Cosmic Ray Detection at the South Pole: The Surface Array Enhancement of IceCube

Shefali, IAP





Cosmic Rays









The IceCube Neutrino Observatory

- ★ In-Ice, DeepCore and Surface Array
- ★ Digital Optical modules DOMs for detection of cherenkov light from neutrino interactions
- ★ Main focus, High energy neutrinos
- ★ Lower energies ~GeV with DeepCore
- ★ Cosmic Ray studies







IceTop: IceCube Surface Array

- ★ Cherenkov tanks filled with Ice and readout with PMTs (DOMs)
- ★ Cosmic Rays reconstruction from PeV to EeV
- \star Veto against atmospheric background for the In-Ice







IceTop: IceCube Surface Array

- Cherenkov tanks filled with Ice and readout with \star **PMTs**
- Cosmic Rays reconstruction from PeV to EeV \star
- Veto against atmospheric background for the In-Ice \star

600

400

200

-200

-400

-60 -600

-400

-200

Y (m)

Signal Attenuation due to snow accumulation \star Snow Depth 10/Dec/2020









Ω

X (m)

200

400

600

2.5

0.5



Surface Array Enhancement





KSETA Plenary '23

Science Case

- ★ Cross Calibration with the In-Ice and IceTop
- ★ Unique possibility to study cosmic rays with multi-channels
- ★ Lowered energy threshold for air shower reconstruction
- ★ Better understanding of the hadronic
 Interactions and perform mass
 composition studies
- ★ Improved veto for the In-Ice detector





The measurement Chain







Prototype Station



Air shower reconstruction with * Radio and Scints both wrt to IceTop



https://arxiv.org/pdf/2107.08750.pdf



Pole Activities: Station Zero

- ★ First Station at Pole since Jan '23
- \star All scintillators swapped with new:
 - Updated electronics
 - Riveted and glued edges
 - Elevated to ~1.5m
- \star One antenna swapped
 - New mount
 - New LNAs (Low Noise Amplifiers)





Pole Activities: Station Zero

- ★ First Station at Pole since Jan '23
- \star All scintillators swapped with new:
 - Updated electronics
 - Riveted and glued edges
 - Elevated to ~1.5m
- \star One antenna swapped
 - New mount
 - New LNAs

Commissioning Ongoing!















Scintillators





- ★ 16 plastic scintillator bars made of polystyrene
- ★ Wavelength shifting optical fibres
- ★ Silicon Photomultiplier board
- \star uDAQ: microprocessor based readout board







Scintillator Readout: uDAQ





KSETA Plenary '23

Production Chain: Electronics' Calibration







KSETA Plenary '23



Production Chain: Assembly

Inlay Preparation



Optical Coupler



uDAQ and light tightness











Calibration Setup

- ★ Test setup for Scintillator calibration:
 - Metal Housing
 - Lead Shielding
 - Temperature control for central DAQ for summer tests





Lead plates on top and bottom



Mass Production







- 100 scintillation detectors produced and tested in 21/22 at KIT, including R&D, and 6+1(station 0) stations for the pole
- One station each at Auger, and TA for cross calibration and Gen2 R&D







Calibration Measurements





Energy Calibration

SKIT

- ★ Calibrate the MIP energy using radioactive sources with known decay spectra
- ★ Sources used with decay scheme in MeV range:
 - Co-60
 - Cs-137
 - o Na-22







SKIT

Operation at Pole

- ★ Air Shower Measurements

 ~<u>16hr measurement runs</u>
 Maximum threshold
 Trigger Radio > 6 scintillators
 - ~2hr Calibration runs:
 - Voltage scan on limited range





High gain: ~50P.E/MIP; ~1300 ADC/MIP; 25 ADC/P.E





Operation at Pole

- \star Air Shower Measurements
 - ~16hr measurement runs
 - Maximum threshold
 - Trigger Radio > 6 scintillators
 - ~2hr Calibration runs:
 - Voltage scan on limited range
- ★ Planned Special runs
 - Threshold Scan
 - Voltage Scan





IceCube Group



Hadronic Cosmic Ray Interaction model Anisotropy tests studies for Gen2 Spring 2023 Collaboration Meeting - Aachen Low energy mass ARCH 12 - 17, 2026 composition (ML) Mass Composition Radio detection with IceTop (ML) with SAE Gamma-hadron Multi-messenger with GW-v separation (ML)



KSETA Plenary '23

SKIT

Summary and Outlook

- ★ Station "0" at the Pole under commissioning :)
- ★ Production and calibration of next ~6 stations for upcoming season complete
- ★ Energy Calibration ongoing
- ★ R&D stations at various sites
- MIP stabilization implementation for future stations
- Data processing for combined reconstruction with IceTop





BACKUP





SiPM Gain with SPOCK





KSETA Plenary '23

SiPM gain v/s low temp





SiPM gain versus temp!







- Check of functionality: high gain histogram data obtained at 3 stages:
 - > After production
 - At freezer tests at PSL
 - At final Deployment





Scintillator Readout



