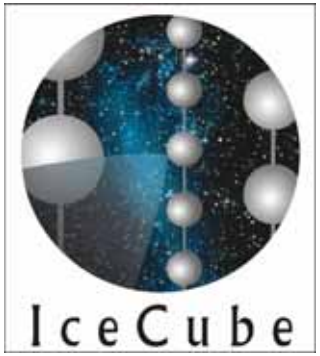
AMANDA-IceCube

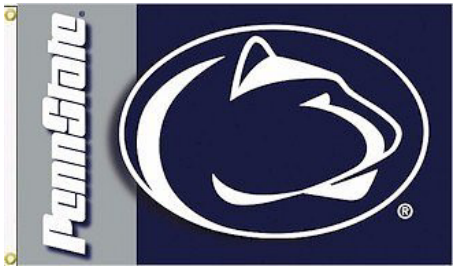
Astroparticle Physics with Neutrinos



Brendan Fox

Pennsylvania State University

for the IceCube Collaboration



Electroweak Interactions & Unified Theory - XLIInd Rencontres de Moriond - 2007

The IceCube Collaboration

29 institutions
~250 people

- Bartol Research Institute, Delaware, USA
- Pennsylvania State University, USA
- UC Berkeley, USA
- UC Irvine, USA
- Clark-Atlanta University, USA
- University of Alaska, Anchorage, USA
- Univ. of Maryland, USA

- University of Wisconsin-Madison, USA
- University of Wisconsin-River Falls, USA
- LBNL, Berkeley, USA
- Southern University and A&M College, Baton Rouge, USA

- Chiba University, Japan
- University of Canterbury, Christchurch, NZ

- Universite Libre de Bruxelles, Belgium
- Vrije Universiteit Brussel, Belgium
- Université de Mons-Hainaut, Belgium
- Universiteit Gent, Belgium
- Humboldt Universität, Germany
- Universität Mainz, Germany
- DESY Zeuthen, Germany
- Universität Dortmund, Germany

Amundsen-Scott Station

- Universität Wuppertal, Germany
- MPI Heidelberg, Germany
- RWTH Aachen
- Uppsala university, Sweden
- Stockholm university, Sweden
- Oxford university, UK
- Utrecht university, Netherlands

Outline

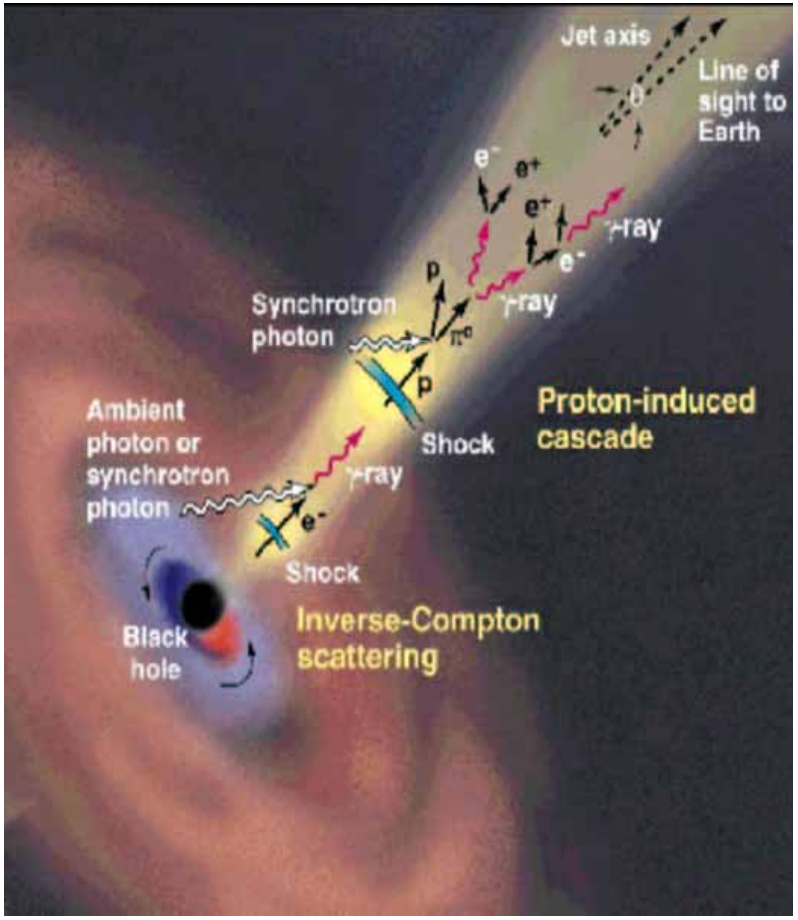
- Physics Goals
- AMANDA
  - What is it?
  - Recent results
- IceCube
  - What is it?
  - First look at IceCube data
  - Status of the construction
- Outlook

Physics Opportunities

Science potential with IceCube is vast …

- Point source searches
  - AGNs, remnant supernovae (position)
  - GRBs (time correlation)
- Diffuse neutrinos
- Cosmic ray physics (via IceTop surface array)
  - Composition, energy spectrum
- Search for exotic particles and new physic
  - (indirect) WIMP searches
  - Neutrino oscillations?
  - charm production from high-energy neutrinos
  - New stuff: monopoles, q-balls, *etc.*
- Supernova neutrinos

Astrophysics: what's the question?



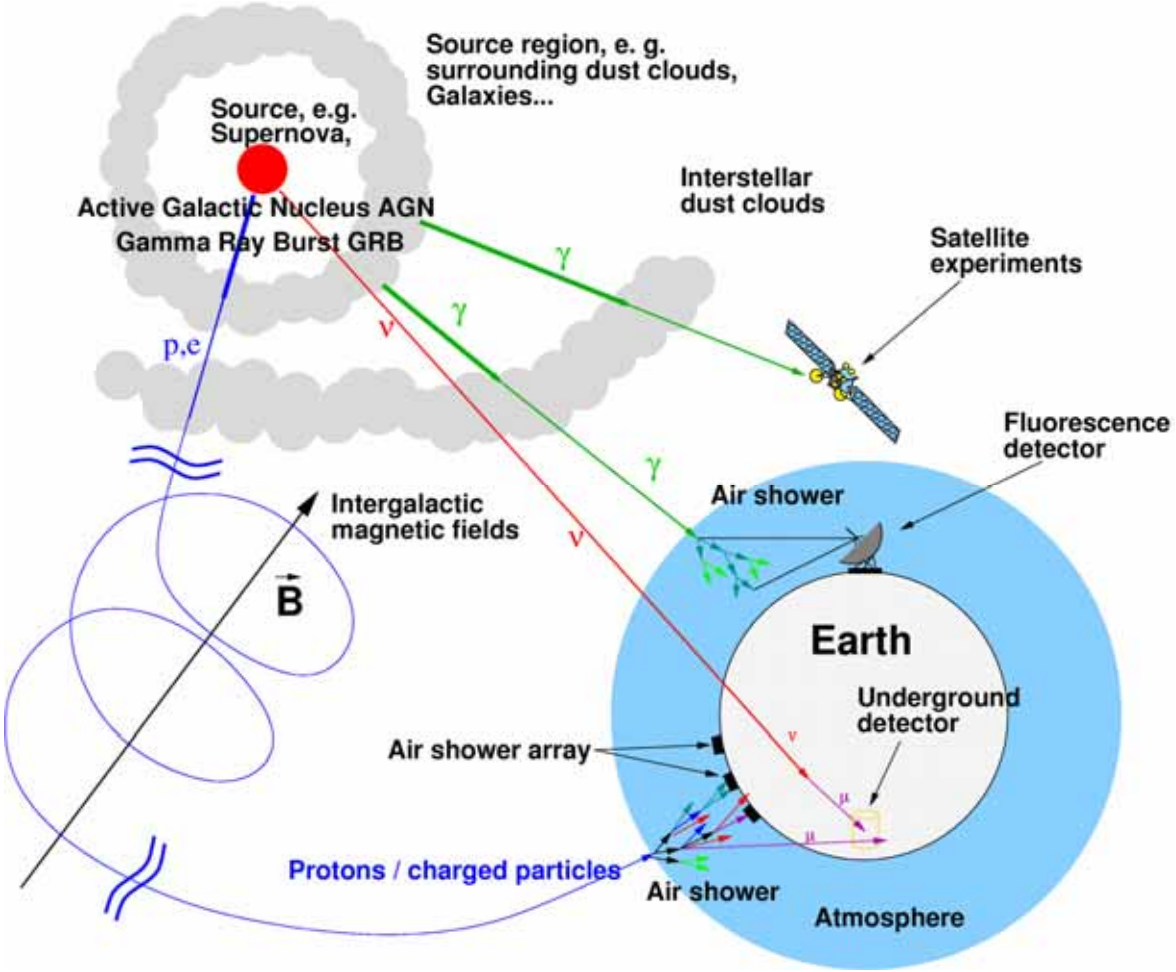
- AGNs, GRBs, *etc*.
  Know: 1) emit photons at TeV scale
  2) probably emit p at EeV (10^9 GeV) scale w/broken power law spectrum?

But, don't know by what process?

- Astrophysical engine (black hole) power jets
- Shock waves propagate thru medium
- Particles scatter repeatedly off shocks
  > Fermi acceleration of electrons
  > photons from inverse Compton scattering
  > gives energy spectra of $1/E^2$ power law
- And for protons …

$$p + (p \text{ or } \gamma) \rightarrow \pi^0 \rightarrow \gamma$$
$$\rightarrow \pi^{\oplus} \rightarrow \mu^{\pm}\nu_{\mu} \rightarrow e^{\pm}\nu_e\nu_{\mu}$$

Particles From Outer Space



- photons

  + points to source
  + detect over large E range
  - universe sort'a opaque

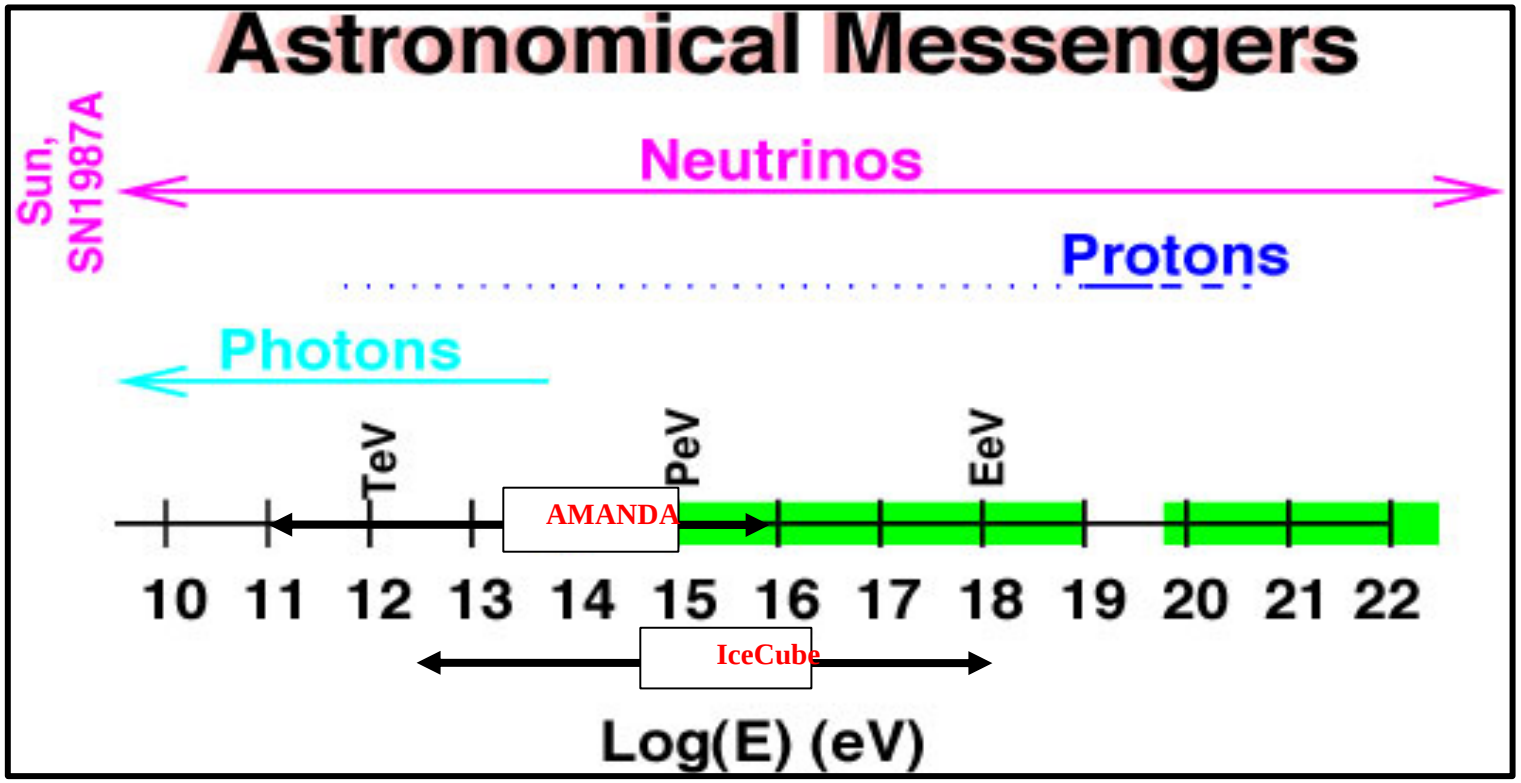
- protons (nuclei)

  + detect over large E range
  ~ can id at low E, not so easily at high E (AUGER)
  - does not point to source

- neutrinos

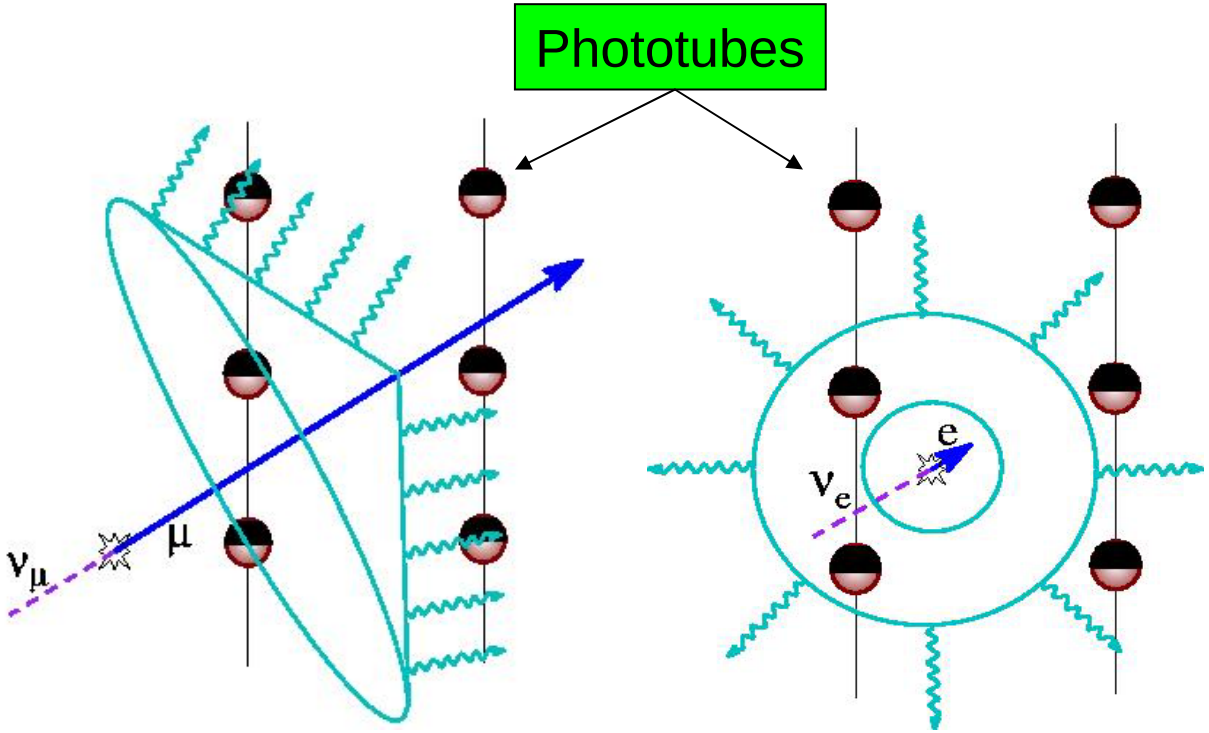
  + points to source
  - hard to detect

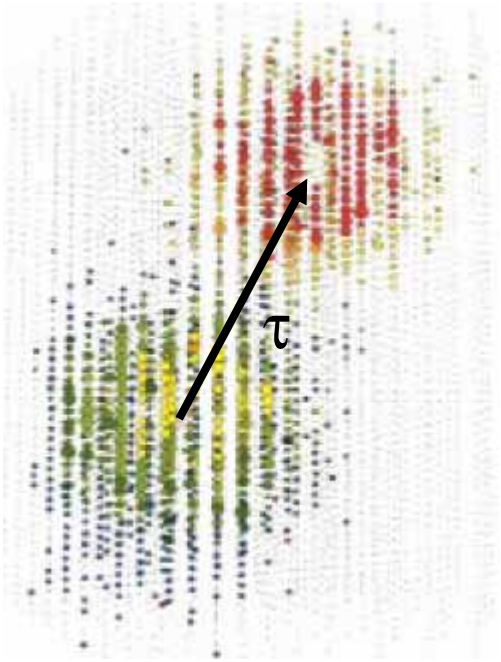
A Summary of Particles



- Protons: bent by galactic magnetic fields below 10 EeV (10^{19} eV)
  strongly attenuated above 50 EeV (GZK cut-off)
- Photons: (largely) absorbed in interstellar media above ~1 TeV
  absorbed (via pair-production) above 50 TeV
- Neutrinos: cover all energy range, point back to source, …

Neutrinos: How We See Them





Muon neutrino

Track: + increased detection volume
+ μ points along ν_μ, *i.e*. to source
- cosmic ray μ background
- energy measurement “okay”

Electron neutrino

Cascade: - must be in detector
- μ background (brems’ng)
- limited pointing capability
+ good energy measurement

(also includes NC ν_μ)

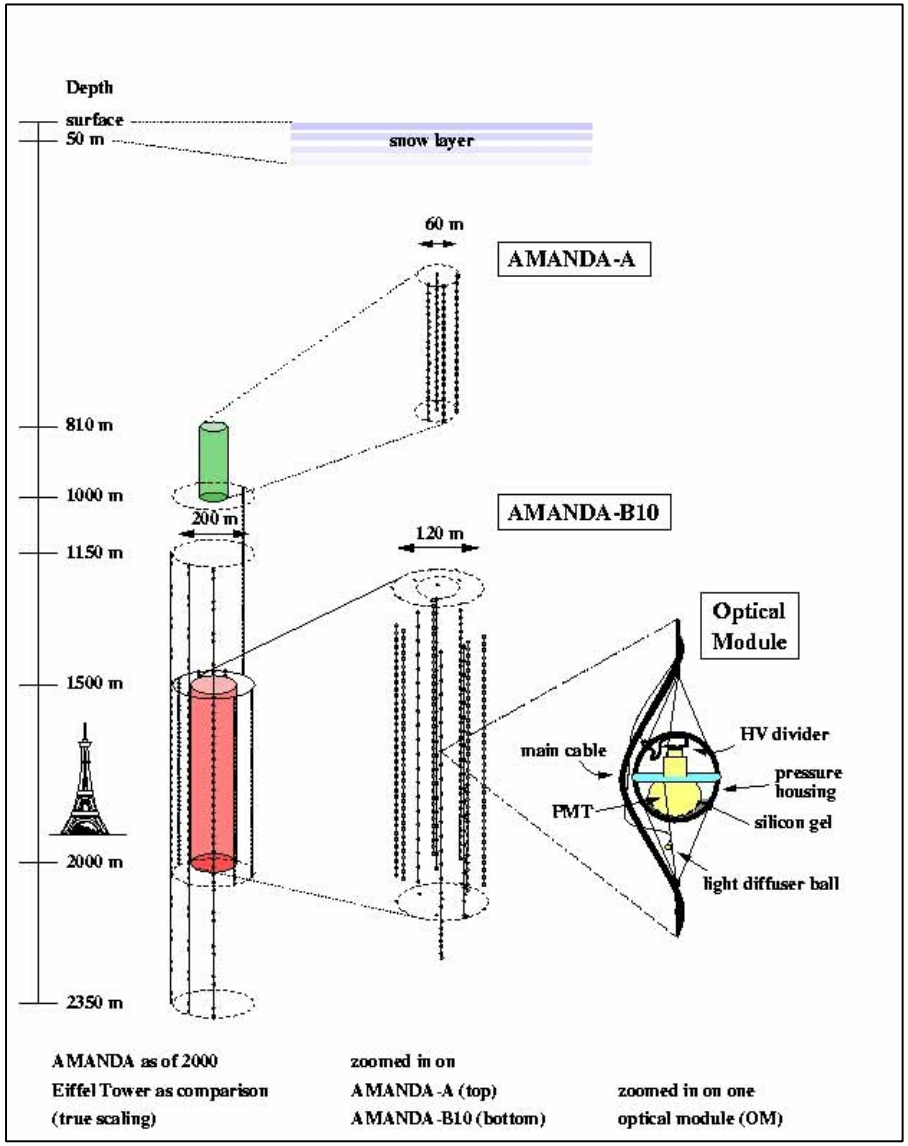
Tau neutrino

Hybrid: - must be in detector
- need E>o(1000 TeV)
+ nil background
+ pointing capability
+ best energy measurement

AMANDA Detector

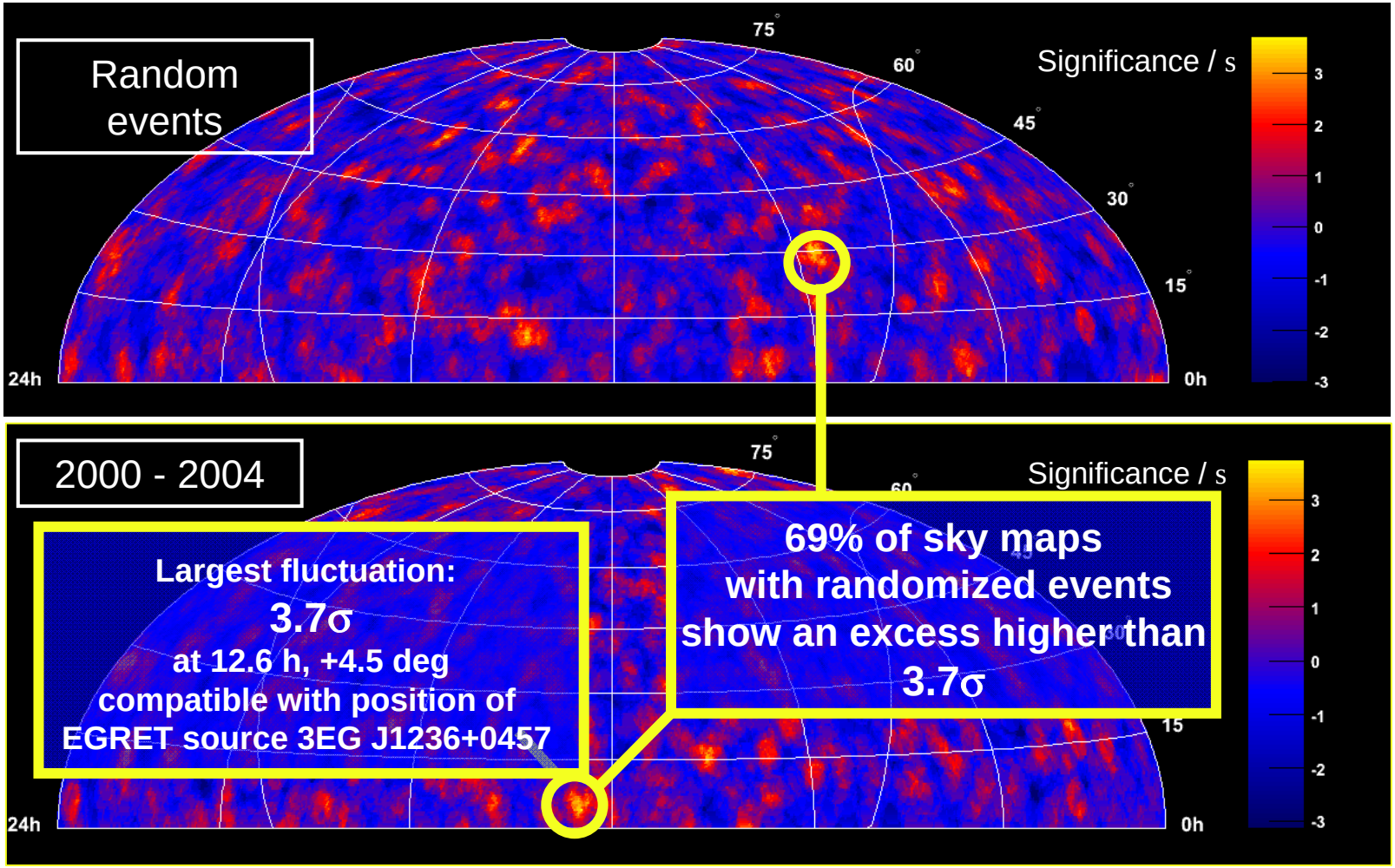
- 677 analog OMs deployed along 19 strings
  - 10 strings 1997 (AMANDA B10)
  - 3 strings 1998 (AMANDA B13)
  - 6 strings 2000 (AMANDA II)
- 200 m diameter, 500 meters height; AMANDA II encompasses 20 Mton instrumented ice volume.
- Analog PMT signals go to surface via electrical and optical transmission lines;
- Conventional TDC / ADC technology for AMANDA has been entirely replaced by transient waveform readout system.

… now a part of IceCube!



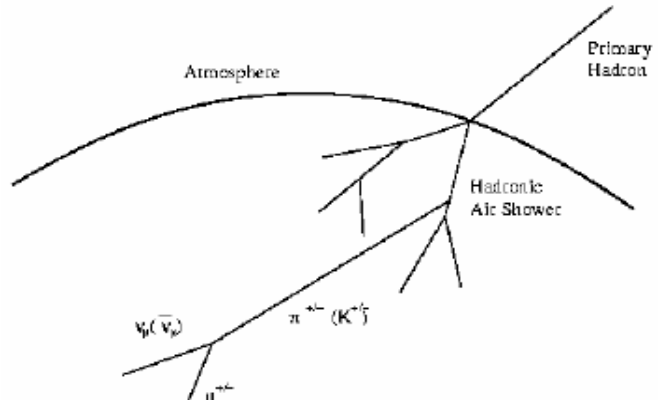
AMANDA : 2000-4 Skymap

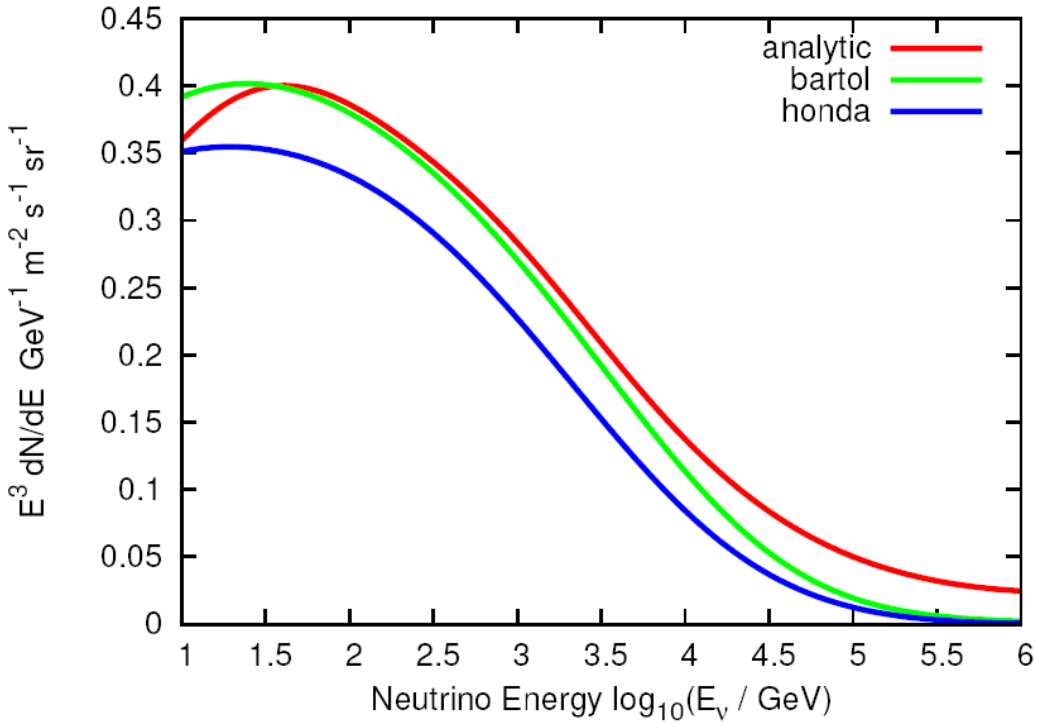
AMANDA II (19 strings) since 2000



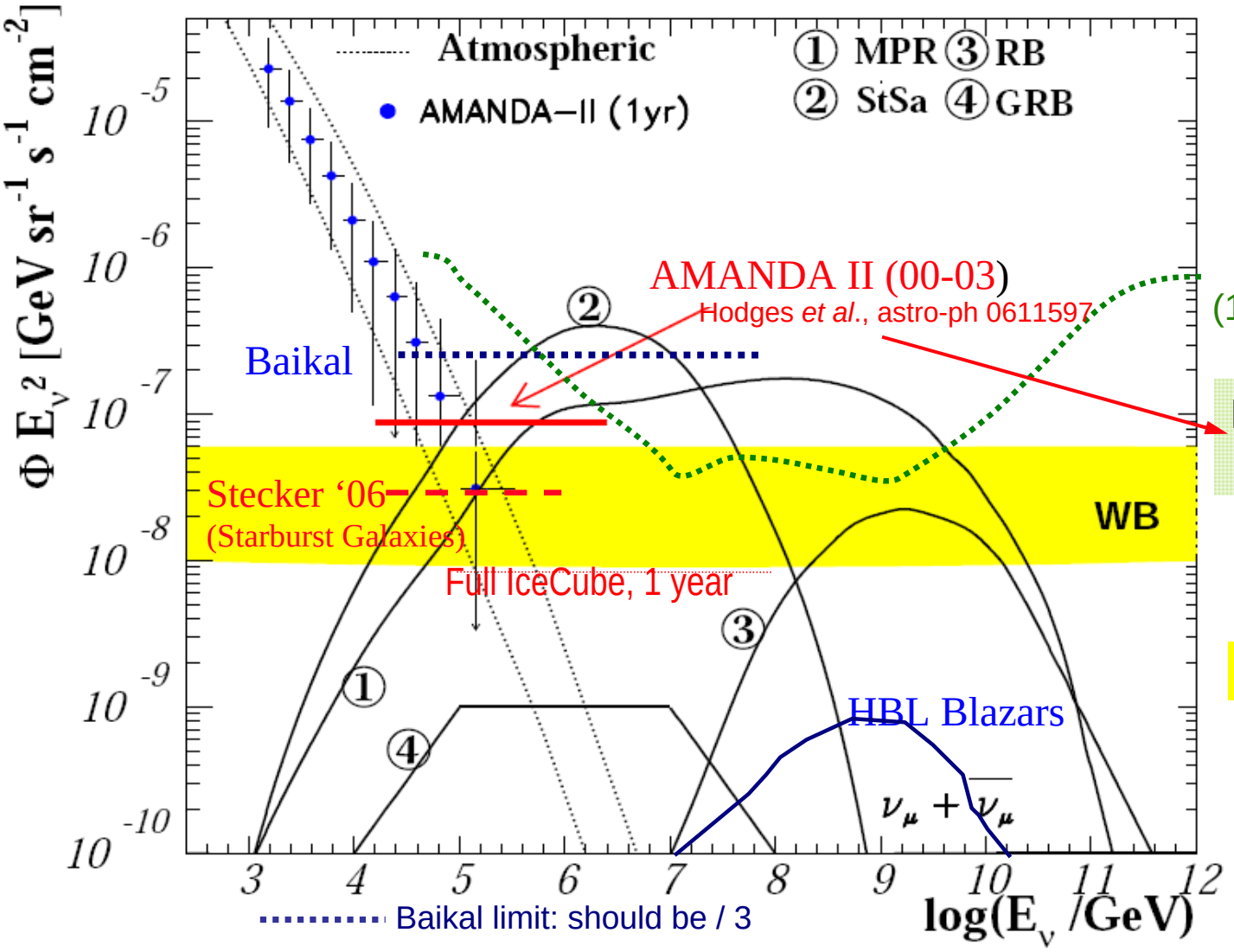
Atmospheric Neutrinos

- Dominant background
  - Point source searches
  - Diffuse neutrinos
- Useful “calibration beam”
  - Establish IceCube as a neutrino detector!





AMANDA : Diffuse Flux



Halzen:
astro-ph/0611915

MPR bound
(15.8 TeV - 2.51 PeV)

$E^2\Phi_{\nu_\mu}(E) < 8.8 \cdot 10^{-8}$ GeV cm^{-2} s^{-1} sr^{-1}

E^{-2} hypothesis

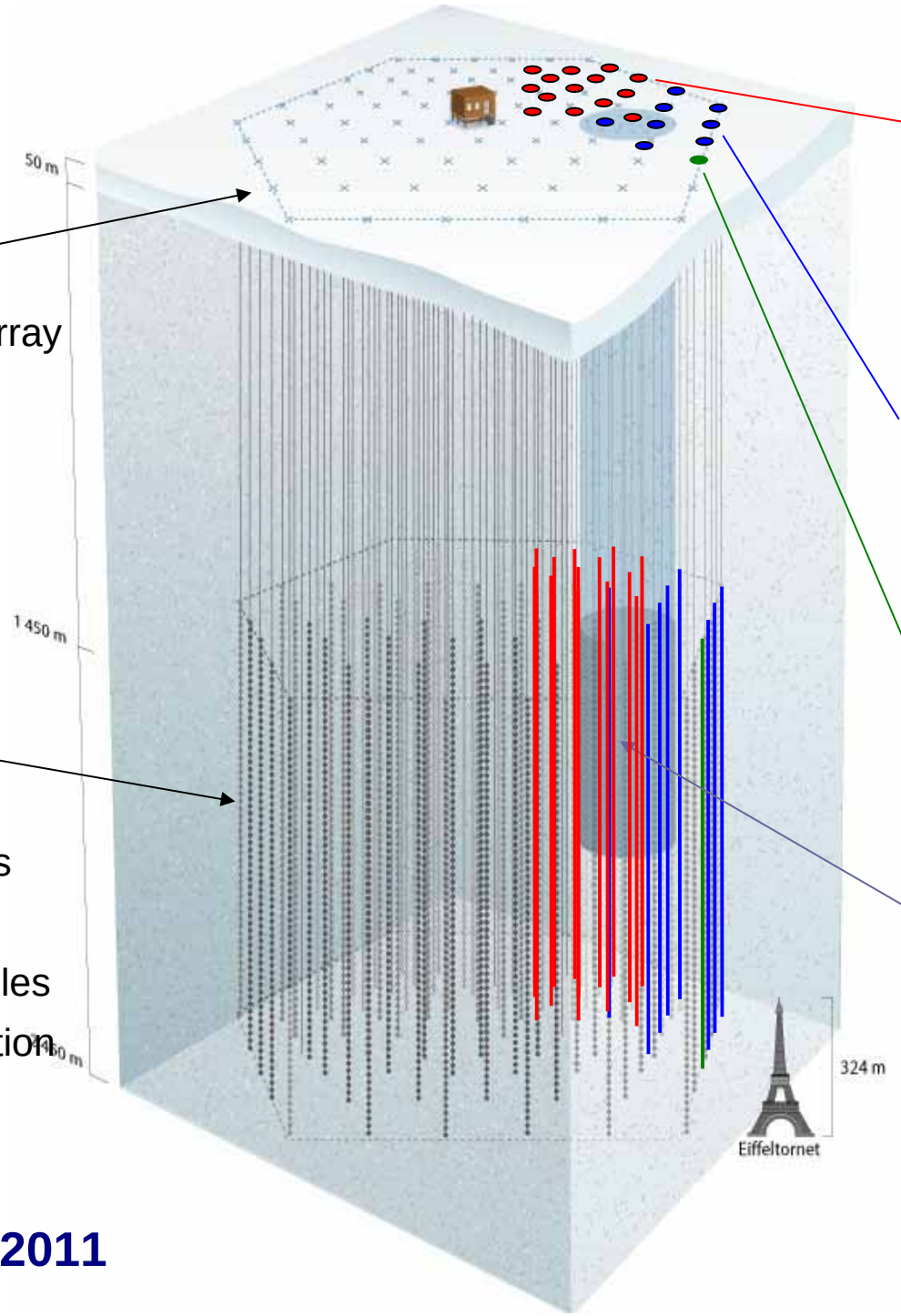
IceTop

Surface air shower array

IceCube

70-80 strings, each
w/60 optical modules

17 m between modules
125 m string separation



2006-2007:
13 strings - all good

2005-2006:
8 strings - all good

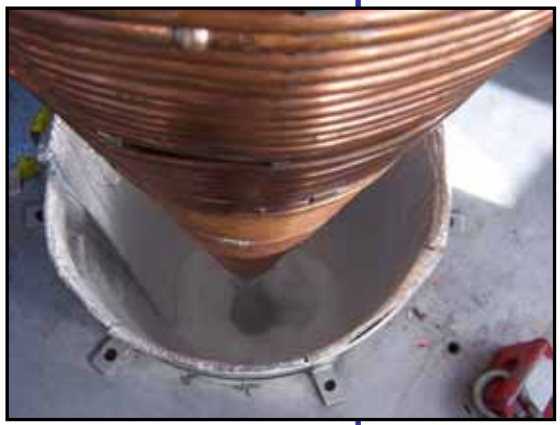
2004-2005 : 1 string
First data in 2005

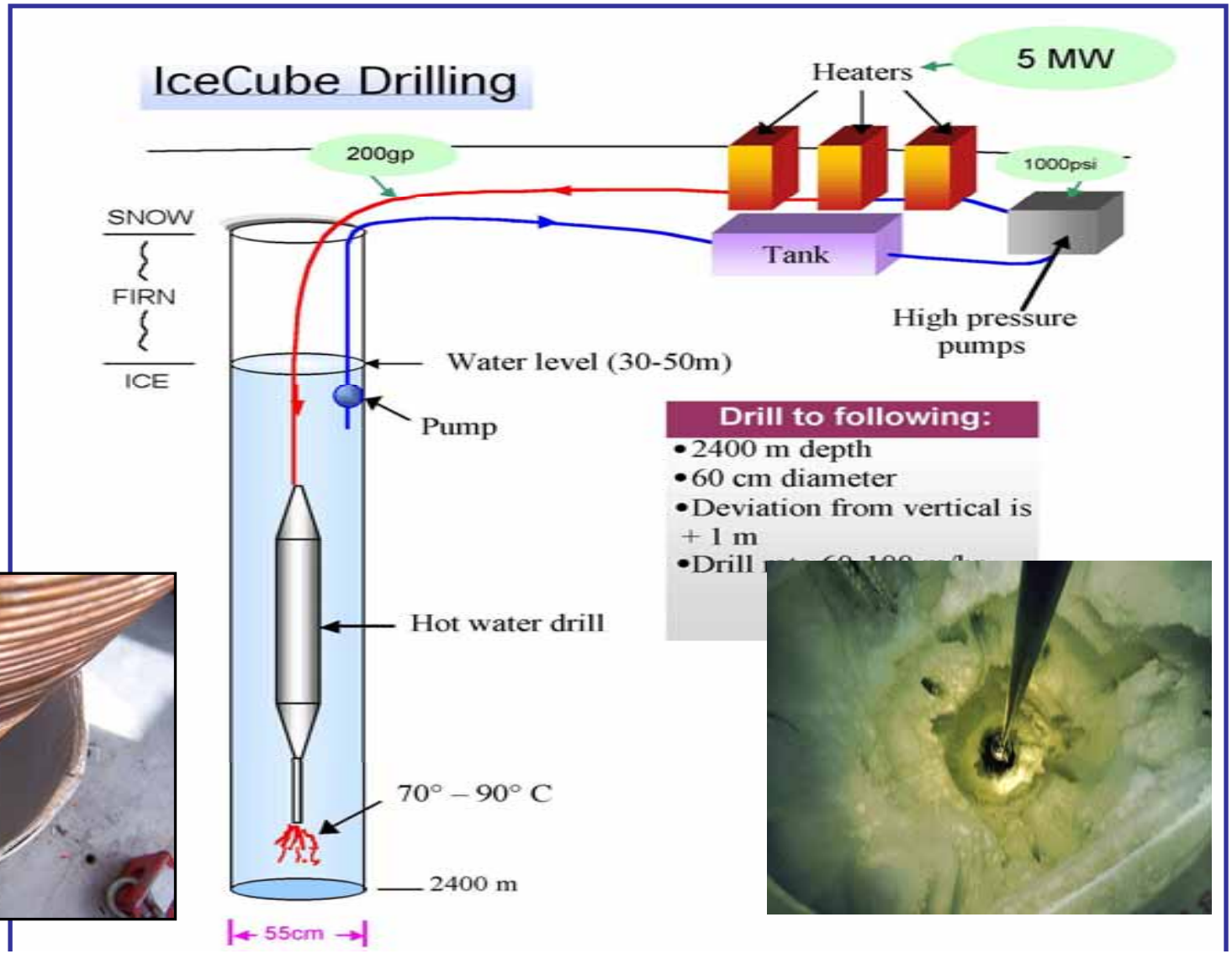
AMANDA

19 strings
677 modules

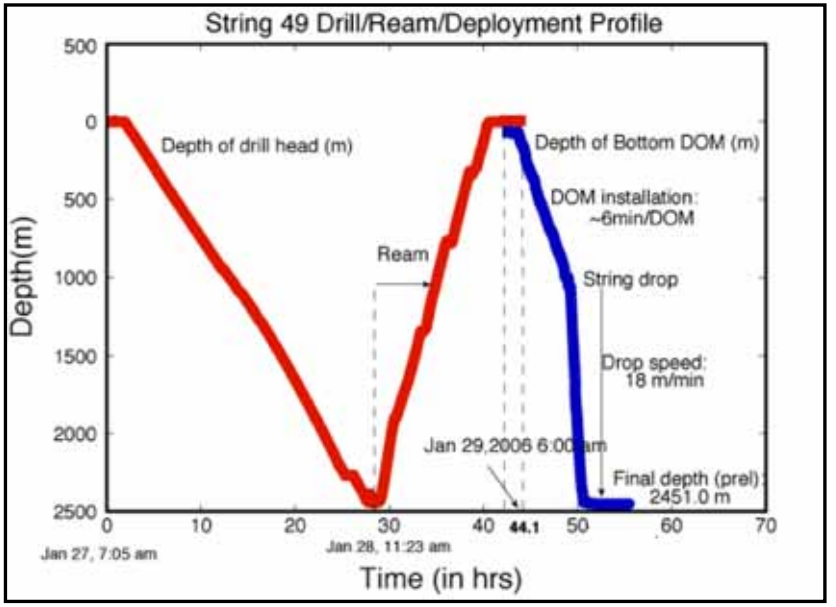
Completion by 2011

Schematic of Hot Water Drilling

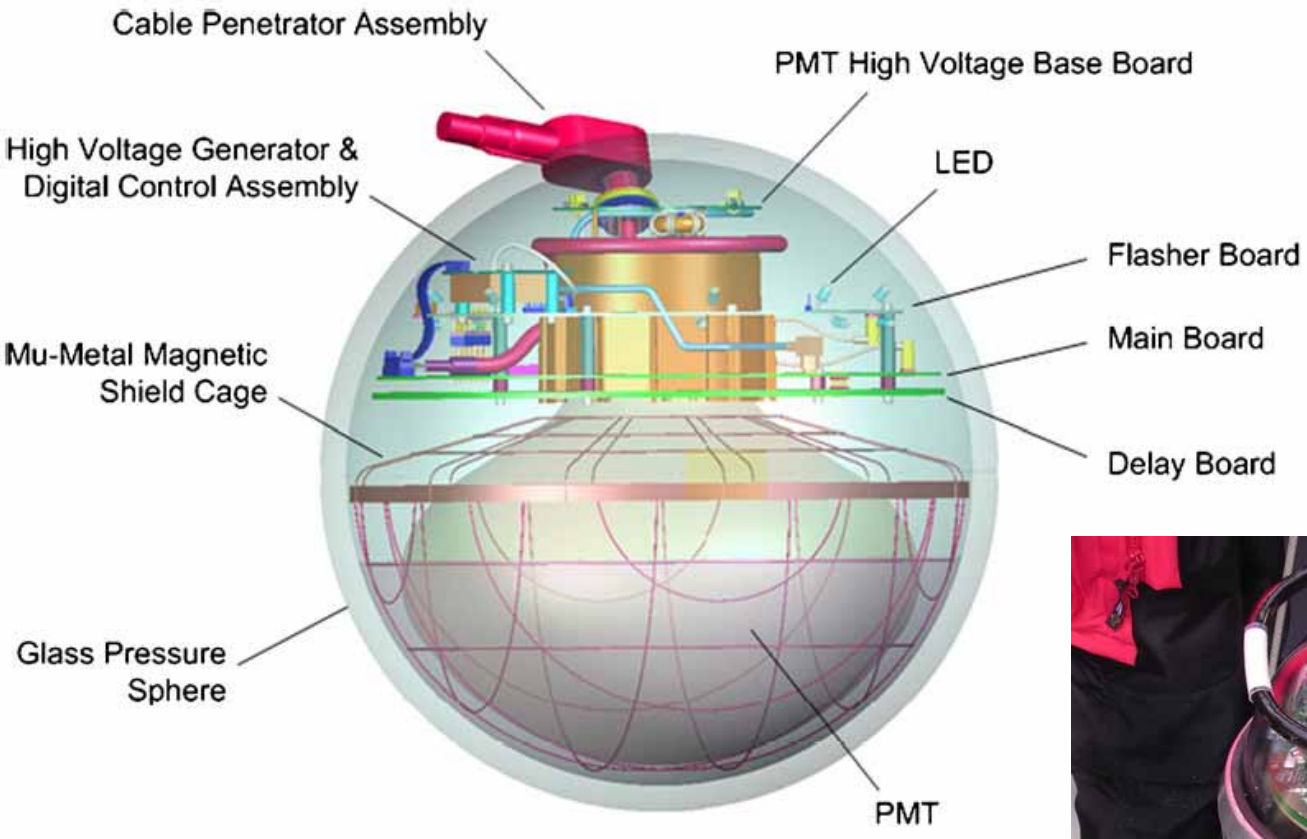


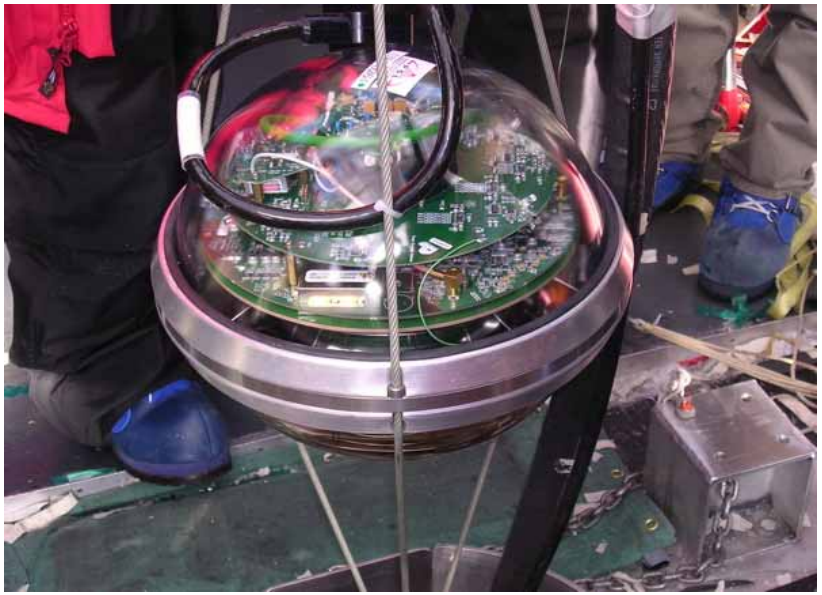


String Deployment



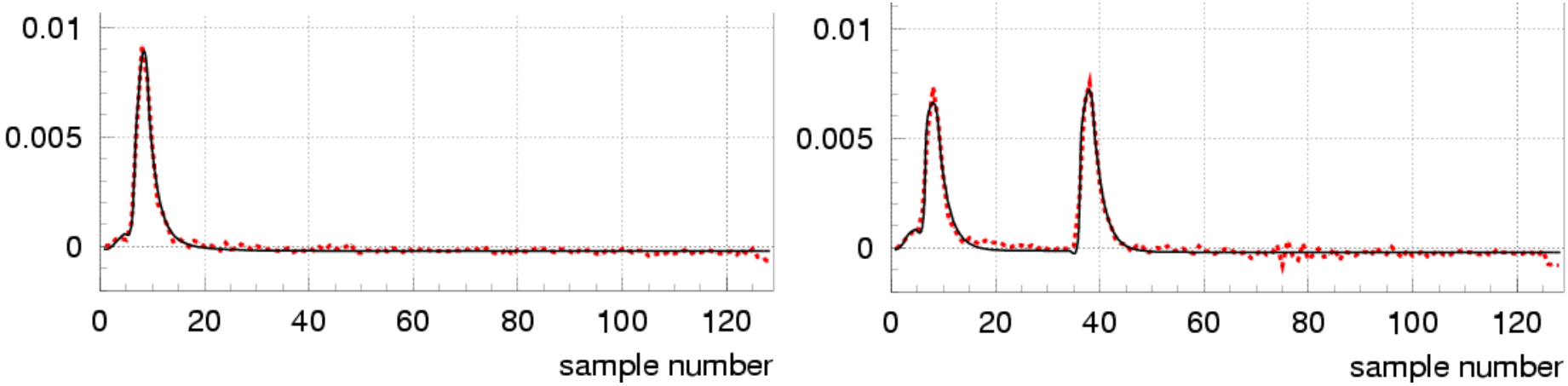
IceCube Digital Optical Module

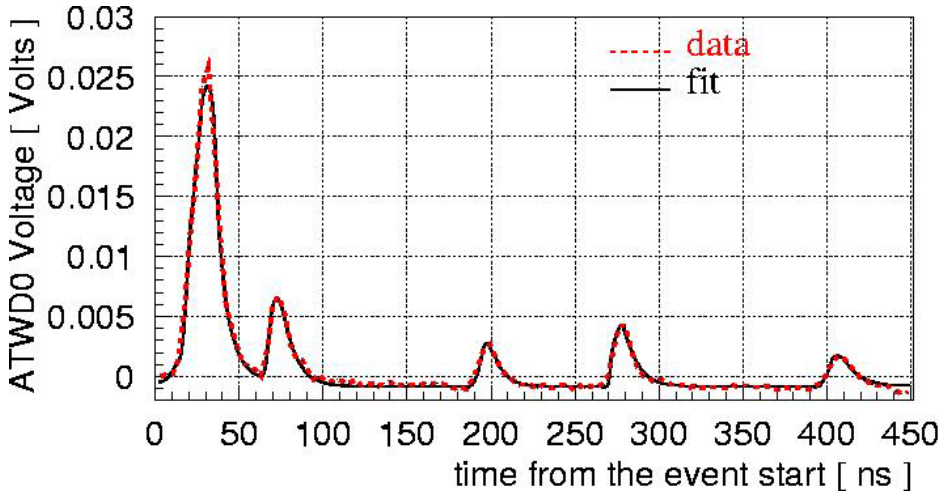




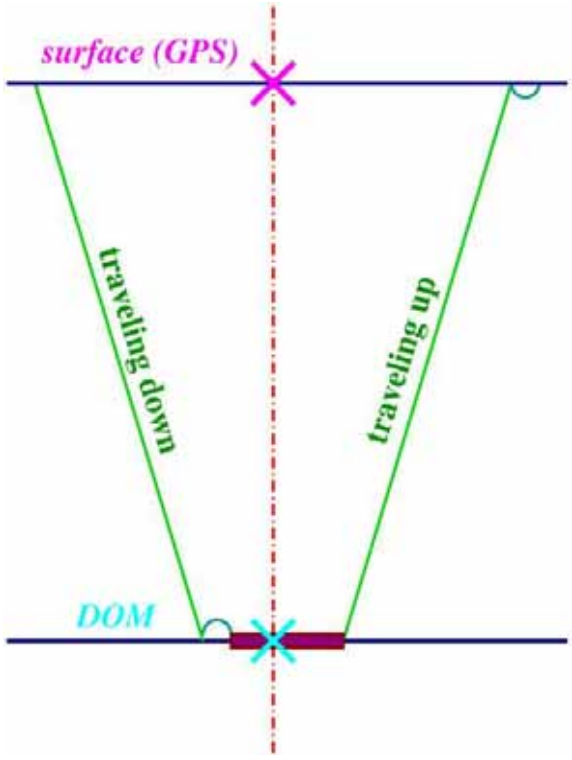
- Low intrinsic noise ~ 500 Hz
- Fast digitization 30 ms/channel
- Waveform: 4 channels/128 sample
- Low power consumption 5 W per DOM
- Up to 12 μs combined waveform length
- Variable sampling speed: 250 - 800 MHz
- Up to 200-300 p.e./10 ns charge resolution

IceCube Digital Optical Module



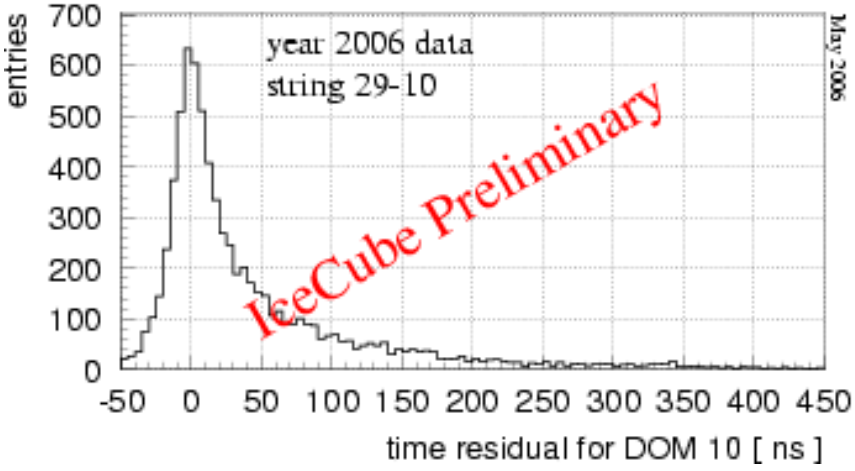


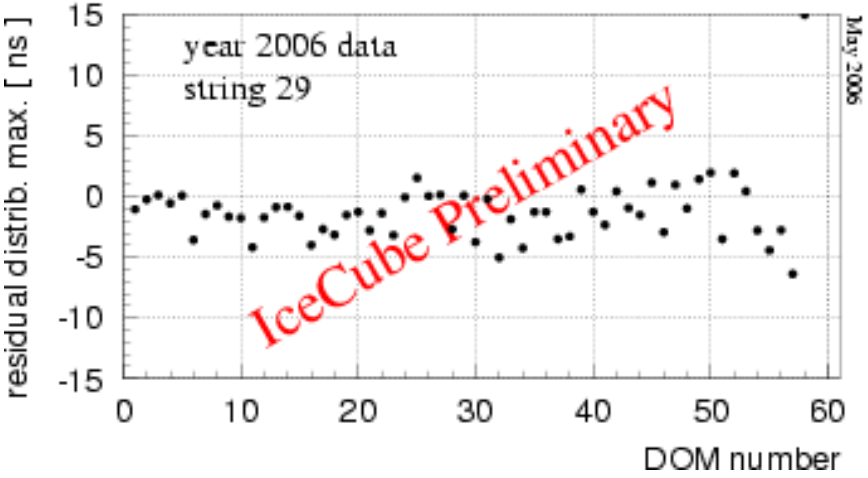
DOM-to-DOM Synchronization



RAPCAL: Sync each DOM to GPS time

… check with reconstructed tracks

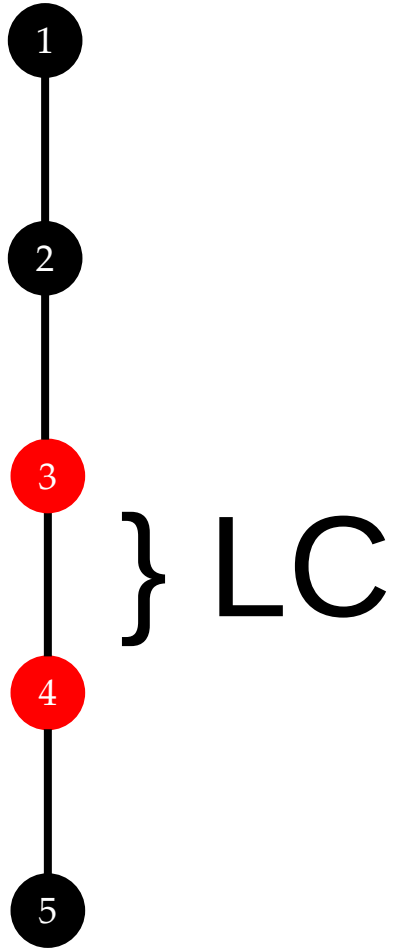




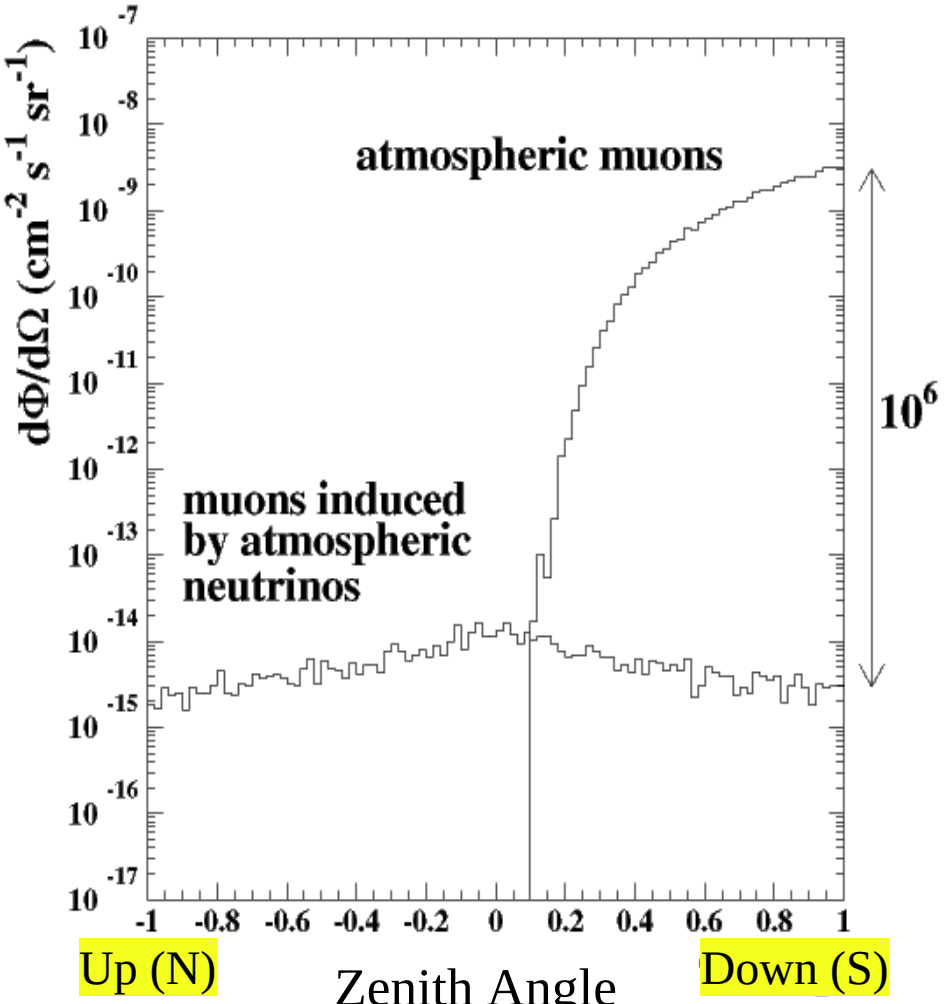
IceCube Triggering

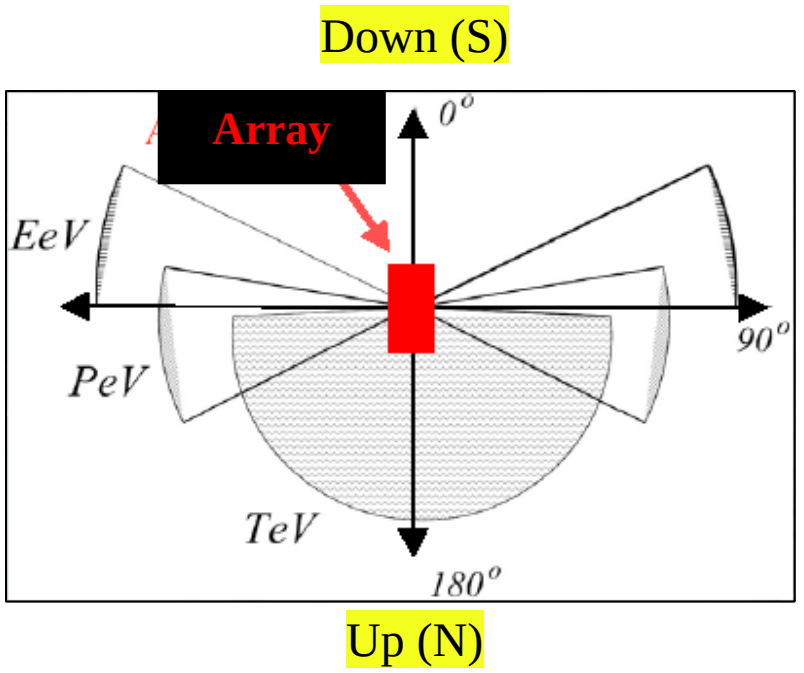
- InIce:
  - Local coincidence between neighboring modules (variable time window: presently = 1 us)
- On the surface:
  - require $N_{\mathbf{DOMs}} \geq 8$ within 5 us window

- Form event from all “hits” within ⌖8 us of trigger



Angular Acceptance for ν_μ

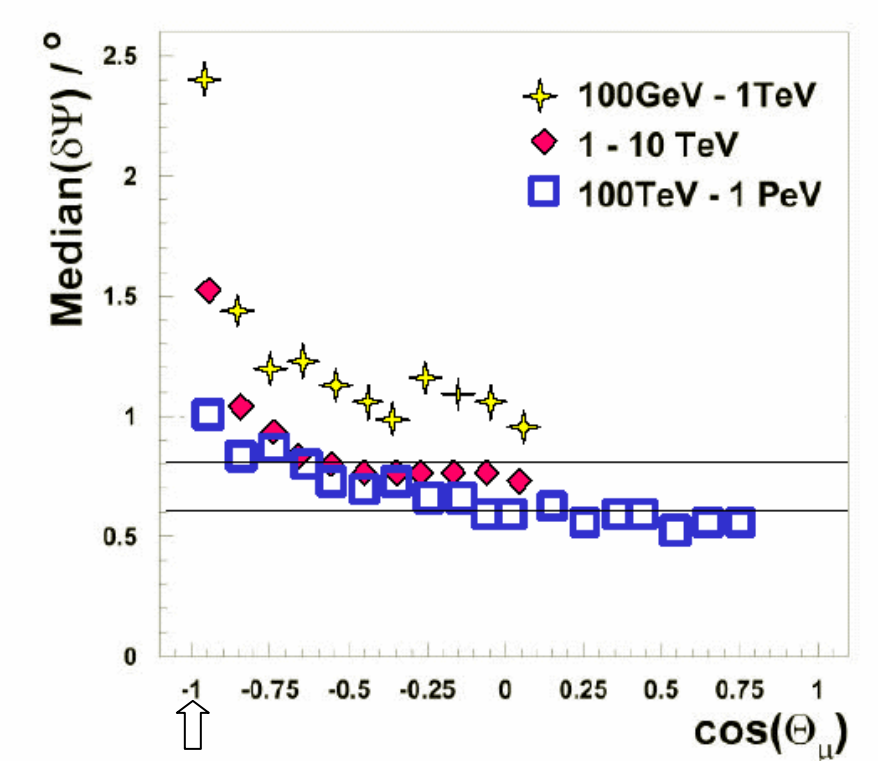




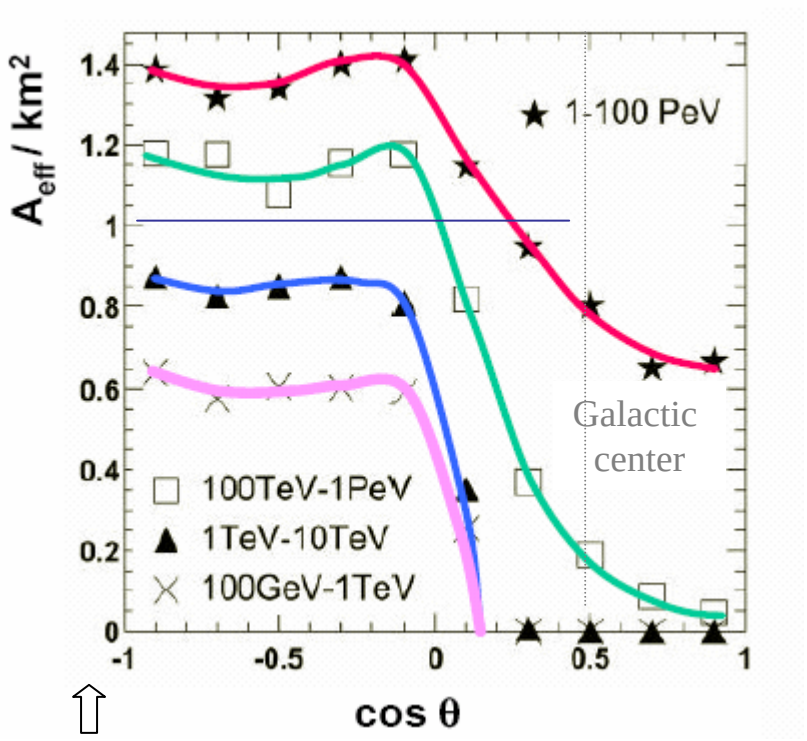
- Large μ background from above (Southern sky) for E < 100 TeV
- Earth becomes opaque at E > 1 PeV

As a "ν_μ" Observatory

Angular resolution



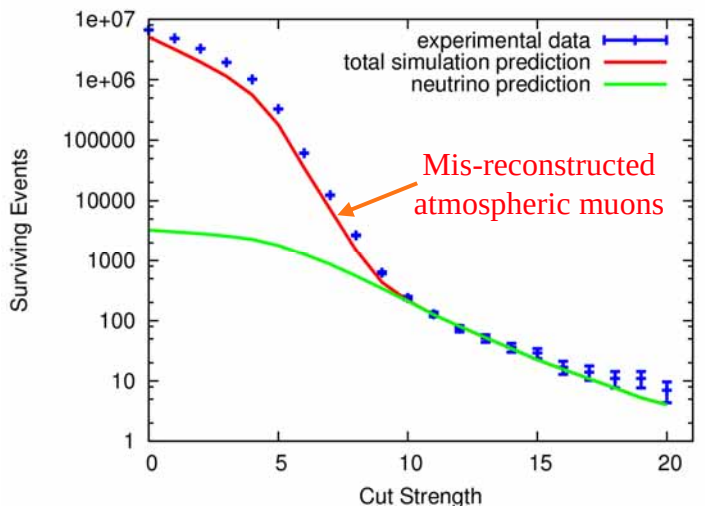
Effective Area for Muons

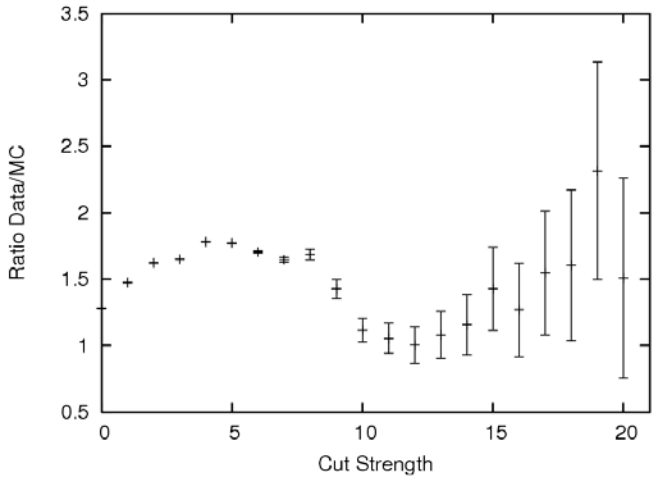


Monte-Carlo studies: using LE timing, not waveform, reconstruction.

IceCube-9 (2006)

1. Online filtering at Pole to isolate sample of "good" up-going candidates
2. Transfer this sample by satellite to North
3. More refined analysis …
   … Log-likelihood reconstruction, *etc*.
   … apply additional quality cuts, *etc*. to gain more down-going muon rejection





RESULT

Ratio of data to simulation:

$$\mathcal{R} = 1.05 \pm 0.24_{sys} \pm 0.09_{stat}$$

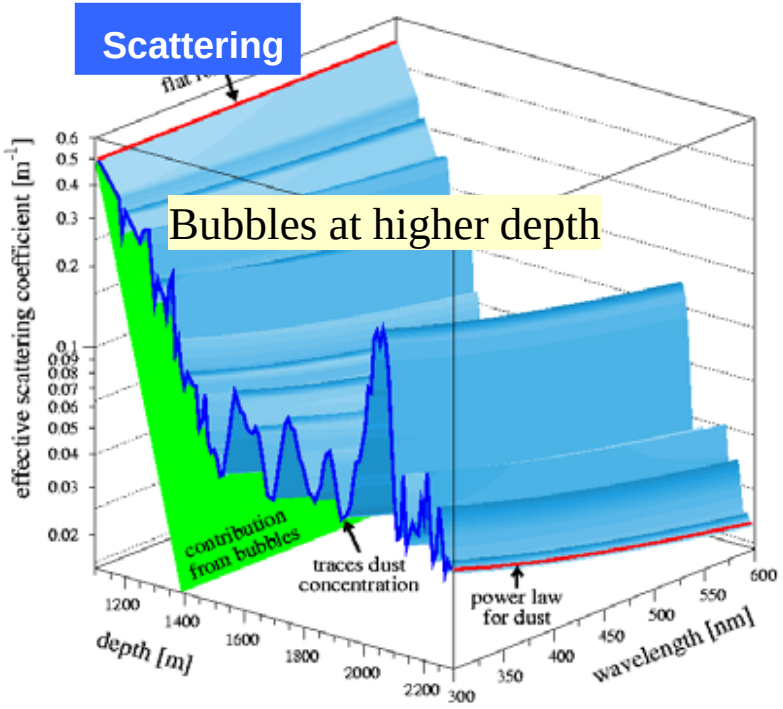
At selected cut strength of 10:

234 up-going ν_μ in 137.4 live-days of data
(purity of neutrino sample > 95%)

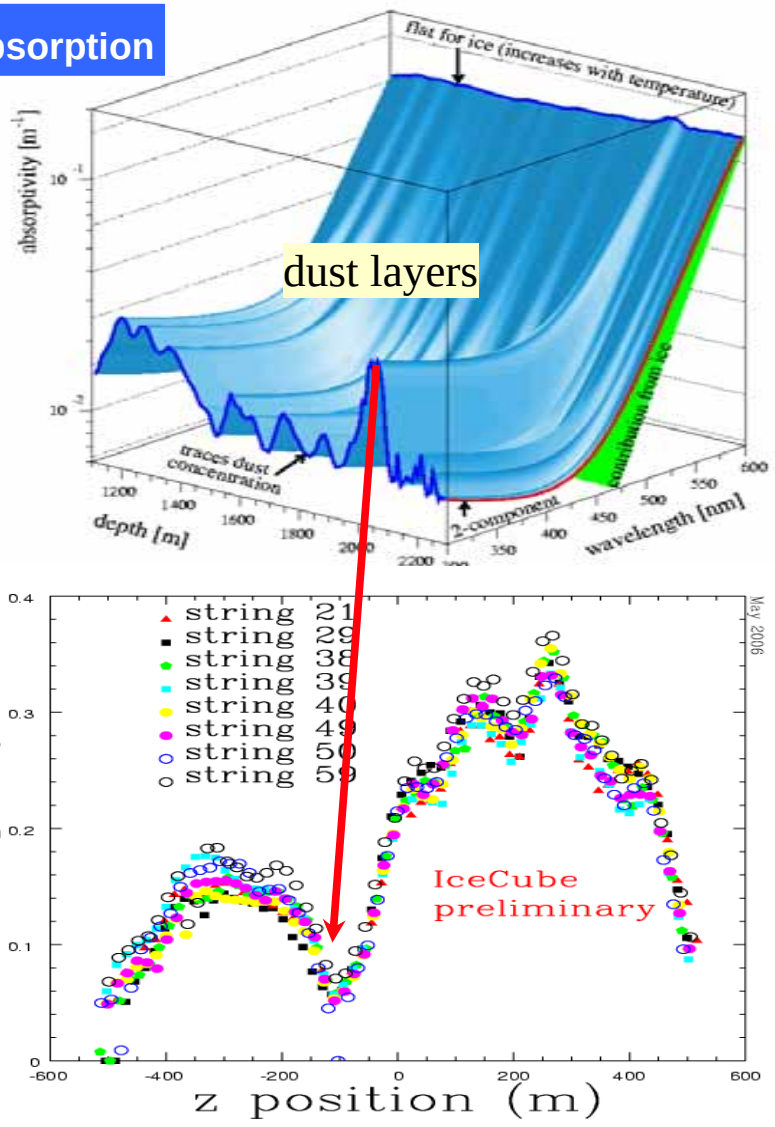
J. Pretz, Ph.D. thesis (Maryland)
[DRUM 1903-4163]

Ice Properties

Scattering



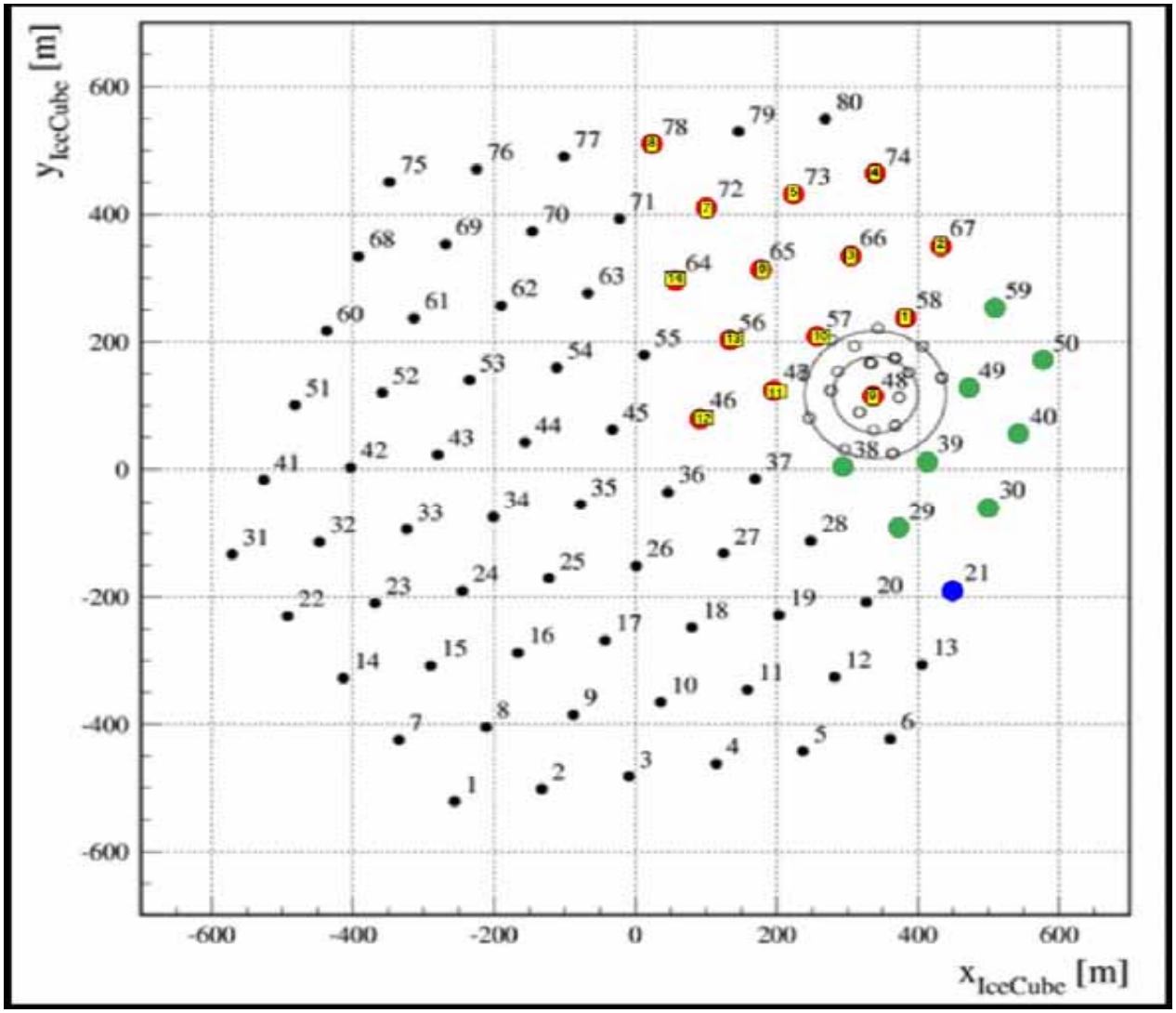
Absorption



Average optical parameters:

- λ_{abs} ~ 110 m @ 400 nm
- λ_{sca} ~ 20 m @ 400 nm

The Detector Deployment



04/05 ●
1 IceCube string
4 IceTop stations

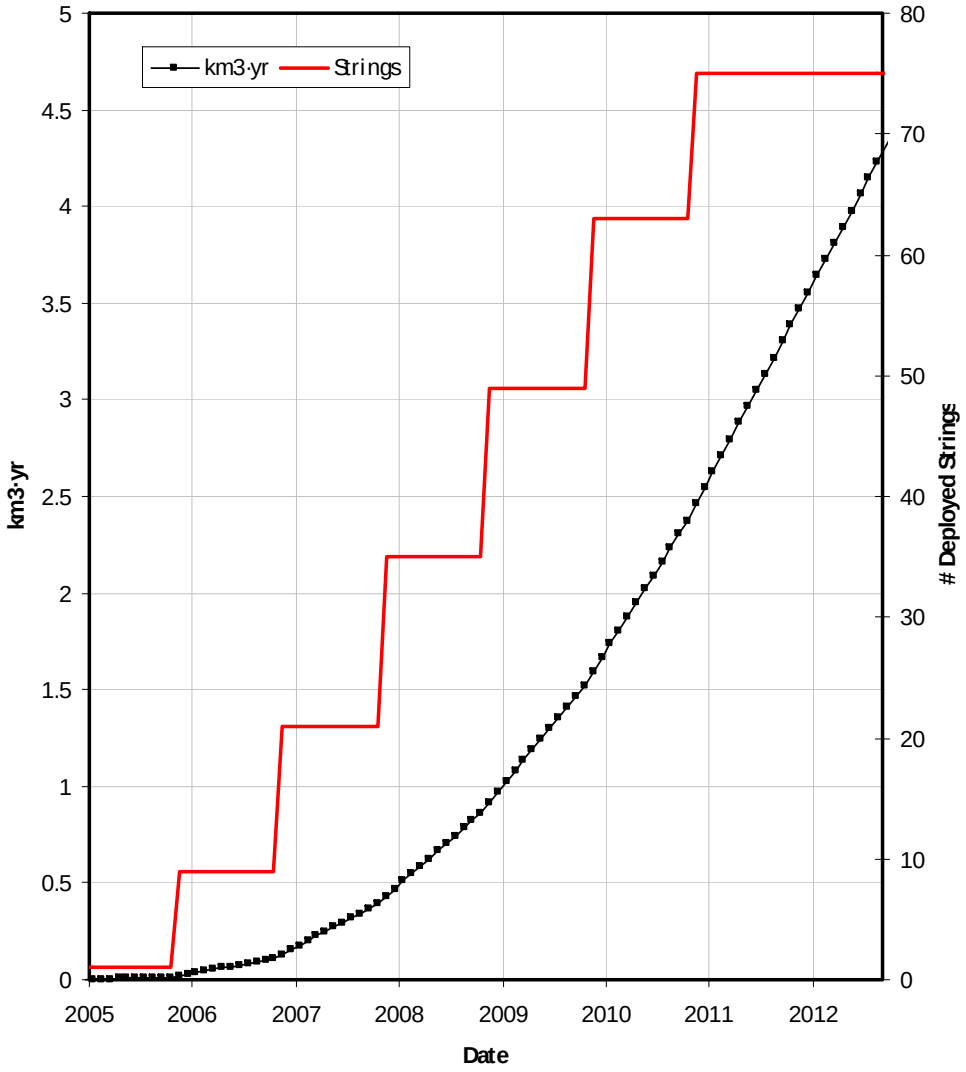
05/06 ●
9 IceCube strings
16 IceTop stations

06/07 ●
22 IceCube strings
26 IceTop stations

* String 64: only firn-drilled
will be deployed ’07/08

Completion: 2011

Prospects
(Integrated Exposure)



- Graph shows *cumulative* $km^3 \cdot yr$ of exposure ⩤ volume
- 1 $km^3 \cdot yr$ reached 2 years *before* detector is completed
- Close to 4 $km^3 \cdot yr$ at the beginning of 2nd year of full array operation.

Look for Neutrinos above EeV

- GZK p+CMB $\gamma \rightarrow \pi \rightarrow \nu$

  ... cutoff at ~50 EeV in CR spectra

- What is the highest energy to

  which a particle is accelerated?

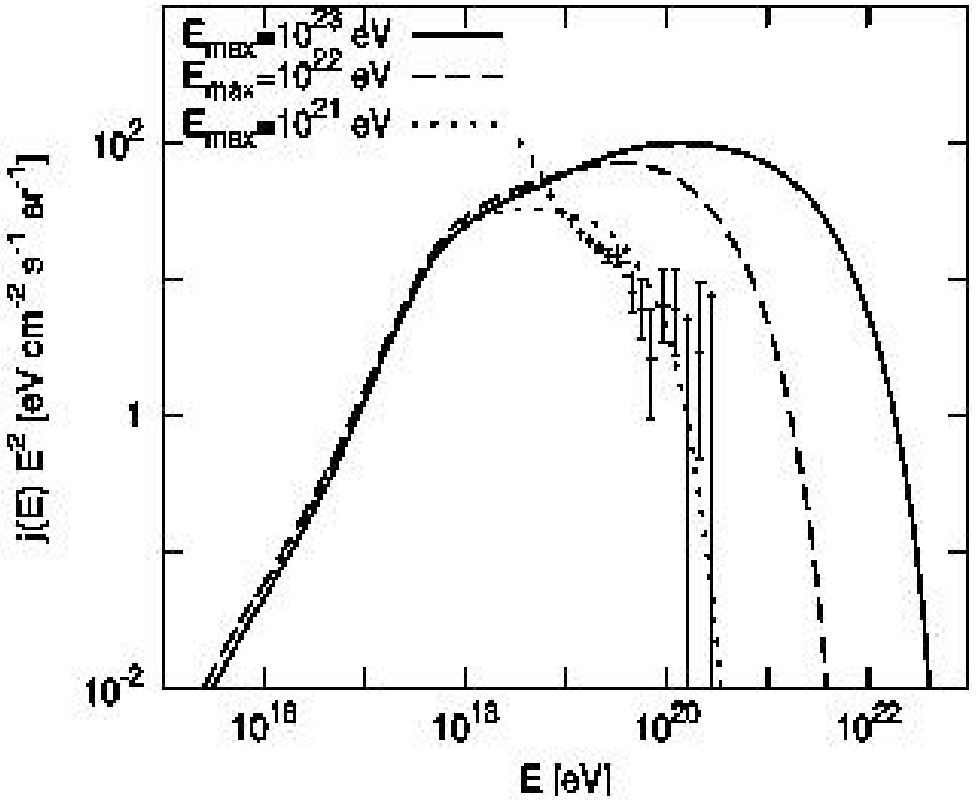
- Look for neutrinos …

  … background is basically none

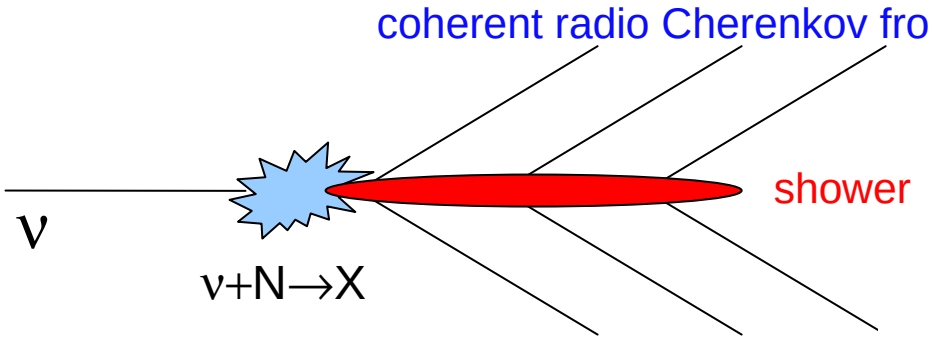
  … but need large detector to see

  such small fluxes

Neutrino flux at different endpoints for acceleration

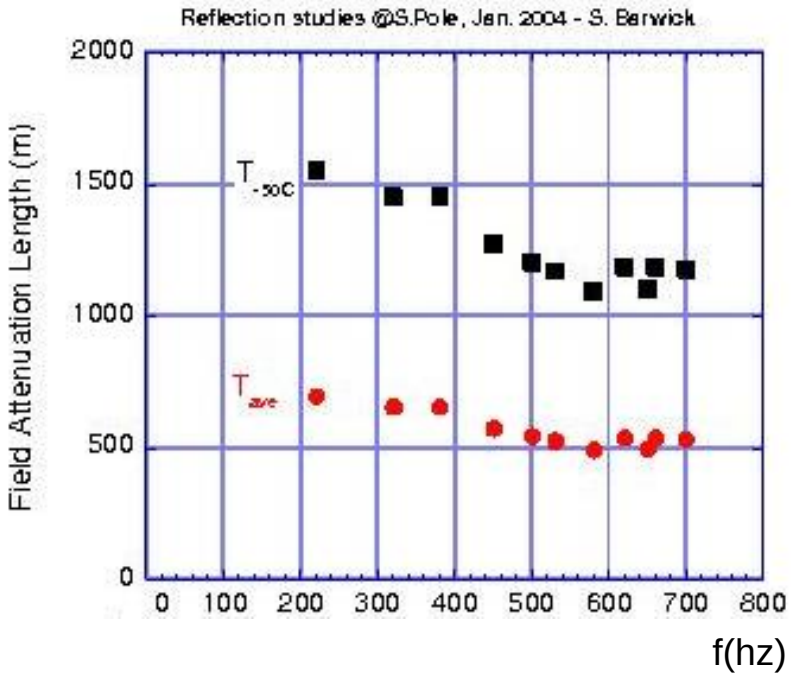


Radio - Neutrinos above EeV



RICE pioneered this work in Ice with AMANDA …

3 radio modules (AURA) to study deploying with IceCube



Ice is very transparent to radio
compare ~25m absorption length in optical

Schematic of Deployed Modules

RADIO IN 2006/7

Digital Radio Module

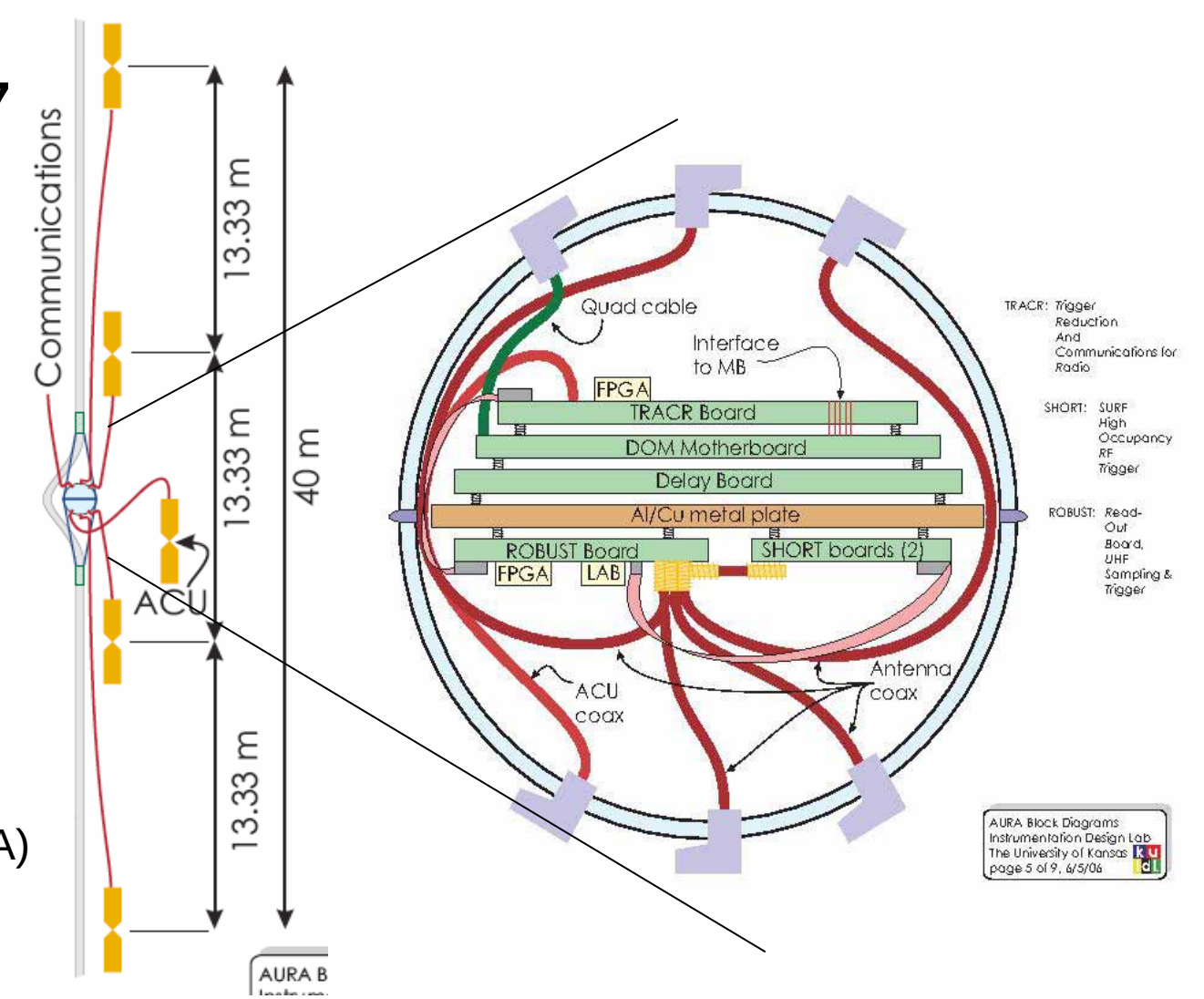
4 DRMs, 1 per string

Codeployment with IceCube in 2006/7

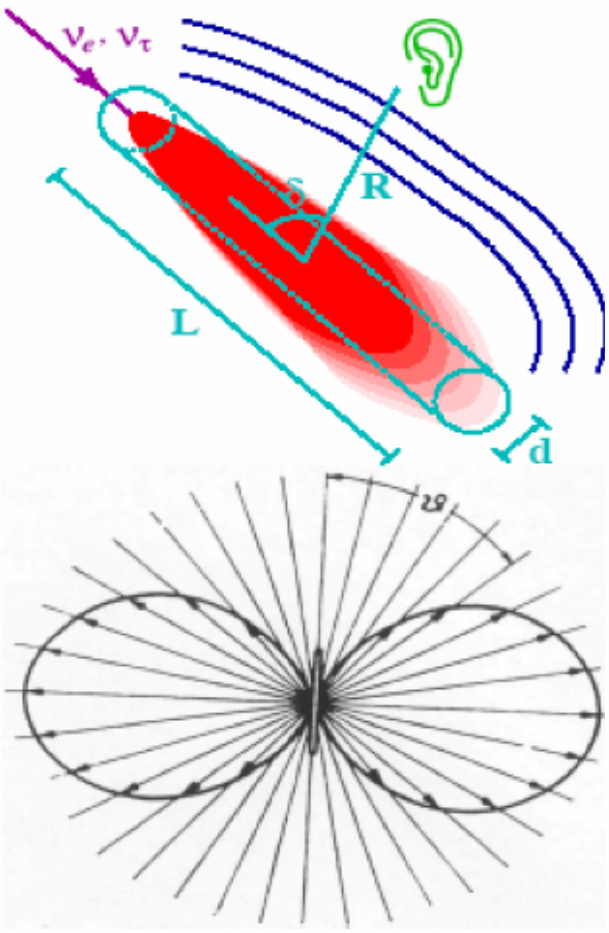
1400 m depth

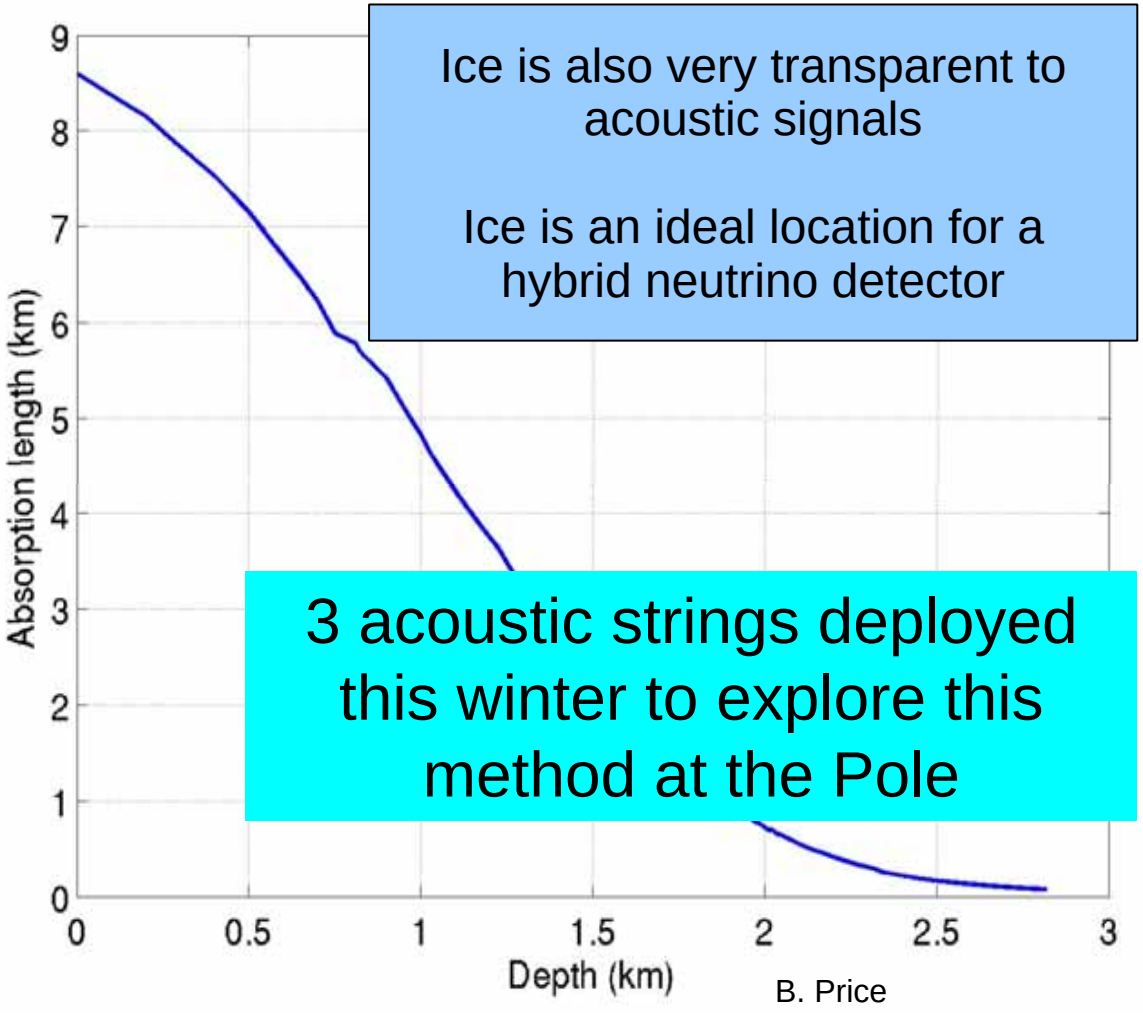
Digitizing in ice with LABRADOR chip

Multi-band trigger (similar to GLUE,ANITA)



Acoustic - Neutrinos above EeV





Ice is also very transparent to acoustic signals

Ice is an ideal location for a hybrid neutrino detector

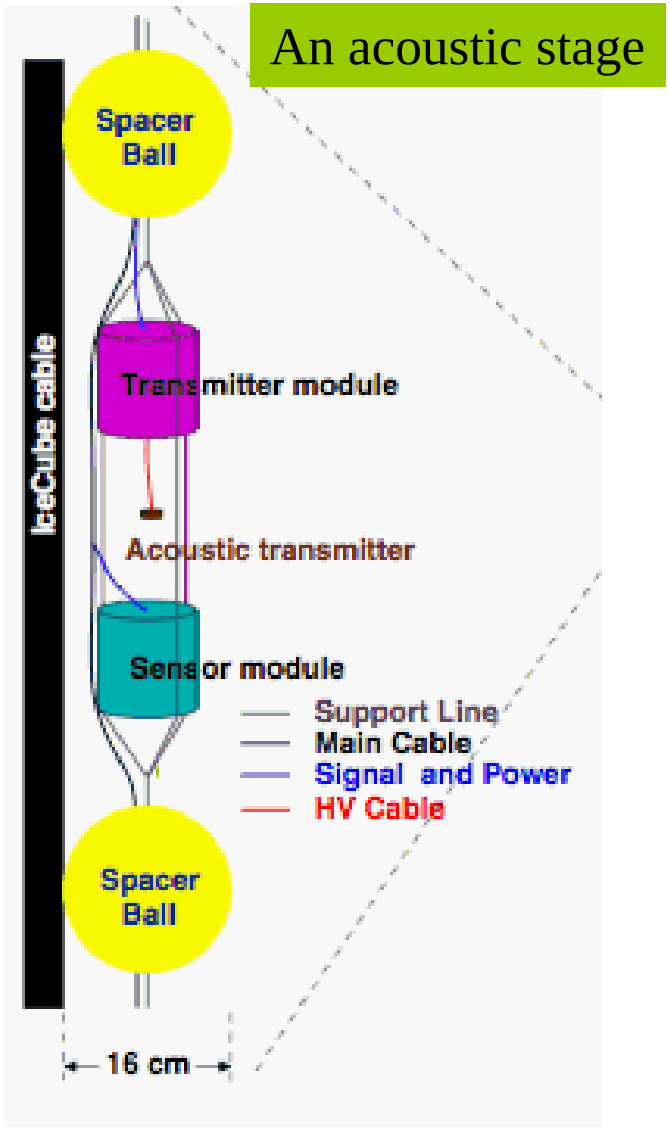
3 acoustic strings deployed this winter to explore this method at the Pole

B. Price

Schematic of Deployed Modules

SPATS (South Pole Acoustic Test Setup):

-- deploy up to ~400m below ice surface
-- R&D stage:
  * absorption length
  * refraction effect
  * noise
-- 21 acoustic stages in 3 holes
  * each: 3 receivers and 1 transmitter per stage



Closing

- AMANDA continues to operate well into its next decade of life
  - Icecube-9 see muon neutrinos
  - First atmospheric result
- IceCube successfully deployed 13 more strings, now 22
  - 25% of the detector deployed, ~1 $km^3 \cdot yr$ of data in ~2 years
  - New strings “surround” AMANDA, look at contained events
  - On schedule for completion in 2011 (as planned)
  - IceTop deployed 26 tanks
- First look at future radio/acoustic prospects

… the physics from IceCube is just around the corner

Token South Pole Picture

The Drill Camp