Reconstruction and simulation with multi PMT optical moduls for IceCube-Gen2

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IceCube Neutrino Observatory

**What**

Cubic kilometer array of optical sensors

**Where**

In a depth of 1.5km to 2.5km within the ice of the south pole

**How**

Detection of Cherenkov light emitted by secondary particles created in neutrino interactions

**Why**

Detection of high energetic cosmic neutrinos created in extreme cosmic environments
IceCube Neutrino Observatory

**Optical sensor**
10” photo multiplier and readout electronics in a pressure resistant glass sphere also called Digital Optical Module (DOM)

**String**
One string consists of 60 DOMs with ~17m spacing in between each module. Between two strings there is a distance of ~125m.

1 2 5 m

String

125m

IceCube Neutrino Observatory

String

125m

Optical sensor

10” photo multiplier and readout electronics in a pressure resistant glass sphere also called Digital Optical Module (DOM)
IceCube Neutrino Observatory

**Achievements**
First detection of extra-terrestrial high energetic neutrinos (arXiv:1311.5238)

**Limitations**
No cosmic neutrino sources were detected due to the small neutrino flux => increase instrumented volume

(Starting track event with a deposited energy of ~250TeV)
IceCube-Gen2

High Energy Array (HEA)
- ~120 additional strings
- ~250m string spacing
- Instrumented volume ~7 times larger than IceCube
- Target neutrino energy >=100TeV
Multi PMT Digital Optical Module (mDOM)

- One mDOM with 24 3" PMTs
- $4\pi$ acceptance
- Detection of local coincident hits
- Intrinsic direction information
Event simulation

\[ \nu \]

ANIS
Event simulation

ANIS

Geant 4 (up to 1TeV)
or parameterized function
Event simulation

Geant 4 (up to 1TeV) or parameterized function
Event simulation

Geant 4 (up to 1TeV) or parameterized function

glass, gel, angular acceptance, wavelength acceptance
Data / Simulation processing

Detection process / Simulation

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Energy, direction, vertex

Detector

Detector response (detected photons over time per PMT)

Reconstruction + Analysis

Physical analysis

Neutrino energy, direction, flavor, vertex

Reconstruction algorithm
Reconstruction strategies

Simple reconstruction strategies
- Vertex: Center Of Gravity (COG) for the detected light within the detector
- Direction: Least square fit of timing information of detected light
- Energy: Number of hit DOMs or collected light as energy proxy

More advanced reconstruction strategy
- Reconstruct the event parameters using a maximum LLH approach
Max LLH event reconstruction

- Optical module (with hit)
- String
- Optical module (without hit)
Max LLH event reconstruction
Max LLH event reconstruction

- Photo electrons
- Time
- simple reconstruction algorithms
- est. source parameter (energy, direction, vertex)
Max LLH event reconstruction

*Photo electrons*

*Lookup tables*

*est. source parameter (energy, direction, vertex)*
Max LLH event reconstruction

Photo electrons

Calculate LLH

Vary source parameter (using a minimizer)
Max LLH event reconstruction

- Calculate LLH
- Vary source parameter (using a minimizer)
Max LLH event reconstruction

- Find maximum LLH
- Return respective source parameter

Reconstruction only successful when lookup tables are correct!
Evaluation of lookup tables

Example config:
Energy = 1TeV
Angle = 90°
Distance = 100m

N = 10000
Summery and Outlook:

- Sensitivity studies for IceCube Gen2 with mDOMs require:
  - Simulations (Toolset ready and working)
  - Reconstructions methods (not tested yet)

- Preformance studies will be started soon

- Direct comparison between IceCube DOMs and mDOM (and other possible modules) possible

- Possibility of Direct Reconstruction (no lookup tables needed) will be investigated
Event reconstruction with max LLH

Event topology (detector signal) → Simple first guess reco. algorithms → Event hypothesis (Energy, Pos, Dir, etc.)

Use minimizer to vary $<\text{energy}, \text{pos}, \text{dir}>$ until local min is reached

Calculate LLH for event hypothesis to look like the actual event

Lookup table