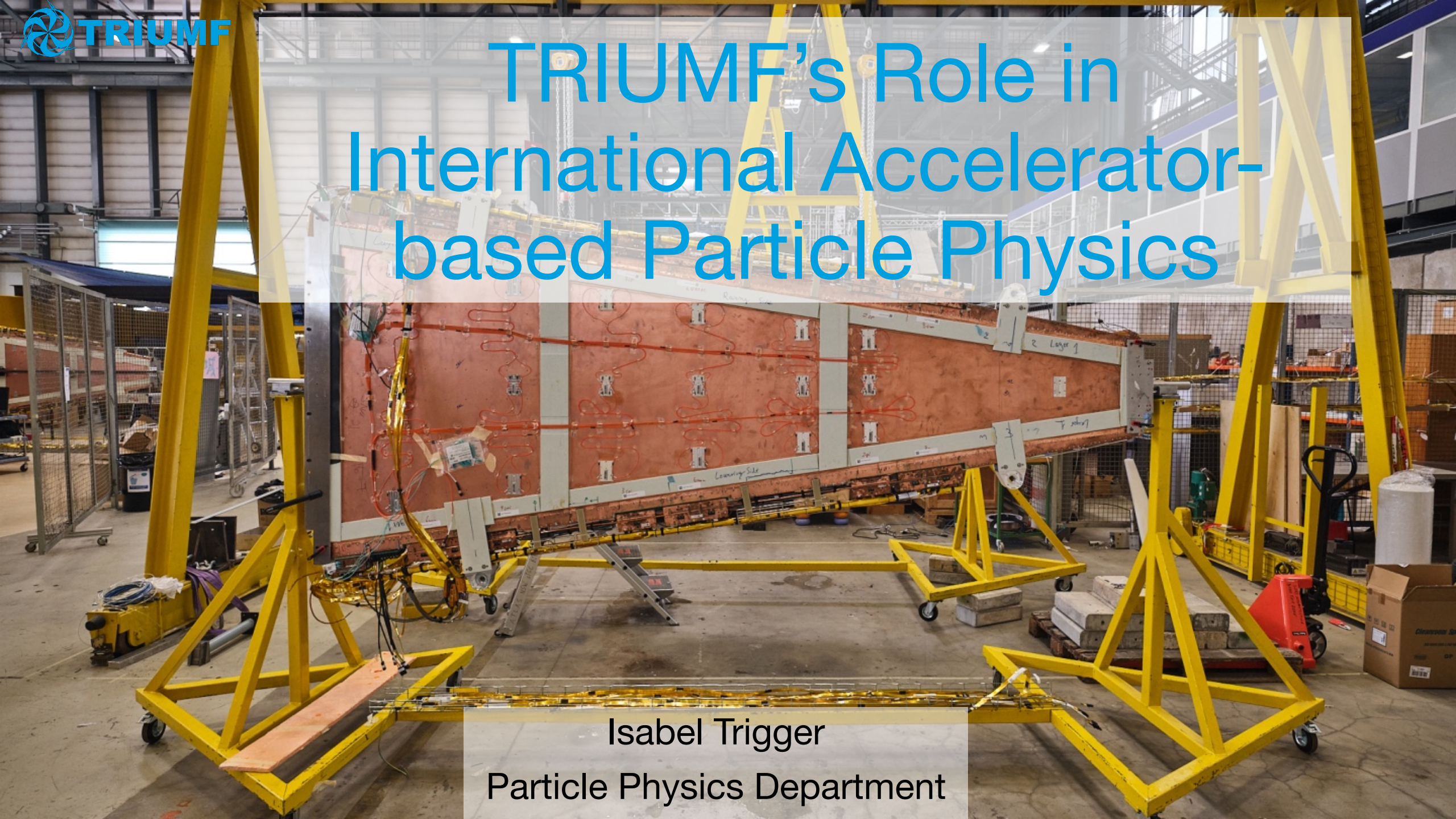


# TRIUMF's Role in International Accelerator- based Particle Physics



Isabel Trigger  
Particle Physics Department

# International particle physics: the frontiers

- TRIUMF & SNOLAB attract many international users to Canada
  - But Canada alone cannot host *all* the world's best facilities
- For highest energies and beam intensities we go international
  - *Faster, Higher, Stronger...*
- Projects covered:
  - ATLAS at CERN LHC (highest beam energy)
  - T2K/HyperKamiokande “at” JPARC
  - Belle-II at KEK SuperKEKB (highest luminosity)
  - NA62 at CERN SPS

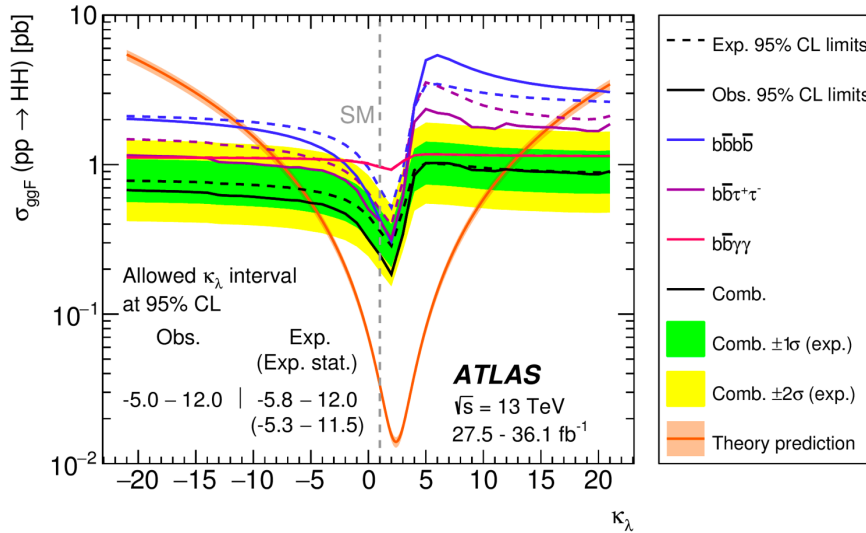


# ATLAS at the Large Hadron Collider (CERN)

- $\sqrt{s}=13$  TeV p-p collisions
- Peak lumi:  $2.1 \times 10^{34}$  cm<sup>-2</sup>s<sup>-1</sup>
- Peak interactions / BX: ~60
- Integrated lumi @13 TeV:
  - 147 fb<sup>-1</sup> recorded
  - 139 fb<sup>-1</sup> good for physics
- Can measure processes with cross-sections <1 pb
- 43 grant signers (38.5 FTE)
- 2900 scientific authors
  - (120 Canadian)
  - 1800 grad students (80 Canadian)

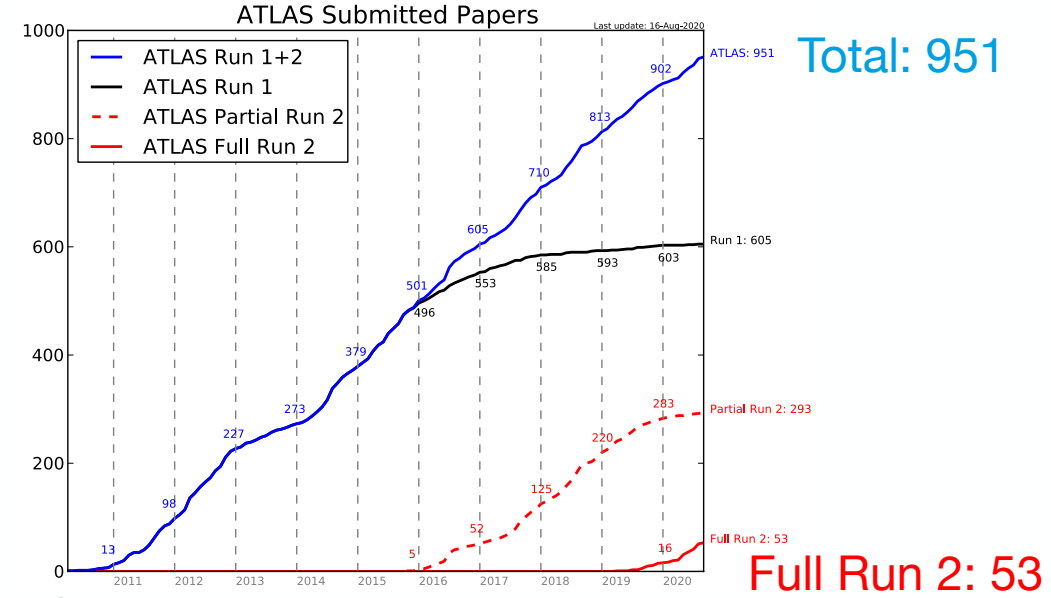


# ATLAS Science Goals

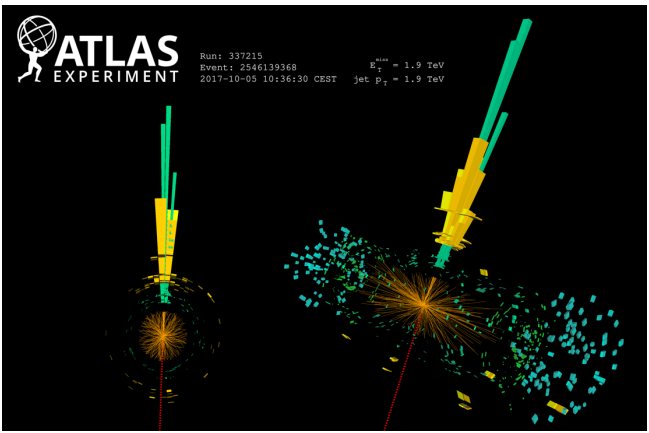


Limits on Higgs self-coupling from di-Higgs production

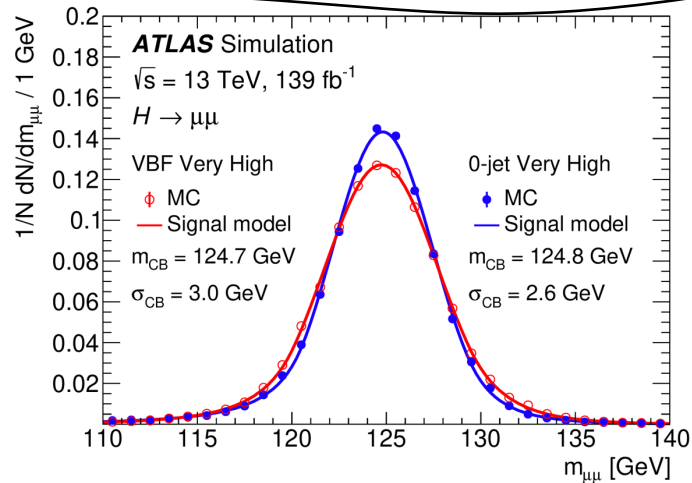
Higgs coupling to 2<sup>nd</sup> gen fermions



- ATLAS was designed to
  - Discover / study Higgs boson
  - Search for BSM physics including
    - Dark Matter candidates
    - Supersymmetry
    - Additional generations
    - Additional gauge bosons
  - Measure properties of top quark, gauge bosons produced in unprecedented numbers to constrain SM



Monojets



# ATLAS-Canada High-Performance Computing



- 10 Tier-1 centres operate 24/7 receiving raw ATLAS data for storage, reprocessing, calibration and reconstruction
  - TRIUMF Tier-1 stores 10% of total ATLAS data
  - Reprocessed data distributed back to CERN, to other Tier-1 centres, and to Tier-2 centres worldwide.
- TRIUMF-operated Tier-1 connected to CERN via dedicated high-speed, high-bandwidth light fibre link provided by CANARIE, Canada's advanced research network.
- Grew from initial 112 cores, ~10 TB storage in 2006, to 7700 cores and 11 PB of disk and 31 PT of tape storage
  - one of Canada's largest dedicated to scientific project.
- Outgrew TRIUMF space, now co-located with Compute Canada CEDAR facility at SFU
  - Still TRIUMF-operated
  - Cost efficiencies from larger CC Simon Fraser University location
  - infrastructure support, room to grow as ATLAS prepares for High Luminosity Era when experiment will generate 10X as much data.
- Capacity will continue to grow significantly in coming years.
  - ATLAS CPU demand increases with data-taking rate
  - Long-term storage needs increase with integrated luminosity

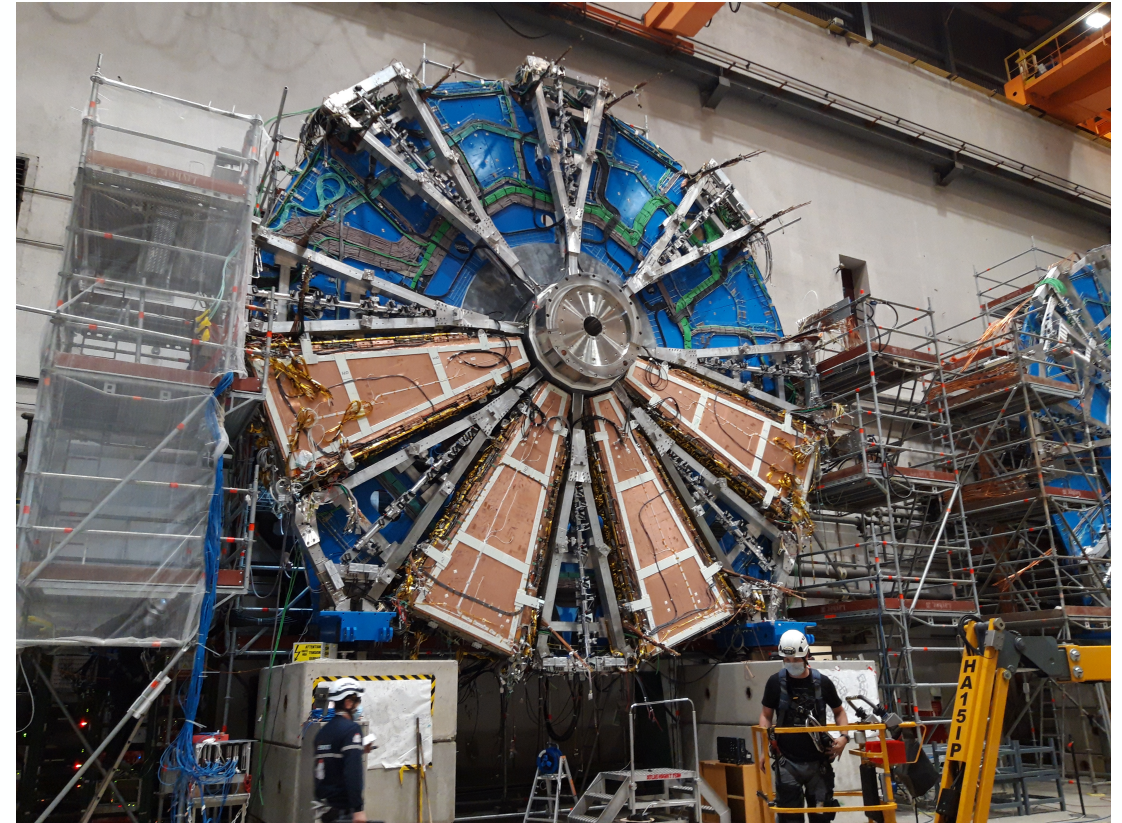
SFU data centre



2020-08-17

# ATLAS Status

- LHC Long Shutdown 2
  - Began Dec. 2018
  - Cavern to close Feb. 2022
- Upgrades to accelerator complex to prepare for HL-LHC after 2025
- Upgrades to ATLAS to reduce lumi-correlated “fake” triggers. Canada and TRIUMF work on:
  - LAr calorimeter trigger granularity
  - New Small Wheels for muon spectrometer



# ATLAS-Canada Muon Spectrometry



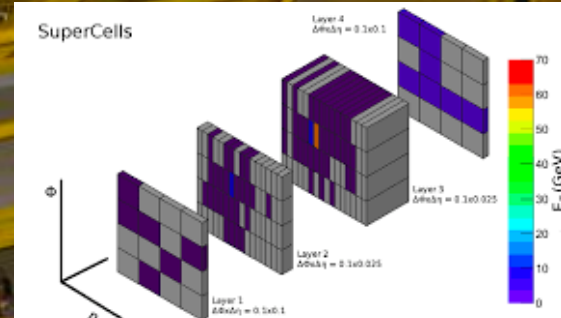
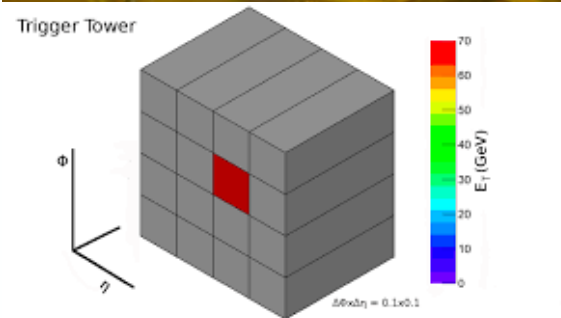
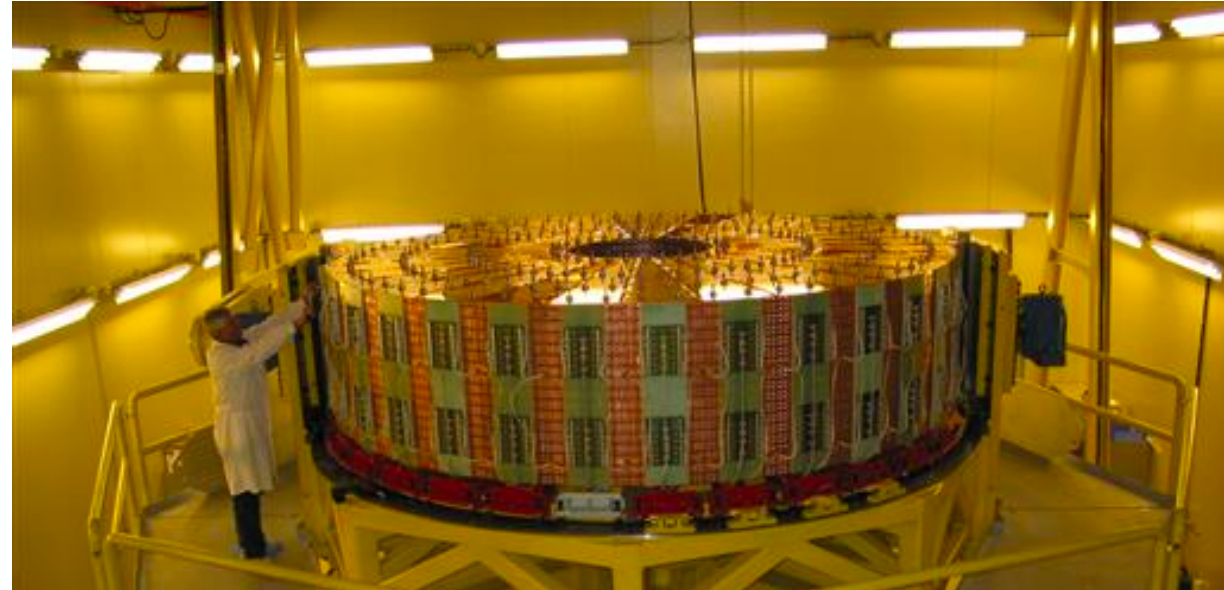
Semi-clean “tent” in Proton Hall Extension, Spray room in ARIEL lab

2020-08-17

- Two New Small Wheels (~10 m diameter)
- Goal:
  - maintain tracking performance with much higher backgrounds... AND...
  - Veto muon candidates without track segment pointing to IP upstream of end-cap toroids to reduce fake forward muon trigger rate by 90%
- Each wheel: 16 sectors
  - 8 large, 8 small
- Each sector:
  - 2 MicroMegas wedges primarily for tracking and
  - 2 small-strip Thin Gap Chamber wedges primarily for trigger
- ¼ of sTGC quadruplets are made in Canada
- TRIUMF production almost done; Canadian production to be complete March 2021
- 2<sup>nd</sup> wheel installation driving end of LS2

# ATLAS-Canada LAr Calorimetry

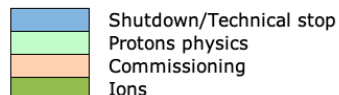
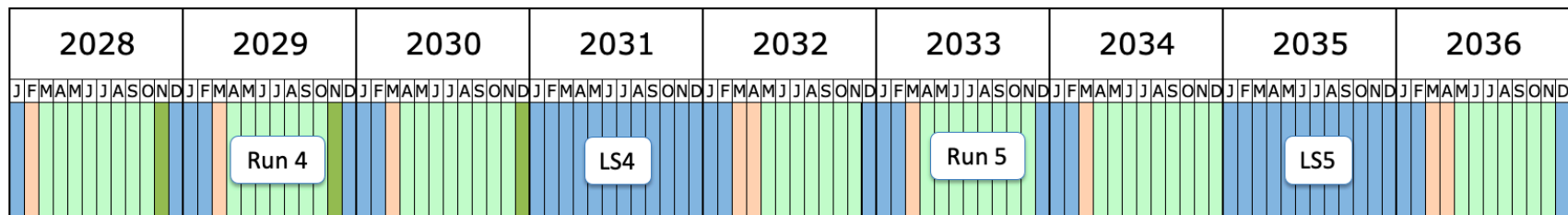
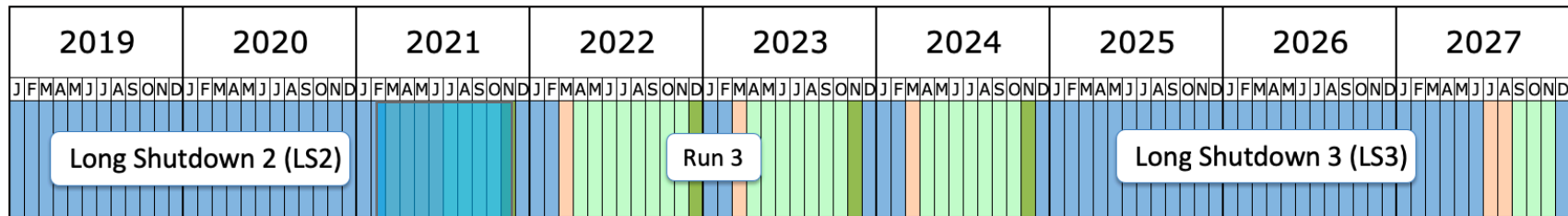
- 2 (of 4) Hadronic End-Cap wheels & all 4 Hadronic Forward modules & Cryo feedthroughs made in Canada
  - See [Pietro Giampa talk](#) on Argon detectors
  - Will last full life of ATLAS
  - HEC front-end boards *in LAr*
- But... while detector itself has very fine granularity, current Level-1 trigger reads coarse “towers” (many cells)
  - Replacing trigger electronics with earlier digitization, allows earlier particle ID & noise discrimination in trigger
  - Canadian baseplanes all completed on time, under budget
- LAr phase-2 leverages CFI funds to set up new ASIC development/design/manufacturing infrastructure/expertise at TRIUMF
  - Other Canadian projects can benefit in future.



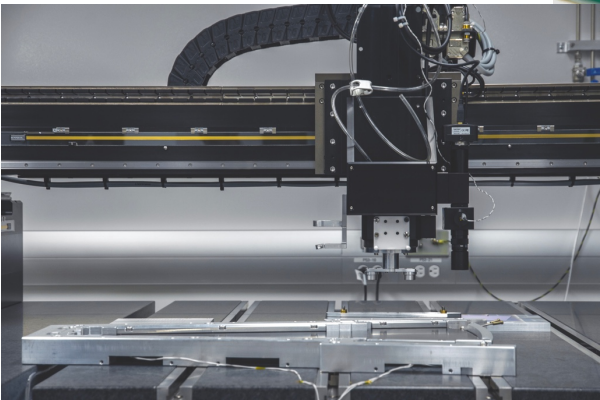
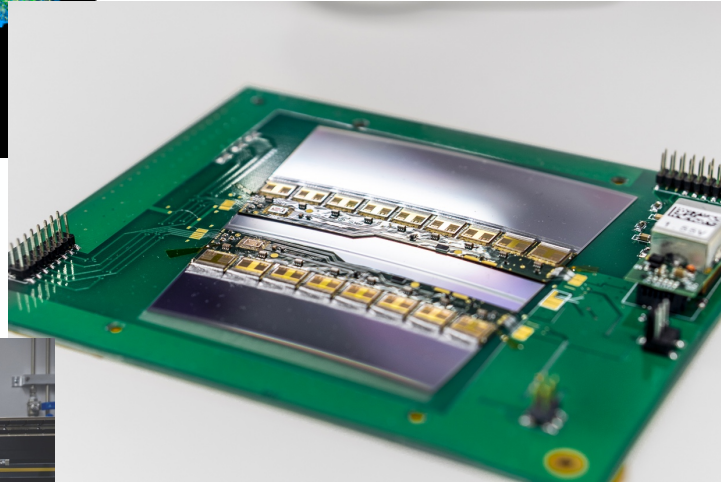
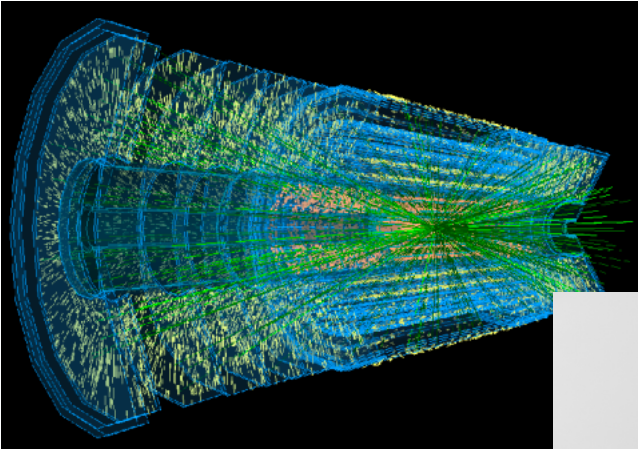


# ATLAS (Farther) Future Plans

- LHC Long Shutdown 3 (~2025-27) to increase lumi to  $7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$  (~200 pp collisions per bunch Xing)
- Enables measurements needing 3-4  $\text{ab}^{-1}$ 
  - Higgs self-coupling;
  - other precision Higgs (e.g. 2<sup>nd</sup> gen), top, gauge boson;
  - statistically limited SUSY searches...
- Significant accelerator upgrades; Canada's in-kind contribution is again via TRIUMF (see [Bob Laxdal's talk](#))
- ATLAS upgrades include complete replacement of Inner Tracker with all-silicon ITk



# ATLAS-Canada Inner Tracker



- ITk is international effort involving >100 ATLAS institutes in >20 countries
- To be installed in LS3
- Constructing in Canada:
  - 1500 (of 7000) end-cap modules
    - 1000 in TRIUMF-SFU-UBC consortium,
    - 500 “Back East”
  - Final mounting of modules to 90 (/384) petals also at TRIUMF
    - (1 petal =  $1/32$  of a disc)
- Have new clean room, equipment & expertise to continue Si sensor development for future large (or smaller) detectors
  - See SciTech [talk](#) (Hessey) & Rad-Hard Semiconductor Tracking Devices [talk](#) (Koffas) for details

# Tokai-to-Kamoikande (T2K) at J-PARC

- Goal: establish  $\nu_{\mu} \rightarrow \nu_e$  oscillations, determine from  $\nu$  oscillations whether neutrinos violate CP
- J-PARC generates (anti-) $\nu_{\mu}$  beam 295 km from far detector SuperKamiokande
  - SuperK: water-Čerenkov detector
  - 50 kt pure water (22.5kt fiducial)
  - Now doped with Gd for better neutron detection
  - 2.5° off-axis (oscillation max. - 🍁 idea...)
- T2K collaboration: 26 Canadians (~8 grant holders, ~4 FTE, 23 authors from 7 institutes)
  - Currently 2 grad students
- Latest results exclude 35% of  $\delta_{CP}$  values at  $3\sigma$
- Slight preference for upper octant of  $\Theta_{23}$  and normal hierarchy



~480 members (~350 authors), 69 institutes, 12 countries+CERN

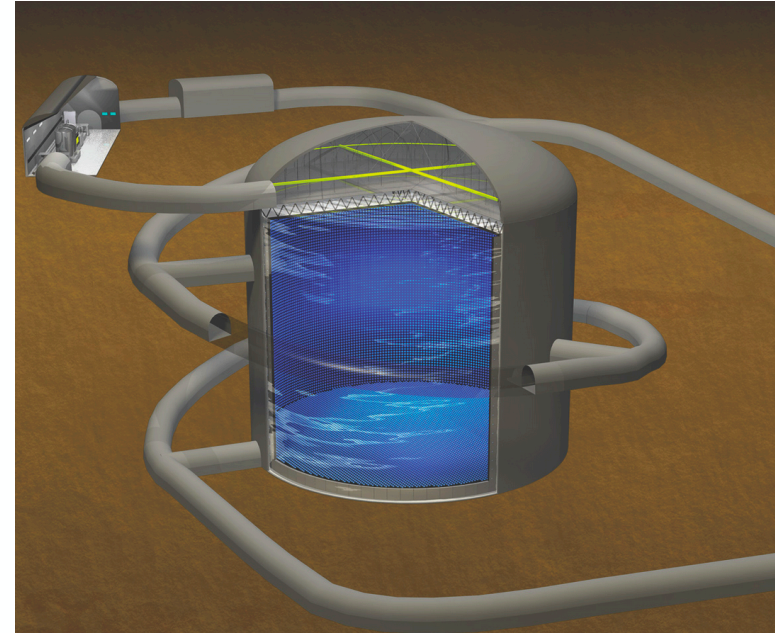
# T2K & SK: Canadian contributions



- Canadian institutions among T2K founders
- TRIUMF took leadership role to build many challenging components of T2K
- Built key Near Detector components:
  - Time Projection Chambers,
  - Fine Grained Detector
- Provided Proton Beam Instrumentation:
  - Optical Transition Radiation Monitor,
- TRIUMF built/operated remote handling system for target station
- Compute Canada essential to T2K reconstruction & analysis
- Photodetector Test Facility (PTF) at TRIUMF being used in calibration of SK detector response

# HyperKamiokande

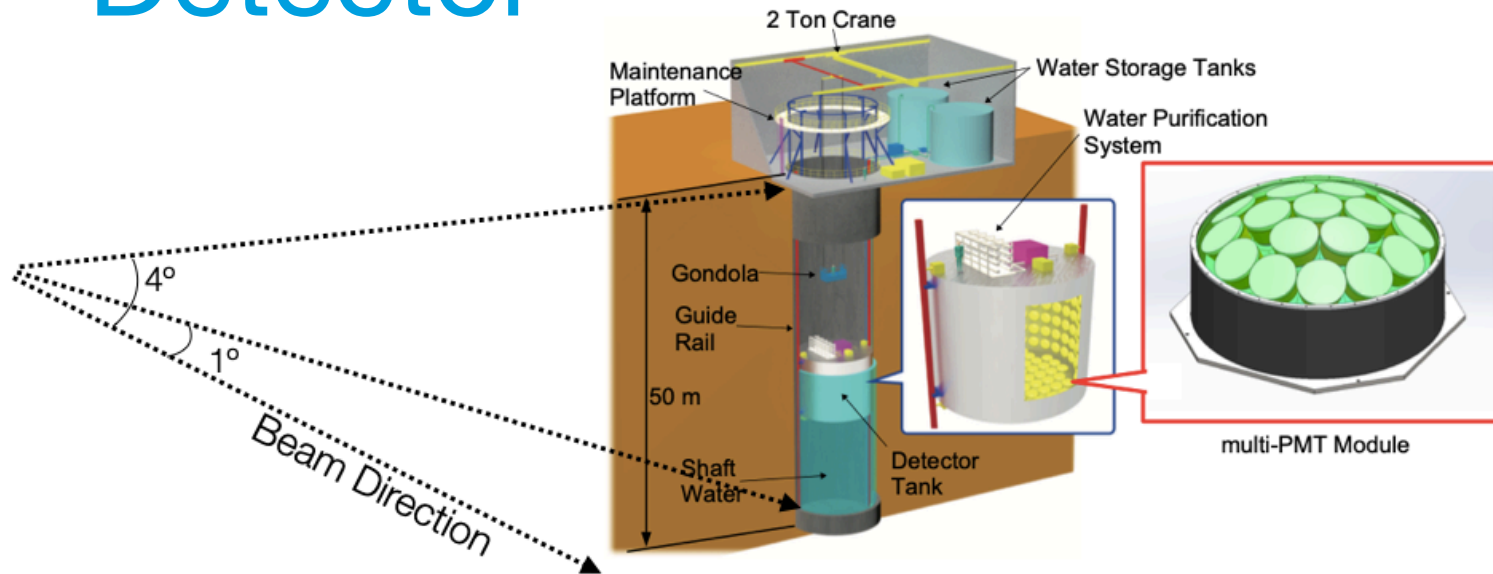
- 260 kton water Čerenkov detector
  - 187 kton fiducial, ~8X SuperK
- Physics program: neutrino oscillations, proton decay, supernova neutrino detection, dark matter search...
- Officially approved by Japan February 2020 (incl. IWCD)
  - Seed funding from U.Tokyo allowed construction to start
- 8 Canadian institutes, 12 grant-signing faculty (~6 FTE), 4 postdocs, 6 grad students
- Expect TRIUMF to fill technical leadership role in HK, similar to T2K
- Potential for TRIUMF contribution to beam line remote handling



Entrance yard construction



# HyperK: Intermediate Water Čerenkov Detector



mPMT prototype at TRIUMF

- Same target as far detector, 600 t, Gd-loaded
- Movable target, adjustable off-axis angle
- Fine granularity: multiPMT concept adopted from KM3NeT
  - Development for HK/IWCD led by TRIUMF
- 🍁-conceived and 🍁-led

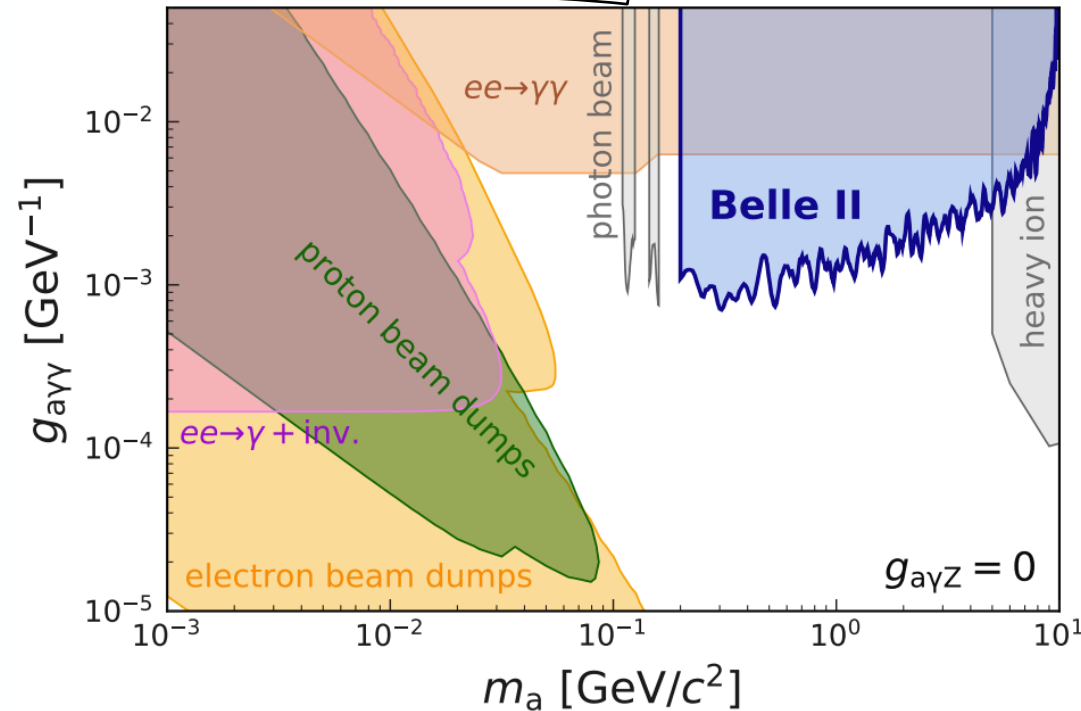
# Belle II at SuperKEKB

- Goal: 30X combined  $\int \mathcal{L}$  of BaBar + Belle, primarily recorded at Y(4S) ( $10.58 \text{ GeV}/c^2$ )
  - 74  $\text{fb}^{-1}$  collected since start in 2018 (Goal: 50  $\text{ab}^{-1}$ )
  - New 2-layer pixel detector in 2022;
  - New final focus 2026
  - Run through 2030 to get full data set.
- Canada joined after major hardware construction well under way, took on significant software / operational responsibilities for calorimeter:
  - Calibration operations; software validation
- 980 members, 117 institutions, 26 countries.
  - 8 Canadian grant-signing (5.4 FTE)
  - 3 Canadian post-docs, 10 grad students
- Do not anticipate contributing to major detector upgrade.
  - Canadian studies show calorimeter will survive well.
- Chiral Belle proposal: polarized  $e^-$  beam
  - Requires hardware for spin rotators and polarimeter.
  - R. Baartman, Th. Planche (Accelerator Div.) & T. Junginger (UVic/TRIUMF) have signed NOI for this project grant
- CFI proposal for Belle II data centre (15% of data) under review.



# Belle II at SuperKEKB

Search for Axion-like particles (ALPs):



Upper limit (95% CL) on ALP-photon coupling from [arxiv:2007:13071](https://arxiv.org/abs/2007.13071) with first 445 pb<sup>-1</sup>.

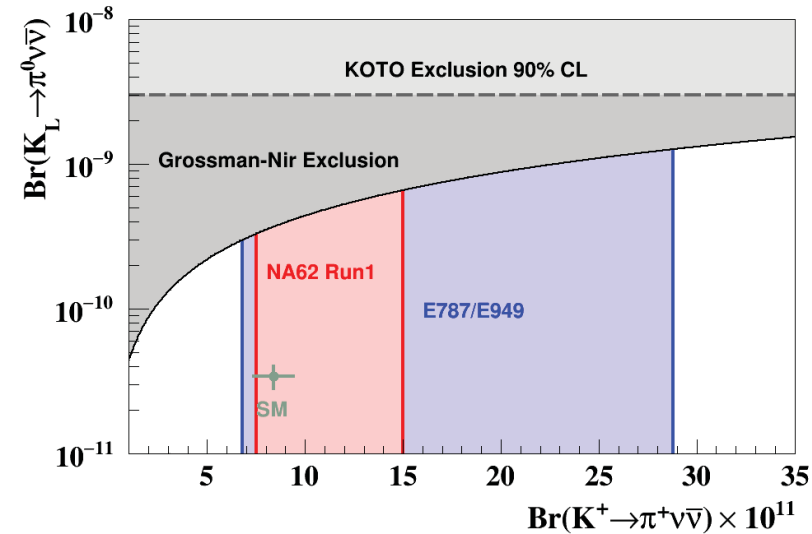
- Search for new physics in wide range of final states with precise Standard Model predictions:
  - Precision measurements of CKM matrix elements
  - Rare decays, including  $\tau$ ;
  - Forbidden decays (e.g. lepton flavour violation);
  - Symmetries (e.g. CP violation).
  - Indirect mass reach for these complements and can exceed LHC direct search limits.
- Continued investigation of weak force.
- Direct searches for non-SM particles (e.g. dark sector).



# CERN NA62: Rare Kaon Decays $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

- 75 GeV  $K^+$  decay in flight
  - Ultra-rare decays with highest CKM suppression  $A \sim (m_t/m_W)^2 |V_{ts}^* V_{td}| \sim \lambda^5$
  - Goal: 20% precision
  - Result of 2016-18 data:
    - 20 events found, SM prediction  $9.8 \pm 0.9$  with expected background  $6.8^{+1.0}_{-0.8}$
  - $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (11.0^{+4.0}_{-3.5 \pm 0.3}) \times 10^{-11}$  ( $3.5\sigma$ ) ([ICHEP2020](#))
  - In good agreement with SM prediction:  $(8.4 \pm 1.0) \times 10^{-11}$  ([Buras et al, JHEP11\(2015\)033](#))
- Detector improvements in progress
  - 2021-24 operation planned
  - Expect 50 events with improved S/N
- Also other rare decay limits & new particle searches

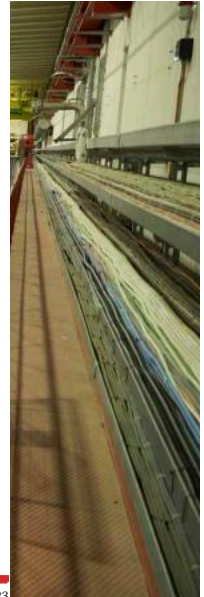
## Grossman-Nir limit



ICHEP 2020

New result on the search for the  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  decay at NA62 (R. Marchevski)

23



Faculty: Doug Bryman (UBC/TRIUMF), Toshio Numao (TRIUMF)  
NSERC support through 2023

Compute Canada Resources (CPU and storage on CEDAR)

LKr TPC for purity monitoring built at TRIUMF & assembled @CERN

UV SiPMs & charge preamps in LKr

Collaboration with TRIUMF Machine Learning (W.Fedorko):

improves  $\pi/\mu$  id/rejection by X5; signal acceptance +25%.

# Summary

- TRIUMF continues to make substantial and essential contributions to:
  - Detector design, construction & operation
  - Accelerator component design & construction
  - High-performance computing
  - Data analysis (supports scientists, joint faculty, post-docs & students)
- International collaborations rely on:
  - Particle Physics Department
  - SciTech Department
  - Accelerator Division
  - Engineering Services / Design & Fabrication
  - Computing Support
- Important for long-range vision to keep an eye on the evolving needs of large international projects and make sure TRIUMF stays ahead of curve