

IceCube Upgrade simulation

Overview and status

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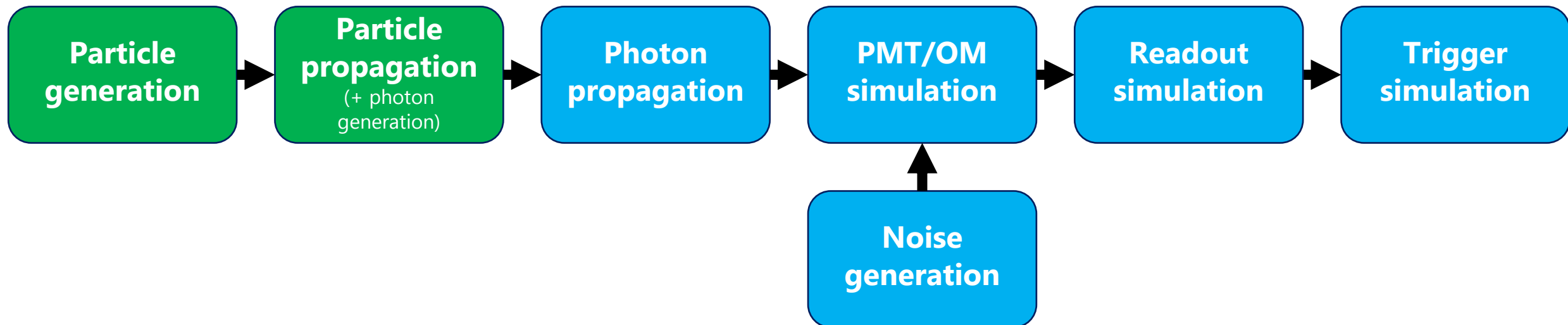
IceCube simulation workshop 2020

UNIVERSITY OF COPENHAGEN



Simulation chain

- **The good:** We have a working end-to-end Upgrade simulation chain
- **The bad:** Plenty of placeholders/hacks
- **The goals:**
 - “As-designed” Upgrade detector simulations by Summer 2021
 - Physics potential paper with latest simulations and reconstructions



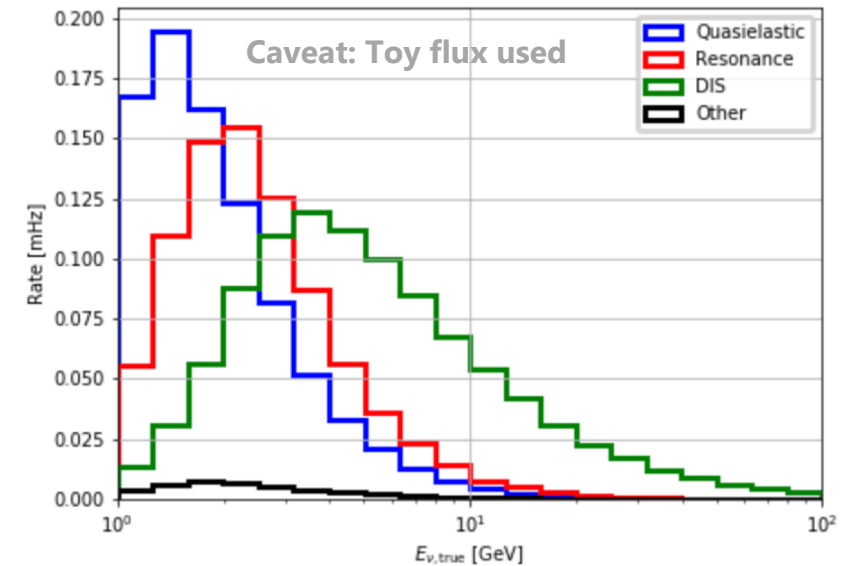
Particle generation & propagation

Existing tools can be re-used

GENIE, MuonGun, PROPOSAL, ...

Need to update to recent GENIE version

Investigation into low energy interactions required (quasi-elastic, resonance and DIS at comparable rates)



Particle
generation

Particle
propagation
(+ photon
generation)

Photon
propagation

PMT/OM
simulation

Readout
simulation

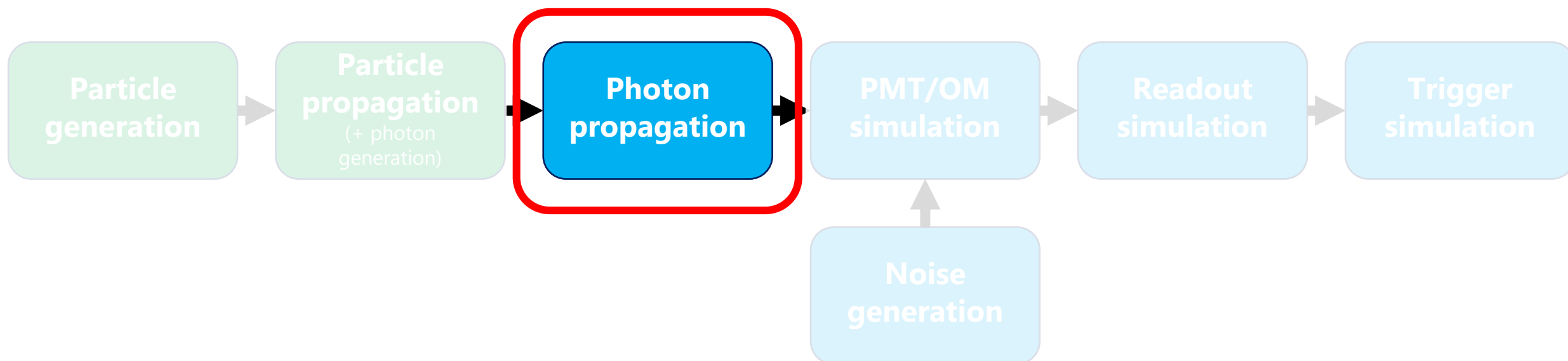
Trigger
simulation

Noise
generation

Photon propagation

Using CLSim

- Mostly does what we need already
- Currently limited to sensors with IceCube DOM radius → needs update (different sizes, non-spherical)



Noise (1 of 2)

1. Detailed modelling of radioactive decays in mDOM glass
2. Injected into mDOM GEANT4 model to determine noise

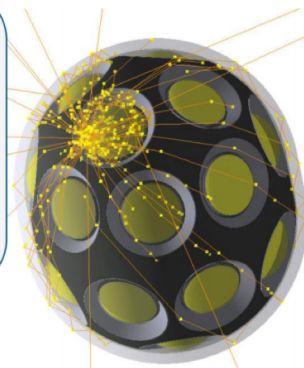
Geant4 simulation:

- Isotopes are generated randomly in glass vessel
- Photons produced via
 - Cherenkov (electrons)
 - **Scintillation** (energy deposition in glass)
- Only PMT hits are saved (QE included!)
- PMT background not included!

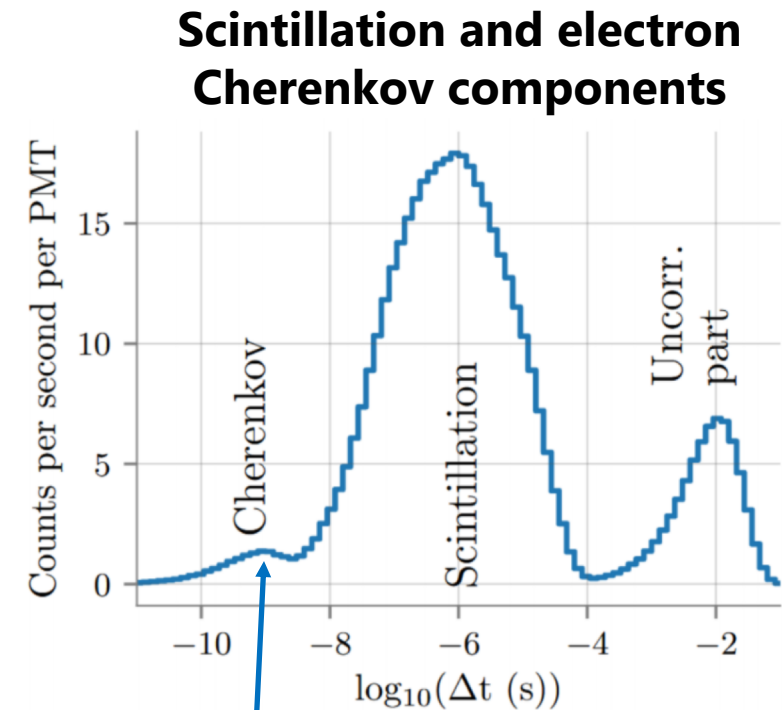
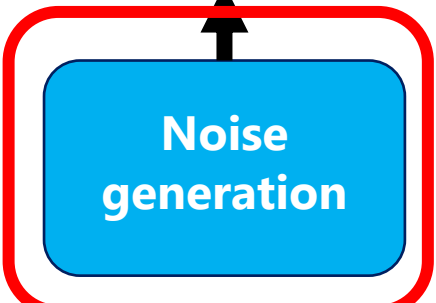
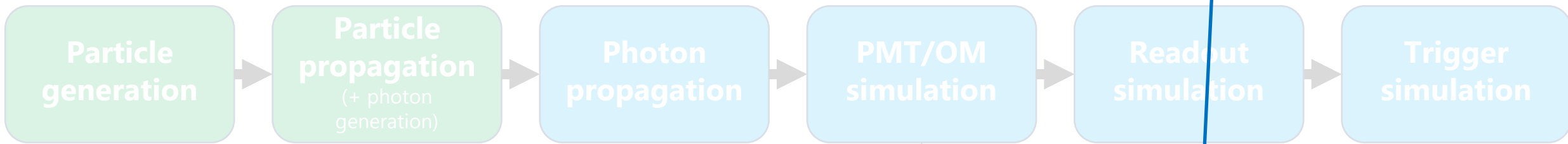
Scintillation properties of glass measured in lab:

- Yield (Nr of photons per deposited energy)
- Lifetime (time distribution of emission)
- Spectrum

Measurements in this talk



Martin Unland



Note: Cherenkov Δt actually peaks at $\mathcal{O}(10 \text{ ps})$, but smeared by $\mathcal{O}(\text{ns})$ TTS

Noise (2 of 2)

Martin Unland, Michael Larson

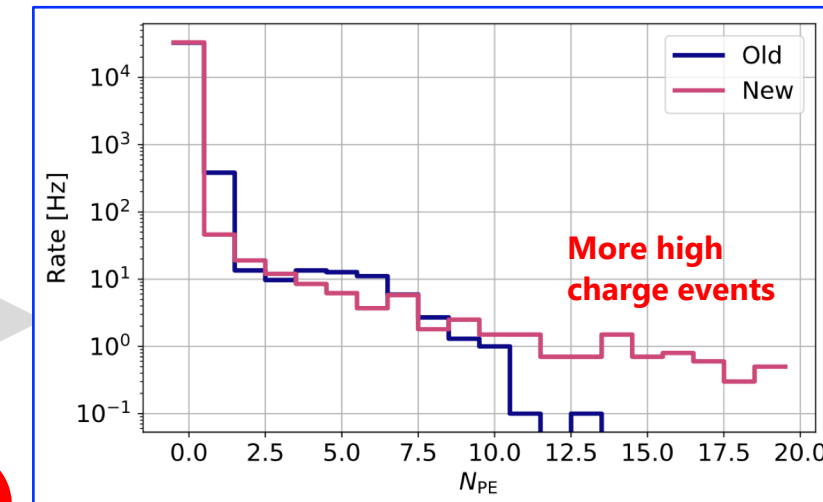
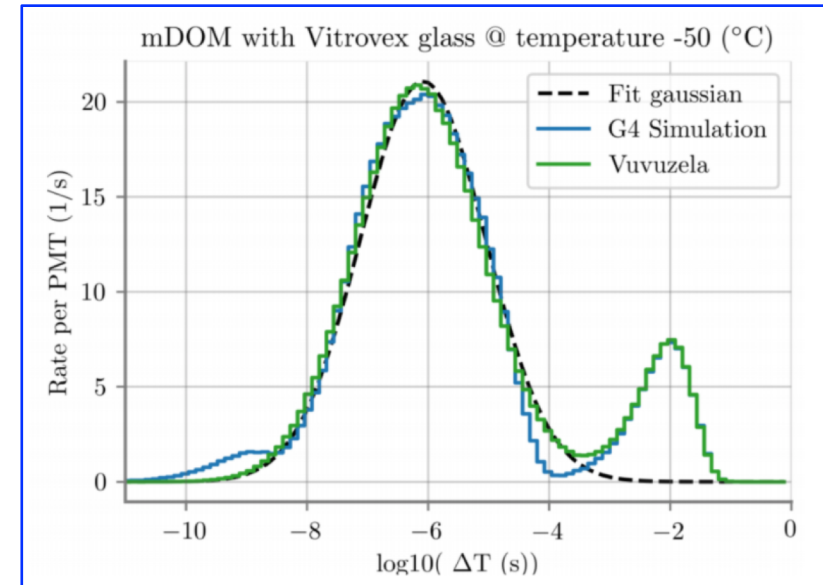
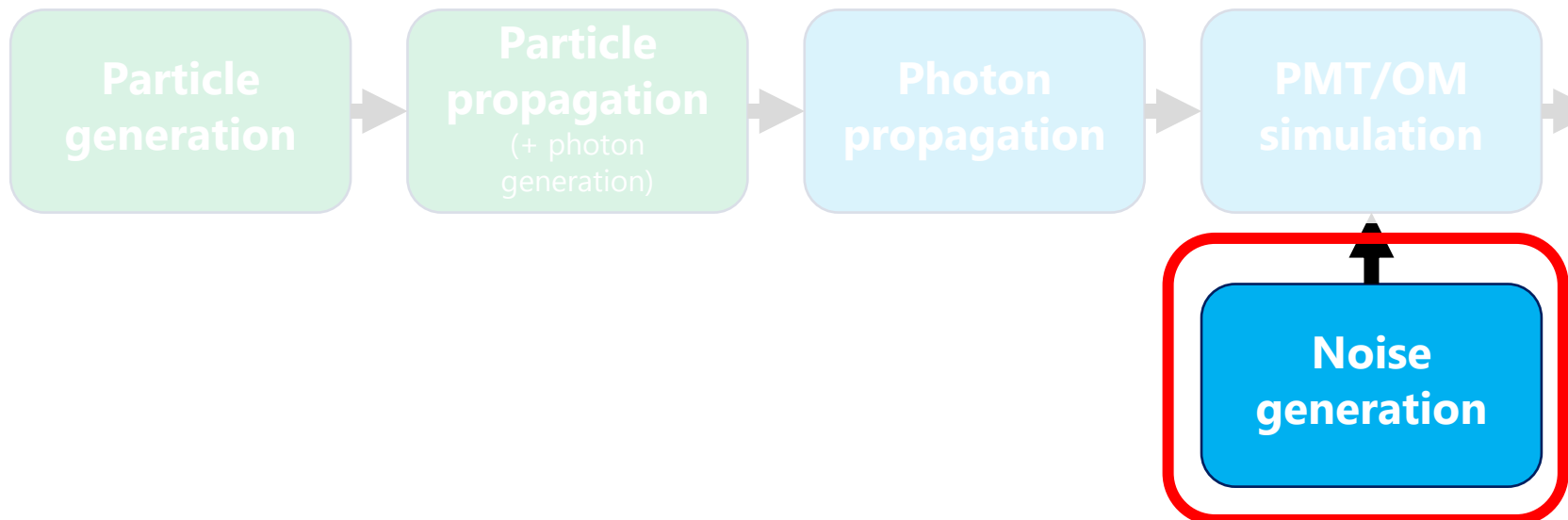
mDOM noise implemented in vuvuzela by sampling from pre-generated noise hit files (from GEANT4 simulations)

More accurate than tuned vuvuzela parameterisation

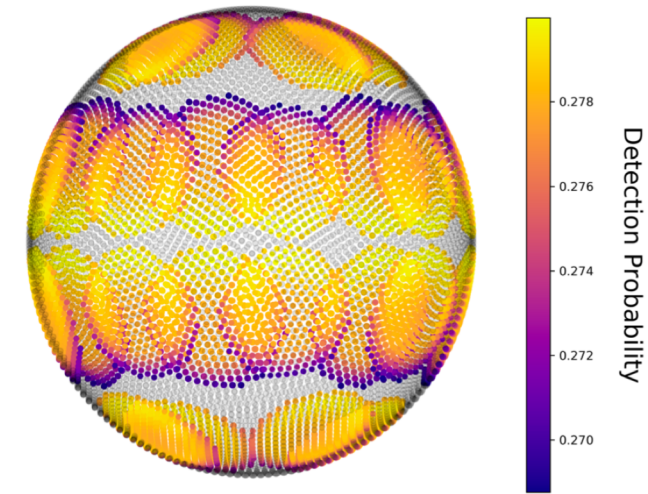
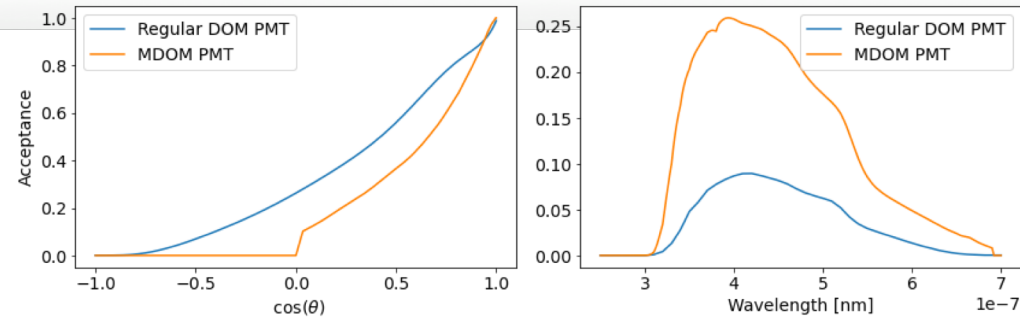
- Includes Cherenkov component
- Captures correlated noise between PMTs

Would like similar for DEgg

Currently uses vuvuzela parameterisation tuned to lab data



mDOM simulation



Modelled as flat disks on surface of sphere

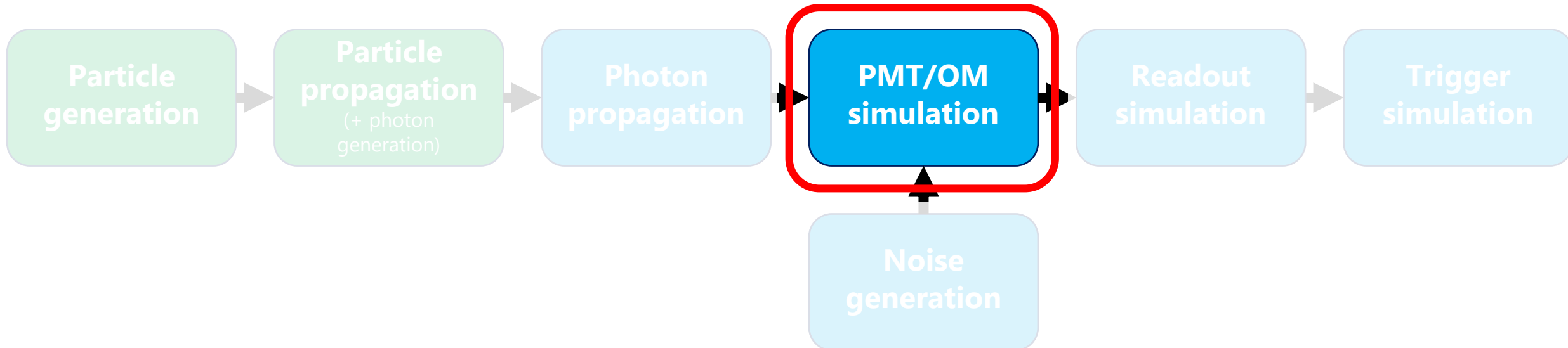
Wavelength and angular acceptance per PMT

Glass and gel taken into account

Hacks required due to CLSim OM size/shape limitations

Unsquash DOM from 13" sphere (back-propagate photons + waistband elongation)

Eventually want more unified treatment with other sensors



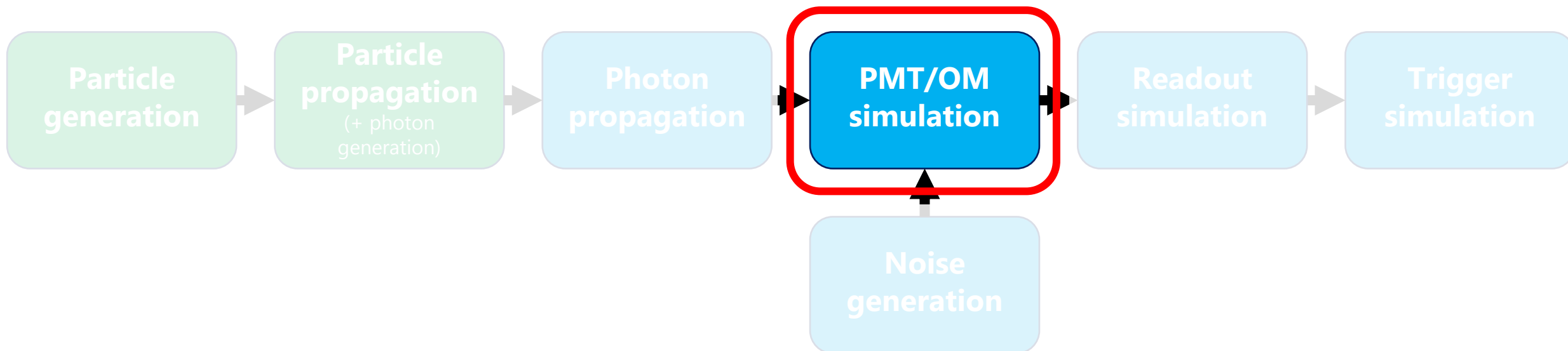
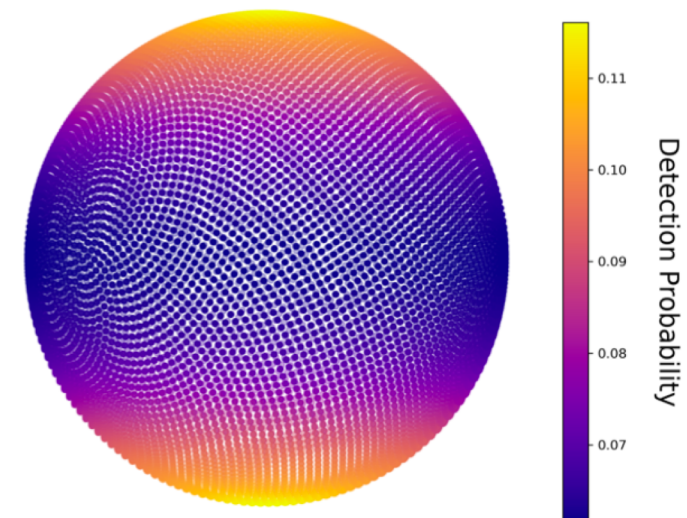
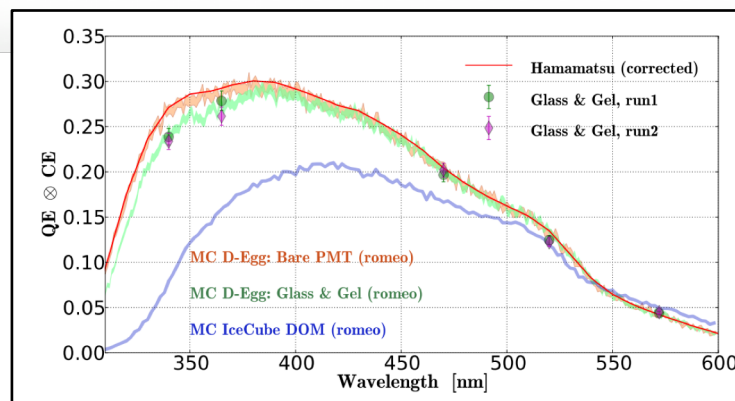
DEgg simulation

Currently essentially two IceCube PMTs

Same dimensions, QE, PMT simulation, etc
Wrong PMT size (10'' vs 8'') used

Forced to be spherical due to CLSim limitations

Need someone to update this



PMT simulation

Currently use:

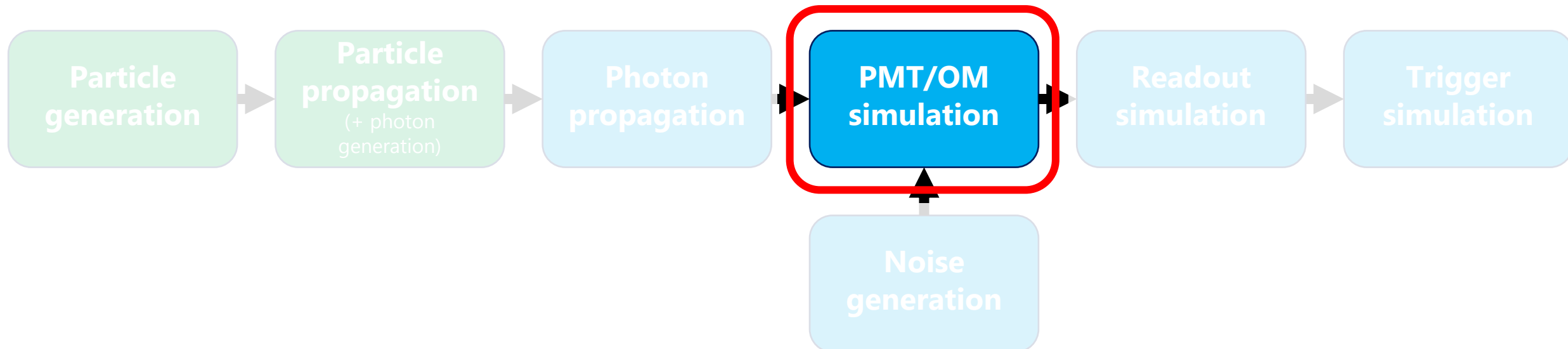
- Simple mDOM PMT simulator (TTS + SPE)
- IceCube PMT simulator "as is" for DEgg
- All use standard IceCube SPE template

Plan to update IceCube PMT simulator (PMTResponseSimulator) and use for all PMTs

Similar fundamental behavior

Steering for each PMT type (e.g. size, TT, TTS, SPE template, etc) from data sheet and lab testing

Need someone to do this work



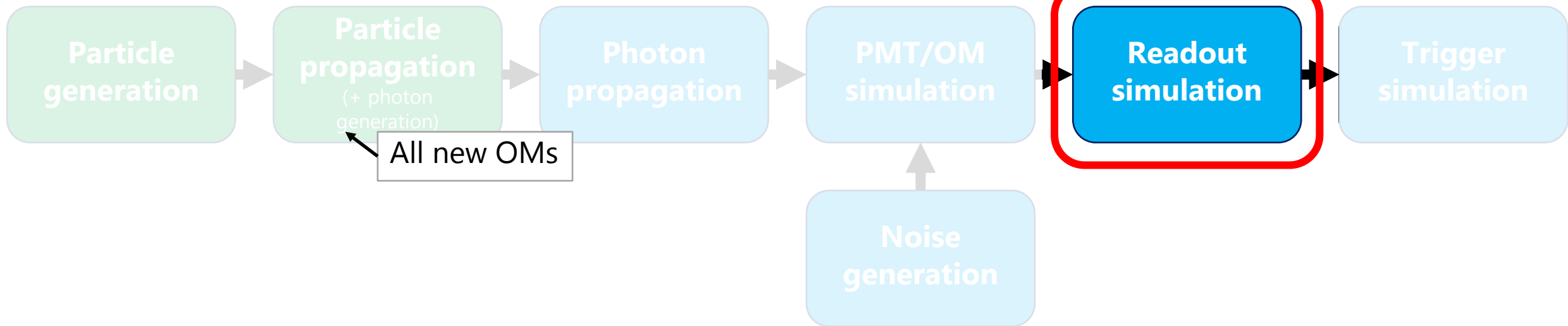
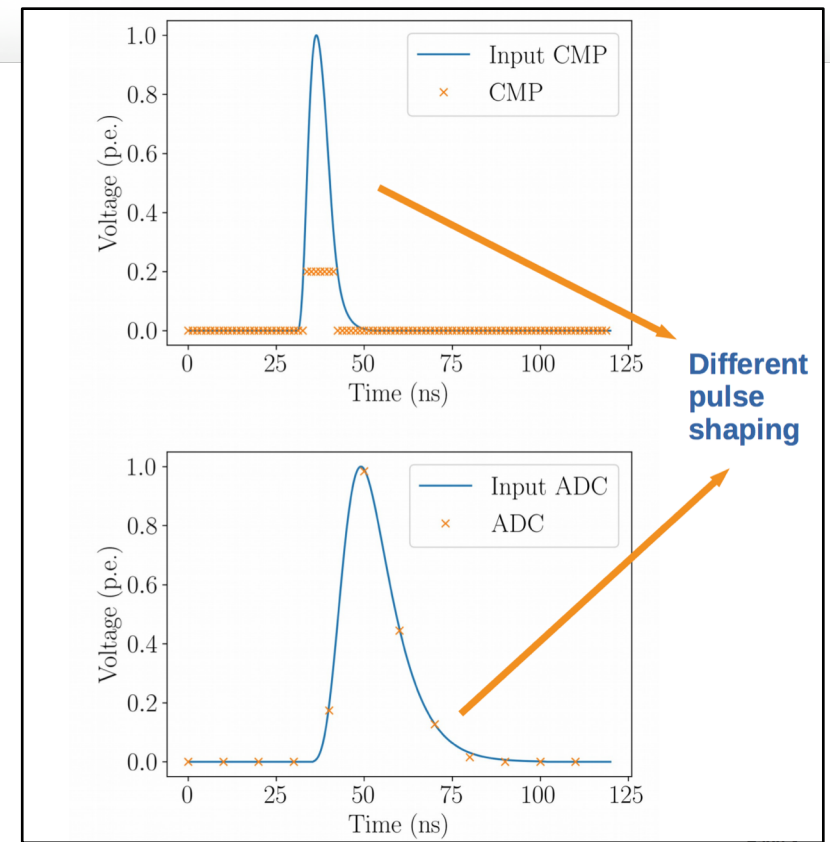
Readout simulation

Readout electronics have been under development

Currently have very simple placeholder in simulation for all new sensors:

- Merge pulses within 10 ns
- 10 ns pulse width for all pulses (→ 10 ns resolution)

Realistic mDOM frontend simulation and pulse reconstruction now under development (Leander Fischer)



Trigger and filter simulation

Simple cylinder trigger

Software local coincidence

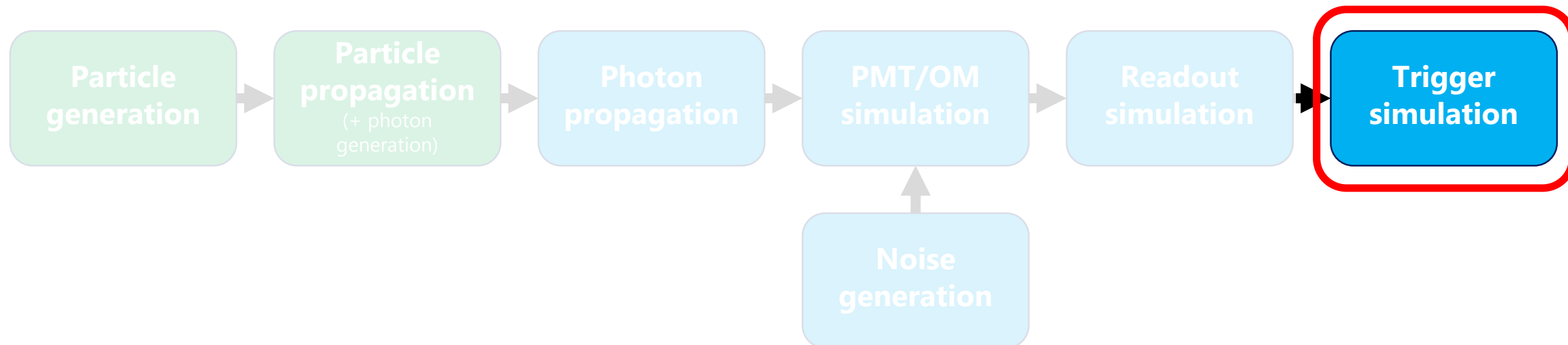
Upgrade and Upgrade+DeepCore triggers

DeepCore filter updated include Upgrade physics region sensors in fiducial volume

Noise pulse cleaning in need of dedicated study

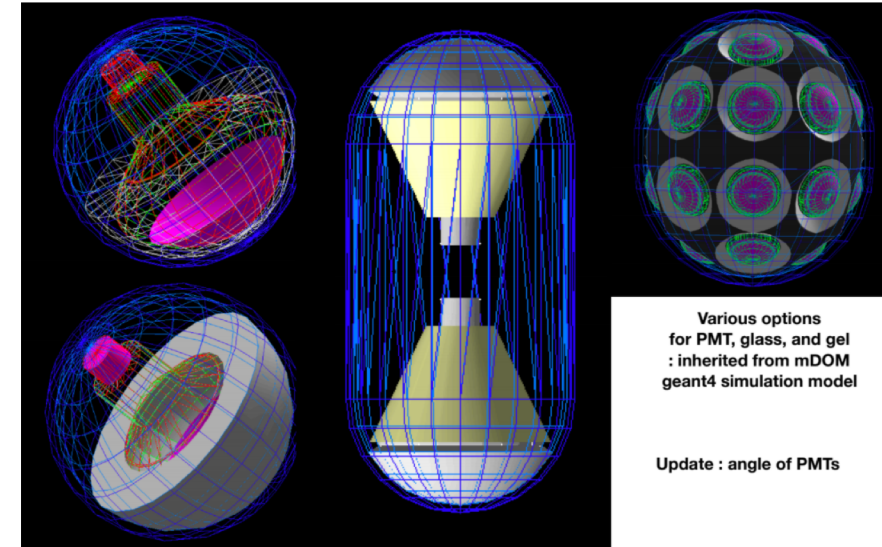
Good enough for now, more detailed study required in future

Coincidence noise trigger rates, high-purity 2Mton fiducial volume filter?, ...

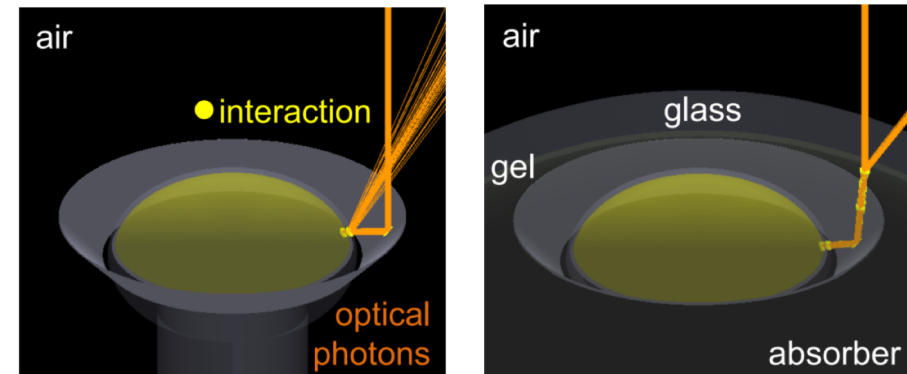


GEANT4 OM models

- Various GEANT4 models out there
 - mDOM (Münster)
 - DEgg (Chiba)
 - Generic system for many OM types (Nahee)



- Want to bring these together into a single unified framework
 - In IceCube svn
 - Common scripts for:
 - Noise modelling
 - Extract acceptance curves
 - ...



- Interested in directly using GEANT4 models in production simulation
 - May require this level of fidelity for high precision analyses

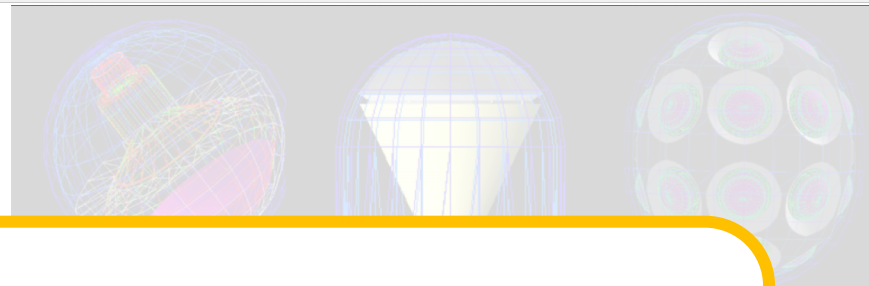
GEANT4 OM models

- Various GEANT4 models out there

Ultimately want unified software framework for all sensors

- GEANT4 models
 - Extraction of acceptance curves
 - Extraction of pre-generated noise files
 - Sensor acceptance model
 - PMT simulation
 - GEANT4 sensor → production MC integration
- Also want to directly use these tools in DirectReco

- May require this level of fidelity for high precision analyses



ions
and gel
mDOM
on model

f PMTs

sorber

New MC sets

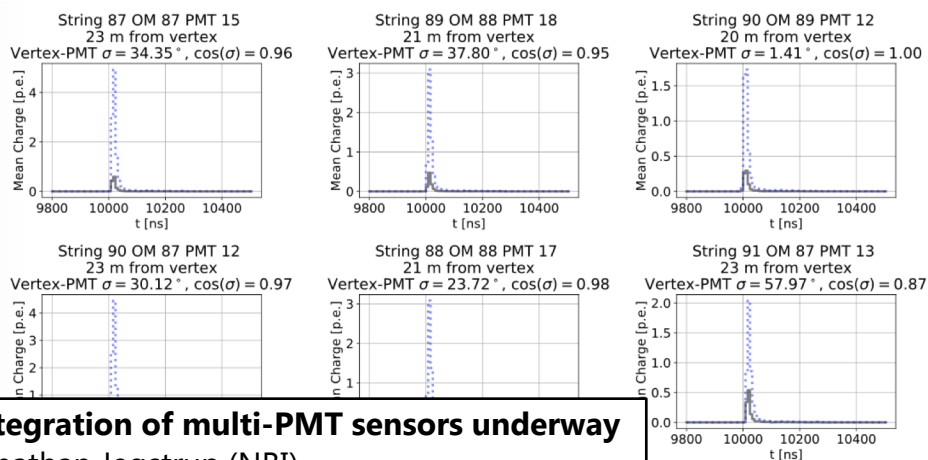
- New GENIE neutrino MC sets produced recently: **1{2,4,6}58**
 - Latest mDOM noise
 - SLC bug fix
 - Recent geometry
- High statistics (1.5M events)
 - Requested for machine learning reconstruction development
- See Upgrade simulation [wiki](#) for details

Reconstruction

- Table-based reconstruction does not scale well to multi-PMT OMs
- Moving ahead with other options
 - Machine learning
 - DirectReco

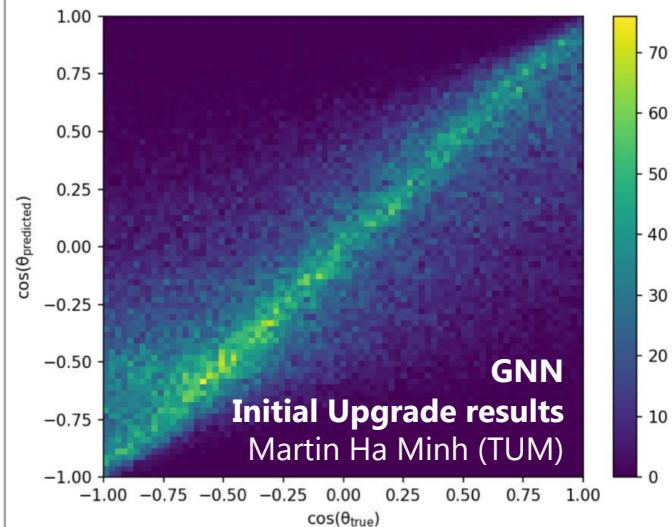
DirectReco

- On-demand simulation of hypothesis
 - Replaces tables in millipede reco

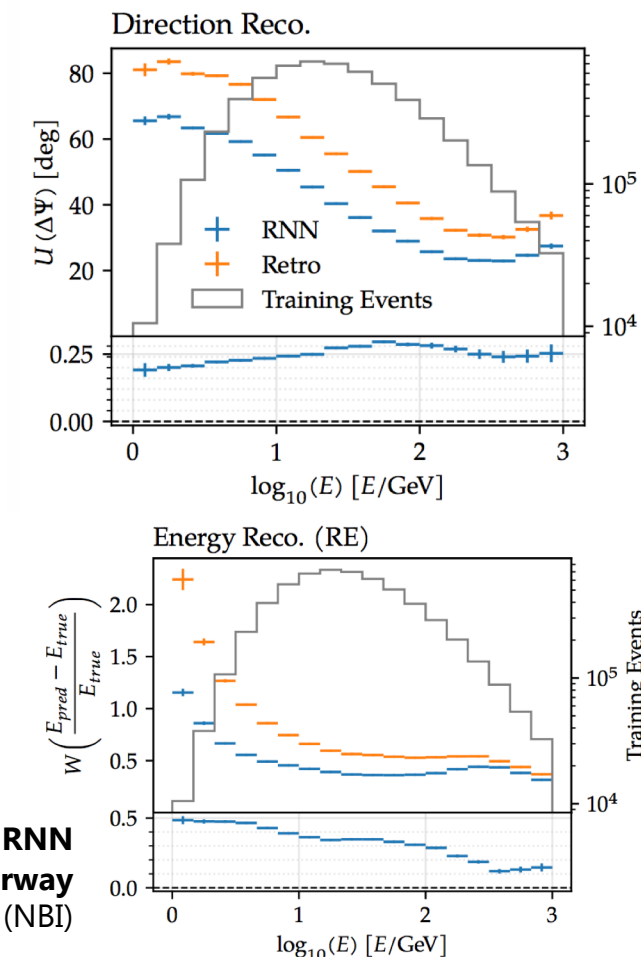


Integration of multi-PMT sensors underway
Jonathan Jegstrup (NBI)

Machine learning



Surpassing table recos in DeepCore with RNN
Upgrade support underway
Mads Ehrhorn and Bjørn Hübschmann Mølvig (NBI)

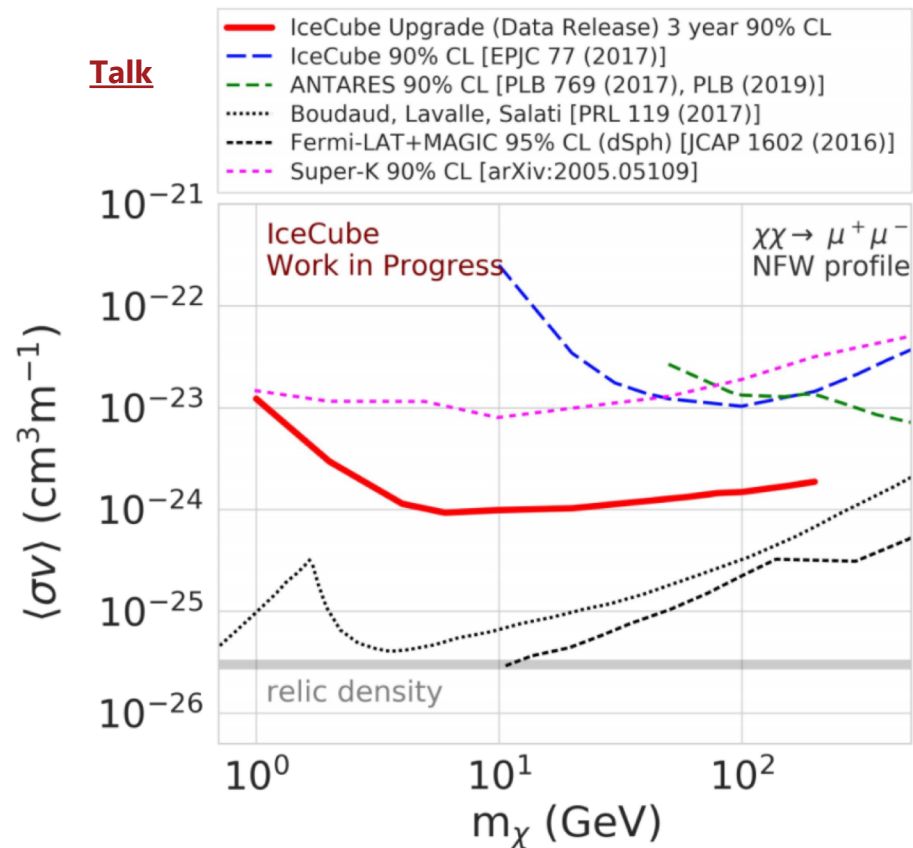


Recent physics studies

Updated GC DM annihilation sensitivities

Sebastian Baur

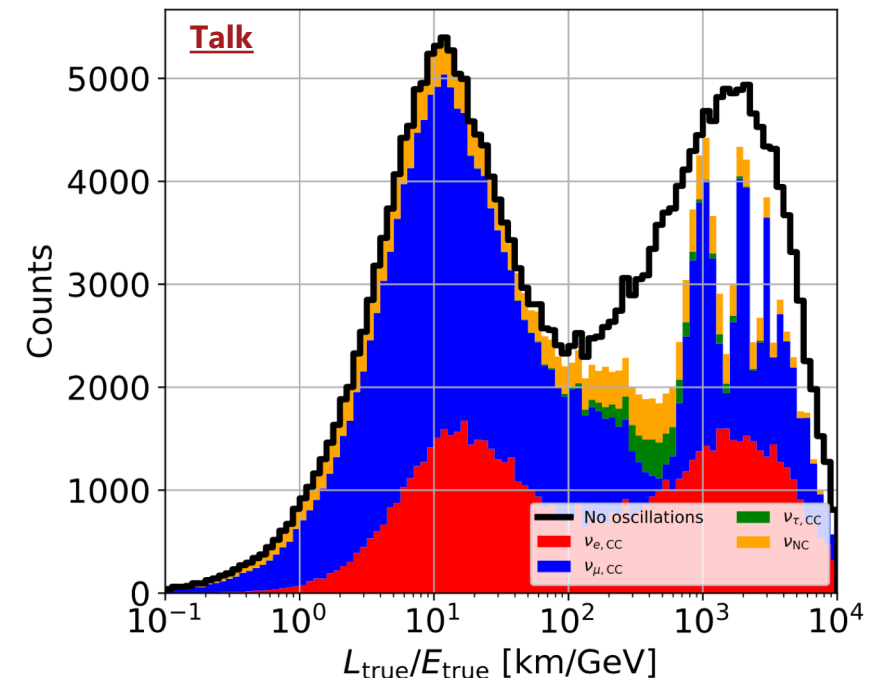
Latest event selection, including energy in fit



Sensitivity to higher order oscillations

Tom Stuttard

Promising signs that we can resolve oscillation bands



Task list

- More people sorely needed to work on Upgrade simulations
- See [task list](#) for inspiration
- Contact me if interested

Detector simulation

[\[edit\]](#)

Maintainer: Tom Stuttard

Category	Task name	Task description	Status	Task owner(s)
mDOM	GEANT4 model	Detailed GEANT4 model of OM, including geometry, materials (including glass, gel). Supports photon or decay simulations.	Preliminary model in place.	Alexander Kappes, Nahee Park?
mDOM	GEANT4 decays	Implement radioactive decays in OM glass (based on lab measurements) in GEANT4 models.	Preliminary model in place	Martin Unland
mDOM	Production sim model	Derive OM photon acceptance curves (or some other model) at PMT, vs wavelength, incidence position, incidence angle). Parameterised from GEANT4 models & lab tests. Not required if directly use GEANT4 model in production simulations.	Preliminary geometric angular acceptance model + wavelength dependence implemented. Out-of-date (not derived from latest GEANT4 models).	TBC
mDOM	PMT model	Model response of PMT to incident photons. Aim to have a single model (based on existing PMTResponseSimulator) that supports all PMTs, steered using datasheet values and lab measurements.	Initial discussions between experts started	Wing Ma?
mDOM	SPE template	Distribution of charge observed for a single photoelectron. Expected that IceCube SPE template code can be re-used, tuned to lab measurements.	Not started	TBC
mDOM	Noise model (parameterised)	Tune vuvuzela parameters to match lab measurements and GEANT4 simulations. Derive new dt parameterisation to account for correlated noise between different PMTs on multi-PMT OMs.	Parameterisation tuned to GEANT4 model, but does NOT include correlations between PMTs. Currently choosing pre-generated noise model as baseline.	Martin Unland, Michael Larson

Simulation code map

MC scripts:

- [Step1](#) (event generation)
- [Step2](#) (photon propagation)
- [Step3](#) (detector simulation)
- [Step4](#) (filtering, pre-processing)

Make photons ([I3CLSimMakePhotons](#))

Upgrade+DeepCore filter ([DeepCoreFilter](#))

Photons → PEs

 ([MakePEsFromPhotons](#))

- mDOM ([mDOMMakeHitsFromPhotons](#), [I3PhotonToMCHitConverterForMDOMs](#))
- DEgg ([DEggMakeHitsFromPhotons](#), [I3PhotonToMCPEConverterForDEGG](#))

Detector sim

 ([DetectorSim](#))

- mDOM PMT ([mDOMPMTSimulator](#))
- DEgg PMT ([PMTResponseSimulator](#), e.g. IceCube PMT)
- Readout placeholder ([mcpulse to recopulse](#))

TriggerSim ([RunUpgradeTriggers](#))

Outlook

- We have an end-to-end Upgrade simulation chain
 - Has enabled physics studies
- Now aiming for “as designed” detector simulations by next Summer
 - Major challenge → **more people required**
 - DEgg needs particular attention
 - Hardware designs finalising, time is now for simulation development
- Also looking to start coordination with OM testing to make sure we get the data we need for high fidelity detector simulations
- Also plenty of work to get full IceCube software suite Upgrade-ready