IceCube-Gen2における新型光検出器D-Eggの南極氷河特性較正用LEDの最適化

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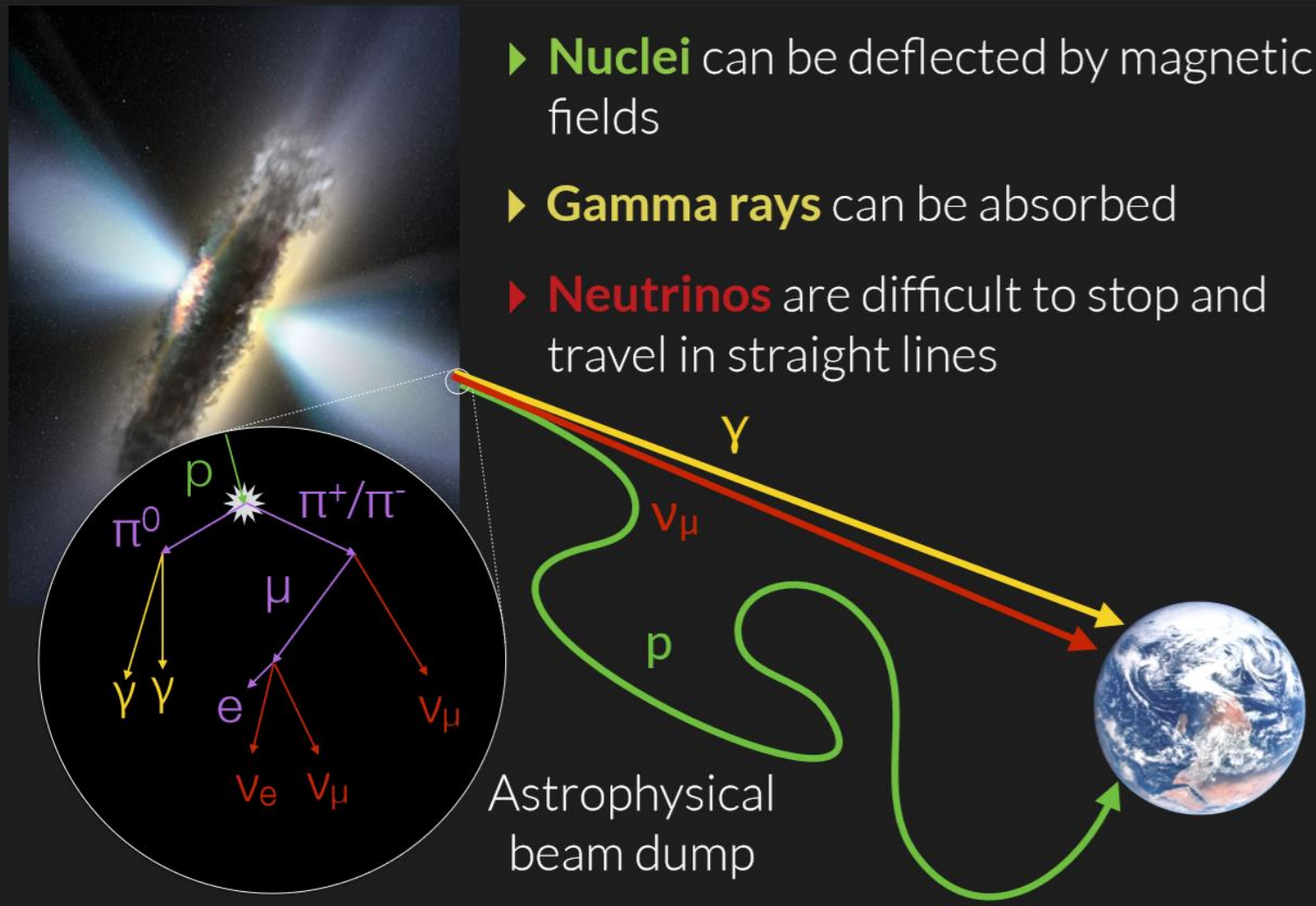
ICECUBE GEN2

自己紹介

- 桐木彩由美
- 千葉大学大学院修士1年
- IceCube千葉大グループ所属 (2017年4月~)
- IceCube-Gen2用検出器開発
- Geant4 simulation

Neutrino astronomy

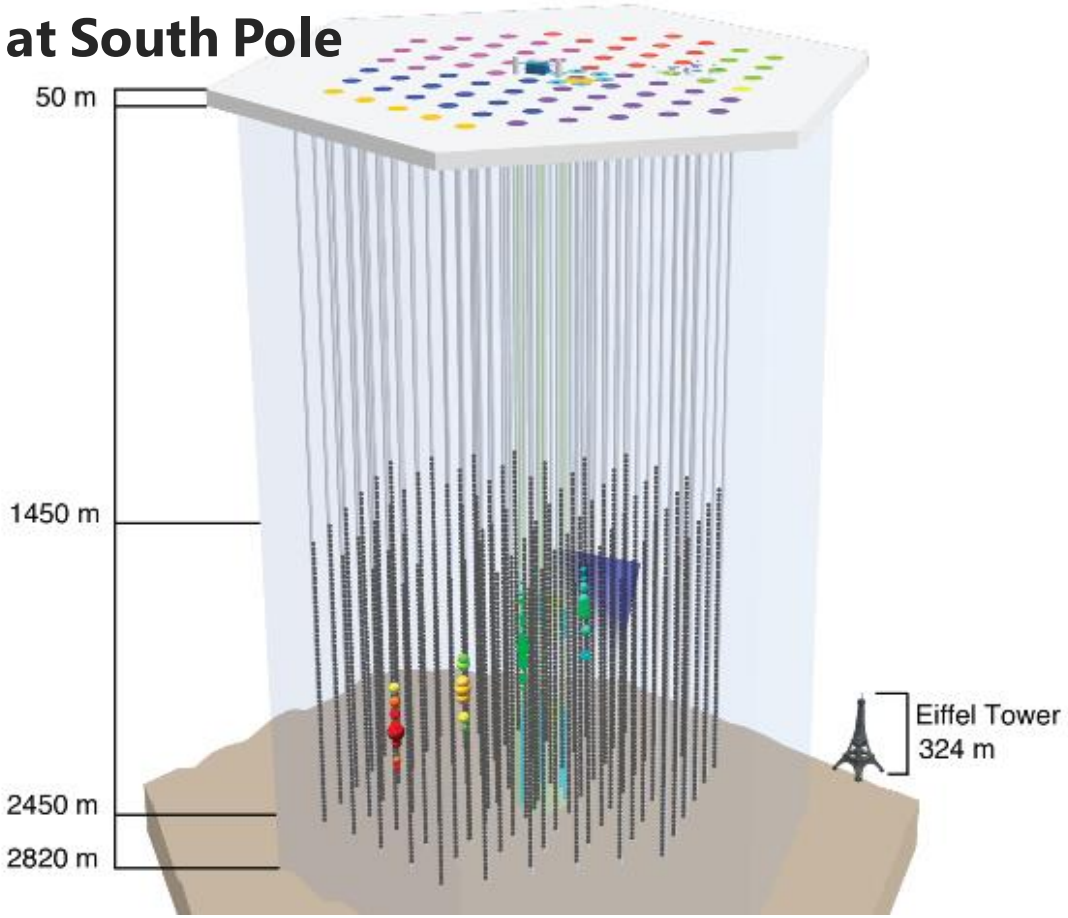


Physics of astrophysical neutrino sources

=physics of cosmic ray sources

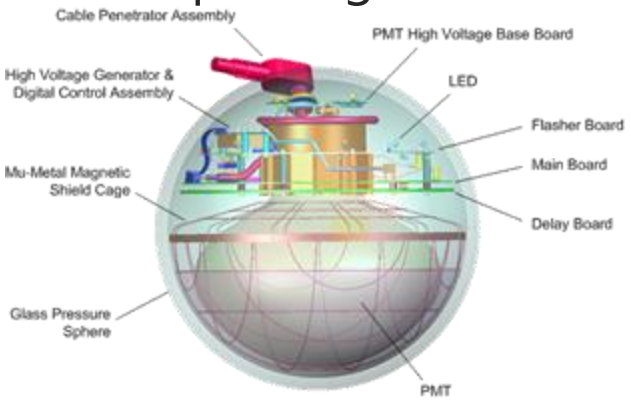
IceCube neutrino observatory

Observatory for high-energy neutrinos at South Pole



Digital optical module "DOM"

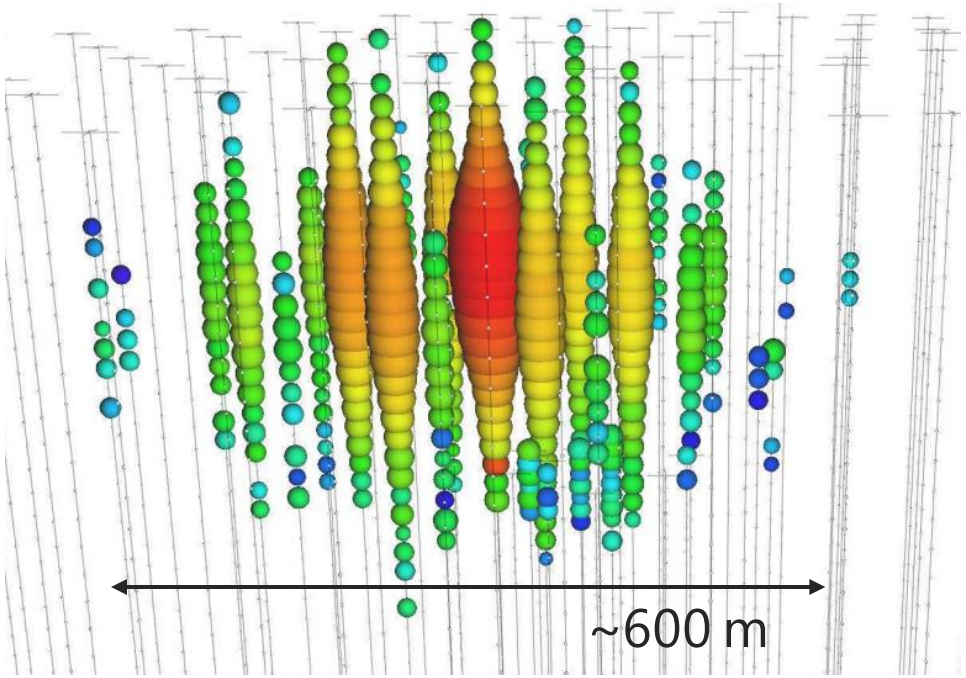
- 10" PMT looking down in sphere glass
- 60 DOMs on each of 86 strings



- Neutrinos interact with atoms in the ice
- Cherenkov photons from secondary particles are detected by DOMs
- light pattern allows to reconstruct particle direction and energy

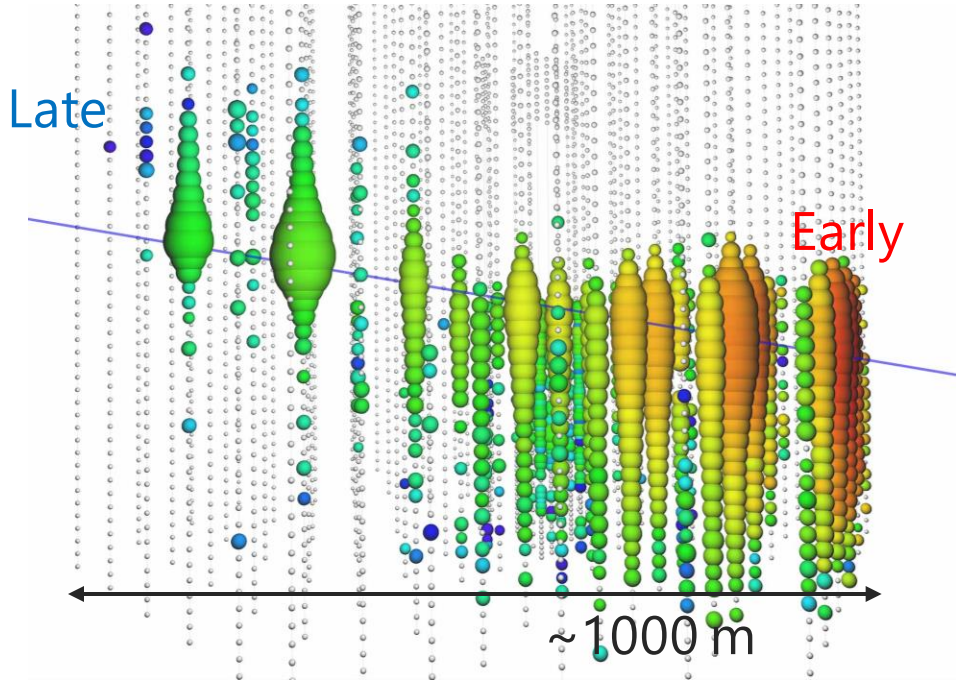
Neutrino event types

Cascade-like events



- Charged current interactions of ν_e, ν_τ
- Neutral current interactions

Track-like events



- Charged current interactions of ν_μ
- Good angular resolution of 1°

IceCube-Gen2 project

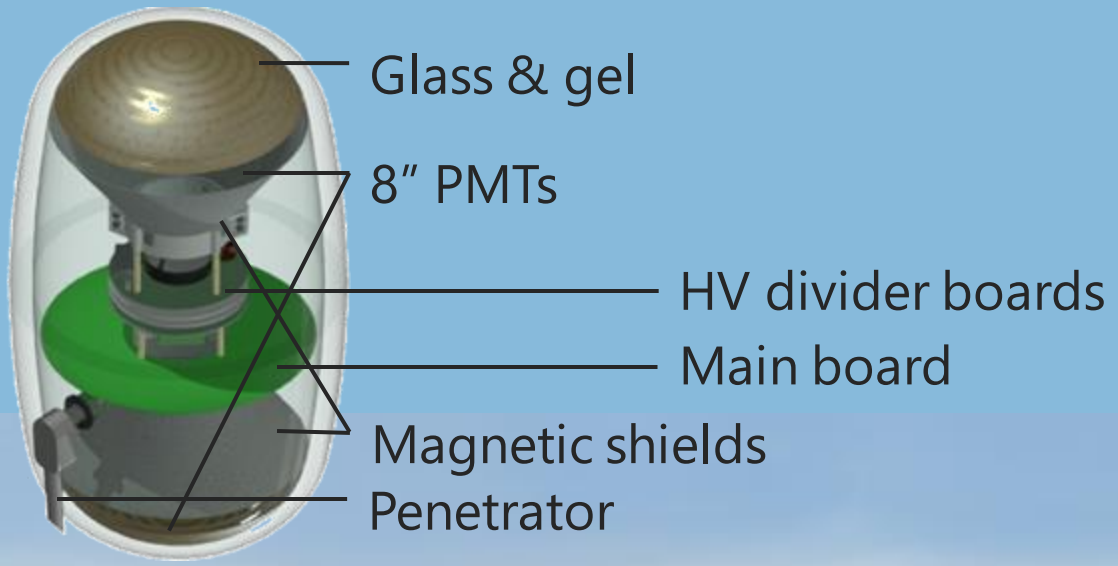
Envisioned IceCube-Gen2

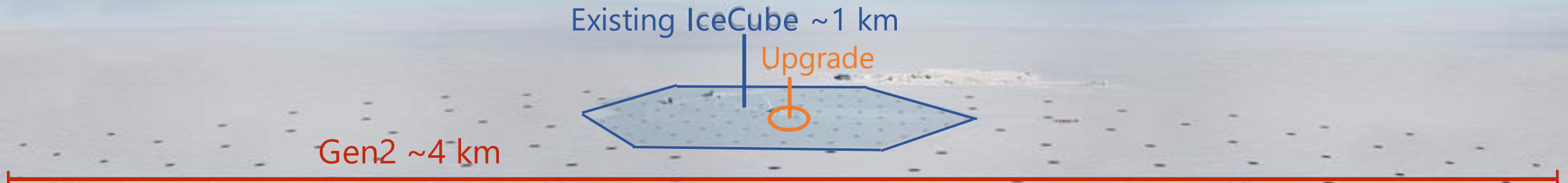
+ 120 strings, 10,000 new modules

Phase 1, "IceCube Upgrade"

+ 7 strings, 100—125 new modules / string

New module from Chiba, "D-Egg"

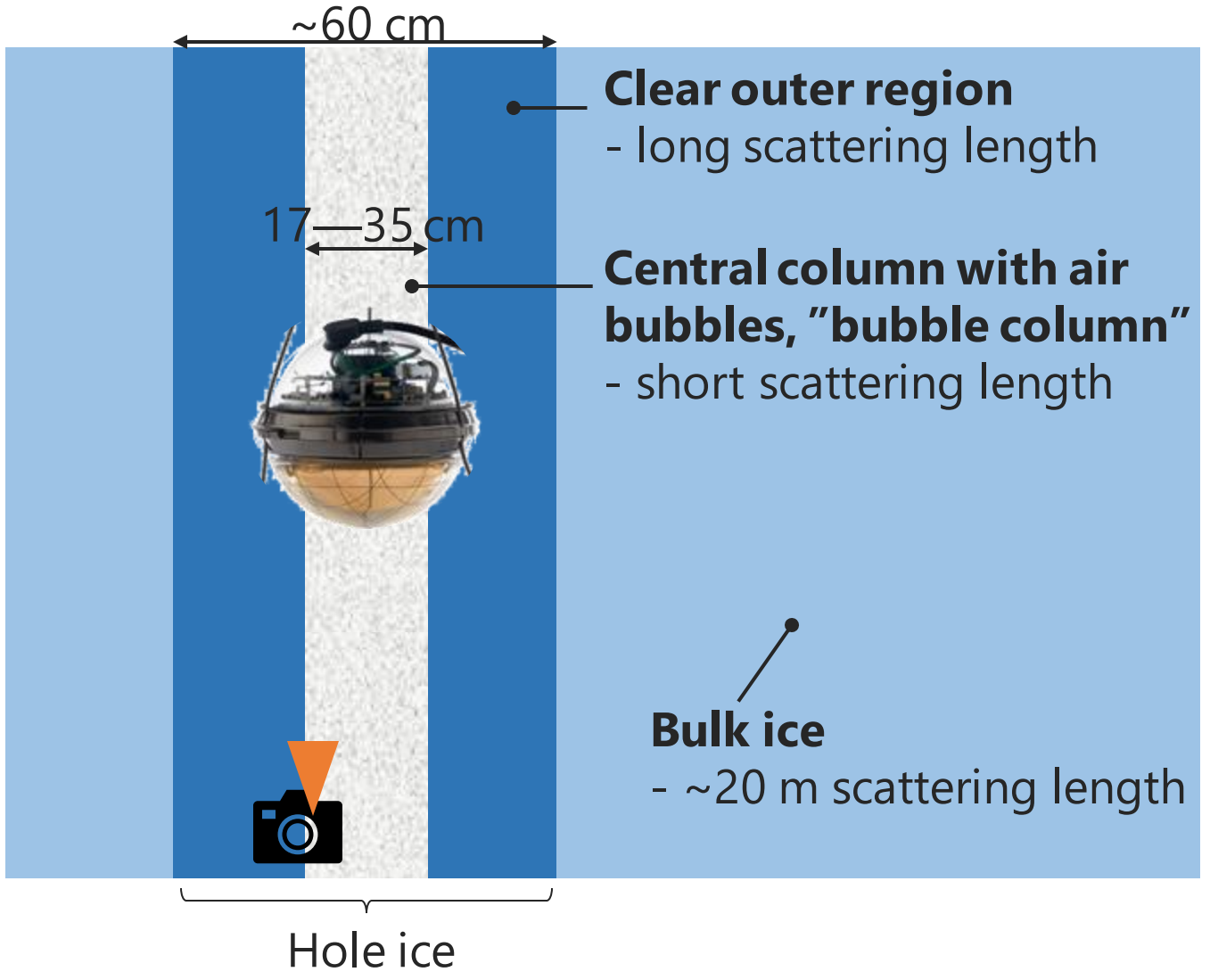




Hole ice

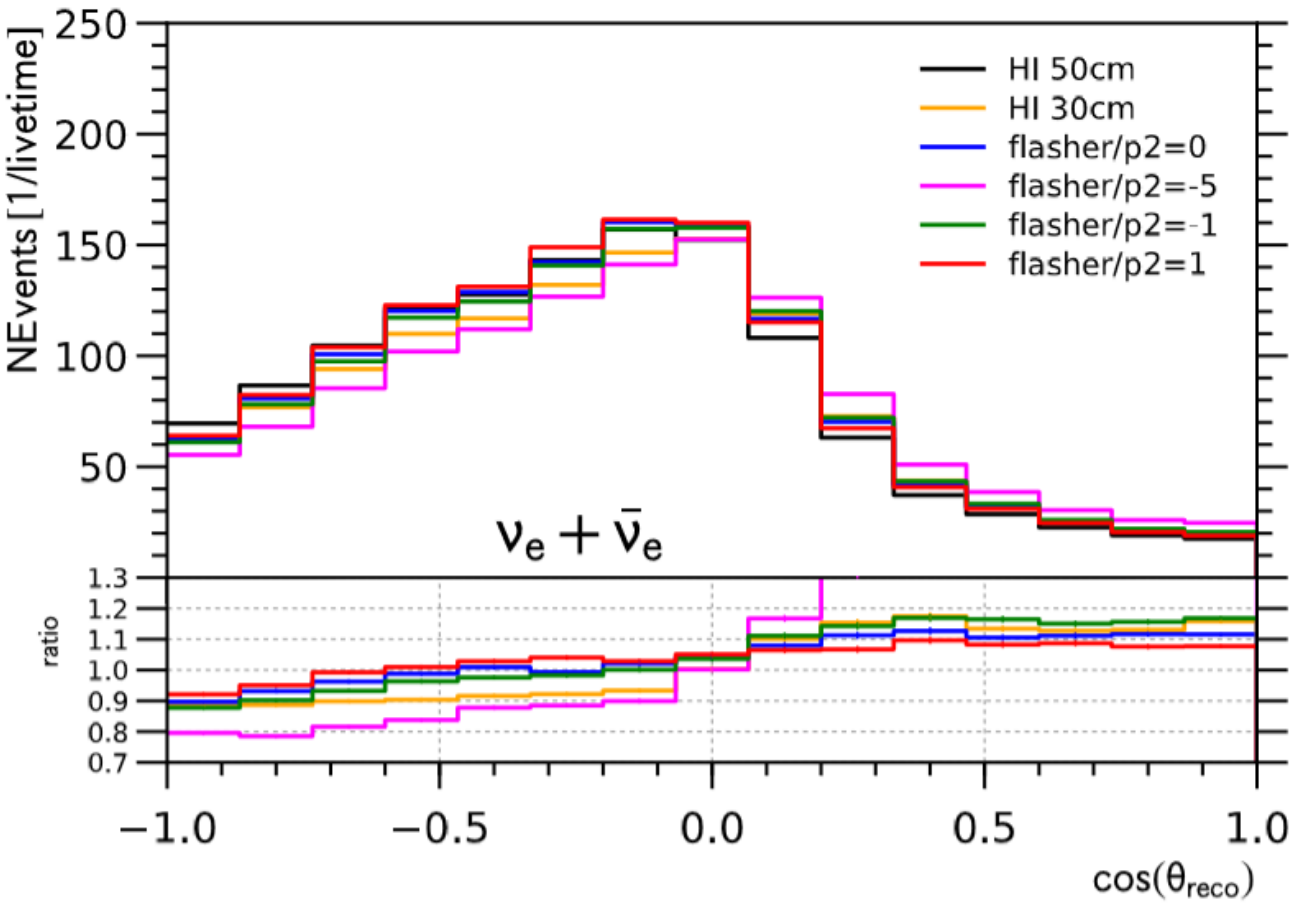
- Refrozen water in the drill holes
- Not well understood

Hole ice seen by camera



Importance of hole ice properties

Hole ice model has significant effects on reconstructions of cascade events



- Above ~1 TeV
- A mix of cosmic and atmospheric neutrinos
- Reconstructed arrival directions of electron neutrinos

- Results largely depend on the choice of the hole ice model

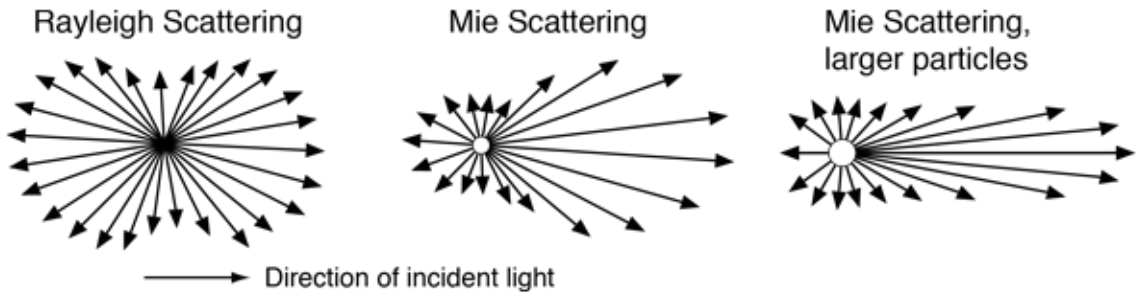
  → the uncertainty of hole ice needs to be improved

Mie scattering

Light scattering

Target size $\lesssim$ wavelength/10 $\Rightarrow$ Rayleigh scattering

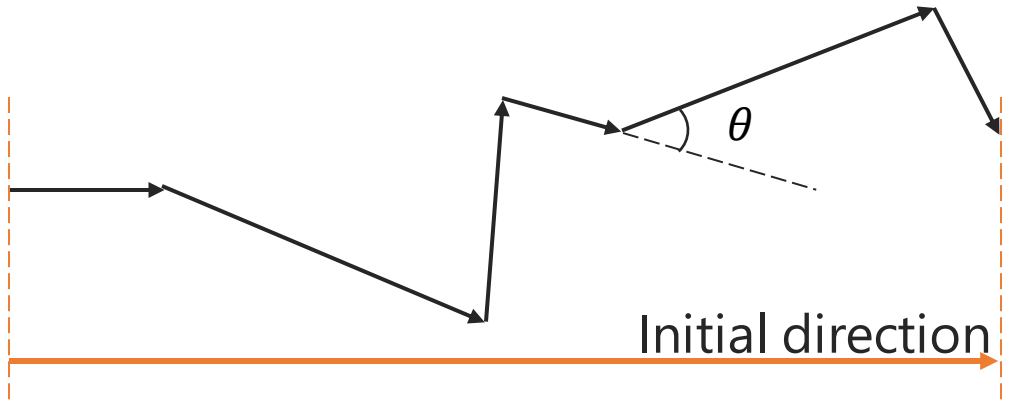
Target size $\gtrsim$ wavelength/10 $\Rightarrow$ Mie scattering



Forward peaked scattering

Parameters of Mie scattering

- $\langle \cos\theta \rangle$: average cosine of scattering angle
- λ_s: average distance between scatterings



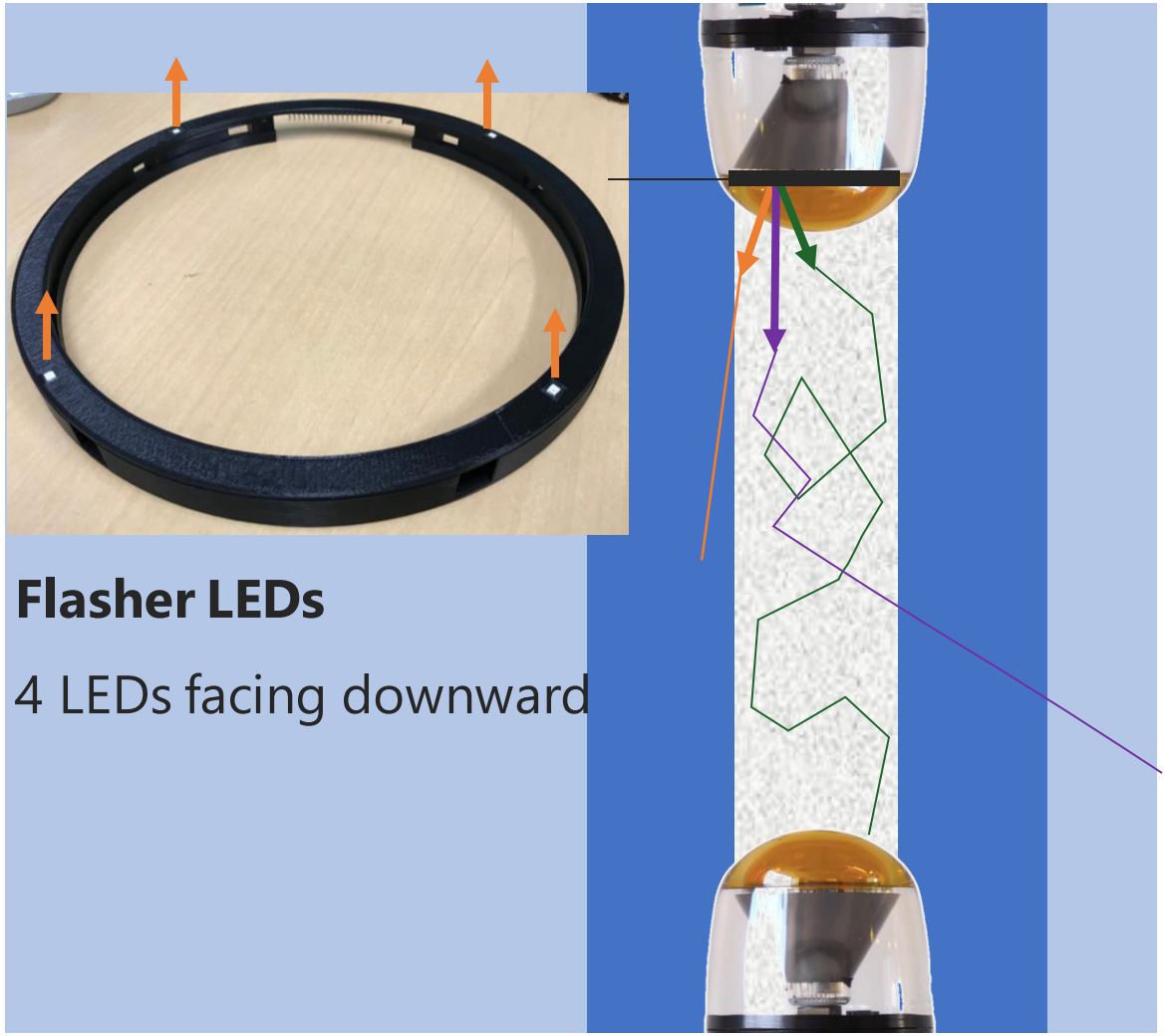
$\lambda_s \langle \cos\theta \rangle^n$ after n steps

$\downarrow \quad n \to \infty$

- $\lambda_e = \frac{\lambda_s}{1-\langle \cos\theta \rangle}$: effective scattering length

http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html

Hole ice measurements with D-Egg



Flasher LEDs

4 LEDs facing downward

Things to be understood

- Bubble size & distribution $\Leftrightarrow \langle \cos\theta \rangle$ & λ_s
- Bubble column diameter

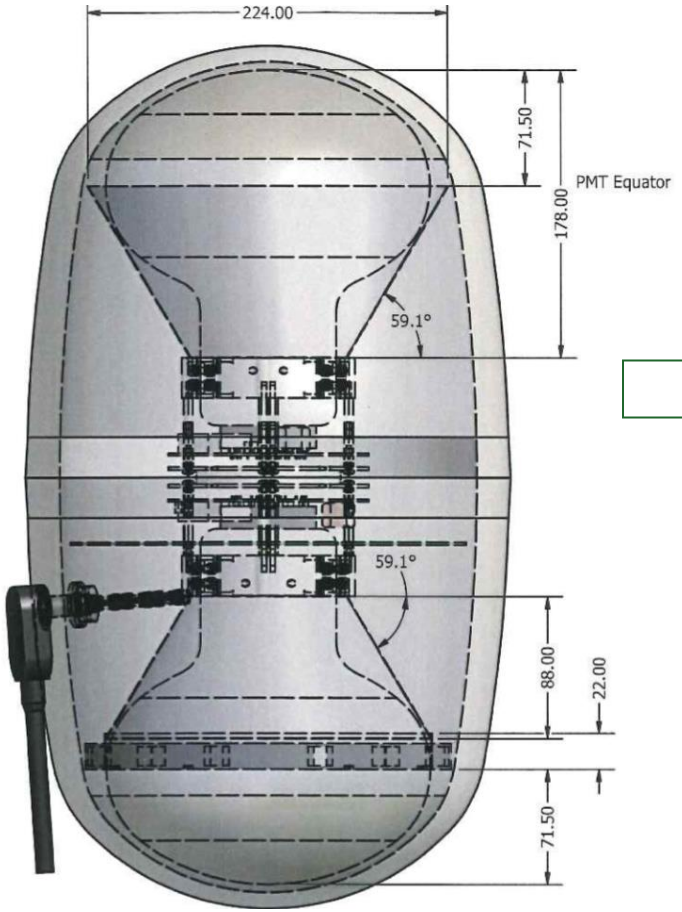
Things to do

- Optimize LED profiles;
  Time profile / Intensity / wavelength
- Find observables sensitive to the hole ice properties

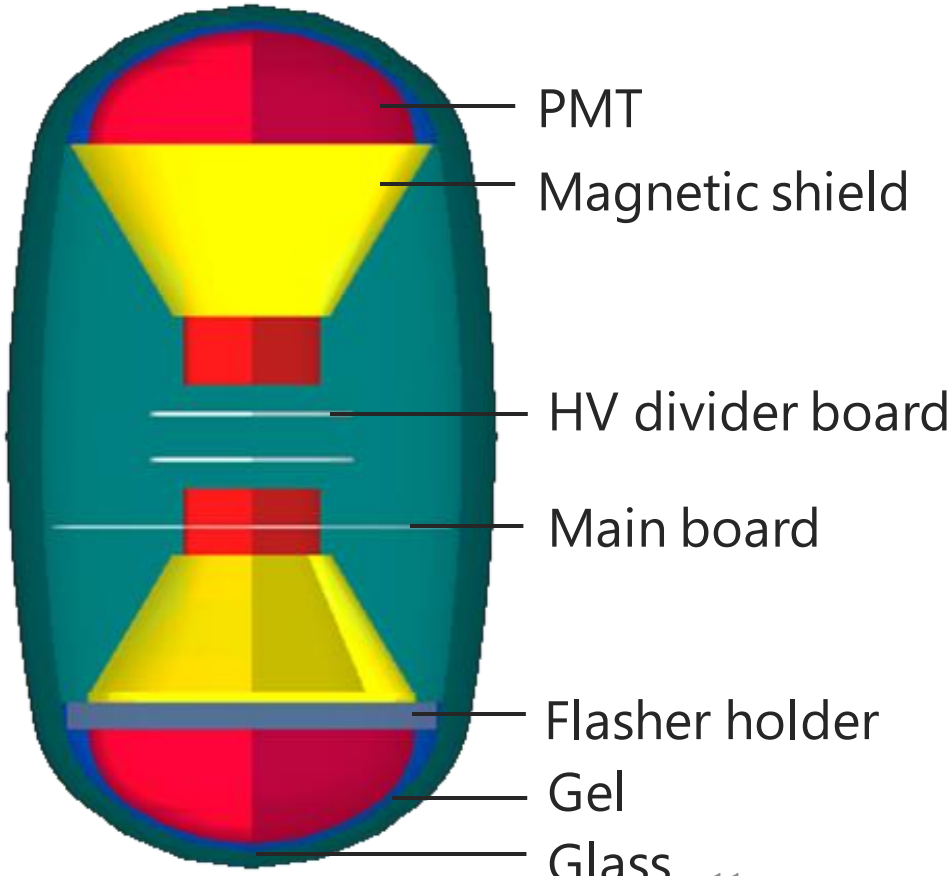
Implementing D-Egg to GEANT4

Actual D-Egg

CAD file



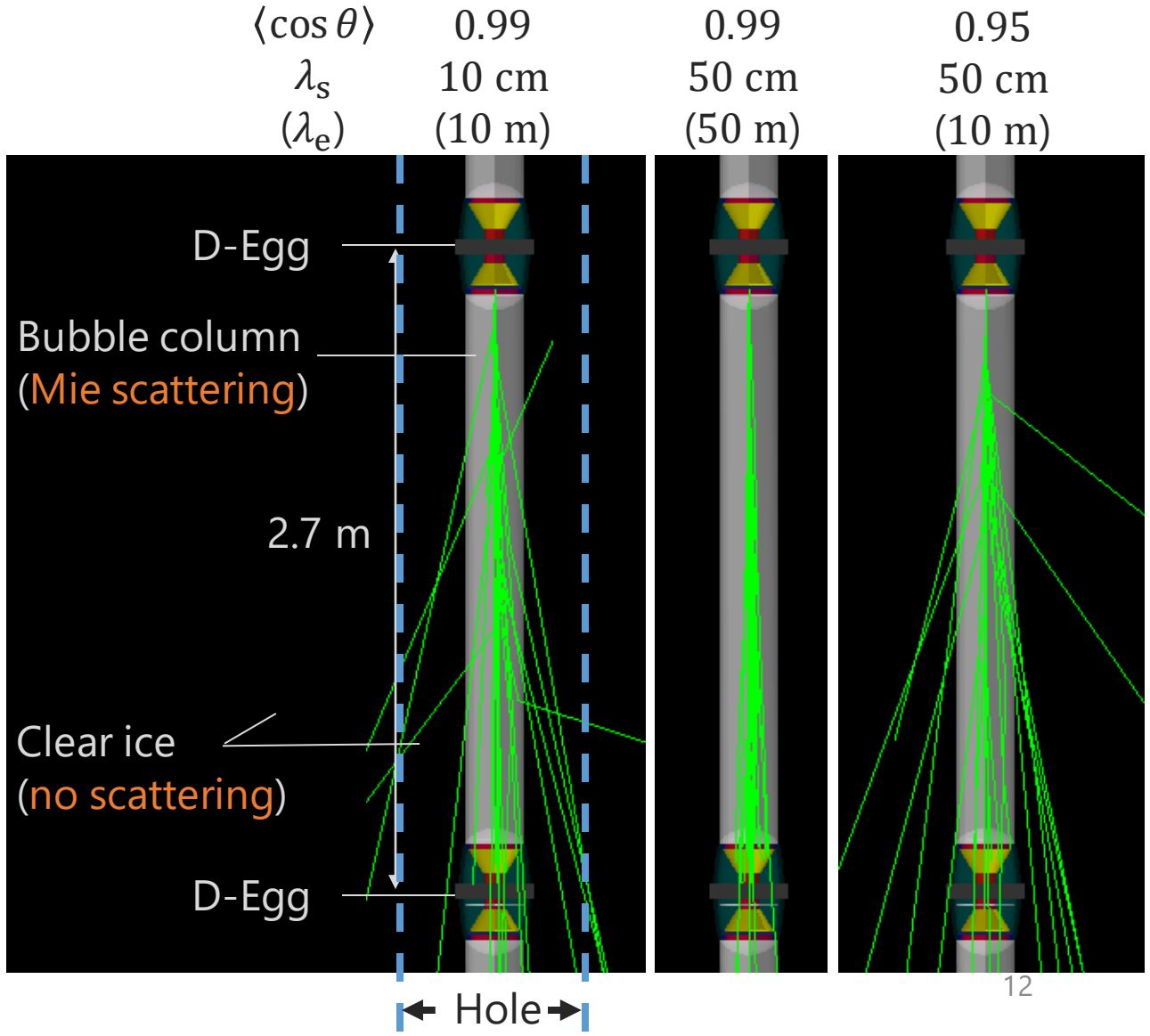
D-Egg in GEANT4



Simulation setting

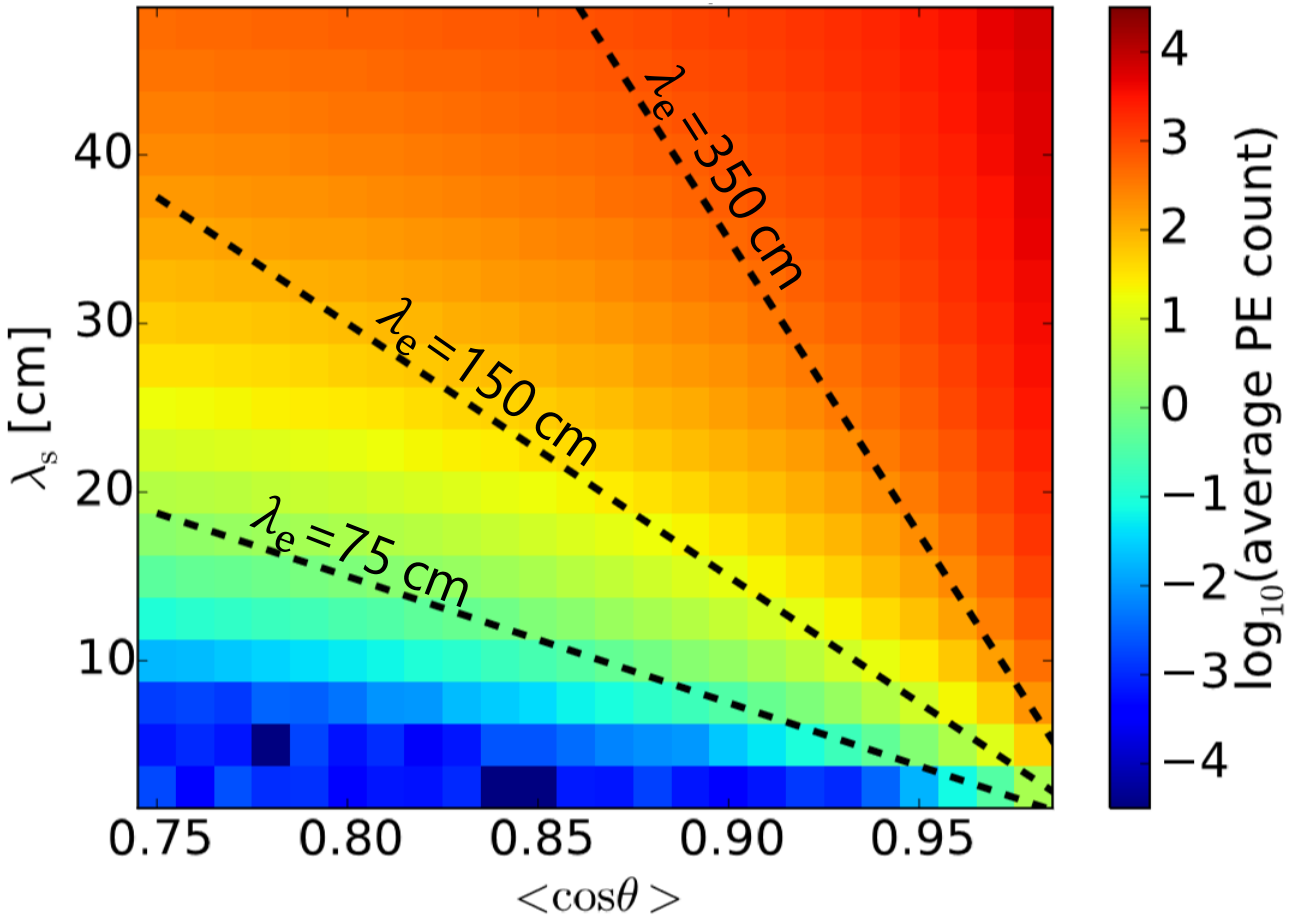
- Light source:
  - Perfectly collimated
  - Wavelength 405 nm
  - 10^5 photons

- Simulated distribution of photons on photo cathodes with different values of $\langle \cos\theta \rangle$, λ_s and bubble column size
- Took into account PMT response (QE, CE)
- Checked how sensitive #PEs is to the parameters of hole ice

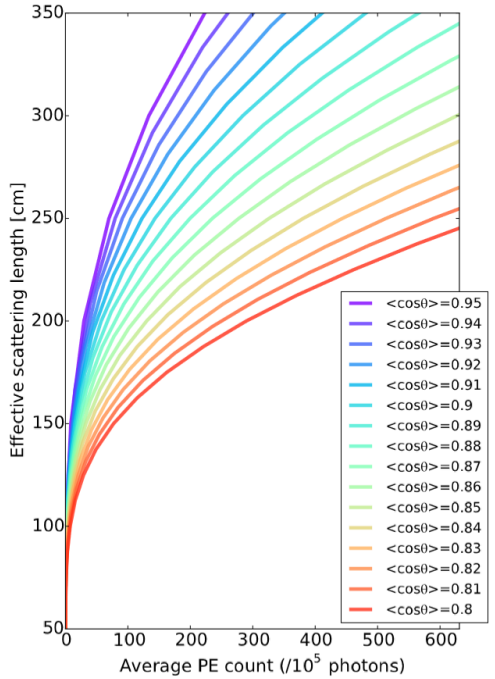


$\langle \cos\theta \rangle$ & λ_s

Bubble column size: 25 cm

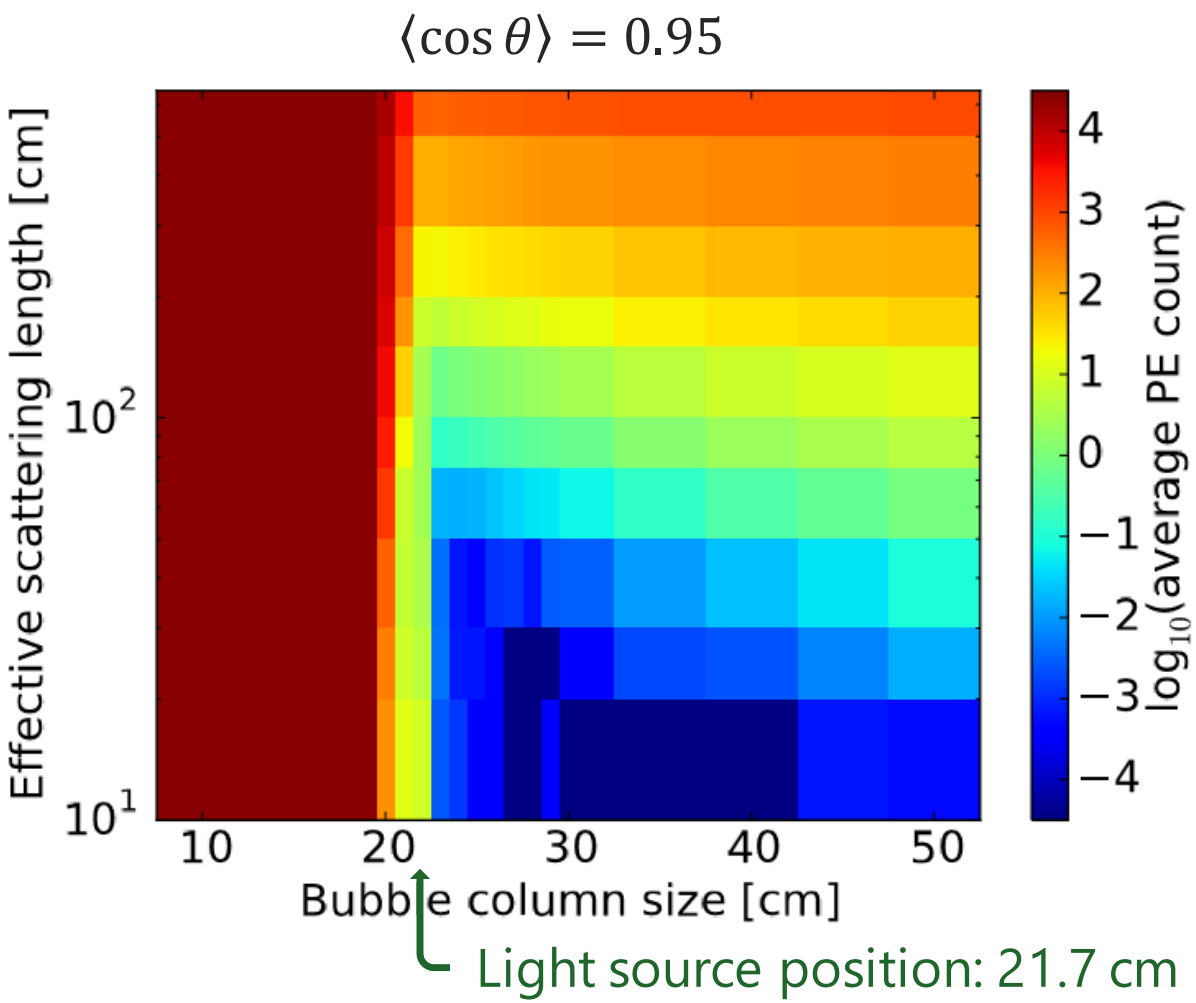


- Less PEs as smaller $\langle \cos\theta \rangle$, shorter λ_s
- $\lambda_e = 75$—350 cm: Estimated region until now(?)
- Effective scattering length can be determined to be in a certain region→

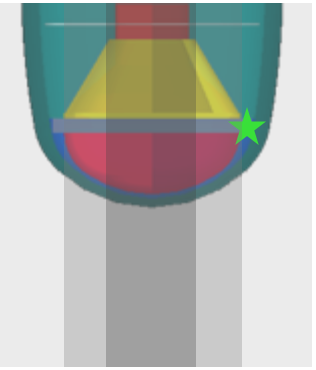


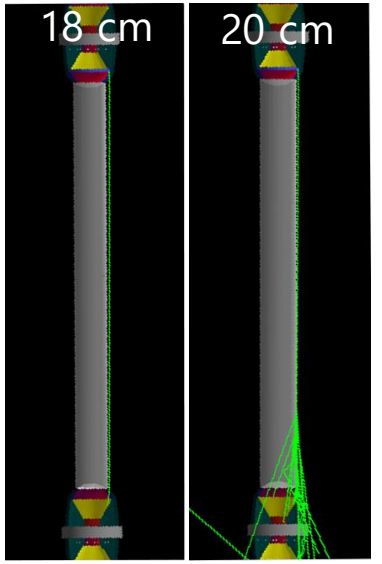
Different bubble column size→

Bubble column size & λ_e



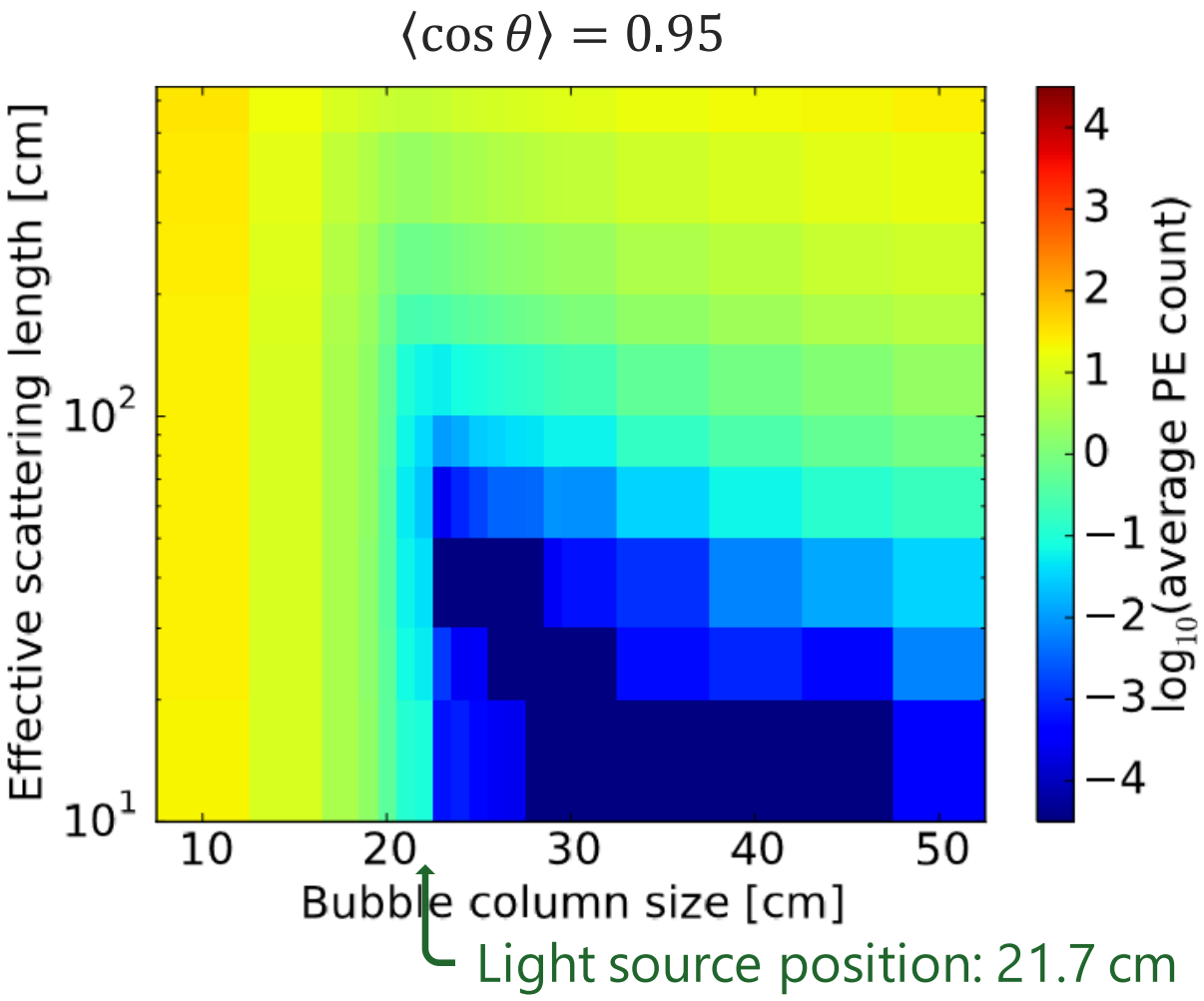
- When large bubble column, more PEs as larger bubble column
  …Bubble column traps photons
- When small bubble column, no difference among bubble column sizes and scattering lengths
  …All photons arrive at the photo cathode through only clear ice

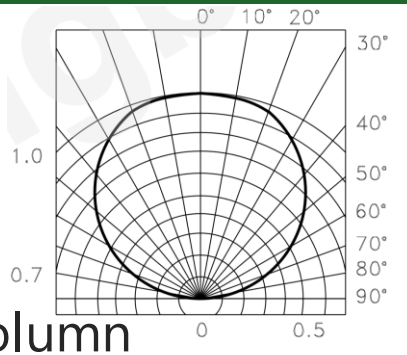




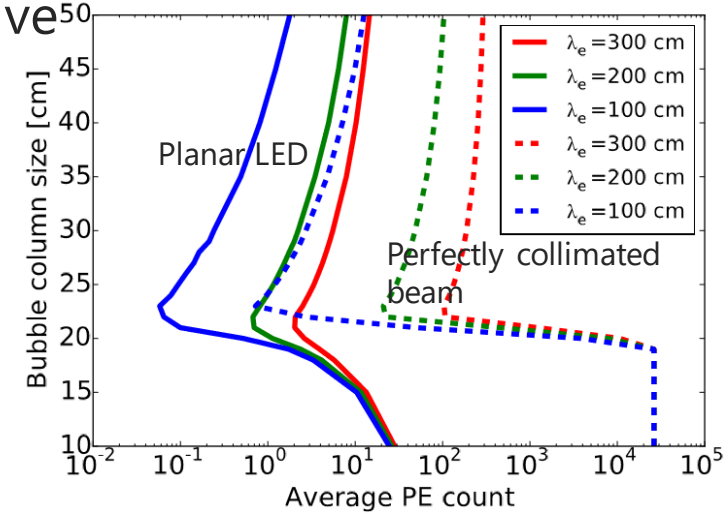
Wide angle LED→

Bubble column size & λ_e



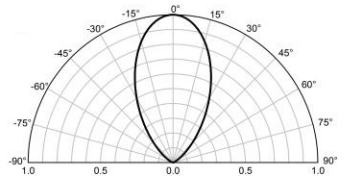


- Planar LED
- When large bubble column, more PEs as larger bubble column
- When small bubble column,
  - less PEs as larger bubble column
  - not sensitive to λ_e

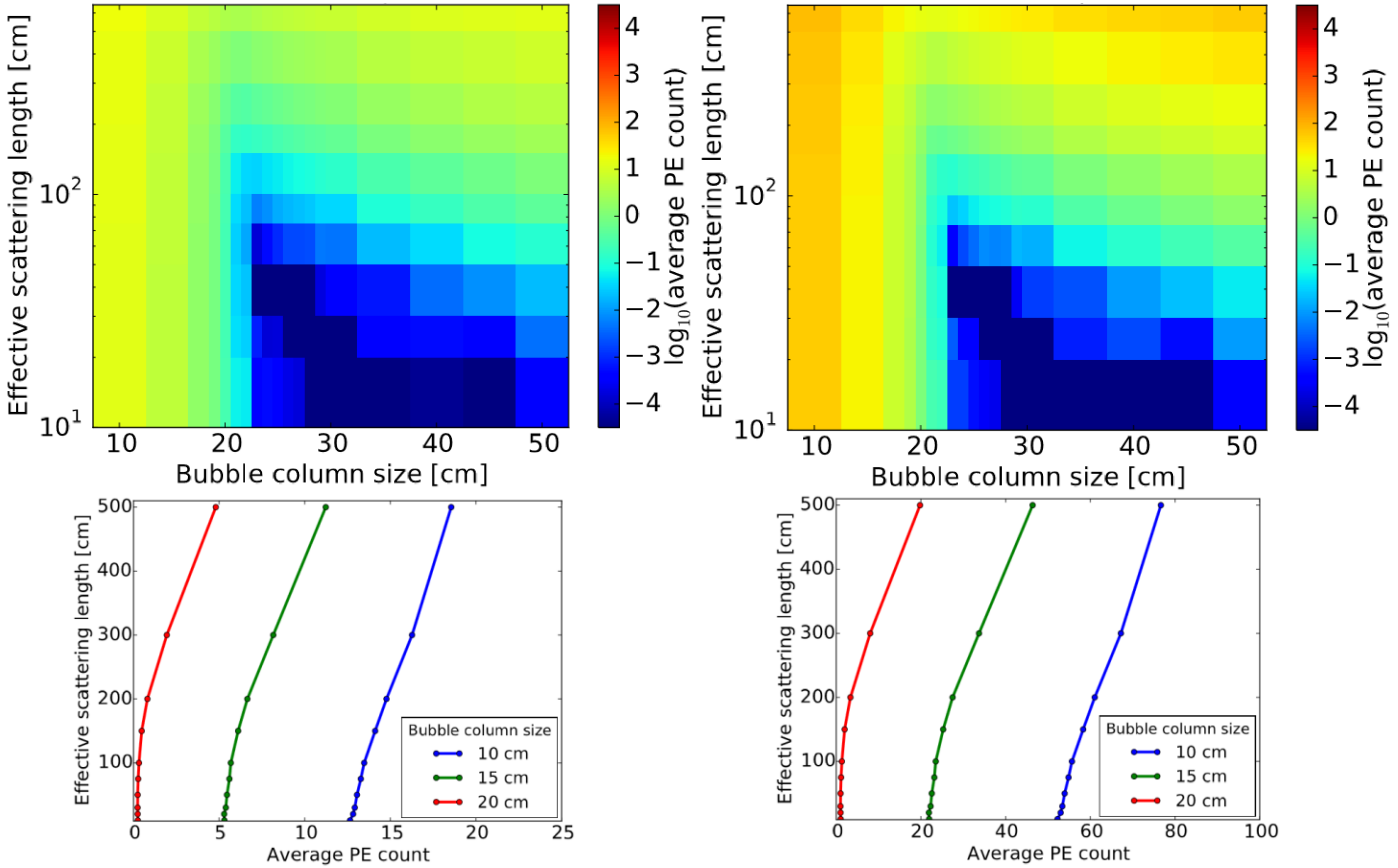


Bubble column size & λ_e

$\langle \cos\theta \rangle = 0.95$



Hemispherical LED



Parabolic LED

- Difficult to determine scattering length if small bubble column
- Remaining task:
  - ✓ To find a way to measure scattering length when small bubble column
  - ✓ To estimate #photons required to measure short scattering length

Outlook

- Independently understanding of the 3 parameters of hole ice: $\langle \cos\theta \rangle$, λ_s and bubble column size
  - Detection by other D-Eggs
  - Cameras inside D-Eggs
    →Probably the best way to know bubble column shape
- Systematic errors:
  - Intensity and angular distribution of LEDs
  - Alignment of 2 D-Eggs

Summary

- Hole ice is the refrozen ice in drilled holes
- Hole ice measurement is one of the major purposes of IceCube Upgrade
- D-Egg has flasher LEDs for hole ice study and now under development
- Goal of this study is to decide properties of flasher LEDs with GEANT4 simulations
- Simple ideal setting is introduced as a first simulation
- Checked how sensitive #PEs is to bubble column size and Mie scattering parameters (3 in total)
- In this setting, when 2 of the parameters are fixed, #PEs shows differences among the other parameter if bubble column is larger than light source position
- Another way of measurement is needed