The status of selected next generation double-beta decay experiments

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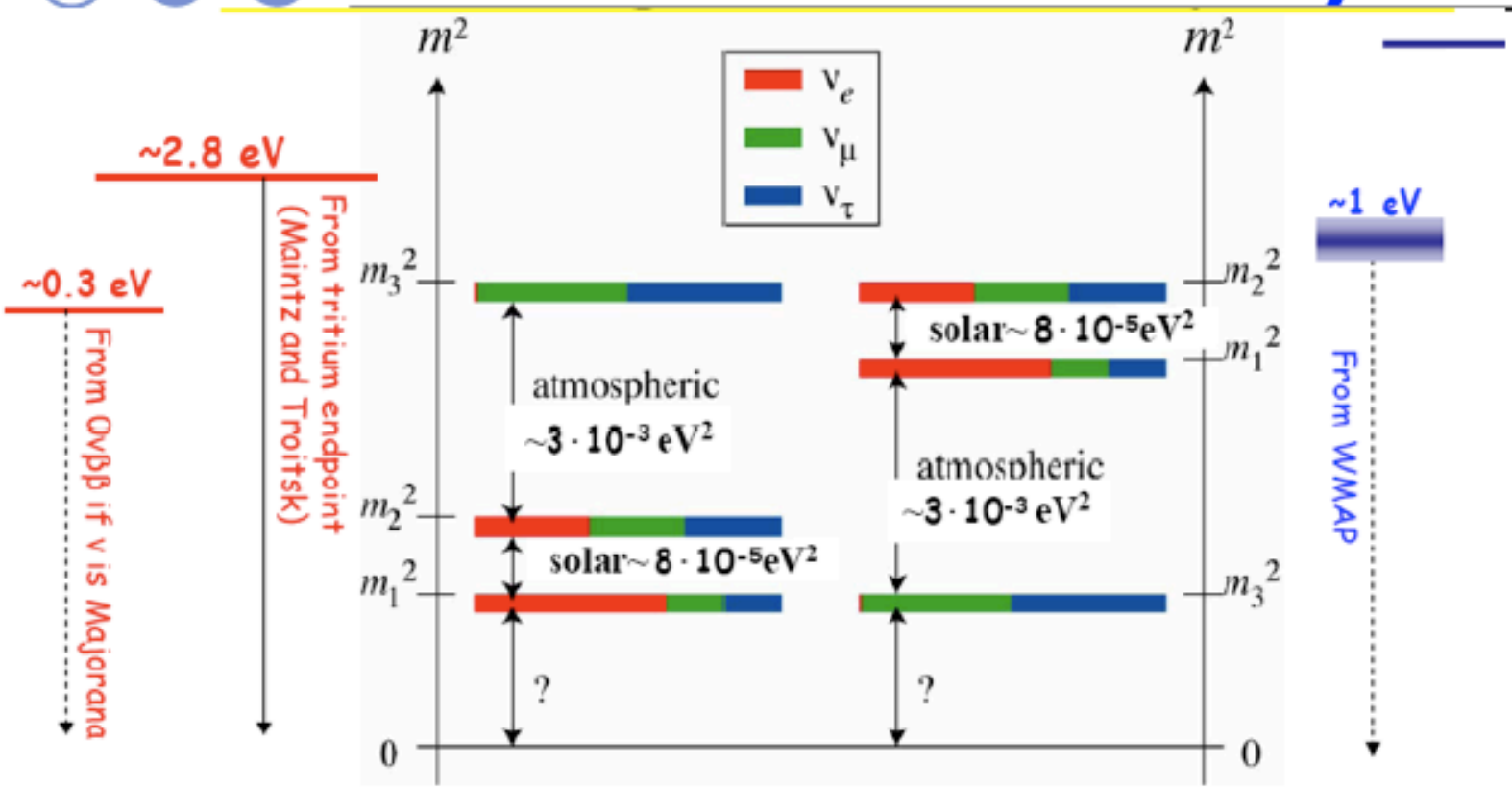
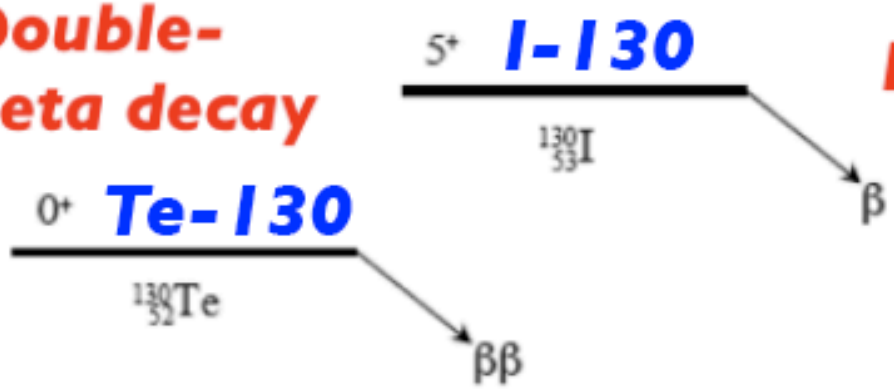
The Neutrino Hierarchy Problem



The neutrino oscillation experiments analyzed all together give us this picture; however, there are only bounds on the lightest neutrino mass eigenstate!

Double-beta decay

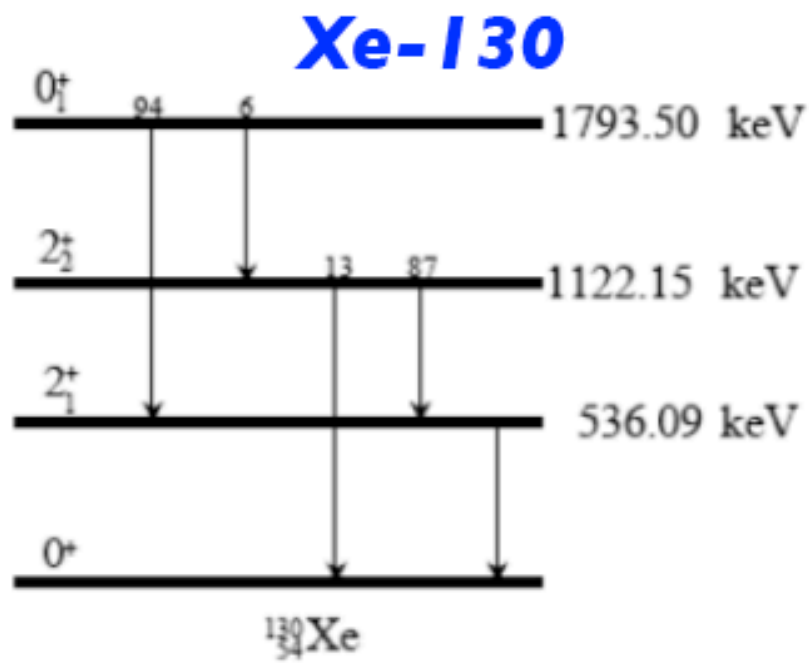


Effects of pairing forces

Weak decay to I-130 energetically forbidden

2527.518 (13) keV FSU

$Q_{\beta\beta} = 2528 \pm 1.3$ keV



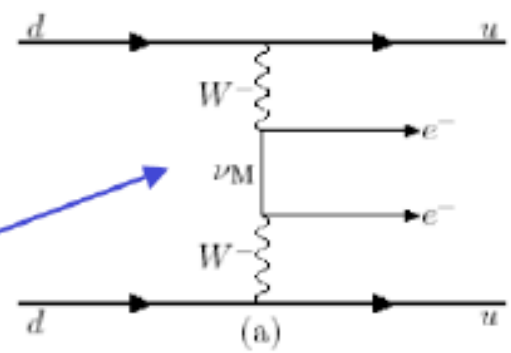
Motivation for $0\upsilon\beta\beta$ Search

$$^{Z}A \Rightarrow {}^{Z+2}A + 2e^{-}$$

- Immediate Implications of Discovery:
  - Neutrino is Majorana (own antiparticle)
  - Total Lepton Number is not conserved
  - Neutrino has mass (known)
- Well-studied example: Exchange of virtual neutrino

$2\upsilon\beta\beta$: Observed 2nd Order Weak Process.

$$^{Z}A \Rightarrow {}^{Z+2}A + 2e^{-} + 2\bar{\nu}_e$$

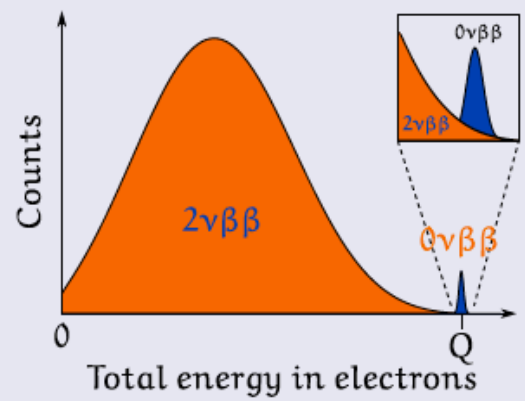


$0\nu\beta\beta$ in Experiments

Experimental Signature:

All the energy is shared between the 2 electrons: monochromatic line at the Q-value of the decay.

Examples $\Rightarrow \begin{cases} {}^{130}\mathrm{Te}: & E_Q = 2528 \text{ keV } [4, 5] \\ {}^{76}\mathrm{Ge}: & E_Q = 2039 \text{ keV } [6] \end{cases}$



Experimental Sensitivity $S^{0\nu}$:

Defined as the decay time corresponding to the minimum number of detectable events above background (B).

$$S^{0\nu} \propto \epsilon \cdot i.a \cdot \sqrt{\frac{M \cdot T}{B \cdot \Gamma}}$$

Isotopic Abundance

Detector Mass

Live time

Efficiency

Background Counts

Energy Resolution

$0\nu\beta\beta$ decay rates

Experiments can measure the decay rate $\Gamma^{0\nu}_{1/2}$

$$\Gamma^{0\nu}_{1/2} = \left[\tau^{0\nu}_{1/2}\right]^{-1} = G^{0\nu}\left|M^{0\nu}\right|^2\left|\langle m_\nu\rangle\right|^2 , \quad \begin{cases} G^{0\nu} & : \text{Phase Space Factor;} \\ \left|M^{0\nu}\right|^2 & : \text{Nuclear Matrix Elements;} \\ \left|\langle m_\nu\rangle\right|^2 & : \text{Neutrino Majorana Mass.} \end{cases}$$

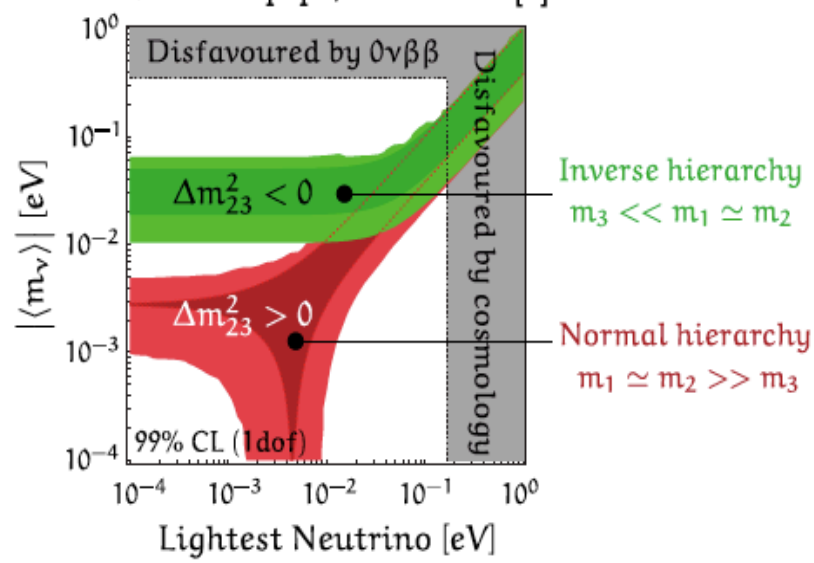
where $|\langle m_\nu\rangle|^2 = \left|\sum_{i=1}^{n=3} m_i U_{ei}^2\right|$ is the Effective Majorana Mass

Observation of $0\nu\beta\beta$ would prove that

1. lepton number is not conserved ($\Delta L = 2$);
2. neutrinos are Massive Majorana Particles ($\nu = \overline{\nu}$).

It could also give informations on the absolute scale of neutrino masses and on the neutrino mass hierarchy (through $|\langle m_\nu\rangle|$)

arXiv:hep-ph/0606054v3 [3]



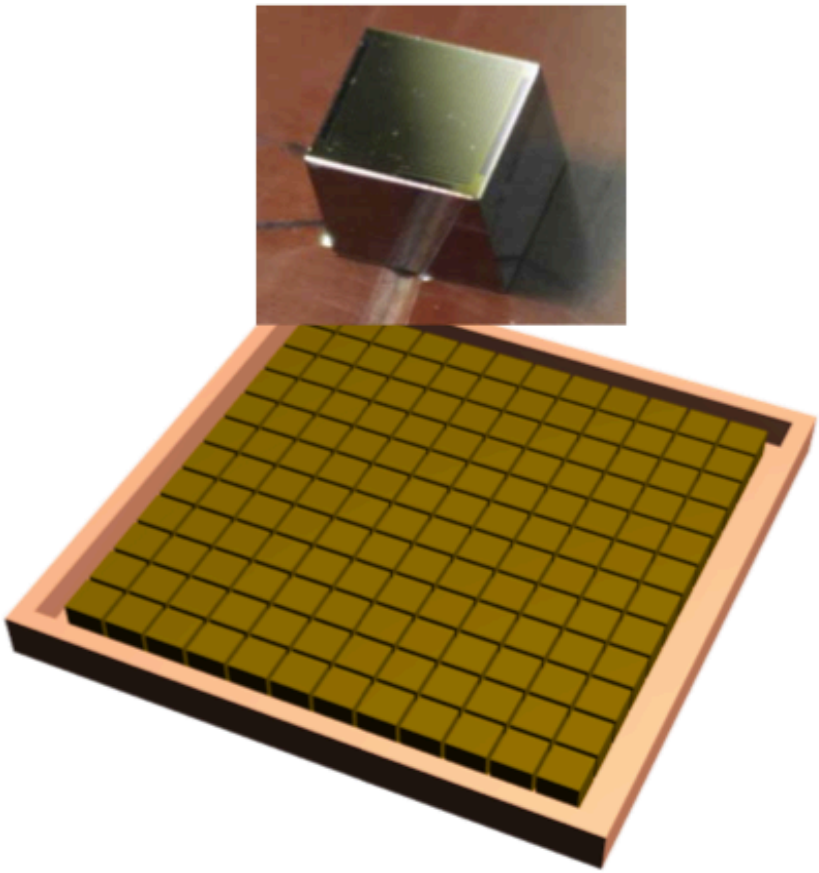
We will discuss only selected next generation double-beta decay experiments that are approved and under construction:

- ***COBRA***
- ***CUORE***
- ***EXO-200***
- ***GERDA***
- ***Kamiokande-Xe***
- ***Majorana Demonstrator***

The idea

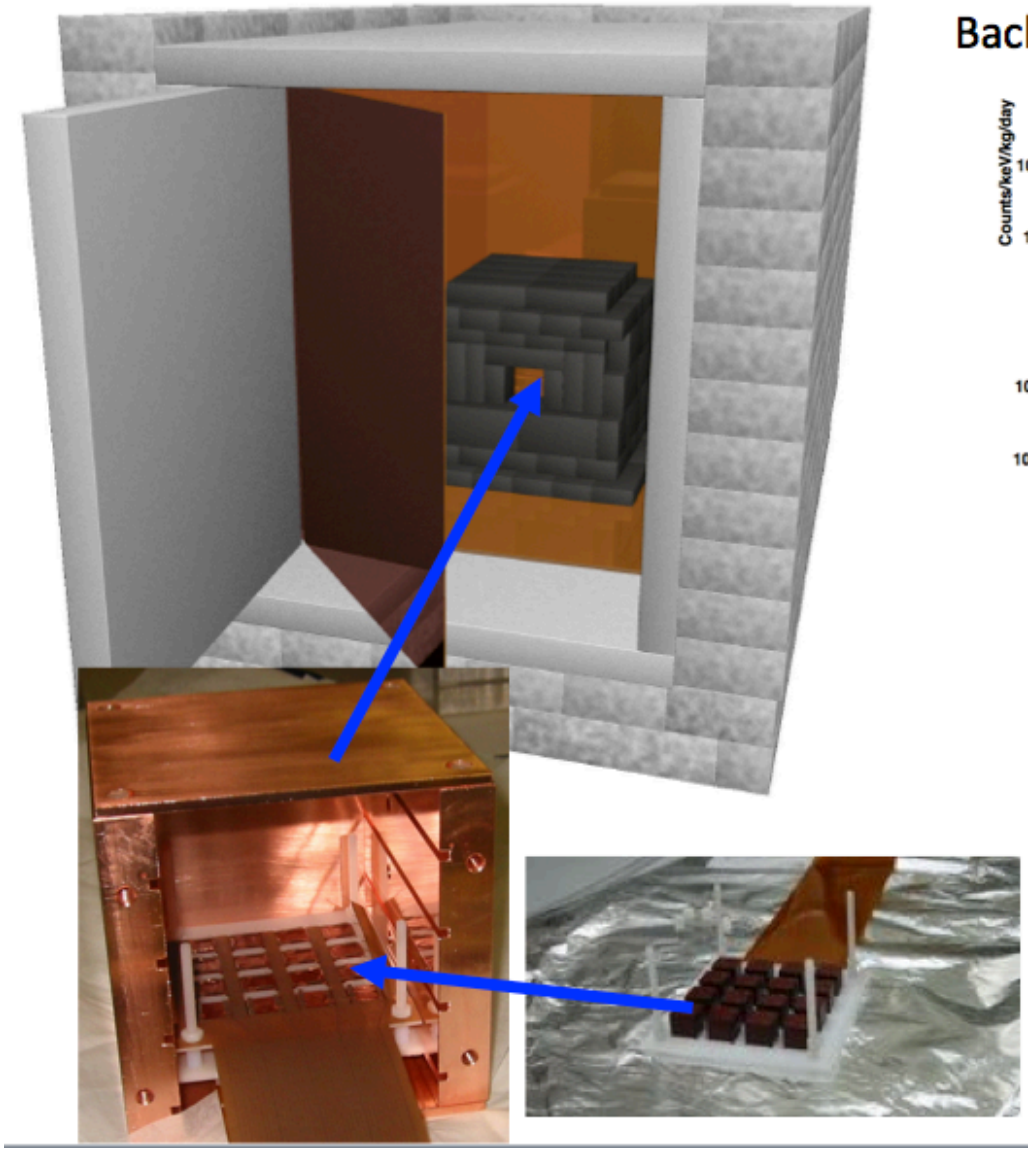
K. Zuber, Phys. Lett. B 519,1 (2001)

Use large amount of CdZnTe Semiconductor Detectors

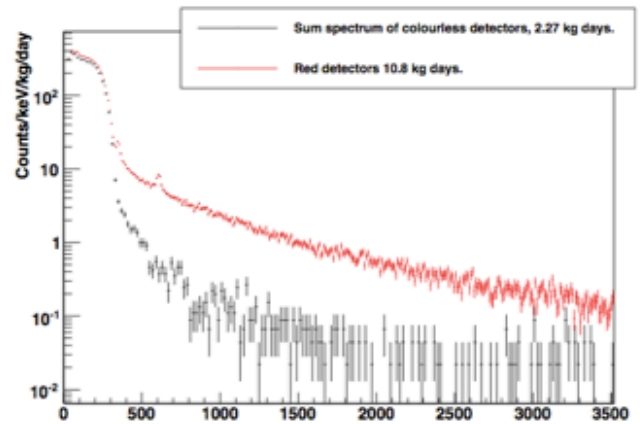


- Source = detector
- Focus on 116Cd
- Semiconductor (Good energy resolution, clean)
- Room temperature
- Modular design (Coincidences)
- Tracking/Pixelisation („Solid state TPC“)

Setup at Gran Sasso Lab



Current spectrum (black)
Background at 2810 keV about 5 cts/keV/kg/yr

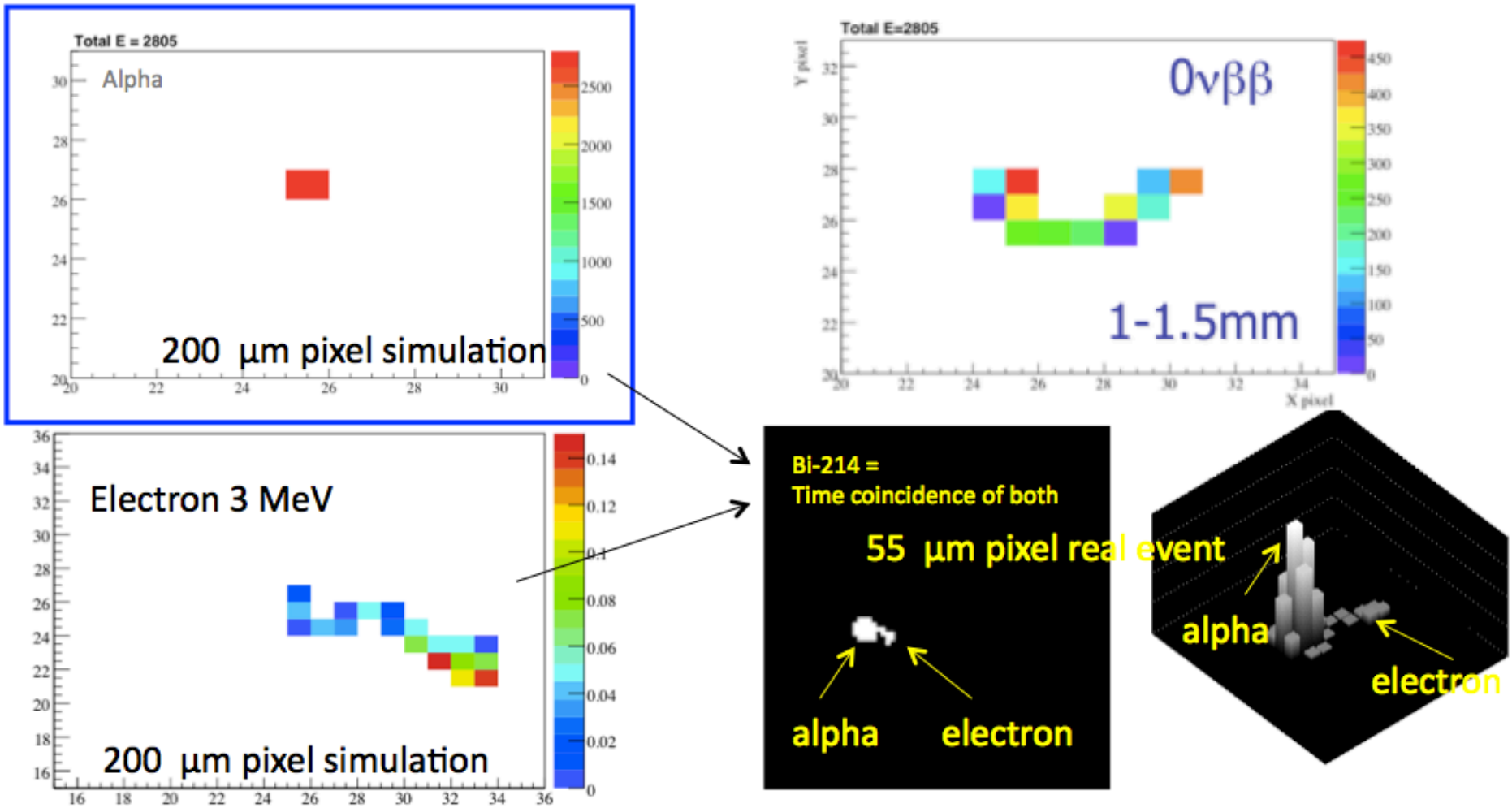


Currently ongoing upgrade:

-64 detectors (in hand)
- new DAQ
- Pulse shape information (done)
- Improvement on shielding
- new location at LNGS (former HdMo cabin)

The pixel option – Semiconductor tracker

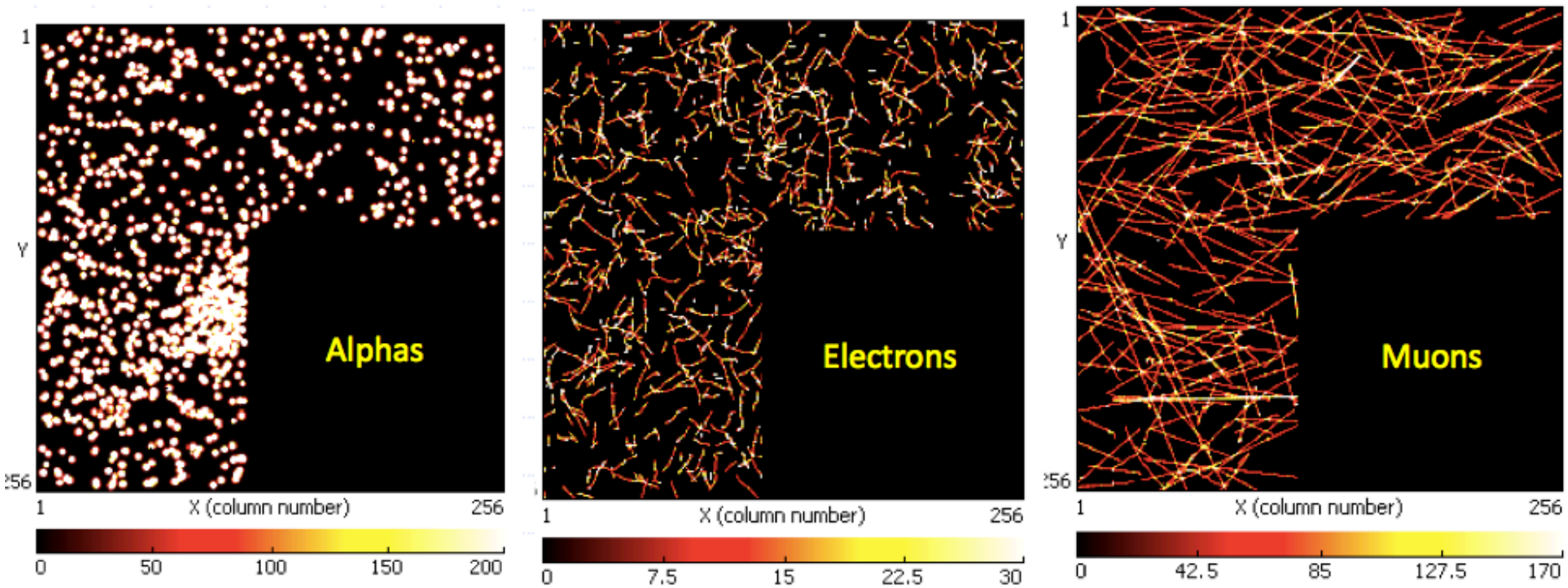
Idea: Massive background reduction by particle identification



Particle identification works !!!

Preselected samples

256x256 pixels, 55μm



According to simulations particle identification due to pixels should reduce background by 3 orders of magnitude

CUORE

Cryogenic Underground Observatory for Rare Events

A search for neutrino-less double beta decay of Te-130 in the Laboratori Nazionali del Gran Sasso, Assergi, Italy

CUORE uses the bolometric technique with TeO_2 single crystal bolometers.

CUORE: the collaboration

Present Collaboration

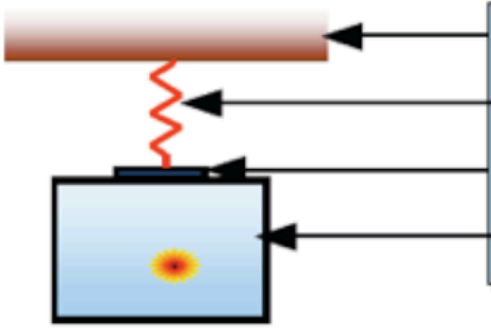
64 European collaborators

32 US collaborators

5 Chinese collaborators

CUORE/Cuoricino Bolometer

TeO_2 Bolometer: Source = Detector



Heat sink: Cu structure (8 mK)
Thermal coupling: Teflon (G = 4 pW/mK)
Thermometer: NTD Ge-thermistor (dR/dT ≅ 100 kΩ/μK)
Absorber: TeO_2 crystal (C ≅ 2 nJ/K ≅ 1 MeV / 0.1 mK)

For E = 1 MeV:

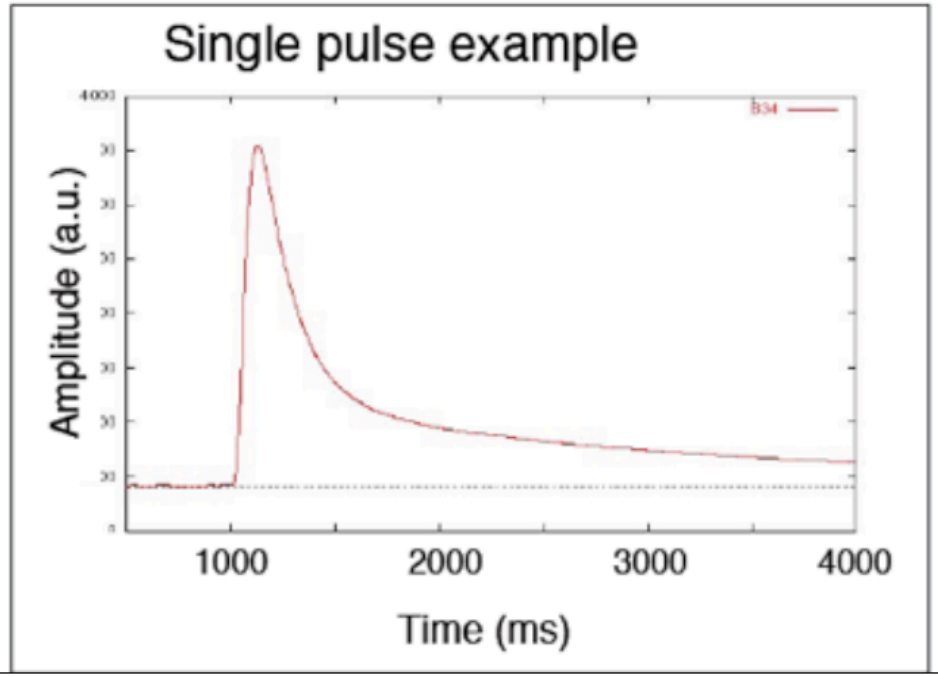
$\Delta T = E/C \cong 0.1$ mK

signal size: 1 mV

Time constant:

$\tau = C/G = 0.5$ s

Energy resolution (FWHM):
~ 5-10 keV at 2500 keV



I bolometri di Cuoricino

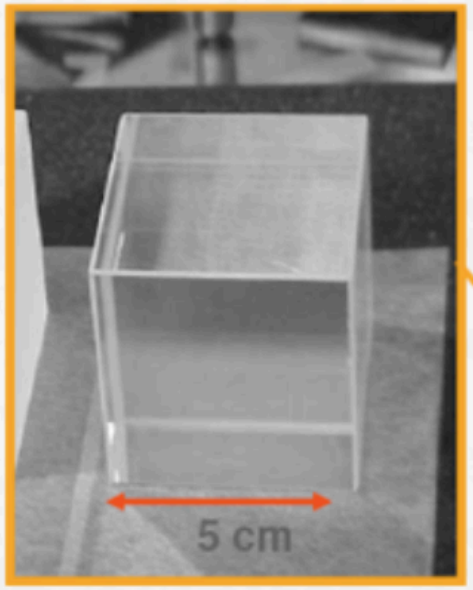
Cristallo Assorbitore

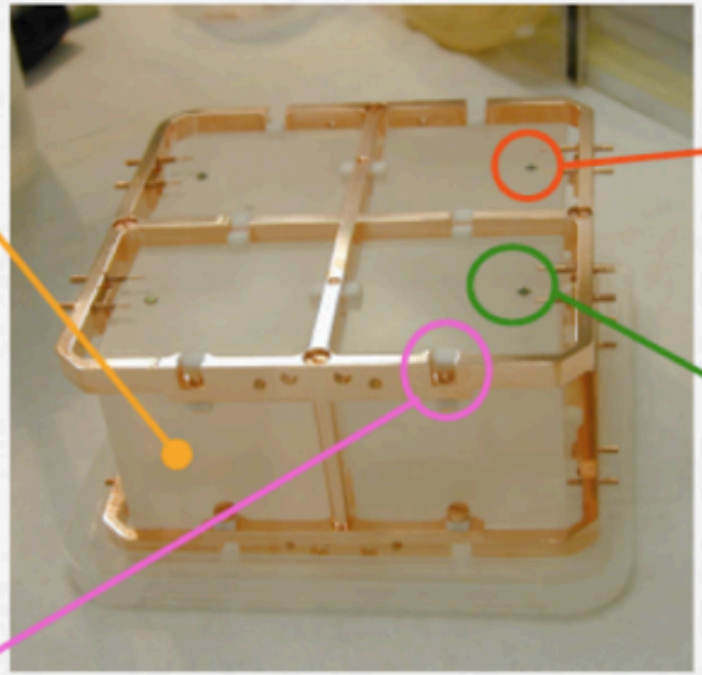
L'assorbitore è un cristallo **5x5x5 cm³** di **TeO_2** il quale contiene il nucleo candidato **^{130}Te**

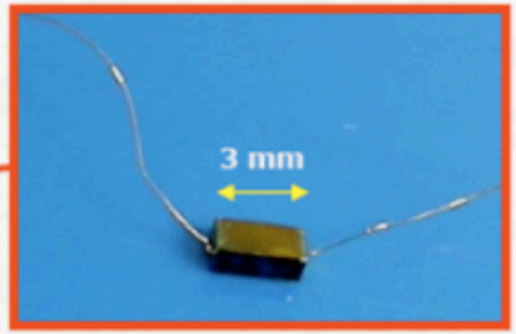
Sensore di temperatura

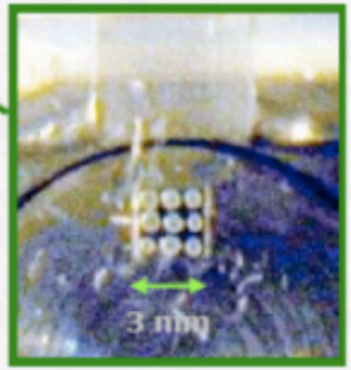
Il segnale termico è misurato tramite un **Termistore di Ge NTD**

$$R(T) = R_0 \exp \sqrt{\frac{T_0}{T}}$$



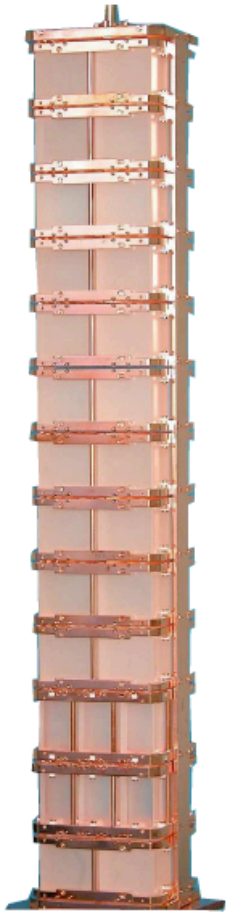


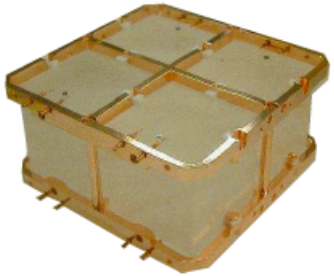




CUORICINO

CUORICINO[10, 11, 12] (2003 - 2008) is still the largest bolometric experiment ever realized.





$5 \times 5 \times 5\ \mathrm{cm}^3$
790 g

$3 \times 3 \times 6\ \mathrm{cm}^3$
330 g

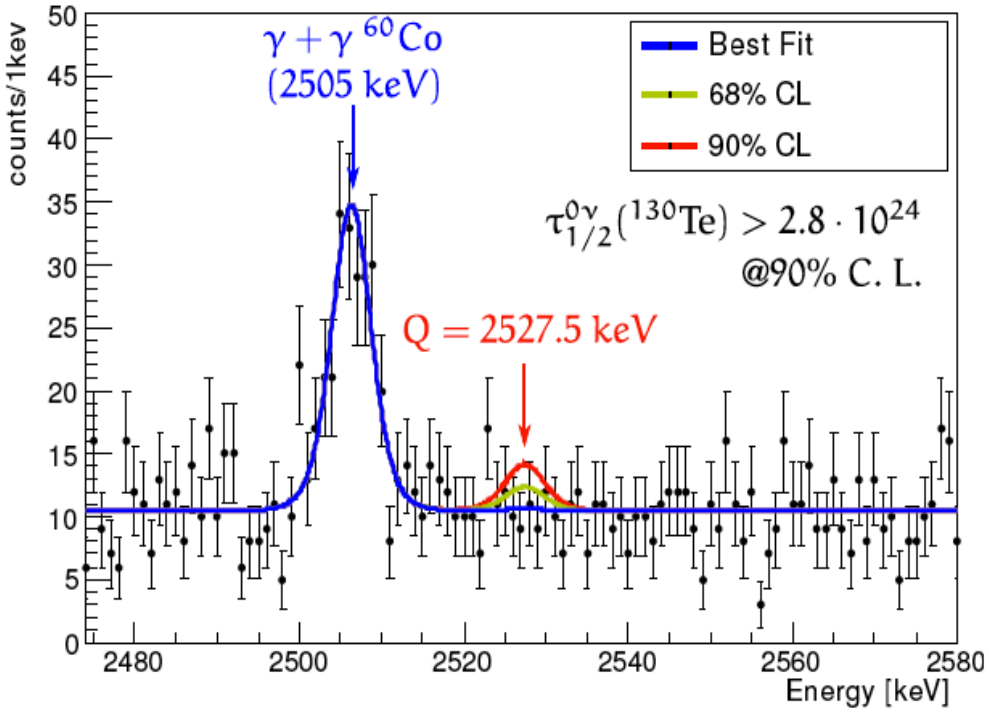
CURICINO: 62 TeO_2 Crystals

- It took datas form April 2003 to June 2008;
- 11 modules of 4 TeO_2 crystals $5 \times 5 \times 5$ cm^3 (790 g);
- 2 modules of 9 TeO_2 crystals $3 \times 3 \times 3$ cm^3 (330 g);
  - 14 crystals of no-enriched ^{130}Te (34.2% [8])
  - 2 crystals enriched in ^{130}Te (75% [13]);
  - 2 crystals enriched in ^{128}Te (82.3%);

Total mass of TeO_2: 40.7 kg
Total mass of ^{130}Te: 11.3 kg

CUORICINO $0\nu\beta\beta$ results

Total exposure: 19.75 kg·y of ^{130}Te (big crystals alone: 15.8 kg·y of ^{130}Te)



NME References

1. R(QRPA): F. Simkovic *et al.*, PRC 77 (2008) [14];
2. pn(QRPA): O. Civitarese *et al.*, JoPCS 173 (2009) [15];
3. ISM: J. Menendez *et al.*, NPA 818 (2009) [16];
4. IBM: J. Barea and F. Iachello, PRC 79 (2009) [17];

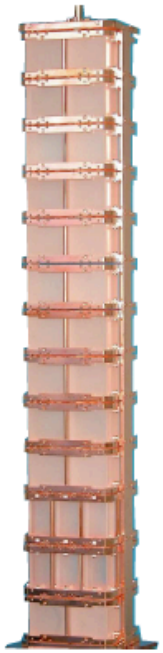
Background: (0.153 ± 0.006) c/keV/kg/y [18]

Lower Limit, Half-life: $\tau^{0\nu}_{1/2}(^{130}\mathrm{Te}) > 2.8 \cdot 10^{24}$ y (90% C. L.) [18]

Upper Limit, Majorana Mass: $m_{\nu_e} < (300 \div 710)$ meV [18]

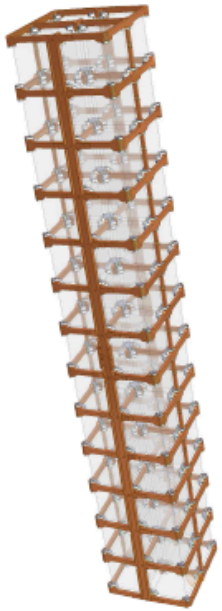
CUORE Program

CUORICINO
2003 - 2008



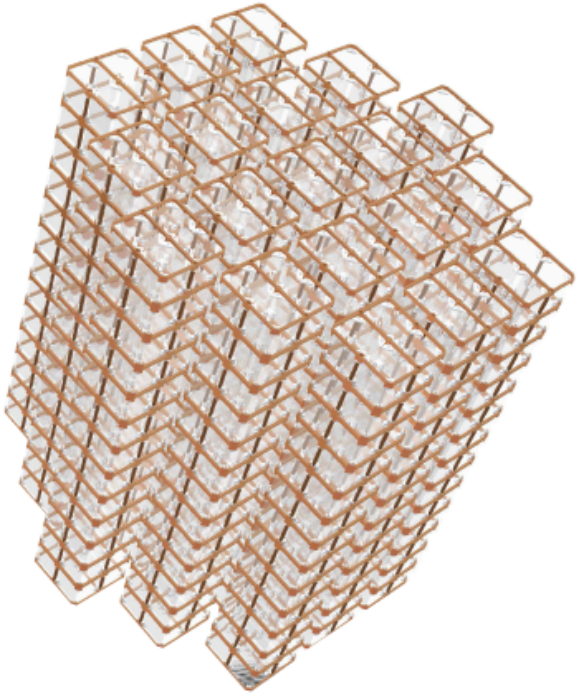
1 Tower
$44 + 18 = 62$ crystals
$\simeq 11$ kg of ^{130}Te
$B = 0.153$ c/keV/kg/y

CUORE-0
2011 - 2014



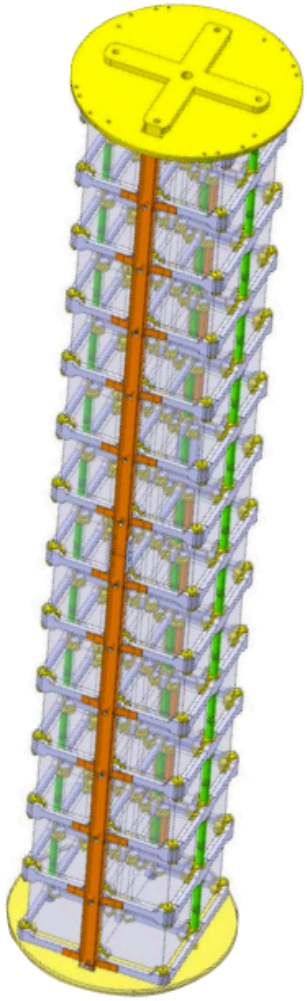
1 Tower
52 crystals
$\simeq 11$ kg of ^{130}Te
$B = (0.05 \div 0.18)$ c/keV/kg/y

CUORE
2013 - 2018



19 Towers, 52 crystals each
988 crystals
$\simeq 206$ kg of ^{130}Te
$B = (0.01 \div 0.001)$ c/keV/kg/y

The near future: CUORE-0

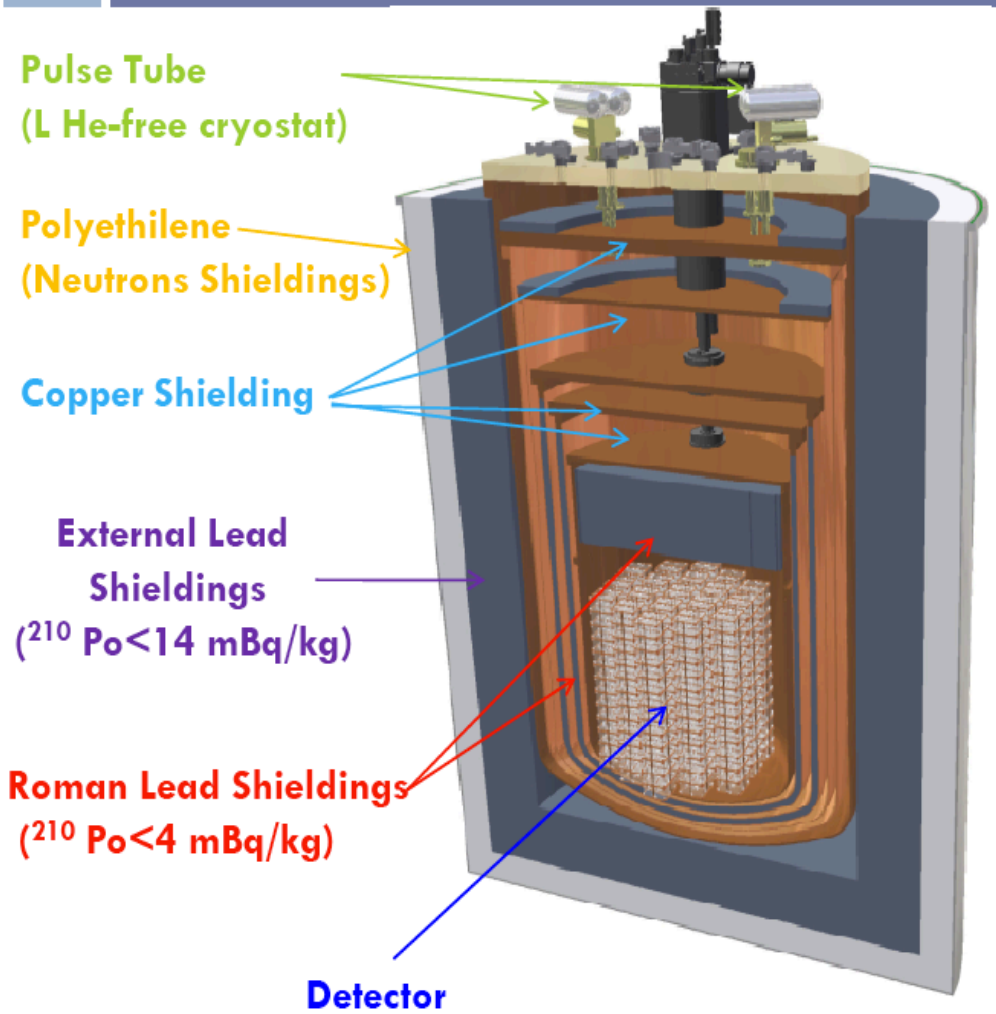


CUORE-0

- A single tower (52 TeO_2 crystals) realized with the same procedure of CUORE;
  1. crystals from the same production line;
  2. same copper and PTFE;
  3. CUORE-like copper surface cleaning;
  4. same assembly line;
- The tower will be installed in Hall A cryostat (the same as CUORICINO);
- Many aspects can be analyzed with CUORE-0;
  1. detector performances;
  2. radioactive background;

CUORE-0 will be assembled in the next months at LNGS and then put into operation before the end of the year.

CUORE (Cryogenic Underground Experiment for Rare Events)



- 998 TeO_2 crystals 5x5x5cm^3 (750g), arranged in 19 towers;
- 741 kg of TeO_2 -> 206 kg of ^{130}Te
- Resolution 5 keV @ 2615 keV (FWHM)
- Background aim: 0.01-0.001 c/keV/kg/y

Main concepts:

- Stringent controls on radioactivity
- Heavy shielded (Roman lead)
- High efficiency in bkg rejection thanks to close packet geometry

The EXO Collaboration

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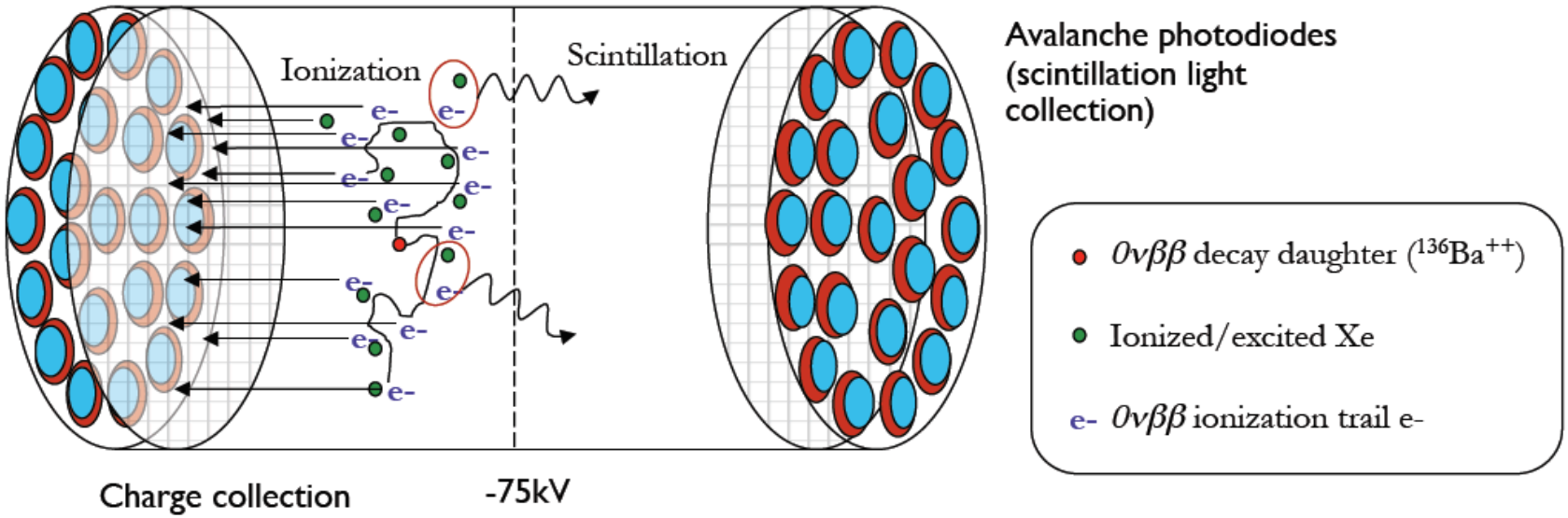
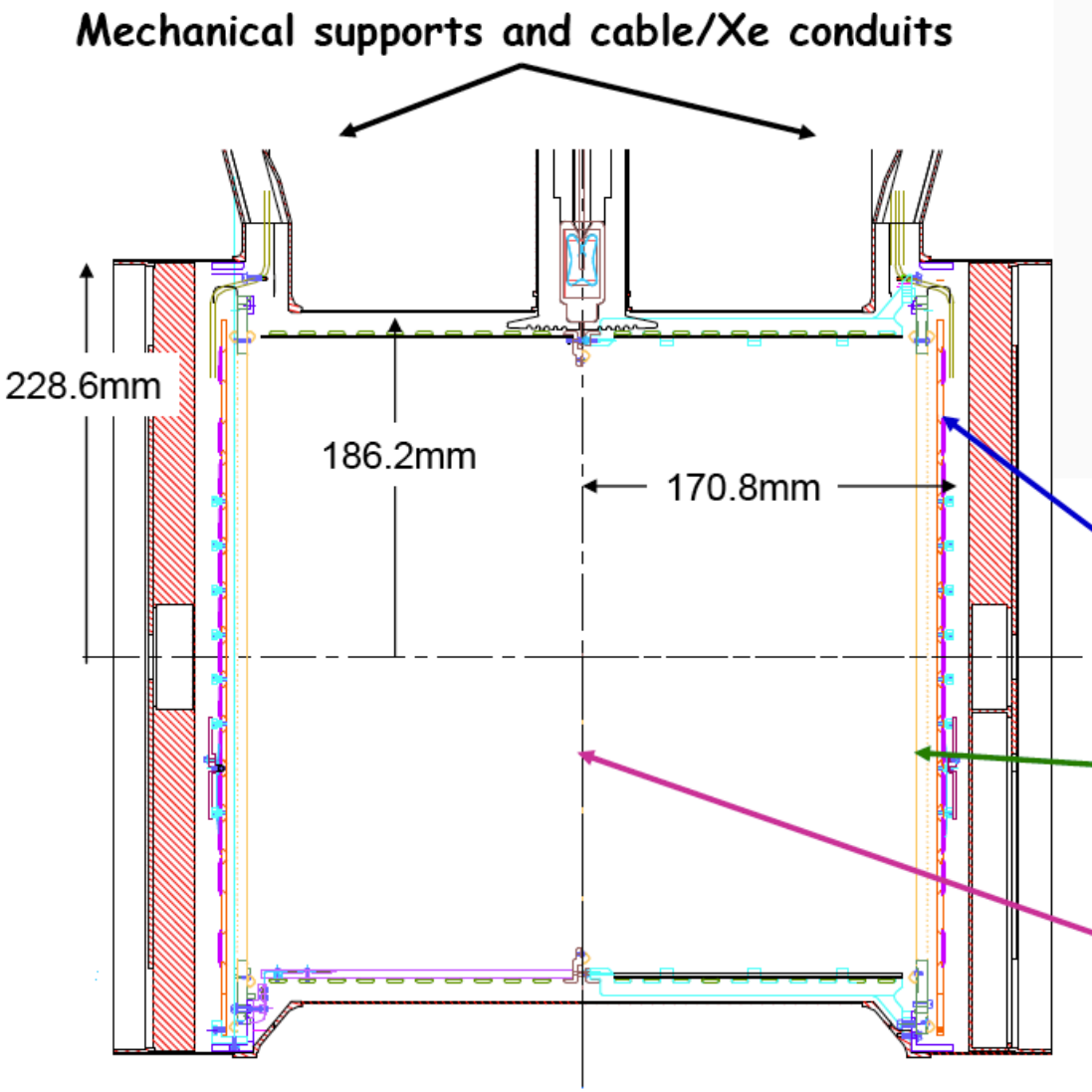
Physics Dept Stanford U., Stanford CA

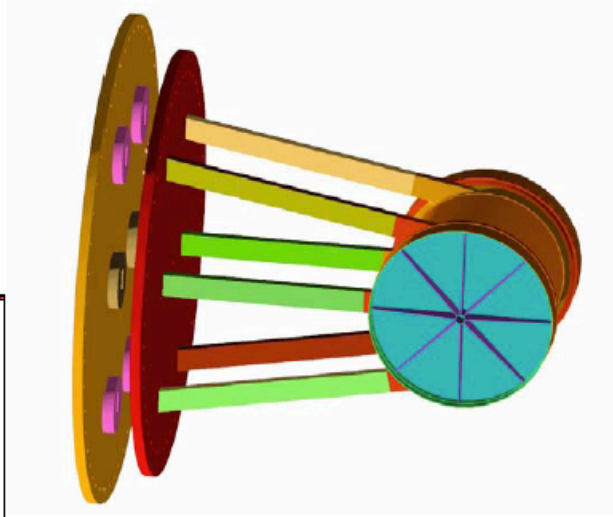
EXO-200



- Ionization along track is collected on X-Y wires (at 60 degree angle)
- Scintillation light (175nm) is collected on Avalanche Photo Diodes (APDs)
- Energy reconstruction from combined ionization and scintillation signals yielding predicted $\Delta E/E = 1.4\%$ at $Q_{\beta\beta}$
- Position reconstructed from charge distribution and t_{SCINT}-t_{ION} ; needed for Ba extraction in full scale EXO

EXO chamber "hugs" the fiducial volume very closely!





2x300 large area
(1.6cm active diameter)
unmounted APDs

Inductive and charge
collecting wire planes

Cathode grid

EXO-200 TPC basics

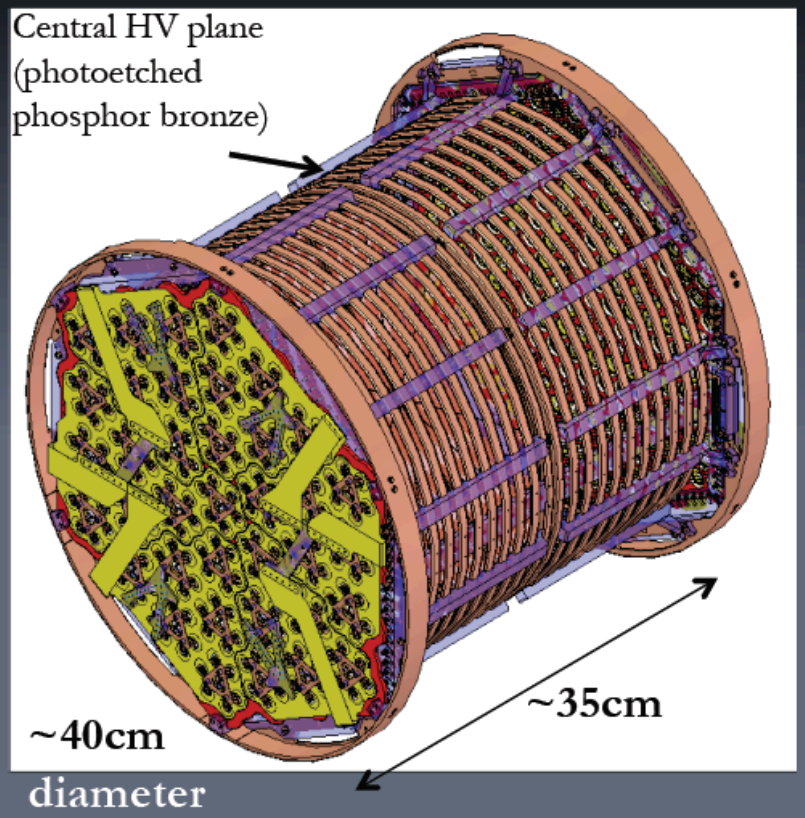
- The detector measures both the ionization electrons and the scintillation light to get best energy resolution.
  - In addition, the position of the decay is measured to get spatial distributions and (for later) the position of the Ba ion.
  - Info on event topology also important for background separation.

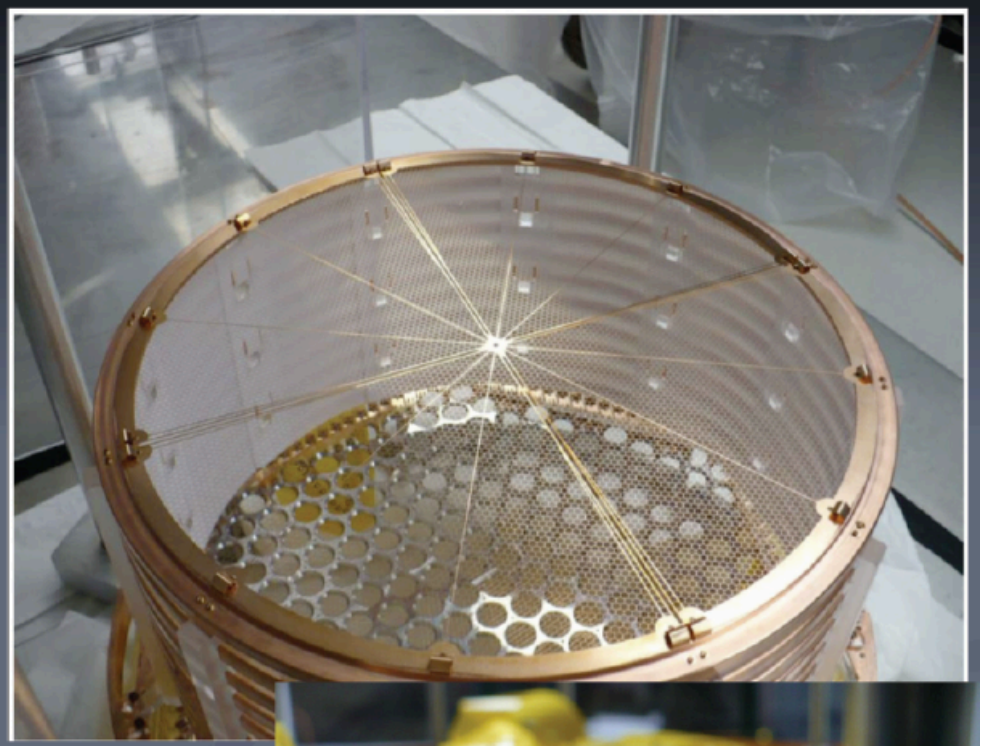
- The detector is a cylinder of ~40cm ID by ~40cm inner length.

- The cylinder is split by a cathode plane at the center so there are two symmetric drift regions. The cathode runs at negative HV.
  - Max HV is ~ 70kV (~3.5 kV/cm drift). Energy resolution improves with drift field, but there are arguments that separation of 1 vs 2 primary electrons might be better at lower fields.
    → field optimization is an important mission of EXO-200

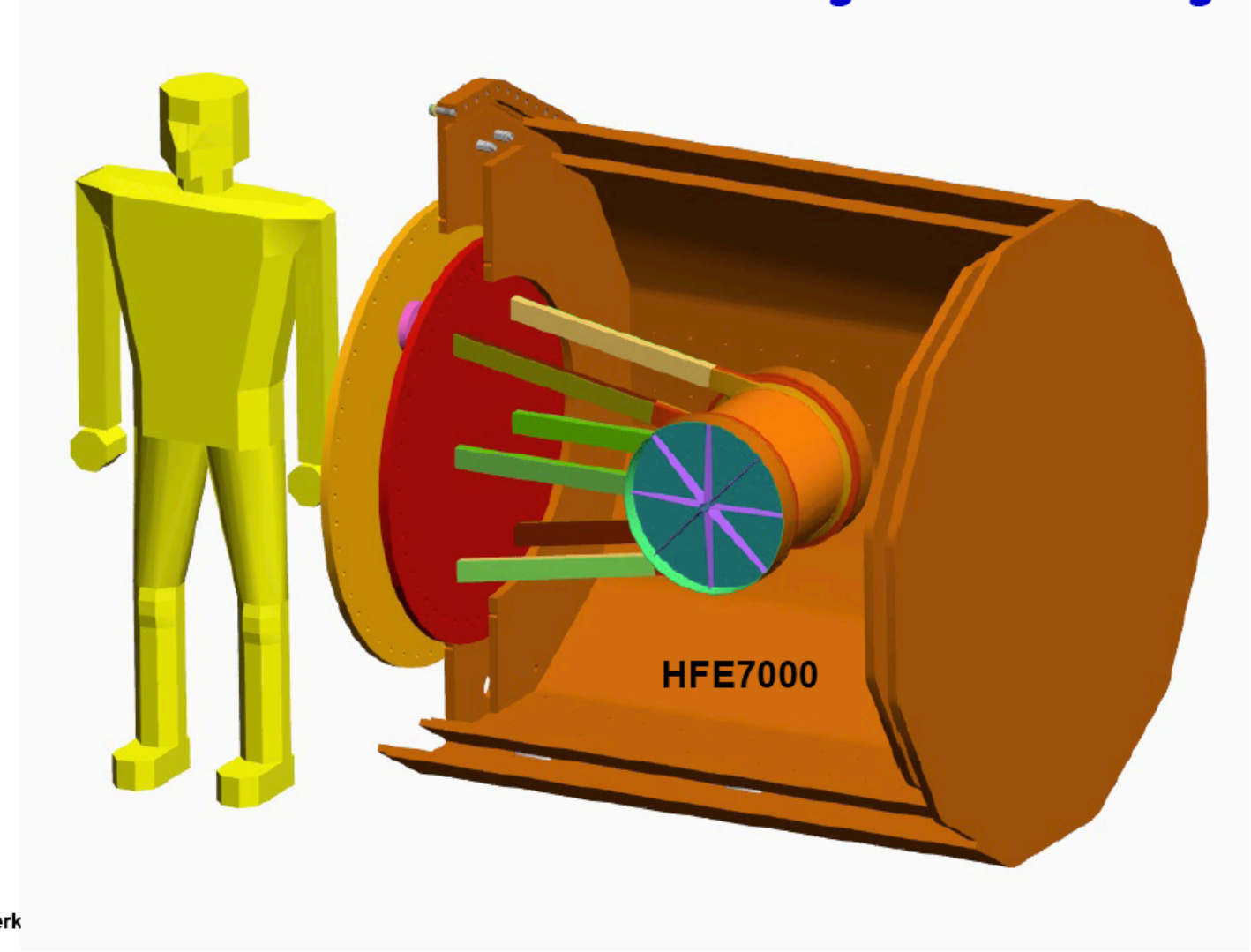
- Readout "style":
  - Crossed wires, 100μm wires, 3mm pitch, ganged in groups of 3
    48ch x, 48ch y, total 96 ch per 1/2 detector
    (Pad readout rejected because of high channel count)

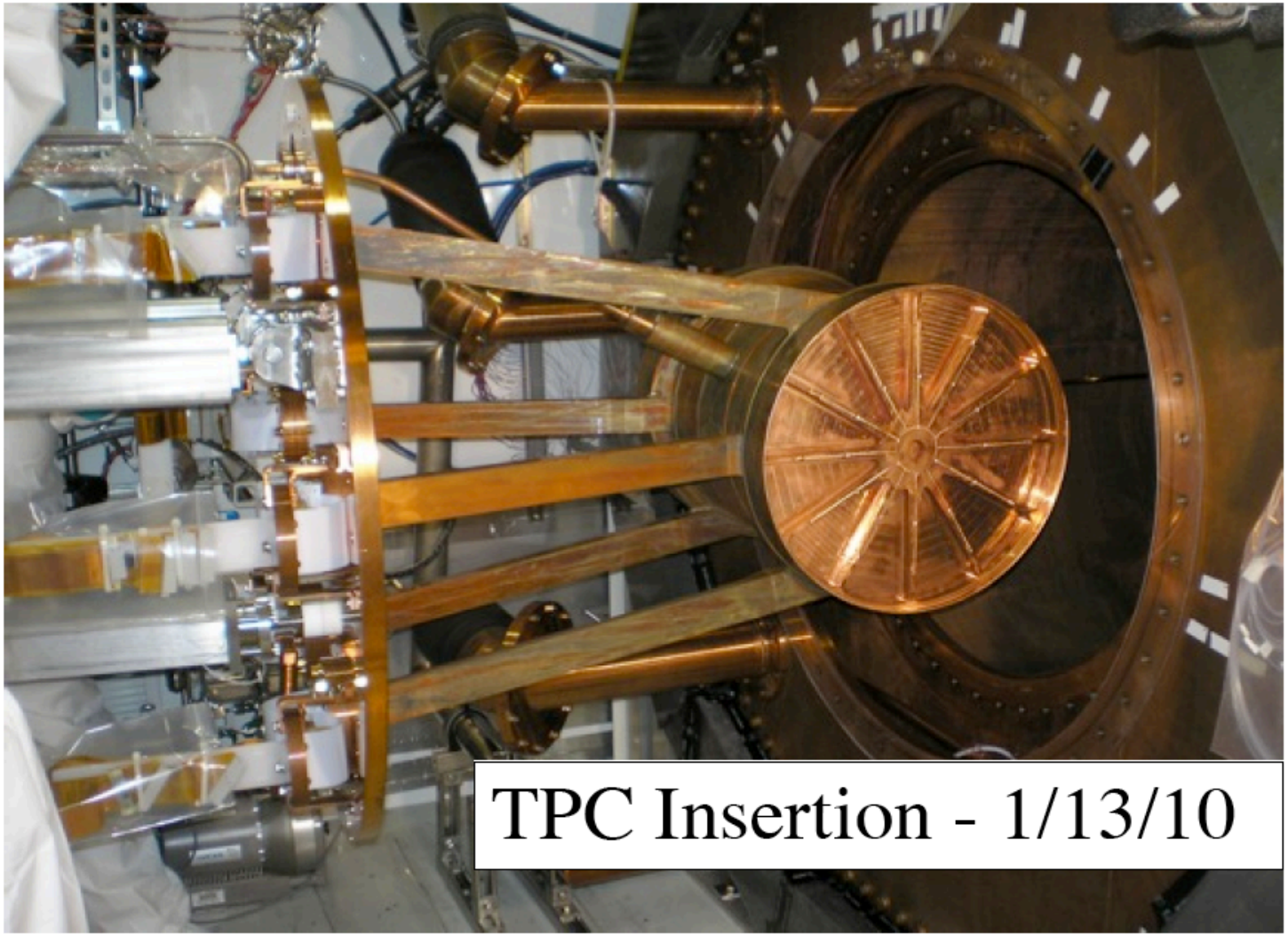
EXO-200


Central HV plane
(photoetched
phosphor bronze)
~40cm
diameter
~35cm

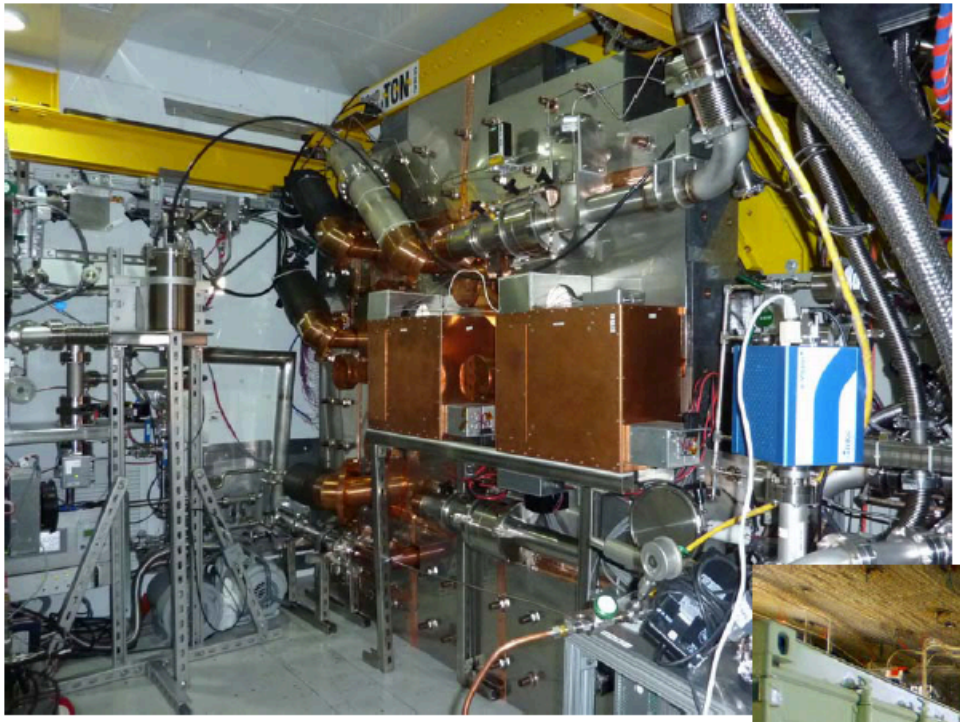


The TPC vessel sits in a low background, copper cryostat filled with ultra-clean HFE7000 refrigerant/shielding fluid





TPC Insertion - 1/13/10



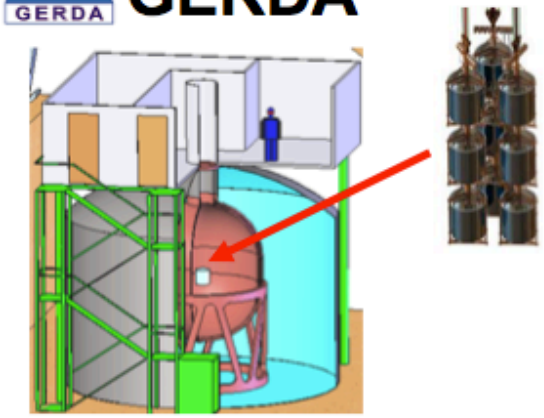
Front shield
& Rn enclosure

Veto counter installed
and commissioned

Low background
data taking started

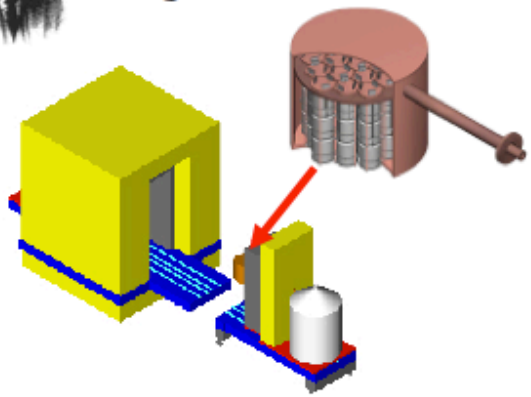
Two new ^{76}Ge Projects:

GERDA



- 'Bare' ^{enr}Ge array in liquid argon
- Shield: high-purity liquid Argon / H_2O
- Phase I: 18 kg (HdM/IGEX) / 15 kg nat.
- Phase II: add ~20 kg new enr. Detectors; total ~40 kg enriched detectors

Majorana



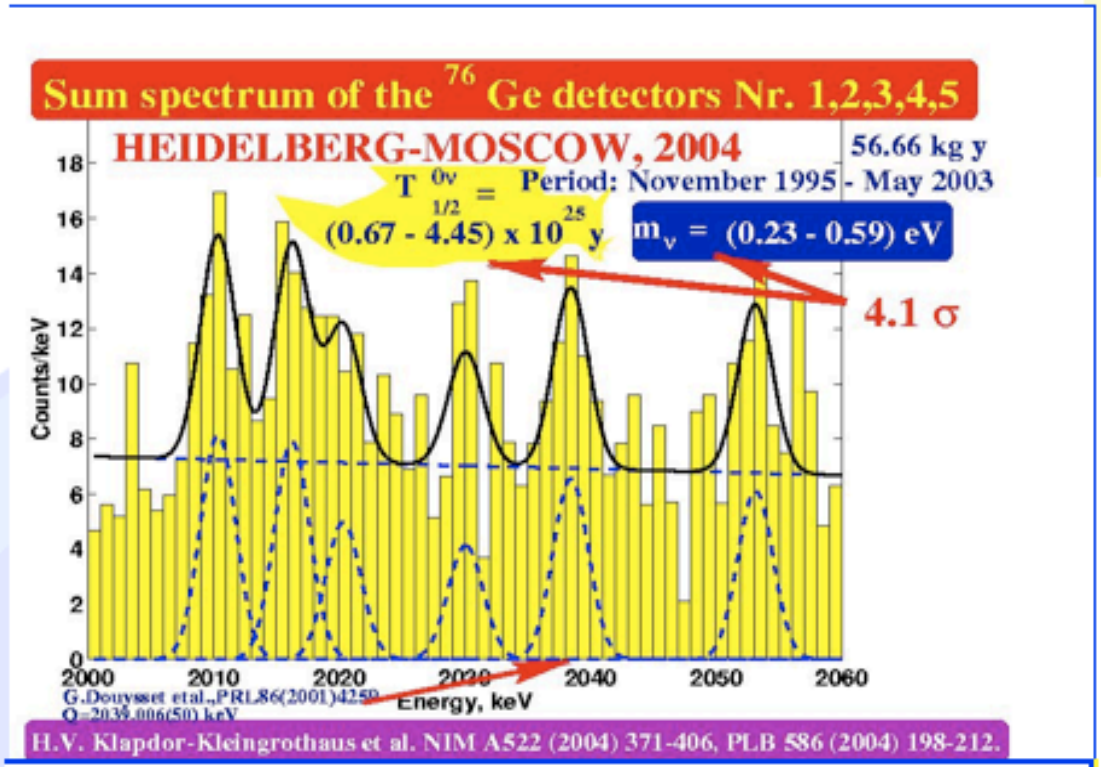
- Array(s) of ^{enr}Ge housed in high-purity electroformed copper cryostat
- Shield: electroformed copper / lead
- Initial phase: R&D demonstrator module: Total ~60 kg (30 kg enr.)

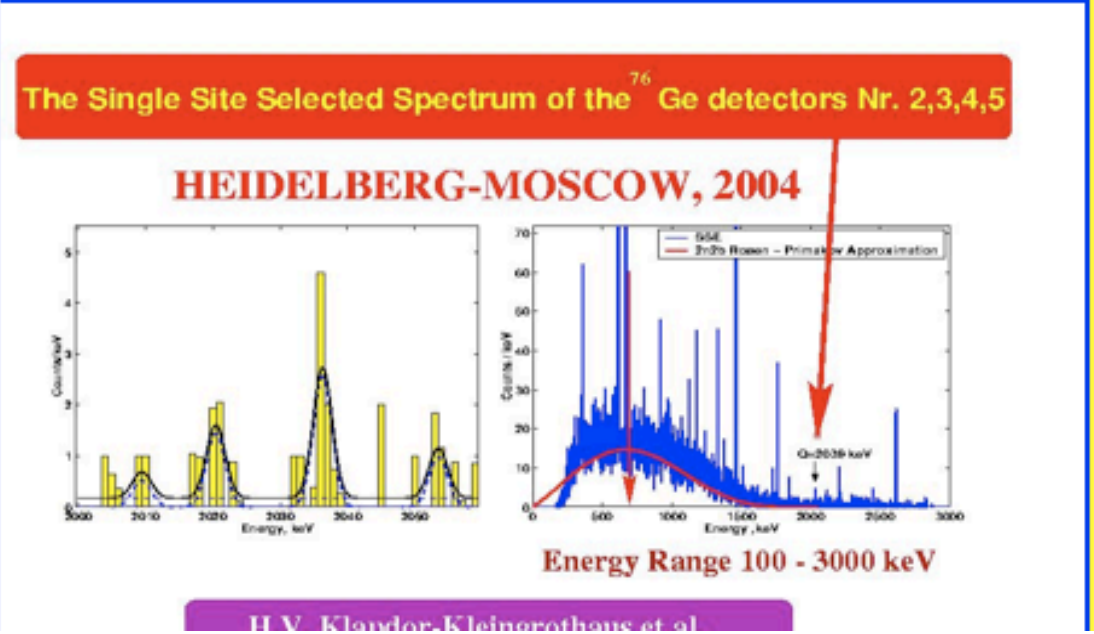
Physics goals: degenerate mass range
Technology: study of bgds. and exp. techniques

LoI
- open exchange of knowledge & technologies (e.g. MaGe MC)
- intention to merge for O(1 ton) exp. (inv. Hierarchy) selecting the best technologies tested in GERDA and Majorana

Characteristics of ^{76}Ge for $0\nu\beta\beta$ search

- **Favorable nuclear matrix** element $|M^{0\nu}|=3 – 9$
- **Reasonable slow $2\nu\beta\beta$ rate** ($T_{1/2}$ = 1.4 × 10^{21} y) and **high $Q_{\beta\beta}$ value (2039 keV)**
- Ge as **source and detector**
- **Elemental Ge** maximizes the source-to-total mass ratio
- **Industrial techniques** and facilities available to enrich from 7% to ~86%
- **Intrinsic high-purity** Ge diodes & HP-Ge detector technologies well established
- **Excellent energy resolution**: FWHM ~3 keV at 2039 keV (0.16%)
- Powerful signal identification & background rejection possible with **novel detector** concepts:
  - time structure of charge signal (PSA) using **BEGe detectors**
  - granularity
  - **liquid argon** scintillation as **active veto system**
- **Best limits** on $0\nu\beta\beta$ - decay used Ge (IGEX & Heidelberg-Moscow) $T_{1/2}$ > 1.9 × 10^{25} y (90%CL) **[& claim for evidence]**





$$T_{1/2}^{0\nu}(^{76}Ge) = 2.23^{+0.44}_{-0.31} \times 10^{25}\, y$$

H.V. Klapdor-Kleingrothaus and his colleagues reanalyzed the Heidelberg - Moscow Experiment data and concluded that the data does support the claim of first observation of zero-neutrino double-beta decay.

This has been highly controversial; however, it cannot be refuted nor confirmed except by experiment.

GERDA

~ 100 members
19 institutions
6 countries

M. Agostini [n], M. Allardt [c], E. Andreotti [e], A.M. Bakalyarov [l], M. Balata [a], I. Barabanov [j], M. Barnabe-Heider [f], L. Baudis [s], C. Bauer [f], N. Becerici-Schmid [m], E. Bellotti [g,h], S. Belogurov [k,j], S.T. Belyaev [l], G. Benato [o,p], A. Bettini [o,p], L. Bezrukov [j], T. Bruch [s], V. Brudanin [d], R. Brugnera [o,p], D. Budjas [n], A. Caldwell [m], C. Cattadori [g,h], F. Cossavella [m], E.V. Demidova [k], A. Denisov [j], S. Dinter [m], A. Domula [c], V. Egorov [d], F. Faulstich [m], A. Ferella [s], K. Freund [r], F. Froborg [s], N. Frodyma [b], A. Gangapshev [j], A. Garfagnini [o,p], S. Gazzana [l,d], P. Grabmayr [r], V. Gurentsov [j], K.N. Gusev [l,d], W. Hampel [f], A. Hegai [r], M. Heisel [f], S. Hemmer [o,p], G. Heusser [f], W. Hofmann [f], M. Hult [e], L. Ianucci [a], L.V. Inzhechik [j], J. Janicsko [n], J. Jochum [r], M. Junker [a], S. Kianovsky [j], I.V. Kirpichnikov [k], A. Kirsch [f], A. Klimenko [d,j], K-T. Knoepfle [f], O. Kochetov [d], V.N. Kornoukhov [k,j], V. Kusminov [j], M. Laubenstein [a], V.I. Lebedev [l], B. Lehnert [c], S. Lindemann [f], M. Lindner [f], X. Liu [q], A. Lubashevskiy [f], B. Lubsandorzhiev [j], A.A. Machado [f], B. Majorovits [m], G. Marissens [e], G. Meierhofer [r], I. Nemchenok [d], S. Nisi [a], C. O'Shaughnessy [m], L. Pandola [a], K. Pelczar [b], F. Potenza [a], A. Pullia [i], M. Reissfelder [f], S. Riboldi [i], F. Ritter [r], C. Sada [o,p], J. Schreiner [f], U. Schwan [f], B. Schwingenheuer [f], S. Schönert [n], H. Seitz [m], M. Shirchenko [l,d], H. Simgen [f], A. Smolnikov [f], L. Stanco [p], F. Stelzer [m], H. Strecker [f], M. Tarka [s], A.V. Tikhomirov [l], C.A. Ur [p], A.A. Vasenko [k], O. Volynets [m], M. Wojcik [b], E. Yanovich [j], P. Zavarise [a], S.V. Zhukov [l], D. Zinatulina [d], F. Zocca [i], K. Zuber [c], and G. Zuzel [b].

[a]) INFN Laboratori Nazionali del Gran Sasso, LNGS, Asse
[b]) Institute of Physics, Jagellonian University, Cracow, I
[c]) Institut für Kern- und Teilchenphysik, Technische Universität Dresde
[d]) Joint Institute for Nuclear Research, Dubna, Russ
[e]) Institute for Reference Materials and Measurements, Geel
[f]) Max Planck Institut für Kernphysik, Heidelberg, Ger
[g]) Dipartimento di Fisica, Università Milano Bicocca, Mila
[h]) INFN Milano Bicocca, Milano, Italy
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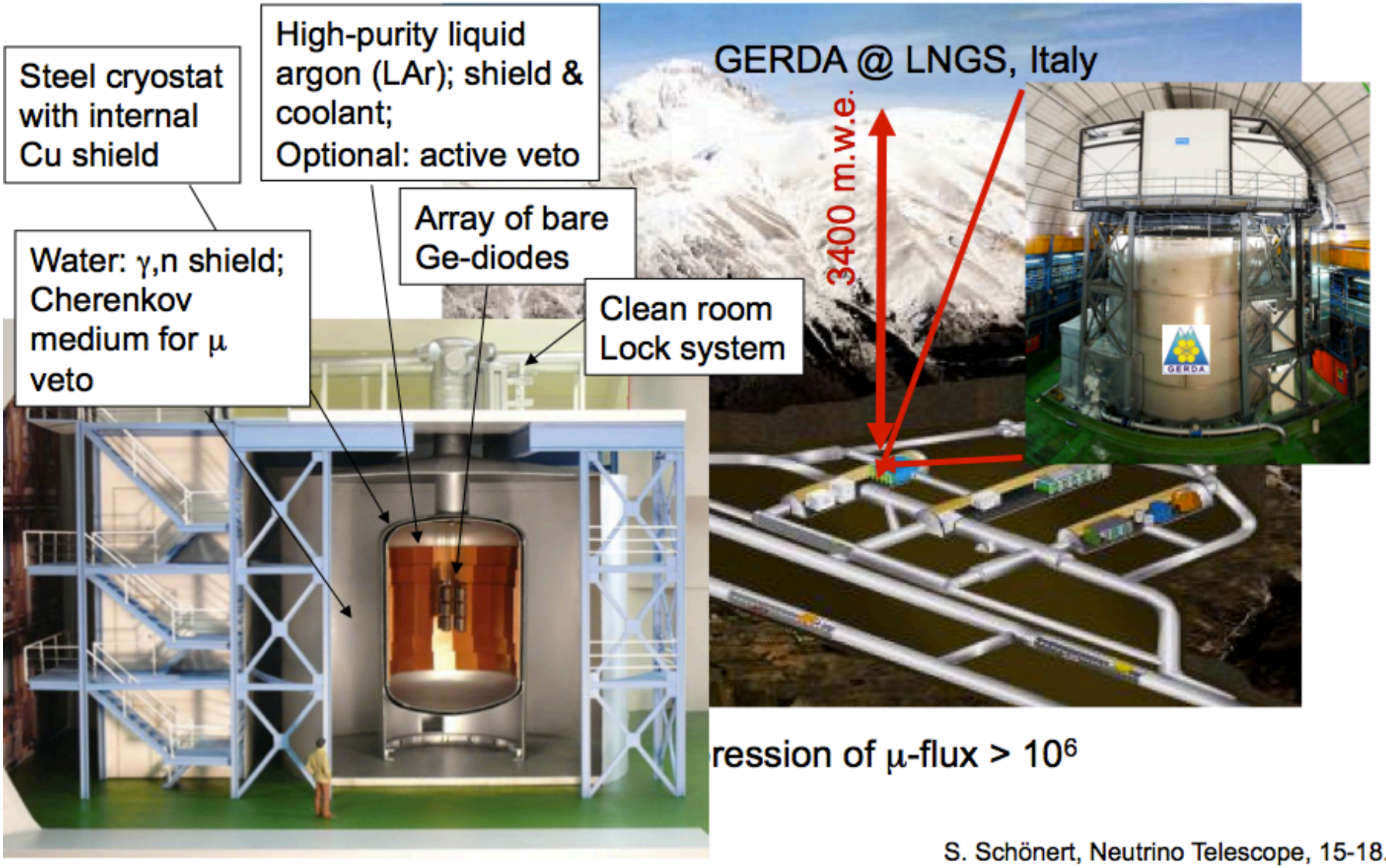
[l]) Russian Research Center Kurchatov Institute, Moscow,
[m]) Max-Planck-Institut für Physik, München, Germa
[n]) Physik Department E15, Technische Universität München
[o]) Dipartimento di Fisica dell'Università di Padova, Pado
[p]) INFN Padova, Padova, Italy
[q]) Shanghai Jiaotong University, Shanghai, China
[r]) Physikalisches Institut, Eberhard Karls Universität Tübingen, Tübingen, Germany
[s]) Physik Institut der Universität Zürich, Zürich, Switzerland

Background reduction:

Deep underground site for suppression of cosmic ray muons &
graded shielding against ambient radiation &
rigorous material selection &
signal analysis

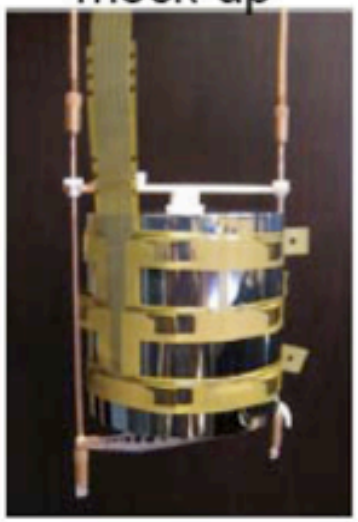


ression of μ-flux > 10^6

Phase II Detectors:

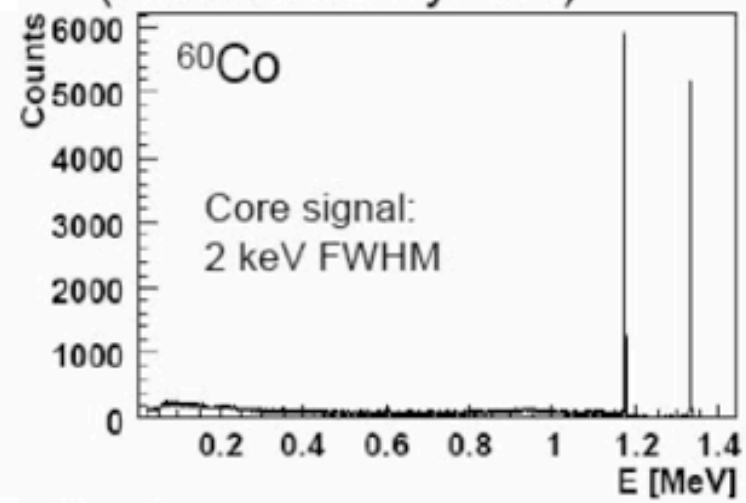
"True-coaxial" natural detectors

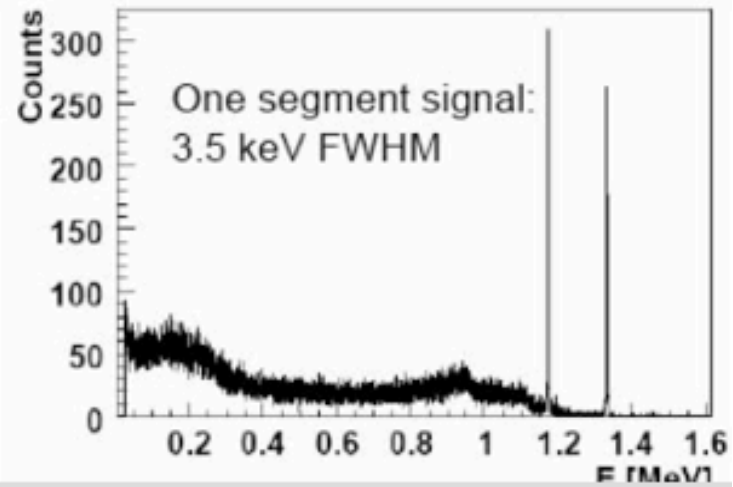
mock-up



- 6–fold–ϕ segmented p-type
- 18–fold (6-ϕ; 3-z) segmented n-type

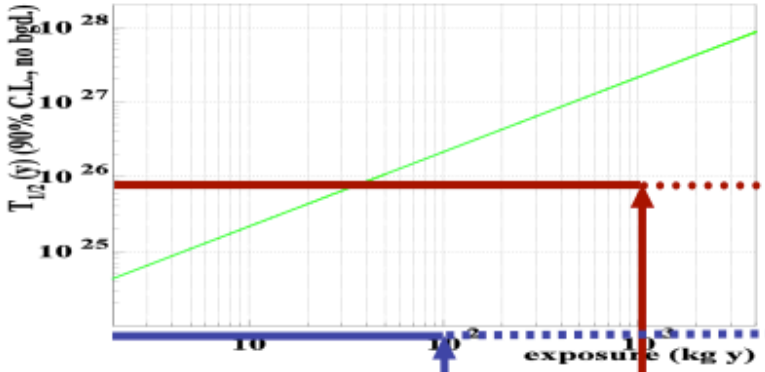
18-fold segmented detector (in standard cryostat)






© Jan Hattenbach
Inauguration of the GERDA experiment at the LNGS
9. November 2010
GERDA

Phases and physics reach



$2 \cdot 10^{27}$ (90 % CL) * → <24 - 41 meV

$2 \cdot 10^{26}$ (90 % CL) * → <75 - 129 meV

$3 \cdot 10^{25}$ (90 % CL)*

KK →

*: no event in ROI

GERDA Phase I

GERDA Phase II/ Majorana Demonst.

GERDA Phase III/ Majorana

assuming $|M^{0\nu}|$=2.99-8.99 [Smol&Grab PRC'10] and 86% enrichment

required for 'background free' exp. with ΔE~3.3 keV (FWHM): **$O(10^{-3})$** **$O(10^{-4})$** counts/(kg·y·keV)

Background requirement for GERDA/Majorana:

⇒Background reduction by factor **10^2 - 10^3** required w.r. to precursor exps.

⇒Degenerate mass scale **$O(10^2$ kg·y)** ⇒ Inverted mass scale **$O(10^3$ kg·y)**

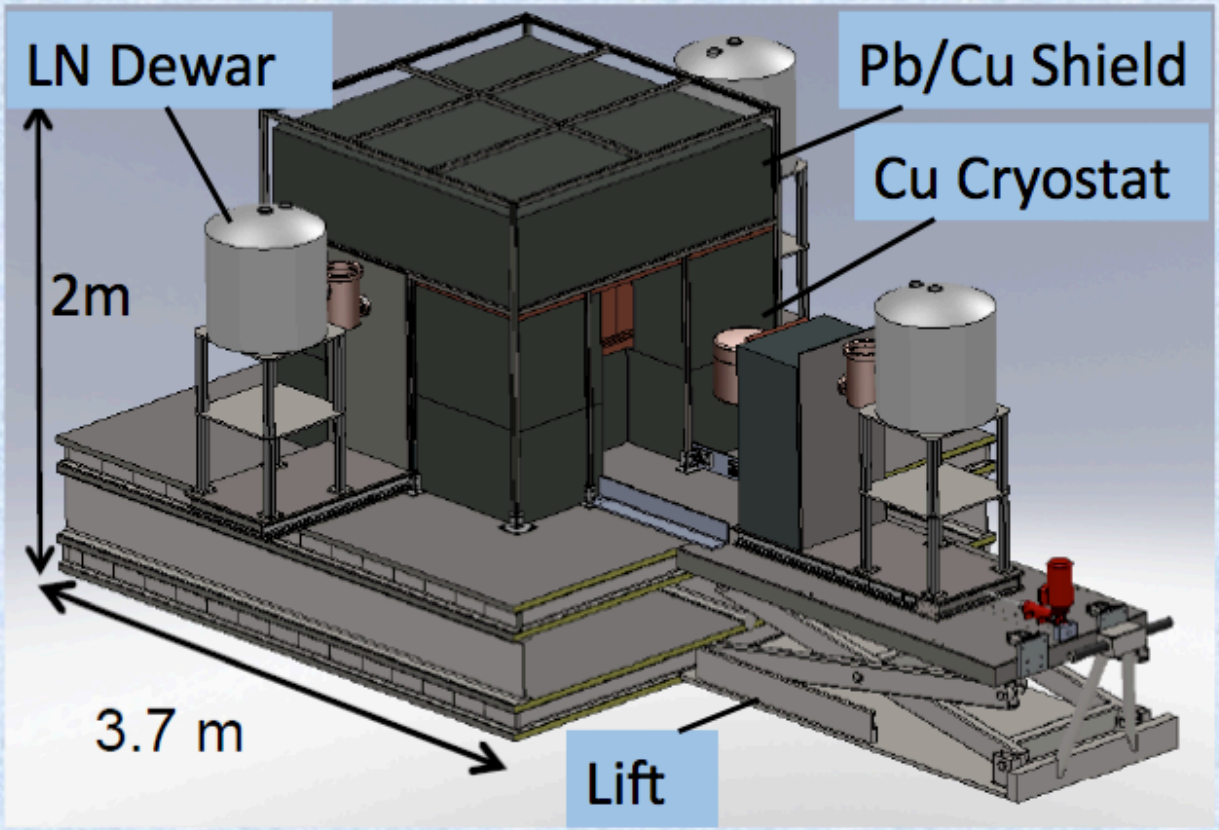
Conclusions & Outlook

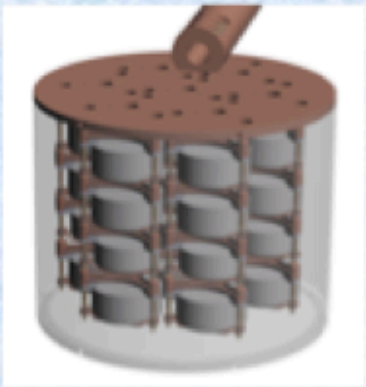
- GERDA experimental **installations completed** successfully; cryogenic and auxiliary systems operate very stable
- Detector **commissioning** with **non-enriched detectors** started summer 2010 and is still ongoing
- **Initial count rate** (run 1-3,5) **dominated by ^{42}K** (^{42}Ar progenitor) due to concentration of ^{42}K close to the detectors by E-field of diodes ⇒ **field-free configuration**
- **12 commissioning runs** with different detectors, read-out schemes, E-field configurations completed successfully
- Background with **non-enriched detectors currently at 0.05 cts/(keV kg year).** Goal for Phase I: 0.01 cts/(keV kg year).
- Deployment of first string(s) with **enriched detectors Phase I** soon to study background with enriched detectors ⇒ start of Phase I physics run

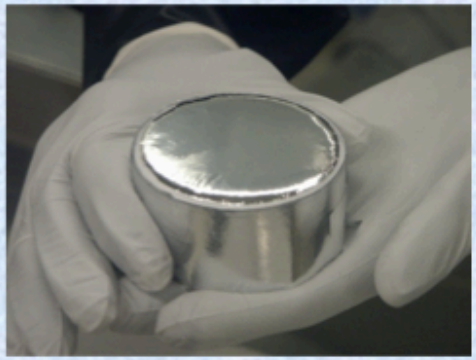
Conclusions & Outlook (cont.)

- Thick-window **p-type BEGe** detectors for **Phase II**
- Powerful **particle ID** and **background discrimination** by pulse shape analysis: MSE/SSE, p+ contact (α) and n+ (β) surface events
- Full **production chain tested** for BEGe Phase II detectors
- 37.5 kg of 86% **^{enr}Ge** (in form of GeO2) successfully transformed to **35.4 kg** (94%) of 6N
- Crystal **pulling** and **detector production** under preparation
- **Liquid argon instrumentation** shown in **GERDA-LArGe** test stand to be a powerful method to discriminate backgrounds: **implementation in GERDA if needed**

The MAJORANA DEMONSTRATOR



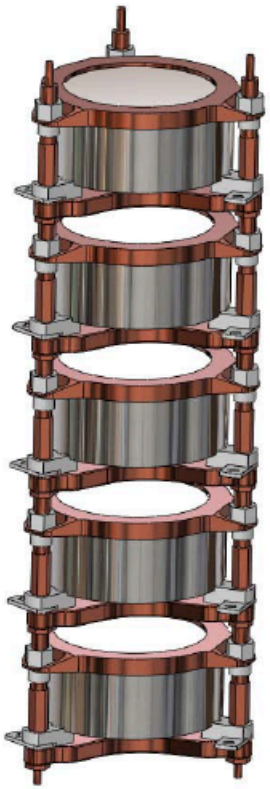


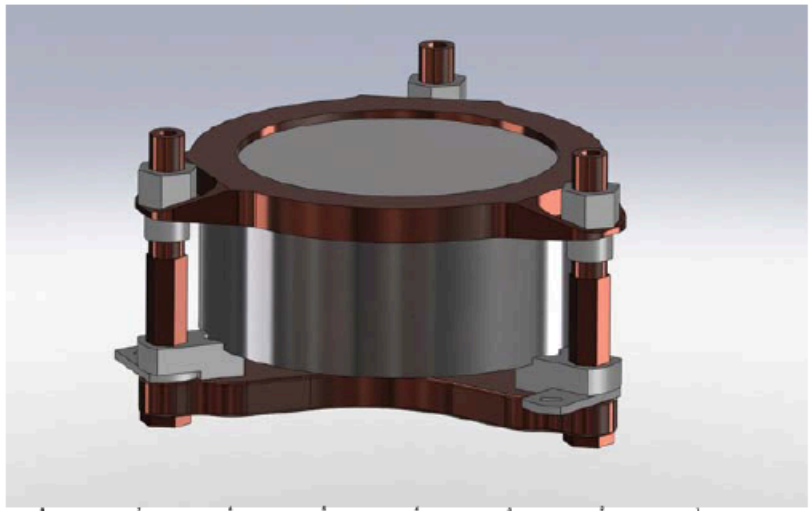


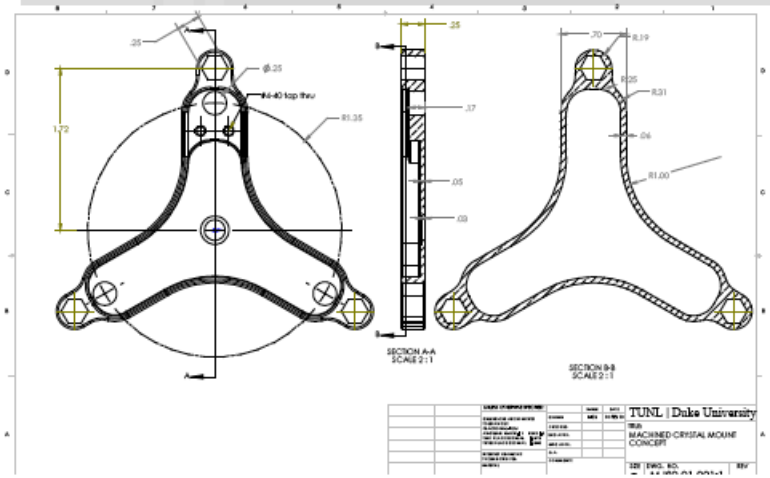
- The MAJORANA experiment is a US-led effort that will be deployed at the Sanford lab in South Dakota
- The design focuses on the use of high purity material and will use a Pb/Cu shield
- The experiment will be run in phases and will culminate with the use of 60 kg of Ge (30kg of which will be enriched)

Engineering Design status: Module

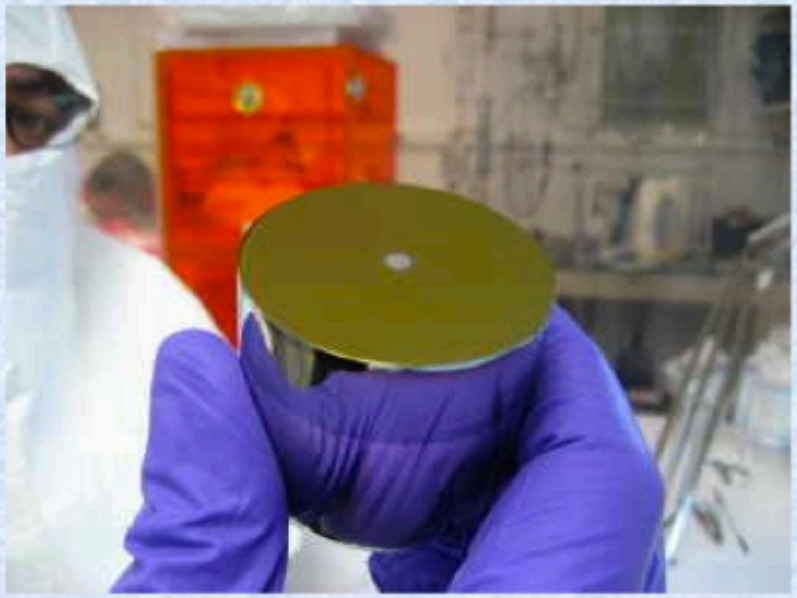
- Proven design in canary cage thermal test
  - Modifications underway to improve thermal performance
  - Modifications underway for clean fabrication techniques

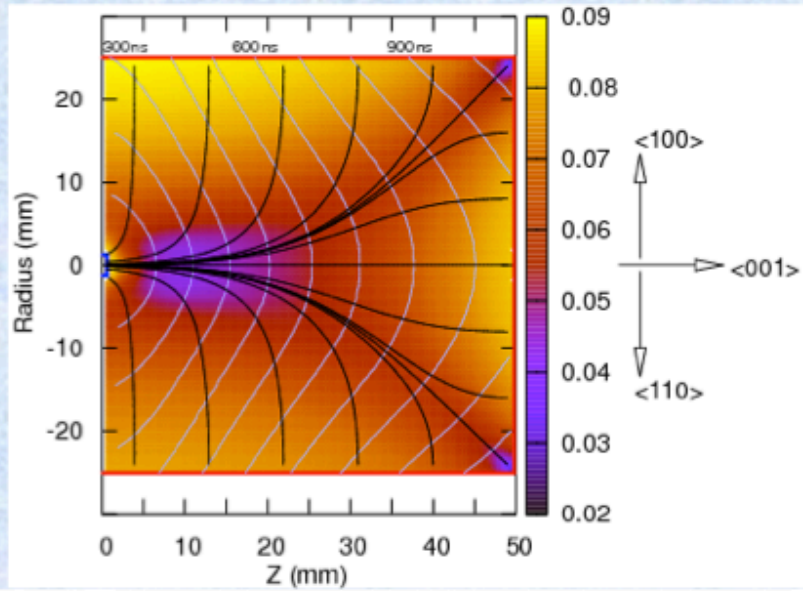




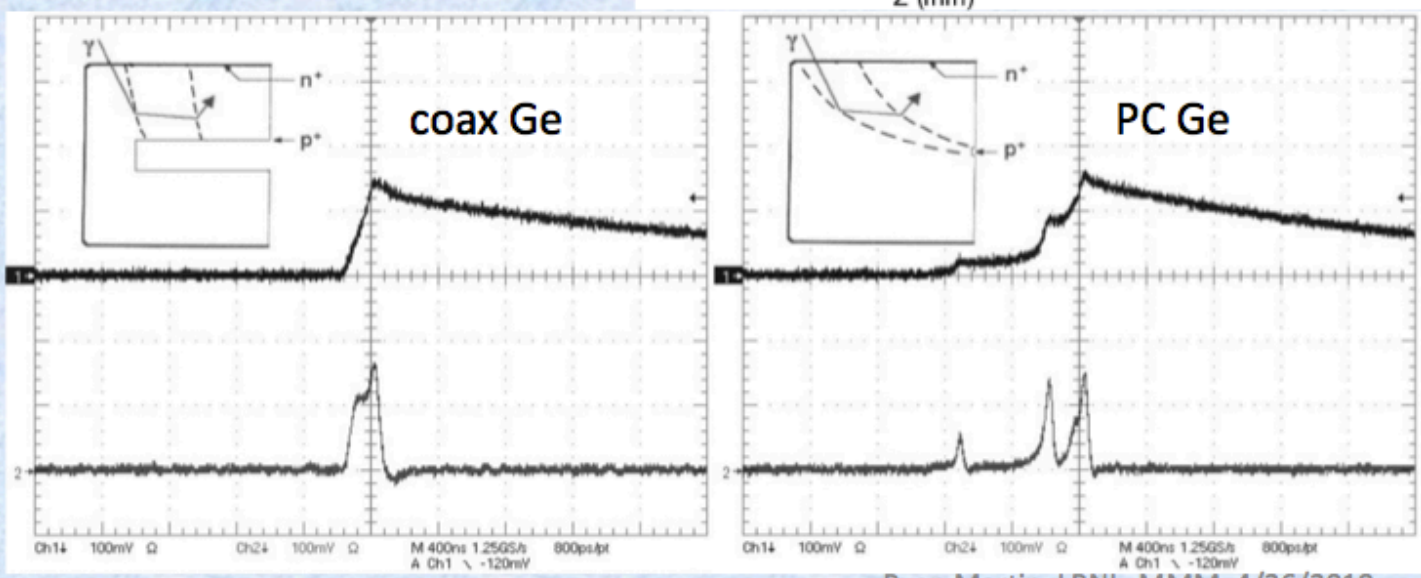


Point contact Ge detector

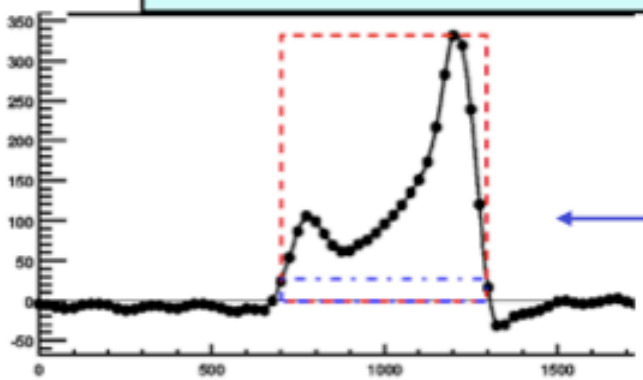


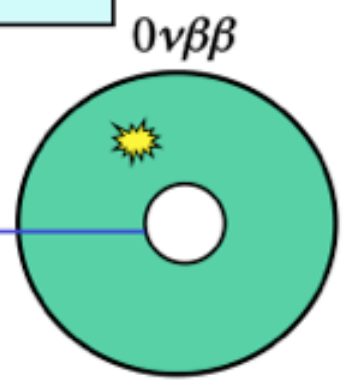


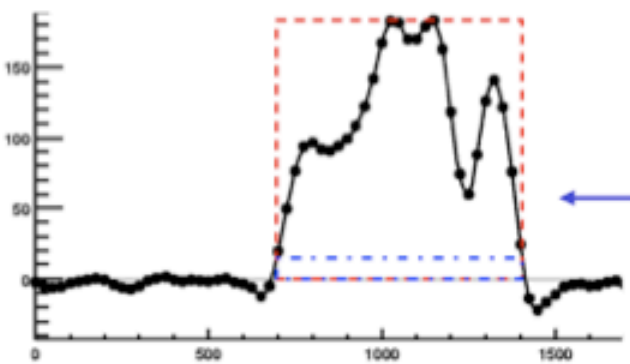
Point contact Ge detector allow multi-site events to be identified- invented by Paul Luke (LBNL)

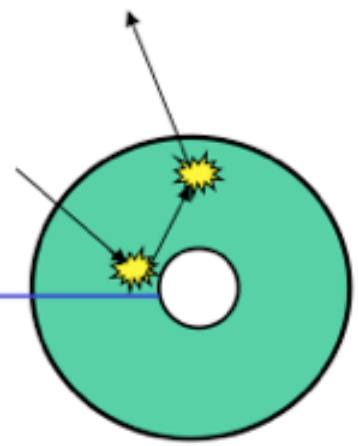


Pulse-shape discrimination



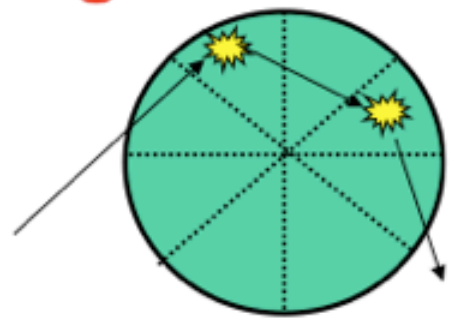




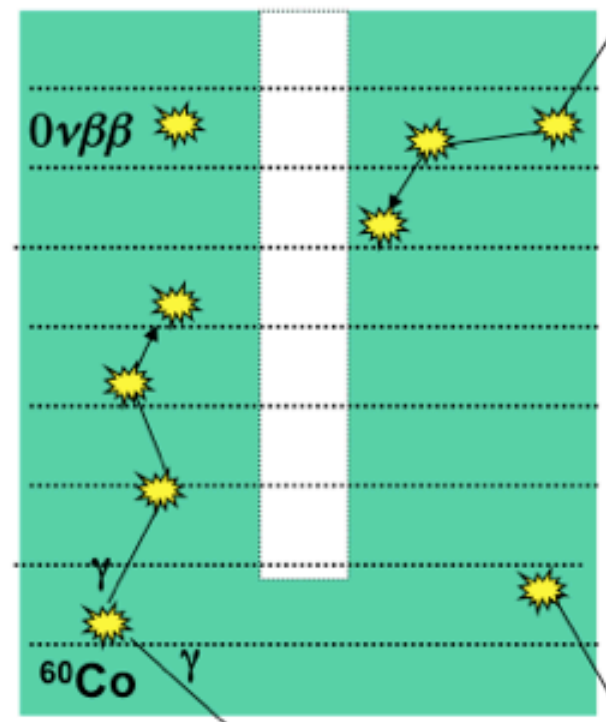


γ ("High" Energy)

Segmentation



γ ("High" Energy)



γ ("Low" Energy)

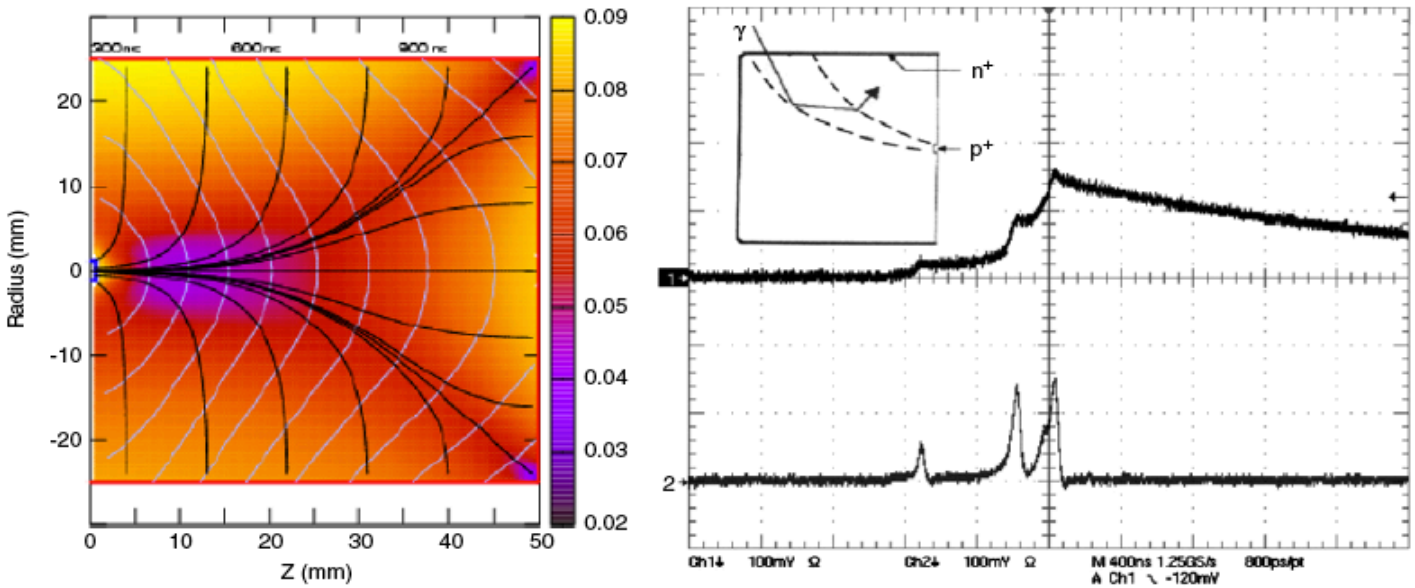


Fig. 1. The left figure shows charge-drift paths (dark) and isochrone lines (light) of a point-contact detector. Two events on the same isochrone appear as a single event. The color scale indicates the drift velocity of holes (in mm/ns). The right figure shows the charge pulse (top) and current pulse (lower) of a multisite event, from a gamma ray.

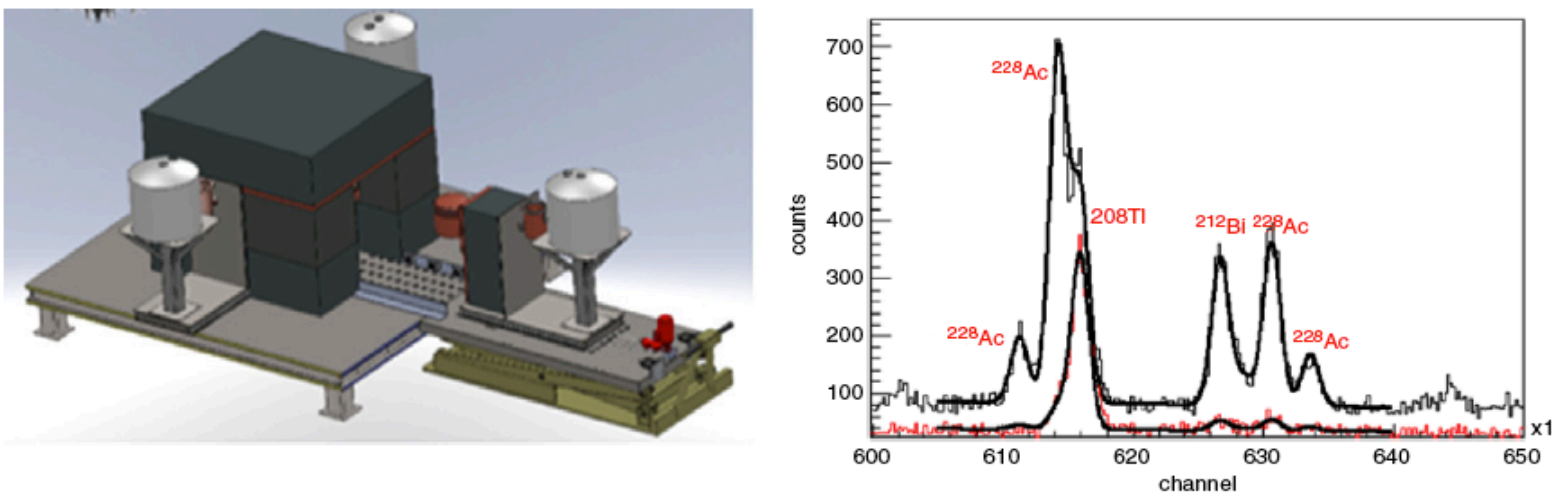
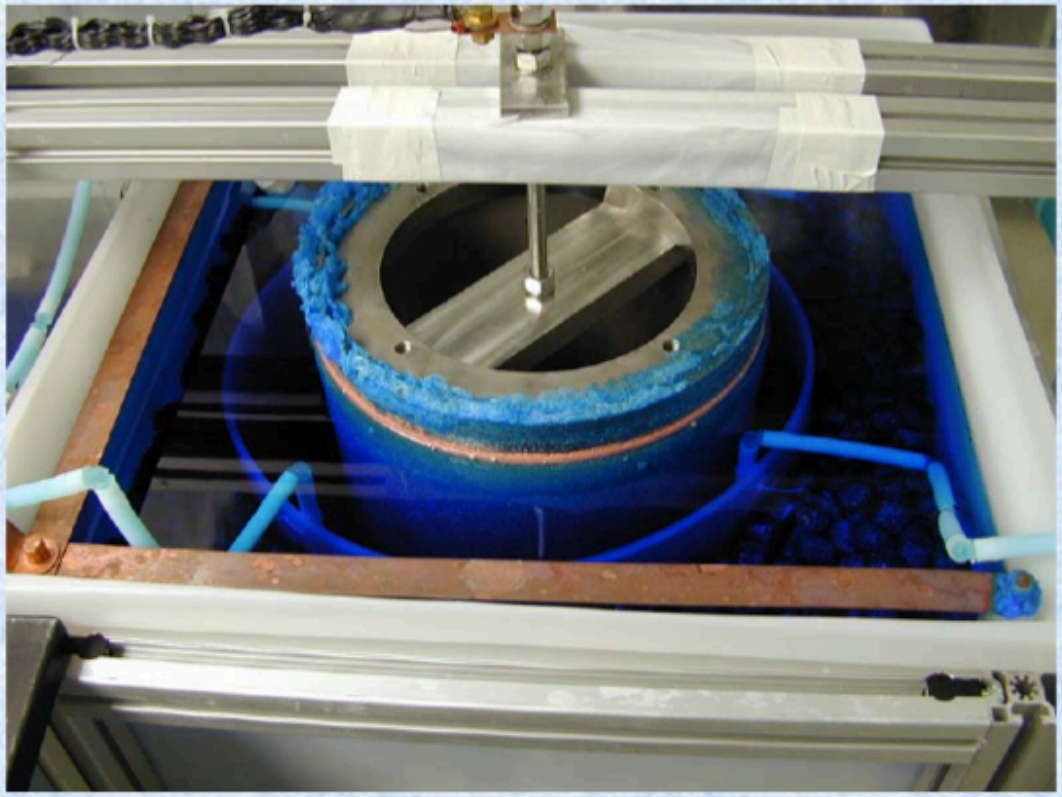
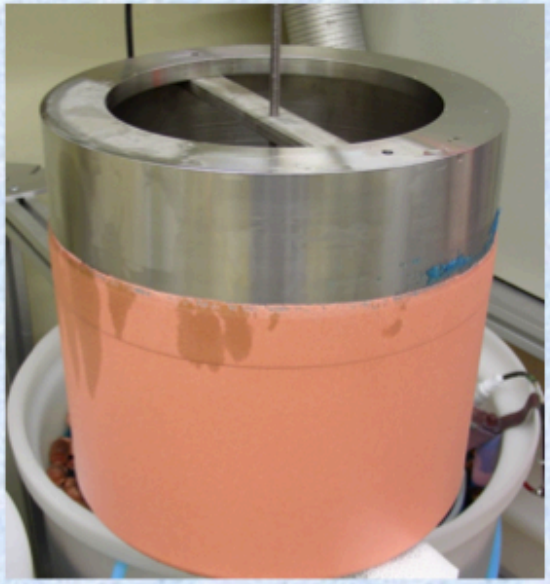


Fig. 2. Artist's conception of the DEMONSTRATOR shield (left panel), and the result of applying pulse-shape analysis on a spectrum from a calibration source of ^{232}Th irradiating a BEGe detector (right panel).

Electroformed copper

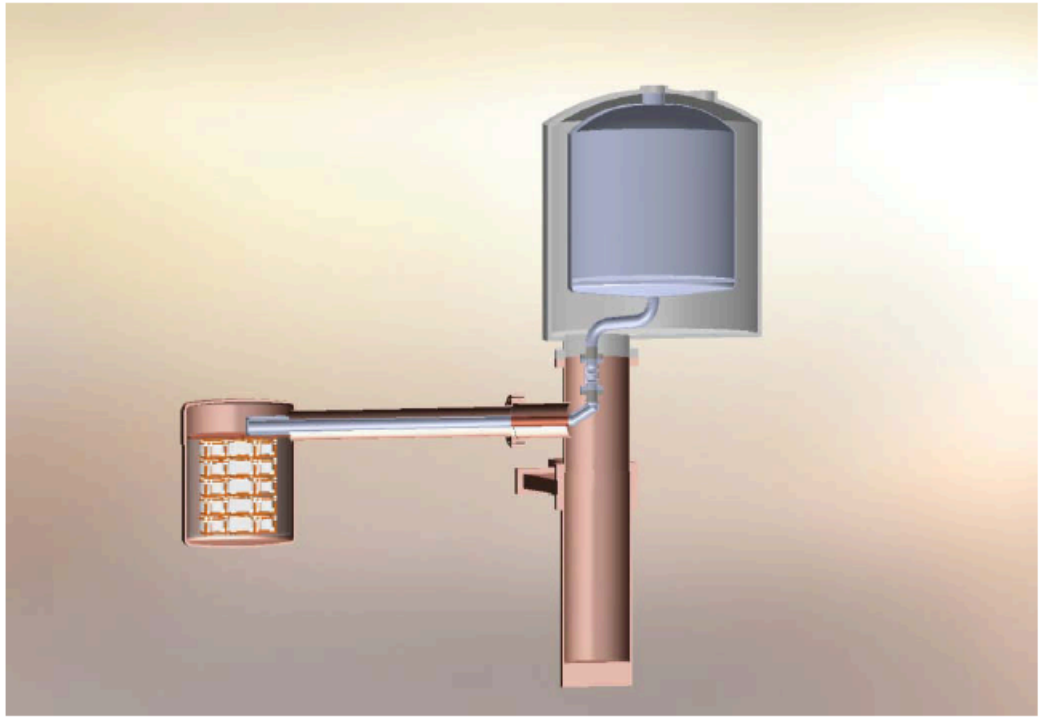




- The use of electroformed copper removes impurities and significantly reduces backgrounds; goal is 0.3 μBq ^{232}Th and ^{238}U/kg Cu (~0.08 x 10^{-12} g/gCu)
- The copper is electroformed on steel mandrels that have the same diameter as the cryostats
- A total of 16 baths will be deployed underground. The material from the electroformed cylinders will be machined into various components

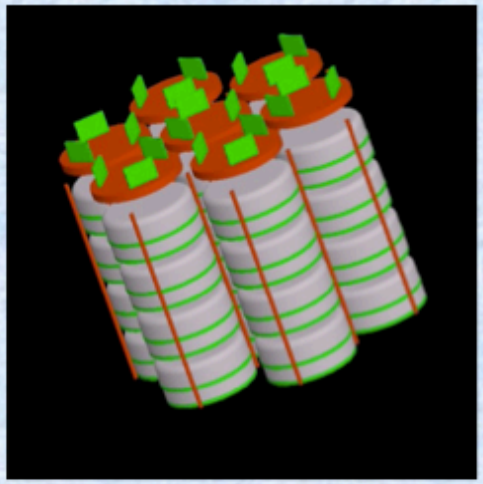
Thermosiphon cooling for coldplate

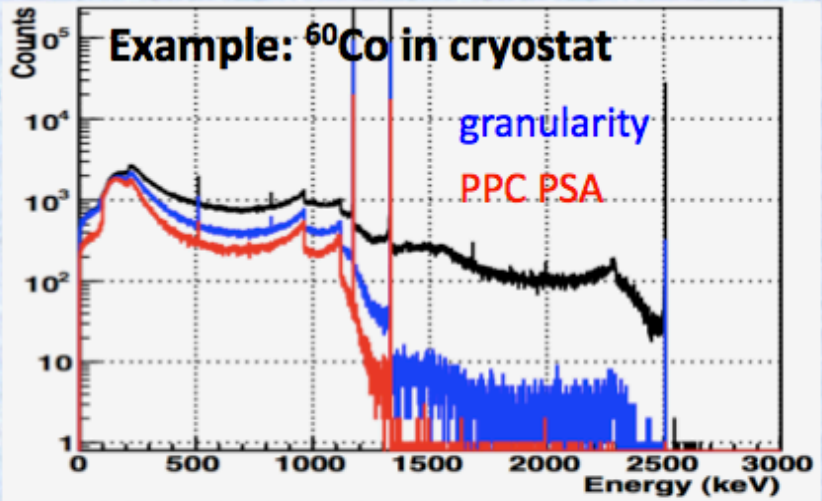
- Solid Copper cold finger temp rise ~17K
- Thermosiphon temp rise <5K
- Better scaling to 1-tonne cryostat
- Shorter e-forming production time



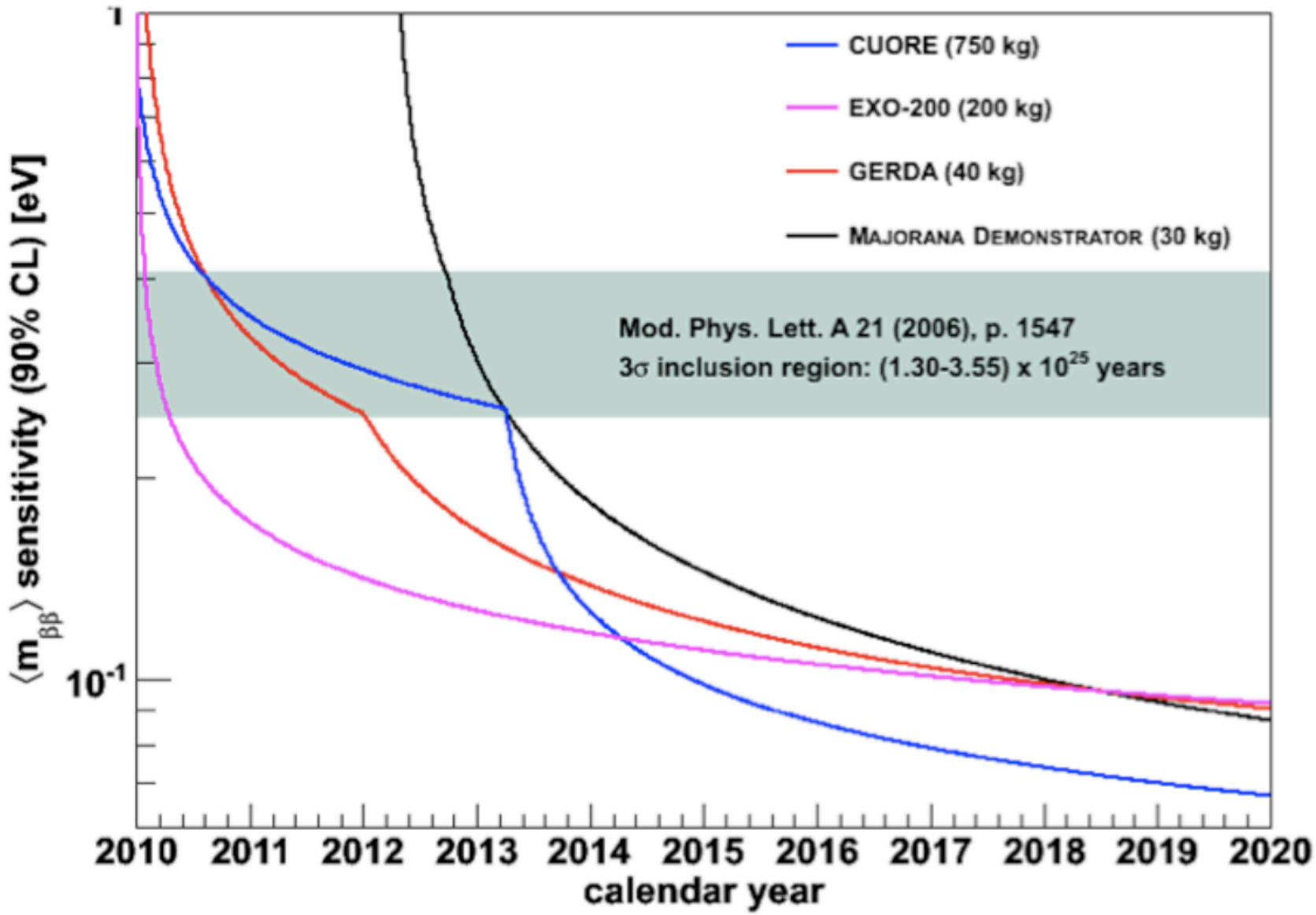
Detector Simulation

- The MAJORANA and GERDA collaborations have worked on the MaGe Monte Carlo simulation package (using Geant4 and ROOT)
- O(5) publications
- Pulse shape calculations also implemented
- Simulation and Analysis task lead is at LBNL





Estimated Schedules



Towards a 1 tonne Ge experiment

Sensitivity depends on energy resolution, background rate and exposure:

$$\langle m_{\beta\beta} \rangle \propto \left(\frac{b\Delta E}{M t_{live}} \right)^{\frac{1}{4}}$$

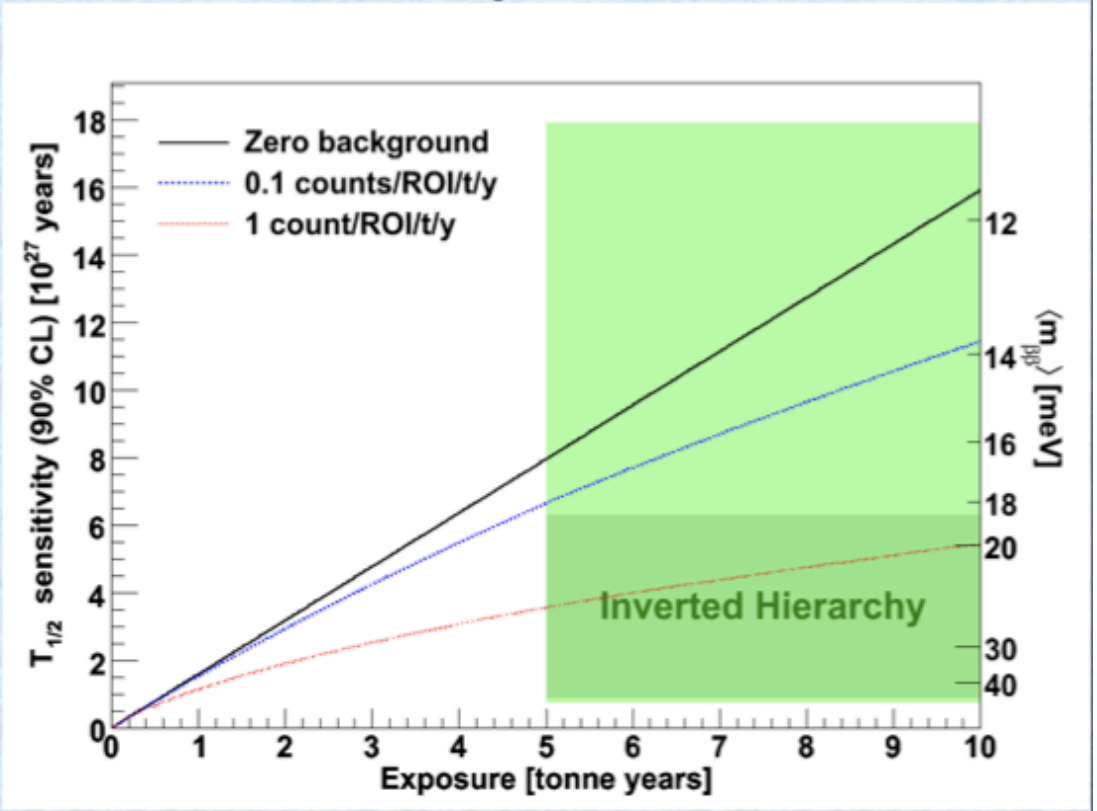
background rate

energy resolution

active mass

live-time

Half life (years)	~Signal (cnts/ton-year)	~Neutrino mass scale (meV)
10^{25}	530	400
5×10^{26}	10	100
5×10^{27}	1	40
$>10^{29}$	<0.05	<10



A 1 tonne experiment is well suited for exploring mass scales down to the atmospheric neutrino oscillation mass-squared difference.

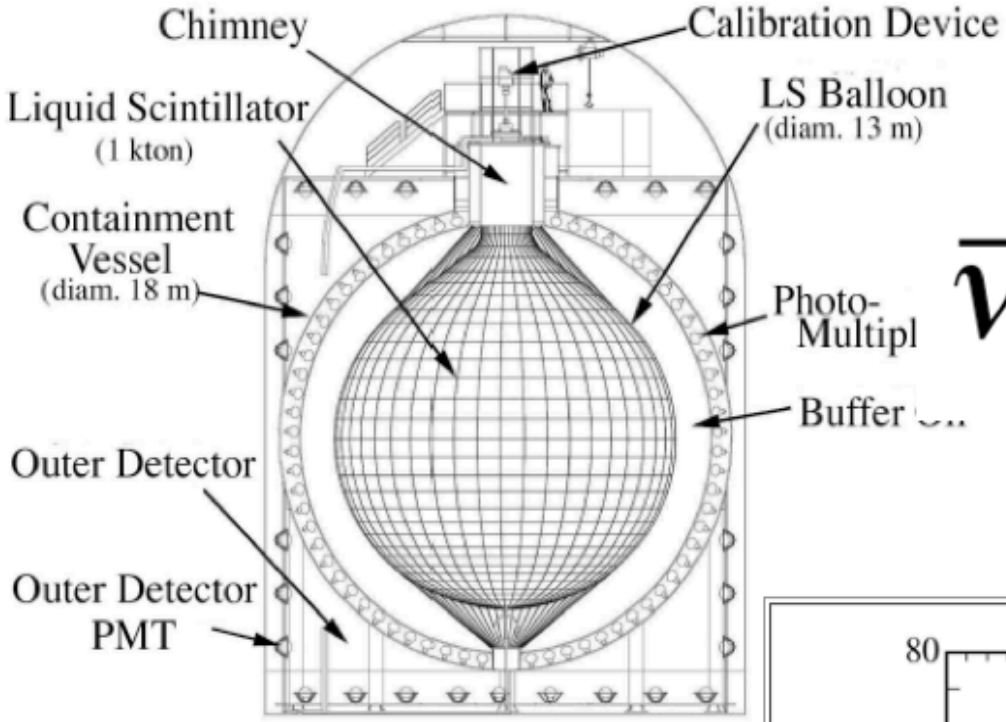
Perspectives for 2β0ν Search at KamLAND

Yuri Efremenko: UTK, IPMU

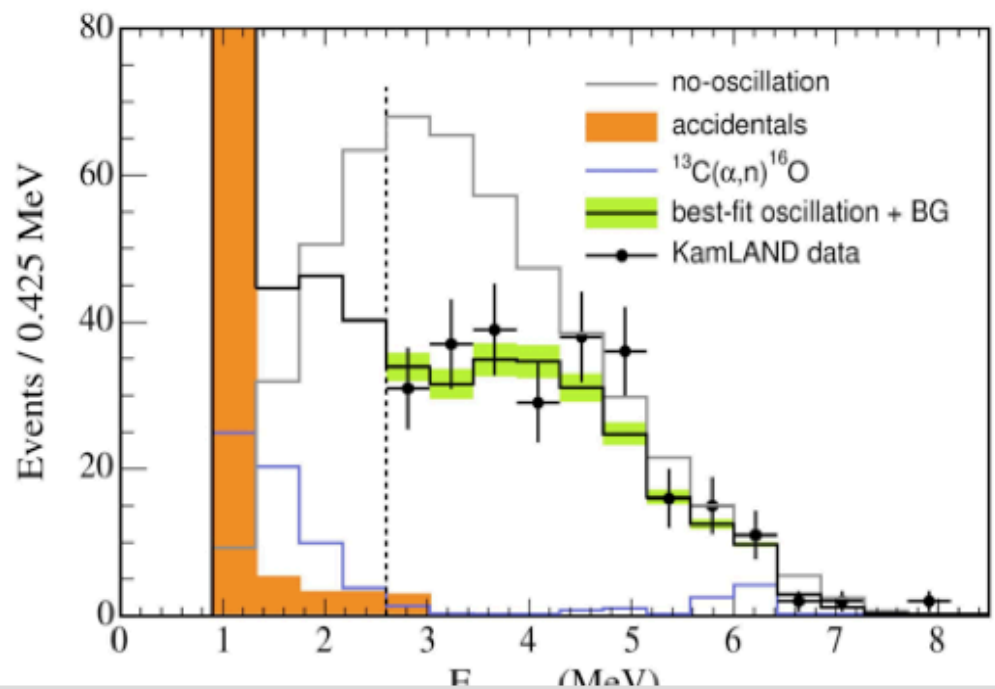
MEDEX'11: June, Prague 2011

(On behalf of the KamLAND-Zen collaboration)

KamLAND



$$\bar{\nu}_e + p \Rightarrow n + e^+$$



The neutron slows down in the scintillator and is captured in a Gd nucleus. This results in capture-gamma rays delayed in time from the

Xenon

Noble gas
Dissolvable in Liquid Scintillator
Density 5.894 g/l
Melting point -111.7 °C
Boiling point -108.2 °C
World production ~27 t/y
Applications: Illumination, Anesthesia, Particle detectors, Ion thrusters

^{136}Xe

Natural Abundance:	8.9%
Q value:	2476 keV
$T_{1/2}$ 2β2ν	$>10^{22}$ y.
$T_{1/2}$ 2β0ν for 50 meV	$\sim 3.0 \div 4.4 \cdot 10^{26}$ y.

KamLAND Zen

Mini balloon

Radius:	1.58m
Material:	nylon-6
Thickness	25μm
Density	1.14 g/cm3
Weight	900g

Xe loaded liquid scintillator

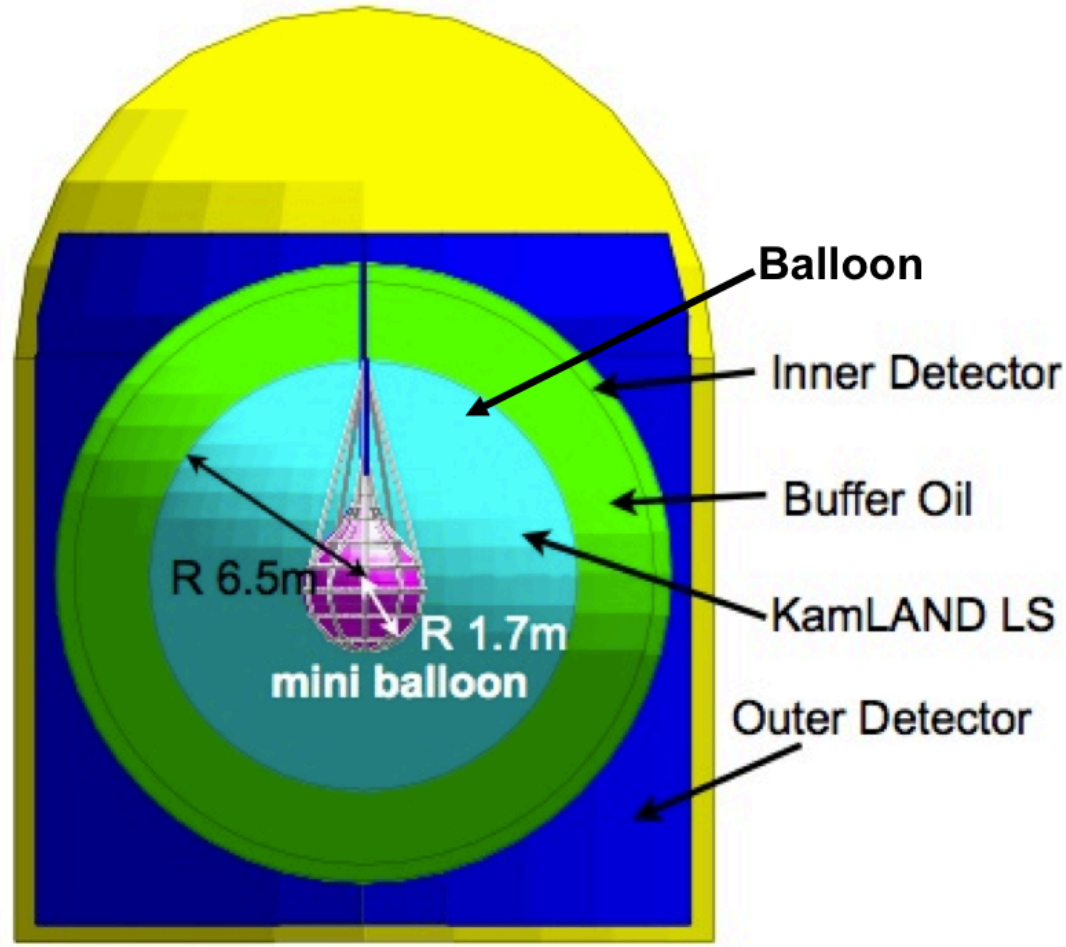
91.7% enriched ^{136}Xe 400kg (3.0wt%)

Composition ratio

Decane	82.3 %
Pseudocumene	17.7 %
PPO	2.7g/l

Density : same as KamLAND liquid scintillator (0.777 g/cm^3)

Light yield : same as KamLAND liquid scintillator



Energy Resolution: 6.8%/ √ E(MeV)

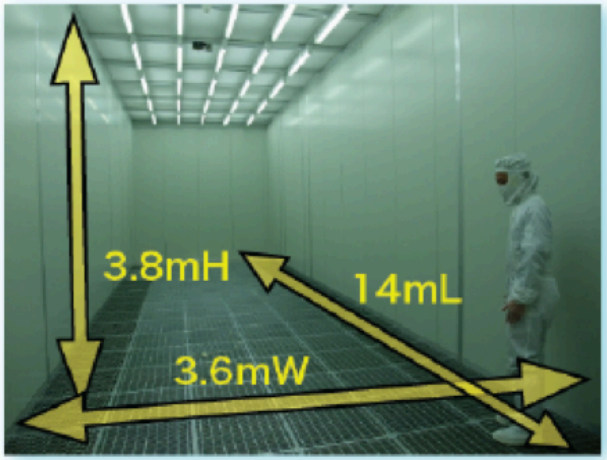
Vertex Resolution: 12.5cm/√E(MeV)

Mini Balloon Status

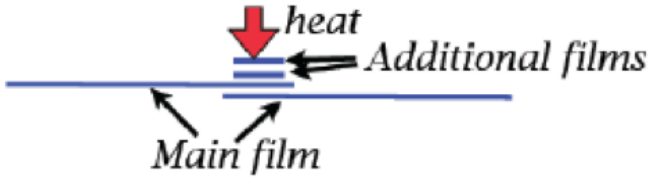
By Shirai-san

Super clean room is ready !
(at Nishizawa center of Tohoku Univ.)

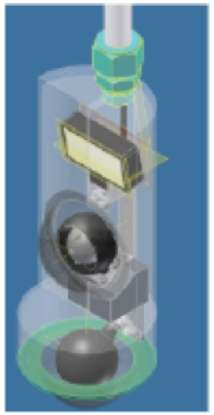
Class 1 (=1 particle(>0.1μm) /feet^3)



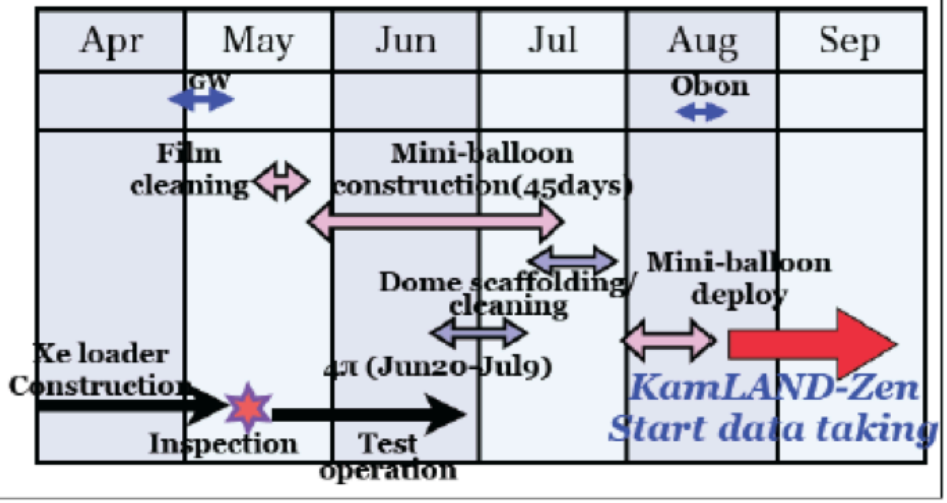
Welding method and conditions has been established.



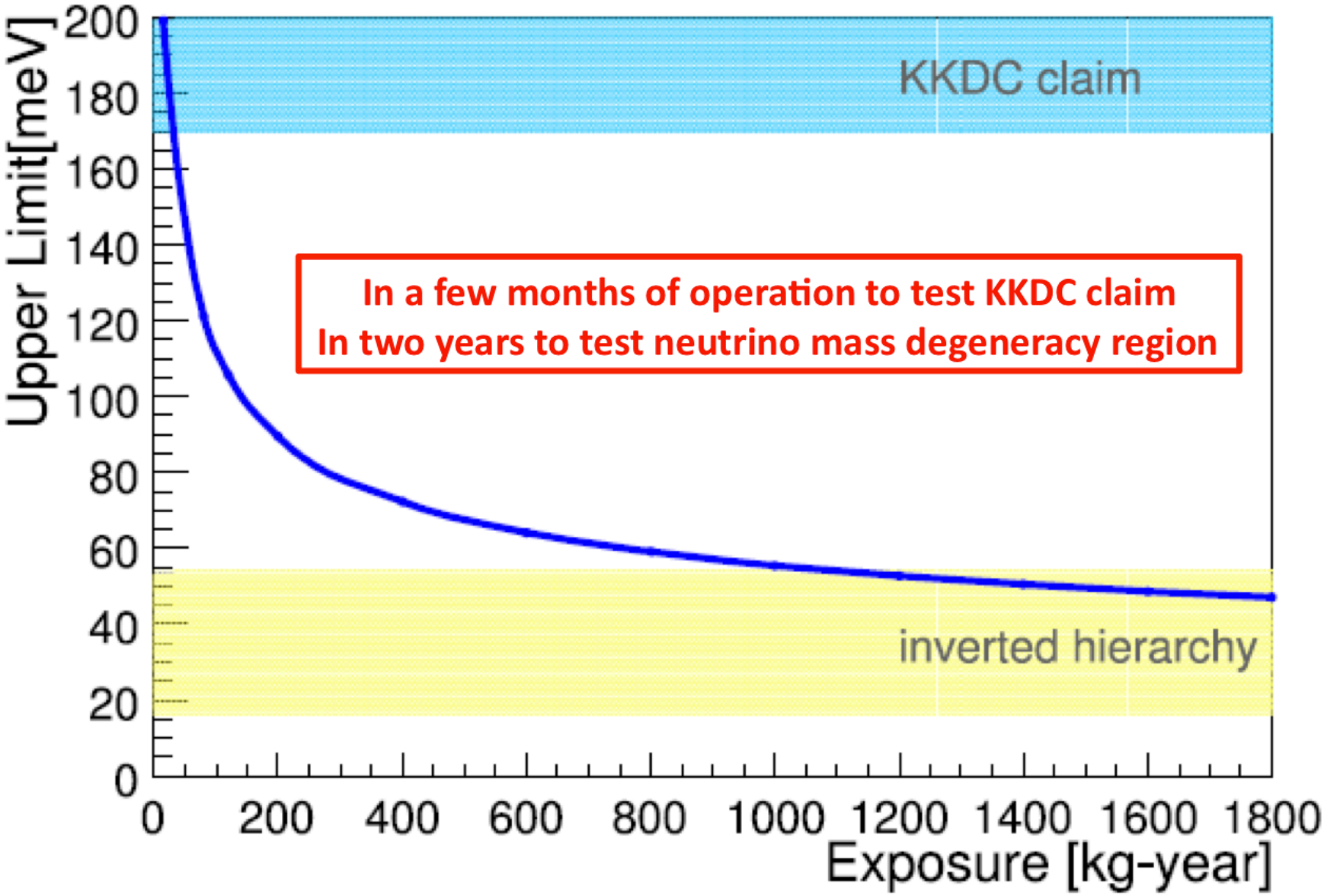
Final checks and preparation of the balloon construction and deployment are ongoing.



Designing the monitor cameras and lights in the deployment are finished and will be ordered soon.



KamLAND-Zen Sensitivity



Present Status and Plans

Xe handling system is in place

370 kg of ^{136}Xe are in the mine (50 kg are coming soon)

Xe LS system has been assembled

Mini Balloon is being made

Final Calibration for Reactor phase is ongoing

Scintillator mixing – July

Chimney modification – July

Mini Balloon deployment and filing – August

Data Taking from September

First result later this year

Other Experiments

Experiment	Isotope	Mass	Technique	Present Status	Location
CANDLES	^{48}Ca	0.35 kg	CaF_2 scint. crystals	Prototype - 2009	Kamioka
CARVEL	^{48}Ca	1 ton	CaF_2 scint. crystals	Development	Solotvina
COBRA	^{116}Cd	183 kg	^{enr}Cd CZT semicond. det.	Prototype	Gran Sasso
CUORICINO	^{130}Te	11 kg	TeO_2 bolometers	Complete - 2008	Gran Sasso
CUORE	^{130}Te	200 kg	TeO_2 bolometers	Construction - 2012	Gran Sasso
DCBA	^{150}Ne	20 kg	^{enr}Nd foils and tracking	Development	Kamioka
EXO-200	^{136}Xe	160 kg	Liq. ^{enr}Xe TPC/scint.	Construction - 2009	WIPP
EXO	^{136}Xe	1-10 t	Liq. ^{enr}Xe TPC/scint.	Proposal	DUSEL
GEM	^{76}Ge	1 ton	^{enr}Ge det. in liq. nitrogen	Inactive	
GENIUS	^{76}Ge	1 ton	^{enr}Ge det. in liq. nitrogen	Inactive	
GERDA	^{76}Ge	≈35 kg	^{enr}Ge semicond. det.	Construction - 2009	Gran Sasso
GSO	^{160}Gd	2 ton	Gd_2SiO_5:Ce crys. scint. in liq. scint.	Development	
KamLAND	^{136}Xe	200 kg	^{enr}Xe disolved in liq. scint.	Contruction - 2012?	Kamioka
MAJORANA	^{76}Ge	26 kg	^{enr}Ge semicond. det.	Construction - 2011	SUL
MOON	^{100}Mo	1 t	^{enr}Mofoils/scint.	Development	
NEXT	^{136}Xe	80 kg	gas TPC	Development	Canfranc
SNO+	^{150}Nd	55 kg	Nd loaded liq. scint.	Construction - 2011	SNOLab
SuperNEMO	^{82}Se	100 kg	^{enr}Se foils/tracking	Proposal	Frejus
Xe	^{136}Xe	1.56 t	^{enr}Xe in liq. scint.	Development	
XMASS	^{136}Xe	10 ton	liquid Xe	Inactive for $\beta\beta$	Kamioka
HPXe	^{136}Xe	tons	High Pressure Xe gas	Development	

FINAL CONCLUSION

The Next Generation neutrino less double-beta decay experiments should:

1. ***Determine the Validity of the KKDK Claim of Discovery***
2. ***If Not, then Probe Neutrino Mass Scales of 50-100 milli-eV***

For a more detailed discussion see:

F.T. AVIGNONE III, S.R. ELLIOTT and J. ENGEL
"Double beta decay, Majorana neutrinos, and neutrino mass,"
REVIEWS OF MODERN PHYSICS VOL. 80, APRIL-JUNE 2008.