Abstract
The IceCube Neutrino Observatory was designed to detect neutrinos at energies greater than 100 GeV. Due to subfreezing temperatures, the photomultipliers’ dark noise rates are particularly low. This enables IceCube to search for neutrinos from galactic supernovae by measuring an increase in the overall hit number, deduced from scintillator, in the detector coming from the Cerenkov light of interactions of MeV neutrinos in the ice.

A new feature to the standard DAQ, called HitSpooling, is running in IceCube since 2013. By buffering the untriggered hit information of the photomultipliers we have access to the full raw data stream of the detector in case of a supernova. In combination with the standard scaler data, the HitSpooling feature leads to a better understanding of background processes coming from atmospheric muons and radioactive decays.

Furthermore, the status of the galactic supernova search as well as systematic and detector stability studies are presented.

Input

Introduction

- Neutrino interaction in ice: Dominant interaction in ice for supernova neutrinos with energy O(10 MeV) is the inverse beta process: \( \bar{\nu_e} + p \rightarrow e^- + n \)
- Postrion tracks of about 0.56 x E [cm/MeV]
- Monte Carlo: For 10^9 neutrinos interactions in ice from a supernova at 10 kpc distance we expect to detect up to 3.6 million neutrino induced PMT hits.
- Supernova detection principle: monitoring the count rates of individual DOMs in ms bins.
- Scaler data stream is decoupled from the hit data stream that holds more detailed information, but is only saved for events that trigger and may not be available in the case of a supernova.

Data Streams

- **Hit Spooling**
  - **Hit Spool Data**
    - **Basis for IceCube’s standard analysis channel**
      - Individual hits are combined to a global trigger rate
      - Data distribution approximated by Gaussian distribution:
        - Expectation values and corresponding standard deviations for noise values
        - Most likely collective rate deviation, \( \Delta \eta \), and its uncertainty, \( \sigma_{\Delta \eta} \) give the significance \( \Sigma = \Delta \eta / \sigma_{\Delta \eta} \)
        - **SN candidate trigger**: \( \Sigma > 5.2 \)
    - **Hit Spool**
      - Additional to hits in memory: hits data buffered to disk in DOMHub (dashed line in diagram)
      - 2 MB of data per second per string
      - Buffers filled in a cycle in files of variable duration
      - Buffer length up to 16 hours
      - HitSpooling independent of other DAQ elements
      - Data transfer to central storage in case of an SN candidate trigger is handled by the HitSpool Interface services

Hitspool Processing

- **Hit Spool Processing**
  - HitSpool data is processed offline in the North
  - Hybrid processing system:
    - Triggers (from hit data stream):
      - Simple Majority Trigger
      - Reconstruction and calculate significance
  - Processing optimised for keeping background and identify even sub-threshold atmospheric muons

Processing Chain

- **Motivation**
  - Subtraction of triggered atmospheric muons already improves significance distribution (see box below)
  - For best separation between noise & signal:
    - Identify and subtract hits as associated to atmospheric muons that did not trigger
  - Cleaned data set with narrowed significance distribution and reduced non-Gaussian tails

Tools

- **Hit cluster identification**
- Inverted hit cleaning
- NoiseEngine [Lars13]
- Identification of tracks by hit pair angular multiplicity
- Estimation of track’s consistency

- **Sub-threshold muon candidates**

Supernova Search

- **Supernova Neutrinos in IceCube**
  - IceCube collaboration
  - Supernova analysis algorithm based on subte changes in the background rate
  - Single DOM noise averages at 540 Hz
  - Considered background for supernova search:
    - Uncorrelated Poissonian contributions:
      - Neutrality, thermal noise, field emission
      - Atmospheric muons
      - Other DOMs space
      - Cherenkov radiation and/or scintillation
  - Suppression of correlated noise:
    - Artificial deadtime of 250 µs applied to every hit in scaler data
    - Remaining noise rate 285 ± 26 Hz [NIM10]
  - Triggered atmospheric muons
  - Muon trigger rate in IceCube per DOM: 16 Hz
  - Removing hits associated with muon trigger improves the significance distribution
  - Further improvable by using HitSpool data (see next column)
  - Measured significance distributions without (black line) and with (shaded grey) subtraction of atmospheric muons for data taken from April 2008 to May 2011 (significances \( \Sigma > 6 \) are kept blind)
  - The distributions hardly overlap with the significances expected for the three supernova models studied assuming two progenitor radial distribution models for our Milky Way (solid line: XCAV), with dashed lines: [PRD09]
  - Simulated significance distribution for the detection of a supernova as function of distance for the Hudepohl [PRL10], Lawrence-LiveMore [AP18] and Black Hole [A307] models

Ref


HitSpool Data

- **Basis for IceCube’s Supernova data acquisition system and supernova analysis channel**
  - Firmware integrated scaler adds asynchronously all PMT pulses in intervals and assigns them a timestamp
  - Supernova DAQ [A&A11] collects scaler data from individual DOMs and retrans in global 2 ms intervals
  - Supernova DAQ calculates individual noise rates
  - Data distribution approximated by Gaussian distribution:
    - Expectation values and corresponding standard deviations for noise values
    - Most likely collective rate deviation, \( \Delta \eta \), and its uncertainty, \( \sigma_{\Delta \eta} \) give the significance \( \Sigma = \Delta \eta / \sigma_{\Delta \eta} \)
    - Supernova DAQ issues an alert to SNEWS [NP04] for standard deviation \( \sigma > 5.2 \)

Scalermaintain

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Sub-trigger Muons

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