NEXO and the Long Range Plan

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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
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% (σ) 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 \((\beta\beta nn)\) decay of \(^{136}\text{Ba}\)
- Most precise measure of any \((\beta\beta nn)\) decay rate (by factor of 2)
- First experiment to challenge Klapdor-Kleingrothaus claim of observation of \((\beta\beta 0\nu)\) 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

Charge readout tiles
Light sensors
Field shaping rings

~150 kg
~5000 kg
Energy resolution

- Require $\sigma_E/E < 1\%$ at $Q_{BB}$, 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

5 years exposure   \(0\nu\beta\beta\) counts corresponding to \(T_{1/2} = 6.6 \cdot 10^{27}\) yr
Single Site Spectrum
For inner 500 kg

Only works for a Homogeneous, Very pure material

e.g. TPC
nEXO Sensitivity

Effective Majorana mass vs. $M_{\text{total}}$

For the mean values of oscillation parameters (dashed) and for the $3 \sigma$ errors (full)

- EXO-200 (Nature 2014)
- Final EXO-200
- nEXO, No Ba-tagging
- nEXO, With Ba-tagging

$\langle m_{\beta\beta}\rangle$ (eV)

$M_{\text{total}}$ (eV)
The nEXO Collaboration

25 Institutions in Canada, USA, Switzerland, Germany, China, South Korea and Russia
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. Sherbrooke 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
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’
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
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
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.