Calibration strategy in ice

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IceCube

Precision IceCube Next Generation Upgrade

Bundesministerium für Bildung und Forschung

Excellence Cluster Universe

TUM LMU ESO

Technische Universität München

Outline

Antarctic ice is a special detector medium

IceCube calibration program: current status and achievements

Measurements in the laboratory

Calibration plans for the future (PINGU)

Calibration of a detector deployed in natural ice

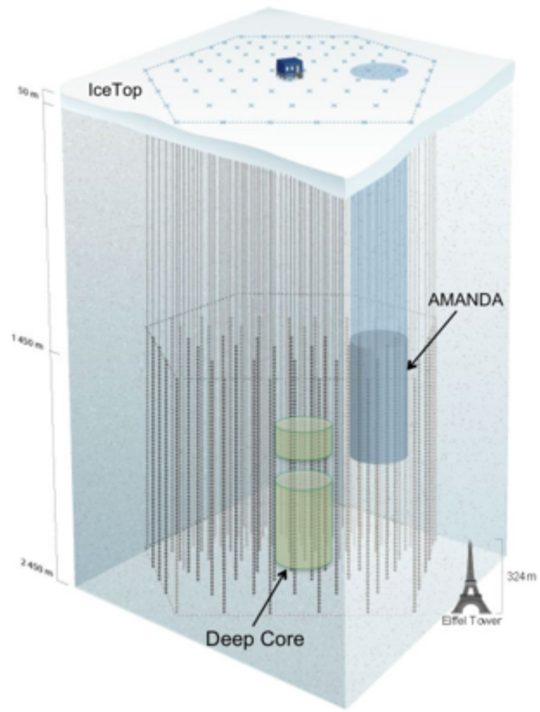
IceCube and its in-ice extensions is a grid of optical sensors in **natural Antarctic ice**

After deployment → no access to the deployed hardware

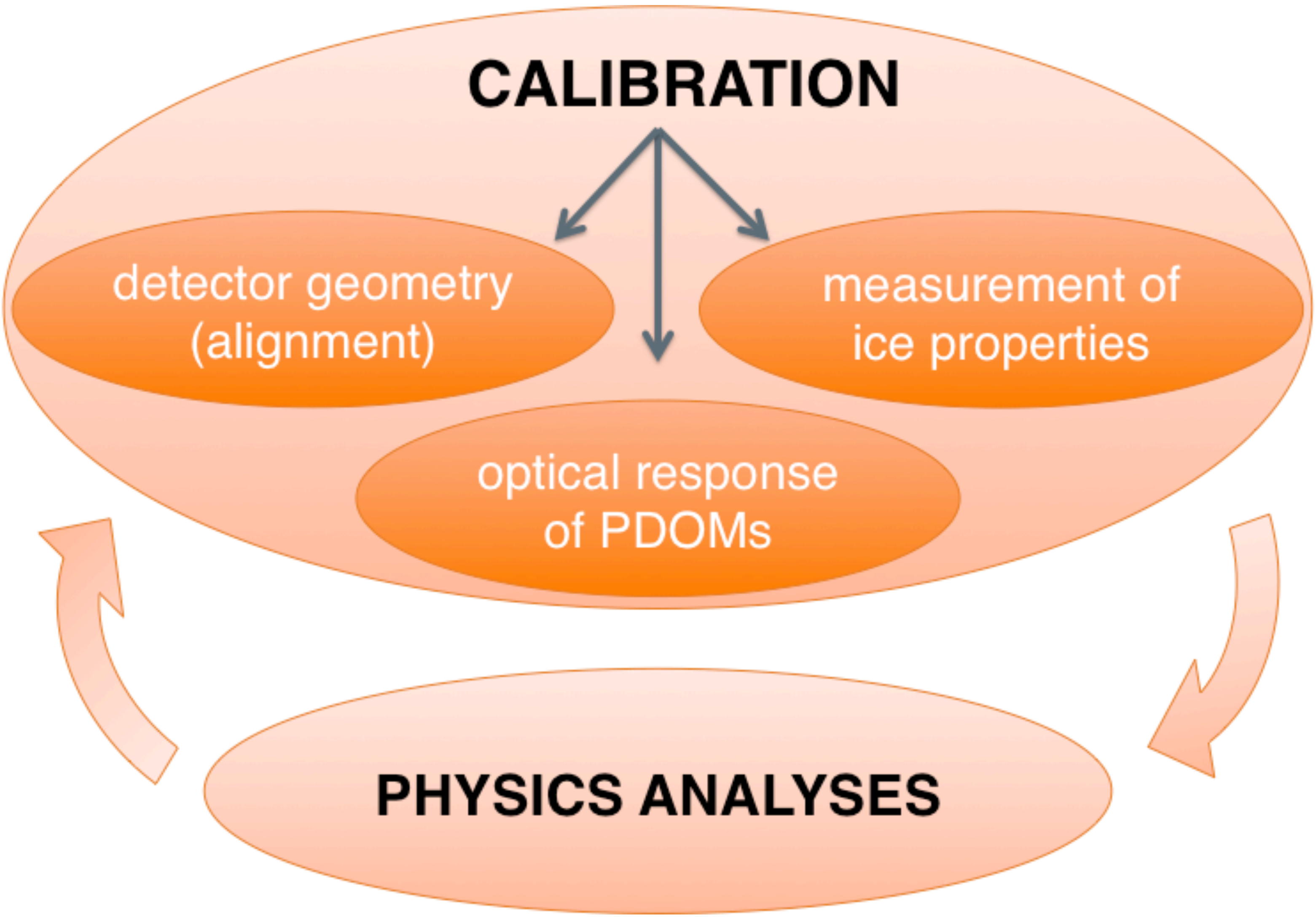
Detector calibration is an iterative process

Variety of tools for calibration

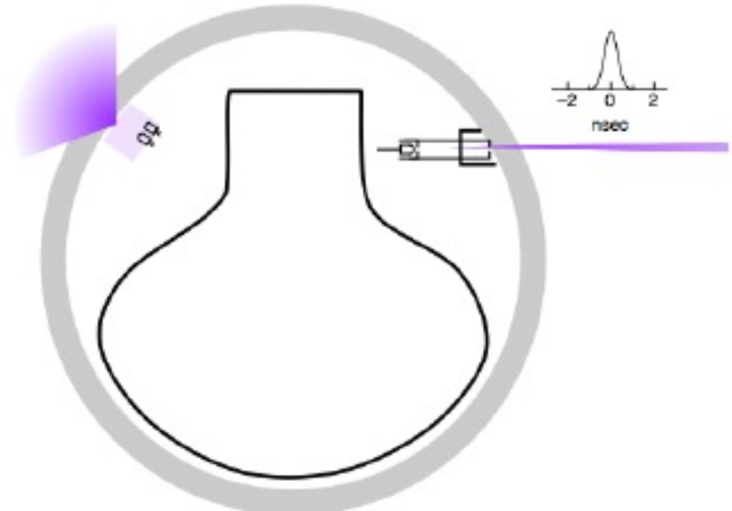
- Natural sources of Cherenkov light
- Artificial in-situ light sources and tools



Calibration is an iterative process



Geometry calibration



During deployment

- Survey data
- Pressure sensors
- Laser ranger for vertical DOM to DOM distance

After deployment use flashers to triangulate final DOM position and measure DOM orientation

Systematic uncertainties affect resolution and absolute energy scale

Bulk ice optical properties (scattering & absorption)

Hole ice

DOM efficiency & angular response

10 - 15 %

Current tools for calibration:

- **Minimum ionizing muons**
- **LED flashers (each DOM)**
- Hole ice camera on a string
- Dust logger and laser

+

Add in the future:

< 3 %

- POCAM
- Michel electrons
- Hole ice camera at each DOM
- **Degassing**

Calibration in the future and open questions (PINGU case)

Goal: to connect PINGU calibration precision to physics reconstruction precision

- How precise do we need to be to achieve physics goals?
- Can we demonstrate that precision in PINGU?
- Can we calibrate to that level?

Energy scale and resolution + angular resolution + geometry

- Main instrumental effects are DOM response and ice properties both local (hole) and global (bulk)

Studies in progress for updated PINGU LoI

Multiple cross-checks on energy scale at the few % level

Measurement of DOM sensitivity in laboratory (< 3%)

- Simulate photon interaction and photon transport

Calibration light sources measurement in laboratory (< 3%)

- Check in ice reconstruction for scale error
  - LED flashers
  - Precise diffuse light sources (POCAM)

Stopping low energy muons

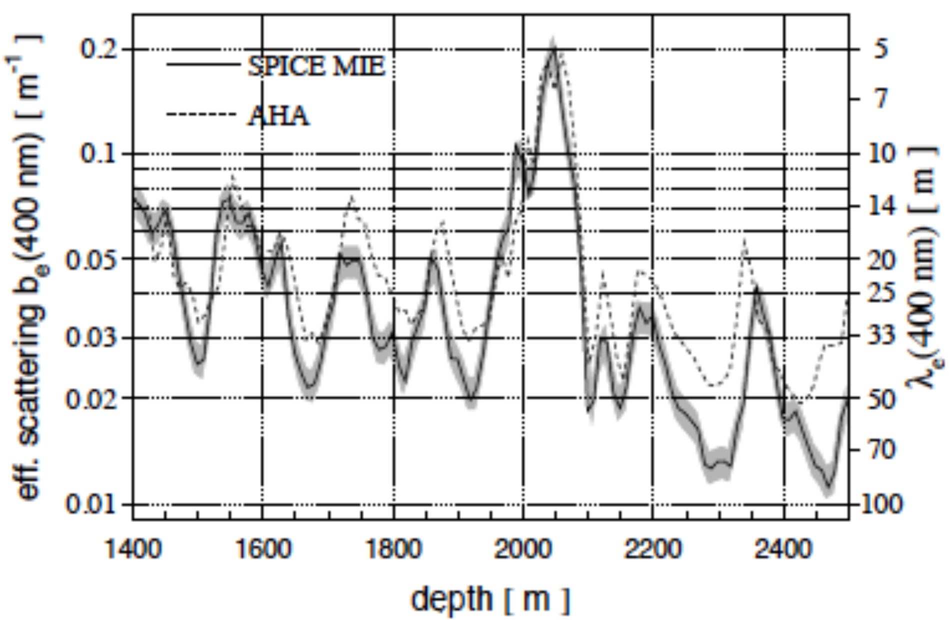
- Response as a function of distance from track
- New exploratory investigation: Michel electrons

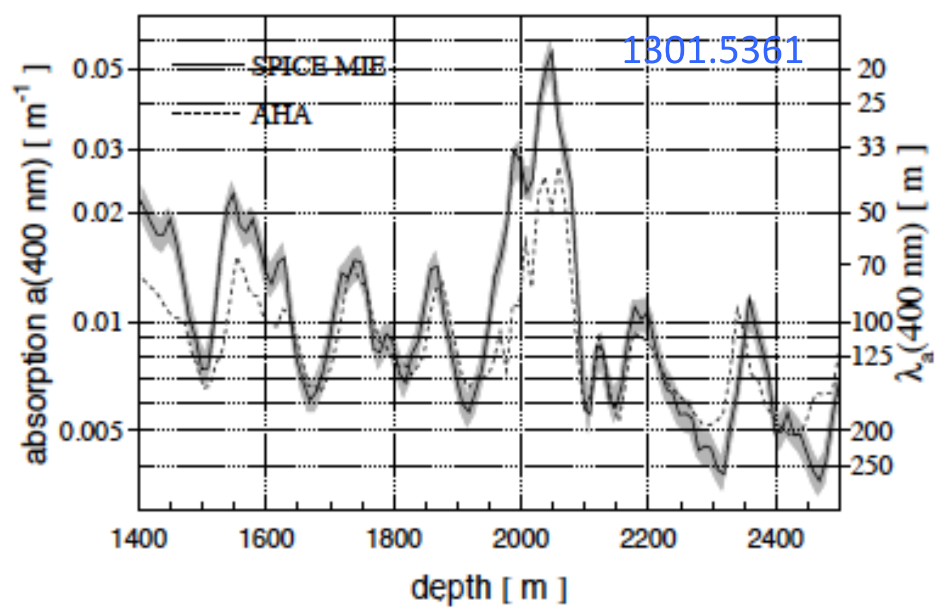
Example: evolution of bulk ice model error using LED flasher data

Model error → difference between received charge per DOM in simulation and data

IceCube ice models:

Model name	Year	New feature in ice model	Error
SPICE Mie	(2010)	ice layer tilt, fit to scattering function	29%
SPICE Lea	(2012)	fit to scattering anisotropy	20%





Strategy for addressing uncertainties in ice and DOM sensitivity

Use known sources of model error as a guide

- Reconstruct SPICE Lea simulation with SPICE Mie tables
  - Model error due to anisotropy, a proxy for unsimulated effects in the bulk ice

Reconstruct simulation with smeared individual DOM efficiencies

- Model error due to scatter in individual DOM efficiency is a proxy for unsimulated individual DOM effects based on the relative DOM efficiencies fits

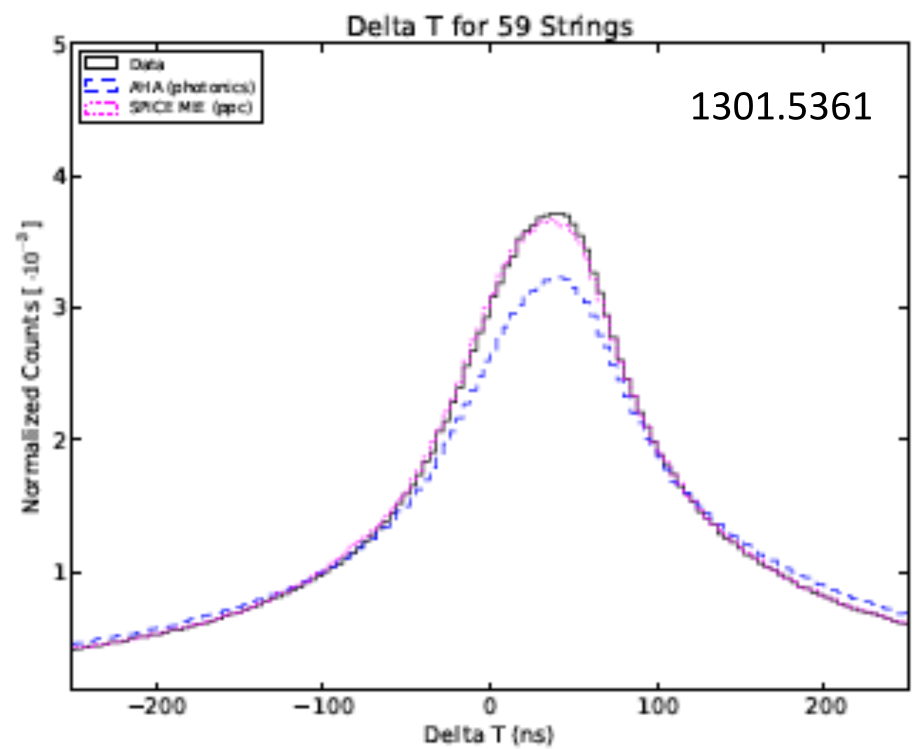
Strategy for addressing uncertainties in ice and DOM sensitivity → hole ice

Quantitative strategies for hole ice measurements

- Light from flasher received below/above flasher
- Δt distribution of direct hits from muons (sensitive to scattering function)

Qualitative strategy

- Camera measurement



It is great to have eyes in the ice: camera system on each DOM (present and future)

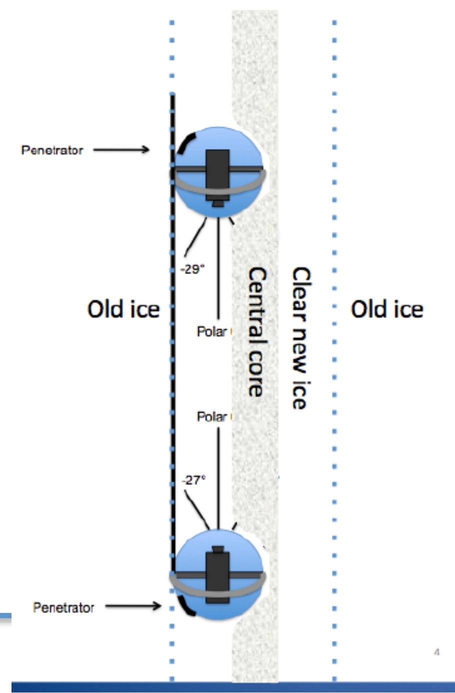
See local variations in light propagation (becoming important)

Environment of each DOM can be significantly different

Camera can help answer questions:

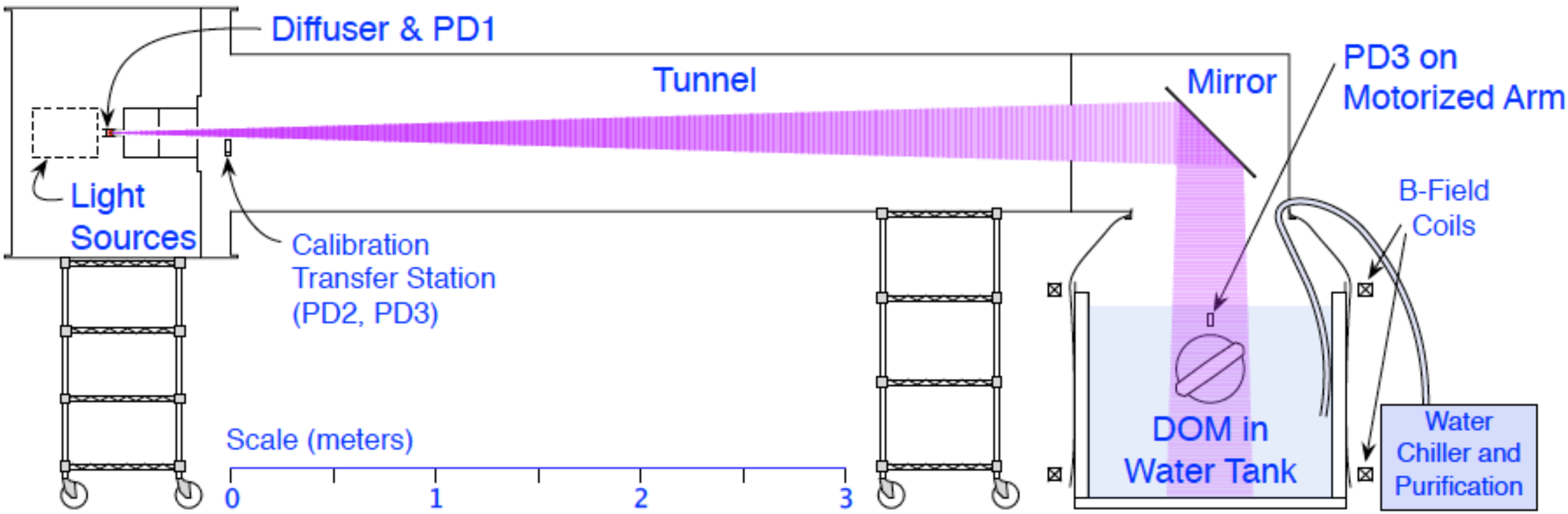
- DOM orientation & position with respect to the hole ice?
- Are there any impurities, cracks, bubbles, ...
- Where is the cable located ?
- Quantify DOM-DOM variation
- Dust deposition on DOM surface
- …

Camera system in IceCube



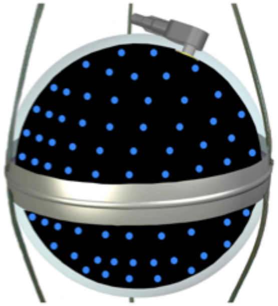
New DOM calibration facility at UW Madison to measure DOM optical sensitivity

Multi-wavelength light monitored by 3 photodiodes



Targeted precision: < few %

POCAM - Precision Optical CAlibration Module (1 per string)



Multiport integrating sphere (in existing IC pressure sphere)
uniformly illuminating large detector volume at precision of 1-2%

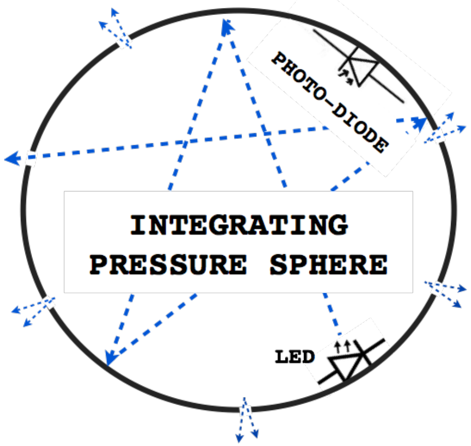
Whole interior covered with a diffuse white reflective coating

- barium sulfate, teflon, tyvek, …

Light source – intense & fast multi-wavelength LEDs

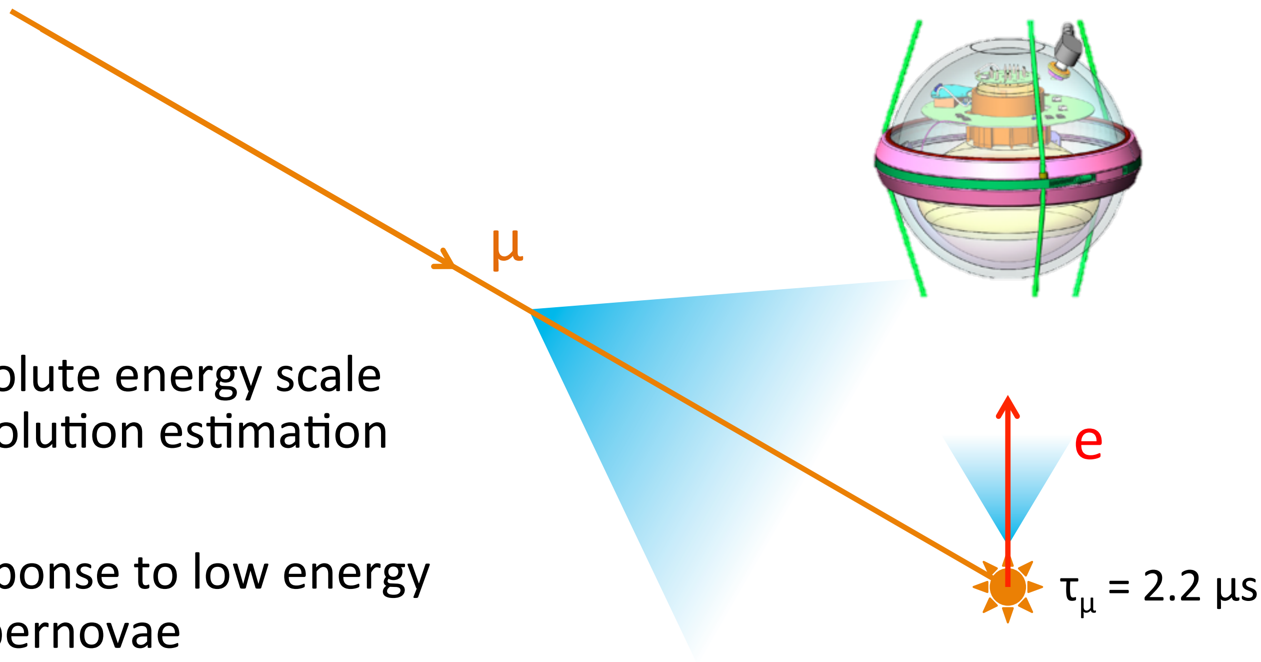
Light detector – photodiode (small area → high speed)
– SiPM (reduced after-pulsing & crosstalk → expensive)

Electronics for self-monitoring
photons / pulse / port, pulse time, pulse shape, …



Can we make use of Michel electrons in ice?

Study detector response to low energy charged leptons



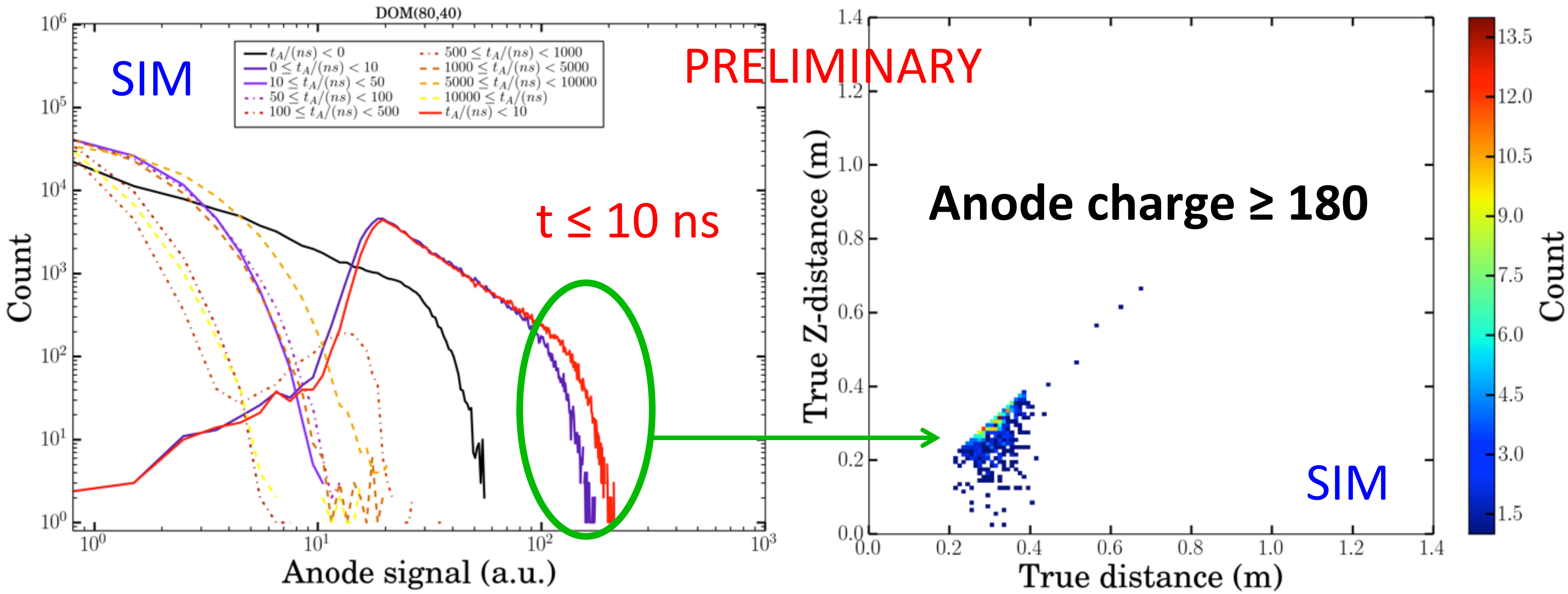
Why?

- Open doors to absolute energy scale calibration and resolution estimation
- PID
- Study detector response to low energy neutrinos from supernovae
- DOM by DOM hole ice variation

Muon background simulation: 2 interesting events / 0.5 h

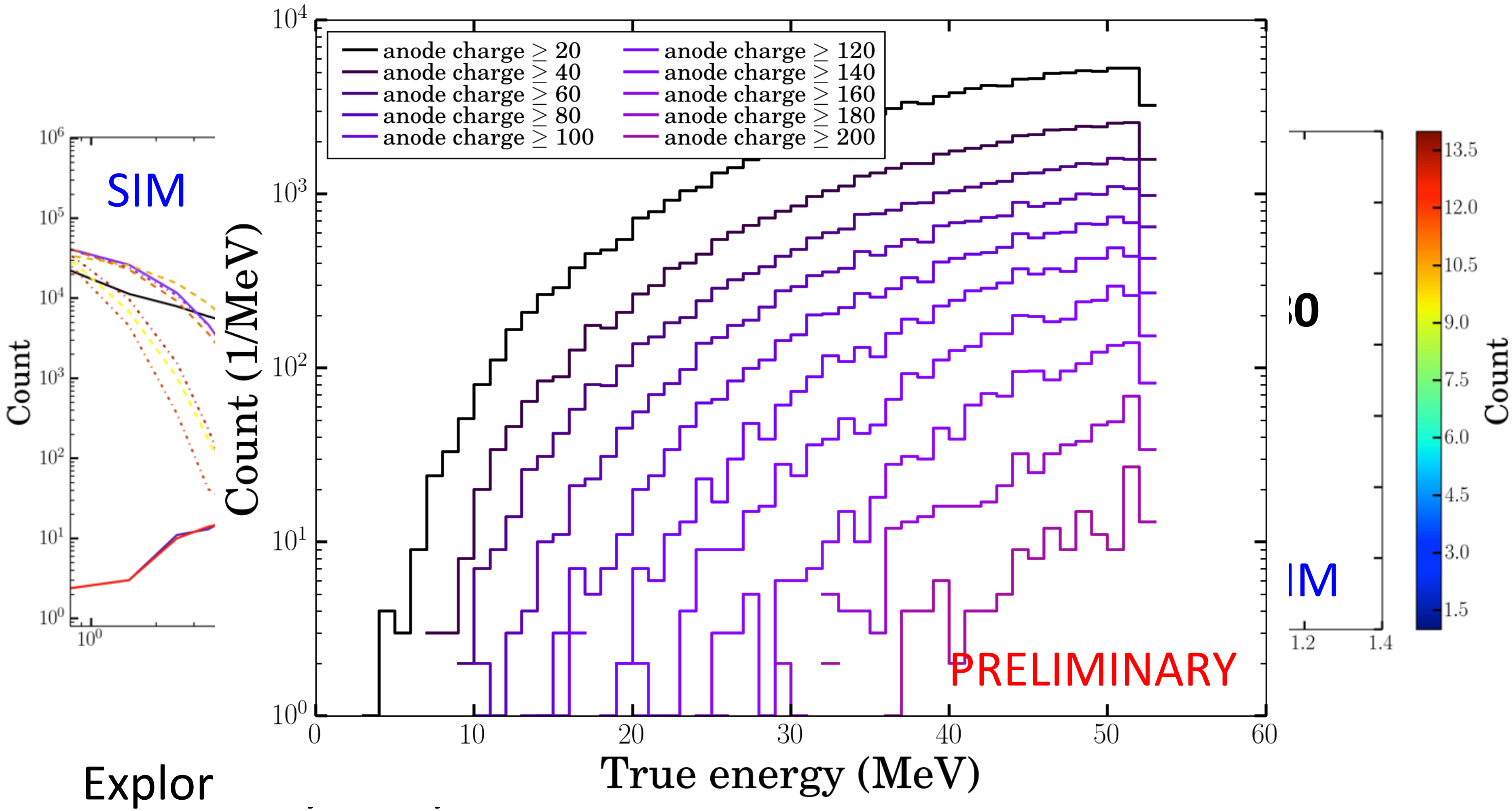
But… It's definitely challenging

Only Michel electrons with vertex very close to a DOM produce signals with large amplitude



Exploratory study

Only Michel electrons with vertex very close to a DOM produce signals with large amplitude



Conclusions

Huge progress

Calibration of IceCube detector is an ongoing iterative process

Calibration in IceCube is an interplay of a variety of tools (LED flashers, LE muons, in ice camera,…)

New calibration devices / techniques are considered for IceCube future extensions (per DOM camera, POCAM, Michel electrons…)

Work ongoing…

Ice scattering anisotropy in SPICE Lea