IceCubism: How and When a Cube Will Capture Cones

- The IceCube Detector:
  - Physics Goals
  - Detector Design & Predicted Performance
    - In-Ice array
    - IceTop array
  - Status and Schedule
- Picasso vs. Halzen
The IceCube Collaboration

Institutions: 12 US, 11+1 European, 1 Japanese, and 1 South American; About 110 members

- Belgium
  - U. Libre de Bruxelles, U. de Mons-Hainaut, Vrije U. Brussel
- France
  - Laboratoire Bâteau-Lavoir/Paris
- Germany
  - BUGH Wuppertal, DESY-Zeuthen, U. Mainz
- Japan
  - Chiba U.
- The Netherlands
  - Utrecht U.
- Sweden
  - Kalmar U., Stockholm U., Uppsala U.
- UK
  - Imperial Coll.
- USA
- Venezuela
  - U. Simon Bolivar
IceCube Physics Goals: Discovery!

Astronomical Messengers

- Neutrinos
- Protons
- Photons

Sun, SN1987A

Log(E) (eV)

10 11 12 13 14 15 16 17 18 19 20 21 22
IceCube Physics Goals: Possible UHE $\nu$ Sources

- Detect and reconstruct UHE neutrinos at $\sim 10$ TeV to $\sim 10$ PeV (broadened to TeV to EeV for certain signatures). Distinguish neutrino flavors over large energy ranges.
- Specifically, search for UHE neutrinos from:
  - Point sources (AGN, GRBs, ...)
  - Diffuse sources
  - WIMPs
  - Topological defects
- Other searches/goals:
  - Cosmic-ray composition (with IceTop)
  - Monopoles
  - Supernovae
IceCube Physics Goals: Expected Performance

- Thus far, only $\nu_\mu \rightarrow \mu$ studies have been performed (see astro-ph/0305196):
  - Effective area after cuts
  - Angular resolution: (Will improve with better reconstruction.)
IceCube Physics Goals: Anticipated Reach

• Again, only $\nu_\mu \rightarrow \nu_\mu$ studies have been performed (astro-ph/0305196):
  - **Point source detection**
    - With 3 years of data, either
      - detect point source flux of $E^2(\nu) \, dN_\nu/dE_\nu = 7 \times 10^{-9} \, cm^{-2}s^{-1}sr^{-1}GeV$ at $5\sigma$
      - OR place 90% C.L. limit at $E^2(\nu) \, dN_\nu/dE_\nu = 2 \times 10^{-9} \, cm^{-2}s^{-1}sr^{-1}GeV$
  - **Diffuse $E^{-2}$ source detection**
    - With 3 years of data, detectable at minimum strength of $E^2(\nu) \, dN_\nu/dE_\nu = 1 \times 10^{-8} \, cm^{-2}s^{-1}sr^{-1}GeV$
  - **GRB detection**
    - Following Waxman-Bahcall formulation, see $5\sigma$ effect after observation of 200 GRBs in coincidence with satellite(s)

• Expect significant improvement (relative to AMANDA) in ability to reconstruct energy and perhaps direction of individual cascades, and energy and direction of $\nu_\tau$ events
Detector Design

- Detect Cherenkov light emission induced by UHE $\nu$ interactions

- Buried array of 4800 Digital Optical Modules (DOMs) containing PMTs and digitizing electronics,
  - on 80 strings,
  - from about 1400-2400m in depth.
- Plus IceTop: 80 dual-tub bi-DOM stations
Detector Design: Layout (top view)

Option 1: “The Guitar”

Option 2: “Option 8”

Surrounds AMANDA, avoids airplane runway. Not quite a cube.

Dr. P. Picasso, 1909, Posthumous Honorary IceCube Collaborator & Sympathizer
Detector Design: South Pole Station Upgrade

- Improved recreational facilities
- (Better scientific facilities, too)

HENA Workshop, Paris, June 2003

IceCube/Doug Cowen/Penn
IceCube Status and Schedule: Overview

• First major milestone: deploy at least 1, and hopefully more like 6, strings + tubs in 04-05 season
• Construction of “Enhanced Hot Water Drill” progressing nicely
• 20 production DOMs are now being assembled and tested
• IceTop prototyping underway
• Software design and construction underway on many fronts
IceCube Status & Schedule: EHWD

- Gigantic reel for ~2.7-km hose built
- Full length of hose acquired
  - 120m (and smaller) sections
  - ~60mm ID, 90mm OD
- Reel to be disassembled and shipped to Pole this autumn

EHWD system: fabricated at Physical Sciences Laboratory at UW-Madison
Keeping IceCube in Hot Water

- Water pumps and pre-heating and main heating plants assembled
**EHWD Goals**

- **At Pole in upcoming 03-04 season:**
  - Assemble drill supply hose reel
  - Spool drill supply hose onto reel
  - Assemble deployment tower #1
  - Shake-down mobile drilling structure

- **For 04-05 season:**
  - Complete assembly and checkout of entire system
  - Drill up to 6 holes, with full complement of DOMs
Digital Optical Modules (DOMs) and Associated Hardware

- **DOM consists of**
  - PMT (Hamamatsu 10-stage R7081-02)
    - 24 in hand
  - Main board (LBNL)
    - 20 in hand
  - Flasher board (UW)
    - 370 or 400nm Nichiya LEDs
    - Goal: $10^9 \gamma$/pulse
    - Prototypes exist
  - HV board (ISEG, DESY)
    - Prototypes exist
  - Mu-metal shield (ITEP, DESY)
    - In hand
  - Connectors, cables (Ericsson?)
  - Pressure vessel (Benthos)
    - 24 in hand
DOM Assembly

DOM assembly to occur initially at PSL (UW-Madison), then in production mode at PSL, DESY-Zeuthen and Sweden. Labor time per DOM: <7 hrs. Process time per DOM: ~100 hrs.
DOM Main Board

- Consists of:
  - Custom ASIC to digitize data: ATWDs
  - On-board FPGA, CPU, memory to manage and sparsify data
  - Precision local clock
  - Local light source and electronic pulser for calibration purposes
  - Communications circuitry

- 20 currently being yoked to PMTs inside DOMs

DOM Main Board designed and fabricated by LBNL
DOM Design Requirements

- Intrinsic total noise rate: < 500Hz
- System-wide timing resolution: < 5ns
- Dynamic range: 200pe/15ns, 2000pe integrated
- Digitization depth: 4µs
- Fast on-board sparsification
- Local coincidence triggering
- Self-calibrating
- Field-programmable
- TCP/IP-compatible (with IceCube custom surface hardware)
**DOM Status**

- **Early prototypes of DOM (AMANDA string 18)**
  - Have some problems which have hampered full exploitation for *physics* (it was a rush job building and installing them), but...
  - Certainly worked more than well enough to give us confidence to use the DOM design concept for IceCube

- **Newer versions of DOM**
  - 20 Main Boards have been tested
  - 2 have been inserted into full DOM w/PMT etc. Currently being tested; so far so good!
IceTop

- **Purposes:**
  - Do cosmic-ray physics @E<10^{18}eV
    - Measure shower size at surface & energy deposition in deep detector simultaneously
    - Composition studies
  - Veto downgoing muons for InIce array
  - Provide tagged muons for calibration of InIce array

Can tag ~5% of single μ for calibration and veto

Larger showers easier to veto

Veto threshold ~10^{17}eV
IceTop Design

Two Ice Tanks 3.6 m² x 1 m deep
- Coincidence between tanks = potential air shower
- In-tank coincidence + 2-tank anti = potential muon

Two DOMs
High Gain w/station coincidence: 1 p.e. resolution
Low Gain: 1 µ resolution

Design & Implementation of IceTop:
Bartol Research Institute, UW, UWRF
IceTop Status

- Freezing technique tested successfully in million-pound Australian beef freezers at Port of Wilmington, Delaware and at Pole
  - Takes $O$(month) to freeze!
  - Does not require babysitting
  - Results in clear ice

- IceTop-specific DOM modifications in process

- Software integration in design stage

- Simulation effort underway
Data Acquisition System

- Requirements:
  - Handle ~1kByte event size @ ~1.5kHz
  - Continuous time calib. of each DOM
  - Flexible triggering system
  - Robust and easy to maintain
  - Perform calib. & monitoring tasks

- DOMs' digitized data → TCP/IP packets early on
  - Allows us to use standard, widely-used protocols to implement DAQ system

- JAVA-based system
  - String processor
    - handles 1 string's 60 DOMs,
    - forms local triggers,
    - does timing calibrations,
    - etc.
  - Trigger
    - InIce trigger: temporal, topological
    - IceTop trigger: temporal, topological
    - Global trigger: InIce + IceTop + AMANDA + ...
  - Event Builder

Design & implementation of DAQ: LBNL, Mainz, Penn State, UW
• Using assembled DOMs and production testing DAQ software
  - DOM on-board pulser
  - Zeroth Light!

Design & implementation of Production-DAQ: Penn State, UW
IceCube Reconstruction & Analysis Software

- Software systems downstream of DAQ will be largely C++ and ROOT-based, with some JAVA interfaces and support for old C and Fortran codes.
- With this system, we will get filtered data out of Pole and analyzed much more efficiently than with AMANDA.

HENA Workshop, Paris, June 2003  IceCube/Doug Cowen/Penn State
Picasso vs. Halzen: A Psychological Case Study

- In 1940, Picasso applied for French citizenship. He was denied. He never re-applied nor did he ever publicly tell anyone about it.
- In 1999, Halzen applied for IceCube funding. It was approved by multiple peer reviews, but denied by President Bush. Halzen re-applied, and never stopped talking about IceCube.
  - IceCube is now fully funded and under construction.
  - IceCube “first light” will occur in 04/05 with up to 6 strings.
  - Merci Francis!

Document taken by Germans in WWII, then by Soviets, recently returned to France in 2000.
One Thing I Do Not Find Funny

Amanda/Antares complementarity

HENA Workshop, F

L. Moscoso
Fin
IceCube Physics Goals: Neutrino Flavor ID

- Filled area: particle id, direction, energy
- Shaded area: energy only
- Detect neutrinos of all flavours at energies from $10^7$ eV (SN) to $10^{20}$ eV
IceCube String Deployment Schedule

<table>
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<tr>
<th>Hole N</th>
<th>0-8</th>
<th>16-24</th>
<th>32-40</th>
<th>48-56</th>
<th>64-80</th>
<th>88-96</th>
<th>104-112</th>
<th>120-136</th>
<th>144</th>
</tr>
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<tbody>
<tr>
<td>Hole N+1</td>
<td>8-24</td>
<td>32-48</td>
<td>56-64</td>
<td>72-80</td>
<td>88-96</td>
<td>104-112</td>
<td>120-136</td>
<td>144</td>
<td></td>
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<tr>
<td>Hole N+2</td>
<td>8-24</td>
<td>32-48</td>
<td>56-64</td>
<td>72-80</td>
<td>88-96</td>
<td>104-112</td>
<td>120-136</td>
<td>144</td>
<td></td>
</tr>
</tbody>
</table>

- Drill firm hole
- Drill hole N
- Release hole N to deployment team
- Disassembly and move drill equipment to hole N+1
- DOM testing & deployment preparation
- DOM deployment
- Transfer TOS to Hole N+2, Counting House checkout, & IceTop deployment