Calibration strategies for Hyper-Kamiokande

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Workshop on the evolution of advanced electronics and instrumentation for Water Cherenkov experiments
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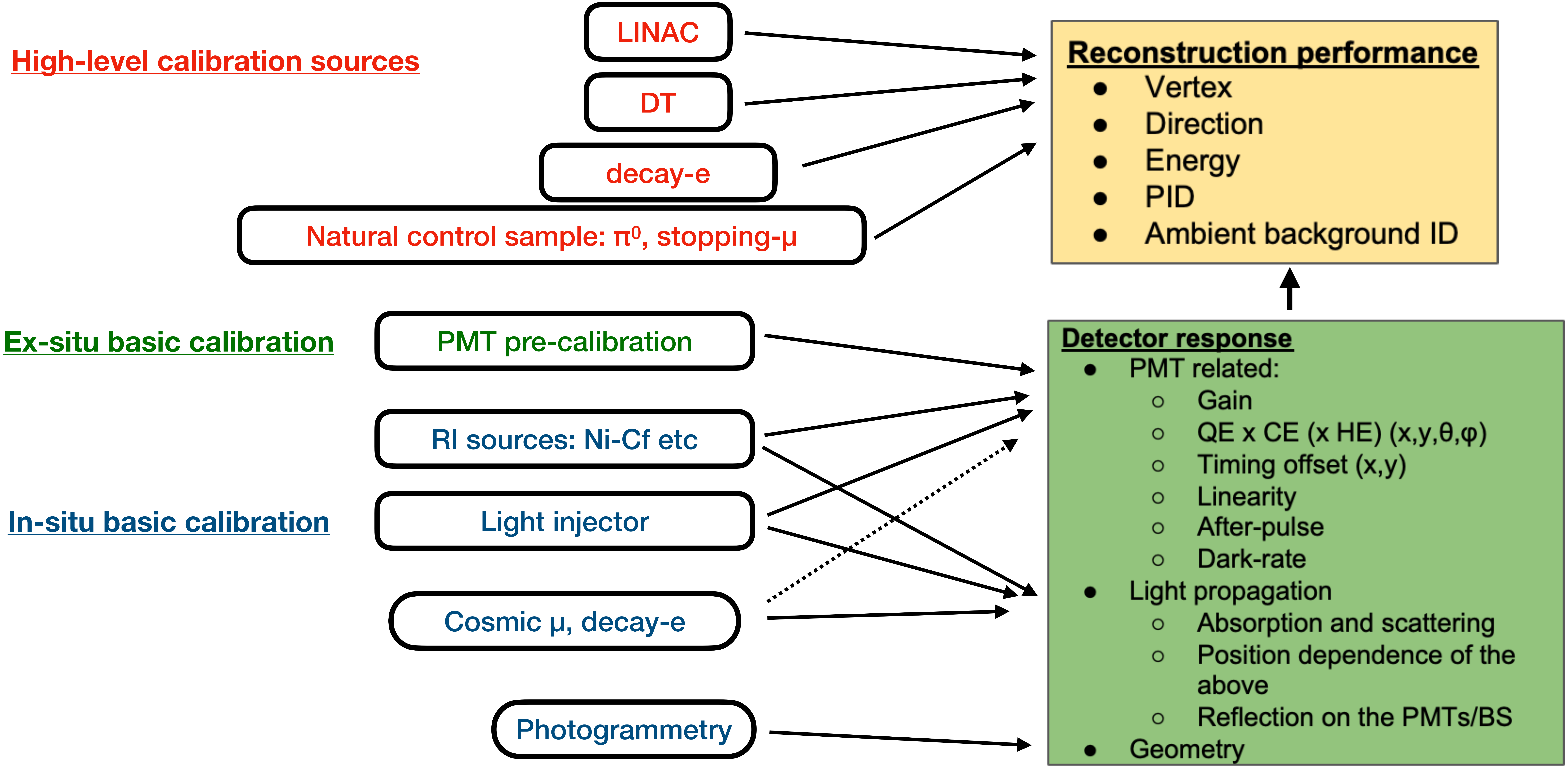
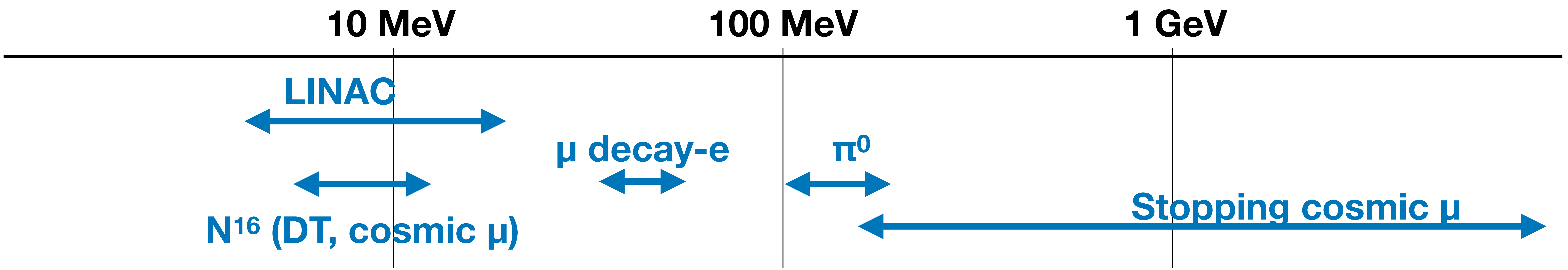
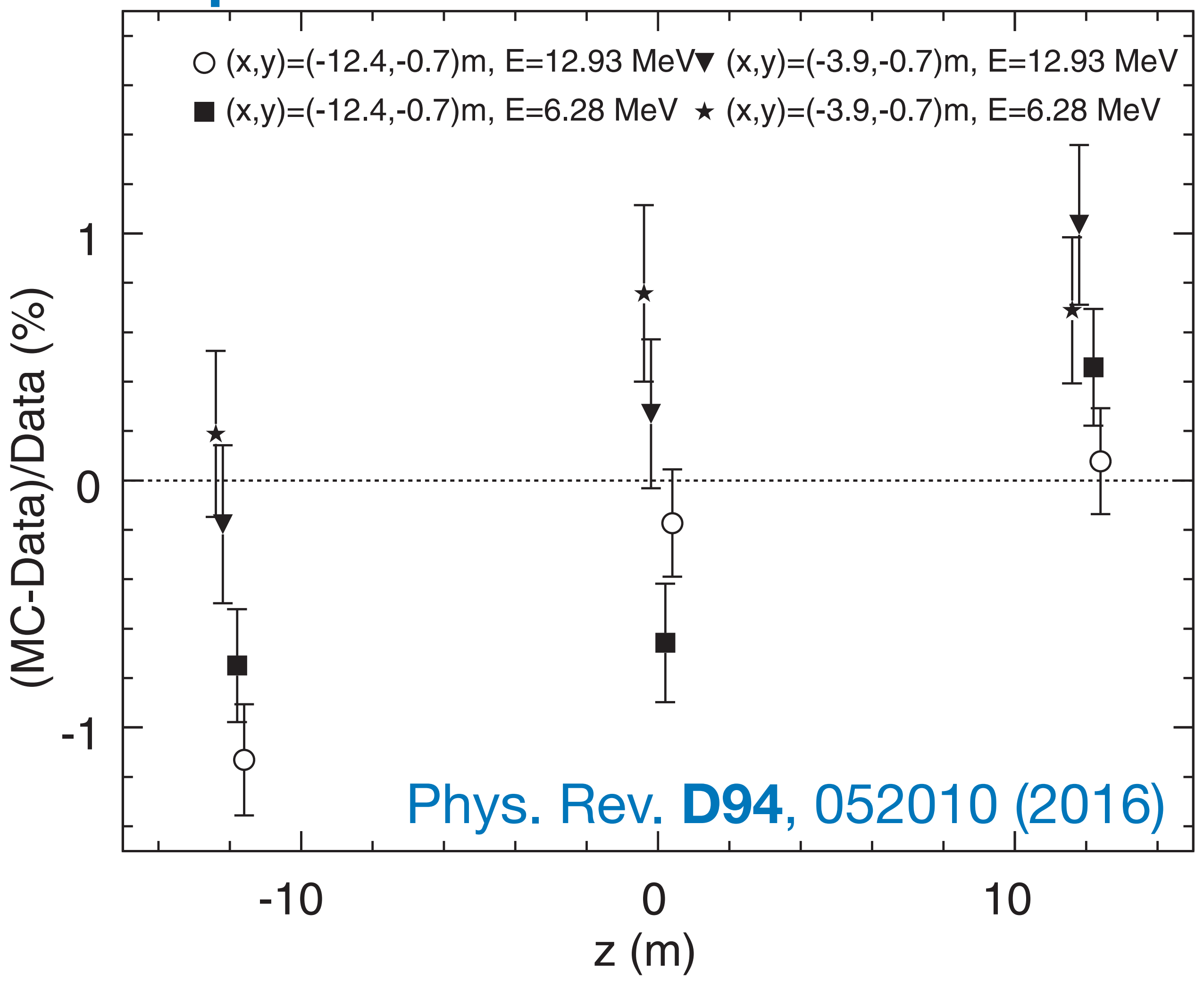
Calibration methods overview

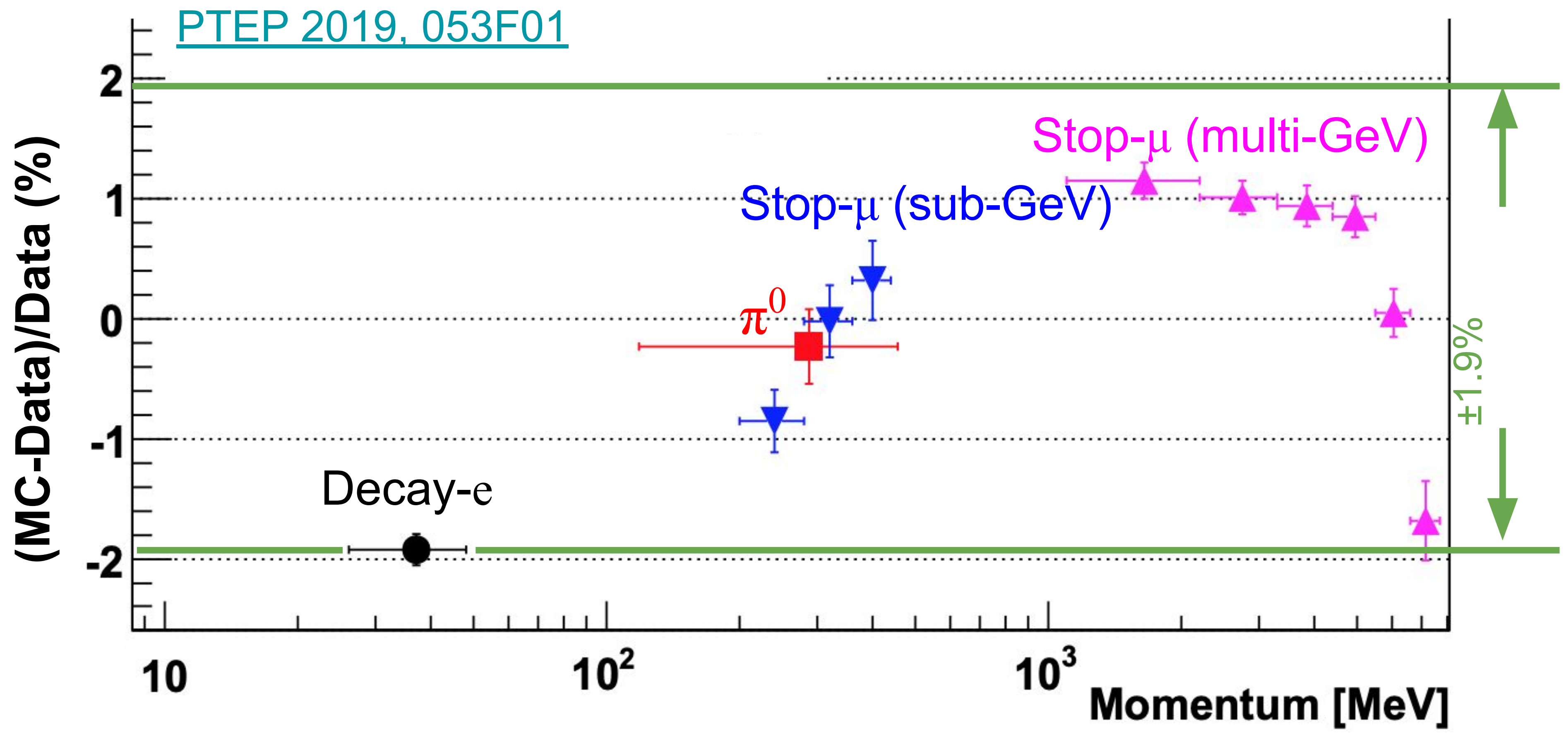


High-level calibration: absolute energy scale



Super-K LINAC

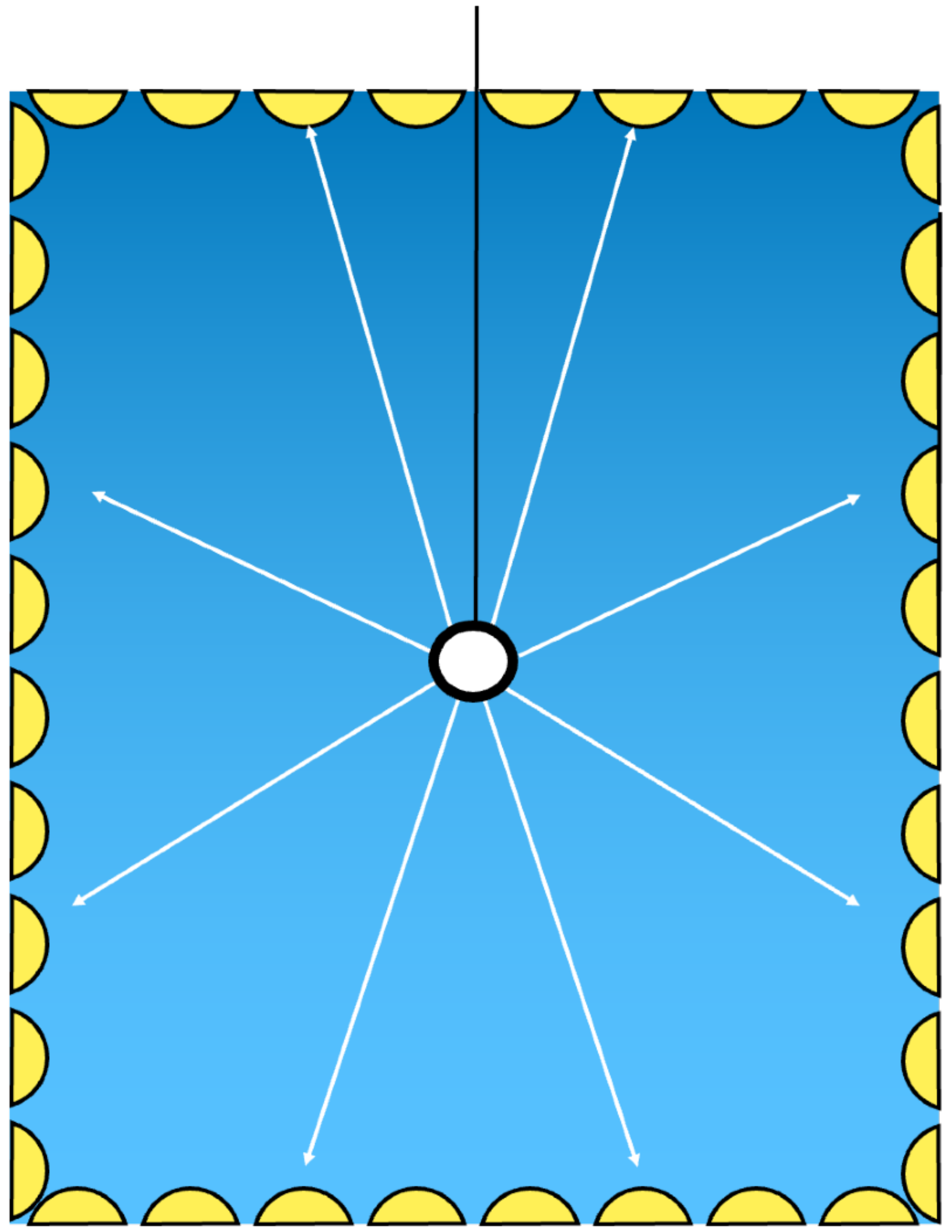




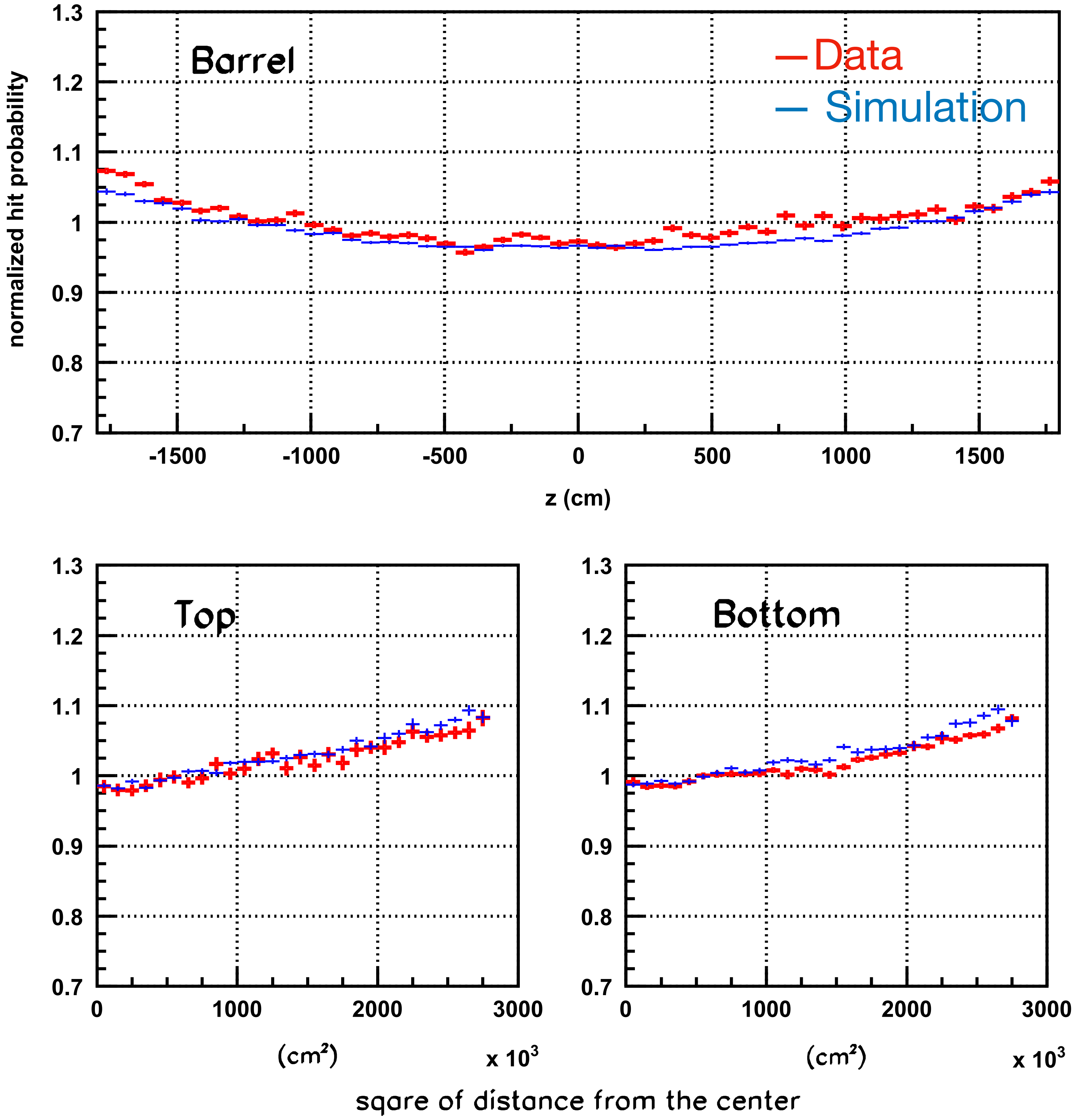
- Many absolute energy calibration methods to cover the wide range of energy
- Essential for setting absolute scale, but often limited with position, direction or statistics
- To further improve, better understanding of basic detector response is essential

Basic calibration example: PMT detection efficiency

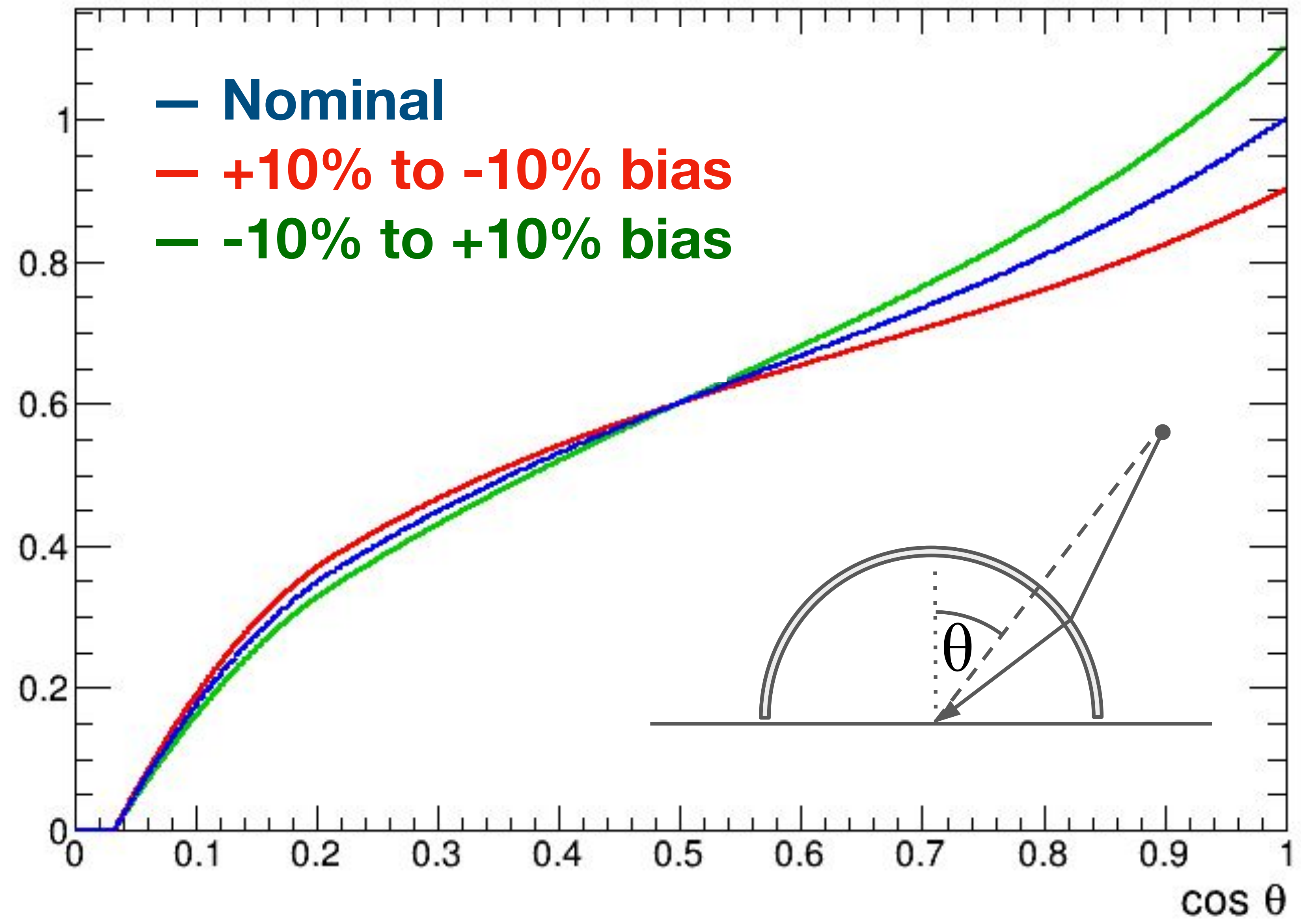
- Relative PMT detection efficiency measurement with a light source at the detector center (like Super-K)
- Uniform Cherenkov light from a Ni-Cf source
- 1% level statistical precision achievable
- Systematic uncertainties remain due to degeneracies of:
  - PMT angular response
  - Light attenuation in water



Super-K measurement:
Nucl. Inst. Meth. A **737** (2014) 253–272

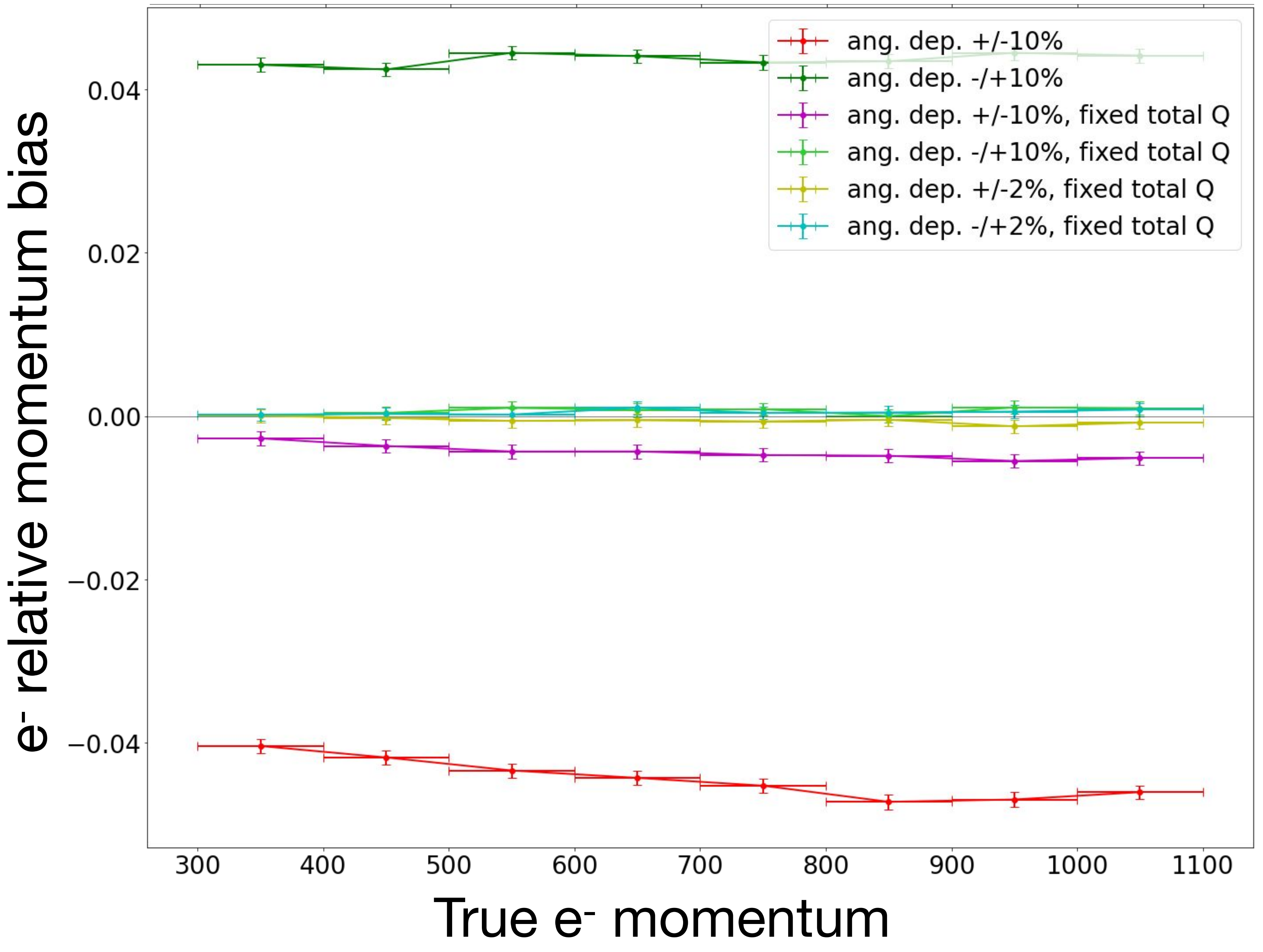


Effect of PMT angular response

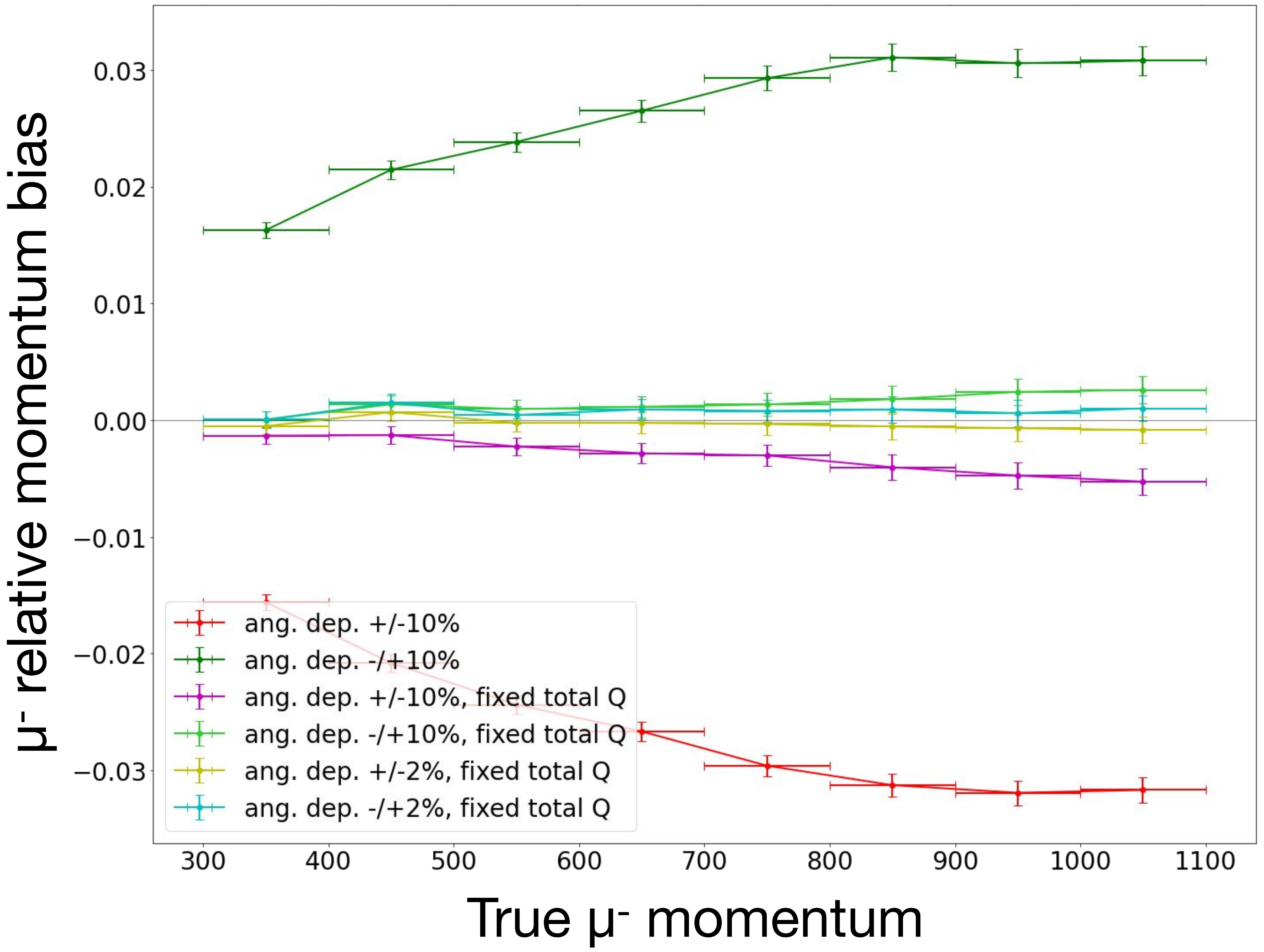


- Studying impact of varying detector response to reconstruction with simulation
- 10% bias in angular response results in a % level momentum bias, even after normalizing with total charge

Relative electron momentum reconstruction bias



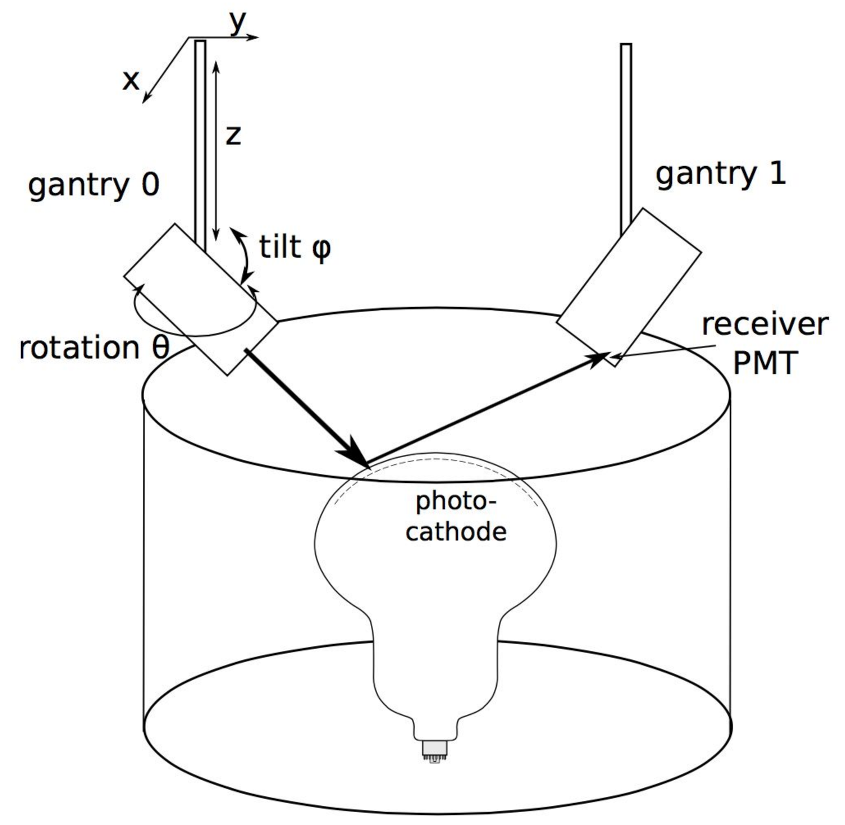
Relative muon momentum reconstruction bias



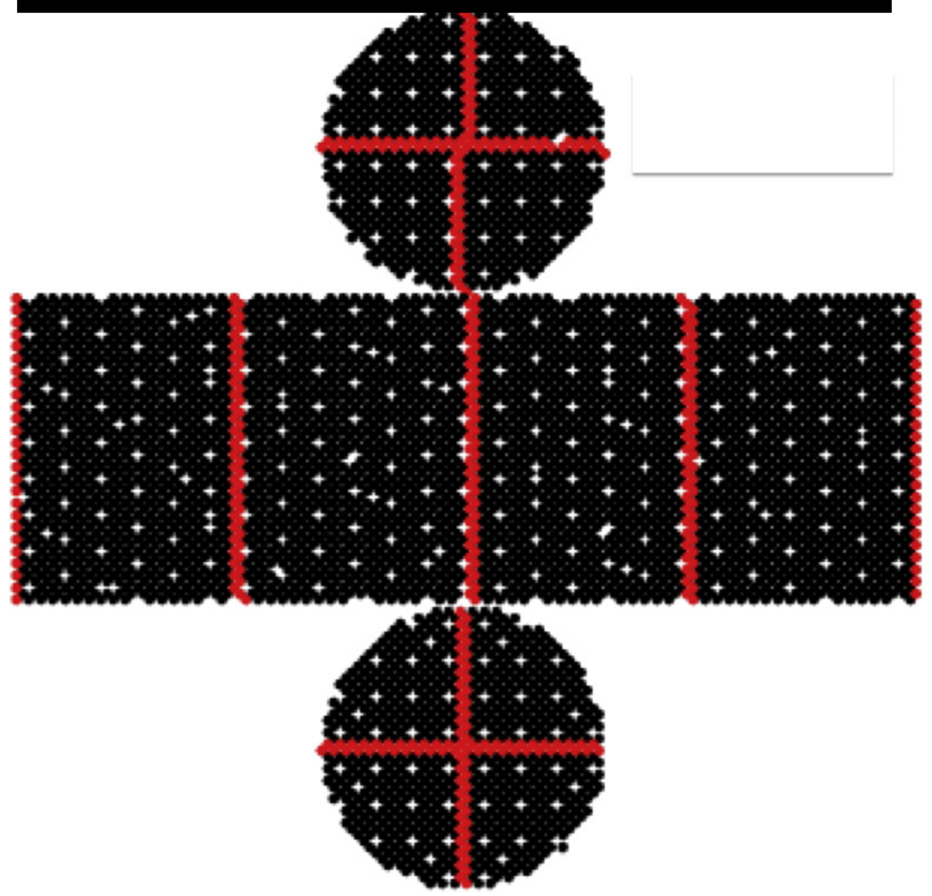
How to resolve the degeneracies

PMT pre-calibration

- Make detailed measurement of responses prior to the installation for subset of the PMTs
  - Better characterization of PMT response
  - Act as “Standard PMTs” after installation to the detector



Location of the “standard PMTs” in Super-K



Cross-calibration with mPMT

- mPMTs have advantages of:
  - Large variety of PMT pointing direction

    ➡Disentangle PMT angular response and light traveling direction
  - Better timing resolution

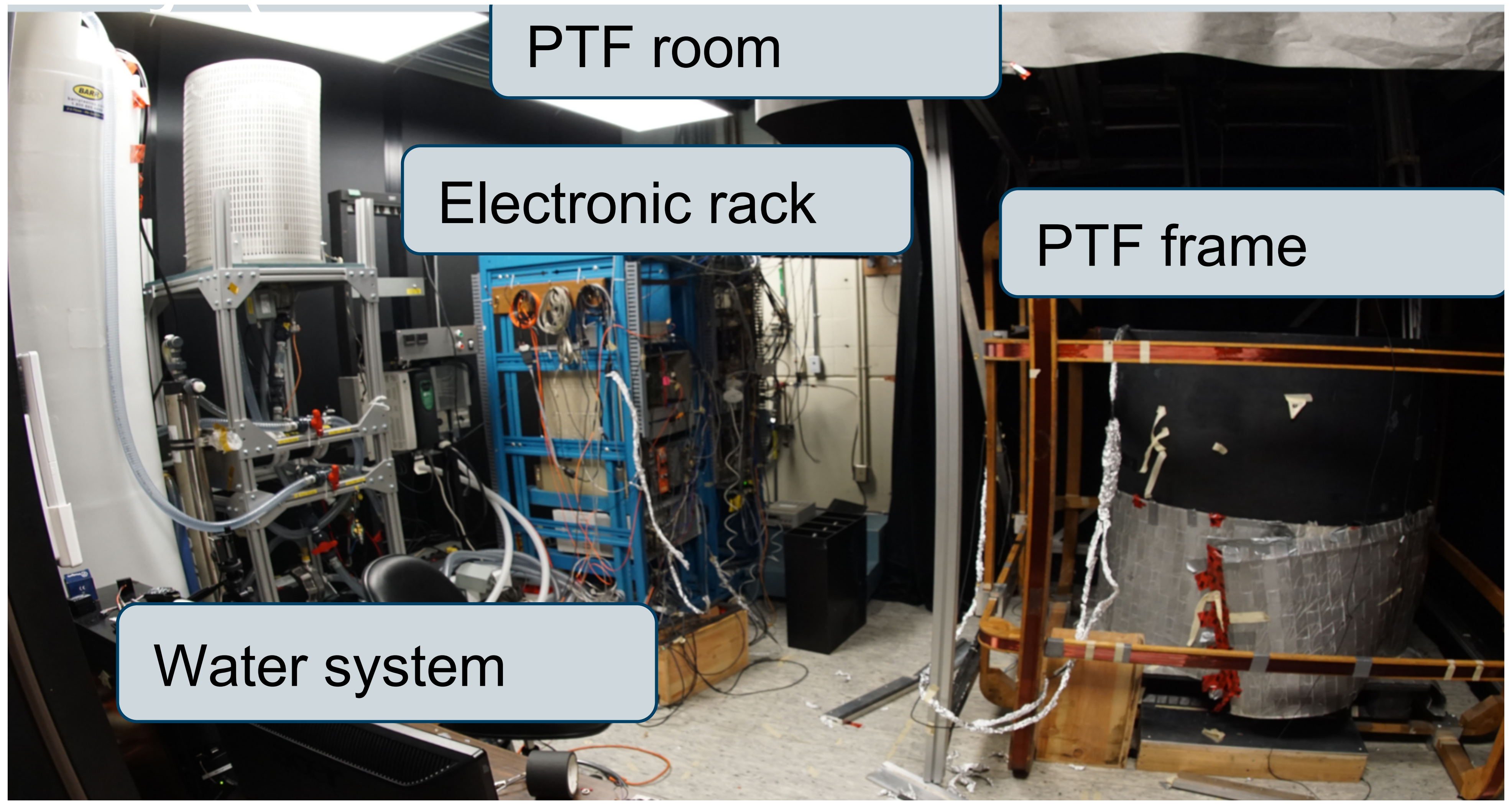
    ➡Better separation of indirect photons

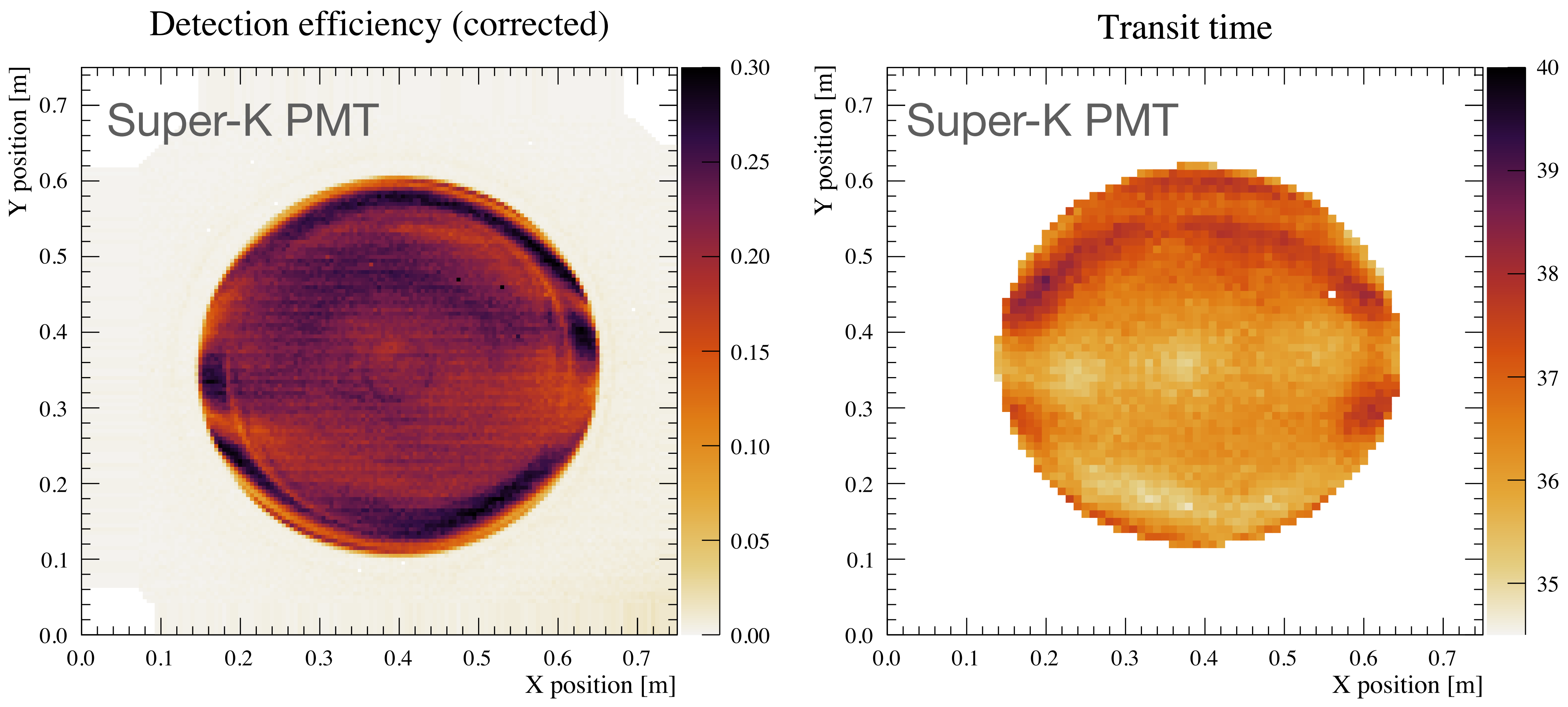
PMT pre-calibration

- Two major efforts:
  - A very detailed PMT response characterization at the Photomultiplier Testing Facility (PTF) at TRIUMF
  - Simpler, but larger volume measurements at Kamioka
- PTF currently measuring a Super-K PMT. Almost ready to start Hyper-K PMT measurements.
- Already produced Hyper-K PMTs being measured at Kamioka
  - Learning their basic characteristics (gain, timing response, dark rate, after pulse, B-field dependence, long-time stability etc)

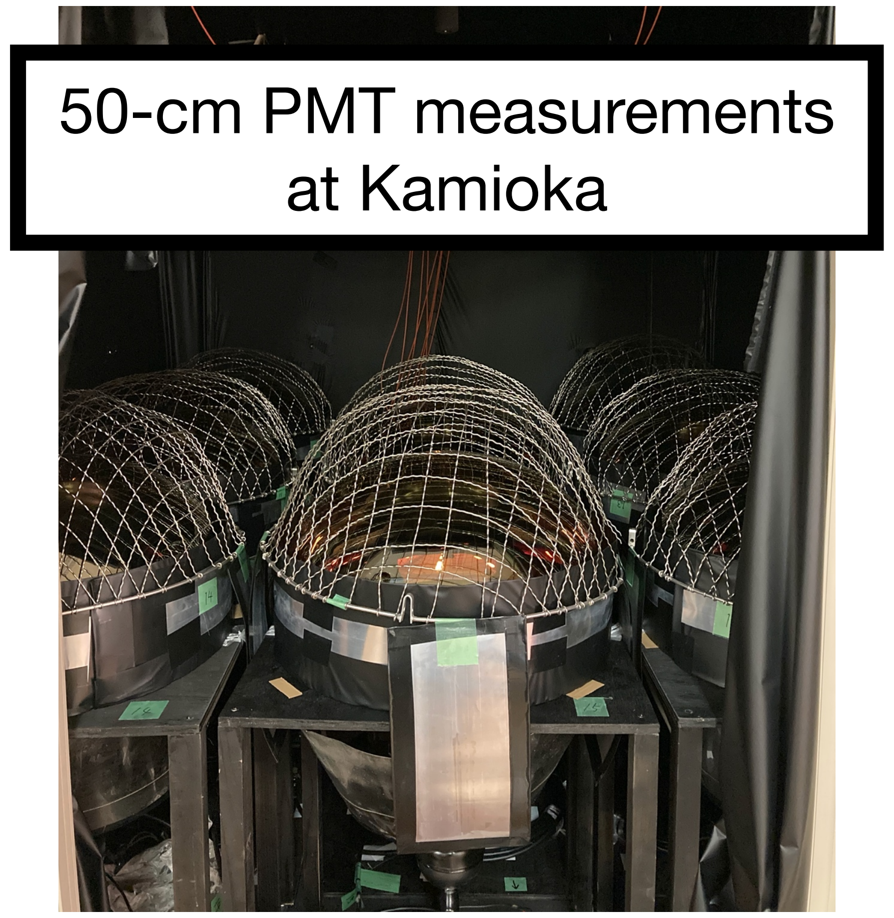
Developing pre-calibration program

Photomultiplier Testing Facility at TRIUMF



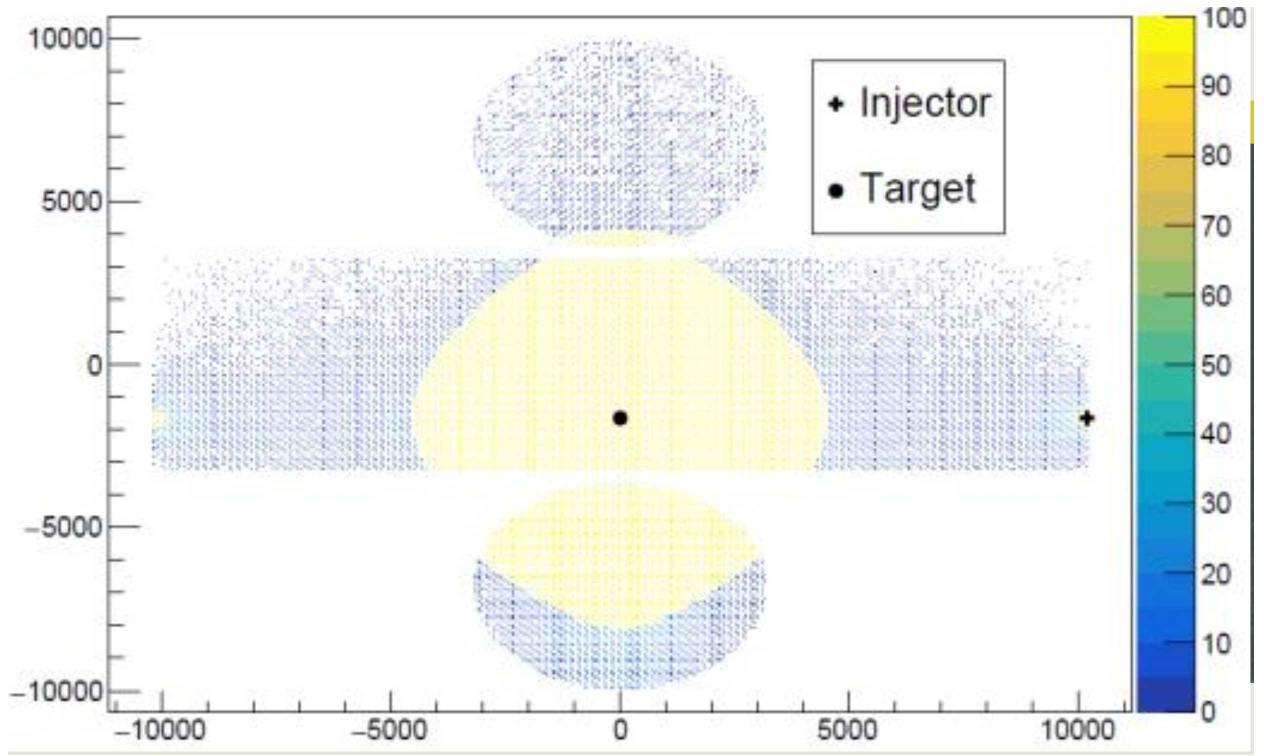


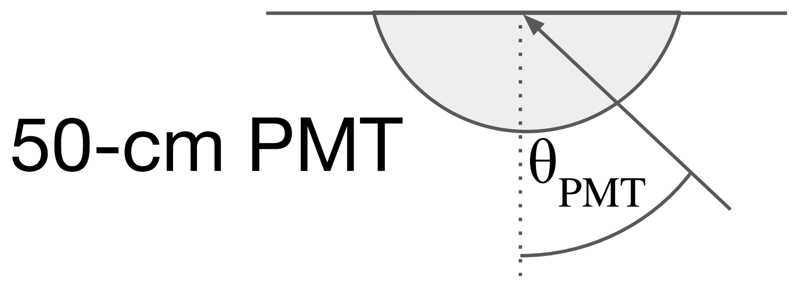
50-cm PMT measurements at Kamioka

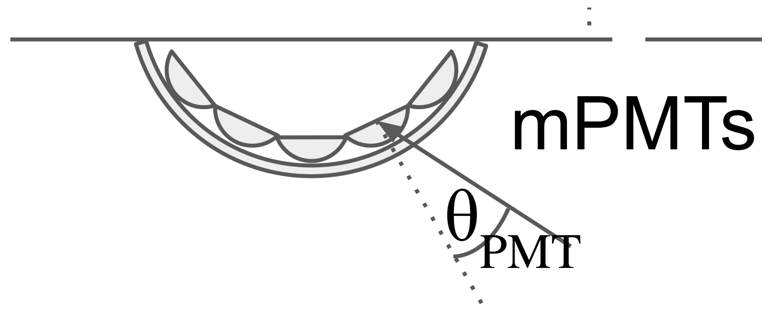


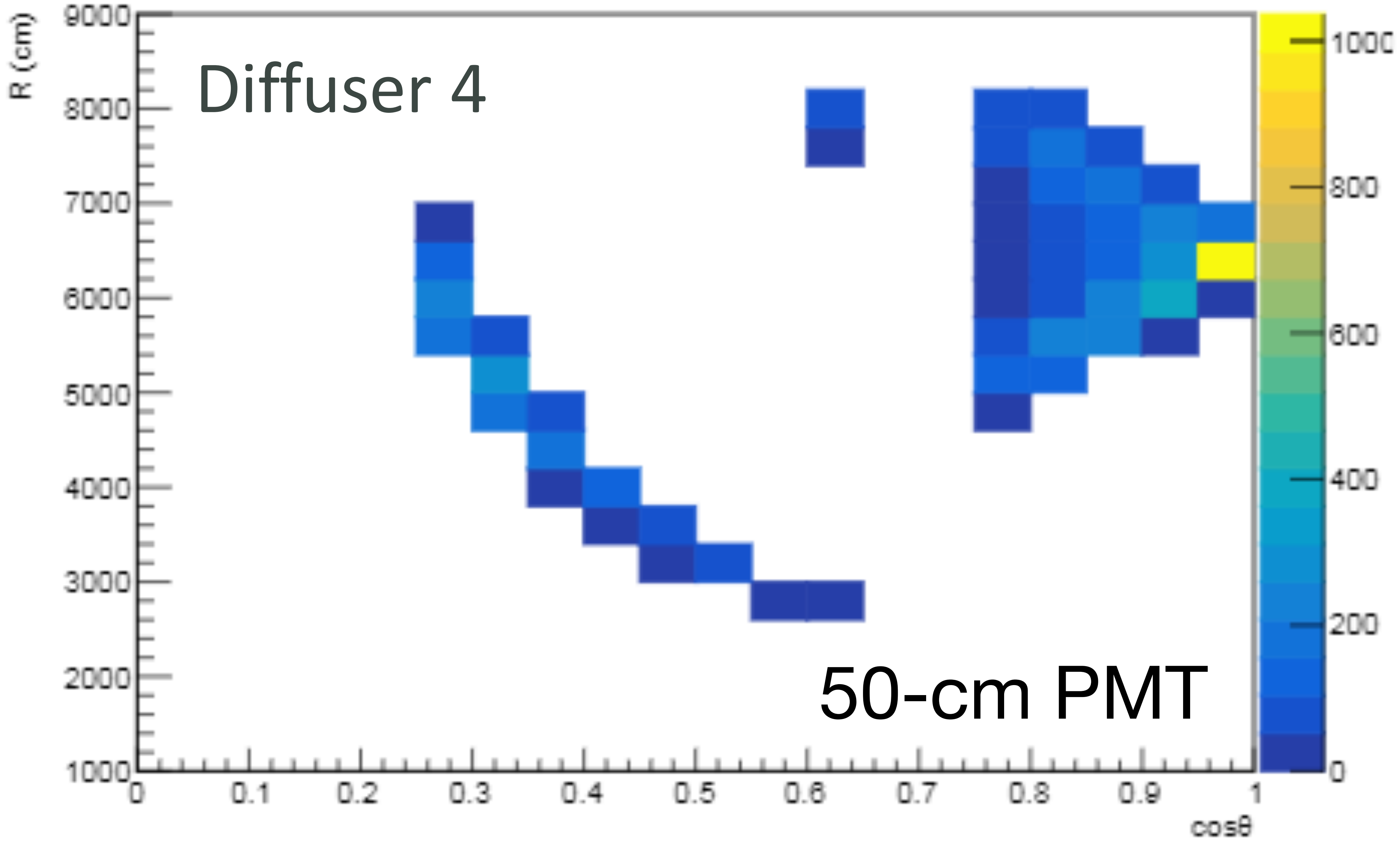
Light attenuation measurement with mPMT

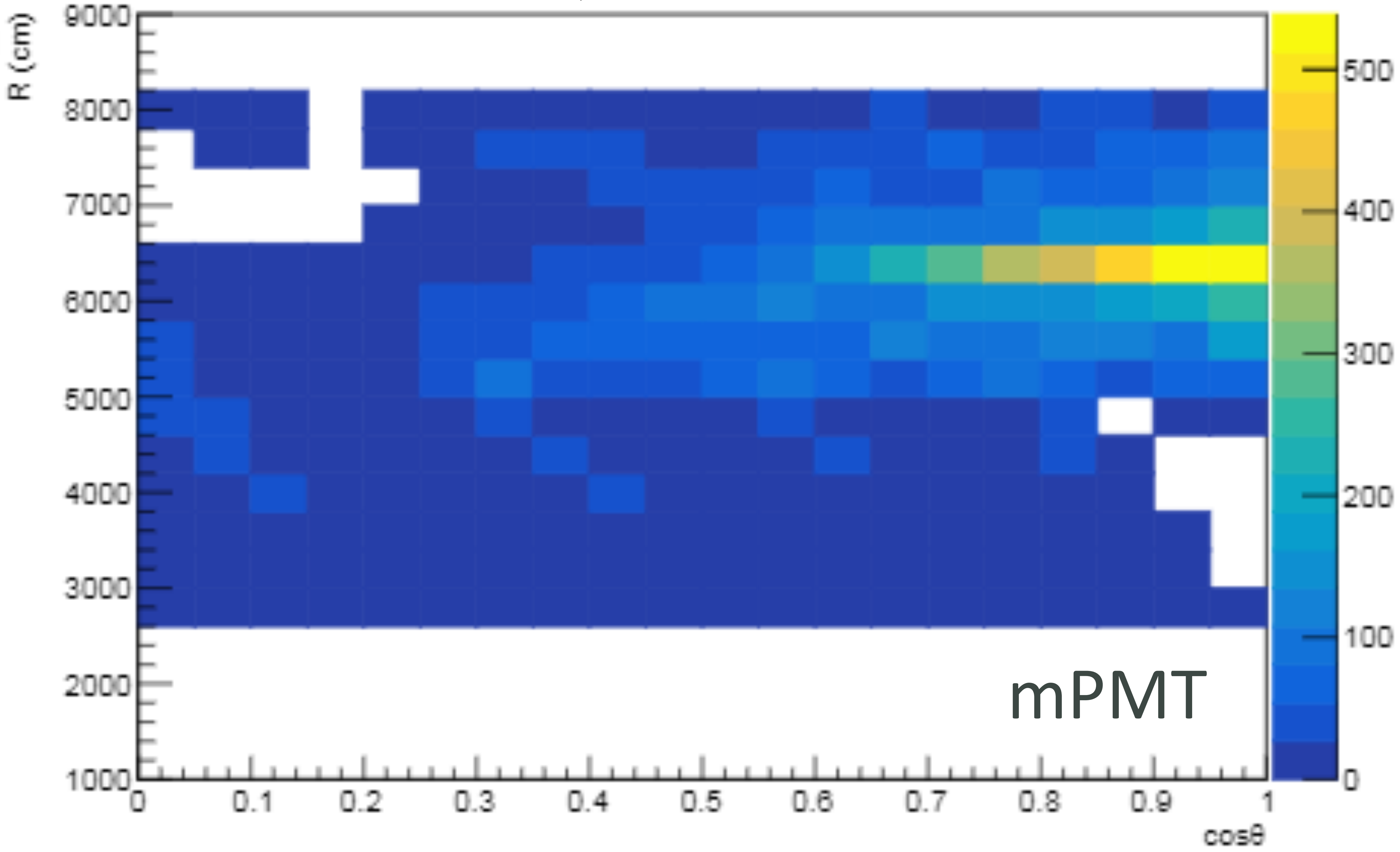
- Measurement of light attenuation length using optical light injected from a side-wall injector
- Large distance-angle correlation for 50-cm PMTs
- mPMTs can cover a full range of travel distance at a consistent incident angle







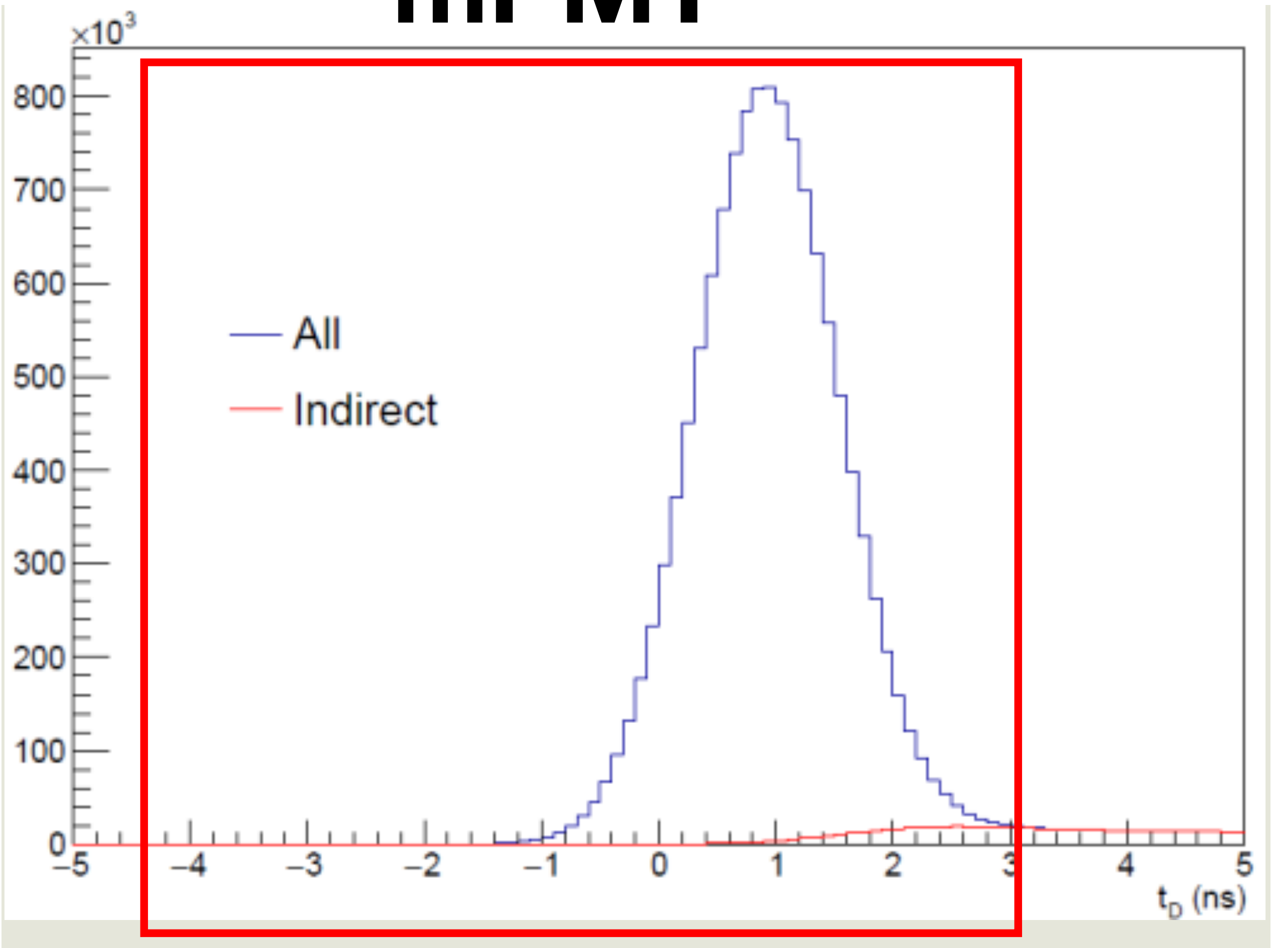




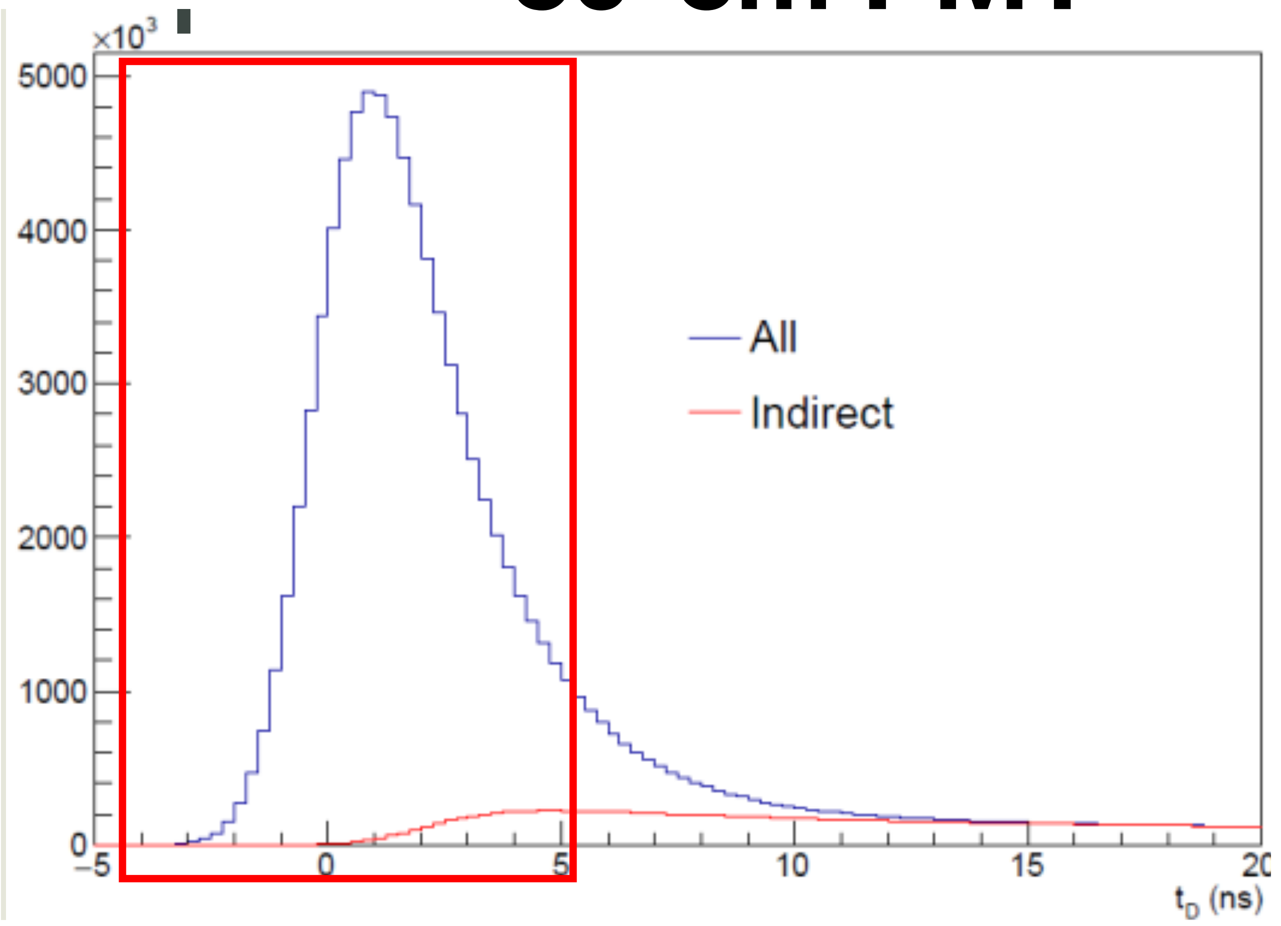
Attenuation length measurement

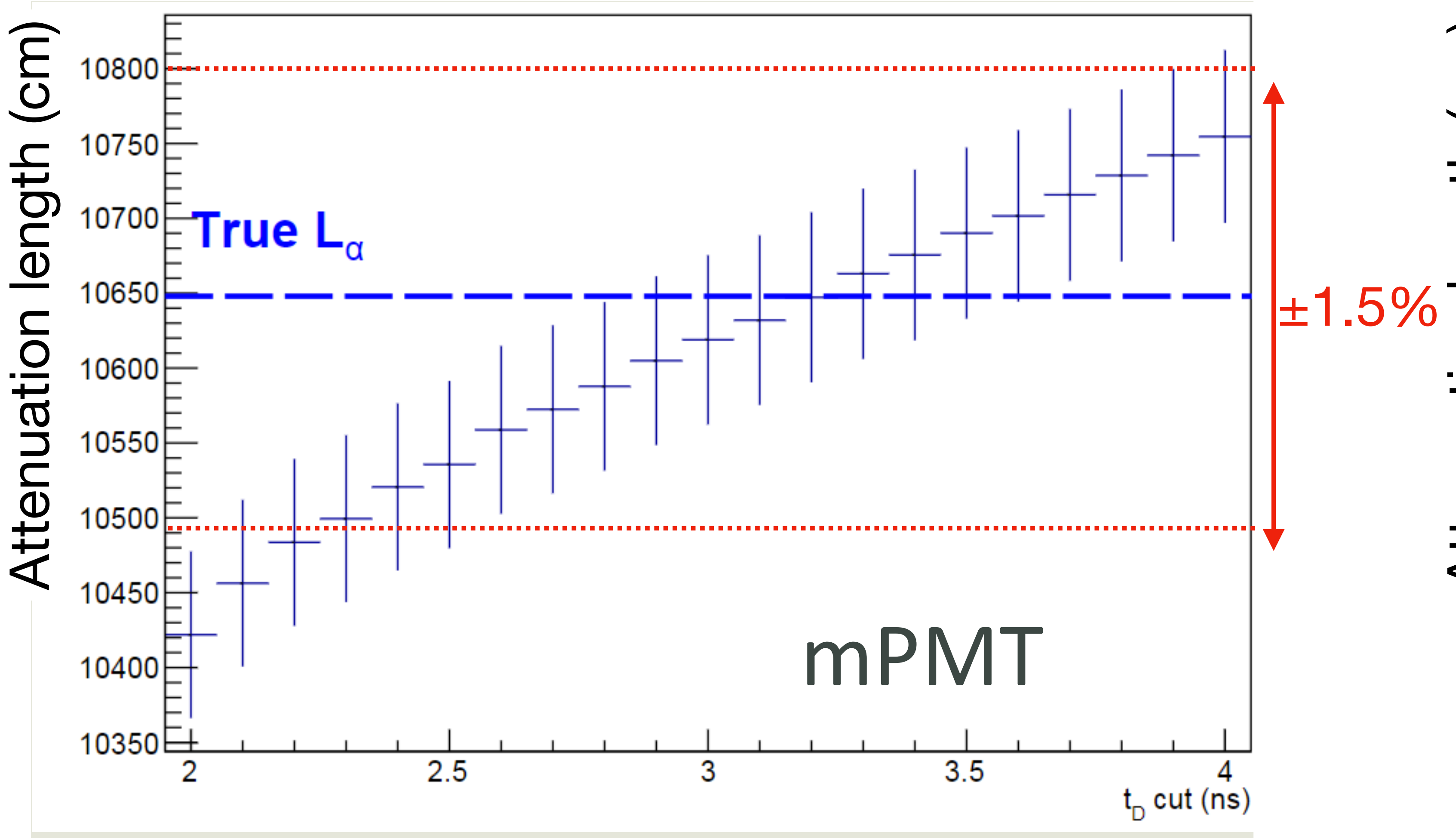
- Fit for attenuation length
- Results sensitive to indirect light contribution
- Better separation of indirect light with time window cut
- Measured attenuation length with mPMT less dependent on timing cut criteria
    - Less potential bias due to timing resolution uncertainty

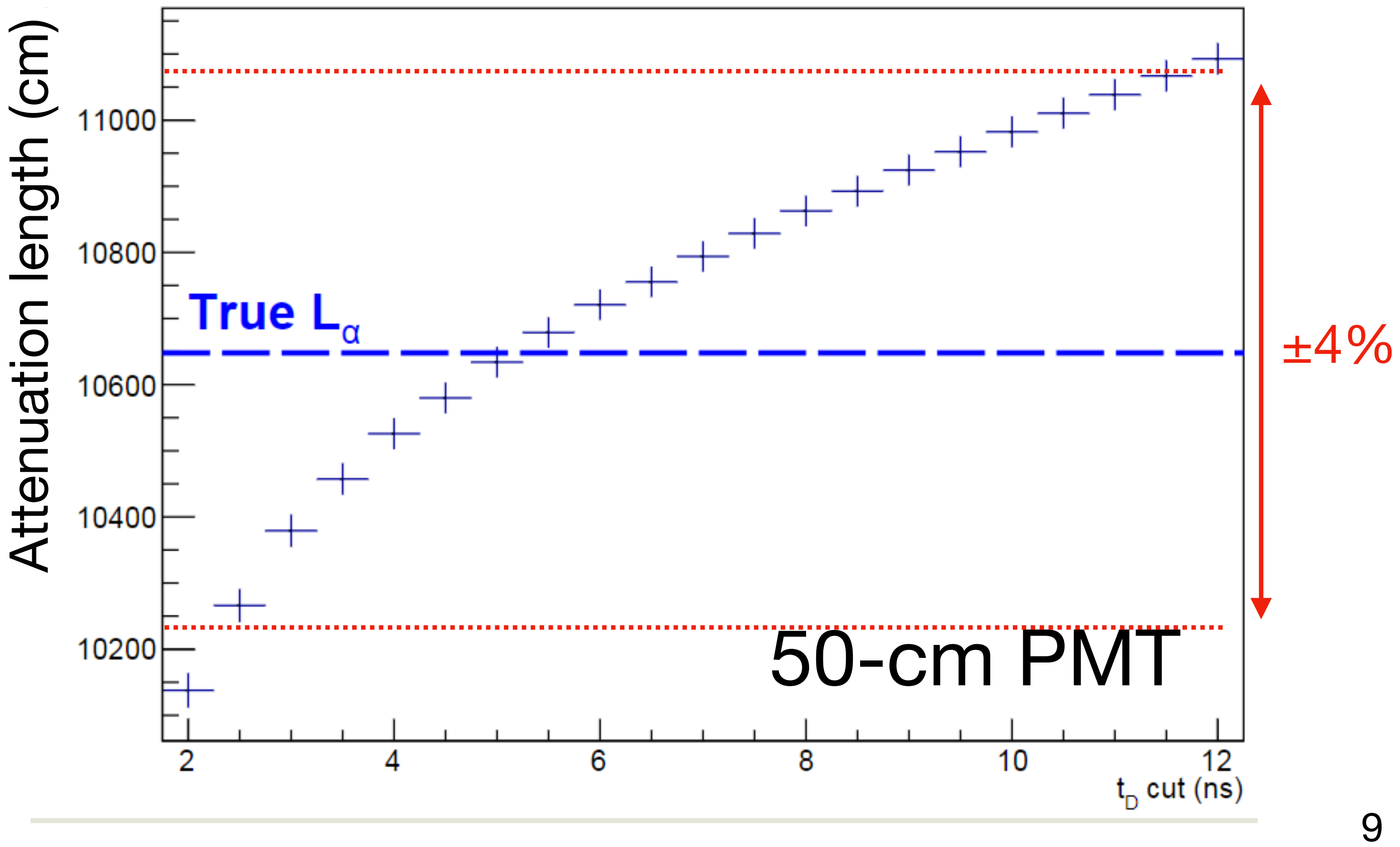
mPMT



50-cm PMT

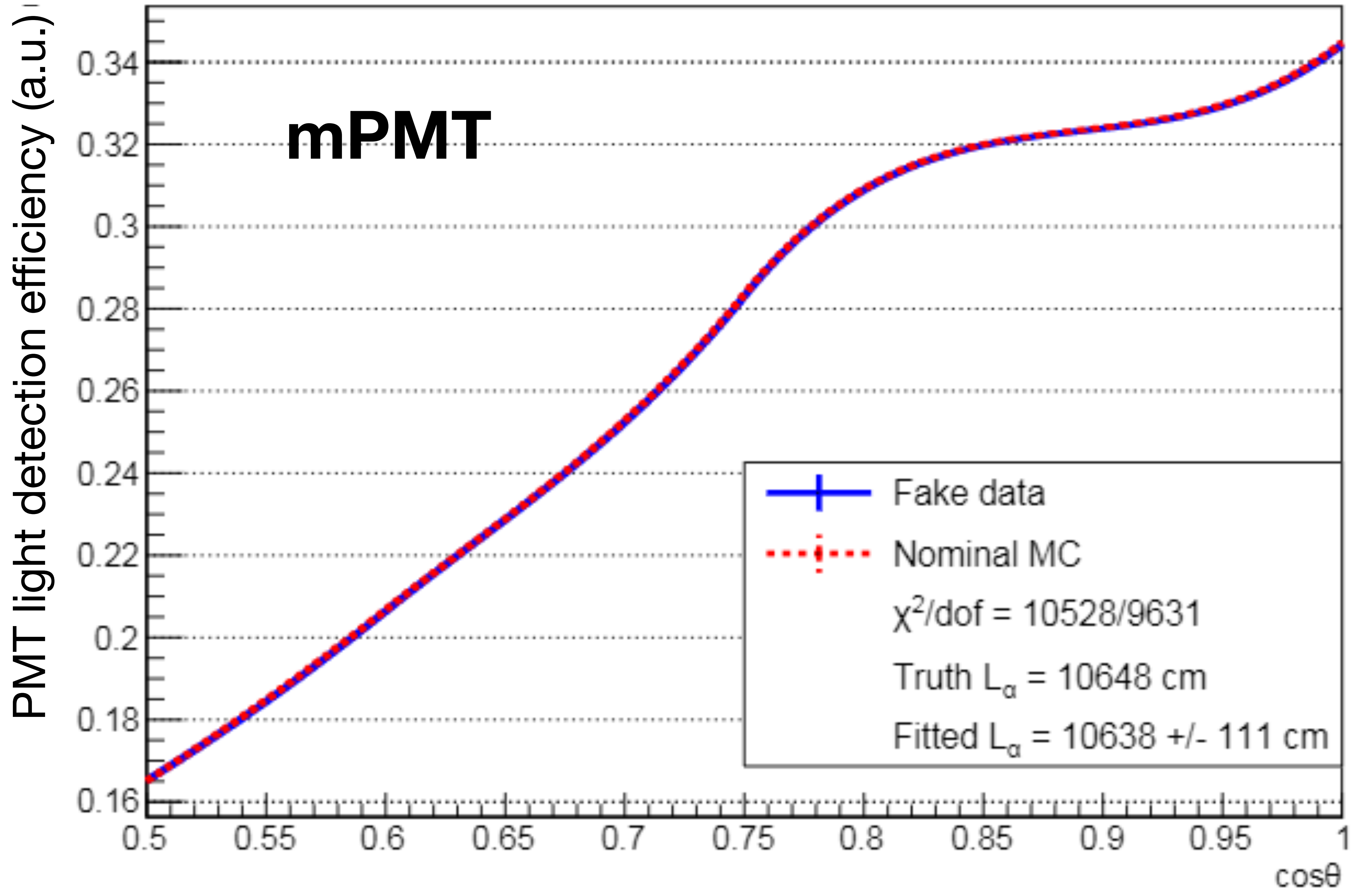


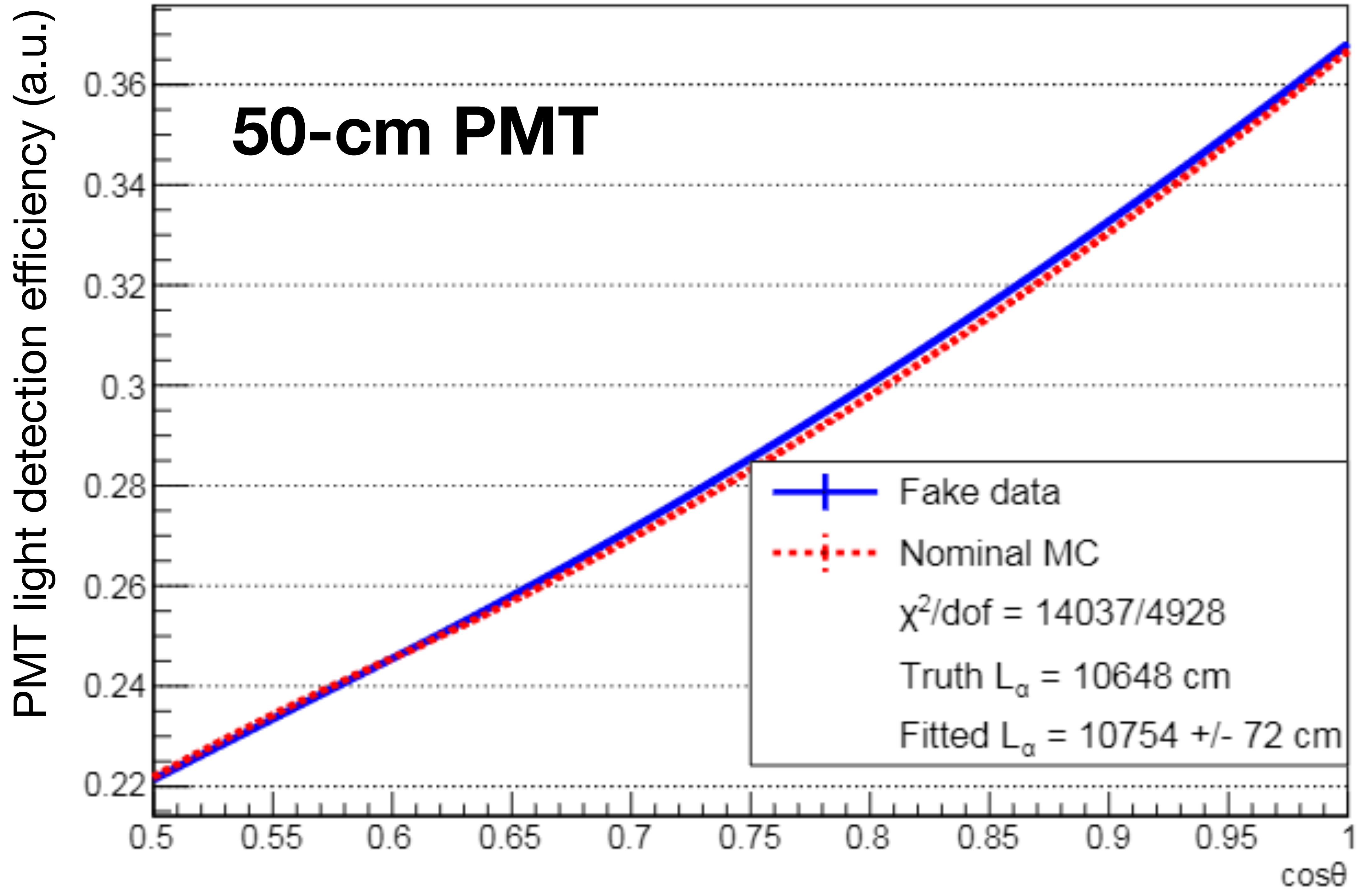




Optical parameter fitting with intentional bias

- Introduce ~1% angular bias to the light intensity as a fake data
- Simultaneously fit (Light intensity) x (Water attenuation) x (PMT angular response)
  - Fit with mPMT fit successfully recovers truth value, while significant bias revealed for 50-cm PMTs





mPMTs capable to measure detector responses with smaller systematic uncertainty

Optimizing mPMT geometry and arrangement

Summary

- Variety of calibration sources to cover both high-level and basic detector response calibration for Hyper-Kamiokande
- Essential to fully utilize them to achieve required calibration precision
- Resolving parameter degeneracies is a key for precise basic detector response calibration
- Actively studying methods for
  - PMT pre-calibration
  - Optical measurements with multi-PMT
- Many more studies ongoing to maximize/optimize calibration capability in coming years!