EXO 200 Archive

Kevin Graham
for the EXO Collaboration

SNOLAB Workshop August 21, 2013

The EXO Collaboration

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TRIUMF, Vancouver BC, Canada – P.A. Amandruz, D. Bishop, J. Dilling, P. Gumplinger, R. Kruecken, C. Lim, F. Retiere, D. Sinclair, V. Strickland

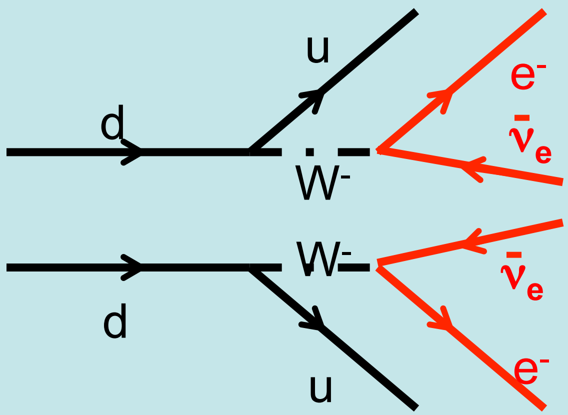
2013

What is the Mass of Neutrinos?

1) Tritium Beta Decay

2) Neutrinoless Double Beta Decay

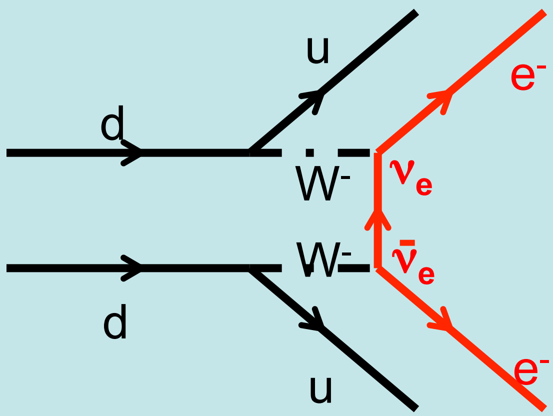
Neutrinoless Double Beta Decay



$$\left[T_{0\nu}^{1/2}\right]^{-1} = G_{0\nu}\left|M_{0\nu}\right|^2\left\langle m_{\beta\beta}\right\rangle^2$$

G **= phase space factors (easy)**
|*M*| = nuclear matrix elements (hard)

$m_{\beta\beta} = |\sum_i U_{ei}^{\ 2}\ m_i|$



are neutrinos Majorana particles ?

ΔL=2 lepton number violation?

neutrino mass scale

neutrino mass hierarchy

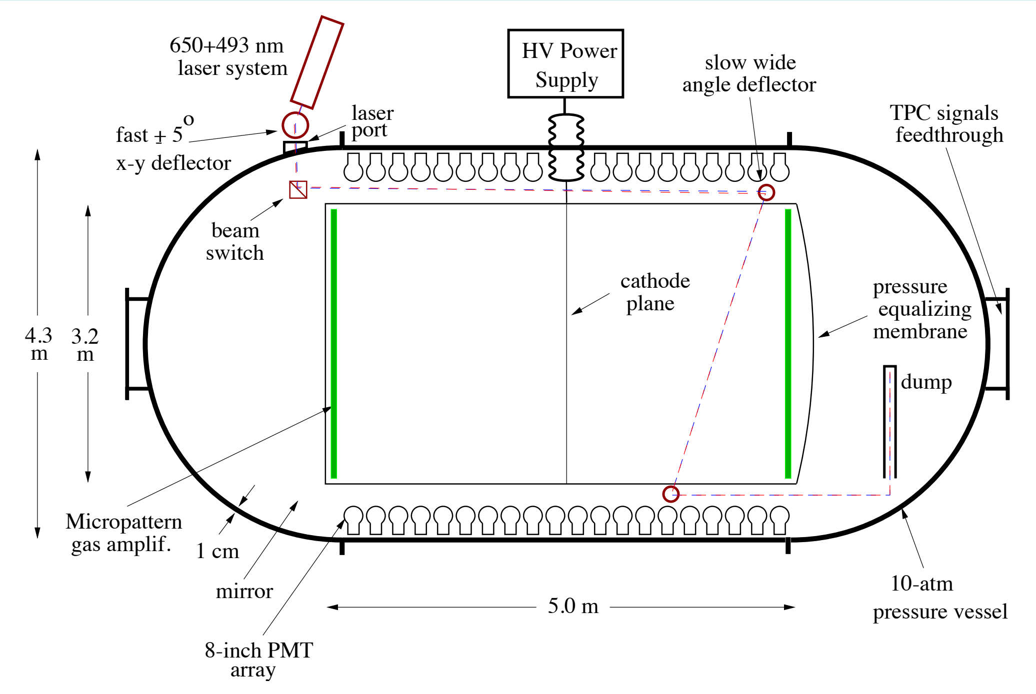
Double Beta Decay Isotopes

Isotope	Natural Abundance (%)	Q-value (MeV)
Ca 48	0.19	4.27
Ge 76	7.8	2.04
Se 82	9.2	3.00
Zr 96	2.8	3.35
Mo 100	9.6	3.03
Pd 110	11.8	2.01
Cd 116	7.5	2.80
Sn 124	5.6	2.29
Te 130	35.	2.53
Nd 150	5.6	3.37
Xe 136	8.9	2.48

Year 2000: 'Start' of the Program

M. Danilov (Moscow, ITEP) , R. DeVoe (IBM, Almaden Res. Ctr.) , A. Dolgolenko (Moscow, ITEP) , G. Giannini (Trieste U.) , G. Gratta (Stanford U., Phys. Dept.) P. Picchi (Frascati & Turin, Cosmo-Geofisica Lab & Turin U.) , A. Piepke (Alabama U.) , F. Pietropaolo (INFN, Padua) , P. Vogel (Caltech) , J.L. Vuilleumier (Neuchatel U.) Y.F. Wang (Stanford U., Phys. Dept.) , O. Zeldovich (Moscow, ITEP)

Detection of very small neutrino masses in double-beta decay using laser tagging



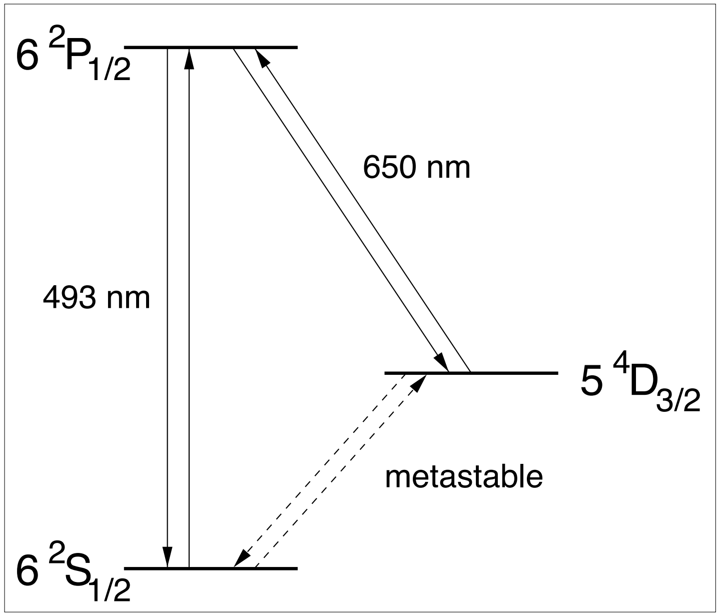
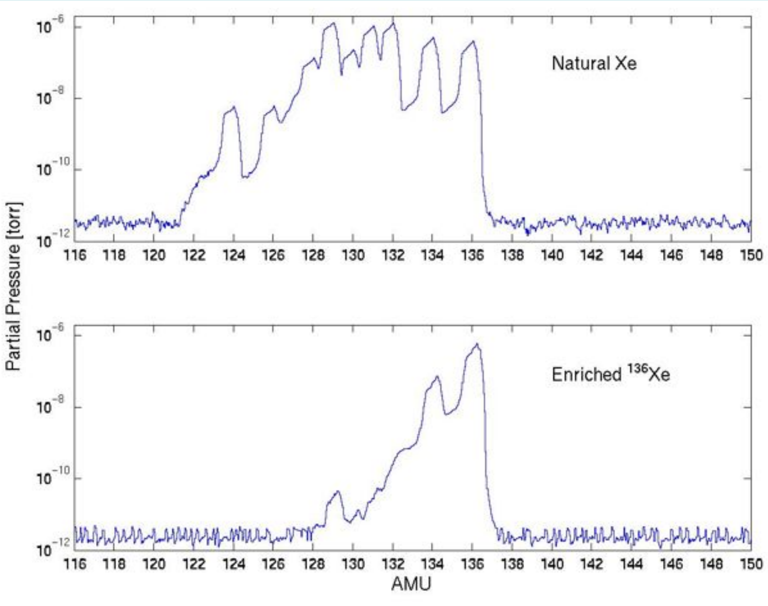


Fig. 1. Atomic level scheme for Ba^+ ions.

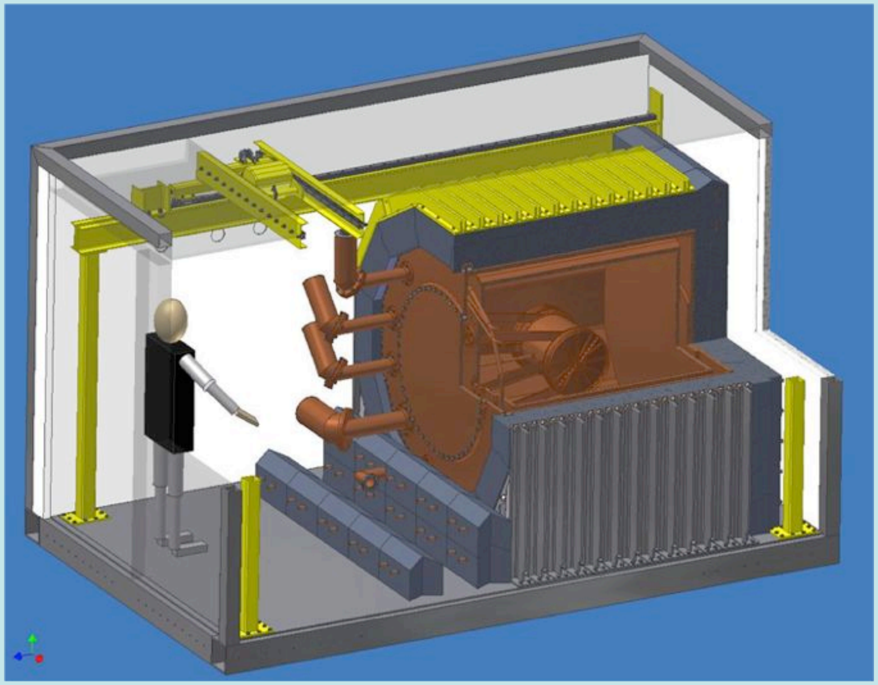
Funding commences ~2001

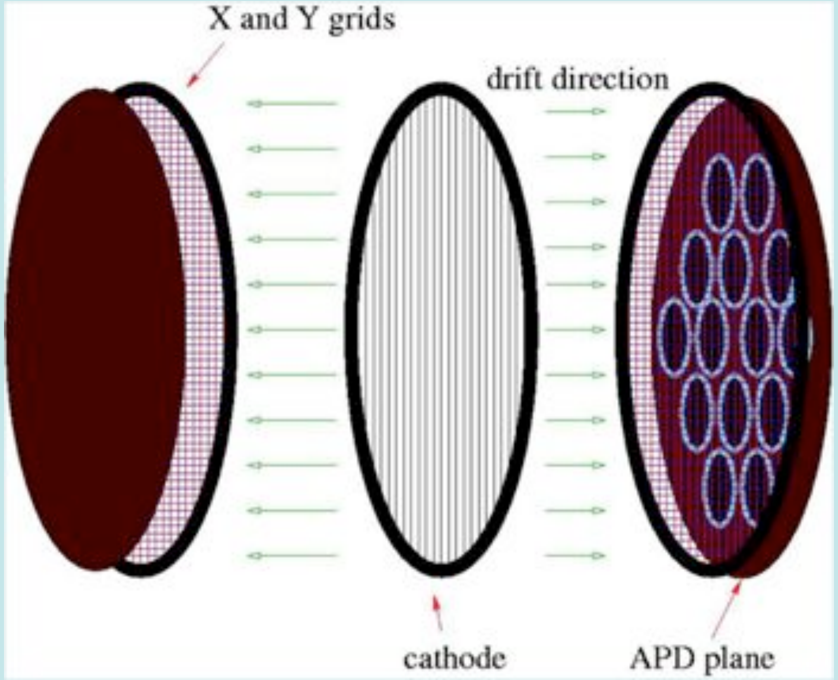
^{136}Xe Procurement

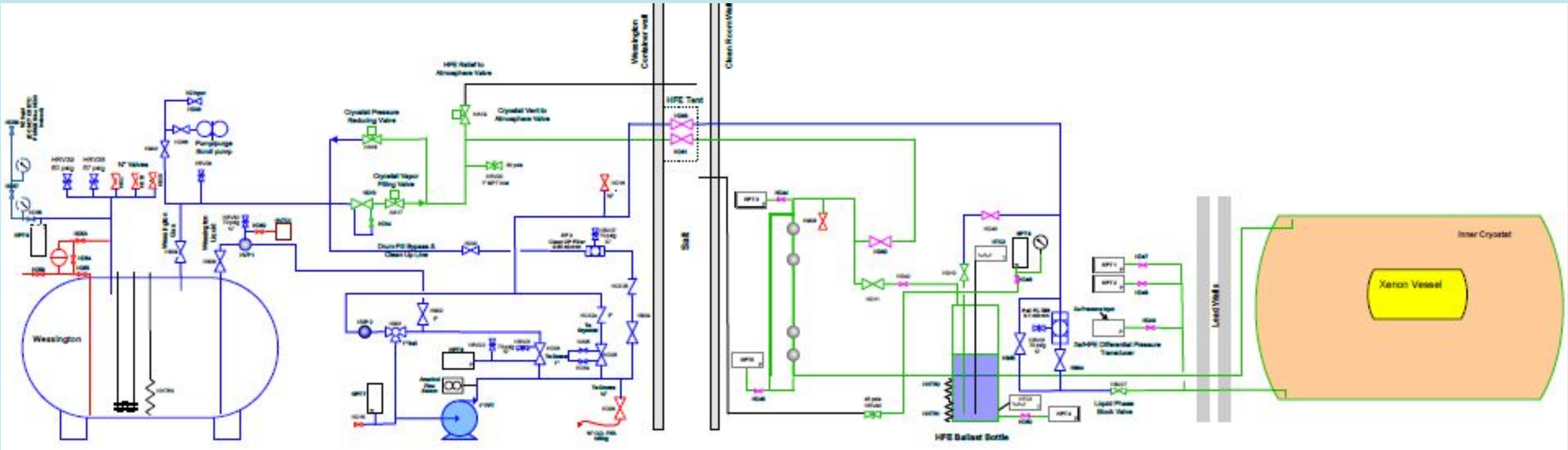
- order placed Oct 8, 2001
- enriched xenon delivered summer 2002 (2003)



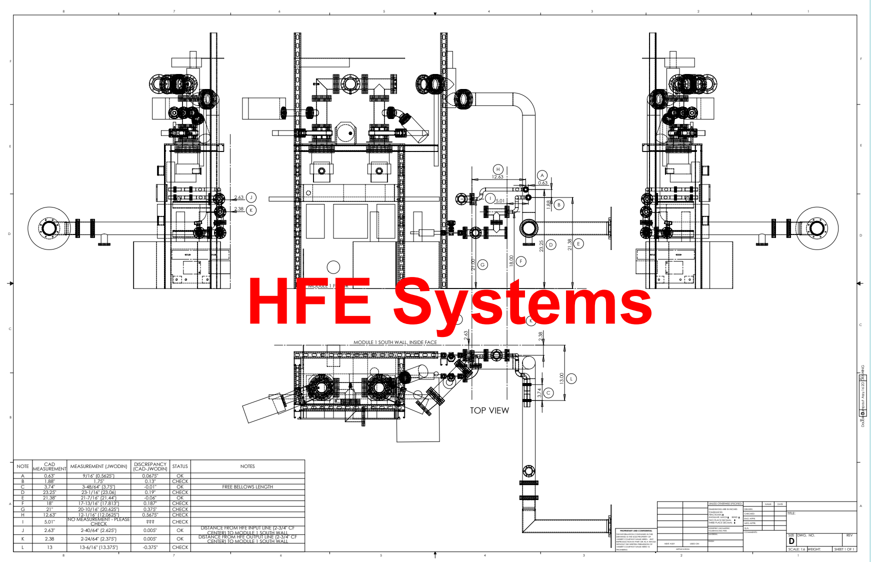
Detector Design

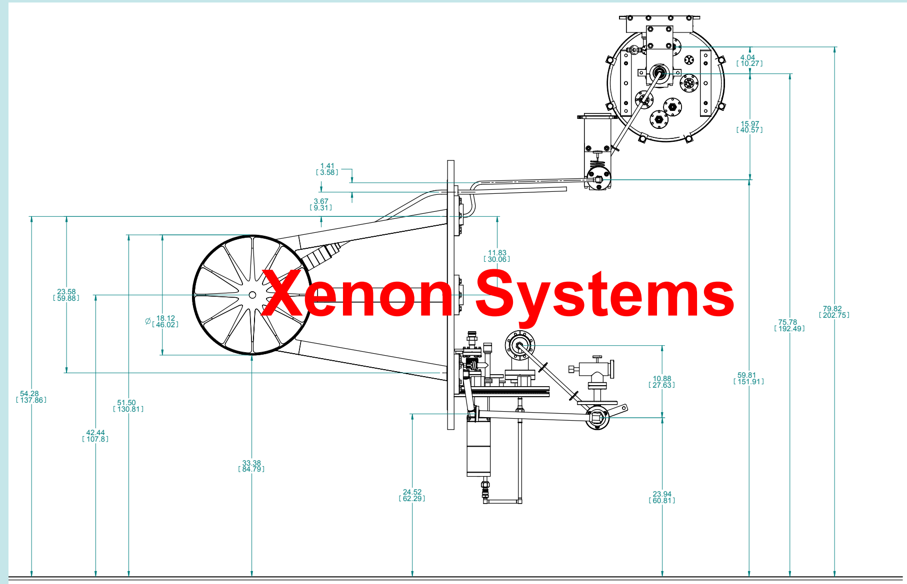


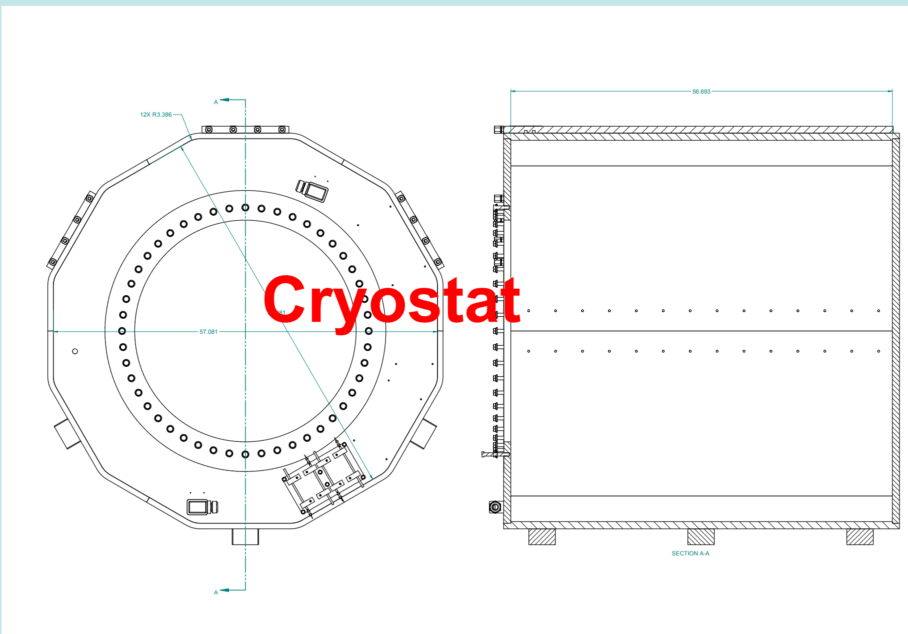


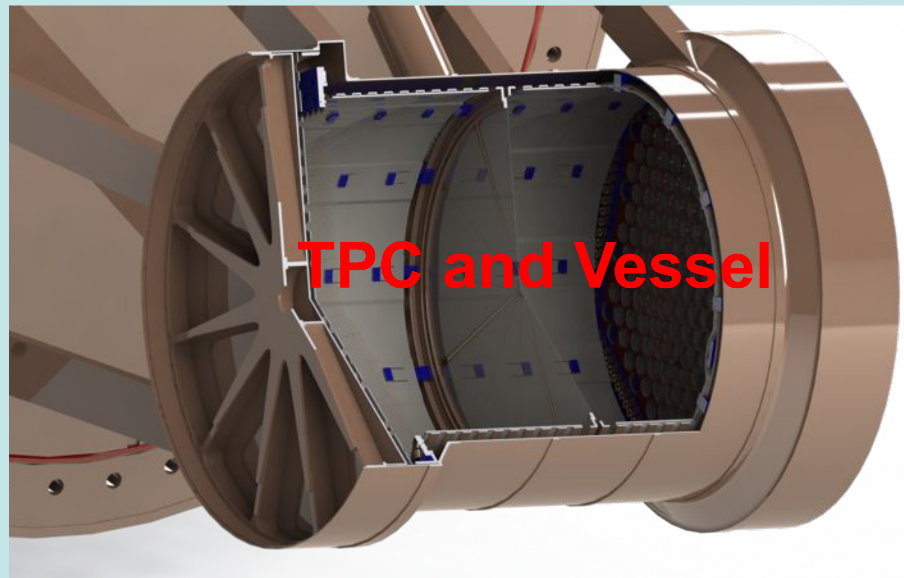


Year 2005: Design Finalized



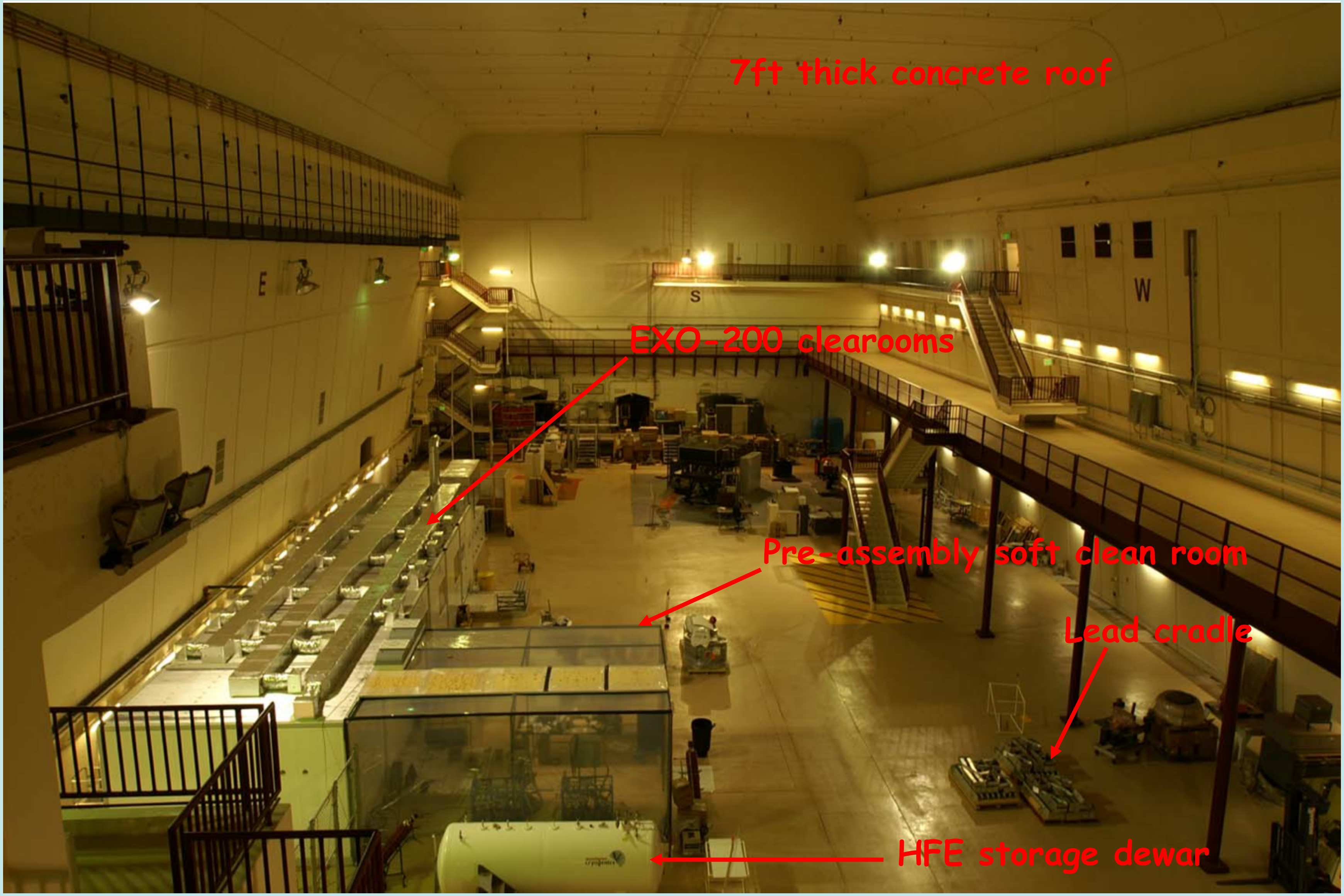




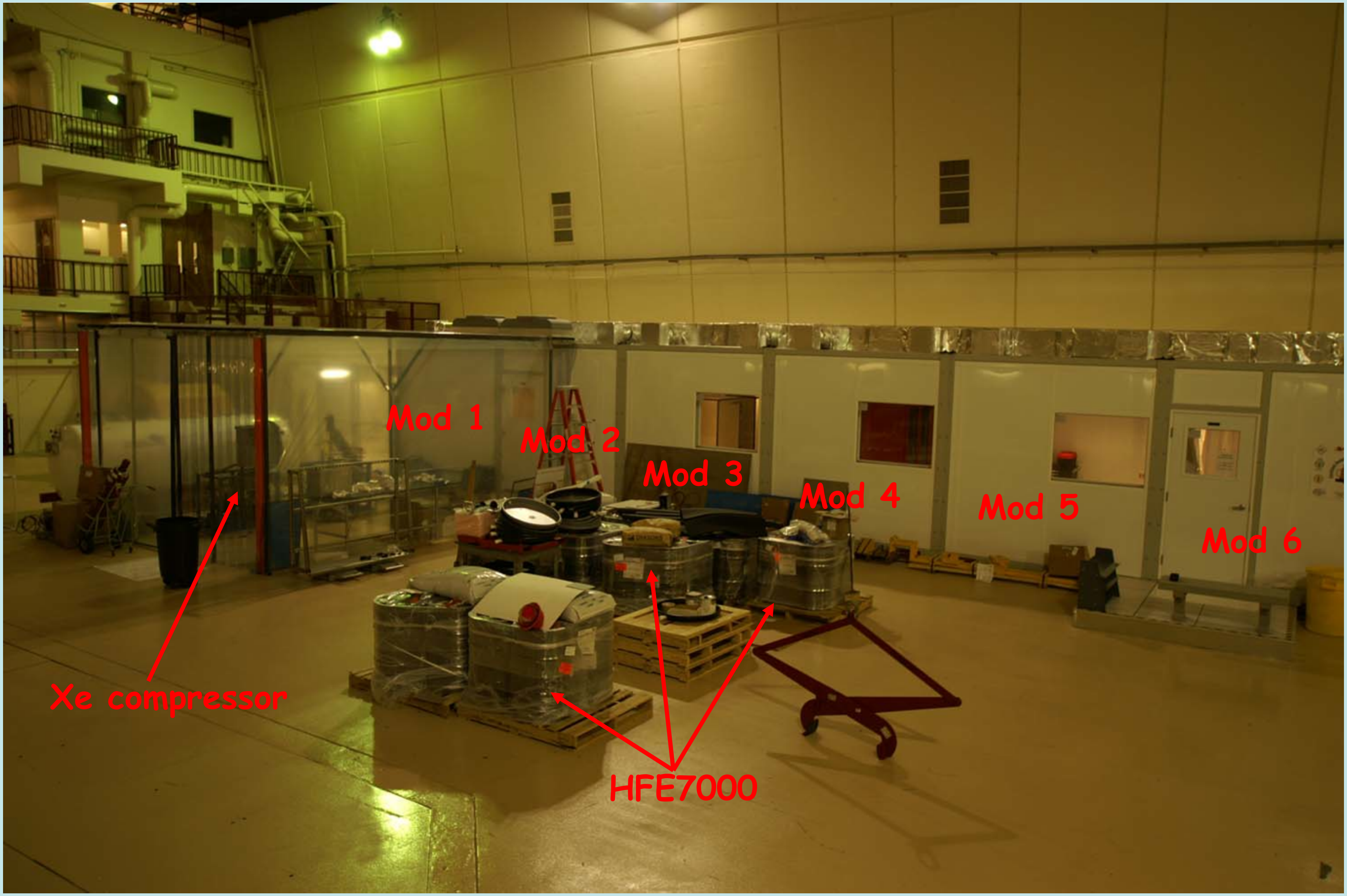


Schedule Revisions

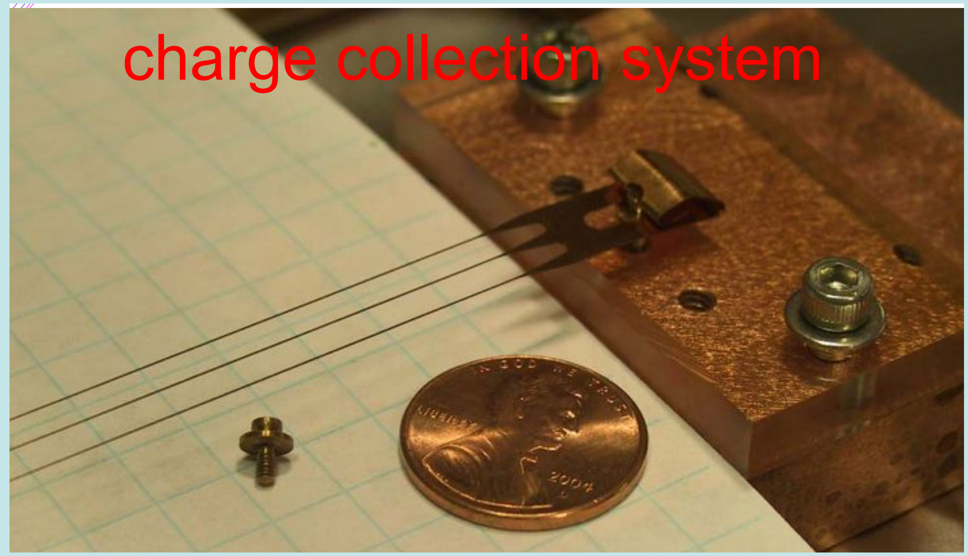
Year 2004: Cleanrooms Received at Stanford



Year 2004: Cleanrooms at Stanford



Years 2004-2006: Testing and Building



Component Assays

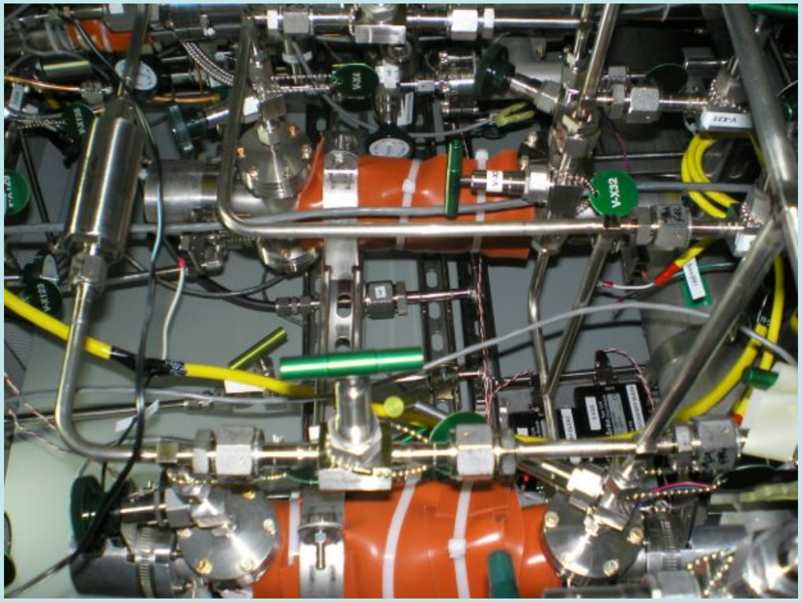
Systematic study of trace radioactive impurities in candidate construction materials for EXO-200 **Nucl.Instrum.Meth. A591 (2008) 490-509**

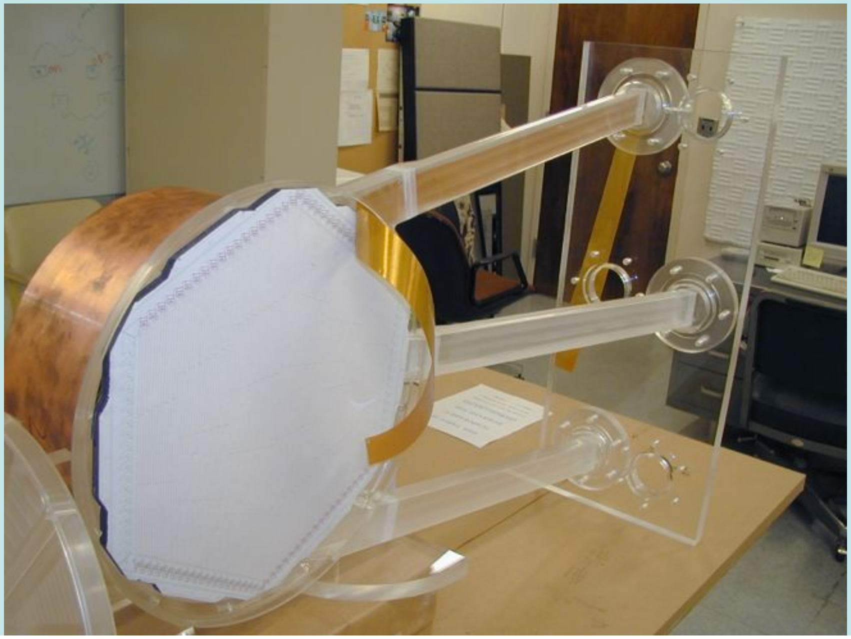
Table 3: Measurement results for K, Th, and U concentrations in a variety of materials. Manufacturer production lot numbers or arbitrary identifiers are indicated for materials where multiple lots were studied. Uncertainties are quoted at 68% C.L. and limits are 95% C.L. Results which are less than than 3-σ above zero (not including systematic scaling uncertainties) are reported as upper limits. GD-MS measurements have a factor of two uncertainty. In the "method" column, "A.G. Ge" refers to above ground germanium counting. Measurements with methods of "Balazs Analytical Services" or "Shiva Inc." were performed by the commercial services of the respective companies. Entries 31 and 38 list data taken from Refs. [18] and [19] respectively as indicated. Where available, germanium counting results for ^{60}Co and ^{137}Cs activities are given within the sample descriptions.
* Indicated NAA results may be affected by a neutron flux calibration discrepancy described in Sec. 5. The tabulated results do not include systematic uncertainties arising from this discrepancy.

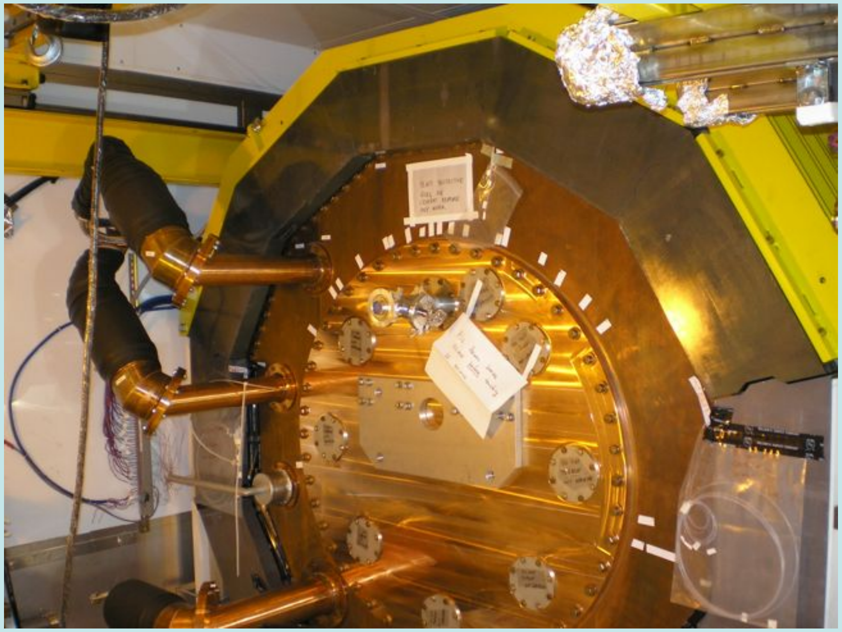
#	Material	Method	K conc. [$10^{-9}g/g$]	Th conc. [$10^{-12}g/g$]	U conc. [$10^{-12}g/g$]
		Bulk Copper			
1	Norddeutsche Affinerie, NOSV copper made May 2002.	Shiva Inc. GD-MS	0.4	<5	<5
2	Norddeutsche Affinerie, NOSV copper made May 2002.	Ge	<120	<35	<63
3	Norddeutsche Affinerie OFRP copper made May 2006, batch E263/2E1.	ICP-MS	<55	<2.4	<2.9
4	Norddeutsche Affinerie OFRP copper made May 2006 batch E262/3E1.	ICP-MS	<50	<2.4	<2.9
5	Rolled Norddeutsche Affinerie OFRP copper, May 2006 production. Rolled by Carl-Schreiber GmbH.	ICP-MS	-	<3.1	<3.8
6	TIG welded Norddeutsche Affinerie OFRP copper made May 2002. No cleaning after welding. Result are normalized to length of weld.	ICP-MS	-	<9.8 pg/cm	10.2±3.4"pg/cm
7	Valcool VNT 700 metal working lubricant, concentrate.	A.G. Ge	38000±11000	<10000	<3700
8	Water alcohol mixture, lubricant for machining of Cu parts.	A.G. Ge	<44000	<18000	<3800
		Lead			
9	JL Goslar cutting oil. Used for cutting 98% distilled water, 2% cutting oil. ^{60}Co: <1.8 mBq/kg, ^{137}Cs: <12 mBq/kg.	Ge	93500±1000	<790	3650±510
10	Paint for lead bricks, JL Goslar, type: Glasurit MS-Klarlack. Proportions: 2 paint, 1 hardener, 0.1 solvent.	Ge	720±170	<170	790±90
11	EXO Pb, JL Goslar smelting lot 3-706.	ICP-MS	-	<1	<1
12	EXO Pb, JL Goslar smelting lot 3-706.	GD-MS	<15	<6	<6

>300 components tested (also update JINST paper)

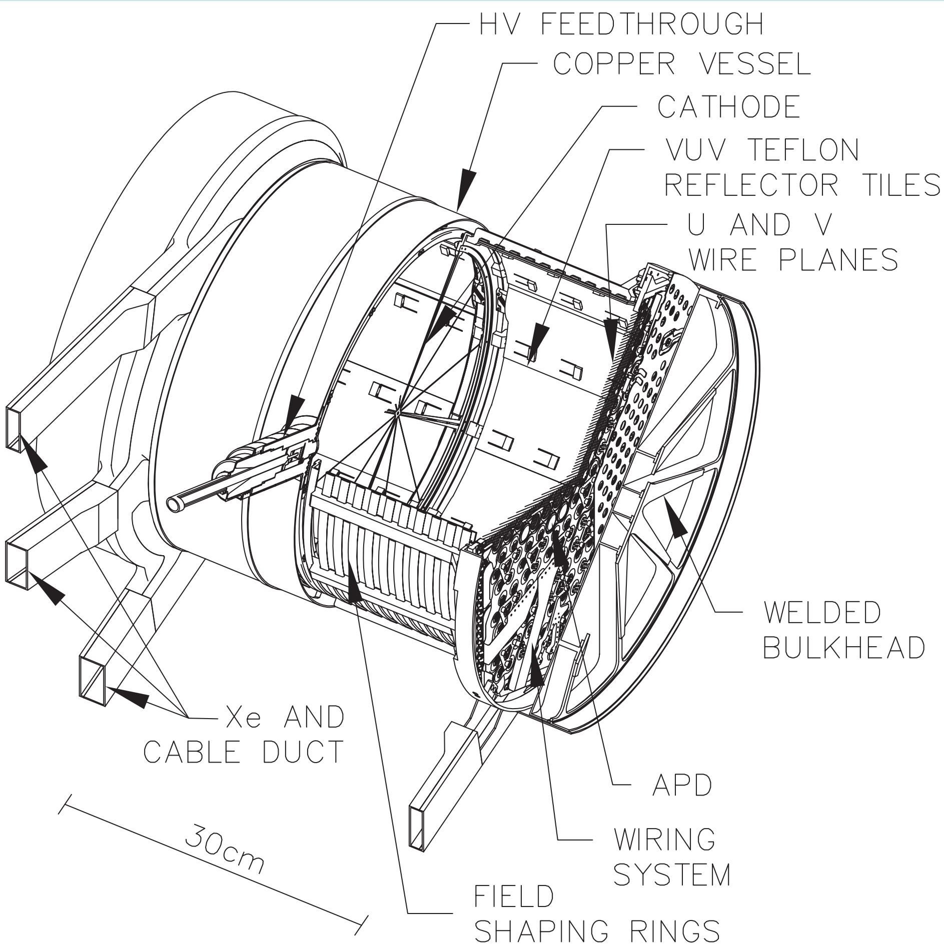
Detector Construction

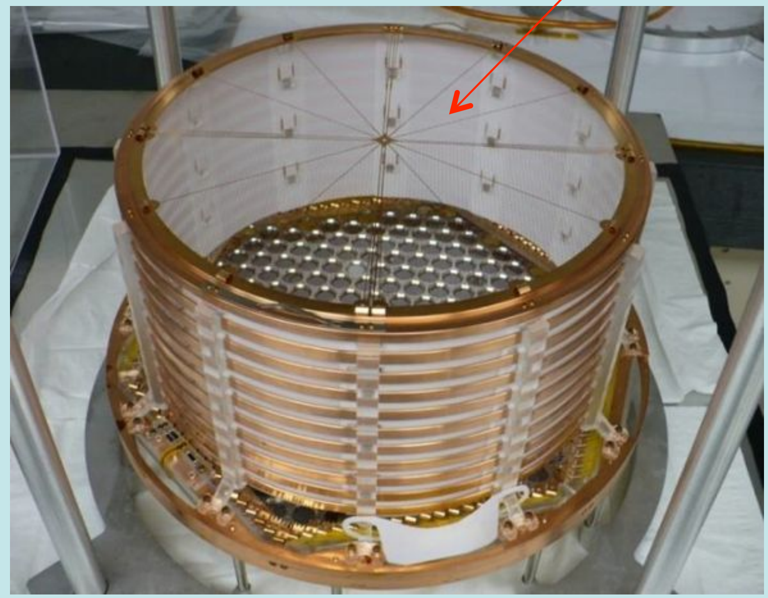


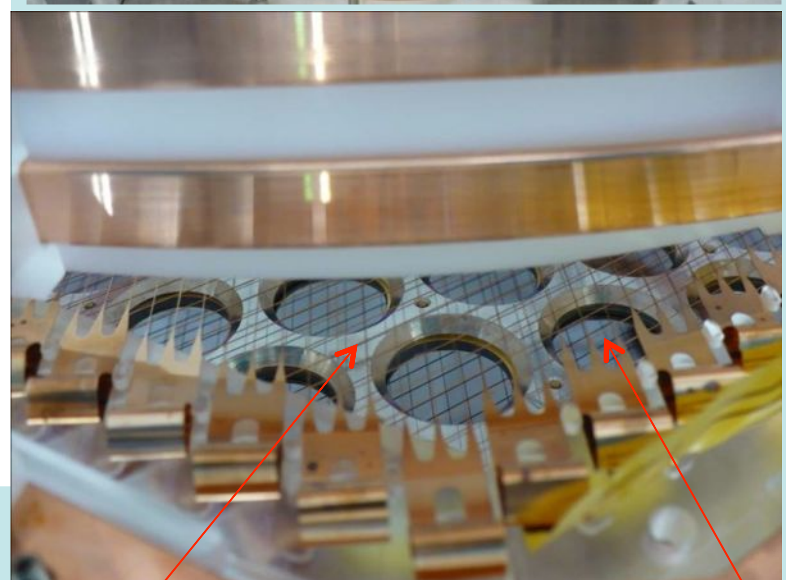




Detector Construction

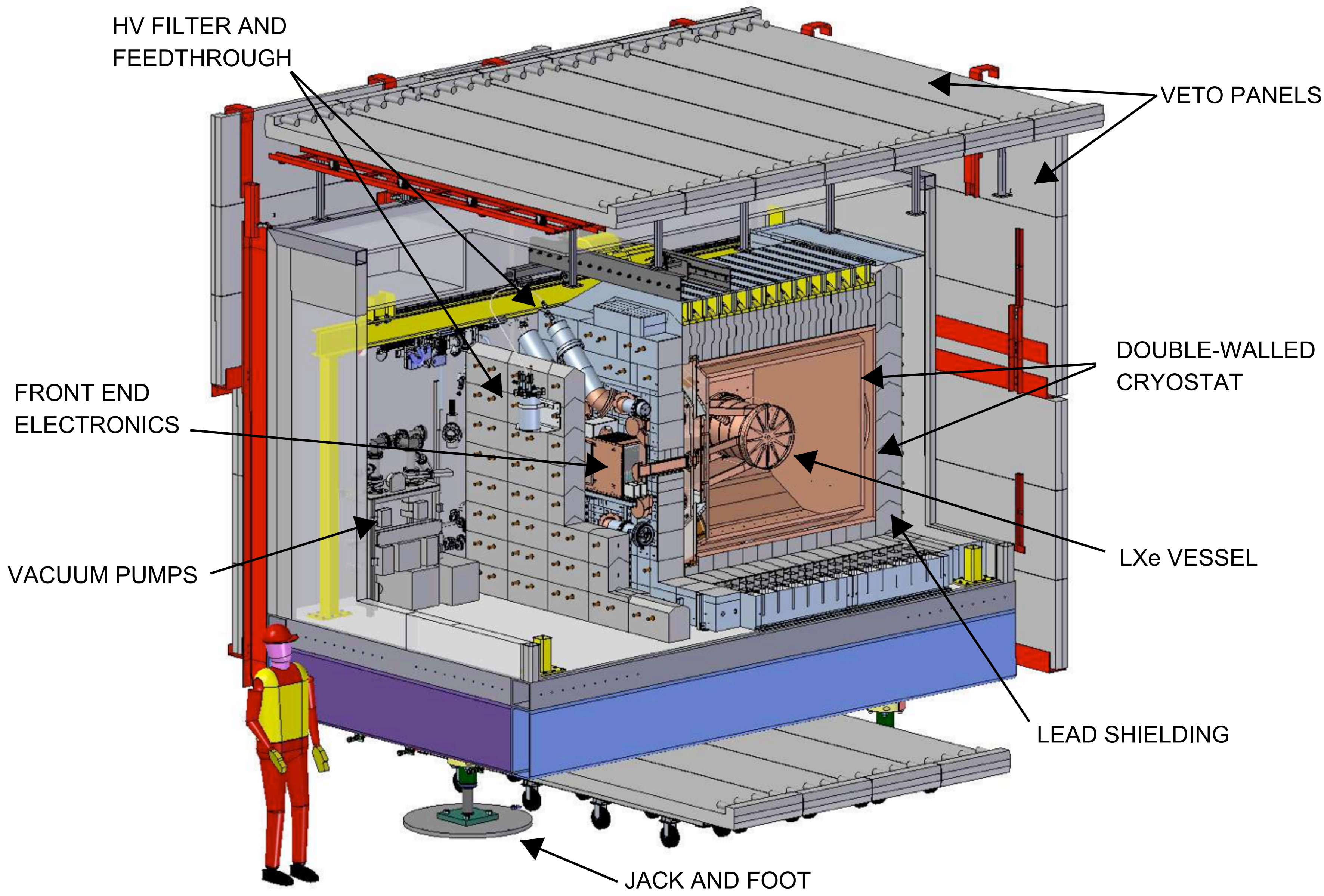




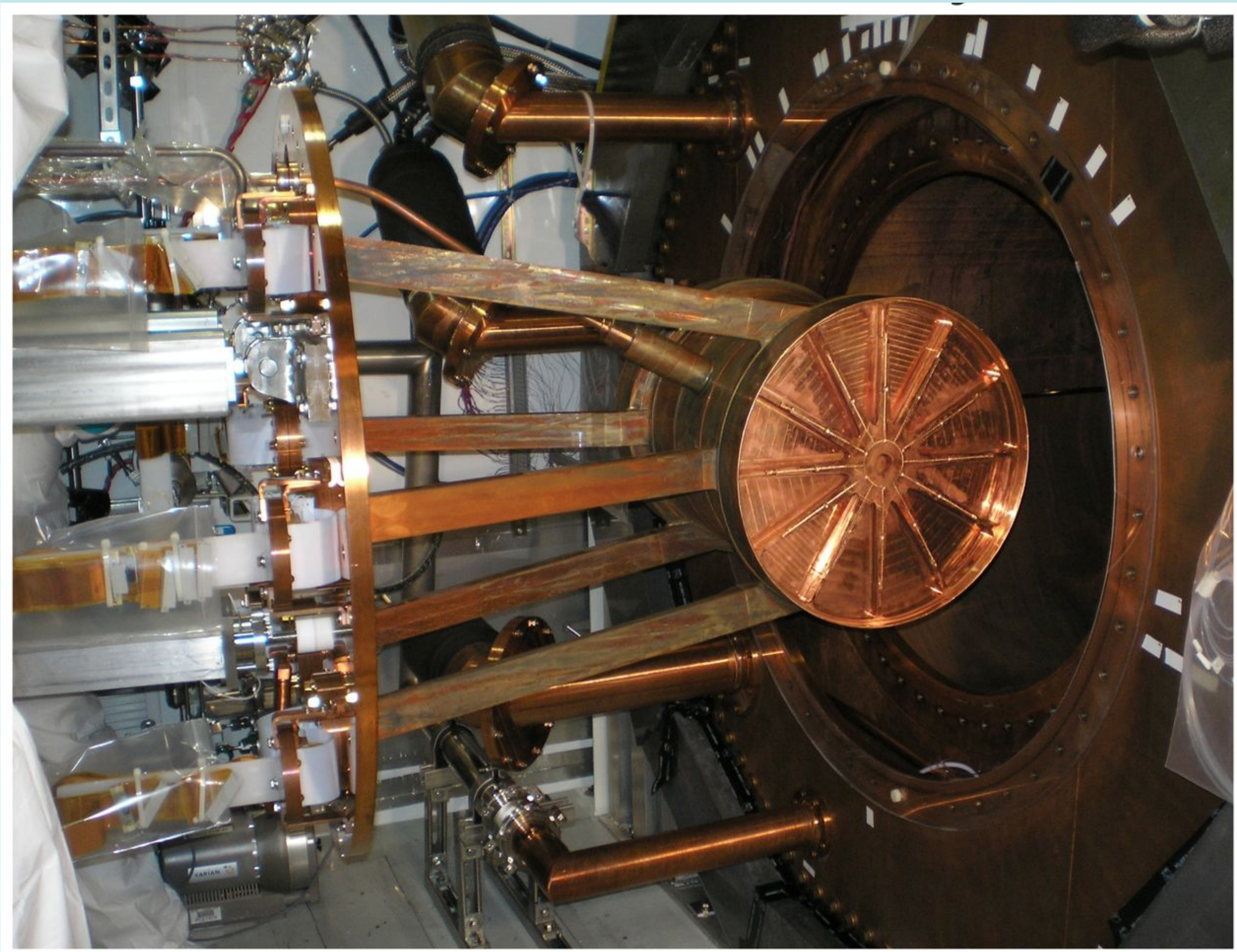


Year 2006: Cleanrooms installed at WIPP

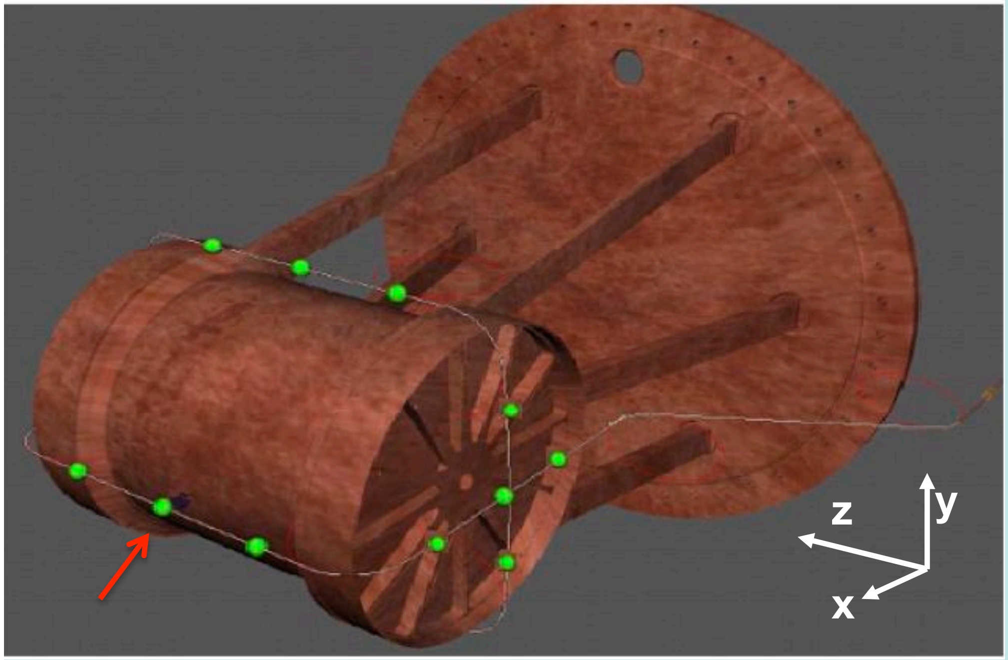
EXO-200 Detector



Year 2010: TPC Deployment



Calibration System

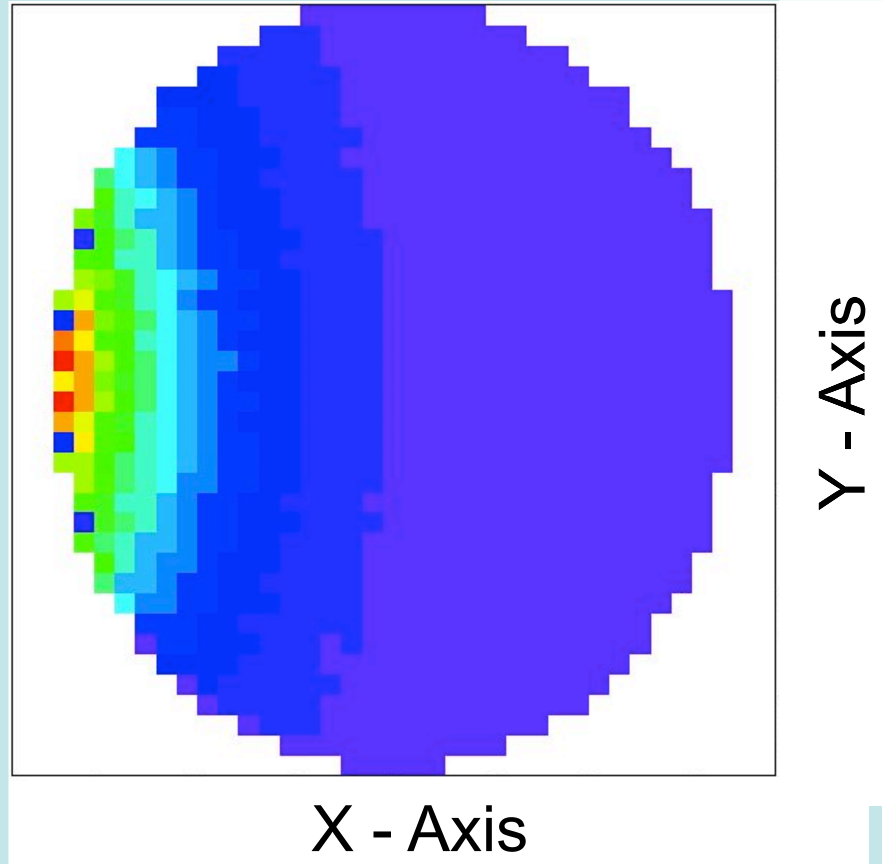


Calibration source locations

Sources:

^{137}**Cs,** ^{60}**Co,** ^{228}**Th**

Custom designed, miniature source



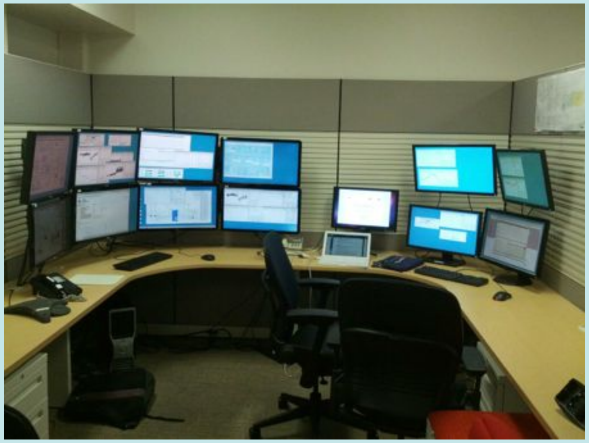
x-y distribution of events

Detector Operation

- initial operation solely from WIPP/Carlsbad
- now each group has a remote control station

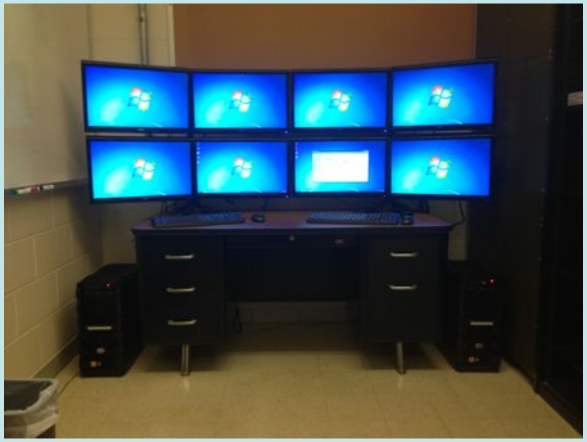
UMass

SLAC

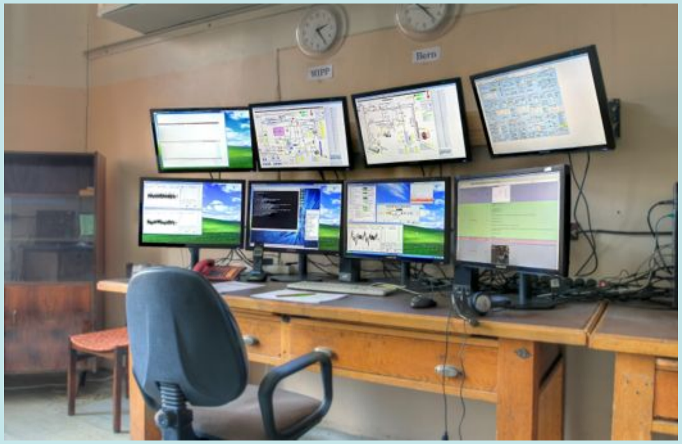


Laurentian

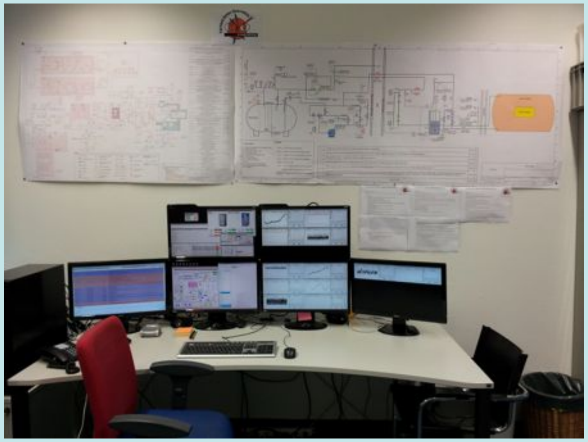
Illinois



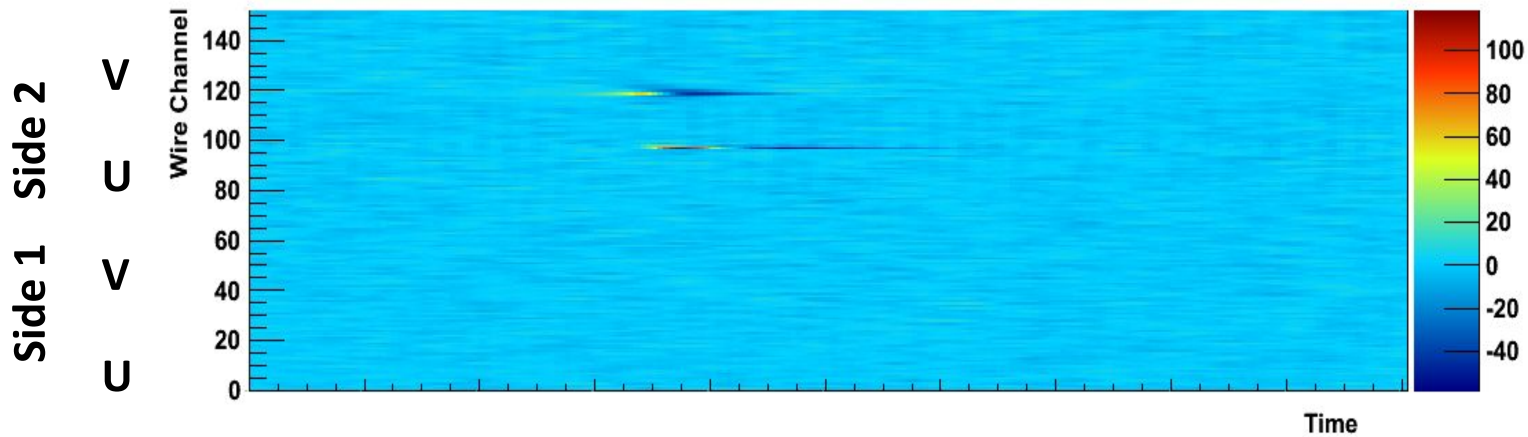
ITEP

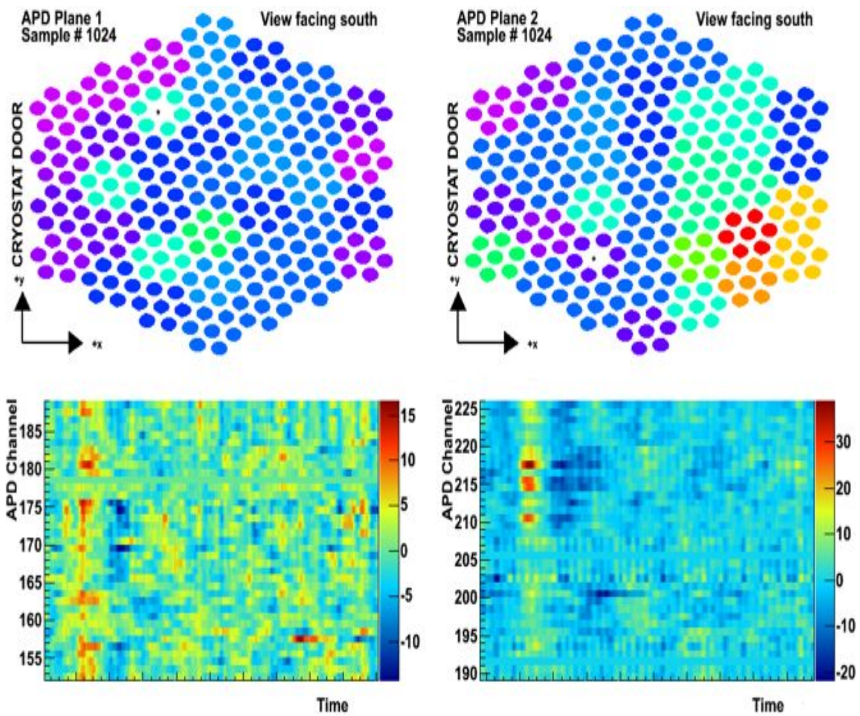


BERN



Year 2010: Commissioning - Single Site Event in EXO-200





Top display is charge readout (V are induction wires and U are collection wires).

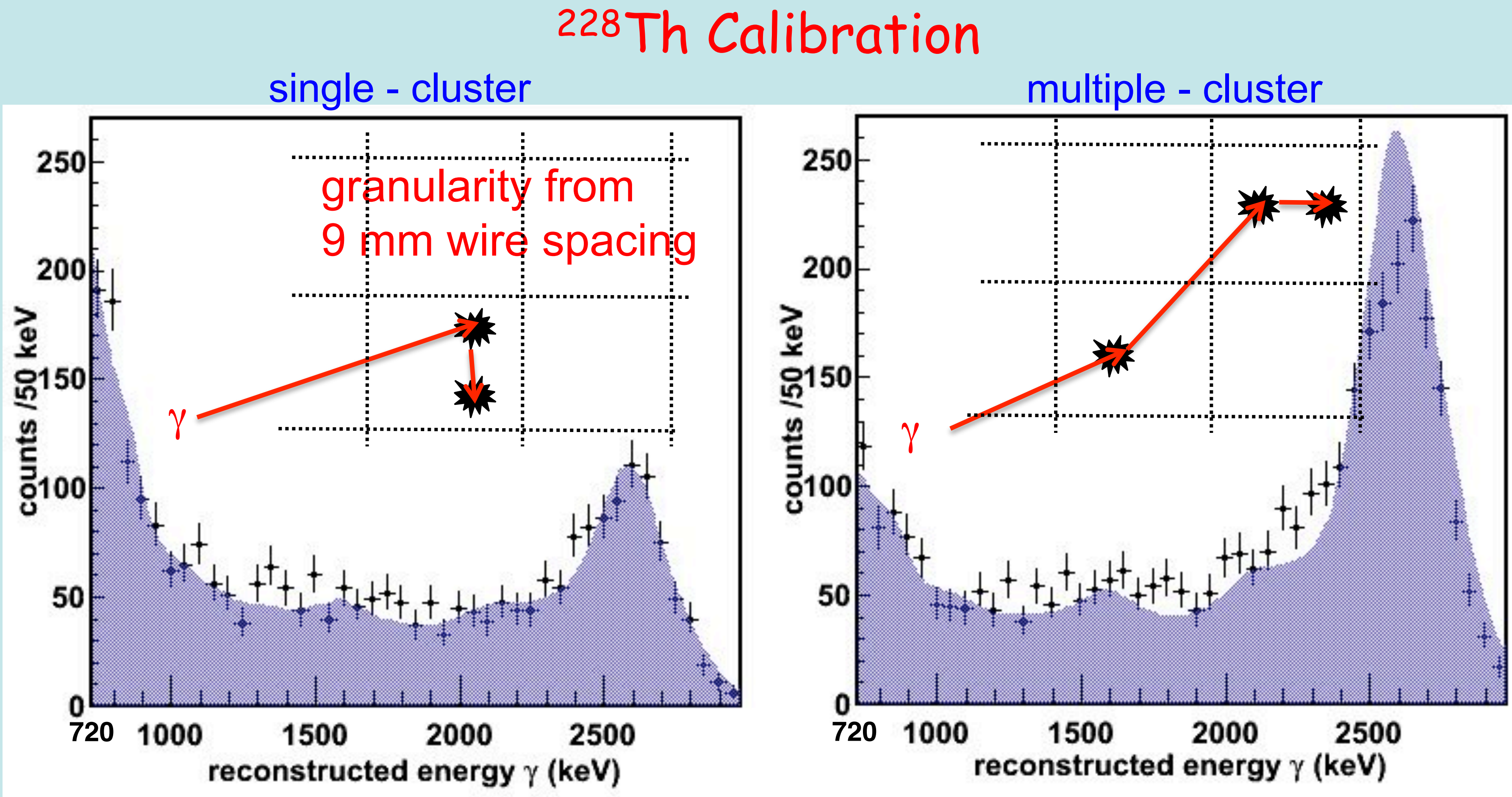
Left display is light readout. APD map refers to the sample with max signal.

Scintillation light is seen from both sides, although more intense and localized on side 2, where the event occurred.

Small depositions produce induction signals on more than one V wires but are collected by a single U wire. V signal always comes before U.

Light signals precede in time the charge ones

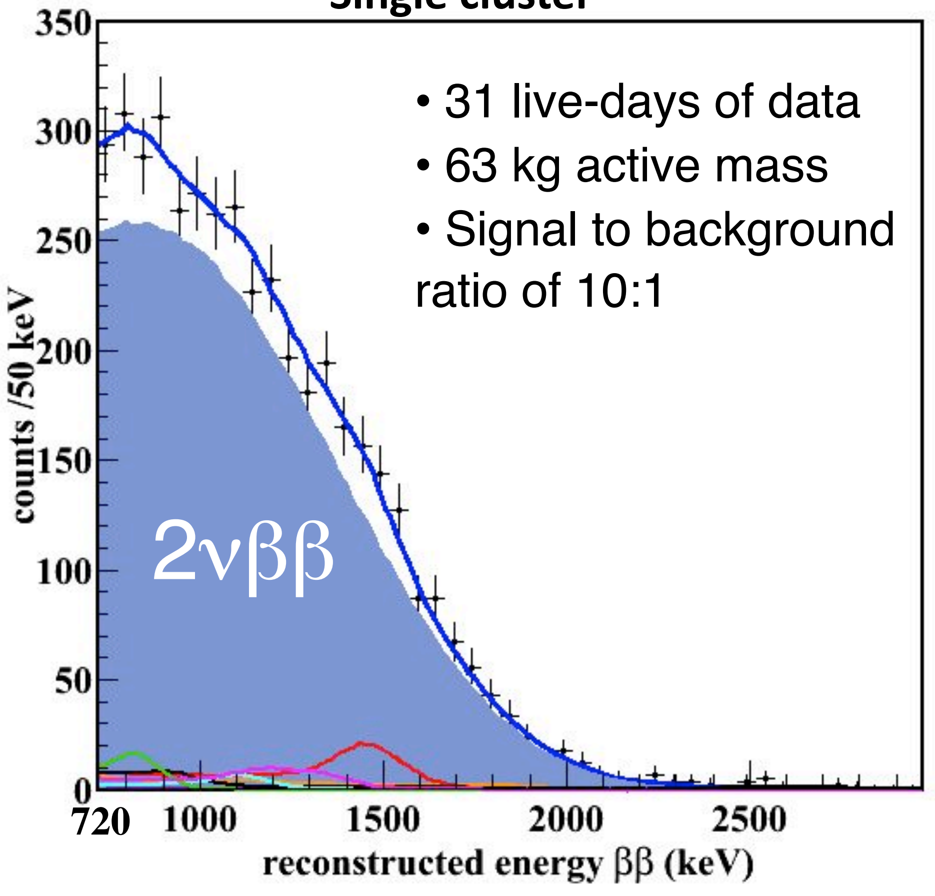
Year 2011: June 1 start of physics



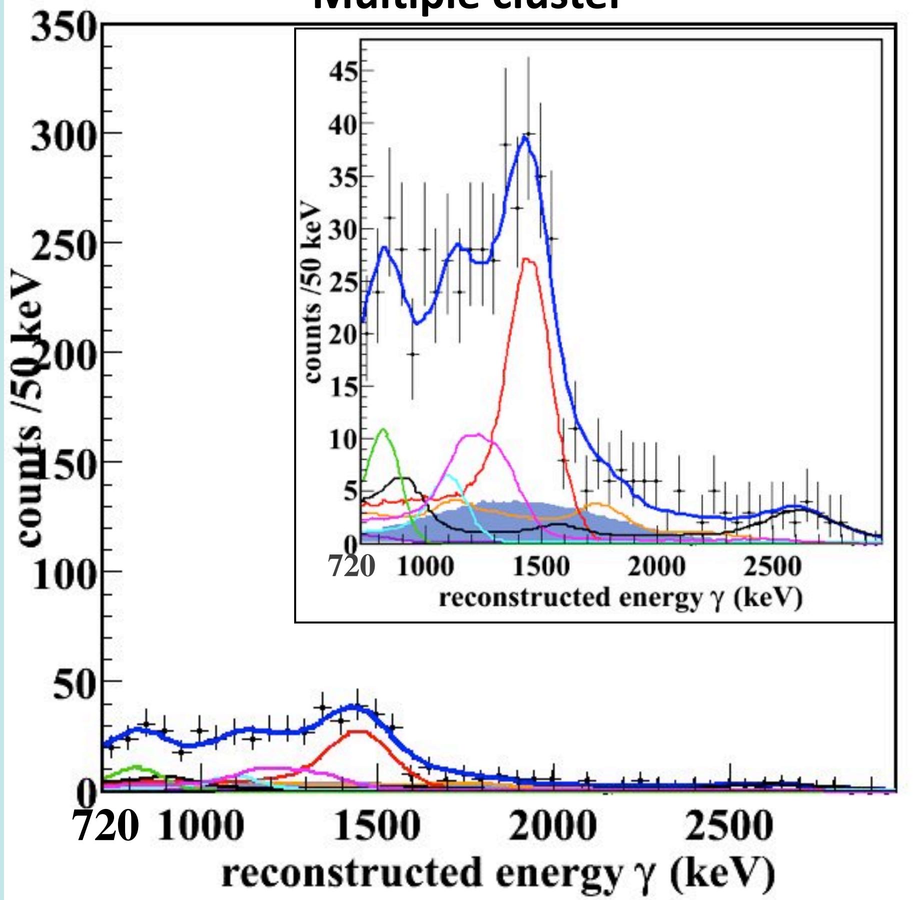
spatial calibration: separate single-site signal from multi-site gammas
energy calibration: narrow energy window for 0nbb search

Year 2011, August: 2νββ observation

Single cluster



Multiple cluster

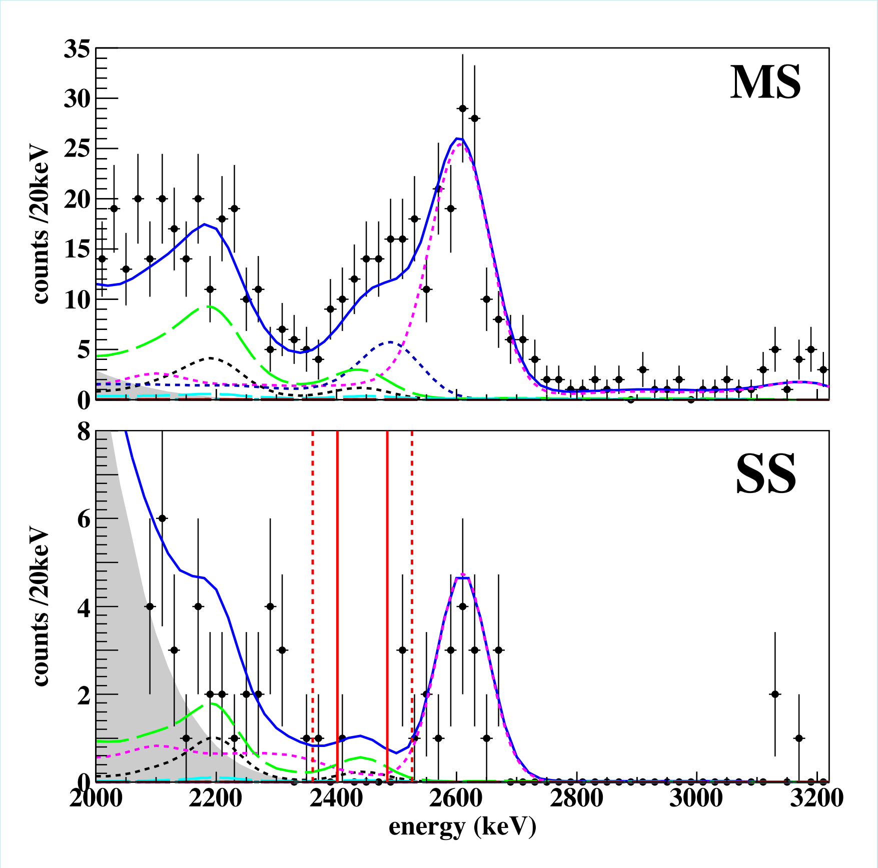


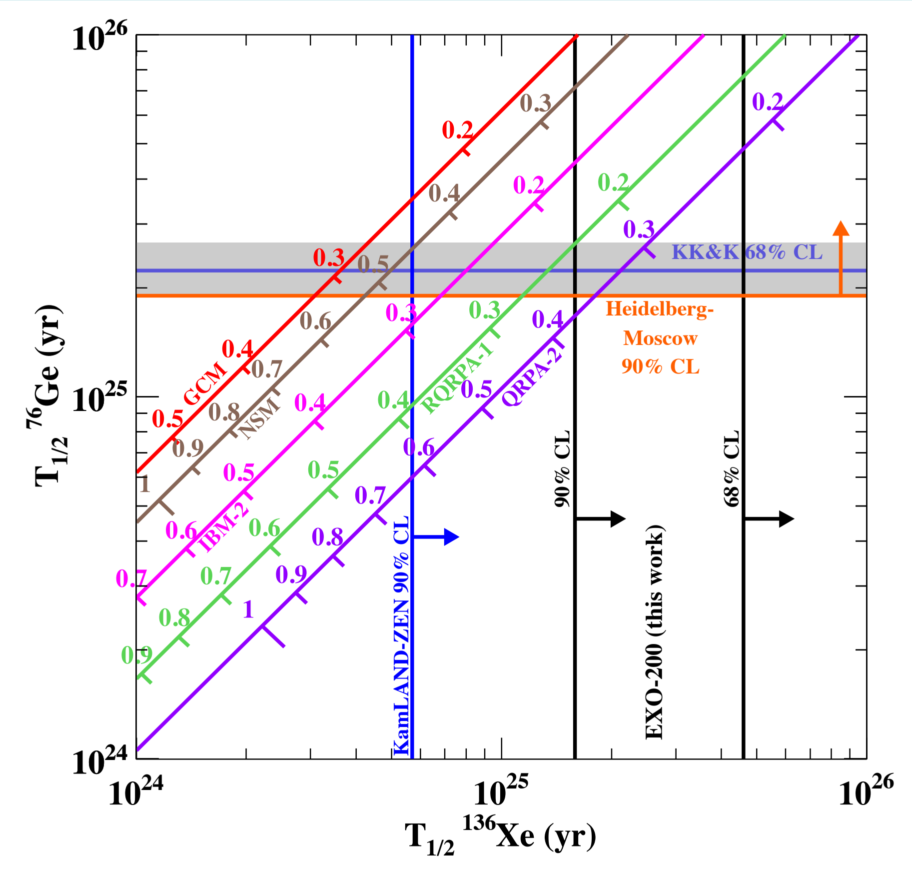
Observation of two-neutrino double-beta decay in Xe-136 with EXO-200
Phys. Rev. Lett. 107 (2011) 212501

2νββ $T_{1/2}$ = (2.11 ± 0.04 stat ± 0.21 sys) x 10^{21} yr

Year 2012: First 0νββ Search Paper

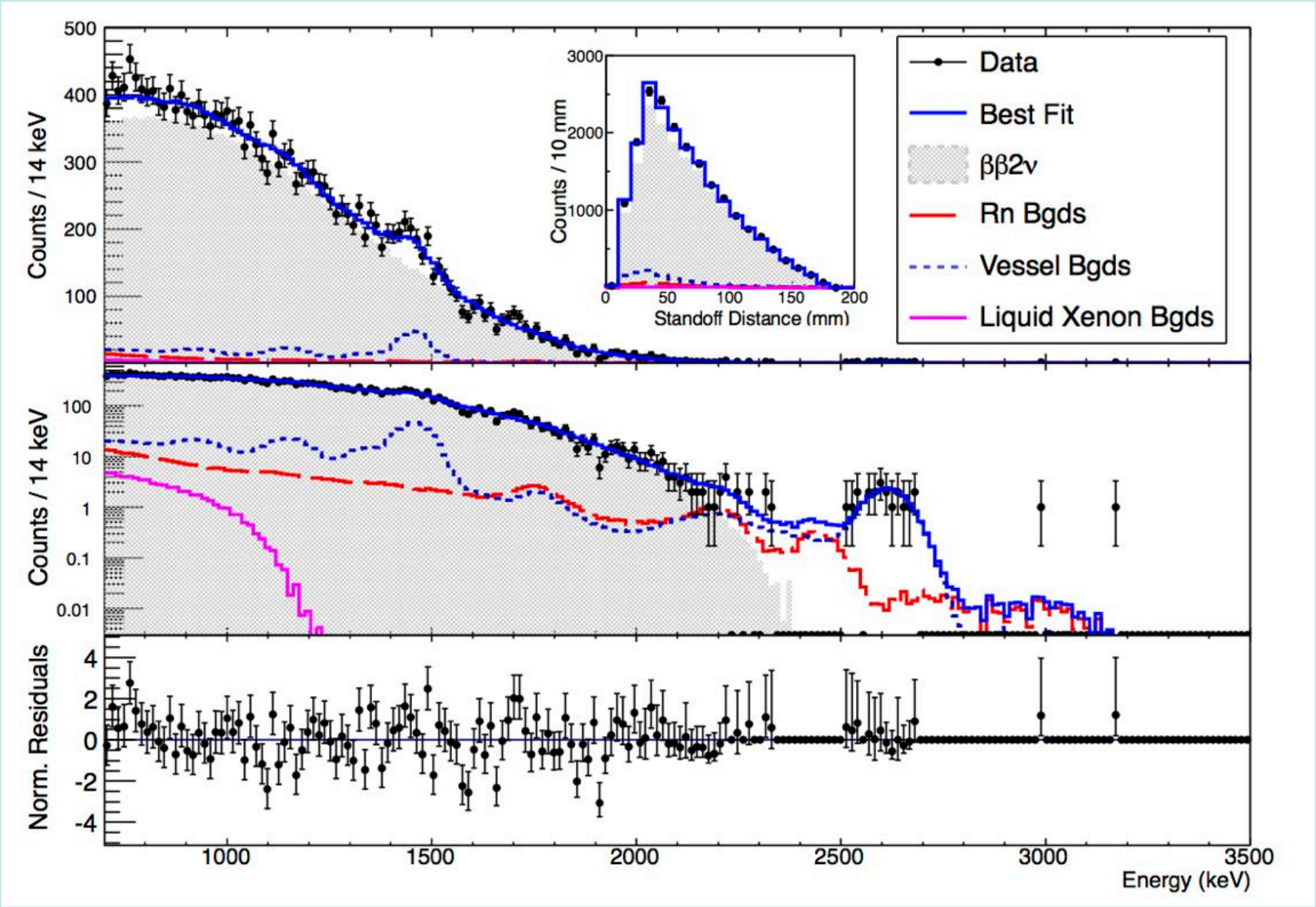
- $T_{1/2}^{0\nu\beta\beta}(^{136}Xe) > 1.6 \times 10^{25}$ yr (90% C.L.),
- effective Majorana masses of less than 140–380 meV,





Year 2013: 2νββ Update Paper

2νββ $T_{1/2}$ = (2.172 ± 0.017 stat ± 0.06 sys) x 10^{21} yr



Publications

- An improved measurement of the 2 half-life of 136Xe with EXO-200, submitted to PRC
- Search for Neutrinoless Double-Beta Decay in ^{136}Xe with EXO-200
  Phys. Rev. Lett. 109 (2012) 032505
- The EXO-200 detector, part I: Detector design and construction JINST 7 (2012) P05010
- Xenon purity analysis for EXO-200 via mass spectrometry Nucl .Instrum. Meth. A675 (2012) 40-46
- Observation of two-neutrino double-beta decay in Xe-136 with EXO-20 Phys. Rev. Lett. 107 (2011) 212501
- A xenon gas purity monitor for EXO Nucl. Instrum. Meth. A659 (2011) 215-228
- A magnetically-driven piston pump for ultra-clean applications Rev. Sci. Instrum. 82 (2011) 105114
- A simple radionuclide-driven single-ion source Rev. Sci. Instrum. 81 113301 (2010)
- Characterization of large area APDs for the EXO-200 detector Nucl.Instrum.Meth.A608 (2009)
- A microfabricated sensor for thin dielectric layers Rev. Sci. Instrum. 79, 045101 (2008)
- Systematic study of trace radioactive impurities in candidate construction materials for EXO-200
  Nucl.Instrum.Meth.A591 (2008)
- A liquid xenon ionization chamber in an all-fluoropolymer vessel Nucl.Instrum.Meth.A578 (2007)
- A linear RFQ ion trap for the Enriched Xenon Observatory Nucl.Instrum.Meth.A578 (2007)
- Observation of single collisionally cooled trapped ions in a buffer gas. Phys. Rev. A 76, 023404 (2007)
- Mobility of thorium ions in liquid xenon Nucl.Instrum.Meth.A555 (2005)
- Correlated Fluctuations between Luminescence and Ionization in Liquid Xenon Phys. Rev. B 68 (2003)
- Detection of very small Neutrino Masses in double-beta decay using laser tagging
  Phys. Lett. B 480, 12 (2000)

Summary

- EXO200, from inception to operation, has (mostly) gone smoothly
- many challenges were overcome (including site logistics)
- now in 'steady state' operating mode with remote control

- first measurement of $2\nu\beta\beta$ for ^{136}Xe
- $0\nu\beta\beta$ results competing with world's best
- updated $2\nu\beta\beta$ submitted for publication
- new $0\nu\beta\beta$ result with latest exposure very soon

- will continue to optimize analysis for further improvements
- additional physics might be pursued
- potential upgrades to detector being considered
- physics running until ~2015
- additional R&D operation for nEXO possible beyond that