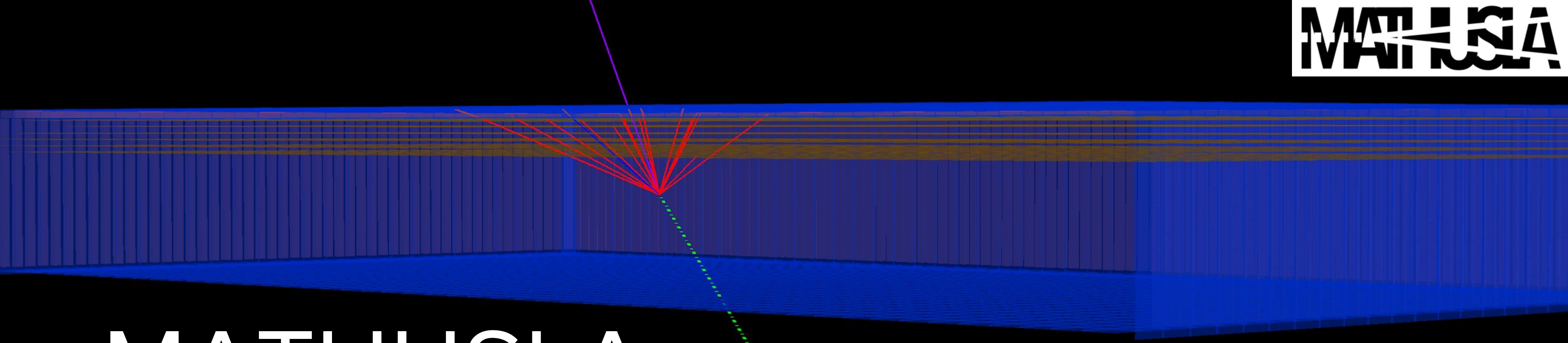

MATHUSLA

Ultra-Long-Lived Particles: The Lifetime Frontier

Mason Proffitt

on behalf of the MATHUSLA collaboration

UNIVERSITY of WASHINGTON

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Simulated MATHUSLA event display by Martin A. Subieta Vasquez

Motivation

- High intensity, high energy collisions (ATLAS/CMS at the (HL-)LHC) offer a great potential source of LLPs, with the highest available mass reach
- ...but neutral LLPs are very challenging to detect: only signatures are MET or a displaced vertex
- Only limit on lifetime ($c\tau \lesssim 10^7 - 10^8$ m) is from impact on Big Bang nucleosynthesis
- If $c\tau$ is much greater than the radial detector length L, the probability to decay inside the detector is proportional to $L/(c\tau)$
- For these ultra-long-lived particles (ULLP), the likelihood of the displaced vertex ending up within a ~10 m detector can be very small
- With such low rates, the huge amount of activity in the main LHC detectors makes it nearly impossible to distinguish ULLP signals from very rare background events

Motivation

- Solution to this ULLP problem:
  - New detector that minimizes background as much as possible, while maintaining reasonably large radial detector size and solid angle coverage relative to the main interaction point (IP)
- Any underground experiment limited by available space and excavation/installation cost
- Going to the surface is (relatively) cheap and easy
- ~100 m of rock provides excellent shielding from collision/beam backgrounds
- Signal rate isn't affected by the distance since $c\tau \gg 100$ m
- Only extra background is increased cosmic ray muon rate
  - Rarely pointed towards IP and is coming from the opposite direction (from above instead of below)

Motivation

For exotic Higgs decays, number of ULLPs decaying within a detector given the production of N_h Higgs bosons is:

$$N_{\text{obs}} \sim N_h \cdot \text{Br}(h \to \text{ULLP} \to \text{SM}) \cdot \epsilon_{\text{geometric}} \cdot \frac{L}{bc\tau}$$

where b = Lorentz boost of ULLP ($|p|/m$)

For ULLP masses ≳ 20 GeV, setting L ~ 20 m and geometric efficiency $\varepsilon_{\text{geometric}}$ ~ 10% allows detection of a few events with the HL-LHC even at the BBN lifetime limit

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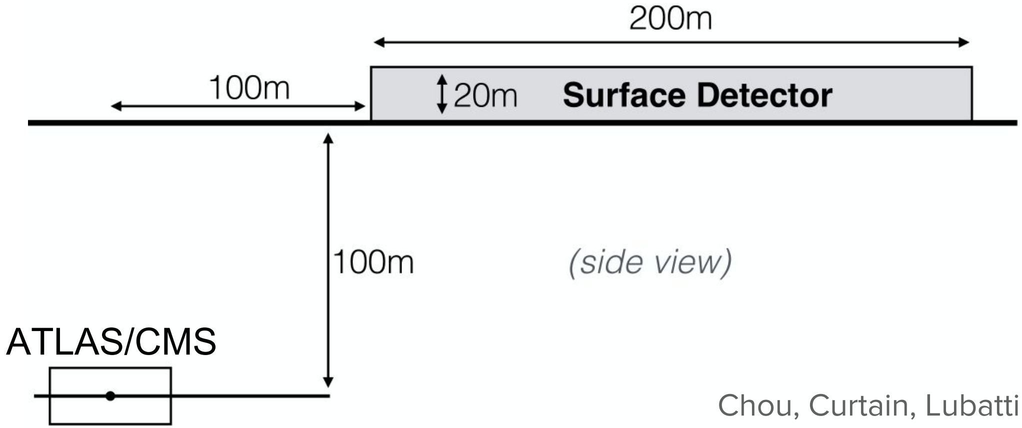
MATHUSLA detector proposal

MAssive **T**iming **H**odoscope for **U**ltra-**S**table neutra**L** p**A**rticles

Building dimensions: 200 m × 200 m × 20 m

Location: Next to the surface buildings of ATLAS (point 1) or CMS (point 5)

Timeline: HL-LHC (~2025)



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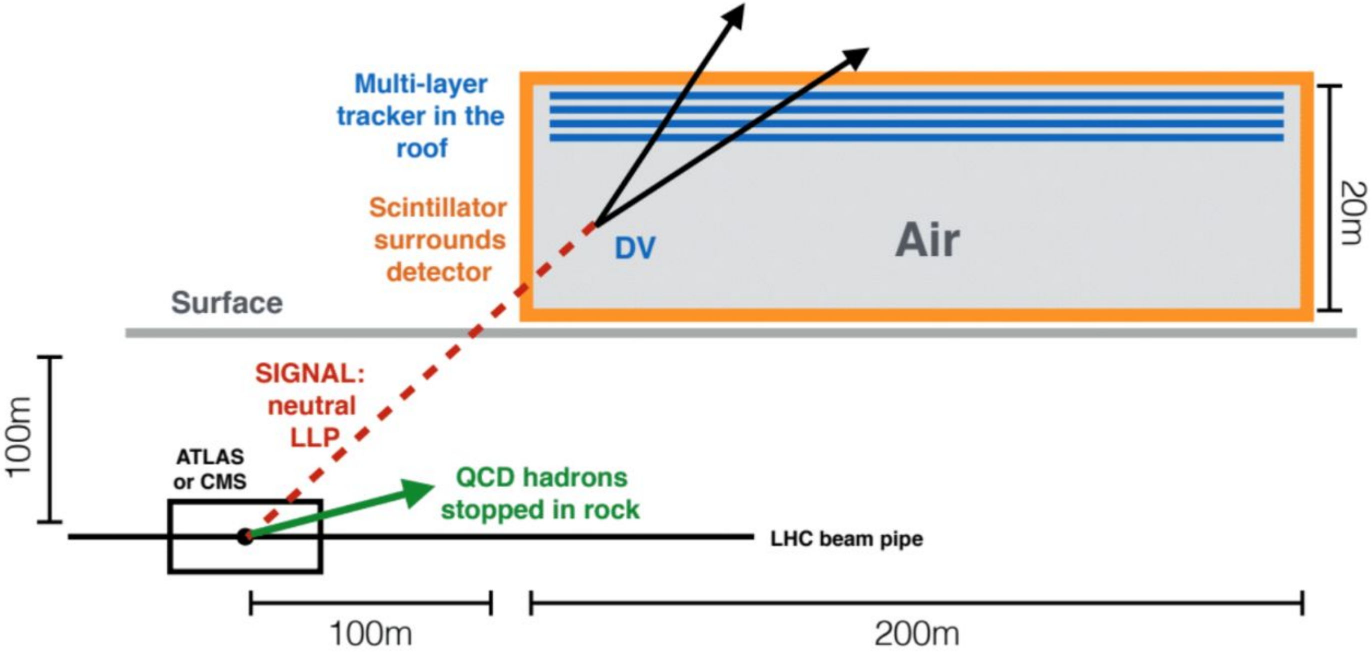
MATHUSLA detector proposal

Would nearly span from here (council chamber) to the globe...

and be almost as tall!

Detector design

Simple concept: effectively just a large (mostly empty) box to enclose displaced vertices



Detector design

- Using two robust, well-understood technologies:
    - Scintillator planes:
        - Covering entire boundary of detector volume
        - Used for triggering and rejecting incoming SM particles
    - 5 RPC layers placed horizontally near top of the volume:
        - Tracking, vertex reconstruction, rejection of downward-traveling particles (cosmic ray muons)
    - The ~1 ns and ~1 cm resolutions expected to be needed for tracking and background rejection are very attainable, have been proven with the above in existing detectors
    - Could replace scintillators with all RPCs ⇒ single technology detector
- Can be built as several smaller modules (e.g., 20 m × 20 m × 20 m)
    - Would streamline deployment, improve flexibility to funding availability, allow placing modules above both ATLAS and CMS

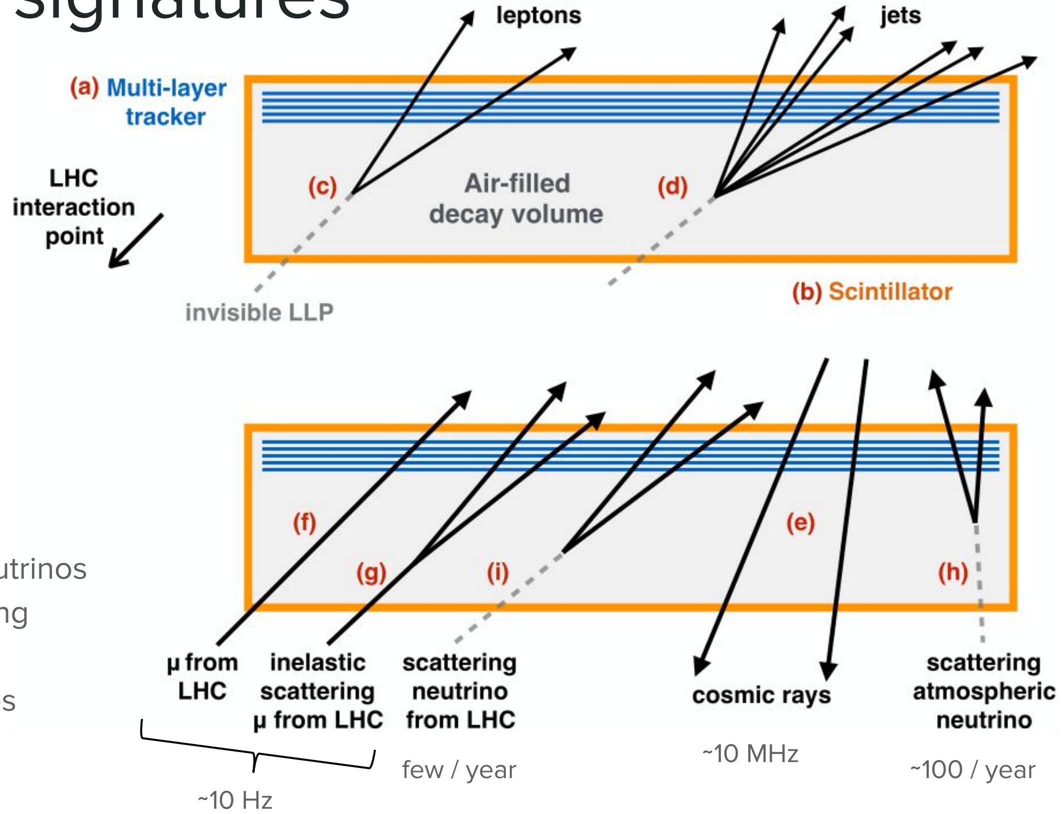
MATHUSLA

Signal and background signatures

Example signals for MATHUSLA:

Main backgrounds:

- Veto from bottom scintillator plane and requiring upward-going tracks gets rid of everything but neutrinos
- Atmospheric neutrino scattering rejected by vetoing narrow cones of tracks pointing away from IP
- Can also reject most neutrino scattering final states (which include non-relativistic protons) from timing



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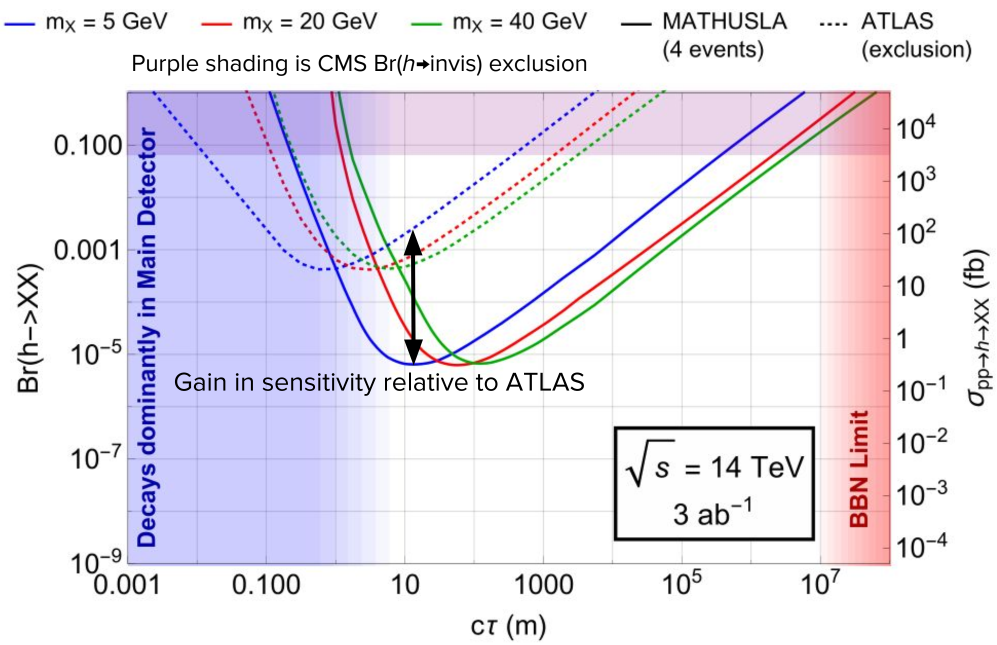
Estimated sensitivity

Aiming to reduce background events over the entire HL-LHC run to $O(1)$

⇒ Sensitive to $O(1)$ signal events!

Plot shows predicted MATHUSLA sensitivity to exotic Higgs decays to ULLPs from requiring 4 signal events



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Cosmic ray physics potential

- Along with such a large surface detector, valuable cosmic ray data comes "for free"
- Probe the spectrum of primary cosmic rays
- Unprecedented measurements of muon bundles—hundreds of parallel muons produced in extensive air showers
    - Possible to capture a huge section of an individual shower simultaneously
- Able to make new measurements of nearly horizontal cosmic ray muons

Simulation

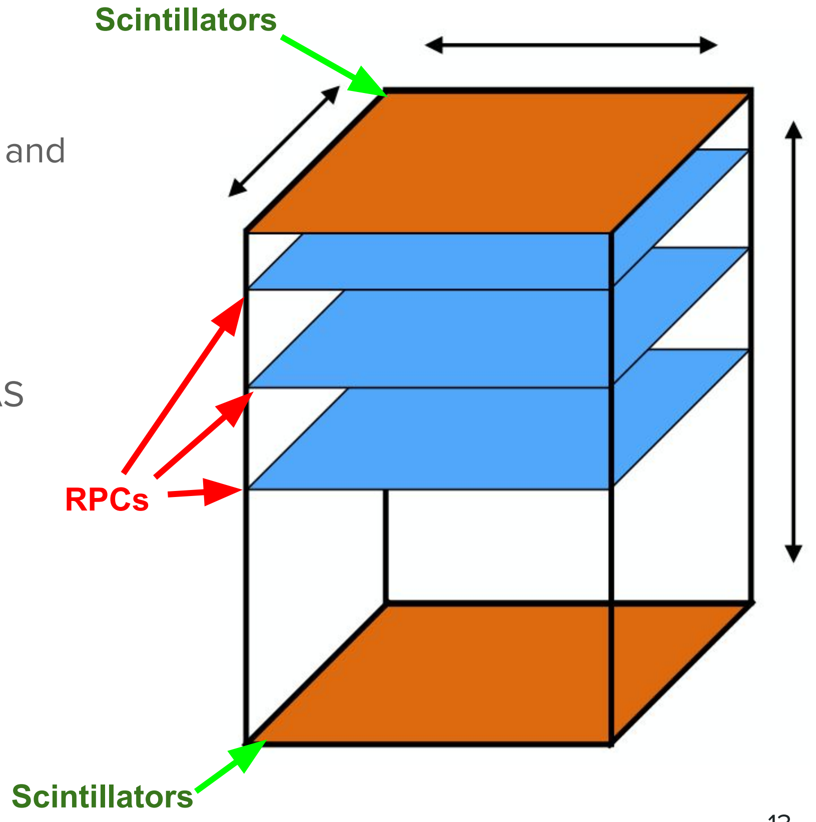
- Ongoing work on simulating signal and background for MATHUSLA
  - MadGraph/Pythia for generating signal events and incoming muons from LHC collisions
  - GENIE for simulating neutrino scattering
  - CORSIKA for cosmic ray simulation
  - Simulating detector response in Geant4
- Because geometric coverage is not 100%, idea is to get spectrum of particles (muons, neutrinos) coming from LHC collisions in MadGraph/Pythia, then create a "particle gun" directly in G4 to send into detector simulation
- Image on title slide comes from initial simulation tests

MATHUSLA test stand

Relatively small detector to validate the basic design concept and improve understanding of backgrounds for MATHUSLA

Main goals:

- Detect upward-going particles at the surface from ATLAS collisions and characterize these signatures and rates
- Test timing resolution needed to distinguish these from downward-going cosmic ray particles



MATHUSLA test stand

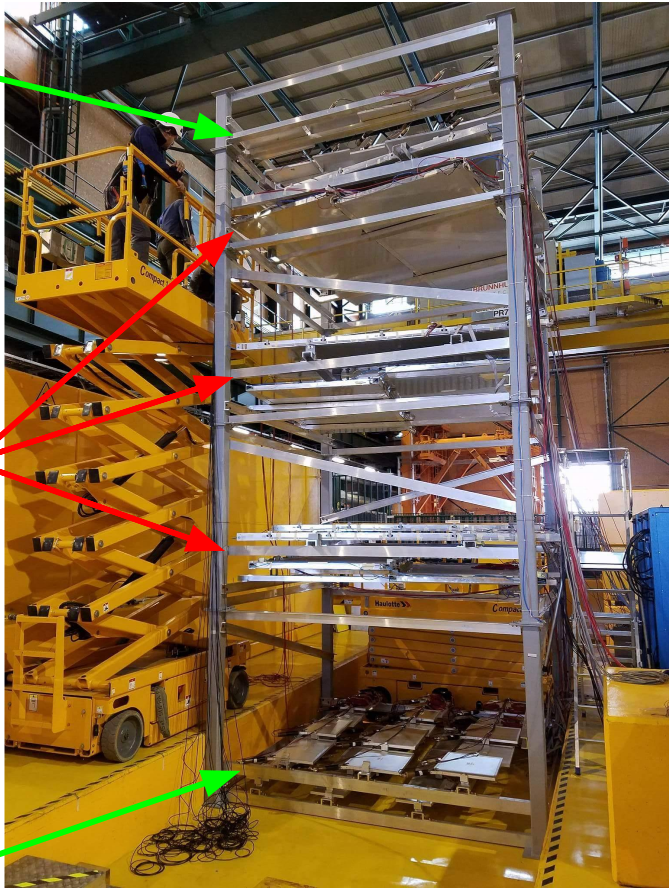
Using 59 borrowed scintillators (from DØ) and 12 RPCs (from ARGO)... all well beyond their originally designed use!

Active surface area: 2.5 m × 2.5 m

Height: 6.7 m

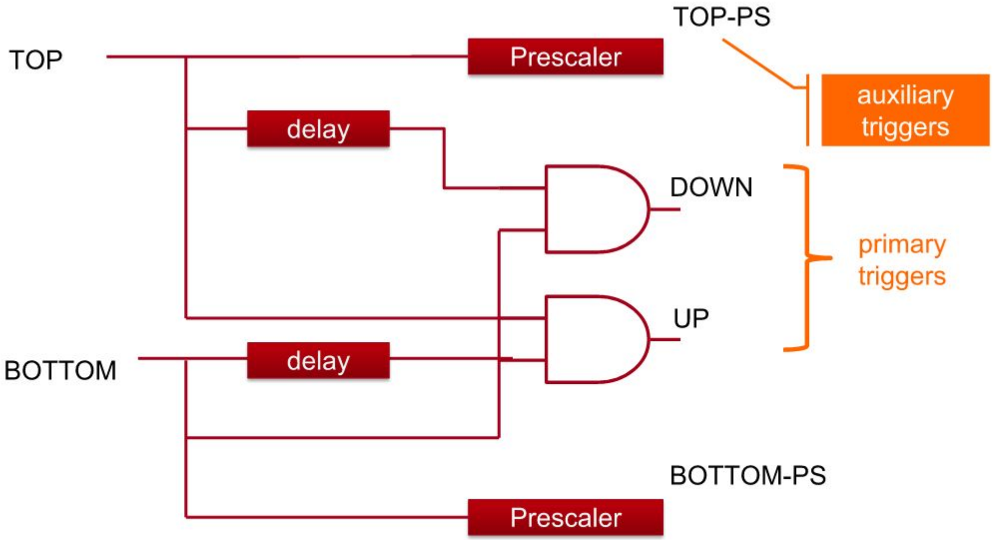
Data readout:
TDC + ADC readout for scintillators, TDC + strip address for RPCs

Shown here in the buffer zone of SX1, ~100 m directly above ATLAS



Test stand TDAQ

- 4 types of triggers, defined by TOP and BOTTOM scintillator planes + timing logic
- All scintillator + RPC data is recorded by VME modules
- VME readout by a controller connected to the DAQ PC
- Data is stored on disk (in a custom format) and sent to an online monitoring application



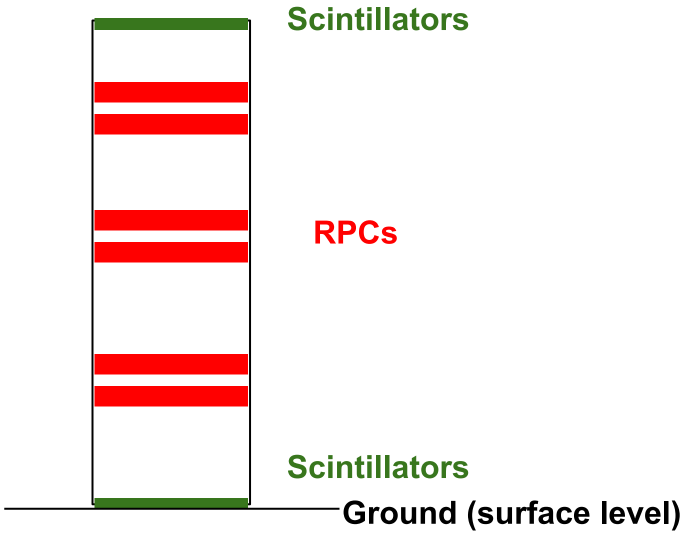
Test stand operation

- Tested scintillators and constructed test stand last summer through autumn
- Installed at point 1 in November, collected data for about a week
- Moved to Prévessin for year-end LHC shutdown
- Started running again there in March, about a month of data
  - Coincidentally ended up in front of the H8 beamline from SPS
  - Have data corresponding to periods with and without horizontal muon flux from the beam
  - Fixed a major RPC efficiency problem (LV setting)
  - All scintillators and RPCs seem to be behaving reasonably well (pending more thorough testing)
- Currently back at point 1, waiting for installation area to be ready again

"Tracking" (by hand)

Next few slides: simple demonstration of spatial mapping of all RPC hits in one event with one track through each plane of RPCs, starting from the top

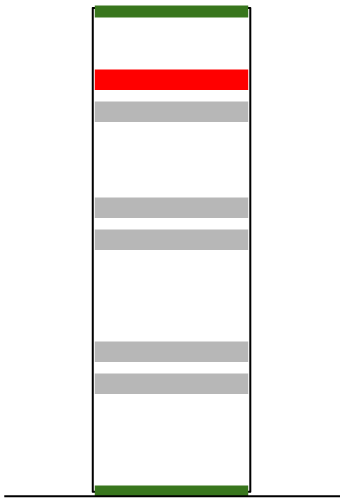
Schematic key for test stand:

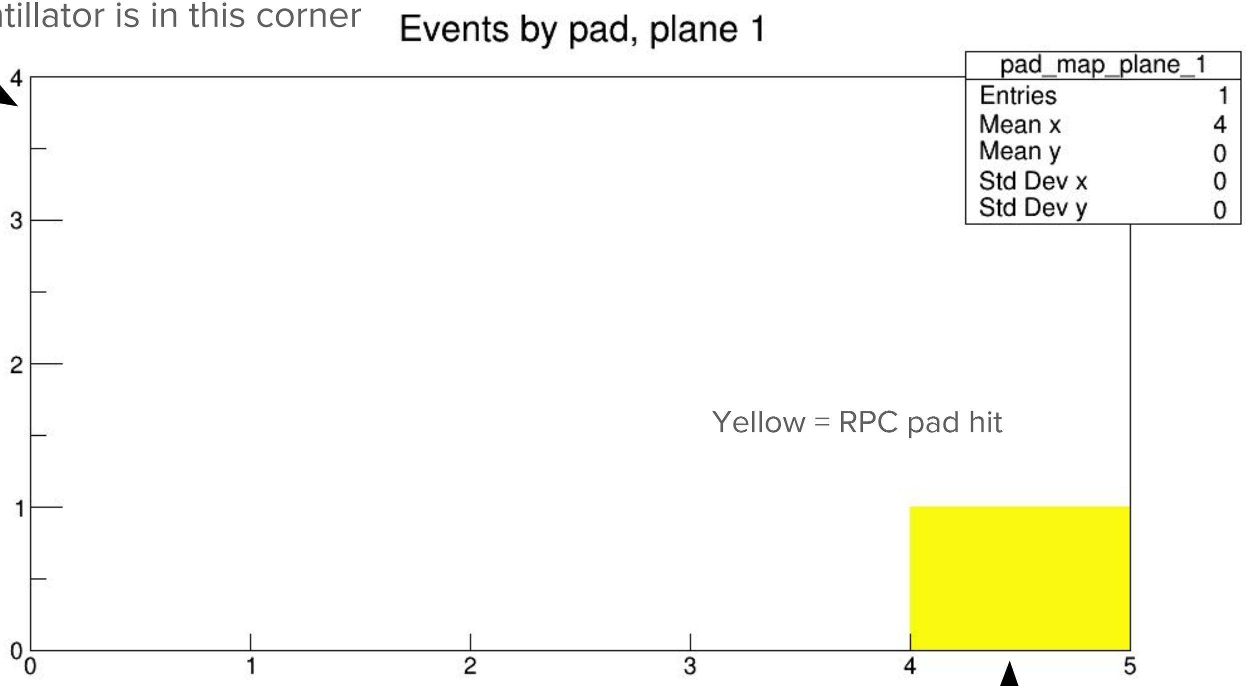


"Tracking" (by hand)

Triggering bottom scintillator is in this corner

(Plot is a top down view)

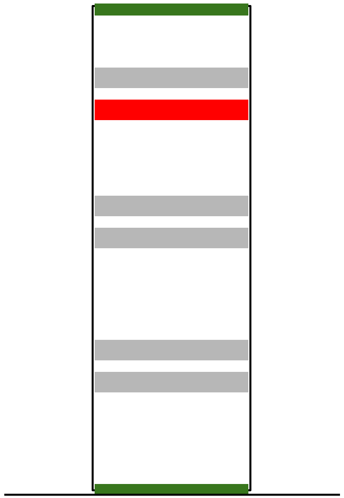


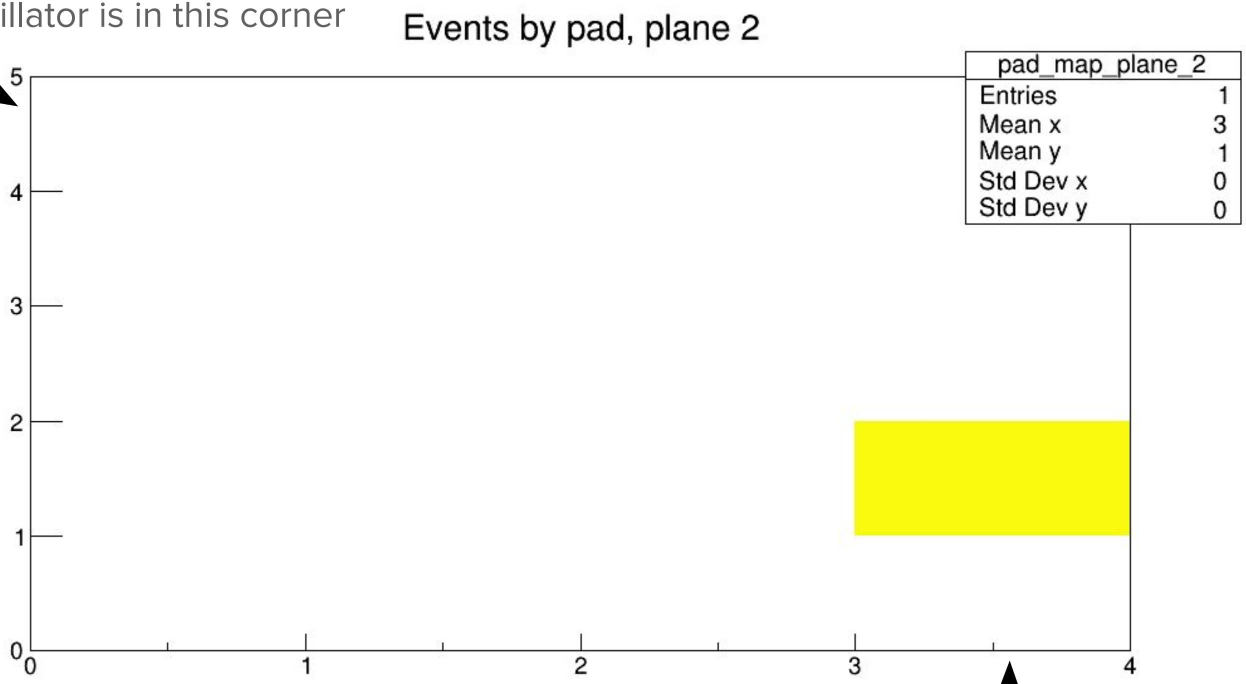


Triggering top scintillator is in this corner

"Tracking" (by hand)

Triggering bottom scintillator is in this corner





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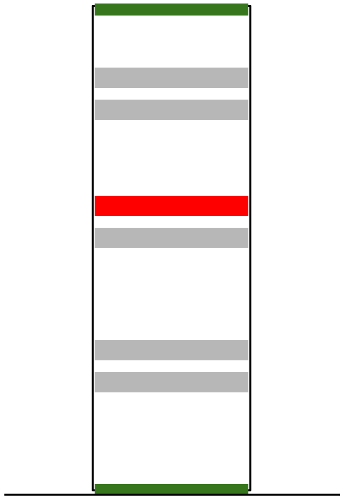

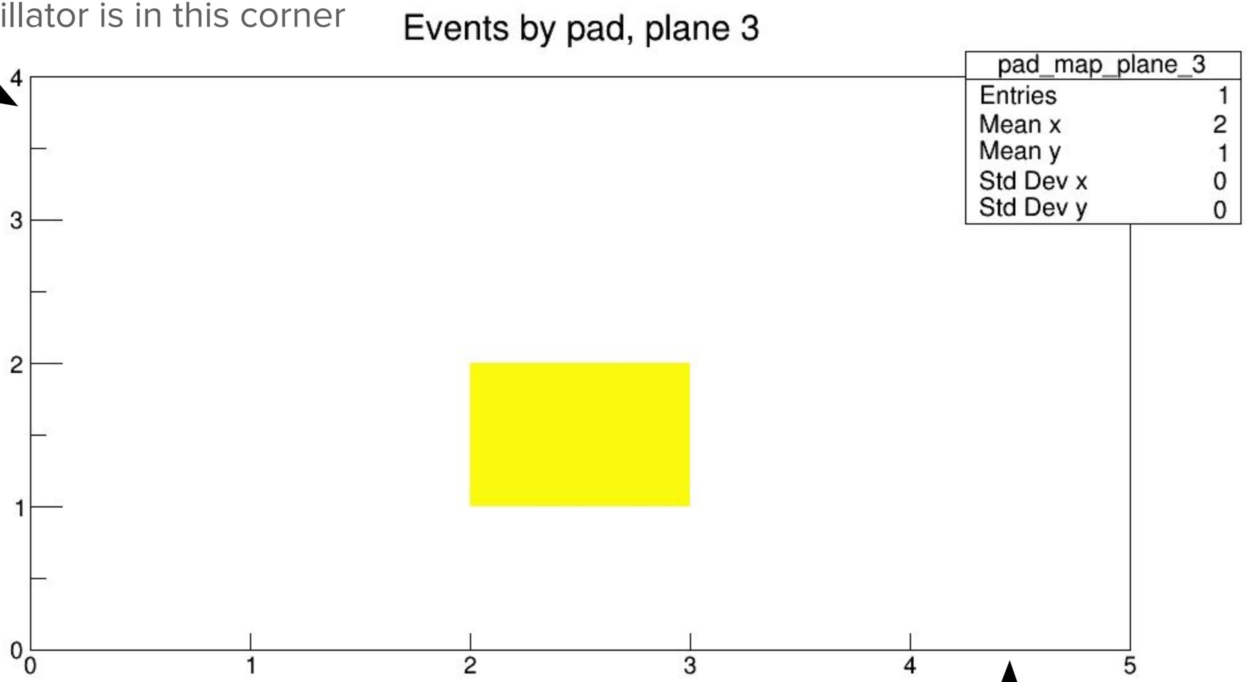

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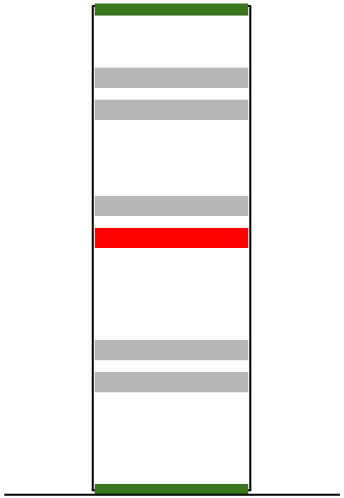

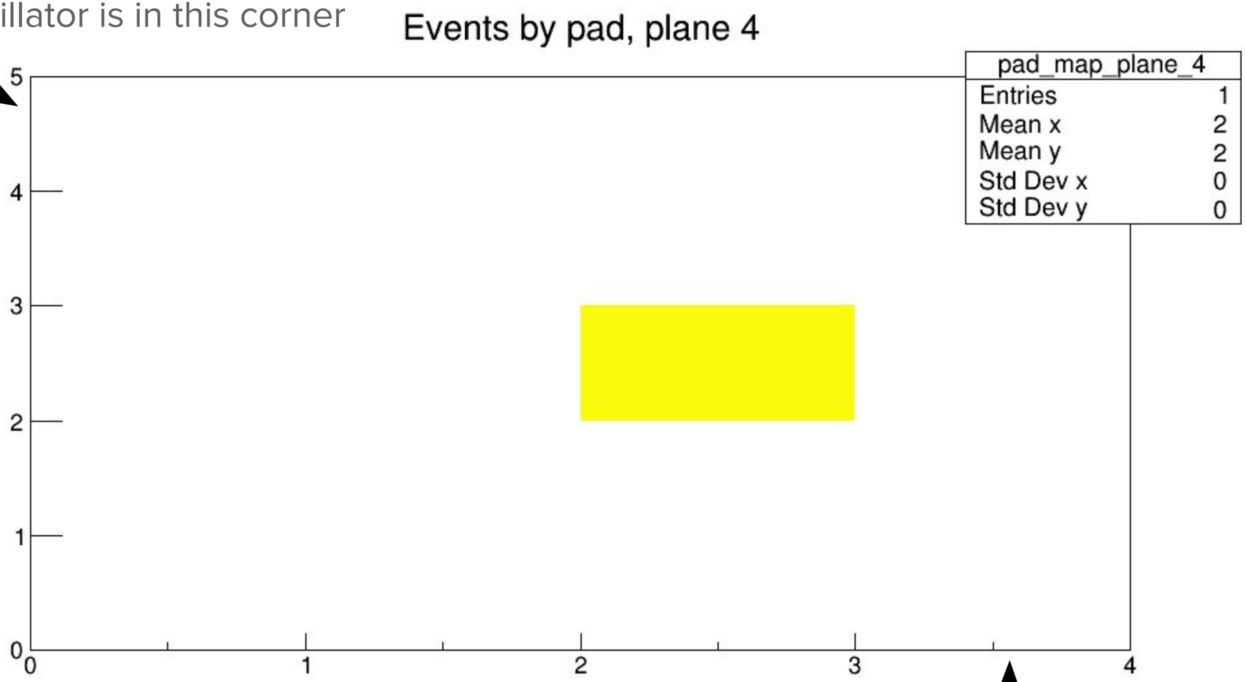

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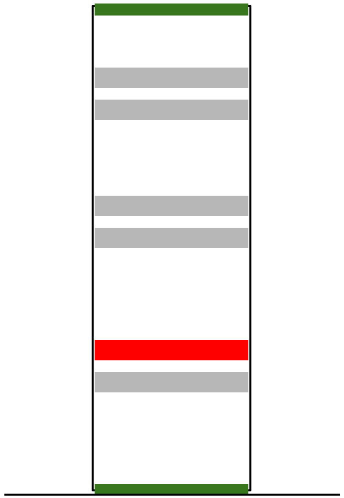
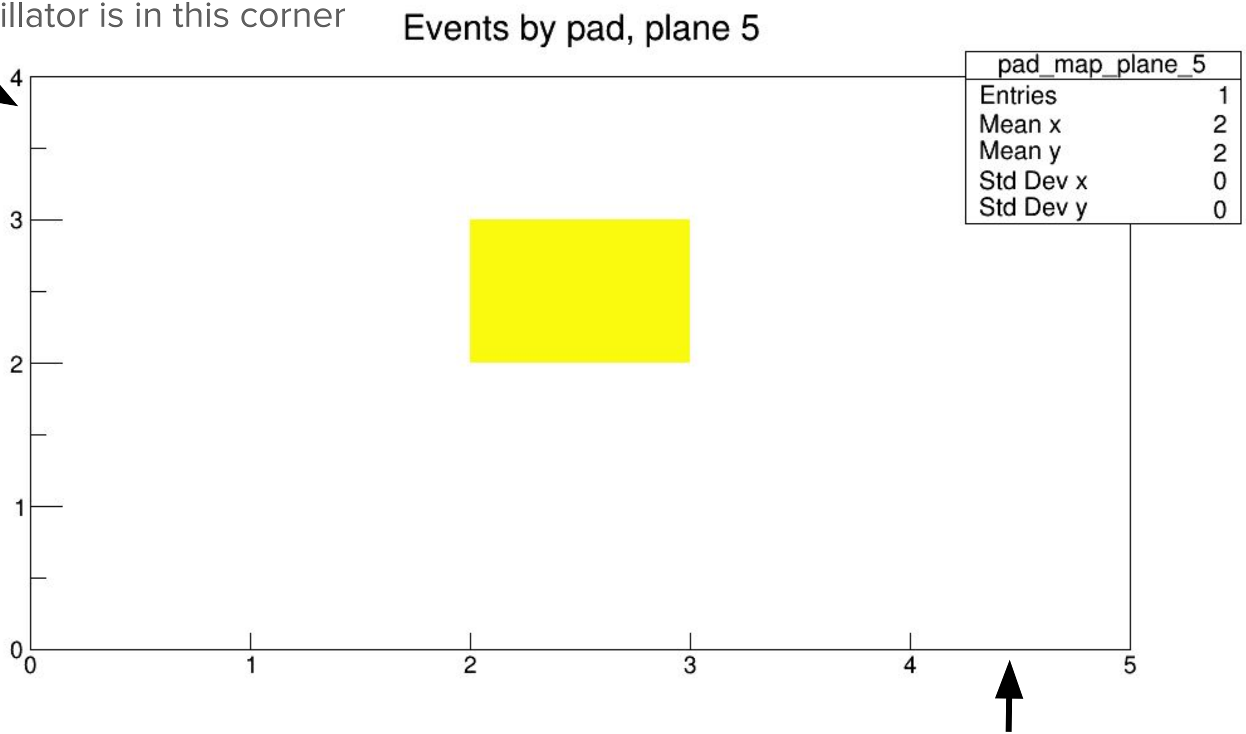
"Tracking" (by hand)

Triggering bottom scintillator is in this corner

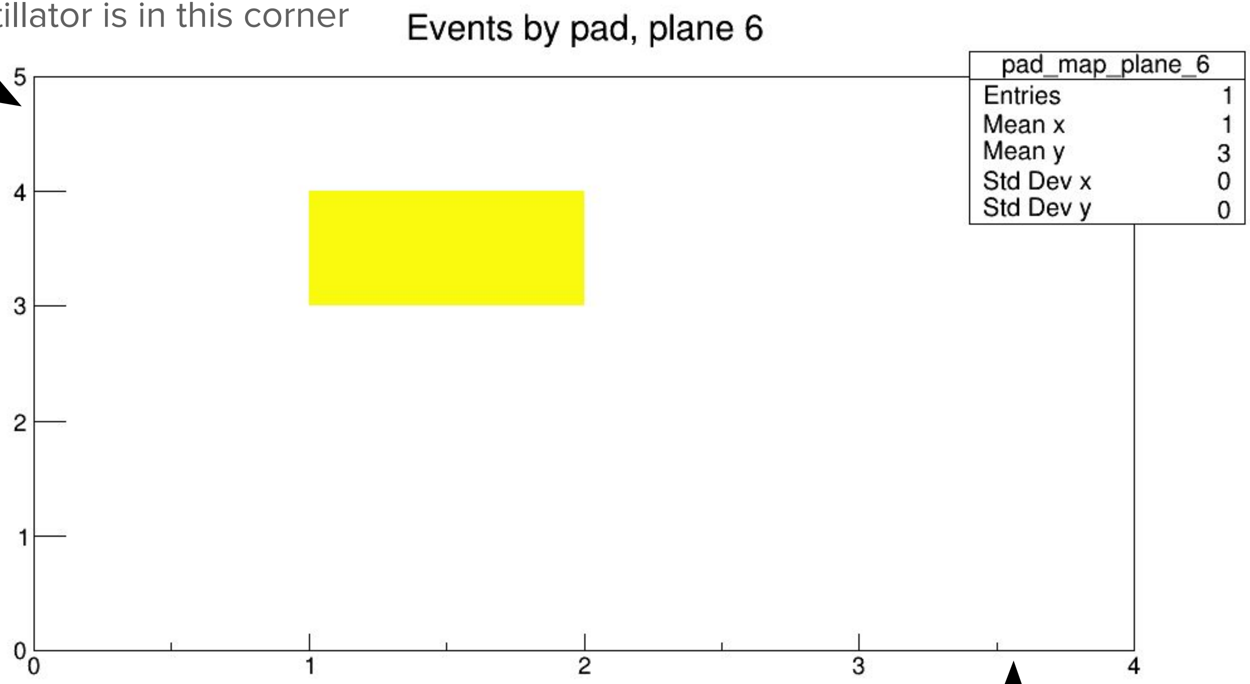


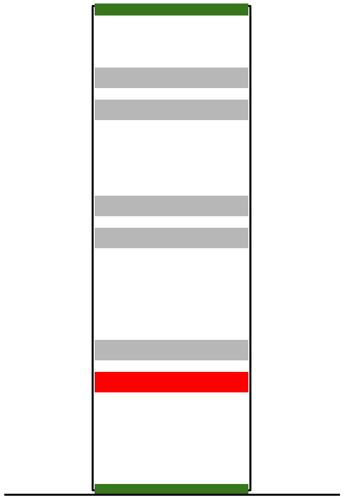


Triggering top scintillator is in this corner

"Tracking" (by hand)

Triggering bottom scintillator is in this corner



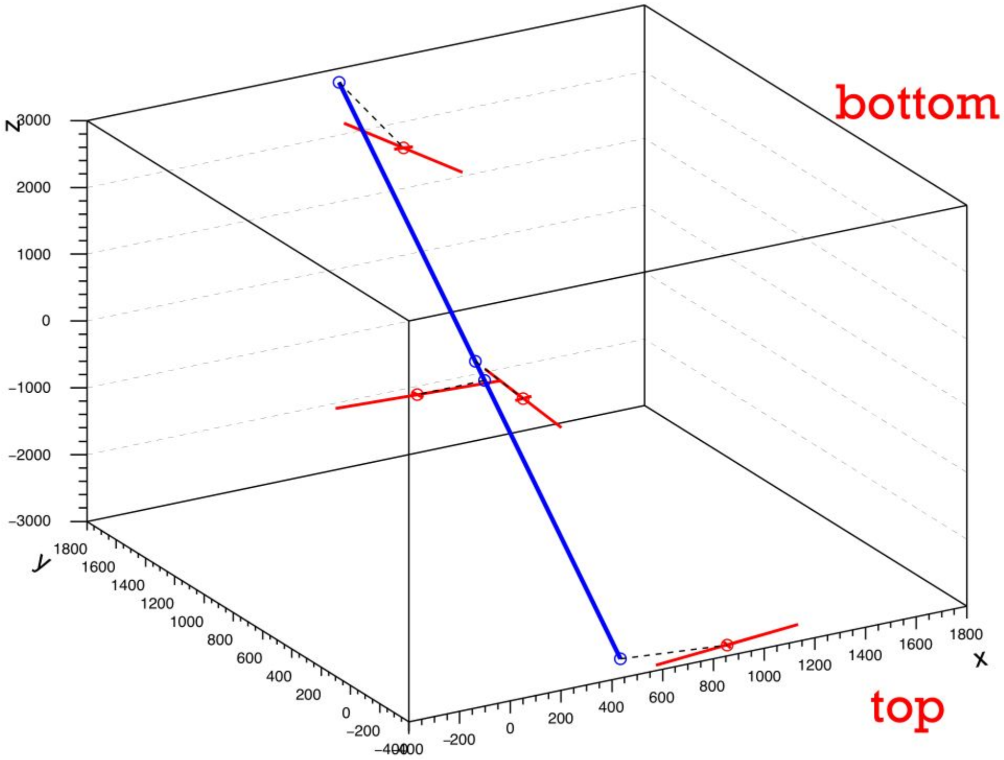


Triggering top scintillator is in this corner

(Actual) Tracking

Very preliminary!

Need to work out some bugs, verify mapping data to coordinates, allow for multiple tracks



Current status and outlook

- MATHUSLA physics case whitepaper (nearly) ready (next couple weeks)
- Ongoing analysis of test stand data:
  - Writing analysis framework
  - Starting tracking
  - Optimizing RPC voltage settings
  - Timing calibration
- Simulation work in progress
- Preparing letter of intent (next few months)
- Lots of work to do!
  - Limited by number of people and time availability; anyone interested is encouraged to join!
  - Contact: mathusla.experiment@cern.ch