Enhanced light collection with a wavelength shiftingtrap

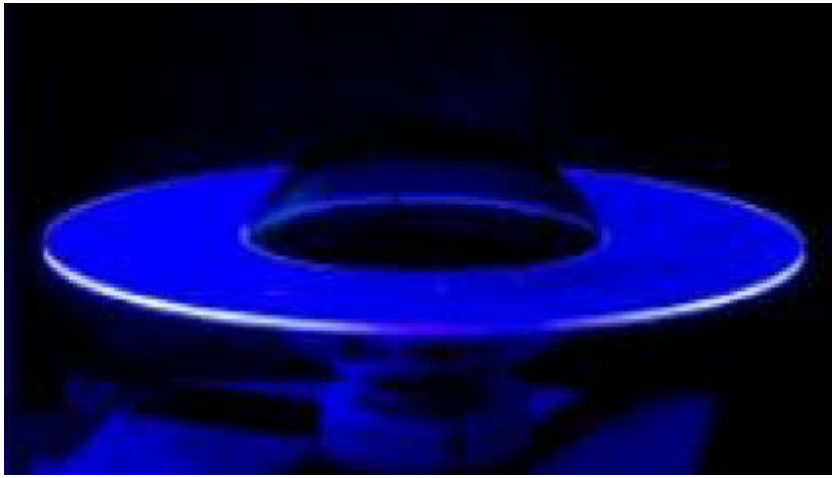
P. Gumplinger, F. Nurozler
(Undergraduate student), F. Retière

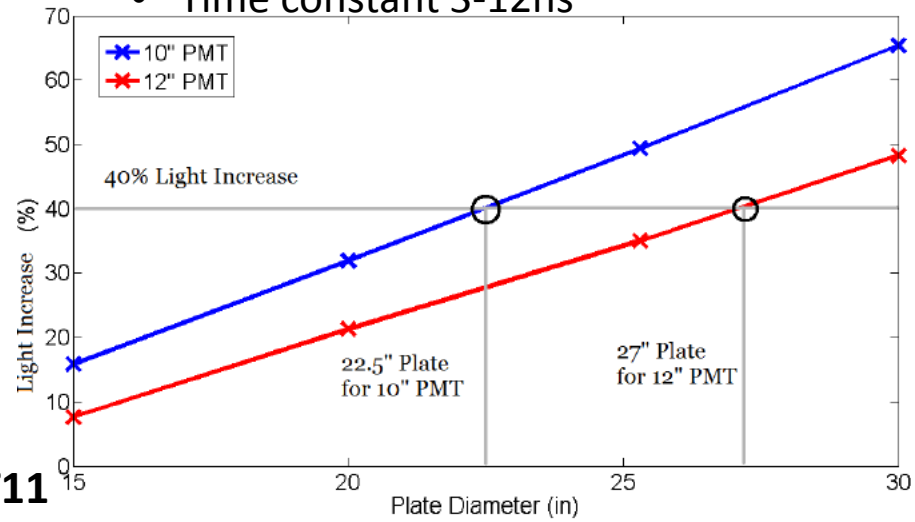
Motivations

- Baseline photon detection solution at Hyper-K
  - 20” PMT (same form factor as Hyper-K)
    - Possibly using Hybrid Photo-detector, i.e. APD rather than dynodes
  - 20% active (photo) coverage
  - PMT quantum efficiency not very well matched to Cerenkov light
- Can we do better or cheaper than that?
  - Smaller PMTs with light collectors
    - Lower cost
    - Lower dark noise
    - Better transit time spread

Wavelength shifter "Mexican hat" solution investigated for LBNE

- Pros
  - Up to 40% gain in light collection
  - Does not require additional PMT
  - Preserve prompt light
- Cons
  - Some light reemitted in water
    - may worsen position reconstruction
  - Worse position resolution
  - Delayed photo-electron from WLS
    - Time constant 3-12ns





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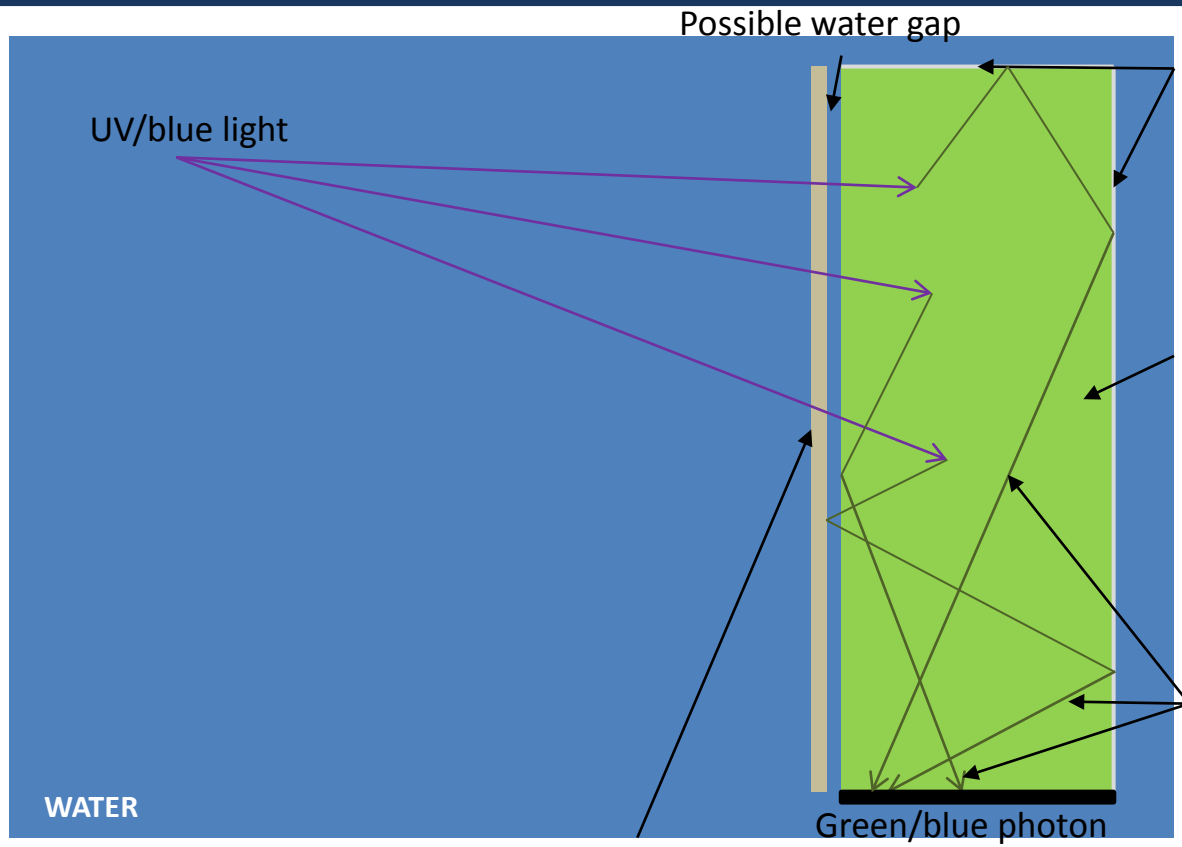
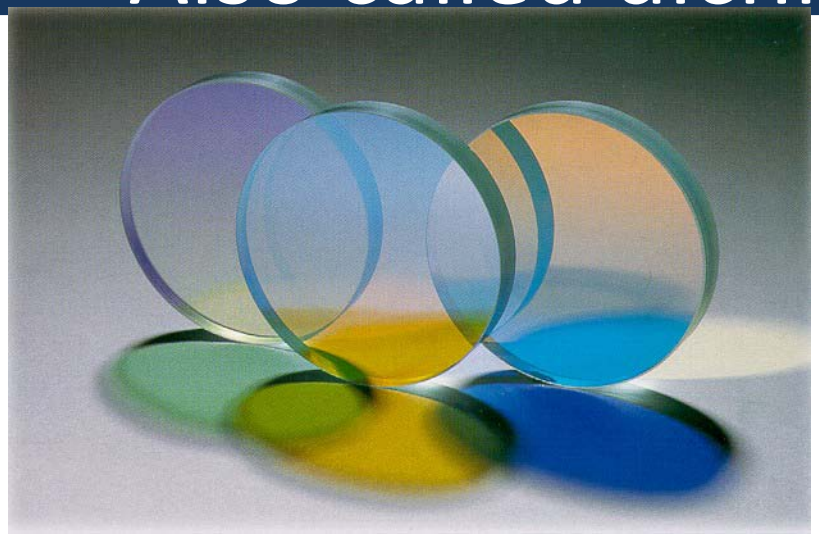
Trapping reemitted light

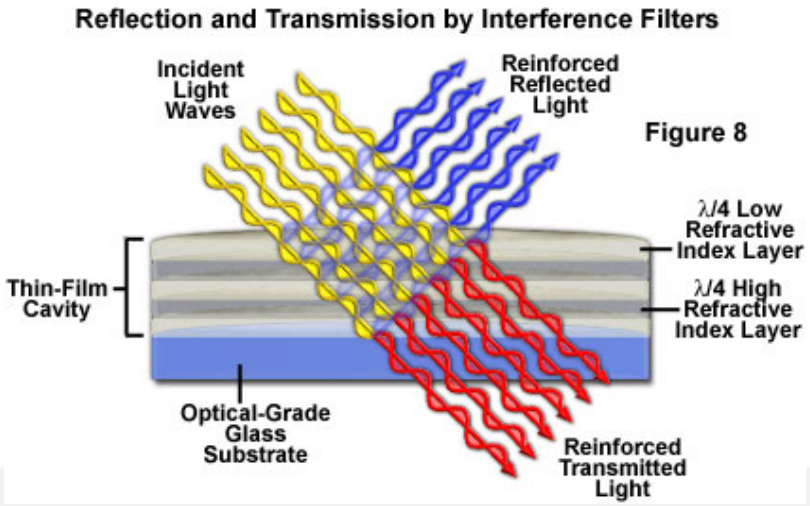


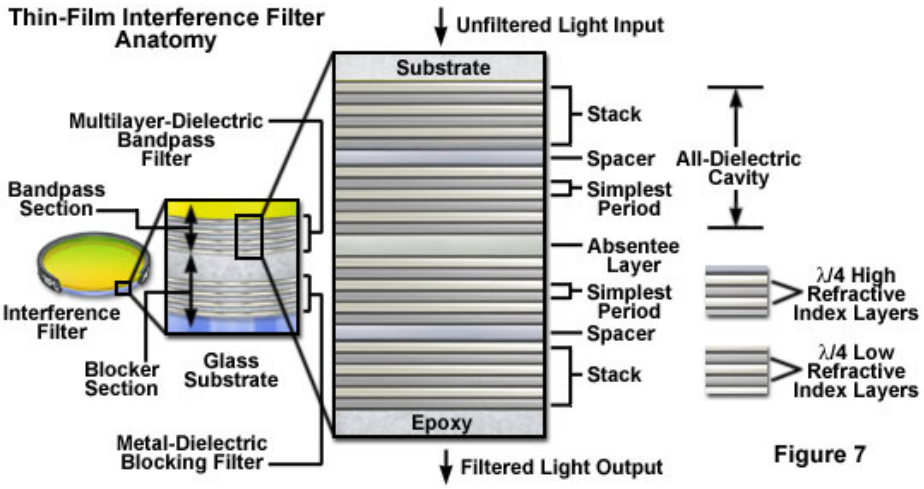
Trapping efficiency:

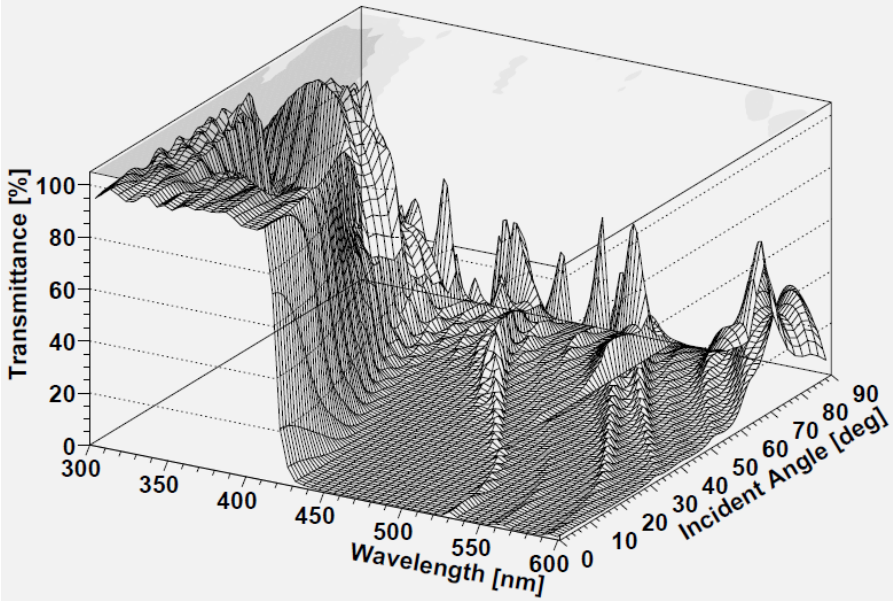
- ~30% with total internal reflection independently of number of bounces
- $98.5\%^{nbounce}$ with mirrors
- Can combine both

How interference filters work
Also called dichroic filters/mirrors





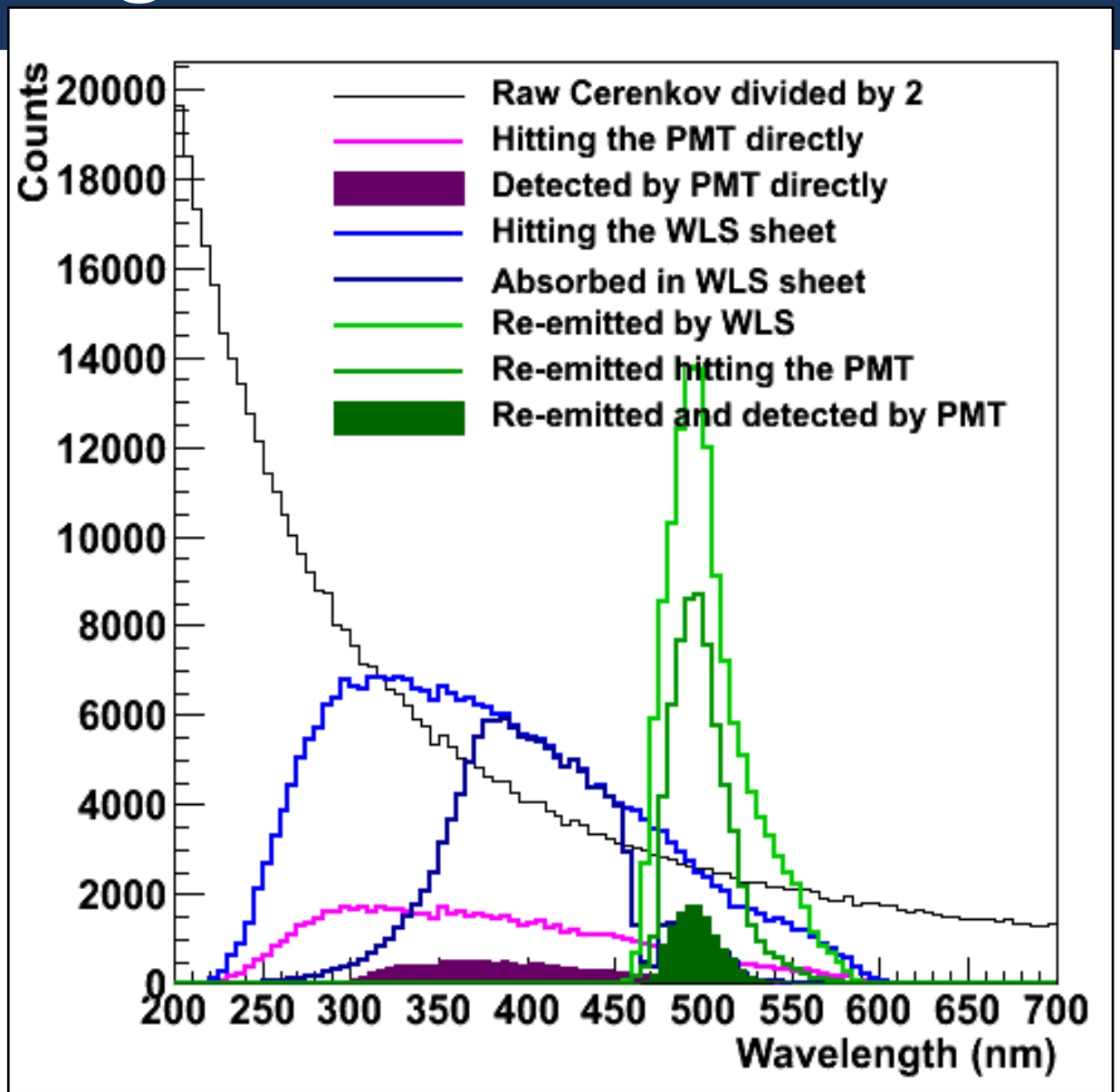




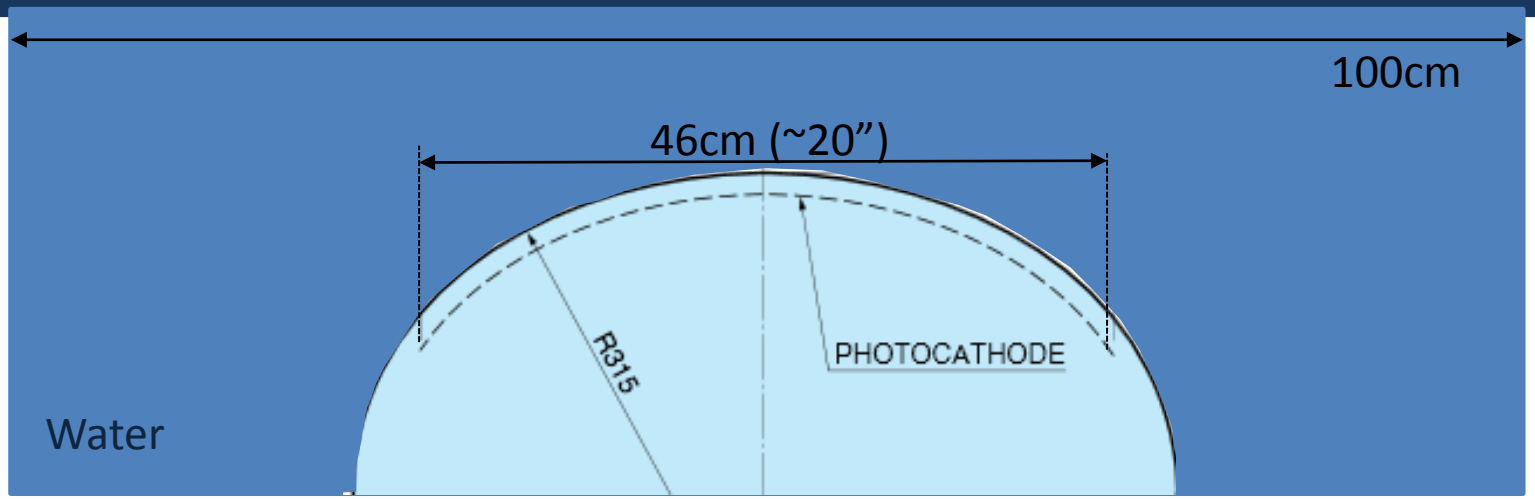
Simulation framework

- GEANT4 based
  - Dichroic mirror simulations implemented by P. Gumplinger
    - Reflectance vs angle and wavelength
    - Not used yet because optimization is tricky
- GEANT4 gun = Cerenkov photons
  - Wavelength distribution follow Cerenkov spectrum
  - Uniform spatial distribution 1x1 m^2
  - Normal incidence
- Detector simulations (not full HK simulations)
  - Vary geometry
  - Use BC482A (Saint Gobain wavelength shifter) absorption and emission spectrum
    - Only absorb blue (not UV). Could be improved with UV absorption

Light detection vs wavelength

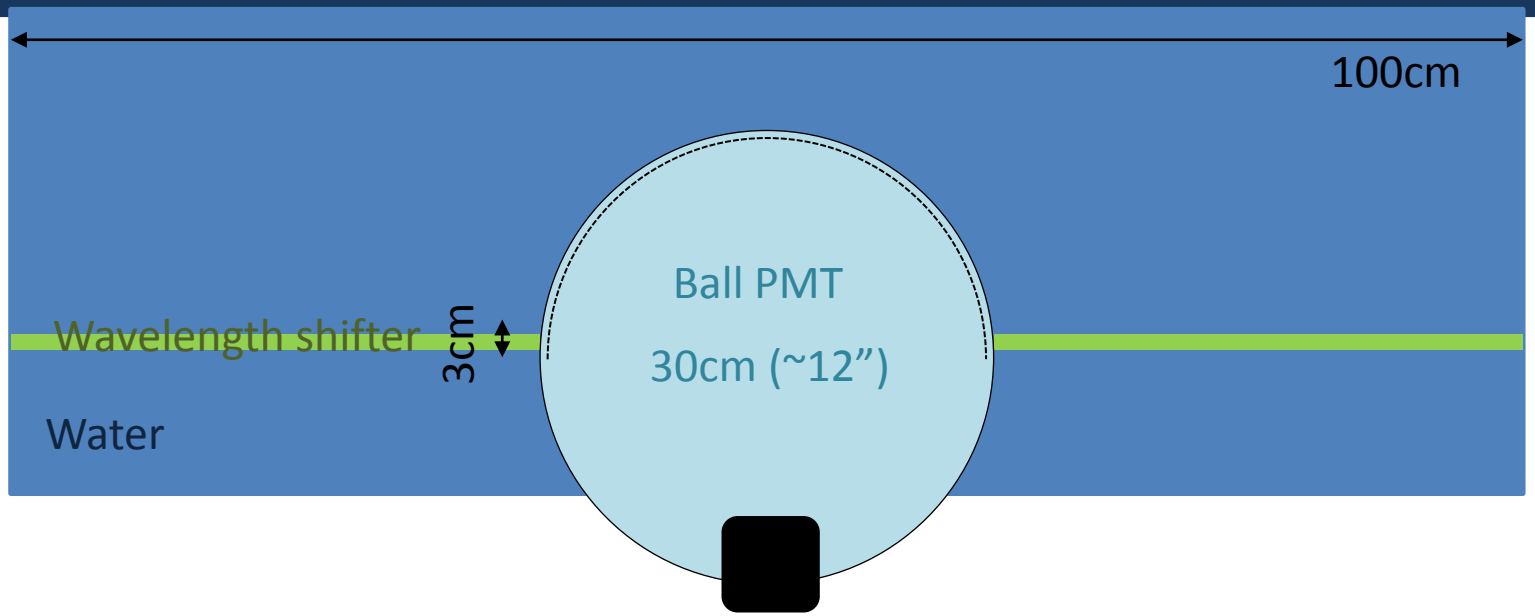


HK default configuration



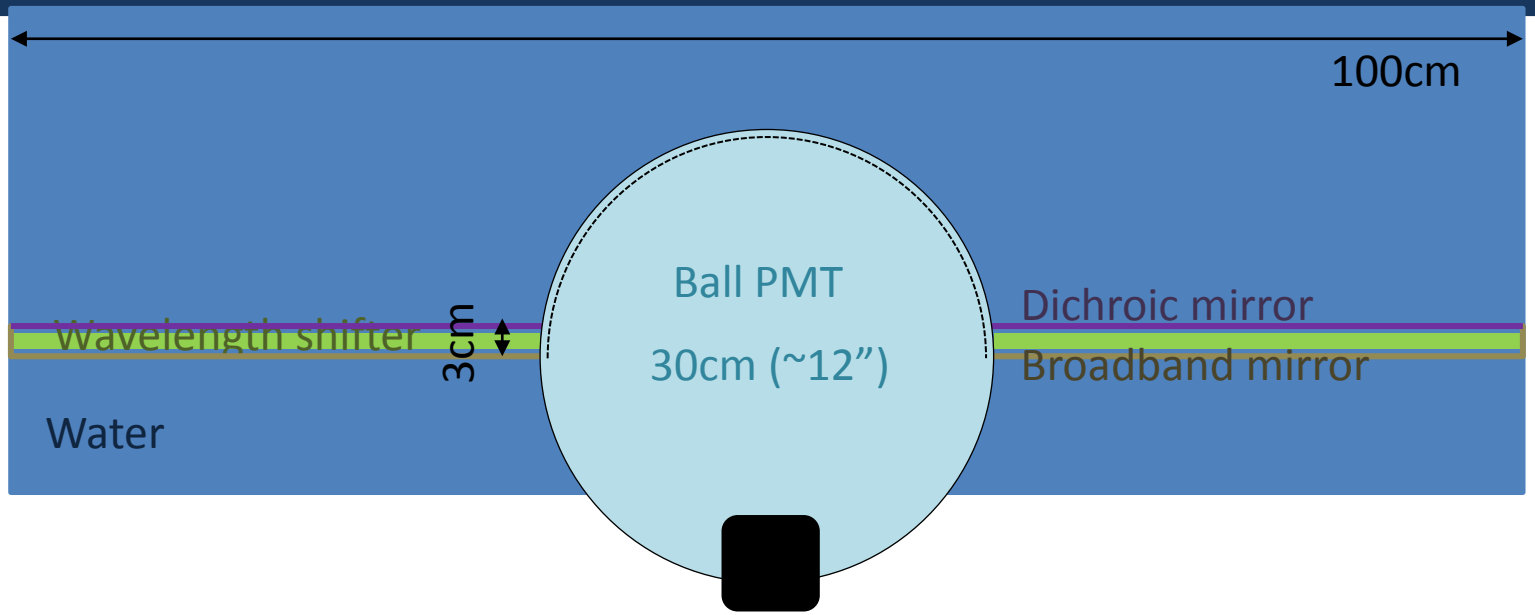
- 20" PMT every 100 cm (assumed)
- Will normalize everything to this configuration
  - Ignore photo-detection efficiency variation with wavelength

Thin wavelength shifter



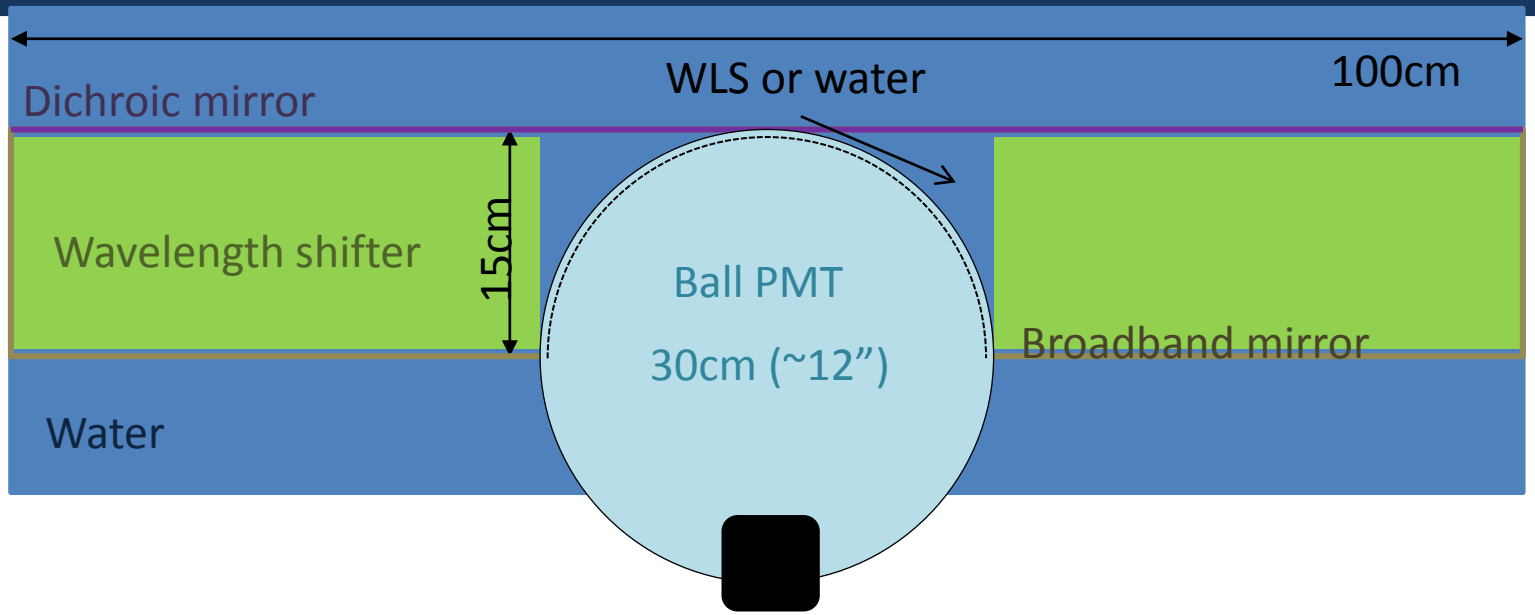
- Solution investigated for LBNE
  - Using longer plate

Thin wavelength shifter + mirrors



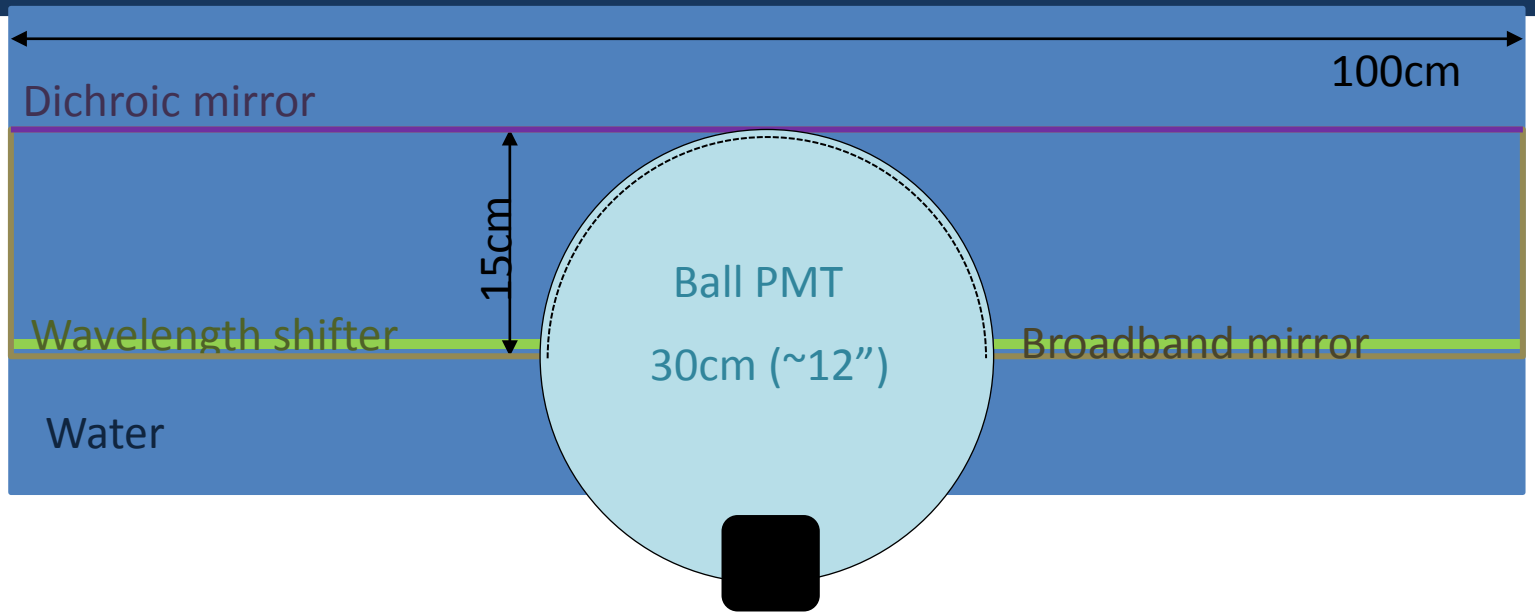
- Solution proposed last August
- Mirrors capture photons that escape WLS
  - Escape probability depend on number of bounces

Thick wavelength shifter



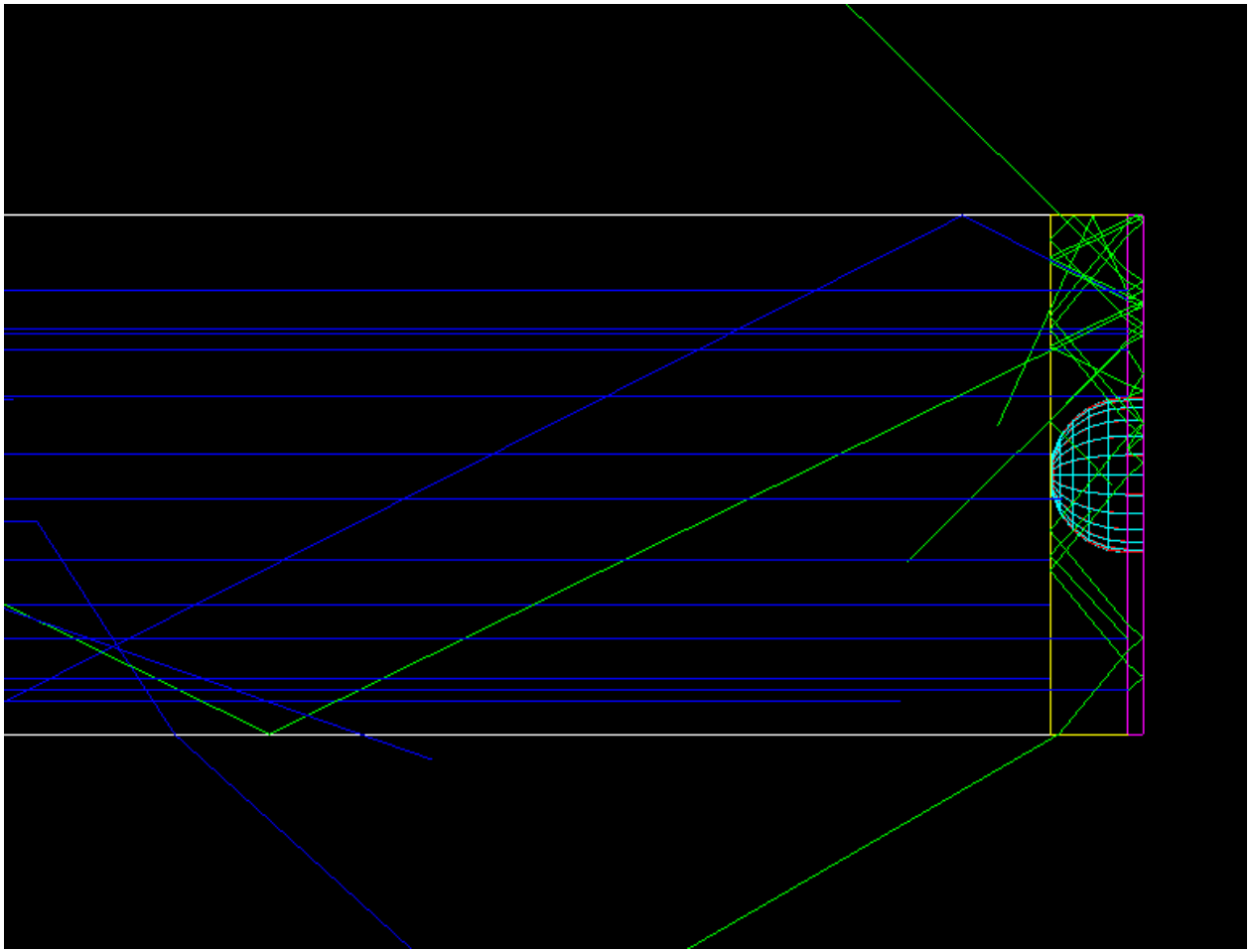
- Solution proposed in January 2013
- Thick wavelength shifter to minimize number of bounces
  - WLS shadow PMTs for large angle
  - Cerenkov photon go through mirror: filter out green photons

Thick box but thin WLS

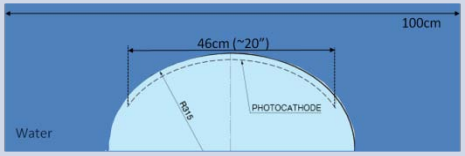
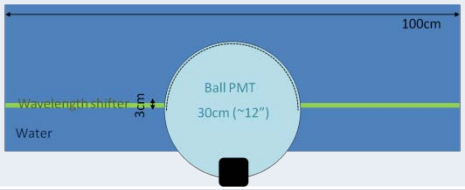
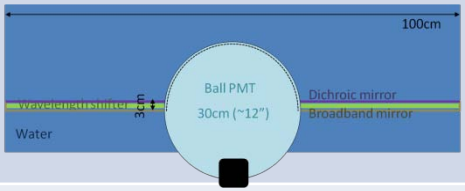
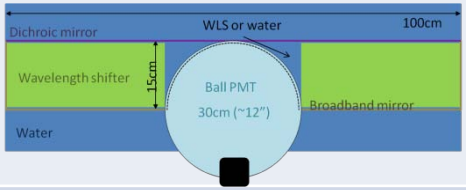
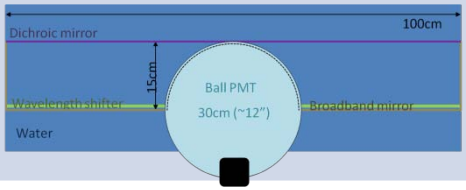


- May not need thick wavelength shifter
  - Fill up box with water
  - Use WLS only to shift from blue/UV to green for trapping with dichroic mirror

Simulation example

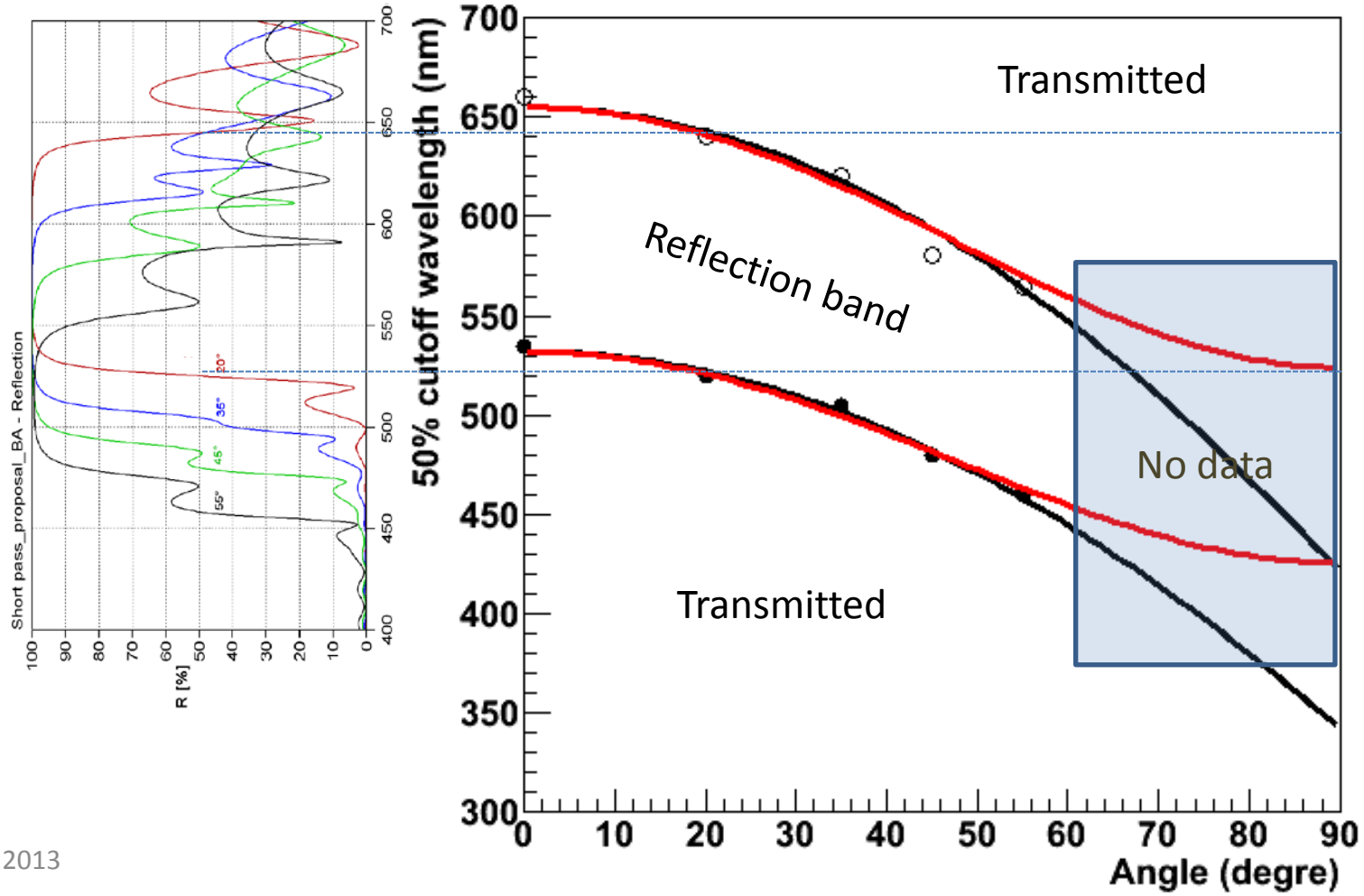


Performance: photon collection

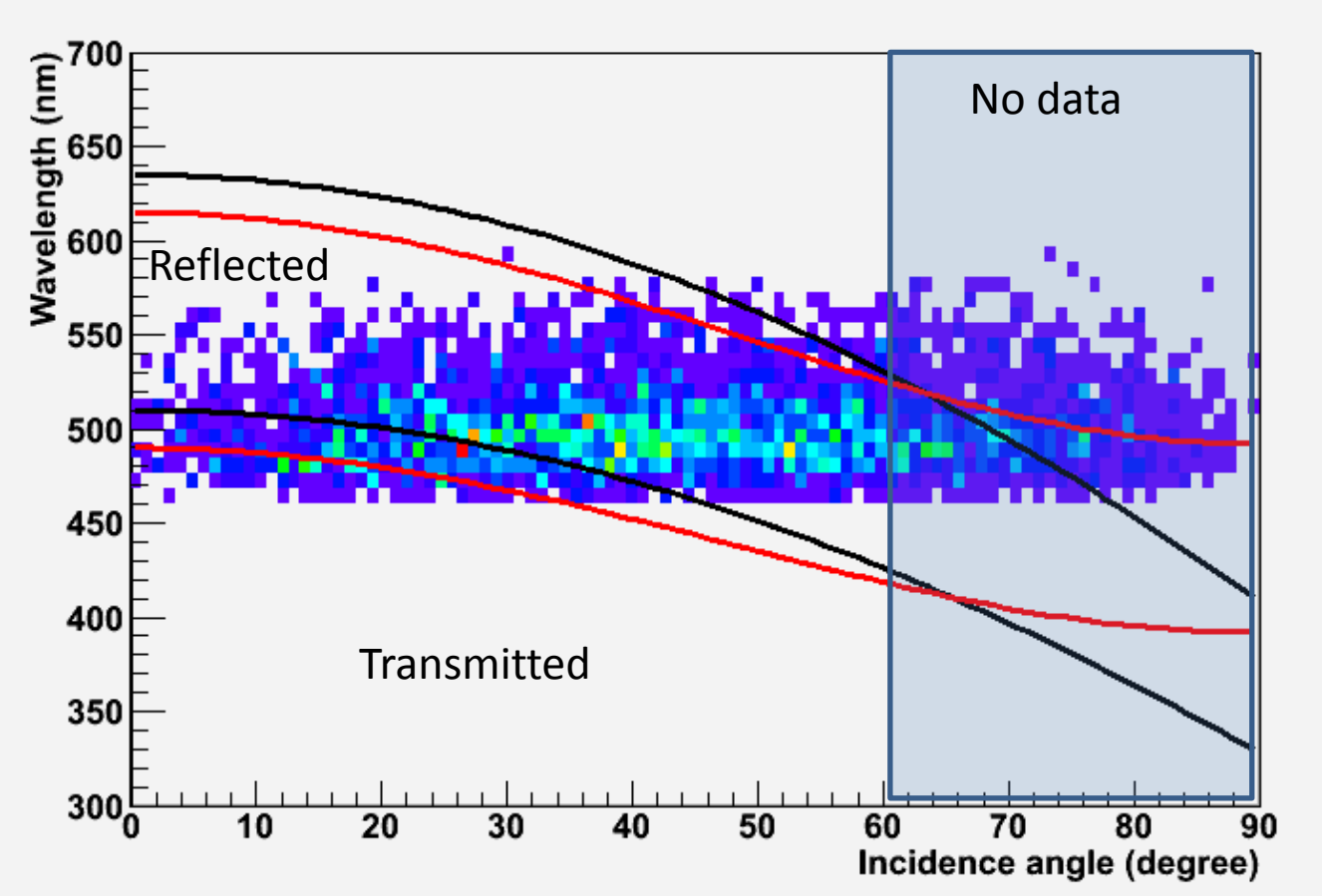
Configuration		# direct	# WLS	# WLS-ext
20” PMT		1*	0	0
12” PMT + 3cm WLS + side mirrors		0.42	0.15	0.3
12” PMT + 3cm WLS + side & back mirrors + dichroic mirror		0.42	0.42	0.84
12” PMT + 15cm WLS + side & back mirrors + dichroic mirror		0.38	1.7	~3
12” PMT + 5mm WLS + side & back mirrors + dichroic mirror		0.38	1.2	2.4

Dichroic mirror tuning with wavelength and angle

Calculations by
Laseroptik GMBH



Dichroic mirror tuning with wavelength and angle

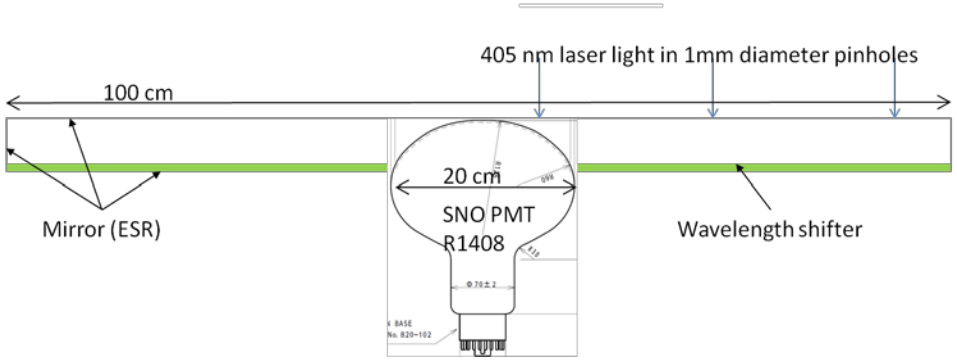


Overall performance consideration

	20” PMT	12”PMT + thick WLS	12” PMT + thick WLS + extended WLS
Normalized PDE x photo-coverage (using HQE PDE)	1	1.8	3
Granularity	25 cm disk	1x1 m2	1x1m2
1D position resolution	11.5cm	27.2cm	~30cm
Single photon timing resolution	3.5ns (transit time spread)	12.5ns	12.85ns

- Is the gain in photo-coverage worth the lost timing and position resolution?
  - Can we find faster wavelength shifter?

Build prototype by end of the year



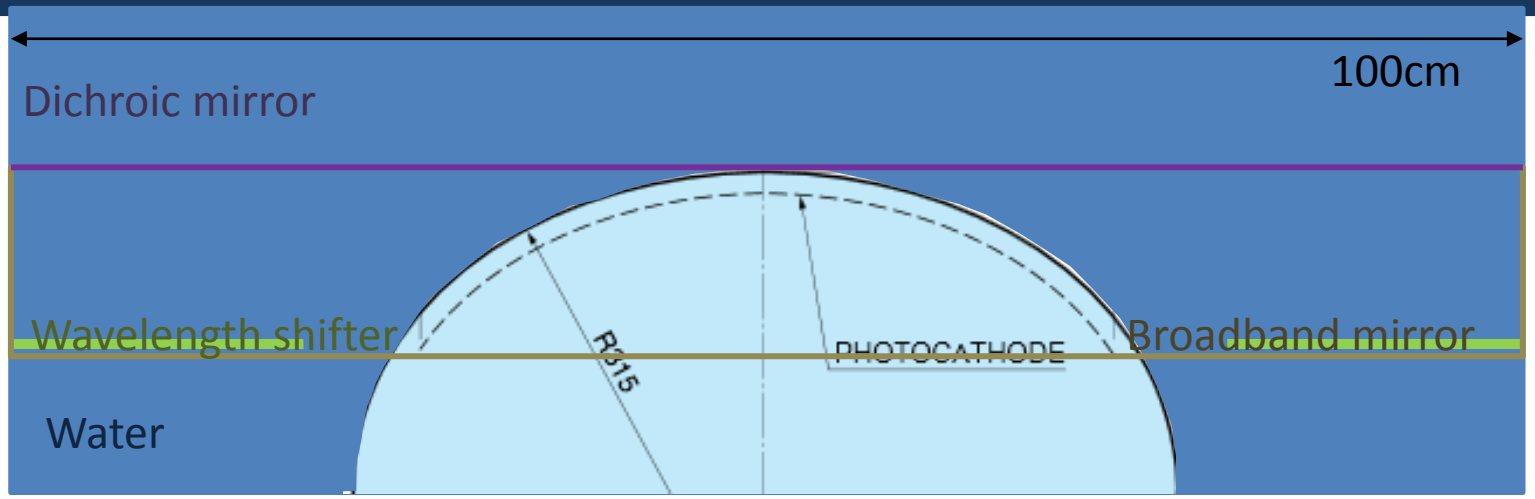
- Short of money
  - Do with what we have
    - 8” SNO PMT on hand
  - Could certainly use a 12” PMT
- Test in H.Tanaka PMT tester setup

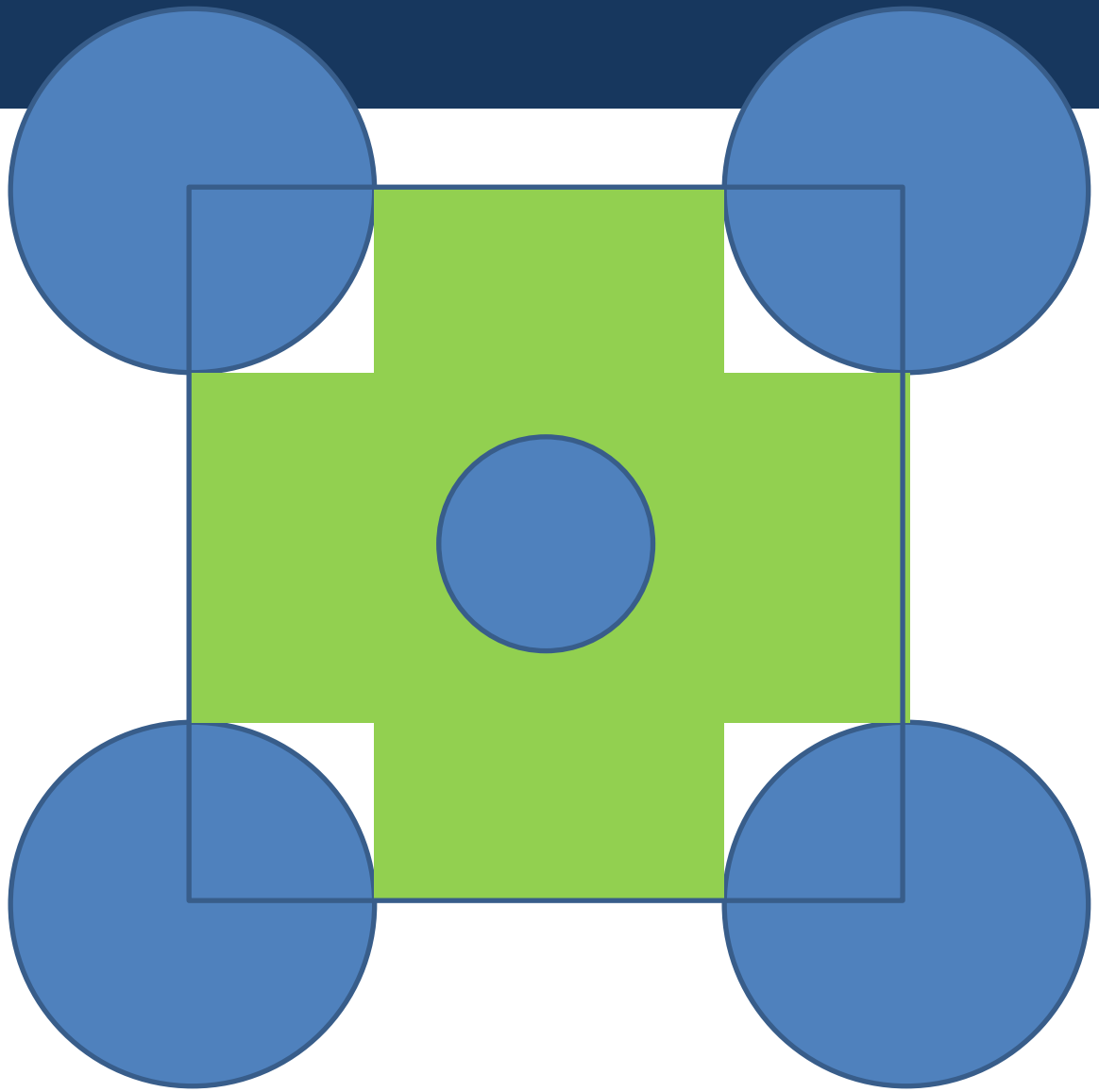
- Dichroic mirror
  - Investigate optimum configuration
    - Simulate thin film
  - Investigate large area manufacturing
    - Flat panel display technology?
  - Mock-up dichroic mirror using perforated broadband mirrror if necessary
- Wavelength shifter
  - Procure UV/blue→green from Eljen and Saint-Gobain

Summary and outlook

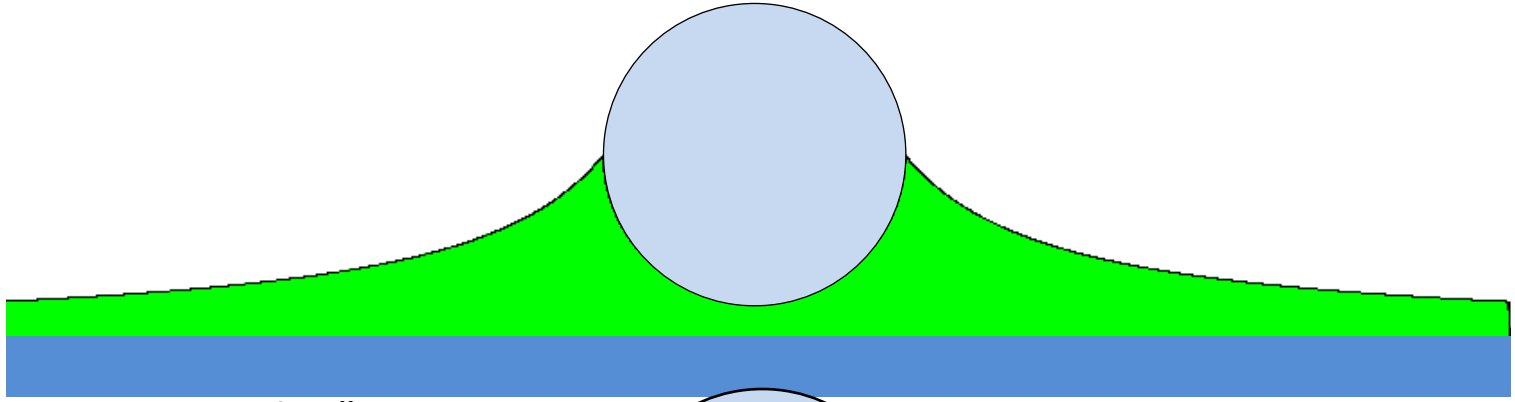
- The combination of thick wavelength shifter and dichroic mirror is promising
  - As much as factor of 3 photon gain
    - Need UV/Blue wavelength shifter for optimum results
- Next steps
  - Investigate pros and cons of enhanced photon collection vs worth timing/position resolution
    - Investigate π^0 reconstruction with fiTQun + Wcsim
      - Good combination of low and high energy reconstruction
    - Investigate different configurations.
      - A. Konaka suggestion: ½ 20” PMT (good timing for high energy) + ½ photon trap (for low energy)
  - Build a full scale prototype
  - Secure R&D money

Thank you


100cm
Dichroic mirror
Wavelength shifter
Broadband mirror
Water
R315
PHOTOCATHODE

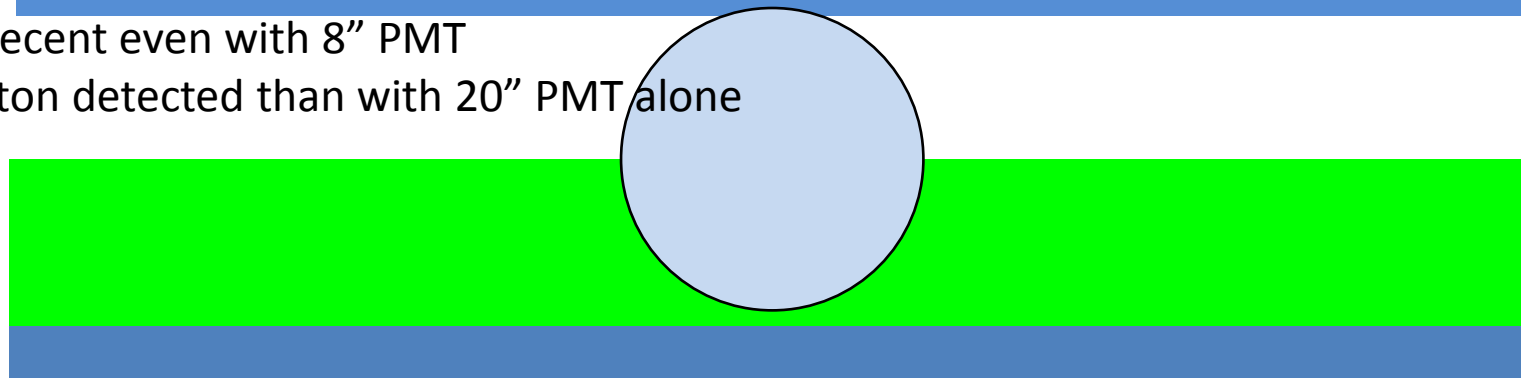


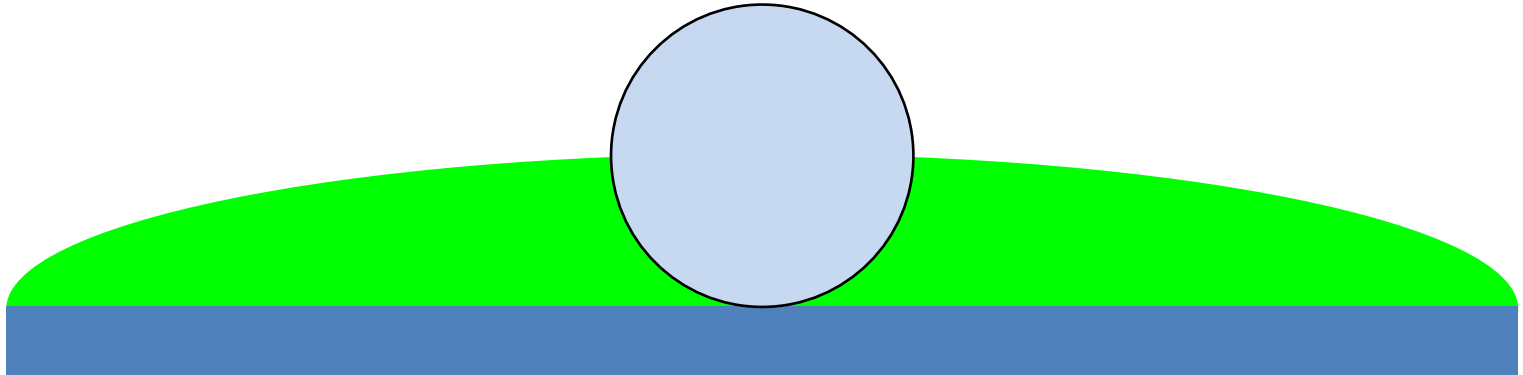
Many solution investigated
Box seems to be best



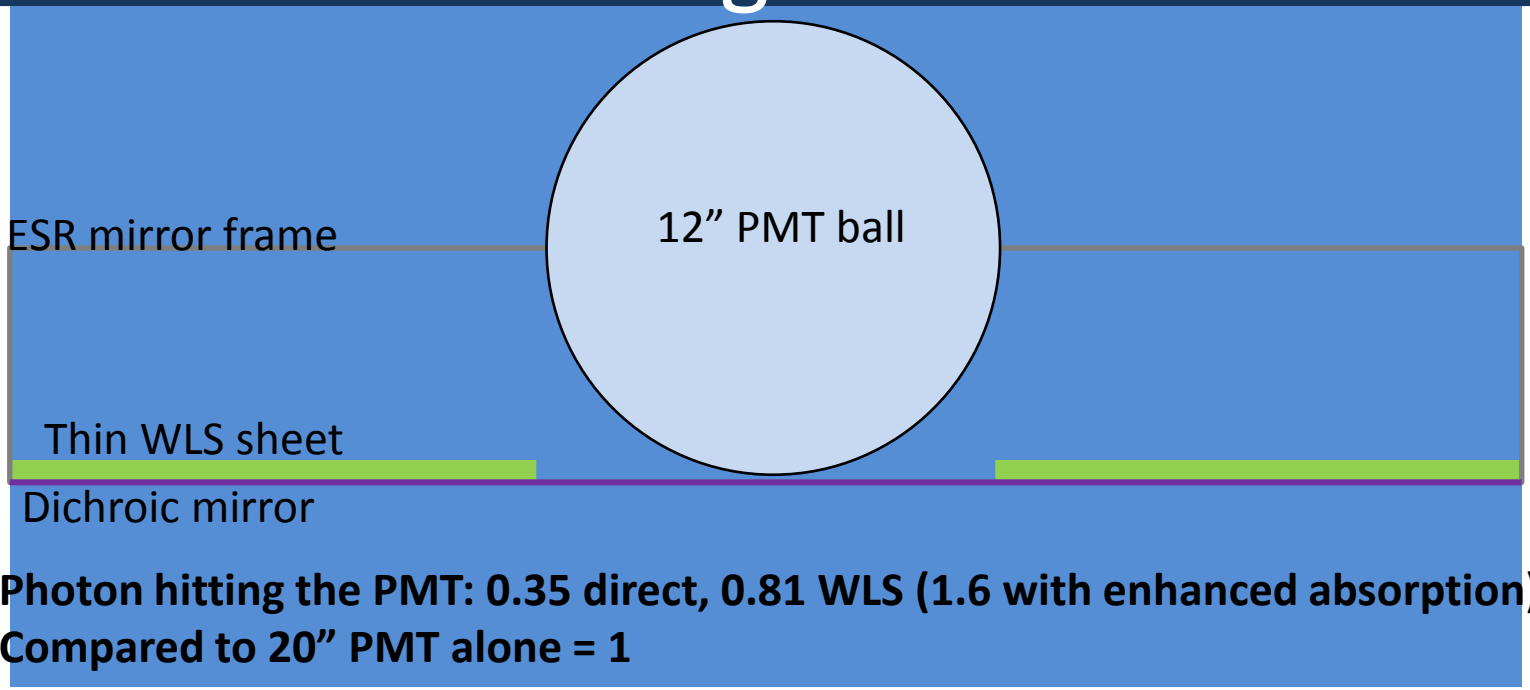
Solution decent even with 8” PMT

More photon detected than with 20” PMT alone





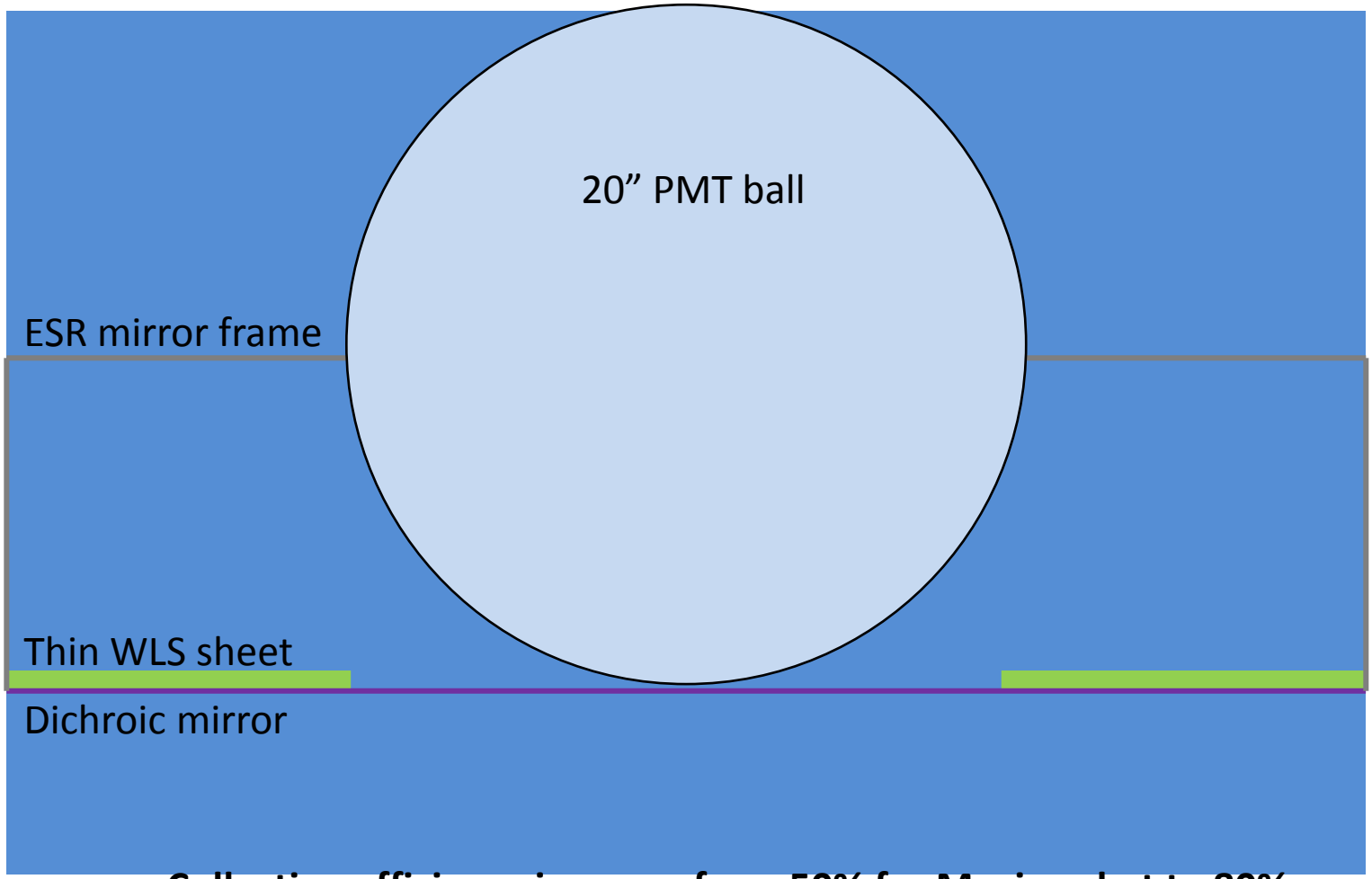
My best guess for the optimum configuration



Photon hitting the PMT: 0.35 direct, 0.81 WLS (1.6 with enhanced absorption)
Compared to 20” PMT alone = 1

- 12” PMT with half ball photo-cathode coverage
- Thin WLS ~100x100x0.5 cm^3 sheet with hole in center
  - Optimize for UV-blue absorption and low green light attenuation
  - If possible use water-like index of refraction material
- Confine WLS photons with frame in water
  - Dichroic mirror on tank side & Enhanced Specular Reflector on outside
  - Exact shape to be optimized

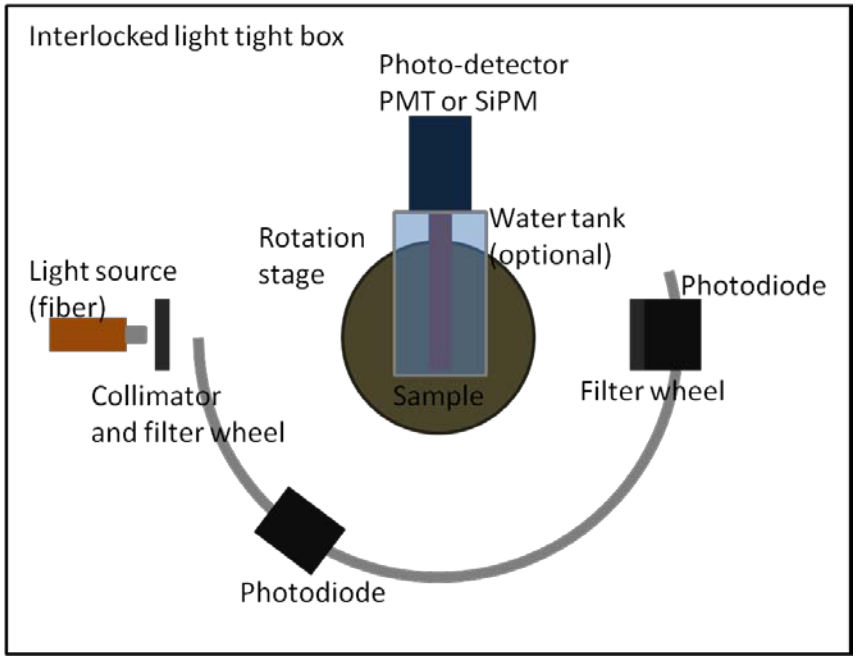
Or with 20” PMT



Collection efficiency increase from 50% for Mexican hat to 80%.
Normalized WLS photon detected = 0.9 (+1 direct photon)
With enhanced WLS absorption = 1.8 (+1 direct photon)

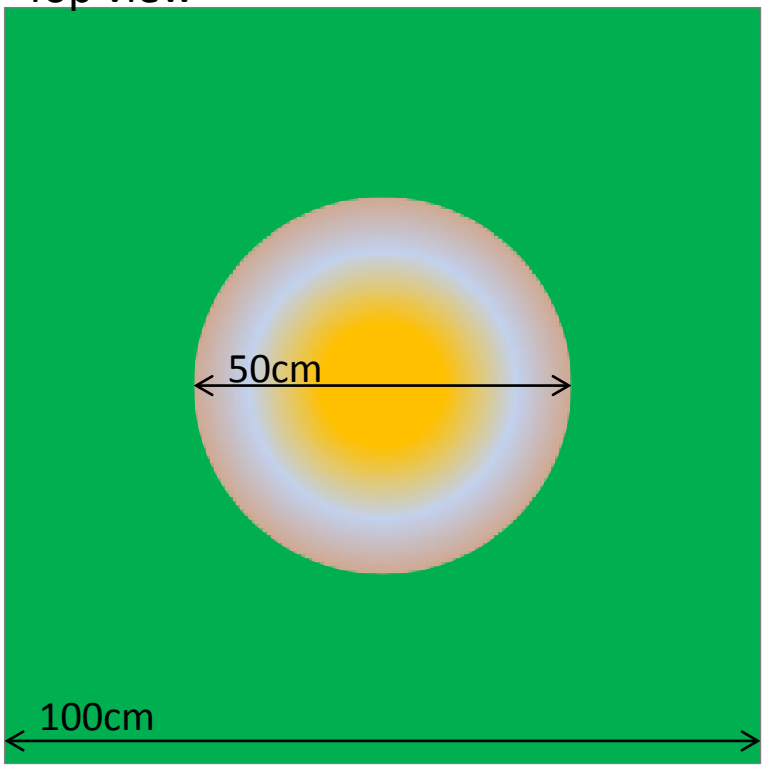
Next step 3: build a prototype

- Small scale to test light collection



- Full scale prototype
  - Straightforward to machine a slab of WLS and couple it to a PMT
  - Can we get large enough mirror?
  - How to test it?
  - ... This may not happen until next year

Top view



Side view