Considerations for Optical Calibration at HK

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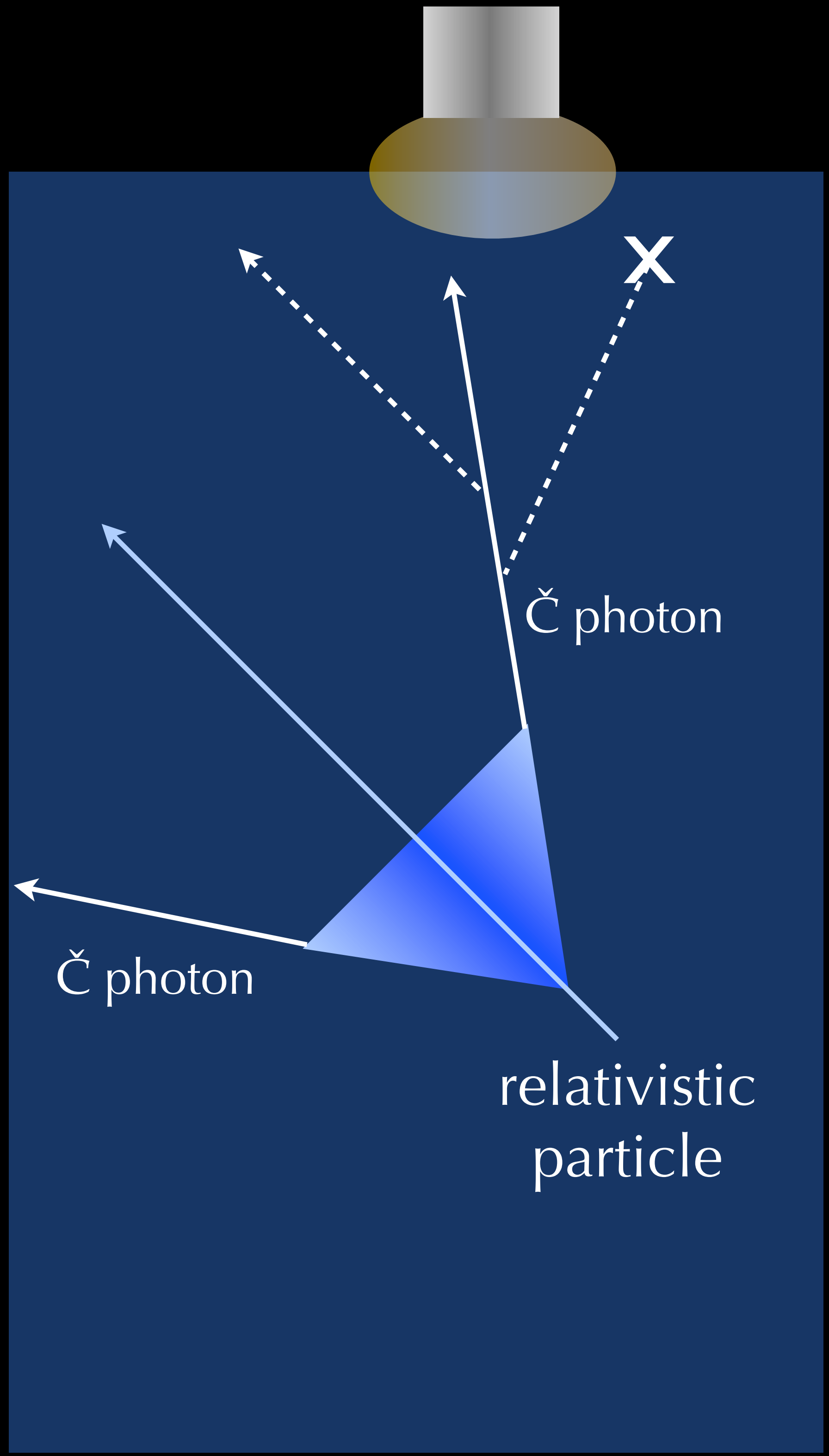
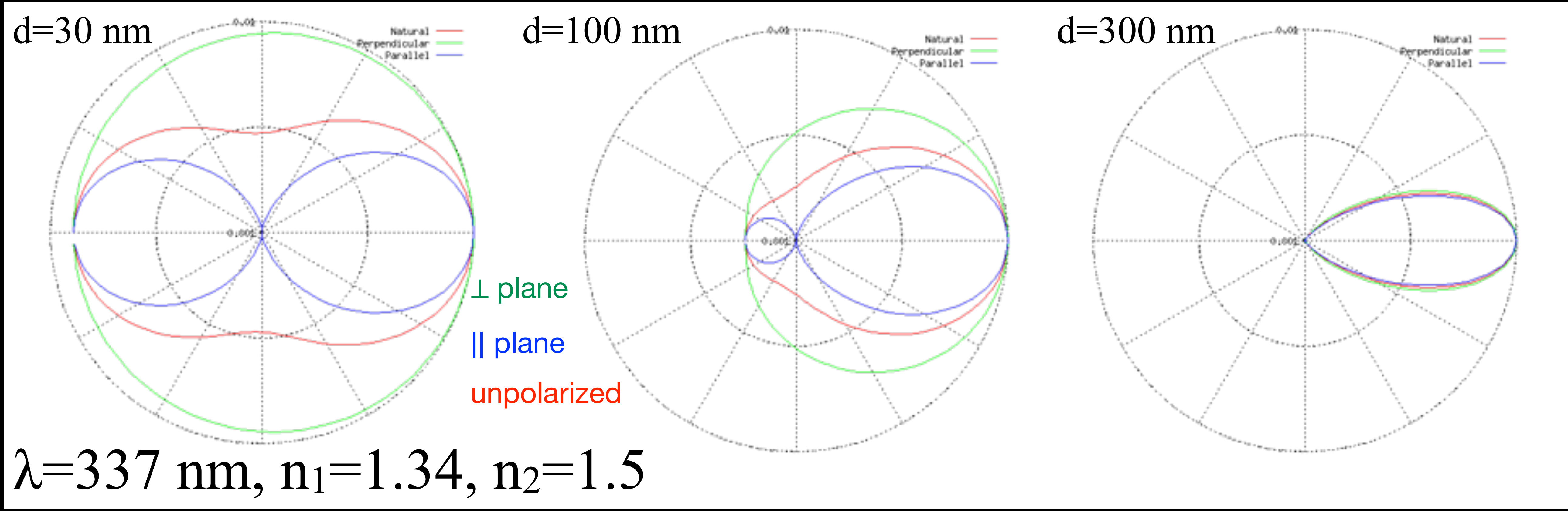
Introduction

- "Optical Calibration": understanding the process of Č photon detection
  - starts with production of Č photons in water
  - ends with absorption of photons
    - in water, walls of the detector, PMT . .
- water is the medium/the medium is water:
  - induces Č radiation from relativistic charged particles (radiator) → index of refraction
  - medium through which optical photons pass subject to a variety of optical phenomena
- account for the boundary of the detector
  - reflection/absorption of photons off the "black sheet" (~80% of surface)
  - reflection/absorption of photons on the PMT.



Scattering in water

- "Rayleigh": scattering off local thermal fluctuations in the medium
  - scattering rate determined by n, compressibility, temperature
  - "dipole": $L \propto 1/\lambda^4$, isotropic in ⊥ plane, $\cos^2\theta$ in || plane
    - generic behavior for light scattering off isotropic objects $\ll \lambda$
- "Mie": scattering of particulate contamination/impurities
  - depends on size of particles ($\sim d^6$) and Fresnel factor



http://omlc.ogi.edu/calc/mie_calc.html

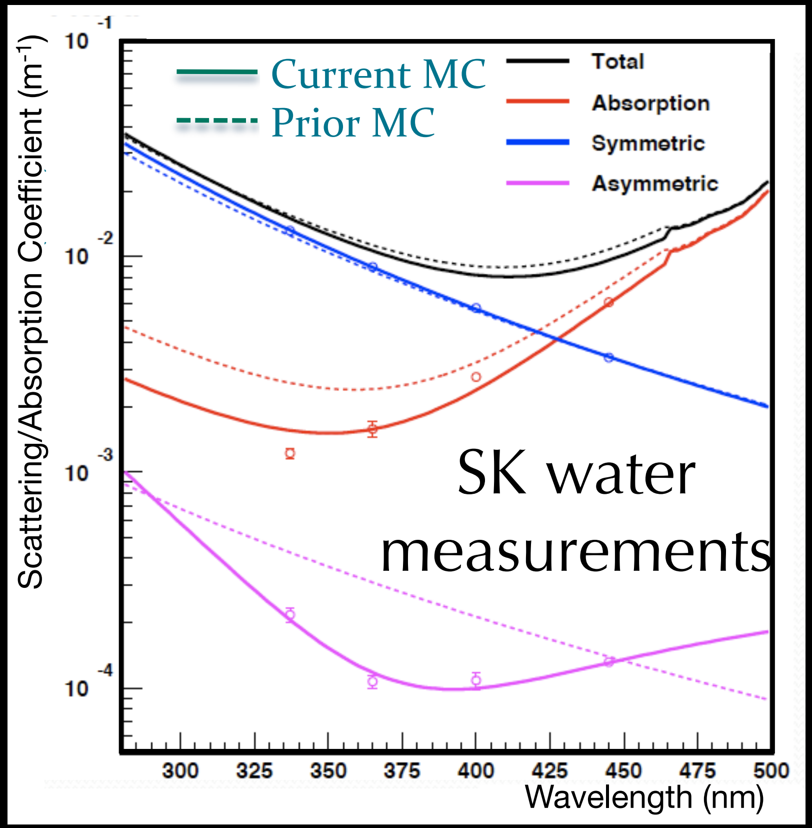
Absorption, Range

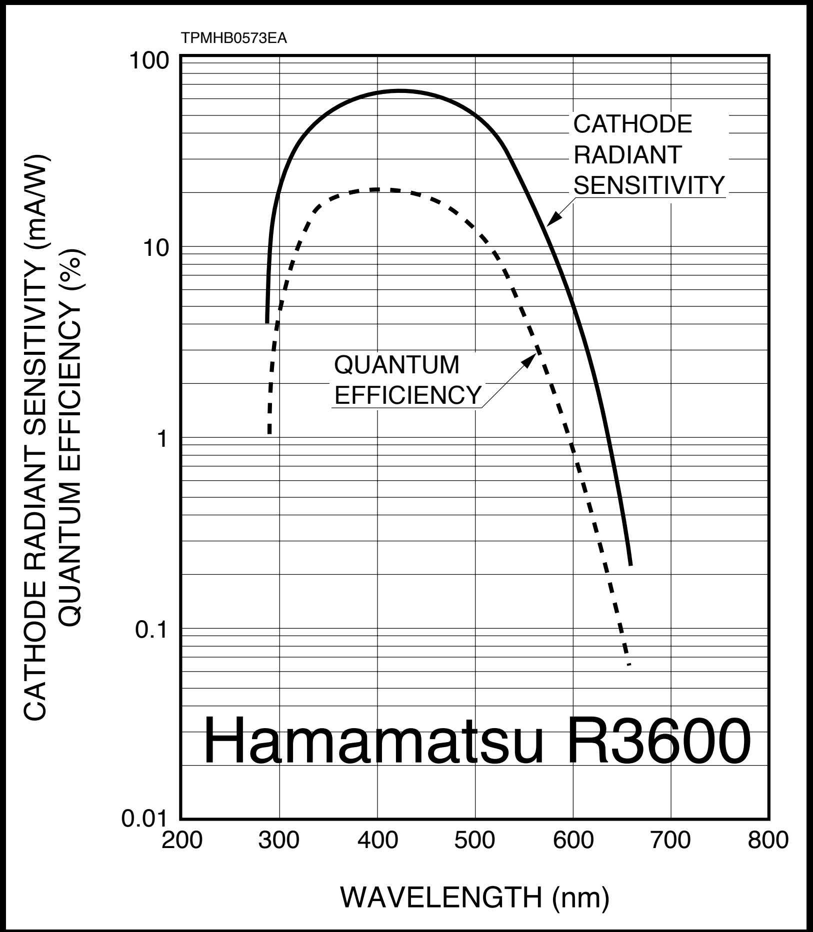
- In addition to scattering, Č photons can be absorbed (or re-emitted at a wavelength where it cannot be detected).

All processes are wavelength dependent

- Č photons are emitted with ~$1/\lambda^2$ spectrum
- photocathode sensitivity
  - rises sharply at 270-290 nm (glass)
  - decreases rapidly > 500 nm
- water transparency
  - decreases rapidly >500 nm

Relevant wavelengths range is ~300-500 nm

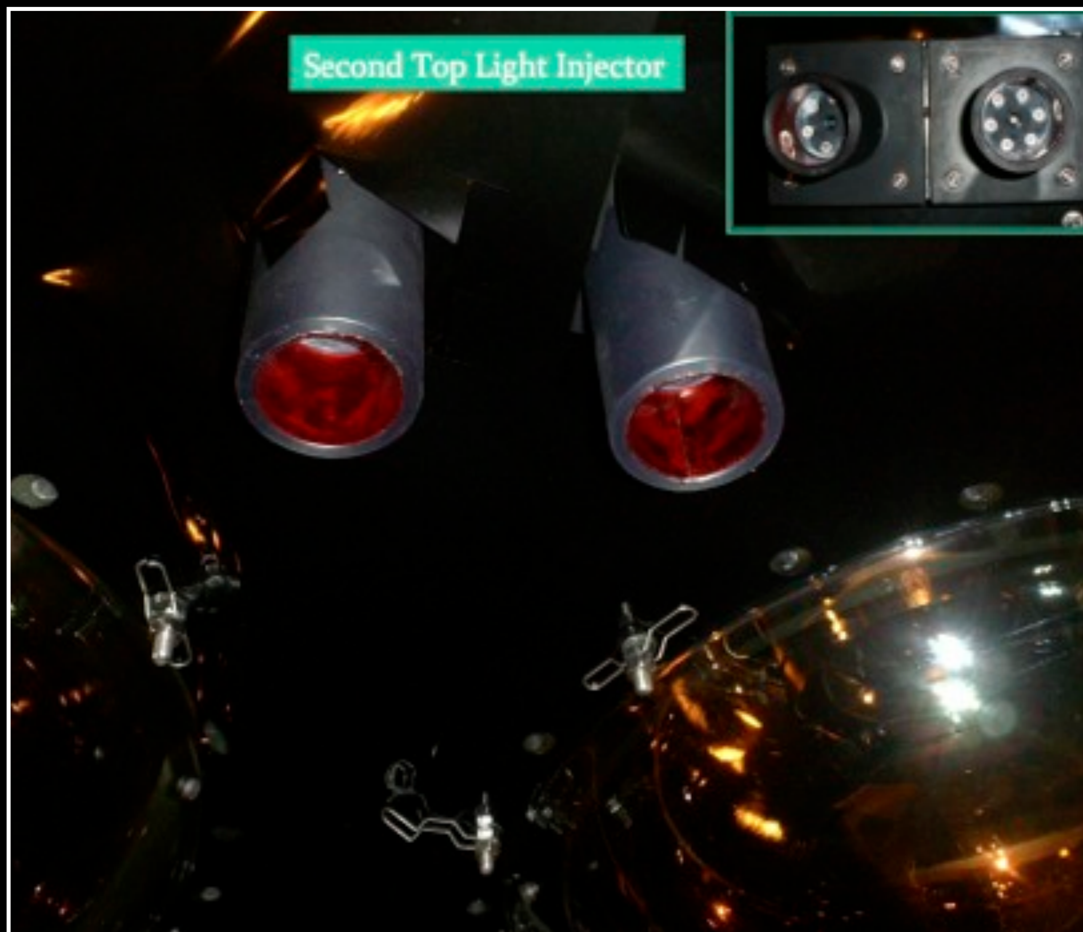




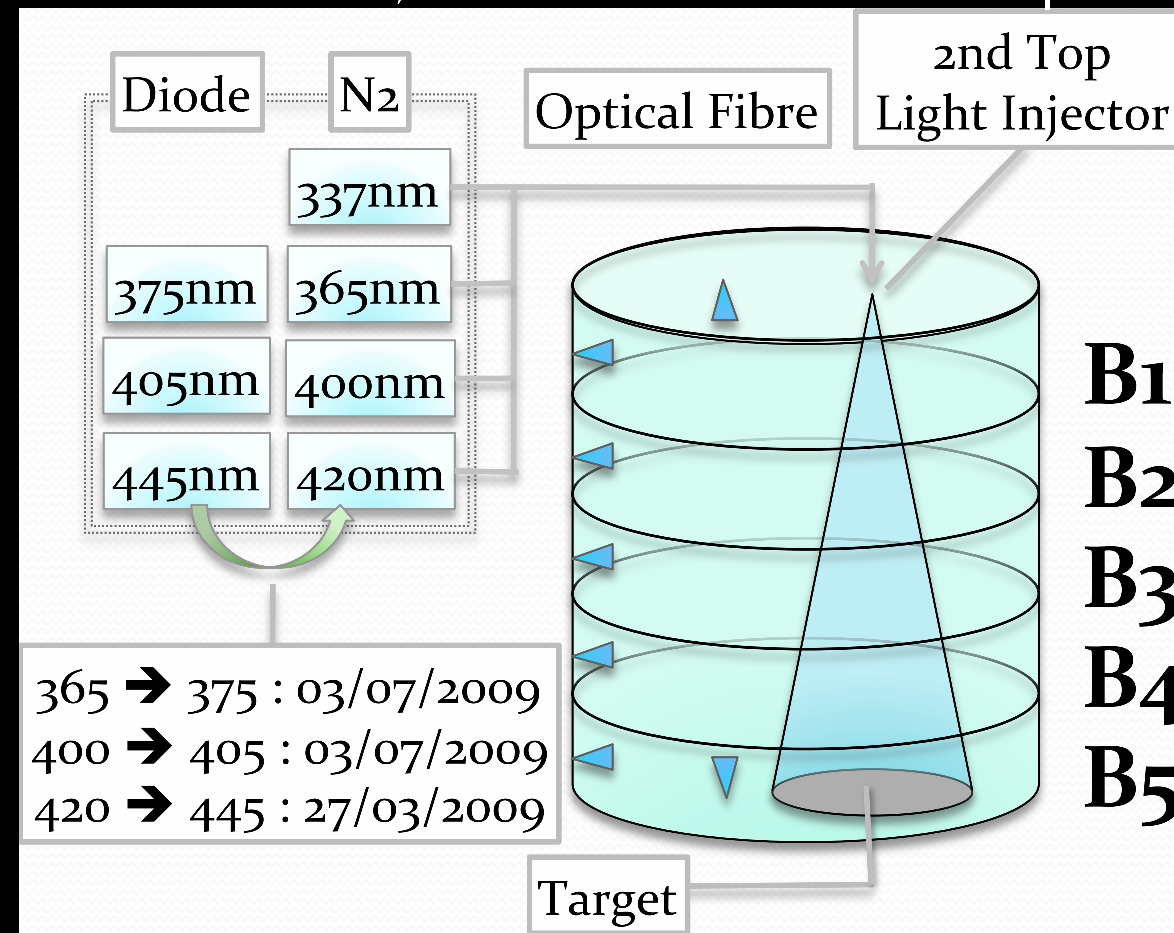
Data/Analysis Strategy

- Generic method:
  - Inject light with known properties into the detector
  - Simulate the light in Monte Carlo simulation ("MC")
  - vary/tune optical parameters in MC until data and MC "agree"
- Variations:
  - Light source:
    - collimated light source? diffuse "ball"?
    - fixed injection point? variable source deployment?
  - Analysis:
    - what are the "parameters"? (water only? PMT and others?, etc.)
    - fit samples or parameters separately or global fit across samples?
  - Systematic uncertainties:
    - tuning sets the parameters for MC/data agreement
    - parameters have uncertainties. What to do with them?

SK Calibration Hardware



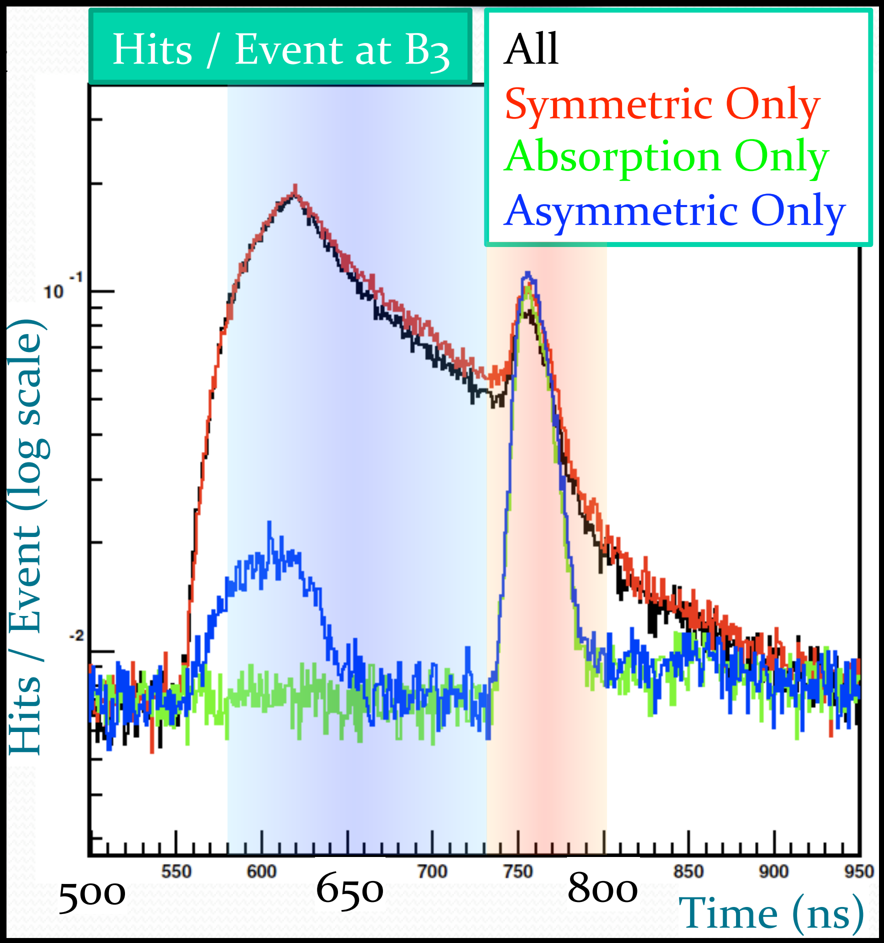
T. McLachlan, T2K-SK/SKLB workshop 2009

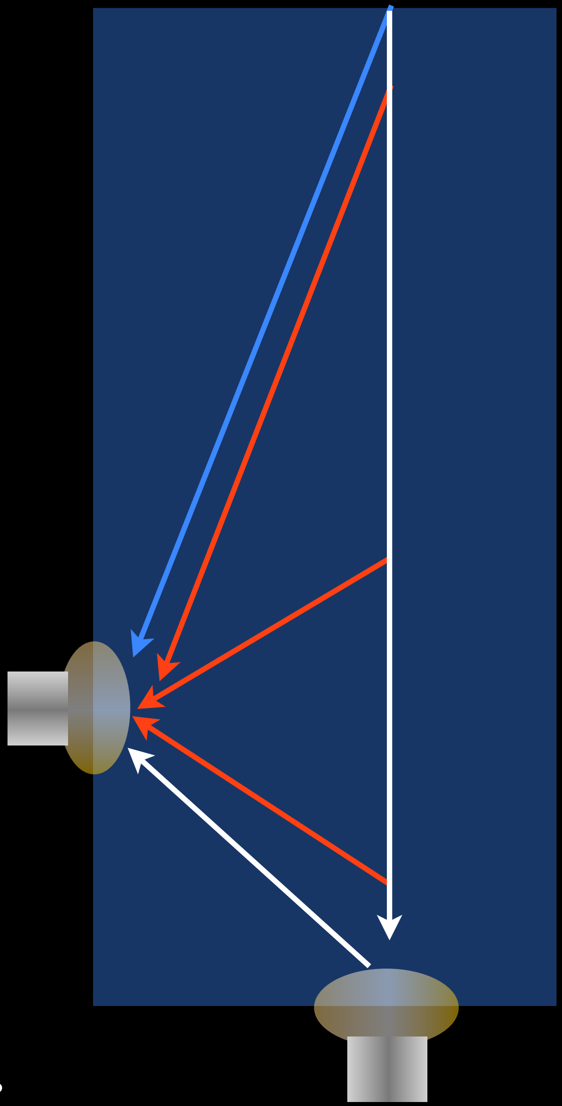


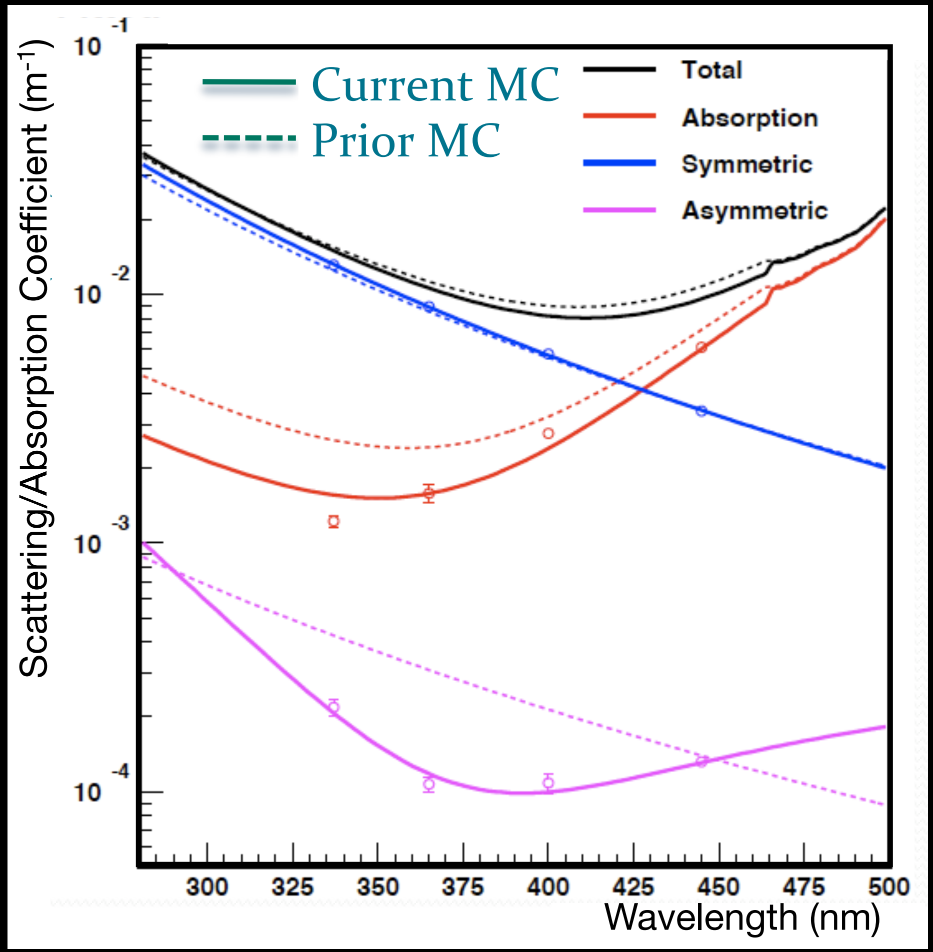
- Fixed injection points at various points in the detector
  - collimated light from N_2/diode laser at various wavelengths
  - profile measured directly in the data with bottom PMTs
- Photons undergoing optical phenomena separate in arrival time for PMTs at a fixed height in the detector.

Analysis

T. McLachlan, T2K-SK/SKLB workshop 2009

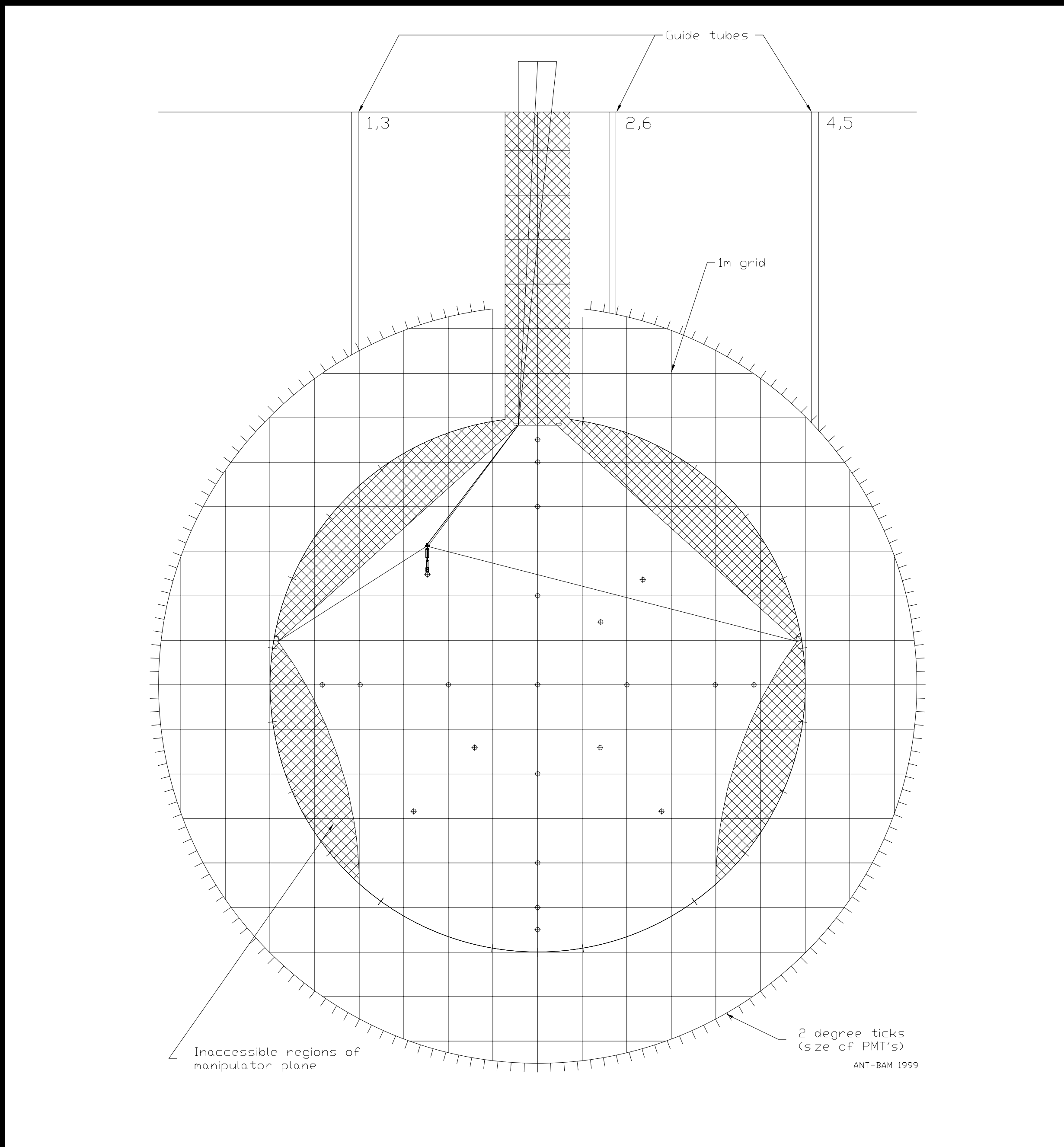


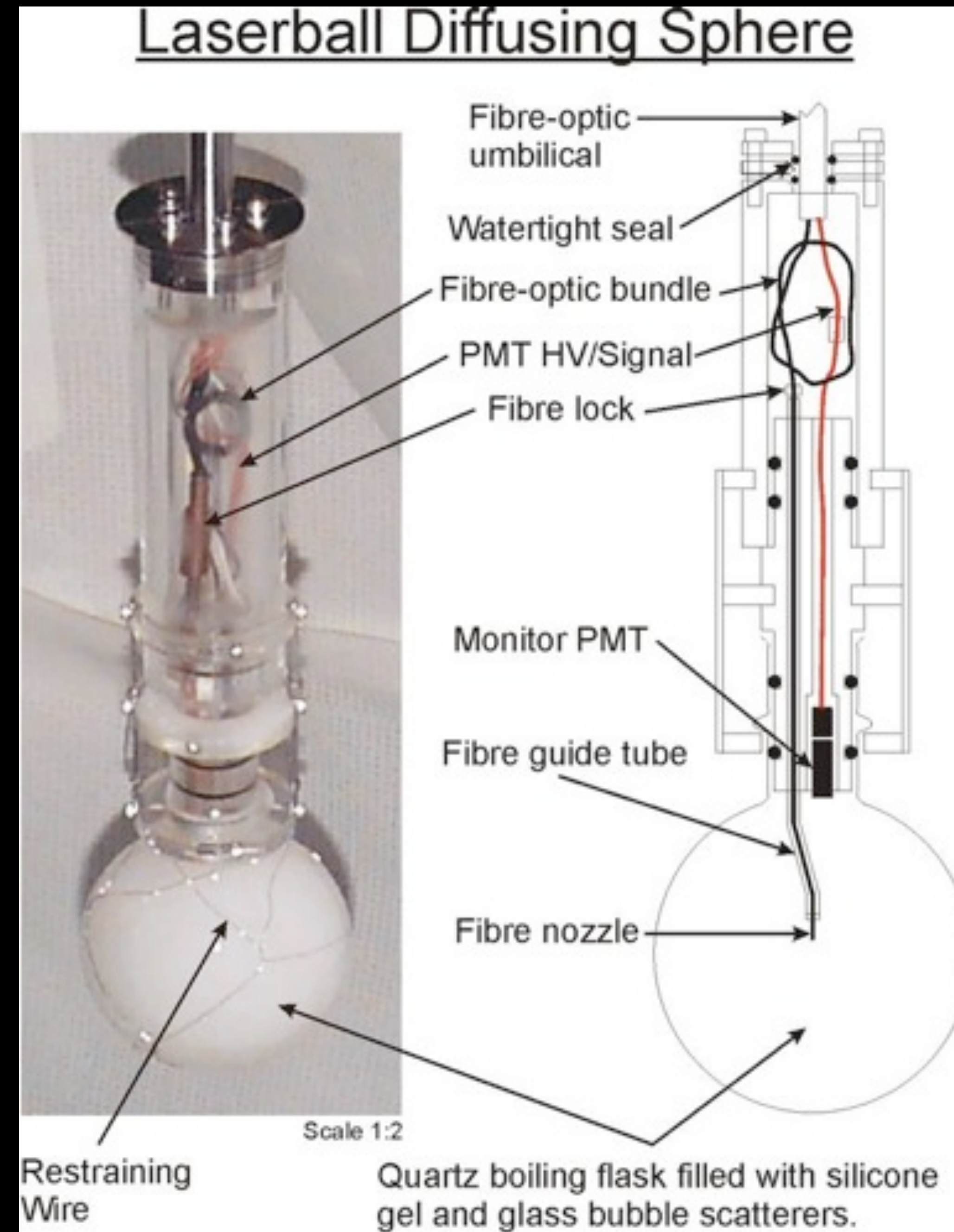




- At each wavelength:
  - Region before reflection peak used to extract water optical parameters (absorption, (a)symmetric scattering) in fit
  - Region in reflection peak used to extract PMT reflection parameters (complex index of refraction)

SNO Calibration Hardware

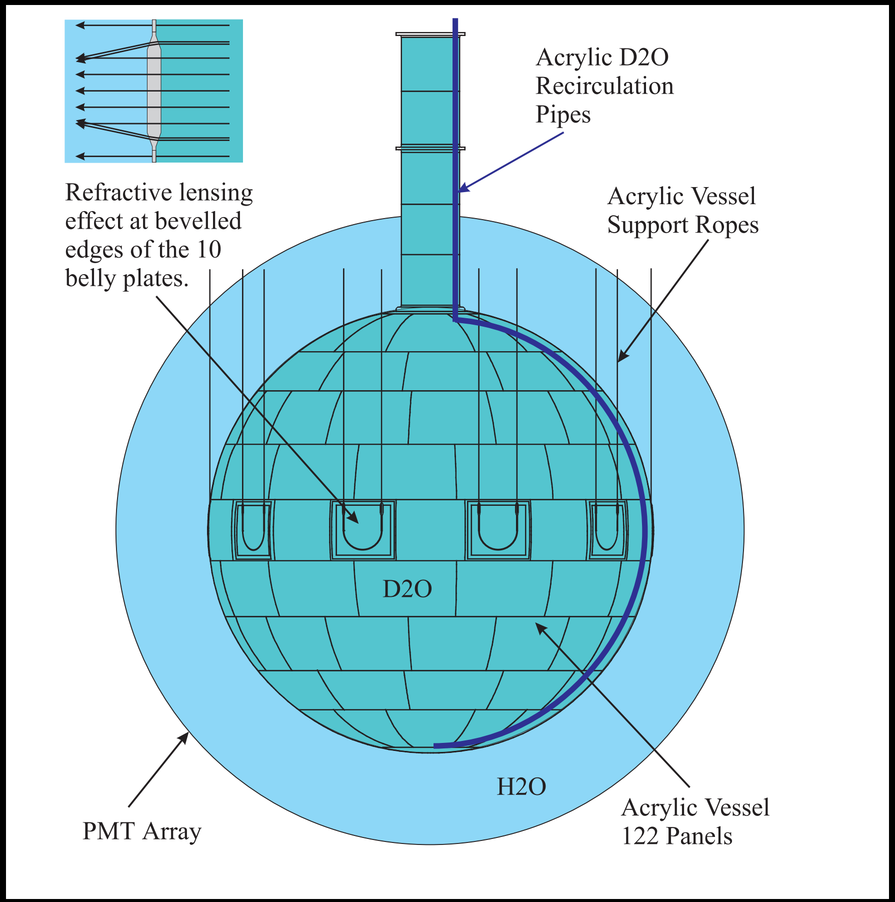


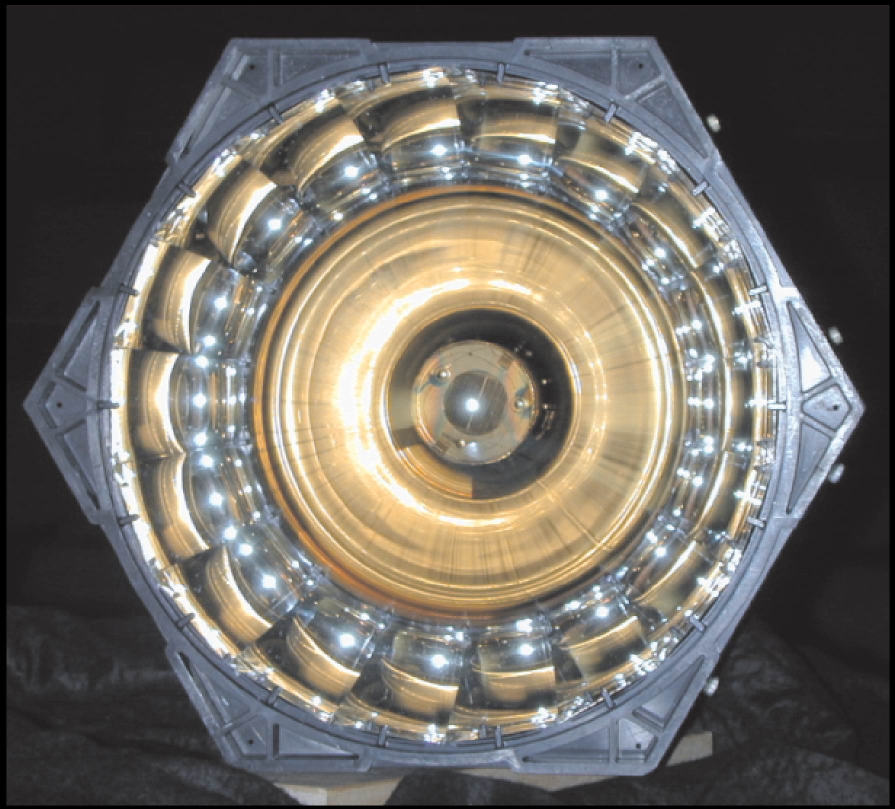


B. Moffat, PhD Thesis

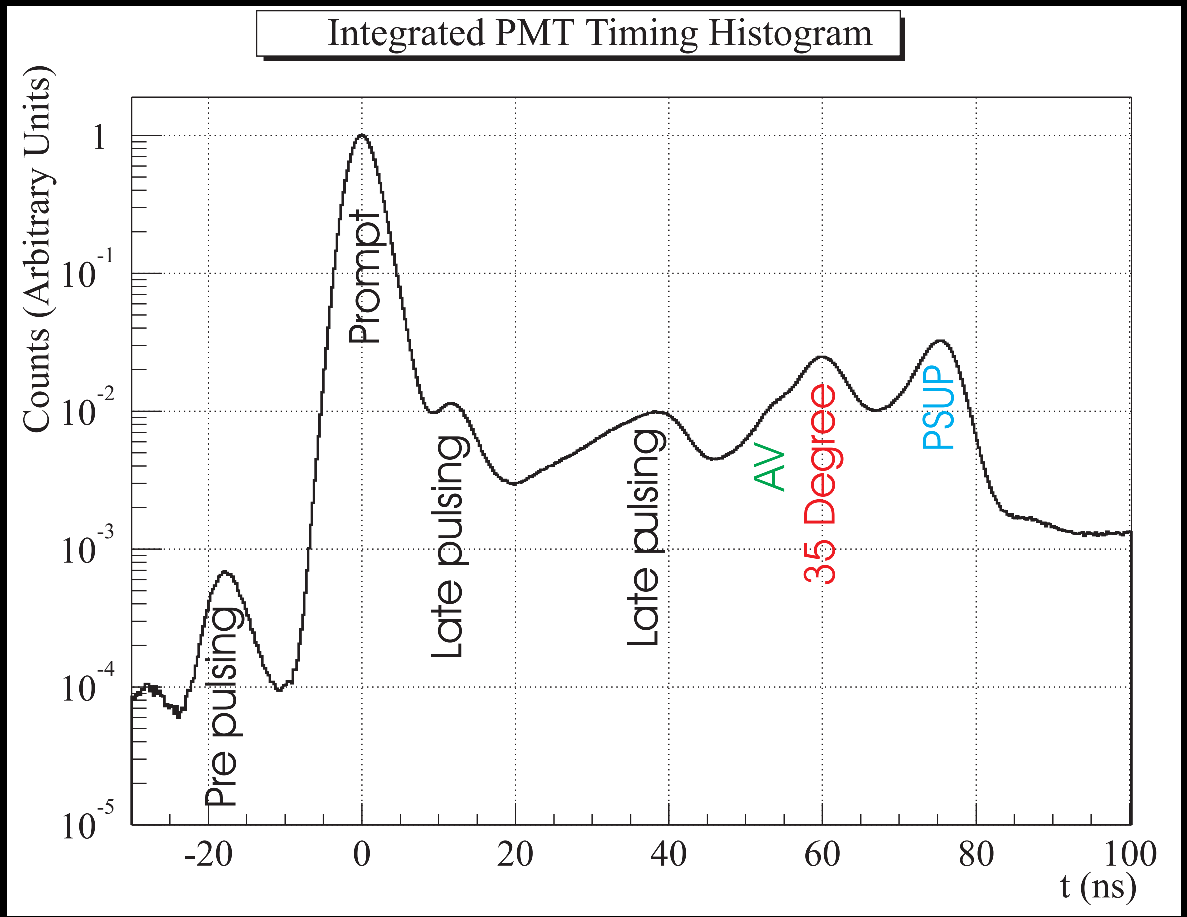
- “Laserball” injects pseudo-isotropic light into the detector
- Laserball moved around within detector to illuminate from different positions (see Szymon’s talk)

SNO Optical Environment





- "Richer" optical environment
  - "Onion" structure of detector:
    - inner D_2O target volume
    - acrylic vessel
    - outer H_2O buffer
    - PMT support structure (PSUP)
  - Light collectors on PMTs



B. Moffat, PhD Thesis

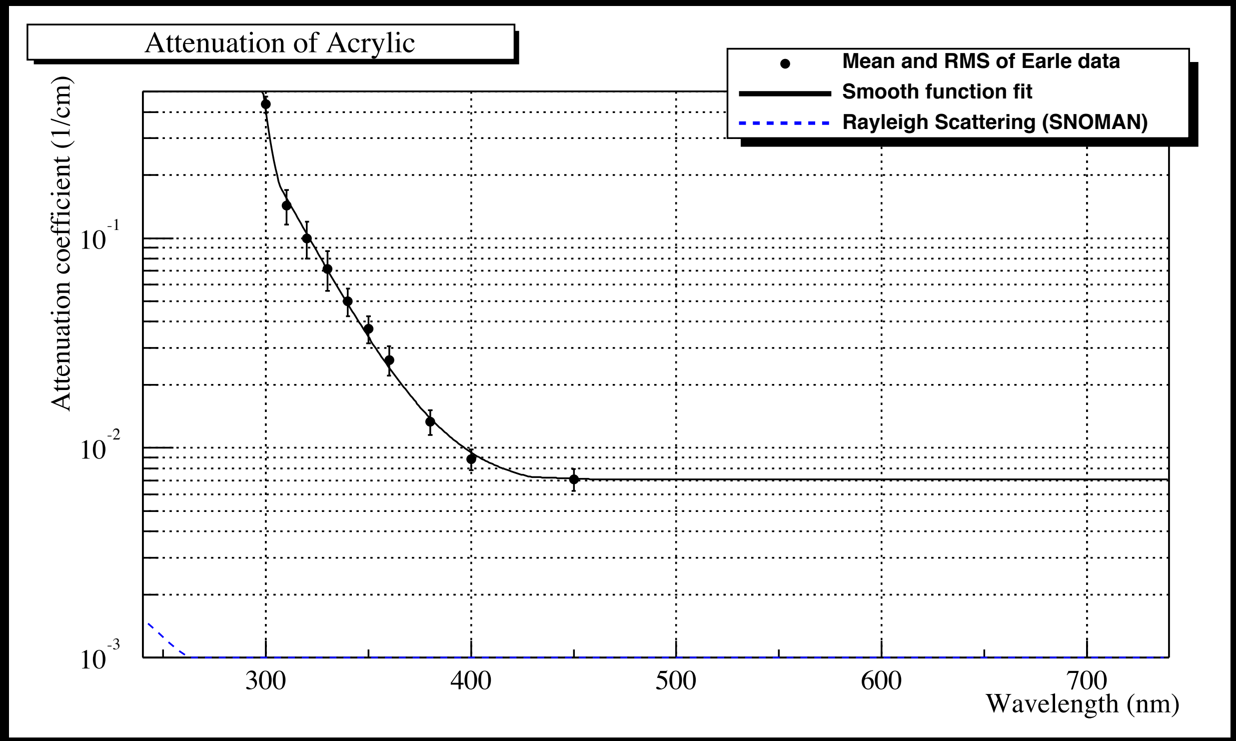
Analysis:

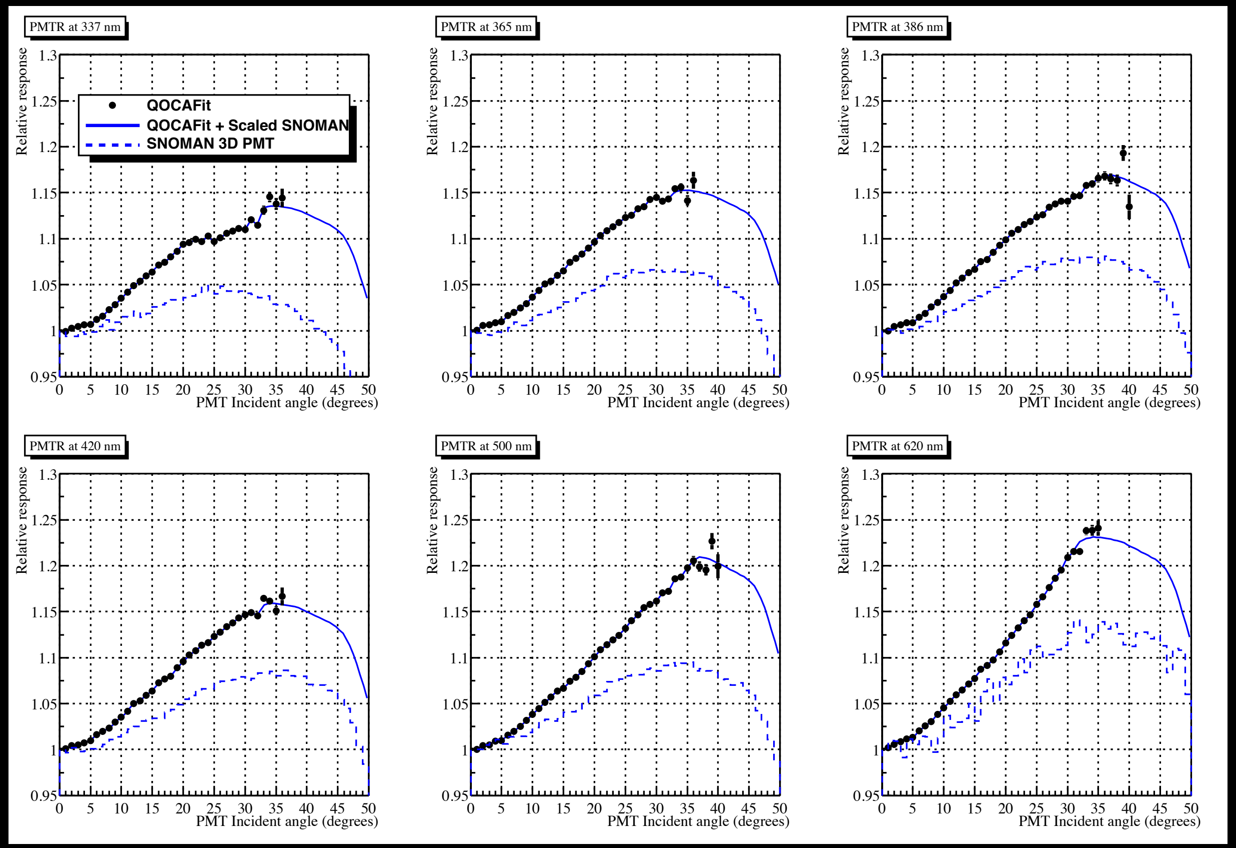
- Parameters associated with:
  - attenuation in D_2O
  - attenuation in acrylic vessel
  - attenuation in H_2O
  - angular response of PMT
  - intensity profile of laser ball

  extracted with a global fit is performed at each wavelength

- Global fit of parameters associated with unrelated optical processes (water vs. reflection, etc.) and nuisance parameters.

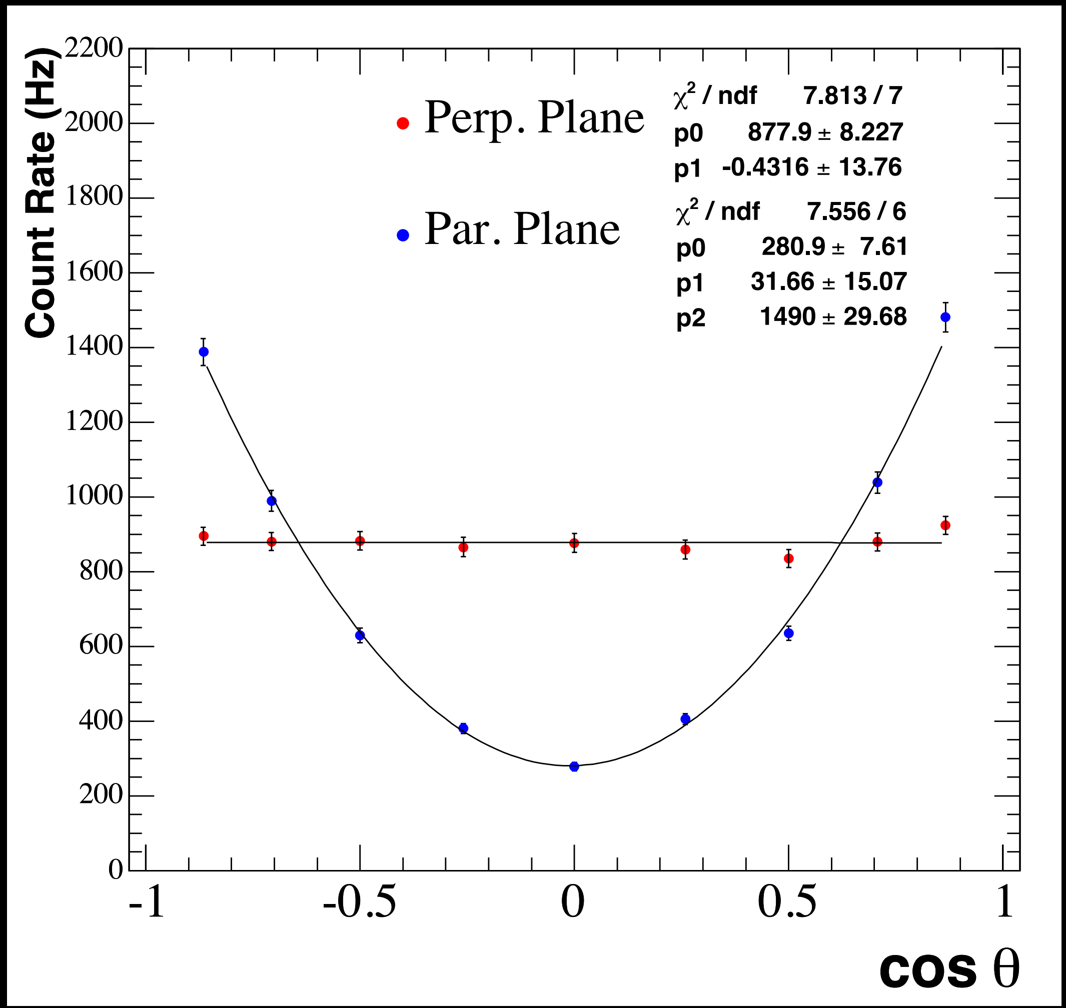
B. Moffat, PhD Thesis



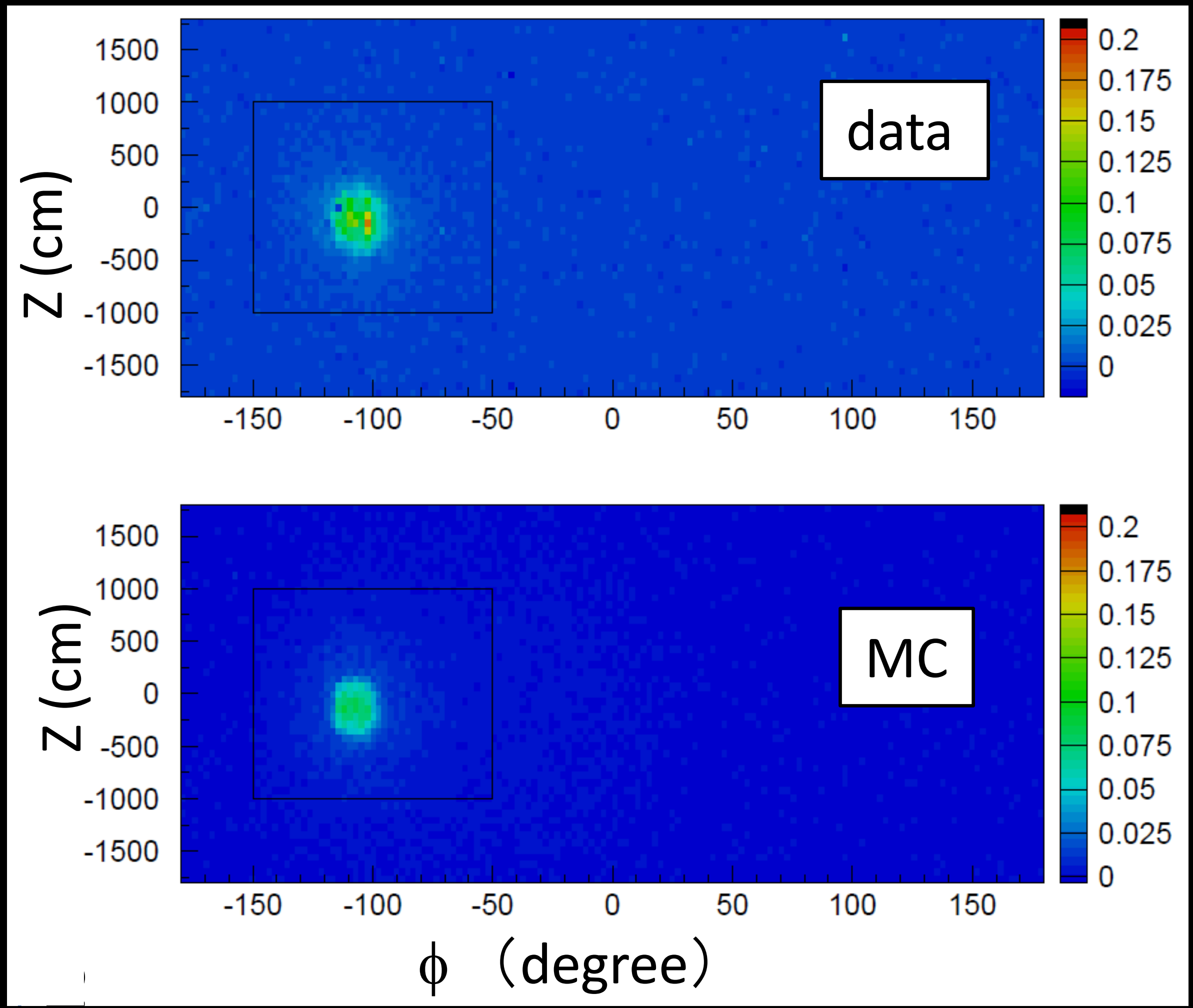


Dedicated measurements

J. Kameda



B. Brown FERMILAB-CONF-04-282-E



- ex-situ measurement of scattering angular distribution at MiniBooNE
- Measurement of black sheet reflectivity within the SK detector

- A program of dedicated/external measurements will help
  - construct optical model in the Monte Carlo simulation
  - identify features that might be difficult to see in the calibration data

Challenges/Outlook for HK:

- Fortunately, experience gained on SK will gives us a big head start on the optical calibration strategy for HK
  - Suggest that we have laser injection points in HK as in SK
    - this can be accommodated in advance in the detector design
  - Also consider a laser ball-like system to be deployed
    - we will almost certainly have a source deployment system at HK
      - laser ball should be designed as part of it.
- In preparation:
  - consider *ex situ* measurements to characterize and build optical model for materials introduced into the detector.
  - consider advancing the state-of-the-art in analysis techniques
    - (more) global fits may allow resolution of more detailed issues (position dependent water quality, etc.)
    - MC is a useful tool to get a head start and to define needs

MC chain/Calibration hierarchy

Particle State
- Source (e/γ)
- Cosmic μ (+decay e)
- neutrino (neut, etc.)

Particle tracking
- Energy loss
- Multiple scattering
- Decays
- Interactions/production

Optical Photon
- Č light production
- photon propagation
- photosensor optics

PMT response
- photocathode response
- threshold, digitization, etc.

- (My personal view with a strong LBL bias)

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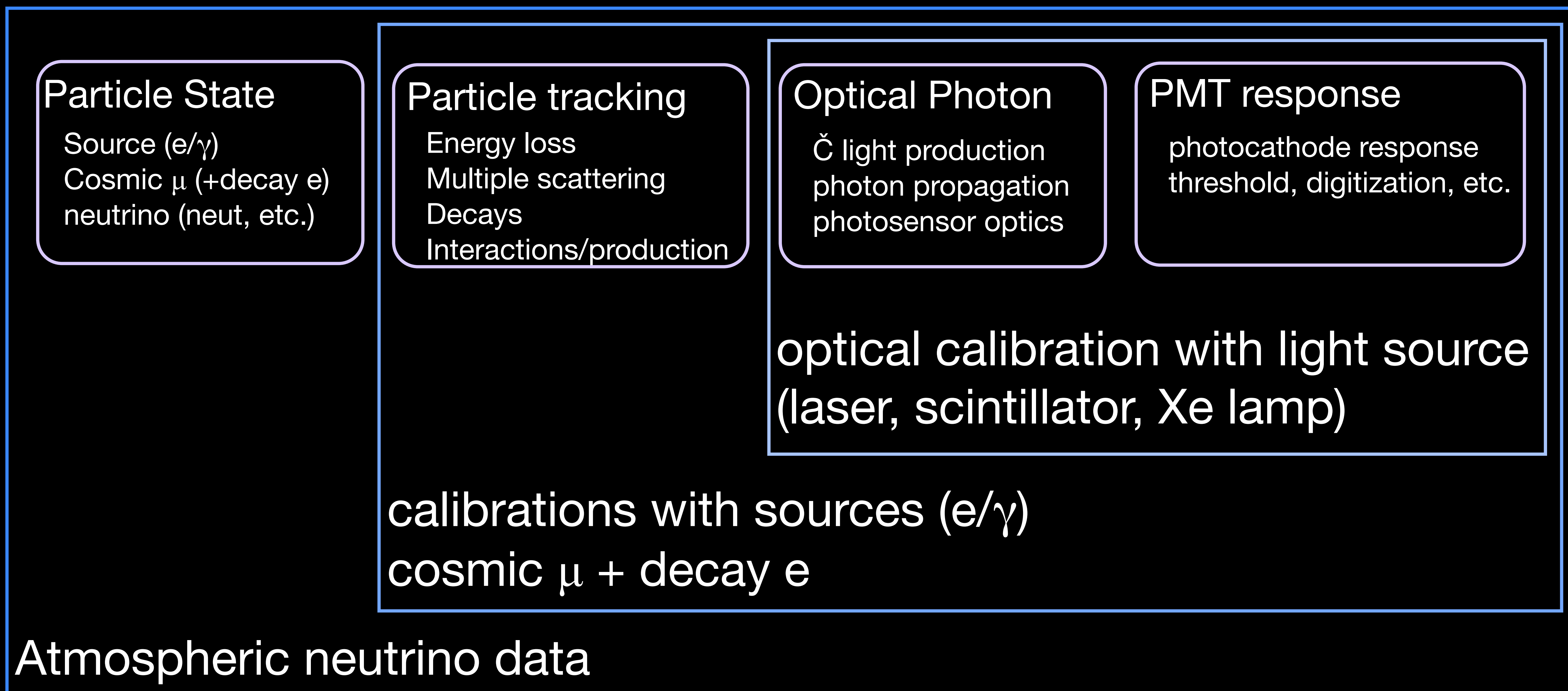

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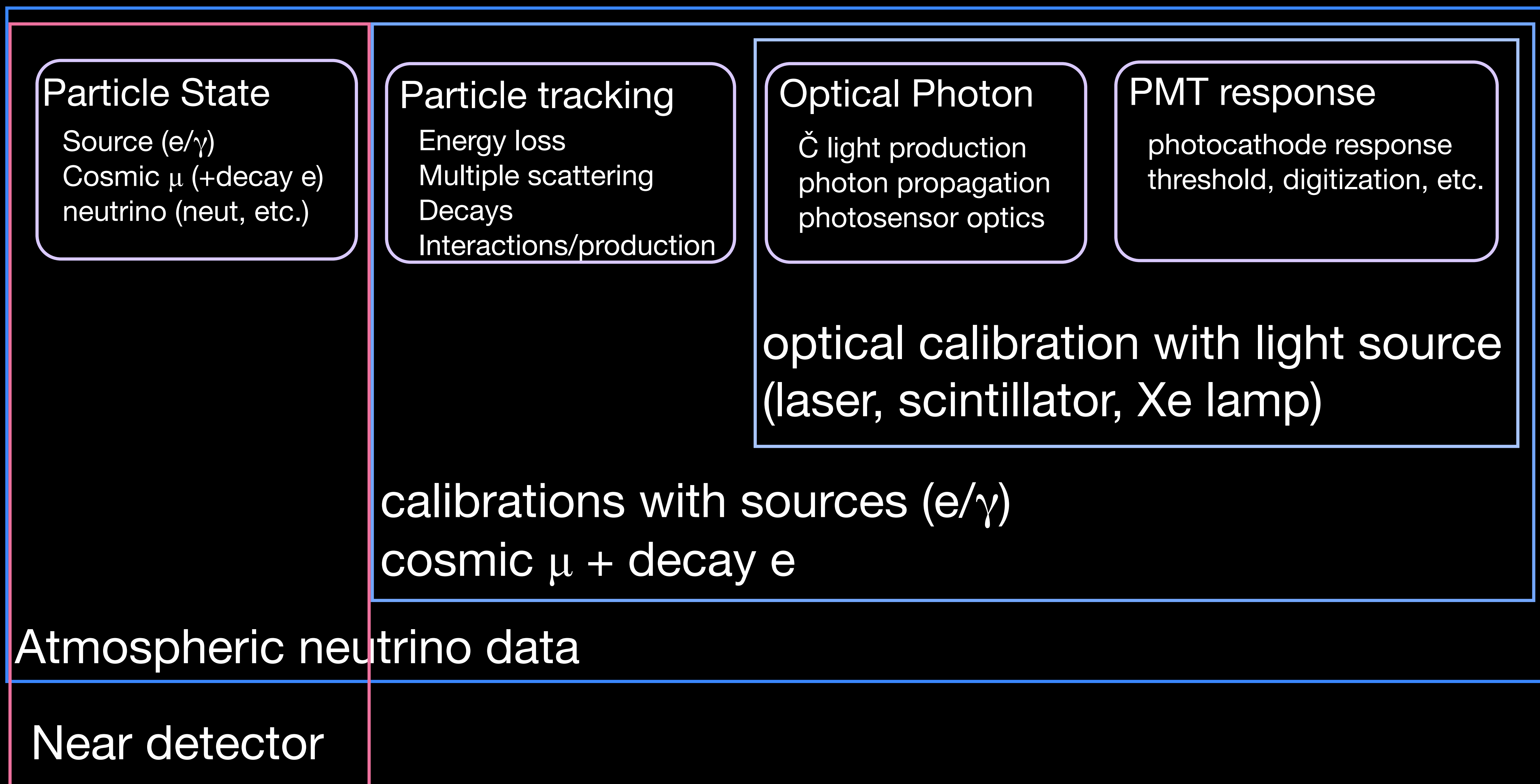

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Atmospheric neutrino data

Near detector

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ex-situ?

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