Recent results from IceCube and AMANDA and prospects for the future

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Cosmic ray Spectrum

Cosmic rays have been observed with energies in excess of $10^{20}$ eV.

The origin of these energetic particles remains an enigma.

The observed fluxes of these particles sets the scale for cosmic ray observatories.

Extragalactic Gyroradius exceeds size of the galaxy.
Astronomical Messengers

Neutrinos

Protons

Photons

Log(E) (eV)

Observable distance (Mpc)
Cable for power, communication and support

digital optical modules

Cerenkov radiation from a muon traveling through the ice
Why neutrinos make a good proxy

- accelerator
- target
- proton
- directional beam
- magnetic fields
- black hole, merging neutron stars...
- Shock
- $\gamma$
- $\pi^0$
- $e^-$
- $e^+$
- $e^-$
the Antarctic Muon and Neutrino Array
**IceTop**

Air shower detector
80 pairs of ice Cherenkov tanks
Threshold ~ 300 TeV

**InIce**

Planned 80 strings of 60 optical modules each
17 m between modules
125 m string separation

2004-2005: 1 string
2005-2006: 8 strings
2006-2007: 13 strings deployed

Current configuration
- 22 strings
- 52 surface tanks

**IceCube**

Current configuration
- 22 strings
- 52 surface tanks

2007/08: add 14 to 18 strings and tank stations
Completion by 2011.
Crude energy measurement can be obtained by counting the number of fired DOMs.

Direction determined by time of arrival of Cerenkov light.

Muon and neutrino colinear to 1 degree or at 1 TeV.

signature of $\nu_\mu$. 

$10^{13}$ eV (10 TeV) 

$6 \times 10^{15}$ eV (6 PeV)
Cascades

375 TeV

Multi-PeV

Tau neutrinos only expected over a very long baseline since oscillations make ratios of neutrino flavors 1:1:1.
IceCube energy and directional resolution, flavor discrimination

Neutrino flavor

ντ

νe

νμ

supernovae

Full flavor ID

Showers vs tracks

IceCube flavor ID, direction, energy

IceCube triggered, partial reconstruction

Log(ENERGY/eV)

ν̄e

νe

νμ

6 9 12 15 18 21

TeV PeV

Log(ENERGY/eV)
The Digital Optical Module (DOM)

- 10” PMT in 13” Glass sphere

- Mother Board:
  - 2 ASIC (ATWD) chips to digitize PMT signals in 3.3ns samples
  - FPGA for DAQ
  - CPUs and SDRAM for communication, calibration, buffering data

- High Voltage Generator & Base Board
- LED Board for calibration

- Dynamic range: 1 pe to 25000 pe
- Low photon counting background: in-ice rates of order 700 Hz
- Complete, self-contained, reconfigurable digital data acquisition system
- High-precision timing over vast network of 1000’s of sensors to nanosecond scale.
Cosmic rays and downgoing muons

primary cosmic ray

Threshold energy: 300 TeV

IceTop

IceCube

1450 m

2450 m

π+

μ+

e+

ν

ν

ν

ν
Atmospheric muons as a "testbeam"

- Compare independent zenith angle reconstructions
- Plot time between hits in in-ice and ice-top DOMs versus the distance between them

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.
Atmospheric Neutrinos

Atmospheric muons come from above

Atmospheric neutrinos are isotropic

γ
ν
CMB

cosmic accelerator
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

tightening cuts

low energy threshold set by range of secondary muons
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Point source search: IC9

maximum likelihood analysis

probability distribution of signal events (point spread ~2 deg.)

10-20% improved sensitivity over binned analysis

probability distribution of background events

hottest spot: 3.35 \(\sigma\)

0.25° x 0.25° grid

source strength weight

60% of background trials gave a chance clustering of events at 3.35 \(\sigma\) somewhere in the sky
Source catalogue

Perform maximum likelihood test for 26 well motivated neutrino source candidates chosen a priori

- MGRO J2019+37, TeV J2033+4130
- Blazars: Mrk 421, Mrk 501, 1ES 1959+650, 1ES 2344+514, H 1426+428, BL Lac (HBL), 3C66A (LBL), 3C 454.3, 4C 38.41, PKS 0528+134, 3C 273, M87, Per A, Cyg A (Radio loud and GeV EGRET Quasars)
- \(\mu\)-quasars: SS433, Cyg X-3, Cyg X-1, LSI +61 303 (pulsar?) (HMXB), GRS 1915+105, XTE J1118+480, GRO J0422+32 (LMXB)
- SNRs: Crab, Geminga, Cas A
Neutrinos in coincidence with gamma-ray bursts?

GLAST launch in 2009!
• Look for spatial and temporal coincidences with satellite observations-low background search
• New satellites, swift, GLAST, improve observations
• IceCube will be sensitive to Waxman Bahcall fluxes within 1 year of full detector operation (~70 bursts)!

All flavor limits by AMANDA

Diffuse astrophysical neutrinos

When the flux is too low to resolve a point source, you can still see evidence of hadronic acceleration.

Astrophysical neutrino energy spectrum has different energy profile form atmospheric nu’s.

Use number of hit channels, Nch, to approximate energy distribution.
IceCube already has better instantaneous sensitivity than AMANDA-II!
• Earth becomes opaque to neutrinos at high energies—look to the horizon

• Very bright!—due to stochastic processes—cut hard on energy related variables.

AMANDA II

a UHE event in IceCube

\[ \frac{dE}{dx} \propto E \]

9 EeV
Supernova detection

Expect a burst of low energy (MeV) neutrinos from core collapse of supernovae.

\[ \nu_e^+ + p \rightarrow n + e^+ \]

Detection via increase in “dark noise” rate-low noise PMTs (300Hz) enhance IceCube’s sensitivity.

Burst of neutrinos observed by 3 different neutrino observatories 3 hours before the observation in the visible.
Particle physics with IceCube

Too many topics to cover here- many new techniques under investigation

- Neutrino properties
- Atmospheric neutrinos
- Violation of equivalence principle (VEP), violation of Lorentz invariance (VLI)
- WIMPs
- Monopoles, Exotica
Too many topics to cover here—many new techniques under investigation

• Neutrino properties
• Atmospheric neutrinos
• Violation of equivalence principle (VEP), violation of lorentz invariance (VLI)
• WIMPs
• Monopoles, Exotica
• Look for relativistic monopoles above the Cerenkov threshold (>0.75c for direct monopoles, >0.52c for delta electrons)

• Extremely bright events—8000 times brighter than a muon

• Allows a search for downgoing as well as upgoing monopoles

• Accelerated by large scale magnetic fields

• Mass related to GUT scale—Relativistic for m<10^{14} GeV
Relativistic monopoles

IceCube relativistic monopole limit will supercede the best AMANDA limit with only 9 strings!
IceCube sensitivity to slow moving particles is presently limited by a trigger threshold of 8 hit DOM is 5 $\mu$s- but investigation into a more sophisticated trigger requirement are underway.

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The Sun sinks maximally 23° below the horizon at the south pole. Cosmic Rays: μ, γ, π, κ, ...

Horizontal events very important!

Also look for Wimps trapped in the gravity well of the earth. They will appear to come from the center of the earth.

**WIMPs (weakly interacting massive particles)**
• Look for excess of events over atmospheric expectation coming from the direction of the Sun

• Blind by randomizing in azimuth
Earth WIMPs

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The Future

• We are already operating the largest neutrino detector in the world.
• Installed strings are immediately operational.
• First analyses (and publication!) already complete, thanks to data filtering at the Pole and subsequent satellite transmission.
• Analysis techniques are continually refined as we gain operational knowledge—improved analysis sensitivity.
• An additional 14-18 strings will be added in austral summer of 07-08.
• 1 cubic kilometer (80 strings) will be instrumented by 2011.
• Efforts are underway to develop the technology to build a GZK scale neutrino detector after IceCube is complete.