二重ベータ崩壊実験のアップデート
― Neutrino 2008から ―

阪大･理

小川　泉

目次

1. Introduction
2. 現在進行中の実験
   – CUORECINO
   – NEMO-3
3. R&D段階の実験
   – COBRA
   – Kiev
   – MAJORANA
   – SNO+
4. 建設中の実験
   – CUORE-0
   – EXO-200
   – GERDA
5. CANDLES
6. まとめ

Introduction

ニュートリノ放出を伴わない二重β崩壊

- 観測されると…
  - ニュートリノはマヨラナ型である
  - 質量パラメータ

有効マヨラナニュートリノ質量

$$\left[T^{0\nu}_{1/2}(0^+ \to 0^+)\right]^{-1} = G^{0\nu}(E_0, Z)\left|M_{0\nu}\right|^2 \langle m_\nu \rangle^2$$

  - レプトン数保存則の破れ
    - レプトジェネシス

Sensitivity :当面の目標 IH

Regions Allowed by Neutrino Oscillation Data

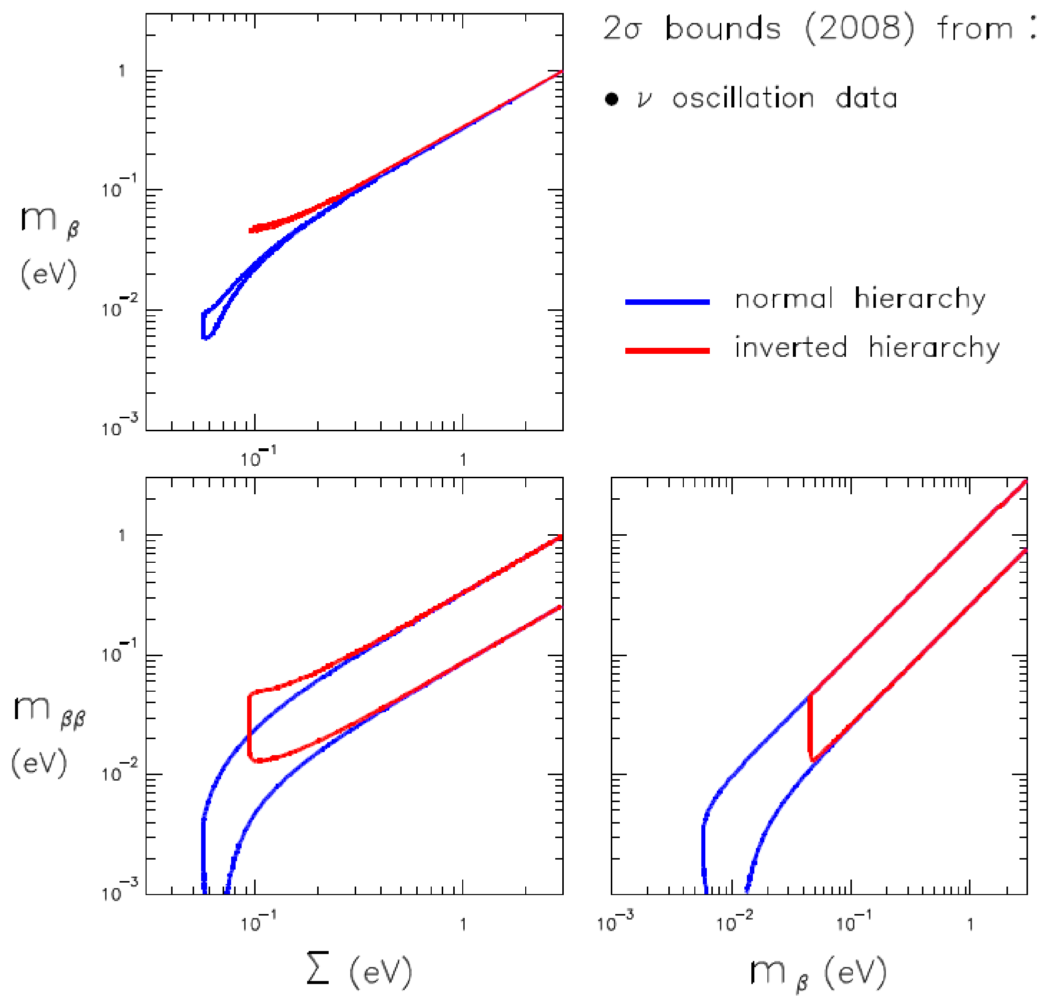


FIG. 3: Bands allowed at 2σ by neutrino oscillation data, in each of the three coordinate planes of the parameter space $(m_\beta, m_{\beta\beta}, \Sigma)$, for both normal and inverted hierarchy.

Double beta decay isotopes

isotope	Q (keV)	ab.(%)	isotope	Q (keV)	ab.(%)	isotope	Q (keV)	ab.(%)	isotope	Q (keV)	ab.(%)
46Ca	990.4	0.004	98Mo	112	24.13	130Te	2529	34.08	170Er	654	14.93
48Ca	4272	0.187	100Mo	3034	9.36	134Xe	830	10.44	176Yb	1087	12.76
70Zn	1001	0.62	104Ru	1300	18.62	136Xe	2468	8.87	186W	488	28.43
76Ge	2039	7.61	110Pd	2000	11.72	142Ce	1417	11.114	192Os	414	40.78
80Se	134	49.61	114Cd	537	28.73	146Nd	70	17.2	198Pt	1047	7.163
82Se	2995	8.73	116Cd	2805	7.49	148Nd	1929	5.7	204Hg	416	6.87
86Kr	1256	17.3	122Sn	366	4.63	150Nd	3368	5.6	232Th	842	100
94Zr	1144	17.4	124Sn	2287	5.79	154Sm	1251	22.75	238U	1145	99.28
96Zr	3350	2.8	128Te	867	31.74	160Gd	1730	21.86			

(pink) $Q > 3.3$ MeV ; $Q_\beta(^{214}\mathrm{Bi})=3.27$ MeV

V.I. Tretyak and Y.G. Zdesenko 2002

(yellow) $Q > 1.7$ MeV

Present Limits for 0ν double beta decay

Candidate nucleus	Detector type	(kg yr)	Present $T_{1/2}^{0\nu\beta\beta}$ (yr)	<m> (eV)
^{48}Ca			$>1.4*10^{22}$ (90%CL)	
^{76}Ge	Ge diode	~47.7	$>1.9*10^{25}$ (90%CL)	<0.35*
^{82}Se			$>1*10^{23}$ (90%CL)	
^{100}Mo			$>4.6*10^{23}$ (90%CL)	
^{116}Cd			$>1.7*10^{23}$ (90%CL)	
^{128}Te	TeO_2 cryo		$>1.1*10^{23}$ (90%CL)	
^{130}Te	TeO_2 cryo	~12	$>3*10^{24}$ (90%CL)	<0.19 - 0.68
^{136}Xe	Xe scint	~4.5	$>1.2*10^{24}$ (90%CL)	<1.1 - 2.9
^{150}Nd			$>1.2*10^{21}$ (90%CL)	
^{160}Gd			$>1.3*10^{21}$ (90%CL)	

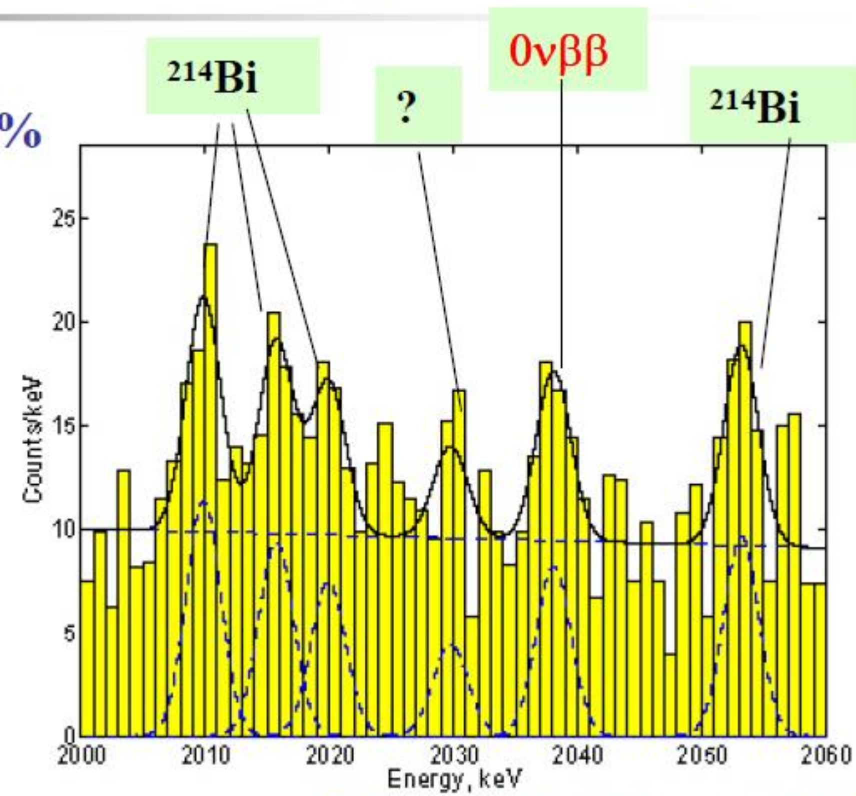
** But also claim of signal by part of same group (see Cattadori's talk)*

Heidelberg-Moscow experiment @ LNGS: claim of evidence of $0\nu\beta\beta$ of ^{76}Ge (2004)

MT = 10.9 kg (86% ^{76}Ge) x 13 yr x 0.8% = 72 kg yr

b = 0.11 cts/(kg keV yr) before PSA

Resolution ΔE = 3.27 keV



Claimed evidence of $0\nu\beta\beta$ @ 4.2 σ

$T_{1/2}$ = 1.2 x 10^{25} y

Corresponding to

M_{ee} = 440 meV with KK ME

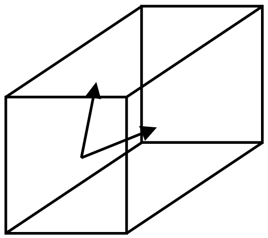
Signal found at

$Q_{\beta\beta}^{exp}$ = 2038.70 ± 0.44 keV

$Q_{\beta\beta}^{theo}$ = 2039.06 ± 0.05 keV

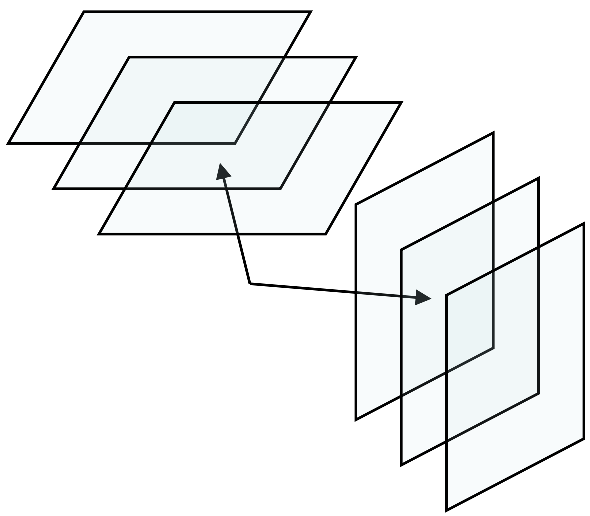
検出器タイプ

- 線源と検出器が一体
  - シンチレーター(シンチレーション光)
  - 半導体検出器（イオン化電子空孔対）
  - ボロメーター
    - エネルギーを温度上昇で測定



高効率、高エネルギー分解能

- 線源と検出器が別
  - 軌跡検出器
    - エネルギーを軌跡検出器で測定



ノイズを効率的に落とせる

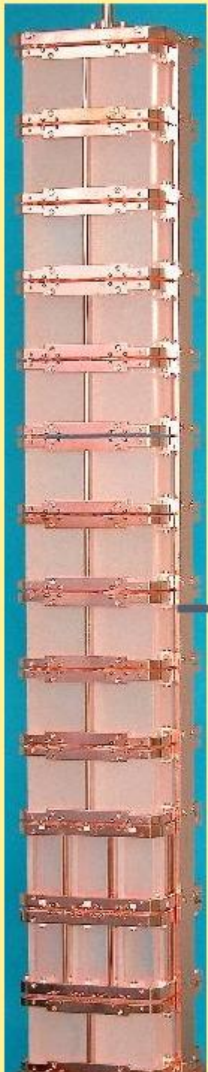
Experimental projects

Project	Target	Detector type	Status
CANDLES	^{48}Ca	Scintillator	Constructing (III地下)
COBRA	^{116}Cd	Semiconductor	R&D
CUORE	^{130}Te	Bolometer	CUORICINO…running CUORE-0…constructing
DCBA	^{150}Nd	Tracking	R&D
EXO	^{136}Xe	Liq. Xe TPC 他	EXO-200…constructing
GERDA	^{76}Ge	Semiconductor	Phase-I … constructing
MAJORANA	^{76}Ge	Semiconductor	R&D
Kiev	^{100}Mo, ^{116}Cd,..	Scintillator	R&D
MOON	^{100}Mo	Tracking	R&D
NEMO	^{82}Se, ^{100}Mo,…	Tracking	NEMO-3…running Super-NEMO… R&D
SNO+	^{150}Nd	Liquid scintillator	R&D
XMASS	^{136}Xe	Gas scintillator	R&D

現在稼働中の実験

- CUORICINO
- NEMO-3

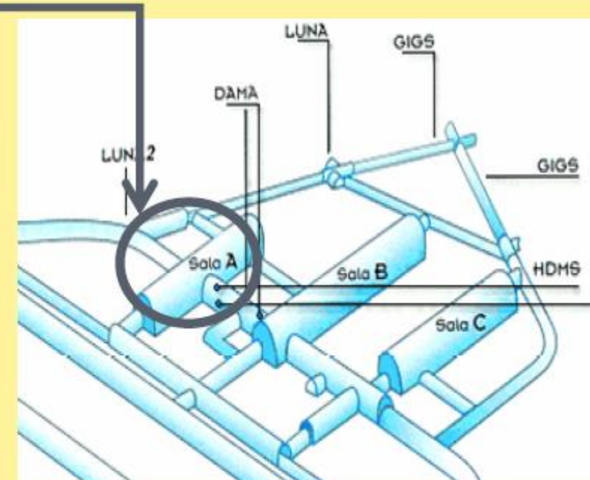
CUORICINO: the present



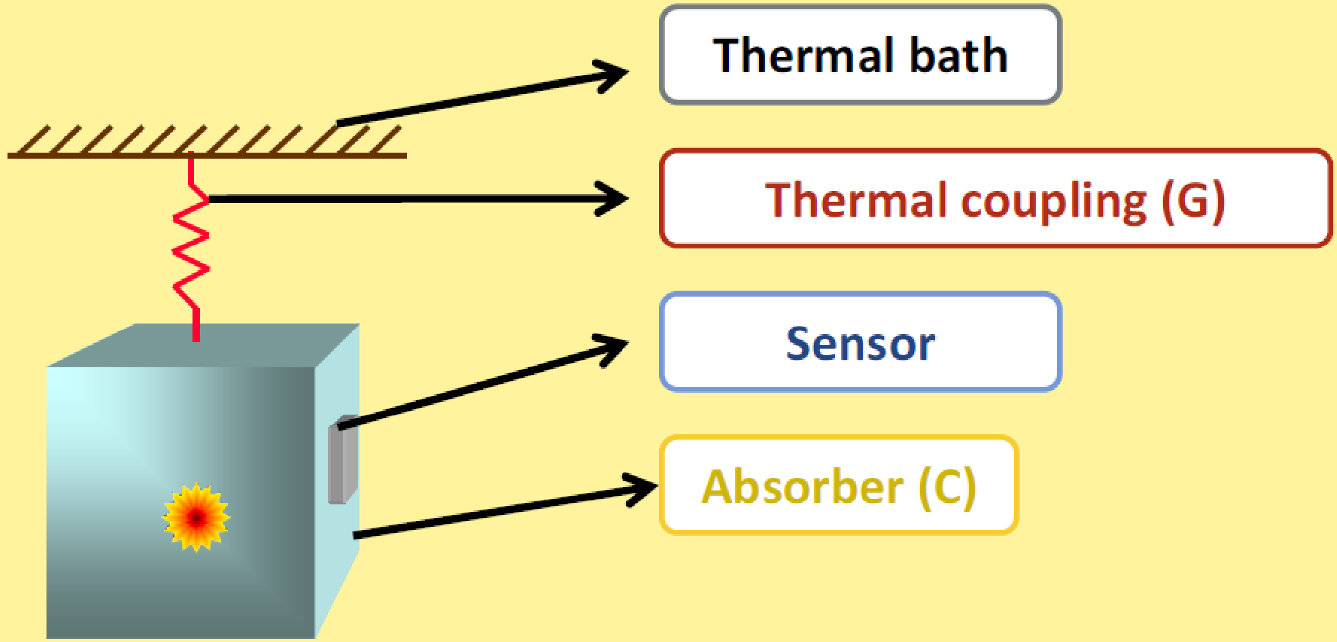
Isotope: ^{130}Te	Modules
• High natural abundance (33.9%) • High Q-value (2530keV) almost out of γ-bkg	• 11 modules of 4 crystals each 5x5x5 cm^3 • 2 modules for 9+9 3x3x6 cm^3 crystasls

Absorber: TeO_2	Active Mass
• Low thermal capacity • Big crystals available • Very high radiopurity	• 40.7 kg TeO_2 • 11.2 kg ^{130}Te • 5 x 10^{25} nuclei ^{130}Te

Laboratori Nazionali del Gran Sasso: 3500 m.w.e.



Bolometers as True Calorimeters

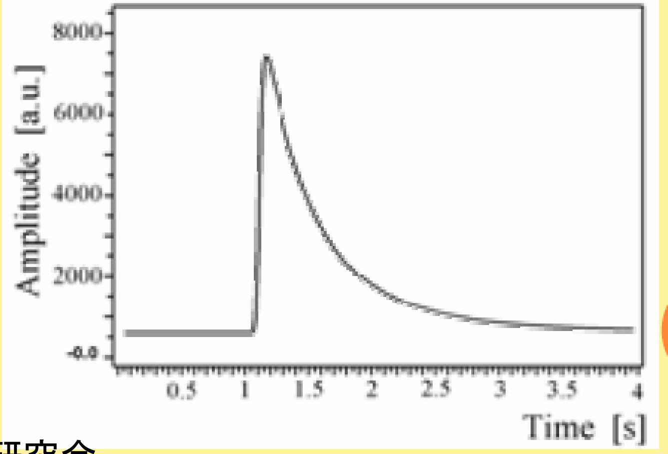


Basic Physics: $\Delta T = E/C$

Implication: Low C ⍰ Low T

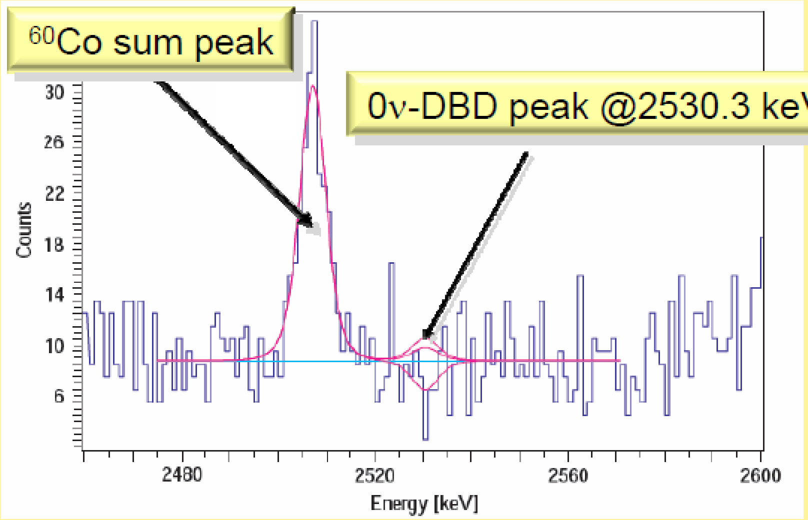
Bonus: (almost) No limit to ΔE ($k_B T^2 C$)

Not for all : $\tau = C/G$ R1s



2

CUORICINO: an update



*Anticoincidence background spectrum: the **bb**-0**n** region*

Total statistic ~ 15.53 kg (^{130}Te) × y
data analyzed up to August 2007

b = 0.18 ± 0.01 c/keV/kg/y

Maximum Likelihood
flat background + fit of 2505 peak

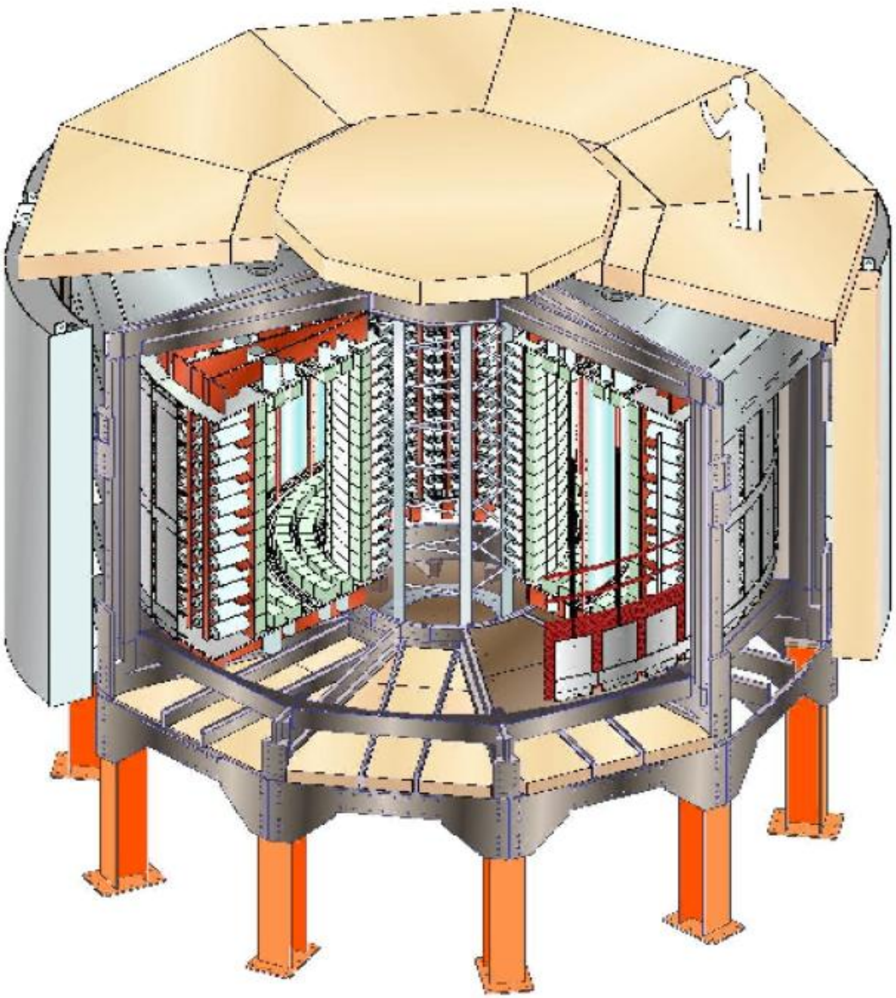
$$\tau^{0\nu}_{1/2} \geq 3.1 \cdot 10^{24}\ y\ (90\%\ CL)$$

$$\Rightarrow \langle m_\nu \rangle \leq 200 - 680\ meV^{*}$$

8

* Dependent on the value for the nuclear matrix elements

Fréjus Underground Laboratory : 4800 m.w.e.



Source: 10 kg of ββ isotopes
cylindrical, S = 20 m², d ~ 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

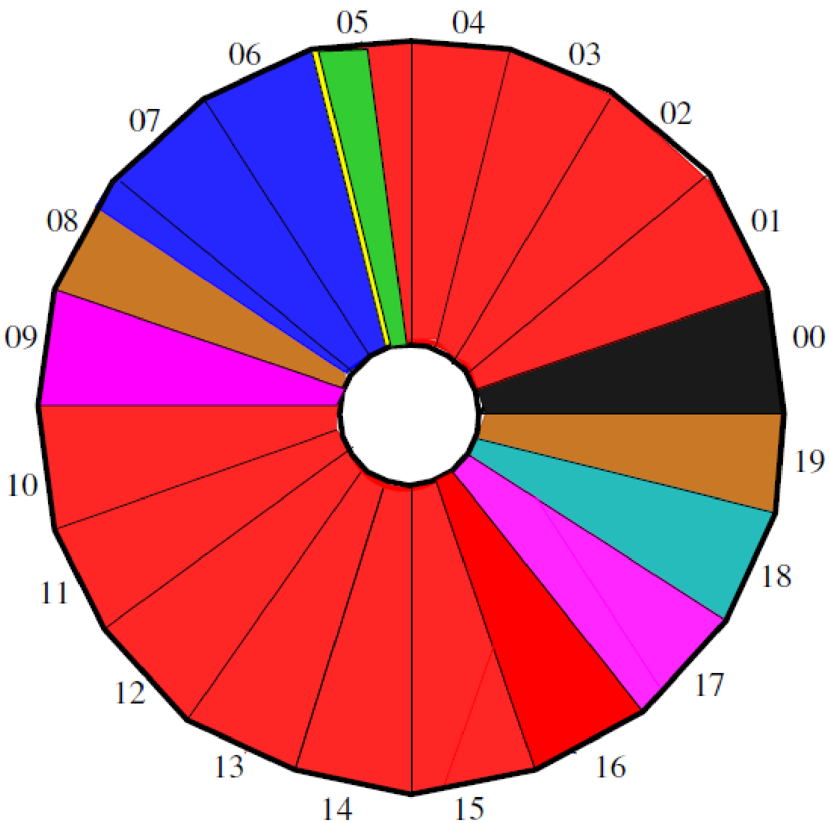
Calorimeter:
1940 plastic scintillators
coupled to low radioactivity PMTs

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

Particle ID: e^-, e^+, γ and α

4

ββ decay isotopes in NEMO-3 detector



^{100}Mo 6.914 kg
$Q_{\beta\beta}$ = 3034 keV

^{82}Se 0.932 kg
$Q_{\beta\beta}$ = 2995 keV

ββ0ν search

ββ2ν measurement

^{116}Cd 405 g
$Q_{\beta\beta}$ = 2805 keV

^{96}Zr 9.4 g
$Q_{\beta\beta}$ = 3350 keV

^{150}Nd 37.0 g
$Q_{\beta\beta}$ = 3367 keV

^{48}Ca 7.0 g
$Q_{\beta\beta}$ = 4272 keV

New Results

^{130}Te 454 g
$Q_{\beta\beta}$ = 2529 keV

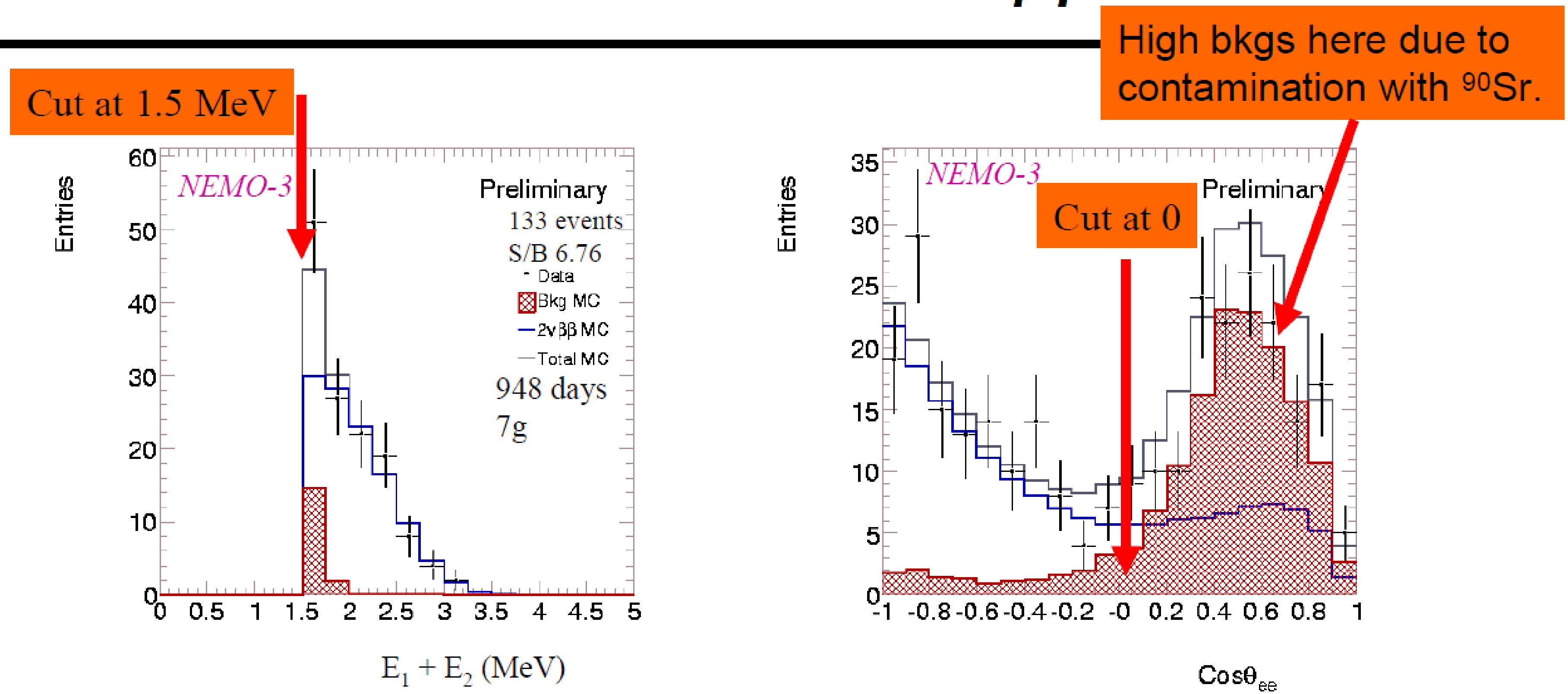
^{nat}Te 491 g

Cu 621 g

External bkg measurement

(Enriched isotopes produced by centrifugation in Russia)

New result: ^{48}Ca ββ

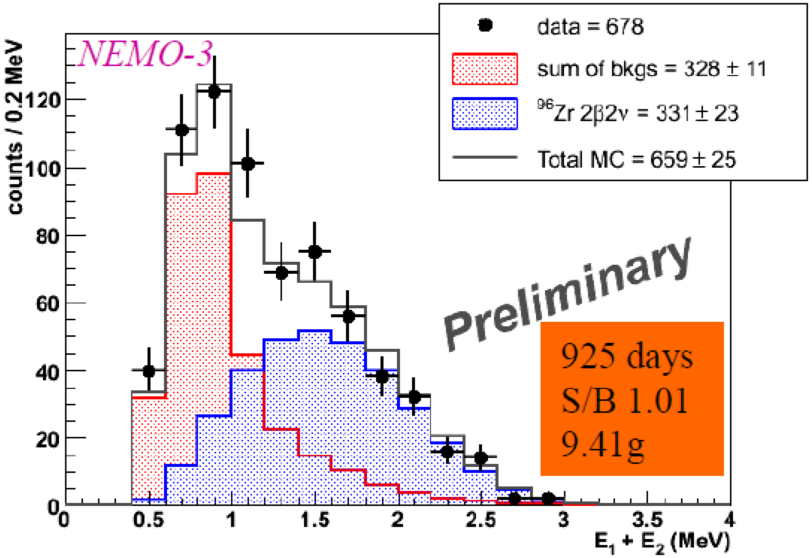


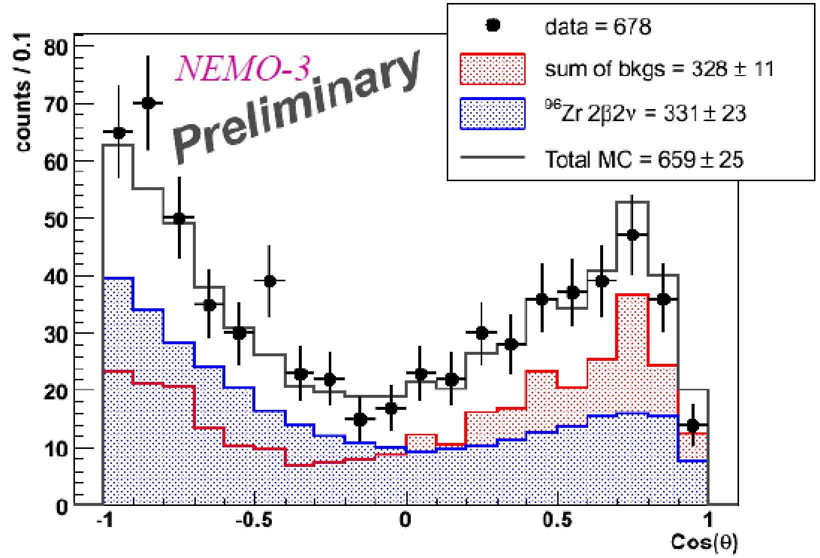
Preliminary results: $T_{1/2}$ (2νββ) = [4.4 $^{+0.5}_{-0.4}$ (stat) ± 0.4 (syst)] x 10^{19} y

$T_{1/2}$ (0νββ) >1.3 x10^{22} y (90% C.L) ➡ <m_ν> < 29.6 eV (90%CL), Eff. 22%

Refs: E Caurrier et al., Phys. Rev. Lett. 100 (2008) 052503 (NME)

New result: ^{96}Zr 2νββ





Preliminary result:

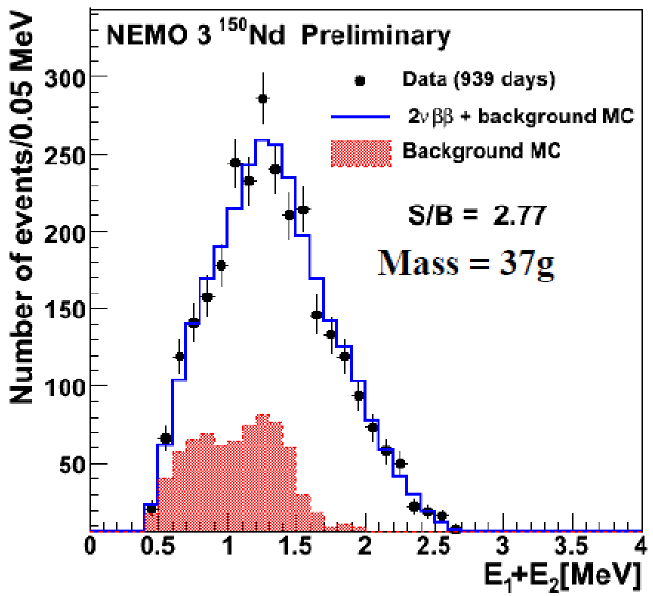
^{96}**Zr:** $T_{1/2}(2\nu\beta\beta) = [2.3 \pm 0.2(\text{stat}) \pm 0.3(\text{syst})] \times 10^{19}$ y

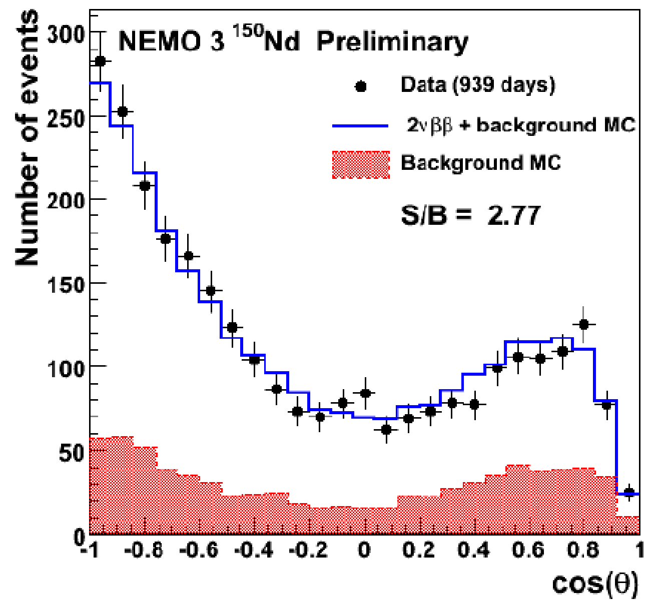
$T_{1/2}(0\nu\beta\beta) = 8.6 \times 10^{21}$ y (90% C.L) ➡ $<m_\nu> < 7.4 - 20.1$ eV (90%CL), Eff. 19%

Refs for NME : Simkovic, et al., Phys. Rev. C 77 (2008) 045503

Kortelainen and Suhonen, Phys. Rev. C 76 (2007) 024315

Recent result: ^{150}Nd 2νββ (Moriond)





Preliminary results: $T_{1/2}$ (2νββ) = [9.20 $^{+0.25}_{-0.22}$ (stat) ± 0.62 (syst)] x 10^{18} y

Expected $T_{1/2}$ (0νββ) = 1.45 x 10^{22} y

Observed $T_{1/2}$ (0νββ) = 1.8 x 10^{22} y (90% C.L.) Eff. 19%

<m_ν> < 1.7 – 2.4 eV (90%CL), QRPA (2007, corrected paper compared to 2006) deformation not taken into account

<m> < 4.8-7.6 eV: pseudo-SU(3) Hirsh (95) deformation taken into account

Ref for NME : V. Rodin et al., Nucl. Phys. A 793 (2007) 213.
J.H. Hirsch et al., Nucl. Phys. A 582 (1995) 124.

12

R&D段階の実験

- COBRA
- Kiev
- MAJORANA
- SNO+

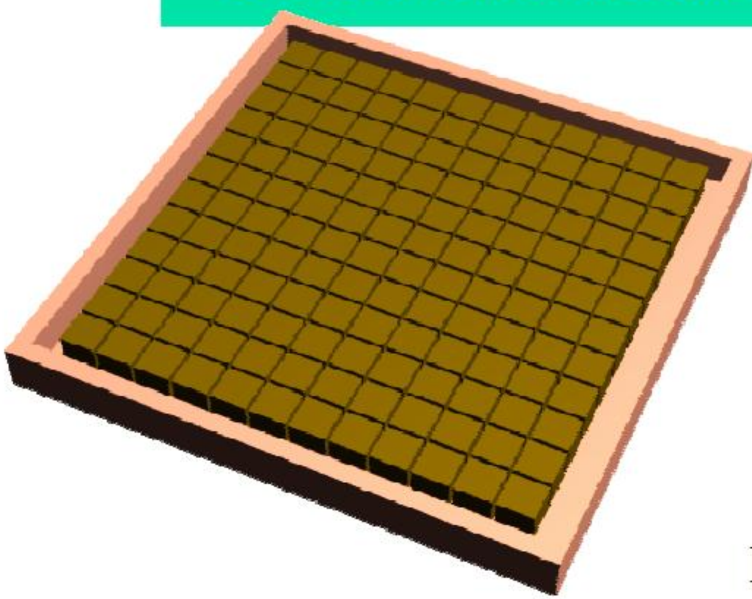
COBRA

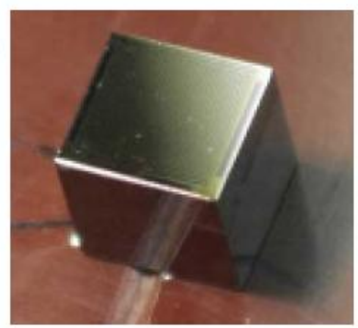
http://cobra.physik.uni-dortmund.de

Slides courtesy of Kay Zuber.

Location LNGS

Use large amount of CdZnTe Semiconductor Detectors

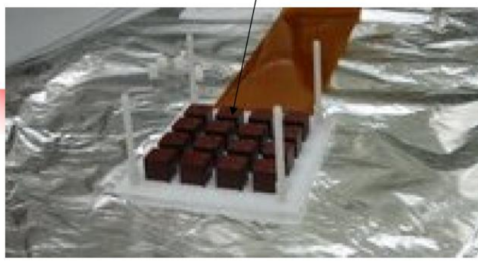


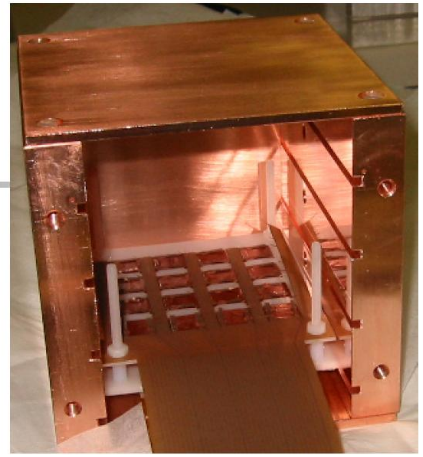


Large array of CdZnTe detectors

K. Zuber, Phys. Lett. B 519,1 (2001)

The first layer(16 detectors, 1 cm^3 , 6.4 g each) of CdZnTe array: full array 64 detectors

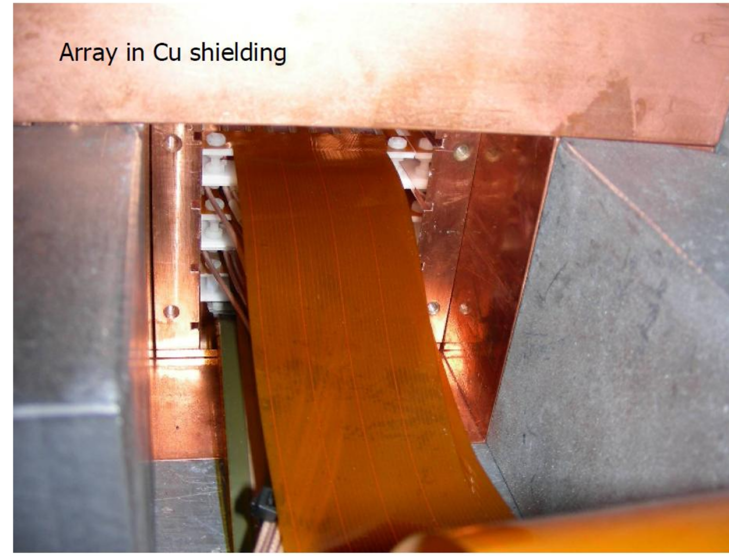




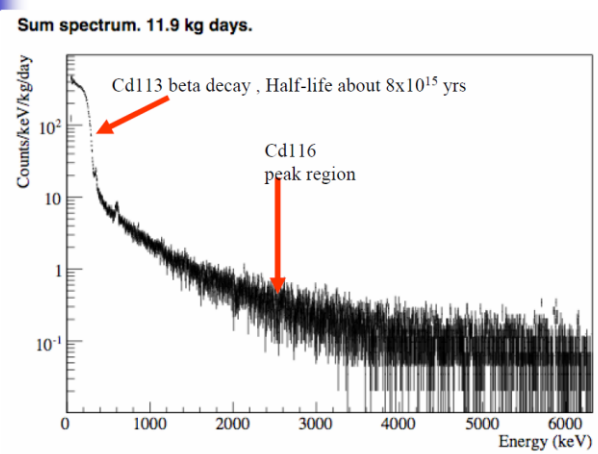
Readout: Energy

Started installation at LNGS in april 2006, world wide largest array of this type of detector

64 detector array (Oct. 07)

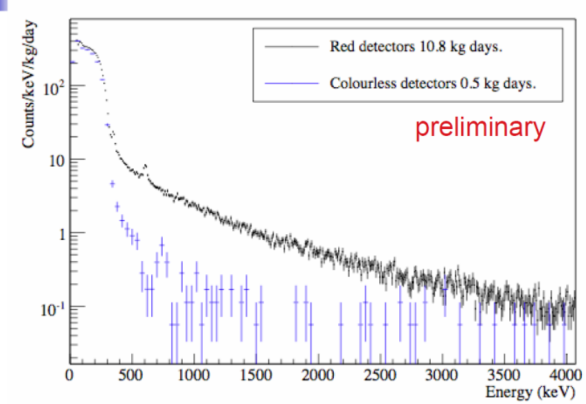


Sum spectra of first 16 detectors



Dominated by radon in air and red passivation on detector surface

Alternative painted detectors (four 1 cm^3 CdZnTe)

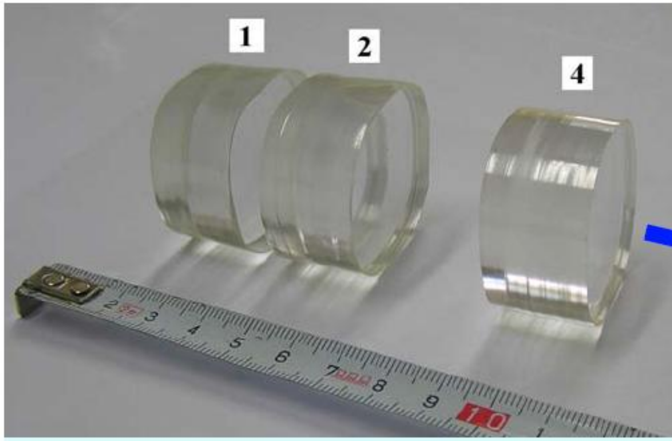


blue= colourless painted detectors + nitrogen flushing
black = 16 layer with red passivation + air

Kiev group

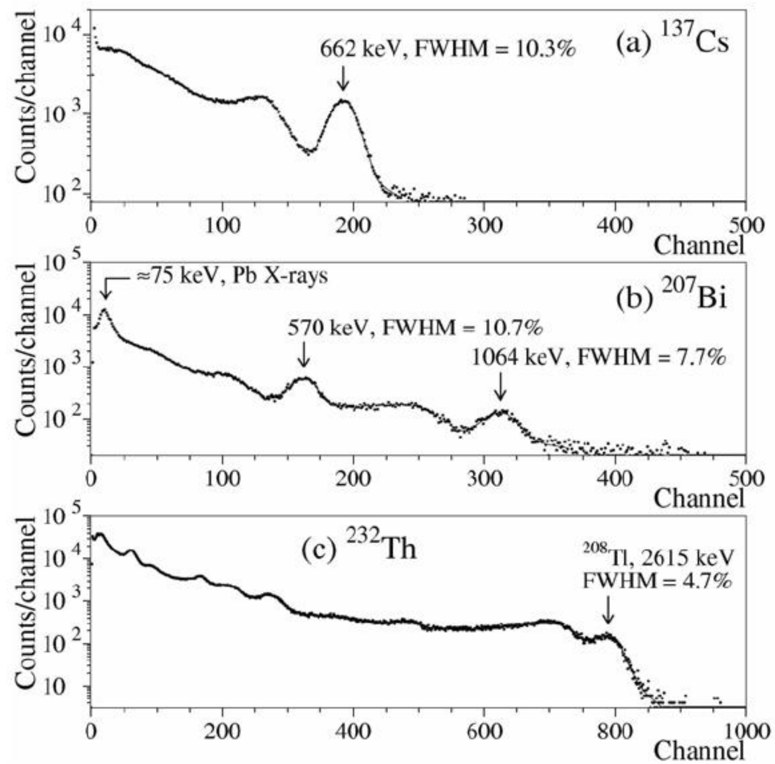
- Experiments developed and/or considered in the past with different scintillating crystals with different isotopes
  - e.g. CAMEO, CARVEL, etc.
  - possible deployment of crystals in large, existing detectors (e.g. Borexino, SNO)
- Currently the following scintillating crystals (and experiments) are being developed
  - $^{116}CdWO_4$ — ^{116}Cd, Q-value = 2.80 MeV
    also ^{106}Cd $\beta^+\beta^+$decay, Q-value = 2.77 MeV
  - $CaMO_4$ — ^{100}Mo, Q-value = 3.03 MeV
  - $ZnWO_4$ — ^{64}Zn, Q-value = 1.10 MeV

$CaMoO_4$ crystal scintillators
2β decay of ^{100}Mo



CARAT, Lviv, Ukraine

ICMSAI, Moscow, Russia



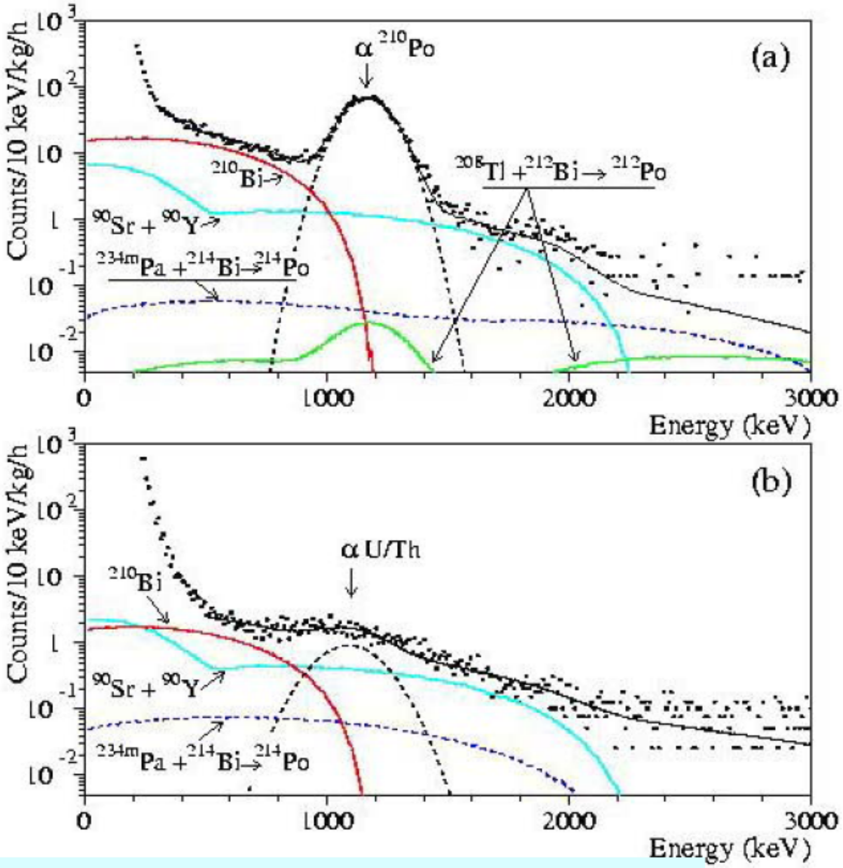
Energy resolution FWHM=10.3% for 662 keV γ line of ^{137}Cs was obtained with $CaMoO_4$ crystal scintillators produced by CARAT

NIMA 584 (2008) 334

22

$CaMoO_4$ radiopurity

CARAT, Lviv, Ukraine



ICMSAI, Moscow, Russia

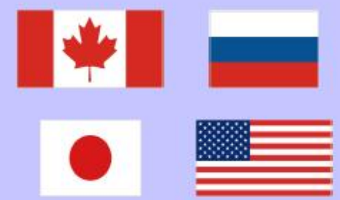
NIMA 584 (2008) 334

Source	Activity (mBq/kg) CARAT	ICMSAI
^{232}Th	< 0.7	< 1.5
^{228}Th	0.2-0.4	0.04
^{238}U	< 0.5	< 1.5
^{226}Ra	2.1-2.5	0.13
^{210}Pb	< 400	< 17
^{210}Po	400-500	< 8
^{40}K	< 1 - <3	< 3
^{90}Sr	<60 - <180	< 23

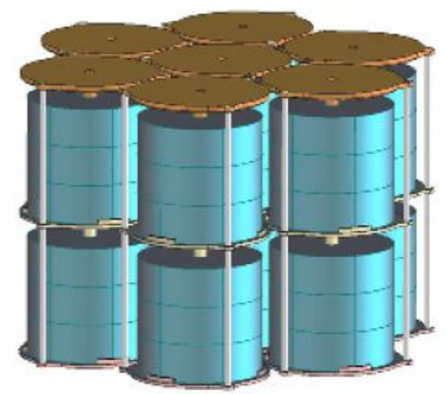
measured in the Solotvina Underground Lab

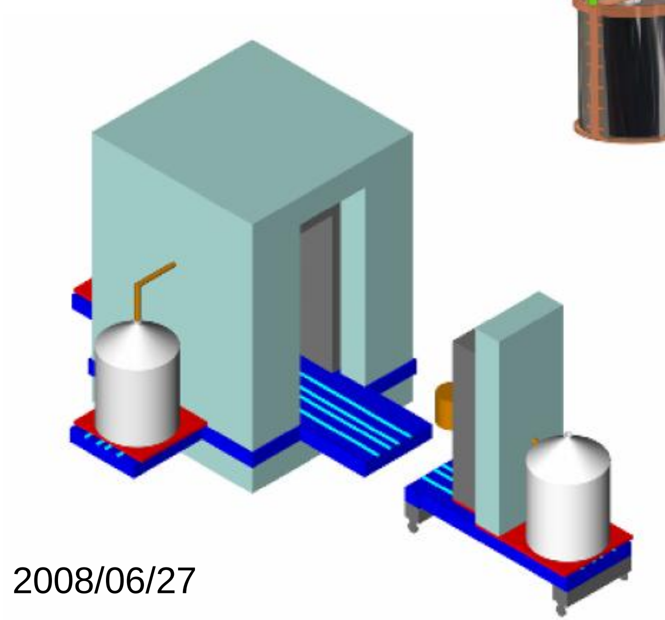
23

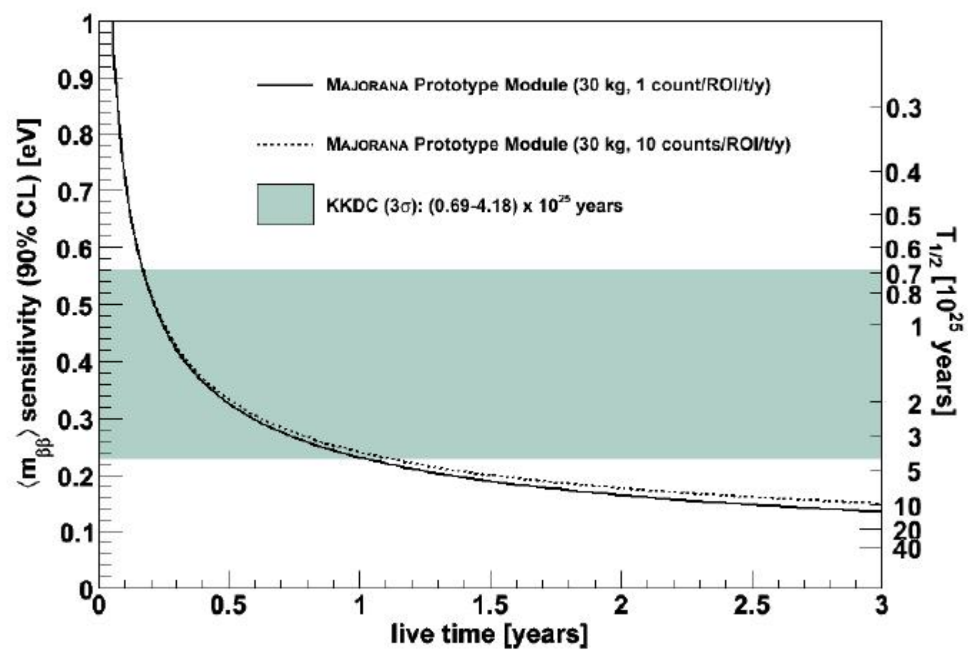
MAJORANA ^{76}Ge $0\nu\beta\beta$ -decay



Slides courtesy of dr. Steve Elliott



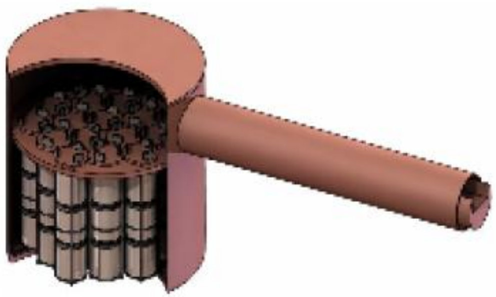


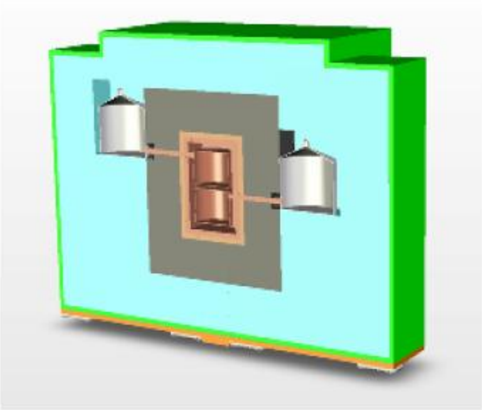


POSTER #56

The MAJORANA Demonstrator Module

Detectors are deployed in string and operated in an ultra-clean, electroformed Cu cryostat





- 60-kg of Ge detectors
  - 30-kg of 86% enriched ^{76}Ge crystals required for science goal; 30-kg non enriched
  - Examine detector technology options p- and n-type, segmentation, point-contact.
- Low-background Cryostats & Shield
  - ultra-clean, electroformed Cu
  - naturally scalable
  - Compact low-background passive Cu and Pb shield with active muon veto
- Located underground 4850' level at SUSEL/DUSEL
- Background Goal in the $0\nu\beta\beta$ peak region of interest (4 keV at 2039 keV)
  - **~ 1 count/ROI/t-y** (after analysis cuts)

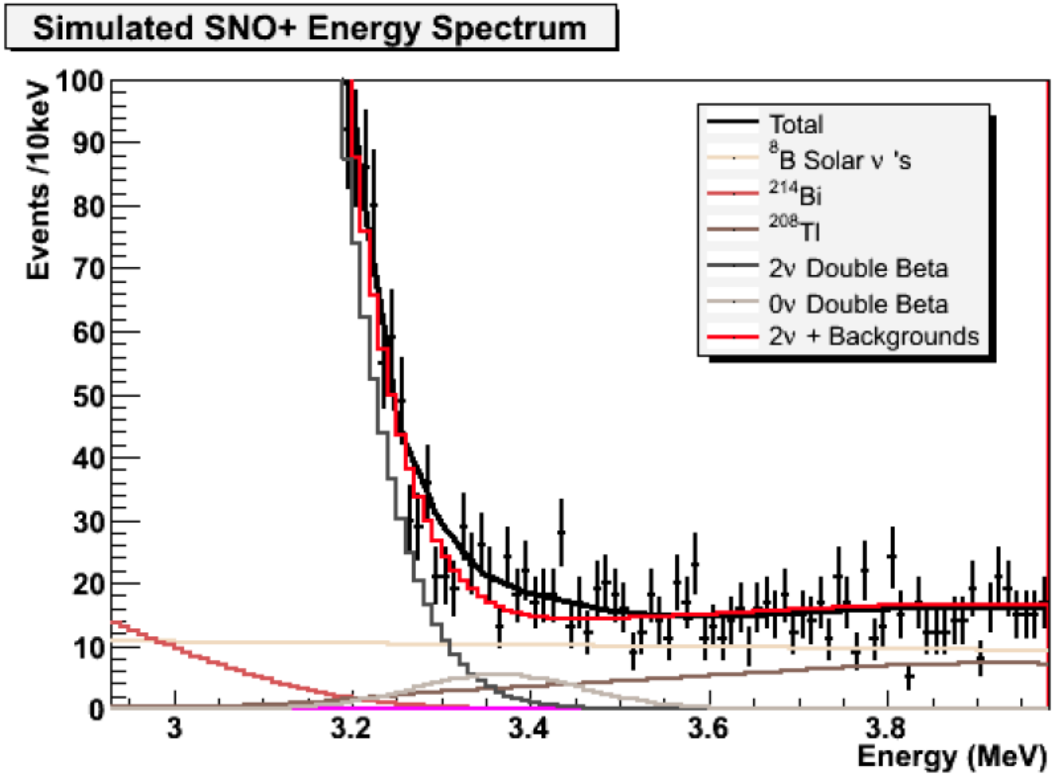
Present Status

- Approved & Supported: As a R&D Project by DOE NP & NSF PNA
- Progress towards Demonstrator Module
  - UG clean room laboratory space should be available early 2009 at Sanford Laboratory (Homestake gold mine, Lead, SD).
  - UG Electroforming facility will be initial focus due to required time to prepare Cu parts of shield.
  - Early prototype cryostat with point-contact detectors will soon follow.
  - Working with industrial partner to develop Ge refinement process that could be located either near detector fabrication facility or UG.
- SEGA: enriched segmented detector
  - We have completed our initial performance testing of this detector
    - First enriched segmented detector: works well as designed
  - Presently assembling detector into low-background cryostat
    - Plan to move to WIPP for operation in late 2008

Experimental Programs – IV

- SNO+ with Nd-loaded liquid scintillator
  - …also called SNO++
- 0.1% Nd in 1000 tons of scintillator
  - with natural Nd corresponds to 56 kg of ^{150}Nd isotope
- sensitivity below 100 meV with natural Nd
- meters of ultra-low background self-shielding against gammas and neutrons
  - leads to well-defined background model
- liquid detector allows for additional *in-situ* purification
- possibility to enrich neodymium at French AVLIS facility

56 kg of ^{150}Nd and $<m_\nu>$ = 100 meV



- 6.4% FWHM at Q-value
- 3 years livetime
- U, Th at Borexino levels
- 5σ sensitivity
- note: the dominant background is ^{8}B solar neutrinos!
- ^{214}Bi (from radon) is almost negligible
- ^{212}Po-^{208}Tl tag (3 min) might be used to veto ^{208}Tl backgrounds; ^{212}Bi-^{212}Po (300 ns) events constrain the amount of ^{208}Tl

Status of SNO+

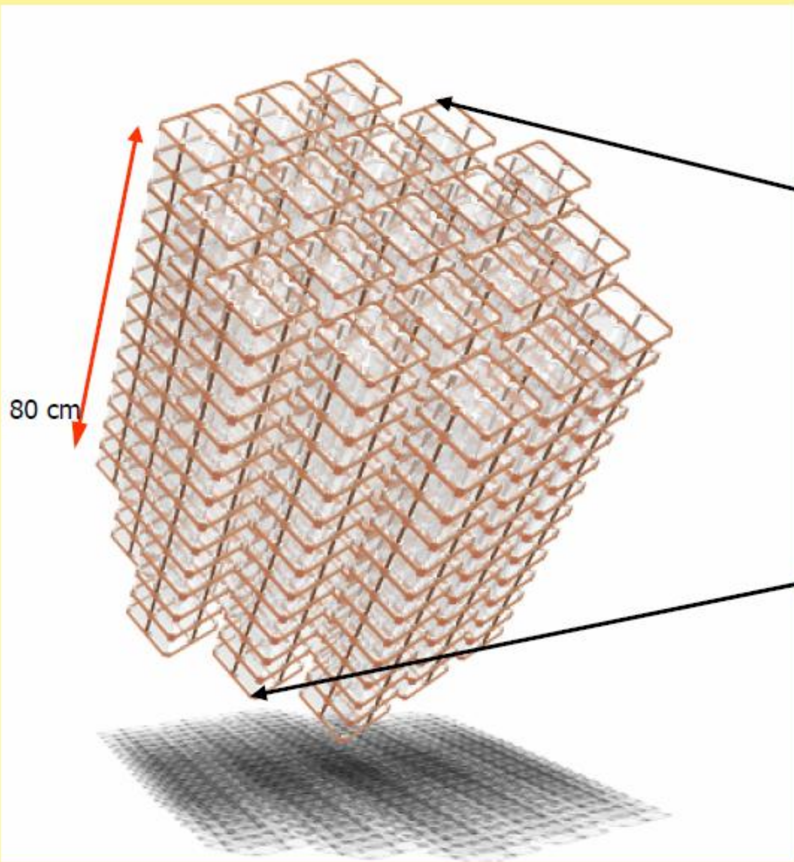
- funded by NSERC for final design/engineering and initial construction 2008-2010
- submission of full capital proposal to CFI in Q4 2008 with decision in Q2 2009
- construction of hold-down net begins in 2009
- construction of scintillator process and purification begins in 2010
- end of 2010 → ready for scintillator filling
- *new collaborators welcome!*

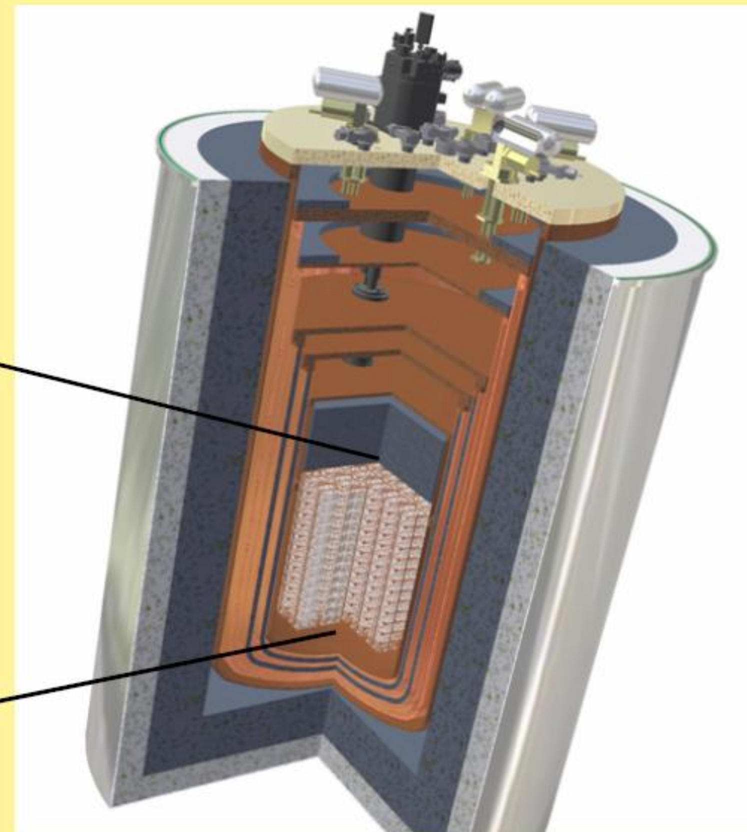
建設中の実験

- CUORE-0 @Gran sasso
- EXO-200 @WIPP
- GERDA @Gran sasso

CUORE: The (near) Future

CUORE will be a closely packed array of
988 detectors
741 kg of TeO_2
204 kg of ^{130}Te



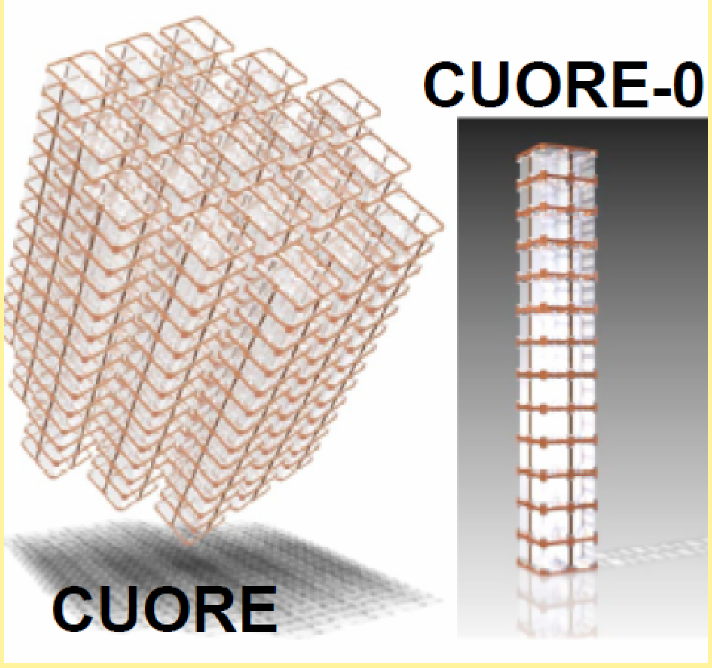


19 towers with
13 planes of
4 crystals each

9

CUORE-0: The Demonstrator

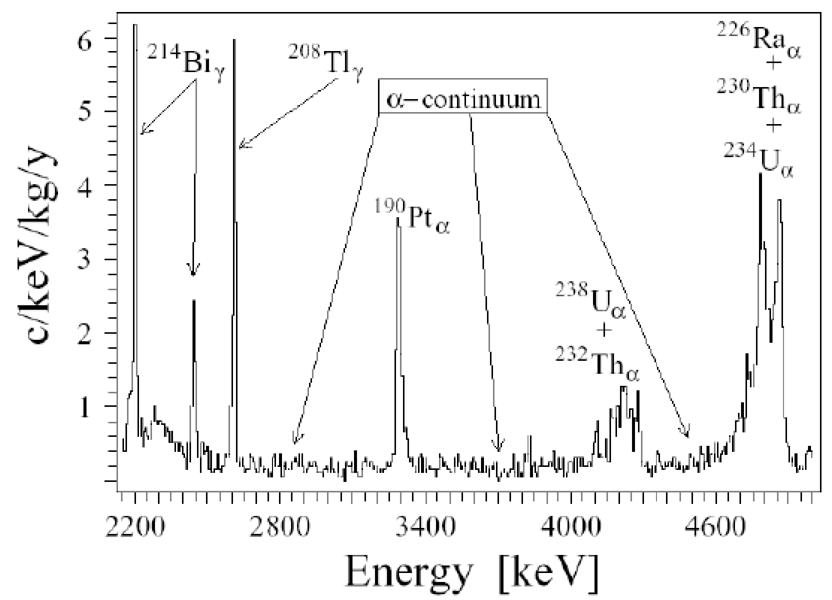
CUORE-0 will be the first CUORE tower to be installed in the dilution refrigerator in hall A of LNGS, presently housing Cuoricino



Motivations of CUORE-0

- Test with high statistics the many improvements done on several technical aspects of the assembly procedure:
  - gluing
  - holder
  - zero-contact approach
  - wires
  - …
- CUORE-0 background should be around 1/3 of Cuoricino background in the DBD energy region and close to the CUORE target in energy degraded alpha region
- CUORE-0 will be a powerful experiment that will overtake soon Cuoricino sensitivity

Sources of Background @ 2.530 MeV



CUORICINO

- Flat background above 2615 keV
- Natural extrapolation below
- Contribution to the 0ν-DBD region: ~ 70%
- In R&D already decreased by a factor ~ 5

The **GOAL for CUORE** background is: $10^{-2} \div 10^{-3}$ c/keV/kg/y

Contribution from intrinsic contaminations ~ 10^{-3} c/keV/kg/y

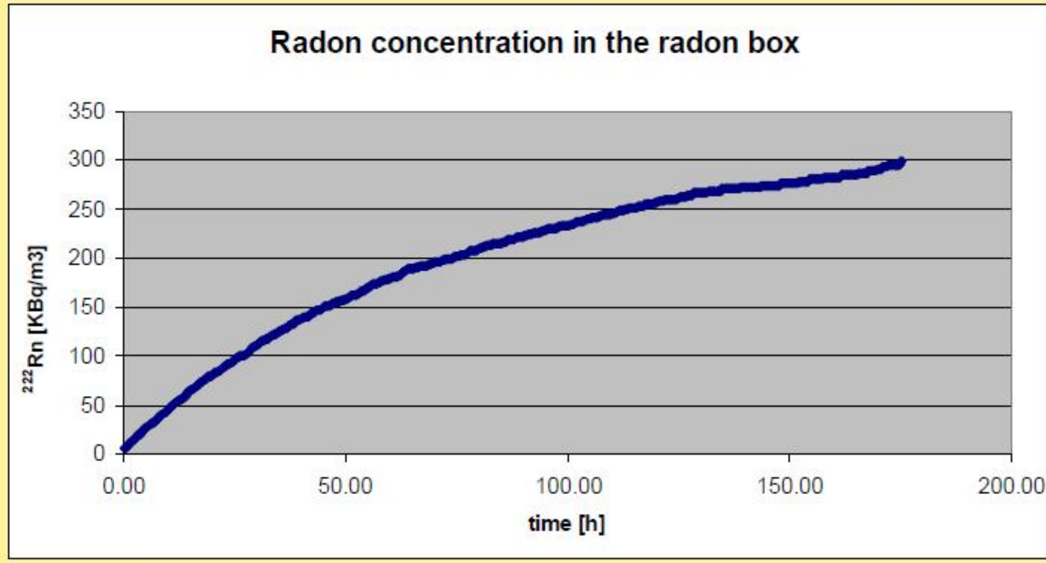
Contribution from neutrons: ~ 3×10^{-4} c/keV/kg/y

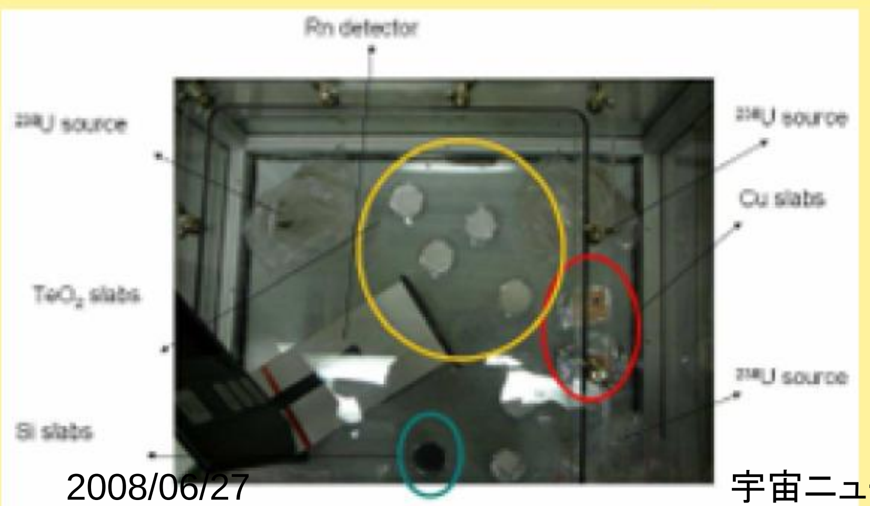
Contribution from surface contaminations < 5×10^{-2} c/keV/kg/y

13

Radon: The big enemy

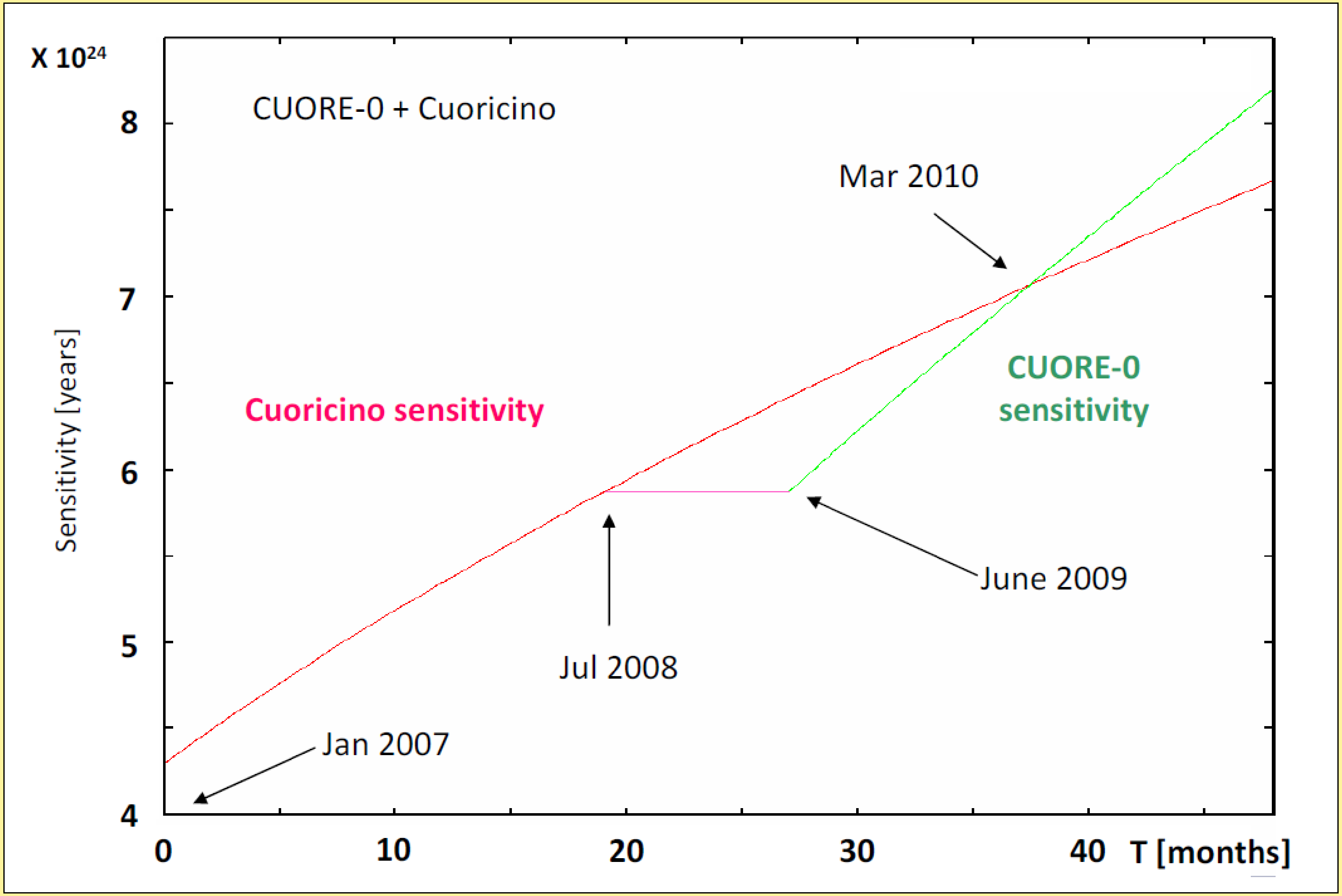
TEST: expone crystals and structure materials to Rn-source





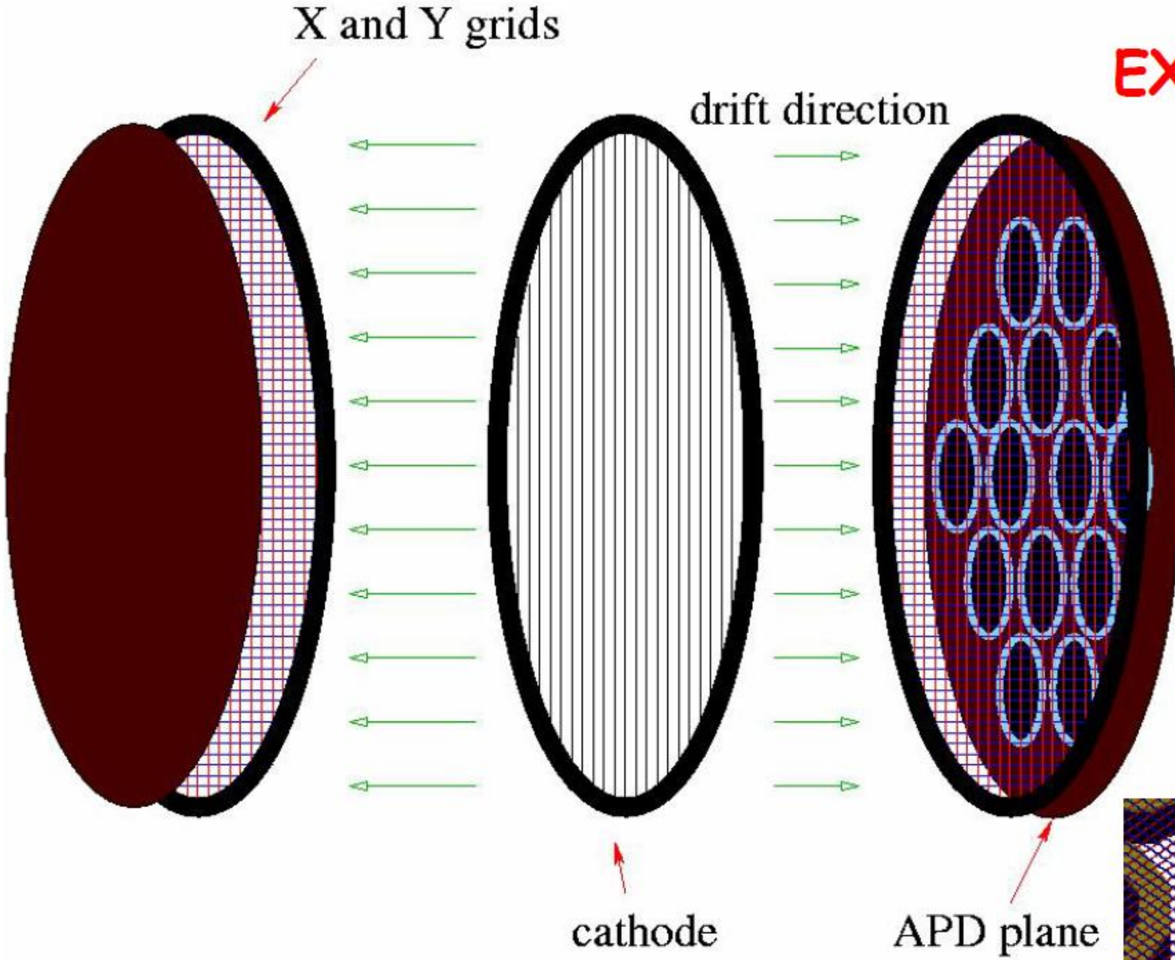
15

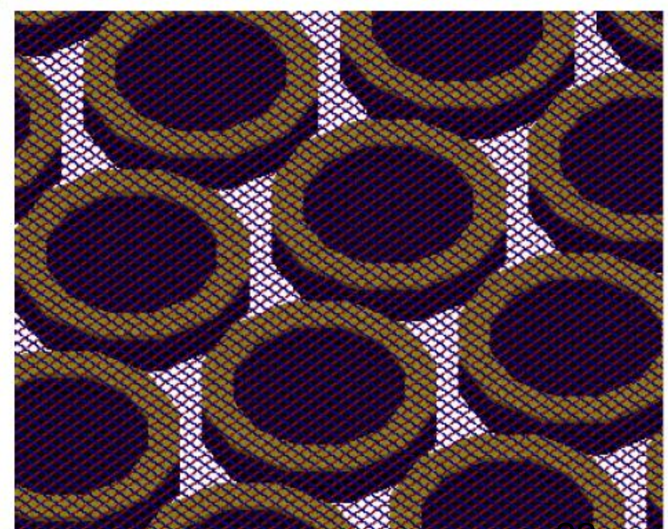
CUORE-0 vs Cuoricino



21

EXO-200 TPC basics





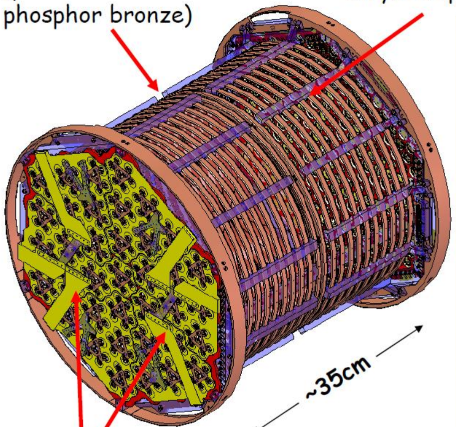
Neutrino 2008

Giorgio Gratta

EXO-200 LXe TPC field cage & readout planes

Central HV plane (photo-etched phosphor bronze)

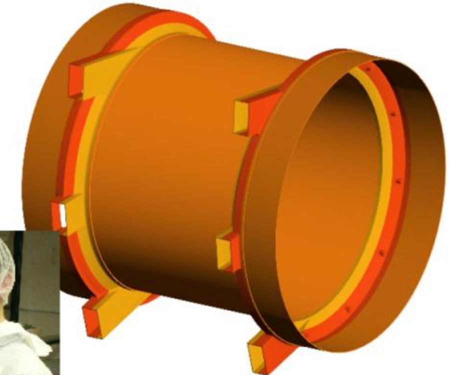
acrylic supports



flex cables on back of APD plane

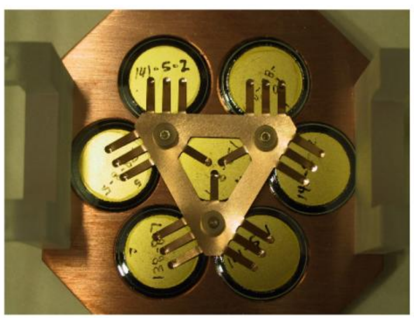
EXO low activity copper vessel "hugs" the fiducial volume very closely

- Very light (~1.5mm thin, ~15kg) to minimize materials



- Different parts e-beam welded together
- Field TIG weld(s) to seal the vessel after assembly (TIG technology tested for radioactivity)
- All machining done under (shallow) shielding

~500 "Bare" LAAPD

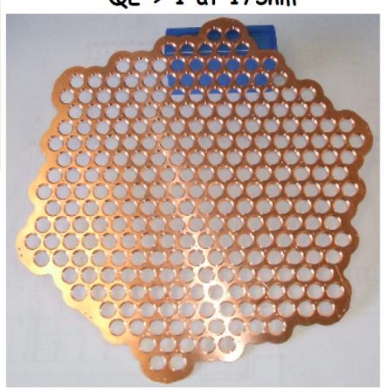


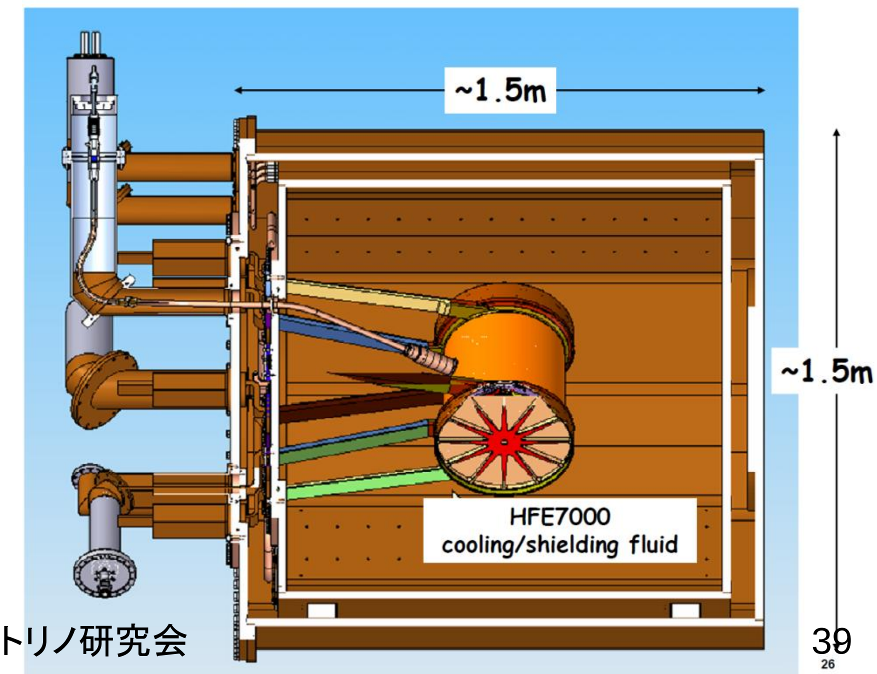
Gain set at 100-150

V~1500V
ΔV < ±0.5V
ΔT < ±1K APD is the driver for temperature stability
Leakage current OK cold

APDs are ideal for our application:
- very clean & light-weight,
- very sensitive to VUV

QE > 1 at 175nm



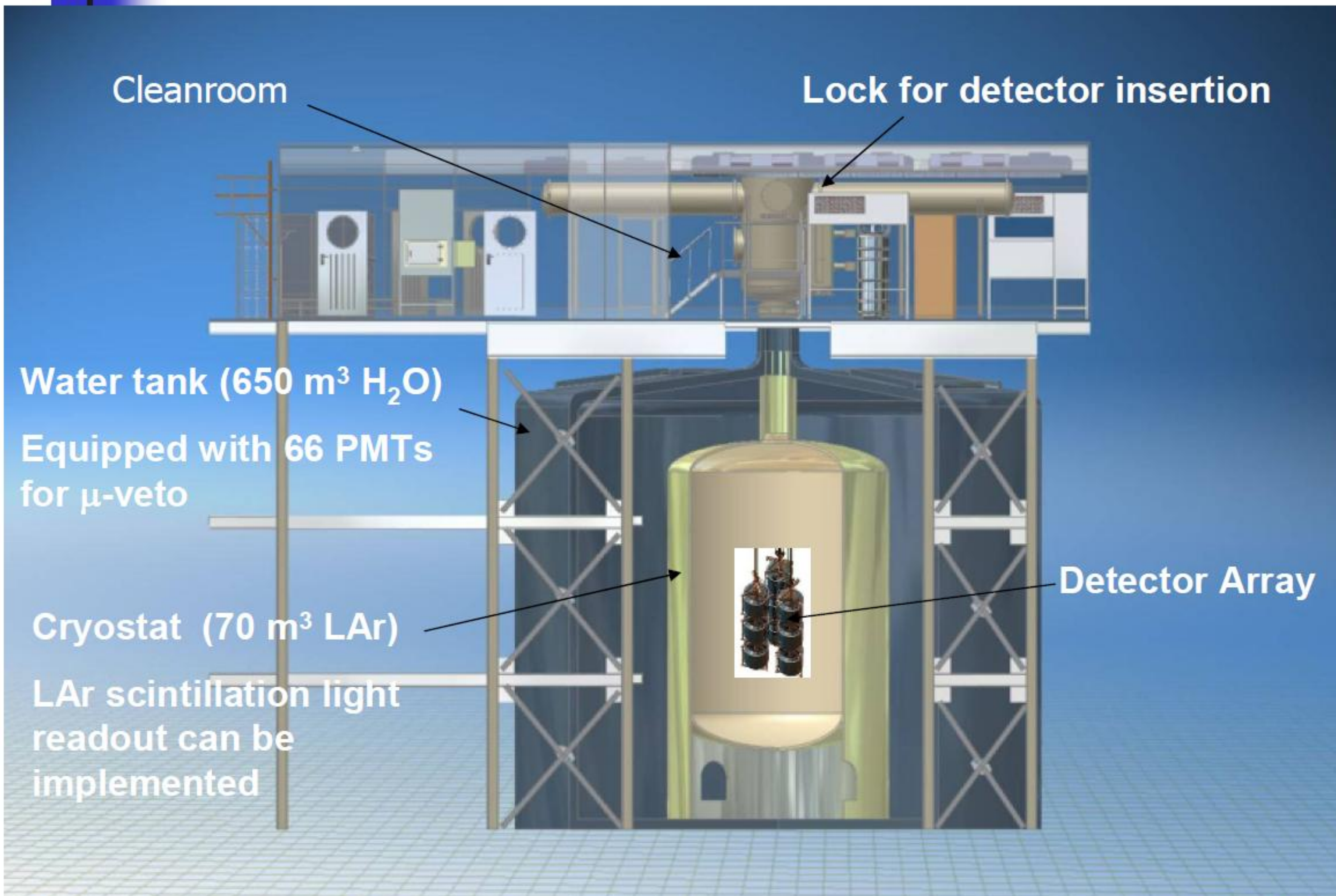


EXO-200 at WIPP

Phases of GERDA

- Phase I:
  - Use of existing ^{76}Ge-diodes from Heidelberg-Moscow and IGEX-experiments
  - 8 detectors for 17.9 Kg of ^{enr}Ge
  - Expected Background ~ 10^{-2} count/(kg·keV·y) dominated by crystal internal backg. → KKDC evidence verified in an external background-free setup.
- Phase II:
  - Add new diodes (+22 kg, total: ~40 kg ^{enr}Ge) able to discriminate SSE/MSE.
  - Demonstration of bkg-level <10^{-3} count/(kg·keV·y)
- Eventually Phase III:
  - If background OK
  - If KKDC-evidence not confirmed: $\mathcal{O}$(1 ton) experiment by a worldwide collaboration with Majorana

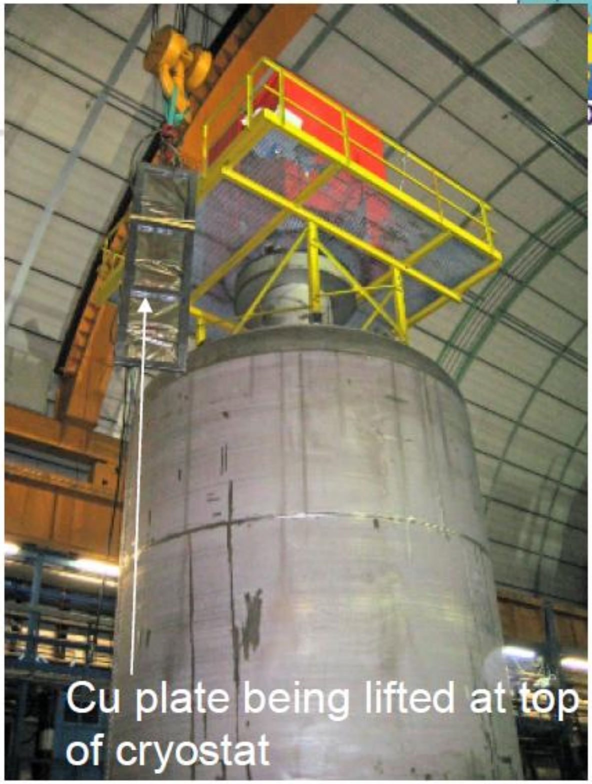
GERDA design



GERDA:Status of Cryostat

Built with low activity steel

1-5 mBq/kg

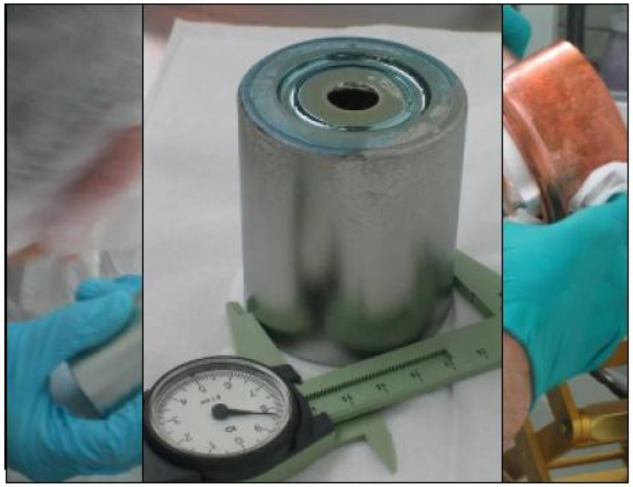


- Cryostat arrived at LNGS: 6 March 2008
- Rn emanation OK
- Mounting of inner Cu shielding plates (thickness 3/6 cm) completed
- LAr evaporation rate tested (< 2% day^{-1})
- LAr scintillation light readout to reduce external bckg in detectors can be implemented

-17- C. Cattadori

Status of Phase I detectors

- IGEX and HdM diodes were removed from their cryostats and measured
- 17.9 kg enriched and 15 kg non-enriched crystals (GENIUS-TF) available
- Reprocessing of all diodes at manufacturer (ongoing)
- Stored underground during reprocessing dead-time (HADES)
- Dedicated low-mass Cu holder constructed for each diode.



Resolutions of former HdM (ANG) and IGEX (RG) detectors measured in original cryostats after delivery and maintenance to LNGS

	ANG1	ANG2	ANG3	ANG4	ANG5	RG1	RG2	RG3
FWHM [keV]	2.54	2.29	2.93	2.47	2.59	2.21	2.31	2.26
Mass [kg]	0.980	2.906	2.446	2.400	2.781	2.150	2.194	2.121

Schedule of forthcoming activities (2008-2009)

- Water Tank & PMTs for μ-veto water Cerenkov May-June 2008.
- Technical Building & Superstructure: Summer 2008
- Lock & Clean Room: 2008-2009
- Commisioning: ~ first semester 2009

In parallel:

- Complete Reprocessing of all Phase I crystals, assemble 3-fold strings, integrate cold FE with detector string, etc…………….

Candles

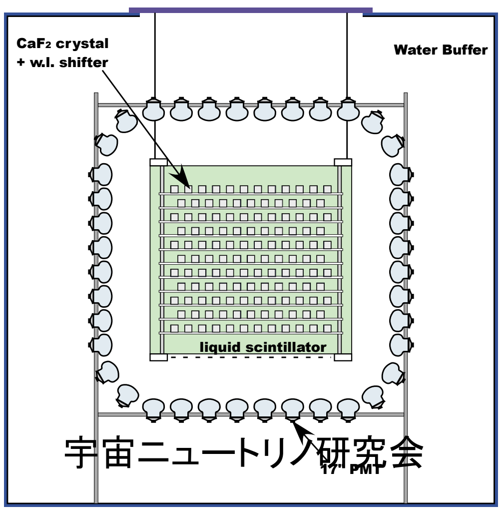
Why ^{48}Ca ?

- Largest Q value (4.27 MeV)
  - next largest; ^{150}Nd (3.3 MeV)
  - large phase space factor
  - almost background free
    (γ: 2.6 MeV, β: 3.3 MeV)

- Low Natural abundance → 0.187%
  - large detector
  - Enrichment

Concepts of CANDLES

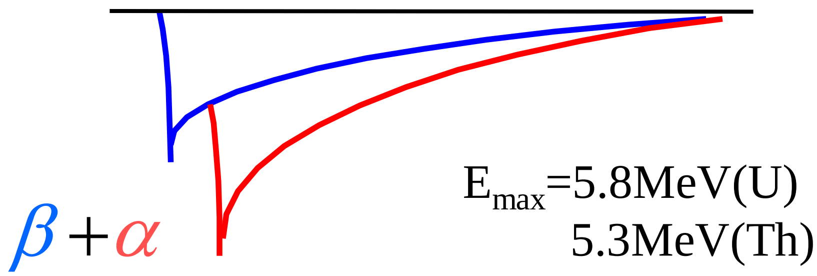
- undoped CaF_2 (CaF_2(pure))
  - ^{48}Ca ($Q_{\beta\beta}$=4.27 MeV)
  - 300 kg 3 t 100 t
- Liquid Scintillator (LS)
  - 4π active shield
  - Passive shield
  - wavelength shifter for CaF_2
- Photomultiplier
  - large photo-coverage



Radioactive BG inside CaF_2

- Natural Radioactive BGs ~$Q_{\beta\beta}$
  - Maximum energy
    - γ~ 2.6 MeV, β~3.3 MeV, α (max)~2.7 MeVe.e. (quench;f_α ~ 0.3)
  - Successive decays of α, β, γ in decay chain
    - ~1 μsec decay time CaF_2

Pulse shape



Development of High Purity CaF_2 Crystals

CaF_2(Eu) in ELEGANT VI
U-chain(^{214}Bi) :1100 μBq/kg
Th-chain(^{220}Rn) : 98 μBq/kg

U and Th
(ICP-MS)

Raw Materials $CaCO_3$, HF → **CaF_2 Powder** → **Fused CaF_2** → **CaF_2 Crystal**

Radioactivities in CaF_2 Powder (HPGe measurement) ↔ Radioactivities in CaF_2(pure) Crystal (α-ray measurement)

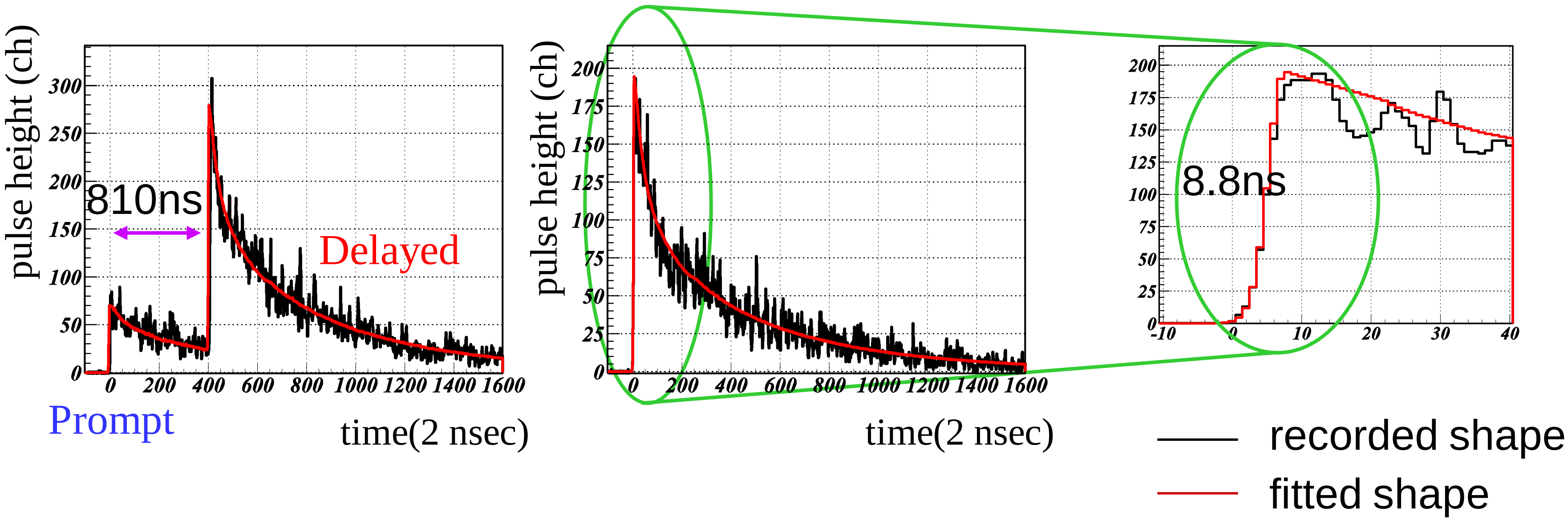
Powder selection
Crystal growing

101 crystals

U-chain(^{214}Bi) ~36 μBq/kg …1/30 of Previous Crystals (14±5 μBq/kg ;Best)
Th-chain(^{220}Rn) ~29 μBq/kg …1/3 of Previous Crystals (6±1 μBq/kg ;Best)

Rejection of Double Pulse

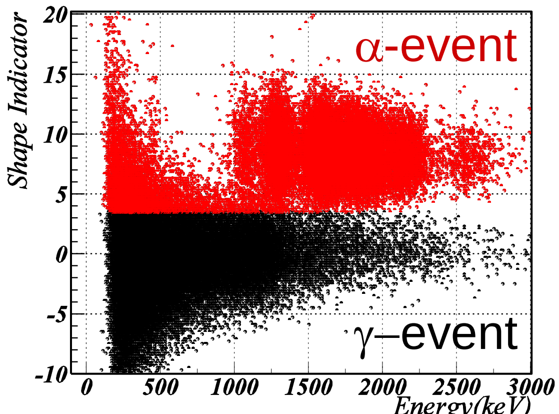
Typical Pulse Shape (500 MHz FADC)

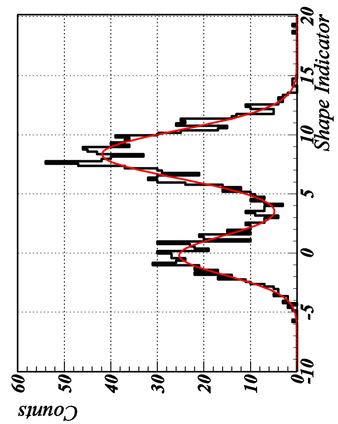


99% of double pulse
events will be rejected

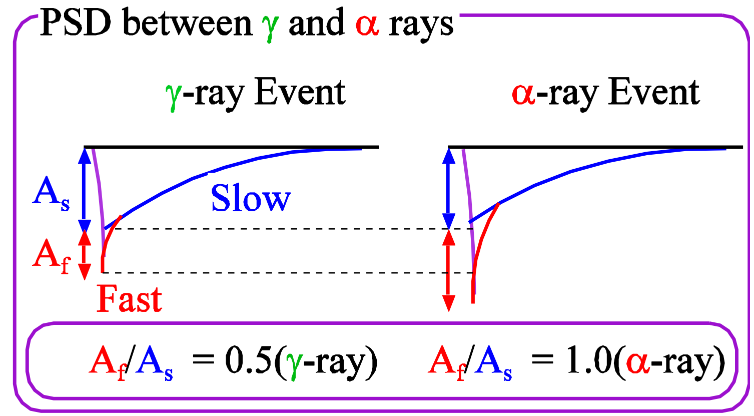
Pulse Shape Discrimination

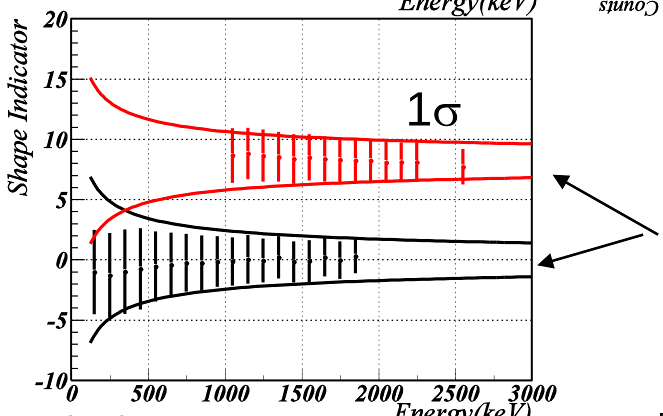
- Pulse Shape discrimination
  - Shape Indicator (PRC **67**(2003) 014310)





Difference in decay shape between α and γ rays





mean value:
no energy dependence (>1 MeV)

~99.7% reduction at ***Q***-value

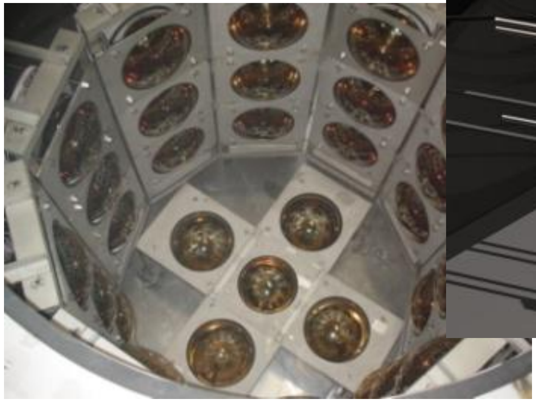
CANDLES III at Osaka

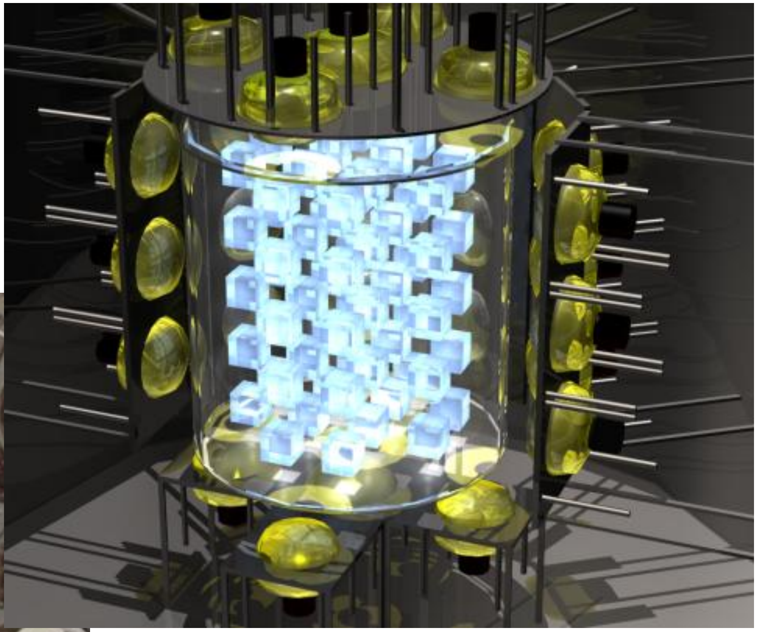
Liquid scintillator

$^{\phi}1000 \times {}^{h}1000$ acrylic container

H_2O Buffer : passive shield

$^{\phi}2800 \times {}^{h}2600$





PMT:15" PMT (× 8) : R2018
13" PMT (×32) : R8055

33.4% photo-coverage

CaF_2 : 10^3 cm^3 × 60
(191 kg)

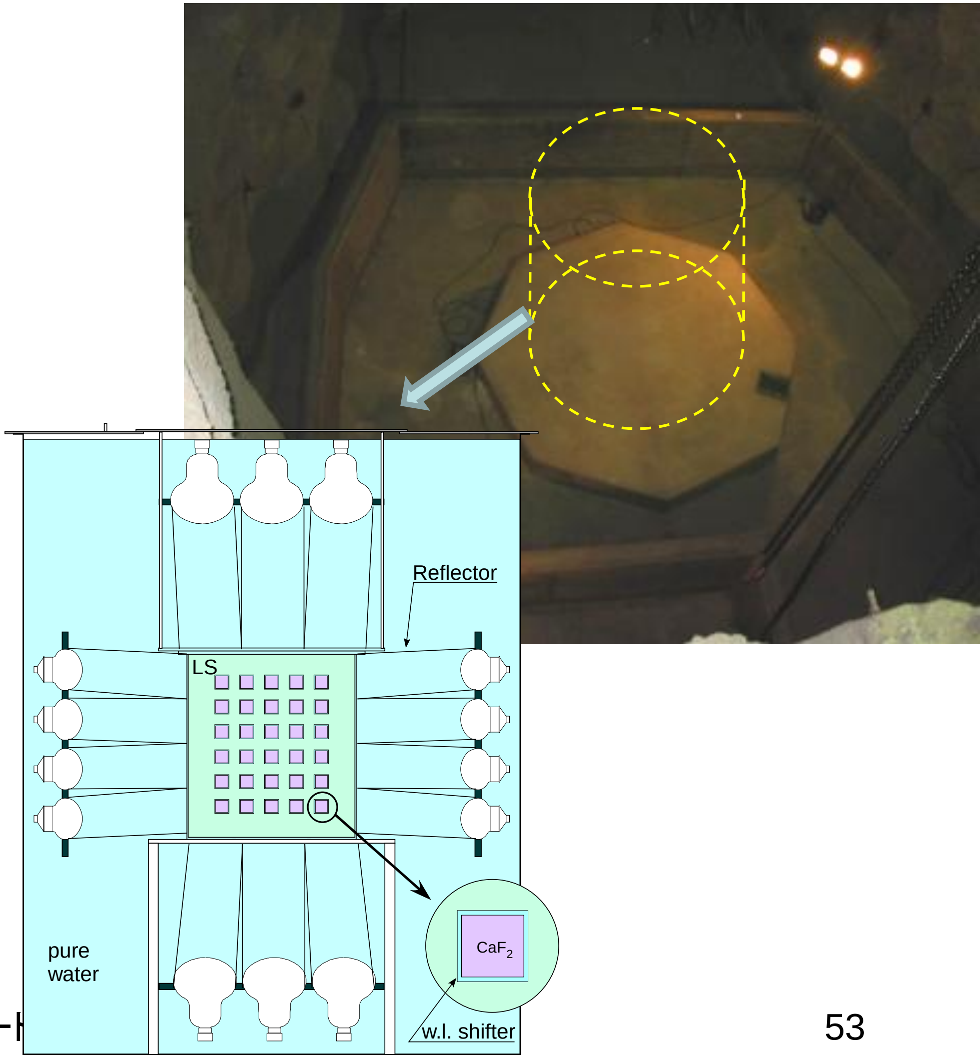
CANDLES III地下

- 神岡新実験室 (実験室D)

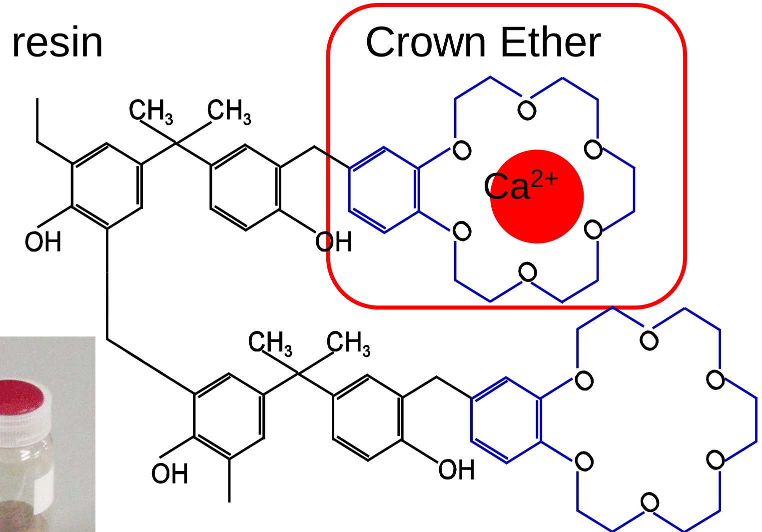
Scale-up version of CANDLES-III, “Sanchika” will move on next winter

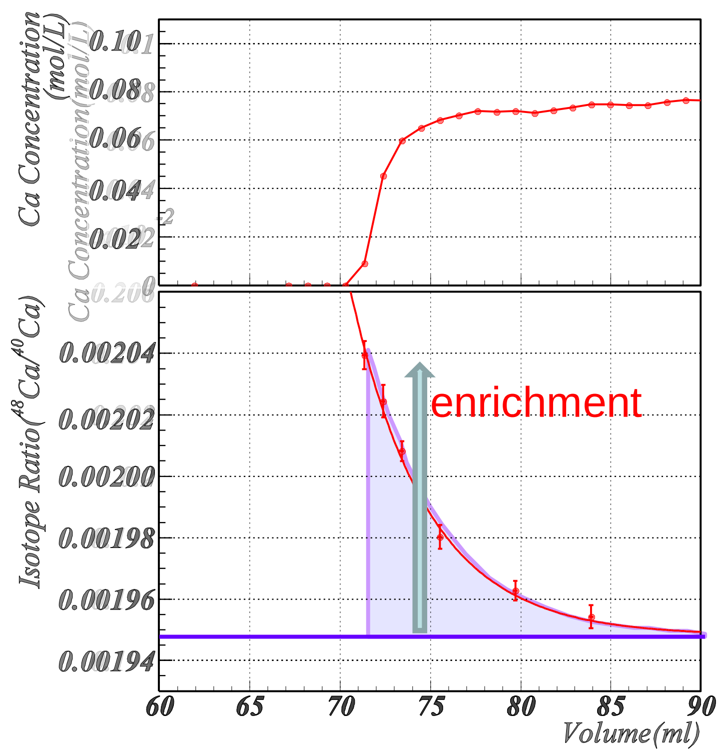
CaF_2: 60(191kg) ⇨ 96(305kg)

$\langle m_\nu \rangle \sim 0.5$ eV



Challenge on enrichment of ^{48}Ca





- Held by electrostatic attraction between negatively charged O^- of the C-O dipoles & cation (Ca^{2+})

まとめ

- 二重ベータ崩壊実験
  - Majorana粒子の証明
- ここ数年以内
  - $m_\nu \sim 100$ meVの感度を持つ実験が稼働開始 (CUORE, GERDA, EXO,…)
  - CANDLES III地下：神岡にて建設開始
    ^{48}Caのenrichment
- Inverted hierarchy領域へ向けて