CUORICINO results & perspectives for CUORE

Fabio Bellini

Università di Roma "La Sapienza" & INFN Roma

on behalf of the

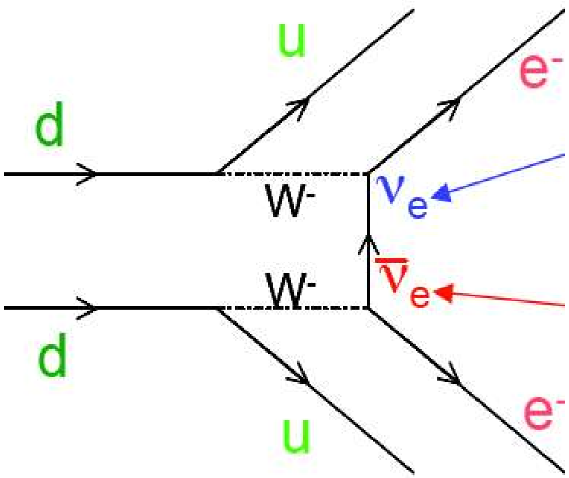
CUORE Collaboration

9th International Workshop on Particle Physics and the Early Universe

Bonn, Germany Aug 28-Sept 01 2005

Neutrinoless Double Beta Decay: $\beta\beta 0\nu$

- **From ν oscillation experiments:** $M_\nu \neq 0$, $|\Delta M^2_{12}| << |\Delta M^2_{13}|$
- **Still missing: absolute mass scale and hierarchy, phases, Dirac or Majorana nature?**



$$\beta\beta 0\nu : (A,Z) \rightarrow (A,Z+2) + 2e^-$$

Forbidden in Standard Model even for Dirac massive ν

$$chirality\ flip : m_\nu \neq 0$$

$$\nu_{majorana} : \nu \equiv \bar{\nu}\ (Lepton\ number\ violation)$$

phase space ~Q^5

Effective Majorana mass

ν mixing matrix and phases

$$(\tau^{\beta\beta 0\nu})^{-1} = G(Q,Z)\,|M_{nucl}|^2\,|\langle m_{\beta\beta}\rangle|^2$$

$$\langle m_{\beta\beta}\rangle = \sum m_{\nu_k} \eta_k |U_{ek}|^2$$

Nuclear matrix element(NME): big uncertainties

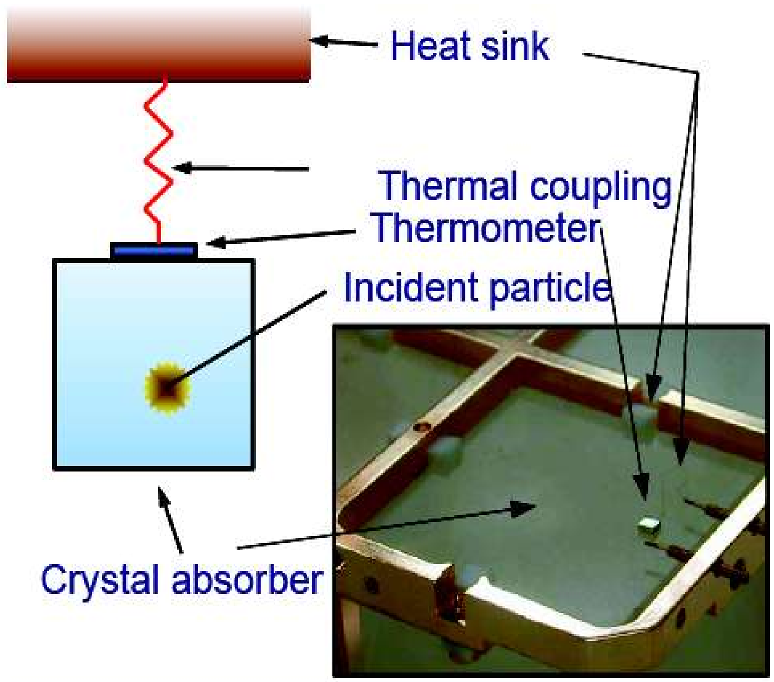
Constraints on $m_{\beta\beta}$ translate in limits on $m_{\nu min}$

- One controversial claim (4.2 σ) Klapdor-Kleingrothaus et al. Phys. Lett. B 586 (2004) 198

$$\langle m_\nu \rangle < [0.1 \div 0.9]\,eV\ best\ value\ \langle m_\nu \rangle = 0.44\,eV$$

CUORICINO experimental approach

- Bolometric technique: energy is measured as a temperature increase in the detector
- Homogeneous detector: $\beta\beta0\nu$ source = absorber



- Low temperature calorimeter
  - $\Delta T = E/C \Rightarrow$ low C
    $\Rightarrow$ dielectrics @ low T (~ 10mK) : $C \sim T^3$
  - Thermometer: NTD Ge thermistor
    $\Delta T \Rightarrow \Delta R$
    $\Rightarrow$ 0.1 mK/MeV -> 1mV/MeV
- Statistical fluctuation: $\sigma(E) = K_B C T^2 \sim 10$ eV
- Typical pulse decay time: $\tau \sim 10^{2\text{-}3}$ ms

- Active isotope: ^{130}Te
  - Natural abundance 33.9% $\Rightarrow$ low cost
  - Transition energy $Q_{\beta\beta} = (2528.8 \pm 1.2)$ KeV
    large phase space and low background
  - Predicted half life:

$$\langle m_\nu \rangle \approx 0.3\, eV \rightarrow \tau^{\beta\beta 0\nu} \approx 10^{25}\, y$$

- Absorber material: **TeO_2**
  - Low heat capacity
  - Possibility to grow large crystals
  - Good intrinsic radio-purity

Homogeneous Detector sensitivity

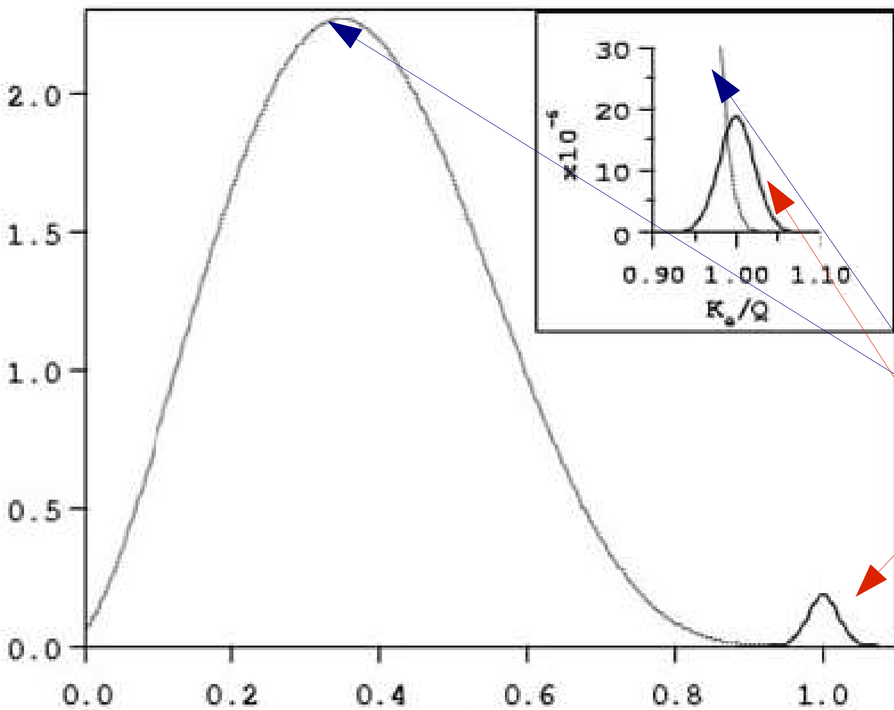
- Sensitivity $S^{\beta\beta0\nu}$: lifetime corresponding to the minimum number of detectable events above background @ a given C.L.

detector mass [kg] • measuring time [y]

$$S^{\beta\beta0\nu} \propto a \cdot \epsilon \cdot \left(\frac{M\,T}{\Gamma\,b} \right)^{1/2} \quad \Rightarrow \quad \langle m_{\beta\beta} \rangle \propto \frac{1}{(a\,\epsilon\,G)^{1/2} |M_{nucl}|} \cdot \left(\frac{b\,\Gamma}{M\,T} \right)^{1/4}$$

isotopic abundance • detector efficiency

energy resolution[keV] •bkgd [counts/keV/Kg/y]



Sum electron energy/total energy Q

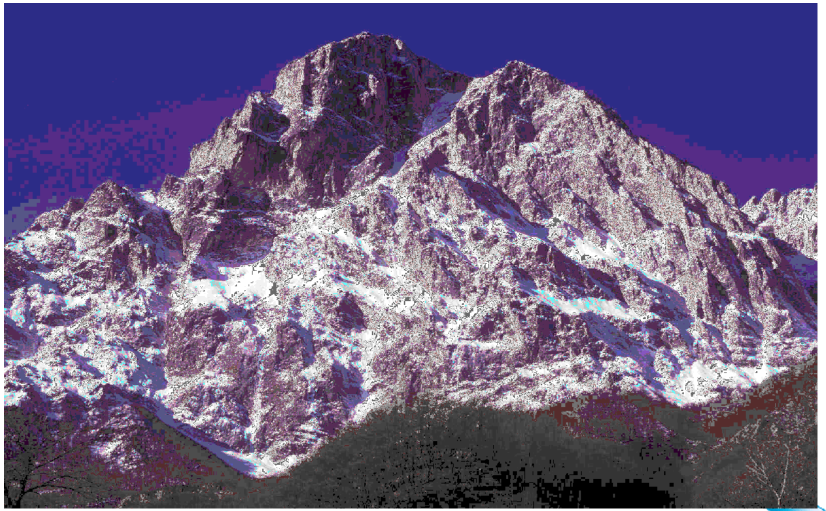
- Irreducible background from SM allowed ββ2ν:

$$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$$

- ββ2ν:continuum with maximum @ Q/3
- ββ0ν:sharp peak at Q_{max} smeared by detector resolution

- Look for (A-Z) even-even nuclei: ββ2ν suppressed
- Need **excellent ΔE resolution**

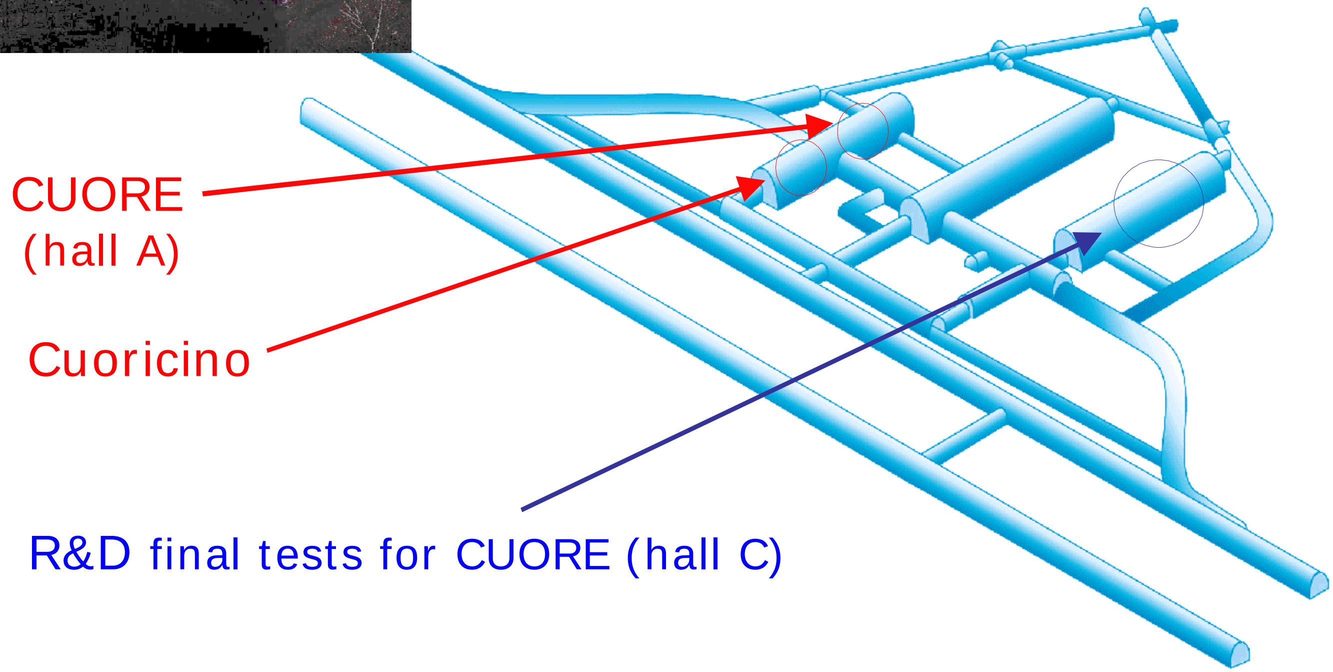
CUOR(ICINO) @ LNGS



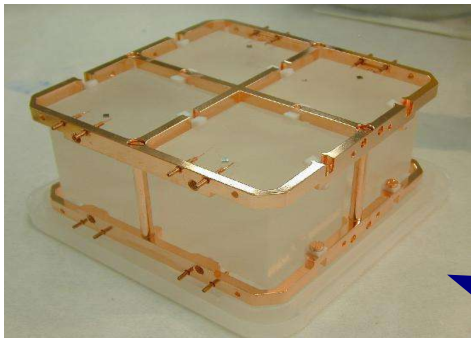
Cuoricino experiment is installed in the

Underground National Laboratory
of Gran Sasso
L'Aquila – ITALY

the mountain providing a **3500 m.w.e. shield** against cosmic rays



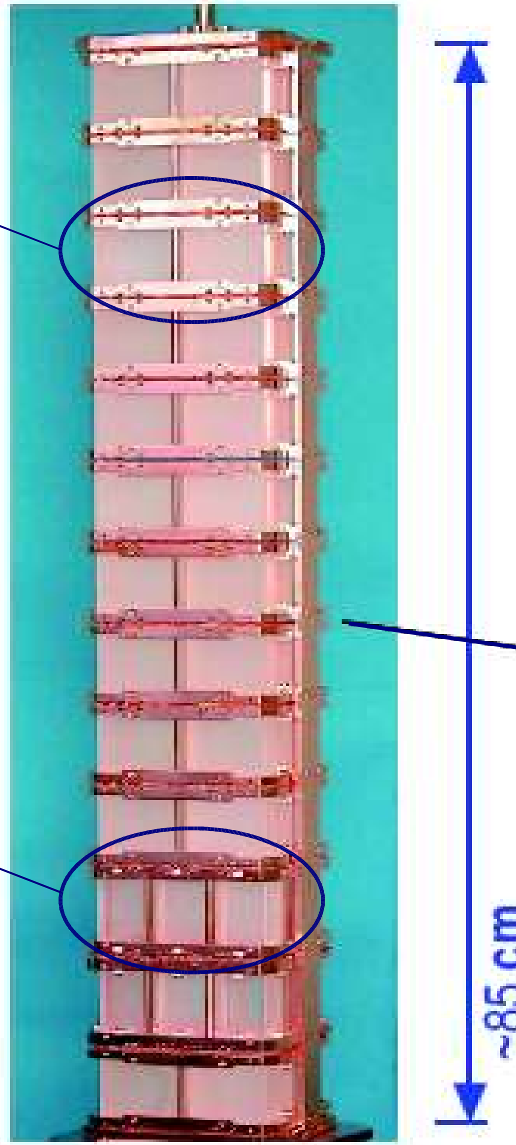
CUORICINO Tower

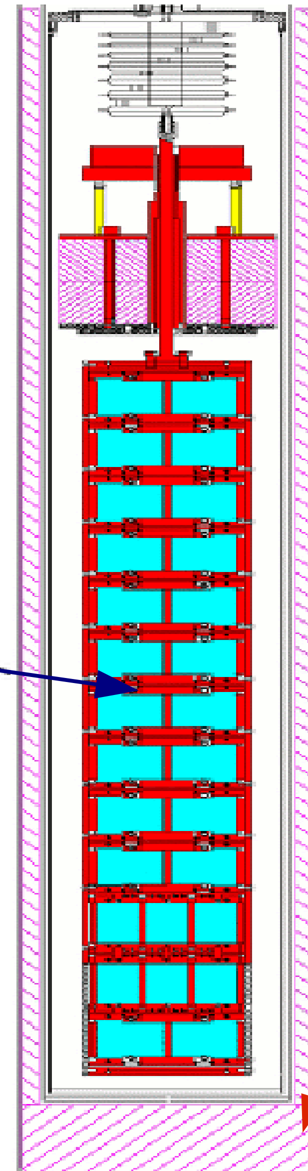


11 modules: 4 detector
5x5x5 cm^3=790 g each

2 modules 9 detector
3x3x6 cm^3=330 g each

4 enriched: 2 ^{130}Te + 2^{128}Te





Total Active mass:

- **TeO_2 = 40.7 Kg**
- **^{130}Te = 14.1 Kg**
- **^{128}Te = 0.54 Kg**

Installed in a dilution refrigerator (10 mK) surrounded by:

- **Roman Pb inner shield (1cm) lateral**
- **20 cm Pb external shield**
- **Neutron shield: B-polyethylene ~10 cm**
- **Anti-radon box: nitrogen overpressure**

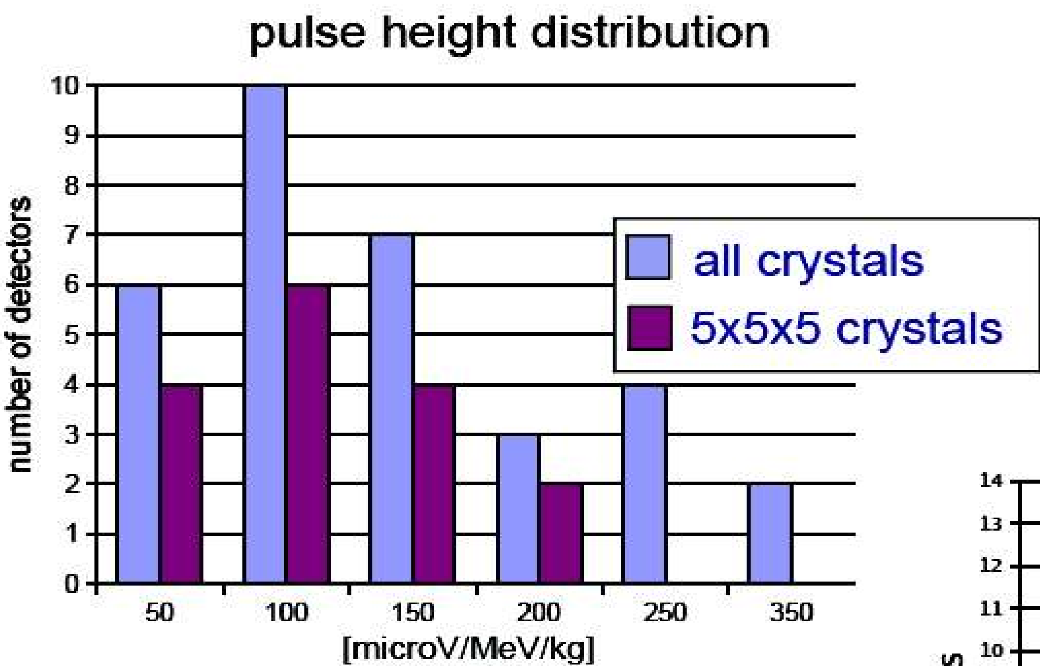
CUORICINO assembly

- **Careful material selection: crystals grown from pre-tested activity powders**
- **Careful cleaning of PTFE, Cu and TeO_2 surfaces**
- **Clean conditions for detector assembling**

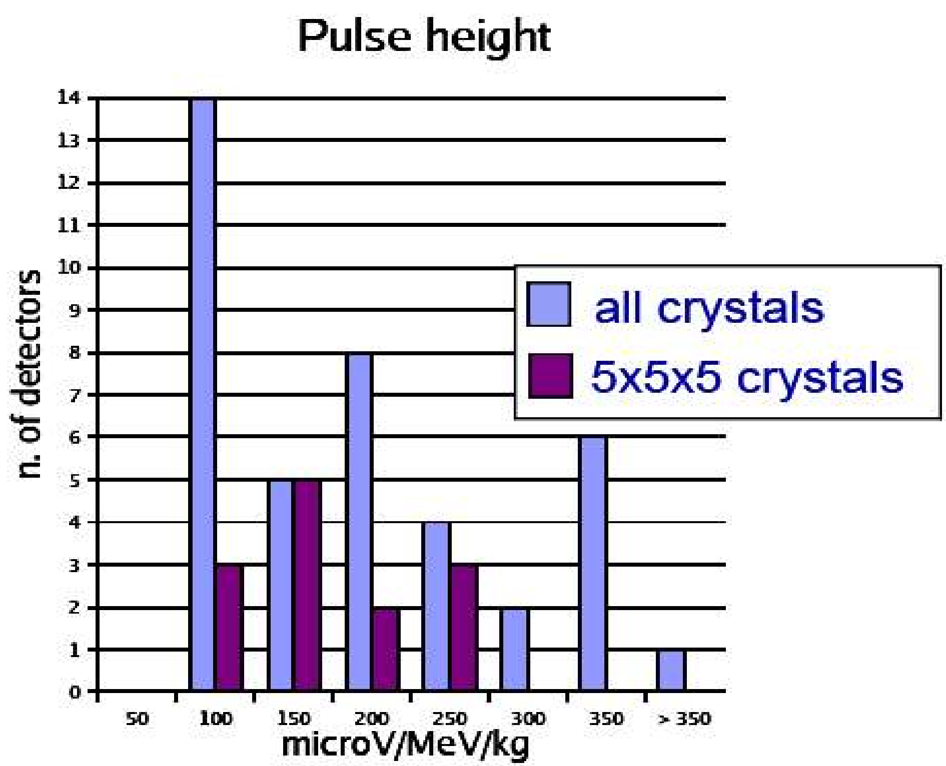
Data taking and performances

- **CUORICINO duty cycle: Source calibration Th wires ~3days**
  Bkgd measurements ~3-4weeks

live time ~64%



RUN I: February -November 2003
Cooling down problems:
some electrical connection lost
3x3x6 cm^3 (104±35) mV/MeV/Kg
5x5x6 cm^3 (120±75) mV/MeVKg

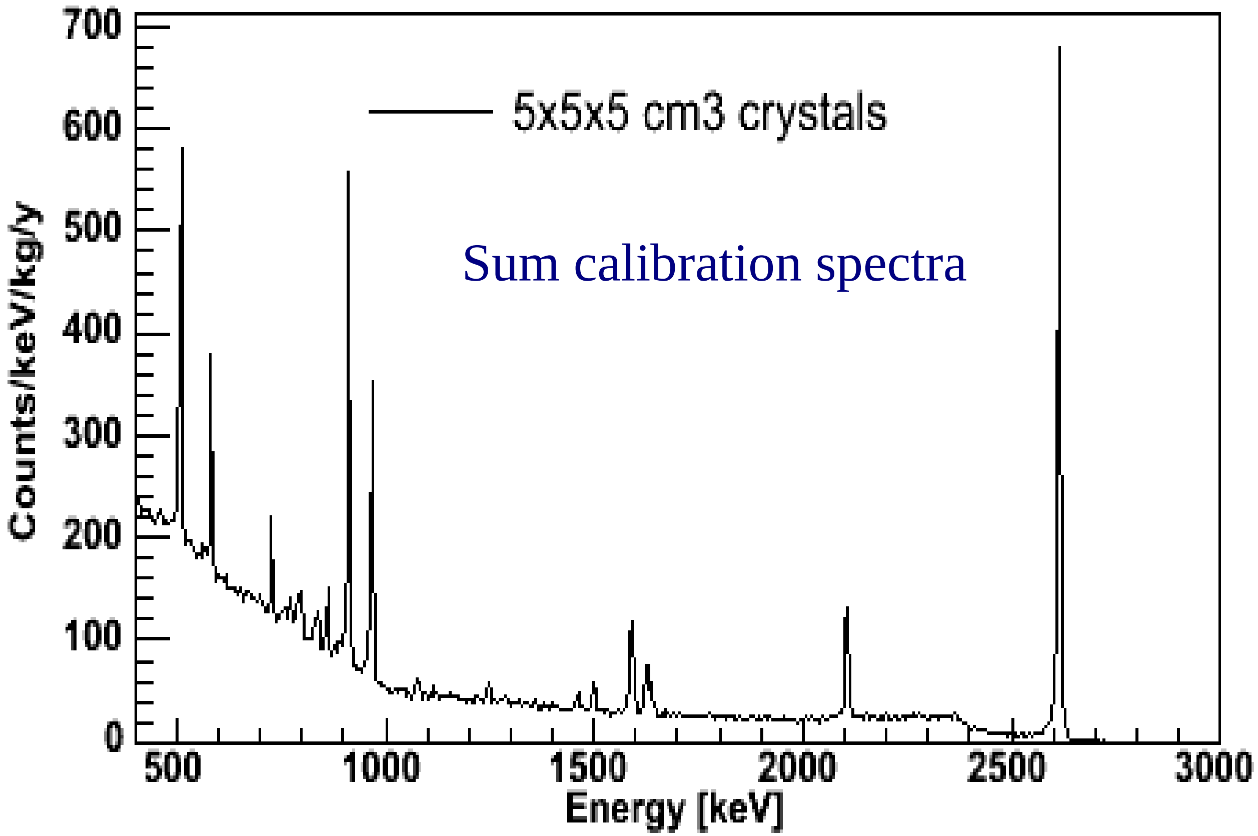


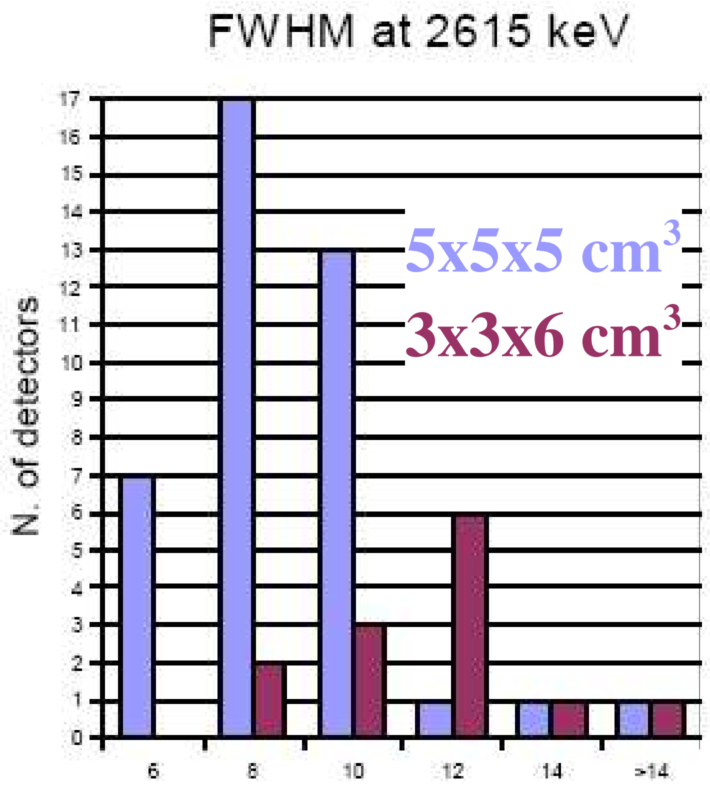
RUN II: May -December 2004
3x3x6 cm^3 (147±60) mV/MeV/Kg
5x5x6 cm^3 (167±99) mV/MeV/Kg

Calibration spectra: energy resolution

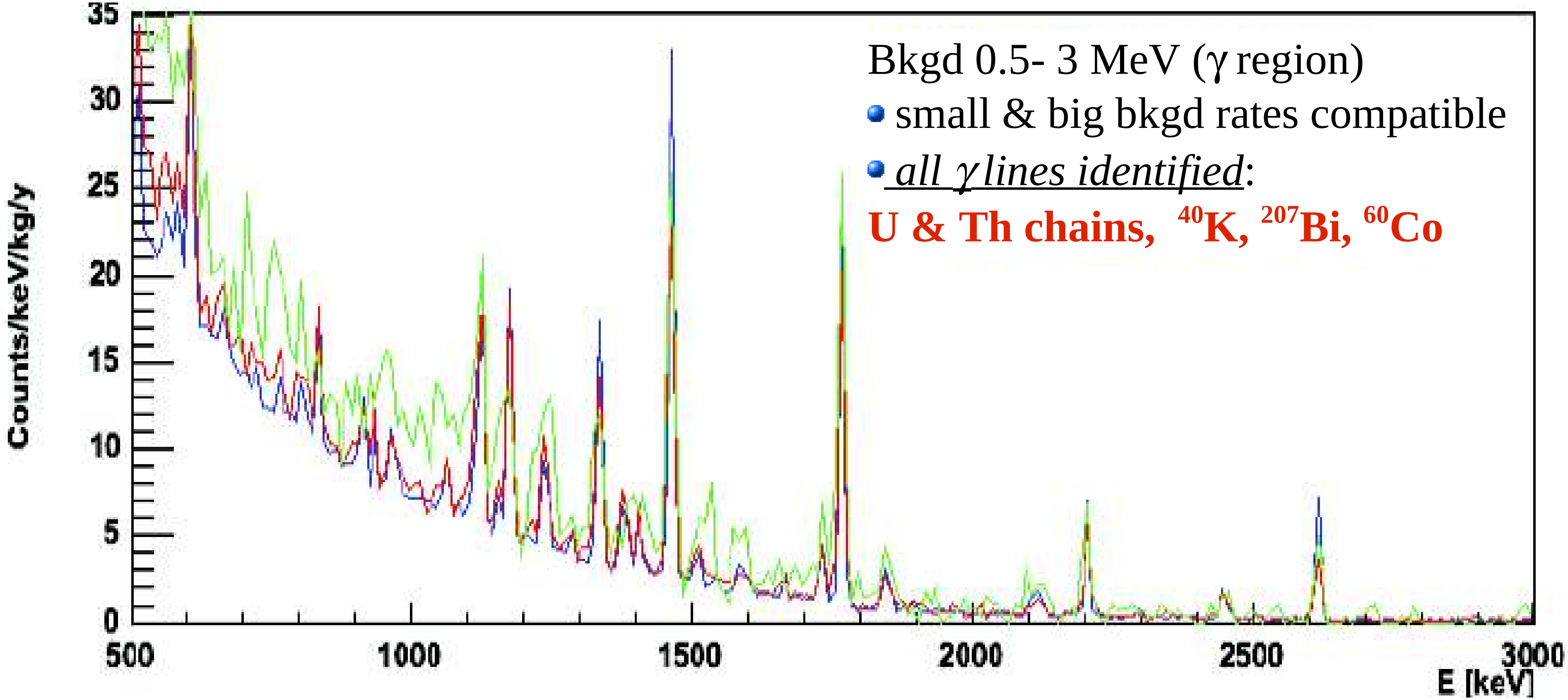
- ^{232}Th γ–source external to the cryostat:

<ΔE> @2615 KeV ^{208}Tl γ–line
average 5x5x5 cm^3 crystal: FWHM 7.5±2.9 KeV
average 3x3x6 cm^3 crystal: FWHM 9.6±2.5 KeV





Sum background spectra



Bkgd 0.5- 3 MeV (γ region)

- small & big bkgd rates compatible
- *all γ lines identified*:

U & Th chains, ^{40}K, ^{207}Bi, ^{60}Co

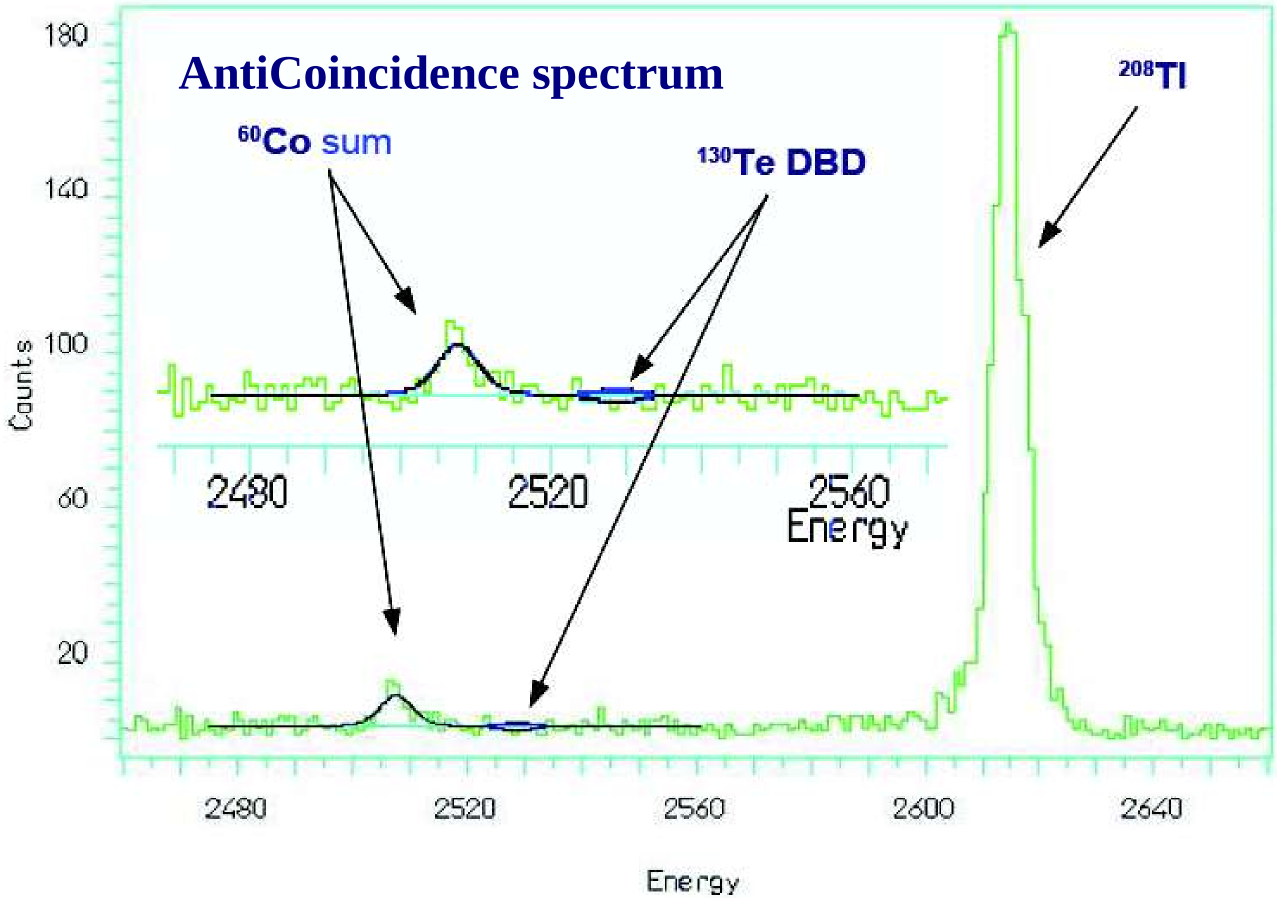
<ΔE> @2615 KeV

5x5x5 cm^3 crystal	4.3Kg ^{130}Te•y	FWHM ~7.5KeV
3x3x6 cm^3 natural crystal	0.5Kg ^{130}Te•y	FWHM ~12KeV
3x3x6 cm^3 enriched crystal	0.2Kg ^{130}Te•y	peak not visible

CUORICINO $\beta\beta0\nu$ result

hep-ex/0501034 accepted by PRL

- Total statistics: **5 Kg ^{130}Te•y**
- ML fit in **2470-2560 KeV** region
- **No peak found** @ $\beta\beta0\nu$ energy
- Bkgd ($\beta\beta0\nu$ region):
  0.18 ±0.01 c/keV/Kg/y
- Detector efficiencies: ~**86.4%**
- Fitting systematic error: **~5%**



$$\tau_{1/2}^{\beta\beta0\nu} > 1.8\cdot 10^{24}\, y\ @\ 90\, C.L. \quad \Rightarrow \quad \langle m_{\beta\beta0\nu}\rangle < [0.2 \div 1.1]\, eV$$

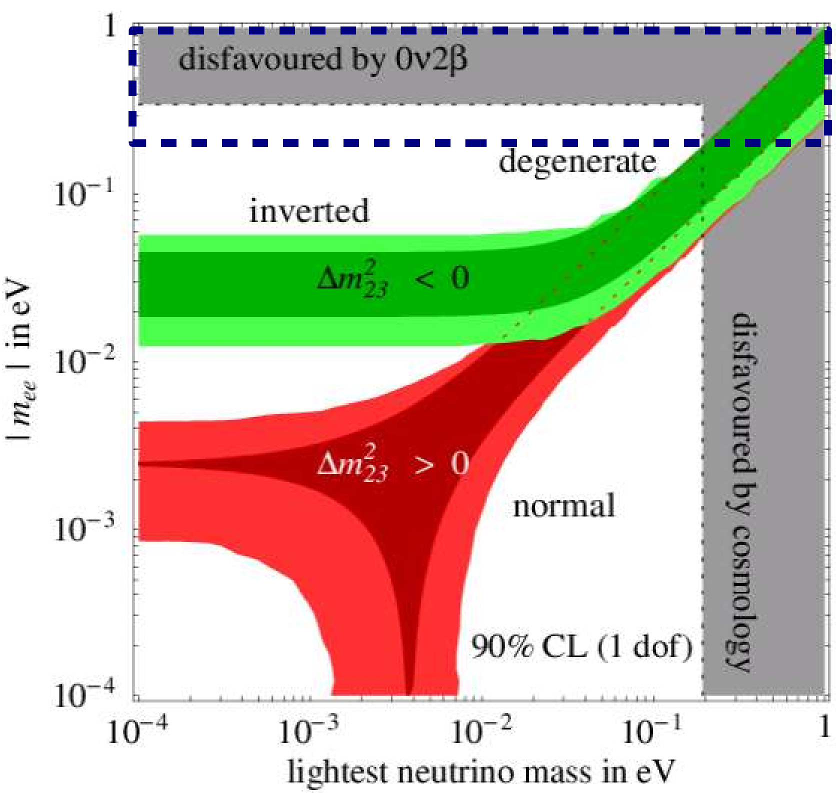
Expected sensitivity in 5 years : $\langle m_\nu \rangle < [0.07 \div 0.5]\, eV$

Spread due to NME uncertainties

CUORICINO sensitivity & discovery potential

CUORICINO results: $\langle m_{\beta\beta 0\nu} \rangle < [0.2 \div 1.1]\, eV$

Klapdor-Kleingrothaus HM: $\langle m_{\nu} \rangle < [0.1 \div 0.9]\, eV$ $\langle m_{\nu} \rangle = 0.44\, eV$



A. Strumia, F. Vissani hep-ph 05030246

- Could CUORICINO test HM result?

Nuclear Matrix Element **Staudit et al.**

Ref.:	(20)	(80)	(81)	(82)	(24,83)	(84)
Expected event number in 3 y in a 16 keV energy window (2 FWHM)	141	37	251	57	44	53
S/N ratio (σ)	7.4	2.0	13	3.0	2.3	2.8

1 σ BKG fluctuation = $(0.18 * 16 * 40.7 * 3)^{0.5} = 19$

- **Good chances to have a positive indication**
- **But : cannot falsify HM if no signal is seen**

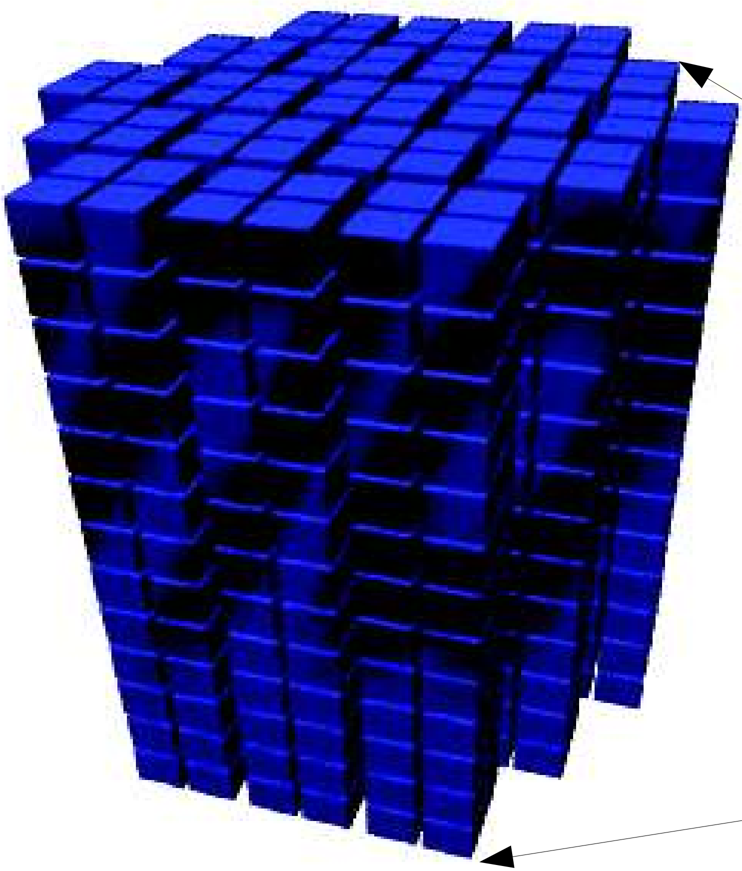
Cryogenic Underground Observatory for Rare Events

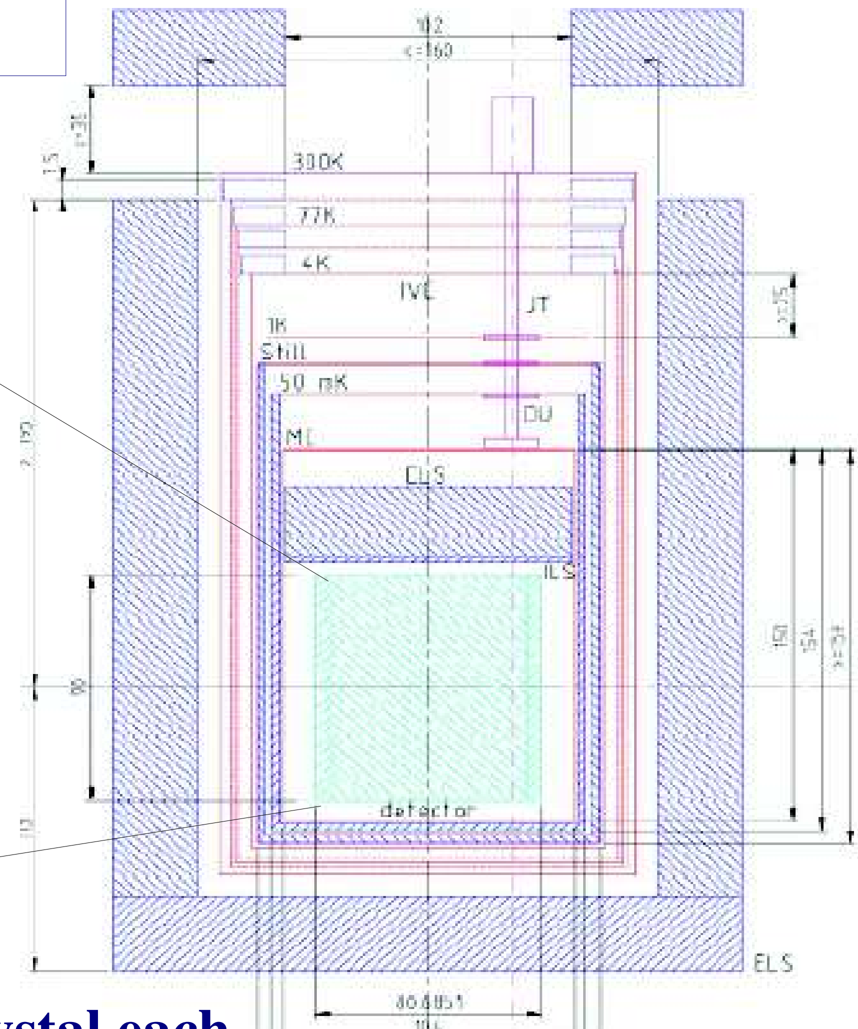
- ββ0ν, Cold Dark Matter, Axions searches   proposal hep/ph 0501010

Closed packed array of 988 TeO_2 5x5x5 cm^3 crystals

741 Kg TeO_2 ⇒ 203Kg ^{130}Te

Single dilution refrigerator
~10 mk

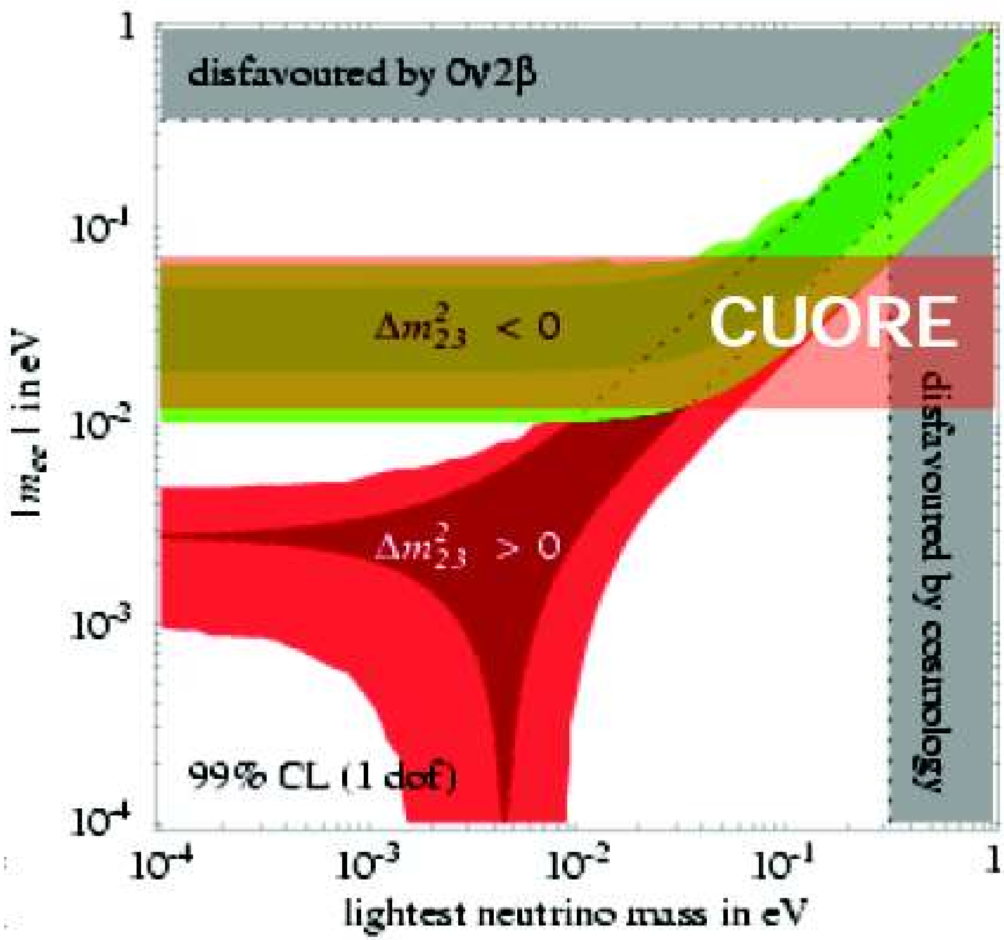




19 CUORICINO like towers: 13 planes of 4 crystal each

CUORE expected sensitivity

CUORE ββ0ν sensitivity will depend strongly on the bkgd level and detector performance



CUORE GOAL:
test inverse hierarchy: 10-50 meV

In five years of data taking

B(counts/keV/kg/y)	Δ(keV)	$T_{1/2}$(y)	$\lvert\langle m_\nu\rangle\rvert$ (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

Spread due to NME uncertainties: main obstacle to answer basic questions on ν nature

CUORICINO vs CUORE ββ0ν background

- **CUORICNO ββ0ν background:** *preliminary*
  - **~40% 2615keV ^{208}Tl line tail**: from **Th** chain via multi-Compton events. *Source located in the cryostat*
  - **~60% flat bkgd**: degraded α particles from **crystal surface(10%)** & **material facing crystals (50%)**
  - ~**negligible** contribution from 2515 KeV ^{60}Co tail due *Cu cosmogenic activation*

- **CUORE Evaluation (MonteCarlo simulation based on CUORICINO, miDBD, Ge measurements)**
  - **Neutron & environmental** background reduced by **lead and neutron shield**
  - **Cosmogenic Cu and Te activation** reduced by **underground storage of materials**
  - ββ2ν decay contribution < 10^{-3} **counts/kev/KeV/y**

  } **no problem**

  - **Bulk contaminations: Te0$_2$ ~10^{-13}g/g, Cu ~10^{-12}g/g** ⇒ $2 \bullet 10^{-3}$ **counts/kev/KeV/y**

  2615keV ^{208}Tl reduced by properly shielding in CUORE cryostat + selection of construction materials

  - **Surface contmination ~10^{-9}g/g for Te0$_2$& Cu** ⇒ $7 \bullet 10^{-2}$ **counts/kev/KeV/y** ← **problem!!**

  Reduced by **compact and granular** CUORE structure **(self-shielding detector)** but not enough

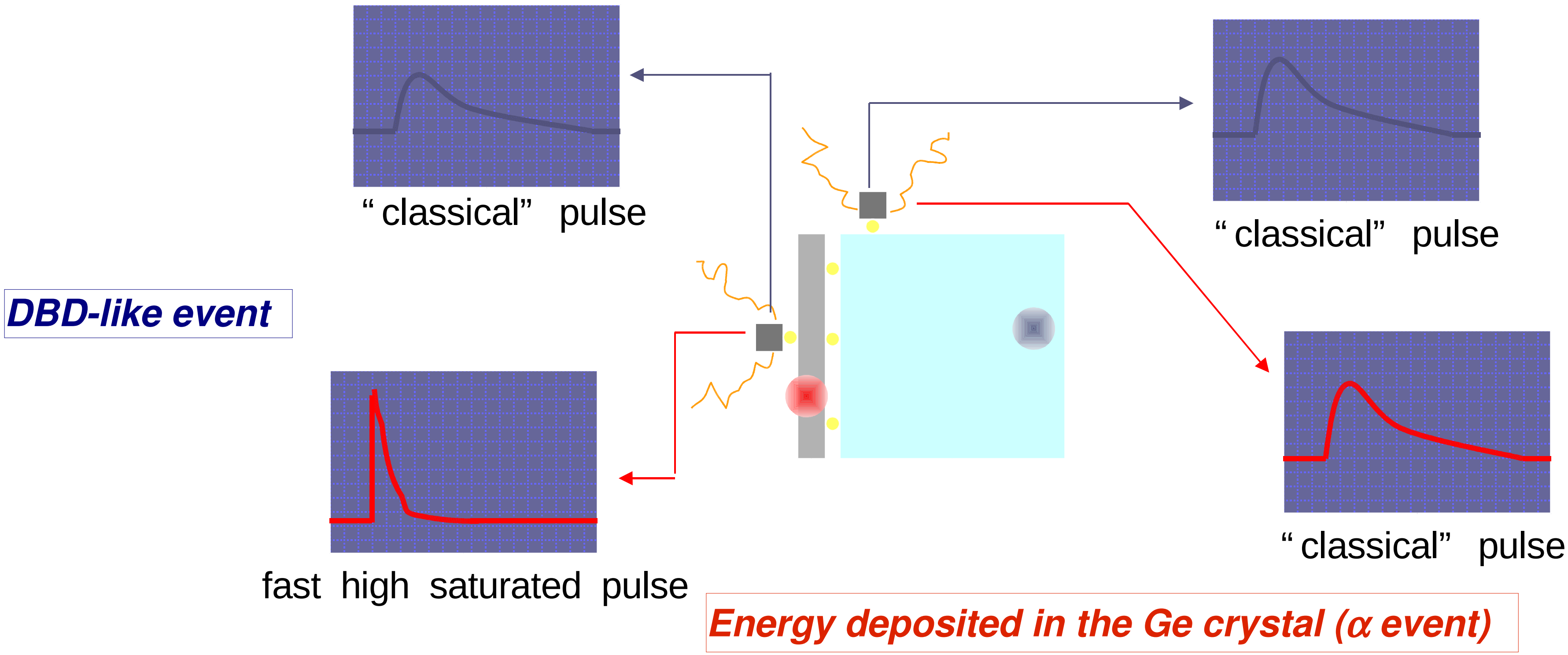
  to reach CUORE goal: require reduction factor 4 for Te0$_2$ & 10 for Cu surface

CUORE R&D

Cleaning test (Hall C Sept-Nov 2004):

- CU: etching, electro-polishing, passivation
- Crystal: etching (Nitric acid), lapping with clean powder (2μ SiO_2)
- New assembling procedure with selected materials
- Reduction of a factor 4 on crystal surface contamination(*CUORE milestone reached*) and a factor 2 on Cu surfaces (still a factor 5 missing)

- New passive procedure (plasma cleaning) & surface sensitive detectors development for active bkgd rejection *under test*



Conclusion

- CUORICNO:
  - The most sensitive ββ0ν decay running experiment:

$$\tau_{1/2}^{\beta\beta 0\nu} > 1.8 \cdot 10^{24}\, y\ @\ 90\, C.L. \quad \Rightarrow \quad \langle m_{\beta\beta 0\nu} \rangle < [0.2 \div 1.1]\, eV$$

  - Good chances to confirm KK-HM experiment
  - CUORICNO proved the feasibility of CUORE
  - Crucial informations for background identification

- CUORE:
  - Cryostat and hut construction will start soon
  - Intense R&D activity to reduce background and optimize construction and assembly
  - Enrichment option still open: only core (2^{nd} phase)
  - The inverse hierarchy will be explored
  - Start data taking: 1^{st} January 2010