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Ultra long-lived particles searches with MATHUSLA

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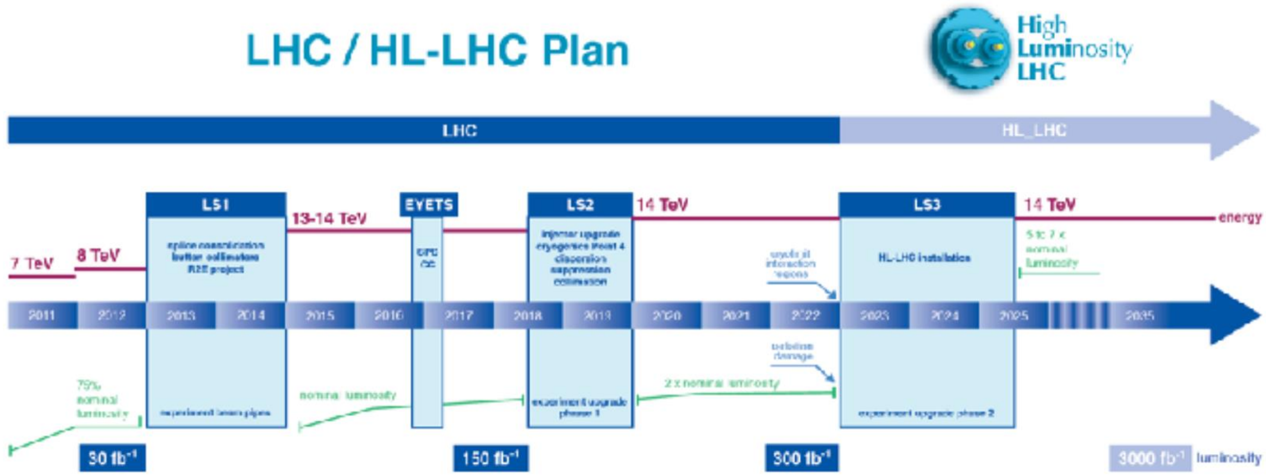
ON BEHALF OF THE MATHUSLA COLLABORATION

Outline

- The physics case for the MATHUSLA project
- The MATHUSLA test stand in 2017-2018 and a few very preliminary results
- Prospects for the MATHUSLA project in 2018

High Luminosity LHC

- CERN is the only lab in the world where you can produce Higgs bosons (and it will be that way for a long while)



  - the HL-LHC plan is to run for 10 years (beginning in ~2025) and accumulate >3000/fb of data over that time
    - This will require significant effort and money to upgrade the accelerator and detectors to handle the challenging conditions
    - Over that time, ~1.5x10^8 Higgs bosons will be produced
      - FCC-ee may reach 10^6 Higgs boson/year

Why Long-lived Particles -summary

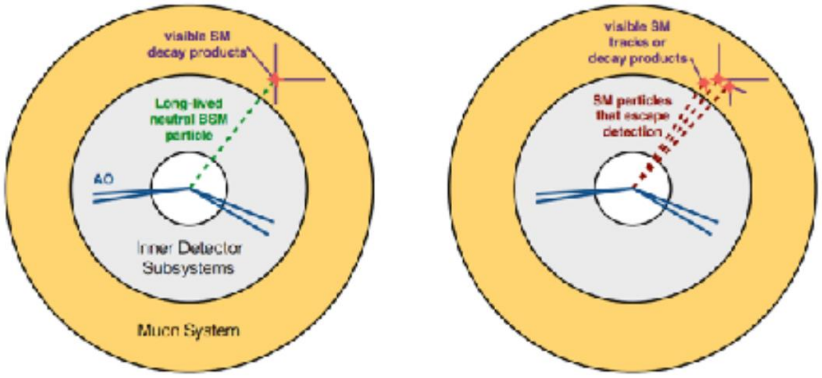
- Standard Model (SM) completed by discovery Higgs boson in 2012
- Focused attention on what SM does not address
  - Dark Matter
  - Matter-antimatter asymmetry of our universe
  - Naturalness of electro-weak scale, absent obvious TeV-scale signals of physics Beyond the SM (BSM)
- Virtually every theory/model that extends the SM to address these open issues either allows for or requires long-lived particles (LLPs)
  - Life-times ($c\tau$) can range from a few 100 μm to the Big Bang Nucleosynthesis (BBN) limit of $10^7 - 10^8$ meters
  - Covering such a large $c\tau$ range poses a major experimental challenge
- Higgs boson a particularly good place to search for LLPs
  - Very narrow width Γ/m almost two orders of magnitude smaller than most SM particles
  - Studies of Higgs couplings allow for 30-40% invisible decays
  - Higgs couples well to hidden sector scalar portals

Principles for ULLPs

- Two basic challenges for finding ultra-long-lived particles (ULLPs)
  - depth x geometrical acceptance

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

    - CMS/ATLAS are large detectors with with considerable acceptance, but…
  - backgrounds
    - QCD induced fake backgrounds are a limiting factor

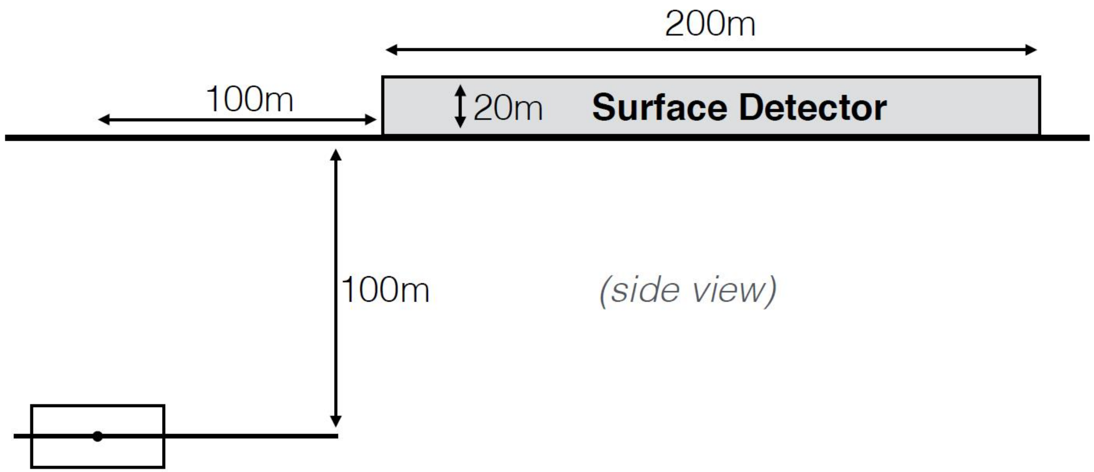


Signal Trigger iso event from BSM (a)
Signal Trigger iso event from SM QCD (b)

MATHUSLA

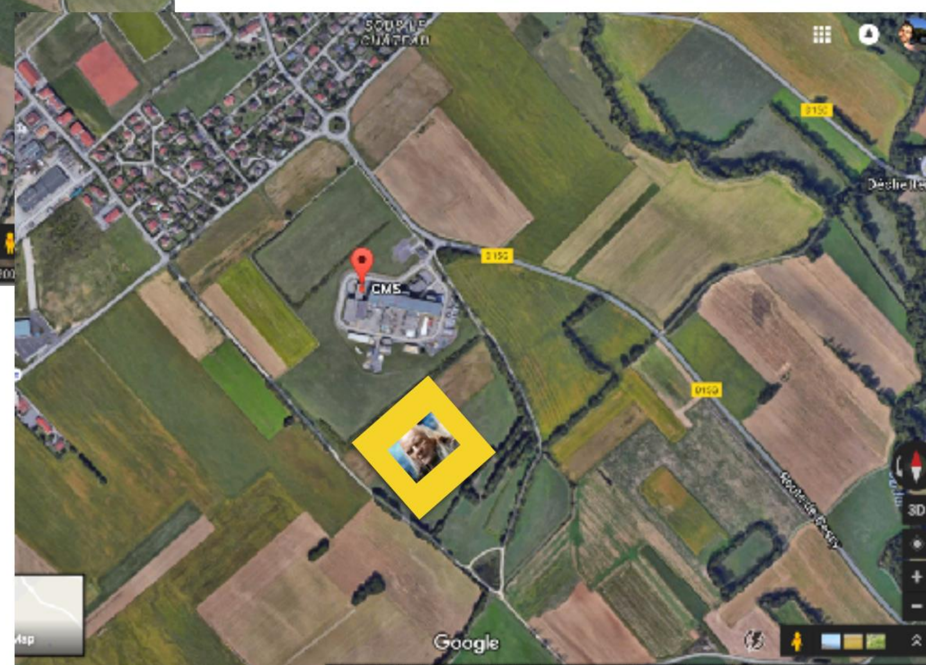
[JPC, D. Curtin, H. Lubatti arXiv:1606.06298]

- **MA**ssive **T**iming **H**odoscope for **U**ltra-**S**table **N**eutra**L** **PA**rticles



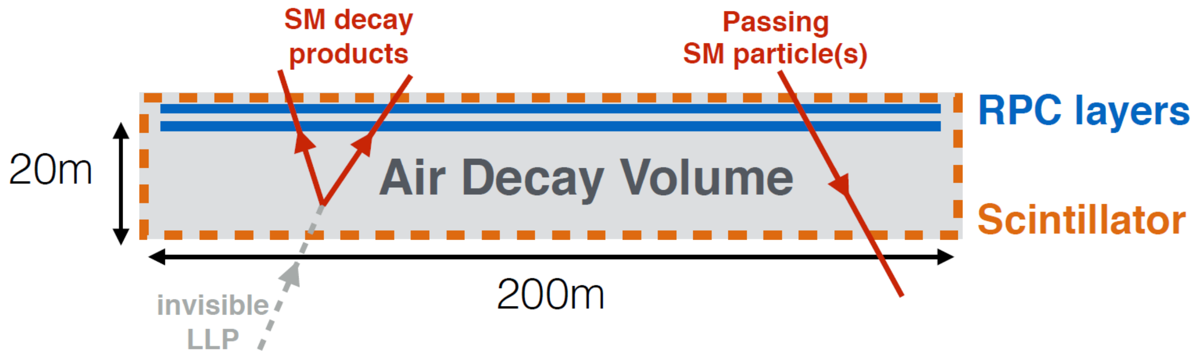
- a dedicated **surface detector** for ultra-long-lived particle (ULLP) decays
  - ~5% geometric coverage
  - minimal RPC/scintillator instrumentation required
  - can be virtually background free

HYPOTHETICAL LOCATIONS



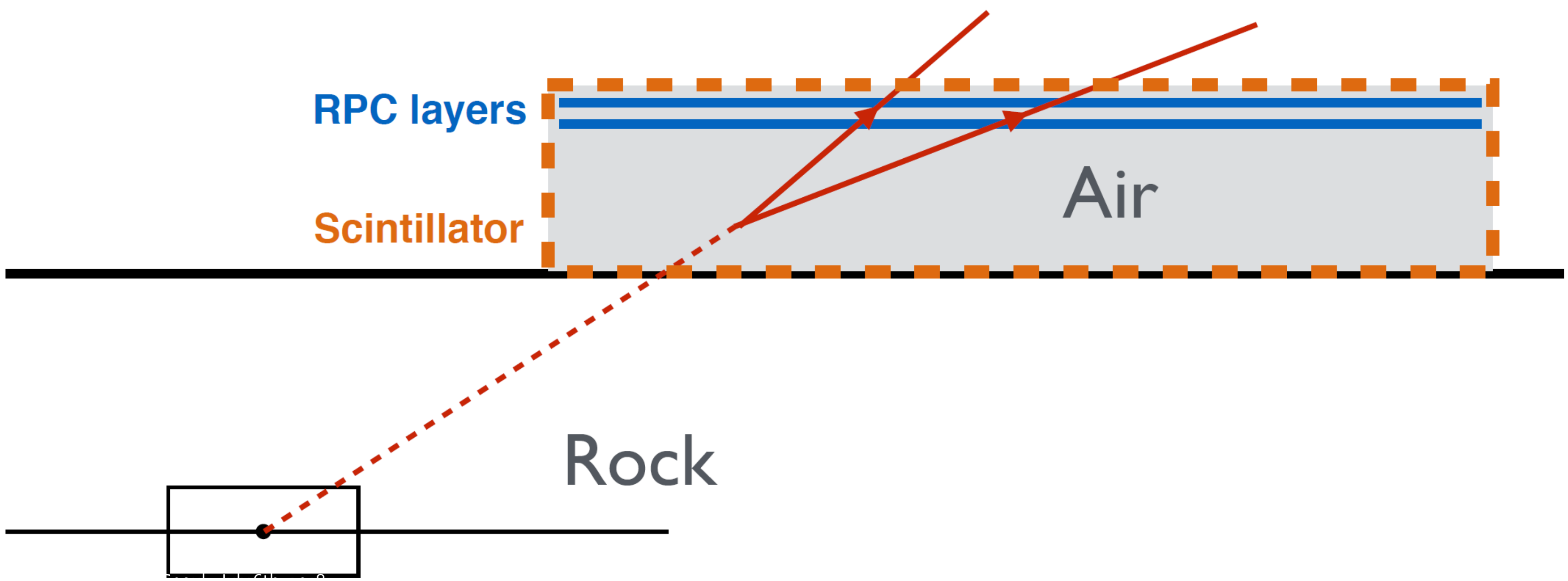
Design Sketch

- Layers of RPCs in the roof act as a directional tracker
- Scintillators give additional veto:
  - ~ns timing, ~10 cm position resolution
  - Reconstructed vertex and time-of-flight measurement of final states distinguishes LLP decay from passing cosmic rays, neutrino scattering
- Need to minimize instrumentation to keep costs down
  - Sensitivity grows with volume, cost with surface area



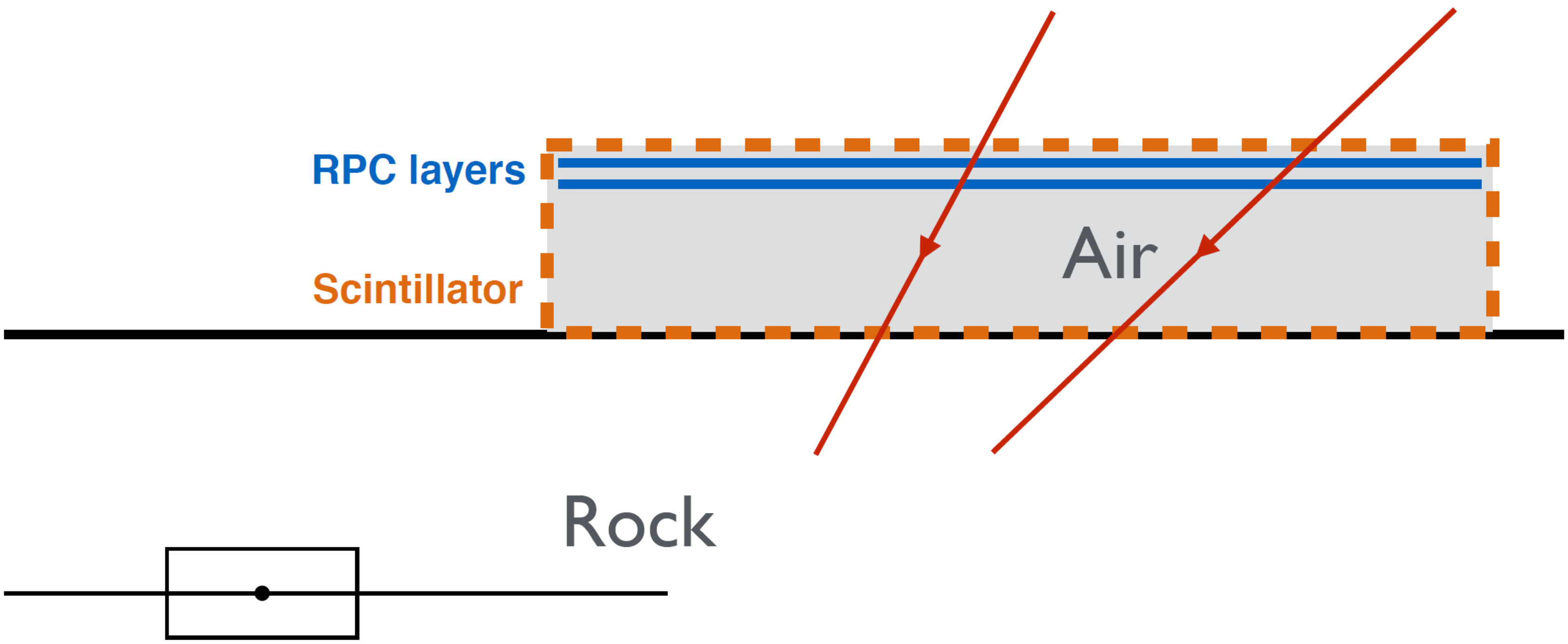
Signal v. Backgrounds

- Signal induces an upward going vertex in the detector
  - possible decay to many charged particles, but should have at least 2
  - particles should typically be relativistically boosted
    - No magnetic field complicates pointing
    - Material could help with particle ID (but induce other backgrounds)



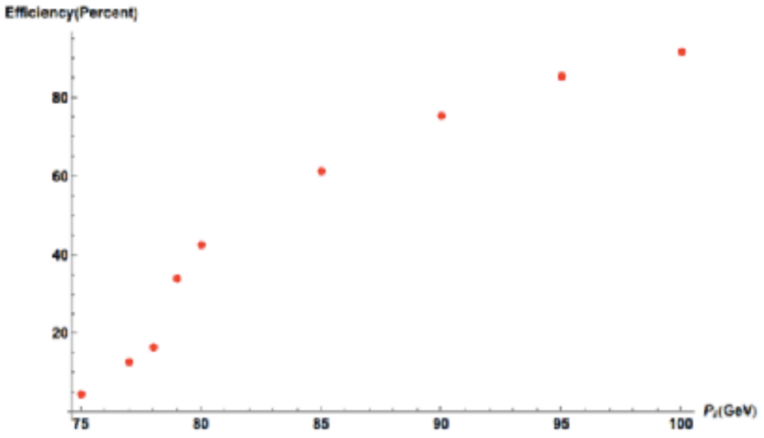
Signal v. Backgrounds

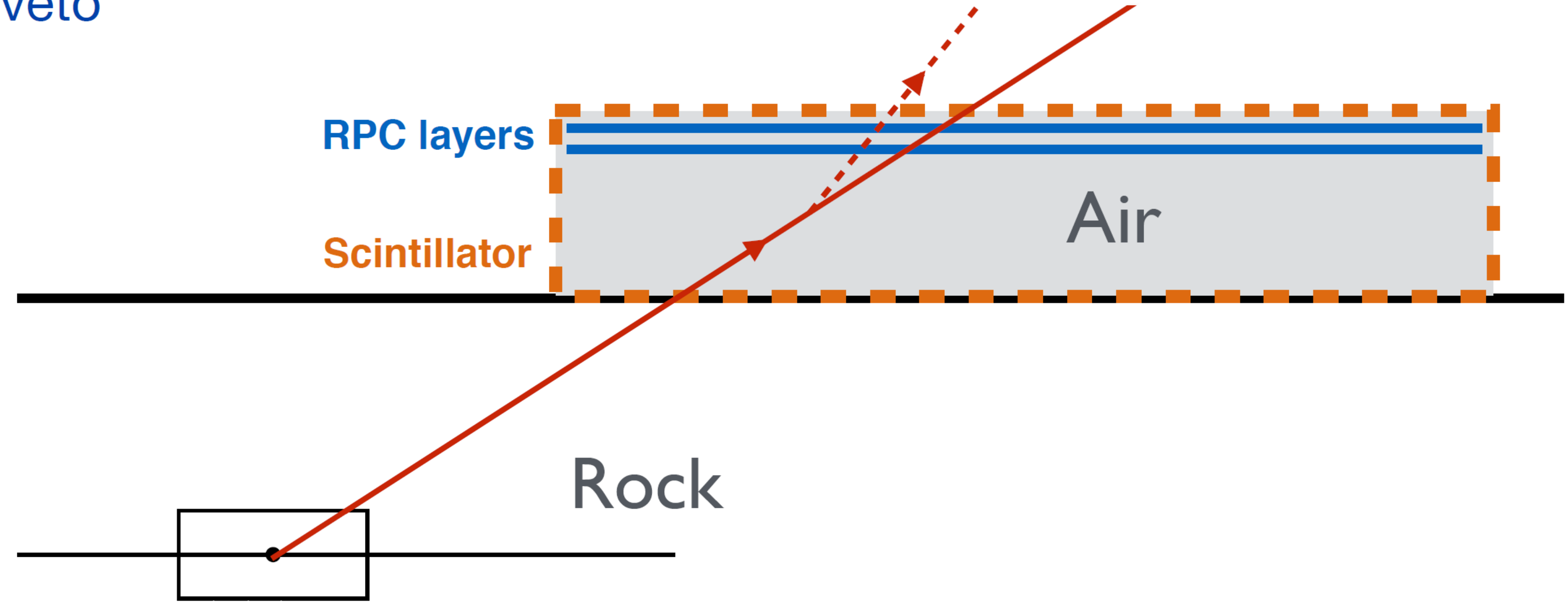
- Cosmic Muons
  - ~10 MHz rate, but many handles to reject
    - downward going, so can be rejected with timing
    - also reject if track punches through the floor
    - no vertex



Signal v. Backgrounds

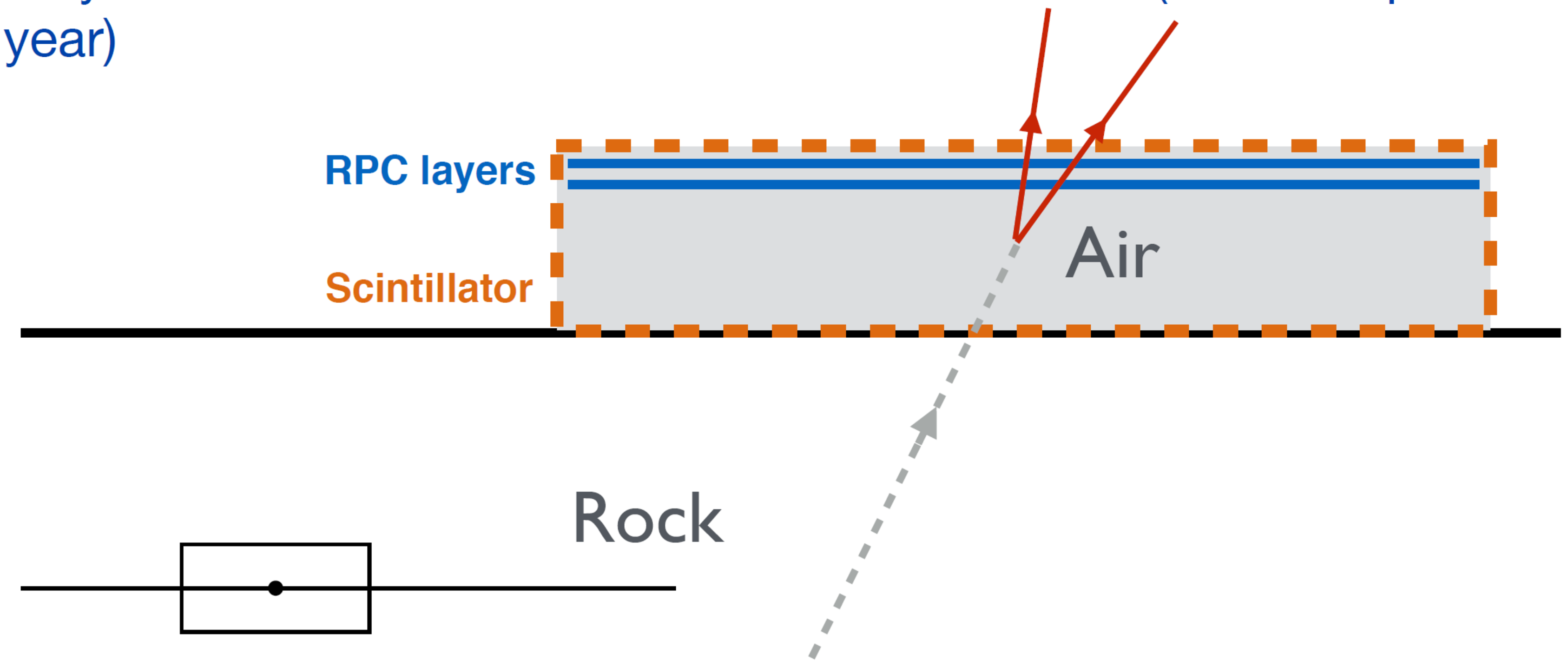
- Muons from the collision
  - ~1 Hz rate
    - veto tracks that pass through floor
    - no vertex
  - inelastic scatter rate is small, and still can be rejected with a floor veto





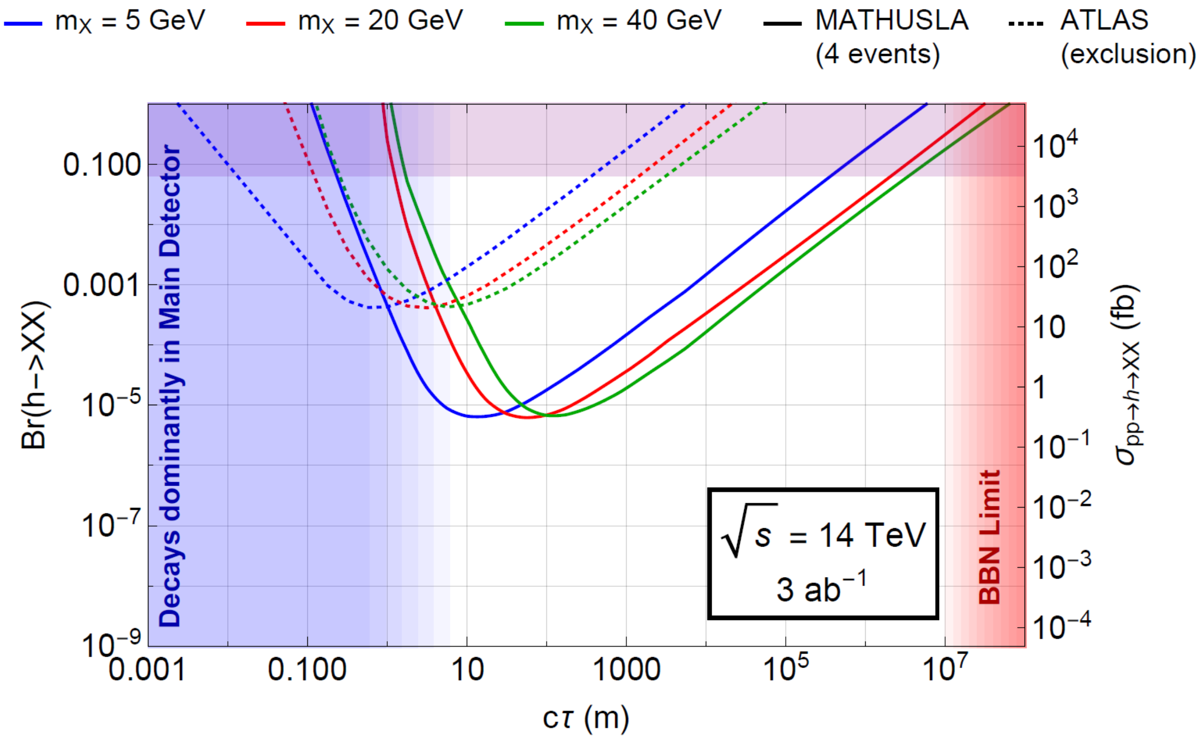
Signal v. Backgrounds

- Neutrino backgrounds
  - Low rate from cosmic neutrinos (10-100 interactions per year above 300 MeV)
    - final state proton is **slow**: reject with time-of-flight
    - also non-pointing; study during beam down-time
  - Very low rate of neutrinos from LHC secondaries (<1 event per year)



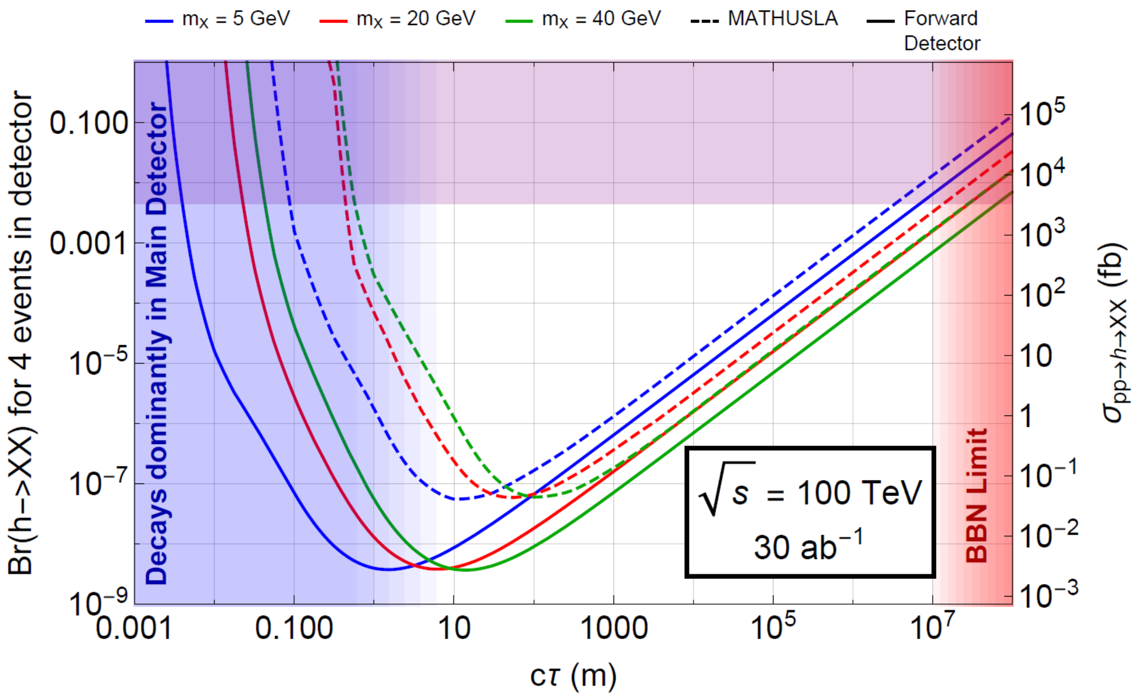
Possible Reach

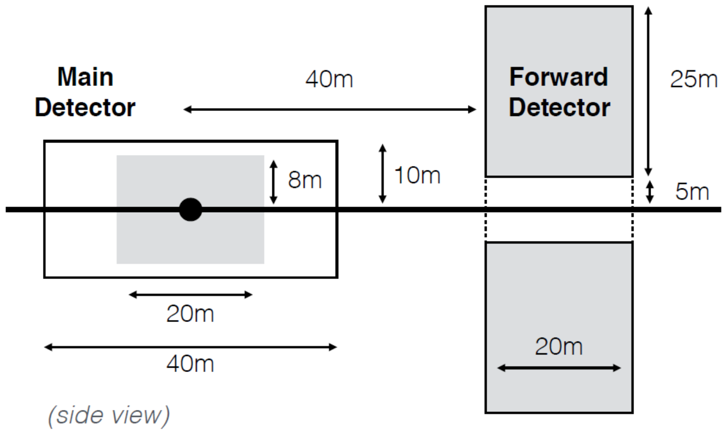
- Such a detector could get close to the BBN limit for **a very large class of models** (not just Higgs portal)
  - ~3 orders of magnitude better than projected ATLAS search over the HL-LHC (assuming zero background)



100 TeV Machine

- Reach for 100 TeV machine is naturally even greater
  - Possibility of dedicated ULLP *underground* detector
    - optimize cost/acceptance/backgrounds





Other Motivations

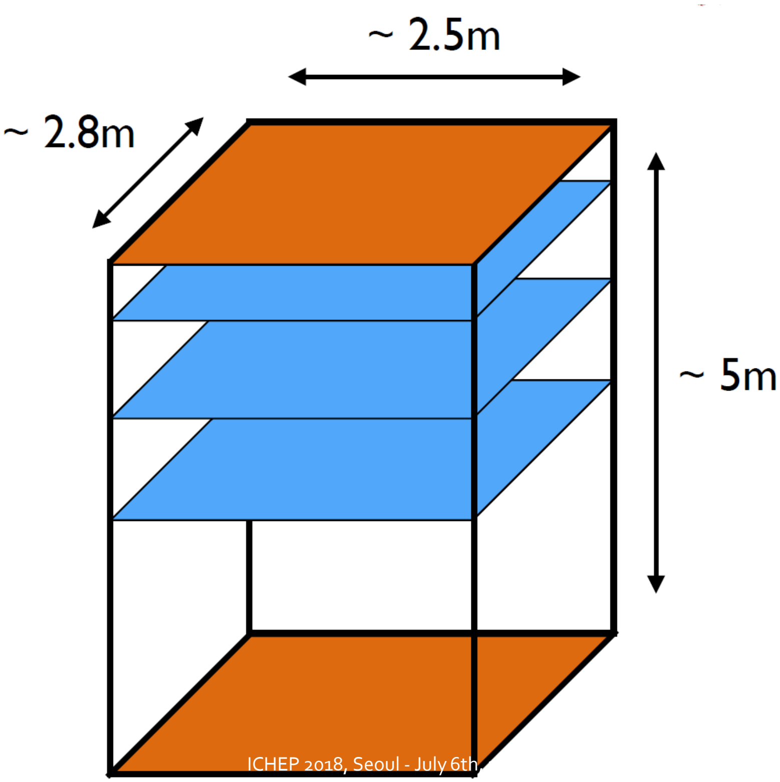
- Many different models produced neutral, long-lived particles
  - ~pb sensitivity at BBN limit to pair-produced neutral ULLPs
- Even potentially observable ULLPs in the main detector might fail to be trigger-able
- Complementary approach for DM searches
  - How do we verify that a MET+X signature is really DM and not ULLP?
  - Observation of MET+X further motivates detector

Next Steps

- Experiment: build a small prototype
  - 20 m^2 of scintillators and phototubes from spares of the D0 experiment at Fermilab
  - RPCs and electronics provided by Rome Tor Vergara group (gas provided in the construction hall by ATLAS)
    - RPC and readout come from ARGO experiment
  - Main goal is to ground the simulation of background rates in experimental measurements
    - should have discernible rate of events from LHC
- Theory: Make a more detailed physics case
  - a comprehensive report making a detailed physics case is aiming for mid 2018

MATHUSLA Prototype

Required to validate design, background estimates, etc..



Few-meter-scale test stand:

A few layers of RPCs…

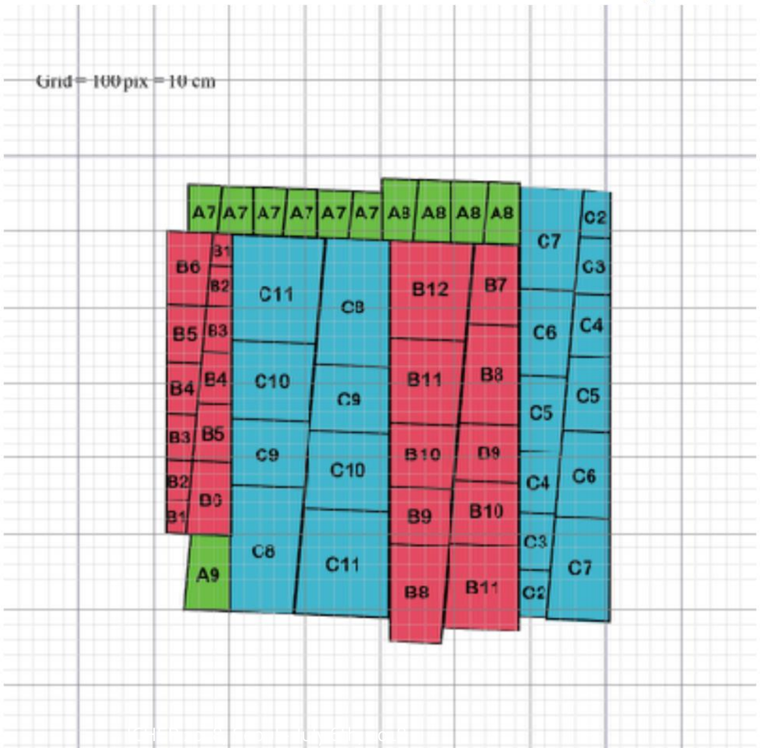
… some scintillator

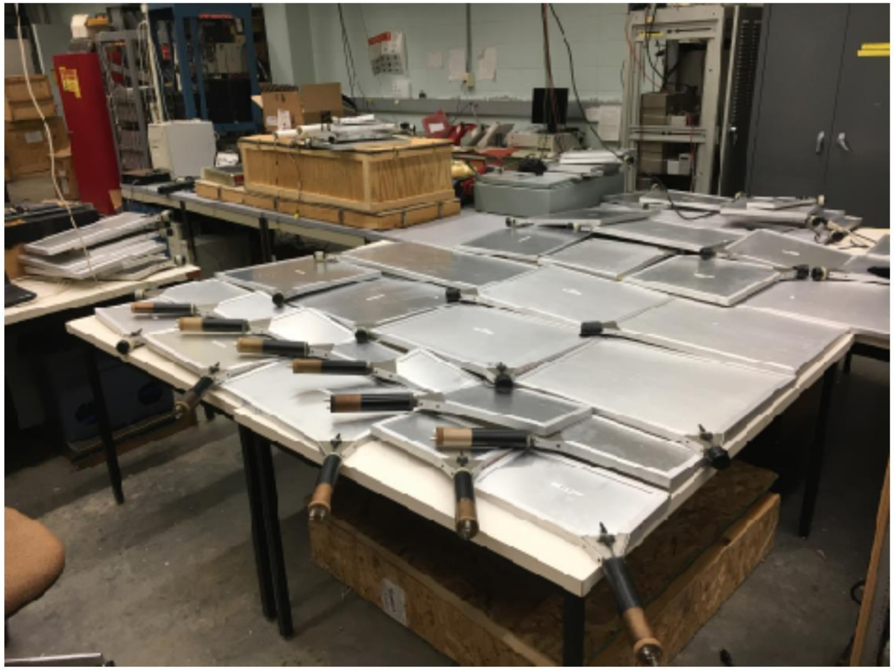
Place in ATLAS installation pit to get data with and without LHC collisions.

→ *approved by Technical coordinator*

Testing Scintillator Tiles

- Use D0 muon tiles + PMTs
  - good timing resolution (~1.5 ns) and noise characteristics
- DAQ from off-the-shelf electronics at CERN e-pool

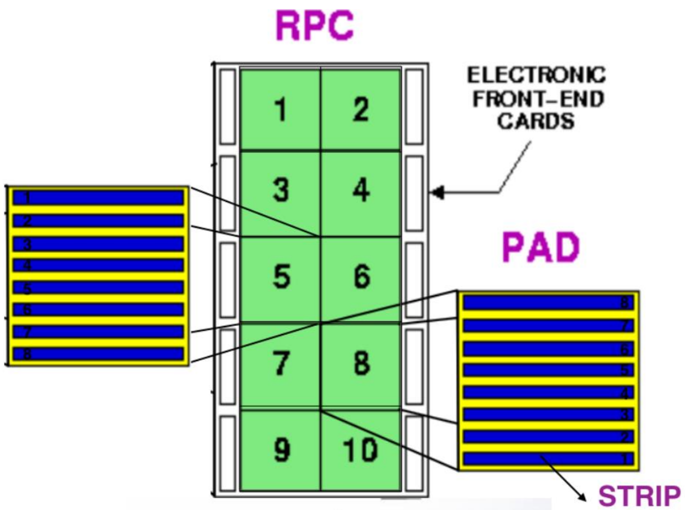


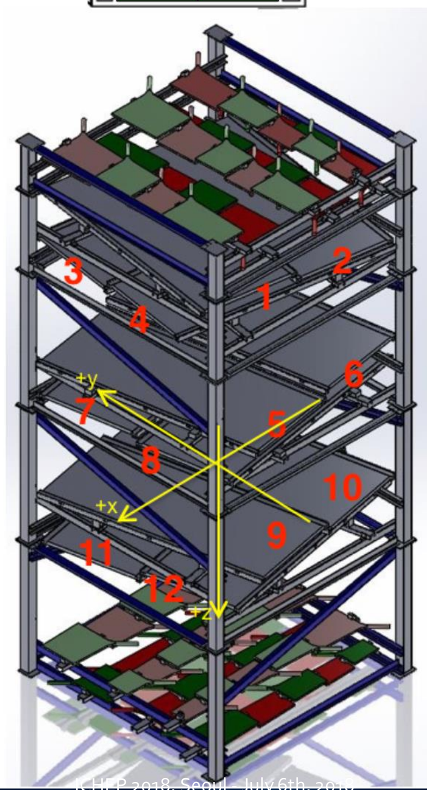


- D0 tiles designed for fish-scale mounting
  - posing a challenge to mount a grid layout

RPCs

- Supplied by University of Rome Tor Vergata, chambers + DAQ systems from prototype of ARGO cosmic shower experiment in Tibet
  - 12 chambers → can use 4 to make an RPC layer of 2.5x2.8 with ~cm tracking resolution in x-y plane
  - 3 layers, O(1m) apart, will give 3D tracking
  - run with ATLAS RPC gas mixture with the addition of Ar (about 20%)
  - gas supplied by collision hall


RPC
ELECTRONIC FRONT-END CARDS
PAD
STRIP
1 2 3 4 5 6 7 8 9 10


+y
+x
+z
1 2 3 4 5 6 7 8 9 10 11 12


HV connector
PAD1
PAD2
PAD3
PAD4
PAD5
PAD6
PAD7
PAD8
PAD9
PAD10
1 2 3 4 5 6 7 8 9 10 11 12

MATHUSLA Demonstrator assembly in ATLAS instrumentation hall, November 2017

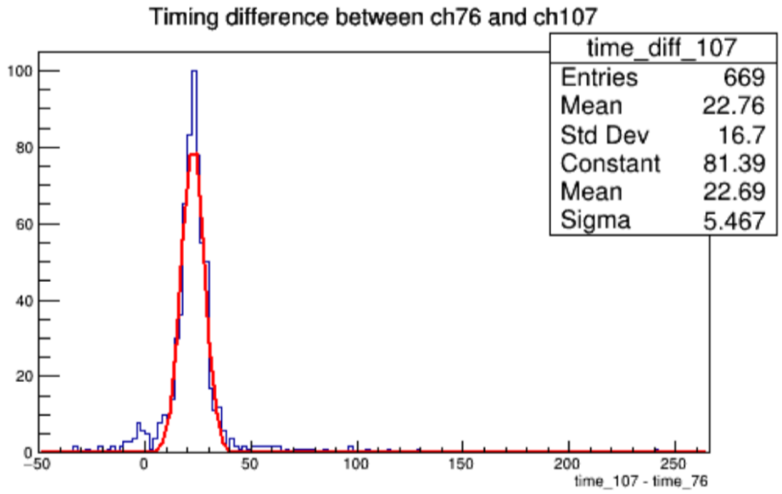
MATHUSLA Demonstrator

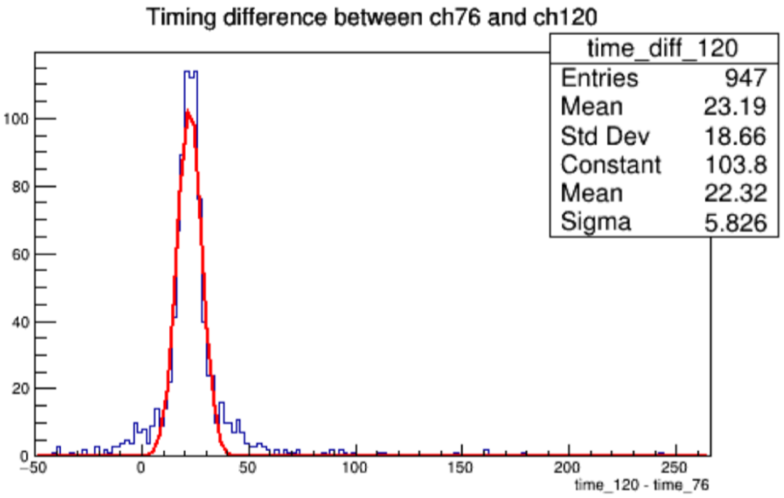
We took a few days of data above ATLAS with LHC beam on in November 2017. This should allow detection of upwards traveling muons produced in collisions, as well as cosmics. Very valuable for first BG rejection and directional track reconstruction studies.

One month of cosmic-ray-only data-taking planned in March 2018 in the H8 area at CERN (required for more careful BG estimation & calibration of Monte Carlo)
Then the set-up will move back to ATLAS P1 surface building in April 2018

DELAY OF BOTTOM COUNTERS

- Top reference counter is SA3-3, TDC channel 76
- Looking at run 498
- x axis is still in TDC counts, NOT ns (1 TDC count = 0.8 ns)

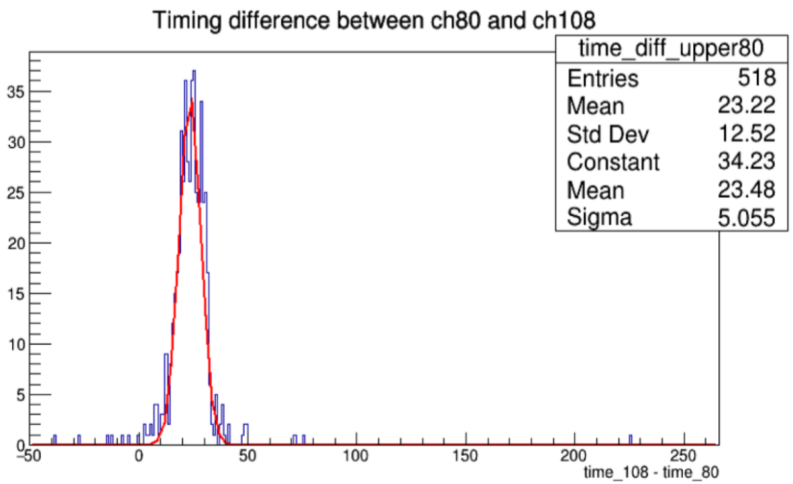


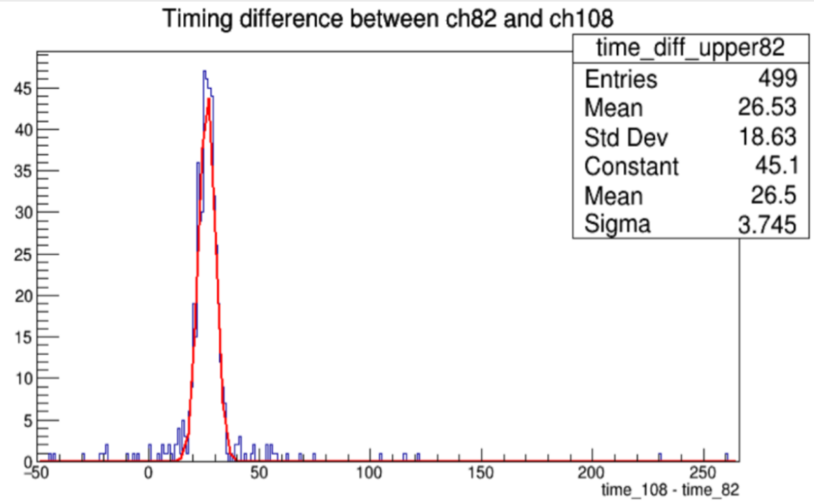


VERY PRELIMINARY

DELAY OF TOP COUNTERS

- Bottom reference counter is SB3-3, TDC channel 108
- Looking at run 498
- x axis is still in TDC counts, NOT ns (1 TDC count = 0.8 ns)

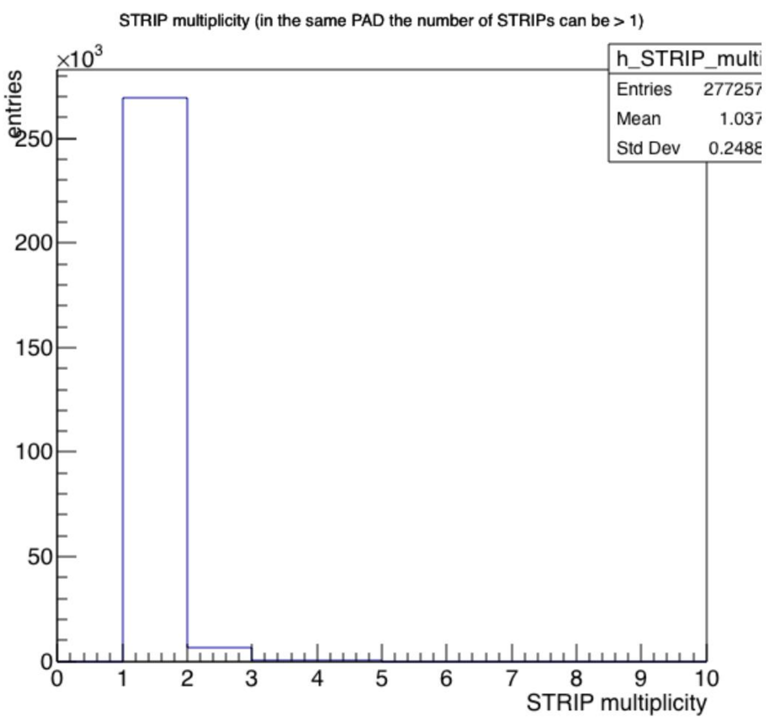


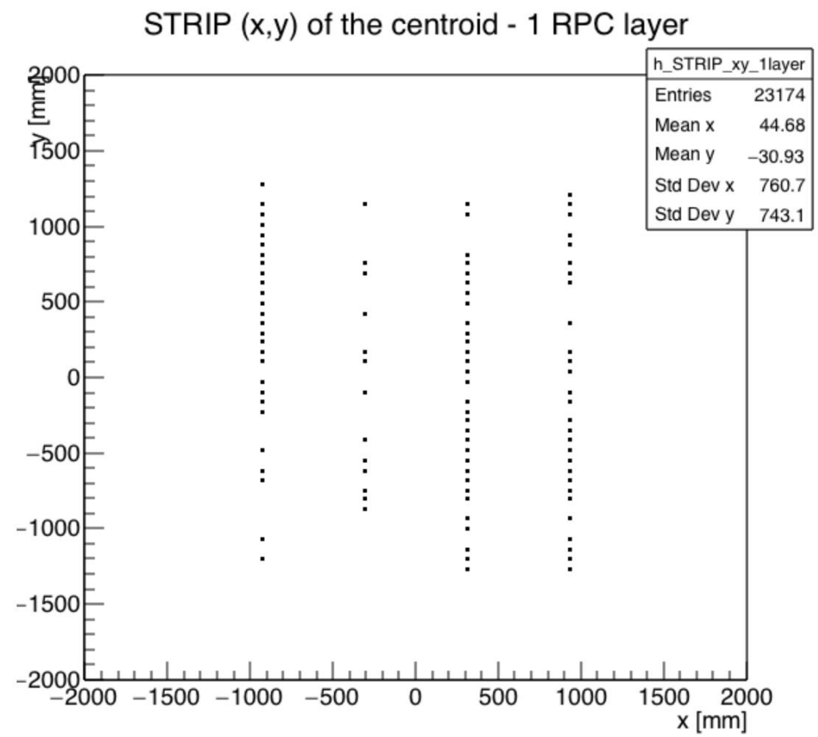


VERY PRELIMINARY

Output of the unpacking code (II)

- Hits saved event by event also in a ROOT tree
  - A TSelector based macro is provided producing some basic distributions





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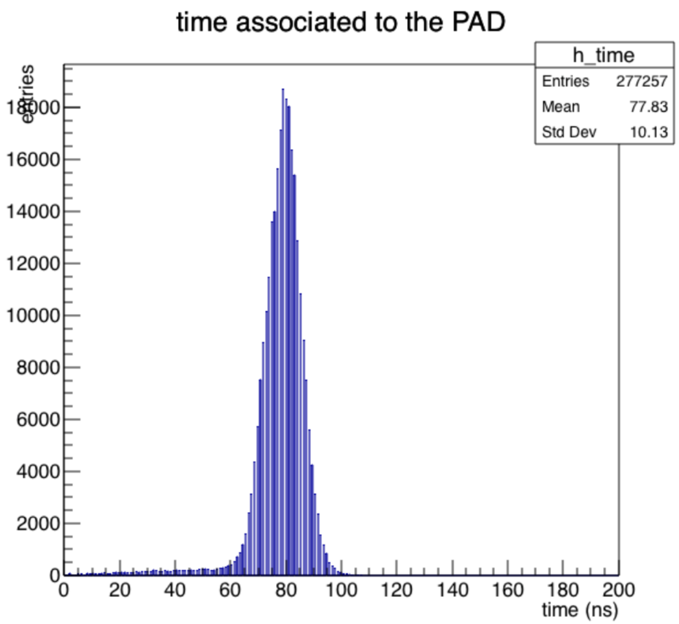
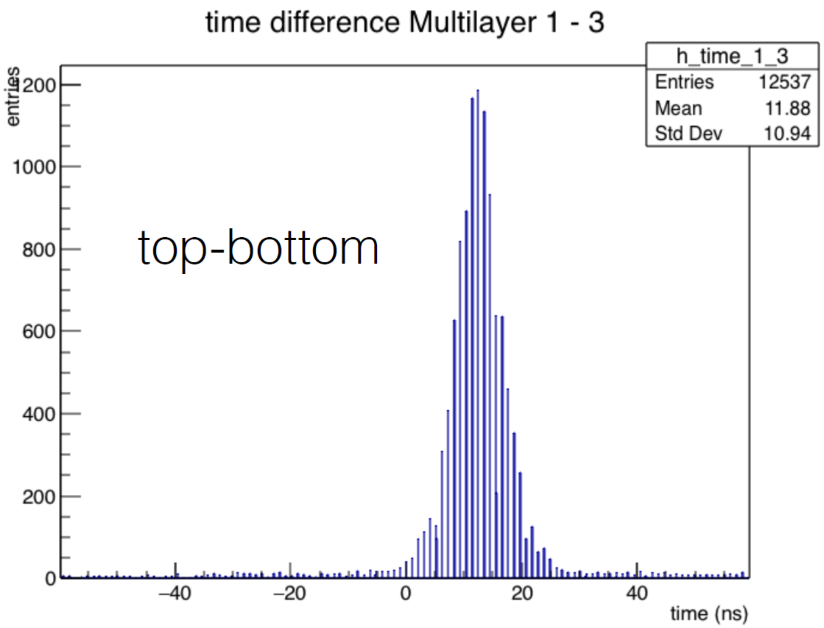




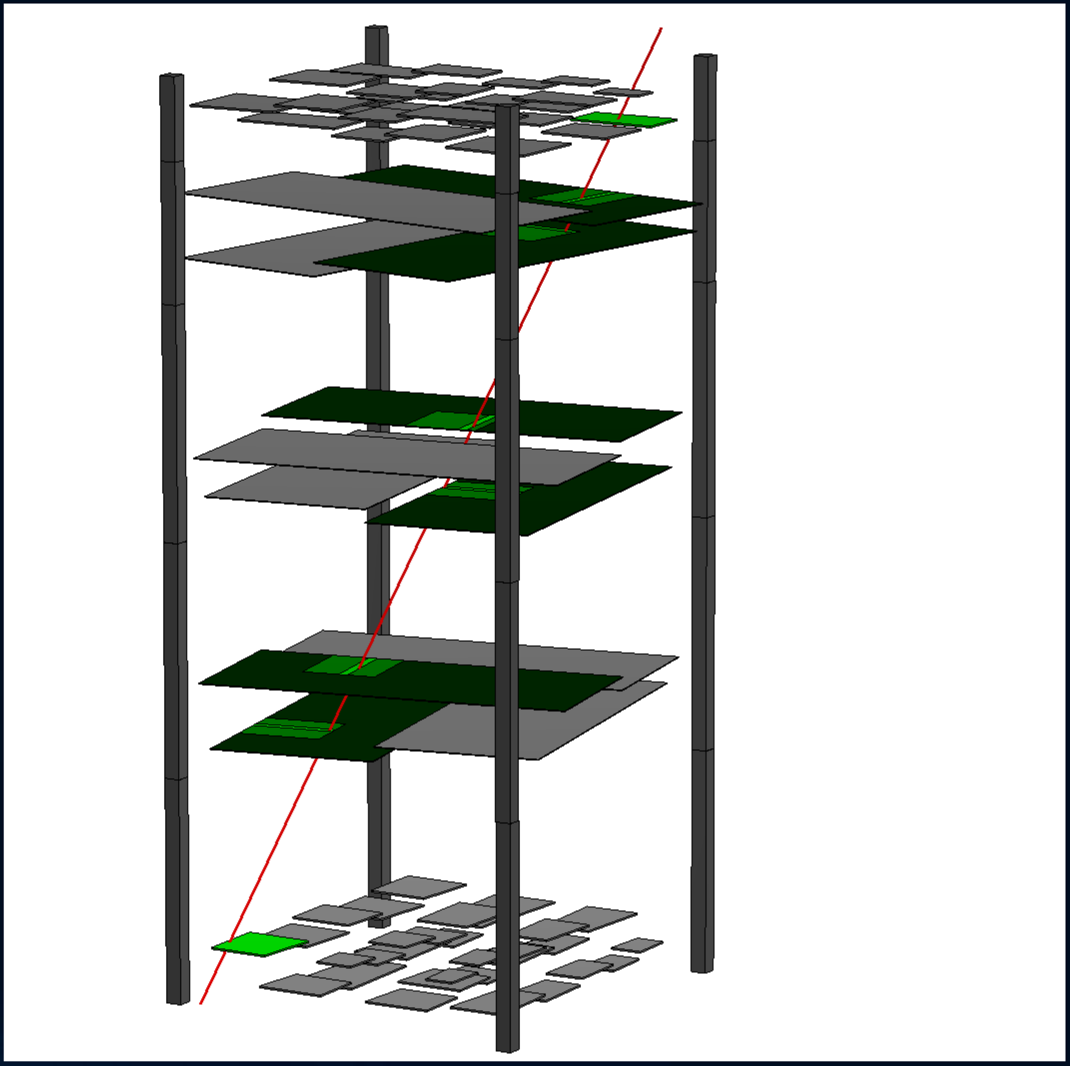
VERY PRELIMINARY

Example of reconstructed track in the MATHUSLA test

- Run 1513
- Event 2110

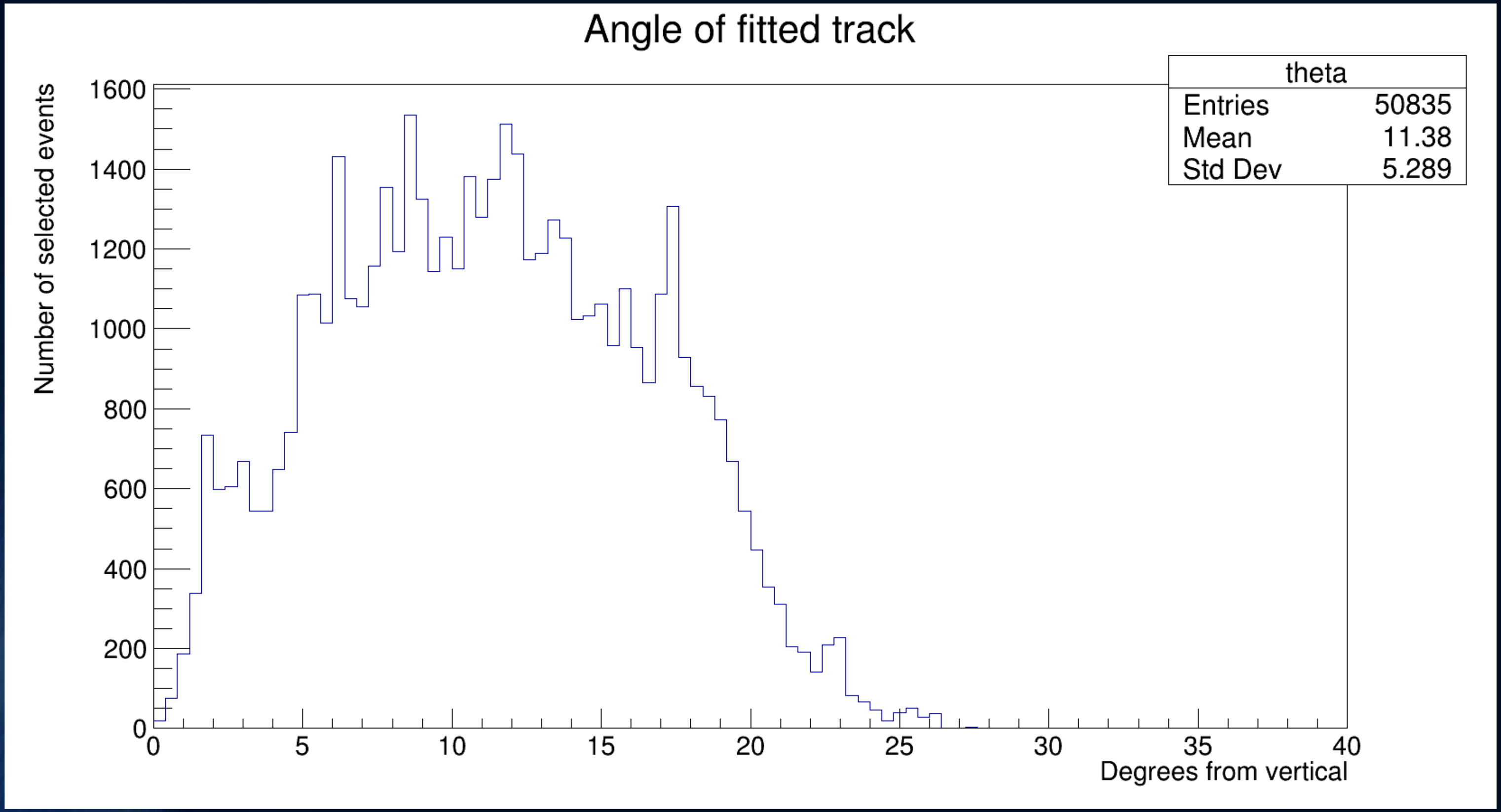
- Dark green: RPC with hit
- Lighter green: RPC pad with hit
- Light green: hits in scintillator tiles and RPC strips

- VERY PRELIMINARY



Angle distribution of tracks in the MATHUSLA test

- First look at angles (VERY PRELIMINARY)



Overview

1. Physics/Organizational Updates:
   - physics case white paper
   - new: cosmic ray physics case
   - new: MATHUSLA joins CERN PBC working group
   - popular press

2. Experimental Updates
   - Aim: Letter of Intent by mid-2018
   - Test stand took data! Analysis in progress.
   - Working towards full detector design
   - Building up simulation/MC framework
   - phenomenology support for LOI?

3. Lots to do, we need more people!
   Experimentalists and Cosmic Ray Physicists, please join us!

Fond thanks to

- Prof. Henry Lubatti (UW @ Seattle, U.S.A.) for leading the MATHUSLA project with enthusiasm
- Prof. Rinaldo Santonico for supporting this effort effectively and strongly
- Prof. Guido Ciapetti, my Ph.D. supervisor, who was one of the first proposers of the MATHUSLA project