Hole-ice simulation in clsim

Icecube calibration call, 2018-03-02

Sebastian Fiedlschuster
sebastian@fiedlschuster.de

Erlangen Centre for Astroparticle Physics

2018-03-02

IceCube
South Pole Neutrino Observatory

ecap Erlangen Centre for Astroparticle Physics

FAU Friedrich-Alexander Universität Erlangen-Nürnberg

Motivation and Scope

- No explicit hole-ice simulation included in clsim, yet only angular sensitivity approximation
  - $\rightarrow$ No asymmetries possible, e.g. DOM position relative to hole ice
- Master thesis (ending Aug 2018)

Motivation and Scope

- No explicit hole-ice simulation included in clsim, yet only angular sensitivity approximation
  → No asymmetries possible, e.g. DOM position relative to hole ice
- Master thesis (ending Aug 2018)

1. clsim approximates hole ice using a convolution function for the angular acception.
2. e.g. photons hitting a dom from below are made more unlikely to be detected.
3. but no actual simulation of the changed ice properties.
4. i.e. we can't have asymmetries like shifted DOM positions relative to the hole ice.
5. that's why I'm trying to implement propagation through cylinders with changed ice properties in clsim.

Hole-ice simulation in clsim

Icecube calibration call, 2018-03-02

Sebastian Fiedlschuster
sebastian@fiedlschuster.de

Erlangen Centre for Astroparticle Physics

2018-03-02

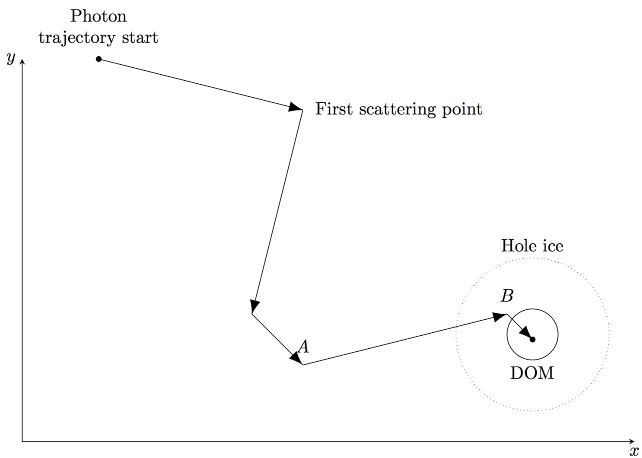
Resources

Usage examples can be found on github:

`https://github.com/fiedl/hole-ice-study`

Contents

How does it work?

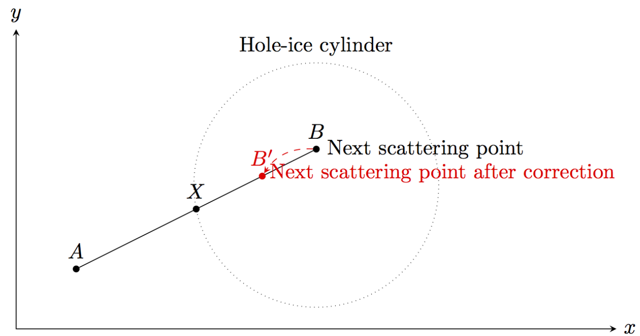


Source: https://github.com/fiedl/hole-ice-study#how-does-it-work

What is actually done:

- In photon propagation simulation, one simulation step consists of everything between two scatterings, i.a.
  - randomizing the distance to the next scattering point
  - randomizing the scattering angle
  - moving the photon to the next scattering point
  - checking for absorption
  - checking for detection at a DOM
- Hole ice simulation adds another task to each simulation step:
  - Calculate the portion of the photon trajectory in the step that runs through hole ice
  - Correct the distance to the next scattering point for the changed ice properties within the hole ice
  - Correct the distance to absorption as well

How does it work?

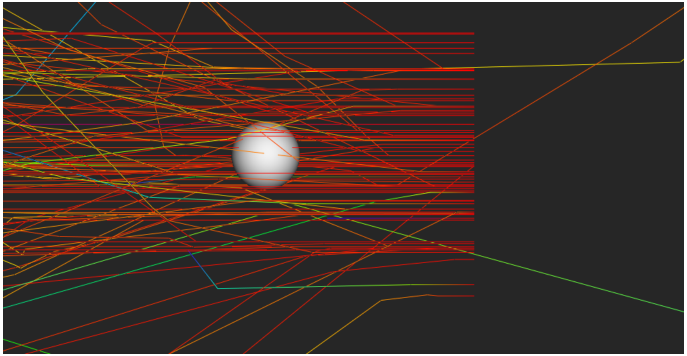


Source: https://github.com/fiedl/hole-ice-study#how-does-it-work

What is actually done:

- In photon propagation simulation, one simulation step consists of everything between two scatterings, i.a.
  - randomizing the distance to the next scattering point
  - randomizing the scattering angle
  - moving the photon to the next scattering point
  - checking for absorption
  - checking for detection at a DOM
- Hole ice simulation adds another task to each simulation step:
  - Calculate the portion of the photon trajectory in the step that runs through hole ice
  - Correct the distance to the next scattering point for the changed ice properties within the hole ice
  - Correct the distance to absorption as well

Scattering example



Shoot photons onto the DOM. Top view.
No hole ice at all.

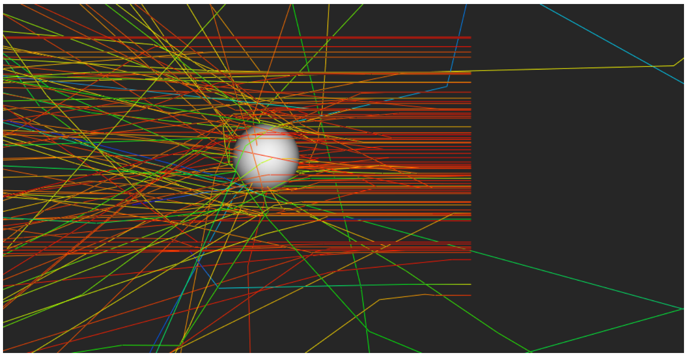
$$\lambda_{\text{sca,hole-ice}} = \frac{1}{1} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

Colors indicate simulation steps, i.e. number of scatterings relative to the total number until absorption. Red: Photon just created, blue: Photon about to be absorbed.

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=1.0 --absorption-factor=1.0 --distance=1.0
↪   --plane-wave --number-of-photons=1e2 --number-of-runs=1
↪   --number-of-parallel-runs=1 --save-photon-paths --cpu
steamshovel tmp/propagated_photons.i3
```

Source: `https://github.com/fiedl/hole-ice-study/issues/39`

Scattering example



Shoot photons onto the DOM. Top view.
Change the scattering length inside the hole ice to be 1/10 of the scattering length outside.

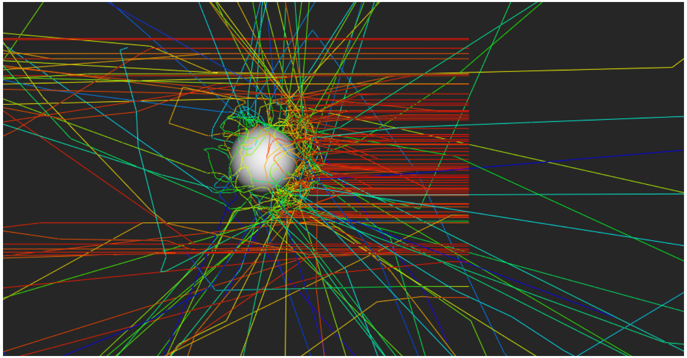
$$\lambda_{\text{sca,hole-ice}} = \frac{1}{10} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

Colors indicate simulation steps, i.e. number of scatterings relative to the total number until absorption. Red: Photon just created, blue: Photon about to be absorbed.

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.1 --absorption-factor=1.0 --distance=1.0
↪  --plane-wave --number-of-photons=1e2 --number-of-runs=1
↪  --number-of-parallel-runs=1 --save-photon-paths --cpu
steamshovel tmp/propagated_photons.i3
```

Source: https://github.com/fiedl/hole-ice-study/issues/39

Scattering example



Shoot photons onto the DOM. Top view.
Change the scattering length inside the hole ice to be 1/100 of the scattering length outside.

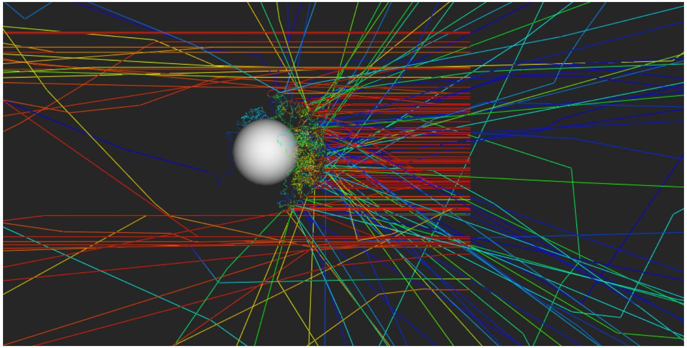
$$\lambda_{\text{sca,hole-ice}} = \frac{1}{100} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

Colors indicate simulation steps, i.e. number of scatterings relative to the total number until absorption. Red: Photon just created, blue: Photon about to be absorbed.

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.01 --absorption-factor=1.0 --distance=1.0
↪  --plane-wave --number-of-photons=1e2 --number-of-runs=1
↪  --number-of-parallel-runs=1 --save-photon-paths --cpu
steamshovel tmp/propagated_photons.i3
```

Source: https://github.com/fiedl/hole-ice-study/issues/39

Scattering example



Animation on youtube: `https://youtu.be/BhJ6F3B-I1s`

Shoot photons onto the DOM. Top view.
Change the scattering length inside the hole ice to be 1/1 000 of the scattering length outside.

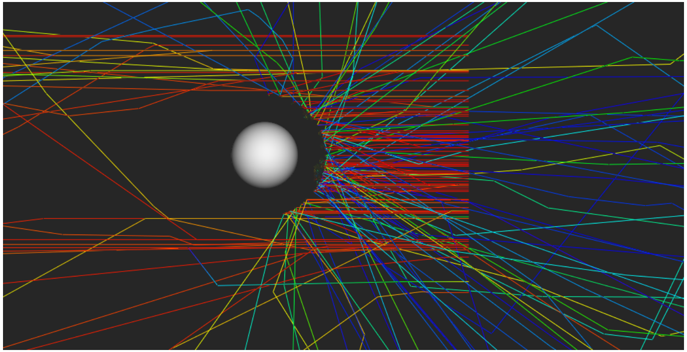
$$\lambda_{\text{sca,hole-ice}} = \frac{1}{1\,000}\,\lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \lambda_{\text{sca,bulk}}$$

Colors indicate simulation steps, i.e. number of scatterings relative to the total number until absorption. Red: Photon just created, blue: Photon about to be absorbed.

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.001 --absorption-factor=1.0 --distance=1.0
↪  --plane-wave --number-of-photons=1e2 --number-of-runs=1
↪  --number-of-parallel-runs=1 --save-photon-paths --cpu
steamshovel tmp/propagated_photons.i3
```

Source: `https://github.com/fiedl/hole-ice-study/issues/39`

Scattering example



Shoot photons onto the DOM. Top view.
Change the scattering length inside the hole ice to be 1/10 000 of the scattering length outside.

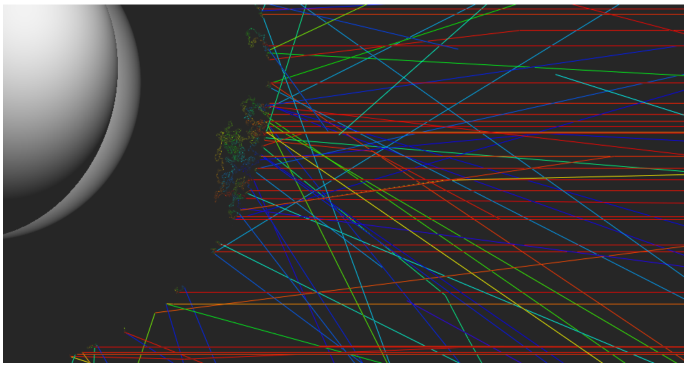
$$\lambda_{\text{sca,hole-ice}} = \frac{1}{10\,000} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

Colors indicate simulation steps, i.e. number of scatterings relative to the total number until absorption. Red: Photon just created, blue: Photon about to be absorbed.

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.0001 --absorption-factor=1.0 --distance=1.0
↪  --plane-wave --number-of-photons=1e2 --number-of-runs=1
↪  --number-of-parallel-runs=1 --save-photon-paths --cpu
steamshovel tmp/propagated_photons.i3
```

Source: `https://github.com/fiedl/hole-ice-study/issues/39`

Scattering example



(Magnification)

Shoot photons onto the DOM. Top view.
Change the scattering length inside the hole ice to be 1/10 000 of the scattering length outside.

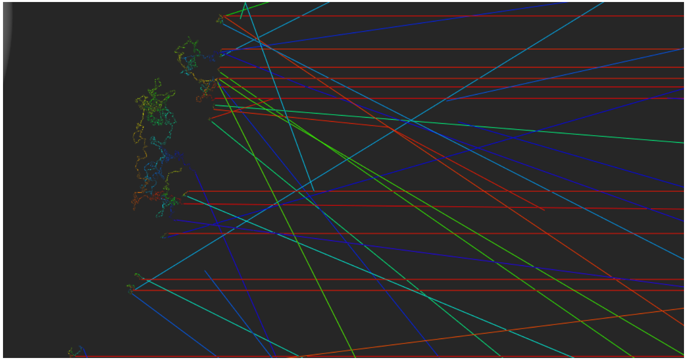
$$\lambda_{\text{sca,hole-ice}} = \frac{1}{10\,000} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

Colors indicate simulation steps, i.e. number of scatterings relative to the total number until absorption. Red: Photon just created, blue: Photon about to be absorbed.

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.0001 --absorption-factor=1.0 --distance=1.0
↪  --plane-wave --number-of-photons=1e2 --number-of-runs=1
↪  --number-of-parallel-runs=1 --save-photon-paths --cpu
steamshovel tmp/propagated_photons.i3
```

Source: `https://github.com/fiedl/hole-ice-study/issues/39`

Scattering example



(Magnification)

Shoot photons onto the DOM. Top view.
Change the scattering length inside the hole ice to be 1/10 000 of the scattering length outside.

$$\lambda_{\text{sca,hole-ice}} = \frac{1}{10\,000} \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \lambda_{\text{sca,bulk}}$$

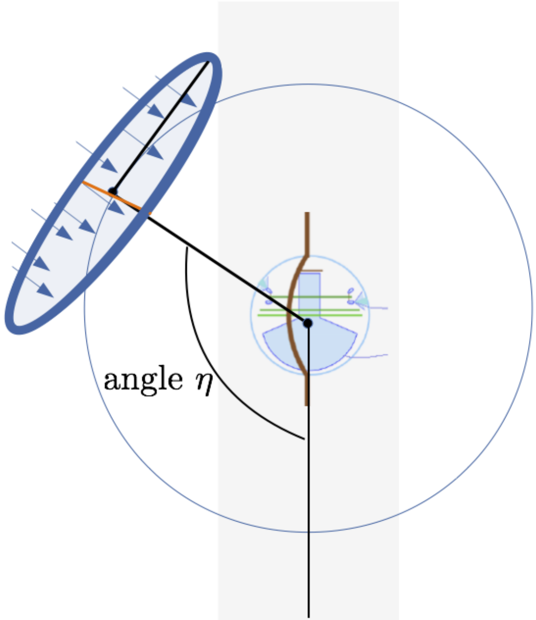
Colors indicate simulation steps, i.e. number of scatterings relative to the total number until absorption. Red: Photon just created, blue: Photon about to be absorbed.

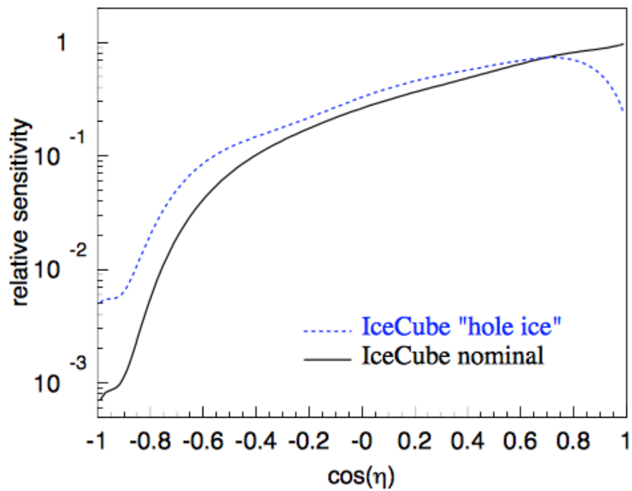
```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.0001 --absorption-factor=1.0 --distance=1.0
↪  --plane-wave --number-of-photons=1e2 --number-of-runs=1
↪  --number-of-parallel-runs=1 --save-photon-paths --cpu
steamshovel tmp/propagated_photons.i3
```

Source: https://github.com/fiedl/hole-ice-study/issues/39

Angular acceptance

For each angle η, shoot photons onto the DOM and count hits.



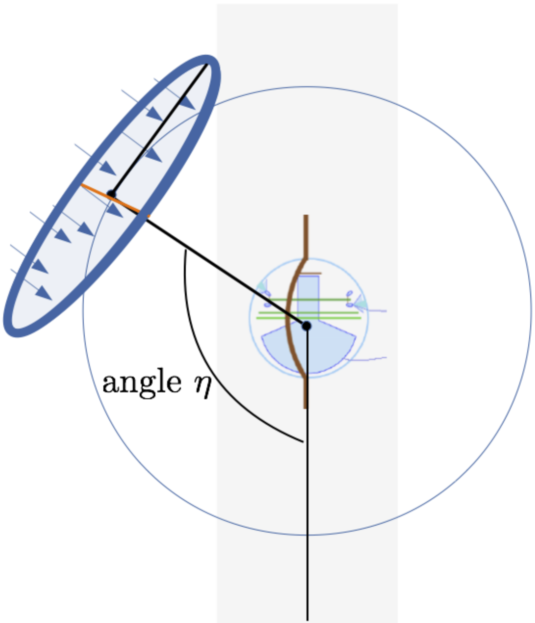


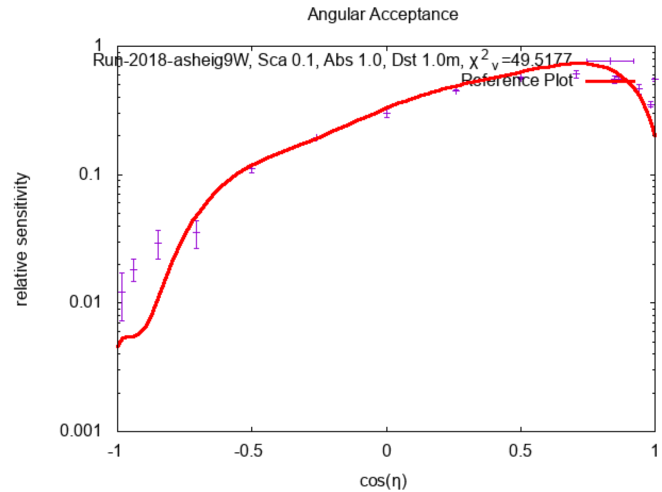
Angular acceptance *reference curves*. The nominal model is based on lab measurement, the hole ice curve on previous simulations.

Source: Image: Martin Rongen, Calibration Call 2015-11-06, DARD Update, Slide 9
Plot: Measurement of South Pole ice transparency with the IceCube LED calibration system, 2013, figure 7. See also: `https://github.com/fiedl/hole-ice-study/issues/10`

Angular acceptance

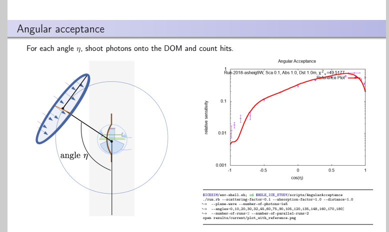
For each angle η, shoot photons onto the DOM and count hits.






```
$ICESIM/env-shell.sh; cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.1 --absorption-factor=1.0 --distance=1.0
↪  --plane-wave --number-of-photons=1e5
↪  --angles=0,10,20,30,32,45,60,75,90,105,120,135,148,160,170,180]
↪  --number-of-runs=2 --number-of-parallel-runs=2
open results/current/plot_with_reference.png
```

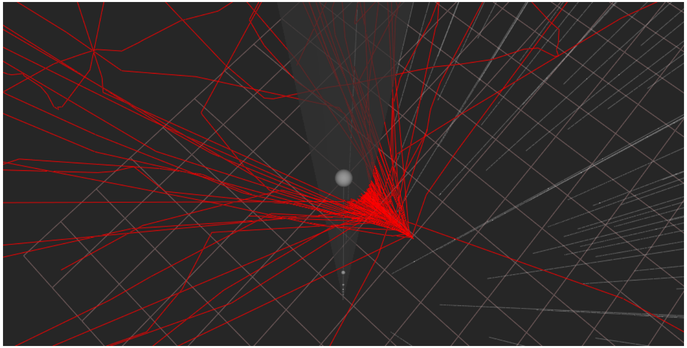
Source: Image: Martin Rongen, Calibration Call 2015-11-06, DARD Update, Slide 9
Plot: Measurement of South Pole ice transparency with the IceCube LED calibration system, 2013, figure 7. See also: https://github.com/fiedl/hole-ice-study/issues/10



- One way to compare the new simulation to existing results, is to plot angular-acceptance curves.
- I.e. for each angle η, which is the angle between the starting direction of the photon and the column axis, shoot photons onto the DOM, propagate them in simulation and count hits.
- The current hole-ice approximations are convolutions onto the DOM angular acceptance.
- This is an example using the new hole-ice simulation with arbitrary ice parameters (data points) compared to the old reference curve (red).

Instant absorption

Visualizing instant absorption with clsim and steamshovel. DOM radius: 10 cm, hole ice radius: 30 cm



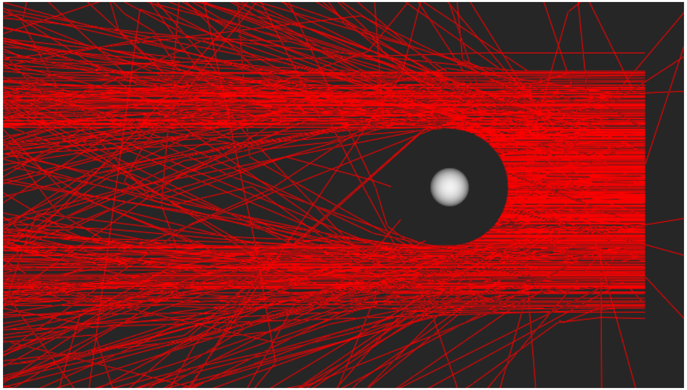
Photon point source, 3d view

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/FiringRange
./run.rb \
    --scattering-factor=1.0 --absorption-factor=0.0 \
    --distance=1.0 \
    --number-of-photons=1e3 --angle=90 \
    --number-of-runs=1 --number-of-parallel-runs=1 \
    --save-photon-paths --cpu
steamshovel tmp/propagated_photons.i3
```

Source: https://github.com/fiedl/hole-ice-study/issues/22

Instant absorption

Visualizing instant absorption with clsim and steamshovel. DOM radius: 10 cm, hole ice radius: 30 cm

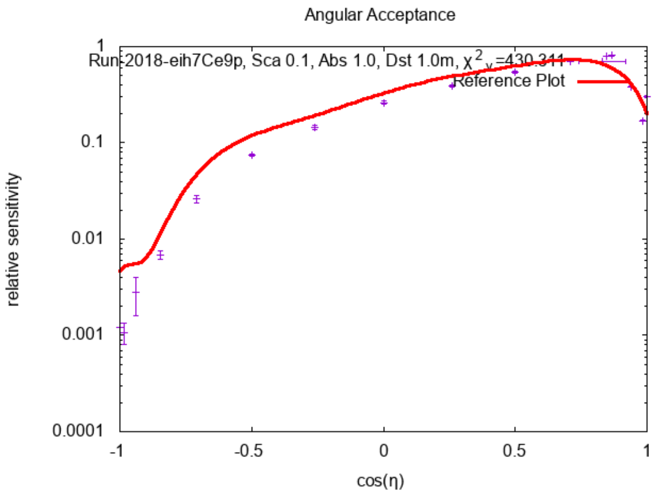


Plane wave photon source, top view

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/FiringRange
./run.rb \
    --scattering-factor=1.0 --absorption-factor=0.0 \
    --distance=1.0 --plane-wave \
    --number-of-photons=1e3 --angle=90 \
    --number-of-runs=1 --number-of-paralle-runs=1 \
    --cpu --save-photon-paths
steamshovel tmp/propagated_photons.i3
```

Source: https://github.com/fiedl/hole-ice-study/issues/22

Fixed source example



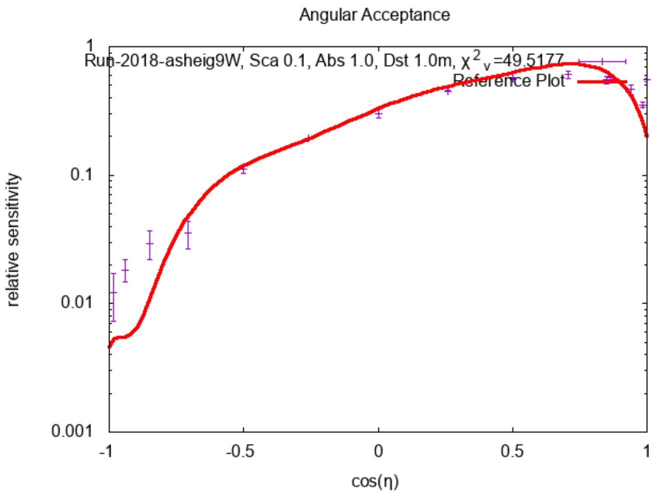
For each angle η, shoot photons **from a fixed point** onto the DOM and count hits. Hole-ice radius: 30 cm

$$\lambda_{\text{sca,hole-ice}} = \frac{1}{10} \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \lambda_{\text{sca,bulk}}$$

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.1 --absorption-factor=0.1 --distance=1.0
↪   --number-of-photons=1e5
↪   --angles=0,10,20,30,32,45,60,75,90,105,120,135,148,160,170,180]
↪   --number-of-runs=2 --number-of-parallel-runs=2
open results/current/plot_with_reference.png
```

Source: `https://github.com/fiedl/hole-ice-study#angular-acceptance-example`

Plane wave example



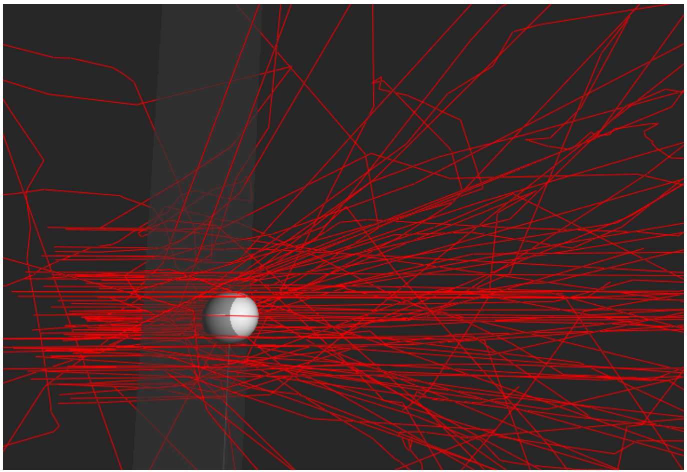
For each angle η, shoot photons **from planes** onto the DOM and count hits. Hole-ice radius: 30 cm

$$\lambda_{\text{sca,hole-ice}} = \frac{1}{10} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.1 --absorption-factor=1.0 --distance=1.0
↪  --plane-wave --number-of-photons=1e5
↪  --angles=0,10,20,30,32,45,60,75,90,105,120,135,148,160,170,180
↪  --number-of-runs=2 --number-of-parallel-runs=2
open results/current/plot_with_reference.png
```

Source: `https://github.com/fiedl/hole-ice-study#plane-wave-example`

Asymmetry example



For angle $\eta = \pi/2$, shoot photons from planes onto the DOM and count hits.
Hole-ice radius: 30 cm

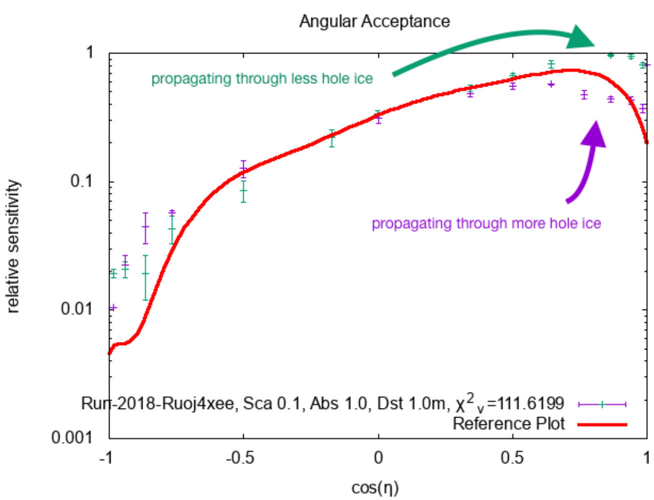
$$\lambda_{\text{sca,hole-ice}} = \frac{1}{10} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

The **hole-ice is shifted in x-direction against the DOM** position by 20 cm.

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.1 --absorption-factor=1.0
↪  --distance=1.0 --plane-wave --number-of-photons=1e2
↪  --cylinder-shift=0.2 --save-photon-paths --cpu
steamshovel tmp/propagated_photons.i3
```

Source: https://github.com/fiedl/hole-ice-study#asymmetry-example, https://github.com/fiedl/hole-ice-study/issues/8

Asymmetry example



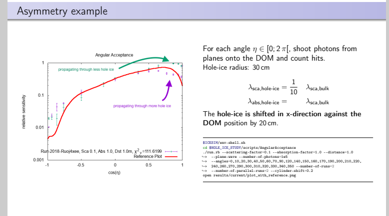
For each angle $\eta \in [0; 2\,\pi[$, shoot photons from planes onto the DOM and count hits.
Hole-ice radius: 30 cm

$$\lambda_{\text{sca,hole-ice}} = \frac{1}{10} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

The **hole-ice is shifted in x-direction against the DOM** position by 20 cm.

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.1 --absorption-factor=1.0 --distance=1.0
↪ --plane-wave --number-of-photons=1e5
↪ --angles=0,10,20,30,40,50,60,70,90,120,140,150,160,170,190,200,210,220,
↪ 240,260,270,290,300,310,320,330,340,350 --number-of-runs=2
↪ --number-of-parallel-runs=2 --cylinder-shift=0.2
open results/current/plot_with_reference.png
```

Source: https://github.com/fiedl/hole-ice-study#asymmetry-example, https://github.com/fiedl/hole-ice-study/issues/8



- In data points, one sees upper curve and lower curve.
- Because of the asymmetry, on one way, the distance through the hole ice is smaller, on the other way, larger.

Outlook: What is possible

- Direct detection
- Separate positions for hole-ice cylinders
- Nested columns
- Cables as cylinder partials

Outlook: What is still missing

- Absolute ice properties in hole ice rather than relative to respective bulk ice layers
- Separate ice properties for each cylinder
- Comparison to ppc results
- Grid scan to find best match with reference plot
- See also: `https://github.com/fiedl/hole-ice-study/issues`

Thanks for your attention!

Any input you might have is welcome:

`https://github.com/fiedl/hole-ice-study/issues`

Slack: `@fiedl`