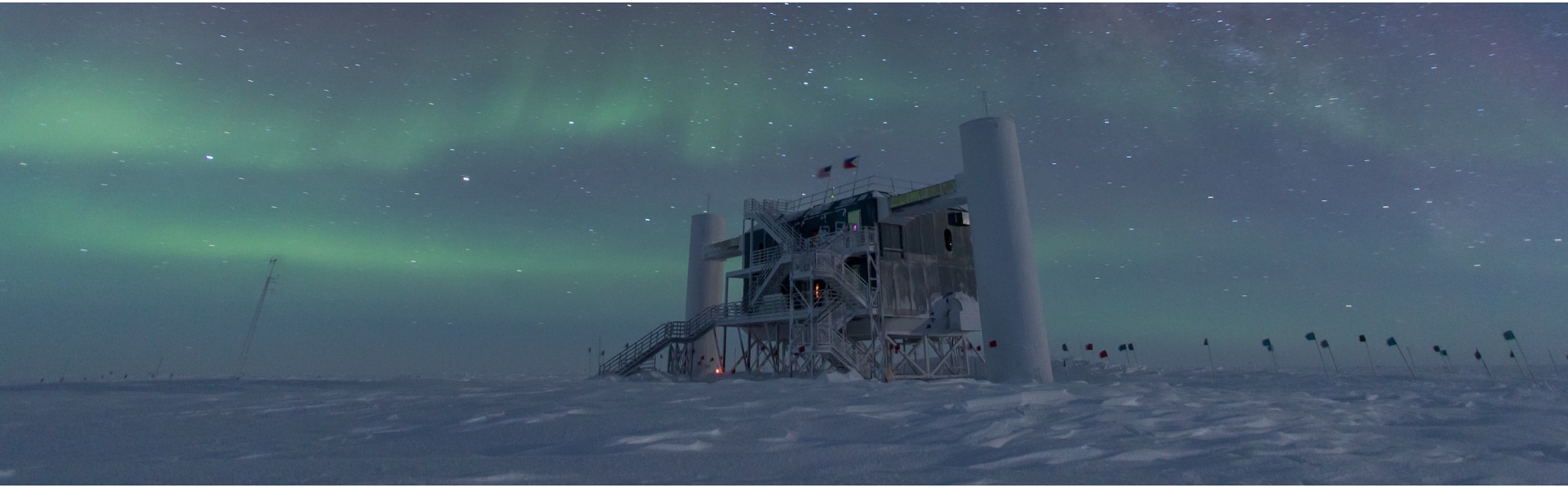


Photon Propagator Requirements for the Upgrade & Gen2

Michael Larson

Photon Propagator Workshop

19 October 2021

IceCube South Pole Neutrino Observatory

University of Maryland 18 56

PDOM

New Modules in Upgrade, Gen2

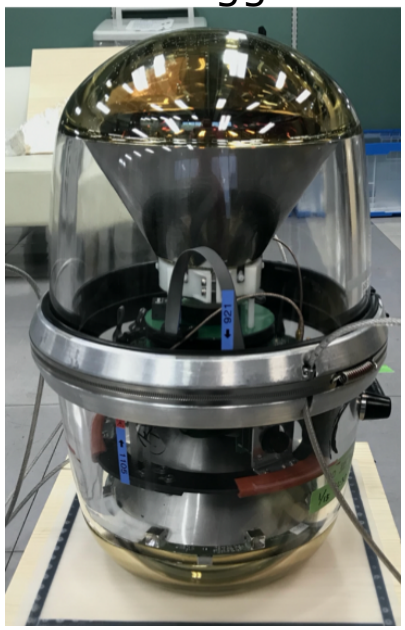
Simplest case: Gen1-sized spherical modules with 1 PMT

New Modules in Upgrade, Gen2

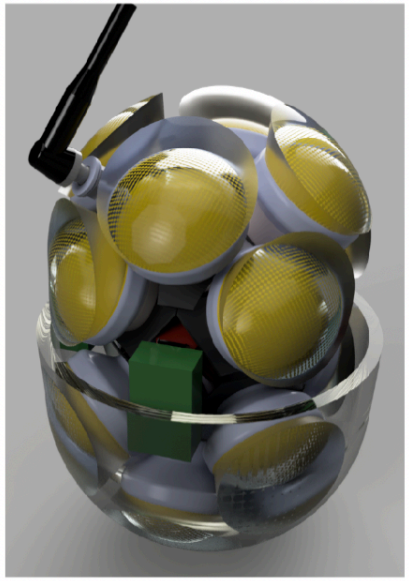
PDOM

mDOM

D-Egg



LOM-16



Internal layout study:
Vedant Basu @ UW-Madison

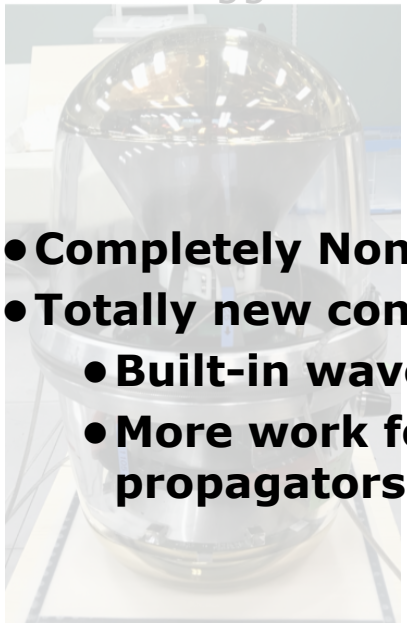
Non-spherical modules with multiple PMTs
More challenging, but still "normal" modules
No new paradigm needed

New Modules in Upgrade, Gen2

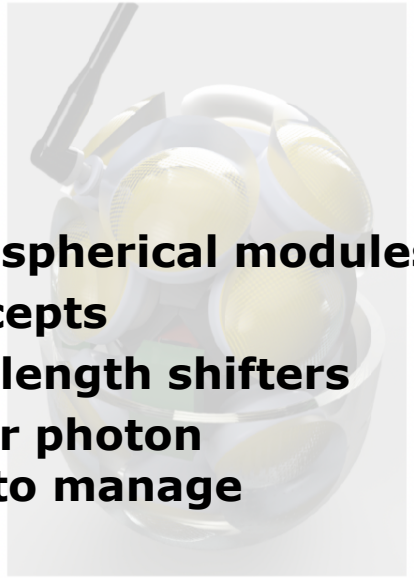
PDOM

mDOM

D-Egg

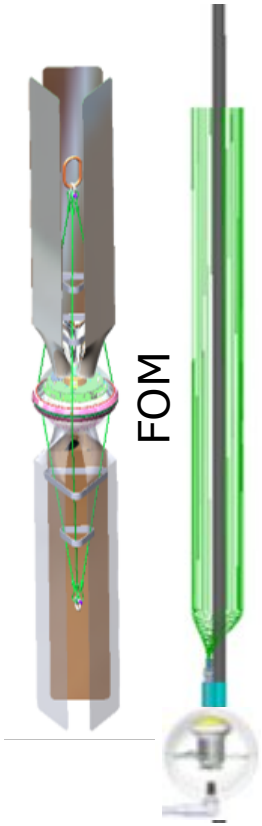


LOM-16



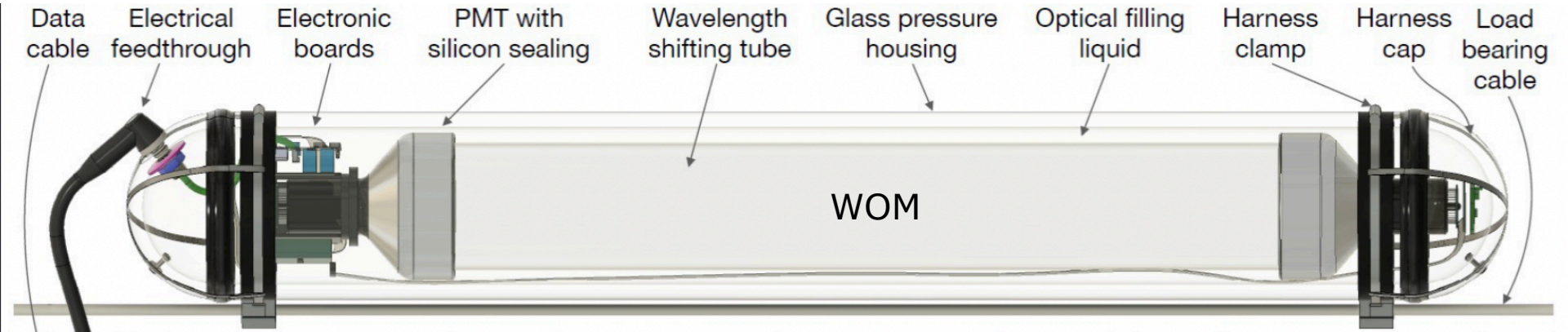
Internal layout study:
Vedant Basu @ UW-Madison

- **Completely Non-spherical modules**
- **Totally new concepts**
  - **Built-in wavelength shifters**
  - **More work for photon propagators to manage**



FOM

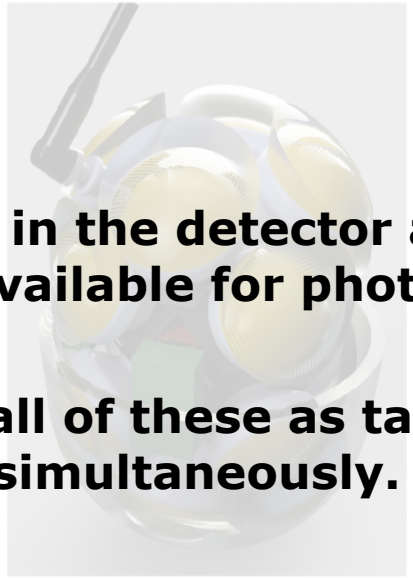
ACOM



New Modules in Upgrade, Gen2

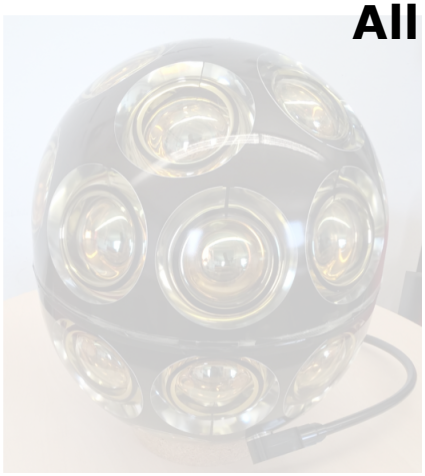
PDOM

D-Egg



LOM-16

Internal layout study:
Vedant Basu @ UW-Madison



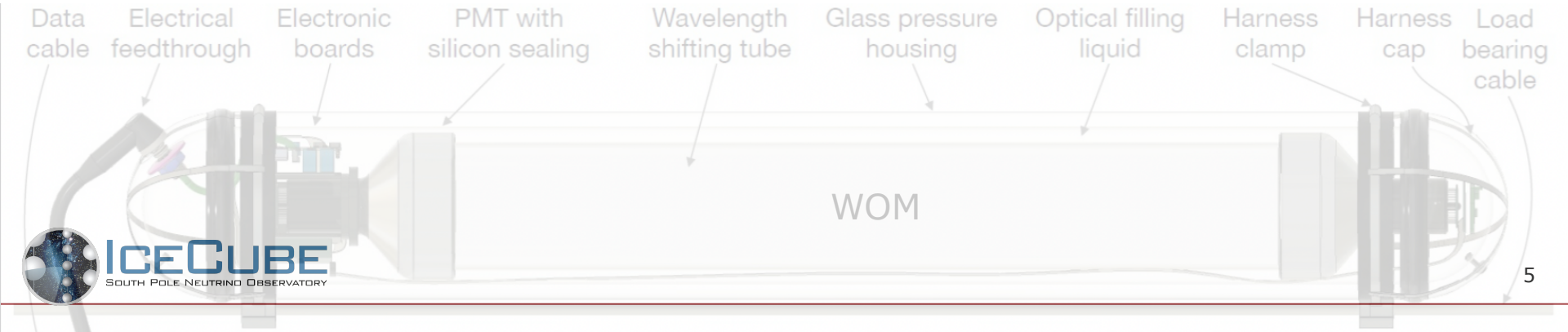
mDOM

DOM

ACOM

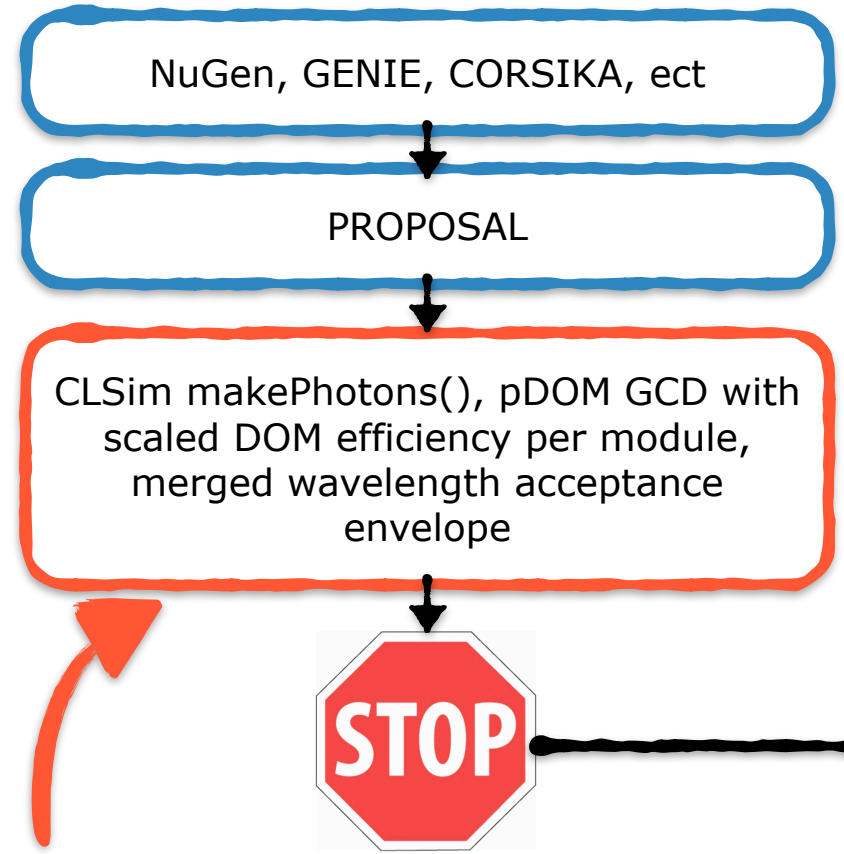
All of these will exist in the detector at the same time and be available for photons.

Need to support all of these as targets of photons simultaneously.

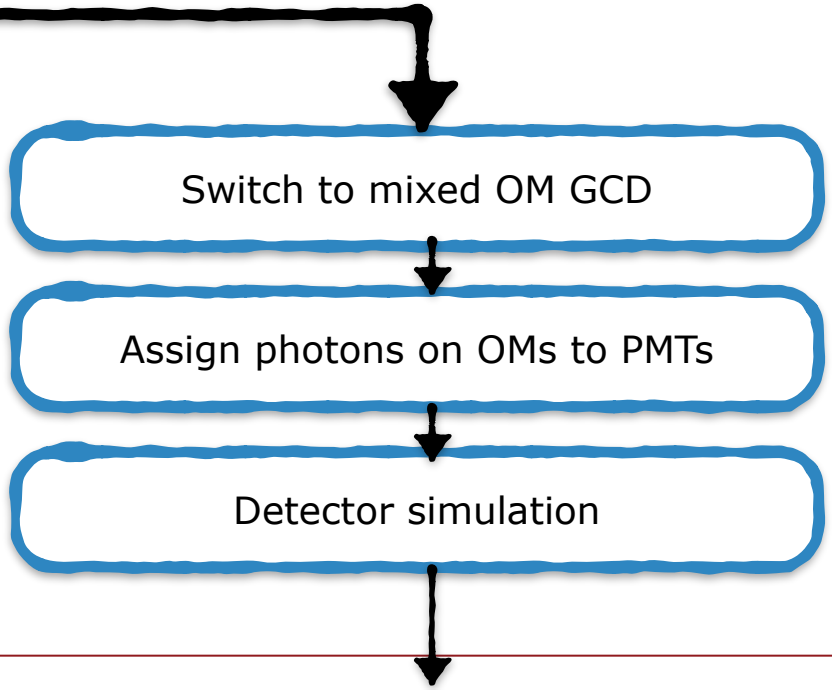


IceCube
South Pole Neutrino Observatory

Current Strategy using CLSim

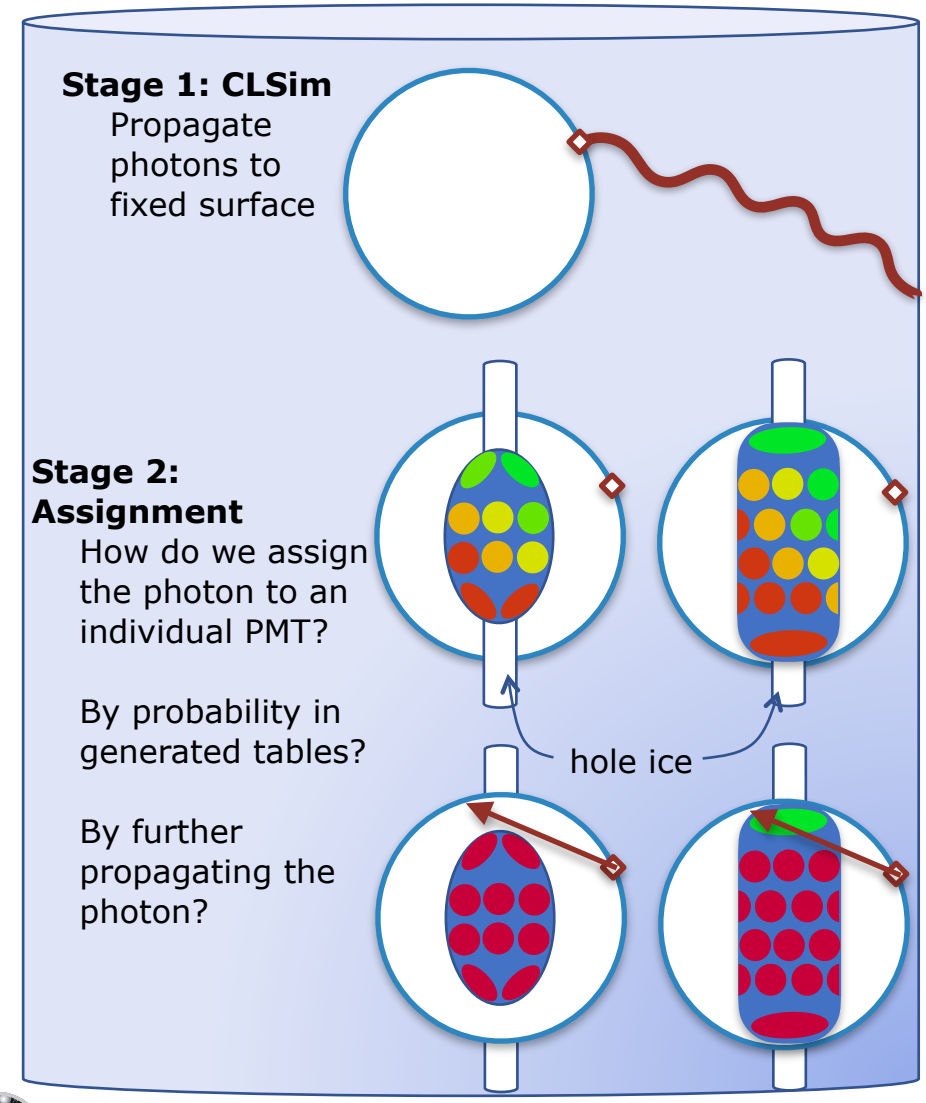


- Strategy so far "works" for PDOM, mDOM, DEgg, and LOM (but **not** for FOM, ACOM, WOM)
- Requires propagating to 13" spheres, saving photons to frame and reading in later modules
  - Potentially memory-intensive process
- Assignment to PMTs requires handcrafted PhotonToMCPE converters for each new module geometry.




```
"""
Propagate photons to 13 inch spheres, using an effective Cherenkov spectrum
scaled so that it can be downsampled to the quantum efficiencies of each
sensor, scaled up so that they are equivalent to `EfficiencyScale` times
the the pDOM area
"""
```

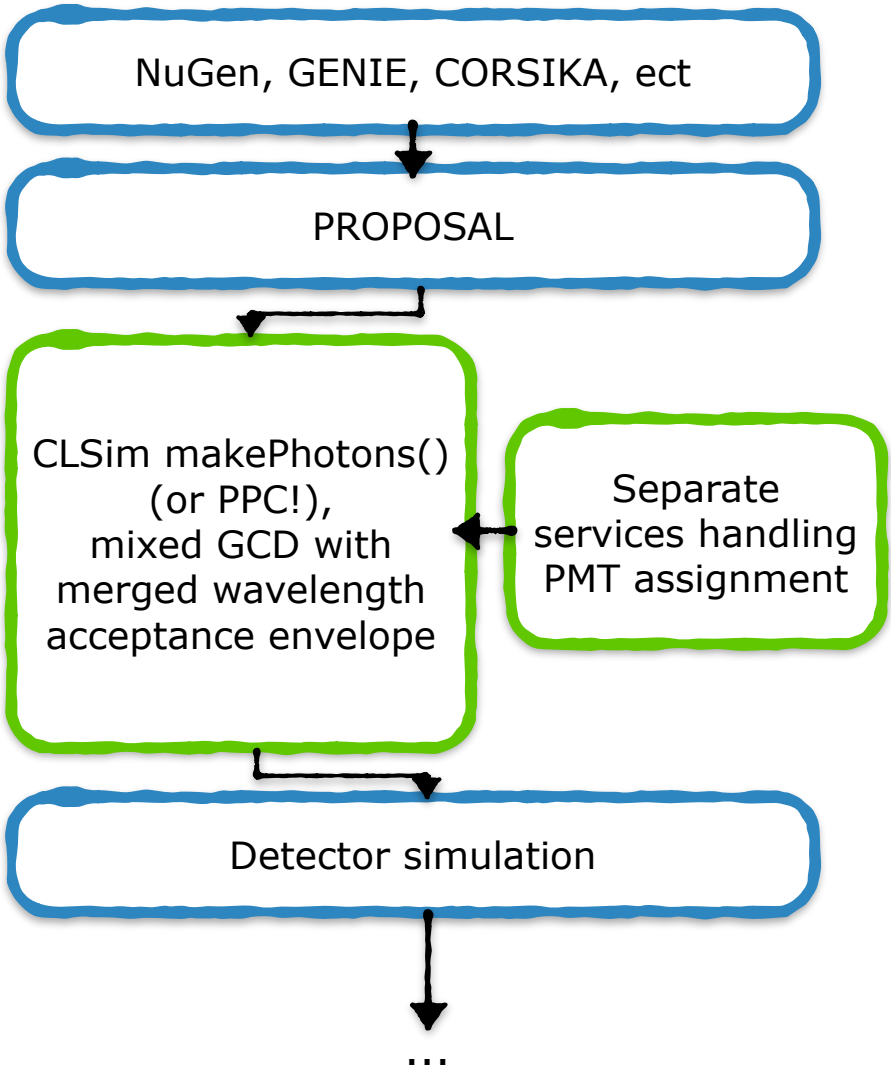
Assigning Hits to PMTs



- Changing module geometry might require editing converters
- PhotonToPE converters need to propagate photons from 13" spheres to real PMT boundaries
  - Gel included, but only as absorbing medium
  - Ignores scattering near/in the modules. Could introduce minor calibration problems
  - Also requires reimplementing oversizing calculations per-module
- Question: Do we currently handle reflections from ice/ glass interface?

Preferences for New Versions

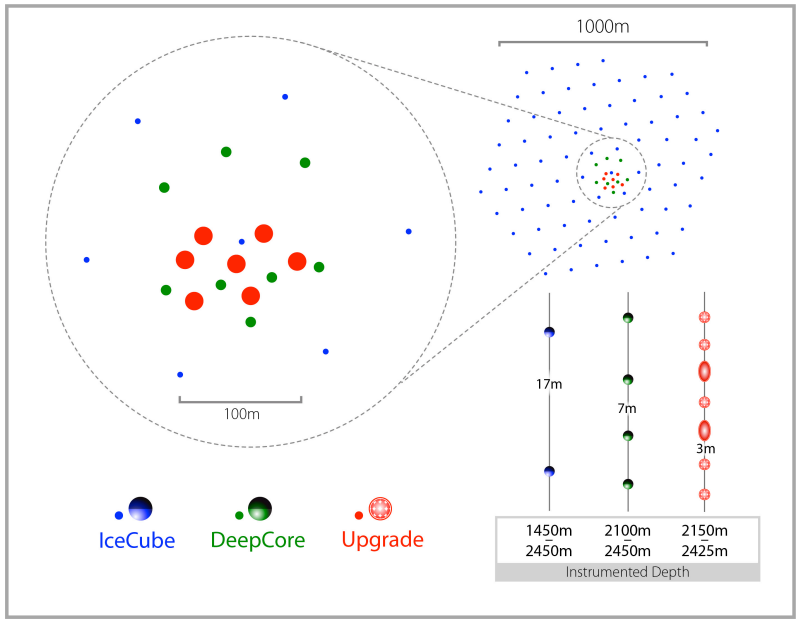
- Writing photons to the frame is **expensive**. Would prefer to avoid it.
- In ideal world, could write PEs to non-spherical PMTs directly without saving intermediate photons
  - Now possible in PPC, but not CLSim
  - Could make plugin services to define how to do this for each module
- Was important when testing detector configs for Upgrade. No longer needed there, but may still be useful in Gen2. Can we fix this while still allowing the old behavior?

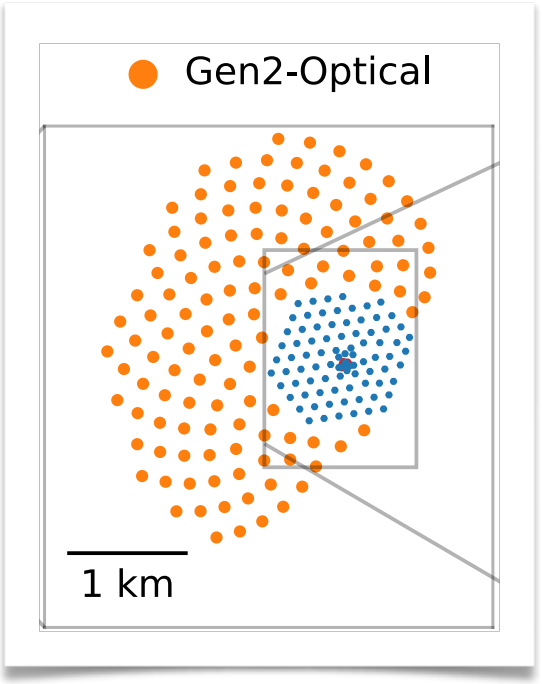


Efficiency Issues to Consider

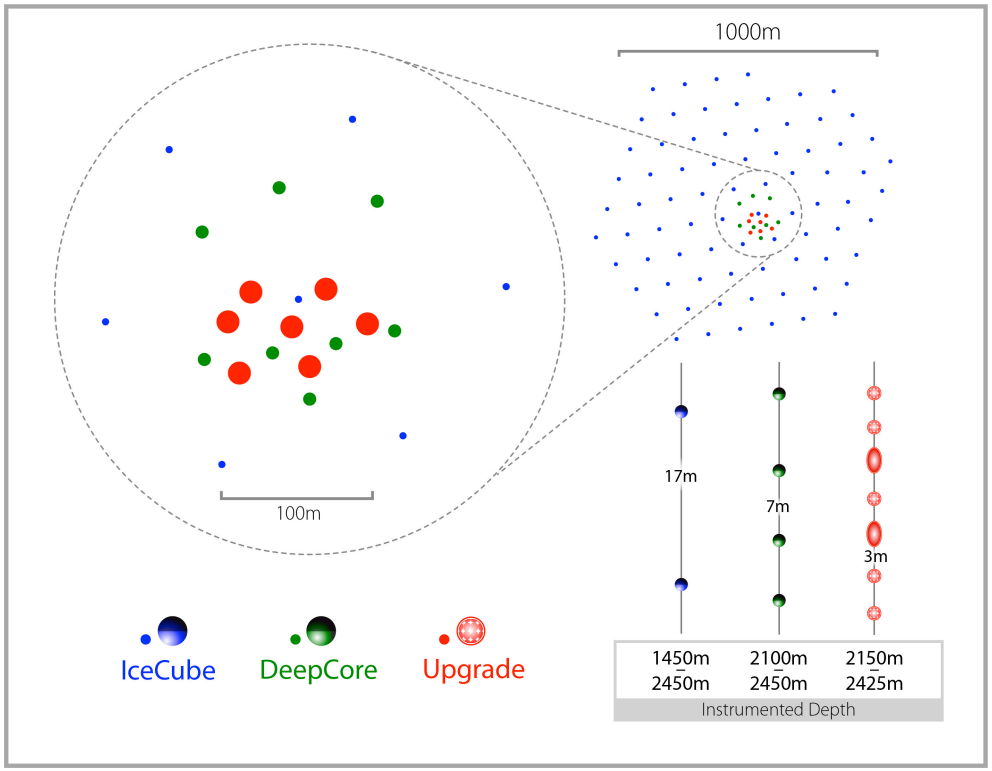
- Upgrade:
  - Adding 700 OMs and 10k new PMTs to GCD. Probably fine with current settings
  - GPU loading is sub-optimal. Better ways to handle it?

- Gen2
  - Adding 10k OMs and 150k+ PMTs to GCD. Will we have memory issues?
  - How can we simulate 10-100 PeV events efficiently?
  - What oversizing is safe to use?
  - Hybrid mode? Not supported for multi-pmt modules due to tables limitations



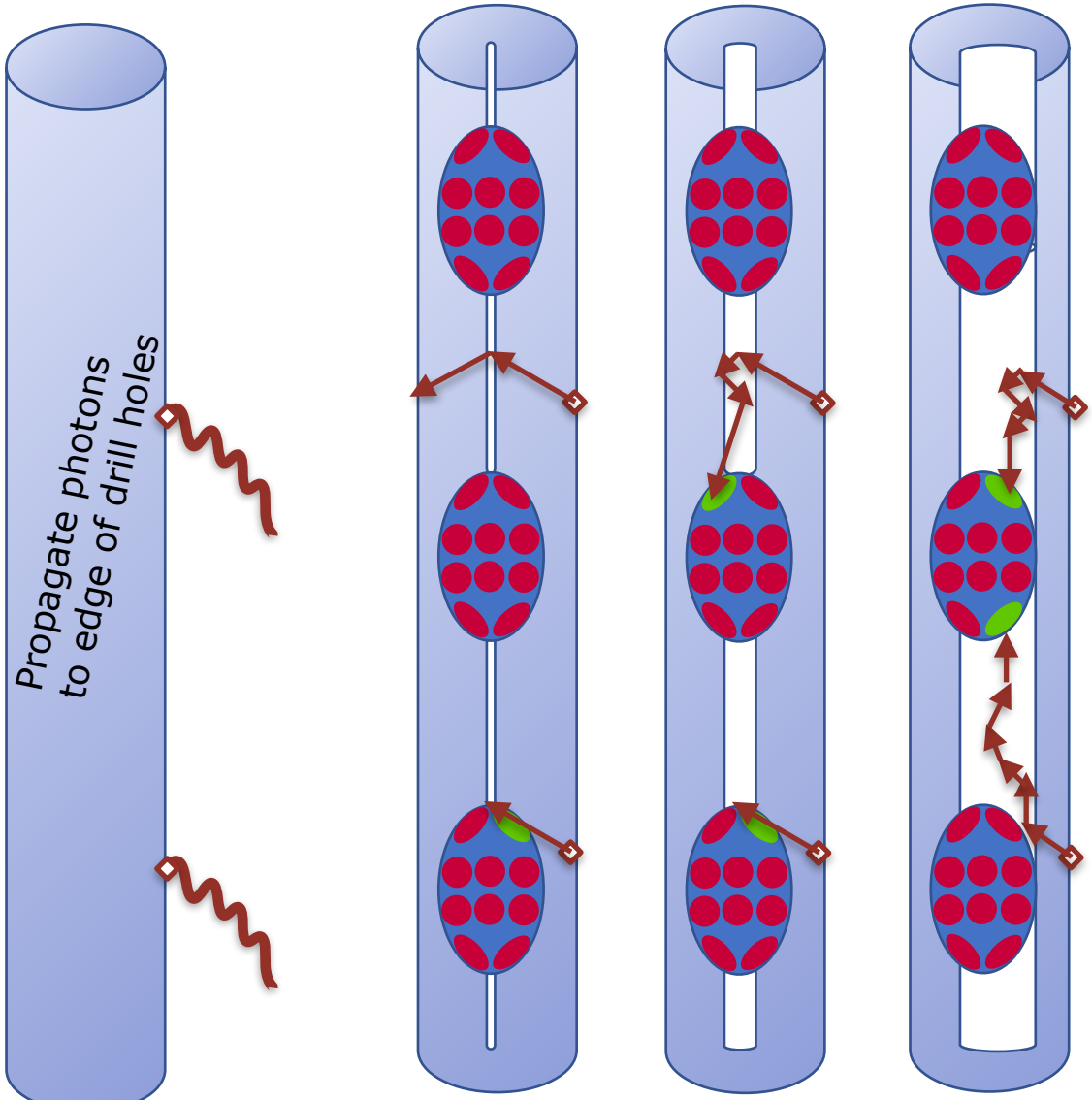


Ice Parameterizations: Hole Ice



- Upgrade strings closer than ever before.
- Is impact of photons crossing bubble column visible on nearby strings?
  - Do we need direct hole ice simulation now?
- Are angular acceptance curves still a viable strategy when using multi-PMT modules?
  - If so, how do we fold in the orientations and hole ice?

Generation of Hole Ice Systematics Sets

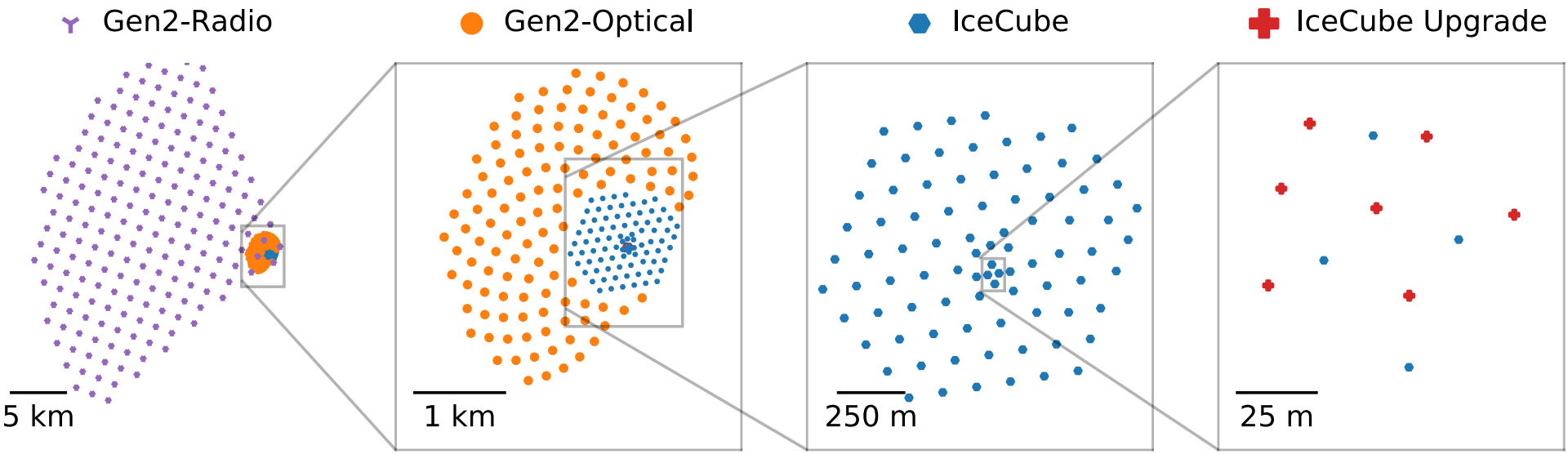


Load photons, propagate to modules

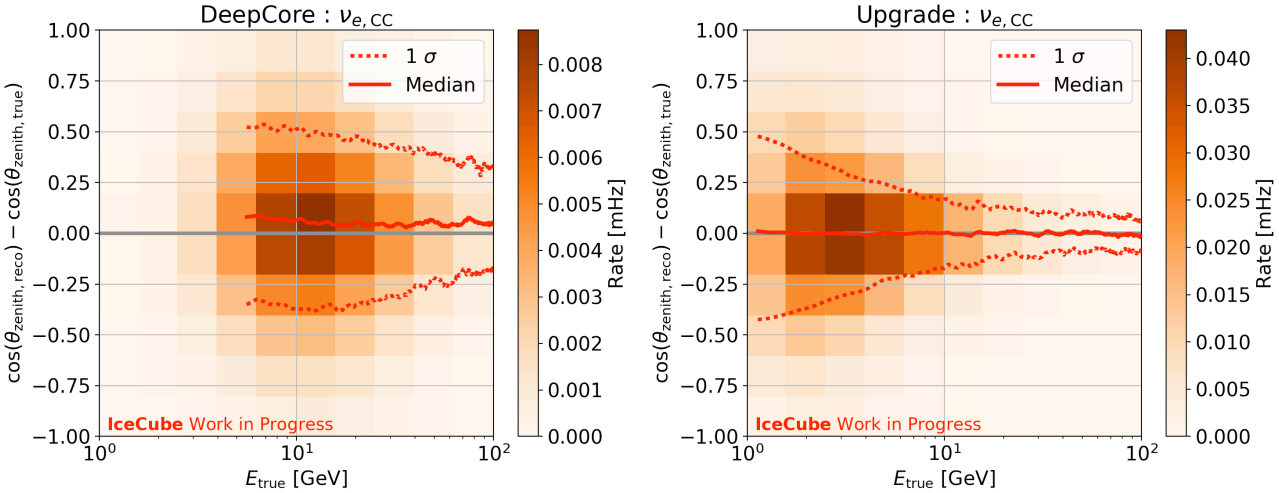
- Generation of hole ice systematics sets is "simple" with angular acceptance curves
- If doing direct hole ice simulation, life gets more complex
- Can we save photons at the drill holes, then do "last mile" propagation later?
  - Would save processing power at cost of disk space

Ice Parameterizations: Tilt

- Gen2 will span several kilometers in width
  - How much will tilt matter over distances of 3 km?
- Are there other long-distance effects that may be important?



Reconstructions and Photon Tables

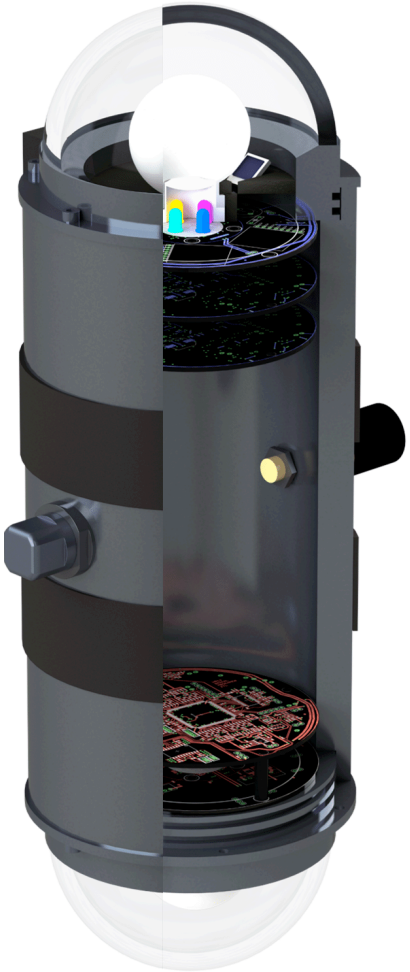


- Likelihood-based reconstructions have indirect dependence on photon propagators via reconstruction splines

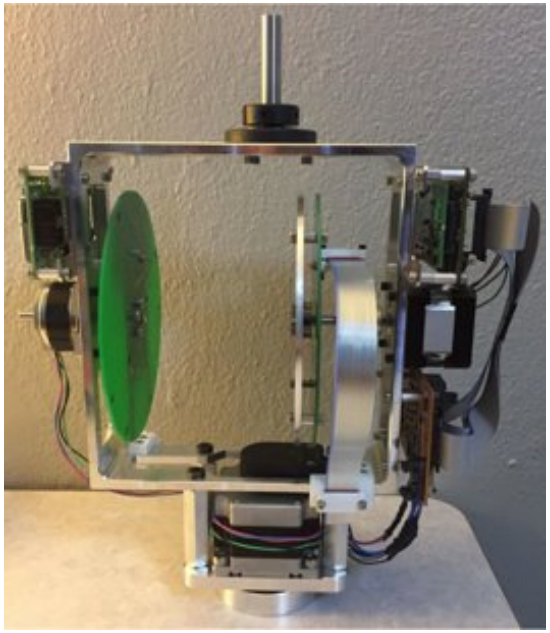
- Simplified reco splines exist for mDOMs in Upgrade, Gen2
  - Both assume homogenous ice, no hole ice to generalize to all PMTs
  - Able to be used in millipede, splineMPE reconstructions

- **We need to generate new, more realistic tables** or abandon them in favor of the new machine learning techniques. Prefer the former

Support for calibration devices (pencil beam, POCAM)



- Definitely not my expertise...
- Currently supported in PPC, but not in CLSim
  - Probably fine: calibration work is exclusively PPC
- My understanding is that we're just repurposing the flasher simulation framework
  - I think this is fine, but better ask someone more involved in calibration devices



Wrapping Up

- Our current methods "work" for Upgrade/Gen2, but significant work will be needed soon
  - Better support for non-spherical modules
  - Support for wavelength-shifting modules
  - Decisions regarding how to handle photon assignment
  - Need for oversizing/hybrid mode for high energies

- Considerations for the future:
  - Direct bubble column simulation in Upgrade?
  - Any other long-distance effects?

- **Badly need new reco splines. Requires support from experts**.
  - Have simplified solutions, but these aren't viable long-term
  - Potentially less of an issue with Upgrade (small size, less ice variation), but likely to hit this wall with Gen2 in 1-2 months
  - Alternatively: abandon LLH-based reconstructions for machine learning

Final Question

```
"""
Propagate photons to 13 inch spheres, using an effective Cherenkov spectrum
scaled so that it can be downsampled to the quantum efficiencies of each
sensor, scaled up so that they are equivalent to `EfficiencyScale` times
the the pDOM area
"""
```

- Tray segment docstring describing how we simulate new modules
- We've been using `EfficiencyScale=2.2` for mDOMs and `EfficiencyScale=1.5` for DEggs
- Performance studies for a next-generation optical sensor for IceCube-Gen2 has this table
- What's the difference? Are we using the wrong number? **Should our simulation DOM efficiency be twice as good for the new modules?**

Table 2: Effective area of optical modules (preliminary)

Name	Effective area (400 nm) [cm^2]	Cherenkov-averaged effective area * [Ratio to Gen-1 DOM]
Gen1 DOM	34 – 37*	1
mDOM	108	3.5 – 4.0
D-Egg	94	2.8 – 3.2
mEgg †	103	3.2 – 3.6
LOM–16†	105	3.2 – 3.7
LOM–18†	118	3.6 – 4.2

∗ Variation comes from a difference of the treatment of the detection efficiency of PMTs.
† If high quantum efficiency PMT is available, these improve by 30%.