IPP Scientist Report

Steven Robertson
steven.robertson@ualberta.ca

IPP / University of Alberta

IPP AGM
CAP Congress
June 26, 2026

INSTITUTE OF
PARTICLE
PHYSICS

UNIVERSITY OF
ALBERTA

About me

- Ph.D. UVic 1999 (Sobie, OPAL)
- SLAC postdoc 1999 – 2003 (BABAR)
- IPP Research Scientist since 2003
- IPP Principal Research Scientist since 2021
- UofA since Sept 2022

- IPP Summer Student coordination (since 2017)
- Belle II
  - PhD student (Trevor Shillington) Lepton Flavour Violation in $B \to K \tau^+ l^-$ ($l = e, \mu$)
  - Chair of Belle II Speakers Committee
  - Previously: Diversity committee co-convener, Publication committee member, physics subgroup convener, ...
  - CDC (drift chamber) upgrades?
- MATHUSLA
  - PI of Canadian SAP project grant
  - Member of collaboration management team
  - Previously: coordinated overall detector R&D program, substantial contributions to Scintillator/WLSF/SiPM R&D, teststands, CDR etc.
- P-ONE
  - MSc student (Tyler Martin) MIST system development (with Juan Pablo Yanez Garza)
  - Technical coordination for P-ONE demonstrator

IPP summer student program

IPP summer student program

As a non-member state, Canadian students can participate in the CERN program, at full cost, via the IPP program.

- Over 100 Canadian students have participated in the program since 2007
    - Many have continued on to permanent positions in particle physics (or related fields), including in the Canadian community
- 5 students participating in 2026 (heading to CERN this weekend!)

- Candidates selected by IPP council then directly admitted to the CERN program
- IPP students are required to hold an NSERC USRA position (or equivalent) spanning 16 weeks
- First 8 weeks (May – June) are spent at a Canadian university (or TRIUMF) working with a Canadian supervisor on a USRA project of their choice
- Last 8 weeks (July – Aug) are spent at CERN participating in the CERN summer student program

IPP summer student program

Research projects during the first two months can encompass anything within the scope of the IPP (i.e. USRA supervisor is an IPP member and/or funded via SAPES)

- While at CERN, students have the opportunity to conduct research under the supervision of a CERN-based researcher on anything within the CERN program

- **Theory projects** are included (either in Canada, at CERN, or both)
- **Non-CERN-affiliated projects** are encouraged during May – June; we will arrange for students to be paired with CERN-based projects for July – Aug.
- IPP students have the option of continuing their USRA research project if it is a CERN project and if adequate supervision is available (this is frequently the case for ATLAS projects)
- The IPP collects a list of project proposals from prospective supervisors, but students are free to pursue USRA projects which are not on that list

https://particlephysics.ca/research-activities/undergrad-program-cern

Belle II

Belle II

Very substantial Canadian participation in Belle II, building on a long history of B Factory research at BABAR.

- ► continued large involvement by IPP scientists

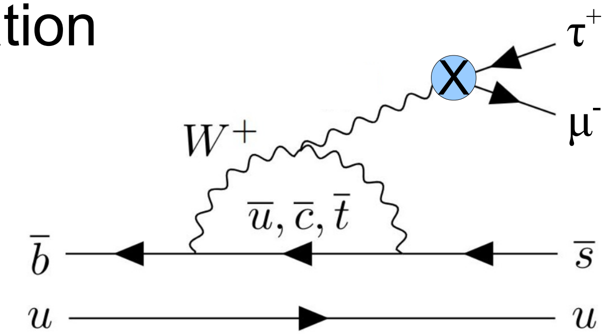
- see presentation by Chris Hearty

Currently nearing the end of a 2-year term as chair of the Belle II Speakers Committee (SC)

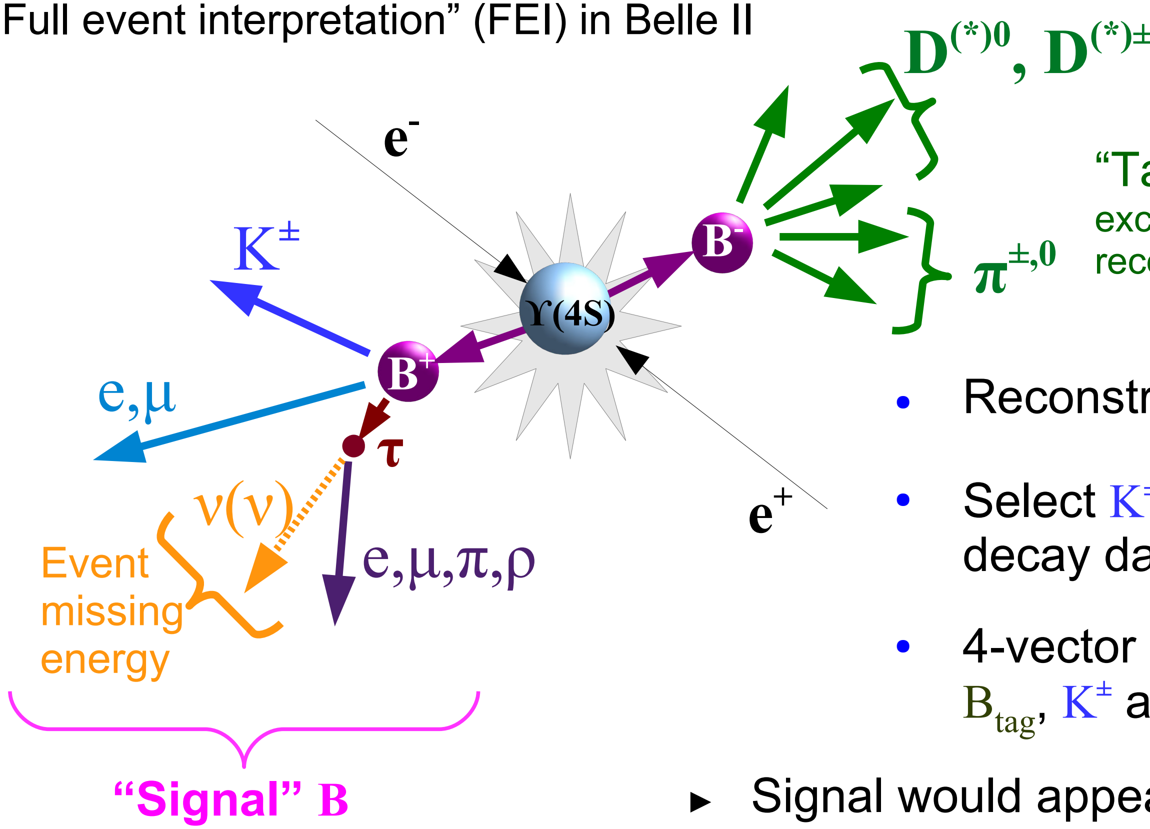
- SC negotiates and coordinates all Belle II physics presentations at roughly 80 conferences per year (~200 talks in total)
- Drafting/submitting abstracts, contact with organisers, selection of speakers, review of content etc.
- 15 Belle II contributed talks at ICHEP this year, including 2 by Canadian students

Lepton flavour violating B decays with 3rd generation leptons:

- Possible explanation for excess seen in $B^+ \to K^+ \nu\nu$



Exploit exclusive hadronic tag reconstruction methodology developed by BABAR/Belle called "Full event interpretation" (FEI) in Belle II



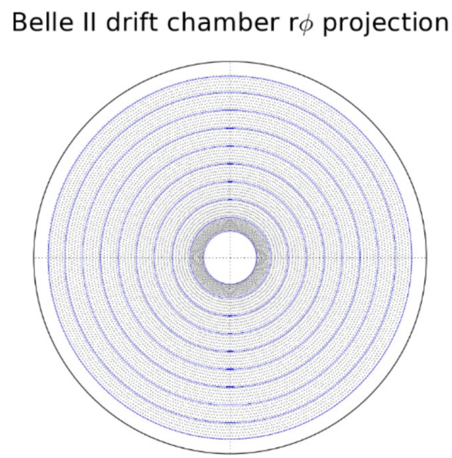
- Reconstruct B_{tag}
- Select $K^\pm$, primary lepton e,μ and τ visible decay daughter e, μ, π or ρ
- 4-vector of τ can be fully determined from B_{tag}, $K^\pm$ and primary lepton

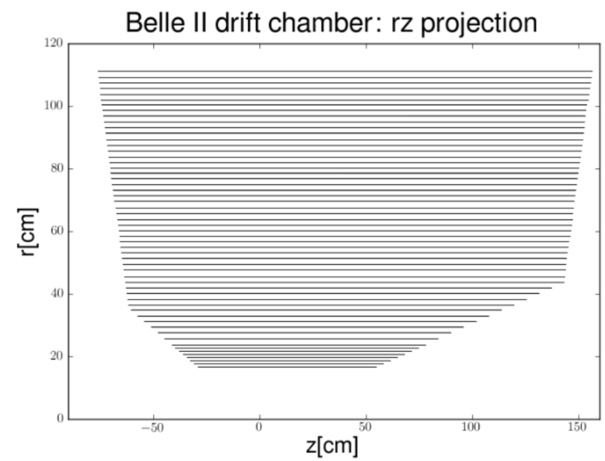
▸ Signal would appear as a narrow peak at the τ mass

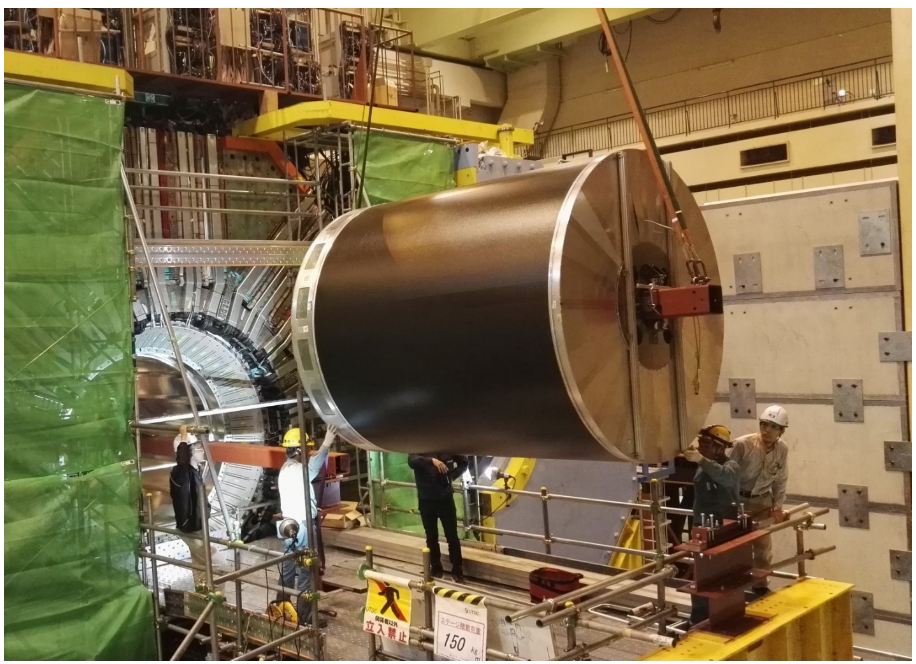
Belle II

Drift chamber upgrade:

- Large leakage current observed in Belle II drift chamber (CDC) due to high background rates
- Risk of Malter effect, and gain degradation due to leakage current and accumulated charge







Various aging and performance studies ongoing

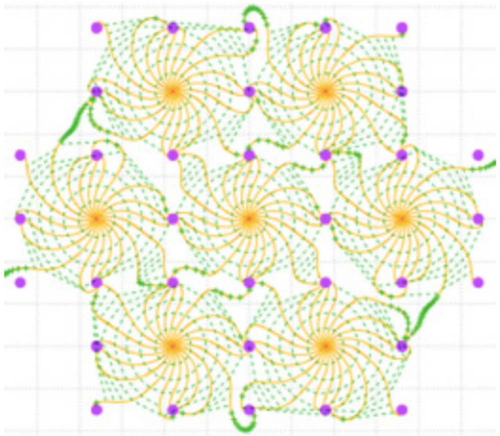
Options:

- Continue to use existing CDC (possibly with reduced HV/gain)

or

- Replace drift chamber, possibly with a silicon inner detector and a new outer drift chamber

Belle II

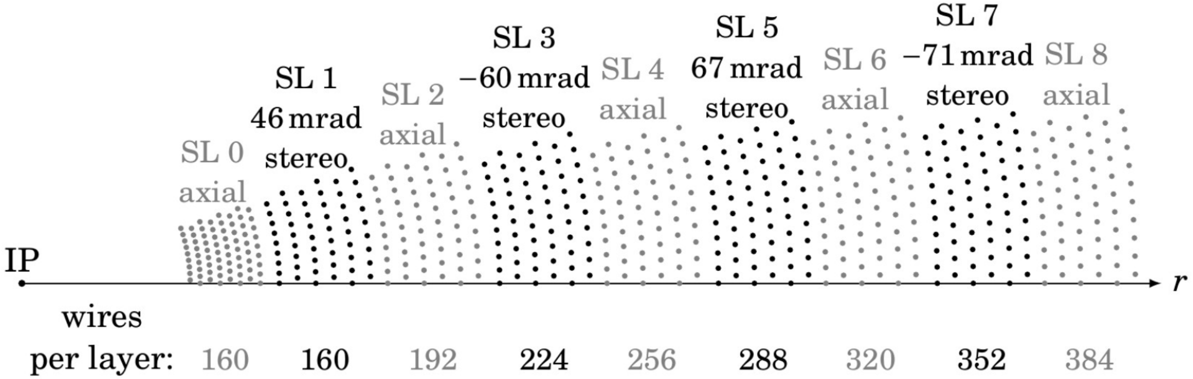


Strategy to be decided at upcoming collaboration meeting:

- Replacement on the timescale of LS2 (2032 -2033) would require a TDR for the new detector during 2027
- Canadian groups have been approached regarding possible participation in this upgrade.
  - Blake, Warburton and Robertson have expressed interest
- Same timescale as Chiral Belle beam polarization project, but no overlap between participants

Current CDC geometry:

- 56 wire layers in 9 superlayers
- Rectangular cells, with 8 field wires surrounding each sense wire
- 14336 wires

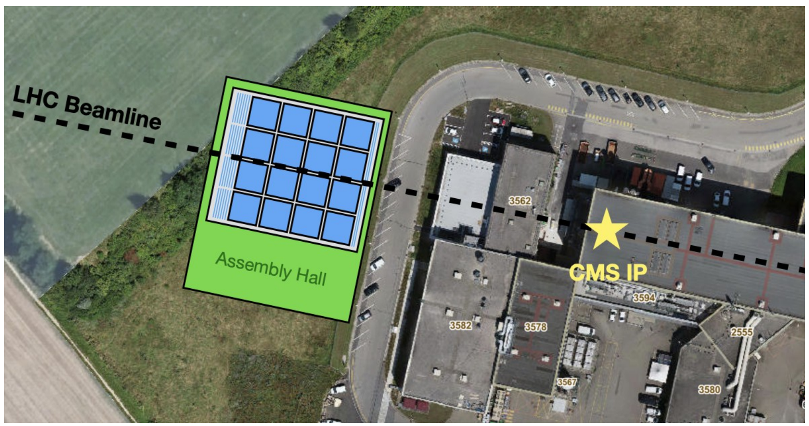


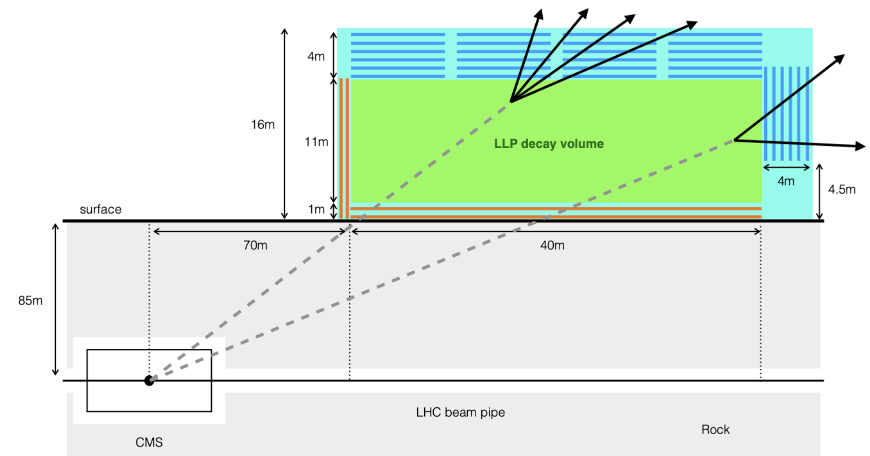
MATHUSLA

MATHUSLA

MATHUSLA is a proposed detector for Long-Lived Particles (LLPs) at the HL-LHC

- Large volume detector to reconstruct decay vertices of LLPs produced in pp collisions, located at the surface adjacent to one of the LHC interaction regions (CMS)





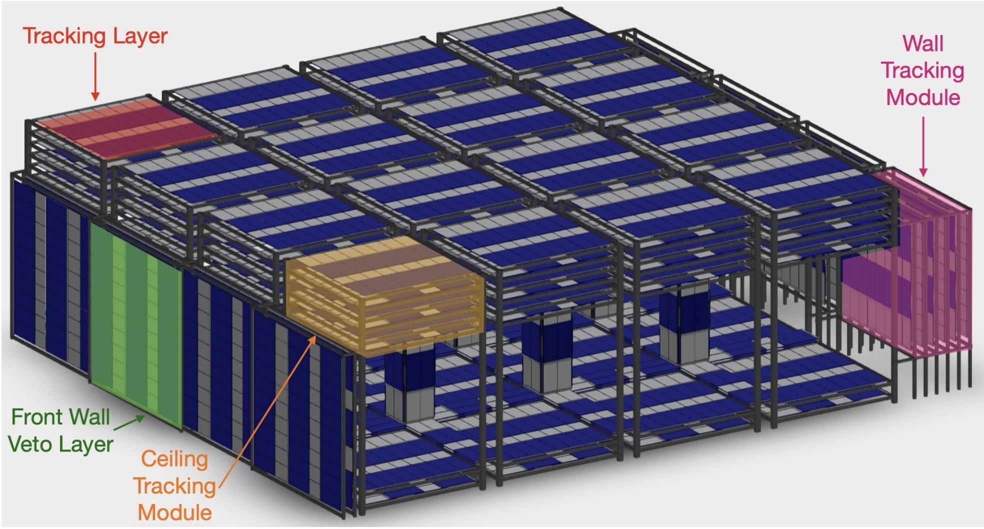
Primary physics objective is hadronically decaying LLPs from a few GeV to TeV scale

- Multi-track decay vertices exploiting timing information from multiple tracking layers
- Shielded from SM LHC interactions by ~100m of overburden
- Modular detector concept based on ~10m x 10m tracking planes
- Can potentially provide Level 1 triggers directly to CMS, and/or perform combined offline analysis with CMS using event timestamps

MATHUSLA

Status

- Canadian funding via NSERC SAP project grant: Robertson (UofA), Diamond, Curtin (UofT), Russell (UVic)
- Conceptual Design Report for 40m x 40m (MATHUSLA40) released in 2025 (scoped from original 100m x 100m x 40m detector concept)
- New CERN task force for Non-Collider Physics Programme (NCPP) to evaluate various proposals for "transverse" LLP experiments (transition from existing "Physics Beyond Colliders" PBC group)
- ANUBIS, CODEX-b, and MATHUSLA have been collaborating to provide robust benchmark model comparison, background estimates etc.
- Anticipating a combined workshop in the fall (likely at CERN), in advance of the annual PBC meeting in early December



Conceptual design report (40m x 40m):
https://arxiv.org/abs/2503.20893

European Strategy brief:
https://arxiv.org/abs/2504.01999

D. Curtin and J.S. Grewal, Phys.Rev.D 109 (2024) 7, 075017.
https://arxiv.org/abs/2308.05860

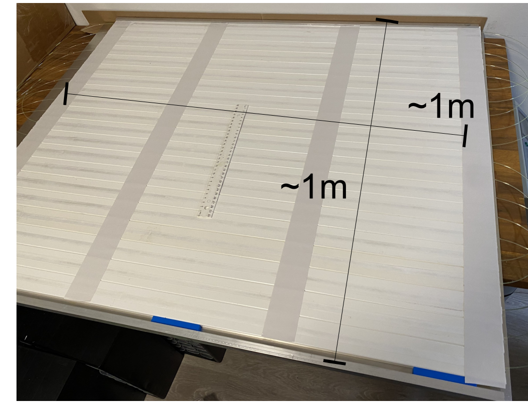
Caleb Miller will give a MATHUSLA talk next week at the LLP workshop next week in Cambridge

(IPP 50th Anniversary Connect Postdoctoral Fellow)

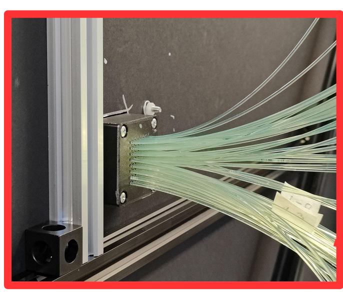
MATHUSLA test-stands

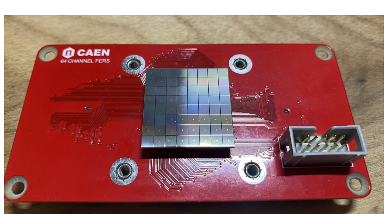
Ongoing testing of prototype scintillator bar modules in two large cosmic ray hodoscopes

- Tracking with four-layer x-y arrays with looped WLSF and 80cm layer spacing
- Scintillator bars, fiber and SiPMs with close to MATHUSLA nominal specifications



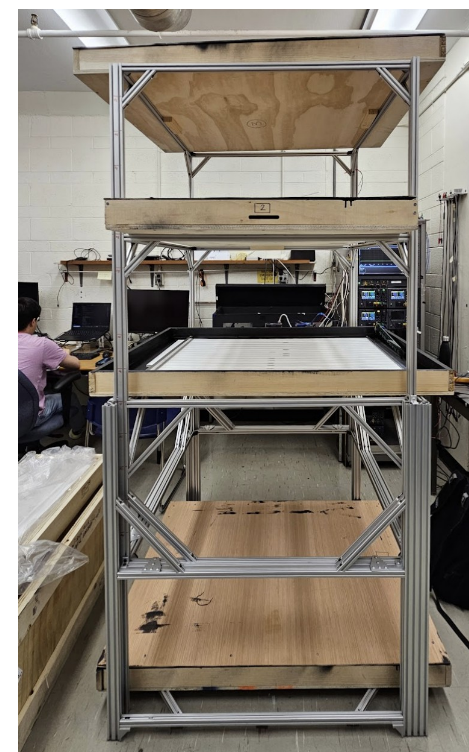
UVic: Full-length (~5m) WLSF routed to single 64-SiPM array with CAEN readout system





UofT: Individual SiPMs mounted on front face of scintillator bars

- Custom preamps mounted on bar module
- More similar to final MATHUSLA design, but different WLSF configuration



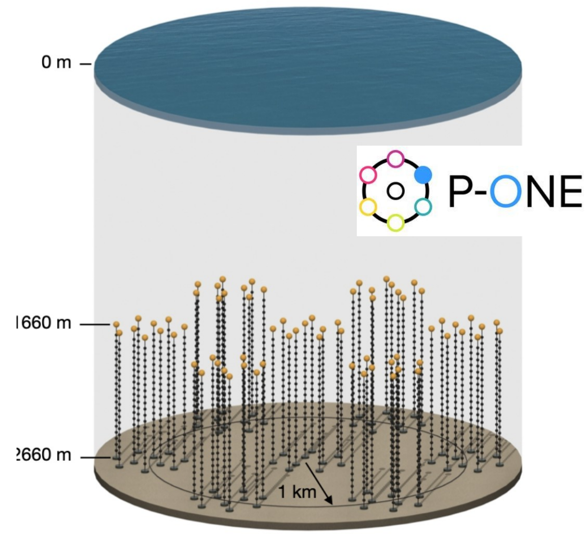
P-ONE

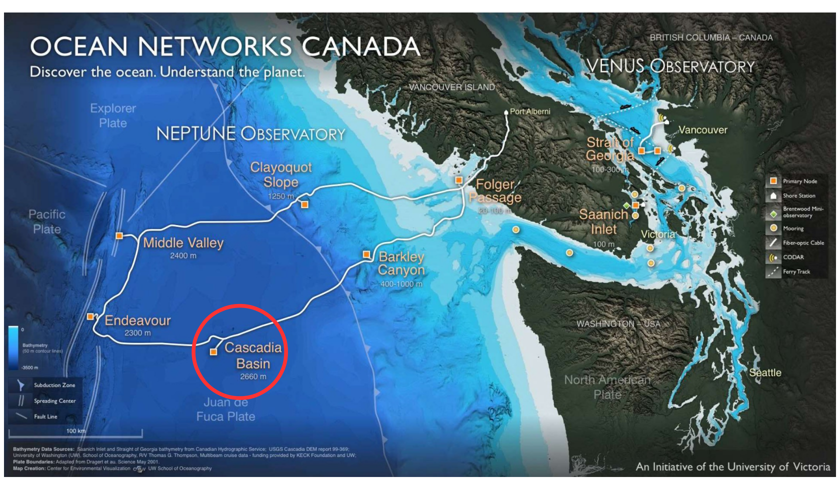
P-ONE

Pacific Ocean Neutrino Experiment (P-ONE) will be situated in the Cascadia basin off the west coast of Vancouver Island

Water provides cosmic ray shielding, neutrino interaction medium and radiator

- Water depth of 2660m
- Segmented array sampling approach, with ~70 strings total, in 7 clusters of 10 strings
- 20 optical modules per string, 50m vertical spacing
- Target of a fraction of a degree direction resolution for high energy muon tracks (from ν_{μ} interactions)



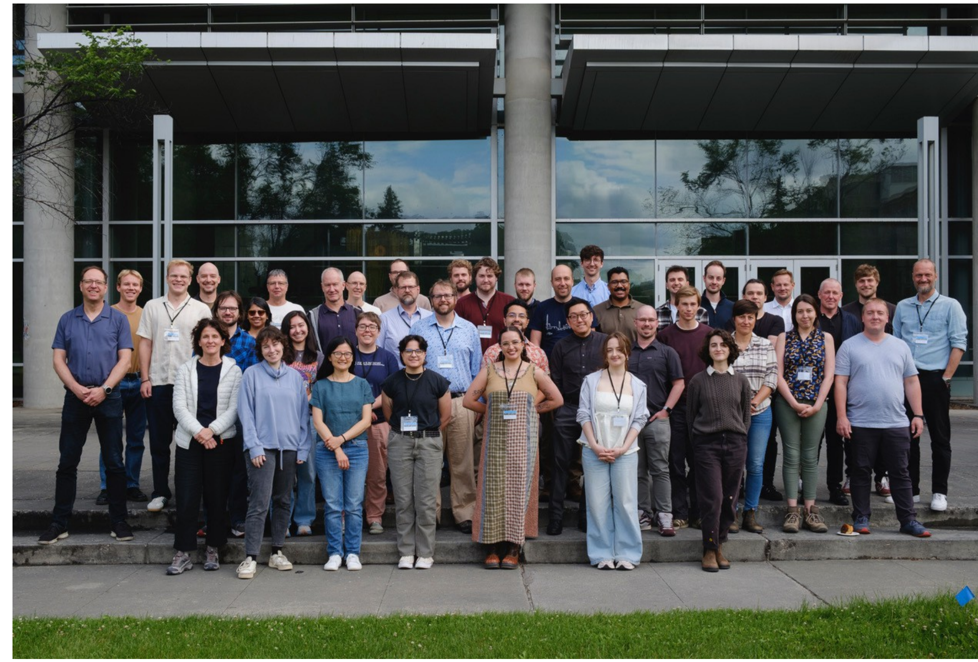


- Planned deployment site recently relocated ~25km east to outside of the new Tang.ɢwan – ḥačxwiqak – Tsigis Marine Protected Area

P-ONE

Canadian participation from SFU, UofA, Queen's, UVic and TRIUMF, Ocean Networks Canada (ONC)

- International collaborators from Germany, US, Poland, UK



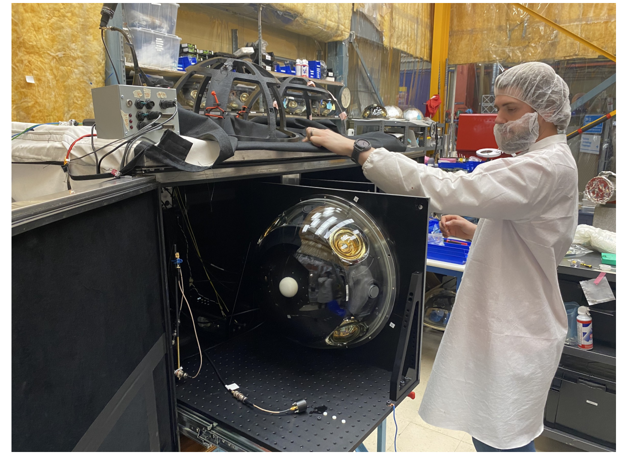
P-ONE collaboration meeting UofA June 2026

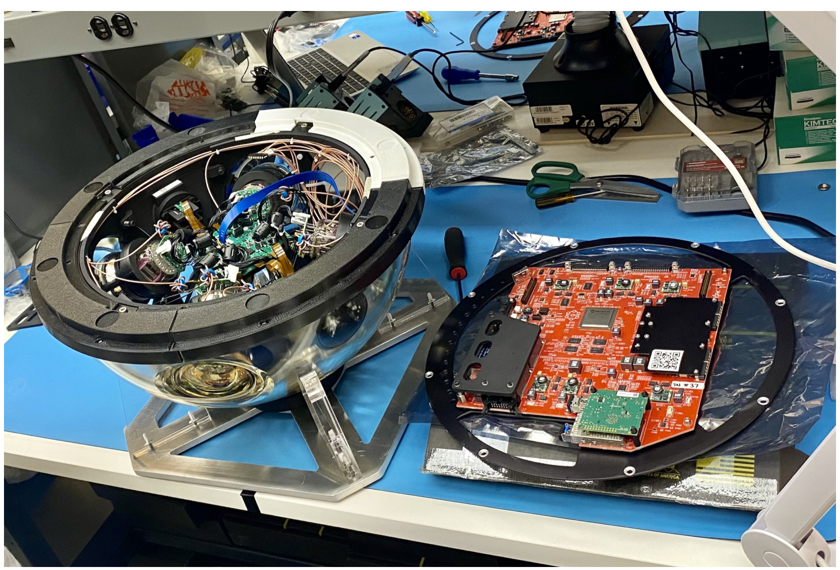
- Collaboration has been working towards deployment of first string during 2026 season

P-ONE

Current status:

- First string, P-ONE-1 assembly and testing at TRIUMF during spring 2026
- “Wet test” this week
- Deployment planned for early fall 2026





P-ONE-1 “wet test” Granville Island June 2026

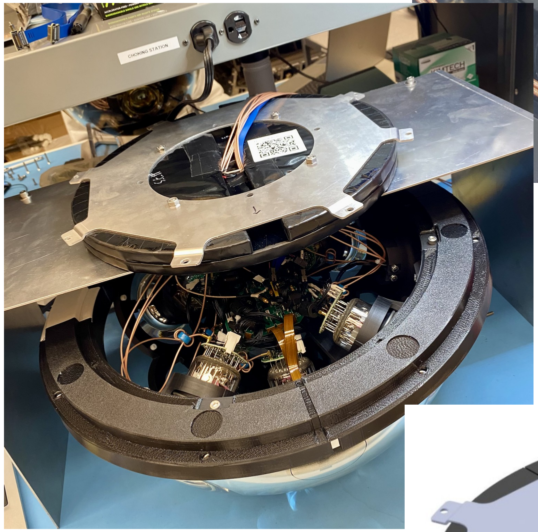
P-ONE

P-ONE-D “demonstrator” funded in last CFI round. Additional three strings to be built and deployed by end of 2028:

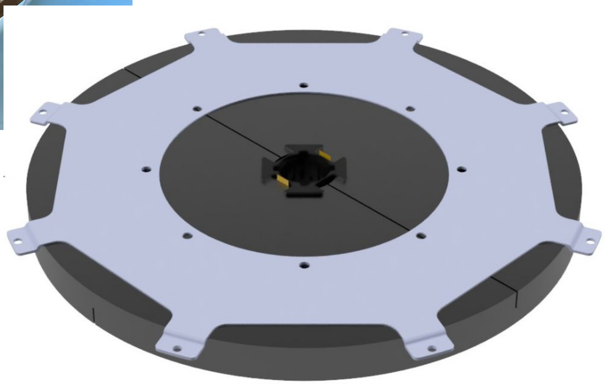
- Modest changes to electronics (PMT μBases, main processing and interposer boards) currently being reviewed
- Modifications to MIST scintillator-based muon detector system
- Modest changes to vertical cable design, and to underwater junction box(es) with the goal of reducing costs

► Initial cluster of four strings

Challenges in production, testing and integration to be addressed over the next year or so



See talk by Tyler Martin on P-ONE MIST system (PPD) M3-9 Neutrinos



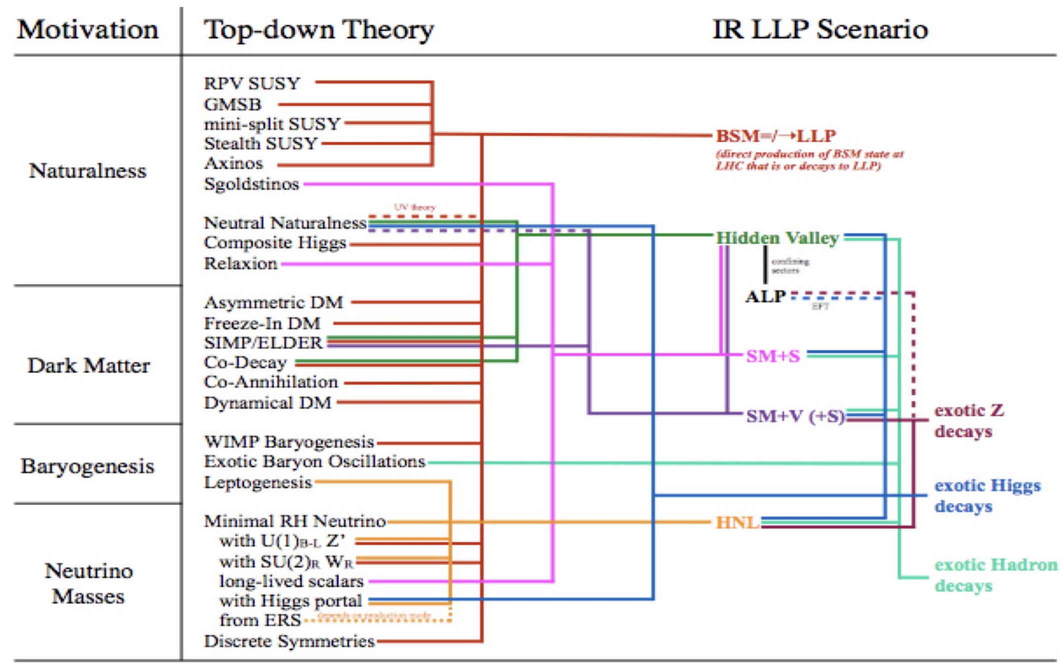
Extras

IPP summer student program

- 2024: Josephine Brewster • Thomas Larrivee • Denaisha Kraft • Thomas Hepworth • Zachariah Charlesworth • Lea (Elio) Desbiens
- 2023: Sarah Wang • Peter Xiangyuanl • Dean Ciarniello • Natalia Litvak • Thomas Peterson • Hunter Sharron • Ben Schever
- 2022: Jonathan Barrett • Angela Moskal • Leandro Rizk • Michaela Robert • Ruchi Soni • Ethen Sun • Kyran Klazek-Schryer
- 2021: Paula Bosca • Darren Zeming Chan • Cole Coughlin • Paul Deguire • Michael Grehan • Kristopher Samant • Roxane Theriault
- 2020: Matthew Ens • Gillian Godden • Panagiotis Kaloyannis • Patrick Li • Haolin Liu• Michael Sloan • Alex Wen
- 2019: Sam Connolly • Genevieve Hayes • Kaitlyn Liang • Khaled Madhoun • Doris Rusu
- 2018: Jonathan Corbett • Lia Formenti • Luke Polson • Joshua Sandor • Gareth Smith
- 2017: Jared Barron • Shannon Egan • Rose Kudzman-Blais • Rachel Richardson • Frank David Wandler
- 2016: Sam Abernethy • Eleanor Fascione • Jeffrey Krupa • Theodore Tomalty • Dominique Trischuk
- 2015: Nuiok Dicaire • Matt Grant • Alan Morningstar • Martina Ojeda
- 2014: Emil Noordeh • Matthew Quenneville • Jessica Strickland
- 2013: Syed Haider Abidi • Natascha Hedrich • David Layden • Sebastien Rettie • Olivia Wasalski
- 2012: Aysha Abdel-Aziz • Matthew Bluteau • Kyle Boone • Martin Friedl • Ryan Killick
- 2011: Terry Buck • Nigel Burke • Charles Collins-Fekete • Allison MacDonald • Stephen Portillo
- 2010: Karol Krizka • Matthew LeBlanc • Ian Moult • Kate Pachal • Sebastien Picard
- 2009: Ossama Abouzeid • Grace Dupuis • Catherine LaFlamme • Ilya Feige • Matthew Low • Robert Keyes
- 2008: Stefan Guindon • Nikolina Ilic • Andrew Louca • Tom McCarthy
- 2007: Jason Rabinovitch

Full list of students, along with their project reports, is available on the IPP web site at
https://particlephysics.ca/research-activities/undergrad-program-cern-papers

MATHUSLA



Approved CERN experiments:

- SHiP
- FASER

} Forward / low p_T

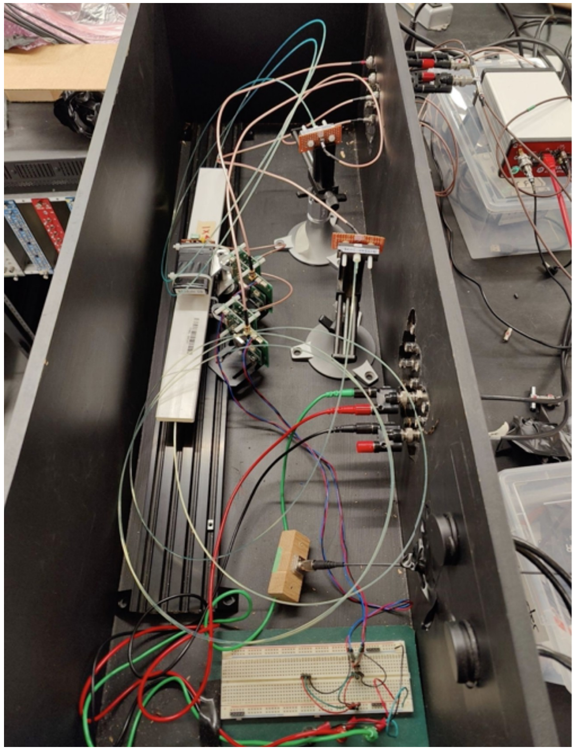
Proposed experiments:

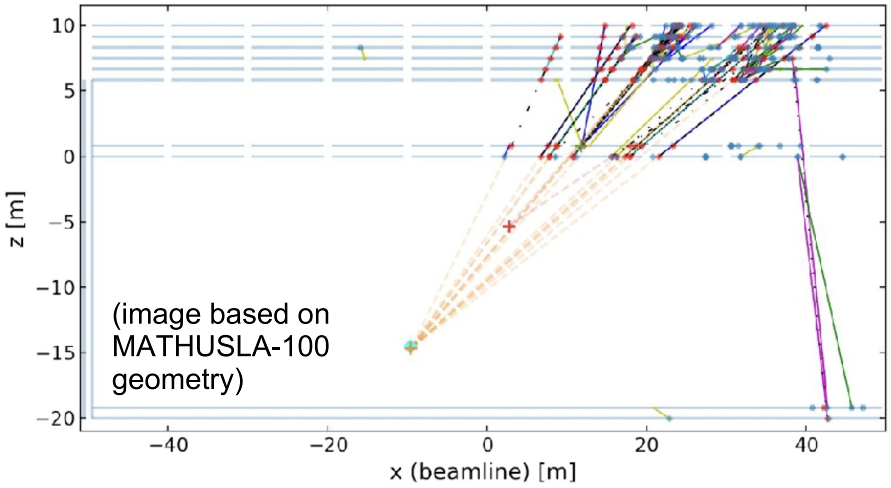
- ANUBIS
- CODEX-B
- **MATHUSLA**

} High p_T

R&D activities

- Studies of new WLSF formulations with higher yield, shorter decay times and longer attenuation lengths
  - Light yield impacts timing resolution (not efficiency), and reduces material costs
- Cost/performance optimization for SiPMs
  - SiPM performance not a limiting factor
  - Define QA/QC criteria
- Detailed GEANT4 simulation studies with robust pattern recognition/ track finding (Kalman filter) and vertexing





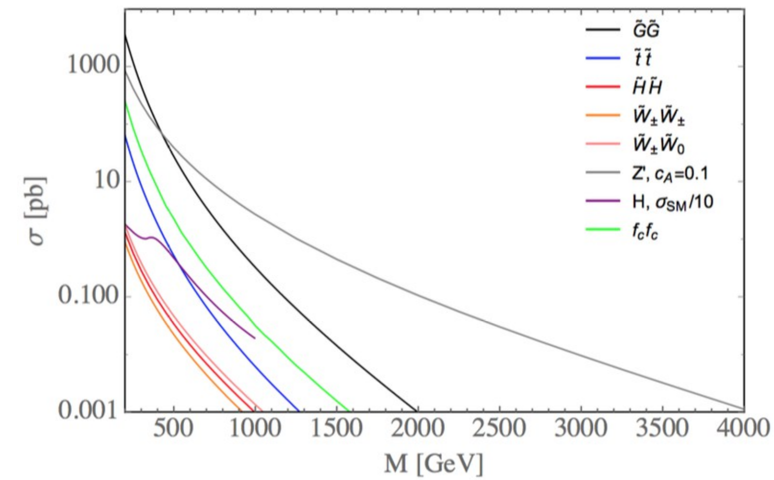
"Global" performance optimization of extrusion, WLSF and SiPMs still to be performed (i.e. detailed technical design)

Physics objectives

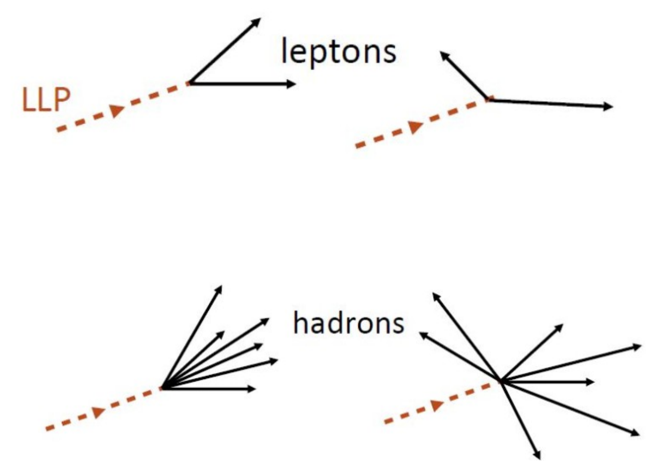
MATHUSLA can search for two general categories of physics signatures:

- Hadronically decaying LLPs ranging from a few GeV to TeV scale
  - High multiplicity final states are relatively easy to vertex and distinguish from backgrounds
  - Large improvement over LHC for LLPs with mass < ~100 GeV *(LHC searches are background limited and difficult to trigger)*

Any production process with σ > 1fb can give a signal.
Sensitivity to multi-TeV scales:



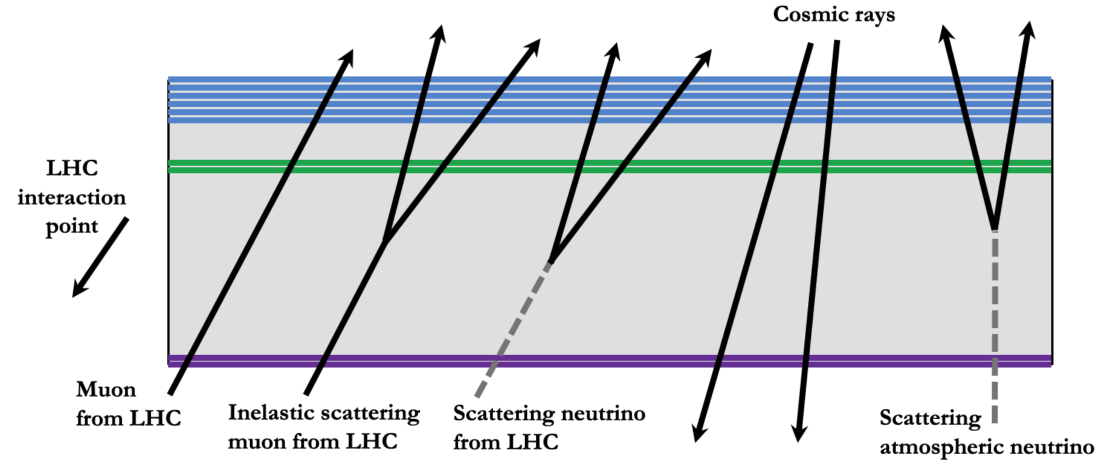
- LLPs with mass less than a few GeV (any decay mode)
  - Typically low multiplicity (i.e. 2 tracks) final states
  - Sensitivity **very dependent on detector geometry and performance** due to both signal efficiency and background rejection requirements
  - Forward / low p_T experiments likely more sensitive, so lower priority for MATHUSLA



Backgrounds

Primary physics target (high multiplicity decay vertices) is essentially background-free

- Secondary physics target of low-mass, low multiplicity LLP decays have backgrounds that need to be carefully studied



LHC muons:

- Muons with E > 40 GeV can penetrate rock shielding, but do not generally form vertices
- Delta rays and rare decays can be rejected based on vertex topology

GeV-scale atmospheric neutrinos:

- Scattering within the decay volume result in a few events per year
- Can be effectively vetoed using time-of-flight track measurements

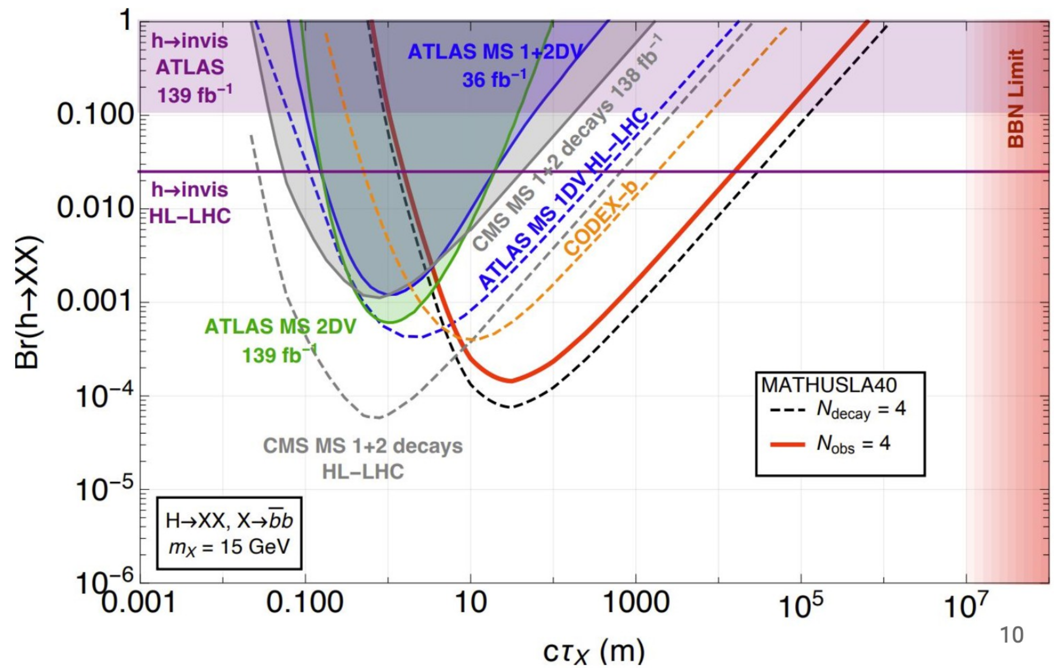
Cosmic rays:

- ~300 kHz flux to entire detector; rejected by directionality (timing) and topology
- Cosmic ray nucleons can undergo inelastic backscatter in detector floor
- Results in O(100) non-relativistic Ks^0 (over life of experiment) traveling into MATHUSLA volume and decaying into charged particles that could reach the ceiling trackers.
- Can be characterized with beam off, and distinctive low momentum signature

New physics sensitivity

MATHUSLA-40 Benchmark analysis: $h \rightarrow XX$ LLP, with $X \rightarrow$ hadrons

- Backgrounds, in order of severity:
  - Cosmic ray inelastic interactions, (most importantly protons and neutrons): simulated using PARMA
  - LHC muons: MadGraph + Pythia for EW & bb production, propagate through rock to detector in GEANT4
  - Atmospheric neutrinos: simulate interaction with detector material, support structure and air in GENIE



- LHC muons and atmospheric neutrinos can be completely eliminated by signal selection cuts, with typical signal efficiency ~ 50%

► MATHUSLA events can be matched via timestamps with triggered ATLAS/CMS events, or can even provide a L1-trigger signal to the nearby experiment