EXO 200 Update

Kevin Graham
for the EXO Collaboration

IPP Meeting June 15, 2014

MRS Resources

- Carleton, Queen's, and Victoria have MRS personnel managed with the aid of a Prioritization Board

  see http://www.ipp.ca/sapmrs/index.shtml

- these resources are available for the support of any/all SAP work across Canada

- contact Board chair Tom Mattison to obtain support or local managers Kevin Graham (Carleton) Tony Noble (Queen's) Dean Karlen (Victoria)

- provide a short description of requested work and approximate schedule and FTEs required

Available Resources

- **Carleton**
  - Philippe Gravelle (machinist/technician - over 20 years experience with particle detector design, fabrication, and assembly)
  - Yves Baribeau (electronics specialist - 5 years experience at Carleton following industry career)
  - Matt Bowcock and Rodney Schnarr (designers - combined 12 years experience at Carleton developing designs for various experiments)
- **Queen's**
  - Dave Bearse (fabrication of ultralow-background acrylic chambers and lightguides, acrylic bonding, and radon emanation assays)
  - Phil Harvey (hardware control and programming robotic devices and instruments, software for data acquisition and visualization software)
- **Victoria**
  - Paul Poffenberger (detector technologist - PhD physicist with over 20 years experience in detector simulation, design, assembly, testing, and data acquisition)

The EXO-200 Collaboration

University of Alabama, Tuscaloosa AL, USA - D. Auty, T. Didberidze, M. Hughes, A. Piepke, R. Tsang

University of Bern, Switzerland - S. Delaquis, G. Giroux, R. Gornea, T. Tolba, J-L. Vuilleumier

California Institute of Technology, Pasadena CA, USA - P. Vogel

Carleton University, Ottawa ON, Canada - V. Basque, M. Dunford, K. Graham, C. Hargrove, R. Killick, T. Koffas, F. Leonard, C. Licciardi, M.P. Rozo, D. Sinclair

Colorado State University, Fort Collins CO, USA - C. Benitez-Medina, C. Chambers, A. Craycraft, W. Fairbank, Jr., T. Walton

Drexel University, Philadelphia PA, USA - M.J. Dolinski, M.J. Jewell, Y.H. Lin, E. Smith, Y.-R Yen

Duke University, Durham NC, USA - P.S. Barbeau

IHEP Beijing, People's Republic of China - G. Cao, X. Jiang, L. Wen, Y. Zhao

University of Illinois, Urbana-Champaign IL, USA - D. Beck, M. Coon, J. Ling, M. Tarka, J. Walton, L. Yang

Indiana University, Bloomington IN, USA - J. Albert, S. Daugherty, T. Johnson, L.J. Kaufman

University of California, Irvine, Irvine CA, USA - M. Moe

ITEP Moscow, Russia - D. Akimov, I. Alexandrov, V. Belov, A. Burenkov, M. Danilov, A. Dolgolenko, A. Karelin, A. Kovalenko, A. Kuchenkov, V. Stekhanov, O. Zeldovich

Laurentian University, Sudbury ON, Canada - B. Cleveland, A. Der Mesrobian-Kabakian, J. Farine, B. Mong, U. Wichoski

University of Maryland, College Park MD, USA - C. Davis, A. Dobi, C. Hall

University of Massachusetts, Amherst MA, USA - J. Abdollahi, T. Daniels, S. Johnston, K. Kumar, A. Pocar, D. Shy

University of Seoul, South Korea - D.S. Leonard

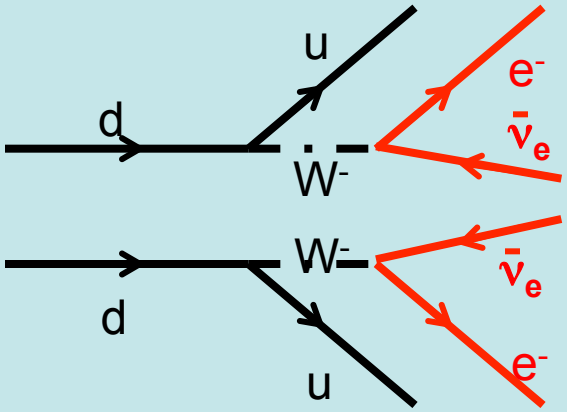
SLAC National Accelerator Laboratory, Menlo Park CA, USA - M. Breidenbach, R. Conley, A. Dragone, K. Fouts, R. Herbst, S. Herrin, A. Johnson, R. MacLellan, K. Nishimura, A. Odian, C.Y. Prescott, P.C. Rowson, J.J. Russell, K. Skarpaas, M. Swift, A. Waite, M. Wittgen

Stanford University, Stanford CA, USA - J. Bonatt, T. Brunner, J. Chaves, J. Davis, R. DeVoe, D. Fudenberg, G. Gratta, S.Kravitz, D. Moore, I. Ostrovskiy, A. Rivas, A. Schubert, D. Tosi, K. Twelker, M. Weber

Technical University of Munich, Garching, Germany - W. Feldmeier, P. Fierlinger, M. Marino

TRIUMF, Vancouver BC, Canada – J. Dilling, R. Krucken, F. Retière, V. Strickland

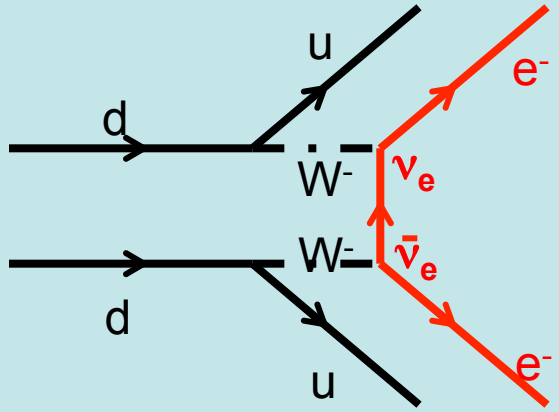
Neutrinoless Double Beta Decay



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

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?

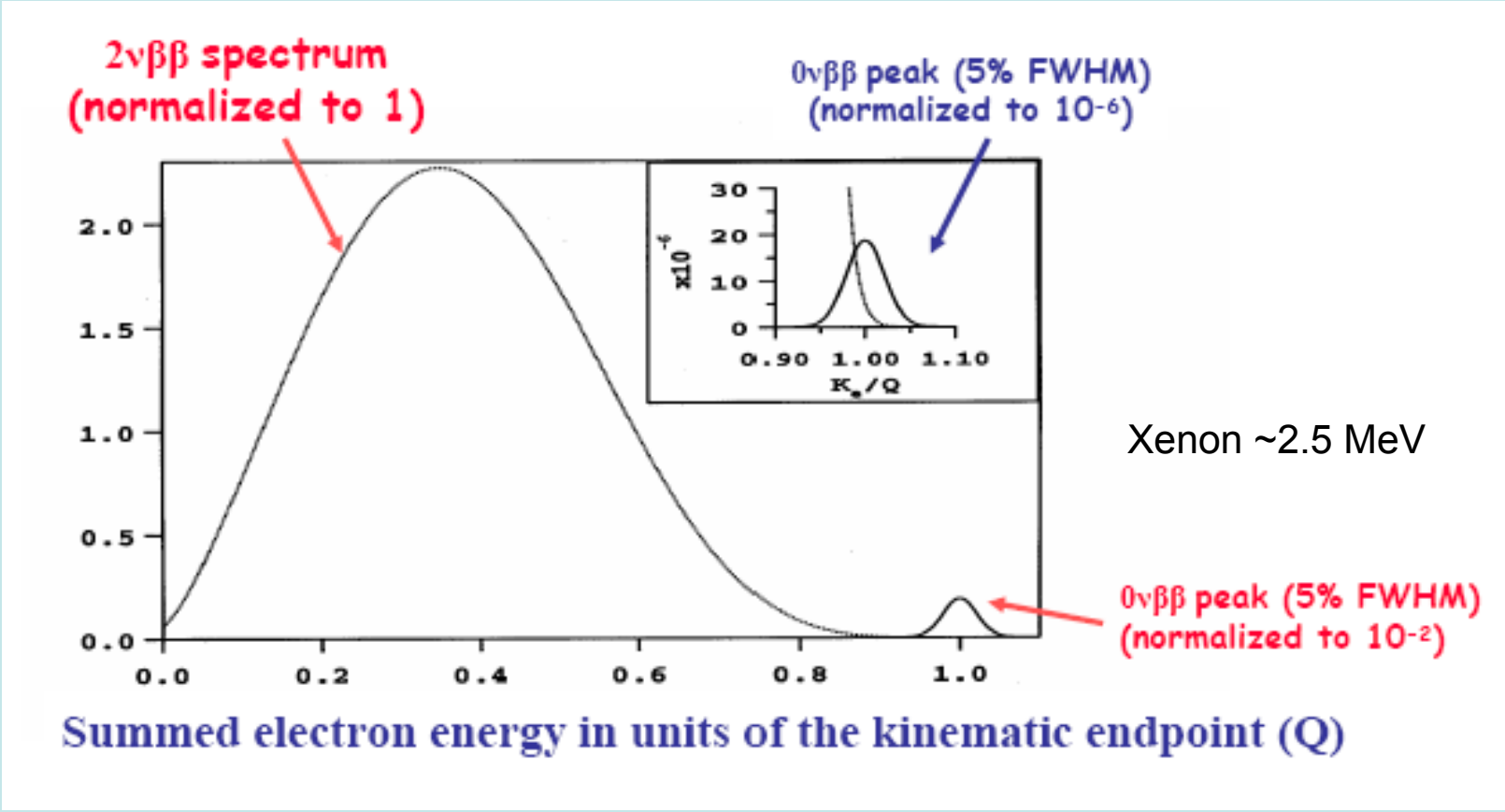
neutrino mass scale

neutrino mass hierarchy

Double Beta Decay of ^{136}Xe

$^{136}Xe \rightarrow Ba^{++} + 2e^{-} + (2\nu)$

- search for excess of events at sum energy of the electrons ~2.5 MeV
- key is to have extremely low backgrounds in that energy range

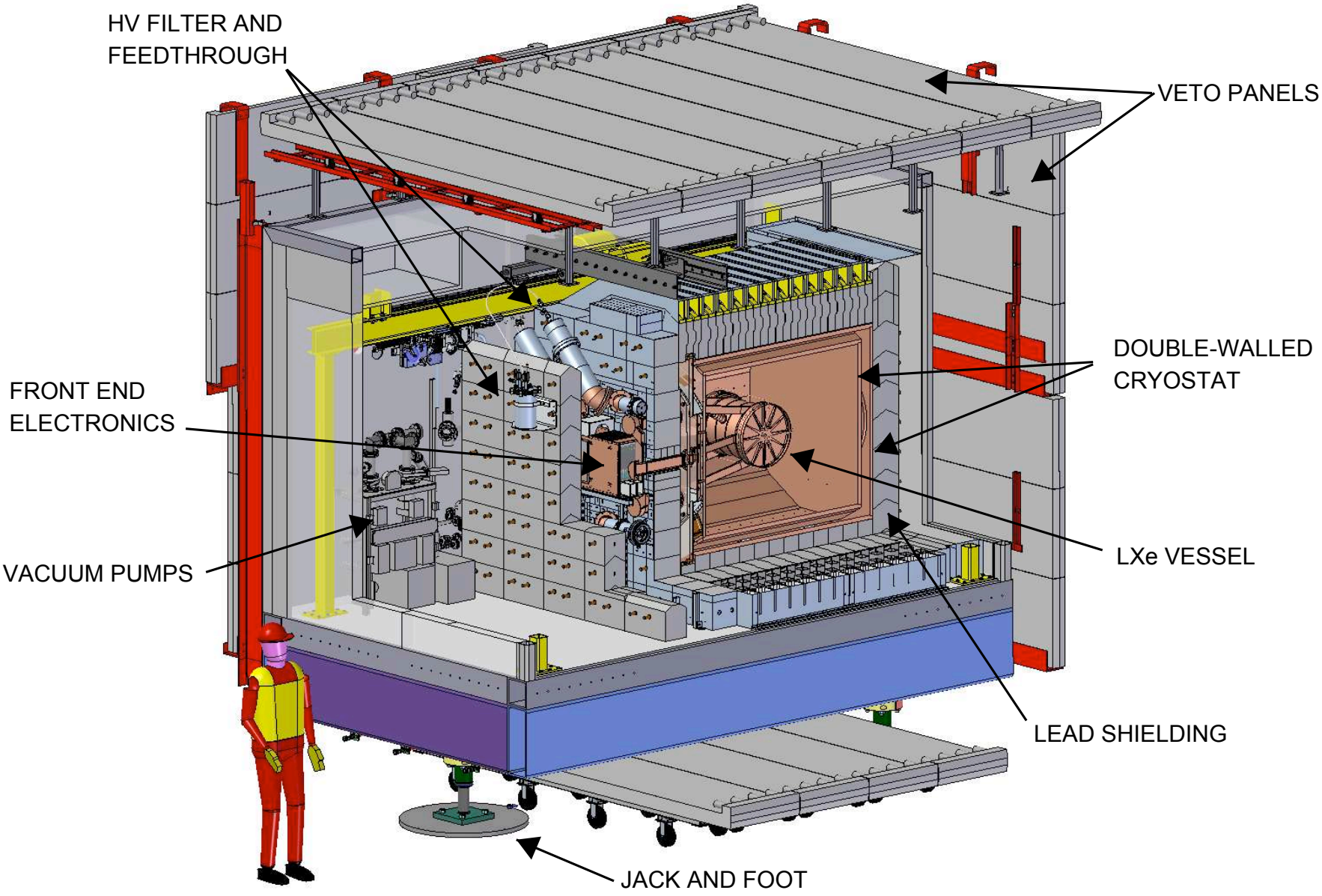


EXO Program

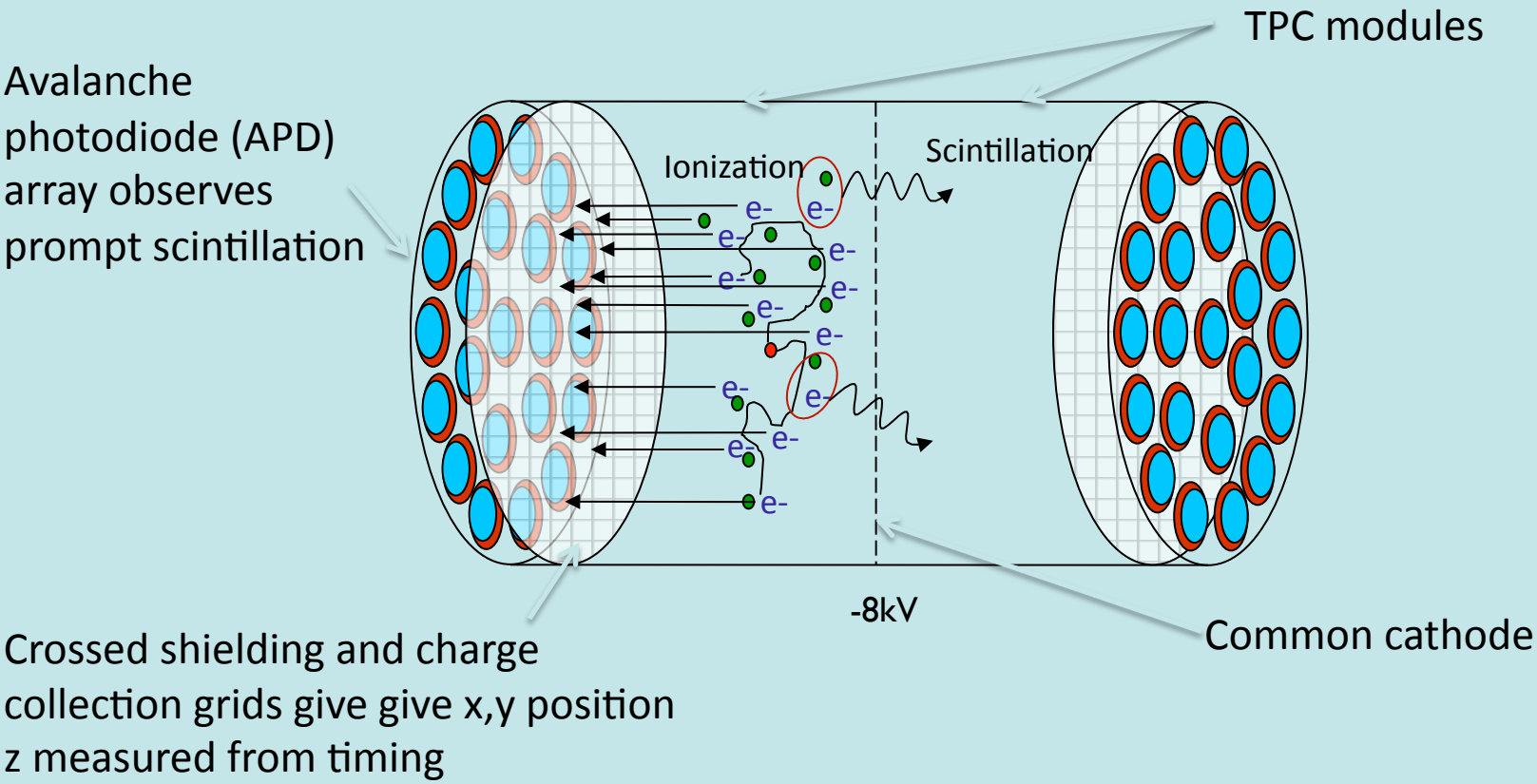
- EXO-200
  - upgrade electronics and install de-radonator
  - continue physics for ~2 years
  - update 0nbb analysis and complete other physics searches
- nEXO
  - developing next generation 5-tonne detector
  - liquid-phase with improved detector response
  - pursuing SNOLAB cryopit as host site
- Barium tagging
  - continuing to pursue both gas and liquid phase options
  - laser spectroscopic tag suitable for either case
  - challenge to demonstrate efficient extraction from detector

EXO-200 at WIPP

EXO-200 Detector

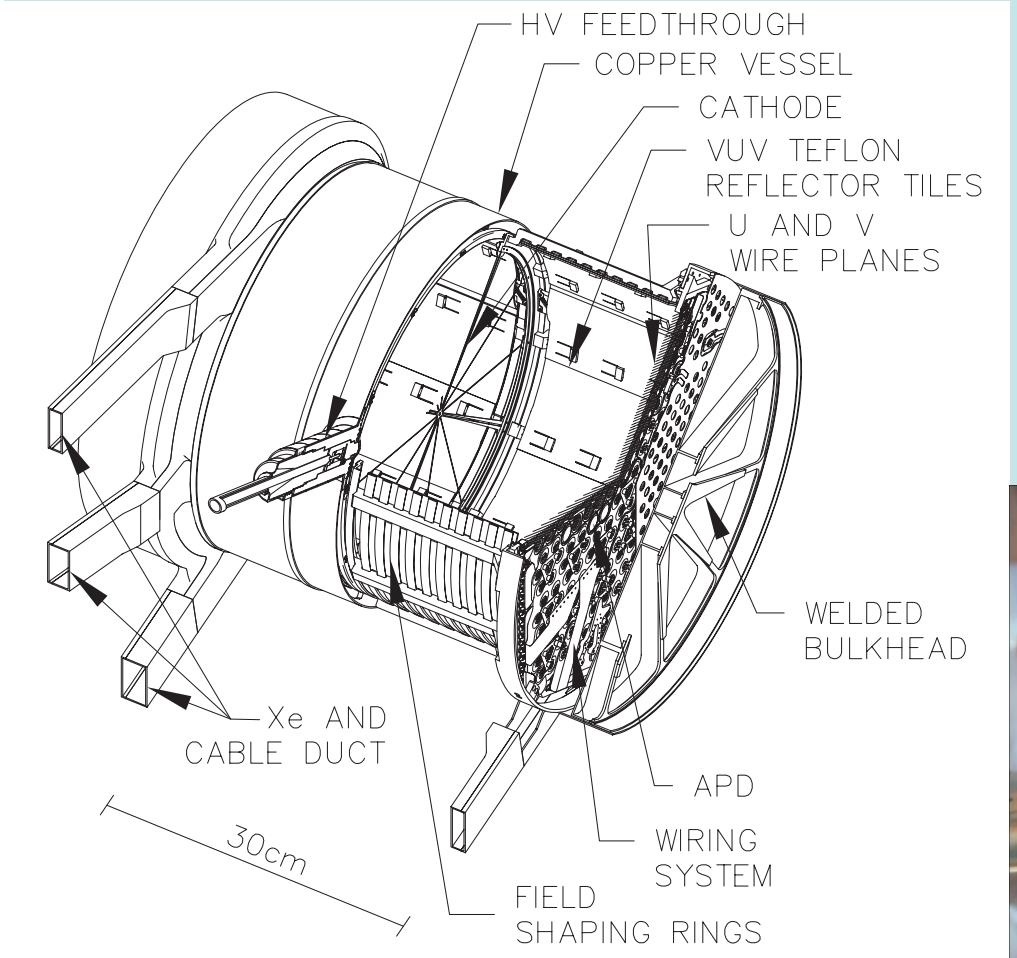


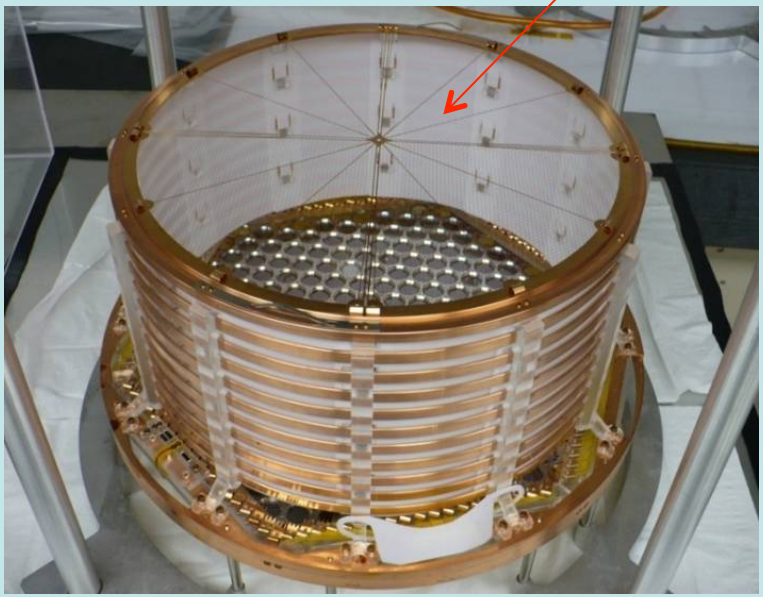
EXO200: Liquid Xenon (~200 kg) Time Projection Chamber

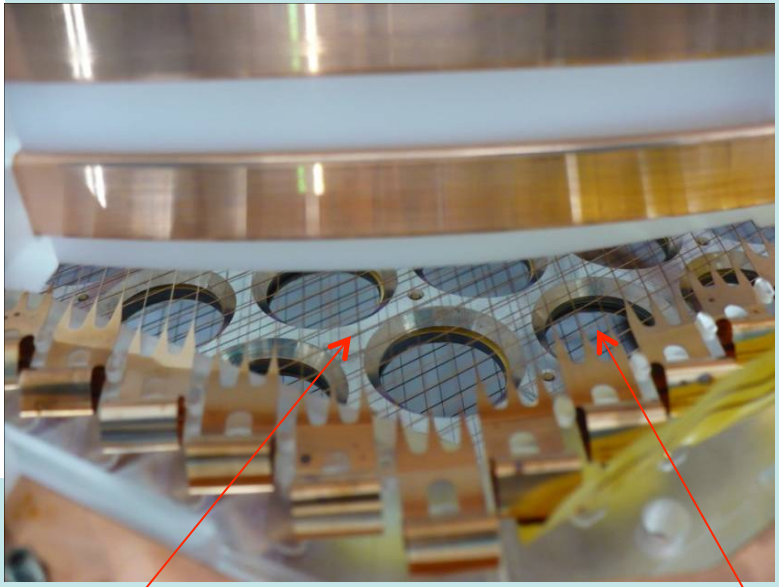


- Measure both ionization (wires) and scintillation (APDs)
- Event energy from the combination of ionization and scintillation
- reject some gamma backgrounds because Compton scattering results in multiple energy deposits

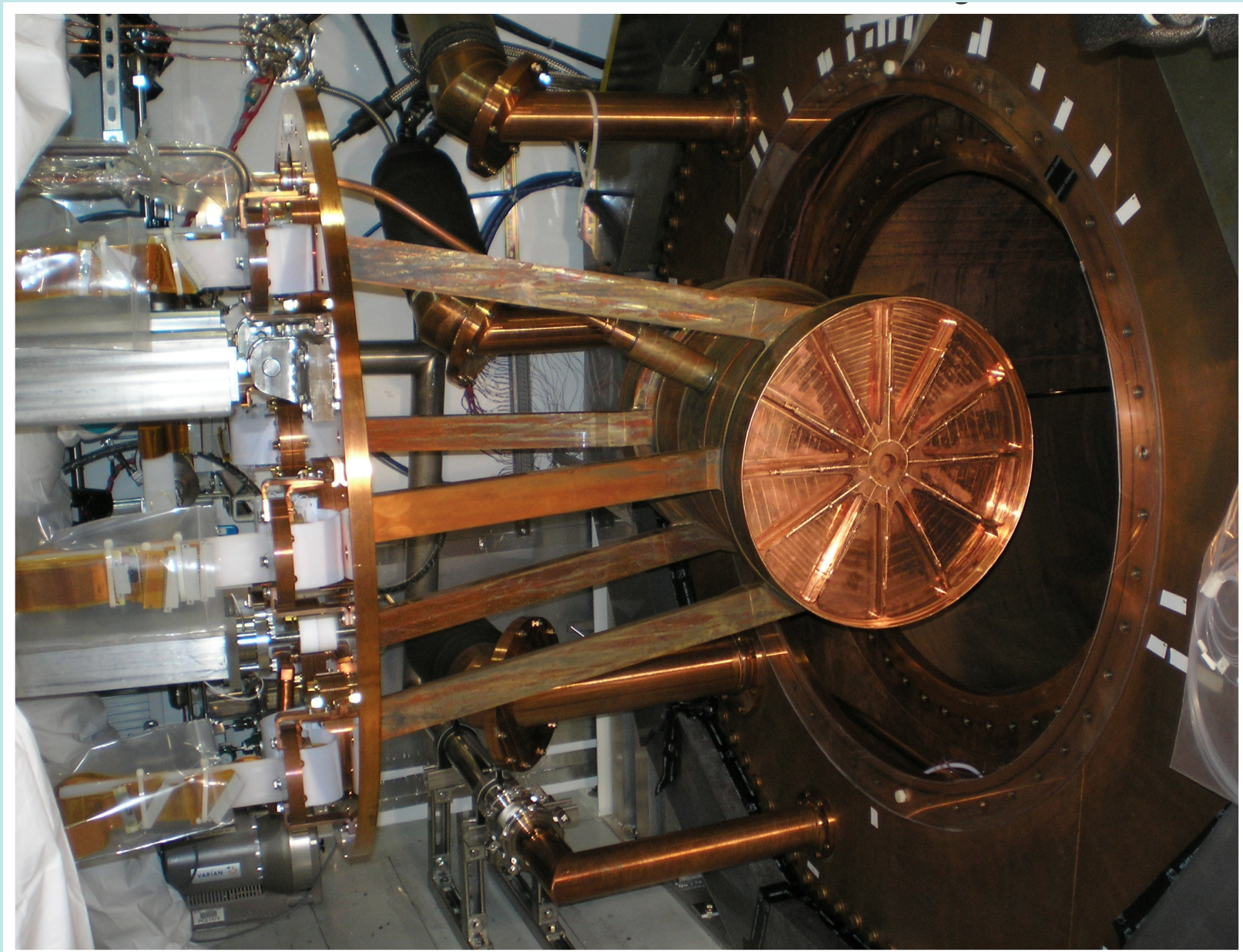
Detector Construction



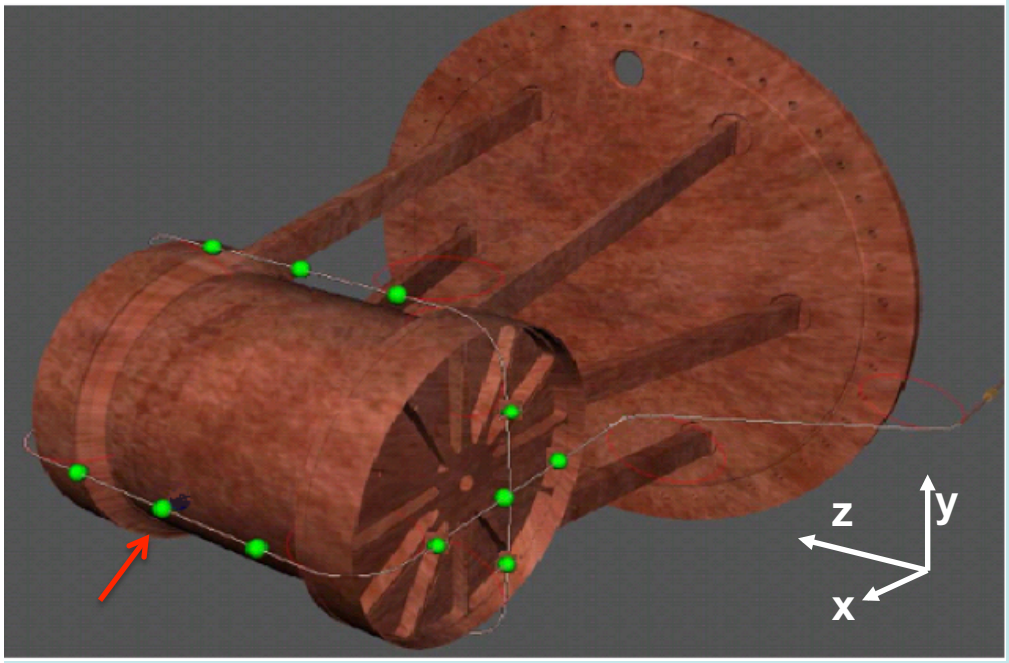




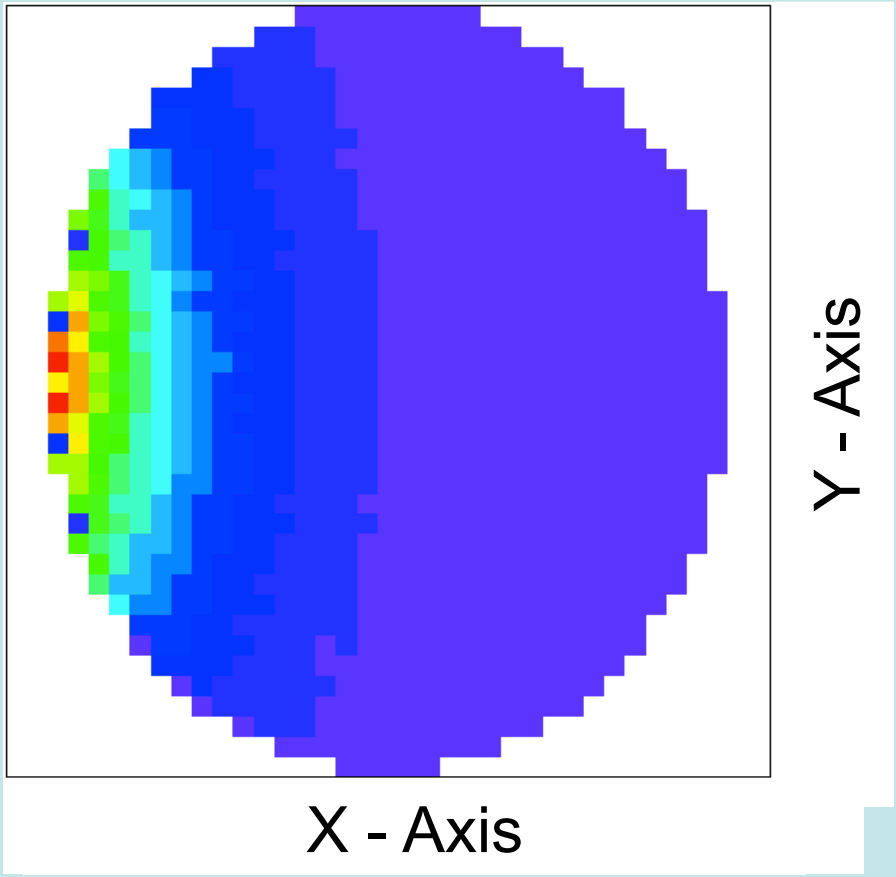
TPC Deployment



Calibration System



Calibration source locations



x-y distribution of events

Sources:

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

Custom designed, miniature source

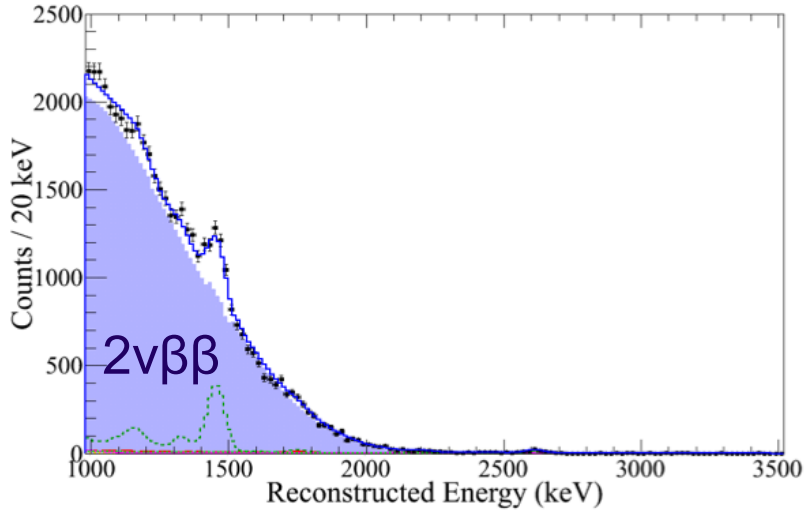
Background Rejection

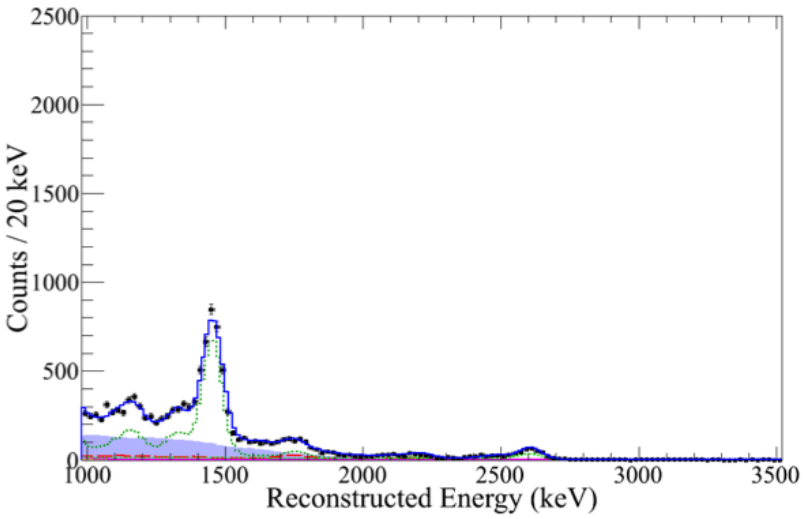
Single Site (SS)

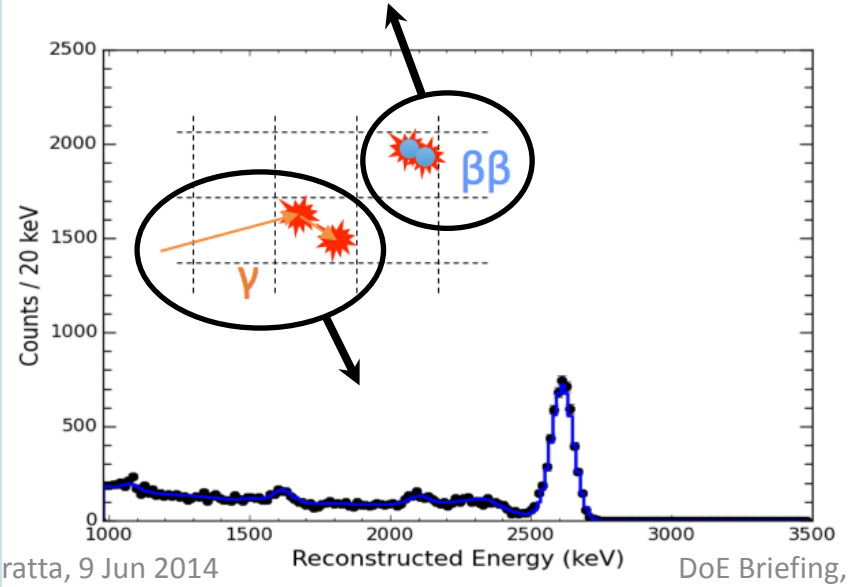
Multiple Site (MS)

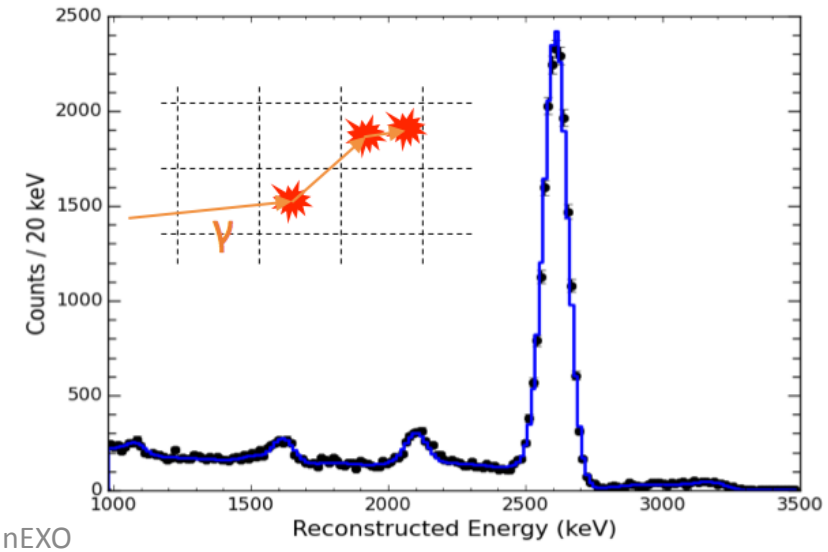
Low Background Data

^{228}Th Calibration Source



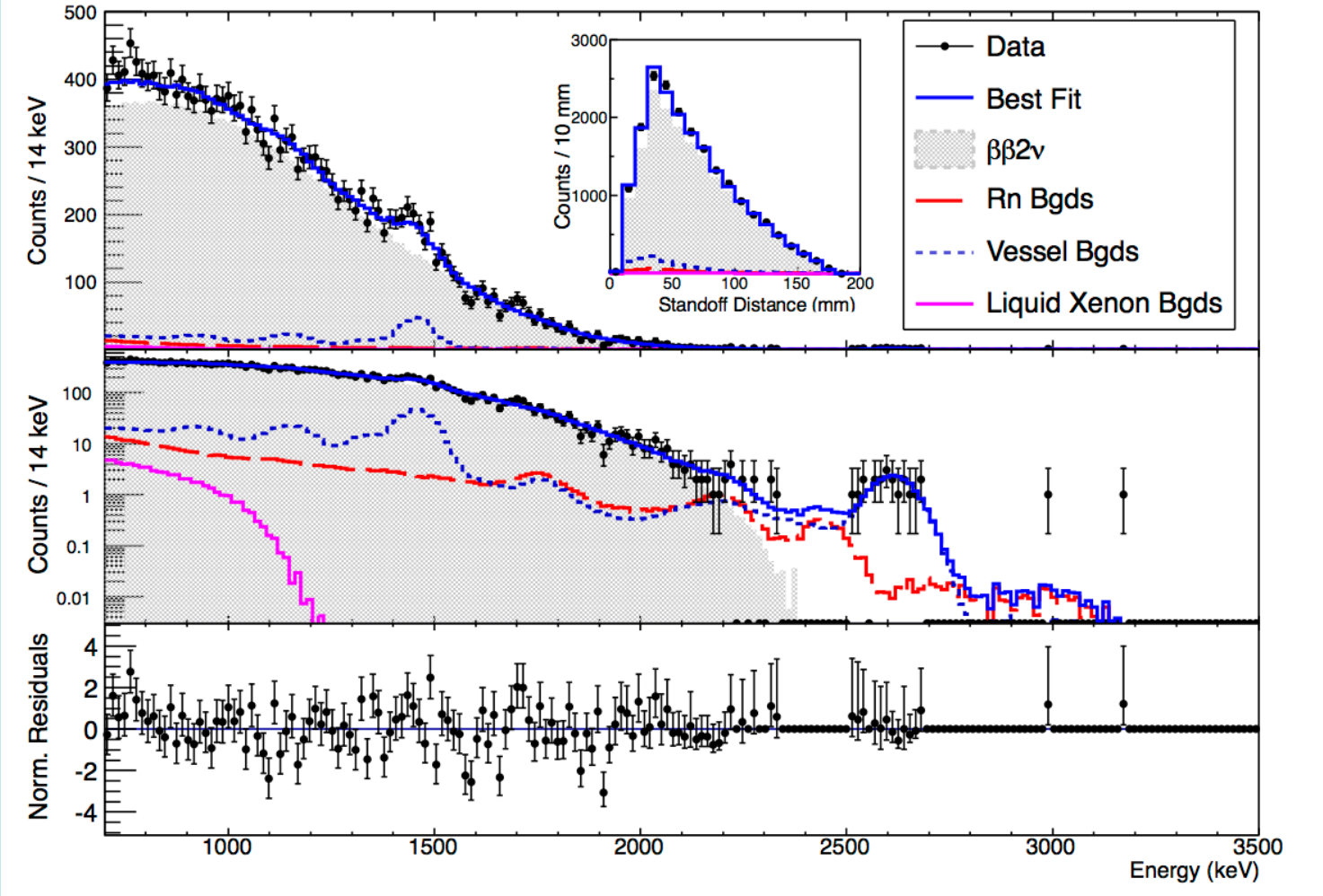






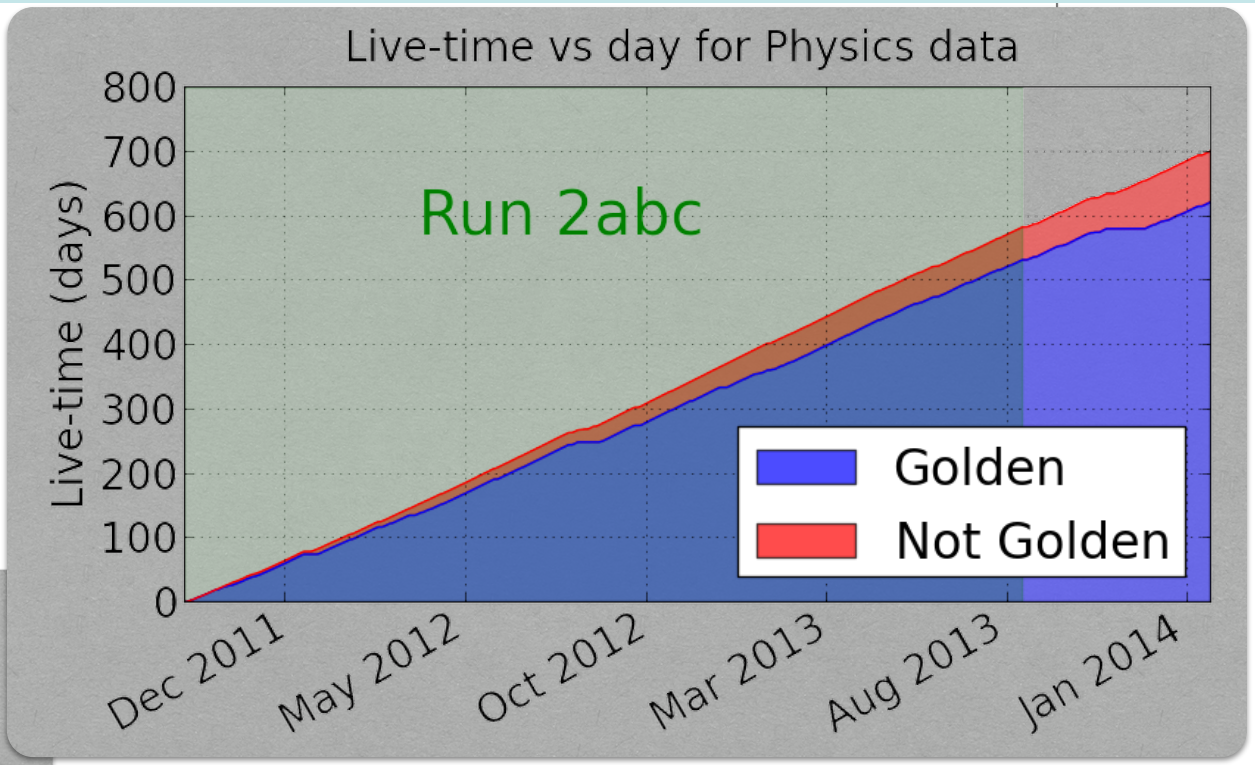
2νββ Update Paper

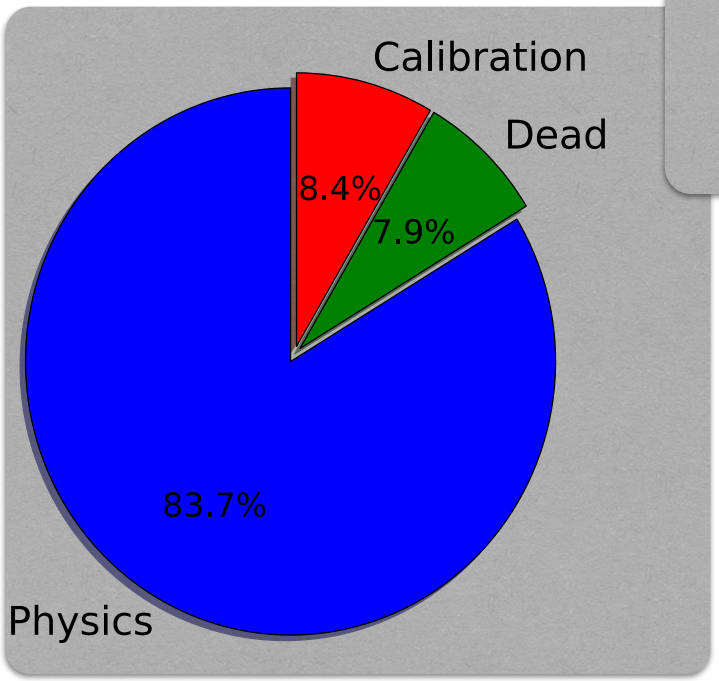
$2\nu\beta\beta$ $T_{1/2}$ = (2.172 ± 0.017 stat ± 0.06 sys) x 10^{21} yr



Updated 0νββ Dataset

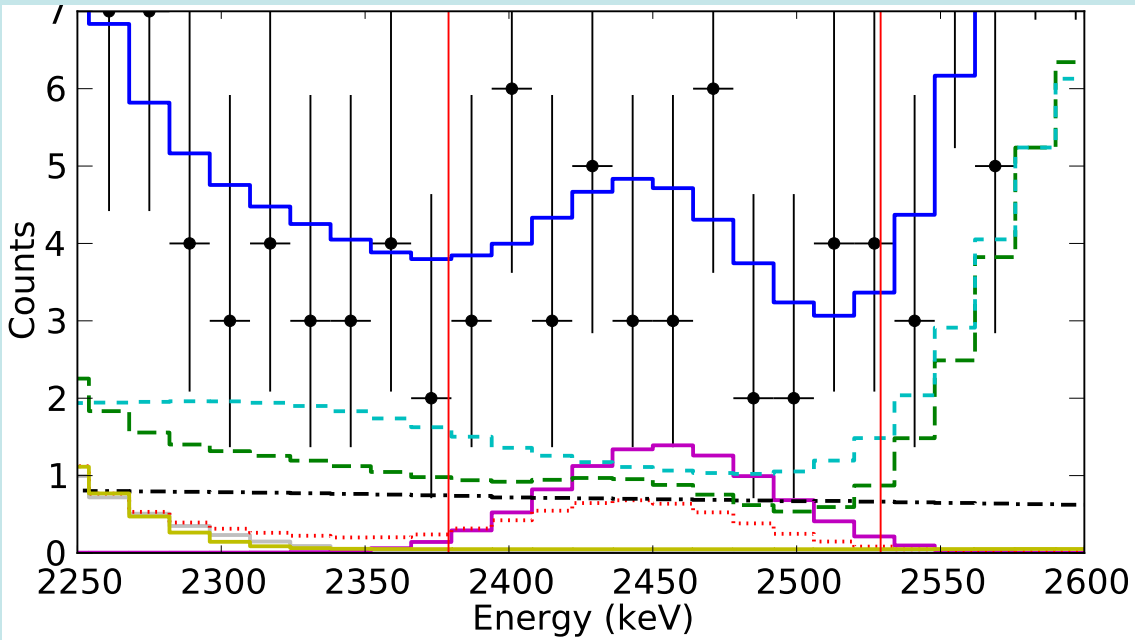
nature
(12 June 2014, online 4 June)
doi:10.1038/nature13432





Accumulation of "Golden" data
447.60 ± 0.01 days livetime
(100 kg·yr, 736 mol·yr ^{136}Xe exposure)
(6 Oct 2011- 1 Sep 2013)

0νββ Search Update



Backgrounds in ± 2σ ROI	
Th-228 chain	16.0
U-232 chain	8.1
Xe-137	7.0
Total	**31.1 ± 3.8**

Data
Best Fit
Rn
LXe bgd
n-capture
^{232}Th (far)
Vessel
$0\nu\beta\beta$
$2\nu\beta\beta$

From profile likelihood:

$T_{1/2}^{0\nu\beta\beta} > 1.1 \cdot 10^{25}$ yr

$\langle m_{\beta\beta} \rangle < 190 - 450$ meV

(90% C.L.)

***Nature* (2014)**
doi:10.1038/nature13432

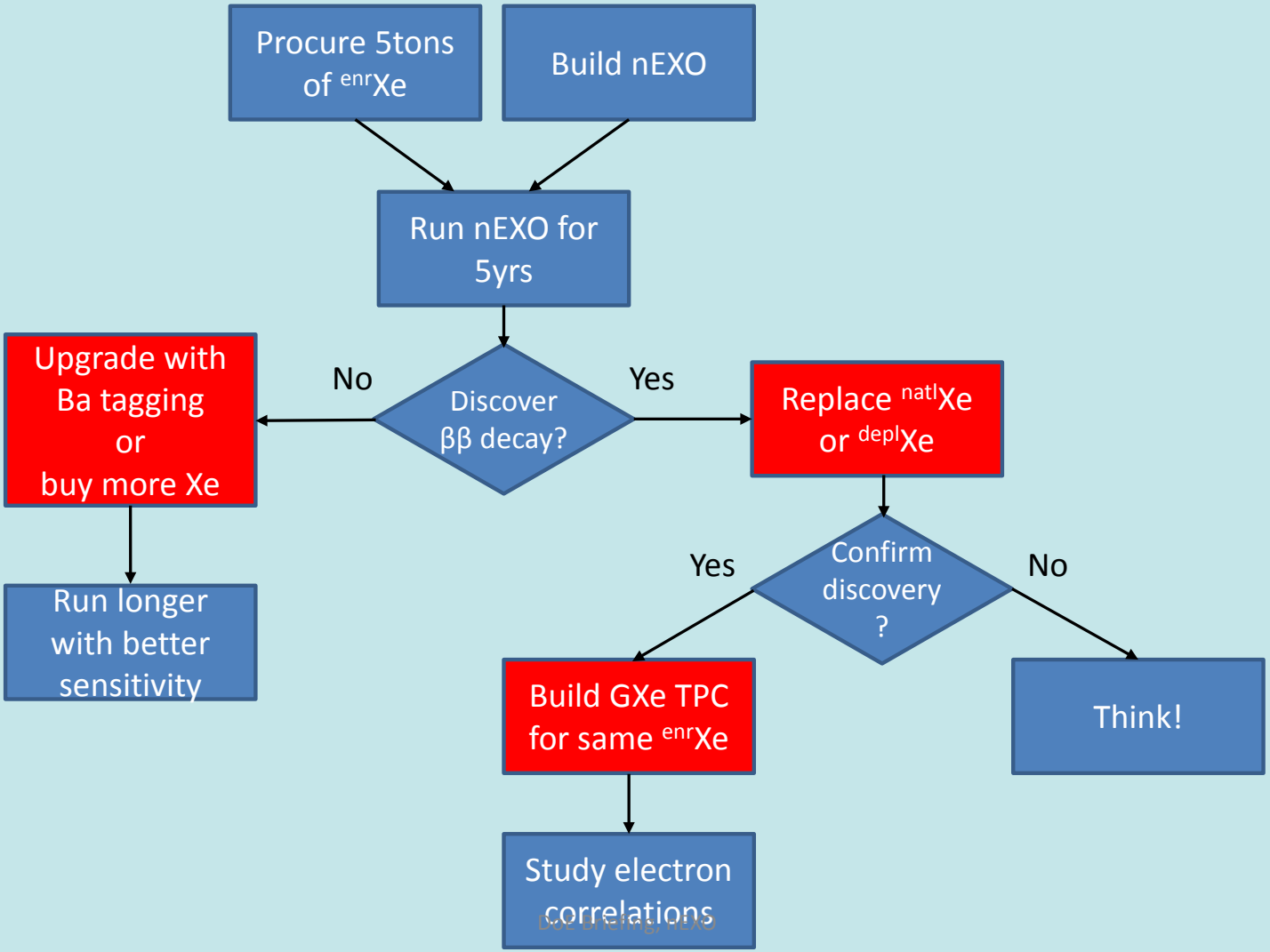
Publications

- Search for majorana Neutrinos with the first two years of EXO-200 data, **Nature 510 (2014) 229–234**
- An improved measurement of the 2 half-life of 136Xe with EXO-200, **Phys.Rev. C89 (2014) 015502**

- 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)

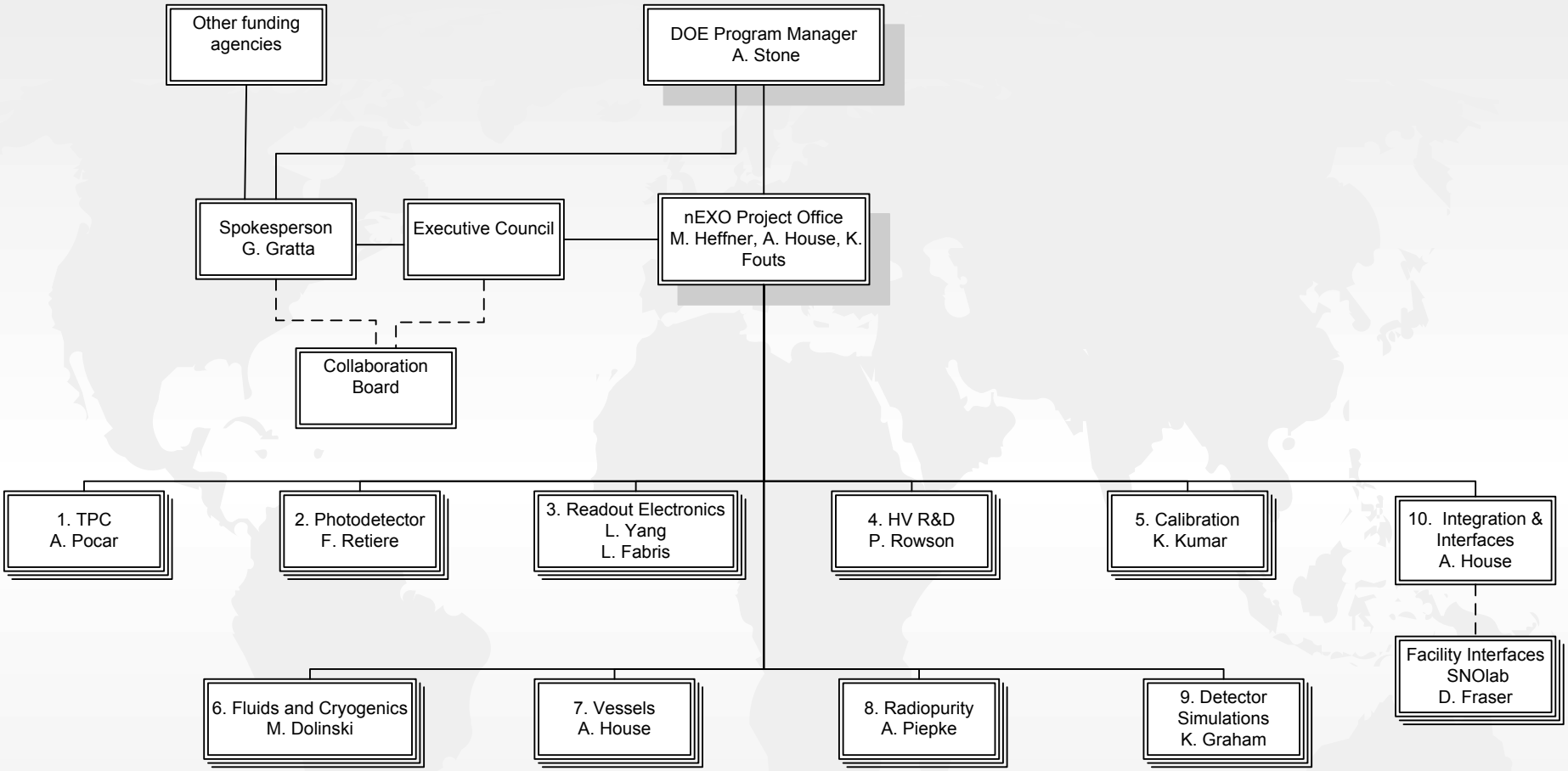
nEXO Plan

Flexible program based on the initial nEXO investment

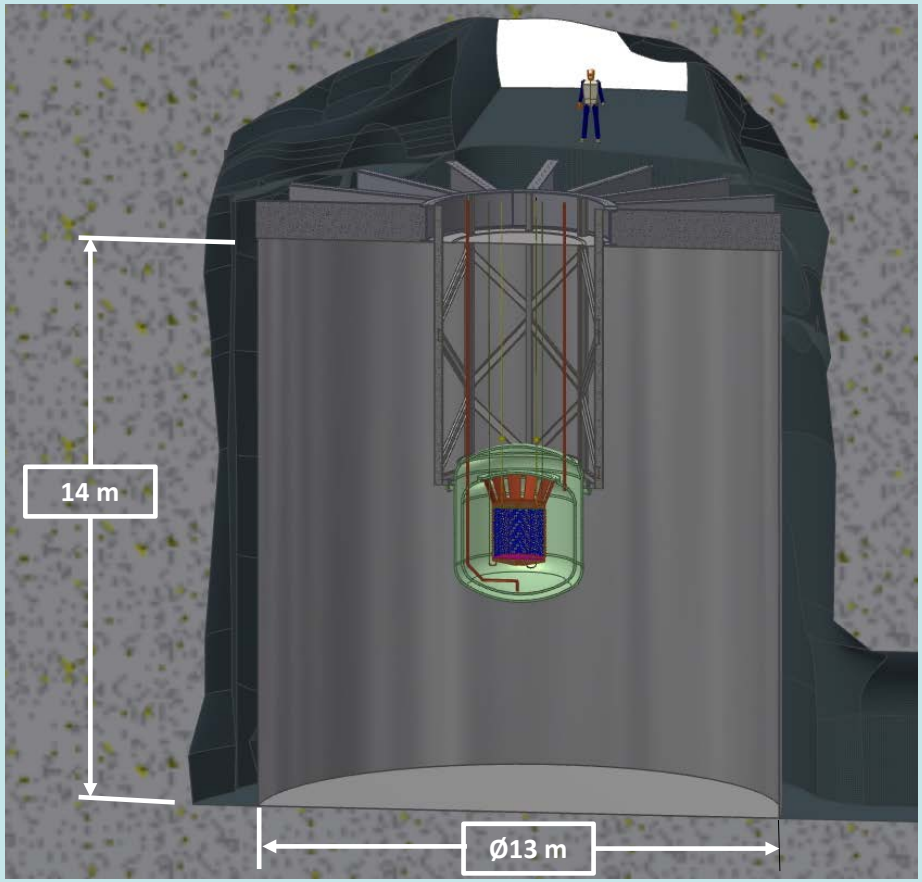


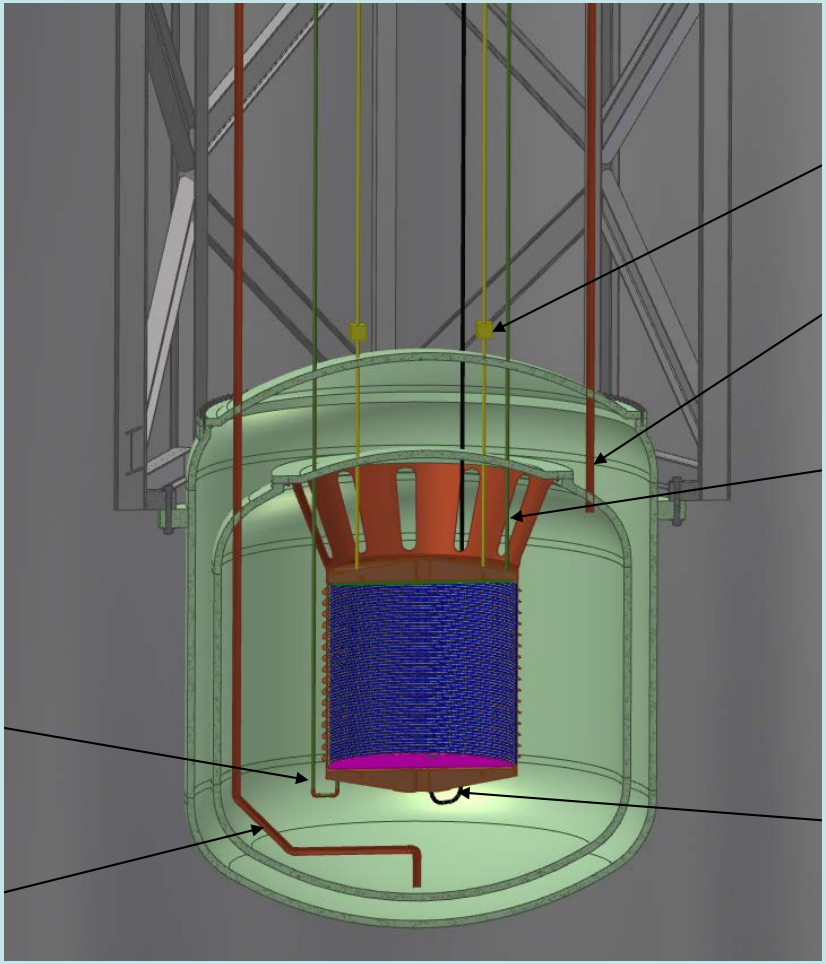
Organization for nEXO R&D Phase

- collaboration is growing
- Canadians in several key positions

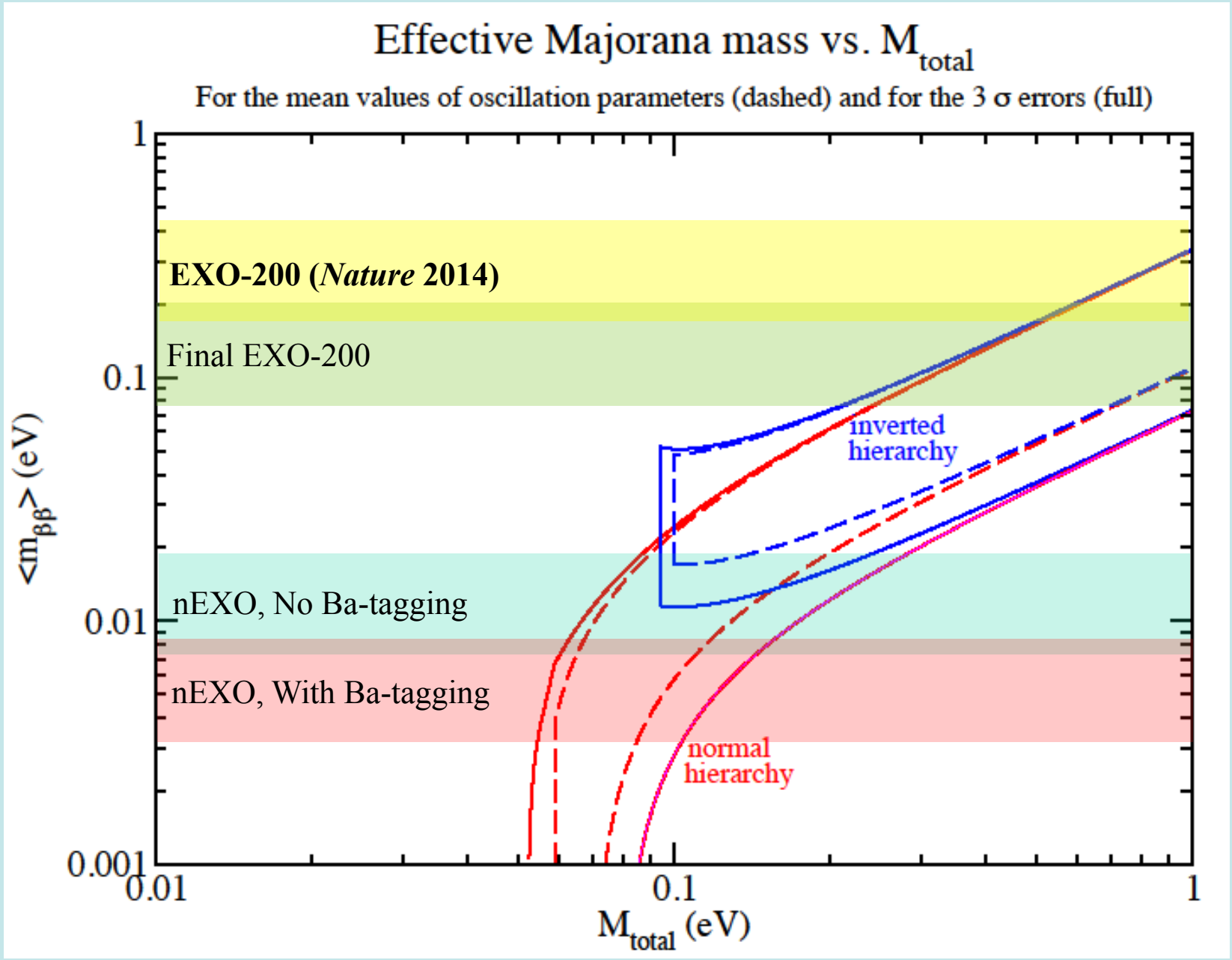


nEXO Detector Concept





nEXO Sensitivity



Summary

- EXO200 has been a tremendous success
- at the forefront of $0\nu\beta\beta$ effort with many publications
- two accidents at WIPP have prevented access…hope to re-enter before fall but timing is uncertain
- aim for ~2 additional years of livetime with upgrades
- additional R&D operation for nEXO possible beyond that

- nEXO design development and R&D well underway
- follow EXO-200 success and know where improvements can be made
- NSAC committee to exist until 2016 followed by down-select committee in the following year