

NEW CALIBRATION METHODS FOR ICECUBE, DEEPCORE AND PINGU



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INTRODUCTION

IceCube is the world's largest neutrino telescope, deployed in the natural Antarctic ice at the South Pole. IceCube is optimized for detection of neutrinos with energies ranging from 100 GeV up to the PeV scale.

PINGU (Precision IceCube Next Generation Upgrade) [1] is a future megaton extension of IceCube for the energy range between a few GeV and 50 GeV.

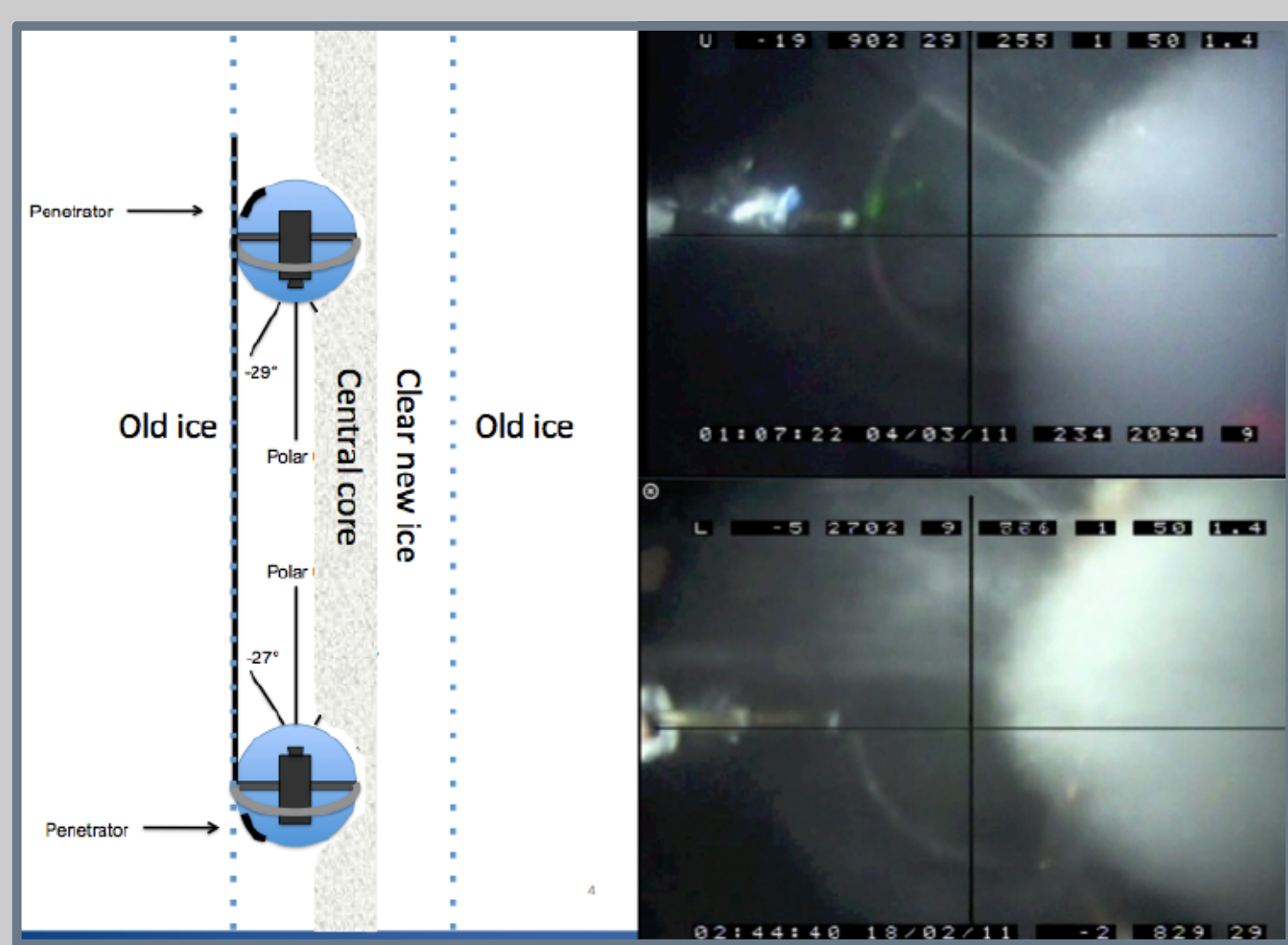
Neutrinos of all flavors are detected indirectly via Cherenkov radiation emitted along the traces of secondary charged particles produced in NC/CC weak interactions in Antarctic ice.

Cherenkov photons are detected with **PINGU Digital Optical Modules (PDOMs)** each containing 10" PMT and processing electronics. PDOMs are arranged in a grid of 40 strings w/ 60 modules each (Lol baseline).

PINGU's calibration program aims to reduce systematic uncertainties to ~2-5%, impacting mainly the energy scale determination. Light propagation in ice & PDOM sensitivity are essential to PINGU's physics.

Oscillation analyses for example will greatly benefit from reduced systematic uncertainties.

PINGU CALIBRATION STRATEGY & IMPROVEMENTS



Left: Sketch of refrozen hole ice showing a column with increased scattering due to air bubbles. Right: Photograph of hole ice in IceCube taken with a high resolution camera.

Drilling → water degassing and monitoring of hole refreezing with high resolution cameras

Detector geometry → position of each PDOM will be determined during deployment. Those positions will be fine-tuned using triangulation with in-situ light sources.

PDOM response → reduce uncertainties below 5% with help of:

- low energy muons (in-situ)
- wavelength resolved measurement of PDOM angular response (lab)

Bulk ice properties (highly position-dependent) → measurement of light scattering and absorption in ice at short distances to better than 3% and determining energy scale using:

- monitored in-situ calibration light sources with known properties
 - low energy muons
- adopted from IceCube

Exploratory investigation: usage of Michel electrons for energy calibration in PINGU

MICHEL ELECTRONS FROM DECAYS OF STOPPED MUONS

Huge rate of atmospheric muons in IceCube / PINGU

Michel electrons with $E_{\max} = 53$ MeV reach distances up to 25 cm → directional "point" source of Cherenkov photons

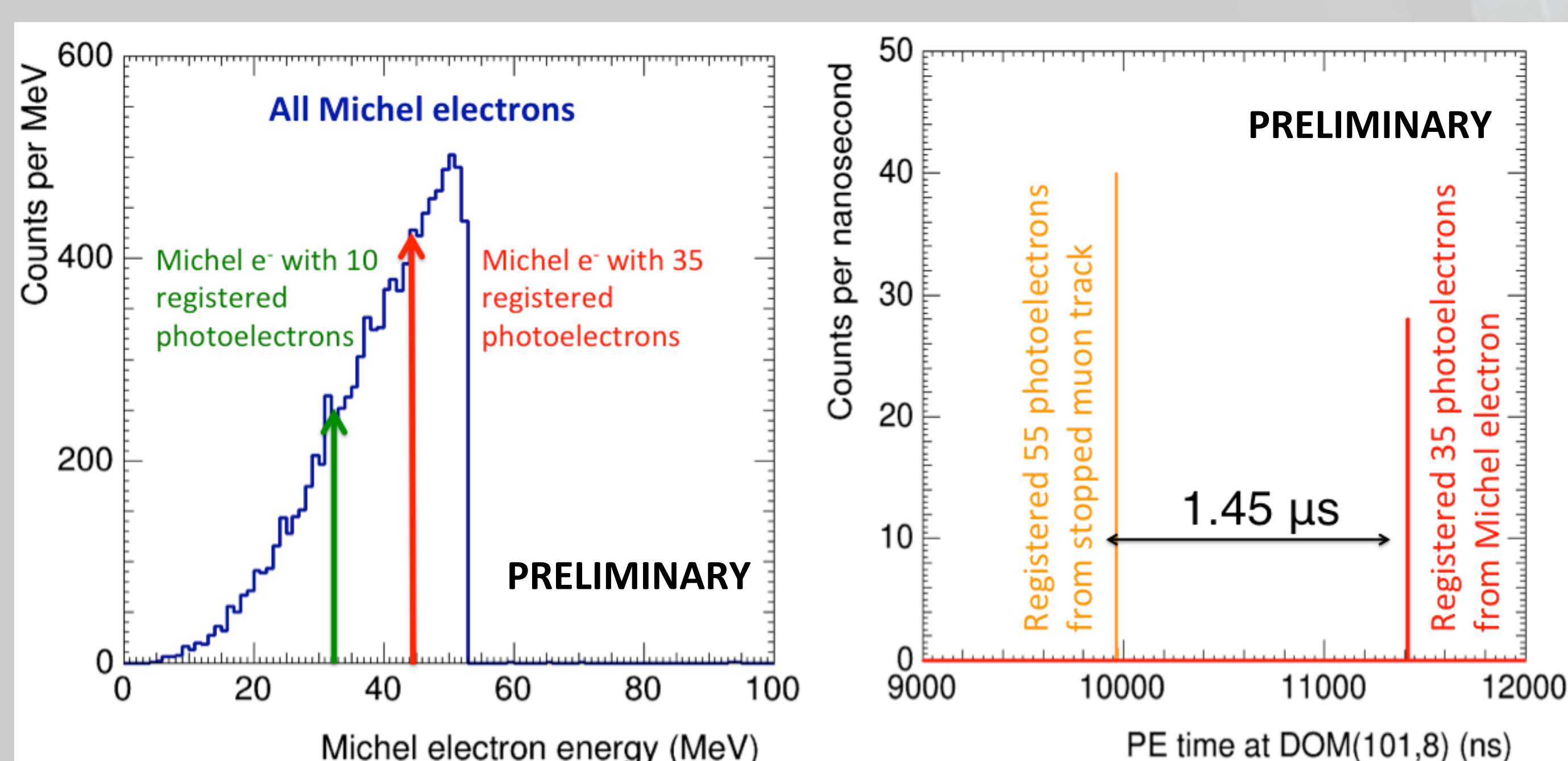
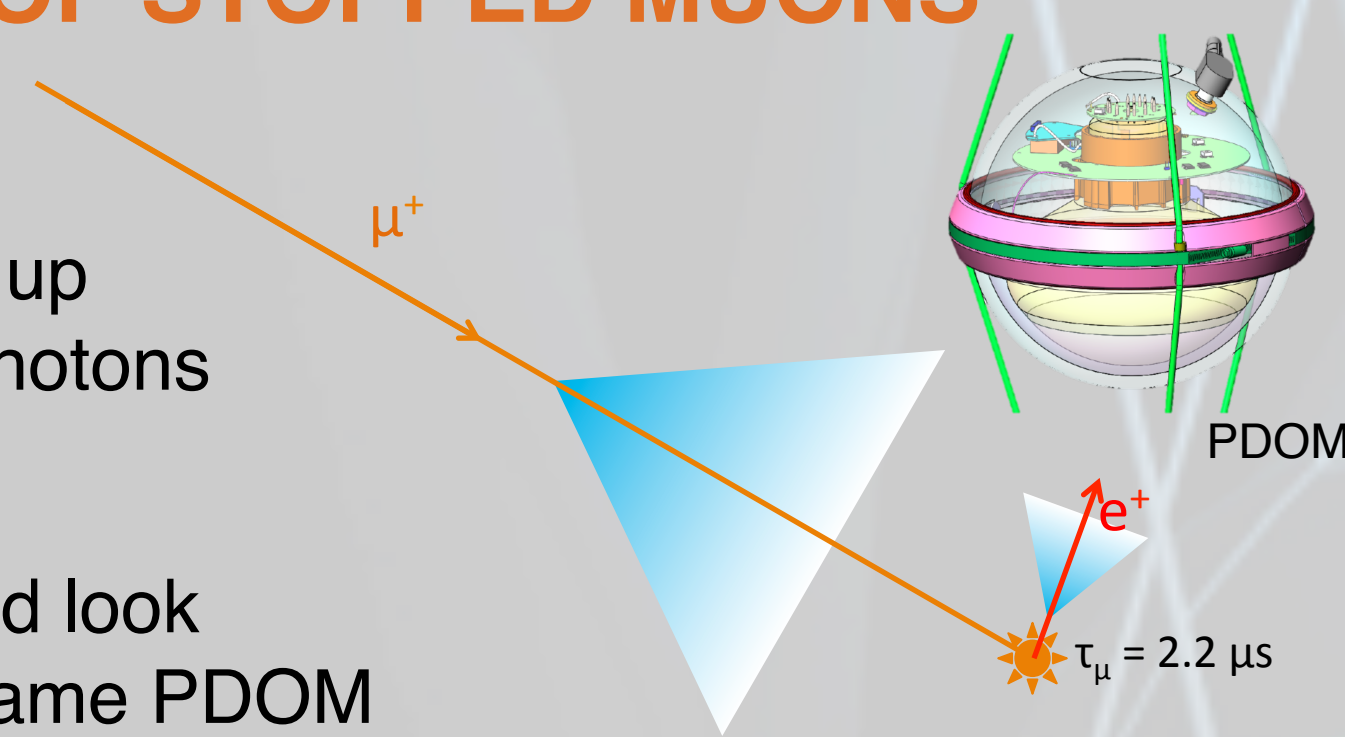
Signature → delayed light signal with $\tau_{\mu} = 2.2$ μ s

Strategy: identify stopped muon close to a PDOM and look for delayed Michel electron signal registered by the same PDOM

Preliminary result: found 2 candidates for "Michel calorimetry" in 1/2 hour of simulated data

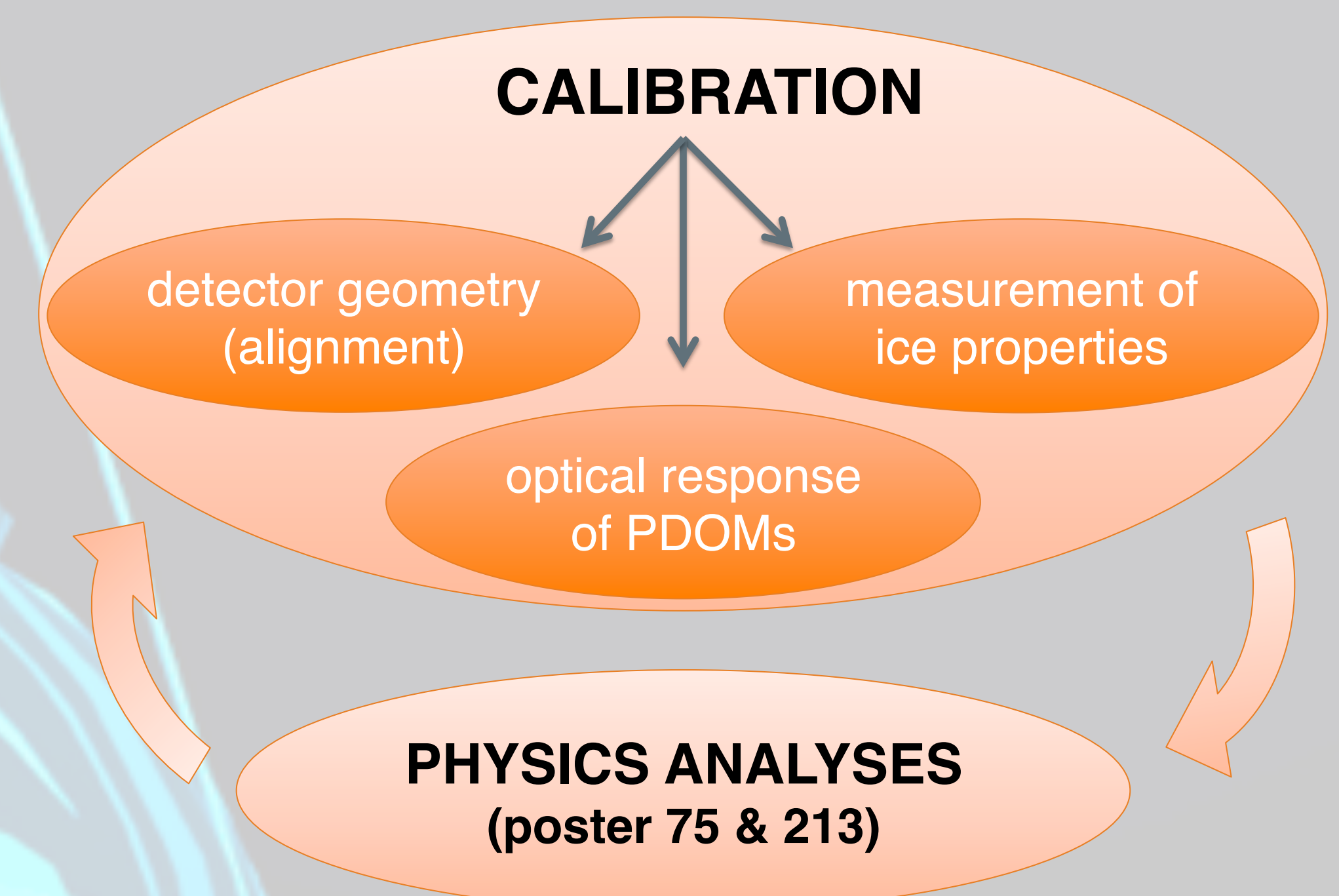
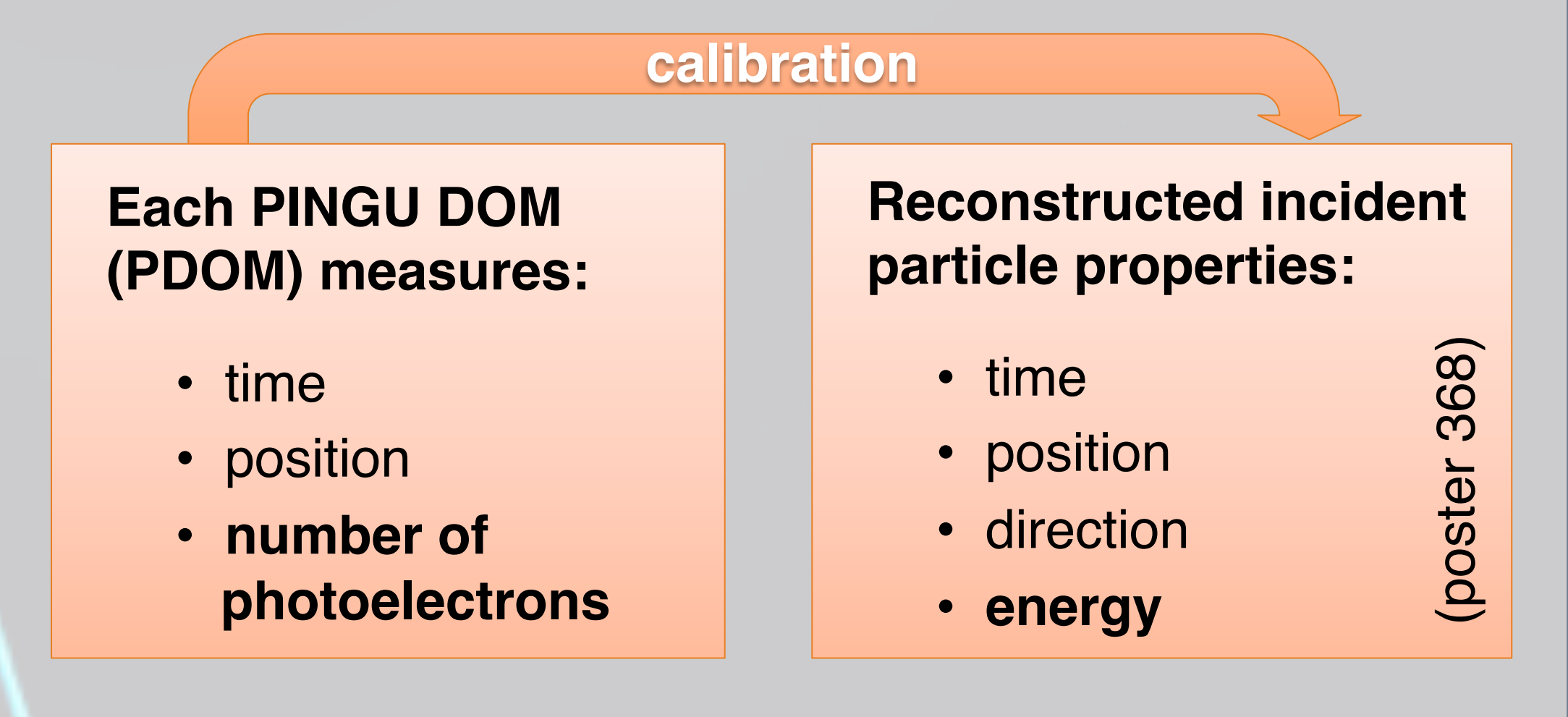
Outlook: study PDOM response to Michel electrons with dedicated simulation

Potential other uses: low energy muon PID and indication of muon stopping point



Left: Monte-Carlo true energy distribution of Michel electrons (blue). Colored arrows indicate the energy of found candidates for "Michel calorimetry" in 1/2 hour of detector lifetime. Right: Time of registering photoelectrons at the same PDOM from mother muon (orange) and delayed daughter Michel electron.

EVENT RECONSTRUCTION



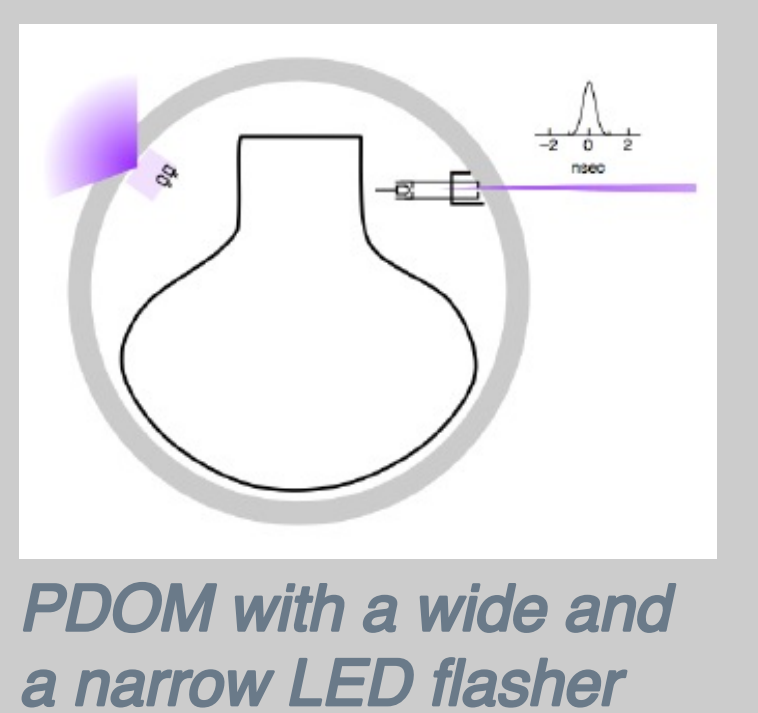
ARTIFICIAL CALIBRATION LIGHT SOURCES

LED "flashers" installed in every PDOM

Experience gained in IceCube shows that per-DOM LED "flashers" are very useful versatile devices for calibration.

PDOM "flasher" design is based on that of IceCube with proposed additional features:

- LED light output: individual calibration and monitoring (< 3%)
- LED direction (~1°) and a variety of orientations
- wide/narrow beam with short pulses (1-2 ns)



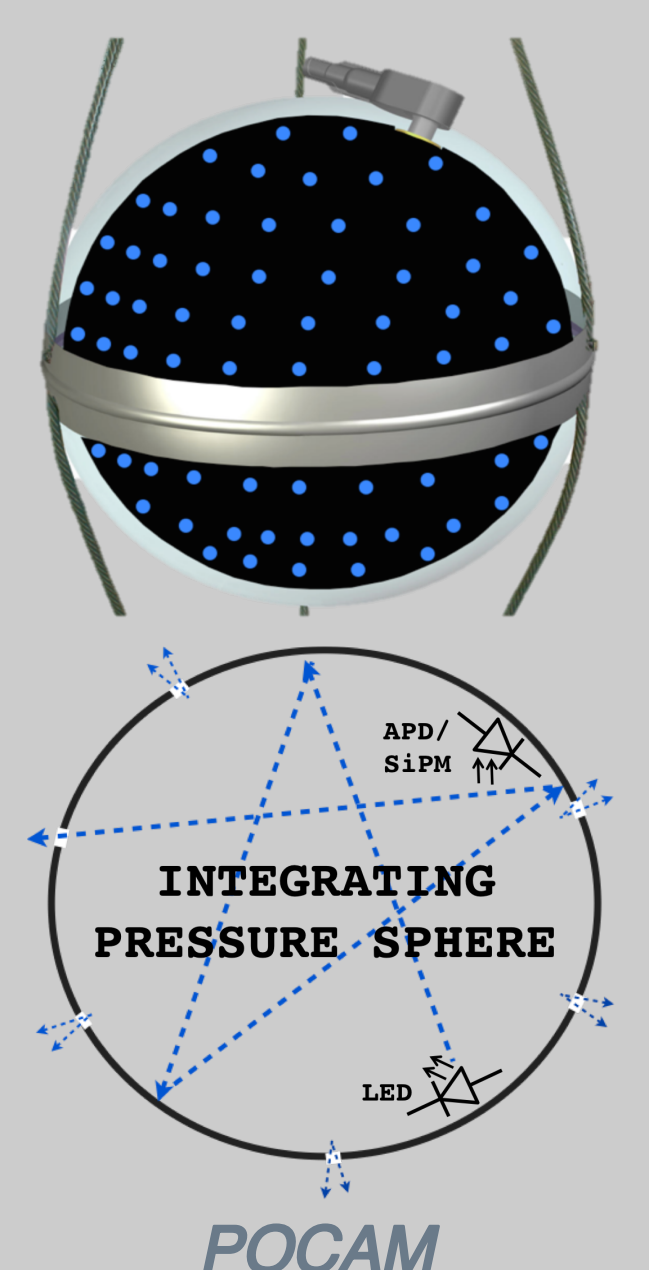
POCAM – a new Precision Optical CALibration Module

POCAM is a new diffuse light source proposed in addition to LED "flashers" and deployed 1 module per PINGU string

The goal is to uniformly illuminate a large volume at precision of ~1-2%

POCAM's features:

- multiport integrating sphere placed into IceCube pressure sphere
- multi-wavelength LED delivering light pulses of few tens of ns
- light detector (APD or SiPM) monitoring pulsed light emission



ACKNOWLEDGMENTS

We acknowledge the support from the following agencies: U.S. National Science Foundation-Office of Polar Programs, U.S. National Science Foundation-Physics Division, University of Wisconsin Alumni Research Foundation, the Grid Laboratory Of Wisconsin (GLOW) grid infrastructure at the University of Wisconsin - Madison, the Open Science Grid (OSG) grid infrastructure; U.S. Department of Energy, and National Energy Research Scientific Computing Center, the Louisiana Optical Network Initiative (LONI) grid computing resources; Natural Sciences and Engineering Research Council of Canada, WestGrid and Compute/Calcul Canada; Swedish Research Council, Swedish Polar Research Secretariat, Swedish National Infrastructure for Computing (SNIC), and Knut and Alice Wallenberg Foundation, Sweden; German Ministry for Education and Research (BMBF), Deutsche Forschungsgemeinschaft (DFG), Helmholtz Alliance for Astroparticle Physics (HAP), Research Department of Plasmas with Complex Interactions (Bochum), Germany; Fund for Scientific Research (FNRS-FWO), FWO Odysseus programme, Flanders Institute to encourage scientific and technological research in industry (IWT), Belgian Federal Science Policy Office (Belspo); University of Oxford, United Kingdom; Marsden Fund, New Zealand; Australian Research Council; Japan Society for Promotion of Science (JSPS); the Swiss National Science Foundation (SNSF), Switzerland; National Research Foundation of Korea (NRF); Danish National Research Foundation, Denmark (DNRF).