# Recent Results from AMANDA II

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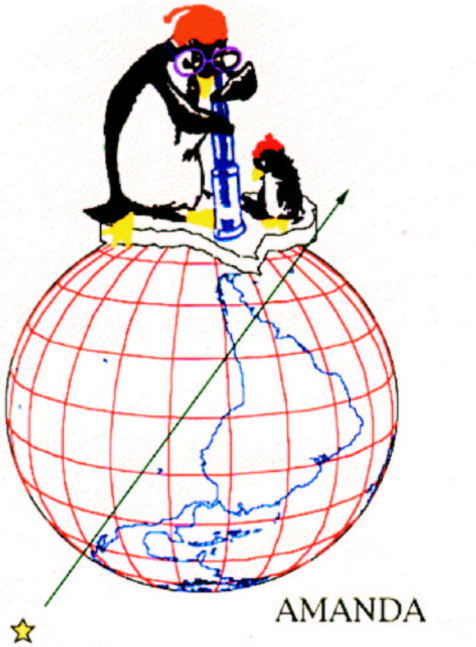


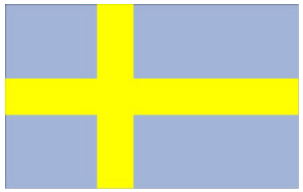

INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS – ICHEP 2002
Amsterdam

# The AMANDA Collaboration

- Bartol Research Inst. – Univ of Delaware, Newark, DE
- Penn State University,University Park, PA
- University of Wisconsin – Madison, Madison, WI
- University of Wisconsin – River Falls, River Falls, WI
- Lawrence Berkeley Nat'l Laboratory, Berkeley, CA
- University of California, Irvine, Irvine, CA
- University of Kansas, Lawrence, KS

- ULB – IIHE, Brussels, Belgium
- University of Mons-Hainaut, Mons, Belgium

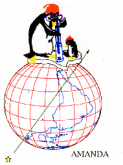
- BUGH Wuppertal, Germany
- DESY-Zeuthen, Zeuthen, Germany
- University of Mainz, Mainz, Germany



- Uppsala University, Uppsala, Sweden
- Stockholm University, Stockholm, Sweden

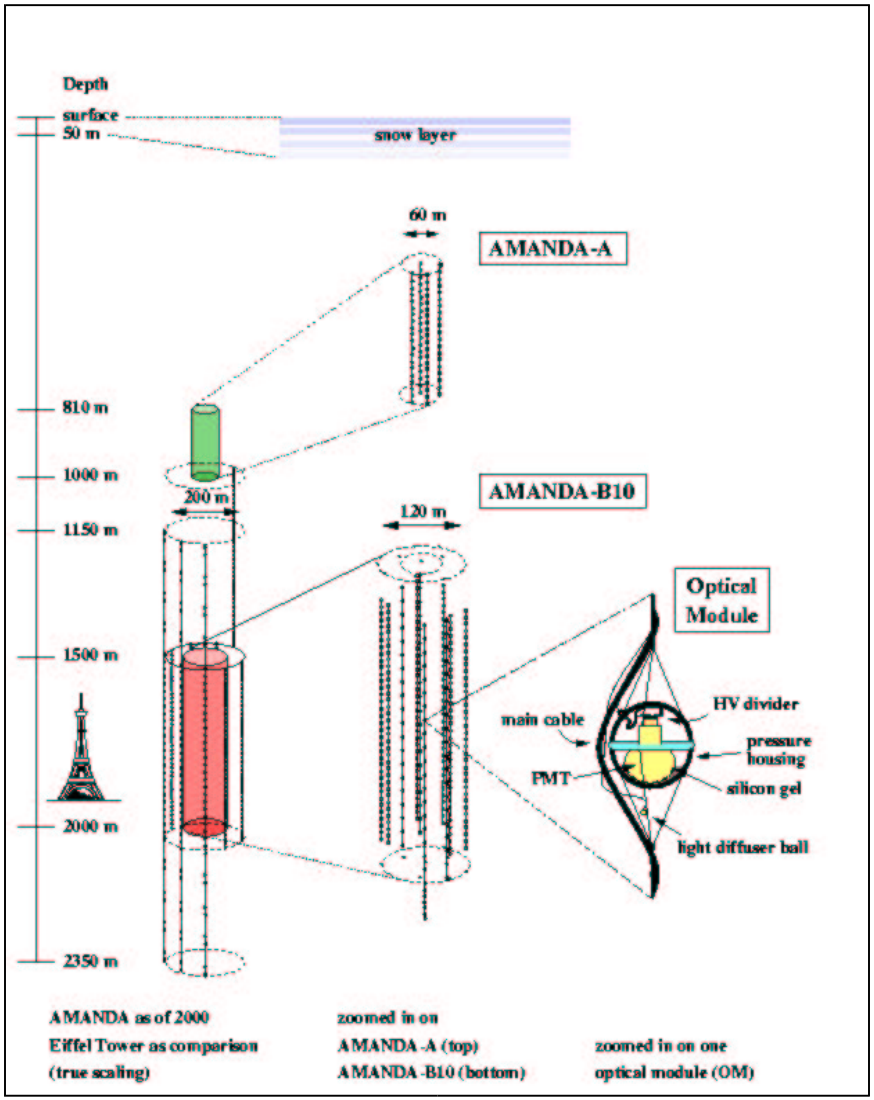
- Imperial College, London, UK

- Universidad Simon Bolivar, Caracas, Venezuela



# The South Pole Site

# The AMANDA Neutrino Telescope

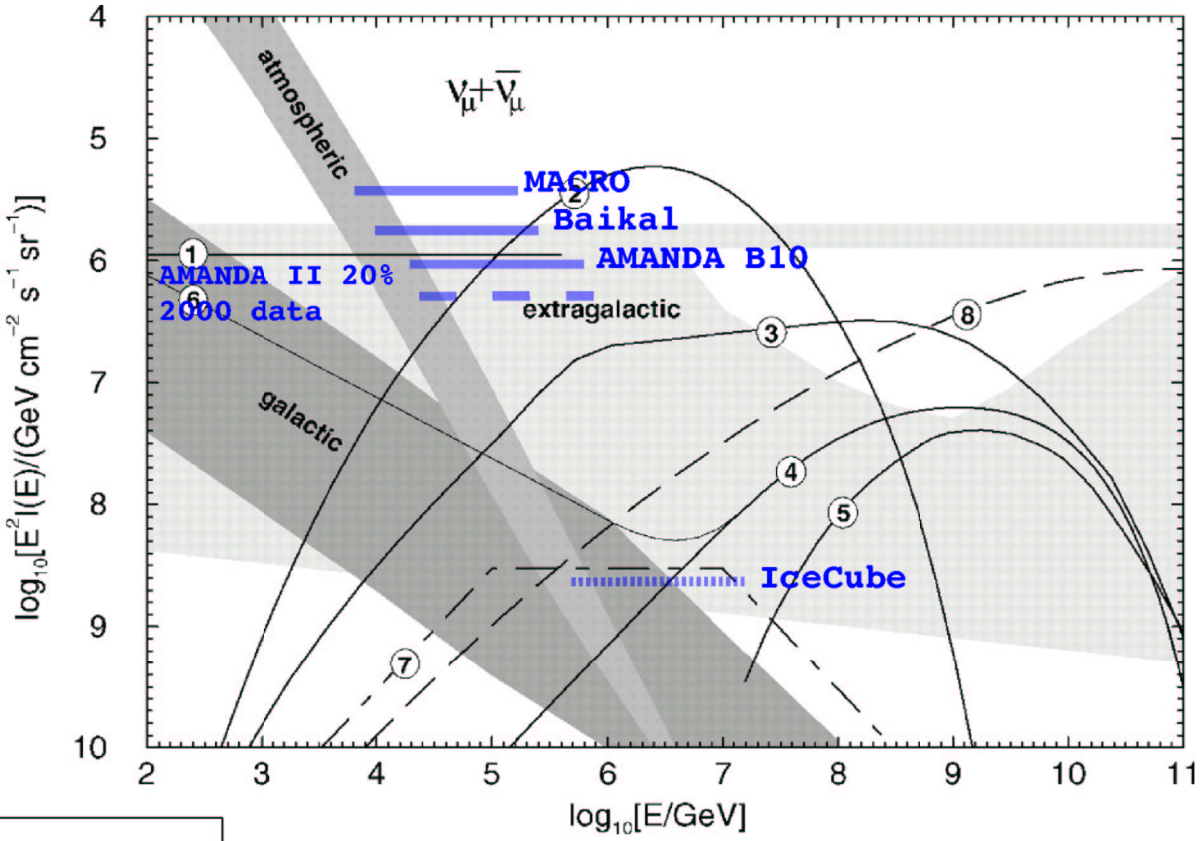


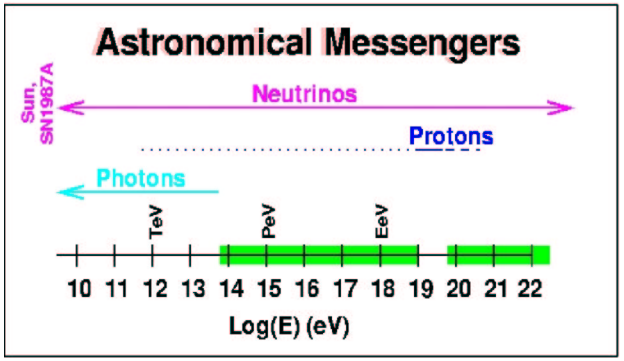

- 677 OMs deployed along 19 strings
  - 10 strings 1997 (AMANDA B10)
  - + 3 strings 1998 (AMANDA B13)
  - + 6 strings 2000 (AMANDA II)
- Located < 1 km from South Pole
- Mean depth = 1730 km
- 200 m diameter, 500 meters height; AMANDA II encompasses 20 Mton instrumented ice volume!
- 1.5 billion muons/year – largest astrophysical detector in the world

AMANDA B10 was the 1st underice detector to extract HE neutrino astrophyics – AII is competent successor that has been streamlined in many aspects.

# Fluxes of UHE Neutrinos

1. AGN core pp
2. AGN core pγ
3. Mannheim pγ
4. blazar pγ
5. pγ on CMBR
6. pp blazar on host galaxy
7. GRB
8. topological defects



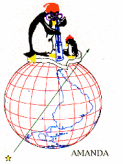

Mannheim & Learned, *Annu. Rev. Nucl. Part. Sci*, 2000:**50**

# Status of AMANDA Analyses

- 1997 analyses completed
  - Published results
    - Atmospheric neutrinos
    - WIMPs
    - Supernova search
  - Submitted
    - Cascades (CC e, tau, NC muon)
    - Point sources
  - Under internal review
    - GRBs
- 1998 dataset (AMANDA B10): problems with first pass filtering; currently redoing
- 1999 dataset (AMANDA B10): filtering completed, analyses underway
- 2000 dataset (AMANDA II): filtering completed, analyses underway
  - Status of 2000 analyses...
    - Atmospheric neutrinos (100%)
    - HE diffuse neutrinos (20%)
    - HE point source search (time scrambled data)
    - Neutrino-induced cascades (20%)
- 2001 dataset: filtering to be completed this summer.
- 2002 dataset: *online filtering being done at Pole in realtime /w/ ~ 75% efficiency mu w.r.t. offline filtering.* Filtered data promptly avail. in NH via satellite.

*All analyses post-1997 are blind so that we do not bias ourselves toward (or away from) signals.*

# AMANDA B10 Results



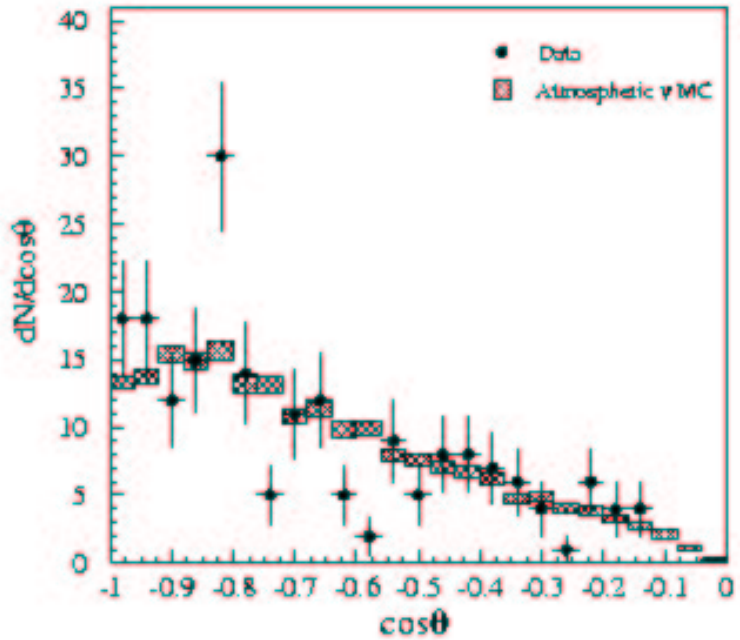
# B10 Results – Atmospheric Neutrinos

- Atmospheric neutrinos separated from CR by up-going signature
- B10 measurement based on 130.1 days livetime

$N_{DATA} = 204$ events

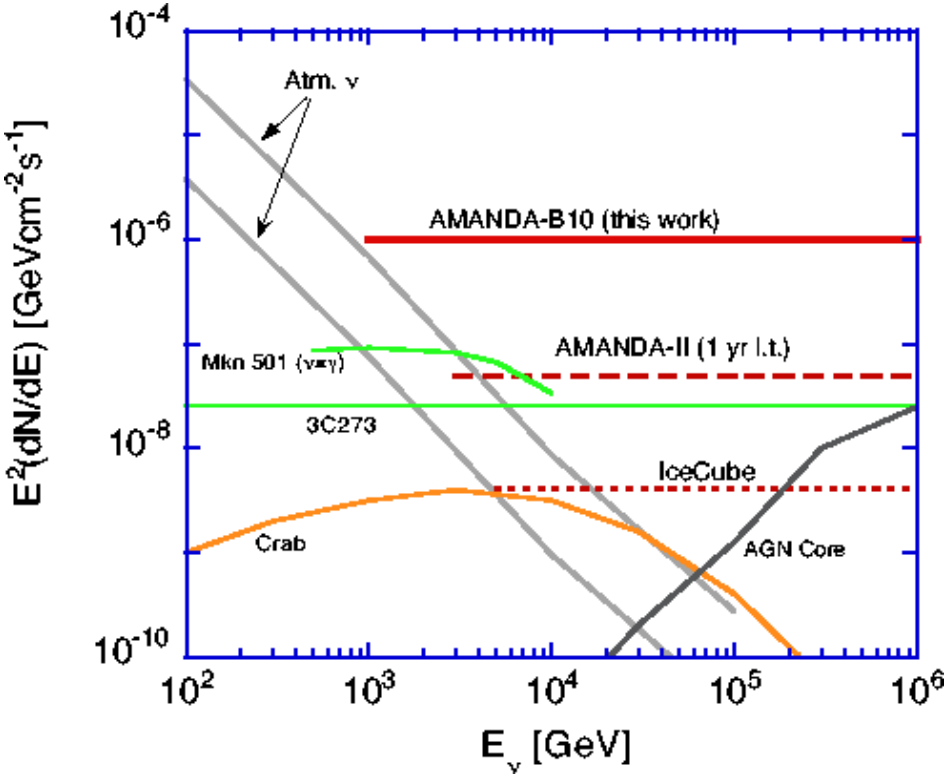
$N_{MC} = 279 \pm 3$ events

- Data, MC normalized in plot
- Background contamination estimated 5-10%.

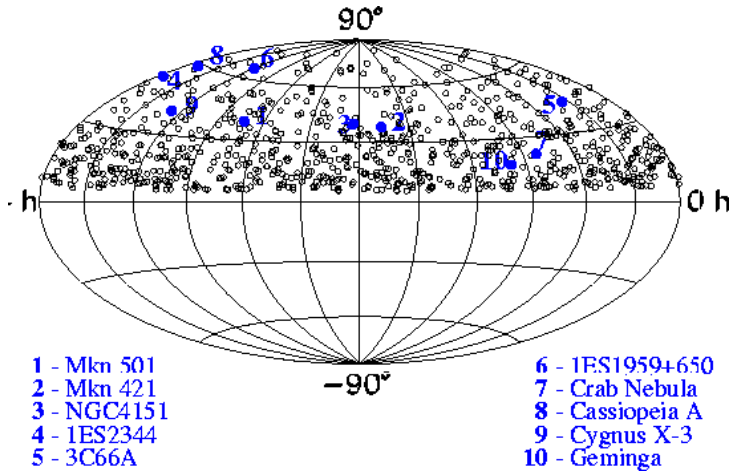



Accepted for pub. by PRD.
astro-ph/0205109

# B10 – Point Sources

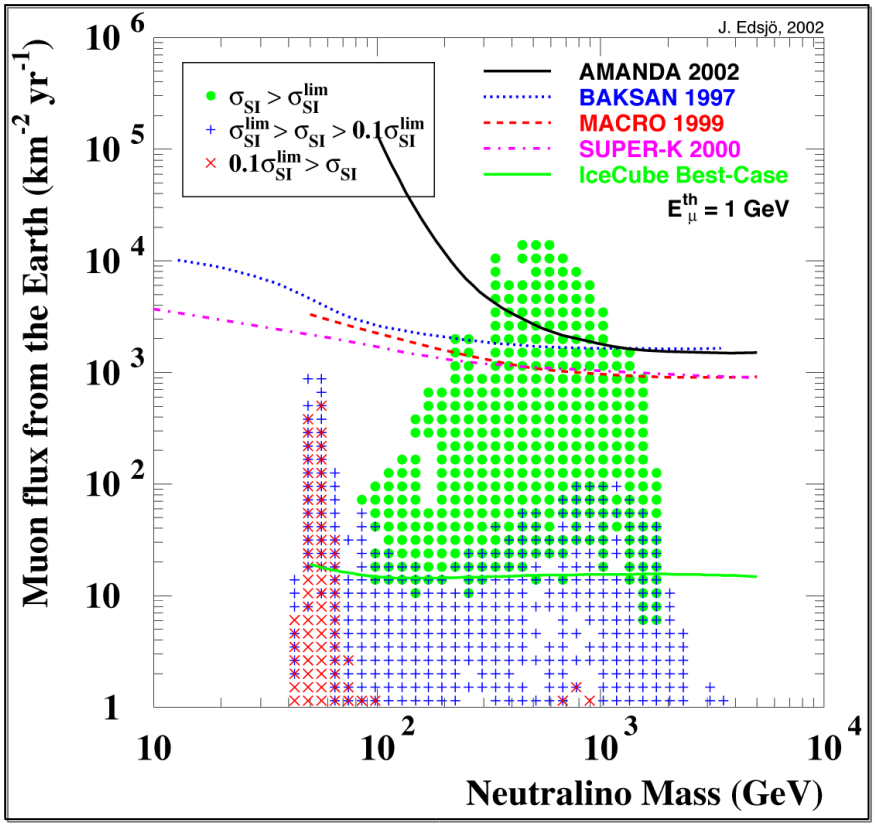



- Northern hemisphere skyplot divided into 154 bins (11° in zenith, var. in azimuth)
- Looser cuts than atmospheric neutrino analysis – increases detector sensitivity.
- 815 events remain




Soon (now?) to be submitted to APP

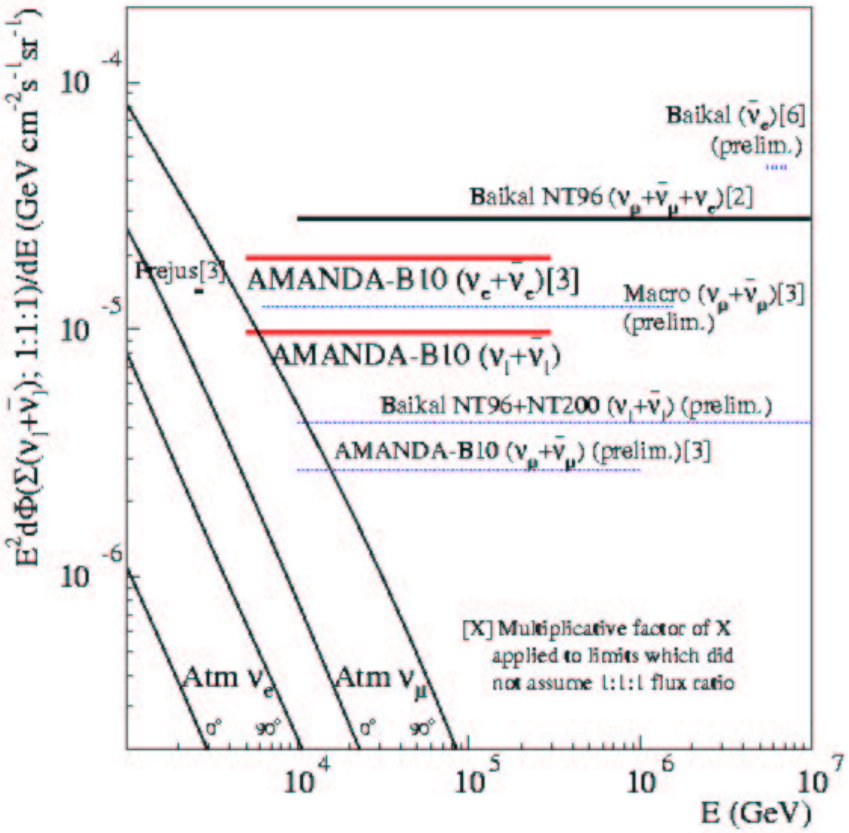
# B10 – WIMPs from the Earth's Center




- Signal : excess of upgoing muons in restricted zenith range ($\theta > 165^{\circ}$) about the nadir.
- Recent direct search by EDELWEISS (astro-ph/0206271) puts severe constraints on WIMPs from the Earth.

Accepted for pub. by PRD.
astro-ph/0202370

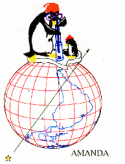
# B10 – Cascade Results




- Cascade is generic term for EM and/or hadronic shower
  - Electron neutrinos (CC+NC)
  - Tau neutrinos (CC+NC)
  - *Muon neutrinos* (NC – muon is not visible)
- 3-flavor search
- Analysis requires full reconstruction of cascade vertex, energy.
- Threshold energy 4 TeV due to strong background cuts

Submitted to PRD
astro-ph/0206487

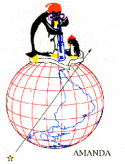
# AMANDA II – Year 2000



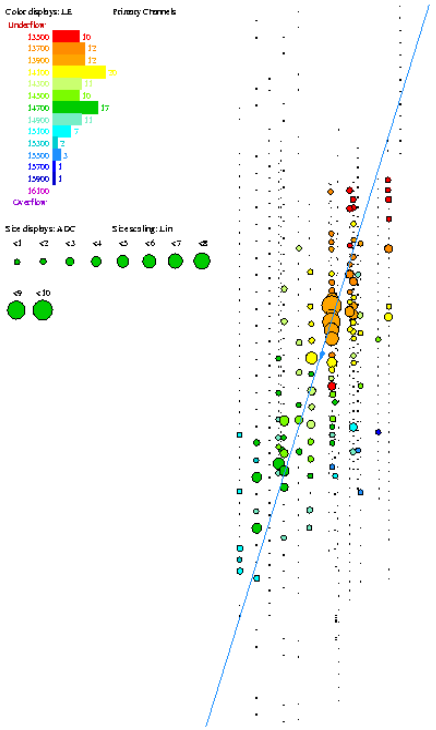
# AMANDA II vs B10

The AMANDA II detector has several advantages over AMANDA B10:

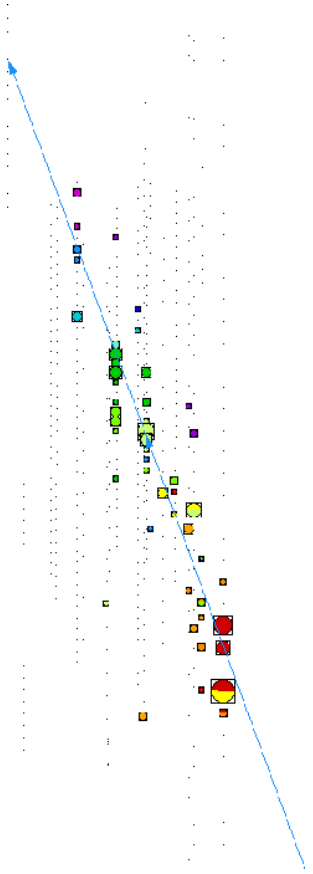
- Larger effective area/volume (~ 4x)
- Better acceptance at horizon
  - Lower background from misreconstructions near horizontal
  - For PeV-scale muon neutrinos – **this is where majority of events are contained!**
- Better angular resolution
- Better energy resolution
- AMANDA II has slightly higher energy threshold due to increase of multiplicity trigger (18 → 24 to keep data rate at ~ 100 Hz) but see later.
- Optical readout of AII channels gives increased photoelectron resolution – we are beginning to fully exploit this with wavefrom readout of channels.



# Muon Events in AMANDA II



Downward-going cosmic-ray muon



Upward-going $\nu$-induced muon

# Atmospheric Neutrino-Induced Muons

- Starting with loose standard quality cuts, tighten cuts in discrete steps, examine data and MC
- Data/MC normalized at tightest cut level (Data/MC without normalizing ~ 150%)
- Good agreement from cut levels 4-8; data still contains unsimulated background at lower levels:
  - Detector effects (crosstalk, ...)
  - Ice structures

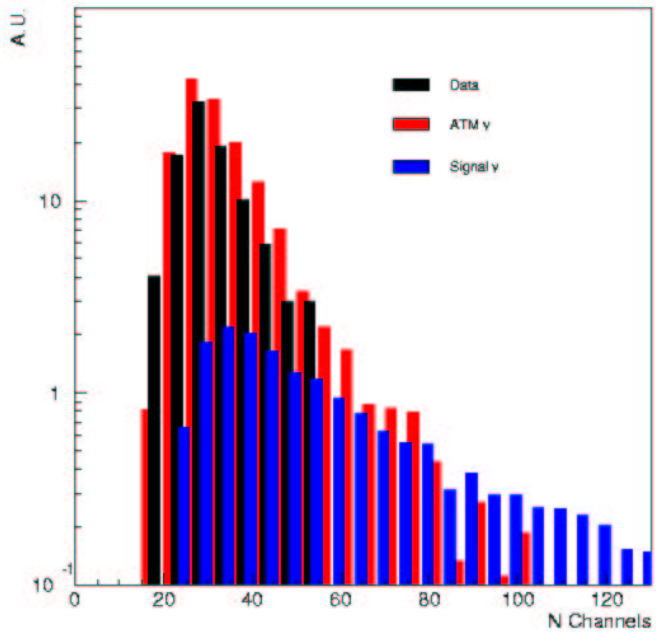
# A-II Atmospheric Nu (continued)

Distribution of candidate neutrino-induced muons versus cosinus of the zenith angle at cut level 4.


Distribution of N channels hits for candidate neutrino-induced muons at cut level 4. Note cut @ Nch < 50 to distinguish from diffuse HE signal.

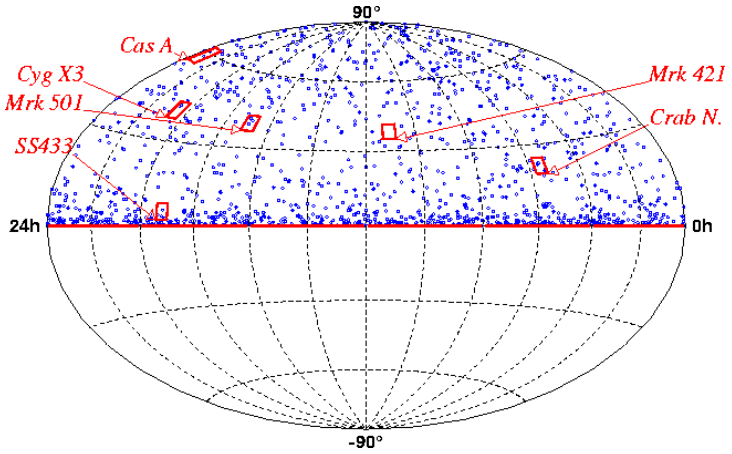
# HE Diffuse Neutrino-Induced Muons

- HE diffuse muon search for extra-galactic neutrinos – assumes harder spectrum: source flux model is generic diffuse model, $\Phi = 1.0\text{E-}06\ E^{-2}$
- Background (ATM $\nu$) suppressed by energy cuts: either simple N channel cut or linear hit density cut.
- Plot at right shows data (black), signal (blue), and background (red) from atmospheric neutrinos for 20% of data sample analysed (35 d).
- Data histogram above 50 channels has been intentionally obscured from view.




- *PRELIMINARY* limit from 20% 2000 data (35 d):
  $\Phi < 7\text{E-}07\ E^{-2}\ cm^{-1}\ s^{-1}\ sr^{-1}\ GeV$

# Search for Point Sources

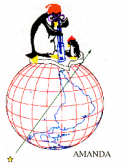



- Skyplot of upward-going muons selected for point source analysis (N events). The azimuth has been randomized by scrambling the times.
- Angular resolution
  - AII: 1.5˚ - 2.5˚ (zenith dependent)
  - B10: 3˚ - 4˚

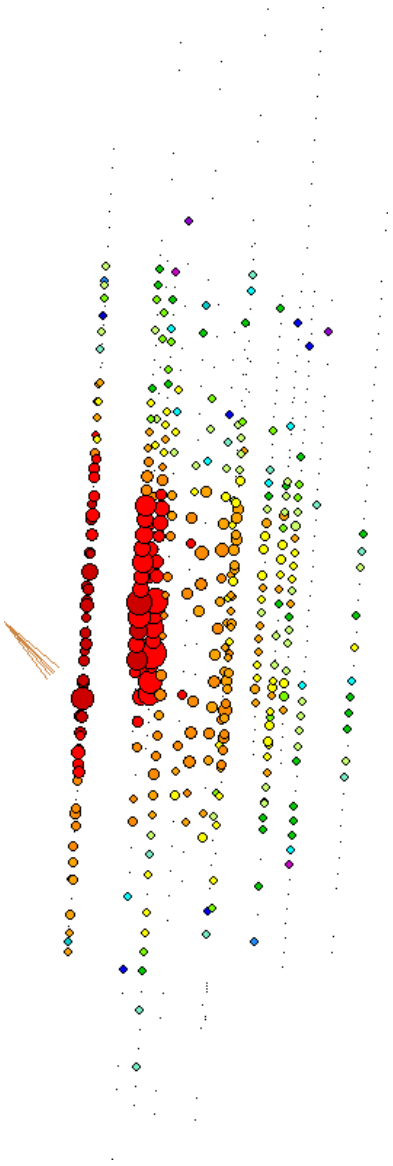
Sensitivity estimates of this analysis for handful of selected point sources (locations shown in skyplot above).

| Object | $\alpha$ [h] | $\delta$ [°] | $N_{km^2,yr}$ | $\Phi_\mu$ 2000 | | | $\Phi_\mu$ limit |
|---|---|---|---|---|---|---|---|
| | | | | $Q_{cut}$ | $N_{BG}$ | expect. sens. | 1997(a) |
| SS433 | 19.2 | 5.0 | **252** | 0.85 | 4.6 | 6.1 | 58.2 |
| Cygnus X-3 | 20.5 | 41.0 | 4.8 | 0.85 | 1.1 | 1.7 | 6.2 |
| Crab Nebula | 05.6 | 22.0 | – | 0.8 | 1.6 | 2.9 | 21.0 |
| Cassiopeia A | 23.4 | 58.8 | – | 0.85 | 1.9 | 1.6 | 1.0 |
| Markarian 421 | 11.1 | 38.2 | – | 0.8 | 1.5 | 1.9 | 5.8 |
| Markarian 501 | 16.9 | 39.8 | – | 0.8 | 1.5 | 1.9 | 5.8 |

$N_{km^2,yr}$: predicted event numbers [5] per year and km$^2$
$\Phi_\mu$: expected sensitivities [$10^{-15}$cm$^{-2}$s$^{-1}$] (1997 comparison: 90 % CL flux limit)
Assumed $E^{-2}$ spectrum – integral limits/sens. $E_\nu > 10$ GeV



# AMANDA II Cascades



EM or hadronic showers – cascades – distinguish themselves from muons in pattern of light deposition in AMANDA: cascades create (very roughly) spherical distributions which can be approximated to eminate from a point source.

Cascades must be (semi) contained. However, looking for neutrinos in cascade channel still worthwhile:

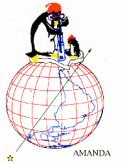
- Cascades (especially double bang $\tau$) have unique signature distinct from throughgoing muons
- Energy resolution for cascades necessarily superior to through-going muons because of contained event topology.

# A-II Cascades (continued)

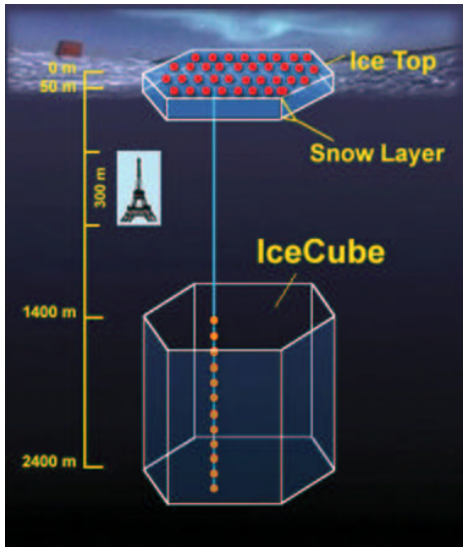
- Note acceptance over full sphere! This becomes an important feature, particularly at E > 100 TeV where earth absorption attenuates signal from lower hemisphere.
- *Anticipated* fluxes of terrestrial neutrinos (in 250 d of AMANDA-II data):
  - ATM nu: 0.15 ± 0.1
  - Prompt charm: 0.5 ± 0.3
- **Actual** limit of astrophysical neutrinos from 20% of 200 data:
  $\Phi < 4\times10^{-6}\ E^{-2}\ cm^{-1}\ s^{-1}\ sr^{-1}\ GeV$

# Future of AMANDA II

- 2001 data processing begins this summer. 2002 data filtered at Pole in real-time.
- AMANDA II, now running since Feb. 2000, will continue to take data at least until IceCube fully constructed.
- This year, 48 optical channels outfitted with 100 MHz waveform readout. WF and "muon" DAQ information merged offline.
- Next year, entire detector will be instrumented with WF digitizers.
- 2005+: AMANDA DAQ integrated with IceCube / IceTop at global trigger level. AMANDA detector will initially be necessary for calibration of IceCube.



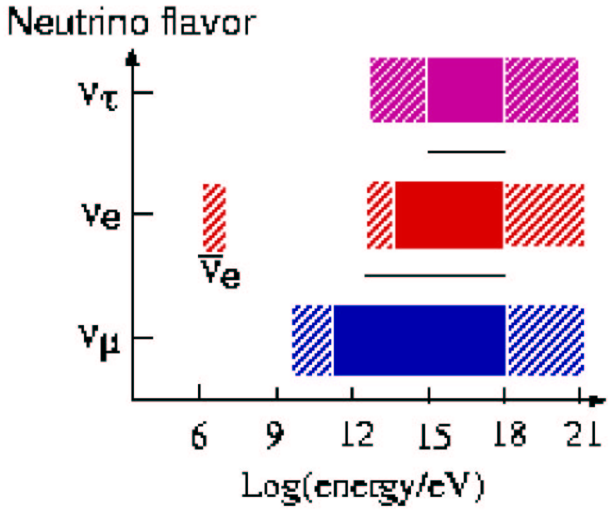
# IceCube: the next generation detector




## IceCube is two detectors:

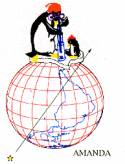
- IceTop surface air shower array
  - 80 stations of two tanks each
  - Functions as stand-alone airshower detector and veto for IceCube.
  - 1 $km^2$ area
- Subsurface array of 80 strings
  - 60 (digital) OMs per string: 4800 OMs!
  - String spacing 125 m
  - 1 $km^3$ instrumented volume!

- IceCube is a *discovery* instrument for UHE/EHE astrophysical neutrinos.
- Figure at right gives IceCube sensitivity to neutrino flavors (shaded) and flavor discrimination (solid).

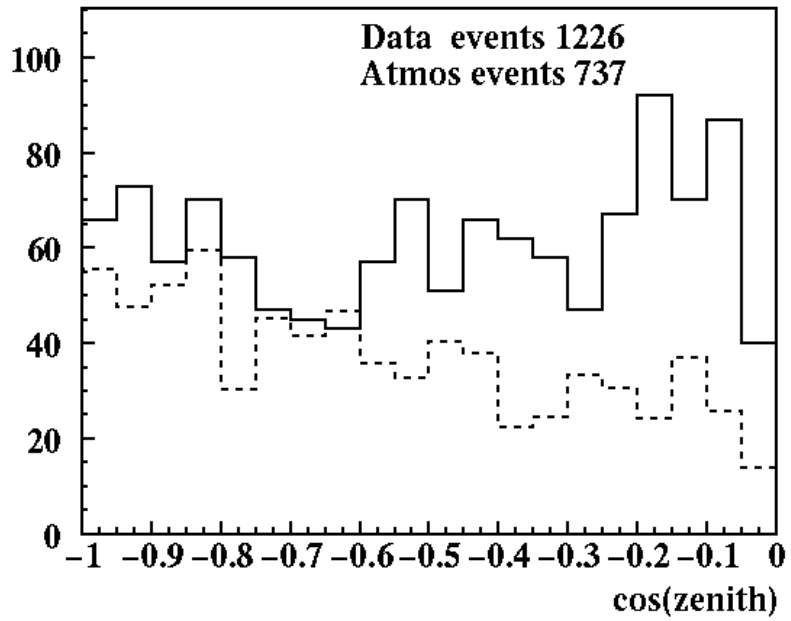


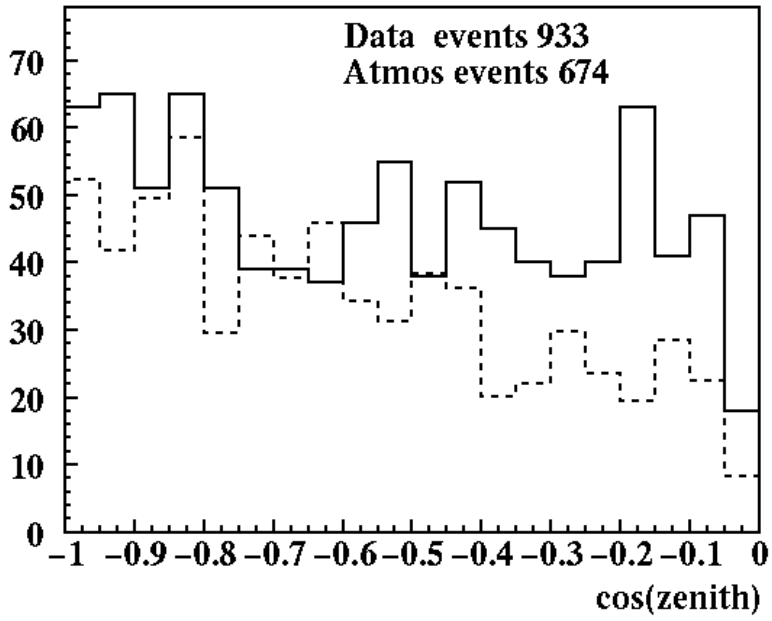
# Conclusions

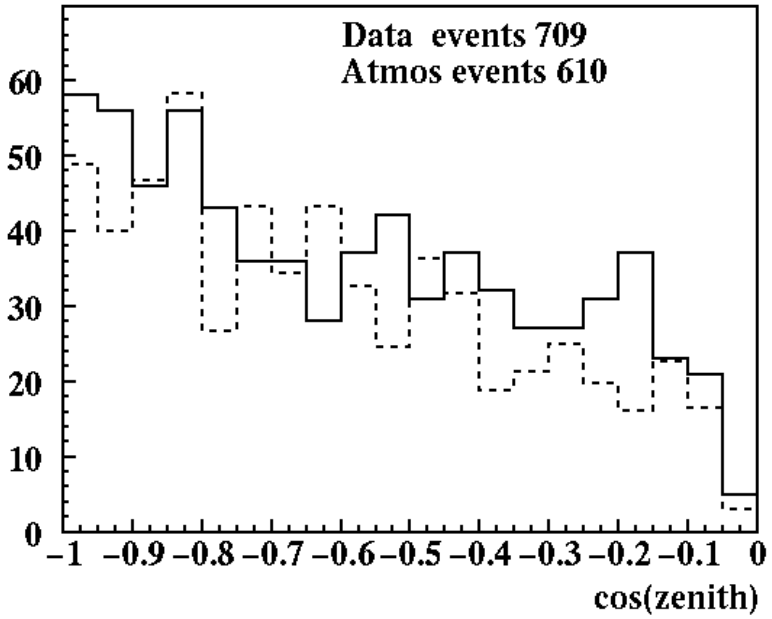
- AMANDA II detector is running – data analysis for 2000 run season, the first after commissioning the last 6 strings, is well underway.
- 2001 data analysis will begin very soon – transition from 2000 not that difficult since no major detector changes.
- 2002 data taking season the first to test out online filtering at Pole; it returns 4 ATM nu / day!
- Major hardware upgrade next year as AMANDA II moves to full waveform readout – this is in preparation to phase AMANDA into larger, next generation IceCube neutrino telescope (currently funded and in development phase).

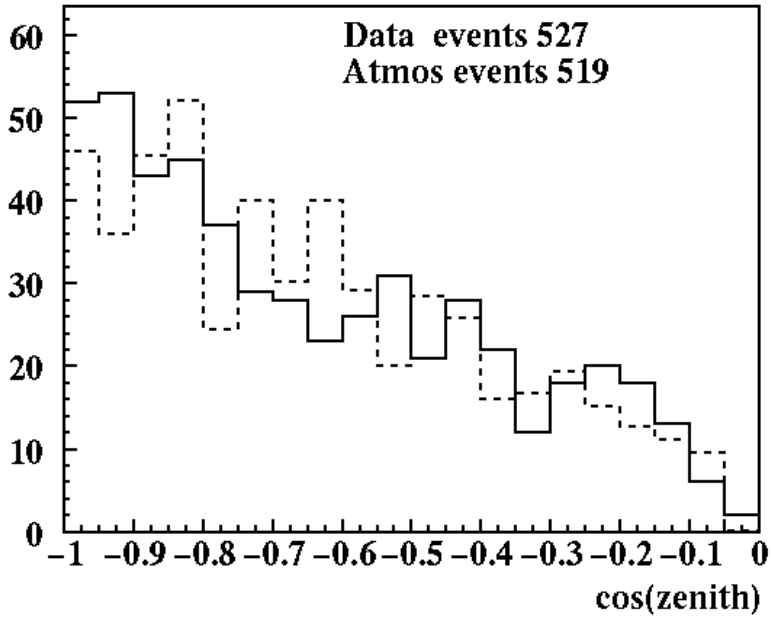


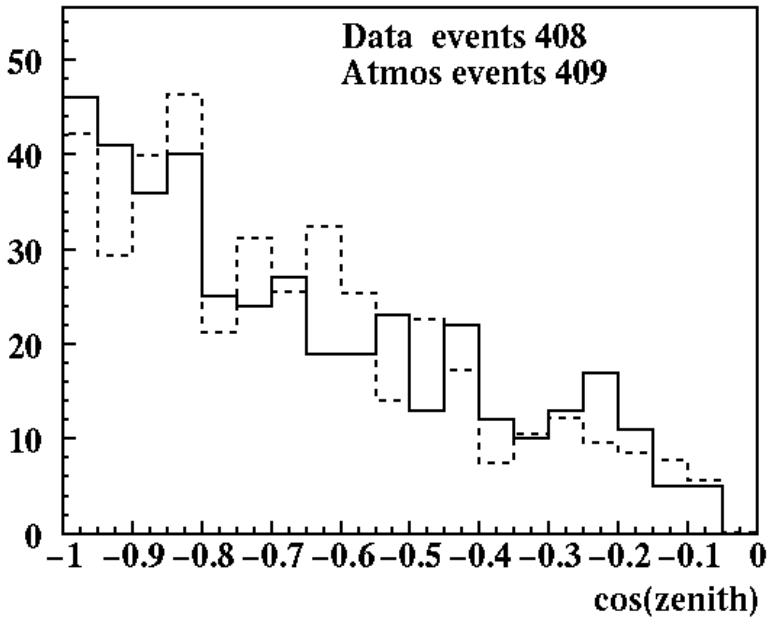
# Cosine theta vs. cuts levels for ATM nu

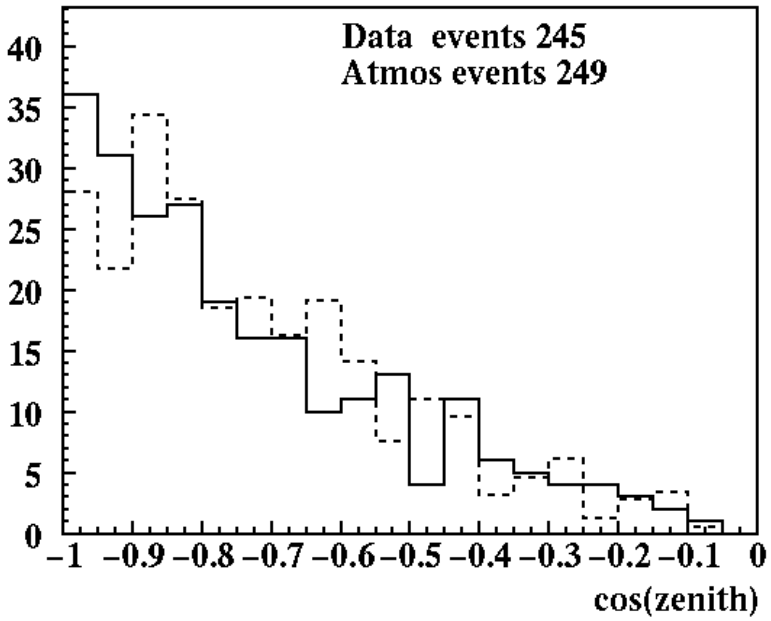


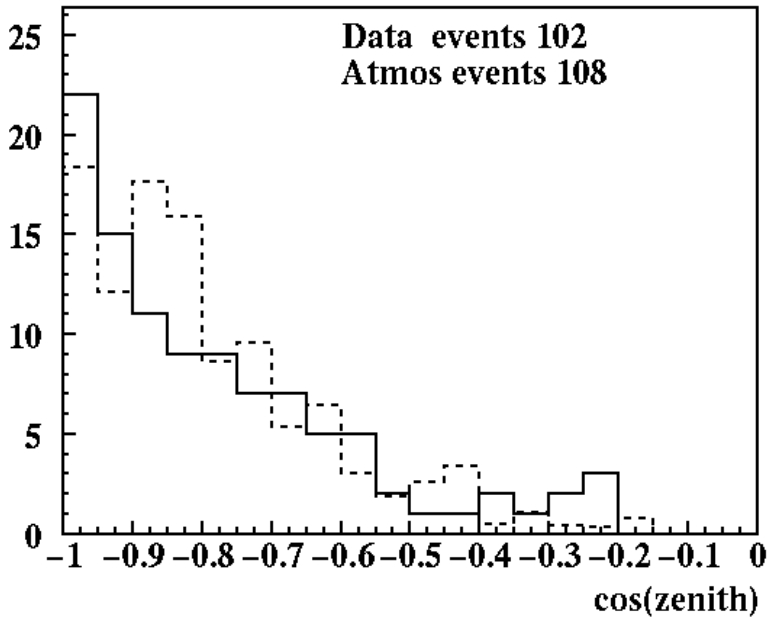



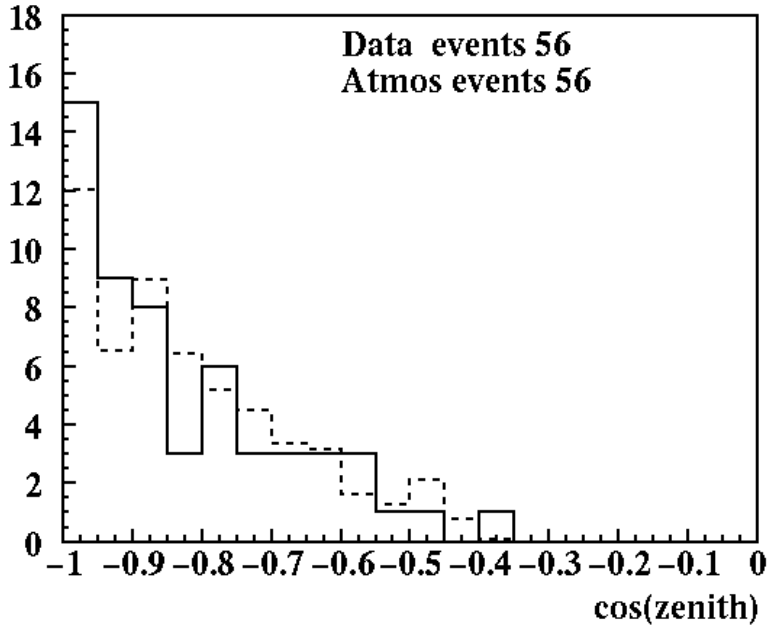

Data events 709
Atmos events 610
60
50
40
30
20
10
0
−1 −0.9 −0.8 −0.7 −0.6 −0.5 −0.4 −0.3 −0.2 −0.1 0
cos(zenith)


Data events 527
Atmos events 519
60
50
40
30
20
10
0
−1 −0.9 −0.8 −0.7 −0.6 −0.5 −0.4 −0.3 −0.2 −0.1 0
cos(zenith)


Data events 408
Atmos events 409
50
40
30
20
10
0
−1 −0.9 −0.8 −0.7 −0.6 −0.5 −0.4 −0.3 −0.2 −0.1 0
cos(zenith)


Data events 245
Atmos events 249
40
35
30
25
20
15
10
5
0
−1 −0.9 −0.8 −0.7 −0.6 −0.5 −0.4 −0.3 −0.2 −0.1 0
cos(zenith)


Data events 102
Atmos events 108
25
20
15
10
5
0
−1 −0.9 −0.8 −0.7 −0.6 −0.5 −0.4 −0.3 −0.2 −0.1 0
cos(zenith)


Data events 56
Atmos events 56
18
16
14
12
10
8
6
4
2
0
−1 −0.9 −0.8 −0.7 −0.6 −0.5 −0.4 −0.3 −0.2 −0.1 0
cos(zenith)

# Hot Water Drilling

- AMANDA string design accomodates deployment strategy: drill 2 km holes with 192° F hot water
- Hole diameter 50 cm but varies v depth to correct for ice temperature profile.
- Drilling time 84 – 160 hoursfor AMANDA strings.
- IceCube drill – **Wotan** – will use thicker diameter hose to accomplish same job in 30 hours!

# Optical Module Deployment

- After drill extraction, AMANDA strings containing
  - HV/electrical signal cable
  - Optical signal fibers
  - Optical calibration fibers

  are lowered into the holes
- Optical modules are attached in deployment shack as string is inserted.
- Whole process takes 15 – 20 hours from drill extraction.

# Optics in the Ice

- Natural ice medium very clear below loose-packed firn layer (0-200 m from surface).
- Intense scattering due to bubbles down to 1500 m
- Below 1500 m, good ice properties:
  - Scattering length ~ 30 m
  - Absorption length ~ 100 m
- Difficult to do proper treatment of ice optics in montecarlo:
  - Ice layers simulated, but
  - Photons crossing layers are problem – we are currently testing new code that handles this correctly.