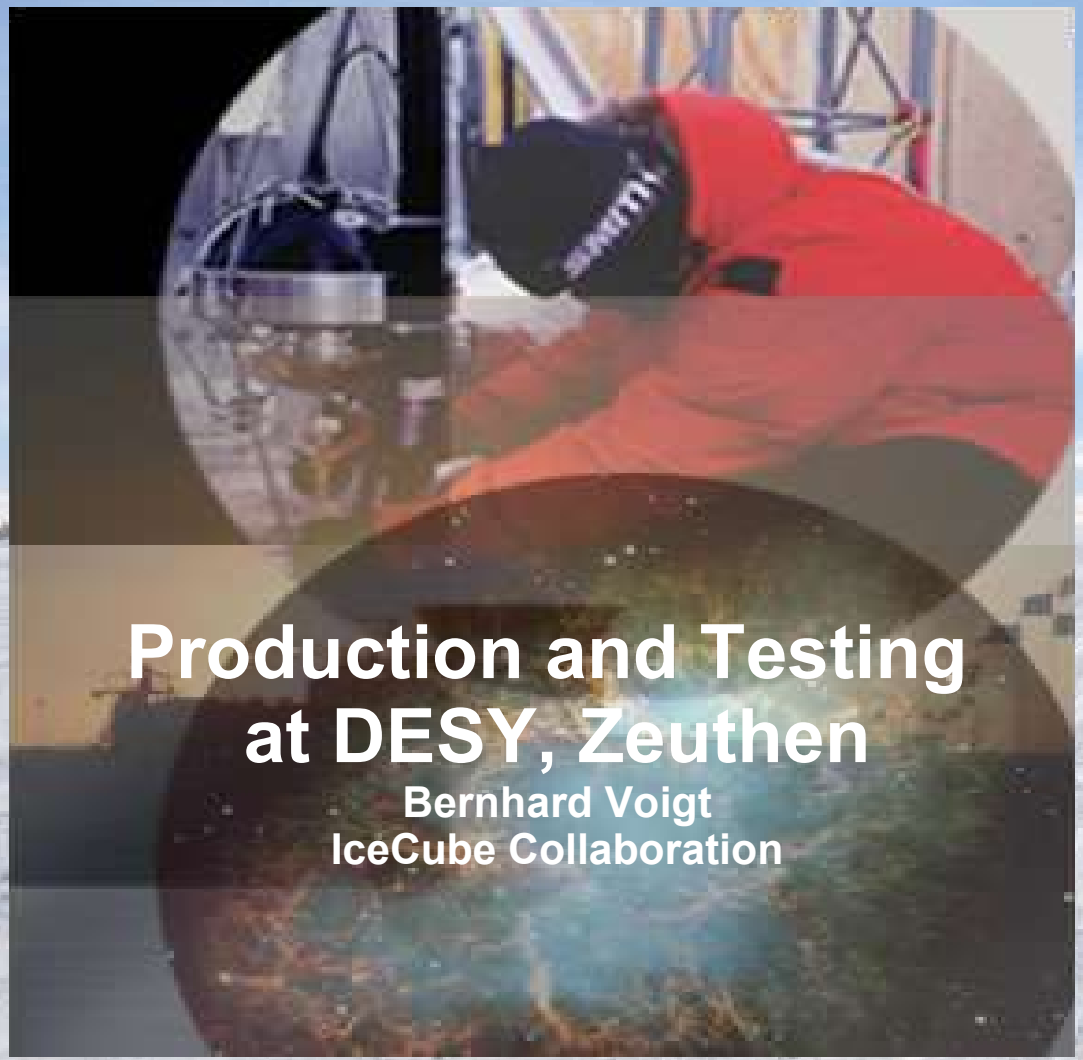
The IceCube Integrated Digital Optical Module (DOM)

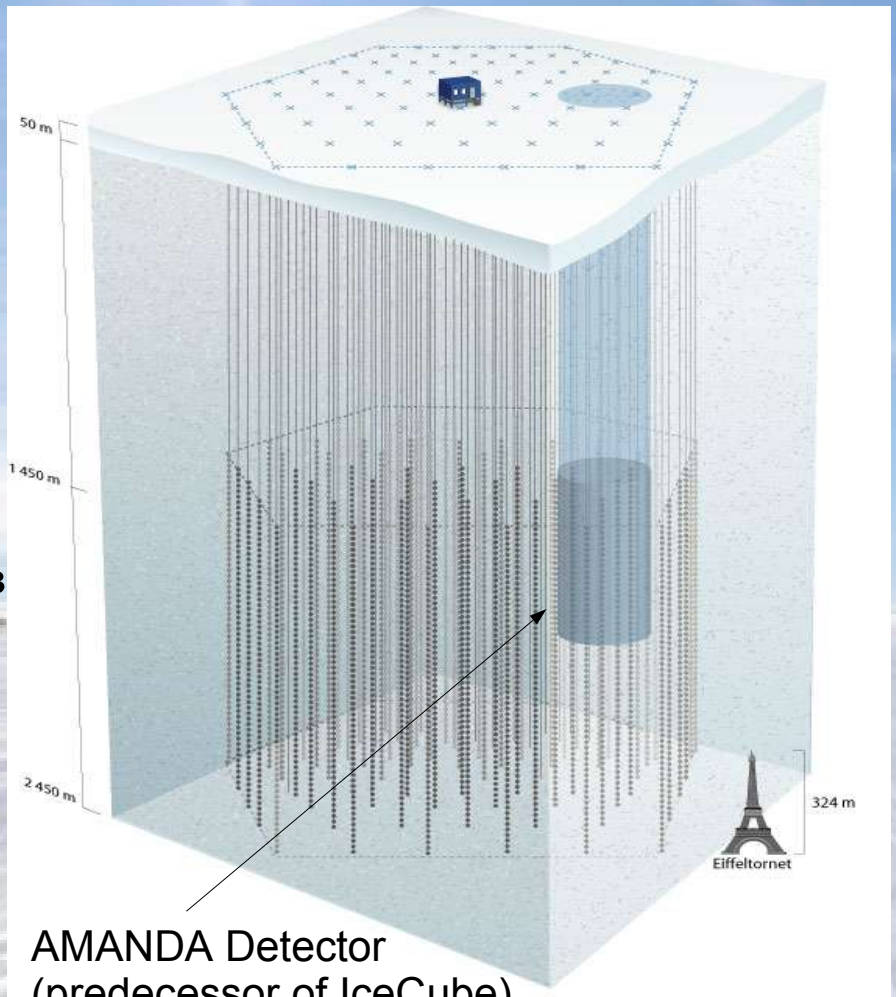


Production and Testing at DESY, Zeuthen

Bernhard Voigt
IceCube Collaboration

The IceCube Project

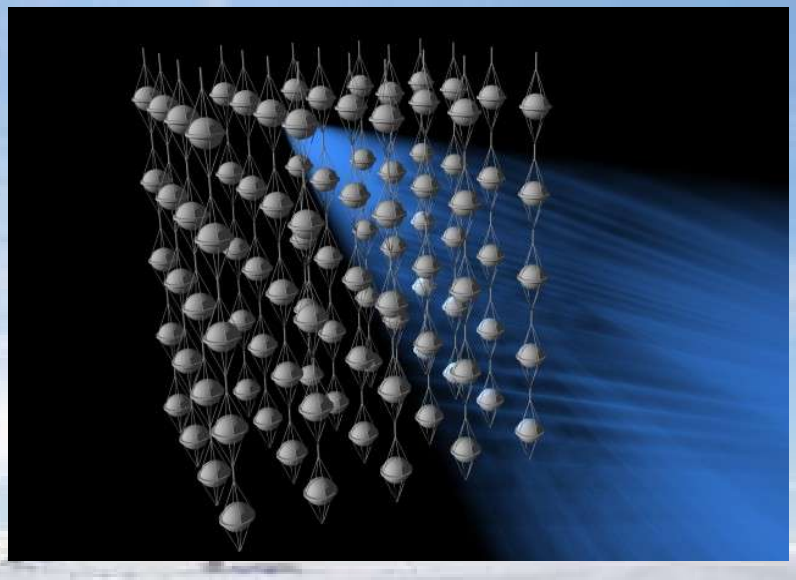
- High energy neutrino telescope located at the South Pole
- International collaboration
  - Belgium, Germany, Great Britain, Japan, Netherlands, New Zealand, Sweden, USA
- Antarctic ice as detection volume
- The effective volume is about 1 km³
- Construction started – first string deployed in January
- Instrumentation completed in 2010
- Physics motivation e.g.:
  - Search for sources of high energetic neutrinos and cosmic rays
  - Search for Dark Matter
  - Supernovae monitor

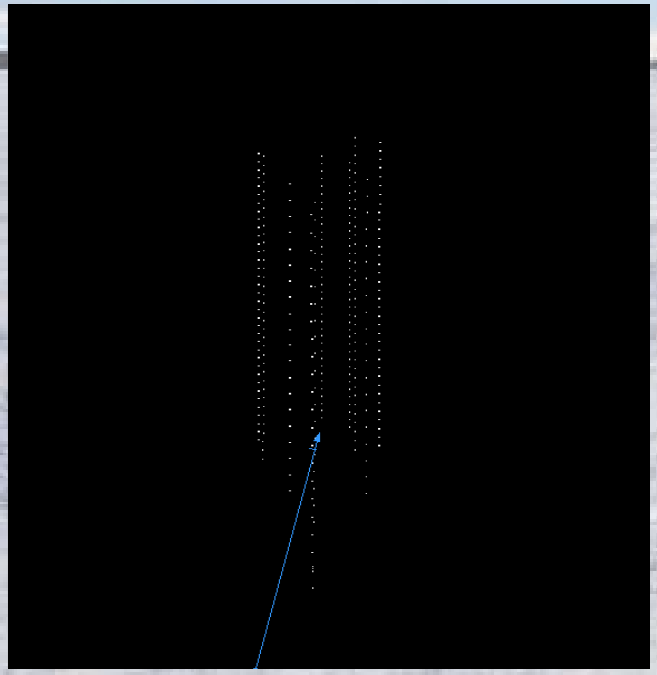


AMANDA Detector
(predecessor of IceCube)

The Detection Principle

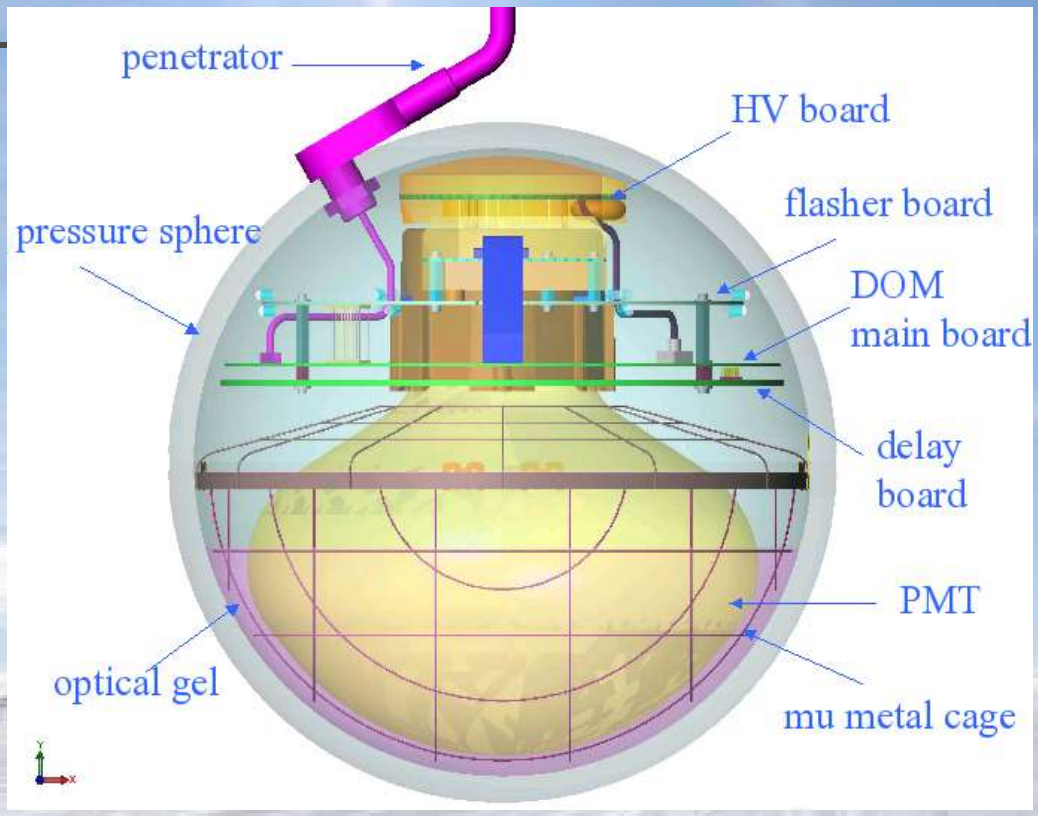
- Neutrino interaction in the antarctic ice produces charged particles, e.g. muons
- Čerenkov radiation for $v_\mu > c_{Eis}$ can be detected with photomultipliers



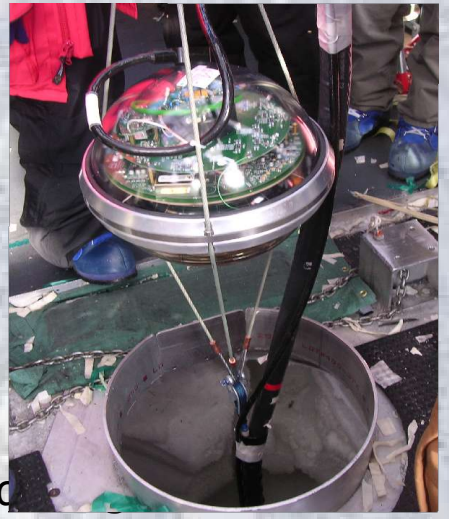


- Arrival time of the Čerenkov light allows reconstruction of the incident neutrino direction
- Light intensity provides additional information about the energy of the neutrino

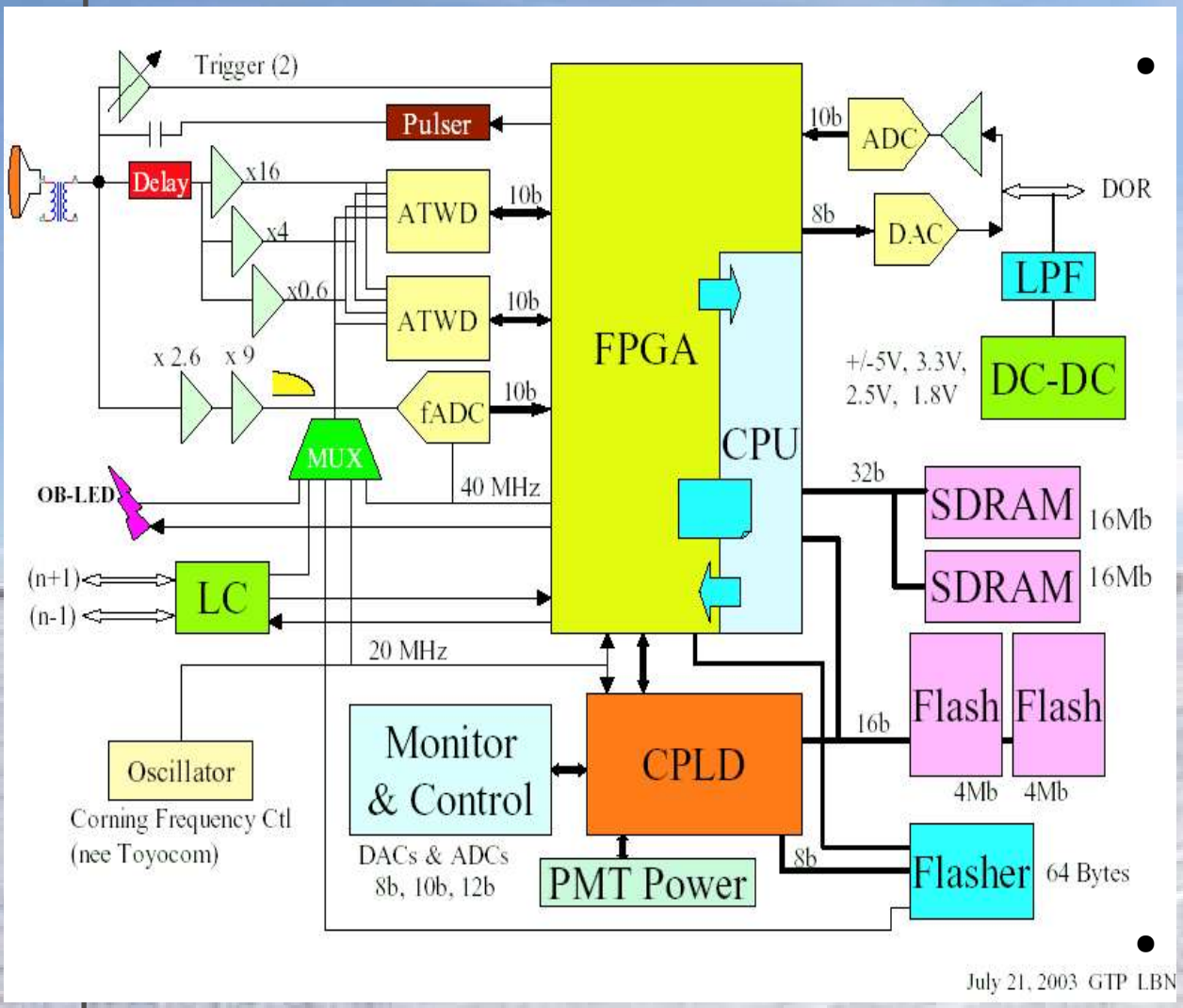
The Digital Optical Module



- Stand-alone Čerenkov light detector
  - 10-inch Photomultiplier
  - High voltage generator
  - In situ data acquisition circuits
  - Flasher board for calibration/testing – light signals to neighboring DOMs
  - Metal cage shields magnetic field of the earth
  - Transparent gel for optical coupling and mechanical protection
- Connection to the surface via one twister pair copper cable
- In ice a total of 4200 Digital Optical Modules (DOM)
  - 60 DOMs are grouped on a string
  - vertical spacing 17m; string spacing 125m
- Surface cosmic ray shower array (IceTop)



DOM Electronic Circuit (Schematic)

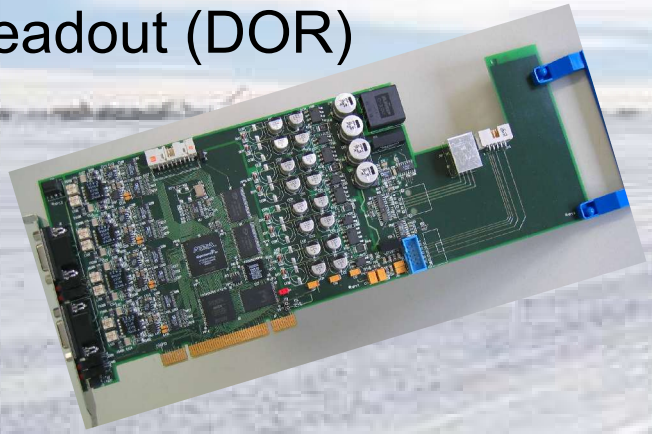


- Front end electronics:
  - High speed sampling
    - 2 Analog Transient Waveform Digitizer (up to 300MHz sampling rate)
    - Flash ADC
  - Different amplification channels (wide signal range)
  - Additional multipurpose channel (diagnostics)
  - Electronic pulser for calibration
  - Tunable discriminator
- Oscillator with high stability (0.5ns/s drift)

- FPGA and CPLD allows reprogrammable logic circuits
- CPU and RAM for communication, DAQ, compression, calibration

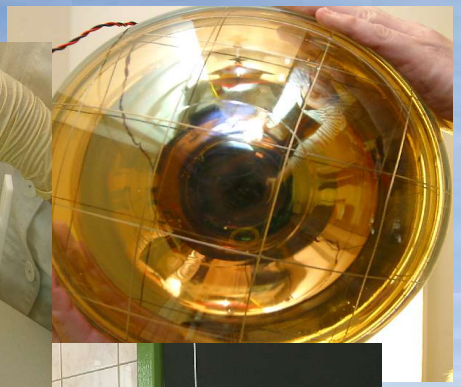
Surface Data Aquistion

- Standard server computer as string processor (domhub)
  - Integrated power supply (96V)
  - Controls up to 64 DOMs
- Custom made PCI PC card (developed in Zeuthen) – Digital Optical Readout (DOR)



- Linux driver provides a high level communication interface
- DOM – DOR communication is package based protocol

DOM Production at DESY



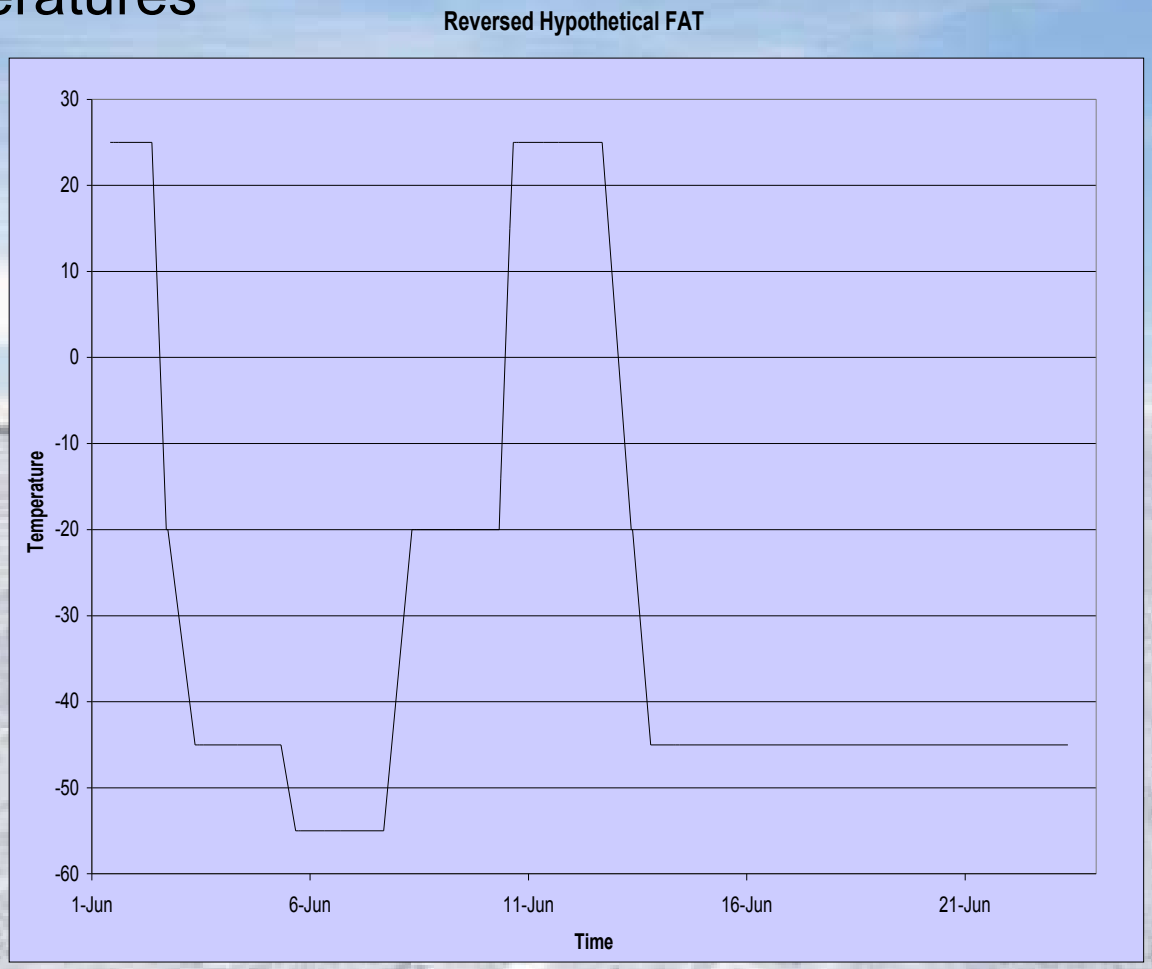
- Production of 1300 Optical Modules within the next 4 years
- Production comprises:
  - Gel mixing, filling and potting PMTs
  - Collar mounting and assembly of electronic components
  - Sealing of DOMs at low pressure
  - Harness DOM with suspension
- Finally pack DOMs and ship them to the pole

DOM Testing

- Electronic and optical requirements
  - Reboot- and communication over a wide temperature range from +20°C to -45°C
  - Single photo electron detection
  - Wide dynamic signal range – capable to handle large light pulses with up to several 1000 photo electrons per microsecond
  - Time resolution better than 5ns for single photo electron pulses
  - High voltage calibration of the PMT better than 5%
  - Optical sensitivity within low variations for different DOMs
  - Dark noise rates less than 1kHz in ice

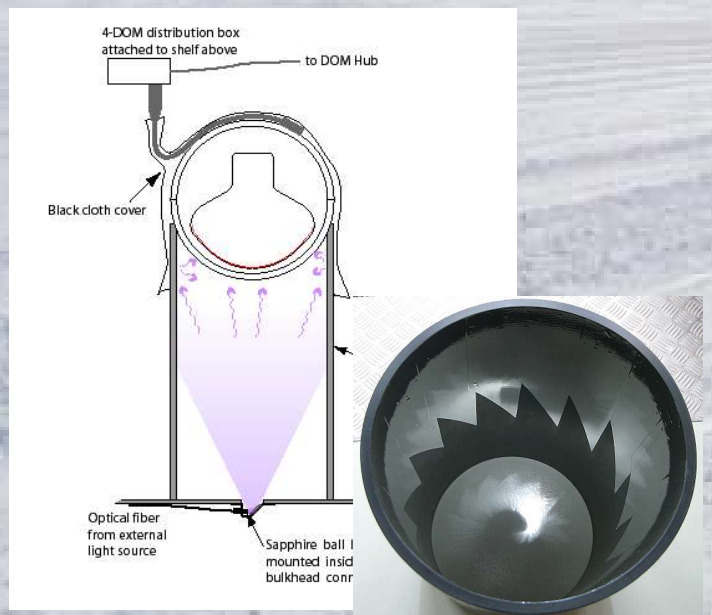
DOM Final Acceptance Test (FAT)

- A full set of different tests is performed for defined temperatures
  - Test of the electronics (mainly running diagnostic programs, checking the hardware components)
  - PMT high voltage calibration
  - Rate monitoring while DOMs are illuminated with light of different wavelength
  - Dark rate monitoring
  - Data taking with a DAQ system similar to the final low level south pole DAQ (Linearity and time resolution tests)



Dark Freezer Lab

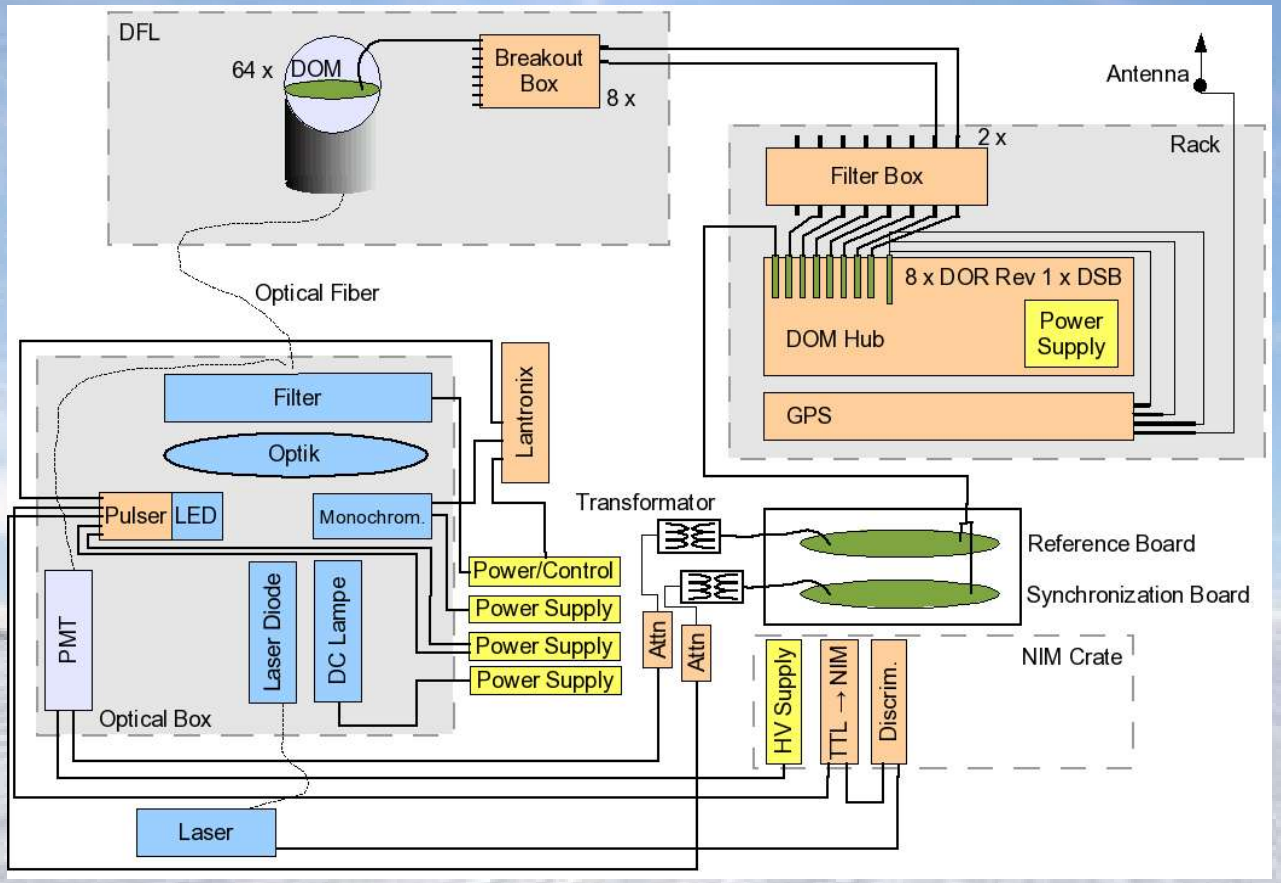
- Large cooling chamber (4 x 6 x 2 m)
- Temperature control with cooling aggregate and heaters
- Minimal temperature for test cycle is -45°C (in the US -55°C for IceTop DOMs)
- Optical fibers and mirror system installed on each test station



- DOMs sit on top of cylindric cans
- Cans are taped with aluminum foil to distribute the light
- DOMs are covered with black plastic bags to keep them as dark as possible for the measurements

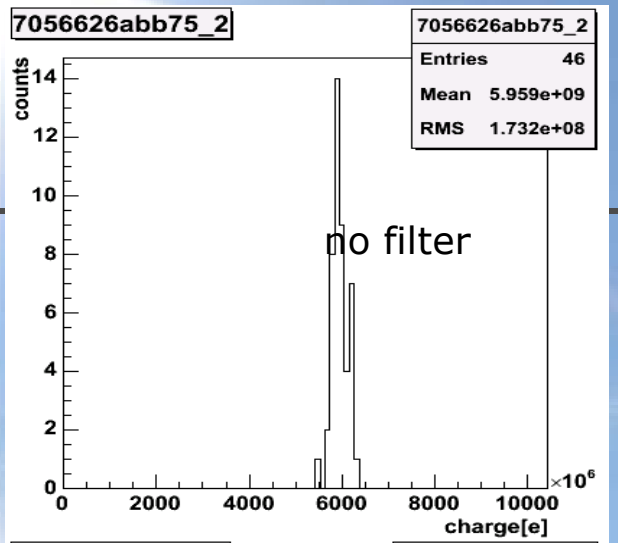
Test Environment Setup

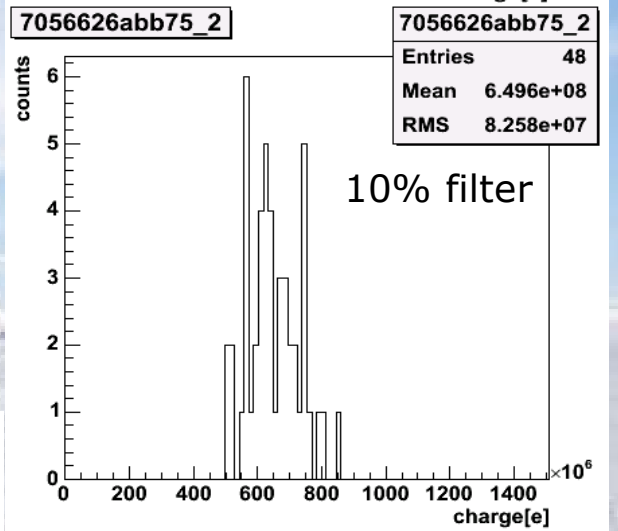
- Dark Freezer Lab (DFL) with 64 test stations
- Same DAQ and wiring as for the South Pole system
- Simulated cable length (up to 3km)
- Light system allows simulation of events
- Different light sources:
  - Laser for time calibration, pulsed LED for linearity test, DC lamp with monochromator for optical sensitivity test
- Light is distributed equally to the DOM stations via optical fibers
- Time synchronization of multiple domhubs with a global GPS clock

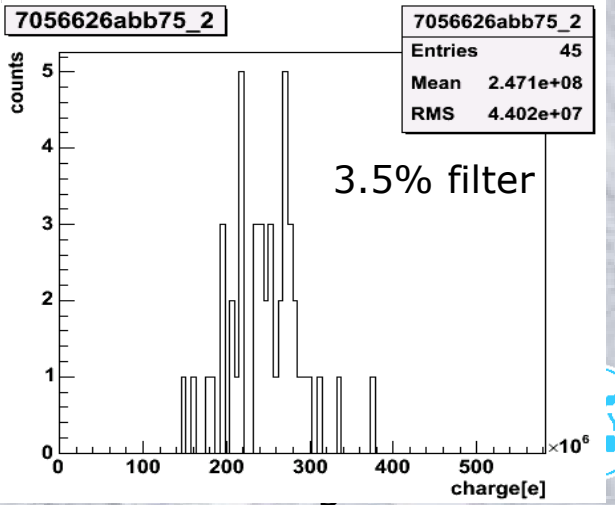


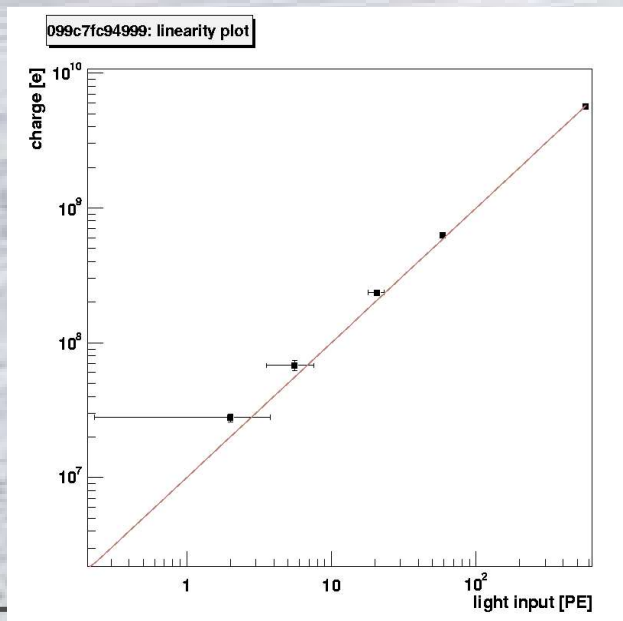
Linearity

- DOMs are illuminated with different light intensities
  - using a pulsed LED with different power settings
  - different filters are brought into the light path to attenuate the amount of light
- Plots show the charge distribution for different filter settings (low to high attenuation)
- Plotting the mean charge versus light intensity gives the linearity characteristic for a DOM



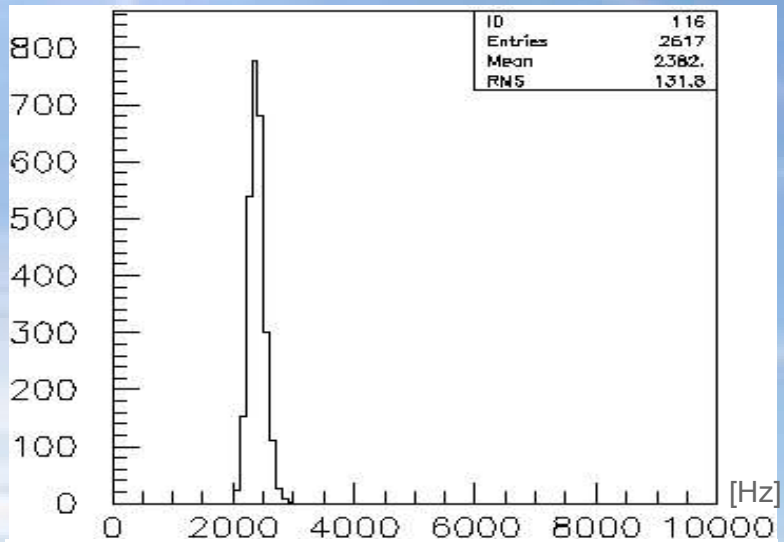




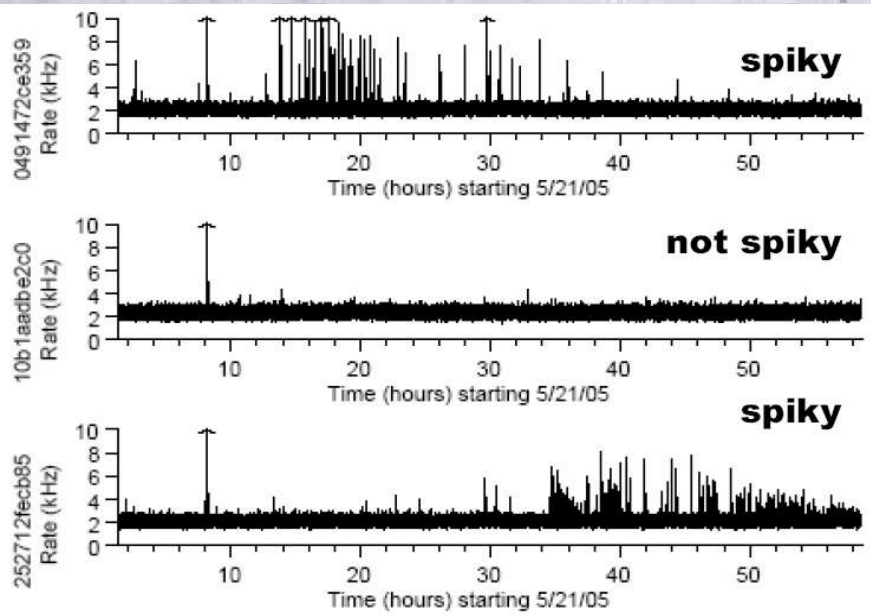


Dark Noise

- Readout on board scaler – discriminator crossings of PMT signal
- Plot the noise rate distribution
- Requirements:
  - Mean noise rate < 3kHz and no outliers within 5σ
  - Noise rate in ice is much lower (~800Hz)



Histogram of the dark noise rates for a single DOM



- Search for spikes in noise rate background – maybe an indication for problematic PMTs or HV generators
- Coincidence spikes are likely caused by some outside influences

Summary

- The IceCube Experiment, a huge neutrino telescope is under construction
- DESY contributes to the production of the essential detector components – the Digital Optical Module
- Optical Modules are produced and tested under antarctic conditions
- The first two years of production have been successfully accomplished
- In order to improve the knowledge of the detector characteristics, detailed classification of the DOM properties is necessary and therefore acquired during testing
- We are waiting for the next deployment season in order to keep IceCube growing