ENHANCED PHOTON TRAP FOR HYPER-K

Carsten Rott *(SKKU)*

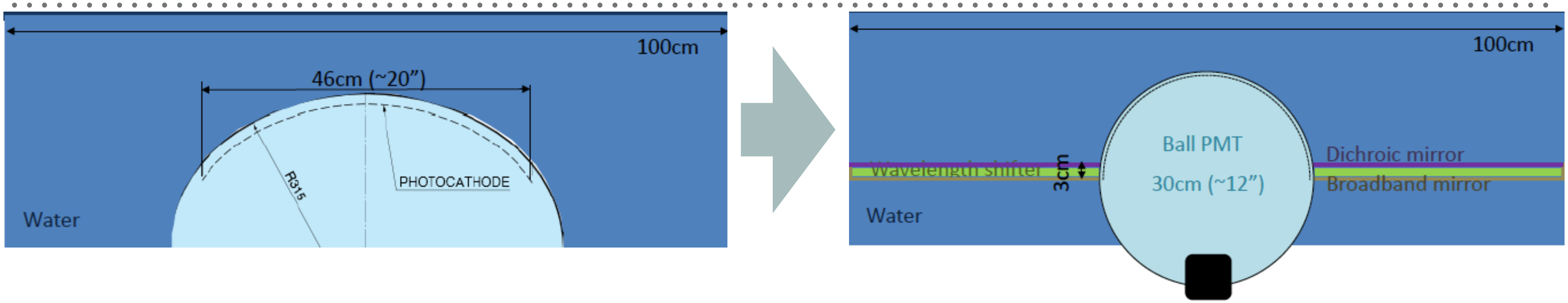
in collaboration with

Peter Gumplinger *(TRIUMF)*, ***Seongjin In*** *(SKKU)*, ***Fırat Nurözler*** *(TRIUMF)*, *and* ***Fabrice Retière*** *(TRIUMF)*

OUTLINE

- Motivation
- Enhanced photon trap design
- Performance study
- Application to Hyper-K
- Conclusions Plans

MOTIVATION



➤ Price tag of large volume neutrino detectors could be significantly be reduced by utilising photon traps that rely on smaller PMTs

Pros

➤ Cost Reduction

➤ Larger photo sensitive area with higher photon detection efficiency

➤ Smaller PMTs (lower dark noise, smaller timing spread)

Cons

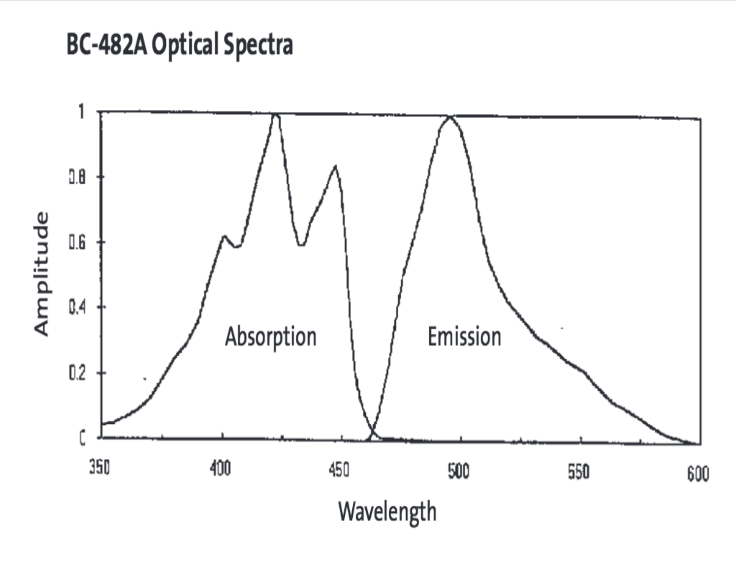
➤ Timing resolution

➤ (slightly) larger position uncertainty on detected photon

Added complexity in reconstruction

ENHANCED PHOTON TRAP EXAMPLE

Wavelength shifter

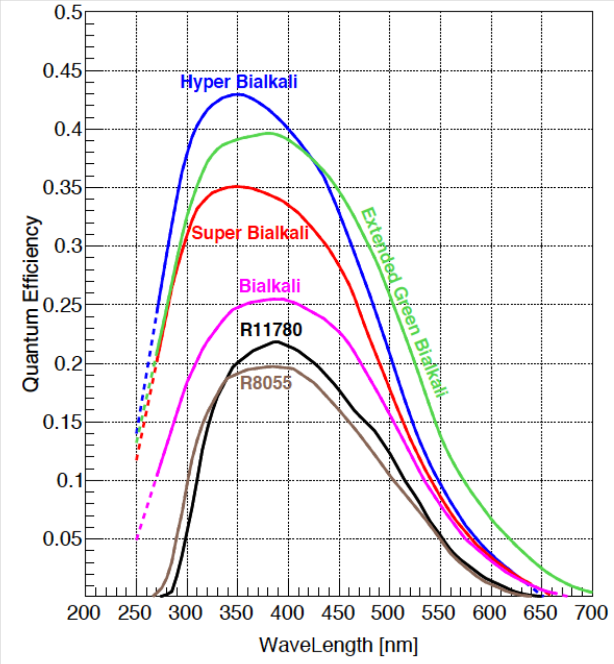


Broadband mirror

High reflectivity

Example …
3M Enhanced Specular Reflector

PMT



Dichroic mirror

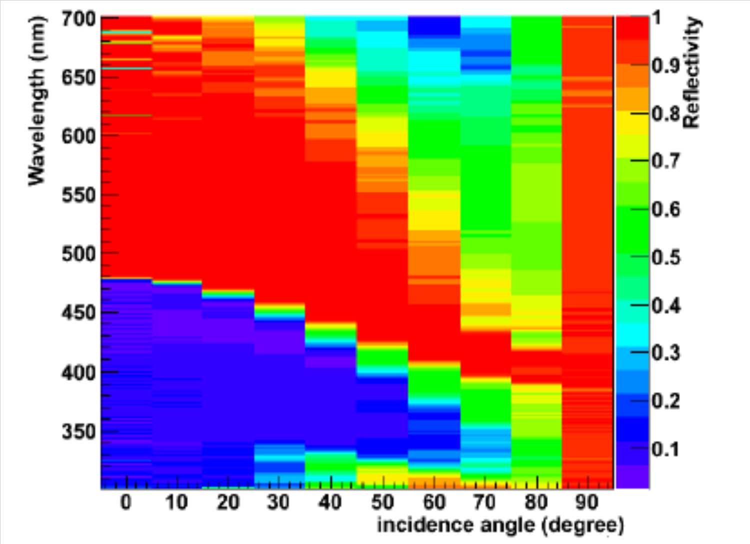
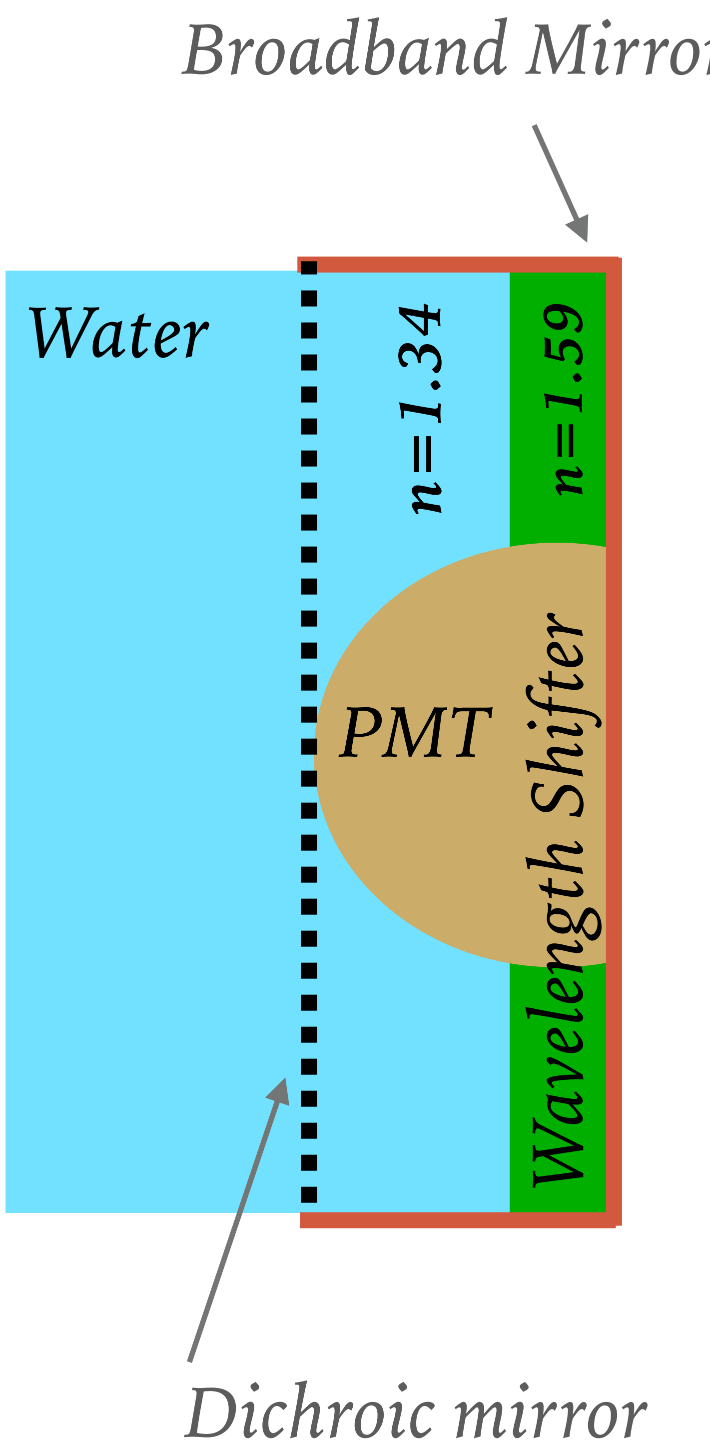


Figure 4. Customized dichroic mirror reflectivity used for our study.



WAVELENGTH SHIFTER

Saint Gobain BC-482A

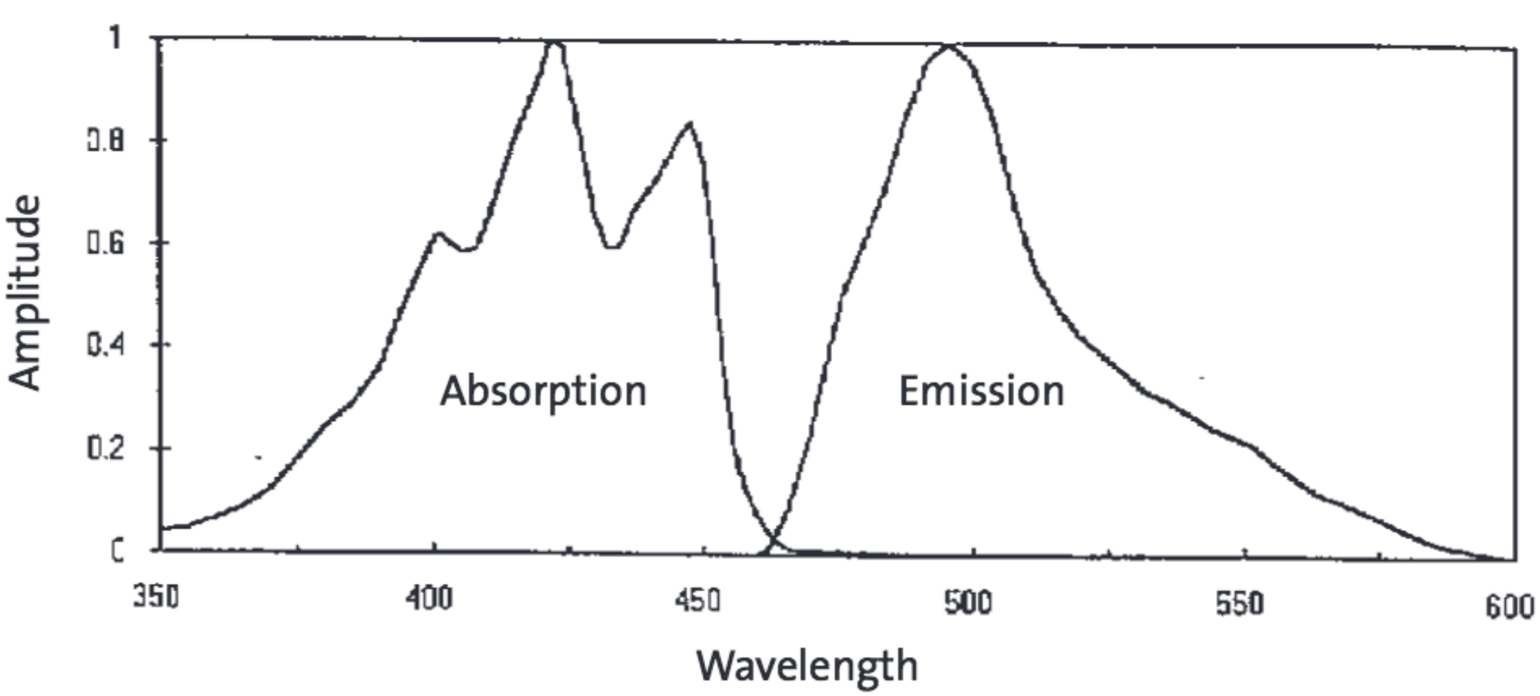
blue to green

St. Gobain candidates

- *BC-480: 330 nm → 425 nm*
- *BC-482A: 420 nm →500 nm*
- *BC-484: 380 nm → 435 nm*

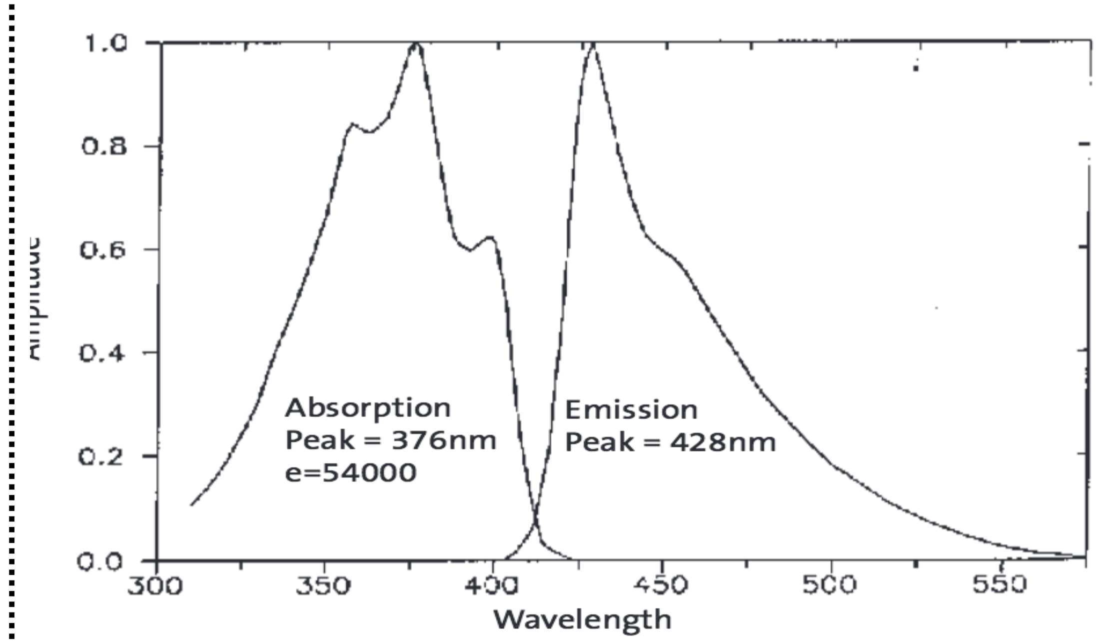
	BC-482A	BC-484
Scintillation Properties	Green	Blue
Decay Time (ns)	12	3
Light Attenuation Length, cm	400	350
Absorption Peak, nm	420	375
Wavelength of Max. Emission, nm	494	430
Use with	BC-408 & 412	BC-414

BC-482A Optical Spectra



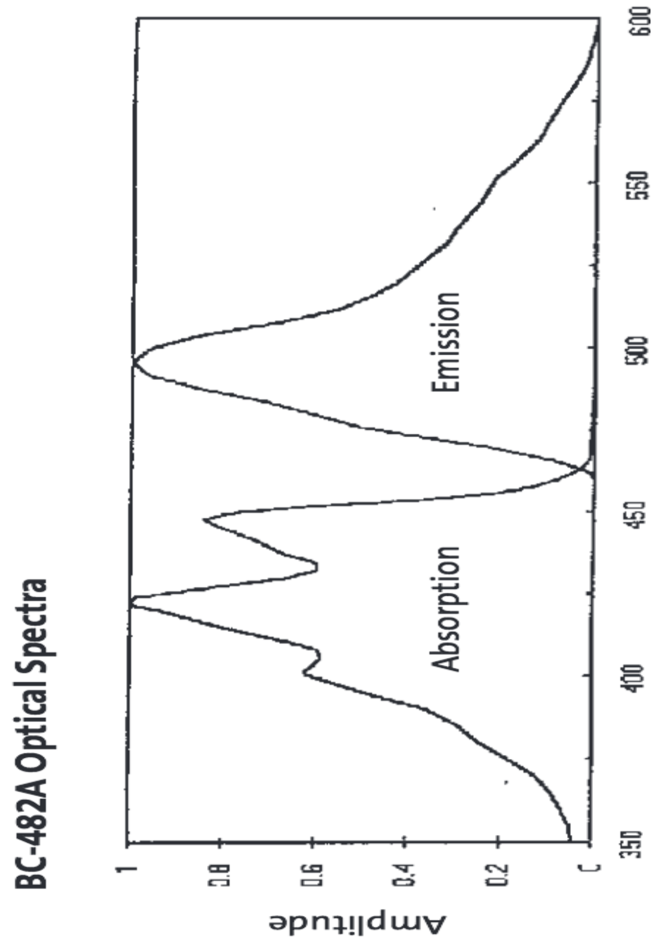
used for the current study

BC-484 Optical Spectra



BROADBAND MIRROR

Designed by Iridian Spectral Technologies



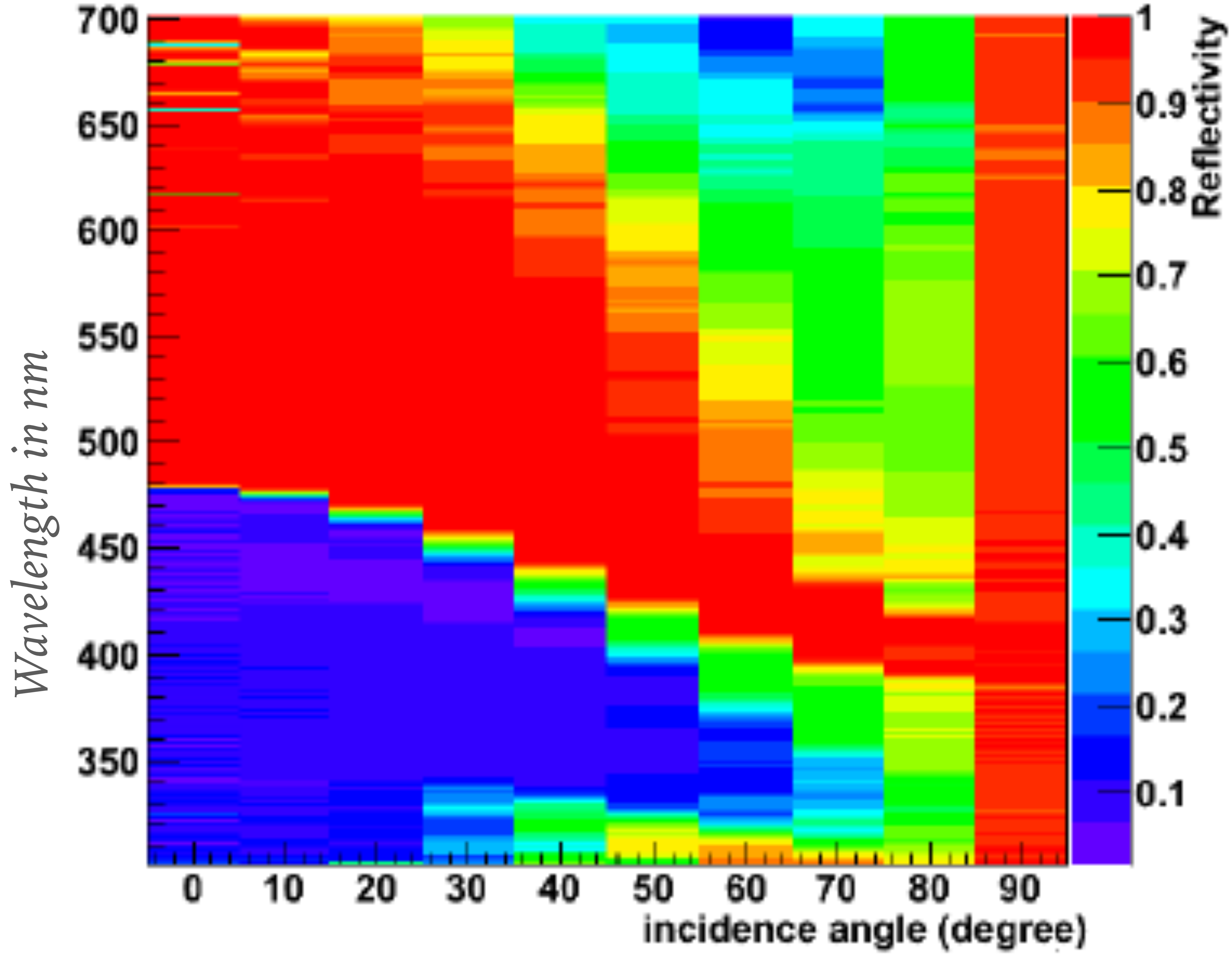
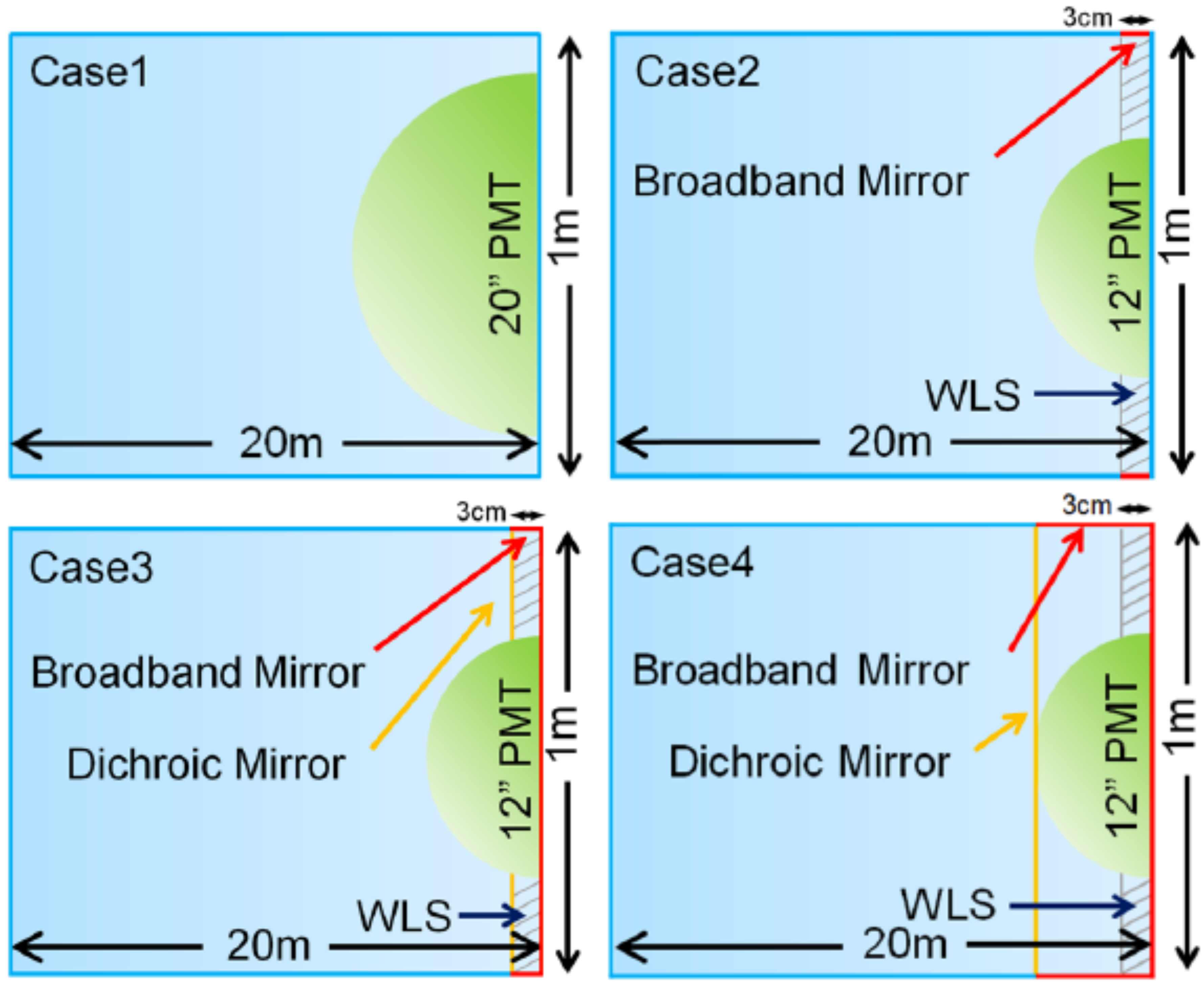


Figure 4. Customized dichroic mirror reflectivity used for our study.

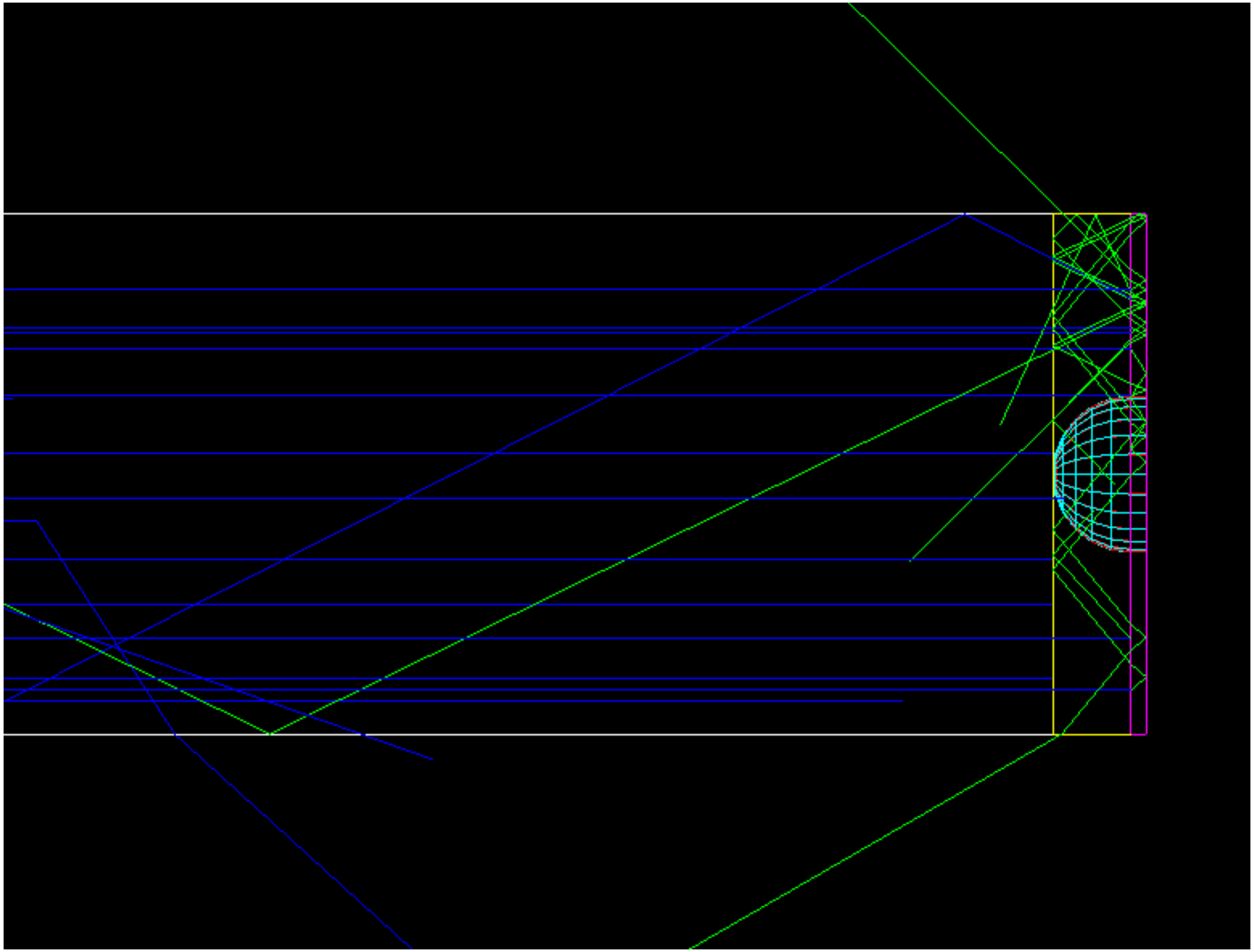
TEST CASES

- Consider four different setups
  - 20” PMT
  - WLS Trap
  - WLS with dichroic mirror
  - Full trap (dichroic mirror encloses PMT)



SIMULATION PACKAGE

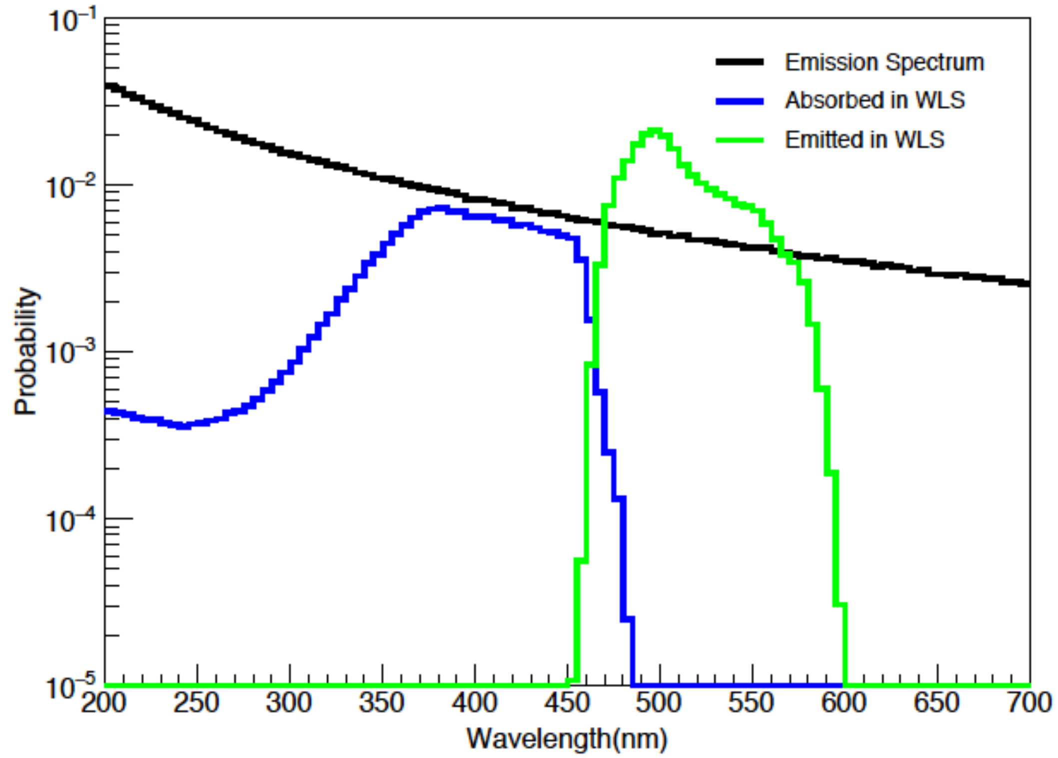
- Customised simulation with GEANT4

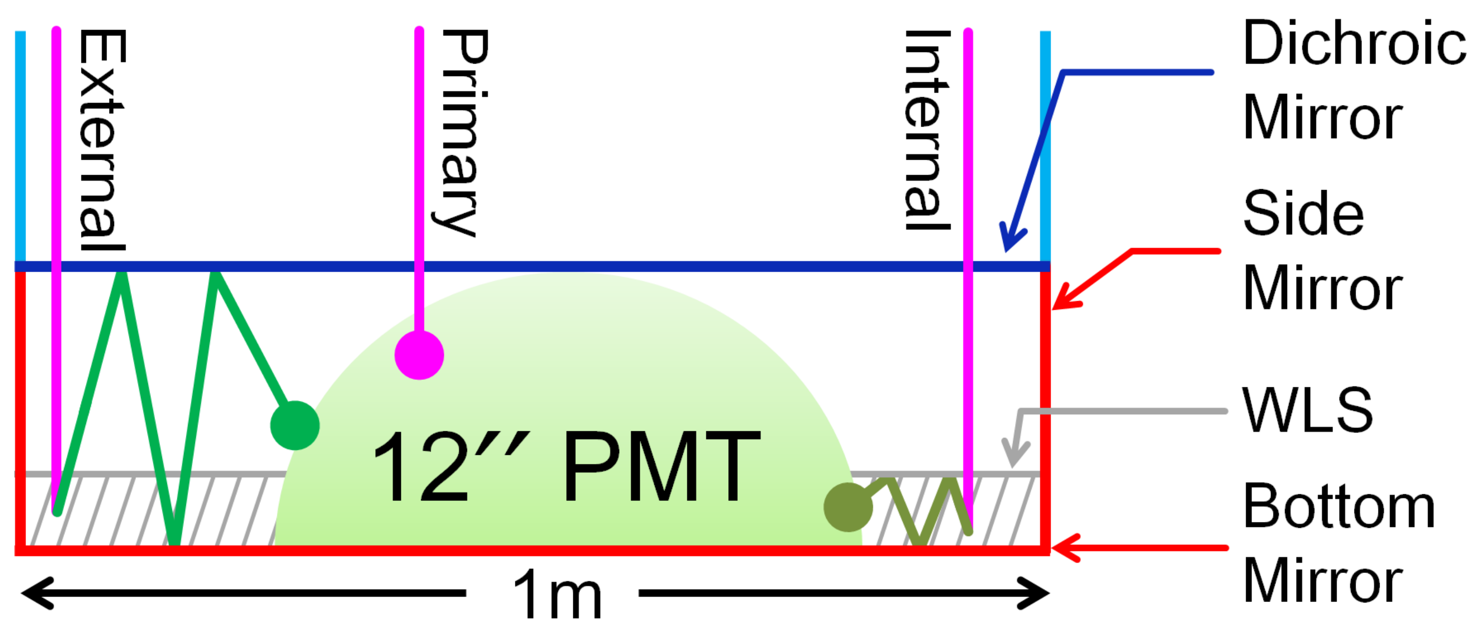


TEST SETUP

- Cherenkov spectrum generated 200-700nm
- Photons are injected 20m away from the Photon trap
- Photons are injected perpendicular to the "Wall"
  - Define the "path" how photons are detected to evaluate the benefit of the different elements of the photon trap

COLLECTION EFFICIENCIES

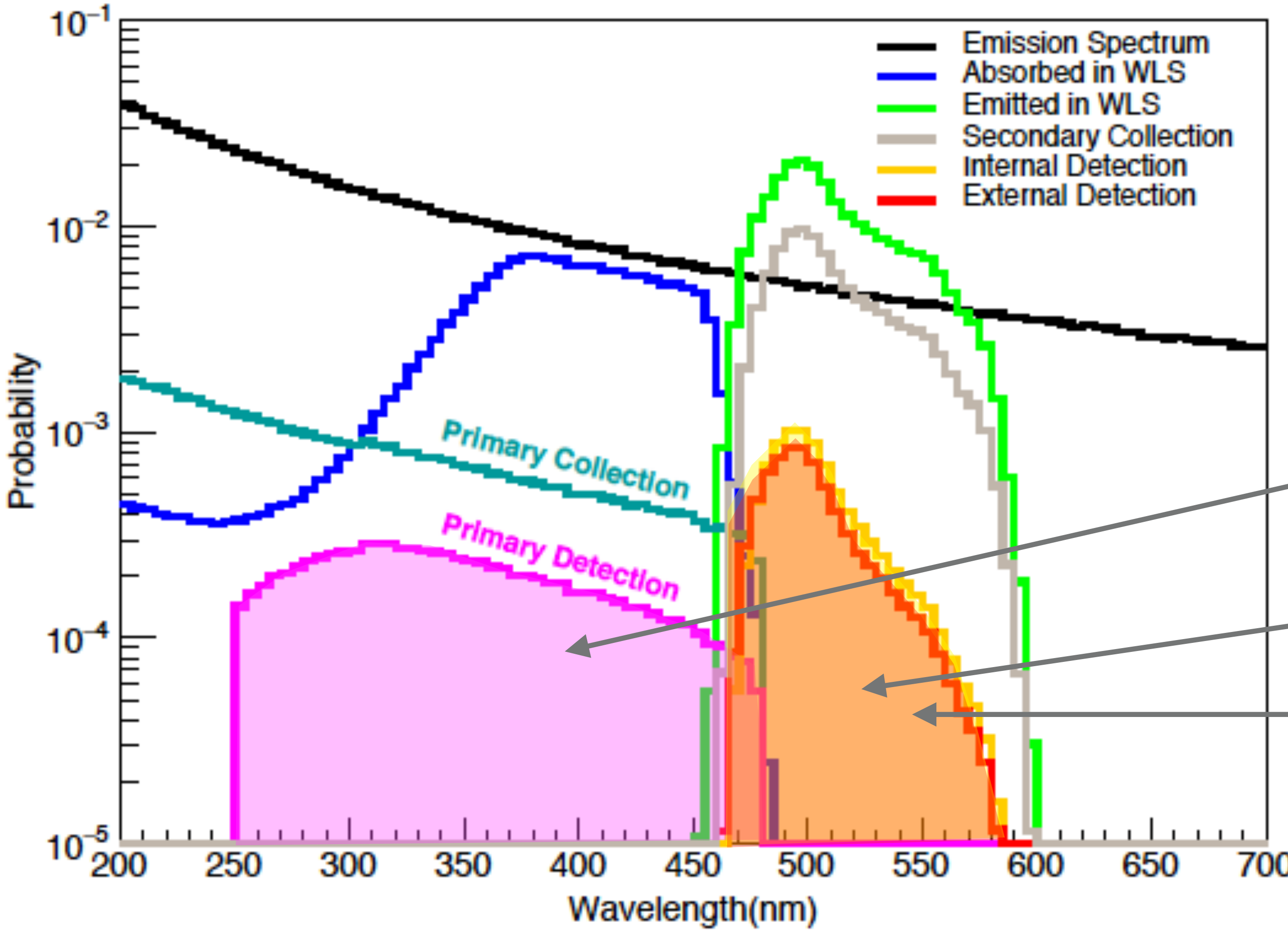




	Configuration	Primary	Internal	External	Total
1	20" PMT	1.00			1.00
2	12"PMT + WLS	0.38	0.32		0.70
3	12"PMT + WLS +Dichroic	0.38	0.36	0.10	0.84
4	Full Trap	0.31	0.37	0.30	0.98

➤ Total collection efficiency is reduced compared to a single 20" PMT

DETECTION EFFICIENCIES



For ***detection efficiency*** *account for the* ***wavelength dependent QE*** *of the PMT.*

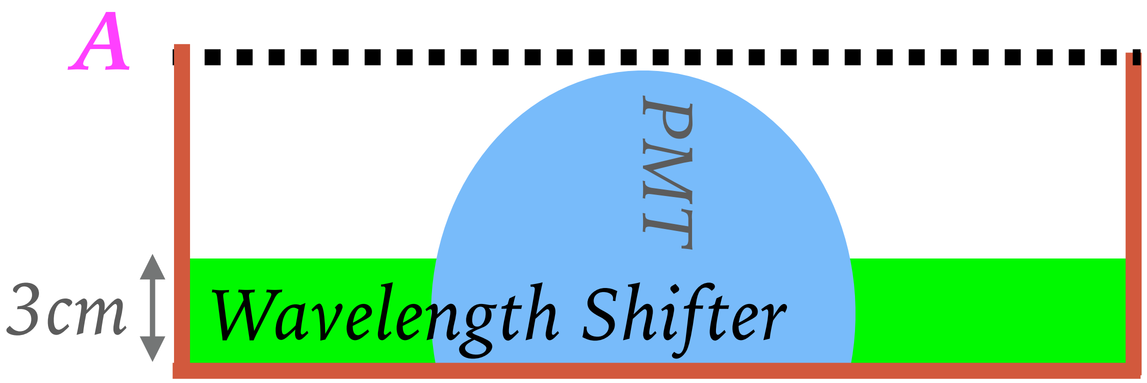
We use Super Bialkali as example

	Configuration	Primary	Internal	External	Total
1	20" PMT	1.00			1.00
2	12"PMT + WLS	0.38	0.56		0.94
3	12"PMT + WLS +Dichroic	0.38	0.61	0.18	1.17
4	Full Trap	0.32	0.64	0.52	1.48

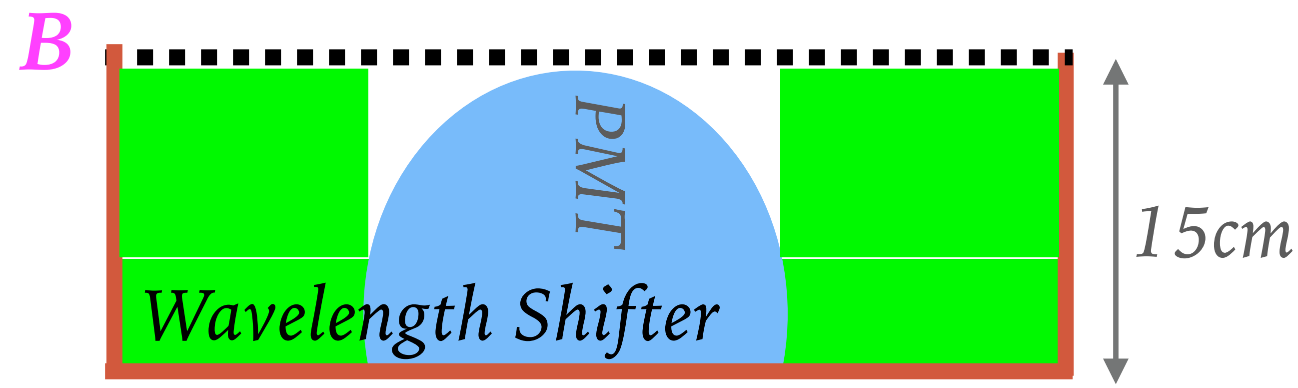
- Total detection efficiency is increased compared to a single 20" PMT

DEPENDENCE ON WLS THICKNESS (DETECTION EFF.)

➤ Efficiency can be enhanced by increasing the thickness of the Wavelength shifter



Benchmark design 3cm WLS

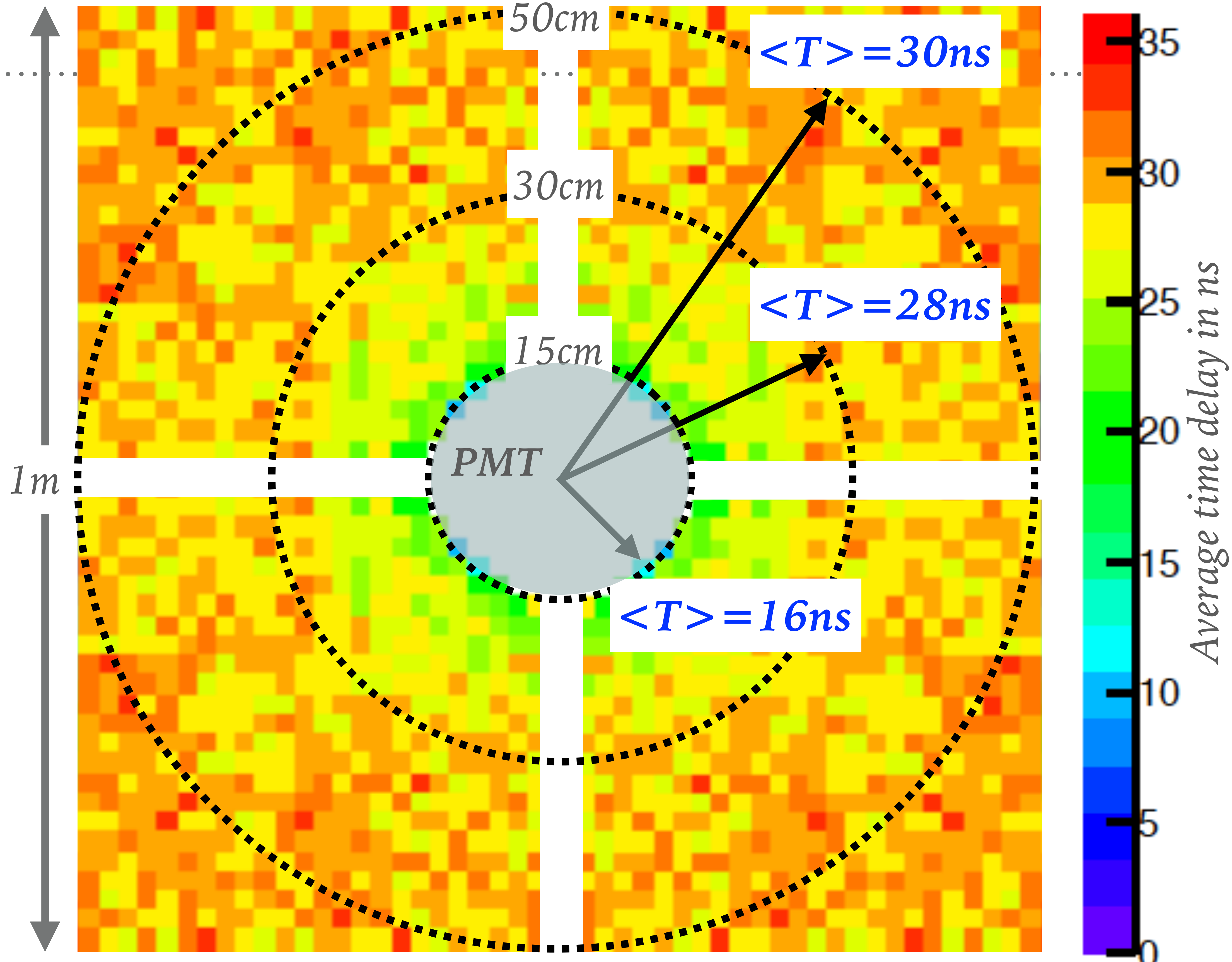


Efficiency increase ~20% for 15cm WLS thickness

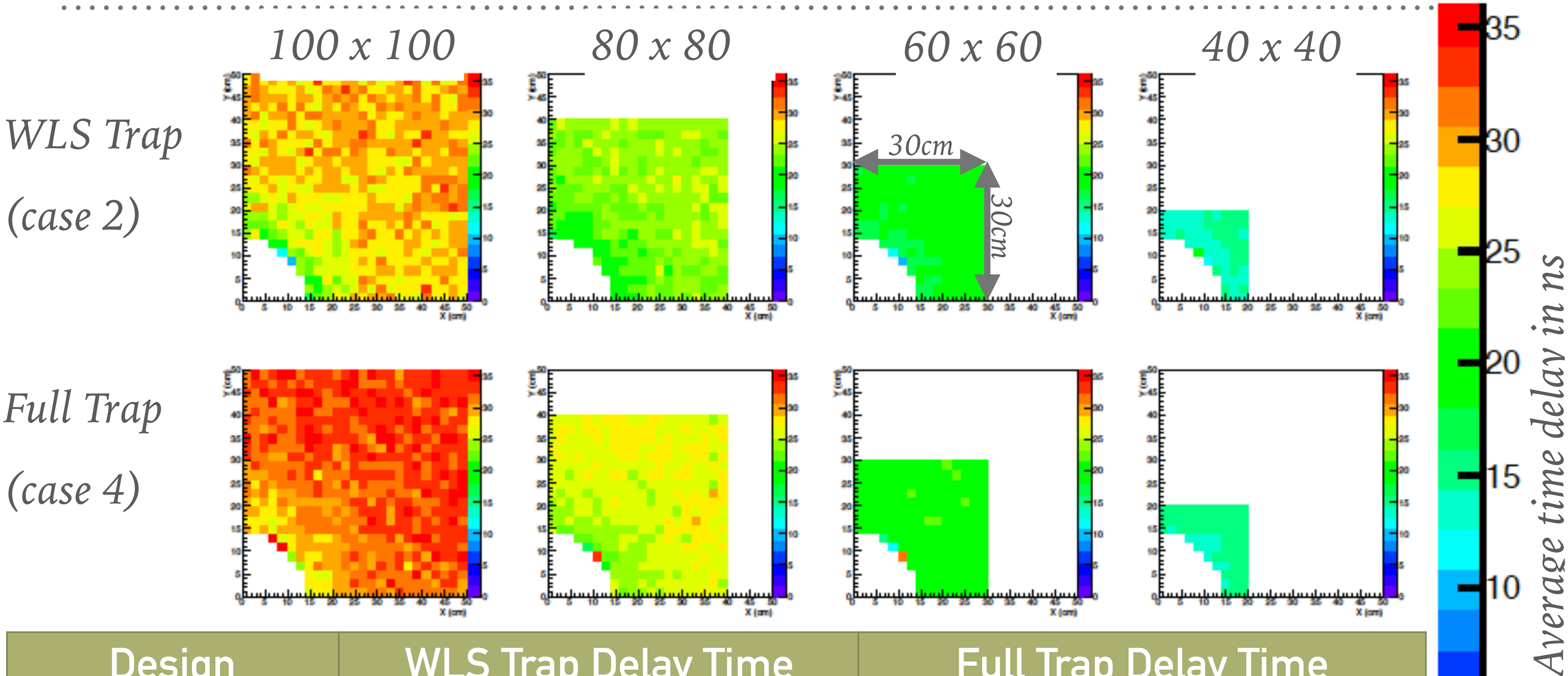
	Configuration	Primary	Internal	External	Total
	20" PMT	1.00			1.00
	Full Trap (0.5cm WLS)	0.32	0.28	0.61	1.21
A	Full Trap (3.0cm WLS)	0.32	0.64	0.52	1.48
B	Full Trap (15.0cm WLS)	0.32	0.79	0.66	1.77

➤ 20% increase in efficiency by going to "thick" WLS

TIMING


50cm
30cm
15cm
<T>=30ns
<T>=28ns
<T>=16ns
PMT
1m
35
30
25
20
15
10
5
0
Average time delay in ns

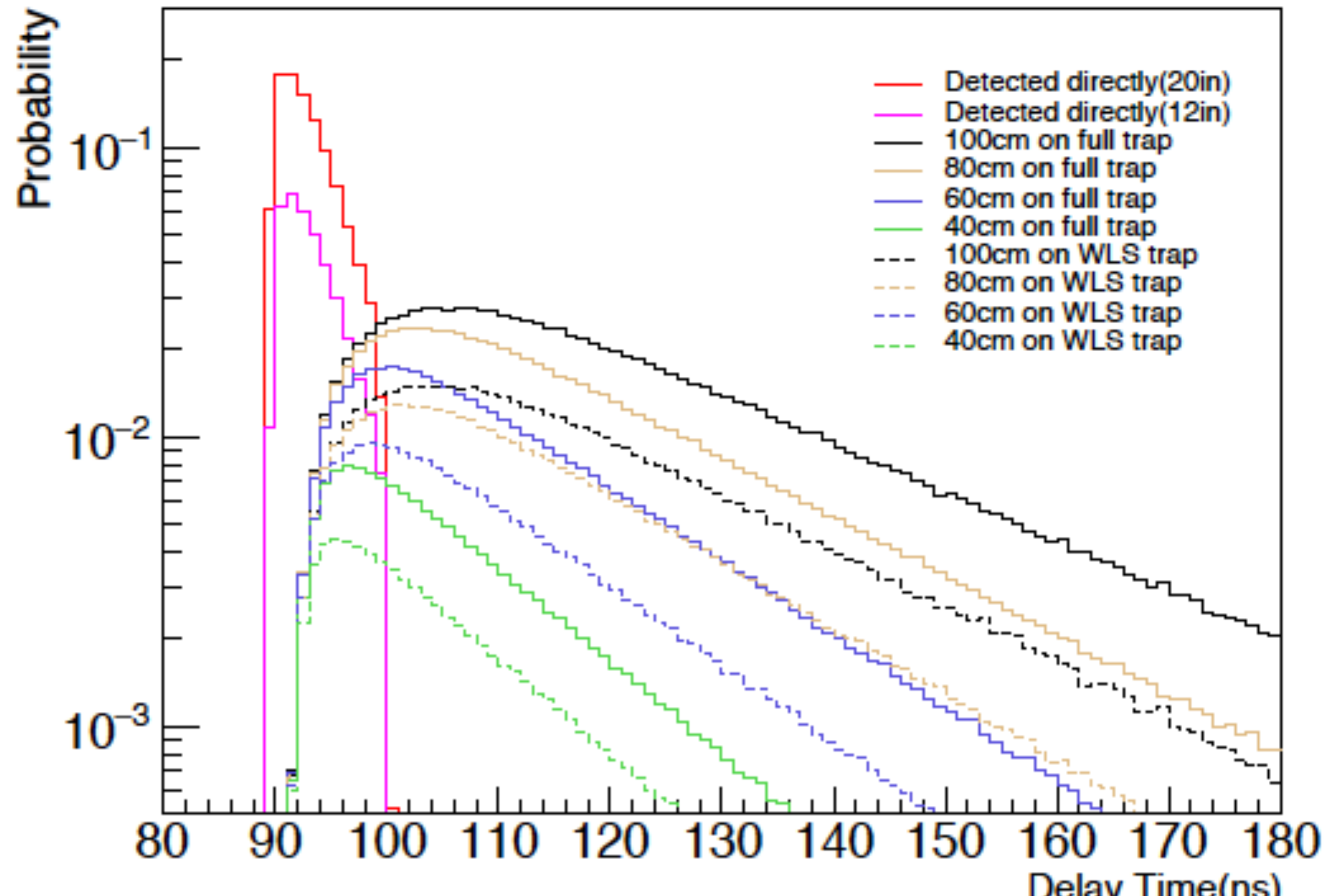
TIMING DELAY (DETECTION EFFICIENCY)



Design Size (cm^2)	WLS Trap Delay Time		Full Trap Delay Time	
	Mean (ns)	RMS (ns)	Mean (ns)	RMS (ns)
100 x 100	26.2	20.5	29.2	22.0
80 x 80	22.0	18.3	24.6	19.7
60 x 60	17.6	15.8	19.4	16.8
40 x 40	13.1	13.1	14.1	13.5

TIMING DISTRIBUTION

- Timing distribution of detected photons
- Time relative to emission (20m away)
- WLS Remission time delay dominating for 60cm x 60cm designs and smaller.
  - Faster WLS (~3ns) be beneficial



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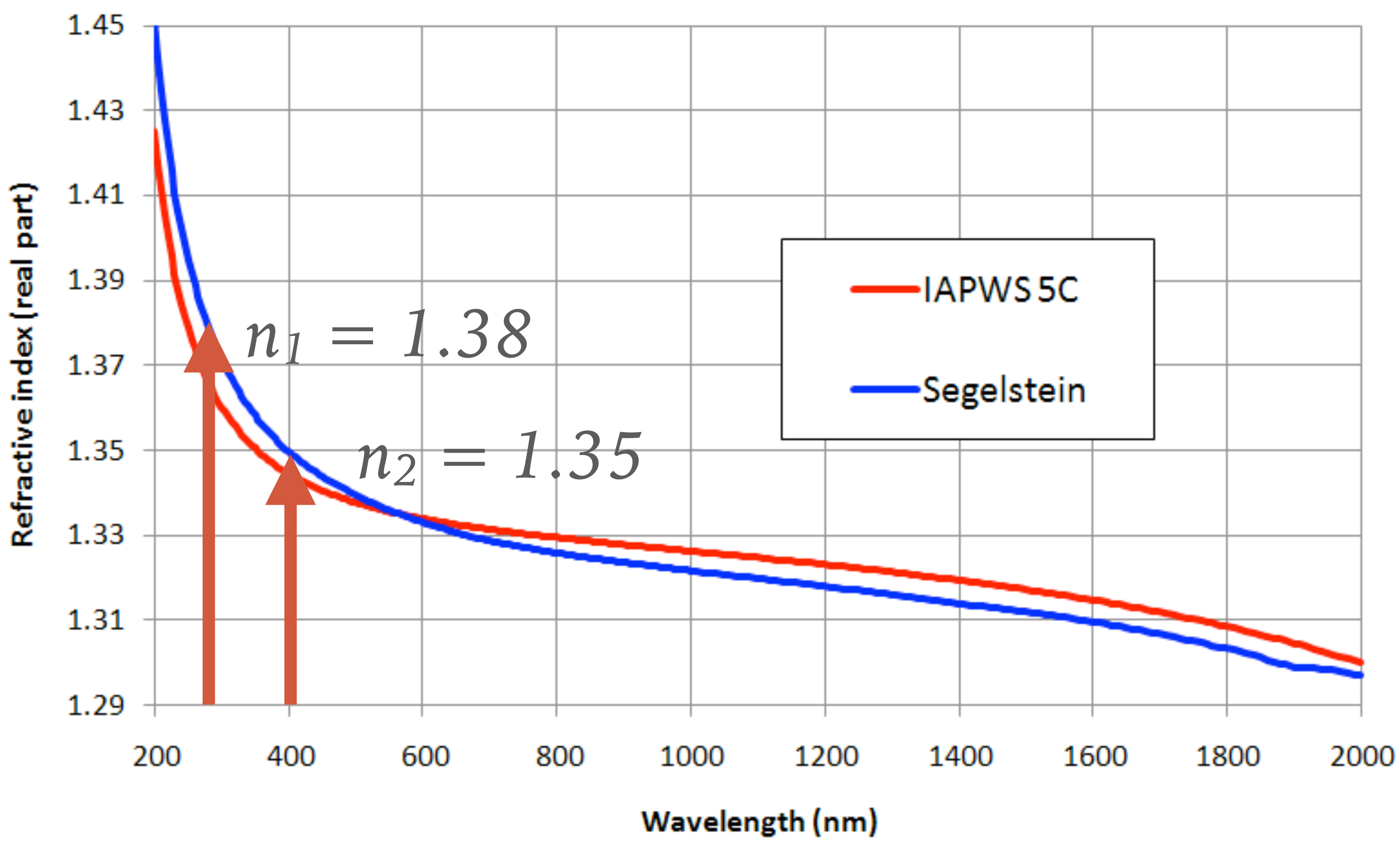
times include the delay for reemission (~12ns)

NOTE ON TIMING DISTRIBUTION

- Photons were injected 20m away from the photon trap
  - Light propagation is wavelength dependent
    - Reference time is set with single PMT which has peak efficiency at 300nm, however WLS has peak efficiency around 400nm
      - Artificial delay of 4ns introduced by injecting 20m away



$$n = \frac{c}{v} \qquad \Delta t = \frac{L(n_1 - n_2)}{c}$$

calculate for 20m → ~2ns

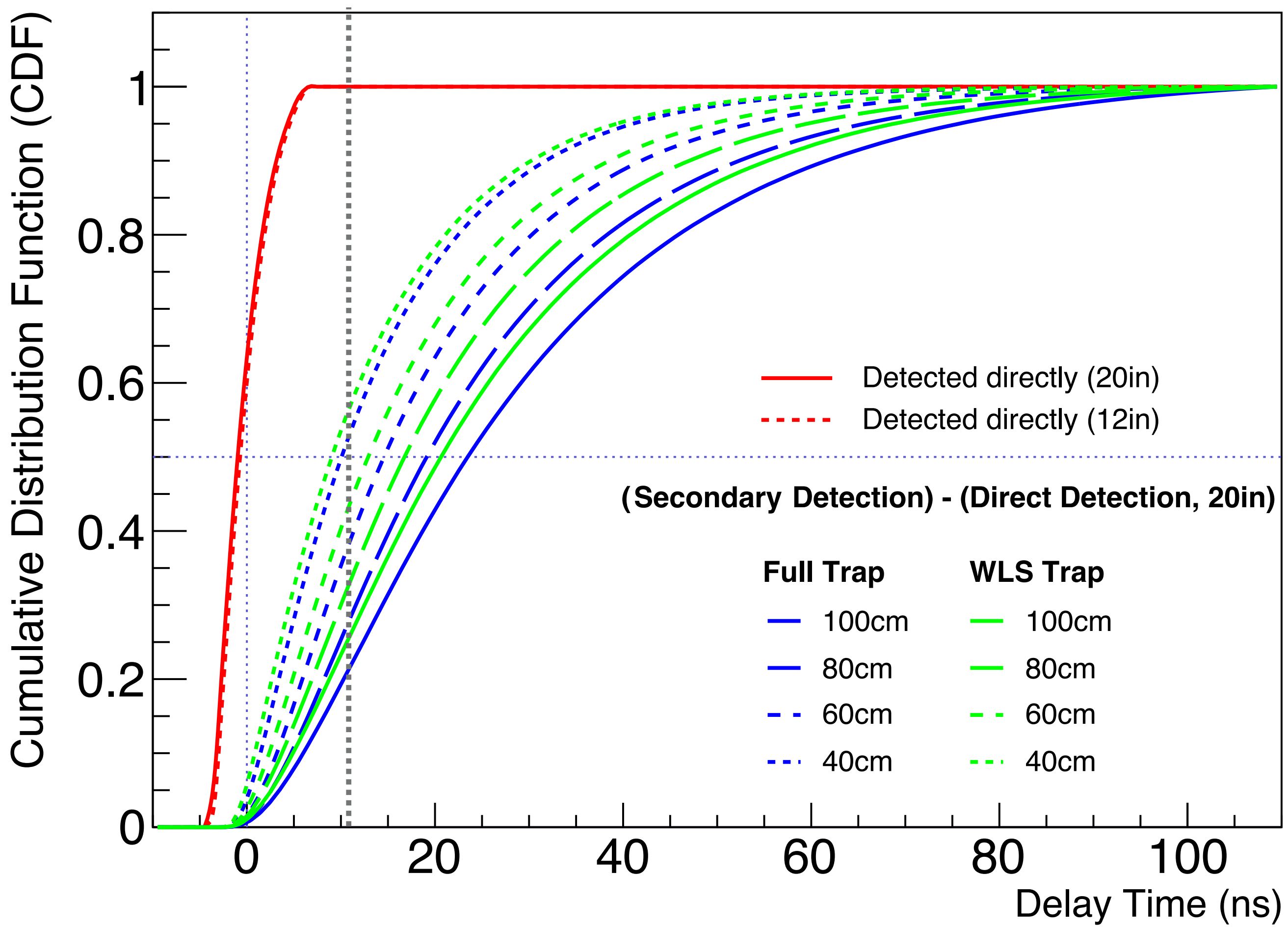
observed ~3-4ns (?)

IAPWS 5C: "Release on refractive index of ordinary water substance as a function of wavelength,temperature and pressure" (September 1997) published by International Association for the Properties of Water and Steam (IAPWS)

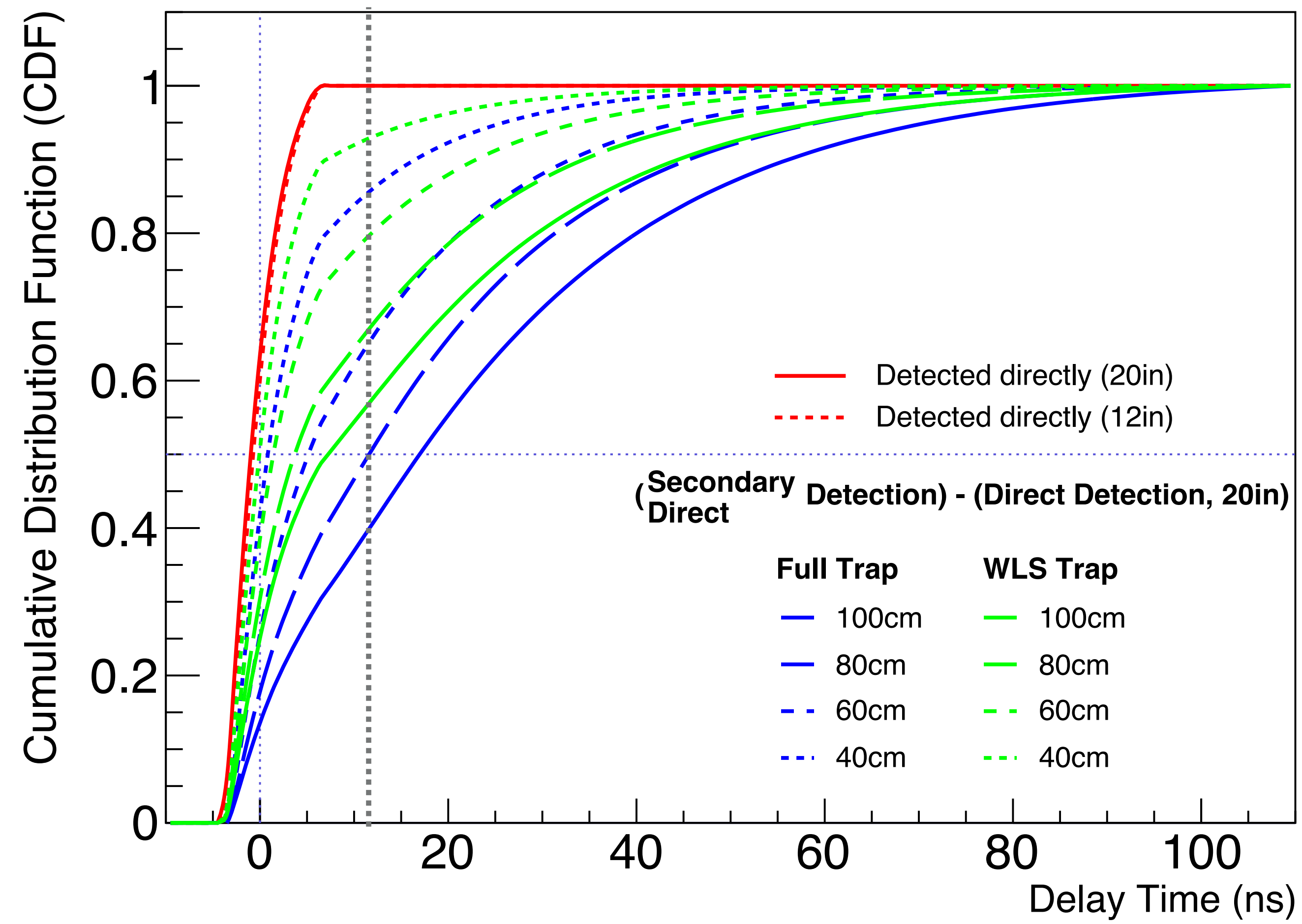
***D. Segelstein**, "The Complex Refractive Index of Water", M.S. Thesis, University of Missouri, Kansas City (1981)*

CUMULATIVE TIMING DISTRIBUTIONS

Timing by detection channel



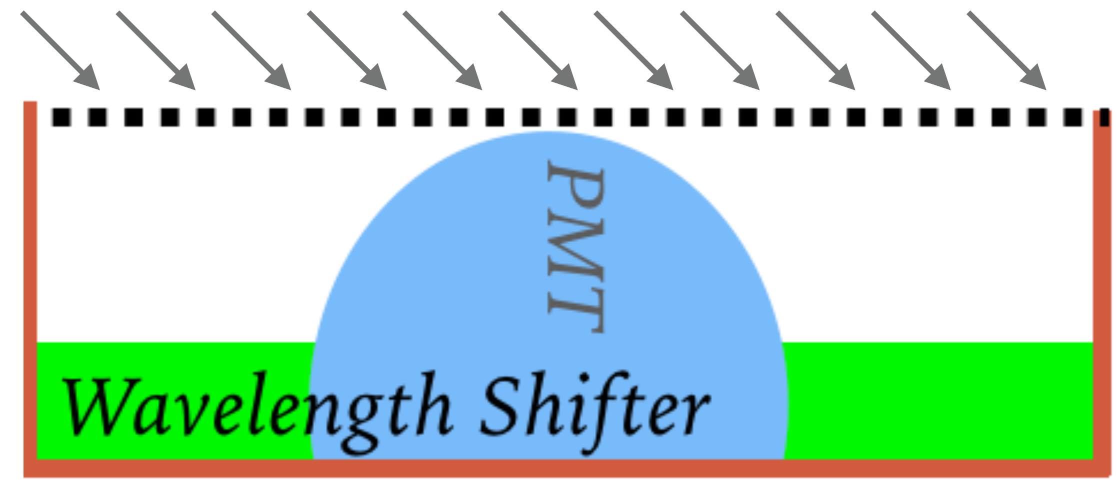
Timing distribution combined



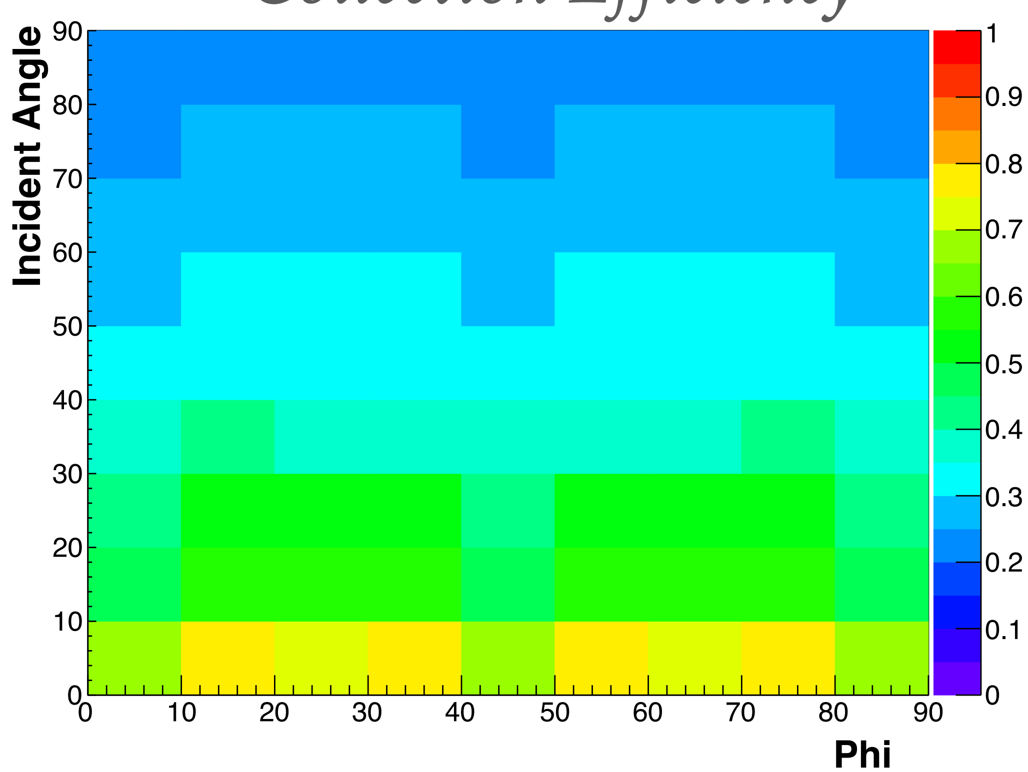
For WLS trap 50% of photons are detected within 10 ns window

ANGULAR DEPENDENCE OF INJECTION

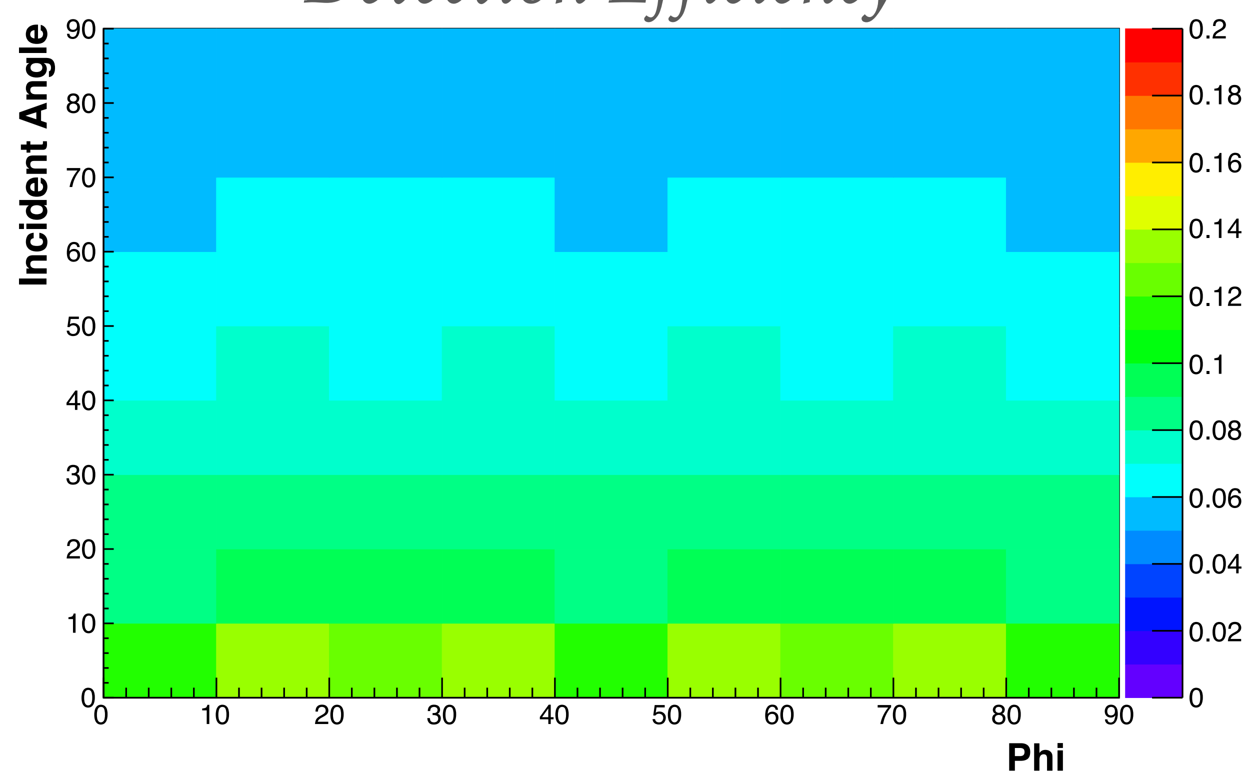
- Detection efficiency depends on the injection angle
  - Inject uniformly right above the photon trap with the same incident angle
    - Negligible dependence on φ, stronger dependence on θ(incident angle)



Collection Efficiency



Detection Efficiency

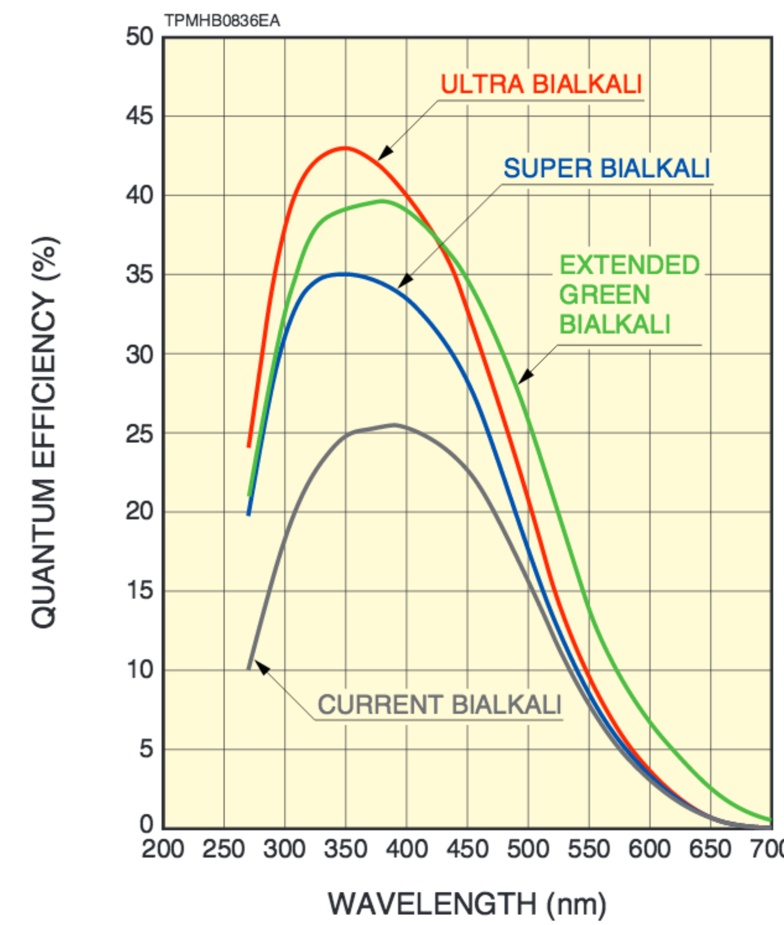


APPLICATIONS TO HYPER-K

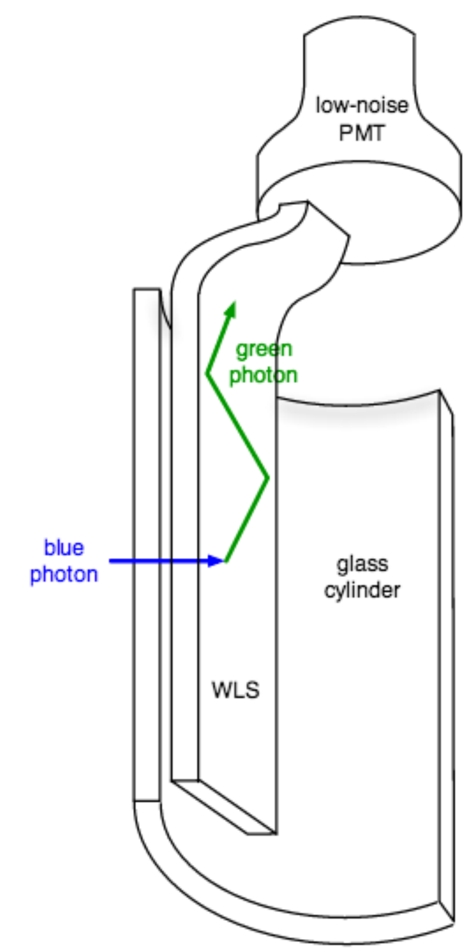
- Inner detector
  - Enhanced photo traps can be superior to large PMTs in photo coverage
  - Timing worse, but depends on the physics goals
    - “Direct photons” for reconstruction
    - Hybrid detector
      - within same tank / individual tanks
- Outer detector
  - Possibility to increase inner volume by reducing size requirement for outer volume

CONSIDERATIONS

- Enhanced photon trap can be further optimisation considerations
  - Impact of choice of PMT ~20%
  - Still need to investigate “Extended Green”
  - Investigate other WLS
- Incident angle dependence needs to be measured
- Feasibility to Hyper-K
  - Many small PMTs as part of a large photon trap ?
- Synergy with other R&D efforts
  - Example: Wavelength shifting optical module (WOM)



https://www.hamamatsu.com/resources/pdf/etd/p-dev_2015_TOTH0023E.pdf



PINGU LOI
http://arxiv.org/pdf/1401.2046.pdf

CONSIDERATIONS

- Reflected photons
  - Reflected photons add an additional “signal” but require more sophisticated reconstruction
  - fiTQun uses 5% reflectivity of liners, full study needed with increased reflectivity.
- Radio purity of wavelength shifters
  - WLS typically have very high radio purity
- Durability of wavelength shifters
  - WLS have been used in long duration collider experiments with minimal degradation

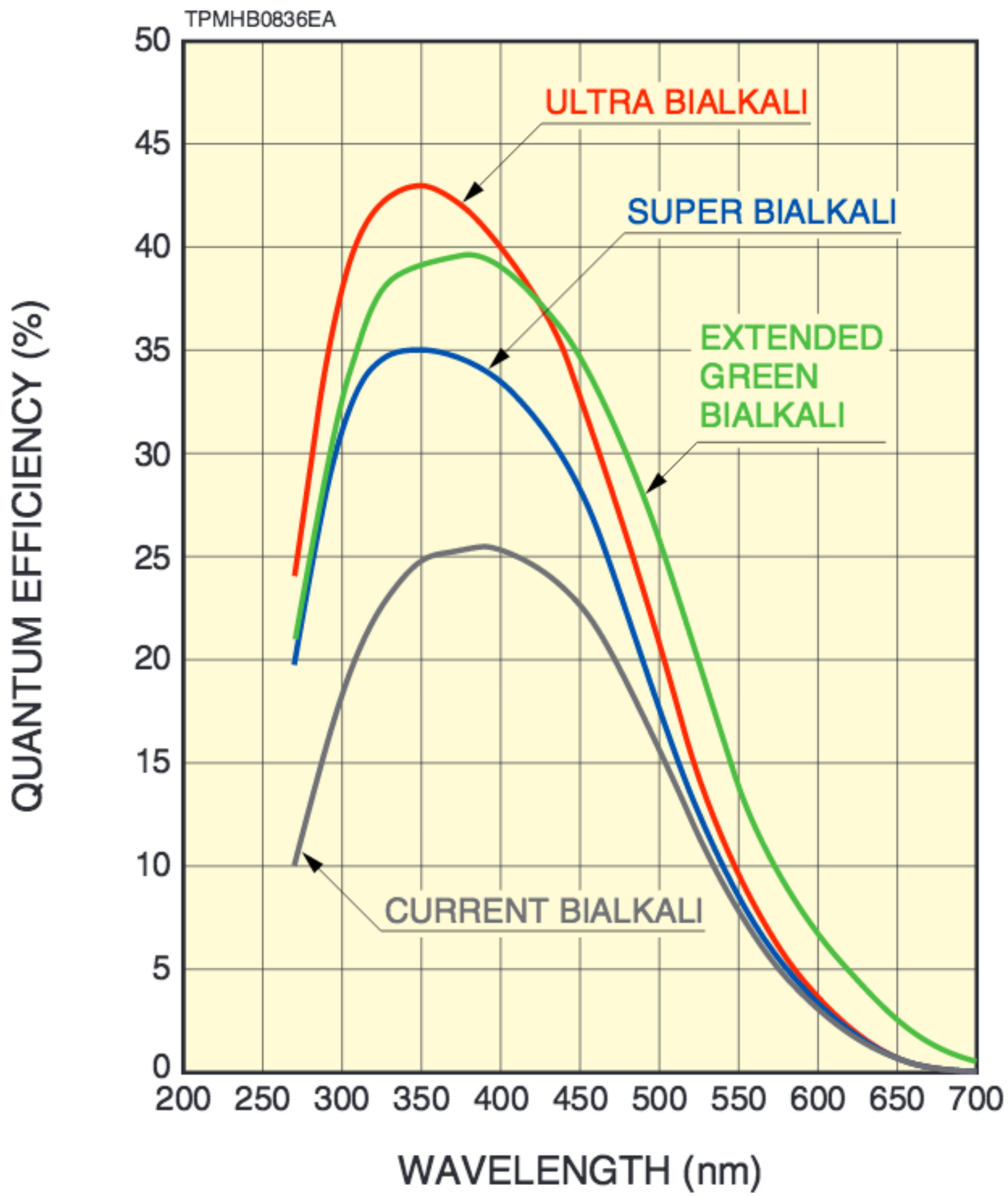
CONCLUSIONS

- Enhanced photon traps could help to reduce costs
- Further optimisations of photon trap design
- Plan to publish design / performance of photon trap
- Seeking funding in Korea and Canada
- Aim to build prototype
- Detailed costing of enhanced photon trap
- Implementation to Hyper-K simulation framework need
  - Impact on physics

BACKUP SLIDES

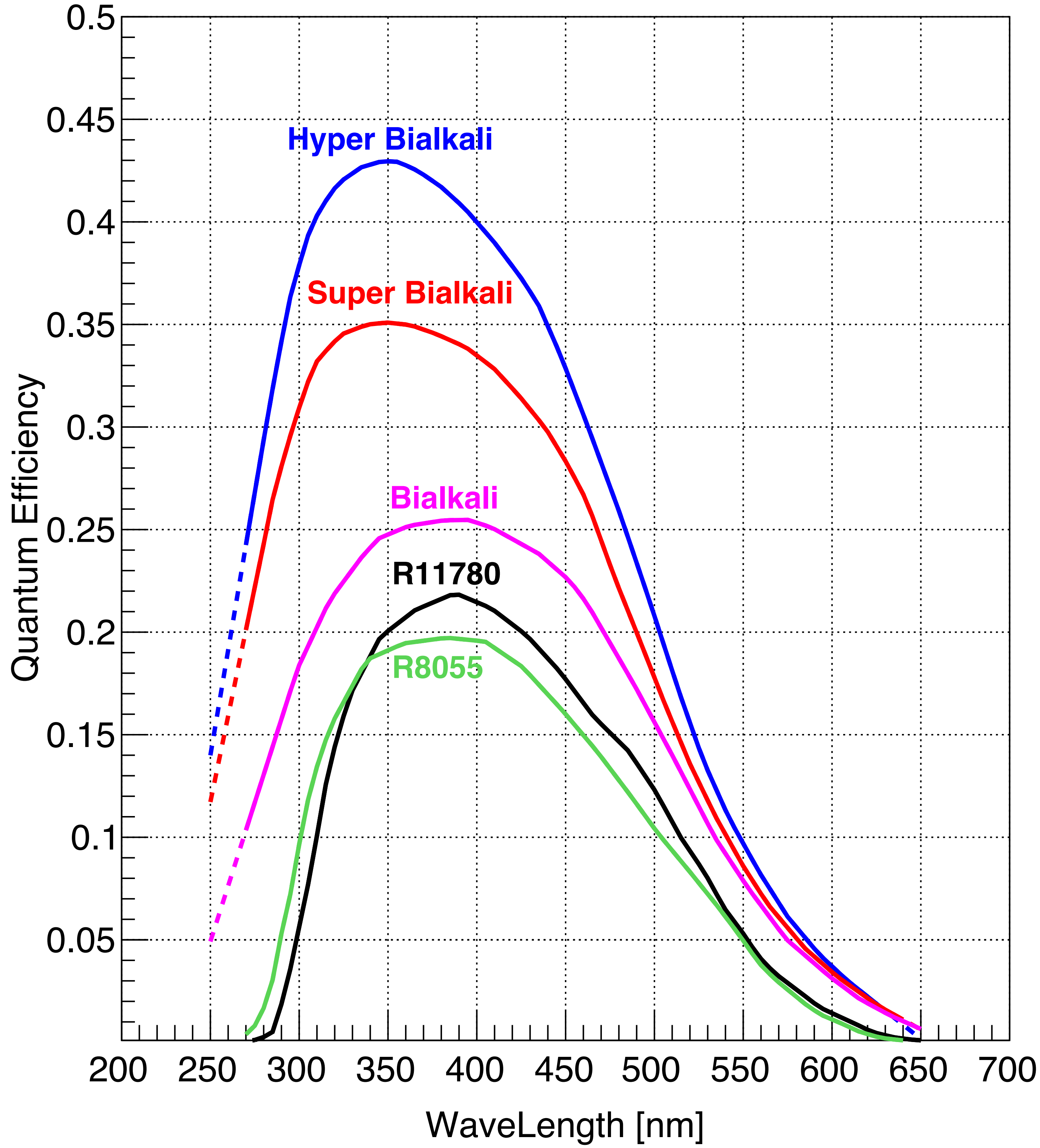
PHOTOMULTIPLIER TUBE

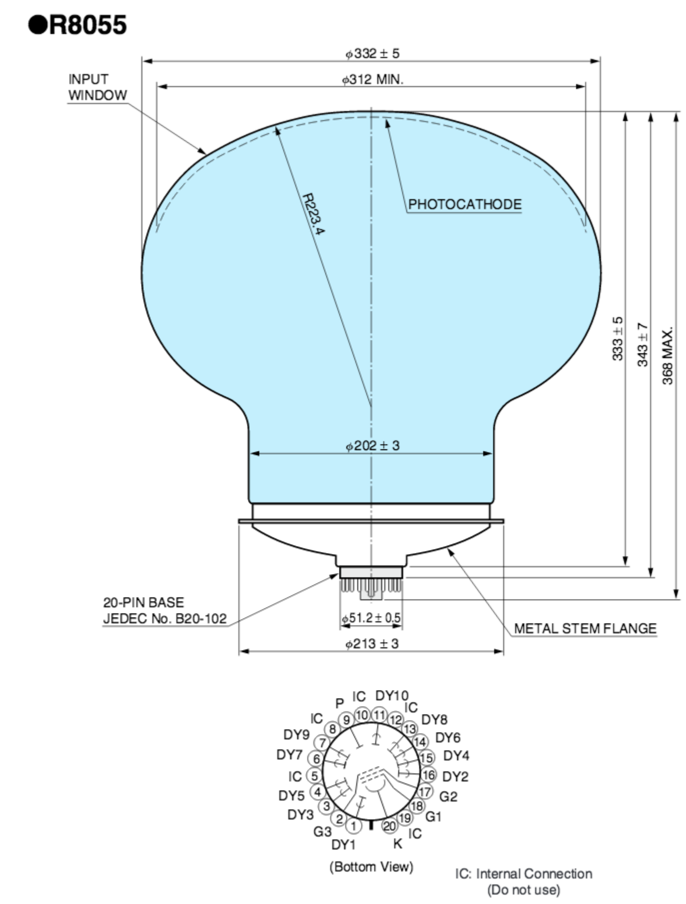
https://www.hamamatsu.com/resources/pdf/etd/p-dev_2015_TOTH0023E.pdf



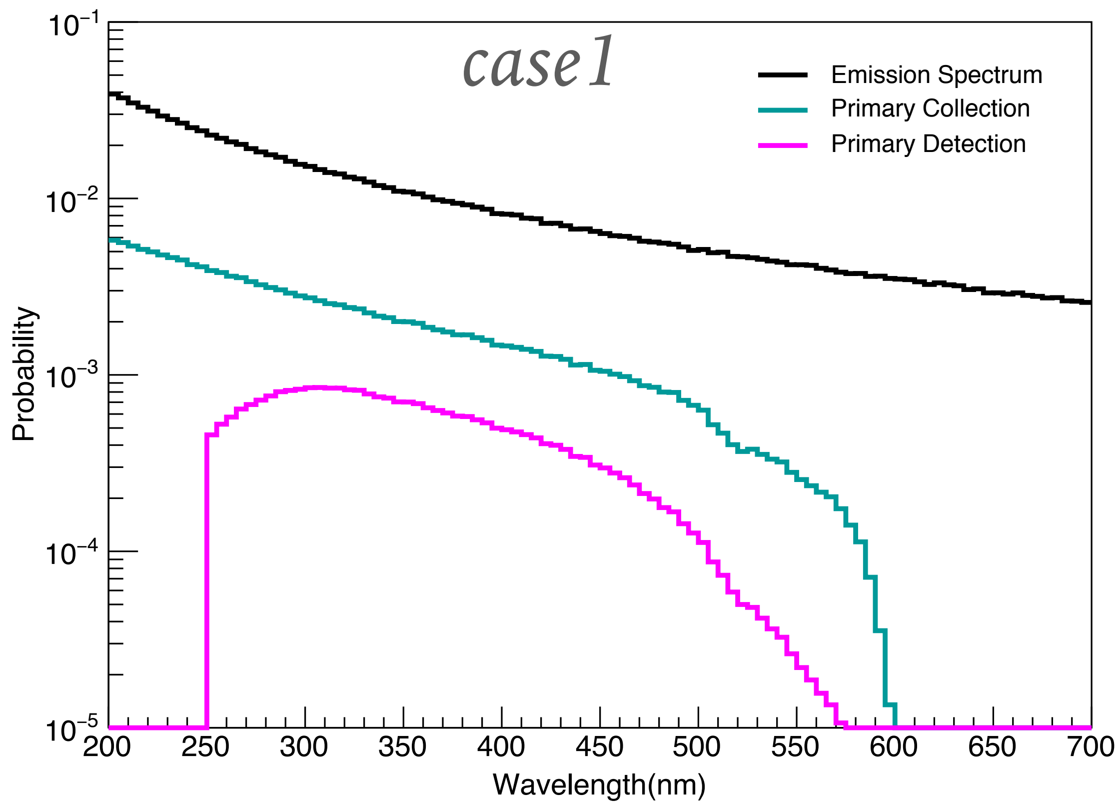
H)

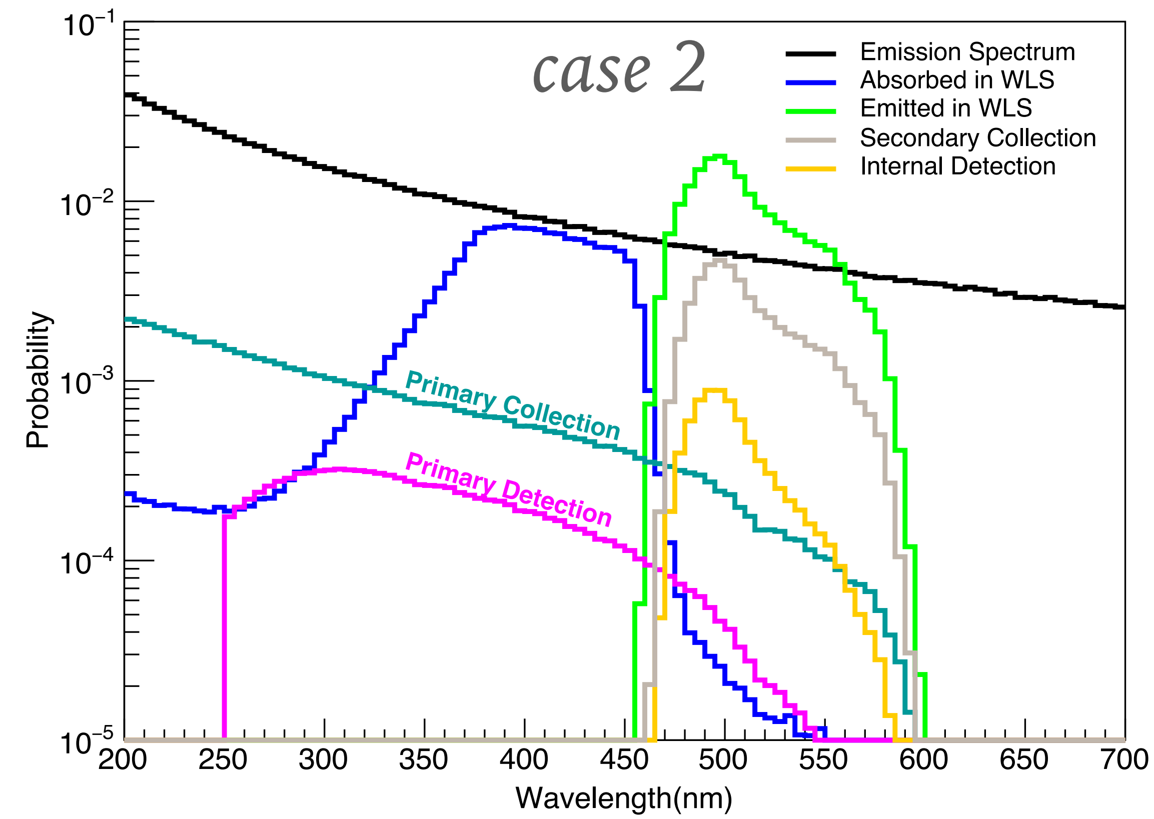
PHOTOMULTIPLIER TUBE

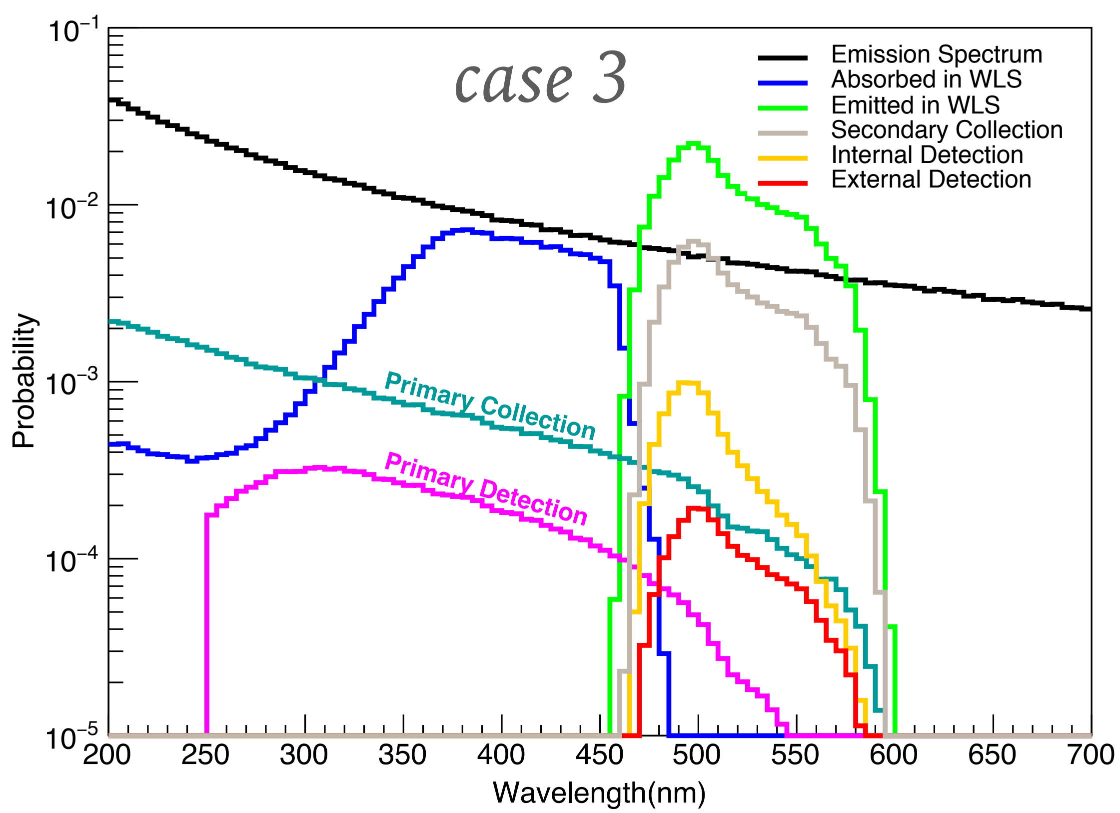


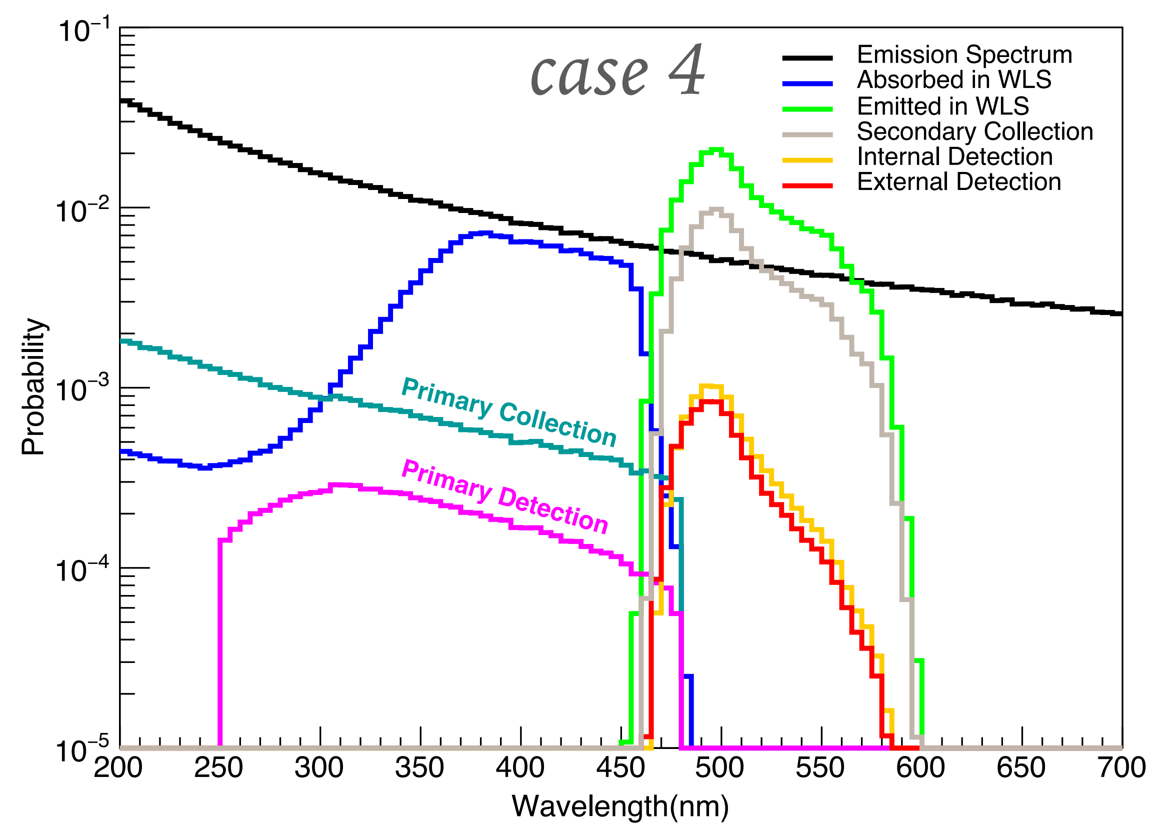


SPECTRA FOR THE DIFFERENT CASES









PHOTON COLLECTION EFFICIENCY MAPS