Light simulations in LArSoft for the 3x1x1 and 6x6x6 detectors

Spanish WA105 Meeting
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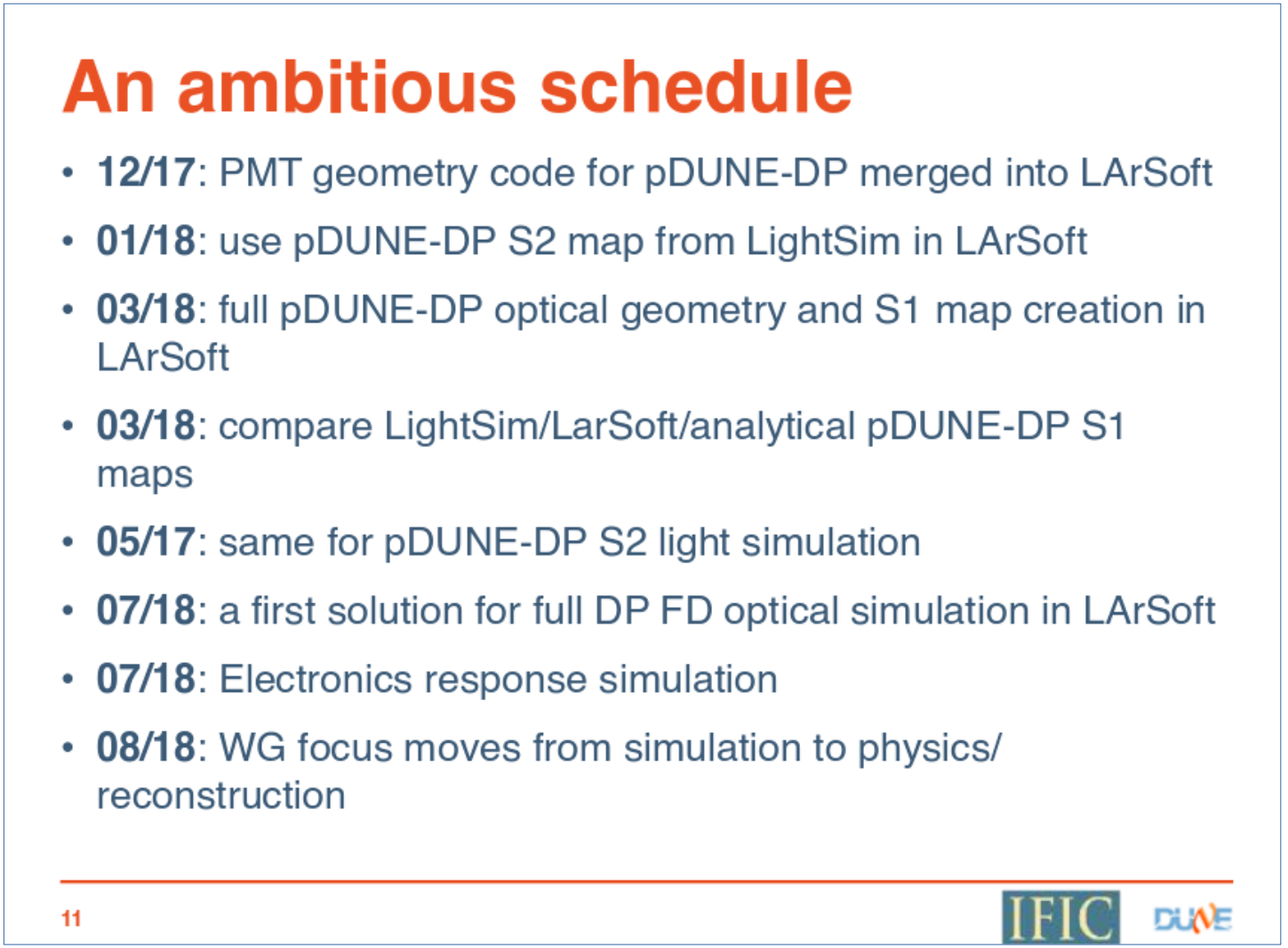
  - Complete light simulation (S1 and S2) implemented for protoDUNE DP and for WA105 3x1x1 m3.
  - Propagation of light approximated through a *Light Map* generated with LightSim, an external package (LAPP). It includes:
    - Rayleigh scattering, absorption of detector elements, TPB response, arrival time of each photon.
  - Quantum efficiency and LAr absorption also included (outside the map).
  - PMT response not implemented (on going).
- Light simulation in **LArSoft**:
  - Necessary to compare with Single Phase, and for DUNE.
  - No S2 implemented.
  - Very simple geometry. Important elements for the light simulation are missing (cathode, grid, field cage, etc.).

Light Simulation in LArSoft

There are two options to simulate light in **LArSoft**:

- **Full Optical Simulation**:
  - It includes generation and propagation of S1 light (including Cherenkov radiation).
  - Many physical parameters can be modified (Absorption length spectrum, Rayleigh spectrum, Scintillation Yield).
  - It tracks every photon. Very heavy.
- **Fast Optical Simulation**:
  - It parametrizes the propagation of the S1 light through a *Photon Library* (generated through a Full Optical Simulation). It includes:
    - Rayleigh scattering, absorption of detector elements and **LAr absorption**.
  - It assumes isotropic generation of light (no Cherenkov radiation).
  - Physical parameters are used in the generation of the library (i.e. a new library is required for different purities).
  - The *Photon Library* assigns to every photon a probability to reach a PMT, and then, the arrival time is parametrised according to the geometry. Much faster.

Planning for the Dual Phase Photon Detection simulation work:

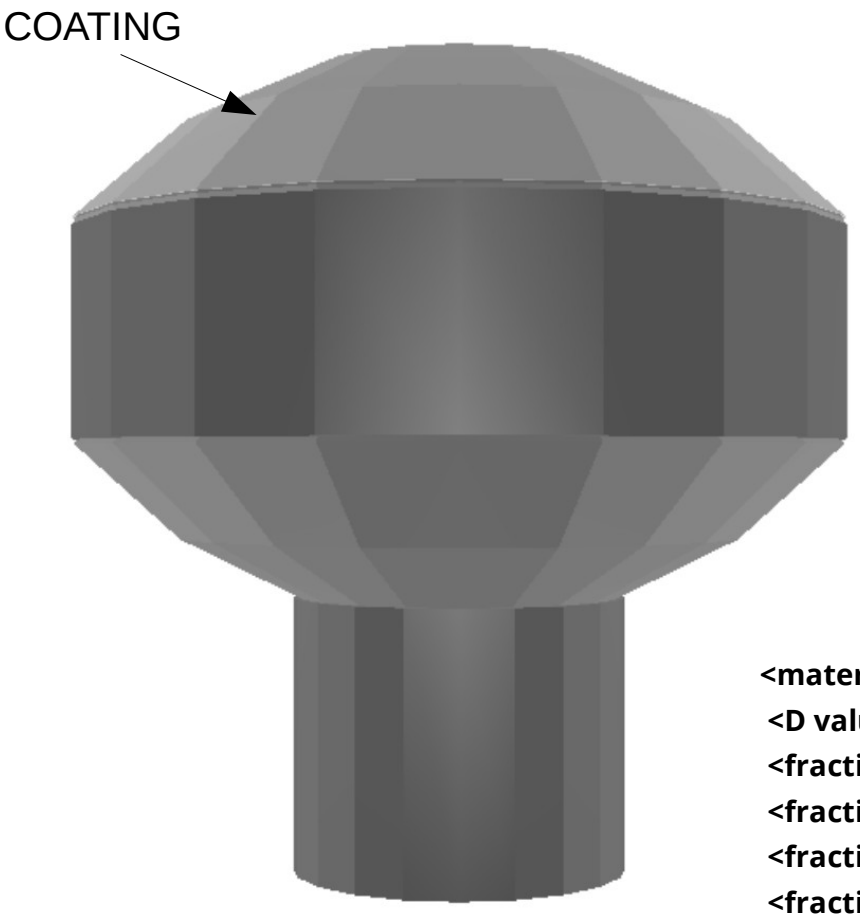


From Michel Sorel's presentation on DP Photon Detection Consortium Meeting (November 3th):
https://indico.fnal.gov/event/15824/

Work done so far:

- Implementation of a detailed PMT Geometry.
- Positioning of the PMTs inside the detector for the 3x1x1 and protoDUNE DP.
- First tests generating a Photon Library natively in LArSoft (full optical simulation).
- Conversion of LightSim Light Maps into LArSoft Photon Library format (for both geometries, protoDUNE DP and 3x1x1)
- Implementation of a S1 Photon Library in protoDUNE PD and 3x1x1.

PMT Geometry



- Same geometry as LightSim (the software from LAPP that generated the light maps).
- One volume for the whole PMT (in glass) + another one for the coating.
- Plus an acrylic plate for some of the 3x1x1 PMTs.
- The coating is defined as the **volOpDetSensitive.**

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 <D value="2.74351" unit="g/cm3"/>
 <fraction n="0.600" ref="SiO2"/>
 <fraction n="0.118" ref="Al2O3"/>
 <fraction n="0.001" ref="Fe2O3"/>
 <fraction n="0.224" ref="CaO"/>
 <fraction n="0.034" ref="MgO"/>
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 <fraction n="0.013" ref="TiO2"/>
</material>
```

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<material name="Acrylic">
  <D value="1.19" unit="g/cm3"/>
  <fraction n="0.600" ref="carbon"/>
  <fraction n="0.320" ref="oxygen"/>
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 </material>
```
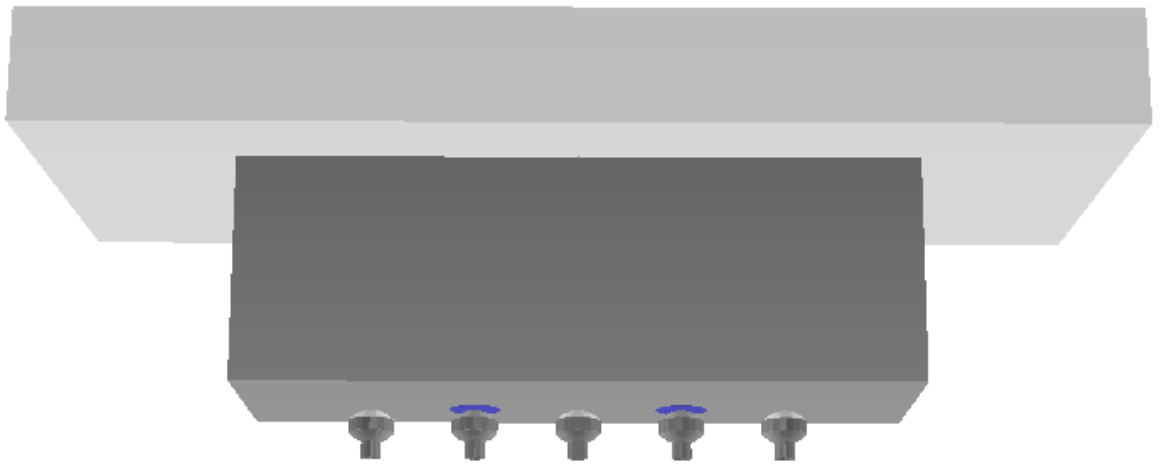
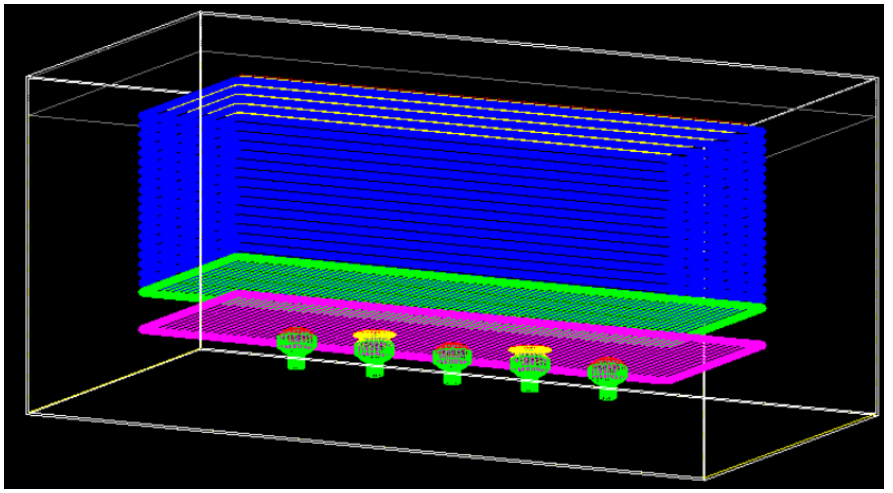

WA105-3×1×1 m3 DP LAr-TPC

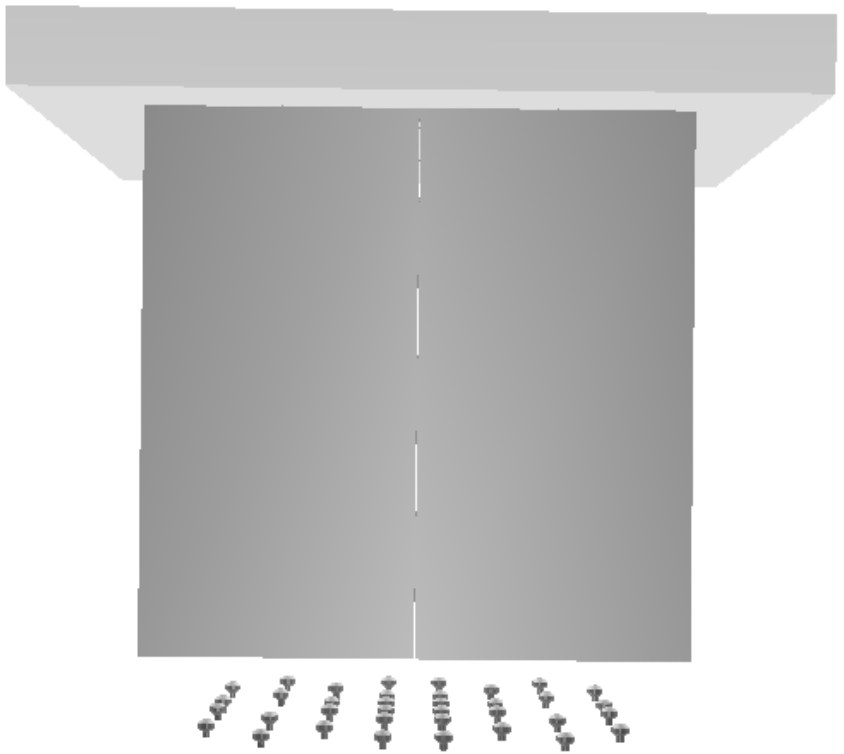


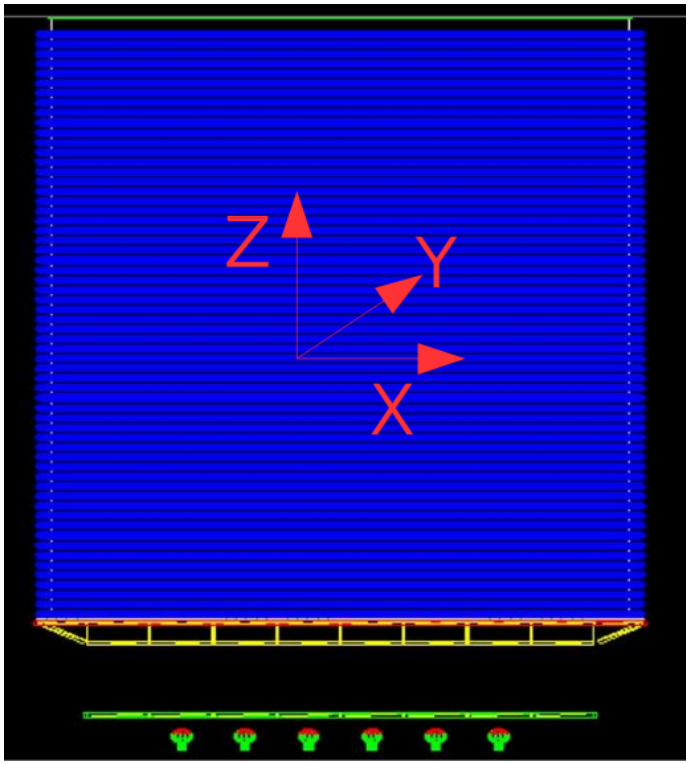


Up: View of the implemented geometry in LArSoft (left) vs LightSim (right).

- 5 PMTs.
- 3 directly coated and 2 with a TPB coated plate.
- In both configurations, the TPB coating is defined as the **volOpDetSensitive.**

ProtoDUNE DP 6x6x6





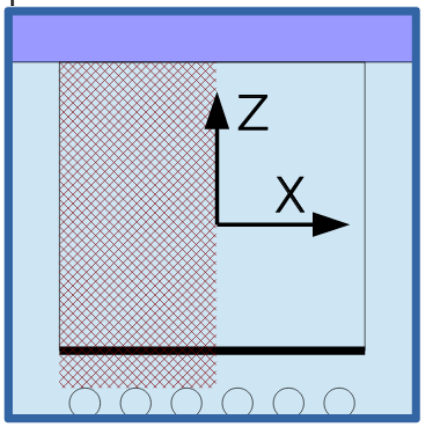
Up: View of the implemented geometry in LArSoft (left) vs LightSim (right).

- 36 PMTs, all TPB coated.
- Two PMT positions have been considered, and included in the perl script (uniform and non uniform).

Light Maps

- QScan uses the light maps to compute the number of collected photons and their arrival time distribution.
- They are generated with LightSim by the LAPP team (Annecy) using a complete geometry (see slides before).
- It contains 4 parameters per VoxelxPMT:
  - Probability to reach the PMT [visibility].
  - Travel time distribution (landau fit) [t0,MPV,σ].
- Every voxel is a cube of 25x25x25 cm^3.
- LAr absorption process is not included in the map generation. To be parametrized when using the map.
- Several maps with different configuration have been generated.
- Parameters used in the generation of the maps:

Rayleigh scattering length	55cm 350cm	(128nm) (435nm)
Absorption on stainless-steel and copper	100% 50%	(128nm) (435nm)
LAr refractive index	1.38 1.25	($\lambda < 130$nm) ($\lambda > 130$nm)



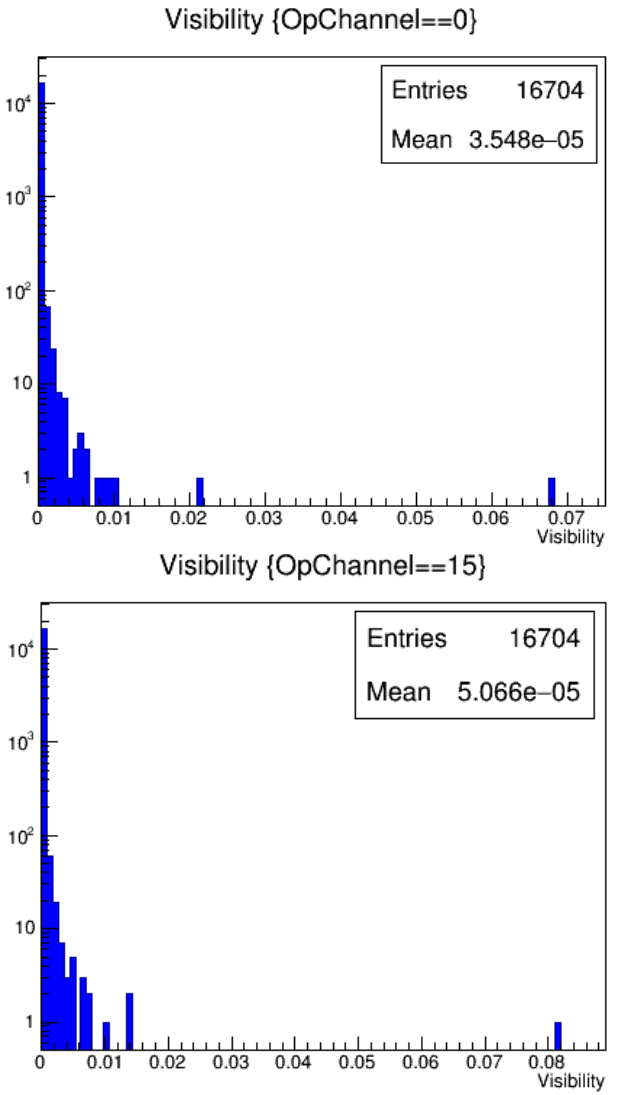
24x24x29 voxels for protoDUNE DP (see above that the volume included in the light maps is larger than the active volume in the drift direction).

4x4x12 voxels for WA105 3x1x1m³.

More information in Anne Chappuis' presentation: https://indico.fnal.gov/event/15325/

From a Light Map to a Photon Library

- A simple macro that reads the visibility* of every PMT per Voxel, and store it in a tree, taking care of:
  - The different system of coordinates LarSoft-LighSim (drift direction in bold): $(x,y,\mathbf{z})_{\text{LighSim}} = (y,z,\mathbf{x})_{\text{LArSoft}} = (z,x,\mathbf{y})_{\text{LArSoft\_ROT}}$
  - Keeping the PMT numbering.
  - Assigning the right Voxel ID.
- The time response has not been included.
- See in the right the visibility distribution for 2 PMTs (channel 0 in the corner, and channel 15 in the center).

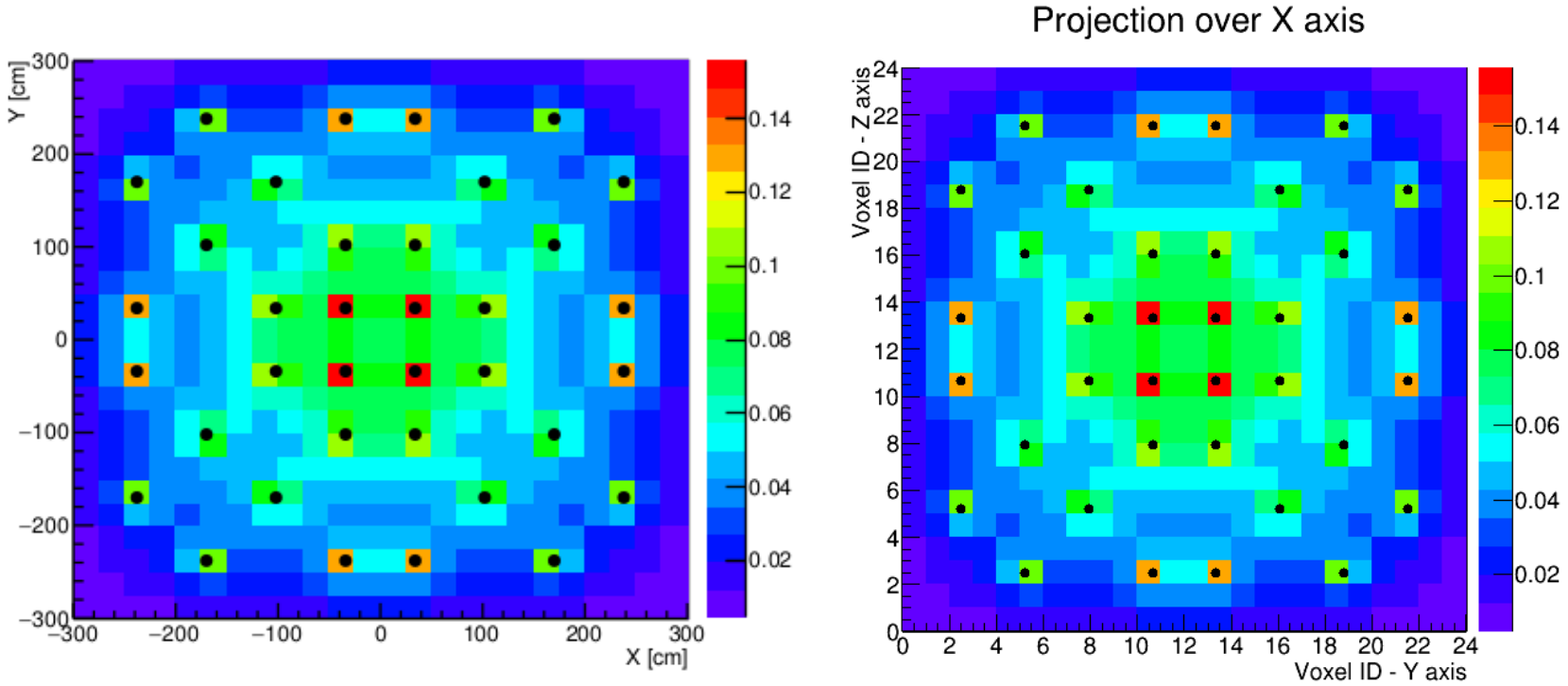


(One entry per voxel)

* The visibility assigned to every pair voxel-PMT is defined as the probability for a photon generated in the centre of the voxel, to reach the corresponding PMT.

ProtoDUNE DP Photon Library

Photon Libraries are already available in LArSoft for protoDUNE DP with the two PMT positioning (uniform and non uniform), and for the WA105 3x1x1 detector.



LightSim Light Map (left) vs imported LArSoft Photon Library (right).
This plot shows the vertical projection (sum) of the visibility (probability of a photon generated in a voxel to reach any PMT).
The binning corresponds with the voxel size.

Status and very next steps

Situation now of the Dual Phase simulation in LArSoft:

- Fast Optical Simulation:
  - Reading the maps, we can simulate (in a very preliminary status) the number of **S1 photons that reach the photo-cathode** (TPB response is already included in the maps), with a parametrized arrival time given by the geometry.
  - LAr absorption not included for now.
- Full Optical Simulation:
  - Without maps, we cannot perform a good simulation of S1 light (full optical), since the geometry in LArSoft is still very basic.
  - TPB response not included.

To do:

- Comparisons with Qscan: Quantity of S1 photons generated for muons in different positions (ongoing).
- To implement the S2 LightMaps (Michel Sorel).
- To complete the geometry and the TPB response to generate PhotonLibraries in LArSoft natively, this means, to be able to perform Full Optical Simulations (as a further step).
- To implement the electronic response, the quantum efficiency and LAr absorption.