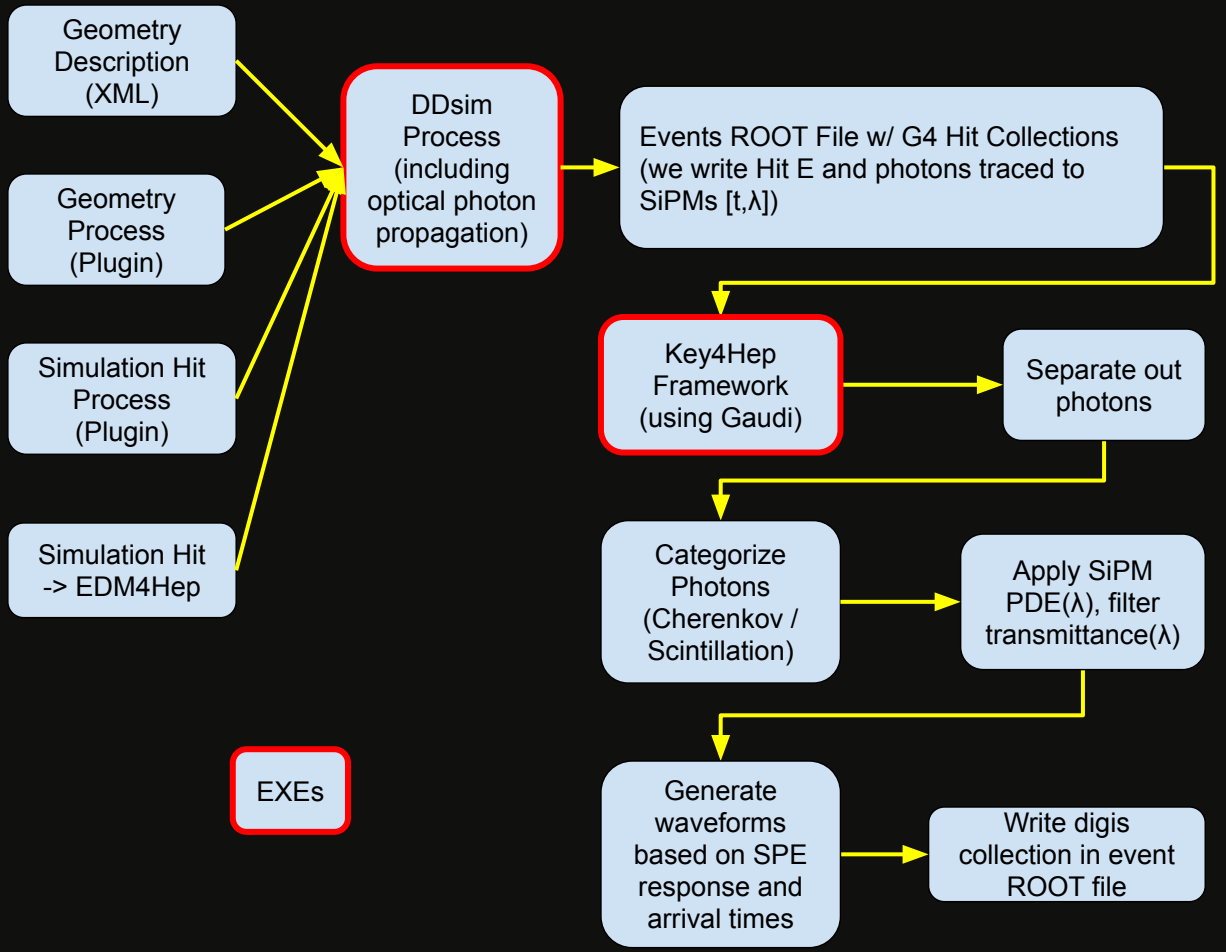
DR Digi Generation

Thomas Anderson, Sarah Eno, Kenichi Hatakeyama, Bob Hirosky, Hayden Hollenbeck, Sasha Ledovskoy, Jon Wilson

20–Jan–2026

Digi Production Process

Goal: Use standard tools DD4hep amd Key4hep stack for geometry and materials management and to produce realistic digis.



k4RecCalorimeter/RecCalorimeter/src/components/SimulateSiPMwithOpticalPhoton.h

Structure for generic SiPM models has been implemented by Key4hep team:

```
class SimulateSiPMwithOpticalPhoton : public Gaudi::Algorithm {
...
// Input collections
...
  mutable k4FWCore::DataHandle<edm4hep::RawTimeSeriesCollection> m_timeStruct{m_inTimeColl,
Gaudi::DataHandle::Reader, this};
  mutable k4FWCore::DataHandle<edm4hep::RawTimeSeriesCollection>
m_wavelenStruct{m_inWavlenColl, Gaudi::DataHandle::Reader, this};
...
  // SiPM properties (defaults set based on Hamamatsu S14160-1310PS)
  Gaudi::Property<double> m_sigLength{this, "signalLength", 200., "Signal length in ns"};
  Gaudi::Property<double> m_sampling{this, "sampling", 0.1, "SiPM sampling rate in ns"};
  Gaudi::Property<double> m_risetime{this, "risetime", 1., "Signal rise time in ns"};
  Gaudi::Property<double> m_falltimeFast{this, "falltimeFast", 6.5, "Signal ...  decay time in ns"};
// many more definable properties in the Class
// Cell size, DCR, PDE(lambda), sampling parameters, etc.
```

Interface only, all parameters, algos must be brought by the user

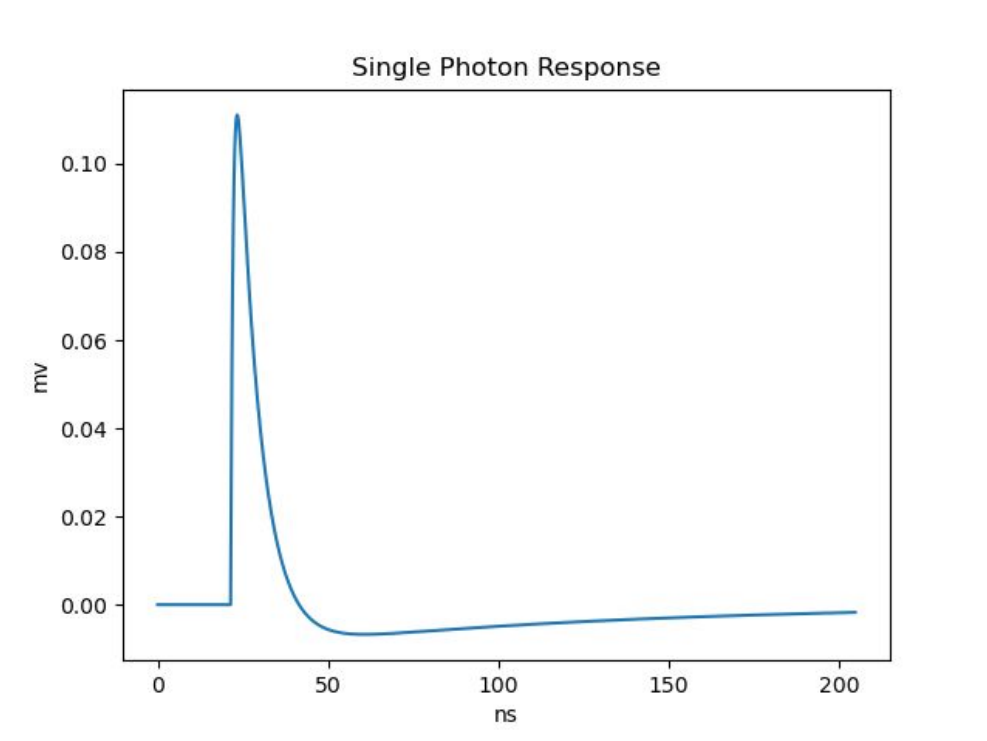
Our initial development still uses a custom algorithm, but should be straightforward to implement in the Key4hep team's distributed class.

We begin with a hits collection of photons arriving at the SiPM. Our simulation includes crystals, an optical impedance matching layer, a SiPM window and finally the SiPM sensitive region, where photons are counted as hits and killed.

Photon hits are then processed by our Gaudi Algorithm to produce models of the analog waveform based on an SPE response model.

Still very preliminary. Plenty of cross checks and code clean up to do!

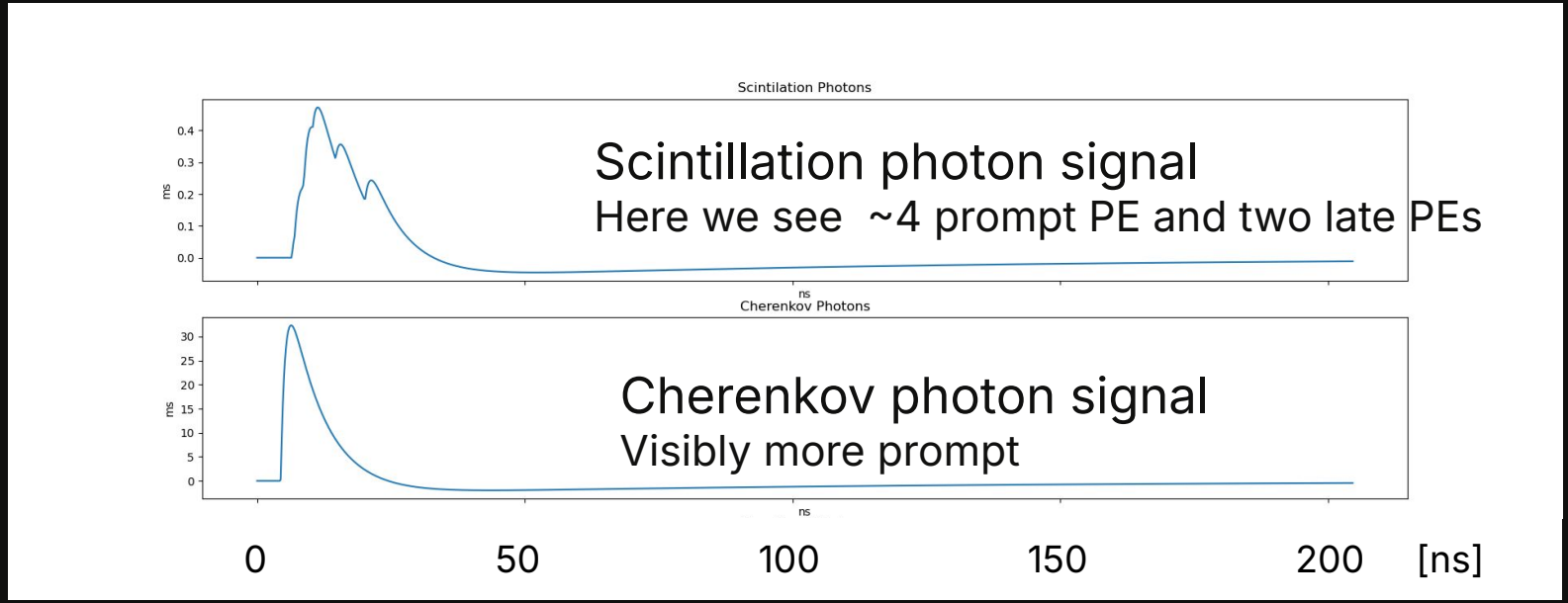
Example of SPE model



This model approximates the waveform (SiPM + amplifier response) used in our 2024 DESY test beam studies.

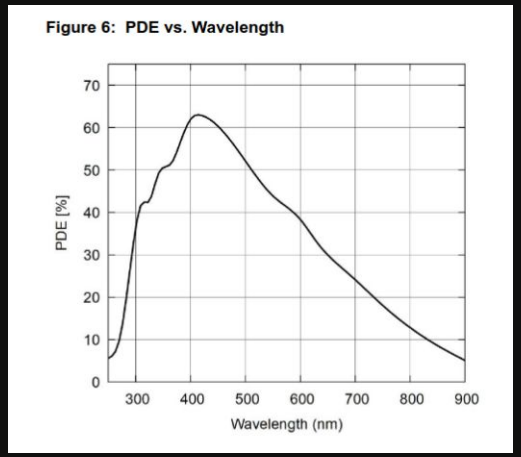
Waveform generation (PWO)

Low stats example show distribution of photon arrival times in scint signal

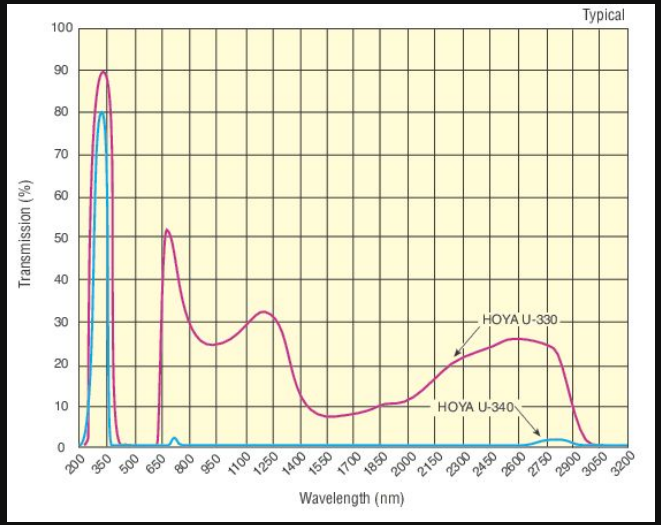


Filters applied to photon lists

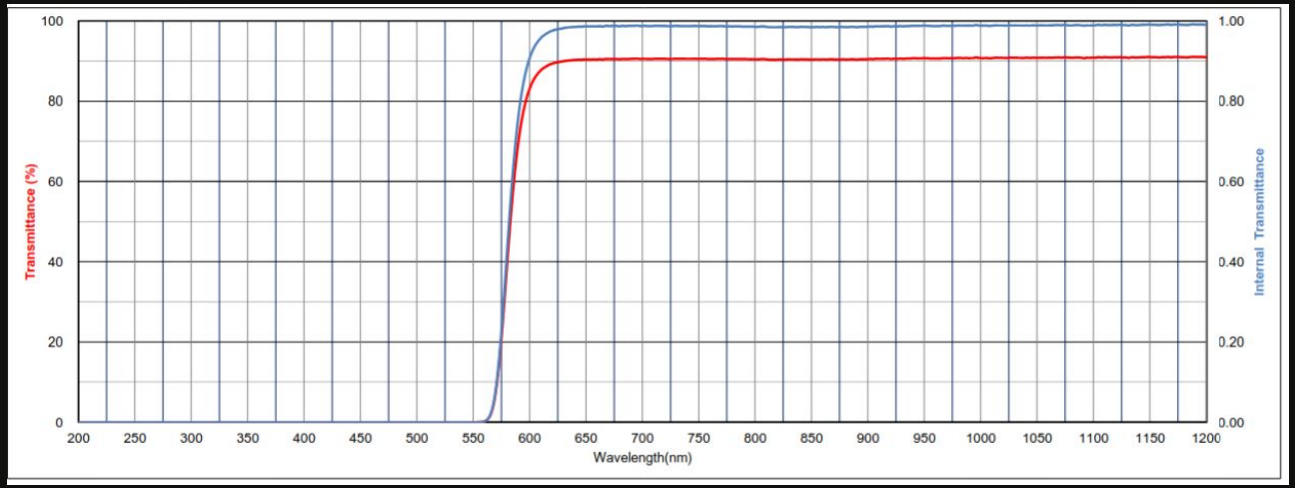
Broadcom PDE
AFBR-S4N66P024M



Hoya U330

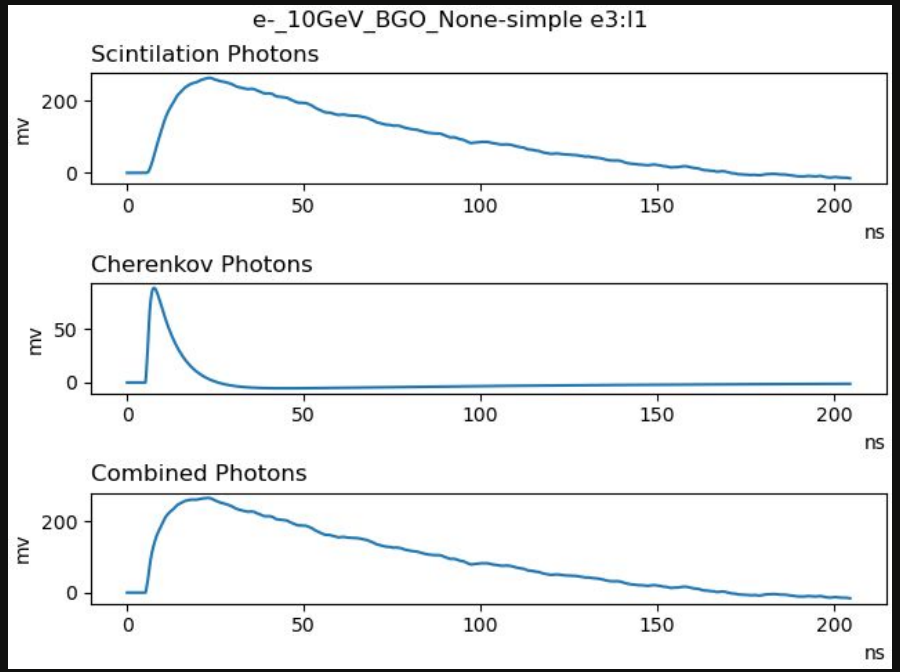


Hoya O58

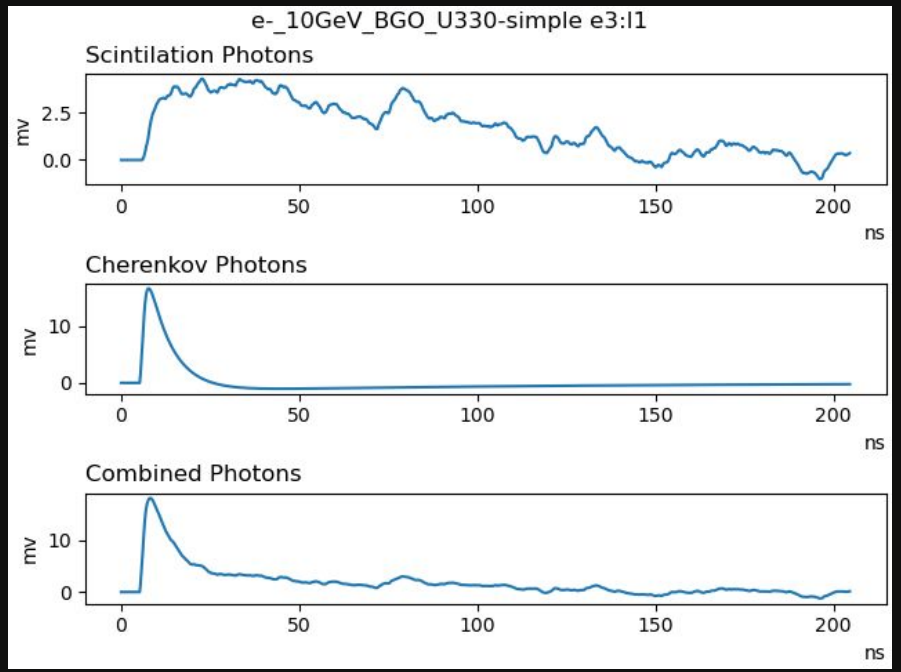


BGO Examples 10 GeV e-

No Filter

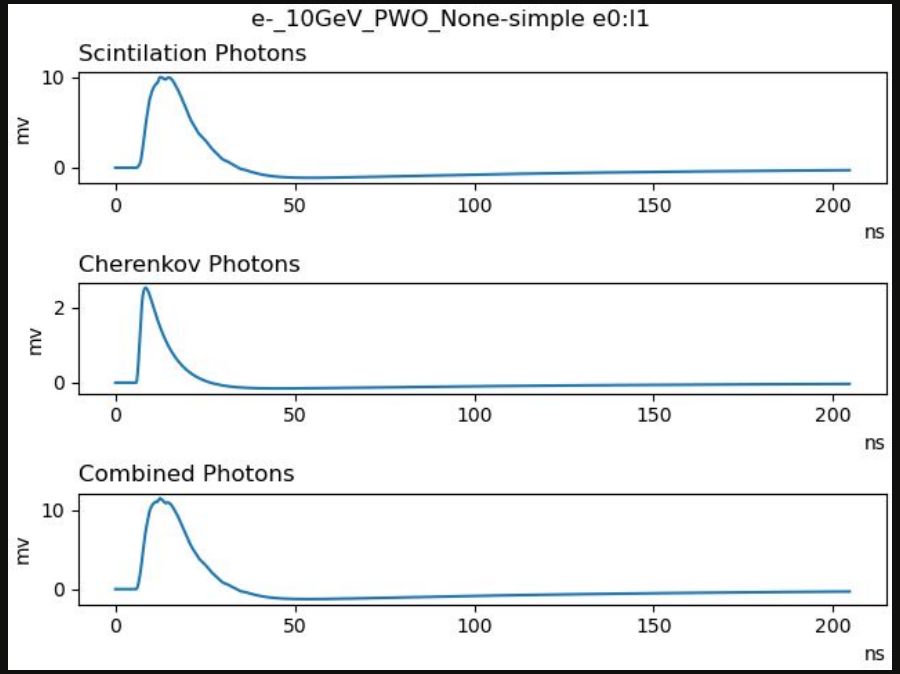


U330 Filter

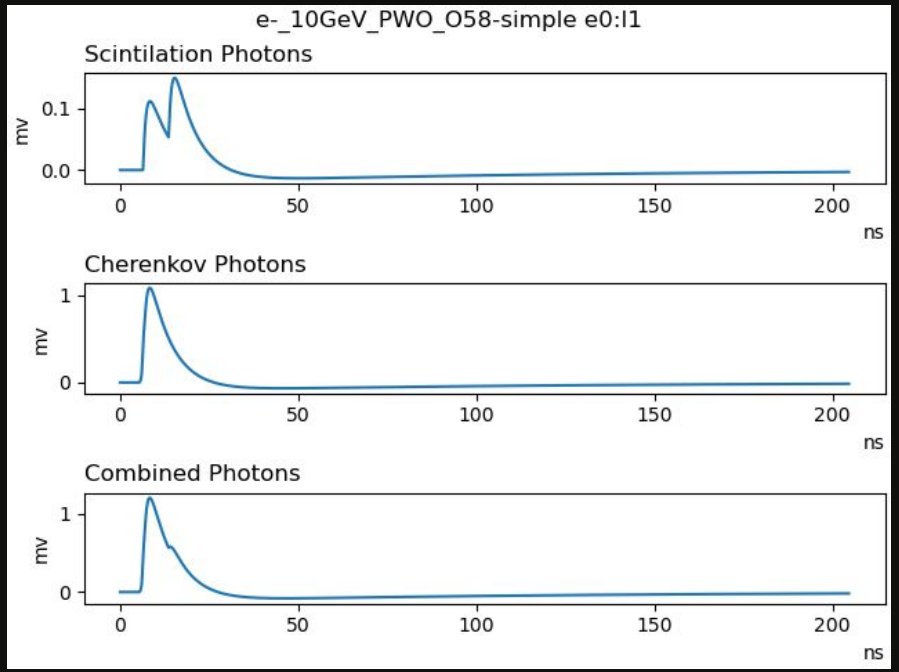


PWO Examples 10 GeV e-

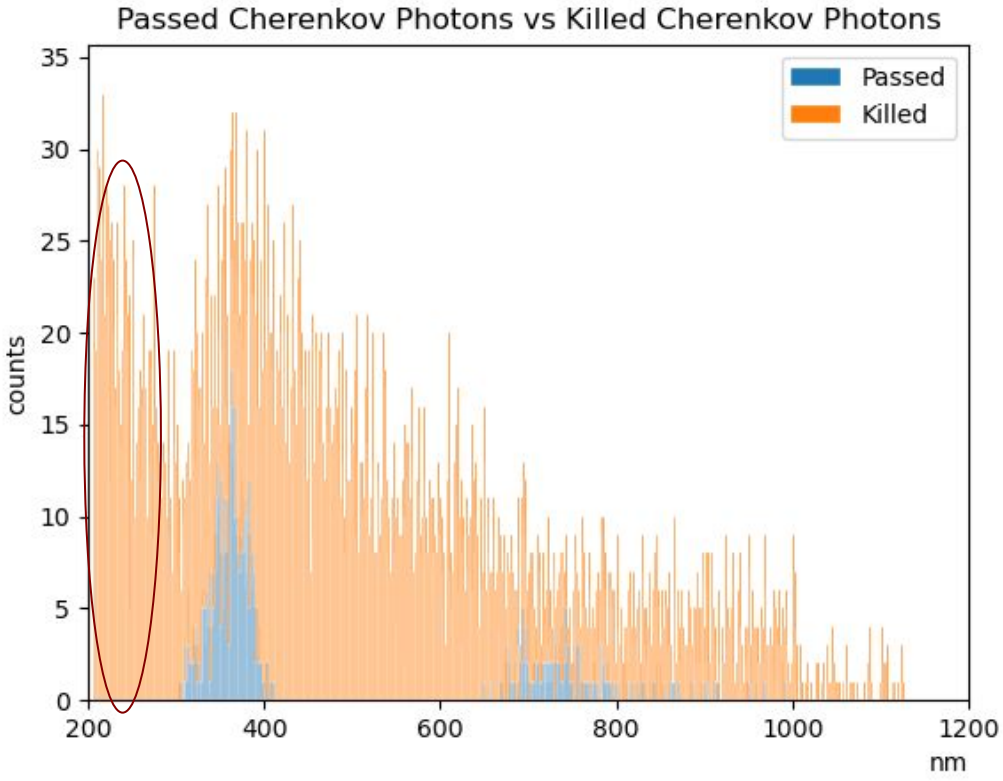
No Filter

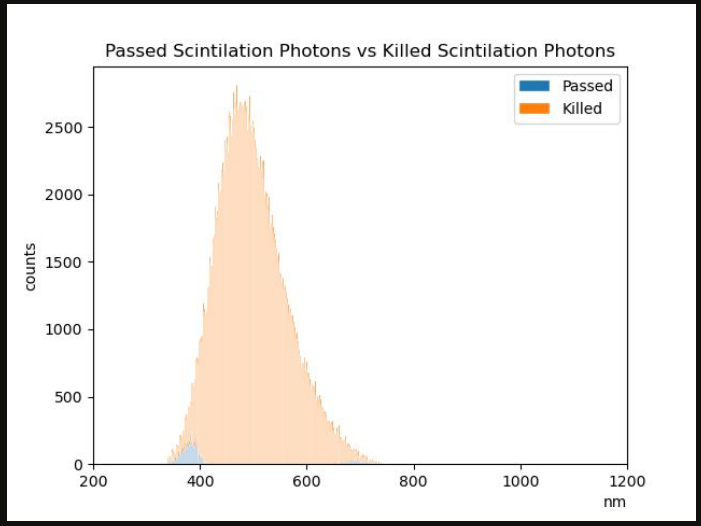


O58 Filter



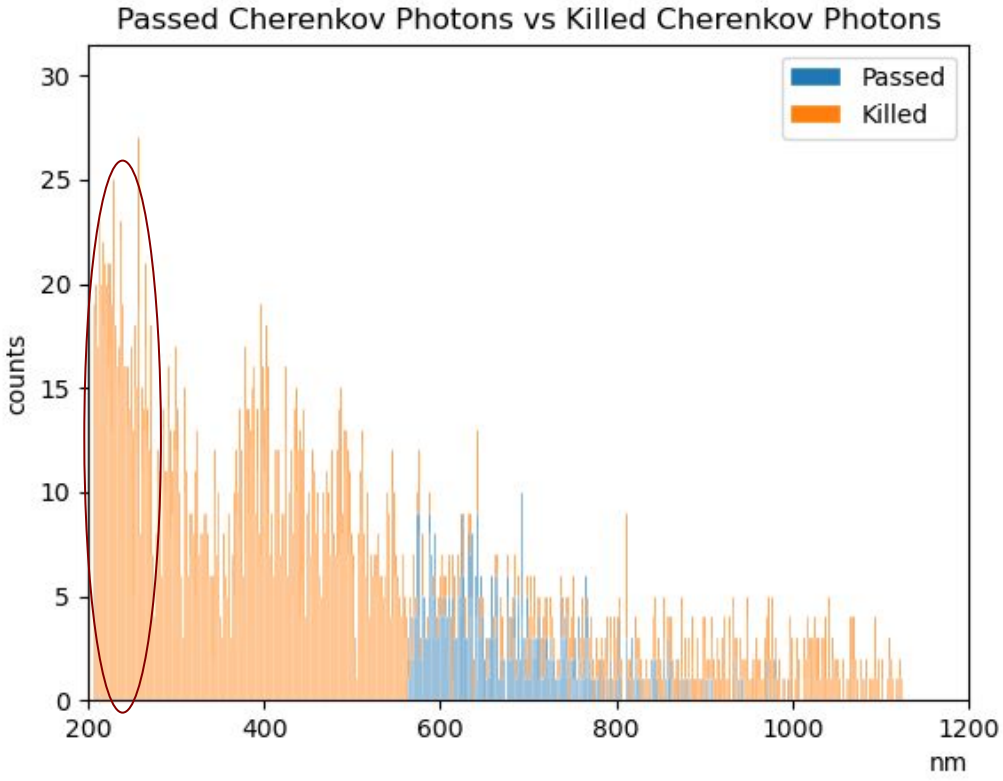
BGO+HoyaU330+SiPM PDE (Broadcom)

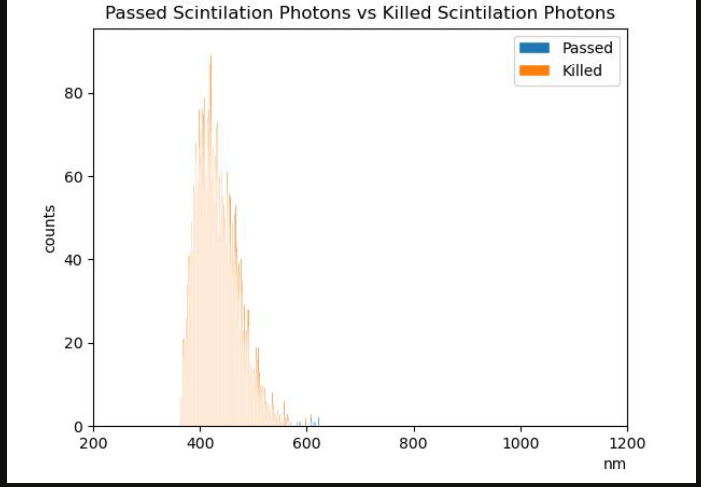




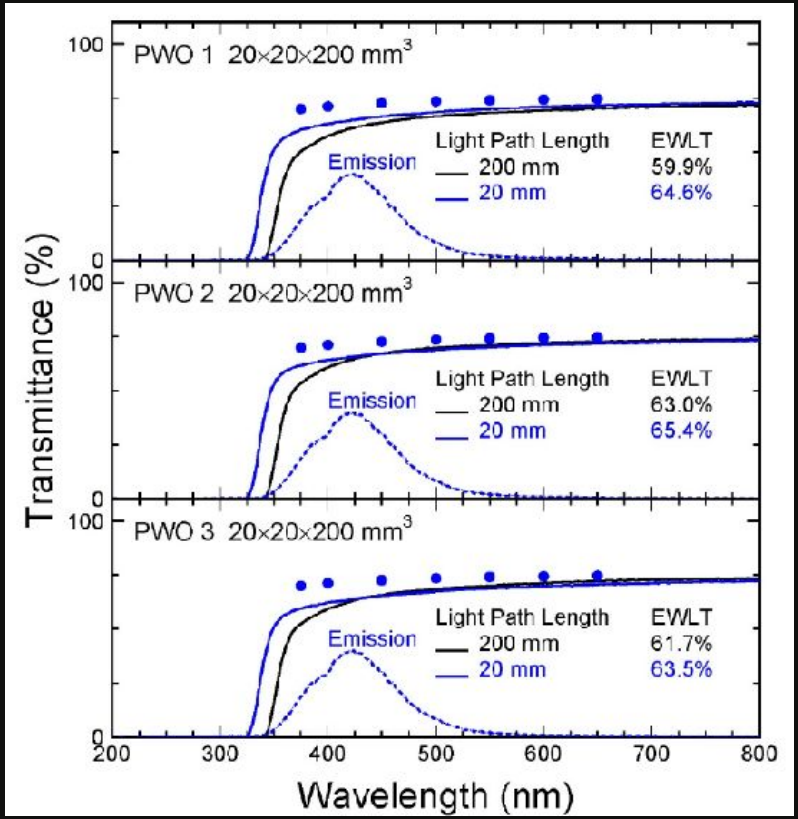
Need to check source & effect of photons below transmission cutoff. SiPM windows?

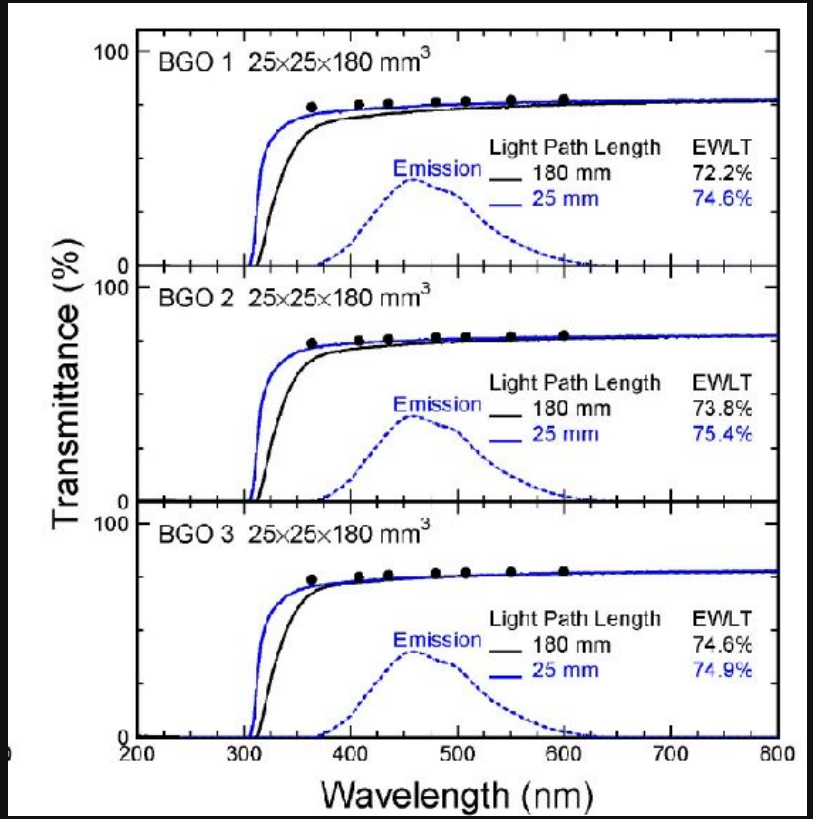
PWO+HoyaO58+SiPM PDE (Broadcom)





Expected Transmittance





Some To Do's for the optical waveforms

- Dedicated classes for hardware and/or parameter file support (remove hard coding)
- Code cleanup, improve structure and docs
- Extend/improve SiPM + filter models
- Merge our code with existing SiPM template in gaudi
- Review structure for storing processed digis in the event
- Include examples/CI tests after merging code into the stable repo
- Work with Wonyong on digi integration with full detector sim

Longer term:

- Develop a version of parameterization code as used in CMS (application of method to $\hat{C}$ light t.b.d.)
- Work with Celeritas team for gpu integration
- ...

Celeritas advertisement

- GPU accelerated Monte-Carlo detector simulation
- Existing support for EM physics (electrons, gammas)
- Development underway for optical physics
  - Absorption, Rayleigh & Mie scattering, wavelength shifting
  - Support for complex boundary processes and coatings
  - Cherenkov and scintillation directly from EM particles or from list of energy depositions
- Minimal integration into existing Geant4 workflows
- Ongoing integration efforts with ATLAS, CMS, DUNE, etc.

Application	Runtime (s)	Speed-up
Geant4	478.990	1x
Celeritas CPU - Event	116.251	4.12x
Celeritas CPU - Track	6.739	71.1x
Celeritas GPU	0.485	988x

- *Event - Geant4 compatible per-event parallelism*
- *Track - per-track parallelization over OpenMP with 64 threads*

988 CPU : 1 GPU performance tracks with previous results

Open question: keep photon hits → digi generation all on the GPU?

Possible future development goal!