MATHUSLA

Status Update

PBC General Working Group Meeting

Dec 3 2021

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on behalf of the MATHUSLA Collaboration

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Outline

- Reminder: MATHUSLA Concept
- Layout updates
- Hardware timing & testing studies
- DAQ design
- Background simulations
- Track & vertex reconstruction software

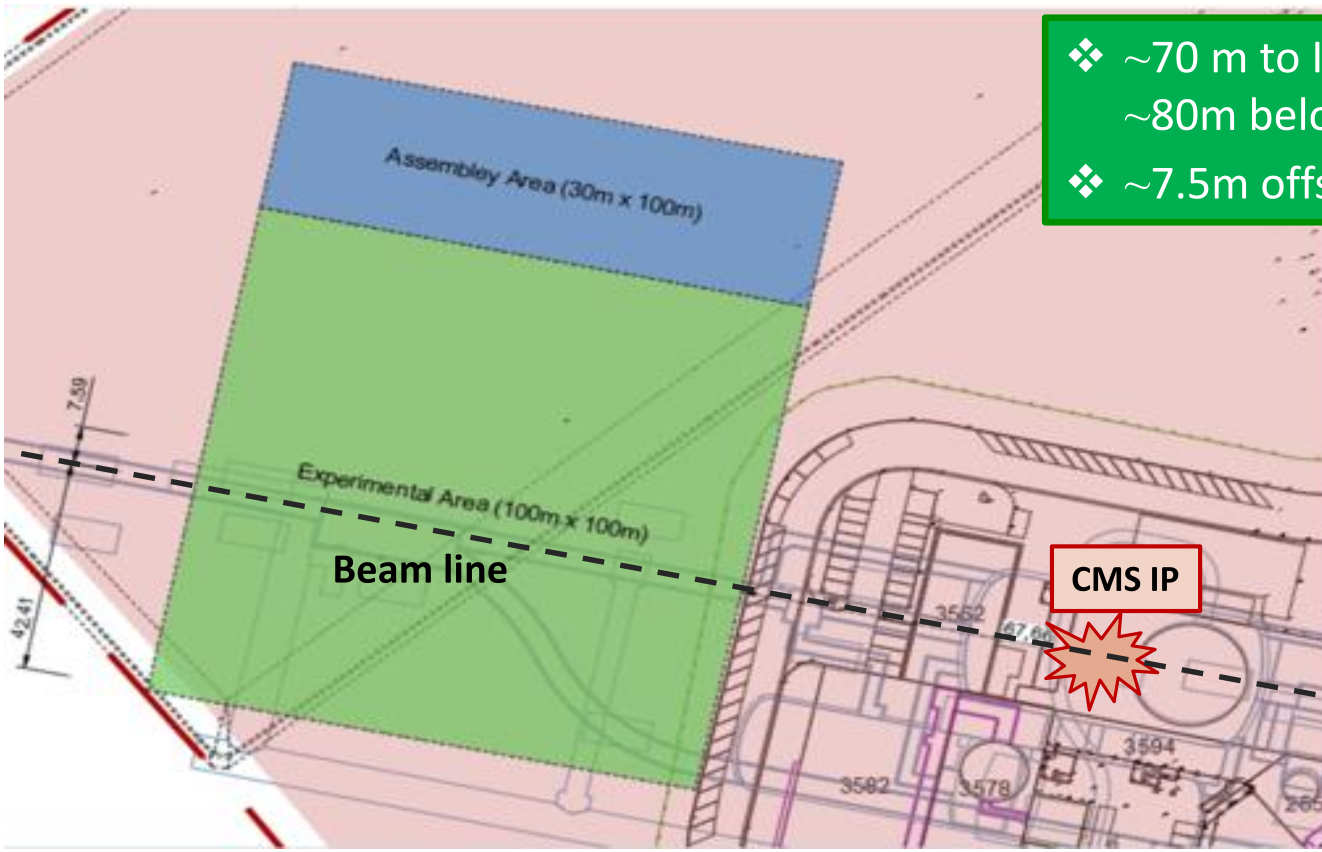
Previous status reports:
LHC LLP (May 2021) https://indico.cern.ch/event/980853/contributions/4361206/
PBC (March 2021) https://indico.cern.ch/event/1002356/contributions/4229617/
LHC LLP (Nov 2020) https://indico.cern.ch/event/922632/contributions/4098280/

MATHUSLA Concept

- arXiv 1606.06298
- arXiv 1806.07396
- CERN-LHCC-2018-025

➢ Dedicated detector **sensitive to neutral long-lived particles that have lifetime up to the Big Bang Nucleosynthesis** (BBN) limit ($10^7 - 10^8$ m) for the HL-LHC

➢ Proposed **large area surface detector located above CMS** with **robust tracking** and **background rejection**



❖ ~70 m to IP on surface, with IP ~80m below surface
❖ ~7.5m offset to the beam line

MATHUSLA Concept

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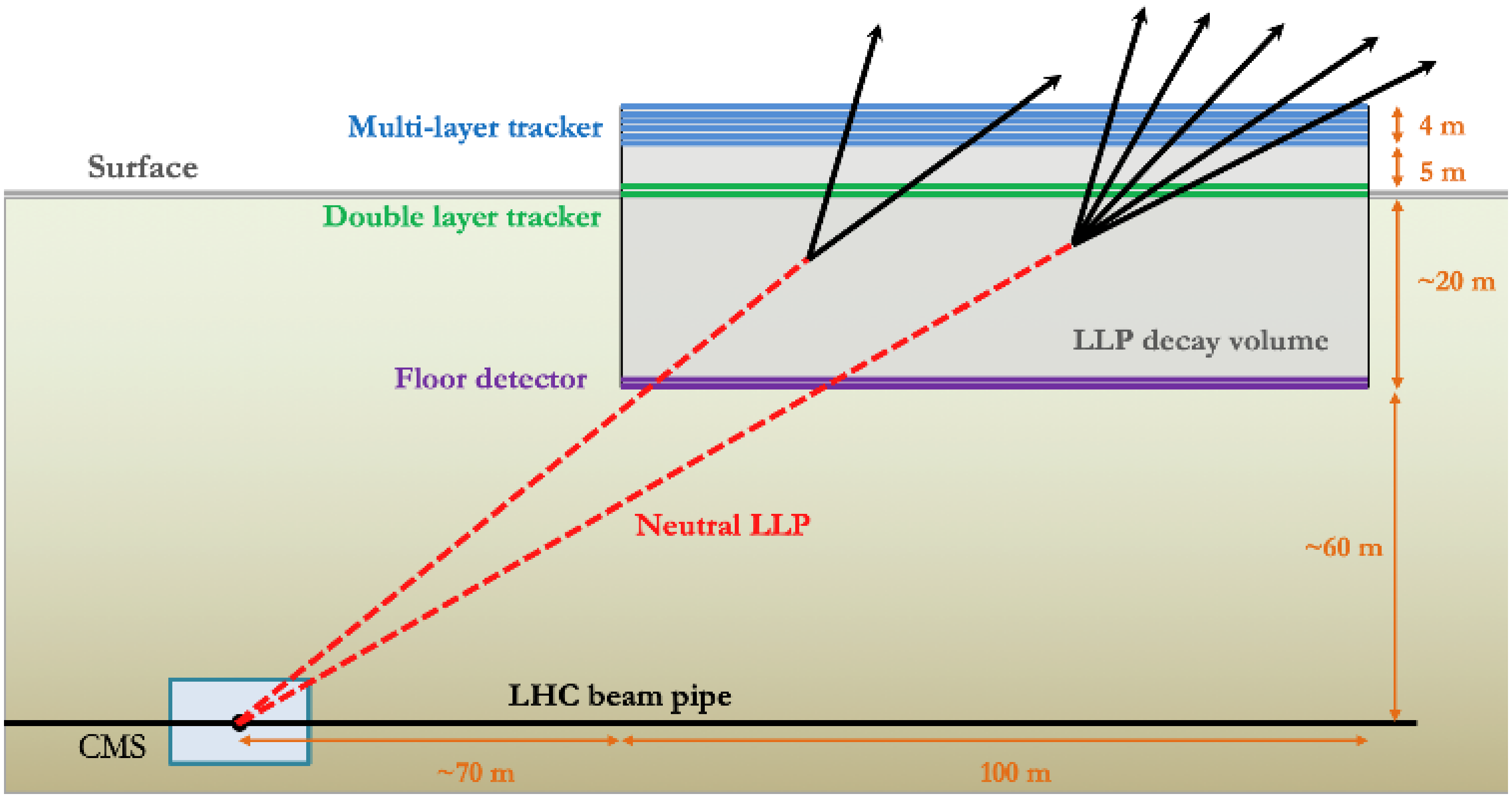
- LLPs decaying inside MATHUSLA reconstructed as displaced vertices, ~0-background analysis
  - 4D tracking with ~ns timing resolution
  - >100 m of rock shield from IP background
- Can run **standalone** or **"combined" to CMS**



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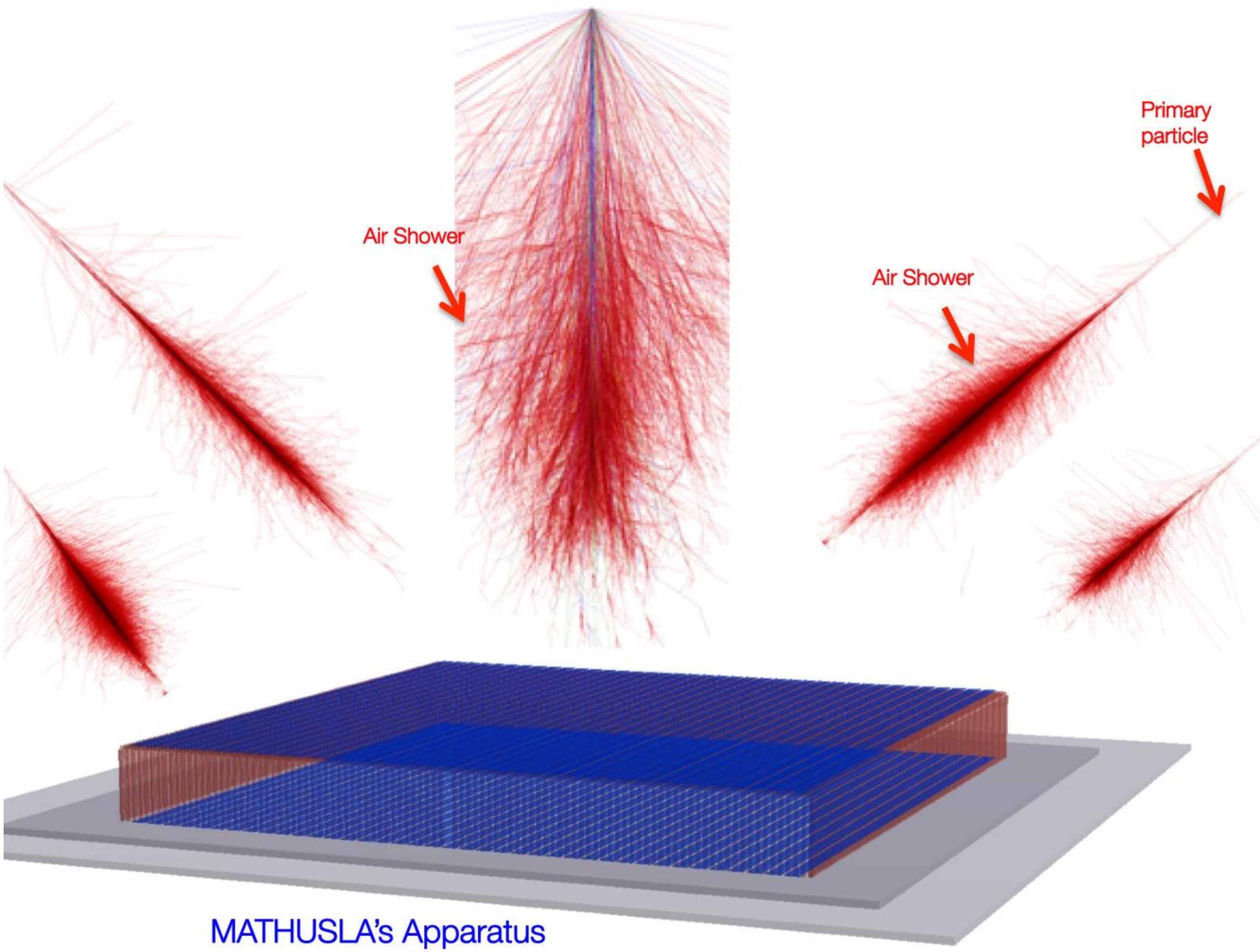
- Measurements of cosmic ray showers provide a guaranteed physics return

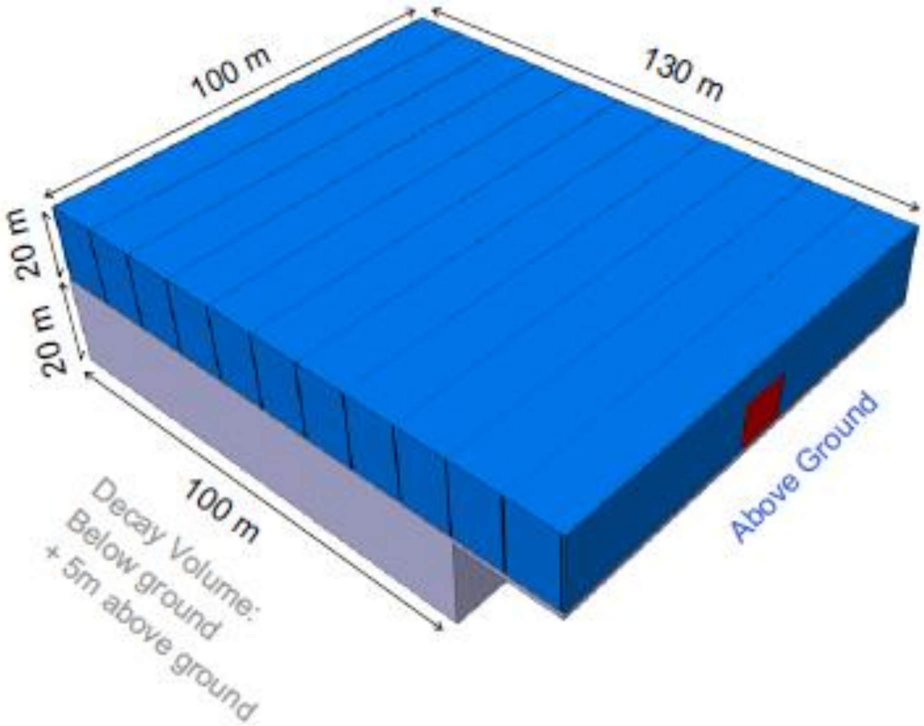


CR white paper coming out in a few months: physics case for adding a layer of **RPC detector** to current scintillator layers

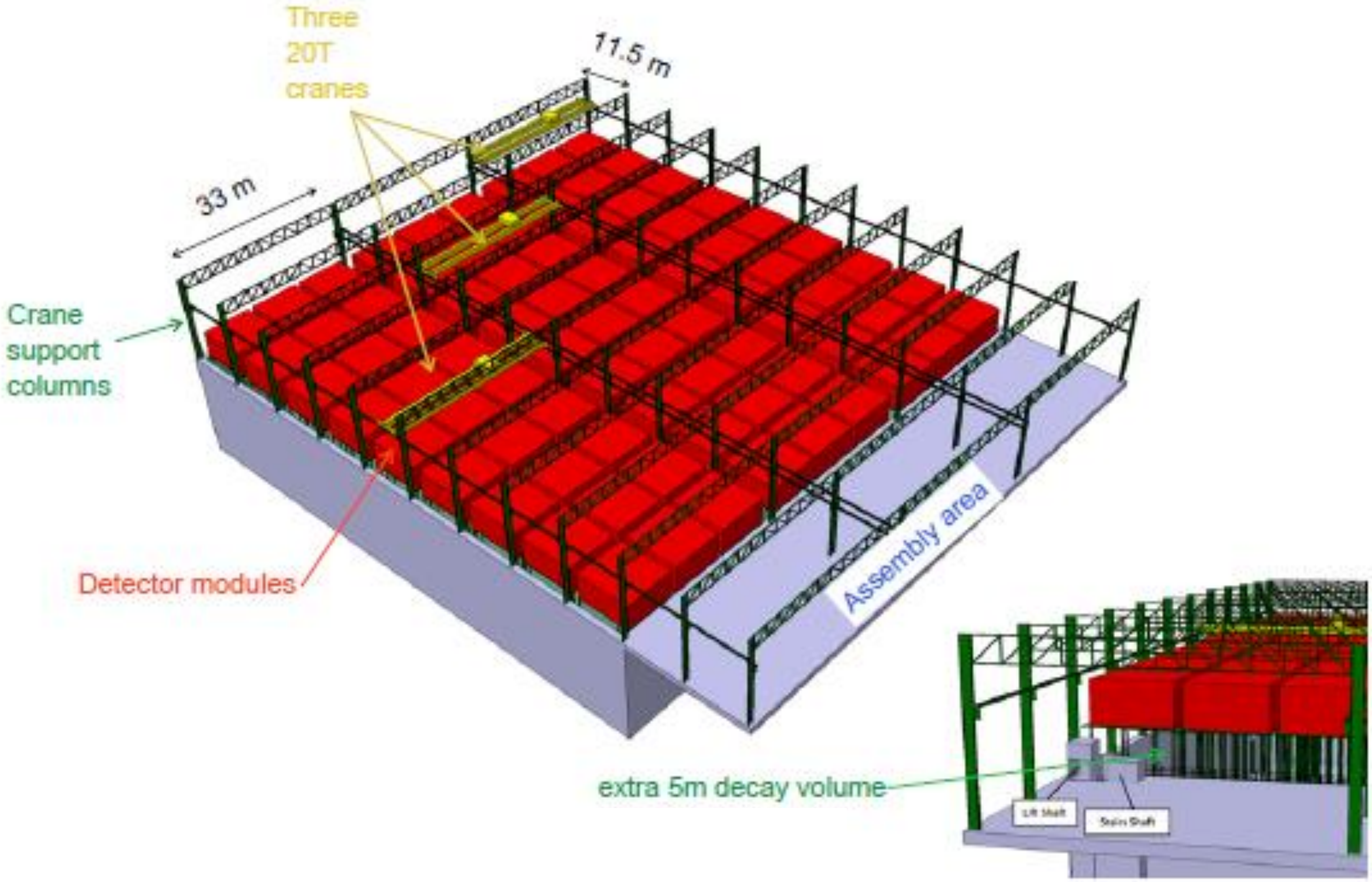
MATHUSLA Layout @ P5

- Worked with Civil Engineers to define **building and layout of MATHUSLA at P5**
- Layout **restricted by existing structures** based on concept and engineering requirements

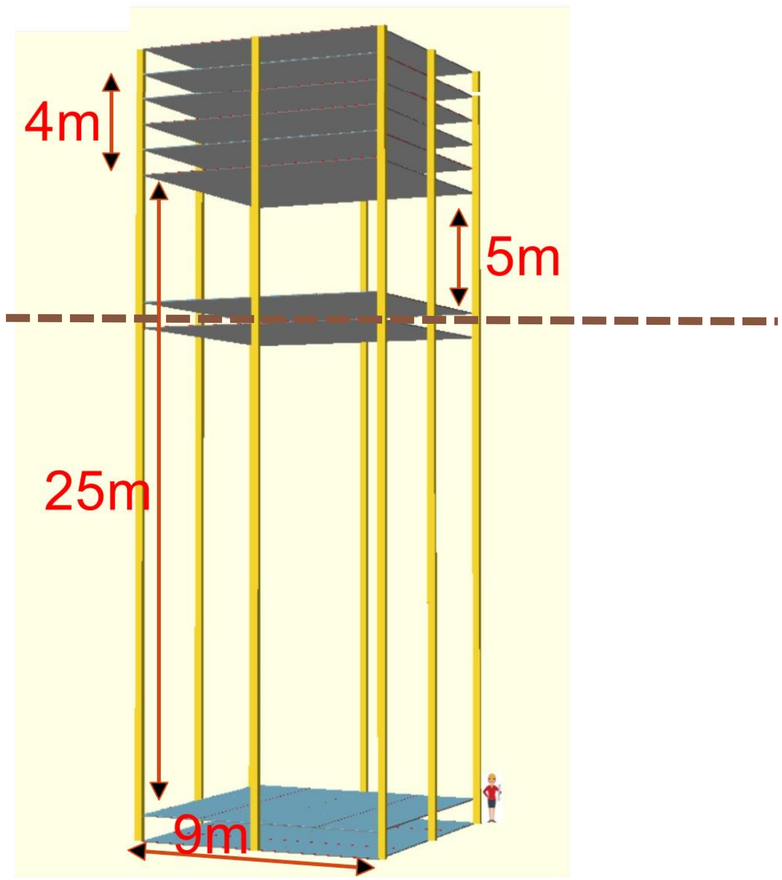
- Decay volume ~100 x 100 x 25 m^3
- Modular design



MATHUSLA Layout @ P5



Module & Plane Layout



6-layer tracking/timing detectors, 80 cm inter-layer separation

Additional **tracking/timing double layer at ground level**

Tracking/timing double layer floor detector

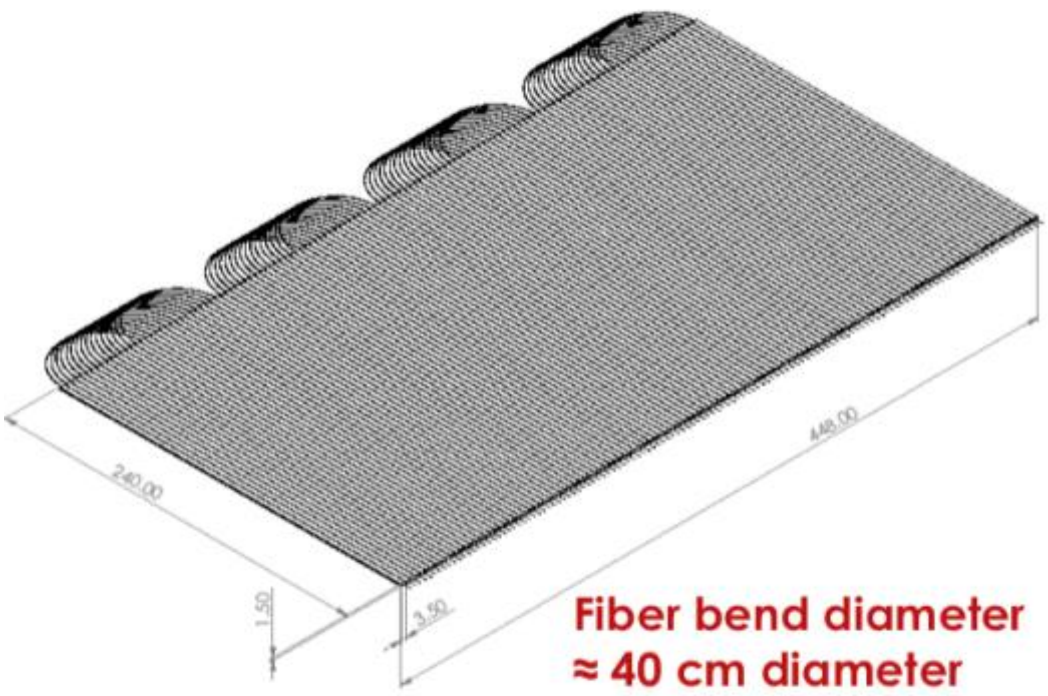
- Total ~ **25 m height for decay volume**
- Individual detector units each **9 x 9 x 30 m^3**

Module & Plane Layout

Extruded scintillator bars with wavelength shifting fibers (WLSF) connected to SiPMs

Currently considering possible layouts for the scintillating detector planes, e.g.

- all SiPM connections on one side of layer with 2.4 m extruded bars
- 128 bars → 2.4 x 4.48 m^2 units (8 units to cover ≈ 9x9 m^2 with overlaps)



Advantages

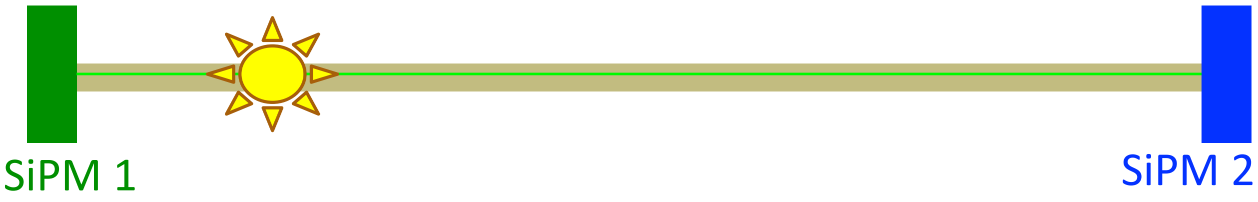
- SiPMs on same side simplifies DAQ read out
- Cooling, insulation all in one unit on one side

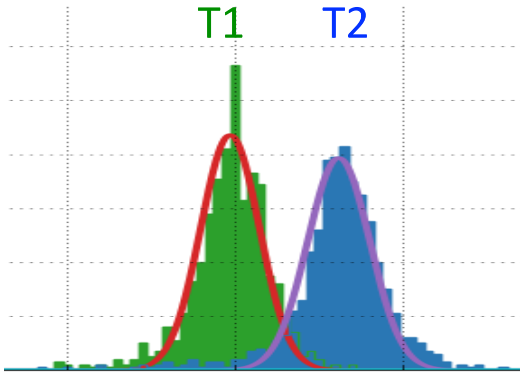
Complications

- WLSF "assembly" work required, with higher probability of damaging fiber during installation
- Protective cover on WLSFs required

Hardware Timing & Testing

- **To reconstruct hit position along scintillator bar: use difference in arrival time between separate measurements at two ends**
  - **Target timing resolution ~1 ns**

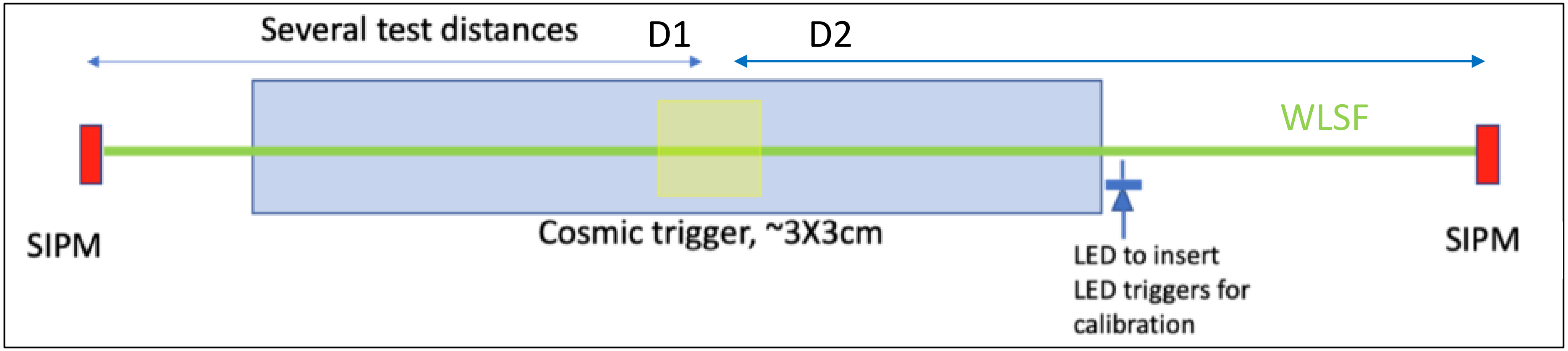


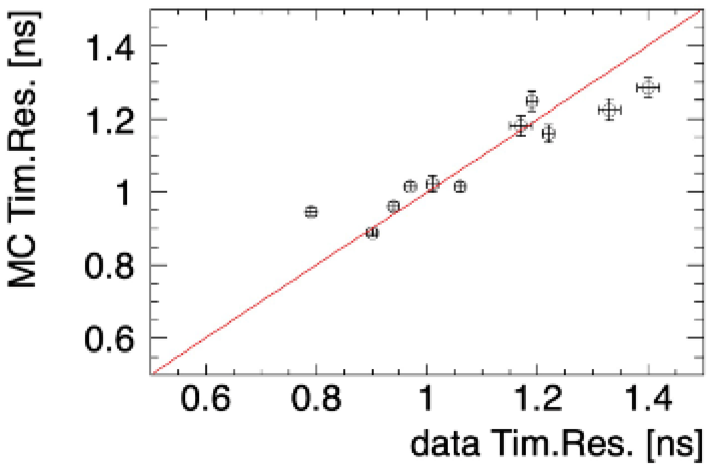


- Critical feature of the detector design
  - Separates downward- from upward-going tracks
  - Rejects low-β particles from neutrino QIS
  - 4D tracking and vertexing reduces fakes/combinatorics
- **Currently under investigation:**
  - **Different vendors/models of scintillator, WLSF, SiPM**
  - **Dark current and SiPM cooling**
  - **Geometry optimisation: bar dimensions, number & thickness of fibers per bar, etc.**

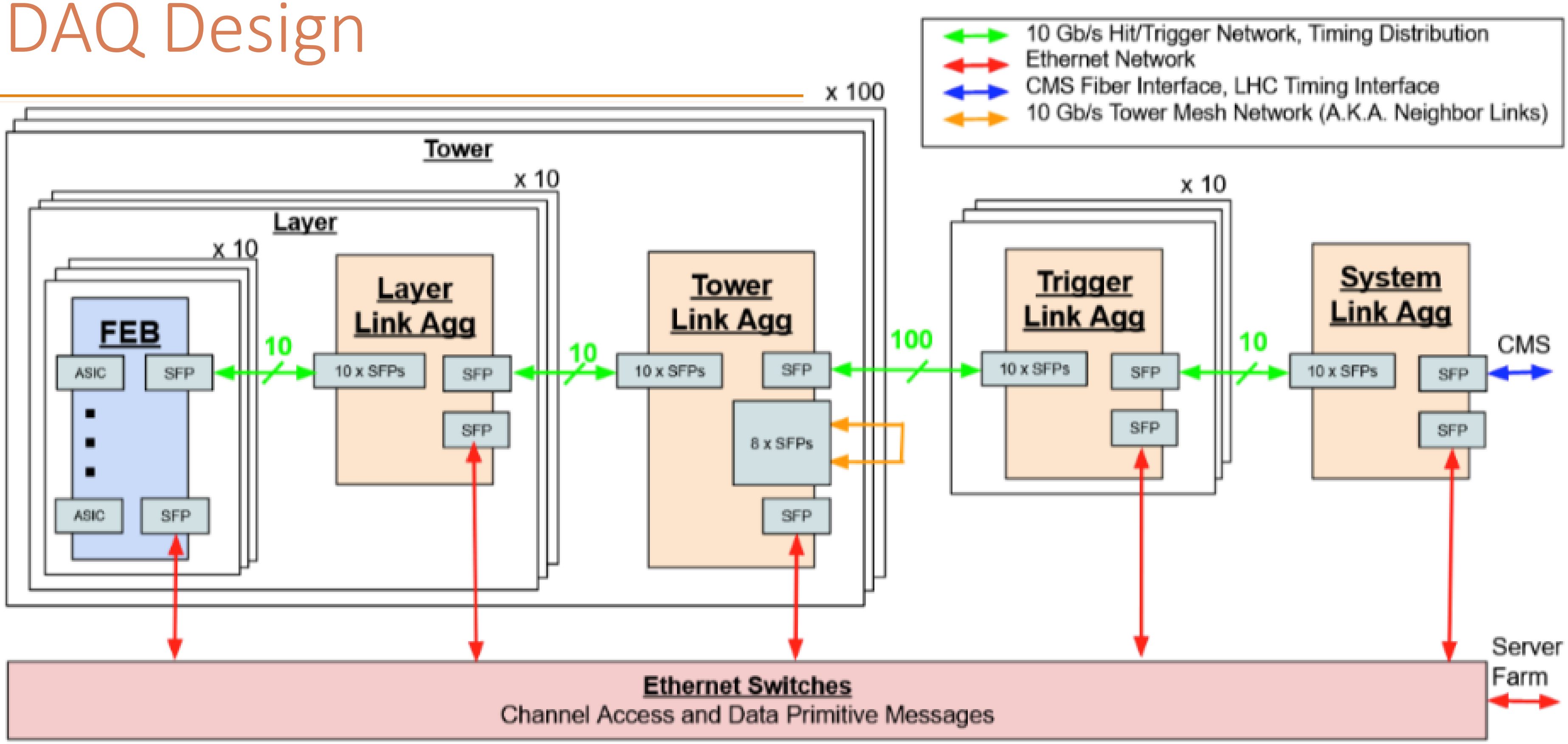
Hardware Timing & Testing

Ongoing characterization studies using **small lab setups and GEANT4 simulations** indicate resolution goal is achievable



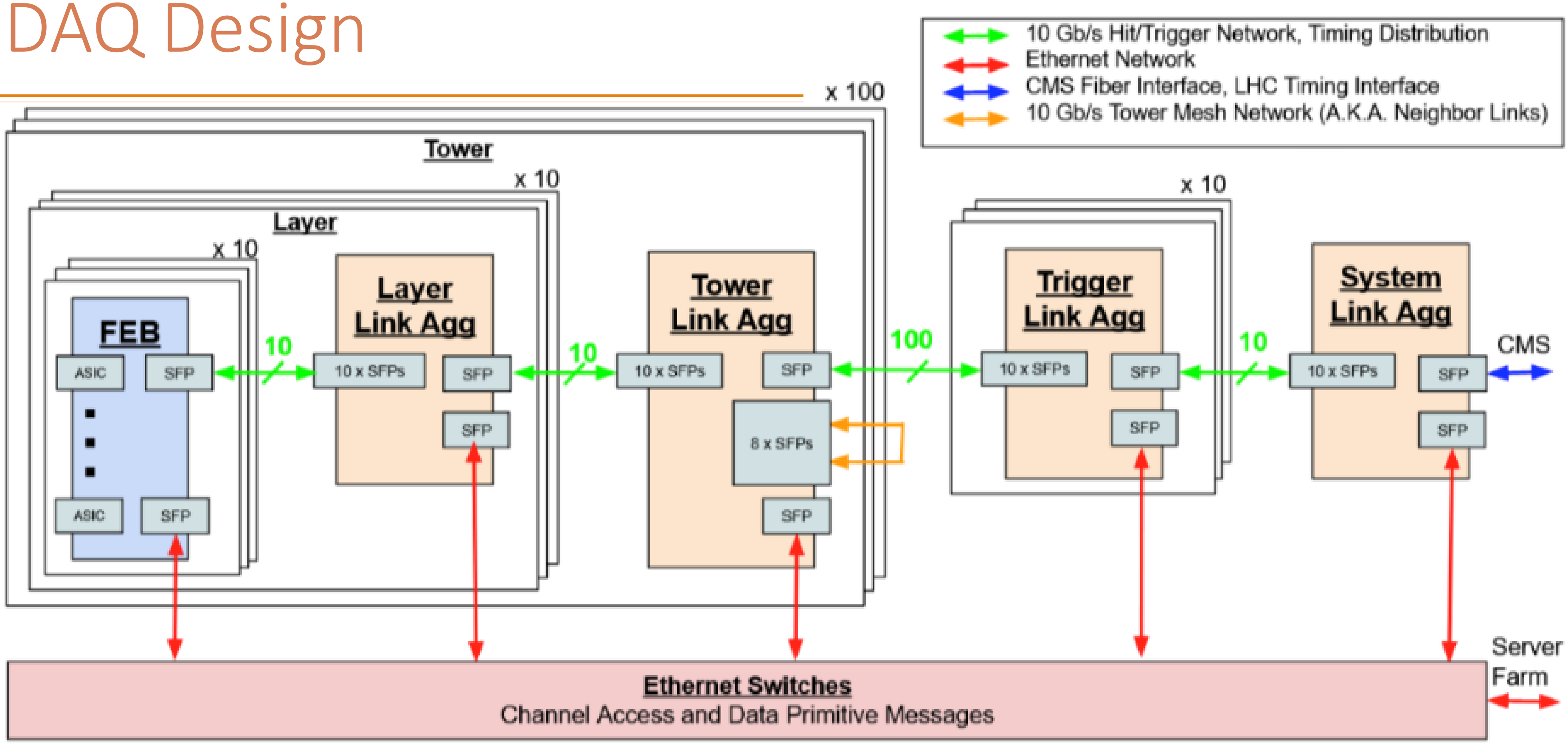


DAQ Design



- Modular design of FEBs and link aggregation boards
- All hits stored in buffer storage
- Data rate is well within COTS servers

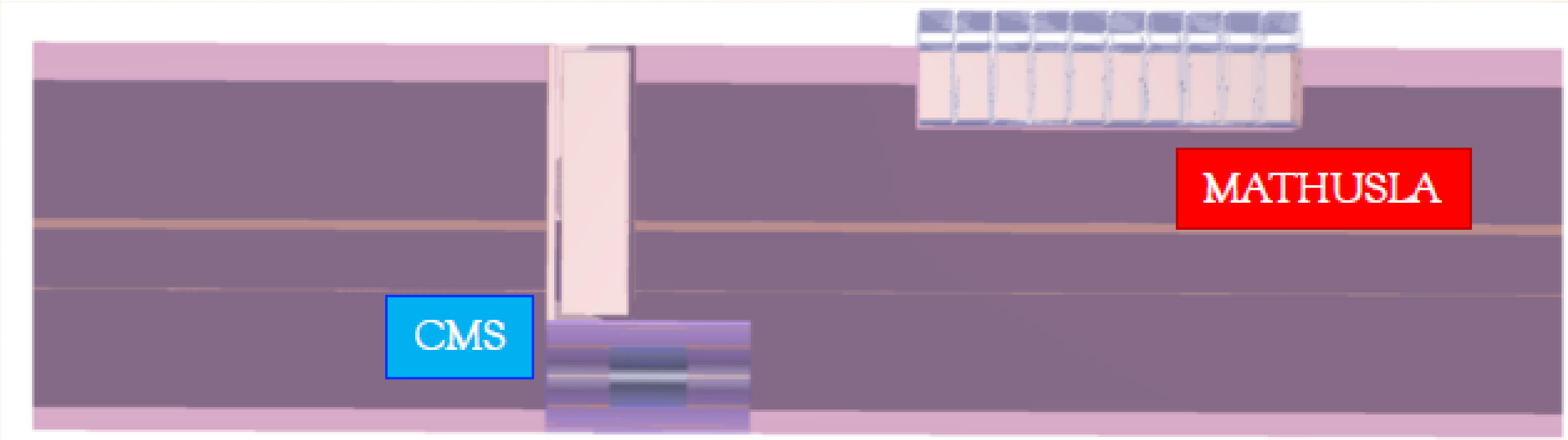
DAQ Design



- **MATHUSLA Trigger**
  - Tower agg module triggers on upward-going **tracks** within 3x3 tower volume
  - Selects data from buffer for permanent storage
- **Trigger to CMS**
  - Upward-going **vertex** forms trigger to CMS
  - Trigger latency estimates appear compatible with CMS L1 latency budget

Background Simulations

- **Use GEANT4 to model particle interactions in matter**
  - Cavern, access shaft, CMS, rock, and detector are all modeled
  - Rock model is from a geological survey (same as for test stand)

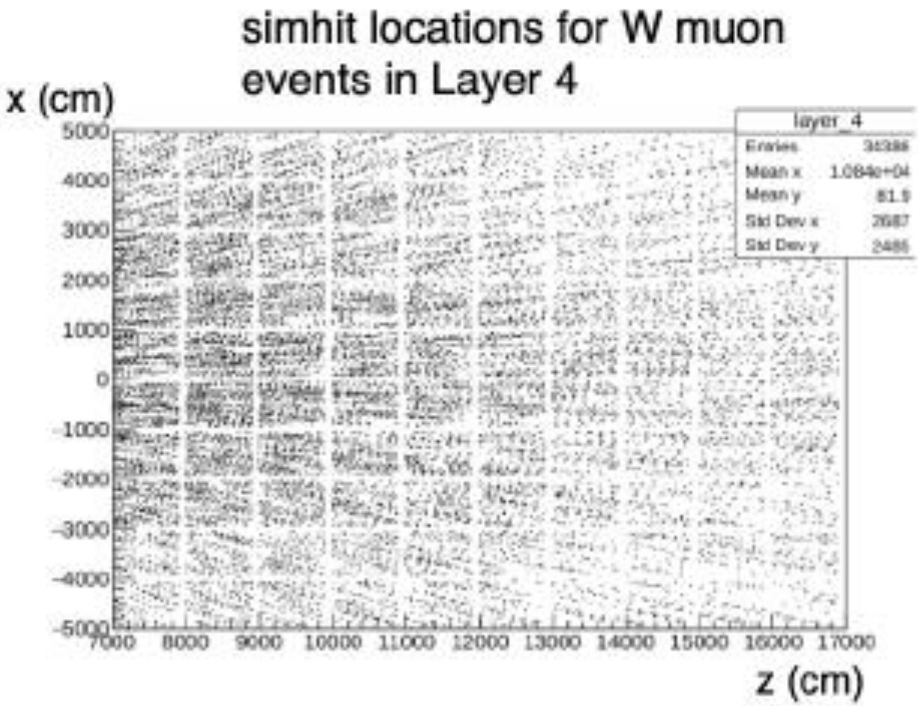


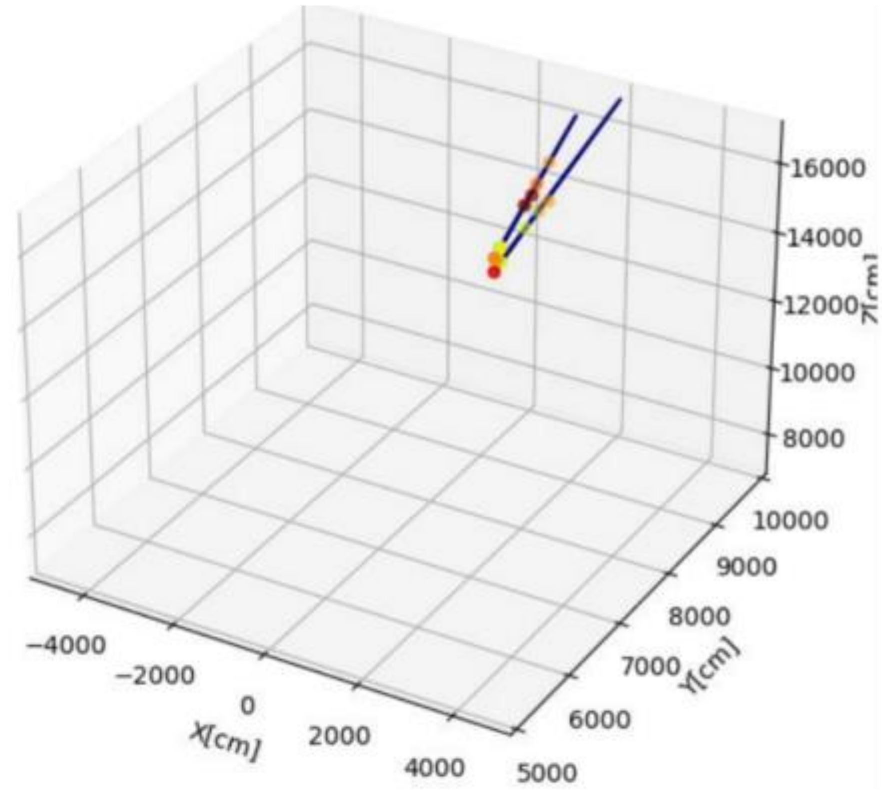
- Backgrounds under study:
  - Upward-going muons from collisions (Pythia8)
  - Backscatter (to upwards going V^0) from downward-going cosmic rays (Parma)
  - Neutrino interactions (Genie3)
- Backgrounds rejected with a high-coverage floor veto + topological constraints on the vertices

Background Simulations

e.g. upward-going muons:

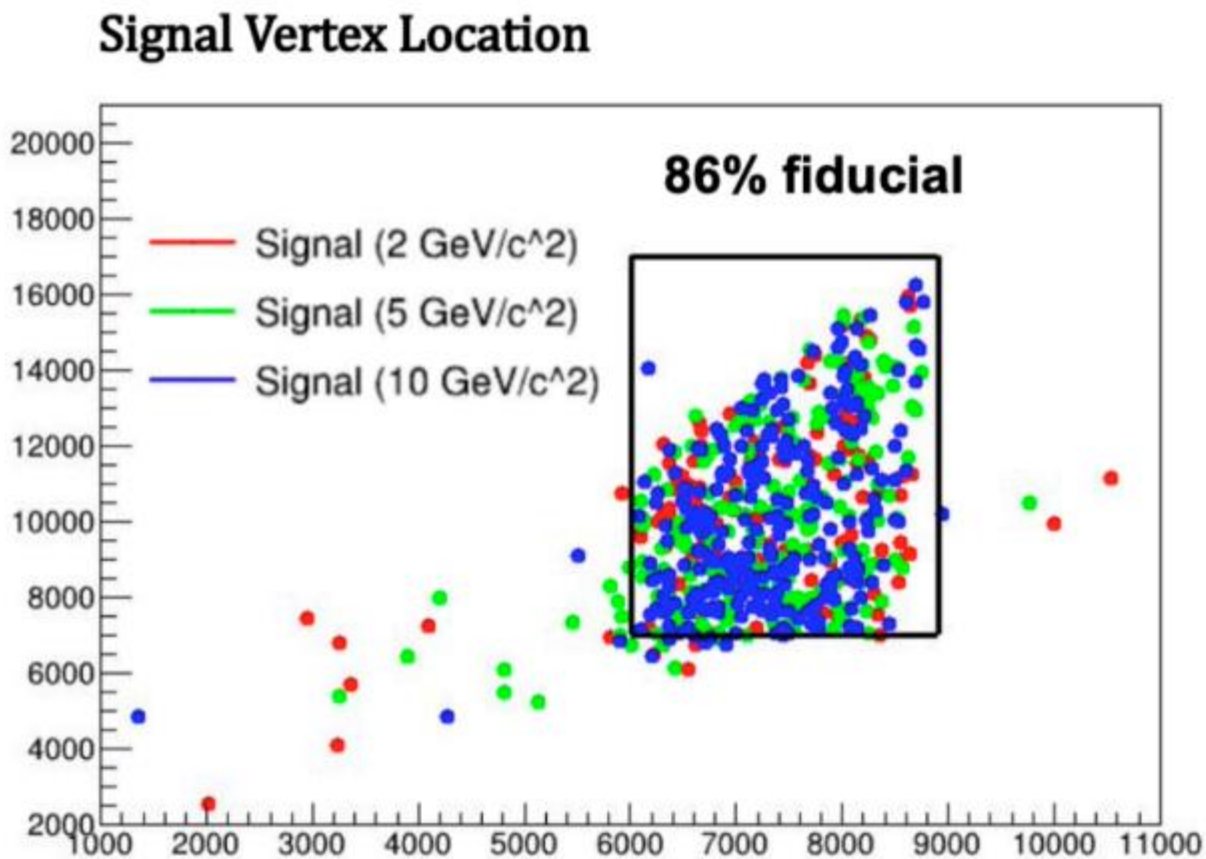
- Expect $\sim 10^{11}$ from W events over lifetime of HL- LHC, $\sim 10^{9}$ will reach MATHUSLA
- Can create vertices in a few different ways: delta-rays, induced EM showers, 5-body decay in flight





Track & Vertex Reconstruction Software

Implementation of **custom tracking algorithms** (based on Kalman filtering) + **"4D" vertex formation**, to achieve high LLP reconstruction efficiency for low-multiplicity LLP final states in MATHUSLA's unique environment



Conclusions & Plans

- MATHUSLA has extensive reach and versatility to probe the LLP landscape
- Significant progress is being achieved on multiple fronts
  - DAQ design
  - Detector plane layout
  - Scintillator/fiber/ SiPM characterization
  - Simulations of rare backgrounds
  - Track & vertex reconstruction software
  - Cosmic ray studies, to be published soon – including physics case for addition of an RPC layer
- Hope to finish TDR by mid-2022, followed by prototype module and full detector for HL-LHC
- New member contributions always welcome!

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

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