Update on EXO-200 and nEXO

Thomas Brunner
IPP AGM
June 7, 2019
Searching for $0\nu\beta\beta$ in $^{136}\text{Xe}$ with EXO

EXO-200:
- EXO-200 first 100-kg class $\beta\beta$ experiment
- 200kg liquid-Xe TPC with ~80% Xe-136
- Located at the WIPP mine in NM, USA
- Decommissioned in Dec. 2018
- Analyze data from end-of-run calibration campaign → data will inform the detailed design of nEXO

nEXO:
- future 5-ton liquid Xe TPC
- Enriched in Xe-136 at ~90%
- SNOLAB cryopit preferred location by collaboration
- Design of nEXO well advanced

6/7/2019
Thomas Brunner

EXO-200 CAP talk
W1-11 Caio Licciardi

nEXO CAP talks
M1-8 Yang Lan
M1-8 Soud Al Kharusi
W1-7 J-F Pratte
W1-7 Austin de St. Croix
W1-11 Jacques Farine
W1-11 Fatemeh Edalatfar
W1-11 Giacomo Gallina
R2-5 Thomas McElroy
Canadian contribution to EXO-200

• Service work by students at Canadian institutions: Lucas Darroch (McGill) is responsible for Xe purity and data base and Yang Lan (TRIUMF) is responsibility for data quality.
• Analysis coordinator for the past years has been Caio Licciardi (Laurentian).
• Jacques Farine (Laurentian) has been and continues to chair the EXO-200 collaboration board.
• Thomas Brunner (McGill) has been one of the run coordinators responsible for the daily operation of EXO-200 part of the EXO-200 management team.
• HQP training with EXO-200 at Carleton, Laurentian, McGill and TRIUMF
Decommissioning of EXO-200 in December 2018 at WIPP with Canadian contribution.
Latest EXO-200 Results

No statistical significant signal observed

Phase I+II: 234.1 kg⋅yr $^{136}$Xe exposure
Limit $T_{1/2}^{0νββ} > 3.5 \times 10^{25}$ yr (90% C.L.)
$\langle m_{ββ} \rangle < (93 – 286)$ meV
Sensitivity $5.0 \times 10^{25}$ yr
EXO-200 publications to date (since 2018)

• J.B. Albert et al. "Search for 0νββ Decay with the Upgraded EXO-200 Detector" PRL 120 (2018) 072701
• D.S. Leonard et al. "Trace radioactive impurities in final construction materials for EXO-200" NIMA 871 (2017) 169
• J.B. Albert et al. "Searches for Double Beta Decay of 134Xe with EXO-200” PRD 96 (2017) 092001
• J.B. Albert et al. "Measurement of the Drift Velocity and Transverse Diffusion of Electrons in Liquid Xenon with the EXO-200 Detector" PRC 95 (2017) 025502
• J.B. Albert et al. "First Search for Lorentz and CPT Violation in ββ Decay with EXO-200” PRD 93 (2016) 072001
• J.B. Albert et al. "Search for 2νββ decay of 136Xe to the 0_1^+ excited state of 136Ba with EXO-200” PRC 93 (2016) 035501
• J.B. Albert et al. "Investigation of radioactivity-induced backgrounds in EXO-200” PRC 92 (2015) 015503
• J.B. Albert, et al. "Search for Majorana neutrinos with the first two years of EXO-200 data” Nature 510 (2014) 229
• J.B. Albert, et al. "An improved measurement of the 2νββ half-life of 136Xe with EXO-200” PRC 89 (2014) 015502
• A. Dobi, et al. "Xenon purity analysis for EXO-200 via mass spectrometry” NIM A 675 (2012) 40
• N. Ackerman, et al. "Observation of Two-Neutrino ββ Decay in Xe-136 with EXO-200” PRL 107 (2011) 212501
Status of nEXO

nEXO design is well advanced!

**Milestone 2018:**
nEXO baseline described in a pre-Conceptual Design Report
arxiv:1805.11142v2
Milestone II: Projected nEXO Sensitivity


Projected sensitivity based on actual background level measurements!

- $g_A = g_{A}^{\text{free}} = -1.2723$
- Band is the envelope of NME:
  - QRPA: F. Šimkovic et al., PRC 87 045501 (2013)
  - SkyrmeQRPA: M.T. Mustonen and J. Engel PRC 87 064302 (2013)
nEXO publications (since 2018)

Characterization of the Hamamatsu VUV4 MPPCs for nEXO (paper led by G. Gallina and TRIUMF group)
Accepted for publication in NIM (2019) (nEXO collaboration)

Study of Silicon Photomultiplier Performance in External Electric Fields

VUV-sensitive Silicon Photomultipliers for Xenon Scintillation Light Detection in nEXO

nEXO Pre-Conceptual Design Report
arXiv:1805.11142v2 (nEXO Collaboration)

Characterization of an Ionization Readout Tile for nEXO

Sensitivity and Discovery Potential of nEXO to Neutrinoless Double Beta Decay

Imaging individual Ba atoms in solid xenon for barium tagging in nEXO
R&D beyond nEXO baseline

3D digital SiPM technology: SPAD array layer
- Top tier: 150 mm wafer (custom process using DALSA CCD production line)
- 1x1 to 5x5 mm² SPAD array
- 50-100 um diameter front-side illuminated shallow P+N type SPAD (~0.4 um depth)
- 4 um width / 22 um depth optical/electrical isolation trench (highly doped polysilicon filling)
- 2D process for SPAD development

Validate light-transport simulations for nEXO
Measure Cherenkov light in LXe
Application for medical imaging (10-ps PET)

Hear more today (June 7) at PPD Meeting on Detectors for Astroparticle Physics
News from south of the border

Tonne-scale double-beta decay has CD-0 with US DoE
(Formally as of Nov 2, 2018)

This “Mission Need” statement does not mean nEXO is the project, nor does it mean that the money for the project has been identified.

Yet, this is a substantial step forward.

To a large extent, this means that, at this point, DoE Office of Nuclear Physics is invested in the enterprise.

Neutrinoless double beta decay experiment is a line item in the US DoE Congressional Budget Request FY2020.
CFI Innovation Fund round 10 proposal

• The nEXO team has been preparing a trans-Canadian, multi-institutional proposal requesting time-critical components for nEXO (Lead institution: McGill) in the upcoming CFI round.

• The goal for Canada is to provide key components to the nEXO experiment, based on present expertise:
  • The Outer Detector (water tank and muon veto) with Top Deck/Platform.
  • Water purification and assay system for the water shield and muon veto.
  • Infrastructure for SiPM tile testing at TRIUMF and stave testing at SNOLAB.
  • SiPM technology development (3DdSiPM development).
  • Cryogenic components for Xe recirculation and purification system.
  • Contribution to acquisition of enriched Xe.

• We are requesting CFI IF support for nEXO-specific components. Additional support from SNOLAB is provided through the CFI MSI program (layout planning, project management, engineering).

• We passed Gate 0 of the TRIUMF and SNOLAB Gate review process → additional reviews prior to CFI NOI and proposal submission according to TRIUMF and SNOLAB project life cycle.
Interface between nEXO and SNOLAB

• Several meetings between nEXO and SNOLAB:
  • SNOLAB (R.F) participated in CFI kick-off meeting at McGill May 2018.
  • Meeting of nEXO Canada members at SNOLAB in August 2018.
  • Meeting of nEXO project management with SNOLAB October 2018.
  • Outer Detector mini workshop at McGill with participation from SNOLAB engineering team and nEXO Level 2 managers and nEXO project team in February 2019.

• Active and productive communication between nEXO and SNOLAB:
  • Mehwish Obaid is point of contact at SNOLAB.
  • Mehwish Obaid is now invited the nEXO Level 2 managers group meeting.

Currently, SNOLAB's engineering office dedicates roughly 20 hrs/week for the items mentioned in the previous slide.

SNOLAB is also providing project management support.
News from the Canadian Team

• The Canadian EXO co-leadership was recently elected:
  Jacques Farine (Laurentian University) and
  Thomas Brunner (McGill University).

• Dr. Daryl Haggard (McGill) is collaborating with the team on astro-particle physics searches with the Outer Detector.

• Dr. Ania Kwiatkowski (TRIUMF) is collaborating on Ba-tagging developments.

• Current senior members of the Canadian Team (FTE):

<table>
<thead>
<tr>
<th>Carleton</th>
<th>Laurentian</th>
<th>McGill</th>
<th>Sherbrooke</th>
<th>TRIUMF/UBC</th>
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<tr>
<td>Razvan Gornea</td>
<td>Erica Caden</td>
<td>Thomas Brunner</td>
<td>Serge Charlebois</td>
<td>Jens Dilling</td>
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<td>(0.3)</td>
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<td>(0.6)</td>
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<td>Thomas Koffas</td>
<td>Bruce Cleveland</td>
<td>Daryl Haggard*</td>
<td>Rejean Fontaine</td>
<td>Reiner Kruecken</td>
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<td>(0.2)</td>
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<td>Jean Francois Pratte</td>
<td>Fabrice Retiere</td>
<td>Ania Kwiatkowski*</td>
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<td>(0.3)</td>
<td>(0.9)</td>
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<td>David Sinclair*</td>
<td>Caio Licciardi</td>
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<td>Ubi Wichoski</td>
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* D.H. and A.K. are collaborating on specific developments but are not a member of the nEXO collaboration.
** D.S. is member of EXO-200 only.

The team thanks David Sinclair for his great leadership and support over the years!

TOTAL FTE 7.1
nEXO personnel in Canada

<table>
<thead>
<tr>
<th>Position</th>
<th>Total</th>
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<th>Visible Minorities</th>
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<tr>
<td>MSc student</td>
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<tr>
<td>UG student</td>
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<td>4</td>
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<td><strong>nEXO Canada total</strong></td>
<td><strong>64</strong></td>
<td><strong>12</strong></td>
<td><strong>12</strong></td>
</tr>
</tbody>
</table>

In the tradition of particle physics we include students at all levels in our research!
The nEXO collaboration at the last collaboration meeting, Jan 2019 Ft. Collins CO

- The nEXO collaboration consists of about 160 scientists from 33 institutions in 7 countries.
- Since last summer 2018 added:
  - Erica Caden (SNOLAB/Laurentian, ON, Canada)
  - Simon Viel (Carleton, ON, Canada)
  - Kyle Leach (Colorado School of Mines, CO, USA)
- In discussions with a number of other colleagues
  ➔ We are planning to grow further
Required computing resources in Canada

• Individual groups are running small jobs/batches on Compute Canada infrastructure.

• We foresee an increase in computational needs to allow us to run GEANT simulations in parallel to NERSC in the US.

• We greatly benefit from software through CMC.

• However, we do not have numbers on the required resources at this point.
Financial support of nEXO in Canada

nEXO R&D Supported by:
- SAP Project
- RTI
- Carleton MRS
- Universite de Montreal MRS