# MATHUSLA

*Status and goals*

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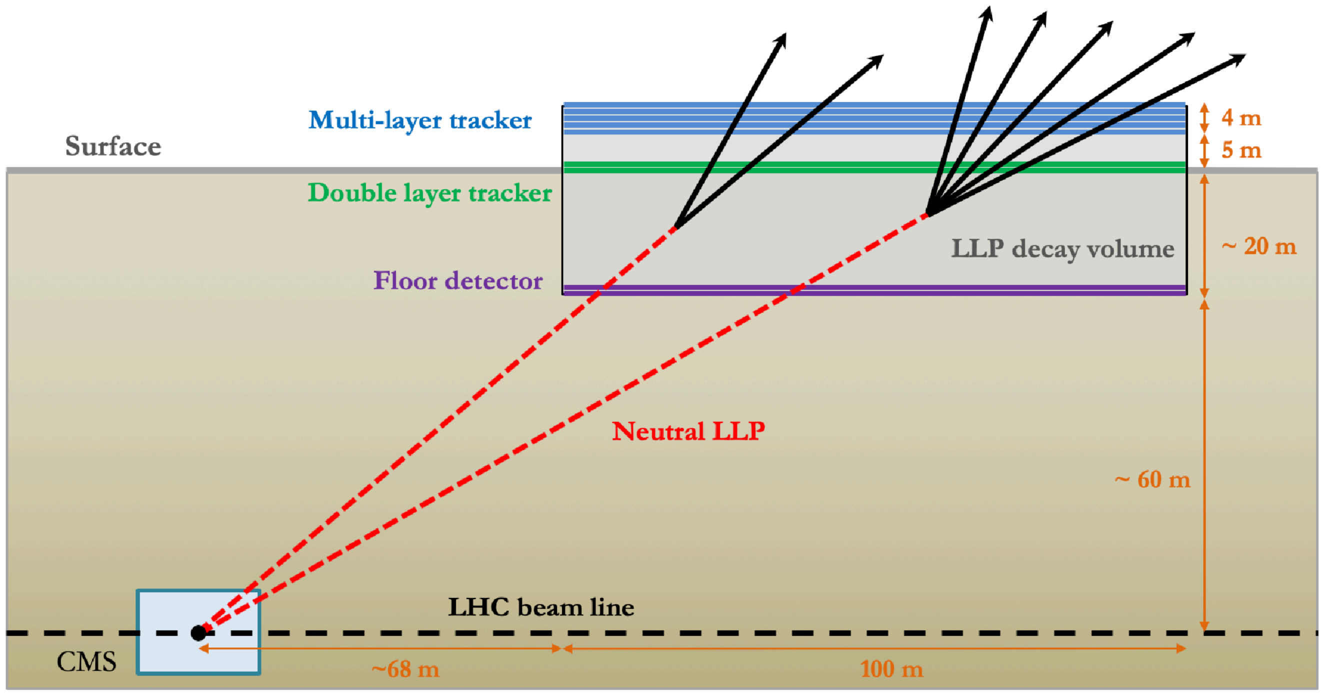
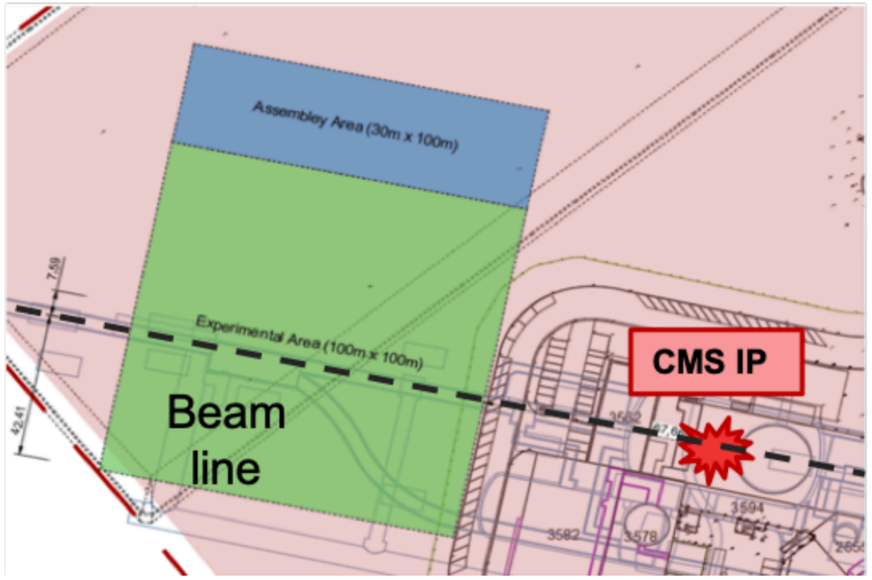
# INTRODUCTION

[PLB (2017) 01 043]

- MATHUSLA is a dedicated detector for long-lived particles
  - Designed to have applicability across a broad range of potential final states
  - Conceptually simple: build a big empty box with trackers on CERN-owned land near CMS
    - LLPs that decay inside will be reconstructed as displaced vertices
    - Backgrounds can be ~O(1) because 80+ m rock shielding suppresses IP backgrounds and 4D tracking from ~ns timing are distinct criteria for signal identification



# MATHUSLA COLLABORATION

- International collaboration including members & institutions from
  US, Canada, Chile, Bolivia, Mexico, Italy, Switzerland, …
  - TDR in progress, aim publish early 2022.
  - Begin MATHUSLA operation with HL-LHC!
- Physics justification detailed in ~200 page report [1806.07396]

**A Letter of Intent for MATHUSLA: a dedicated displaced vertex detector above ATLAS or CMS**

1811.00927
LHCC-I-031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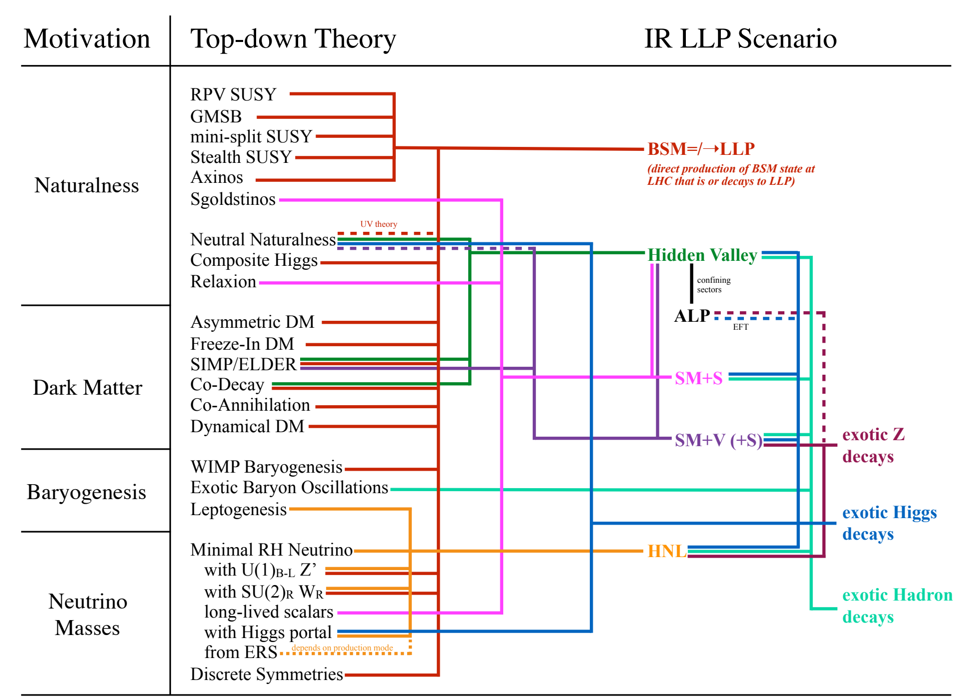
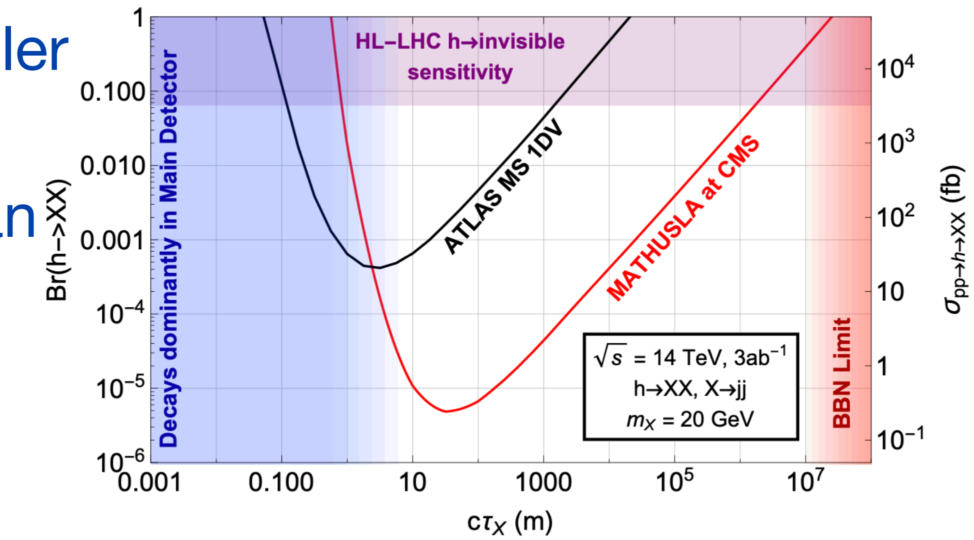
**Long-Lived Particles at the Energy Frontier: The MATHUSLA Physics Case**

1806.07396

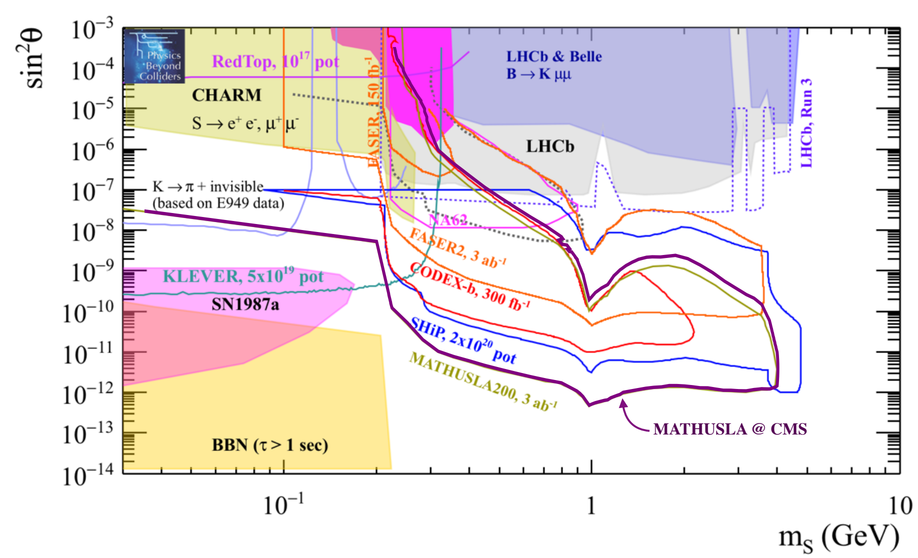


# Design Principles

- In the long lifetime regime > 100m, MATHUSLA has roughly same chance of "catching" an LLP decay in its decay volume as the main detectors
  - Greater depth of decay volume compensates for smaller solid angle coverage
  - For LLP searches, MATHUSLA's greater sensitivity than ATLAS/CMS is due to
    - near-zero backgrounds
    - no trigger limitations



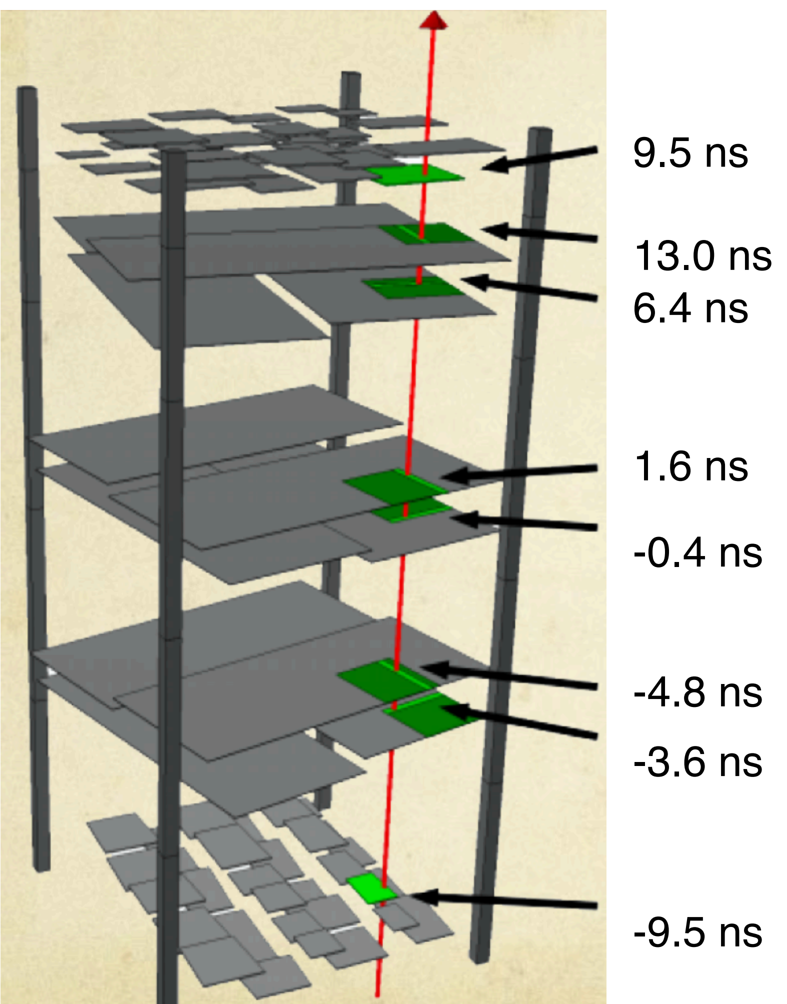

- Therefore, MATHUSLA will beat the main detectors for LLP signals where main detector searches are significantly impeded by background and trigger considerations (up to 1000x better reach)
- Targets (in order of priority)
  - Hadronically decaying LLPs from few GeV to TeV
  - LLPs with mass < few GeV (any decay mode)
  - Cosmic Ray Physics

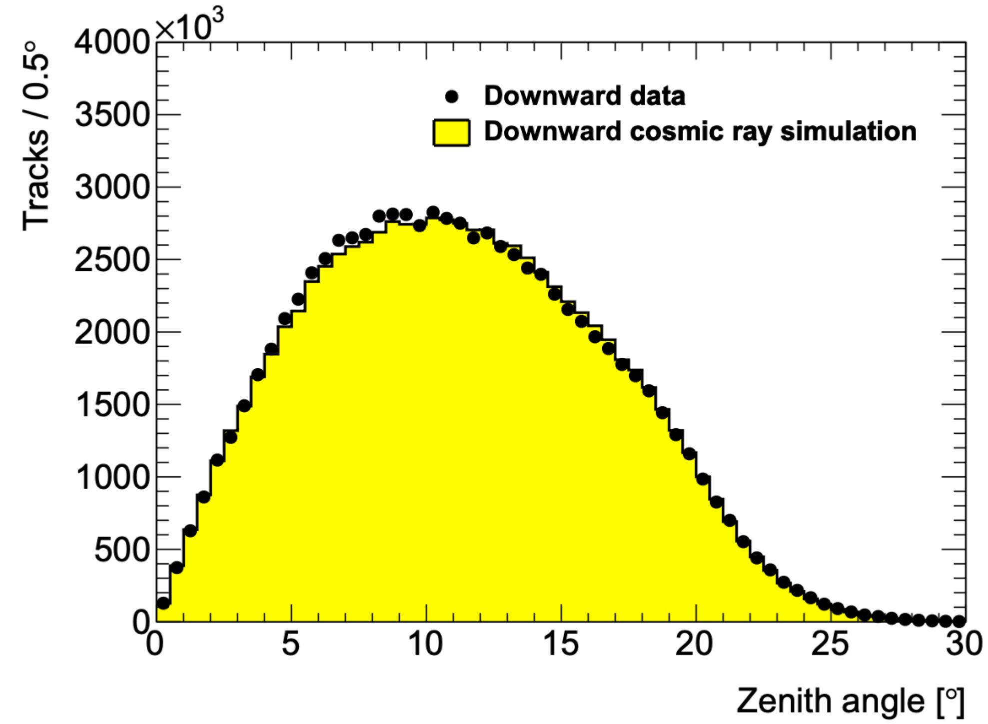


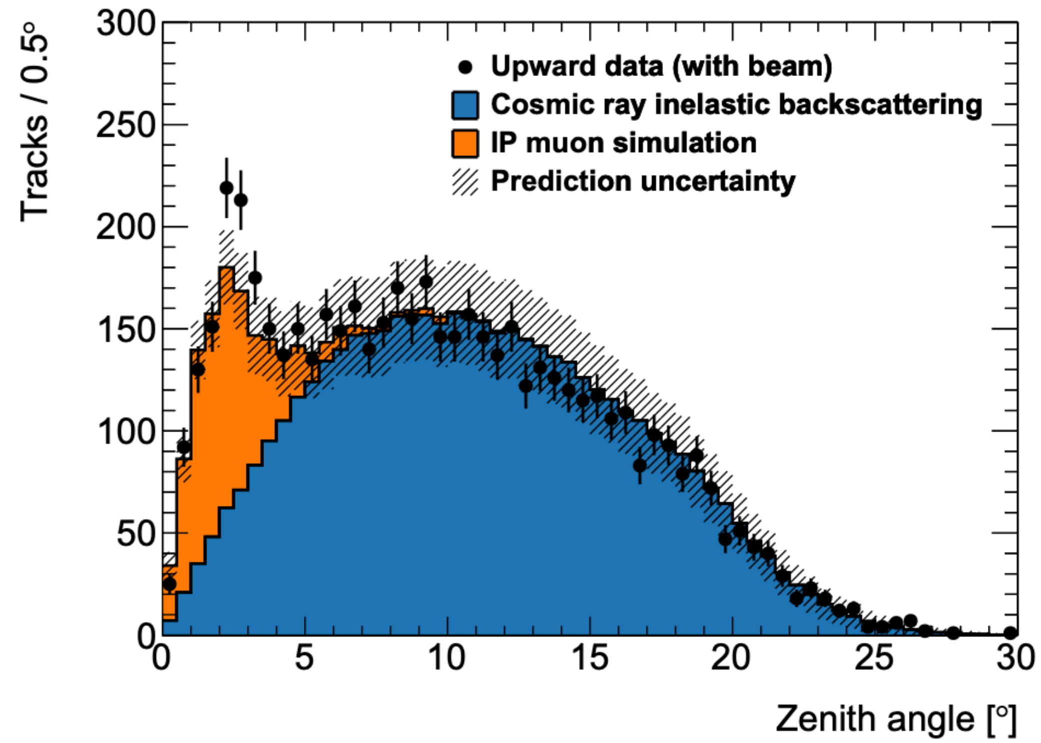
# Test Stand Results

[NIM A (2020) 164661]

- Test stand operated above ATLAS in 2018 — combination of plastic scintillator and RPCs
  - Both downward and upward rates/ angular distributions well predicted by simulation O(~10%)



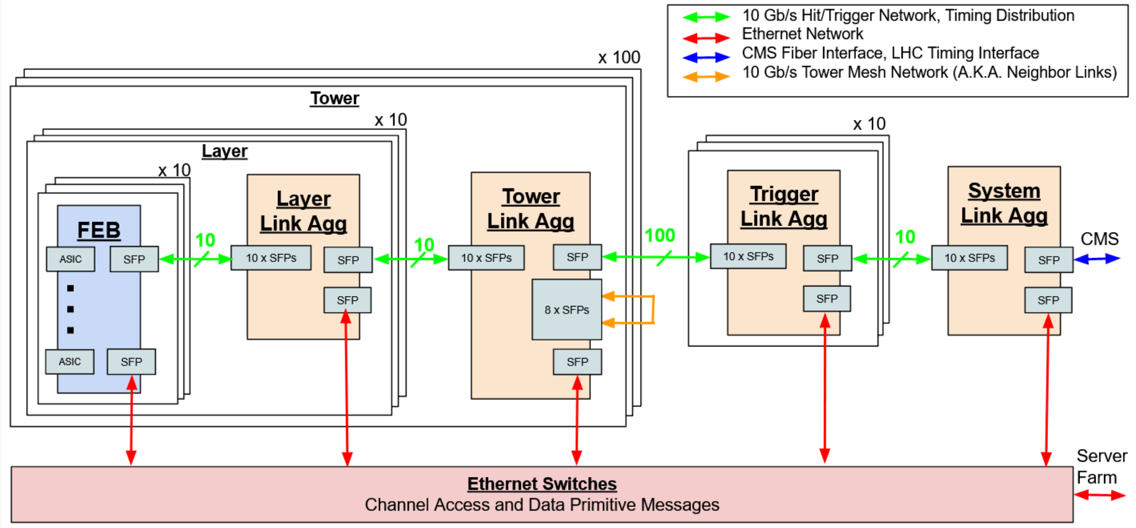



# Ongoing Developments

- Collaboration is engaged in R&D for basic hardware/engineering of detector:
  - extruded scintillators, fibers, SiPMs, trigger & DAQ design
  - Simulation studies (LLP + Backgrounds)
- Implementing on custom tracking algorithms for MATHUSLA's unique environment to achieve high LLP reconstruction efficiency for low-multiplicity LLP final states
  - Low track multiplicity final states require careful optimization of detector geometry, tracking algorithm design, etc.
  - Backgrounds from IP muons and cosmic backscatter (e.g. neutral kaons) can create induce reconstructable vertices in the detector
- Cosmic Ray Studies
  - CR physics case white paper coming out this year 2021

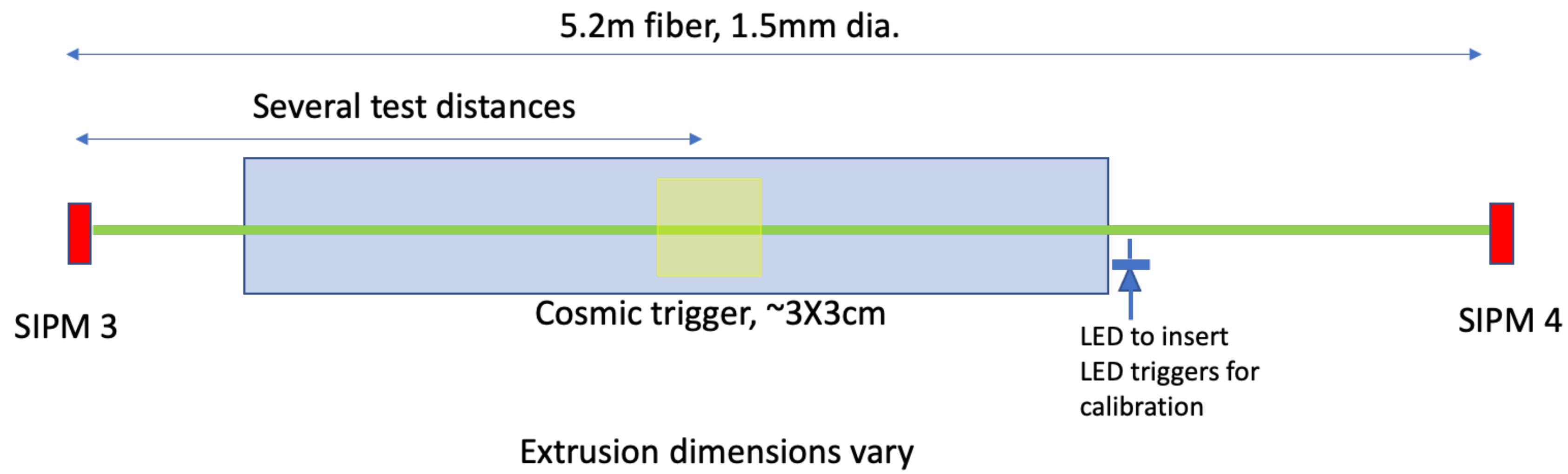
# DAQ Design

- DAQ
  - Modular design of the Front End Boards and link aggregation boards
    All hits stored in buffer storage Data rate is well within COTS server
- Trigger
  - Tower aggregation module triggers on upward going tracks within 3 x 3 tower volumes
  - Selects data from buffer for permanent storage
- Trigger to CMS
  - Upward-going vertex forms trigger to CMS
  - MATHUSLA trigger latency estimates appear compatible with CMS L1 latency budget



# SCINTILLATOR TIMING AND TESTING

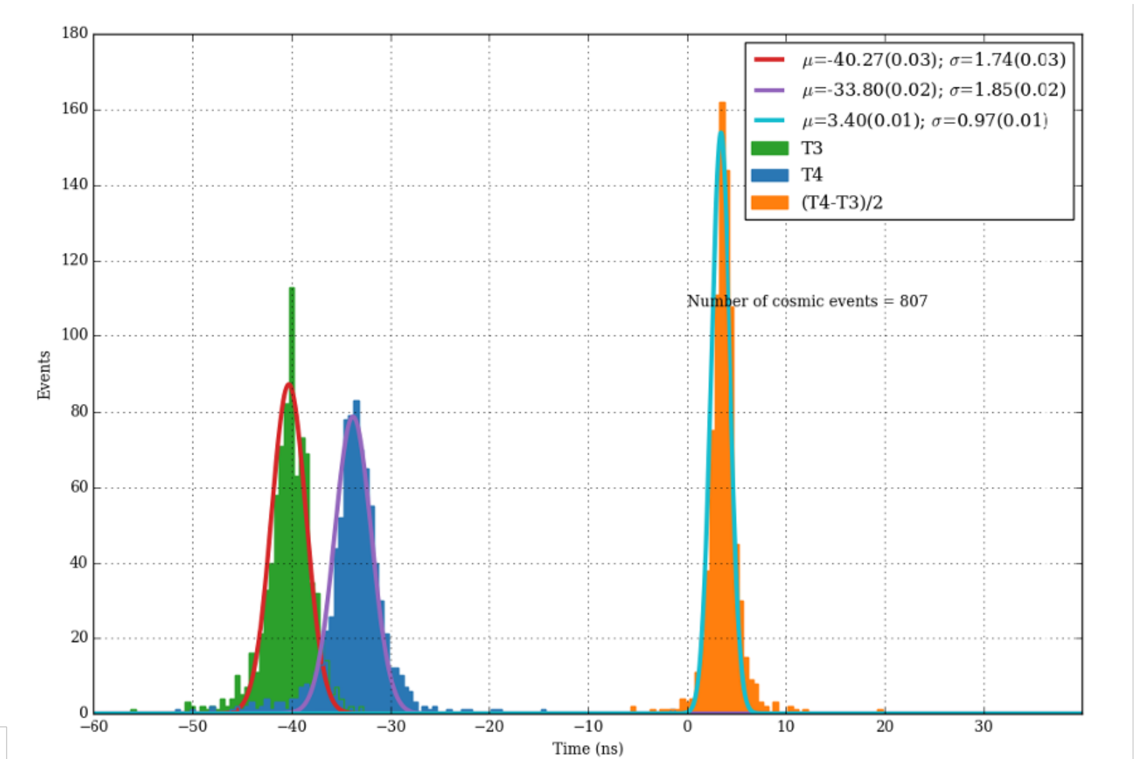
**Cosmic setup:** 2 small cosmic trigger counters define cosmic ray, light is measured at each end of fiber by SIPMs. Various algorithms to determine time resolution of difference.




- Target timing resolution is ~1 ns
  - Use difference in arrival time between separate measurements at two ends of extruded scintillator
  - Critical feature of the detector design
    - Separates downwards from upwards going tracks
    - Reject low beta particles from neutrino QIS
    - 4D tracking and vertexing reduces fakes/combinatorics

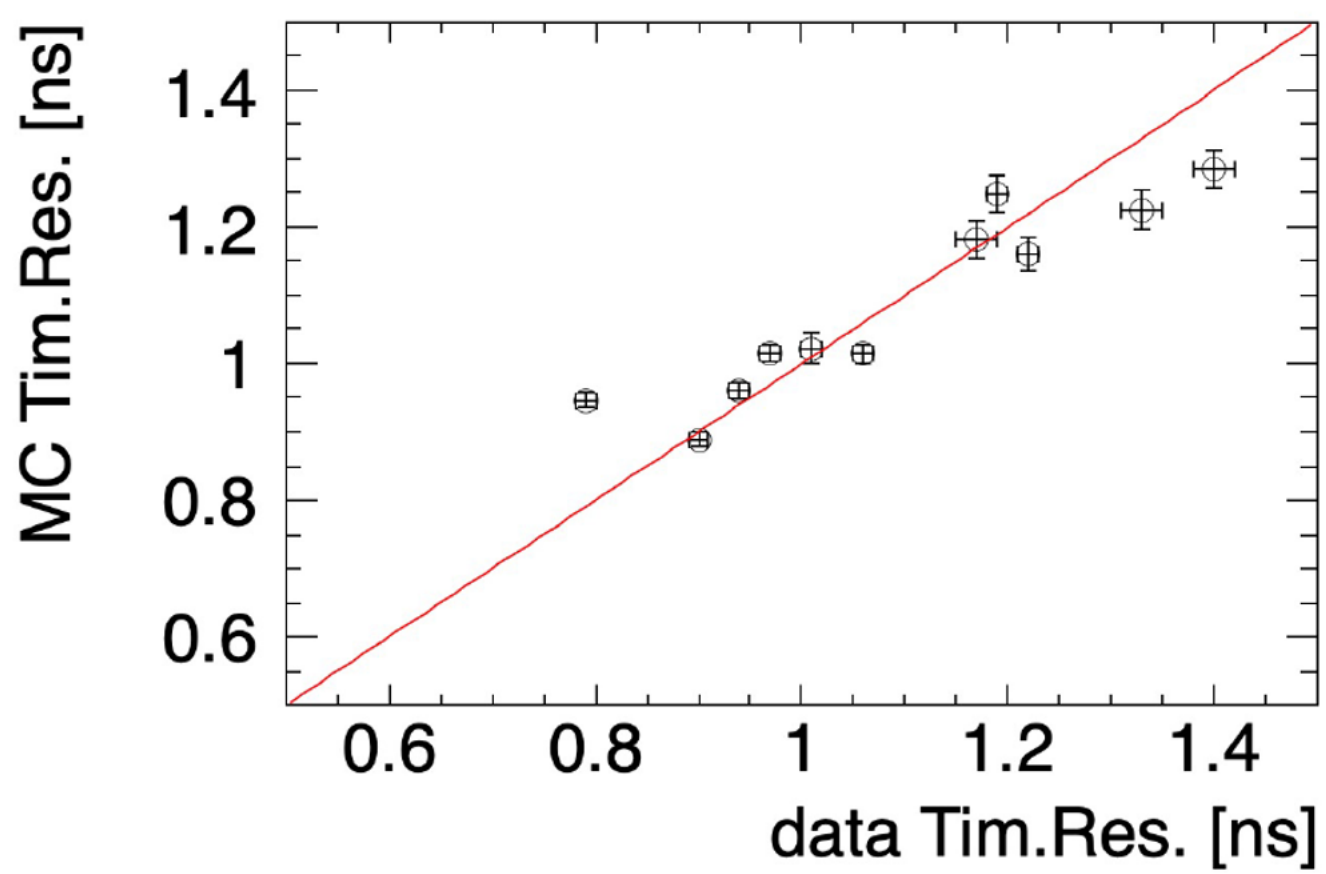
# SCINTILLATOR TIMING AND TESTING

- Use Geant to study extrusion and fiber choice to identify critical parameters
  - Goal of <1ns timing is achievable




DT result for cosmic run.

- 2X5 cm extrusion cross section
- 5m fiber, BCF92, 1.5mm diameter
- 1pe constant threshold

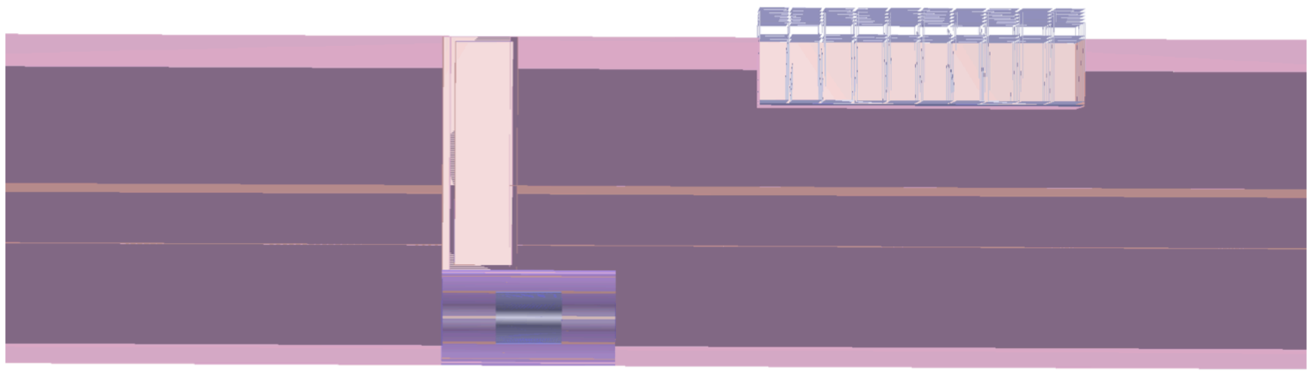


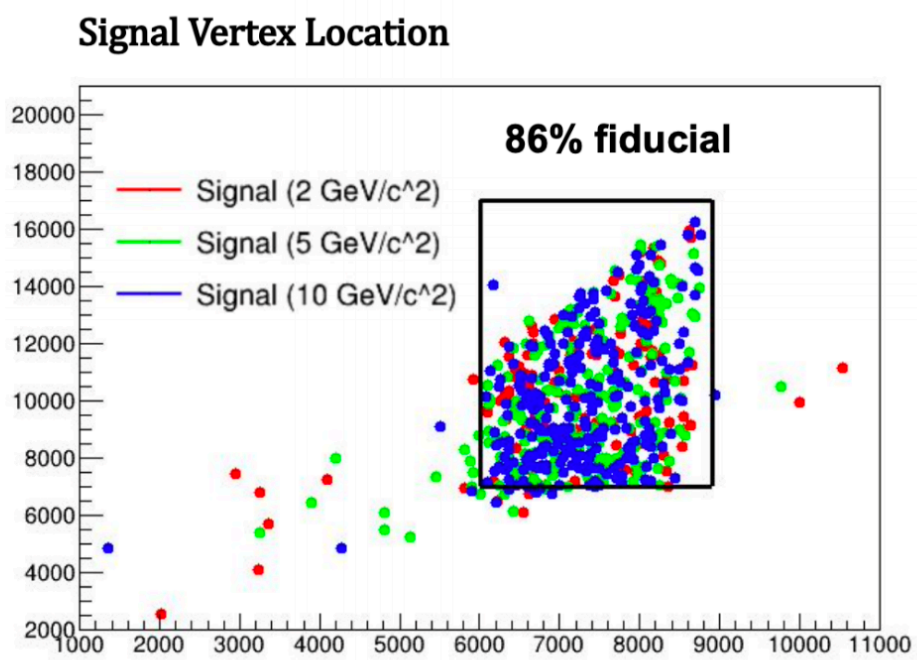

- Different extrusion thickness
- Different fiber diameters
- Different fiber lengths
- Different fiber vendors

# Simulation of backgrounds

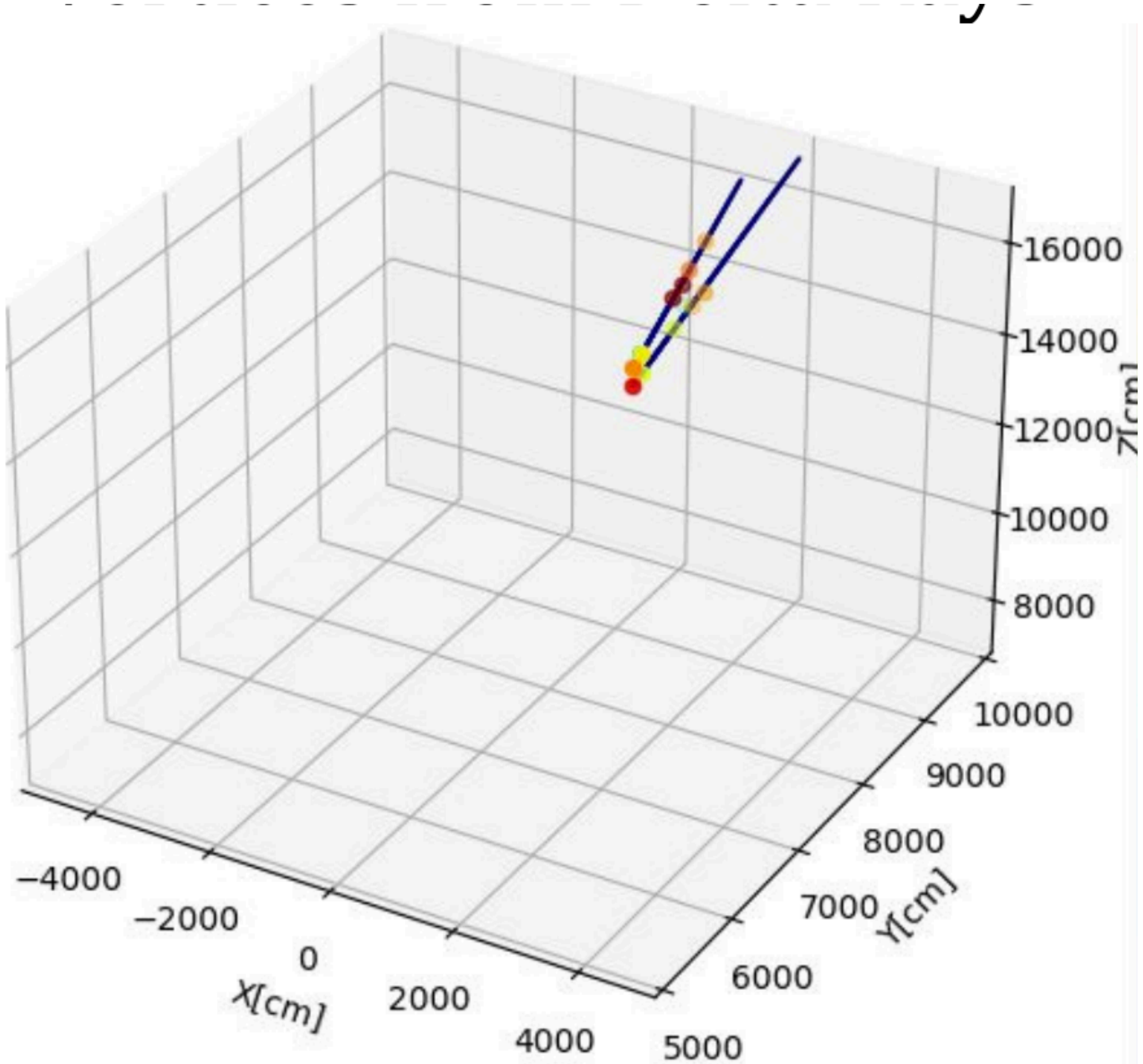
- Use Geant to model particle interactions in matter
- Backgrounds under study:
  - Upwards going muons from collisions (Pythia8)
  - Backscatter (to upwards going $V^0$) from downwards going cosmic rays (Parma)
  - Neutrino interactions (Genie3)
- Analysis software uses Kalman Filtering to reconstruct tracks and form 4D vertices

- Cavern, access shaft, CMS, rock, and detector are all modeled
  - Rock is from a geological survey (same as for test stand)





# IP Muon backgrounds




- We expect ~$10^{11}$ muons from W events over lifetime of HL-LHC
  - ~$10^{9}$ will reach MATHUSLA
- These muons can create vertices in a few different ways
  - Delta-rays
  - Induce EM Showers
  - 5-body decay in flight
- Backgrounds are suppressible with a high-coverage floor veto + topological constraints on the vertices

# CONCLUSIONS

- MATHUSLA has extensive reach and versatility to probe the LLP landscape
  - Significant progress is being achieved on multiple fronts: simulation of rare backgrounds, DAQ design, scintillator/fiber/SiPM properties, cosmic ray physics case
  - New member contributions always welcome!
- Hope to finish TDR by early 2022, followed by prototype module and full detector for HL-LHC