

# NEW PHOTON TRAP DESIGN PROPOSED FOR NEXT-GENERATION NEUTRINO TELESCOPES

KOUN CHOI<sup>a,b</sup> AND CARSTEN ROTT<sup>c,b</sup>

<sup>a</sup> INSTITUTE FOR BASIC SCIENCE, KOREA (E-MAIL: koun@ibs.re.kr), <sup>b</sup> SUNGKYUNKWAN UNIVERSITY, KOREA, <sup>c</sup> UNIVERSITY OF UTAH, USA



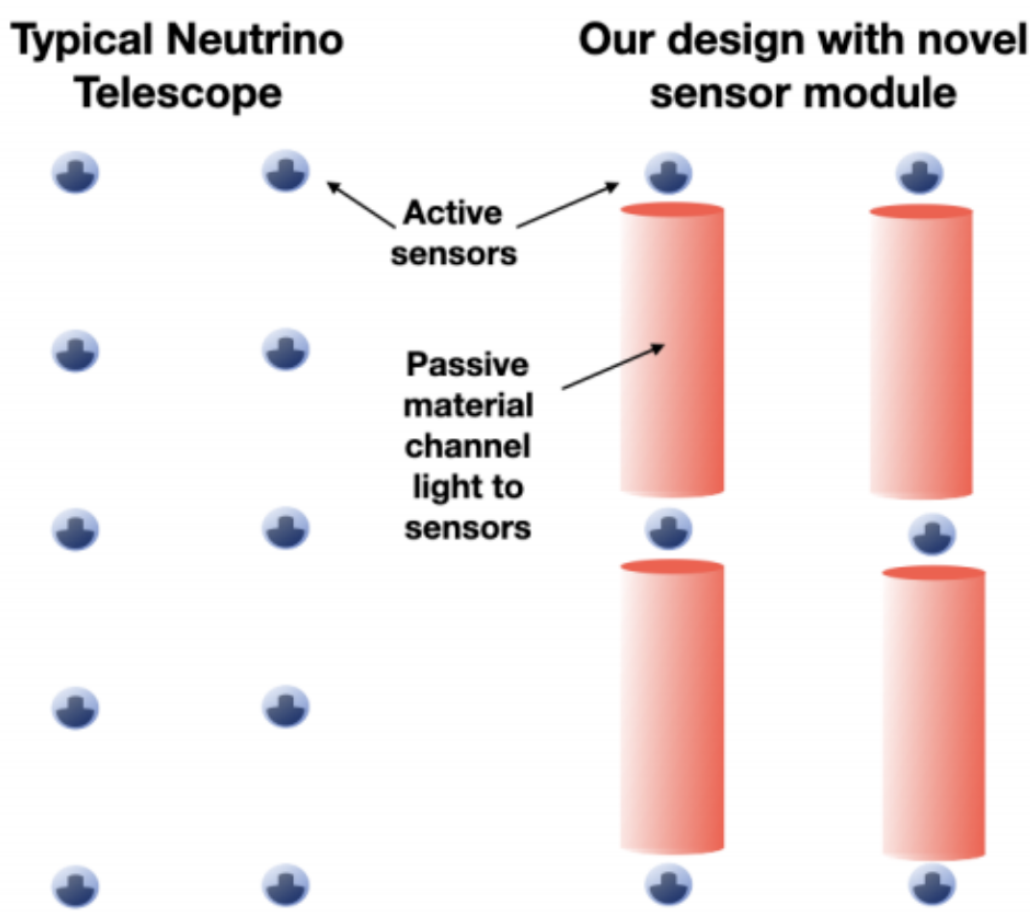
## INTRODUCTION

An optimized optical module for calorimetry with potential benefits:

- Improved energy resolution & threshold
- Increased veto efficiency for widely spaced array

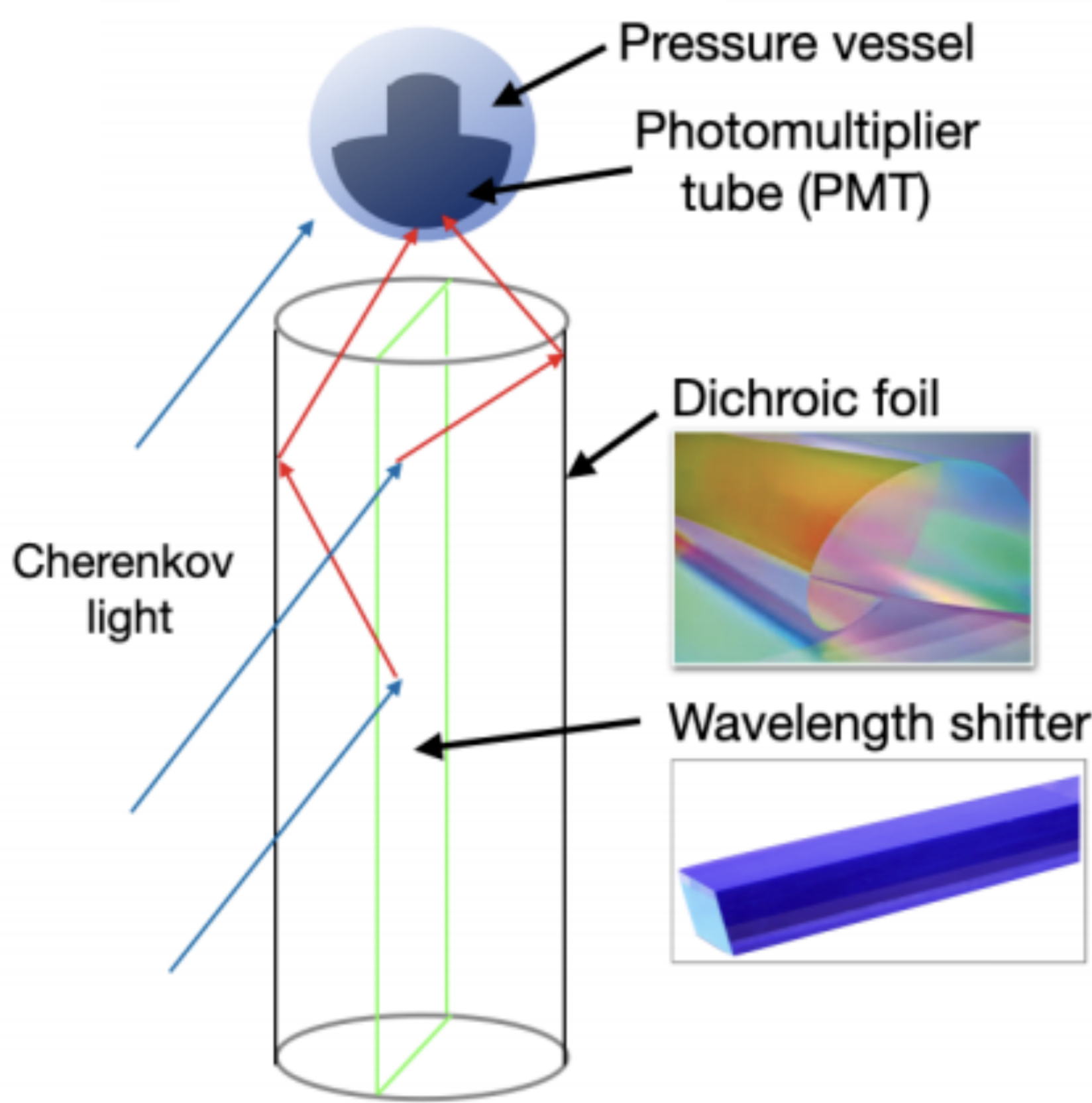
Desirable properties of new photosensor:

- Cost-efficient & simple design (Easily scalable and adaptable)
- Durable in the water or Ice, reliable for long-time exposure
- (In case of IceCube-Gen2) Easy to assemble & deploy at the South Pole
- Directly freeze into the ice; reduce cost & risk



## DESIGN

- A photon trap using Wave Length Shifter (WLS) [1, 2, 3] by which photons are efficiently absorbed and re-emitted
- Channeling photons to existing photosensor module by reflection on the surrounding dichroic film [1]
- “delayed photons” collected by the photon trap will significantly enhance signal efficiency, at the cost of reduced timing resolution



Desired Dichroic film property

- 100% transmittance below 400nm not to block primary photons (WLS captures photons between 250-400nm & re-emit above 400nm)
- 100% reflectance above 400nm to efficiently trap the re-emitted photons

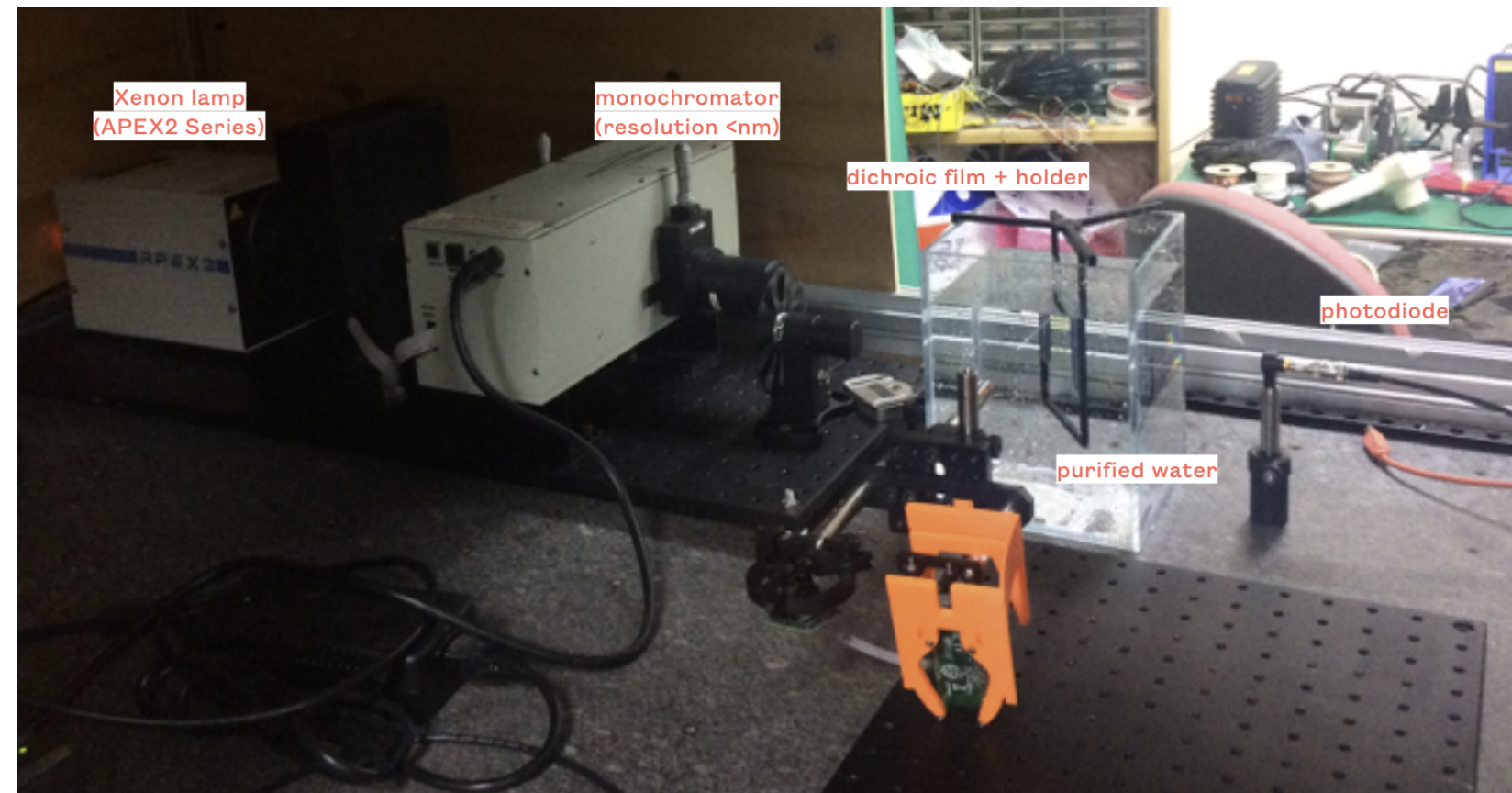
- Thin **dichroic foil** is wrapped in cylinder shape, which is deformable (does not resist pressure from freezing water)
- WLS plates are crossed each other (>1cm thickness for sufficient absorption)



## DICHROIC FILM MEASUREMENT SET UP

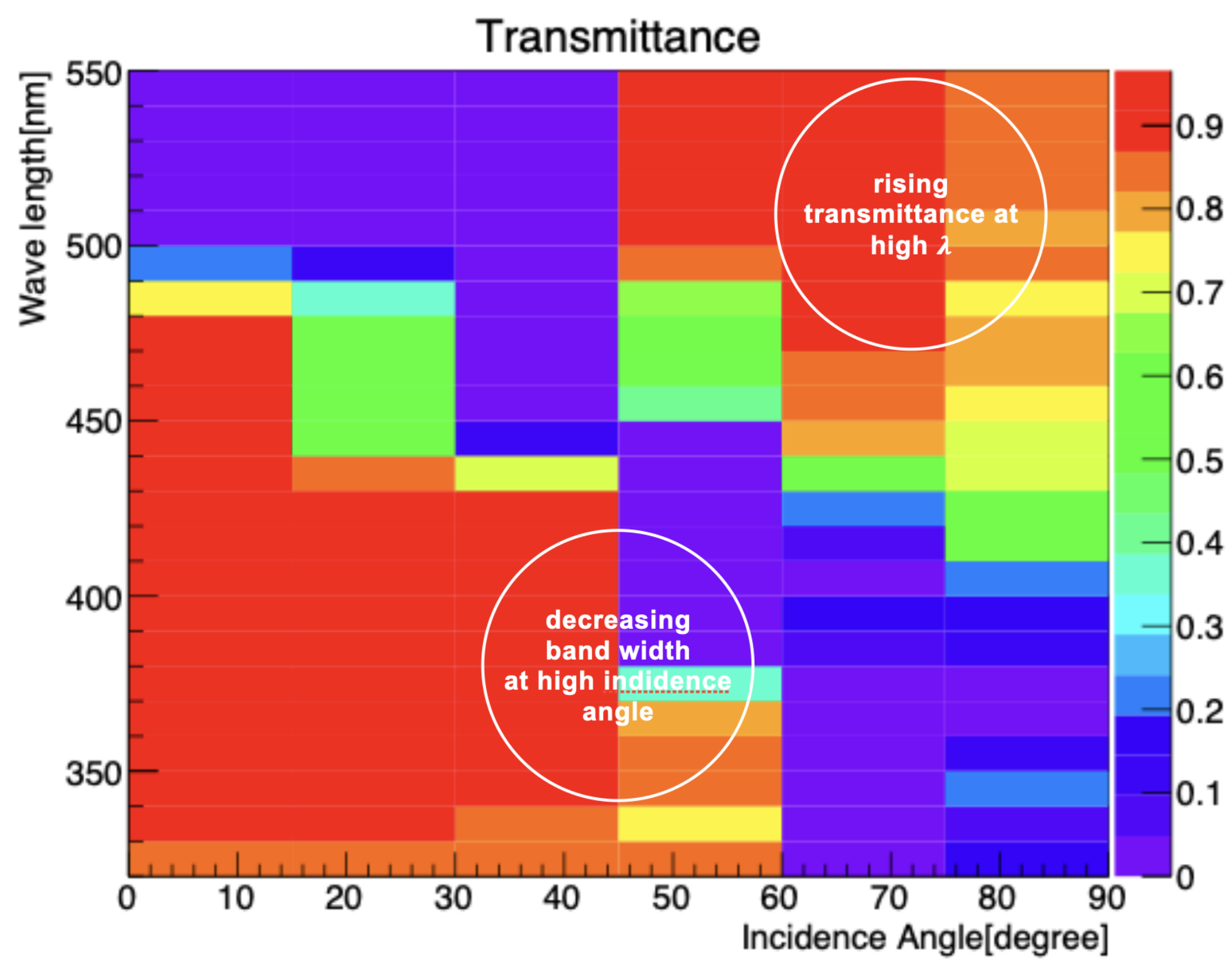
To measure transmittance of dichroic film in the water at different incident angles

Dichroic film **DF-Chill** produced by 3M company for window decoration purpose is tested



- Collimated beam by Xenon lamp (APEX2 Series)
- Monochromator scans wavelength ranging 300nm - 550nm (resolution <1nm)
- Customized 3D-printed holder to deploy film in the water tank at different incident angles
- Compares beam intensity detected by photodiode with and without dichroic film to calculate transmittance

## DICHROIC FILM MEASUREMENT RESULT



Transmittance of 3M DF-Chill in the water

- Sharp edge around 500nm at incident angle 0° observed (as in the spec sheet)
- At higher incident angles, band width decreases & transmittance rises at higher wavelength (Not optimized behavior for trapping secondary photons)

## SIMULATION

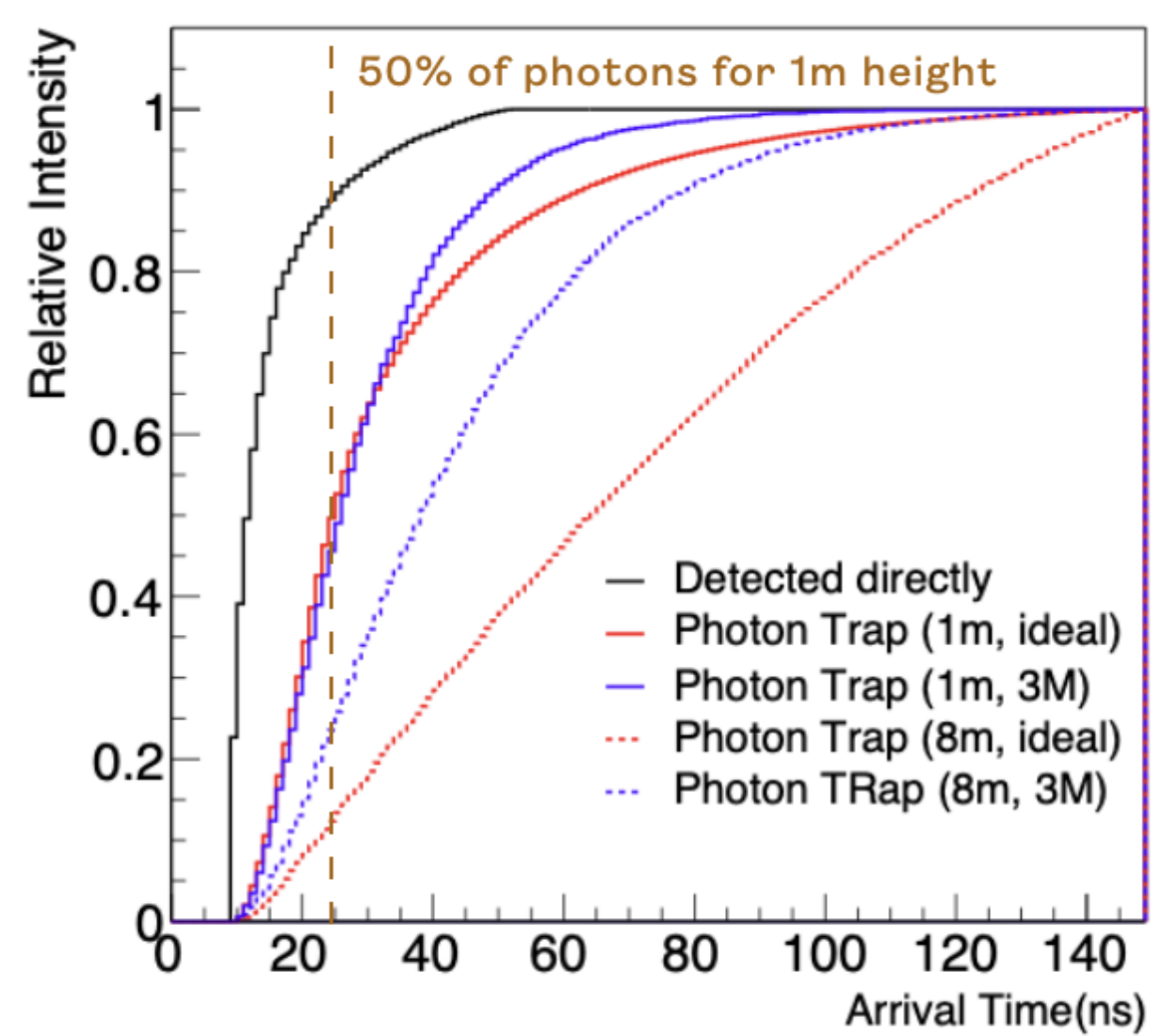
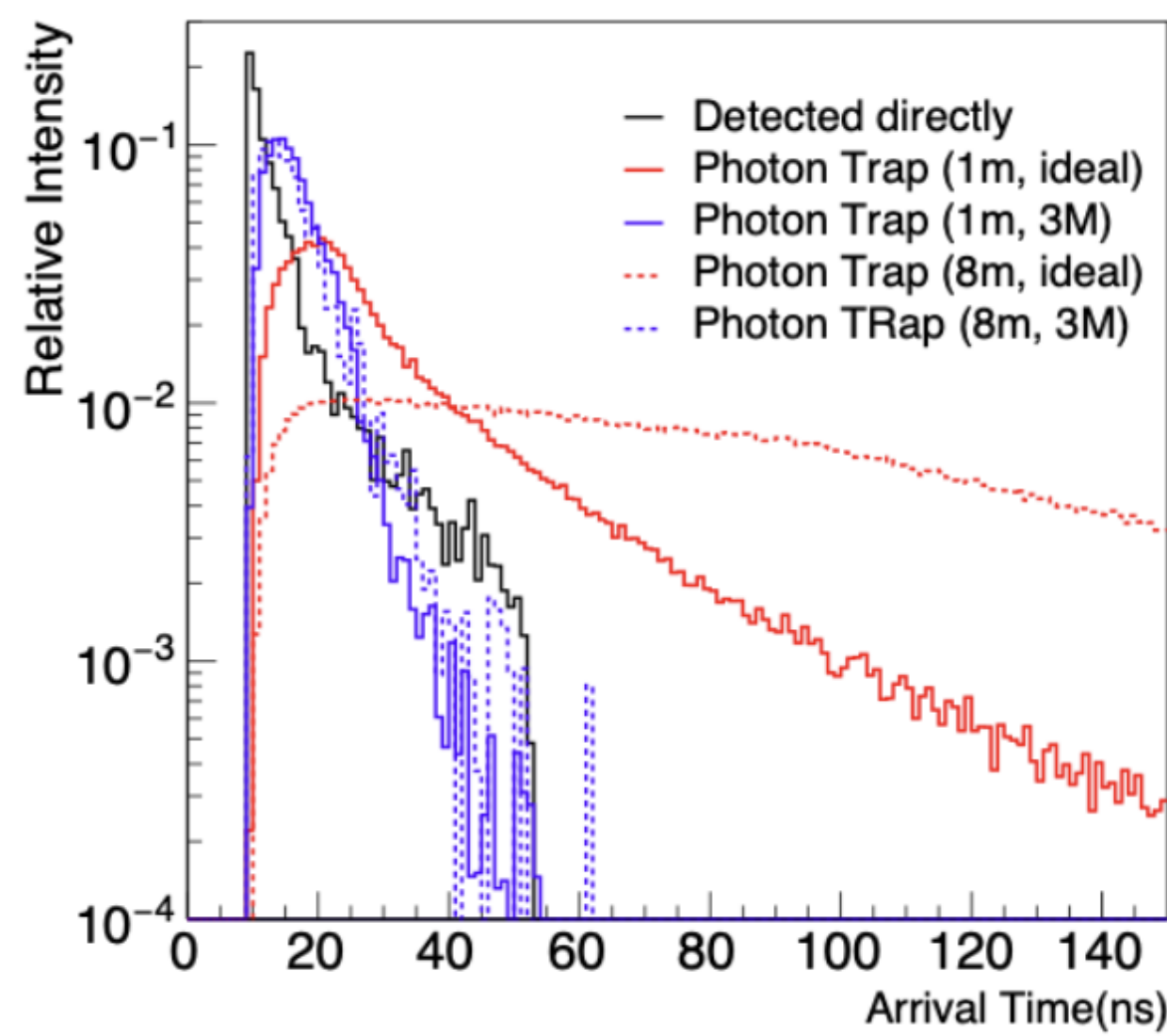
- Customized GEANT4 simulation (modified version of [1])
- 10,000,000 photons are injected following Cherenkov spectrum at 2m distance to all directions
- 3-inch PMT (Hamamatsu R12199)
- 3-inch (diameter) x 1m (height) Photon Trap
- Wave Length Shifter: EJ-286 by Eljen technology (refractive index  $n=1.59$ , re-emission time constant  $t=1.2$  ns)
- Two types of dichroic film tested:
  - case1 (‘ideal’ case): a step-function transmittance at 400nm
  - case2 (‘realistic’ or ‘3M’ case): measured 3M DF-Chill values

## RESULT

Number of collected photons (collected photons  $\times$  Quantum Efficiency) is shown in the table. All numbers are divided by the number of collected primary photons in the PMT-only design.

	primary photons	secondary photons
PMT only ( $\times$ QE)	1 (0.10)	0 (0)
ideal ( $\times$ QE)	0.79 (0.071)	6.1 (1.5)
3M ( $\times$ QE)	0.49 (0.064)	0.33 (0.081 $\pm$ 0.004)
WLS only ( $\times$ QE)	0.94 (0.097)	0.51 (0.12)

- In ideal case, total (primary + secondary) photon detection efficiency increases  $\sim 16$  times (0.1 $\rightarrow$ 0.071+1.5)
- In 3M case, total collection efficiency improves 50% (0.1 $\rightarrow$ 0.064+0.081)



Arrival time distribution (left) & Cumulative arrival time distributions (right)

## REFERENCES

- [1] Rott et al., JINST 12 (2017) 11, P11021, e-Print: 1708.01702
- [2] Bartos et al., Nature Commun. 9 (2018) 1, 1236, e-Print: 1706.06589
- [3] Ehler et al., JINST 14 (2019) 03, P03021, e-Print: 1812.06460

## CONCLUSION

- Promising preliminary result from the design with idealized dichroic film (ideal bandpass and perfect mirroring) indicates up to a 16x enhanced photon detection efficiency with 1m photon trap
- Feasibility of the design requires further studies & design can be improved; we’re in contact with 3M technicians to check the possibility to optimize the bandpass of the dichroic film & discussion on supporting structure is on-going with mechanical/optical engineers