Searches for long-lived particles with MATHUSLA

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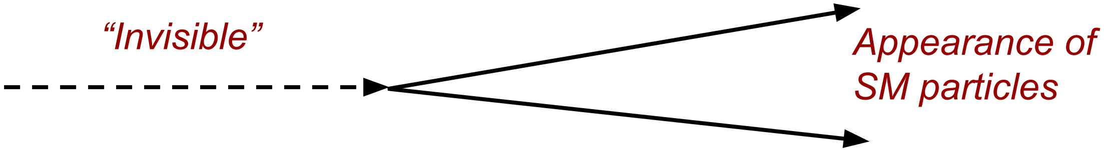
New Technologies and Methods to Uncover BSM Physics Symposium

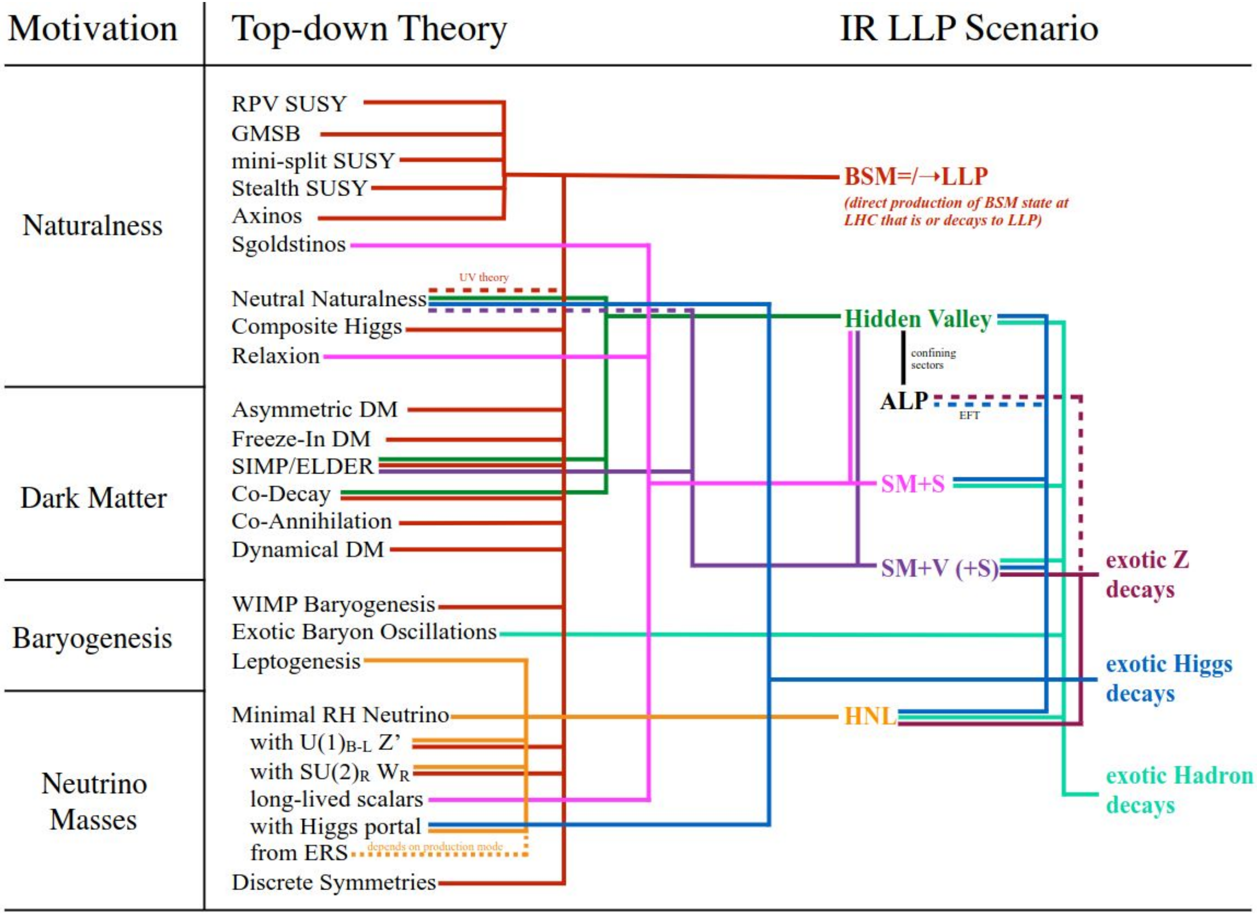
The search for BSM physics spans a wide range of experiments and signal types

Neutral LLPs are a natural place to look for BSM as:

1. LLPs occur in the SM
2. LLPs are included in many BSM theories
3. Dark matter candidates

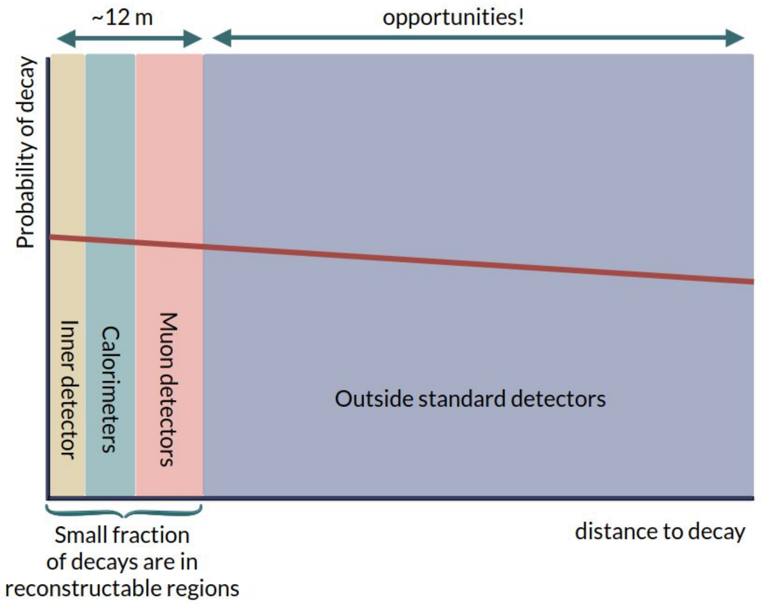


LLP Motivations



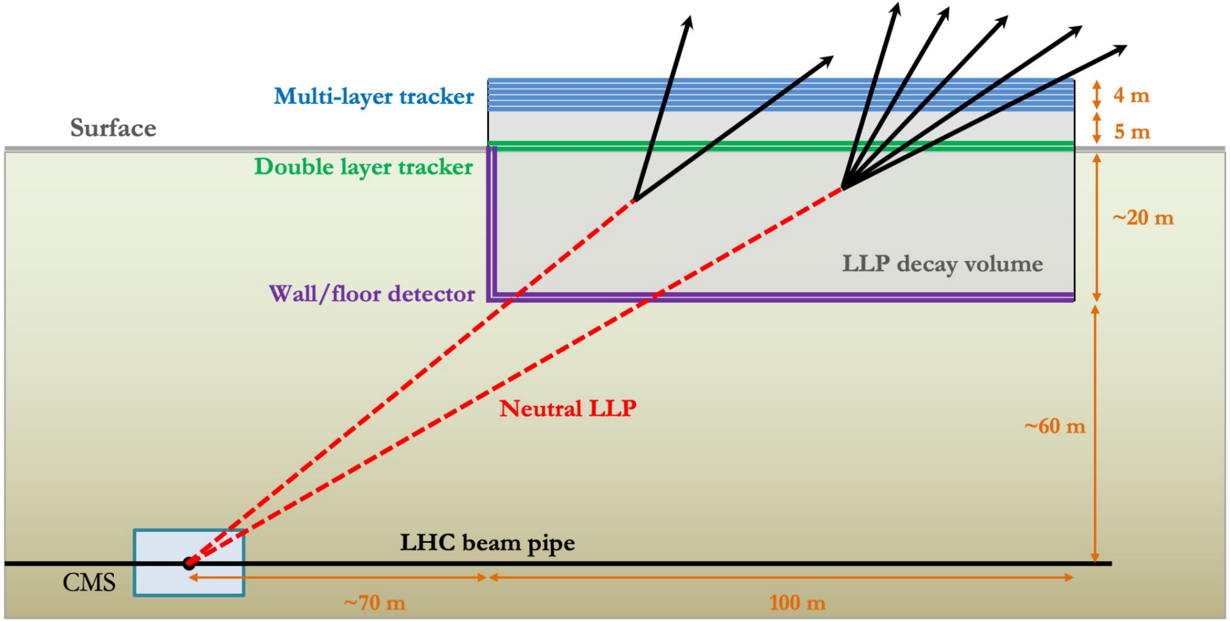
Searching for LLPs

If extremely long-lived neutral particles exist, only a tiny fraction will decay within traditional detectors

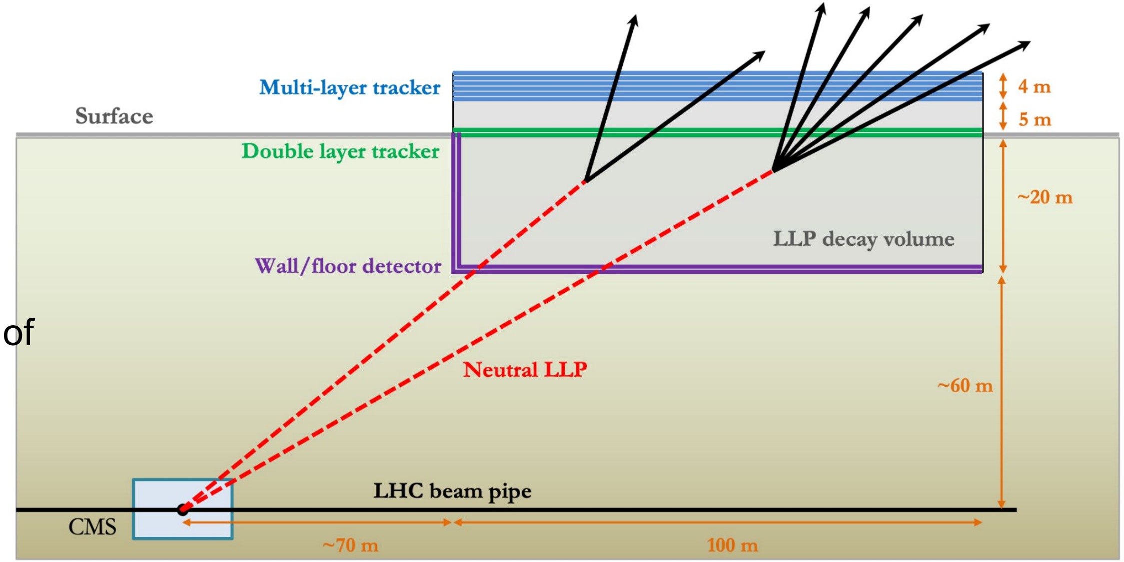


Searching for LLPs

MAssive Timing Hodosope for Ultra-Stable neutraL pArticles



What is MATHUSLA?



MATHUSLA is looking for the appearance of long-lived neutral particles (LLPs) originating from within the CMS detector

100m x 100m x 25m decay volume

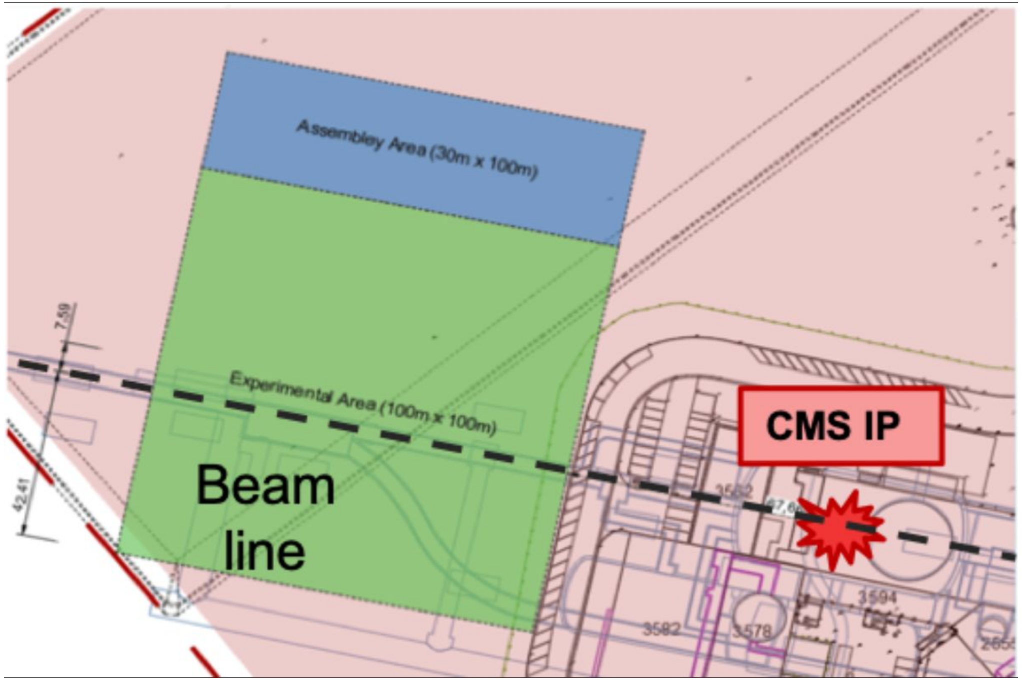
By instrumenting a large area and providing a large decay volume at “the surface”, MATHUSLA can take advantage of the HL-LHC collisions to search for LLPs

What is MATHUSLA?

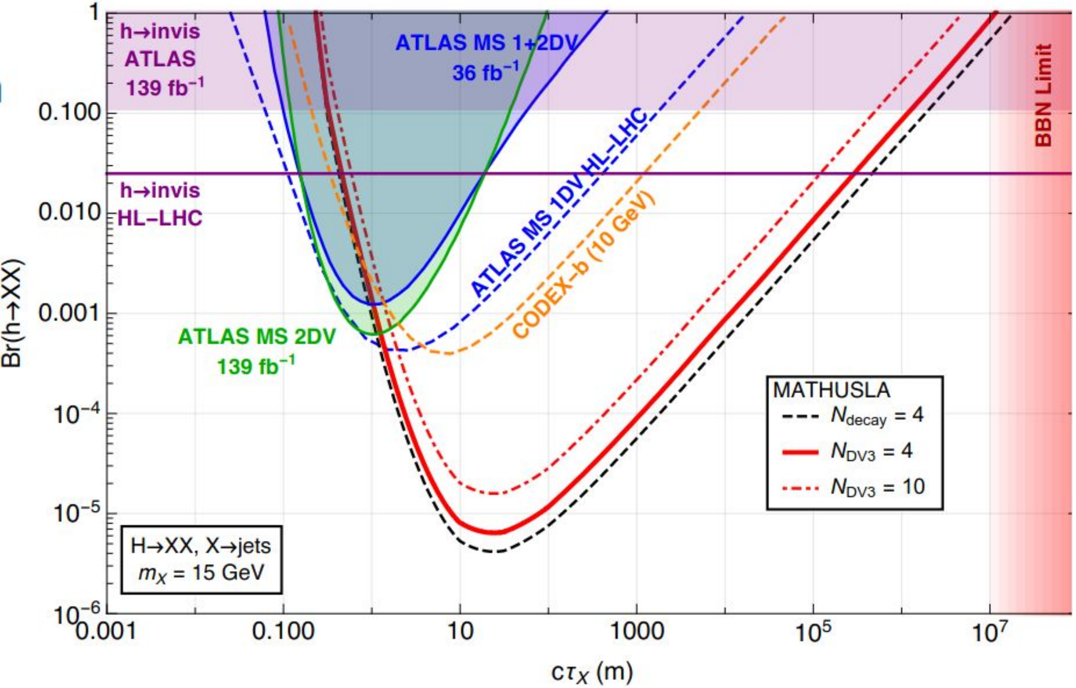
An available area that CERN already owns has been identified

MATHUSLA is largely independent of CMS (some co-triggering ideas later)

Construction and operation will not affect HL-LHC timelines or operations



MATHUSLA Physics



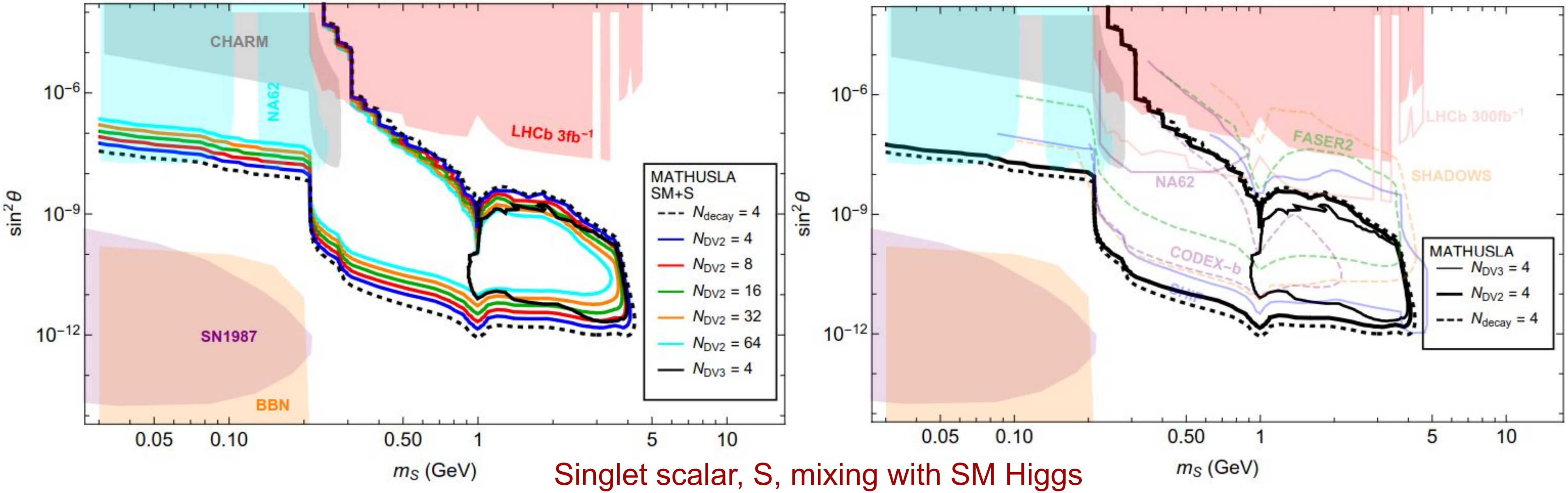
The main search mode is for hadronically decaying LLPs

~1000x increase in sensitivity compared to ATLAS and CMS for lifetimes >10m

DV3 - At least 3 observable charged particles from the LLP decay intersect at least 4 detector panes, across any of the modules.

MATHUSLA Physics

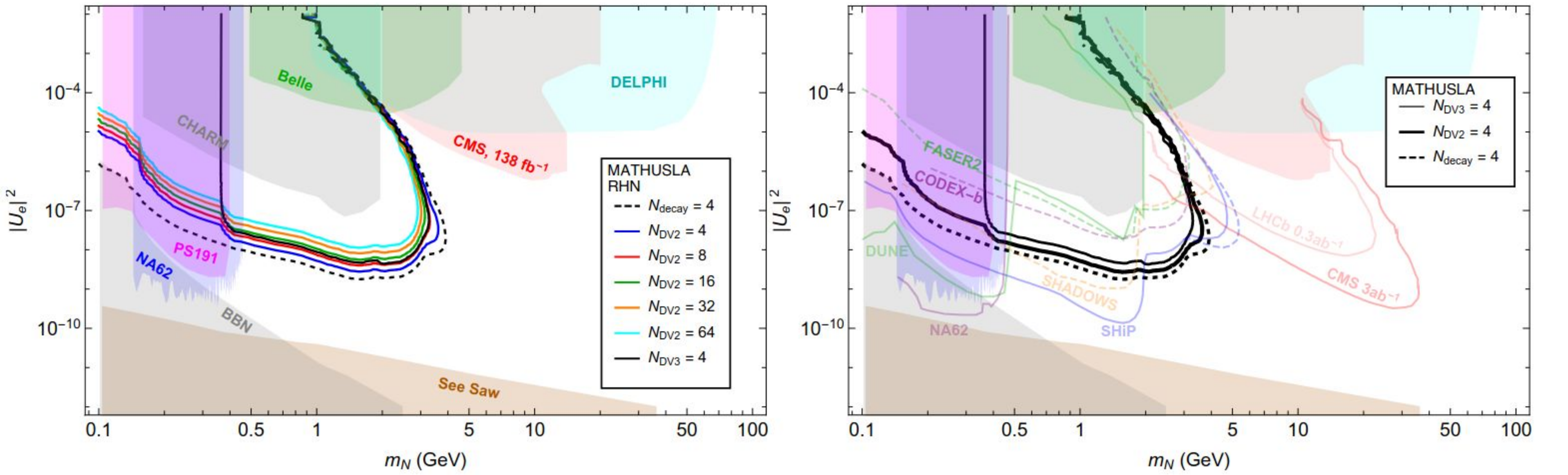
MATHUSLA offers strong sensitivity to small BSM mixing angles



Singlet scalar, S, mixing with SM Higgs

MATHUSLA Physics

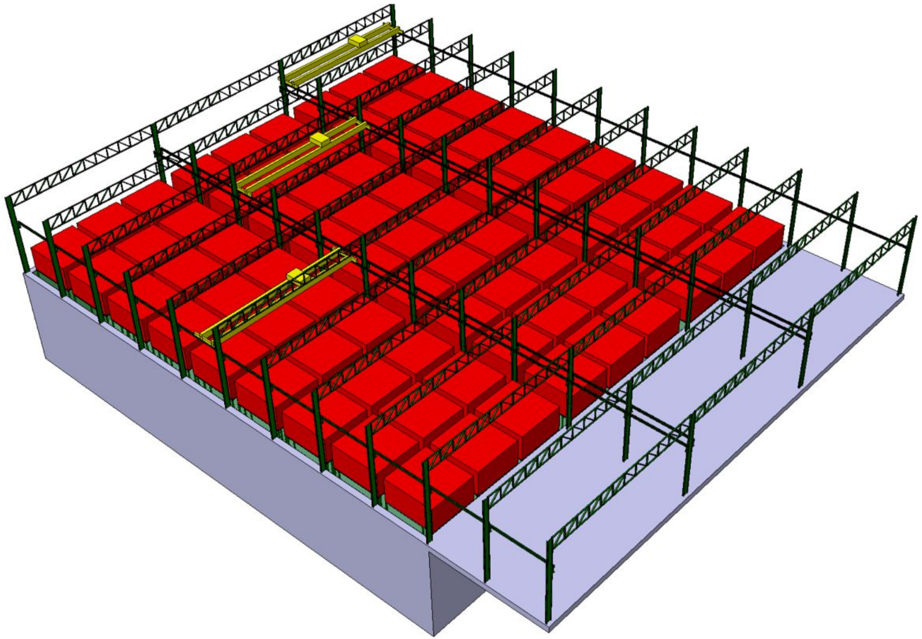
As well as searches for heavy neutral leptons (right handed neutrinos)



MATHUSLA Detector

The design of the MATHUSLA detector is highly modular

This allows for operations to start after installation of the first module, and data taking to proceed in parallel with the installation of additional modules

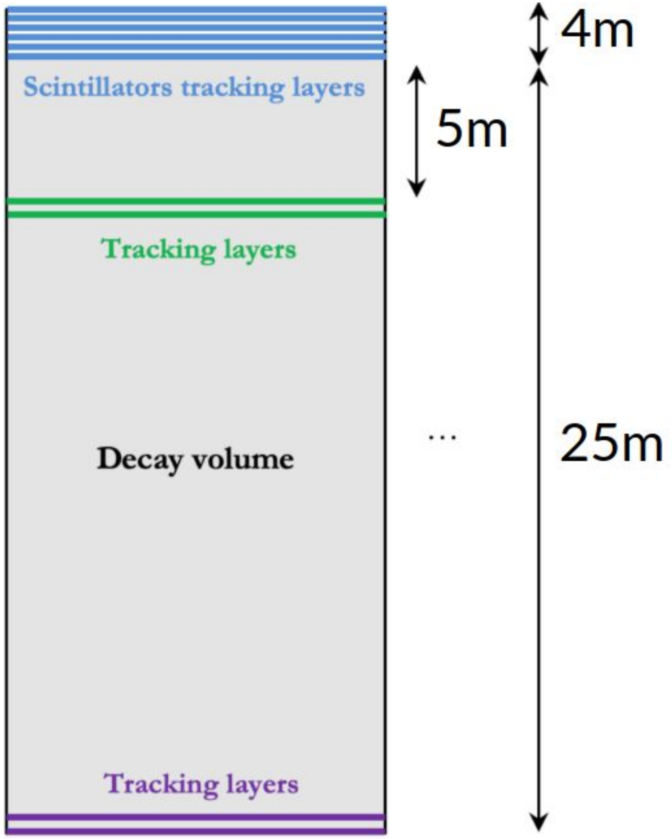


10 x 10 units, each 9m x 9m x 30m

MATHUSLA Detector

Each module is made of:

1. Six primary tracking layers on top
2. Two layers for additional tracking information
3. A large decay volume
4. Two layers on the floor to flag incoming SM particles



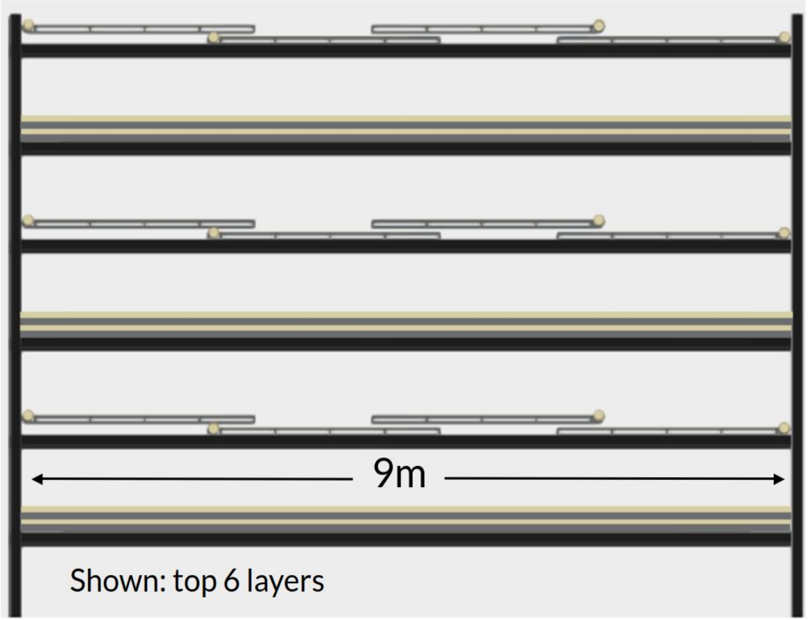
All layers are identical, adjacent layers are rotated 90°

MATHUSLA Detector

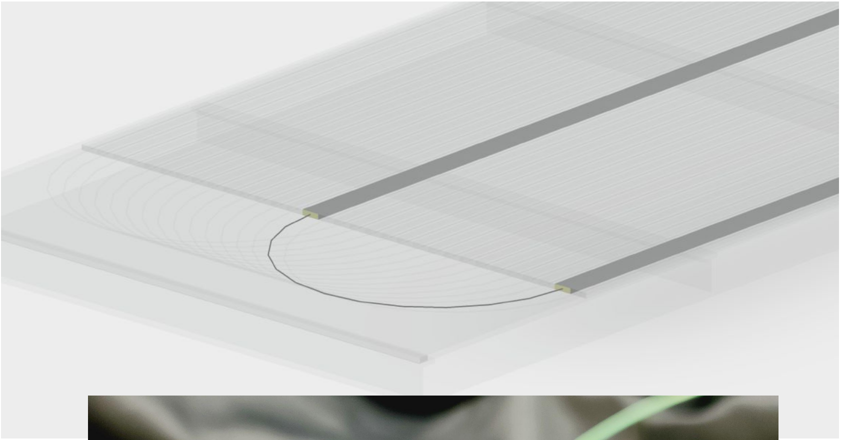
Each layer is further segmented into 4 sheets of scintillator

Each sheet contains 256 scintillator bars that are 2.5 m in length

Overlapping sheets, and rotating layers ensures no gaps in coverage within modules

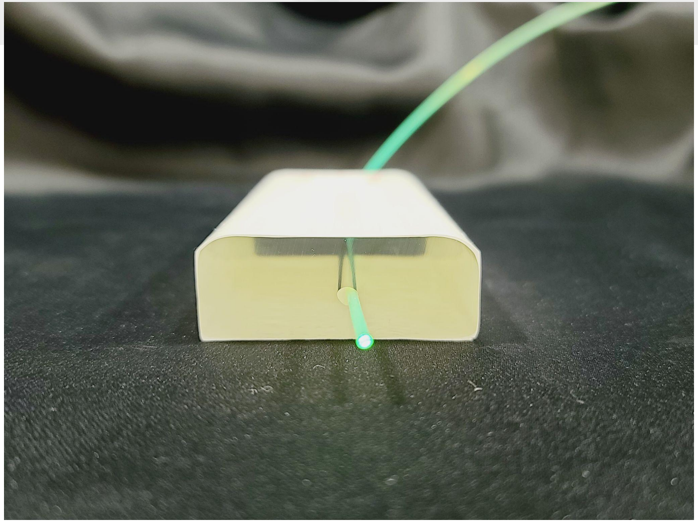


MATHUSLA Detector



Each bar is an extruded scintillator, 1 cm thick by 3.5 cm wide and 2.5m long

Running a 1.5mm diameter wavelength shifting (WLS) fibre through the center allows for effective light collection



Cost is a major design consideration

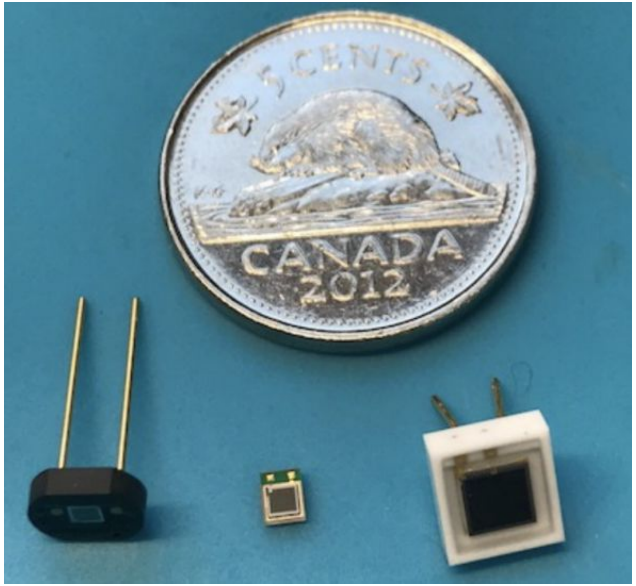
MATHUSLA Detector

At each end of the fibre a Silicon Photomultiplier (SiPM) collects the light

A coincident signal in both SiPMs provides position information and noise rejection

Currently testing a number of SiPMs for performance

- Temperature dependence, dark noise, efficiency, etc…



Performance Requirements

In order to effectively reconstruct LLPs and reject backgrounds MATHUSLA requires:

1. Timing resolution of ~1 ns
    a. Required to determine direction of travel between layers
    b. Gives ~15 cm resolution of position along bar
2. Transverse position resolution of ~1cm
    a. Constrains the scintillator bar width to 3.5 cm

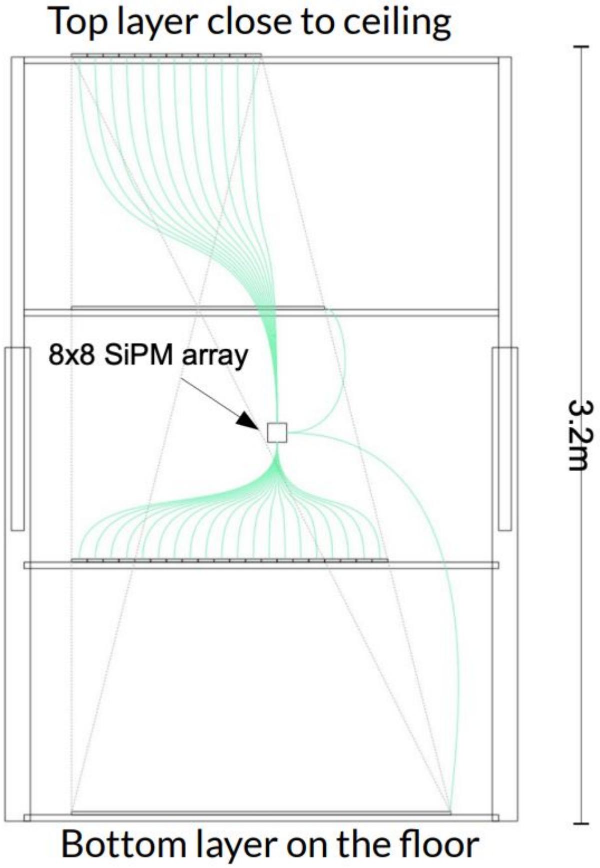
Lab tests of multiple WLS fibres show these resolutions are achievable

MATHUSLA @ UVIC

Constructing a 64 channel “mini-MATHUSLA”

Four layers of ~1m x 1.5m sheets of scintillator

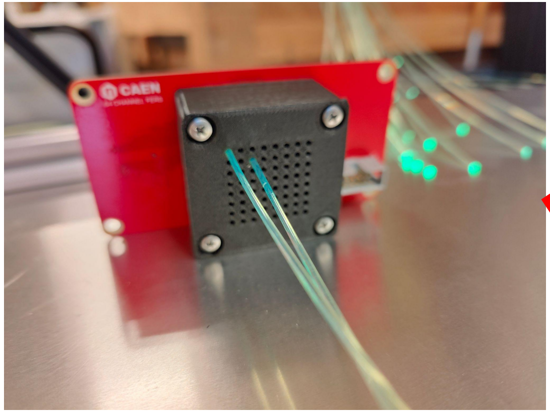
Replicate MATHULSA layers to study cosmic signals, validate the simulation, quantify environmental effects, etc…



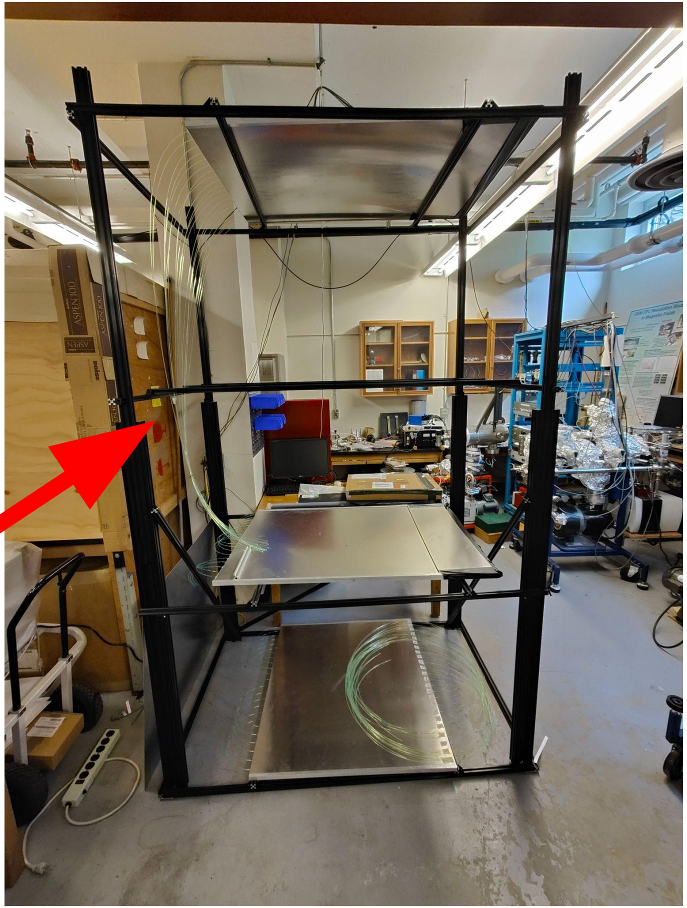
MATHUSLA @ UVIC

¾ layers in place, building the 4th layer now

Working to source material to enclose and light-tight the test stand



SiPM array will be mounted around here

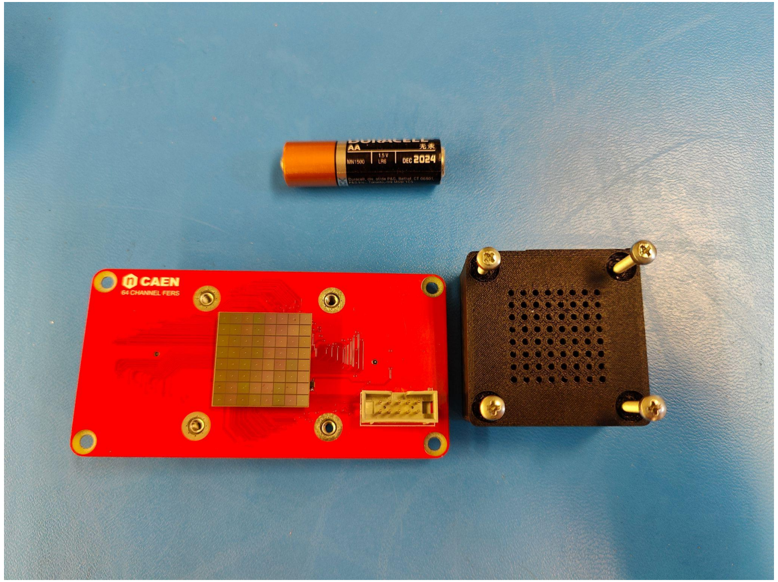


MATHUSLA @ UVIC

64-Channel Hamamatsu S13361-3050AE-08

Custom 3D printed light shield

Darkbox tests show no light leakage between channels

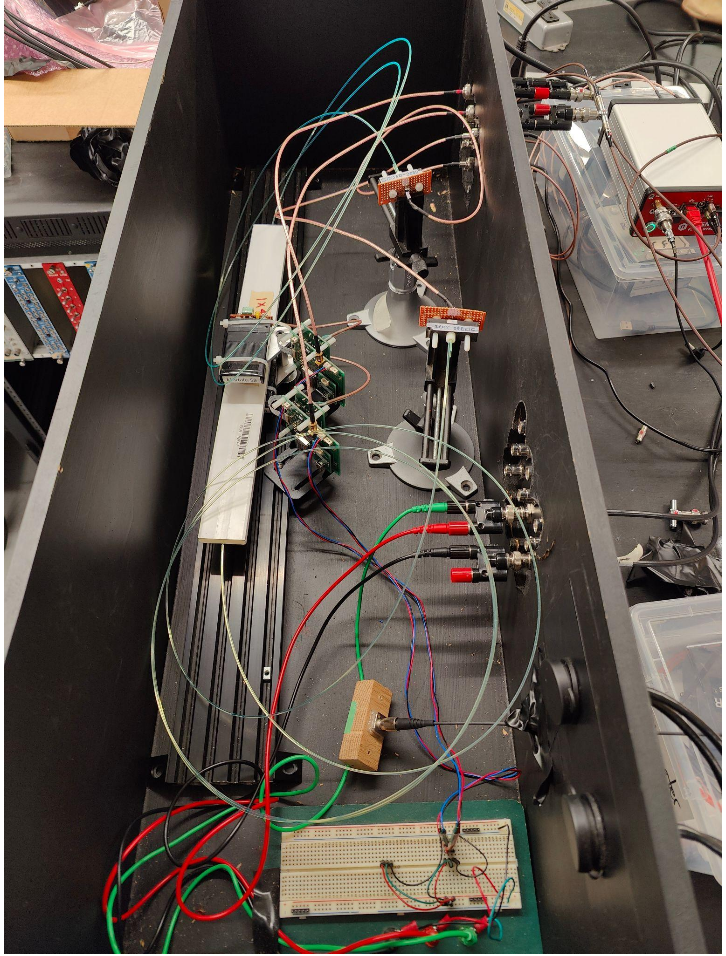


MATHUSLA @ UVIC

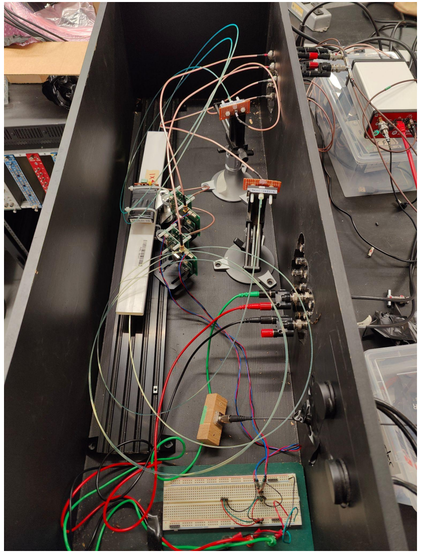
Darkbox used to test performance of various parts

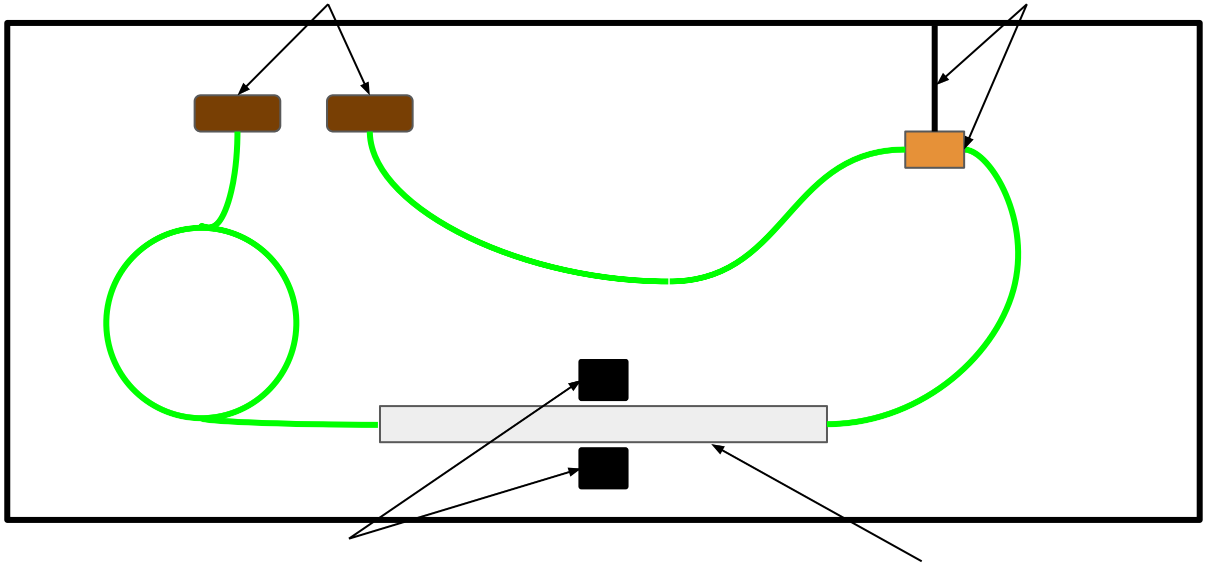
Two summer students, Branden Aitken and Sarah Alshamaily, working on various projects while we construct the test stand

- Timing/position resolution
- Light yield
- Light leakage and fibre stress
- Temperature effects



MATHUSLA @ UVIC





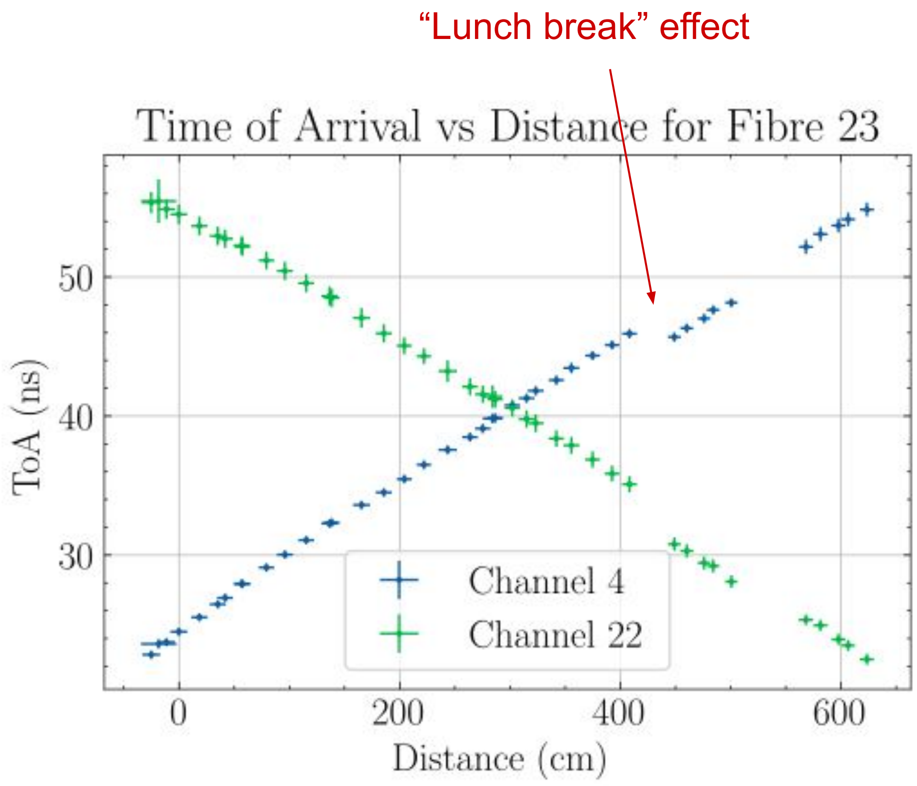
MATHUSLA @ UVIC

Dark box study to characterize position resolution

~30s data taking with 1kHz pulser every ~10cm

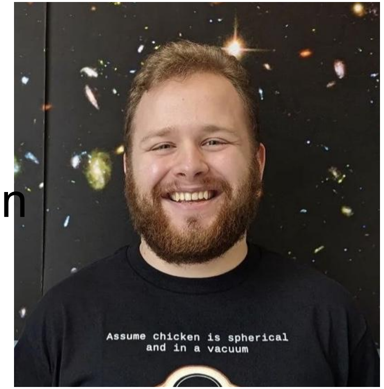
Linear relationship between distance and timing lost over ~1h stop in measurements

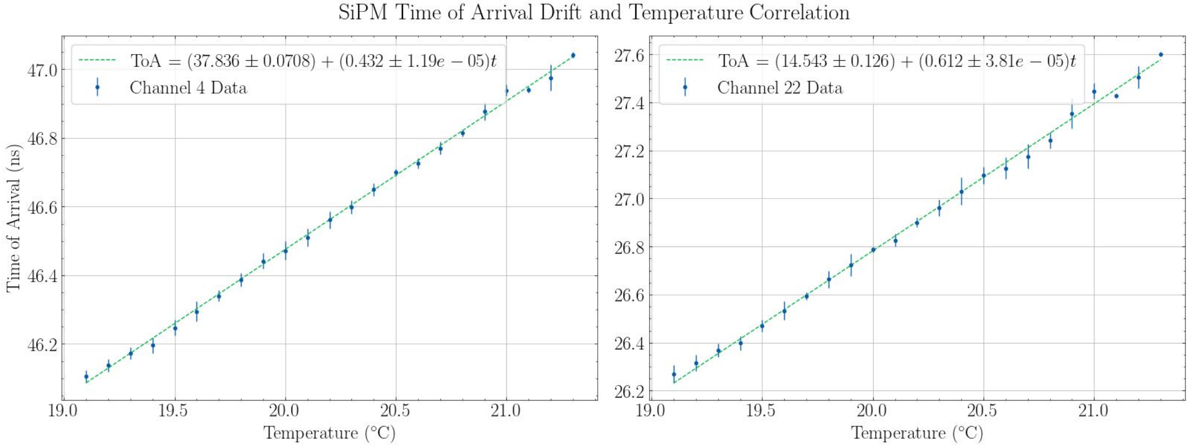
Performance change due to: voltage on time? Temperature? Fibre sliding in pulser block? Change in fibre bending radii?

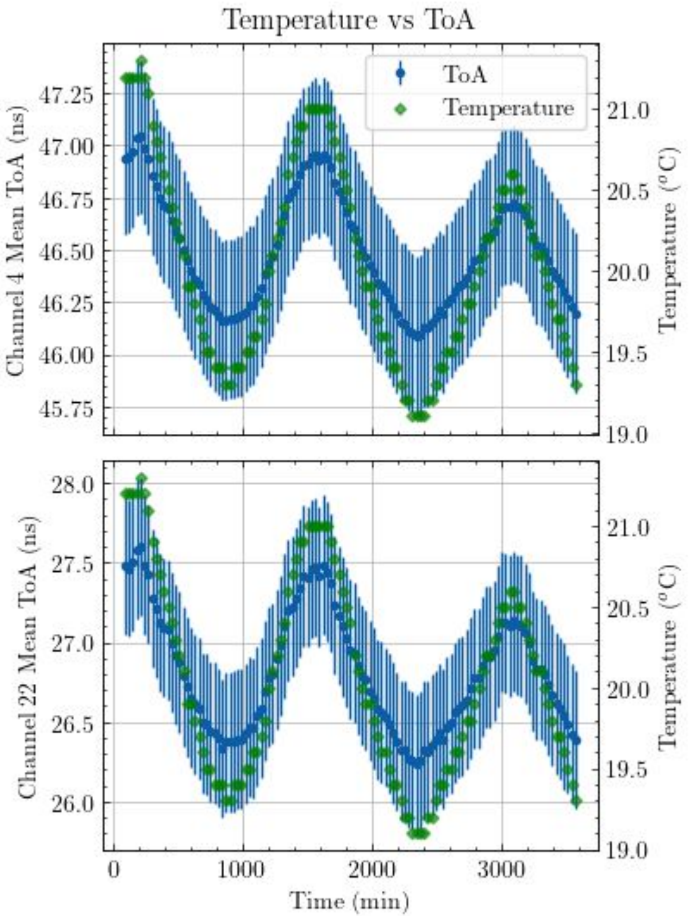


MATHUSLA @ UVIC

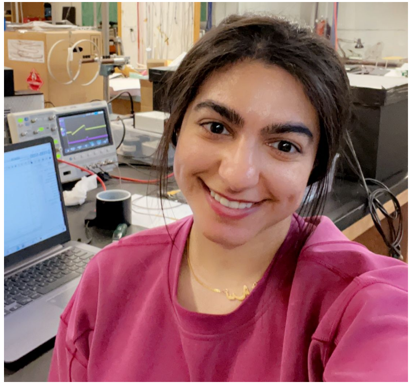
Using a temperature probe, Branden Aitken has tracked the temperature dependence of the SiPMs





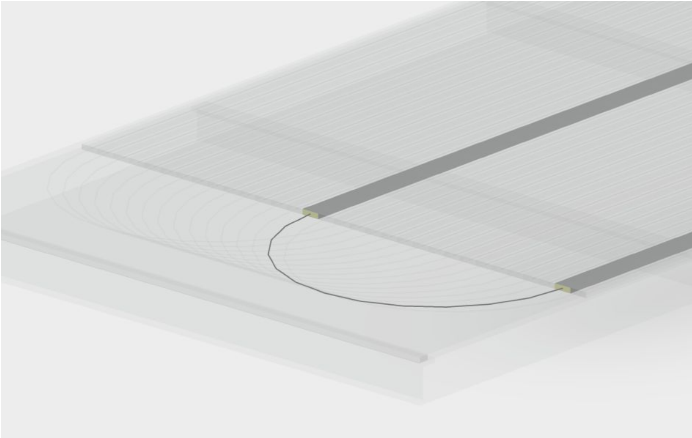


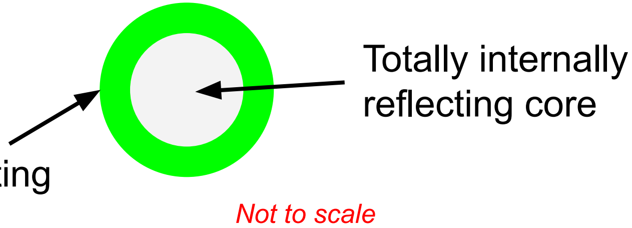
MATHUSLA @ UVIC



Sarah Alshamaily has been working to working to understand/verify the effects of over-bending the fibres

Studying whether fibres in close contact can leak light between the fibres

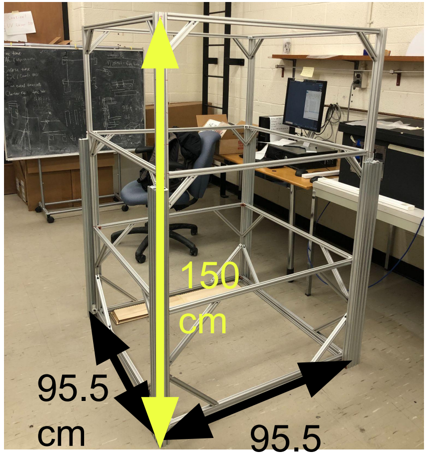


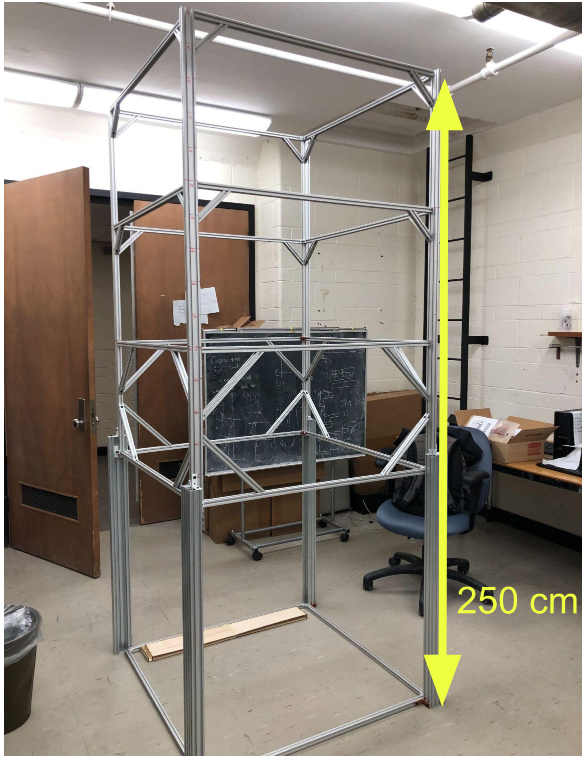


MATHUSLA @ UofT

The Toronto team is also constructing a test stand

- Extendable frame
- Up to 5 layers

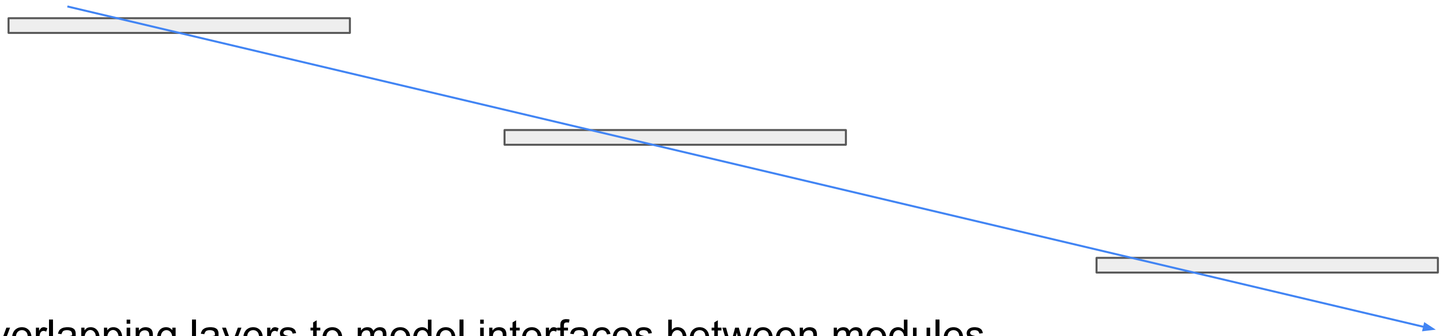




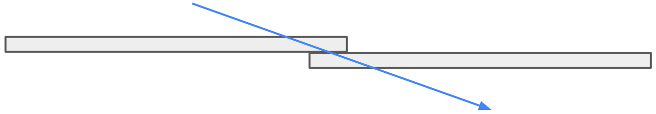
MATHUSLA @ UofT

Planned studies:

- PCB design & fabrication issues (noise, robustness, etc.)
- DAQ readout issues (multi-channel time-of-flight measurements, etc.)
- “Large angle” tracking

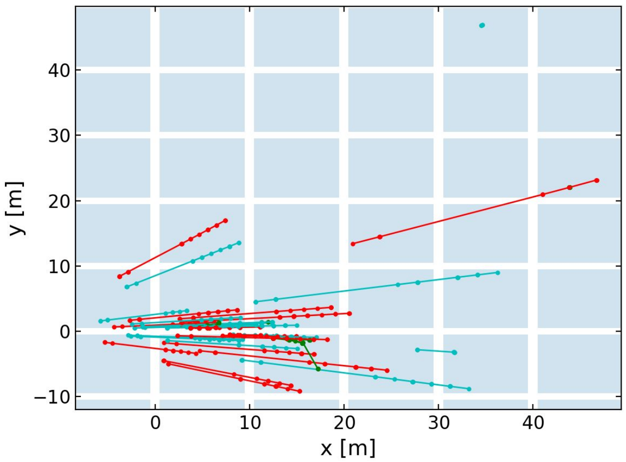


- Overlapping layers to model interfaces between modules

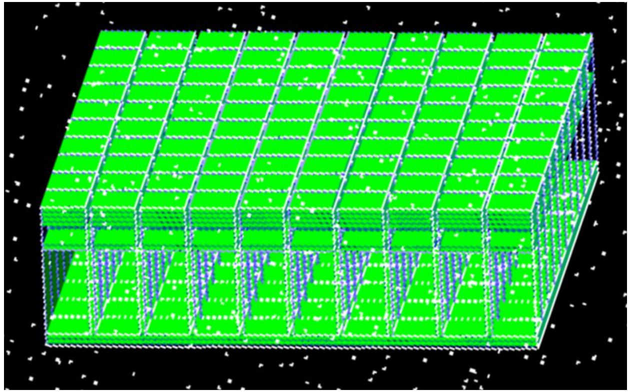


MATHUSLA @ UofT

Developing the MATHUSLA simulation



MATHUSLA geometry implemented in GEANT4

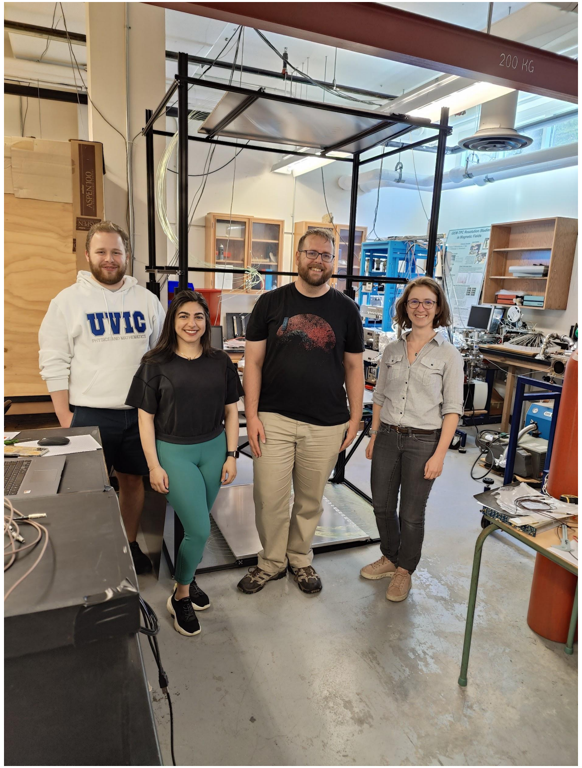


Event reconstruction software

1. Digitization
2. Pattern recognition (Kalman Filter)
3. Track parameter estimation (Kalman Filter)
4. Vertex parameter estimation

Next steps for MATHUSLA

UVIC Team



Conceptual design report is nearing final form

A. Critical step in becoming an official CERN experiment

Lots of work to do testing components and finalizing technical design

Snowmass Update:

https://arxiv.org/abs/2203.08126

MATHUSLA in Canada

UVIC

Faculty

Heather Russell

Postdoc

Caleb Miller

Summer Students

Branden Aitken

Sarah Alshamaily

UofA

Faculty

Steven Robertson

UofT

Faculty

Miriam Diamond

David Curtin

Postdoc

Runze Tom Ren

Grad Students

Jaipratap Grewal

Gabriel Owh

Summer Students

Simran Hiranandi

MATHUSLA Collaboration

Fermilab

TEL AVIV UNIVERSITY

UNIVERSITY OF ALBERTA

SLAC NATIONAL ACCELERATOR LABORATORY

THE UNIVERSITY OF ARIZONA

IFIC INSTITUT DE FÍSICA CORPUSCULAR

UNACH Universidad Autónoma de Chiapas

Universidad Andrés Bello

ESCUELA NACIONAL de CIENCIAS de la TIERRA

University of Victoria

UNIVERSITAS MAJOR PACENSIS DIVI ANDREÆ

UNIVERSITY of ROCHESTER

UNIVERSIDAD SAN FRANCISCO

UNIVERSITY OF WASHINGTON 1861

Università degli Studi di Palermo

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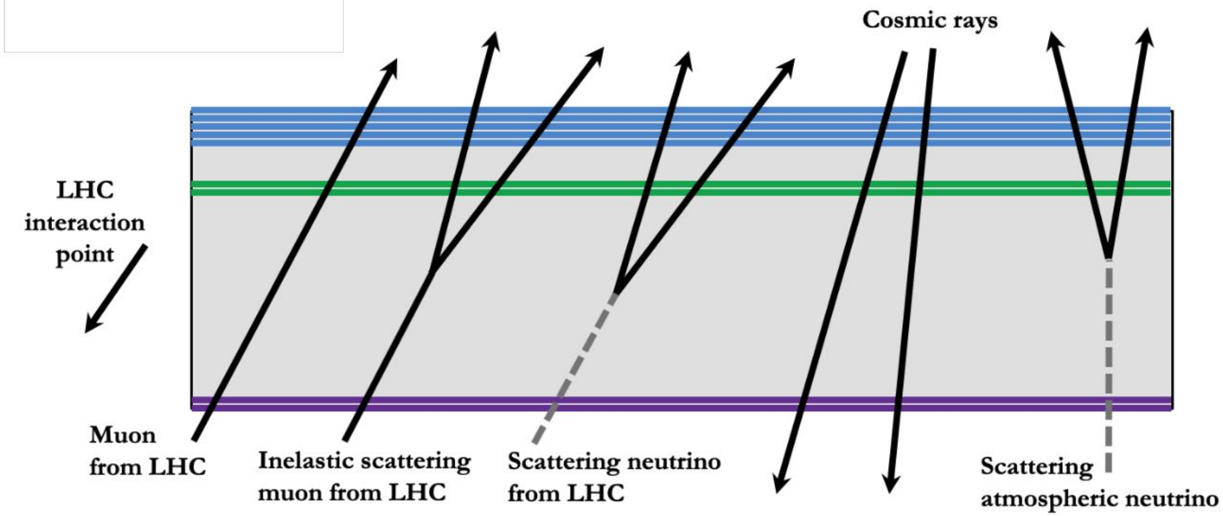
Warsaw University of Technology

Backup Slides

Backgrounds

Cosmic rays dominate the MATHUSLA background rate but are vetoed by their direction of travel

Muons from CMS are vetoed by the floor layers



WLS Fibre Timing Resolution