# Potential of MATHUSLA for Cosmic Ray Physics Research

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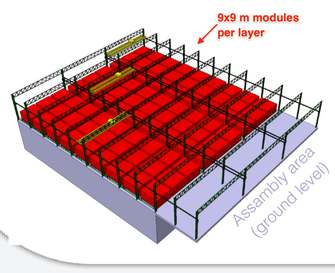
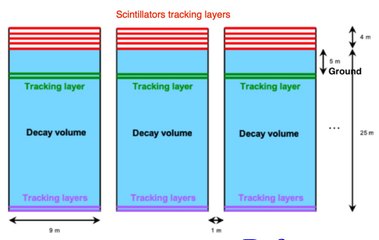
## EXPERIMENTAL DESIGN

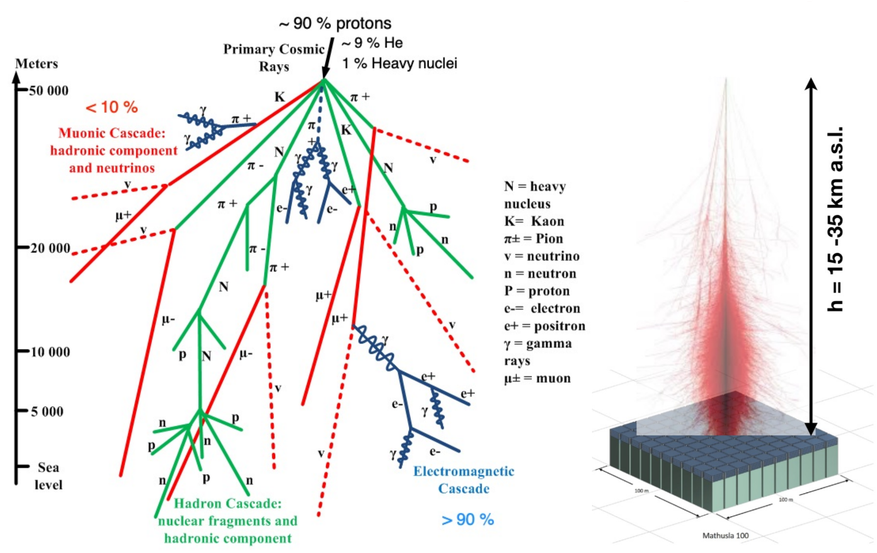
- Tracking system will consist of nine scintillator layers: five on the top (trigger); two intermediate (tracking performance); and two at bottom (veto system).
- Scintillator bars (4.5m x 4cm x 2cm) read out using wavelength shifting fibers coupled to SiPMs to wavelength.
- Detector consist of 9 m units with 9 layers of scintillator bars with hermetic coverage.
- Resolutions expected are: +/-1cm traverse to bar and order of +/- 10 cm longitudinally and timing resolution of 1 ns.




## A first glance

### MATHUSLA can also detect Extensive Air Showers (EAS)





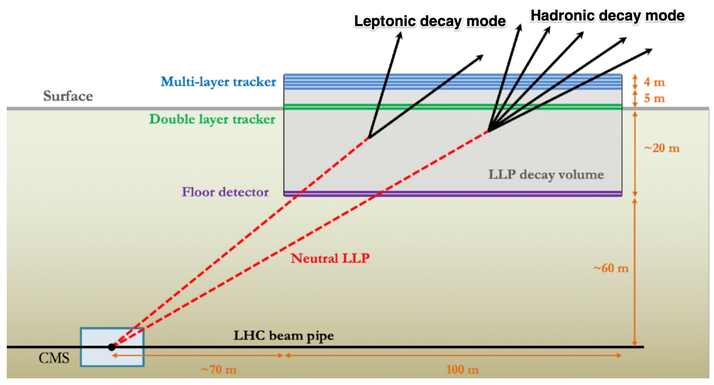


Reference proposal: Letter of Intent for Mathusla, CERN-LHCC-2018-025, LHCC-I-031

## MATHUSLA OVERVIEW

### MAssive Timing Hodoscope for Ultra Stable neutraL pArticles

- Will build a large volume (100x100x25 m) hodoscope to look for Long Live Particles' decays in a very low background conditions.
- Detector would be located above CMS-CERN detector @ ~70 m from interaction point.
- The goal is to have MATHUSLA ready to take data at HL-LHC turn-on.



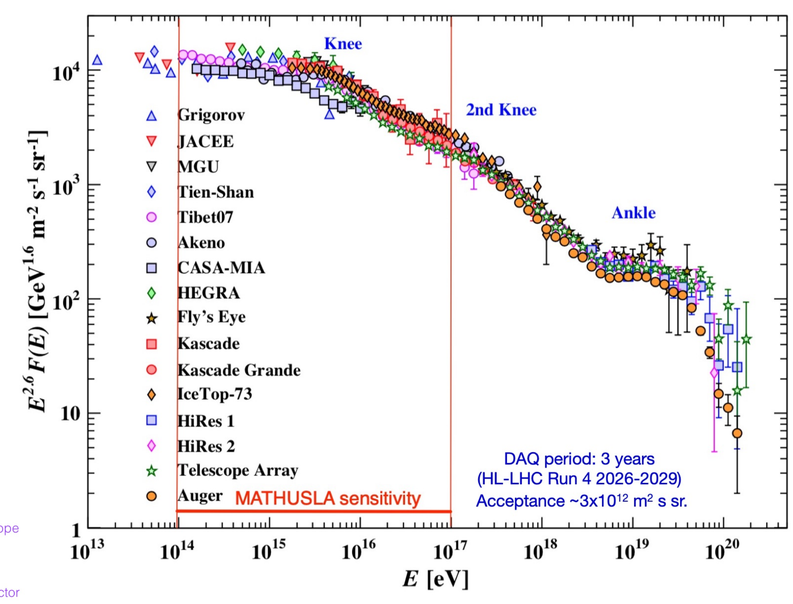

# MATHUSLA as a Cosmic Ray Detector

## Why MATHUSLA?

- MATHUSLA will cover a large area ($10^4$ m$^2$) with radiation detectors, which makes it a very sensitive detector for EAS.
- Preliminary MC studies reveal that MATHUSLA would be a very competitive Cosmic Ray detector among its peers within the energy spectrum range (0.1 to $10^2$ PeV).
- Adding an RPC (Resistive Plate Chamber) detector layer, would make MATHUSLA a unique detector to enhance EAS capability detection in comparison with its peers.

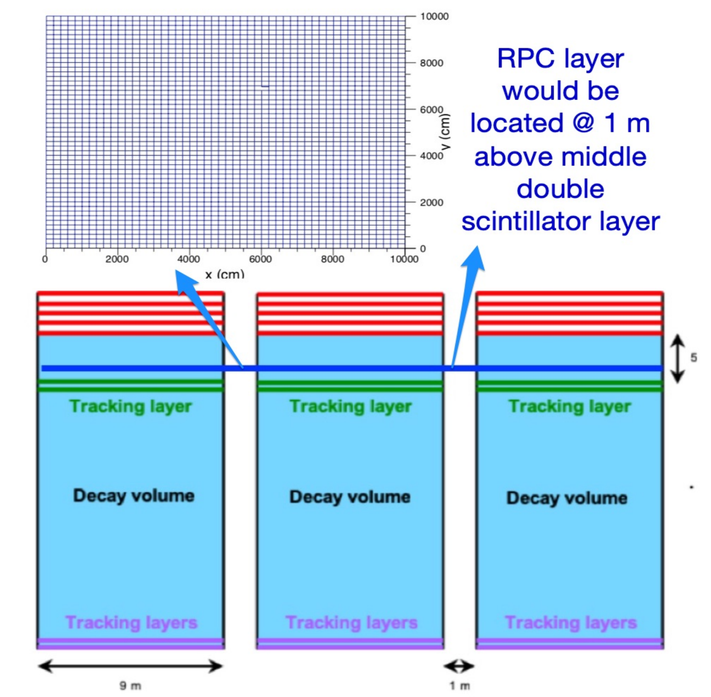
| Experiment | Energy range (PeV) | Altitude (m a. s. l) | Size ($10^4$ m$^2$) | Technique |
|---|---|---|---|---|
| MATHUSLA-100 | (0.1, $10^2$) | 380-436 | 1 | RPC, TD |
| HAWC-Outrigger | ($10^{-4}$, $O(1)$) | 4100 | 12 | WCD |
| Taiga | $> 0.1$ | 675 | 25 | IACTs |
| IceTop [9] | (1, $10^3$) | 2835 | 100 | ICD |
| LHAASO | ($10^{-4}$, $10^2$) | 4410 | 100 | WCD,AC,Sci. |
| TALE (TA) | (30, $10^5$) | 1550 | $10^3$ | FD, Sci. |

RPC: Resistive plate chamber
TD: Tracking detector
WCD: Water Cherenkov detector
IACT: Imaging air Cherenkov telescope
ICD: Ice Cherenkov detector
Sci: Scintillator detector
AC: Air Cherenkov
FD: Atmospheric fluorescence detector




## RPC extra layer highlights

- EAS enhance detection capabilities adding an RPC extra layer.
- Charge particles densities up to several $10^4$ particles per m$^2$.
- Measuring particles arrival times of 1st particle for strip @ time resolution of 1 ns.
- We're considering ARGO[1]-like design that has strips (digital readout) and pads (analog readout).
- The pad array would consist in 2500 big pads (2x2 m$^2$). This pad array would provide fine spatial-time resolution of EAS information.

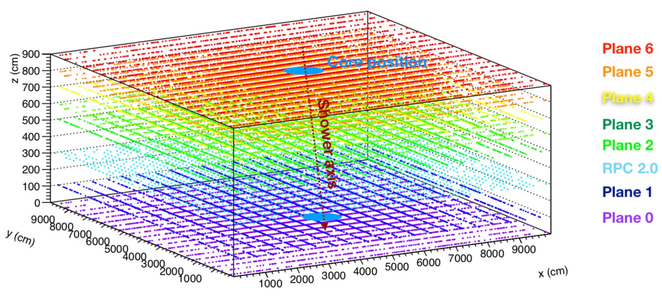



[1]B. Bartoli et al., Astroparticle Physics 67 (2015) 47-61

## Corsika QGSJETII-04 MC simulations

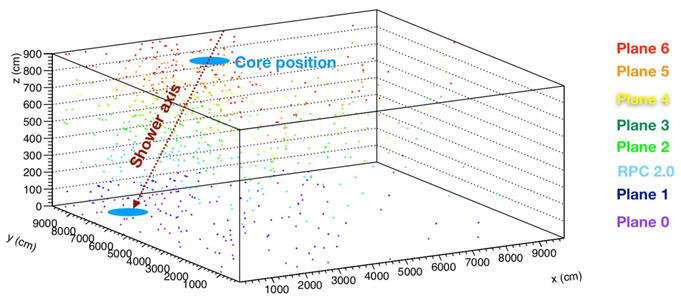
### Vertical Showers

- Primary Cosmic Ray Particle (CRP) proton $\log_{10}$(E/GeV) = 6.71, zenith angle = 6.97°.
- Very clear EAS signal on each layer of MATHUSLA (high particle density).
- Core position and particles arrival times of the shower front reconstructed.

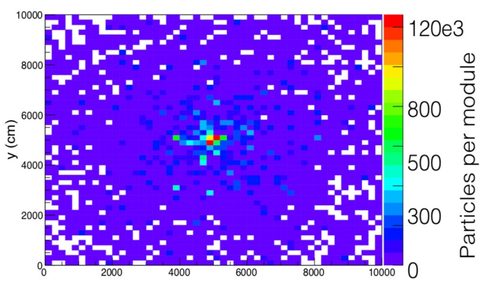



### Inclined Showers

- Primary CRP proton $\log_{10}$(E/GeV) = 7.62, zenith angle = 74.60°.
- Very clear EAS signal on each layer of MATHUSLA (low particle density).



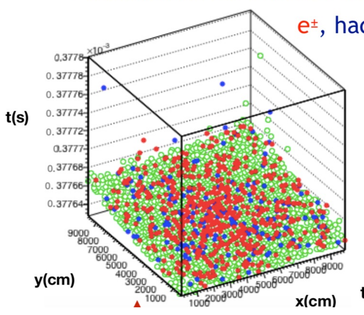

Shower core position and density at RPC




Core reconstruction with spatial and time information

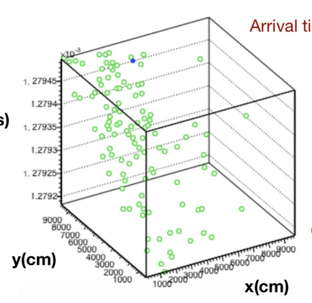
Arrival times of shower front

e±, hadrons, μ±




Electrons and muons arrive faster than hadrons




Muons are the dominant component

## SUMMARY

### Advantages and physics potentials

- Full coverage (~80%) with RPCs makes MATHUSLA a unique detector for EAS studies.
- Detailed spatial and time information from EAS.
- MATHUSLA would provide new muon data @ PeV energies for inclined EAS.
- Very useful information for energy spectrum around the knee.
- CR anisotropy studies in arrival directions of EAS.
- Test of hadronic interaction models (muon bundles).

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