# Simulation of photon propagation in water for large scale underwater Cherenkov neutrino telescopes

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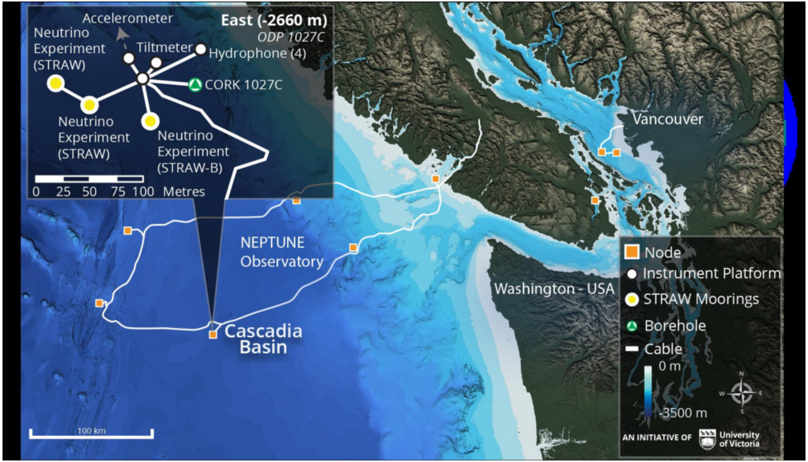
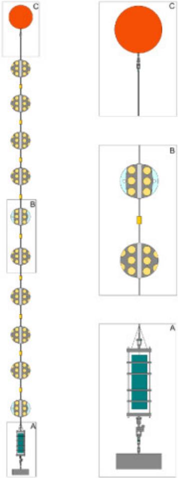
KISD seminar
Kraków 2023-04-21

P-ONE

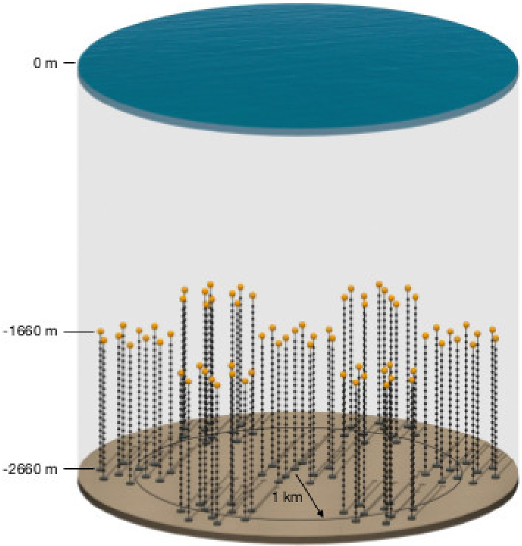
THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

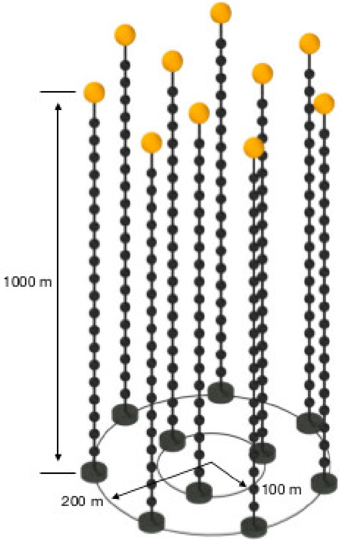
# Pacific Ocean Neutrino Telescope



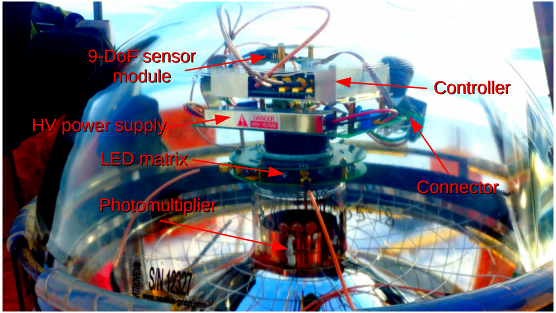
# P-ONE design



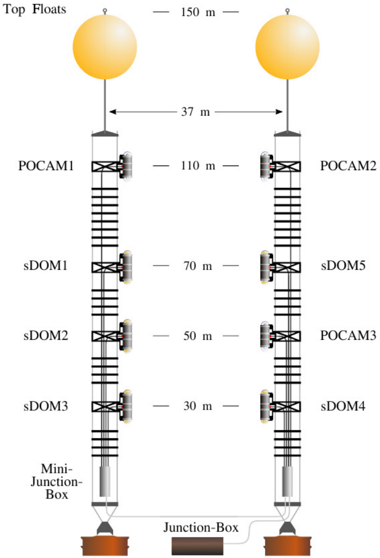



# Eye of the telescope – Optical Module

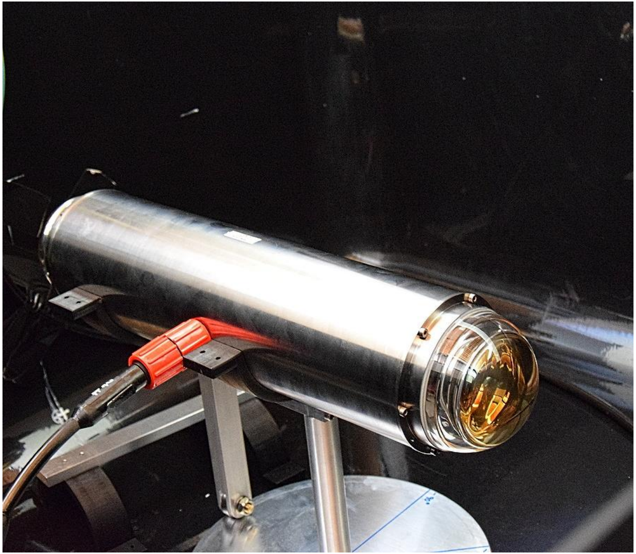
# Eye of the telescope – Optical Module in Baikal-GVD



# Pathfinder – STRAW-a

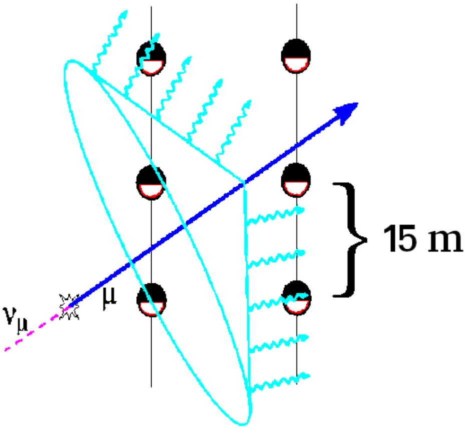


# STRAW-a devices

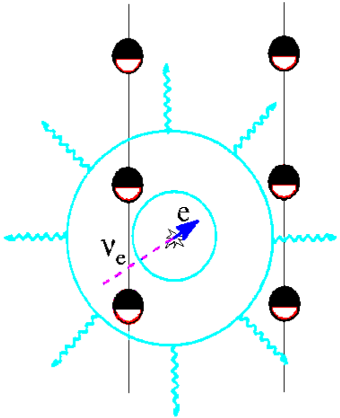


# How to observe a neutrino interactions?

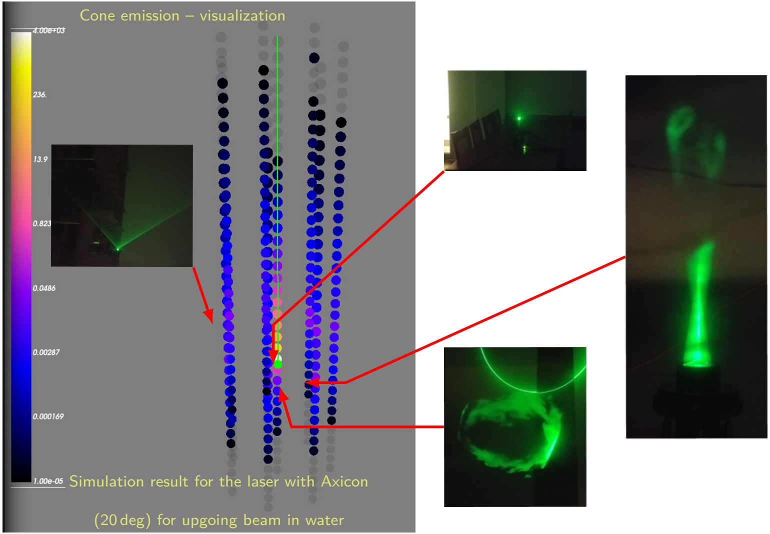
$\sim$km-long muon tracks from $\nu_\mu$




$\sim$10m-long cascades from $\nu_e$, $\nu_\tau$



# Observer position – observed result




- Medium: air
- Observation conditions: Distributed mist from air humidifier (~65 %RH, ~21 °C)

# Ray Tracing – introduction

## Ray Tracing

Forward or Backward Ray Tracing (RT) are methods for calculate effects of particle propagation in medium

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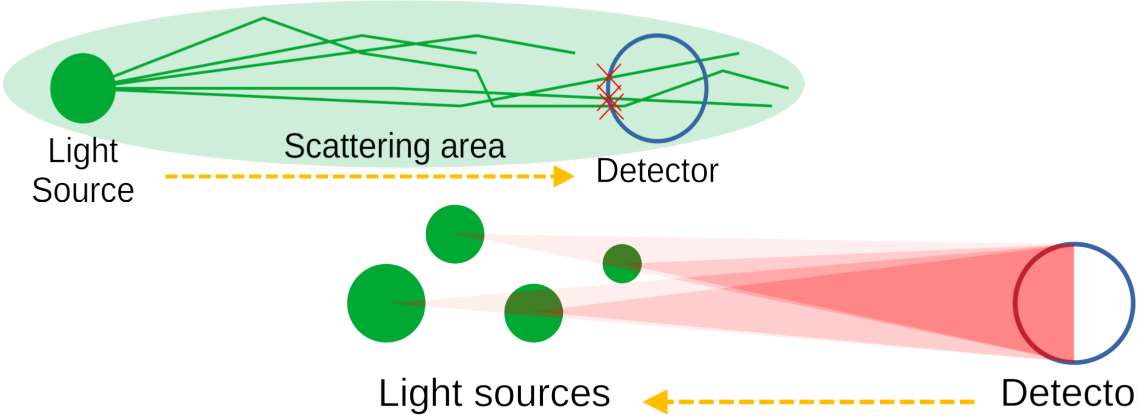
## Pretorian

Own environment for fast simulation of light propagation in water

# Basic Ray Tracing methods

FORWARD RAY TRACING




BACKWARD RAY TRACING

# Scattering and absorption

Light scattering in medium can be described by phase functions. The Henyey-Greenstein Phase Function[1] was used because of one-parameter description of forward and backward scattering relations. For more complex medium another function should be used, but method can be the same.

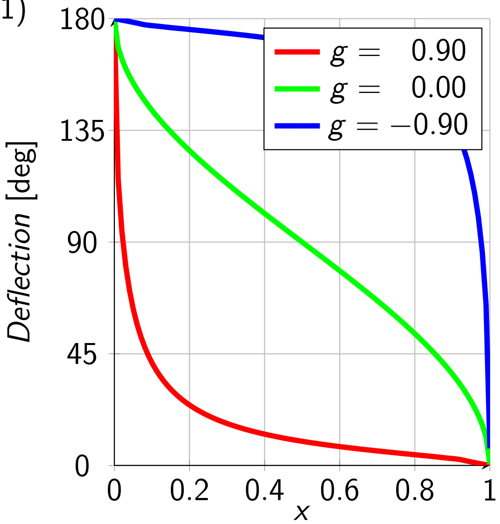
$$p(\theta, g) = \frac{1}{4\pi} \frac{1 - g^2}{(1 + g^2 - 2g\cos\theta)^{3/2}}, \tag{1}$$

where $g$ adjust forward to backward scattering ratio ($1 \rightarrow$ only forward, $0 \rightarrow$ isotropic and for $-1 \rightarrow$ only backward scattering), $\theta$ is scattering angle. Integral of this function over $4\pi$ steradians is unity.

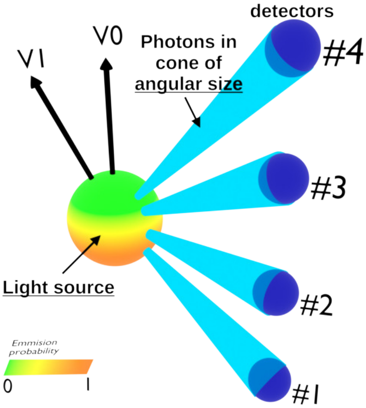
[1] Henyey, L. G. and Greenstein, J. L., "Diffuse radiation in the Galaxy.", *The Astrophysical Journal*, vol. 93, pp. 70–83, 1941. doi:10.1086/144246

# Photon propagation

**procedure** $\xi$
    **return** random uniformly distributed $[0:1)$
**end procedure**
**procedure** DEFLECTION$(x,g)$
    **return** $\frac{1}{2g}\left(1+g^2-\frac{1-g^2}{1+g(2x-1)}\right)$
**end procedure**
**if** $\xi < \frac{\frac{1}{L_a}}{\frac{1}{L_a}+\frac{1}{L_s}}$ **then**
    absorption
    $\Delta\phi = 0, \Delta\theta = 0$
**else**
    scattering
    $\Delta\phi = 2\pi\xi, \Delta\theta = \text{DEFLECTION}(\xi,\text{g})$
**end if**
$\Delta s = \frac{-log(\xi)}{\frac{1}{L_a}+\frac{1}{L_s}}$



# Phase function integration

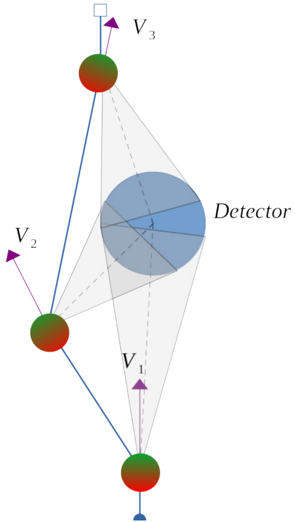



Parametrization of light source is scattering phase function (Eq. 1). By integrating over the surface limited by the cone we can obtain number of photons emitted from this slice.

For isotropic source ($g = 0$) number of photons is simply related to surface of the slice.

For $g = 1$ source behave like collimated laser beam.

# Hybrid Ray Tracing




1. Propagate photons by Forward RT and check intersections
2. New light sources at scattering points
3. Calculate number of photons from new light sources

- New light sources are parametrized by scattering function
- To calculate how many photons reached the detector from these sources, use the Backward RT (include propagation effects)

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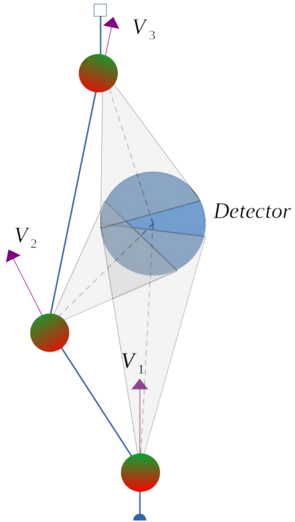


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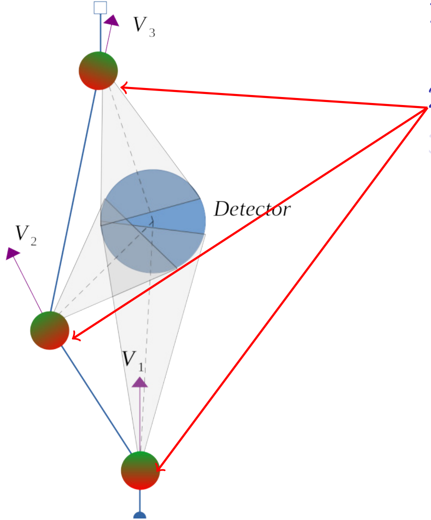


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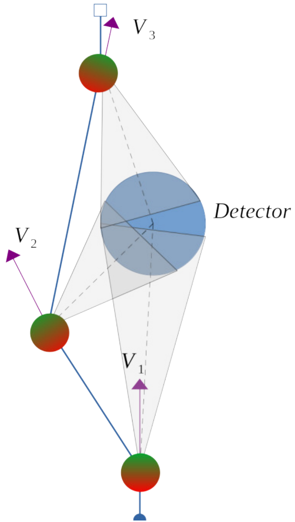


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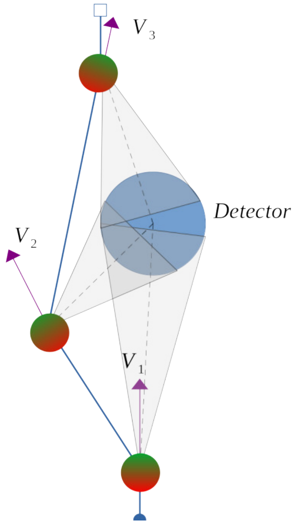


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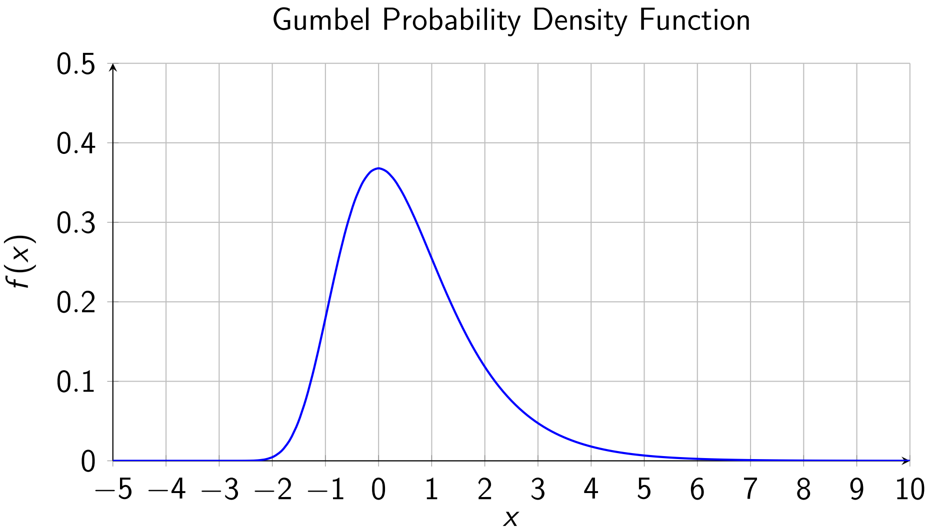
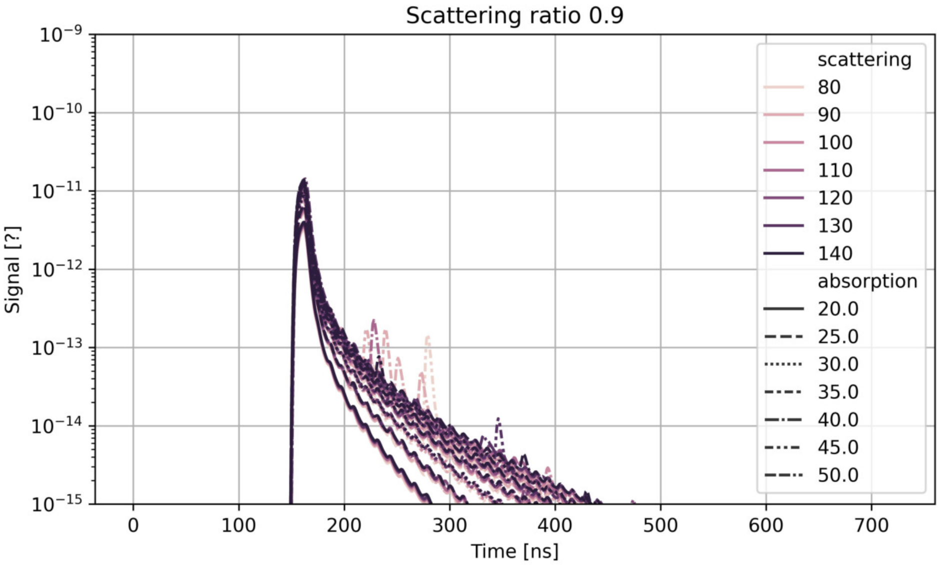
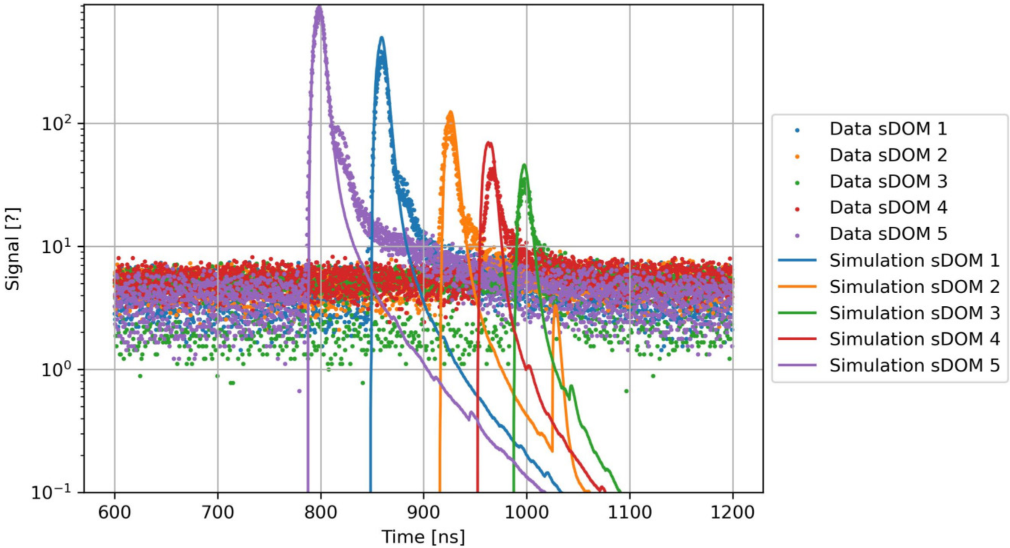
# How convert photons to signal?



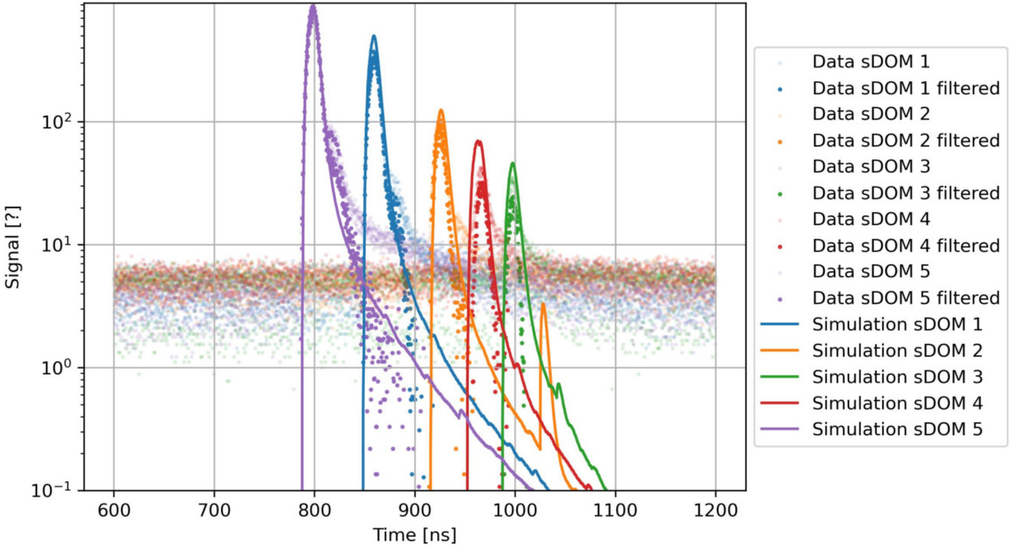
# Pathfinder – STRAW simulations



# STRAW simulations vs data



# STRAW simulations vs data without noise?




Thank You!