# NEXO and the Long Range Plan

David Sinclair
NP/IPP Long Range Planning Meeting
Edmonton, June 2015

# Outline of talk

- Why the LRP should include double beta decay searches
- Description of the NEXO project
- Recent successes of the EXO program
- Total Project cost
- Possible Canadian funding requests
- Use of Canadian lab infrastructure
- Note – this brief is being presented to  both CINP and IPP

# Scientific Case

- Observation of neutrinoless double beta decay would offer a significant new window to new physics of both particles and nuclei
- Particle physics:
  - Are neutrinos Majorana or Dirac?
  - Where does neutrino mass come from?
  - Is total lepton number violated or conserved?
  - What is the actual neutrino mass scale?
- Cosmology
  - Can we detect CP violation in the neutrino sector
  - Is leptogenesis a route to baryon asymmetry
  - Note – 2 of the 3 phases in the neutrino mixing matrix are only accessible through neutrinoless double beta decay

# Scientific Case

- Nuclear physics
  - Common models differ by factors ~2 on rates for($\beta\beta0\nu$) Can we use this to discriminate among them?
  - Is $g_A$ quenched in nuclear matter or is the quenching seen in small basis shell model calculations an artifact of truncation?
  - Can new information about nuclear matter come from a study of ($\beta\beta0\nu$) matrix elements
- Complementary programs in Canada – SNO+

# Timeliness

- People have been searching for neutrinoless double beta decay for many decades (starting with Fireman's work in 1952)
- From SNO and other experiments we now know that neutrinos possess mass and that mixings are large
- There is reason for optimism that detection may not be too far away
- Technical progress made for low background experiments such as SNO are essential for the next generation of ton scale experiments
- Availability of deep, low background laboratory essential

# The EXO Program

- EXO (Enriched Xenon Observatory) has pioneered the use of liquid xenon detectors for the search for neutrinoless double beta decay
- EXO-200 is a 200 kg (about 100 kg fiducial) detector which has operated at the WIPP facility in New Mexico. It is a TPC giving full reconstruction of events with both light and charge readout to achieve a 1.4% ($\sigma$) energy resolution
- NEXO is a planned 5T liquid xenon detector planned for SNOLAB
- For many more details see talk by K. Graham

# Recent Accomplishments

- First observation of (ββνν) decay of $^{136}Ba$
- Most precise measure of any (ββνν) decay rate (by factor of 2)
- First experiment to challenge Klapdor-Kleingrothaus claim of observation of (ββ0ν)decay
- Among the most sensitive searches for this elusive decay

# The NEXO Project

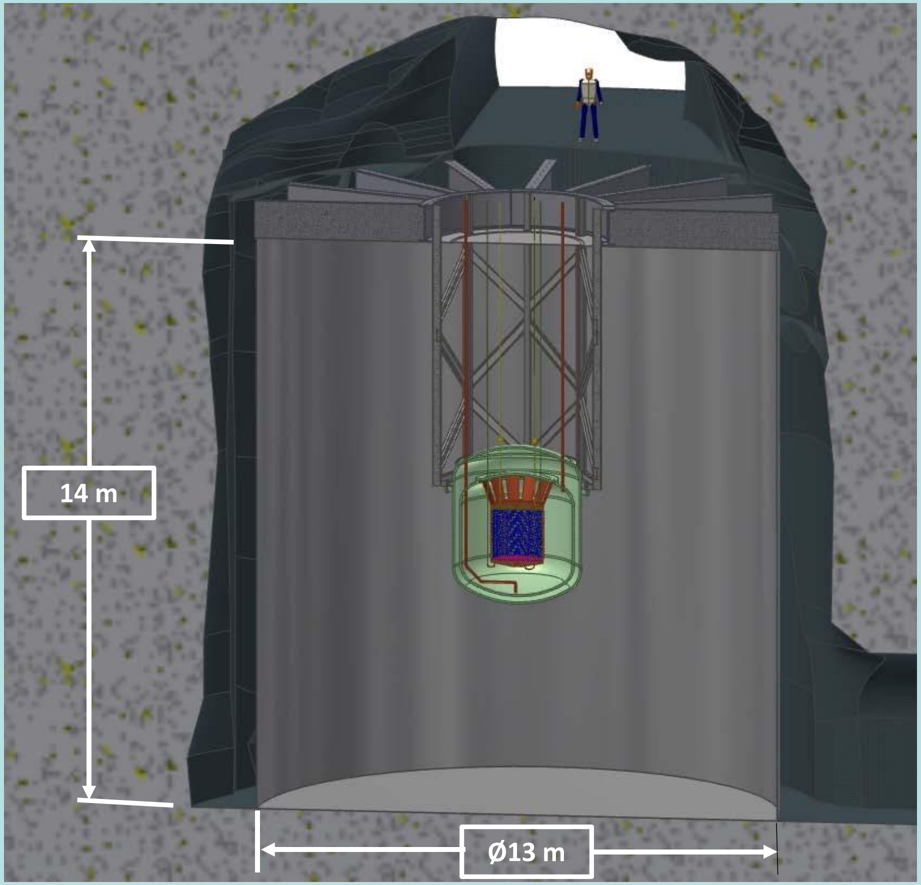
- We are close to the limits of the 200 kg EXO-200 detector
- Need a major increase in target mass to push to new limits
- Want to cover the ‘inverted mass hierarchy’
- Requires a detector of about 5 T xenon mass
- Use existing detector as a guide but make changes where scaling does not work so well

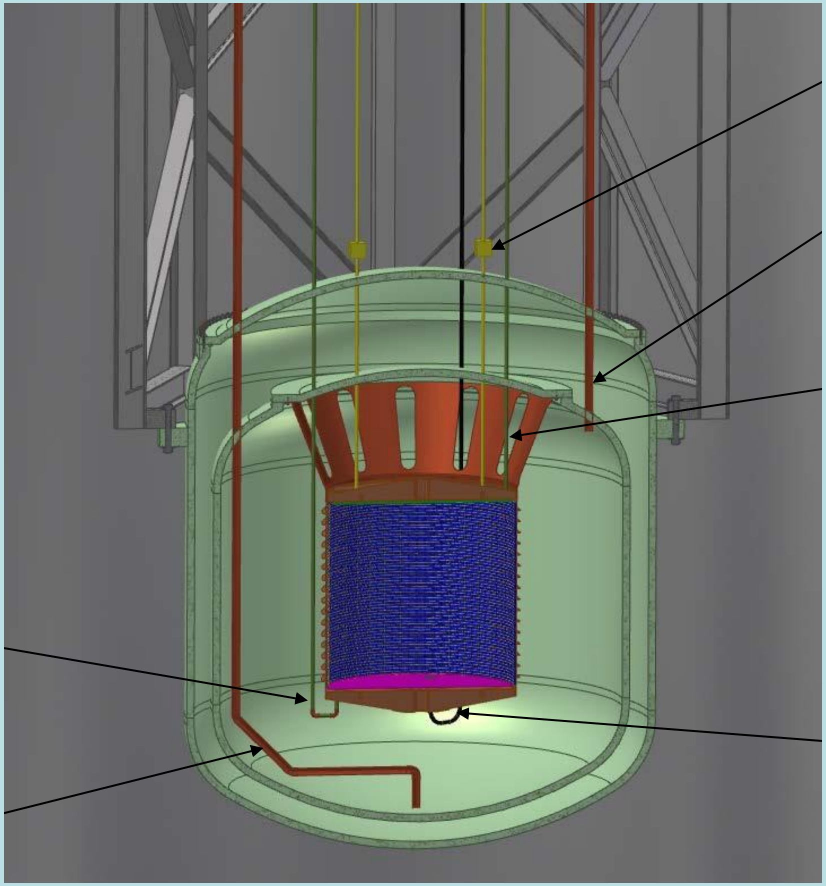
# nEXO Location

- WIPP is not suitable for a large detector
  - Insufficient depth to limit cosmogenic backgrounds
  - Cannot accommodate large water shields/vetos
  - Salt creep is a major problem
- Plan to move to SNOLAB

# nEXO Detector Concept

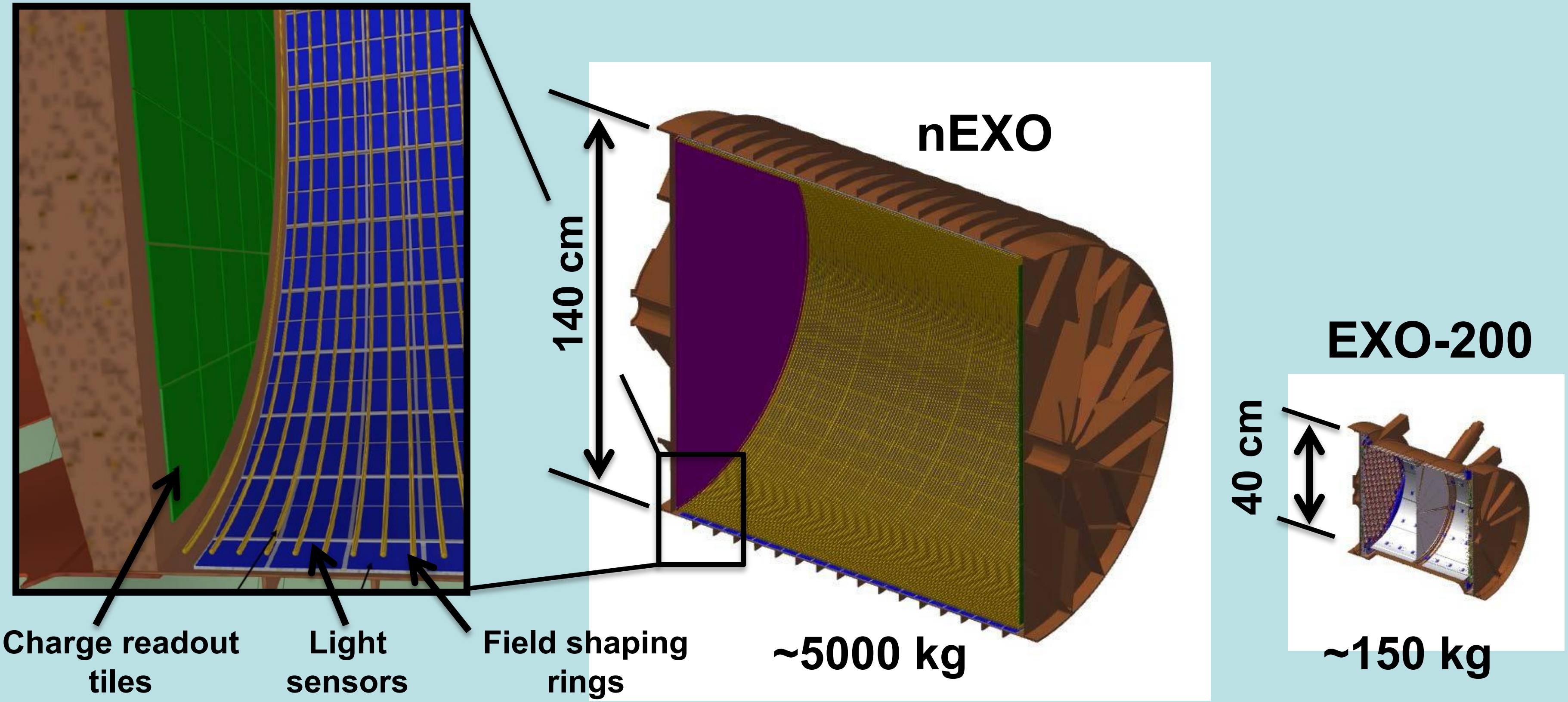
- follow success of EXO-200 with key detector improvements
    - reduced electronics noise
    - improved energy resolution (~1%) (improved light coverage)
    - finer charge readout granularity  (better multi-site ID)
    - increased self-shielding (very low backgrounds in central region)



# TPC concept

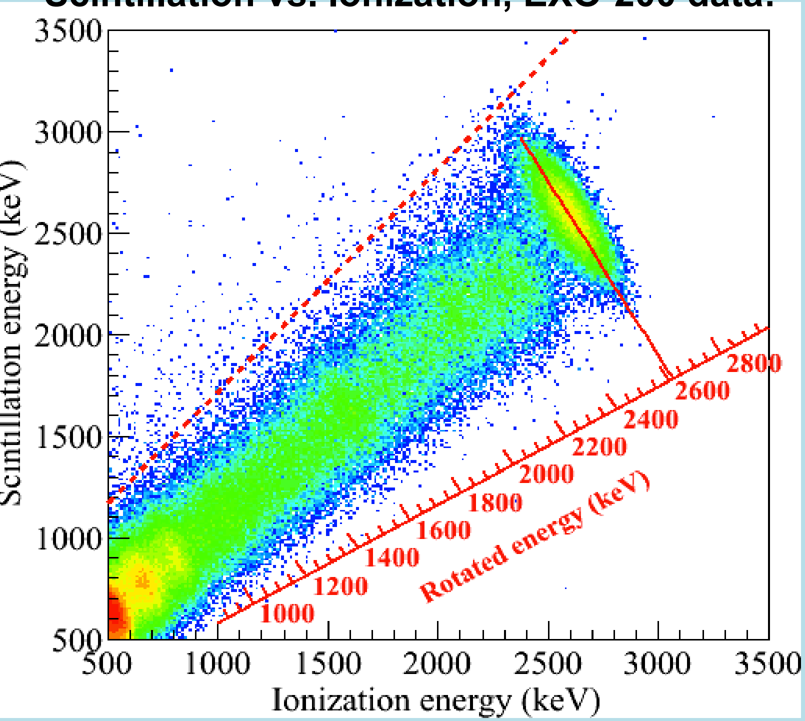
- maximize 'clean' volume with all components at edges…self-shielding
- proof-of-principle demonstrated with EXO-200
- large reduction in backgrounds at centre for nEXO…detailed measurement of background from outer portions



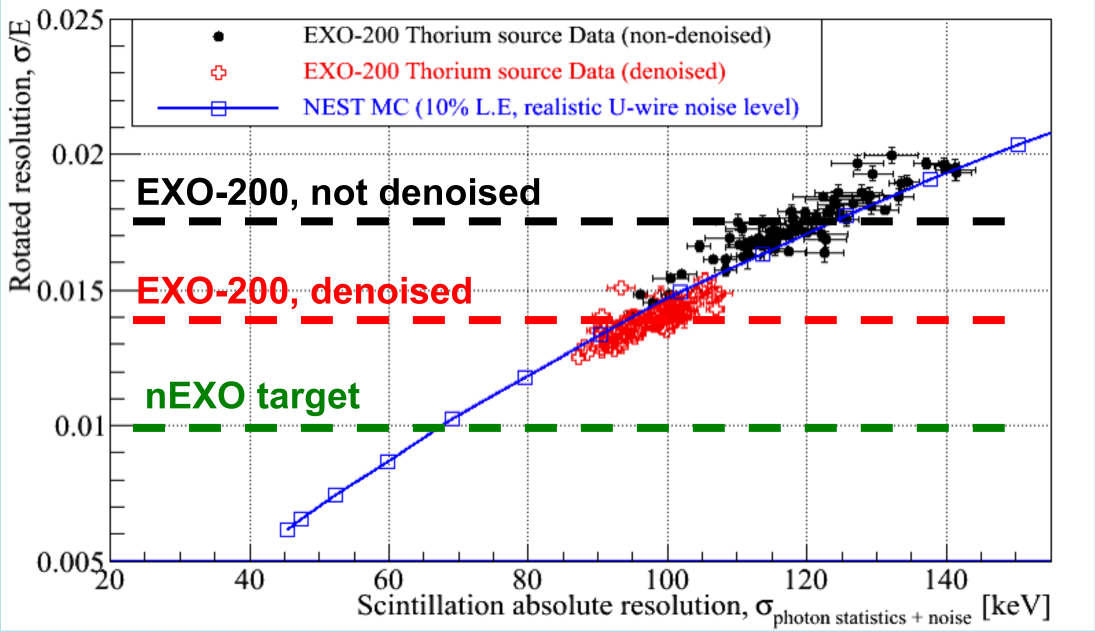
# Energy resolution

- Require $\sigma_E/E < 1\%$ at $Q_{\beta\beta}$, which requires measuring both charge and light with minimal readout noise
- Have demonstrated 1.4% resolution in EXO-200, simulations indicate that 1% resolution is attainable with improved readout electronics for light sensors
- Planned upgrades to EXO-200 electronics should also achieve 1% resolution

**Scintillation vs. Ionization, EXO-200 data:**




**Simulated rotated resolution vs. readout noise:**

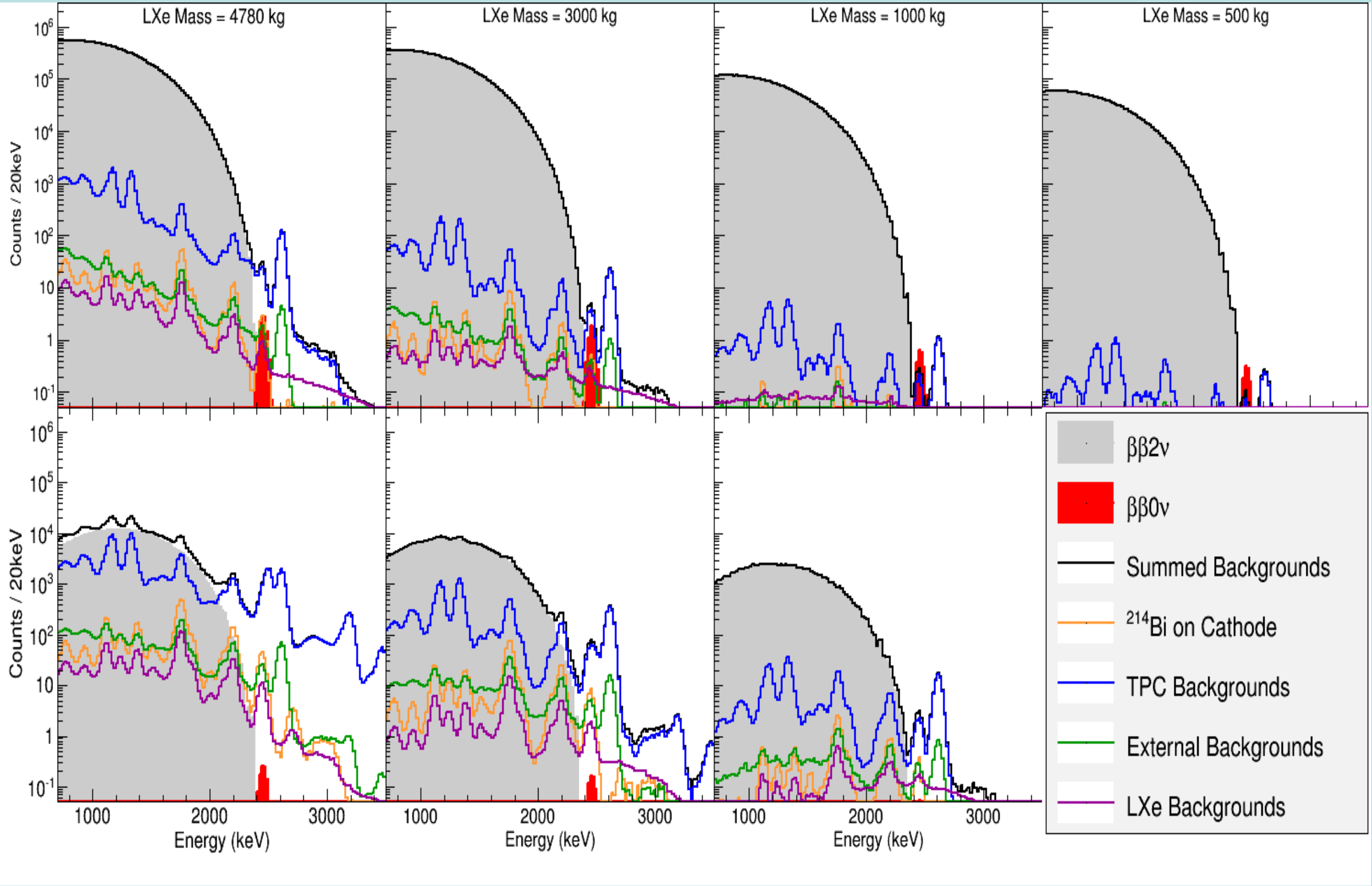


# nEXO MC Simulations

- extensive GEANT4 simulations are being carried out to optimize nEXO
- reject backgrounds with: 1) multiplicity 2) self-shielding 3) energy spectrum
- use a multi-dimensional fit to optimize information use

single-site

multi-site

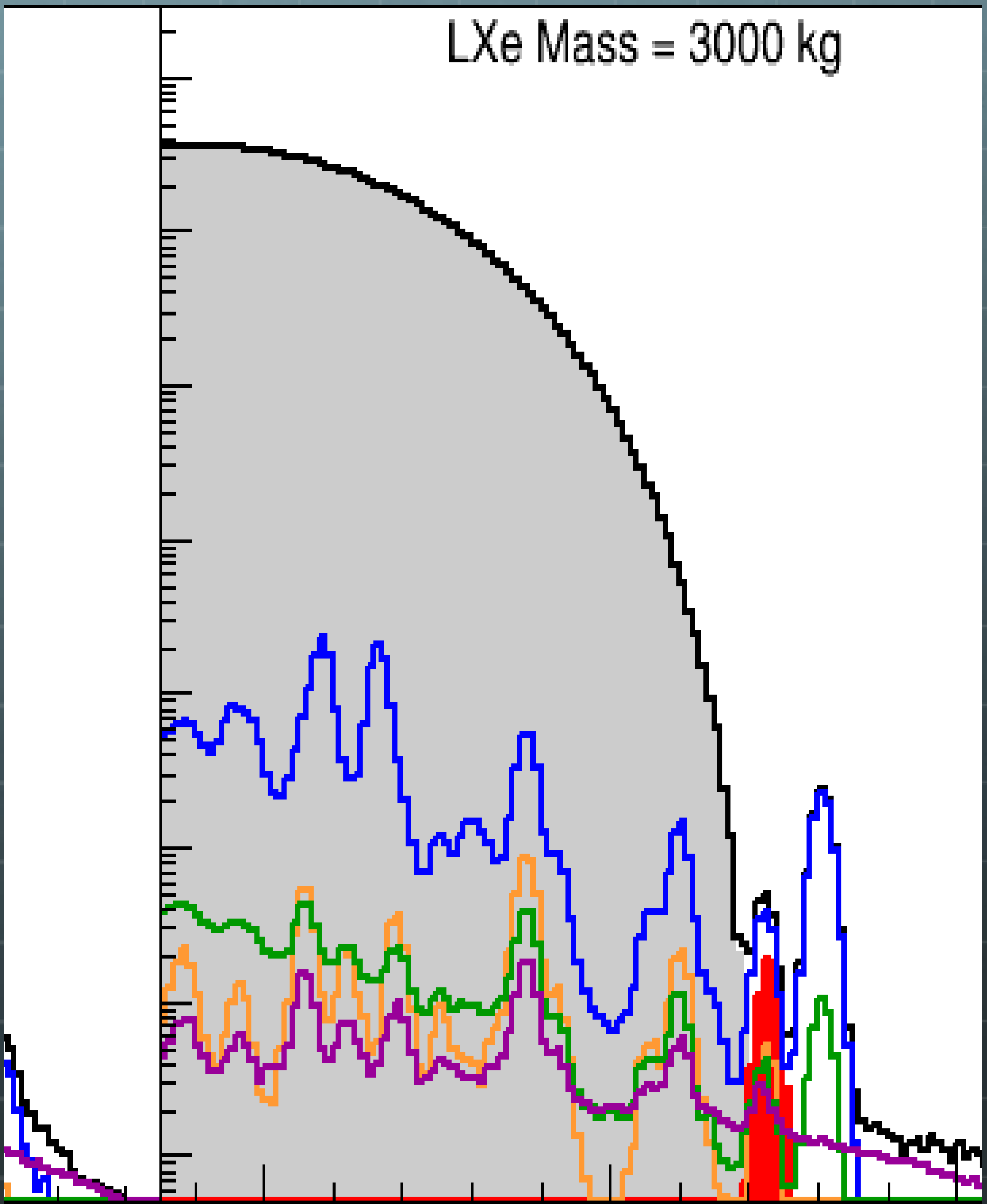



5 years exposure    0νββ counts corresponding to $T_{1/2}=6.6\cdot10^{27}$ yr

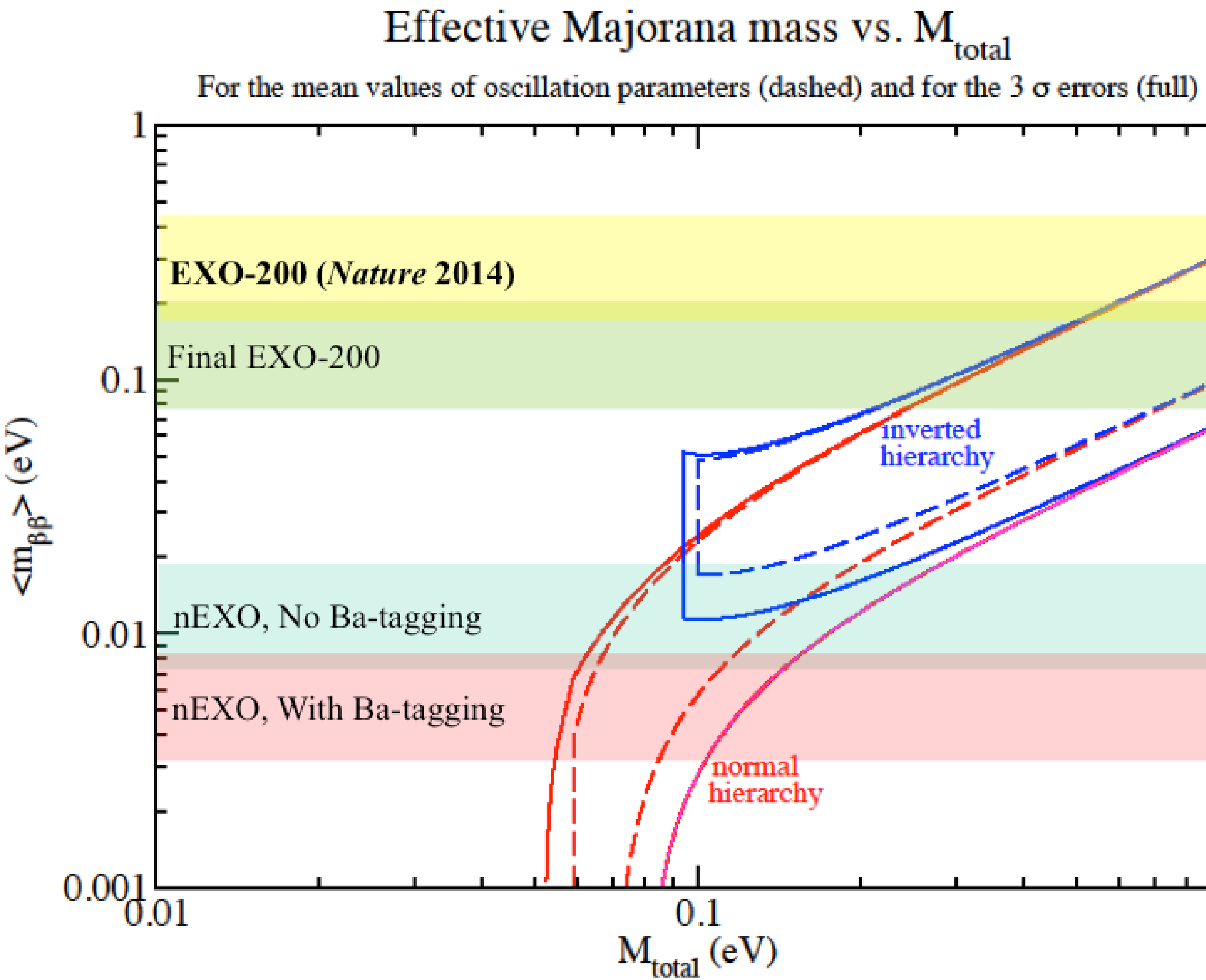
Single Site Spectrum
For inner 500 kg

Only works for a
Homogeneous,
Very pure material

e.g. TPC



# nEXO Sensitivity



# The nEXO Collaboration

- 25 Institutions in Canada, USA, Switzerland, Germany, China, South Korea and Russia

# The nEXO Collaboration

Enriched Xenon Observatory EXO for double beta decay

**University of Alabama, Tuscaloosa AL, USA** - T. Didberidze, M. Hughes, A. Piepke, R. Tsang
**University of Bern, Switzerland** - S. Delaquis, R. Gornea, T. Tolba, J-L. Vuilleumier
**Brookhaven National Laboratory, Upton NY, USA** – M. Chiu, G. De Geronimo, S. Li, V. Radeka, T. Rao, G. Smith, T. Tsang, B. Yu
**California Institute of Technology, Pasadena CA, USA** - P. Vogel
**Carleton University, Ottawa ON, Canada** - Y. Baribeau, V. Basque, M. Bowcock, M. Dunford, K. Graham, P. Gravelle, R. Killick, T. Koffas, C. Licciardi, E. Mane, K. McFarlane, R. Schnarr, D. Sinclair
**Colorado State University, Fort Collins CO, USA** - C. Chambers, A. Craycraft, W. Fairbank, Jr., T. Walton
**Drexel University, Philadelphia PA, USA** - M.J. Dolinski, J.K. Gaison, Y.H. Lin, E. Smith, Y.-R Yen
**Duke University, Durham NC, USA** - P.S. Barbeau, G. Swift
**University of Erlangen-Nuremberg, Erlangen Center for Astroparticle Physics, Erlangen, Germany** – G. Anton, J. Hoessl, T. Michel
**IHEP Beijing, People's Republic of China** - G. Cao, X. Jiang, H. Li, Z. Ning, X. Sun, N. Wang, W. Wei, L. Wen, W. Wu
**University of Illinois, Urbana-Champaign IL, USA** - D. Beck, M. Coon, S. Homiller, J. Ling, J. Walton, L. Yang
**Indiana University, Bloomington IN, USA** - J. Albert, S. Daugherty, T. Johnson, L.J. Kaufman, T. O'Conner, G. Visser
**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
**Lawrence Livermore National Laboratory, Livermore, CA, USA** – M. Heffner, A. House, S. Sangiorgio
**University of Massachusetts, Amherst MA, USA** - J. Dalmasson, S. Johnston, A. Pocar
**Oak Ridge National Laboratory, Oak Ridge TN, USA** – L. Fabris, R.J. Newby, K. Ziock
**IBS Center for Underground Physics, Daejeon, South Korea** - D.S. Leonard
**SLAC National Accelerator Laboratory, Menlo Park CA, USA** - T. Daniels, A. Odian, P.C. Rowson
**University of South Dakota, Vermillion SD, USA** – R. MacLellan
**Stanford University, Stanford CA, USA** - T. Brunner, J. Chaves, R. DeVoe, D. Fudenberg, G. Gratta, M. Jewell, S.Kravitz, D. Moore, I. Ostrovskiy, A. Schubert, K. Twelker, M. Weber
**Stony Brook University, SUNY, Stony Brook, NY, USA** – K. Kumar, O. Njoya, M. Tarka
**Technical University of Munich, Garching, Germany** - P. Fierlinger, M. Marino
**TRIUMF, Vancouver BC, Canada** – J. Dilling, P. Gumplinger, R. Krücken, F. Retière, V. Strickland

# Canadian Involvement

- Canada has been part of the EXO program since 2004
- Initially J. Farine (Laurentian) C. Hargrove and D. Sinclair(Carleton/TRIUMF) with engineers K. McFarlane and V. Strickland worked on design phase of EXO-200
- Soon joined by B. Cleveland and U. Wichoski (Laurentain) and K. Graham (Carleton)
- Contributions included calibration systems, radon control, process system design concepts, veto system mechanical construction, trace assays….
- Responsibilities also included maintaining the gas option

# Canadian Involvement in Exploitation

- Shift taking at WIPP, Control centers established at both Carleton and Laurentian
- K. Graham is first analysis coordinator
- Continued engineering support for enhancements
- Participation in many analysis areas
  - Very nice paper on ion properties in xenon just submitted, led by Brian Mong (Laurentian) (arXiv 1506.00317)
- Jacques Farine is elected Collaboration Board Chair

# Canadian participation in nEXO

- Collaboration is growing!
  - T. Koffas has joined working mainly on barium tagging
  - TRIUMF (Vancouver) joins (J. Dilling, P. Gumplinger, R. Krücken, F. Retière, V. Strickland
  - New Hire at Carleton (joint with Triumf) (Razvan Gornea) and CRC-1 expected
  - New hire at McGill (joint with Triumf) (Thomas Brunner)
- We now comprise about 30% of the collaboration

# Canadian Responsibilities

- F. Retière is the Manager, Photosensor group, Also member of nEXO executive
- K. Graham is manager of simulation group
- J. Farine has radon assay and abatement responsibilities
- D. Sinclair is Collaboration Board Chair and member of project executive
- Barium tagging continues as a focus of our activity

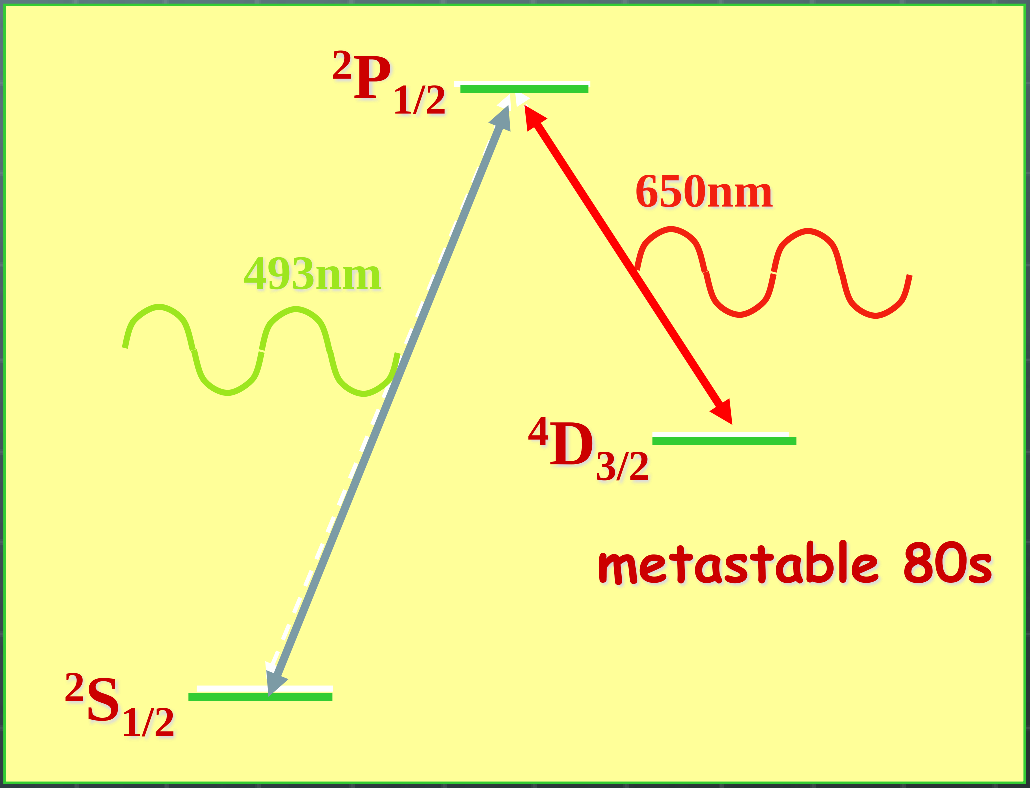
# Photo-detector Development

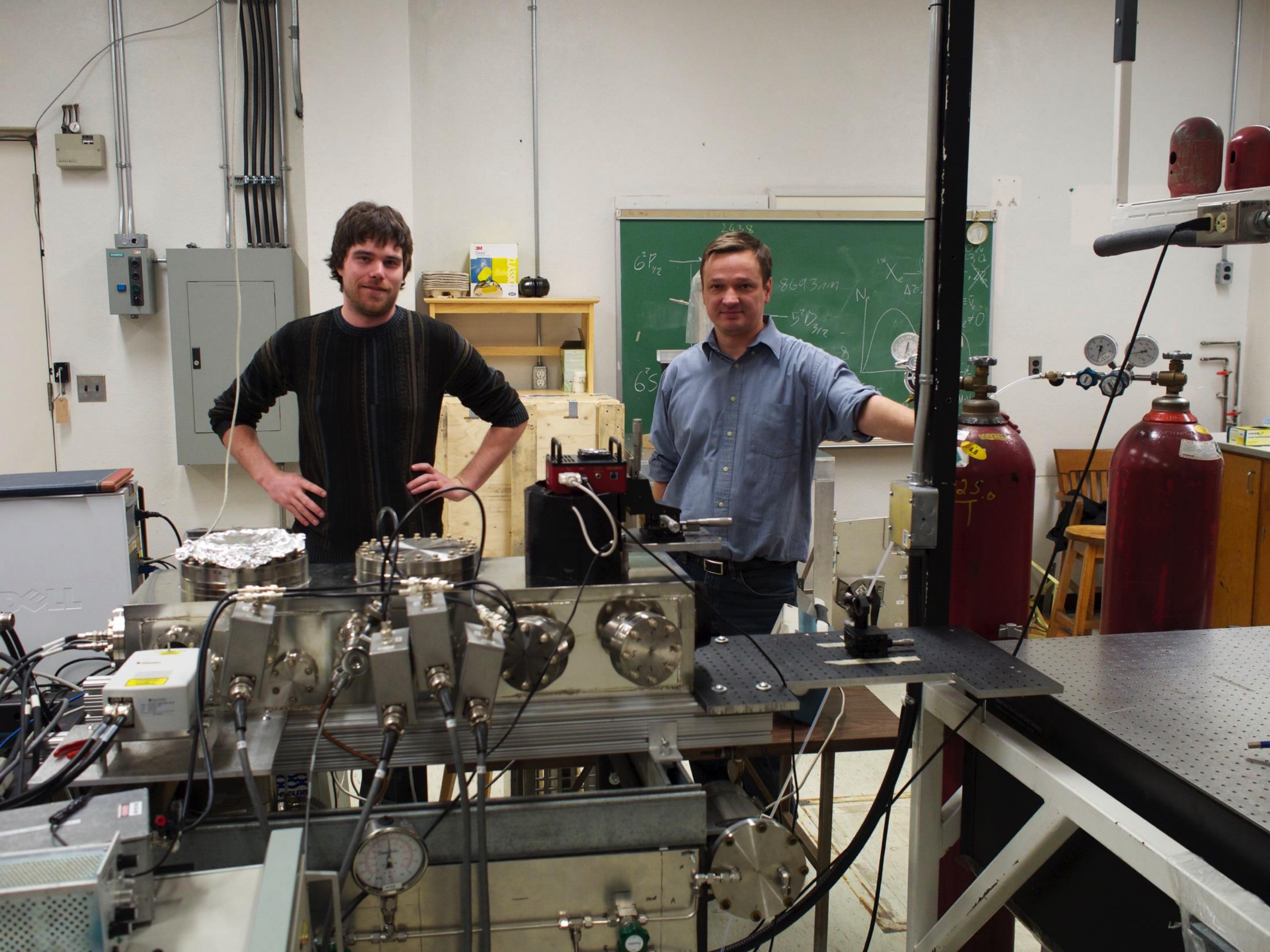
- Pushing new technological development for large area SiPM systems
- 3D integration
- Triumf – U. Sherbroke collaboration
- Likely to lead to other applications

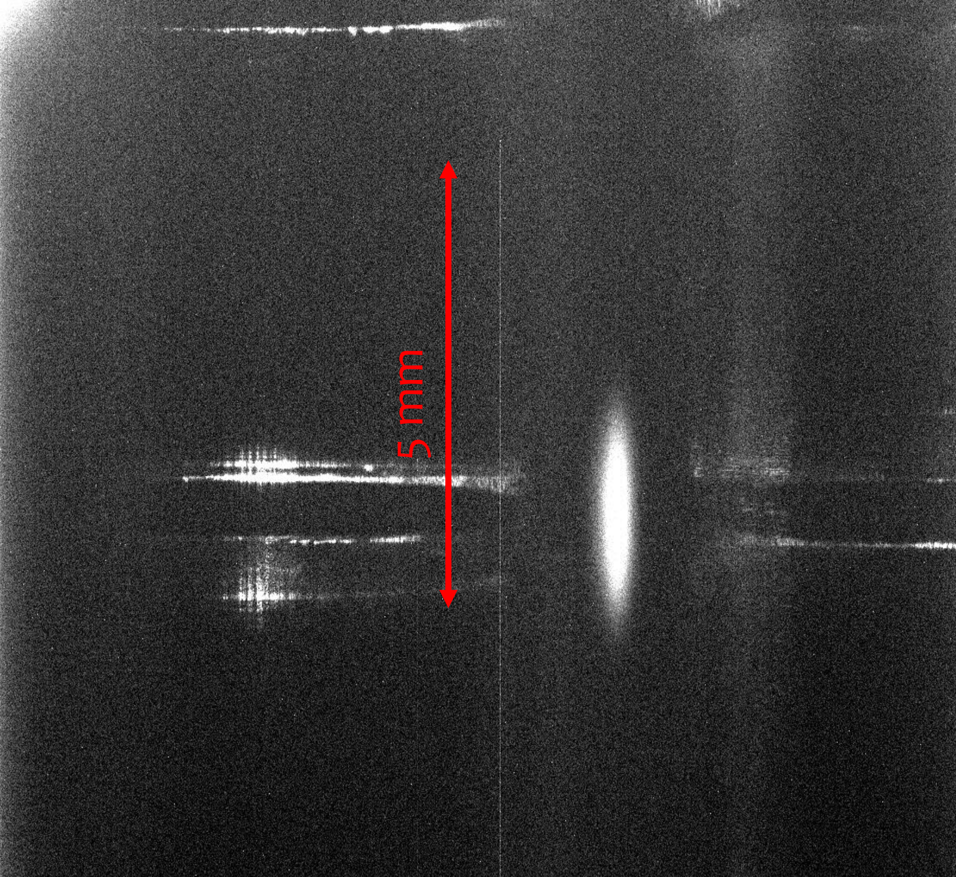
# Barium tagging

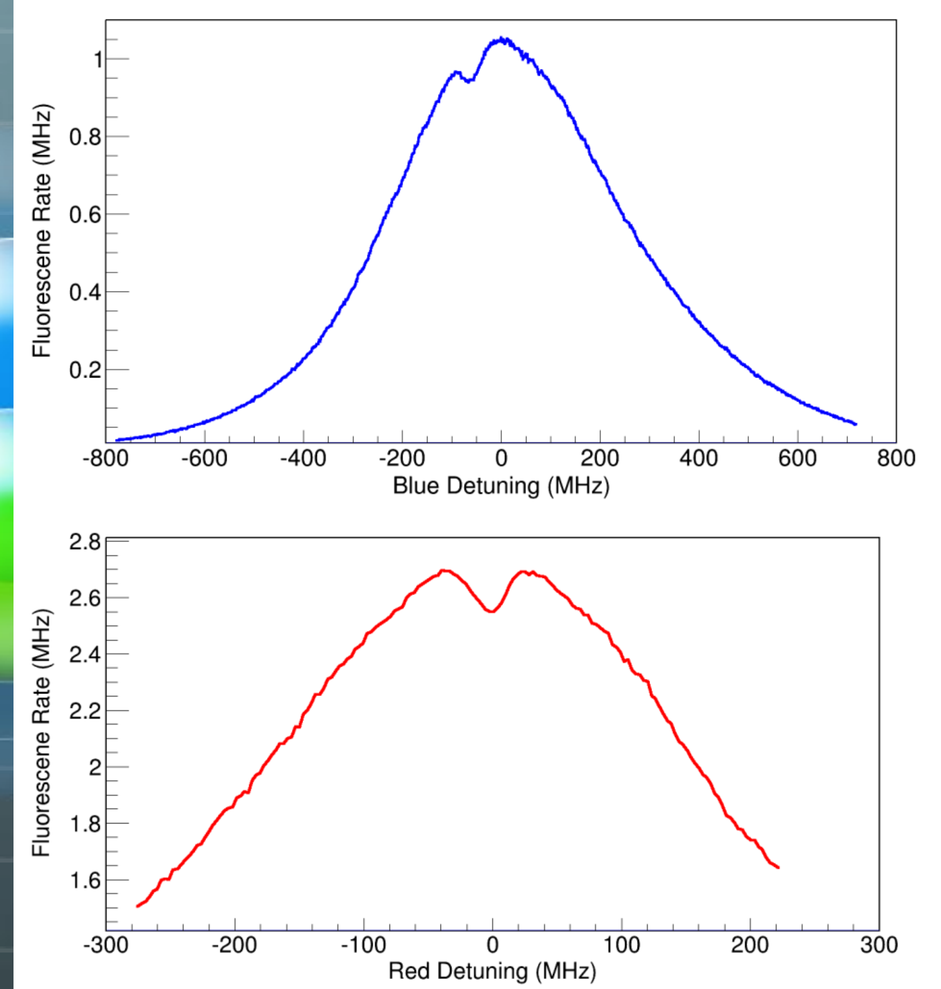
Requires Ba+ ion

Double beta decay produces Ba++








Trapping potential defined by the two 5mm segments at -10V

Laser wavelength scans of blue and red light

# Project Timescale

- Schedule is largely driven by US decision making.
  - McKeown committee has recommended that double beta decay be a high priority for US funding.
  - McKeown committee is now looking at research needs to support a downselect
  - Based on this report, DOE/NSF will issue call for proposals for R&D
  - NSAC review of all priorities for NP underway
  - Downselect expected ~2017
- After this (assuming selection) the project will follow the DOE CDn process.
- The US collaboration has also been growing and now includes 4 National Labs.
- Strict project management will come from National Labs (currently LLNL and SLAC coordinate this)
- Construction could start in 2018

# Canadian Lab Support

- Triumf plays a major role through participation of its scientific team
- Likely to be calls on Triumf engineering team for specialized support (to be supported through the capital award)
- Expect expanded scientific participation by SNOLAB scientists
- Expect increasing engineering support from SNOLAB as host laboratory, subject to passing relevant ‘gates’

# NSERC Support

- We currently receive $530k/a for operations support from NSERC
- This must grow to reflect and support
  - The new faculty joining the project
  - The increased FTE involvement of the Triumf scientists
  - The increased SNOLAB scientific activity
- Scaling with FTE would bring this up to ~$1.2M/a
- The awards will allow student and Postdoc participation in EXO-200 operation and analysis, R&D required for final nEXO design, development of the detector

# Capital Support

- The nEXO design has not yet been costed but we can make estimates. LZ is a similar sized xenon detector and has a total cost of ~$70M. Similar level of US national lab involvement
- nEXO will also need enriched xenon. Cost from previous orders is about $50M
- Canada should be looking to contribute ~30% of cost.
- A substantial portion can be the use of the Cryopit

# Capital costs

- We would seek a Canadian contribution of perhaps $10-20M from CFI and Ontario, possibly through the 'exceptional opportunities' program
- The sum might be on the high side for the size of collaboration but it is perhaps unique in leveraging foreign contributions of order $100M in a Canadian based project.