

Update on EXO-200 and nEXO

Thomas Brunner

IPP AGM

June 7, 2019



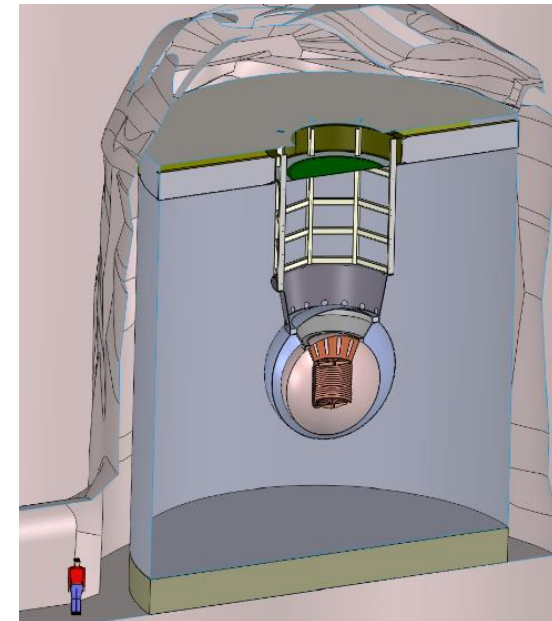
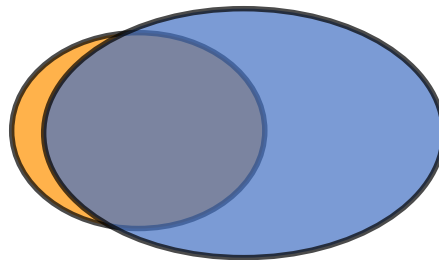
Searching for $0\nu\beta\beta$ in ^{136}Xe with EXO

EXO-200:

- EXO-200 first 100-kg class $\beta\beta$ experiment
- 200kg liquid-Xe TPC with $\sim 80\%$ 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 $\sim 90\%$
- SNOLAB cryopit preferred location by collaboration
- Design of nEXO well advanced



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

Canadian contribution to EXO-200 cont.



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

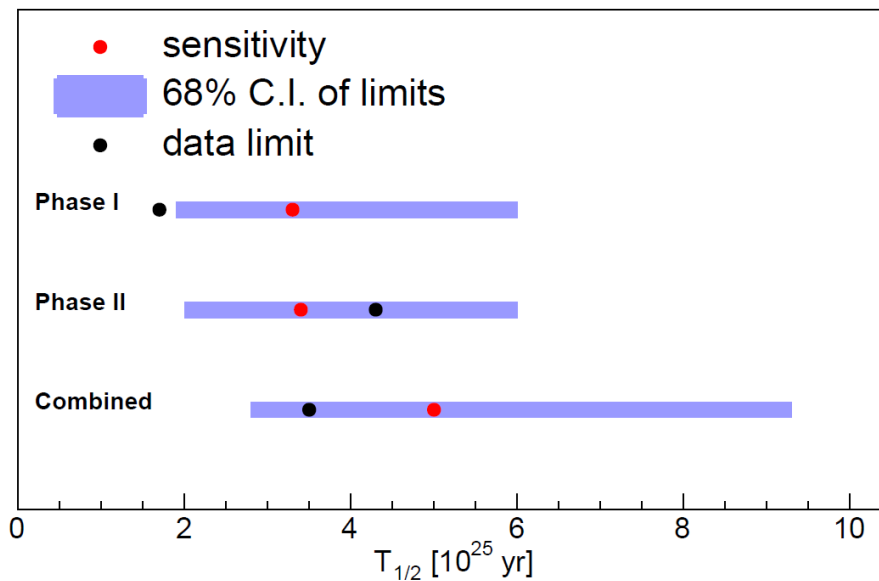
Limit $T_{1/2}^{0\nu\beta\beta} > 3.5 \times 10^{25}$ yr (90% C.L.)

$\langle m_{\beta\beta} \rangle < (93 - 286)$ meV

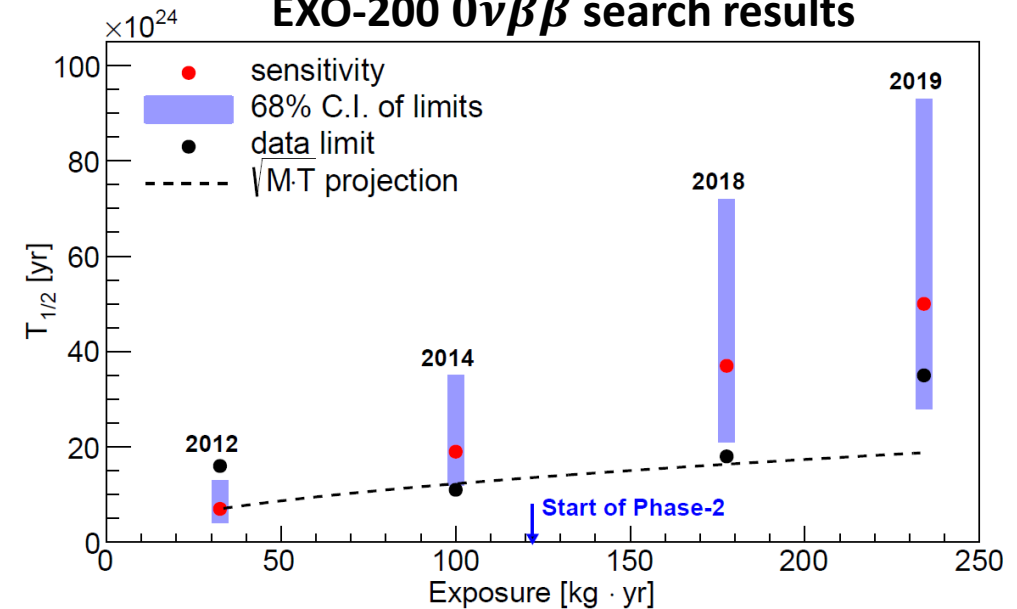
Sensitivity 5.0×10^{25} yr

Background contribution to $Q \pm 2\sigma$

(counts)	^{238}U	^{232}Th	^{137}Xe	Total	Data
Phase I	12.6	10.0	8.7	32.3 ± 2.3	39
Phase II	12.0	8.2	9.3	30.9 ± 2.4	26



EXO-200 $0\nu\beta\beta$ search results



2012: *Phys.Rev.Lett.* 109 (2012) 032505

2014: *Nature* 510 (2014) 229-234

2018: *Phys. Rev. Lett.* 120, 072701 (2018)

2019: *arXiv* 1906.02723

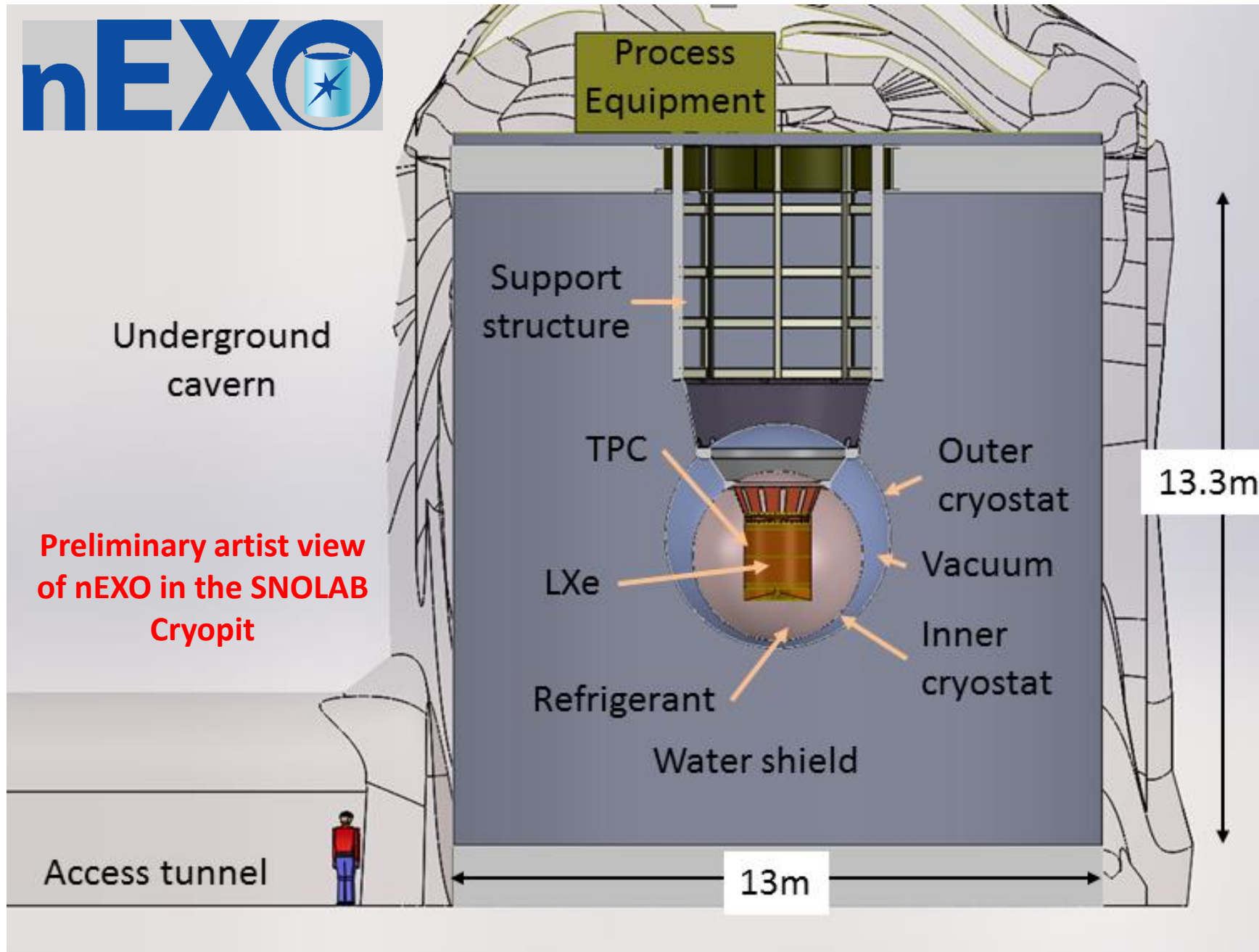
EXO-200 publications to date (since 2018)

- G. Anton et al. "Search for Neutrinoless Double-Beta Decay with the Complete EXO-200 Dataset" arXiv:1906.02723
- S. Delaquis et al. "Deep Neural Networks for Energy and Position Reconstruction in EXO-200" JINST 13 (2018) P08023
- J.B. Albert et al. "Search for nucleon decays with EXO-200" PRD 97 (2018) 072007
- J.B. Albert et al. "Search for $0\nu\beta\beta$ 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 ^{134}Xe 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
- C.G. Davis et al. "An Optimal Energy Estimator to Reduce Correlated Noise for the EXO-200 Light Readout" JINST 11 (2016) P07015
- J.B. Albert et al. "Cosmogenic Backgrounds to $0\nu\beta\beta$ in EXO-200" J. Cosmol. Astropart. Phys. 4 (2016) 029
- J.B. Albert et al. "First Search for Lorentz and CPT Violation in $\beta\beta$ Decay with EXO-200" PRD 93 (2016) 072001
- J.B. Albert et al. "Search for $2\nu\beta\beta$ decay of ^{136}Xe to the 0_1^+ excited state of ^{136}Ba with EXO-200" PRC 93 (2016) 035501
- J.B. Albert et al. "Measurements of the ion fraction and mobility of alpha and beta decay products in LXe using EXO-200" PRC 92 (2015) 045504.
- J.B. Albert et al. "Investigation of radioactivity-induced backgrounds in EXO-200" PRC 92 (2015) 015503
- J.B. Albert, et al. "Search for Majoron-emitting modes of $\beta\beta$ decay of ^{136}Xe with EXO-200" PRD 90 (2014) 092004
- 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 $2\nu\beta\beta$ half-life of ^{136}Xe with EXO-200" PRC 89 (2014) 015502
- M. Auger, et al. "Search for Neutrinoless $\beta\beta$ Decay in ^{136}Xe with EXO-200" PRL 109 (2012) 032505
- M. Auger, et al. "The EXO-200 detector, part I: Detector design and construction" J. Inst 7 (2012) P05010
- 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 $\beta\beta$ Decay in Xe-136 with EXO-200" PRL 107 (2011) 212501
- A. Dobi, et al. "A Xenon Gas Purity Monitor for EXO" NIM A 659 (2011) 215
- F. LePort, et al. "A magnetically-driven piston pump for ultra-clean applications" Rev. Sci. Inst. 82 (2011) 105114
- R. Neilson, et al. "Characterization of large area APDs for the EXO-200 detector" NIM A 608 (2009) 6875
- D. Leonard, et al. "Systematic study of trace radioactive impurities in candidate construction materials for EXO-200" Nucl. Ins. Meth. A 591 (2008) 490

Status of nEXO

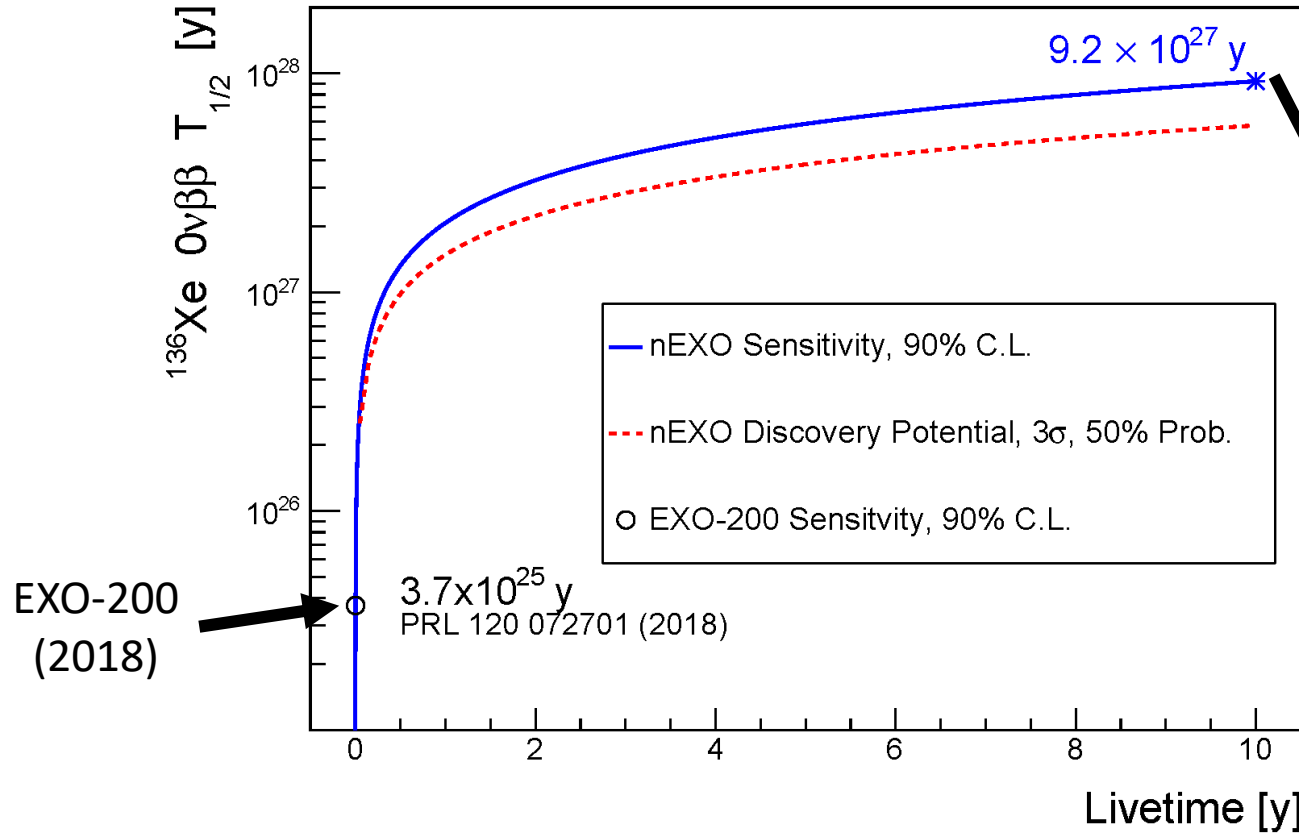
nEXO design is well advanced!

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

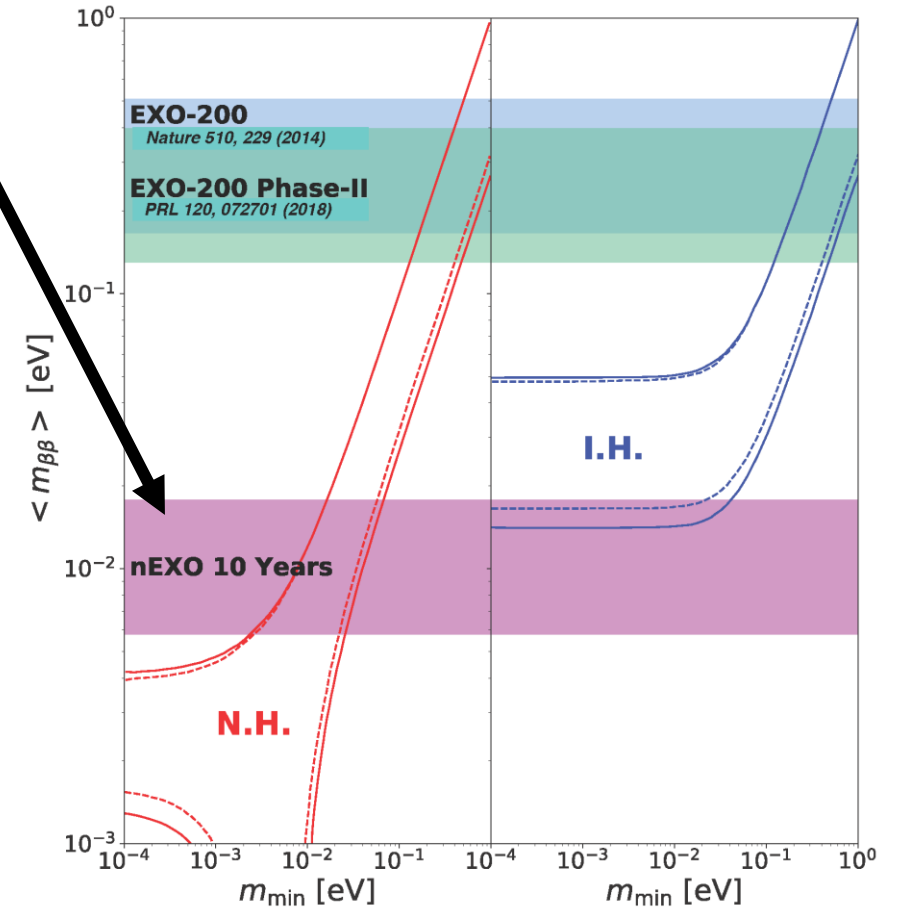


Milestone II: Projected nEXO Sensitivity

J.B. Albert et al. Phys. Rev. C. 97 065503 (June 2018)



Projected sensitivity based on actual background level measurements!



- $g_A = g_A^{\text{free}} = -1.2723$

- Band is the envelope of NME:

EDF: T.R. Rodríguez and G. Martínez-Pinedo, PRL 105, 252503 (2010)

ISM: J. Menendez et al., Nucl Phys A 818, 139 (2009)

IBM-2: J. Barea, J. Kotila, and F. Iachello, PRC 91, 034304 (2015)

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

JINST 13, T09006 (2018) (arXiv:1807.03007) (nEXO Collaboration)

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

IEEE Transactions on Nuclear Science 1 (2018) (arXiv:1806.02220)(nEXO Collaboration)

nEXO Pre-Conceptual Design Report

arXiv:1805.11142v2 (nEXO Collaboration)

Characterization of an Ionization Readout Tile for nEXO

JINST 13, P01006 (2018) (arXiv: arXiv:1710.05109v1)(nEXO Collaboration)

Sensitivity and Discovery Potential of nEXO to Neutrinoless Double Beta Decay

Physical Review C 97, 065503 (2018) (arXiv: arXiv:1710.05075v1)(nEXO Collaboration)

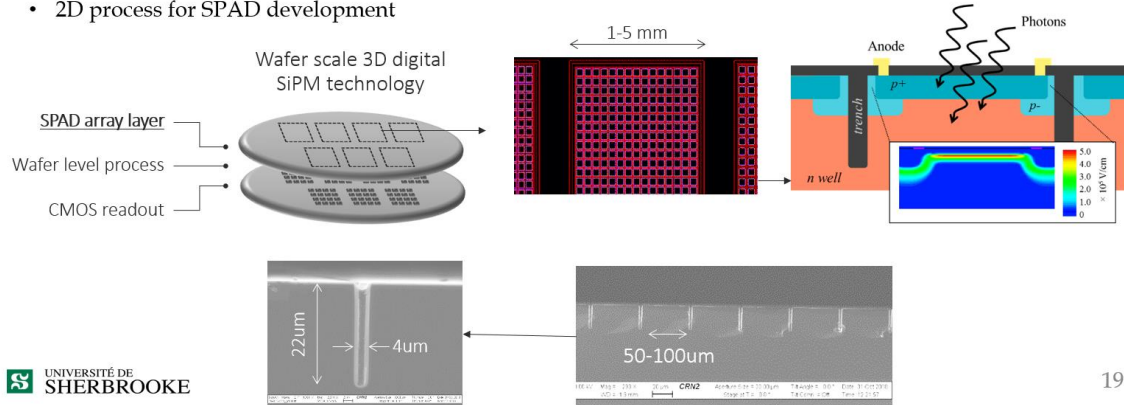
Imaging individual Ba atoms in solid xenon for barium tagging in nEXO

Nature 569, 203 (2019) (arXiv:1806.10694)(nEXO Collaboration)

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



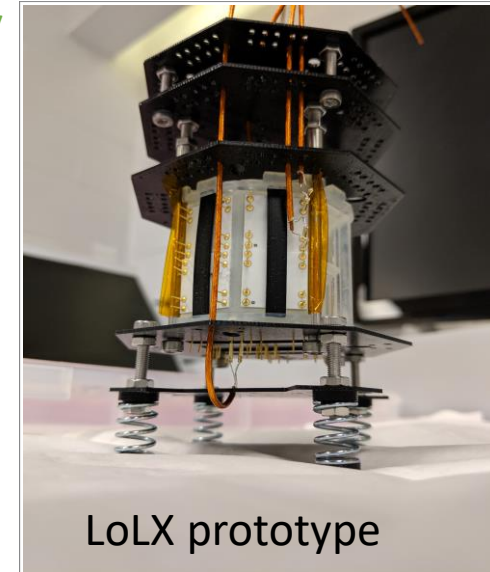
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W1-7 J-F Pratte



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

R2-5 Thomas McElroy



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

- 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):

Carleton	Laurentian	McGill	Sherbrooke	TRIUMF/UBC
Razvan Gornea (0.7)	Erica Caden (0.3)	Thomas Brunner (0.9)	Serge Charlebois (0.6)	Jens Dilling (0.1)
Thomas Koffas (0.1)	Bruce Cleveland (0.2)	Daryl Haggard* (0.1)	Rejean Fontaine (0.1)	Reiner Kruecken (0.2)
Simon Viel (0.3)	Jacques Farine (0.9)		Jean Francois Pratte (0.9)	Fabrice Retiere (0.5)
David Sinclair**	Caio Licciardi (0.7)			Ania Kwiatkowski* (0.1)
	Ubi Wichoski (0.4)			
				TOTAL FTE 7.1

* 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.

nEXO personnel in Canada

Position	Total	Women	Visible Minorities
Faculty	17	3	1
Postdocs	8	2	2
PhD student	7	1	2
MSc student	14	2	3
UG student	19	4	4
nEXO Canada total	64	12	12

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

***Fonds de recherche
sur la nature
et les technologies***

Québec



Arthur B. McDonald
Canadian Astroparticle Physics Research Institute



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