Calibration study for PINGU

H. P. Bretz, A. Kappes, R. Shanidze, A. Shmelkin

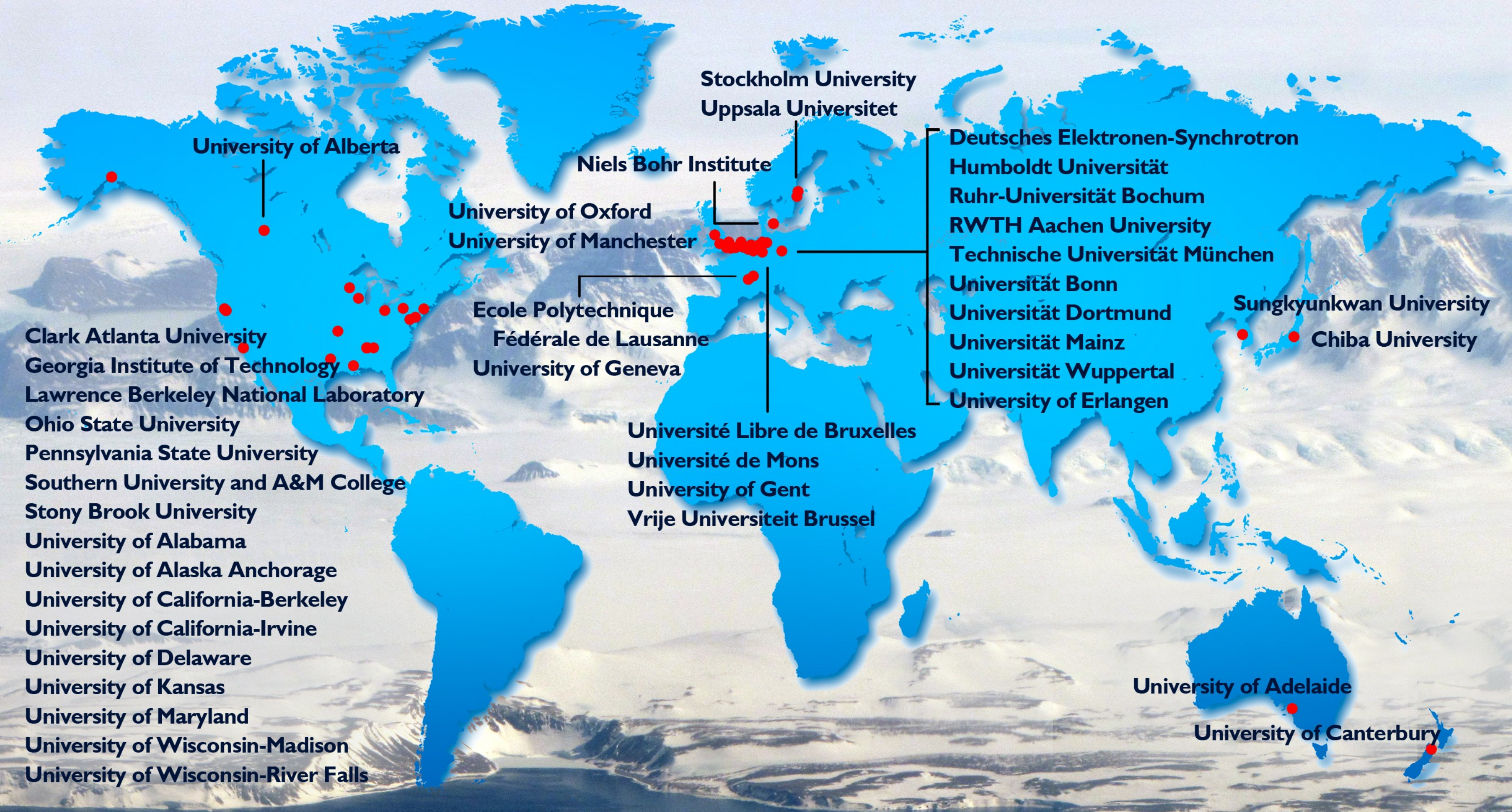
for the IceCube collaboration & PINGU

HELMHOLTZ
GEMEINSCHAFT

ICECUBE

DESY

The IceCube Collaboration & PINGU



International Funding Agencies

Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education & Research (BMBF)
German Research Foundation (DFG)

Deutsches Elektronen-Synchrotron (DESY)
Inoue Foundation for Science, Japan
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)

University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

Outline

- PINGU:
  Design concept and configuration

- Calibration for PINGU:
  - Calibration tasks
  - Calibration with atmospheric muons
  - LED flashers

- Simulation of LED-flashers
  - Current status

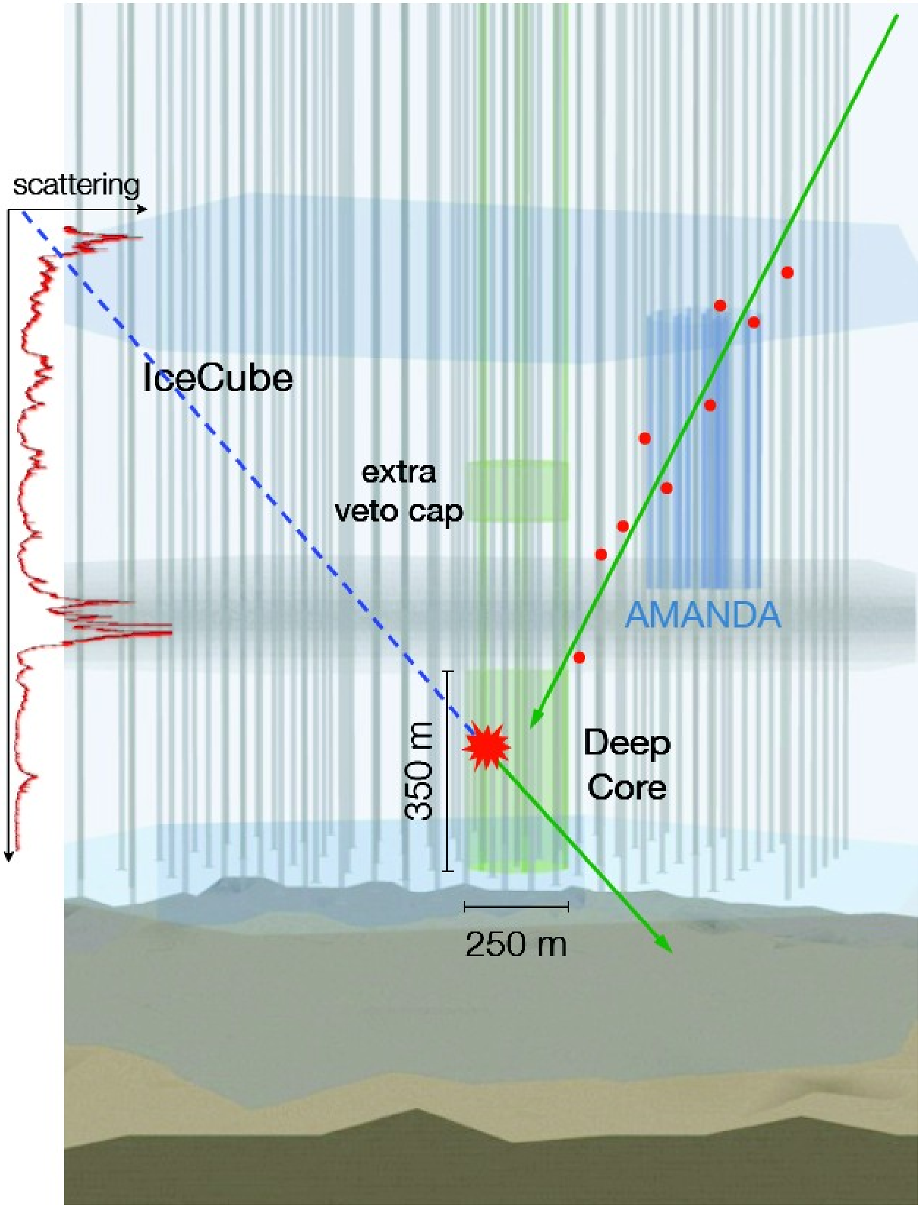
- Summary and outlook

PINGU design concept

PINGU (**P**recision **I**ceCube **N**ext **G**eneration **U**pgrade):

- Reach a few GeV E_{ν} threshold
  - main goal: measurement of neutrino mass hierarchy
- Add in-fill strings to IceCube/DeepCore array
  - further increase module density and continue to exploit 2km depth and surrounding IceCube/DeepCore array as active cosmic ray muon veto
- Co-deploy improved/new calibration devices to decrease systematic uncertainties in PINGU
- Improve refrozen hole ice clarity

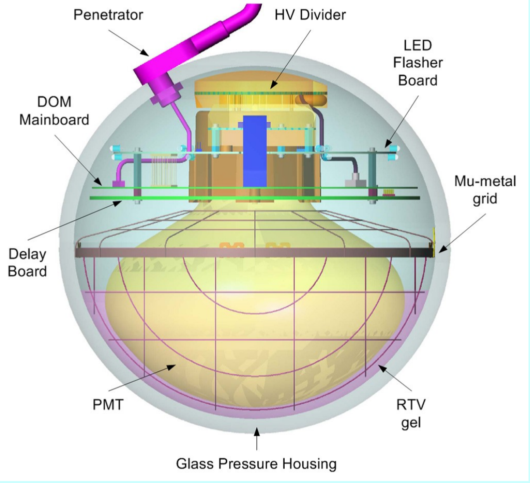
PINGU location: inside IceCube/DeepCore



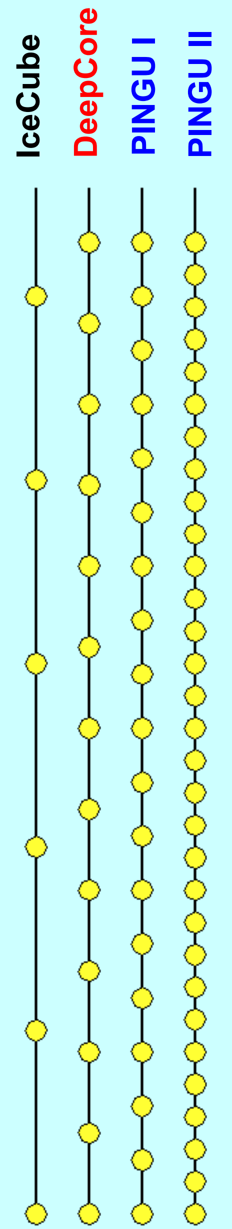
- IceCube/DeepCore:

  Densely instrumented region at the center of IceCube, below ~2000m, in the clearest ice λ_{eff} > ~ 40-50 m

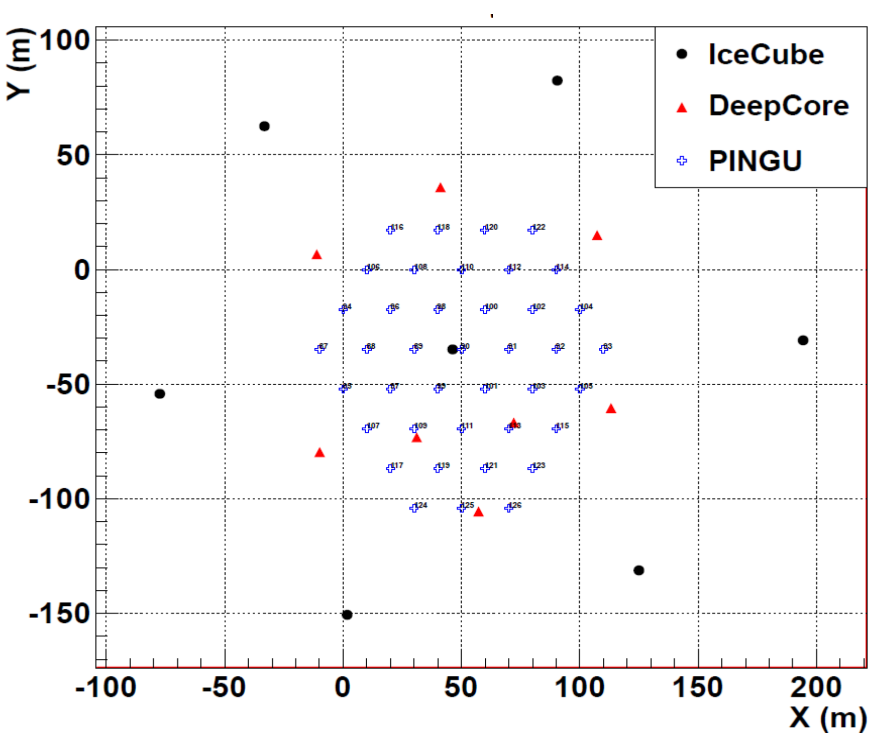
- Digital Optical Module (DOM)
  13 inch. pressure resistant glass sphere with 10 inch. PMT and electronic boards



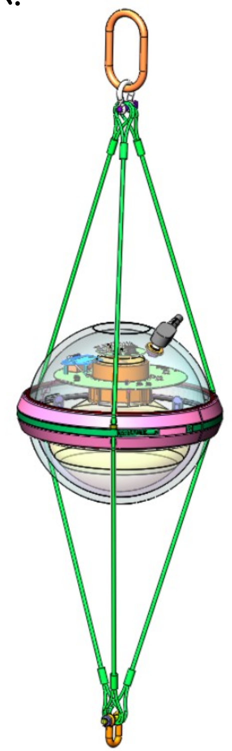
PINGU configuration



- IceCube : 17 m (60 DOMs)
- DeepCore: 10 m (top 10 DOMs)
  7 m (bottom 50 DOMs)
- PINGU I: 5 m (60 DOMs)
  PINGU II: 3 m (100 DOMs)



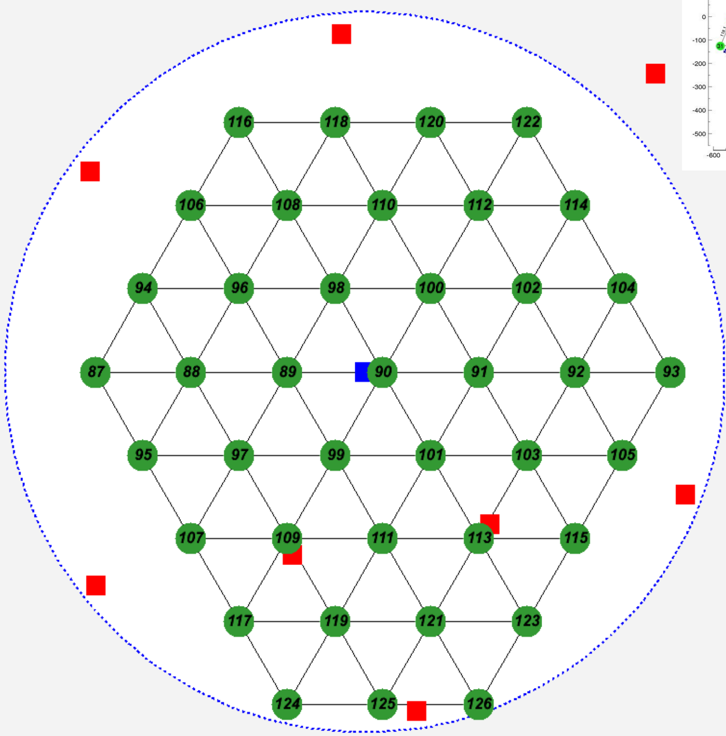
Hardware: IceCube hardware with various modifications to minimize cost and risk.

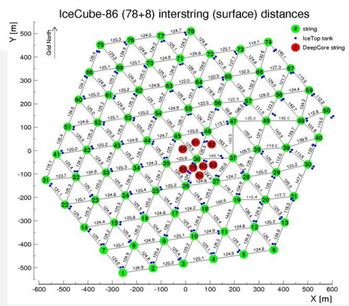


Deep sea/ice technology session:
Perry Sandstrom "Design Engineering for PINGU DOMs".

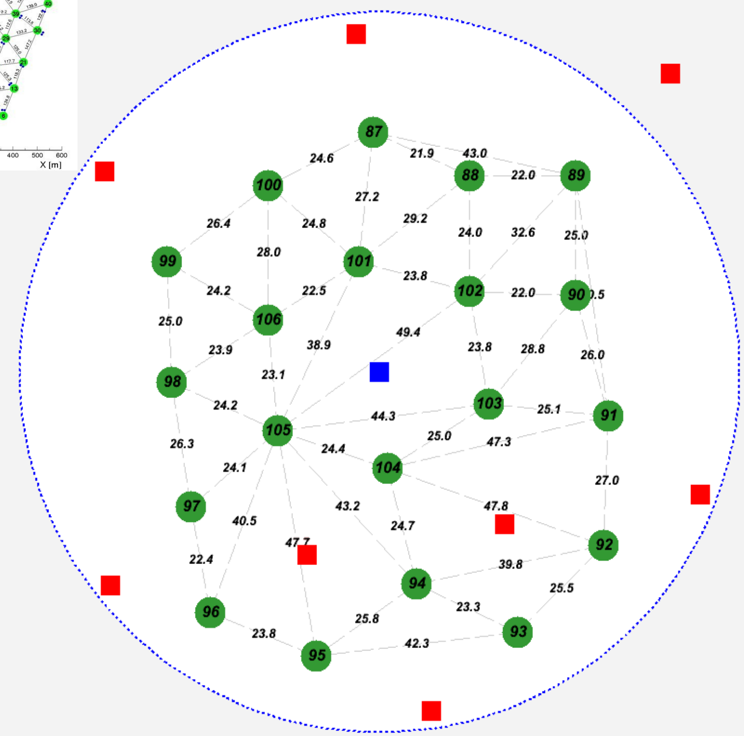
PINGU configurations with 40 and 20 strings

40 string configuration





20 string configuration

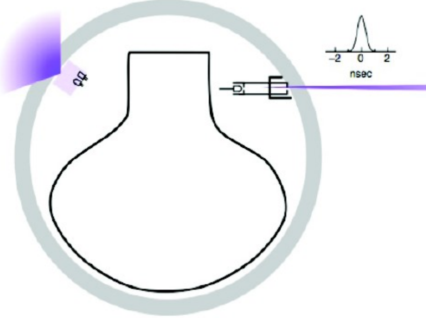


Closest distance between 2 strings: 20 m.
(same for all strings in this configuration)

IceCube string #36 is indicated by a blue square. Red squares: 8 DeepCore strings
Radius of the Circle, around IceCube String #36 is R=75 m.

Calibration tasks in PINGU

- PINGU: a detailed calibration program to measure and verify the detector geometry, response of PINGU DOMs and the properties of ice in the PINGU volume.



PDOM with modified LED flasher

- Calibration light sources for the PINGU DOMs:
  - Atmospheric muons (steady-state physics data taking)
  - Calibration with LED flashers

  - LED flashers in all PINGU DOMs.

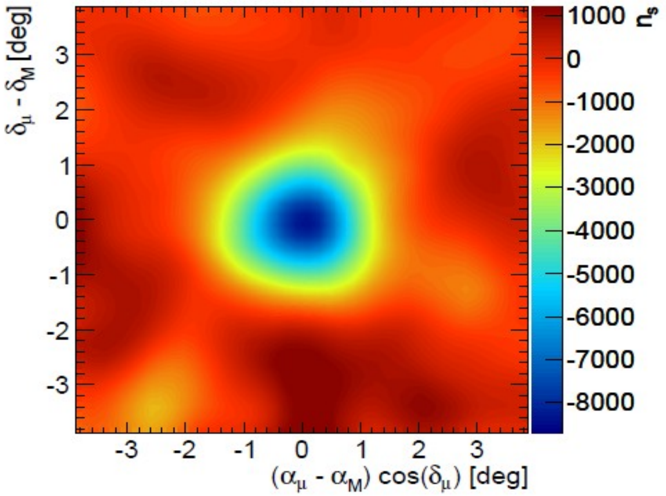
  - Optimization of the LED parameters and configuration to achieve required precision. (light output, angular emission profile, timing and orientation, wavelength)

- Goal for PINGU calibration:

  Reduction of current IceCube uncertainty on DOM acceptance and efficiency, ice properties : 10% -> 5%.

Calibration with atmospheric muons

- Atmospheric muons: source of Cherenkov photons with well defined parameters (wavelength, intensity) and emission profile.



Moon shadow observation in IceCube (IC-59) [arXiv:1305.6811]

- Atmospheric muon rate in DeepCore:
  SMT3 (N_{hits}>3, in 2. 5μs) < 10 Hz
  (0.4% of standard IceCube SMT8)

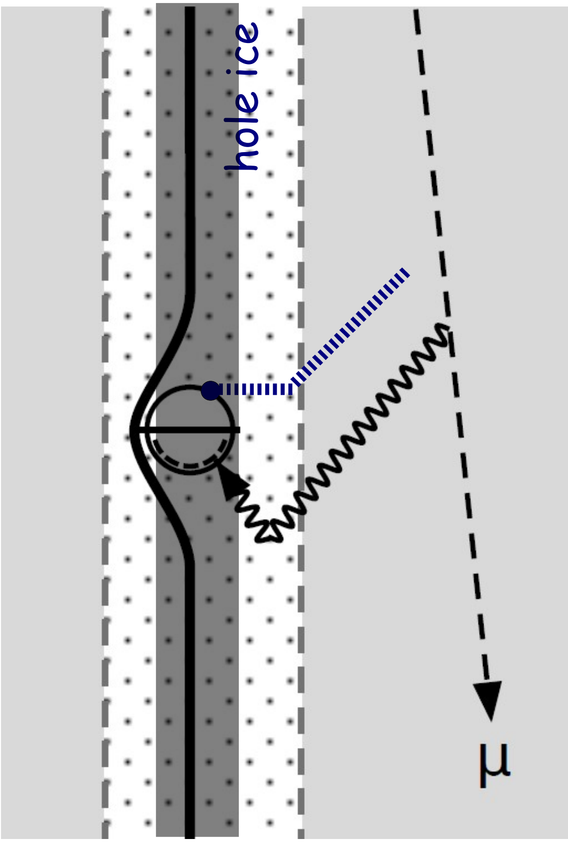
- Angular resolution of reconstructed muons in IceCube and orientation of the detector -> observation of the Moon shadow.

- Muons detected in PINGU could be reconstructed twice:
  - with IceCube DOMs
  - with PINGU DOMs

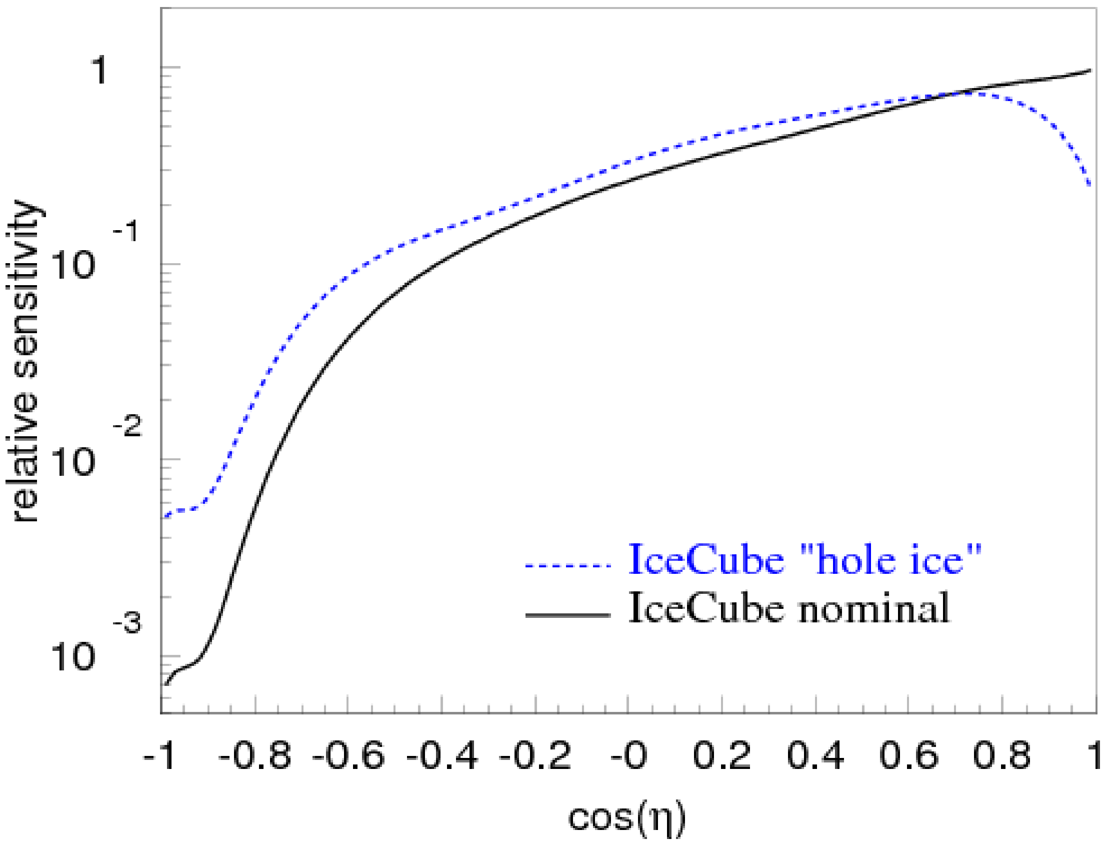
  Angular resolution for muons in PINGU could be obtained from these reconstructions.
  (Simulations with the "muon gun" software could be used for the the studies)

IceCube hole ice

The hole ice: the refrozen column of ice in which the DOM strings are embedded.

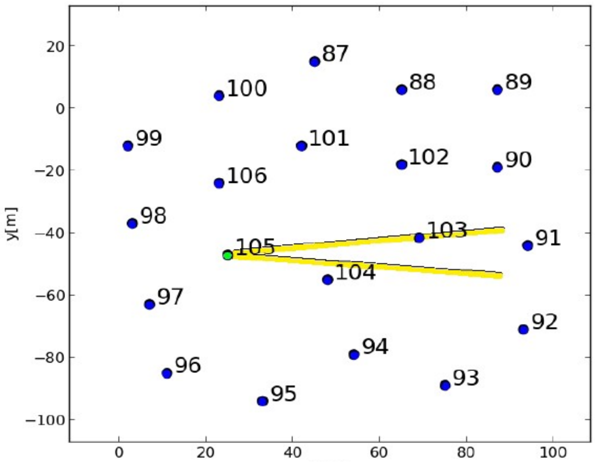


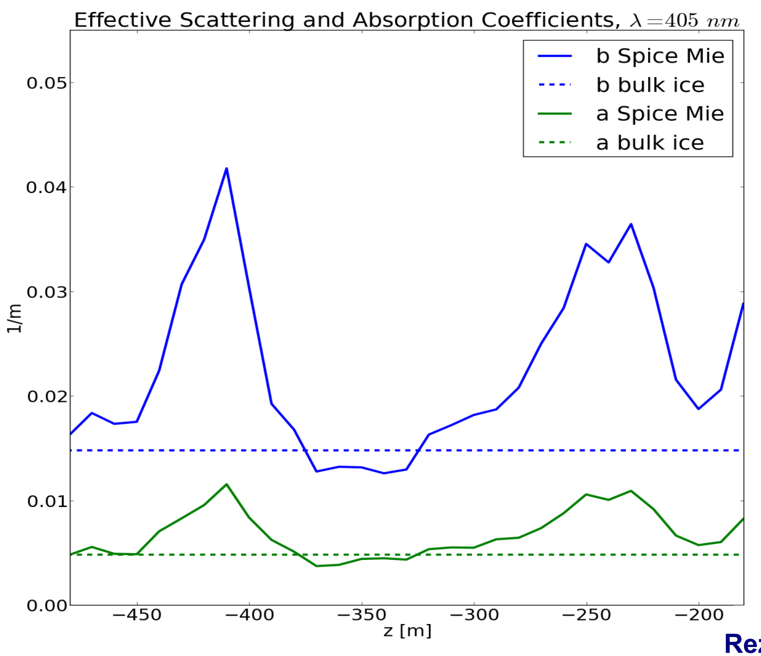
Properties of ice in the IceCube/ DeepCore holes are different from the properties of "bulk ice".



IceCube DOM angular sensitivity vs. cos(η), where η is the photon arrival angle with respect to the PMT axis. The nominal model, based on a lab measurement, is normalized to 1.0 at cosη=1. The area under both curves is the same.

Simulation of LED flasher events





Current simulation parameters:

- Single horizontal LED (105, 30)
- Pulse width: 30 ns
- Pulse brightness: ~$2\text{x}10^9$ photons
- 3 different angular profiles:
  - narrow (1.5°), regular (9.0°), wide(70°)

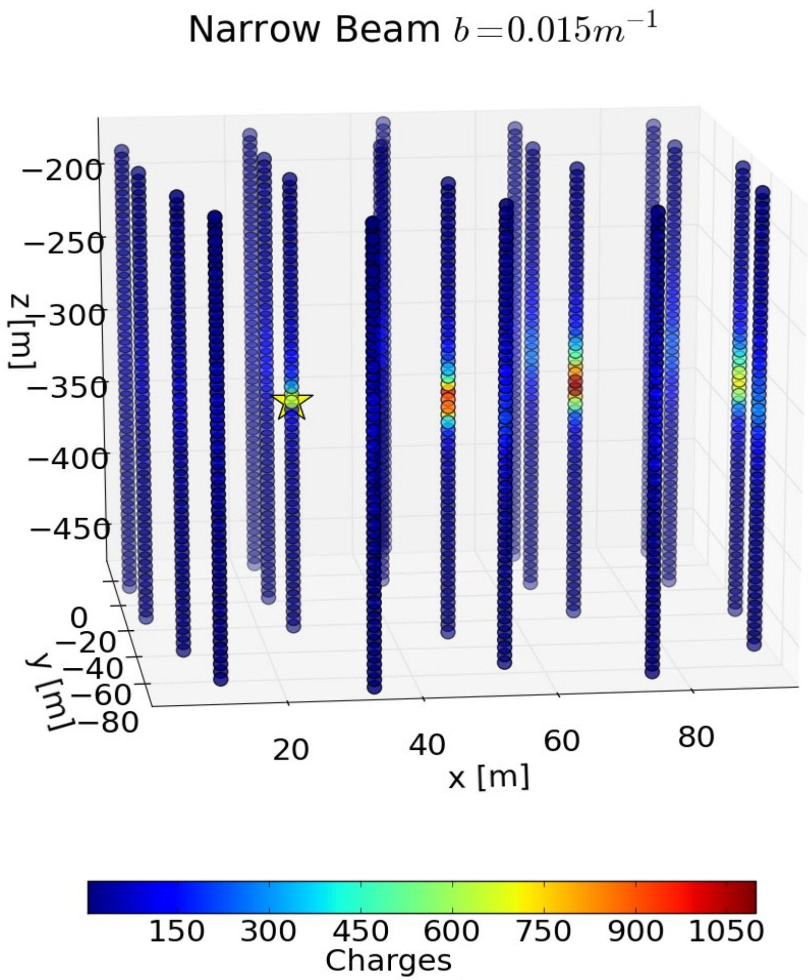
Each photon produced in the simulation is propagated by CLSim code, taking into account ice absorption and scattering.

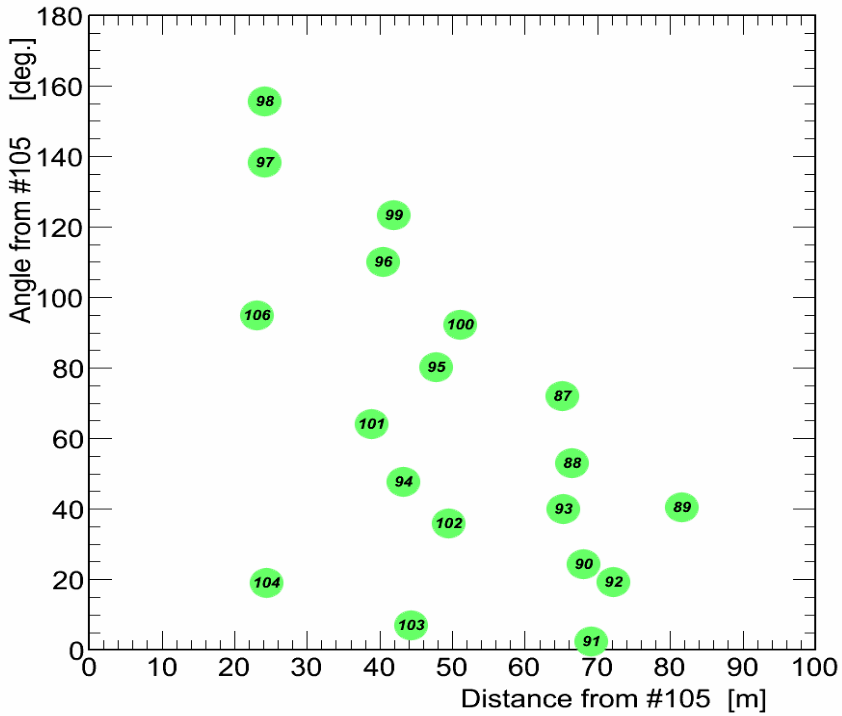
- The "bulk ice" model(*) used in these Simulations is defined by 2 parameters:
  - absorption and scattering length

  (b_{eff} = 0.015 – 0.017 m^{-1}, Δb_{eff}=0.0005 m^{-1})

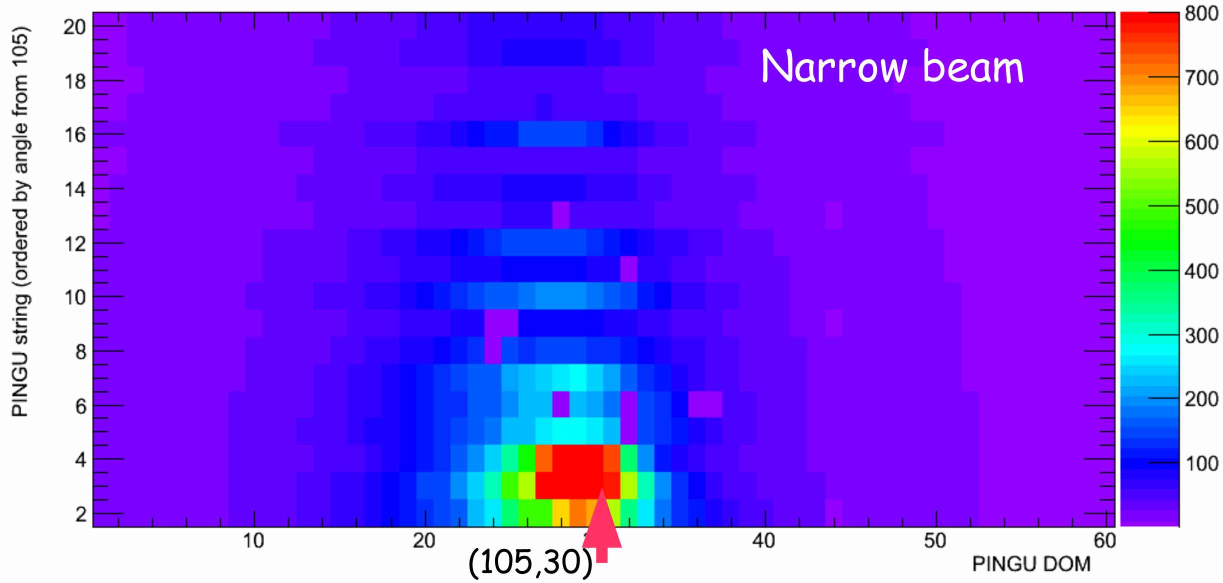
* *see Dawn Williams talk about the light propagation in the ice*

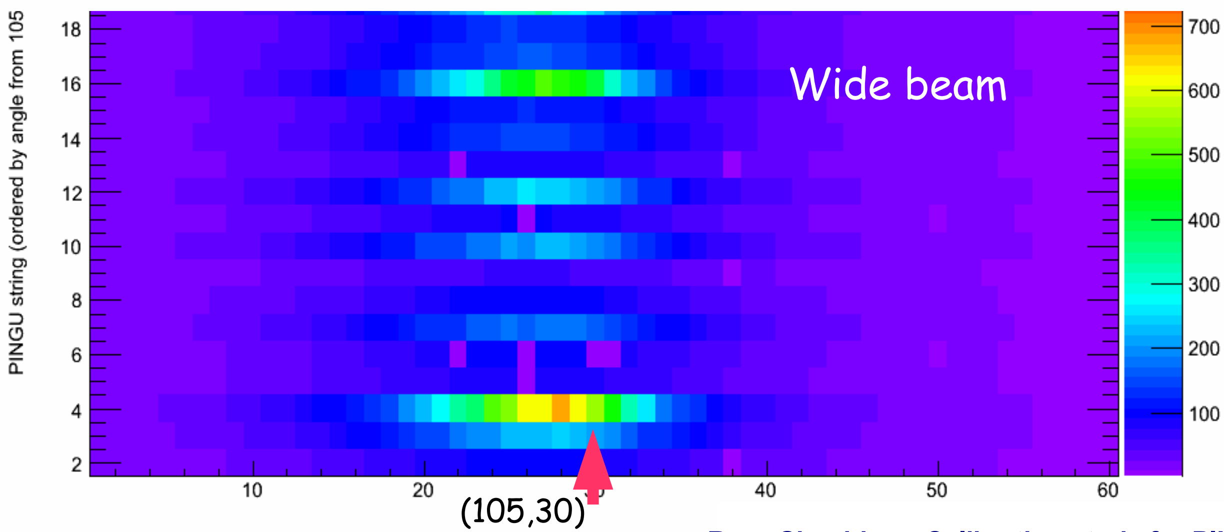
Simulation of LED flashes





Charge distribution in the PINGU DOMs



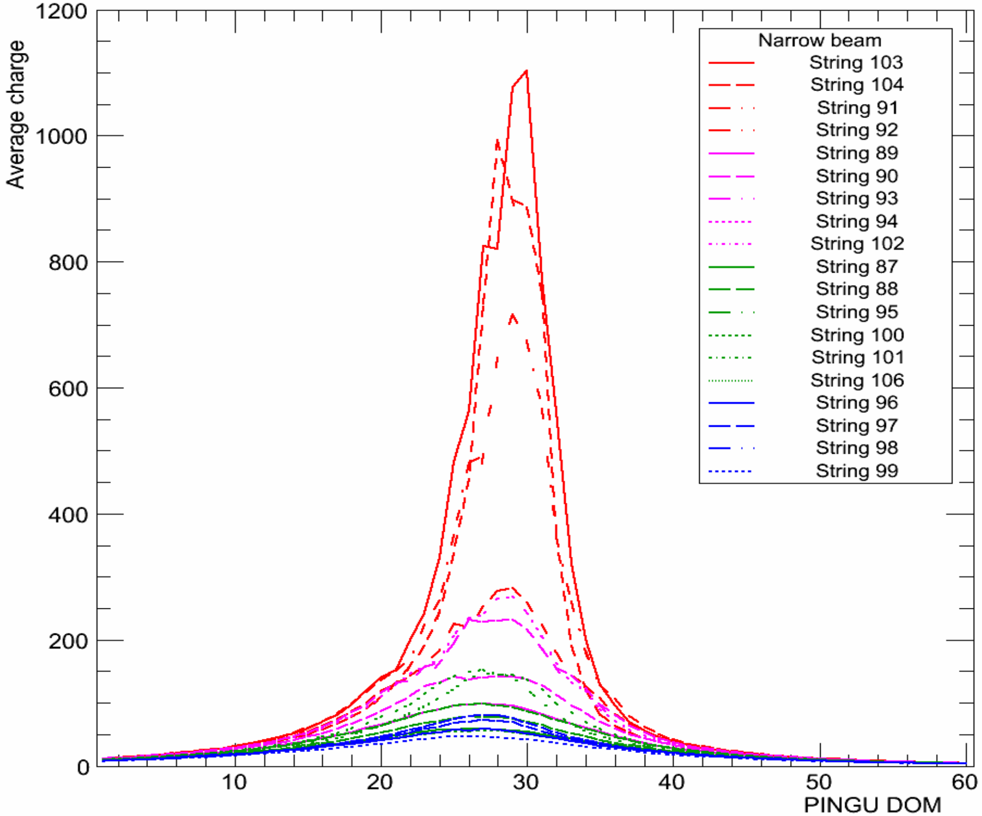


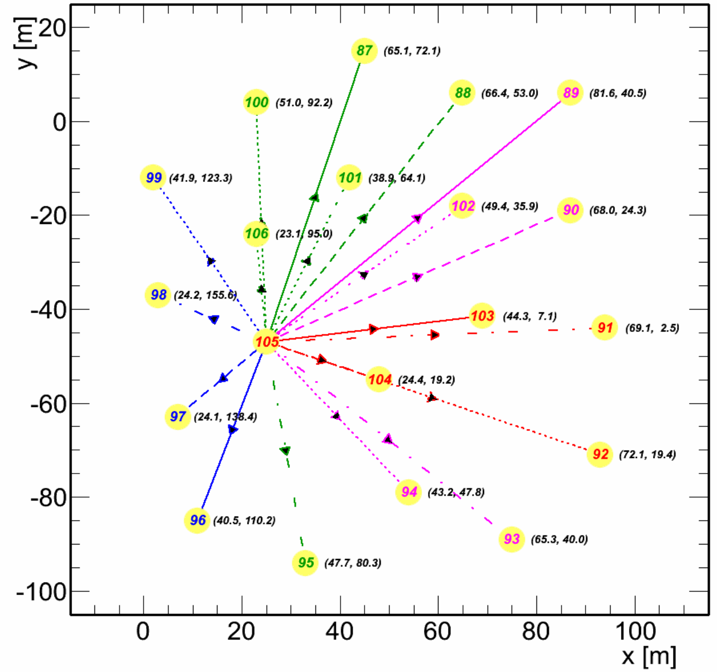
Distribution of average charge in PINGU DOMs from LED flash (105,30) with narrow (upper Fig.) and wide angular profile.

(averaged over 1000 events)

19 PINGU strings are ordered according to their angle visible from the flash direction.

Narrow beam (1.5°)

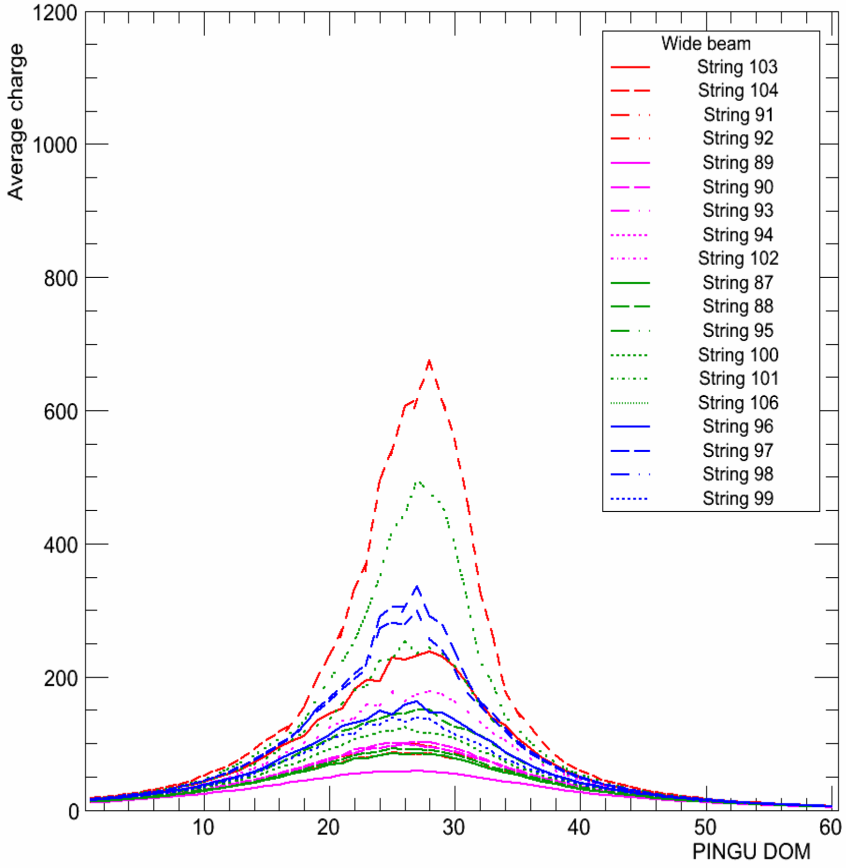


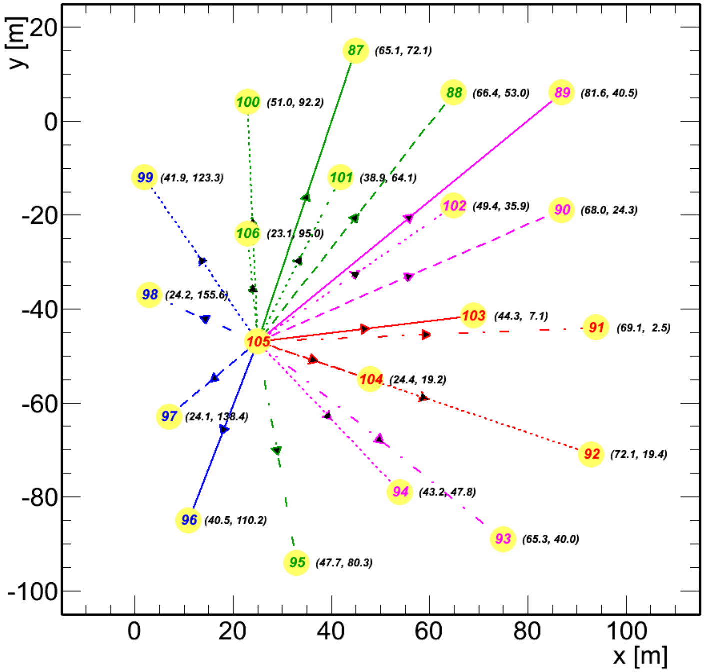


The distances [m] and angles [deg] (numbers in the brackets) from the "flashing string" 105.

- Charge distribution induced by LED flash (105,30) on the PINGU DOMs with narrow beam.

Wide beam (70°)

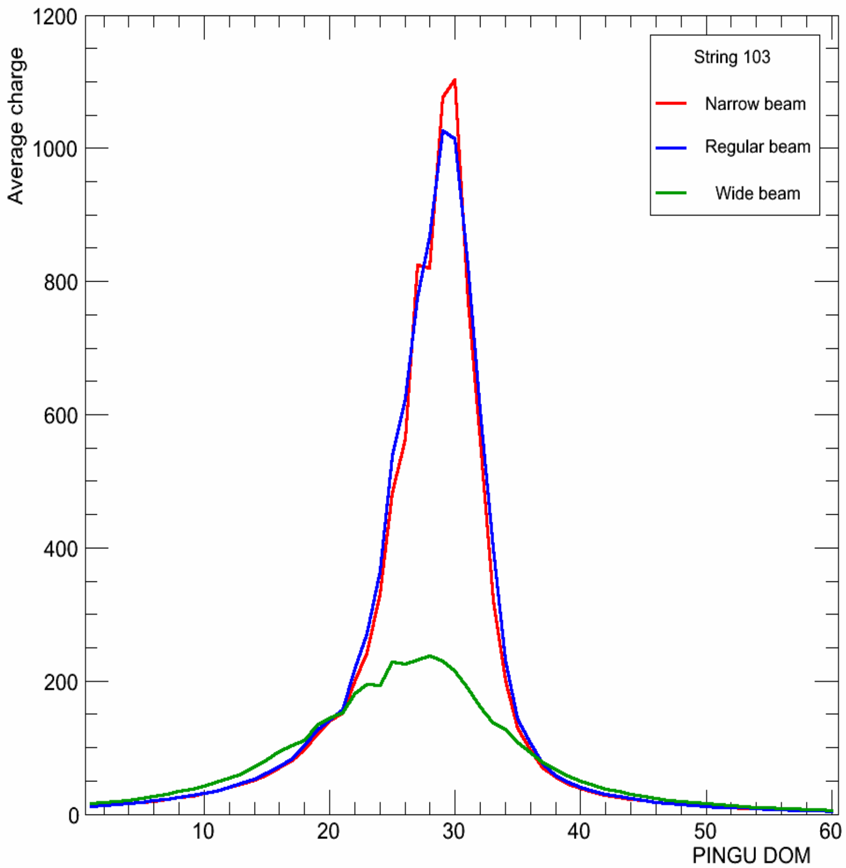


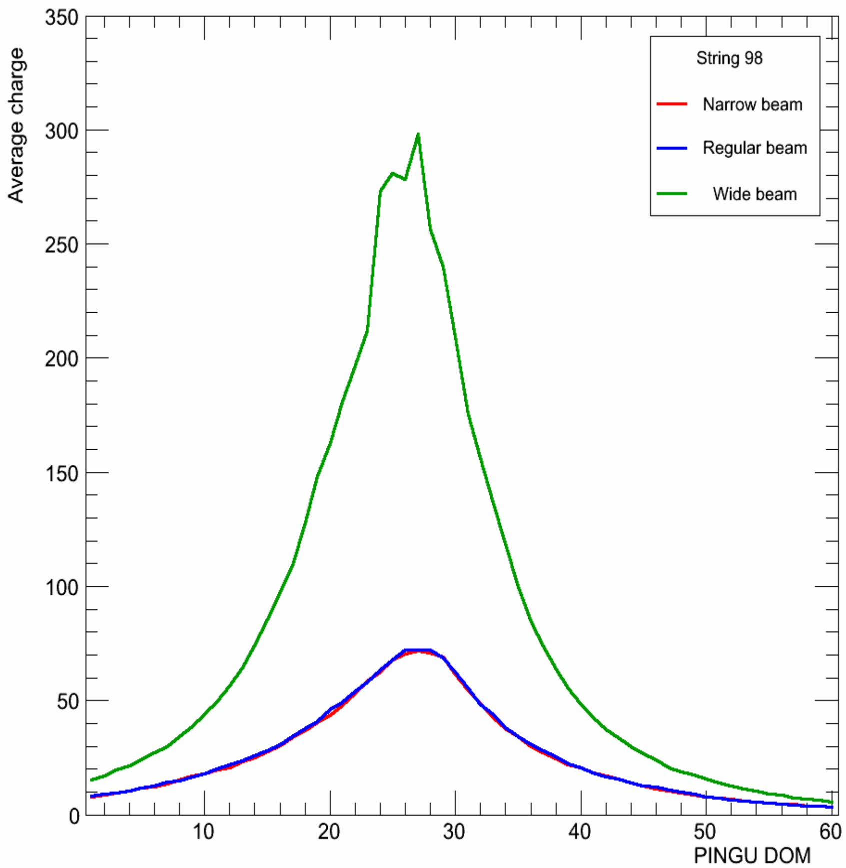


The distances [m] and angles [deg] (numbers in the brackets) from the "flashing string" 105.

- Charge distribution induced by LED flash (105,30) on the PINGU DOMs with wide beam.

Charge distributions vs. Emission profile

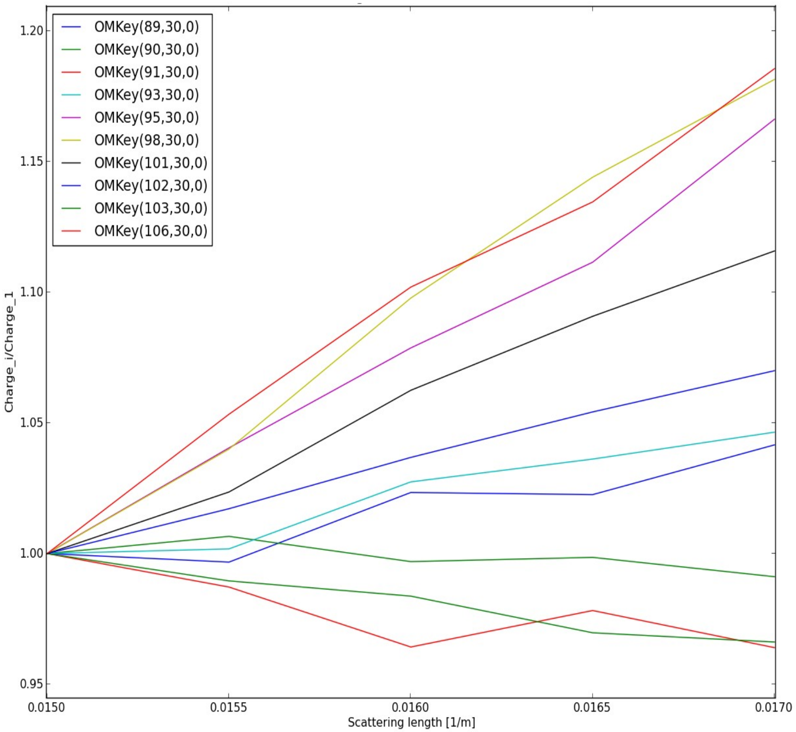




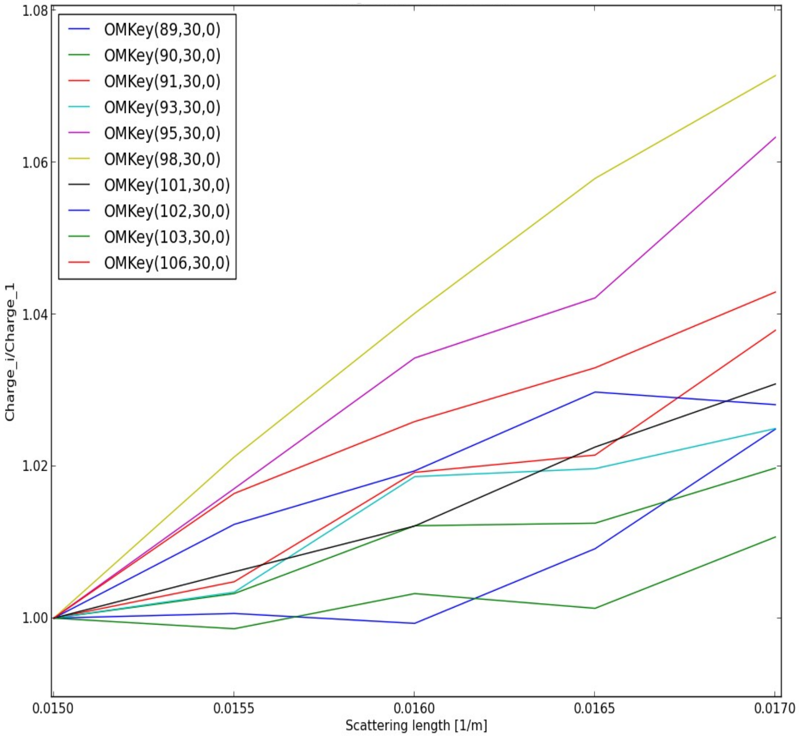
Charge distribution induced by LED flash (105,30) with different angular profile in the forward (string 103, 44.3m, 7.1°) and backward directions (string 98, 24.2m, 155.6°)

Charge ratios vs. scattering length

Narrow beam



Wide beam



Charge distribution of the selected PINGU DOMs as a function of scattering length for the narrow (left) and wide(right) LED emission profiles.

Summary

- The next generation upgrade of IceCube detector (PINGU) aims at lowering neutrino detection threshold to a few GeV by adding new in-fill strings to IceCube/DeepCore array.

- Precision reconstruction of neutrino direction and energy in PINGU, requires accurate in citu calibration and monitoring of DOMs and high-level control for systematic effects like those caused by ice properties.

- The LED- flashers with different angular profile were simulated for the PINGU configuration with 20 strings and 60 PDOMs/string. (CLSim software / DESY GPU farm)

- Response of PINGU DOMs were studied for the bulk ice model with different absorption and scattering length.

Outlook

- Including the DOM timing information in the study of ice properties in the PINGU volume.
- Study of different ice models including "bulk" ice, a model with few layers and current IceCube models.
- Reconstruction of DOM/LED orientation for different angular profiles of emission.
- Optimizing the LED parameters and configuration in order to reduce uncertainty on DOM acceptance and efficiency from current 10% to 5%.