Measurement of the High Energy Astrophysical Neutrino Flux Using Electron and Tau Neutrinos Observed in Four Years of IceCube Data

The high-energy universe is known to be violent. On Earth scientists have observed Ultra High Energy Cosmic Rays (UHECRs) with energies that are ~7 orders of magnitude larger than the maximum energy the most powerful man-made particle accelerator can achieve. Their origin however, despite decades of observations, remains elusive. Powerful astrophysical phenomena that could give rise to high-energy particle acceleration have traditionally been observed with light (gamma rays) and very recently with gravitational waves. A unique probe to provide valuable information about the sources and production mechanisms of these UHECRs can be neutrinos, electrically neutral, sub-atomic particles that are inevitably produced when high-energy protons interact. Neutrino detection however is challenging and requires massive instruments of huge - at least $1km^3$ - volumes.

The IceCube Neutrino Observatory, located at the geographical South Pole in Antarctica, has been fully operational since December 2010. It consists of 86 cable strings, each carrying 60 light sensors (DOMs) that have been melted deep into the glacier at depths between 1450m and 2450m. It continuously monitors a total volume of $1km^3$ of clear Antarctic ice for faint flashes of light associated with neutrinos that interact inside or near the detector. In 2013 IceCube reported one of its biggest discoveries, the observation of highly energetic neutrinos that presumably originate from outside our own galaxy. High-energy neutrino astronomy became a reality.

In this dissertation we study the spectral properties of this flux of high-energy astrophysical neutrinos using IceCube data, recorded in a four-year period from 2012 to 2015. As part of this work a new neutrino selection method has been developed. We isolated a pure sample of high-energy astrophysical neutrinos from overwhelming backgrounds arising from particle production in Earth's atmosphere using state of the art machine-learning techniques. In addition to increasing the number of detected neutrinos (a more than 10-fold increase over previous works), we extended the energy range of the observed neutrinos and significantly improved the systematic uncertainty. The data sample in this dissertation contains ~400 astrophysical electron and tau neutrinos thereby increasing the significance of the original IceCube discovery to beyond 8 standard deviations. We find the astrophysical neutrino spectrum to be well described by a single power-law, without further spectral characteristics, in agreement with expectations from Fermi-type acceleration of high-energy particles at astrophysical sources.

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