The IceCube-Gen2
High Energy Array

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Neutrinos as astrophysical messengers

Neutrino from atmospheric air showers often accompanied by muons
Astrophysical neutrinos

- **IceCube**
  - 1 km$^3$ neutrino detector located at South Pole
  - In full operation since 2011
- Observed astrophysical neutrinos
- Several independent analyses
- First light in field of neutrino astronomy
The PeV Scale
Many questions

- So far, observed astrophysical flux is consistent with a isotropic flux of equal amounts of all neutrino flavors
- No evidence for a point source in several analyses
- Where are the point sources?
- What is the spectrum? Cutoff?
- What is the flavor composition?
- Multi-messenger physics?
- GZK neutrinos?
IceCube: Gen2

- While able to deliver amazing discoveries, IceCube is limited by the small numbers of astrophysical neutrinos
  - ~few 10’s of astrophysical neutrinos per year
- The IceCube-Gen2 High Energy Array will instrument a significantly larger volume (~10 km$^3$)
  - Deliver significantly larger samples of astrophysical neutrinos
- Gains in sensitivity can grow rapidly, especially for transient events.
  - Detection of multiple events more likely
  - Sensitive to wider classes of transient phenomena
Antarctic Ice

- Construction of IceCube has yielded a wealth of data on the optical properties of glacial ice.
- Absorption length for Cherenkov light is large.
- We can extend instrumented length above and below current instrumented volume.
- 25% gain in instrumented volume.
Gen2 High Energy Array: Realization

- Benchmark detector designs have been simulated that:
  - Add strings around the IceCube instrumented volume
  - Add ~120 strings
    - Vary string spacing uniformly (200m, 240m and 300m)
  - Edge-weighted geometry to evaluate the impact on veto techniques

Spacing: 240 m
Volume: 8.0 km³
Spacing: 200 m  
Volume: 6.0 km$^3$

Spacing: 300 m  
Volume: 11.9 km$^3$

Spacing: 125 / 240 m  
Volume: 6.2 km$^3$
Spacing: 240 m
Volume: 8.0 km$^3$
Spacing: 300 m
Volume: 11.9 km$^3$
Angular resolutions

- Gen2 geometries show promising angular resolutions
- Using IceCube reconstructions: 0.3-0.5 degree
- Selecting highest quality track events (~10%): 0.1 degree
- Expect improvements as reconstructions improve for Gen2 geometries
Point source sensitivity

- Evaluation of point source sensitivity is a work in progress for Gen2
- Improved Gen2 specific event selections, reconstructions and methods will increase sensitivity.
- 10 years of observation with Gen2 HEA is equivalent to >200 yrs of IC86
- Gains in southern hemisphere are strong.
-contained cascades arise from charge current interactions of e/τ neutrinos and neutral current interactions of all flavors.

• Observation of these events is important

• Observed energies are directly relatable to neutrino energies

• Can probe source mechanisms by flavor and neutrino-antineutrino ratios

• Glashow resonance key tag for anti-$\nu_e$

### Table I. Expected number of contained neutrino-induced cascades per year with 5 PeV $E_{\text{vis}}$

<table>
<thead>
<tr>
<th>$\Phi_{\nu_e}$ [GeV$^{-1}$cm$^{-2}$s$^{-1}$sr$^{-1}$]</th>
<th>interaction type</th>
<th>pp source</th>
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<tbody>
<tr>
<td>$1.0 \times 10^{-18} (E/100 \text{ TeV})^{-2.0}$</td>
<td>GR</td>
<td>0.88</td>
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<tr>
<td></td>
<td>DIS</td>
<td>0.09</td>
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<td>$1.5 \times 10^{-18} (E/100 \text{ TeV})^{-2.3}$</td>
<td>GR</td>
<td>0.38</td>
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<tr>
<td></td>
<td>DIS</td>
<td>0.04</td>
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<td>$2.4 \times 10^{-18} (E/100 \text{ TeV})^{-2.7}$</td>
<td>GR</td>
<td>0.12</td>
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<tr>
<td></td>
<td>DIS</td>
<td>0.01</td>
</tr>
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</table>
Atmospheric neutrino surface veto

- Down-going atmospheric neutrino backgrounds will be accompanied by particles from parent shower.
- Can be used a veto backgrounds in the Southern sky.
- Studies of detector designs and optimizations are ongoing.
IceCube-Gen2 Facility

The IceCube Gen2 Facility

IceCube-Gen2 Radio Array
IceCube Gen2 High Energy Array (HEA)
IceCube-86, IceTop
Deepcore/PINGU
IceCube Gen2 Cosmic Ray Array (CRA)

Bedrock

≈ 14 km
IceCube-Gen2 Facility

- The IceCube-Gen2 collaboration intends to build an integrated particle-astrophysics science facility at South Pole
- IceCube + Gen-2 HighEnergyArray - Neutrino astronomy at the highest energies
- DeepCore + PINGU - Neutrino oscillations and the mass hierarchy
- Surface detector - Cosmic ray physics and surface veto for atmospheric backgrounds
- Radio detector - Search for GZK neutrino signals
- Wider physics reach - WIMPs, Beyond standard model physics, …
IceCube-Gen2 Facility

- IceCube detector systems designs evolving for use in Gen 2
- Gen2 DOM
  - New electronics
  - Enhanced hot water drill
  - Modular, efficient system
IceCube-Gen2 Facility

- Alternative DOM designs with the aim to increase detector sensitivity
- Increased light collection
- Increased directional information
- Currently under study.
Gen2 at ICRC

• Several IceCube Gen2 specific contributions (talks and posters) here
  • Surface veto design studies: 1070, 1156
  • Calibration devices: 1133, 1145
  • Hardware development: 1137, 1147, 1148
  • PINGU science potential: 1174
  • Cosmic ray science potential from an extended surface detector: 694
Summary

• IceCube-Gen2 High Energy Array will deliver significantly larger samples of astrophysical neutrinos

• Understand these events and how they connect to the high-energy universe

• IceCube-Gen2 facility will provide samples of neutrinos from a few GeV to EeV energies.

• The IceCube-Gen2 collaboration are developing proposals in the US and worldwide to see this facility constructed.
• Thanks!