

## **RECENT RESULTS FROM ICECUBE**

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## **COSMIC RAYS, COSMIC ACCELERATORS**

### Cosmic ray energies extend up to $> 10^{20} \text{ eV}$







## **COSMIC ACCELERATORS**



Candidate sites: gamma ray bursts, active galactic nuclei, supernova remnants Acceleration in shocks → E<sup>-2</sup> energy spectrum Distant sources → low fluxes → large detector





## THE ICECUBE NEUTRINO OBSERVATORY



Located at the Amundsen-Scott South Pole station near the geographic south pole

Instrumented volume of 1 km<sup>3</sup>

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



IceCube Coll., JINST 9 (2014), P03009



PMT waveforms digitized in ice

IceCube Coll., JINST 12 P03012 (2017)





## NEUTRINO SIGNATURES IN ICECUBE



Red = early Blue = late Larger = more charge

Double bang signature only resolved in IceCube above 100 TeV energy

A shower is also seen for all flavor neutral current events



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## BACKGROUNDS TO ASTROPHYSICAL NEUTRINO SEARCH

### 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

Phys. Rev. Lett. 110 (2013) 151105





## **SELECTING NEUTRINOS: DOWNGOING**







## HIGH ENERGY STARTING EVENTS







## ASTROPHYSICAL NEUTRINO SPECTRUM

Compatible with a single power law and with measurement from upgoing muon neutrinos, this data sample cannot distinguish between single and dual power law

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In progress:

Energy-dependent vetos for starting tracks and cascades

Searches for partially contained events





## SEARCH FOR POINT SOURCES



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

ICRC 2017





## 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



arXiv: 1707.07081, submitted to Phys. Rev. Lett.



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## 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 Gen2 High Energy Array Surface air shower detector/veto array Radio detector PINGU: Precision IceCube Next Generation Upgrade





## ASTROPHYSICAL NEUTRINOS IN GEN2





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## TAU NEUTRINO APPEARANCE IN GEN2 PHASE I







# IMPROVING ICECUBE RECONSTRUCTION



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