Simulating cylindrical modules using ppc

Experiences from simulating WOMs with ppc

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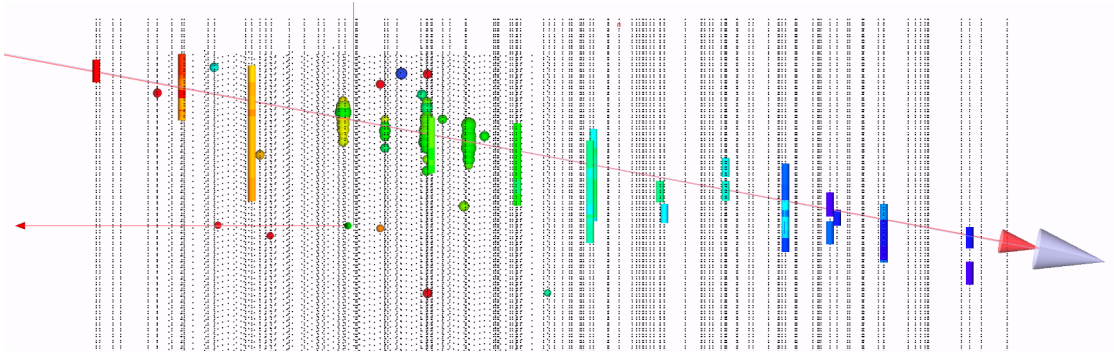
What did I do?

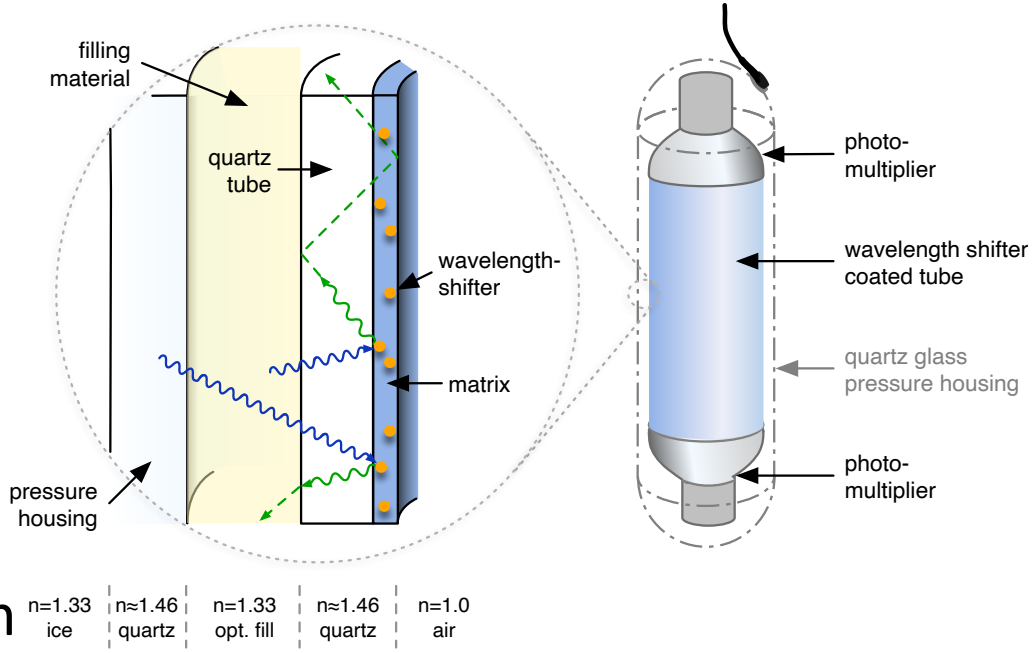
- Simulated WOMs (cylinder) in IceCube Gen2
- Used ppc for photon propagation since I simulated exotic particles
- Developed interim solution to simulate cylindrical modules

  → could also be used for clsim



Short Introduction - WOM

- „**W**avelength shifting **o**ptical **m**odule“
- Cylindrical module
- Uses wavelength shifter to detect photons between 250 and 400 nm
- Photons are trapped in quartz-cylinder and get detected by PMTs
- Light has to pass through different layers

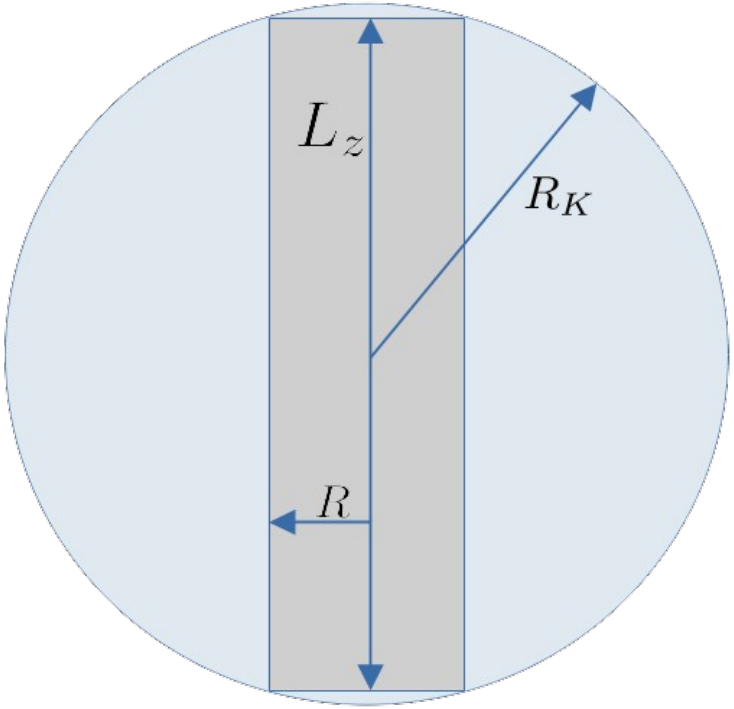


Starting position

- Problems:
  - ppc simulates spheres → need to develop calculation to decide whether a cylinder is hit by a photon that hits this sphere
  - Radius of spheres can be adjusted → hard coded and only adjustable for all modules in simulation
  - No PhotonSeries in ppc
  - Optical properties of standard-DOM are directly implemented in ppc → need to adjust some values to simulate other devices
- Simulated Cerenkov-spectrum, since optical effects are calculated later
- Adjusted ppc to get photonSeriesMap

Lightpropagation for the WOM

- Set radius so that cylinder is in sphere
- Use position and direction of photons on sphere to calculate if WOM is hit
- Problem: Photons that hit sphere but not cylinder aren’t further simulated
- Turn off properties of DOMs in ppc
- Calculate position, direction and incidence angle of photons on cylinder
- Use this information + wavelength of the photon to decide if photon is collected



Developed code

- Before PhotonSeriesMap was implemented in ppc:
  - Sollution that uses MCPESeries and MCTree to identify photons that hit WOM
- With PhotonSeriesMap:
  - Iterate over photons, could possibly be also used in clsim
- In ppc:
  - Use only Cerenkov-spectrum (wv.dat)
  - Deactivate angular sensitivity (as.dat)
  - Adapt efficiencies for each module (eff-f2k)
- Developed I3Module for WOM that writes MCPESeries

Optical properties

- Calculate transition T through materials with fresnel-formula depending on incidence angle α
- Calculate different efficiencies depending on wavelength

  → Overall: use lookup tables to decide if photon is collected, use efficiencies as probability
- Not done in ppc, but could be in the future

Fresnel-formulas

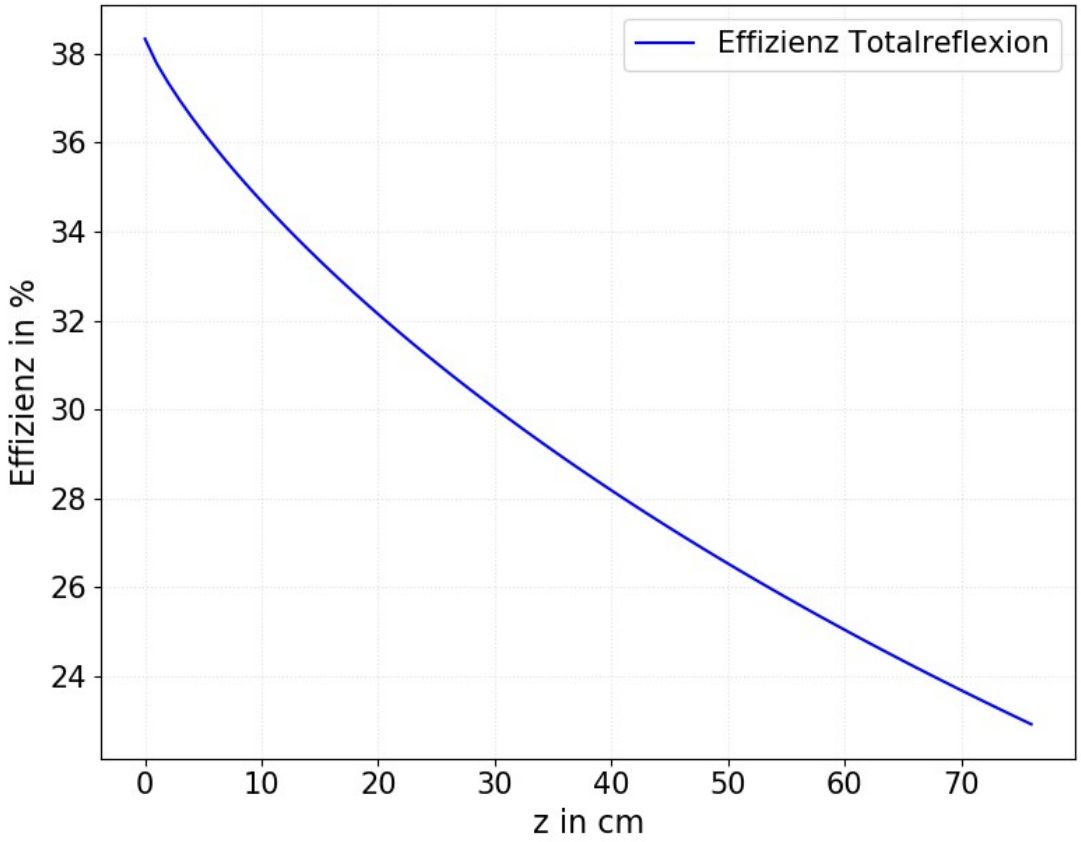
$$t_s = \frac{2n_1 \cos(\alpha)}{n_1 \cos(\alpha) + n_2 \cos(\beta)}$$

$$t_p = \frac{2n_1 \cos(\alpha)}{n_2 \cos(\alpha) + n_1 \cos(\beta)}$$

$$T = \frac{n_2 \cos(\beta)}{n_1 \cos(\alpha)} \cdot \left| \frac{t_s + t_p}{2} \right|^2$$

Efficiencies

- Efficiencies I used for the WOM (and dependencies from photon):
- Transmission through materials (direction)
- Absorption in materials (direction)
- Absorption from WLS (wavelength)
- PMT QE & emission from WLS
- Efficiency of photon trap (position)



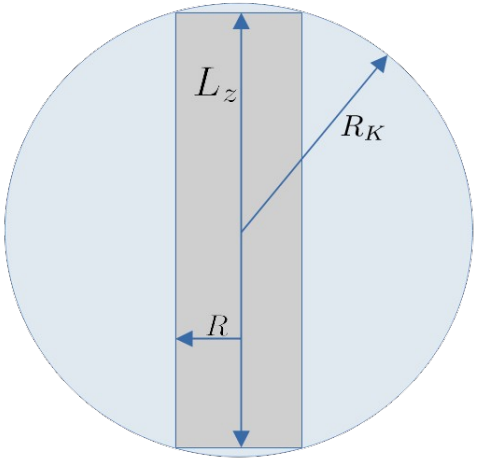
Outlook

- Simulating spheres and then propagating to elongated module is possible → maybe do this directly in propagator?
- But: Photons that don’t hit cylinder are lost at the moment
- Would be great if different module-types could be used simultaneously
- Maybe generalize how efficiencies are stored in lookup tables
- Then use global parameter to choose which module-type is used

Backup

Lightpropagation for the WOM - calculation

- Sort out photons with $|z| > \frac{L_z}{2}$ because they can't hit the cylinder's surface
- Parameterize path of photon as $g : \vec{x} = \vec{r} + \vec{p} \cdot s$ with position $\vec{r}$ and direction $\vec{p}$
- Parameterize cylinder as $[\vec{c} - (\vec{c} \cdot \vec{e_z})\vec{e_z}]^2 = R^2$
- Hit of photon on cylinder if $s^2 + \chi \cdot s + \xi = 0$ has a sollution
- Depending on parameters $\chi := \frac{2(p_x r_x + p_y r_y)}{p_x^2 + p_y^2}$ $\xi := \frac{r_x^2 + r_y^2 - R^2}{p_x^2 + p_y^2}$



Lightpropagation for the WOM

$$\chi := \frac{2(p_x r_x + p_y r_y)}{p_x^2 + p_y^2} \qquad \xi := \frac{r_x^2 + r_y^2 - R^2}{p_x^2 + p_y^2}$$

- No sollution for $\xi > (\frac{\chi}{2})^2$
- If there is a sollution
  calculate the position, direction and incidence angle of photon on cylinder
- At the end check $|z| > \frac{L_z}{2}$ for the new position of the photon