

Hole-ice simulation in clsim

Icecube calibration call, 2018-03-02

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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)



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Resources

Usage examples can be found on github:

<https://github.com/fiedl/hole-ice-study>



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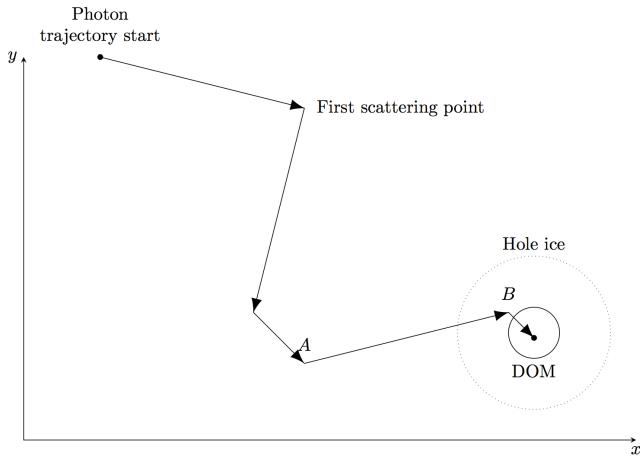
4 Outlook

- Separate cylinder positions
- Cable shadows
- Nested cylinders
- Direct detection
- Work to be done



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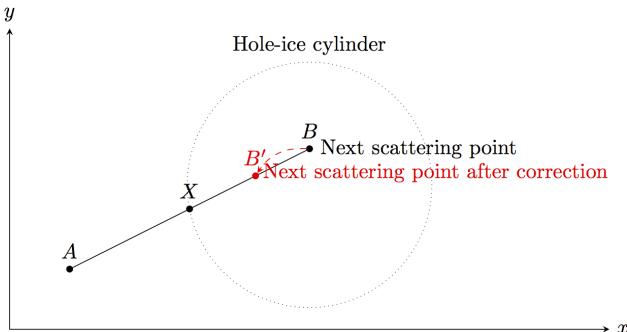
How does it work?



- In current 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

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

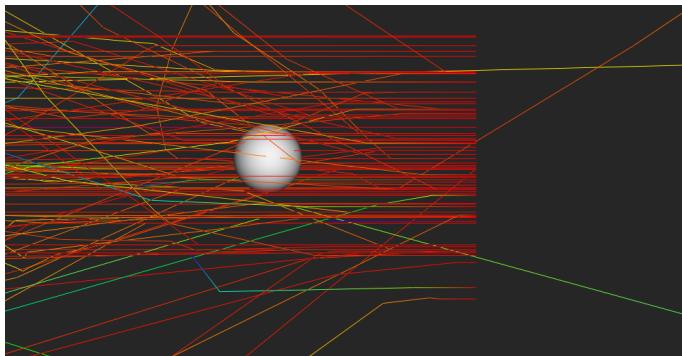
How does it work?



- In current photon propagation simulation, one simulation step consists of everything between two scatterings, i.a.
 - randomizing the distance to the next scattering point
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 - 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

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

Scattering example



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

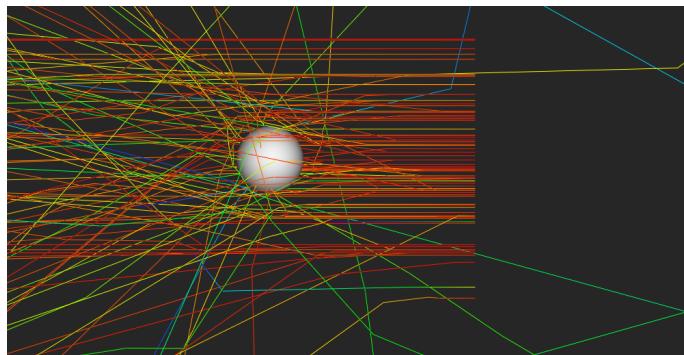
$$\lambda_{\text{sca,hole-ice}} = \frac{1}{1 - \lambda_{\text{sca,bulk}}}$$
$$\lambda_{\text{abs,hole-ice}} = \lambda_{\text{sca,bulk}}$$

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=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.

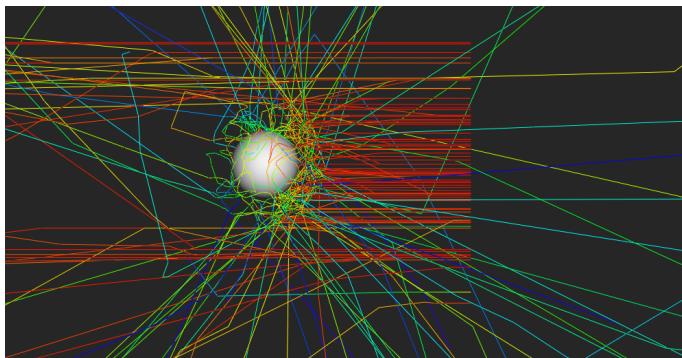
$$\begin{aligned}\lambda_{\text{sca,hole-ice}} &= \frac{1}{10} & \lambda_{\text{sca,bulk}} \\ \lambda_{\text{abs,hole-ice}} &= & \lambda_{\text{sca,bulk}}\end{aligned}$$

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.

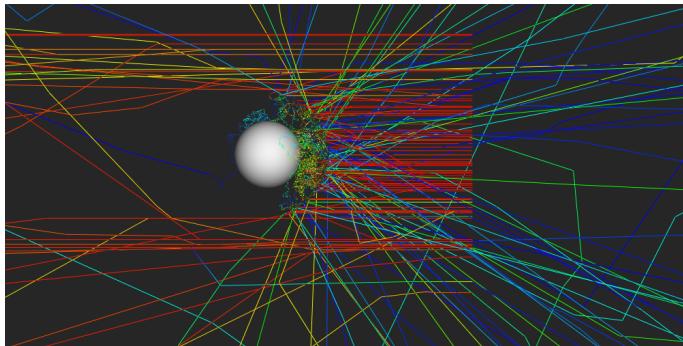
$$\lambda_{\text{sca,hole-ice}} = \frac{1}{100} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \lambda_{\text{sca,bulk}}$$

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-IIis>

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.

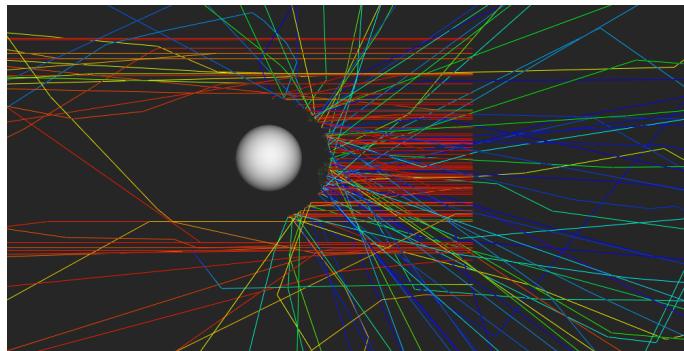
$$\lambda_{\text{sca,hole-ice}} = \frac{1}{1\,000} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

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=0.001 --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.

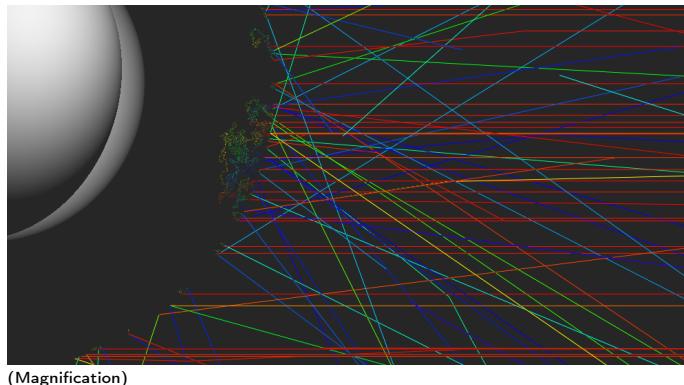
$$\lambda_{\text{sca, hole-ice}} = \frac{1}{10\,000} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs, hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

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



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.

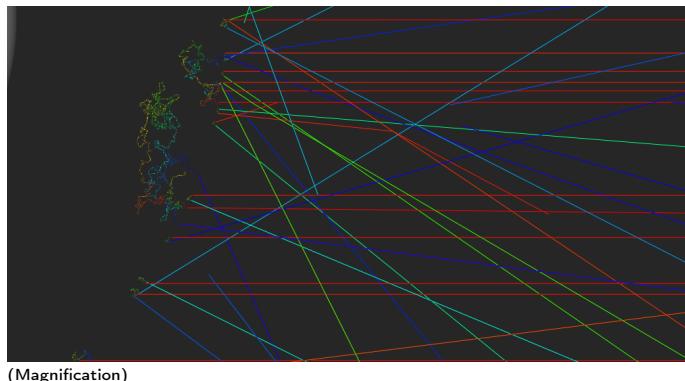
$$\lambda_{\text{sca, hole-ice}} = \frac{1}{10\,000} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs, hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

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.

```
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    --plane-wave --number-of-photons=1e2 --number-of-runs=1
    --number-of-parallel-runs=1 --save-photon-paths --cpu
steamshovel tmp/propagated_photons.i3
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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.

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

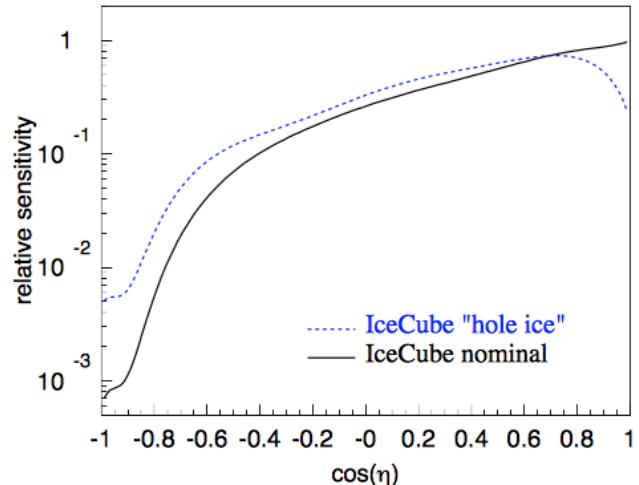
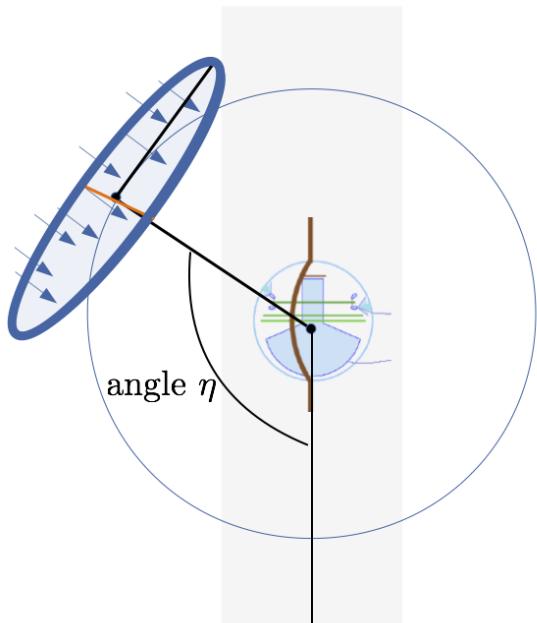
Colors indicate simulation steps, i.e. number of scatterings relative to the total number until absorption. Red: Photon just created, blue: Photon about to be absorbed.

```
$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>

Angular acceptance

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



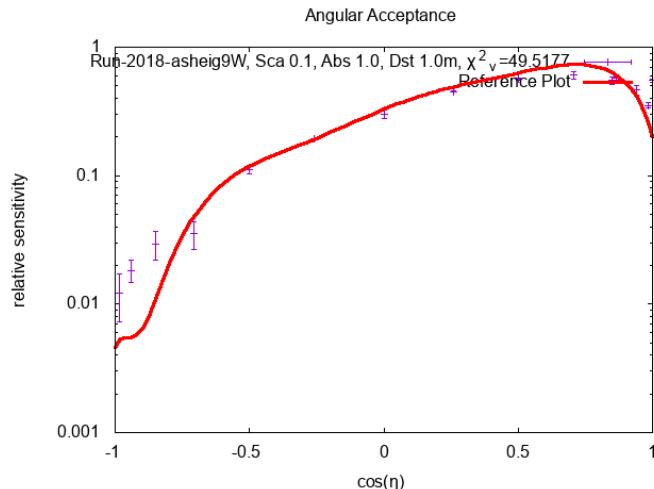
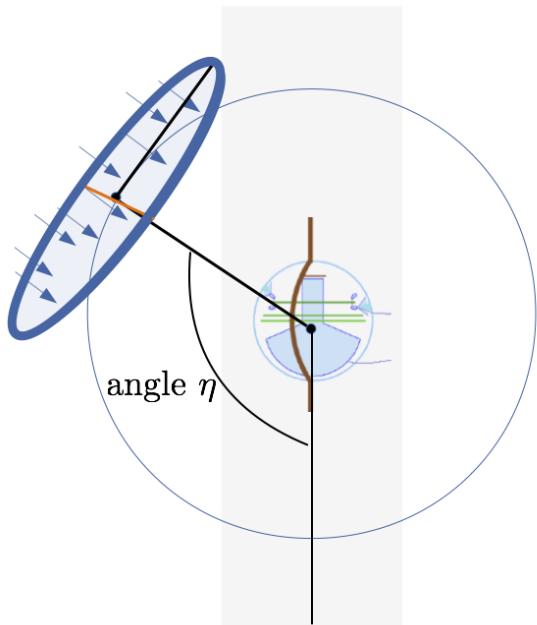
Angular acceptance *reference curves*. The nominal model is based on lab measurement, the hole ice curve on previous simulations.

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.



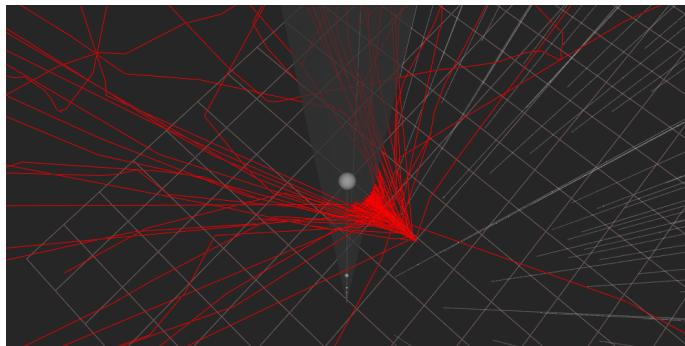
```
$ICESIM/env-shell.sh; cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.1 --absorption-factor=1.0 --distance=1.0
--plane-wave --number-of-photons=1e5
--angles=0,10,20,30,32,45,60,75,90,105,120,135,148,160,170,180]
--number-of-runs=2 --number-of-parallel-runs=2
open results/current/plot_with_reference.png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

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>

Instant absorption

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



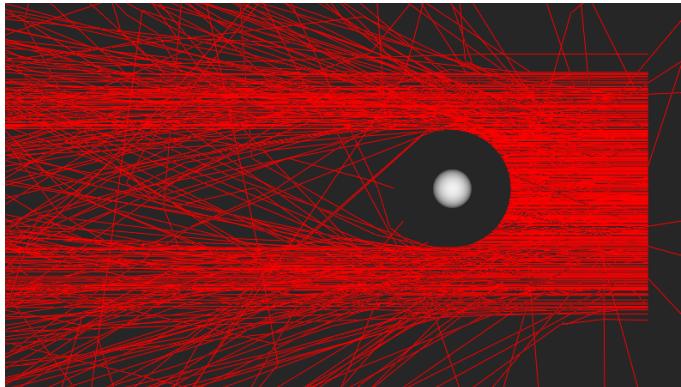
Photon point source, 3d view

```
$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

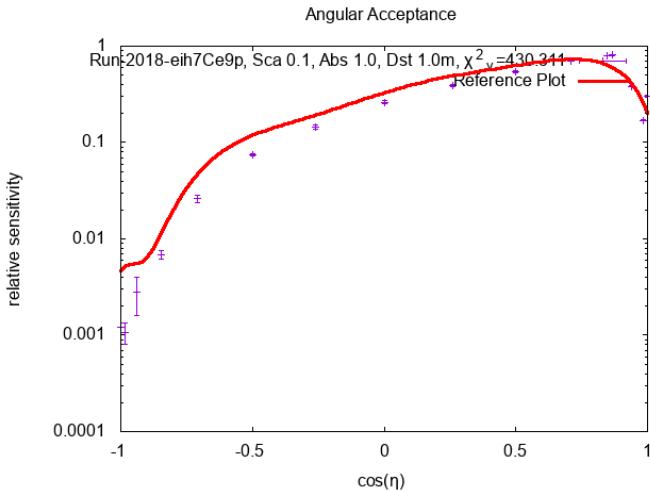


Plane wave photon source, top view

```
$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-parallel-runs=1 \
    --cpu --save-photon-paths
steamshovel tmp/propagated_photons.i3
```

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

Fixed source example



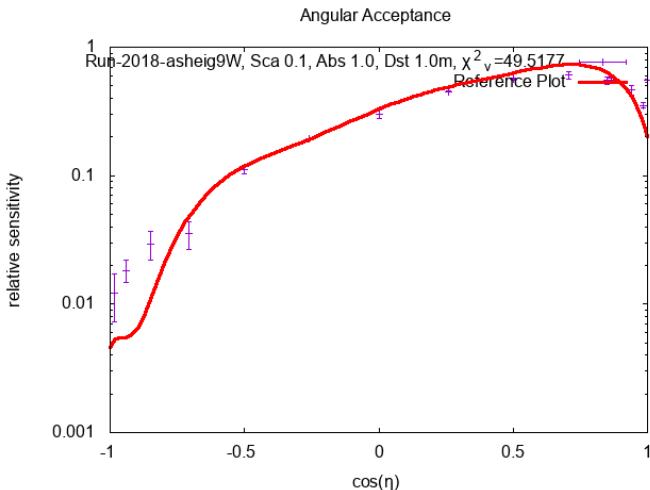
For each angle η , shoot photons **from a fixed point** onto the DOM and count hits. Hole-ice radius: 30 cm

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

```
$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



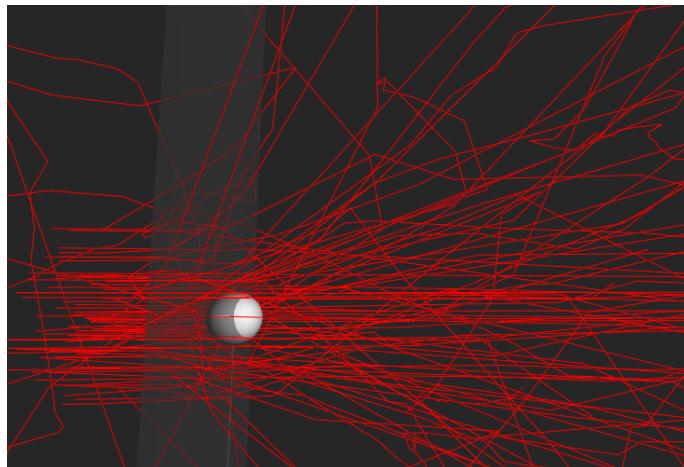
For each angle η , shoot photons **from planes** onto the DOM and count hits. Hole-ice radius: 30 cm

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

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/AngularAcceptance
./run.rb --scattering-factor=0.1 --absorption-factor=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

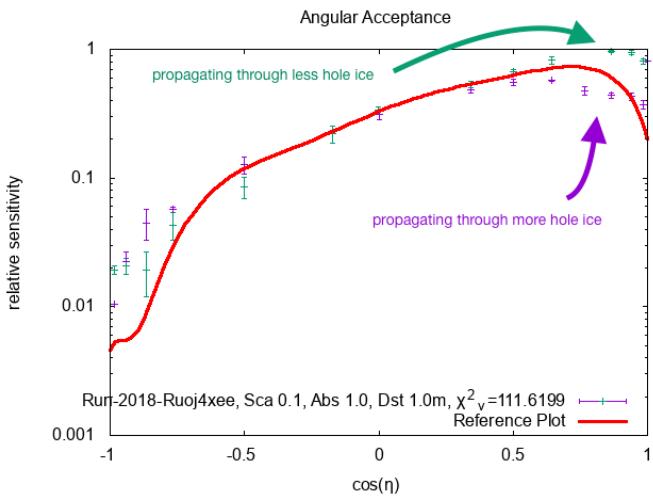
$$\lambda_{\text{sca,hole-ice}} = \frac{1}{10} \quad \lambda_{\text{sca,bulk}}$$
$$\lambda_{\text{abs,hole-ice}} = \quad \lambda_{\text{sca,bulk}}$$

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

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

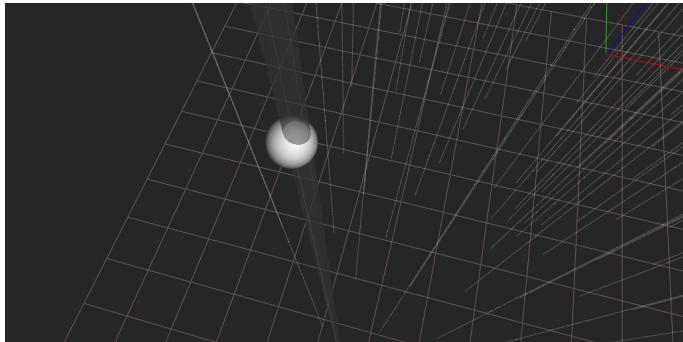
$$\lambda_{\text{abs,hole-ice}} = \lambda_{\text{sca,bulk}}$$

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
```

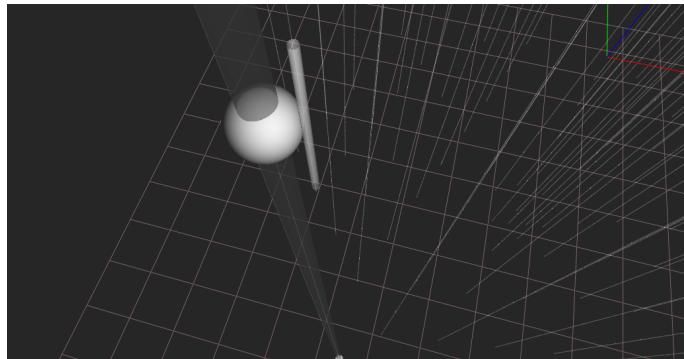
Source: <https://github.com/fiedl/hole-ice-study#asymmetry-example>, <https://github.com/fiedl/hole-ice-study/issues/8>

Separate hole-ice cylinder positions



- Each string can have its own hole-ice cylinder configuration
 - cylinder position
 - cylinder radius
 - DOM positions — DOMs may not be perfectly centred relative to the hole ice
- Currently configurable in Geometry frame.
Q: Is there a better place to configure this?
- Still work to be done:
 - Ice properties need to be configurable for each cylinder: <https://github.com/fiedl/hole-ice-study/issues/9>

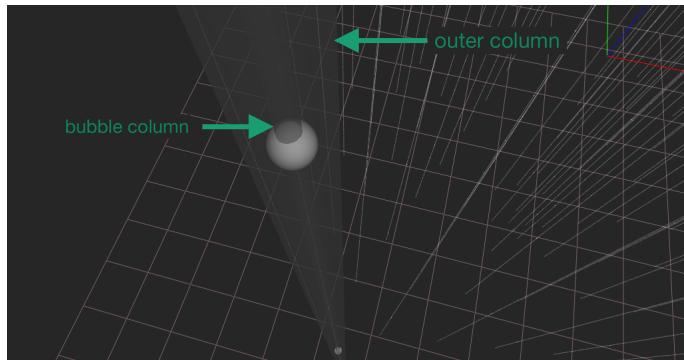
Cable shadows



- Cables can be modelled as separate cylinders
 - for each DOM separate position
 - 1 m height
 - configured for instant absorption
- This image:
 - DOM radius: 16.5 cm
 - bubble-column radius: 8.0 cm
 - cable radius: 2.0 cm
- Still work to be done:
 - Ice properties need to be configurable for each cylinder: <https://github.com/fiedl/hole-ice-study/issues/9>
 - z-range needs to be implemented in hole-ice code: <https://github.com/fiedl/hole-ice-study/issues/34>

Source: <https://github.com/fiedl/hole-ice-study/issues/35>

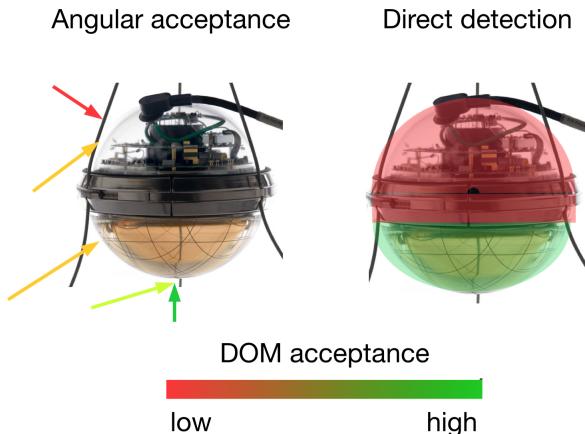
Nested hole-ice cylinders



- Hole-ice cylinders can be nested
 - for each string separate positions
 - for each string and each column separate radii
- This image:
 - DOM radius: 16.5 cm
 - bubble-column radius: 8.0 cm
 - outer-column radius: 30.0 cm
- Still work to be done:
 - Ice properties need to be configurable for each cylinder: <https://github.com/fiedl/hole-ice-study/issues/9>

Source: <https://github.com/fiedl/hole-ice-study/issues/7>

Direct detection



- The DOM looks downwards by design
- Currently, the hit position is not used when determining DOM acceptance, just the photon direction when hitting the DOM (*DOM angular acceptance*)
- Direct detection: Accept all hits below the waist band, reject all others
- Direct detection is easy with `clsim`
 - Hit position is known and guaranteed to be on the DOM sphere
 - Idea: Accept hits depending on z of the hit position
 - Patch is a couple of lines: `fiedl/clsim@96a2e3f`
- Still work to be done:
 - Implement a switch for direct detection vs. DOM angular acceptance

<https://github.com/fiedl/hole-ice-study/issues/32>

Source: Image: Martin Rongen, *Status and future of SpiceHD DARD*, 2017, Slide 17,
See also: <https://github.com/fiedl/hole-ice-study/issues/32>

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
- Study performance impact
- See also: <https://github.com/fiedl/hole-ice-study/issues>

Martin's wish list

Feature	Possible	Done	In progress	Will be done by me
Separate hole-ice positions for each string	✓	✓		
Nested cylinders: Bubble column and outer column	✓		✓	yes
Cable shadows using cylinder parts	✓		✓	yes
Direct detection	✓		✓	yes
Absolute scattering and absorption lengths in hole ice (better description of current understanding of hole ice than relative properties)	✓			?
Vertical gradient of scattering length in bubble column	✓			no

See also: List of issues on github: <https://github.com/fiedl/hole-ice-study/issues>

Thanks for your attention!

Any input you might have is welcome:

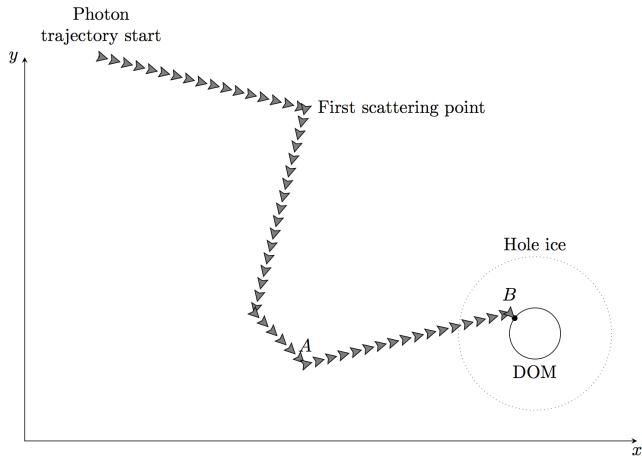
<https://github.com/fiedl/hole-ice-study/issues>

Slack: @fiedl

Video illustration of a simple example:

<https://youtu.be/BhJ6F3B-I1s>

Naive propagation algorithm



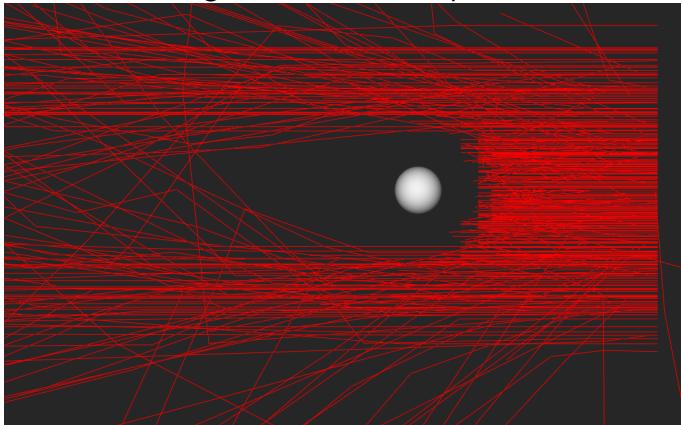
Naive algorithm:

- Propagate photon a tiny distance
 - At current position:
 - Check for random scattering
 - Check for random absorption
 - Check for collision with DOM
- **Hole ice is easy** because all ice properties can be locally evaluated
- **But performance is bad** because there are lots of simulation steps even for long distances without interaction

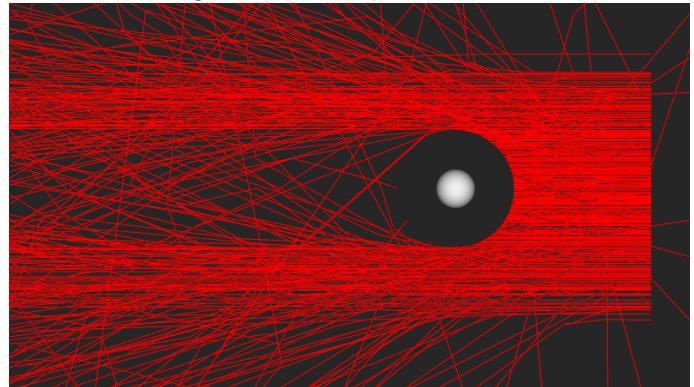
Coordinates-vs-vectors bug

Scenario: Instant absorption. Top view. Mathematics of intersection calculations and starting conditions are the same in both figures.

Before: Treating coordinates as separate variables

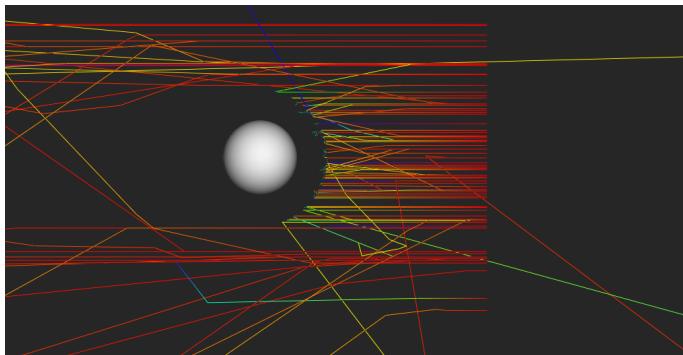


After: Treating vectors as opencl-native vectors



Source: <https://github.com/fiedl/hole-ice-study/issues/28>

Scattering example



- Hole-ice absorption length: about 5 cm
- Hole-ice scattering length factor: 0.001

```
$ICESIM/env-shell.sh
cd $HOLE_ICE_STUDY/scripts/FiringRange
./run.rb --scattering-factor=0.001 --absorption-factor=0.00033 --distance=1.0
--> --number-of-photons=100 --number-of-runs=1 --number-of-parallel-runs=1
--> --save-photon-paths --cpu --plane-wave
steamshovel tmp/propagated_photons.i3
```
