AMANDA Collaboration -99

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Calibration Tools

AMANDA Calibration Tools

In-Situ Devices
- LED beacons, 450nm
  - Geometry
  - Ice Properties
- DC light sources
  - 313nm, 350nm
  - Attenuation
- N2 Laser, 337nm
  - Geometry
  - Ice Properties
- Acoustic Transceiver
  - Geometry at 100m
- Hole Ice devices
  - Transmissometers
  - Turbidity
  - Water purity

Surface Devices
- YAG, 532nm, 10kHz
  - Geometry, T0s
- Dye laser, 20 Hz
  - Ice Properties

External Detectors
- SPASE2/VULCAN
  - Absolute Pointing
  - Geometry
  - Energy Calib.
- GASP
  - Track reconstruction
  - Geometry
  - Pointing Resolut.
- RICE
  - >PeV Energy Res
  - Cascade Efficiency

Atm muons gives angular sensitivity
Atm neutrinos give absolute effective areas, volumes
‘98-’99 Technical Summary

- Three strings using Am-II technology were installed in Jan ’98
  - 42 OMs per string
  - All OMs were Hybrid electrical/optical design
  - Deployed to a depth of 2350m
  - Instrumented length spanned ~1200m
- New DAQ installed
  - High speed readout
  - VME-based, improved functionality
  - Real time filtering of data (‘99)
  - Specialized “string-based” trigger implemented
- Dual-Camera system deployed
  - Visual assessment of hole profile
  - Monitor refreezing dynamics
- Drilling technology pushed to limit
  - Improvements planned
- High speed satellite link in use
  - ~2GB/day capability
  - Real time monitoring of system performance
IceCube Budget per OM
2400m hole, central conf.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Cable</td>
<td>$0.8 k</td>
</tr>
<tr>
<td>Fiber optic Cable (signal and calibration)</td>
<td>$1.8 k</td>
</tr>
<tr>
<td>Electrical Penetrator/connector</td>
<td>$0.4 k</td>
</tr>
<tr>
<td>Include breakout/connectorization/testing</td>
<td></td>
</tr>
<tr>
<td>Fiber Optic penetrator/connector</td>
<td>$0.5 k</td>
</tr>
<tr>
<td>Include breakout/connectorization/testing</td>
<td></td>
</tr>
<tr>
<td>OM (8” PMT)</td>
<td>$2.3 k</td>
</tr>
<tr>
<td>LED, LD w/active base</td>
<td></td>
</tr>
<tr>
<td>Electronics (Front End, Trigger, DAQ, HV)</td>
<td>$1.0 k</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$6.8 k</td>
</tr>
</tbody>
</table>

ICECUBE Cost per OM: Analog optical Fiber Optical
Assumption: 2400m deep hole
Outrigger Design can save ~12% in cable costs
Logistics Projections: NSF

- Science Cargo capacity (C130 flights)
  - All polar science support (IAO, NAOA, etc)

<table>
<thead>
<tr>
<th>F.Year</th>
<th>Available</th>
<th>Committed</th>
<th>IceCube</th>
</tr>
</thead>
<tbody>
<tr>
<td>97</td>
<td>187</td>
<td>187</td>
<td></td>
</tr>
<tr>
<td>98</td>
<td>144</td>
<td>144</td>
<td></td>
</tr>
<tr>
<td>99*</td>
<td>132</td>
<td>132</td>
<td></td>
</tr>
<tr>
<td>00*</td>
<td>84</td>
<td>69</td>
<td></td>
</tr>
<tr>
<td>01*</td>
<td>76</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>02*</td>
<td>80</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>140</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>04</td>
<td>160</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>05</td>
<td>190</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Initiate IceCube activities in FY00, but 16 string deployment delayed until FY03?
IceCube Budget

- **Hardware costs**
  - ~$6-8 k/OM with baseline technology

- **Labor**
  - OM construction and testing
  - Cable construction and connectorization
  - Deployment/drilling labor?
  - ~$1-2 k/OM

- **Drill Costs**
  - New drills for 16 hole/season, portability
  - New technology for 6000 gal/hole
  - ~$?

- **Summer Camps**
  - Cost per season ~?

- **Buildings**
  - No new science construction until FY04?
  - Modification of MAPO, interior cable vaults

- **Satellite Bandwidth costs?**
# IceCube Budget (Summary)

<table>
<thead>
<tr>
<th>Category</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware (Strings, surface equip.)</td>
<td>$35M</td>
</tr>
<tr>
<td>Logistics (drilling, fuel, summer camp)</td>
<td>$20M</td>
</tr>
<tr>
<td>Personnel (US only)</td>
<td>$20M</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$75M</strong></td>
</tr>
</tbody>
</table>
# IceCube Milestones

<table>
<thead>
<tr>
<th>Year</th>
<th>Milestones</th>
</tr>
</thead>
<tbody>
<tr>
<td>FY98</td>
<td>Begin Am-II construction</td>
</tr>
<tr>
<td>FY99</td>
<td>B10-analysis paper, Prepare IceCube proposal</td>
</tr>
<tr>
<td>FY00</td>
<td>Complete Am-II array (6-7 holes per season), string technology selection</td>
</tr>
<tr>
<td>FY01</td>
<td>Start IceCube (8 holes), Mobile drilling tests, pre-deployment procedures, integration of drill team in deploy., Semi-automation of calibration</td>
</tr>
<tr>
<td>FY02</td>
<td>Start construction of 16 strings, deploy 8</td>
</tr>
<tr>
<td>FY03</td>
<td>Deploy 16 strings per season</td>
</tr>
<tr>
<td>FY04-06</td>
<td>Complete IceCube</td>
</tr>
</tbody>
</table>
IceCube Workshop Summary

- Tremendous scientific interest
- IceCube is viable scientifically and technologically
- Immediate opportunities for new collaborators
  - Simulation of signal
  - Amanda-II test-bed for technology ideas
What is next?

- Concentrate on finishing B10 analysis
  - Atmospheric neutrinos paper
  - Search for astrophysical neutrinos

- Continue to refine IceCube simulation
  - Background

- Simulate signal and background for interesting, but difficult, physics goals to establish viability
  - Sensitivity for neutrino oscillations
Summary and Conclusions

HE ν- arrays are extremely flexible instruments

Wide range in E sensitivity
  - 10 GeV - 10 PeV, perhaps more
Wide range in source location
  - atmosphere - cosmologic
Neutrino flavor ID is possible
Wide range of physics opportunities

Initial analysis of AMANDA: 80 live-days

Atm nu cuts give ~22 events presently

Angular distributions consistent with MC
No point sources observed, but early in analysis
  > 1 life year on tape
Efficiencies are improving
Energy estimates should improve sensitivity

Era of multi-messenger astronomy
HE Neutrino Sources:
Intensity Predictions

\[
\log_{10}(E^2 \frac{dJ}{dE}) \text{ (GeV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1})
\]

\[
\nu_\mu + \bar{\nu}_\mu
\]
Event Rates (per 0.1 km$^2$ yr)
### Survey of Event Rate Predictions

#### Point Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Rate (/km² · yr) $E_{\mu} &gt; 1$ TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNa Remnant</td>
<td>3</td>
</tr>
<tr>
<td>AGN (3C273)</td>
<td>1-100</td>
</tr>
<tr>
<td>Mk421, Mk501</td>
<td>1-10 from $\gamma$ flux, $\sim 3$/burst</td>
</tr>
<tr>
<td>GRB</td>
<td></td>
</tr>
</tbody>
</table>

#### Diffuse Sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Rate (/km² · yr · sr) $E &gt; 1$ TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGN</td>
<td>400-800</td>
</tr>
<tr>
<td>AGN jets</td>
<td>45</td>
</tr>
<tr>
<td>GRB</td>
<td>10</td>
</tr>
<tr>
<td>Atm $\nu$</td>
<td>1000</td>
</tr>
</tbody>
</table>
A_{eff}(E_{\mu}) for HE $\nu$-arrays

Area increases with energy
Area decreases with increasing rejection factor
- Selection criteria for HE sources different than for Atm. neutrinos
## Search Strategies

<table>
<thead>
<tr>
<th>Source</th>
<th>Rejection method</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point Source (e.g., AGN)</td>
<td>1. up-down</td>
<td>$(10^9 \text{ /yr})(M)$</td>
</tr>
<tr>
<td></td>
<td>2. direction</td>
<td>$\times (d\Omega/2\pi)$</td>
</tr>
<tr>
<td></td>
<td>3. energy?</td>
<td></td>
</tr>
<tr>
<td>Burst (e.g., GRB)</td>
<td>1. up-down</td>
<td>$(10^9 \text{ /yr})(M)$</td>
</tr>
<tr>
<td></td>
<td>2. direction</td>
<td>$\times (d\Omega/2\pi)$</td>
</tr>
<tr>
<td></td>
<td>3. time stamp</td>
<td>$\times (dt/3\times10^7)$</td>
</tr>
<tr>
<td></td>
<td>4. energy?</td>
<td></td>
</tr>
<tr>
<td>Diffuse flux (e.g. Atm. ν)</td>
<td>1. up-down</td>
<td>$(10^9/\text{yr})(M)$</td>
</tr>
</tbody>
</table>
Up to this point, analysis has concentrated on medium energy events.
AMANDA-II

- AM-II string ('00)
- Am-B array ('97)
- 42 Hybrid OMs/string
- Test bed for new technology
- Good ice 1400m-2300m
DeepIce Science & Technology

- Proposal to NSF to integrate planned expansion beyond AMANDA-II with seismology, glaciology, and biology
  - Resources for AM-II operation
  - Six high technology strings to enhance medium energy physics objectives
  - Radio detection of PeV-scale events
  - Large phase array for seismology at the earth’s rotation axis
  - Program of drill development (mobility and rapid access to ice cores)
  - Biologists interested in land-glacier interface
  - Strong education and outreach component

- Site review by NSF completed on Feb. 23
  - Notification of Award: end of summer ‘99
Neutrino Oscillation Search

- For vertical Atm $\nu$ events
  - $E_{\text{GeV}} = L_{\text{km}} \delta m^2 (eV^2)/1.2 \sim 27 \text{ GeV}$
- Use high density in-fill of AMANDA-II
  - Utilize string architecture of HE $\nu$-telescopes
  - Measure $E_\nu$ of contained events with calorimetry
  - Calibrate efficiency of vertical events with Am-A

- Use Am-II to veto atm muon background
- Measure cascade and muon cherenkov light
- AMANDA 500m tall ($E_\mu < 100 \text{ GeV}$)
Principle of Operation
Signal/Noise vs Rejection
(Point Source Search)

- Strong rejection yields best S/N
- \( S/N \sim \frac{A_{\text{eff}}}{(N_B d\Omega)^{0.5}} \sim \frac{A_{\text{eff}}}{(d\Psi N_B^{0.5})} \)
Angular Distributions

![Graph showing angular distributions](image)
MC angular distribution

![Graph showing MC angular distribution with coxine zenith and events surviving on the y-axis. The graph includes a legend with event counts on a logarithmic scale.]
Angular distribution of Atm. $\nu$ candidates

![Angular distribution of Atm. $\nu$ candidates](image)
What’s next? - using $N_\gamma$

- So far, reconstruction based primarily on the arrival time of the photons; event selection based on timing and geometric variables.

- We are concentrating on developing an energy variable using $N_\gamma$ at each OM
  
  - $E_\mu$: “brightness” increases for $E > \sim 0.5$ TeV
    - Background is reduced dramatically
    - Angular response to $\nu$ is improved
  
  - $E_{\text{casc}}$:
    - calorimetry provided by diffusion of photons to $d > 100m$
    - Angular resolution $\sim 10$ degrees

- We have analyzed 80 days live time, but have $>1$ year on tape (5x increase).
AMANDA Analysis

- First look results - hot off the press!
- 80 days live time (113 days)
- Atm $\nu$ and point source search
AMANDA sky plots (80 days)
Energy Improves Angular Uniformity of AMANDA-B10

Neutrino Effective Area vs. Cos(Zenith)

![Graph showing Neutrino Effective Area vs. Cos(Zenith)]

- No Cut
- With Energy Cut
- Without Energy Cut

Effective Area (m²)

Cos(Zenith)
Am-B4 Atm. ν candidates

- Clean separation of n-candidates from background population
  - But angular acceptance limited to near zenith
DeepIce STC
IceCube Angular Resolution
Cascade Events (0.8-800 TeV)

IceCube Simulation: Cascade Events

Angular resolution (degrees)

E_cascade(TeV)

University of California-Irvine
S. Barwick
IceCube Progress

- Simulations of $A_{\text{eff}}$ for 1-1000 TeV muons
  - Optimization of configuration complete

- Simulations of $V_{\text{eff}}$ for 1-1000 TeV cascades

- Trigger simulated in software (LBL group)
  - Straightforward hardware solution

- Real time monitoring and filtering software installed in VME DAQ (Jan 99).

- Am-II will contain IceCube prototype systems
  - Digital OM string approved by NSF
  - Analog OM based on Laser Diode transmission

- Management structure being defined - similar to new AMANDA management structure

- Project management software implemented
Flux limit for Mk421

- Space angle resolution ~ 4.5 deg
  - ~ constant solid angle bin
- \( F_{\mu} < \frac{N_{\text{events}}}{A_{\text{eff}}(E)t(s)} \)
- For most selective condition (level 4)
  \[
  A_{\text{eff}} = 400 \text{ m}^2, \text{nearly indep. E}
  
  N_{\text{events}} = 2.3 \text{ for 90\% CL}
  
  T = 6.9 \times 10^6 \text{ s}
  \]
  \[
  F_{\mu} < 8.25 \times 10^{-14} /\text{cm}^2\text{s}
  
  \text{MACRO (< 9 \times 10^{-14} /\text{cm}^2\text{s} )}
  \]