Scintillation **light simulation** in the context of **DUNE** dual phase **Liquid Argon TPC**

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Light signal in a dual phase LArTPC

Charge particle crossing LAr

Direct excitation

Ionisation
e- / ion pair creation

recombination

scintillation **photon** → light collection

electron drifted toward the anode → charge collection

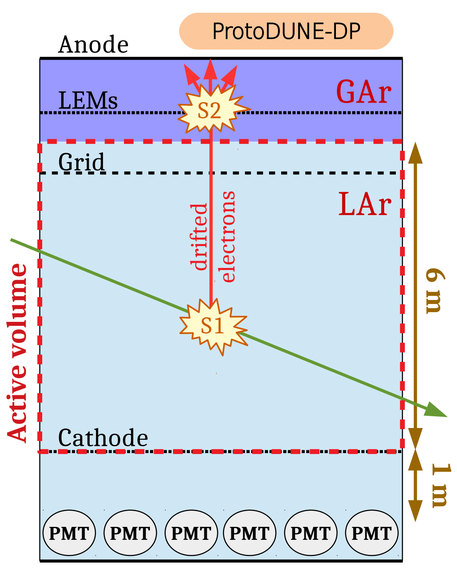
Dual phase LArTPC

Light signal = Light produced in LAr + Light produced in GAr

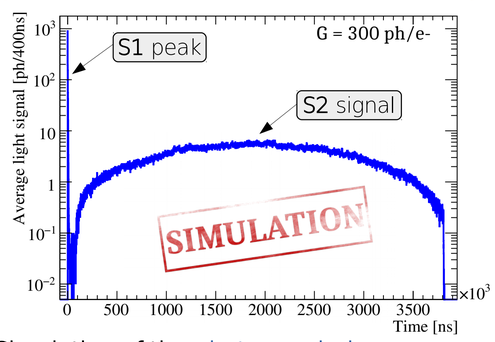
S1 S2

Scintillation in LAr (prompt signal – signal S1)
- λ = 128 nm (9,69 eV)
- 2 components with different lifetimes: 6 ns and 1600 ns

Electro-luminescence in GAr (signal S2)
- Due to the drifted electrons
- Mainly produced during e^- amplification in the LEMs
- λ = 128 nm (9,69 eV)
- 2 components with different lifetimes: 7 ns and 3200 ns



Signal induced by a 5-GeV muon crossing the entire drift volume (ProtoDUNE-DP)



Simulation of the photon emission process:
- S1 (scintillation) based on NEST approach [1]
- S2 based on an electro-luminescence gain G

G = number of photon produced in GAr / drifted e^-

Light propagation simulation : Light maps

Main issue: Very time-consuming simulations

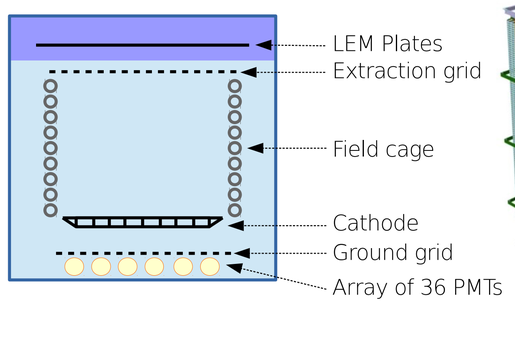
Solution: build a map that gives for each PMT and each photon emission point in the detector:
- Probability to reach the PMT ("visibility")
- Parametrisation of the arrival time

LAr and GAr volumes are split in voxels → Generation of N photons at the centre of each voxel → Photons are tracked across the detector (based on Geant4) → Travel time distribution obtained for each PMT → Extraction of time distribution parameters (fit) → Light maps

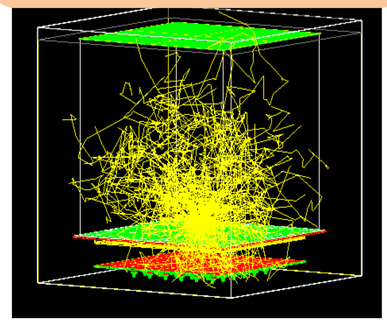
Light maps were produced using LightSim software, for ProtoDUNE-DP and 3x1x1 demonstrator

Light propagation simulation characteristics

Components that have an impact on photon trajectories



Photon trajectories in ProtoDUNE-DP



Light maps characteristics

- Rayleigh scattering length : 55 cm [2] (VUV photons)
  350 cm (visible photons)
- Absorption on stainless-steel and copper: 100% (VUV photons)
  50% (visible photons)
- LAr refractive index : 1.38 (VUV photons)
  1.25 (visible photons)
- Wavelength shifter (TPB) conversion efficiency:
  100% with isotropic re-emission

Travel time parametrisation

- ProtoDUNE-DP (6x6x6 m^3): Landau
- 3x1x1 demonstrator: Double-exponential or triple-exponential (depending on the maps)

Extra parameters (not included in the maps)
- LAr Absorption length: 30 m [3]
  Exponential parametrisation
- Quantum efficiency: 20% for all PMTs

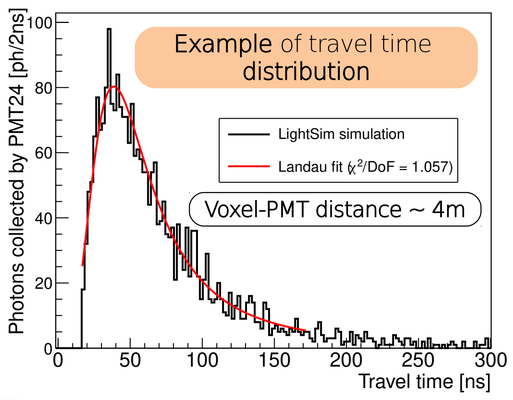
Travel time parametrisation (ProtoDUNE-DP)

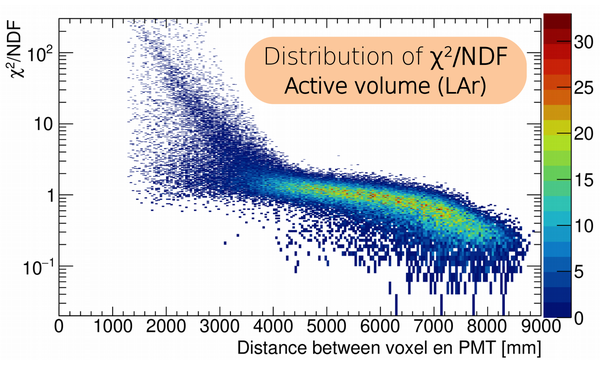
- Distribution shapes strongly depend on the distance to the PMT
- Distribution with less than 50 photons (= visibility lower than $5x10^{-7}$) are not taken into account
- Reconstruction using a Landau fit

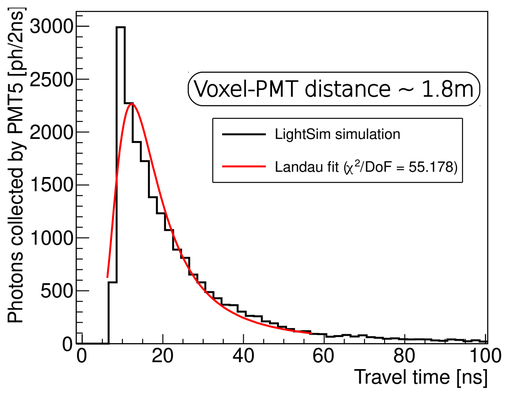
→ Satisfactory in most cases

→ Can be optimized for voxels close to the PMTs (narrow distributions)

Parameters stored in the maps:
- t0 (first bin with $N_{entries} > 0$)
- MPV and σ from the Landau fits







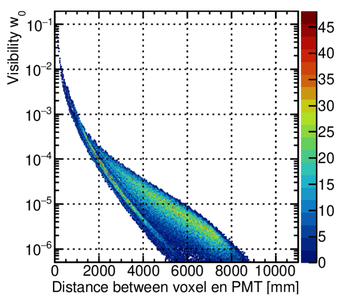
Visibility (ProtoDUNE-DP)

Stored in the maps

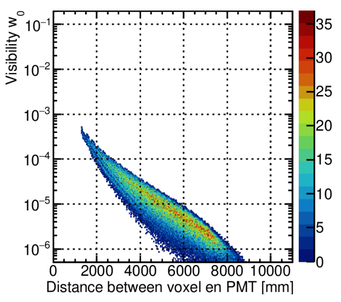
$$\text{Visibility} = \frac{\text{Number of photons reaching the PMT}}{\text{Number of generated photons}}$$

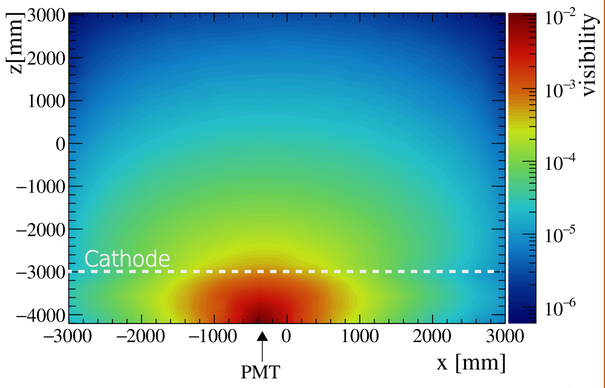
Visibility seen by a central PMT (after 3D interpolation)

Total volume (LAr)



Active volume (LAr)



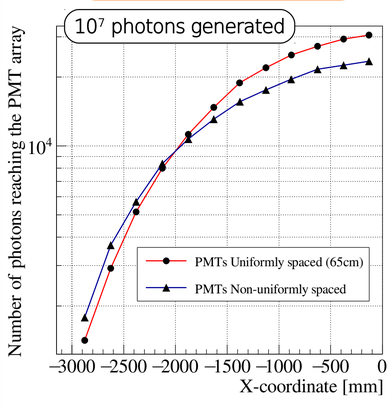


For DUNE, investigation of the possibility to parametrise the visibility as a function of the voxel-PMT distance

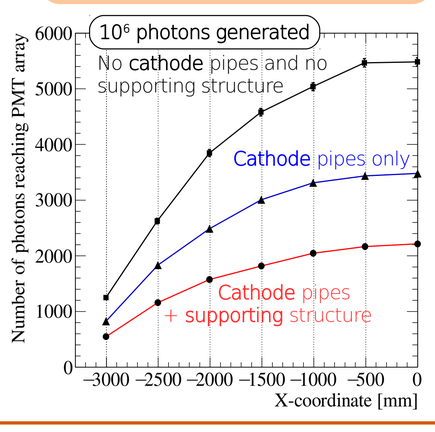
Light simulation studies using light maps

Design impact on the light collection (ProtoDUNE-DP)

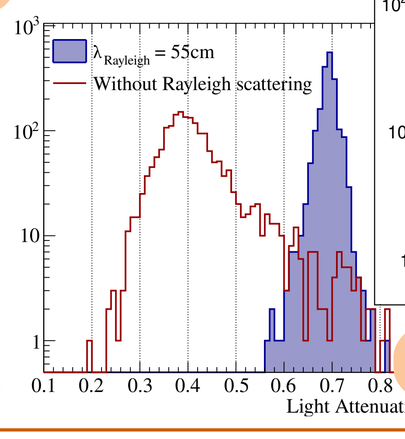
PMT positioning impact



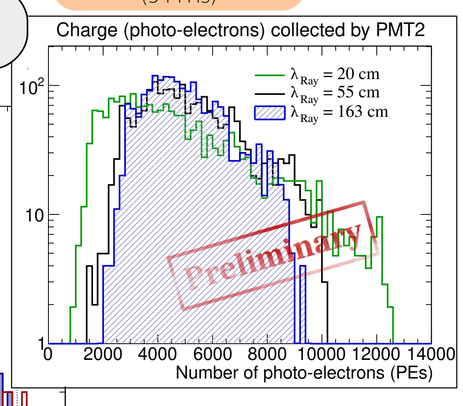
Light attenuation due to the cathode



Rayleigh scattering impact on the light collection

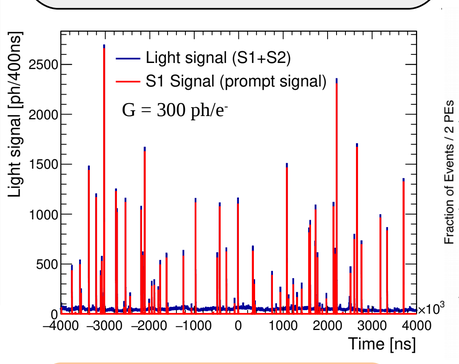


3x1x1 demonstrator (5 PMTs)



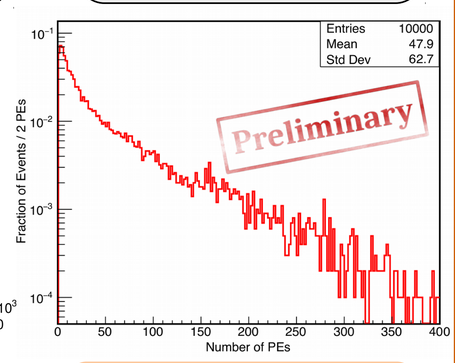
Attenuation due to the cathode and the ground grid in ProtoDUNE-DP

Light signal induced by cosmic muons in ProtoDUNE-DP



Light maps + QScan software

Supernova neutrinos (SN) in ProtoDUNE-DP



Light maps + LArSoft software

Conclusions

- Light maps have been generated for both ProtoDUNE-DP and 3x1x1 m^3 prototypes.
- Comparison between WA105 3x1x1 demonstrator light data and simulations are ongoing and already promising.
- Simulations for ProtoDUNE-DP allowed us to study the design impact on the light collection.
- Studies on the impact of Rayleigh scattering and LAr absorption processes are ongoing, using ProtoDUNE-DP and 3x1x1 demonstrator simulations.
- Studies on the performance of the light collection system in ProtoDUNE-DP using the light maps are ongoing.
- As light map generation for DUNE may be too heavy, others possibilities like analytical approach or parametrisation from the maps are studied.

[1] M. Szydagis et al, arXiv: 1106.1613v1
[2] E. Grace et al, arXiv: 1502.04213v3
[3] B.J.P. Jones et al, arXiv: 1306.4605v2

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