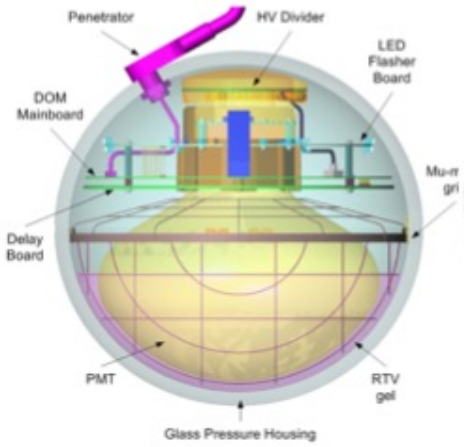
Upgrade/gen2 OM configuration in ppc



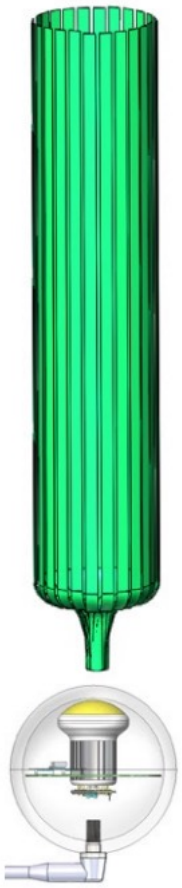












D. Chirkin, UW-Madison

Configuration files: om.conf

```
# name  module  area    beta    Rr      Rz      num     dir     cable
Default -1      1       0.49    0.1651  0.1651  1       180 0   90
Default 20      1       0.49    0.1651  0.1651  1       180 0   90
mDOM    40      1       0.95    0.178   0.2055  24      33 0    45
                                                        33 90
                                                        33 180
                                                        33 270
                                                        72 22.5
                                                        72 67.5
                                                        72 112.5
                                                        72 157.5
                                                        72 202.5
                                                        72 247.5
                                                        72 292.5
                                                        72 337.5
                                                        108 22.5
                                                        108 67.5
                                                        108 112.5
                                                        108 157.5
                                                        108 202.5
                                                        108 247.5
                                                        108 292.5
                                                        108 337.5
                                                        147 0
                                                        147 90
                                                        147 180
                                                        147 270
PDOM    110     1       0.49    0.1651  0.1651  1       180 0   90
DEgg    120     1       0.5     0.150   0.267   2       180 0
                                                        0 0
WOM     140     1       -2      0.057   -0.650  2       180 0
                                                        0 0
FOM     150     1       -2      0.1524  -0.6096 2       180 0
                                                        0 0
LOM-16  170     1       1       0.156   0.222   16      35 0
                                                        35 90
                                                        35 180
                                                        35 270
                                                        57 -45
                                                        57 45
                                                        57 135
                                                        57 225
                                                        123 720
                                                        123 810
                                                        123 900
                                                        123 990
                                                        145 -45
                                                        145 45
                                                        145 135
                                                        145 225
```

Nominal/high-QE IceCube DOM (legacy/new tables)

wv.dat

```
0.00000000 265.
0.00008594 275.
0.00016545 285.
0.00023922 295.
0.00026260 305.
0.00159125 315.
0.00674635 325.
0.02148403 335.
0.05086936 345.
0.09798414 355.
0.15199135 365.
0.21392158 375.
0.27810481 385.
0.34290594 395.
0.40740505 405.
0.47048256 415.
0.53060305 425.
0.58642167 435.
0.63801181 445.
0.68561840 455.
0.72907412 465.
0.76787692 475.
0.80281049 485.
0.83465433 495.
0.86393911 505.
0.89059949 515.
0.91308850 525.
0.93046755 535.
0.94420183 545.
0.95555651 555.
0.96524596 565.
0.97344983 575.
0.98031902 585.
0.98584527 595.
0.99023700 605.
0.99355119 615.
0.99604905 625.
0.99769795 635.
0.99877149 645.
0.99939597 655.
0.99976730 665.
1.00000000 675.
```

Bin edges, cumulative values calculated up to given bin edge

Sampling curve normalized to 1, normalization factor is 2450.08 photons/meter

Ratio values (high-QE/nom.) specified at given wavelengths

wv.rde

```
265 1
275 1.93958
285 0.729873
295 1.3418
305 1.44198
315 1.49617
325 1.55564
335 1.53486
345 1.50815
355 1.50349
365 1.48393
375 1.45768
385 1.43024
395 1.39155
405 1.35661
415 1.31859
425 1.30156
435 1.2887
445 1.29715
455 1.30476
465 1.29582
475 1.27535
485 1.25751
495 1.23881
505 1.20744
515 1.20201
525 1.2399
535 1.27412
545 1.22985
555 1.15301
565 1.06739
575 1.01229
585 0.982817
595 0.955795
605 0.916208
615 0.890728
625 0.744745
635 0.547548
645 0.641742
655 0.673114
665 0.729799
675 0.725893
```

```
vec/cre d7(43) R 6.4522e-06 6.4522e-06 6.4522e-06 6.4522e-06 2.198e-06 0.000133904 0.000555681 0.0016953 0.0035997 0.00613409 0.00745927\
 0.00905798 0.00992467 0.0105769 0.0110961 0.0114214 0.0114425 0.0111527 0.0108086 0.0104458 0.00997631 0.00931025 0.00875166 0.00832258\
 0.00797672 0.00756251 0.0066377 0.00533358 0.00437894 0.00375835 0.00332798 0.00292125 0.00253349 0.00211154 0.00173633 0.00135527 0.00\
105466 0.000720102 0.000484382 0.000291111 0.000178231 0.00011443 5.09155e-05

vec/inp d7(1) 0

vec/cre l(43) R 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410 420 430 440 450 460 470 480 490 500 510 520 530 540 550 \
560 570 580 590 600 610 620 630 640 650 660 670 680

R=0.178
R=0.16510
*R=0.110
pi=3.141592654
A=[pi]*[R]*[R]
MESS DOM area [A]
sigma d=d7/[A]

vec/wri l,d7 r.wv_20 'f4.0,f13.10'
sh cat r.wv_20

c=2*[pi]*1.e9/137.03599911
MESS [c]

sigma w=l/1000
sigma n=1.55749-1.57988*w+3.99993*w**2-4.68271*w**3+2.09354*w**4

sigma ch=[c]*(1-1/n**2)/l**2
sigma ph=d*ch

vec/inp ph(1) 0
vec/inp ph(43) 0

vec/cre x(42) R
vec/cre y(42) R
sx=0
sy=255

do i=1,42
sx=[sx]+10*ph([i])
sy=[sy]+10
vec/inp x([i]) [sx]
vec/inp y([i]) [sy]
enddo

MESS SUM=[sx]

sigma x=x/[sx]
vec/pl y%x
vec/pl y%x ! sl
ticks Y
vec/wri x,y wv.dat 'f10.8,f5.0'
```

```
awk '{a[$1]=$2}
function intr(x,x1,x2,y1,y2){return (y2*(x-x1)+y1*(x2-x))/(x2-x1)}
END {
  for(i=260; i<=680; i+=10){
    if(i==260){x1=i+5; x2=i+15}
    else if(i==680){x1=i-5; x2=i-15}
    else{x1=i-5; x2=i+5}
    print i, intr(i,x1,x2,a[x1],a[x2])
  }
}' wv.rde > wv.rde-shifted

./oms.sh as.nominal | awk '{a=$1*1.e4} END {while(getline<"r.wv_20") print $1, a*$2}' > om.wv_20.0

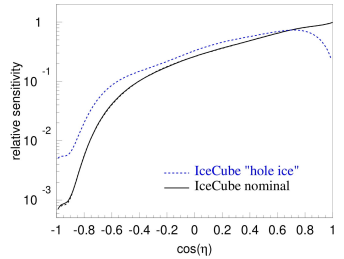
awk 'BEGIN {while(getline<"wv.rde-shifted") a[$1]=$2}
{ print $1, $2*a[$1+0] }'_om.wv_20.0 > om.wv_20.1
```

Effective area curve from photonics's efficiency.h file. Includes QE, glass/gel (head-on illumination)

Scaled for DOM size

New file format

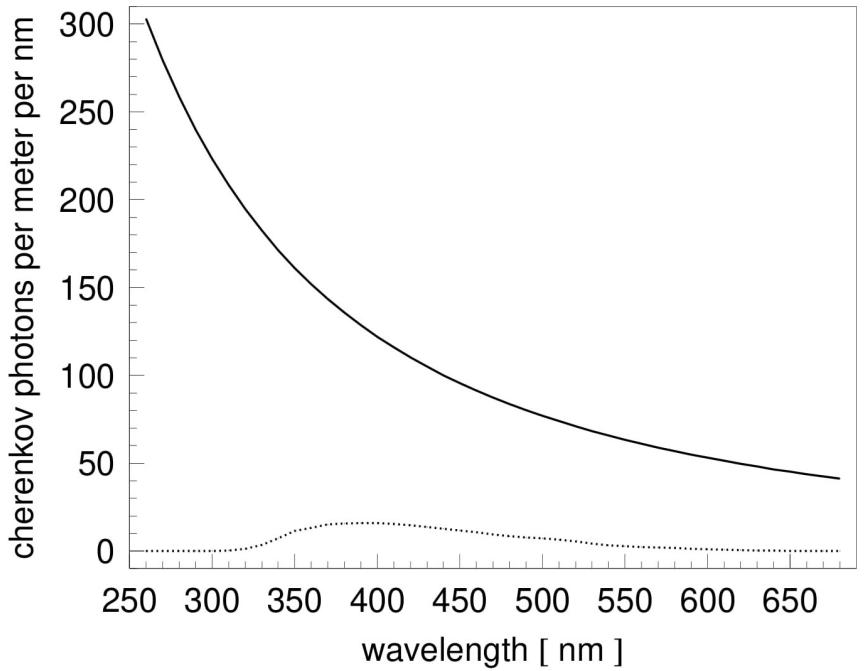
Cherenkov spectrum

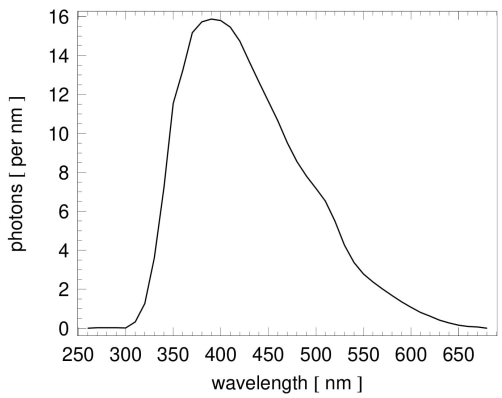


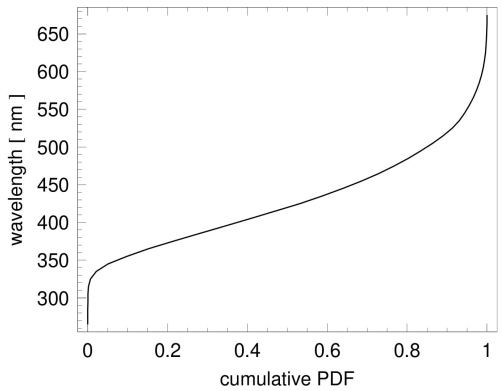
Multiplied by average of lab/nominal angular sensitivity of 0.335822

New file format

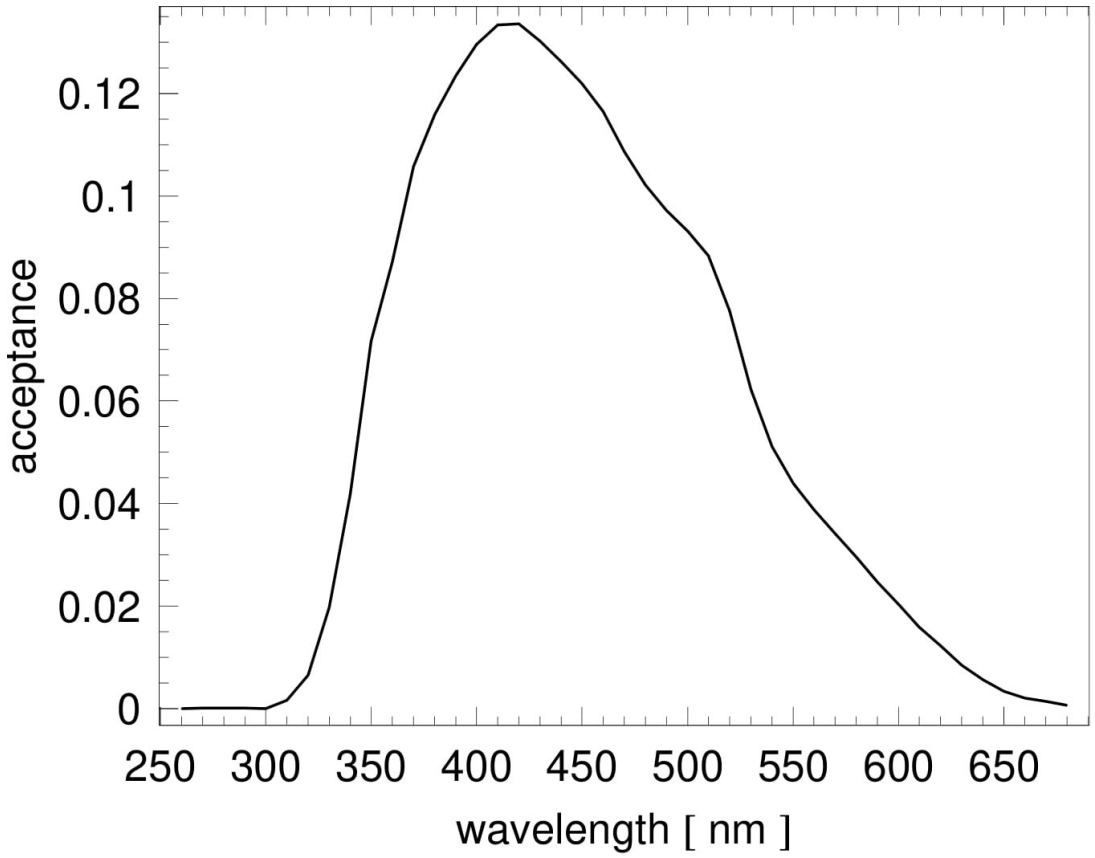
Old (legacy) file format







Calculated for a spherical DOM with radius 16.51 cm



This fraction of photons crossing the DOM sphere result in PMT pulses (incl. sub-threshold pulses)

Degg

```
DEgg_QE_2020 = np.array([
    0.0000000000,
    0.0000000000,
    0.0014173291,
    0.0027492361,
    0.0168123472,
    0.0703623327,
    0.1576423318,
    0.2472103992,
    0.3087822354,
    0.3452194334,
    0.3623264026,
    0.3681137180,
    0.3682212792,
    0.3668332904,
    0.3637927376,
    0.3567732628,
    0.3477607381,
    0.3370898403,
    0.3253668455,
    0.3119149659,
    0.2955751105,
    0.2759533538,
    0.2568625270,
    0.2409934127,
    0.2277159270,
    0.2144429538,
    0.1933444223,
    0.1591530771,
    0.1262102495,
    0.1045703413,
    0.0895099801,
    0.0778350600,
    0.0672140113,
    0.0570386038,
    0.0471045961,
    0.0378461567,
    0.0295626275,
    0.0217850574,
    0.0157359436,
    0.0104950196,
    0.0069289982,
    0.0040945808,
    0.0020563920,
    0.0000000000,
    0.0000000000])
```

```
glass_acceptance = np.array([
    0.0000000000,
    0.0055691893,
    0.0059021983,
    0.0198940069,
    0.1058271349,
    0.2994911597,
    0.5403497641,
    0.7370245908,
    0.8618323115,
    0.9252335190,
    0.9545107825,
    0.9782781674,
    0.9861681087,
    0.9952247053,
    0.9996944675,
    0.9985962389,
    0.9976549104,
    0.9989423498,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000])
```

```
gel_acceptance = np.array([
    0.0000000000,
    0.0000000000,
    0.1101148293,
    0.5230861391,
    0.8610631192,
    0.9587070313,
    0.9763844288,
    0.9864872375,
    0.9920127145,
    0.9965008031,
    0.9980510798,
    0.9988183092,
    0.9998541581,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000,
    1.0000000000])
```

```
https://github.com/icecube/icetray/blob/gen2-optical-sim/mDOM-WOM-simulation/python/traysegments/degg.py#L72
    domEfficiency = I3CLSimFunctionFromTable(250*I3Units.nanometer, 10*I3Units.nanometer, acceptanceCurve)
    angularAcceptance = GetIceCubeDOMAngularSensitivity(holeIce=expandvars("$I3_SRC/ice-models/resources/models/angsens/as.nominal"))

DEgg PMT
awk 'BEGIN {R=13.1; r=19.0/2; pi=3.141592654; beta=sqrt(1-(r/R)^2); print beta, 4*pi*R^2*(1-beta)/2, pi*R^2*((1-beta)/2)}'
beta=0.688548 curved_area=335.826 average_area=83.9564

pDOM PMT:
awk 'BEGIN {R=13.67; r=22.0/2; pi=3.141592654; beta=sqrt(1-(r/R)^2); print beta, 4*pi*R^2*(1-beta)/2, pi*R^2*((1-beta)/2)}'
beta=0.593706 curved_area=477.042 average_area=119.261

we use: 3.141592654*(22.0/2)^2*0.335822=127.657 (perhaps due to more sensitive area beyond the first radius of 22.0)
```

```
awk 'BEGIN {
n=0; while(getline<"new-qe") a1[n++]=$1
n=0; while(getline<"new-glass") a2[n++]=$1
n=0; while(getline<"new-gel") a3[n++]=$1

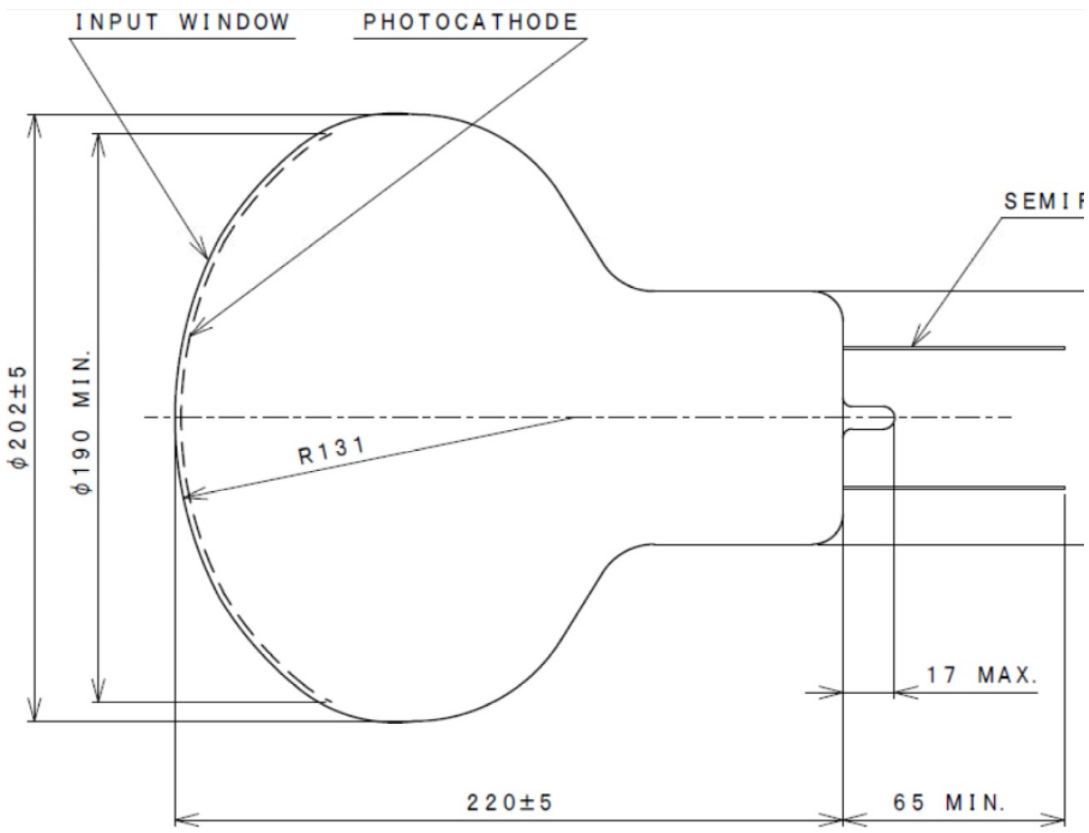
for(i=0; i<n; i++) print 250+10*i, a1[i]*a2[i]*a3[i] > "new"
}'


# 1 PMT average_area=83.9564
awk '{print $1, $2*2*83.9564}' new > om.wv_120.0
```

New file format

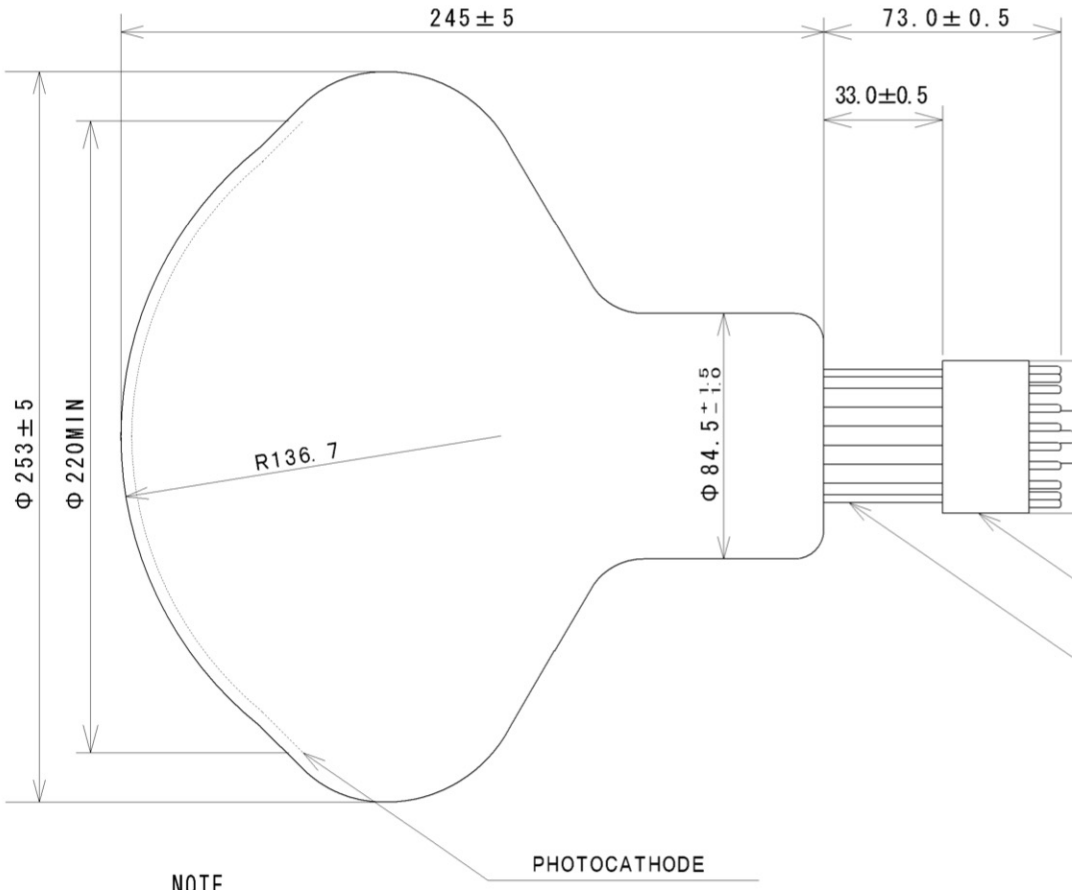
Tables from https://github.com/icecube/icetray/blob/gen2-optical-sim/mDOM-WOM-simulation/python/traysegments/degg.py

DEgg PMT



β=0.69 A(head-on)=284 cm^2 A(curved)=336 cm^2

DOM PMT



β=0.59 A(head-on)=380 cm^2 A(curved)=477 cm^2

mDOM

```
# Acceptance for a 3"PMT inside a mDOM as implemented in IceTray
# Basically the product of QE, survival prob of glass and gel for wavelengths
# 2016
# wavelength [nm]    acceptance
2.5000000000000000e+02 0.0000000000000000e+00
2.5200000000000000e+02 0.0000000000000000e+00
2.5400000000000000e+02 0.0000000000000000e+00
2.5600000000000000e+02 0.0000000000000000e+00
2.5800000000000000e+02 0.0000000000000000e+00
2.60
2.62
2.64
2.66
2.68
2.70
2.72
2.74
2.76
2.78
2.80
2.82
2.84
2.86
2.88
2.90
2.92
2.94
2.96
2.98
3.00
3.02
3.04
3.06
3.08
3.100000000000000000e+02 3.69909163596479975e-03
3.120000000000000000e+02 7.79213793928864755e-03
3.140000000000000000e+02 1.31993484875094942e-02
3.160000000000000000e+02 1.95549390310597523e-02
3.180000000000000000e+02 2.65430773475804106e-02
3.20000000000000000
3.22000000000000000
3.24000000000000000
3.26000000000000000
3.28000000000000000
3.30000000000000000
3.32000000000000000
3.34000000000000000
```

```
# Angular acceptance of a PMT inside the mDOM normed to theta = 0
# Simulated with Geant4 by L.Classen, modified by T.Kittler
# Ice was used as surrounding medium
# Set to 0 for theta >= 90deg in order to be consistent with the flat disk approach in clsim
# Jul 2016
# cos(theta)    normed acceptance
-8.660255074501037598e-01 0.0000000000000000e+00
-8.480
-8.290
-6.975
-3.489
-4.371
3.489937633275985718e-02 1.021921671687712196e-01
6.975650787353515625e-02 1.172029570754011402e-01
```

I couldn't find a diagram with PMT cathode area curvature, so I fitted the part of angular sensitivity curve from Lassen's Geant4 simulation that I figured corresponds to the direct "on PMT" (as opposed to "from reflector") part. The fit found 73% of light comes direct on PMT with beta=0.84.

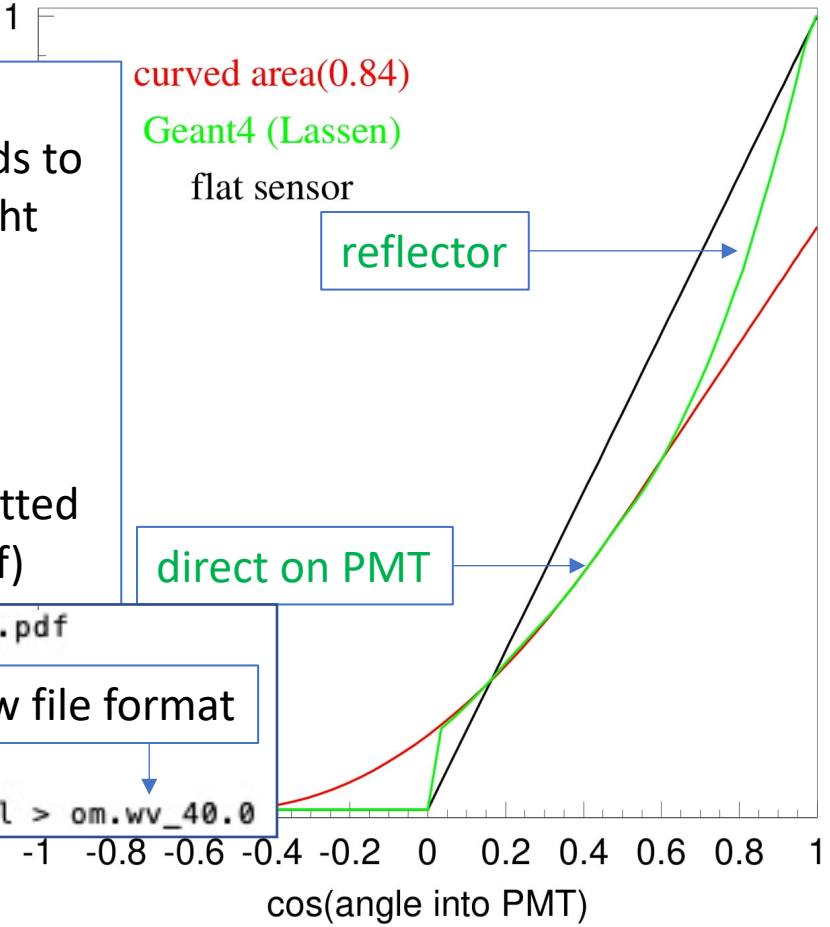
→ Effective solid-angle-averaged area is $\pi*(7.75/2)^2/(2*(1+0.84))$ cm^2.

I don't yet have a parameterization of the reflected part, so the entire curve was fitted with a single-parameter curve with a resulting fitted β=0.95 (to be used in om.conf)

```
# https://www.epj-conferences.org/articles/epjconf/pdf/2019/12/epjconf_vlvnt2018_06004.pdf
# 77-78 mm diameter (3" PMT) R12199-01 --> 7.75 cm
# beta=0.84 (for 73.4% of light - w/o reflector part - see a_all.sh)
# beta=0.95 overall fit to 1-parameter function

awk 'BEGIN {pi=3.141592654; a=24*pi*(7.75/2)^2/(2*(1+0.84))}{print $1+0, a*$2}' a.total > om.wv_40.0
```

New file format



Acceptance table from https://github.com/icecube/icetray/blob/gen2-optical-sim/mDOM-WOM-simulation/resources/mDOM/Acceptance_PMT_in_mDOM_IceTray.txt

And ang. sens. from https://github.com/icecube/icetray/blob/gen2-optical-sim/mDOM-WOM-simulation/resources/mDOM/AngularAcceptancePMT_FlatDisk_mDOM_cosineNotCorrected_Jul16.txt

LOM

At this point we merely use the mDOM acceptance curve.

Radius of glass container is 51 mm, curvature of 65 mm.

$\beta=\mathrm{sqrt}(1-(51/65)^2)=0.62$

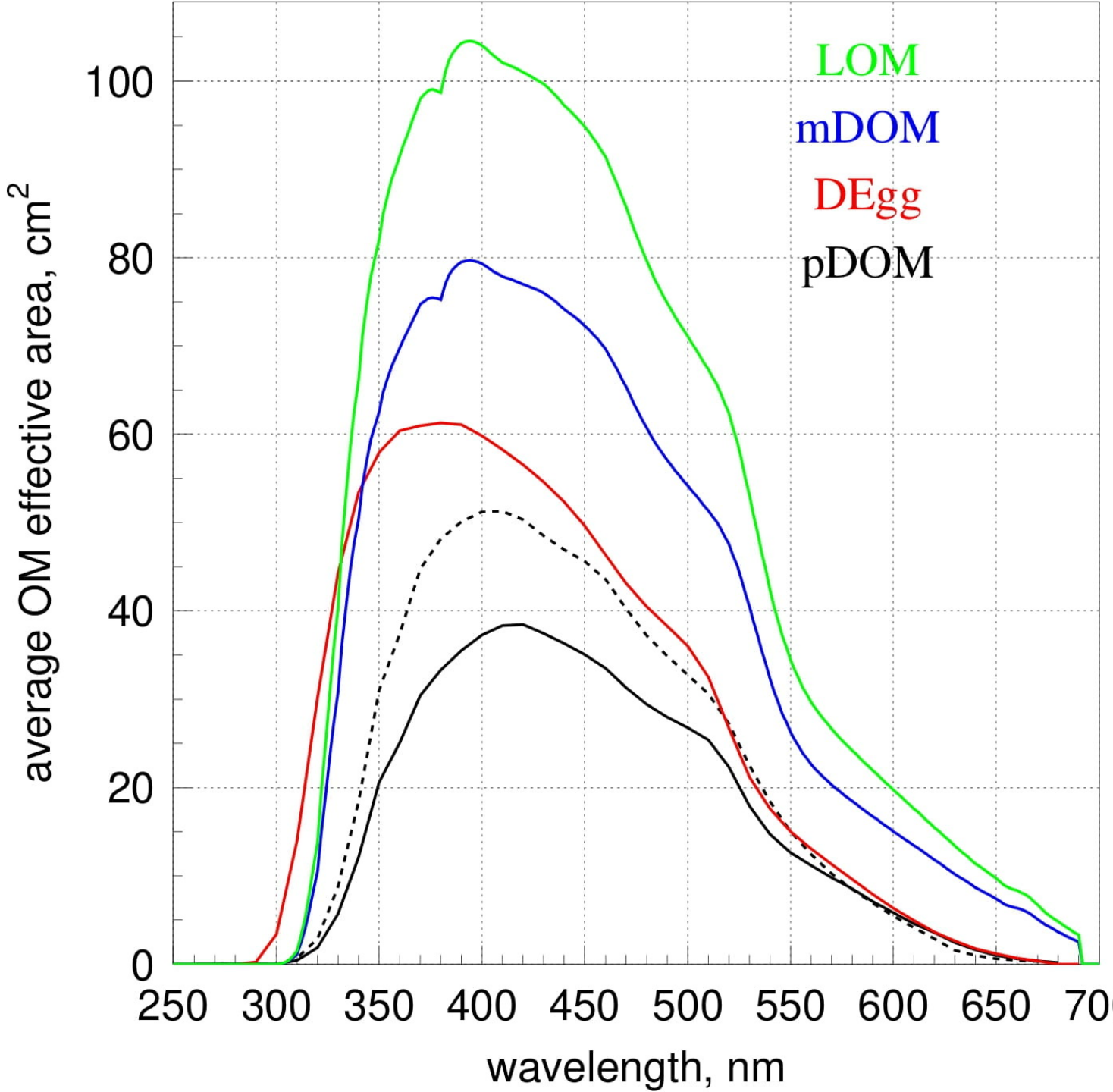
Then effective solid-angle-averaged area for 1 PMT is $\pi*(5.1)^2/(2*(1+0.62))$ $cm^2=25.22$ cm^2.

For LOM-16, this is x16 = 403.524

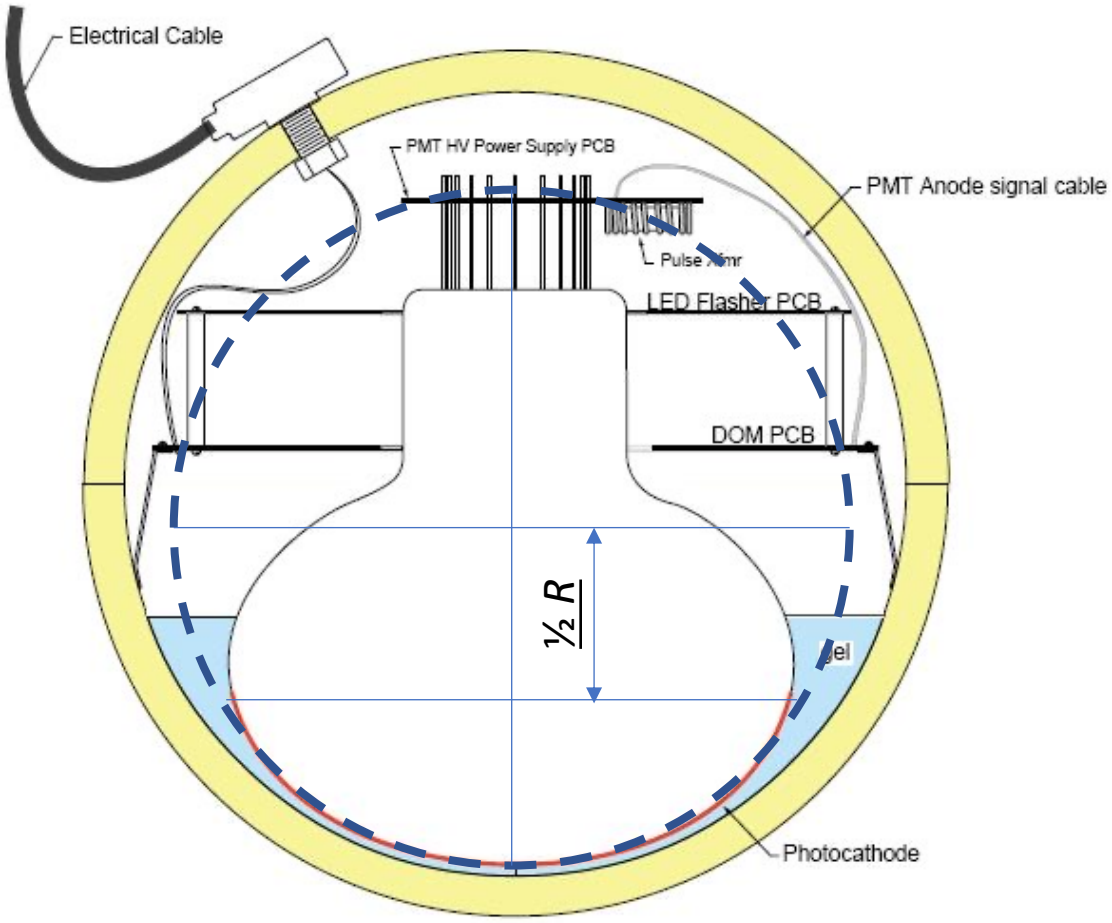
For mDOM we have $24*\pi*(7.75/2)^2/(2*(1+0.84)) = 307.65$ cm^2.

Therefore, solid-angle-averaged area of LOM-16 is that of mDOM times 1.31163

comparison

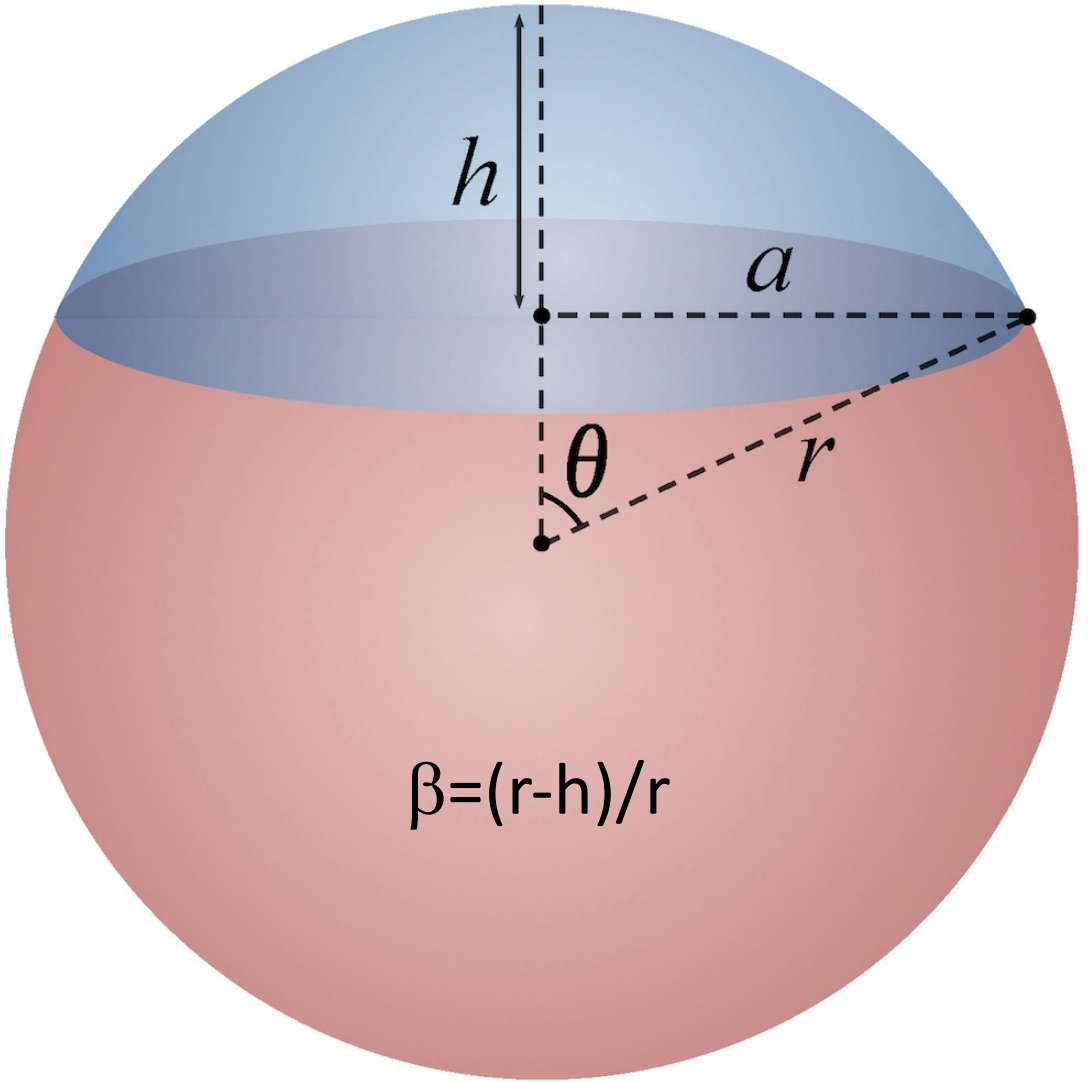

LOM
mDOM
DEgg
pDOM
average OM effective area, cm^2
wavelength, nm
0
20
40
60
80
100
250
300
350
400
450
500
550
600
650
700

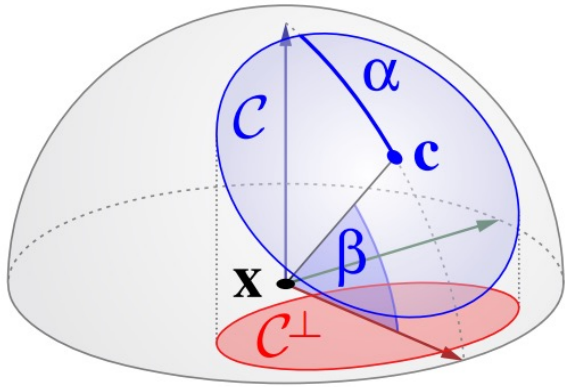
backups

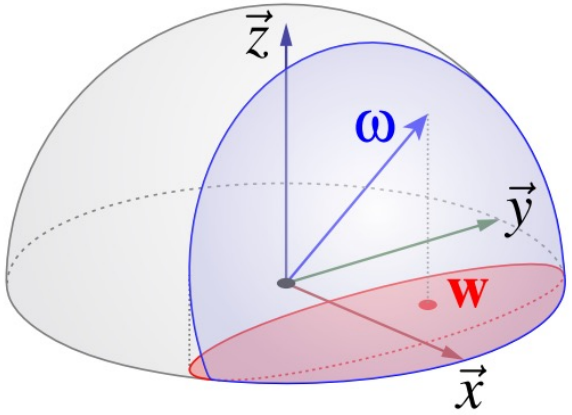


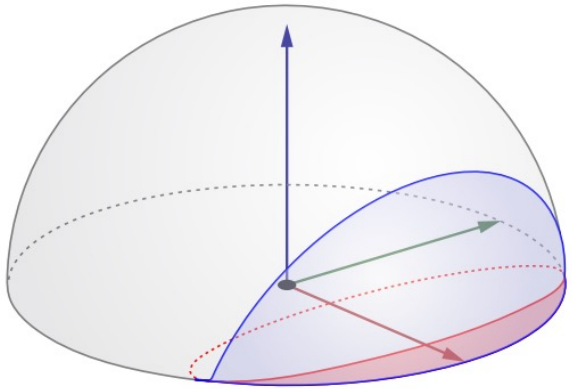
Schematic view of OM with Digital and Optical Analog Capability

Figure 62: Schematic profile view of a generic Digital Optical Module, showing pressure sphere, optical coupling gel, PMT, signal processing electronics board, LED flasher board, PMT base, and electrical penetrator.









$$q = r\cdot\sqrt{1-\beta^2}$$

$$h_1 = \frac{\beta r}{tg\theta} \qquad h_2 = \frac{\beta r}{\sin\theta}$$

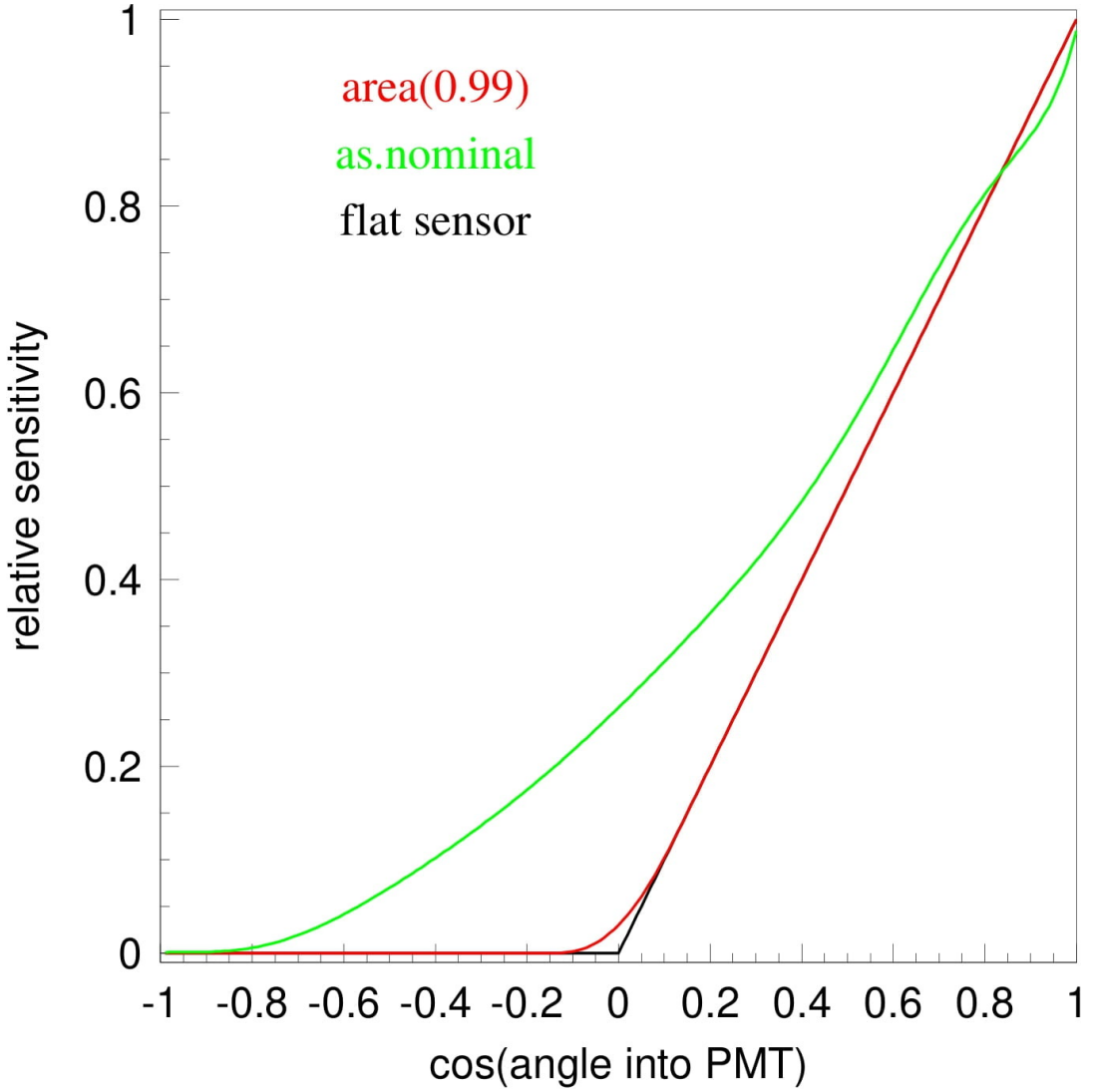
$\cos(\theta) > 0.33$
HD

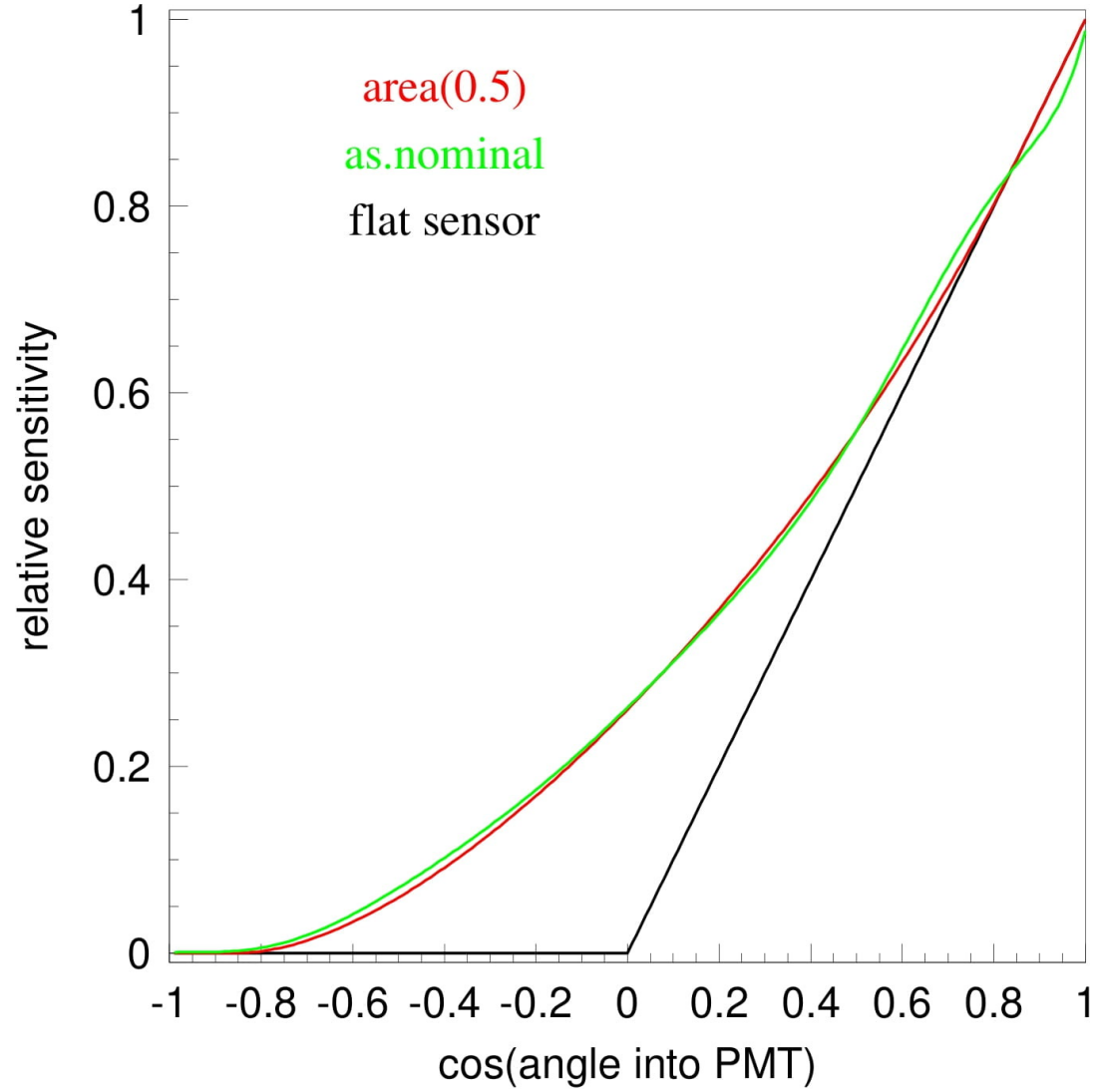
$$a\left(\frac{h}{r}\right) \equiv a = r^2\left(\alpha - \frac{\sin 2\alpha}{2}\right)$$

$$\alpha = \arccos\frac{h}{r}$$

X-area =

$$\pi r^2(1-\beta^2)\cos\theta - a\left(\frac{\beta/tg\theta}{\sqrt{1-\beta^2}}\right)\cos\theta + a\left(\frac{\beta}{\sin\theta}\right)$$


area(0.99)
as.nominal
flat sensor
relative sensitivity
cos(angle into PMT)
1
0.8
0.6
0.4
0.2
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1


area(0.5)
as.nominal
flat sensor
relative sensitivity
cos(angle into PMT)
1
0.8
0.6
0.4
0.2
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1

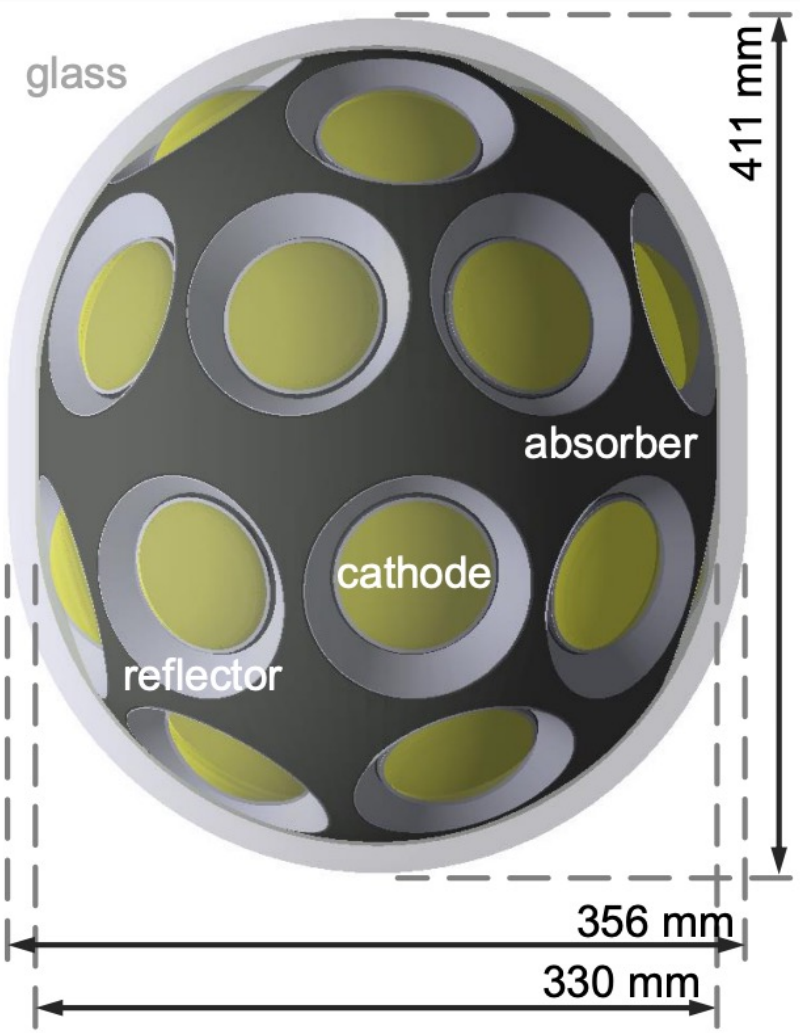
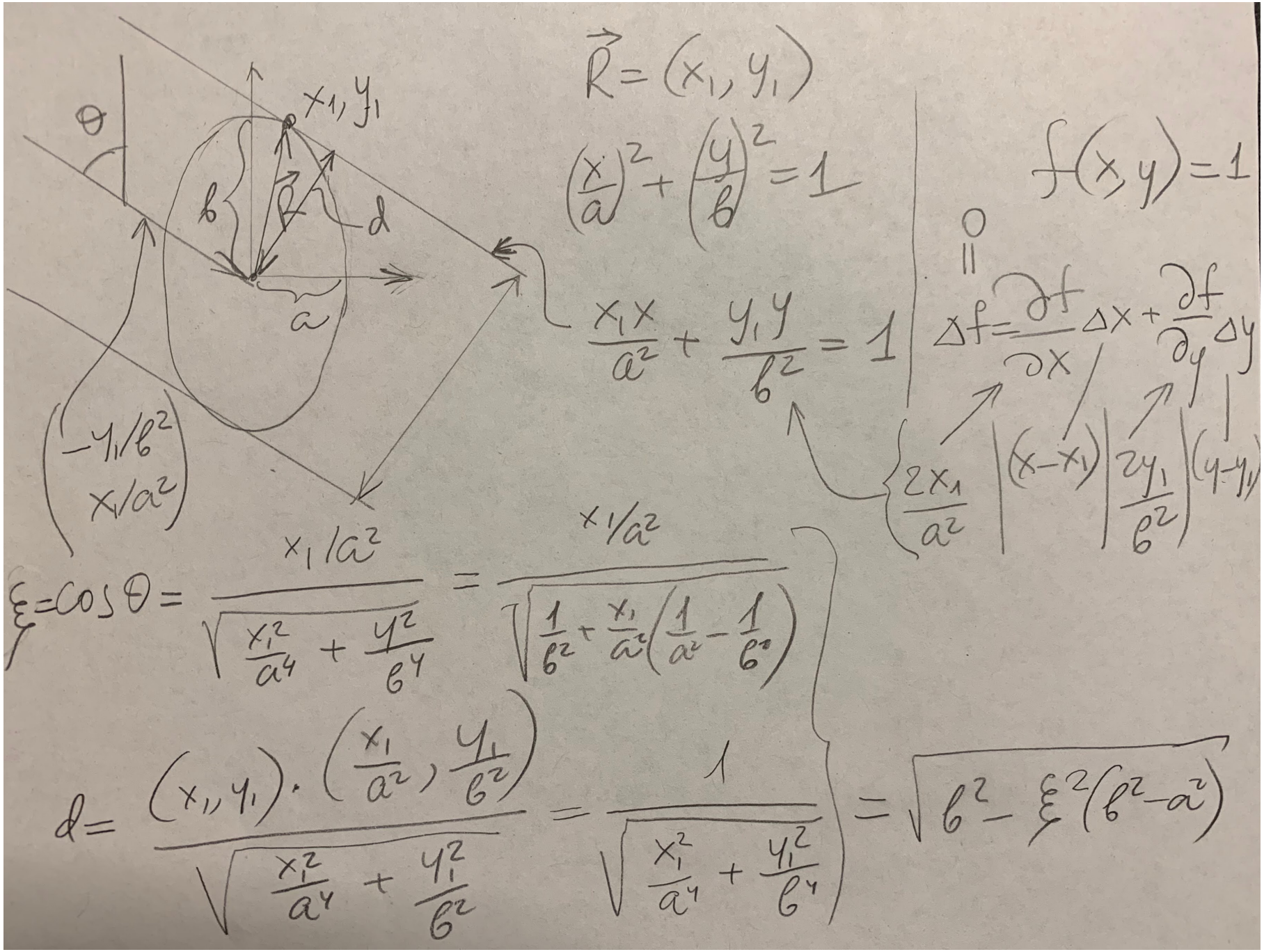




Figure 1: The shape of D-Egg. The height of the glass is 534 mm and the diameter at the equator is 300 mm.

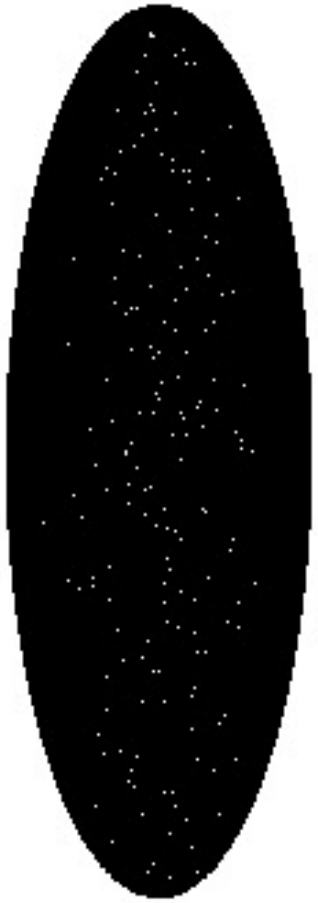


To calculate acceptance chance for a photon that lands on the spheroid sensor we need the sum of all visible cross-sections of PMTs divided by the cross-sectional area of the sensor for that direction.

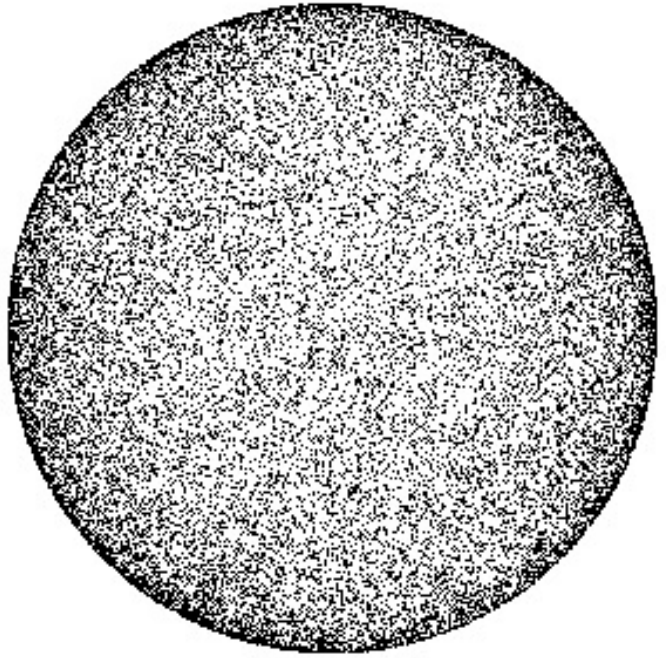
Maximum of ratio of PMT area sum to sensor area determines the “surface efficiency” of the sensor, and the photons are simulated to uniformly cover the area of the sensor. The angular sensitivity is applied thereafter.

The solid-angle averaged and “flat” areas are easily related to each other at initialization. Still, recommend using average effective sensor area as input (to minimize errors due to angular sensitivity interpretation and simulation)

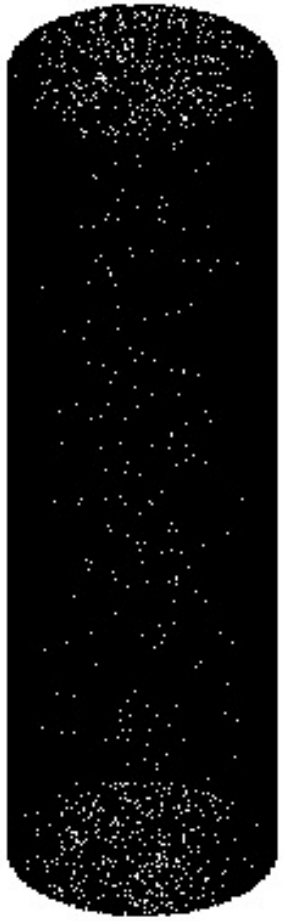
Sensor shapes implemented in ppc



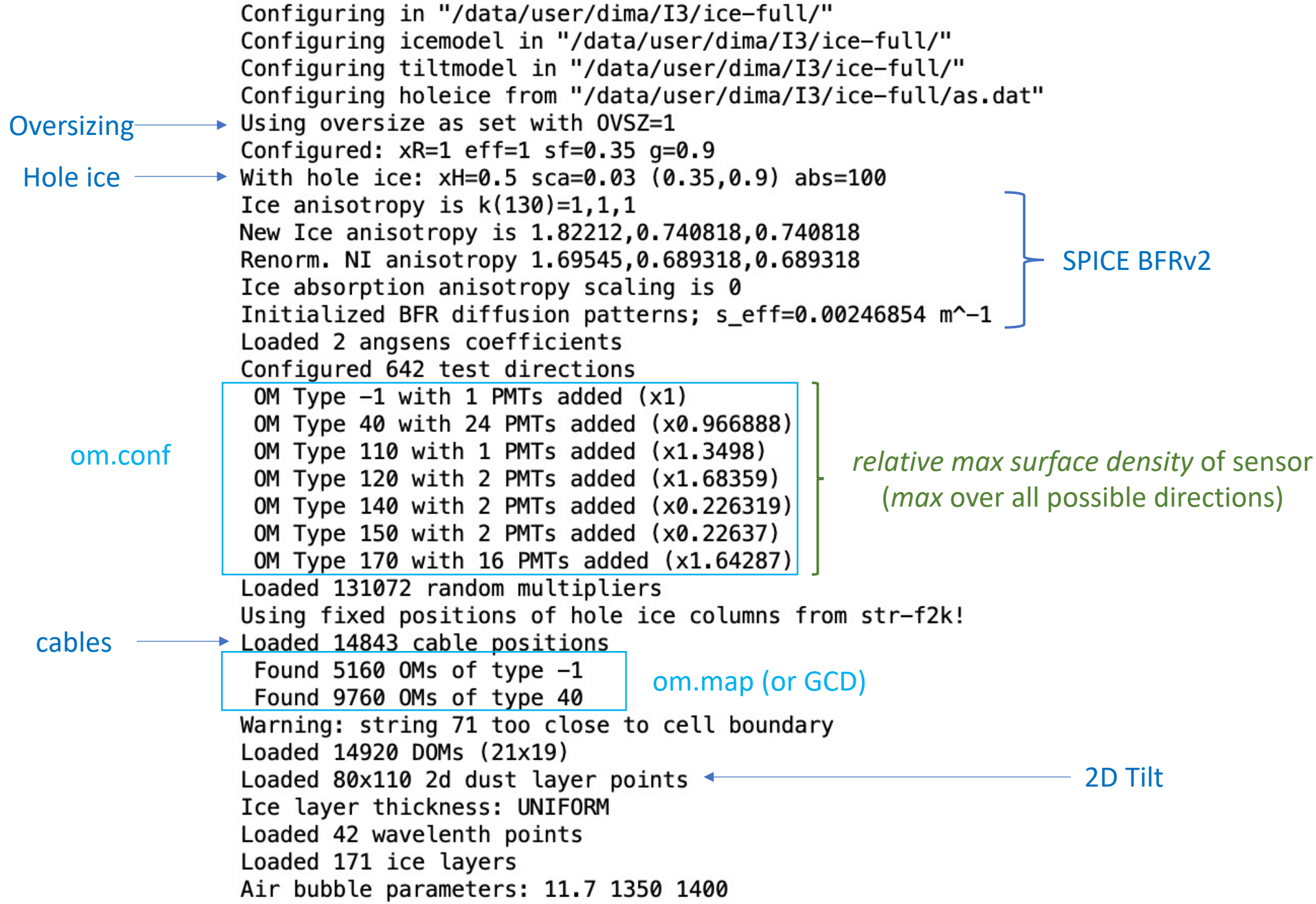
Spheroid (mDOM, Degg, LOM)



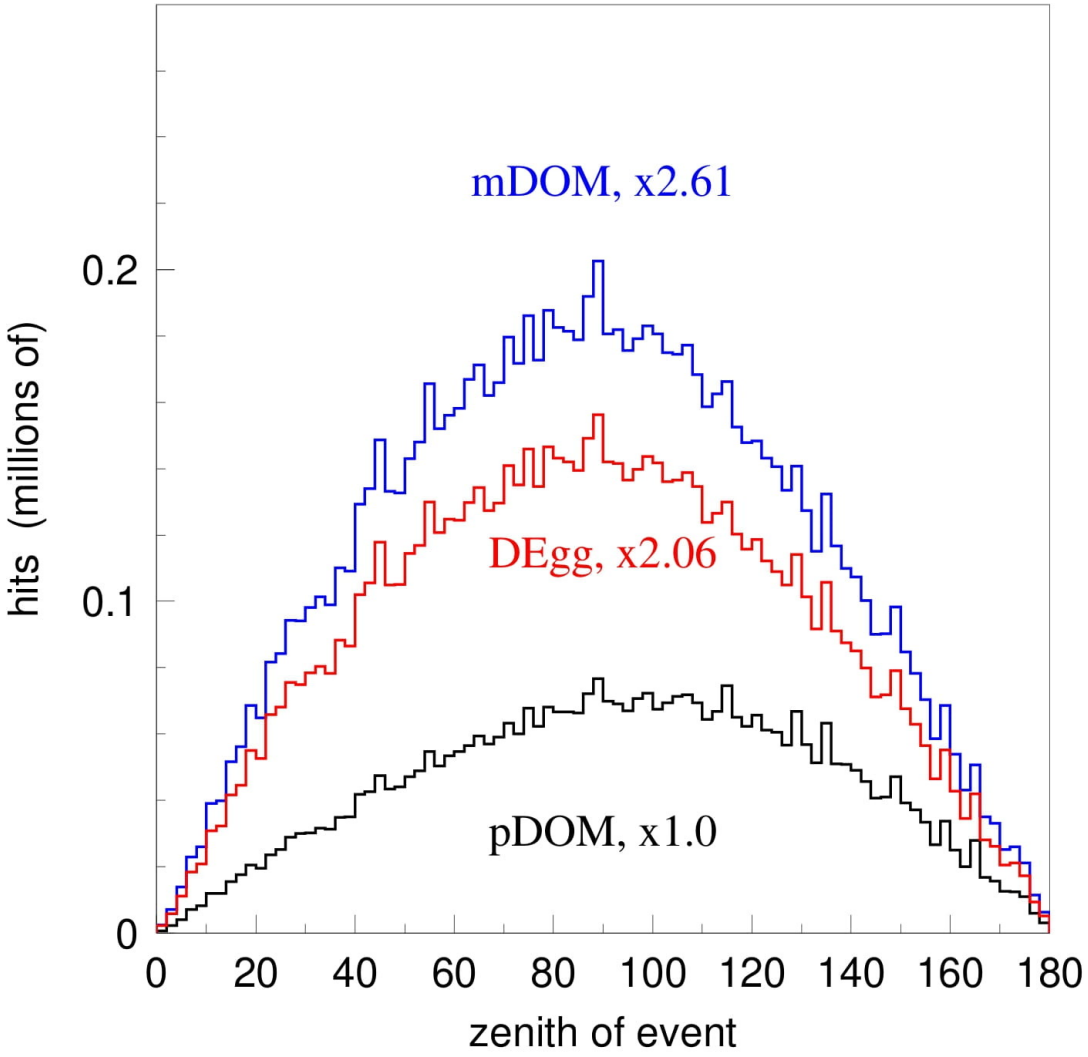
Sphere (DOM, pDOM)

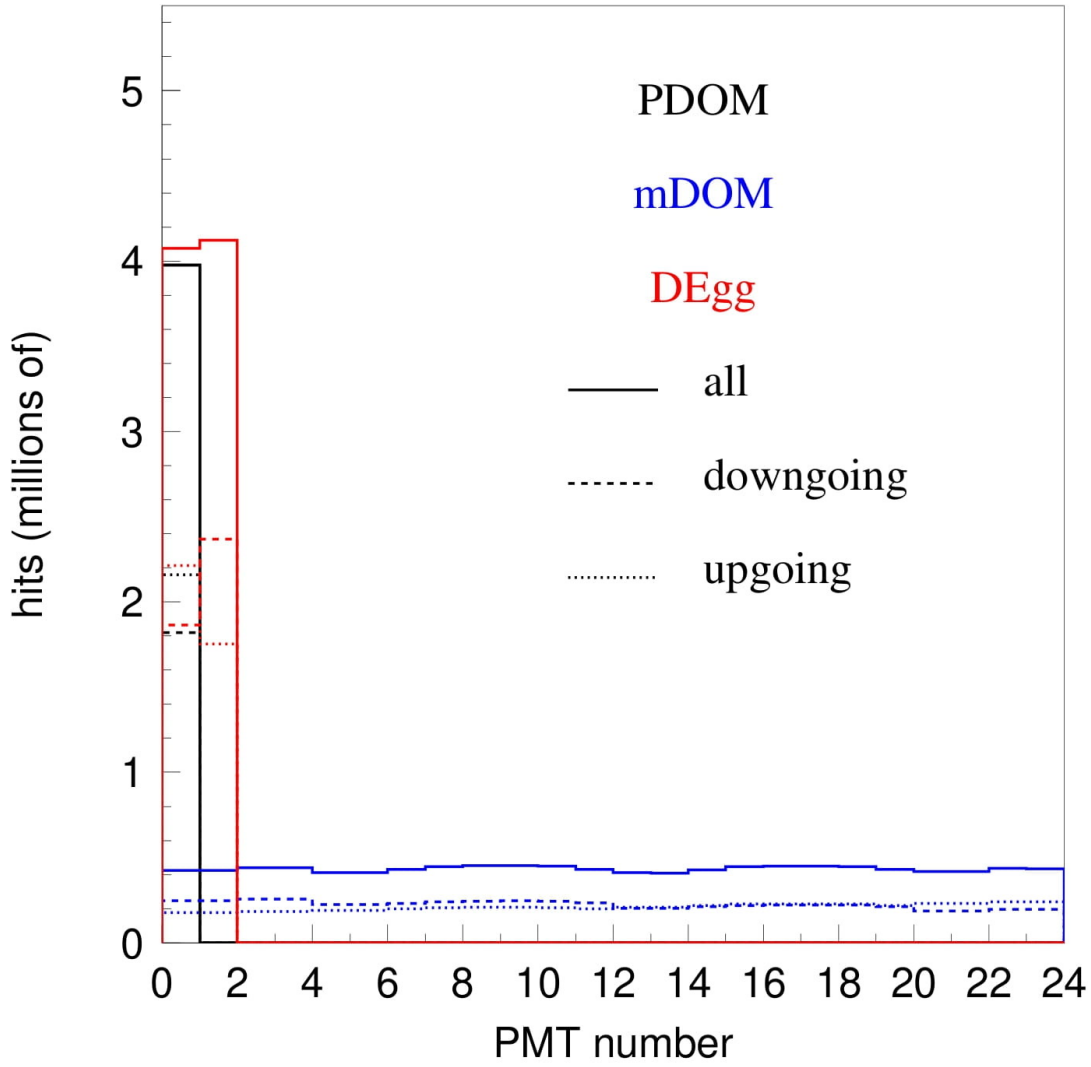


Cylinder (FOM, WOM)


Configuring in "/data/user/dima/I3/ice-full/"
Configuring icemodel in "/data/user/dima/I3/ice-full/"
Configuring tiltmodel in "/data/user/dima/I3/ice-full/"
Configuring holeice from "/data/user/dima/I3/ice-full/as.dat"
Oversizing
Using oversize as set with OVSZ=1
Configured: xR=1 eff=1 sf=0.35 g=0.9
Hole ice
With hole ice: xH=0.5 sca=0.03 (0.35,0.9) abs=100
Ice anisotropy is k(130)=1,1,1
New Ice anisotropy is 1.82212,0.740818,0.740818
Renorm. NI anisotropy 1.69545,0.689318,0.689318
Ice absorption anisotropy scaling is 0
Initialized BFR diffusion patterns; s_eff=0.00246854 m^-1
SPICE BFRv2
Loaded 2 angsens coefficients
Configured 642 test directions
om.conf
OM Type -1 with 1 PMTs added (x1)
OM Type 40 with 24 PMTs added (x0.966888)
OM Type 110 with 1 PMTs added (x1.3498)
OM Type 120 with 2 PMTs added (x1.68359)
OM Type 140 with 2 PMTs added (x0.226319)
OM Type 150 with 2 PMTs added (x0.22637)
OM Type 170 with 16 PMTs added (x1.64287)
relative max surface density of sensor
(max over all possible directions)
Loaded 131072 random multipliers
Using fixed positions of hole ice columns from str-f2k!
cables
Loaded 14843 cable positions
Found 5160 OMs of type -1
Found 9760 OMs of type 40
om.map (or GCD)
Warning: string 71 too close to cell boundary
Loaded 14920 DOMs (21x19)
Loaded 80x110 2d dust layer points
2D Tilt
Ice layer thickness: UNIFORM
Loaded 42 wavelenth points
Loaded 171 ice layers
Air bubble parameters: 11.7 1350 1400

Response to isotropic flux of muons and electron cascades, IceCube with all sensors replaced





Sensor eff. area ratios (to pDOM):
2.06 (DEgg), 2.57 (mDOM)

- PPC can simulate elongated and/or multi-PMT sensors

- some external configuration files are currently necessary (in resources/ice/update – copy these into your PPCTABLESDIR directory)

- Collecting info for configuration of sensors within icetray:
  - OM geometry (PMT orientations and angular sensitivity response of individual PMTs)
  - *Wavelength-binned solid-angle-averaged* **effective area**s

- This information needs to come from dedicated (Geant?) studies including internal sensor structure, glass/gel transmission, quantum efficiencies, guiding cones, etc.

What is needed from detailed sensor simulation

Solid-angle-averaged **effective area** vs. wavelength, determined as follows:

- For *uniform* ($1m^2$) *isotropic* flux of photons calculate which fraction of them result in PMT pulses, including sub-threshold pulses. The product of resulting fraction and $1m^2$ is the **effective area**
- This accounts for all photon losses and details of sensor geometry, such as PMT quantum and collection efficiencies, transmission through glass, gel, guiding cones and other obstructions
- This should be done without any scattering or absorption in ice. I call this "*vacuum with ice refractive index*". Any propagation up to the sensor's outer surface is performed by the photon propagator.

What is needed from detailed sensor simulation

PMT orientations and angular response within the optical module

Where PMTs are facing normally out the PMT response will mainly depend on incident angle wrt. PMT axis. I have so far assumed that all PMTs in the same module can be described by a symmetrical (around a certain direction, often same as the PMT axis) function of incident angle

This is what is known in IceCube as lab-measured angular sensitivity function. It is usually normalized to 1 for directions into the PMT along the PMT axis, but normalization is not important (as it is calculated out internally at initialization)

For more complicated PMT orientations like in LOM, may need to specify this per PMT as a function of both angles of incident photon wrt. PMT within the OM. Hoping this can be approximated by a symmetrical (around a certain axis close to PMT axis) function of angle between photon and axis.

What is needed from detailed sensor simulation

For cylindrical wavelength-shifting sensors additionally need time-delay and loss functions of distance between photon landing coordinates and cylinder ends

Currently assuming angular sensitivity is just sin(zenith), but can implement something different.

Because the **effective area** is given as solid-angle-averaged, small errors in the description of angular response of PMTs will lead to vanishing errors (Liouville theorem).

- If the **effective area** were given for a certain specific direction, errors in the description of angular acceptance would lead to major errors in overall OM response.

1) # of Cherenkov photons in $d\lambda$ is $\frac{dN_e}{d\lambda} \cdot d\lambda$
(emitted per meter of bare muon track)

2) ice propagation results in a loss (fraction) function that adds time delay component (t) and arrival direction ($\vec{n}$) and landing coordinates ($\vec{r}$) on a OM sensor: $F(\vec{n}, \vec{r}, t)$

3) Quantum efficiency, PMT acceptance, and losses due to glass and gel transmission are all together another fraction $Q(\vec{n}, \vec{r})$

All of these depends on wavelength λ, but since photons do not change wavelength, we have:

$$\underline{\text{Total \# of pulses}} = Q(\vec{n},\vec{r}) \cdot F(\vec{n},\vec{r},t) \cdot \frac{dN_e}{d\lambda} =$$

per $\Delta\lambda, \Delta\vec{n}, \Delta\vec{r}, \Delta t$

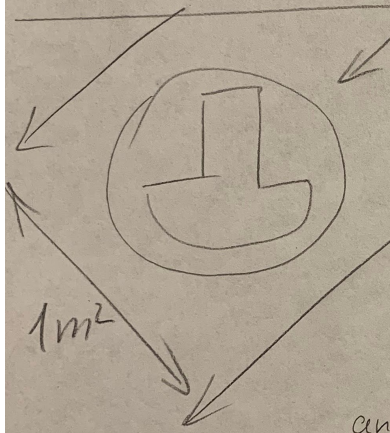
$$= \underbrace{F(\vec{n},\vec{r},t)}_{\text{ice propagation}} \cdot \underbrace{\frac{d\int_{\lambda_0}^{\lambda} Q(\vec{n},\vec{r},\lambda') \cdot \frac{dN}{d\lambda} d\lambda}{d\lambda}}_{\text{photon sampling function}} \Big\} \text{cherenkov-convolved acceptance}$$

Frank-Tamm formula
(# of Cherenkov photons emitted by bare muon track)

$$\frac{d^2E}{dx\, d\omega} = \frac{e^2}{c^2}\left(1 - \frac{1}{\beta^2 n^2}\right) \omega\, d\omega$$

$$E = N \cdot \hbar\omega \qquad \omega = \frac{2\pi c}{\lambda} \qquad \alpha = \frac{e^2}{\hbar c}$$

$$\Rightarrow d\left(\frac{dN}{dx}\right) = 2\pi\alpha\left(1 - \frac{1}{\beta^2 n^2}\right)\frac{d\lambda}{\lambda^2}$$



fraction f results in pulses (incl sub-threshold)

$\Rightarrow$ Then $f \cdot 1m^2$ = eff. area

if average eff. area (over solid angle) is known,
and PMT ang. sens. is known
and PMT geometry inside OM is known
$\Rightarrow$ can calculate eff. area for given direction

OM is simulated as a shape (e.g., spheroid) cross-sectional area of which is $A(\theta)$

Then: # of Cherenkov pulses is $d\left(\frac{dN}{dx}\right) \cdot \underbrace{\frac{\text{Eff. Area}(\theta)}{A(\theta)}}_{\text{acceptance}}$

Since $A(\theta)$ does not depend on λ, recommend "Cherenkov-weighted eff. area" + wavelength dependence curve

↳ $\int d\left(\frac{dN}{dx}\right) \cdot \text{EffArea} \Big/ \int d\left(\frac{dN}{dx}\right)$