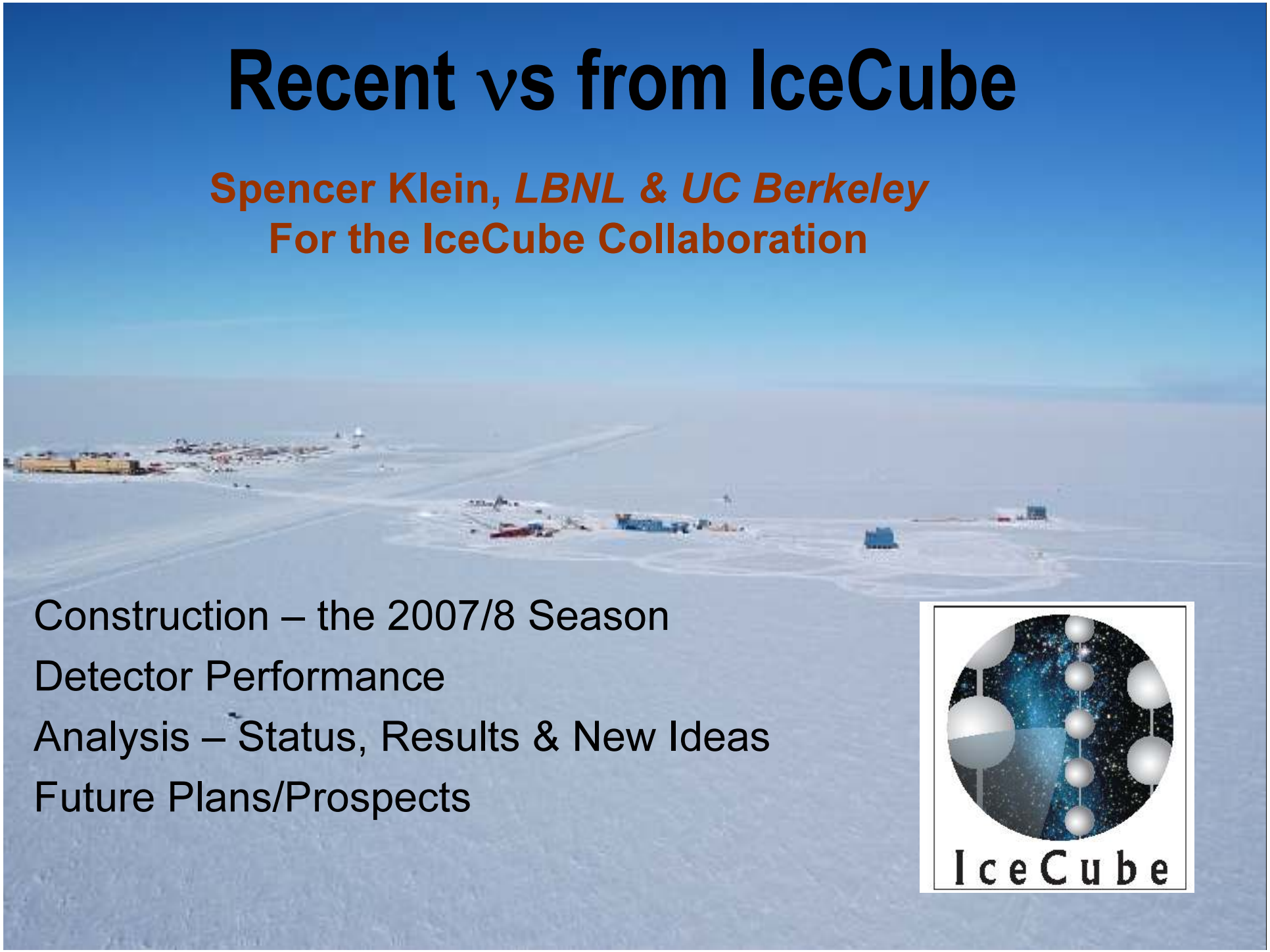
Recent νs from IceCube

Spencer Klein, *LBNL & UC Berkeley*
For the IceCube Collaboration



Construction – the 2007/8 Season

Detector Performance

Analysis – Status, Results & New Ideas

Future Plans/Prospects

THE ICECUBE COLLABORATION

USA:
Bartol Research Institute, Delaware
Pennsylvania State University
UC Berkeley
UC Irvine
Clark-Atlanta University
University of Maryland
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,

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

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

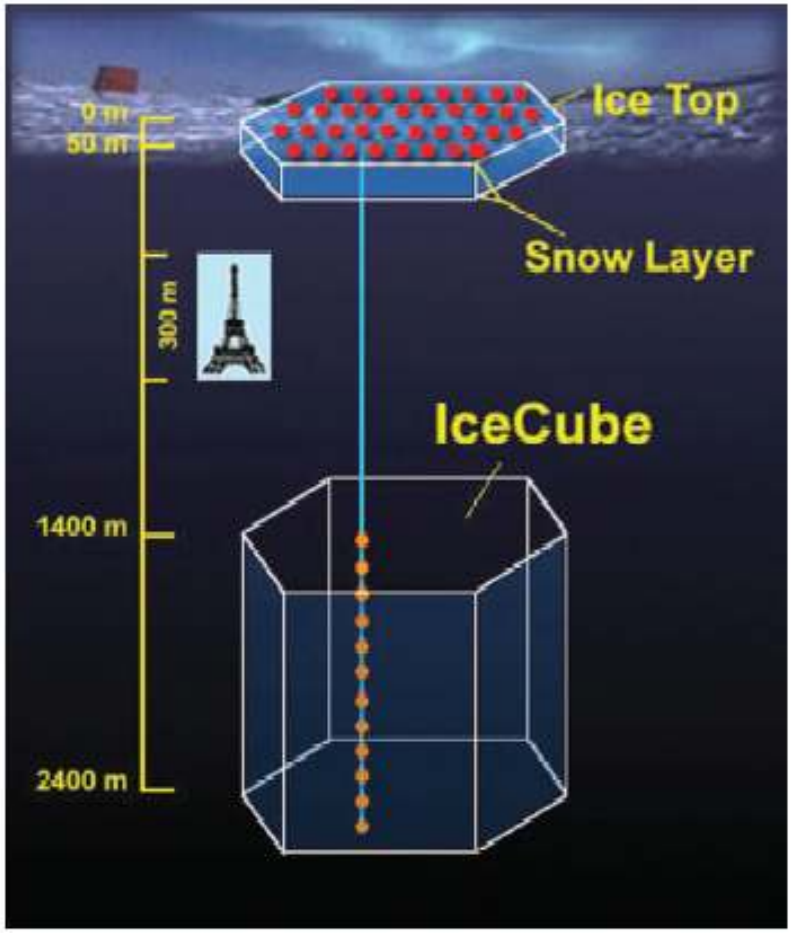
Japan:
Chiba university

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

New Zealand:
University of Canterbury

IceCube on One Slide

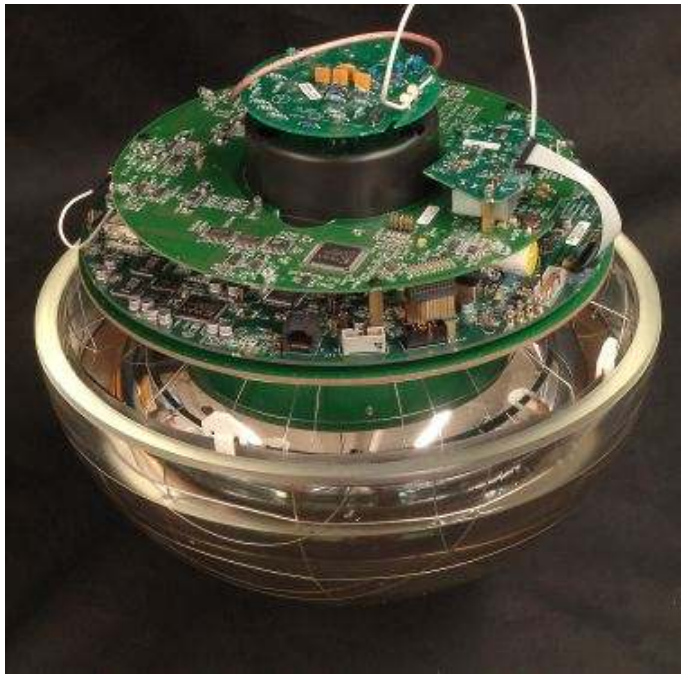
- IceCube detects Cherenkov radiation from the charged particles produced in ν interactions
- 4800+ autonomous digital optical modules (DOMs)
  - 80+ strings with 60 modules
    - 125 m hexagonal grid
  - 1450 to 2450 m deep
  - --> 1 km^3 volume
- μ energy threshold ~ 100 GeV
  - Analysis dependent!!!
- IceTop 1 km^2 surface array
  - 160 ice-filled tanks
    - 2 DOMs instrument each tank
  - ~ 300 TeV threshold for showers

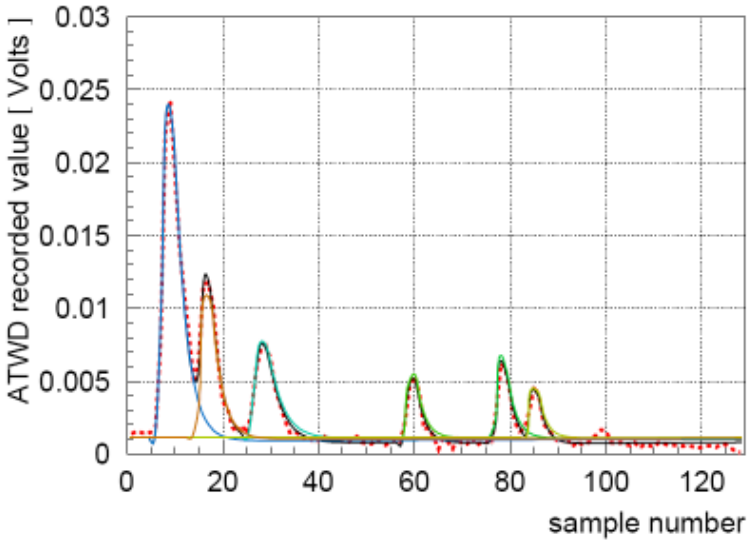


Temperature: -20^{0}C to -40^{0}C
(-55^{0}C in IceTop)
Pressure@2450 m ~ 240 atmospheres

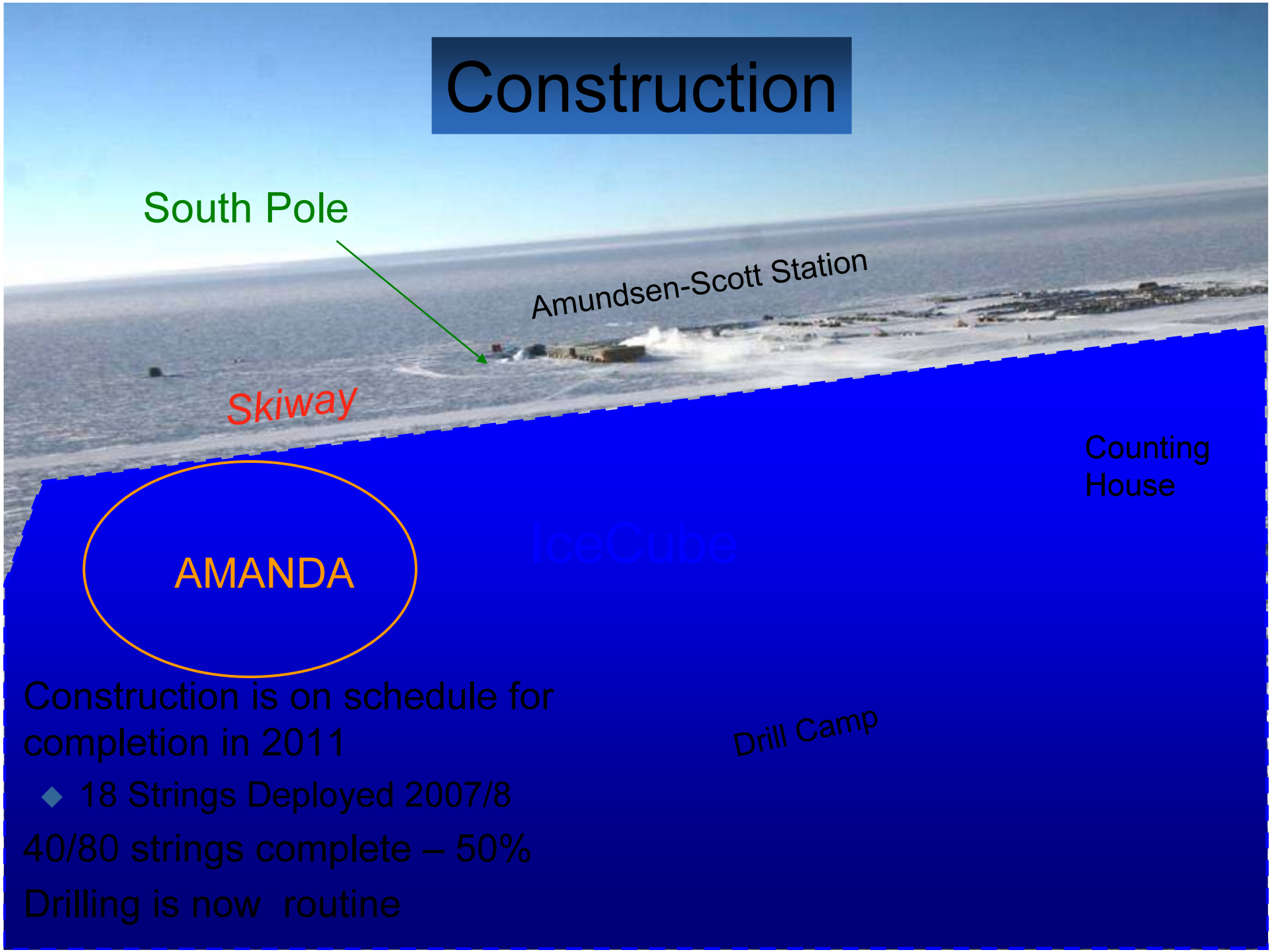
Optical Modules

- 35 cm pressure vessel
- 25 cm Photomultiplier w/ HV
- Autonomous data collection
  - 300 MSPS waveform digitizer
    - 400 nsec recording time
    - 3 channels --> 14 bit dynamic range
  - 40 MHz 10-bit ‘fast’ ADC
  - Self triggering
    - ~1/4 photoelectron threshold
  - 3.5 Watts of power
- Digital data packets sent to surface
- 1-2% of DOMs fail during deployment/freeze-in
- 6+1 DOMs failed after comissioning
  - 15 year survival probability: 96%





Waveform decomposition into photon arrival times


Construction
South Pole
Amundsen-Scott Station
Skiway
Counting House
AMANDA
IceCube
Drill Camp
Construction is on schedule for completion in 2011
18 Strings Deployed 2007/8
40/80 strings complete – 50%
Drilling is now routine

The IceCube Hot water drill

Drill camp (5 MW hot water heater)

Hose Reel

Hot water hoses (2)

IceTop Tanks
(w/ sun shield)

Drill head

Solar heated
Facilities

Drill speeds ~ 2 m/minute

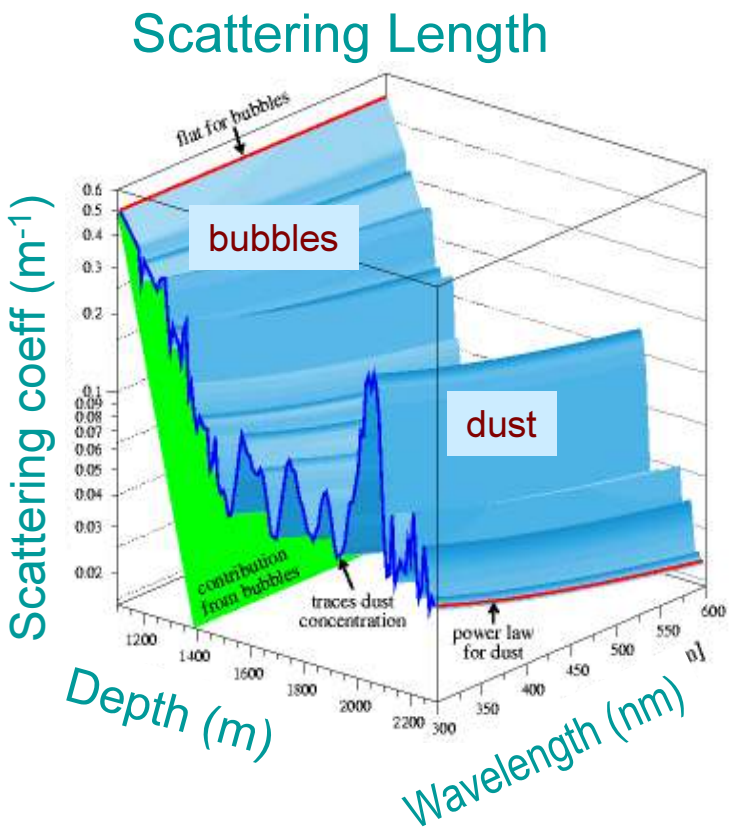
~40 hours to drill a hole

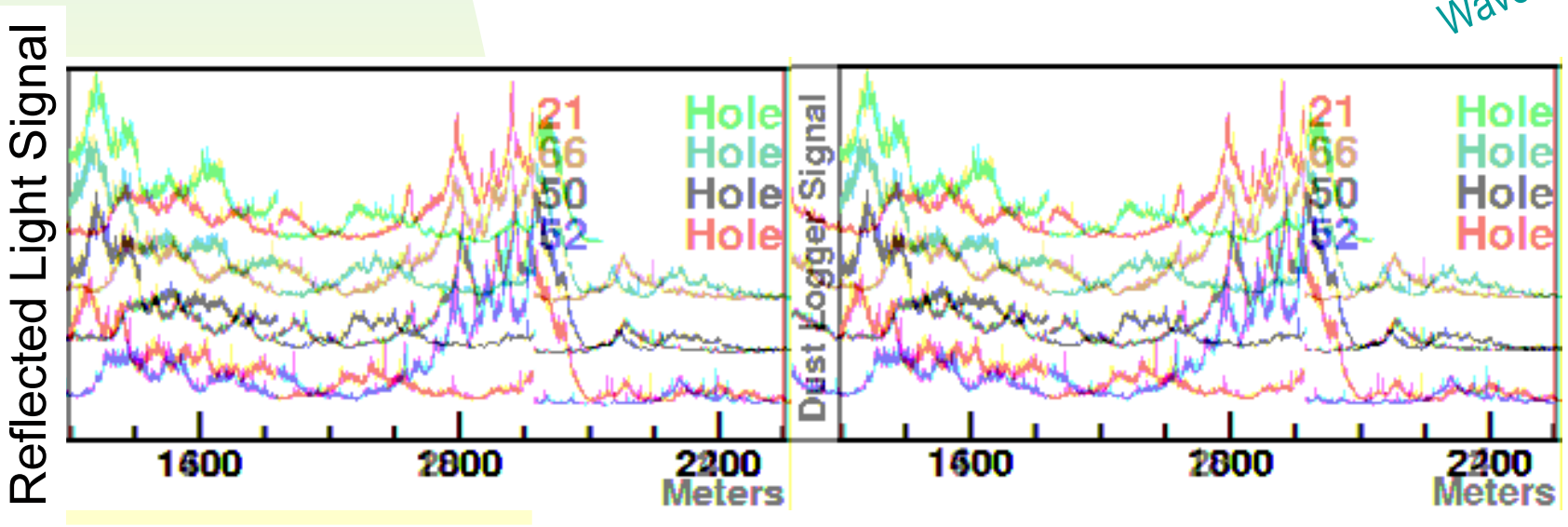
~12 hours to deploy a string

Deploy: DOMs, pressure sensors, Std. Candle, dust logger, …

Ice Properties

- Analyses are sensitive to the optical properties of the ice.
- Determine light absorption & scattering length vs. depth
  - LED, laser light sources
  - 'Dust logger' profiles dust
    - layers are not 100% planar
    - Up to 70 m/km tilt





Datasets

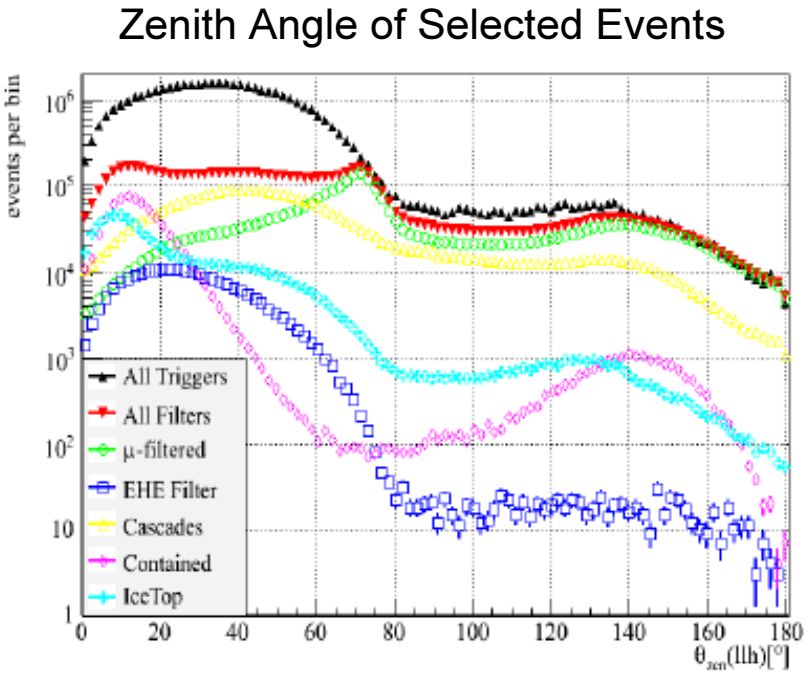
#Strings	Year	Run Length	CR μ Rate	ν rate	Trigger Rate
IC1	2005	-	-	2	-
IC9	2006	137 days	80 Hz	~ 1.5/day	150 Hz
IC22	2007	319 days	550 Hz	~ 20/day	670 Hz
IC40	2008	~ 1year	1000 Hz		1400 Hz
IC80	2011	10 years	1650 Hz	~ 200/day	TBD

Triggers

- Local Coincidence
  - Data currently saved if 2 nearest or next-to-nearest neighbors on a string fire within 1 μs
  - Will soon save partial information for isolated hits
- Multiplicity Trigger – 8 DOMs within 5 μs
- Single String Trigger added 2008
  - 5 of 7 adjacent DOMs within 1.5 μs
  - More sensitive for low energy ν
- Topological Trigger for low energy horizontal muons is under study

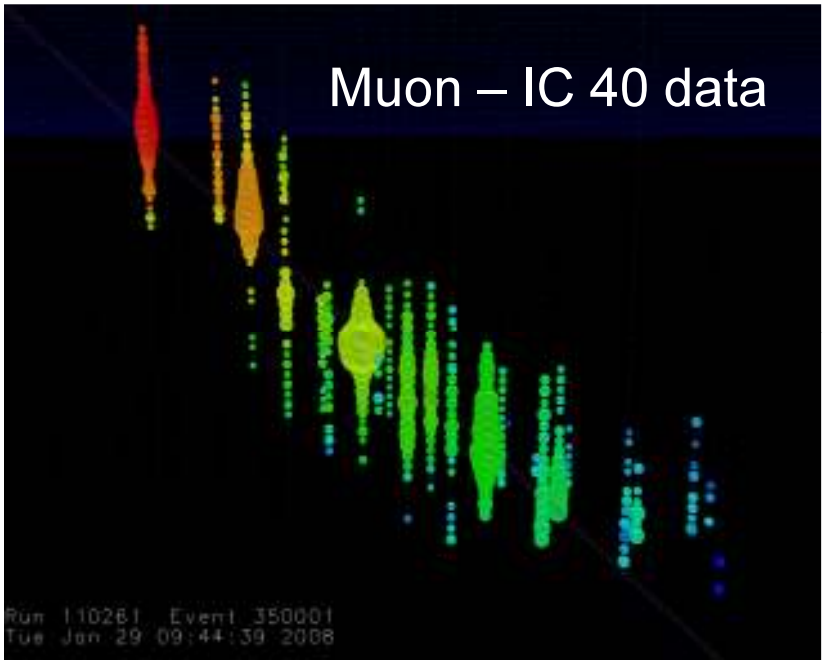
Pole Filters

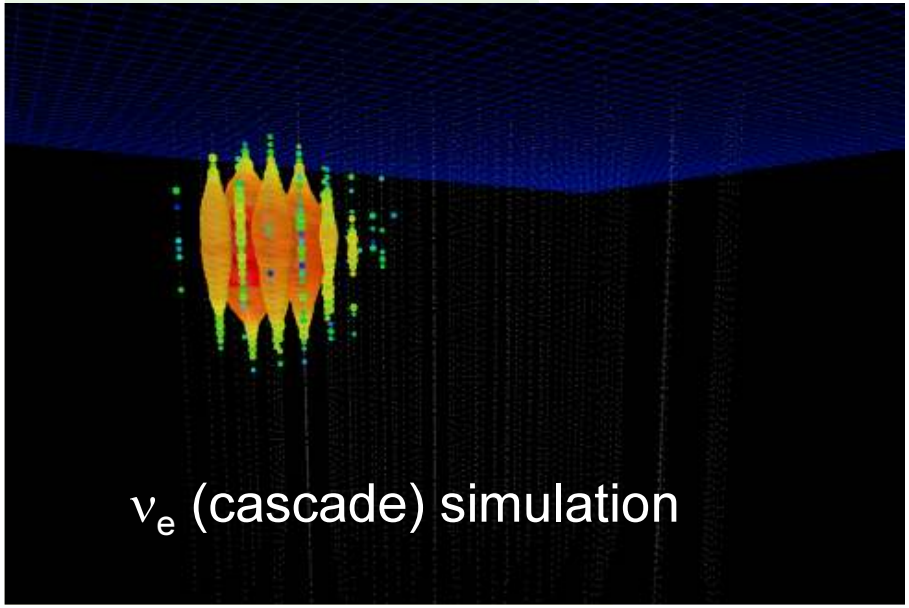
- Data is filtered with simple reconstructions at Pole, for
  - Upward going muons
  - Cascades (ν_e & neutral current ν_x)
    - Cascade filter also finds ν_τ events
  - Contained Events
    - Low energy ν interactions
  - Extremely high energy events
  - Starting/stopping events
  - Moon filter
  - Air Showers
- "Interesting" events sent North via satellite
  - 6% of events selected (~ 80Hz)
- Total ~ 32.5 GBytes/day

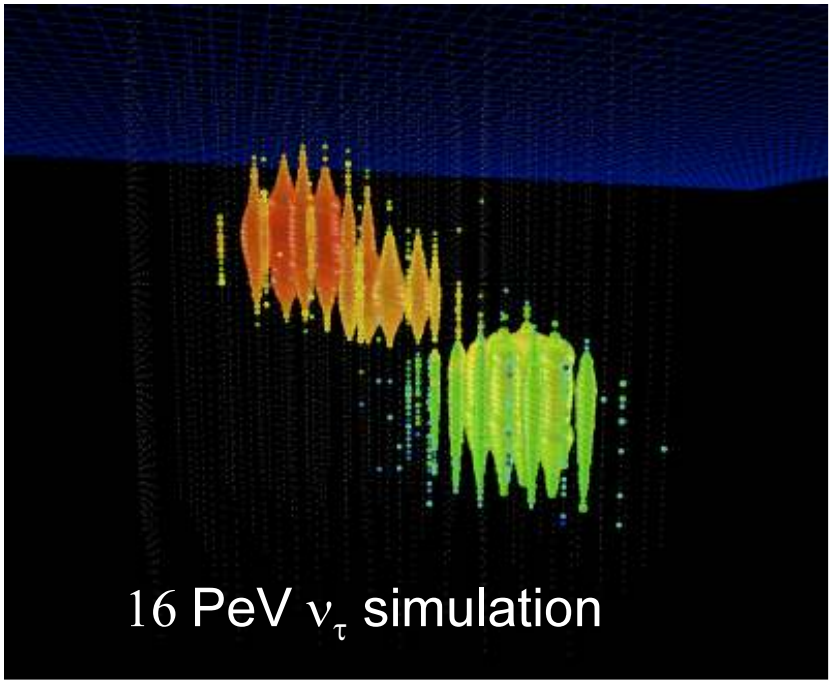


Topological Flavor Identification

- ν_μ produce long μ tracks
  - Angular resolution ~ 1^0
- ν_e, NC ν_x cause showers
  - ~ point sources ->'cascades'
    - Good energy resolution
- ν_τ 'double bang events
  - Other ν_τ topologies under study
- Starting μ also under study

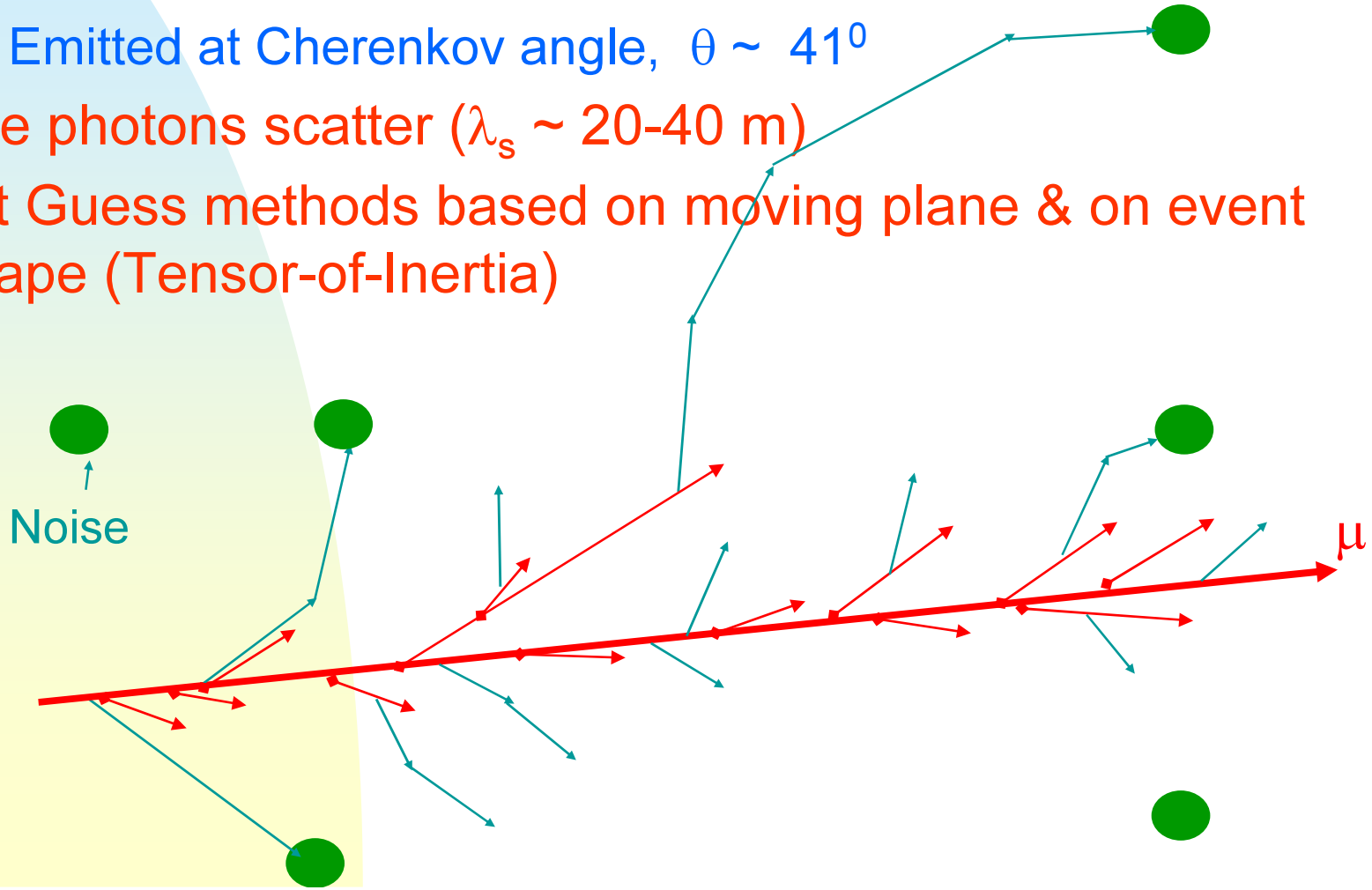






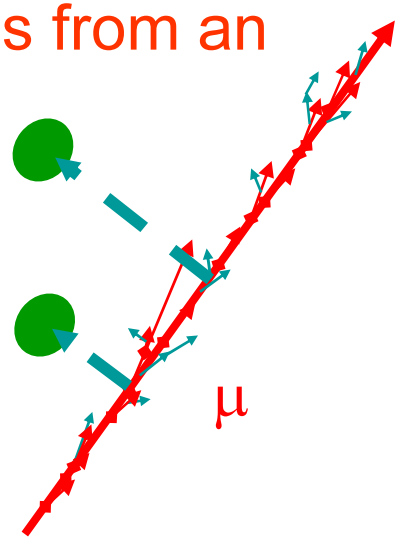
Muon Tracking

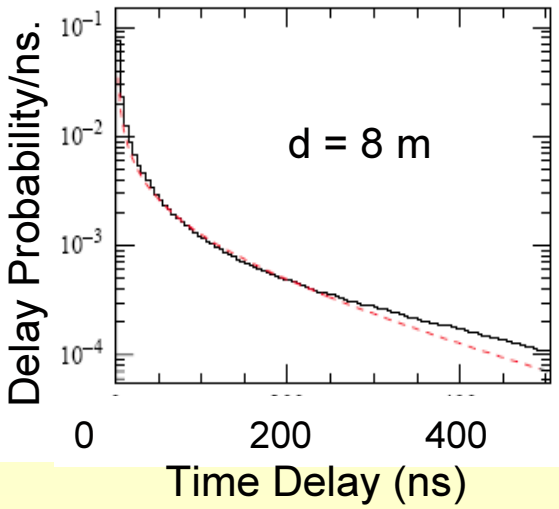
- Muons emit Cherenkov radiation
  - + radiation from showers from bremsstrahlung, e^+e^- pairs and electroproduced hadrons
  - Emitted at Cherenkov angle, $\theta \sim 41^0$
- The photons scatter ($\lambda_s \sim$ 20-40 m)
- 1st Guess methods based on moving plane & on event shape (Tensor-of-Inertia)

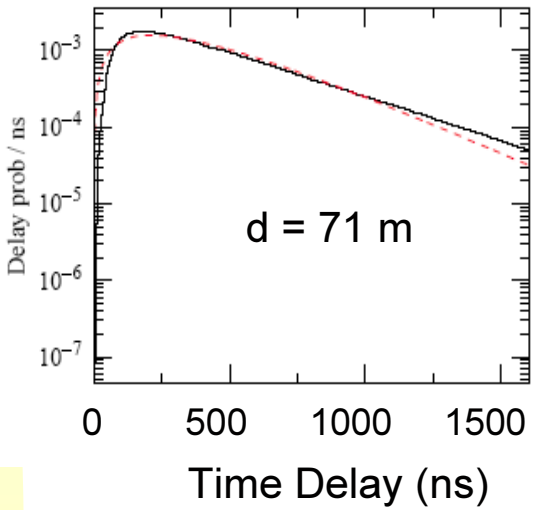


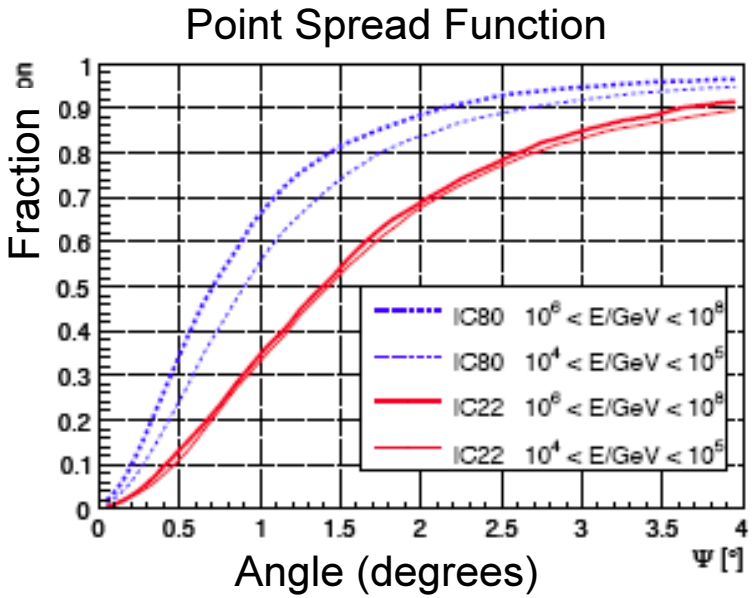
Maximum Likelihood Reconstruction

- Functions give arrival time distribution for photons from an infinite linear track to a DOM
  - Perpendicular distance, position, angles, depth
- Include noise probability
- Use multiple seeds and/or scan direction space
  - Avoid false and/or shallow minima
- Angular resolution depends on track length
  - ~ <1 degree for long tracks

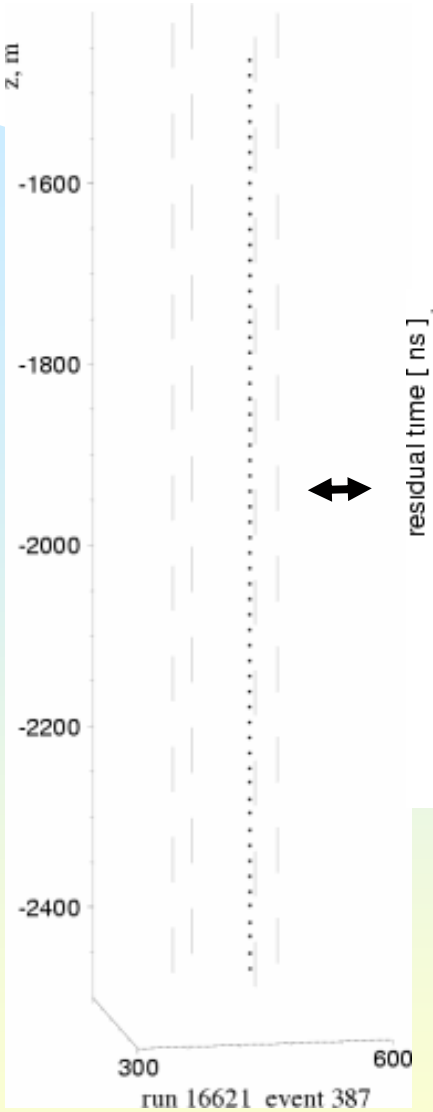


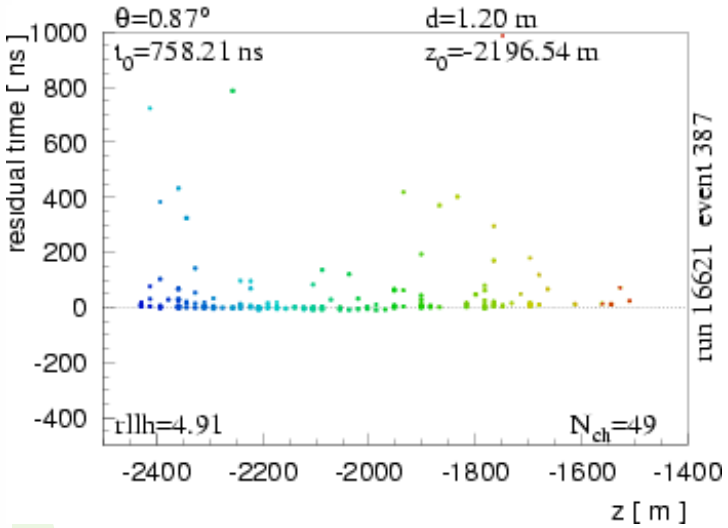






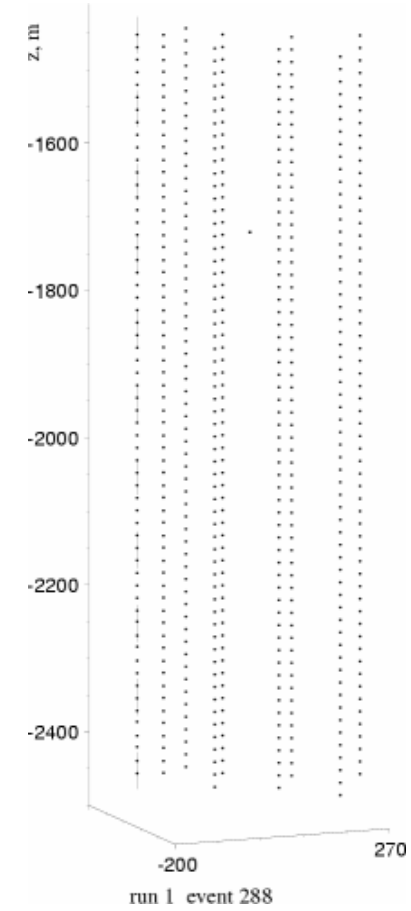
Neutrinos Observed





Time residuals from fit
Direct & scatted photons

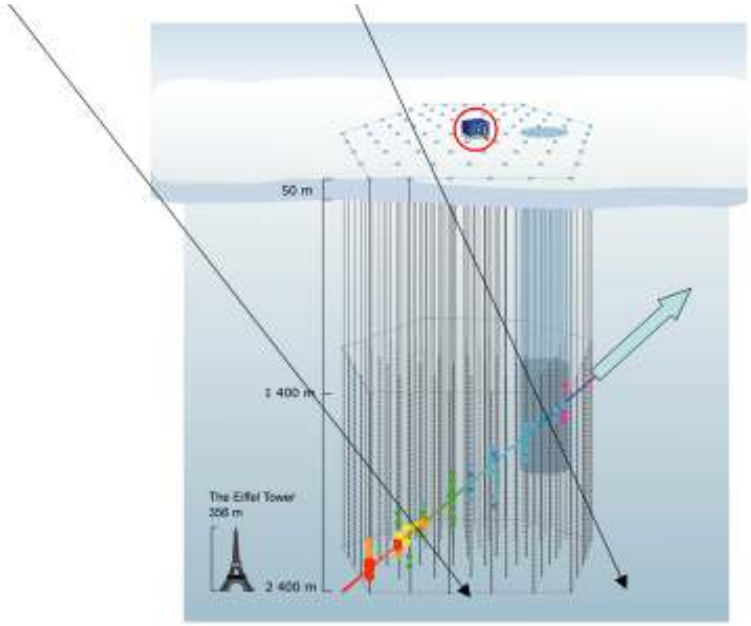
A 2005 Neutrino candidate
49 DOMs hit in String 21

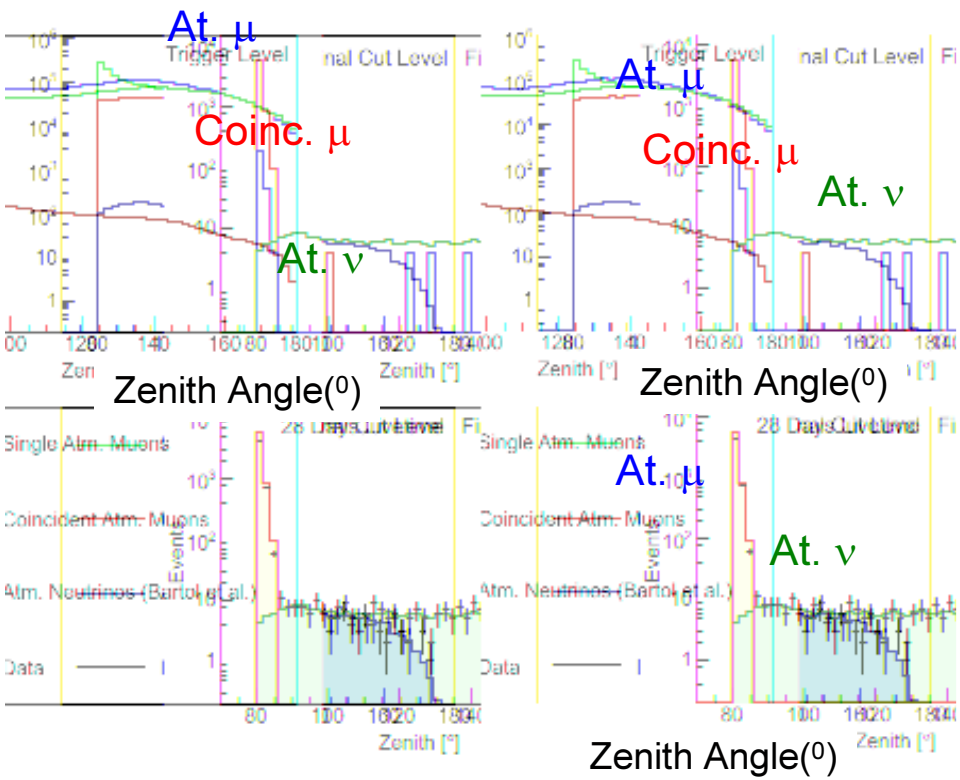


2006 Neutrino candidate
24 DOMs hit in 2 strings

Coincident Muons

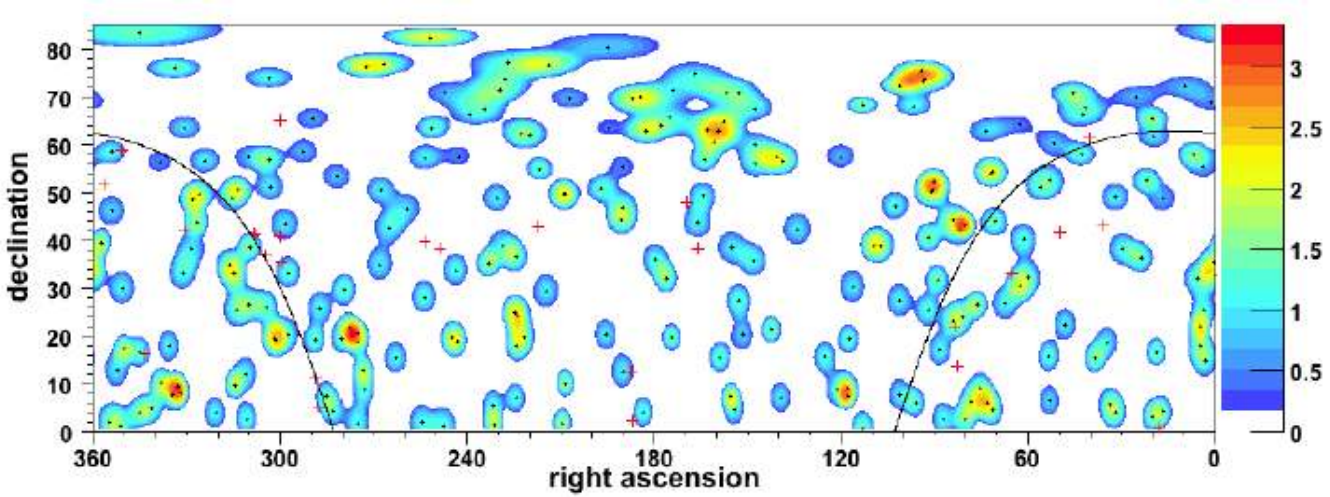
- IceCube is big enough to observe overlapping μ from independent air showers
  - N ~ (detector size)^2 Δt
    - Time window Δt ~ detector size ~ 1 μs
- These events can mimic upgoing muons and cascades
- Tailored cuts can remove these events, leaving a clean ν sample



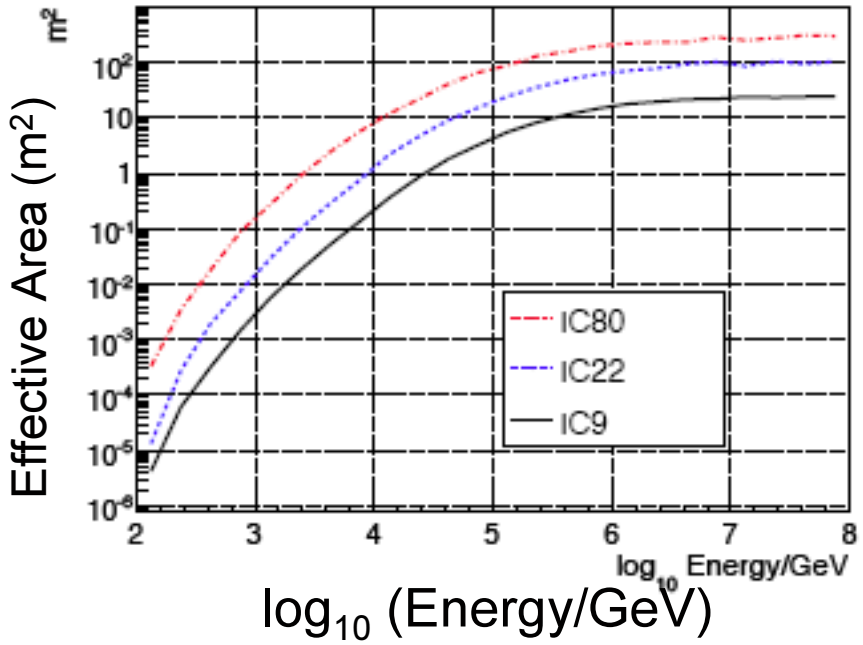


IC-9 Point source search

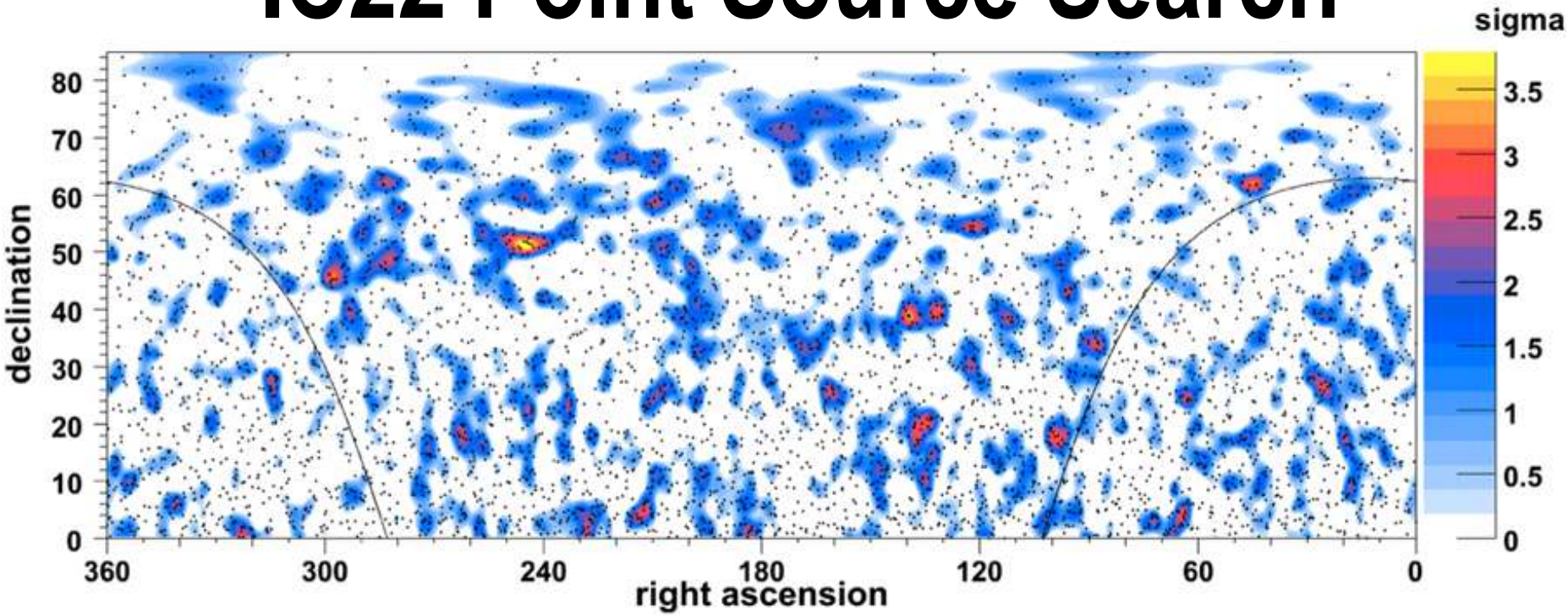
IC-9 Skymap



- IC-9 found 233 ν in 137 d
  - Rate ~ for atmospheric ν
  - No Sources Seen
    - All-sky search
    - 26 source list



IC22 Point Source Search



5000 ν_μ map. **Scrambled** in right ascension

22 strings for 250 days

- ~ 20 ν_μ/ day

1.5 degree resolution

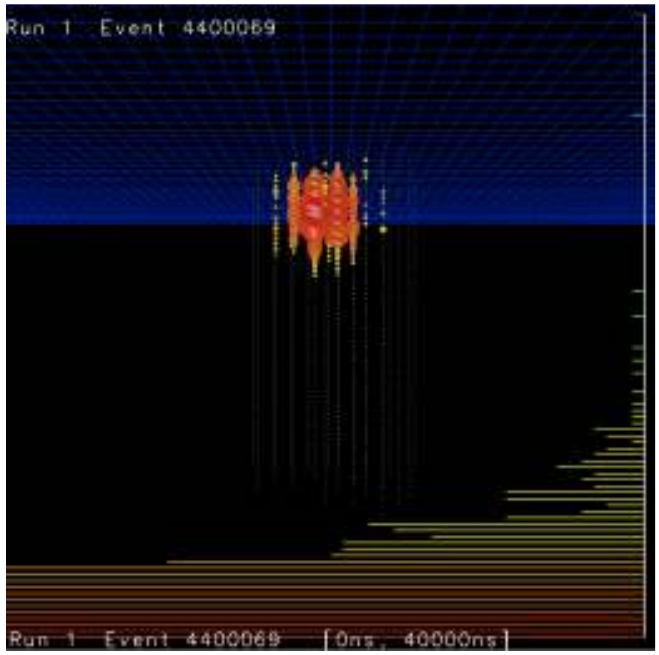
~ 5* as sensitive as IC-9 (for E^{-2} spectrum)

Better than AMANDA 5-year result

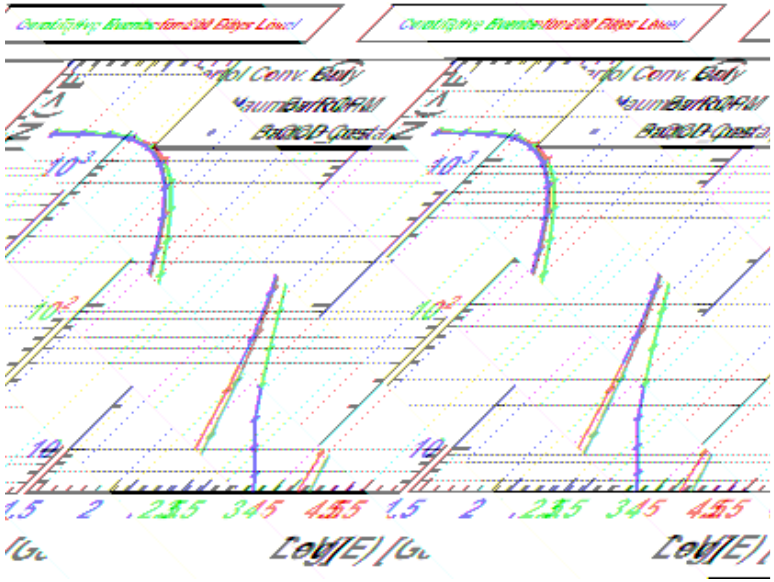
IC-22 Diffuse ν_μ search also underway (Gary Hill - poster)

IC22: The quest for ν_e

- Searches for extra-terrestrial and atmospheric ν_e
  - Atmospheric flux is ~ 2 orders of magnitude below ν_μ
- Select events based on topology, relative likelihood for cascade and muon hypotheses, and zenith angle under muon hypothesis
- Isolation cuts
  - No activity in detector top/sides
- ~ 1500 ν_e interactions after Pole filter
  - ~ 100 events above 3 TeV
- N.b. NC ν_μ are background(?)

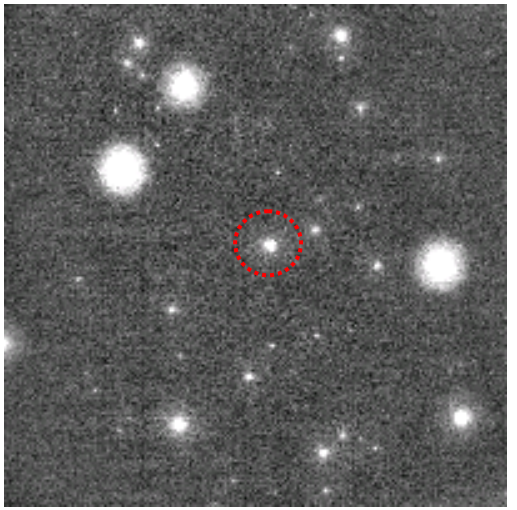


Simulated ν_e
E = 182 TeV

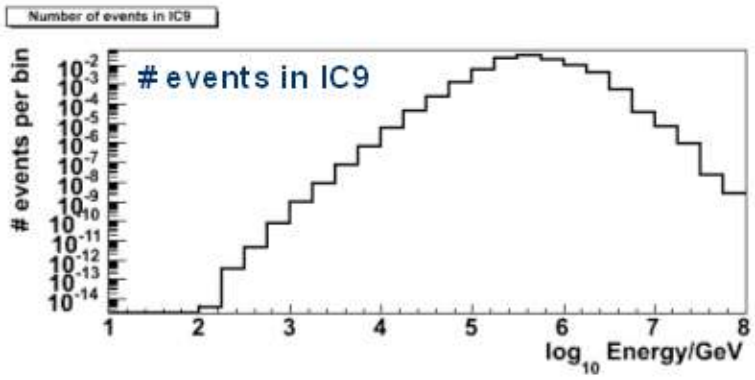


ν_μ & cascades from GRB's

- Triggered burst searches
  - 93 SWIFT bursts during IC22 running
    - All but a handful are useful
  - Unblinding for northern hemisphere bursts soon
- Untriggered searches in progress
- GRB080319B (seen by SWIFT)
  - Brightest burst ever
    - briefly visible to the naked eye
  - Redshift 0.94
  - IceCube was in a 9-string test mode
    - Predict ~ 0.1 ν_μ w/ a fireball model
      - Assumed Lorentz boost = 300
      - Large model uncertainties



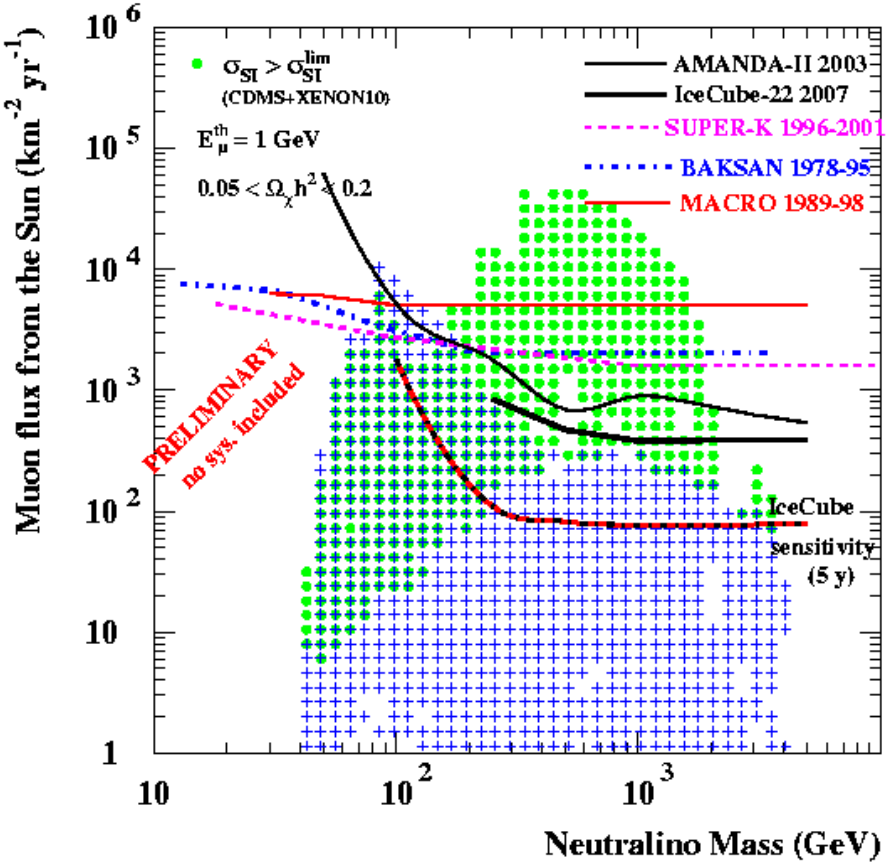
GRB080319B



Modelled ν energy spectrum for GRB080319B

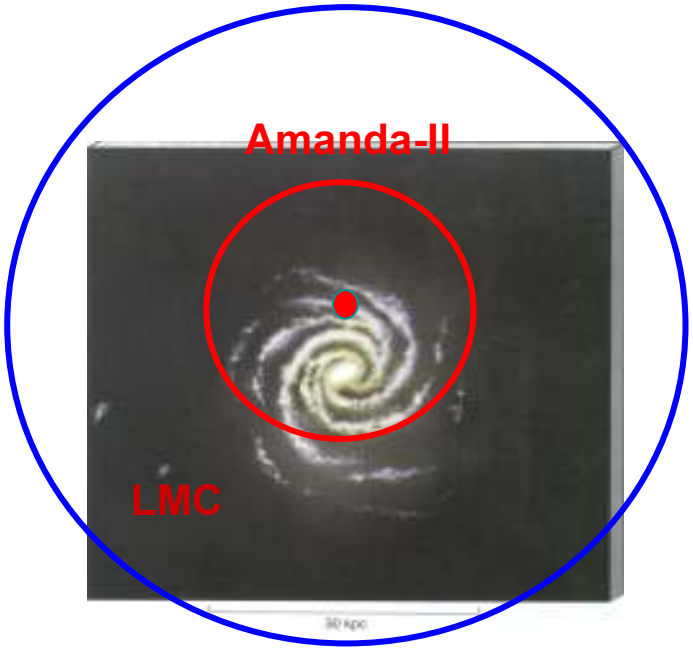
ν from WIMP annihilation in Earth or Sun

- Today: IC22 Results from Sun
- Sun is below horizon
  - June 1- Sept. 23
- Model WIMPs
  - Mass (100 GeV to 5 TeV)
  - Hard or soft ν spectrum
- Select upgoing μ
- Count events w/in ~ 3^0 of sun
  - Exact cut is WIMP mass dependent
- No excess found
  - Limits at right

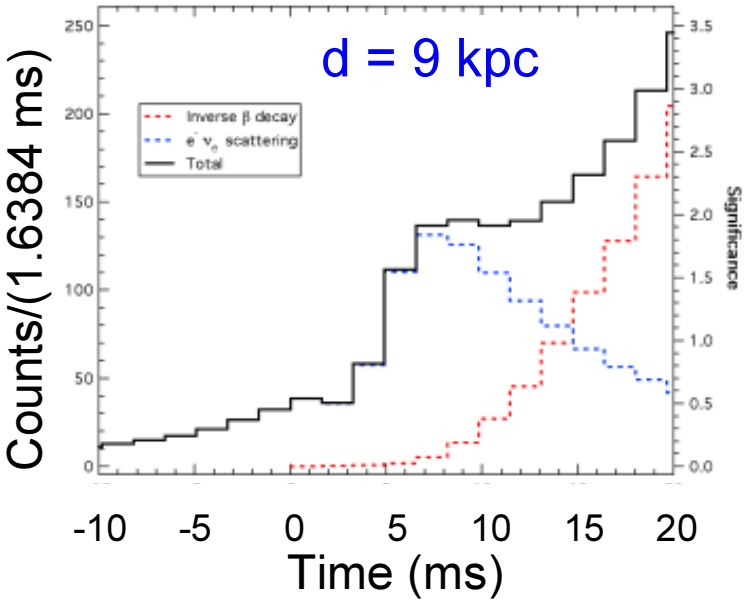


Other Physics

- MeV ν from supernovae
  - Look for coherent increase in PMT rates
  - ~ 350 Hz w/ 51.2 μs deadtime
  - Sensitive to d ~ 30 kpc
    - Large Magellanic Cloud
  - May be able to observe initial electron capture (deleptonization) pulse
- Supersymmetry
  - Pairs of upward going particles
    - Typical separation ~ 100 m
- Magnetic Monopoles
  - Highly ionizing relativistic monopoles
  - Slow monopoles that catalyze proton decay

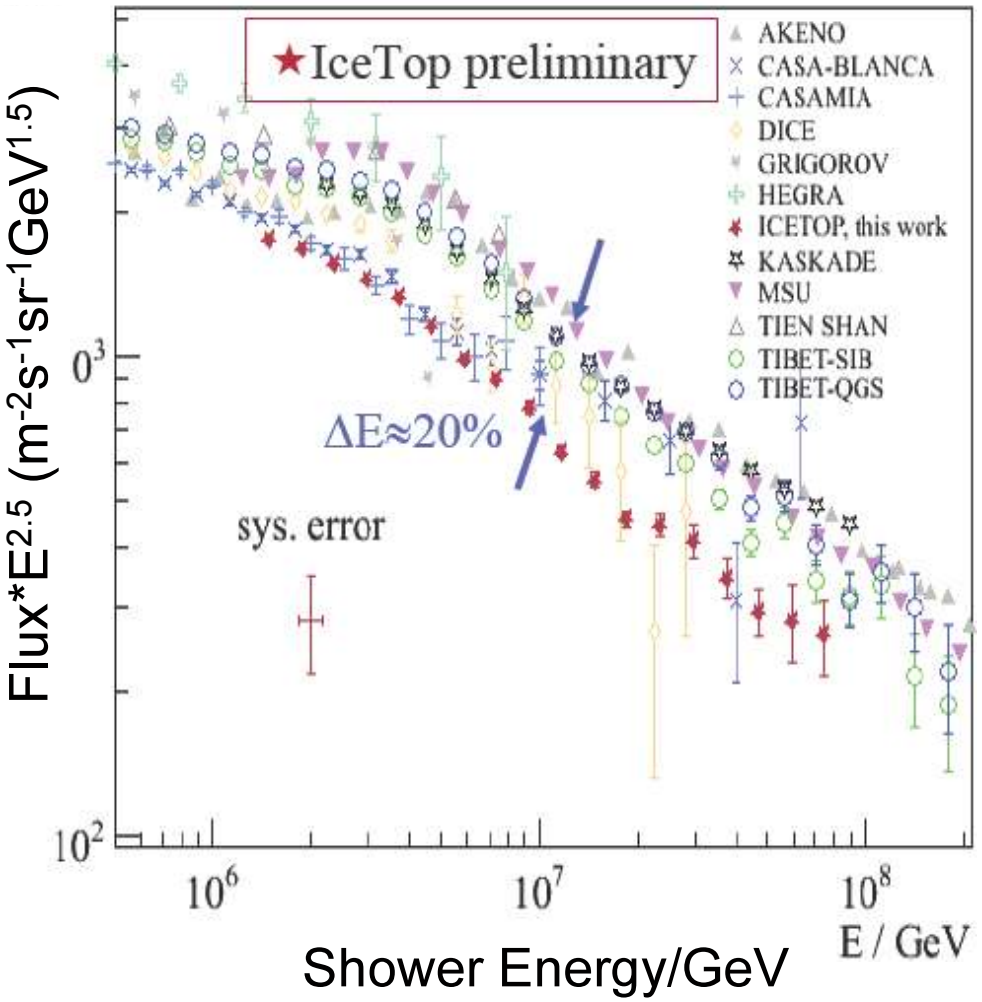


IceCube



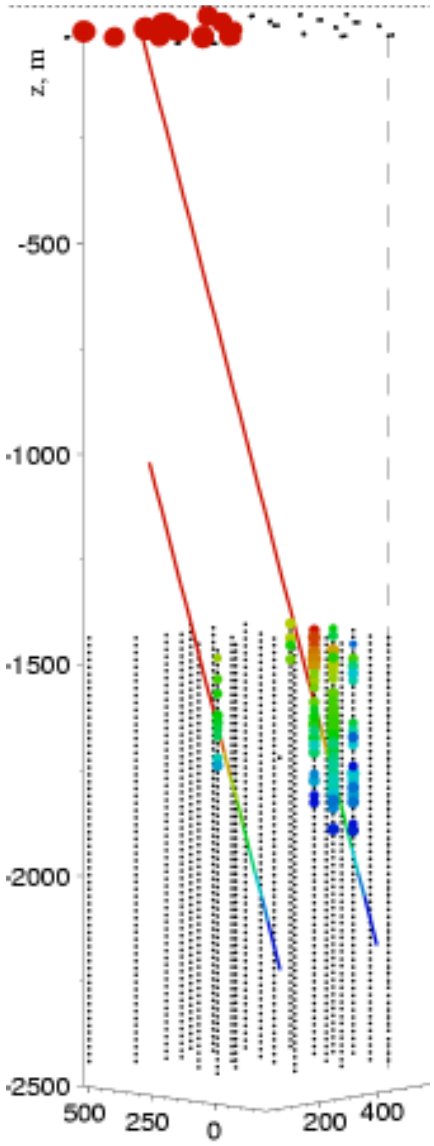
Cosmic Ray Spectrum

- Standard shower reconstruction
- Require that flux is independent of zenith angle
  - Composition dependent
- Fit requires mixed composition
  - Good fit to poly-gonato & 2-component (Fe + p) model
  - Spectral index consistent with previous results
- Systematic Errors still under study



High p_T muons in air showers

- Study μ far from the shower core/μ bundle
- IceTop measures shower energy, direction & core position
- Measure μ energy by range or dE/dx
- μ p_T = E_μ*core_distance/production_height
  - Need model for production height
- Minimum μ-bundle separation ~ 100 m
  - p_T (min) ~ 3 GeV/c
- High p_T μ rate sensitive to composition
  - Analyze in pQCD framework
  - Collider-like analysis
- Expect a few 1,000 high p_T μ/year in IC80

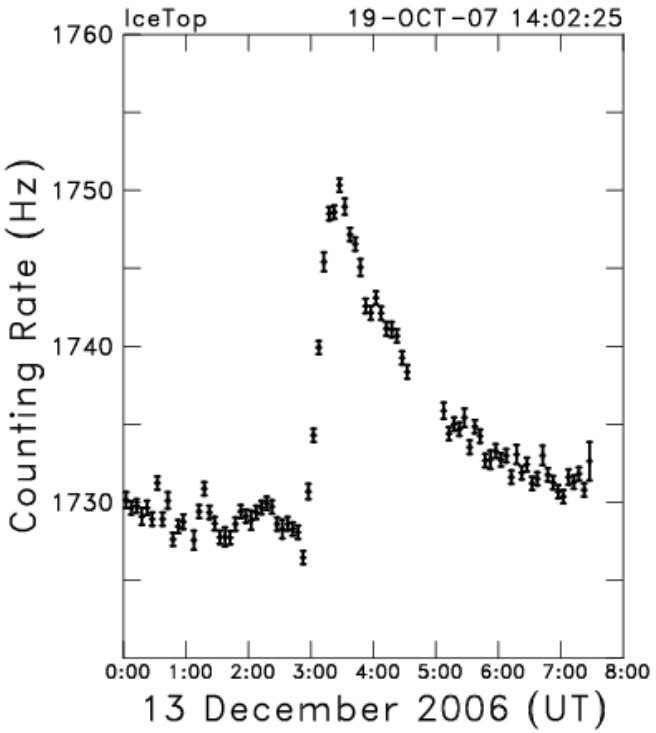


An IC-22 event
11 IceTop Stations
84 DOMs near the core
12 DOMs 400 m from core

Solar Physics

- IceTop is sensitive to showers from ~ 1 GeV particles emitted by the sun during outbursts
- Monitor IceTop tank rates, energy
  - Different tanks have different thresholds
    - Can extract energy spectrum in 1-10 GeV region
- Large rate increase seen during solar outburst, Dec. 13, 2006
  - No large spectral changes during outburst
- IceCube is part of an international monitoring network

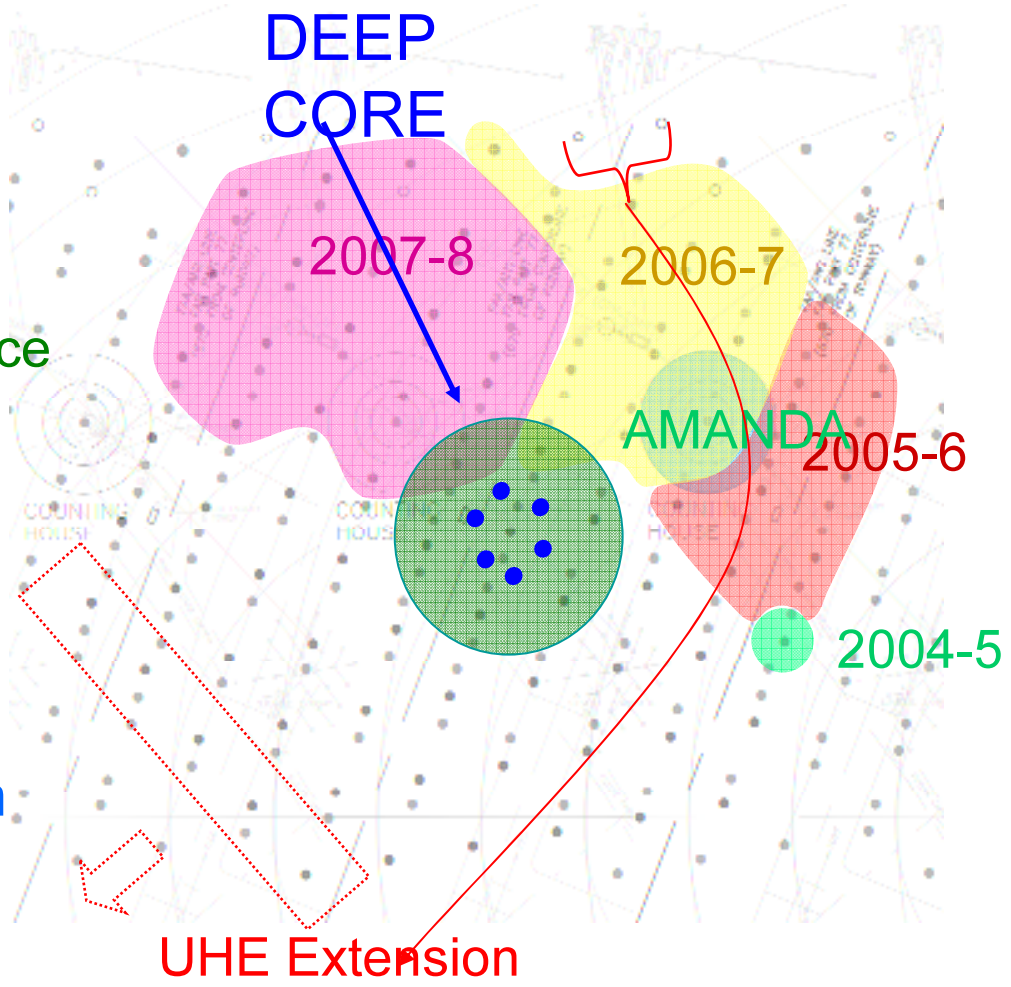
Dec. 13, 2006 solar Outburst
Seen by an international Monitoring network



Avg. IceTop counting rate

“Toward a graded array

- Broaden energy range
- 6 new “Deep Core” strings
  - lower energy threshold
  - Smaller spacing
    - 13 strings total
    - 72 m grid
  - 60 DOMs/string
    - 7 m spacing in deep clear ice
    - High Quantum Eff. PMTs
      - 30% higher
  - Rest of IceCube is veto
- Possible EHE optimization
  - Move outer strings outward
  - Larger effective area at high energies
  - Reduces efficiency of Deep Core veto?



Near-Future Plans

- Multi-Messenger Astronomy
  - Correlations w/ ROTSE, AGILE, MAGIC, LIGO
- Use Moon Shadow to Check pointing, angular resolution
  - Expect 1.6σ deficit w/ IC22
- 3 Prototype Digital Radio Modules deployed with IceCube strings
  - Coincident events observed from surface sources
- Hydrophones deployed in 4 Icecube holes
  - Speed of pressure and shear waves measured

Radio

Acoustic

Logistics is the key to IceCube

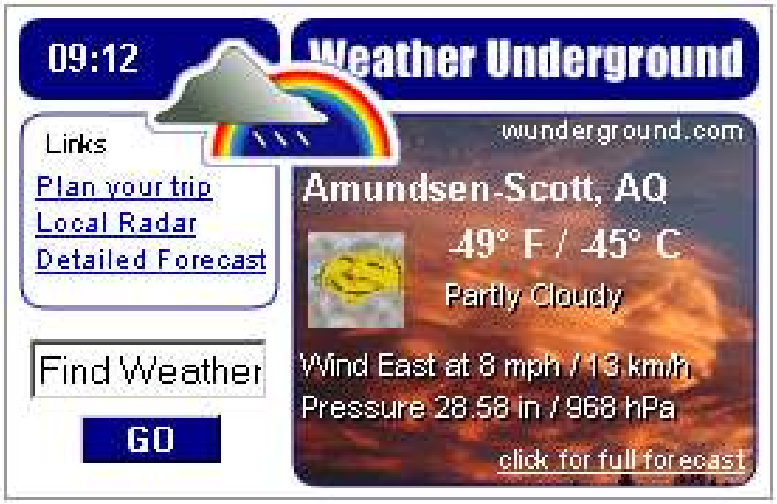
Thanks to the U. S. National Science Foundation, Raytheon Polar Services Corporation, the U. S. Air Force and the New York Air National Guard for their help.

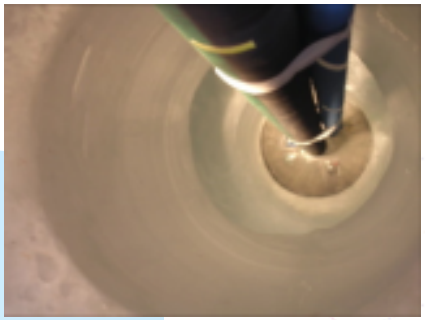
Thank also to the people of Christchurch, gateway to Antarctica

Conclusions

- IceCube deployment is 50% complete
  - The hardware is working very well
    - ☞ Good predicted long-term reliability
- IC-22 Analyses are emerging
  - We have observed atmospheric neutrinos and solar flares, and set limits on WIMP annihilation in the sun
  - Future plans include a move toward a graded array, and radio and acoustic extensions
- For more information see these posters
  - Enhanced Energy Reach of IceCube - Albrecht Karle
  - Diffuse ν_μ - Gary Hill
  - Acoustic Properties of Ice - Rolf Nahnhauer
  - IceCube Deep Core - Doug Cowen

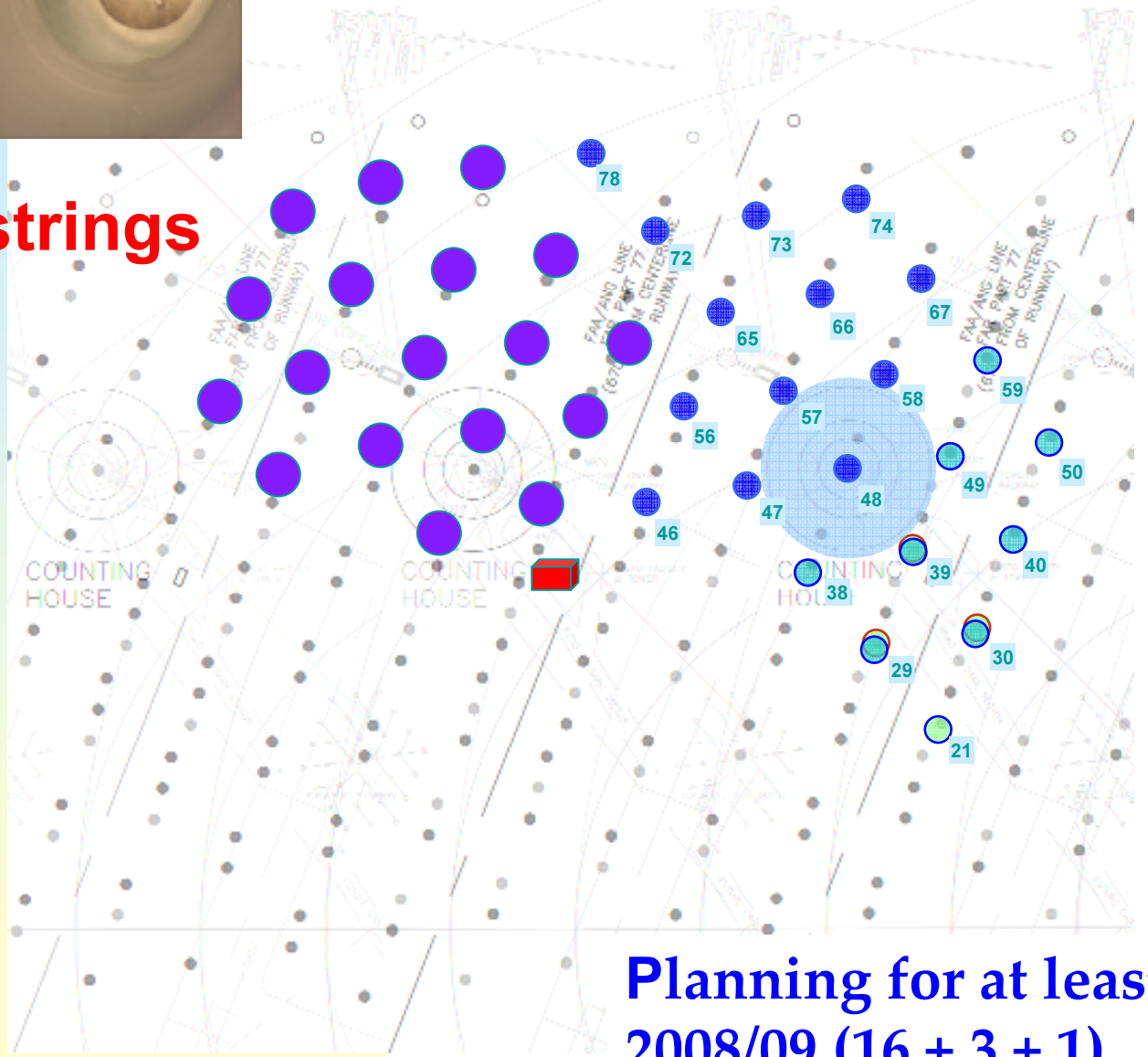
Backups, etc.


09:12
Weather Underground
wunderground.com
Links
Plan your trip
Local Radar
Detailed Forecast
Amundsen-Scott, AQ
-49° F / -45° C
Partly Cloudy
Find Weather
GO
Wind East at 8 mph / 13 km/h
Pressure 28.58 in / 968 hPa
click for full forecast



Installation Status & Plans

40 strings



AMANDA

IceCube string deployed 01/05

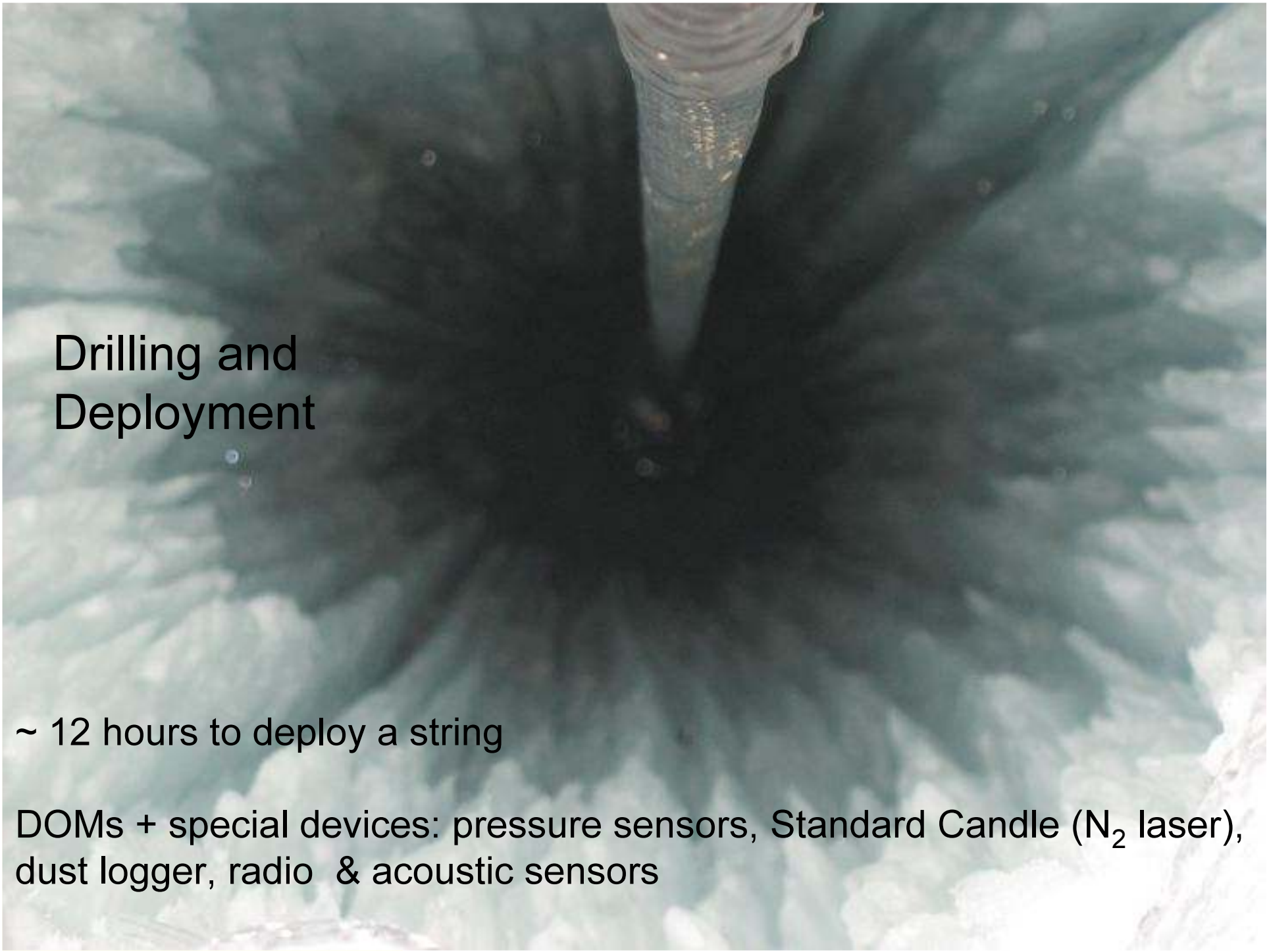
IceCube string deployed 12/05 – 01/06

IceCube string and IceTop station deployed 12/06 – 01/07

IceCube string deployed 12/07 – 01/08

IceCube Lab commissioned

Planning for at least 16 strings in 2008/09 (16 + 3 + 1)



Drilling and Deployment

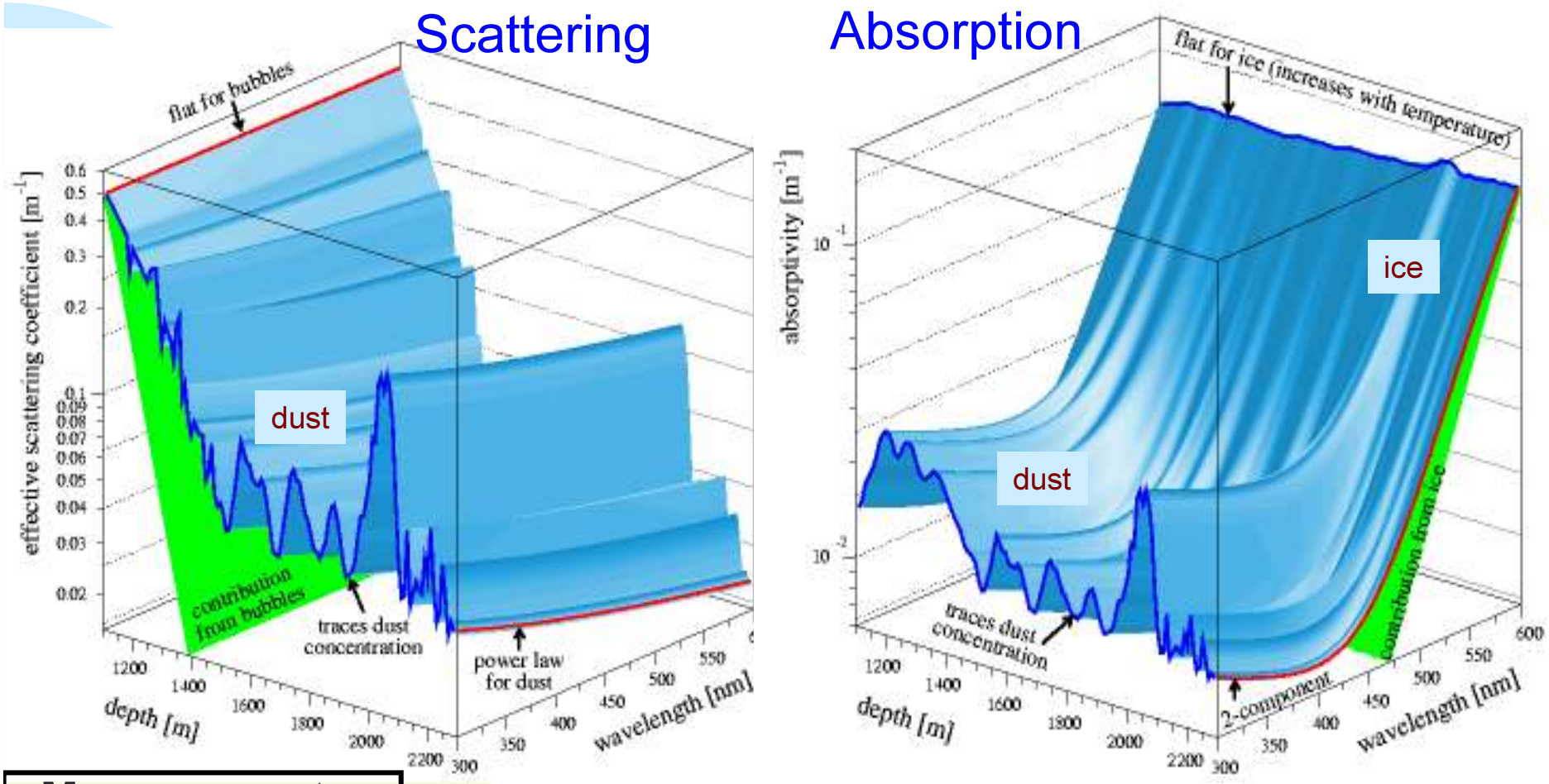
~ 12 hours to deploy a string

DOMs + special devices: pressure sensors, Standard Candle (N_2 laser), dust logger, radio & acoustic sensors

Optical properties of the ice

Scattering

Absorption



Measurements:

in-situ light sources

atmospheric muons

Dust Logger

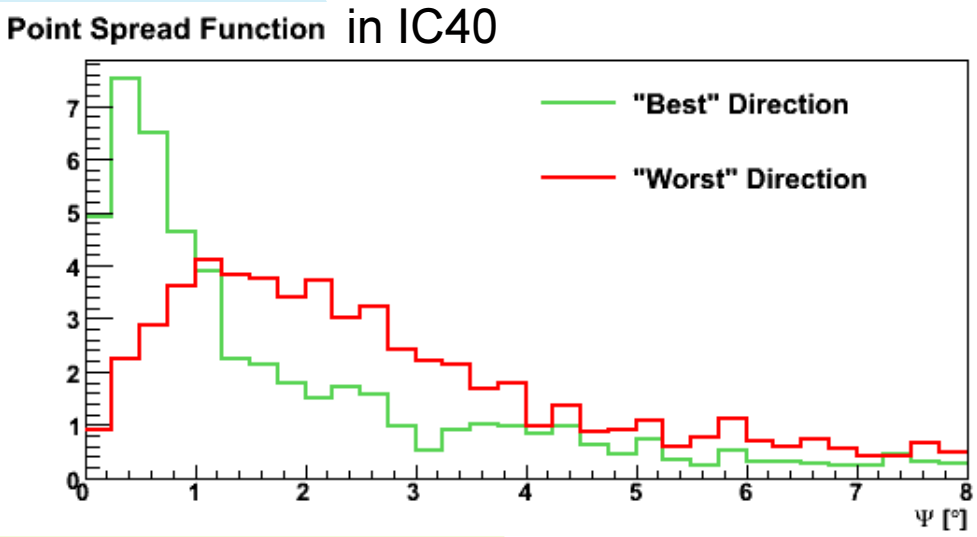
Average optical ice parameters:

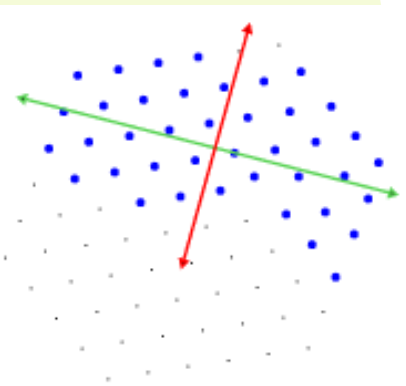
λ_{abs} ~ 110 m @ 400 nm

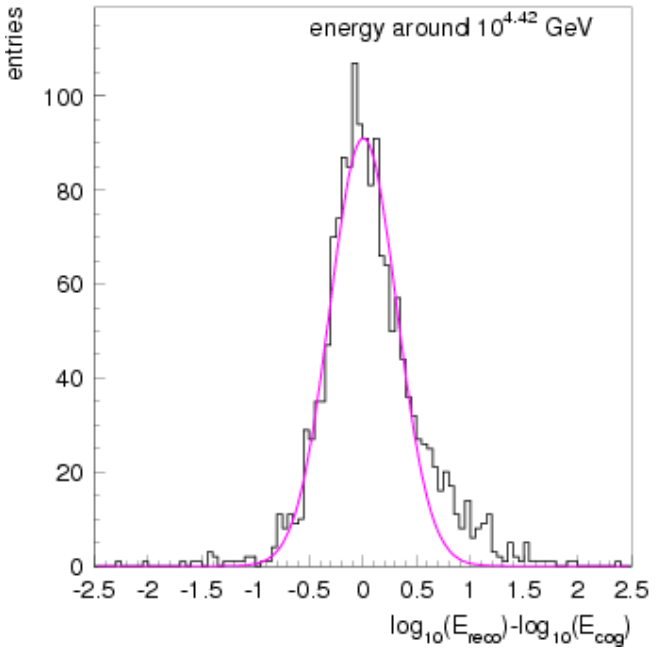
λ_{sca} ~ 20 m @ 400 nm

Angular & Energy Resolution

Resolution depends on track length in detector & on event selection
For IC22 (and even IC40), the maximum depends on the Azimuthal angle





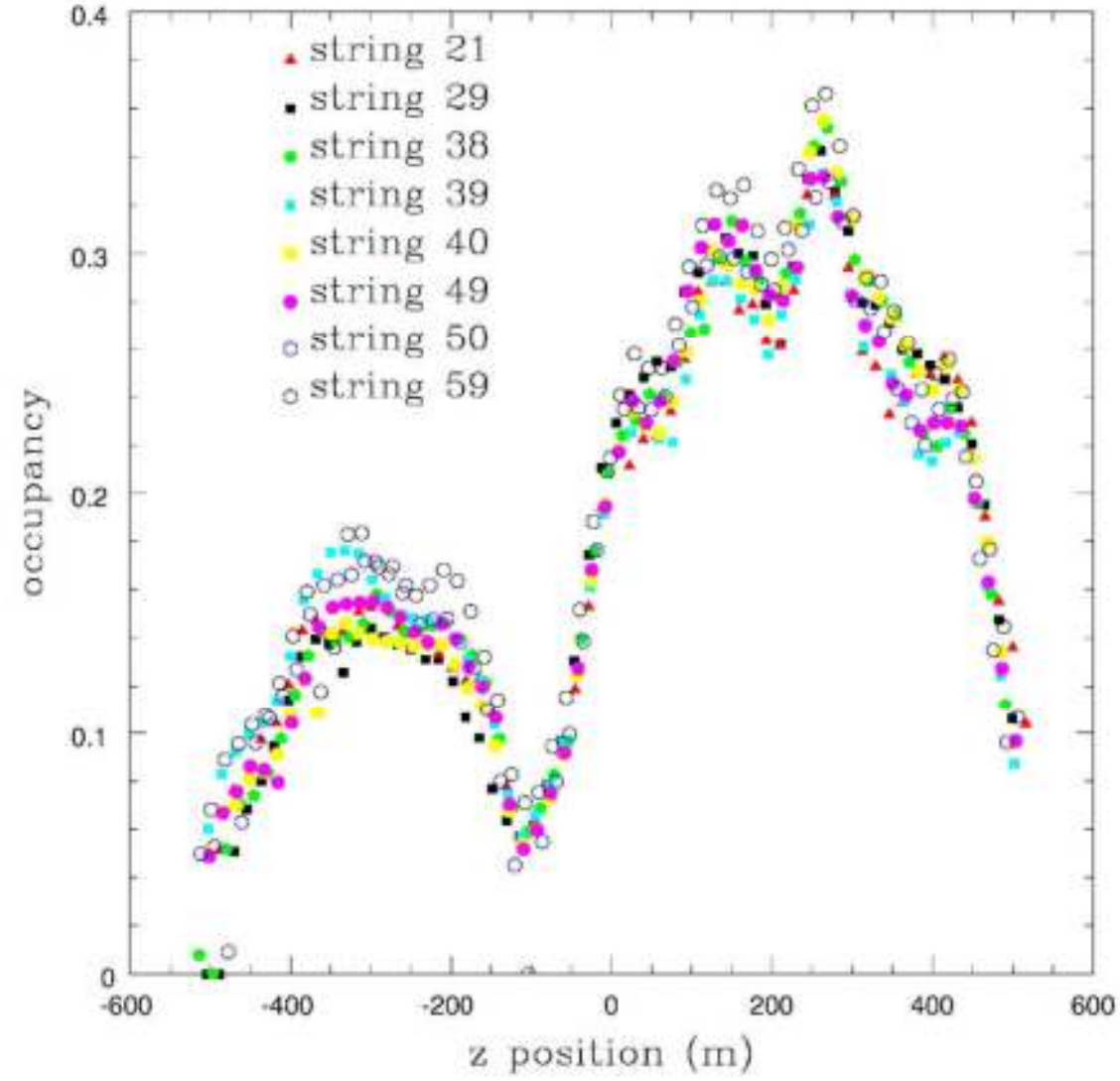


Energy Resolution
$\sigma(\log_{10}E) \sim 0.3$

DOM Occupancy

probability a DOM is hit in events that have >7 hits on a string

Shows depth-dependence of ice properties

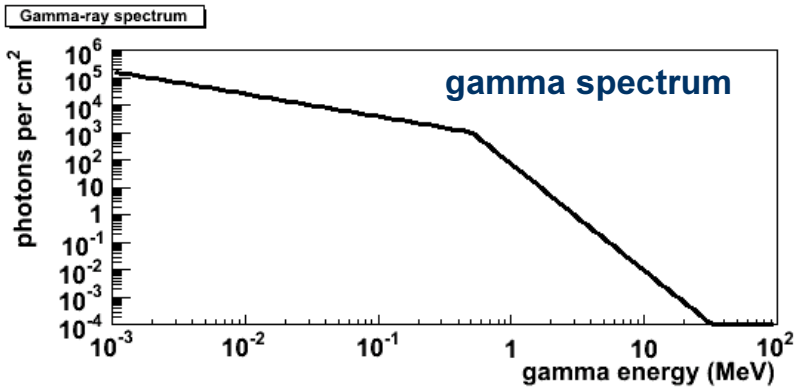


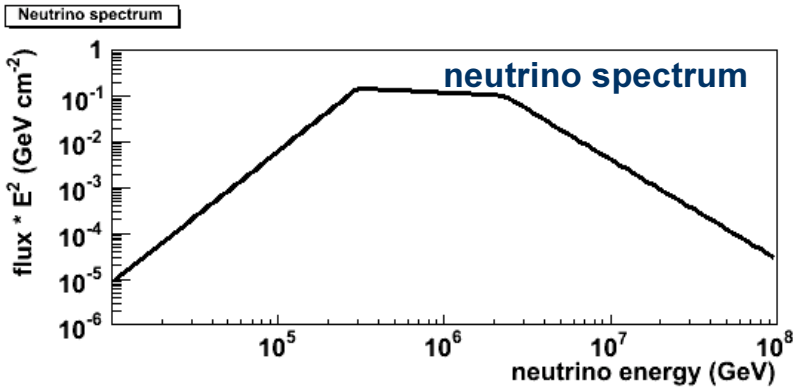
IceCube and GRB080319B

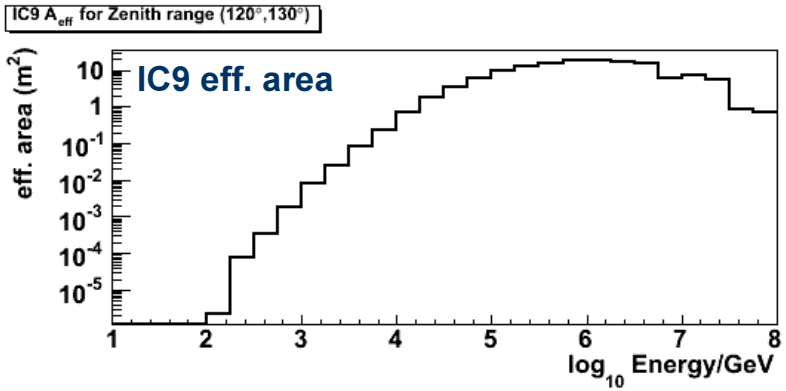
Detector was operating in maintenance mode during GRB080319B

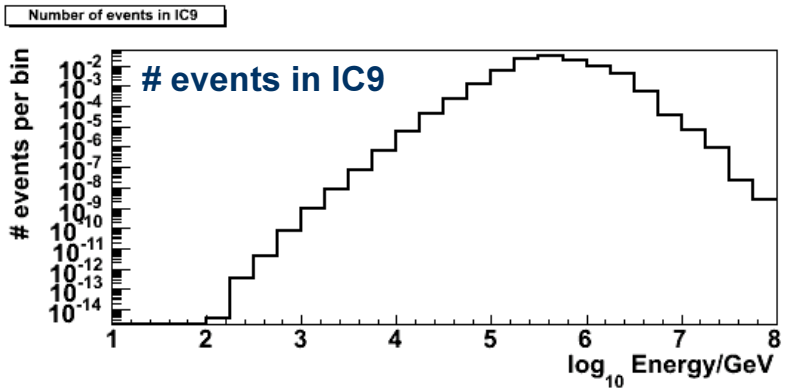
Standard fireball model Calculation

Analysis under way





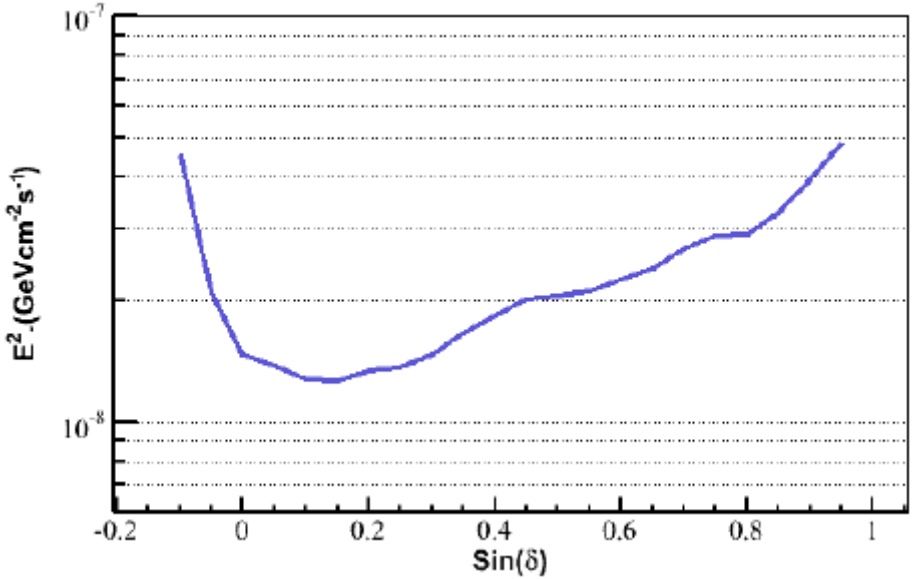




Expected # of obs. events ~0.1 but large fluctuations in neutrino flux possible

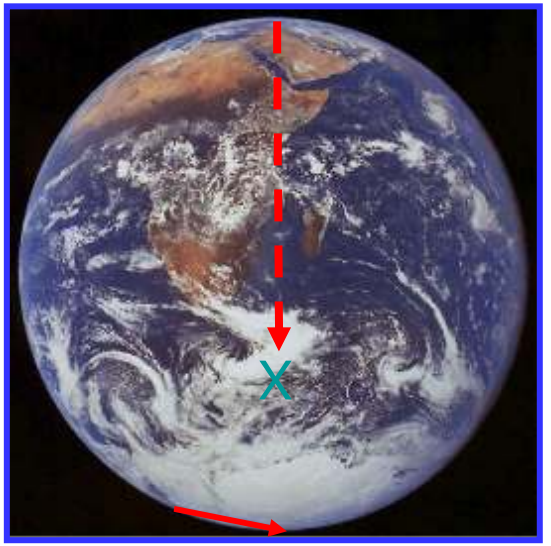
IC22 point source searches

- Two independent analyses
- Much work on optmization
  - Angular resolution ~ 1.5 degrees
    - Resolution is improved by the cuts
- Nearly ready for unblinding
- Expect ~ 20 atmospheric ν events/day
- Expected sensitivity (E-2) ~
  - 5 times better than IC9

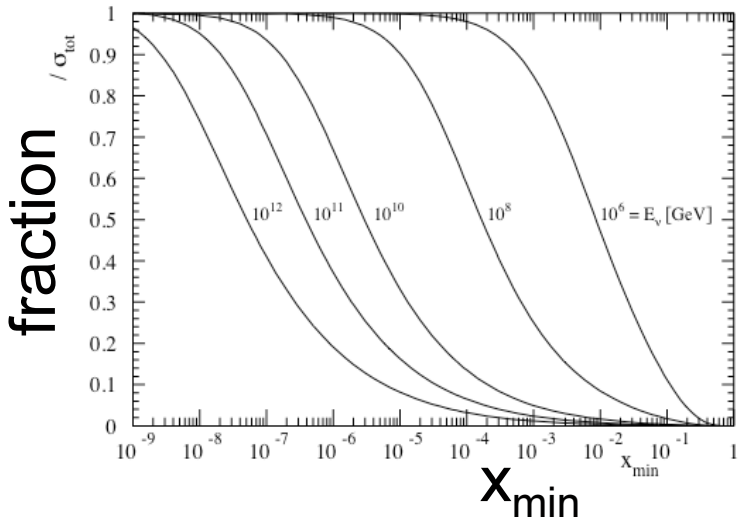


Measuring $\sigma_{\nu N}$ by neutrino absorption in the earth

- The earth becomes opaque to neutrinos with energies > ~ 200 TeV
  - Higher energy ν are horizontal or downward going
- Measure cross section by studying ν flux as f(zenith angle, energy)
  - Measure $\sigma_{\nu N}$ for 100 TeV < E_ν < few PeV
    - Sensitive to weak charge (quarks) to x~ few 10^{-4}



Absorber thickness
Depends on zenith angle



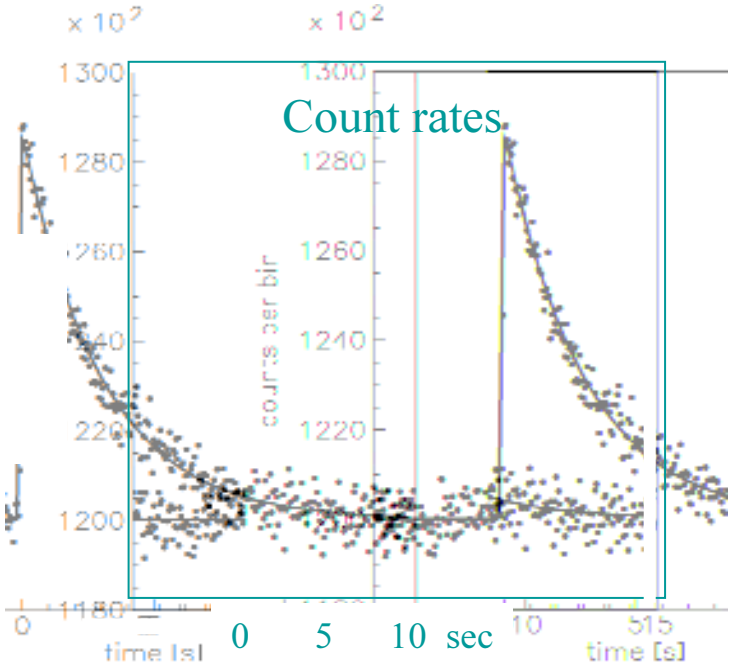
J. Jalilian-Marian, 2004

Supernova Monitor

AMANDA II:
95% of Galaxy

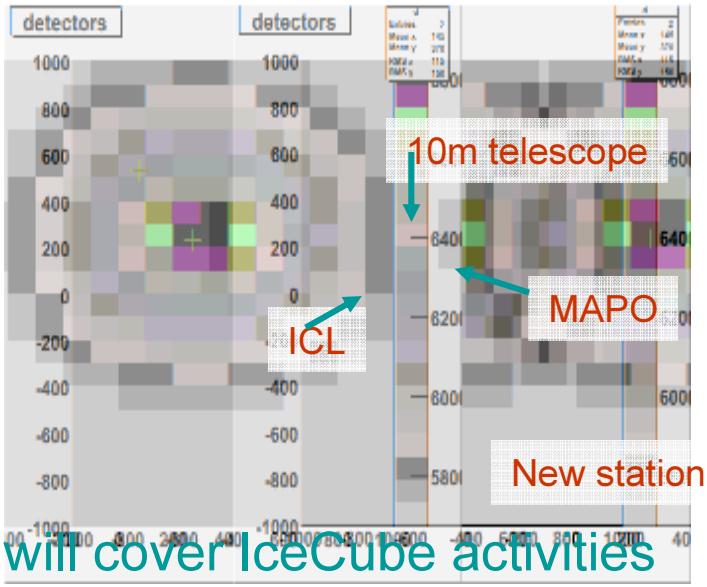
IceCube:
Milky Way + LMC

msec time resolution



Radio ν detection

- 3 “Digital Radio Modules” deployed on IceCube strings
  - Modified DOMs, with 4 radio receivers + 1 transmitter
    - One DRM was transmitter only
  - 2 antenna above, 2 below
- Coincident events observed
  - Timing allows localization
  - 10 m telescope clearly seen
- Discussions about future array configuration, antenna optimization etc. ongoing



Will hear ‘overview’ from Peter Gorham. I will cover IceCube activities

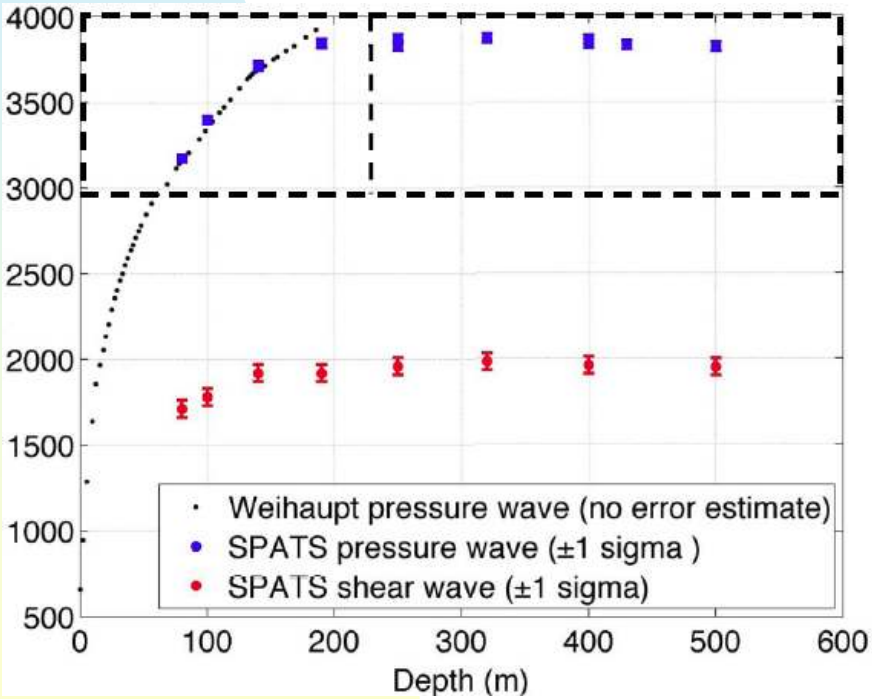
Acoustic ν detection

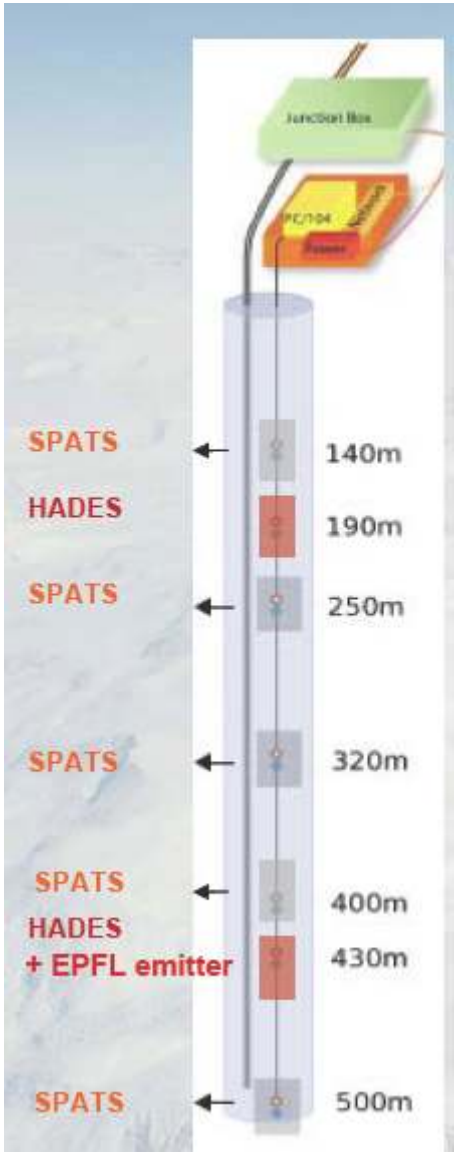
- Hydrophones deployed in 4 IceCube holes
  - Transmitters & receivers
- Pingers deployed in watery holes
- Noise levels are stable
- Attenuation length at least 80 to 300 m, depending on method
  - Many systematics
- Velocity of pressure and shear waves measured
  - Depth dependence follows density dependence
- Working toward a hybrid radio/acoustic/optical detector
- coincident events == gold!

An acoustic test string being deployed in an IceCube hole

Pressure and Shear Waves

- Two distinct transmission methods
- Velocities measured for both
- Depth dependence due to ice density variation in firn





Working toward a hybrid radio/acoustic/optical detector
coincident events == gold!