MATHUSLA

EXPLORING THE LIFETIME FRONTIER

SEARCHING FOR LONG-LIVED PARTICLES WITH MATHUSLA

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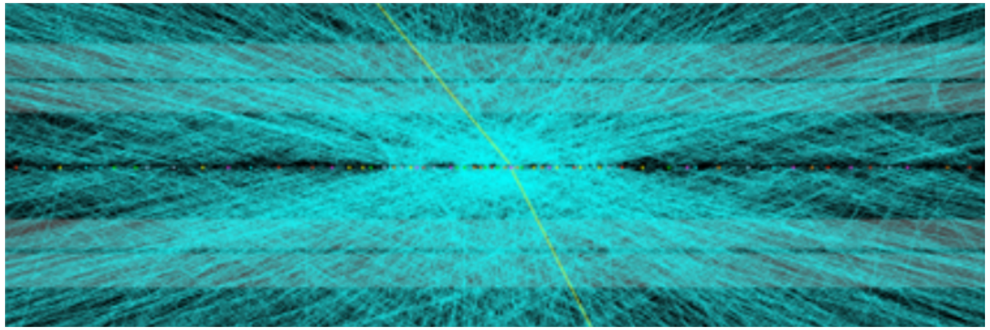
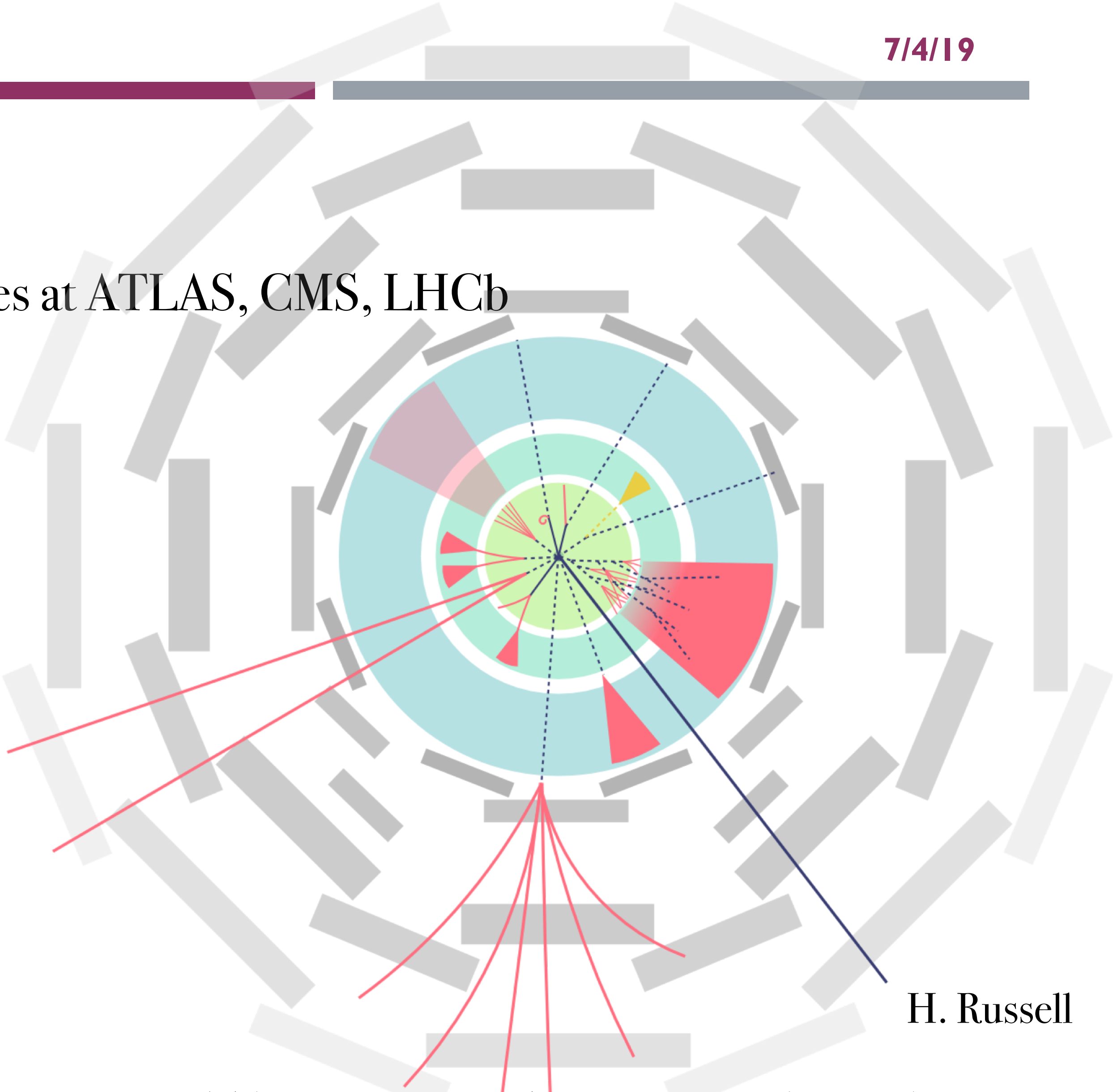
MATHUSLA: Motivation

There are many current long-lived particle (LLP) searches at ATLAS, CMS, LHCb
These searches have a few limiting factors:

- Triggers
- Size of detector
- Backgrounds from collisions (including pileup)
- Backgrounds from beam





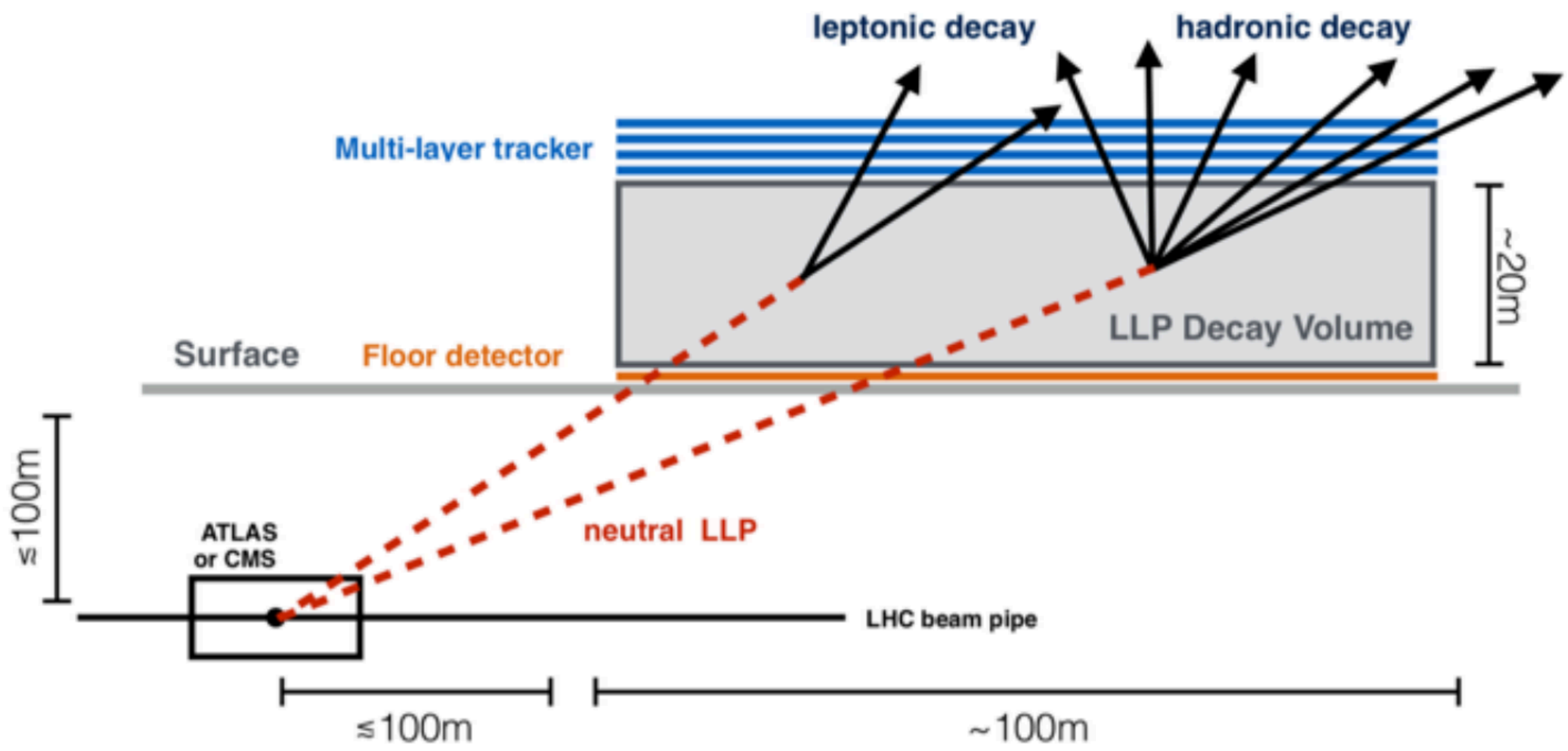
H. Russell

A dedicated detector in a clean, background-free environment would have increased sensitivity: this is the motivation behind MATHUSLA!

MATHUSLA: MAssive Timing Hodoscope for Ultra StabLe pArticles

Large detector with air decay volume on surface above CMS interaction point

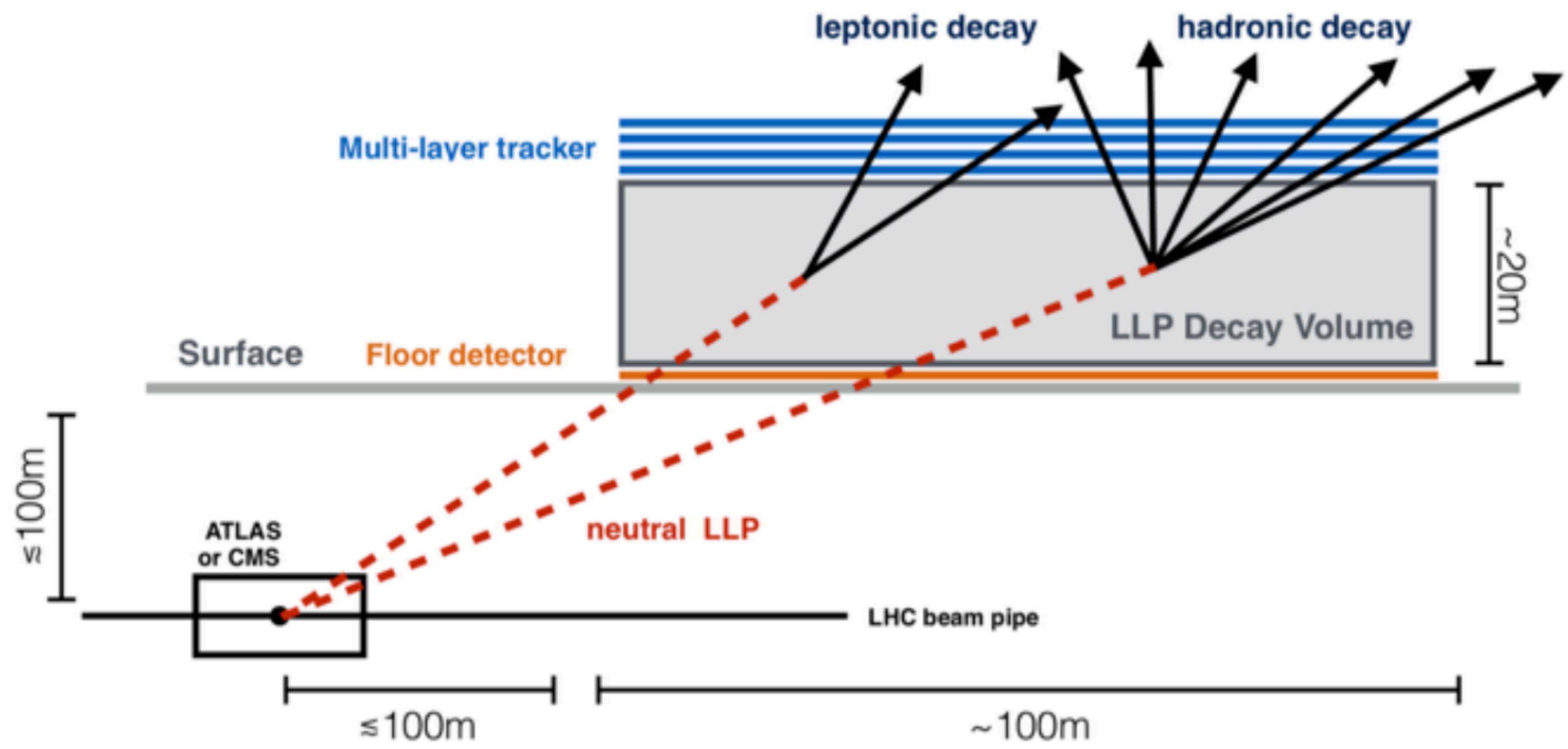
- O(100 m) rock provides shielding from QCD backgrounds
- Then have to deal with cosmic rays and atmospheric neutrinos…
- Requires downwards veto (good timing capabilities)



MATHUSLA: MAssive Timing Hodoscope for Ultra StabLe pArticles

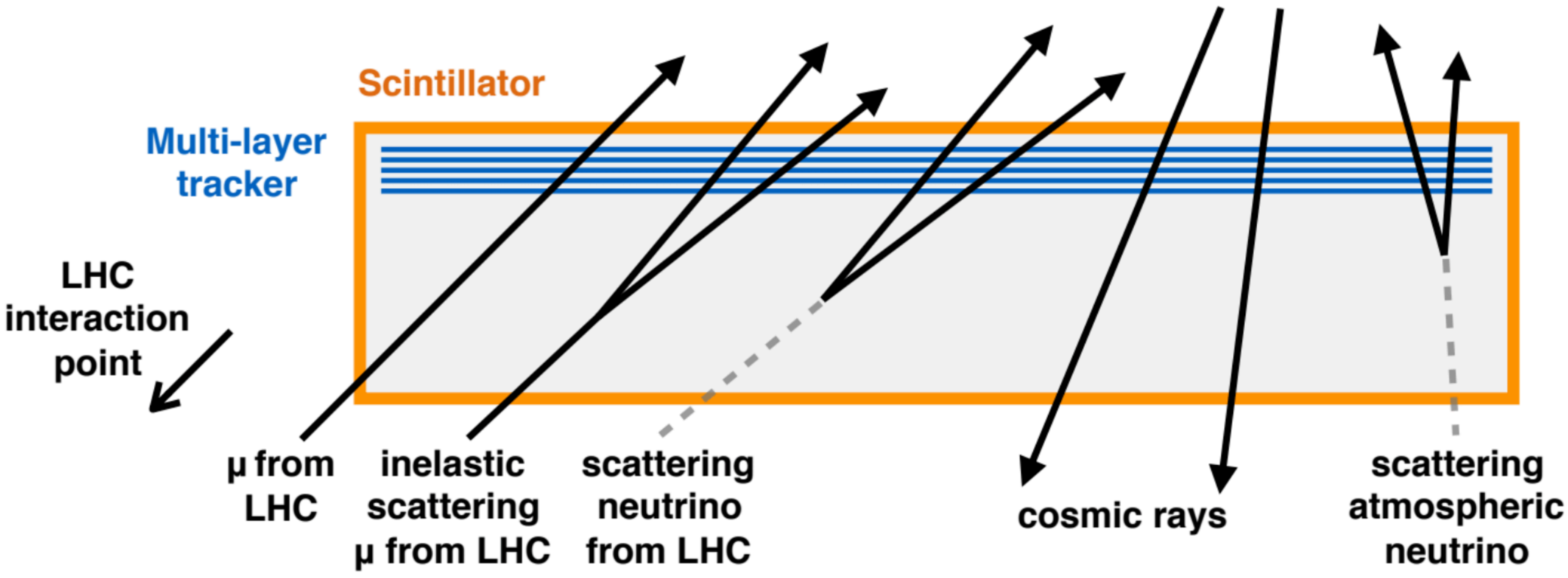
Original design gives sensitivity to neutral LLPs up to the Big Bang Nucleosynthesis (BBN) limit (10^7-10^8 m)

- 5 layers for tracking in roof (originally RPCs, now considering scintillators)
- 2 layers of tracking on floor to veto particles coming from IP and interactions occurring near the surface



MATHUSLA Backgrounds

Cosmic rays:	1 per cm^2 per minute
LHC collision backgrounds:	10 Hz
Upward atmospheric neutrinos that interact in air decay volume:	10-100 per year above 300 MeV Most have low momentum proton



MATHUSLA: MAssive Timing Hodoscope for Ultra StabLe pArticles

Designed for excellent background rejection and vertex reconstruction
Submitted a Letter of Intent (LoI) in November 2018: https://arxiv.org/abs/1811.00927
Theory white paper making our physics case: https://arxiv.org/abs/1806.07396

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

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

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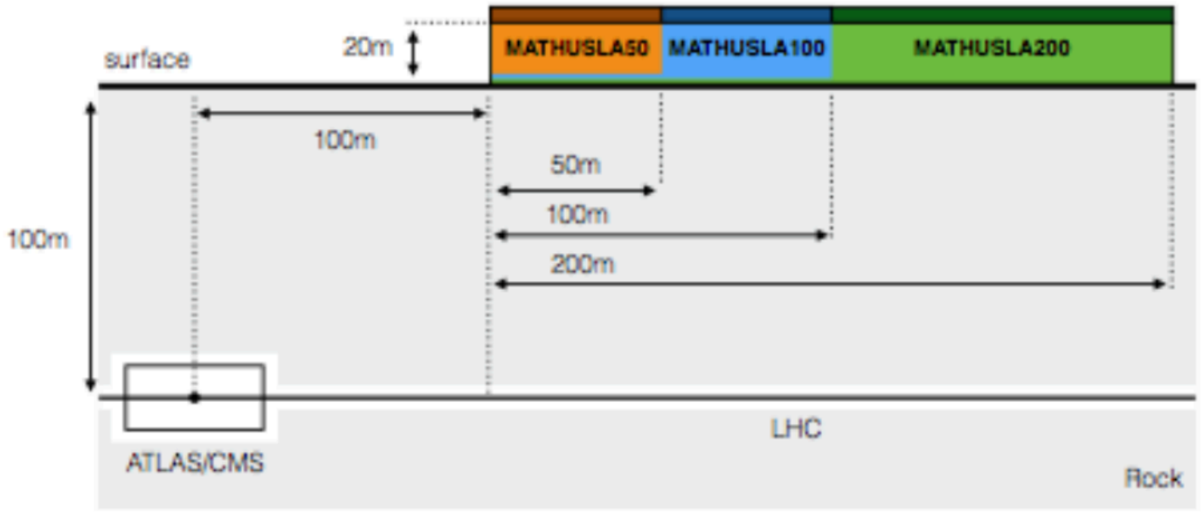
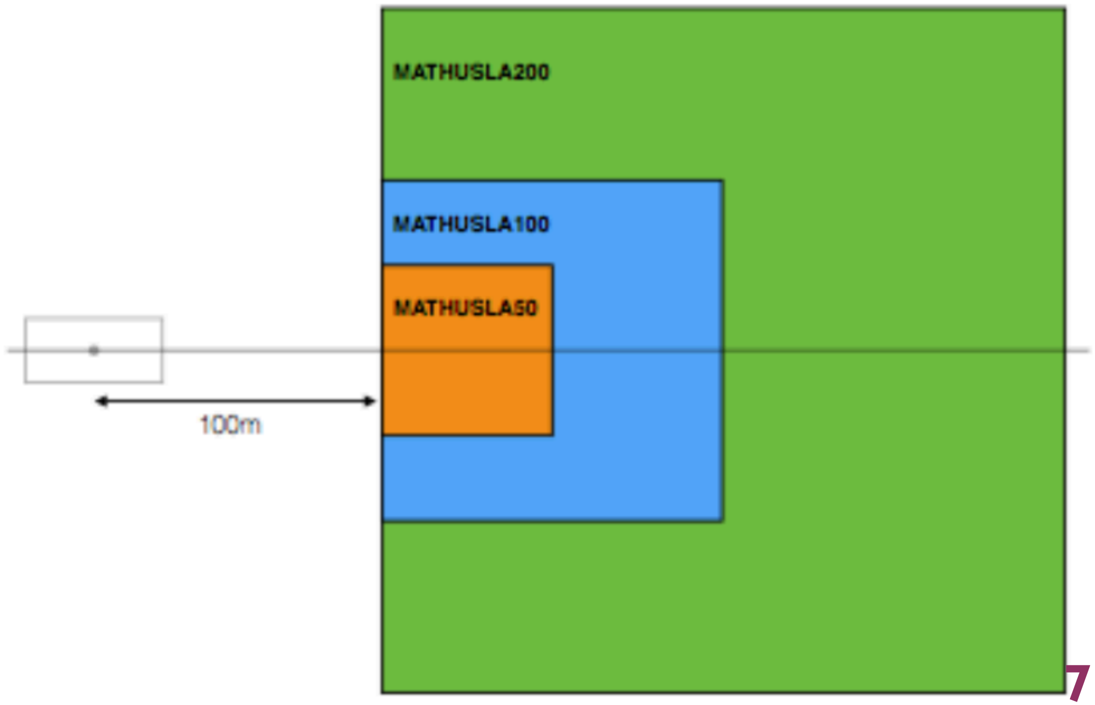
MATHUSLA Detector

3 benchmark sizes were considered for the LoI: 50x50 m^2, 100x100 m^2, 200x200 m^2

These considerations were made to evaluate the physics possible and the costs associated with each, to optimize our design. The 100x100 m^2 footprint is now our baseline.



side view



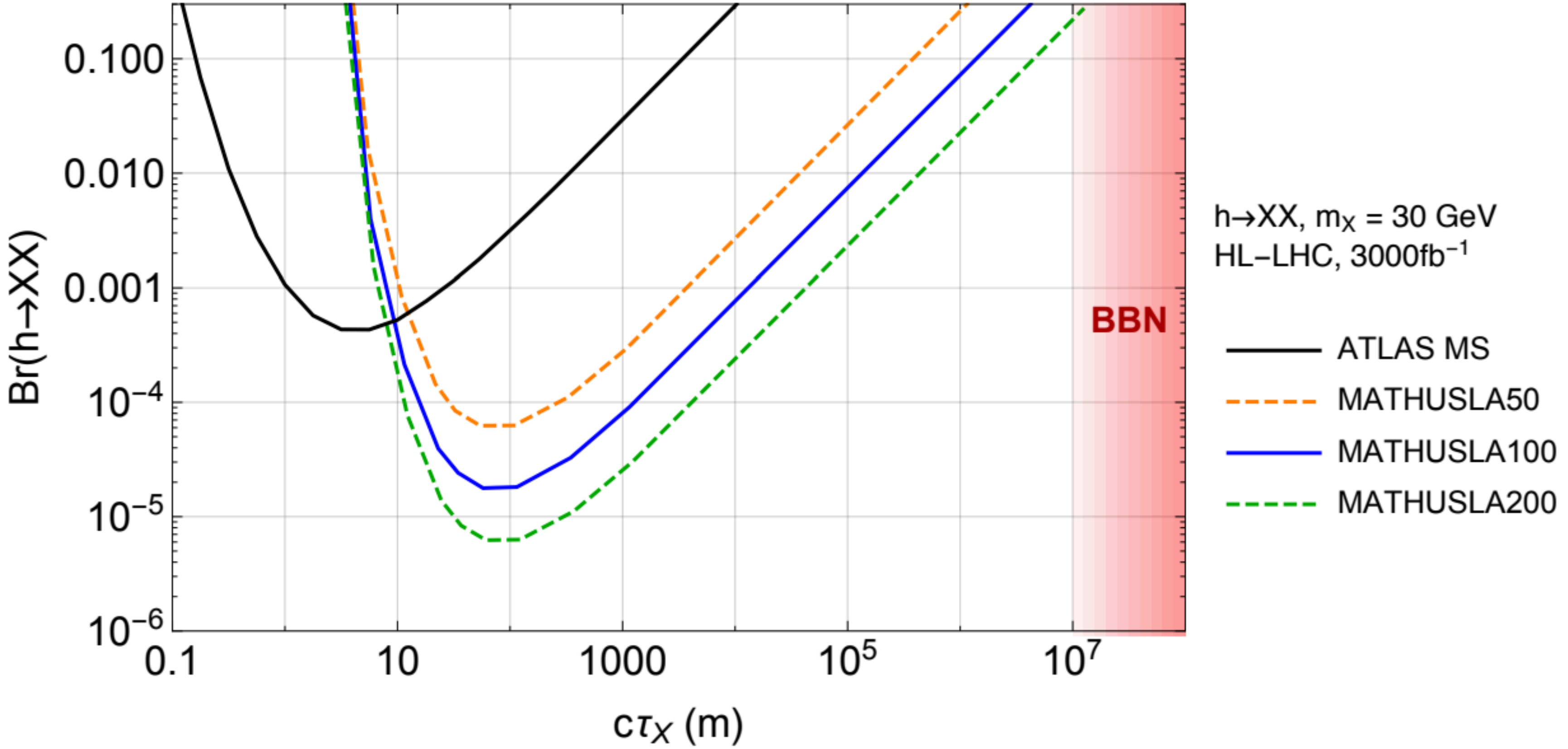
aerial view

MATHUSLA Detector

3 benchmark sizes were considered for the LoI: 50x50 m^2, 100x100 m^2, 200x200 m^2

Smaller size → decreased sensitivity

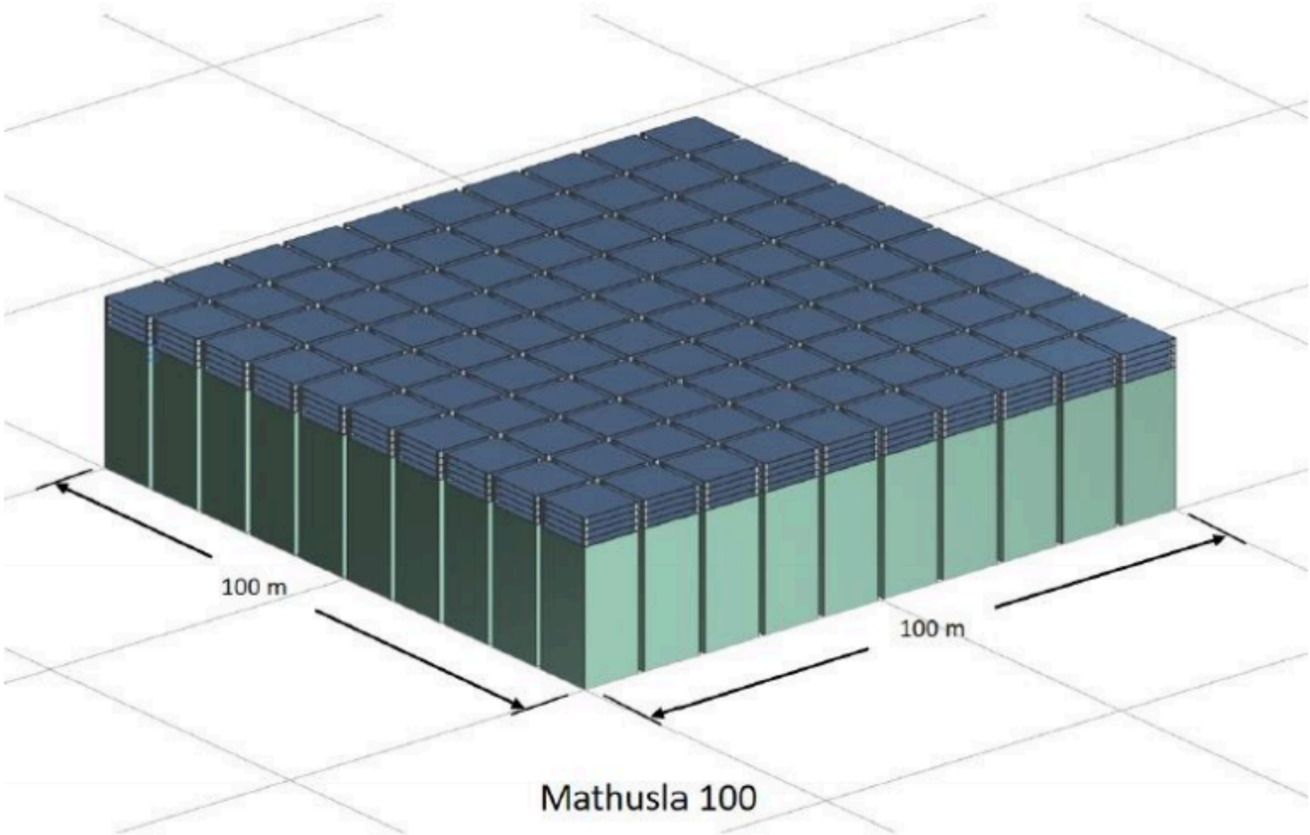
These limits assume the detector is 100 m horizontally displaced from IP and that the IP is 80 m below the surface (CMS)



Modular Concept

Current design uses a modular configuration:
Allows for staged integration with incremental ramp-up

Closer to the IP → increased sensitivity: can consider installing the modules slightly below the surface.



- Towers with 9x9 m^2 footprint
- 1 m gaps between modules
- 5 tracking layers
- 2 veto layers on floor
- <u>25 m air decay volume</u>

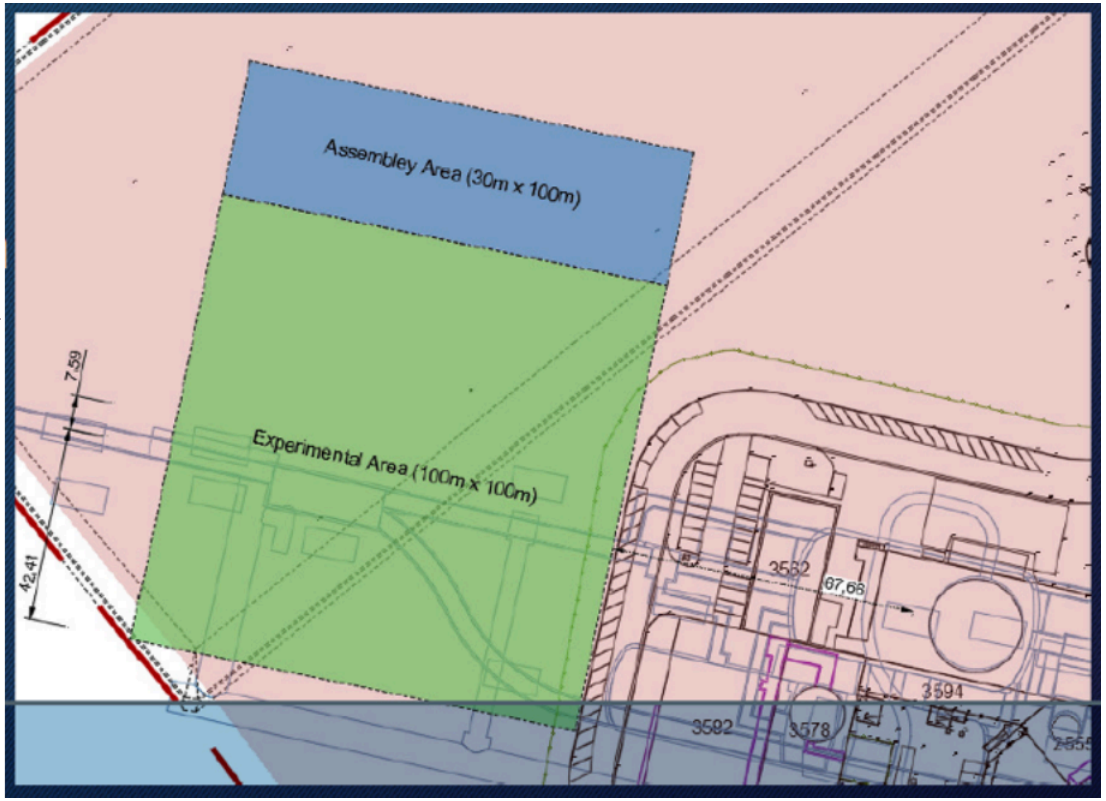
Detector Configuration and Surface Location

Studying several possible configurations on the surface above CMS, aiming to maximize our sensitivity given the land available

This is our current baseline

Working with CERN civil engineers to determine feasibility of excavating to install MATHUSLA slightly below surface level and constructing a building with crane coverage in which to assemble, install, and house MATHUSLA

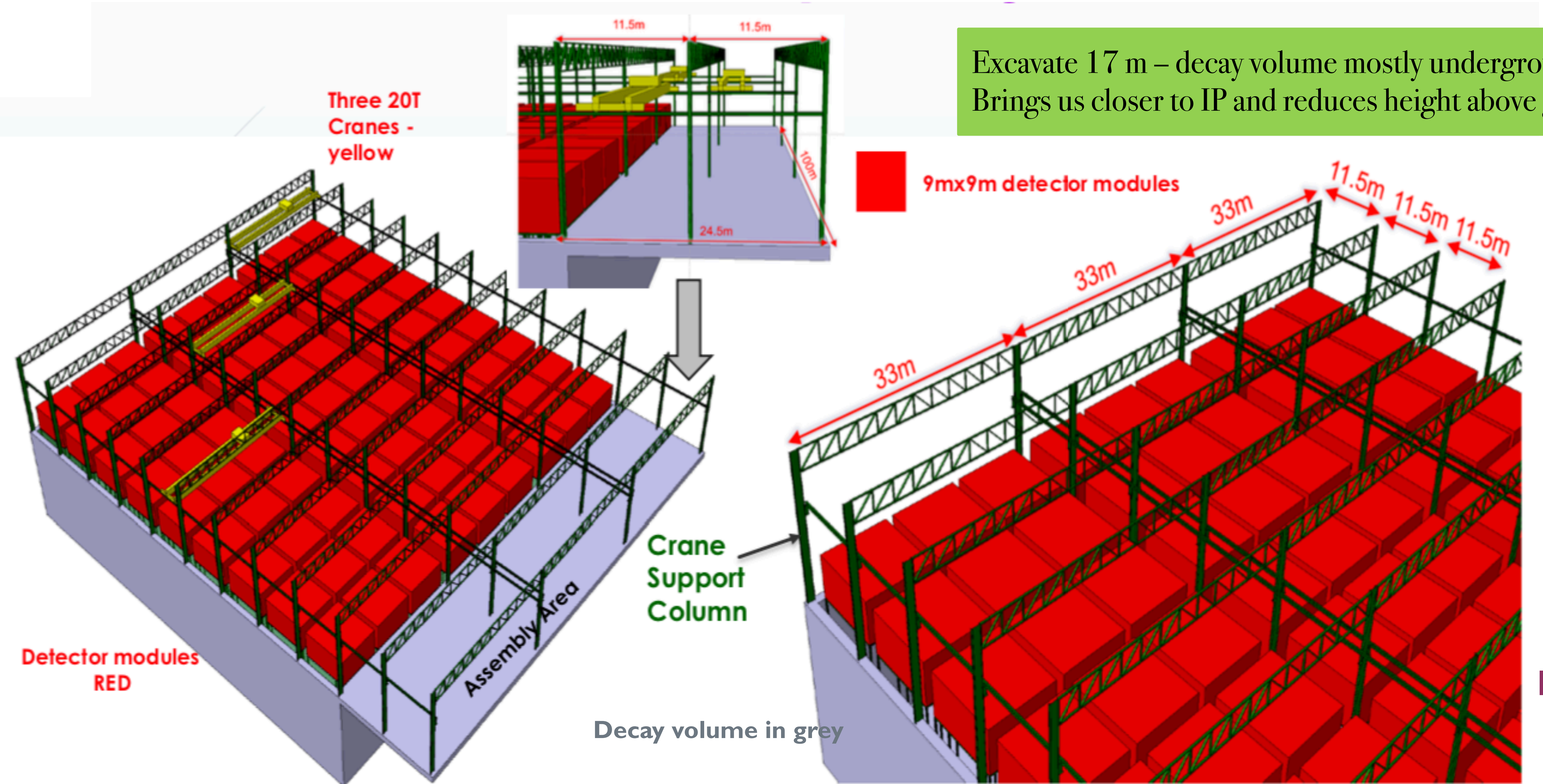
- 100x100 m^2 experimental area
- 30x100 m^2 assembly area
- ~7.5 m offset to center of beam
- ~68 m to IP horizontally
- IP is 80 m below surface
- Excavate 17 m



With the specifications of this 100x100 m^2 configuration, we approach the sensitivity of the original 200x200 m^2 design from slide 8

Detector Configuration and Surface Location

Excavate 17 m – decay volume mostly underground
Brings us closer to IP and reduces height above ground



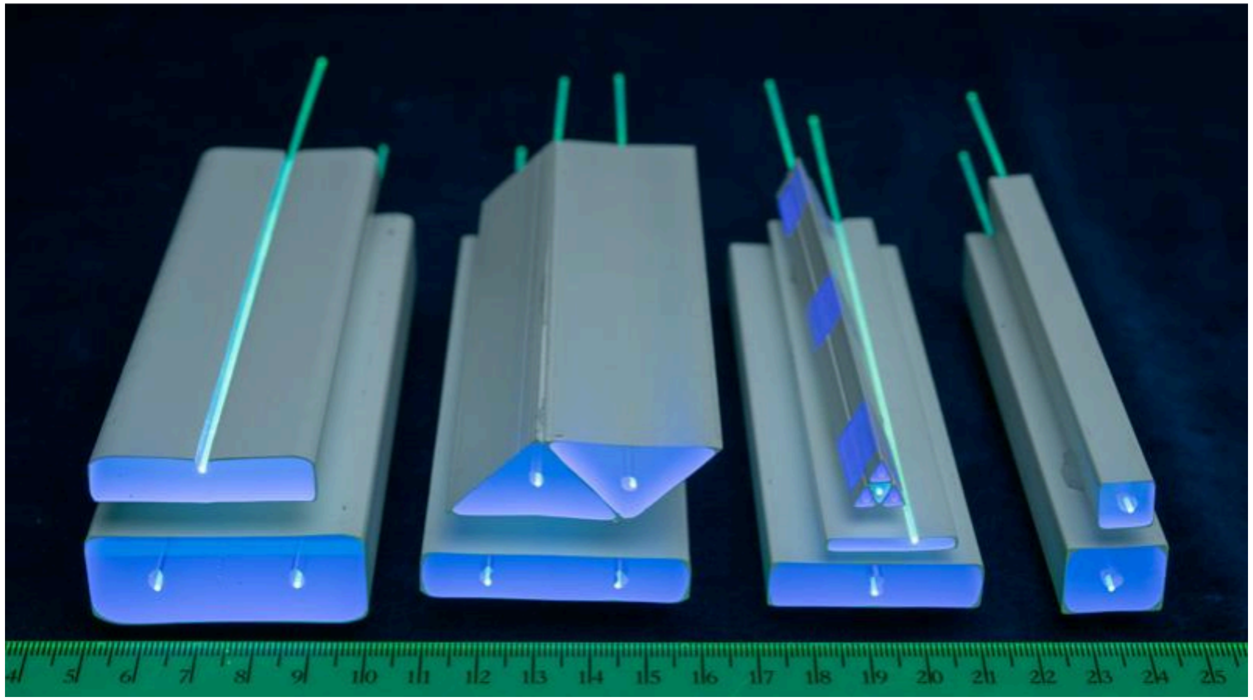
Detector Material

We are investigating using extruded scintillator bars with wavelength shifting fibers embedded in the bars that are readout by Si photomultipliers (SiPMs).

Advantages: timing resolution can be competitive with RPCs, no need to use high voltages or gas (RPC gas mixture for ATLAS and CMS has high Global Warming Potential, won't be allowed at HL-LHC)

Concept:
5m x 4cm x 2cm bar with wave-length shifting readout at both ends

- Transverse resolution $\sigma = 4\text{cm}/\sqrt{12} \approx 1\text{cm}$
- Time difference between two ends gives longitudinal resolution
    - Aiming for ~1cm, have started R&D to determine achievable resolution
    - Propagation speed in fiber about 16 cm/ns
    - Need time difference resolution of ~90 ps per SiPM



MATHUSLA Test Stand

In order to guide background studies and understand LHC collision backgrounds (in particular the upwards muon rate), we build a 2.5x2.5 m^2 test stand and took data on the surface above the ATLAS detector in 2018.

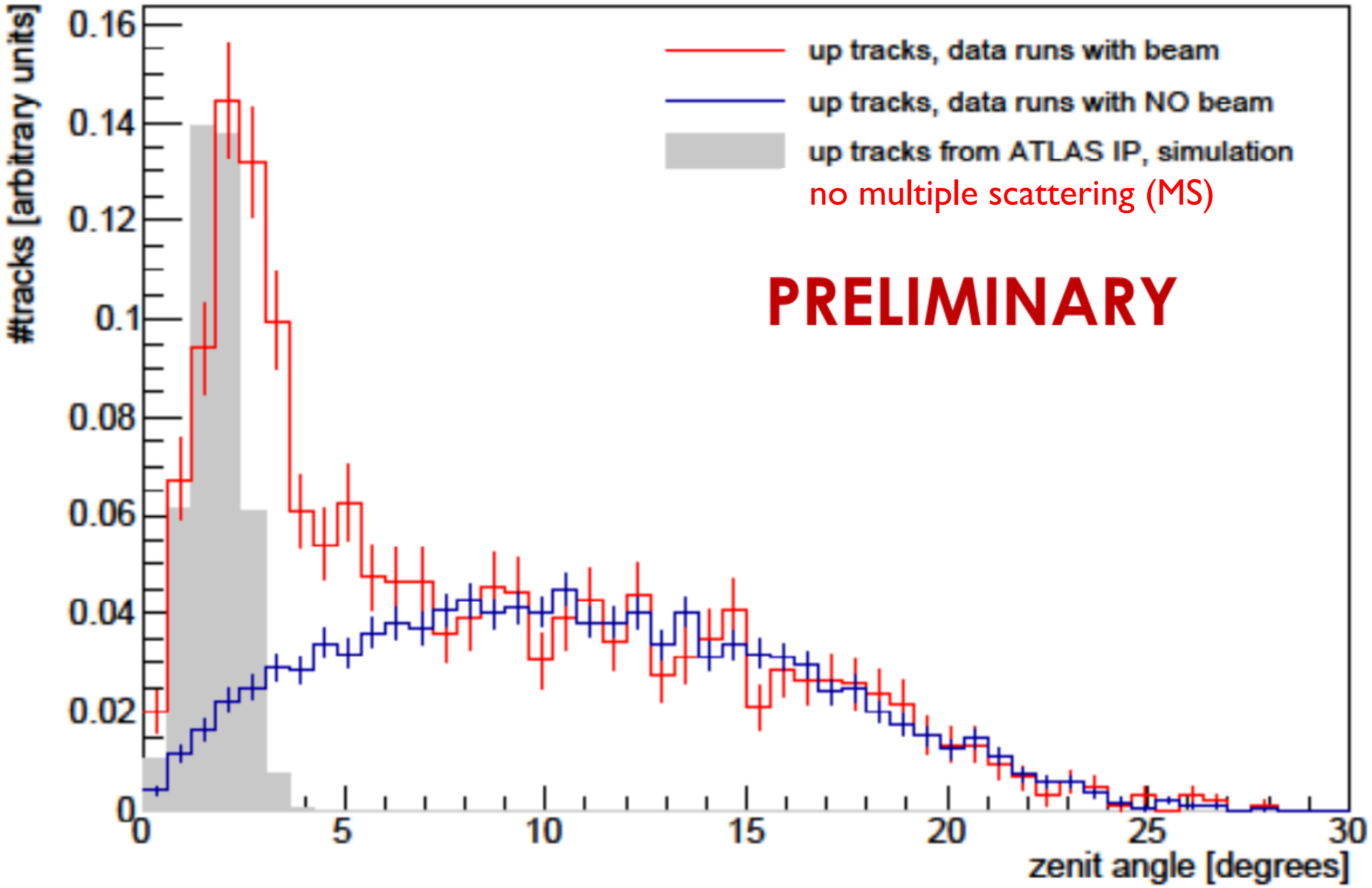
- Two layers of scintillators recycled from the D0 forward muon trigger wall – thanks to Dmitri Denisov
- Three layers of RPCs from ARGO experiment – thanks to Rinaldo Santonico Rome Tor Vergata

Timing resolution for both RPCs and scintillators σ ~2.5 ns

MATHUSLA Test Stand – Preliminary Results

These results are preliminary – NOT corrected for efficiency and multiple scattering not taken into account in simulation

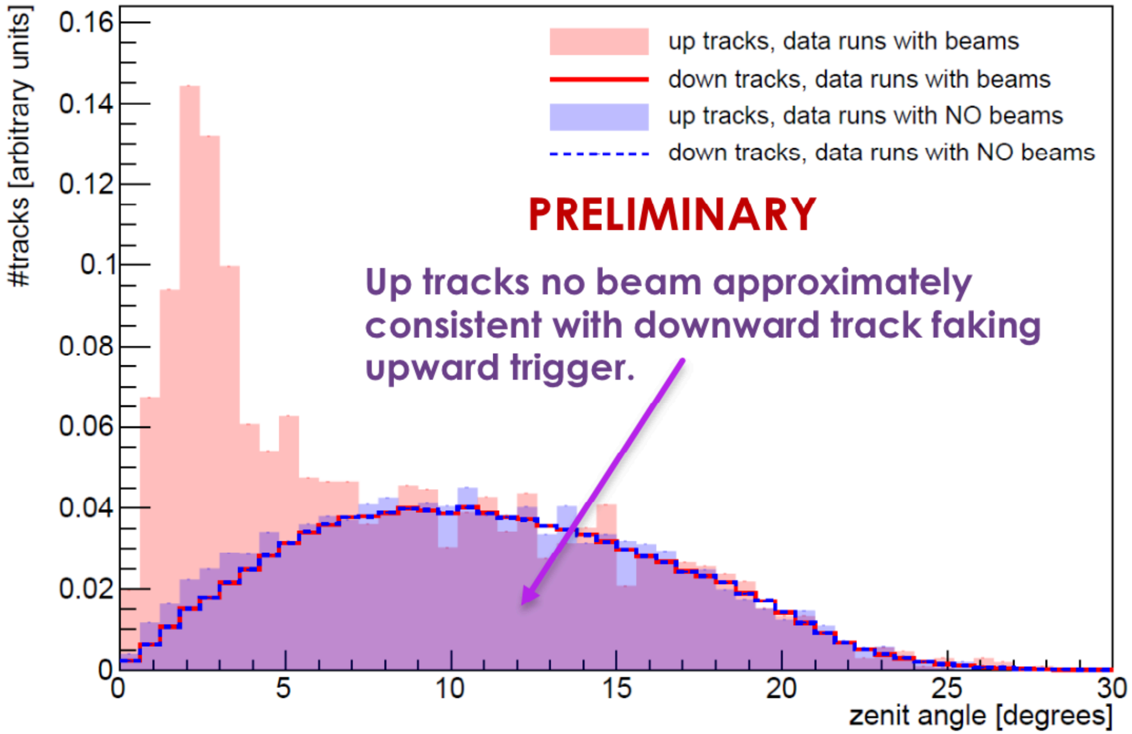
The spike in upwards tracks with zenith angle < ~4° is consistent with particles originating from collisions at IP

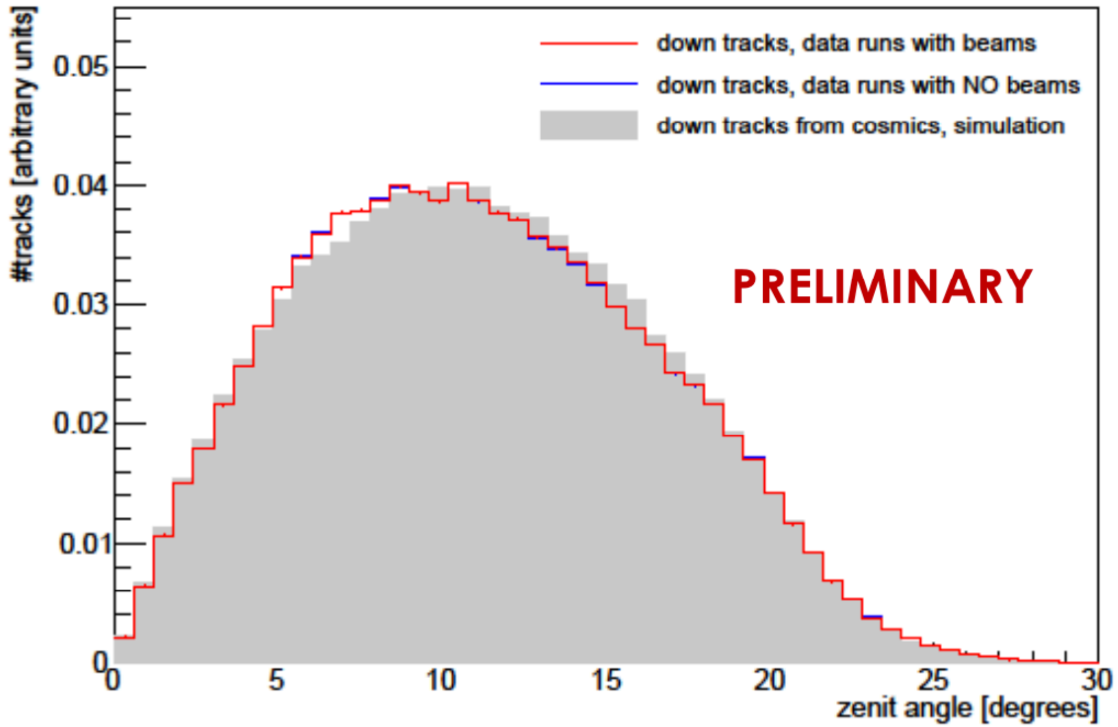


MATHUSLA Test Stand – Preliminary Results

The long tail of upwards tracks with and without beam are consistent with being misidentified downwards tracks, which is expected given our timing resolution and the height of the test stand

The downwards tracks, with and without beam, are consistent with being cosmics



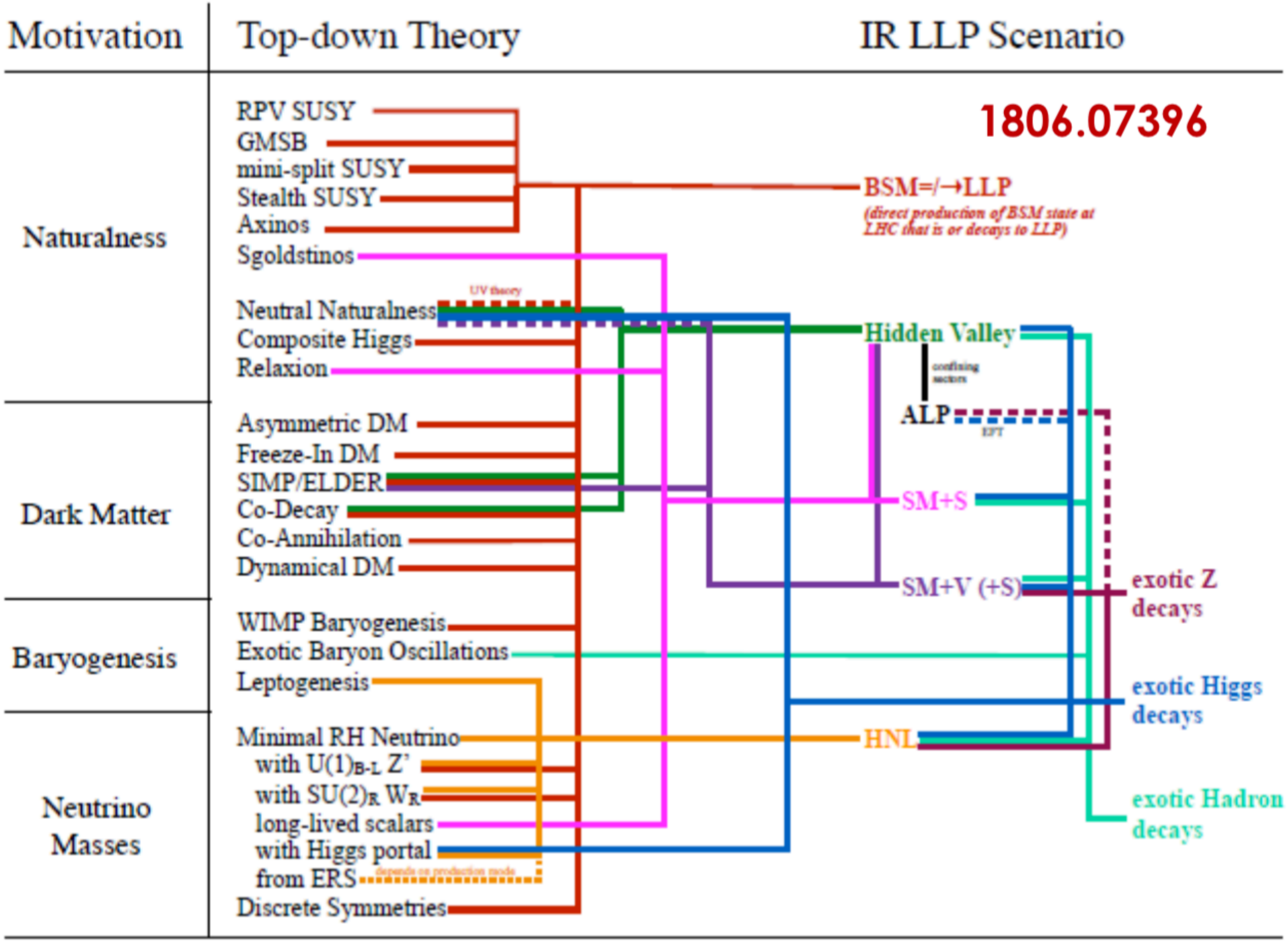


Summary

- We are continuing to work on our test stand results, to finalize our measurement of the upwards rate from the LHC
- We are finalizing our detector footprint
- We are working on the building details and plan to get a preliminary cost estimate this year
- We aim to choose a tracker technology choice early next year
- We aim to complete a Technical Design Report (TDR) by end of 2020

BACKUP

Physics Potential



MATHUSLA Trigger

- Baseline is to collect all detector hits with no trigger selection and separately record trigger information
- Trigger unit consists of 3x3 modules
- Move information to central processor
- Trigger separately recorded and used for connecting to CMS detector bunch crossing

- CMS Level-1 trigger latency is 12.5 μs for HL-LHC
- Conservatively assuming a 200m detector with 25m height located 100m from the IP, LLP with $\beta = 0.7$, optical fiber transmission to CMS with v_{fiber}=5 μs/100 m
- MATHUSLA has 9 μs or more to form trigger and send information to CMS Level-1 trigger
- If problem to associate MATHUSLA trigger to unique bunch crossing, the approved CMS HL-LHC Level-1 allows for recording multiple bunch crossings
- Thanks for Alex Tapper for information about CMS HL-LHC Level-1 trigger