Diffusers & WbLS for Neutrinos

Developments in Water Based Cherenkov Detectors for Future Supernova Core Collapse Events

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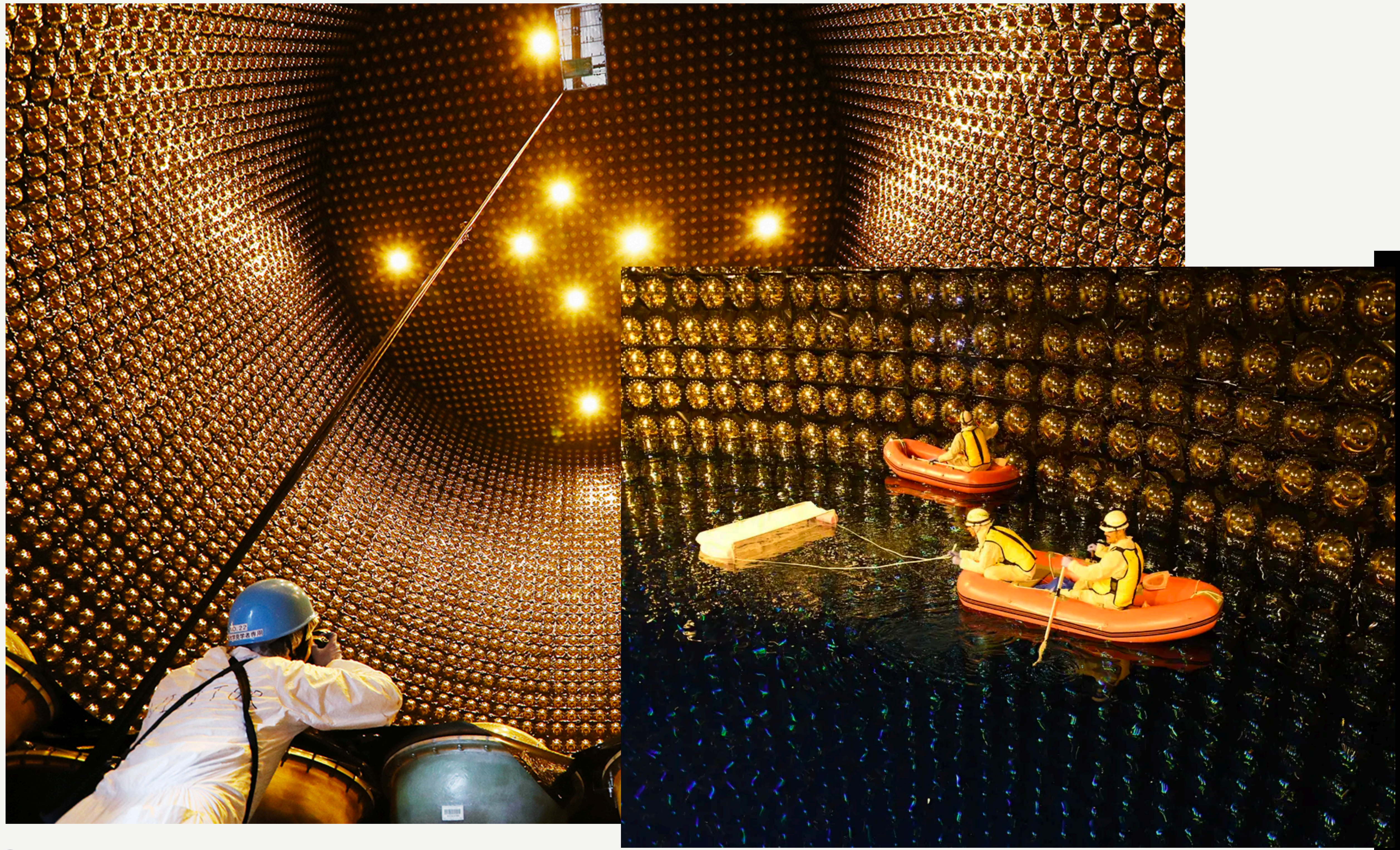
The detectors I work on

When one experiment isn't enough

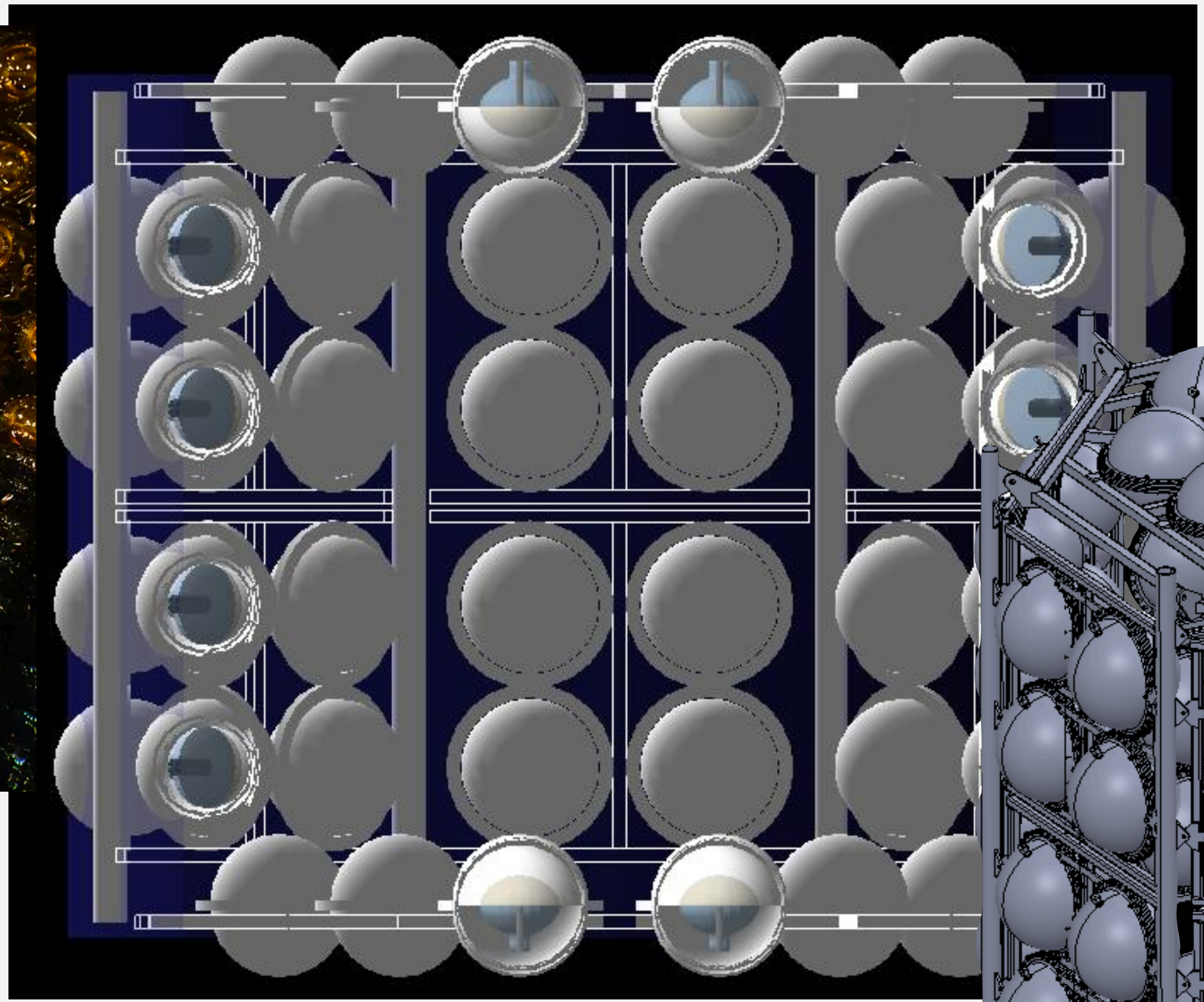


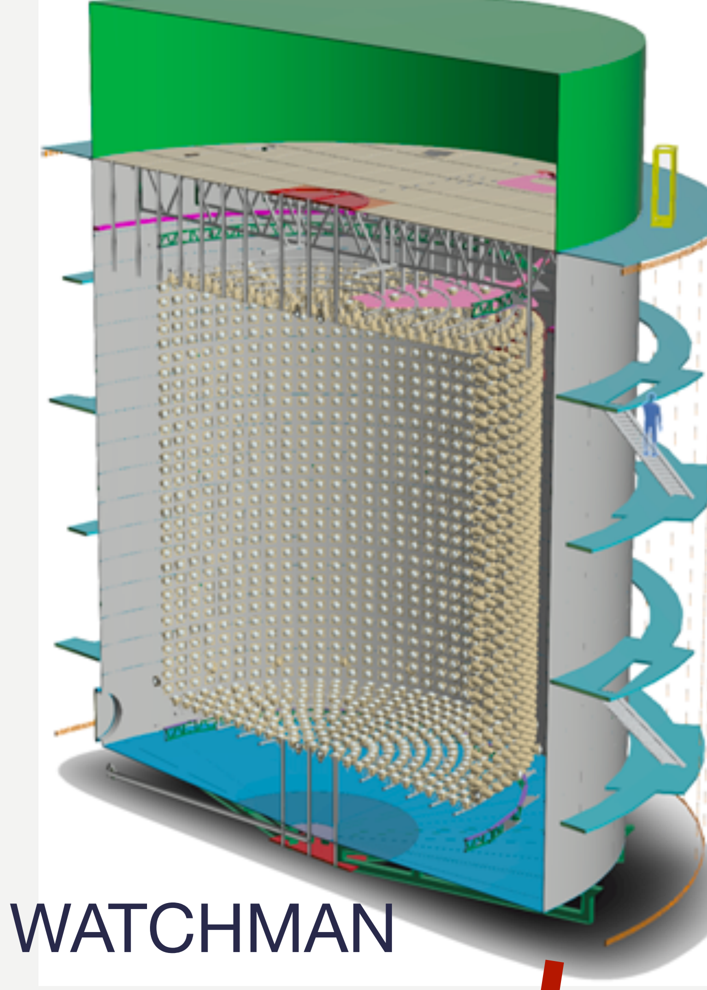
<u>Super-Kamiokande</u>

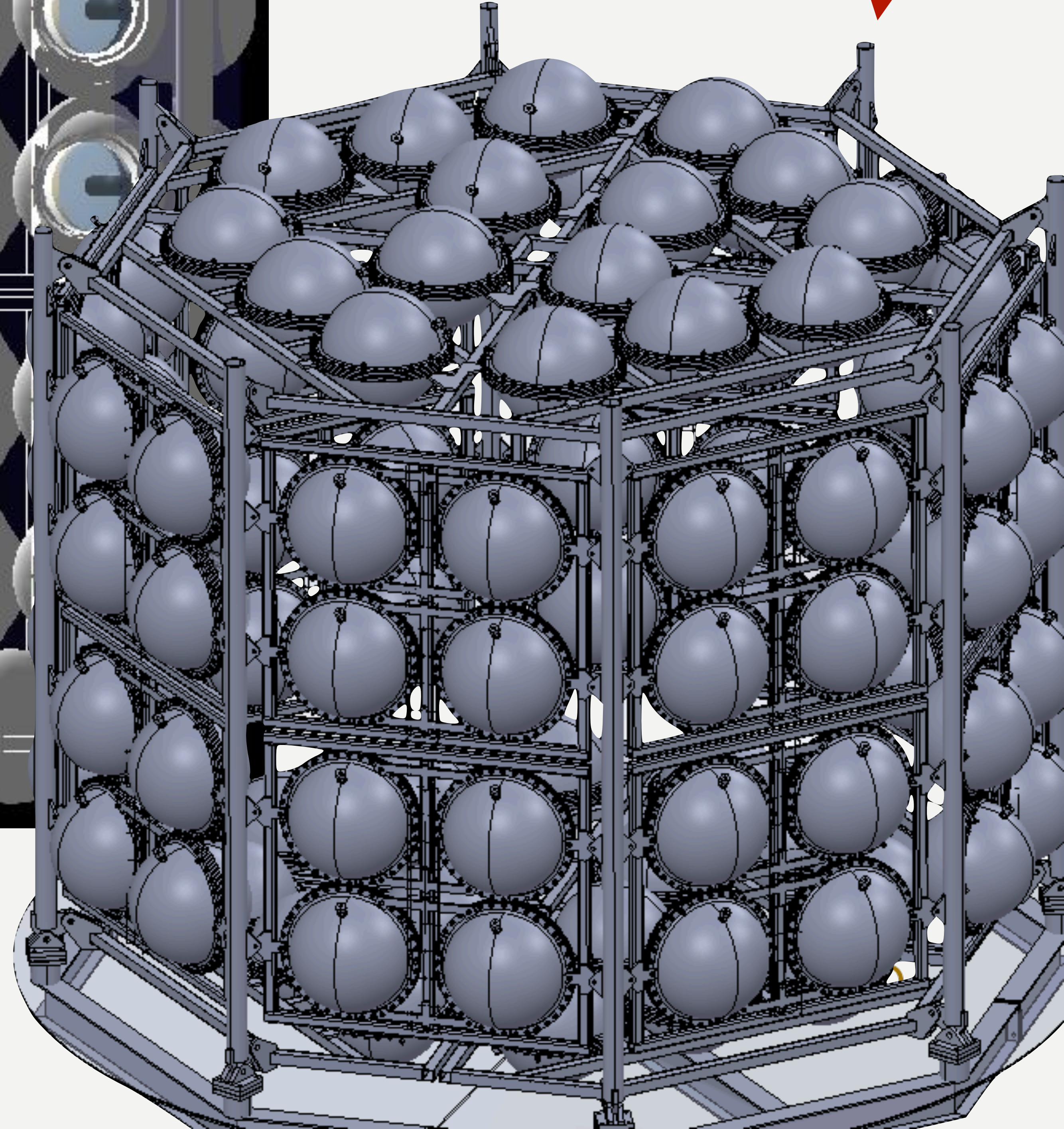
- 50 kton water Cherenkov detector
- 13,000 PMTs

<u>BUTTON-30</u>

- 30 tons of water (WbLS)
- 96 PMTs
- Radius =1.8 m, Height =2.7 m





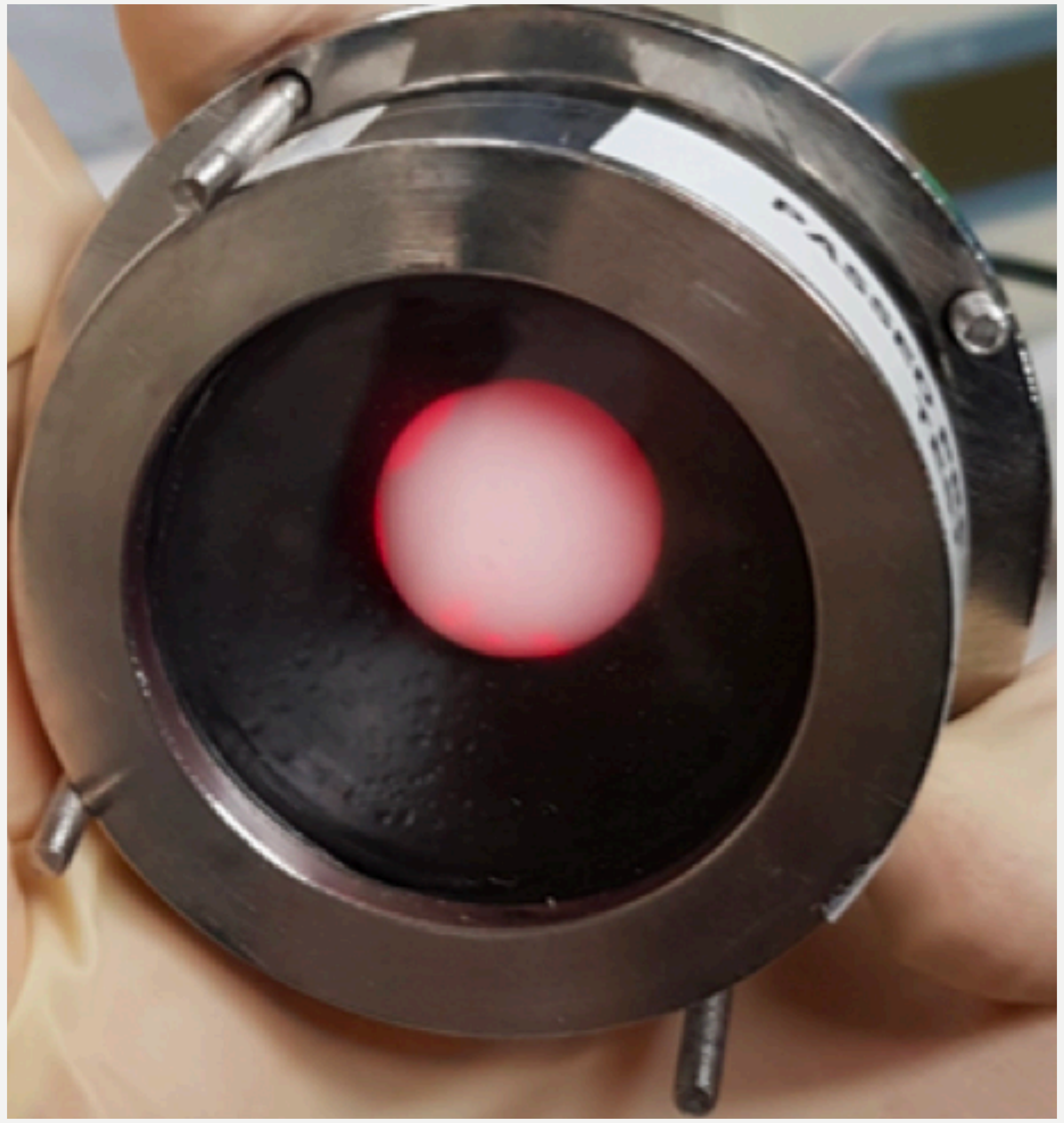


Diffusers

Diffusers at Super-K

The UK calibration system

- Diffusers form part of the UK light injection system for Super-K
- Diffusers produce a uniform light cone with an opening angle of 40°
- By measuring the light seen from a known source (Diffuser), detector performance can be monitored and uncertainties reduced
- A log-likelihood fitter will extract the attenuation (z_α) and PMT angular response ($A(\theta)$) for super-K diffusers
    - $PE = I_s(\theta_s, \phi_s)e^{-R/z_\alpha}A(\theta)\Omega(R,\theta)$



Where the attenuation is given by

$$z_\alpha = a(\lambda) + b(\lambda)$$

$a(\lambda)$ is the absorption and $b(\lambda)$ is the scattering.

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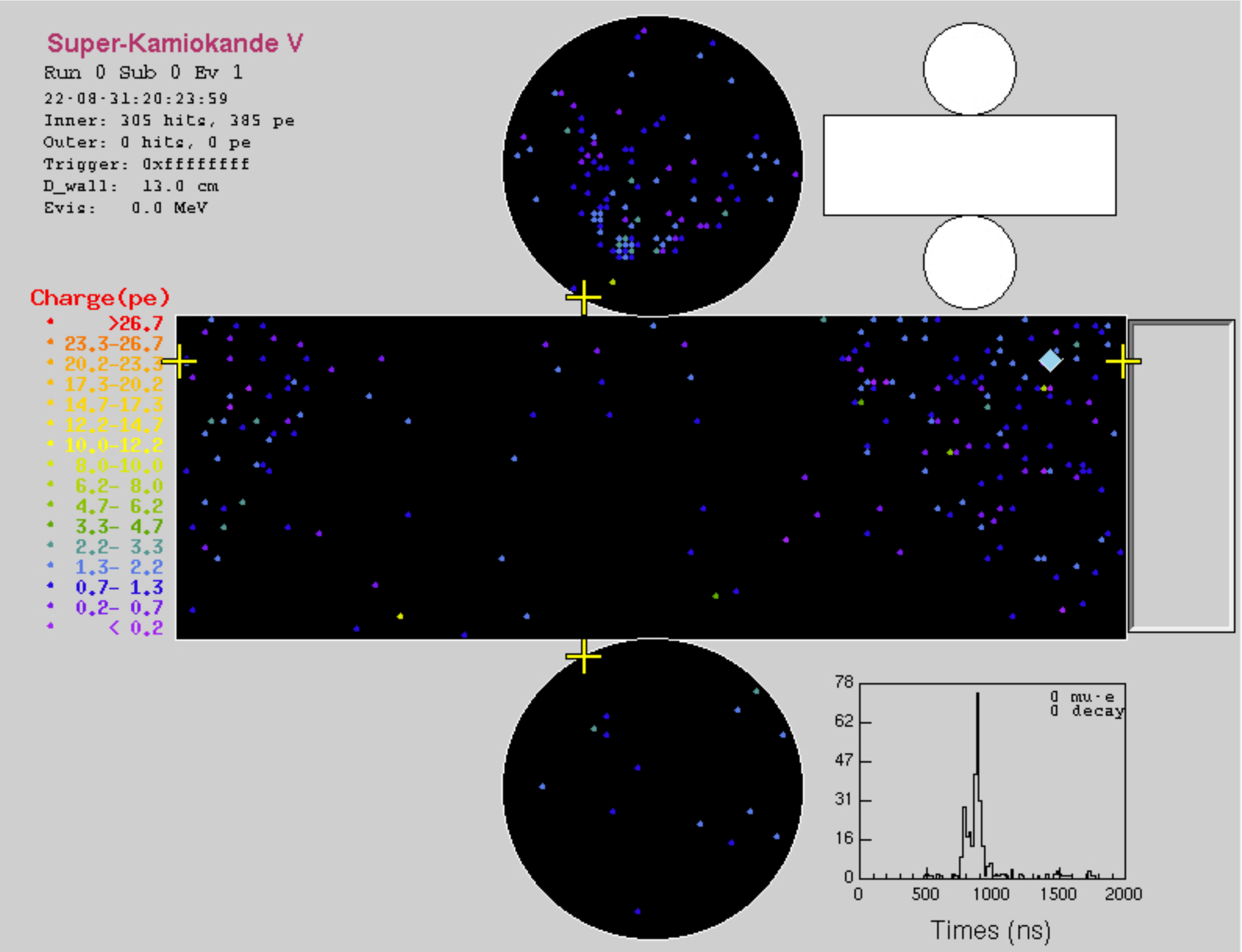
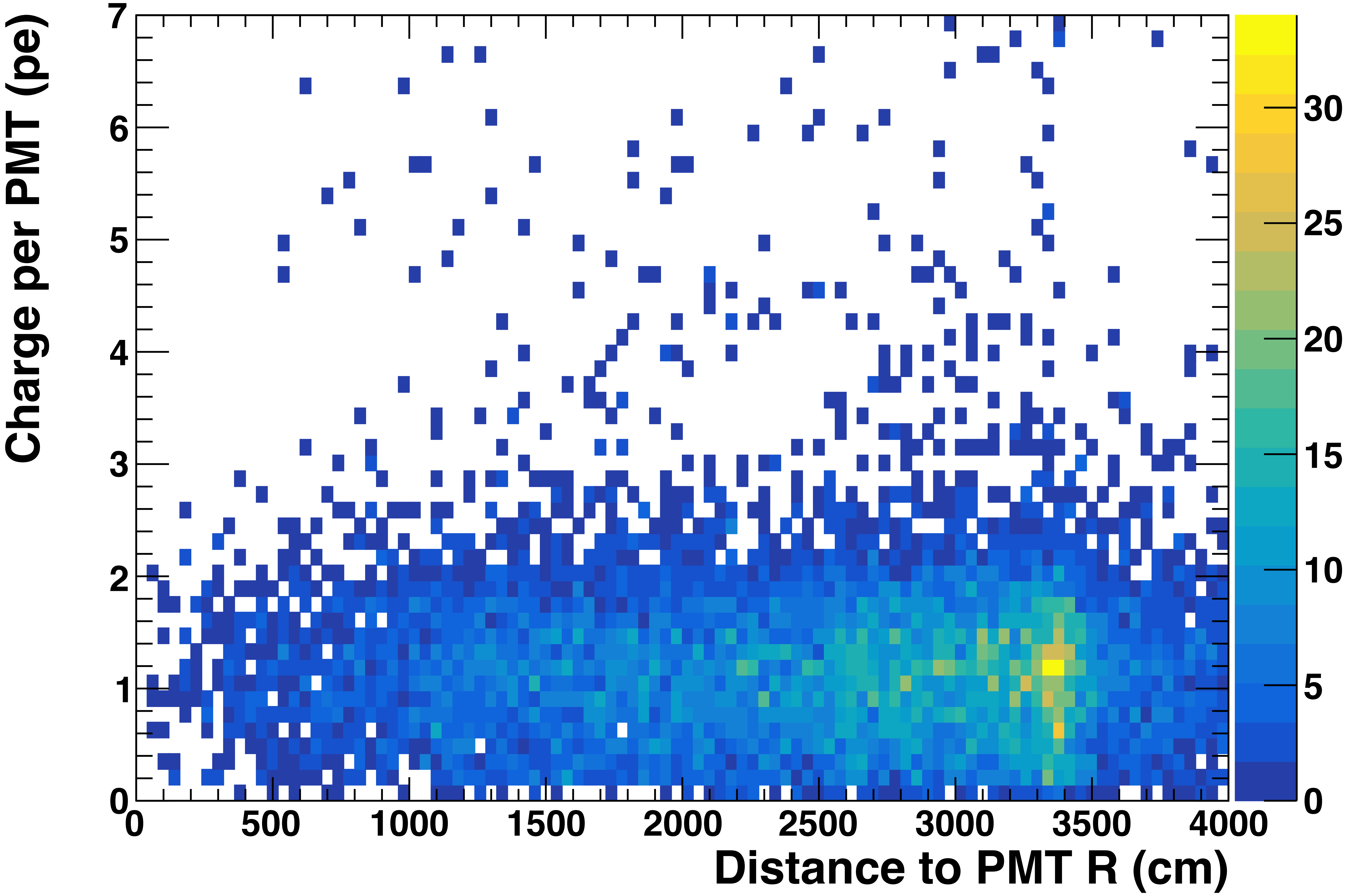
Diffusers at Super-K

The UK calibration system





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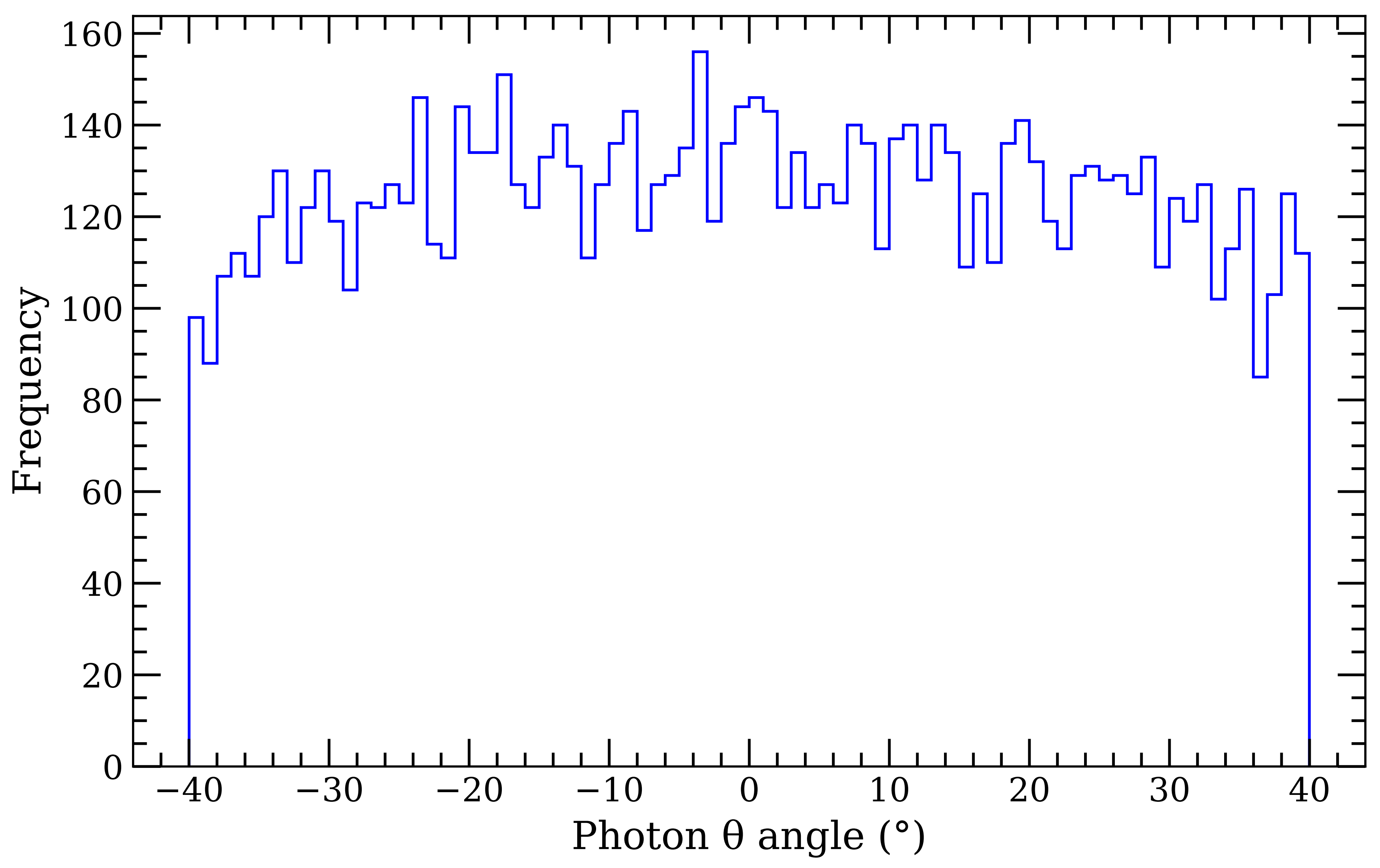
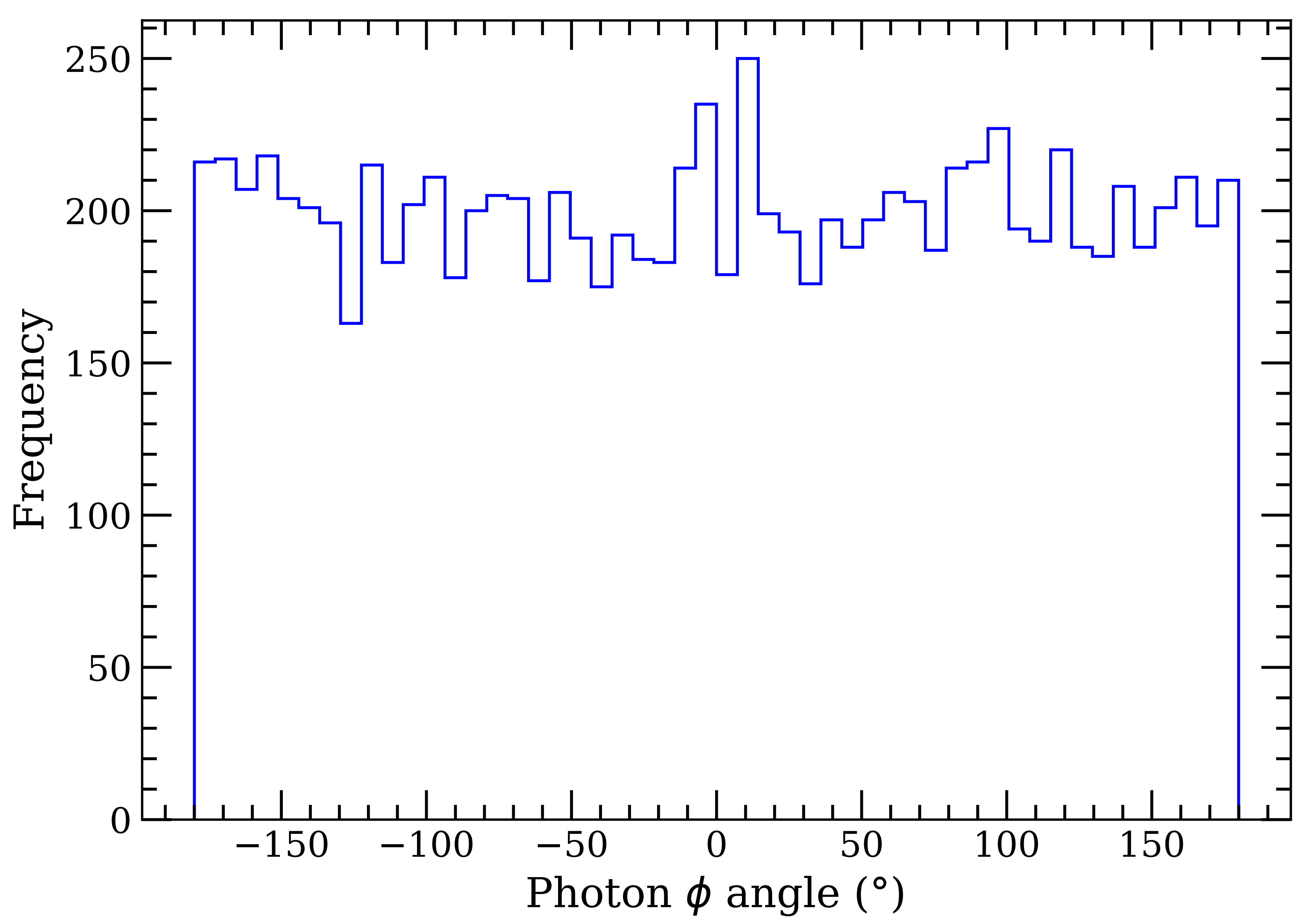
Diffusers for BUTTON

Smaller tank Bigger Problems

- Button will use the same diffusers as Super-K
- I have been developing generator for simulations of diffusers
- Data from Warwick University on diffuser profile from Super-K already added to generator
- Once completed it can be tested if attenuation can be found in a small tank





Water based Liquid Scintillator (WbLS)

Future of Cherenkov Detectors

What about scintillator

- There are some advantages to a water Cherenkov detector and some advantages to scintillator detectors

Cherenkov detectors (water)

Advantages

- Great particle identification
- Can reconstruct position and energy of event

Disadvantages

- Limited by Cherenkov Threshold 0.8 MeV electron events (~3.49 MeV [1] (SK solar limit))
- Poor energy resolution at low energy (10MeV) (due to low light yield)

Liquid Scintillator

Advantages

- Sensitive to low energy events
- High count rate efficiency

Disadvantages

- Expensive to buy in large quantities
- Risk to environment and people

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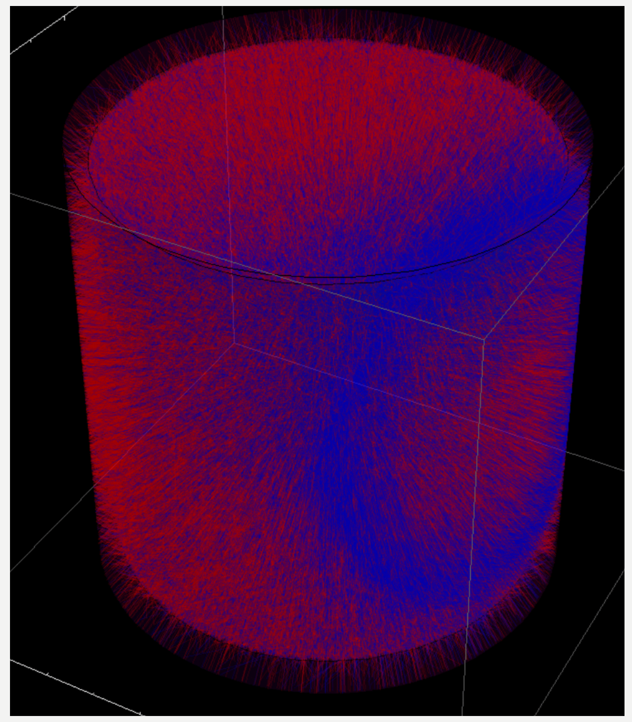
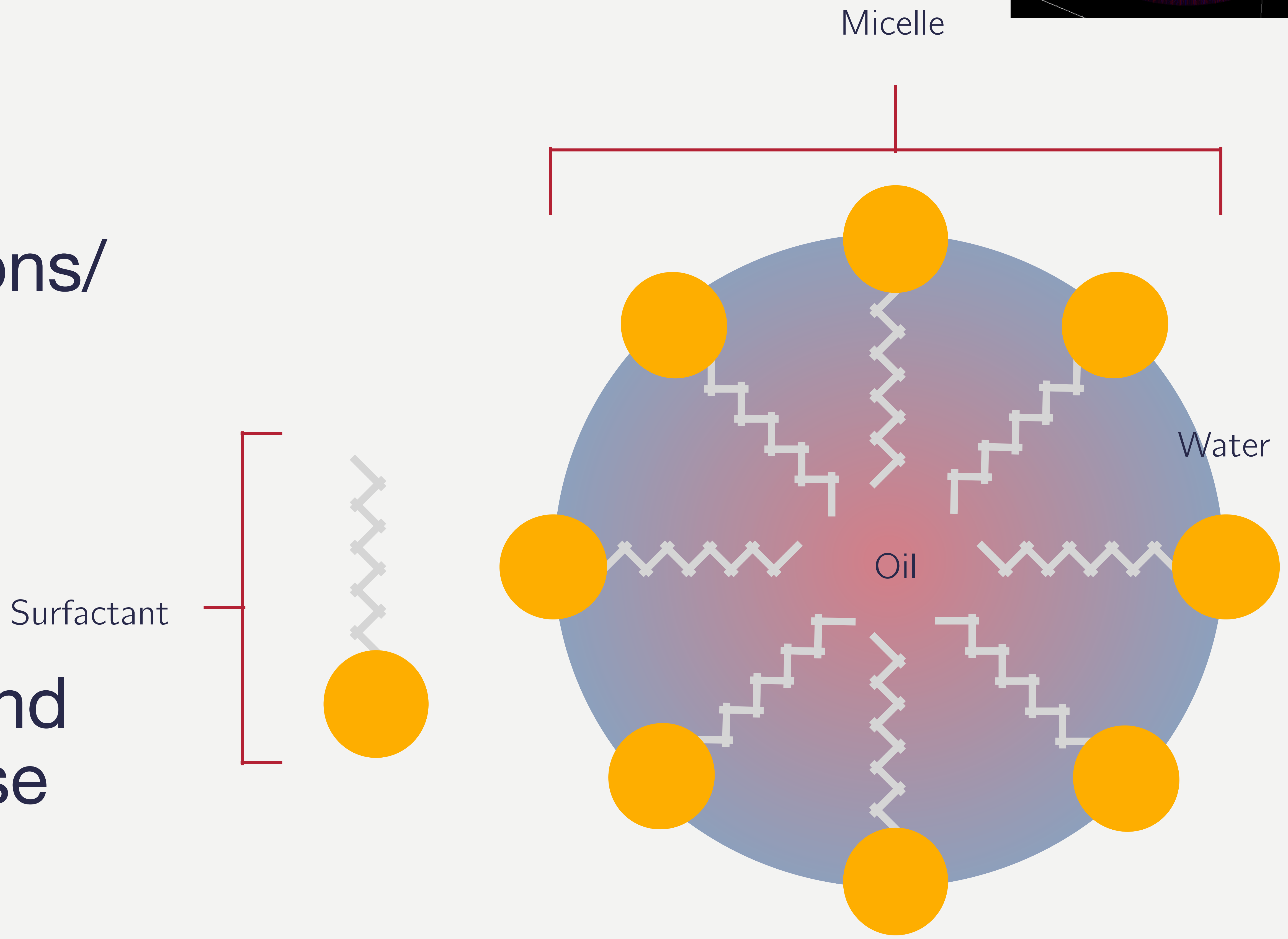
B. Land (Berkeley)



Water-based Liquid Scintillator

Best of both worlds

- Why not mix water and scintillator?
- 1% Scintillator gives ~100 optical photons/MeV [2]
- Keeps the particle identification and position for high energy events
- Useful in studies from reactor ranging and neutrinoless double beta decay to diffuse supernova backgrounds

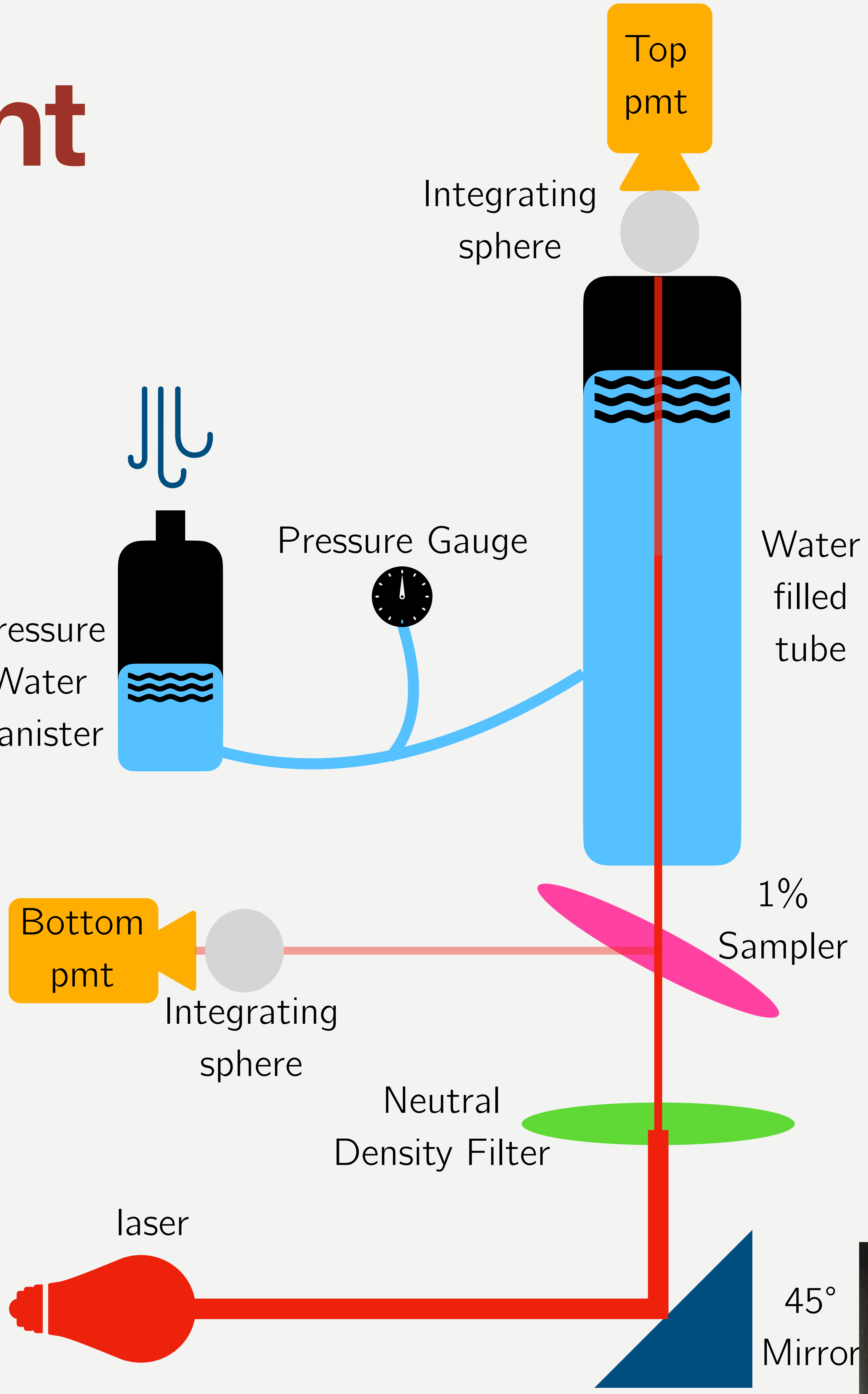


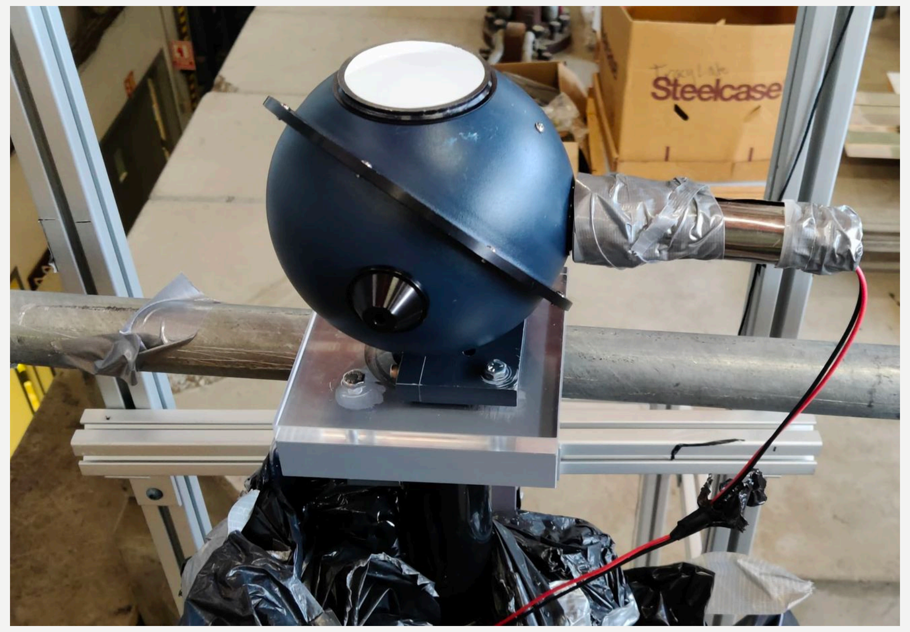
 [2] arXiv:1409.5864

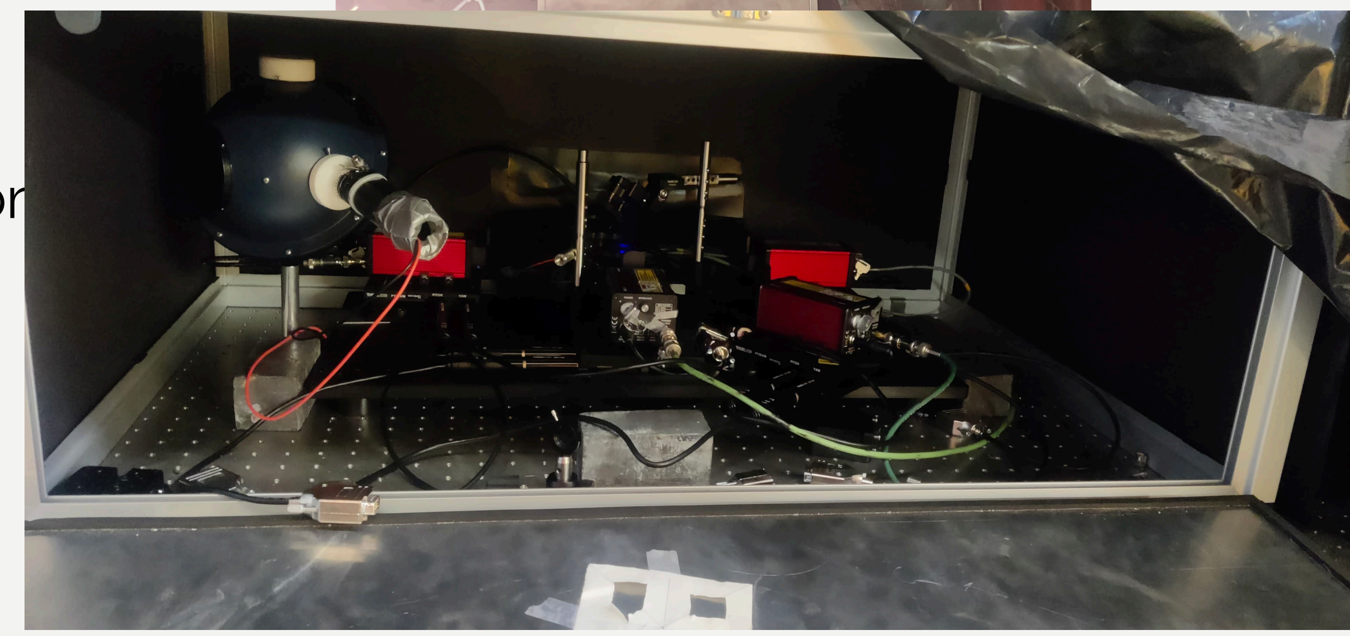
The Attenuation of Light

Doing the Dirty Work

- Scattering and Attenuation Measuring Device (SAMD)
- Want to measure the attenuation of light in WbLS to improve simulations
- Important for our simulations and systematic uncertainties







Measuring the Attenuation

410 nm WbLS

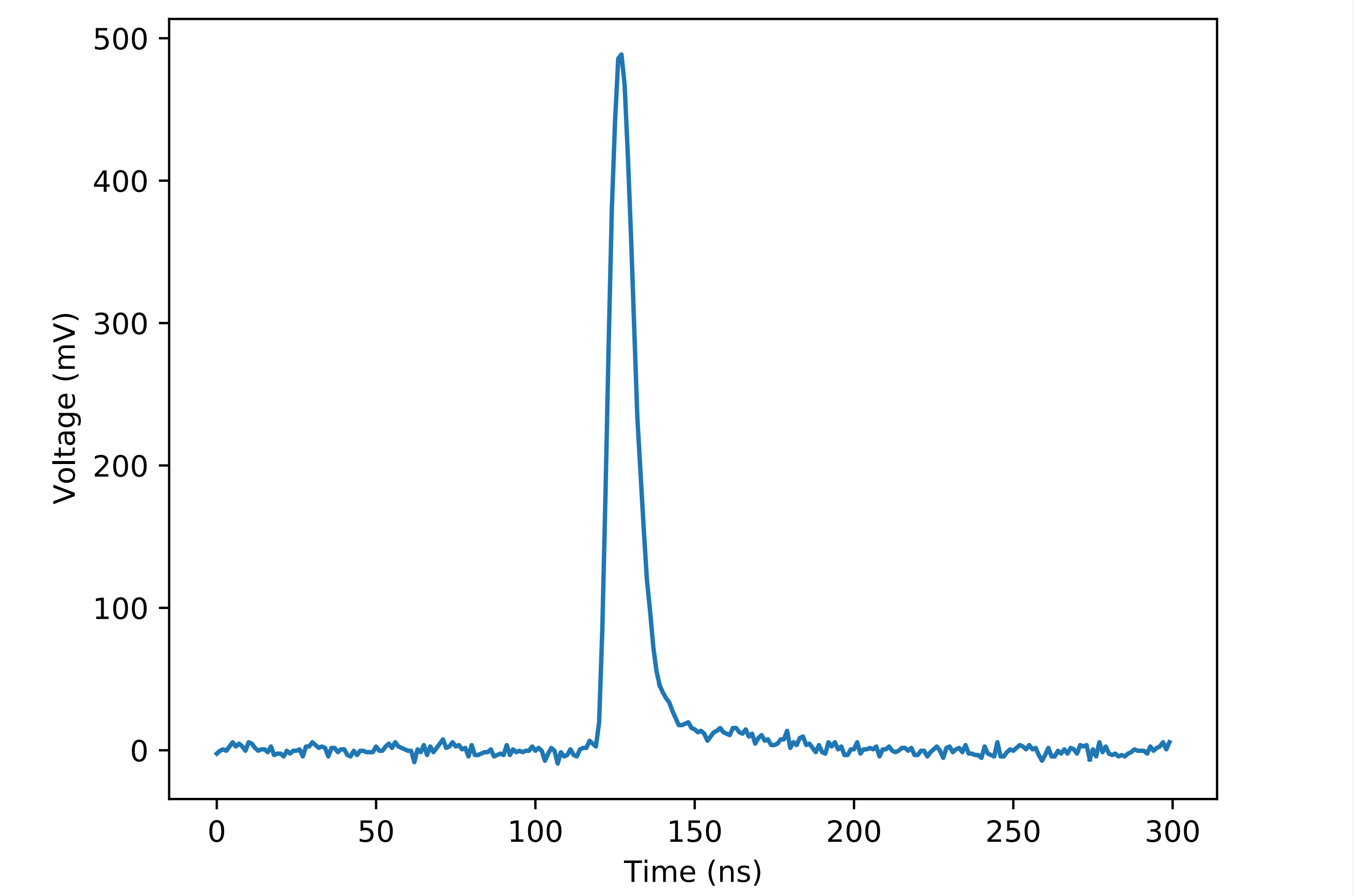
- Integrate over the peak to get intensity

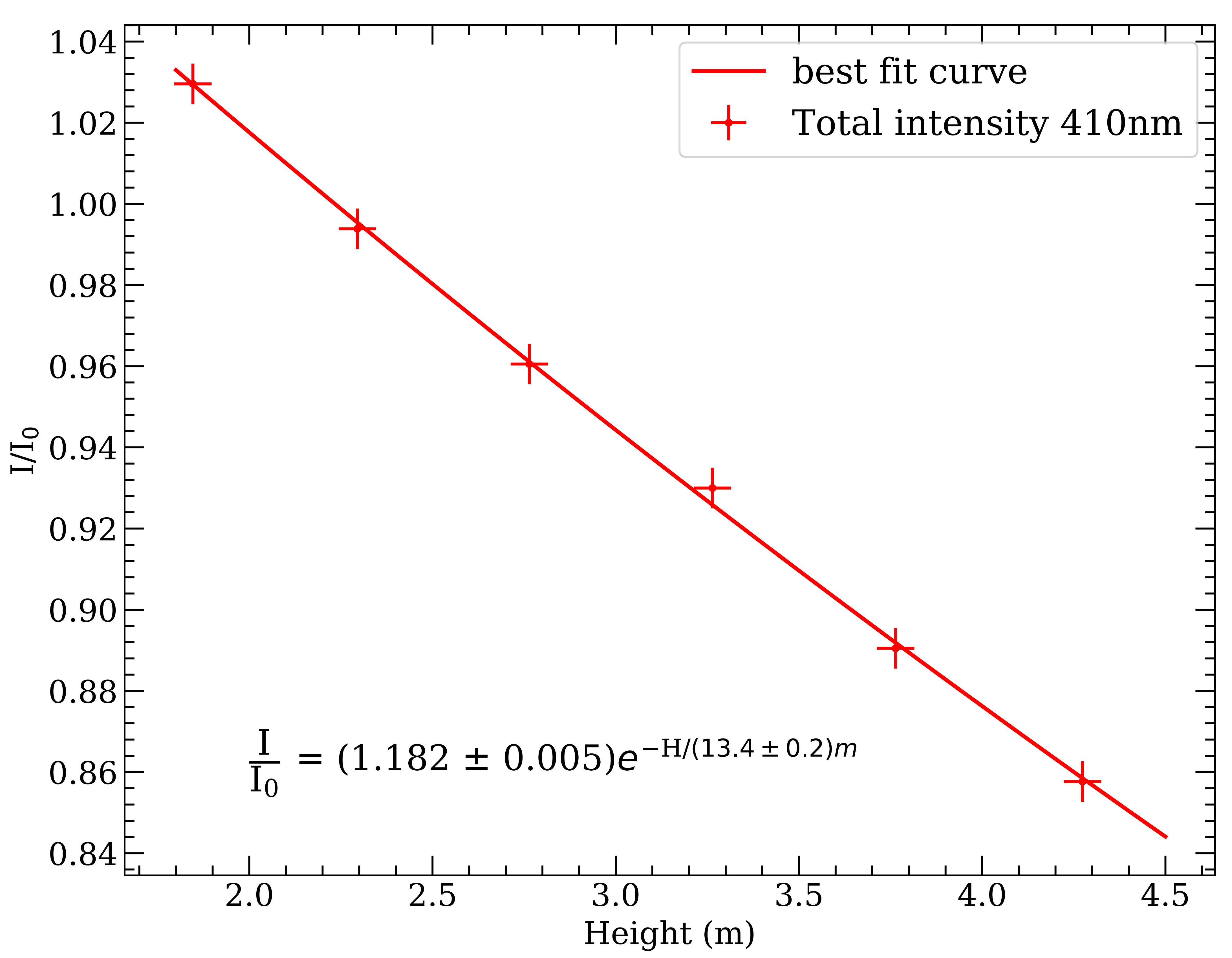
- The ratio of top to bottom PMT is taken as a function of height

- Orthogonal distance regression is used to fit an exponential to the data

$$\frac{I}{I_o} = \epsilon e^{\frac{-H}{z}}$$

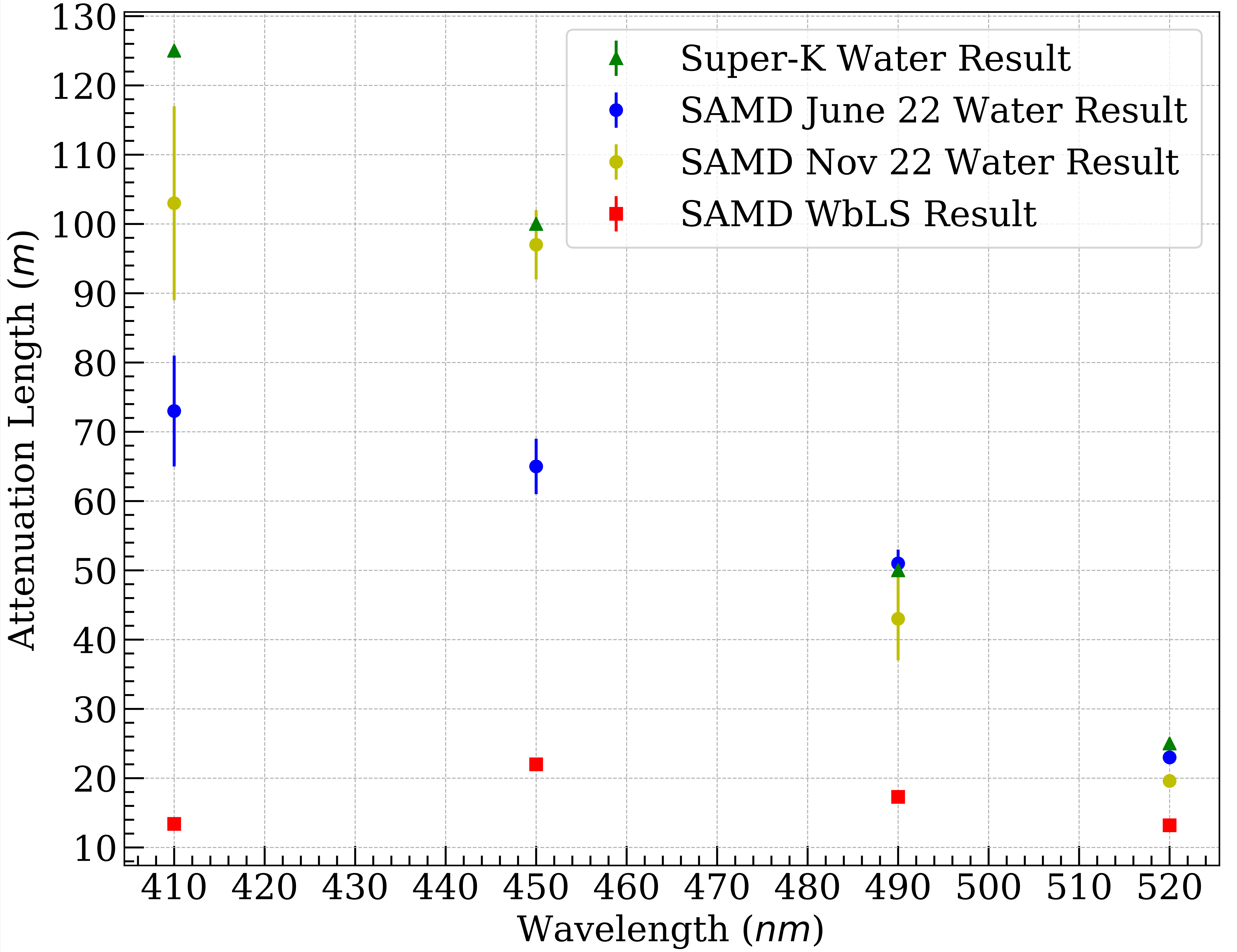
- This system could be used in WbLS detectors like BUTTON





Data taken at UC Davis

Attenuation Coefficient



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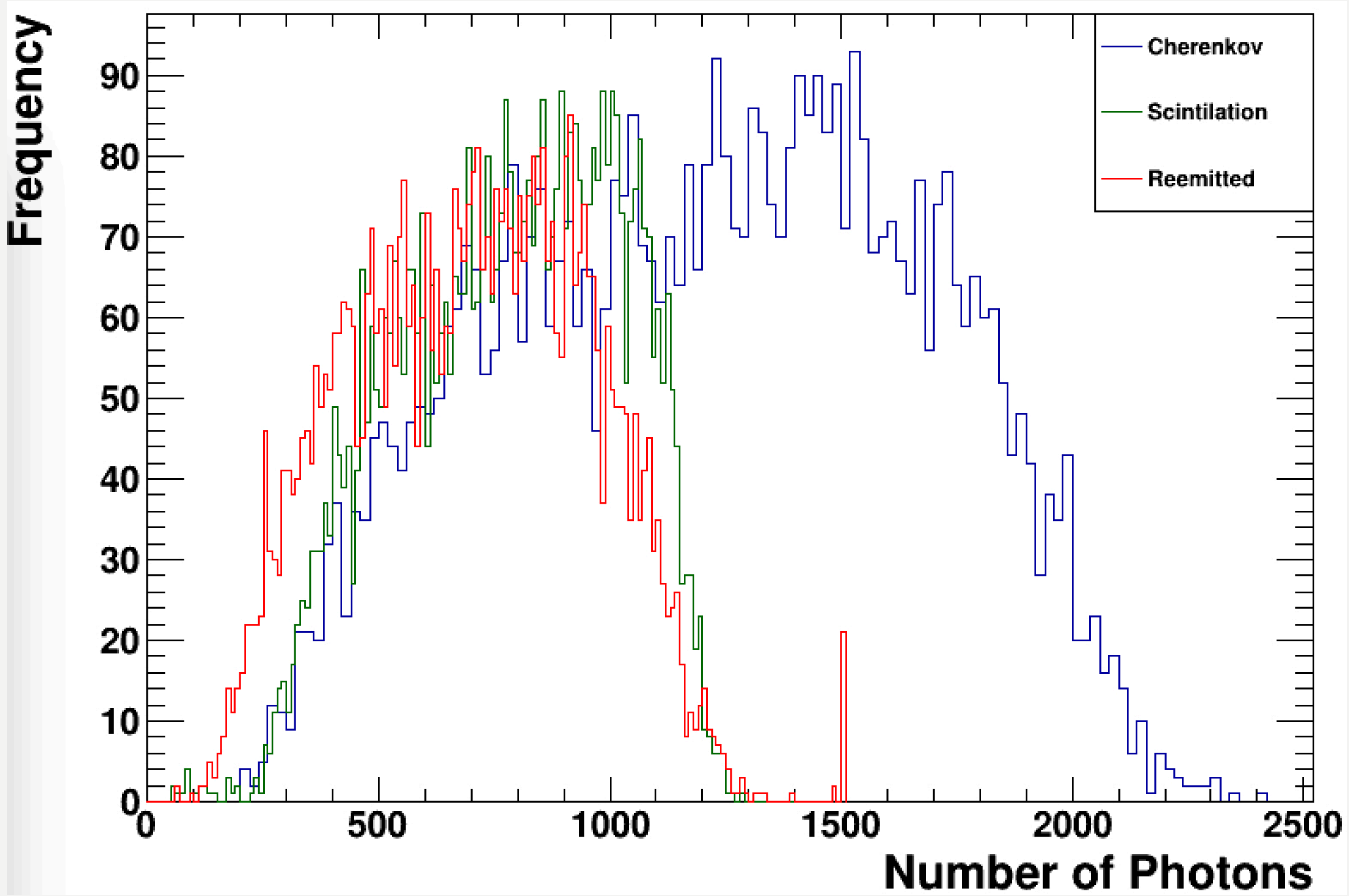
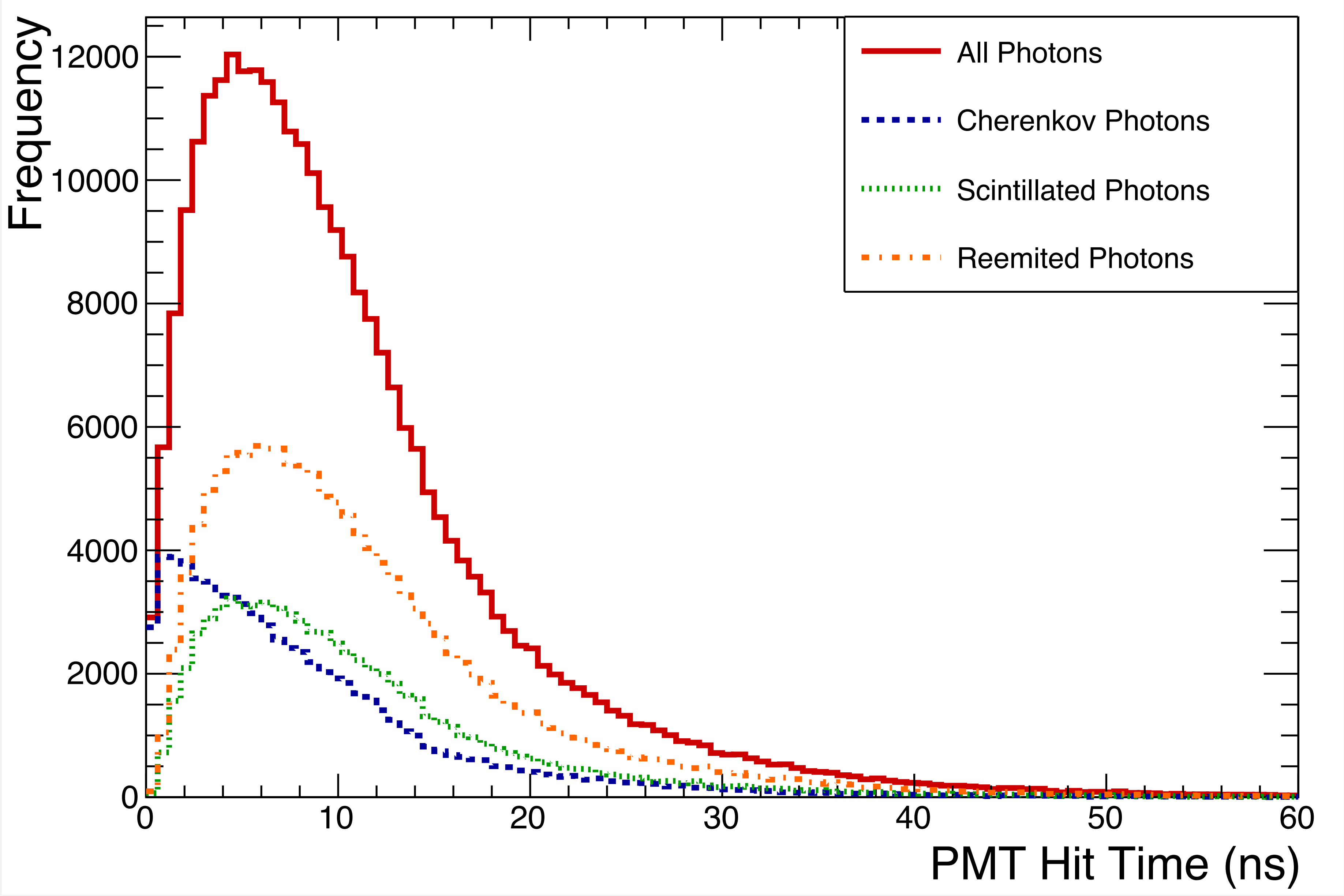
WbLS in BUTTON

Testing the results

- WbLS has been added to BUTTON simulation (RATPAC) by American collaborators
- Want to confirm that fill type behaviour is as we expect
- Looking at the photon type and the time profile
- See the separation in time of the different photon types
- Can also add the SAMD attenuation measurement to the simulation





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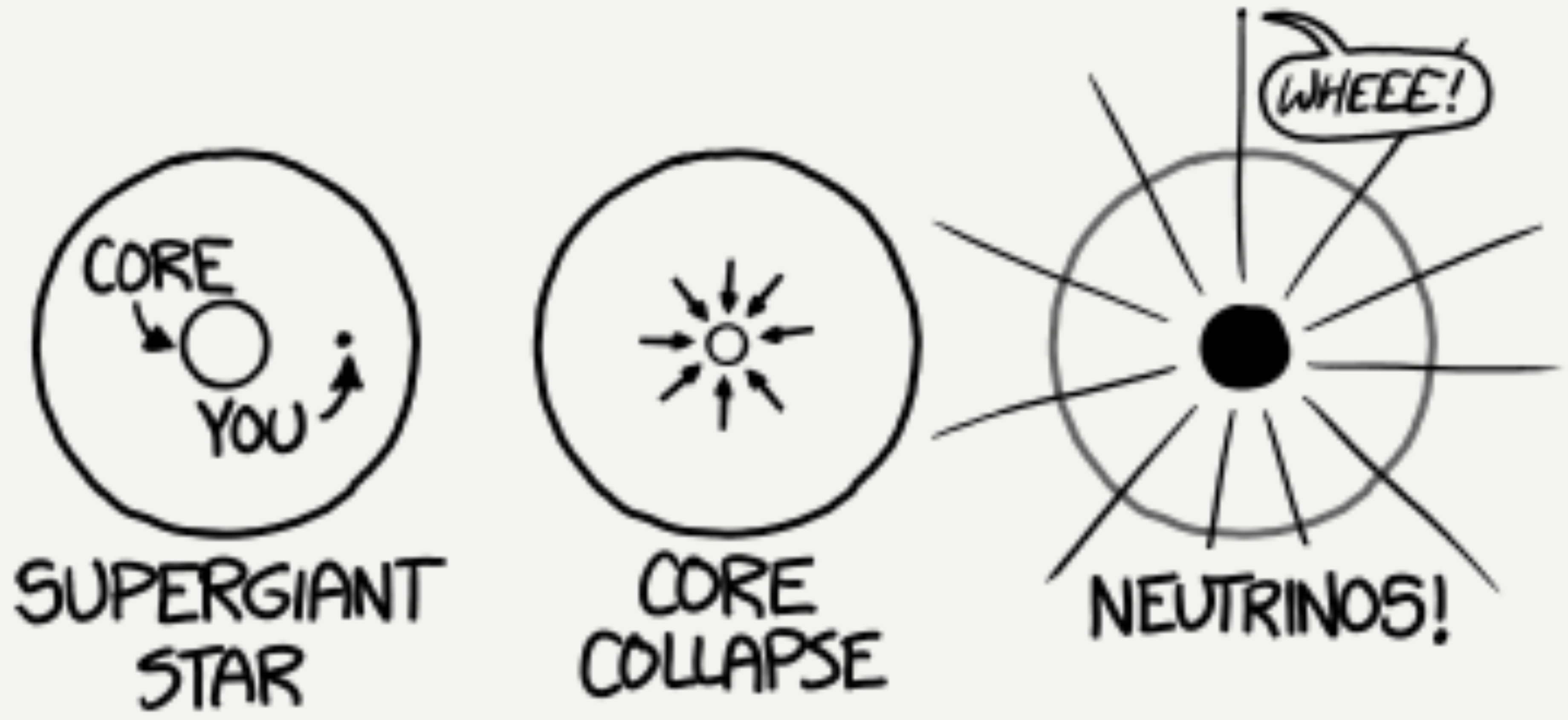
Supernova Neutrinos

Supernova Neutrinos

When stars go bang 💥

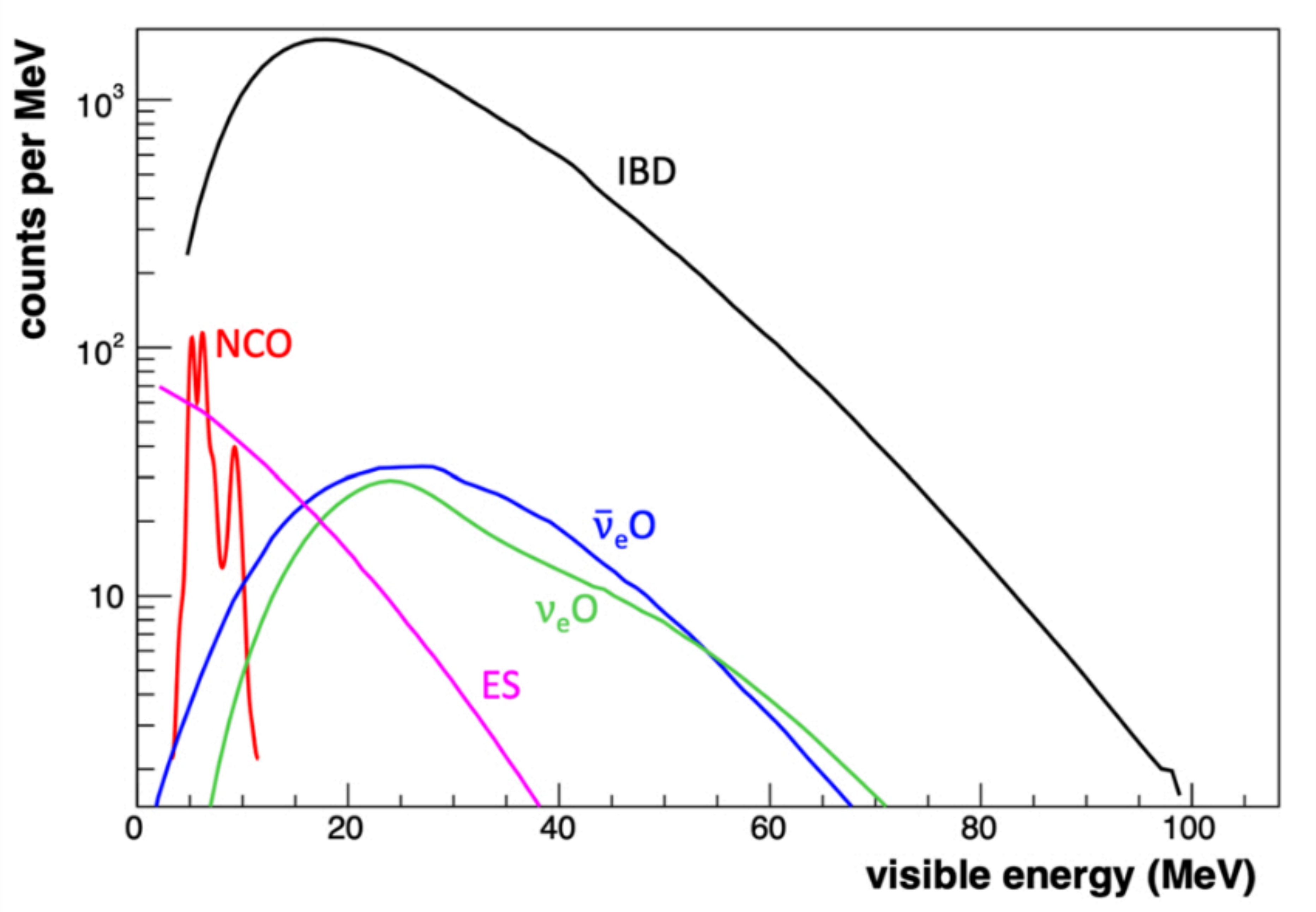


- Stars ($M \gtrsim 8M_{\odot}$) can undergo core collapse at the end of there life (making neutron stars and black holes)
- 99% of supernova energy is released in neutrinos (10^{53} erg~10^{46}J~10^{64} eV) within 10 s with energy between ~10-60 MeV
- Rear event —> 1-3 SN per centry (in or galaxy (O(10) kpc))
- Next event could tell us a lot
    - Supernova mechanisms, Neutrino mass hierarchy, Neutrino mixing, Axion-like particle (BSM), Nucleosynthesis, Stellar evolution, Progenitor structure etc

WbLS and Supernova

Looking for Supernova Neutrinos

- One advantage of Gd-WbLS is separation of Electron Scattering (ES) signal from the Inverse Beta Decay (IBD) signal
- This will allow for supernova pointing (angle of the neutrino is persevered in the electron)
- Currently working on separating ES from IBD signals in WbLS Detectors
- The progress of BUTTON-30(100) will help in future development of THEIA (& AIT) which would provide complementary information with DUNE & Hyper-K



[3] THEIA: an advanced optical neutrino detector, M. Askins, et el, Eur. Phys. J. C (2020) 80:416 https://doi.org/10.1140/epjc/s10052-020-7977-8

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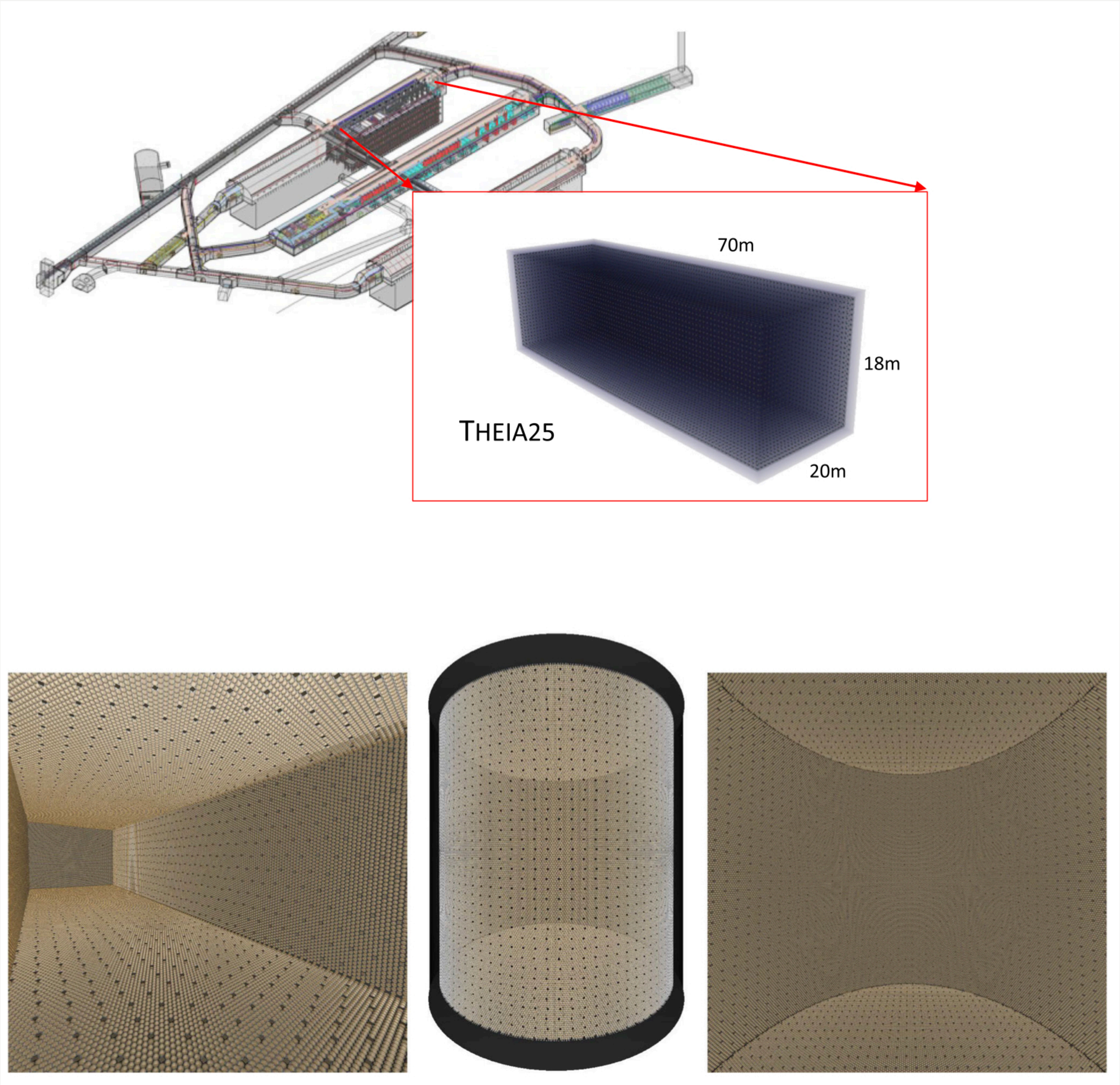
Thank You for Listening

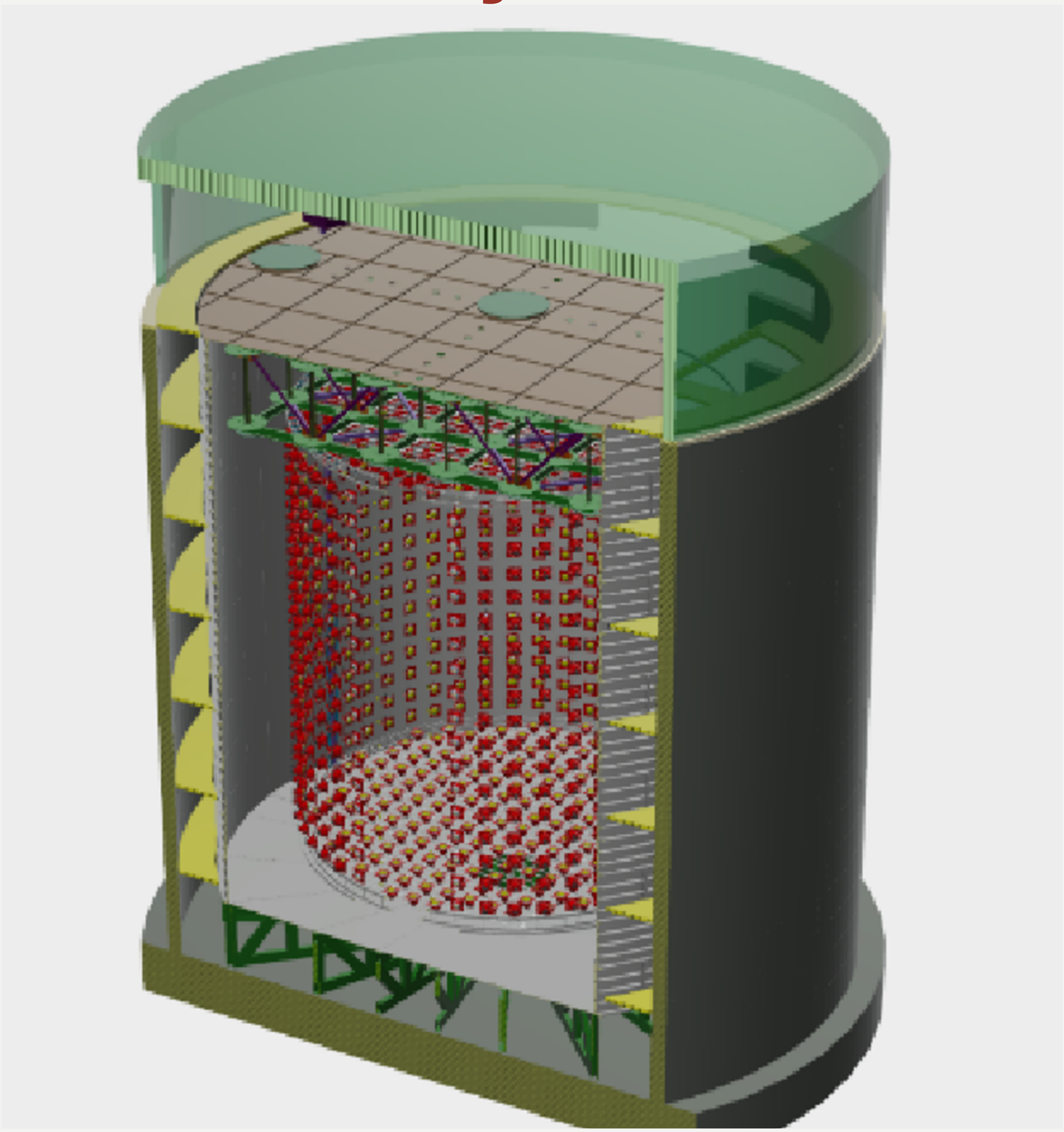
Back up

Detectors of the future

THEIA - DUNE (SK)



AIT - Boulby



Eur. Phys. J. C (2020) 80:416 https://doi.org/10.1140/epjc/s10052-020-7977-8

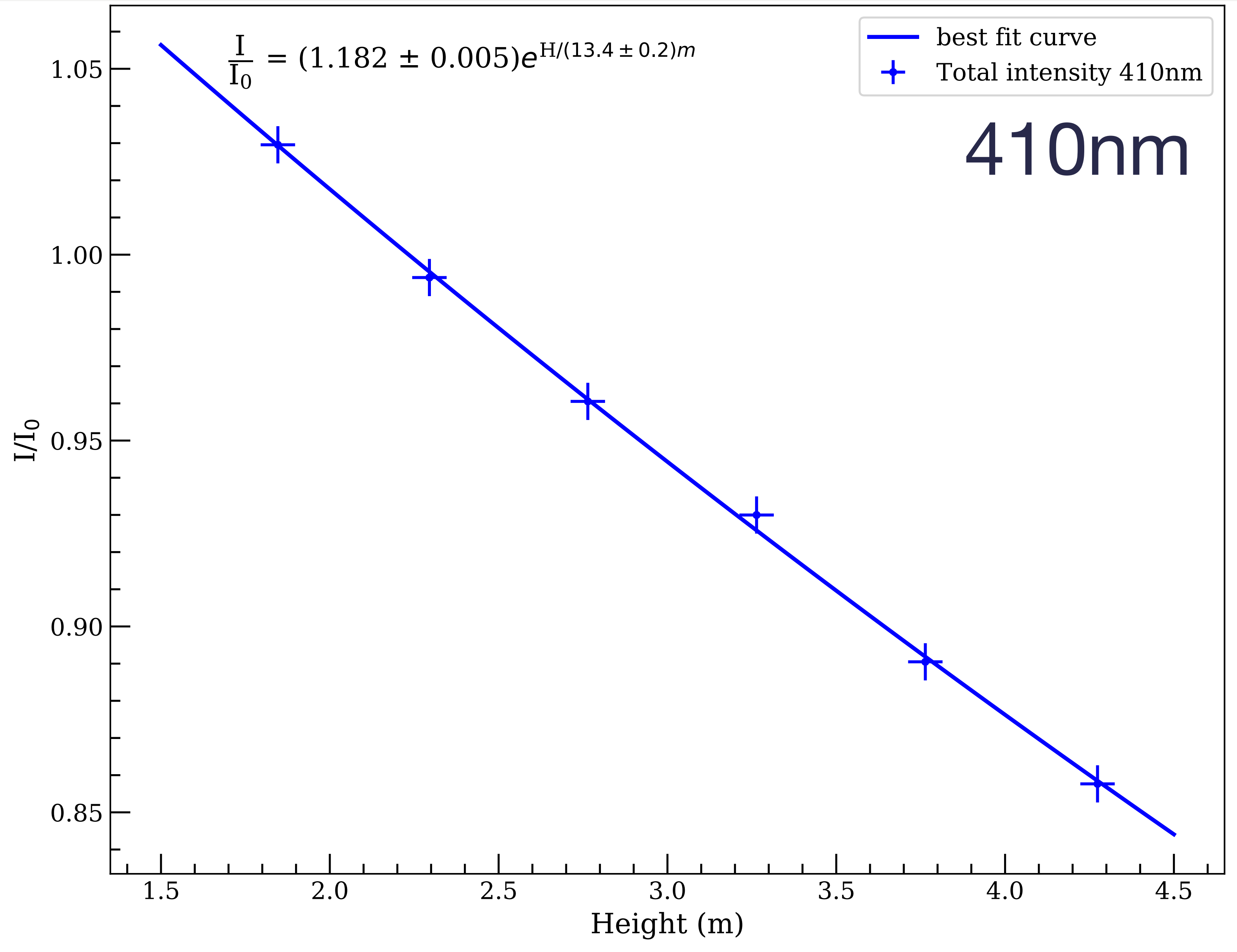
Results table

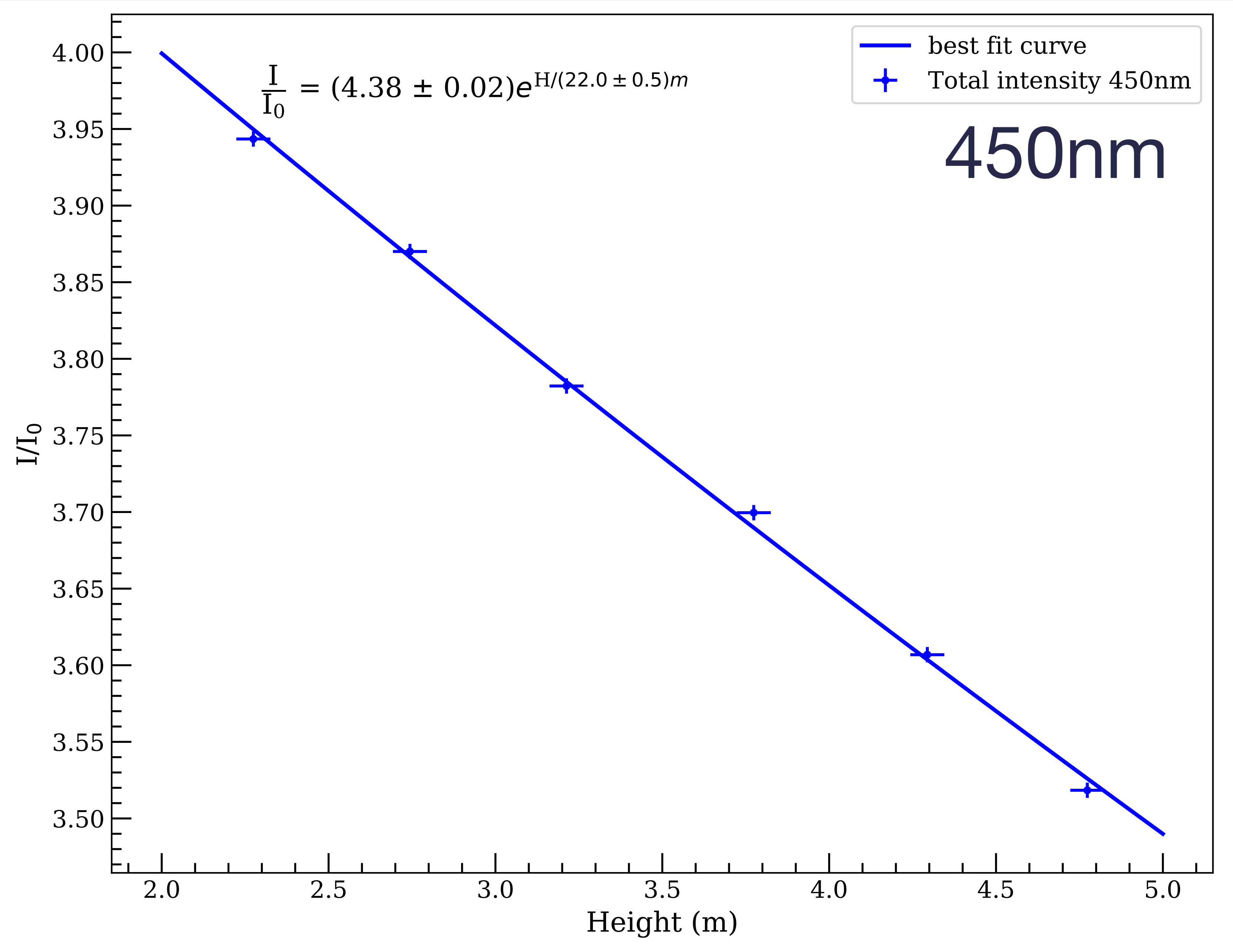
Getting it all together

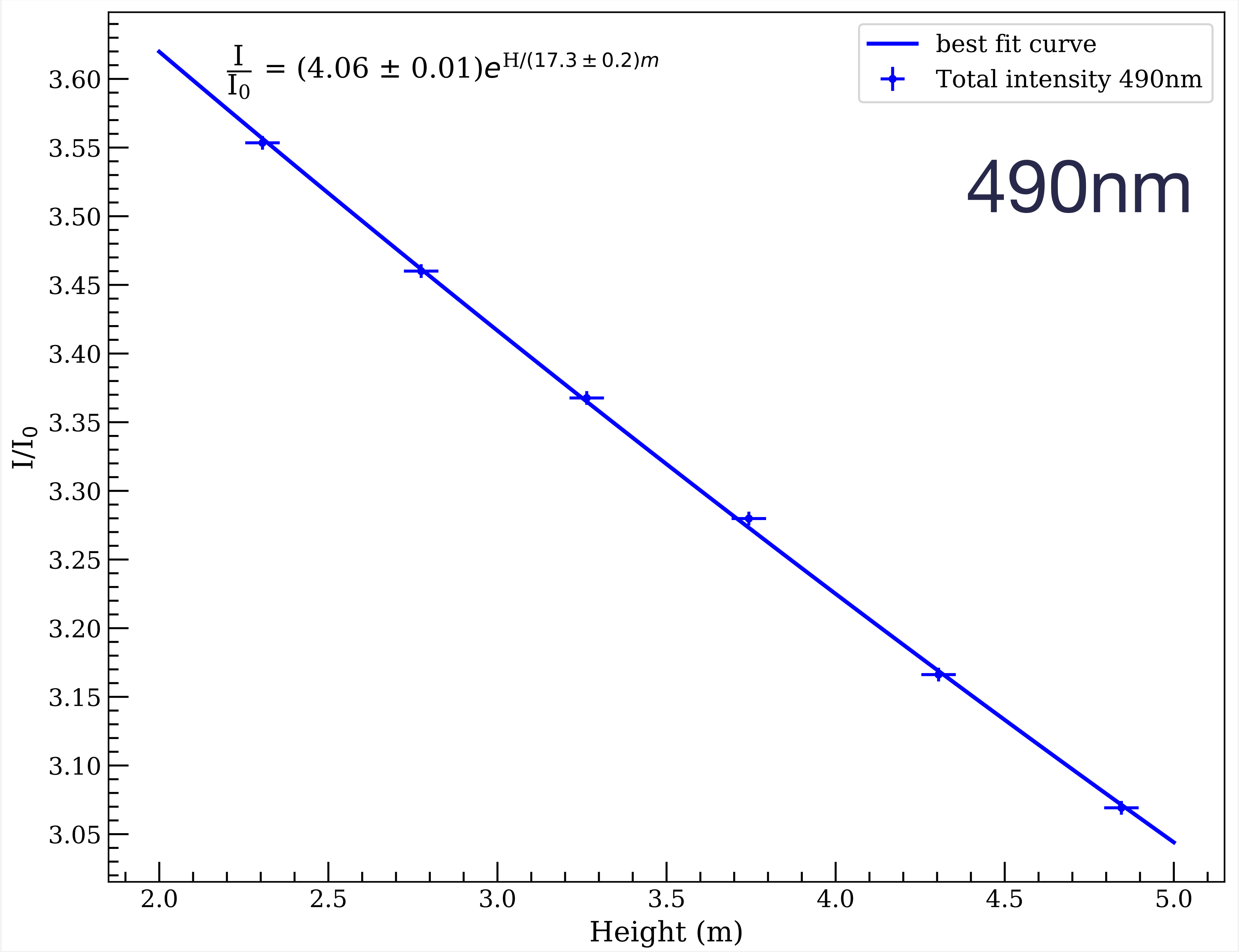
$$\frac{I}{I_o} = \epsilon e^{\frac{-H}{z}}$$

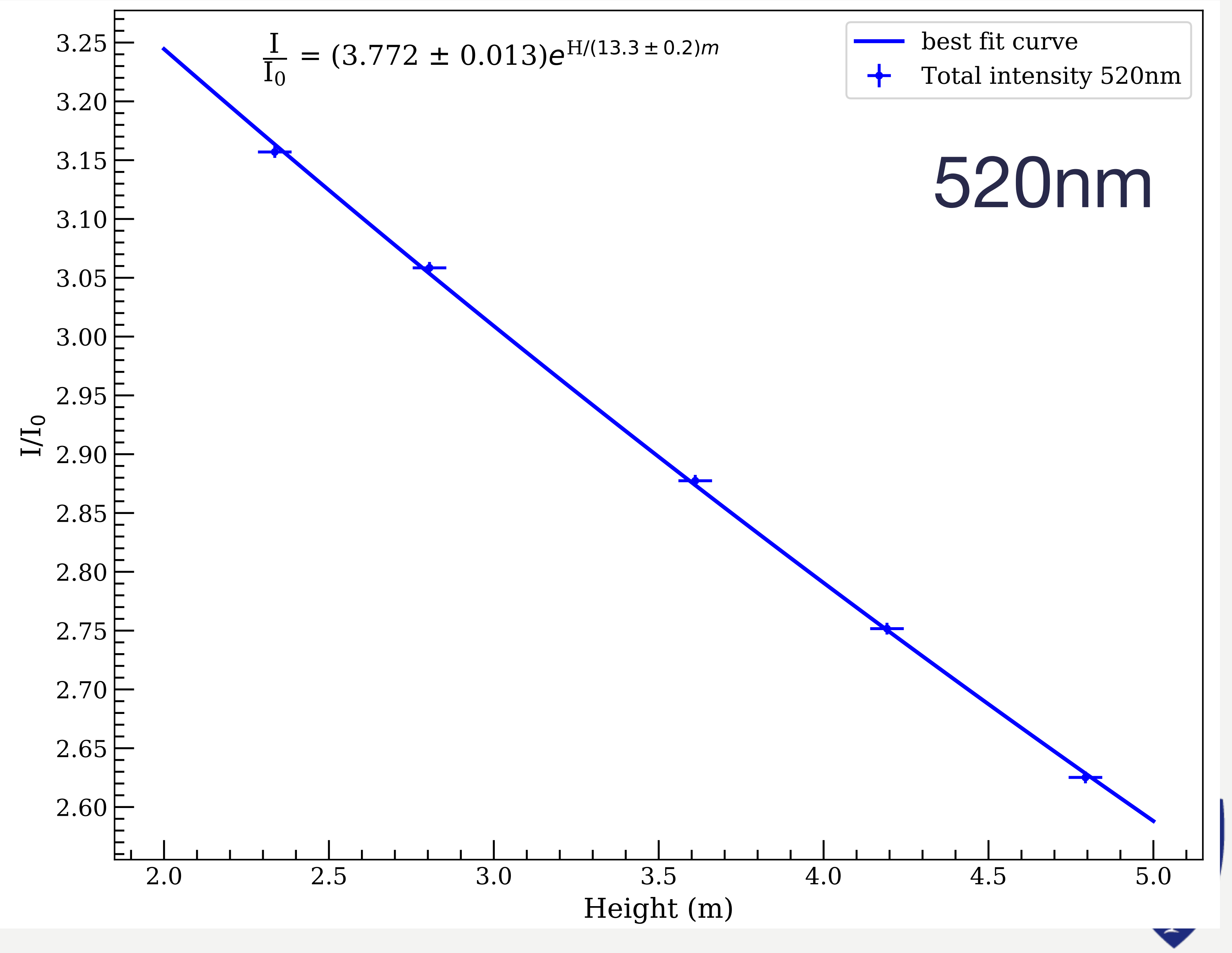
Measurement	410nm		450nm		490nm		520nm	
	ε	z(m)	ε	z(m)	ε	z(m)	ε	z(m)
Water June 2022	1.051±0.004	73±8	1.155±0.004	65±4	0.746±0.001	51±2	1.79±0.01	23±1
Water Nov 2022 (Davis only)	1.103±0.005	103±14	2.219±0.004	97±5	3.83±0.05	43±6	3.483±0.005	19.6±0.2
Pope	-	188	-	108	-	66.6	-	24
WbLS Nov 2022 (Davis only)	1.183±0.005	13.4±0.2	4.38±0.02	22.0±0.5	4.06±0.01	17.3±0.2	3.77±0.01	13.3±0.2

All 4 lasers WbLS attenuation   Taken Nov 2022









Data taken Tianqi Zhang and Davis group

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