Research in Experimental Particle Physics at Carleton University

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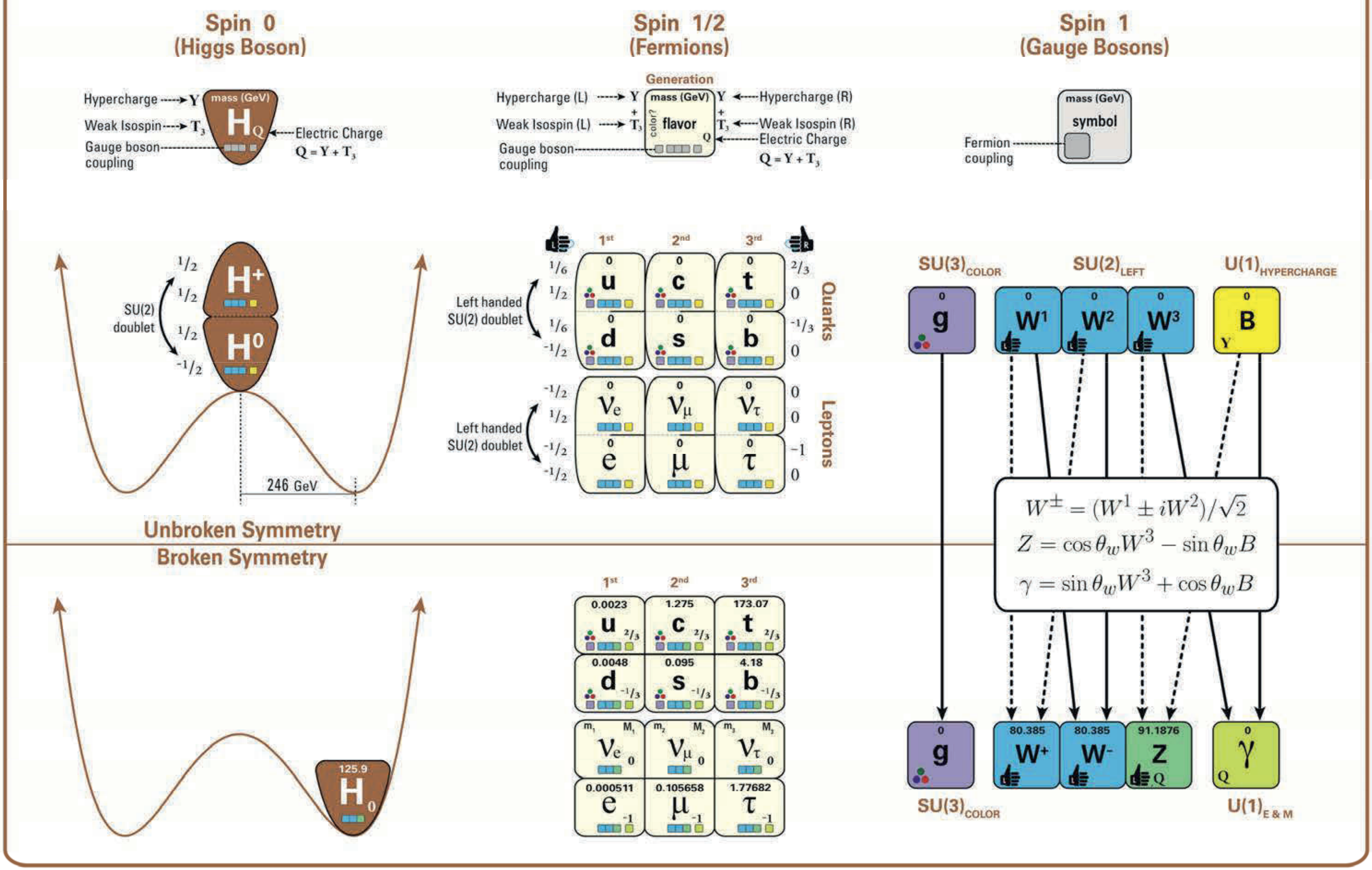
Using slides from S. Viel, T. Koffas, K. Graham, J. Heilmann

October 26th, 2020

The Standard Model of Particle Physics



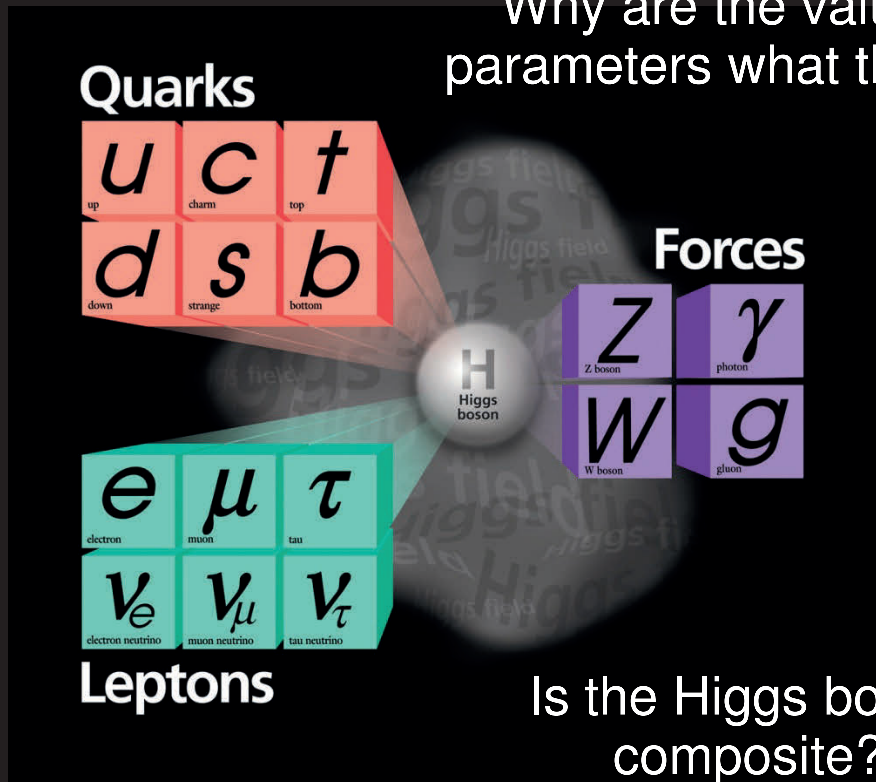
Questions beyond the Standard Model

What is dark matter?

Does dark matter interact with ordinary matter?

What explains the asymmetry between matter and antimatter?

Why are the values of Standard Model parameters what they are measured to be?



Are there any more fundamental forces?

Are they unified at very high energy?

How can we measure neutrino masses?

How do neutrinos acquire their mass?

Are neutrinos their own antiparticles?

Are there sterile neutrinos?

Is the Higgs boson composite?

Is its mass fine-tuned?

What about gravity?

What is dark energy?

Why are there 3 generations of matter?

Are there more undiscovered particles?

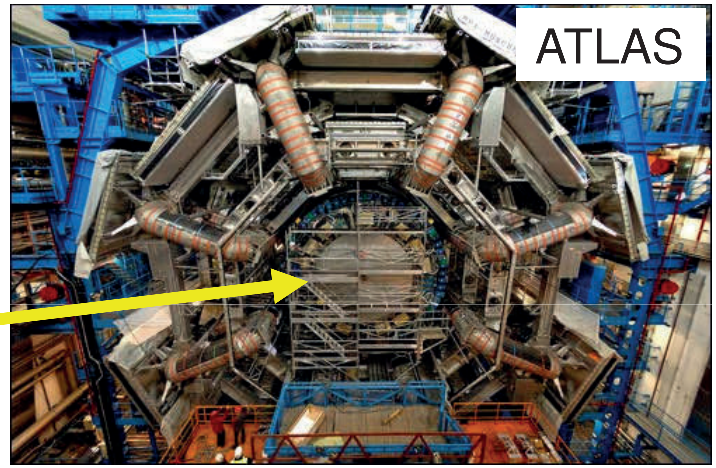
Are there extra dimensions of space?

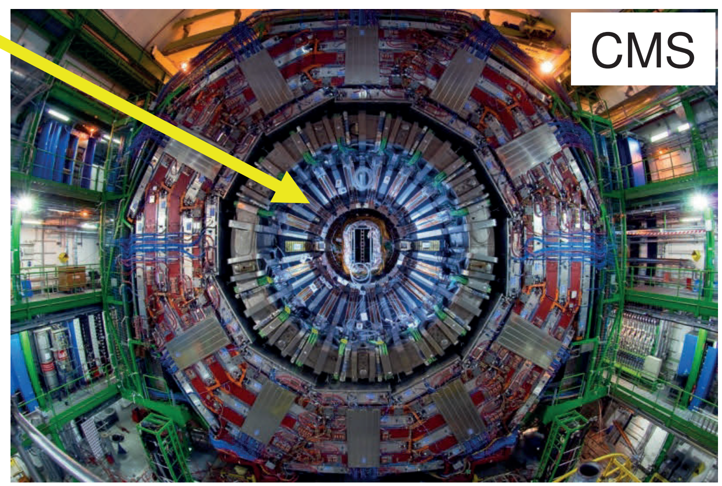
Collider Physics:

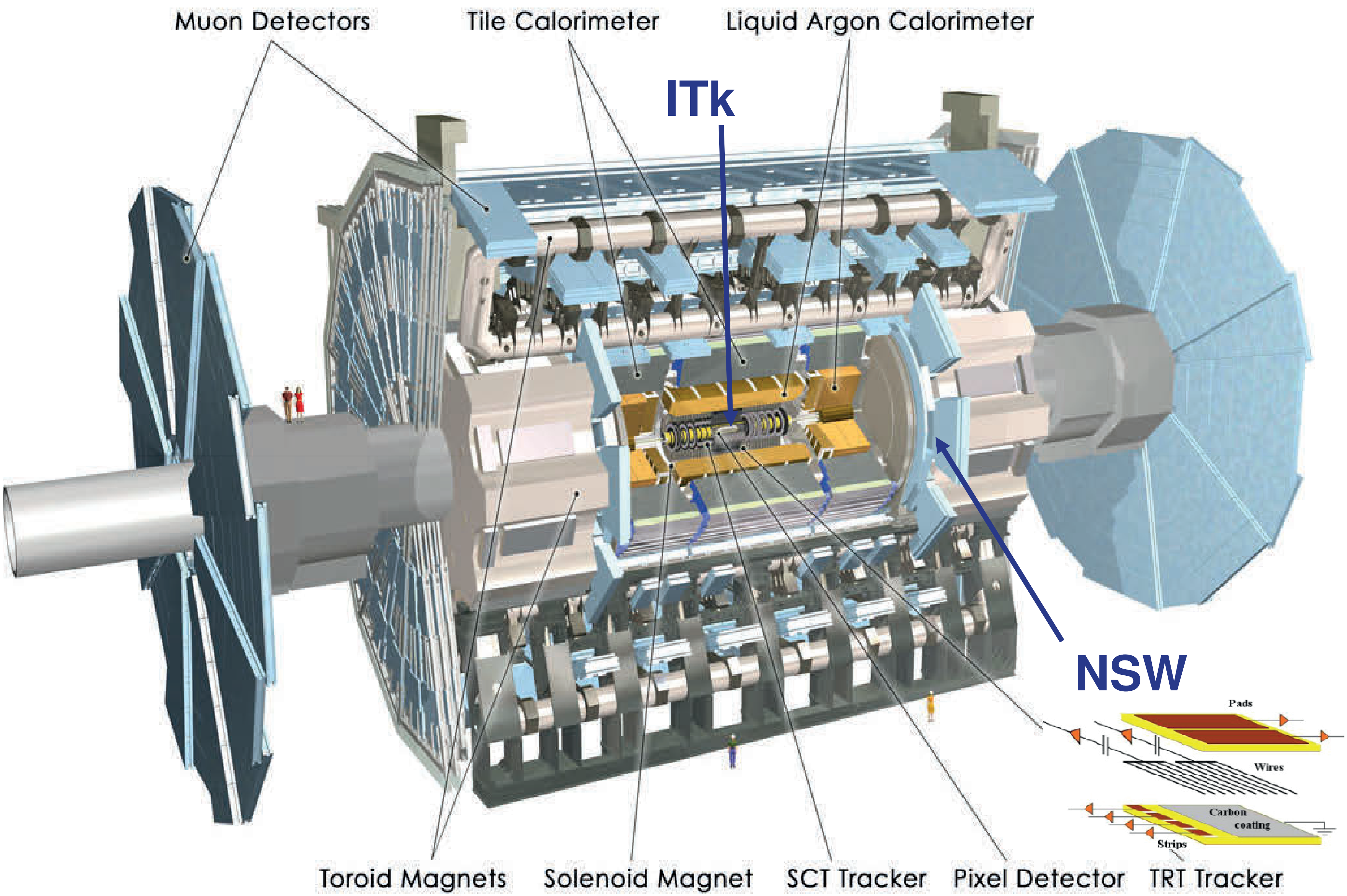
ATLAS at the Large Hadron Collider

Large Hadron Collider

- The **Large Hadron Collider** (LHC) is the world's most powerful particle accelerator
  - **Centre-of-mass energy in 2015-2018: $\sqrt{s}$ = 13 TeV (design 14 TeV)**
  - **Average of 56 proton-proton collisions every 25 ns → 1.4 billion/s (reached in 2018)**

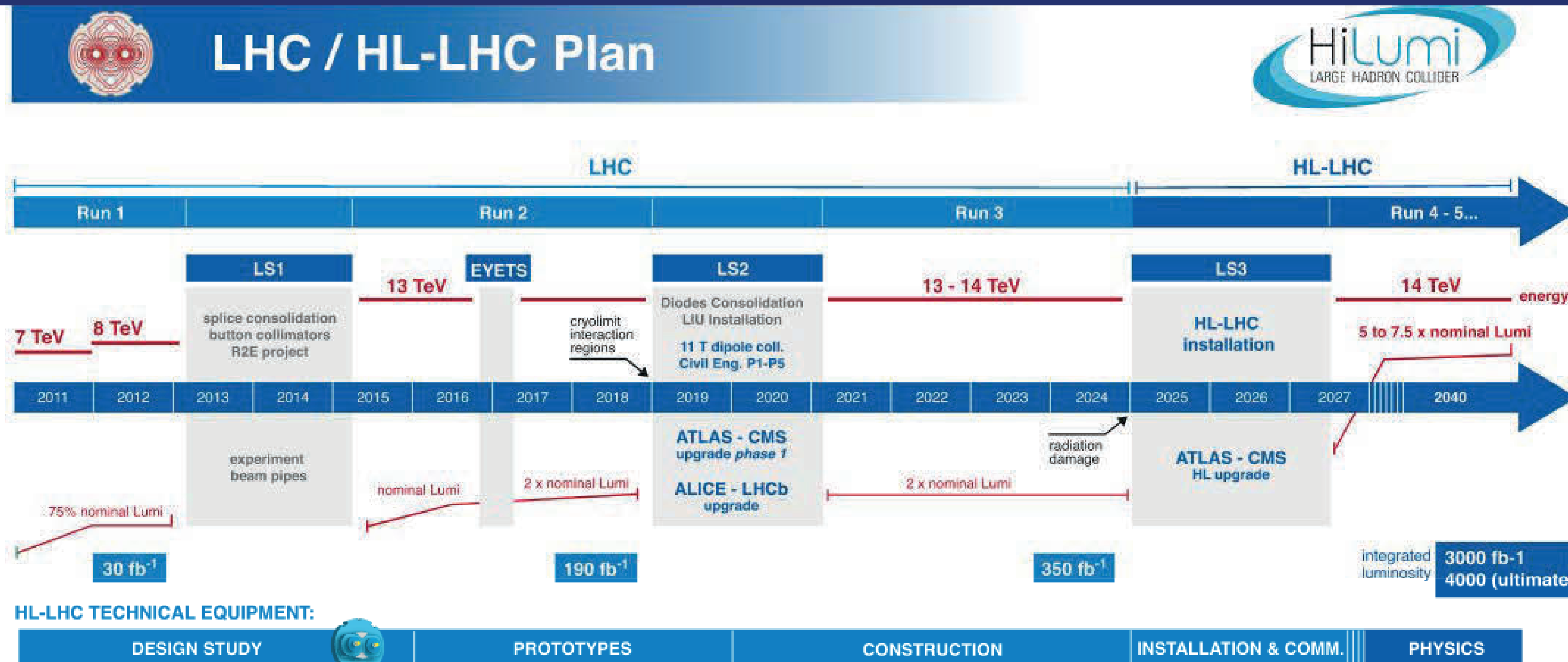






Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
ITk
NSW
Pads
Wires
Carbon coating
Strips
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker

High-Luminosity Large Hadron Collider



- Detector upgrades in construction with responsibilities at Carleton University:
  - **New Small Wheels (muon detector built with thin gap ionization chambers)**
  - **Inner Tracker (radiation tolerant silicon strip tracking detectors)**

- **Precise measurements of the Higgs boson parameters (and many other Standard Model processes)**

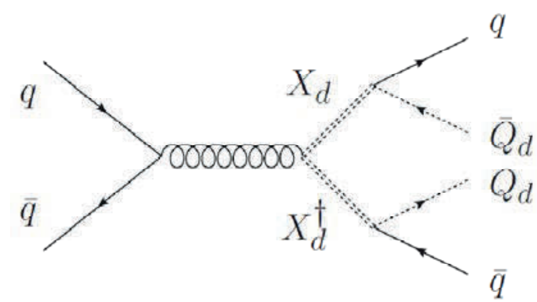
- **Search for new physics (Dark Matter/Energy)**

- **Machine-learning applications to particle physics**

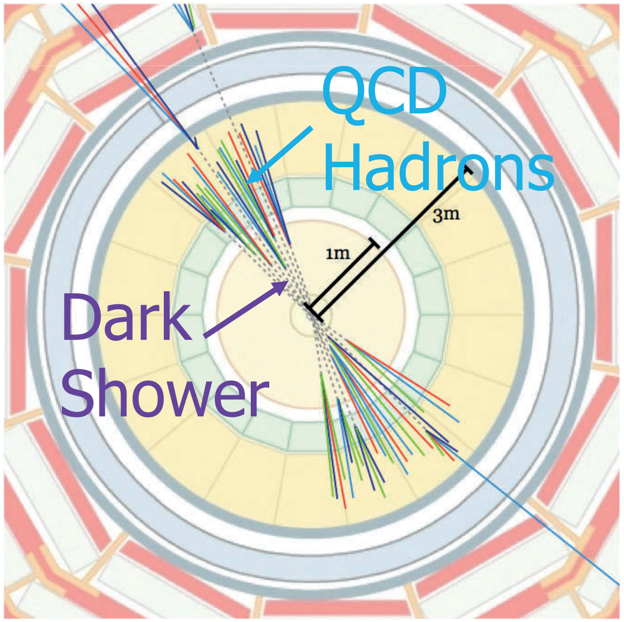
Search for DM with Machine Learning techniques

<u>Physics Analysis</u>

- Searching for evidence of Dark Matter in 'emerging jets' with ATLAS



- We are developing a sensitive search for unique jet-like signals with displaced vertices utilizing machine-learning tools



Contact information

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ATLAS ITk and R&D activities at Carleton University

Motivation and goals

- Construct charged particle tracking detector for the high-luminosity phase of the LHC
- **To be used for physics research at CERN during 2026-2036**
- **Needs to operate under very challenging conditions**
- **Based on state-of-the-art thin silicon sensors and novel, radiation-hard readout electronics**

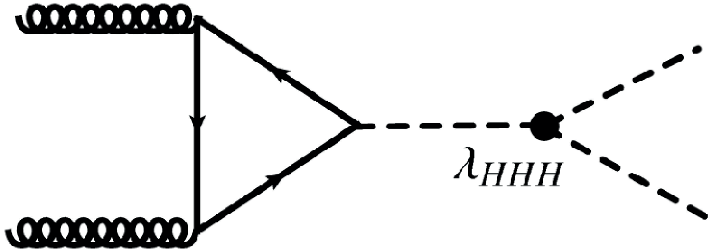
- class 100, 1000, and 10000 clean rooms (as required)
- manual wire bonding system (adequate to for hybrid to test-frame bonds, but not ASIC bonding to hybrid or sensors)
- manual wafer/chip probing stations and test equipment
- microscopes for doing inspection and basic metrology

Canadian-made ITk data acquisition prototype using Carleton's micro-fab facility

- **Two main areas of expertise at Carleton University**
  - **Thin solid-state sensor design, R&D, characterization (with specialization on surface effects)**
  - **Computer chip (ASIC) development and characterization**

ITk @ HL-LHC: DiHiggs (HH) Factory

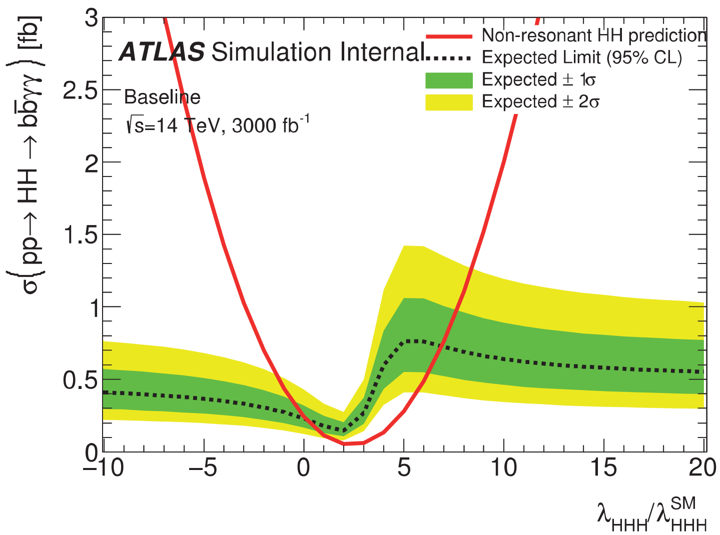
Di-Higgs production relevant to investigation of Higgs self-coupling λ_{HHH}



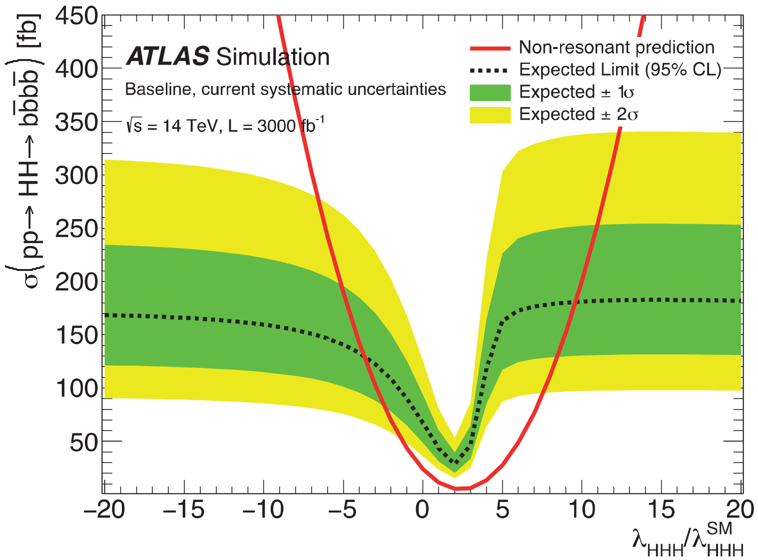
Prevalent Higgs decay modes:

- **$HH \rightarrow bb\gamma\gamma$; cleaner signal**
- **$HH \rightarrow bbbb$; most copious**

ITk is the key ATLAS detector element to detect those very rare events



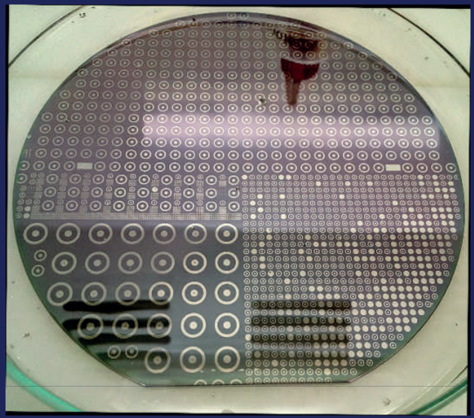
$HH \rightarrow bb\gamma\gamma$ cross-section vs. λ_{HHH} with 3000 fb^{-1} of data



$HH \rightarrow bbbb$ cross-section vs. λ_{HHH} with 3000 fb^{-1} of data

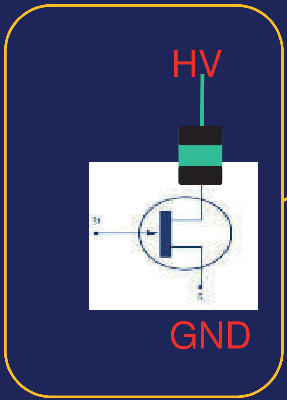
Beyond the HL-LHC: Future Colliders Technology Challenges

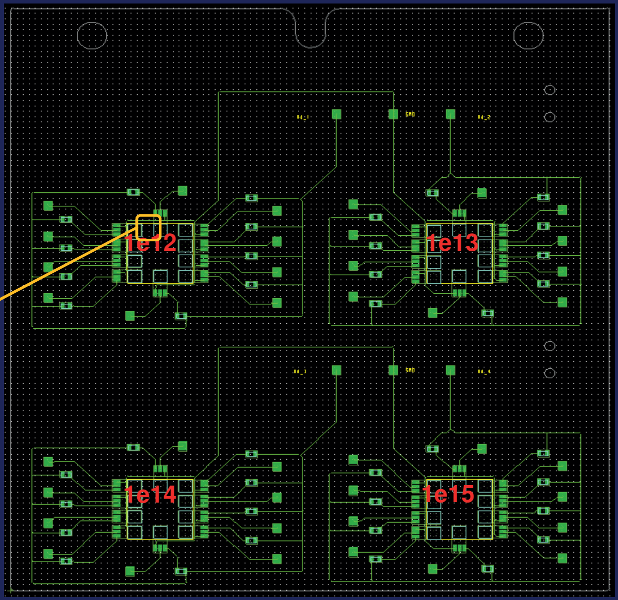
- Radiation-hard semiconductor devices in the R&D forefront of particle physics community
  - Led to construction of Si tracking detectors at the LHC and HL-LHC
- Focus shifting to meet the technology challenges for future colliders beyond the HL-LHC
- Extremely high radiation levels close to collision points
- Poses major challenges on semi-conductor technology
  - Material quality (defects, doping, radiation effects,…)
  - New materials beyond Si (which may reach its limitations)
  - Understand physics of radiation damage
    - And develop microscopic physics models
  - Sensor design, detector layouts, readout ASICs, data handling,…



Device under test for radiation hardness

PCB holding up to 40 GaN devices





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Astroparticle Physics at SNOLAB

SNOLAB

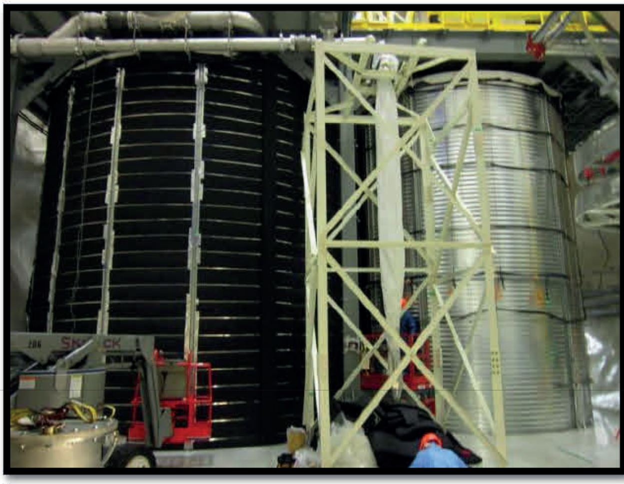
MINING FOR KNOWLEDGE

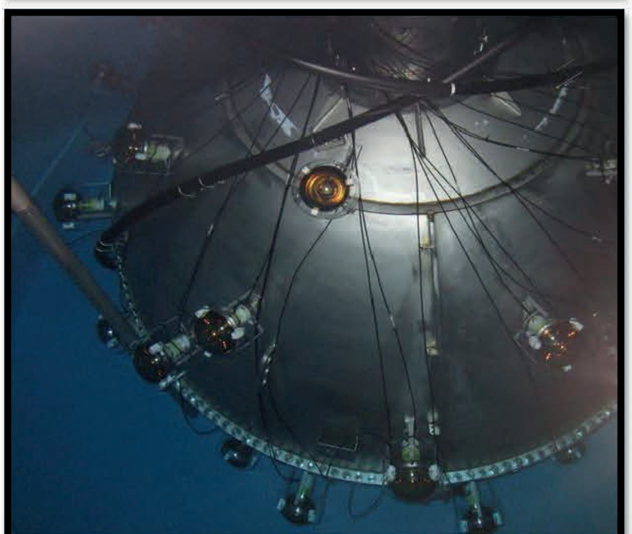
CREUSER POUR TROUVER... L'EXCELLENCE

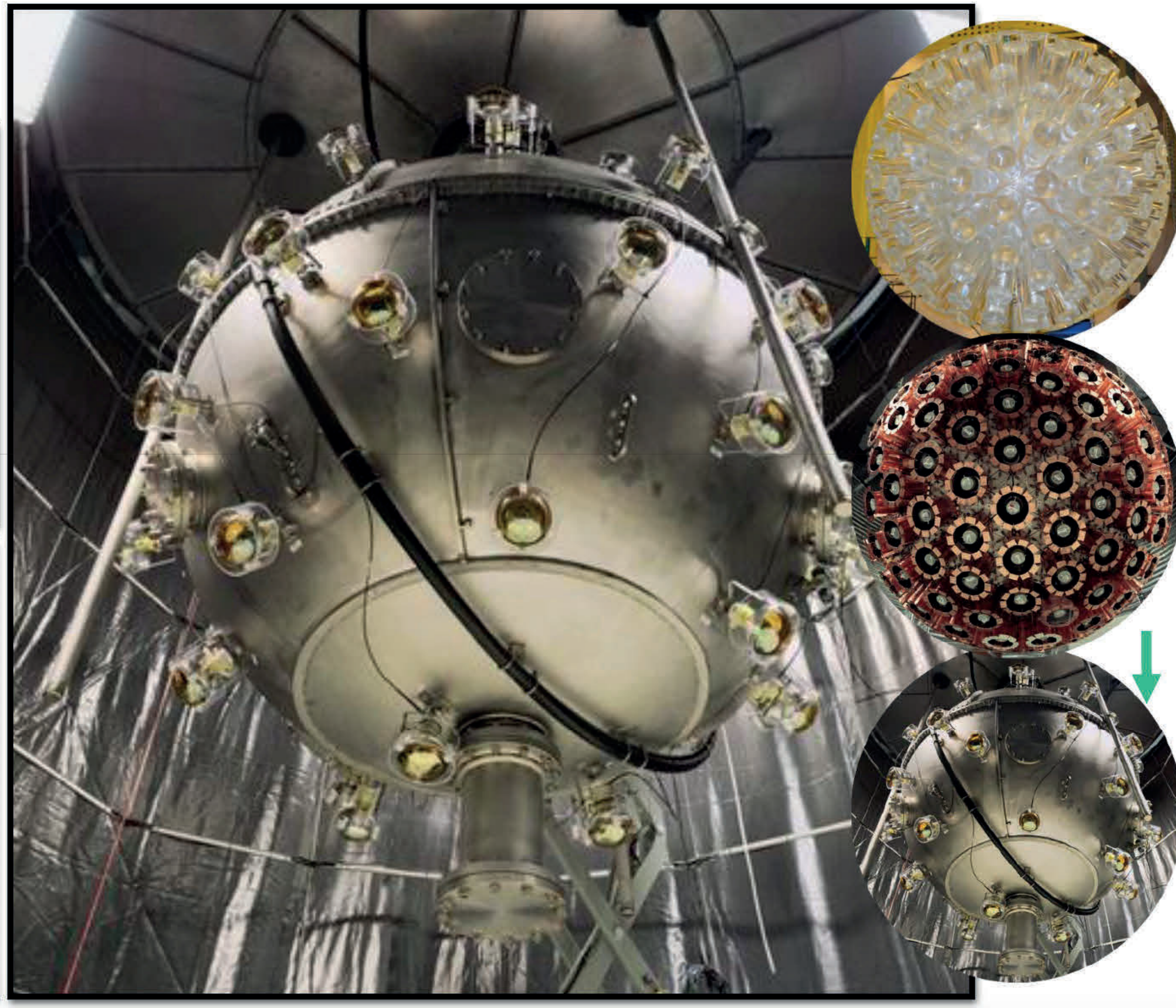
2070 m underground

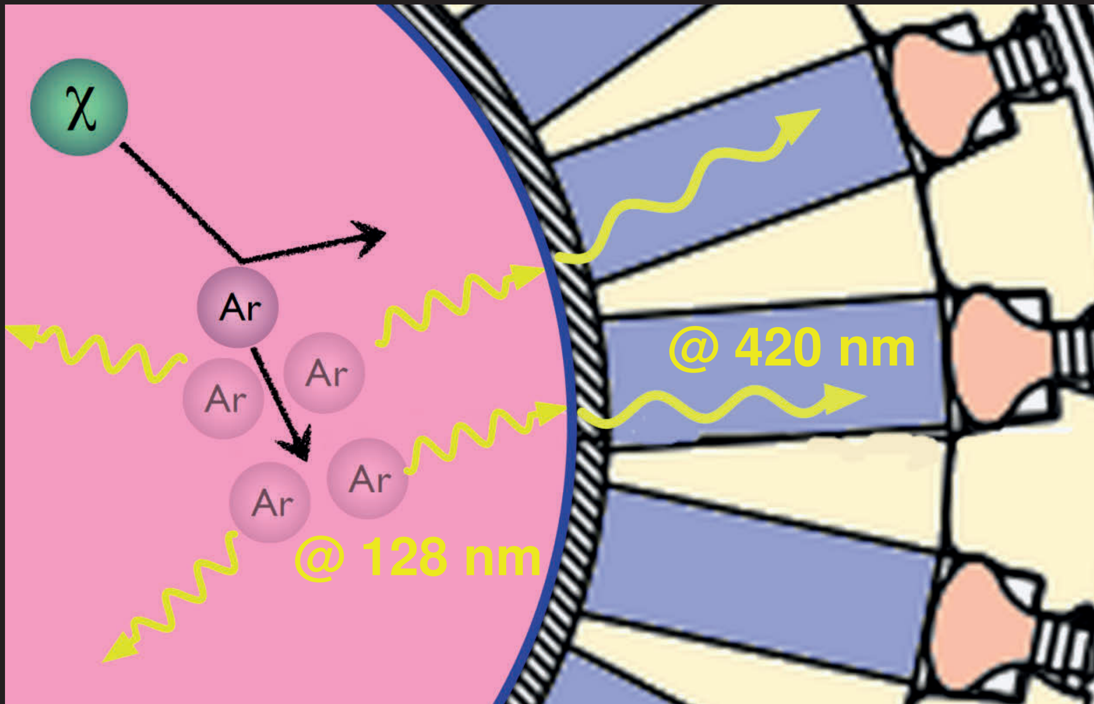
DEAP-3600: 255 PMTs are collecting scintillation light from 3.3 tonnes of liquid argon in a low background acrylic sphere

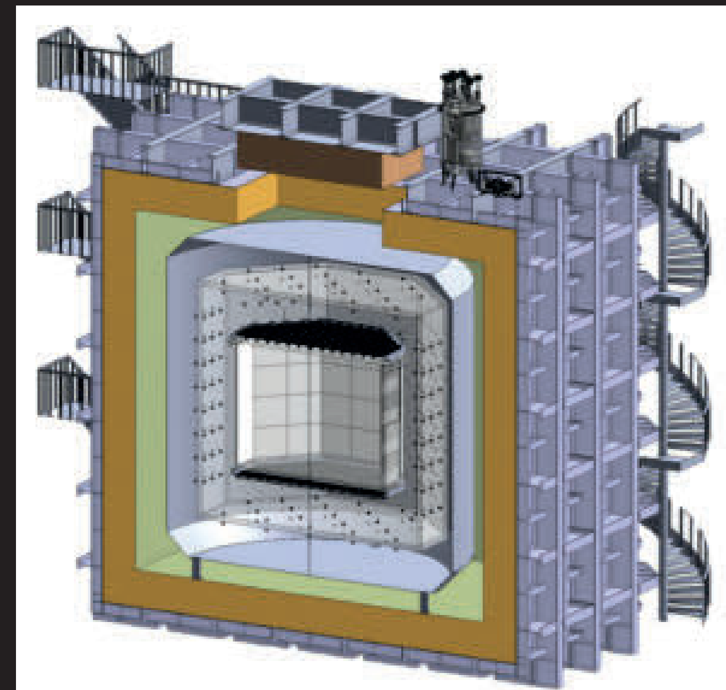
Water tanks in Cube Hall











Main challenge is to maximize the sensitivity to dark matter scattering while rejecting background events

R&D on the next generation detectors e.g. DarkSide 20k and ultimately a 400 tonnes LAr super detector

- Slow scintillator to reject alpha-induced surface events

- Reduction of the Ar-39 isotope by employing aged argon and distillation techniques

- COLD: High capacity LAr cryogenic facility at Carleton University

Contact information

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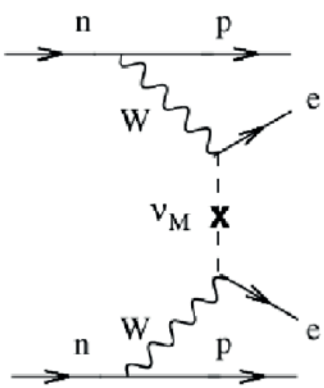
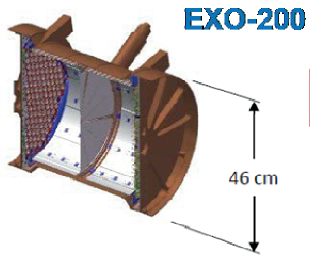
Search for 0νββ with EXO

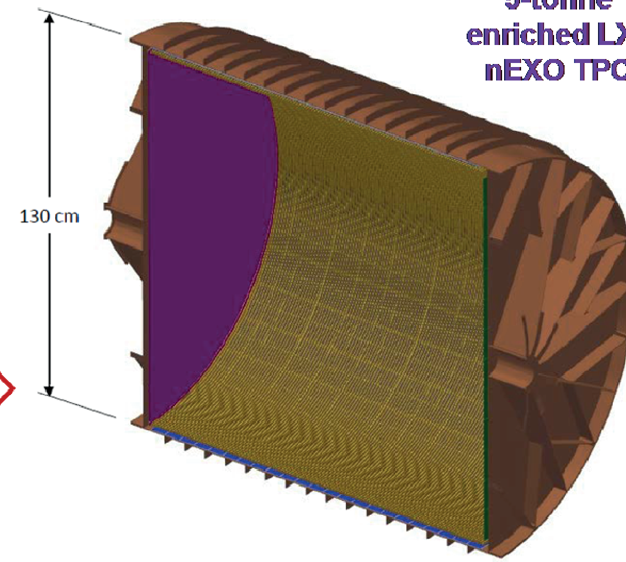


0νββ decay
in Xe-136

Designed and
optimized from
EXO-200
experience!



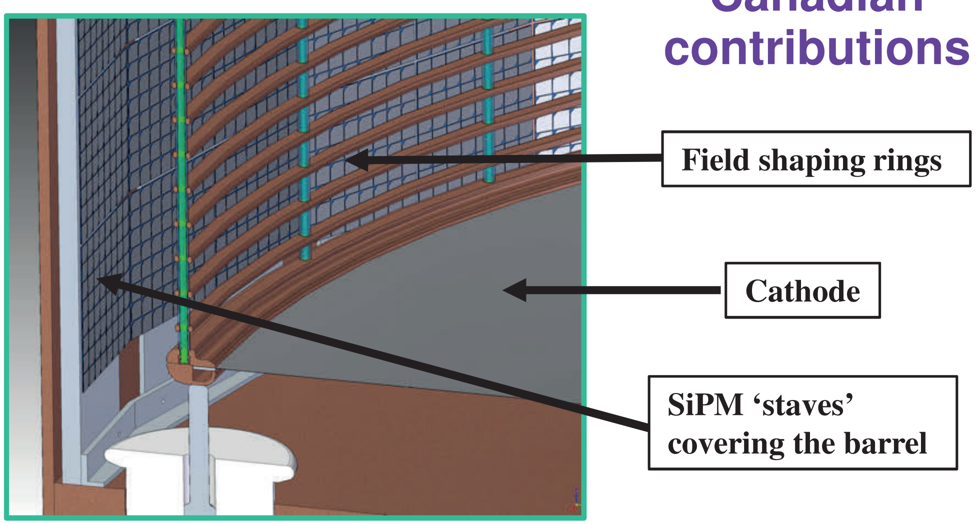
Evolution!

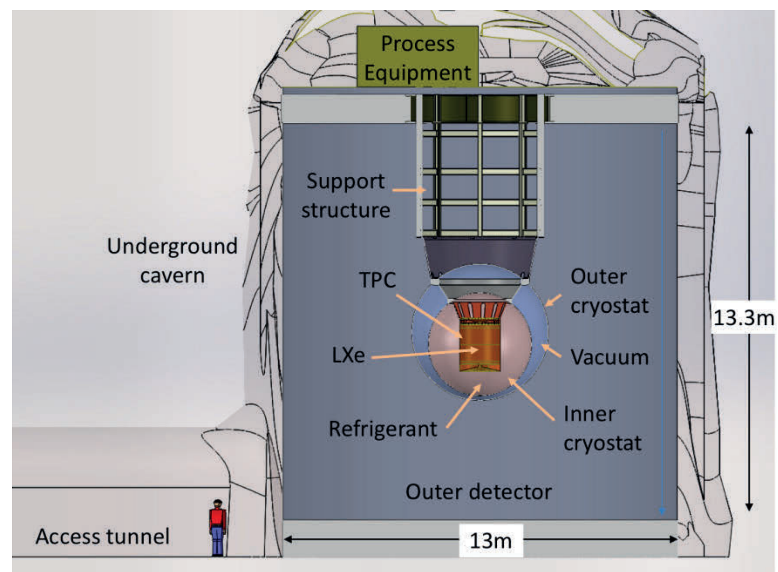


5-tonne
enriched LXe
nEXO TPC

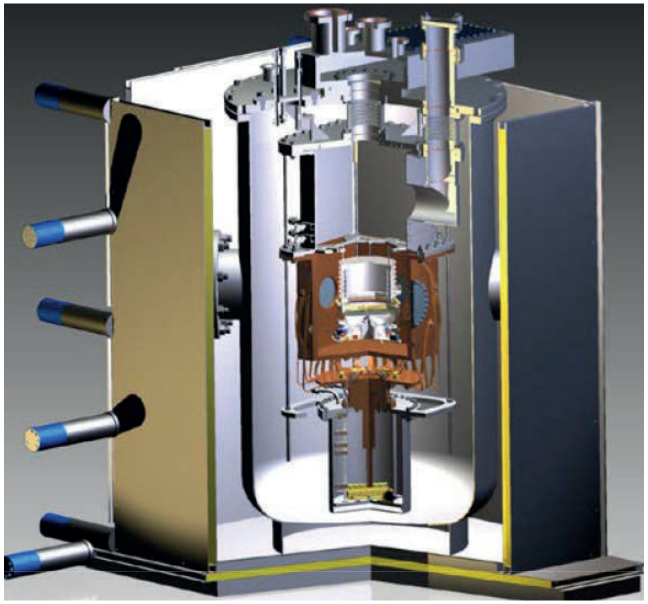
- Provides irrefutable evidence for violation of lepton number conservation
- Constitutes the discovery of a new type of elementary particle, i.e. Majorana neutrino
- Bring a possible connection to new mass generating mechanism (seesaw mechanism)
- Provides an avenue toward explaining the matter-antimatter asymmetry of the Universe

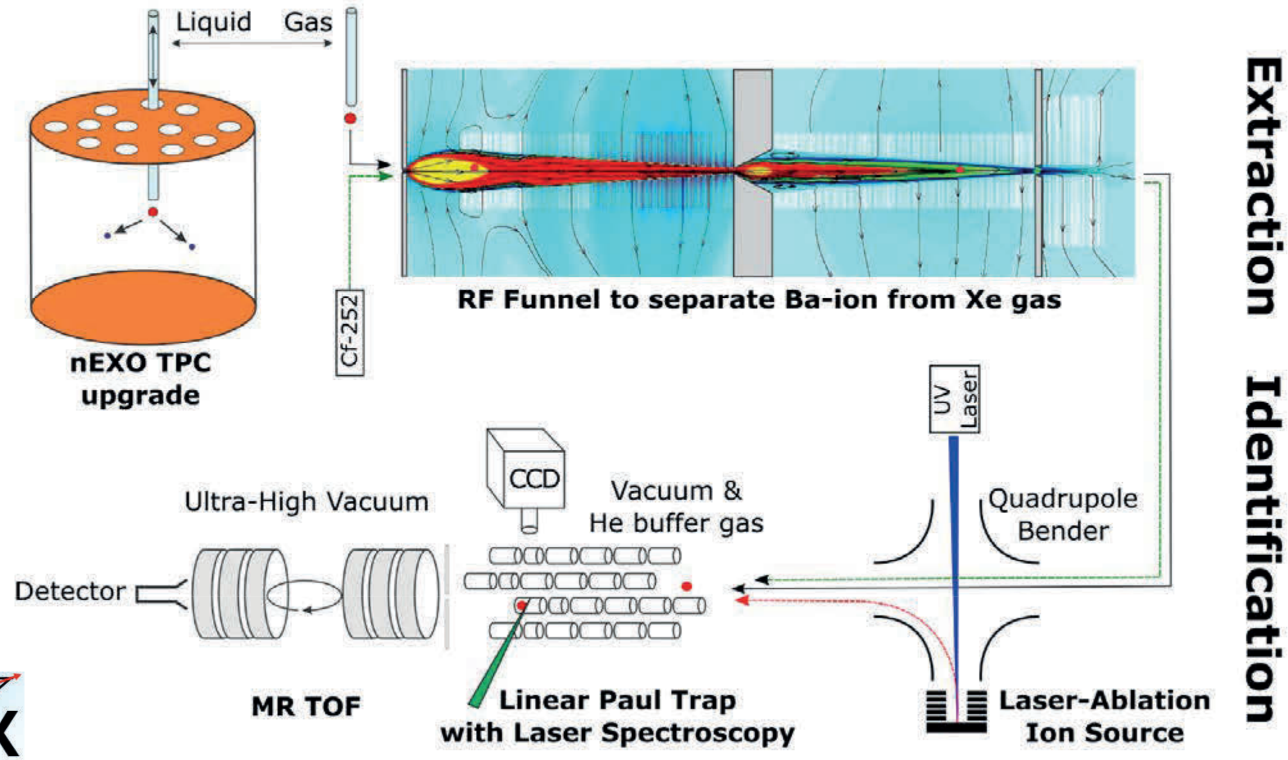
Canadian contributions





R&D for next generation $0\nu\beta\beta$ detectors





Complete elimination of residual radioactive backgrounds

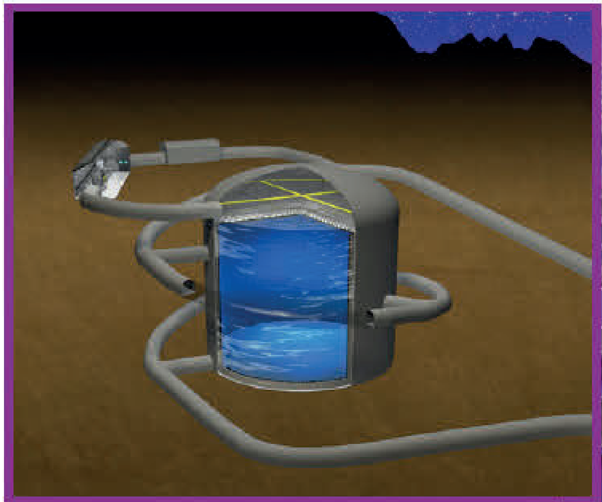
Unique opportunity when operating a LXe TCP with Xe-136

Advanced photon detection improving signal collection

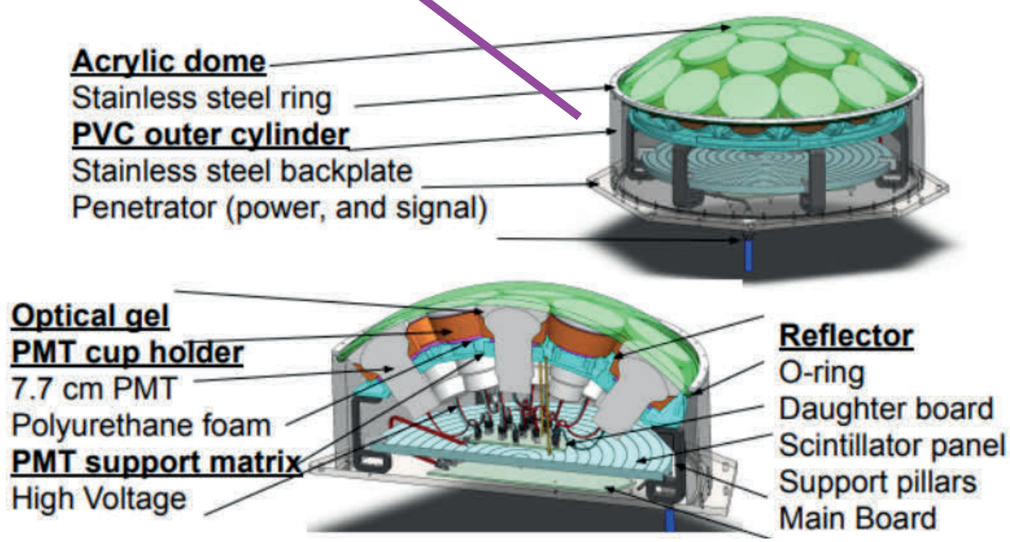
Signal to background discrimination using Cherenkov light

Development of extensive experimental skills relevant to the future academic career or for working in the high tech industry

Contributions to the future neutrino physics program



Hyper-Kamiokande



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