Five-Year Plan 2025-2030

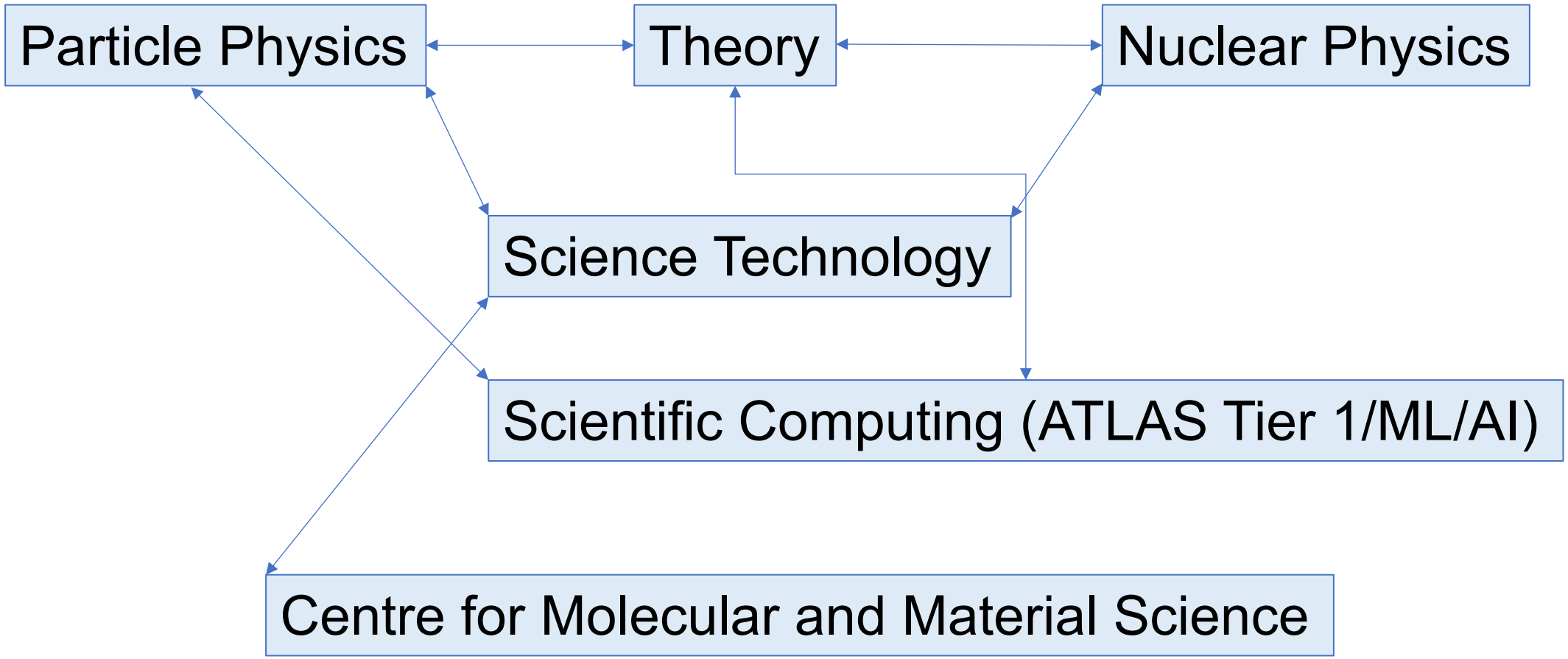
Physical Sciences Division

Science Week 2023

August 2, 2023,TRIUMF, Vancouver

Petr Navratil
Interim Director, Physical Sciences

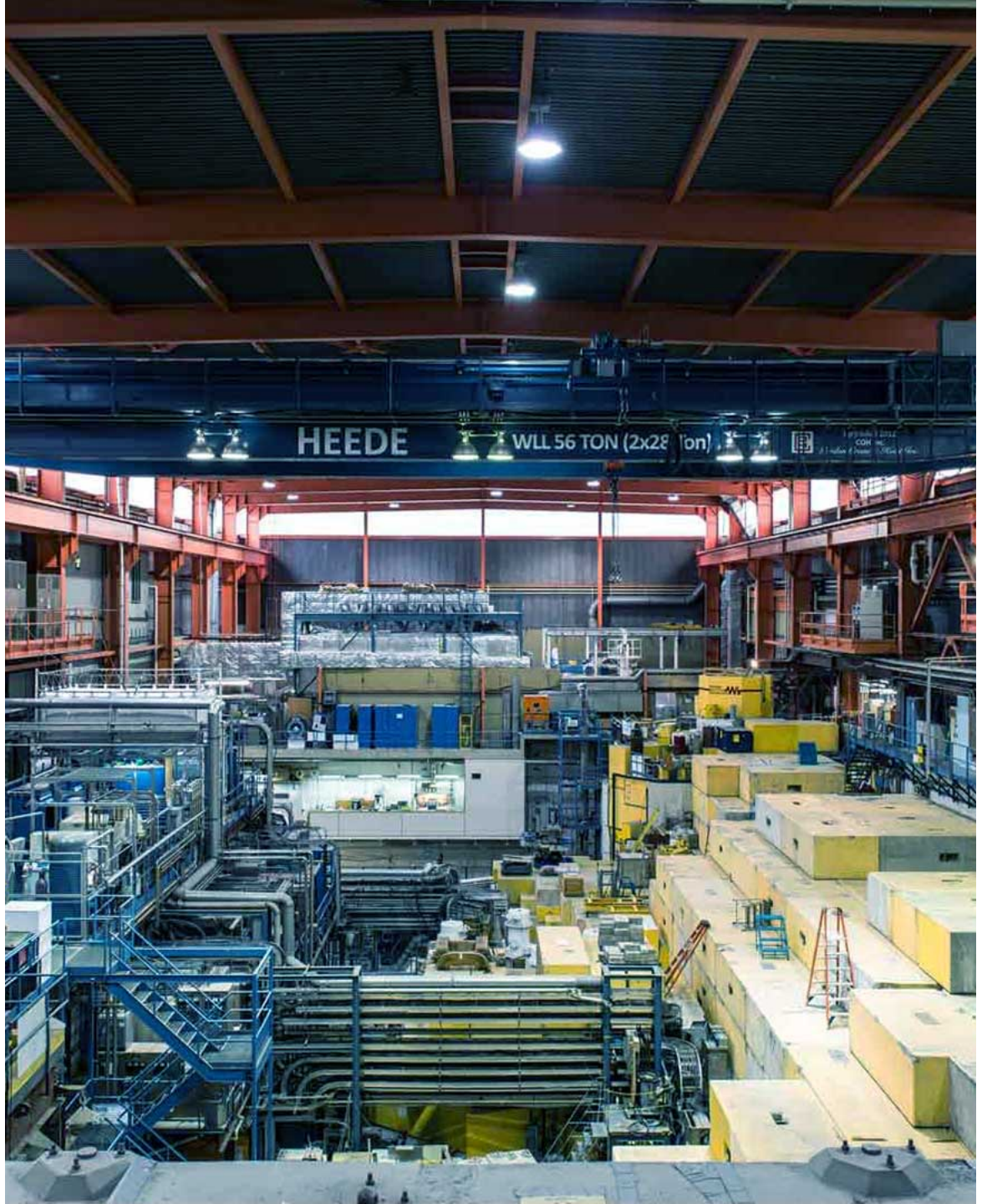
Physical Sciences Division



Physical Sciences Division Mission Statement

- To make discoveries, lead and contribute to research that address the most compelling questions in particle physics, nuclear physics, and materials science.
- To act as Canada's steward for the advancement of facilities, expertise, and technologies that enable outstanding science in those fields.
- To enhance connections to the Canadian and international communities.
- To train highly skilled personnel, transfer knowledge, inspire the public, and carry out research for the benefit of all Canadians.

Physical Sciences Division planning process for 5YP 2025-2030



2023-08-01

Physical Sciences Division planning process for 5YP 2025-2030

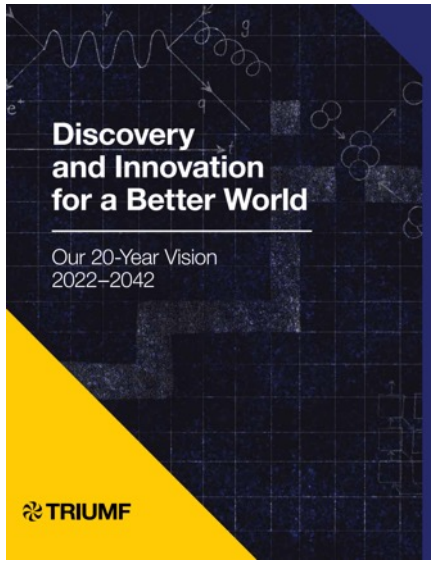
- Process started in spring 2022
- Focus on
  - Alignment with
    - TRIUMF 20-Year Vision
    - TRIUMF Goals & Objectives
  - Delivering Science from ARIEL
- Bottom-up approach – start at departmental level
  - Discussions at the DH+D meetings
  - BAE retreat on June 13, 2022
    - Consider current effort & “blue-sky” scenario

All Three Science Divisions

Deliver high-impact science

Become a hub for interdisciplinary education and training

Inspire Canadians to discover and innovate

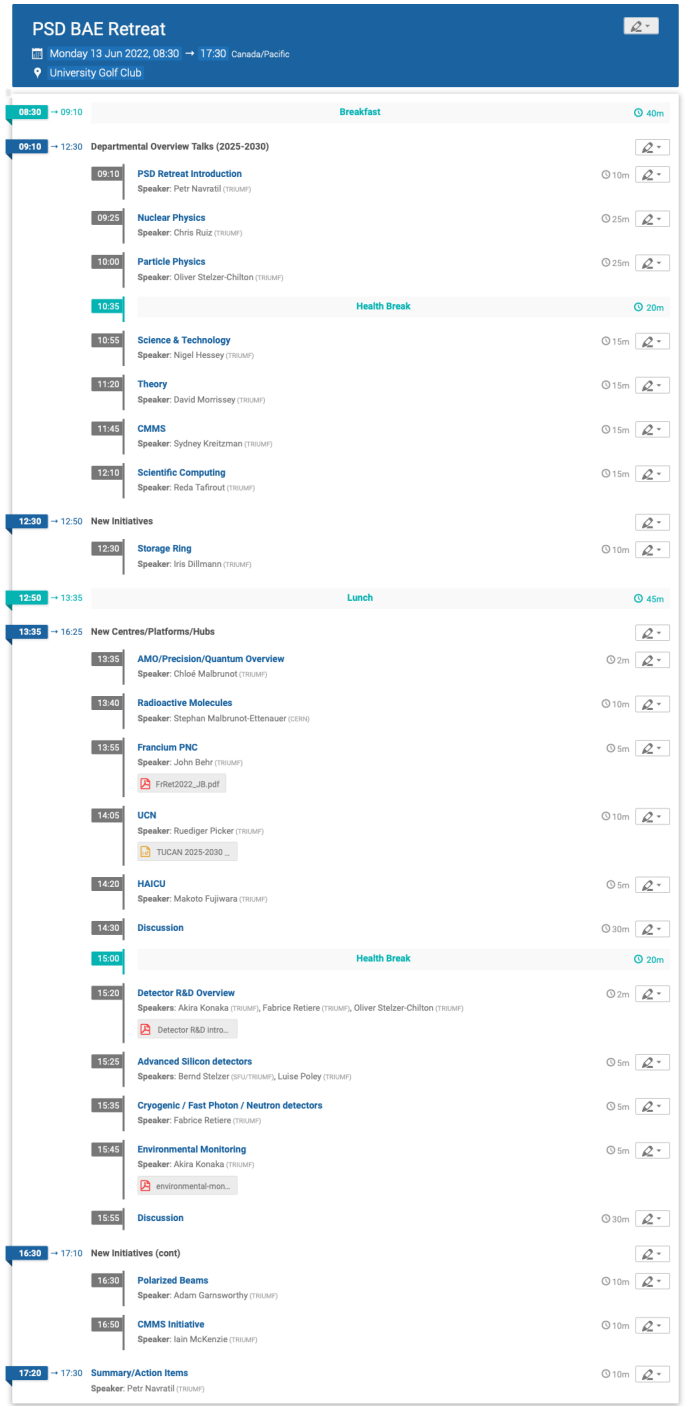


PSD BAE Retreat 2022
5YP 2025-2030 Preparation

- Held on Monday June 13th, 2022, at the University Golf Club (hybrid)
  - More than 30 participants

- Departmental Overview Talks
- New Initiatives
  - Storage Ring
  - Polarized Beams
  - CMMS Initiative
- New Centres/Platforms/Hubs
  - AMO/Precision/Quantum
  - Detector R&D

Input for TRIUMF Science Week
Input for the 5YP 2025-2030 document



Physical Sciences Division planning process for 5YP 2025-2030

- Discussions with the Leadership Team
- Engagement with broader community
  - Science Week, July 18-22, 2022

All Three Science Divisions

NRC Evaluation of TRIUMF in parallel with the 5YP planning process

- **Peer Review Committee** (November 29 – December 3, 2022)
  - PSD participated in plenary talks, parallel sessions, poster session, tour

Peer Review Committee Members
Dr. Souzan Armstrong (Commerc)
Dr. Kimberly S. Budil, Chair
Dr. Simon R. Cherry (LS)
Dr. Alexandra Gade (NP)
Dr. Michel Gingras (MS)
Dr. Brad Sherrill (NP, ACC)
Dr. Elizabeth H. Simmons (PP)
Dr. Frank Zimmermann (ACC)

November 30th

Time	Event		
11:30 – 13:00	Parallel Sessions Detailed presentations and discussion of past performance and future plans:		
	Particle Physics **Room: Theory Room**	Nuclear Physics **Room: Auditorium**	Materials Science **Room: MOB Boardroom**
	Accelerators **Room: ISAC II Conference Room**	Life Sciences **Room: MOB Conference Room**	TRIUMF Commercialization / TRIUMF Innovations ***CLOSED SESSION***

November 29th

Plenary	Plenary Lead	Question 1: To what extent is TRIUMF a platform for scientific excellence? (knowledge creation, connecting role, infrastructure)	Question 2: Is TRIUMF focusing on the right areas to stay relevant to serve the needs of the TRIUMF community and beyond?	Question 3: To what extent does TRIUMF have the capacities, competencies, and facilities needed to achieve its objectives moving forward?	Question 4: To what extent is the governance of TRIUMF effective/efficient? Are there efficiencies to be gained?
Introduction	Kate Pachal	✓	✓	✓	
Overview	Nigel Smith	✓	✓	✓	✓
Particle Physics*	Isabel Trigger	✓	✓	✓	
Nuclear Physics*	Chris Ruiz	✓	✓	✓	
Accelerators*	Thomas Planche	✓	✓	✓	
Life Sciences*	Conny Hoehr	✓	✓	✓	
Materials Sciences*	Iain McKenzie	✓	✓	✓	
TRIUMF Innovations & Industrial Partnerships*	Kathryn Hayashi	✓	✓	✓	✓
Strategic Planning	Sean Lee	✓	✓	✓	✓
Governance & Management	Nigel + BoG representative	✓	✓	✓	✓

NRC Evaluation of TRIUMF in parallel with the 5YP planning process

- **Peer Review Committee** (November 29 – December 3, 2022)
  - PSD participated in plenary talks, parallel sessions, poster session, tour
  - Committee report mostly positive
    - It states that the committee was very favorably impressed with TRIUMF
    - Highlights TRIUMF potential
    - Notices that TRIUMF is under resourced
    - Notes that "*the poster session was most enjoyable*"

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PRC report:

November 29th

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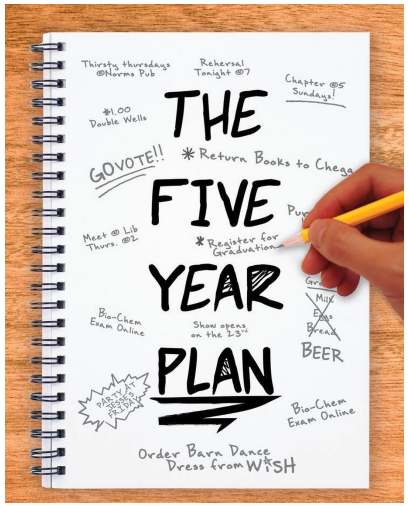
Physical Sciences Division planning process for 5YP 2025-2030

- Drafts of new initiative white papers
  - Center for Quantum Sensing & Precision Physics
  - Detector Development Centre
  - AI Centre
  - Innovation Centre (new building)
  - TRIUMF Conference and Learning Centre

- Division & Departments involved in outcome planning
  - Submitted budget estimates, estimates of FTE requirements
- Review and prioritization done by the TRIUMF Leadership Team

All Three Science Divisions

- BAE retreat on June 2, 2023



PSD BAE Retreat 2023

- BAE retreat on Friday June 2nd, 2023 at the University Golf Club
  - Dense program with good discussions
    - Focus on ongoing science, proposed detector, quantum & AI centers, ARIEL science opportunities
  - Almost 50 participants
    - PSD BAEs and P&S scientists plus invited BAEs from other divisions
  - Joined by Nigel Smith in the afternoon

PSD BAE Retreat

Friday 2 Jun 2023, 08:00 → 17:30 Canada/Pacific

University Golf Club

Description: Join Zoom Meeting
https://ubc.zoom.us/j/4049607458?pwd=aEJEQ2JyTG1tTkYyTkNwQVcwTUxDdz09

Meeting ID: 404 960 7458
Passcode: 494154

08:00 → 08:30 Breakfast 30m

08:30 → 08:35 PSD Retreat Introduction 5m
Speaker: Petr Navratil (TRIUMF)

08:35 → 09:50 ARIEL Science

08:35 Theory 15m
Speaker: Nicole Vassh (TRIUMF)

09:00 BeEST 10m
Speaker: Annika Lennarz (TRIUMF)

09:20 ARIEL Science Summary 20m
Speaker: Adam Garnsworthy (TRIUMF)

09:50 → 10:05 Science now and future

09:50 Scientific Computing 10m
Speakers: Reda Tafirout (TRIUMF), Wojciech Fedorko (TRIUMF)

10:05 → 10:35 Break 30m

10:35 → 11:00 Science now and future

10:35 Science & Technology 15m
Speaker: Nigel Hessey (TRIUMF)

11:00 → 12:10 Detector Center (What is existing, what is planned, SciTech vs Center, what do we want in the next 5YP)

11:00 Input from Particle Physics, Nuclear Physics, CMMS, Life Sciences 20m
Speakers: Cornelia Hoehr (TRIUMF), Greg Hackman (TRIUMF), Kenji Kojima (TRIUMF), Luise Poley (TRIUMF)

11:45 Detector Center 15m
Speaker: Fabrice Retiere (TRIUMF)

12:10 → 13:00 Lunch 50m

13:00 → 14:10 Quantum Center (What is existing, what is planned, what do we want in the next 5YP)

13:00 Input from Nuclear Physics, CMMS, Accelerator, Particle Physics 25m
Speakers: Jens Lassen (TRIUMF Canada's particle accelerator centre), Makoto Fujiwara (TRIUMF), Sarah Dunsiger (TRIUMF / Simon Fraser University), Stephan Malbrunot-Ettenauer (CERN)

13:40 Quantum Center 15m
Speaker: Dr Chloé Malbrunot (TRIUMF)

14:10 → 14:25 AI Center

14:10 AI Center 5m
Speaker: Wojciech Fedorko (TRIUMF)

14:25 → 14:55 Break 30m

14:55 → 16:55 Science now and future

14:55 Nuclear theory (non-ARIEL) 15m
Speaker: Jason Holt (TRIUMF)

15:15 Nuclear Physics (non-ARIEL) 15m
Speaker: Barry Davids (TRIUMF)

15:40 CMMS (non-Quantum) 15m
Speaker: Iain McKenzie (TRIUMF)

16:10 Particle Theory 15m
Speaker: David Morrissey (TRIUMF)

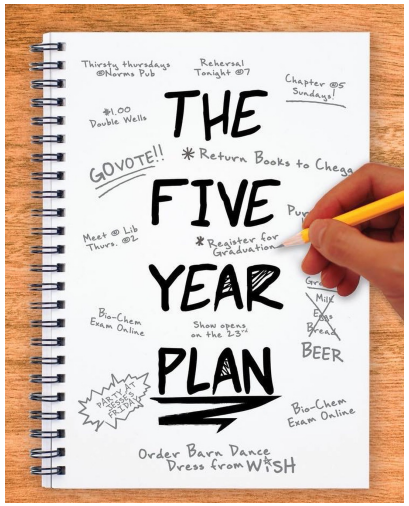
16:35 Particle Physics 20m
Speaker: Oliver Stelzer-Chilton (TRIUMF)

17:00 → 17:05 Close Out 5m
Speaker: Petr Navratil (TRIUMF)

Physical Sciences Division planning process for 5YP 2025-2030

- Development of the TRIUMF Five Year Request for Support (2025 – 2030) document ongoing
  - Presented to ACOT and Board of Governors
  - TRIUMF's Key Operational Themes
    - Delivering new infrastructure for scientific impact
    - Ensuring operational excellence
    - Training the diverse talent of tomorrow
    - Refurbishing legacy facilities
    - Evolving TRIUMF's program towards the future
  - Substantial incremental request will be submitted
    - More than 50% increase of the current funding, which is $292M ($267M+$25M)
  - Request to PSD experiments to provide input on:
    - What exciting science results can be achieved by 2030?

All Three Science Divisions

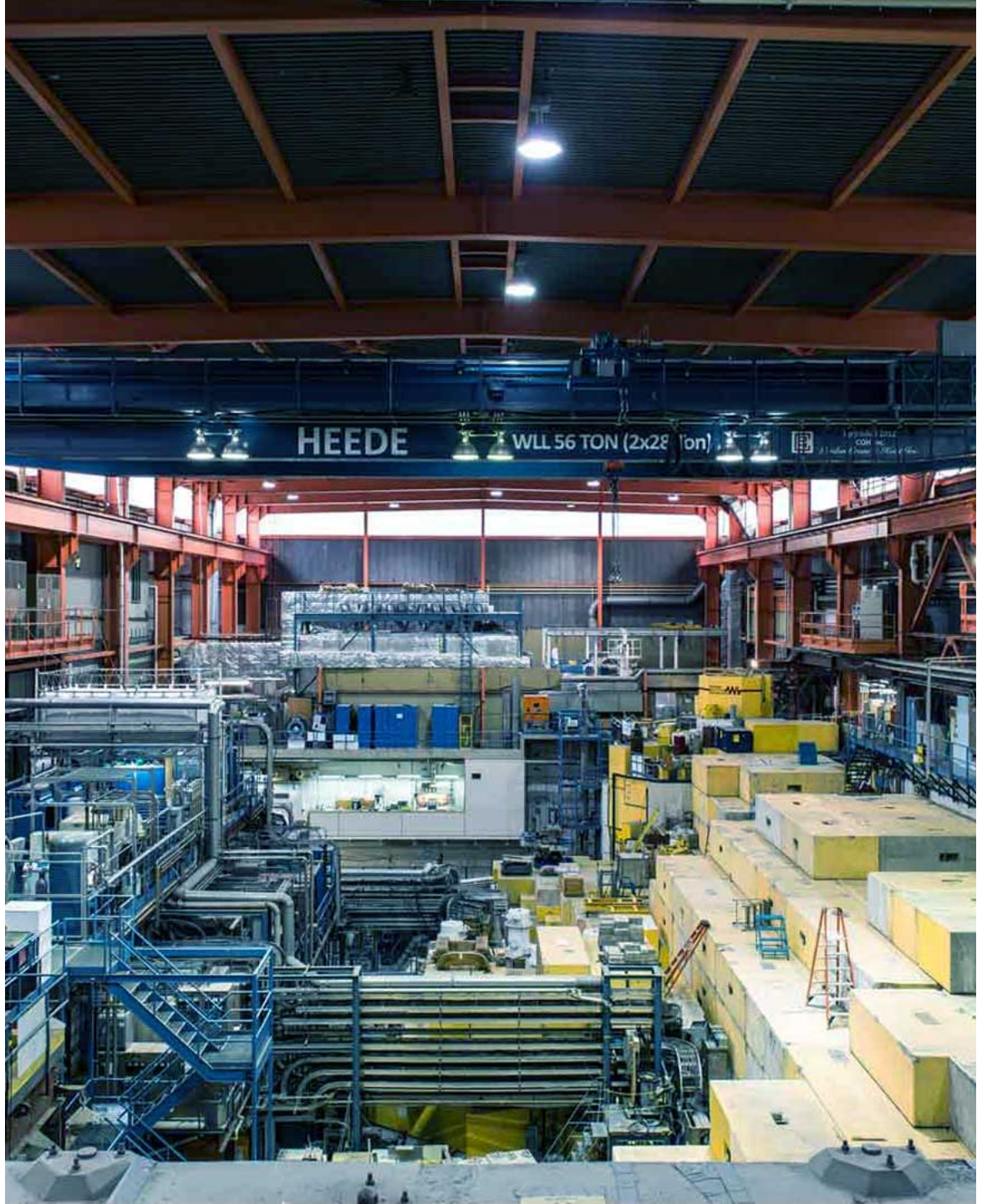


Exciting science results by 2030

World leading experiments exploring the time-reversal and CP violation

- shedding light on the matter-antimatter asymmetry in the Universe, one of the greatest challenges in physics

Radioactive Molecule Program



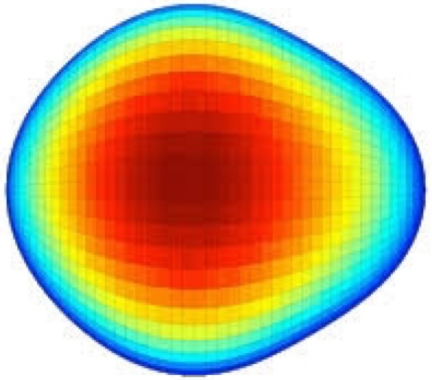
Radioactive Molecules

… for searches for CP-violating nuclear Schiff moment

^{199}Hg present 'gold standard'

$|d_{Hg}| < 7.4 \cdot 10^{-30}$ e cm (95% confidence limit)

$|S_{Hg}| < 3.1 \cdot 10^{-13}$ e fm^3 *B. Graner et al., Phys. Rev. Lett. 116, 161601 (2016)*



Enhancement factors in our approach:

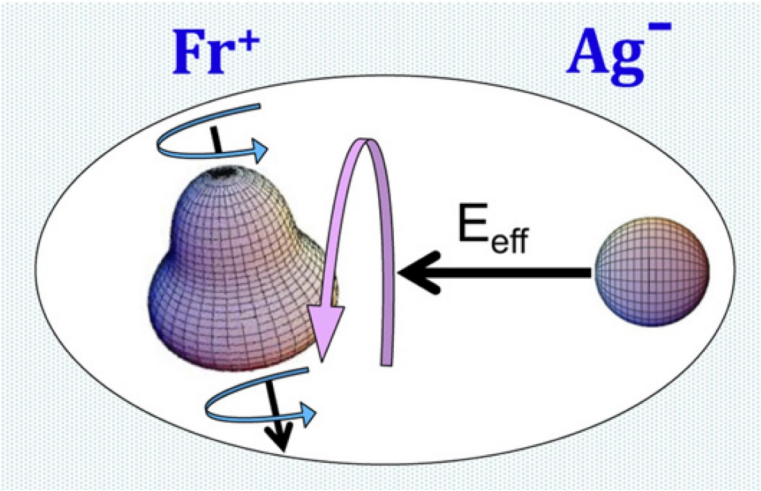
- **octupole** deformed nuclide $\times 10^2$-10^3
- in polar molecule $\times 10^3$-10^4 } compared to ^{199}Hg
- in atom or ion trap $\times 10^3$ compared to beam

all known cases in radionuclides

Example: ^{223}FrAg

- **intrinsic enhancement of 10^7 compared to ^{199}Hg**

V. V. Flambaum and V. A. Dzuba. Phys. Rev. A 101, 042504 (2020)
T. Fleig. private communications with D. DeMille (2022)



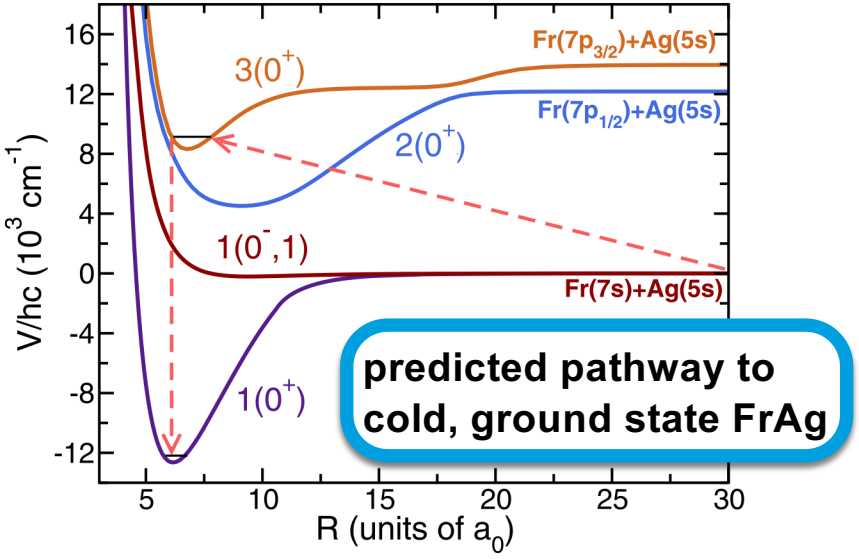
The Case of ^{223}FrAg

Awarded US$2.8 million grant by Gordon and Betty Moore Foundation

- **Schiff moment:**
  - **intrinsic enhancement of 10^7 compared to ^{199}Hg**
  - **"x1000 improved measurement by 2030"**

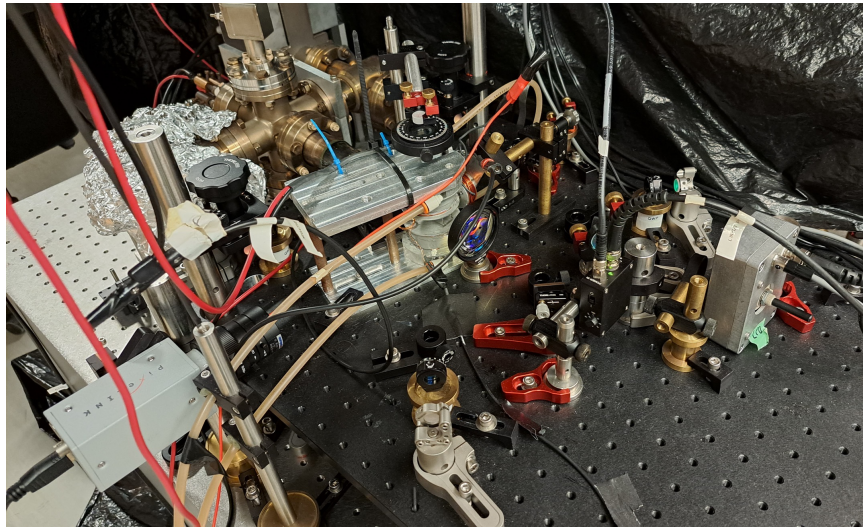
ARIEL enabled

- ultracold molecule assembled from laser-cooled Fr and Ag atoms
- ^{223}Fr ($T_{1/2}$=22 min) at ISAC: 1.3 · 10^7 ions/sec
- infrastructure and expertise at TRIUMF's Fr trapping facility
- first exp. goal: measurement of Fr s-wave scattering length
  - input to form ultracold Fr approaching Bose Einstein Condensate
  - determined from two-colour photoassociation (2PA)

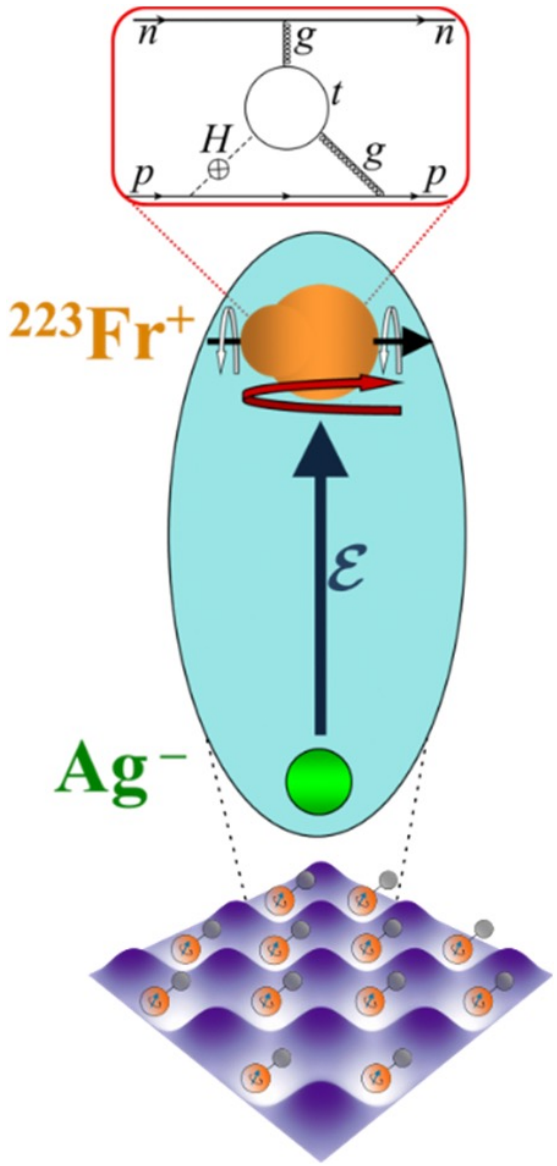


predicted pathway to cold, ground state FrAg

J Kłos et al., New J. Phys. 24, 025005 (2022)



Offline MOT setup at UBC to develop 2PA with low atom number

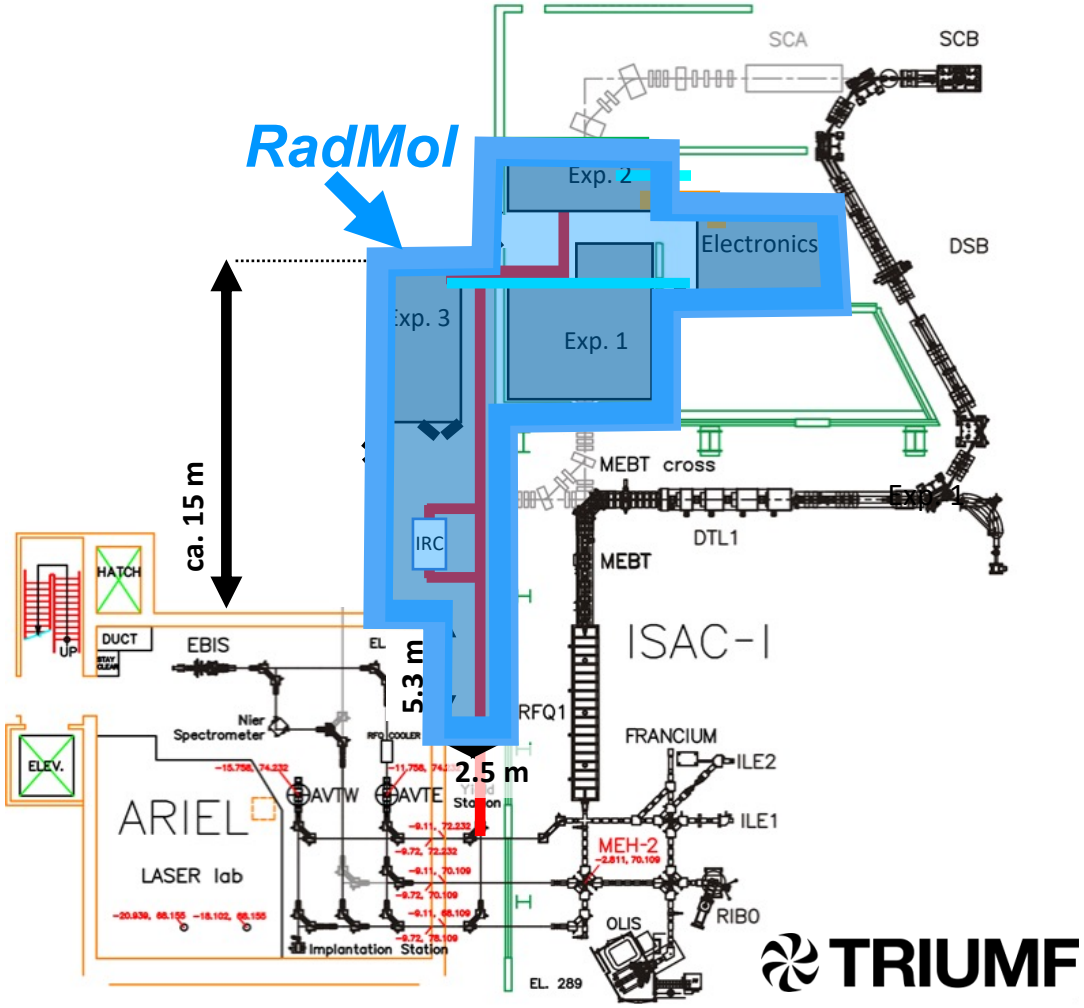


Alan Jemison's talk on Thursday

RadMol - long term plan

ARIEL enabled

a radioactive molecule lab for fundamental physics



Goal:

- dedicated laboratory to study of radioactive molecules
- to host 3 experimental stations
- precision studies for searches for new physics
- Molecular EDM with unprecedented sensitivity to nuclear T-breaking Schiff moments
- provision for expansions into other fields

TRIUMF advantages:

- large variety in radioactive ion beams (RIB)
- high beamtime availability (3 independent RIBs)
- existing laboratory space for large, multi-station program

Current Canadian Team:

- 12 faculty and staff physicists

RadMol Collaboration

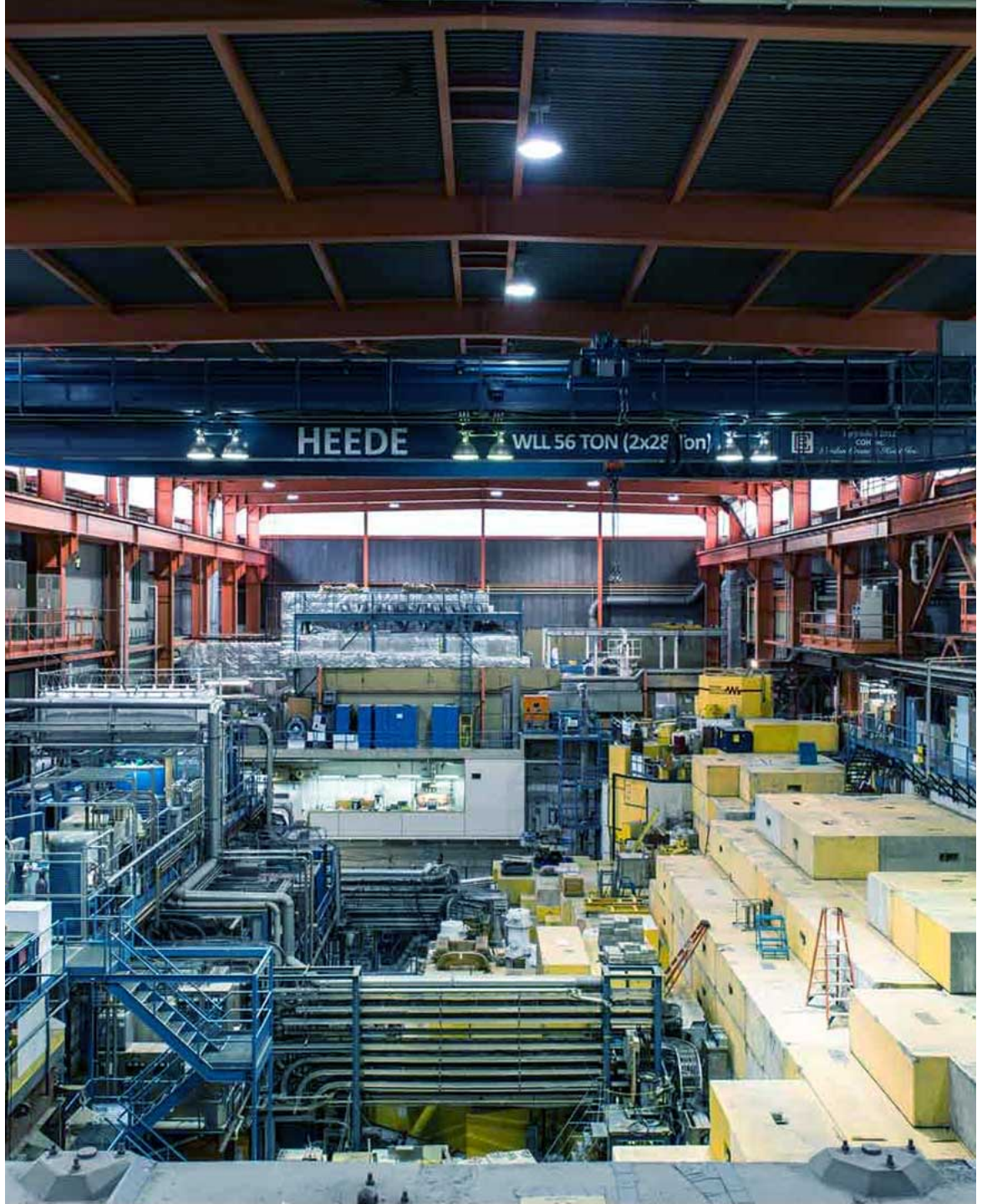
University of Toronto, UBC, University of Manitoba, uOttawa, University of Waterloo, TRIUMF, McGill, Uni Kassel, Manchester, University of Chicago, KU Leuven, Philipps Universität Marburg, MIT

Exciting science results by 2030

World leading experiments exploring the time-reversal and CP violation

- shedding light on the matter-antimatter asymmetry in the Universe, one of the greatest challenges in physics

Ultra-Cold Neutron (UCN) Program neutron EDM & lifetime



TUCAN
TRIUMF Ultra Cold
Advanced Neutron source

UCN

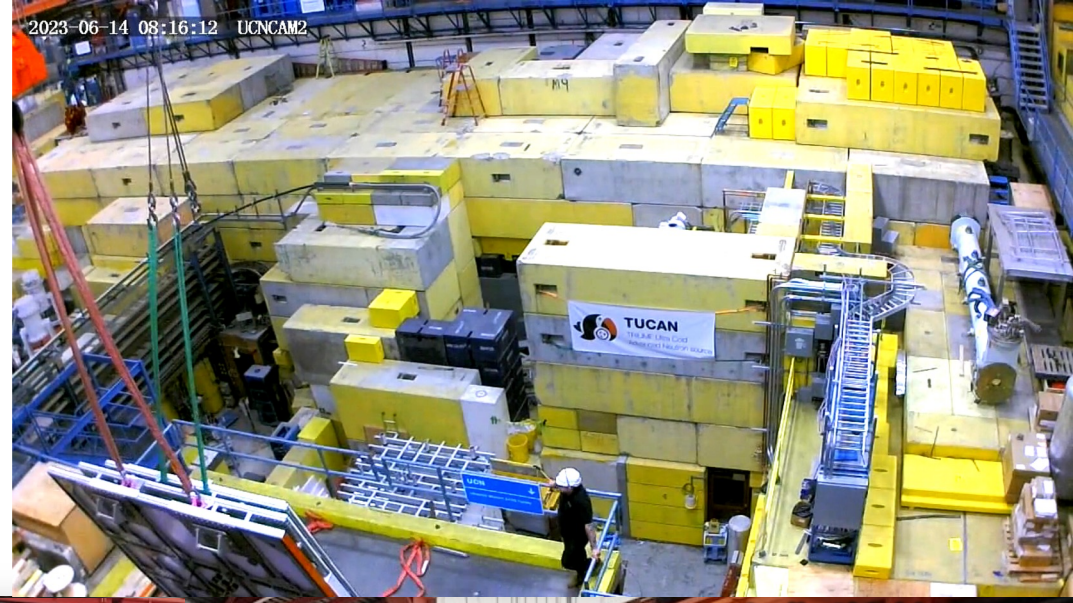
Progress towards the world's strongest ultracold neutron source

Liquid He transfer & return lines tested

EDM storage cell tests at J-PARC completed

Magnetically Shielded Room for EDM experiment taking shape

First cryo testing September 2023, UCN production planned for 2024
nEDM data taking starting in 2025



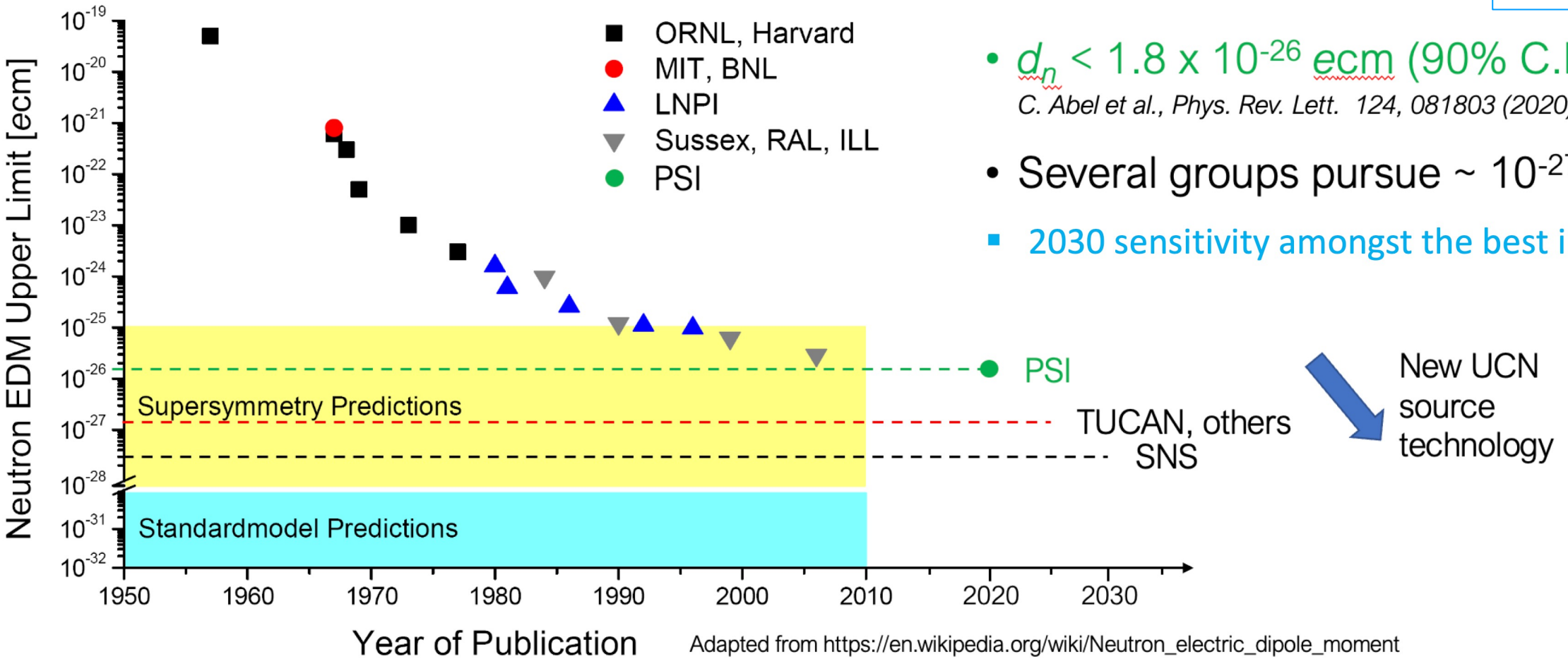
Liquid helium transfer line

Magnetically Shielded Room

TUCAN - EDM

- EDM experiments essentially search for sources of CP violation beyond the standard model.
- Lowering EDM limits seriously restricts BSM theories.

BL1A enabled



- $d_n < 1.8 \times 10^{-26}$ ecm (90% C.L.)
  C. Abel et al., Phys. Rev. Lett. 124, 081803 (2020)
- Several groups pursue ~ 10^{-27} ecm,
  - 2030 sensitivity amongst the best in the world!

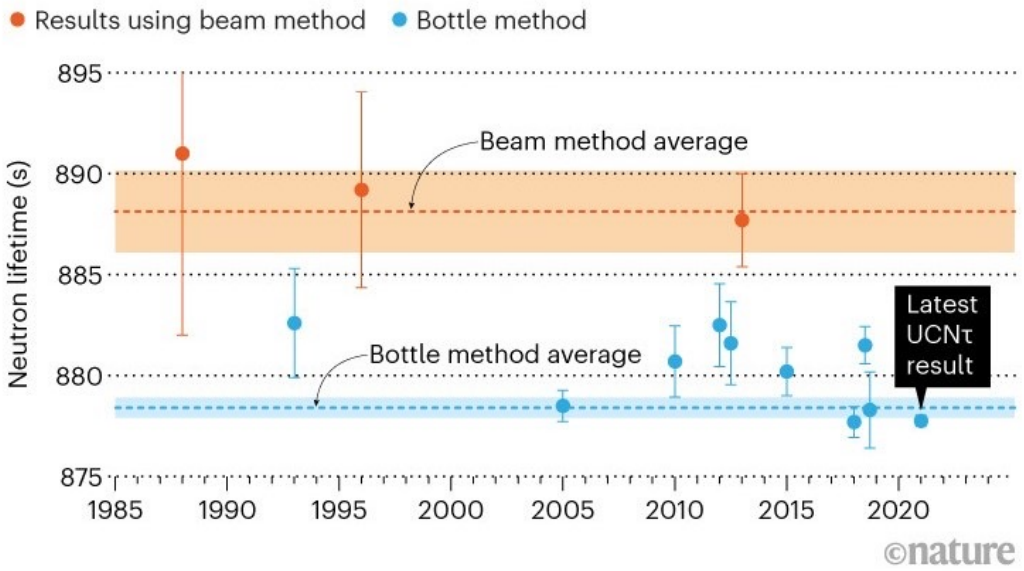
Adapted from https://en.wikipedia.org/wiki/Neutron_electric_dipole_moment

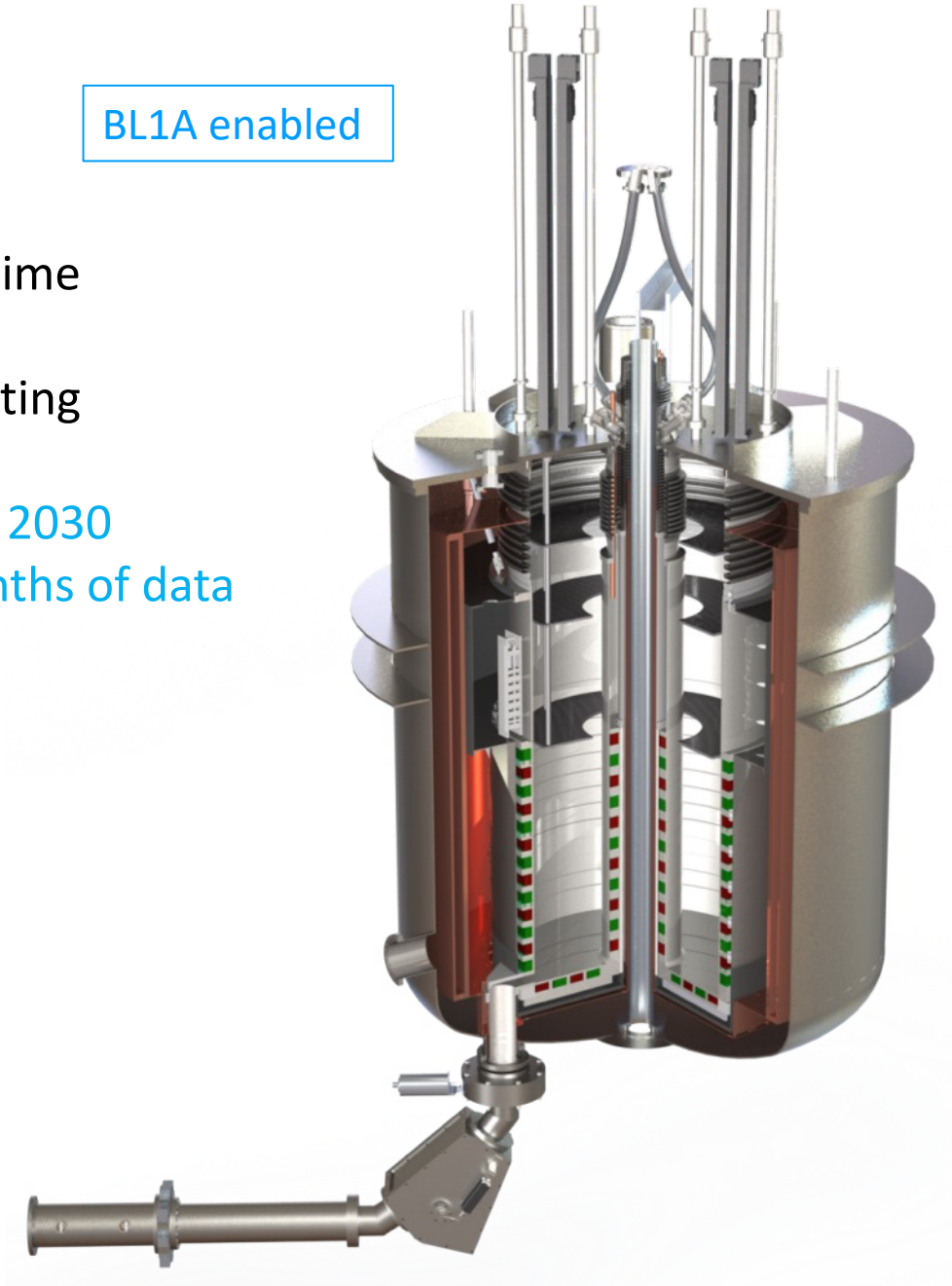
Discovery, accelerated

Neutron Lifetime Measurement

BL1A enabled

- PENeLOPE (Precision Experiment on the Neutron Lifetime Operating on Proton Extraction)
- Using magneto gravitational storage in a superconducting magnet developed at TU Munich
- Utilizing 2nd port of the UCN source seems feasible by 2030
- Worlds best <0.1s measurement only requires ~2 months of data





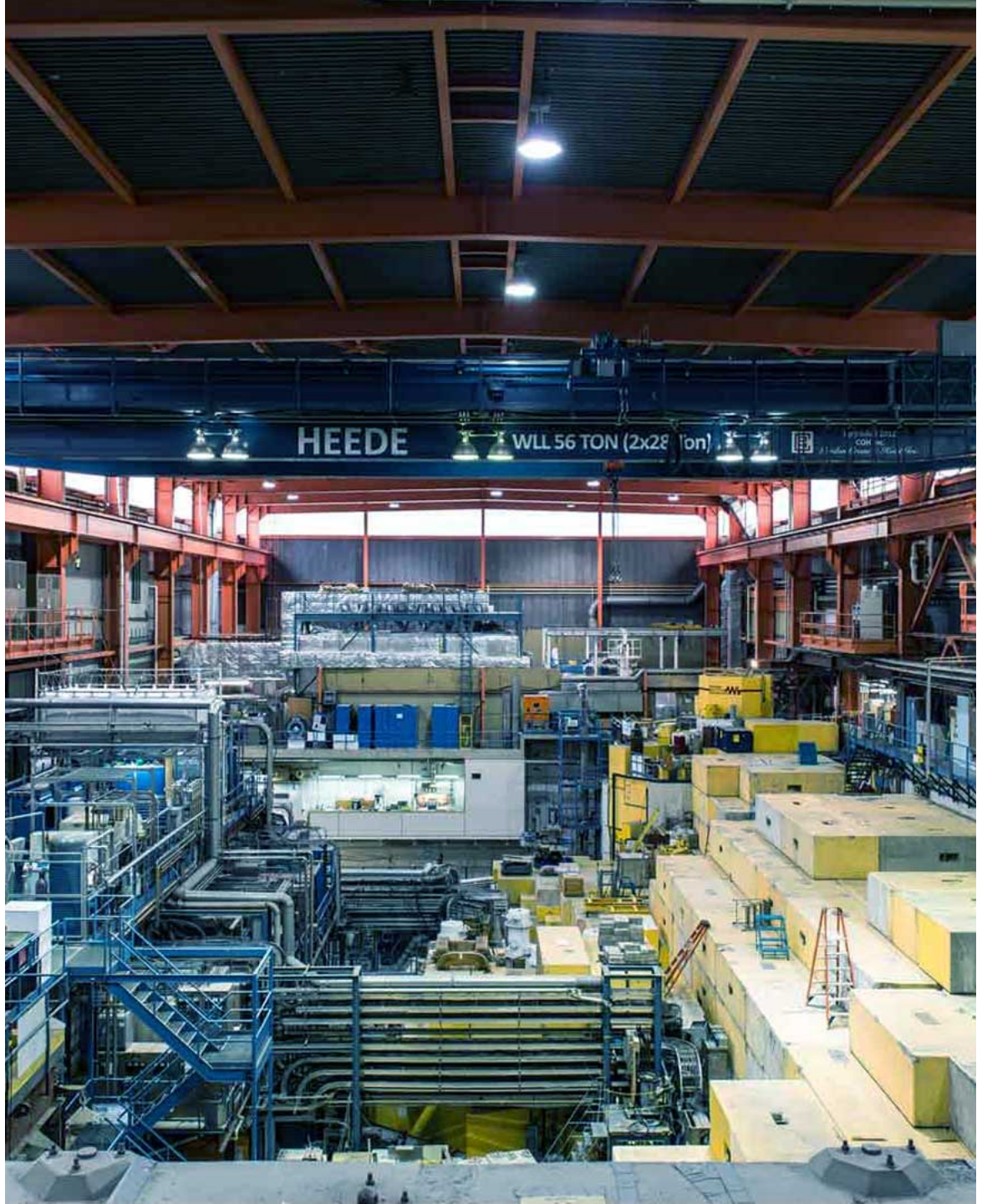
Discovery, accelerated

Exciting science results by 2030

World leading experiments exploring the time-reversal and CP violation

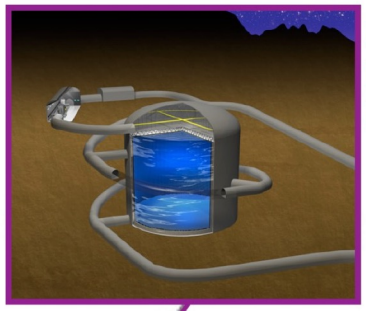
- shedding light on the matter-antimatter asymmetry in the Universe, one of the greatest challenges in physics

Hyper-Kamiokande (Hyper-K) experiment probes the CP symmetry violation in the neutrino oscillations



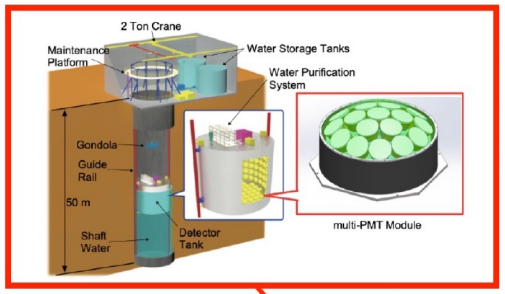
T2K / Hyper-K

New water Čerenkov "intermediate" detector (IWCD) under TRIUMF leadership

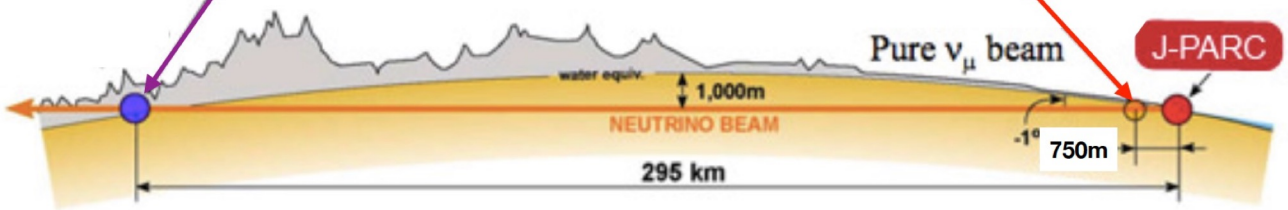


Hyper-Kamiokande Detector

~185 kton fiducial mass

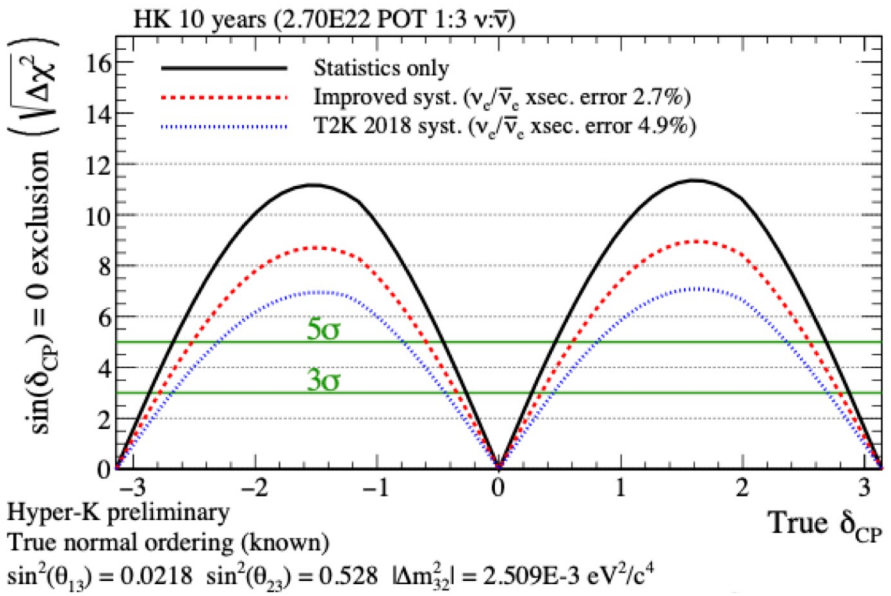


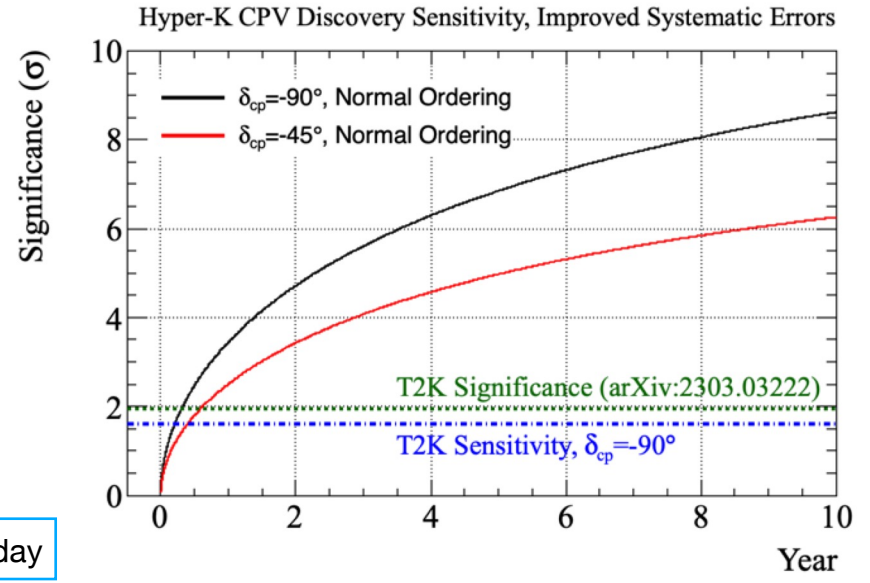
Intermediate Water Cherenkov Detector



- Major goal is the search for CP violation in neutrino oscillations!
- 2020 T2K reported 2σ hint in nature!
- 2030 will be 2 years of Hyper-K data taking! – significance depends on δ_{CP}
- Will also make precise measurements of parameters governing oscillations Θ_{13}, Θ_{23}, Δm^2_{32}

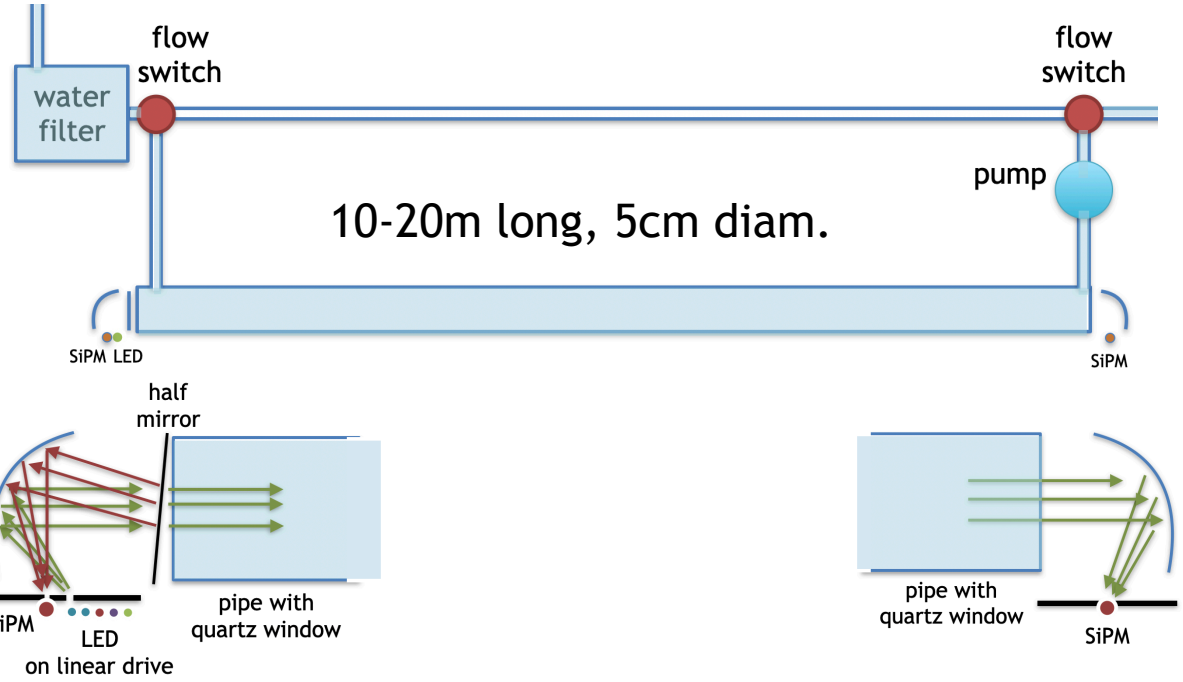
Xiaouye Xi's talk on Tuesday

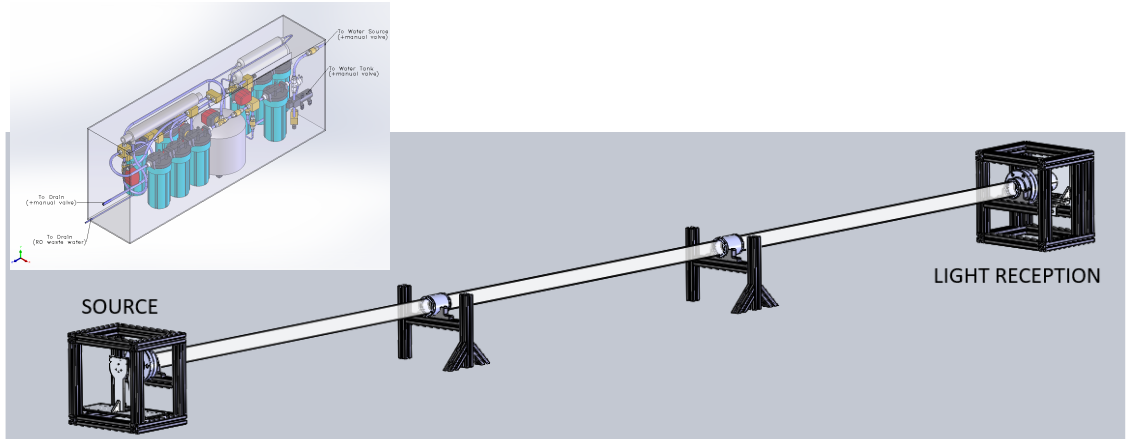




Discovery, accelerated

Water monitoring project – based on technology developed for the Hyper-K detector





- In-line continuous monitoring of the water
- Pulsed LED light through 10-20m sample water
  - 230 - 700nm
  - parabolic mirror focus
  - Relative measurement by SiPM at source/reception
- Relative to purified water
  - ultra-pure (RO)
  - particle filter (MF,NF)
  - ion exchange resins
  - UV steriliser (organic)

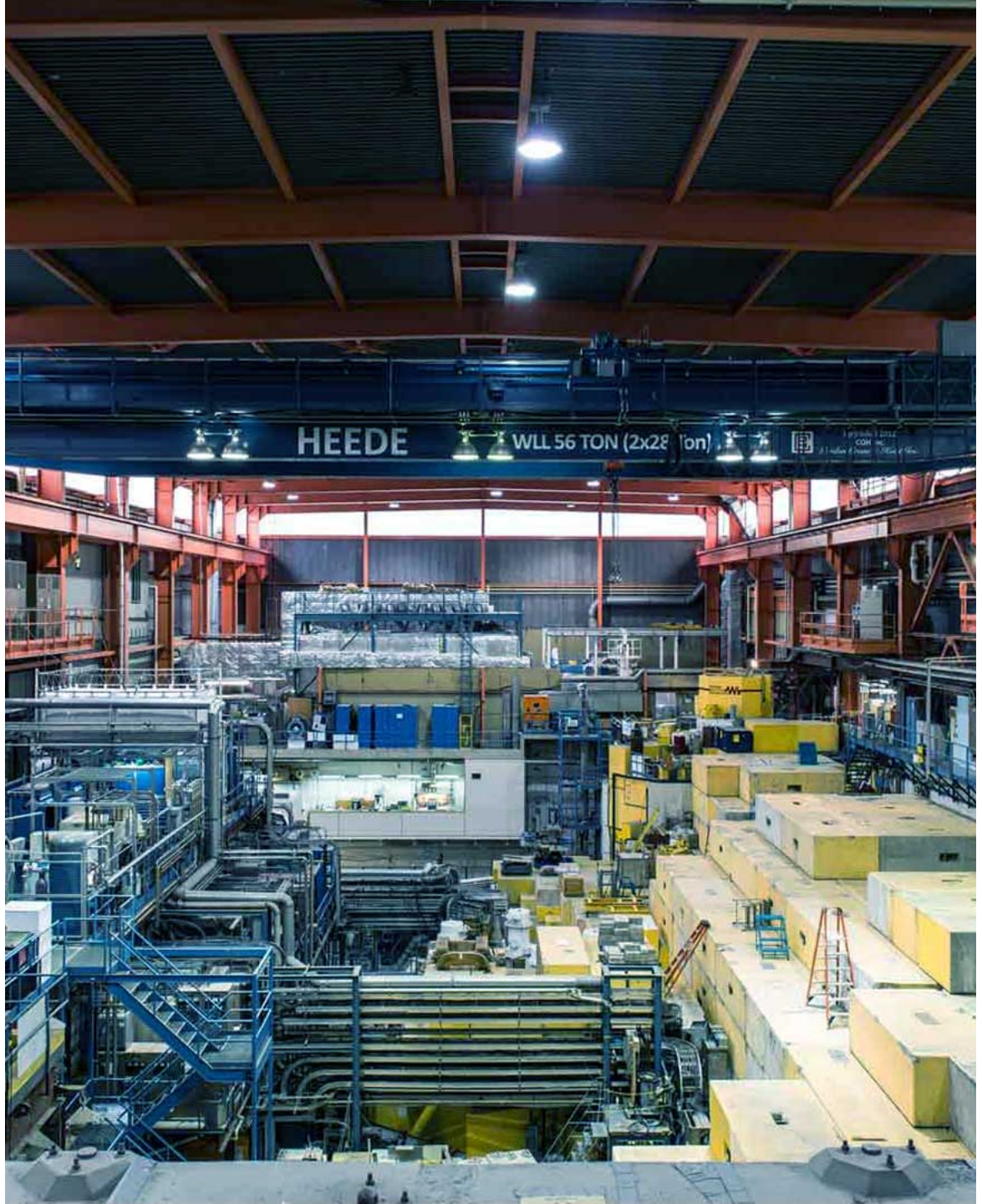
Akira Konaka's session on Wednesday

Exciting science results by 2030

Sterile neutrino searches at ARIEL

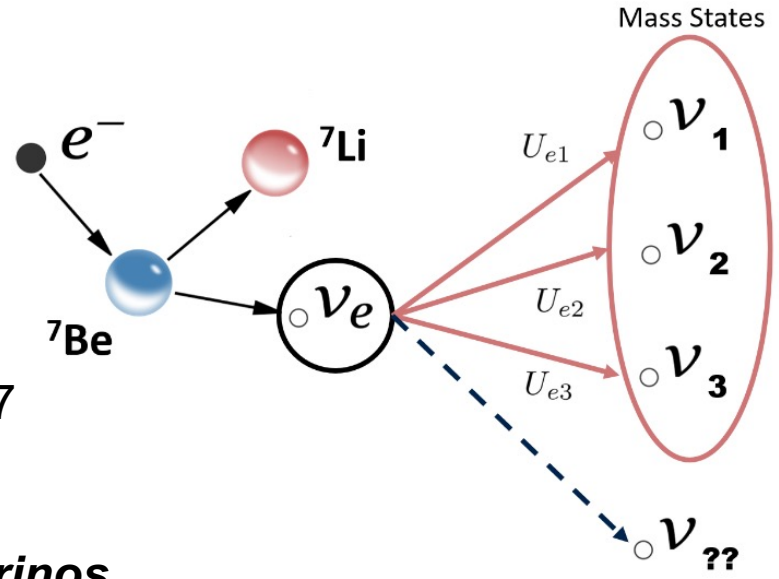
BeEST (Beryllium Electron-capture with Superconducting Tunnel junctions) experiment

Quantum sensing technology of superconducting tunnel junction radiation detectors (STJs) – new exciting science opportunities at ARIEL



The BeEST – Beryllium Electron-capture with Superconducting Tunnel junctions

- The BeEST experiment searches for **sterile neutrinos in the keV mass range** using the **nuclear electron capture decay of ^{7}Be** implanted into superconducting tunnel junction (STJ) radiation detectors
- **Pure two-body final state that consists of the recoiling daughter nucleus and the emitted ν_e**
- ^{7}Be is ideal candidate because of its:
  - pure two-body final state
  - Relatively large decay energy (862 keV)
  - Relatively high recoil energy (~ 50 eV)
  - Simple atomic and nuclear structure
- Measurement uses **momentum reconstruction** of the ~eV-scale lithium-7 **nuclear recoil** energy spectrum following neutrino emission



➔ ***Only relies on existence of heavy neutrino admixture to active neutrinos. Not on model-dependent details of their interactions!***

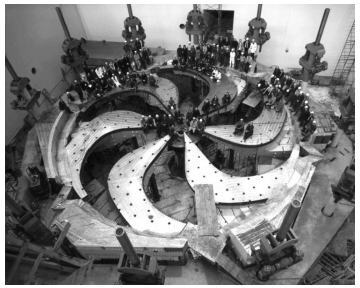
By making a precision measurement of the low-energy recoiling atom, information on momentum conservation with the neutrino can be directly probed!

Synergy with TRIUMF particle theory

The BeEST - Experimental Concept

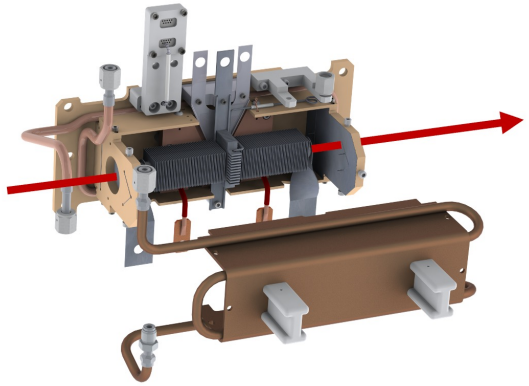
Annika Lennarz's talk on Thursday

ARIEL enabled



480 MeV p+ beam produced in cyclotron

UC_x production target

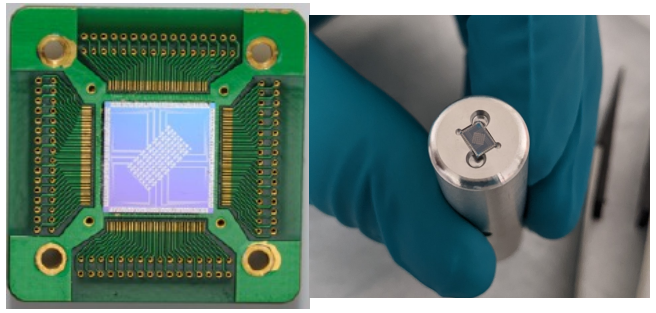


Laser ionization

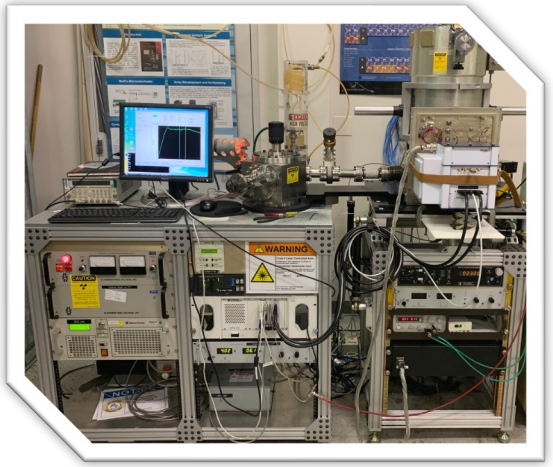
^7Be ($T_{1/2}$ = 53 d)

20 - 30 kV acceleration

Implant into Superconducting Tunnel Junction (STJ) Sensors at TRIUMF-ISAC

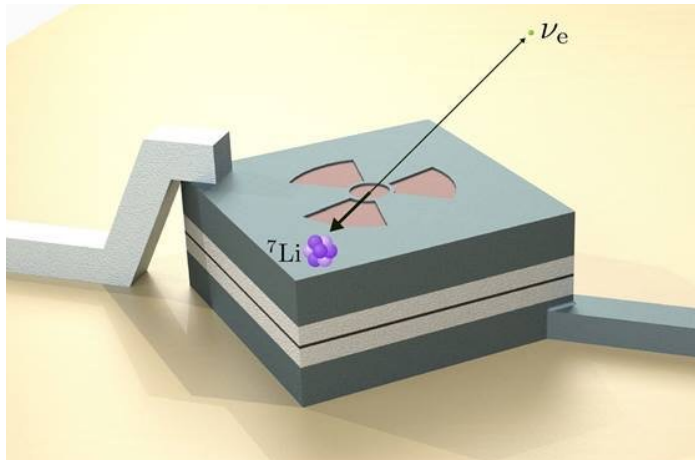


Cool to < 100mk in an Adiabatic Demagnetization Refrigerator.

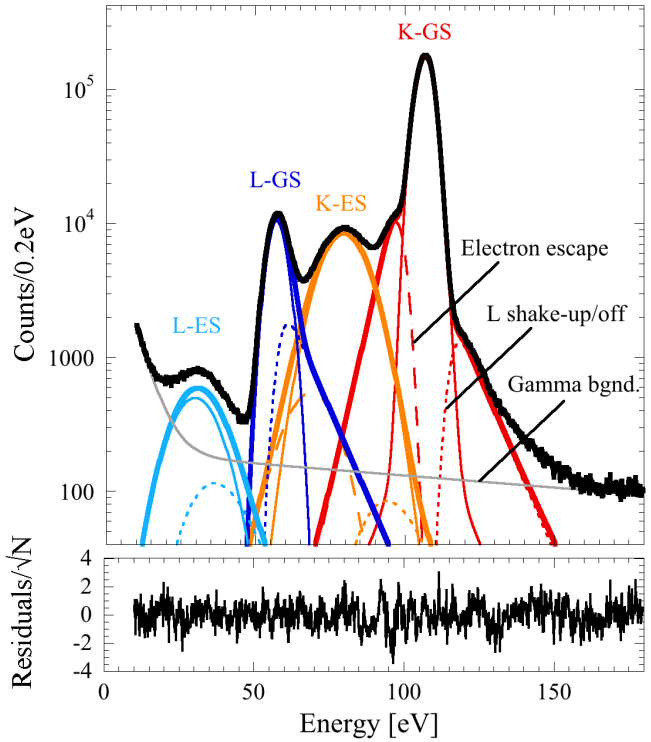


Lawrence Livermore National Laboratory

Measure eV-scale nuclear recoils from ^7Be EC decays in STJ sensors at LLNL.

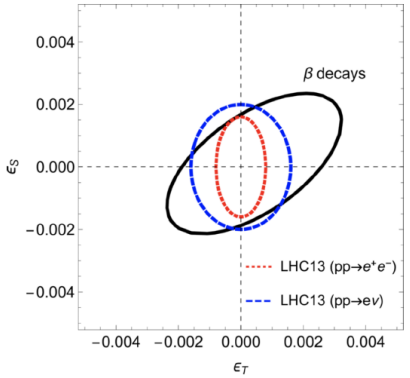


The BeEST has already obtained the **best laboratory mixing limits** in the range between 100–800 keV, **ARIEL enables improving these limits by 3 orders of magnitude**



Fully Explore the Extensive Nuclear Toolbox with STJs

THE BeEST



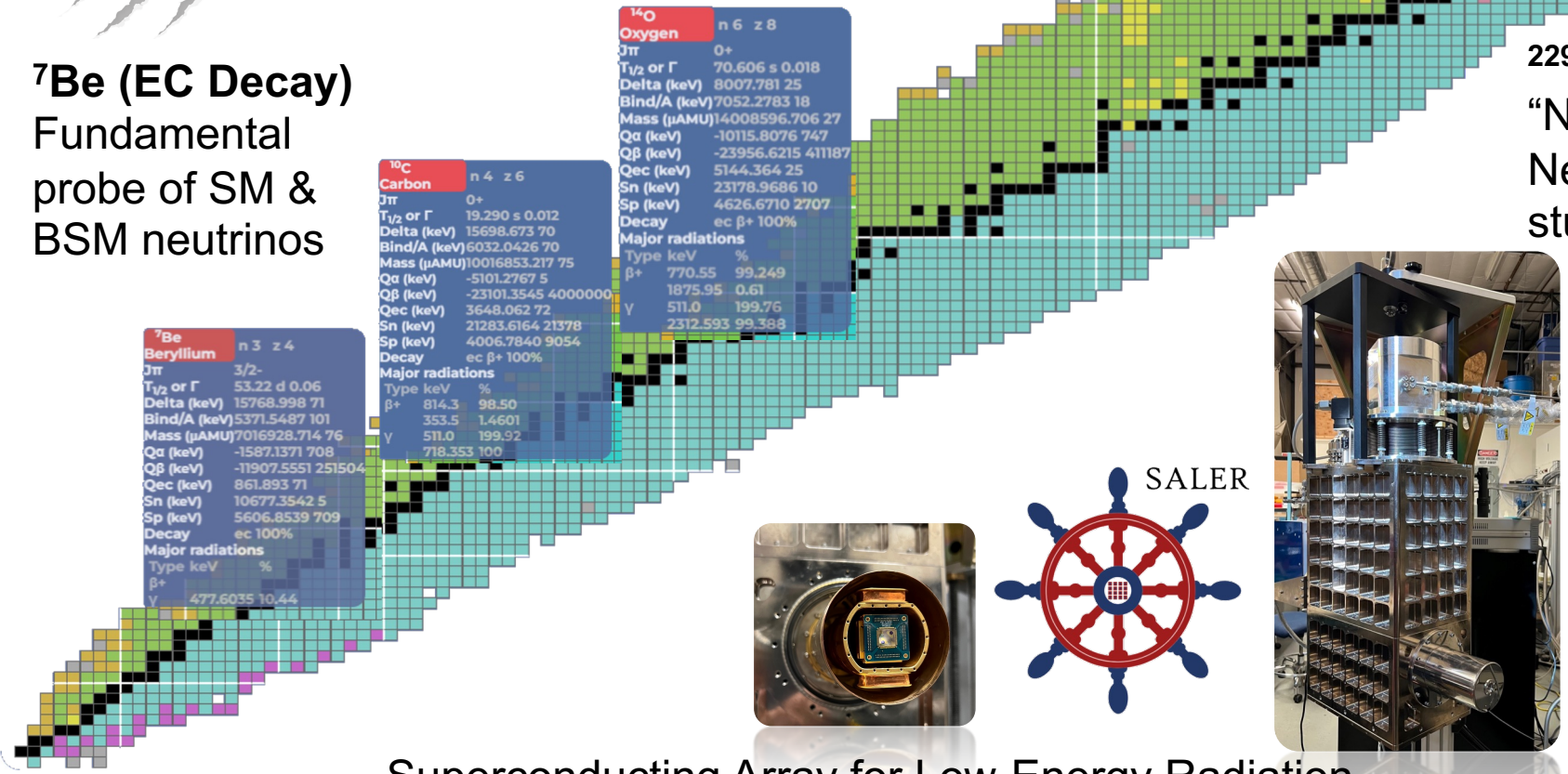
N≈Z Systems (β⁺ Decay)
Most sensitive laboratories for CKM unitarity tests and searches for exotic currents (~10 TeV scale)

$T_{1/2} \leq 1$ min

^{7}Be (EC Decay)
Fundamental probe of SM & BSM neutrinos

^{229}Th (State)
"Nuclear Clock"
Next-generation studies of time

Isomer $T_{1/2} \leq 10$ μs



SALER

Superconducting Array for Low-Energy Radiation

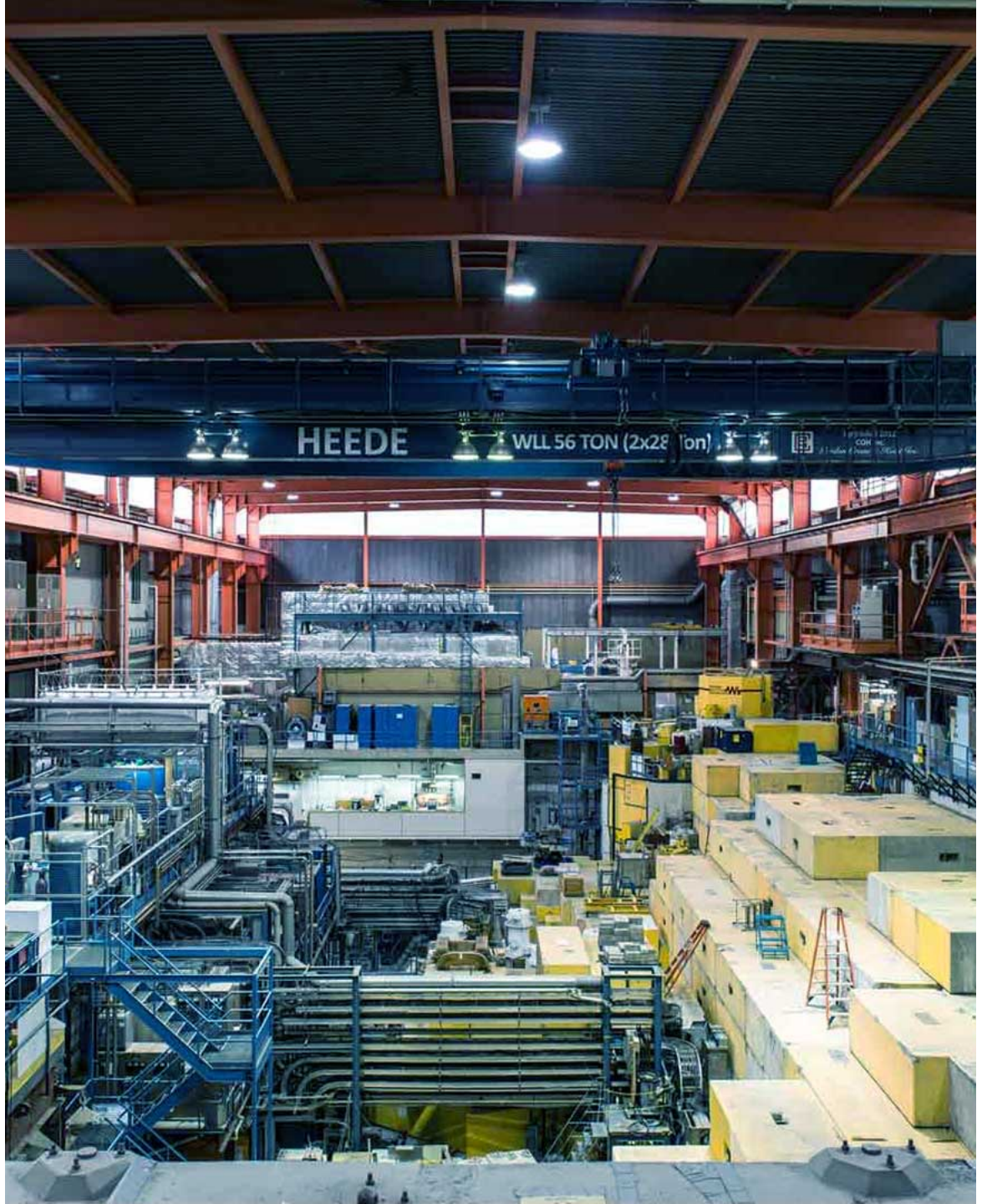
Slide from K. Leach

Exciting science results by 2030

Tests of Fundamental Symmetries at ARIEL

Francium PNC Facility (Fr-PNC)

TRINAT (neutral atom trap)

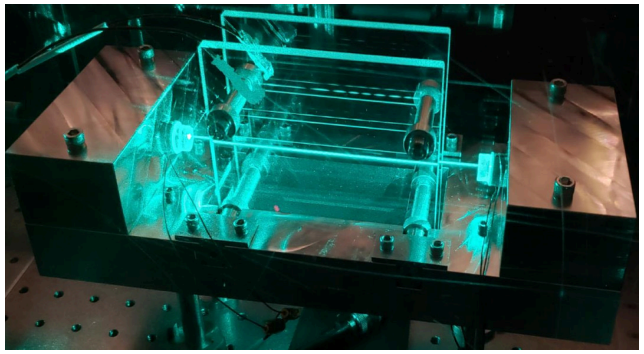


Precision RIB Measurements / Fundamental Symmetries

ARIEL enabled

Francium PNC Facility (Fr-PNC)

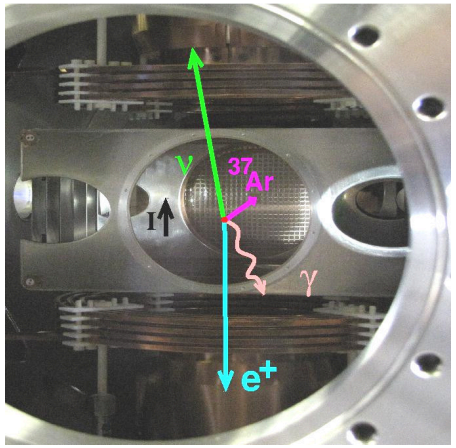
- Currently at level of E1/M1 Stark transition measurement → Sensitivity & methodology proven
- Atomic Parity-violating signal expected 2024
- APV measurement competitive with others, 2025+
  - Competitive electron-quark neutral weak coupling + nuclear anapole – higher momentum transfer → sensitivity to different BSM physics
- These measurements need maximum yields of $^{208\text{-}213}$Fr → n-dependent effects



FRANCIUM UHV Power Buildup Cavity
(T. Hucko, ACOT 2021)

TRINAT (neutral atom trap) → TRINAT-γ

- Extend β-ν-γ from T-reversal symmetry breaking in ^{37}K (expected finished in current 5YP)
- Consider isospin symmetry-breaking in isospin-suppressed Fermi-GT ^{36,45,47}K for V_{ud}
- Develop case for time-reversal enhancement by isospin-suppressed F-GT → competitive search for Time-breaking, Parity-even isospin-breaking, BSM nucleon-nucleon interactions



TRINAT Trap

Exciting science results by 2030

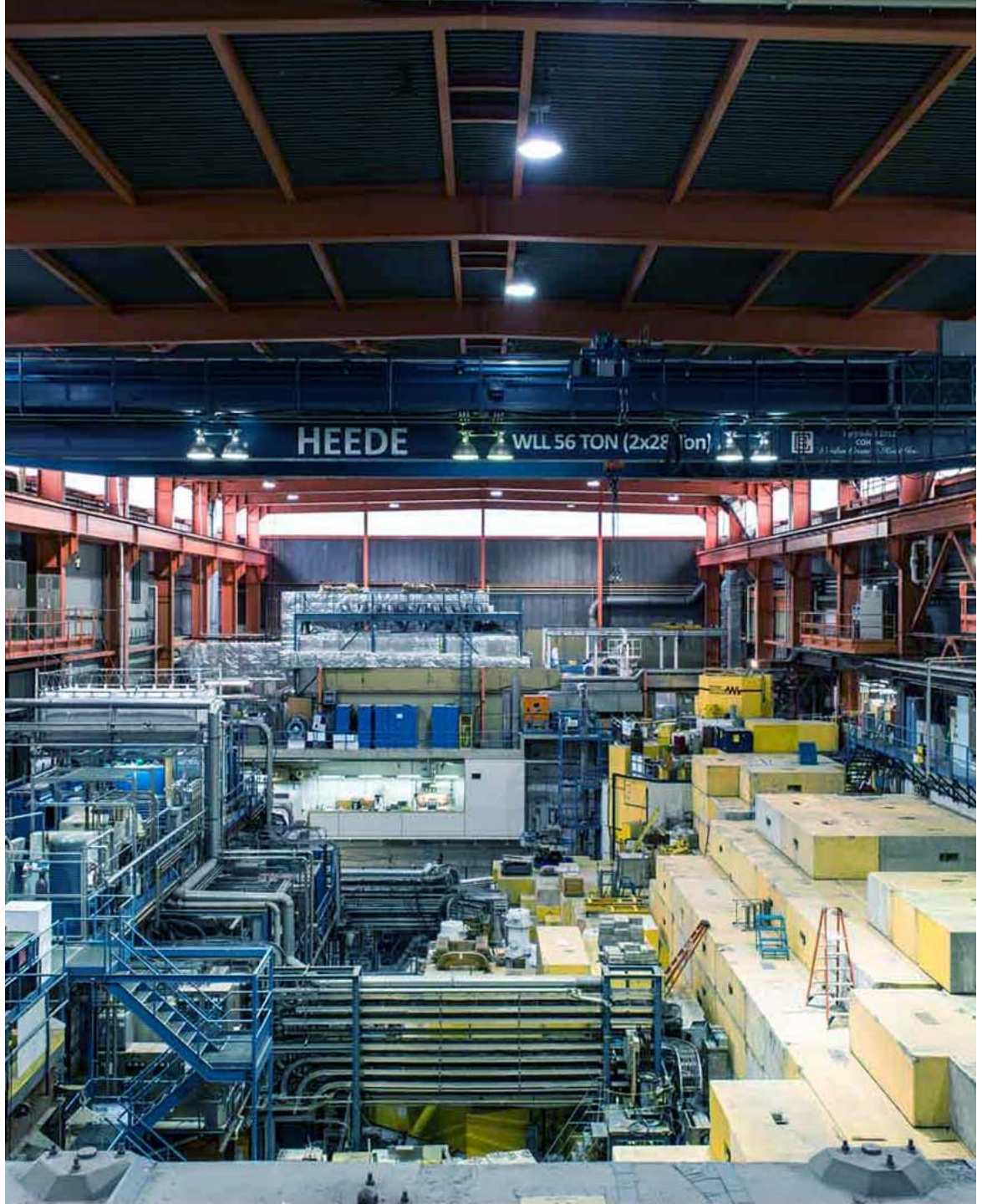
Tests of Fundamental Symmetries, Nuclear Astrophysics & Nuclear Structure Studies at ARIEL

GRIFFIN Decay Spectrometer

TITAN Ion Trap Facility

Understanding of the detailed nature of the nuclear forces and how atomic nuclei emerge from them

How chemical elements are produced in stars and in the Universe?



Greg Hackman's talk on Thursday

Decay Spectroscopy & Mass Measurements: Structure & Fund. Symmetries

ARIEL enabled

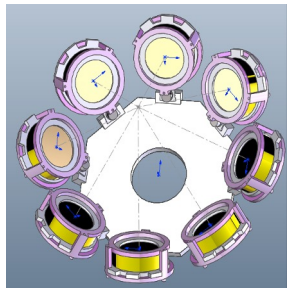
GRIFFIN Decay Spectrometer

- Wide-ranging and active science program in nuclear structure, nuclear astrophysics and fundamental symmetries → continue with ISAC and further ramp up with ARIEL. → New n-rich isotopes, higher yields, cleaner beams
- New upgrades will ensure competitive edge over worldwide competition + enable new science opportunities.
  - Upgrade SCEPTAR beta-tagging array to ARIES.
  - Upgrade PACES conversion electron spectrometer to CEDAR.
  - New RCMP detector (DSSD box built by Uni. of Regina) to enable charge-particle spectroscopy (eg. β-delayed proton and alpha)

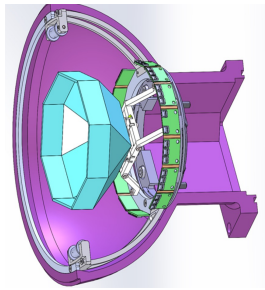
"Everything except the neutrino!"

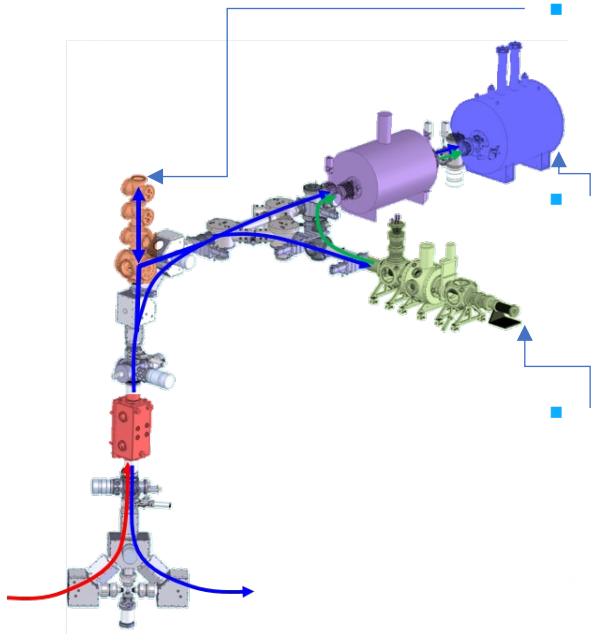
New capability (2025-2030):
Delivery of spin-polarized beams to GRIFFIN

CEDAR

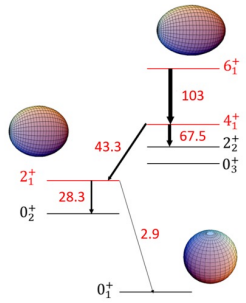


ARIES





Shape coexistence



TITAN Ion Trap Facility

- MR-TOF: Program of measuring r-process nuclei for astrophysics (masses), plus instrument of standard for measuring low intensities from ARIEL
- MPET (Penning Trap): Precision mass measurements, v. high precision (1:1E+10) of heavy superallowed β-emitters → V_{ud}
- EBIT (highly-charged ions)
  - In-trap decay spectroscopy: nuclear structure & Astro
  - Extreme UV spectroscopy → absolute charge radii of heavies (e.g. Fr, Ra) for EDMs
  - Highly-charged radioactive molecules: establishing existence → RadMol facility

Nicole Vassh's and Ali Mollaebrahimi's talks on Monday

Ragnar Stroberg's talk on Thursday

Synergy with TRIUMF *ab initio* nuclear theory and r-process modeling

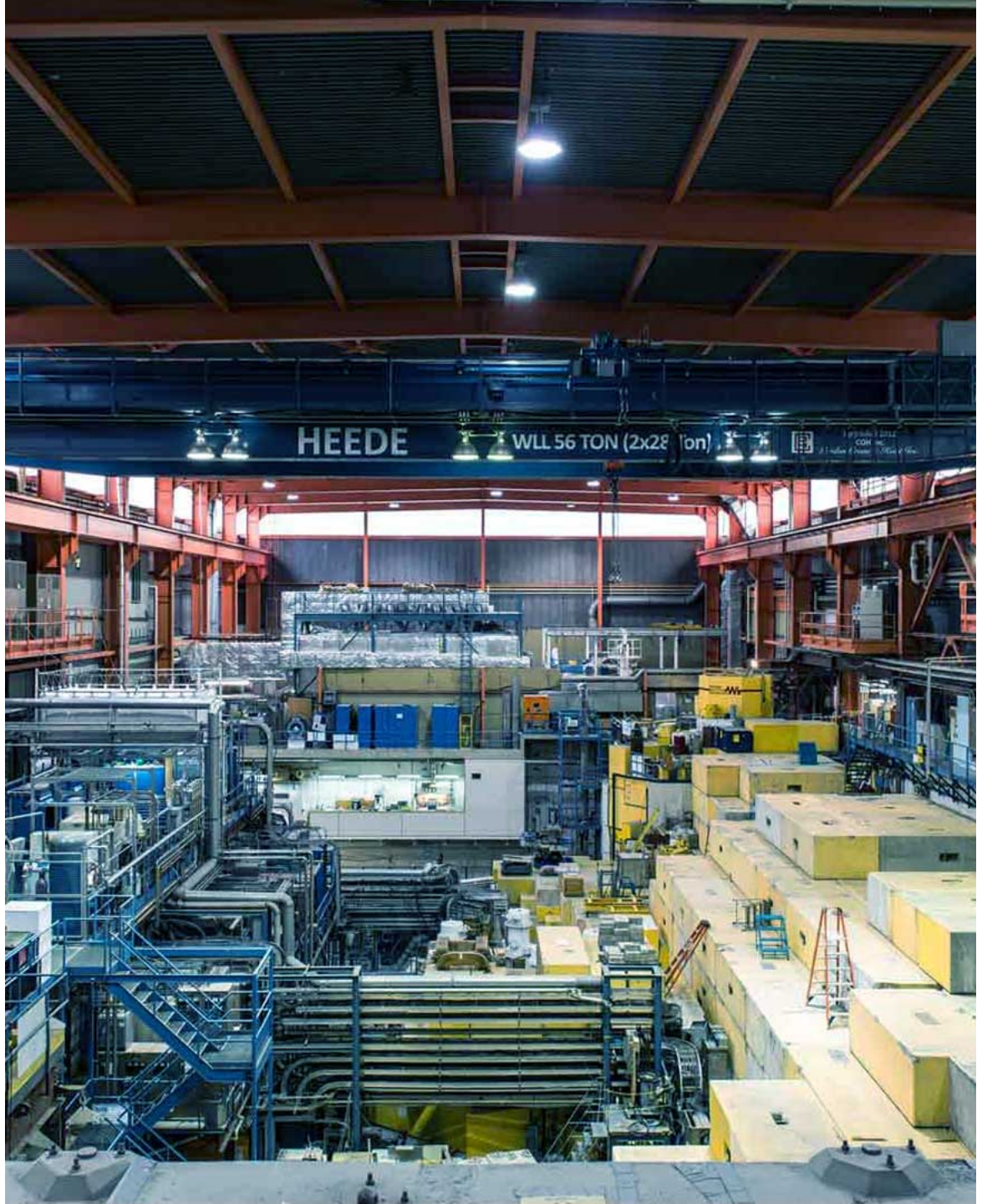
Exciting science results by 2030

Nuclear Astrophysics & Nuclear Structure Studies at ARIEL

DRAGON/TUDA/SONIK
Astro TPC
TIGRESS and EMMA
IRIS & EXACT TPC

Understanding of the detailed nature of the nuclear forces and how atomic nuclei emerge from them

How chemical elements are produced in stars and in the Universe?



Greg Hackman's talk on Thursday

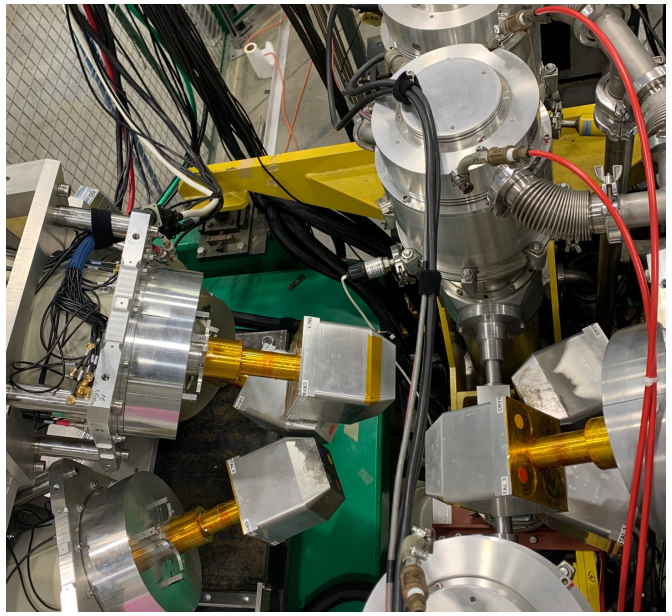
ARIEL enabled

Precision RIB Measurements / Nuclear Astrophysics / Nuclear Structure

DRAGON/TUDA/SONIK

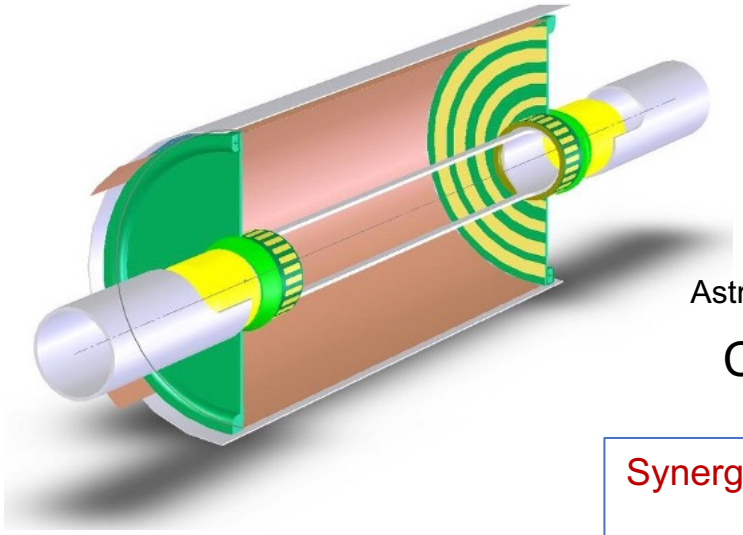
- V. high intensity stable beam experiments with RF-booster cavity
  - Direct capture, low cross-section → weakly bound halo states, astrophysics
- Long RIB runs → statistics, systematics, coverage, completeness
  - Many excited states measured in single run
- New detectors: use of GRIFFIN HPGe, Surrey $LaBr_3$ array, neutron detection at target for (α,n)
  - Eventual development of replacement array for BGO
- Competitive or unique world-standard direct measurements of radiative capture, (p,α), (α,p) + elastic scattering

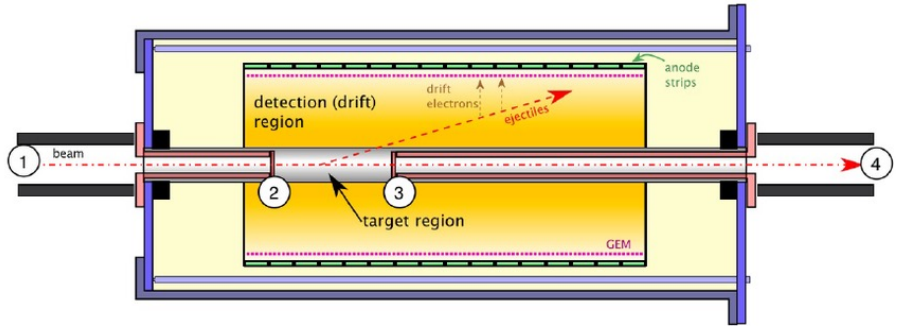
GRIFFIN Clovers @ DRAGON



Astro TPC (formerly known as TACTIC)

- TPC for v. low cross section / high beam intensity
  - V. low energy astrophysics measurements e.g. (p,α), (α,p), (α,n) for light nuclei e.g. Big Bang Nucleosynthesis, CNO etc
  - Modified version for heavy mass
- Co-axial separated design
- New UrWELL GEM technology
- Future → flexible silicon detectors





Astro TPC (York/TRIUMF)

Complete “direct measurement toolkit”

Synergy with TRIUMF *ab initio* nuclear theory and r-process modeling

ARIEL enabled

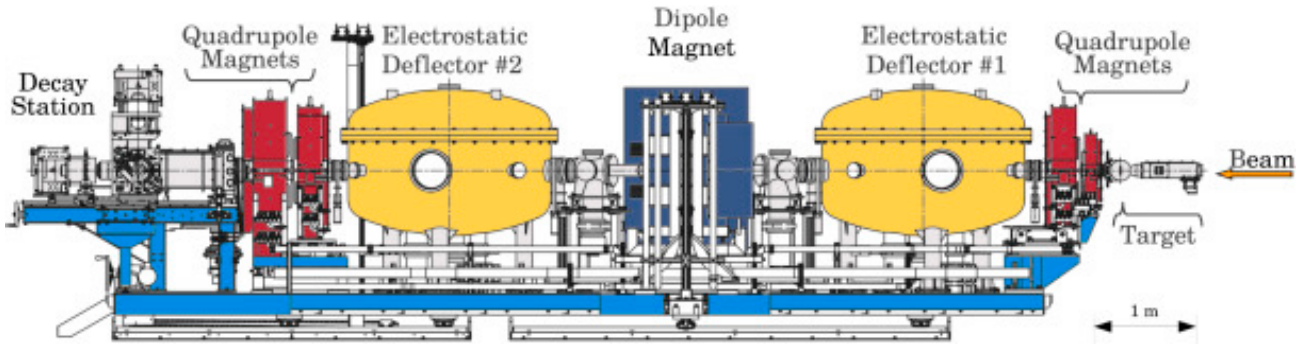
Pioneering & Precision RIB Measurements / Nuclear Structure and Astrophysics

Louis Wagner's talk on Monday

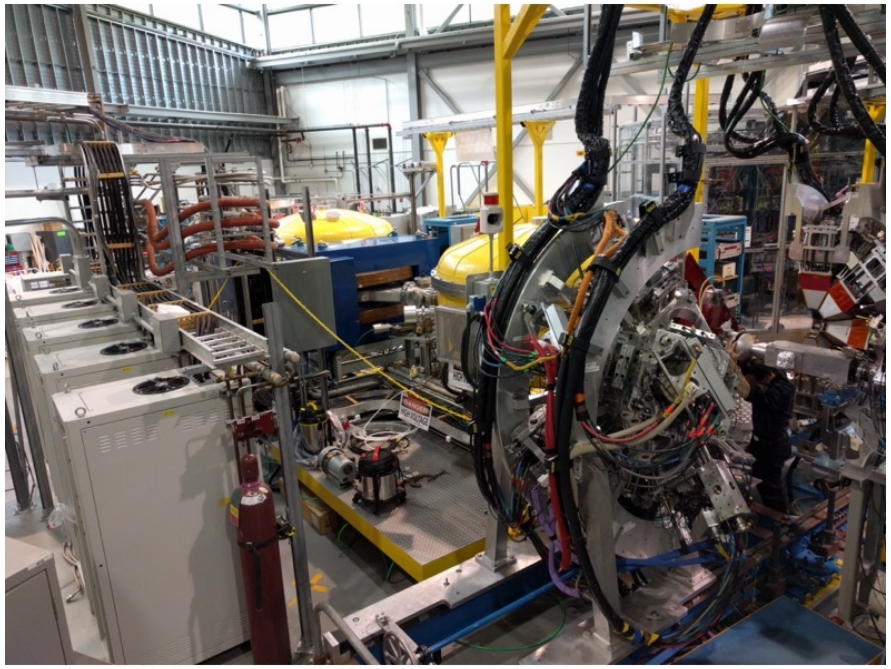
Paul Garrett's talk on Thursday

TIGRESS and EMMA

- Nuclear structure frontiers with RIBs:
  - Isospin: Exoticism, new magic numbers, indications of collectivity, ground states and small number of excited states
  - Precision & Sensitivity: nature of shapes and shape coexistence, microscopic origin of magic numbers, collectivity, rich excited structures and transitions
- Precision requires **high efficiency and high RIB flux** (intensity and time): highly efficient Ge detectors + recently upgraded GRIFFIN-style DAQ for ~30× the data throughput
- CANREB and ARIEL will push the frontiers of precision and sensitivity:
  - cleaner beams with lower isobaric contamination (esp. of fission products) & higher mass resolution lead to sensitivity; especially relevant for higher-mass fission peak largely unexplored by TIGRESS so far;
  - longer beam times and higher intensities will permit precise measurements



Experiments in synergy with GRIFFIN+DESCANT will establish path of the i-process → abundances of rare earth elements in the solar system



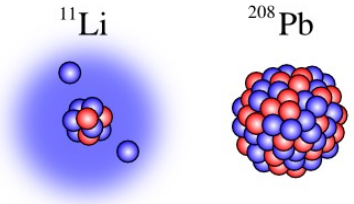
TIGRESS coupled to the EMMA recoil spectrometer target position

ARIEL enabled

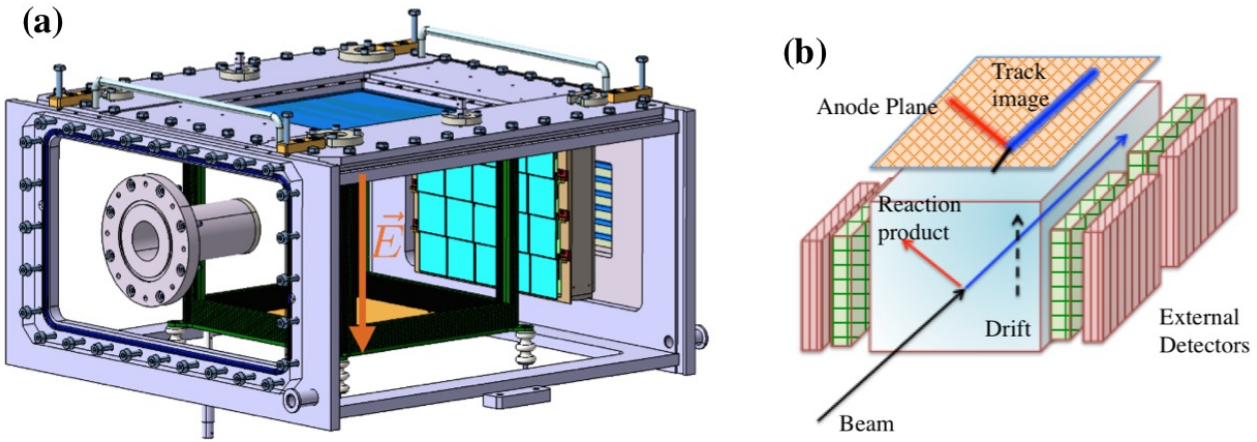
Pioneering & Precision RIB Measurements

IRIS

- Nuclear structure frontiers with RIBs:
  - Exploit CANREB increase in charge breeding efficiency
  - Structure of exotic halo nuclei – ^{11}Li
  - Shell evolution in heavier nuclei
  - *r*-process nucleosynthesis studies
  - ^{28}Al(p,α) studies for core-collapse supernovae



→ IRIS is always operating right at edge of possible RIB intensities → needs operational optimization and full capabilities of ARIEL/CANREB



EXACT-TPC

- Active target, allowing for ^{4}He or ^{3}He targets
  - With ARIEL, can measure ^{136,137}Sn(α,α') to search for resonances just above *n* threshold
  - Ideal tool to search for isoscale monopole resonance as well
- Complementary to IRIS transfer reactions (*d,p*) (*p,d*) (*d,t*) to get knowledge of neutron orbitals, EXACT e.g. allows for (^{3}He,*d*) for proton orbitals to looks for changes in nuclear shells in heavy nuclei
- Two nucleon transfer for pairing correlations using (^{3}He,*p*) to study proton-neutron pairing in nuclei.
- Astro: *rp*, *r* process. Indirect measurements for proton capture in ^{23}Al;. ^{35}K, ^{59}Cu, ^{61}Ga
- Thick target to measure excitation spectrum across various energies for resonant capture reactions

"We envision that for a major part of the experiments the proposed EXACT-TPC and the IRIS facility will be operated simultaneously with the TPC being located behind IRIS in the same beamline."

← EXACT TPC

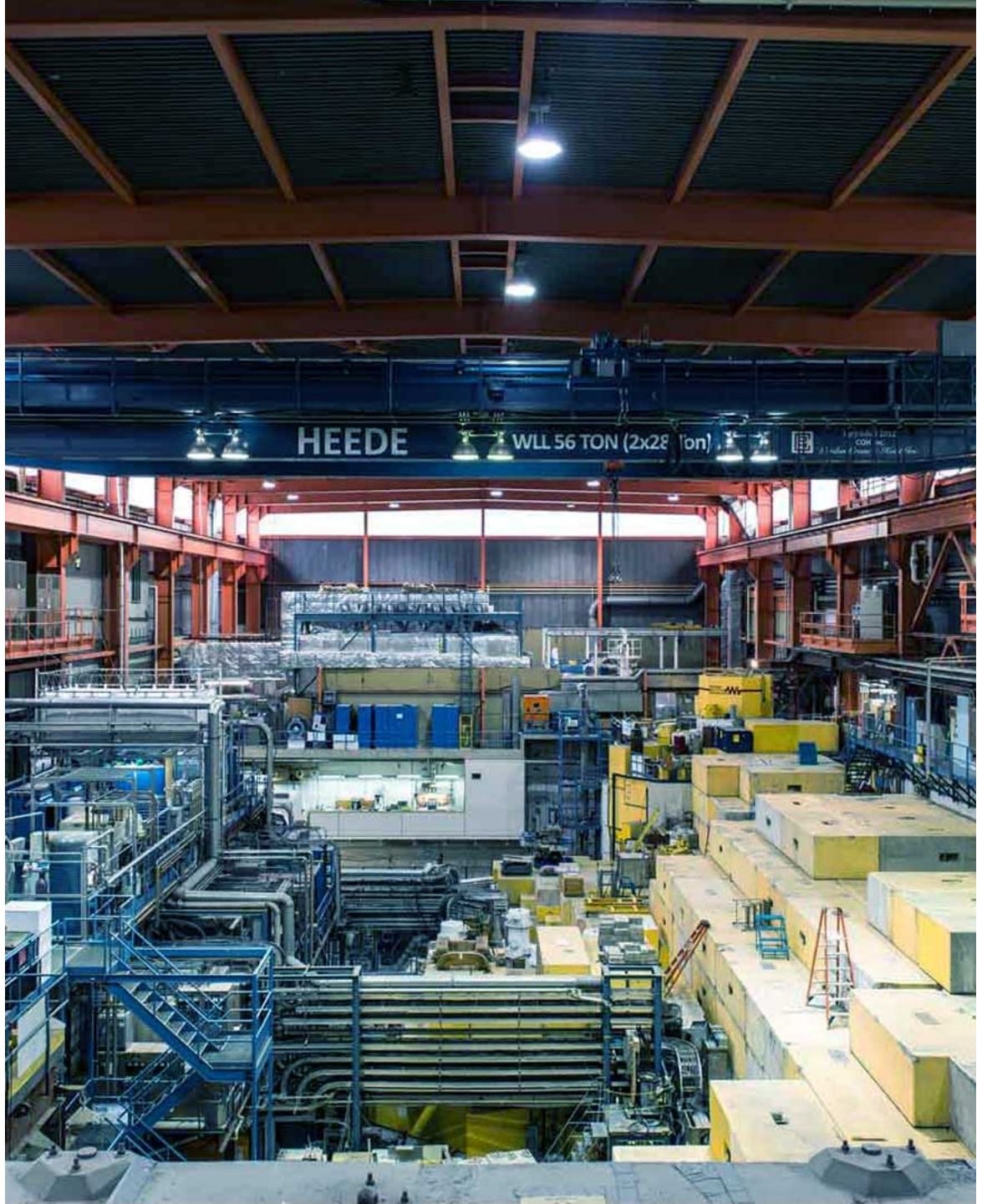
Synergy with TRIUMF *ab initio* nuclear theory and r-process modeling

Exciting science results by 2030

ATLAS

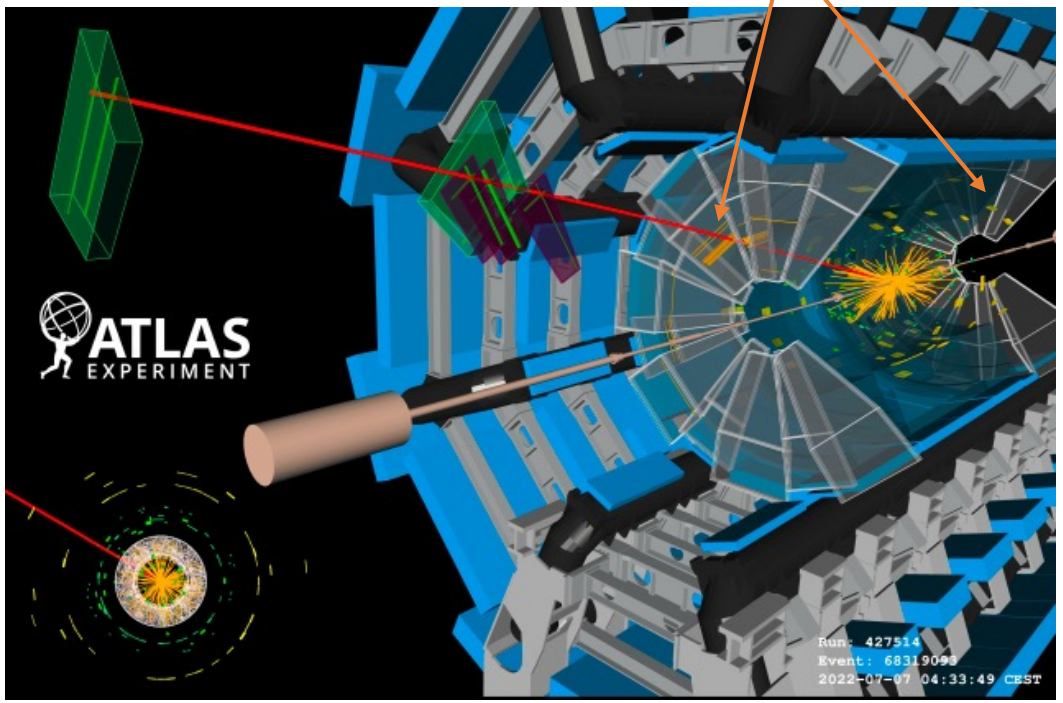
Measuring Higgs couplings by measuring HH production

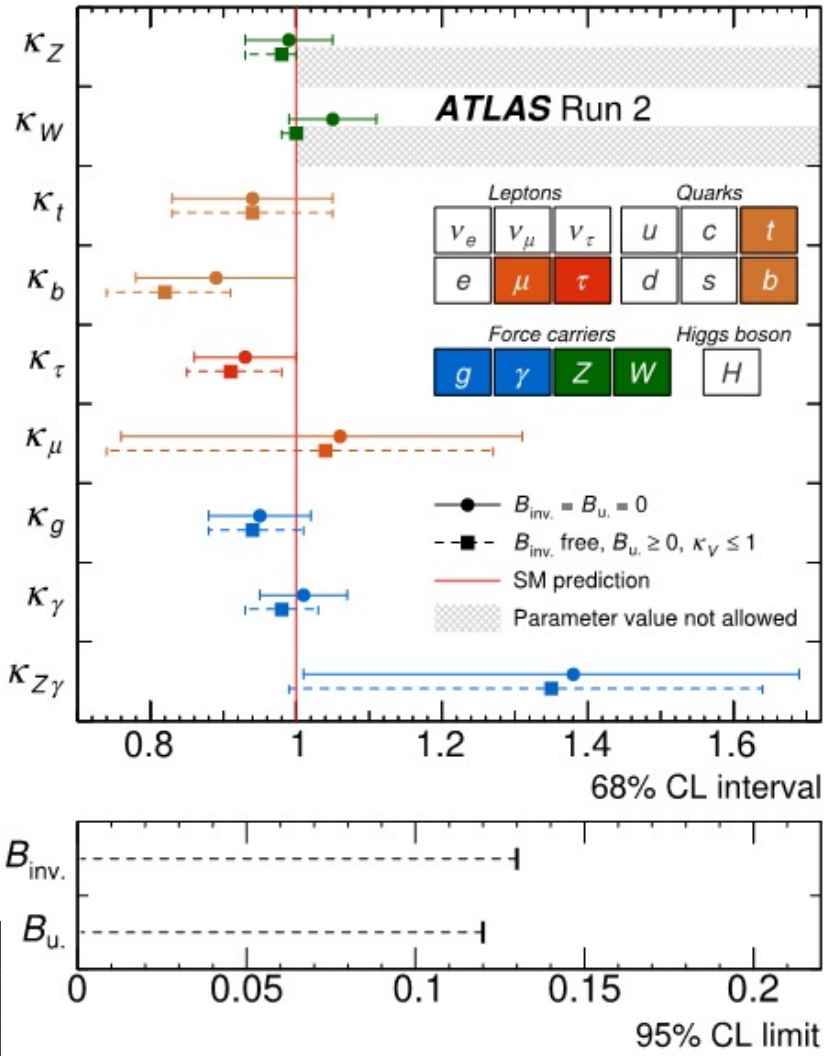
Direct information on the Higgs potential



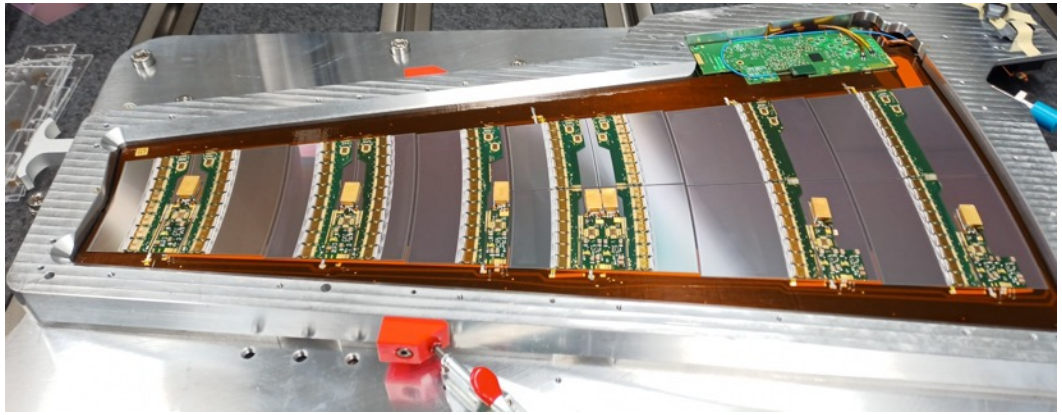
ATLAS

LHC Run 3 has started in 2022 and the New Small Wheels are starting to take data

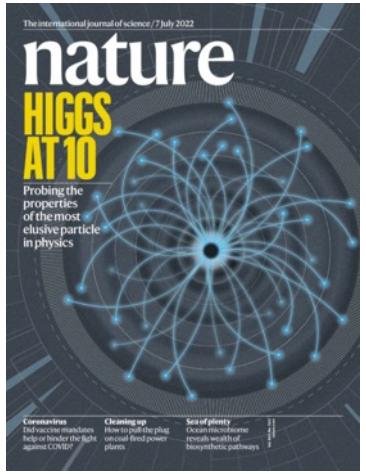




First ATLAS ITK petal with all modules assembled in Vancouver!



50% of sensor probing completed!



Milestone measurements of Higgs boson properties, couplings to matter

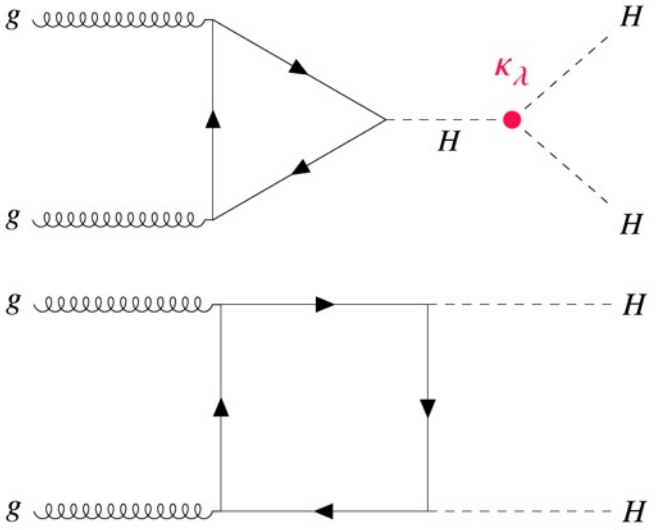
10 Year anniversary paper in nature

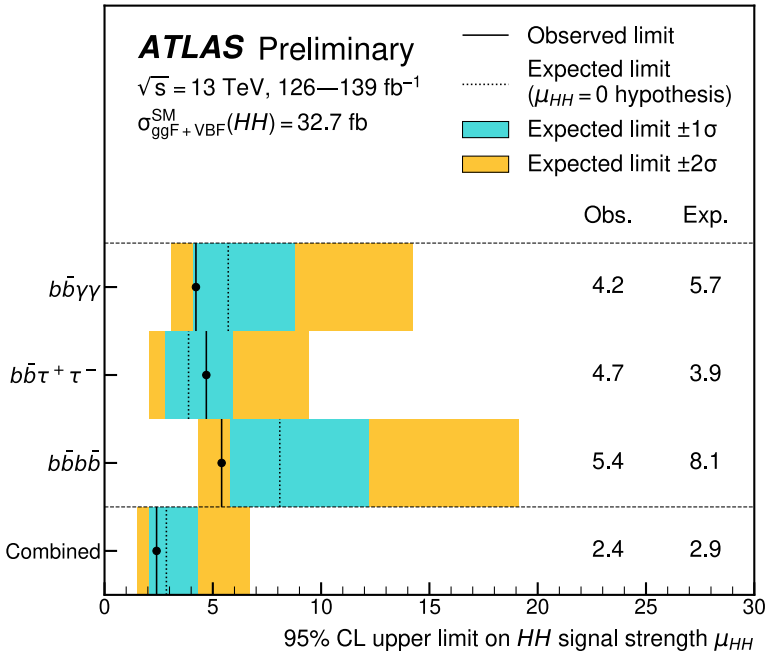
Discovery, accelerated

ATLAS

TRIUMF runs ATLAS Tier 1 Center

- 2030 will be half way through Run 4!
- Physics with 3x the dataset: huge range of interesting physics options
  - Higgs and Standard Model measurements become much more precise (Higgs couplings, M_W, etc)
  - Search program - higher energy, new signatures, new detector
  - *Potential new discoveries in Dark Matter, VLQ, SUSY, long lived particles, new extended Higgs sector, …*
- A flagship analysis for future runs of the LHC
  - Measuring κ_λ by measuring HH production
- K_λ gives direct information on the Higgs potential
  - Expect evidence of HH production by 2030!





Marco Valente's talk on Tuesday

Discovery, accelerated

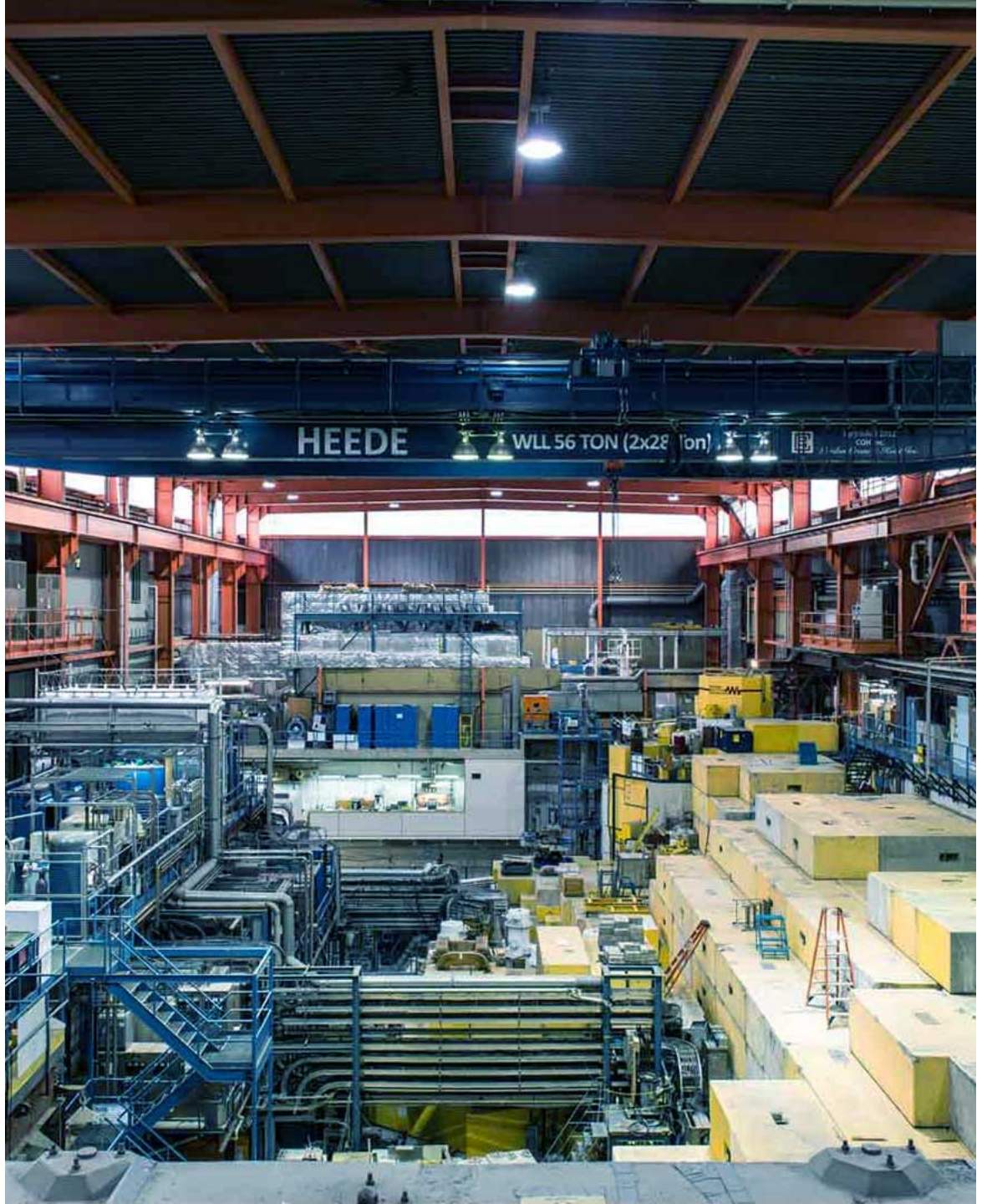
Exciting science results by 2030

ALPHA / HAICU

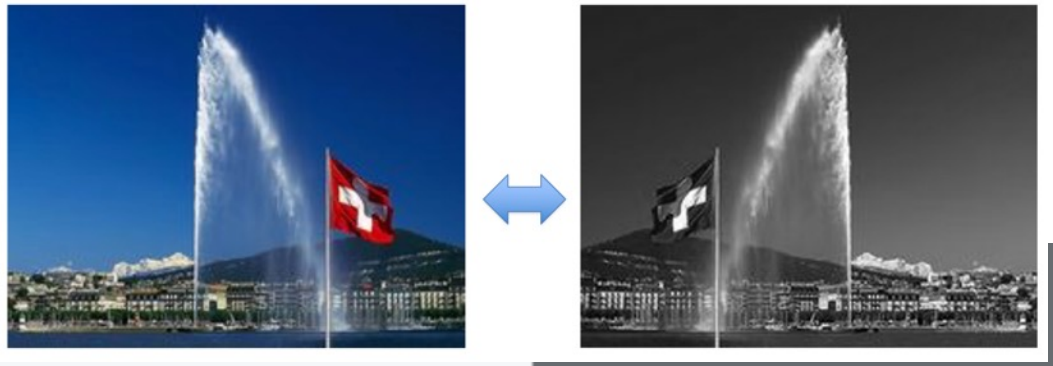
Test of CPT, Quantum Field Theory

Most precise measurement of the gravitational constant for anti-matter

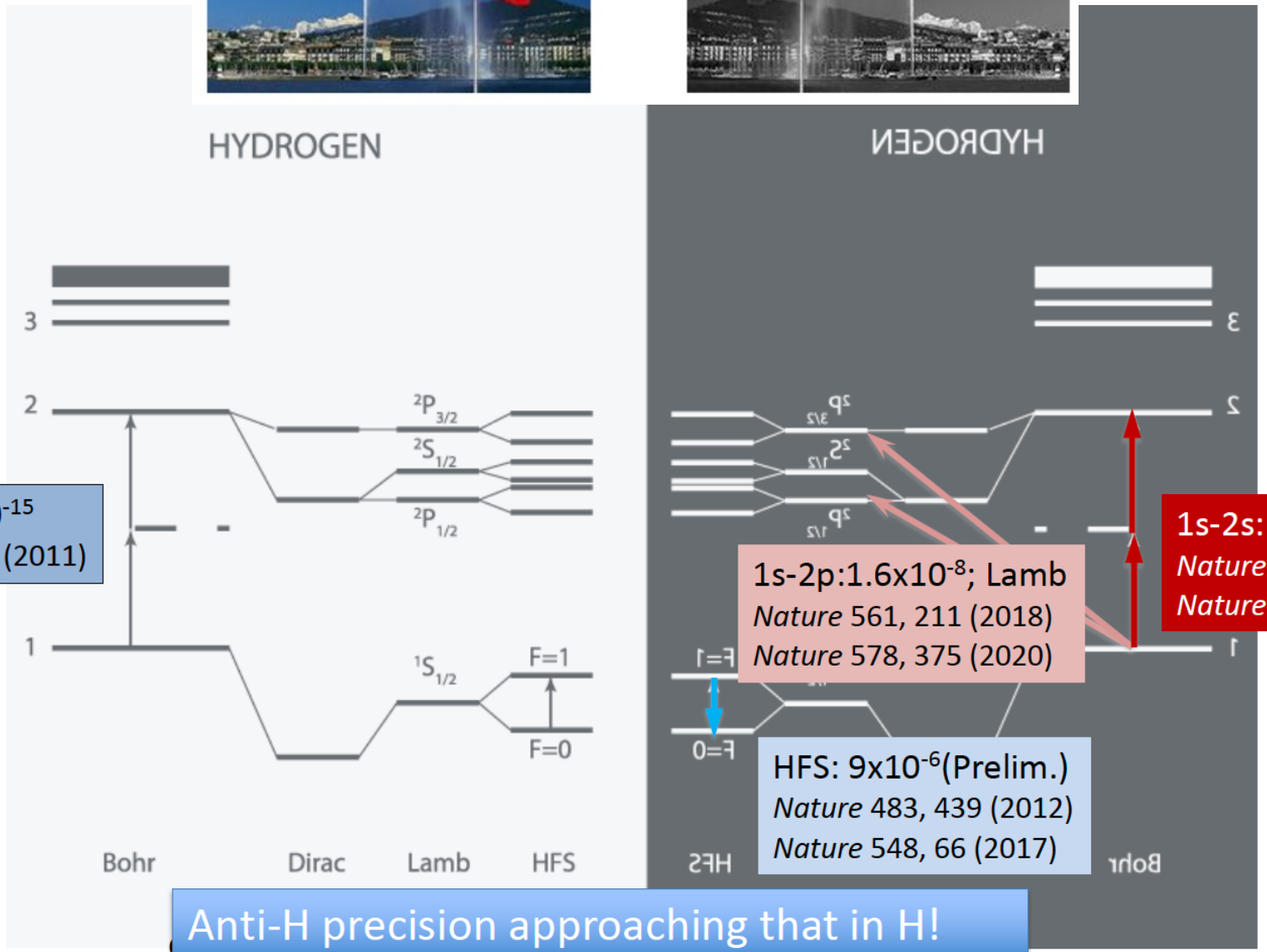
Quantum sensing techniques applicable to antimatter
- anti-atomic fountain



ALPHA / HAICU



- Test of CPT, Quantum Field Theory
- Equivalence Principle
- HAICU:
- First H fountain, Interferometer



1s-2s: 4×10^{-15}
PRL 107, 203001 (2011)

1s-2s: 2×10^{-12}
Nature 541, 506 (2017)
Nature 557, 71 (2018)

1s-2p:1.6×10^{-8}; Lamb
Nature 561, 211 (2018)
Nature 578, 375 (2020)

HFS: 9×10^{-6}(Prelim.)
Nature 483, 439 (2012)
Nature 548, 66 (2017)

- ALPHA-2 2023 run ongoing
- HAICU, space at TRIUMF identified Infrastructure being prepared at TRIUMF

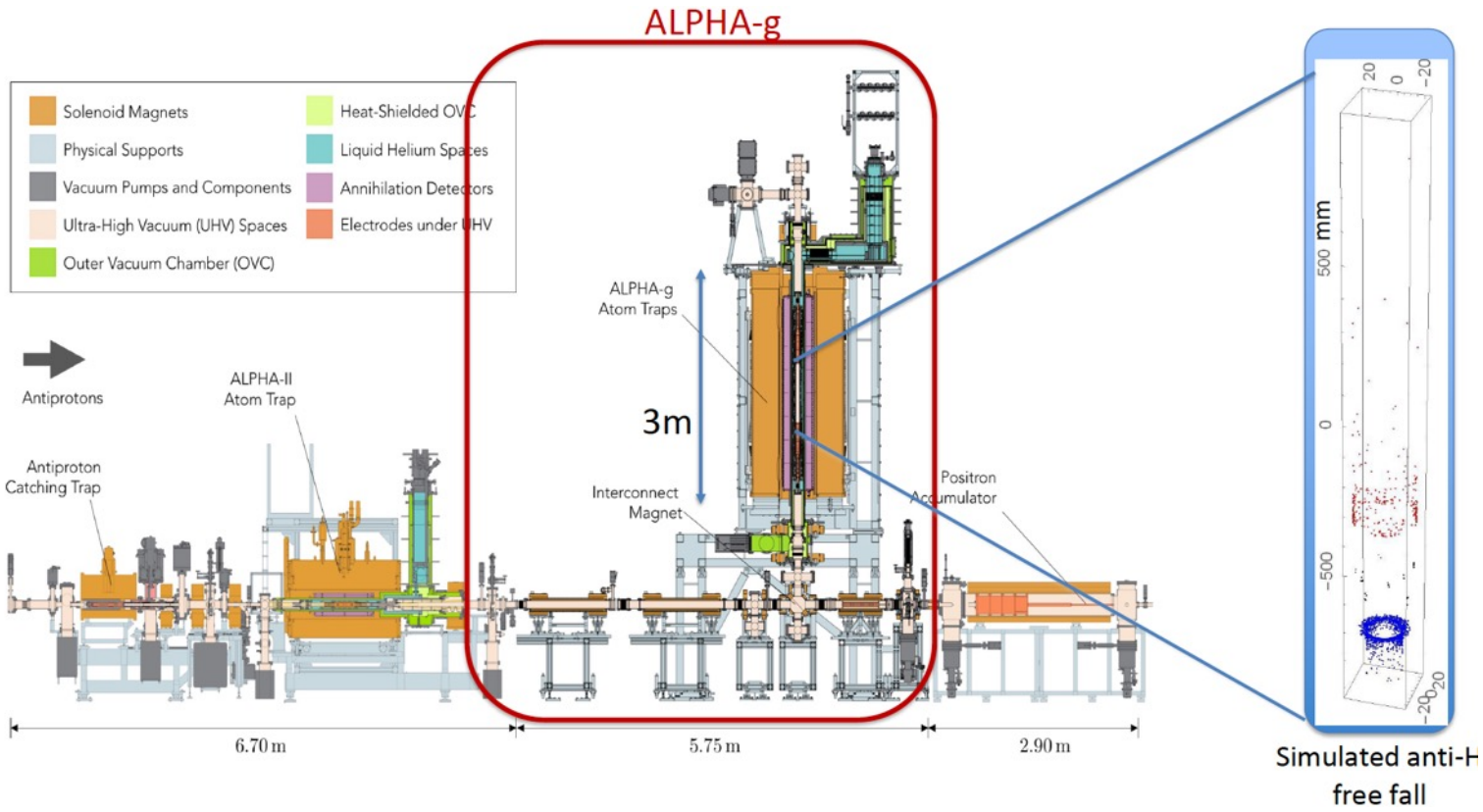
Charge neutrality
Nature 539, 373 (2016)
Gravity (ongoing)

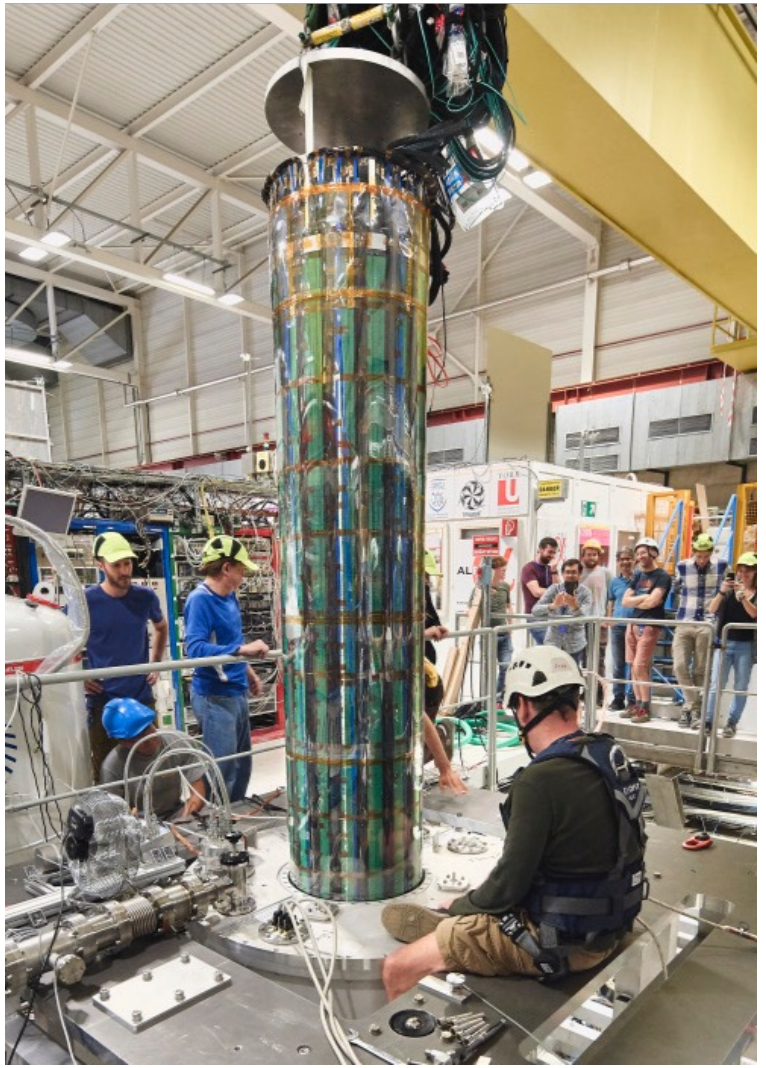
Anti-H precision approaching that in H!

Discovery, accelerated

Chukman So's talk on Tuesday

ALPHA / ALPHA-g





- Detector for a measurement of gravity with antimatter
- By 2030 potentially most precise measurement of g'

Commissioning of ALPHA-g

First data being analyzed!

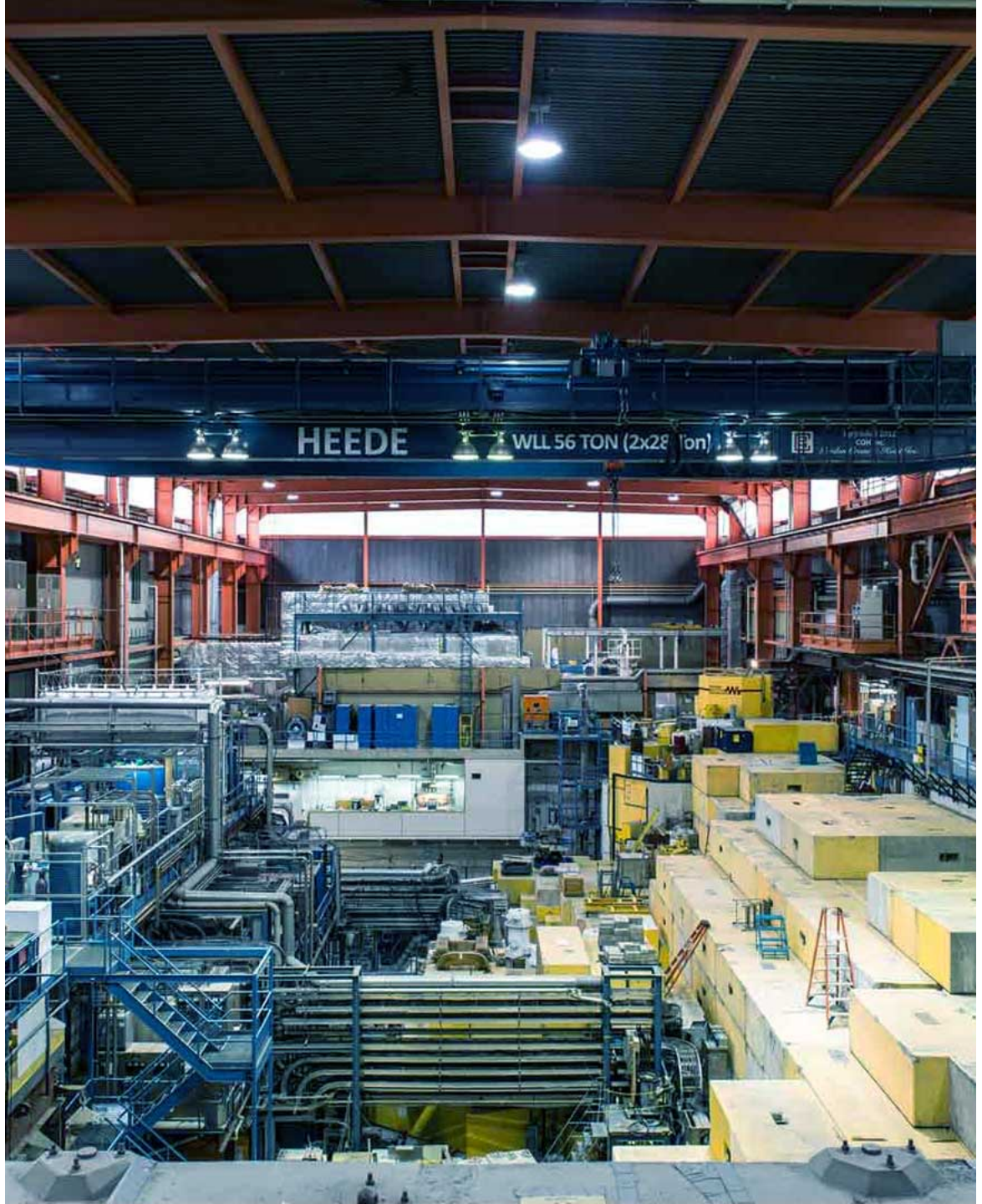
Discovery, accelerated

Exciting science results by 2030

nEXO

Search for the neutrinoless double-beta decay in 5 tons of ^{136}Xe isotope. Located 2 km underground at SNOLAB

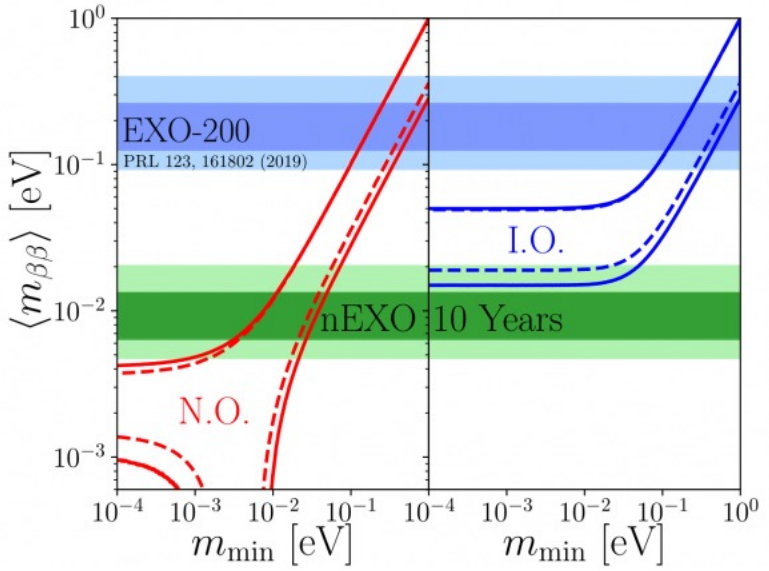
TRIUMF delivers all Silicon Photo-Multipliers



Neutrinoless Double Beta Decay Experiment nEXO

- Search for the neutrinoless double-beta decay in ^{136}Xe isotope
  - Beyond 10^{28} year half-life sensitivity
  - Led by US DOE LLNL
  - To be located 2 km underground at SNOLAB
  - In Canada two CFI projects funded
- TRIUMF leads the development of the Silicon Photo-Multipliers
  - Effort lead by TRIUMF SciTech dept
- TRIUMF *ab initio* nuclear theory applied to compute nuclear matrix elements required for the analysis

By 2030, TRIUMF will deliver all SiPMs for nEXO



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THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Experimental Physics

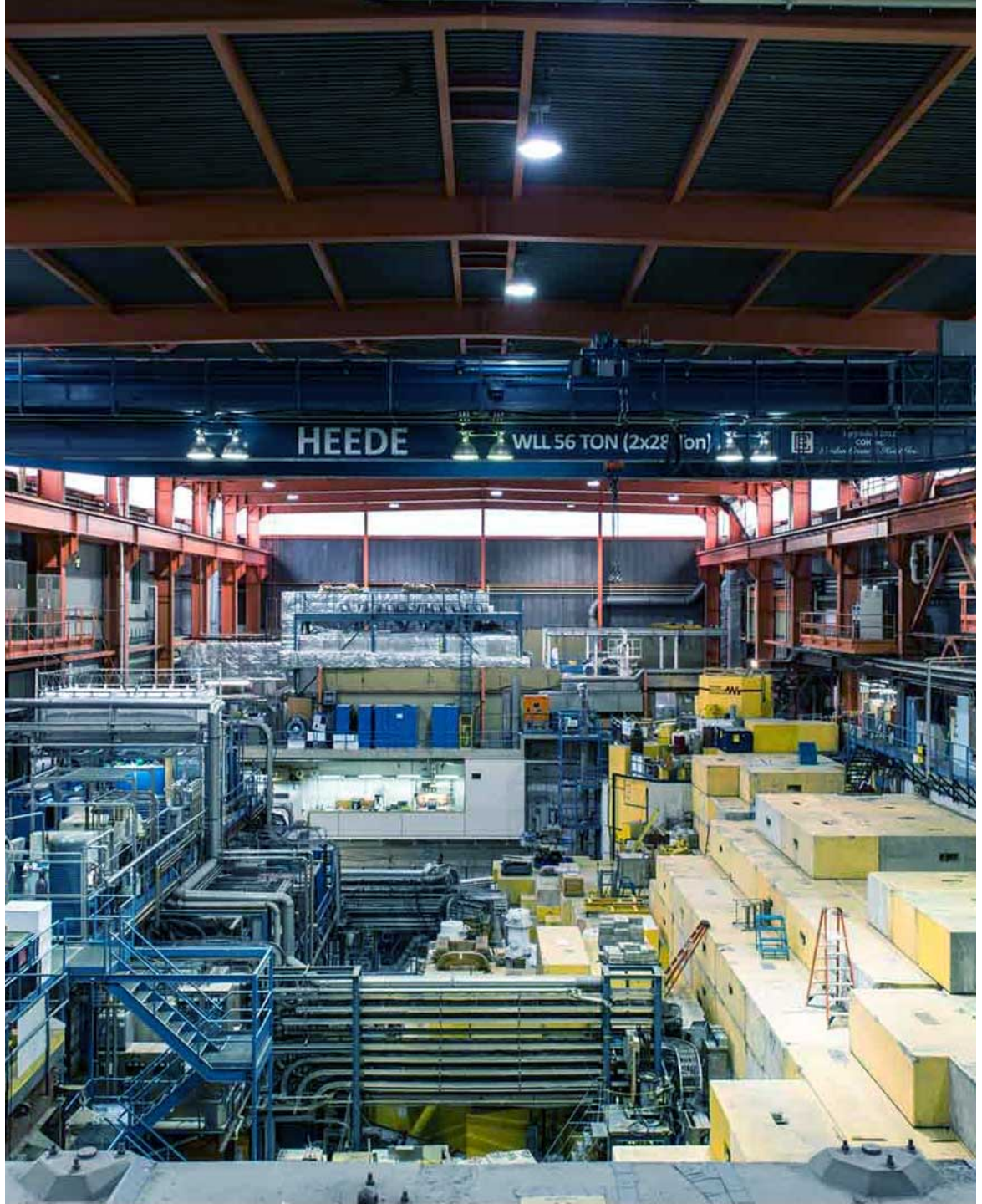
Performance of novel VUV-sensitive Silicon Photo-Multipliers for nEXO

G. Gallina[1,35,a], Y. Guan[2,36], F. Retiere[1], G. Cao[2,36,b], A. Bolotnikov[3], I. Kotov[3], S. Rescia[3], A. K. Soma[4], T. Tsang[3], L. Darroch[5], T. Brunner[1,5], J. Bolster[6,37], 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[7,35], D. C. Moore[7], G. Adhikari[8], S. Al Kharusi[5], E. Angelico[9], I. J. Arnquist[10], P. Arsenault[11], I. Badhrees[12,38], J. Bane[6], 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[11], D. Chernyak[21], M. Chiu[3], B. Cleveland[18,19], R. Collister[12], M. Cvitan[1], J. Dalmasson[9], T. Daniels[22], K. Deslandes[11], R. DeVoe[9], M. L. di Vacri[10], Y. Ding[2], M. J. Dolinski[4], A. Dragone[16], J. Echevers[23], B. Eckert[4], M. Elbeltagi[12], L. Fabris[24], W. Fairbank[25], J. Farine[12,18,19], Y. S. Fu[2,36], D. Gallacher[5], P. Gautam[4], G. Giacomini[3], C. Gingras[5], D. Goeldi[12,40], 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. Hößl[27], A. House[14], W. Hunt[14], A. Iverson[25], X. S. Jiang[2], A. Karelin[13], L. J. Kaufman[16], R. Krücken[1,28,39], A. Kuchenkov[13], K. S. Kumar[6], A. Larson[29], K. G. Leach[30], B. G. Lenardo[9], D. S. Leonard[31], G. Lessard[11], G. Li[2], S. Li[23], Z. Li[8], C. Licciardi[12,18,19], R. Lindsay[32], R. MacLellan[15], M. Mahtab[1], S. Majidi[5], C. Malbrunot[1], P. Margetak[1], P. Martel-Dion[11], L. Martin[1], J. Masbou[33], N. Massacret[1], K. McMichael[17], B. Mong[16], K. Murray[5], J. Nattress[24], C. R. Natzke[30], X. E. Ngwadla[32], J. C. Nzobadila Ondze[32], A. Odian[16], J. L. Orrell[10], G. S. Ortega[10], C. T. Overman[10], S. Parent[11], A. Perna[18], A. Piepke[21], N. Pletskova[4], J. F. Pratte[11], V. Radeka[3], E. Raguzin[3], G. J. Ramonnye[32], T. Rao[3], H. Rasiwala[5], K. Raymond[1], B. M. Rebeiro[5], G. Richardson[7], J. Ringuette[30], V. Riot[14], T. Rossignol[11], P. C. Rowson[16], L. Rudolph[5], R. Saldanha[10], S. Sangiorgio[14], X. Shang[5], F. Spadoni[10], V. Stekhanov[13], X. L. Sun[2], A. Tidball[17], T. Totev[5], S. Triambak[32], R. H. M. Tsang[21], O. A. Tyuka[32], F. Vachon[11], M. Vidal[9], S. Viel[12], G. Visser[34], M. Wagenpfeil[27], M. Walent[18], K. Wamba[26], Q. Wang[20], W. Wang[21], Y. Wang[2], M. Watts[7], W. Wei[2], L. J. Wen[2], U. Wichoski[12,18,19], S. Wilde[7], M. Worcester[3], W. H. Wu[2], X. Wu[20], L. Xie[1], W. Yan[2], H. Yang[20], L. Yang[8], O. Zeldovich[13], J. Zhao[2], T. Ziegler[27]

Exciting science results by 2030

DarkLight

Search for new bosons (X17) around 10-20 MeV mass decaying to e^+e^-

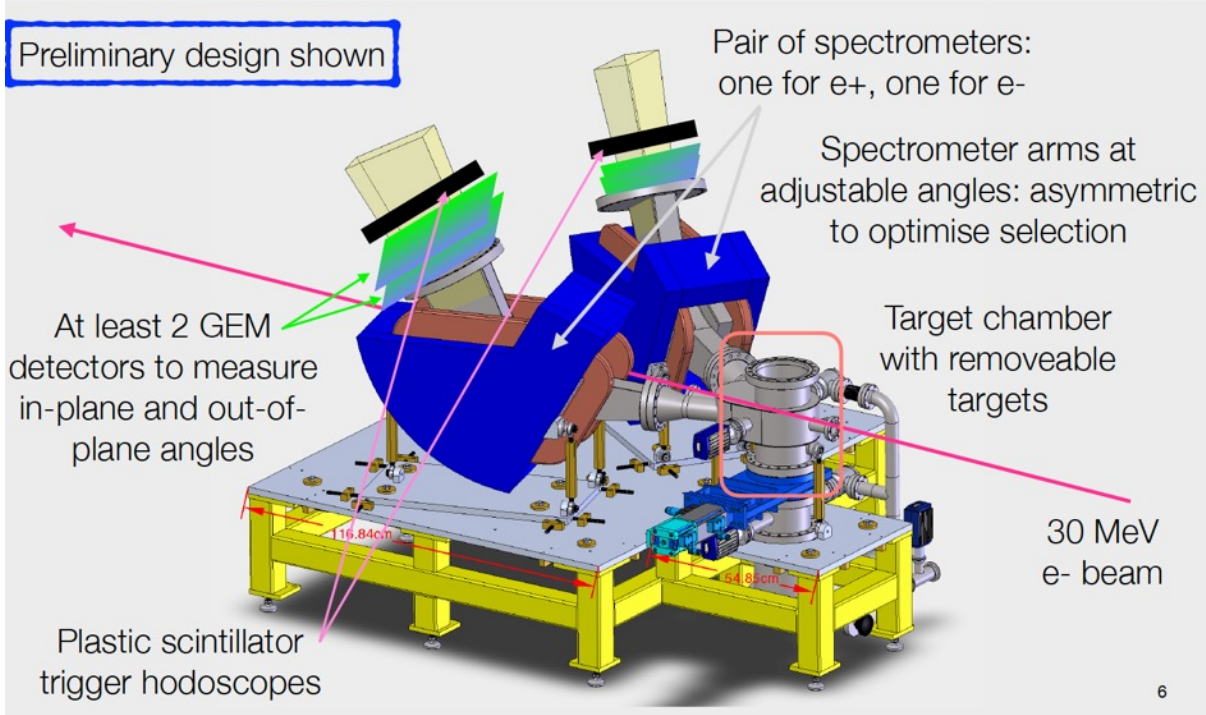


DarkLight

ARIEL enabled

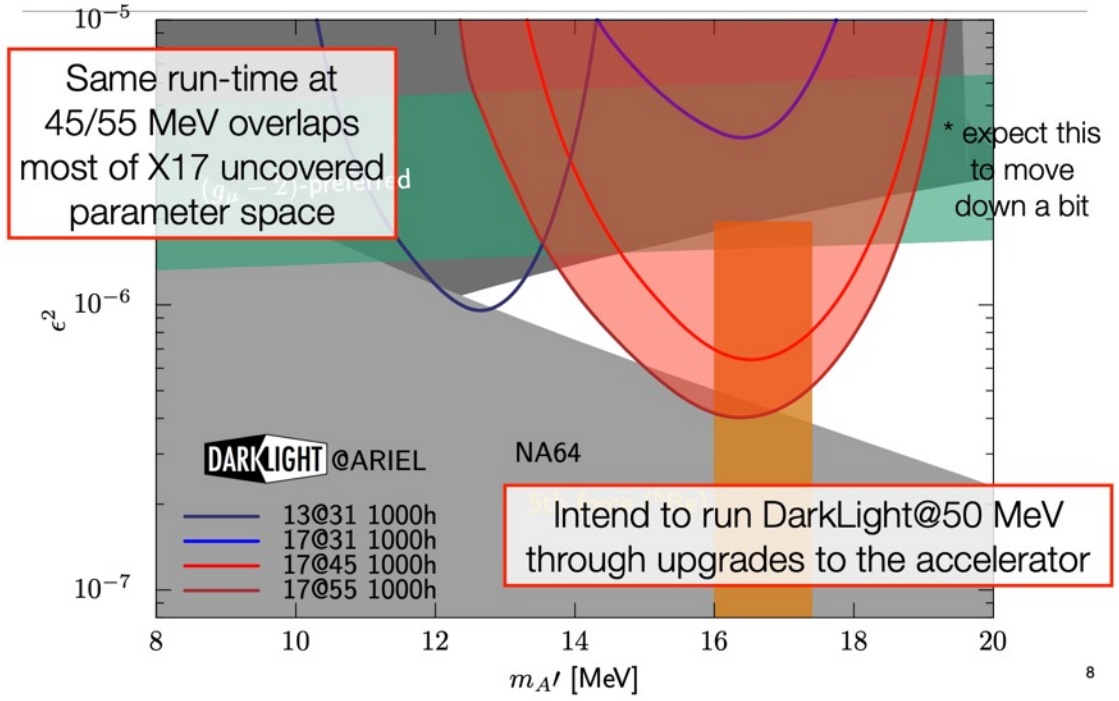
- New experiment at ARIEL e-linac to search for new bosons around 10-20 MeV mass decaying to e^+e^-
- Experiment design essentially finalized, technical reviews in progress
- Want to begin installation of 30 MeV experiment this fall

Experiment overview



Sensitivity at 30 and 50 MeV accelerators

By 2030 full parameter scan completed

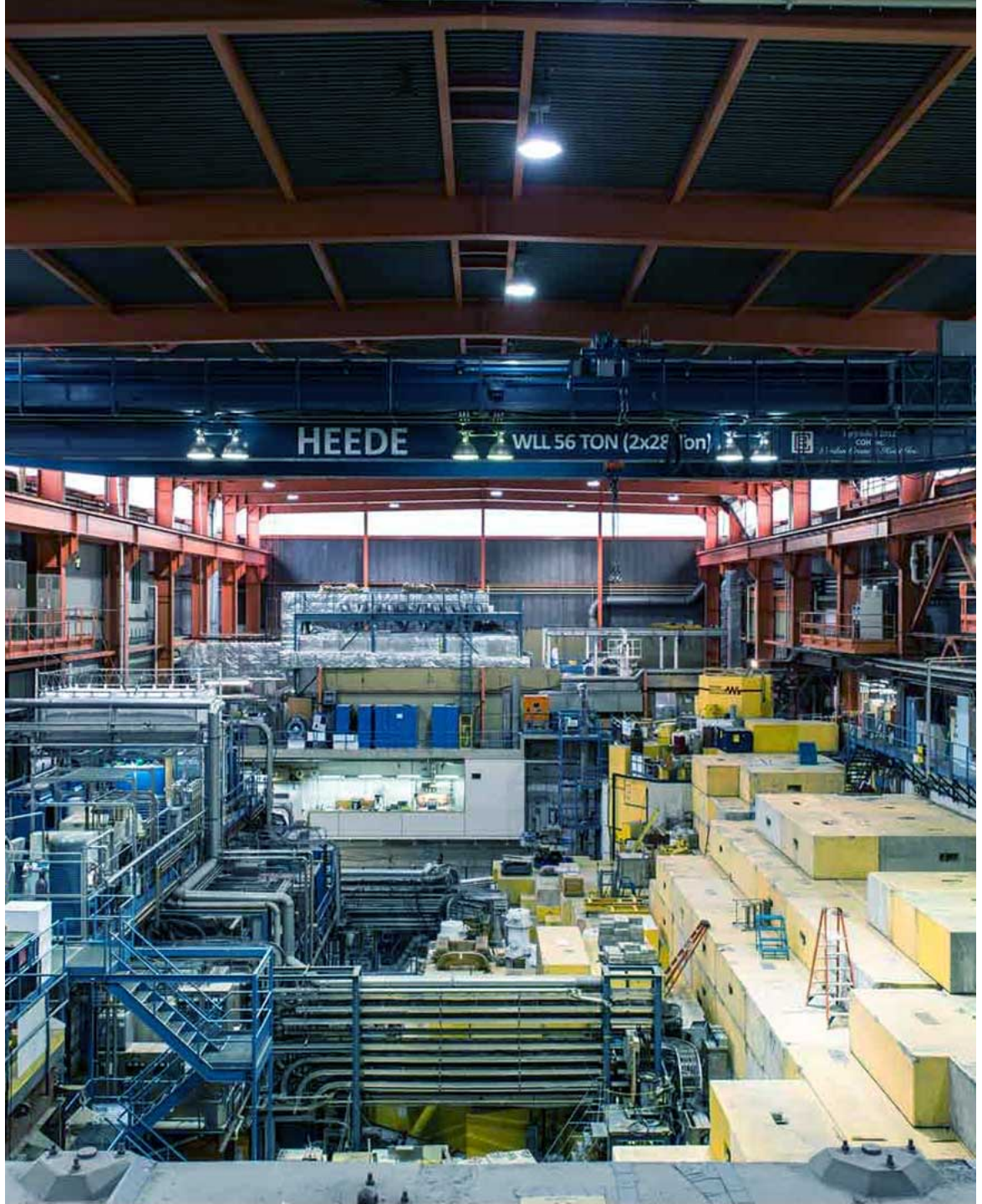


Discovery, accelerated

Exciting science results by 2030

PIONEER

Worlds most precise e-μ universality test

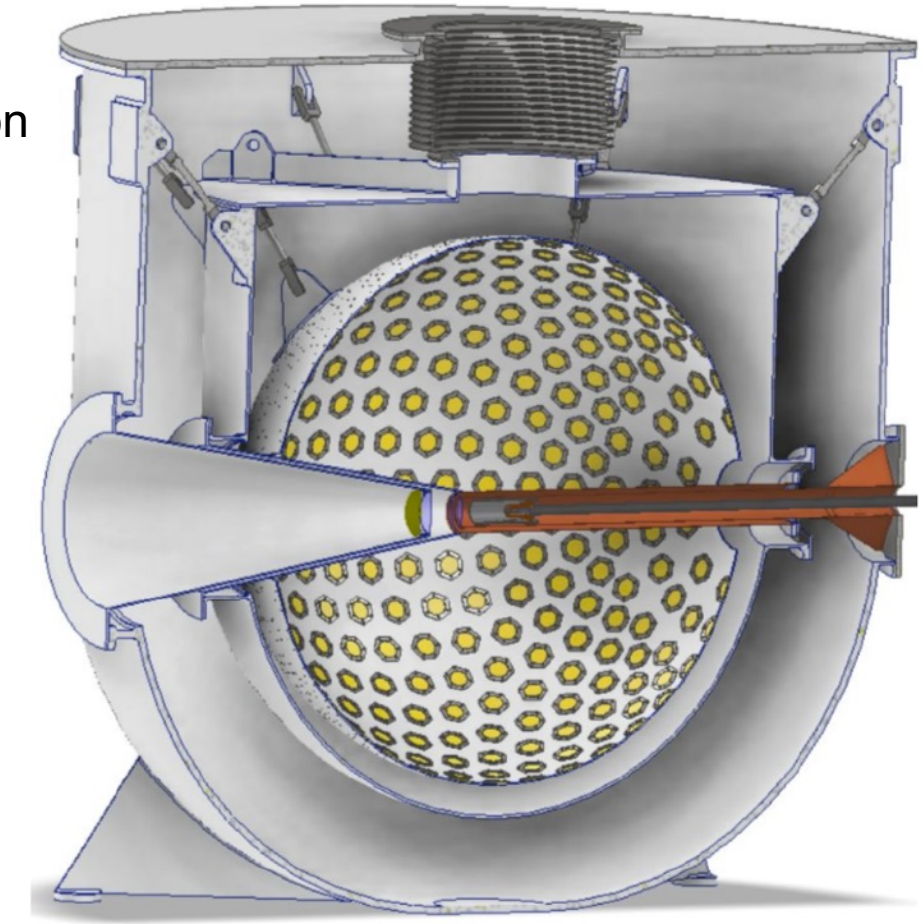


PIONEER@PSI

- Major new experiment addressing emerging Standard Model anomalies in flavor physics
- TRIUMF group aims at leading calorimeter design & construction
- Beam test at PSI with large LXe cryostat foreseen for Fall 2024
- Assembly test at TRIUMF

- By 2030: 1st phase: measurement of
- $R^{\pi}_{SM} = (\pi \to e\nu(\gamma))/(\pi \to \mu\nu(\gamma))$:
- Worlds most precise e-μ universality test

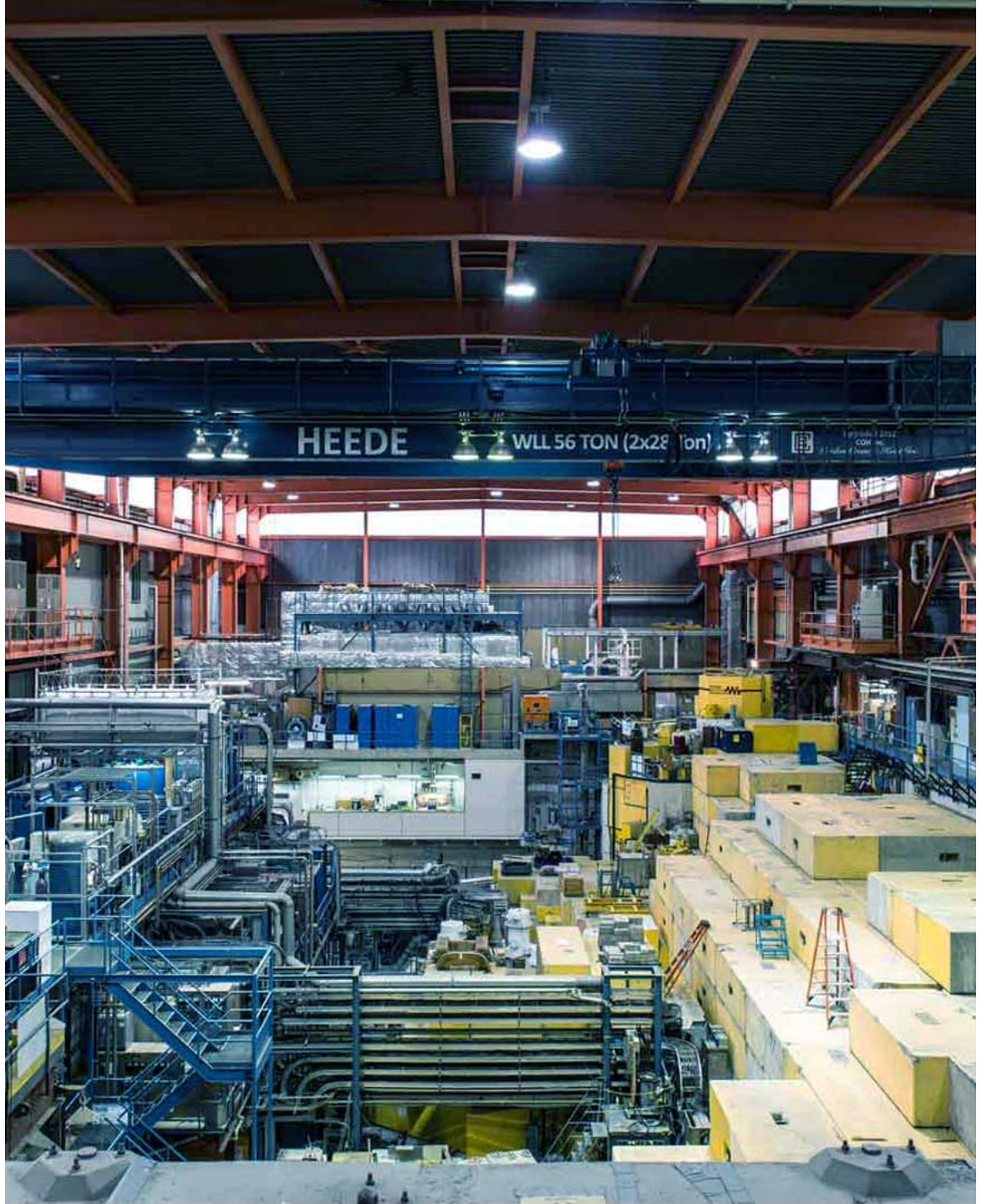
- Sensitive to high mass and low mass new physics
- 2nd and 3rd phases: $R^{\pi\beta} = \frac{\Gamma(\pi^+ \to \pi^0 e^+ \nu}{\Gamma(\pi^+ \to all)} : O(\pm 0.2\% \to \pm 0.05\%)$ pristine V_{ud} extraction



Quantum Materials Research

μSR, βNMR

Green Technologies – Li battery testing



Quantum Materials Research at TRIUMF

- Advance Quantum Technologies
- Enable green technology solutions
- Engage with new complimentary initiatives
  - THz, CANS (Accelerator based neutrons)

- New facility capabilities, i.e.,
  - μSR @ M9H : ➔ new quantum materials / sustainability / battery research;
    - The first muon decay channel with full transverse polarization spectroscopic functionality

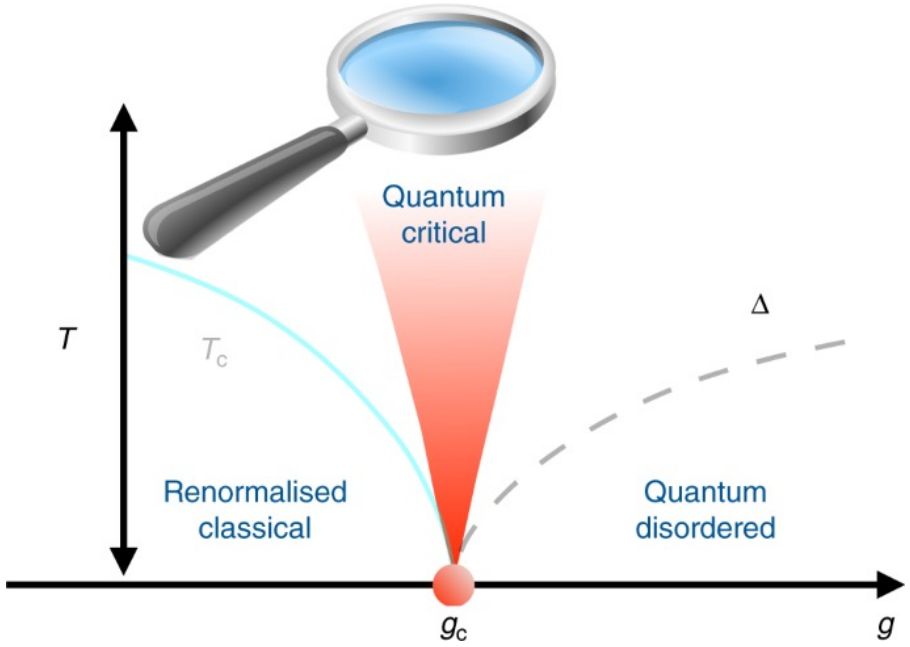
BL1A enabled

  - μSR @ M9A : ➔ hydrogen storage / new quantum materials;
  - Increased βNMR beam-time (15 weeks vs 5) and/or experimental capacity

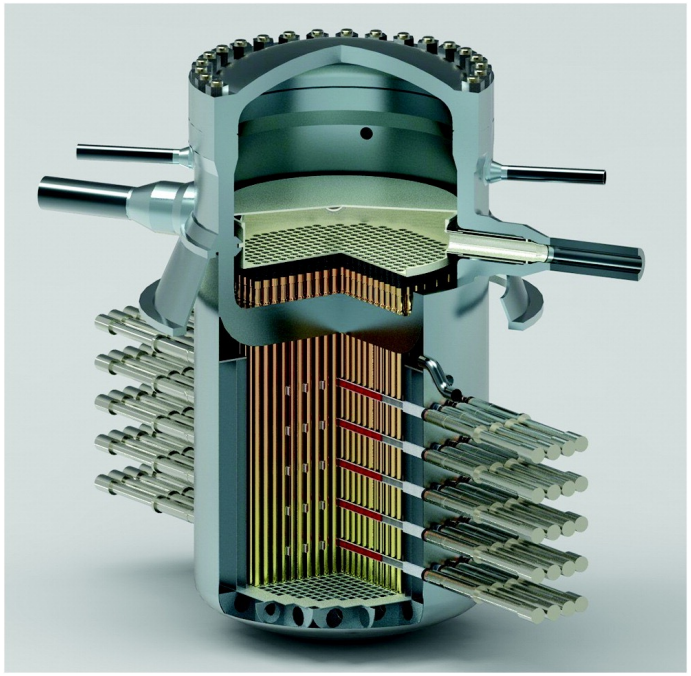
ARIEL enabled

Andrew McFarlane's talk on Thursday

High Pressure with M9H



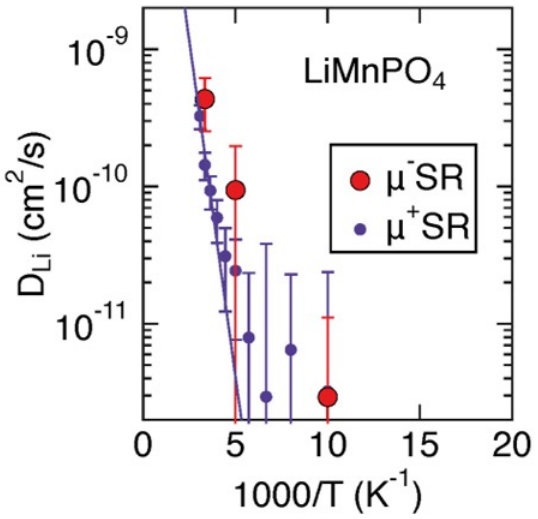
Use applied pressure as a tuning parameter for investigations of unusual states of quantum criticality that occur when conventional order is suppressed by quantum fluctuations.

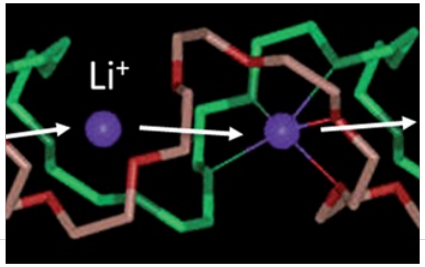


Gen IV supercritical water-cooled reactor

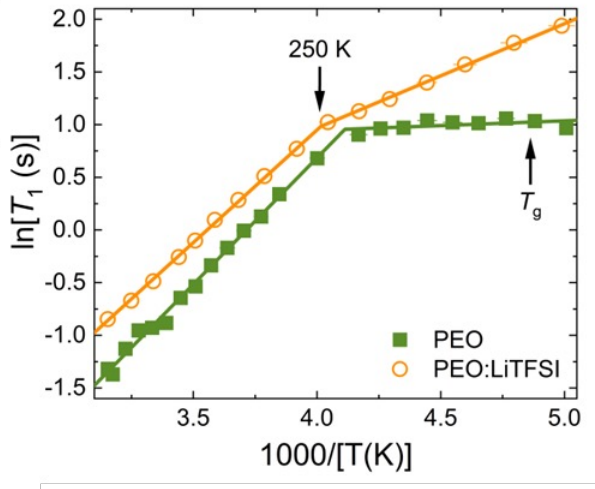
Study chemicals and chemical reactions under extreme conditions (e.g., high temperature and pressure).

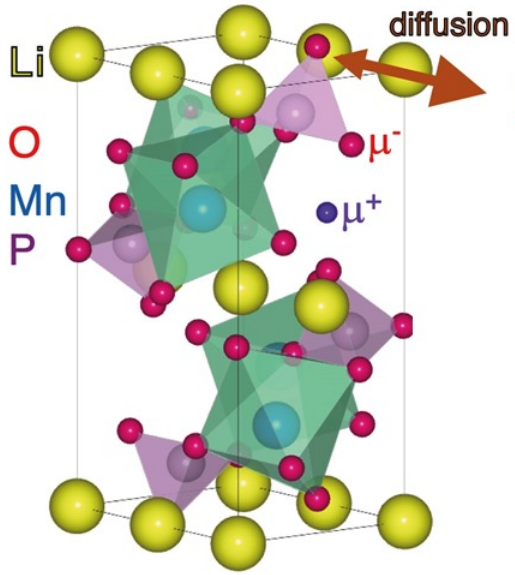
Battery Materials

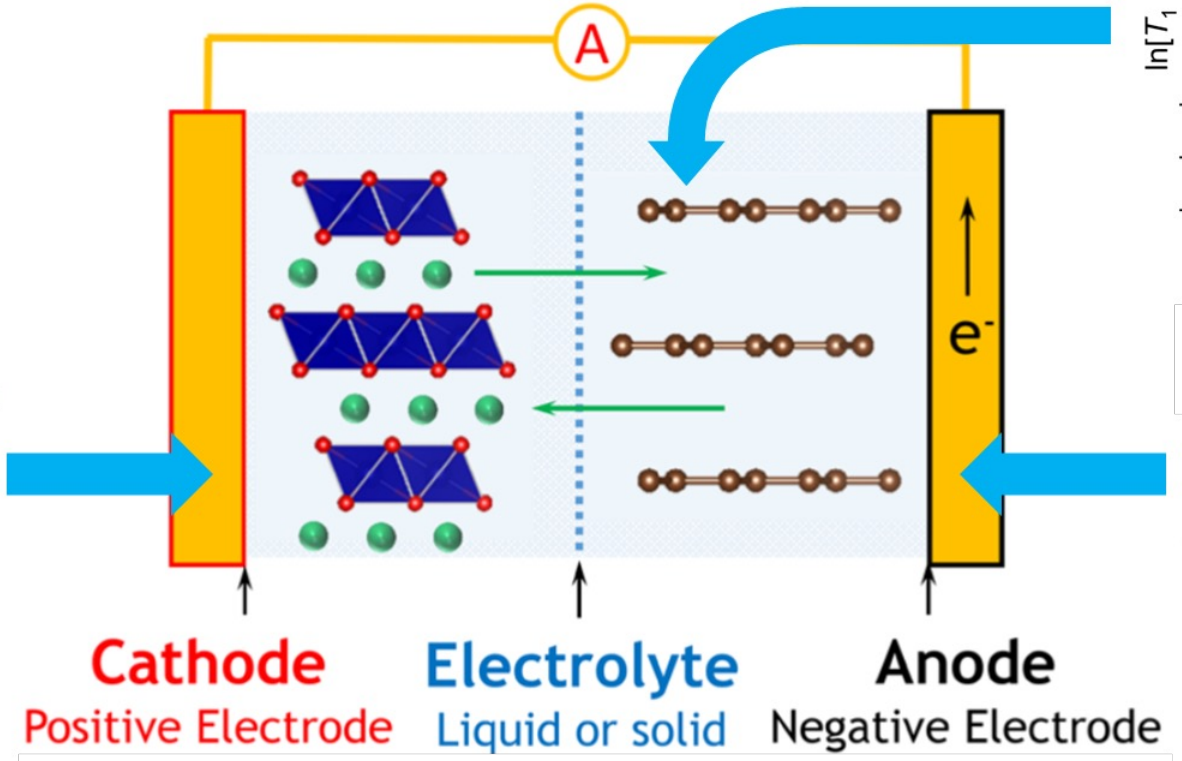




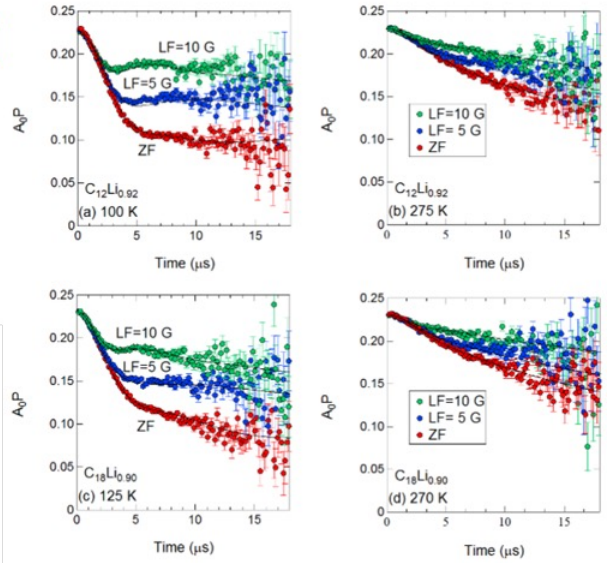
$^8Li^+$ β-NMR







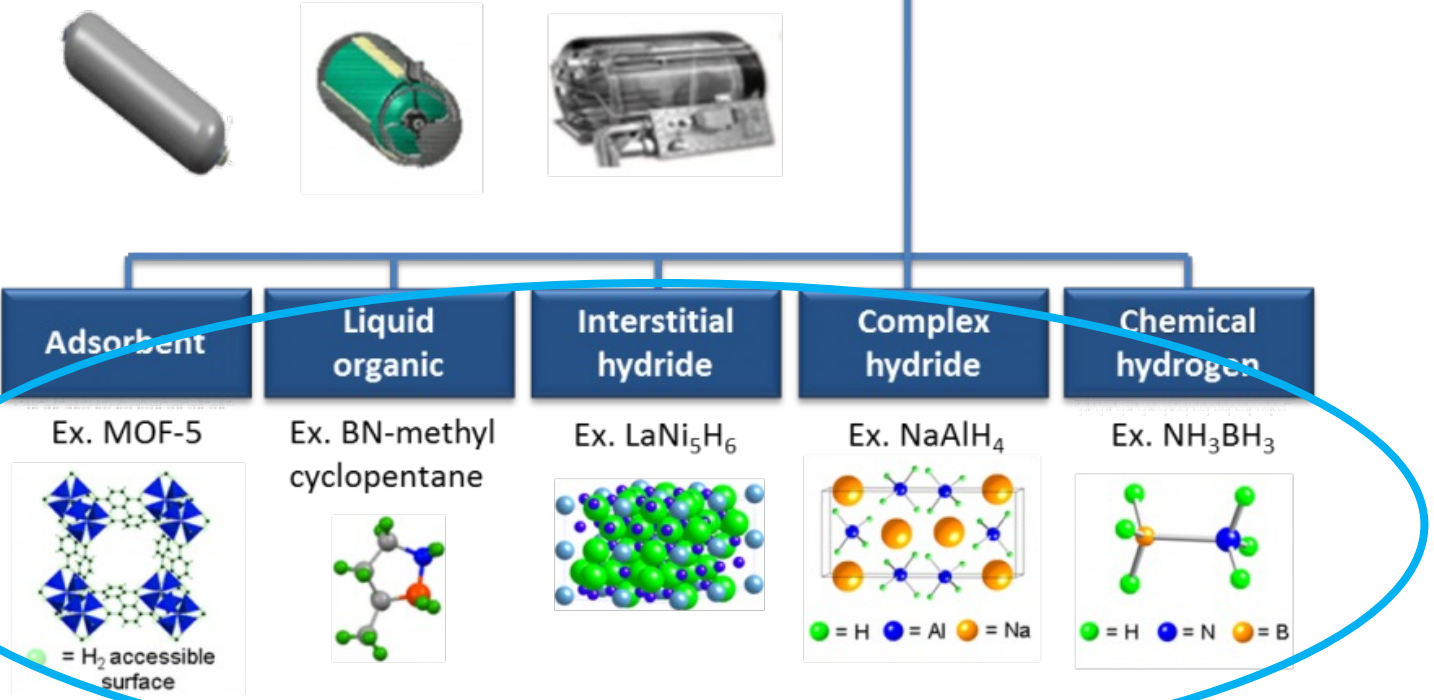
μSR

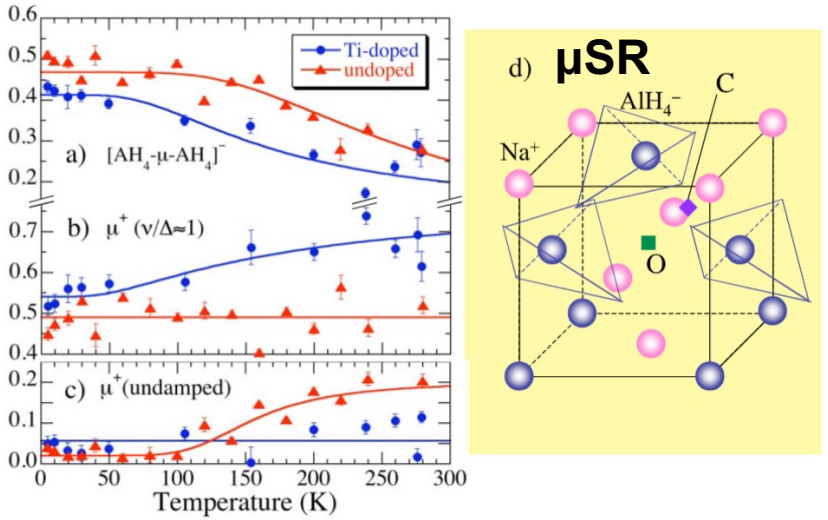


Green Technology

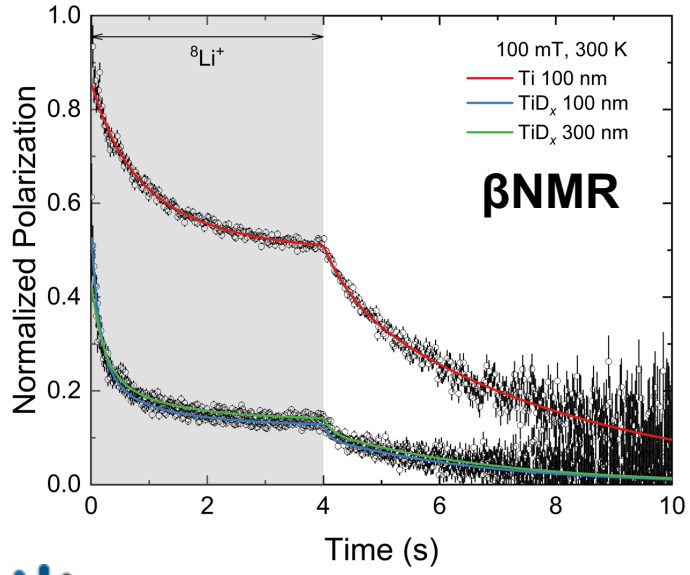
How is hydrogen stored?

- **Physical-based**
  - Compressed Gas
  - Cold/Cryo Compressed
  - Liquid H_2
- **Material-based**
  - Adsorbent — Ex. MOF-5
  - Liquid organic — Ex. BN-methyl cyclopentane
  - Interstitial hydride — Ex. $LaNi_5H_6$
  - Complex hydride — Ex. $NaAlH_4$
  - Chemical hydrogen — Ex. NH_3BH_3





R. Kadono et al.
Phys. Rev. Lett. **100**, 026401 (2008)



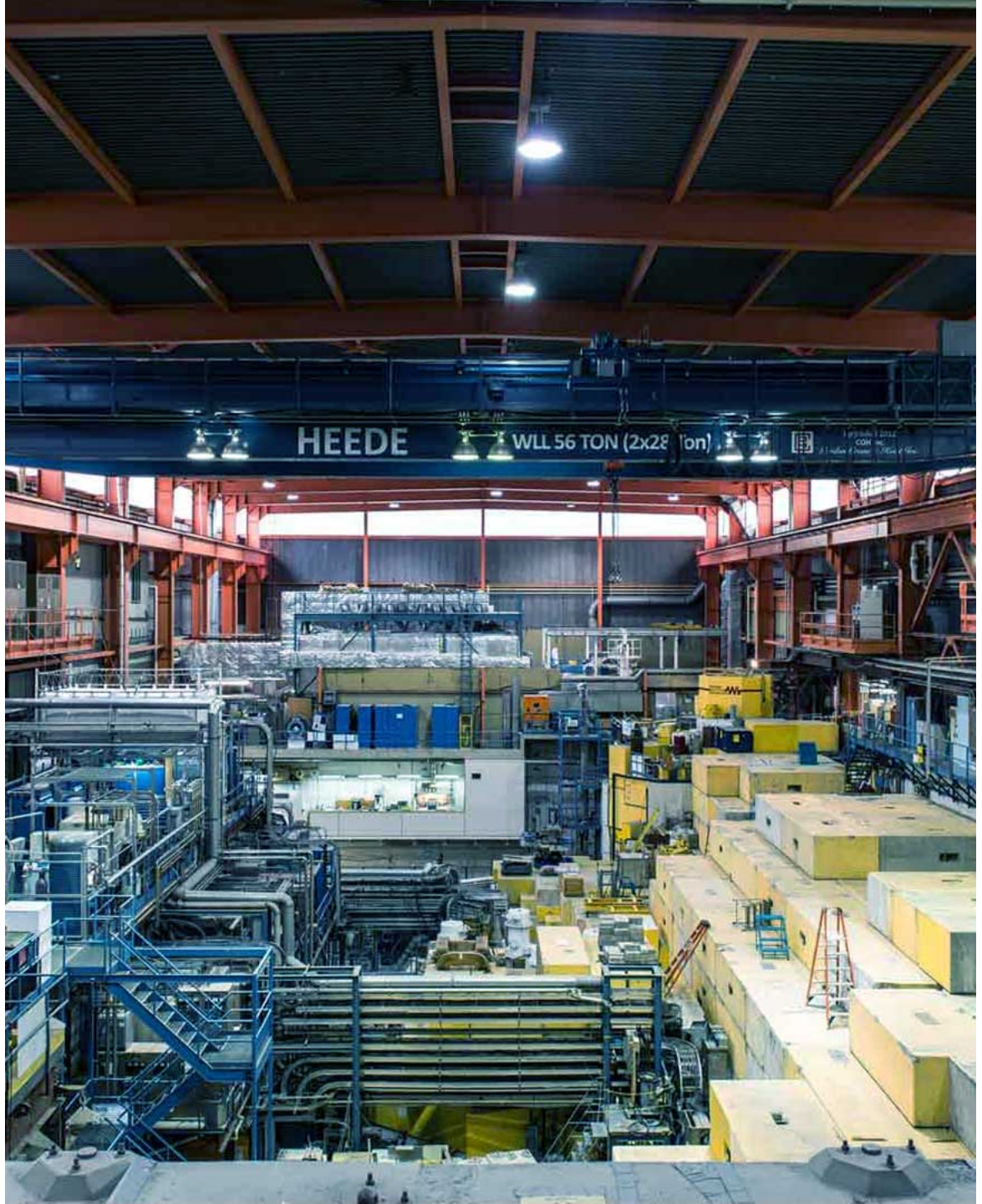
Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

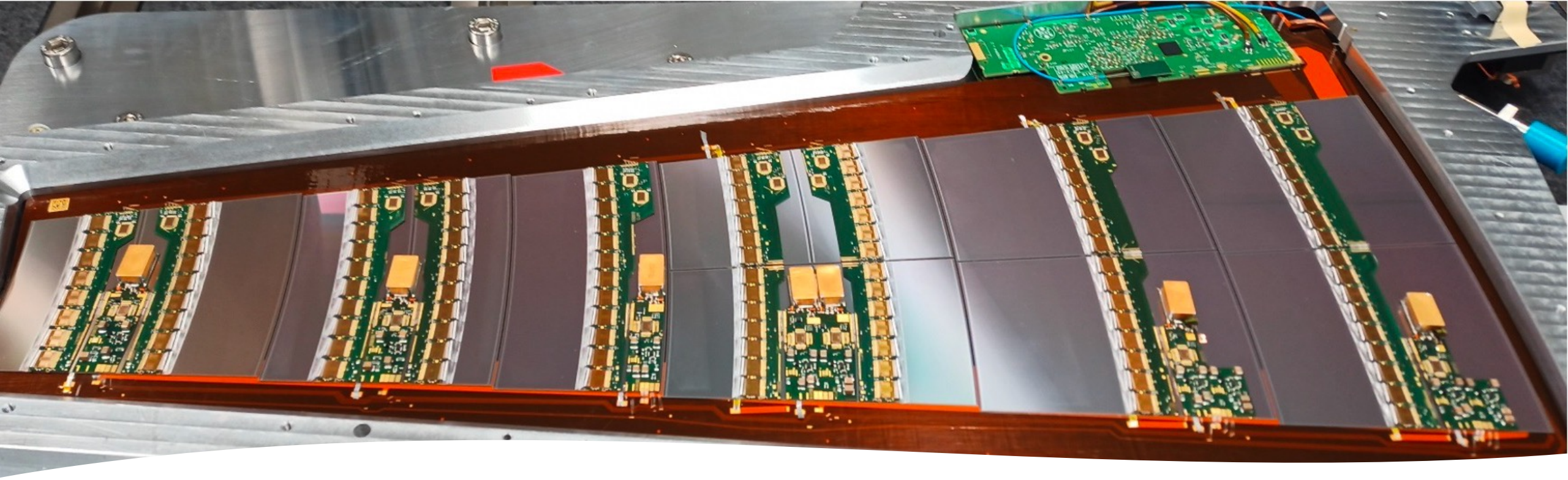
New initiatives aligned with the 20-year vision

Centers at TRIUMF

- Detector Development
- Quantum Technologies
- Data Science

Strengthen core competencies with KEY expertise that enables new capabilities and technologies and training





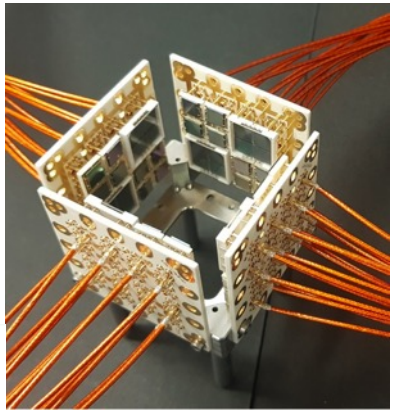
Detector Center

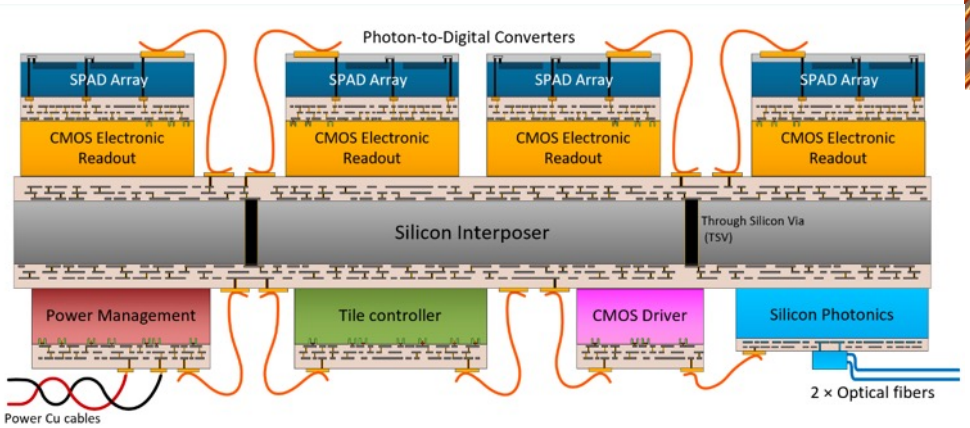
- R&D focus for state-of-the-art detectors that leads to new capabilities and spin-offs
  - The first TPC in an experiment (TRIUMF E104)
  - The first SiPM in an experiment (T2K FGD)
- Facilitate detector development used and available across the laboratory and Canada
- Provide key expertise not available through e.g. CFI hires

Discovery, accelerated

The Road Ahead

- Leverage on existing infrastructure ATLAS ITK, nEXO
  - Radiation hard silicon detectors for future colliders (CMOS, LGAD)
  - Collaboration with ECFA Detector Development Roadmap DRD2, DRD3
  - Digital Single Photon detection (SiPM)
- Other technologies being looked at
  - Liquid noble detectors
  - Optical fibres for dosimetry





Discovery, accelerated

Funding

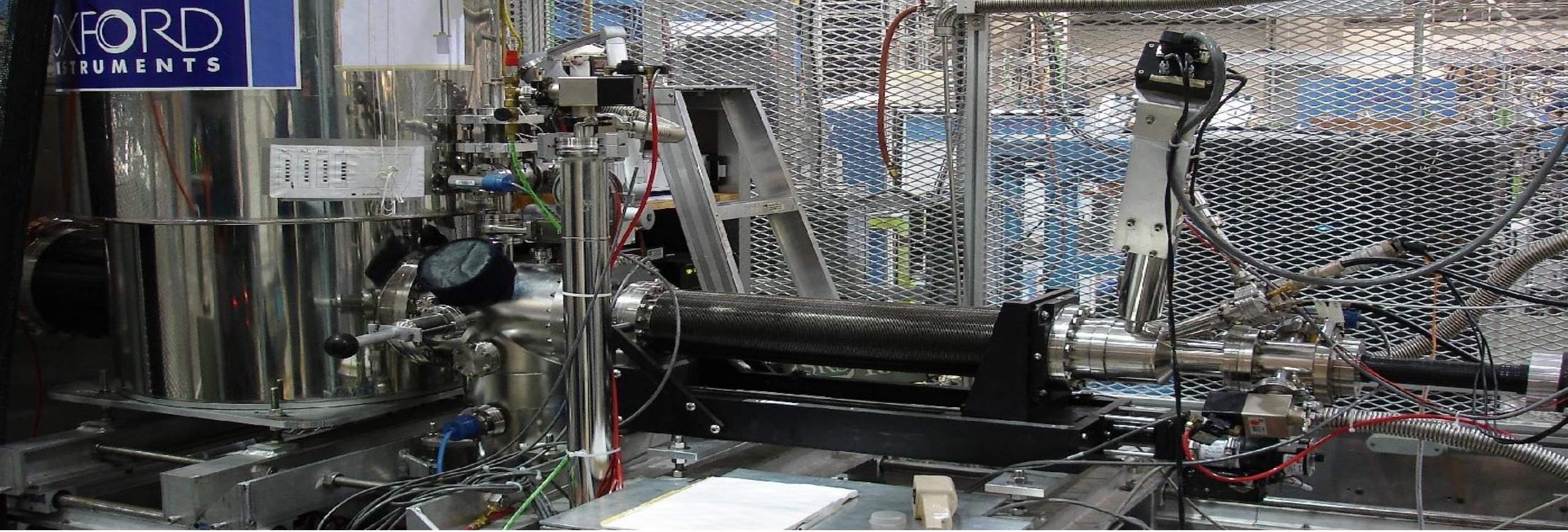
- R&D for world class center would require expertise currently not existing in the Science & Technology
  - Difficult to hire and retain on a temp basis and needs long term perspective (Five Year Plan)
- Complementary to core expertise
- Funding multipliers for dedicated hardware and personnel through (multi-disciplinary) projects grants

NSERC CRSNG | CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE | New Frontiers in Research Fund / Fonds Nouvelles frontières en recherche | INNOVATION.CA CANADA FOUNDATION FOR INNOVATION / FONDATION CANADIENNE POUR L'INNOVATION

Training

- TRIUMF has an excellent track record on graduate student training and has a first class undergraduate & coop program
- Building on GRIDS, opportunity for a CREATE program
  - On-the-job training in cutting-edge research environment
  - Work integrated learning, in collaboration with e.g. BCIT

TSI/GRIDS2023
Graduate Instrumentation and Detector School

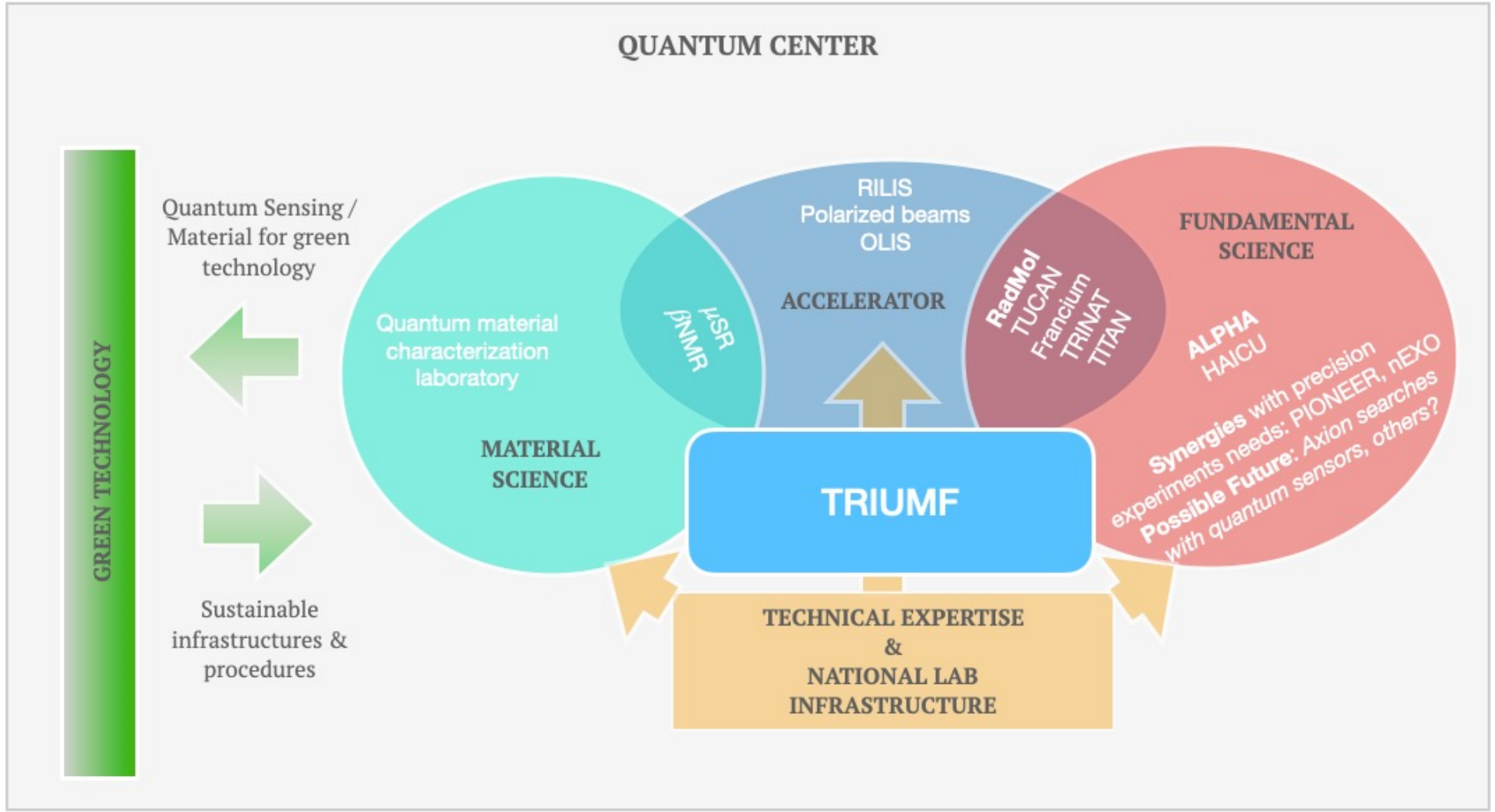


Quantum Center

- Enhance the leading edge in TRIUMF's existing experimental programs which employs quantum techniques (spin polarized beams μSR and βNMR, TUCAN, ALPHA, Francium trapping, RILIS, etc)
- Connect Canadian researchers in novel use of quantum experiments
- Establish & support new flagship experiments at TRIUMF
  - RadMol, HAICU, etc
- Characterization laboratory to enable material characterization for green technologies (batteries and hydrogen storage devices)

Discovery, accelerated

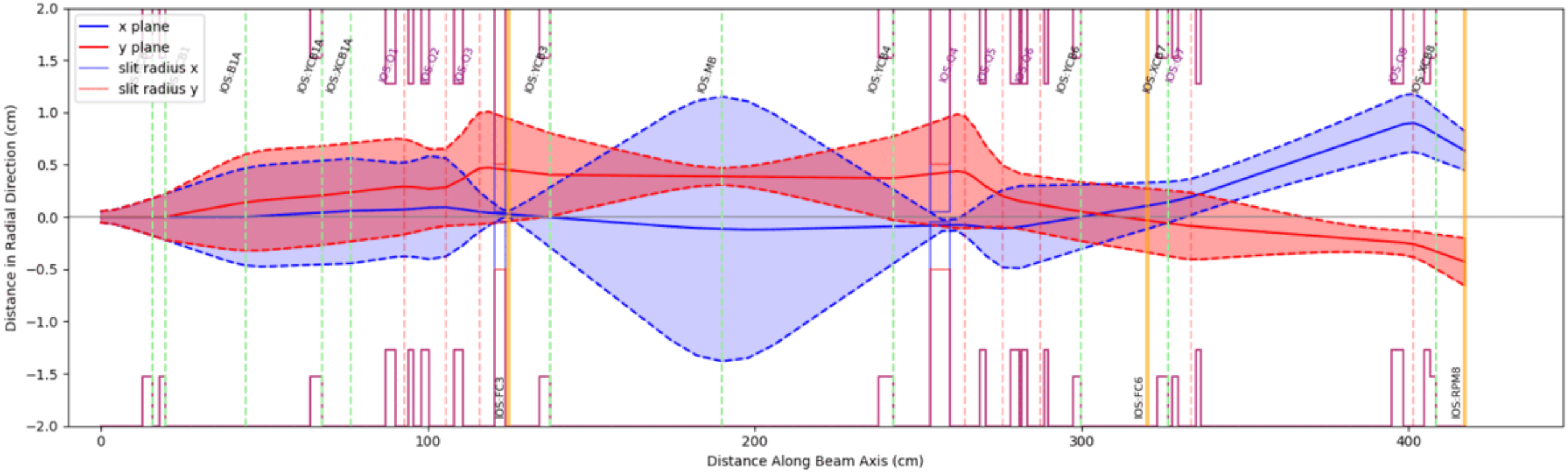
Quantum Center (Center For Quantum Sensing & Precision Physics)



Quantum Center

- Existing quantum experiments spans across the laboratory divisions and departments
- They very often require common technical support & infrastructure
  - Cryogenics handling and design, laser metrology, coating expertise, magnet design
- Pool the resources and sustain the expertise in the long term and allow better cross-fertilization across departments and divisions
- Provides a structure that allows R&D stage critical to the development of new ideas prior to funding requests
- Act as a wedge for longer-term growth in quantum technologies – in alignment with 20 Year Vision

- Initial step: Quantum Forum at TRIUMF with regular talks

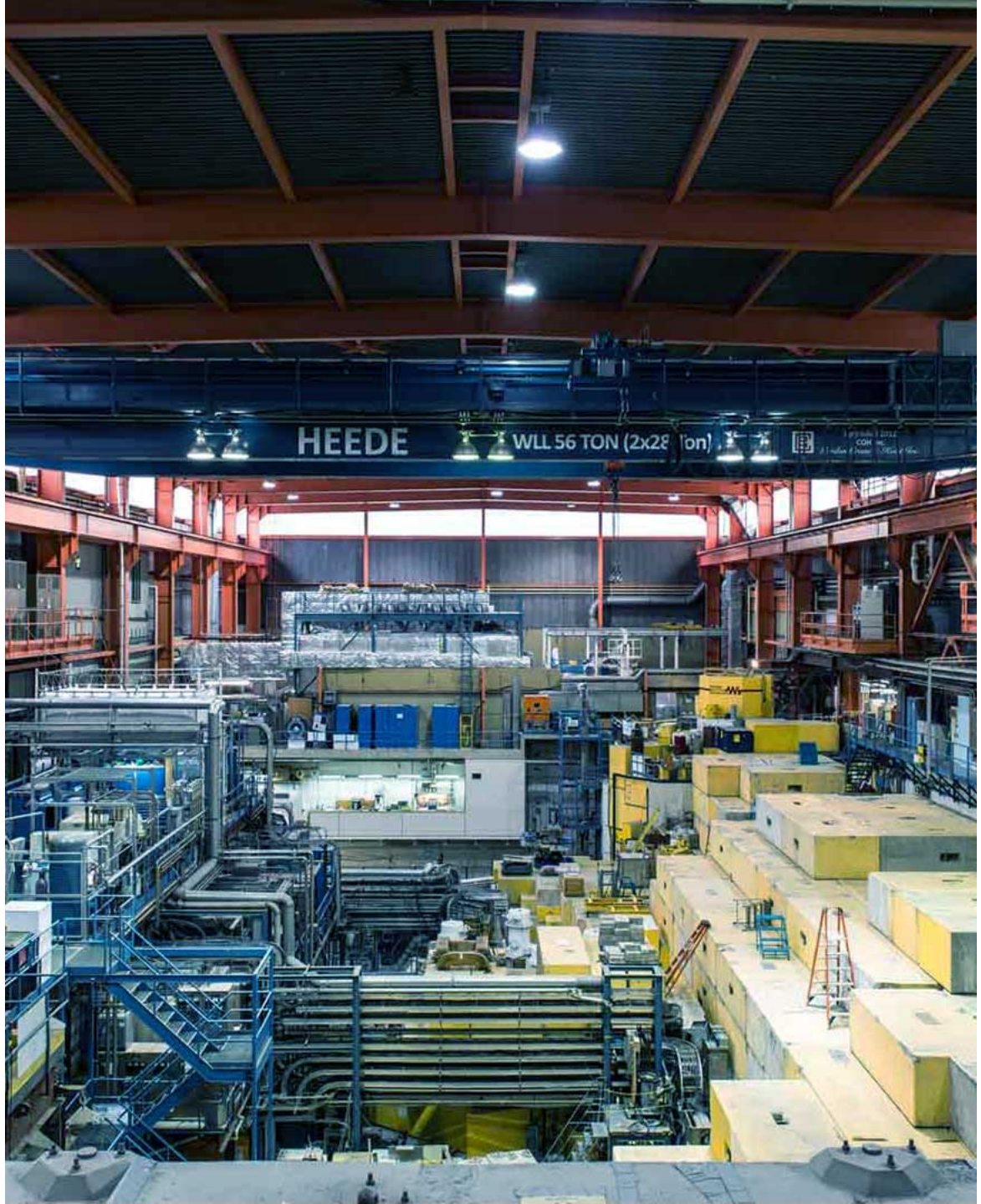


AI Center

- Application of the latest scientific computing algorithms & techniques
  - Artificial Intelligence, Machine Learning, Quantum Annealing
- Enhance Research Output
- Accelerator: AI-based beam tuning → better operations
- Vehicle for taking advantage of National Quantum Strategy
  - Research (Alliance Quantum / International / Consortia)
  - Talent (CREATE / MITACS)
  - Commercialization Pillar (incl NRC AQC)

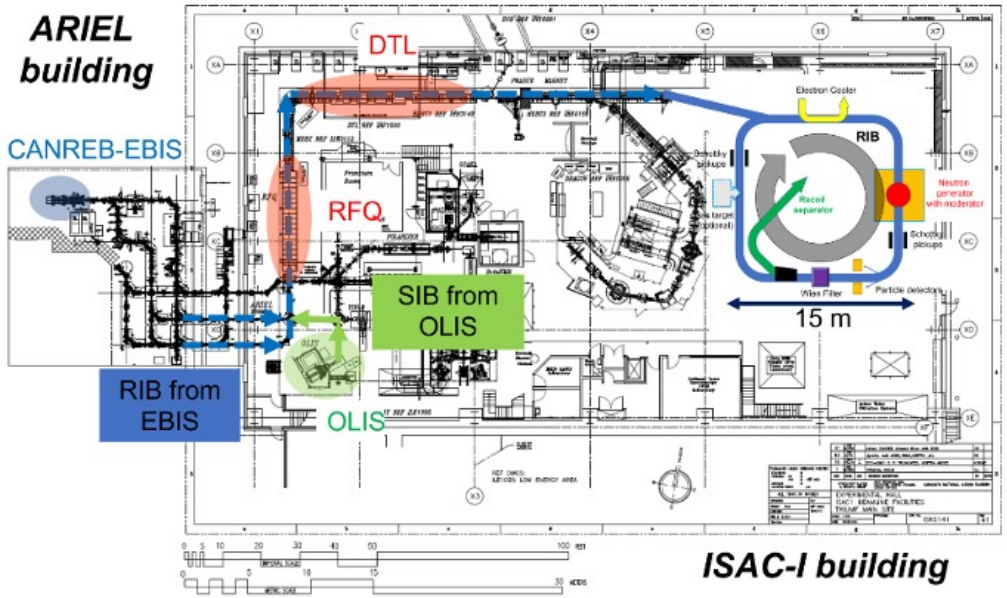
Discovery, accelerated

Other ongoing or planned projects



TRIUMF Storage Ring (TRISR) - Feasibility study in 2025-2030

- TRISR – a storage ring for neutron capture on radioactive nuclei
  - Direct measurement in inverse kinematics
  - Coupled to ISAC radioactive beam facility
  - High-flux neutron generator – “neutron target” that intersects with orbiting ion beam
  - Nuclear astrophysics applications – r-process
- **Dark matter searches**
  - SNOLAB – SuperCDMS, ARGO, DEAP, SNO+
  - DarkSide – Gran Sasso National Laboratory
- **P-ONE** – Pacific Ocean Neutrino Experiment



Summary

PSD scientists will deliver breakthrough science results, train numerous HQPs, and enable new technologies for societal benefits in the next five-year period

Thank you
Merci