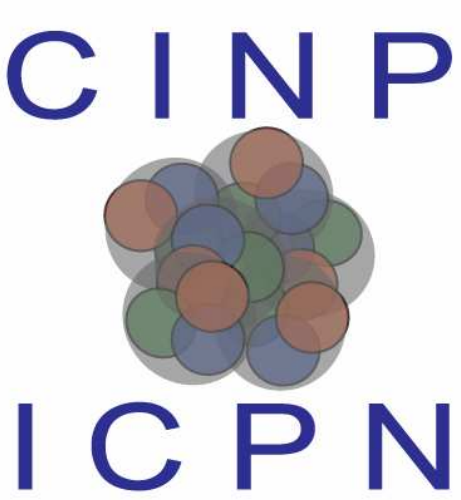


Canadian Institute of Nuclear Physics

Institut canadien de physique nucléaire

NSERC Subatomic Physics Context Session
December 12, 2022

What is the CINP?

- The CINP is a formal organization of the Canadian nuclear physics research community to promote excellence in nuclear research and education, and to advocate the interests and goals of the community both domestically and abroad
  - Federally incorporated under the Canada Not–for–profit Corporations Act
- Represents researchers covering all aspects of experimental and theoretical nuclear physics. Co–ordinates planning on a national scale and exchanges information within and between the various sub–fields of nuclear physics
- Leads initiatives to strengthen the level and quality of nuclear physics research in Canada, including fellowships, undergraduate research scholarships, student travel awards, and targeted conference support

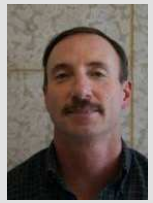
CINP Governance

Institutional Members
McGill University
Memorial University of Nfld
Mount Allison University
Saint Mary's University
Simon Fraser University
TRIUMF
University of Guelph
University of Manitoba
University of Northern B.C.
University of Regina
University of Winnipeg

Pay Annual Dues and Elect Board

Board of Directors
Gwen Grinyer *President*
Thomas Brunner
Michael Gericke
Rituparna Kanungo
Jeff Martin
Chris Ruiz

Executive Director
Garth Huber



Treasurer
Greg Hackman

Scientific Working Groups

SWGs facilitate collaboration among researchers with common interests, and to enhance the profile of a specific research area within Canada

- **Provide input to CINP external scientific briefs**
- **Hold topical workshops or other initiatives**
- **Encourage new collaborative efforts**

- **Individual Members may belong to one or more SWGs**
- **Nuclear Theory SWG was created in 2021 in follow up to Long Range Planning consultations**

SWG	Chair	Institution
Nuclear Structure	Adam Garnsworthy	TRIUMF
Nuclear Astrophysics	Iris Dillmann	TRIUMF
Fundamental Symmetries	Gerald Gwinner	University of Manitoba
Hadron Structure/QCD	Svetlana Barkanova	Memorial University of Newfoundland
Nuclear Theory	Alexandros Gezerlis	University of Guelph
Nuclear Physics Education and Training	Juliette Mammei	University of Manitoba

CINP Individual Membership

CINP Membership December 1, 2022	
Total Membership	171
Faculty (Full) Members	88
Associate Members (Grad Students, PDFs, Professor Emeriti)	83
Experimentalists	125
Theorists	45

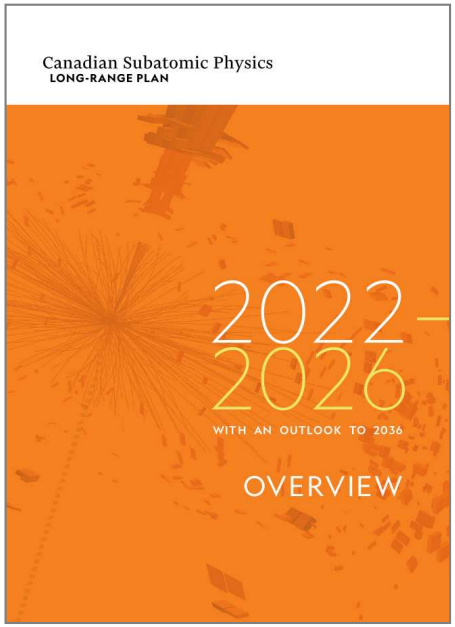
SWG Membership	
Nuclear Astrophysics	**70**
Nuclear Structure	**74**
Fundamental Symmetries	**77**
Hadrons/QCD	**57**
Nuclear Theory	**31**
Nuclear Physics Education & Training	**54**

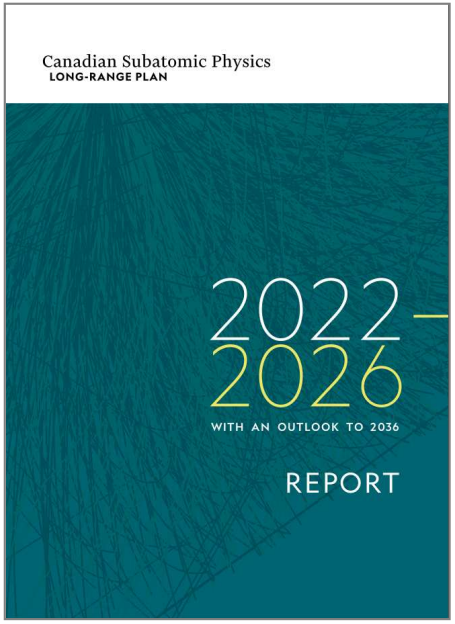
CINP 2022 Accomplishments

- **Nuclear Physics Representation**
  - **The CINP has been vital in giving the nuclear physics community a coherent and strong voice**
  - Suggests new members to SAPES, provides input to NSERC, CFI, ISED on matters of importance to NP
  - NP Community Representative at Advisory Committee on TRIUMF (ACOT), April and October annually
  - Periodic meetings with TRIUMF, IPP, MDI Directors
  - NP input to Pan–Canadian MRS Resource Planning Board ~6 meetings/yr
  - Formal observer to NuPECC (Nuclear Physics European Collaboration Committee)
    - Submitted “Canadian Nuclear Physics Research context document for NuPECC Long Range Plan” in October 2022

CINP role in 2022–26 Long Range Plan

- **CINP was one of three commissioning bodies** (with NSERC, IPP) **of Canadian Subatomic Physics Long Range Plan**
- CINP Exec Dir is an Ex–Officio member on LRPC, CINP leaders Rituparna Kanungo, Jeff Martin, Juliette Mammei voting members
- **CINP undertook broad consultation with the Canadian Nuclear Physics Research community**
- Produced a substantial White Paper: 187 pages that fed into the LRP. Available from cinp.ca





CINP Undergraduate Research Scholarships (URS)

- **Allows gifted undergraduates to work with supervisor on nuclear physics research for 16 weeks in summer**
- **A supervisor can nominate only their best student for the award. Process is competitive, with only top ~50% nominees selected.**
- **Award:**
  - $5k student stipend which must be matched by supervisor to at least $9k
  - $1300 travel supplement available if the supervisor intends to send the student to a laboratory or to work with a second collaborator for an extended period

– **CINP URS is complementary to NSERC USRA in several key aspects:**

1) Gifted international students studying in Canada are eligible to apply for the CINP URS, but not the NSERC USRA.
2) An important element of the URS is the optional Travel Award, which allows the supervisor to send student to a lab or work with second collaborator for an extended period. This can have a significant impact on the quality of the research experience for some undergrads. NSERC USRA has no such component.

CINP 2022 Undergraduate Research Scholarships

Student	Supervisor	Project Title
Minya Bai (McGill)	Thomas Brunner (McGill)	Characterization of an in–gas laser–ablation ion source for nEXO's Ba–tagging developments
Vincent Bruening (Mt Allison)	David Hornidge (Mt Allison)	Commissioning of the CATS large NaI detector
Quaid Hawkins (Guelph)	Khashayar Ghandi (Guelph)	Cherenkov radiation in a plasma
August Mendelson (Manitoba)	Russ Mammei (Winnipeg)	Nab silicon characterization with 30 keV protons
Dhruval Shah (Regina)	Gwen Grinyer (Regina)	Beta–delayed charged particle spectroscopy of Si–22,23
Abbygale Swadling (Calgary)	Timothy Friesen (Calgary)	Towards the first direct measurement of the Lamb shift in anti–hydrogen

2020 MRS grant renewal allowed CINP to increase URS program from 5 to 6 scholarships

Selection Committee: Juliette Mammei (Manitoba), Chris Ruiz (TRIUMF), Garth Huber (Regina)

CINP Graduate Fellowship (GF)

- **Intended to attract or retain very gifted Ph.D. candidates to conduct nuclear physics research in Canada**
- **Award:** $12,000 scholarship to PhD student of high merit
  - Awardee's supervisor or home institution must agree to supplement the GF from institutional or research funds to a value of not less than $32,000
  - During fellowship period, the awardee is eligible to access conference travel funds by application to CINP Junior Scientist Travel program
- **Criteria:** In addition to academic and scientific criteria, application has EDI component
  - applicants wrote 1 page description of what role a PhD student and CINP Graduate Fellow can plan in promoting and advancing EDI in our community
- **A new initiative, proposed in CINP's 2020 MRS grant application. Awarded funds allow 1 GF to be awarded**
- **CINP redirected funds saved from little COVID–19 Travel to enable 2 GF to be awarded for the next 3 years**
- 10 applications were received so competition was very tight. Based on quality of applicants, we could easily justify further doubling of #awards

CINP 2022 Graduate Fellowships

- **Fatemeh Gorgannejad (Manitoba)**
  - She has been designing, developing, constructing, and commissioning the pion detector system for the MOLLER experiment funded by CFI and NSERC. The pion detector system gives access to the physics of pion production
  - In addition to providing the experimental input for important background corrections in the Fundamental Symmetries results of the MOLLER experiment, there will be specific physics results out of this pion detector of relevance to the Hadronic/QCD field of CINP
  - Fatemeh works under the supervision of Wouter Deconinck (Manitoba)

- **Adam Powell (Calgary)**
  - He joined the University of Calgary in early 2019 and has spent most of his time at CERN with the Antihydrogen Laser Physics Apparatus (ALPHA) Collaboration.
  - His research is focused on experiments with antihydrogen including microwave spectroscopy and measurements of the gravitational free fall, as well as characterizing magnetic fields inside the experiment using electron plasmas.
  - Adam works under the supervision of Timothy Friesen (Calgary)

Selection Committee: Gwen Grinyer (Regina), Gerald Gwinner (Manitoba), Jason Holt (TRIUMF), David Hornidge (Mt. Allison)

CINP 2022 Accomplishments

- **Community Outreach:**
  - **CINP facilitates new connections and allows the disparate Canadian nuclear physics community to develop a common identity**
  - CINP website http://cinp.ca/ updated regularly
  - 2 Newsletters, May and November annually

CINP ICPN

Canadian Institute of Nuclear Physics
Institute Canadien de Physique Nucléaire

Home | About CINP | Nuclear Physics | Programs | Outreach | Membership | Governance

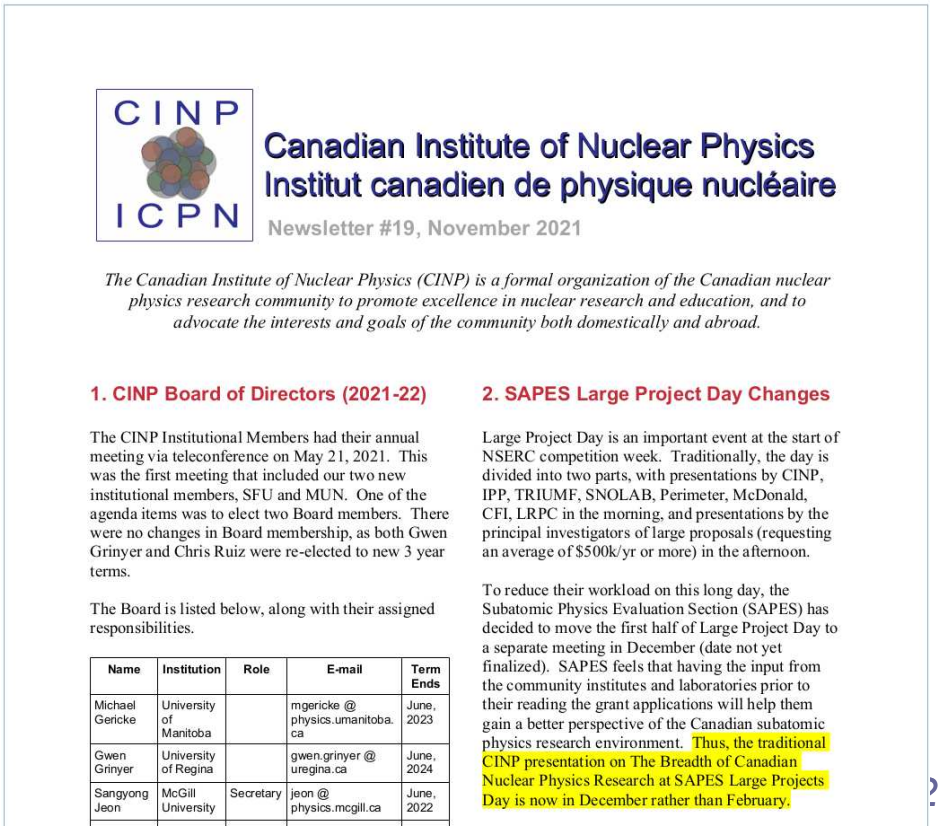
Information and News
- Jobs / Announcements
- Newsletters
- Conference Support
- AGM slides
- CINP White Papers

Scientific Working Groups
- Overview
- Nuclear Astrophysics
- Nuclear Structure
- Fundamental Symmetries
- Hadronic Physics/QCD
- Education and Training

Important Links
- Subatomic Physics Long Range Plan
- NSERC News
- SAPES Chair Reports (2010-)
- GSC-19 Chair Reports (2001-09)
- IUPAP Working Group WG.9

GRIFFIN with DESCANT and SCEPTAR

The Canadian Institute of Nuclear Physics is a formal organization of the Canadian nuclear physics research community to promote excellence in nuclear research and education, and to advocate the interests and goals of the community both domestically and abroad.



CINP ICPN

Canadian Institute of Nuclear Physics
Institut canadien de physique nucléaire

Newsletter #19, November 2021

The Canadian Institute of Nuclear Physics (CINP) is a formal organization of the Canadian nuclear physics research community to promote excellence in nuclear research and education, and to advocate the interests and goals of the community both domestically and abroad.

1. CINP Board of Directors (2021-22)

The CINP Institutional Members had their annual meeting via teleconference on May 21, 2021. This was the first meeting that included our two new institutional members, SFU and MUN. One of the agenda items was to elect two Board members. There were no changes in Board membership, as both Gwen Grinyer and Chris Ruiz were re-elected to new 3 year terms.

The Board is listed below, along with their assigned responsibilities.

Name	Institution	Role	E-mail	Term Ends
Michael Gericke	University of Manitoba		mgericke @ physics.umanitoba.ca	June, 2023
Gwen Grinyer	University of Regina		gwen.grinyer @ uregina.ca	June, 2024
Sangyong Jeon	McGill University	Secretary	jeon @ physics.mcgill.ca	June, 2022

2. SAPES Large Project Day Changes

Large Project Day is an important event at the start of NSERC competition week. Traditionally, the day is divided into two parts, with presentations by CINP, IPP, TRIUMF, SNOLAB, Perimeter, McDonald, CFI, LRPC in the morning, and presentations by the principal investigators of large proposals (requesting an average of $500k/yr or more) in the afternoon.

To reduce their workload on this long day, the Subatomic Physics Evaluation Section (SAPES) has decided to move the first half of Large Project Day to a separate meeting in December (date not yet finalized). SAPES feels that having the input from the community institutes and laboratories prior to their reading the grant applications will help them gain a better perspective of the Canadian subatomic physics research environment. Thus, the traditional CINP presentation on The Breadth of Canadian Nuclear Physics Research at SAPES Large Projects Day is now in December rather than February.

CINP Research Scientists ?

As SAPES frequently asks us:

"If there are IPP research scientists, why do you not propose CINP research scientists?"

we feel it is best to address it here.

- The option to have Research Scientists funded by NSERC is not open to CINP.
  - The ability to apply for funds and build up an independent research program is vital to attracting good applicants. But if NSERC funds are used to pay part of a researcher's salary, that person is not eligible to apply or co–apply for NSERC grants.
  - The IPP Research Scientist program received an exemption from this rule many years ago, when circumstances were very different.
- This causes a certain inequity, places significant strain on the SAP envelope, and "locks in" the support of certain programs for a very long time frame.

CINP Research Scientists ?

Some consensus has emerged within CINP:

- Bridge Faculty Positions are a better model.
  - Would allow a strategic building of highly promising research areas within Canada in a more economic fashion.
  - Avoids the long term tie–up of funds towards a specific program.
- Need to secure an alternate source of funding.
  - Avoids the NSERC applicant exemption problem.
  - More fiscally sustainable, avoids strain on SAP envelope.
  - No source for such funds presently available.

CINP would like to be constructive and work with IPP toward a long–term solution which will be of benefit to the entire SAP community.

CINP Scientific Summary

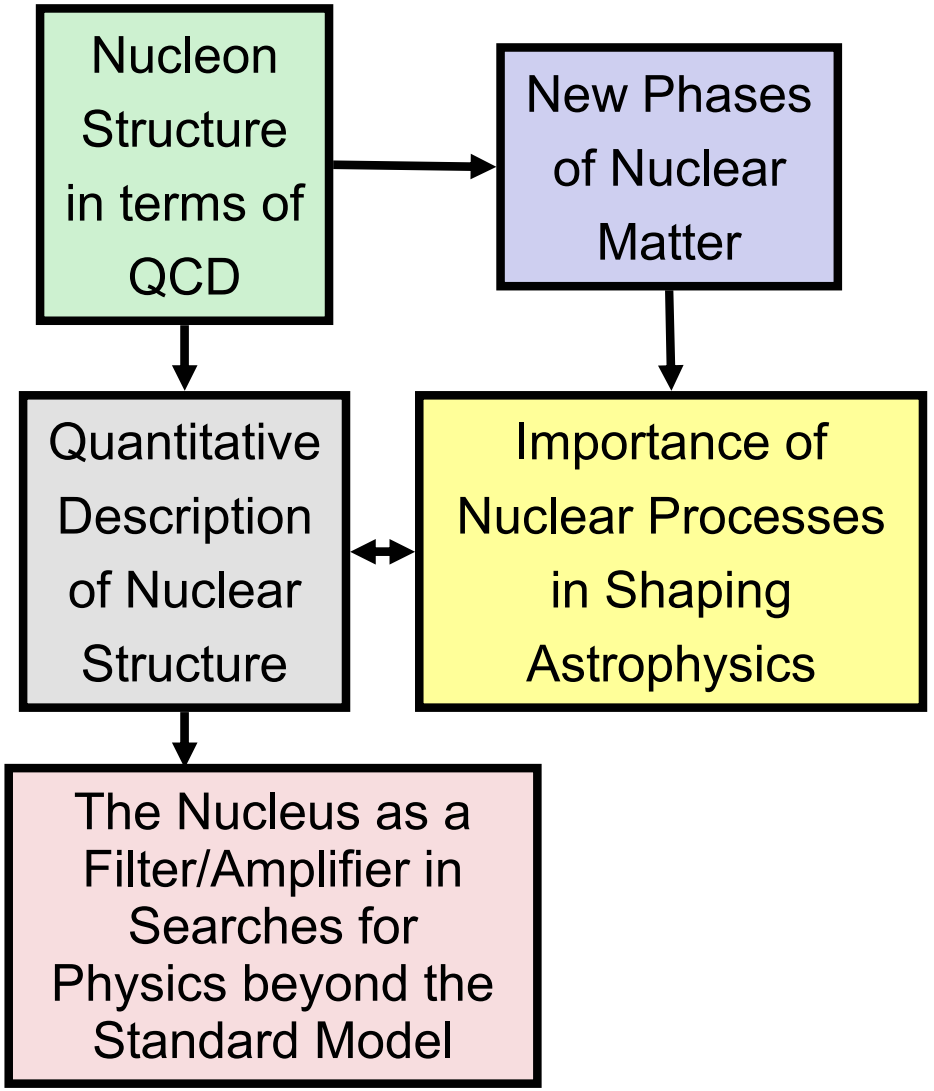
CINP
ICPN

A Few Slides on:

The Breadth of Canadian Nuclear Physics Research
and
Important Current and Future Priorities

Nuclear Physics is driven by fundamental investigations on the origin, evolution and structure of strongly interacting matter

- **Broad international consensus on the key questions of significance to the broader community**
- **Driven by the criteria of research excellence and critical mass of effort, Canadian nuclear physicists have *self–selected* their efforts to make substantive contributions to these "big questions"**



How do Quarks and Gluons give rise to the Properties and Phases of Strongly Interacting Matter?

CINP ICPN

- **Although much is known about QCD in the perturbative regime, one of the central problems of modern physics is the connection of observed hadron properties to QCD**
- This is a major research effort internationally, and the Canadian experimental efforts are concentrated off shore
- Canadian theory contributions in Lattice QCD, Radiative Corrections, and other areas
- Exotic nuclear matter existed during the first moments after the Big Bang, and can be recreated in relativistic nuclear collisions at RHIC and LHC
- There are some very active Canadian theorists contributing to our understanding of the phase diagram of nuclear matter using intensive high performance computing techniques

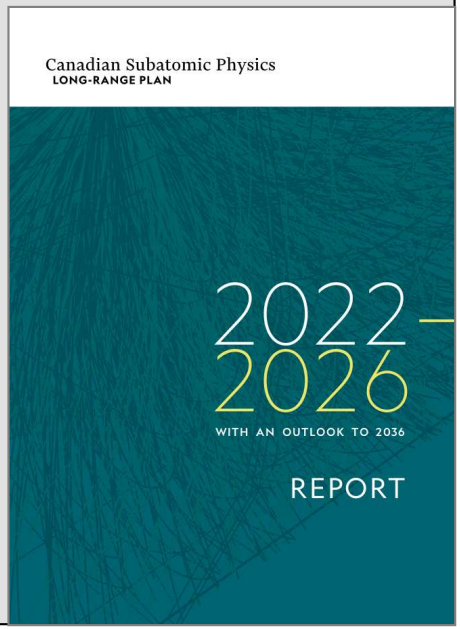
How do Quarks and Gluons give rise to the Properties and Phases of Strongly Interacting Matter?

CINP ICPN

Canadians have made substantive detector contributions to the JLab 12 GeV Upgrade, and have moved to data collection and analysis mode

- GlueX (exotic hybrid mesons) Hall D
- Pion and Kaon Form Factors Hall C

- **Medium term (2022–26):** Canadians involved in data taking and analysis of data. JLab Eta Factory (JEF) is planned with upgraded GlueX equipment for 2021–26
- **Longer term (2027-36):** SoLID experiment at JLab
- Canadian participation at Electron–Ion Collider will uniquely address profound questions about nucleons, including the origin of hadronic mass, the origin of nucleon spin, and the emergent properties of dense systems of gluons



2022 Research Highlight

- GlueX @ JLab: Search for Hybrid Mesons

CINP ICPN

Physics Analyses

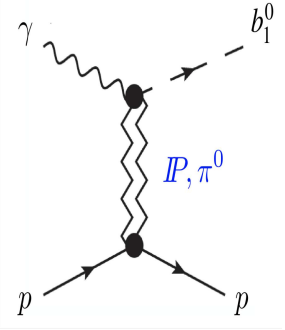
- **Physics Convenor**: Beam Asymmetry & Vector-Pseudoscalar WGs
- **Machine Learning:** for particle anomaly detection and OCC
- **$b_1\pi$ exotics doorway**: axial vector decay, LQCD predictions; xsections, angular moments and pioneering **PWA**

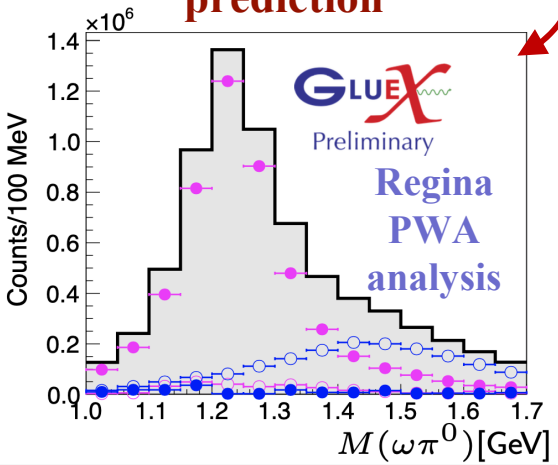
$$\gamma p \to p b_1(1235) \to p[\omega]\pi^0 \to p\pi^+\pi^-2\pi^0$$

Theory: $\pi_1(1564)$ exotic decays through $b_1\pi$ (and not $\eta^{(\prime)}\pi$); S/D-wave ratio prediction

GlueX Preliminary

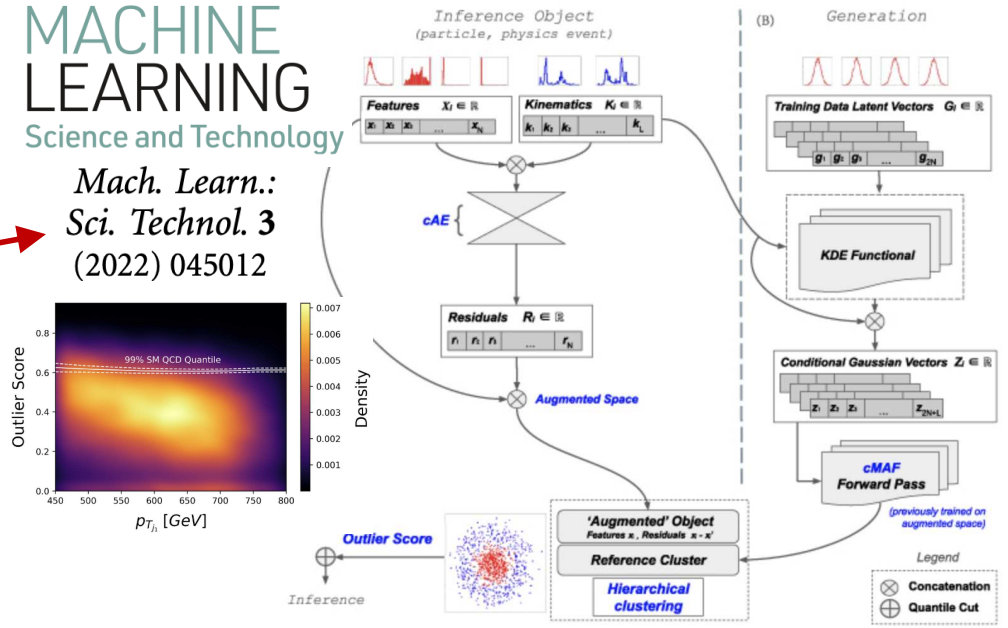
Neutral b_1





MACHINE LEARNING
Science and Technology

Mach. Learn.: Sci. Technol. **3** (2022) 045012



'Flux+Mutability': a conditional generative approach to one-class classification and anomaly detection

Service Contributions

- **Calorimeter Coordinator**
- **Barrel Calorimeter:** Monitoring & calibration each run period (LEDs, π^0 gain, cosmics)
- **Calorimetry upgrade**: FCAL–II for rare eta decays & SM-Dark Sector experiment (2023)
- **Machine Learning:** applied to particle ID and photon-neutron discrimination

2022 Electron–Ion Collider Status
– Inflation Reduction Act funding of US$138.24M

Recently from EIC Project Manager, Jim Yeck (Brookhaven Nat Lab):

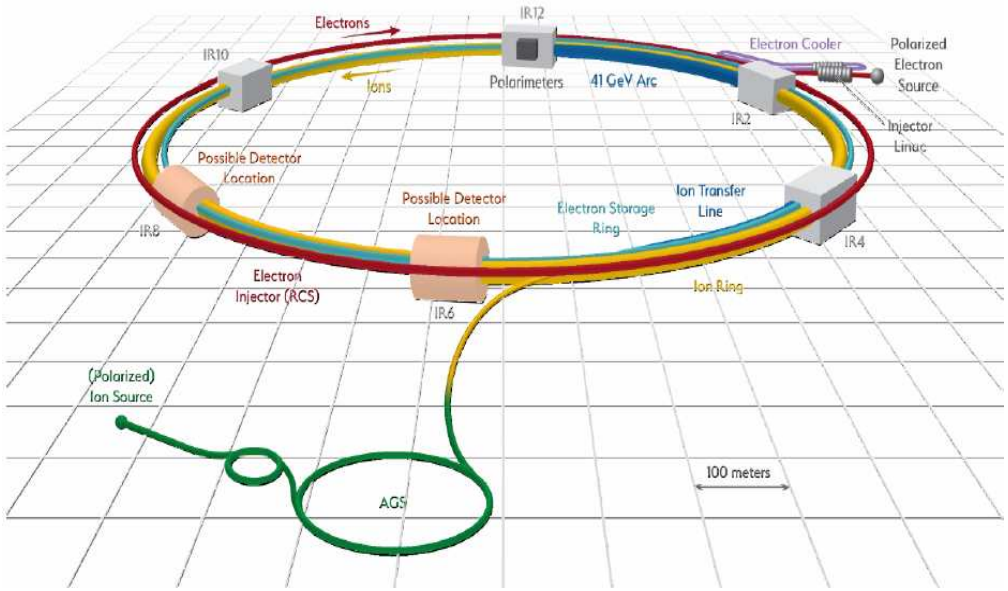
- Inflation Reduction Act funding is a game changer and mitigates risk of slower than optimum ramp of new funding to the US$150M/year needed
- All funds through CD–3A approved by Congress
- Shift from progress constrained by funding to progress determined by ability to advance the design through hiring, partnering and collaboration

Anticipated DOE approvals in early 2024:

- CD–2: Performance Baseline Approval, establishes Total Project Cost, schedule, performance, annual funding profile
- CD–3A: Long Lead Procurement Approval, key factor in mitigating risk and determining project schedule and cost

Longer Term Schedule:

- CD–4A: Start of operations Apr 2031–Apr 2032
- CD–4: Project Completion: Apr 2032–Apr 2034



US Department of Energy (DOE) engaged with international partners

- Resource Review Board (RRB) similar to LHC experience is being set up
- Members are funding agency delegates
- NSERC, CFI and TRIUMF have represented Canada at EIC RRB pre–planning meetings virtually and in–person in DC
- 1st EIC RRB meeting planned for April 2023

2022 Research Highlight
– EIC Canada involvement in Detector Proposals

CINP ICPN

Science Requirements and Detector Concepts

EIC YELLOW REPORT

Nucl. Phys. A 1026 (2022) 122447 1–902

2021: From Yellow Report…

… **to two large detector proposals** with Canadian involvement

2022: Proposal Selection

… **to one large EIC Project detector Collaboration (EPIC)**

- Joint WG's formed and consolidation process undertaken
- Coordination with EIC project on development of technical design

EIC Canada focus areas

Hardware:

- **Calo:** Si–pixel imaging + SciFi hybrid barrel, PbWo + SciGlass hybrid endcaps
- **Calo:** Barrel, e^-/Hadron endcap
- **Electron Polarimetry:** HV-HAPS
- Building towards significant CFI–IF proposal for Calorimetry in 2025 competition

Simulations:

- **EPIC Software WG co–convenor**: W. Deconinck
- **Software framework:** community–oriented (dd4hep, edm4hep, ACTS)
- **Novel AI work:** inner tracker design optimization, calo design using hierarchical density-based clustering
- **Event generators:** far forward region studies (ZDC, B0)
- **Physics:** Meson Form Factors at high Q^2, XYZ Spectroscopy, Charged lepton universality ($e \rightarrow \tau$)

University of Manitoba · Mount Allison University · University of Regina

How does the structure of nuclei emerge from nuclear forces?

CINP ICPN

- **A key goal of nuclear physics research is the development of a comprehensive, predictive theory of complex nuclei**
- This has driven the recent development of high quality radioactive beams, allowing both neutron and proton numbers to vary over a wide range
- Areas of active inquiry include:
  - Studies of neutron halos and skins
  - Tests of *ab-initio* theories in light and medium mass systems
  - Evolution of nuclear shell structure as a function of the neutron-proton asymmetry proton and neutron number
  - Studies of nuclear collectivity, shape coexistence, and nuclear shape transition

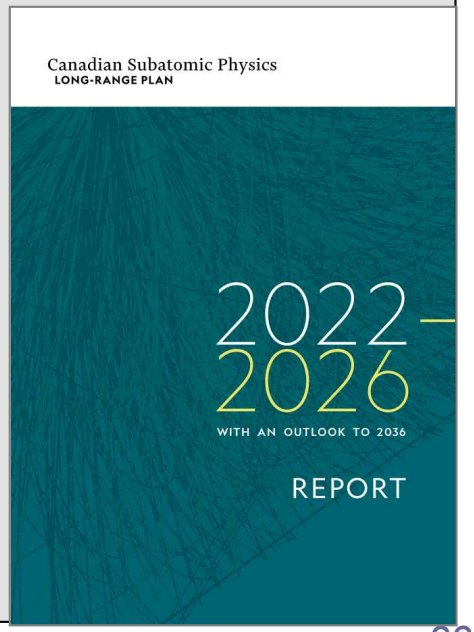
How does the structure of nuclei emerge from nuclear forces?

CINP ICPN

Medium term (2022–26): Highest priority is to capitalize on the recent investments in new world–class detector infrastructure at ISAC. New detector systems, such as EXACT-TPC and RCMP, will begin physics prgrams at ISAC

Longer term (2027-36): ARIEL will be a next generation rare–isotope beam facility, new beam species, higher intensities, cleaner beams, longer beam periods

- High quality work off–shore at GSI, RIKEN, FRIB, JLab & Interactional involvement @ ISAC
- Global ab–initio calculations of all nuclei may become possible in next 5–15 years, making statistical analyses of properties and limits of nuclei from first principles a reality
- Nuclear structure investigations relevant to 0vββ may become a future direction



2022 Research Highlight

– Proton radii of $^{16\text{-}24}$O portray new shells *N*=14 & 16

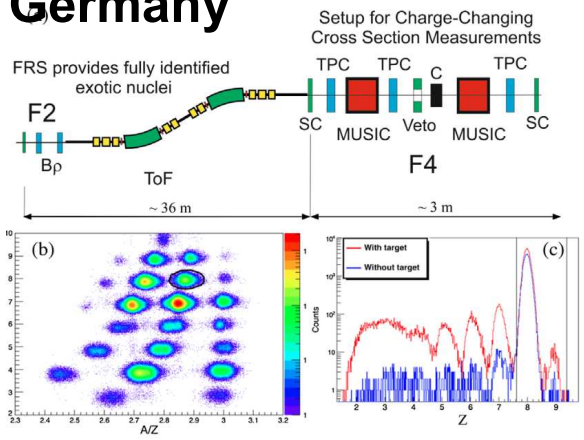
PHYSICAL REVIEW LETTERS **129,** 142502 (2022)

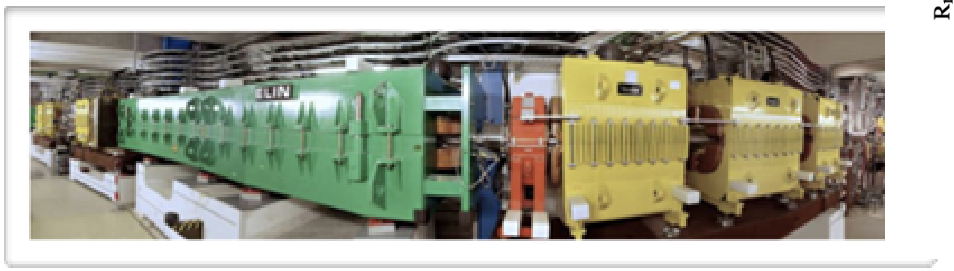
Proton Distribution Radii of $^{16–24}$O: Signatures of New Shell Closures and Neutron Skin

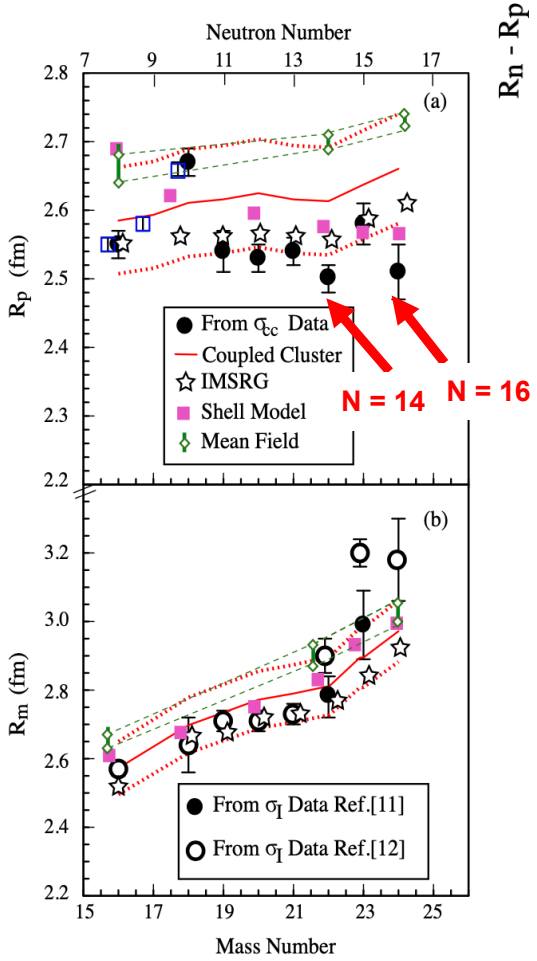
S. Kaur, R. Kanungo, W. Horiuchi *et al.*

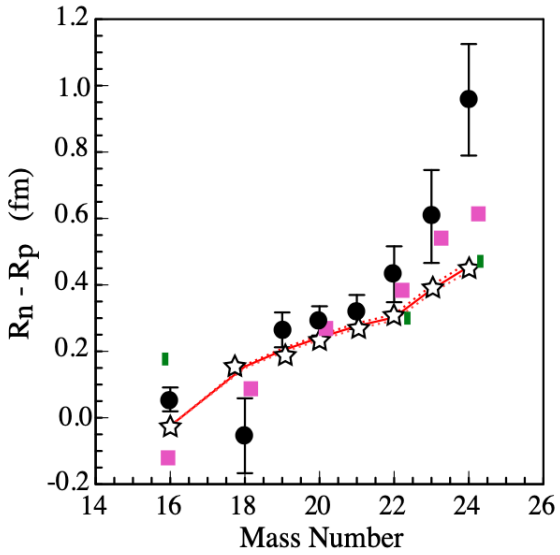
Dips in proton radius of ^{22}O & ^{24}O show *N* = 14 & 16 new shells arising from *p-n* tensor monopole interaction.

@ FRS, GSI Germany









Thick neutron skin unveiled in $^{22\text{-}24}$O.

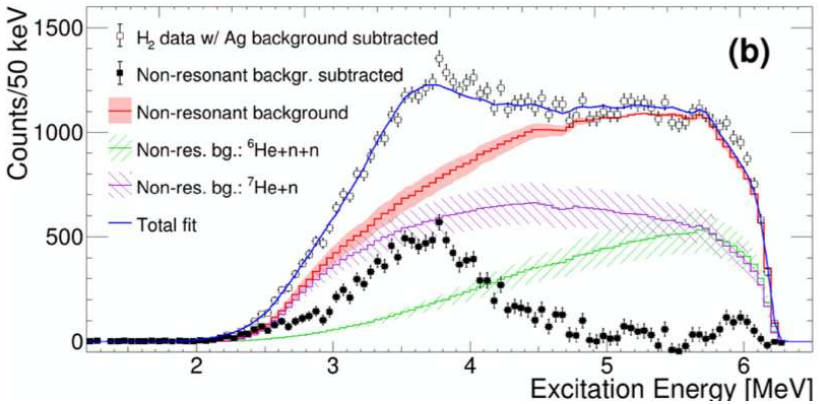
2022 Research Highlight

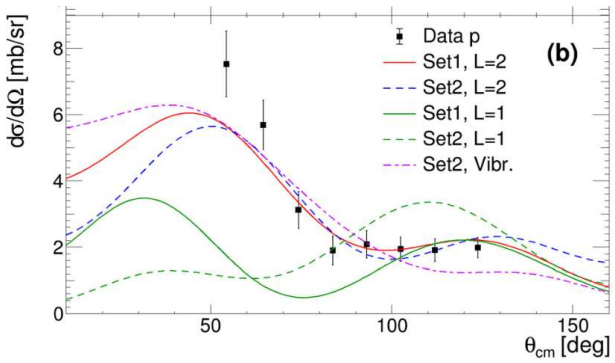
– ^{8}He deformation: IRIS facility measurement

CINP ICPN

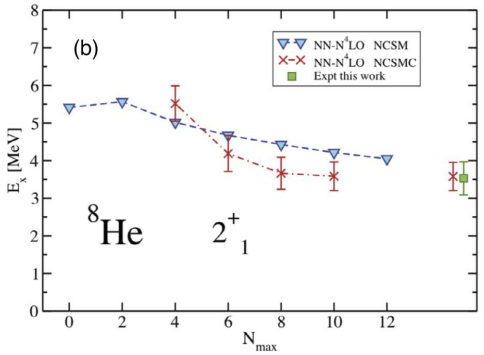
^{8}He doubly-magic (Z= 2, N = 6 subshell closure)

Yet shows large neutron deformation in 2^{+} state !





TRIUMF Nuclear Theory



Physics Letters B 822 (2021) 136710

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Proton inelastic scattering reveals deformation in ^{8}He

M. Holl [a,b], R. Kanungo [a,b,*], Z.H. Sun [c,d], G. Hagen [c,d], J.A. Lay [e,f], A.M. Moro [e,f], P. Navrátil [b], T. Papenbrock [c,d], M. Alcorta [b], D. Connolly [b], B. Davids [b], A. Diaz Varela [g], M. Gennari [b], G. Hackman [b], J. Henderson [b], S. Ishimoto [h], A.I. Kilic [g], R. Krücken [b], A. Lennarz [b,i], J. Liang [i], J. Measures [j], W. Mittig [k,l], O. Paetkau [b], A. Psaltis [i], S. Quaglioni [m], J.S. Randhawa [a], J. Smallcombe [b], I.J. Thompson [m], M. Vorabbi [b,n], M. Williams [b,o]

Media coverage

PHYS.ORG

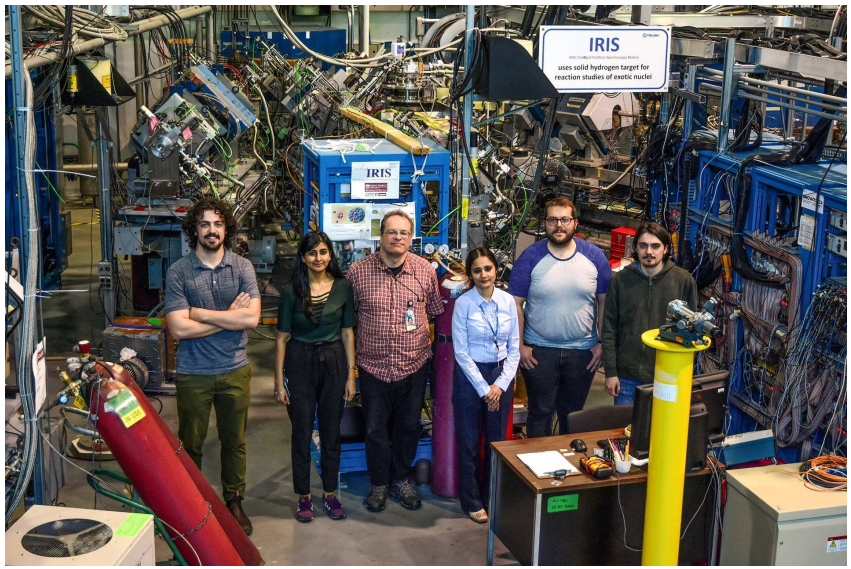
NOVEMBER 17, 2021

A glimpse of deformation in helium-8

Apple news

SCIENMAG: Latest Science and Health News

TRIUMF's IRIS provides a glimpse of deformation in helium-8



2022 New Research Capabilities

– New particle detector for GSI storage rings

- Particle detector PLEIADES (**Partic**LE **s**Ilicon-scintill**A**tor **DE**tector for **S**torage rings) has been installed and successfully commissioned at the **Experimental Storage Ring (ESR) at GSI Darmstadt/ Germany** in June 2022

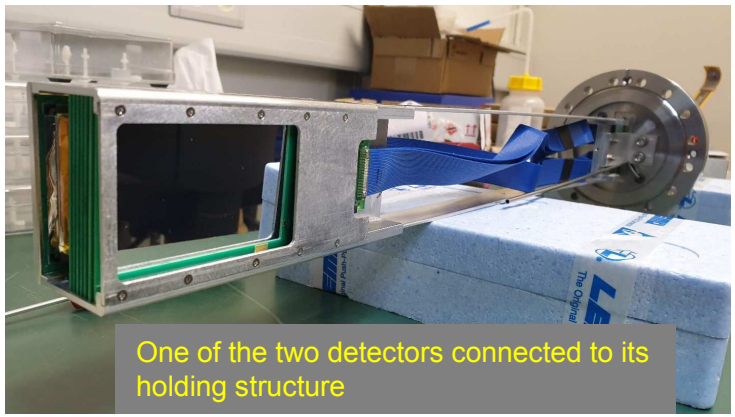
- One of three detectors for **the ILIMA Collaboration at FAIR**: Multi-purpose Si stack detector to identify and count heavy ions from rare nuclear decay processes (e.g. bound-state beta-decay) or reactions

  - Canadian R&D contributions since 2014:
    - NSERC RTI-1 and Individual Discovery Grant (PI: I. Dillmann, TRIUMF/UVic)
    - FAIR Technical Design Report
    - Detector design & development (strong Canadian contribution), detector construction and electronics (Canadian lead), new data acquisition system (Canadian lead)

  - 2022 Progress:
    - Detector construction completed and **installed in Experimental Storage Ring** (ESR) at GSI Darmstadt / Germany
    - New FEBEX data acquisition system installed
    - Commissioning with beamtime in June 2022
    - **MITACS** awarded 3-month research stay (**Globalink Research Award**) for UBC PhD student **Guy Leckenby at GSI (May-August 2022)**

  - Next Steps : Accepted proposals for beamtimes at FAIR Phase-0 (>2024)
  - Collaboration: TRIUMF, TU Munich, University of Saitama, GSI/ FAIR Darmstadt

Postdoctoral Researcher Chris Griffin and UBC PhD student Guy Leckenby inside the ESR cave at GSI


One of the two detectors connected to its holding structure

TRIUMF · Technical University of Munich · Saitama University 埼玉大学 · GSI Helmholtzzentrum für Schwerionenforschung · FAIR — Facility for Antiproton and Ion Research in Europe · NSERC CRSNG

What is the role of radioactive nuclei in shaping the visible matter in the universe?

CINP ICPN

- Nuclear astrophysics addresses many fundamental questions including: the origin of the elements, the connection of observed solar abundances and nuclear structure phenomena, the structure of neutron stars, the equation of state for asymmetric nuclear matter, etc.
- Interdisciplinary: New era in nuclear astrophysics has opened with use of radioactive beam facilities, improved astronomical observation and modeling
- Multi–messenger nuclear astrophysics is already being carried out, with the aim to better understand various aspects of the creation of nuclei in stellar events. e.g. Observation of GW170817 and follow up observations gave much new informationabout the rapid neutron capture process

What is the role of radioactive nuclei in shaping the visible matter in the universe?

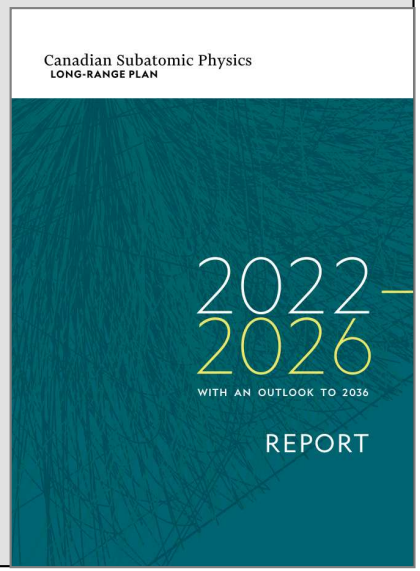
CINP ICPN

Medium term (2022–26): **Majority of domestic program is carried out at ISAC, complemented with off-shore activities at GSI (Germany), RIKEN (Japan), FRIB (USA), GANIL (France)**

- The flexibility of several ISAC detectors to be combined allows a wide coverage of experiments that are not easily possible elsewhere, e.g. EMMA + TIGRESS, GRIFFIN + DESCANT, TITAN EBIT + 8π, DRAGON + GRIFFIN, detectors.

Longer term (2027-36): **Canadian program will profit from full implementation of ARIEL facility at TRIUMF**

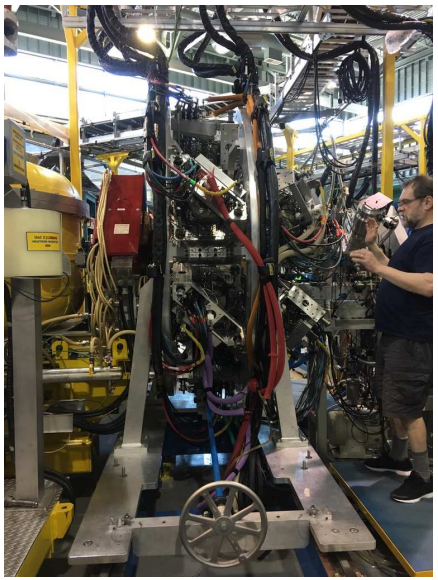
- New detectors planned to take full advantage of upcoming photofission beams and intense re–accelerated heavy nuclear beams from ARIEL, e.g. EXACT–TPC
- **TRIUMF Storage Ring (TRISR)** Proposal for a low–energy storage ring with a neutron generator at ISAC is underway

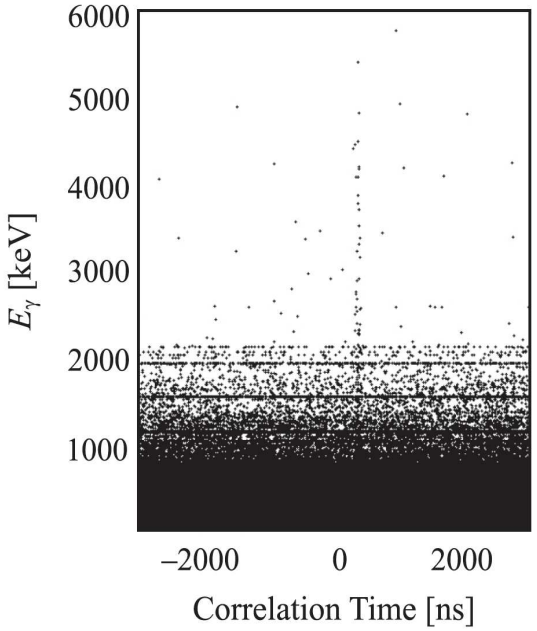


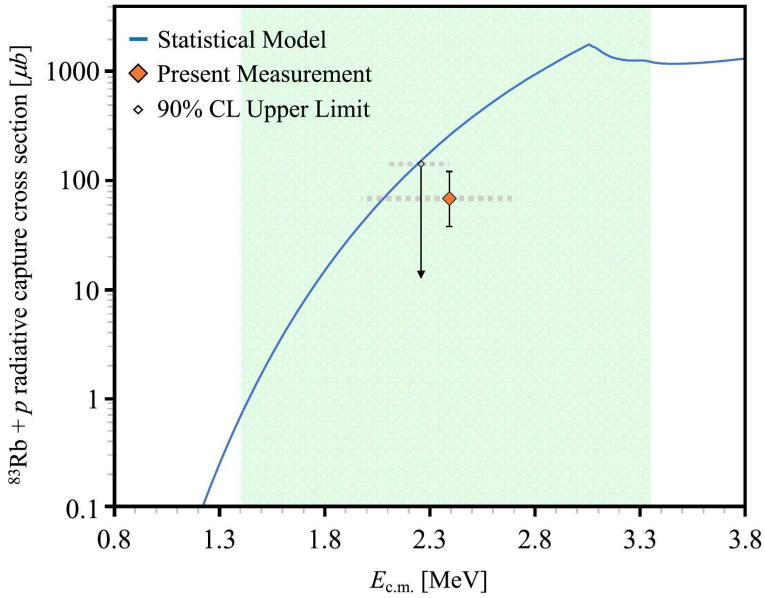
2022 Research Highlight

– ^{83}Rb(p,γ)^{84}Sr and the abundance of strontium

- First direct measurement of an astrophysical *p* process reaction cross section using a radioactive ion beam
- Measurement of ^{83}Rb(p,γ)^{84}Sr cross section in inverse kinematics with polyethylene target
- γ rays detected using TIGRESS surrounding target in coincidence with ^{84}Sr recoils at EMMA focal plane
- Measured cross section found to be smaller than prediction of statistical model, implying less destruction and therefore higher final abundance of ^{84}Sr in supernovae
- G. Lotay et al., Physical Review Letters **127**, 112701 (2021)





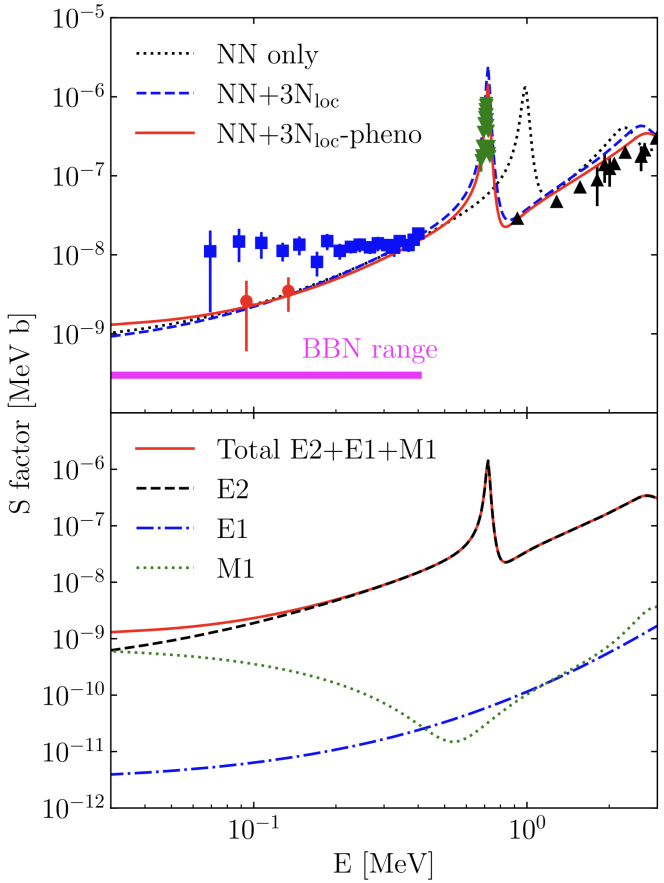


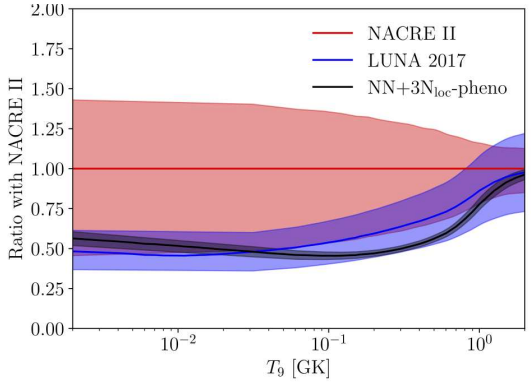
2022 Research Highlight

– Radiative Capture Reaction ^{4}He(d,γ)^{6}Li

CINP ICPN

- **Responsible for ^{6}Li production in BBN**
  - 10^3 discrepancy between theory/observation
- Deficiency in observation, theory, or new physics?
- *Ab Initio* NCSMC calculation with chiral forces
- Radiative capture S-factor
  - •Dominated by *E2*
  - •*M1* significant at low energy
  - •*E1* negligible (isospin supressed)
- Thermonuclear reaction rate
  - •Smaller than NACRE II evaluation
  - •Agrees with LUNA; reduced uncertainty





PHYSICAL REVIEW LETTERS **129,** 042503 (2022)

***Ab Initio* Prediction of the ^{4}He$(d,\gamma)^6$Li Big Bang Radiative Capture**

C. Hebborn,[1,2,*] G. Hupin,[3] K. Kravvaris,[2] S. Quaglioni,[2] P. Navrátil,[4] and P. Gysbers[4,5]

TRIUMF Nuclear Theory

What Physics Lies Beyond the Standard Model?

CINP ICPN

- **Studies of fundamental symmetries via very precise low and intermediate energy experiments have been part of nuclear physics since its inception**
- Complementary to direct probes by high energy physics since precision lower energy experiments indirectly probe mass scales and parameter spaces not otherwise accessible

The Canadian NP program is very active, addressing:

- **Time Reversal and CP violation:**
  - **TUCAN n–EDM search; Fr–EDM, Radioactive Molecules @ ISAC**
- **Neutral Current Weak Interactions**
  - **MOLLER PV e^- Scattering @ JLab; Atomic Parity Violation @ ISAC**
- **Majorana Neutrinos:**
  - **$0\nu\beta\beta$ studies @ SNOLab; BeEST search for keV–scale ν @ ISAC**
- **CPT, Lorentz and Weak Equivalence Principle violation: ALPHA @ CERN**
- **CKM Matrix Unitarity: GRIFFIN, TITAN @ ISAC**
- **Beta–Neutrino Correlations: TRINAT neutral atom trap @ ISAC**

What Physics Lies Beyond the Standard Model?

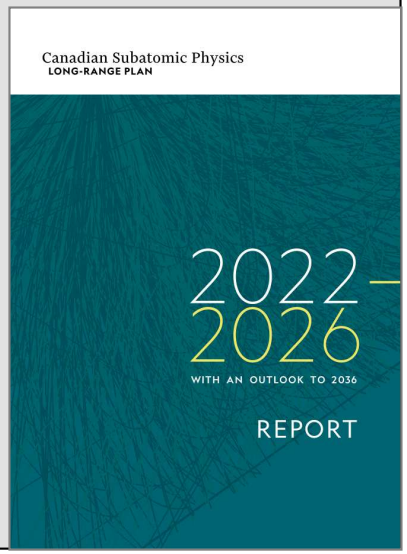
CINP ICPN

Medium term (2022–26):

- ISAC program: Laser–trapped Francium, GRIFFIN β–decay, TRINAT, TITAN
- TUCAN and ALPHA–g upgrades completed
- NaB cold neutron experiment underway
- MOLLER @ JLab construction begun, run to ~2030
- Positive funding decision on nEXO 5 tonne detector

Longer term (2027-36):

- Precision spectroscopy with radioactive molecules will be major new effort @ ISAC
- FrPNC to start atomic PV run @ ISAC
  - Possible extension to cold Fr, Ag molecules
- Deployment of HAICU by ALPHA Collaboration
- Fundamental Symmetries @ EIC



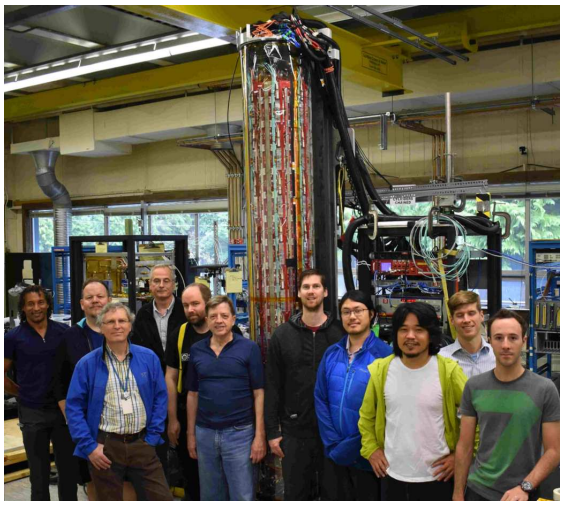
2022 Research Highlight
– ALPHA: Antihydrogen Symmetry Tests

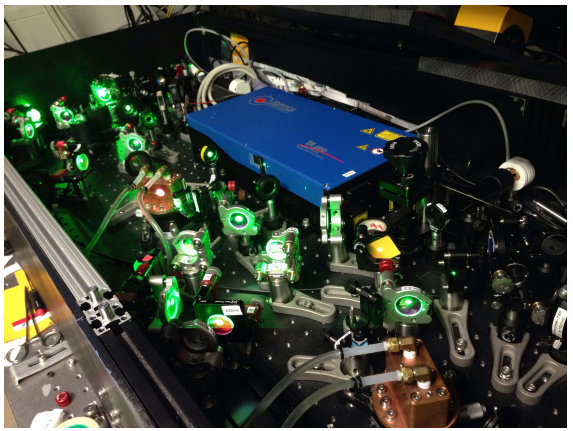
ALPHA–Canada: UBC, SFU, Calgary, York, TRIUMF
- A leading group in ALPHA Collaboration at CERN
- 40% of the Collaboration; *est*. 2005

ALPHA Objectives
- Precision measurements on antihydrogen
- Test of CPT symmetry (ALPHA–2)
- Weak Equivalence Principle for antimatter (ALPHA–g)
- R&D on Quantum Techniques for antimatter (HAICU)

Recent Milestones
- ALPHA–g apparatus has been commissioned; started initial data taking for gravity measurement
- Improved 121 nm laser, leading to improved cooling with ALPHA–2

New faculty members anticipated to join next SAPES competition (2023–24)


ALPHA–g TPC built at TRIUMF


121 nm laser developed at UBC

2022 New Research Capabilities
– TUCAN upgrade begins installation

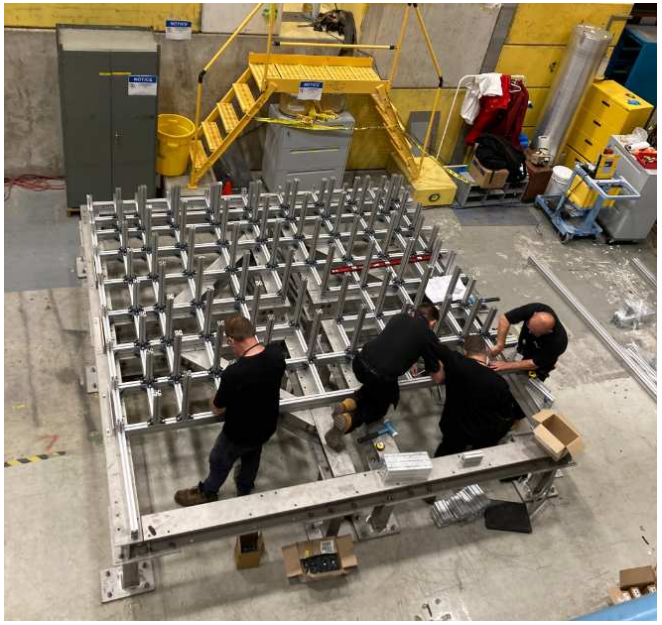
- **Measurement of the neutron electric dipole moment with an uncertainty approaching 10^{-27} e cm, an order of magnitude better than the present world's best.**

- Recent progress:
  - 2017–2019 operated prototype UCN source at TRIUMF, leading to several key publications on performance, such as the effect of superfluid helium temperature on UCN production.
  - Since receiving CFI Innovation Fund support in 2017, we have been pursuing an upgrade to this facility to make a world-class EDM measurement.

- 2022 Progress and plans for 2023:
  - Components of UCN source in preparation for installation. Major installation of ^{3}He refrigerator from Japan planned for early 2023. Cryogenic tests plannned for 2023.
  - Installation of magnetically shielded room (MSR) for the EDM experiment began installation October 2022. Will be completed in summer 2023. Magnetic tests planned for 2023.

- Current team: 11 faculty members, 5 postdocs, and 13 grad students from UBC, U. Manitoba, U. Winnipeg, UNBC, and TRIUMF. Strong collaboration with Japan, matching contributions for CFI–IF project.

UCN production volume prepared at TRIUMF, now being prepared for final welding, Nov. 2022

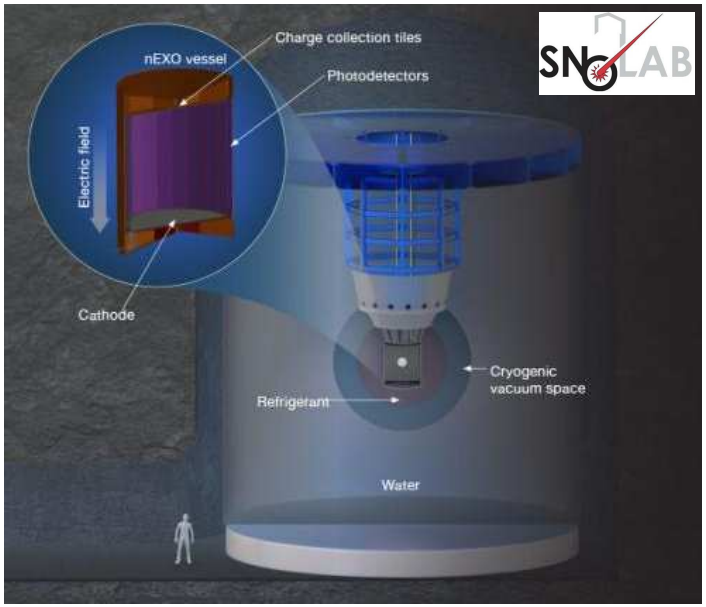


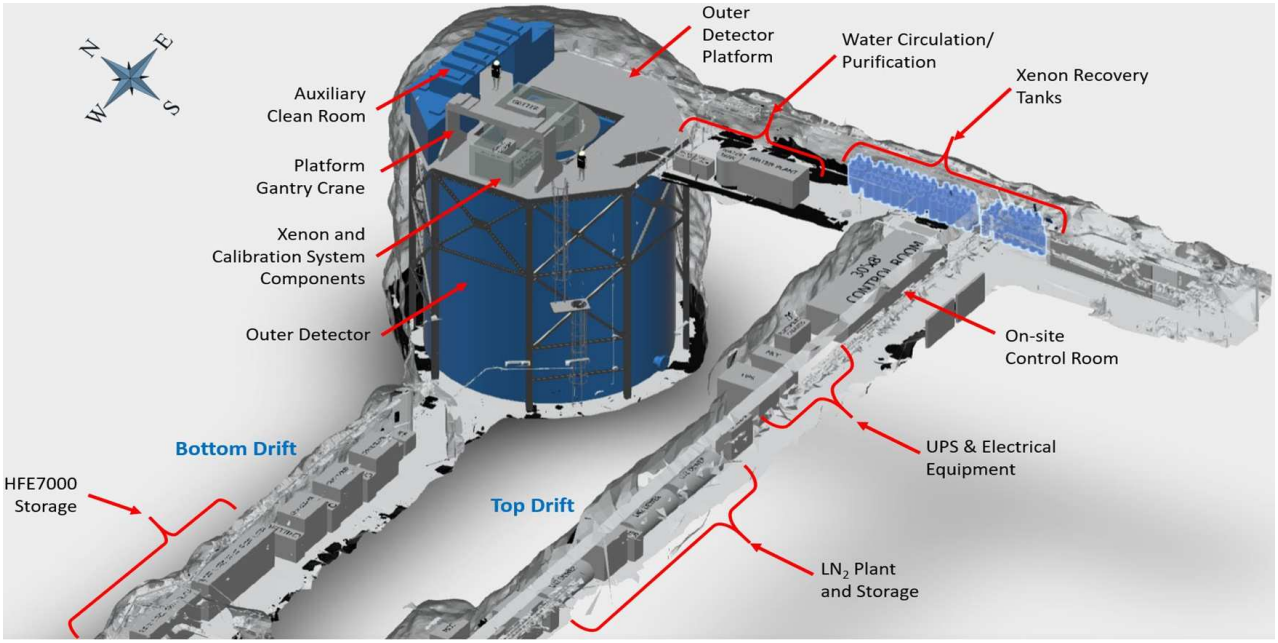
MSR installation at TRIUMF, Oct. 2022

Searching for 0νββ at the Tonne–Scale

- nEXO is a proposed liquid Xe single–phase Time Projection Chamber searching for 0νββ in Xe–136
- Projected sensitivity of nEXO $T_{1/2}^{0\nu\beta\beta}$ >10^{28} years (J. Phys. G: Nucl. Part. Phys. 49 015104 (2022))

- **Observation of 0νββ always implies new physics**:
  - Majorana neutrinos
  - Lepton number violation
  - Probe new mass mechanism up to GUT scale
  - Help explain observed cosmic baryon asymmetry





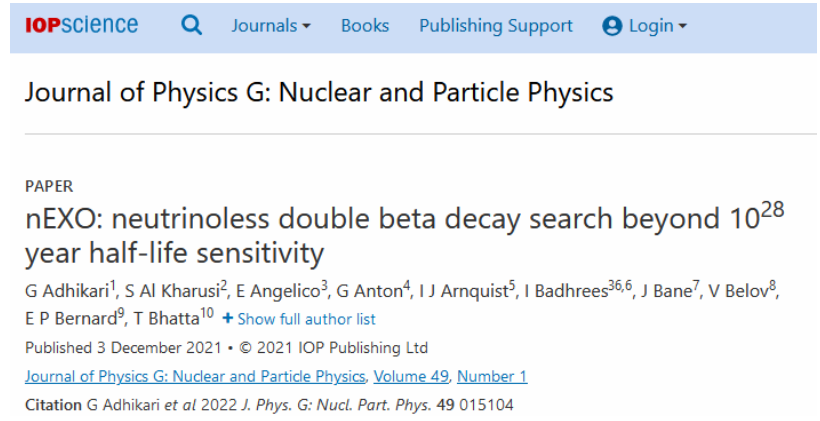
- **Thanks to SNOLAB for providing resources to greatly advance the design of nEXO at the Cryopit**
- For more details: nEXO pCDR (arXiv:1805.11142)

2022 Research Highlight
– nEXO: Searching for 0νββ at the Tonne–Scale

CINP ICPN

Canadian scientists are heavily involved in development of key components of nEXO:

- Canadian groups have been contributing to the EXO scientific program since 2004 with EXO-200 and nEXO.
- Canadian groups now constitute about 20% of scientists in nEXO, the second largest group by country.
- Since 2019 Canadian groups are leading two detector subsystems with SNOLAB as the lead institution and contributing to 5 other subsystems.
- Updated sensitivity study (2022) has ben co-led by a Canadian faculty (C. Licciardi)
- Performance study of SiPMs for nEXO has been led by TRIUMF post doc (G. Gallina).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Journal of Physics G: Nuclear and Particle Physics

PAPER

nEXO: neutrinoless double beta decay search beyond 10^{28} year half-life sensitivity

G Adhikari[1], S Al Kharusi[2], E Angelico[3], G Anton[4], I J Arnquist[5], I Badhrees[36,6], J Bane[7], V Belov[8], E P Bernard[9], T Bhatta[10] + Show full author list

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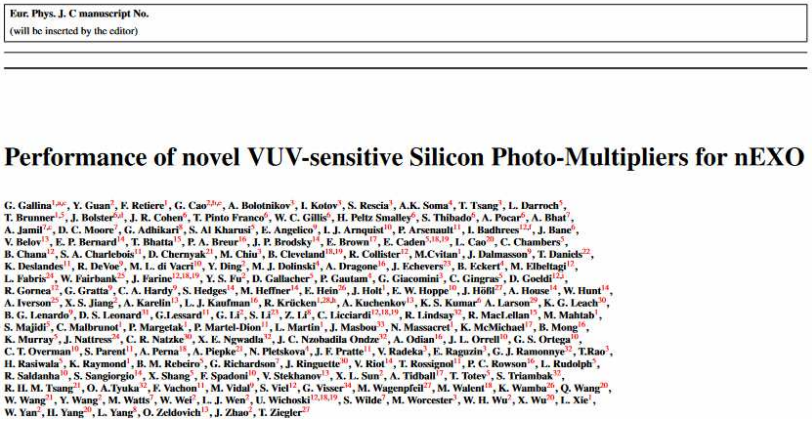
Citation G Adhikari *et al* 2022 *J. Phys. G: Nucl. Part. Phys.* **49** 015104


Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

Performance of novel VUV-sensitive Silicon Photo-Multipliers for nEXO

G. Gallina[1,a,e], Y. Guan[2], F. Retiere[1], G. Cao[2,b,e], A. Bolotnikov[3], I. Kotov[3], S. Rescia[1], A.K. Soma[4], T. Tsang[5], L. Darroch[5], T. Brunner[1,c], J. Bolster[6,d], J. R. Cohen[6], T. Pinto Franco[6], W. C. Gillis[6], H. Peltz Smalley[6], S. Thibado[6], A. Pocar[6], A. Bhat[7], A. Jamil[7,e], D. C. Moore[7], G. Adhikari[8], S. Al Kharusi[9], E. Angelico[9], I. J. Arnquist[10], P. Arsenault[11], I. Badhrees[12,f], J. Bane[7], V. Belov[13], E. P. Bernard[14], T. Bhatta[15], P. A. Breur[16], J. P. Brodsky[14], E. Brown[17], E. Caden[5,18,19], L. Cao[20], C. Chambers[5], B. Chana[12], S. A. Charlebois[21], D. Chernyak[21], M. Chiu[1], B. Cleveland[18,19], R. Collister[12], M.Cvitan[1], J. Dalmasson[5], T. Daniels[22], K. Deslandes[11], R. DeVoe[9], M. L. di Vacri[10], Y. Ding[7], M. J. Dolinski[4], A. Dragone[16], J. Echevers[23], B. Eckert[4], M. Elbeltagi[17], L. Fabris[24], W. Fairbank[25], J. Farine[12,18,19], Y. S. Fu[7], D. Gallacher[5], P. Gautam[4], G. Giacomini[1], C. Gingras[5], D. Goeldi[12,f], R. Gornea[12], G. Gratta[9], C. A. Hardy[9], S. Hedges[14], M. Heffner[14], E. Hein[26], J. Holt[1], E. W. Hoppe[10], J. Höhn[27], A. House[14], W. Hunt[14], A. Iverson[23], X. S. Jiang[7], A. Karelin[13], L. J. Kaufman[16], R. Krücken[12,18,h], A. Kuchenkov[13], K. S. Kumar[28], A. Larson[29], K. G. Leach[30], B. G. Lenardo[9], D. S. Leonard[31], G.Lessard[11], G. Li[9], S. Li[32], Z. Li[6], C. Licciardi[12,18,19], R. Lindsay[33], R. MacLellan[15], M. Mahtab[1], S. Majidi[5], C. Malbrunot[1], P. Margetak[1], P. Martel-Dion[17], L. Martin[1], J. Masbou[33], N. Massacret[1], K. McMichael[17], B. Mong[26], K. Murray[5], J. Nattress[24], C. R. Natzke[30], X. E. Ngwadla[12], J. C. Nzobadila Ondze[32], A. Odian[16], J. L. Orrell[33], G. S. Ortega[10], C. T. Overman[10], S. Parent[11], A. Perna[18], A. Piepke[23], N. Pietskova[1], J. F. Pratte[11], V. Radeka[3], E. Raguzin[3], G. J. Ramonnye[29], T.Rao[3], H. Rasiwala[1], K. Raymond[1], B. M. Rebeiro[5], G. Richardson[7], J. Ringuette[10], V. Riot[18], T. Rossignol[11], P. C. Rowson[16], L. Rudolph[1], R. Saldanha[10], S. Sangiorgio[31], X. Shang[7], F. Spadoni[10], V. Stekhanov[13], X. L. Sun[7], A. Tidball[17], T. Totev[5], S. Triambak[22], R. H. M. Tsang[23], O. A.Tyuka[32], F. Vachon[11], M. Vidal[12], S. Viel[12], G. Visser[23], M. Wagenpfeil[27], M. Walent[18], K. Wamba[26], Q. Wang[20], W. Wang[21], Y. Wang[7], M. Watts[1], W. Wei[7], L. J. Wen[7], U. Wichoski[12,18,19], S. Wilde[1], M. Worcester[3], W. H. Wu[7], X. Wu[20], L. Xie[1], W. Yan[7], H. Yang[30], L. Yang[8], O. Zeldovich[12], J. Zhao[7], T. Ziegler[27]

https://arxiv.org/abs/2209.07765

Accepted for publication in Eur. Phys. J. C.

nEXO

Funding Updates

- CFI IF2020 "Enabling the search for neutrinoless double-beta decays in Xe–136 with nEXO" (project $16.6M) has been approved under the condition that nEXO is funded by the US Department of Energy (DOE).
- January 2022: DOE funding defining project start was received January 2022 to support preparation towards CD1.
- Early 2022: Following DOE's announcement, CFI partially lifts condition on nEXO CFI–IF 2020.
- **April 2022: NSERC approves nEXO's request for renewal of funding with a significant increase in support.**
- *July 2022:* nEXO Canada submits CFI–IF 2023 proposal "Searching for neutrinoless double beta decay with nEXO at SNOLAB" (project $24.4M) requesting funding for Canadian deliverables towards the construction of nEXO at SNOLAB Cryopit.
- October 2022: DOE funding received to prepare for Critical Decision 1 (CD1) review (Conceptual Design Stage). CD1 anticipated for early 2024.
- **Fall 2022: following DOE funding of nEXO, CFI lifts the condition on nEXO's CFI–IF 2020**.

Nuclear Physics High–Priority Science

- **Flagship Projects with Broad Physics Outcomes:**
  - TRIUMF ARIEL–ISAC Experiments
  - Electron–Ion Collider
- **Flagship Projects with Strategic Physics Outcomes:**
  - JLab 12 GeV Program
  - Offshore RIB Experiments
  - ALPHA/HAICU, MOLLER, TUCAN