

# IceCube / IceTop

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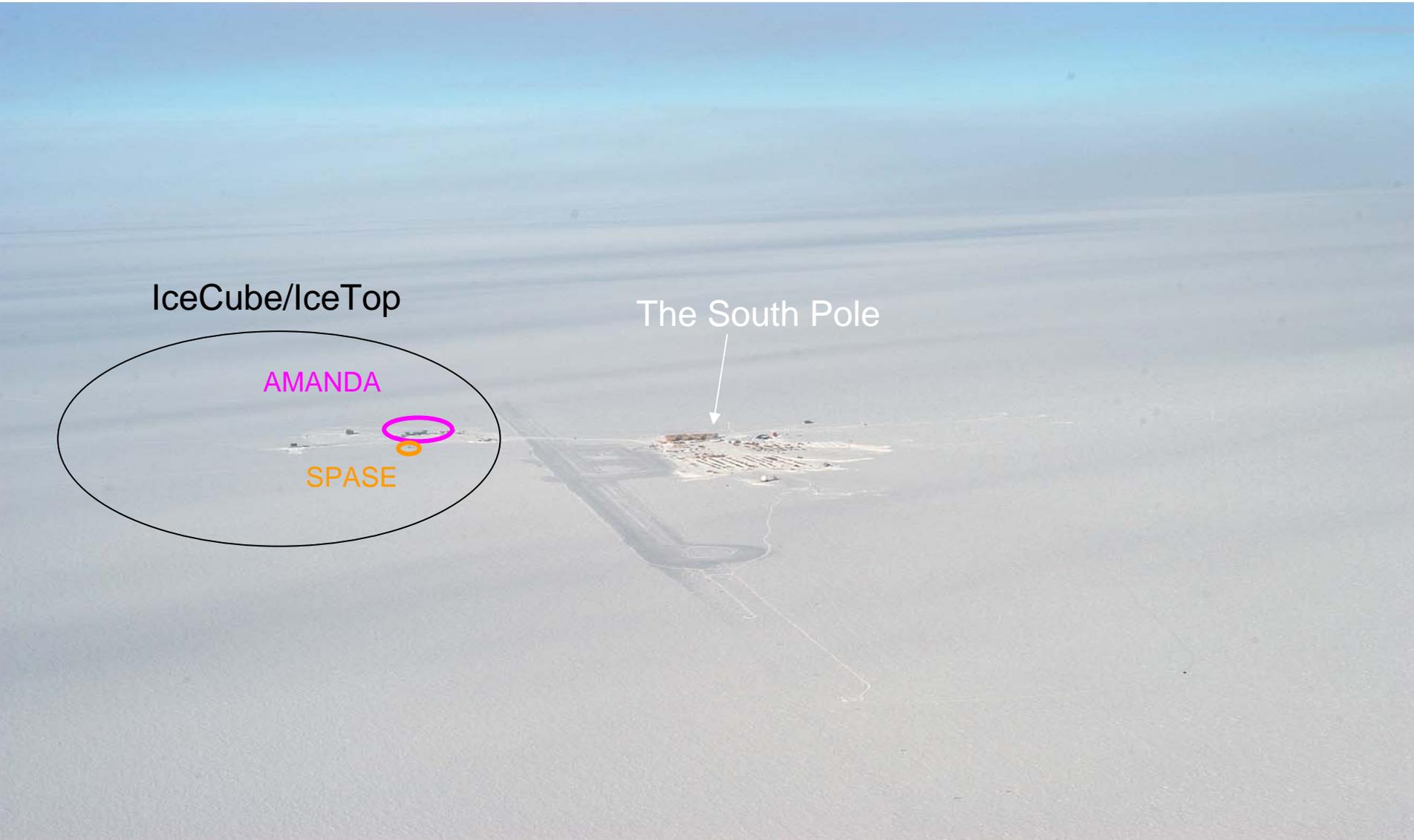
Aspen Cosmic Ray Workshop

April 25-30 2005

# IceCube Project

{ AMANDA  
SPASE  
IceCube Array  
IceTop Array }

@ South Pole



IceCube/iceTop

The South Pole

AMANDA

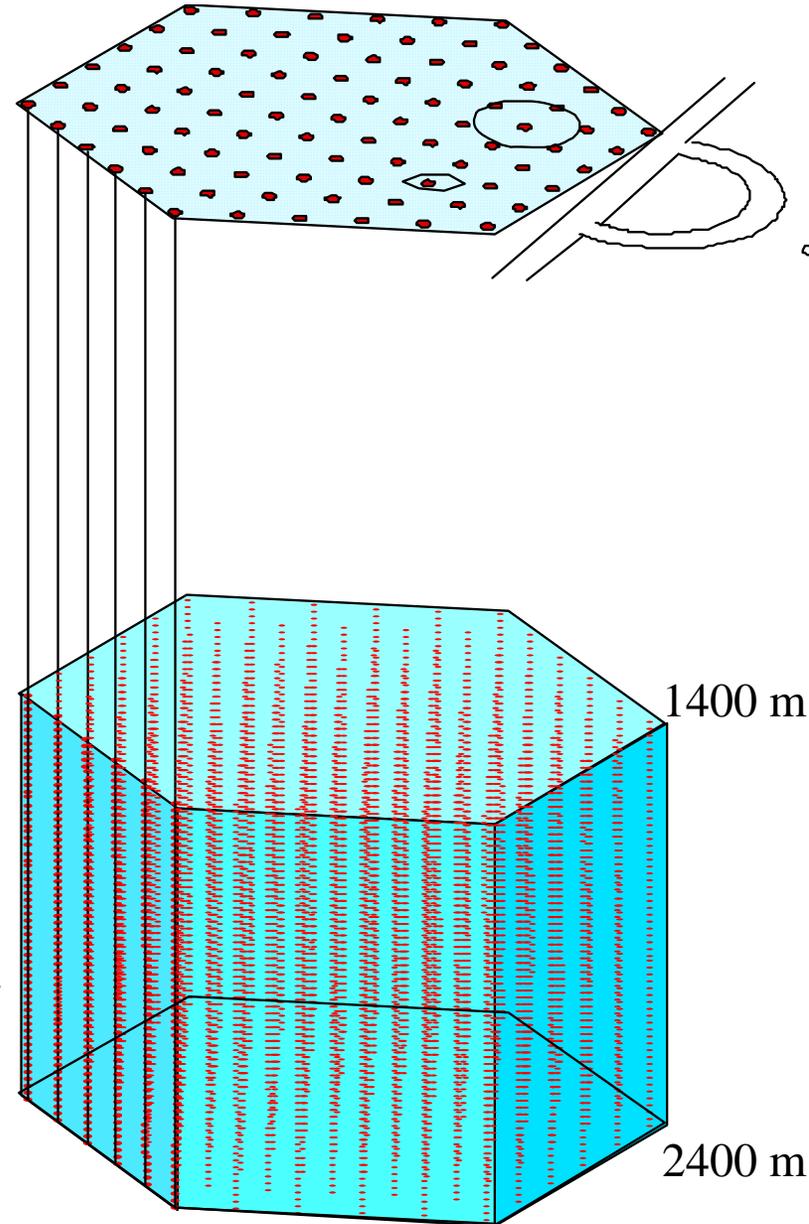
SPASE

# IceTop

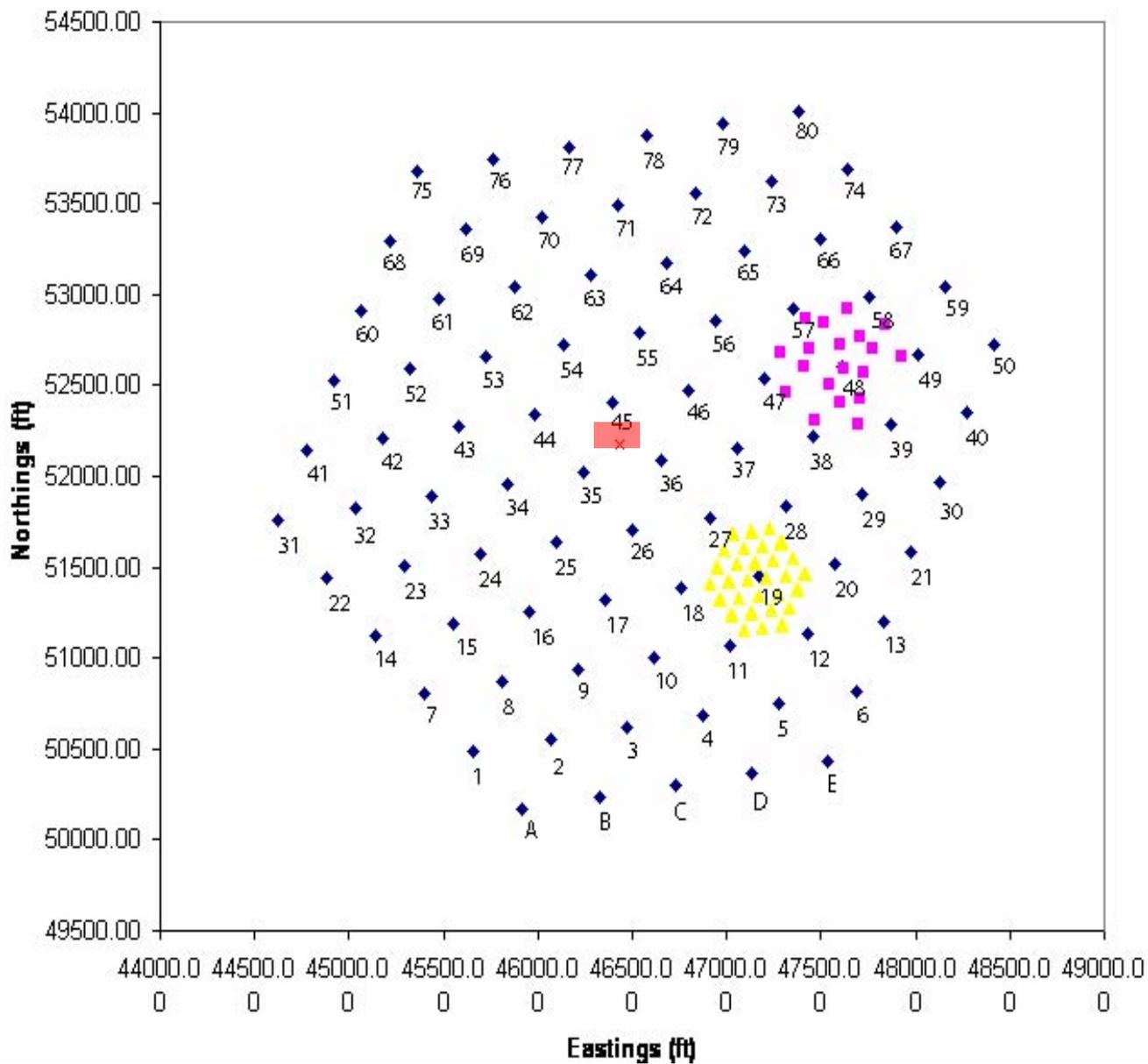
- 1 km<sup>2</sup> Air Shower Array
  - 1 station on top of each IceCube string
  - 2 ice tanks per station
  - 2 PMTs in each tank
- 
- IceTop will detect Air Showers of energies  $3 \times 10^{14}$  eV to  $\sim 10^{18}$  eV

# IceCube

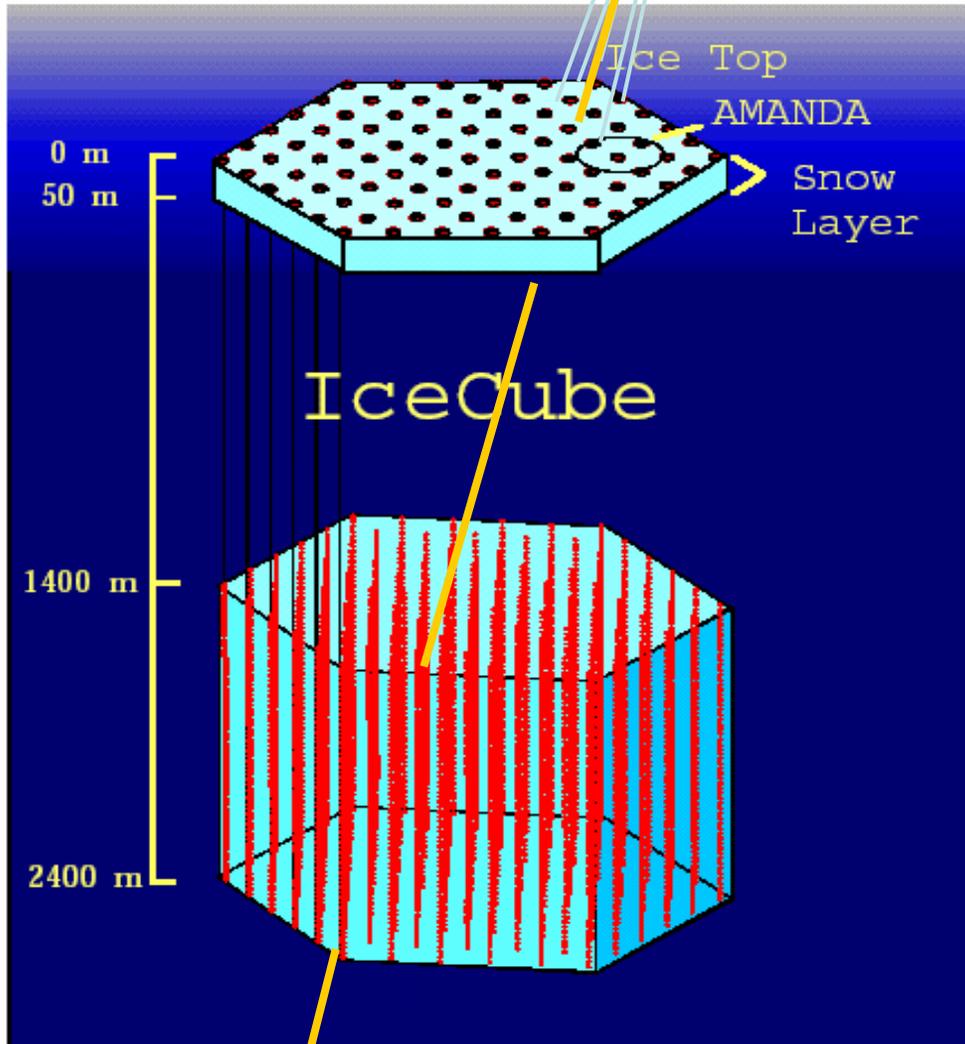
- 1 km<sup>3</sup> High Energy Neutrino Telescope
- 4800 PMTs
- 80 Strings
- IceCube is designed to detect neutrinos of all flavors at energies from  $10^7$  eV to  $10^{20}$  eV



# IceCube String Locations ~ 125m apart



# IceTop: The surface array of IceCube



Surface array is unique opportunity for  $\nu$ -telescope in deep ice

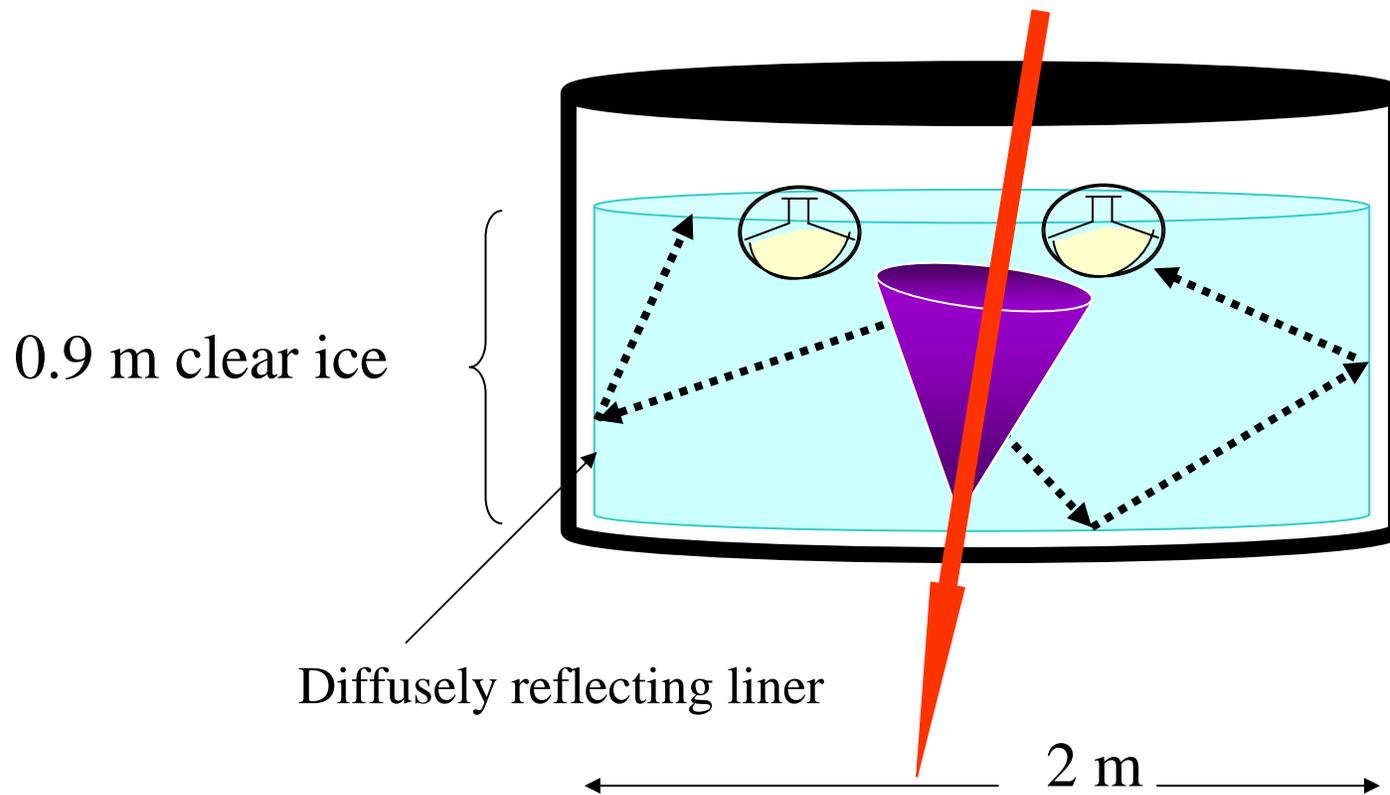
- Calibration
  - Absolute Pointing
  - Angular resolution
- Veto
  - Tagging background for study and rejection

A 3D air shower array for cosmic-ray physics

Demonstrated by SPASE/AMANDA  
But, 5000 x larger acceptance  
wider energy range, better resolution

# IceTop Design

## Ice Cherenkov Tank



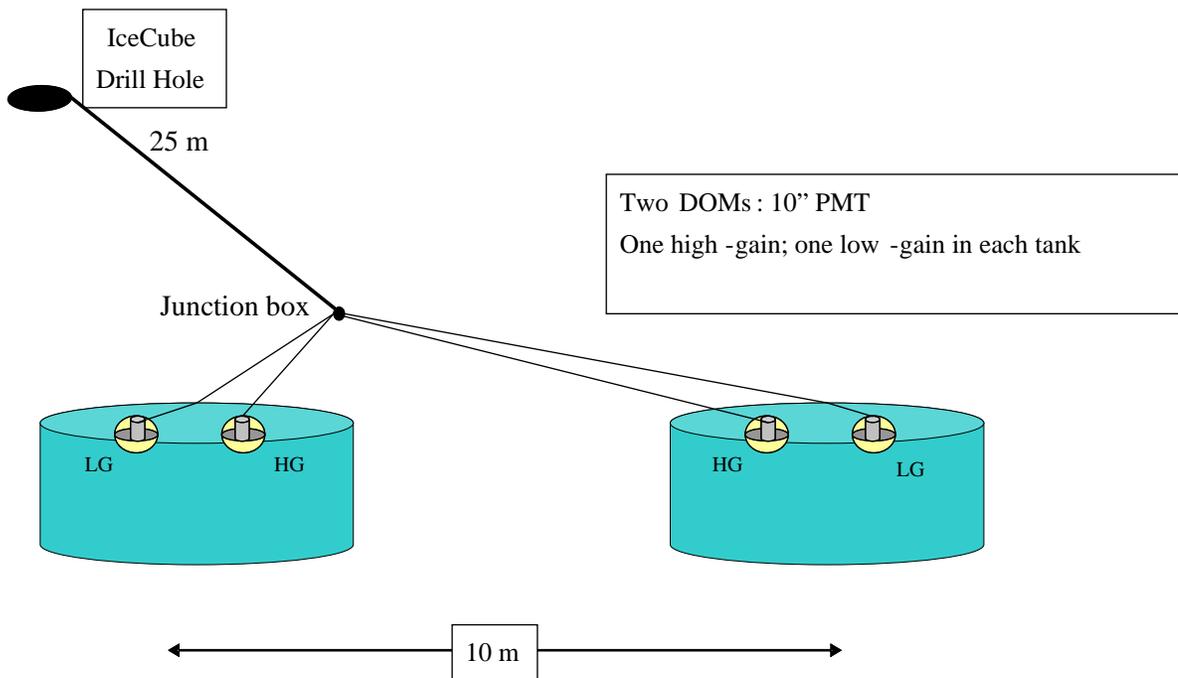
# IceTop Design

- **Single particles (low-energy  $e^\pm$ ,  $\mu$ ,  $\gamma$  for tank calibration)**
  - Remnants of low energy interactions
  - $\sim 2.5$  kHz for 30 MeV threshold (10 pe)
  - Muons deposit 200-300 MeV (70 pe)
- **Small showers (few TeV for tagging single  $\mu$  in deep-ice)**
  - Typical source of  $\mu$  background in deep detector ( $E_\mu \sim 0.5$  TeV initially)
  - 10-20 m footprint on ground
    - Coincidence between two tanks at a station
    - No signal in neighboring stations
    - No IceTop trigger
    - Check each in-ice event for such surface activity
- **Large showers ( $E > 300$  TeV for air showers and muon bundles in deep-ice)**
  - IceTop trigger: 4 stations hit in  $\sim 300$  ns window

# IceTop Design

## IceTop Station

- 2 Ice Tanks 10m apart
- Local coincidence between 2 tanks
- 1 Low Gain, 1 High Gain PMT in each tank for dynamic range



# The Digital Optical Module (DOM)

- 10" PMT in 13" Glass sphere
- Mother Board:
  - 2 ASIC (ATWD) chips to digitize PMT signals in 3.3ns samples
  - FPGA for feature recognition
  - CPUs, disks for communication, calibration, buffering data

- Incredible dynamic range: 1 pe to 25000 pe
- Low photon counting background: in-ice rates of order 700 Hz
- Complete, self-contained, reconfigurable digital data acquisition system
- High-precision timing over vast network of 1000's of sensors to nanosecond scale.



# 04/05 deployment season



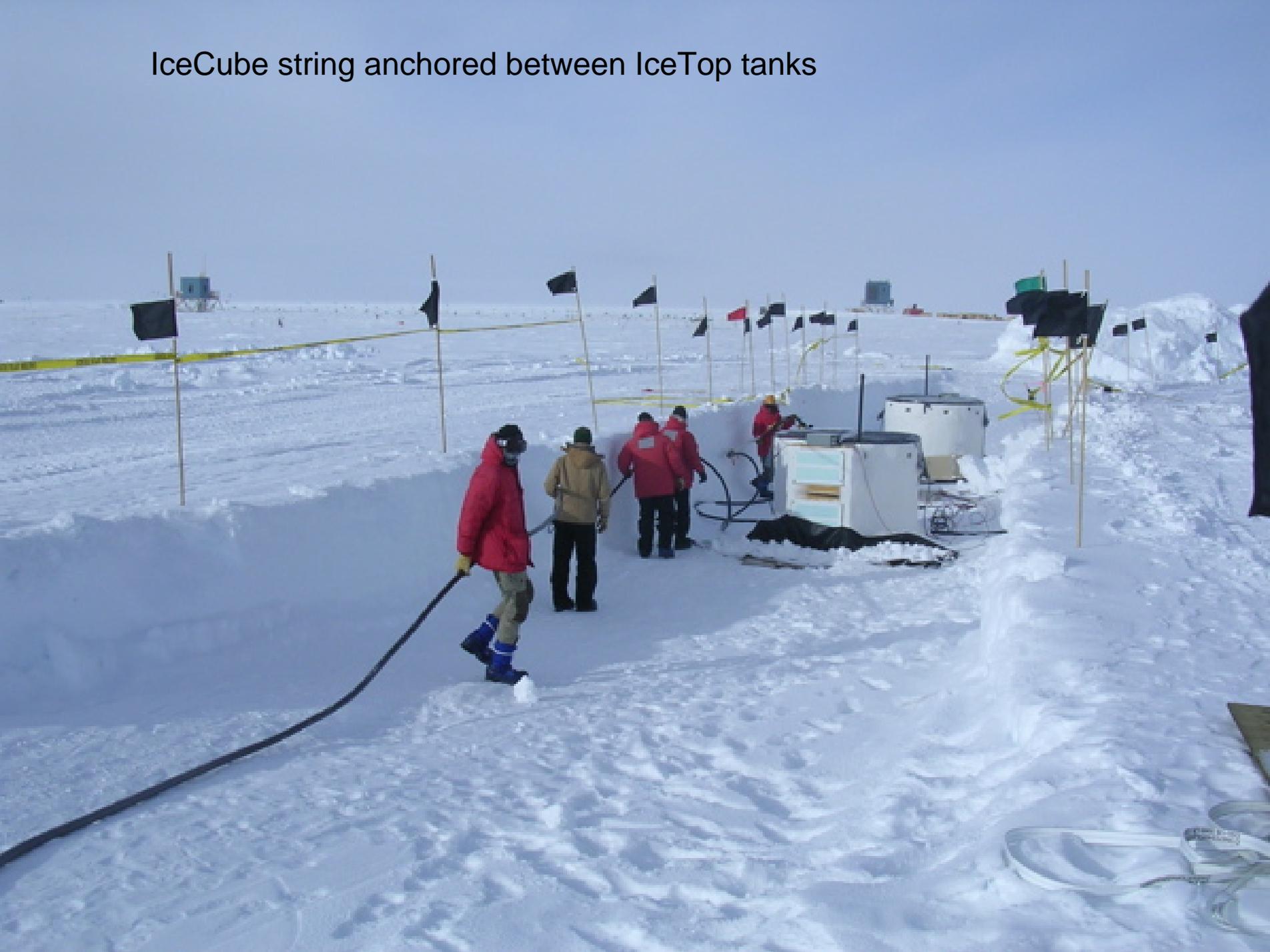
4 IceTop Stations deployed in December 2004  
1st IceCube string deployed on Jan 29 2005

1st IceCube String

60 DOMs 17m apart



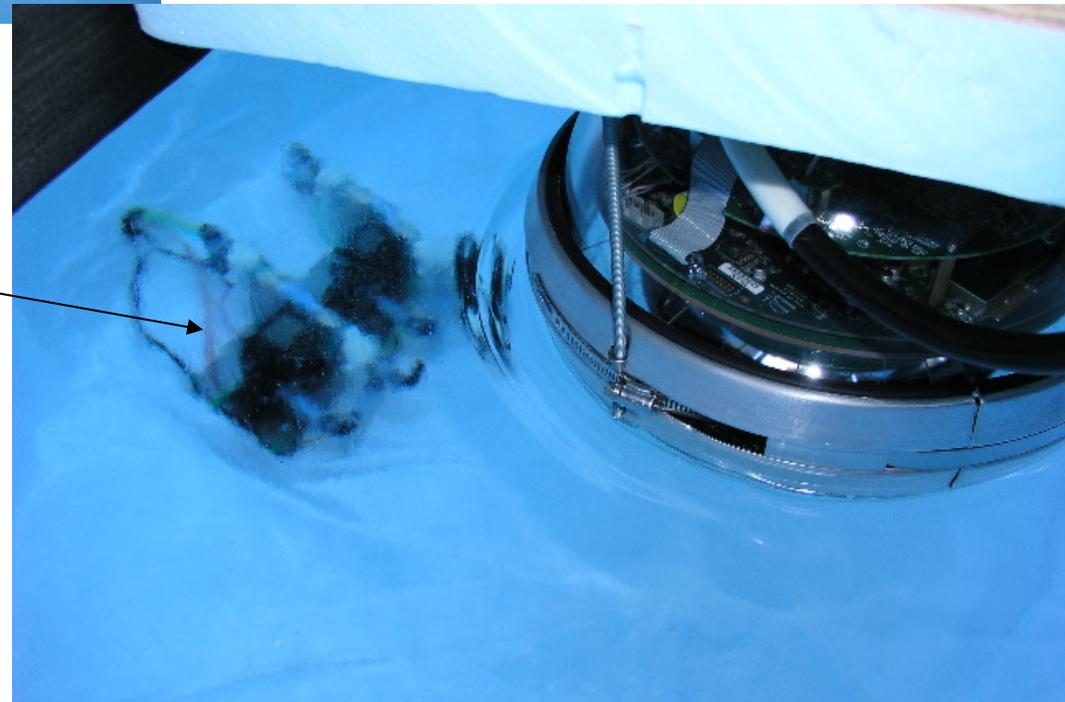
IceCube string anchored between IceTop tanks



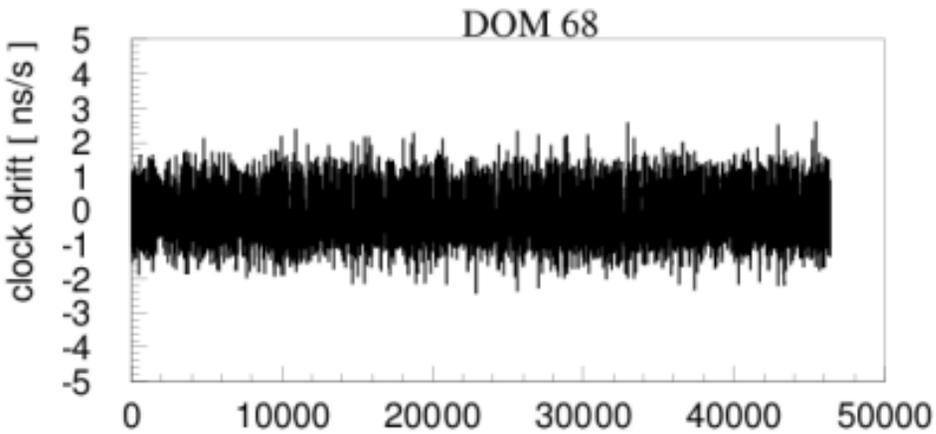


2 DOMs frozen in IceTop Tank

Freeze control unit  
under ~75cm clear ice

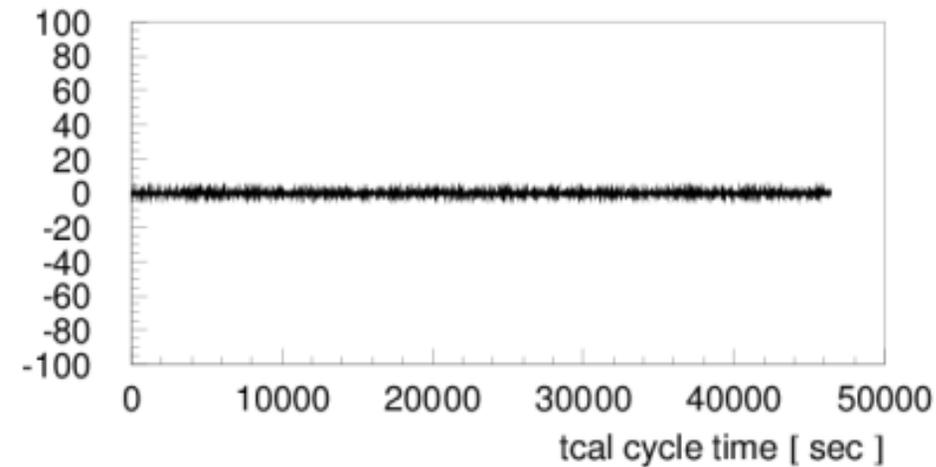


# DOM clock stability (IceTop)



Timing:

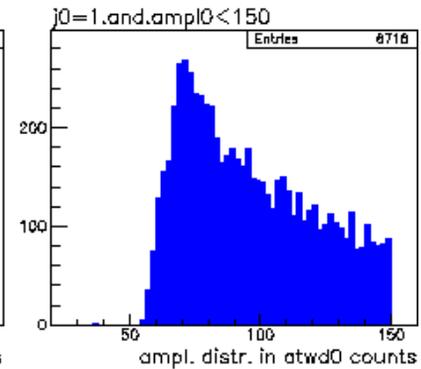
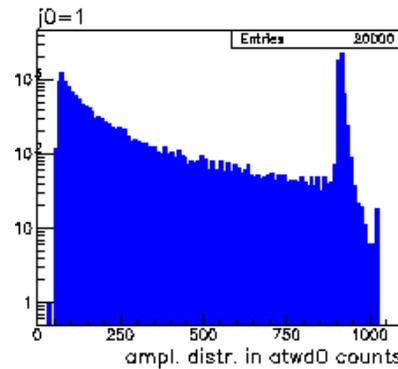
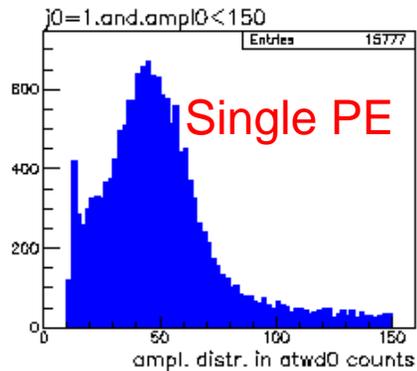
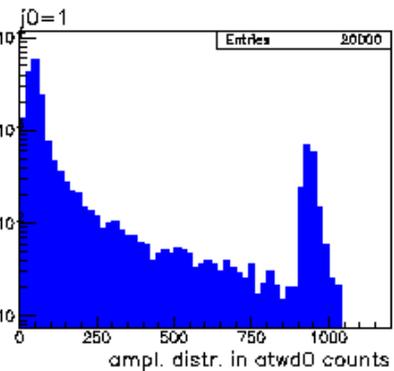
Clock calibration: of order 2 ns rms



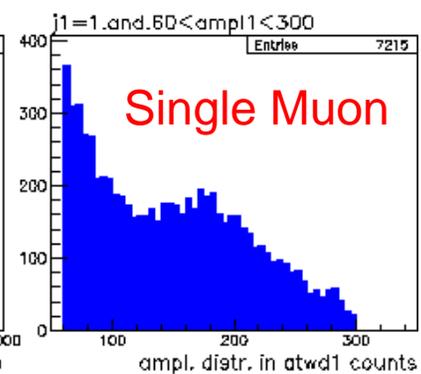
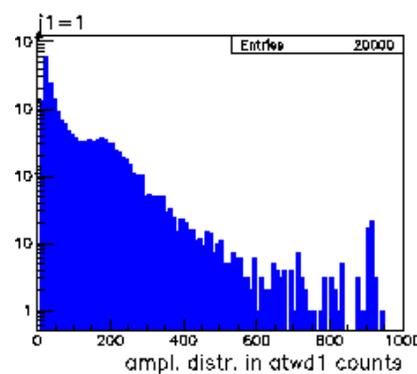
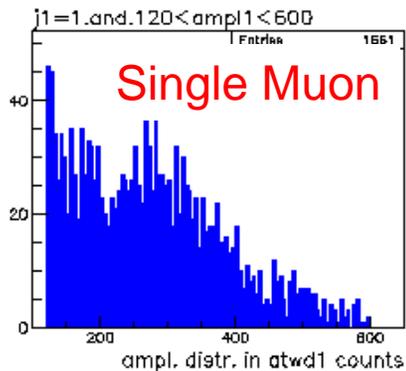
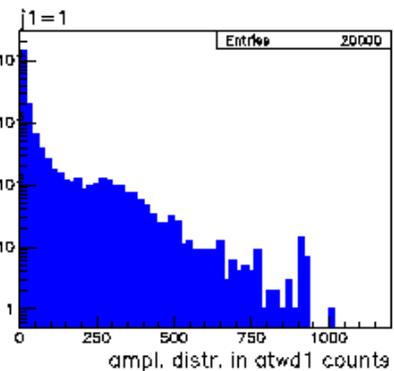
# IceTop DOM Gain Calibration

$1 \times 10^7$  gain, low threshold

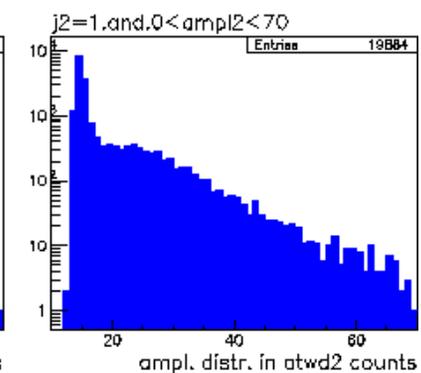
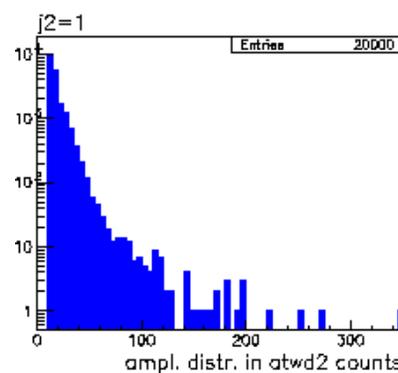
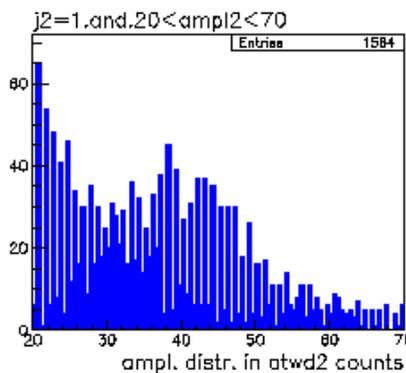
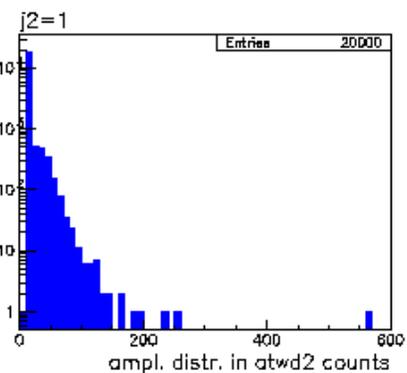
$5 \times 10^6$  gain, high threshold



ATWD  
Channel 0

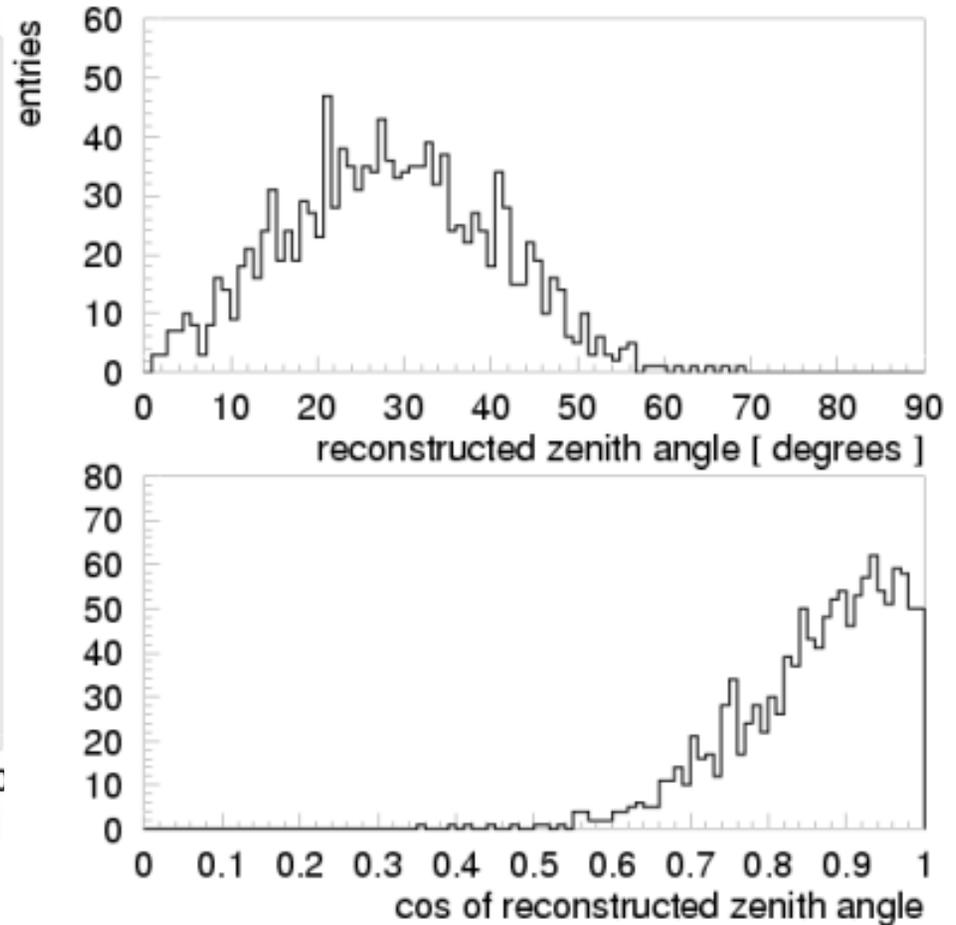
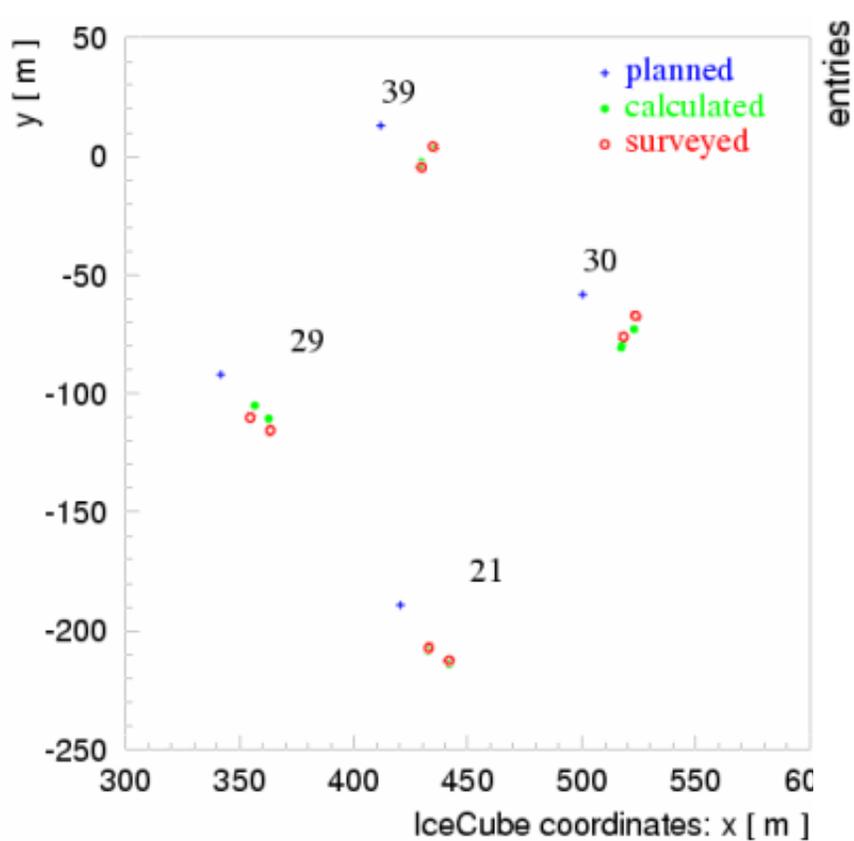


ATWD  
Channel 1



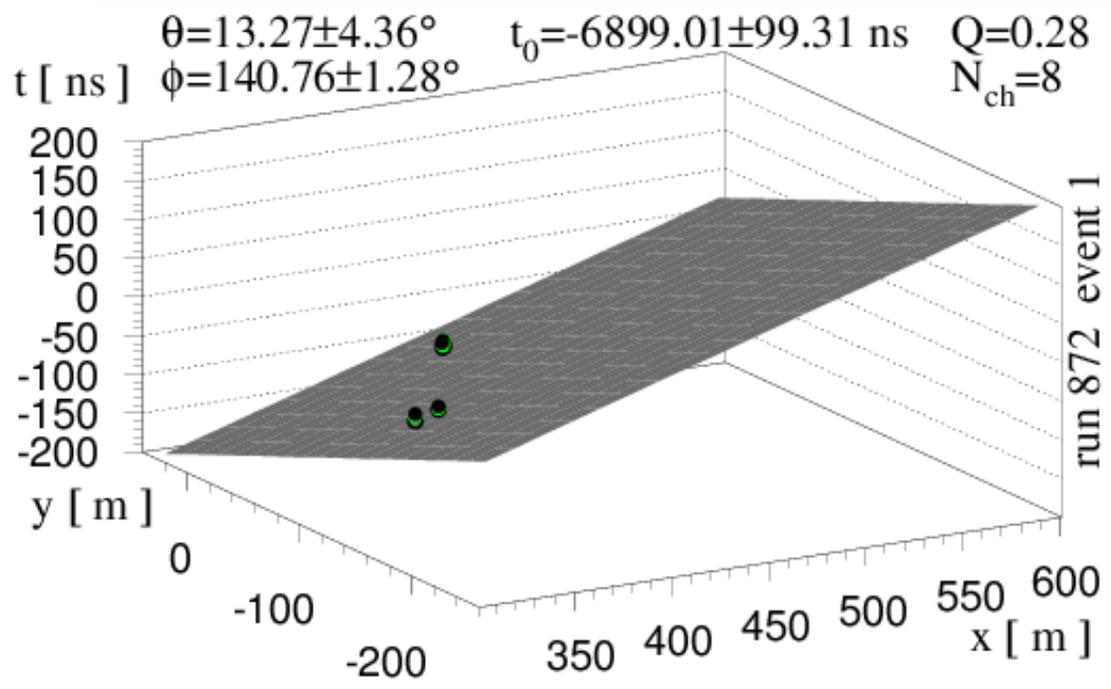
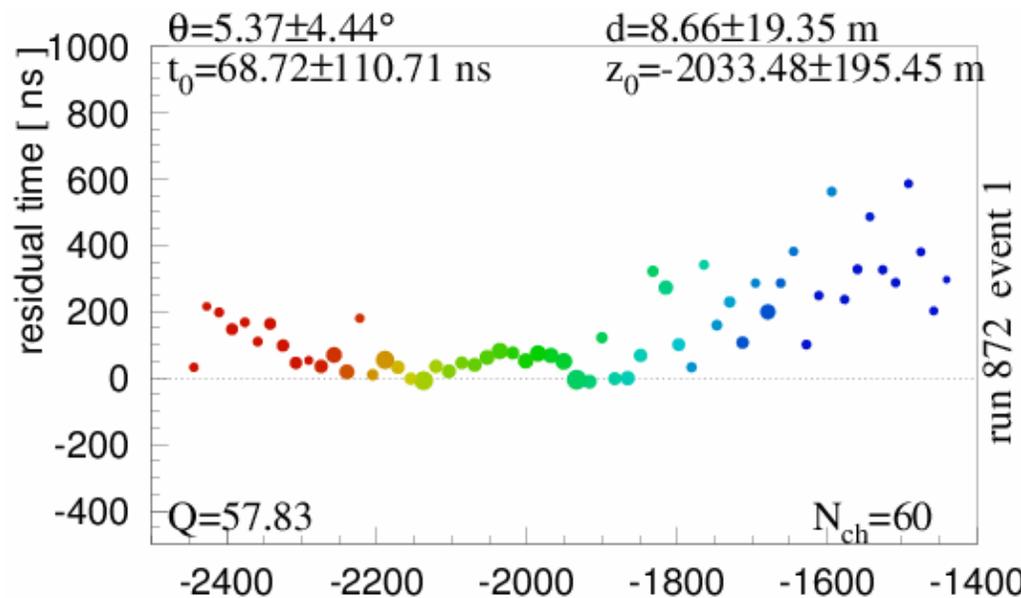
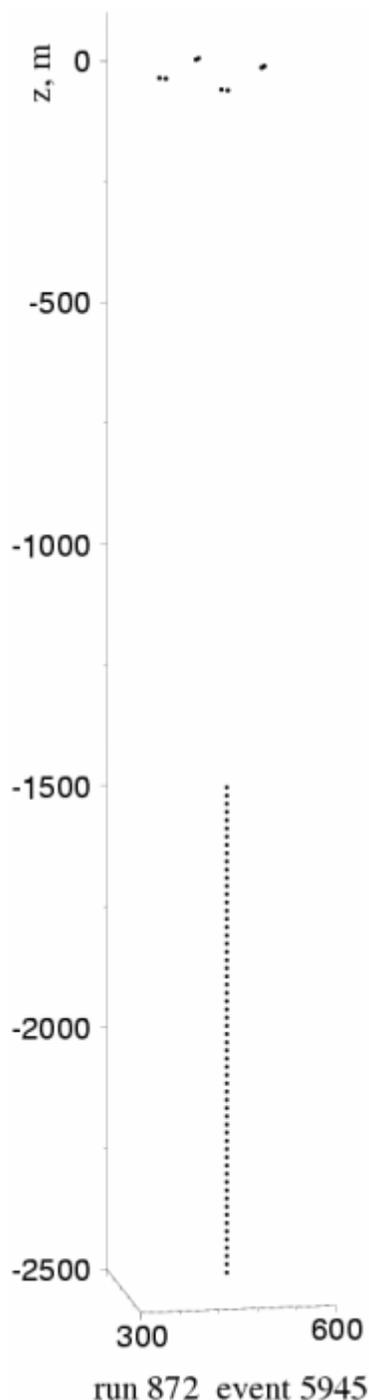
ATWD  
Channel 2

# plane wave shower reconstruction

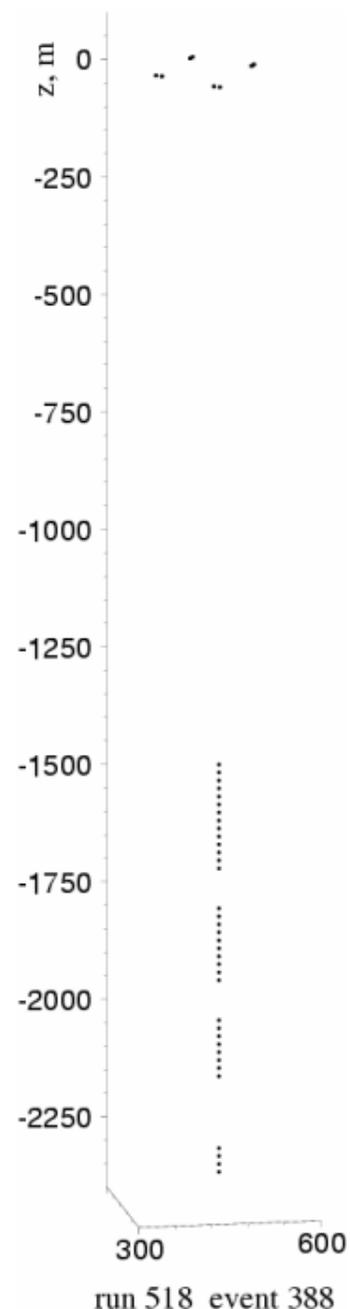
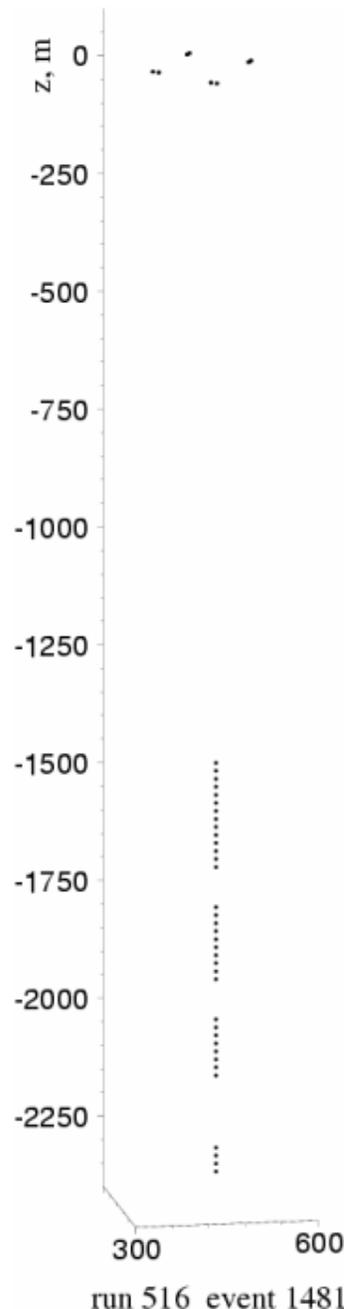
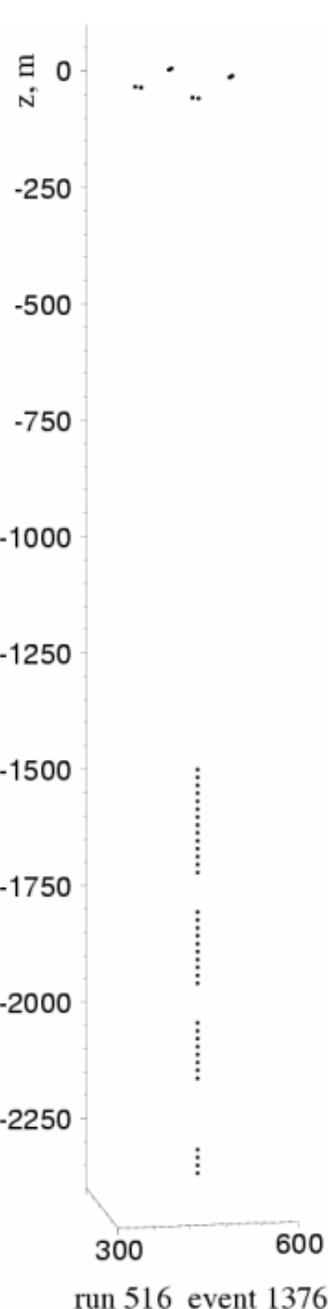




# Run 872 Event 5945



# IceTop – In-Ice coincident events

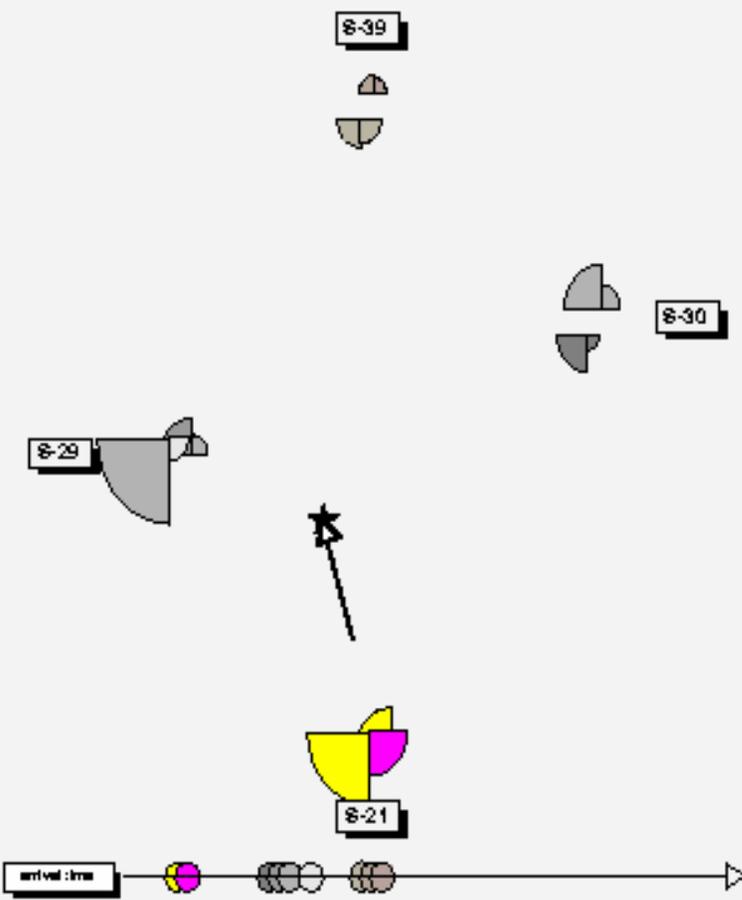


# Sample Event Waveforms

## High gain DOMs

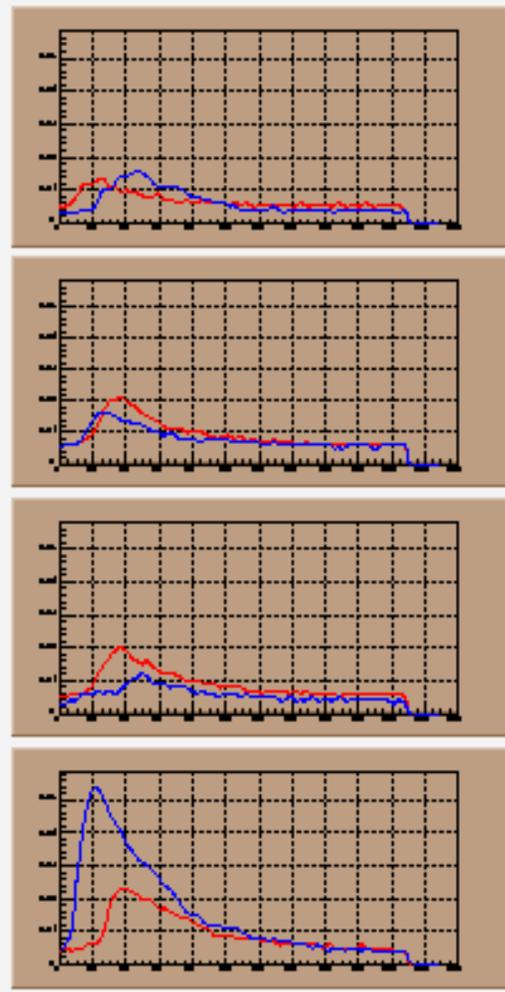
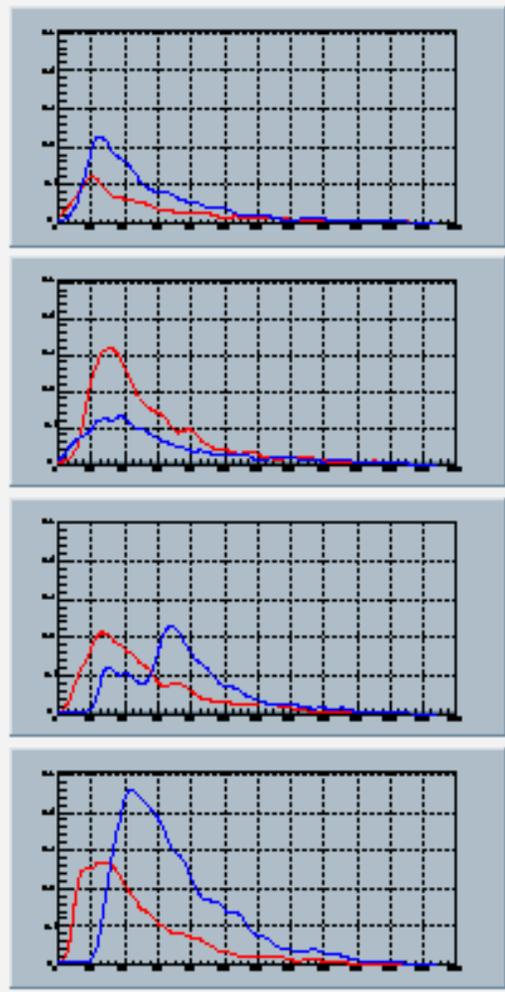
## Low gain DOMs

Theta = 33.82, Phi = 106.7  
GPS 66397639696018611 (0.1ms)



HG\_y\_max = 0.8049 atved\_ch = 1

LG\_y\_max = 0.0583 atved\_ch = 1

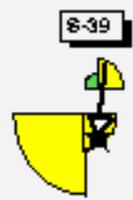


Y axis 0.05 Volts per grid

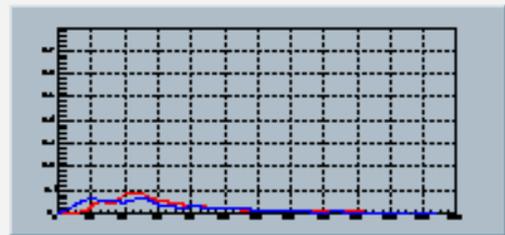
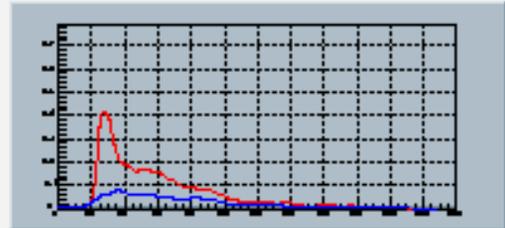
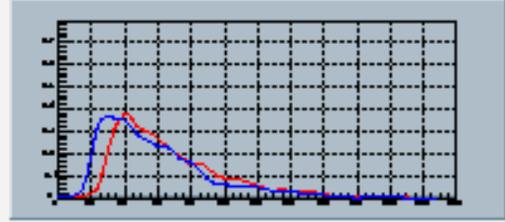
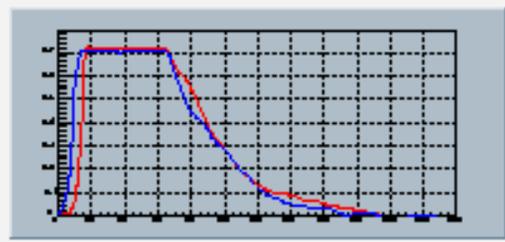
X axis 20ns per grid

# Sample Event Waveforms

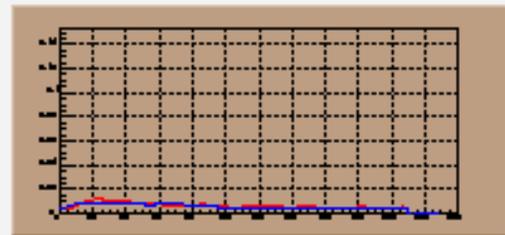
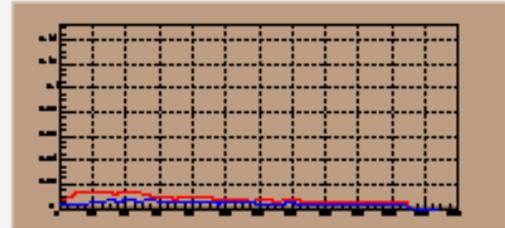
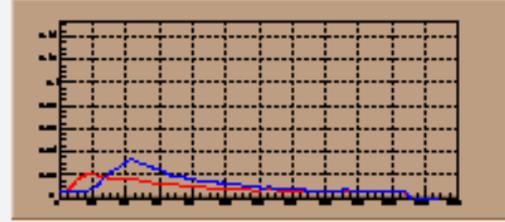
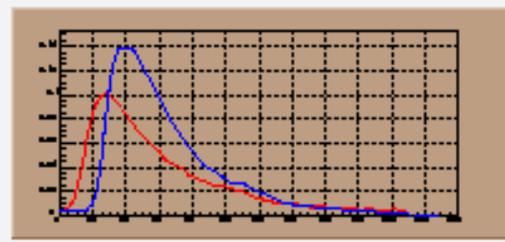
Theta = 19.48, Phi = -98.49  
GPS 86397879 148750956 (0.1ms)



HG\_y\_max = 0.792 atwd\_ch = 1



LG\_y\_max = 0.1529 atwd\_ch = 1



# Sample Event Waveforms

Theta = 37.89, Phi = -25.14

GPS 66397198935208317 (0.1ms)

S-39



S-29



S-30



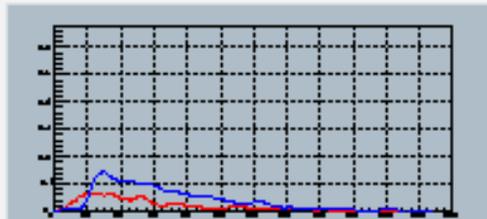
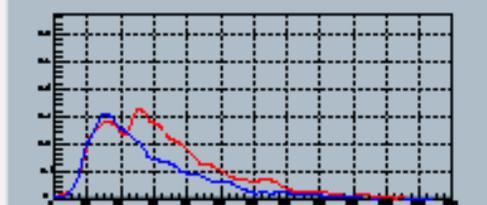
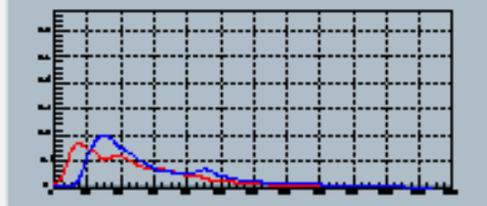
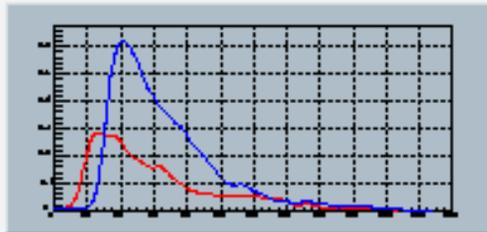
S-21



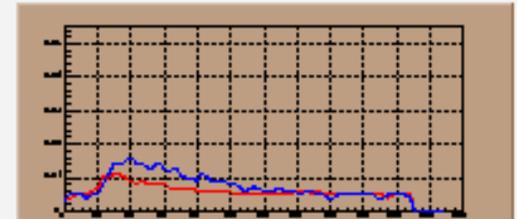
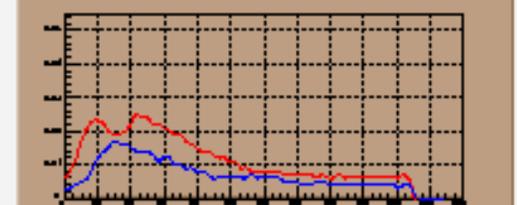
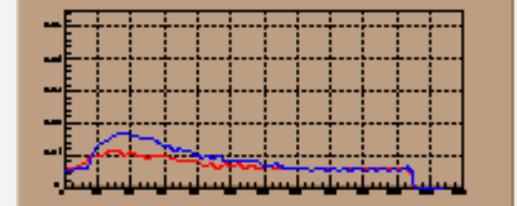
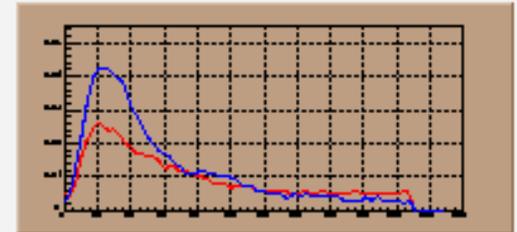
arrived : time



HG\_y\_max = 0.6734 atwd\_ch = 1

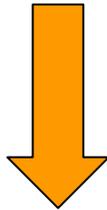


LG\_y\_max = 0.055 atwd\_ch = 1



## IceTop Timeline

Austral Season	04/05	05/06	06/07	07/08	08/09	09/10
# of stations	4	12	16	18	18	12



Successful engineering year

- All 76 (60 IceCube + 16 IceTop) DOMs are working
- Excellent timing precision is achieved
- Detailed waveforms bring extra dimension to analysis

