



Measurement of the Integral Intensity of Near Horizontal Muons with HAWC

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For the HAWC collaboration

<https://www.hawc-observatory.org/collaboration/icrc2019.php>

ICRC 2019, Madison WI, 7 – 31 – 2019

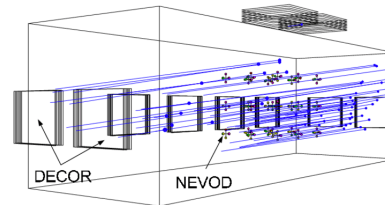
Outline

- Ancillary science topics of interest to HAWC.
- The HAWC detector as a Hodoscope
- Effective Area of HAWC to Near Horizontal Muons
- Rock Overburden
- Muon Counts and Exposure Vs Depth
- Integral Intensity.

Ancillary Science Topics of Interest

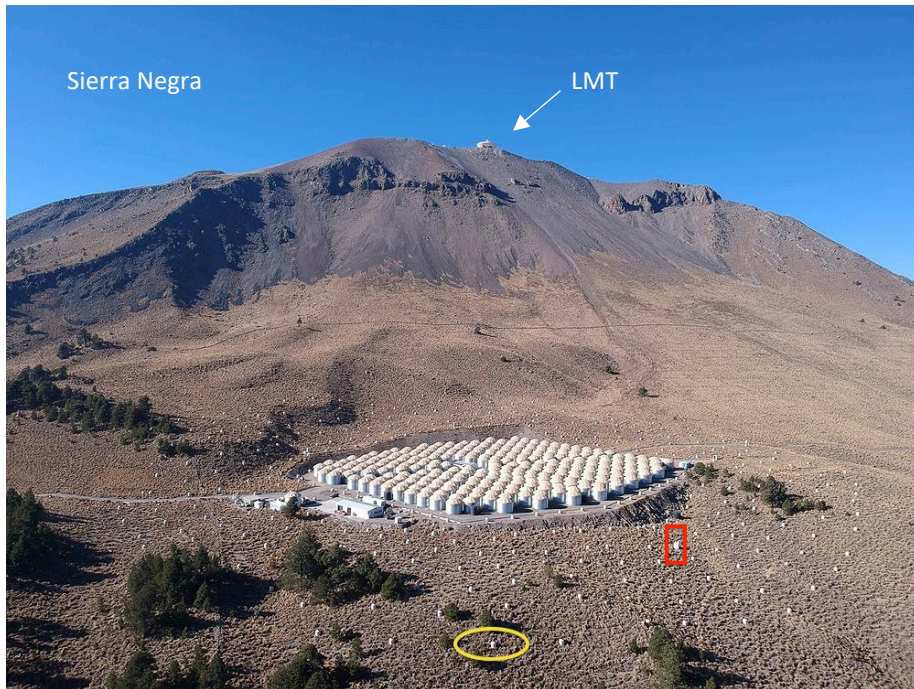
- Neutrino interactions within the Volcanoes (primarily Pico de Orizaba)
 - PS2-111: Prospects of Earth-skimming neutrino detection with HAWC
 - **Hermes Leon Vargas**, Instituto de Física, UNAM
- Cosmic Ray Composition near the Knee - Multiple Muon Events
 - Simultaneous arrival of multiple muons
 - HAWC has the potential to see these events
 - DECOR-NEVOD is approximately 8 WCDs in HAWC
 - HAWC has observed a few multi muon events
- Previous ICRC 2017 detection of High Energy muons: 1.2 Hz
 - PoS(ICRC2017)512

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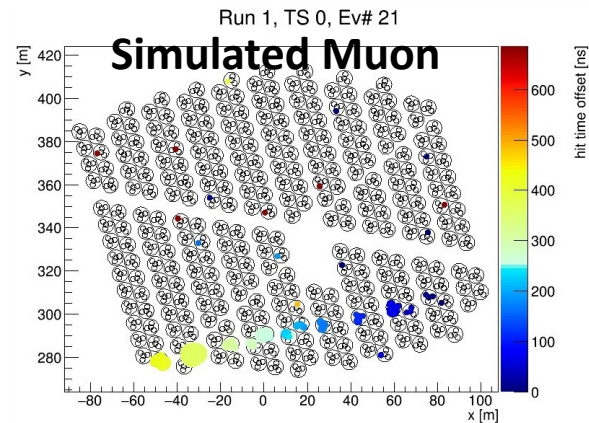
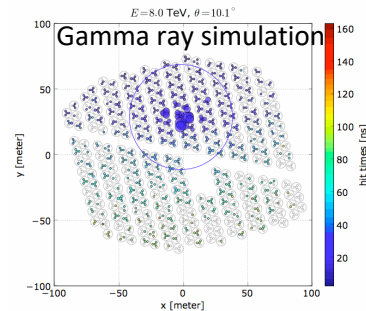
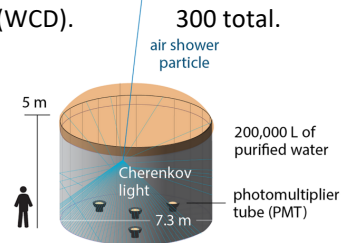


Décor-Nevod: Investigation of Muon Bundles in Horizontal Cosmic Ray Flux, ICRC 2003, Igor Yashin et al.

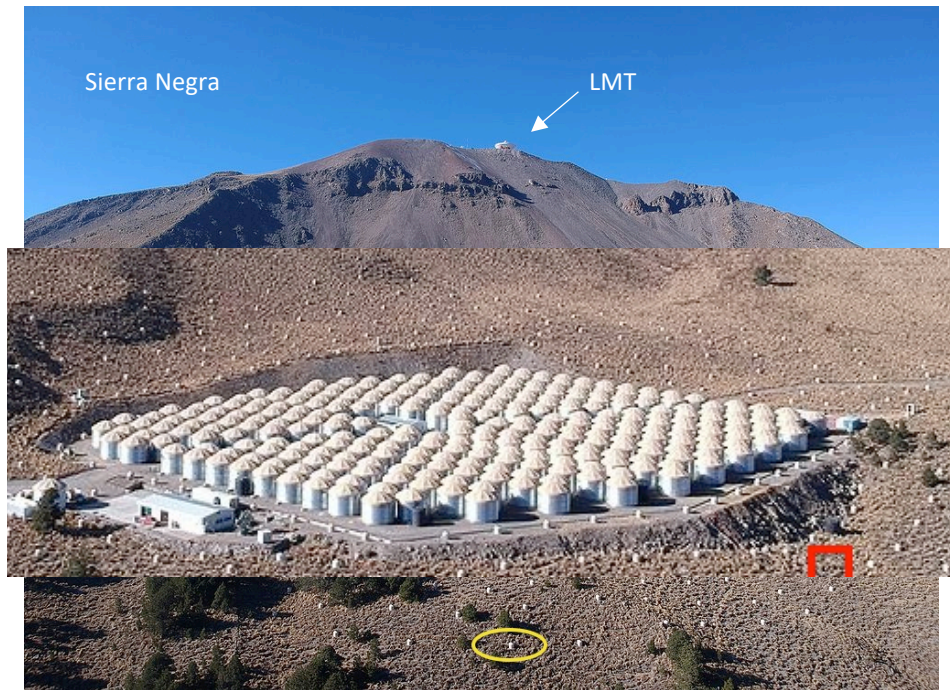
HAWC – High Altitude Water Cherenkov



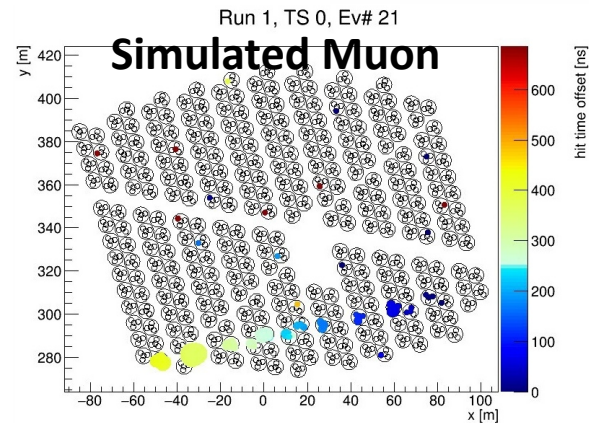
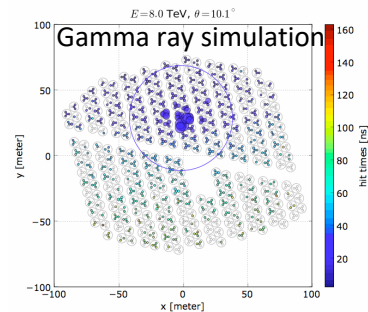
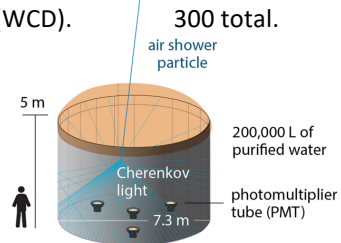
Water Cherenkov Detector (WCD).



HAWC – High Altitude Water Cherenkov

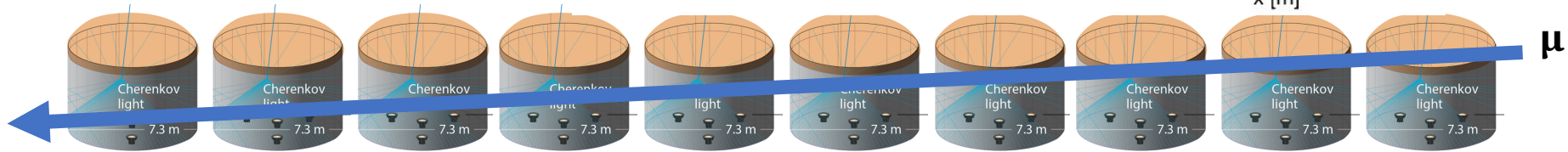


Water Cherenkov Detector (WCD).





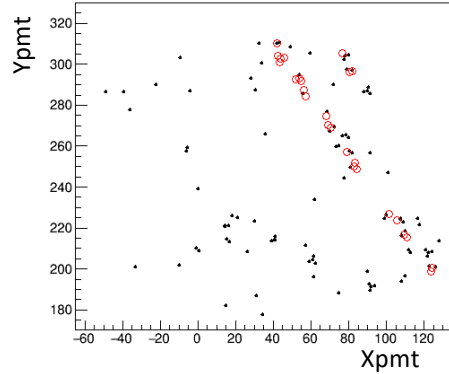
THE UNIVERSITY OF UTAH
Department of
Physics & Astronomy



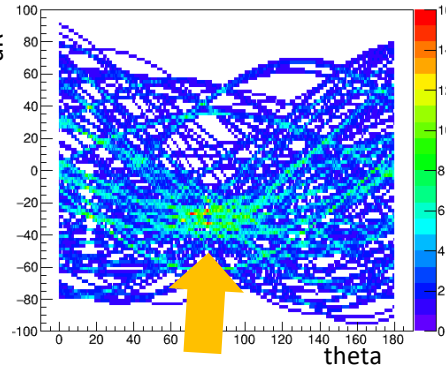
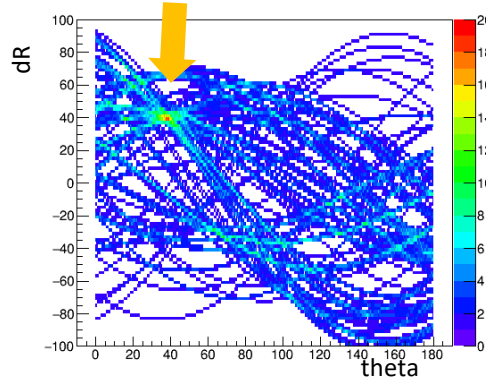
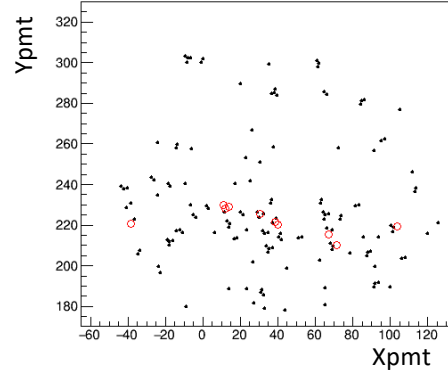
Muon Identification in 2 Steps:

Step 1

Muon



Air Shower



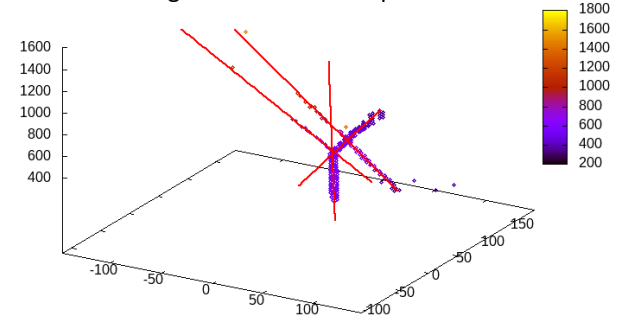
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Near Horizontal Muons with HAWC

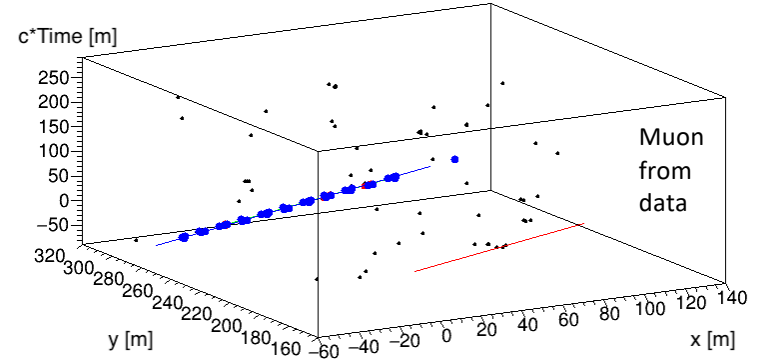
Step 2

'input_0.dat' using 1:2:3

3D Hough Transform Example*



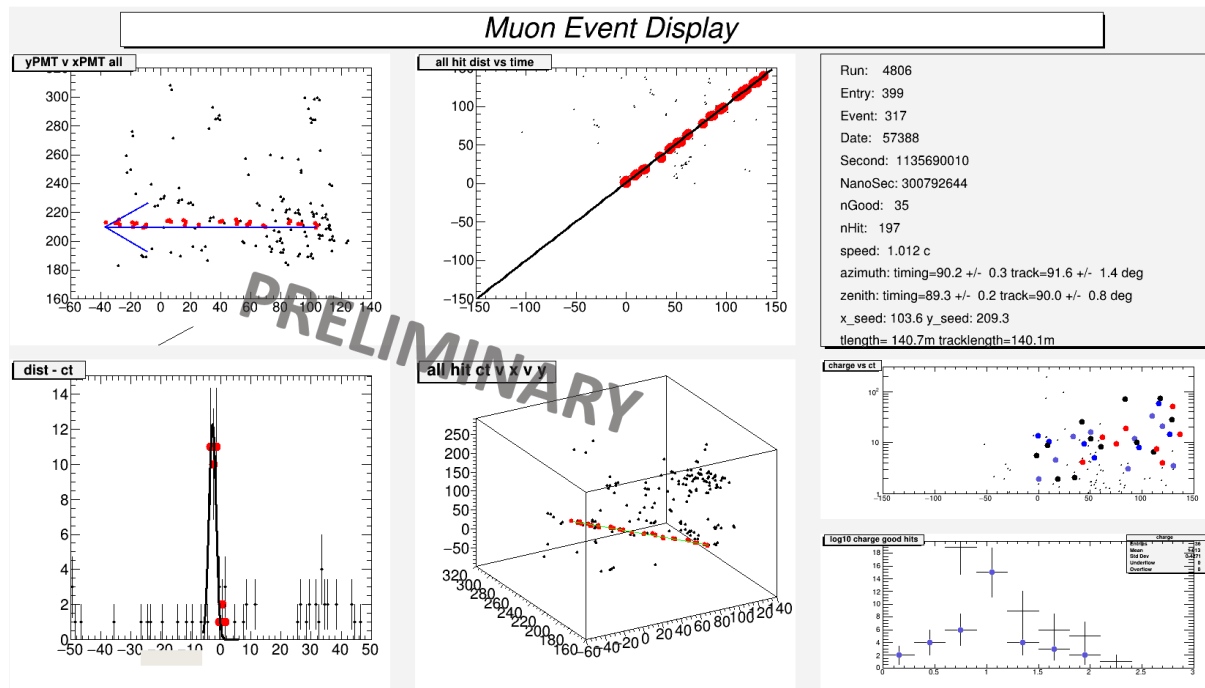
all hit ct v x v y



* <https://doi.org/10.5201/ipol.2017.208>

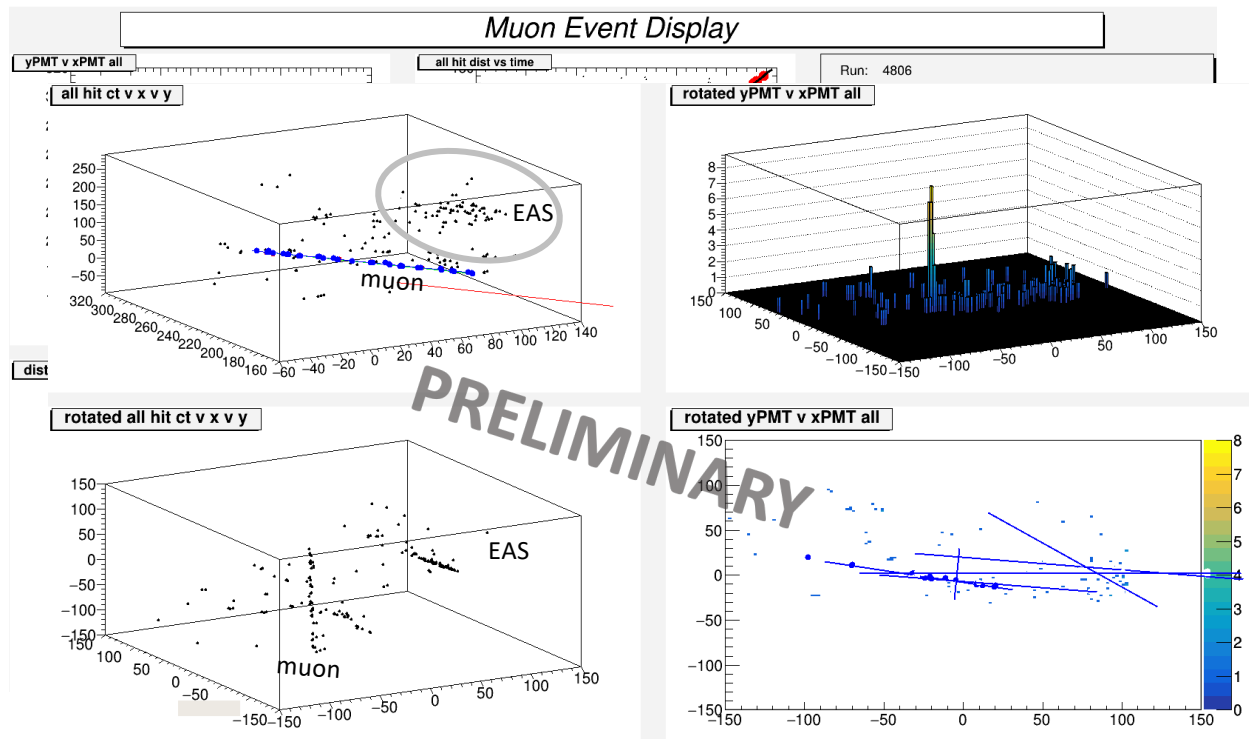
The potential power of the 3D Hough Transform

- Muon coincident with & independent of an EAS
- $X \times Y \times (c * T)$ space shows independent separation.
- This is currently done by our human eye.
 - Automation in progress



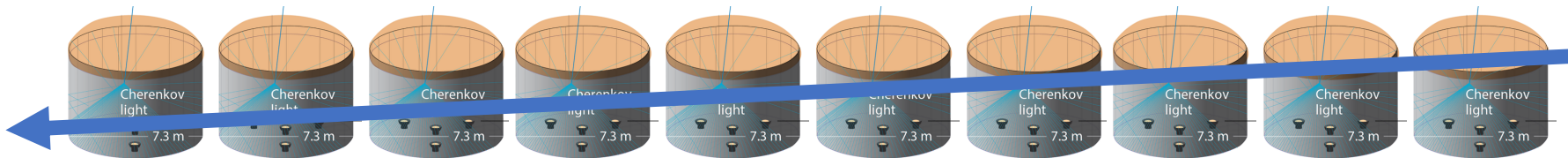
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- Multi-Muon Events
 - Similar to EAS events for RH_{frac} values.
 - These are wider events than single muons.
 - Bundles are up to 10 m wide or single muons separated by 10's of meters. As seen by other experiments and HAWC.

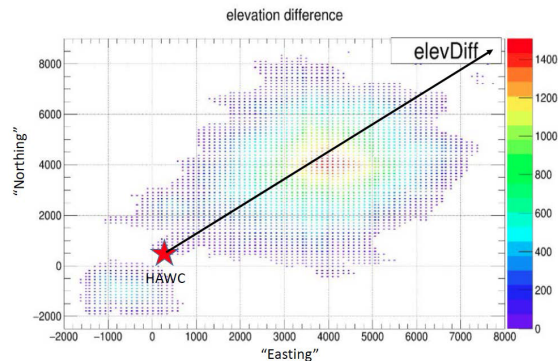
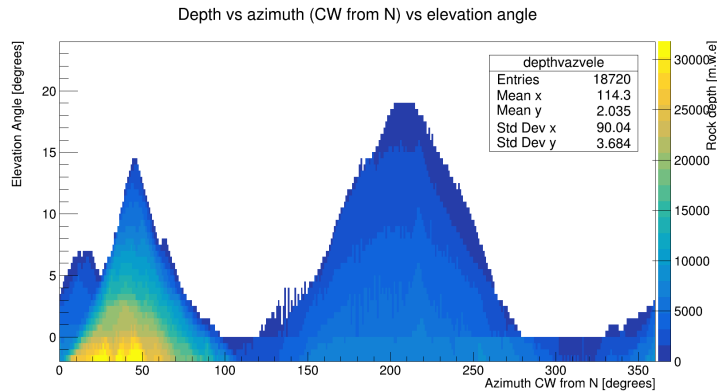


Effective Area & Acceptance

- Geometrical based on linear track length in WCDs
 - “Perfect HAWC” – 10 cm track length in any WCD
 - “Reasonable HAWC” – 3.5 m track length per WCD + 10 WCDs (~80 m Cut on Data)
- Geant4 based simulation partially implemented

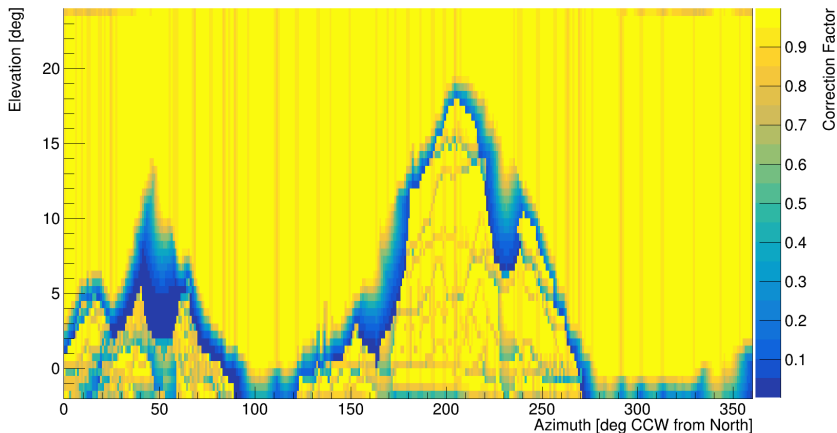


Depth Edge Effect consideration within the Volcanoes.



- Azimuth & Zenith Reconstruction uncertainty impacts the rock overburden.
- Muons reconstructed near an edge, are actually more likely to come from significantly less overburden.
- We apply a correction factor cut (> 0.9) to avoid rapid changes in overburden.

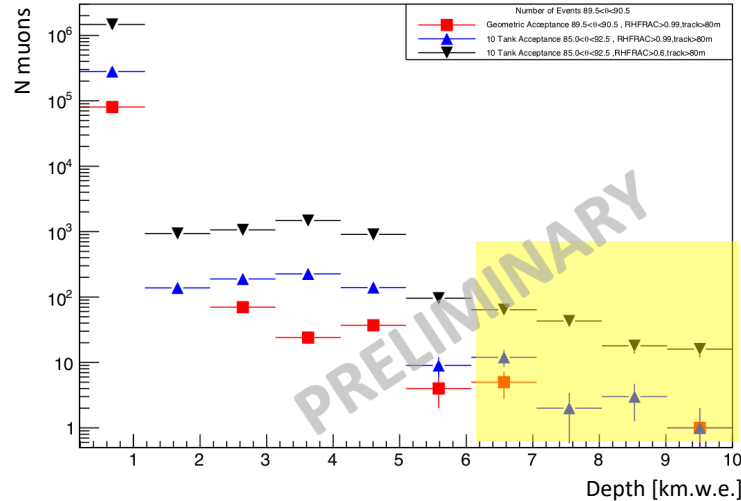
Depth Bias Acceptance Correction



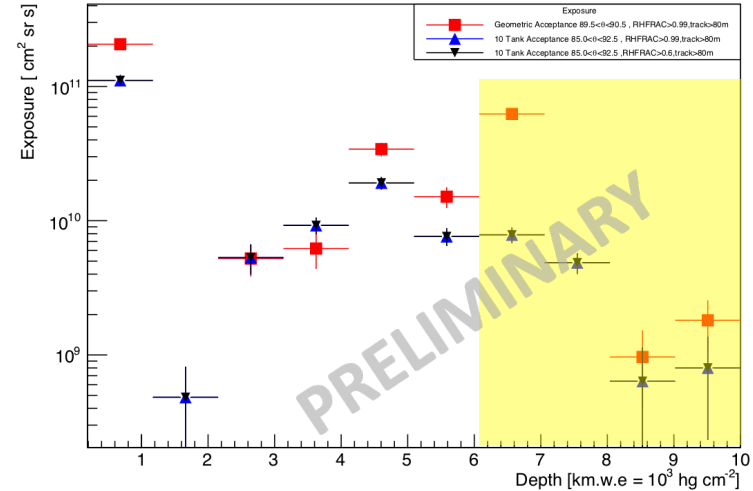
Preliminary Integral intensity results

17 Days worth of triggered data processed, 150 days in progress

Nmu v Depth

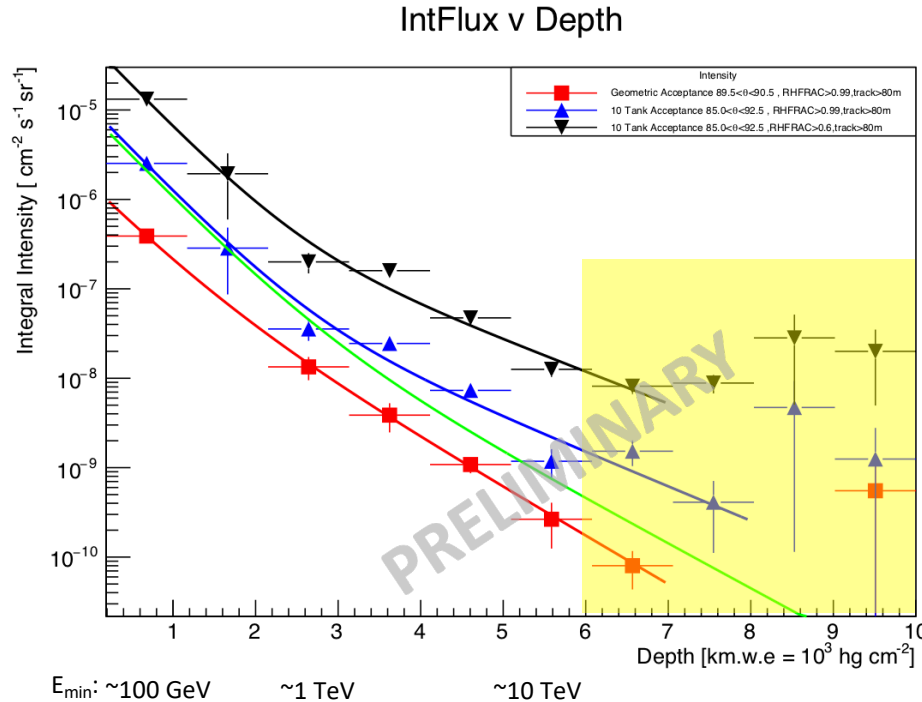


Exposure v Depth



Depth bins > 6 km.w.e. are found to be associated with edge effects or background.

Integral Intensity of Near Horizontal Muons with HAWC



Green line is from the previous measurements compiled by Bugaev, E. V. et al.:
doi 10.1103/PhysRevD.58.054001

E_{\min} estimation from PDG 29 Cosmic Rays eq. 29.5, standard rock

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Outlook

- We demonstrate a good understanding of HAWC for Near Horizontal Muon events.
- We are working to implement Photoelectron information into the Muon identification algorithm
 - This will further aid in the Air Shower - Muon/Muon Bundle identification.
 - Charge deposited per WCD will increase with additional muons passing through that water volume.
- Thank you

Extra slide

Double Muon, reported in the last ICRC conference.

Run 4806, TS 1811, Ev# 348

