Dear IceCube community,

It is with a deep sorrow that we announce the end of the glorious AMANDA era. We (winter-overs) were given the difficult task to switch off the instruments that kept her alive, and hold her hand till her last breath.

At exactly 3:11pm (03:11 UTC) today, Monday May 11th, everything was over, she went away in piece. Her outstanding data production over the years, her reliability, and everything that was learned by building and operating her, and that made IceCube a realistic project, will remain in our memories forever.

To AMANDA,

Erik.
IceCube is 75% complete (59 strings)

59-string configuration to start physics data taking in a few days

first results from the 2007 data taking period (22 strings) are comming

analysis of the data taken with the 40-string configuration (2008) under way

the low-energy extension, DeepCore, funded. First string deployed

stay tuned for the ICRC in Lodtz
status of IceCube construction

results from the 22 and 40-string configuration

the DeepCore low-energy extension

summary
19 strings/stations installed during the 2008-2009 austral summer

**Total of 59 strings and 118 IceTop tanks** → over two thirds complete!

Integrated exposure reaching 1 km$^3$.year
IceTop

Ice Cherenkov Tank

0.9 m clear ice
Diffusely reflecting liner

2m

\( \mu \) signals from IceTop DOMs

IceCube drill hole

Junction box

Two DOMs per tank, 10'' PMT
One high gain, one low gain

tank A

tank B

to DAQ

25 m

10 m
5MW x 30 hrs = 0.56 TJ!

AMANDA drilling (1950m) 90 hrs deployment: 18 hrs
IceCube drilling (2450m) 40 hrs, deployment: 10 hours
Each DOM is an autonomous data collection unit

- **PMT**: Hamamatsu, 10”
- **Digitizers**:  
  - **ATWD**: 3 channels. Sampling 300MHz, capture 400 ns  
  - **FADC**: sampling 40 MHz, capture 6.4 ms  
Dynamic range 500pe/15 nsec, 25000 pe/6.4 ms

- **Flasher board**:  
  12 controllable LEDs at 0° or 45°

  Clock stability: \(10^{-10} \approx 0.1\) nsec / sec  
  Synchronized to GPS time every \( \approx 5\) sec at 2 ns precision

- **Dark Noise rate** ~ 400 Hz  
- **Local Coincidence rate** ~ 15 Hz  
- **Deadtime** < 1%  
- **Timing resolution** \(\leq 2-3\) ns  
- **Power consumption**: 3W
Analyses sensitive to the optical properties of ice

South Pole Ice: extremely pure but presence dust layers

Determine optical properties using LED and LASER sources

Average optical parameters at 400 nm:
\[ \lambda_{\text{abs}} \sim 110 \text{ m}, \lambda_{\text{sca}} \sim 20 \text{ m} \text{ above the dust layer} \]
\[ \lambda_{\text{abs}} \sim 220 \text{ m}, \lambda_{\text{sca}} \sim 40 \text{ m} \text{ below the dust layer} \]
• IceCube will be able to identify
  - $\nu_\mu$ tracks from $\nu_\mu$ for $E_\nu > 100$ GeV
  - cascades from $\nu_e$ for $E_\nu > 10$ TeV
  - $\nu_\tau$ for $E_\nu > 1$ PeV

• background
  mainly downgoing $\mu$ bundles
  (+ uncorrelated coincident $\mu$'s)
  - exp. rate at trigger level $\sim 1.7$ kHz
  - atm. $\nu_\mu$ rate at trigger level $\sim 200$/day

$\nu_\mu \rightarrow \mu$

$E_\mu = 6$ PeV

$\nu_\tau \rightarrow \tau + \text{"cascade"}$

$\nu_e \rightarrow e \rightarrow \text{"cascade"}$

$E_\nu = 375$ TeV

~300 m @ $E_\tau = 1$ PeV

IceCube: an all-flavour neutrino telescope
Astrophysics
- point source search (steady/transient)
- diffuse search
- supernova

Cosmic Ray physics (with IceTop)
- composition
- primary energy spectrum

Particle Physics/New Physics
- neutrino oscillations
- dark matter search
- SUSY searches
- magnetic monopoles
- TeV gravity

A flavour of ongoing analyses:
- Extreme high-energy diffuse search
- High-energy point source search (steady, time dependent, flares)
- Low-energy point source search
- Atmospheric neutrino oscillation measurements
- Measurement of the atmospheric neutrino energy spectrum
- Search for atmospheric neutrino-induced cascades
- Searches for neutralino dark matter (Sun, Earth, Halo)
- Indirect searches for Kaluza-Klein dark matter (Sun)
- Search for relativistic and slow monopoles
- Search for staus in cosmic ray showers
- Supernova search
- All-particle cosmic ray energy spectrum
- Study of high p_T muons in cosmic ray air showers
- Large scale cosmic rays anisotropy
- Search for high energy tau neutrinos
- Search for Quantum Gravity with high-energy atmospheric neutrinos
example: background rejection in IceCube-22

Background:
- atmospheric muons
- coincident atmospheric muons
- atmospheric neutrinos

High-purity atmospheric neutrino sample achieved after quality cuts
look for neutrinos with $E_n > 10^8$ GeV

background: atmospheric muon bundles

use energy estimators (number of photons)

select events with $\#PE > 10^4$
$E^2 \frac{dN}{dE}$ [GeV cm$^{-2}$ s$^{-1}$ sr$^{-1}$]

- IC9 137 days
- IC22 242 days
- Preliminary
- Sensitivity

AMANDA-II 807 days Upper Limit

Log $10 [E \text{ (GeV)}]$

10$^{-9}$ 10$^{-8}$ 10$^{-7}$ 10$^{-6}$ 10$^{-5}$ 10$^{-4}$

$(n_{\mu} \text{ limits. All flavour limits)}$

Diffuse limits/sensitivities

- IceCube 9 strings 137 days
- Assumes a 1:1 flavor ratio at Earth
- Full IceCube 1 yr
- W&B limit/2 (transparent sources)
- AMANDA-II 2000-2002 UHE limit (prelim.)
- AMANDA-II 2000-2002 unfolding (prelim.)
- RICE 1996-2005 (all-flavor/3)$^*$ limit
- Baikal 1996 - 2002 (all-flavor/3)$^*$
- AMANDA-II 2000 Cascades (all-flavor/3)$^*$
- AMANDA-B10 1997 UHE (all-flavor/3)$^*$
- AMANDA-B10 1997, diffuse
- MACRO
- Frejus
- Max uncertainty in amts$^*$
- Honda et al. amts, v + prompt amts$^*$
- Barr et al. amts, v
276 d livetime in 2007
5114 data events
4700 expected atmospheric neutrinos
769 expected atmospheric muons

Hottest spot found at RA 153°, DEC. 11°
est. nSrcEvents = 7.7  est. gamma = 1.65
pre-trial p-value: \(-\log_{10}(p): 6.14\)  (4.8 sigma)

Post-trials p-value of analysis is \(\sim 1.34\%\)  (2.2 sigma)

Concentrate on selecting good upgoing events
Perform point source search using:
  - a priori list of 28 source candidates
  - all sky search from dec \(-5^\circ\) to \(+85^\circ\)
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<th>Obj. Name</th>
<th>ra(deg)</th>
<th>dec(deg)</th>
<th>p-value (pre-trial)</th>
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(only excesses reported, otherwise given as "---")

Lowest p-value (0.07) is for 1ES 1959+650.
Not significant after trial factor of 28 sources in list.
UHE allows for searches above the horizon (southern sky)

276 d livetime in 2007
1885 data events
853 expected atmospheric neutrinos
769 expected atmospheric muons

median angular resolution
\( (E^{-2}) \quad 1.3^\circ \)
\( (E^{-1.5}) \quad 1.2^\circ \)

central 90% energy interval
\( (E^{-2}) \quad 8 \text{ TeV} - 20 \text{ PeV} \)
\( (E^{-1.5}) \quad 80 \text{ TeV} - 5 \text{ EeV} \)
Joint operation with the denser AMANDA array allows for searches for lower energy neutrinos.

**Galactic Plane Scan:**
- hottest spot: $l=75.875$, $b=2.675$ (gal. coord.)
- smallest pre-trial p-value: 0.0037 (2.7 sigma)
- expected in 95% of randomized samples

**A priori Source Candidate List:**
- Crab Nebula
- Cas A
- SS433
- LS I +61 303

**Galactic Plane map**
use 41 bursts between June 07-March 08

• binned search around burst position

-\begin{tikzpicture}
  \node[anchor=south west,inner sep=0] at (0,0) {
    \includegraphics[width=\textwidth]{binarytree.png}
  };
\end{tikzpicture}

• unbinned search (sliding window) adds an energy estimator in the likelihood to further distinguish from atm. n background

Naked eye GRB080319B (19/03/2008)
(9/40 strings taking data)

• duration 70s
• position RA=217.9°, DEC=+36.3°
• z=0.94, 1.6Gpc
• brightest GRB ever observed
• expect 0.1 events for G=300

\begin{tikzpicture}
  \node[anchor=south west,inner sep=0] at (0,0) {
    \includegraphics[width=\textwidth]{GRB080319B.png}
  };
\end{tikzpicture}
neutralino-induced neutrinos:

\[ \chi \chi \rightarrow \text{signature: } n \text{ excess from Sun/Earth's center direction} \]

- \( \Omega_m \approx 23\% \), \( \Omega_b \approx 4\% \) → non-baryonic matter
- MSSM candidate: the neutralino, \( \chi \)

A lot of physics uncertainties involved:
- relic density calculations
- DM distribution in the halo
- velocity distribution
- \( \chi \) properties (MSSM)
- interaction of \( \chi \) with matter (capture)
• measurement of the atmospheric neutrino flux important as background for other analyses

• IceCube will collect high statistics of atmospheric neutrinos ~70K/year

• AMANDA result consistent with expectation and previous calculations (SuperK blue area)

• allowed regions for the normalization \((1+\alpha 1)\) and change in spectral index \((\gamma)\) of the conventional atmospheric neutrino flux, relative to Barr et al
Violation of Lorentz Invariance leads to modified dispersion relation: \[ E_a^2 = p_a^2 c_a^2 + m_a^2 c^4. \]

Different maximum attainable velocities \( c_a \) (MAVs) for different particles: \( \Delta E \sim (\delta c/c)E \)

- mixing of MAV eigenstates \( \Rightarrow \) oscillations
  \( \rightarrow \) new mixing angle \( z \) and phase \( h \)

- For atmospheric \( \nu \), conventional oscillations turn off above \( \sim 50 \) GeV \( (L/E \text{ dependence}) \)

- VLI-induced oscillations turn on at high energy \( (L/E \text{ dependence}) \), and distort the zenith vs energy spectrum

atmospheric \( \nu_{\mu} \) survival probability

Large sample of HE atmospheric neutrinos \( (>4K \text{ events } >0.1 \text{ TeV in } 807 \text{ d livetime}) \)

\[ 90\% \text{ CL limit set on VLI for maximal mixing angle: } \delta c/c \leq 2.8 \times 10^{-27} \]

IceCube: sensitivity of \( \delta c/c \sim 10^{-28} \)
SLOW
- light emission from products of induced p decay
  main channel \( e^+ p^0 \rightarrow \sim 1 \text{GeV} \) EM shower
  - signature: 'slowly' moving bright particles
  - other exotics with similar signatures:
    nuclearites & Q-balls

RELATIVISTIC
Cherenkov-light \( \propto (n/2a)^2 = (1.33*137/2)^2 \)
\rightarrow 8300 times brighter than \( \mu \)‘s!

signature: extremely bright events
>1 pulse per PMT
4p sensitivity

\[ \Phi \]
moon shadow

- deficit of events from direction of moon in the IceCube 40-string detector (3 months of data) confirms pointing accuracy.

- analysis is important for study of detector systematic effects
• Aim: lower energy threshold through a denser core in the center of the IceCube array

• 6 additional strings of 60 high quantum efficiency PMTs

• denser instrumentation, 7 m DOM vertical spacing (17m in IceCube), 72 m inter string spacing (125m in IceCube)
• **full sky sensitivity** using IceCube surrounding strings as a veto

◊ access to southern hemisphere, galactic center and all-year Sun visibility

• preliminary studies show $10^4$ background rejection with 98% signal efficiency possible
Radio/acoustic emission completely dominant over optical at >EeV under study: 91 holes, 1 km spacing 5 radio+300 acoustic sensors/hole

**radio:**
- use Askryan effect: coherent Cerenkov emission of particle showers
- Radiated power prop. to $E_\nu^2$, ns duration pulse
- Ice is extremely RF transparent in the interesting MHz -GHz range, $l_{\text{att}} \sim \text{km}$

**acoustic:**
- sudden energy deposit of EeV particle shower $\rightarrow$ heating $\rightarrow$ sudden thermal expansion $\rightarrow$ acoustic pulse
- Amplitude prop. to $E_n \sim \text{mPa}$ pulse of ms duration

both methods in exploratory phase:
- assess South Pole ice properties
- develop hardware

senders/receivers deployed in a few IceCube strings in 2007
all is well at the South Pole....
the IceCube collaboration

USA:
- Bartol Research Institute, Delaware
- University of California, Berkeley
- University of California, Irvine
- Pennsylvania State University
- Clark-Atlanta University
- Ohio State University
- Georgia Tech
- University of Maryland
- University of Alabama, Tuscaloosa
- University of Wisconsin-Madison
- University of Wisconsin-River Falls
- Lawrence Berkeley National Lab.
- University of Kansas
- Southern University and A&M College, Baton Rouge
- University of Alaska, Anchorage

Sweden:
- Uppsala Universitet
- Stockholm Universitet

UK:
- Oxford University

Netherlands:
- Utrecht University

Switzerland:
- EPFL

Germany:
- DESY-Zeuthen
- Universität Mainz
- Universität Dortmund
- Universität Wuppertal
- Humboldt Universität
- MPI Heidelberg
- RWTH Aachen

Belgium:
- Université Libre de Bruxelles
- Vrije Universiteit Brussel
- Universiteit Gent
- Université de Mons-Hainaut

Japan:
- Chiba University

New Zealand:
- University of Canterbury

33 institutions, ~250 members
http://icecube.wisc.edu