MATHUSLA

https://mathusla-experiment.web.cern.ch/

Massive Timing Hodoscope for Ultra Stable neutraL pArticles

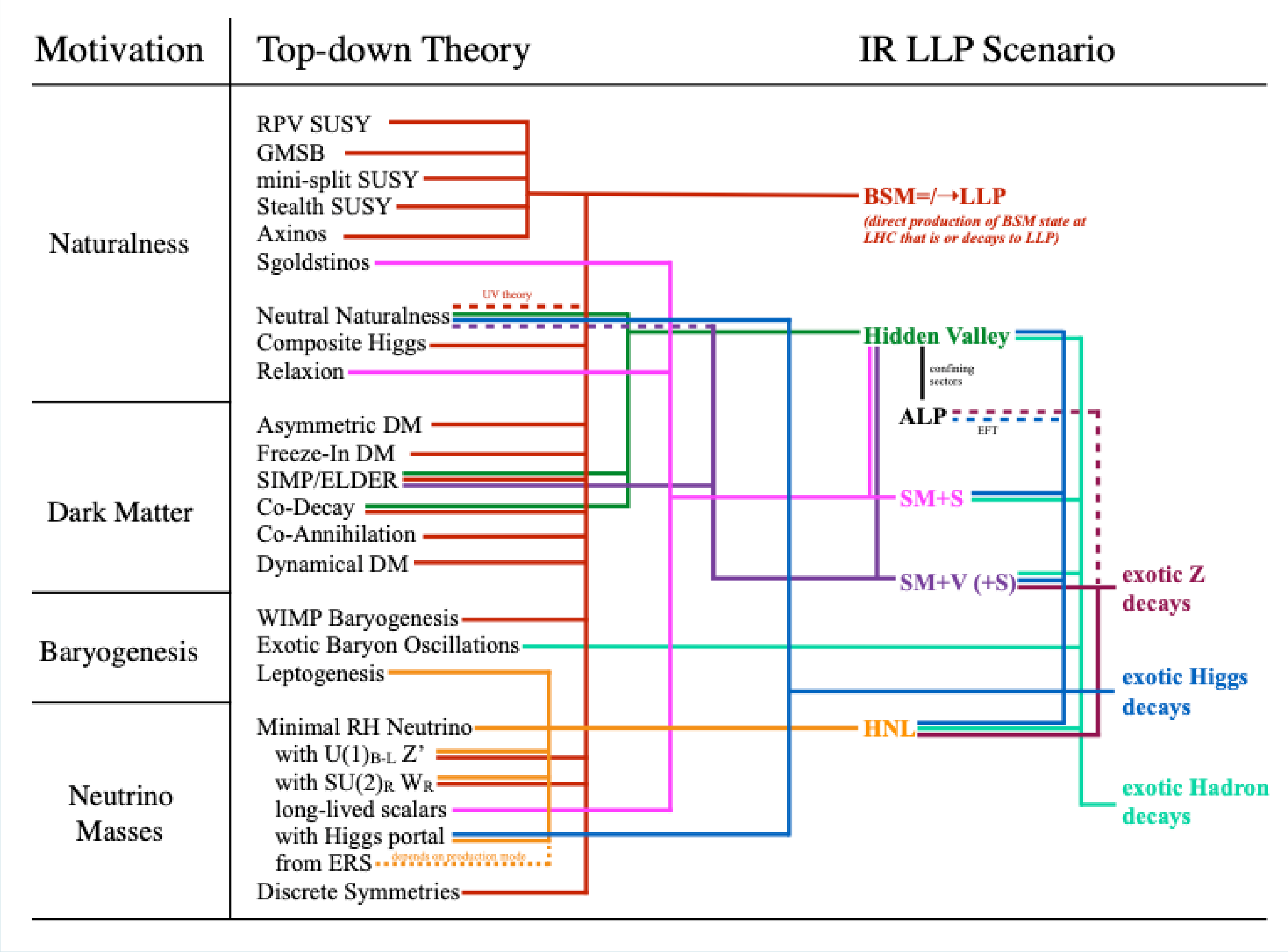
Proposed LHC auxiliary transverse LLP Detector to take data during the entire HL-LHC operation in order to have sensitivity to long-lived particles with lifetimes up to 0.1 s (BBN limit).

Auxiliary LHC detectors are widely supported in Snowmass study and European Strategy Update.

Snowmass White Paper arXiv:2203.08126v2
LHCC LOI arXiv:1811.00927
Updated LHCC LOI arXiv:2009.01693

Theoretical Motivation for These Searches

MATHUSLA would enable discovery of LLPs that are part of the solution to the Hierarchy Problem, reveal nature of Dark Matter, Baryogenesis, Neutrino masses, and other BSM phenomena

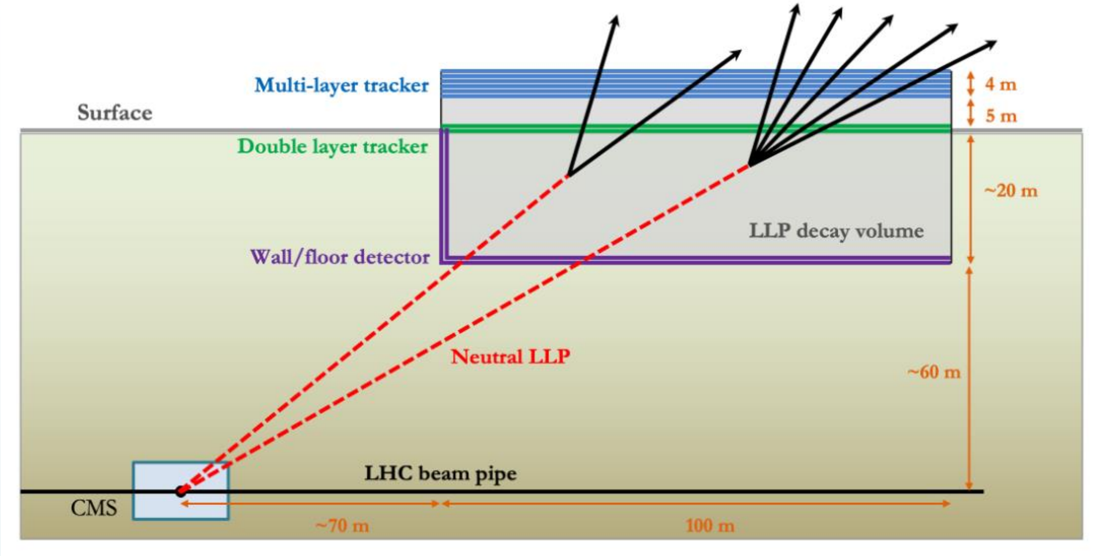


Long-Lived Particles at the Energy Frontier: The MATHUSLA Physics Case 1806.07396

pp Collision Backgrounds

- Despite the many interaction lengths of the ATLAS and CMS calorimeters, many hadronic jets punch through, resulting in large muon detector rates that limit long lifetime searches.
- Based on our experience with searches for LLP decays to hadronic jets in the ATLAS muon spectrometer, significantly more shielding is REQUIRED because punch-through backgrounds were the limiting factor.
- The MATHUSLA surface detector, protected by about 80 meters of rock is free of such limiting backgrounds and has no trigger rate limitations.
- The absence of pp collision backgrounds allows MATHUSLA to extend LLP searches well beyond what is possible in ATLAS and CMS.

Detector Overview



Wall and floor scintillator layers to flag LHC muons.

Located on surface at P5 to detect neutral LLPs produced in pp collisions in the CMS IP.

Sensitivity to $c\tau = 10^7$ m for O(pb) production cross sections.

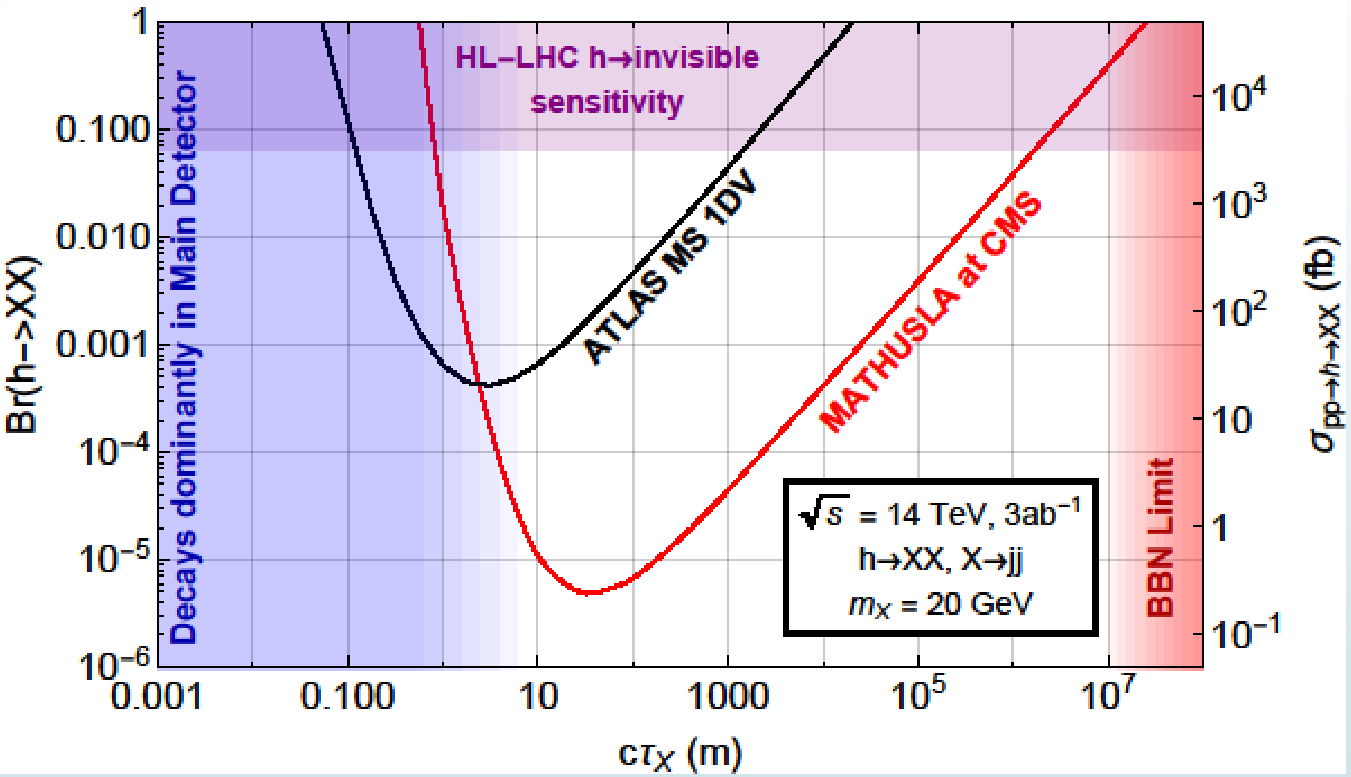
O(80m) of rock removes pp collision backgrounds.

Scintillator timing separates upward tracks from LLP decays from downward cosmic rays.

Robust tracking for vertex reconstruction.

MATHUSLA Physics Reach

- **Primary Physics Case: hadronically decaying O(10-100 GeV) LLPs**

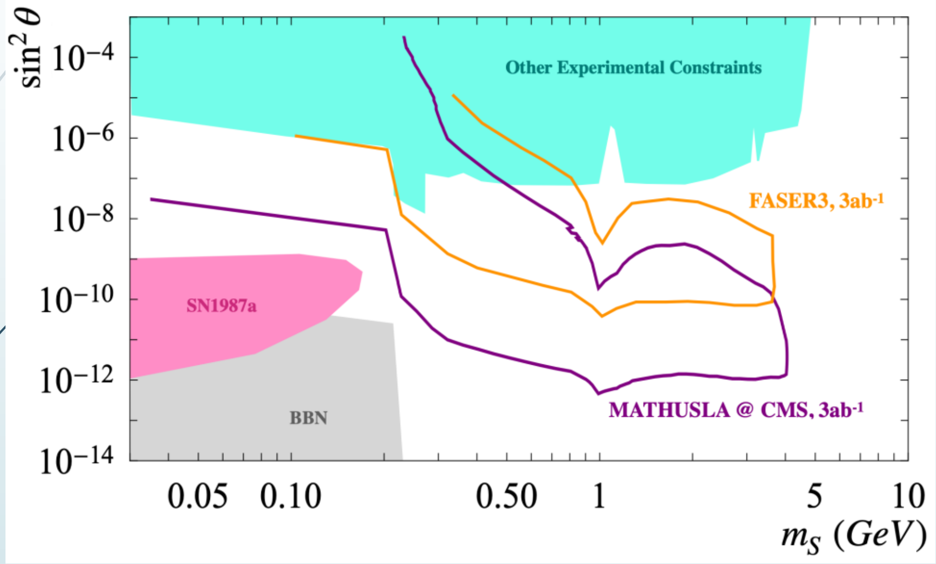


- **1000 times reach improvement over ATLAS HL-LHC projection.**
- **For h → LLP can reach 0.1s lifetime – BBN limit**

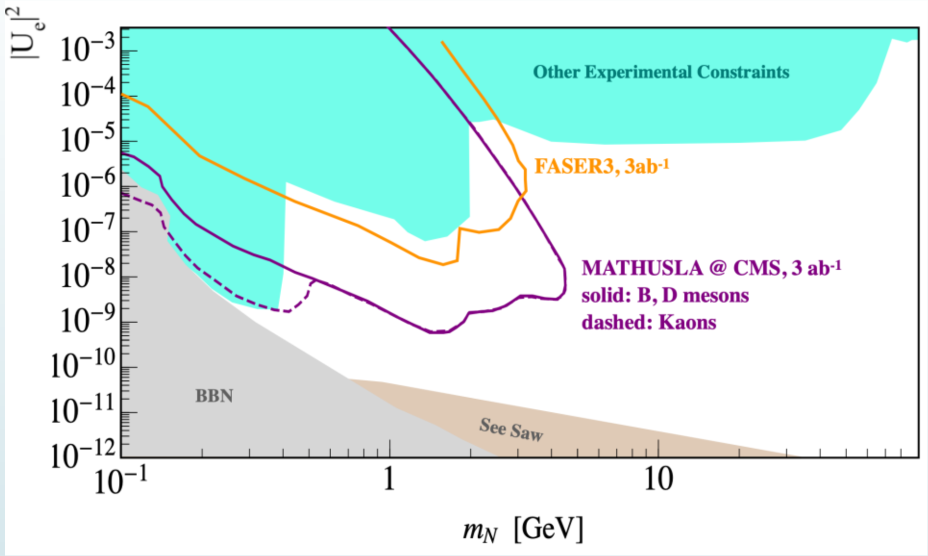
MATHUSLA Physics Reach

- **Secondary physics case: GeV-scale LLPs from B, D meson decays**

Singlet Scalar LLP



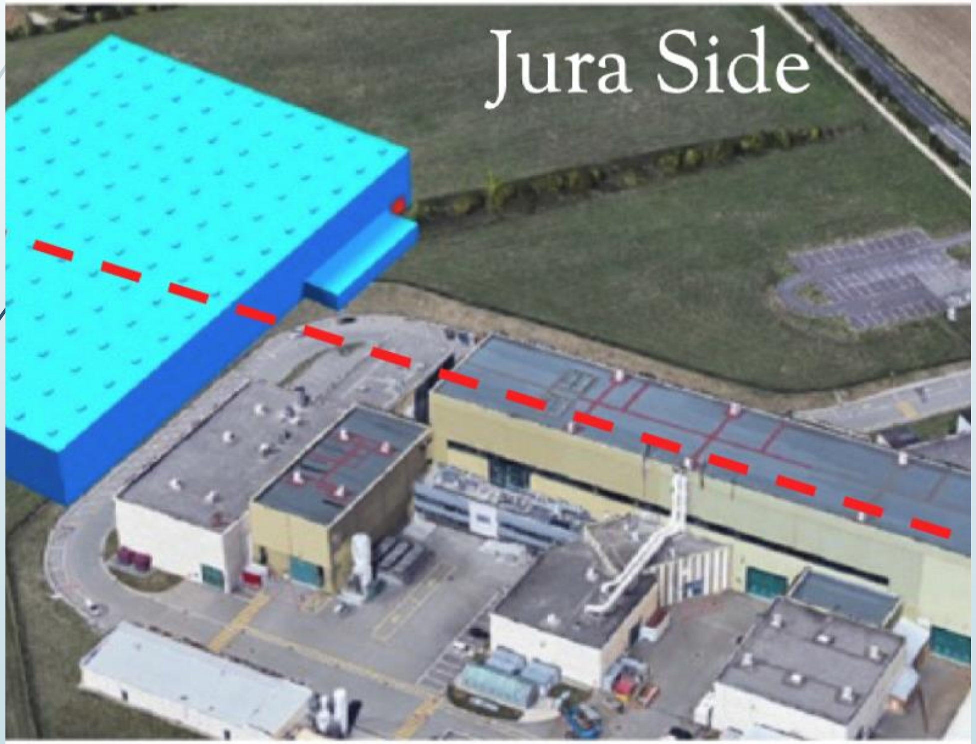
Right-handed Neutrino LLP

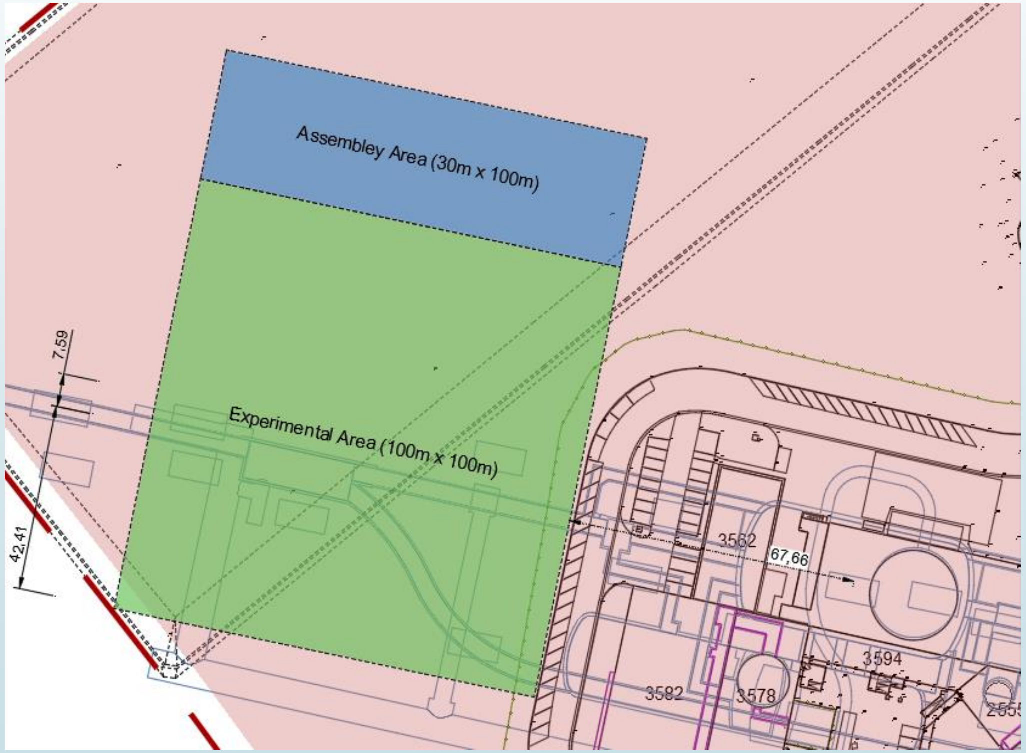


- Greatly extends discovery potential to smaller mixing angles.
- **Significant complementarity with FASER, which probes similar masses but shorter lifetimes.**

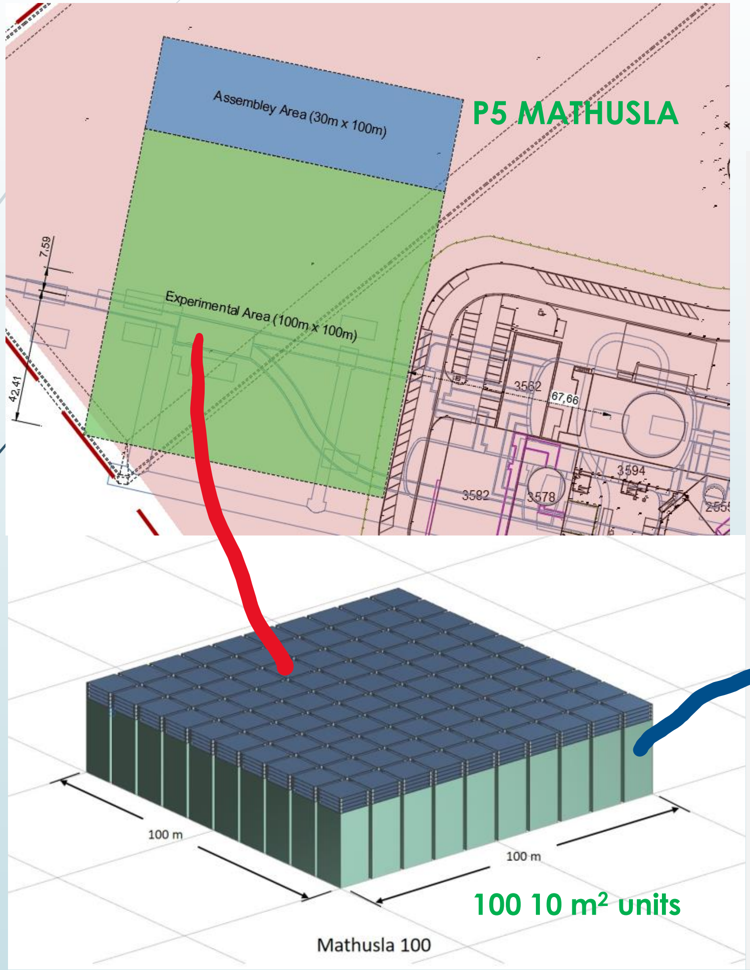
MATHUSLA at P5

- **Proposed building to house MATHUSLA on CERN owned land at P5**

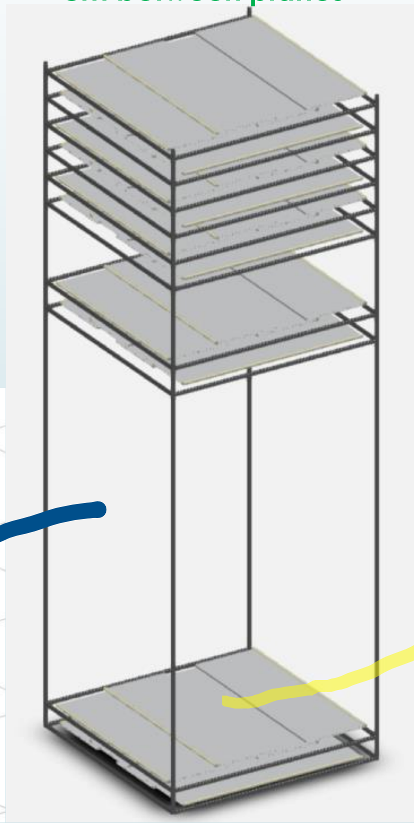


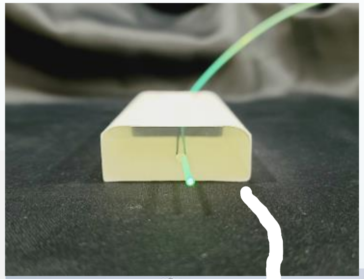


MATHUSLA Detector Overview

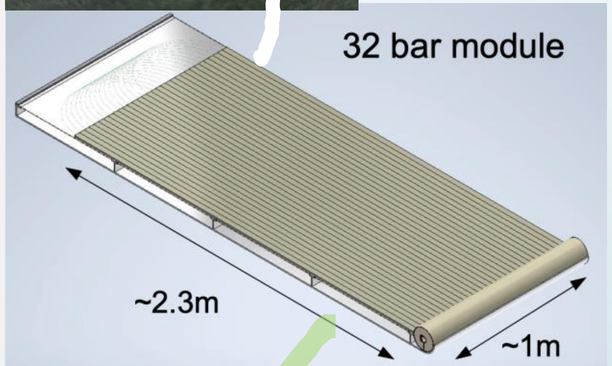


Each $10m^2$ unit has 10 scintillating detector planes; 80 cm between planes





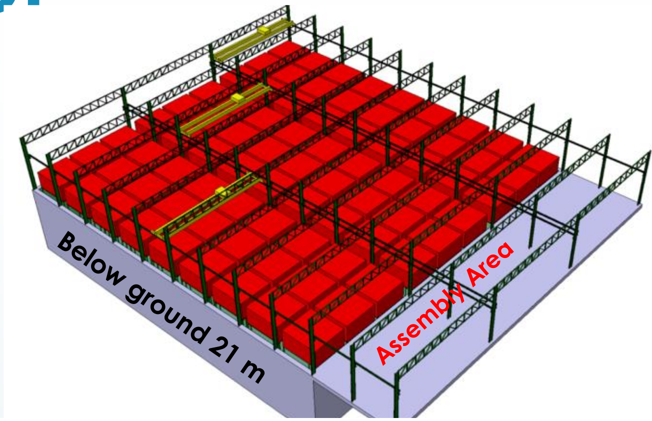
Extruded Fermilab scintillating bar with coextruded cladding and a central hole for WLS fiber as shown

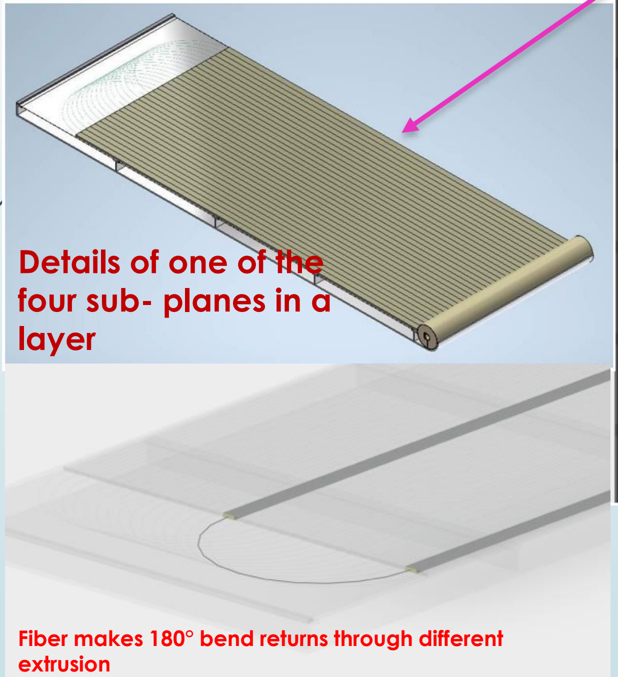


The 9 m^2 detector planes comprised of 32 scintillating bar modules

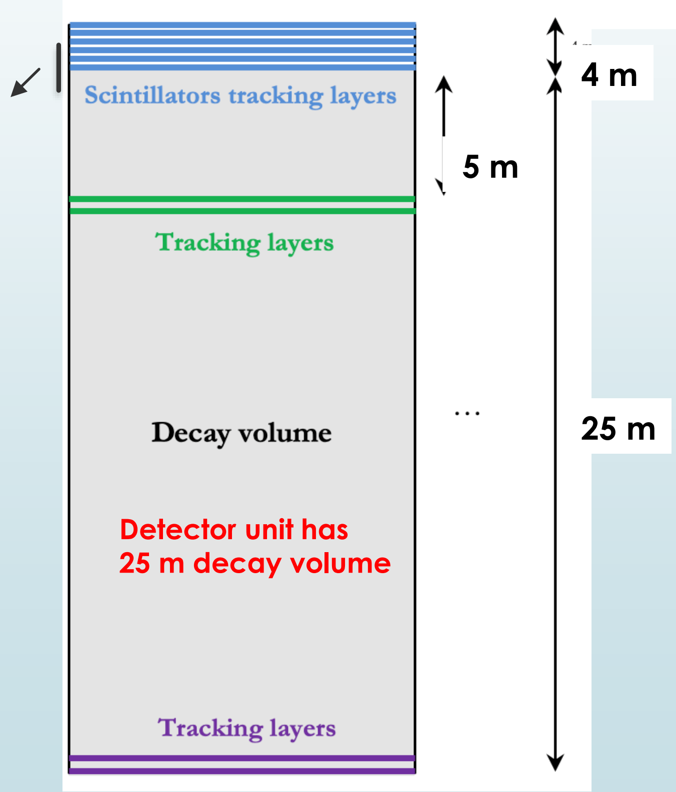
MATHUSLA Baseline Modular Concept

- 100 9mX9m detector units
- Total of 10 scintillating/tracking planes per detector unit
- Staged installation of modules & incremental ramp-up
- 25 m decay volume

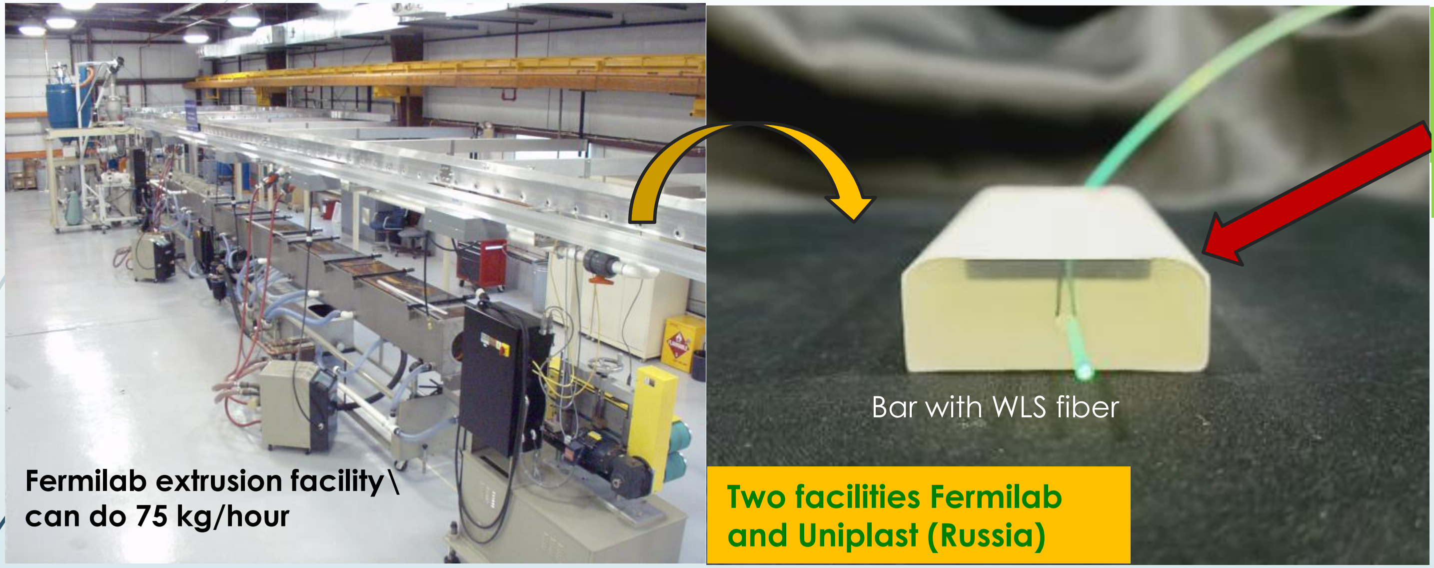




- Detail of the top 6 scintillating planes -
- Alternate layers have the extrusions running at 90
- Each layer of scintillating planes comprises 16 separate extrusion planes.
- Overlap between the extrusion planes guarantees full detection coverage.



Extruded Scintillators



Base line bar dimension
Extruded bars 2.35 m long,
3.5 cm wide and
1 cm thick

Extruded scintillators from Fermilab widely used:

- **mu2e cosmic ray veto**
- **MINERVA**
- **Belle-2…**

Scintillating bars provide the spatial and timing coordinates that allow for a track reconstruction in 4 dimensions (three space coordinates and time).

Resolution:
- **Timing 1 ns**
- **Longitudinal 15 cm**
- **Transverse 1 cm**

How to Characterize New Physics

- When LLP decays are observed in MATHUSLA, understanding underlying physics is crucial.
- The CMS detector, which has 4pi coverage of the pp interaction, will allow us to understand the underlying physics.

LLP Trigger

- Sending the LLP trigger to CMS would provide full event information.
- Technically challenging because of the CMS Level-1 trigger latency with their Phase-2 trigger upgrade.
- We confirmed the feasibility of this trigger in a detailed study.
  - Select MATHUSLA tracks that go upwards (based on timing).
  - Necessary to include particle transit times from IP, the signal propagation time in MATHUSLA, the trigger algorithm time, and signal transmission time back to CMS.
  - Resource usage reasonable with current generation of FPGAs such as Kintex XCKU040 and XCKU19P.

DAQ

- MATHUSLA data rates are dominated by cosmic rays.
- Consequently, we plan to use commodity hardware to stream all hits to a buffer storage.
- Relevant hits can then be selected for archival storage; this can be thought of as a high-level trigger (HLT) with hours of trigger latency.

Cost Estimates

- CERN traditionally covers infrastructure costs (building, cranes…)
- Detector Material Costs
  - Detector material: extruded scintillator bars, WLS fiber SiPMs, Al honeycomb…
    42,000 USD per detector plane → 42M USD for full detector
  - Support Structure material: box beams Hexcel…
    216000 USD per detector unit → 22M USD for full detector
- Assembly of scintillator planes at CERN and installation: engineers, technicians, riggers… 2.7M USD
- Detector Trigger and DAQ: 30M USD
- TOTAL 97M U.S. dollars, to be shared among multiple funding sources
- Distribution among international collaborators to be determined.

Schedule Goal

- Ready for HL-LHC collisions.
- Staged installation beginning about 2.5 years before HL-LCH pp collisions.
  - Installation of one 9x9 m^2 unit O(1-week)
  - Can begin data taking when a few modules are installed.

MATHUSLA Collaboration

Fermilab

TEL AVIV UNIVERSITY

University of Victoria

UNIVERSIDAD SAN FRANCISCO

UNIVERSITY OF TORONTO

UNIVERSITY OF ALBERTA

OU

CERN

Università di Roma Tor Vergata

SLAC NATIONAL ACCELERATOR LABORATORY

UNIVERSITY OF WASHINGTON 1861

ZEWAIL CITY
ESTABLISHED 2000
INAUGURATED 2011

THE UNIVERSITY OF ARIZONA

IFIC INSTITUT DE FÍSICA CORPUSCULAR

UNIVERSITAS MAJOR PACENSIS DIVI ANDREÆ

Università degli Studi di Palermo

RUTGERS THE STATE UNIVERSITY OF NEW JERSEY 1766

UNACH Universidad Autónoma de Chiapas

INFN BOLOGNA

BENEMÉRITA UNIVERSIDAD AUTÓNOMA DE PUEBLA 1578

UNIVERSIDAD MICHOACANA DE SAN NICOLÁS DE HIDALGO

Universidad Andrés Bello

ESCUELA NACIONAL de CIENCIAS de la TIERRA

UNIVERSITY of ROCHESTER
MELIORA 1850

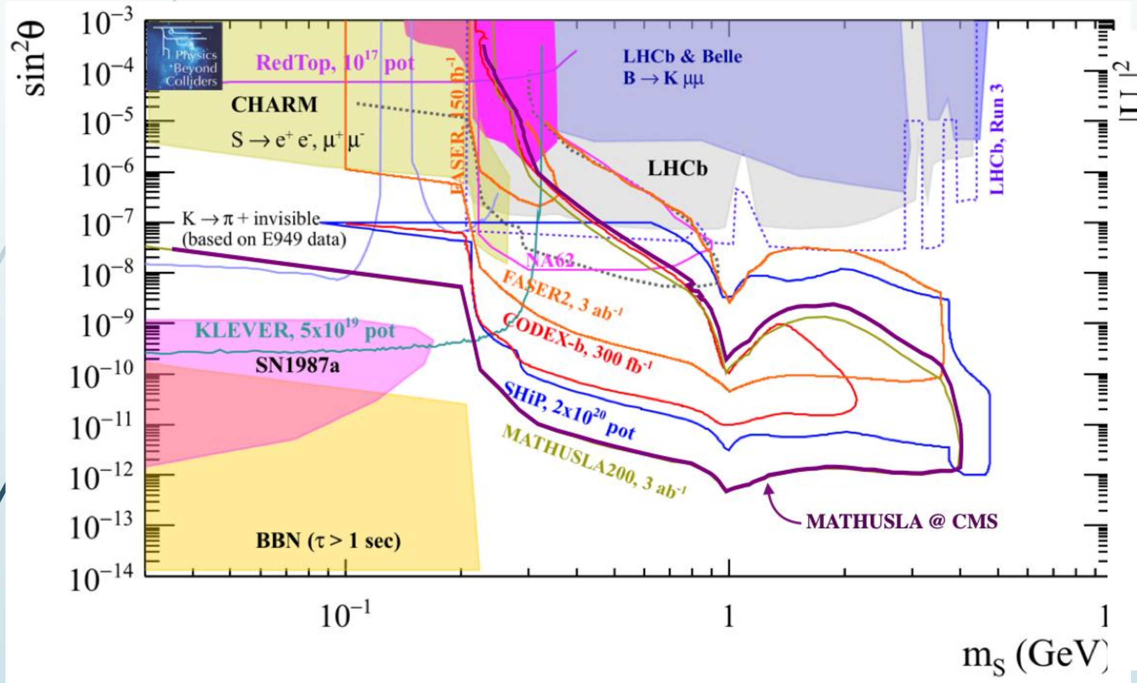
ESG

Warsaw University of Technology

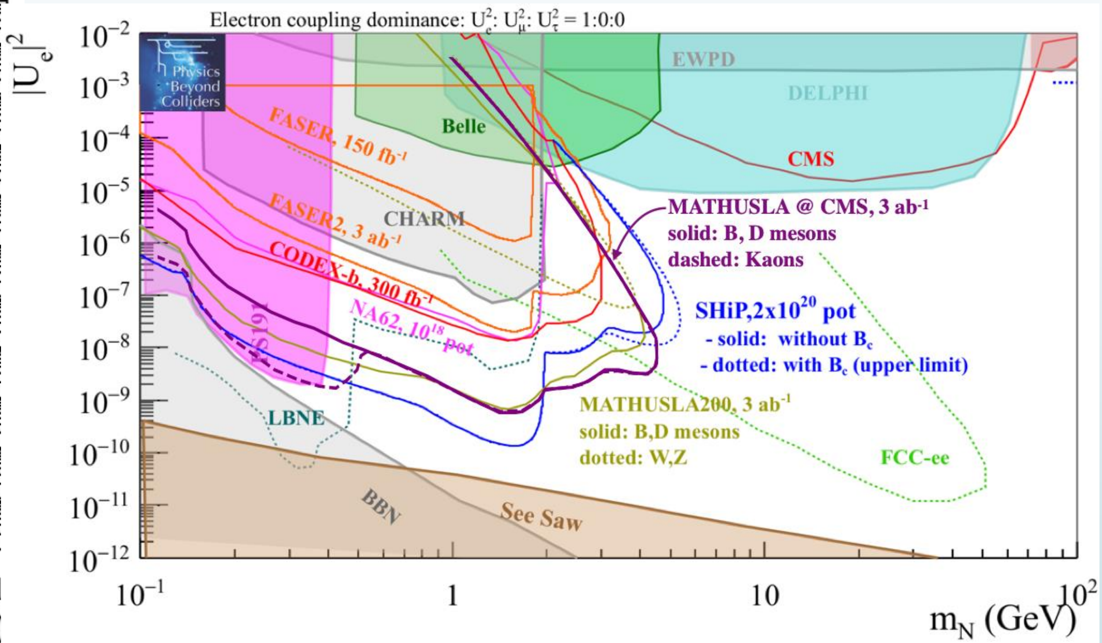
Supporting Material

MATHUSLA Physics Reach

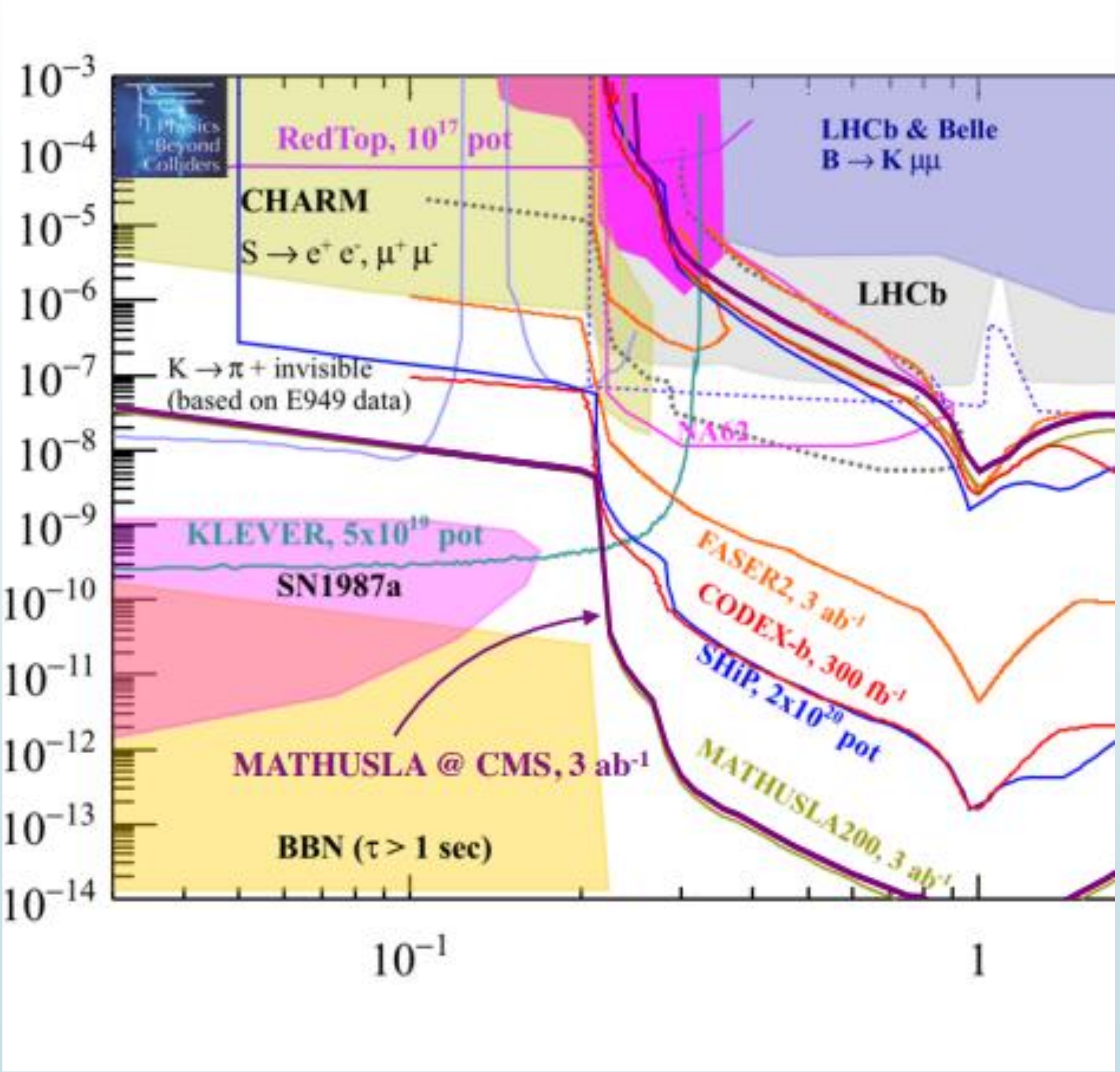
Singlet Scalar LLP



Right-Handed Neutrino LLP



Singlet scalar mixing with Higgs, mixing angle θ with B(h→ ss) = 1%

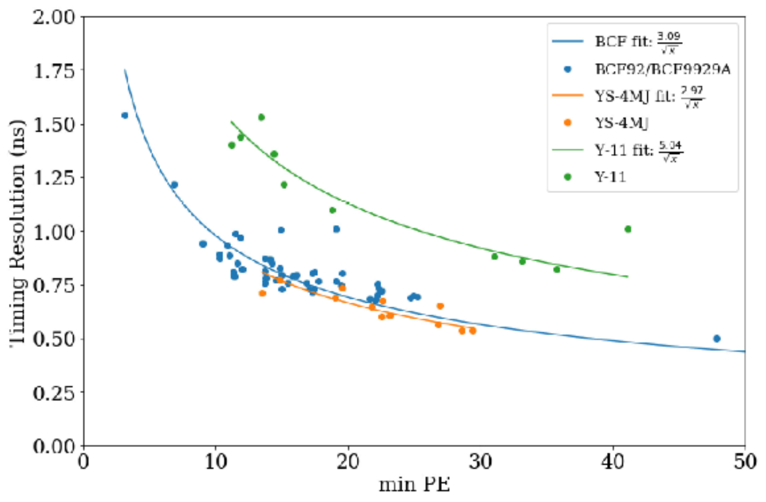


Timing resolution studies

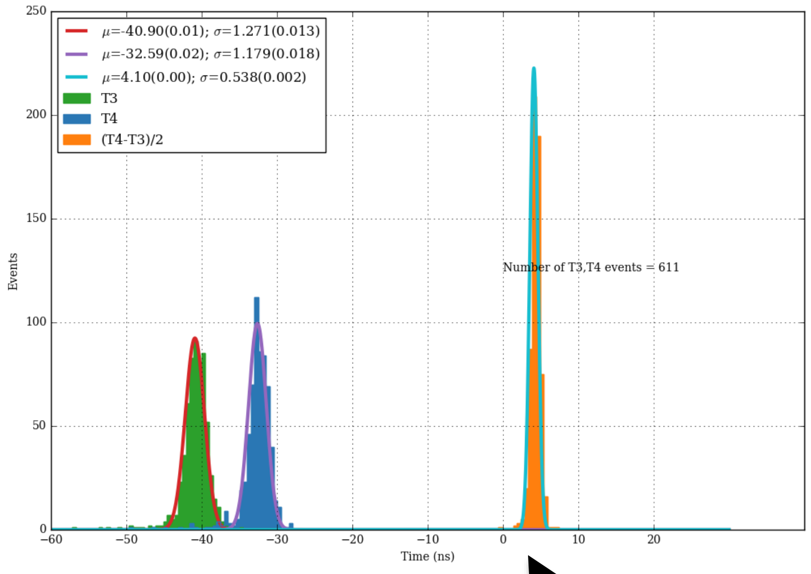
J. Freeman, Fermilab

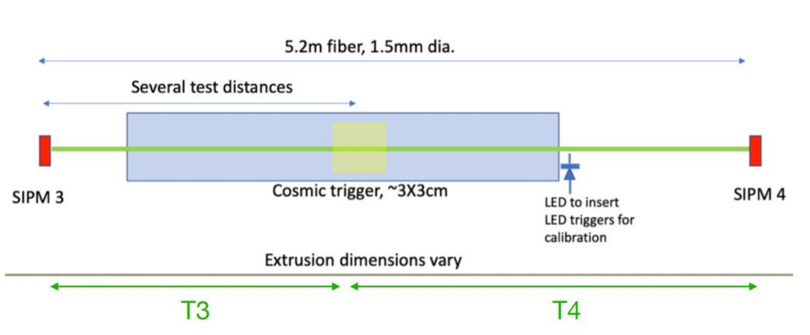
Base line bar dimension
Extruded bars 2.35 m long, 3.5 cm wide and 1 cm thick

Resolution vs. min PE for Saint-Gobain (BCF) And Kuraray WLS fibers



Obtain better than 1 ns with >15 photoelectrons





Best resolution observed for one special fiber: 0.538 ns,