HAWC High Energy Upgrade
with a Sparse Outrigger Array

35th International Cosmic Ray Conference 2017
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for the HAWC Collaboration
The High-Altitude Water Cherenkov Observatory (HAWC)

Pico de Orizaba

Location: Puebla, Mexico
Altitude: 4100 m above sea level
Area: 22000 m²
Completed in March 2015 with 300 Water-Cherenkov Detectors.
The High-Altitude Water Cherenkov Observatory (HAWC)

Operates day and night.
Large field of view: ~ 2 steradians
Energy range: 0.1 - 100 TeV
>10 TeV Showers at HAWC

Footprint of a ~10 TeV shower is comparable to the main HAWC array.
>10 TeV Showers at HAWC

Edge dominant
Motivation for Outriggers

- When shower core falls outside of the main array, it can be mis-reconstructed as a lower energy shower closer to the array.

So we have an uncertainty on the location of the shower.

- Which eventually affects:
  - Direction reconstruction.
  - Energy reconstruction.
  - Gamma hadron separation.
So how can we deal with this?
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HAWC Outrigger Array Description

- A sparse outrigger array around the main HAWC array.
- It is mainly optimized for energies > 10 TeV.
- Increase in instrumented area by a factor of 4-5.
- Consist of 350 outrigger tanks, with one Hamamatsu R5912 8" PMT in each of them.
5 sections of 70 outriggers.
For each **Node:**

- **3 FlashADC cards:**
  - 12 bit FADC sampled at 250 MHz.
  - Flexible digital multiplicity trigger.

- **24 channels per card,** 1 channel per outrigger.

**Flash Adc eLectronics for the Cherenkov Outrigger Node.**
Calibration of Outrigger PMTs

- Full calibration of the PMT using
  - A laser $\lambda = 398$ nm.
  - HV = 1500 V.
  - A 6db attenuator.
Typical Example Event

Sample Size = 4 ns
Typical Event Reconstruction

- All Used Tanks
- Simulated Core
- COM Guess
- Reconstructed Core
Fiducial Cuts for Outriggers

- All Used Tanks
- Simulated Core
- COM Guess
- Reconstructed Core

HAWC300 = 70 m
HAWC+OR = 170 m
Core Resolution Comparison with and without Outriggers

- The data points are at the 68% containment area value of (fit core − true core) histogram.
- Fiducial cuts:
  1> Energy Range : 0.3 TeV to 300 TeV.
  2> Maximum zenith angle : 45 degree.
  3> Minimum Number of Main Array Tanks Hit = 20.
Trigger Effective Area Vs. Simulated Energy

- MA Trigger → 40 Channels.
- OR Trigger → At least 2 OR in any sub-section.
- MA+OR Trigger → MA trigger and OR trigger both, as well as only MA trigger.
- Area → Area of the simulated showers.
- Zenith angle < 13 degree.

Preliminary
Conclusions

- **What we will achieve with outriggers?**
  - More accurate determination of the core position (above 7TeV ~75% improvement).
  - Increased trigger effective area above a few TeV by a factor of ~5.

- **Current status:**
  - The installation of outriggers is currently taking place.
  - Software for combined analysis of outrigger + main array is being developed.
  - Testing of FALCON with outrigger tanks is being performed on site.

- **Future plan:**
  - Merging of the outrigger system with the central readout system (late summer).
  - Deployment of full outrigger array by the end of 2017.
  - Start taking data from the beginning of 2018, enhanced sensitivity above 10 TeV.
Thank You for Your Attention
Back Up Slides
On Site Measurements

Vikas Joshi, HAWC Outriggers, ICRC 2017
On Site Measurements
Measurement of the rate for a multiplicity 2 and 4, amongst 4 similar tanks.
Trigger and Not Trigger Comparison for Outriggers

- Total OR Hit → The total number of Outrigger got hit.
- Triggered OR Hit → The number of Outrigger got readout.

- Left panel is showing the profiles of Total OR hit and Triggered OR Hit with simulated energy.
- Right panel is showing the subtraction of these two profiles.
Outrigger Trigger Ratio with Energy

- $N_{\text{total}} \rightarrow$ Total number of outrigger got hit.
- $N_{\text{triggered}} \rightarrow$ Total number of outrigger readout.
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