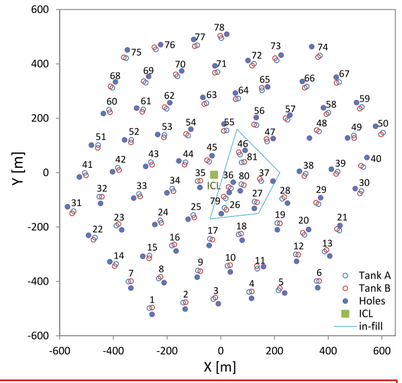
Discrimination of muons for mass composition studies of inclined air showers detected with IceTop

Aswathi Balagopal V.[1] for the IceCube Collaboration, PoS(ICRC2021)212

[1]*University of Wisconsin-Madison*

1 *The IceTop Array*

- IceTop: the cosmic-ray array on the surface of the IceCube Neutrino Obseratory
- 162 ice-Cherenkov tanks with 2 tanks grouped into one station
- 2 optical sensors per tank to collect Cherenkov light from particles (mainly electromagnetic (EM) and muonic) in an air shower



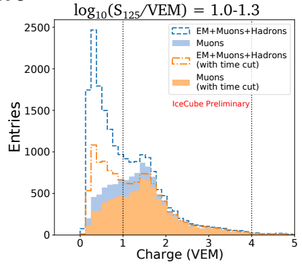
Motivation & Goal

- Identification the mass composition of the air-shower primary for inclined air showers on an event-by-event basis
- Discriminate muons from EM particles
- Test of hadronic interaction models
- Independent cross-check of other composition analyses with IceTop using a different data sample

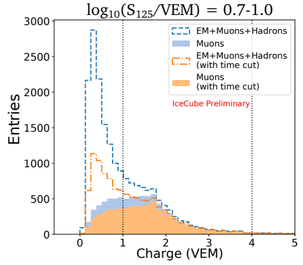
2 *Selection of Muons in Inclined Air Showers*

- Showers with zenith angle (θ) bins: 45-50°, 50-55°, 55-60° and energy range $10^{7.3}$-10^{8} GeV
- Energy proxy: S_{125}, the charge deposited by the shower at 125 m distance from the axis
- Charge and time-based selection of muon-like hits
- Tank hits with deposited charge of 1-4 VEM (charge deposited by vertical equivalent muon) are chosen
- Choose hits predominantly from early muons by comparing the observed shower curvature to the theoretical prediction of the curvature

Iron showers, θ = 45-50°, $\log_{10}(S_{125}/\text{VEM})$ = 1.0-1.3



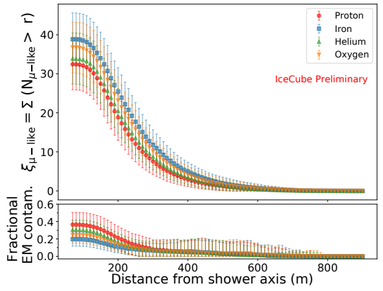
Proton showers, θ = 50-55°, $\log_{10}(S_{125}/\text{VEM})$ = 0.7-1.0



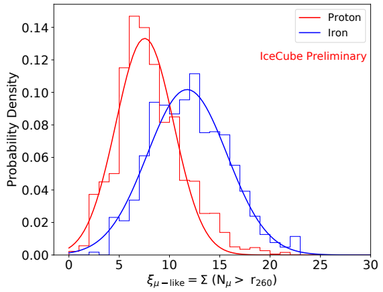
3 *Muon-like Parameter*

- Sum up all selected hits above each distance bin from the shower axis to get $\xi_{\mu\text{-like}} = \Sigma N_{\mu\text{-like}} > r$
- Distance at which we get the best separation bewteen $\xi_{\mu\text{-like}}$ of H and Fe is chosen as the reference distance

Lateral distribution of $\xi_{\mu\text{-like}}$ for various primaries shows good separation between them



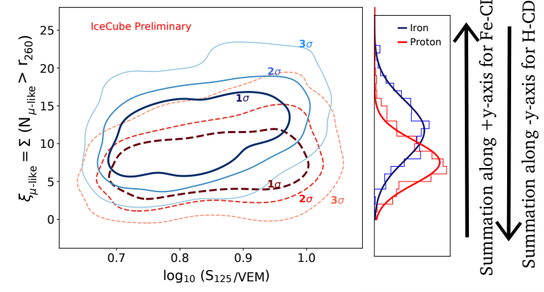
H and Fe distributions of $\xi_{\mu\text{-like}}$ and their Gaussian fits for showers with θ = 55-60°, $\log_{10}(S_{125}/\text{VEM})$ = 0.7-1.0



4 *Classification of Events as Heavy or Light*

- Probability-density distribution of $\xi_{\mu\text{-like}}$ at the reference distance for H and Fe showers within each θ and S_{125} bin is drawn
- Determine the marginal cumulative distribution for each slice of $\log_{10}(S_{125})$ for iron (Fe-CD) and proton (H-CD)

Probability-density distributions for H and Fe showers with θ = 50-55°, log10(S125/VEM) = 0.7-1.0

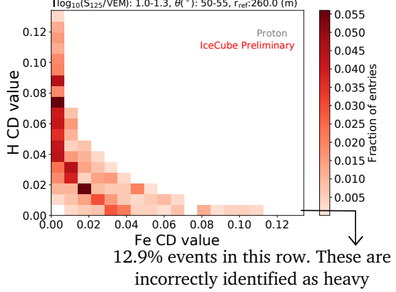


- Each point in this $\log_{10}(S_{125})$-$\xi_{\mu\text{-like}}$ space will have a Fe-CD value and H-CD value, which is used to classify each event as light or heavy

5 *Verification*

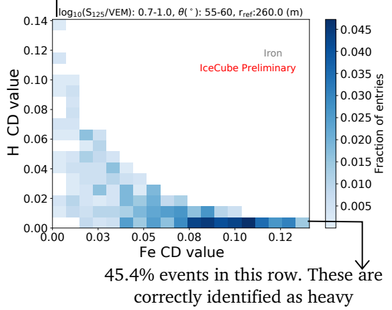
- Pass the simulations through the classifier to test it
- Get the H-CD and Fe-CD value of each event

46.2% events in this column. These are correctly identified as light



12.9% events in this row. These are incorrectly identified as heavy

2.7% events in this column. These are incorrectly identified as light



45.4% events in this row. These are correctly identified as heavy

- Events with low H-CD are identified as heavy and events with low Fe-CD are identified as light
- At least 40-50% of events correctly identified; a smaller fraction misidentified

6 *Conclusion*

- A method to determine the composition of inclined air showers on an event-by-event basis is shown
- Based on the charge and time information, we determine the muon-like parameter, $\xi_{\mu\text{-like}}$, at a reference distance where maximum separation is seen between H and Fe
- Probability-density distribution of $\xi_{\mu\text{-like}}$ for H and Fe is used to obtain H-CD and Fe-CD values, based on which each event is classified as light or heavy
- Further tests with other hadronic interaction models and application of the method to data is foreseen in the future

References

[1] M. G. Aartsen, et al. J. Instrum. 12, P03012 (2017)
[1] R. Abbasiet al. Nucl. Instr. and Meth. in Phys. Res. A 700 (Feb.,2013) 188–220
[2] M. G. Aartsen et al. Phys. Rev. D100no. 8, (2019) 082002

Contact: abalagopalv@icecube.wisc.edu