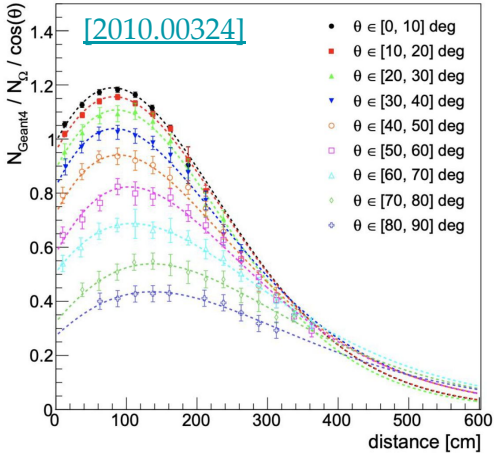
Full Optical Simulation with the New LArG4

Alejandro Sánchez Castillo
asanchezcastillo@ugr.es

February 2023

UNIVERSIDAD DE GRANADA[1]

Introduction:



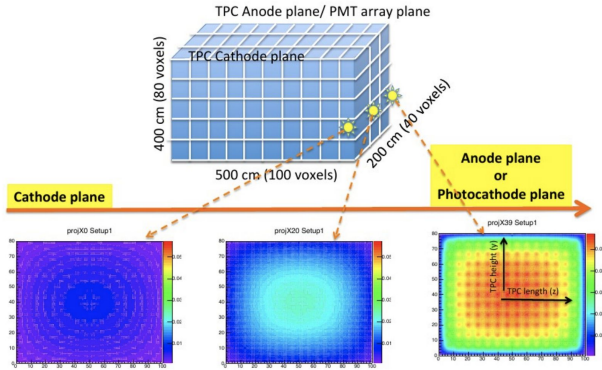
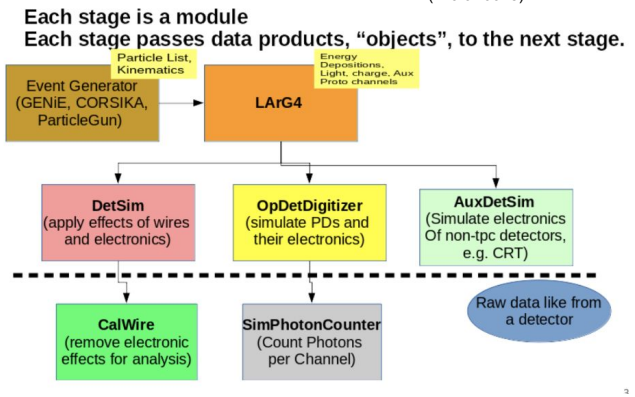


Image from here.

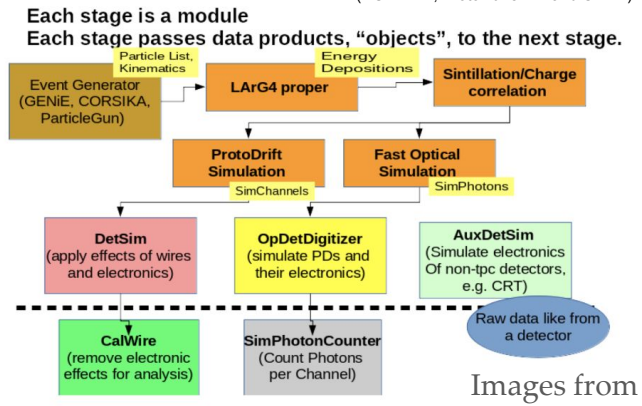
- We need to simulate generation, transport and detection of photons in our detector.
- Full optical simulations are prohibitively slow. Fast optical methods (semi-analytic, optical libraries, GNN) are implemented to save time and resources. Still full optical simulation needs to be run at least once.
- Full optical simulation can also be used for instance to quantify the importance of Cherenkov light signal.

New LArG4 vs Legacy LArG4:

(MicroBoone)



(DUNE VD, ProtoDune-HD and SBND)



Images from here.

- In the new LArG4 optical properties (refractive index, Rayleigh scattering, WLS spectrum…) are read from the geometry file.

- Since the migration to the new LArG4 the full optical simulation has not been working.

LArG4 issues:

```
services.PhysicsList.enableOptical: true
services.PhysicsList.enableScintillation: true
services.PhysicsList.ScintillationStackPhotons: true
services.PhysicsList.ScintillationTrackSecondariesFirst: true
services.PhysicsList.ScintillationTrackInfo: true
services.PhysicsList.enableCerenkov: true
services.PhysicsList.CerenkovStackPhotons: true
services.PhysicsList.CerenkovTrackInfo: true
services.PhysicsList.enableRayleigh: true
services.PhysicsList.enableBoundary: true
services.PhysicsList.enableAbsorption: true
services.PhysicsList.enableWLS: true
services.PhysicsList.Verbosity: 0
```

```
%MSG-s ArtException:  PostEndJob 17-Nov-2022 06:25:50 CST ModuleEndJob
---- EventProcessorFailure BEGIN
  EventProcessor: an exception occurred during current event processing
  ---- ScheduleExecutionFailure BEGIN
    Path: ProcessingStopped.
    ---- OtherArt BEGIN
      sim::ParticleList::insert - ERROR - track ID=1 is already in the list
      The above exception was thrown while processing module larg4Main/largeant run: 1 subRun: 0 event: 1
    ---- ParticleList END
    Exception going through path simulate
  ---- ScheduleExecutionFailure END
---- EventProcessorFailure END
---- FatalRootError BEGIN
```

- Even after turning on optical physics in the fhicl file and modifying accordingly the geometry file, the full simulation crashed halfway through.
- There was a bug in one of the functions managing how particles are saved.

LArG4 issues:

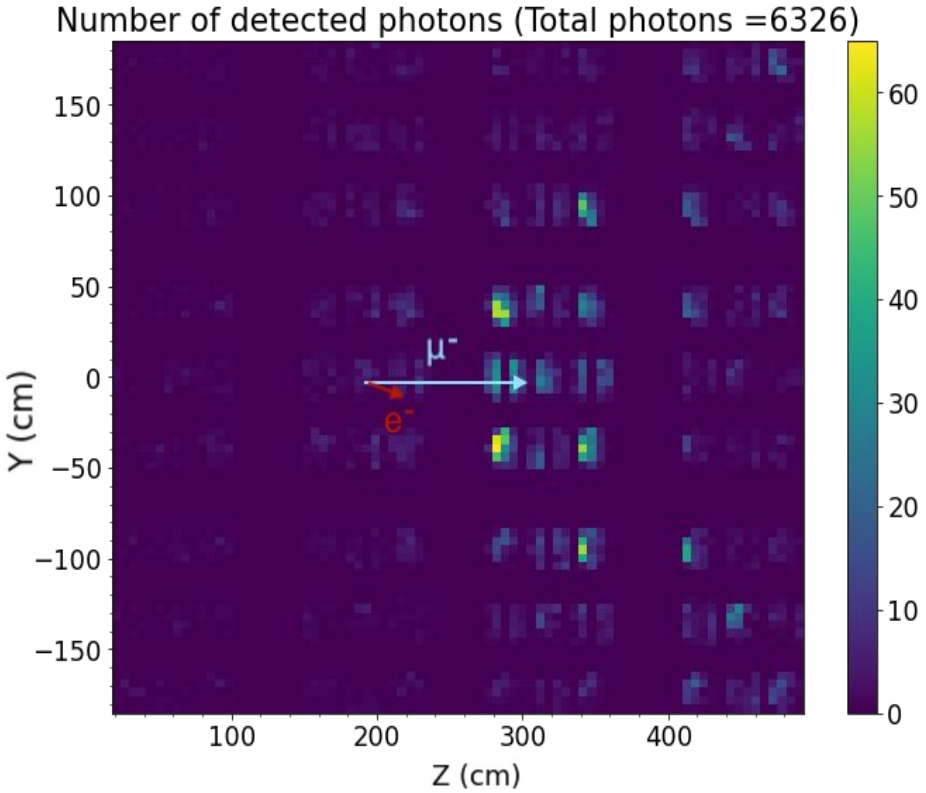
```
if (track->GetProperTime() != 0)
{
  return;
}
fParticleList.Add(fCurrentParticle.particle);
```

```
// Check the energy of the particle.  If it falls below the energy
// cut, don't add it to our list.
G4double energy = track->GetKineticEnergy();

  if (energy < fenergyCut && pdgCode != 0 ) {

  fdroppedTracksMap[this->GetParentage(trackID)].insert(trackID);
  fCurrentParticle.clear();
  // do add the particle to the parent id map though
  // and set the current track id to be it's ultimate parent
  fParentIDMap[trackID] = parentID;
  fCurrentTrackID = -1 * this->GetParentage(trackID);
  fTargetIDMap[trackID] = fCurrentTrackID;
  return;
}
```

srcs/larg4/larg4/pluginActions/ParticeListAction.cc [LArG4 modification]

- Every time a particle is created, it is saved to a particle list.
- When scintillation/Cherenkov light photons are produced, their mother particle is erroneously added to the list after each step. Also particles with energy below an energy cut were not saved.
- Prevent this behaviour by only adding particles whose proper time = 0 and not saving particles with E<EnergyCut and PDG!= 0.

First full optical simulations:



- After fixing the bug we managed to run the first full optical simulations with the new LArG4 in SBND.
- Cerenkov light from a low energy electron (0.03 GeV) and a low energy muon (0.3 GeV).
- There is a high granularity as we are storing the positions where photons hit the detector (information from PhotonHit object, described in slide 9).

Modified Geometry for the Full Optical Simulation:

```
<volume name="volOpDetSensitive">
        <materialref ref="LAr"/>
        <solidref ref="PMT_Underside"/>
        <auxiliary auxtype="SensDet" auxvalue="PhotonDetector"/>
</volume>
<volume name="vol_PMT_in">
        <materialref ref="matVacuum"/>
        <solidref ref="PMT_inside"/>
</volume>
<volume name="vol_PMT_Back">
        <materialref ref="STEEL_STAINLESS_Fe7Cr2Ni"/>
        <solidref ref="PMT_Back"/>
</volume>
<volume name="volPMT">
        <materialref ref="LAr"/>
        <solidref ref="PMTVolume"/>
        <auxiliary auxtype="SensDet" auxvalue="SimEnergyDeposit"/>
        <auxiliary auxtype="StepLimit" auxvalue="0.01" unit="mm"/>
        <auxiliary auxtype="Efield" auxvalue="0."/>
        <physvol>
                <volumeref ref="vol_PMT_Back"/>
                <position name="pos_PMT_Back" unit="mm" x="0" y="0" z="-51"/>
        </physvol>
        <physvol>
                <volumeref ref="volOpDetSensitive"/>
                <position name="pos_PMT_Underside" unit="mm" x="0" y="0" z="-48.5"/>
        </physvol>
        <physvol>
                <volumeref ref="vol_PMT_in"/>
                <position name="pos_PMT_in" unit="mm" x="0" y="0" z="-48.5"/>
        </physvol>
</volume>
```

localProducts_larsoft_09_63_00_e20_prof/
sbndcode/v09_63_00/gdml/
sbnd_v02_00_nowires.gdml

- I will be using SBND geometry file as my test case. With the current geometry optical detectors are defined once and replicated throughout the detector.
- All of them are automatically assigned ID=0.

Modified Geometry for the Full Optical Simulation:

```
<volume name="volPMT7">
        <materialref ref="LAr"/>
        <solidref ref="PMTVolume"/>
        <auxiliary auxtype="SensDet" auxvalue="SimEnergyDeposit"/>
        <auxiliary auxtype="StepLimit" auxvalue="0.01" unit="mm"/>
        <auxiliary auxtype="Efield" auxvalue="0."/>
        <physvol>
                <volumeref ref="vol_PMT_Back"/>
                <position name= "pos_PMT_Back " unit="mm" x="0" y="0" z="-51"/>
        </physvol>
        <physvol copynumber="7">
                <volumeref ref="volOpDetSensitive"/>
                <position name= "pos_PMT_Underside " unit="mm" x="0" y="0" z="-48.5"/>
        </physvol>
        <physvol>
                <volumeref ref="vol_PMT_in"/>
                <position name= "pos_PMT_Underside " unit="mm" x="0" y="0" z="-48.5"/>
        </physvol>
</volume>
```

- We need to define each optical detector independently and give it its own ID.
- Geometry file contains now a definition for each optical channel.

```
services.LArG4Detector.volumeNames: [
      "volTPCActive",
      "volCryostat",
      "volTPCPlaneVert",
      "volXArapuca0", "volXArapuca1", "volXArapuca2",
      "volXArapuca3","volXArapuca4", "volXArapuca5",
      "volXArapuca18", "volXArapuca19", "volXArapuca20",
       "volXArapuca21", "volXArapuca22", "volXArapuca23",
```

- Fhicl file has to be changed accordingly to include the new sensitive volumes.

PhotonHitConverter:

```
class PhotonHit {
private:
  int ID;        // copy number of Photodetector
  int processID; // distinguish between Cerenkov and Szintillation photons.
  double edep;
  double xpos;
  double ypos;
  double zpos;
  double time;
```

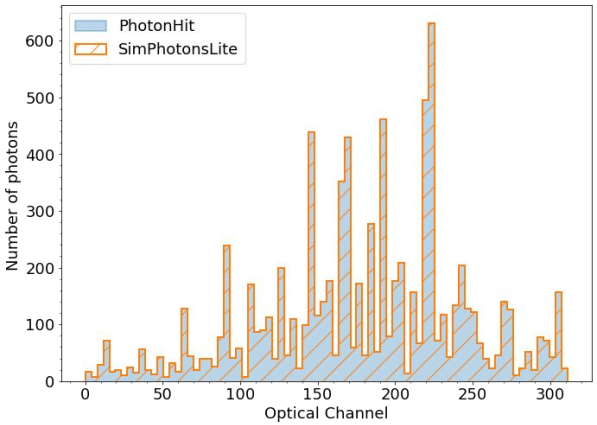
```
physics:
{
  producers:
  {
    photonhitconverter: {
                         module_type:      "PhotonHitConverter"
                         UseLitePhotons: true
                        }
  }
```

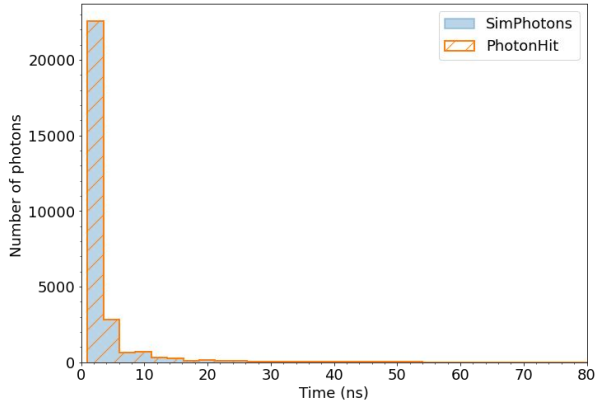
srcs/larsim/larsim/PhotonHitConverter
[larsim modification]

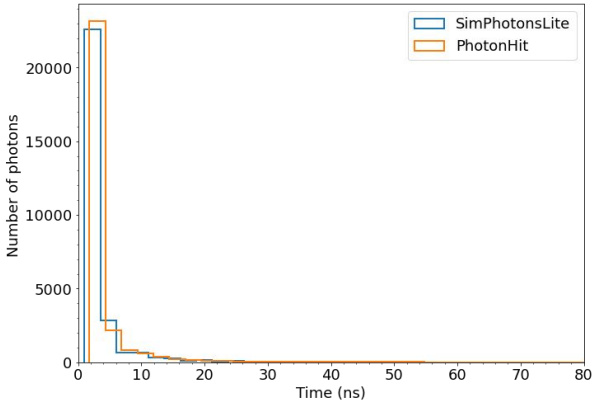
- The objects created by artg4tk are PhotonHits, which cannot be inserted into LArSoft workflow.
- We created a new larsim module (PhotonHitConverter) that converts PhotonHits to SimPhotons/SimPhotonsLite.
- Output is fhicl-configurable. It is possible to choose between SimPhotons/SimPhotonsLite.

PhotonHitConverter validation:

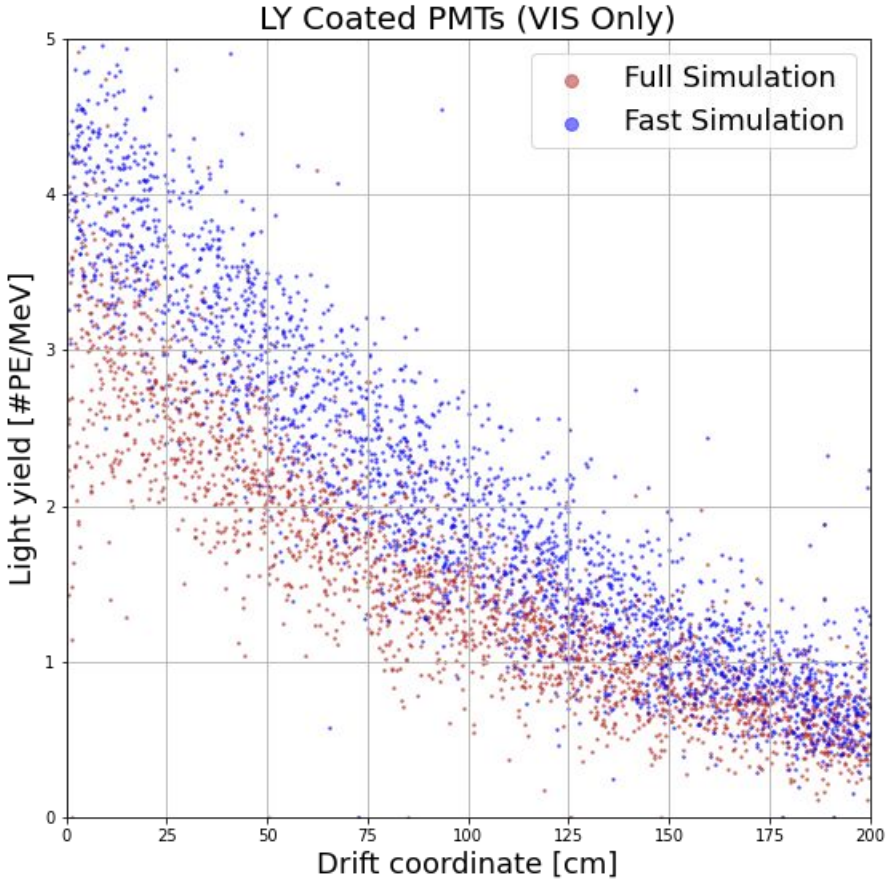
- Crosscheck the implementation of the module with the truth information from the PhotonHits.
- After this conversion the information from the full simulation can be inserted into LArSoft workflow for further stages.







Geant4-GDML problem found.



- There is a significant discrepancy for VIS light (~30%).
- Due to a bug with the reading of the optical properties by Geant4. Reported in 2020 and solved for version > v10_07. (LArSoft runs v10_06).
- Geant4 does not save reflectivities correctly. Only the reflectivity of the first surface is saved, all the others are taken as the first one.
- In our geometry all reflectivities set to the stainless steel reflectivity.

Summary:

- Full optical simulations can be successfully run with the new LArG4 and its products inserted into LArSoft workflow. Fast optical methods can finally be calibrated after the migration.
- Changes made are applicable to any LArTPC experiment within LArSoft framework.
- Some optical properties require an updated version of Geant4 (>v10_07).
- Preparing pull request to include modification in LArG4 ParticleListAction.cc and add PhotonHitConverter module to larsim.