RECENT RESULTS FROM ICECUBE

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COSMIC RAYS, COSMIC ACCELERATORS

Cosmic ray energies extend up to > 10^{20} eV


\[ p\gamma \rightarrow \Delta^+ \rightarrow p\pi^0 \]
\[ \pi^0 \rightarrow \gamma\gamma \]
\[ pp \rightarrow pn\pi^+ \]
\[ p\gamma \rightarrow \Delta^+ \rightarrow n\pi^+ \]
\[ \pi^+ \rightarrow \mu^+\nu_\mu \]
\[ \mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu \]
COSMIC ACCELERATORS

Candidate sites: gamma ray bursts, active galactic nuclei, supernova remnants

Acceleration in shocks $\rightarrow$ $E^{-2}$ energy spectrum

Distant sources $\rightarrow$ low fluxes $\rightarrow$ large detector
Located at the Amundsen-Scott South Pole station near the geographic south pole

Instrumented volume of $1 \text{ km}^3$

86 cables called “strings”, with 60 Digital Optical Modules between 1450 and 2450 m deep

Denser “DeepCore” subarray in the center

81 IceTop surface detectors

Completed in 2010
ICECUBE DOM

PMT waveforms digitized in ice

IceCube Coll., JINST 12 P03012 (2017)

IceCube Coll., JINST 9 (2014), P03009
NEUTRINO SIGNATURES IN ICECUBE

Double bang signature only resolved in IceCube above 100 TeV energy

Red = early
Blue = late
Larger = more charge

A shower is also seen for all flavor neutral current events
IceCube Science
Cosmic ray air showers produce muons and neutrinos

Muons (downgoing): 3 kHz at trigger level
Atmospheric neutrinos: few hundred per day

Background rejection:
High energy
Contained events
Upgoing events

SELECTING NEUTRINOS: DOWNGOING
HIGH ENERGY STARTING EVENTS

80 events in 6 years

Expected background:

15.6^{+11.4}_{-3.9} atm. neutrinos

25.2 ± 7.3 atm. Muons

Best fit spectrum:

\[ E^{-2}\phi = 2.46 \pm 0.8 \times 10^{-8} \times (E/100\text{TeV})^{-0.92}\text{GeV/cm}^2/\text{s sr} \]
Compatible with a single power law and with measurement from upgoing muon neutrinos, this data sample cannot distinguish between single and dual power law.

In progress:

- Energy-dependent vetos for starting tracks and cascades
- Searches for partially contained events
SEARCH FOR POINT SOURCES

+ showers
x tracks

No significant clustering found

Resolution is < 1° for tracks, 10° for showers at energies above 100 TeV

Track events are sent as public GCNs for follow up by telescopes
Search for Tau Neutrinos

Double pulse in single IceCube DOMs – no signal seen (IceCube Coll., Phys. Rev. D 93, 022001 (2016))

Null results still consistent with statistical fluctuation

Double shower in high energy starting events – no signal seen (ICRC 2017)
DEEPCORE AND ATMOSPHERIC NEUTRINOS

Denser spacing and higher quantum efficiency PMTs \(\rightarrow\) lower energy threshold

Outer IceCube strings act as a veto

Use atmospheric neutrinos passing through the Earth to study neutrino oscillation physics

Many energies and baselines available: use this to control systematic effects
ATMOSPHERIC MUON NEUTRINO DISAPPEARANCE

ICECUBE GEN2

What are the point sources of neutrinos?

What are the spectral characteristics of the astrophysical neutrinos?

What is the flavor content of astrophysical neutrinos?

Neutrino physics at low energies: tau neutrino appearance, neutrino mass ordering
ASTROPHYSICAL NEUTRINOS IN GEN2

$E^2 \times \phi$ [GeV s$^{-1}$ sr$^{-1}$ cm$^{-2}$]

$E$ [GeV]

ICRC 2017

Diffuse $\gamma$ (Fermi LAT) IceCube (ApJ 2015)
Cosmic rays (Auger) Gen2 (15 years)
Cosmic rays (TA)
• $\nu_\mu$ disappearance

• $\nu_\tau$ appearance

• Precise calibration of IceCube optical properties and DOM response
GEN2 PHASE 1
TAU NEUTRINO APPEARANCE IN GEN2 PHASE I
Gen2 Phase I calibration devices to improve modeling of optical properties of ice and DOM response

New calibrations will be applied to the entire accumulated IceCube data set (~10 years)
SUMMARY

IceCube has observed high energy astrophysical neutrinos, from as yet unidentified sources.

Work continues to verify the properties of the energy spectrum and the flavor content of the astrophysical neutrino flux.

IceCube has competitive results for atmospheric neutrino oscillation physics, at higher energies than long baseline experiments.

Planning is underway for the next generation of IceCube.