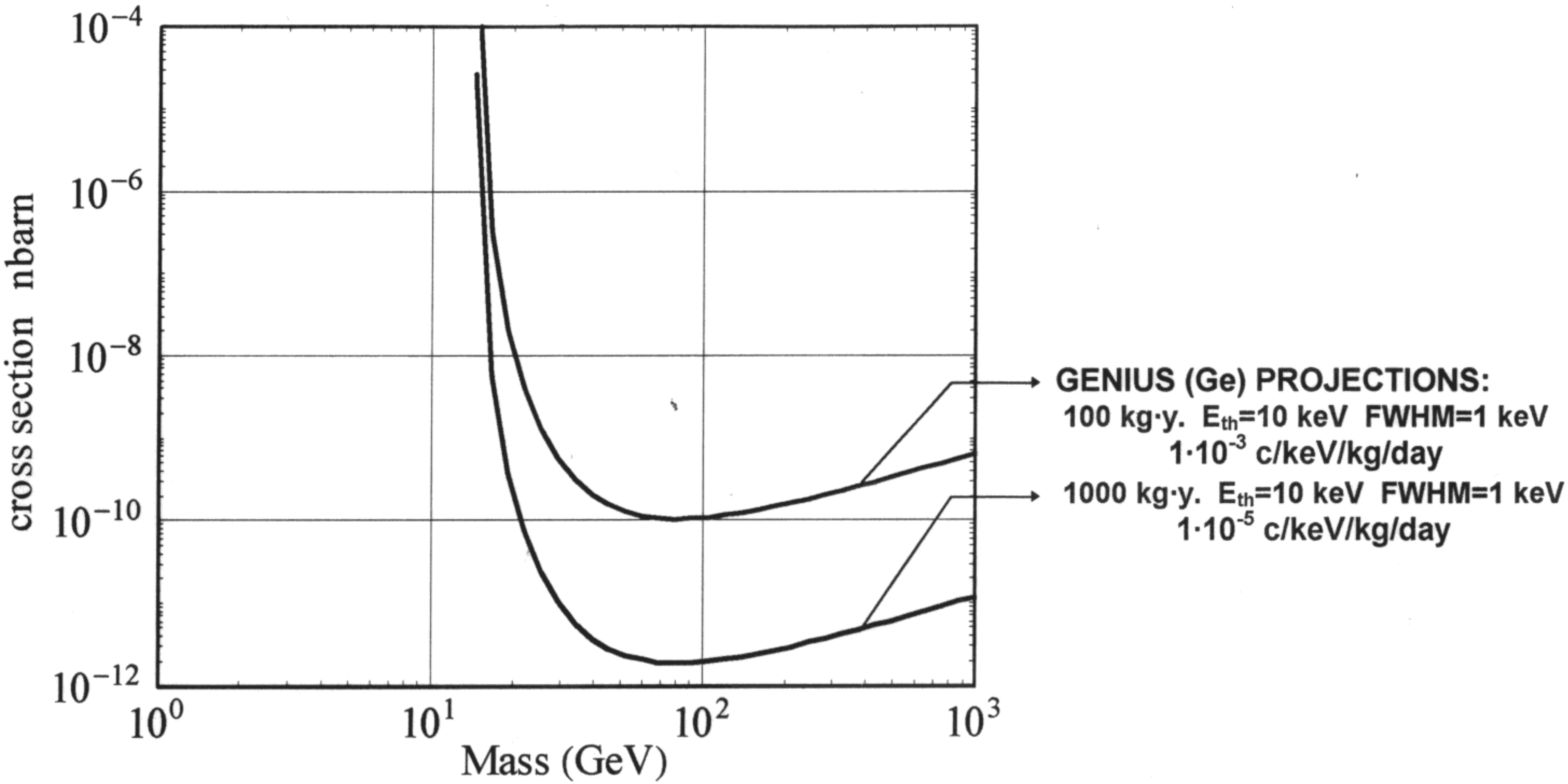
CUORE Zaragoza University



GE-COMBINED EXCLUDED
NaI DAMA EXCLUDED
NaI DAMA CANDIDATE
CUORICINO (TeO2) PROJECTIONS:
42 kg·y. Eth=2 keV. FWHM=2 keV
3·10^-3 c/keV/kg/day
GEDEON (Ge) PROJECTIONS:
24 kg·y. Eth=2 keV FWHM=1 keV
2·10^-3 c/keV/kg/day
cross section nbarn
10^-4
10^-6
10^-8
10^-10
10^-12
10^0
10^1
10^2
10^3
Mass (GeV)



cross section nbarn
10−4
10−6
10−8
10−10
10−12
10^0
10^1
10^2
10^3
Mass (GeV)
CDMS - Stanford (Ge) PROJECTIONS:
2 kg·y. Eth=2 keV FWHM=1 keV
1·10-2 c/keV/kg/day
CDMS - Soudan (Ge) PROJECTIONS:
20 kg·y. Eth=2 keV FWHM=1 keV
1·10-4 c/keV/kg/day



10^-4
10^-6
10^-8
10^-10
10^-12
cross section nbarn
10^0
10^1
10^2
10^3
Mass (GeV)
GENIUS (Ge) PROJECTIONS:
100 kg·y. Eth=10 keV FWHM=1 keV
1·10^-3 c/keV/kg/day
1000 kg·y. Eth=10 keV FWHM=1 keV
1·10^-5 c/keV/kg/day

Prospects for Annual Modulation of WIMP signals with CUORICINO

- ★ 42 kg of TeO_2 suitable to look for WIMP seasonal effects and explore the DAMA region.
  For $\sigma^n \sim 10^{-5}$pb (top of the region) and $B \leq 0.1$ c/keV.kg.y , one year of statistics will allow to discriminate a 5% effect at the 3σ level.
- ★ Also different target from that of DAMA would help in qualifying the type of coupling of the hypothetical neutralino.
- ★ Long time stability and systematics effects in MIBETA (20-TeO_2 array) need to be known before making reliable predictions for the CUORICINO potential in rate annual modulation searches.

Prospects for Solar Axion Searches with CUORICINO (and other crystal detectors)

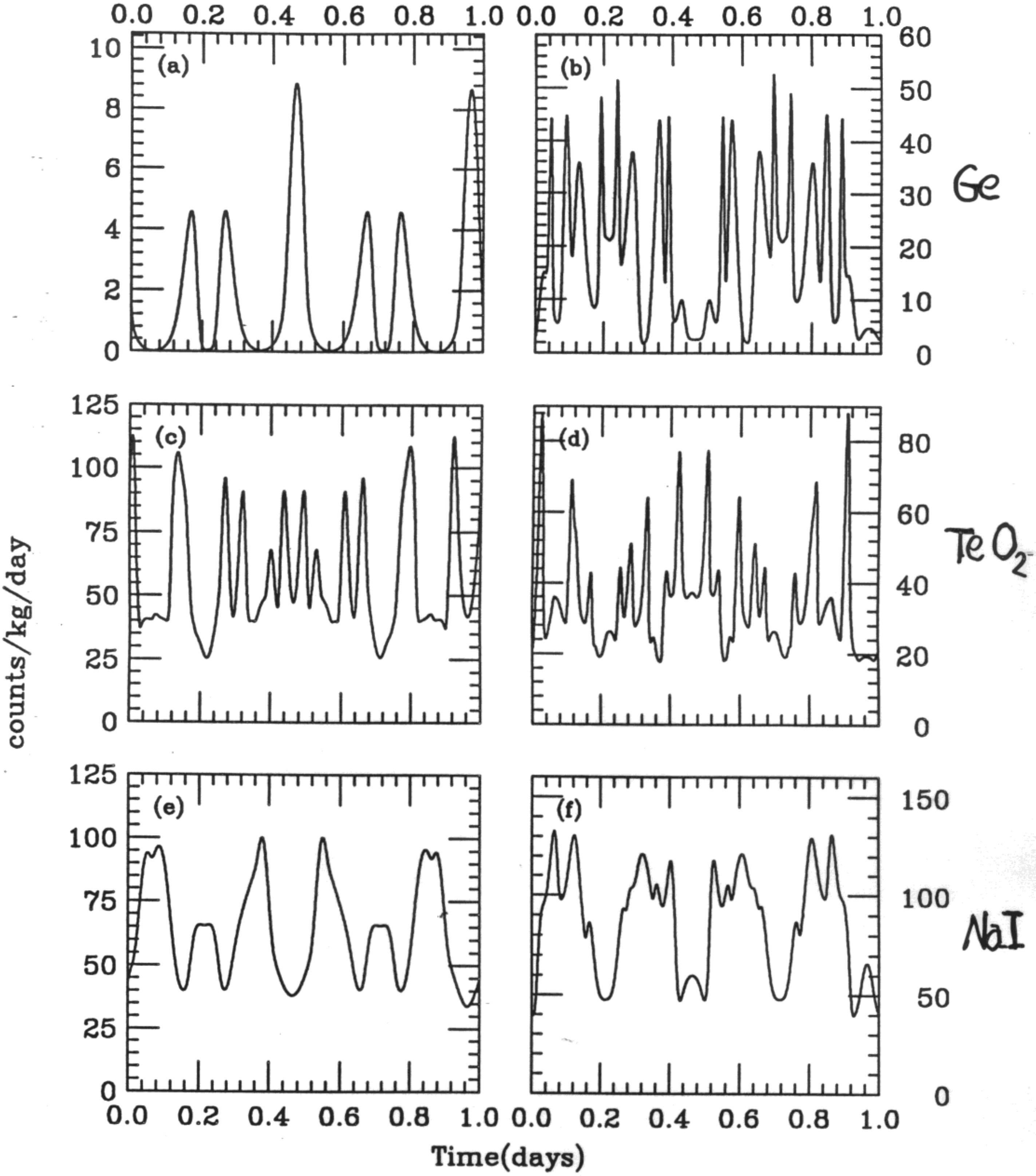
Solar axions ($E_a \sim$ 2-10 keV, peaked at 4 keV) can be Primakoff-converted into photons (X-rays) in a crystal detector (coupling $g_{a\gamma\gamma}$).
When incident angle with a given crystalline plane fulfils Bragg condition, $\bar{q}_a = \bar{G}_{lattice}$ coherence follows $\Rightarrow$ rate enhanced. The resulting correlation of the signal with the position of the sun in the sky produces a sub-diary time variation of the rate, genuine signature of the axion, to be looked for in the data.

Helioseismological bound $g_{a\gamma\gamma} < 10^{-9}\,GeV^{-1}$ sets the minimal sensitivity goal in crystal detectors. Notice the globular cluster bound $g_{a\gamma\gamma} \leq 6\times10^{-11}\,GeV^{-1}$.

Upper bound of $g_{a\gamma\gamma}$ derived from the non-appearance of the axion signal in a given crystal.

$$g_{a\gamma\gamma} \leq g_{a\gamma\gamma}^{limit} \cong K\left(\frac{B}{MT}\right)^{1/8} \times 10^{-9}\,GeV^{-1}$$

For a flat background B (c/keV.kg.day) and exposure M(kg) T(year). K is a function of the parameters of the crystal as well as of the experimental threshold and resolution.



(a)
(b)
(c)
(d)
(e)
(f)
Ge
TeO2
NaI
counts/kg/day
Time(days)

Running axion searches with Crystals

SOLAX Coll.

PNNL / South Carolina / TANDAR / Zaragoza
at Sierra Grande Mine
~1 kg Ge crystal $\Rightarrow$ $g_{a\gamma\gamma} < 2.7\times10^{-9}$GeV^{-1}

MOZA Coll.

Zaragoza / PNNL / South Carolina, at Canfranc
234 g Ge Crystal, currently running
Preliminary results (200 days) $g_{agg} < 3\times10^{-9}$GeV^{-1}.

MIBETA

Milan at Gran Sasso
20×0.340 kg TeO_2 crystals, currently running
Orientation of Lattice planes of the crystals, known
Results to appear soon

Prospects for CUORICINO

TeO_2 crystals of CUORICINO have some advantages over Ge detectors:

larger mass,
known orientation of the crystals,
cross-section for Primakoff conversion depends on Z^2.

However, instrumental performances, as well as specific features of the TeO_2 crystal detector limit the relative gain with respect to Ge.

See Tables for prospects with CUORICINO, CUORE and other crystal detectors.

Conclusion:
The sensitivity required for crystal-detectors to explore range of $g_{a\gamma\gamma}$, compatible with solar bound $g_{a\gamma\gamma} < 10^{-9} GeV^{-1}$ is within reach. Globular cluster limit still far away.

Prospects FOR SOLAR AXION Detectors

	B (c/keV.kg.day)	$g_{a\gamma\gamma}$ ($\times 10^{-9}$ GeV^{-1})
Γ = 2 keV (K=3)	5	2.1
	0.5	1.6
	0.1	1.3
	0.05	1.2
	0.01	0.95
Γ = 1keV (K=2.9)	0.5	1.5
	0.1	1.2
	0.05	1.1

CUORICINO
M = 42 kg TeO_2
E_{thr} = 5 keV
Exposure:
2 years (statistics)

$$g_{a\gamma\gamma} < g_{a\gamma\gamma}^{lim} \cong K\left(\frac{B}{MT}\right)^{1/8} 10^{-9} GeV^{-1}$$

CUORE
M = 765 kg TeO_2
E_{thr} = 5keV
Exposure:
2years (statistics)

	B (c/keV.kg.day)	$g_{a\gamma\gamma}$ ($\times 10^{-9}$ GeV^{-1})
Γ = 2 keV (K = 3)	1	1.2
	0.5	1.1
	0.1	0.9
	0.05	0.82
	0.01	0.67
Γ = 1 keV (K = 2.9)	0.5	1.1
	0.1	0.87
	0.05	0.8

Prospects FOR SOLAR AXION Detectors

	B (c/keV.kg.day)	$g_{a\gamma\gamma}$ ($\times 10^{-9}$ GeV^{-1})
Γ = 2 keV (K=3)	5	2.1
	0.5	1.6
	0.1	1.3
	0.05	1.2
	0.01	0.95
Γ = 1keV (K=2.9)	0.5	1.5
	0.1	1.2
	0.05	1.1

CUORICINO
M = 42 kg TeO_2
E_{thr}= 5 keV
Exposure:
2 years (statistics)

$$g_{a\gamma\gamma} < g_{a\gamma\gamma}^{lim} \cong K\left(\frac{B}{MT}\right)^{1/8} 10^{-9} GeV^{-1}$$

CUORE
M = 765 kg TeO_2
E_{thr}= 5keV
Exposure:
2years (statistics)

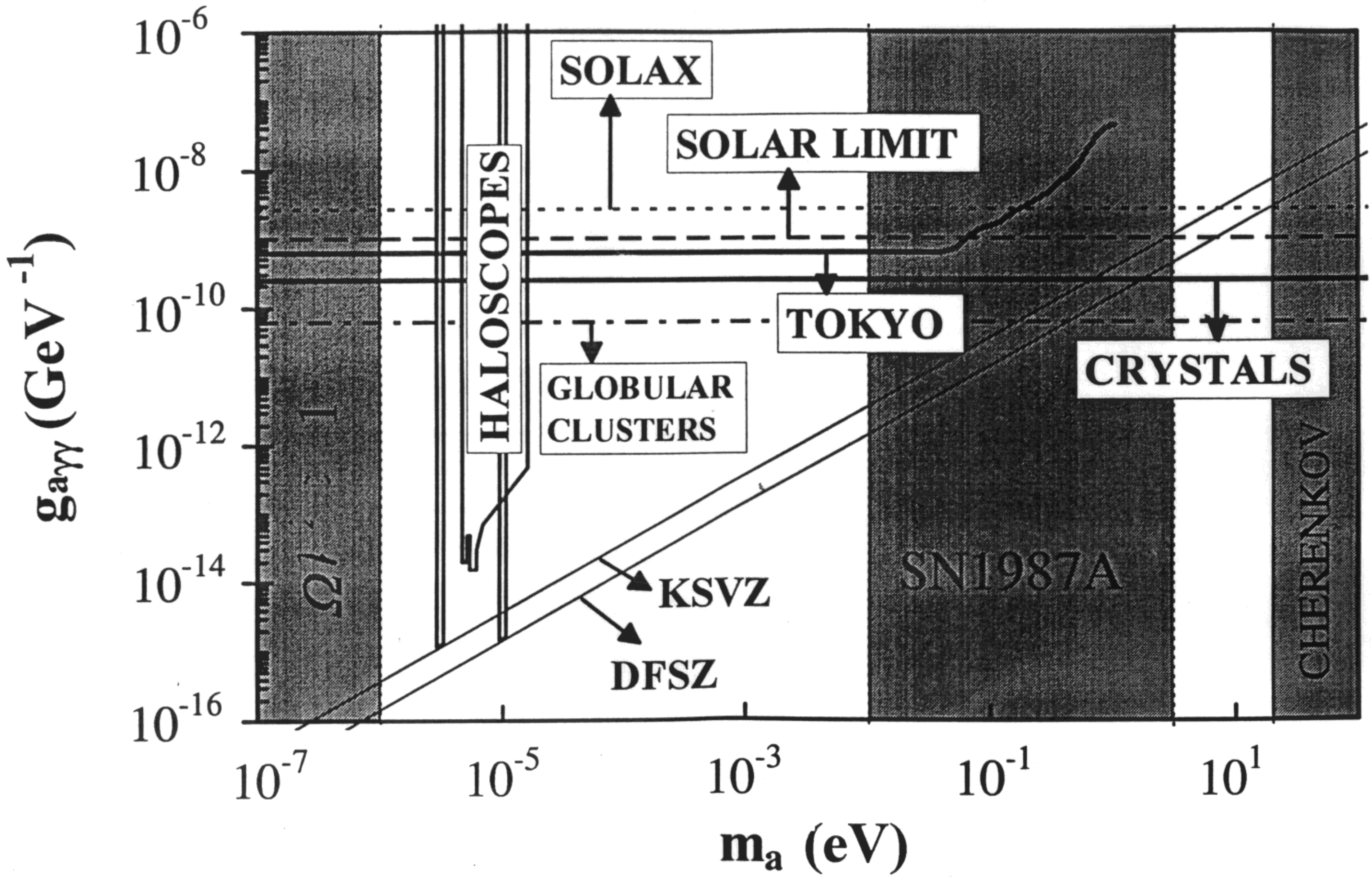
	B (c/keV.kg.day)	$g_{a\gamma\gamma}$ ($\times 10^{-9}$ GeV^{-1})
Γ = 2 keV (K = 3)	1	1.2
	0.5	1.1
	0.1	0.9
	0.05	0.82
	0.01	0.67
Γ = 1 keV (K = 2.9)	0.5	1.1
	0.1	0.87
	0.05	0.8

Table 1

Axion search sensitivities for

- ✓ running (DAMA),
- ✓ being installed (CUORICINO, ANAIS)
- ✓ and planned (CUORE, GENIUS) experiments are compared to the result of SOLAX.

		K	M (kg)	b (c/kg.keV.day)	E_{th} (keV)	FWHM (keV)	$g^{lim}_{a\gamma\gamma}$(2years) (GeV^{-1})
SOLAX	Ge	2.5	1	3	4	1	2.7×10^{-9}
GENIUS	Ge	2.5	1000	1×10^{-4}	4	1	3×10^{-10}
CUORICINO	TeO_2	3	42	0.1	5	2	1.3×10^{-9}
CUORE	TeO_2	2.8	765	1×10^{-2}	3	2	6.3×10^{-10}
DAMA	NaI	2.7	87	1	2	2	1.4×10^{-9}
ANAIS	NaI	2.8	107	2	4	2	1.6×10^{-9}
	Pb	2.1	1000	1×10^{-4}	4	1	2.5×10^{-10}



SOLAX
SOLAR LIMIT
HALOSCOPES
TOKYO
GLOBULAR CLUSTERS
CRYSTALS
KSVZ
DFSZ
SN1987A
CHERENKOV
Ω ~ 1
10^-6
10^-8
10^-10
10^-12
10^-14
10^-16
10^-7
10^-5
10^-3
10^-1
10^1
g_aγγ (GeV^-1)
m_a (eV)

Time Profile of CUORICINO