IceCube Instrumentation and Online Systems

The IceCube Collaboration

1 Introduction

1.1 IceCube Science

(1 page)

1.2 A Functional Description of the IceCube Instrument

In order to observe astrophysical neutrinos, the primary science goal of the experiment, IceCube exploits the fact that charged particles moving through the ice at super-luminal speed emit Cherenkov photons. An enormous detection volume is required since the cross-sections of neutrinos are small for producing secondary charged particles in interactions with ordinary matter. The glacial ice cap at the South Pole is about 3 km thick and therefore predestined as operation site since it is not only offering aplenty interaction material but also a medium with unmatched high quality. Cherenkov light is produced in cascades of neutrino-induced muons penetrating the deep, other high-energy particles as well as generated by by cosmic-ray muons that result from cosmic-ray interactions in the atmosphere above Antarctica. Due to a Cherenkov photon yield of $\mathcal{O}(10^5)$ visible photons per GeV of shower energy, the long optical attenuation length in South Pole ice and large-area photomultipliers (PMTs) it is possible to instrument cubic kilometers of ice with a rather wide spacing of detectors. The basic detection unit in IceCube in order to capture the Cherenkov light is the digital optical module or *DOM* which is covered in great detail in Sec. 2. Encapsulated in a 1/2" thick glass pressure sphere to withstand the extreme pressure in the deep ice, the main components of a DOM are a 10" PMT, embedded high-voltage generation, a flasher calibration board, and a mainboard containing the analog and digital processing circuitry for PMT pulses. The digitized data is fed to a central computing facility at the surface via a unique cable system, see Sec. 3. Aspects of detector deployment and ice drilling are covered in Sec. 4. An overview of the data flow as well as its readout, processing and filtering are subjects of Sec. 5 where we also cover the data handling, monitoring and operational performance of the observatory. The IceCube instrument consists of three sub-detectors – IceCube, DeepCore and IceTop – using the same instrumentation design of embedded digital optical modules and associated surface readout. A schematic layout of the array is shown in Fig. 1

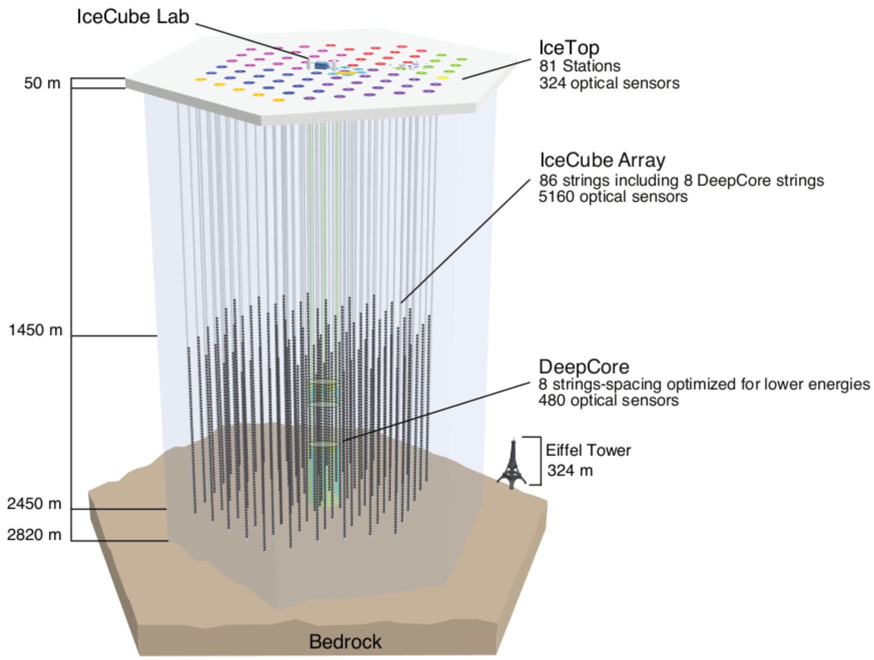

Figure 1: The IceCube Neutrino Observatory with its sub-array DeepCore and the air shower array IceTop.

1.2.1 IceCube

In order to detect the Cherenkov photons emitted by charged particles traversing the ice, 5160 DOMs are deployed between 1450 m and 2450 m below the glacial surface on 86 vertical strings each holding 60 DOMs deployed along a copper cable. The main *deep-ice* array consists of 78 strings with a vertical separation of the DOMs on each string of 17 m. These strings are deployed on a hexagonal grid with 125 m horizontal spacing and spanning a volume of one cubic kilometer of ice. *Talk about energy range covered by this instrumentation and primary science goal*

1.2.2 DeepCore

The remaining subset of in-ice DOMs is deployed in the deep ice below a depth of 1750 m forming a denser instrumented volume. This sub-array, the DeepCore [1] consists of eight specialized and closely spaced strings of sensors located around the central IceCube string. Its inter-string spacings of 75 m and inter-DOM spacings of 7 m are optimized for the detection of atmospheric neutrinos with energies typically in the range from 100 GeV to 400 TeV [3].

1.2.3 IceTop

IceTop [4] consists of 81 clear ice-filled Cherenkov tanks that are arranged in pairs on the same, approximately 125 m, triangular grid as the vertical cables that carry the deep sensors of IceCube. The two tanks at each surface station are separated from each other by 10 m. Each tank contains two standard IceCube DOMs. Air showers initiated in the atmosphere by cosmic rays are typically spread over a number of stations. The light generated in the tanks by the shower particles (electrons, photons, muons and hadrons) is a measure of the energy deposit of these particles in the tanks.

2 The Digital Optical Module

(Chris Wendt; 10 pages)

2.1 A Functional Description of the DOM

2.2 Mainboard

Cite the DAQ article[5].

2.3 The Photomultiplier

Cite the PMT article[2].

2.4 High Voltage

2.5 Flasher Board

2.6 Pressure Housing and Optical Gel

2.7 Mu-metal Magnetic Shield

2.8 Cable Penetrator

2.9 Mechanical Mounting - Harness Assembly

2.10 Production and Testing

2.11 Calibration

2.11.1 DOMCal

2.11.2 Flasher Calibrations

2.12 Performance and Reliability

We have over N DOM years in ice. What can be said about the reliability? This section could be quite important.

3 The Cable Systems

3.1 Surface Cables

3.2 Surface-to-DOM Cables

3.3 Surface Junction Boxes

4 Drilling and Deployment

5 IceCube Online Systems

(John K; 12-15 pages)

5.1 Data Flow Overview

An overview of the data flow from DOMs to the satellite. Description of architecture and levels of data reduction, starting with a review of LC and proceeding to triggers and then filters. Secondary streams and SNDAQ. I3Live, experiment control, and monitoring.

Figure: data flow diagram indicating major subsystems to be described in this section: DAQ (incl. SNDAQ), PnF, I3Live, and SPADE/JADE.

5.2 SPS and SPTS

South Pole System: breakdown of computing hardware used at the pole between hubs, DAQ, PnF, other machines, and infrastructure. Internal network bandwidth. Redundancy, system monitoring (Nagios), and paging system.

Brief mention of SPTS as northern test and validation system. Replay capabilities.

5.3 Data Readout and Timing

5.3.1 Communications and Cable Bandwidth

Description of communications protocol and messaging strategy. Reference to RAPCal and how it fits in.

5.3.2 Master Clock System

The GPS clock and time string fanout tree, from master clock (and hot spare), to Tier I and Tier II fanouts, the DSB card, and into the DOR card.

5.3.3 DOR Card and Driver

DOR card description: comms / readout, power control and measurement, RAPCal initiation, and clock string readout. Clock modes (internal / external). DOMs per card and cards per hub.

Brief description of driver. Proc file interface. Data transfer over PCI bus via DMA.

Figure: Combined clock fanout tree hierarchy and hub diagram (DSB and DOR cards, power distribution).

5.4 Processing at the Surface

(Dave G; 2-3 pages)

Big-picture description of what DAQ does: collecting hits from the DOMs, triggering on HLC hits, and packaging waveforms into events.

5.4.1 DOMHub and Hit Spooling

Responsibility of StringHub. Splicer and description of HKN1 algorithm. Forwarding of HLC hit times to trigger. Translation of DOR times into UTC. Servicing event readout requests (defer discussion to event builder section). Generation of secondary streams.

Hitspooling. Mention of hit daemon plans.

5.4.2 Supernova System

SN secondary stream from DOMs and SNDAQ reference. Interface to hitspooling.

5.4.3 Triggers

General description of trigger architecture. Separation of trigger window and readout window. How trigger windows depend on geometry. Thorough escription of all different trigger algorithms. Trigger and readout window merging.

Table: standard settings for triggers

Figure: trigger windows and readout windows.

Figure: example bright multi-trigger event.

Figure: SLOP triplet geometry?

5.4.4 Event Building

Readout requests to StringHub components and packaging of waveforms into events. Spooling to disk and interface to PnF.

5.4.5 Configuration

Tree of XML configuration files for components, triggers, and DOM settings.

5.4.6 Distributed Network Control

CnC server description. XML-RPC.

5.5 Online Filtering

(Erik B.; 3-4 pages)

5.5.1 Overview

Big picture view of what PnF is and does (route data from DAQ output to files for pickup by data handling, applying calibration, recos and filters along the way, TFT content, etc)

5.5.2 System Design

Cover the overall system design and tech used (CORBA, I3Inlet/I3Outlets, etc) and how all pieces fit together and are controlled (mention pf2live). Words about historical operation in Plan B in early seasons, plan A.

5.5.3 Components

A brief description of each PnF component.

I3DAQDispatch

PnF Server

PnF Clients

DB Cache

Realtime Followup server and clients

5.5.4 Performance

Overall rates and known limits (server + I/O limits)

Average system latency Figure: plot of typical latency including run transition?

5.6 Data Handling

(P. Meade; 1 page)

Generation description of system architecture. Stream definitions, dropboxes, and data pickup. Archival vs. transfer to TDRSS system.

5.7 I3Live and Remote Monitoring

(J. Braun; 1 page)

I3Live duties of experiment control and realtime monitoring. Component descriptions. Failover modes, alarms, and interface to paging system. Monitoring system and Moni2.0. Interface to ITS and its replacement system, I3MS.

5.8 Operational Performance

(John K.; 1 page)

Explanation of how design choices, system monitoring, and winterovers result in high uptime. Discussion of median downtime and various causes of downtime. Possible basic failure analysis of hardware components.

Figure: DAQ full uptime and clean uptime percentage.

Figure (optional): Downtime histogram.

6 Outlook

Discuss Gen2 here.

References

[1] R. Abbasi, Y. Abdou, T. Abu-Zayyad, M. Ackermann, J. Adams, J. Aguilar, M. Ahlers, M. Allen, D. Altmann, K. Andeen, et al. The design and performance of IceCube DeepCore. *Astroparticle physics*, 35(10):615–624, 2012.

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[3] R. Abbasi, Y. Abdou, T. Abu-Zayyad, J. Adams, J. Aguilar, M. Ahlers, K. Andeen, J. Auffenberg, X. Bai, M. Baker, et al. Measurement of the atmospheric neutrino energy spectrum from 100 GeV to 400 TeV with IceCube. *Physical Review D*, 83(1):012001, 2011.

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