Solution(s) for improving the overall photo-detection efficiency at Hyper-K

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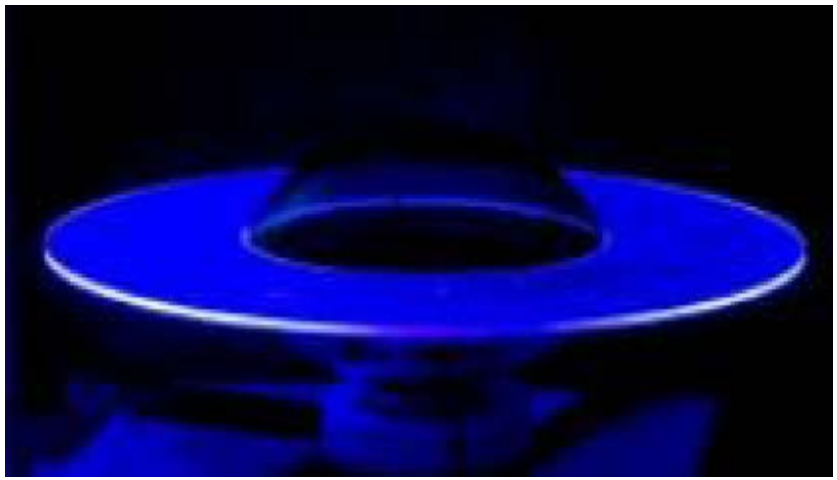
TRIUMF

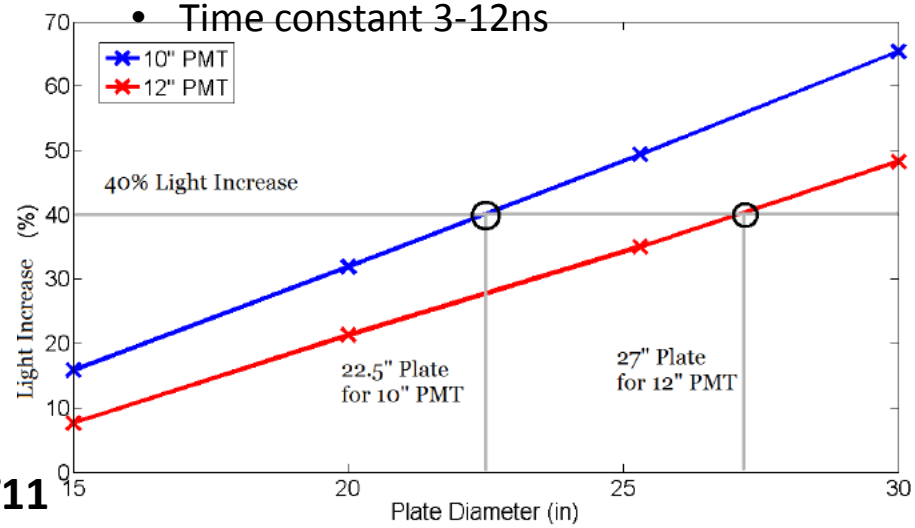
Motivations

- 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
  - Water index of refraction limit trapping efficiency
  - Delayed photo-electron from WLS
    - Time constant 3-12ns



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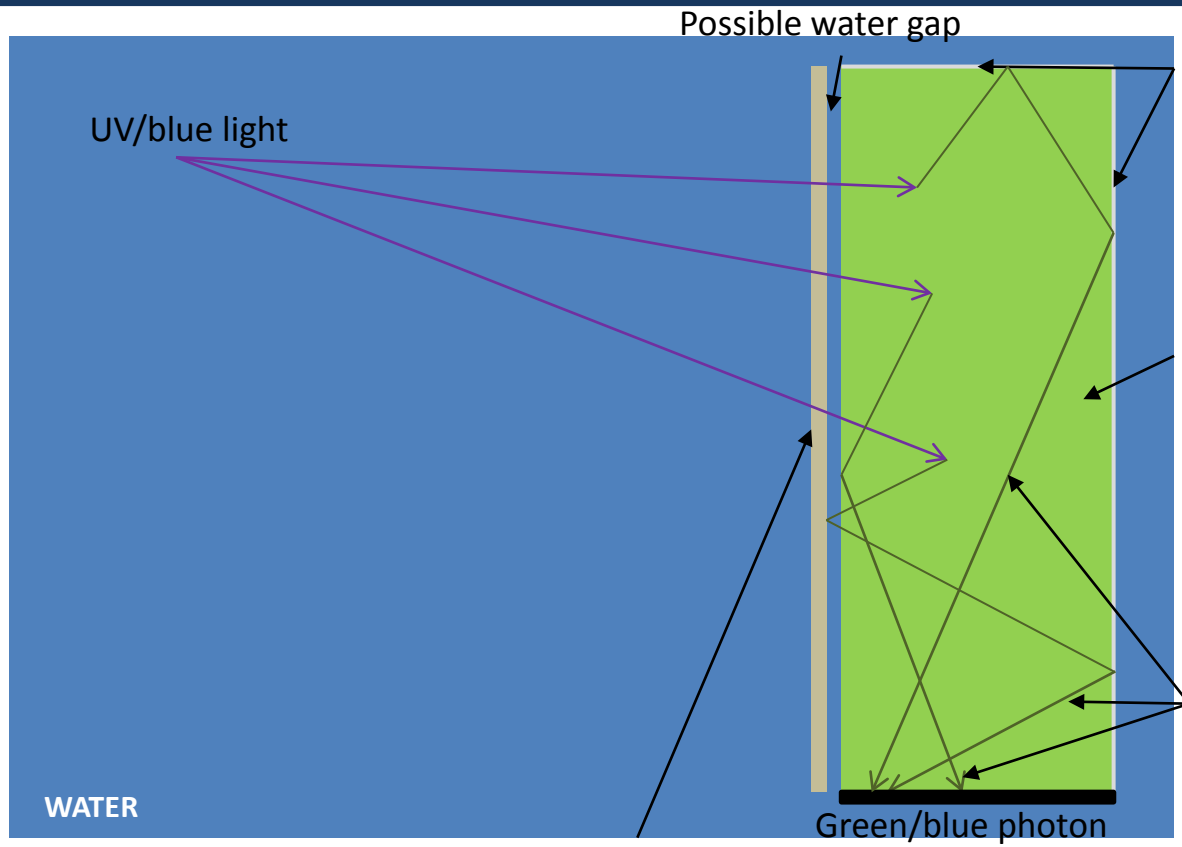
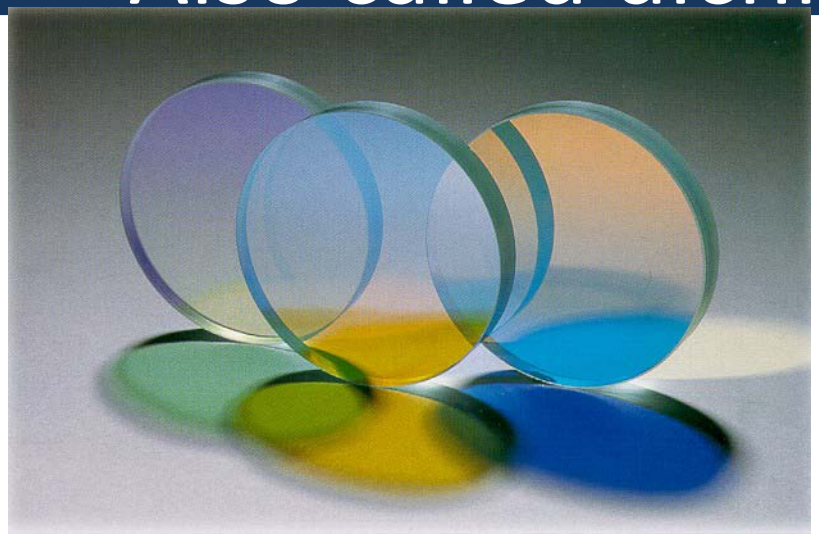
Trapping reemitted light

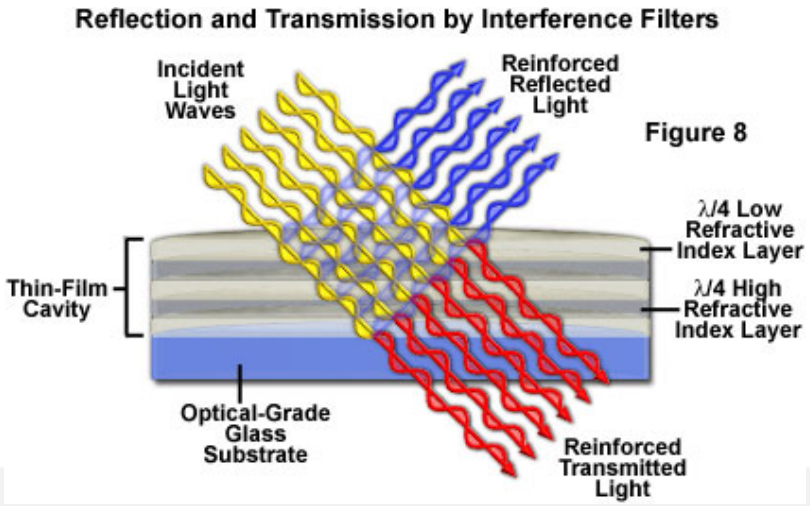


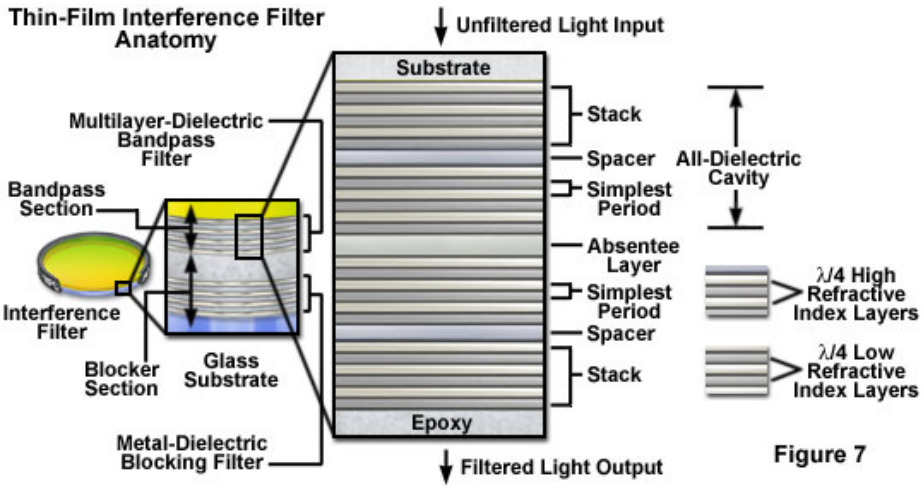
Trapping efficiency:

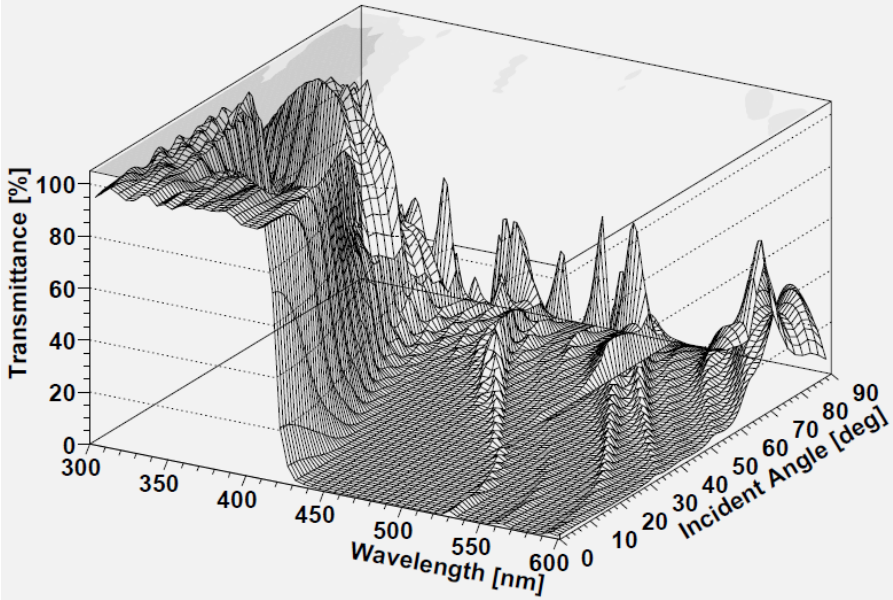
- ~30% with total internal reflection independently of number of bounces
- $98.5\%^{nbounce}$ with mirrors
- Can combine both

How interference filters work
Also called dichroic filters/mirrors



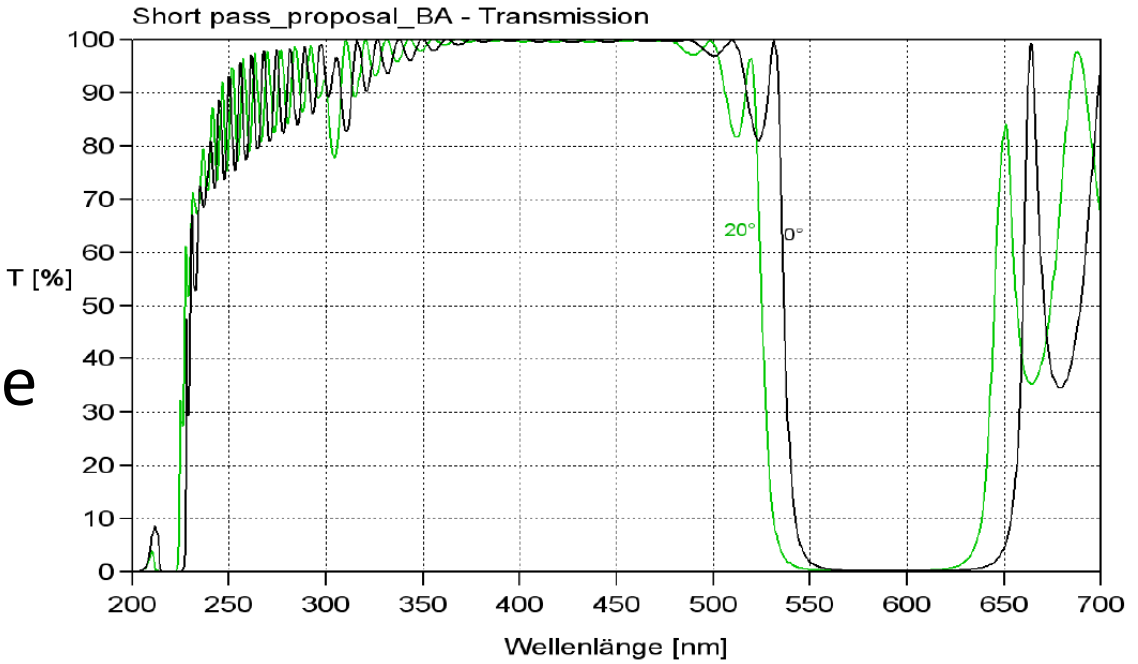


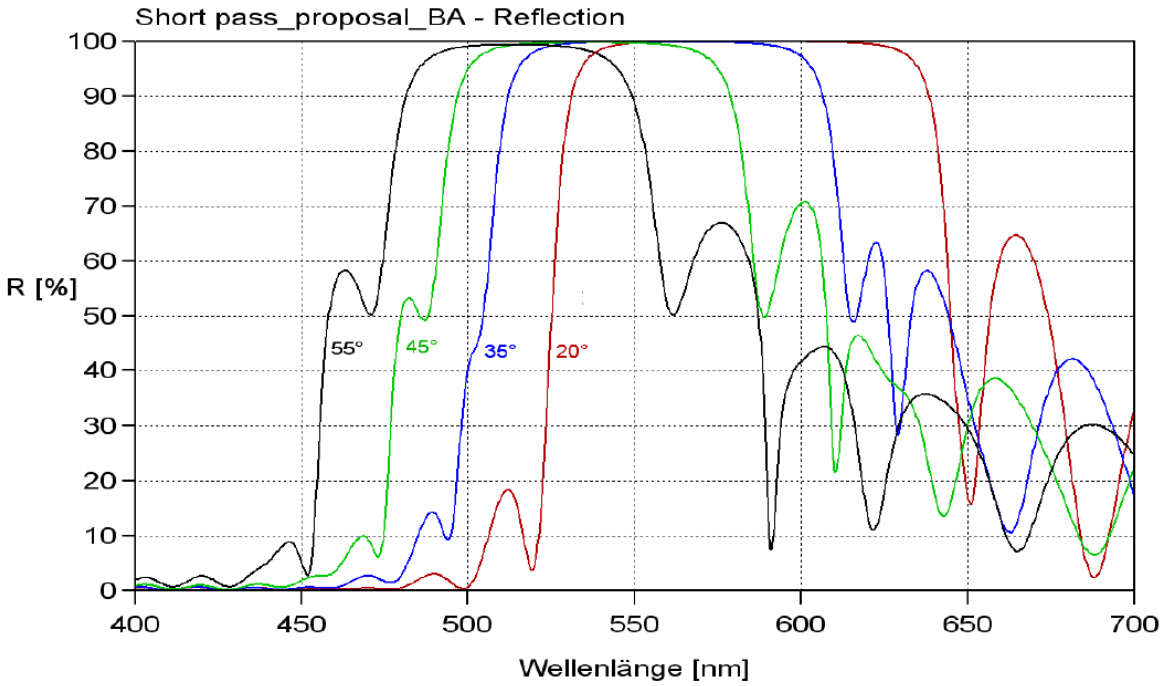




Possible solution from Laseroptik

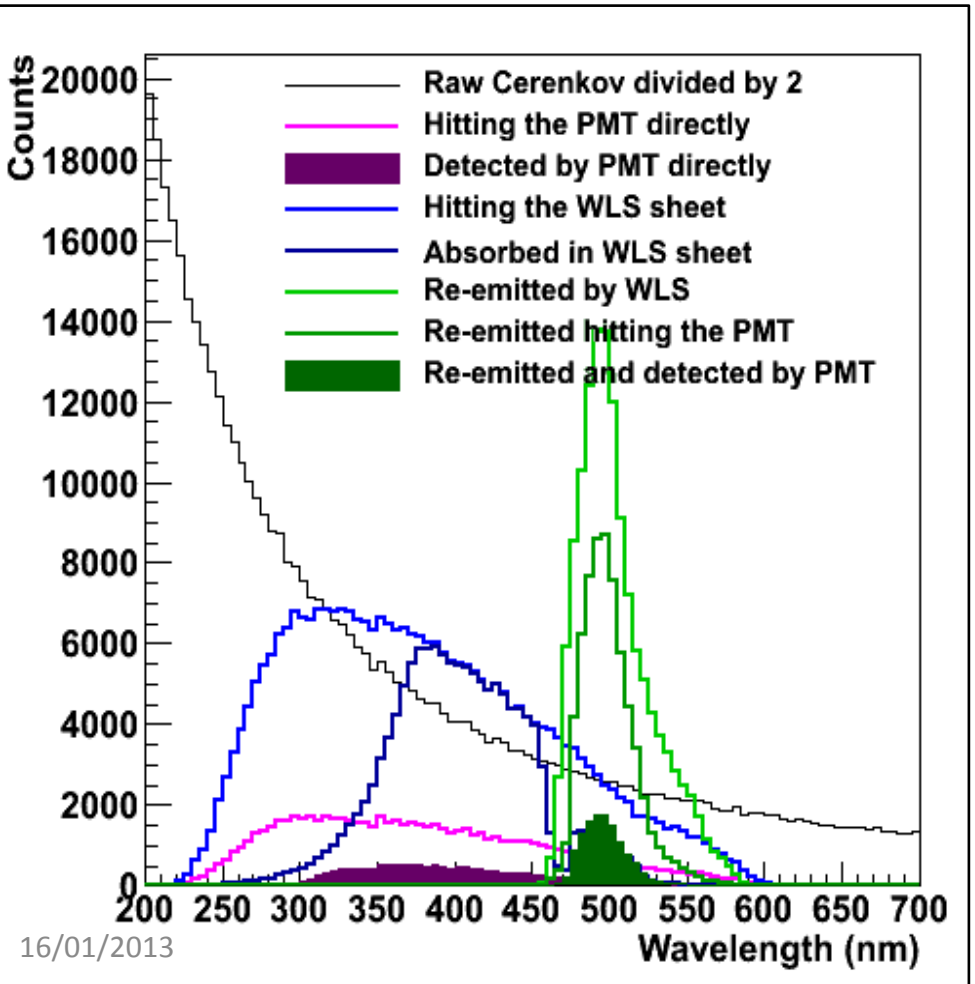
- Reflection at large angle is important
  - Strong correlation between wavelength and angle
  - With total internal reflection
    - Max angle hitting the mirror = 56.8 degres
- Angular dependence not simulated yet





Light detection vs wavelength

50 cm diameter PMT, dichroic mirror, 100x100x3 cm^3 thick WLS sheet



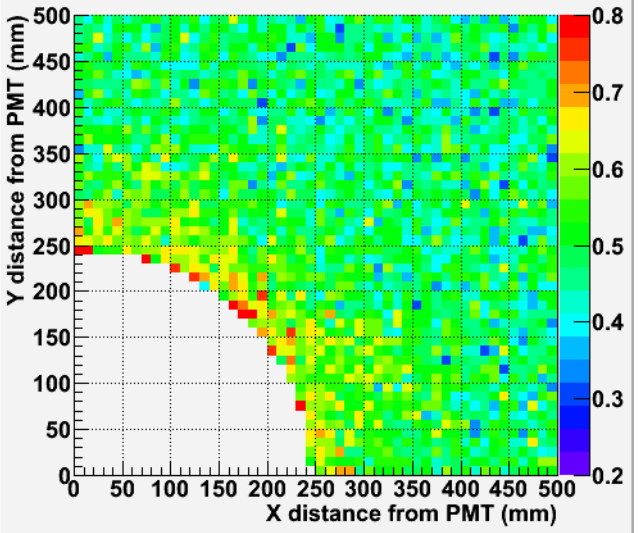
- GEANT4 simulations
- Use existing wavelength shifter BC482-A
  - Absorb light between 350 nm and 450 nm
    - Is it true that absorption is small below 350 nm?
    - Assume 30% absorption efficiency
  - Reemit in green 460-560 nm
    - Some light will be trapped in WLS
    - 100% reemission efficiency
- Extend absorption range to UV
  - Possible combining two WLS
    - Worsen timing
  - Saint Gobain and Eljen willing to try

Light collection efficiency with 20” PMT

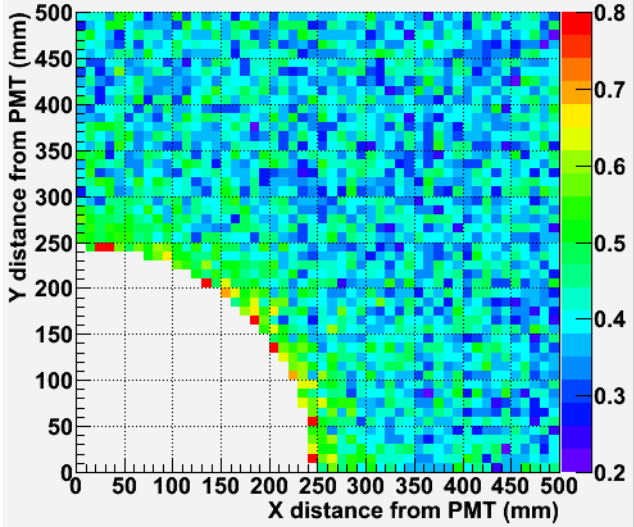
Thickness = 3 cm

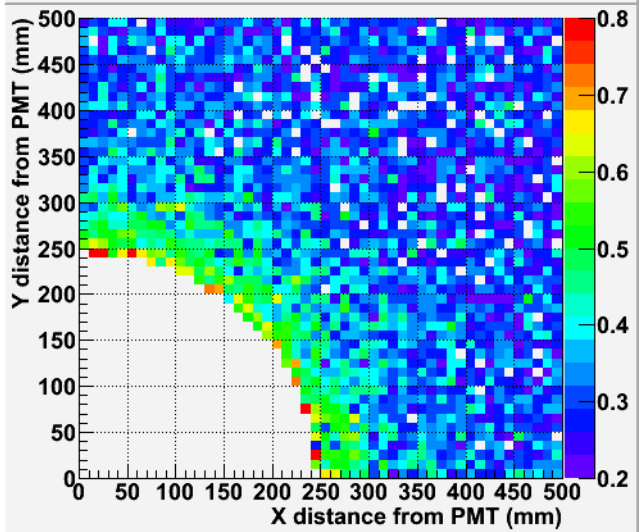
Thickness = 1 cm

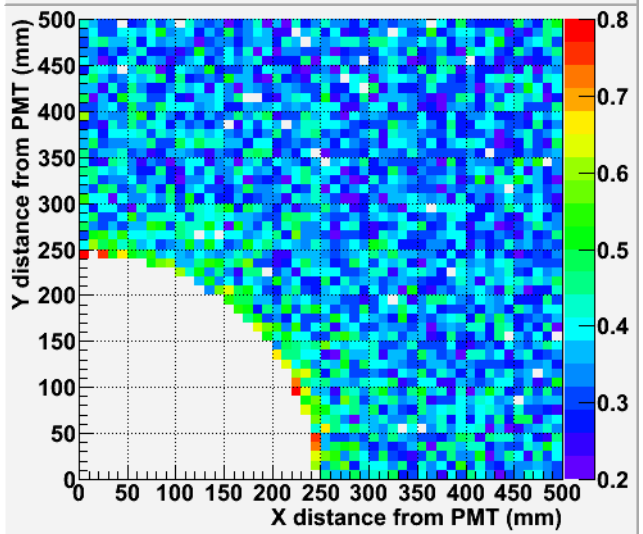
Dichroic mirror



Total internal reflection







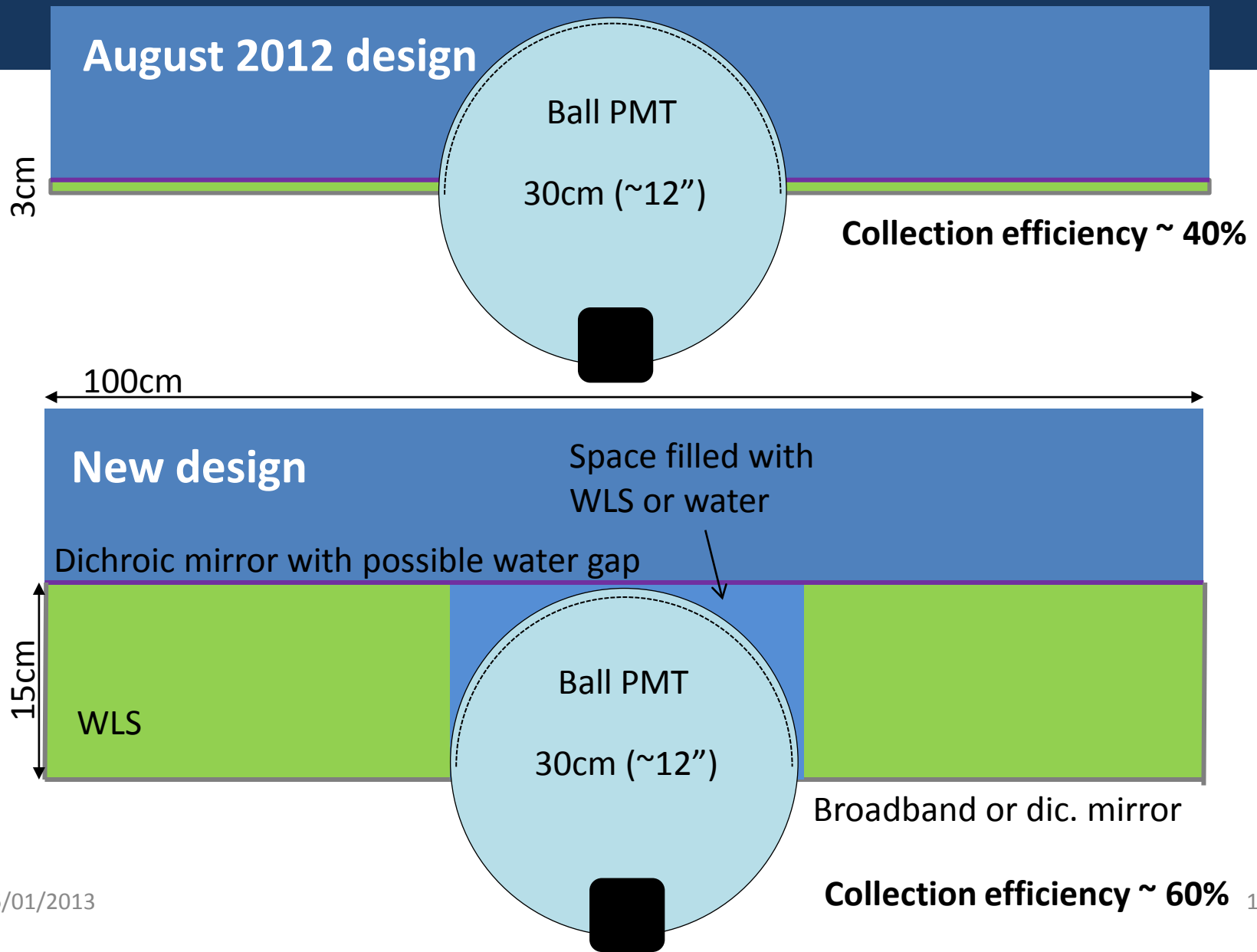
“Mexican” hat options wrt baseline design

Configuration	Direct photon hitting PMT	WLS geom. eff.	WLS det. eff.	WLS photon hitting PMT
20” PMT (baseline Hyper-K design)	1	0	N/A	0%
20” PMT, 100x100x3cm^3 WLS, mirror	1	75%	50%	0.56
20” PMT, 100x100x1cm^3 WLS, mirror	1	75%	33%	0.37
20” PMT, 100x100x3cm^3 WLS, no dichroic mirror	1	75%	43%	0.48
20” PMT, 100x100x1cm^3 WLS, no dichroic mirror	1	75%	35%	0.39
12” PMT, 100x100x3cm^3 WLS, mirror	0.35	90%	35%	0.47

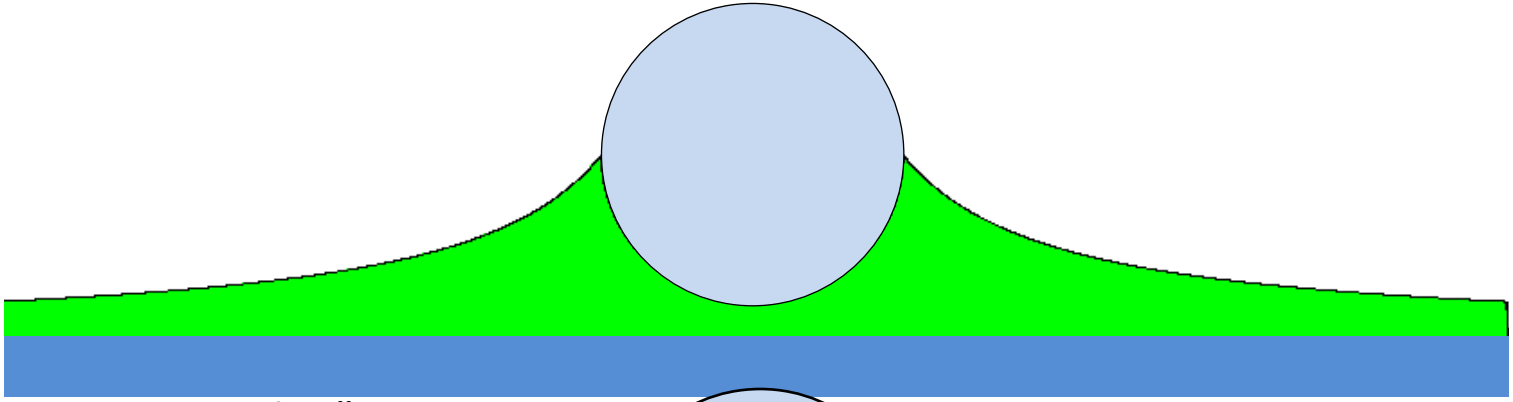
Assume WLS absorption-reemission efficiency = 30% for BC482A
Could be a factor of 2 larger combining UV-blue and blue-green WLS

Dichroic mirror does not help for thin sheet due to large number of bounces

Minimizing the number of bounces

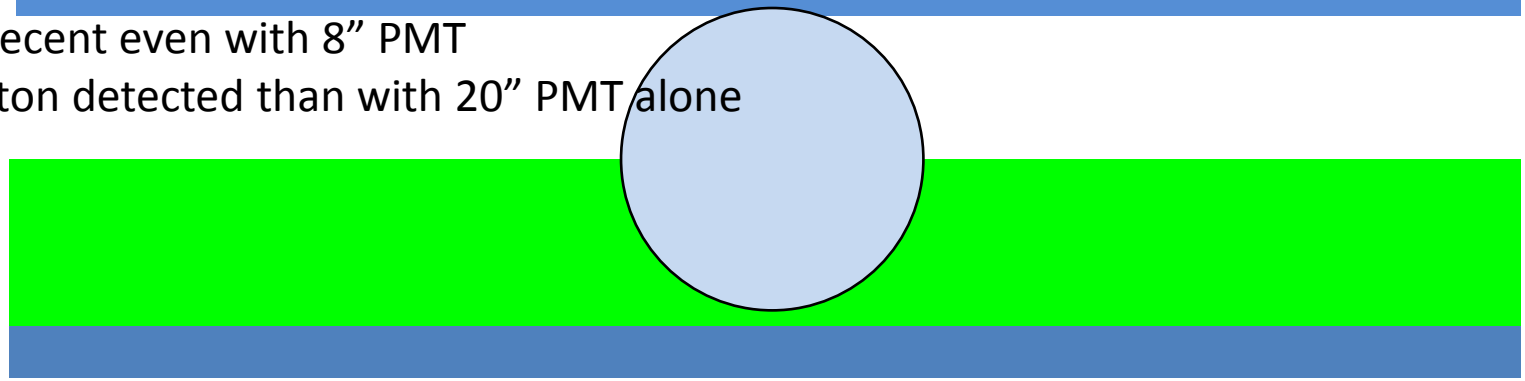


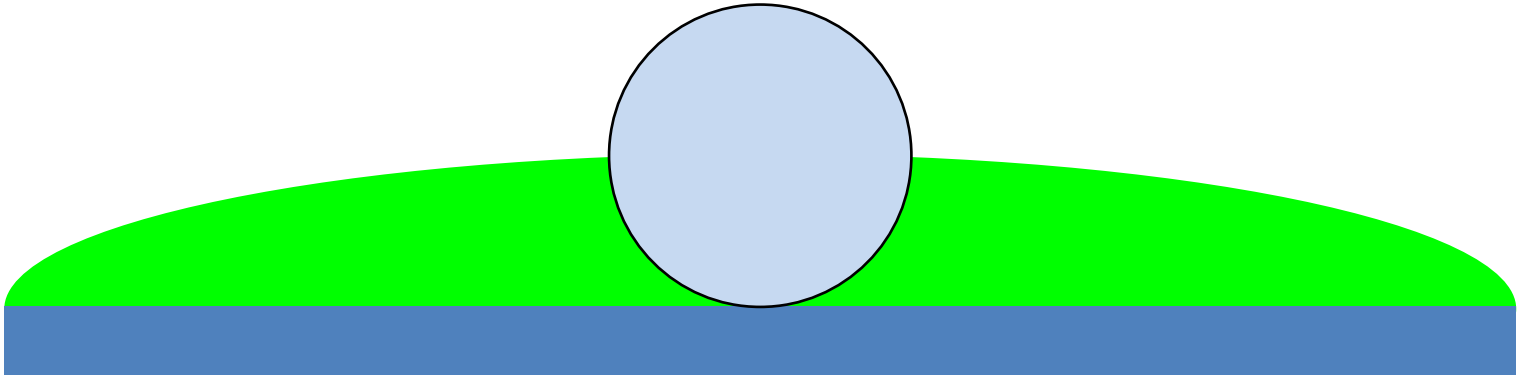
Many solution investigated
Box seems to be best



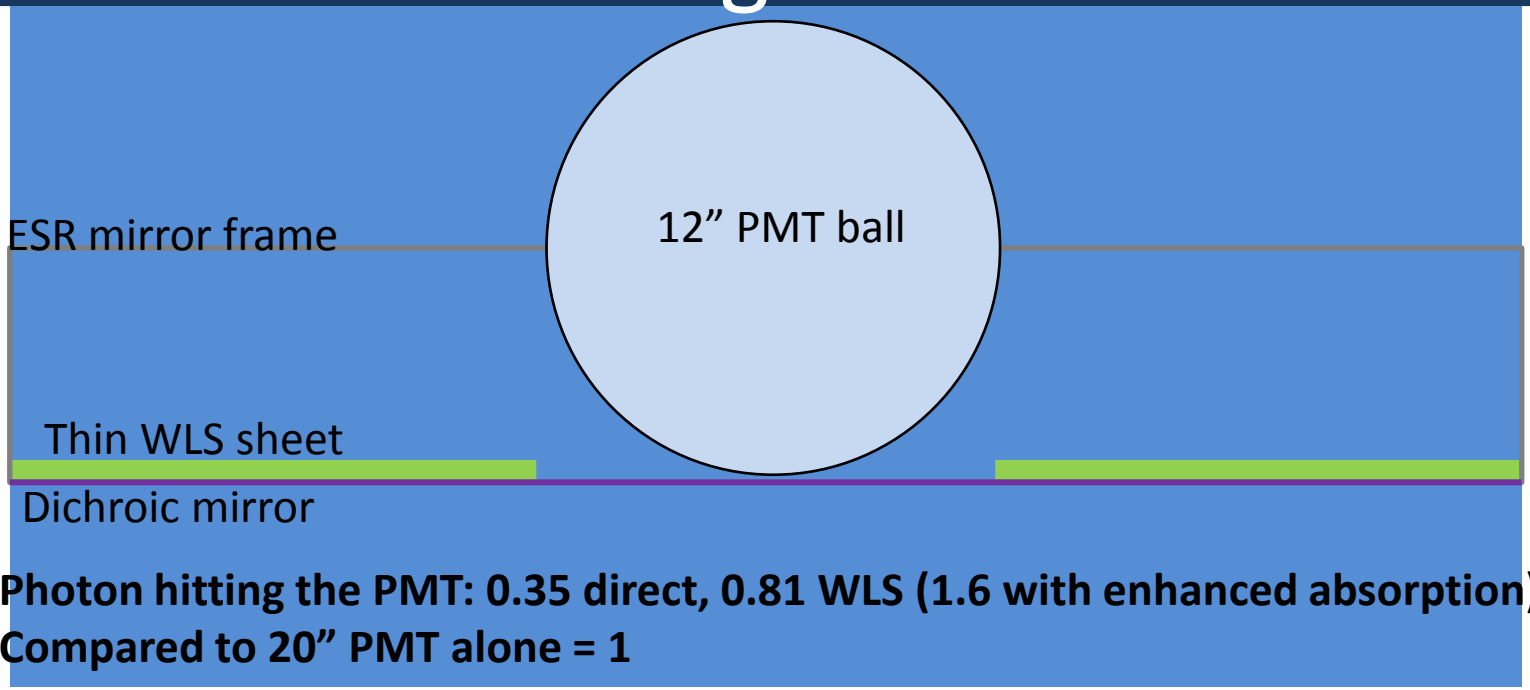
Solution decent even with 8” PMT

More photon detected than with 20” PMT alone





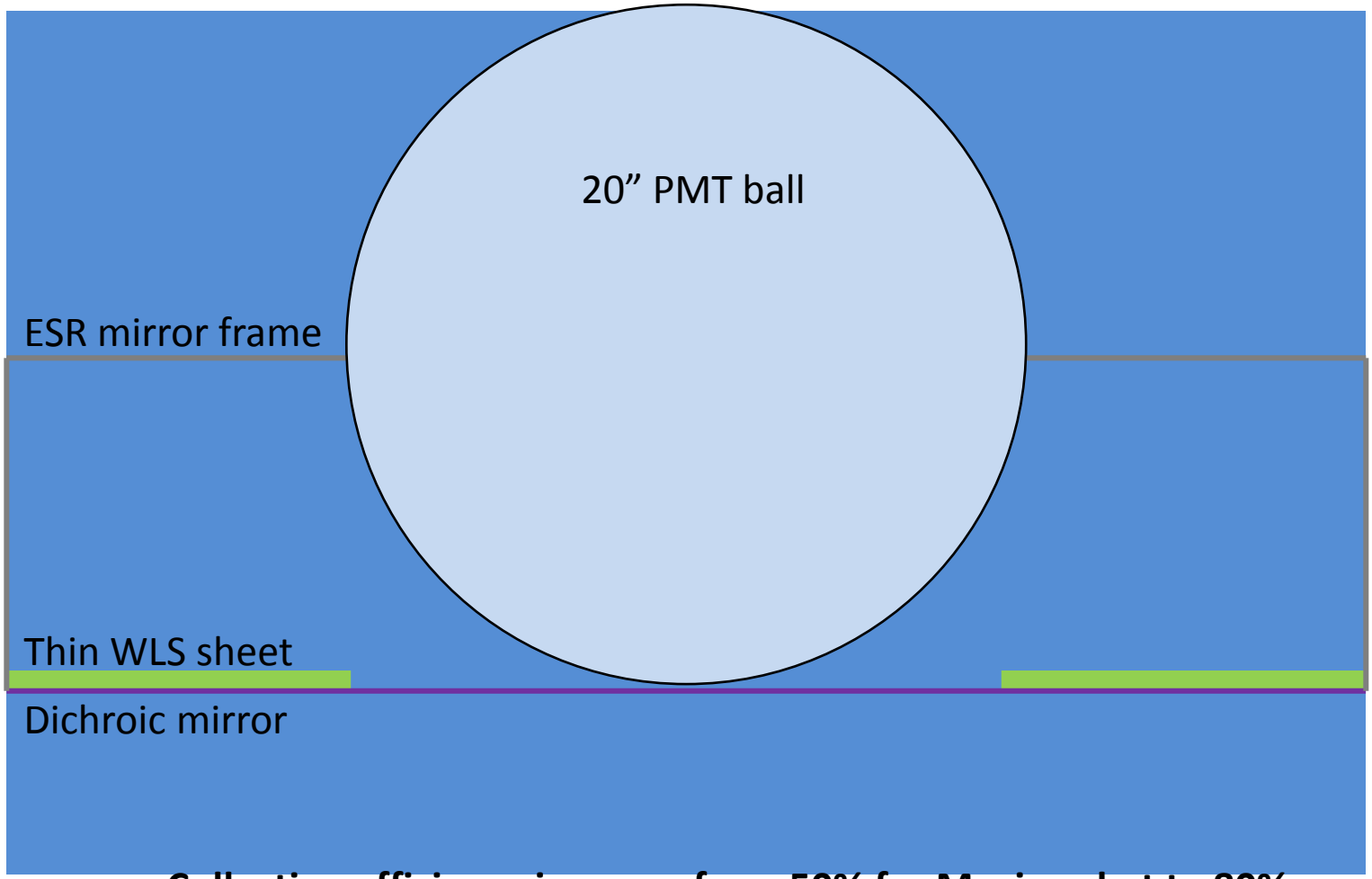
My best guess for the optimum configuration



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)

Brief summary of simulations

PMT type	Direct photon	Blue to green WLS photons	Blue-UV to green WLS photons
20” Ball PMT	1	0.9	1.8
12” Ball PMT	0.35	0.8	1.6
8” Ball PMT	0.17	0.75	1.5

- Ball (extended photo-cathode) necessary
- Box shape mostly filled up with water is best
  - Not 100% clear why yet
- Developing enhanced blue-UV to green WLS is compelling

Next steps 1: more simulations

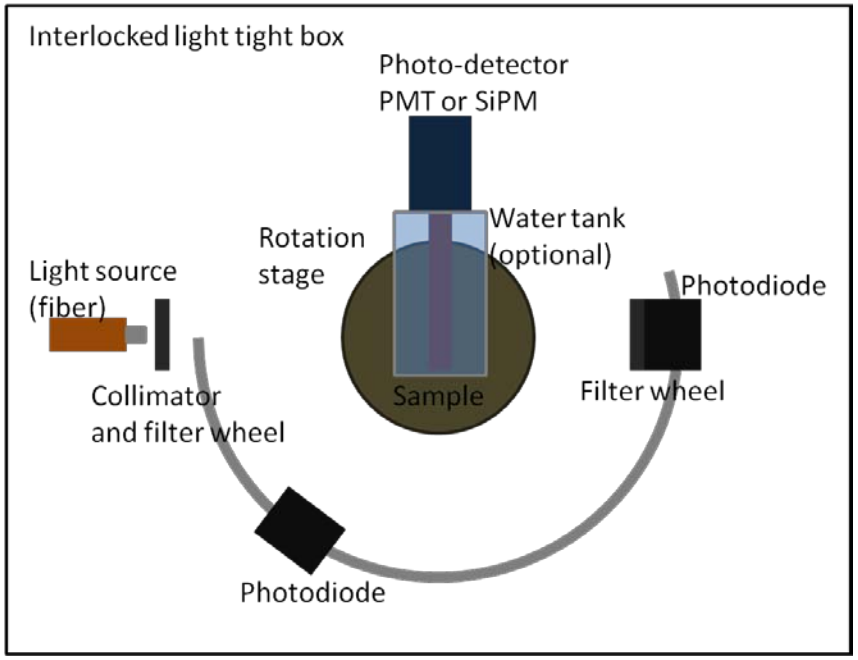
- Detector specific
  - Add angular dependence of reflectivity
  - Determine “optimum” solution
    - Fully understand result
  - Investigate PMT to WLS coupling
    - Having to use optical grease would be very inconvenient
- Within Hyper-K
  - Which solution really works best?
  - Trade of between number of photon detected and timing resolution
  - Granularity gets worse?

Next step 2: identify material and construction solution

- Refurbish spectro-photometer
  - Measure material optical property vs wavelength and angle
  - Money requested for refurbishment
    - If grant awarded money will be available in April
- Dichroic mirror
  - Acquire prototype
  - Investigate mass scale production
- Wavelength shifter
  - Combine UV to blue and blue to green?
  - Plastic with same index of refraction as water?
    - No total internal reflection but easy coupling to PMT
- PMT: Half ball PMT is certainly better

Next step 3: build a prototype

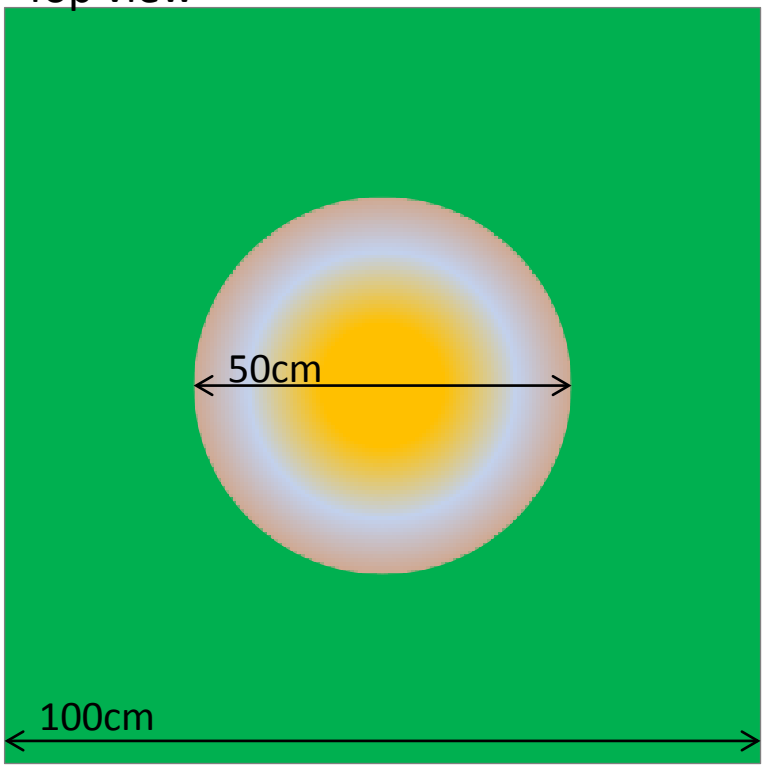
- Small scale to test light collection



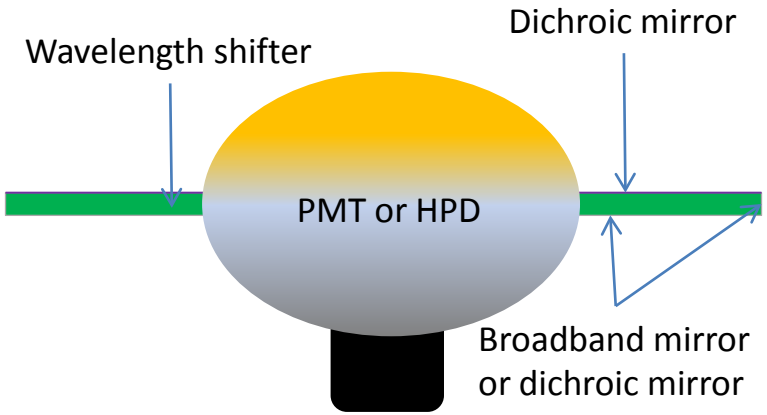
- Full scale prototype
  - Straightforward to machine a slab of WLS and couple it to a PMT
  - Can we get large enough mirror?
  - How to test it?
  - ... This may not happen until next year

Thank you

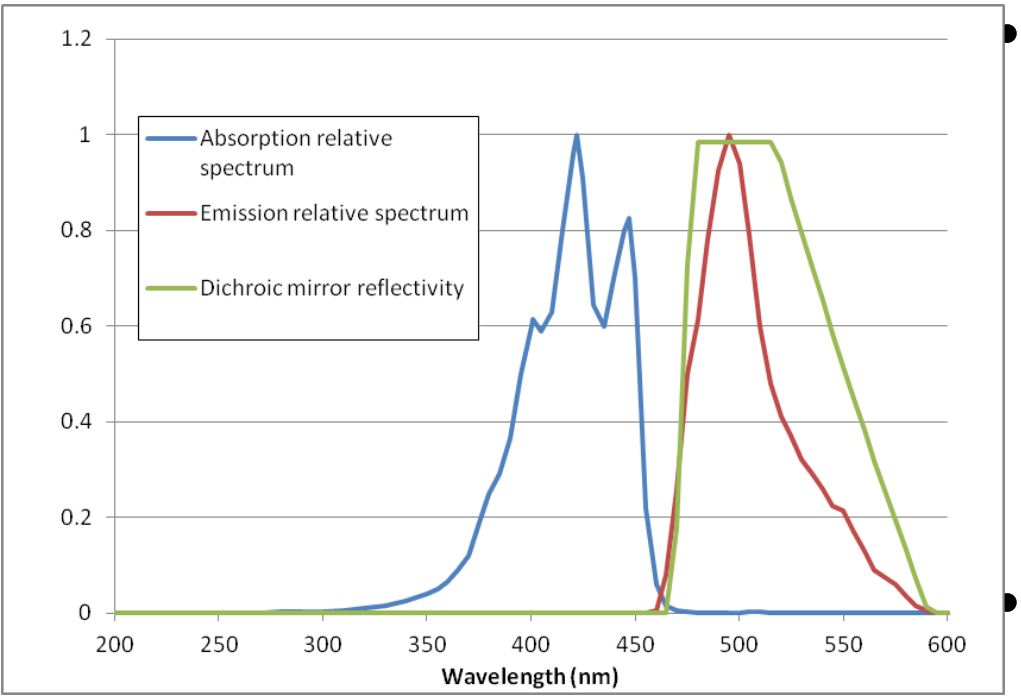
Top view



Side view



Simulated performances Assumptions



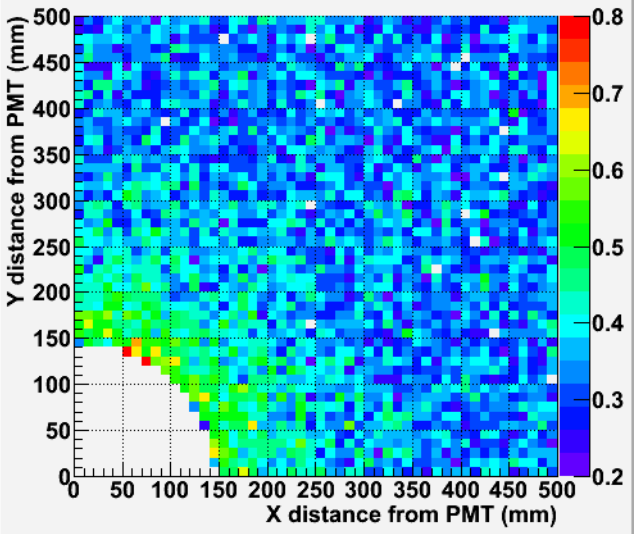
- Wavelength shifter BC482A blue to green shifter
  - Misses a lot of UV light
  - Perfect polish
    - Important for Total Internal Reflection
- Simple dichroic filter simulations
  - Still some issues in GEANT
  - No angular dependence
  - Reflectivity = 98.5%

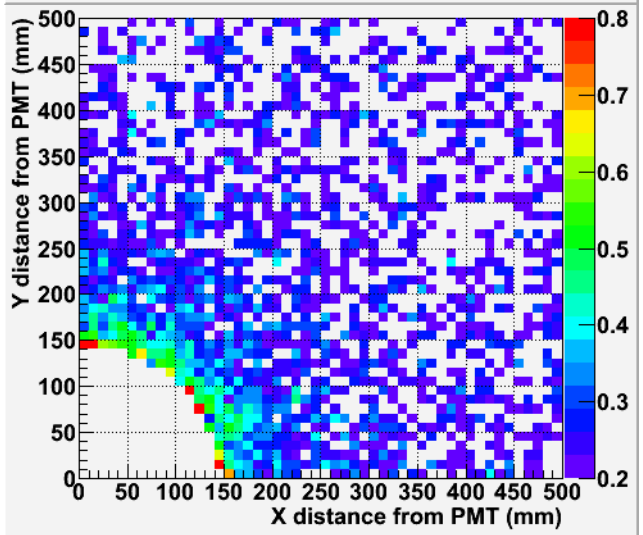
Simulated performances: 2) light collection with 20” PMT

Thickness = 3 cm

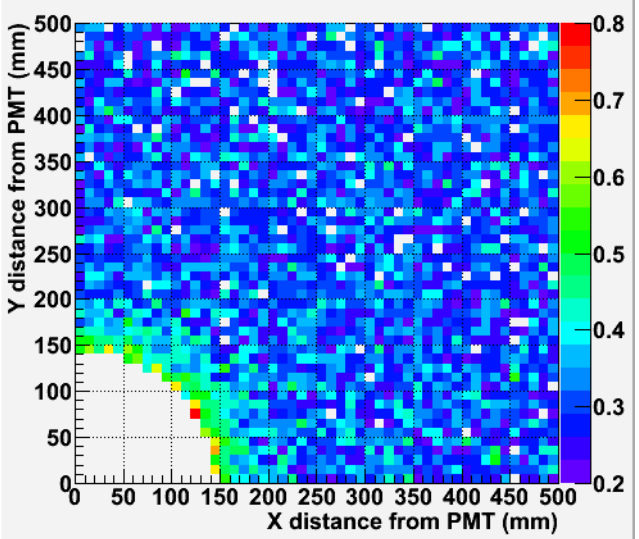
Thickness = 1 cm

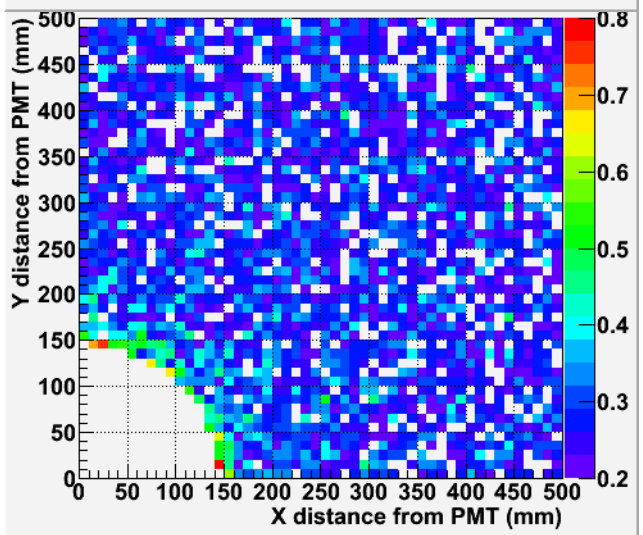
Dichroic mirror

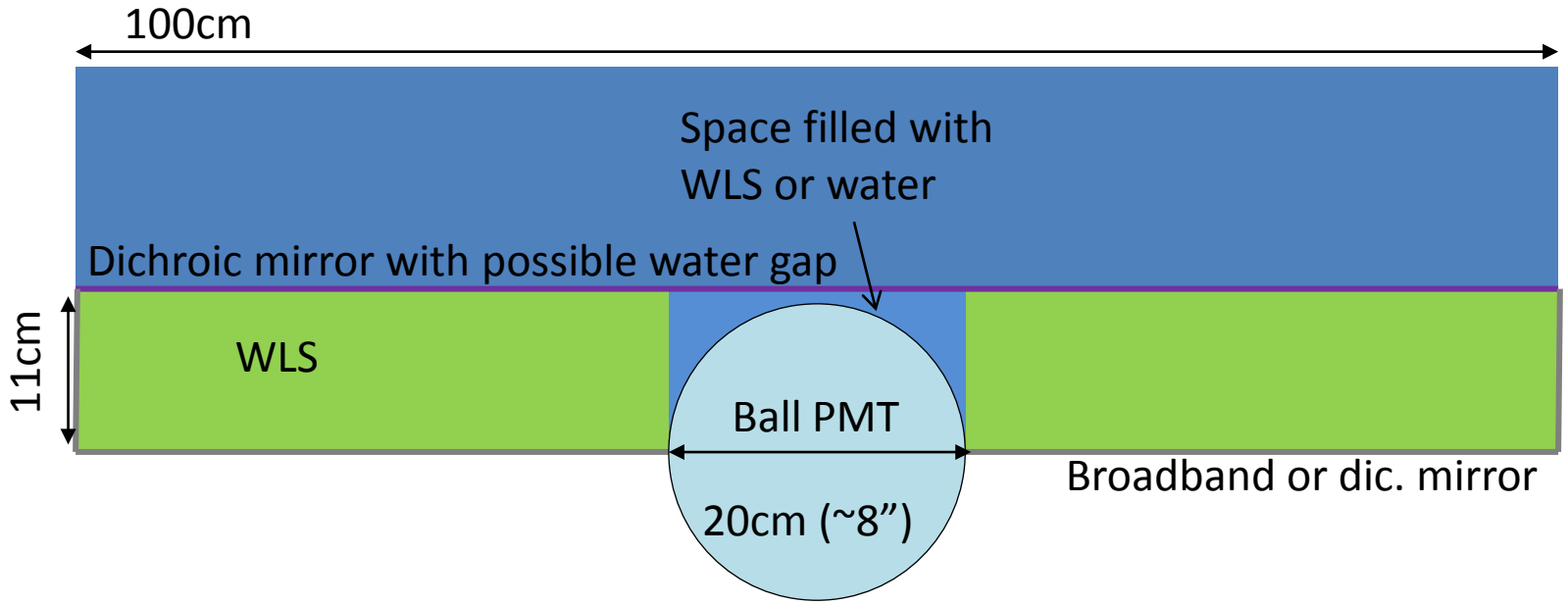




Total internal reflection






100cm
Space filled with
WLS or water
Dichroic mirror with possible water gap
11cm
WLS
Ball PMT
20cm (~8")
Broadband or dic. mirror